Louisiana Geological Survey

NewsInsightsonline

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The Louisiana Geological Survey (LGS) originated in 1869 and was later officially established by the Louisiana legislature in 1934 (Act 131). LGS is presently a research unit affiliated with Louisiana State University having been legislatively transferred in 1997 from the Louisiana Department of Natural Resources. LGS currently reports through the Executive Director of the Center for Energy Studies to the LSU Vice President of Research and Economic Development.

LGS Mission Statement

The mission and goals of LGS are to preform geological investigations that benefit the state of Louisiana by:

- Encouraging the economic development of the natural energy, mineral, coastal, water, and environmental resources of the state through appropriate research projects;
- Provide unbiased geological information on natural and environmental hazards and other issues as and when called upon to do so by state, federal, or other agencies and private companies and citizens;
- Ensure the effective transfer of geologic information through research publications, presentations at professional conferences and other meetings, production of geologic maps, etc.

Continuing budget cuts for the last five years have resulted in the reduction of the LGS state budget by approximately 58% from about five years ago. The state's severe deficit budget situation coupled with the oil and gas industry downturn, matching requirements for contracts and a lack of sufficient staff with necessary expertise have made successfully getting externally funded research contracts difficult.

LGS currently has 14 full time and 2 part time staff including all categories of personnel. A summary description of ongoing LGS projects is as follows.

Contracts/Grants

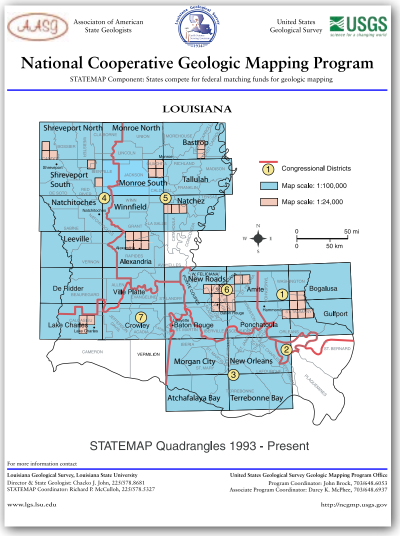
Geologic Mapping

Surface-geologic mapping projects conducted by the Louisiana Geological Survey (LGS) during the past 20 years comprise 1:100,000-scale compilations of 30 × 60 minute geologic quadrangles and 1:24,000-scale field-mapped 7.5-minute geologic quadrangles. The vast majority of these mapping efforts were funded under the STATEMAP component of the National Cooperative Geologic Mapping Program (NCGMP), begun in 1993 and administered by the U.S. Geological Survey (USGS).

The principal goal of this program of geologic mapping for LGS initially was to prepare statewide surface geology coverage at 1:100,000 scale in 30 × 60 minute quadrangle format. This scale was emphasized because it is at the large end of the range of intermediate scales, and preserves abundant detail from source mapping done at larger scales (principally 1:62,500 and 1:24,000) while yet covering relatively large areas. By the close of FY 2013, LGS had completed 30 × 60 minute geologic quadrangle coverage of the entire state (30 sheets total) with a mix of published lithographs and draft open-file compilations.

Since the late 1990s LGS also has prepared 7.5-minute geologic quadrangles at 1:24,000 scale totaling 53 sheets. Forty-three were prepared with STATEMAP support, and the other ten were prepared for the U.S. Army Corps of Engineers within the Fort Polk region, southcentral Louisiana.

State map 2015-2016 deliverables completed and submitted included geological maps and pamphlets covering four 7.5 minute quadrangles in two study areas (Poverty Point area in northeastern Louisiana and the Amite River Valley north-northeast of Denham Springs).



Associaton of American State Geologists

United States Geological Survey

National Cooperative Geologic Mapping Program

STATEMAP Component: States compete for federal matching funds for geologic mapping

LOUISIANA

STATEMAP Quadrangles 1993 - Present

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http://ncgmp.usgs.gov

Geologic map coverage generated at 1:100,000 and 1:24,000 scales since the advent of the STATEMAP program in 1993.

The Louisiana Geological Survey

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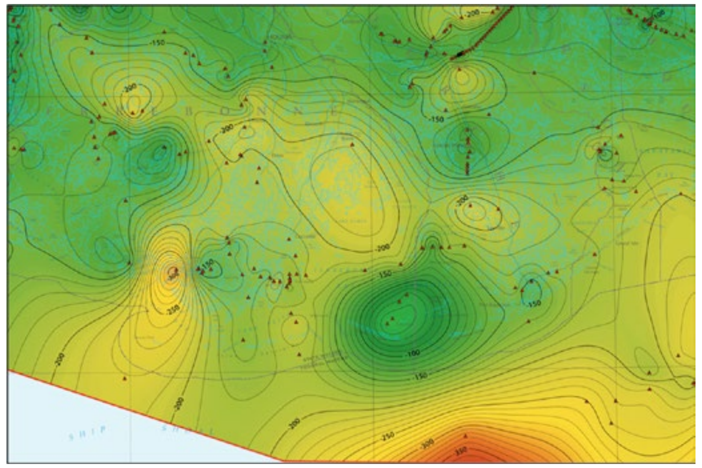
(1) encouraging the economic development of the natural resources of the state (energy, mineral, water, and environmental);

(2) providing unbiased geologic information on natural and environmental hazards; and

(3) ensuring the effective transfer of geological information.

The Louisiana Geological Survey was created by Act 131 of the Louisiana Legislature in 1934 to investigate the geology and resources of the State. LGS is presently a research unit affiliated with the Louisiana State University and reports through the Executive Director of the Center for Energy Studies to the Vice Chancellor for Research and Graduate Studies.

GIS Development of the Buried Holocene-Pleistocene Surface in The Louisiana Coastal Plain



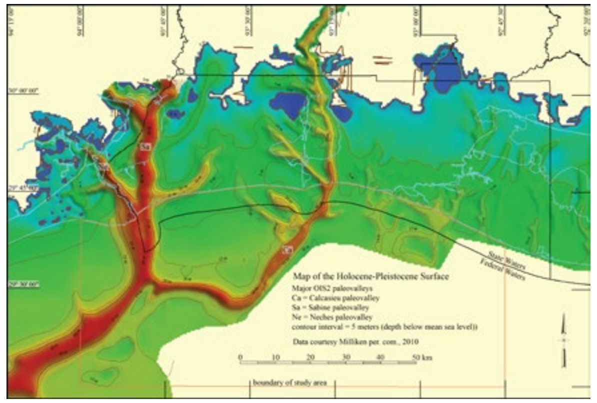
Barataria – Structure map of the H-P surface within the Barataria/ Terrebonne area. Red triangles show location of boring data.

This project was funded by the Water Institute of the Gulf on behalf of the Coastal Protection and Restoration Authority (CPRA) of Louisiana to investigate and develop a three-dimensional GIS dataset of the buried Holocene-Pleistocene regional unconformity known as the "Base of the Holocene" for coastal Louisiana. This research was undertaken because of a lack of a single comprehensive map of the Holocene-Pleistocene surface that covers the entire coastal plain and adjacent continental shelf. Instead, the available data consisted of maps created by various authors at different times in different study areas using different criteria. As a result, many gaps existed in the coverage of these maps as well as conflicts in their interpretations.

The technical work conducted for this project consisted of (1) an investigation and compilation of existing published and unpublished boring data; (2) an analysis of collected data points; (3) the development of the GIS dataset of the Holocene-Pleistocene surface within the study area; (4) an assessment of the accuracy of the source data and (5) the preparation of deliverable GIS data sets, digital maps and a final report with an interpretation of the data. It is intended that this Holocene-Pleistocene surface model of this study area will offer improvement in understanding geologic variables in engineering design of coastal restoration projects, reduce uncertainties in for accessing future geo-environmental conditions, support coastal project planning and decision making and improve data and assumptions used in predictive subsidence modeling.

Continuation and Completion of the Stream Gaging and Rating Curve Study

This ongoing investigation from the last two fiscal years, funded by the Louisiana Department of Natural Resources, was continued for the 2015-2016 fiscal year. This involved collection of stream discharge data using a River Surveyor for measurements for large streams/rivers and a Flow Tracker for measurements of small streams. After collection of stream discharge results, they were included as part of a series of 50 stream rating curves relating discharge to gage level of a stream. Lake level data for four sites (False River, Pointe Coupee Parish; Lake Providence, East Carroll Parish; Black Lake, Natchitoches; Lake Bruin, Tensas Parish) were also monitored and recorded during this period. All data collected were transmitted to DNR. The final report also contained data sets on dams and reservoirs in Louisiana compiled from publicly available sources. The report can be viewed on page 27 of this newsletter.

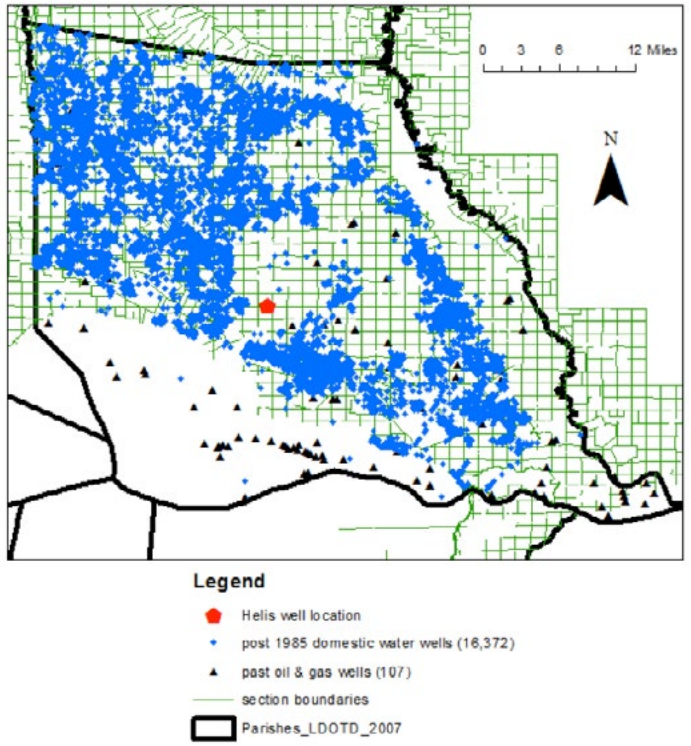


Preservation Potential of Prehistoric Cultural and Sand Resources

This study, started last fiscal year, was to investigate how the paleo-landscape of the late glacial continental shelf responded to the erosive effects of the late Pleistocene-Holocene transgression and was funded by the Bureau of Ocean Energy Management (BOEM). During this period of sea-level rise, wave and tidal movement preferentially eroded the coastal plain interfluves and often spared the valley fills and paleo-valleys that progressively accumulated. As part of this report, these erosive effects of the late Pleistocene-Holocene transgression on preservation of paleo-landscapes and associated features were evaluated using data provided by BOEM. In addition, a final GIS compilation of all these data sets were finalized along with other data collected and evaluated as part of the final report submitted to BOEM.

Baseline Determination of Groundwater Quality in South Central St. Tammany Parish

This parish funded project involved sending letters to owners of private water wells requesting permission to sample the wells which ultimately resulted in sampling of 97 domestic water wells and 3 public supply water wells to determine baseline values for 42 different analytes. This included: aluminum, arsenic, barium, benzene, boron, bromide, butane, cadmium, calcium, chloride, chromium, cobalt, copper, diesel range organics (DRO), electrical conductivity, ethane, ethylbenzene, fluoride, gasoline range organics (GRO), iron, lead, magnesium, manganese, methane, nickel, nitrate, nitrite, oil range organics (ORO), pentane, phosphate, phosphorous, potassium, propane, silicon, sodium, strontium, sulfate, toluene, total dissolved solids, vanadium, xylene(s) and zinc. Sampling was completed between December 2015 and June 2016 and analytical analysis of samples was completed by August of 2016 after which a final report was submitted to the parish. These results can be viewed on page 37 of this newletter.



Helis well site in southern St. Tammany Parish compared to other oil and gas wells and domestic water wells (Louisiana Department of Natural Resources 2011, 2014, 2015a and 2015b).

Evaluation of Water Permit Requests

This three year project funded by DNR, now in its second year, requires LGS to provide DNR with unbiased recommendations for water permit requests. Such applications are mostly for withdrawal of water from running surface water resources submitted to the DNR Secretary pursuant to Act 955 of 2010. Applications are generally received by DNR from other state agencies, parish governments, etc. and are evaluated mainly to determine environmental consequences resulting from the action proposed in the concerned application.

Energy Projects

1. Update and Revision of the 2015 Oil & Gas Map

LGS is currently working on updating the 2015 oil and gas map and is expected to be available in digital format by the end of the fiscal year 2016-2017.

2. Parish Atlas Series

Work on the Parish Atlas Series which started last fiscal year is on hold at present mainly due to the lack of sufficient staff.

3. Integrated CCS in the Louisiana Chemical Corridor

LGS researchers participate in the DOE $3.1 million award to the Center for Energy Studies led research team for the project titled "Integrated CCS in the Louisiana Chemical Corridor"

The U.S. Department of Energy (DOE) has awarded a $1.3 million research grant to an interdisciplinary team of scholars headed up by the LSU Center for Energy Studies. The multi-year project will examine the technical and economic feasibility of developing a commercial-scale carbon capture and storage (CCS) project in Louisiana's industrial corridor between Baton Rouge and New Orleans. CCS is a technology used by industry to capture CO2 emissions produced from the use of fossil fuels in industrial processes, preventing the carbon dioxide from entering the atmosphere.

CES Professor and Executive Director, Dr. David E. Dismukes, will lead a diverse and highly qualified research team investigating this timely and important environmental and economic development opportunity for Louisiana and the Gulf Coast.

The research team includes:

- Brian Snyder (co-principal investigator), assistant professor, LSU Department of Environmental Sciences;
- Keith Hall, associate professor and director, Mineral Law Institute, LSU Law School;
- Juan Lorenzo, associate professor, LSU Department of Geology & Geophysics;
- Chacko John, state geologist and director, Louisiana Geological Survey;
- Brian Harder, research associate, Louisiana Geological Survey;
- Mehdi Zeidouni, assistant professor, Craft & Hawkins Department of Petroleum Engineering;
- Richard G. Hughes, professional-in-residence, Craft & Hawkins Department of Petroleum Engineering.

Dismukes notes that this a unique opportunity for LSU that underscores its strengths in working with a wide range of stakeholder groups to solve applied energy and environmental challenges for our state. The project will include active private sector participation in order to identify large-scale industrial candidate emission sources, such as natural gas processing or petrochemical plants, and then transporting those industrial emissions to either permanent underground storage facilities, or using them in higher-valued energy applications such as enhanced oil recovery (EOR).

The goals of the project are to "define a business case model" in which industrial carbon emissions can be safely and profitably stored, Dismukes notes. There is also a large public awareness and acceptance component to the project. From a technical perspective, LSU will be conducting a number of high-level, supercomputer-based technical evaluations of the sub-basin and its geological potential to safely store large levels of carbon in a single location as well as exploring a myriad number of technical issues associated with the effective monitoring and verification of these permanent CO2 storage sites.

The award is part of the DOE National Energy Technology Laboratory's (NETL) Carbon Storage Assurance Enterprise, or CarbonSAFE, program, which seeks to develop an integrated CCS storage complex constructed and permitted for operation in the 2025 timeframe in several phases.

Geologic Review

This is a continuing environmental geology program which started in 1982 and is funded by DNR and the US Army Corps of Engineers which provides regulatory technical assistance to the Office of Coastal Management of the Louisiana Department of Natural Resources and to three districts of the U.S. Army Corps of Engineers. It assists in the implementation of section 404 of The Clean Water Act and the Louisiana Coastal Resources Program regulations, both of which impact oil and gas operations by mandating that only the least damaging feasible alternative shall be permitted. Oil and gas permit applications made to these two agencies which involve significant environmental impact to vegetated wetlands or other environmentally sensitive areas have their geology, engineering, lease, and site-specific data reviewed and evaluated to determine if any less-damaging feasible alternatives are available. Such alternatives may include reducing the size of ring levees and slips, reducing the length of board roads and canals, the use of directional drilling, and the use of alternate and less-damaging access routes, the goal being to avoid or minimize any environmental damage. The long-term effect of Geologic Review has been an overall approximate 75% reduction in the average length of canals and board roads built in the Louisiana Coastal Zone.

Geophysical Projects

LGS continues development of geophysical techniques, electrical resistivity and magnetometry, for shallow depth features of interest to geology, archaeology, and civil engineering. In studies thus far, the techniques have successfully resolved unmarked cemetery burials, prehistoric human habitations, modern buried pipelines, and lithostratigraphic relationships in the shallow subsurface. Pilot studies investigated anecdotal suggestions of burials and structural features of defunct plantations and military installations as well as the extent of economically important quarry resources. Two additional pilot studies in Texas identified locations of potential archeological significance at a future dam site and layout features of Antelope Creek (1200-1450 AD) structures. A funded comprehensive geological and geophysical study successfully identified subsurface burials in a neglected historic cemetery, providing the sponsor a reliable guide for future renovations and interments. More recently, these methods have been applied to resolve the internal structure of 5 ka Indian mounds widely distributed in southern Louisiana.

Digital Infrastructure And Data Rescue Of Historic Geological Publications

This USGS funded project under the National Geological and Geophysical Data Preservation Program (NGGDPP) enabled LGS to digitize and scan a large number of historical LGS publications and maps. These were made available in digital (pdf) format and metadata pertaining to each scanned publication were uploaded to the USGS digital catalog.

Is The Great Rainfall and Flood of August 2016 a 100-Year, 500-Year or 5,000-Year Event?

Douglas Carlson

Introduction

In August of 2016 the Amite River watershed experienced a devastating flood that was of historic size in the Baton Rouge, Louisiana area. The flood inundated 10,000s of homes (Figure 1) and 1,000 businesses (Figure 2) alike in between August 12 and August 14 of 2016. The floods inundated the grounds of the author's resident early in the morning of 2016 sometime between 3:30 and 7:00 am Saturday August 13, 2016, and quickly inundated vehicles such that by 7:00 am cars were flooded (Figure 3) with 30 inches of water and by 11:00 am trucks were also flooded (Figure 4) with 54 inches of water in the parking lot.

As a result, the author as well as thousands were evacuated by the Cajun navy (Figure 5) to spend between days and weeks in local shelters scatter throughout East Baton Rouge and Livingston Parish. There were 30,000 people rescued (O'Donoghue, 2016a). The number of people in shelters reached a high on Monday August 15, 2016 of 11,000 declined to 6,000 by Wednesday August 17, 2016 (foxnews.com, 2016) and 4,000 by Friday August 19, 2016 (Bauerlein and Patel, 2016) when the author returned to home. Ultimately, a large share of these two parishes plus others adjacent parishes were impacted.

Figure 1. An example of the over 100,000 residents flooded. This is a view of near Millerville Road, in Baton Rouge (anonymous, 2016a)

Figure 2. An example of a flooded business in Denham Springs, Louisiana (heavy.com, 2016).

Note the quick stop market included gas pumps which as can be seen from this view are totally under water from the flooding Amite River.

There were over 100,000 residents damaged and over 5,000 business damaged in the area, and billions of dollars of damage (anonymous, 2016b; Gallo and Russell, 2016; and Terrell, 2016). Approximately 30% of the homes in Baton Rouge and in eight surrounding parishes were impacted by the flood (Gallo, and Russell, 2016). In addition, the floods disrupted work for over 250,000 workers in the Baton Rouge area (anonymous, 2016b; and Terrell, 2016). Most of these individuals worked in East Baton Rouge Parish 141,700 (Table 1), but another 132,800 worked in the other 19 parishes impacted (Table 1). The resulting damages on housing units where approximately equally distributed between East Baton Rouge Parish and Livingston Parish with lessor amounts in other southern Louisiana parishes (Tables 2). Both of these two parishes account for approximately 73% of all housing units impacted by the flood (Table 2). The fraction of housing units impacted is far different with approximately 74% of housing units in Livingston Parish were impacted. The fractions impacted in Ascension, East Baton Rouge and Tangipahoa Parishes less than half as large as the fraction impacted in Livingston Parish. The impacted fraction of house was 31% in Ascension Parish, 22% East Baton Rouge Parish and 19% in Tangipahoa Parish (Table 2). Unfortunately, only a small fraction, 22%, of homes in Livingston impacted by the flooded were covered by flood insurance. Results were similar in Ascension Parish and even lower throughout other parishes impacted (Gallo and Russell, 2016).

The vast area covered by the flood explains why there was vast number of homes and business were impacted (Figure 6). The flood covers more 1,000 square miles (Baton Rouge Area Chamber, 2016). The portion of various communities inundated by the August flood in East Baton Rouge Parish varied but was large for all four communities: 81.7% of Central, 47.2% of Zachary, 45.3% of Baker and 27.4% of Baton Rouge (Brproud.com, 2016).

Figure 3. A view of the grounds at 7615 Magnolia Beach Road at 7:35 am.

Figure 4. A view of the grounds at 7615 Magnolia Beach Road at 11:04 am. Just three hours and 29 minutes after the previous view.

Figure 5. The Cajun navy at work evacuating people who could not leave their residences due to their vehicles being flooded (Stole, 2016).

Table 1. Impacts of the great flood of August 2016 on economic activity within parishes of south Louisiana (Terrell, 2016)

Parish	Peak disruption		Monetary impacts (millions of dollars)	
	Number of businesses	Number of employees	Lost labor productivity	Lost Value Added
East Baton Rouge	8,000	141,700	213.0	540.2
Livingston	1,800	18,700	27.0	97.8
Ascension	1,200	17,100	24.9	68.5
Tangipahoa	1,500	17,000	17.4	62.2
Lafayette	3,100	40,000	8.6	31.1
St. Tammany	900	8,000	2.9	8.4
Iberia	600	8,200	1.8	8.0
St. Landry	600	6,300	1.0	3.3
Iberville	100	2,000	1.1	2.9
Vermilion	400	1,700	0.7	2.7
St. Martin	400	3,100	0.5	2.5
Acadia	400	3,900	0.6	2.4
Jefferson Davis	300	2,200	0.3	1.7
Avoyelles	100	1,200	0.4	1.6
East Feliciana	100	800	0.3	0.9
Evangeline	200	1,500	0.2	0.9
Pointe Coupee	100	400	0.1	0.5
Washington	<100	300	0.1	0.4
St. Helena	<100	200	0.1	0.2
West Feliciana	<100	200	0.1	0.2

Table 2. Impacts of the great flood of August 2016 on property within the parishes of south Louisiana (Terrell, 2016).

Parish	2015 total housing units	Flooded housing units	Percentage of all housing units
Livingston	52,104	38,300	73.5%
Ascension	42,471	13,100	30.8%
East Baton Rouge	189,363	41,000	21.7%
Tangipahoa	51,363	9,900	19.3%
St. Helena	5,154	400	7.8%
Pointe Coupee	11,244	600	5.3%
East Feliciana	8,093	300	3.7%
St. Martin	22,250	800	3.6%
Vermilion	25,588	700	2.7%
Acadia	25,634	600	2.3%
Lafayette	95,373	1,900	2.0%
West Feliciana	5,293	100	1.9%
Jefferson Davis	11,642	200	1.7%
Iberia	30,169	400	1.3%
St. Landry	35,940	400	1.1%
Iberville	13,097	<100	<0.8%
Evangeline	14,766	<100	<0.7%
Avoyelles	18,238	<100	<0.5%
Washington	21,345	<100	<0.5%
St. Tammany	100,061	<100	<0.1%

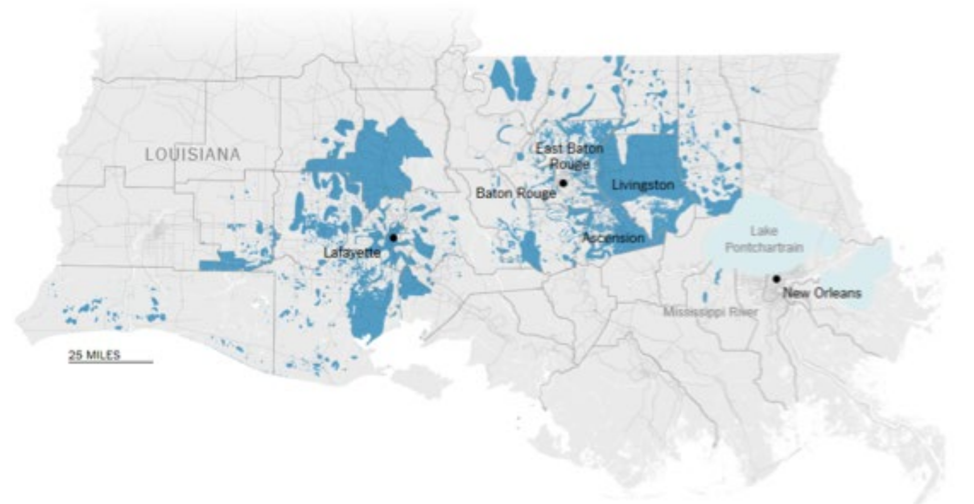


Figure 6. Area flooded in August by the great flood of August (Fesenden and Omri, 2016).

Sources: Stephenson Disaster Management Institute, Louisiana State University; FEMA

Rainfall event

This rainfall event is a result of a low pressure system that formed approximately in Tampa-St. Petersburg, Florida on Monday August 8, 2016 (Keim and Black, 2016). This system slowly moved westward towards Louisiana. It traveled towards the northwestern corner of the Florida panhandle between August 9 to 11, 2016. By August 12, 2016 this system moved into south Louisiana where it remained through August 14, 2016 before finally leaving Louisiana and moved into Texas August 15, 2016 (Keim and Black, 2016). It is shown by the fact that for 55 consecutive hours there was either a trace or measureable amount of precipitation at the Baton Rouge airport weather station (Figure 7). This storm on just the 12 dumped 11.24 inches of rainfall at the Baton Rouge station, which alone is an over the 50-year rainfall event for a single day. This is almost twice the average August monthly rainfall of 5.94 inches as determined from the record from 1954 to 2016 and the single day was more rainfall than all but 4 previous Augusts between 1954 and 2015 at that station. (NOAA, 2016a). For August 11 to 13, 2016 these three days in Baton Rouge had 17.15 inches of rainfall, which is over a 200-yr rainfall event for three days (NOAA, 2016b) which alone broken the single August rainfall record for the Baton Rouge station by 2.67 inches (NOAA, 2016a). In addition, to being a very slow moving system it had a large amount of water within the atmosphere to work with. The third highest atmospheric water content on record since 1948 (Revitte and Welch, 2016).

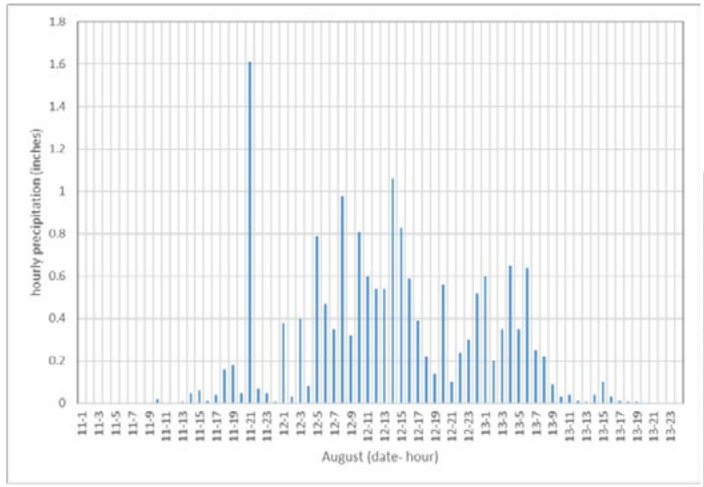


Figure 7. August storm precipitation at Baton Rouge weather station hour by hour August 11, 2016 through August 13, 2016 (NOAA, 2016a).

This past August 10 to 15 an extremely large rainfall event occurred in southern Louisiana (Figure 8). This rainfall broke the previous Louisiana rainfall event in Abita Springs, 24 inches in 1995. Three sites broke that record Brownfields, Denham Springs, and Watson. The rainfall at Watson was over 31 inches (Keim, 2016; and O'Donoghue, 2016b). The area of greatest rainfall is roughly in a line between Washington Parish southwest to Vermilion Parish. A larger portion of East Feliciana, East Baton Rouge, St. Helena, Livingston, and Tangipahoa Parishes had over 15 inches of rainfall (Figure 8). This rainfall event was very usual. This is indicated by the fact that this event's rainfall was fall over what is considered to be a 100-yr rainfall event for two consecutive days, 14 inches or a 1,000-yr rainfall event for two days 21.3 inches (O'Donoghue, 2016b). There are many weather stations that received in a 3-day interval over 15.2 inches of rainfall which is a 100-yr rainfall event (Table 3). The size of these rainfall events are defined by NOAA (2016b). For a large portion of Tangipahoa, St. Helena, East Feliciana, East Baton Rouge Parish and Livingston Parish this event was rare, less than a 1% chance of occurring in any given year which is often referred to as a 100-year rainfall event (Figure 9). In fact, in northern Livingston and East Baton Rouge Parishes this rainfall event has under a 0.1% chance of occurring in a year, that is a 1000-year rainfall event (Figure 9). Within this region are nine weather stations that experienced a 1000-year rainfall (Keim, 2016). The Cocoraha gauge in Watson collected 31.39 inches of rainfall in two days approximately 10 inches more than even the 1,000-year rainfall event (Keim and Black, 2016). There are other stations (Table 4) with over the 14.2-inch rainfall necessary to exceed the 100-yr rainfall event (Keim and Black, 2016). So, it is not surprising with all of this rainfall in portions of the Amite River watershed that major flooding occurred.

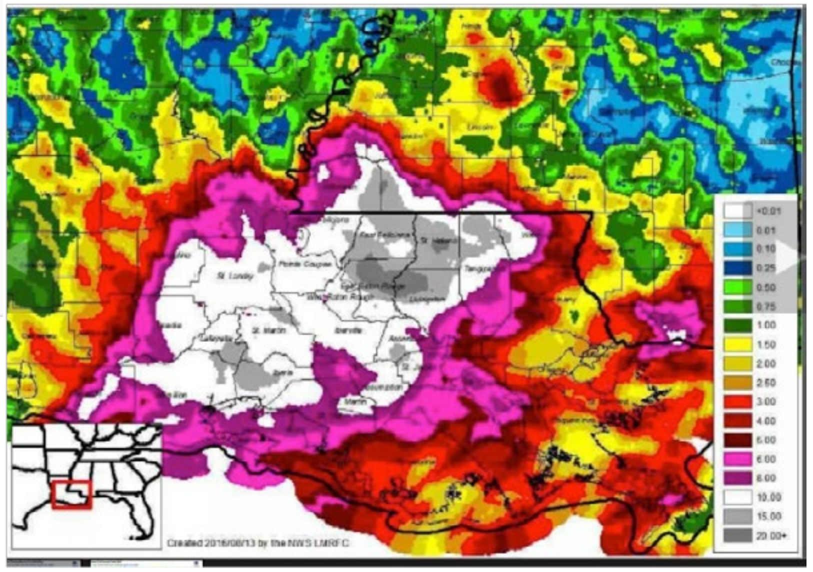


Figure 8. Extent of August 2016 rainfall event, source is Schiefstein (2016).

Table 3. Weather stations that received over 15.2 inches of rainfall in the 72 hours, 3 days, prior to 7 am on Saturday August 13, 2016 (nwschat.weather.gov, 2016).

Station	Rainfall (inches)	This event is:
WBHL1 White Bayou/Zachary	26.14	Over 1000 year rainfall event
LIVL! Livingston	25.52*	Over 1000-year rainfall event
NWDL1 Norwood	22.02	Over 500-year rainfall event
BAKL1 Comite River near Baker	21.18	Over 500-year rainfall event
HOOL1 Hooper Road near Baton Rouge	21.05	Over 500-year rainfall event
PRCL1 Little Sandy Creek Peairs	19.92	Over 200-year rainfall event
KENL1 Kentwood	18.19	Over 200-year rainfall event
COML1 Comite River at Joor Road	17.75	Over 200-year rainfall event
KBTR Baton Rouge Asos	17.05*	Over 100-year rainfall event
DCHL1 Dutchtown # 2	16.49	Over 100-year rainfall event
LFDL1 Bayou Laf Donaldsonville	16.01	Over 100-year rainfall event
CBAL1 Claycut Bayou Antioch	15.41	Over 100-year rainfall event
SBRL1 Baton Rouge Concord	15.38	Over 100-year rainfall event

An asterisk (*) indicates record is incomplete and results could be higher.

Table 4. Weather stations that received over 14.2 inches of rainfall on August 12 and 13, 2016 (Keim and Black, 2016).

Station	Rainfall (inches)	This event is:
Watson	31.39#	Over 1000-year rainfall event
Brownfields	26.83#	Over 1000-year rainfall event
Denham Springs	25.50#	Over 1000-year rainfall event
Monticello	24.02	Over 1000-year rainfall event
Central	22.10	Over 1000-year rainfall event
Livingston	21.86	Over 1000-year rainfall event
New Iberia	21.51	Over 500-year rainfall event
Norwood	21.40	Over 1000-year rainfall event
Wakefield	21.20	Over 1000-year rainfall event
Jackson	21.04	Over 1000-year rainfall event
Lafayette	20.79	Over 200-year rainfall event
Gonzales	18.00	Over 200-year rainfall event
Baton Rouge	16.78	Over 200-year rainfall event
Crowley	16.48	Over 100 year –rainfall event
Abbeville	16.38	Over 100 year-rainfall event
Baton Rouge Sherwood	15.07	Over 100 year-rainfall event
Baton Rouge (Airport)	14.85	Over 100 year-rainfall event
Baton Rouge Concord	14.20	At 100-year rainfall event

A hash mark (#) indicates this rainfall broken the two record for rainfall in Louisiana (Keim and Black, 2016).

What is apparent from rainfall data presented in Tables 3 and 4 is there were eight communities which had rainfall greater than 1,000-year event. In some cases, the rainfall was over the 1,000-year event by several or more inches. In the case of Watson station, the rainfall was almost 10 inches more than a 1,000-year event (Keim and Black, 2016). So, it leads one to think what was the event frequency for these eight sites that had rainfall beyond the 1,000-year event were these 5,000-year or maybe beyond events?

What the term 1,000-year event means is that not it occurs every 1,000 years but means in any given year it has a 0.1% chance of occurring in a year. Each day is independent of the other so it is like rolling dice each time you have a one in six chance of having a particular number show up. So, when thinking of these events which are independent. The chance of a 1,000-year flood event in a year is similar to the chance of rolling dice and having the same number on top four consecutive times.

It appears the first study considering intensity of rainfall for events of 5 minutes to 1 day was first written in 1947 (Jennings, 1947) which was later refined (Hershfield, 1961; and Miller, 1964). These studies consider events that repeat with a frequency of 2 to 100-years (Miller, 1964) or 1 to 100-years (Hershfield, 1961). Later on regional studies were developed for western states (U.S. Weather Bureau, 1953), northeastern states (U.S Weather Bureau, 1959), and for interest for this study south central states (Faiers and Keim, 1997; and Perica et al., 2013). More narrowly focused studies considered intensity of rainfall events of specific frequency of occurrence in Louisiana (Faiers et al, 1994; and Keim and Faiers, 1996) and East Baton Rouge Parish (Russo, 2002). NOAA (2016b) has a web site where results of intensity of precipitation (rainfall) events of specific recurrence intervals between 1 year to 1,000 years for 100s of station throughout the United States. The two and three-day rainfall events have a wide range of possible rainfall intensities (Figure 10). As expected the less frequent a rainfall event is the larger is the amount of rainfall. What is also present is as the frequency of a rainfall event is smaller the uncertainty of the amount of rainfall expands. This is displayed by the increasing difference within the 90% uncertainty lines above and below the man estimated rainfall for an event of a specific recurrence interval (Figure 10).

There are six stations that received more rainfall than the mean value determined for the 1,000-year rainfall event. One of which, Watson, 31.39 inches, was even above the upper bounds of 90% uncertainty value which is 27.7 inches by nearly 3.7 inches. So, what is this event assuming the function that defines rainfall intensity verses recurrence event frequency is consistent as defined by range of events from 1-year to 1,000-year event is present for larger events that are even less frequent in their occurrence than 1,000-year rainfall event. With this in mind the functions defined by 1 through 1000-year event are continue to less frequent events within Figure 11 for two-day rainfall events and Figure 12 for three-day rainfall events. The August rainfall events for individual stations from Tables 4 and 3 are noted within Figures 11 and 12. It appears that Brownfield had an over 2,000-year rainfall event and Watson had an over 4,000-year event (Figure 11). In terms of the records of three day events it appears that neither Livingston or or Central were over the 2,000-year rainfall event for a 3-day event (Figure 12). However, the trend of expanding uncertainty displayed in Figure 9 would continue for these extremely large precipitation events.

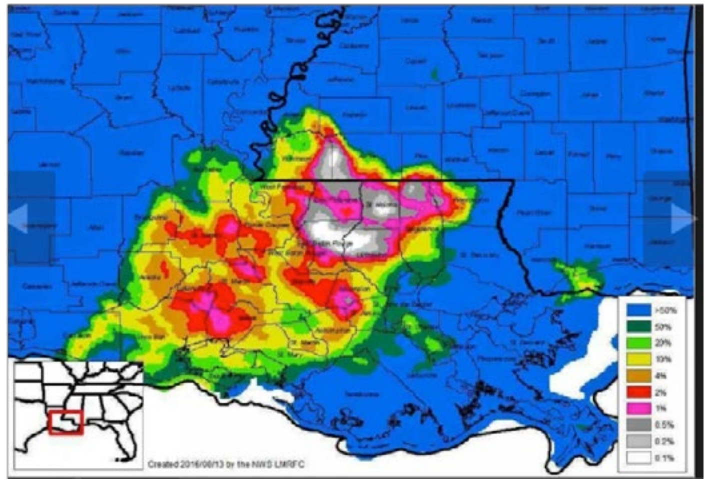


Figure 9. the probability of a rainfall event occurring that is of the magnitude of this past August rainfall event throughout southern Louisiana, source is Schiefstein (2016).

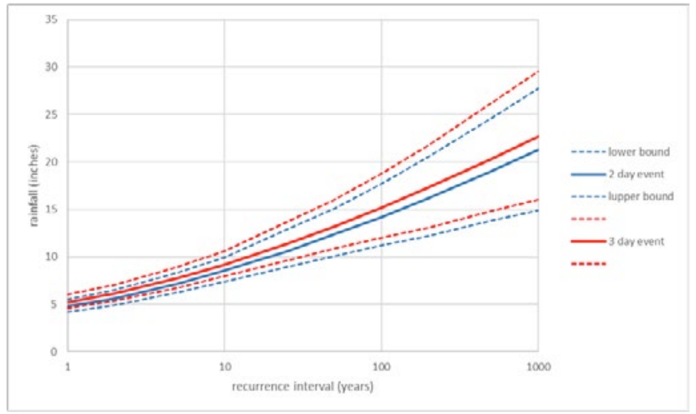


Figure 10. Rainfall amount for 2 and 3 day events for recurrence intervals between 1-year to 1,000-years for Baton Rouge station (NOAA, 2016b). The dashed lines in the same color are the upper and lower bounds of the 90% confidence interval for each given frequency of occurrence.

In addition, to the statistical uncertainty present for very rare events is the question when considering events that occur on average 1,000-years, 0.1% chance any given year, or even rarer does climate change impact this uncertainty. These changes in climate and precipitation could be a result of anthropogenic influences (Graham, 2016; and Pidcock, 2016) or natural influences/cycles. The intensity increase in the northern Gulf of Mexico region is even higher with an observed increase of intensity by 10% since 1900 (Di Liberto, 2016). The projected increase of temperature would cause an approximately increase of the intensity of extreme rainfall events by 3% to 4% for each degree of temperature increase (van der Wiel et al., 2016a). Predicted increases in temperature from various global circulation models indicated that the future increase of temperature will be greater than historical increase of temperature over the past century (U.S. Environmental Protection Agency, 2016). So as a result the frequency of occurrence of extreme rainfall could increase by approximately 40% (Graham, 2016; Pidcock, 2016; and Van der Wiel et al.,2016a). However, the view that climate change will increase probability of extreme precipitation events is not universal. Van der Wiel et al.(2016b) notes that there is no evidence of climatic changes impact on probability of extreme events is not statistically significant due to intrinsic statistical variability of these events. These temperatures changes and resulting precipitation changes in the past 100 years and predicted in the future could be largely a result of anthropogenic activities, but temperature has changed for natural reasons for millions of years (Zachos et al., 2001; Royer et al., 2004; Takashima et al., 2006; Breecker et al., 2010; and Price et al., 2013). These natural changes have also created periods of time in the northern Gulf of Mexico region with drier conditions and wetter conditions (Otvos, 2004 and 2005; Fernarndez et al., 2014) and have influenced the frequency of storm occurs (Alford and Holmes, 1984; Otvos, 2004 and 2005) and their associated extreme rainfalls. These climatic changes have occurred within the Holocene, last 11,000 years (Otvos, 2004 and 2005; and Yoo and Rohi, 2016)

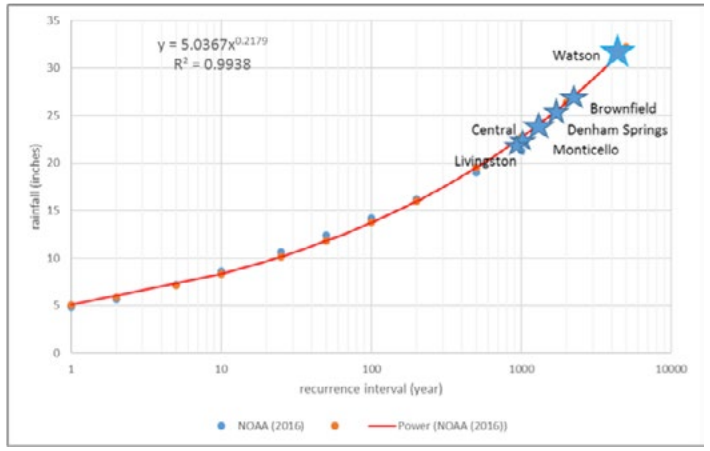


Figure 11. Approximate position as defined by curve by 2-day event curve for rainfall occurrences larger than 1,000-year event.

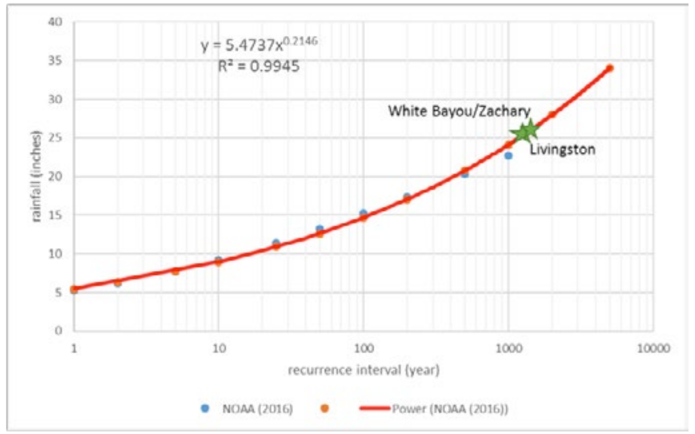


Figure 12. Approximate position as defined by curve by 3-day event curve for rainfall occurrences larger than 1,000-year event.

Flood event

A large portion of the stream gaging stations in the Amite River watershed experienced record level of flooding. Most of these records were broken by more than a two feet (Figure 13, Table 5). There are also eleven gaging stations where record indicates that gage was topped and sometimes destroyed (Table 6). The August flood was far above other noted previous flood events. For example, it more than 10 feet above all but the top ten previous floods recorded and 4.7 feet above the previous record highest flood for the Amite River in Denham Springs (Table 7).

The flood wave that is displayed depends on the position of a gaging station, if it is on the Amite River the main river for Amite River watershed, a major tributary such as Comite River or smaller tributaries. For the Amite River in general rainfall occurred over the whole basin mainly August 12 and 13. However, the peak of the flood wave arrived at later and later times downstream (Figure 13, Table 8). In general, the time the Amite River spent over the previous record flood stage and flood stage increased downstream (Table 8). For a tributary such as Comite River there is often two peaks that occur for the flood wave (Figure 14). The first peak is the initial response of the tributaries watershed to the rainfall event while the second is a backwater response of the rising main river (Amite River) driving water back up the tributary river (Comite River). The arrival time of the first peak varies depending on station site along the Comite while the second peak from backwater response occurs at approximately the same time for all of the stations that experience this peak. Because of the smaller watershed size the tributary will generally have a flood wave peak crest arrive earlier than the flood peak for the main river and the length of time over flood stage will be shorter during first peak (Table 9).

Table 5. Record gages heights for gage stations in Amite River watershed (Baumann, 2016; Revitte and Welch, 2016; and USGS 2016).

Station	Date of previous record	Previous record	Date of new record	New record	Margin broken by
Amite River at Darlington	1/25/1990	22.05 feet	8/12/2016	22.54 feet	0.49 feet
Amite River at Grangeville	4/14/1955	46.47 feet	8/12/2016*	44.62 feet	-1.85 feet
Amite River at Magnolia	4/23/1977	51.91feet	8/13/2016	58.56 feet	6.65 feet
Amite River at Denham Springs	4/8/1983	41.50 feet	8/14/2016	46.20 feet	4.70 feet
Amite River at Bayou Manchac Pt.	14/8/1983	18.85 feet	8/14/2016	*21.50 feet*	2.65 feet
Amite River at Port Vincent	4/9/1983	12.73 feet	8/15/2016	17.90 feet	5.17 feet
Amite River at French Settlement	4/25/1977	7.40 feet	8/16/2016	9.21 feet	1.81 feet
Comite River near Olive Branch	3/18/1961	21.37 feet	8/13/2016	26.96 feet	5.59 feet
Comite River at Port Hudson-Pride Rd.	9/3/2008	30.38 feet	8/13/2016	38.88 feet	8.50 feet
Comite River at Comite Drive	4/7/1983	65.78 feet	8/13/2016	65.79 feet	0.01 feet
Comite River near Comite	6/5/2001	30.99 feet	8/14/2016	34.22 feet	3.23 feet
Comite River at Greenwell Sprs. Rd.	4/7/1983	49.42 feet	8/14/2016	54.06 feet	4.64 feet

The * indicates this is not a record but is close. Value in italics is an estimate according to Revitte and Welch (2016).

Table 6. U.S. stream gaging stations that were either topped and/or destroyed in the August, 2016 flood.

station	Longitude (degree)	Latitude (degree)	Date topped and/ or destroyed	Time topped and/or destroyed
Alligator Bayou near Kleinpeter, LA	91°01’14.6”	30°19’16.5”	August 19, 2016	6:00 pm
Amite River at Port Vincent, LA	90°46’45”	30°16’31”	August 15, 2016	2:00 am
Bayou Fountain at Bluebonnet Blvd near Baton Rouge,, LA	91°06’29”	30°21’30”	August 13, 2016	10:45 pm
Bayou Manchac near Little Prairie, LA	90°55’02”	30°20’25”	August 14, 2016	1:30 am
Comite River near Zachary, LA	91°05’40”	30°38’35”	August 13, 2016	1:00 am
Dawson Cr. at Bluebonnet Blvd near Baton Rouge, LA	91°05’39”	30°22’56”	August 11, 2016	11:45 pm
Jones Cr. at Old Hammond Hwy near Baton Rouge, LA	91°02’40”	30°26’26”	August 12, 2016	7:15 am
Little Sandy Creek at Peairs Rd SE of Milldale, LA	91°00’26.5”	30°38’36.6”	August 12, 2016	9:45 am
Muddy Creek at Manchac Acres Rd near Oak Grove, LA	90°56’47”	30°19’42”	August 14, 2016	11:45 am
Sandy Ck at Alph. Forbes near Greenwell Springs, LA			August 12, 2016	4;45 pm
Welsh Gully at J. Broussard Rd near Prairieville, LA	90°58’08”	30°20’12”	August 13, 2016	3:00 pm

Table 7. Top 30 floods of the Amite River in Denham Springs as defined by gage heights/stage.

Rank	Date	Stage (feet)	Discharge (cfs)	Information source
1	August 14, 2016	46.20	162,000*	USGS (2016)
2	April 8, 1983	41.50	112,000	Ensminger (1998)
3	April 23, 1977	41.08	110,000	Ensminger (1998)
4	January 27,1990	39.88	96,700	Ensminger (1998)
5	March 15, 1921	39.27	93,000	Cragwall (1952)
6	June 9, 2001	38.34	83,500	USGS (2016)
7	January 23,1993	38.15	81,900	Ensminger (1998)
8	April 24, 1979	36.70	68,600	Ensminger (1998)
9	May 27, 1973	36.50	61,800	Neely (1976)
10	May 20, 1953	36.33	67,000	Sauer (1964)
11	September 5, 2008	36.23	67,400	USGS (2016)
12	January 30, 1994	36.10	66,500	USGS (2016)
13	March 30, 1980	35.96	64,200	Ensminger (1998)
14	April 15, 1955	35.95	54,300	Sauer (1964)
15	April 12, 1995	35.93	65,300	USGS (2016)
16	April 17, 1967	35.26	47,800	Neely (1976)
17	April 29, 1997	35.05	59,300	USGS (2016)
18	December 8, 1971	35.01	51,800	Neely (1976)
19	April 29, 1962	34.55	49,700	Neely (1976)
20	March 20, 1961	34.47	49,100	Neely (1976)
21	February 24, 2003	34.17	54,000	USGS (2016)
22	October 7, 1964	34.02	49,900	Neely (1976)
23	January 9, 1998	33.54	50,200	USGS (2016)
24	March 5, 1948	33.46	45,100	Cragwall (1952)
25	December 20, 1995	33.34	49,000	USGS (2016)
26	March 7, 1992	33.27	48,600	Ensminger (1998)
27	February 14, 1966	32.77	39,700	Neely (1976)
28	December 7, 1982	32.7	46,800	USGS (2016)
29	September 7, 1977	32.6	36,800	USGS (2016)
30	March 23, 1943	32.50	40,200	Cragwall (1952)

The * indicates that discharge was determined using the below equation developed from using last 35 yearly maximum flood events.

Y = 209.923x2 – 7960.3x 80453 where Y is discharge in cfs and x is gage height in feet. The above equation has a correlation coefficient with 35 observations of 0.9988.

Table 8. When did the peak of flooding occur on the Amite River and how long was the river above the previous record flood stage and over flood stage for that station. (USGS, 2016). Table 5 is source of record stage.

Station	Arrival time of peak of flooding (day and time)	Time over record flood stage (hours)	Time over flood stage (hours)
Darlington	8/12/2016 at 8:30 pm	6.5	Not available
Grangeville	8/13/2016 at 2:00 am	No record	45
Magnolia	8/13/2016 at 6:00 pm	47	62.5
Denham Springs	8/14/2016 at 5:00 am	56.5	122.5
Port Vincent	8/15/2016 at 1:15 am	98	172.5
French Settlement	8/16/2016 at 3:00 am	98	273
Maurepas	8/17/2016 at 5:30 pm	Not available	Not available

Maurepas record is probably too short for meaningful record which approximately ten years long.

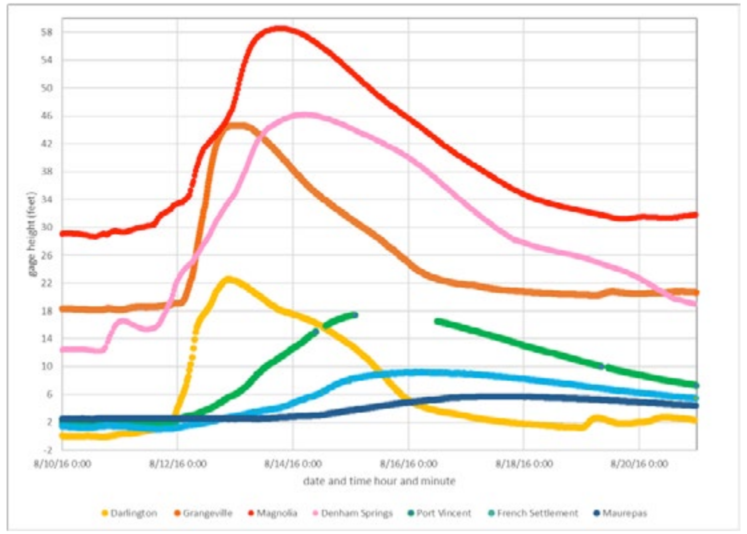


Figure 13. August flood wave for Amite River at seven stations along the river. The order of stations from north to south-down-stream are: Darlington, Grangeville, Magnolia, Denham Springs, Port Washington, French Settlement, and Maurepas.

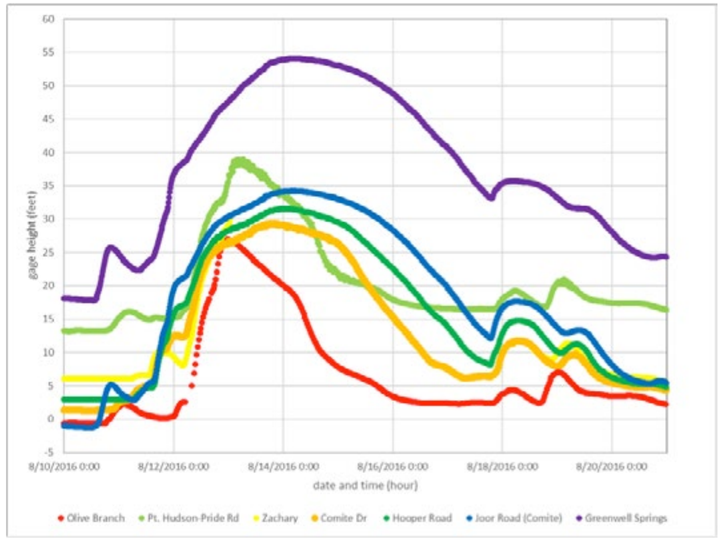


Figure 14. August flood wave for Comite River at eight stations along the river. The order of stations from north to south-down-stream: Olive Branch, Port Hudson-Pride, Zachary, Baker, Comite Drive, Hooper Road, Joor Road (Comite), and Greenwell Springs Road.

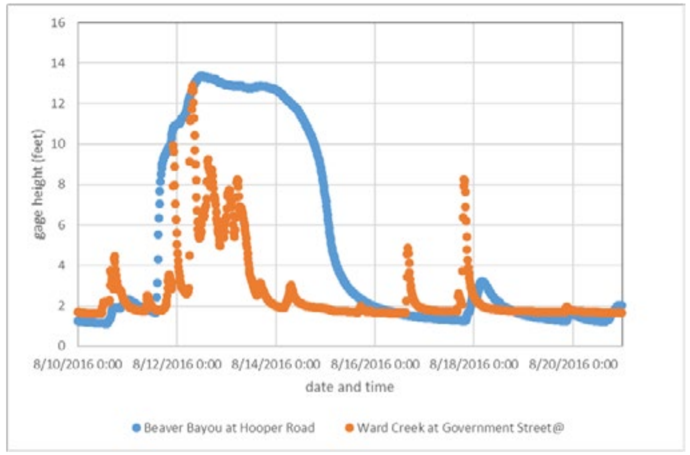


Figure 15. Difference of stream response to August flood wave and urban stream, Ward Creek at Government Street is an urban stream and Beaver Bayou at Hooper Road is a rural stream. The Note gage height for Ward Creek is 30 feet larger than values within plot. This conversion is done show relative responses more clearly.

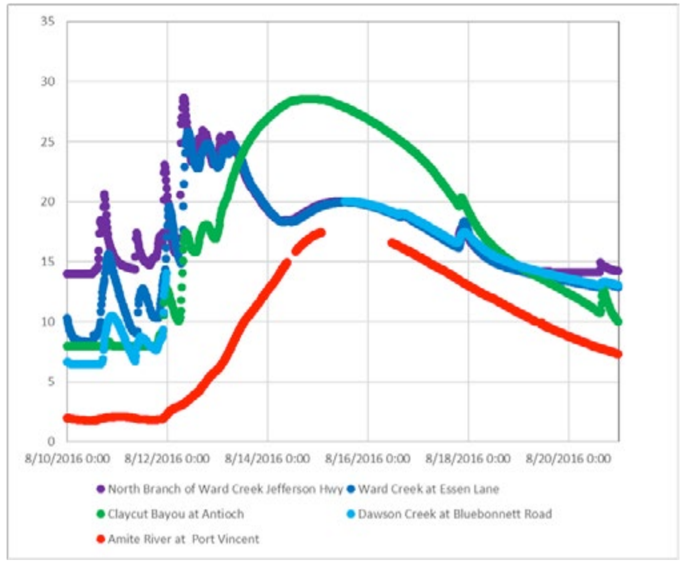


Figure 16. August flood wave for Claycut Bayou, Dawson Creek, North Branch of Ward Creek and Ward Creek at Essen Lane as they experience the back water flood from the Amite River.

Table 9. When did the peak of flooding occur on the Comite River and how long the river was above the previous record flood stage and over flood stage by station. (USGS, 2016). Table 5 and USGS (2016) are sources of record stages.

Station	Arrival time of peak of flooding (day and time)	Time over record flood stage (hours)	Time over flood stage (hours)
Olive Branch	August 13, 2016 0:00 am	24	34.5
Port Hudson-Pride	August 13, 2016 6:30 am	**41.25**	**N.A.**
Zachary	Site damaged before peak	unknown	N.A.
Comite Drive	August 13, 2016 7:45 pm	0.25	N.A.
Joor Road (Comite)	August 14, 2016 3:30 am	57.5	118.5
Greenwell Springs Road	August 14, 2016 2:15 am	64.5	N.A.

A N.A. Flood threshold is not available at USGS (2016) for this station.

The hydrograph for smaller streams is significantly different than for larger streams such as the Amite and Comite Rivers. For the smaller streams there tends to be a pattern of two or more peaks (Figure 15). The second one is often a much broader peak and in some cases even higher. This section peak in the flood wave is the back flooding from the major stream into a smaller stream (Figure 16). The tie between tributary gage height and Amite River gage height becomes clear by Auugst 15, 2016 when gage height values trend closely with the Amite River gage height at Port Vincent (Figure 16). Only when stream approach normal base levels on August 19, 2016 that gage height for Dawson Creek, Ward Creek and North Branch of Ward Creek only Claycut Bayou follows Amite River gage height. This is not surprising because this is by far the closest site to the Amite River. Less common is the response of stream that is far enough upstream and high enough above Amite River to avoid experiencing the back flooding from the Amite. Then the pattern is closely tied to the rate of precipitation (Figure 17).

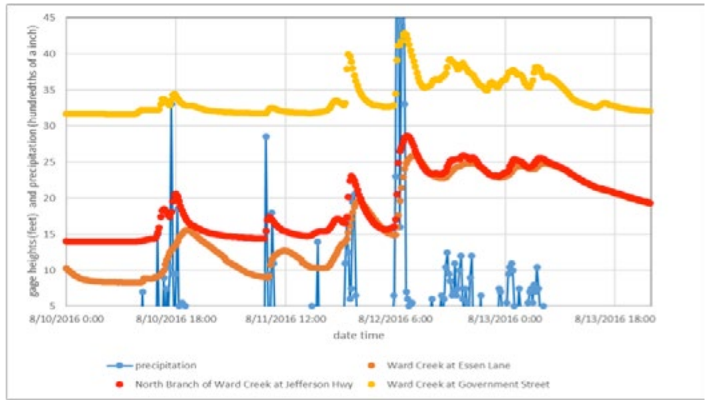


Figure 17. Flashy response to August deluge of Ward Creek at Government Street and Essen Lane and North Branch of Ward Creek at Jefferson Highway in Baton Rouge, Louisiana. Precipitation is 15-minute interval average at Ward Creek Essen Lane and North Branch of Ward Creek at Jefferson Highway.

The flood on the Amite has been described as a 500-year to 1,000-year flood. How is this determined because stream discharge records are generally only 20 to 35 years long (Table 10). Researchers from the USGS have developed a series of studies of flood depth-frequency relations for Louisiana for Louisiana starting with (Cragwell, 1952) through Ensminger, 1998). For example, Lowe (1980) developed a series of equations of the following form $dx = aA^b$ where dx is flood depth for a given recurrence interval in feet, a is regression constant, b is regression coefficient and A is a drainage area in acres. Lowe (1980) developed equations for 25, 50, and 100-year recurrence interval floods. Lowe (1980) only developed equations for streams with 10 or more years of continuous record, 3650 days which yield daily mean values. One caveat that Lowe (1980) noted is that equations are generally valid only for watersheds that have less than 15% paved surfaces. A number of streams in the Amite River watershed have had flood of recurrence intervals of 2,5,10,25,50, and 100 determined (Table 11) by Lee (1985).

Table 10. Length of discharge record for Amite River and Comite River stations where the USGS is measuring discharge

Station	Dates when daily gaging record is present
Alligator Bayou near Kleinpeter	11/8/1999 to present
Amite River near Darlington	10/1/1988 to present
Amite River near Denham Springs	9/1/1938 to present
Amite River near French Settlement	7/4/1996 to present
Amite River at Grangeville	10/1/1993 to 9/30/2000
Amite River at Magnolia	10/1/994 to present
Amite River near Maurepas	10/1/1998 to present
Amite River at Port Vincent	10/1/1987 to 9/30/2015
Bayou Francois at Hwy 61 near Gonzales	4/29/1997 to present
Black Bayou East of Gonzales	5/2/1997 to present
Black Bayou at Hwy 621 near Prairieville	11/26/1997 to present
Bayou Manchac at Alligator B near Kleinpeter	12/16/1997 to present
Bayou Manchac near Little Prairie	2/11/1995 to present
Comite River near Comite (Joor Road)	10/1/1991 to 5/25/2016
Comite River near Mount Olive	10/1/1982 to present
Henderson Bayou near Port Vincent	11/26/1997 to present
New River Canal near Sorrento	4/28/1997 to present

Table 11. Flood discharge value for various floods of recurrence intervals. Values from Lee (1985) have a * after stream/location, values from Neely (1976) have a # after stream/location and values from Ensminger (1998) have a @ after stream/location. All discharges are in cubic feet per second (cfs)

Stream/ location	Watershed Area (sqm)	Stream slope (ft/mile)	Record Length (yrs)	Recurrence interval of years					
				2	5	10	25	50	100
Amite/Darlington#	580	6.4	26	17400	37200	54700	82000	106000	133000
Amite/Darlington*	550	6.4	35	22500	42400	60500	86400	108000	131000
Amite/Darlington@	580	6.4	45	20500	41100	58100	82900	103500	125800
Amite/Grangeville#	741	6.3		19200	35200	46900	62400	75000	88000
Amite/Grangeville@	741	6.3	12	19200	34800	46900	63800	77500	92000
Amite/Magnolia#	884	5.5	26	16100	32800	47100	68800	87700	109000
Amite/Magnolia*	884	5.5	35	25900	43000	55400	72000	85000	98300
Amite/Magnolia@	884	5.5	36	27100	44400	56200	72400	85500	96600
Amite/Denham Springs#	1280	5.2	54	23700	41500	55200	74200	89700	106000
Amite/Denham Springs*	1280	5.2	63	48000	48000	65500	91200	113000	136000
Amite/Denham Springs@	1280	5.2	56	29100	51700	68800	92100	110500	129700
Comite/Olive Branch#	145	8.1		6050	11600	16100	22200	28300	34400
Comite/Olive Branch*	145	8.1	42	6710	13200	18600	26500	33200	40500
Comite/Olive Branch @	145	8.1	51	7190	13400	18300	25100	30500	36200
Comite/Zachary#	230	63	24	9700	16300	21000	27300	32500	37700
Comite/Zachary*	250	6.3	33	10200	17900	23200	30100	35200	40200
Comite/Zachary@	230	6.3	13	8980	15600	20500	27200	32300	37600
Comite/Comite#	284	5.2	31	8620	14400	18800	24800	29600	34700
Comite/Comite*	284	5.2	40	10400	17000	21700	27600	32020	36400
Comite/Comite@	284	5.2	50	11400	18900	24100	30900	36100	41300
Ward/Capital Heights#	4.1	7.2	5	1230	1580	1800	2060	2250	2430
Ward/Government St.*	4.1	NA	14	1280	1720	2020	2390	2670	2950
White Bayou/ Zachary@	45	7.02	21	2930	3610	4010	4460	4780	5070

The probably of a flood can be determined from the equation $P = m/(N+1)$ where m is the rank number of a flood event, N is the number of years of record and P is the fractional probability of flood of recorded size (Roberson, et al., 1988). A probably more familiar term is recurrence interval of a flood which is a reciprocal of the fractional probably which is determined by using the equation $T = N/n$ where T is flood recurrence interval in years, N is number of years of record and n is rank of a flood (Duncan and Fenwick, 2005).

Usually the relationship that relates flood stage to recurrence time is a logarithmic function (Figure 18). Usually the correlation coefficient r is over 0.95, which is a very highly correlation or strong coefficient (Calkins, 2005; and Mathbits.com, 2016). Two data sets were used to develop these curves. One, is the daily mean stage, gage height, values which for this study will include at least 5,000 days in order for a stream to be considered, which is approximately 15 years of gage operation (Table 12). Two, is the large set of streams that have included over 20 years-worth of yearly maximum values but lack 5,000 daily mean gage height values (Table 13). Results of recurrence intervals range from approximately 5 up to approximately 6600 years (Table 12). So in brief an answer to the question about what is the flood it depends on which stream is considered and location along the stream.

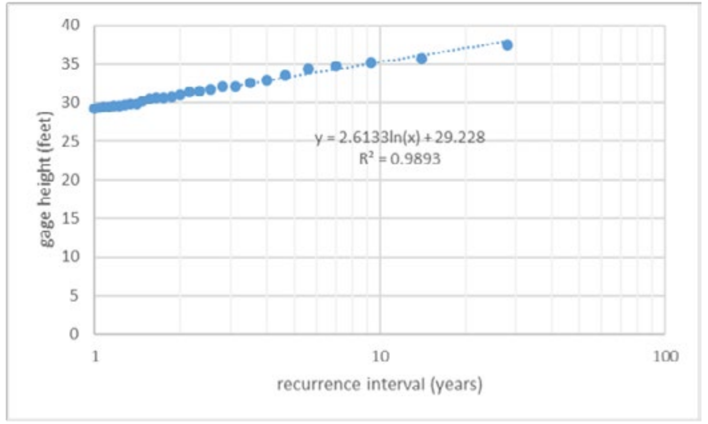


Figure 18. A typical curve for recurrence. This one is for the Amite River for gage site that is near Denham Springs, Florida Avenue. The curve is based on 8,194 daily mean gage heights measured from 10/1/1988 to present over the past 28 years (USGS, 2016).

Table 12. What is the recurrence interval for the August 2016 flood based on daily mean data where x is recurrence interval in years and y is gage height in feet. A N. indicates gage is near a town that is noted and E. is east of a town.

Stream	Location	Days in record	Equation	Regression coefficient r	Recurrence value (years)
Alligator Bayou	N. Kleinpeter	5,455	$Y = 1.29*\ln(x) +7.41$	0.9774	52
Amite River	N. Darlington	7,332	$Y = 1.73*\ln(x) +14.09$	0.9812	26
Amite River	N. Denham Springs	8,194	$Y = 2.61*\ln(x) + 29.23$	0.9946	525
Amite River	N. French Settlement	7,104	$Y = 1.16*\ln(x) + 3.82$	0.9633	96
Amite River	Grangeville	5,338	$Y = 1.68*\ln(x) + 27.53$	0.9820	6,580
Amite River	Magnolia	5,059	$Y = 1.96*\ln(x) +41.52$	0.9661	2,160
Amite River	N. Maurepas	6,511	$Y = 1.18*\ln(x) + 3.81$	0.9823	5
Amite River	Port Vincent	9,221	$Y = 1.91*\ln(x) +6.74$	0.9823	126
Bayou Francois	N. Gonzales	6,714	$Y = 0.841*\ln(x) + 3.38$	0.9003	200
Black Bayou	E. of Gonzales	6,940	$Y = 0.927*\ln(x) + 3.92$	0.9762	7
Black Bayou	N. Prairieville	6164	$Y = 1.17*\ln(x) + 5.94$	0.9446	115
Bayou Manchac	N. Kleinpeter	6,414	$Y = 1.93*\ln(x) + 8.84$	0.9802	25
Bayou Manchac	N. Little Prairie	6,368	$Y = 2.23*\ln(x) + 9.26$	0.9903	9.2
Comite River	N. Comite	8,808	$Y = 3.19*\ln(x) +20.20$	0.9784	73
Comite River	N. Mount Olive	10,990	$Y = 2.80*\ln(x) + 8.46$	0.9882	6.3
Henderson Bayou	N. Port Vincent	5,960	$Y = 1.46*\ln(x) + 4.97$	0.9463	1050
New River Canal	N. Sorrento	6,769	$Y = 0.964*lm(x) + 3.09$	0.9635	93

Table 13. What is the recurrence interval for the August 2016 flood based on yearly maximum data where x is recurrence interval in years and y is gage height in feet. Equations are based on major floods up to water year 2013.

Stream	Location	floods in record	Equation	Regression coefficient r	Recurrence value (years)
Claycut Bayou	At Antioch Rd.	22	$Y = 1.57*\ln(x) + 17.01$	0.9936	1530
Comite River	At Comite Dr.	30	$Y = 3.66*\ln(x) + 53,.30$	0.9863	30
Comite River	Greenwell Springs Road	45	$Y = 3.32*\ln(x) + 37.11$	0.9833	166
Comite River	Near Zachary#	41	$Y = 1.25*\ln(x) + 86.03$	0.9824	20
Jones Creek	At Old Hammond%	75	$Y = 1.26*\ln(x) + 35.10$	0.9904	165
White Bayou	Near Zachary	48	$Y = 0.491*\ln(x) + 90.96$	0.9779	1,270

A hash tag (#) indicates this lowest possible because gaging station was destroyed before the stream crested for the August 2016 flood. A % indicates a portion of record is missing during flooding.

Discussion

In general, the flood recurrence interval is about 100 years while many of the rainfall recurrence values are about 1000 years. So why is there a difference. There are several reasons for the differences. One of the main reasons is differences of storm events. An event such as January 23, 1993 is a winter storm as a result a wide spread frontal system typical of the winter which had an average rainfall of 8.54 inches throughout the basin and yield a flood event depending on station from 10 to 25 years (McCallum, 1998). By comparison the August 2016 flood is a result of a tropical storm (weather.com) which is smaller in areal extent usually approximately one third the size (Quizlet.com, 2016). For the August storm the northern portion of the Amite River watershed had far lower rainfall as indicated by McColmb Mississippi having rainfall of approximately 3 inches and areas near Louisiana – Mississippi border that are 2 to 5-year precipitation recurrences while just a few miles south in St. Helena parish areas where have a 200 to 1000-year precipitation event. This explains why Darlington flood recurrence is the lowest at 26-year while many of the other stations to the south have flood recurrence intervals that are between 100-year and 1,000-years or greater as is the case for: Grangeville 6580-year flood and Magnolia 2160-year flood. The value determine for Magnolia is reasonable as the author observed from walking through two feet of water along Lockhart Road toward first shelter for August 13 and 14 at Lockhart Baptist Church after a boat ride to intersection of Range and Magnolia Beach Road which according to 2012 FEMA flood zone map the walk and part of the boat ride is in the 0.2% annual-chance zone (Lsuagcenter.com, 2016), 500-year flood zone. However, in general recurrence of flood event becomes smaller interval southwards towards end of Comite River or Amite River and in the southern portion of the watershed. (Figure 19). This is reasonable given the influence of storm surges increases down the Amite River. This is apparent when as indicated by tidal influencesthat are clear at Maurepas Station (Figure 20) and French Settlement and Port Vincent stations (Figure 21) during low flow conditions. At these sites the tidal

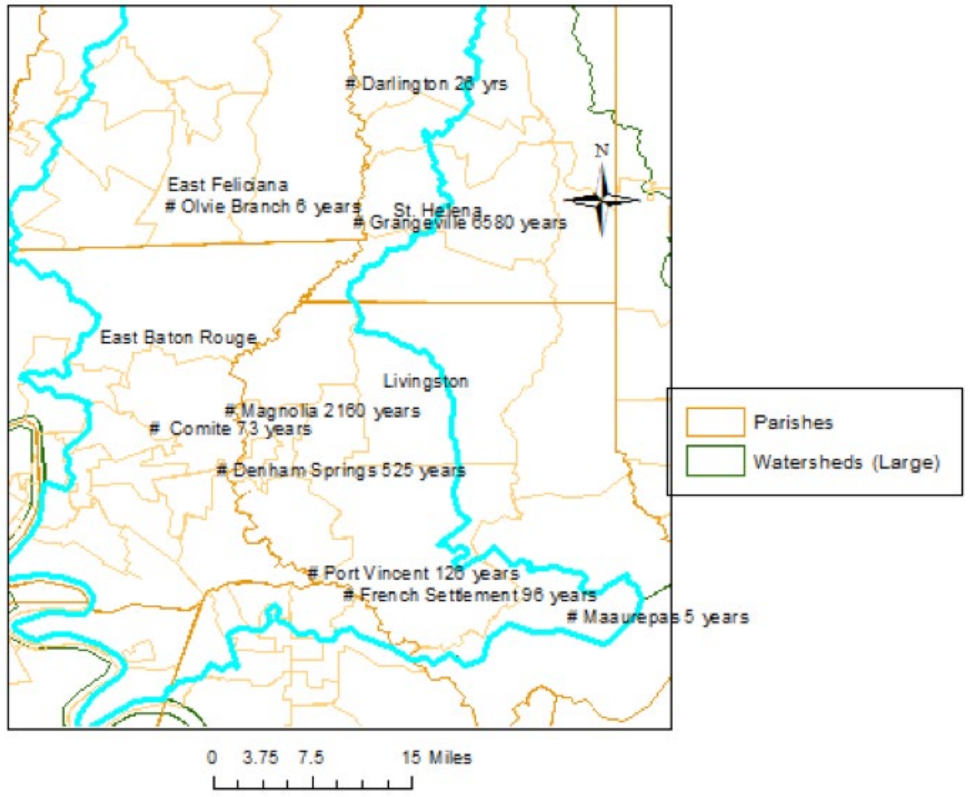


Figure 19. What is the recurrence interval for the flood of August 2016 for various stations that have daily mean records that include over 5,000 days along Amite River and Comite River?

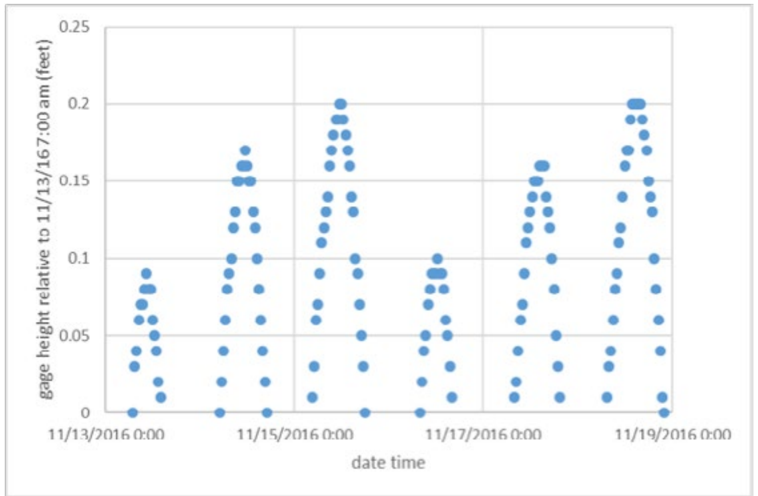


Figure 20. Tidal influence during a typical low flow conditions for Maurepas station on the Amite River. All gage heights are relative to gage height for a station at 0:00 CST November 14 for each station.

variation of water level is, approximately 0.2 to 0.4 feet. Finally, there is no tidal influence in Denham Springs, Magnolia, Grangeville and Darlington gage levels (Figure 22). The daily variation of gage level for these sites is approximately 0.02 to 0.04 feet. Storm surges are predicted to be larger but still the influence is largely south of Interstate 12 and downstream of Darlington, Grangeville, Magnolia, and Denham Springs stations which are north of Interstate 12.

Another thing to remember when considering flood recurrence interval is flooding is dependent on more than precipitation event. It is also dependent on the land use/development within a watershed. The fraction of rainfall that is contributed to runoff varies depending on the type of development (Table 14). These differences tend to decrease for more extreme events but are still present (Table 15).

> **What is clear** is that as a watershed such as Amite River watershed, becomes more developed as forests are being replaced by paved developed areas runoff will increase for the same rainfall event. So, even if there is no increase in the intensity of rainfall as hypnotized as result of global warming there will be increasing flood sizes due to the Amite watershed being developed as businesses and residents move into Livingston Parish, and eastern East Baton Rouge Parish within the watershed.

In summary, this was a 1,000 year or more flood in areas of Livingston and East Baton Rouge Parish north of I-12, but approximately 100-year flood south of the interstate. For areas near Lake Maurepas and north of the Louisiana-Mississippi state line the August flood is a few decade event. What is clear is further development will increase likelihood of major floods similar to the August 2016. This is clear from increasing rate of major flooding along Amite River at Denham Springs which included 15 of the largest 30 floods between 1921 and 1979, 58 years and 15 of the largest 30 floods between 1980 to 2016 including the two largest floods in the last 36 years.

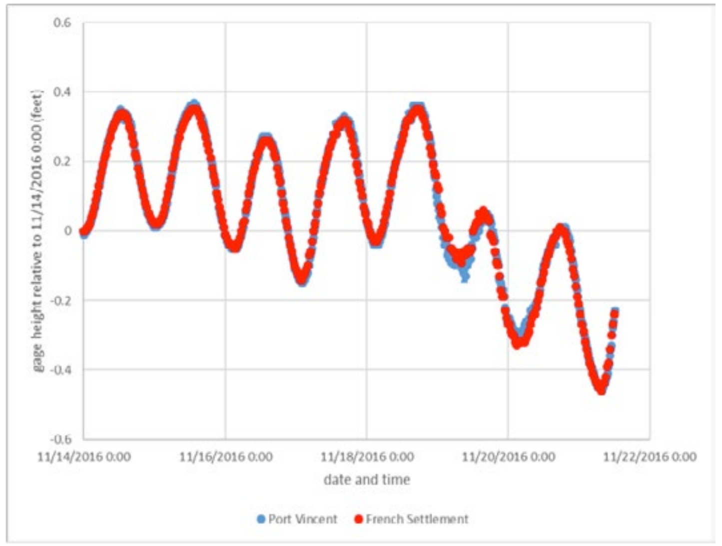


Figure 21. Tidal influence during a typical low flow conditions for French Settlement and Port Vincent stations on the Amite River. All gage heights are relative to gage height for a station at 0:00 CST November 14 for each station.

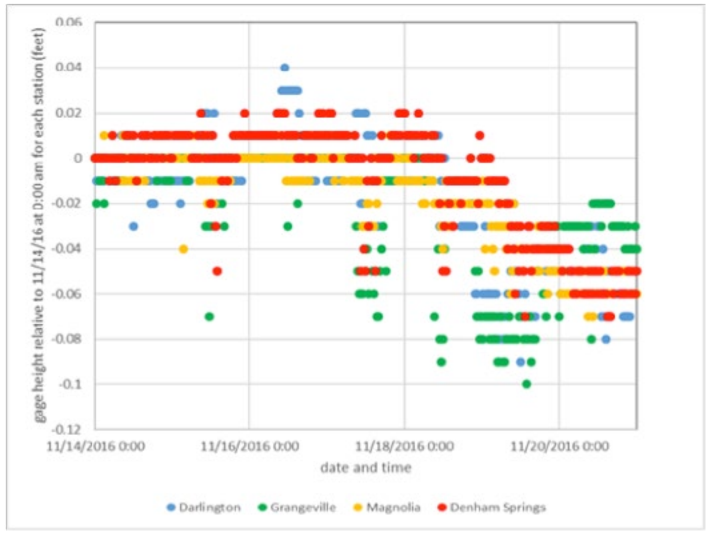


Figure 22. Tidal influence, lack of influence, during a typical low flow conditions for Darlington, Grangeville, Magnolia, and Denham Springs stations on the Amite River. All gage heights are relative to gage height for a station at 0:00 CST November 14 for each station.

Table 14. Fraction of rainfall that become runoff for various types of development, source Roberson et al. (1988). GCSS is grass covered sandy soil and GCCS is grass covered clayey soil.

Type of development	Fraction of rainfall that is runoff	Type of development	Fraction of rainfall that is runoff
Urban Business	0.70 to 0.95	GCSS <2% slope	0.05 to 0.10
Apartments	0.60 to 0.80	GCSS 2% to 8% slope	0.10 to 0.16
Commercial office	0.50 to 0.70	GCSS >8% slope	0.16 to 0.20
Condominiums	0.40 to 0.60	GCCS <2% slope	0.10 to 0.16
Single family homes	0.30 to 0.50	GCCS 2% to 8% slope	0.17 to 0.25
Parks, greenbelts & cemeteries	0.10 to 0.30	GCCS >8% slope	0.26 to 0.36

Table 15. Fraction of rainfall that become runoff for various types of development and magnitude of rainfall events, source Chow et al. (1988).

Type of surface	Recurrence interval in years						
	2	5	10	25	50	100	500
Asphaltic	0.73	0.77	0.81	0.86	0.90	0.95	1.00
Concrete/roof	0.75	0.80	0.83	0.88	0.92	0.97	1.00
<50% grass covered avg.	0.37	0.40	0.43	0.46	0.49	0.53	0.61
50-75% grass covered avg.	0.33	0.36	0.38	0.42	0.45	0.49	0.58
>75% grass covered avg.	0.29	0.32	0.35	0.39	0.42	0.46	0.56
Cultivated avg.	0.35	0.38	0.41	0.44	0.48	0.51	0.60
Pasture/Range avg.	0.33	0.36	0.38	0.42	0.45	0.49	0.58
Forest/Woodlands avg.	0.31	0.34	0.36	0.40	0.43	0.47	0.56

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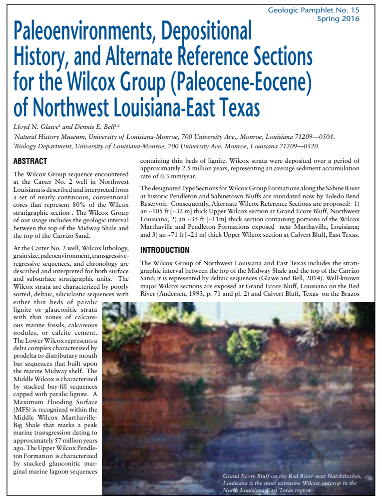
LGS Publications 2016

This years publications include:

- *Paleoenvironments, Depositional History, and Alternate Reference Sections for the Wilcox Group (Paleocene-Eocene) of Northwest Louisiana-East Texas* by L.N. Glawe and D.E. Bell, 2016
- *Tunica Hills Wildlife Management Area and Angola State Penitentiary* by Rick McCulloh, 2016
- *Soda Lake Wildlife Management Area* by Rick McCulloh, 2016
- *Columnar Section of Differentiated Wilcox Group Strata Exposed in Northwest Louisiana* by Richard P. McCulloh, 2016
- *Geologic Mapping Of Natchitoches At 1:100,000 Scale* (Paul Heinrich, Marty Horn, Richard McCulloh, and John Snead)



Geologic Pamphlet No. 15
Spring 2016

Paleoenvironments, Depositional History, and Alternate Reference Sections for the Wilcox Group (Paleocene-Eocene) of Northwest Louisiana-East Texas

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ABSTRACT

The Wilcox Group sequence encountered at the Carter No. 2 well in Northwest Louisiana is described and interpreted from a set of nearly continuous, conventional cores that represent 80% of the Wilcox stratigraphic section . The Wilcox Group of our usage includes the geologic interval between the top of the Midway Shale and the top of the Carrizo Sand.

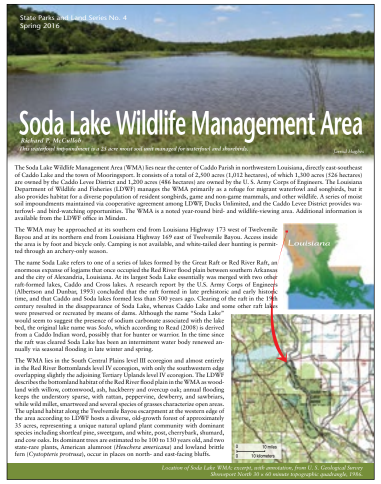
At the Carter No. 2 well, Wilcox lithology, grain size, paleoenvironment, transgressive-regressive sequences, and chronology are described and interpreted for both surface and subsurface stratigraphic units. The Wilcox strata are characterized by poorly sorted, deltaic, siliciclastic sequences with either thin beds of paralic lignite or glauconitic strata with thin zones of calcareous marine fossils, calcareous nodules, or calcite cement. The Lower Wilcox represents a delta complex characterized by prodelta to distributary mouth bar sequences that built upon the marine Midway shelf. The Middle Wilcox is characterized by stacked bay-fill sequences capped with paralic lignite. A Maximum Flooding Surface (MFS) is recognized within the Middle Wilcox Marthaville-Big Shale that marks a peak marine transgression dating to approximately 57 million years ago. The Upper Wilcox Pendleton Formation is characterized by stacked glauconitic marginal marine lagoon sequences containing thin beds of lignite. Wilcox strata were deposited over a period of approximately 2.5 million years, representing an average sediment accumulation rate of 0.3 mm/year.

The designated Type Sections for Wilcox Group Formations along the Sabine River at historic Pendleton and Sabinetown Bluffs are inundated now by Toledo Bend Reservoir. Consequently, Alternate Wilcox Reference Sections are proposed: 1) an ~105 ft [~32 m] thick Upper Wilcox section at Grand Ecore Bluff, Northwest Louisiana; 2) an ~35 ft [~11m] thick section containing portions of the Wilcox Marthaville and Pendleton Formations exposed near Marthaville, Louisiana; and 3) an ~71 ft [~21 m] thick Upper Wilcox section at Calvert Bluff, East Texas.

INTRODUCTION

The Wilcox Group of Northwest Louisiana and East Texas includes the stratigraphic interval between the top of the Midway Shale and the top of the Carrizo Sand; it is represented by deltaic sequences (Glawe and Bell, 2014). Well-known major Wilcox sections are exposed at Grand Ecore Bluff, Louisiana on the Red River (Andersen, 1993, p. 71 and pl. 2) and Calvert Bluff, Texas on the Brazos

Grand Ecore Bluff on the Red River near Natchitoches, Louisiana is the most extensive Wilcox outcrop in the North Louisiana-East Texas region



State Parks and Land Series No. 4
Spring 2016

Soda Lake Wildlife Management Area

Richard P. McCulloh

This waterfowl impoundment is a 25 acre moist soil unit managed for waterfowl and shorebirds.

Jarrod Hughes

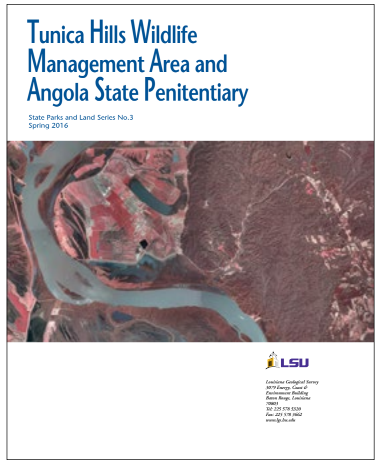
The Soda Lake Wildlife Management Area (WMA) lies near the center of Caddo Parish in northwestern Louisiana, directly east-southeast of Caddo Lake and the town of Mooringsport. It consists of a total of 2,500 acres (1,012 hectares), of which 1,300 acres (526 hectares) are owned by the Caddo Levee District and 1,200 acres (486 hectares) are owned by the U. S. Army Corps of Engineers. The Louisiana Department of Wildlife and Fisheries (LDWF) manages the WMA primarily as a refuge for migrant waterfowl and songbirds, but it also provides habitat for a diverse population of resident songbirds, game and non-game mammals, and other wildlife. A series of moist soil impoundments maintained via cooperative agreement among LDWF, Ducks Unlimited, and the Caddo Levee District provides waterfowl- and bird-watching opportunities. The WMA is a noted year-round bird- and wildlife-viewing area. Additional information is available from the LDWF office in Minden.

The WMA may be approached at its southern end from Louisiana Highway 173 west of Twelvemile Bayou and at its northern end from Louisiana Highway 169 east of Twelvemile Bayou. Access inside the area is by foot and bicycle only. Camping is not available, and white-tailed deer hunting is permitted through an archery-only season.

The name Soda Lake refers to one of a series of lakes formed by the Great Raft or Red River Raft, an enormous expanse of logjams that once occupied the Red River flood plain between southern Arkansas and the city of Alexandria, Louisiana. At its largest Soda Lake essentially was merged with two other raft-formed lakes, Caddo and Cross lakes. A research report by the U.S. Army Corps of Engineers (Albertson and Dunbar, 1993) concluded that the raft formed in late prehistoric and early historic time, and that Caddo and Soda lakes formed less than 500 years ago. Clearing of the raft in the 19th century resulted in the disappearance of Soda Lake, whereas Caddo Lake and some other raft lakes were preserved or recreated by means of dams. Although the name "Soda Lake" would seem to suggest the presence of sodium carbonate associated with the lake bed, the original lake name was *Sodo*, which according to Read (2008) is derived from a Caddo Indian word, possibly that for hunter or warrior. In the time since the raft was cleared Soda Lake has been an intermittent water body renewed annually via seasonal flooding in late winter and spring.

The WMA lies in the South Central Plains level III ecoregion and almost entirely in the Red River Bottomlands level IV ecoregion, with only the southwestern edge overlapping slightly the adjoining Tertiary Uplands level IV ecoregion. The LDWF describes the bottomland habitat of the Red River flood plain in the WMA as woodland with willow, cottonwood, ash, hackberry and overcup oak; annual flooding keeps the understory sparse, with rattan, peppervine, dewberry, and sawbriars, while wild millet, smartweed and several species of grasses characterize open areas. The upland habitat along the Twelvemile Bayou escarpment at the western edge of the area according to LDWF hosts a diverse, old-growth forest of approximately 35 acres, representing a unique natural upland plant community with dominant species including shortleaf pine, sweetgum, and white, post, cherrybark, shumard, and cow oaks. Its dominant trees are estimated to be 100 to 130 years old, and two state-rare plants, American alumroot (*Heuchera americana*) and lowland brittle fern (*Cystopteris protrusa*), occur in places on north- and east-facing bluffs.

Location of Soda Lake WMA: excerpt, with annotation, from U. S. Geological Survey Shreveport North 30 × 60 minute topographic quadrangle, 1986.



Tunica Hills Wildlife Management Area and Angola State Penitentiary

State Parks and Land Series No.3
Spring 2016

LSU

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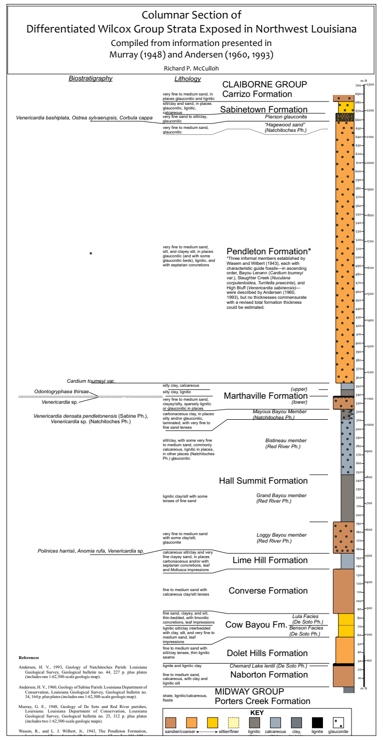

Columnar Section of
Differentiated Wilcox Group Strata Exposed in Northwest Louisiana
Compiled from information presented in
Murray (1948) and Andersen (1960, 1993)
Richard P. McCulloh

*Three informal members established by Wasem and Wilbert (1943), each with characteristic guide fossils—in ascending order, Bayou Lenann (*Cardium toumeyi* var.), Slaughter Creek (*Nuculana corpulentoidea, Turritella praecinta*), and High Bluff (*Venericardia sabinensis*)—were described by Andersen (1960, 1993), but no thicknesses commensurate with a revised total formation thickness could be estimated.

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Andersen, H. V., 1993, Geology of Natchitoches Parish: Louisiana Geological Survey, Geological bulletin no. 44, 227 p. plus plates (includes one 1:62,500-scale geologic map).

Andersen, H. V., 1960, Geology of Sabine Parish: Louisiana Department of Conservation, Louisiana Geological Survey, Geological bulletin no. 34, 164 p. plus plates (includes one 1:62,500-scale geologic map).

Murray, G. E., 1948, Geology of De Soto and Red River parishes, Louisiana: Louisiana Department of Conservation, Louisiana Geological Survey, Geological bulletin no. 25, 312 p. plus plates (includes two 1:62,500-scale geologic maps).

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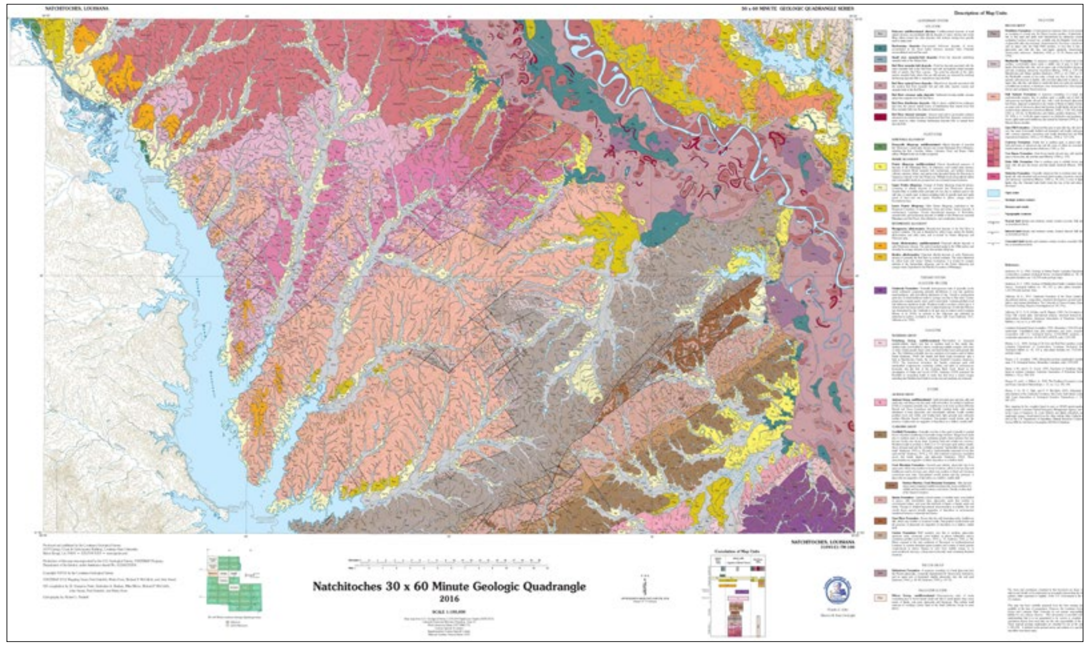


Conference Publications and Presentations

LGS research staff authored/co-authored publications and made presentations at various professional conferences at detailed below:

Carlson, D. 2016, Global climate change depends on more than combustion of fossil fuels: Gulf Coast Association of Geological Societies Transactions, v.66, p. 63-69.

Carlson, D. 2016, Subsidence rate in New Orleans, Louisiana, dependence on location and time: Gulf Coast Association of Geological Societies Transactions, v.66, p. 101-120.

Carlson, D. 2016, Influences of water quality of the Wilcox Aquifer in northwestern Louisiana: Gulf Coast Association of Geological Societies Transactions, v.66, p.701-713.

Bentley Sr., S. J., M. D. Blum, J. Maloney, **L. Pond**, and **R. Paulsell**, 2016, The Mississippi River source-to-sink system: Perspectives on tectonic, climatic, and anthropogenic influences, Miocene to Anthropocene, Earth Science Reviews, v. 153, p. 139-174.

Lewis, K. A., K. deMutsert, J. Steenbeck, **R. H. Peele**, J. H. Cowan Jr., J. Bruszowski, 2016, Employing ecosystem models and geographic information systems (GIS) to investigate the response of changing marsh edge on historical biomass of estuarine nekton in Barataria Bay, Louisiana, USA: Ecological Modeling (online).

Twilley, R. R., S. J. Bentley Sr., Qin Chan, D. A. Edmonds, S. C. Hagen, Nina S-N Lam, C. S. Willson, K. Xu, D. Braud, **R. H. Peele**, and A. McCall, 2016: Sustainable Science, Springer, Published online 26May; doi:10.1007/S11625-016-0374-4.

McCulloh, R. P., 2016, Little Creek structure, northwestern La Salle Parish, Louisiana: Geological Society of America Abstracts with Programs, v. 48, no. I, doi:10.1130/abs/2016SC-271780.

Heinrich, Paul, R. Paulsell, R. Milner, J. Snead, and H. Peele, 2016, Investigation and GIS development of the buried Holocene-Pleistocene surface in the Louisiana Coastal Plain; Poster presentation, 32nd Annual Louisiana Remote Sensing and GIS Workshop on 26 April, 2016, Lafayette, LA.

McCulloh, R. P., 2016, The challenge(s) of surface-geologic mapping in Louisiana; Presentation to the monthly meeting of the Baton Rouge Geological Society on 13 May, 2016, and at the 32nd Annual Louisiana Remote Sensing and GIS Workshop on 26 April, 2016, Lafayette, LA.

McCulloh, R. P., P. Heinrich, and J. Snead, 2016, South Louisiana Surface Geology Mapping; Presentation to the Baton Rouge Geological Society October meeting open to the public at the EBR Parish Bluebonnet Library in connection with Earth Science Week.

Paulsell, R., 2016, Investigation and GIS Development of the buried Holocene- Pleistocene surface in the Louisiana Coastal Plain: RSGIS Workshop, Lafayette, LA (poster).
Note: Robert Paulsell was a volunteer planning committee member for this workshop).

LGS Outreach Activities

Earth Science Week: Sponsored Nationwide by the American Geoscience Institute (AGI) and at the request of LGS, Louisiana Governor John Bell Edwards issued a proclamation declaring October 9-15 as Earth Science Week 2016. This weeks celebration placed emphasis on energy, palentology, water quality, conservation and climate change.

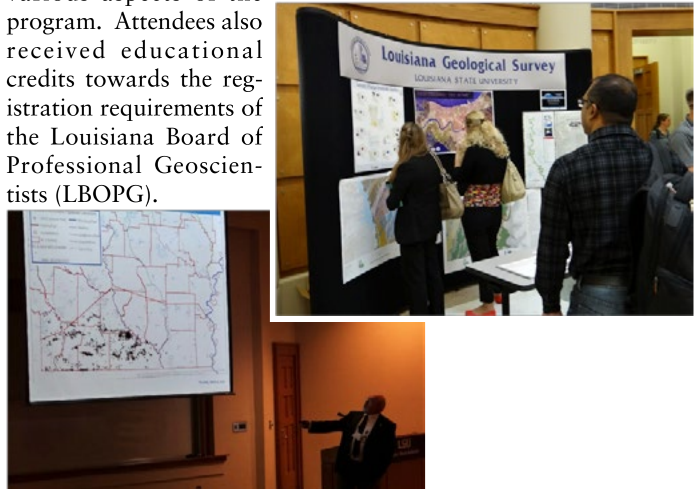
As in previous years, LGS received 50 educational kits from AGI which were distributed to K-12 school earth science teachers with the assistance of the Louisiana Department of Natural Resources Office of the Public Information Director.

Louisiana Governor John Bel Edwards

John Snead, Rick McCulloh and Paul Heinrich particapted in Geologic Mapping Day

In collaboration with the Baton Rouge Geological Society (BRGS) LGS sponsored a Geologic Mapping Day at the East Baton Rouge Parish Bluebonnet library where LGS researchers (John Snead, Rick McCulloh and Paul Heinrich) presented different aspects of geologic map production. The event was open to the public and was very well attended by BRGS memebers as well as the public. A wall display of quadrangle geologic maps was also done for this event.

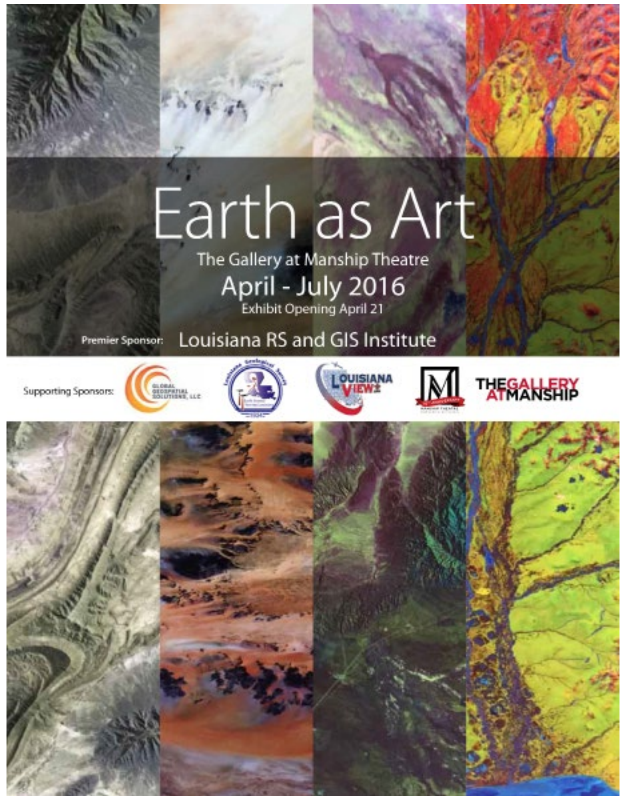
Tenth Annual Groundwater Symposium : The Louisiana Geological Survey and the Louisiana Water Research Institute (LSU) organized and hosted the "Groundwater, Surface Water and Water Resources" Symposium on March 24-25, 2016. It was a very well attended symposium (100+) and many LGS staff members were involved in various aspects of the program. Attendees also received educational credits towards the registration requirements of the Louisiana Board of Professional Geoscientists (LBOPG).

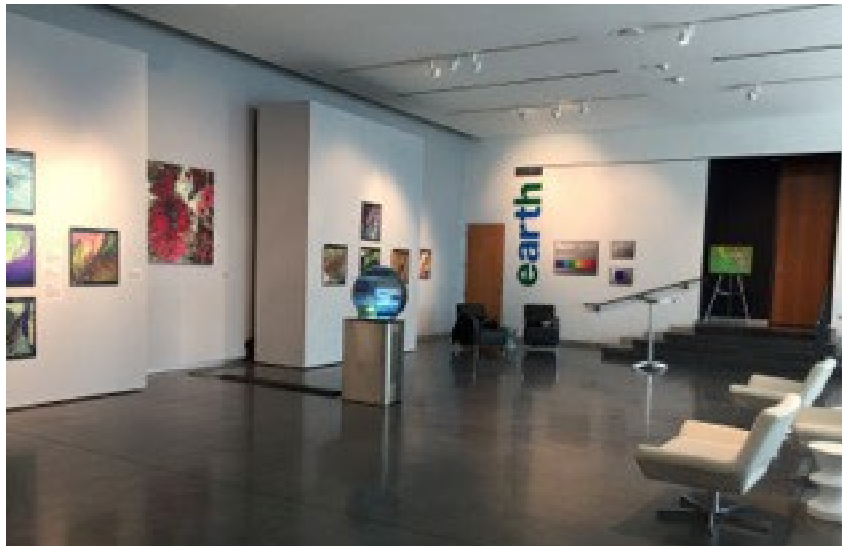


Oral presentation by Thomas Van Biersel, Louisiana Department of Natural Resources, presenting "Current Status of Interstate Water Supply Diversion from the Lower Mississippi River" on March 24, 2016

Earth As Art (exhibit) : LGS was cosponsor of this exhibit along with the LA-RS-GIS Institute, Global Geospatial Solutions LLC and Louisiana View which was displayed at the Manship Gallery from April 21- July 12, 2016. The exhibit featured stunning images of the surface of Planet Earth captured by the Landsat Satellite jointly operated by USGS and NASA. The exhibit which was free and open to the public was a major success and was viewed by a large number of people.

DISCOVERING THE WORLD THROUGH GIS
GISday
2016





LGS Resource Center

The LGS Resource Center consists of a core repository and log library. It is located behind the old Graphic Services building on River Road. Most of our cores are from the Smackover and Wilcox Formations. The core facility has more than 30,000 feet of core from wells mostly in Louisiana. The well log library contains over 50,000 well logs from various parishes in the state. The Core Lab is equipped with climate controlled layout area, microscopes, and a small trim saw. The core and log collections are included as part of the LSU Museum of Natural History as defined by the Louisiana Legislature and is the only one of its kind in Louisiana.The LGS Resource Center is available for use by industry, academia and government agencies, and others who may be interested. Viewing and sampling of cores can be arranged by calling Patrick O'Neill at 225-578-8590 or by email at poneil2@lsu.edu. Please arrange visits two weeks in advance. A list of available cores can be found at the LGS web site (www.lgs.lsu.edu).

Results From Three and Half Year Study of Louisiana Streams

Douglas Carlson and Marty Horn

Introduction

Monitoring of streams by stream gaging is used to determine fluctuations of flow. This is important because streams are a natural resource that influences wildlife habitat and associated recreational activities and other economic activities (Shaffer, 2000). Stream gaging information can be used to minimize impacts of droughts and floods, siting of wastewater treatment plants and water supply intakes (Shaffer, 2000), designing bridges, dams, flood control structures and flood plan designation (Shavanda, 2011).

Often stream flow data programs are developed in response to local economic and hydrologic stimuli. Although most of the stations and studies are in response to local needs the resulting data never the less adds up to a wealth of information on stream flow throughout the United States since 1900 (Benson and Carter, 1973). Currently the United States Geological Survey (USGS) notes that there are 8 different reasons for stream gaging: 1) for determining groundwater contribution to stream flow; 2) for determining impact from man-made storage-system or diversions and can be used for estimation of behavior of ungagged systems; 3) by water managers for flood control, water supply, and navigation; 4) for information for flood and water supply forecasting; 5) for evaluation of water quality in rivers, lakes, reservoirs, and estuaries; 6) for planning and designing of specific projects, for example reservoirs, levees, water treatment facilities, or hydroelectric power plants; 7) for water investigation studies; and 8) for dividing water resources for treaties, compacts and decrees (Wahl et al., 1995).

Stream gaging involves determining discharge which is a multiple of a stream's cross-sectional area times the stream's flow velocity. This involves determining depth of water and water velocity at a number of points across the stream (Shaffer, 2000).

Water level measurements for stream gages comes in two types: peak levels (flood crest elevations) and stage as a function of time. These measurements can be made either automatically or manually. For flood crest measurements the automatic system can include a wooden scale or staff inside a pipe that has a few small holes at its base for water to enter. A small amount of cork is placed in the pipe and will adhere to the staff-scale at the highest water level (Chow et al., 1988).

For continuous measurements, manual methods of measuring stage can involve use of staff gage observations or sounding devices that signal level when they reach water (Chow et al., 1988), for example an electrical tape with a weight attached to its end. Automatic records have been made by a variety of techniques: systems that sense water level by bubbling a continuous stream of gas (usually carbon dioxide) into water (Chow et al., 1988); another type is a Stevens type system which includes a float counter balance weight and a recording drum and paper (Sanders, 1998).

Rating curves are developed from gage height which is directly measured by the stream gage and discharge which is determined by a variety of techniques profiling stream's width, depth of water, and flow velocity at a number of points across the stream. These curves need to be checked and modified throughout time because river channel shapes and depths could change as time passes. These changes can be a result of either deposition or erosion of sediments on the bottom and sides of the river's channel (Olson and Morris, 2007, USGS, 2013a).

At the start of this study the USGS is running 242 sites for stream flow in Louisiana (USGS, 2013b). However, most include gage height information, but there is no information on discharge. Near the start of this project discharge was determined at only 74 sites (USGS, 2013b) two years later the USGS was running 256 sites and discharge was being determined at 72 sites (USGS, 2015). Many of the sites that lack discharge results are in the tidal zone with typical flow in two directions, so discharge values do not make sense as a normal stream which has a single flow direction. Discharge in a tidal zone will be a function of a combination of stream discharge and tide flow which will yield a complex and confusing rating curve. However, there are still many streams that currently have only gage height information that are not in a tidal zone. It is this set of streams that are the focus of the (LGS) study for the development of additional rating curves. These additional sites, 51, would expand the number of streams with rating curves by approximately 70% from the 2013 set of 74 sites. These sites are located throughout Louisiana (Figure 1, 2 and 3) with a focus over developing shale gas plays: Haynesville of northwest Louisiana, dense brown shale in northern Louisiana and Tuscaloosa in central Louisiana towards southeastern Louisiana.

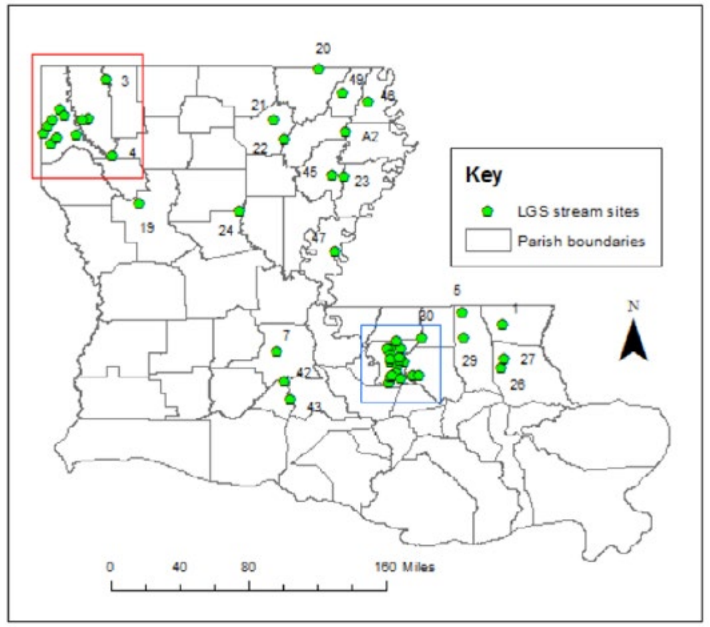


Figure 1. Map of site locations where rating curves are being developed at current USGS stream stage sites throughout Louisiana. Area in red rectangle is Figure 2 near Shreveport, Louisiana and area in blue rectangle is Figure 3 near Baton Rouge, Louisiana.

Methods

Use of the River Surveyor for determining stream discharge

One of the instruments used for the determination of most of this extension study's stream discharge values was the River Surveyor S5 ADP (SonTek/YSI Incorp, 2011), here after referred to as River Surveyor. This is a boat shaped instrument which is about 2 ft. wide and 3 ft. long (Figure 4). This instrument was used anytime there was a significant portion of the stream where the depth of water was over 1.5 ft. The other instrument, the Flow Tracker®, was used at many sites particularly for small streams during low flow conditions when the depth of the stream was usually less than 1.5 ft.

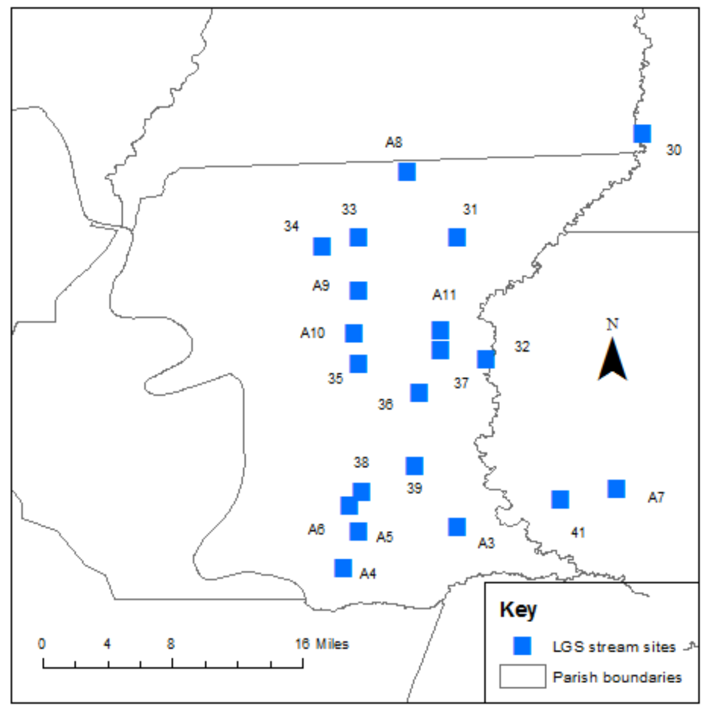


Figure 2. Map of locations where rating curves are being developed in East Baton Rouge and Livingston Parishes at current USGS stream stage sites.

Figure 4. A close up view of the River Surveyor. Box towards bow end (left) is power source, the tower near stern (right) is global positioning system (GPS) unit used for locating boat on universal grids (latitude-longitude or State Plan Coordinates (UTM).

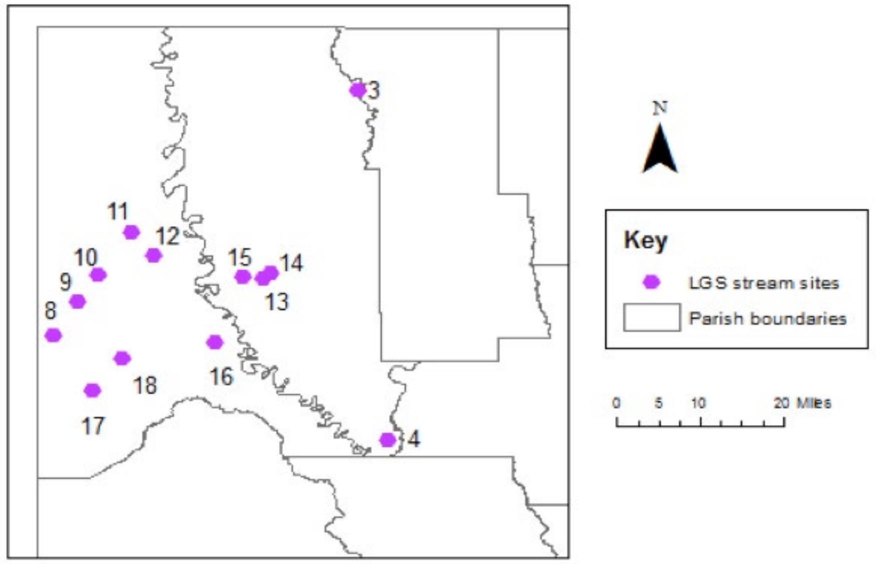


Figure 3. Map of locations where rating curves are being developed in Caddo and Bossier Parishes at current USGS stream stage sites.

The River Surveyor is an acoustic Doppler profiler system, which has four profiling beams and one vertical beam. The four profiling beams are directed off the bow and stern, and off the port and starboard sides of the boat (SonTek/YSI Incorp, 2011). The vertical beam has the lowest frequency, 1 Mega Hertz (MHz), which allows extension of the depth of measurement while the four profiler beams are 3 MHz, which allows greater sensitivity to of the measurement of the Doppler shifts due to moving parcels of water (Son/YSI Incorp., 2011). The River Surveyor has a global positioning system (GPS) which allows the computer to define the exact position of the boat at all times and to provide a record of the profile's position in map coordinates either latitude-longitude or UTM systems, (SonTek/YSI Incorp, 2011

LGS staff when conducting discharge measurements using the River Surveyor there is between one and three individuals involved in the measurement. These surveys can be conducted either from the banks of a stream with personnel on opposite sides of the stream (Figure 5) or from a bridge deck (Figures 6 to 8). For a survey from a stream's banks two people on opposite sides of the stream pull the River Surveyor (Figure 5) back and forth across a stream at least twice. The four or more discharge values calculated by the River Surveyor for the four or more trips across the stream are then averaged and that value plus information on stream gage value obtained from the USGS stream gaging webpage is listed for that stream on a given time and date and noted as a part of the stream's data set for later development of its rating curve.

Figure 5. LGS staff measuring stream discharge for Bayou Fountain at Bluebonnet Boulevard in Baton Rouge on March 7, 2013.

Since August of 2013 LGS staff started measuring stream discharges using the River Surveyor in a slightly different manor than a bank-pull (Figure 5), a bridge-pull (Figure 6 to 8). A bridge pull River Surveyor measurement involves one or two individuals. For a survey one person holds into the rope and boat and walks back and forth across the bridge moving the boat from approximately bank to bank (Figure 8). The other person carries the computer and makes sure the antenna maintains contact with the boat which usually involves keeping the antenna near or over the bridge deck's rail. In addition, help is often needed to move the rope around existing USGS gage box (Figure 8). A one-man operation requires using the cell phone for monitoring results as the survey is being conducted. For this operation moving the boat and working through a series of computerized steps on the cell phone was completed by one person. As with the bank survey there are four or more discharge values measured by the River Surveyor for the four or more trips across the stream which are averaged and then that value plus information on stream gage value obtained from the USGS stream gaging webpage was listed for that stream on a given time and date and included as part of the stream's data set for later development of its rating curve.

Figure 6. Close up view of computer and River Surveyor for a bridge survey at the Little River near Rochelle, Louisiana on April 4, 2014.

Figure 7. LGS staff getting ready to place River Surveyor over the edge of the bridge to start survey of Little River near Rochelle, Louisiana on April 4, 2014.

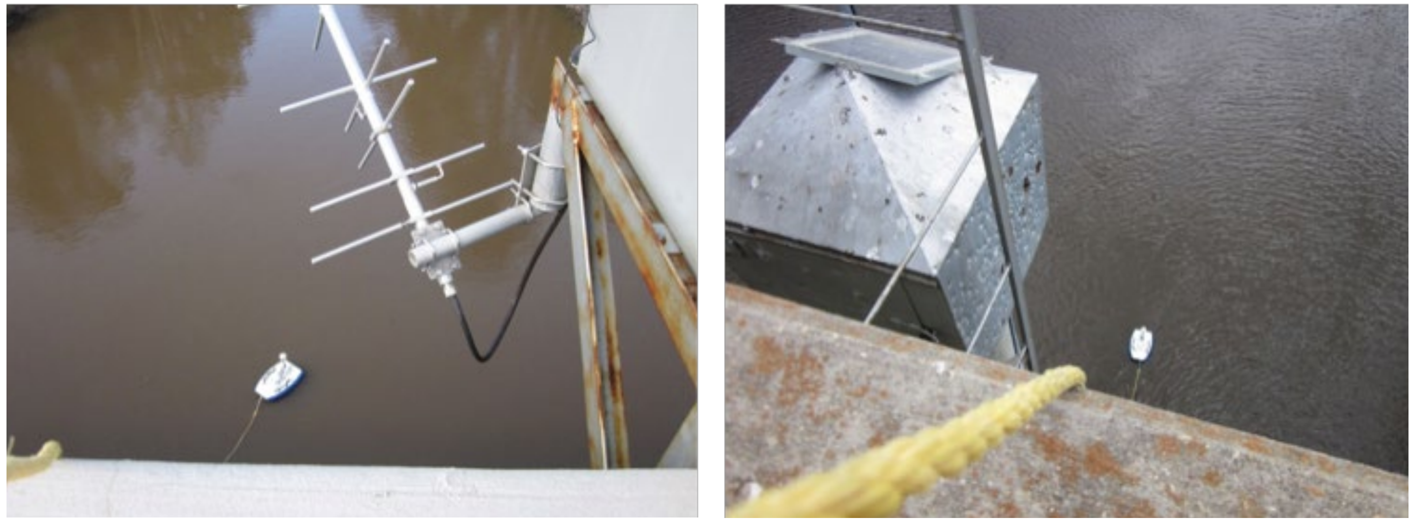


Figure 8. One obstacle that exists for many bridge surveys which is not a problem for a bank survey, the stream gage box and associated stilling towers, left image is from Bodcau Bayou survey on April 30, 2014 and right image is from Twelvemile Bayou survey on April 30, 2014.

Use of the Flow Tracker for determining stream discharge

The second instrument used for determining stream discharge is the Flow Tracker. The Flow Tracker was used for this study's measurements of discharge for small and shallow the streams that generally have depth of water is under 1.5 ft., the lower limit for use of the River Surveyor.

For this instrument the mounting pin which measures stream velocity should be orientated parallel to the banks and perpendicular to the tag line across a stream used for position measurements of both depth and lateral positions for sites where there is a determination of flow velocity (SonTek/YSI Incorp, no date). For this study the number of positions used for velocity determination along the tag line is between 12 and 21.

The Flow Tracker works by sending out an acoustic signal to measure the Doppler shift of a moving parcel of water that is 4 inches from the instrument. The signal bounces off this parcel of water and these rebound signals are recorded at two receivers (SonTek/YSI Incorp, 2009a).

It appears that the LGS meter needs a depth of water over 2 inches. Due to safety considerations this instrument should be used where the depth of water is less than three feet (Son Tek/YSI Incorp., no date). For this study for practical reasons when wading across the streams depths have been less than 2 ft. (Figure 9 and 10). There is really no reason to wade in deeper stream conditions as the River Surveyor is available for deeper stream conditions.

There are three general solution methods that can be used by the Flow Tracker to determine a stream's discharge. The med-section method, which is the typical method used by the USGS (SonTek/YSI, 2009a). Other methods are similar to mid-section except for the mean method area which is defined as a series of trapezoids rather than rectangles in the mid-section method. The 11 or more rectangles-trapezoids for area calculation of a profile are in turn multiplied by velocities at a center of a rectangle to yield discharge in that segment. Then the 11 or more area discharges are summed for the total stream discharge. For solution of discharge through either rectangle or trapezoid there

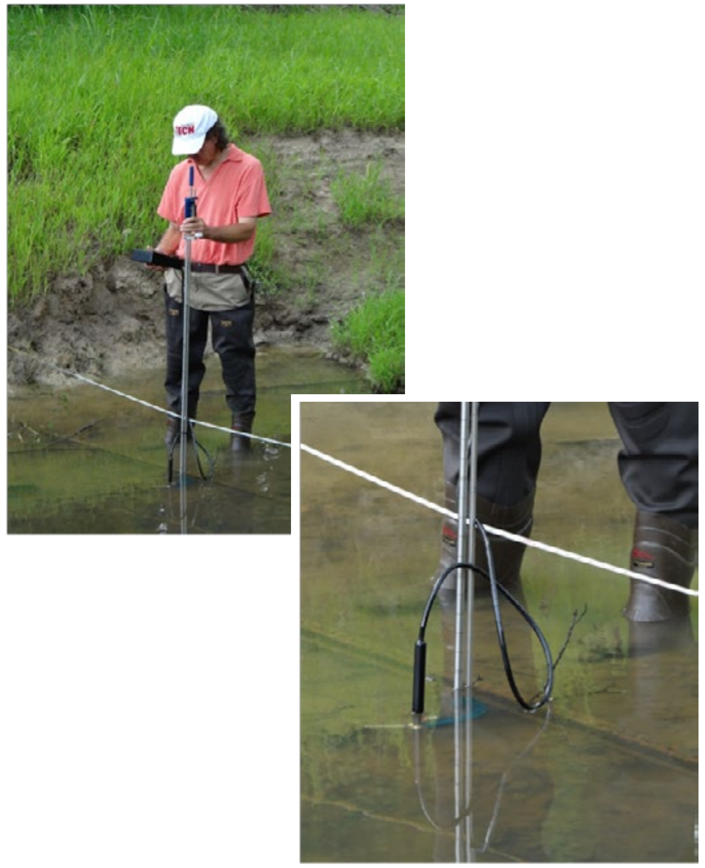


Figure 9. LGS staff conducting a Flow Tracker survey of Beaver Bayou near Wax Road in Baton Rouge, Louisiana on June 20, 2013.

Figure 10. LGS staff conducting a Flow Tracker survey of Shettleworth Bayou near Shreveport, Louisiana on April 30, 2014, image on right is a close up view of the Flow Tracker in operation for survey of Shettleworth Bayou on April 30, 2014.

is a need for width of rectangles or trapezoids, depth at the center of a rectangle or a trapezoid, and velocity as measured by the Flower Tracker at the center of the rectangle or trapezoid. A third method is similar to mean using depth average on edges of rectangles or trapezoids rather the central depth within each rectangle or trapezoids. After this slight difference for area the calculations are similar to the mean method. Then these three discharge values are averaged for the stream discharge value that is included within set of values for rating curve development.

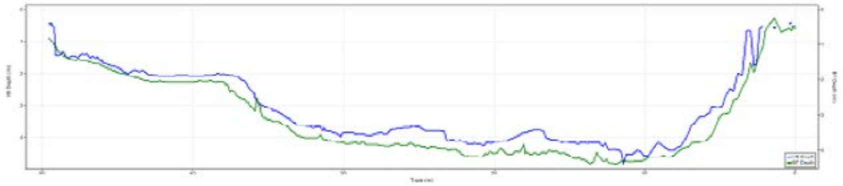
Results

Discharge measurements

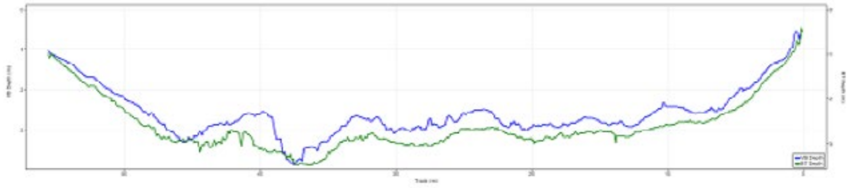
The River Surveyor creates a track of the boat position in either state plan coordinates or latitude and longitude, river profile (cross-section), and distribution of stream velocity through the area of the stream's cross section. Path is displayed relative to north-south orientation. River cross-sections tend to appear in one of three forms. A typical cross-section in an area where there is a cut bank and point bar where the channel is deep close to one edge (cut bank side) and shallow with a gentle increase in depth on the opposite side of the stream (point bar side) can be seen in Figure 11a. More common cross-section is Figure 11b, which occurs usually in an area with a fairly straight channel and which lies between meander bends within the stream's channel. The last type of channel is a fairly rectangular shaped channel, Figure 11c, which appears to occur most often for small urban streams which are probably channelized for flood control reasons in their urban settings.

The velocity distributions also come in three general types, which will explain why there are three types of channel cross-sections. Figure 12a is an example of a channel where one side is the cut bank side and the other is a point bar side. The velocity is highest (reds and oranges) on the cut bank side and is lowest (blues and purples) on the point bar side. This all makes sense when you consider erosion is happening on the cut bank side where fastest stream flow occurs and deposition occurs on the point bar side where slowest stream flow occurs (Plummer et al., 1999). In a straight portion of a channel the distribution of stream velocity tends to be highest towards the center (Figure 12b) and lower near the edges, which is to be expected in these areas which tend to have relatively uniform distribution of stream velocity across a stream's channel (Plummer et al., 1999). The distribution of stream velocity is similar in the rectangular stream channel (Figure 12c) where flow velocity like the straight stream segment is highest in the middle and tends to be lower towards the edges of the channel.

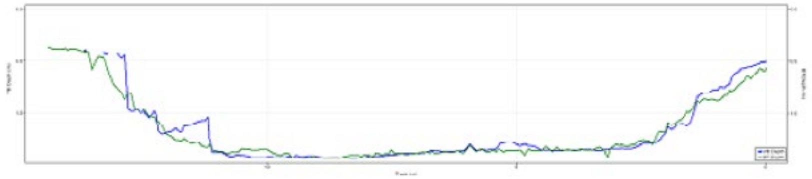
This study included determination of 541 discharge values using the River Surveyor, and the Flow Tracker (Figure 13) since the start of the study. In general discharges measured by the river surveyor are far larger than those measured by the flow tracker. There have been generally 10 or 11 measurements of discharge as a function of gage height measurement at each of the 51 sets throughout the study (Figure 14).



a) Bayou Vermilion near Carencro on April 16, 2013

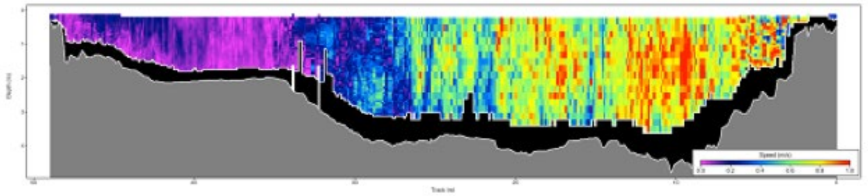


b) Vermilion River near Carencro on April 16, 2013

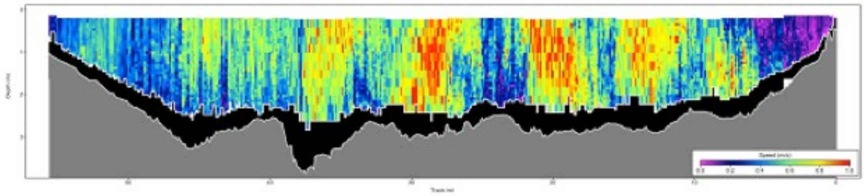


c) Jones Creek @ Old Hammond Hwy Baton Rouge on April 11, 2013

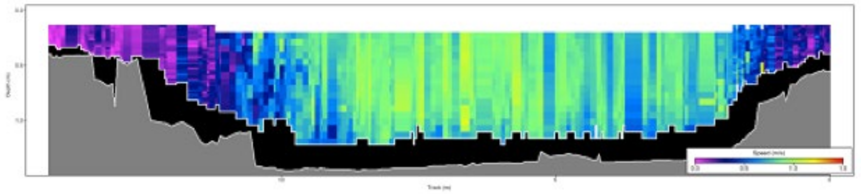
Figure 11. Three typical cross section profiles.



a) Bayou Vermilion near Carencro on April 16, 2013



b) Vermilion River near Carencro on April 16, 2013



c) Jones Creek @ Old Hammond Hwy Baton Rouge on April 11, 2013

Figure 12. Flow velocity across three examples straight segment, cut-bank point bar, over central change

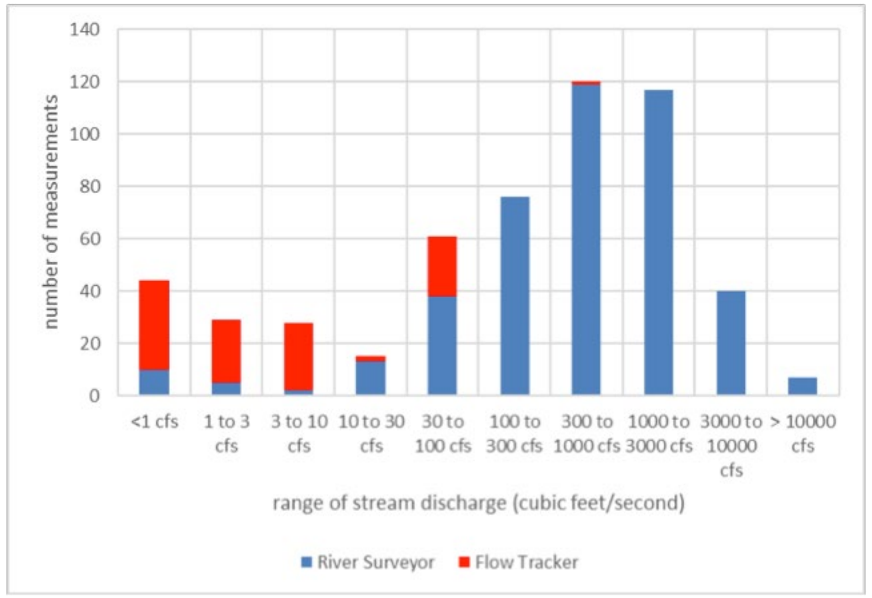


Figure 13. Distribution of stream discharge results as function of which technique was used to determine discharge rates throughout the stream study ending on June 30, 2016.

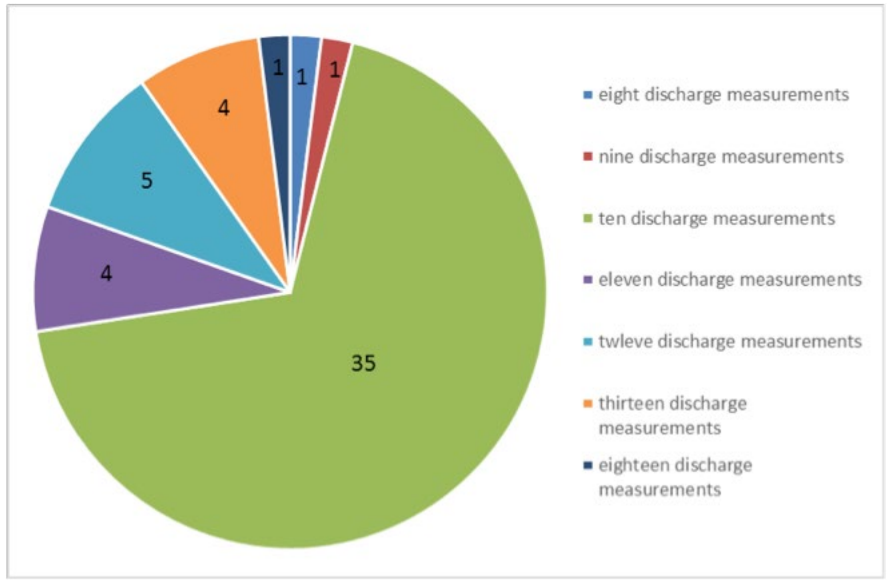


Figure 14. Distribution of sites by number of discharge measurements conducted at a site. Total of 541 values of discharge determined which about 10.61 measurement per stream site at the end of the stream study as of June 30, 2016.

Development of Rating Curves

Rating curves are developed by relating measurements of discharge and gage heights to each other (Chow et al, 1988). The rating curve is then used to convert records of water level (gage height) to flow rates (discharges). Rating curves need to be checked periodically to ensure the relationship between discharge and gage height has remained constant or maybe there is a new curve and associated equation. The change could be a result of changes in bed elevation by scouring of sediment or additional deposition (Chow et al., 1988). Ideally the number of observation pairs of discharge and gage height should be at least 15 and should be distributed uniformly within the range of measurable stream discharge values which for practical reasons will be below large to extreme flood events (Domeneghetti et al, 2012).

This study generated a set of 69 rating curves and associated equations that have been developed. When completing the regression relating discharge to gage height only simple regressions were considered: linear equation, power equation, exponential equation or logarithmic equation. Initial assumption for this study is the most familiar curve a linear equation (Figure 15), which.is the one that is best. Only, if exponential, logarithmic or power function result yields an over 50% reduction of $1-R^2$ was it included in results of this study. Power equation (Figure 16) is the most common alternative, ten times, that have yielded a reduction of $1-R^2$ by 50% or more relative to a linear function. Less frequently the exponential equation (Figure 17), seven times, yielded a reduction of $1-R^2$ by 50% or more relative to a linear function. Logarithmic function never meets this standard of reduction to be included in the set of equations with this study's set of equation results.

In the last year of the study a number of streams were measured during the extremely large discharges due to the March 8 to 11, 2016 deluge were included within the stream study. Many streams in the Shreveport area were measured for discharge during and shortly after the deluge that hit northern Louisiana March 8 to 11, 2016. There were five streams that had discharges over 10,000 cfs: Flat River at High Island 18,801 cfs on March 24, 2016; Twelve Mile Bayou near Dixie 18,304 cfs on March 25, 2016 and 16,340 cfs on March 9, 2016; Bayou Pierre at Powhatan 13,457 cfs on March 11, 2016; and Bodcau Bayou near Sarepta of 12,386 cfs on March 10, 2016; and one of which was over 100,000 cfs: Little River at Rochelle, LA on March 11, 2016 at 104,500 cfs as a result this deluge in northern Louisiana. The discharge of the Little River is similar to the previous record discharge of the Amite River on April 8, 1983 of 112,000 cfs (USGS, 2016).

In addition to the goal of the study to have at least 10 discharge-stage measurement pairs another goal is the have significant range of conditions measured from low flow to near flood conditions. This goal is defined by having observations of discharge for a range of stages, gage heights, that would include over 90% of the daily mean stages recorded between 2011 and 2015. By the end of this study seven streams: Bodcau Bayou near Sarpeta, Paw Bayou near Greenwood, Twelvemile Bayou near Dixie, Flat River at Shed Road near Bossier City, Red Chute at Dogwood Trail near Bossier City, Bayou Pierre at Powhatan, and Chauvin Bayou near Monroe meet this goal of range of stages. All of these streams are in northern Louisiana and experienced the March 2016 deluge. This still indicates there is clearly a need for continued measurements to capture both extreme high gage heights (flood events) after storms and extreme low flow events after significant droughts. With a focus of trying to follow up after major storms in northcentral and southern Louisiana. The greater range allows for the vast majority of gage height to discharge value conversions using the developed rating curves to be interpolations rather than extrapolations which tend to have greater uncertainties than discharge values determined from interpolations (Baldassarre and Montanari, 2009). Baldassarre and Montanari (2009) noted for their study of the Po River in Italy that rating curve errors from interpolation were 1.2% to 1.7% depending rating curve function used and extrapolation using the same function yielded rating curve errors of 11.5% to 13.8%. That is extrapolation errors were approximately 8 to 10 times larger than interpolation errors. These results are typical for uncertainty which is large for extrapolation of rating curve results especially for high flow-flood conditions. In fact, it is recommended not to extrapolate a rating curve beyond twice the discharge of the largest value used to create it (Giovanni BRACA, 2008). Only if pressed should an extrapolation of a rating curve over twice maximum discharge be done and then an estimate can be completed using the following techniques: areal comparison of peak-runoff rates; conveyance-slope-method; flood routing; and step-backwater method (Rantz, 1982). Of these methods Rantz (1982) recommends the conveyance-slope method which involves use of Manning equation. This would involve use of Manning's equation noted below:

Q = 1.49(R2/3S1/2)/n

where Q is discharge, A is area of cross-section, n is roughness coefficient, S slope of stream surface which approximately slope of the stream's bed, and R hydraulic radius which is A of cross-section divided by P surface distance cross stream at its bed (Chow et al., 1988) which could be approximated as the stream width at the top of the water surface. So, it is wise to minimize the possible conditions that are within the extrapolation range to yield a more useful and accurate rating curve. In summary, the past 3.5 year is a good start but should continue and should be similar to the USGS efforts elshwhere. The USGS has continued monitoring and modifying rating curves as needed for some of Louisiana for decades.

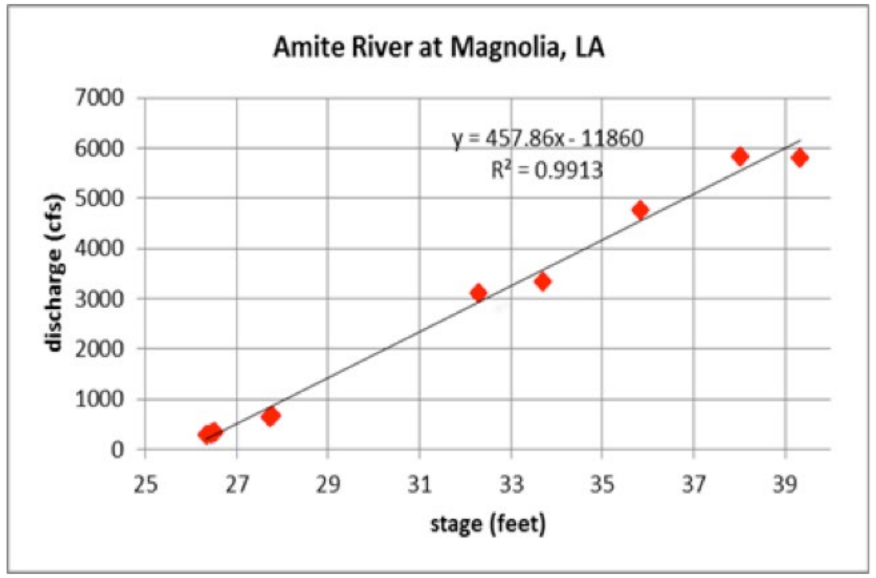


Figure 15. An example of a linear regression result for a rating curve relating stream discharge to gage heights, stage.

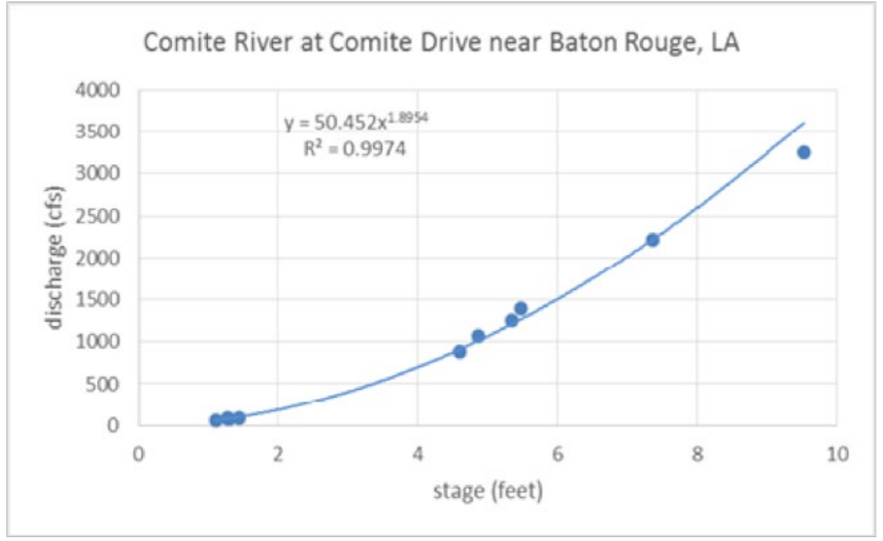


Figure 16. An example of a power regression result for a rating curve relating stream discharge to gage heights.

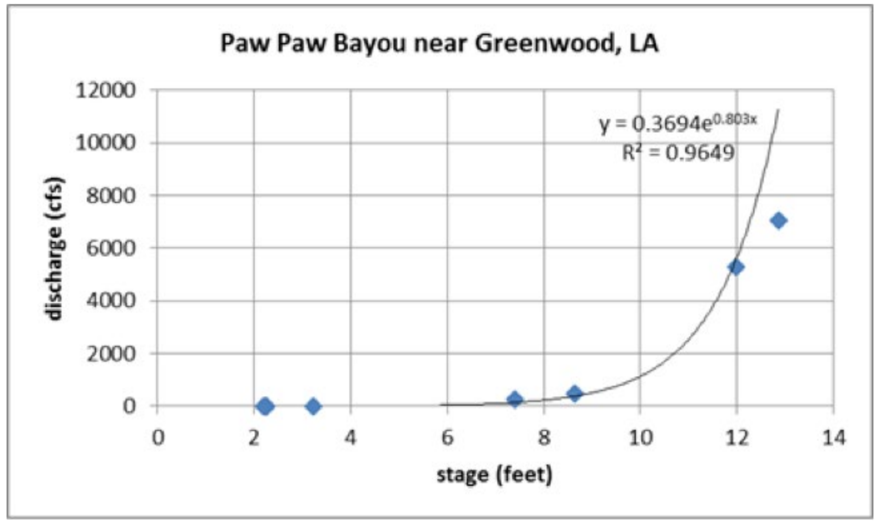


Figure 17. An example of an exponential regression result for a rating curve relating stream discharge to gage heights.

Acknowledgement

Thanks to Louisiana Department of Natural Resources for support of this study.

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Groundwater Quality of Upper Ponchatoula Aquifer in South Central St. Tammany Parish

Douglas Carlson and Marty Horn

Introduction

The Tuscaloosa Formation shale has been recently estimated to contain up to 50 billion barrels of petroleum. This shale is present throughout central to southeast Louisiana (Figure 1). To develop this vast reserve of petroleum, it could be necessary to drill hundreds of wells throughout Saint Tammany Parish. Helis Oil and Gas Company is the first company to drill for oil within the Tuscaloosa Formation shale in Saint Tammany Parish. Their well is located southeast of Abita Springs, Louisiana northeast of Mandeville, Louisiana and north of Lacombe, Louisiana (Figure 2). This well has been opposed by many within the community opposition (Rhoden, 2014). Opposition to Helis has also appeared in court as both St. Tammany Parish (Aguillard, 2014) and the Town of Abita Springs (Tulane, University, 2015a) have filed suits against Helis. However, these suits have been rejected initially (Anonymous, 2015). The possibility of either the parish or the Abita Springs winning their suits is ultimately in question. Since stopping the completion of Helis' horizontal well that well be hydraulically fractured is clearly in question it is best to understand what groundwater quality is prior to their drilling and hydraulic fracturing. The possible chemicals associated with hydraulic fracturing of the Helis well is the cause for citizen concern, because the groundwater source in this area, the Southern Hills aquifer, is a sole source aquifer according to the US EPA (US. EPA, no date) but is actually a sole source of any potable water in the area (Sargent, 2011). With these concerns in mind this baseline study has involved collection and analysis of water samples from wells that are generally within a four of miles of the Helis well.

Figure 1. Extent of Tuscaloosa Formation shale, (John et al, 1997).

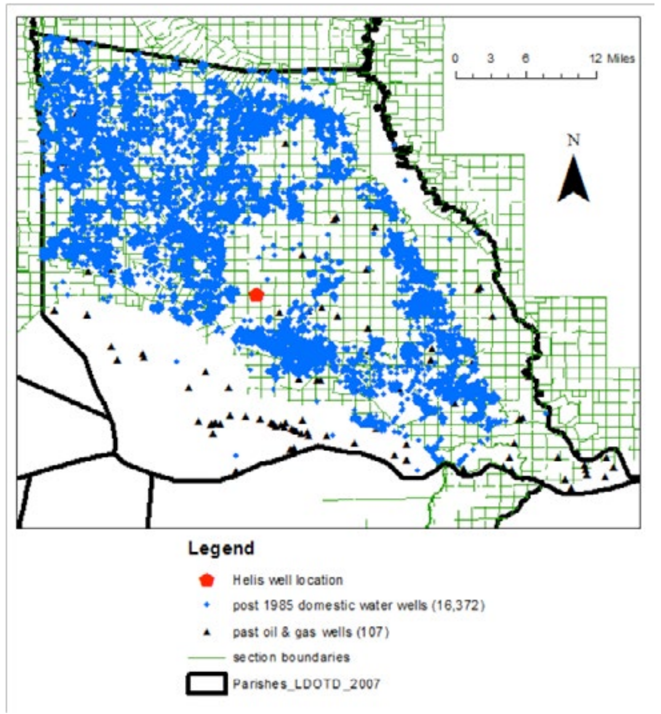

Figure 2. Helis well site in southern St. Tammany Parish compared to other oil and gas wells and domestic water wells (Louisiana Department of Natural Resources 2011, 2014, 2015a and 2015b).

Methods

For this study letters were sent to well owners asking permission to access their property to collect water samples. This involved a series of letter campaigns to well owners. Ultimately the study would involve collecting groundwater samples from 100 wells selected in south central Saint Tammany Parish (Figure 3). The vast majority, 96, wells were selected in this study through a letter campaigns inviting well owners to participate. Four are more distant as a result of invitation from well owner to well owner or others. The focus is within five miles of the Helis well and its expect lateral. All of these wells are known to have screen intervals within the Southern Hills Aquifer system.

After the permission is granted LGS staff scheduled and collected the samples. The water well was purged for approximately 20 minutes prior (approximately one casing and plumbing volume) to the collection of samples for later laboratory testing for natural gases, inorganic ions, gasoline range organics, diesel range organics and oil range organics. First sample collected was an unpreserved 250 ml-bottle of water analyzed for bromide chloride, fluoride, nitrate, nitrite, phosphate, and sulfate, and total dissolved solids (TDS). The second sample of water collected that was one preserved with nitric acid in a 50 ml-bottle later analyzed for: arsenic, barium, boron, cadmium, calcium, chromium, iron, magnesium, manganese, nickel, phosphorous, silicon, sodium, strontium, vanadium, and zinc. Then there was a litter bottle water collected for later analysis to determine concentration of oil range organics, and another liter collected for later analysis for diesel range organics. One 50 ml bottle which was persevered with hydrochloric acid was filled with water such that the bubble of the meniscus bulged over the top of the bottle to avoid any air space for determination of the concentration of gasoline range organics. Lastly two 40 ml bottles were collected for later analysis for head space analysis one for natural gases: methane, ethane, propane, butane, and pentane, and a second four BTEX compounds: benzene, toluene, ethylbenzene, and xylenes. All of these sample bottles were stored on ice and cooled to 4^{0} C in the field, and transferred to a refrigerator in the lab. The unpreserved 250 ml bottle was split into a 5 ml to be analyzed for anions and the remaining portion of the sample was analyzed for TDS. The 5 ml samples were filtered with a 0.45 µm filter so as to remove particles larger than 0.2-0.45 µm which could damage the equipment (Caslab.com., 2000). Analysis was completed using LGS's Dionex ICS-1000 Ion Chromatography System and EPA method 9056 A for determination of inorganic anions by ion chromatography (Caslab.com, 2000) for: bromide, chloride, fluoride, nitrate, nitrite, phosphate, and sulfate the concentration and TDS was determined by gravimetric analysis.

The TDS analysis involved measuring out a beaker's mass before adding a measured volume of water; heating the water for approximately two days in an oven set at 103-105°C and measuring mass of beaker and residual after heating This technique is described in standard methods 160.1 which has a practical range between 4 mg/l to 20000 mg/L (Caslab.com, 1971)

The preserved 50 ml bottle was analyzed by LSU Department of Wetland Biochemistry using their Varian (ICP-OES model MPX) Inductively Coupled Plasma-Optical Emission Spectrometer and the US EPA method 6010B (Caslab.com, 1996a). Prior to analysis samples will be solubilized or digested this study's samples may require digestion because the samples were only acidified in the field and not filter so as to yield the most conservative value of concentration of ions by including ions that are attached to colloidal particles which would be filter out by typical 0.45 um filters but still consumed by well owners unless they have filtered on their tap for drinking water use. Samples are nebulized and the resulting aerosol is transported to the plasma torch. This torch generates the element's emission spectra within the plasma generated. Then the resulting spectra is dispersed by a grating spectrometer and the intensities of the emission lines are monitored by photosensitive devices (Caslab.com, 1996a). The series of observed peaks are matched with sizes of peaks of standards included within the set of unknown samples to allow conversion of observed peak sizes into concentrations of an ion, this analysis is for arsenic, barium, boron, cadmium, calcium, chromium, iron, magnesium, manganese, nickel, phosphorous, silicon, sodium, strontium, vanadium, and zinc.

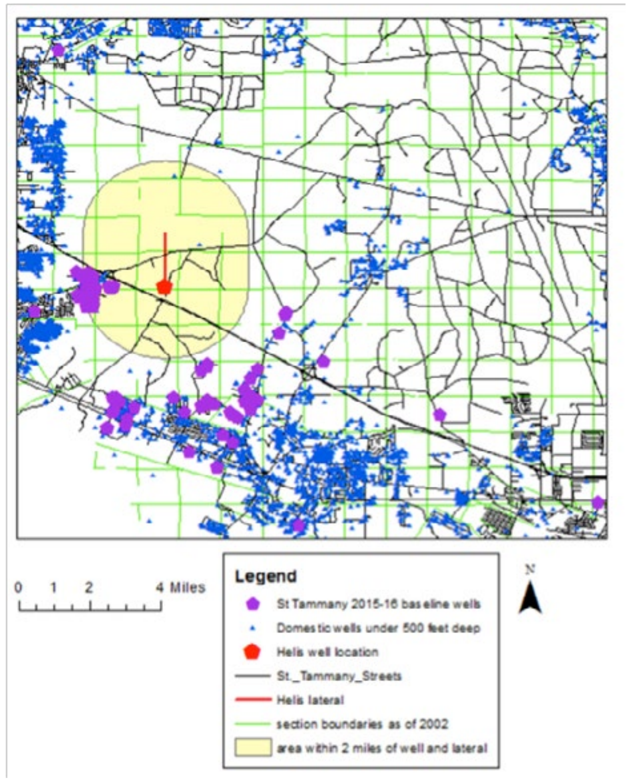

Figure 3. Location of wells sampled within the study are noted. Only more distant ones from Helis well are noted with a well number.

There were two samples collected from every well in the study for later analysis of head space, one is for natural gas content: methane, ethane, butane, propane, and pentane concentrations, the second was collected for head space analysis for BTEX: benzene, toluene, ethylbenzene, and xylenes. These two samples were collected in a 40 ml glass vial with 30-ml of water and 10 ml of headspace, and then stored on ice until analysis by LSU Wetland Biochemistry Lab using their SRI 8610 (gas chromatography) GC. This involves shaking the vial and then wait for an equilibrium to be established between water and headspace. Then a known volume of headspace is injected into the gas chromatograph capillary column where the target gases are separated to be later detected by a flame ionization detector. Reference gas samples are analyzed as well as the with knowns. This allows the conversion of instrument areas into concentrations values for the unknowns. These headspace concentrations can be converted into dissolved gas concentrations can be determined by using Henry's law constant for the target gas, which needs information about the gas concentration in headspace for a gas, bottle volume, sample temperature and volume of headspace injected (TeklabInc.com, no date).

Analysis for Gasoline Range Organics (GRO), Diesel Range Organics (DRO) and Oil Range Organics (ORO) was completed by the method 8015c which involves use of a variety of techniques involving gas chromatography (US. Environmental Protection Agency, 2007). The GRO compounds include a range of alkanes, single chain hydrocarbons with single bonds between carbon and hydrogen atoms within the molecule (McMurry, 1990) from C6 to C10. The DRO compounds include a range of alkanes from C10 to C28.

Results

In general, water quality is good to excellent. Usually the only problems are esthetic, that is the concentration of aluminum, iron, manganese are over U.S. EPA secondary standards for drinking water (Table 1). These are not a concern in terms of impacts on health due to consuming this water. Concentrations over the secondary standard will impact taste, odor and cause staining, and other esthetic problems. Concentrations of analytes that are often concerns from oil and gas produced and waste waters are low. Chloride concentrations are usually below 20 mg/L, far below the typical Louisiana brines which have chloride concentrations of approximately 63,700 mg/L. Similar results were observed for Total Dissolved Solids (TDS), bromide and sodium (Table 2). There were no detections of gasoline range organics (GRO), that is the concentrations were less than 0.1 mg/L for all 100 wells tests, which is far below the U.S. EPA primary drinking water standards for three BTEX compounds included among GRO compounds, ethylbenzene standard is 0.7 mg/L, toluene standard is 1 mg/L and total xylenes standard 10 mg/L. The BTEX compounds are just some of the compounds included within the set of GRO compounds.

Table 1. Summary of water quality observations for St. Tammany study. If there is no EPA standard there is no value entered in column of number over EPA drinking water standard. Note a ppm is a part per million and approximately mg/L for a concentration.

Analyte	Number over detection limit	Non-	mean	Std dev.	Number over EPA drinking water standard
Aluminum	86	14	0.135	0.177	65 to 15*
Arsenic	0	100	<0.04		See note below
Barium	65	35	0.072	0.082	0 (primary)
Benzene#	0	100	Less than 3.4		Probably 0 (primary)
Boron	98	2	0.057	0.038	
Bromide	97	3	0.051	0.033	
Cadmium	1	99	0.01		1 (primary)
Calcium	100	0	4.54	4.44	
Chloride	100	0	8.69	6.76	0 (secondary)
chromium	0	100	Less than 0.007		0 (primary)
Cobalt	1	99	0.008		
Copper	43	57	0.045	0.037	0 (primary)
Diesel Range Organics	2	98	0.67	0.70	
Ethane#	0	100	Less than 0.1		
Ethylbenzene#	0	100	Less than 5		0 (primary
Fluoride	100	0	0.349	0.245	0 (primary) 1 (secondary)
Gasoline Range Organics	0	100			
Iron	91	9	1,14	3,53	41
Lead	0	100	Less than 0.01	0	
Magnesium	98	2	1.79	2.12	
Manganese	100	0	0.048	0.060	32
Methane#	100	0	7.32	10.53	
Nickel	12	88	0.017	0.009	
Nitrate	99	1	0.424	0.245	0 (p

Table 1 continued

Nitrite	25	75	0.030	0.078	0 (primary)
Oil Range Organics	0	100	Less than 0.125		
Pentane#	0	100	Less than 0.1		
pH	52	0	7.78	0.40	
Phosphate	93	7	0.718	0.482	
Phosphorous	100	0	0.387	0.405	
Potassium	100	0	1.56	1.01	
Propane#	0	100	Less than 0.1		
Silicon	100	0	13.5	4.5	
Sodium	100	0	54.2	9.6	
Specific Conductance (µS/cm)	99	0	363	87	
Strontium	100	0	0.058	0.075	
Sulfate	100	0	3.90	3.91	0 (primary)
Toluene#	0	100	Less than 3.3	0	
Total Dissolved Solids	100	0	179	50	0 (primary)
Total Xylene#	0	100	Less than 10.8	0	
Zinc	99	1	0.431	0.509	0 (secondary)

# Indicates a headspace measurement. For these ppm is in air. Note 1 ppm in air is approximately 1parts per billion. All values for arsenic are below pre 2003 arsenic standard of 0.05 mg/L. As for current standard of 0.015 mg/L it is not sure. Primary standard for cadmium is 0.005. The * indicates range for standard is 0.05 to 0.2 ppm.

Table 2. A comparison of this study's observed water quality results compared to other deeper aquifer and Louisiana and nearby oil and gas field brines. All concentrations are in mg/L unless noted. A @ indicates values is mean from less than 20 observations.

Analyte	Upper Ponchatoula mean (mg/L)		Mean mg/L	
	This study	Other studies	Other aquifers	Louisiana brines
Aluminum	0.135	@<0.001		1.51
Arsenic	<0.04	@<0.002	@<0.,001	
Barium	0.072	@<0.09	@<0.0088	59.0
Boron	0.057	0.38	@0.25	29.5
Bromide	0.051	0.18		109
Cadmium	0.01	@<0.001	@<0.,001	2,600
Calcium	4.54	3.14	2.88	
Chloride	8.69	16.2	46.5	63,700
chromium	<0.007	@<0.01	@<0.01	
Cobalt	0.008	@<0.001	@<0.0018	
Copper	0.045	@<0.0025	@<0.0022	
Fluoride	0.349	0.4	0.31	
Iron	1,14	0.47	0.29	
Lead	<0.01	@<0.001	@<0.0017	
Magnesium	1.79	1.26	0.55	755
Manganese	0.048	0.067	0.06	1.57
Nitrate	0.424	0.54	0.20	
pH	7.78	7.56	8.34	
Phosphate	0.718	@1.33	@1.03	
Phosphorous	0.387	@0.12	@0.36	
Potassium	1.56	1.81	1.35	220
Silicon	13.5	14.0	16.5	18.8
Sodium	54.2	71.4	105	36,800
Specific Conductance (µS/cm)	363	455	405	
Strontium	0.058	0.058	@0.015	160
Sulfate	3.90	4.18	10.2	104
Total Dissolved Solids	179	220	299	103,000
Zinc	0.431	@<0.01	@<0.01	1.70

Sources of other data: for other aquifers: Cardwell et al. (1967); Nyman and Fayard (1978); Dial and Huff (1989); Rapp (1994); and Prakken (2007); sources for other Upper Ponchatoula includes: Cardwell et al. (1967); Nyman and Fayard (1978); Rapp (1994); Tollett et al (2003); Van Biersel et al. (2007a and 2007b); and Prakken, (2007); and sources for Louisiana and nearby brines: Collins (1970); Carpenter et al. (1974); Land et al. (1988); Land and McPhearson (1989); and Losh et al (2002).

The distribution of concentrations for most of the ions is not a normal distribution such is the case for sodium (Figure 4). Another variant of normal distribution is a log normal distribution (Figure 5) such is the case for methane gas concentrations within Upper Ponchatoula aquiferr. Many of the distribution are positively skewed with many low concentrations and a few that are far higher (Figure 6). Among the skewed distribution are ones that are bimodal with one cluster of concentrations that is lower and usual a smaller cluster of concentrations which are higher (Figure 7).

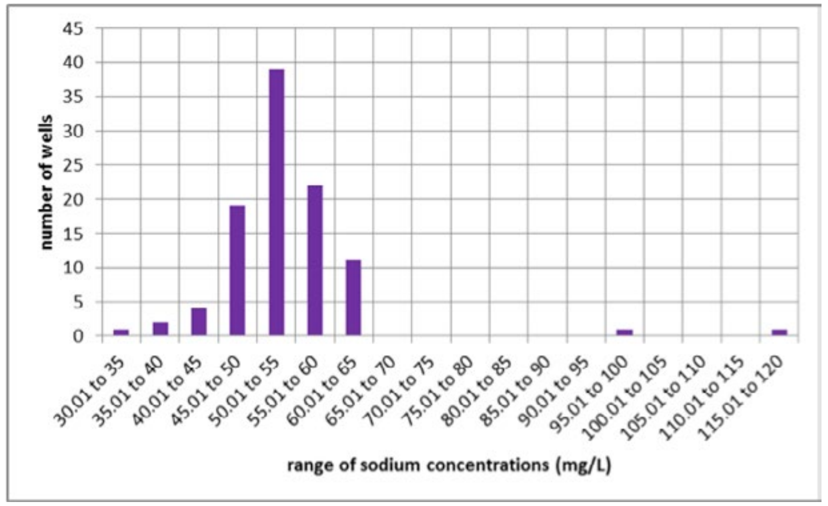

Figure 4. An example of approximately normal distribution is the distribution of sodium concentration among the 100 wells sampled in this study.

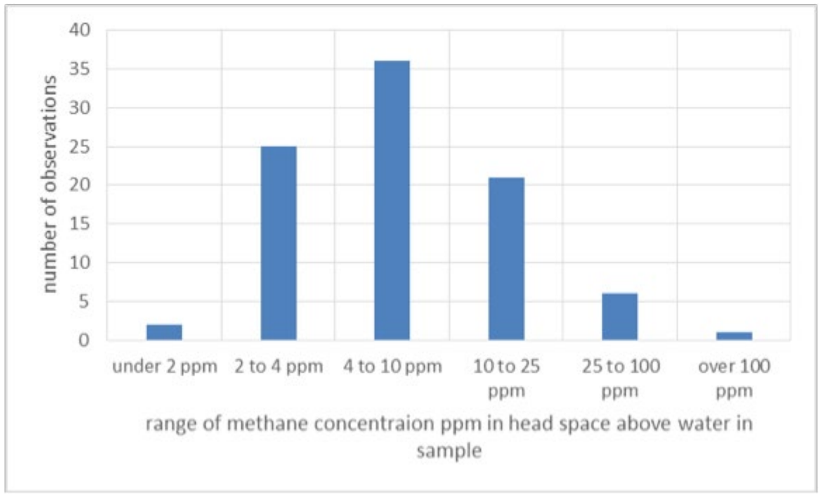

Figure 5. An example of approximately log normal distribution is the distribution of methane concentrations for St.Tammany groundwater samples.

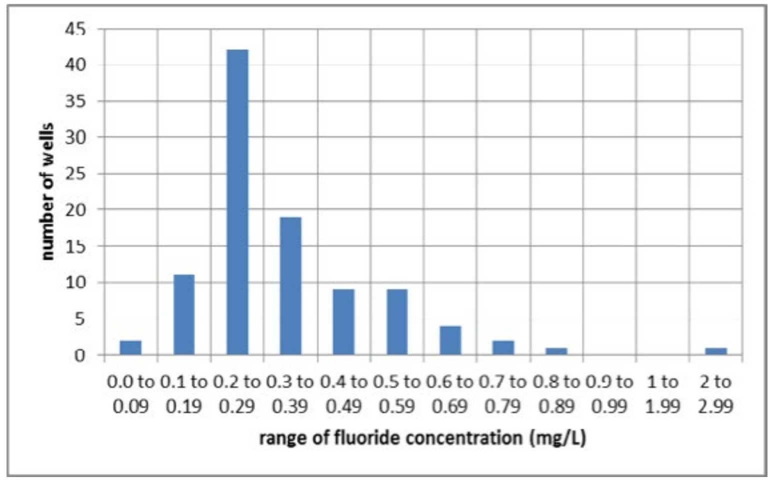

Figure 6. An example of a skewed distribution is the distribution of fluoride concentration among the 100 wells sampled in this study.

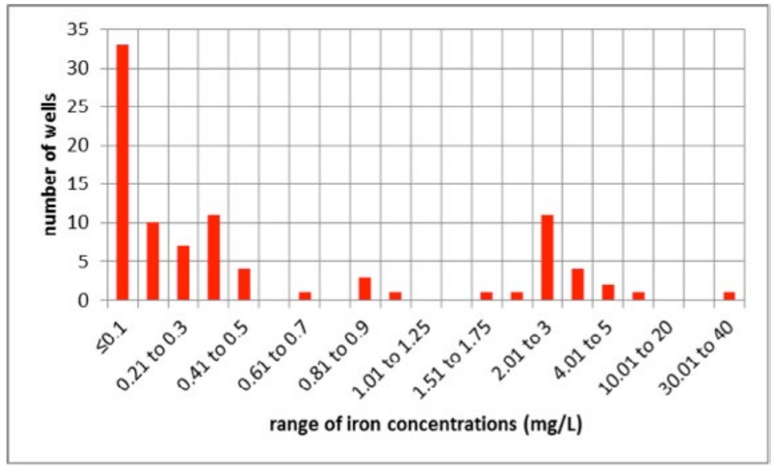

Figure 7. An example of bimodal distribution is the distribution of iron concentration among the 100 wells sampled in this study.

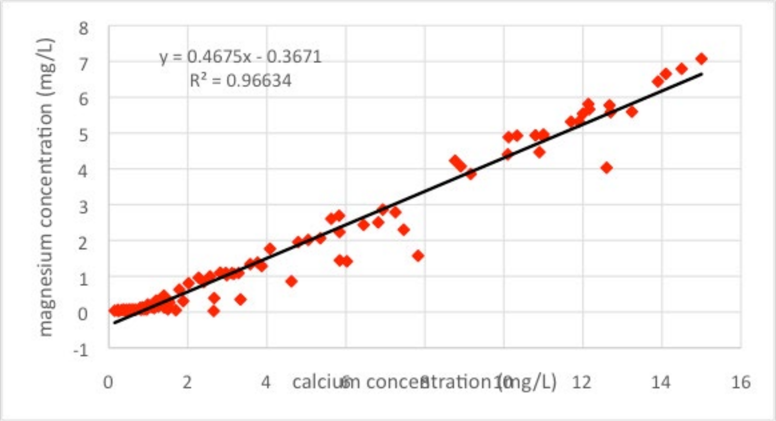

Figure 8. Strong correlation between calcium and magnesium concentrations for St. Tammany Parish samples of Upper Ponchatoula groundwater.

Some the analytes are closely related to each other in concentrations. Two double charged cations, calcium and magnesium, have a very strong correlation (Figure 8). Another strong correlation with an R2 of 0.9479 is between calcium and strontium another double charged cation. All they atoms, calcium, magnesium, and strontium are interchangeable with carbonate molecules within carbonate molecules/crystals such as limestone, dolomite, or aragonite (Tucker and Wright, 1990). Usually correlations are strong if the square of the correlation of coefficient is over 0.9 (references).

For many of the ions there is a pattern visible when concentrations are mapped that concentrations are typically higher for wells in the subdivision that is approximately 1.5 to 2 miles west of the Helis well than for wells south and southeast of the Helis (Figure 9). This appears to be the case for: barium, bromide, calcium, chloride, copper, iron, magnesium, manganese, nitrate, phosphorous, potassium, silicon, strontium sulfate, TDS, and zinc. The reserve is true for only six ions: aluminum, boron, fluoride, methane, phosphate and sodium (Figure 10, and Table 3). Many of these differences are statistically significant (Table 4). In general, when comparing two sets of data if the confidence of the difference is over 95%, p value is under 0.05, the difference is considered statistically significant (Kirk, 1990; and Canover, 1999). Because data sets are not normally distributed, bell shape curve, it is necessary when comparing two sets of data to use a non-parametric test such as Median or Mann Whitney Ranks (Canover, 1999; and Sprent and Smeeton, 2007). There are a number of analytes that appear to have higher concentrations in the northern half of the western subdivision than in the southern portion of this subdivision (Figure 11). The analytes that have higher concentrations within northern portion of the western subdivision are aluminum, barium, bromide, calcium, chloride, copper iron, magnesium, manganese, methane, nitrate, phosphorous, potassium, sodium, strontium and TDS (Table 5). Some of these differences are statistically significant (Table 6). The is one example where concentration of an ion is lower in the northern half of the western subdivision than in southern half of that subdivision is phosphate (Figure 12).

Table 3. A comparison of concentrations for wells in subdivision west of Helis well compared to wells south and southeast of Helis well.

Analyte	Wells south & southeast of Helis well			Wells in subdivision west of Helis well		
	Number	Mean	Std dev.	Number	Mean	Std dev.
Aluminum	43	0.142	0.196	43	0.136	0.159
Barium	27	0.040	0.031	**38**	**0.095**	**0.099**
Boron	47	0.057	0.032	42	0.051	0.032
Bromide	47	0.043	0.024	45	0.063	0.039
Calcium	50	3.15	2.34	**45**	**6.44**	**5.59**
Chloride	50	7.19	5.26	45	10.86	7.69
Copper	23	0.042	0.040	20	0.048	0.034
Fluoride	50	0.431	0.310	45	0.271	0.069
Iron	45	0.274	0.293	**45**	**2.019**	**4.881**
	50	1.03	0.97	**45**	**2.75**	**2.65**
Manganese	50	0.029	0.019	**45**	**0.071**	**0.082**
Methane	47	7.86	7.56	39	6.59	13.80
Nitrate	50	0.417	0.102	44	0.441	0.349
Phosphate	50	0.968	0.394	38	0.542	0.344
	50	0.342	0.117	45	0.452	0.588
Potassium	50	1.31	0.64	45	1.93	1.24
Silicon	50	12.77	4.82	34	14.01	3.77
Sodium	50	56.74	10.37	45	50.83	4.00
Strontium	50	0.034	0.023	**45**	**0.089**	**0.101**
Sulfate	50	3.23	3.76	45	4.30	4.00
TDS	50	174.18	46.10	45	187.98	48.35
Zinc	50	0.428	0.325	44	0.466	0.677

Note there three wells owned by St. Tammany Parish and two distant wells not included in comparisons.

Table 4. The significance of the differences between average concentrations for wells in subdivision west of Helis well compared to wells south and southeast of Helis well. A statistically significant difference by convention has a p value less than 0.05, which indicates the results have less than 5% chance of being from the same statistical set of observations. These significant differences are highlighted in red.

Analyte	Median Test		Mann-Whitney Ranks	
	p value	Significant difference?	p value	Significant difference?
Aluminum	0.824	no	0.3383	no
Barium	0.0355	yes	0.01948	yes
Boron	0.248	no	0.1527	no
Bromide	0.701	no	0.09854	no
Calcium	0.755	no	0.09281	no
Chloride	0.755	no	0.1773	no
Copper	0.439	no	0.4577	no
Fluoride	3.06 x 10^{-5}	yes	5.266 x 10^{-6}	yes
Iron	0.675	no	0.3791	no
Magnesium	0.755	no	0.1238	no
Manganese	0.0185	yes	0.02659	yes
Methane	0.196	no	6.89 x 10^{-3}	yes
Nitrate	0.537	no	0.4024	no
Phosphate	1.33 x 10^{-3}	Yes	1.464 x 10^{-5}	yes
Phosphorous	0.771	No	0.6175	no
Potassium	0.755	No	0.04339	yes
Silicon	0.0323	Yes	0.02127	yes
Sodium	3.40 x 10^{-4}	Yes	4.568 x 10^{-6}	yes
Strontium	0.906	No	0.1026	no
Sulfate	0.471	No	0.03009	yes
TDS	0.259	No	0.0640	no
Zinc	0.537	no	0.2819	no

Table 5. A comparison of concentrations for wells within Pineview Heights portion of the subdivision west of Helis well compared to wells within Pineview Heights Farm and V& L Acres Estates portion of subdivision west of Helis well.

Analyte	Wells in Pineview Heights Farm and V & L Estates			Wells in Pineview Heights		
	Number	Mean	Std dev.	Number	Mean	Std dev.
Aluminum	16	0.103	0.102	25	0.158	0.186
Barium	15	0.049	0.052	**23**	**0.125**	**0.111**
Boron	19	0.059	0.037	23	0.045	0.026
Bromide	19	0.045	0.035	26	0.075	0.038
Calcium	19	3.34	4.23	**26**	**8.70**	**5.42**
Chloride	19	7.49	7.04	26	13.33	7.30
Copper	9	0.043	0.027	11	0.053	0.039
Fluoride	19	0.290	0.083	26	0.257	0.054
Iron	19	0.645	1.299	**26**	**3.02**	**6.18**
	19	1.21	1.80	**26**	**3.88**	**2.63**
Manganese	19	0.071	0.063	26	0.071	0.095
Methane	18	2.72	1.47	**21**	**9.90**	**18.30**
Nitrate	18	0.362	0.462	26	0.496	0.251
Phosphate	19	0.720	0.266	19	0.364	0.324
	19	0.372	0.236	26	0.511	0.748
Potassium	19	1.39	1.12	26	2.33	1.19
Silicon	19	15.29	4.24	26	13.08	3.15
Sodium	19	50.67	3.53	26	50.96	4.37
Strontium	19	0.071	0.137	26	0.102	0.063
Sulfate	**19**	**6.62**	**3.35**	26	2.61	3.62
TDS	19	163.11	19.96	26	206.15	54.99
Zinc	19	0.498	0.952	25	0.443	0.375

Table 6. The significance of the differences between average concentrations for wells in Pineview Heights subdivision compared to wells south of it in Pineview Heights Farms and V & L Acres subdivisions. A statistically significant difference by convention has a p value less than 0.05, which indicates the results have less than 5% chance of being from the same statistical set of observations. These significant differences are highlighted in red.

	Median Test		Mann-Whitney Ranks	
Analyte	p value	Significant difference?	p value	Significant difference?
Aluminum	0.0831	no	0.1244	no
Barium	6.94 x 10^{-3}	yes	5.37 x 10^{-3}	yes
Boron	0.500	no	0.8393	no
Bromide	0.0514	no	0.01439	yes
Calcium	0.0102	yes	8.27 x 10^{-4}	yes
Chloride	3.27 x 10^{-3}	yes	0.04435	yes
Copper	1.000	no	0,6214	no
Fluoride	0.795	no	0.2651	no
Iron	0.0514	no	0.01075	yes
Magnesium	3.27 x 10^{-3}	yes	7.30 x 10^{-4}	yes
Manganese	0.635	no	0.8451	no
Methane	0.0781	no	0.01664	yes
Nitrate	0.0155	yes	1.99 x 10^{-3}	yes
Phosphate	8.56 x 10^{-3}	yes	1.39 x 10^{-3}	yes
Phosphorous	0.899	no	0.4081	no
Potassium	0.0102	yes	0.0185	yes
Silicon	0.181	no	0.1181	no
Sodium	0.465	no	0.3952	no
Strontium	0.0102	yes	9.73 x 10^{-3}	yes
Sulfate	0.0102	yes	1.97 x 10^{-4}	yes
TDS	1.35 x 10^{-3}	yes	5.92 x 10^{-4}	yes
Zinc	0.500	no	0.207	no

In summary although there are differences in water quality throughout the study region most of the water is of good to excellent quality. Usually only EPA drinking water standards exceeded are those that are secondary which are not a health concern. The ions over EPA secondary standards usually are aluminum, iron and manganese (Table 1). For heavy metals and organic analytes almost all measured values are below the detection limit and higher primary EPA drinking water standard. Since the completion of data collection for this study Helis has decided not to drill and hydraulic fracture a horizontal well due to combination of low prices and lower carbon concentration insitu (Rhoden, 2016). However, technological, economic, regulatory, and political environment for of oil production can change through time and this study is still worthwhile for understanding the general water quality of the Upper Ponchatoula Aquifer in south-central St. Tammany Parish.

Acknowledgements

We want to thank St. Tammany Government for their support and access to several of their wells included within this study. We also want to thank all the home owners that grant permission to access their wells. Without there will involvement this study would not be possible as a result very few public supply wells are present within the study area.

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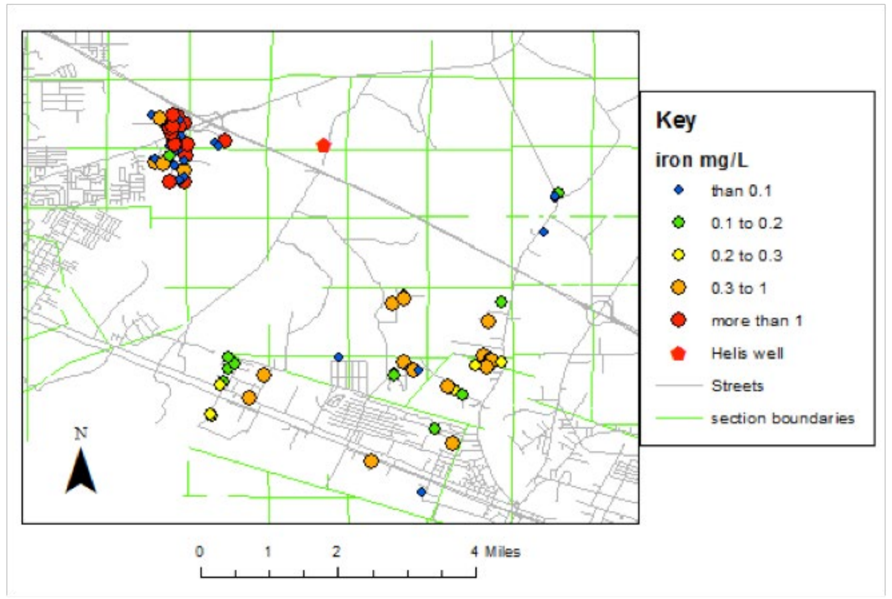

Figure 9. An example where concentrations of an ion are higher for samples in subdivision west of the Helis well compared to samples south and south-east of the Helis well. Iron concentrations throughout south central Saint Tammany Parish.

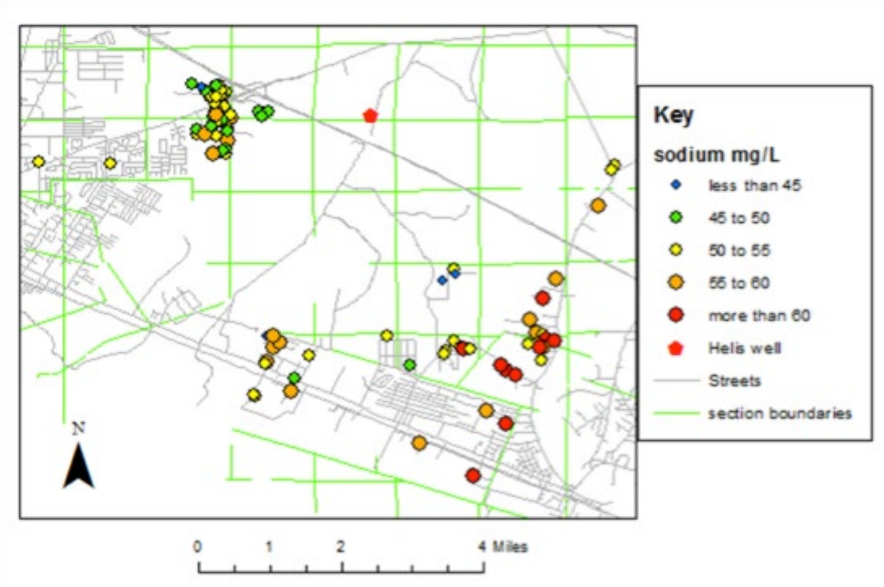

Figure 10. An example where concentrations of an ion are higher for samples south and south-east of the Helis well compared to samples in subdivision west of the Helis well. Sodium concentrations throughout south central Saint Tammany Parish.

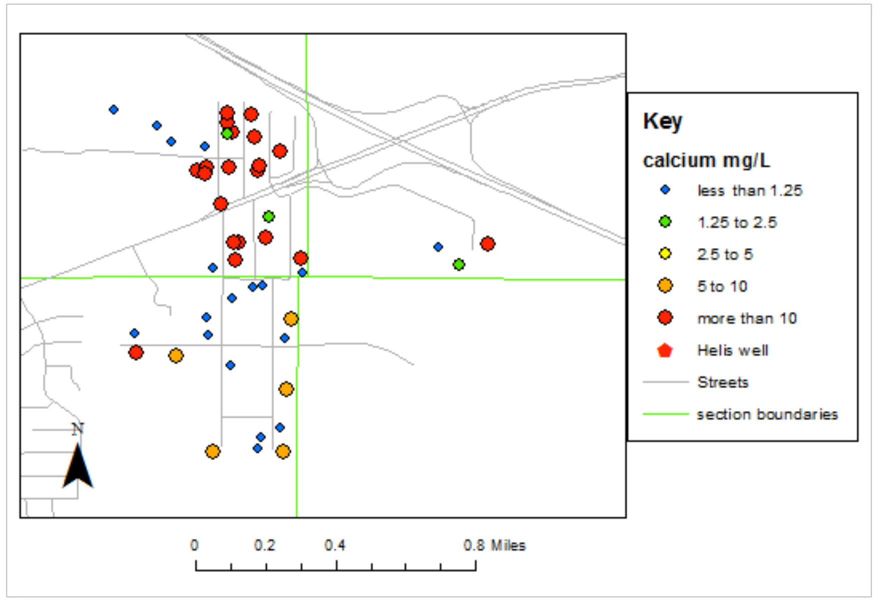

Figure 11. An example where concentrations of an ion are higher for samples in northern half of the subdivision west of the Helis well than those in the southern portion of the that subdivision. Calcium concentrations for the subdivision west of Helis well.

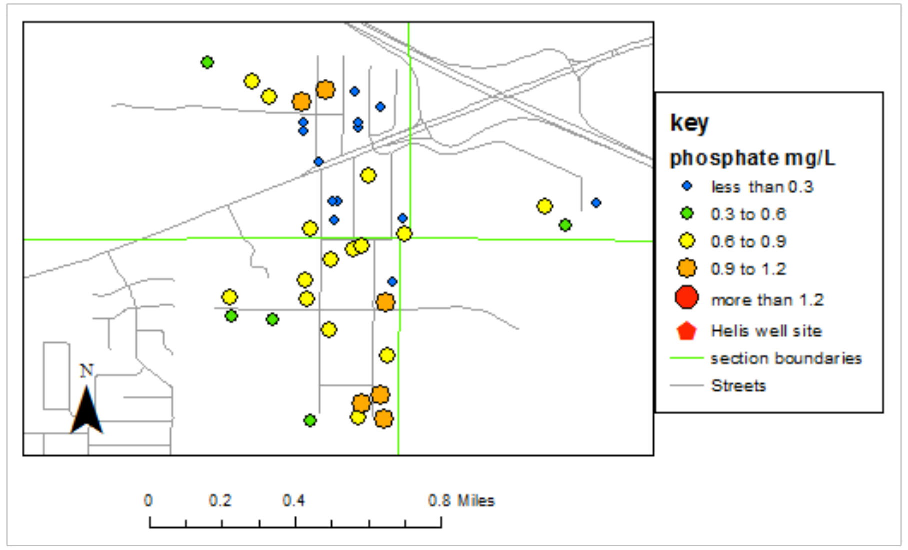

Figure 12. Distribution of phosphate concentrations throughout subdivision west of Helis well.

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The Impact Of Great Deluges Of 2016 And Other Events On Three Louisiana Oxbow Lakes: False River, Lake Bruin, And Lake Providence

Douglas Carlson

Introduction

Oxbow lakes are a common feature within alluvial flood plains in which a meandering stream is located (Miall, 1992; and 2010). These lakes are formed when a stream changes its path often during a flood by cutting off a meander bend (Allen, 1992). The size of oxbow lakes is related to the discharge rate of a stream (Allen, 1992). The Mississippi River has a series of oxbows lakes near the river in northeastern Louisiana (Table 1 and Figure 1), which cover usually 1000 to 3200 acres. These lakes lie within the Mississippi River Alluvium which is generally 75 to 200 feet thick. It tends to thicken towards the river and towards the south (Whitfield, 1975), see Figure 2. This alluvium unit tends to coarsen downwards (Carlson, 2006; and Whitfield, 1975) where the top 15 to 75 feet are clay (Figure 3). Bottoms of oxbow lakes are muddy because after the oxbow lakes is formed all sediment will settle out of the still water yielding a bottom that is muddy (Friedman and Sanders, 1978).

Table 1 .Characteristics of Mississippi River oxbow lakes in Louisiana information sources are: Calhoun and Mc Govern (2008); Ewing, (2009); Ewing et al (2011 and 2014); Walley (2013 and 2014); Daniel (2014 and 2015); Moses et al. (2015); Kesel and McGraw (2015): topozone.com (no date); and mdwfp.com (no date)

Lakes name	Parish it is in	Size in acres		Pool stage (feet)	Depth (feet)	
		Lake	Watershed		Avg.	Max.
Gassoway Lake	East Carroll	800	NA	105	NA	6.5
Lake Providence	East Carroll	1380	11000	90	12	31
Eagle Lake	Madison	4700	NA	76	~12	27
Lake St. Joseph	Madison	1000	14000	66	2.5	6
Lake Bruin	Madison	.2842	13700	62	22.9	NA
Lake St. John	Concordia	2100	9470	54.3	12	28
Lake Concordia	Concordia	1100	5702	48.5	20	50
Cocodrie Lake	Concordia	742	12194	34	6	NA
Raccouurci Old River	Pointe Coupee	4900	NIWBL	26	25	75
False River	Pointe Coupee	3212	34453	16	21	65

NTWBL means watershed is not isolated by levee system constructed along Mississippi River so this site has the Mississippi River's watershed. NA means information is not available from the sources used for this table.

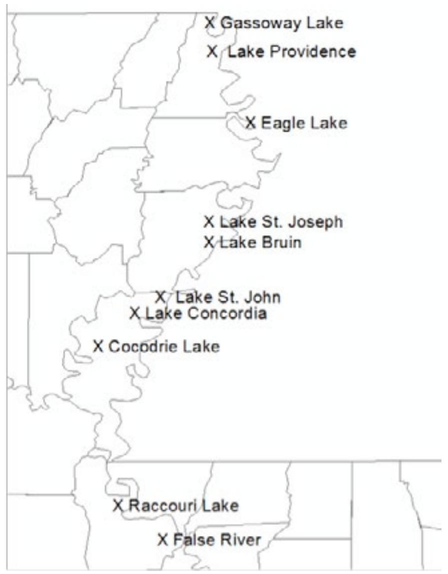

Figure 1. Location of oxbow lakes within the Mississippi River flood plain.

These lakes because of their size and location could be significant sources of water. The main use of water in northeast Louisiana is for irrigation water for crops. This demand has increased over the last fifty (figure 4) years as acres of irrigated land has increase increased (figure 5). These lakes are sources water for irrigation and are used for a variety of recreational activities (Table 2). These recreational activities are significant contribution to the local economy. The mix of uses is partly a function of the lakes depth (Table 1) and the portion of the shoreline that is developed (Table 3).

Because these lakes are important sources of water and economic activity three of these lakes have been monitored by USGS (2016) in the past. Lake Providence has a record of discharge rate from its spillway recorded for 605 days between February 2,1 985 and September 30, 1986. Lake Saint John has a record of gage heights measured for 4,347 days between March 20, 2002 and February 17, 2014 (Figure 6). The longest record is for Lake Bruin of 4,735 days between February 13, 1959 and September 30, 1986 (USGS, 2016d). However, these records tend to be short and sometimes incomplete. With this mind there was need to monitor these lakes, which is the reason behind why the Louisiana Geological Survey (LGS) included monitoring several of these oxbow lakes within a general stream study over the past 3.5 years.

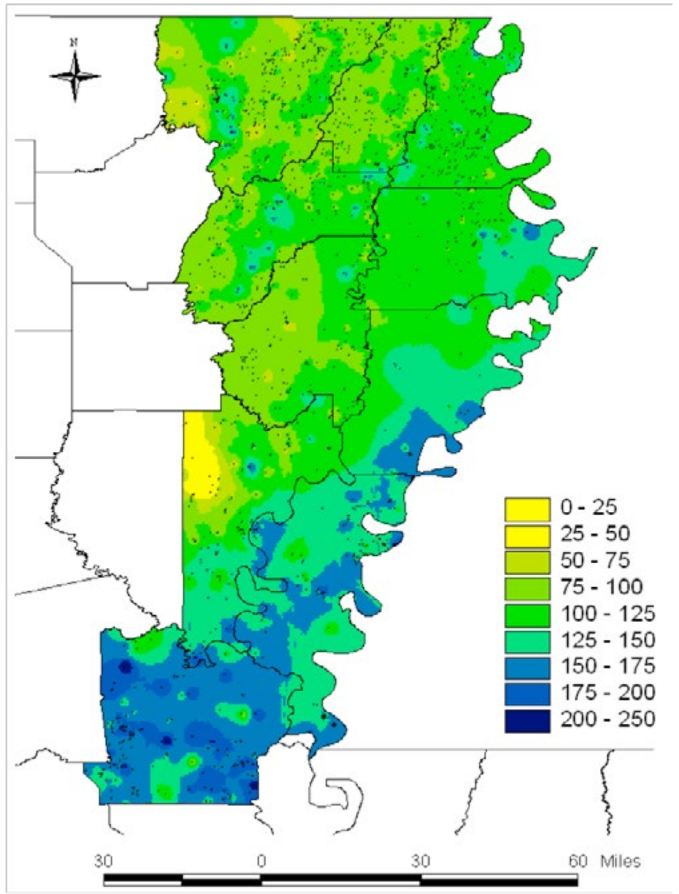

Figure 2. Thickness of Mississippi River Alluvium in northeastern Louisiana (Carlson, 2006, figure 10)

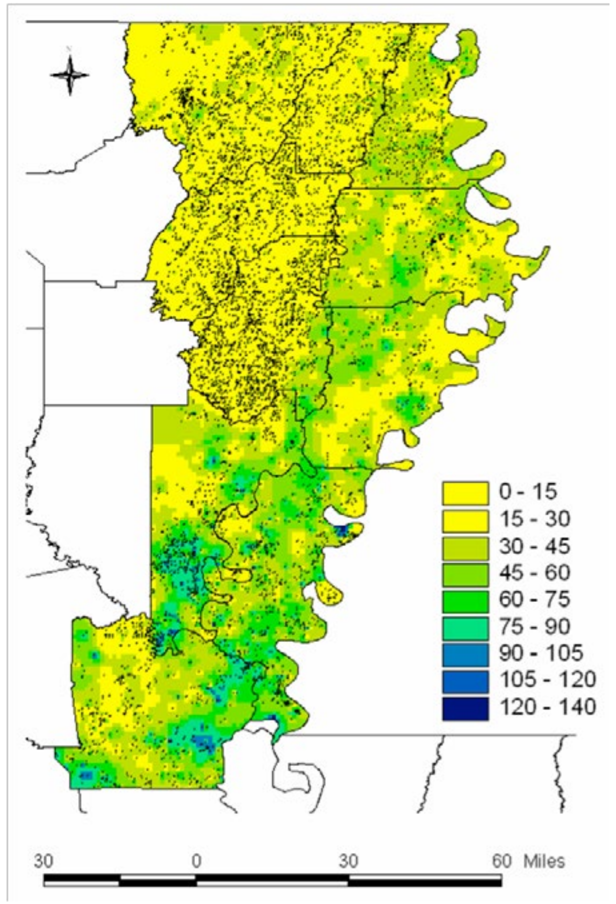

Figure 3. Thickness of the top clay within the Mississippi River Alluvium in northeastern Louisiana (Carlson, 2006, figure 4)

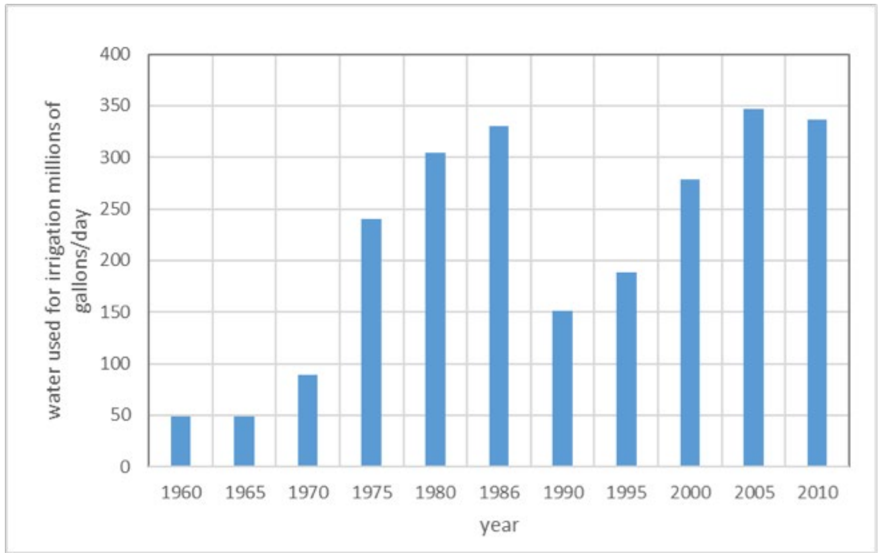

Figure 4. Average daily use of water for irrigation for 10 northeast Louisiana parishes: Avoyelles, Catahoula, Concordia, East Carroll, Franklin, Madison, Morehouse, Richland, Tensas, and West Carroll, sources are: Snider and Forbes (1961), Bieber and Forbes (1966), Dial (1970), Cardwell and Walter (1979), Walter (1982), Lurry (1987), Lovelace (1991), Lovelace and Johnson (1996), and Sargent (2002, 2007, and 2012).

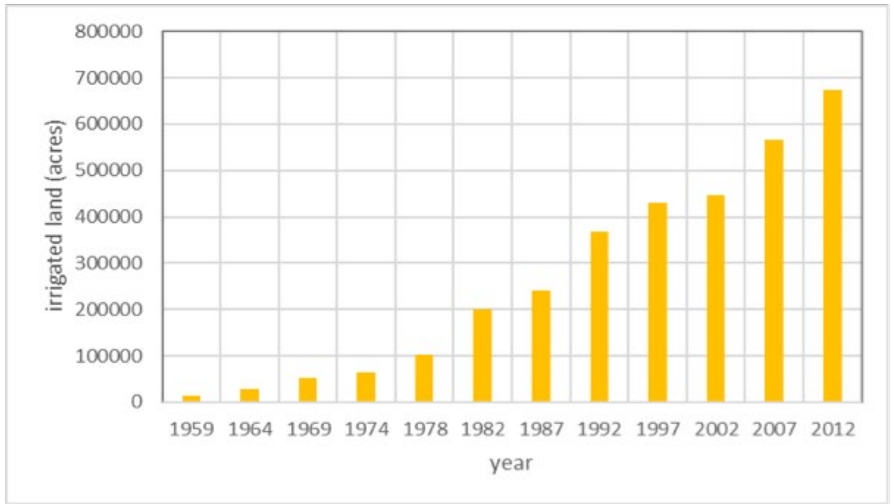

Figure 5. Area of irrigation for 10 northeast Louisiana parishes: Avoyelles, Catahoula, Concordia, East Carroll, Franklin, Madison, Morehouse, Richland, Tensas, and West Carroll, sources is: US Department of Agriculture (2016) ,

Table 2. Uses for various oxbow lakes in the Mississippi River flood plain (Ewing, 2009; Ewing et al, 2011 and 2014; Walley, 2013 and 2014; Daniel, 2014 and 2015; Moses et al., 2015; mdwfp.com, no date)

Lakes name	Irrigation water	Recreational uses:					
		Boating	Fishing	Hunting	Scuba Diving	Skiing	Swimming
Lake Providence	yes residential		yes	no	no	yes	no
Eagle Lake		yes	yes	yes			
Lake St. Joseph	yes	NR.	yes	yes		NR	no
Lake Bruin#	yes	yes	yes	little	no	yes	yes
Lake St. John	yes	yes	yes	minimal	minimal	yes	yes
Lake Concordia	unknown	yes	yes	limited	no	yes	yes
Cocodrie Lake	yes	yes	yes	minimal		yes	yes
Raccouurci Old River	no	yes	yes	yes	no	yes	yes
False River		yes	yes	yes		yes	yes

Sources did not commit on all of these uses, where a commit is not present a blank is left above., and NR means not recommended. The # indicates that this lake is a source for three public water supply systems: Newellton Water System, the Lake, Bruin Water System, and the Tensas Water system.

Table 3. Shoreline length and development for oxbow lakes along the Mississippi River in northeastern Louisiana (Ewing et al, 2011 and 2014; Walley, 2013 and 2014; Daniel, 2014 and 2015; and Moses et al., 2015).

Lake name	Shoreline length	Portion of shoreline that is developed:
Lake Providence	12 miles	Much of it is residential and a few businesses
Eagle Lake	20 miles	
Lake St. Joseph	18 miles	A few camps and residence mainly cropland
Lake Bruin	9.2 miles	Completely except where state park is located
Lake St. John	16 miles	No information
Lake Concordia	17.8 miles	60% residences 40% agricultural cropland & pasture
Cocodrie Lake#	49.5	Moderate development with approximately 600 houses, camps and businesses
Raccouurci	31 miles	Less than 5% is developed otherwise farms and forest
False River	22 miles	90-95% permanent and seasonal residences

The # indicates for shoreline value is a combination of Cocodrie Lake and Black Lake

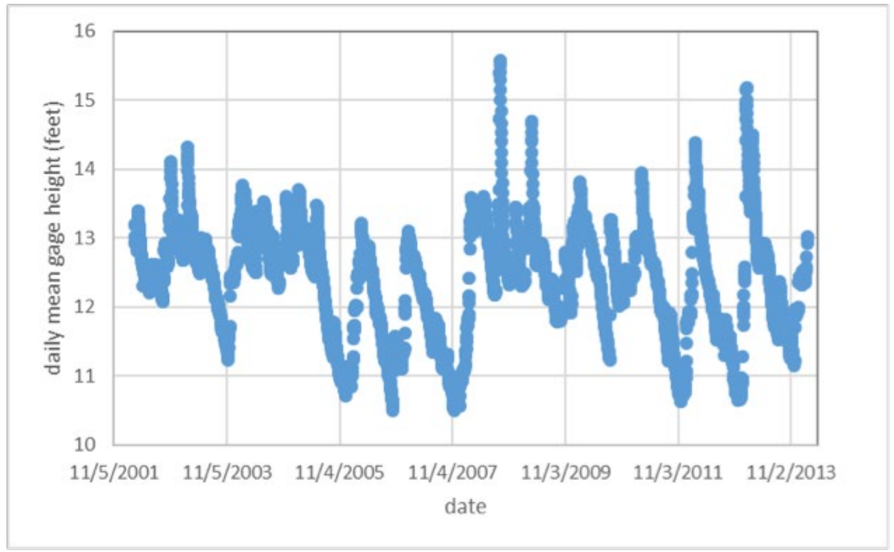

Figure 6. Daily mean gage heights for Lake St. John between 2002 and 2014 (USGS, 2016d).

Methods

Louisiana Geological Survey (LGS) measured gage height with a pressure transducer at five different sites over the past 3.5 years. These gaging sites at the following locations (Table 4, and Figure 7): The pressure transducers directly measure pressure from air and water column above. This pressure is converted into a column of water above the pressure transducer using the following equation:

$$P_m = p_w g h_w + P_a$$

where P_m is measured pressure N/m^2, P_a is atmospheric pressure N/m^2, p_w is density of water kg/m^3, h_w is height of water column above pressure transducer m, and g is acceleration of gravity kgm/s^2. The h_w is related to a reference point on a dock or other structure nearby the pressure transducer housing structure is attached to for the gage height. Lastly this gage height is converted to mean sea level (MSL) by surveying gage reference point relative to a known benchmark or other point which has a known value of elevation relative to MSL.

Once a meter at a site is setup it will record measurements of water level every 15 minutes. However, until May of 2014 the gage heights measured were relative to a local reference and not absolute from mean sea level. On May of 2014 the four sites present at the time were surveyed to yield absolute positions of water levels relative to sea level rather than just a local gage height only. Later elevations were back calculated for earlier measurements of gage heights prior to the surveying for levels relative to mean sea level. The results are that of gage height and elevations were determined over periods of time ranging from approximately 6 to 37 months (Table 4).

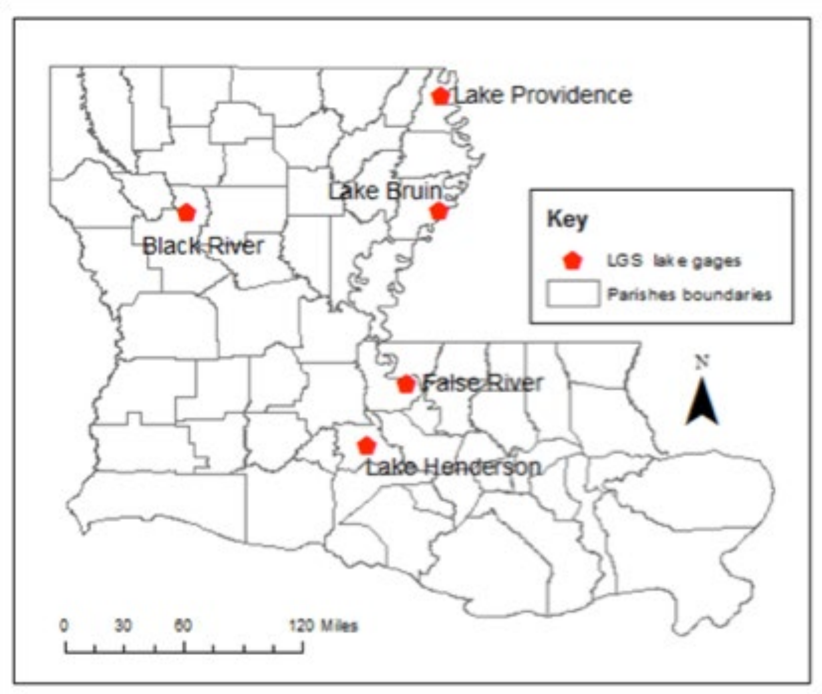

Figure 7. Location of new replacement sites for LGS stream gaging sites.

Table 4. The location of each of the LGS gage sites in degrees and period of record

Station	Longitude	Latitude	starting date	last date
Black Lake, Red River Parish	-93.95947	31.95977	10/28/2013	2/10/2016
False River, Pointe Coupee Parish	-91.43359	30.69246	8/22/2013	9/27/2016
Henderson Swamp Control Structure, St. Martin Parish	-91.72489	30.25162	8/16/2013	5/29/2015
Lake Bruin, Tensas Parish	-91.20175	31.96123	10/28/2013	6/7/2016
Lake Providence, East Carroll Parish	-91.19274	31.81294	12/17/2015	6/8/2016

Results

At the present time there has been between 6 and 37 months of data collected from each of the five LGS monitoring sites. Two sites have been dropped Lake Henderson site and Black Lake site. These two sites were longer monitored due to the equipment being damage multiple times. The Black Lake site was flooded/damaged the past two Marchs in 2015 and 2016. The gage at Lake Henderson was first vandalized sometime between December 24, 2013 and April 26, 2014 then flooded later. The three sites measuring water level for Mississippi River oxbow lakes: False River, Lake Bruin, and Lake Providence are still in operation

False River

False River is an isolated oxbow lake that lies approximately 3 miles from the Mississippi River. Prior to the LGS monitoring of the False River there were measurements occasionally from June 23, 1965 to October 8, 2015 of the False River (Van Biersel, 2015). However, the number of days with a single value is 5400 out of the 18369 days, approximately 29%. The average water surface elevation is 15.93 + 0.96 feet as base on NGVD 1929 elevations. For this observation set the maximum elevation is 21.8 feet and minimum elevation is 13.5 feet. The gage heights reported from LGS work are related to NGVD 1988 elevation, which yields a value 1.2 feet lower than ones reported for NGVD 1929 elevations as for past gage heights in (Figure 8). LGS measurement include a range of water level (Figure 9), of 4.43 feet between August 16, 2013 and May 29, 2015. Generally, the water level was between 13 and 15 feet which was the case for 95.6% of the daily mean water level elevations. By comparison between May 29, 2015 and June 8, 2016 the range of water level is smaller 3.406 feet (Figure 10). However, a smaller share of water levels is between 13 and 15 feet, 89.7% of the daily mean water level elevations.

In the first two years there are three notable changes in water level that one can observe in Figure 9. The first event was that between May 27, 2014 and May 31 there was a sharp rise in water surface elevation to over 17 feet and then between June 1, 2014 and June 12, 2014 and the water surface elevation returned to conditions that were present prior to May 21, 2014 (Figure 9). This is probably a response to a major rainfall event within False River's watershed. Between May 27and May 29, 2014 7.03 inches of rainfall on New Roads which lies on the north shore of False River (Usclimatedata.com, 2015). This rainfall event caused the lake level to rise 2.83 ft.

The second event was an approximately two feet decrease of water elevation between September 5, 2014 and September 15, 2014. This event was a result of a schedule reduction of False River water level which was planned to start on September 2, 2014 (Anonymous, 2014). The plan was to lower the water level 2 ft. to 2.5 ft. then the control gate would be closed with the water level expected to return to preexisting conditions due to rainfall-runoff (Anonymous, 2014). The observed reduction of water level between September 5, 2014 and September 15, 2014 was 1.73ft, which was similar to the range planned for by the Police Jury. The last/third event was an exponential rise of water surface elevation starting February17, 2015 through the latest collection of water elevation data on May 29, 2015. This event makes sense because the plan was to close the control gate no later than March 1, 2015 (Anonymous, 2014).

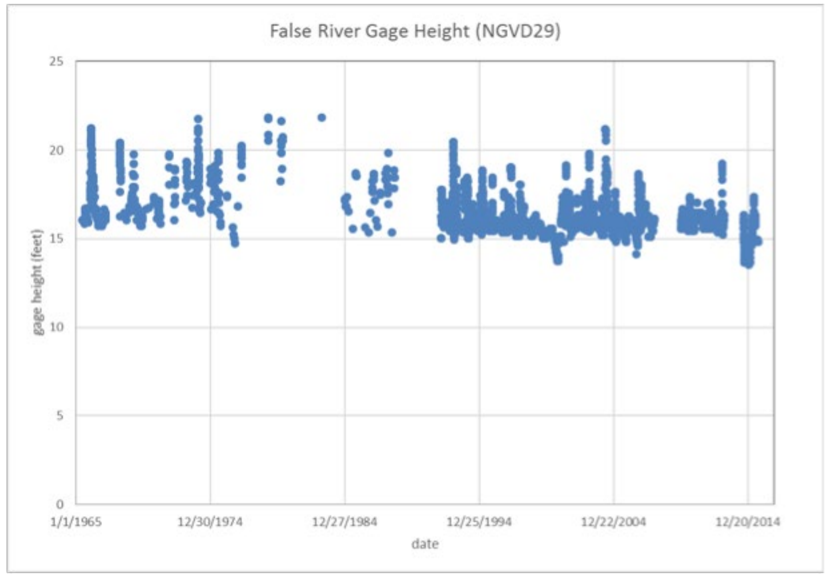

Figure 8. False River water surface elevations between 1965 and 2015.

The water level of False River experienced six significant events between May 29, 2015 and September 27, 2016. As with previous study period discussed some are probably natural events and others are probably artificial events created by changing various control structure gate positions.

The first event is probably a lowering of a gate level causing water level to decrease from a daily mean elevation of 15.88 feet on June 1, 2015 to a daily mean elevation of 14.42 feet on June 7, 2015 (Figure 10). The second event was another water level lowering by opening a gate, which caused daily mean water elevation to decrease from 14.70 feet on August 17 to 13.45 feet on August 24. The third event was probably a gate closing on October 24, 2015 which caused daily mean water elevation to rise from 13.13 feet on October 24, 2015 to 14.66 feet on October 27, 2015 (Figure 10). These changes for gate level are probably done to facilitate the dredging work on the south flats, which is phase I of the restoration of False River. 'This work will continue in the fall of 2016 with more dredging this time in the northern flats (Anonymous, 2015). This work is part of the restoration effort to enhance fishing from False River by making the lake waters deeper and cooler (Jones, 2015).

There are three natural events which are probably the response to two major rainfall events in February and March of 2016. The fourth event is a rise of daily mean water elevation from 15.04 feet on February 2, 2016 when 4.00 inches of rainfall in New Roads, Louisiana (usclimatedata.com, 2016a) to a daily mean water elevation to 16.51 feet on February 4, 2016 (Figure 10). The fifth even is another rise in daily mean water elevation from 13.96 feet on March 10, 2016 to a daily mean water elevation of 15.67 feet on March 14, 2016. This was in response to 5.58 inches of rainfall between March 8 and March 12 that falls in New Roads, Louisiana (usclimatedata.com, 2016a). Since June 8, 2016 there has been one major rainfall, the great August deluge which increase False River water level by 5.20 feet between August 10 and 15, 2016 to 19.19 feet (Figure 11). This maximum is only slightly below the previous record of 20.6 feet during April 1983 flood. Between August 10 and 15 16.27 inches of rainfall occurred (usclimatedata.com, 2016b). It appears from these four large rainfall events that the watershed and lake response in an approximately linear manner as the amount of rainfall increases water level increases approximately 0.3025 feet (~3.6 inches) with each inch of rainfall (Figure 12).

It is clear that False River's water level is controlled frequently. There have been five planned changes that have occurred during the study, August 16, 2013 to May 29, 2015 and other earlier changes were noted by Walley (2014) by either opening or closing gates. This oxbow lake was formed by 1722 and since 1947 this lake has been controlled frequently (Walley, 2014). These events have occurred to assist the dredging associated with the restoration of False River that is an on-going project.

Walley (2014) noted that during a three-month long flood on the False River that it was associated with heavy rains and high stages of the Mississippi River which is an indication that there is a subsurface connection between False River and the Mississippi River. This is reasonable because the maximum depth of False River is 65 feet (-49 ft. below MSL) (Walley, 2014) or 63 feet with average depth of 22 feet (Ensminger, 1999) and the base of the Mississippi River in the vicinity of False River is typically -30 feet to -40 ft. below MSL feet (Little and Biedenharn, 2014). The depth of both False River and Mississippi River is larger than the thickness of the confining clay within Point Coupee Parish which is typically 40 to 60 feet (Louisiana Department of Natural Resources, 2012). In general, water elevation for False River (Figure 9, 10 and 11) is usually below that of the Mississippi River (Figure 13). Because of the dominance of other events, rainfall, opening or closing gates the influence of the Mississippi River level is a secondary influence. However, the water level difference is usually driving water from the Mississippi River under the levees and towards False River. This flow us smaller than surface water flows and management changes. This shows up in the linear regression between False River water level and Mississippi River water level with a the resulting R^2 that is small approximately 0.04 (Figure 14), which is a weak correlation (Taylor, 1990; and Shortell, 2001) to very weak correlation (Bizled, 2002; Moore et al., 2013). This is probably a result of control gate openings and closing and local major rainfall events dominating False River's water level. Maybe it would be more apparent that there is a hydraulic connection between False River and Mississippi River if water level was left to only natural changes. It is clear that from elevation of False River and Mississippi River during the study that water is generally flowing towards False River. The Mississippi River's water level on average 9.08 ± 9.11 feet above that of False River for the same daily mean for the first approximately 2.5 years. For the past year the Mississippi River between May 29, 2015 and June 8, 2016 was higher than False River were the average Mississippi River water elevation that was 19.11 ± 11.21 feet above that of False River for the same daily mean. So, the rising level of False River will probably continue at least until the next major summer time dry season in the Mississippi River watershed lowers the river's water level typically below or near 16 feet for an extended period of time.

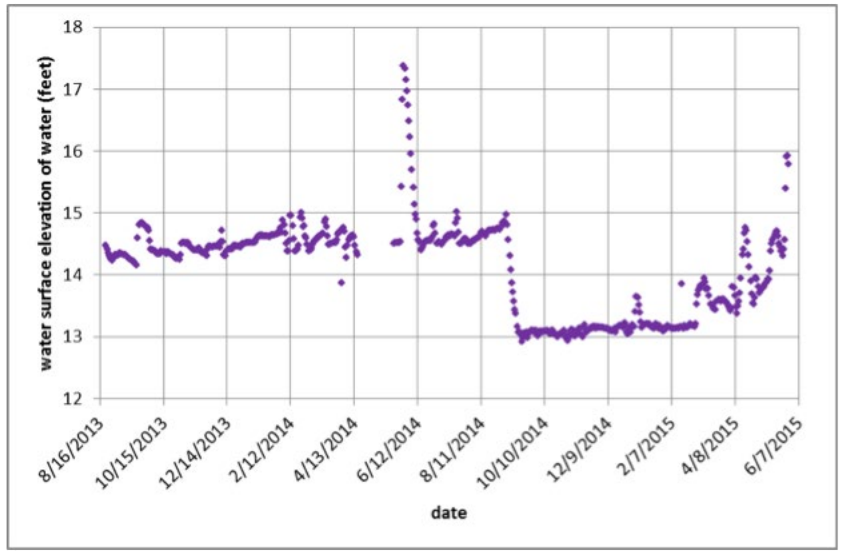

Figure 9. Daily mean water surface elevation measured at False River from August 22, 2013 to May 29, 2015.

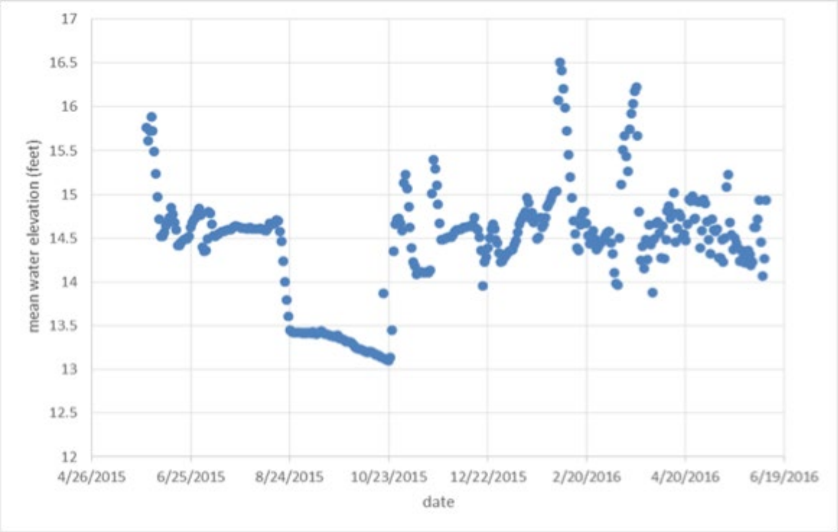

Figure 10. Daily mean water surface elevation measured at False River from May 29, 2015 to June 8, 2016.

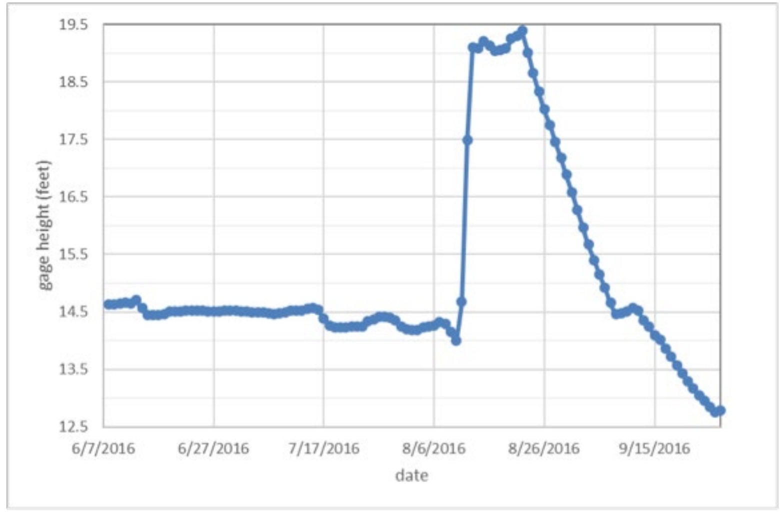

Figure 11. Daily mean water surface elevation measured at False River from June 8, 2016.to September 27, 2016.

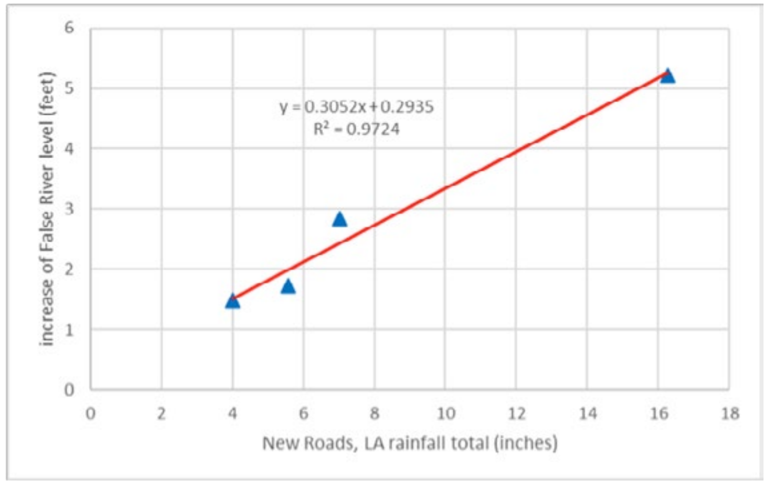

Figure 12. Increase of False River level in response to major rainfall events over the past three and half years in New Roads, Louisiana area

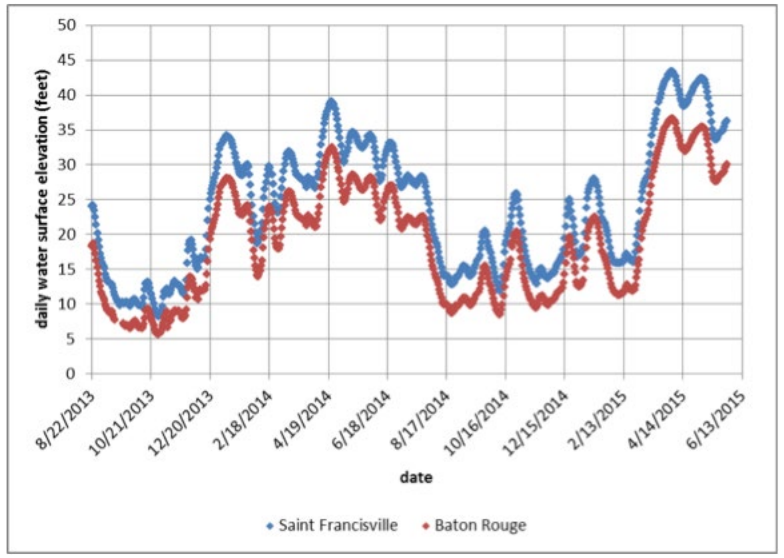

Figure 13. Daily water surface elevations measured of Mississippi River at Baton Rouge and Saint Francisville, Louisiana at 8:00 am each day from August 22, 2013 to May 29, 2015 (RiverGages.com, 2015).

What is different is it appears the correlation between Mississippi River elevation and False River elevation is significantly stronger for May 29, 2015 to June 8, 2016, R^2 is 0.43 Figure 15) then for August 22, 2013 to May 29, 2015, R^2 is 0.04, Figure 15). This is probably a result of over twice as lasrge water level difference driving water from the Mississippi River towards False River. The second possible reason could be the dredging of the south flats has removed low permeability sediment thus reducing the hydraulic resistance of flow between the Mississippi River and False River. Could it be that when dredging occurs as planned for the north flats in the fall of 2016 that the further removal of sediments could further improve the connection between the Mississippi River and False River and thus increase its planned benefit to by allowing the lake to be deeper and cooler for fish/fishing. However, rising lake levels could be a problem for residents along the lake.

Lake Bruin

Before the current LGS study the USGS has measured Lake level of Lake Bruin of 4,735 days between February 13, 1959 and September 30, 1986 (USGS, 2016d). This lake was monitored in two periods February 13, 1959 to September 30, 1964 (Figure 16), and later from November 10, 1977 to September 30, 1986 (Figure 17). Lake Bruin is closer to the Mississippi River than False River and lies within 0.5 miles of the river has experience 3.33 feet of change of water level between October 28, 2013 and June 4, 2015 (Figure 18). Results for the past year have been similar to those in the prior study. The variation of water level is 3.64 feet between June 4, 2015 and June 7, 2016 (Figure 19). Lake Bruin system is less managed than False River. There were no quick changes in water level indicating closing or opening of control structure gates. This lake does have a control structure which has a gate that was constructed in the 1950s. The Tensas Parish Police Jury typically keeps the water level at 62 ft. (Daniel, 2013), which is close to the average daily mean water elevation measured for the LGS study, 62.38 ft. This probably explains why there have been no openings or closing of the gate because the water level has been within 1.5 feet of the goal level. It is probably the smaller watershed to lake size (Table 5) that has reduced the need for frequent opening or closing of gates in the control structure compared to the others four lakes monitored during this study. However, on occasions in the past lake level has been lowered typically four to five feet in September through November in 1988, 1989, 1990, 2005 and 2011 (Daniel, 2013).

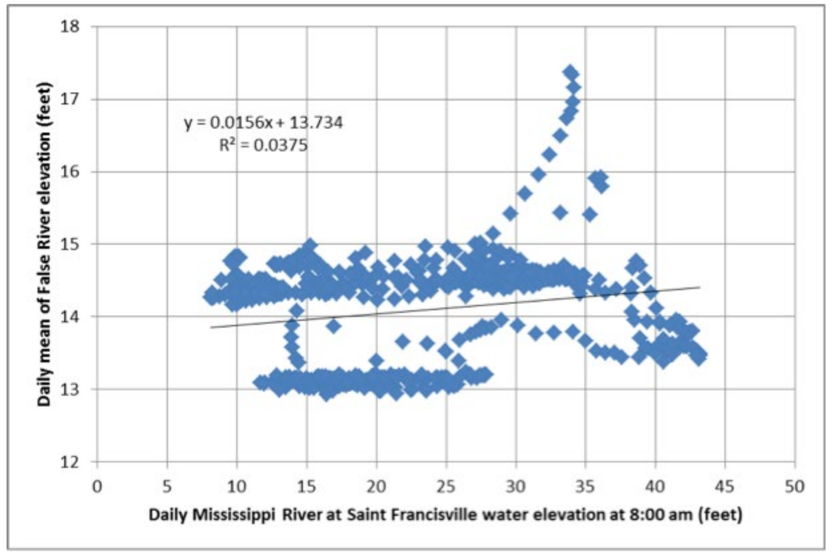

Figure 14. water surface elevation related to Mississippi River water surface elevation at Saint Francisville for time interval of August 22, 2013 to May 29, 2015.

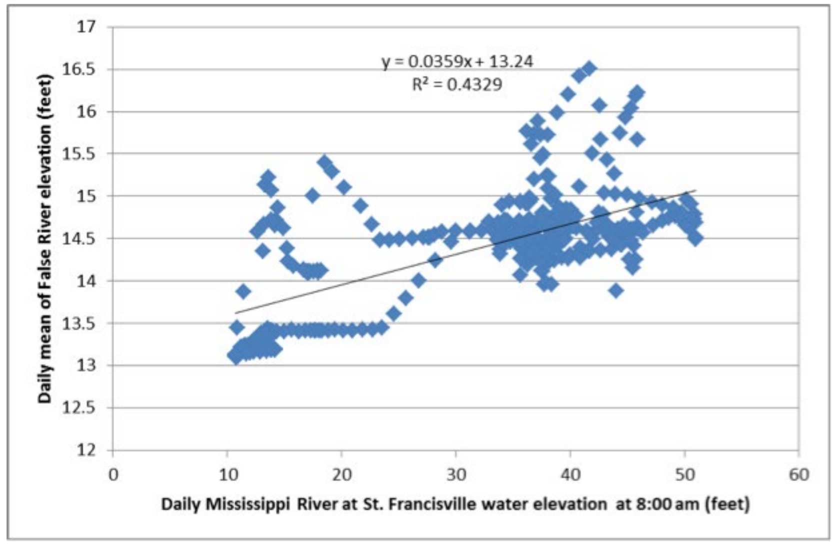

Figure 15. Water surface elevation of False River related to Mississippi River water surface elevation at Saint Francisville for time interval of May 29, 2015 to June 8, 2016.

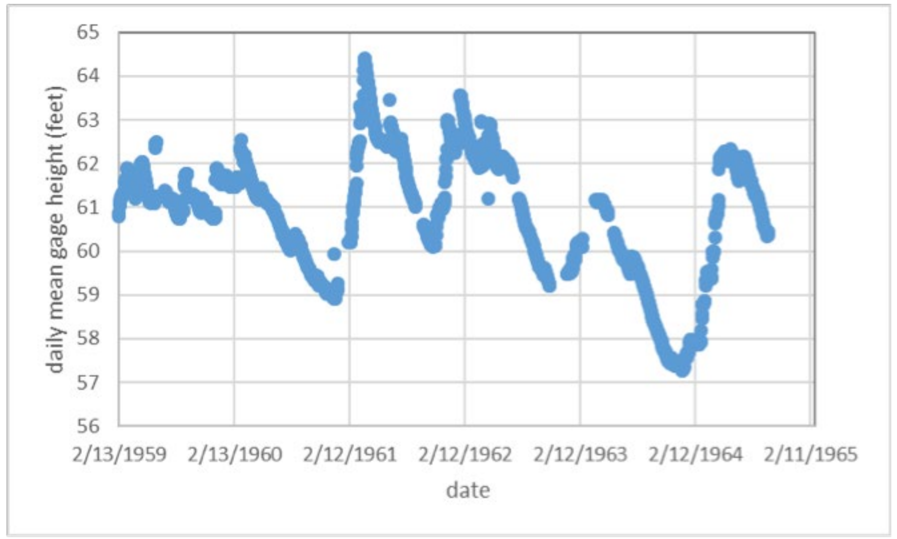

Figure 16. Daily mean water surface elevation measured at Lake Bruin from February 13, 1959 to September 30, 1964.

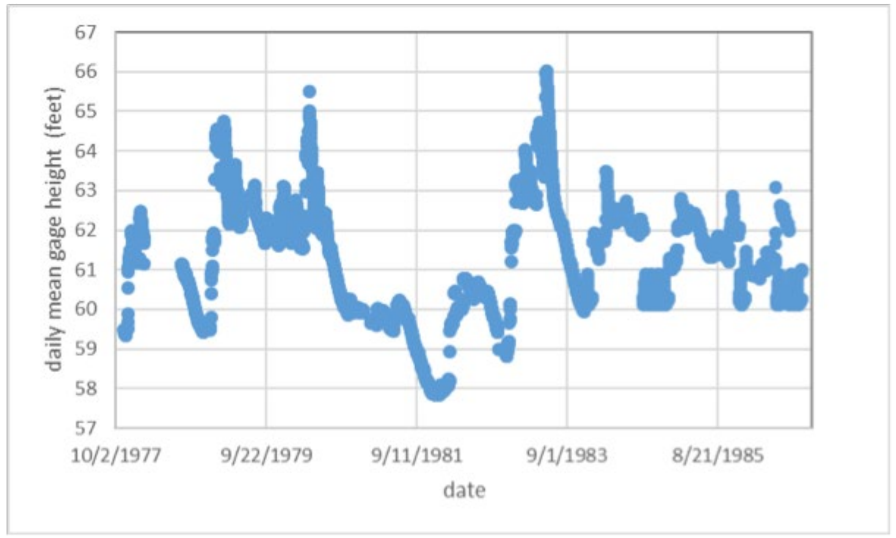

Figure 17. Daily mean water surface elevation measured at Lake Bruin from November 10, 1977 to September 30, 1986.

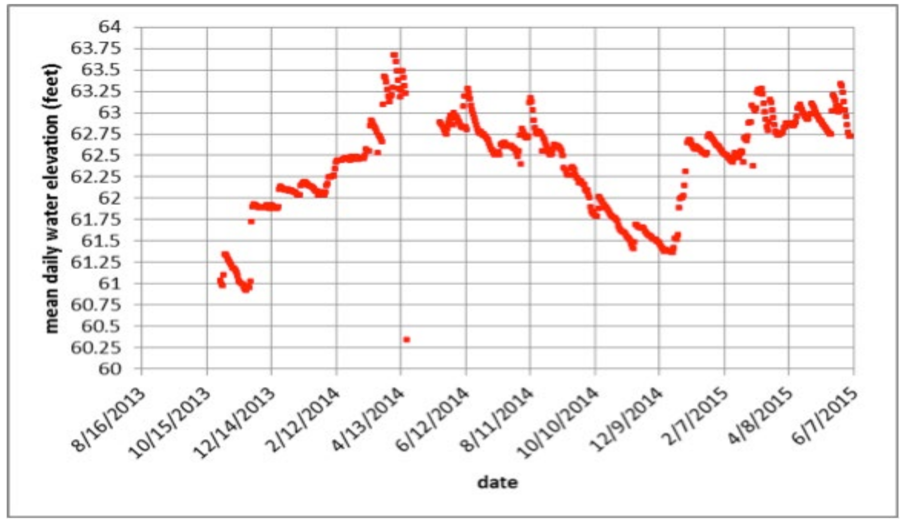

Figure 18. Daily mean water surface elevation measured at Lake Bruin from October 28, 2013 to June 4, 2015.

Table 5. Size of lakes and associated watersheds for 5 lakes monitored by LGS

Lake	area of lake in acres	area of watershed in acres	ratio	source
Black Lake	13,800	588,800	42.7	Yeldell, 2013
False River	3,212	34,453	10.7	Walley, 2014
Henderson Lake	5,000	170,000	34.0	Salyers, 2014a
Lake Bruin	2,842	13,700	4.82	Daniel, 2013
Lake Providence	1,380	11,000	7.97	Daniel, 2015

It appears that the pattern of water level for Lake Bruin is similar to the Mississippi River water level (Figure 20 and 21) with peaks in the winter-spring and troughs in summer-fall. This hints at a possible hydraulic connection between the two. This yearly cycle was clear from a record of the nearby Lake Saint John between October of 2008 and 2014 (USGS, 2015). The physical geometry also indicates this is possible as well. The depth of Lake Bruin is on average 23 ft. with a maximum depth of 49 ft. (Ensminger, 1998). That allows a significant fraction of the lake to have contact with the sands connecting Lake Bruin to the Mississippi River because the confining clay for this portion of Tensas Parish is between 0 and 30 ft. thick (Carlson, 2006). Ensminger (1998) noted that neither the Mississippi River nor groundwater is a source of water and that fluctuations of water level are related to rainfall and runoff. This does not seem to be a reasonable conclusion because the correlation coefficient R between Lake Bruin and Mississippi River is over 0.6 which is considered a moderate correlation (Shortell, 2001; Blized, 2002; and Moore et al., 2013). In addition, a portion of Lake Bruin, the eastern side, is within 0.6 mile of the Mississippi River (Daniel, 2013) and is well within the distances of influence of the Mississippi River expressed in a couple of ways. First, other ox bow lakes such as Lake Saint John's whose nearest point is approximately 3.2 miles from the Mississippi River, has water levels with an R^2 value of correlation with Mississippi River water level at Natchez of 0.799, (Carlson, 2014). A number of other monitoring wells or lakes have water levels that have a correlation coefficient of approximately 0.6 as well (Carlson, 2014). Second, sand boils have appeared at distances of up to 3 miles from the Mississippi River (Carlson, 2014) indicating water is moving from the river under the artificial-natural levees and flows into the area behind levees which has land surface below flood stage of the river. So, a more realistic picture of Lake Bruin's water level is that it is dependent partially on the following: direct precipitation on its surface, runoff flow into it from its surrounding watershed, and groundwater flow into it when water level of Mississippi River is higher than Lake Bruin's water level and reverse when the Mississippi River is lower than Lake Bruin's water level. The seasonal ebb and flow of Mississippi River water towards and away from Lake Bruin is displayed by the two water levels (Figure 20 and 21). The Mississippi River water level is usually higher than Lake Bruin during spring and early summer and lower from late summer through fall. There is approximately a yearly cycle of water levels for both Lake Bruin and Mississippi River. This year long seasonal variation also appears for five cycles for Lake Saint John between October 2008 and March 2014 (USGS, 2015) like the ones for Lake Bruin they are approximately year-long cycles. Throughout the whole study period Lake Bruin's water level is slightly higher 3.6 ± 8.9 feet than the Mississippi River' water level which is not surprising because usually in humid-rainfall rich setting such as Louisiana groundwater should flow towards and down into major sinks such as the Mississippi River (Winter et al., 1998; and Fetter, 2001) and in these settings lakes can be thought of as outcrop of the groundwater (Winter et al.; 1998; and Fetter, 2001) which in this case should cause Lake Bruin's water level to be on average slightly above the Mississippi River level which has been observed.

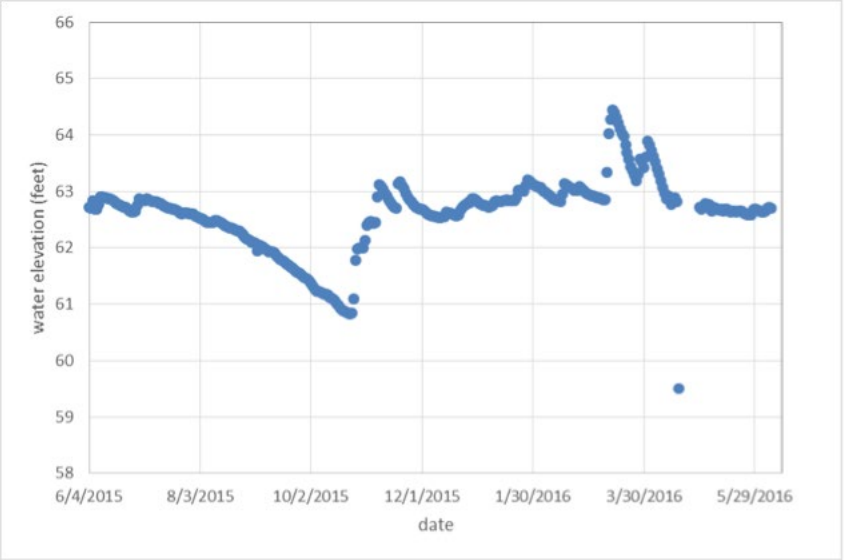

Figure 19. Daily mean water surface elevation measured at Lake Bruin from June 4, 2015 to June 7, 2016.

By contrast during the past year June 4, 2015 to June 7, 2016 the Mississippi River is higher than Lake Bruin (Figure 21). Throughout this study period Mississippi River's water level is slightly higher 3.8 ± 11.3 feet than the Lake Bruin. It is not surprising during the past year the average elevation of Lake Bruin is 62.59 feet, which 0.21 ft. higher than during the previous phase of the stream study that ended in June of 2015. This indicates that in order for this change to occur on average a net addition of approximately 194 million gallons, approximately 530,000 gallons of water are added daily, to Lake Bruin relative to the previous years.

Water levels in groundwater adjacent to a river and the level of a river appear to be related to each other and a transient change of the river's water level influences groundwater levels and chemistry (Heeren et al., 2011). Lake Bruin is acting in a manner similar to a piezometer measuring groundwater level away from a river where variation of water is a damped version where peaks and troughs are approximately in phase. For the first phase of the study the range of water level for the Mississippi River during this study period is 38.56ft., by comparison the range of water level for Lake Bruin is 3.33 ft. For the second phase of the study the Mississippi River water level's range of level was 44.43 feet, by contrast variation of Lake Bruin level varied 3.62 feet. The damping ratio is 11.6 for first phase of study and 12.2 for second phase of the study both are similar to what Wegner (1997) determined in a simulation of the Chena River, Alaska where the ratio is approximately 9 for a point that is approximately half mile from the river.

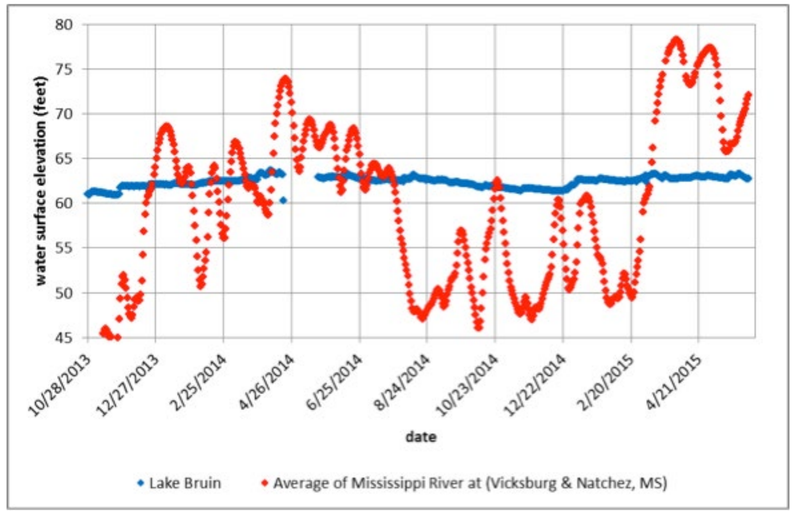

Figure 20. Lake Bruin water surface elevation relative to average of Mississippi River water surface elevation recorded at Vicksburg and Natchez Mississippi between October 28, 2013 and June 4, 2015.

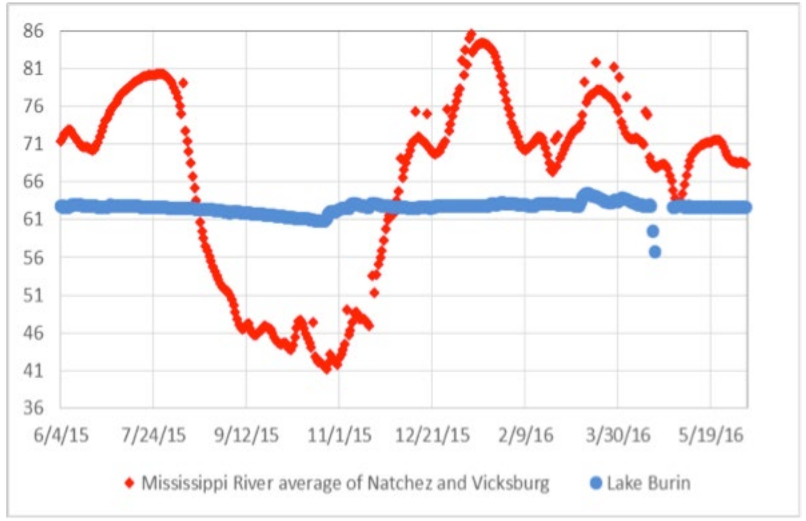

Figure 21. Lake Bruin water surface elevation relative to average of Mississippi River water surface elevation recorded at Vicksburg and Natchez Mississippi for June 4, 2015 to June 7, 2016.

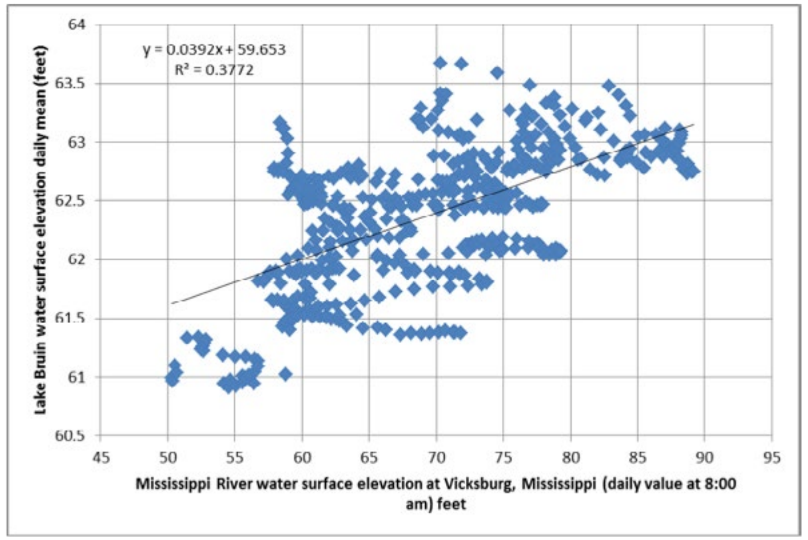

Figure 22. Lake Bruin's water surface elevation related to Mississippi River water surface elevation at Vicksburg for time interval of October 28, 2013 to June 4, 2015.

It appears that peaks and troughs in the Lake Bruin water level records are on average approximately two weeks after the peaks and troughs of the Mississippi River water levels (Figures 20 and 21). This is not surprising considering Wegner (1997) observed that groundwater levels continued to rise after the peak of water level for the Chena River was past. Simulations of the Chena River-groundwater system indicate that at distances of 1000 ft. to 3500 ft. from the river groundwater level continues to rise for five days after water level in the river starts to decline (Wegner, 1997). So a delay of the peak water level in Lake Bruin occurring after the peak of Mississippi River water level appears to be reasonable and this is another indication that the Mississippi River and groundwater influence the level of Lake Bruin.

The correlation between Mississippi River water level and Lake Bruin is moderate with R^2 of 0.3772 and 0.5193 between October 28, 2013 and June 4, 2015 and June 4 and June 76, 2016 respectively (Figures 22 and 23). This correlation is not apparent when examining the two water levels throughout the two periods of study. The reason is Mississippi River water level varies approximately 45feet between the lowest and highest values (Figures 20 and 21), while the water level of Lake Bruin varies approximately 3.7 feet, approximately 9% of the Mississippi River's water level variation.

Lake Providence

The newest site within the LGS set is Lake Providence. The record extends from December 17, 2015 to June 7, 2016. This lake was only briefly monitored by the USGS by measuring discharge at its outfall spillway between February 2, 1985 to September 30, 1986. This record includes 607 discharge values (USGS, 2016d). For the LGS record there are five events recorded causing changes of the level of Lake Providence. All five are rainfall events that are recorded at Lake Providence, Louisiana, which yielded significant rises in lake level (Figure 24 and table 6). This is not surprising given this lake has only two spillways, Baxter Bayou Structure, which is a small spillway that can only lower water level potentially an inch a day (Daniel, 2015). The other is Tensas Bayou weir that is somewhat larger and during high lake levels it accounts for 70% of the water that exits the lake when level is over the weir (Lake Providence Watershed Council, 2016). Although the spillway has existed since 1973 (Daniel, 2015) the lake has been left as a natural system with the spillway only acting as an outlet for excessively high water levels. Daniel (2015) noted that it would take the spillway approximately 2 months to lower lake level 4 feet. The Tensas spillway is poorly defined where the spillway weir elevation is an unknown and it is overgrown and partially obstructed spillway (Lake Providence Watershed Council, 2016). The two spillways combined allowed the water after the March 8-11 rainfall event to be lowered 3 feet within just 15 days (Figure 24). Just 2.5 months later the water level decreased 5 feet although there were two more large rainfall events, March 31 (1.82 inches) and April 12 (4.32

inches), in Lake Providence that added water However, the March 8-12 deluge is the largest rainfall event by far and it has cause lake level to rise 4.81 ft. This is the big event that caused nearly record flooding in the Shreveport area and throughout northern Louisiana (srh.noaa.gov, 2016, and climate.gov, 2016). This was defined as the 500-year precipitation event throughout northern Louisiana and southern Arkansas (Figure 25). In portions of the Lake Providence watershed rain fall in the first two weeks of March 2016 was over 17 inches (Lake Providence Watershed Council, 2016) with over half of the rainfall in just four days March 8 to 11 (Table 6). As with False River it appears that changes in lake level are influenced by precipitation (Figures 12 and 26) in an approximately linear manner.

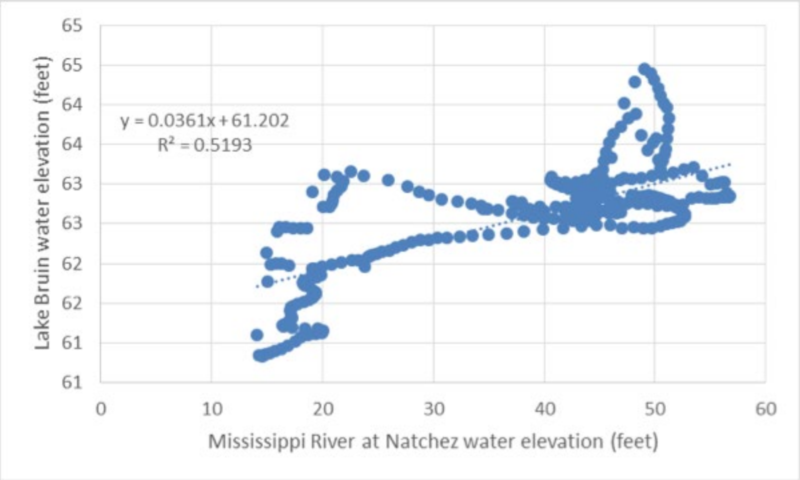

Figure 23 Lake Bruin's water surface elevation related to Mississippi River water surface elevation at Natchez for time interval of June 4, 2015 to June 7, 2016. Only two days when the transducer was clearly failing, yielding odd value which have not been included.

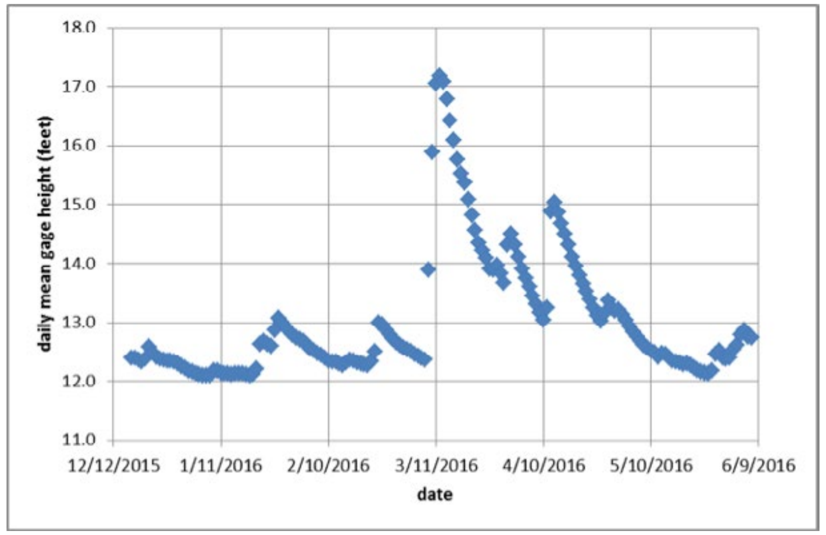

Figure 24. Mean daily water level, gage height, of Lake Providence between December 17, 2015 and June 7, 2016

Table 6. Major precipitation events in Lake Providence area that caused lake level to rise by more than 0.5 feet (usclimatedata.com, 2016c).

Precipitation event	Rainfall total (inches)	Lake level rise (feet)
January 22 to 23 & 26 to 27	3.85	0.877
February 22 to 24	2.51	0.70
March 8 to 11	#9	4.81
March 31	1.82	0.67
April 12	4.32	2.00

A # Interprelated from map of precipitation between March 8 and March 11, 2016 (srh.noaa.gov, 2016).

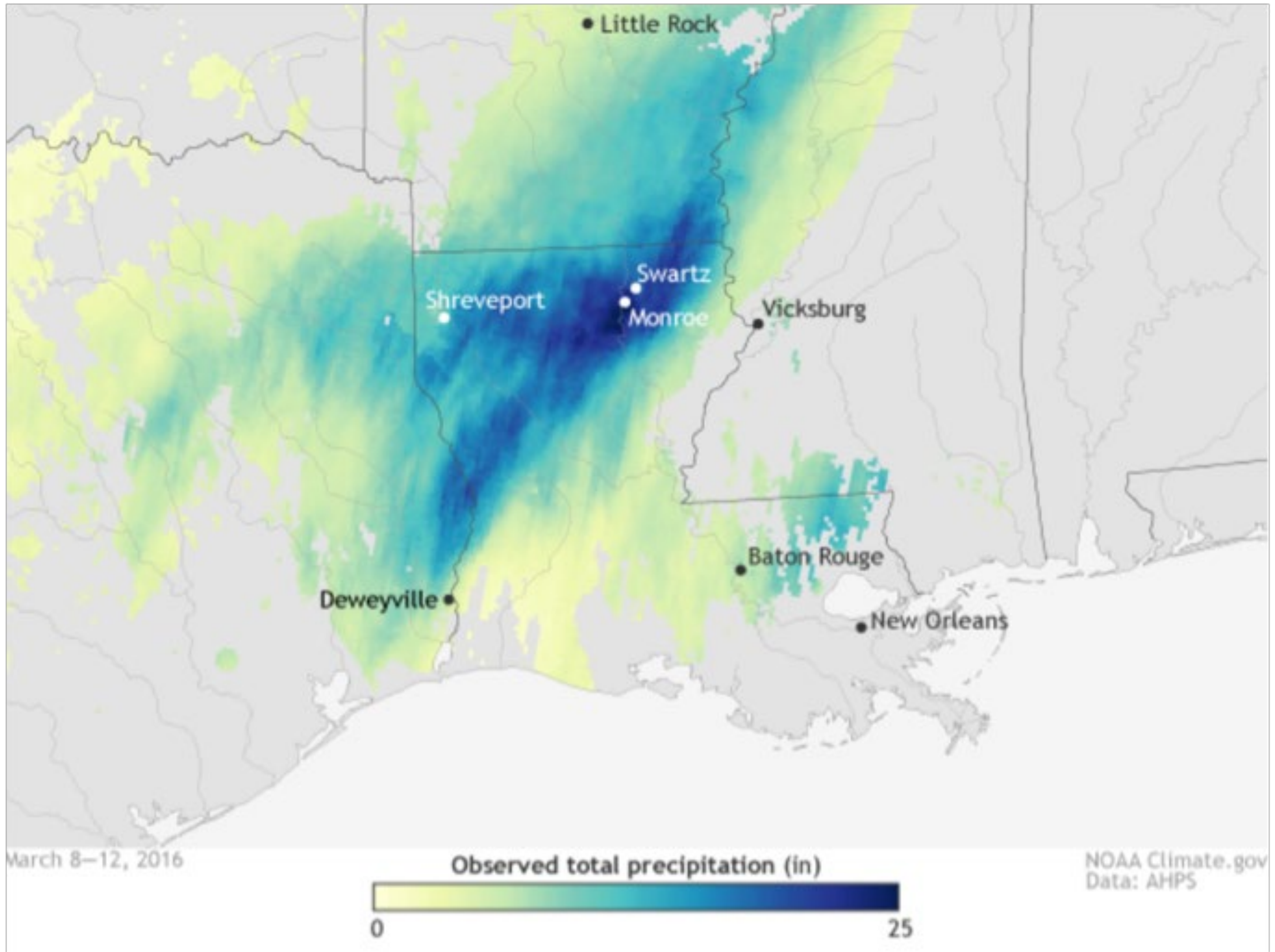

Figure 25. Extreme rainfall event that occurred March 8 to March 12, 2016 throughout northern Louisiana and southern Arkansas (climate.gov, 2016)

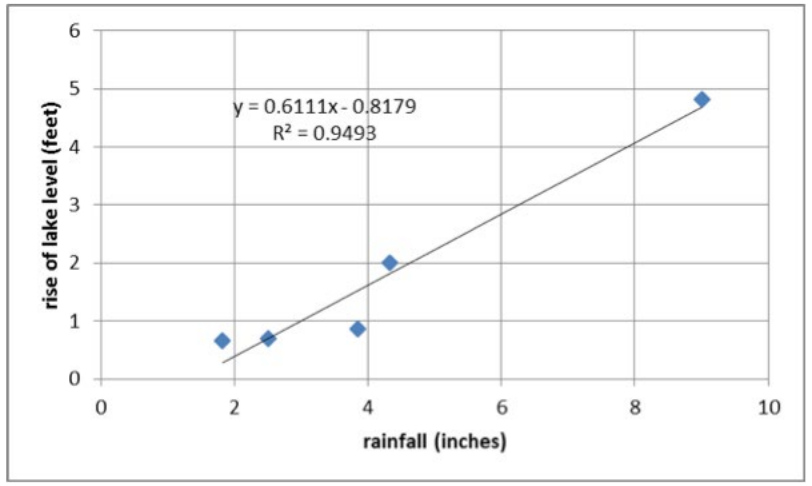

Figure 26. Increase of Lake Providence level in response to major rainfall events over the past six months in Lake Providence, Louisiana area.

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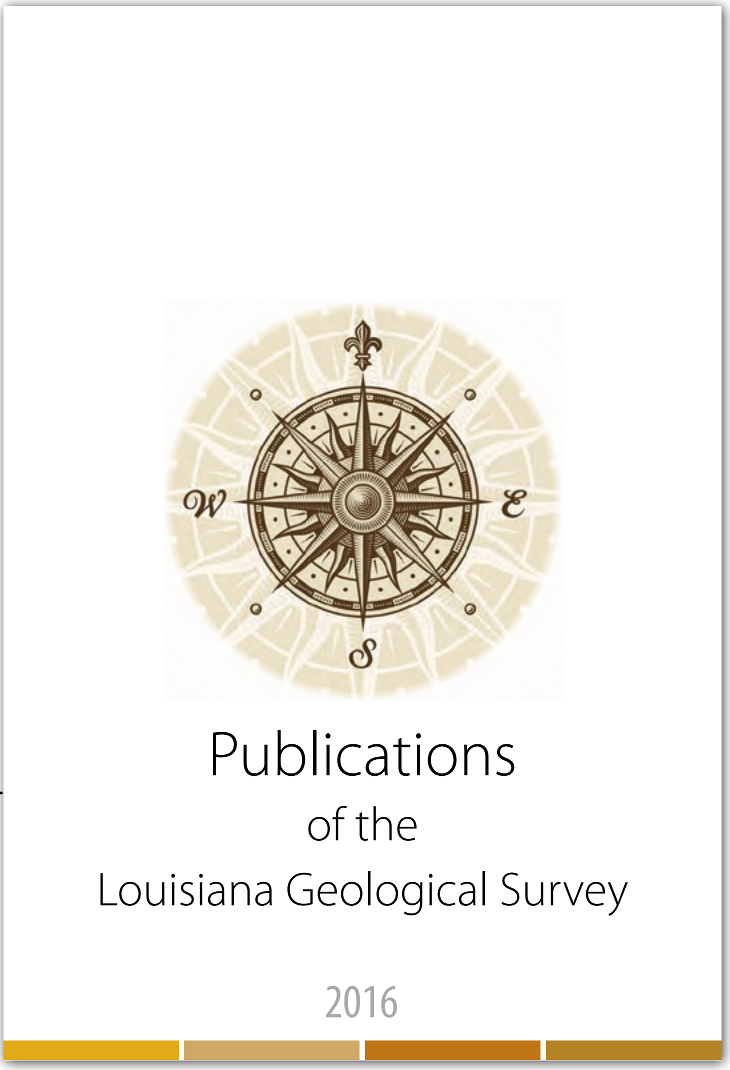

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