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State of the Science to Support Long-Term Water Resource Planning

Capital Area Groundwater Conservation Commission

Adrian McInnis, Ryan Clark, Scott Hemmerling, and Alyssa Dausman

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INTEGRATING APPLIED RESEARCH | LINKING KNOWLEDGE TO ACTION | BUILDING PARTNERSHIPS

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Preface

The Water Institute of the Gulf (the Institute) worked with Dr. Mike Runge (U.S. Geological Survey) and Ms. Ellen Bean (independent consultant) on a facilitated approach for a structured decision-making (SDM) process with the Capital Area Ground Water Conservation Commission (CAGWCC). Through four workshops and multiple meetings, the Institute, Dr. Runge, and Ms. Bean were able to frame and identify five fundamental objectives which led to the identification of potential management alternatives that could address the long-term water resource needs of the Capital Area Ground Water Conservation District (CAGWCD). The five fundamental objectives are imperative in the SDM process because it serves as the foundation for making decisions. The fundamental objectives and management alternatives support CAGWCC's mission statement, "*develop, promote, and implement management strategies to provide for the conservation, preservation, protection, recharging and prevention of waste of the groundwater resources, over which it has jurisdictional authority, for the benefit of the people that the Capital Area District serves.*" In addition to the facilitated approach, this state of the science report was generated to serve as background information to be used by CAGWCC. This document outlines the current state of the science regarding the Southern Hills Aquifer System as it pertains to CAGWCC and necessary information to support the analysis of the potential alternatives outlined in the Framework for a Long-term Strategic Plan for the Capital Area Groundwater Conservation Commission (i.e. planning framework).

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List of Acronyms

Acronym	Term
BRWC	Baton Rouge Water Company
CAGWCC	Capital Area Ground Water Conservation Commission
CAGWCD	Capital Area Ground Water Conservation District
DEM	Digital Elevation Model
EB	East Baton Rouge
GAM	Groundwater Availability Model
HUC	Hydrologic Unit Classification
LiDAR	Light Detection and Ranging
LDH	Louisiana Department of Health
LDEQ	Louisiana Department of Environmental Quality
LDNR	Louisiana Department of Natural Resources
NGWA	National Ground Water Association
LPSC	Louisiana Public Service Commission
SDM	Structured Decision Making
SHAS	Southern Hills Aquifer System
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey

Unit Table

Acronym	Term
°F	Degrees Fahrenheit
ft	Feet
ft/mile	Feet per mile
gpd	Gallons per day
gpm	Gallons per minute
m	Meters
m^3	Cubic meters
mg/L	Milligram per liter
Mgal/d	Million gallons per day
mi^2	Square mile
mm	Millimeters
ppm	Parts per million

Acknowledgements

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Executive Summary

The Capital Area Ground Water Conservation District (CAGWCD) was created by the Louisiana Legislature through Act 678 of 1974 due to concerns in the Baton Rouge region regarding water level declines of as much as 400 ft, saltwater encroachment in several local aquifers, and land subsidence caused by over-pumping of groundwater. The Capital Area Ground Water Conservation Commission (CAGWCC) was chartered in January 1975, and its job is to develop, promote, and implement management strategies to provide for the conservation, protection, and sustainable use of local groundwater resources in CAGWCD. Since 1974, saltwater encroachment has continued into the Southern Hills Aquifer System (SHAS) with multiple studies documenting the presence of increasing chloride levels, an indicator of saltwater intrusion, on the northern side of the Baton Rouge Fault. Pumping of fresh water north of the fault has resulted in lowered water levels and potentiometric surfaces and, therefore, decreased hydraulic head difference between the northern and southern sides of the Baton Rouge Fault. Saltwater has historically existed in the sands south of the Baton Rouge Fault, but the altered hydraulic head difference has created a means by which saltwater is moving northward across the fault which was previously thought to be a more secure barrier to saltwater intrusion. To address the saltwater encroachment challenges, CAGWCC has contracted modeling efforts and other scientific studies to better understand processes related to – and possible implementation of – scavenger wells in this area. In addition, CAGWCC has contracted The Water Institute of the Gulf (the Institute) in partnership with the U.S. Geological Survey (USGS) to facilitate development of a long-term strategic plan. Phase 1 of this effort (now complete) included the development of objectives, performance metrics, actions, and strategies CAGWCC could take over the long term to conserve and protect the SHAS. This report is a summary of literature research regarding Baton Rouge groundwater, the groundwater management actions in the area, and the state of the science in southeastern Louisiana with respect to the SHAS including other relevant information to support the evaluation of alternative strategies for the CAGWCC long-term management plan. Information herein has been collated from various reports as well as identified through the facilitated workshops with CAGWCC and meetings with several experts in the area that have focused on groundwater research.

Introduction

This report is structured to provide background information on the SHAS and how it relates to CAGWCC. The first section of report details aquifer elements and principles for geology, hydrology, and the environment. The second section reports on the management activities such as recharge/discharge, the role of geologic faults in the SHAS, aquifer management, and water use and demand within CAGWCD. The third section reports on the outcome of Phase 1 between CAGWCC and the Institute where, through a structured decision making (SDM) process, fundamental objectives were established and metrics for those fundamental objectives were specified. In addition to establishing fundamental objectives, the management actions of CAGWCC were grouped into portfolios to help summarize where and what CAGWCC is doing and what water management options are available as well as to serve as a measure for comparison looking into the future. Lastly, gaps in information were identified to help CAGWCC improve their management activities and strategies for both short- and long-term water resource planning.

AQUIFER DYNAMICS BACKGROUND

Aquifers are porous media underground where water is present in empty voids between materials such as sand, silt, and clay or in fractures within rocks (Figure 1). Aquifers have a zone of unsaturation (vadose zone) and saturation delineated by whether water is filling the pores between grains. The capillary fringe is the transition area between the unsaturated and saturated zone where groundwater is pulled up due to the physical and chemical composition of the surrounding geology (Alley et al., 1999). In general, there are two types of aquifers: confined and unconfined, as seen in Figure 2 (National Groundwater Association, 2019). A confined aquifer is saturated with water and has relatively impermeable layers surrounding the aquifer unit. Depending on pressure from the surrounding confining layers, a confined aquifer can have potentiometric surfaces above its static water levels, resulting in a condition referred to as artesian. if those water levels, when tapped, flow above ground surface elevation, it is known as a flowing artesian aquifer. Recharge zones for confined aquifers are in areas of permeable soil that connect to the confined aquifer (termed the outcrops) which are normally located away from the major body of the aquifer. For example, the SHAS is a large intertwined system of confined aquifers with recharge areas north of Baton Rouge in Mississippi. Unlike a confined aquifer, an unconfined aquifer's water surface (water table) is at atmospheric pressure and can rise and fall with no impermeable layers above it. In addition, unconfined aquifers have recharge areas within the direct vicinity, usually vertically above the water table where present.

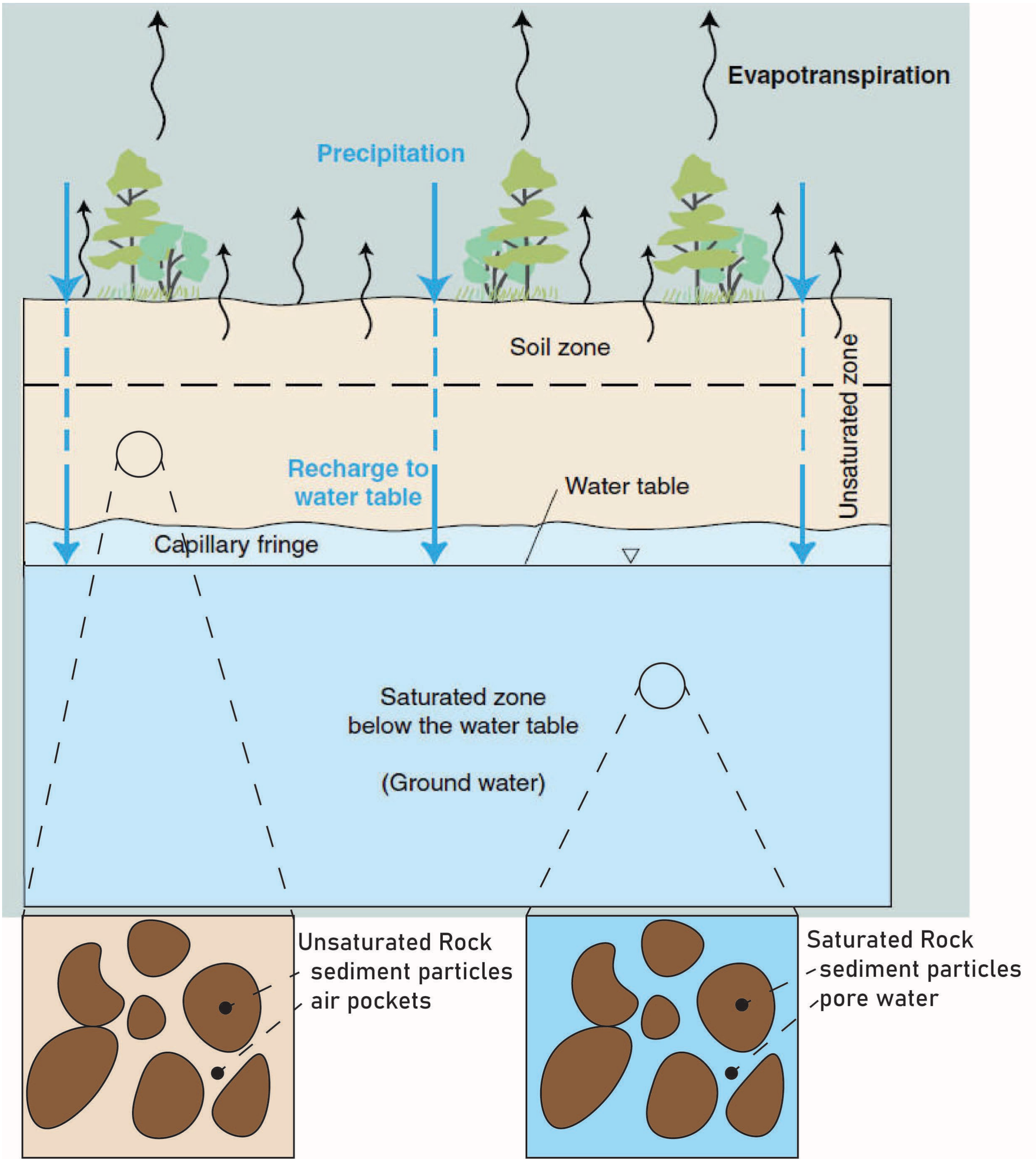


Figure 1. Cross-section of sediment highlighting water infiltration to groundwater layers. Figure modified to illustrate air pockets and pore water in different zones (USGS, 2020).

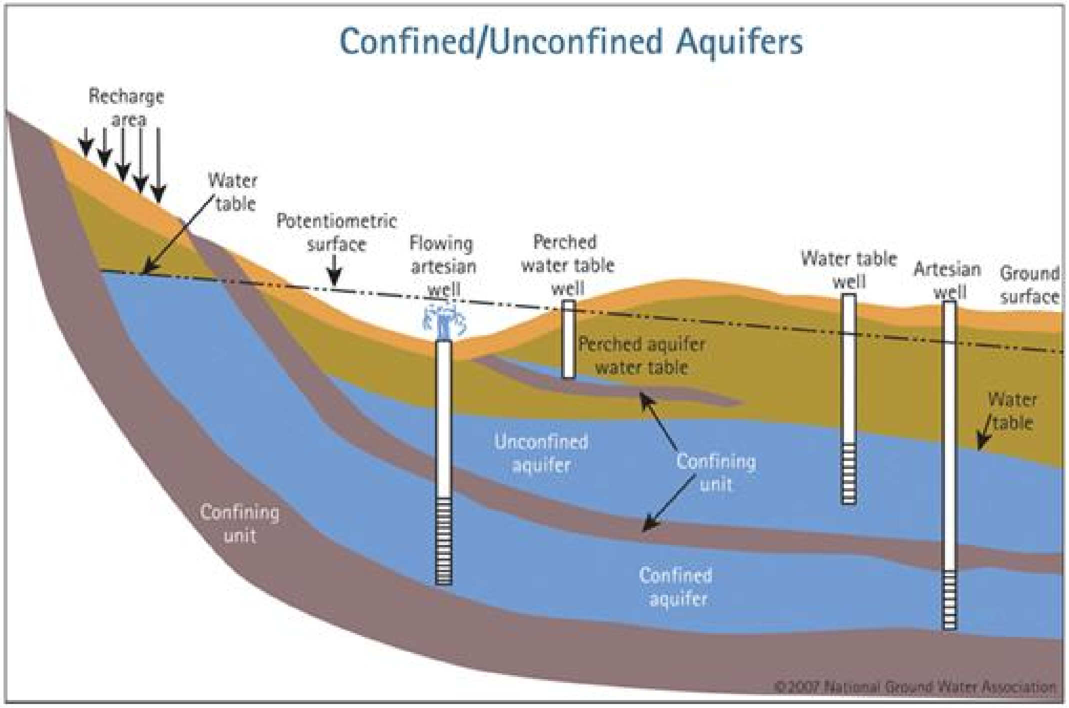


Figure 2. Confined and unconfined aquifer characteristics (National Groundwater Association, 2019).

Aquifer Pumping

When pumping a well, the water and/or pressure within the immediate vicinity around the well will begin to draw down; this can be known as a cone of depression if the decrease in pressure and or water level is large enough. The presence, overall shape, and volume of the cone of depression is dependent on pumping pressure, duration, hydraulic conductivity, aquifer thickness, transmissivity, and the aquifer's storage coefficient. Hydraulic conductivity in an aquifer represents how fast liquid passes through the aquifer material at a specific cross-sectional area, whereas transmissivity represents the same concept as hydraulic conductivity, but with the caveat of how fast liquid passes through a unit width of the aquifer (Figure 3) (Ferris et al., 1962).

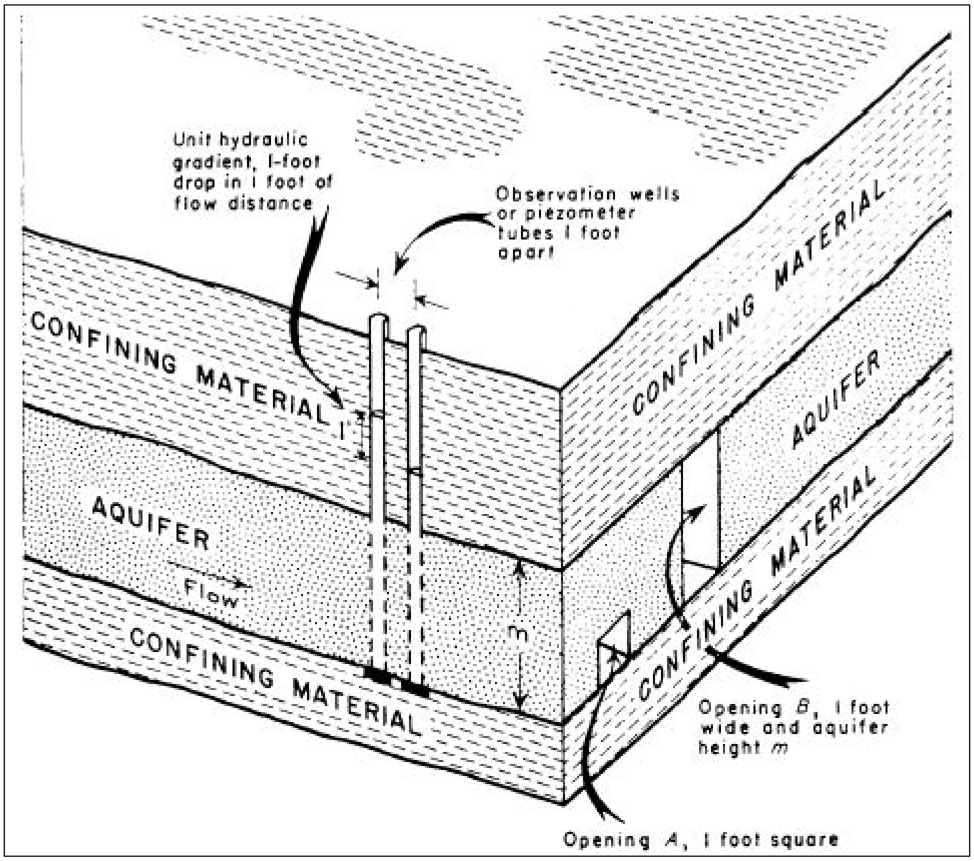


Figure 3. Schematic of hydraulic conductivity and transmissivity. Hydraulic conductivity and transmissivity both represent how fast a liquid passes through a medium, but transmissivity represents one unit width (Opening A) and hydraulic conductivity represents the cross sectional movement (Opening B) of a liquid (Ferris et al., 1962).

The consequences of pumping a confined and unconfined aquifer differ, which can affect the future withdrawal of the aquifer. In an unconfined aquifer, pumping a well excessively can cause a cone of depression by decreasing water levels around the well with little influence on the hydraulic pressure. In a confined aquifer, the hydraulic pressure around the well is lowered while water levels may remain stable. The shape of the cone of depression and the rate at which it expands away from the well depends on the coefficients of transmissivity, storage, and rate of pumping. In a confined aquifer, the storage coefficient is the major difference between unconfined and confined pumping. The storage coefficient is proportional to the thickness of the aquifer. Between an unconfined and confined aquifer, confined aquifers tend to be smaller, thus having a smaller storage coefficient, which causes a large influence on the hydraulic pressure and the resulting cone of depression (Alley et al., 1999).

The major difference pumping between a confined and unconfined aquifer is the effect it has on the resulting cone of depression if over-pumped. In an unconfined aquifer, the water level is drawn down, the cone of depression falls with it, and the aquifer is dewatered in the area of the cone (Figure 4). In a confined aquifer, the materials in the aquifer are not dewatered, but there is the potentiometric drawdown of water (Figure 5). Because of the confining layers and other aquifer characteristics (hydraulic conductivity, storage, transmissivity, and size), the cone of depression in a confined aquifer can be up to 2,000 times larger in volume than an unconfined aquifer (Alley et al., 1999). Also, the aquifer's physical properties may result in cones of depression being spatially different. In the cones of depressions illustrated in Figure 4 and Figure 5, the cone is symmetrical; however, based on the aquifer's physical properties, the cone of depression can take on many different forms and span over different distances at differing rates.

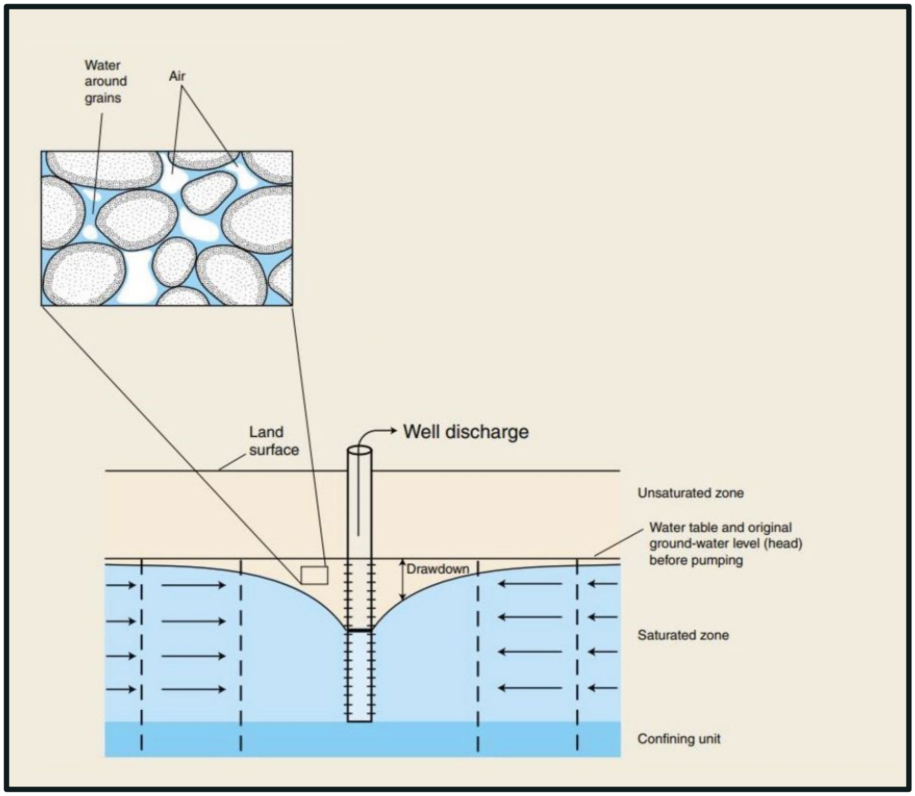


Figure 4. Unconfined aquifer pumping diagram illustrating water table drawdown from a well (Alley et al., 1999).

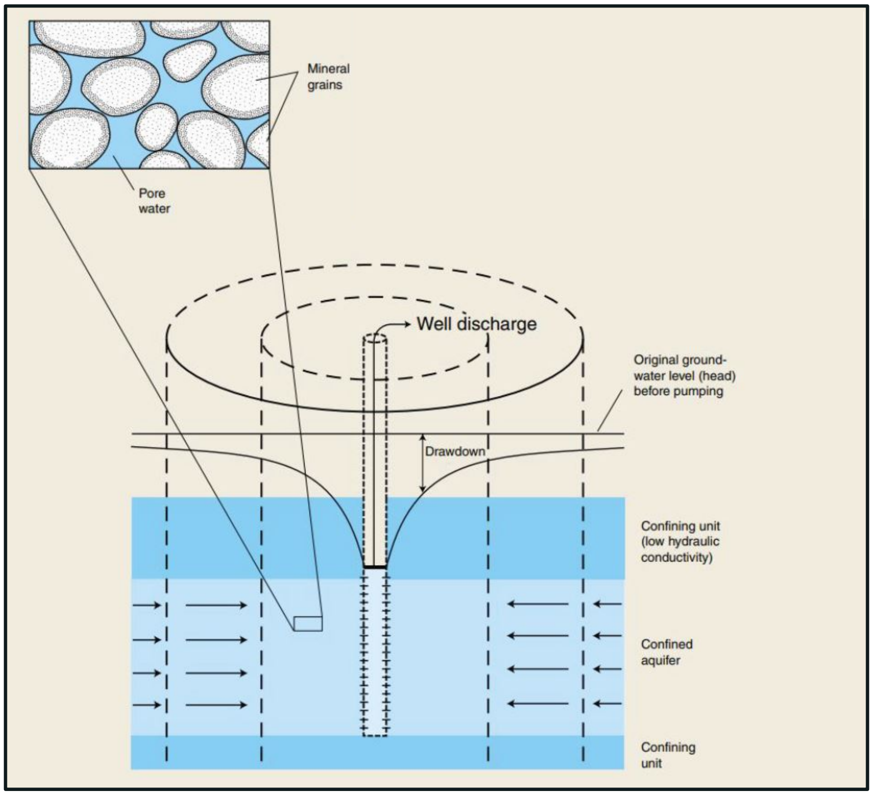


Figure 5. Confined aquifer pumping diagram illustrating water table drawdown from a well (Alley et al., 1999).

Saltwater/Freshwater Dynamics in Coastal Groundwater Systems

Coastal groundwater systems are dynamic as fresh groundwater moves toward the coast. When freshwater and saltwater meet, because saltwater is denser, saltwater sinks below the freshwater (Figure 6). Saltwater intrusion occurs in coastal aquifers when saline groundwater intrudes and contaminates a freshwater aquifer (Dausman & Langevin, 2005). Mixing occurs in the aquifer at the interface between fresh groundwater and saline water. The extent of saltwater intrusion, or the inland position of the saltwater interface, is highly dependent on freshwater levels within the aquifer according to the Ghyben-Herzberg principle (Barlow, 2019). In a static groundwater system, the Ghyben-Herzberg principle states that in relation to a freshwater-saltwater interface, for every foot of freshwater above sea level, there is 40 ft of freshwater below sea level (Figure 6 & Equation 1). If water levels increase in the freshwater part of the aquifer, the interface can move seaward; however, if water levels decrease, the interface may move inland and pose a potential threat to groundwater withdrawals and well fields. Movement of the interface is not instantaneous; months, years, or decades may be required before the interface reaches equilibrium with surrounding water levels. While coastal groundwater aquifer systems are dynamic, upland confined and unconfined aquifers still generally exhibit this principle.

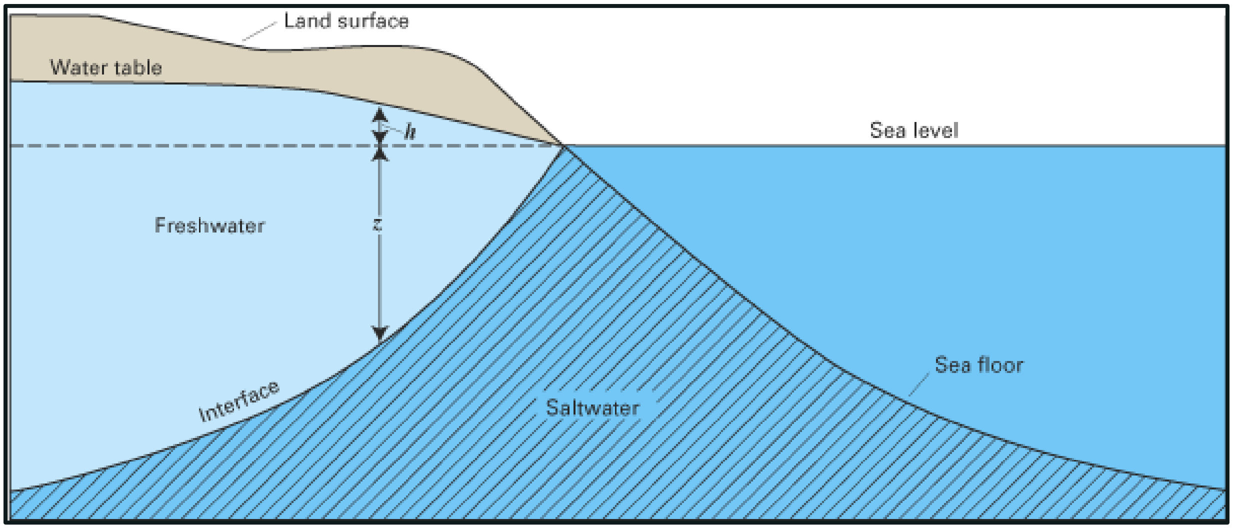


Figure 6. Illustration of freshwater and saltwater interface in a coastal environment with an unconfined aquifer (Barlow, 2019).

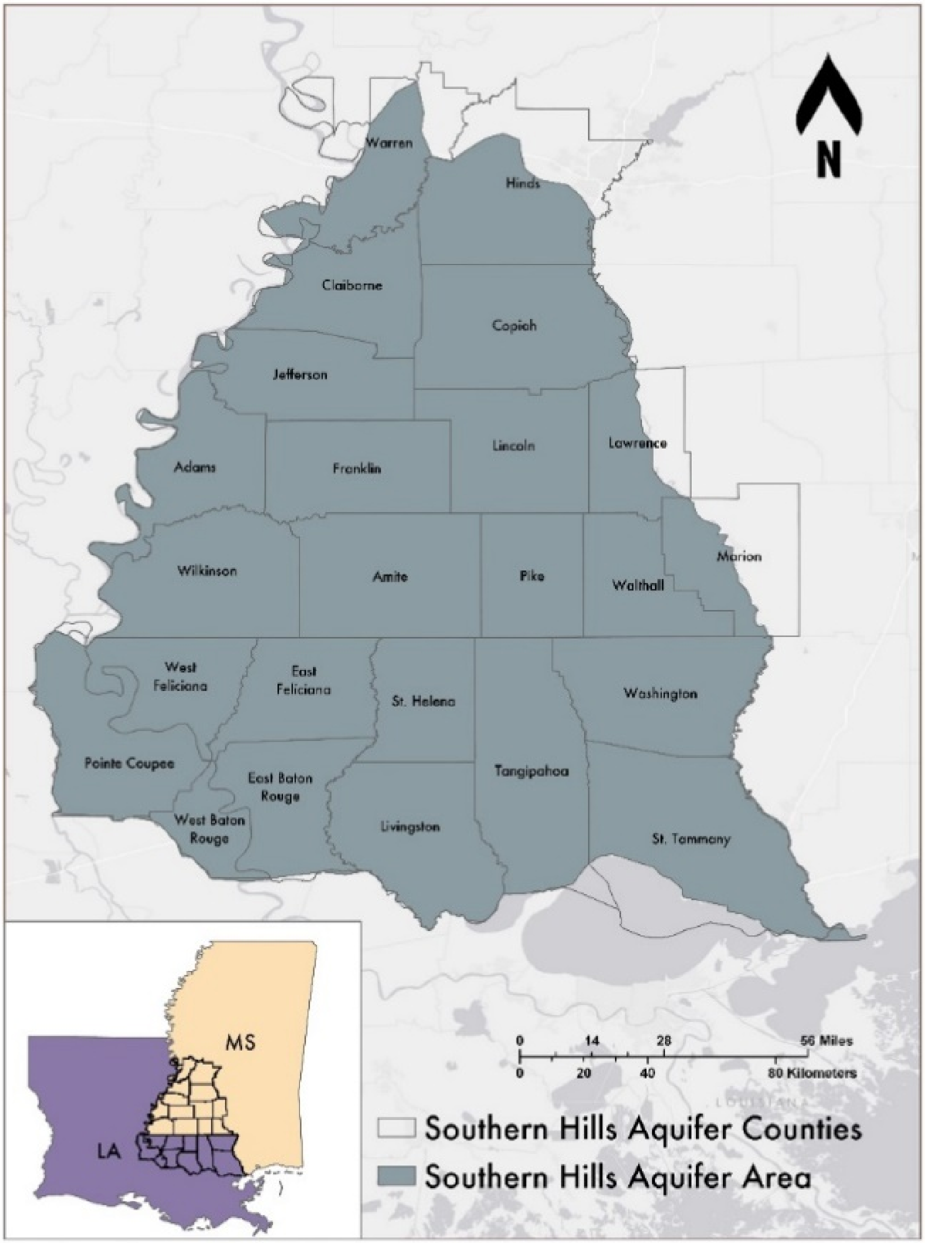
$$z = \frac{Pf}{Ps - Pf} * h \text{ or } z = 40h$$

Equation 1. Ghyben-Herzberg principle, simplified equation. The depth of freshwater below sea level (*z*) is a function of height (*h*), density of freshwater (*Pf*), and density of saltwater (*Ps*).

The SHAS is not a coastal aquifer per se, but it is a confined aquifer with complicated geology as outlined in the following sections. The Ghyben-Herzberg principle generally still applies to the SHAS, but the saltwater is not within the immediate coastal zone. Overall, a fresh groundwater system with water-level declines in an area bordered or underlain by saltwater will have saltwater intrusion into the aquifer. Depending on the amount of drawdown, either water levels and/or hydraulic pressure, as well as aquifer properties and dynamics, the rate of saltwater intrusion will vary.

BACKGROUND OF THE SOUTHERN HILLS AQUIFER SYSTEM

The SHAS covers southeastern Louisiana and spans as far north as Vicksburg, Mississippi (Figure 7). The SHAS covers approximately 14,000 mi^2 and ranges between 200-2,800 ft deep in the Baton Rouge area (Buono, 1983). The aquifer system has been divided into as many as 13 aquifers, although in the Baton Rouge area, 10 are primarily recognized. As the aquifers dip south toward the east-west striking fault called the Baton Rouge Fault, the aquifers start to blend together into 10 singular confined systems (Buono, 1983). Although the system has been locally divided into many confined aquifer units, these aquifers are recognized to be interdependent, collectively forming the SHAS (Hemmerling et al., 2016). A general summary of the geologic ages and names of major water-bearing sand units in the SHAS is included in Table 1. The aquifer names in CAGWCD were determined by their position relative to surface elevation in the Baton Rouge Industrial District (Figure 8 & Figure 9). The Industrial District is a zone adjacent to the Mississippi River and north of downtown Baton Rouge where multiple industries are located and withdraw groundwater from the SHAS (Meyer & Turcan Jr., 1955).

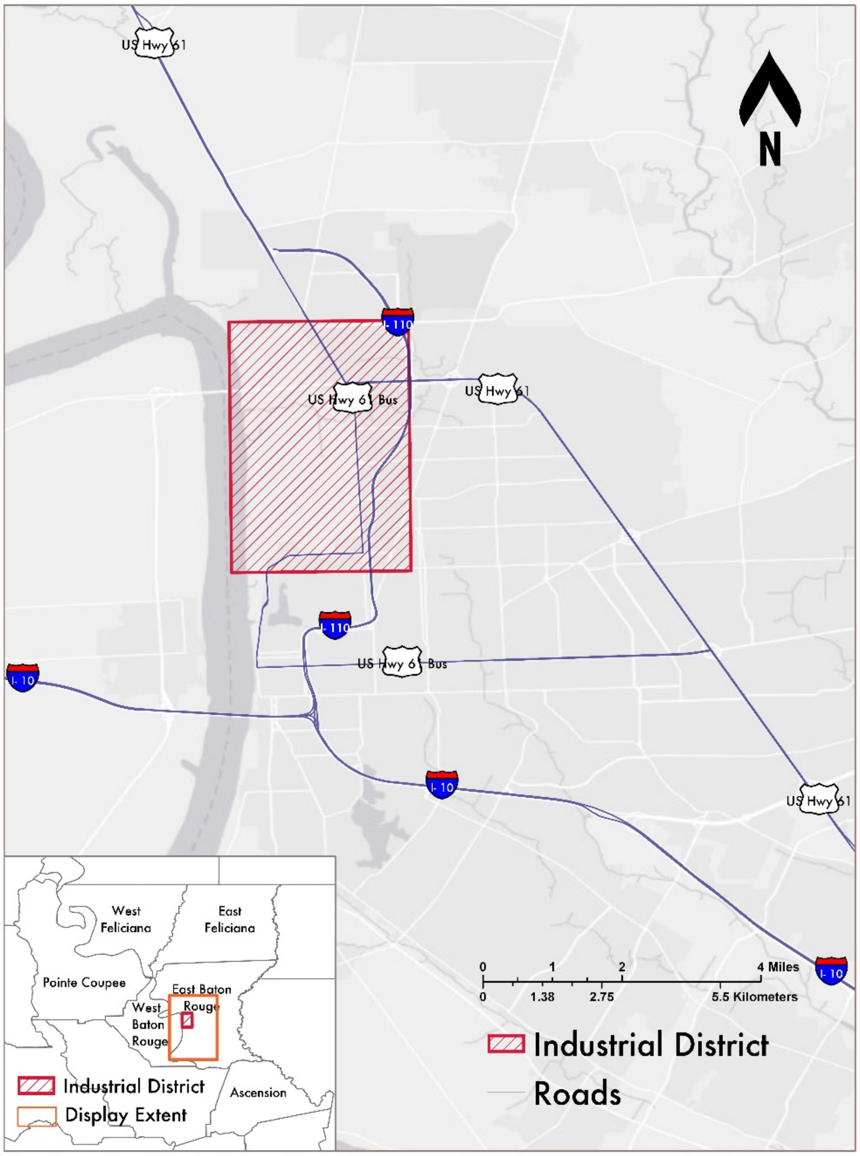


Data Source: Census.gov & https://archive.epa.gov/pesticides/region4/water/groundwater/web/html/r4ssa.html
Esri, HERE, Garmin, (c) OpenStreetMap contributors, and the GIS user community

Figure 7. SHAS extent in Louisiana and Mississippi, U.S.

Table 1. Geology of major sand units in the SHAS (LGS, n.d.)

Geologic Time			Hydrogeologic Unit	
Age (Years Before Present)	**System**	**Series**	**Aquifer System**	**Baton Rouge Area Aquifer Unit**
12,000 to 2.58 million	Quaternary	Pleistocene	Chicot Equivalent	“400 ft” sand
				“600 ft” sand
2.58 to 23.03 million	Tertiary	Pliocene (possibly at top) Miocene	Evangeline Equivalent	“800 ft” sand
				“1,000 ft” sand
				“1,200 ft” sand
				“1,500 ft” sand
				“1,700 ft” sand
			Jasper Equivalent	“2,000 ft” sand
				“2,400 ft” sand
				“2,800 ft” sand



Data Source: https://catalog.data.gov/dataset/tiger-line-shapefile-2016-nation-u-s-primary-roads-national-shapefile
Esri, HERE, Garmin, (c) OpenStreetMap contributors, and the GIS user community

Figure 8. Approximate location of the Industrial District in East Baton Rouge Parish. The surface elevation of each aquifer within the Industrial District yielded aquifer names, i.e., "1,000," "1,500," "2,000 ft" aquifers.

The SHAS is classified as a confined aquifer system with multiple overlapping sand and clay units; the aquifers (sands) are separated from atmospheric pressure by relative impermeability (Figure 9), thus coined as confined (Alley et al., 1999). Originally, the SHAS in the Baton Rouge region was classified as artesian, meaning a well that tapped the aquifer would freely flow higher than the top of the aquifer. All aquifers below "600 ft" in the Industrial District for the SHAS were at one point artesian before the pumping era, which began in the late 1800s/early 1900s (Whiteman Jr., 1980; Meyer & Turcan Jr., 1955). The first-known constructed well in the Baton Rouge area was a public supply well in 1892; records indicated that the well was drilled to 758 ft and that the water would rise to within 6 ft of the surface elevation, 30 ft above mean sea level (Harris, 1905). In 1914, the oil-refining business moved in and industrial pumping began (Meyer & Turcan Jr., 1955).

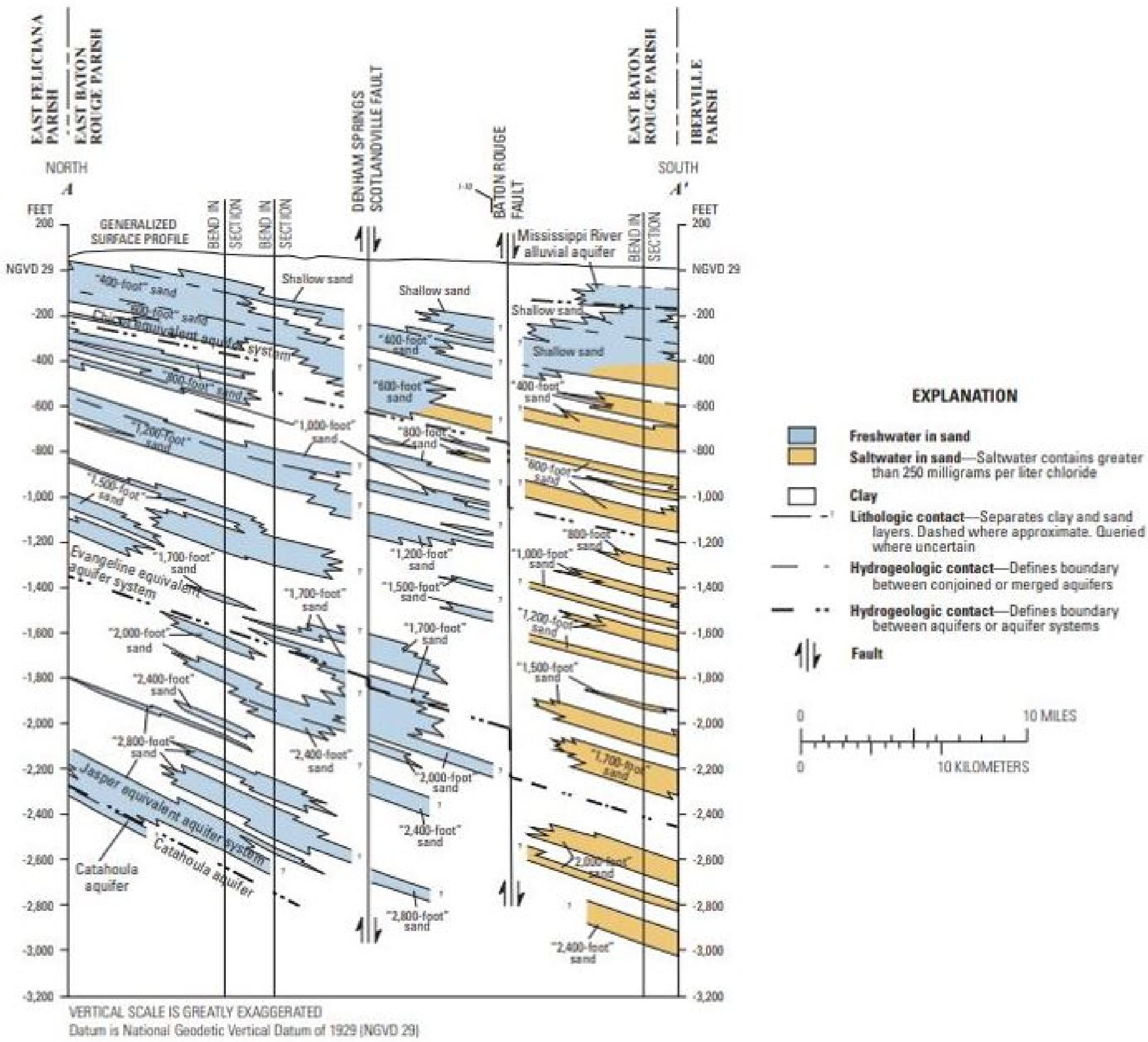


Figure 9. Generalized north-to-south hydrogeologic section of the SHAS. Cross section goes through East Baton Rouge Parish, Louisiana (Griffith, 2003).

Where the aquifers contain multiple sand intervals, the intervals are separated by clays. Within the SHAS there are individual sand and clay beds that vary in size. The sand layers are generally around 75-200 ft thick. Clay intervals between the sand layers are usually 100 ft thick and can be 400-500 ft thick (Table 2,

Table 3, and Table 4) (Whiteman Jr., 1980). The “1,500 ft” and “2,000 ft” sand layers generally dip and thicken to the south and consist of single or multiple 65-95 ft thick intervals of fine to medium sand and 100-300 ft of medium sand. Using the Wentworth grain size classification chart, very fine sand refers to a grain size between $^{1}/_{16}$ to $^{1}/_{8}$ mm, fine grain size refers to $^{1}/_{8}$ to $^{1}/_{4}$ mm, medium as $^{1}/_{4}$ to $^{1}/_{2}$ mm, and coarse being $^{1}/_{2}$ to 1 mm. The average sand unit dips downward, lowers in elevation, approximately 40 ft/mile going from north to south but can vary between 10 to 120 ft/mile depending on the sand unit (Meyer & Turcan Jr., 1955).

Table 2. Hydraulic characteristics of the SHAS (Meyer & Turcan Jr., 1955). The following metrics describe the hydraulic conductivity and average aquifer thickness throughout the sand unit in the SHAS.

Aquifer Unit	Min Thickness (ft)	Max Thickness (ft)	Mean Thickness (ft)	Aquifer Thickness Source	Hydraulic Conductivity (ft/day)	Hydraulic Conductivity Source
“800 ft” sand	50	150	100	(Griffith, 2003)	36	(Griffith, 2003)
“1,000 ft” sand	40	90	65	(Griffith, 2003)	n/a	n/a
“1,200 ft” sand	40	150	95	(Griffith, 2003)	119	(Griffith, 2003)
“1,500 ft” sand	65	95	80	(Griffith, 2003)	142	(Griffith, 2003)
“1,700 ft” sand	130	130	130	(Griffith, 2003)	33	(Griffith, 2003)
“2,000 ft” sand	100	300	200	(Griffith, 2003)	175	(Griffith, 2003)
“2,400 ft” sand	50	250	150	(Griffith, 2003)	79	(Griffith, 2003)
“2,800 ft” sand	50	350	200	(Griffith, 2003)	n/a	n/a

Table 3. Aquifer geologic conditions from major aquifers sampled in 1955 (Meyer & Turcan Jr., 1955).

Aquifer Unit	Grain Size	Yield (gpm)	Transmissivity (gpd/ft)	Storage Coefficient	Specific Capacity (gpm/ft of drawdown)	Source	Notes
"800 ft" sand	Medium-Fine	750	24,000	.001-.000001	12.1	(Meyer & Turcan Jr., 1955)	Data pulled from aquifer recovery test, well EB-467
"1,000 ft" sand	Coarse-Fine				15-26	(Meyer & Turcan Jr., 1955)	EB-398 & 522. No pumping tests were conducted
"1,200 ft" sand	Medium-Fine	1,350	79,000-126,000		38.5	(Meyer & Turcan Jr., 1955)	EB-403
"1,500 ft" sand	Fine sand, silty and sandy clay. Occasional coarse sections	600			25	(Meyer & Turcan Jr., 1955)	
"1,700 ft" sand	Medium - Fine	850-1,245	32,000	.001-.00001	20.2-40	(Meyer & Turcan Jr., 1955)	
"2,000 ft" sand	Fine with occasional gravel	750-2,000	209,000-289,000	.00057-.00079	8-38	(Meyer & Turcan Jr., 1955)	
"2,400 ft" sand	Coarse material is gravel, bulk of material is medium to fine	500-1,000			6-16	(Meyer & Turcan Jr., 1955)	No pump test
"2,800 ft" sand	Granular, coarse - medium	934-1,550			10-18.5	(Meyer & Turcan Jr., 1955)	

Table 4. Water quality characteristics from major aquifers sampled in SHAS

Aquifer Unit	Type	Dissolved Solids (ppm)	Silica (ppm)	Iron	pH	Temperature (°F)	Hardness ($CaCO_3$)	Source	Notes
"800 ft" sand	Soft	208	23	0.04	8.4	78	< 10 ppm	(Meyer & Turcan Jr., 1955)	Data pulled from aquifer recovery test, well EB-120
"1,000 ft" sand	Soft sodium bicarbonate**	190-237*		< 5-340	7.2-8.8	77	2-9 ppm	(Buono, 1983; Meyer & Turcan Jr., 1955; Prakken, 2004)	Well EB-163, low chloride levels, < 10 ppm in 1953
"1,200 ft" sand	Sodium bicarbonate (< .35ppm iron) & alkaline	193-201	30-52	.04-0.35	7.7-8.1	81	< 10 ppm	(Meyer & Turcan Jr., 1955)	Low chloride levels,
"1,500 ft" sand	Very soft sodium bicarbonate	202-219	26-31	0.24-0.25	8.3-8.6	85	2-3 ppm	(Meyer & Turcan Jr., 1955)	Total iron around 0.25 ppm, < 4 ppm chloride
"1,700 ft" sand	Soft sodium bicarbonate (iron being between .01-.04 ppm)	197-200	26-30	0.01-0.04	8.1-8.4	87	< 3 ppm	(Meyer & Turcan Jr., 1955)	Chloride below 5 ppm
"2,000 ft" sand	Very soft sodium bicarbonate	195-241	23-27	0.03-0.23	8.2-9	89	4-10 ppm	(Meyer & Turcan Jr., 1955)	Chloride < 5 ppm

	(iron .03-.13 ppm)								
"2,400 ft" sand	Sodium bicarbonate (iron < .1 ppm)	209-243	22-23	0.03-0.05	> 8.7	91	< 5 ppm	(Meyer & Turcan Jr., 1955)	
"2,800 ft" sand	Sodium bicarbonate	386	25	0.01	8.6	96	4 ppm	(Meyer & Turcan Jr., 1955)	Fresh on top, salty on bottom

Faults in Baton Rouge and the Capital Area Groundwater Conservation District

Within CAGWCD, there are two primary faults, the Denham Springs-Scotlandville Fault and the Baton Rouge Fault (Figure 10). A fault is the boundary between two blocks of sediment/rock that move relative to one another. Both the Denham Springs-Scotlandville and Baton Rouge faults are active, but not known to be able to cause earthquakes. Activity of these faults was determined by breaks in foundations and cracks in roads or slabs along the fault lines. Traditionally, faults were identified via escarpments that are long strips of land that slope in a continuous direction showing the displacement of land on both sides of the fault line (Figure 11). The introduction of Digital Elevation Models (DEM) and Light Detection and Ranging (LiDAR) have made it easier to identify these faults (Figure 10).

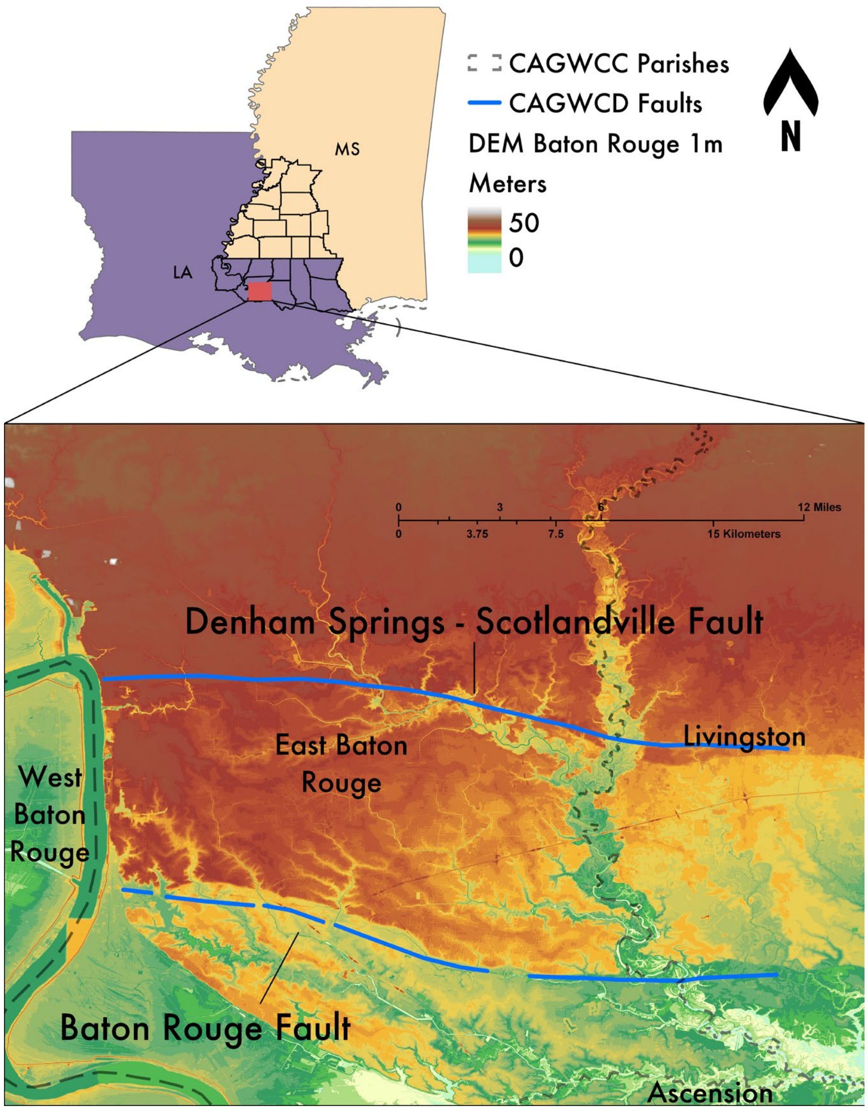


Figure 10. 1 m DEM and approximate location of two faults in Baton Rouge. Denham Springs-Scotlandville Fault (North of Baton Rouge) and the Baton Rouge Fault (within Baton Rouge).

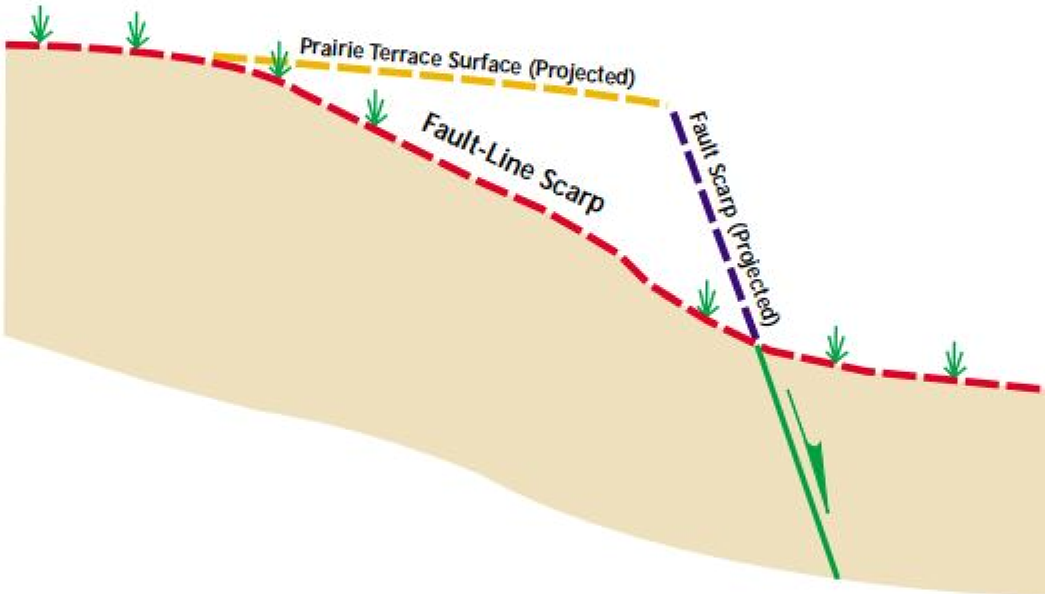


Figure 11. Schematic section across the Baton Rouge Fault (McCulloh, 2001)

The Baton Rouge Fault is one of the several growth faults that run east-west across southeastern Louisiana. These faults tend to exhibit a rollover or "reverse drag" effect that are common to Gulf Coast faults; Figure 12 is a simple diagram of a typical growth fault and shows the rollover effect. As the downthrown block dips, tectonic activity pulls the downthrown block south and new material is deposited along the fault. The land surface on the south side of these east-west faults dip and are normally reversed within the next mile, hence the term rollover. In particular, the Baton Rouge Fault shows this reversal. South of the Baton Rouge Fault, the downthrown block exhibits a northward slope of up to 10 ft/mile (Durham & Peeples, 1956). A defining feature of these growth faults tends to be a different local environment between the northern slope of the downthrown block and the fault. Within Baton Rouge, Clay Cut Bayou represents this transition between the downthrown and upthrown blocks along the Baton Rouge Fault (Durham & Peeples, 1956). As the downthrown block dips south, it creates an offset in the geological layers.

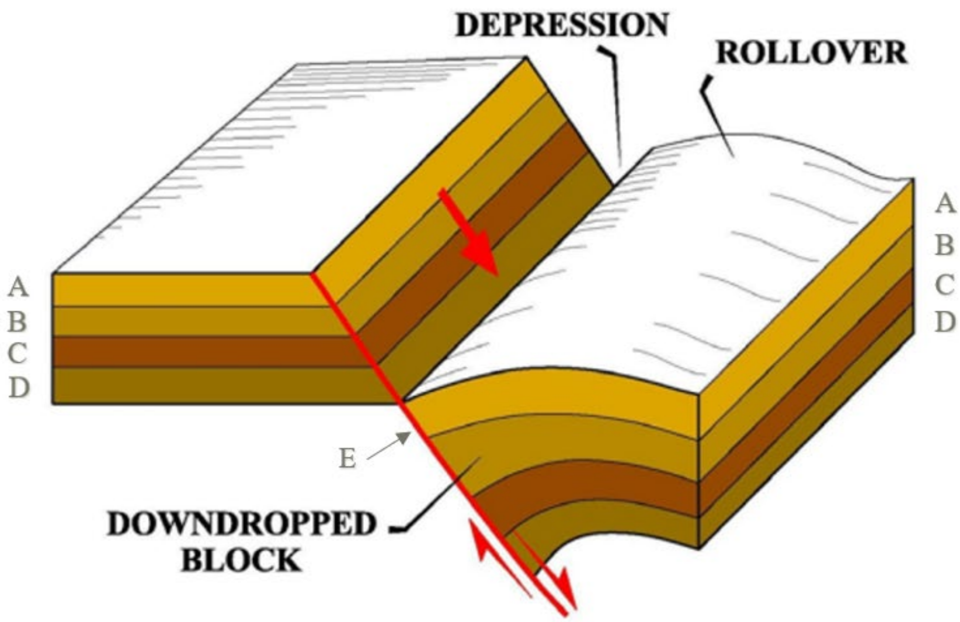


Figure 12. Modified schematic diagram of a typical growth fault with rollover effect (*Effects of Geological Faults on Levee Failures in South Louisiana*, 2005).

Offset represents the displacement between geologic layers across a fault which can be either horizontal or vertical in nature. For example, in Figure 12, layers A-D are displaced across the fault which can differ in distance depending on the fault activity; therefore, depending on the depth of the geological unit, and the angle of the fault (E), a geologic unit may extend farther south. For the SHAS, this represents how sand layers may extend farther south than the approximate location of the Baton Rouge Fault. For example, the Baton Rouge Fault shows an offset of up to 344 ft at the top of the "2,000 ft" sand (Elshall et al., 2013).

Attention tends to be the more focused on the Baton Rouge Fault in the Baton Rouge area because it acts as a leaky barrier to groundwater movement (including saline groundwater) and is the approximate southern limit of freshwater in the SHAS (Figure 10). South of the Baton Rouge Fault, the water in the aquifer system is generally saline and not usable for potable water (Figure 9). The western extent of the SHAS is marked by a zone of saline water within the Pliocene and Miocene sediments (corresponding to the Evangeline and Jasper equivalent "800" to "2,800 ft" sands) that lie beneath the Mississippi River alluvial valley (Hemmerling et al., 2016).

Recharge/Discharge of the Southern Hills Aquifer System

Outcrops of the SHAS (areas of exposed bedrock or areas of permeability where water can enter for groundwater recharge) are primarily located south of Jackson, Mississippi, and in southwestern Mississippi (Figure 7). The farthest northern extent of the outcrops for the SHAS is around Vicksburg, Mississippi, in Warren County (Figure 7). Recharge for the SHAS is primarily from direct percolation of precipitation to the water table in the outcrop areas while discharge is primarily due to pumping (Buono, 1983). Estimates of recharge in the SHAS are relatively unknown, although some estimates have been compiled but at differing scales. A recent approximation of the total amount of water flowing through the Baton Rouge area (Hai Pham & Tsai, 2017) shows that the major proportion of total inflow (recharge) was modeled to come from the east and west boundaries of the model domain (Figure 13). Within the model domain, the Baton Rouge area simulated a total average annual inflow of 580,000 m^3/day (Figure 1413) between the Denham Springs-Scotlandville and Baton Rouge Faults (Hai Pham & Tsai, 2017). Approximately 581,000 m^3/day was estimated as flow leaving the Baton Rouge area that was heavily associated with pumping of groundwater via wells (Hai Pham & Tsai, 2017). The rates of both inflow and outflow have varied over the analyzed time with strong correlations being tied to groundwater pumping (Figure 14).

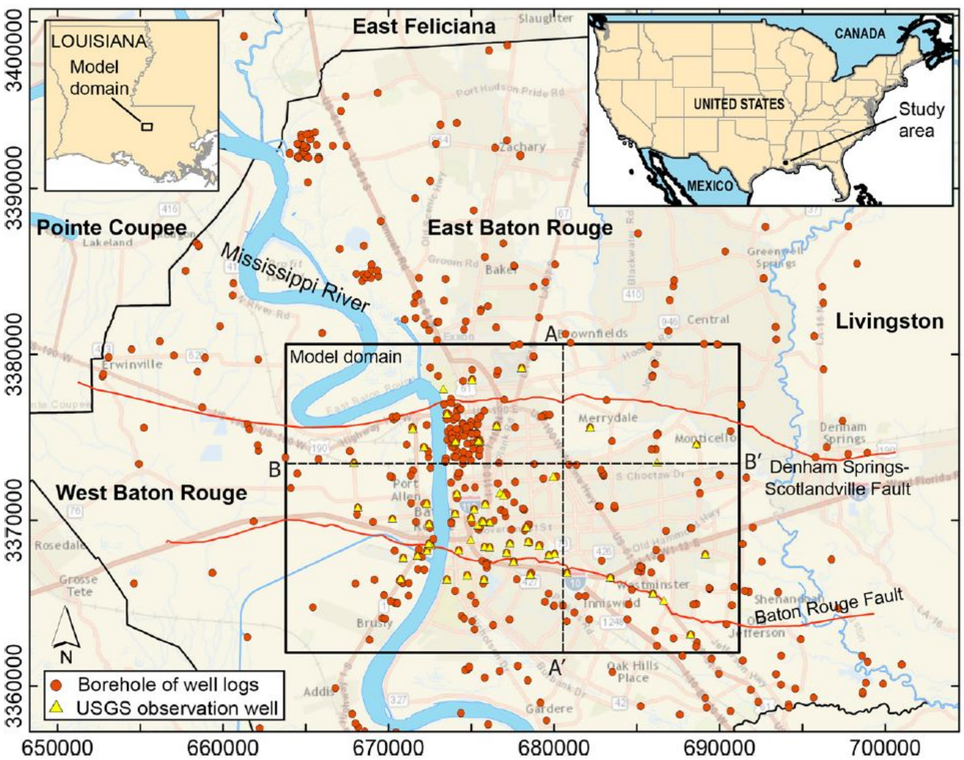


Figure 13. Model domain used to model the complex aquifer system in Baton Rouge (Hai Pham & Tsai, 2017).

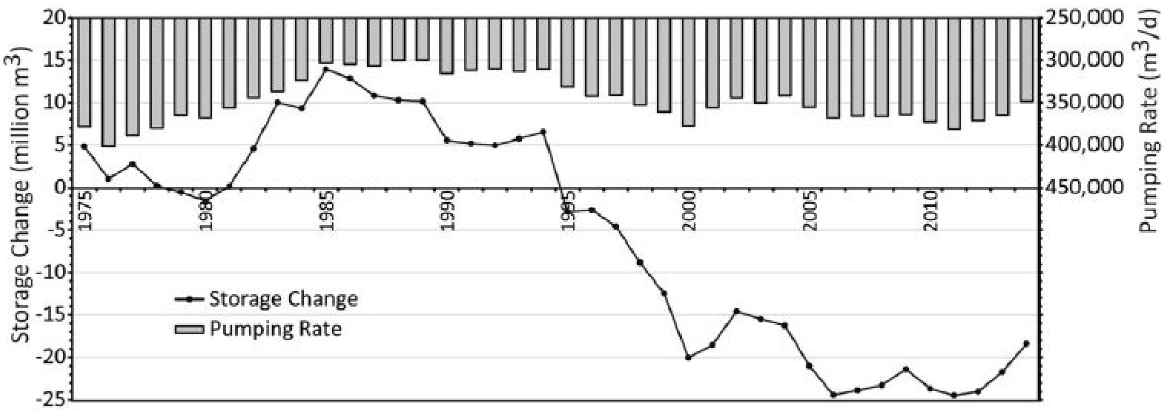


Figure 14. Simulated groundwater storage and well pumping levels in Baton Rouge model domain (Hai Pham & Tsai, 2017).

Historically, the discharge of the SHAS occurred between aquifers as water rose through layers of sand and clay beds as stream runoff or evaporation near the Baton Rouge Fault. These same areas were known to have potentiometric surfaces with water levels as much as 100 ft above sea level (Tomaszewski et al., 2002). With the industrial/public pumping era beginning in the early 1900s, groundwater that historically discharged as upward seepage at land surface was being intercepted as flow to pumped wells. Currently, the major discharge of aquifers in the SHAS is induced by pumped wells. Storage levels of the SHAS aquifers within the Baton Rouge model domain show high correlation with pumping levels (Hai Pham & Tsai, 2017). An excellent demonstration on the correlation between pumping and storage levels in the aquifer can be seen between the years of 1975 to 1985, where pumping rates were lower, consequently yielding a larger increase in storage (Figure 14).

HISTORY OF AQUIFER USE

In 1892, the first recorded public supply well was completed in the Baton Rouge area, and withdrawals for industry began in 1914 (Meyer & Turcan Jr., 1955). In 1953, withdrawals in the Baton Rouge area for public supply and industrial uses were estimated to be approximately 65 Mgal/d (Meyer & Turcan Jr., 1955). By 1960, approximately 210 Mgal/d were being withdrawn in southeastern Louisiana, with approximately 100 Mgal/d in East Baton Rouge Parish (Snider & Forbes, 1960). Extensive cones of depression at major pumping centers (Baton Rouge) had developed by the 1960s (Rollo, 1969). The cones of depression mapped in Figure 15, Figure 16, and Figure represent the potentiometric surface for the "1,500 ft" sand from 1951-2003. The large increase in the cone of depression over time is a result of excess withdrawal and a lagging response in recharge within the area. Over time, as withdrawals in the area have outpaced recharge, the cone has grown to meet the changed hydraulic pressure. By the 1970s, water levels throughout much of southeastern Louisiana were declining in response to large withdrawals in the Baton Rouge area and other smaller withdrawals in southeastern Louisiana.

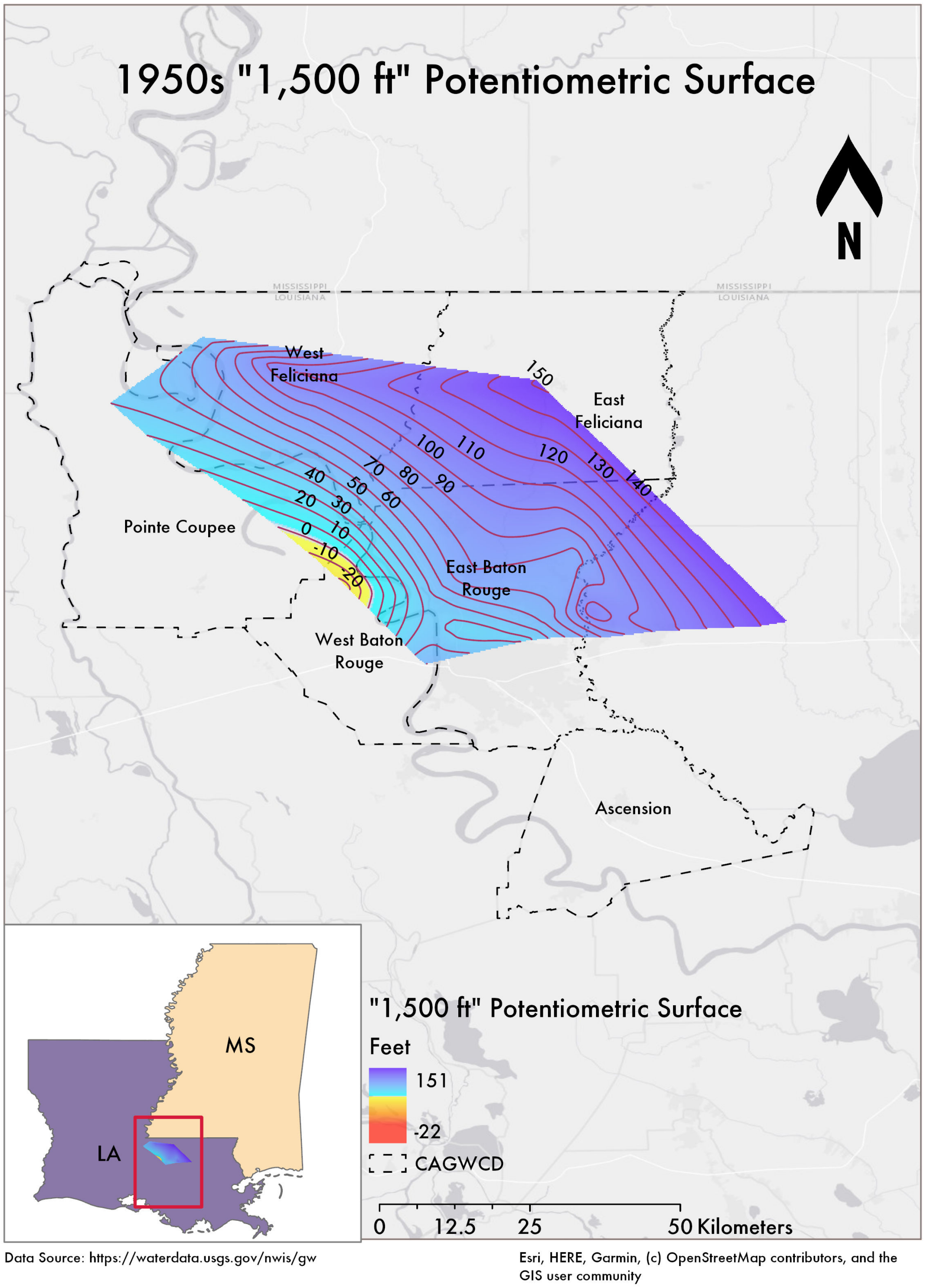


Figure 15. The 1950s "1,500 ft" potentiometric surface was developed using Empirical Bayesian Kriging from 13 different wells with data availability in the "1,500 ft" aquifer between the years 1950-1953 (*USGS Groundwater Data for the Nation*, 2020). The color difference from blue to yellow represents positive to negative potentiometric surface levels.

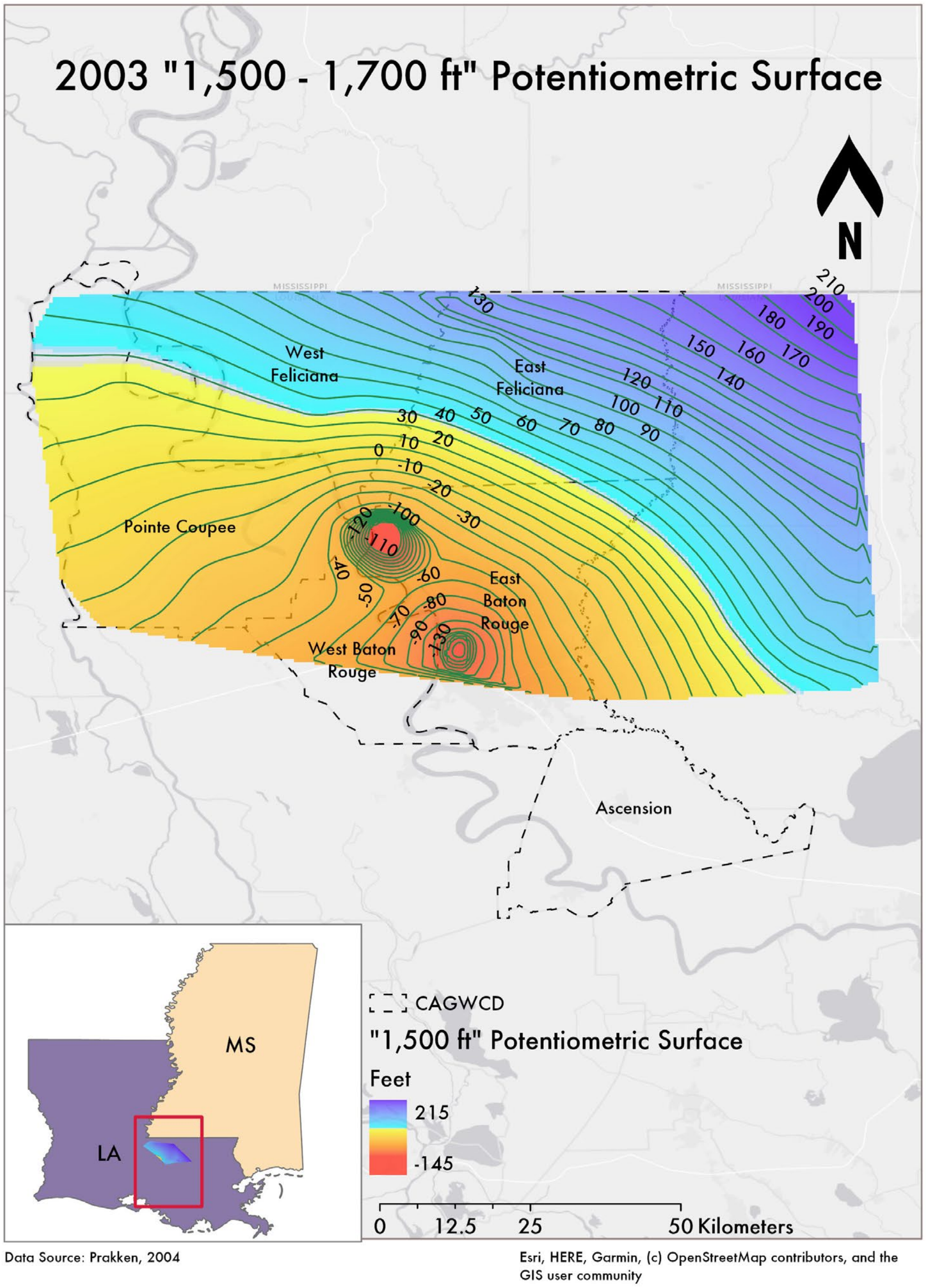


Figure 16. The 2003 "1,500 ft" potentiometric surface adapted from Prakken (2004).

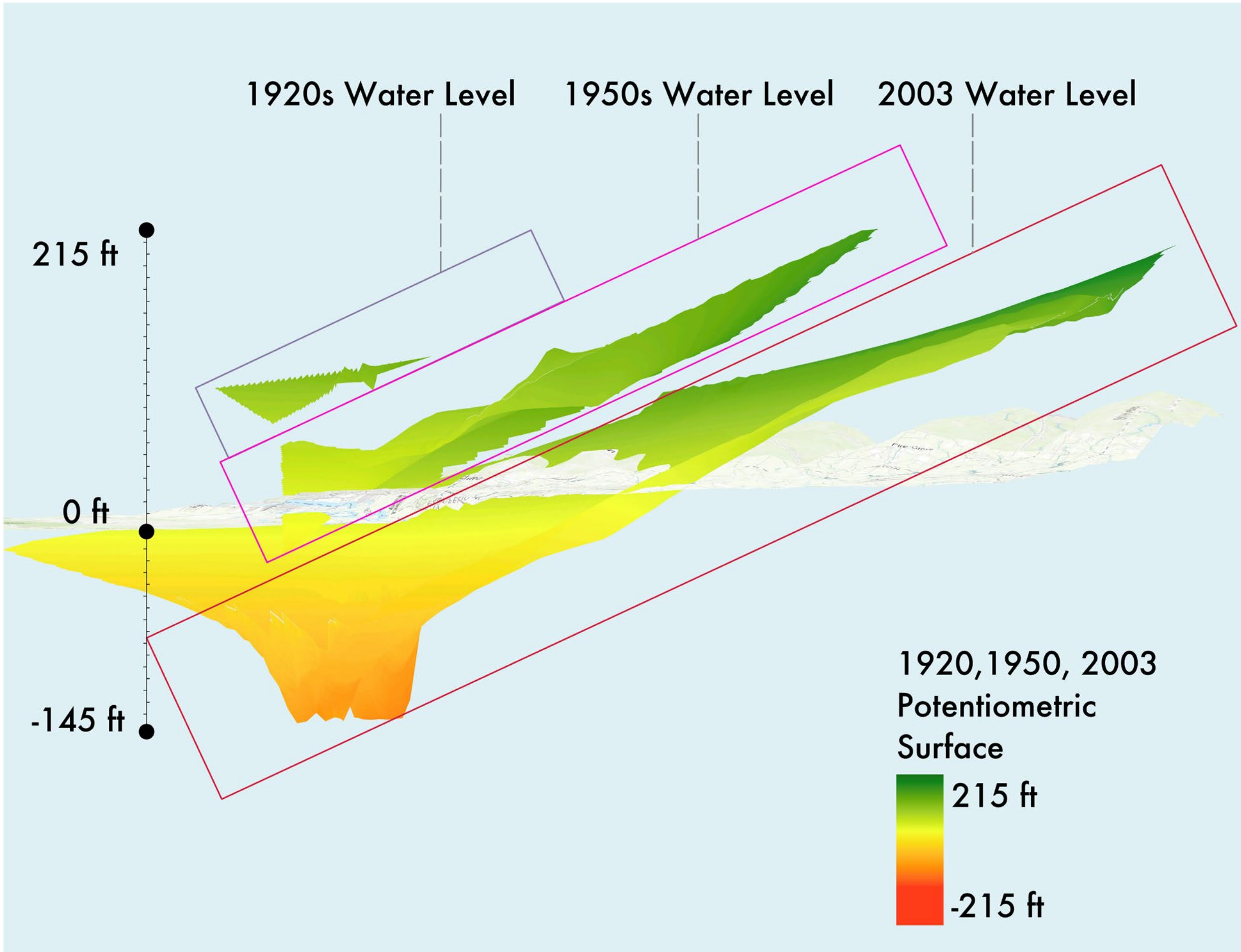


Figure 17. "1,500 ft" 3D potentiometric surfaces of Baton Rouge "1,500 ft" aquifer from the 1920s, 1950s, and 2003 (Prakken, 2004; *USGS Groundwater Data for the Nation*, 2020). The largest drawdown is -145ft in 2003 within in the Industrial District. Data availability was limited to northern border of southeast Louisiana.

In 2000, the SHAS was the third most pumped aquifer in Louisiana at approximately 291 Mgal/d (Tomaszewski et al., 2002). In 2010, approximately 171 Mgal/d of water were withdrawn in East Baton with approximately 150 Mgal/d being groundwater sources (USGS, 2017). By 2014, roughly 293 Mgal/d of groundwater were withdrawn from the 10 parishes that utilize the SHAS (White & Prakken, 2015). Over time, the withdrawal of groundwater from certain aquifers has varied for many reasons and uses including industrial, commercial, domestic, agricultural, and aquaculture. Within the CAGCWD, groundwater from the "1,500," "2,000," "2,400," and "2,800 ft" aquifers have traditionally been the heaviest withdrawn for both industrial and public uses. Over time, usage of the "1,700" and "2,400 ft" sands has continued to increase while withdrawals from the "1,500 ft" has seen a decline (Figure 18).

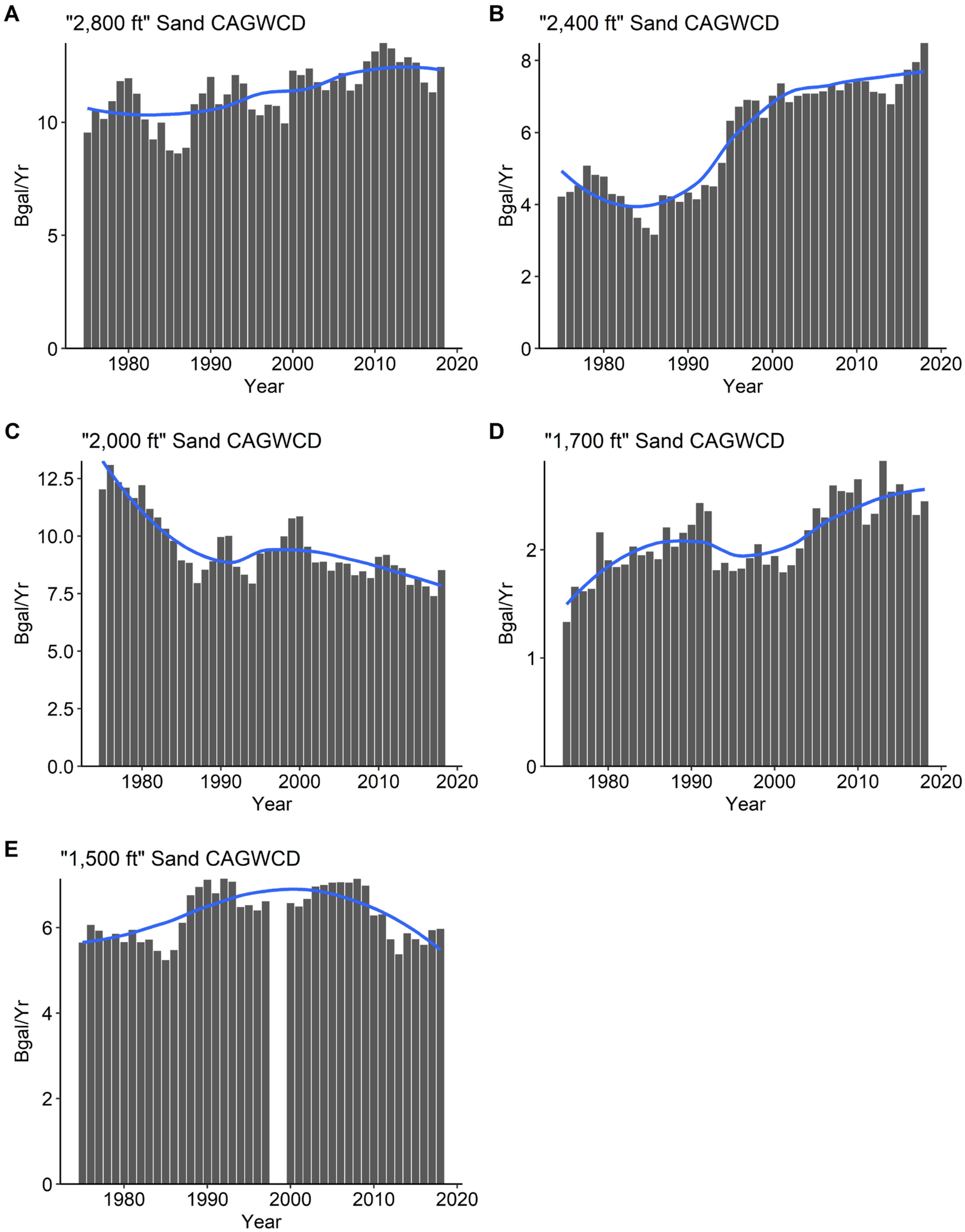


Figure 18. Trends in the SHAS for major sands in CAGWCD (CAGWCC, 2019b).

In the past, the largest aquifer users outside of public supply (Baton Rouge Water Company [BRWC] and West Baton Rouge Gas and Water) included Georgia-Pacific, ExxonMobil, Entergy, Eco-services, Honeywell, and the surrounding cities such as Zachary and Baker. The most significant water resource uses have varied over time, but most recently, Georgia-Pacific implemented reductions in groundwater pumping. In early 2019, Georgia-Pacific began to reduce some of their major operations associated with manufacturing paper (Karlin, 2019). The response of the aquifers with this large decrease in pumping could be significant in determining the resilience of the aquifer, meaning that if water withdrawal would decrease, the aquifer could demonstrate an ability to recover, or not. Early indications from a USGS monitoring well (EB-849, completed in the 1,700 ft sand), located approximately 1 mile east of the Georgia-Pacific facility, shows approximately 100 ft of drawdown from the 1960s to 2019 (Figure 19). This well has shown approximately 50 ft of recovery from a recorded low of 154.56 ft below land surface in October of 2011 to 97.41 ft below land surface in February 2020. More data collection and studies are needed to determine the nature, timing, and spatial distribution of groundwater level rise as a result of reduced aquifer pumping and how the behavior of this example might indicate responses to other changes in withdrawal and in other sand units.

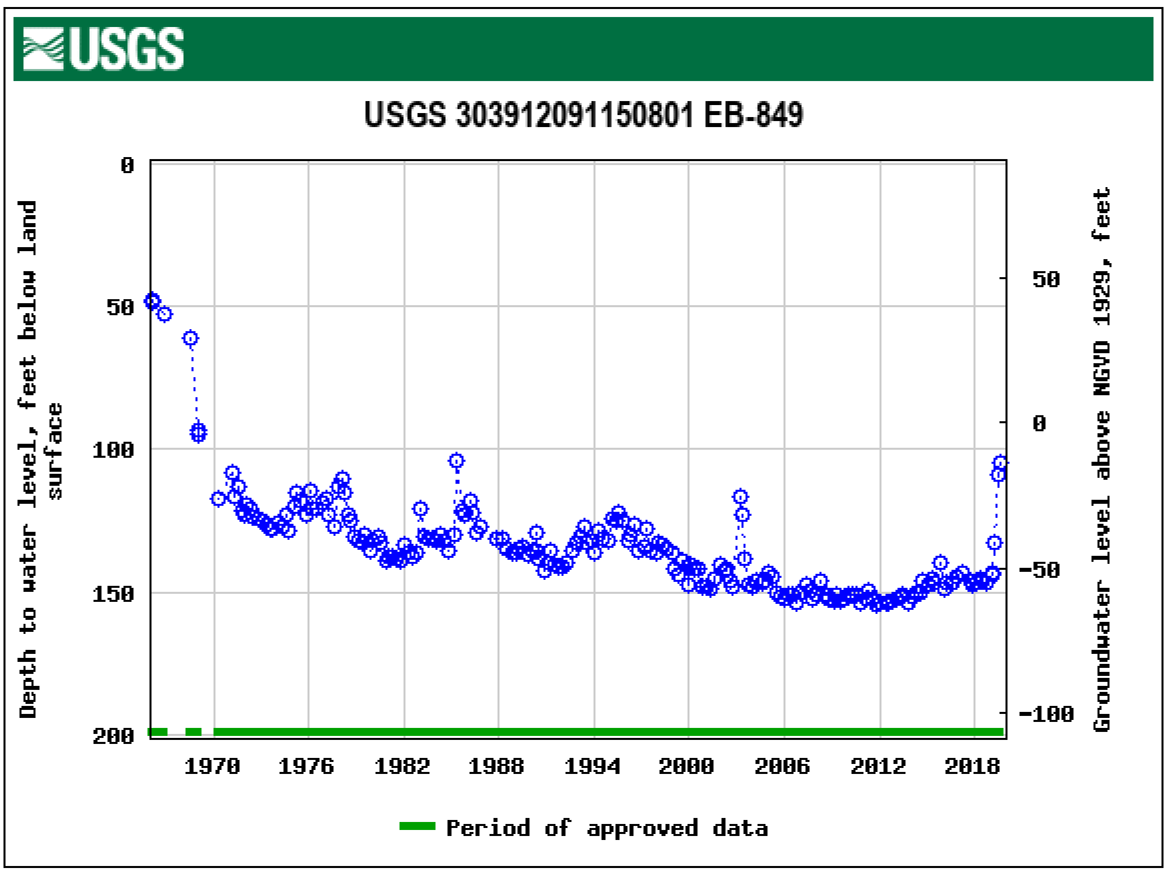


Figure 19. Groundwater level within well EB-849 showing historical trend from the 1970s to 2019.

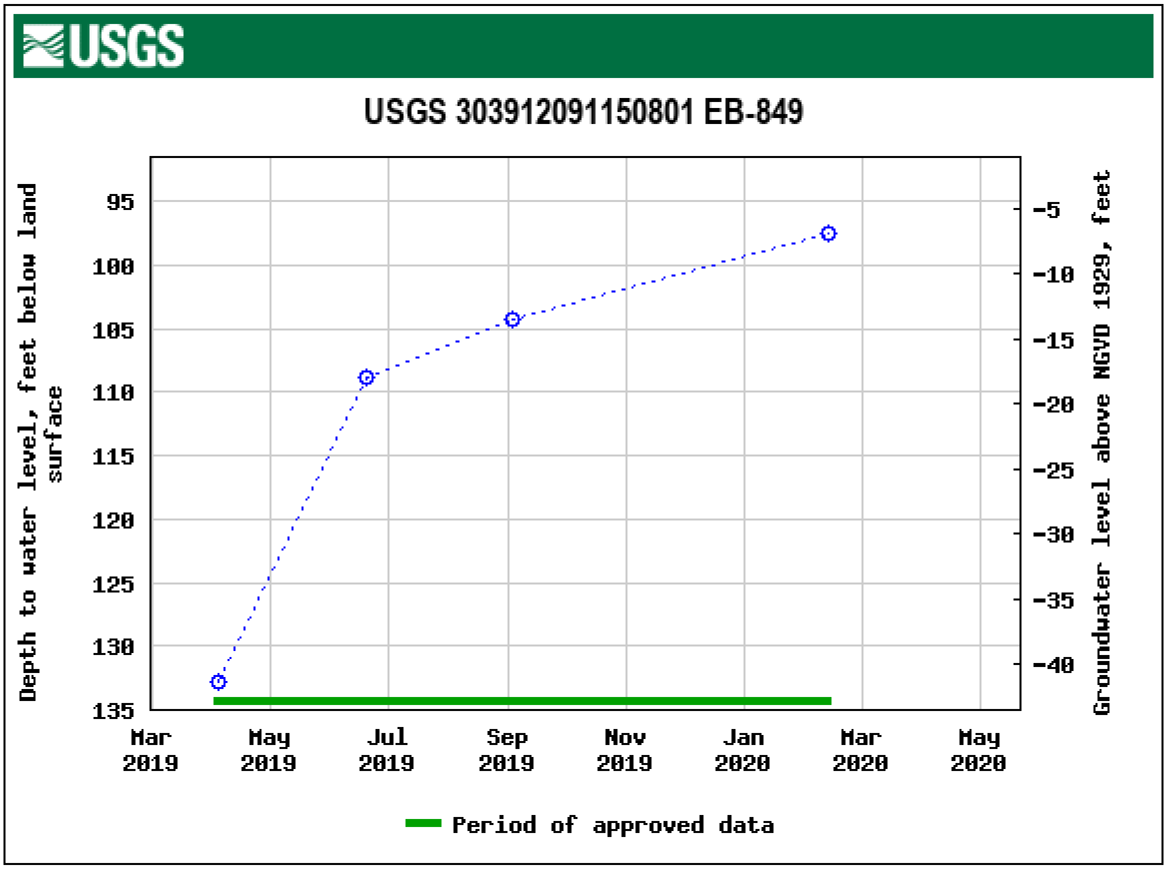


Figure 20. Groundwater level in monitoring well EB-849 (Figure 19) detail from March 2019 - 2020.

The latest USGS report on groundwater use in Louisiana shows that East Baton Rouge Parish accounts for the largest share of groundwater usage in the SHAS (USGS, 2017). The industrial and public sector both withdrew approximately 72 Mgal/d (Collier & Sargent, 2018). Though industrial and public supply have been the largest users of groundwater over time, their withdrawal rates have varied (Figure 21 & Table 5); between 1980 and 1985, the industrial sector decreased groundwater withdrawal rates as much as 29.5 Mgal/d. Public withdrawals though have been steadily increasing over time. Population increase and the addition of Ascension Parish to CAGWCD may also contribute to larger public water use in the near future. Water demand is subject to many factors which includes population growth, technology improvements, supply substitutes (surface water), governmental policy, and other potential unforeseen factors.

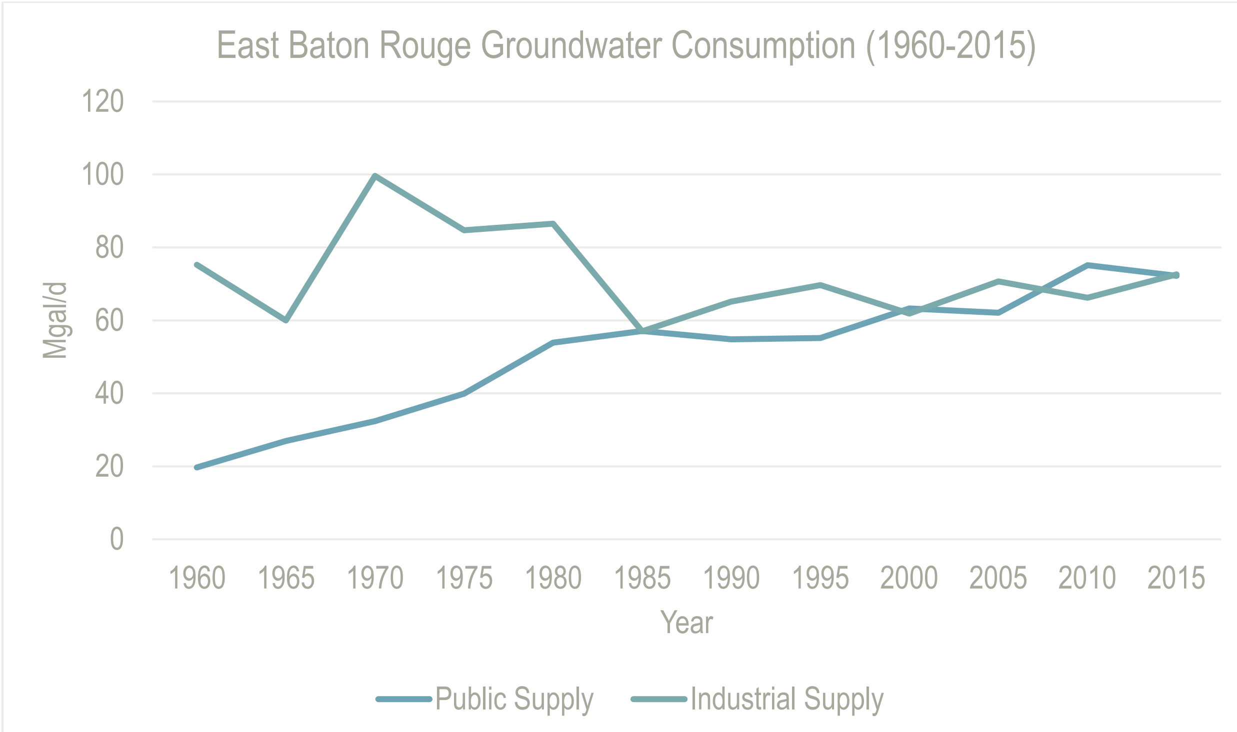


Figure 21. East Baton Rouge Parish public and industrial groundwater use (given in Mgal/d) from 1960-2015. Location: East Baton Rouge Parish (Collier & Sargent, 2018; USGS, 2016).

Table 5. East Baton Rouge records of groundwater withdrawn by sector in Mgal/d (Collier & Sargent, 2018; USGS, 2016).

Year	Aquaculture	General Irrigation	Industrial	Livestock	Power Generation	Public Supply	Rice Irrigation	Rural Domestic	Total Groundwater
1960	0	0	75.25	0.02	0.00	19.7	0	1.45	96.42
1965	0	0	59.99	0.13	7.32	26.93	0	0.94	95.31
1970	0	0.35	99.59	0.28	7.48	32.4	0	0.35	140.45
1975	0	0.19	84.7	0.14	7.14	39.9	0	0.31	132.38
1980	0.06	0.14	86.5	0.14	7.07	53.9	0	1.73	149.54
1985	0.42	0.06	57	0.15	3.00	57.1	0	0.42	118.15
1990	0.95	0.12	65.14	0.24	5.77	54.8	0	0.40	125.73
1995	0.14	0.1	69.68	0.14	5.04	55.16	0	0.26	130.39
2000	0.07	0.27	61.88	0.13	8.31	63.27	0	0.25	135.66
2005	0.02	0.43	70.69	0.16	5.12	62.07	0	0.26	145.91
2010	0.04	0.25	66.22	0.19	7.79	75.12	0	0.28	149.89
2015	0.22	0.39	72.59	0.07	7.4	72.21	0	0.24	153.12

History of Saltwater Intrusion

Saltwater, typically identified using chloride levels as a proxy, in Baton Rouge aquifers was first found in well EB – 123 screened in the "600 ft" aquifer when chloride levels surged from 7 ppm in 1943 to 710 ppm in 1950 (Meyer & Turcan Jr., 1955). Since then, several wells have seen increasing chloride concentrations throughout the SHAS near the Baton Rouge Fault (Rollo, 1969; Tomaszewski et al., 2002; Appendix F: Annotated Bibliography).

Saltwater intrusion within the Baton Rouge sands is attributed to high groundwater withdrawal rates in the Baton Rouge area (Rollo, 1969). There are two stances on the sources of saltwater intrusion into the Baton Rouge aquifers. The first stance is that saltwater has migrated up the Baton Rouge Fault, from older halite, commonly known as rock salt, formations. The second school of thought is that brine associated with fractures in salt domes south of the Baton Rouge Fault has moved north along Miocene sands to the Baton Rouge aquifers (Anderson, 2012; Bray & Hanor, 1990).

In 2007, USGS published a study that revealed eight out of the ten major aquifers north of the Baton Rouge Fault had noticed an increase in chloride levels (Lovelace, 2007). In general, fresh groundwater north of the Baton Rouge Fault contains less than 10 mg/L of chloride. From these 152 samples (Table 6), the "600," "1,000," "1,200," "1,500," "1,700," "2,000," "2,400," and "2,800 ft" sand recorded one or more well samples with background chloride levels above 10 mg/L (Lovelace, 2007; Tomaszewski et al., 2002). Appendix A: "1,500 ft" Sand Saltwater Encroachment and Appendix B: "2,000 ft" Sand Saltwater Encroachment both illustrate the approximate location and extent of saltwater plumes crossing north of the Baton Rouge Fault into the Baton Rouge area.

Table 6. Snapshot of saltwater intrusion in sampled aquifer in East and West Baton Rouge Parish (Lovelace, 2007). Black boxes denote presence of saltwater intrusion. *Chloride reading may not be associated with saltwater migration.

Aquifer Unit	1960s	1970s	1980s	1990s	2000s	2010s	Relative Chloride Impact	Highest Chloride detected (mg/L), 2004-2005	Area Affected
"400 ft"							1	17.1	
"600 ft"							2	49.4	Area between Baton Rouge Fault and Industrial District
"800 ft"							1		
"1,000 ft"							10	9,140	Airline @ Sherwood, Shenandoah, Tiger Bend
"1,200 ft"							7	150	Essen Lane, I-10/12 Split
"1,500 ft"							9	1,010	Larger area, from Port Allen to Tiger Bend, and north to Industrial District
"1,700 ft"							2	50*	
"2,000 ft"							8	266	Area between Baton Rouge Fault and Industrial District
"2,400 ft"							4	129	Airline @ Sherwood, Shenandoah, Tiger Bend
"2,800 ft"							7	262*	Area north of Industrial District

The “1,500 ft” aquifer is one of the most documented aquifers in CAGWCD for water levels, potentiometric surface, aquifer characteristics, and saltwater intrusion. When studies regarding saltwater intrusion in the “1,500 ft” aquifer became more publicly accepted, Baton Rouge grew concerned that their public groundwater supply well would be threatened by the saltwater encroachment. CAGWCC acted by studying alternative methods for mitigation which included scavenger wells, well movement, barrier wells, doublet wells, and connector wells. Ultimately, CAGWCC chose to pursue a connector well. In doing so, CAGWCC submitted a proposal to the U.S. Environmental Protection Agency (USEPA) to help fund the construction of a connector well. A connector well is a well that connects two different aquifers to help restore hydraulic gradient. The hope was to restore the hydraulic gradient to help divert or impede saltwater encroachment.

In January 1995, the USEPA partially funded CAGWCD’s proposal for a connector well in the form of a grant for $391,000; the grant was issued under the Clean Water Act Section 319(h), Non-point Source Implementation. Both the “1,000” and “2,000 ft” aquifers were considered to be candidates for the connector well, but the “1,500 ft” aquifer was chosen because of its importance to public supply and was most vulnerable to immediate saltwater intrusion near the Government Street well field (Dial & Cardwell, 1999). The connector well was constructed to hydrologically connect two aquifers, in this case, the “800” and “1,500 ft” aquifers. By connecting the “800” and “1,500 ft” aquifers, there would be an opportunity to help mitigate the differences in potentiometric surface north of the Baton Rouge Fault, thus preventing saltwater contamination at the Government Street water wells (Dial & Cardwell, 1999). The modeled efforts of the connector well revealed that groundwater would move westward and around the Government Street well field. The well was first made operational in 1999, and a metering system revealed that the connector well injected approximately 475 gpm (Dial & Cardwell, 1999). Today, the connector well is still in operation and appears to continue to function as a connecting source between the “800” and “1,500 ft” aquifers.

Historical Aquifer Management

CAGWCC was created in 1974 to promote the orderly development and conservation of CAGWCD groundwater resources. Traditionally, CAGWCC has managed the CAWGCD with usage fees, well permitting, and voluntary pumping limits. Rules such as the reservation of the “1,000,” “1,500,” and “1,700 ft” aquifers for public supply, groundwater withdrawal fees of $1.00/Mgal, and other actions have been taken to manage groundwater usage (Enabling Legislation CAGWCC Revised Statutes Part XIII, 2015).

CAGWCD is currently composed of six parishes: East Baton Rouge, West Baton Rouge, East Feliciana, West Feliciana, Pointe Coupee, and Ascension (Figure 22). CAGWCC is composed of representatives from each parish including additional members that represent user groups (industry, public supply, and agriculture) as well as from parish governments and state agencies. The two state agencies represented on CAGWCC include the Louisiana Department of Natural Resources (LDNR) – Office of Conservation and the Louisiana Department of Environmental Quality (LDEQ).

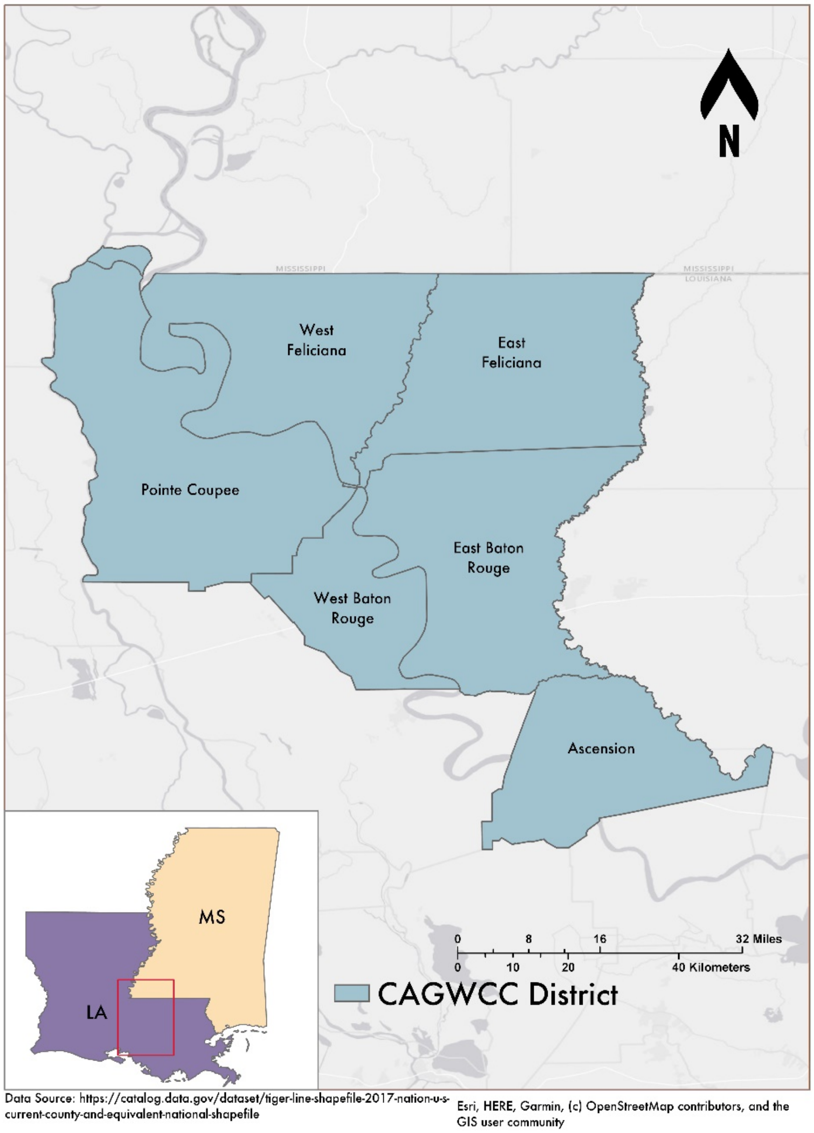


Figure 22. CAGWCD spatial domain.

The LDNR consists of five major divisions: Oil & Gas, Energy, Mineral Resources, Conservation, and Coastal Management (which are further subdivided). Regarding groundwater, the Office of Conservation oversees the Environmental Division, which is responsible for implementing the groundwater management program. The groundwater resources program's purpose is to identify areas of groundwater concern, address groundwater emergencies, establish best management practices, and help establish policies for the state's groundwater.

With regard to environmental water quality, LDEQ is responsible for monitoring the quality of natural resources, including both surface and groundwater. This department issues permits, enforces regulations, monitors, and runs programs that help users whose actions relate to environmental quality. Groundwater is monitored through LDEQ's Water Planning and Assessment Division through their Aquifer Sampling and Assessment Program. The Louisiana Department of Health (LDH) also monitors water quality through their Safe Drinking Water Program. This program monitors more than 1,300 public water systems to ensure both state and federal water quality parameters are met to ensure the safety of water consumers. They do this via monitoring, inspections, and engineering plan reviews of public water systems (LDH, n.d.).

CAGWCC was charged to develop, promote, and implement management strategies to provide for the conservation, protection, and sustainable use of local groundwater resources in CAGWCD (CAGWCC, 2019a). Some of the major actions CAGWCC has undergone include contracting modeling work, scientific studies, connector wells, and the implementation of a scavenger well. Most recently, withdrawal fees have been raised from \$10/Mgal to \$20/Mgal of groundwater withdrawal and CAGWCC installed a monitoring well for the potential of more scavenger wells north of the Baton Rouge Fault.

In 2009, wells EB-917 and EB-918 for the "1,500 ft" sand aquifer and EB-630, EB-1028, and EB-1150 for the "2,000 ft" sand started to detect saltwater intrusion (Lovelace, 2007). With this and supporting evidence about the saltwater intrusion, BRWC contracted Layne Christensen Company, which performed studies and modeling to determine what was the best course of action for BRWC. Dr. Vic Kelson the chief hydrologist and modeler along with Layne Hydro, a division of Layne Christensen Company, offered a solution using a scavenger well system (National Driller Magazine, 2013). Scavenger wells function as a syphon whereby differential pumping pressures extract both saltwater and freshwater separately allowing pumps to continue without the threat of saltwater contamination (Figure 23).

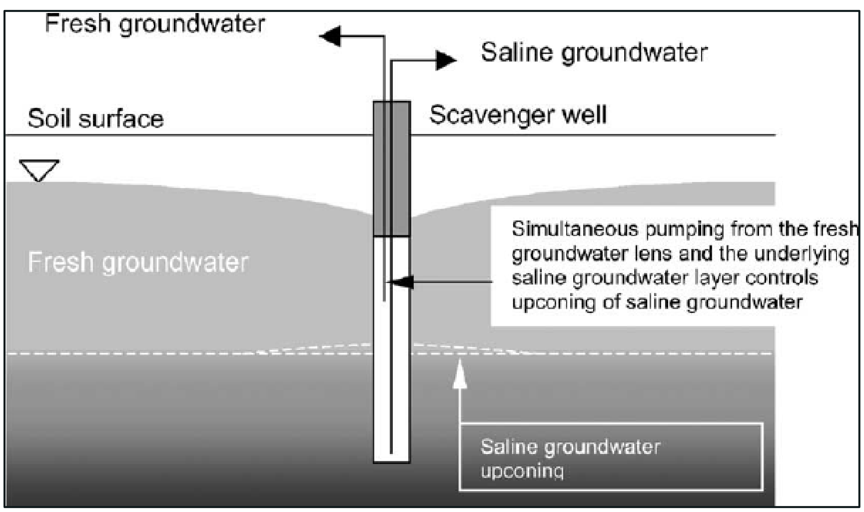


Figure 23. Scavenger well diagram where two different pumps, represented by the vertical black lines within the vertical rectangle, pump at different rates and depths to syphon freshwater and saltwater separately (Ali et al., 2004).

In 2014, Baton Rouge's first scavenger well was installed between 31st and 32nd St. along North St.to prevent saltwater intrusion into the Lula Street pumping station (Figure 24). The Lula Street pumping station is property of the BRWC and functions as one of the primary water well fields for public supply in the Baton Rouge area (Figure 24). Data on the scavenger well are sparse, but modeling efforts in both the

“1,500” and “2,000 ft” sands revealed that the scavenger well attenuates chloride levels near the production wells (Heywood et al., 2014, 2019). In addition to the USGS modeling, Dr. Frank Tsai also concluded that saltwater intrusion could be mitigated using a scavenger well. With successful implementation of a scavenger well along with a pumping rate of 1 Mgal/d, chloride levels were modeled to sustain levels below 150 mg/L for the next 50 years (Tsai, 2011). Other modeling efforts have analyzed the effect a horizontal scavenger well could have on the “2,000 ft” aquifer. Modeled by Jina Yang, and using a surrogate model solution, she was able to determine that the implementation of a horizontal scavenger well could reduce the chloride wedge (Figure 25) significantly if properly optimized for saltwater moving toward the Industrial District (Yin, 2019).

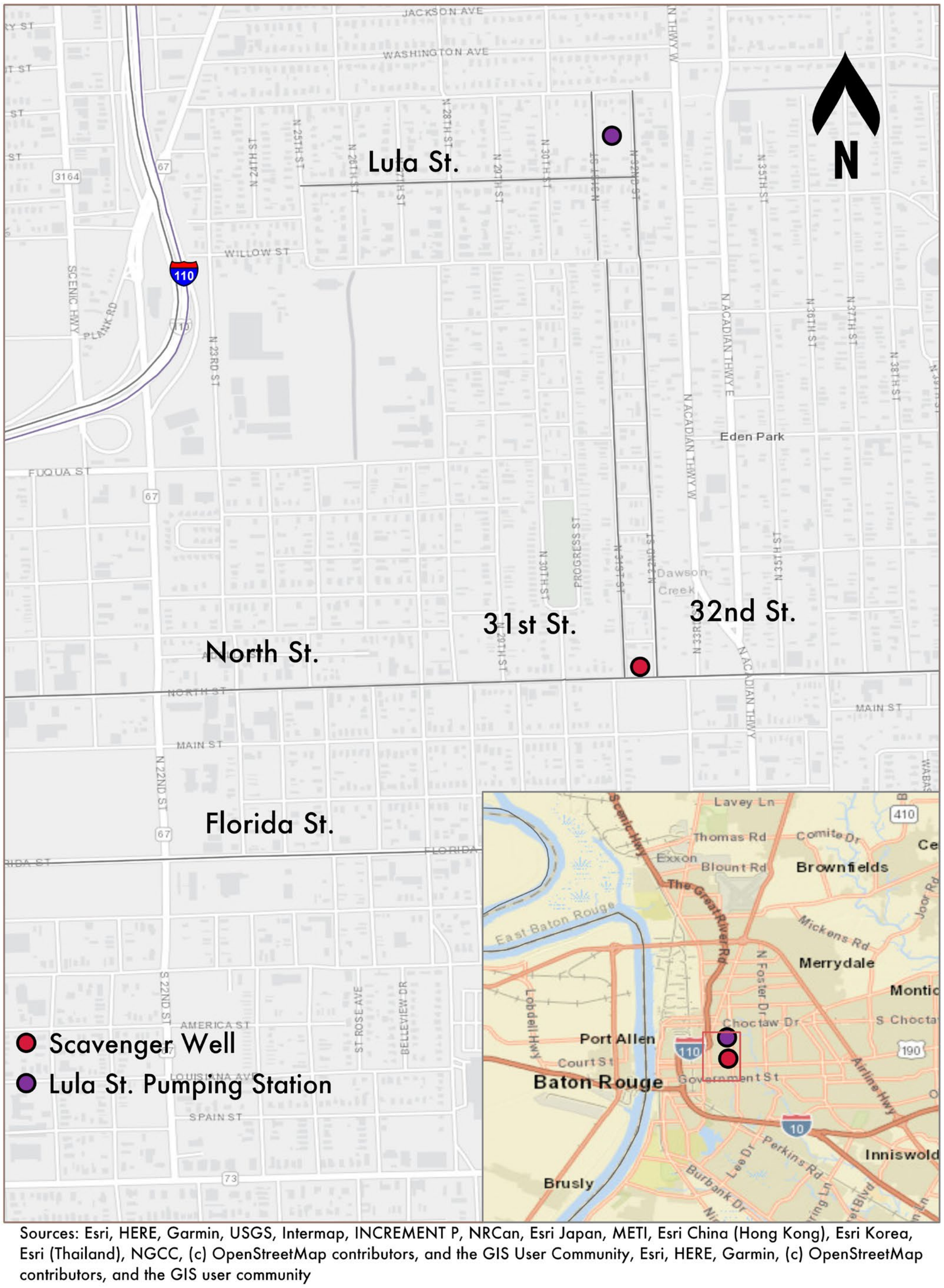


Figure 24. The location of the first installed Baton Rouge scavenger well and one of the largest pumping stations in the Baton Rouge area, Lula St. pumping station.

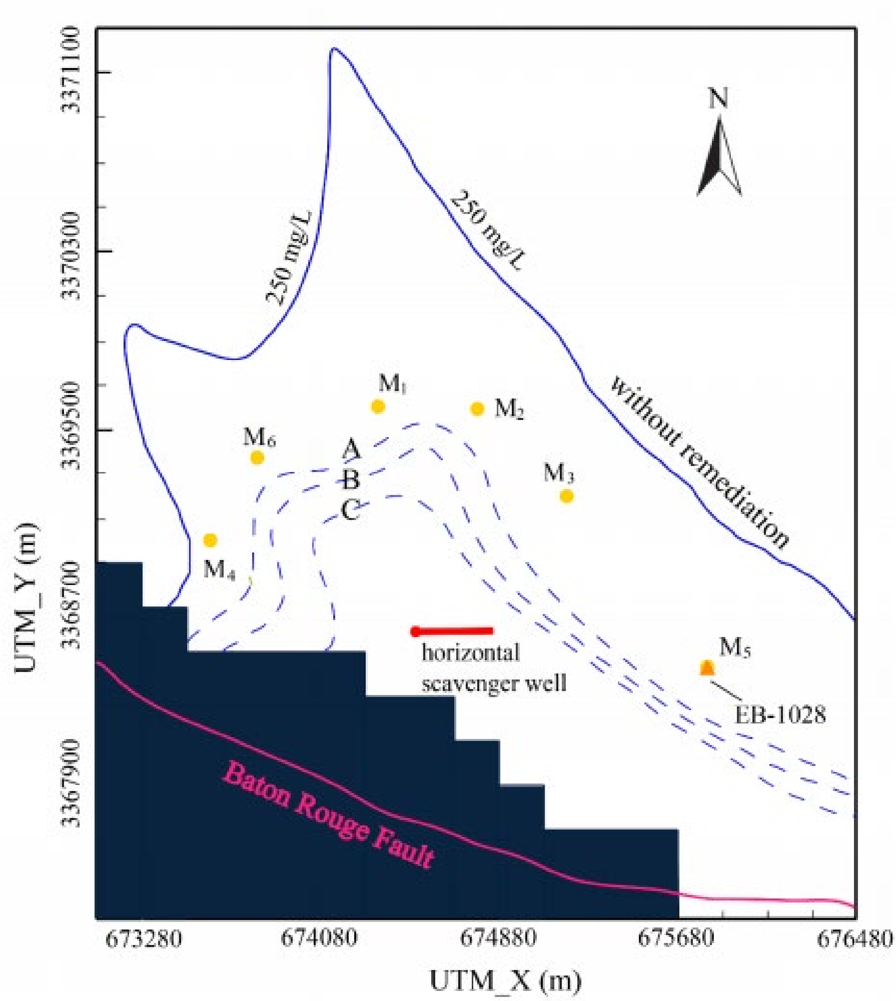


Figure 25. Modeled attenuation of a horizontal scavenger well within the "2,000 ft" aquifer (Yin, 2019).

USGS modeled several different scenarios to help understand the impact of saltwater intrusion north of the Baton Rouge Fault. These modeled scenarios also included the effect a scavenger well could have on saltwater encroachment within the "1,200," "1,500," "2,000," "2,400," and "2,800 ft" aquifers (Table 7). The complex hydrogeology associated with Baton Rouge required both a constant and variable-density groundwater flow model. Across the multiple modeled scenarios within the previously mentioned aquifers, there were eight common scenarios:

1. Maintain current pumping levels;
2. Reduce groundwater withdrawals;
3. Increase groundwater withdrawals;
4. Reduce groundwater withdrawals and incorporate scavenger wells;
5. Maintain groundwater withdrawals and incorporate scavenger wells;
6. Cease pumping in certain aquifers;
7. Combine reduction in withdrawals across different aquifers; and
8. Redistribute groundwater wells to other aquifers.

Table 7. Summary of USGS modeled scenarios with accompanying saltwater plume areas and implementation of a new scavenger well within the "1,200," "1,500," "2,000," "2,400," and "2,800 ft" sands (Heywood et al., 2014, 2015, 2019).

Scenario	Simulation Description	Source
1	Continuation of the 2007 pumping rate through 2047 which served as a benchmark for water levels and chloride concentrations	(Heywood et al., 2014)
2	Effect of reducing groundwater withdrawals from seven selected industrial wells by 10.8 Mgal/d beginning in 2015 on water levels in the "1,500 ft" sand	(Heywood et al., 2014)
3a	2.0 Mgal/d withdrawal from a scavenger well beginning in 2017 at the base of the "2,000 ft" sand with the scavenger well modeled in row 57, column 26	(Heywood et al., 2014)
3b	2.0 Mgal/d withdrawal from a scavenger well beginning in 2017 at the base of the "2,000 ft" sand with the scavenger well modeled in row 68, column 30	(Heywood et al., 2014)
4	3.6 Mgal/d reduction in withdrawals from the "2,000 ft" sand at selected industrial wells beginning in 2015	(Heywood et al., 2014)
5	Cessation of withdrawals from the "2,000 ft" sand within the Industrial District beginning in 2015 (16.625 Mgal/d reduction in withdrawals)	(Heywood et al., 2014)
6	Combined effect of a 1.375 Mgal/d reduction in withdrawals from the "2,000 ft" sand in 2015 with a 2.5 Mgal/d withdrawal from a "scavenger well couple" accompanied by a 1.5 Mgal/d reduction in withdrawals from public supply wells beginning in 2017	(Heywood et al., 2014)
7	3.6 Mgal/d reduction in withdrawals from the "2,000 ft" sand at selected industrial wells beginning in 2016	(Heywood et al., 2014)
8	Cessation of withdrawals from the "2,000 ft" sand within the Industrial District beginning in 2015 (16.625 Mgal/d reduction in withdrawals)	(Heywood et al., 2014)
9	Combined effect of a 1.375 Mgal/d reduction in withdrawals from the "2,000 ft" sand in 2015 with a 2.5 Mgal/d withdrawal from a "scavenger well couple" accompanied by a 1.5 Mgal/d reduction in withdrawals from public supply wells beginning in 2018	(Heywood et al., 2014)
10	Continued groundwater withdrawals at 2012 rates from 2013-2112	(Heywood et al., 2015)

Scenario	Simulation Description	Source
11	Increased groundwater withdrawals from the “1,200 ft” sand between 2013-2112	(Heywood et al., 2015)
12	Modification of groundwater withdrawals from the “2,000 ft” sand between 2013-2112	(Heywood et al., 2015)
13	Modification of groundwater withdrawals with installation of a scavenger well in the “2,000 ft” sand between 2013-2112	(Heywood et al., 2015)
14	Reduction of industrial withdrawals from the “2,000 ft” sand between 2013-2112	(Heywood et al., 2015)
15	Extensive reduction of industrial and public supply withdrawals from the “2,000 ft” sand between 2013-2112	(Heywood et al., 2015)
16	Extensive reduction of industrial and public supply withdrawals with installation of a scavenger well in the “2,000 ft” sand between 2013-2112	(Heywood et al., 2015)
17	Continued groundwater withdrawals at 2016 rates through year 2112	(Heywood et al., 2019)
18	Decreased groundwater withdrawals from the “2,800 ft” sand	(Heywood et al., 2019)
19	Redistribution of groundwater withdrawals from the “1,500 ft” to the “2,800 ft” sand	(Heywood et al., 2019)

Current Aquifer Management

In the Framework for a Long-term Strategic Plan for the Capital Area Groundwater Conservation Commission (i.e. planning framework) document, there is a "business as usual" strategy (Table 8), which details the current efforts CAGWCC is taking to manage the SHAS and assumptions about how it would unfold in the future absent any additional strategic planning. The nature of the strategy is to make use of voluntary efforts to manage groundwater production in select sands and saltwater concentration at select wells. The CAGWCC current management strategy is founded around three primary elements: voluntary production limits on select sands that exhibit signs of saltwater intrusion; engineering solutions (scavenger wells) to address specific saltwater intrusion problems; and an assumption that if additional water is needed in the future, market-driven forces will lead to private investment in infrastructure (Table 8).

Table 8. "Business as Usual" strategy in managing the groundwater in CAGWCD.

Strategy	Action
Permitting	The only change in permitting envisioned in this strategy is that new permits for production will not be granted for sands that have exceeded their voluntary production caps. Two sands currently have voluntary production caps, and in neither case is the cap yet exceeded.
Zoning	In 1975, CAGWCC reserved the "1,500" and "1,700 ft" sands for public supply. Although there is not yet a formal mechanism to enforce this zoning, CAGWCC intends to require construction northward of the Baton Rouge fault zone.
Fee Schedules	Per its legislative mandate, CAGWCC applies uniform fees to all producers to meet its basic costs of operation, with any fee increase being approved by the state's legislature. Domestic and other users receiving water from the BRWC have their fee scheduled determined by the BRWC in conjunction with the Louisiana Public Service Commission (LPSC); currently that fee schedule makes water less expensive for larger users (Appendix D: BRWC Rate Structure Analysis).
Production Caps	This strategy relies on setting voluntary production caps for select sands as needed. In 2013, the "1,500 ft" sand was capped at 25 Mgal/d. In 2014, the "2,000 ft" sand was capped at 23.5 Mgal/d, a further reduction of 1 Mgal/d from the 2013 cap of 24.5 Mgal/d. Both are voluntary, and while no known violations have occurred, there is no mechanism in place to assign responsibility to individual producers for excess production at the sand level.
Pollution Mitigation	BRWC, with permission of CAGWCC, installed a saltwater scavenger well in the "1,500 ft" sand to protect a key source of public supply. CAGWCC is currently scouting locations for a second scavenger well to mitigate saltwater movement within the "2,000 ft" sand.

Strategy	Action
Promoting Awareness	This strategy relies on other organizations, such as the LDNR Office of Conservation, to undertake any direct educational activities related to awareness and conservation of groundwater.
Incentivizing Conservation	This strategy does not include any incentive programs for reducing water consumption.
Water Supplementation	This strategy relies on market-driven forces to motivate and support the creation of any additional sources of water.

Water Use and Demand

Understanding water supply and demand trends throughout a region is important to sustainably managing any water resource. Forecasting water demand is complicated by differing trends in water use over time, trends between users, technology advancements, policy actions, and uncertainty in water supply. With population growth, changing climate variables, and urbanization, forecasting water demand will become increasingly difficult. However, there are many ways water demand can be forecasted. These forecast methods include linear regressions, scenario analysis, and even highly complicated techniques such as machine learning and artificial neural networks which can consider multiple water demand and supply variables simultaneously (Vijai & Sivakumar, 2018).

In 2016, the Institute released a report that helped estimate water budgets and the cost for extracting, treating, and converting water into a usable resource in a southeastern area of Louisiana that also includes parts of the SHAS (Figure 26 & Table 9) and CAGWCD (Hemmerling et al., 2016). That study includes four Hydrologic Unit Classification (HUC) Level 8 watersheds that intersect CAGWCD and provides background data and information on water availability and demand at the HUC8 level.

Figure 26. HUC8 watersheds in CAGWCD (Hemmerling et al., 2016).

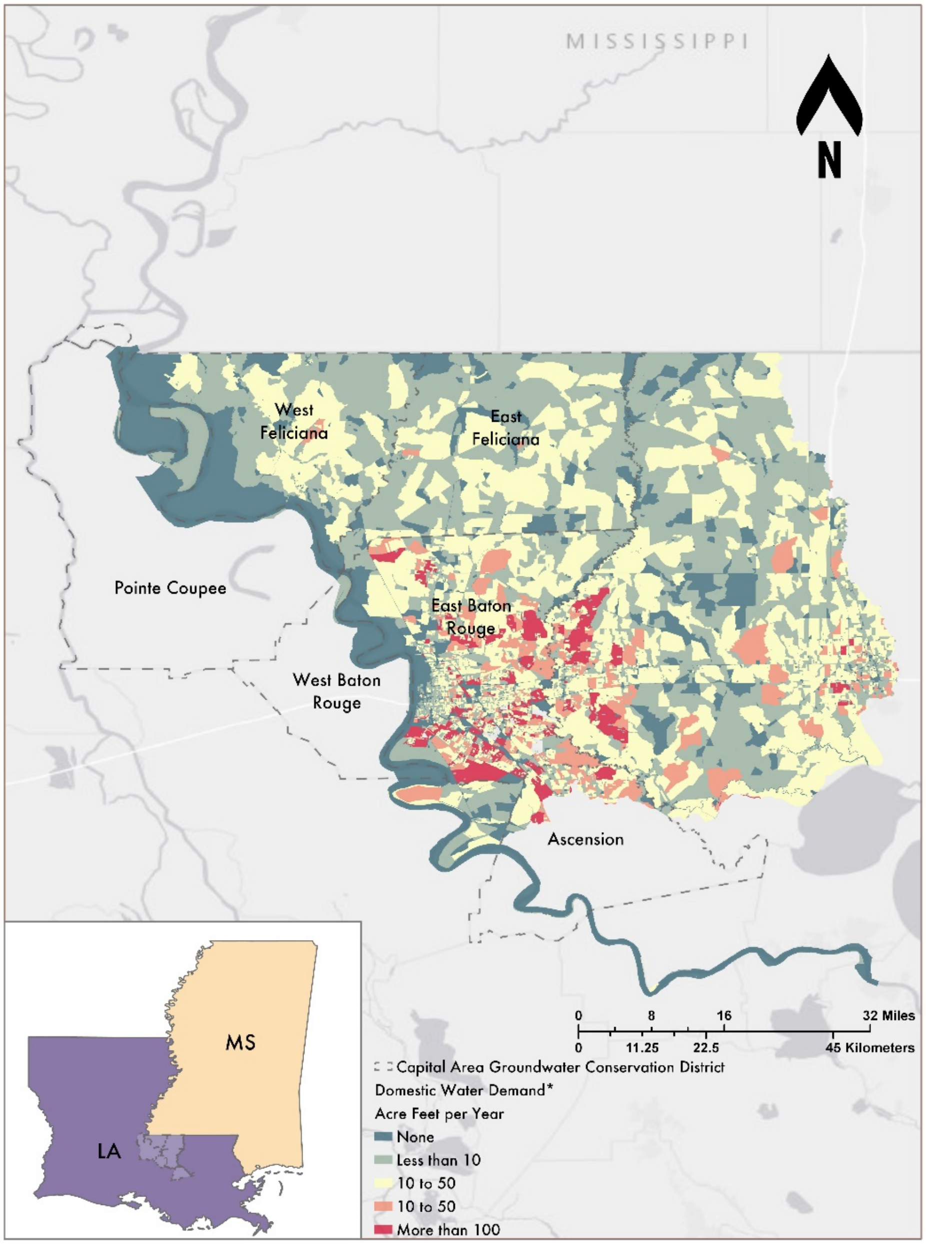


Figure 27. Estimated domestic water demand based on 400 gpd for a family of four (Hemmerling et al., 2016).

Table 9. Southeast Louisiana public and domestic water demand summary (Hemmerling et al., 2016).

HUC8 Watershed	Number of Households	Estimated Freshwater Demand (acre-ft/year)	Number of Public Supply Systems	Population Served	Number of Domestic Water Wells
Lower Mississippi-Baton Rouge	479	215	0	0	9
Tickfaw	37,618	16,855	45	62,925	3,466
Bayou Sara-Thompson	22,060	9,884	22	30,579	293
Amite	213,926	95,851	49	663,741	3,155

The city of Baton Rouge is the defining urban feature of CAGWCD. Within the study area, most of the urban growth is anticipated to occur in a linear pattern moving south toward the more suburban Ascension Parish along Interstate 10 and eastward along Interstate 12 (Hemmerling et al., 2016). With the exception of the Lower Mississippi River HUC8, these four watersheds are expected to see moderate urbanization occurring over the next 50 years (Table 10) with urban expansion expected to grow between 3.4 to 4.5% (Figure 28). The Amite HUC8 is expected to see the greatest decline in groundwater recharge due to urban expansion; this urbanization equates to 1,656 acre ft/year of groundwater infiltration. It should be noted, however, that this value still represents a relatively small proportion of the total groundwater inputs in the region. In addition, groundwater recharge in the Amite River HUC8 likely does not substantially recharge the water-bearing sands of the SHAS.

Table 10. Southeast Louisiana total water balance change under future urbanization scenarios (Hemmerling et al., 2016).

HUC8 Watershed	Change in Groundwater Input (acre ft/year)	% Change in Groundwater Input	Change in Surface Water Input (acre ft/year)	% Change in Surface Water Input
Lower Mississippi- Baton Rouge	-116	-0.2%	6,268	+0.2%

Tickfaw	-828	-0.4%	6,925	+0.6%
Bayou Sara-Thompson	-231	-0.1%	5,868	+0.5%
Amite	-1,656	-0.8%	16,250	+0.7%

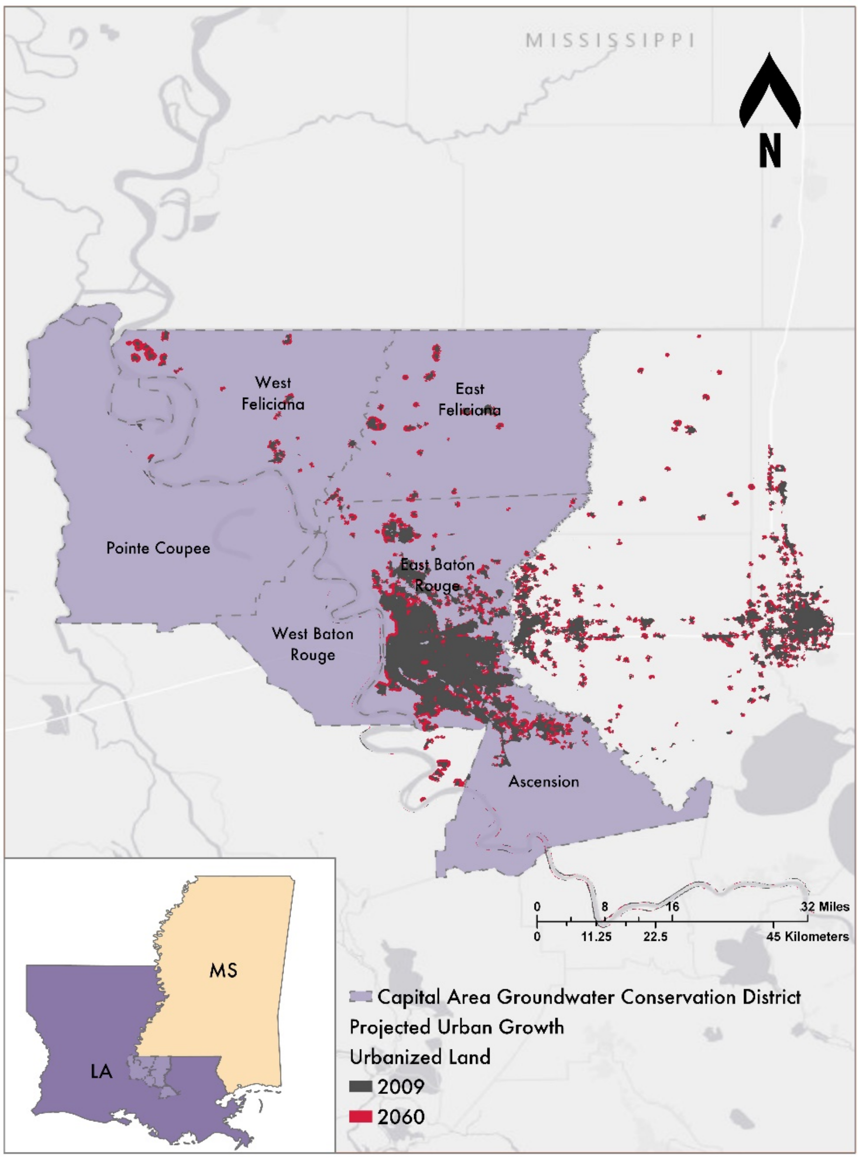


Figure 28. Projected urban growth (2009-2060) (Hemmerling et al., 2016).

While population growth has a spatial component that impacts the inputs to the water budget, there are also societal impacts that are expected to impact the water budget. The greatest population increases are predicted to occur in areas outside of the city, including those suburban areas to the east and southeast of downtown Baton Rouge. When the impacts of this population growth are added into the water balance equation, groundwater withdrawals for public water supplies (including rural supply systems) have a significant effect on the water balance. In addition, should population growth continue south into Ascension Parish with the BRWC responsible for water provision, the price of providing water to those areas and the price of water are both likely to increase (Appendix D: BRWC Rate Structure Analysis). The water budget methodology in Hemmerling et al. 2016 approximated the largest increase in water use within the Amite HUC8 at 3.3% with the smallest increase in the Bayou Sarah-Thompson HUC8 at 1.2% (Table 11).

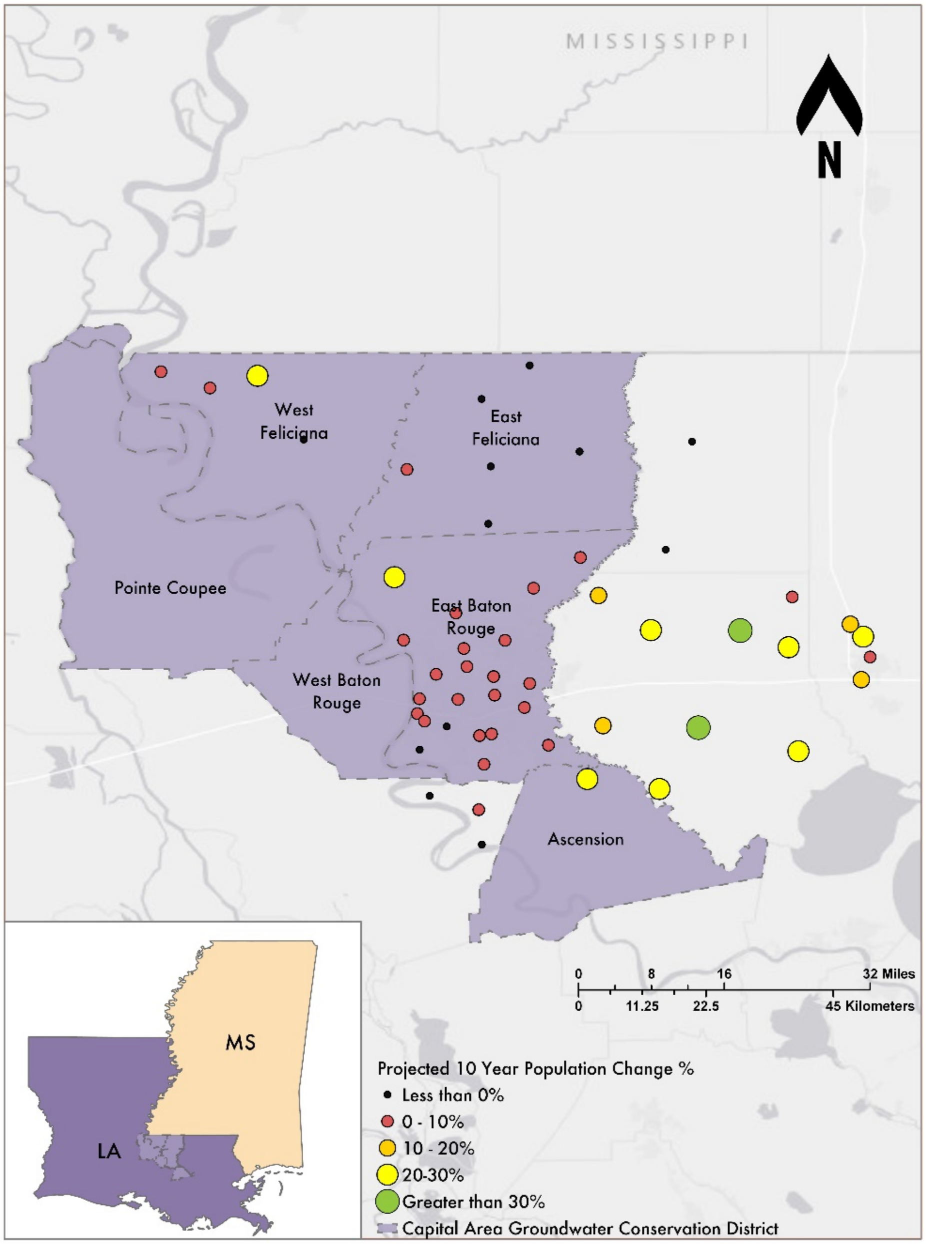


Figure 29. Projected 10-year population change by zip code (Hemmerling et al., 2016).

Table 11. Southeast Louisiana total water balance change under urbanization and population growth scenarios (Hemmerling et al., 2016).

Hydrologic Unit	Change in Groundwater Output (acre-ft/year)	% Change in Groundwater Output	Change in Surface Water Output (acre-ft/year)	% Change in Surface Water Output
Lower Mississippi-Baton Rouge	0	0.0%	0	0.0%
Tickfaw	2,011	1.0%	0	0.0%
Bayou Sara-Thompson	1,936	1.2%	0	0.0%
Amite	7,017	3.3%	0	0.0%

Long-Term Strategic Plan and Scientific Support

CAGWCC (the Commission) is developing a long-term strategic plan to guide its activities and serve as a primary mode of communication to stakeholders and the public. The long-term strategic plan is intended to consider actions and outcomes related to groundwater use of the confined aquifers below the six CAGWCD parishes, also known as the District, projected over the next 50 years (at least). The primary purposes of the plan are to promote:

1. Long-term sustainability of groundwater extraction;
2. Continuity of CAGWCC operations;
3. Long-term planning by water users; and
4. Clear communication with the public.

The plan will describe specific management actions to be taken over time by CAGWCC, the conditions under which those action are to be taken, and the intermediate milestones CAGWCC intends to achieve on the way toward accomplishing its long-term objectives. The actions under consideration include regulation and monitoring of groundwater withdrawal, mitigation of the environmental effects of withdrawal, support of relevant scientific studies, and partnering with agencies to implement measures to conserve, develop, and supplement groundwater resources.

To develop its long-term strategic plan, the Commission is working with the Institute and USGS. The Framework for a Long-term Strategic Plan for the CAGWCC is a companion document to this report which describes the legal, economic, and scientific context of the plan, the fundamental objectives with associated metrics the Commission seeks to achieve in the long term, and the strategic alternatives it is considering. This report complements that planning framework and addresses the currently available scientific basis upon which the fundamental objectives, metrics, and alternatives will be evaluated as part of Phase 2. It also identifies the knowledge gaps that need to be filled to ensure long-term success of the plan.

FUNDAMENTAL OBJECTIVES OF THE CAPITAL AREA GROUNDWATER CONSERVATION COMMISSION PLANING FRAMEWORK

The fundamental objectives for the planning framework are summarized below. For more detailed information related to these five objectives as well as the associated metrics, see the CAGWCC planning framework (Supplementary Material: Framework for a Long-term Strategic Plan for the Capital Area Groundwater Conservation Commission).

Objectives:

1. *Achieve and maintain sustainable and resilient groundwater withdrawal rates from the Southern Hills aquifer system within the District boundaries*;
2. *Manage the aquifer to maximize availability of healthy, high-quality drinking water equitably to all residents of the District indefinitely*;
3. *Manage the aquifer to maximize availability of clean and inexpensive water to commercial and industrial users in the District indefinitely*;

4. *Reduce the movement of saltwater into the Southern Hills aquifer system and slow or halt the advance of the existing saltwater plume*; and
5. *Minimize the risk of subsidence*.

ACTION ELEMENTS AND ALTERNATIVE STRATEGIES OF THE CAPITAL AREA GROUNDWATER CONSERVATION COMMISSION PLANNING FRAMEWORK

There are several action elements identified in the CAGWCC planning framework which address the fundamental objectives. They include actions designed to limit the withdrawal of groundwater, limit or mitigate saltwater intrusion, reduce overall demand for water, and increase the supply of water. While not all action elements defined in the planning framework require additional science and/or data collection, some will require additional science to be implementable and effective; those specific elements are outlined below.

Actions Designed to Limit the Withdrawal of Groundwater

- Permitting (These actions could apply to the granting of a new permit, as a condition of operation, or retroactively)
    - Establish supply/demand accounting basis for issuing permits
    - Require data on both forecasted and metered use as a condition of production
    - Promote water loss reduction via requiring loss audits and associated repairs or retrofitting where required
- Zoning
    - Establish appropriate areas for new well installations
    - Establish ‘sensitive use’ areas based on aquifer status
        - Couple with zoned production limits
    - Optimize spatial distribution and vertical location of wells and pumpage
- Fee Schedules
    - Establish water conservation-oriented fee schedules
        - Increased flat rate
        - Increasing block rates
        - Quantity based surcharges
        - Seasonal rates
- Production Caps
    - Establish voluntary production limits in select sands
    - Establish voluntary production limits across all sands
    - Establish non-voluntary production limits in select sands
    - Establish non-voluntary production limits across all sands
    - Establish production limits on wells producing over X gal/day
    - In conjunction with production caps, a cap-and-trade system could be set up to allow producers to trade allowances

Actions Designed to Limit or Mitigate Saltwater Intrusion

- Pollutant Mitigation and Remediation
    - Scavenger wells to withdraw salt from the aquifer

- Closure or movement of individual wells or well fields
- Injection wells to alter pressure dynamics along the fault zone

Actions Designed to Reduce Demand for Water

- Promoting Awareness
    - Develop and deliver educational curricula for school-age persons
    - Develop and deliver messaging on water supply and domestic consumption to targeted audiences via public service announcements, water bill inserts, community associations, etc.
    - Develop online applications where users could compare their household water use to benchmarks, neighborhood averages, or municipal averages
    - Develop informational materials for relevant local governments and economic development organizations regarding water management as it relates to water supply and demand
- Incentivizing Conservation
    - Develop rebate programs for adopting water conservation technologies at the household level
    - Develop financial support or other incentives for the adoption of improved technologies for industry to reduce water use
    - Develop regulations that incentivize users to find methods to reduce demand, by setting performance standards but not specifying specific practices

Actions Designed to Increase the Supply of Water

- Water Supplementation
    - Treatment facility for river water
    - Bank filtration of river water using shallow wells in the Mississippi River Alluvial Aquifer
    - Capture surface water via reservoir (co-benefits to flood management)
    - Treat wastewater from municipal sources, apply to domestic or industrial needs
    - Treat and recycle industrial-use water
    - Desalination of groundwater
    - Artificial recharge and storage via injection wells
    - Blend water sources
    - Develop financial support for the development of alternative water sources, including for industry, e.g.,
        - Standard bond issue
        - Environmental impact bond (EIB)
        - Other public-private partnership (P3) agreements

Alternative Strategies

The Commission developed three draft alternative strategies for consideration (Table 12). Each strategy is a combination of individual action elements, meant to offer different approaches for achieving and balancing the fundamental objectives. Broadly speaking, these three strategies can be distinguished by the relative emphasis on managing demand or managing supply. Furthermore, each strategy differs in the spatial and temporal application of the various action elements. For example, certain actions may be applied only to select sands, or there may be actions that have greater benefit in the near term whereas others are more relevant in the future or for specific aquifer conditions.

At this stage, the strategies described in Table 12 are draft sketches of the alternatives but provide enough detail to allow for initial evaluation/analysis. Prior to evaluating each strategy against the full set of fundamental objectives, some gaps identified in this state of science report will need to be addressed to ensure the long-term strategic planning is successful over the next 50 years.

Table 12. Draft alternative long-term strategies for achieving the fundamental objectives of the CAGWCC.

Element Categories	Action Elements	A. Business as Usual	B. Manage Demand via Regulation	C. Manage via Partnership
Limit Withdrawal	***Permitting***	No new permits for production from sands that have exceeded their voluntary caps.	Renegotiate existing permits; meter all wells; conduct full use analysis. Set baseline production caps by permit.	Renegotiate existing permits for industrial producers; set permit-based production caps.
	Zonation	Industrial and fault zone restrictions on certain sands.	Establish 3-4 zones based on potentiometric levels and chloride concentration.	None
	Fee Schedules	Flat fee for producers; user fees determined by BRWC and PSC (currently, lower rates for higher use)	(Same as in Alternative A)	Conservation-oriented schemes. Increasing block fees for producers. Work with BRWC and PSC to develop adjusted fee schedule for users.
	Production Caps	Voluntary production caps on select sands, as needed (currently “1,500-foot” and “2,000-foot” sands only)	Set non-voluntary zone- and sand-based production caps. Across-the-board reduction in production over time until caps met. Permits revoked for users who over-produce.	Phased reductions for industrial users.
Manage Salt Intrusion	***Pollutant Mitigation***	Scavenger well in “1,500-foot” sand (operating); “2,000-foot” sand (planned)	Scavenger wells in select sands; expand as needed.	Existing scavenger wells in select sands; intent is to not need more.
Reduce Demand	***Promoting Awareness***	1. Communications with major producers	Joint programming by the Commission and its partners	Joint programming by the Commission and its partners

Element Categories	Action Elements	A. Business as Usual	B. Manage Demand via Regulation	C. Manage via Partnership
		2. Educational programming by partners		
	Incentivizing Conservation	No initiatives	No initiatives	Develop incentives package
Increase Supply	***Water Supplementation***	Market-driven	Market-driven	Build river-water clarifier or other water-treatment facility to produce water for industrial purposes.
	Financing	(Not applicable)	(Not applicable)	Public-private partnership. Bond issue for initial capital; long-term operation by private entity.

SCIENTIFIC NEEDS TO SUPPORT LONG-TERM PLANNING

Phase 1 of the work conducted by the Institute for CAGWCC focused on identifying the problems, objectives, and performance metrics as well as, development of initial alternatives with the Commission for its long-term strategic plan. In addition, the Institute has developed a Framework for a Long-term Strategic Plan for the Capital Area Groundwater Conservation Commission.

The information presented in this section outlines the research gaps that, if filled, will help facilitate the development and implementation of the CAGWCC strategic plan. This report was developed through collating literature and reports (Appendix F: Annotated Bibliography), meeting with several experts working on the SHAS, and working with CAGWCC on their long-term vision for the District. Based on an evaluation of relevant scientific literature and reports, several general topics were identified as requiring additional data for the successful evaluation and implementation of the strategic plan. Those topics include quantification of water supply and demand (including effective data collection and compilation), economic and social analysis, and evaluation of available technologies. Some of these knowledge gaps are proposed to be filled in Phase 2, while others can be filled to support long-term strategic plan implementation, evaluation of success, and adaptively managing the groundwater resource over the long-term. In this section, the topics of water supply and demand as well as evaluation of available technologies will be elaborated.

Water Supply and Demand

Quantifying total available groundwater is a necessary first step toward establishing sustainable levels of groundwater withdrawal. Therefore, quantifying the supply of water from aquifers and estimating demand is necessary to understand the dynamics of a water budget deficit over the long term. The science must be able to support the evaluation of the alternatives, estimate the sustainable yield from each sand, predict the movement of saltwater intrusion, and evaluate the effects of different actions on groundwater availability from the SHAS. A tremendous amount of work has been undertaken to understand the SHAS and the supply of water, the geology, the potentiometric surfaces, and the saltwater intrusion in various sands. The annotated bibliography provides several references and summaries related to hydrogeological modeling and research studies undertaken thus far related to the SHAS (Appendix F: Annotated Bibliography). Current research related to potentiometric maps and extent of saltwater intrusion are outlined in, Appendix A: “1,500 ft” Sand Saltwater Encroachment and Appendix B: “2,000 ft” Sand Saltwater Encroachment.

There are three main bodies of work that speak to water supply in the Baton Rouge are for the SHAS. Dr. Frank Tsai created and calibrated a flow and transport numerical model of the Baton Rouge area where a comprehensive and detailed geology-based approach was taken and integrated into the model to understand the hydraulic character, morphology and depositional setting of the Baton Rouge aquifer system, a necessary component for developing strategies to halt or control the intrusion of saltwater into the Baton Rouge area drinking water supply (Pham & Tsai, 2017).

CAGWCC has also contributed directly to the body of scientific literature by investing in USGS modeling of the Baton Rouge Industrial District to understand saltwater flow and transport in the “1,500” and “2,000 ft” sands (Heywood et al., 2014). USGS utilized variable-density groundwater flow and transport simulations to evaluate scavenger wells and their effect on the withdrawal and diversion of saltwater. The sands that have been modeled thus far include the 10 major sands, but the spatial extent of the detailed portion of the model was confined to within the Industrial District and USGS model domain (Heywood et al., 2014, 2015, 2019; Heywood & Lovelace, 2015).

In addition, the LDNR Office of Conservation invested in the development of a report titled “Water Resources Assessment for Sustainability and Energy Management” which assessed the supply and demand in both ground and surface waters and provided a means to estimate the energy costs associated with water resources use (Hemmerling et al., 2016). That framework included a conceptual water budget that addressed both the total water supply and demand in three different areas of Louisiana. Uniquely, that research analyzed possible shifts in the overall water balance resulting from future population changes and urbanization.

Capital Area Groundwater Conservation Commission Efforts to Understand Supply

During its initial planning discussions, the CAWGCC articulated a vision for managing the SHAS that seeks to balance supply against demand while also maintaining overall aquifer health and concomitant economic benefits of water production. CAGWCC has invested in a detailed numerical groundwater transport and flow model to better understand saltwater transport in relation to pumping pressure near the Baton Rouge fault zone. This investment is relevant to understanding saltwater intrusion in the Industrial District and managing groundwater at that geographic scale (Figure 30 & Figure 31). However, that investment does not support estimating water budgets at each sand level at a District-wide regional scale.

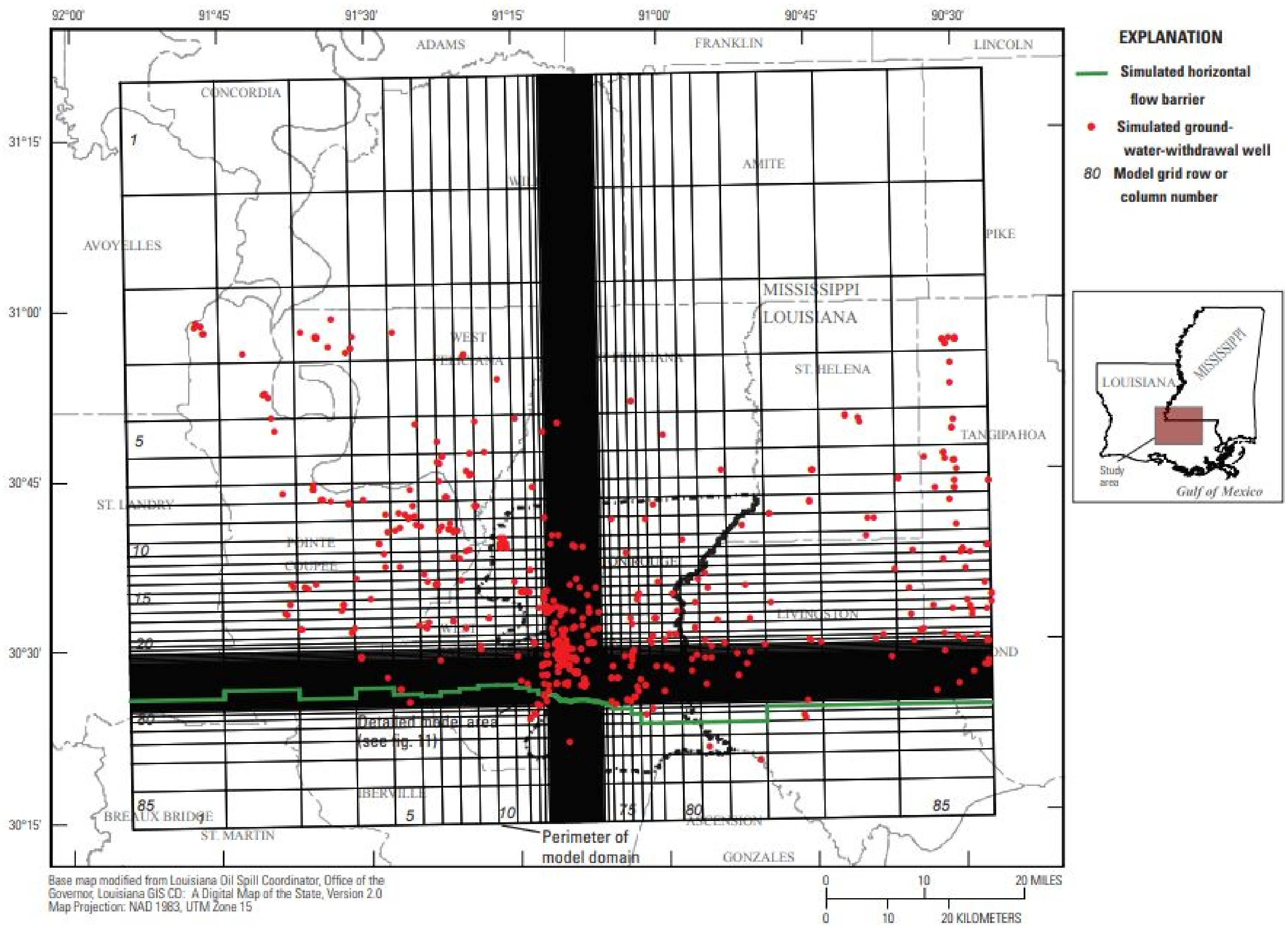


Figure 30. Model domain for simulations of the "1,500" and "2,000 ft" sand saltwater intrusion (Heywood et al., 2014).

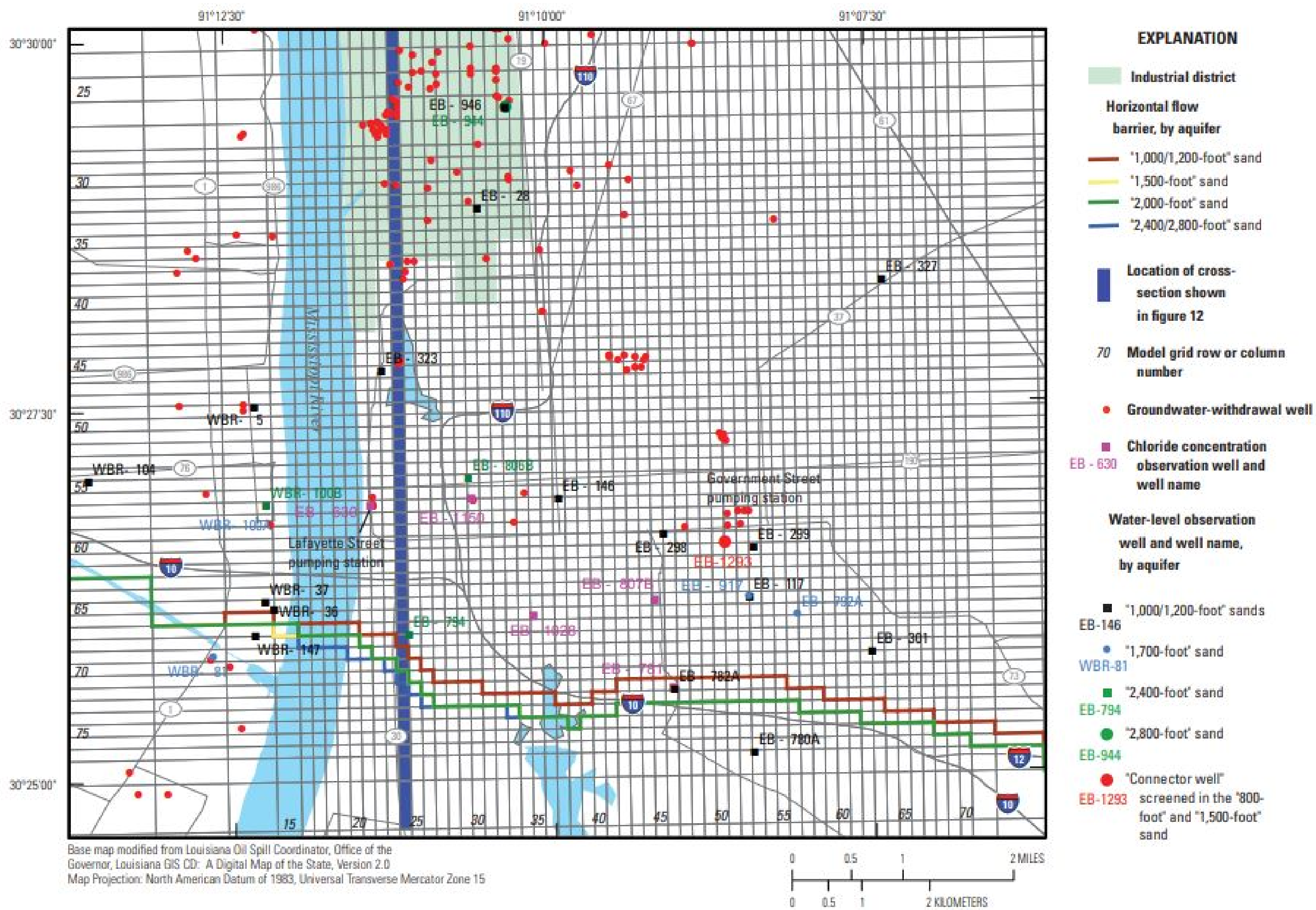


Figure 31. Detail of Industrial District scale for model simulations of groundwater movement (Heywood et al., 2014). See Figure 30 for entire model scale.

Within Phase 2, a CAWGCC investment in a Darcy flow analysis would provide initial estimates of groundwater yield for each sand and support preliminary water budget calculations to support science-based management decisions in the near-term. A Darcy flow analysis will help quantify the amount of water that flows through the Baton Rouge aquifers. Using this analysis, the Commission would more fully understand the volume of water needed to be supplied by alternative water sources should they be necessary, the production caps that may be required based on a given alternative strategy, and potentially other management actions. While a Darcy flow analysis does not consider saltwater intrusion explicitly, inference can be made from output on water levels in proximity to the Baton Rouge Fault. However, this analysis will depend on the quality and quantity of available present-day and historical water level data in each of the aquifer sand units.

To evaluate the full set of alternative strategies related to groundwater supply, a robust Groundwater Availability Model (GAM) developed at a relevant Baton Rouge area spatial scale is needed. This model would be capable of estimating transient groundwater flow and transport at greater resolution and across all variables contained in the set of relevant performance metrics (including water availability, chloride concentration, and potential risk of subsidence). While a density variable may not be needed initially, its implementation is possible. A comprehensive GAM model could support multiple objectives: 1) estimate water budgets at each sand in the SHAS; 2) calculate the cone of depression at scale for each sand unit and model change over time; 3) predict the spatial extent and rate of salt transport within the SHAS; and 4) simulate subsidence under variable groundwater conditions. Model output can help inform the establishment of zones or sensitive areas, the future geographic placement of wells and well operations (well closure, pumping levels, vertical placement of pumps, et cetera), and the efficacy of scavenger well performance as well as to evaluate sustainable levels of water withdrawal at each sand level. The GAM is anticipated to be flexible enough that should the District wish to explore additional management options not identified early on (e.g., the efficacy of injection wells along the fault zone or well optimization), they can do so.

The overall goal of the GAM model is to address all previously discussed items but would also allow for adaptive management over the long term. This model could be extended to gain insights into aquifer resilience which is also included in the fundamental objectives in the planning framework. The GAM should also be able to evaluate low probability, high consequence scenarios to estimate limits on groundwater recovery over different timescales. It is recommended that this model have reasonably short run times to evaluate multiple scenarios quickly, with additional complexity added over time as needed. Additional data and science needed to support such model development are discussed later in the *Data Requirements for Accurate Groundwater Modeling* section.

Capital Area Groundwater Conservation Commission Efforts to Understand Demand

Water demand is dynamic and factors such as population growth, economic activity, technological advances, weather, and consumer behavior can all affect patterns of groundwater use. Long-term planning requires an appreciation of the dynamic nature of groundwater and the appropriate means for forecasting demand would consider both economic and climate conditions. For use in SDM and modeling, factors will need to be quantified and estimated through a range of possible outcomes. Although the estimated values for water supply, demand, population growth, and energy consumption from the Hemmerling et al.

2016 study serve as estimates for part of CAGWCC strategic planning effort, further refinement and exactness are required to properly address CAGWCC's need in managing the SHAS for the entire CAGWCD.

Further model refinement is needed to understand domestic, rural domestic, and agricultural usage. This may also require additional metered wells and access to metered utility data. Many parameters of the water budget can be further refined, including more detailed representations of the physical characteristics of the aquifer units (e.g., lateral heterogeneity of saturated thickness and hydraulic conductivity) as well as more detailed estimates of groundwater recharge that include seasonal effects. For population growth and usage estimation, further refinement of population and economic growth rates can be made to improve water budgeting. While water budgeting can be an effective tool for water planning across the District, specific attention is needed to assess localized imbalances that can be potentially impactful at more local scales within the District. Additional research on the societal responses to changing water conditions would provide valuable information that would allow the assessment framework to more accurately model future changes in water demand and usage.

Apart from societal groundwater demand and associated economic factors, additional data on the impacts of freshwater inflow (balanced with groundwater demand) on habitat suitability for key fish and wildlife species are needed to establish minimum ecological flow levels in the water budget. This would provide valuable information on the amount of groundwater flow needed to maintain ecosystem functionality (Hemmerling et al., 2016). The analyses of the southeastern Louisiana study area in the Hemmerling study focused on four HUC8 watersheds in the greater Baton Rouge area; however, the authors did not specifically cover the entire CAGWCD and some or all of Ascension, Pointe Coupee, and West Baton Rouge Parishes were not included. In order to analyze the CAGWCD scale, the analysis would need to be expanded to include those areas.

Domestic Demand

Detailed historical water consumption data from public suppliers and domestic users across the District needs to be compiled. District-wide population growth (and spatial variation in that growth) is also needed. This can be utilized to forecast future water consumption through the development of a Demand Forecast Model, which would incorporate both historical data, population growth, weather input, and anticipated changes in consumer behavior. Multiple scenarios could then be developed to capture the business-as-usual (i.e., no change in household or per capita consumption), as well as potential impacts of regulation, water pricing policies, and conservation education/incentives. This also necessitates synthesizing the best available information on locally predicted future precipitation patterns to understand drought mediated changes to water consumption. The methodology for a Demand Forecast Model is outlined in Phase 2 (Supplementary Material: Scope of Work).

Industrial Demand

Detailed historical water consumption data also needs to be compiled from industrial suppliers across the District. In addition, commercial/industrial growth and the resulting anticipated water demand also needs to be forecasted, which requires estimates of future resource needs from key large-scale producers/users over a 50 year time scale (the timeframe CAGWCC wants to cover). Both public and industrial users are the two largest consumers in CAGWCD, and accurate information is necessary to predict water demand into the future considering the amount of water being used. However, these estimates need to be further categorized according to usage type which will assist with other evaluation needs such as estimating costs of alternative supply options, determining best management practices, or determining different means to provide additional water supplies. If large-scale producers/users are unable to provide future demand profiles, then historical data, augmented as necessary, could serve as a proxy.

Agricultural & Other Demand

For more detailed water budgets to be calculated, agricultural and non-District regulated demand must be incorporated. Although possibly at a different scale, these users also utilize groundwater from the SHAS sands, which impacts the water budget within the District. Therefore, investments need to be made to determine best estimates of the current spatial consumption by agricultural/other community members throughout relevant aquifers. Also, investments should identify needs to permit wells producing under 50,000 gallons per day.

Evaluation of Technologies to Increase Water Supply

In the event that demand of the aquifer exceeds supply, alternative technological strategies to supplement water to CAGWCD could be necessary. There are many strategies that could be considered for the Commission including surface water treatment, reservoir creation, and even desalinization. These alternatives are outlined in Appendix E: Alternative Water Resource Management Actions.

One of the more discussed concepts for alternative water resources in CAGWCD pertains to surface water treatment. Because the Mississippi River runs through CAGWCD and is a potential source of surface water, this option may have significant potential in providing an alternative water source. There are multiple steps and considerations which would be necessary in implementing surface water treatment that include, but are not limited to: legal analysis, cost benefit analysis, identification of funding, and many others. Not only is the Mississippi River a potential water resource, reservoir creation is also a way to manage water availability and water quality issues. Instances of such reservoirs are evident in regions with highly variable water supply (Appendix E: Alternative Water Resource Management Actions).

Another method of dealing with water quality and water quantity issues could be via desalination plants. Desalinization is the process by which water with high amounts of salinity is converted to freshwater; a common method to accomplish this includes reverse osmosis.

A summary of different technologies that could be considered to support long-term planning for water supplementation are listed below:

- Use of a treatment facility for river water;
- Bank filtration of river water using shallow wells in the Mississippi River Alluvial Aquifer;
- Capture of surface water via reservoir (co-benefits to flood management);
- Wastewater treatment from municipal sources, apply to domestic or industrial needs;
- Treatment and recycling of industrial-use water;

- Desalination of groundwater;
- Artificial recharge and storage via injection wells;
- Blending of water sources; and
- Development of financial support for alternative water sources (e.g., bond issue and/or other P3 agreements).

Water Supply and Demand Summary

Construction of specific aquifer-level water budgets, which detail all inputs and outputs (supply and demand, recharge and withdrawal) and that are scientifically supported by a groundwater availability model of the entire extent of the District, is a fundamental necessity. Water budgets underpin almost every aspect of a water management plan and the actions undertaken in that plan, especially with understanding sustainability at a sand level. If the research and data indicate that demand exceeds the supply of water from the SHAS, CAGWCC will be able to manage the SHAS in a sustainable fashion, but only if they are able to quantify the demand and supply of water.

In summary, the Institute highlights the following research needs required to address groundwater supply and demand topics necessary for development of CAGWCC goals:

- Short-term quantification of groundwater deficit using historical and recent potentiometric surfaces and Darcy flow calculations to enable decision-making in the near-term;
- Simultaneous development of a District-wide, fast-running, screening-level GAM for evaluation of management alternatives. Continued investments in this GAM over the long-term for detailed analyses and ongoing and active groundwater management. This supports supply projection – calculation of past, current, and future supply of water to the SHAS; and
- Demand projection – calculation of future demand, from all user groups, including different industrial use types through the development of a Demand Forecast Model.

DATA REQUIREMENTS TO SUPPORT LONG-TERM PLANNING

A variety of data needs to be compiled to support development and implementation of the long-term strategic management plan. For example, having relevant data and information on the performance metrics for each fundamental objective is necessary for CAGWCC in achieving their outlined vision over the next 50 years. In addition, the GAM, which is also key to understanding supply, needs to be supported by accurate and complete data.

Supply and Demand

To support development of accurate groundwater budgets, a complete database of wells and withdrawals throughout the District must be maintained. This database should include all the necessary and relevant information related to groundwater use for each well, including a well-metering plan and implementation for recording withdrawals. These withdrawals can be included in the GAM and can improve the accuracy of the model for predicting changes in water availability over time with changes in demand. Further areas of research to develop an accurate model include: 1) continued monitoring of water levels; 2) mapping of cones of depression in each sand unit throughout the SHAS over time to support model calibration and validation; and 3) performance metric evaluation related to sustainable use of groundwater over time from each sand. The latter is imperative to successful management of the SHAS. Continued monitoring and improvement of such performance metrics will improve the management of the SHAS.

Saltwater Intrusion

Analysis of the current monitoring system of saltwater intrusion in all sands is needed as well as data surrounding scavenger wells and their potential effects in nearby wells and aquifers. This supports both the GAM development (calibration and evaluation) as well as CAGWCC objective to reduce the movement of saltwater intrusion in the SHAS. In addition, there are also different interpretations of the geology of the SHAS, given the difficulty and cost associated with spatially analyzing a geologic fault with high certainty, alternative investigative methods may be necessary to analyze the heavily developed area around Baton Rouge. Unless a trench could be built, the exact profile of the geologic fault will remain uncertain; there are, however, other ways to analyze the geology associated with a fault that include borings, cone penetration tests, and other potential seismic profiling (Kasman et al., 2004).

Groundwater Conservation

An infrastructure system analysis of groundwater usage could identify water loss from initial withdrawal and end use. Though a system analysis may be costly, identifying ways to improve groundwater usage efficiency is an effective way to address water demand and supply simultaneously. Some conservation activities (e.g., rebate programs) have been shown to reduce water demand between 5-15% (Y. Tsai et al., 2011). Social data collection to support understanding the importance of public opinion about water quality, origination of water sources, groundwater use, and desire for conservation actions such as rebate programs or other activities could aid in understanding the potential for decreasing groundwater demand. These data can be collected via surveys, focus group meetings, and other survey methods. Gaining an understanding of the public's interest for groundwater conservation is essential because conservation initiatives alone could potentially achieve the listed performance objectives or desired outcomes of CAGWCC prior to larger decisions.

Economic Considerations

Other related data on groundwater economics are also needed. Reviewing domestic supply fees from CAGWCD in comparison to other similar geographies would be useful for efforts seeking to evaluate potential conservation incentives by changing fee structures. Fee structures can take on many forms including dynamic pricing based on water availability, increasing block structure (which raises water prices with more water usage), and even surcharge policies (USEPA, 2016). A change in fee structure has the potential to address multiple issues such as water demand and supply while helping fund water resource management activities. The potential for fee structures has been shown to be effective in water resource management, but there are many legal procedures which need to be considered to change fee structures.

Other

There are other data collection activities that support long-term planning. One possibility is to analyze costs of development, operation, and maintenance of alternative water supplies. In doing so, comparisons could be made both within and outside the CAWGCD. Additionally, subsidence could potentially lead to consequences in CAGWCD and should therefore be considered in any resulting management plan. Although the potential for subsidence in CAGWCD may be minimal compared to cases such as the Central Valley of California and Houston, Texas, subsidence can increase the risk of flooding (Kasmarek et al., 2016; USGS, 2019). The CAGWCC's legislation lists evaluation of subsidence risk as an original charged task, and the long-term strategic framework document has a fundamental objective related to minimizing the risk of subsidence (Smith & Kazmann, 1978). To address and measure subsidence over the long term, it is possible that additional data may need to be collected in CAGWCD; establishment of reference sites outside the SHAS cone of depression are required for comparison. Between 1935-1976, the Baton Rouge area experienced 1.67 ft of subsidence with 1.26 ft being attributed to groundwater withdrawals and 0.41 ft due to natural regional subsidence (Figure 32) (Smith & Kazmann, 1978). The CAWGCC was chartered with the mission to address subsidence as one of its core components and ensuring proper diligence in monitoring subsidence into the future will continue the effective management of this issue.

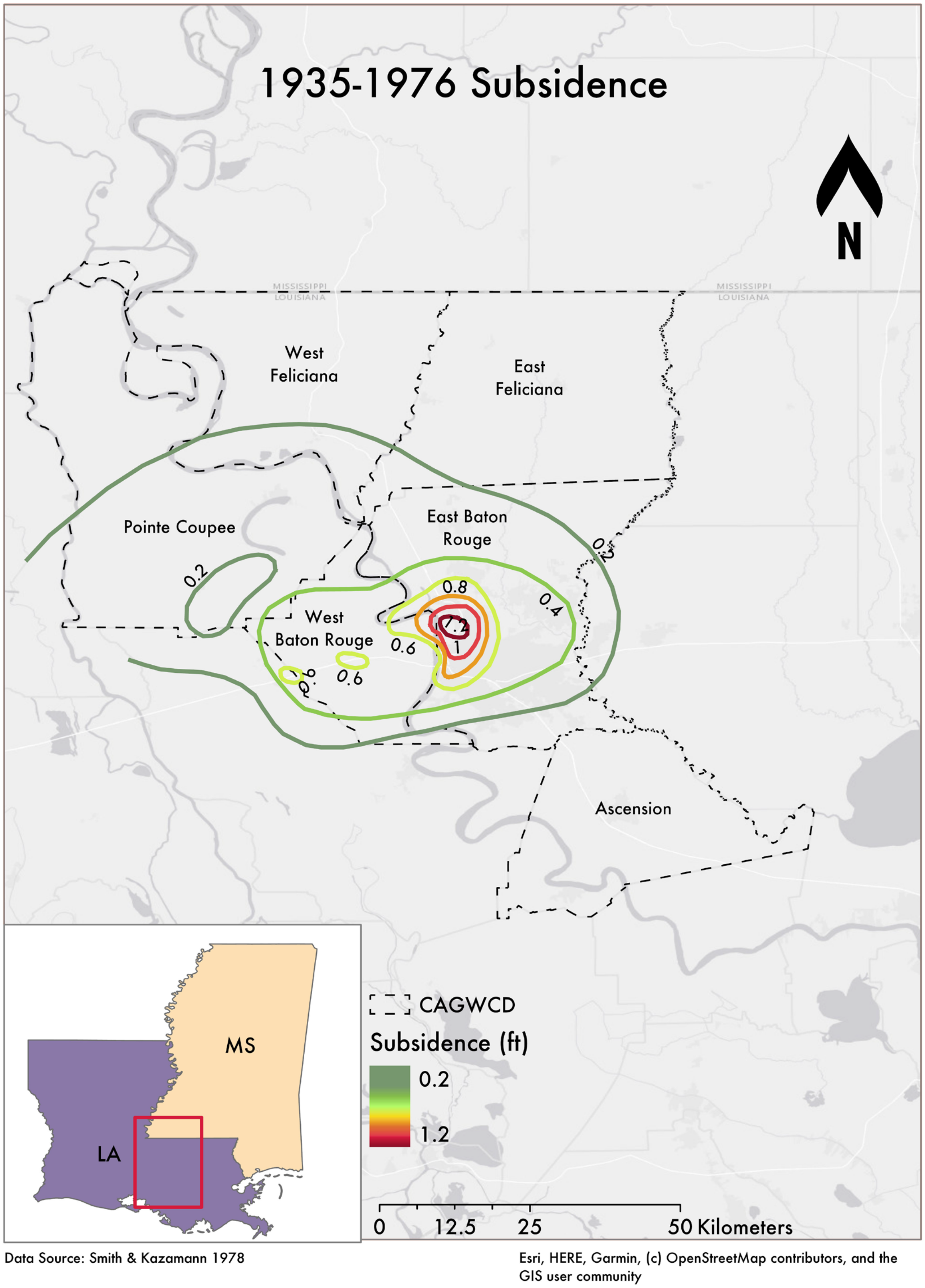


Figure 32. 1935-1976 subsidence measurements in CAGWCD. Features were georeferenced and digitized from Smith & Kazmann (1978).

Data Requirement Summary

In summary, several data collection and compilation needs should be considered to support long-term planning. These include:

- Compile and maintain a complete database of wells and withdrawals throughout the District;
- Establish a well metering plan and implementation for recording withdrawals;
- Continue monitoring and mapping cones of depression to ensure an updated and synoptic view of all sand units of the SHAS throughout recorded time;
- Evaluate the effectiveness and adequacy of the plan for monitoring saltwater concentration and movement;
- Evaluate scavenger wells and their effects on nearby wells in all affected and potentially affected sands;
- Collect social data to understand the importance of public opinion about water quality through surveys and other social research;
- Collect economic data to review:
    - Domestic supply costs and fees from other supply systems and geographies; and
    - Costs for development, operation, and maintenance of alternate water supplies used within and outside the District.
- Evaluate societal willingness to pay and accept for water usage across all water users within the District;
- Resume collection of subsidence data and the potential of adding subsidence monitoring at locations across the District and outside the central cone of depression;
- Collect information on water loss between extraction and end use; and
- Compile the various geologic profiles and interpretations of the sands and the fault to support analysis and utilization in the GAM.

DATA ANALYSIS

Depending on the environmental setting, culture, and availability of water within an area, water may be used for one or many things. In most of the western U.S., which has historically been dry, water is appropriated based on water rights and several laws and policies have been developed. In the eastern U.S., such as in Louisiana, there appears to be much more water because of higher rates of rainfall; however, this is not always the case for potable water. For example, much of Louisiana relies on groundwater when available and only certain areas utilize treated surface water, such as New Orleans. Based on how water is used, how much is necessary for public and or commercial/industrial usage, society may prioritize water differently. It is important to fully understand how society views their water, what they are willing to pay and accept in terms of taste and source. Baton Rouge has a large, accessible, and clean source of groundwater for use. However, should water availability be limited or endangered in any given circumstance, priorities must be clear; public attitudes should serve as a clear indication of what society deems appropriate for their water. By engaging in social science research, literature review, and other forms of surveying, various strategies of water resource management can be evaluated and prioritized that will benefit the CAWGCC in their long-term strategic plan.

Much like understanding public attitudes for water use, capturing the costs associated with such usage is also necessary in long-term planning. Water is used for a multitude of things such as consumption, plant cooling, car washes, hygiene, input for fabrication, and much more. To support long-term planning, CAGWCC needs to fully comprehend what groundwater is being used for, how it is being used, the logistics of water consumption, and what water quality is necessary for different uses. This type of data can be gathered via case studies, investigation, focal group meetings, business analysis, et cetera. For multiple users of a single source of water to work together, understanding how and why water is being used is vital to the community and economy. Should there be cases where a water resource is at risk, alternative resources or strategies need to be analyzed. For example, should public consumption rise to unpredicted levels and industry not be able to switch from groundwater, how will water be managed? Is there an emergency plan for this? How can undesired resource depletion be avoided? By researching the cost and operation of switching to alternative resources or undertaking strategies such as plans to trade water, switch to surface water, or desalinization, CAGWCC is being proactive in their mission to preserve the groundwater for Baton Rouge. Multiple alternatives and strategies for water management can be seen in Appendix E: Alternative Water Resource Management Actions.

From an economic standpoint, water rates are a central subject to water resource management. All users of water have a rate structure be it flat, increasing, or decreasing. By accurately profiling water consumption amount and type of usage, water rates can be tailored to meet the demands of water suppliers (i.e., help pay for operation and maintenance of water facility), basic human consumption, and the ecological/environmental health of ecosystems, aquifers included. Using retrospective analysis and case studies, CAWGCC can analyze how tiered rates could potentially affect the health of the economy and ecosystem. The Environmental Finance Center at the University of North Carolina created a comprehensive dataset with compiled water rate structures broken down by industrial, commercial, wastewater, and more which can serve as a resource for understanding how particular rate structures may be able to appropriately serve CAGWCD (UNC, 2020).

CAGWCC was charged with the protection of the SHAS within CAGWCD. Subsidence was thought to be a large issue originally and, after initial research and withdrawal limits on aquifers, was deemed to be monitored and managed effectively. The amount of subsidence when compared to other areas may be minimal, but local flooding can be extremely damaging in some instances. In 2016, Baton Rouge and parts of southern Louisiana experienced some of the heaviest rain on record over a period of three days. Areas thought to never be subject to flooding were under water, and thousands of households did not have flood insurance. By understanding current subsidence monitoring effort throughout CAGWCD, CAGWCC can better prepare not only its users from flooding, but help the Commission understand how water use and development may affect aquifer recharge and discharge into the future. Subsidence monitoring may be able to identify areas of natural recharge likelihood and determine future storage potential in the SHAS. Subsidence is not only important for surface issues such as pluvial flooding or development damage, but also for the resilience of the SHAS moving forward. If too much water is removed from a confined aquifer, it is possible to damage the aquifer due to compaction from aboveground pressure. The GAM should be able to determine how storage is affected from such subsidence; how the storage is affected is not limited to the volume of space but also its spatial distribution. Each sand within CAGWCD is variable in geography and spatial distribution, but depending on how the subsidence is occurring, naturally or anthropogenically, can affect water supply and availability into the future. Expanding subsidence monitoring throughout CAGWCD is important to understanding how the aquifer is or will be changed moving into the future. With proper identification of subsidence throughout the region, a suitable performance metric for subsidence can help identify thresholds that CAGWCC can act upon. In summary, several data analysis needs should be considered to support long-term planning related to economic, social, subsidence, and geology data:

- Identify social impacts of various strategies and test public attitudes;
- Economic analysis – industrial supply: Quantify industrial needs for usage type/match to water supply type, including costs. Obtain example costs (capital investment and life cycle operations and maintenance) for industrial users of alternate sources within (and outside) the District. Evaluate water rights trading market viability and examples;
- Economic analysis – tiered rates and other economic motivators: Examine the use of tiered rates and other economic motivators such as rebate programs, low-flow technology subsidies, water conservation days, and other methods found in other water management districts;
- Revisit subsidence monitoring, as stated above in the *Data Collection* section, as well as analyze historical and current leveling information across the District to inform understanding of current subsidence rates and future risk;
- Determine threshold for withdrawal rates, above which would cause detrimental and/or unacceptable levels of subsidence. Determine the potential impacts of subsidence on compaction of aquifer sands and clay confining units, as well as impacts on surface water flooding via lowering of the land surface; and
- Continued analysis of existing data to support geologic profile development and interpretation of the sands, confining units, and the fault to support analysis and utilization in the GAM. This includes well logs, aquifer tests, and possibly seismic data if available. This will enable the most realistic three-dimensional understanding and representation of the structural hydrogeology for inclusion in the model.

Science to Support Decision-Making

Managing environmental resources is extremely challenging. More data and information do not always result in better decisions. Additional information pertaining to management decisions should provide clear guidance on how specific actions may impact water resources. The aforementioned science and data gaps should not be considered as an exhaustive list of additional information, but rather used as carefully considered guidelines in the context of the vision of the Commission and its fundamental objectives. Some of the knowledge gaps are recommended to be filled as part of Phase 2 (Supplementary Material: Scope of Work, Phase 2), but others should only be considered as part of Phase 3 or future work if the value of the information will improve the actions made by the Commission.

The Commission has invested in models to support their decision-making and is considering continued investments to support future decisions. As additional data and information become available, models can be updated to improve predictions. However, models as tools have limitations as does all science and information. Acknowledging and addressing uncertainty early in model development will aid in assessing whether a model can provide a reliable prediction based on the management questions being addressed. Management goals and priorities should ultimately inform the required inputs, parameters, and spatial extent of the model. Model considerations can be highly diverse; therefore, clear management goals must be established. Such considerations can include:

- Model resolution (vertical and horizontal);
- Model boundary extent and conditions;
- Inclusion of groundwater flow alone or also pollutant transport (e.g., salt);
- Factoring in water density (related to saltwater concentration);
- Temporal scale of model forecasting; and
- Inclusion of relevant geology in the model and at what resolution.

Furthermore, analyses can be done to understand the value of collecting additional information. These analyses can also be used to inform management decision-making by reducing uncertainty and improving the model's ability to accurately predict scenarios (Walker et al., 2012).

Environmental systems, including groundwater management, are complex because human and natural systems interact so closely. Program managers strive to accommodate this complexity in management decisions. Groundwater management is a perfect example of such intertwined issues. For instance, the issue of subsidence in CAGWCD is complicated both because of anthropogenic and naturally occurring subsidence. Additionally, the issue of groundwater recharge into the SHAS is highly complex because the SHAS is fed primarily from precipitation. Whether that precipitation can percolate into the system depends on the amount of recharge area available, which is directly related to the amount of permeable surface. Accounting for complexity and resulting uncertainty of such diverse variables is inherent in groundwater management. Dr. Mike Runge states "our knowledge of how those systems respond to management actions is often limited; therefore, many of the decisions have to be made in the face of uncertainty" (CEED, 2019). However, this uncertainty should not cripple the decision-maker, but rather encourage decision-makers to move forward in basing management decisions on the best science and information available at the time; with an acknowledgement of the uncertainty and support for reducing uncertainty through the pursuit of further research that targets specific knowledge gaps, science can inform management decisions. Dr. Runge continues, “Sometimes it is worth collecting more information, sometimes it isn’t. The role of science in a decision-making process is to provide the predictions that link the alternative actions to the desired outcomes. Investing in more science is only valuable to a decision maker if it helps to choose a better action” (CEED, 2019).

Next Steps

The results of Phase 1 included the development of fundamental objectives and performance metrics to help better understand how to manage groundwater within CAGWCD. Although much data have been collected, studies performed, and management actions taken, the challenge of managing groundwater is complex and additional information is needed.

Phase 2 would include evaluating the identified alternatives to determine the best combination of actions (i.e., strategy) for meeting CAGWCC's fundamental objectives. Evaluating the alternatives will require additional work to support CAGWCC in its decision-making. This includes understanding supply and demand, the economics related to different actions incorporated in the alternatives, and recharge/discharge (water availability) in each sand. Phase 2 also includes forecasting the consequences of each alternative based on sound data and science; therefore, the evaluation includes groundwater, social and economic modeling/evaluation, and identification of possible tradeoffs (economic or others) between objectives (Supplementary Material: Scope of Work, Phase 2).

This report has been written through the lens of the science and data needed to support CAGWCC long-term management planning. The identified science and data gaps listed in this report can help CAGWCC examine their performance on the identified fundamental objectives, help better manage their current operations, and inform both water suppliers and users moving forward into the future to maintain the SHAS as a usable, affordable, clean, readily accessible, and sustainable water resource.

Appendices

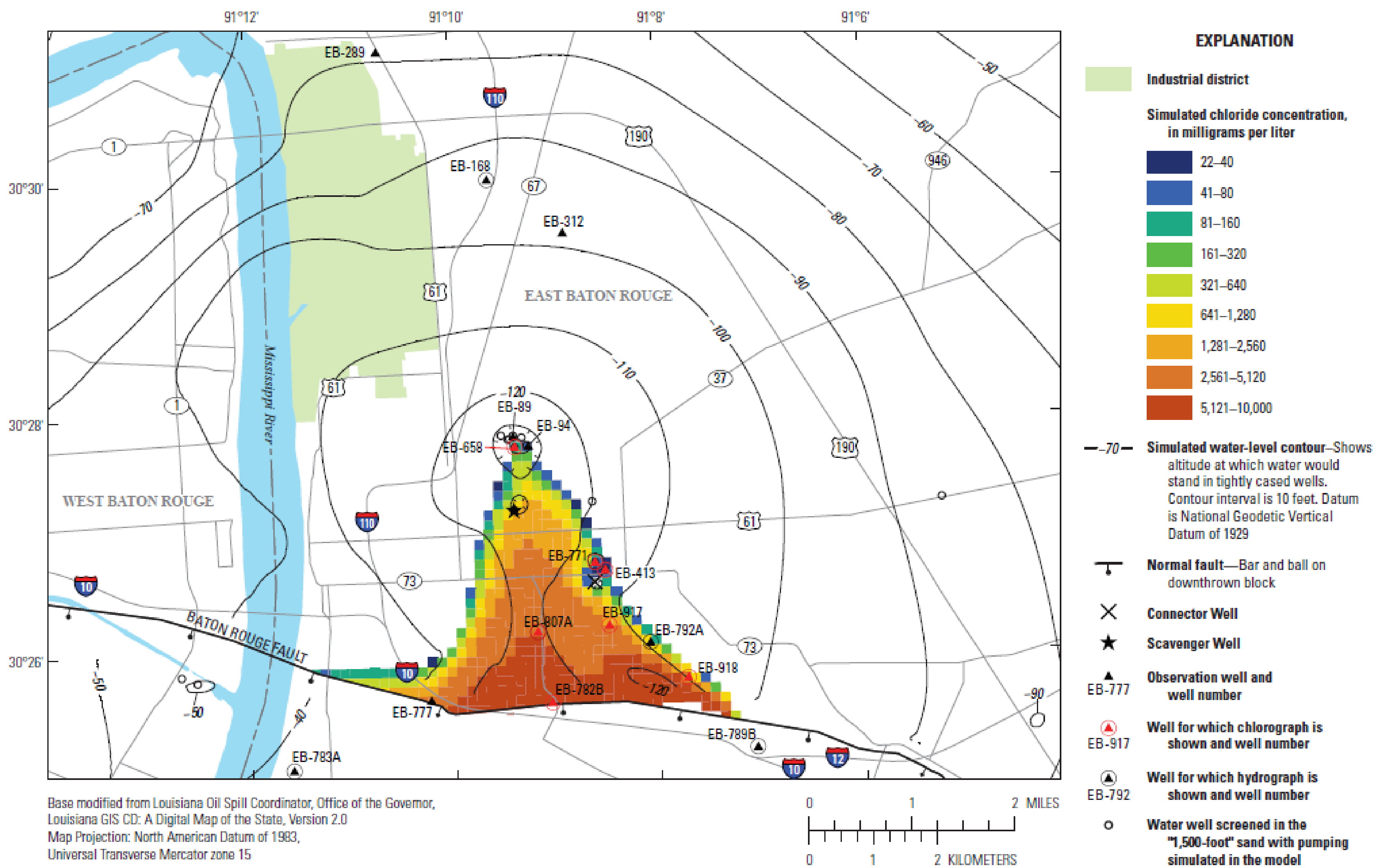


Figure 33. 2016 simulated water and chloride levels at base of the “1,500 ft” aquifer (Heywood et al., 2019).

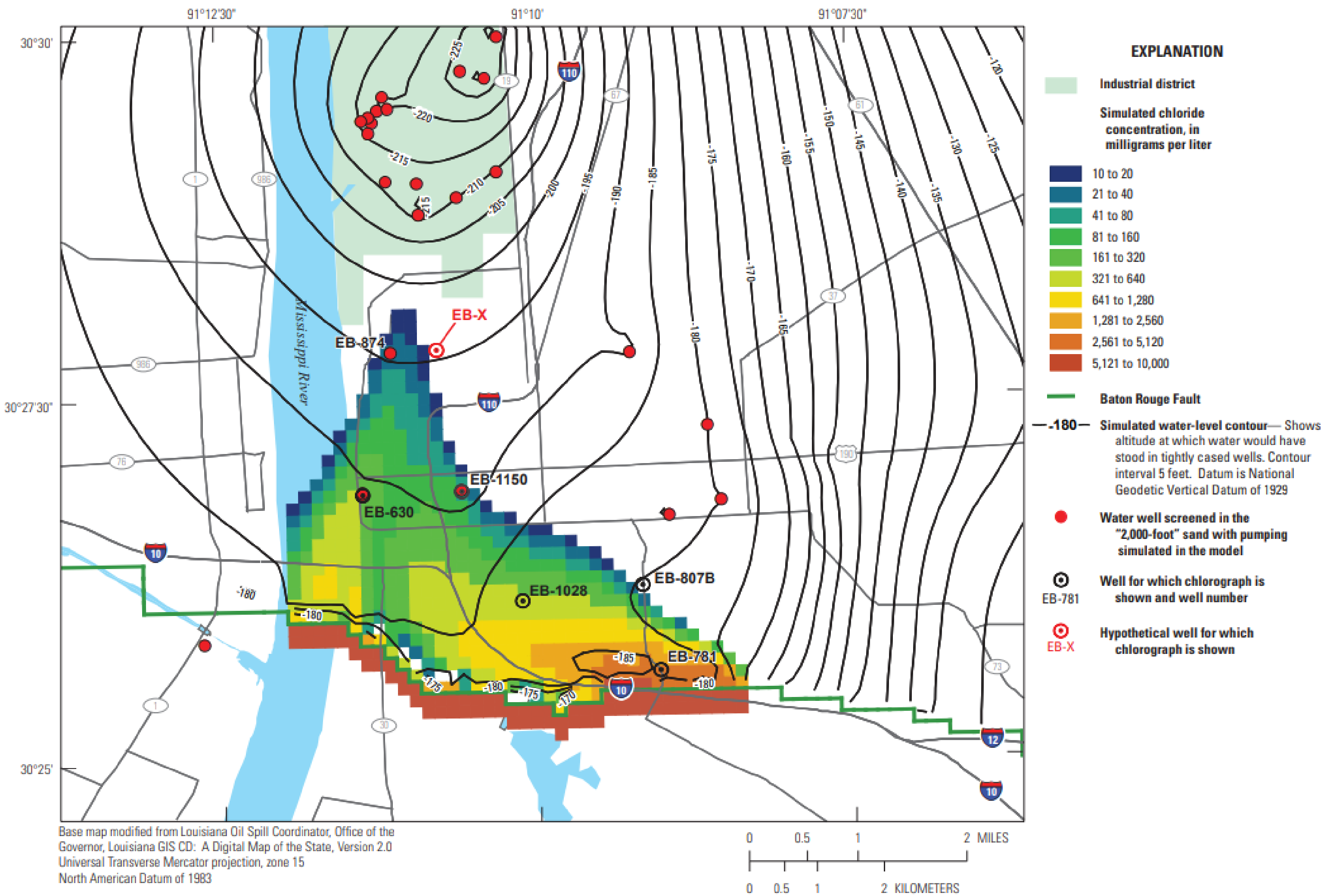


Figure 34. 2012 simulated water and chloride levels at the base of the “2,000 ft” aquifer (Heywood et al., 2015).

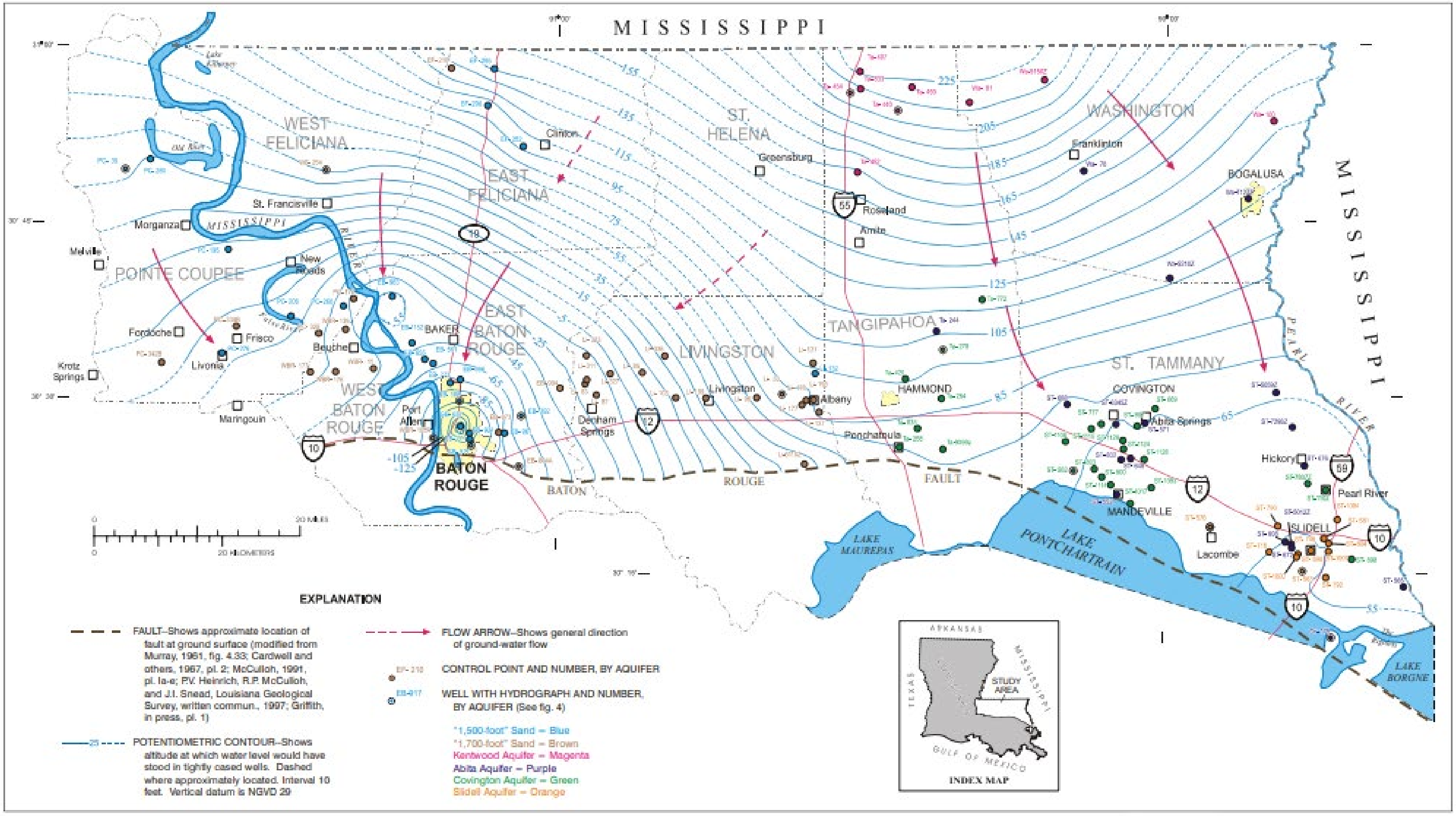


Figure 35. State view of "1,500" & "1,700 ft" sand potentiometric surface (Prakken, 2004).

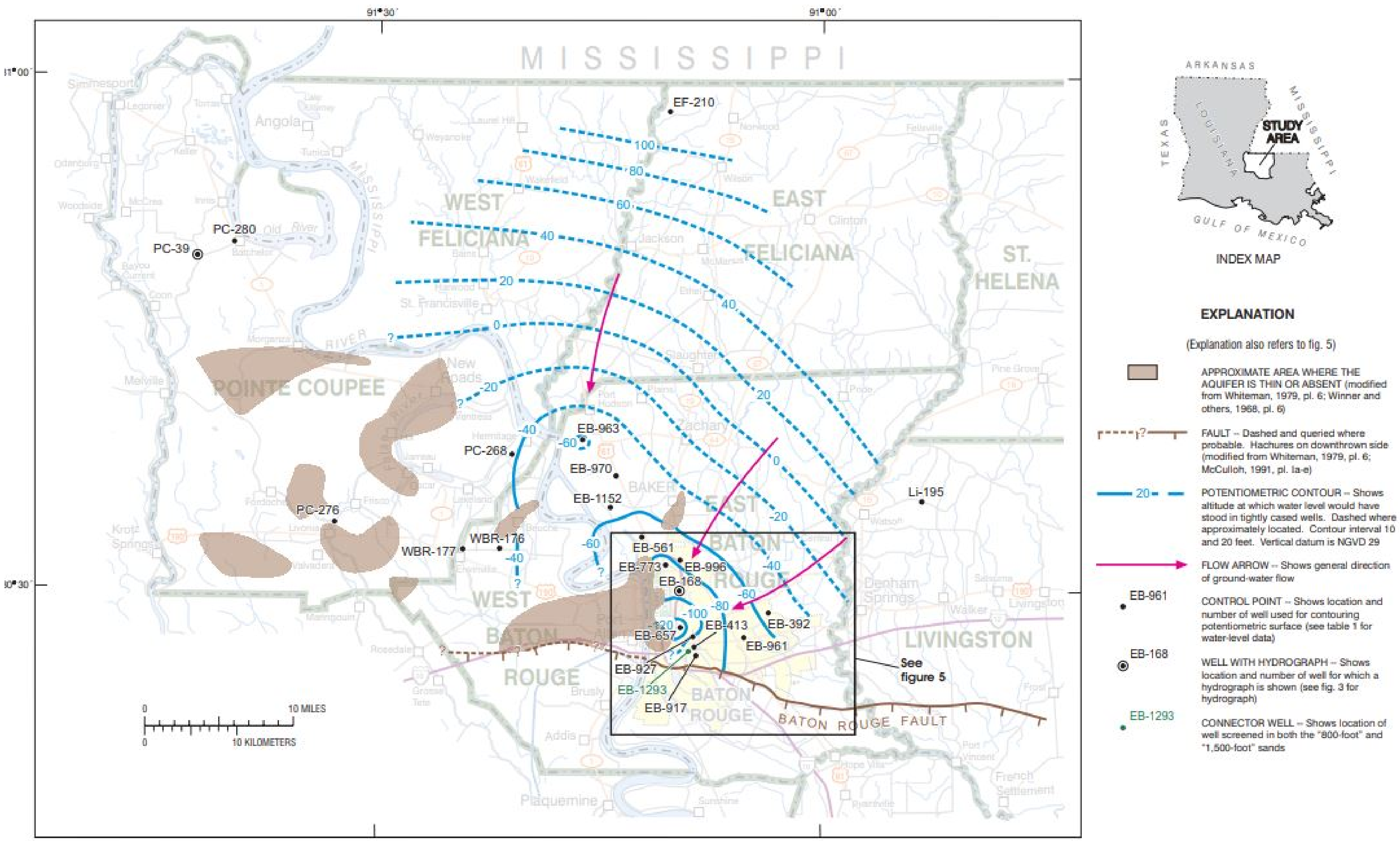


Figure 36. Regional view of “1,500” ft sand potentiometric surface (Tomaszewski & Accardo, 2002).

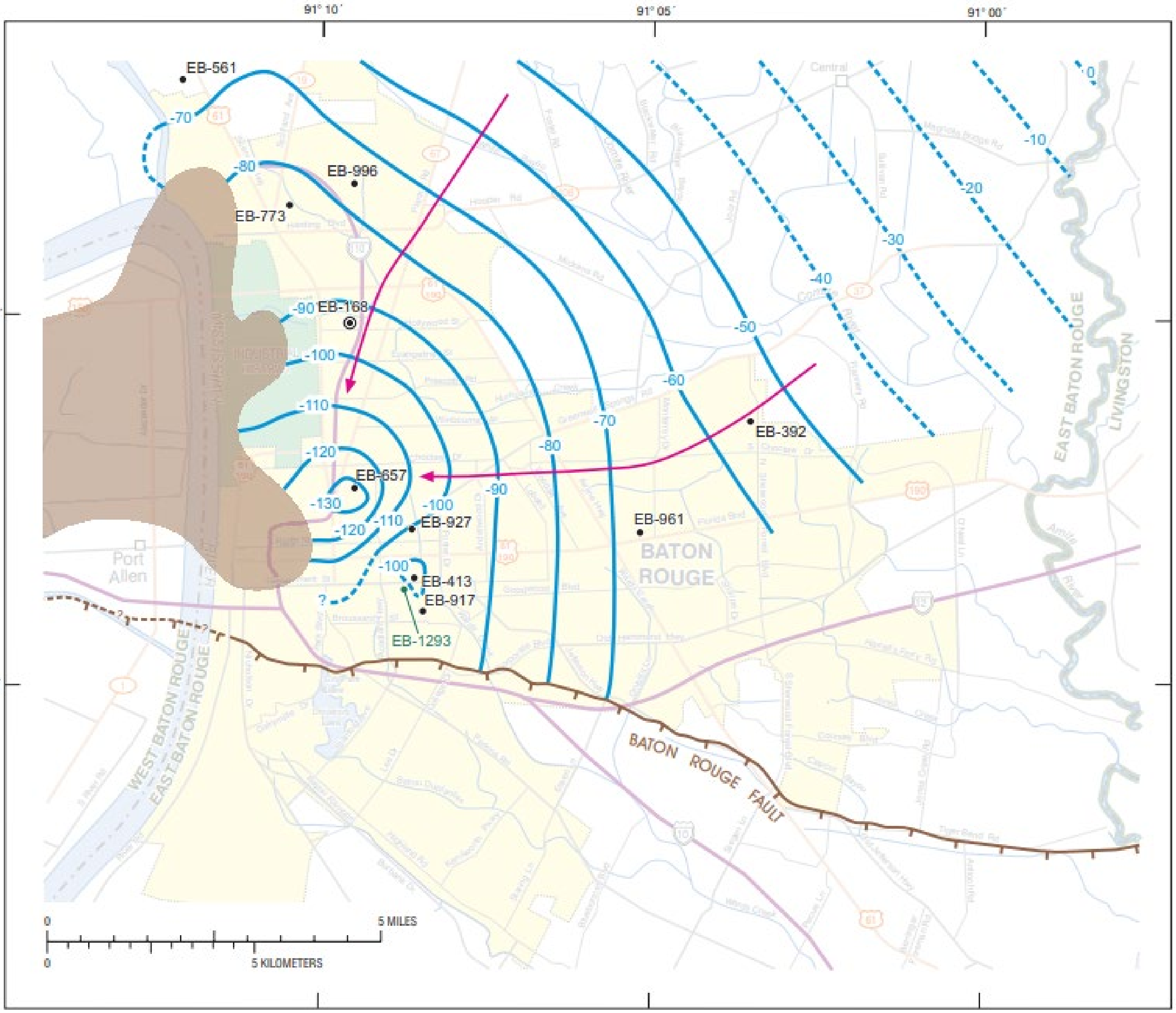


Figure 37. Local view of "1,500 ft" sand, Figure 36, box in potentiometric surface (Tomaszewski & Accardo, 2002). Blue lines represent potentiometric surfaces while the red lines represent the direction of flow. The brown surface represents where the aquifer is absent.

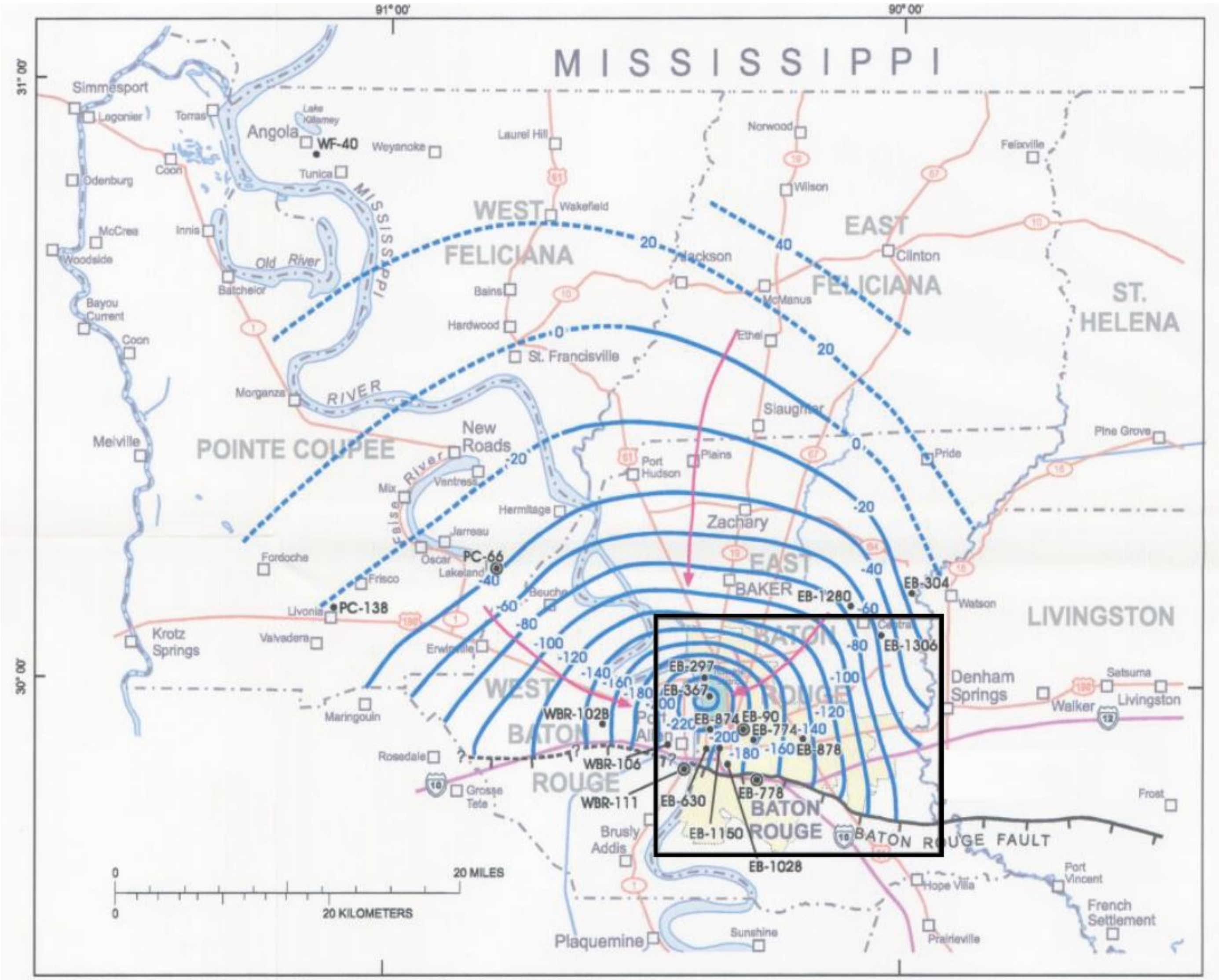


Figure 38. Regional view of "2,000 ft" sand potentiometric surface (Tomaszewski & Accardo, 2002).

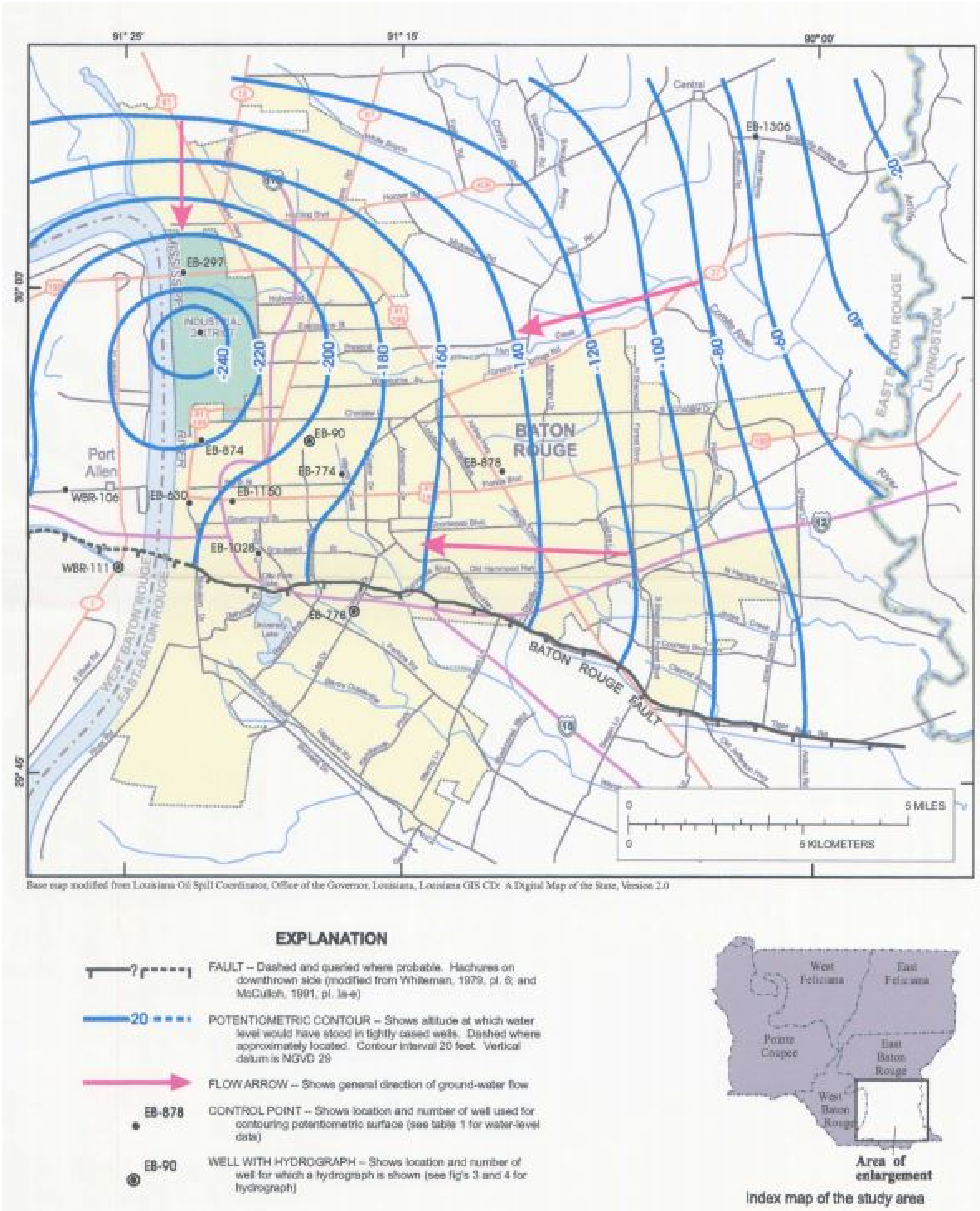


Figure 39. Local view of "2,000 ft" sand, Figure 38, potentiometric surface (Tomaszewski & Accardo, 2002). Blue lines represent potentiometric surfaces while the red lines represent the direction of flow.

Table 13. Water rate structure for BRWC; section A refers to the Baton Rouge area; section B refers to Red Oak area; section C refers to Ascension area; and section D refers to Parish Water Company. These calculations only consider normal water distribution fees and do not include service fees and monthly baseline meter rates (BRWC, n.d.).

A	Cubic ft brackets	0-300	300-497	497-597	597-697	697-797	797-897
	Price/cubic ft for block	$2.84	$1.21	$0.74	$0.74	$0.74	$0.74
	$/cubic ft	$0.0095	$0.0061	$0.0074	$0.0074	$0.0074	$0.0074

B	Cubic ft brackets	0-300	300-400	400-500	500-600	600-700	700-800
	Price/cubic ft for block	$2.72	$1.25	$1.25	$1.25	$1.25	$1.25
	$/cubic ft	$0.00907	$0.01250	$0.01250	$0.01250	$0.01250	$0.01250

C	Cubic ft brackets	0-334	334 - 468	468 - 602	602 - 735	735 - 869	869 - 1003
	Price/cubic ft for block	$6.21	$3.86	$0.47	$0.47	$0.47	$0.47
	$/cubic ft	$0.0186	$0.0289	$0.0035	$0.0035	$0.0035	$0.0035

D	Cubic ft brackets	0-300	300-497	497-597	597-697	697-797	797-897
	Price/cubic ft for block	$3.87	$1.41	$0.94	$0.94	$0.94	$0.94
	$/cubic ft	$0.0129	$0.0072	$0.0094	$0.0094	$0.0094	$0.0094

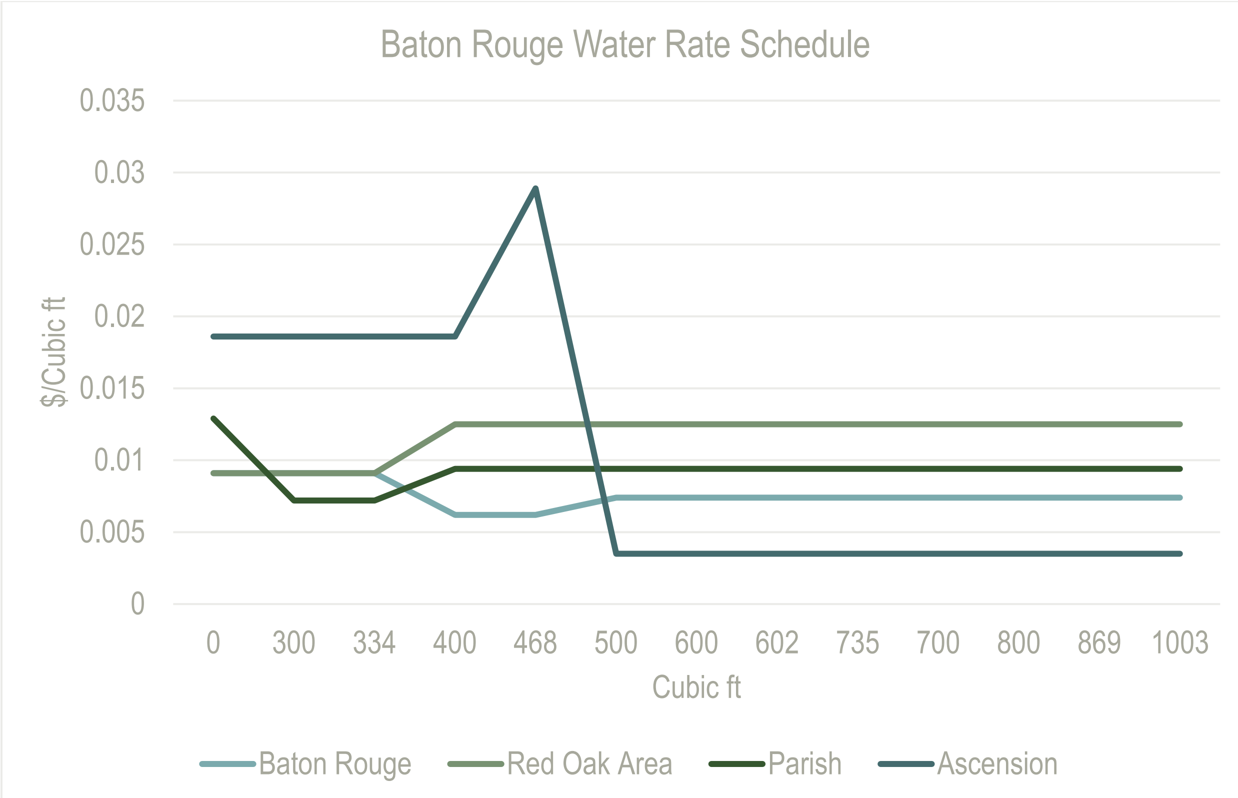


Figure 40. BRWC and other area water rates broken by block groups and price per cubic ft of water given overall volume of water utilized, Table 13.

Considering the potential to supplement water supply if groundwater availability or quality is compromised, CAGWCC may have to find ways to meet demand. The following table and sections outline potential methods to supplement water demand should groundwater availability or quality be an issue (CDWR, 2019).

Table 14. Alternative water resource management strategies. Adopted from the California Department of Water Resources water resource management strategies. Each row represents a different water resource management strategy, and the checkmarks represent which functions/services the water resource strategy addresses (CDWR, 2019).

Strategies to Help Address Water Management Issues	Reduce Drought Impacts	Improve Water Quality	Higher Operational Flexibility & Efficiency	Reduce Flood Impacts	Environmental Benefits	Energy Benefits	More Recreational Opportunities	Reduce Groundwater Overdraft	Improve Food Security	Public Safety and Emergency Response
Reduce Water Demand										
Agricultural Water Use Efficiency		✓	✓		✓				✓	
Urban Water Use Efficiency	✓	✓	✓		✓	✓			✓	
Improve Operational Efficiency & Transfers										
Conveyance — Delta	✓	✓	✓	✓	✓		✓	✓	✓	✓
Conveyance — Regional/Local	✓	✓	✓	✓	✓			✓	✓	

Strategies to Help Address Water Management Issues	Reduce Drought Impacts	Improve Water Quality	Higher Operational Flexibility & Efficiency	Reduce Flood Impacts	Environmental Benefits	Energy Benefits	More Recreational Opportunities	Reduce Groundwater Overdraft	Improve Food Security	Public Safety and Emergency Response
System Reoperation	✓	✓	✓	✓	✓	✓		✓		✓
Water Transfers	✓		✓	✓	✓				✓	
Increase Water Supply										
Conjunctive Management and Groundwater Storage	✓	✓	✓	✓	✓			✓	✓	
Desalination (Brackish and Sea Water)	✓	✓		✓				✓		
Precipitation Enhancement						✓				
Municipal Recycled Water	✓		✓			✓				
Surface Storage	✓		✓	✓			✓	✓	✓	
Surface Storage — Regional/Local	✓	✓	✓	✓		✓	✓	✓	✓	

Strategies to Help Address Water Management Issues	Reduce Drought Impacts	Improve Water Quality	Higher Operational Flexibility & Efficiency	Reduce Flood Impacts	Environmental Benefits	Energy Benefits	More Recreational Opportunities	Reduce Groundwater Overdraft	Improve Food Security	Public Safety and Emergency Response
Improve Flood Management										
Flood Management	✔	✔		✔	✔			✔		✔
Improve Water Quality										
Drinking Water Treatment and Distribution	✔	✔								
Groundwater/Aquifer Remediation		✔							✔	
Matching Water Quality to Use	✔	✔	✔		✔				✔	
Pollution Prevention		✔		✔	✔	✔	✔	✔		✔
Salt and Salinity Management		✔	✔		✔	✔				
Urban Stormwater Runoff Management	✔	✔	✔	✔	✔	✔	✔	✔		✔

Strategies to Help Address Water Management Issues	Reduce Drought Impacts	Improve Water Quality	Higher Operational Flexibility & Efficiency	Reduce Flood Impacts	Environmental Benefits	Energy Benefits	More Recreational Opportunities	Reduce Groundwater Overdraft	Improve Food Security	Public Safety and Emergency Response
Practice Resource Stewardship										
Agricultural Land Stewardship	✓	✓		✓	✓	✓	✓	✓	✓	
Ecosystem Restoration	✓	✓	✓	✓	✓	✓	✓	✓		✓
Forest Management	✓	✓		✓	✓	✓	✓	✓		✓
Land Use Planning and Management	✓	✓		✓	✓	✓		✓	✓	✓
Recharge Area Protection	✓	✓	✓	✓				✓	✓	
Sediment Management		✓	✓	✓	✓				✓	
Watershed Management	✓	✓	✓	✓	✓	✓	✓	✓	✓	
People & Water										

Strategies to Help Address Water Management Issues	Reduce Drought Impacts	Improve Water Quality	Higher Operational Flexibility & Efficiency	Reduce Flood Impacts	Environmental Benefits	Energy Benefits	More Recreational Opportunities	Reduce Groundwater Overdraft	Improve Food Security	Public Safety and Emergency Response
Economic Incentives — Loans, Grants, and Water Pricing	✔		✔		✔					
Outreach and Education	✔			✔	✔	✔			✔	✔
Water and Culture					✔			✔		
Water-Dependent Recreation				✔	✔			✔		

Types of Alternative Water Resource Management Actions

System Reoperation

System reoperation, in the context of water resources, means changing existing operation and management procedures for a water resources system. In particular, system reoperation refers to altering water supply using water management facilities with the goal of increasing desired benefits from the system and meeting demand (California Department of Water Resources, 2016j). System reoperation can refer to many different water management strategies for specific problems including matching water quality to use, water trading, and conveyance. The goal of system reoperation is to improve efficiencies and provide resilience for future water management challenges.

Some examples of system reoperation include integrating groundwater and surface water resources to address water supply issues. In the event water sources are limited or spatially dependent, it may be beneficial to capitalize on water resources by reorganizing water management resources. For example, water needed for agriculture and irrigation may not need to be potable water; therefore, limiting the amount of pumped groundwater and increasing surface water resources would both reduce supply stress on groundwater availability and still meet agricultural demand.

There are two immediate considerations with regards to system reoperation, physical and institutional constraints. From the physical perspective, system reoperation can be limited by existing infrastructure. For instance, if surface water storage was readily available, it would be feasible to switch over to surface water if groundwater resources were jeopardized. Institutional constraints represent the inability to capitalize on available resources. Other than physical constraints such as infrastructure, it may be legally challenging to capitalize on nearby available resources to address water supply and demand.

Water Transfers

Water transfers are a form of flexible system reoperation linked to many other water management strategies, including surface and groundwater storage, conjunctive management, conveyance efficiency, water use efficiency, water quality improvements, planned crop shifting, or crop idling for the specific purpose of transferring water (California Department of Water Resources, 2016k). Water transfers have the potential to improve economic stability and environmental conditions that would otherwise deteriorate with water scarcity granted there is a buyer and seller. A simple example of water transfer could be between two farmers. It could also be in the form of transferring water via tankers or canals.

Other considerations for water transfers include costs, landscape, market forces, and available participants. Who or what would be affected by water transfers? How much does it cost to transfer water? Is the landscape conducive to the efficient and effective possibility of transferring water? What does the governance structure look like? These are a couple of the major considerations for setting up water transfers throughout a region.

Conveyance

Conveyance in water management implies the movement of water and geographically connecting supply to the demand (California Department of Water Resources, 2016b). Water management using conveyance may be a combination of both artificial and natural waterways, or one alone to connect areas in need of water with areas that have water. These systems usually operate within the same watershed or river system. The main benefits of conveyance include steady water supply, predictable water quality, and improved operational flexibility. Conveyance can also be used to improve stream flow conditions, regulate water temperatures, and address water quality.

The main consideration with conveyance is its highly dependent on an interconnected system with the capacity, resources, and topography to manage surface water. Within California, there is a state-wide program and project that uses natural rivers to supply water throughout Central Valley. Both the Friant-Kern and Madera Canal are part of the Central Valley project and supply water to augment irrigation capacity in Fresno, Tulare, Kern, and Madera County.

Flood Management

Flood management is, in a traditional sense, thought of solely protect development and humans from flood water. It should be thought as a balance between exposure of people and property to flooding, the quality of functioning of ecosystems, the reliability of water supply, and economic stability (California Department of Water Resources, 2016e). Restoration of natural floodplains can be constructed in a way that not only protects humans from damage, but also restores balance to ecosystems that were once subject to flooding and improve groundwater recharge efficiency.

There are many ways to address flood management. Some options include flood control districts, irrigation districts, reclamation districts, and water conservation districts. Depending on the geology, topography, hydrological system, development patterns, and economic activity, flood management needs to be flexible so it can address multiple alternative criteria while also ensuring the safety of those subject to flooding.

Desalination

Desalination is the removal of salts from water to produce fresh water (California Department of Water Resources, 2016c). There are many ways to desalinize water including thermal systems, membrane separation, and ion transfer, which can be used to supply water for multiple uses. Desalinization involves multiple steps including pretreatment, post treatment, blending, solids disposal, concentrate. Necessary desalinization steps include raw water, intakes, desalinization, finished water. Depending on the level of treatment will determine the necessary steps. Though the science behind removing salt from water is well-known, desalinization an energy intensive process and tends to be costly at large scales.

In addition to the large up-front capital costs associated with building a desalinization plant, energy usage, permitting and regulatory framework, subsurface extraction, funding, and planning are some of the major obstacles to desalination. Desalinization produces brine, hyper-saline water, and how brine is managed and disposed of is extremely important. Disposal methods include but are not limited to diffusion, deep well injection, and in some cases as surface water discharge.

Conjunctive Management and Groundwater Storage

Conjunctive management or conjunctive use refers to the coordinated and planned use and management of both surface water and groundwater resources to maximize the availability and reliability of water supplies to meet various management objectives. Surface water and groundwater resources differ significantly in their availability, quality, management needs, and use costs. Managing both resources together, rather than in isolation, allows water managers to use the advantages of both resources for maximum benefit (California Department of Water Resources, 2016a).

Conjunctive management thus involves the efficient use of both groundwater and surface water through a coordinated conveyance infrastructure. Water is stored in the groundwater basin that is planned to be used later by intentionally recharging the basin when excess water supply is available.

Surface Storage

Surface storage is the term for the use of human-made, aboveground reservoirs to collect water for later release when needed for a myriad of purposes. The quantity, timing, and location of water demand frequently does not match the natural water supply availability; therefore, storing water when capable can address these demand issues (California Department of Water Resources, 2016i). Reservoir creation is an extremely complicated process involving multiple stakeholders, engineering, planning, and cooperation. Within Louisiana, there are plans of a new reservoir known as the Darlington Reservoir. It would be built for the Amite River and serve in similar capacity to that of Toledo Bend and Cross Lake. Though the development the Darlington Reservoir is still in early planning phases, its location could serve the Baton Rouge population.

The presence of new surface storage allows water managers the flexibility to implement water management strategies more easily and efficiently than without reserves. The stored water can be used for water quality management, ecosystem management, sediment transport, river and lake recreation, hydropower, municipal water use, and even flood control. Current examples for surface storage within Louisiana can be found in Toledo Bend and Cross Lake.

Municipal Recycled Water

"Water which, as a result of treatment of waste, is suitable for a direct beneficial use or a controlled use that would not otherwise occur and is therefore [sic] considered a valuable resource" (California Water Code § 13050). Municipal recycled water benefits the state and individual water users by reducing long-distance water conveyance needs, providing local water supplies, and being a drought-resistant resource. Recycled water is previously used water from region, local, or onsite locations and reused for another or similar purpose (California Department of Water Resources, 2016g).

Some consideration for recycled water though goes beyond water quality. Social perceptions are bound to play a large role in recycled water usage. There are also recycling costs, treatment capacity, treatment options, cross-connection prevention, and dual piping considerations to making recycled water available.

Salt and Salinity Management

Effective and sustainable saltwater management decisions rest in the hands of a wide range of water managers, regulators, facility operators, policy makers, landowners, and other stakeholders in any given watershed (California Department of Water Resources, 2016h). Saltwater management is a complicated issue in water management and requires coordination, detailed research, stakeholder engagement, and usually region scale cooperation.

Within Baton Rouge, saltwater threatens groundwater usage, the major source for CAGWCD. If saltwater were to enter pumps or the groundwater system, fresh water may become contaminated and not usable. In addition, not only would the water be unusable, but industry may have to change operations leading to moving business altogether and disrupting the Baton Rouge economy. As of now, CAGWCC is utilizing scavenger wells to mitigate saltwater encroachment, implemented voluntary pumping regulations on sands, and installed a scavenger and connector well.

Groundwater/Aquifer Remediation

Groundwater remediation removes contaminants which affect the beneficial use of groundwater. Remediation systems can employ passive or active methods to remove contaminants from groundwater (California Department of Water Resources, 2016a). There are both active and passive methods for groundwater/aquifer remediation which include remediation strategies both inside and outside the aquifer/groundwater.

Some examples of aquifer remediation include scavenger wells, chemical injections, and “pump and treat” methods. These strategies aim to directly address saltwater and chemically remove it, physically remove it, or extract and clean it. Variables to be considered in aquifer remediation are subject to the individual aquifer characteristics, water quality, pollutant, and available capital resources.

Matching Water Quality to Use

Matching water quality to use is a management strategy that recognizes not all water uses require the same water quality. One common measure of water quality is its suitability for an intended use; a water quality constituent often is only considered a contaminant when that constituent adversely affects the intended use of the water (California Department of Water Resources, 2016f). Using water more efficiently and effectively reduces supply issues if there are alternative water supply options available to be used.

The largest considerations for matching water quality use are current infrastructure and capital assets for water users. If resources are available to capitalize on different water sources, matching water quality to use can address multiple water resource issues simultaneously. This strategy can afford market participants to specialize and realize gains via comparative advantages, increaser resilience into the economy, and positively benefit water supply.

Economic Incentives – Loans, Grants, and Water Pricing

Economic incentives include financial assistance, water pricing, and water market policies intended to influence water management. These policies could be loans, subsidies, or other economic creative methods. Economic incentives can influence water use, wastewater volume, and source of water supply (California Department of Water Resources, 2016d). They can be created or enhanced by facilitating water market transfers, by creating market opportunities where they did not exist, by expanding opportunities where they currently exist, or by reducing market transaction costs.

The main consideration in managing water through economic incentives is a legal framework and market presence. There is most likely to be both positive and negative externalities associated with such established economic incentives and depending on the societal environment, water supply and demand conditions, incentives can be crafted to address multiple issues at once. Not only would economic incentives encourage water conservation, but it could also work to finance future water management activities.

Outreach and Engagement

Outreach and engagement for water management is the use of tools and practices by water agencies to facilitate contributions by public individuals and groups towards water management outcomes (California Department of Water Resources, 2016g). Engagement and outreach contributions include providing insight to decision-makers on best management practices for water management, adopting water-wise practices, supporting activities that benefit effective water management, promoting collaborative approaches to solving water issues, and ensuring access to education materials regarding water resource management.

Because of the vast impact water management has on multiple facets of an environment, it is extremely important to have an interdisciplinary approach to tackle these issues. Multiple fields of expertise should be brought to the table including scientists, engineers, lawyers, politicians, health experts, planners, and designers, and any other major water users. A good engagement/outreach campaign will inform everyone who can participate in the water resource management discussion. This should allow an avenue/opportunity for individuals to present information to the table which would not have been previously considered.

Bank Filtration

Bank filtration is the concept of utilizing surface water and a porous medium to help pre-treat water before withdrawal from groundwater resources. The bank may refer to a surface water boundary such as a river bank to act as the pre-screening tool (Kelly & Rydlund, 2006). In the event groundwater is compromised, it may be beneficial to have supplementation to CAGWCD in the form of alternative water sources. Withdrawing surface water and treatment of such water can be expensive, but by taking advantage of naturally occurring screens, water can be pre-treated using bank filtration.

Bank filtration can be beneficial in pre-treating surface water, but the longevity, energy requirements, and science behind its efficacy are necessary to consider before implementation. Water quality of such bank filtration may not be worth the upfront cost. If the concept of surface water is a social barrier or if surface water treatment with conventional methods is costly, bank filtration could be considered as an alternative method for pre-treatment.

APPENDIX F: ANNOTATED BIBLIOGRAPHY

1. Ali, G., Asghar, M. N., Latif, M., & Dahri, Z. Hussain. (2004). Optimizing operation strategies of scavenger wells in lower Indus Basin of Pakistan. Agricultural Water Management, 66(3), 239–249. https://doi.org/10.1016/j.agwat.2003.11.005

In the lower Indus Basin of Pakistan, where rainfall is low and water use is high, more than 350 scavenger wells were installed under the left bank outfall drain stage-1 with a capital cost of US$ 12.75 million to provide drainage and to recover fresh groundwater mainly for irrigation purposes. This paper highlights the environmental issues in the pumping and disposal of saline groundwater for sustainability of scavenger wells. Two numerical models (MODFLOW and MT3D) were used to assess the performance of scavenger wells. Changes in the operational strategies of such wells for the concerned hydro-geological conditions are also recommended.

2. Alley, W. M., Thomas, R. E., & O. Lehn, F. (1999). Sustainability of Ground-Water Resources (Technical No. 1186). USGS. https://pubs.usgs.gov/circ/circ1186/pdf/circ1186.pdf

This is a very broad background report that discusses most aspects of groundwater, aquifers, and usage in the United States. There is excellent information, principles, and information on how groundwater functions in a steady state environment and with anthropogenic influence.

3. Anderson, C. (2012). Sources of Salinization of the Baton Rouge Aquifer System: Southeastern Louisiana [Louisiana State University]. https://biotech.law.lsu.edu/blog/Anderson_thesis.pdf

This is a thesis by Callie Anderson which discusses the sources and potential pathways of saltwater intrusion in aquifers of the Baton Rouge area. Under the guidance of Frank Tsai and Jeffrey Hanor, Anderson researched the sources of saltwater both south and north of the Baton Rouge Fault and drew connections between the location of saltwater and potential sources.

4. Barlow, P. (2019). Ground Water in Freshwater-Saltwater Environments of the Atlantic Coast (Government Circular 1262). USGS. https://pubs.usgs.gov/circ/2003/circ1262/#boxb

This webpage provides a thorough documentation of freshwater and saltwater environments of the Atlantic Coast. In particular, the Ghyben-Herzberg principle is discussed presenting formulas and good illustrations on how saltwater and freshwater interact in dynamic environments.

5. Bense, V. F., & M.A. Person. (2006). Faults as conduit-barrier systems to fluid flow in siliciclastic sedimentary aquifers. Water Resources Research, 42, 18. https://doi.org/10.1029/2005WR004480

This paper discusses the effect of sediments, faults, and geology on groundwater flow. More discussion on how saltwater flow along/across a fault in varying types of sediment are presented/explained in some detail here as well.

6. Bianchi, M., Zheng, C., Wilson, C., Tick, G., Liu, G., & Gorelick, S. M. (2011). Spatial connectivity in a highly heterogeneous aquifer: From cores to preferential flow paths. Water Resources Research, 47. https://doi.org/10.1029/2009WR008966

This paper discusses how hydraulic conductivity accounts for total amount of flow within a given system, the Macrodispersion Experiment (Columbus, MS). In all, the fastest 5% flow paths account for 40% of groundwater flow through a system.

7. Brunner, P., Simmons, C. T., Cook, P. G., & Therrien, R. (2010). Modeling Surface Water-Groundwater Interaction with MODFLOW: Some Considerations. Ground Water, 50(2), 174–180.

This paper discussed the considerations and limitations associated with MODFLOW to help better understand how the model works. For the Baton Rouge area, USGS utilized MODFLOW to model scenarios related to saltwater intrusion and scavenger well efficiency.

8. BRWC. (n.d.). BRWC Rates—Baton Rouge Water Company—Ascension Water Company—Parish Water Company, Baton Rouge, Louisiana [Government]. Schedule of Rates & Tariffs. Retrieved February 4, 2020, from https://www.brwater.com/schedule/baton-rouge-water-company.html

This website provides the water rate data for Baton Rouge Water Company. This was analyzed to help understand the rate structure and the Baton Rouge area for a better understanding of water management in CAGWCD.

9. CAGWCC. (2019a). The Capital Area Ground Water Conservation Commission—Mission Statement. About Us: Mission Statement. https://www.cagwcc.com/site2015/aboutus-mission.htm

The website is the home page for the Capital Area Groundwater Conservation commission which describes the mission, technical resources, and other materials related to the regulating body.

10. CAGWCC. (2019b). Capital Area Ground Water Conservation Commission Well Database. Capital Area Groundwater Conservation Commission.

This database is a comprehensive list of wells, well owners, pumpage volumes, and other information for registered wells in the Capital Area Groundwater Conservation District. Using this database, we analyzed the trends in pumping across the aquifers within CAGWCD, the major users, and types of users within each sand.

11. California Department of Water Resources. (n.d.-a). Agricultural Water Use Efficiency. Retrieved August 16, 2019, from http://water.ca.gov/Programs/Water-Use-And-Efficiency/Agricultural-Water-Use-Efficiency

With the use of irrigation and an ideal climate to grow almost anything, California has been given the opportunity to be one of the most productive agricultural producers of food in the United States. This document explains the laws by which agricultural users must abide and other resources on how California governs their agricultural water use.

12. California Department of Water Resources. (n.d.-b). Urban Water Use Efficiency. Retrieved August 16, 2019, from http://water.ca.gov/Programs/Water-Use-And-Efficiency/Urban-Water-Use-Efficiency

Climate change, population growth, land development, and increasing regulations on water use impact our water supply, which means that we must be more diligent in conserving the water we have now, so that we have enough supply for the future. This report helps understand how to use urban water more efficiently.

13. California Department of Water Resources. (2016a). Conjunctive Management and Groundwater Storage: A Resource Management Strategy of the California Water Plan (p. 50). California Natural Resources Agency. https://water.ca.gov/-/media/DWR-Website/Web-Pages/Programs/California-Water-Plan/Docs/RMS/2016/08_ConjMgt_GW_Storage_July2016.pdf

Conjunctive groundwater management and groundwater storage refers to the management between groundwater and surface water to help improve groundwater availability. Within this report there are cases by which conjunctive management has been employed, lessons learned from such actions, and future considerations when dealing with conjunctive groundwater management into the future.

14. California Department of Water Resources. (2016b). Conveyance—Regional/Local: A Resource Management Strategy of the California Water Plan (p. 13). https://water.ca.gov/-/media/DWR-Website/Web-Pages/Programs/California-Water-Plan/Docs/RMS/2016/05_Conveyance_Regional-Local_July2016.pdf

This report outlines the use of conveyance in California, how it is employed, success stories and other governmental actions that have facilitated the use of such actions for irrigation in California.

15. California Department of Water Resources. (2016c). Desalination (Brackish and Sea Water): A Resource Management Strategy of the California Water Plan (p. 51). California Natural Resources Agency. https://water.ca.gov/-/media/DWR-Website/Web-Pages/Programs/California-Water-Plan/Docs/RMS/2016/09_Desalination_July2016.pdf

This report outlines the implementation of desalinization plants in California, their implementation, and pros and cons with the California area. Case examples are included for specific examples and future considerations are also presented to help aide in better management of water in general.

16. California Department of Water Resources. (2016d). Economic Incentives—Loan, Grants, and Water Pricing: A Resource Management Strategy of the California Water Plan (p. 14). California Natural Resources Agency. https://water.ca.gov/-/media/DWR-Website/Web-Pages/Programs/California-Water-Plan/Docs/RMS/2016/27_Economic_Incentives_July2016.pdf

This report outlines multiple economic incentives currently in California and their effect. Examples include low interest loans, grants, water rates and rate structures, rebates, service fees, taxes, et cetera.

17. California Department of Water Resources. (2016e). Flood Management: A Resource Management Strategy of the California Water Plan (p. 50). California Natural Resources Agency. https://water.ca.gov/-/media/DWR-Website/Web-Pages/Programs/California-Water-Plan/Docs/RMS/2016/03_Flood_Mgt_July2016.pdf

This report discusses flood management practices in California and how strategies are formed around areas prone to flooding. In addition, multiple policies, strategies, and case examples are presented to help better understand flood management in California.

18. California Department of Water Resources. (2016f). Groundwater and Aquifer Remediation: A Resource Management Strategy of the California Water Plan (p. 18). California Natural

Resources Agency. https://water.ca.gov/-/media/DWR-Website/Web-Pages/Programs/California-Water-Plan/Docs/RMS/2016/15_Groundwater_Aquifer_Remediation_July2016.pdf

This report is a general outline of groundwater remediation in California via two methods, exactment and treatment and passive remediation. Depending on the intended usage of the aquifer and surrounding options, different treatment options may be more necessary than the other. The source of pollution may be naturally occurring or anthropogenic induced.

19. California Department of Water Resources. (2016g). Matching Water Quality to Use: A Resource Management Strategy of the California Water Plan (p. 15). California Natural Resources Agency. https://water.ca.gov/-/media/DWR-Website/Web-Pages/Programs/California-Water-Plan/Docs/RMS/2016/16_Matching_Water_Quality_Use_2016.pdf

This report discusses the topic of matching water quality to water use. For example, understanding what type of water is necessary for certain actions may better allocate water to help prevent waste.

20. California Department of Water Resources. (2016h). Municipal Recycled Water: A Resource Management Strategy of the California Water Plan (p. 36). California Natural Resources Agency. https://water.ca.gov/-/media/DWR-Website/Web-Pages/Programs/California-Water-Plan/Docs/RMS/2016/11_Municpal_Recycled_Water_July2016.pdf

This report discusses how municipal recycled water is managed in California. Since 2009, changes have been enacted to help incentivize more recycled water. Also, the section outlines the potential for recycling through 2030. Pros and cons of water recycling are discussed, and recommendations are also illustrated.

21. California Department of Water Resources. (2016i). Outreach and Engagement: A Resource Management Strategy of the California Water Plan (p. 21). California Natural Resources Agency. https://water.ca.gov/-/media/DWR-Website/Web-Pages/Programs/California-Water-Plan/Docs/RMS/2016/28_Outreach_Engagement_July2016.pdf

This report discusses how outreach and engagement plays a significant role in water conservation in California. The largest section within this report outlines the major implementation issues with outreach and engagement which include lack of water management understanding, complex governance structures, public perception of water, and others.

22. California Department of Water Resources. (2016j). Salt and Salinity Management: A Resource Management Strategy of the California Water Plan (p. 43). California Natural Resources Agency. https://water.ca.gov/-/media/DWR-Website/Web-Pages/Programs/California-Water-Plan/Docs/RMS/2016/18_Salt_Salininty_Mgt_July2016.pdf

This report discusses how salt is managed in California and discusses both coastal and confined saltwater issues in surface and groundwater. California has a plethora of dynamic costal systems which interact with saltwater. This section discusses saltwater in the context of surface water, but provides excellent background information of collection, storage, and treatment of saltwater.

23. California Department of Water Resources. (2016k). Surface Storage—Regional/Local: A Resource Management Strategy of the California Water Plan (p. 11). California Natural Resources Agency. https://water.ca.gov/-/media/DWR-Website/Web-Pages/Programs/California-Water-Plan/Docs/RMS/2016/13_Surface_Storage_Regional-Local_July2016.pdf

This report discusses how surface storage is used throughout California and what the pros and cons are. Most particularly, identifying suitable locations of storage and the operation. Secondly, the funding of such activities is always a challenge and examples of water storage in the region are identified for case examples.

24. California Department of Water Resources. (2016l). System Reoperation: A Resource Management Strategy of the California Water Plan (p. 19). California Natural Resources Agency. https://water.ca.gov/-/media/DWR-Website/Web-Pages/Programs/California-Water-Plan/Docs/RMS/2016/06_System_Reoperation_July2016.pdf

This report discusses how to reorient existing infrastructure or operations to efficiently use water. Case examples are illustrated throughout California. Depending on the governance of certain water bodies, aligning water to demands is important in obtaining efficiency and whether water supply or demand can be improved upon. Multiple challenges exist within this realm of water management, and this report lays out a useful guideline on how multiple partners collaborated and achieved an effective water management strategy using system reorientation.

25. California Department of Water Resources. (2016m). Water Transfers: A Resource Management Strategy of the California Water Plan (p. 15). California Natural Resources Agency. https://water.ca.gov/-/media/DWR-Website/Web-Pages/Programs/California-Water-Plan/Docs/RMS/2016/07_Water_Transfers_July2016.pdf

Water transfers are more common in the western U.S due to water rights. In California, water transfers serve in an open market whereby if infrastructure is available or the water body is a shared source with some quota, then water can be transferred.

26. CEED. (2019). Decision Point—Connecting conservation policy makers, researchers and practitioners (p. 64). Centre of Excellence for Environmental Decisions. http://decision-point.com.au/wp-content/uploads/2018/12/DecisionPoint-107web.pdf

This report discusses how decision analysis and/or decision science plays a role in addressing uncertainty. How decision analysis is implemented and carried out is identified through a couple of examples and why it is important to go through the proper steps in addressing uncertainty to ensure all information is considered.

27. Chamberlain, E., Hanor, J., & Tsai, F. (2013). Sequence Stratigraphic Characterization of the Baton Rouge Aquifer System, Southeastern Louisiana. The Gulf Coast Association of Geological Sciences, 12.

The aquifer system consists of a “2,800 ft” (850 m) thick succession of south-dipping siliciclastic sandy units and mudstones of Upper Miocene through Pleistocene age. Seventy-five digitized spontaneous potential-resistivity logs for boreholes in the area provided data for interpreting environments of deposition, for correlating sand-rich and mudstone-rich zones, and for identifying periods of low and high rates of sediment aggradation.

28. Collier, A. L., & Sargent, P. B. (2018). Water Use in Louisiana, 2015 (Special Report No. 18; Water Resources Special Report). State of Louisiana Department of Transportation and Development Public Works and Water Resources Division.

This report was published by USGS and provides water usage from registered water users in the entire state of Louisiana for year 2015. The report also breaks down water use by water use profiles such as public, commercial, industrial, and agriculture to help demonstrate usage trends over time.

29. Dausman, A., & Langevin, C. D. (2005). Movement of the Saltwater Intrusion Interface in the Surficial Aquifer System in Response to Hydrological Stresses and Water-Management Practices, Broward County, Florida (Scientific Investigations Report No. 2004–5256; p. 81). USGS. https://pubs.usgs.gov/sir/2004/5256/pdf/sir20045256.pdf

This paper is a comprehensive assessment on the water management activities, water levels, and saltwater intrusion in Broward County, Florida. Model results, hydrologic data, and environmental variables are all discussed in how they affect saltwater intrusion.

30. Dial, & Cardwell, G. T. (1999). A Connector Well to Protect Water-Supply Wells in the "1,500-Foot" Sand of the Baton Rouge, Louisiana Area from Saltwater Encroachment. (Technical Bulletin No. 5; p. 20). CAGWCC with support by a grant under section 319(h) of the Clean Water Act. http://www.dnr.louisiana.gov/assets/OC/env_div/gw_res/ENV2012_01_01/CAGWCC_BULLETIN5.PDF

This report provides background and technical specifics on the connector well that was drilled to help mitigate saltwater intrusion in the 1,500 ft aquifer. The conclusion regarding the effectiveness on saltwater mitigation was yet to be determined based on the time frame associated with this report, but the well was estimated to have a 50-year lifespan and help hydraulically connect both the "800" and "1,500 ft" aquifers.

31. Durham, C. O., & Peeples, E. M. (1956). Pleistocene Fault Zone in Southeastern Louisiana. Gulf Coast Association of Geological Societies Transactions, 6, 65–66.

This page provides some background information on the Pleistocene fault zone which traverses the southeast Louisiana coastal plain and the general characteristics associated with such faults. Also, it describes how multiple wells were constructed along the fault to analyze the fault characteristics.

32. Eckstein, G., & Eckstein, Y. (2005). A Hydrogeological Approach to Transboundary Ground Water Resources and International Law. The American University International Law Review, 19(2). https://digitalcommons.wcl.american.edu/cgi/viewcontent.cgi?referer=https://www.google.com/&httpsredir=1&article=1163&context=auilr

Four cases where groundwater forms part of an international water system are analyzed within this paper. The authors propose six models in which groundwater resources can have international implication and help in the evaluation of the applicability and science regarding the current rules governing shared groundwater resources.

33. Ecology and Environment, INC. (2011). Draft Recommendations for a Statewide Ground Water Management Plan (p. 520). Office of Conservation - Louisiana Department of Natural Resources. http://www.dnr.louisiana.gov/assets/docs/conservation/GroundwaterPlanRec2011.pdf

This is the detailed report that the office of conservation provided to the state of Louisiana to help prepare for managing Louisiana's groundwater. It breaks down groundwater by aquifer systems such

as the Mississippi River Alluvial Aquifer and the Sparta Aquifer. It also discusses water user groups and the relative impact those users have on groundwater resources.

34. Elshall, A. S., Tsai, F. T. C., & Hanor, J. (2013). Indicator geostatistics for reconstructing Baton Rouge aquifer-fault hydrostratigraphy, Louisiana, USA. Hydrogeology Journal, 21(8). https://doi.org/10.1007/s10040-013-1037-5

This paper discusses the complex heterogenous structure of the clays and sands that lie beneath the Baton Rouge area and provides insight into possible avenues for saltwater intrusion across the Baton Rouge Fault.

35. Enabling Legislation CAGWCC Revised Statutes Part XIII, no. La. R.S. 38:3071-3084, Louisiana, 1 (2015). https://www.cagwcc.com/site2015/laws-regs/CAGWCC_Powers_n_Duties-2-19.pdf

This document contains the enabling legislation upon which CAGWCC was built. Updated enabling legislation is expected in the future.

36. ESRI, HERE, Garmin, OpenStreetMap contributors, & GIS user community. (2019). Light Gray Canvas & Satellite Imagery [Background Imagery]. ESRI.

This is a resource for referencing ArcMap service layer credits. Background imagery such as satellite and transit maps are provided for context in maps.

37. Ferris, J. G., Knowles, D. B., Brown, R. H., & Stallman, R. W. (1962). Theory of Aquifer Tests (Technical No. 1536-E; p. 113). USGS. https://pubs.usgs.gov/wsp/wsp1536-E/pdf/wsp_1536-E.pdf

This report represents different types of tests that can help assess the characteristics of an aquifer. In particular, it offers a great explanation as to what types of aquifer tests answer specific questions. For this report, there is a good illustration representing the difference between hydraulic conductivity and transmissivity.

38. Gagliano, Sherwood. Effects of Geological Faults on Levee Failures in South Louisiana (2005). https://www.epw.senate.gov/public/_cache/files/0/6/06b95006-cb07-4572-ae98-d6f2e2cb57fb/01AFD79733D77F24A71FEF9DAFCCB056.111705gagliano-testimony.pdf.

This report was part of a testimony given by Sherwood Gagliano and presented to the U.S. Senate Committee on Environment & Public Works with Senator James M. Inhofe as the Chairman and Senator James M. Jeffords as Ranking Member. In the wake of hurricane Katrina, this testimony spoke to the levee failures in south Louisiana. Background information was presented on the location and types of geologic faults around New Orleans and the role they played on levee failures. For this report, there is a good illustration representing a growth fault and a rollover effect.

39. Griffith, Jason M. (2003). Hydrogeologic Framework of Southeastern Louisiana (p. 14) [Technical]. Louisiana Department of Transportation and Development. https://wise.er.usgs.gov/dp/pdfs/TR72.pdf

This paper is similar to Meyer and Turcan 1955 and discusses the hydrogeologic framework in southeastern Louisiana aquifers. It also serves as a collective report on previous studies regarding southeast Louisiana aquifers and hydrogeology.

40. Griffith, J.M., & Lovelace, J. K. (2003). Louisiana Ground-Water Map No. 16: Potentiometric surface of the “1,500-foot” sand of the Baton Rouge area, Louisiana, spring 2001 (p. 2). USGS, Department of the Interior, Department of the Interior, State of Louisiana Department of Transportation and Development Office of Public Work and Intermodal Public Works and Water Resources Division. https://archive.usgs.gov/archive/sites/la.water.usgs.gov/publications/pdfs/WRI_03-4021.pdf

This is an all in one map and description of the “1,500 ft” sand and its potentiometric surface. The potentiometric surfaces were digitized in this report to help illustrate how the potentiometric surface has changed over time.

41. USGS. (2020, May 31). *Groundwater is the area underground where openings are full of water* [Government]. Groundwater Is the Area Underground Where Openings Are Full of Water. https://www.usgs.gov/media/images/groundwater-area-underground-where-openings-are-full-water

USGS has a photo gallery with multiple groundwater images. This website contains a cross section illustrating the different zones in aquifer.

42. Hai Pham, & Tsai, F. (2017). Modeling complex aquifer systems: A case study in Baton Rouge, Louisiana (USA). Hydrogeology Journal, 25(3), 601–615. https://doi.org/DOI 10.1007/s10040-016-1532-6

Describes challenges in modeling alluvial groundwater networks and implements new model calibration to help underground network for Baton Rouge. Declines of groundwater levels caused land subsidence and reversed flow direction in the vicinity of the Baton Rouge Fault to cause saltwater intrusion.

43. Harris, G. D. (1905). Underground Water of Southern Louisiana (Water-Supply and Irrigation Paper No. 101, p. 123) [Technical]. USGS. https://pubs.usgs.gov/wsp/0101/report.pdf

This paper is one of the first documented reports about subsurface flows in southern Louisiana and how surface water and gulf waters correlate. This paper helps provide some of the first documented wells in the East Baton Rouge area and multiple other parishes.

44. Hemmerling, S., Clark, R. F., & Bienn, H. C. (2016). Water Resources Assessment for Sustainability and Energy Management (p. 119). The Water Institute of the Gulf. Funded by the Coastal Protection and Restoration Authority. http://www.dnr.louisiana.gov/assets/OC/env_div/WaterInstituteWaterPlanningReport071516.pdf

Using published and publicly available data, the Water Institute of the Gulf developed a framework for determining the inputs and outputs of each study area and determined the energy costs associated with extracting, treating, and conveying water for public use.

45. Heywood, C. E., Griffith, J. M., & Lovelace, J. K. (2014). Simulation of Groundwater Flow in the “1,500-Foot” Sand and “2,000-Foot” Sand, with Scenarios to Mitigate Saltwater Migration in the

"2,000-Foot" Sand of the Baton Rouge Area, Louisiana (No. 2013–5227). USGS. https://pubs.usgs.gov/sir/2013/5227/

This paper discusses the USGS's modeling effort on certain sands within CAGWCD where saltwater intrusion is modeled along with scenario analysis. Both the "1,500" and "2,000 ft" sands were modeled with seven scenarios with differing pumping rates, location of wells, and a status quo scenario.

46. Heywood, C. E., Lindaman, M., & Lovelace, J. K. (2019). Simulation of Groundwater Flow and Chloride Transport in the "1,500-Foot" Sand, "2,400-Foot" Sand, and "2,800-Foot" Sand of the Baton Rouge Area, Louisiana (Scientific Investigations Report No. 2019–2105; p. 63). U.S. Department of Interior; USGS. https://pubs.usgs.gov/sir/2019/5102/sir20195102.pdf

Models were utilized to predict how saltwater would migrate in the 1,500, 2,400, and 2,800 ft aquifers within the Baton Rouge area. Three scenarios were analyzed, the first being a status quo operation where withdrawals for 2016 remained constant. The second scenario simulated the effects of reducing the 2,800 ft withdrawals by 10,620 gallons/minute. the third scenario simulated substitution of withdrawals from the 1,500 to 2,800 ft sand by 2,000 gallons. All scenarios were modeled over a period of 2017-2112.

47. Heywood, C. E., & Lovelace, J. K. (2015). Simulation of groundwater flow in the Southern Hills regional aquifer system, and movement of saltwater in the 2,000-foot sand of the Baton Rouge area, Louisiana. USGS. https://www.cagwcc.com/site2015/technical/docs/Heywood_Lovelace_summary_report_2015.pdf

This is an abstract of the paper which provides great detail and sufficient information to understand the modeling process USGS performed on the "2,000 ft" sand.

48. Heywood, C. E., Lovelace, J. K., & Griffith, J. M. (2015). Simulation of Groundwater Flow and Chloride Transport in the "1,200-Foot" Sand With Scenarios To Mitigate Saltwater Migration in the "2,000-Foot" Sand in the Baton Rouge Area, Louisiana (Technical Report No. 2015–5083). USGS. https://pubs.usgs.gov/sir/2015/5083/sir20155083.pdf

This report illustrates the details necessary to understand the modeling efforts to understand the effect of a scavenger well on the saltwater plume and chloride concentrations in the Baton Rouge area. The groundwater model understanding saltwater movement in the "2,000-foot" was discretized for understanding saltwater movement in the 1,200 ft.

49. Karlin, S. (2019, May). First wave of Georgia-Pacific layoffs begin Tuesday, affecting 270 workers | Business | theadvocate.com [News]. https://www.theadvocate.com/baton_rouge/news/business/article_5b79bd96-44d9-11e9-9754-cbb0b995b7e9.html

This news report substantiates Georgia Pacific shutting down some operations related to paper communication business. In early 2019, Georgia Pacific announced their business sector reduction and have also released the upcoming effect on the labor force as well.

50. Kasman, G., Kirkgard, S., & Lew, M. (2004). Evaluation of Fault Rupture Hazard in the Built Urban Environment [Conference Report]. 13th World Conference on Earthquake Engineering. http://www.iitk.ac.in/nicee/wcee/article/13_573.pdf

This report details the difficulties in determining the exact fault structures between rural and urban environments. In addition, the report outlines multiple methods to determine locations of faults via invasive and non-invasive methods for understanding exact fault representation.

51. Kasmarek, M. C., Ramage, J. K., & Johnson, M. R. (2016). Water-Level Altitudes 2016 and Water-Level Changes in the Chicot, Evangeline, and Jasper Aquifers and Compaction 1973–2015 in the Chicot and Evangeline Aquifers, Houston-Galveston Region, Texas (Technical Report Texas: U.S. Geological Survey Scientific Investigations Map 3365, pamphlet, 16 sheets, scale 1:100,000; p. 53). USGS & Prepared in cooperation with the Harris-Galveston Subsidence District, City of Houston, Fort Bend Subsidence District, Lone Star Groundwater Conservation District, and Brazoria County Groundwater Conservation District. http://dx.doi.org/10.3133/sim3365

Between the period of 1973-2015, the city of Houston has experienced recorded subsidence. The extensometers have measured subsidence between 0.095 ft at the Texas City-Moses Lake extensometer to 3.666 ft at another extensometer. Multiple potentiometric surface maps, water level maps, and land surface elevations.

52. Kelly, B. P., & Rydlund, P. H. Jr. (2006). Water-Quality Changes Caused by Riverbank Filtration Between the Missouri River and Three Pumping Wells of the Independence, Missouri, Well Field 2003–05 (Technical Scientific Investigations Report 2006–5174; p. 55). USGS & DOI. https://pubs.usgs.gov/sir/2006/5174/pdf/sir2006-5174.pdf

Bank filtration can drastically improve surface water quality before withdrawal from groundwater resources. In short, bank filtration is using the riverbank, and pulling water from surface water through the ground to act as a primary clarifier. How the bank filtration was implemented and why it was used is explained. Appropriate background information is available, and details of challenges associated with bank filtration are also present in this report.

53. Kuniansky, Eve. L., Dial, D. C., & Trudeau, D. A. (1989). Maps of the “400ft,” “600ft,” and adjacent aquifers and confining beds, Baton Rouge Area, Louisiana (Technical Report No. 48; p. 16). State of Louisiana Department of Transportation and Development and the Capital Area Ground Water Conservation Commission. https://la.water.usgs.gov/publications/pdfs/TR48.pdf

Maps of the “400ft,” “600ft,” and adjacent aquifers and confining beds, Baton Rouge Area, Louisiana

54. Langevin, C. D., Hughes, J. D., Banta, E. R., Niswonger, R. G., Panday, S., & Provost, A. M. (2017). Documentation for the MODFLOW 6 Groundwater Flow Model. Techniques and Methods 6-A55 (Technical No. 6-A55; p. 197). USGS & DOI. https://pubs.usgs.gov/tm/06/a55/tm6a55.pdf

This document discusses the ins and outs of the MODFLOW model, old and new versions. This document is very detailed and meant for an in-depth look at the model itself and how it works and can be further modified.

55. LDH. (2019, August 13). Safe Drinking Water Program | Department of Health | State of Louisiana. Retrieved August 13, 2019, from http://www.ldh.la.gov/index.cfm/page/963

This webpage provides background information on the Louisiana Department of Health Safe Drinking Water Program.

56. LGS. (n.d.). Stratigraphic and Geohydrologic Units of Louisiana [Map]. Louisiana Geological Survey. Retrieved January 15, 2020, from https://www.lsu.edu/lgs/publications/products/stratigraphic-charts-louisiana.php

This map, diagram, represents the stratigraphic hydrogeology of southeastern Louisiana.

57. LGWRC. (2012). Managing Louisiana's Groundwater Resources with Supplemental Information on Surface Water Resources: An Interim Report to the Louisiana Legislature (p. 115) [Interim Report]. Louisiana Ground Water Resources Commission. http://www.dnr.louisiana.gov/assets/docs/conservation/groundwater/12.Final.GW.Report.pdf

The office of conservation was charged with implementing regulations to govern the sustainability of the state's groundwater resources. This report is a summary of the recommendations for Louisiana to help better prepare and plan for the future of Louisiana's groundwater management.

58. Lin, Y.-P., Chen, Y.-W., Chang, L.-C., Yeh, M.-S., Huang, G.-H., & Petway, J. R. (2017). Groundwater Simulations and Uncertainty Analysis Using MODFLOW and Geostatistical Approach with Conditioning Multi-Aquifer Spatial Covariance. Water. https://doi.org/10.3390/w9030164

Uncertainty analysis is handled in highly complex heterogeneous aquifers in multiple ways. Using generalized likelihood uncertainty estimation, the model could minimize iterations and uncertainty and maintain accuracy. Using simulated annealing simulation and spatial correlations, hydraulic head and hydraulic conductivity across multiple aquifer units are discussed.

59. LLA. (2019). Regulation of groundwater Resources Greater Baton Rouge: Capital Area Ground Water Conservation Commission (No. 40180019; p. 55). Louisiana Legislative Auditor. https://lla.la.gov/PublicReports.nsf/782AD0921011AF4E862583F60053DA0D/$FILE/0001CAA9.pdf

The Louisiana Legislative Auditor (LLA) performed an audit on the Capital Area Groundwater Conservation Commission to assess the performance of this public entity and its effectiveness on preserving the groundwater resources of the capital area district. Multiple recommendations were made.

60. Lovelace, J. K. (2007). Chloride Concentrations in Ground Water in East and West Baton Rouge Parishes, Louisiana, 2004-05 [Scientific Investigations Report]. USGS, DOI, & Capital Area Groundwater Conservation Commission. https://pubs.usgs.gov/sir/2007/5069/pdf/sir2007-5069.pdf

Samples were collected from 152 wells to approximately determine the effect of saltwater intrusion using chloride samples from 2004-2005. The results determined that background concentration of chloride, reference level being 10 mg/L chloride, were exceeded in eight sands north of the Baton Rouge Fault. Seven of those sands have increasing chloride levels.

61. McCulloh, R. P. (2001). Active faults in East Baton Rouge Parish, Louisiana (8, p. 6). Louisiana Geological Survey. https://www.lsu.edu/lgs/publications/products/Free_publications/EBR-faults.pdf

This report is a small summarization of the faults in East Baton Rouge Parish. The faults include the Denham Springs-Scotlandville Fault and Baton Rouge Fault, both run east and west through the parish. Technical terms, illustrations, and approximate locations of the East Baton Rouge Parish faults are identified as well as well as the fault's origins.

62. Meyer, R. R., & Turcan Jr., A. N. (1955). Geology and Groundwater Resources of the Baton Rouge Area (p. 144) [Technical]. Department of Interior - USGS. https://pubs.usgs.gov/wsp/1296/report.pdf

This paper is a broad sweep of Baton Rouge geology, the differing sands and clays, and discussion of water availability and quality within all the sands.

63. Nasreen, Mosa, "The Effect of Faults upon Ground Water Flow in the Baton Rouge fault System" (2003). University of New Orleans Theses and Dissertations. 54. https://scholarworks.uno.edu/td/54

This dissertation summarizes the history of subsidence within the Baton Rouge area with detailed analysis on the groundwater flow in the Baton Rouge area. Between 1935-1976, the Baton Rouge area experienced 1.67 ft of subsidence with 1.26 ft being attributed to groundwater withdrawals and 0.41 ft due to natural regional subsidence.

64. National Driller Magazine. (2013). 'Scavenger' Well Guards Baton Rouge's Drinking Water [Magazine Article]. National Driller Magazine. https://www.cagwcc.com/site2015/news/press_releases-15/National%20Driller%20magazine%20-%20Scavenger%20Well%20Guards%20Baton%20Rouge's%20Drinking%20Water,%201%20Sept.,%202013.pdf

This article is essentially a press release of the process of installing a scavenger well in Baton Rouge to protect the Lula St. pumping station. It lacks details on the drilling specs and hydrogeologic studies but mentions key decision makers from Layne Christensen and Baton Rouge Water company.

65. National Groundwater Association. (2019, November 5). Groundwater | Unconfined or water table aquifers. Unconfined or Water Table Aquifers. https://www.ngwa.org/what-is-groundwater/About-groundwater/unconfined-or-water-table-aquifers

This website illustrates basics for both unconfined or water table aquifers. Multiple questions and topics are discussed to help illustrate the basics for unconfined aquifers. In particular, the effect of pumping and unconfined vs confined aquifer is discussed.

66. OpenLearn. (2020, January 2). Groundwater: View as single page [Edu]. Groundwater. https://www.open.edu/openlearn/ocw/mod/oucontent/view.php?printable=1&id=2371

This single page explains the essentials to groundwater, where they are located, what they are, and how they function. Multiple components of groundwater hydrogeology are briefly explained here as well with supporting images to help explain.

67. Prakken, L. B. (2004). Louisiana Ground-Water Map No. 17: Generalized Potentiometric Surface of the Kentwood Aquifer System and the “1,500ft” and “1,700ft” Sands of the Baton Rouge Area in Southeastern Louisiana, March—April 2003. (p. 4). U.S. Geological Survey, Department of the Interior, State of Louisiana Department of Transportation and Development Office of Public Work and Intermodal Public Works and Water Resources Division. https://la.water.usgs.gov/publications/pdfs/SIM_2862.pdf

This is an all in one map and description of the “1,500” and “1,700 ft” sand and its potentiometric surface.

68. Prakken, L. B., & Wright, L. S. (2009). Water Withdrawals and Trends in Ground-Water Levels and Stream Discharge in Louisiana, 1996-2005 (Technical No. 79; p. 57). United States Geological Survey. https://la.water.usgs.gov/publications/pdfs/TR79.pdf

This report details statewide groundwater and stream level trends throughout the state of Louisiana from 1996-2005. Detailed information on the Jasper, Chico, Evangeline, and Sparta aquifer are also mentioned which helps provides context of groundwater within CAGWCD and trends between 1996-2005.

69. Rollo, J. R. (1969). Salt-Water Encroachment in Aquifers of the Baton Rouge Area, Louisiana. https://www.sciencebase.gov/catalog/item/562bc1b0e4b00162522218ac

The report discusses saltwater intrusion within the shallower sands in the Baton Rouge area and how it has changed in response to groundwater withdrawals. It is one of the more commonly cited reports for identifying saltwater intrusion north of the Baton Rouge Fault.

70. Sargent, P. B. (2011). Water Use in Louisiana, 2010 (Special Report No. 17; Water Resources Special Report). State of Louisiana (Department of Transportation and Development) Public Works and Water Resources Division. https://la.water.usgs.gov/publications/pdfs/WaterUse2010.pdf

This report was published by the department of the Interior and provides water usage report for the entire state of Louisiana for year 2010.

71. Scott, L. C., & Collins, J. S. (2018). The Louisiana Economic Outlook: 2019 and 2020. Economics & Policy Research Group E. J. Ourso College of Business Louisiana State University. https://www.oneacadiana.org/sites/default/files/2018-09/LEO_2019-20.pdf

This is a detailed report that is released by LSU’s college of business and discusses the economic outlook for Louisiana on a yearly basis while also making predictions on future trends based on certain key assumptions. Most importantly, it provides a good background summary of the Baton Rouge metropolitan area and the business growth associated with it.

72. Smith, C. G., & Kazmann, R. G. (1978). Capital Area Ground Water Conservation Commission Bulletin No. 2. Subsidence in the Capital Area Ground Water (p. 49). CAGWCC. http://www.dnr.louisiana.gov/assets/OC/env_div/gw_res/ENV2012_01_01/CAGWCC_BULLETIN2.PDF

This report provides an update on the amount of subsidence within the District based on benchmarks and identified locations surrounding pumping locations within the District. There are two metrics commonly associated with subsidence in the region. Between the period of 1935-1976, regional

subsidence was calculated the be 1.67 ft at one extensometer. Annual rates of subsidence compared to benchmarks throughout the Baton Rouge area include: .017, .001, and .03 ft/year.

73. Snider, J. L., & Forbes, M. J. (1960). Pumpage of Water in Louisiana, 1960 (p. 12). Louisiana Department of Public Works, Louisiana Geological Survey. https://la.water.usgs.gov/publications/pdfs/WaterUse1960.pdf

This report is one of the first documented cases of water usage in Louisiana and what types of activities are associated with certain activities. This report is one of the earliest USGS reports used to quantifying groundwater withdrawals and classifying groundwater usage in Louisiana.

74. Tomaszewski, D. J., & Accardo, D. (2002). Louisiana Ground-Water Map No. 20: Potentiometric Surface of the “2,000-foot” Sand of the Baton Rouge Area, Louisiana, May-June 2002 Scientific Investigations Map 2872 (p. 2). USGS, Department of the Interior, State of Louisiana Department of Transportation and Development Office of Public Work and Intermodal Public Works and Water Resources Division. https://pubs.er.usgs.gov/publication/sim2872

This is an all in one map and description of the “2,000 ft” as of 2002. Its potentiometric surface was digitized to help illustrate how water levels within the confined aquifers of CAGWCD have changed over time.

75. Tomaszewski, D. J., Lovelace, J. K., & Ensminger, P. A. (2002). Water Withdrawals and Trends in Groundwater-Water levels and Stream discharge in Louisiana (Technical No. 68; p. 36). United States Geological Survey. https://la.water.usgs.gov/publications/pdfs/TR68.pdf

This report details statewide groundwater and stream level trends throughout the state of Louisiana from 1990-2000. Detailed information on all of the aquifers including Jasper, Chico, Evangeline, and Sparta aquifer are also mentioned.

76. Torak, L. J., & Whiteman, C. D. Jr. (1982). Applications of digital modeling for evaluating the ground-water resources of the “2,000-foot” sand of the Baton Rouge area, Louisiana (Water Resources Technical Report no. 27; p. 87). Louisiana Department of Transportation and Development, Office of Public Works.

The “2,000 ft” aquifer potentiometric surface between the period of 1914-1979 was lowered by 430 ft. Using the digital model available at the time, it was predicted that water levels could remain stable if pumping was reduced by 10% from the 1979 pumping rates.

77. Tsai, F., Beigi, E., Singh, V. P., & Kao, S.-C. (2019). Bayesian Hierarchical Model Uncertainty Quantification for future Hydroclimate Projections in Southern Hills-Gulf Region, USA. https://doi.org/10.3390/w11020268

This paper discusses the multi ensemble hydroclimate model for the Southern Hills aquifer region and the effect a global climate model will have on the recharge rate of the southern hills aquifer. Multiple scenarios (40) were run with varying sources of uncertainty and climate variables to project what evapotranspiration and recharge.

78. Tsai, F. T. C. (2011). Stop Saltwater Intrusion toward Water Wells Using Scavenger Wells. American Society of Civil Engineers, World Environmental and Water Resources Congress. https://ascelibrary.org/doi/pdf/10.1061/41173%28414%2993

With chloride concentrations increasing in sensitive areas for both industrial and public water supply in Baton Rouge, a scavenger well was modeled to help preserve the aquifer and wells for freshwater consumption. It was modeled that chloride concentrations would rise between 750-1500 mg/L over the next 50 years if pumping continued. With the implementation of the scavenger well and running at one million gallons per day, chloride levels could be kept at or below 150 mg/L.

79. Tsai, Y., Cohen, S., & Vogel, R. M. (2011). The Impacts of Water Conservation Strategies on Water Use: Four Case Studies. Journal of the American Water Resources Association, 47(4), 687–701.

Through four different case studies, water conservation resources were implemented to determine the overall effect of such strategies on water demand. The four strategies included: installation of weather-sensitive irrigation controller switches, installation of rainwater harvesting systems in residences, two outreach programs: (a) free home indoor water use audits and water fixture retrofit kits and (b) rebates for low-water-demand toilets and washing machines, and soil amendments to improve soil moisture retention. From these four programs, all were statistically shown to reduce water demand though the experiments were carried out in small samples and non-parametric.

80. UNC. (2020, January 30). North Carolina Water and Wastewater Rates Dashboard [Edu]. North Carolina Water And Wastewater Rates Dashboard. /resource/north-carolina-water-and-wastewater-rates-dashboard

UNC environmental finance center as compiled a comprehensive dataset that represents all water rates throughout North Carolina. The data could be used as a case study to help identify the effects differing water rate structures could have on water demand and water supply.

81. USEPA. (2016, January 25). Pricing and Affordability of Water Services [Overviews and Factsheets]. USEPA. https://www.epa.gov/sustainable-water-infrastructure/pricing-and-affordability-water-services

A collection of resources on the pricing and affordability of water rates. Different strategies for rate structures are discussed along with general trends associated with the rate structure.

82. USEPA. (2016, February 21). Sole Source Aquifer Program | Ground Water Protection—Region 4 | USEPA. Retrieved July 2, 2019, from https://archive.epa.gov/pesticides/region4/water/groundwater/web/html/r4ssa.html#shills

This resource discusses sole source aquifers, what they are, and where they are currently located.

83. USGS. (2014). Enhanced Groundwater Monitoring and Resource Assessment. http://www.dnr.louisiana.gov/assets/OC/GroundWater/USGS.WRC.7302014.pdf

This presentation provides a short discussion on the recommendations to developing a statewide groundwater management plan. In short, there are five recommendations: enhanced water-level network, update potentiometric maps, enhanced chloride monitoring network, water-quality network, and annual water-use estimates.

84. USGS. (2016a). U.S. Geological Survey Water Resources Cooperative Program: Louisiana Water Use Program. U.S. Geological Survey. http://la.water. usgs.gov/WaterUse/default.asp

This website serves as a database center where parishes, water types, and water demand trends can be analyzed within Louisiana.

85. USGS. (2016b). Water Resources of West Baton Rouge Parish, Louisiana (p. 6) [Technical Report]. USGS DOTD. https://pubs.usgs.gov/fs/2016/3068/fs20163068.pdf

This report is a detailed water use summary for West Baton Rouge Parish as of 2010. There is approximate elevation, well stations, faults, and aquifer cross sections for illustration.

86. USGS. (2017). Water Resources of the Southern Hills regional aquifer system, southeastern Louisiana (Fact Sheet, p. 6). United States Geological Survey. https://pubs.er.usgs.gov/publication/fs20173010

Information related to the SHAS and the usage of the SHAS in parishes extending east-west from Point Coupe to St. Tammany Parish is discussed.

87. USGS. (2019, January 6). Land Subsidence in the San Joaquin Valley [Government]. Land Subsidence in the San Joaquin Valley. https://www.usgs.gov/centers/ca-water-ls/science/land-subsidence-san-joaquin-valley?qt-science_center_objects=0#qt-science_center_objects

The San Joaquin valley in California is an excellent example of how excessive groundwater withdrawals and insufficient recharge can induce subsidence. By 1970, the San Joaquin valley experienced 28 ft of subsidence. Though not the same as the Baton Rouge subsidence, this case provides an example on how to better prepare for such subsidence.

88. USGS. (2020, February 20). *USGS Groundwater Data for the Nation* [Government]. National Water Information System: Web Interface. https://waterdata.usgs.gov/nwis/gw

USGS groundwater database serves as a keystone data repository for analysis in the SHAS. Both surface and groundwater data can be downloaded for inspection.

89. Vijai, P., & Sivakumar, B. (2018). Performance comparison of techniques for water demand forecasting. Procedia Computer Science, 143, 258–266.

This paper discusses multiple methods for forecasting water demand and determining which method is most accurate over the short run. As it turns out, a highly complicated forecasting method, Artificial Neural Network (ANN), was the most successful in predicting water demand.

90. Walker, S., Dausman, A., & Lavoie, D. (2012). Gulf of Mexico Ecosystem Science Assessment and Needs—A Product of the Gulf Coast Ecosystem Restoration Task Force Science Coordination Team. EPA. https://archive.epa.gov/gulfcoasttaskforce/web/pdf/gcertf-book-final-042712.pdf

Born out of Executive Order 13554 from "America’s Gulf Coast: A Long-term Recovery Plan after the Deepwater Horizon Oil Spill,” six focus groups were created to identify scientific goals, the state of such goals, and needs to address the issues identified for the Gulf coast. Adaptive management is crucial in addressing problems with levels of uncertainty and applying such principles to the development of goals that address science needs is imperative. For this report, the current state of the Gulf coast system and critical science needs are discussed.

91. White, V. E., & Prakken, L. B. (2015). Water Resources of East Baton Rouge Parish, Louisiana. Department of the Interior, US Geological Survey. https://pubs.usgs.gov/fs/2015/3001/pdf/fs2015_3001.pdf

This report is a detailed water use summary for East Baton Rouge Parish as of 2010. There is approximate elevation, well stations, faults, and aquifer cross sections for illustration.

92. Whiteman Jr., C. D. (1980). Measuring local subsidence with extensometers in the Baton Rouge Area, Louisiana, 1975-1979 (Technical No. 20; p. 25). United States Geological Survey. https://la.water.usgs.gov/publications/pdfs/TR20.pdf

This report details the existence of subsidence in the Baton Rouge area which was determined to be tied to major groundwater withdrawals in the Baton Rouge area. Both local and regional subsidence are considered to help partition what is mostly considering to the subsidence experienced in the Baton Rouge area.

93. Yin, J. (2019). Groundwater Management Optimization and Saltwater Intrusion Mitigation under Uncertainty [Dissertation, LSU]. https://digitalcommons.lsu.edu/cgi/viewcontent.cgi?article=6096&context=gradschool_dissertations

This research focuses on how complex modeling, iteration, machine learning techniques can be applied to optimally and cost effectively model both groundwater withdrawals and saltwater intrusion into the Baton Rouge study area for the Southern hills Aquifer System. Within this paper, there is modeling efforts demonstrating the potential affect a scavenger well could have on saltwater intrusion in the Baton Rouge area.

94. Zarriello, P. (n.d.). *Part 5. HSPF and MODFLOW - Capabilities, Limitations, and Integration*. USGS. Retrieved May 26, 2019, from https://pubs.usgs.gov/sir/2009/5127/pdf/sir2009-5127_part5_508.pdf

This paper is a concise report that discusses the capabilities, limitations, and integration of MODELOW and Hydrological Simulations Program (HSP). The models are discussed in the context of the Pawcatuck River Basin, Rhode Island.