TECHE-VERMILION PUMPING STATION AND FLOW DISCHARGE REGIME ON BAYOU TECHE, LOUISIANA

by

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DEDICATION

This paper is dedicated to my husband, Stuart Nolan, and my son, Titus Clemens, who put up with me over the course of several years while I worked to complete this degree, and to all my incomplete projects that have been languishing while I dedicate my time to an advanced degree.

ACKNOWLEDGEMENTS

I would like to acknowledge Brian Dorr, who helped me work through some of the statistical aspects I struggled with. Also, Brian and my sister, Katie helped fund my penchant for long and drawn-out academic careers. I would also like to acknowledge my parents, Ginny and Dale Lowery, who are both dedicated to life-long learning and encouraged me throughout this journey. And thank you to my advising professor, Dr. William Kleindl.

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ABSTRACT

The flow regime of Bayou Teche, a relic channel of the Mississippi River in Louisiana, has been directly and indirectly altered extensively over the past several decades in response to major flood events, to maintain irrigation practices, and to mitigate the related effects of modifications implemented on connected systems. One of these mitigation strategies was adding a pump station intended to renew flow from the Atchafalaya River to Bayou Teche, which had previously been severed due to flood protection efforts. This severance caused low flow and saltwater intrusion in Bayou Teche which became problematic for the health of this stream and diminished availability of water for agriculture. Therefore, in this paper, I reviewed hydrographic data to determine if the flow had been reestablished as intended. Data were sourced from USGS using daily mean discharge data collected from USGS gauge Bayou Teche at Keystone Lock & Dam near St. Martinville, Louisiana – (07385700). My methods include analysis of pre-control structure mean annual discharge on years 1974-1978 and post-control structure years 1984-1988. Hydrographs, linear regression modeling, and summary statistics did not reveal an increase in stream discharge at this location along Bayou Teche but did reveal significant correlative effects of the pump station in diminishing flow. I conclude that the infrastructure may not have been functioning as intended or was being offset by other factors. A simultaneous increase in water usage when the pump station was complete in anticipation of increased flow may have occurred, which counteracted the intended benefits. Precipitation rates may have contributed as well during the years of interest. My study highlights the complexity of managing interconnected water systems and how complicated efforts to predict and control hydrologic outcomes can be. Additionally, the reliance on USGS hydrographic data demonstrates the value of consistent and reliable monitoring, but also reveals gaps in understanding the entire scope of potential influences.

INTRODUCTION

Regional Hydrologic History

South Louisiana's complex hydrologic history is fraught with extensive anthropogenic alterations and natural disturbances. Levee building in Louisiana, although initially insufficient protection from flood waters of the Mississippi River, began in New Orleans in 1717 (Colten, 2000) by the French. State-funded projects and various levee boards were created throughout the 19th century to mitigate flooding and river meandering. However, levee failures and areas without flood protection continued to experience frequent property damage and loss of life. Eventually, flood protection was turned over to the U.S. Army Corps of Engineers in 1879 with the creation of the Mississippi River Commission (MRC) (Rogers, 2008). The MRC completed an extensive levee system along the Mississippi, going beyond the high-water mark of a 1912 flood by three feet. Still, a devastating flood in 1927 fortified the idea that more must be done to contain and control the Mississippi River to protect property and life (Barry, 1997).

The Atchafalaya River, today a distributary of the Mississippi River, formed in the 15th century during a meander period in the region, which saw the Mississippi River create a 20-mile loop named Turnbull's Bend (Figure 1). This loop captured the Red River, which previously flowed approximately parallel to the Mississippi, making it a tributary of the Mississippi. Simultaneously, the small south-flowing distributary of the Red River became what is now known as the Atchafalaya River. By the time colonizers reached the area, the Red River was

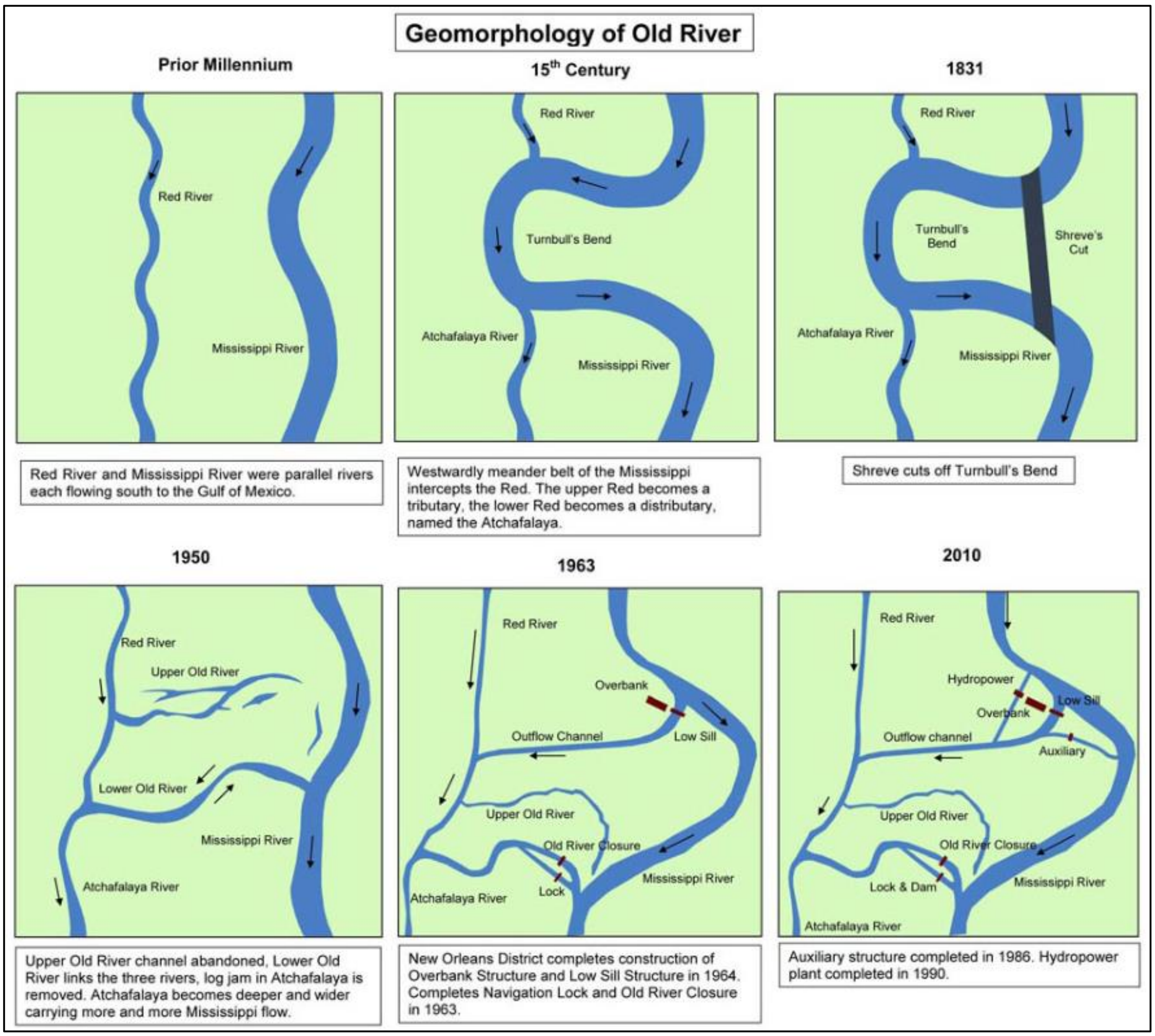

Figure 1. Evolution of Mississippi, Atchafalaya, and Red rivers. Credit: USACE 2011.

feeding into the Mississippi, and the Atchafalaya River headwaters had begun a few miles downstream. Major anthropogenic alterations started in this area in 1831 when Capt. Henry Shreve carved a lane through the neck of Turnbull's Bend to save time navigating along the river. The remaining stretch of the river cut off by Capt. Shreve's activity became known as the Old River and today is the location of several structures that control flow between the Mississippi, Atchafalaya, and Red Rivers. Capt. Shreve also initiated the removal of massive log jams that were located along the Red River and the headwaters of the Atchafalaya River, facilitating flow and sediment to the Atchafalaya River (Fisk, 1952).

Over a century, from 1850 to 1950, engineers and hydrologists monitored flow through the Mississippi and the Atchafalaya Rivers. During that time, the proportion of flow into the Atchafalaya increased from 10 to 30%, leading experts at the U.S Army Corps of Engineers to conclude that within 40 years, the Mississippi would change course and take over the Atchafalaya, abandoning the current longer and lower gradient course that flows through Baton Rouge and New Orleans (Fisk, 1952). In 1963, a control structure was established at Old River, where the original Shreve's cut was created. Since then, several structures have been added to fortify the original structure and provide additional aid when the Mississippi River is at flood stage. These control structures ensure that the Atchafalaya River does not receive more than 30% of the Mississippi River flow at any time.

The Atchafalaya River was also leveed following the great flood of 1927 (Figure 2), which was initially completed in 1946 to a 13-feet height and then improved and raised further to 21 feet in 1973. Consequently, this altered the hydrology of the Atchafalaya basin, including cutting off flow from the Atchafalaya River to various waterways (Piazza, 2014). One of the affected waterways cut off by the levee system along the Atchafalaya River is Bayou Teche, a pre-historic relic channel of the Mississippi River and the focus of this paper.

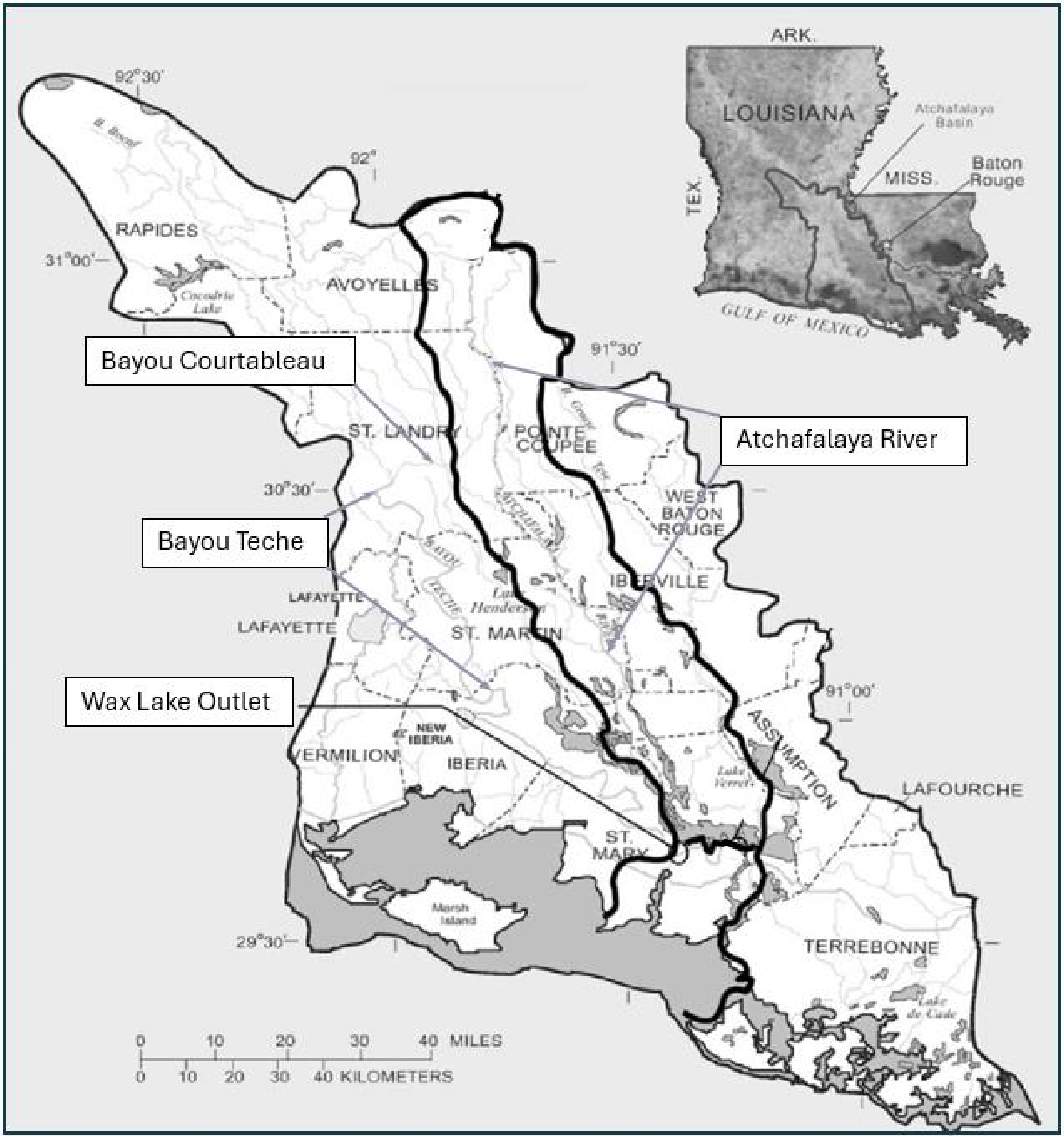

Figure 2. The Atchafalaya Basin and Atchafalaya Basin Protection Levee (thick black boundary). Credit: Xu, 2006.

My paper aims to determine if discharge data in Bayou Teche reflect the goal of increased flow following the completion of the Teche-Vermilion Pumping Station, or if additional factors continue to affect the hydrology of this watershed. Specifically, I will examine how the installation of the Teche-Vermillion Pumping Station altered the flow regime of Bayou Teche following several previous anthropomorphic alterations to the Atchafalaya Basin and connected streams.

SITE DESCRIPTION, METHODS, AND MATERIALS

Bayou Teche Watershed Study Area and History

Bayou Teche, located in south-central Louisiana, is a 125-mile-long waterway with headwaters inland near Port Barre, Louisiana (Bayou Teche river mile 124) and an outfall near Patterson, Louisiana, where it is severed by Wax Lake Outlet (river mile 5). The remaining 8 km (5 mi) portion of Bayou Teche continues past the outlet and empties into the Atchafalaya River near the coast (Figure 3). The Bayou Teche watershed is characterized by a subtropical climate with hot, humid summers, and mild winters. Occasional flooding occurs in the region due to its low-lying topography, precipitation rates, and proximity to the Gulf of Mexico.

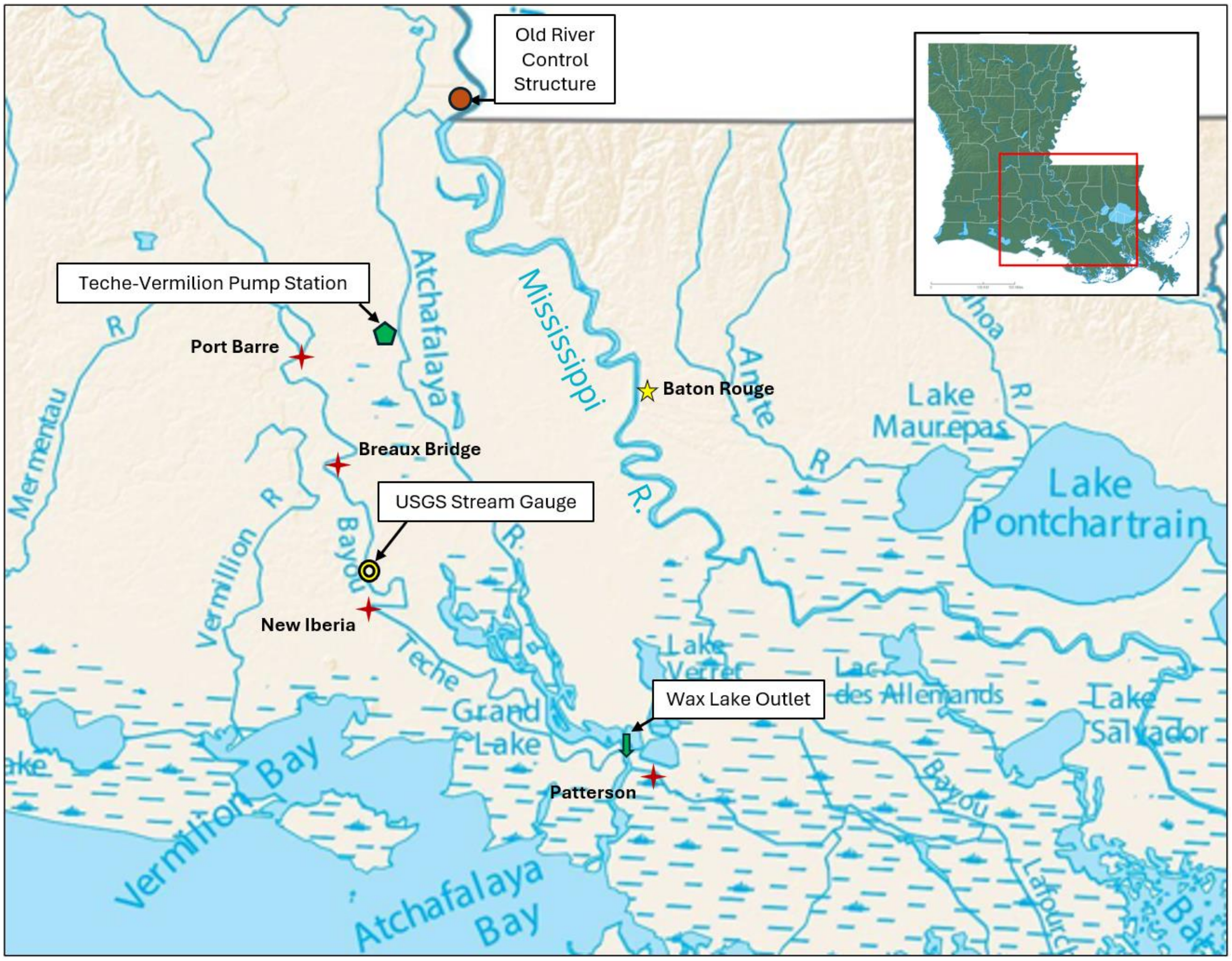

Figure 3. Study area key locations and major streams.

The Bayou Teche Watershed (Figure 4) encompasses an area of approximately 2,210 mi^2 (5,724 km^2) or 1,414,400 acres (572,387 ha). Analysis of the National Land Cover Dataset determined that croplands are 35% of the watershed area while wetlands are 30%, hay/pasture are 11%, forests are 8%, developed urban areas are 5%, and grasslands, shrub-scrub, open space, and barren lands collectively are 10% of the total area (Broussard, 2013).

Previously, this bayou received water from the Atchafalaya River via Bayou Courtableau until the Atchafalaya River levee and W. Atchafalaya Basin Protection Levee, built in the 1940s and expanded in the 1970s, cut off this natural flow (Piazza, 2014). It subsequently became clear that several waterways, including Bayou Teche and the Vermilion River, began to suffer from low flow due to this severance with the Atchafalaya (Garrison, 2001).

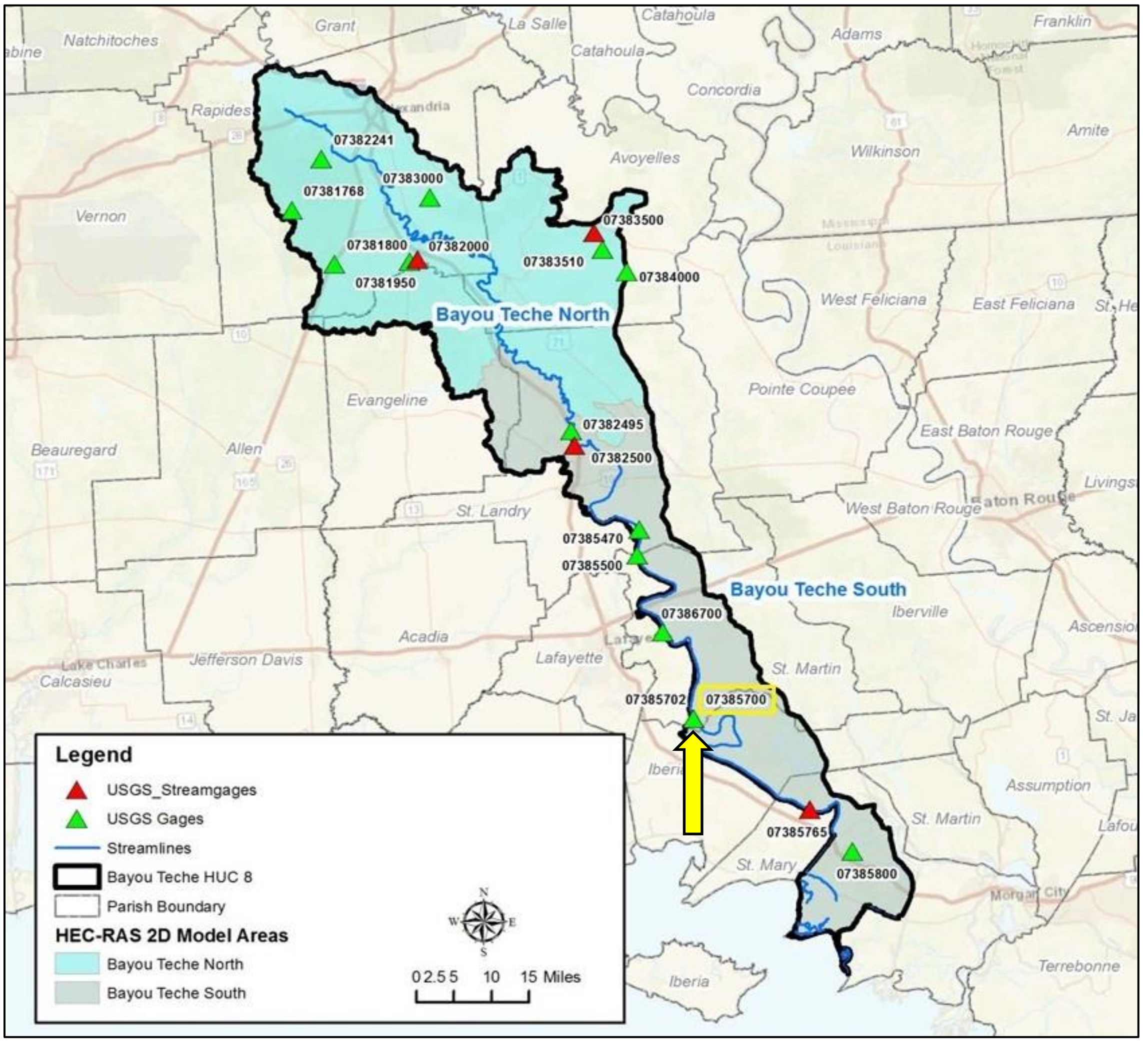

Figure 4. Bayou Teche Watershed HUC 08080102 showing the location of USGS gauges (arrow pointing to Bayou Teche @ Keystone L&D); Credit: Compass PTS JV, 2018.

Irrigation supplied by Bayou Teche during summer and fall accommodates agricultural needs for rice and sugarcane, while irrigation provided by the Vermilion River accommodates rice farming needs. Both rice and sugarcane are water-intensive crops, and although irrigation along both basins has diminished over time, the remaining irrigation is an ongoing problem for the basins' water demands. During years of lower-than-usual precipitation, saltwater flowed up these waterways, although saltwater intrusion was more severe in Vermilion River (Baker, 1988).

To mitigate these issues, a series of flow control structures were installed to deliver water from the Atchafalaya into Bayou Courtableau, which feeds into Bayou Teche and eventually the Vermilion River. The Teche-Vermilion Pumping Station, completed in 1982, pumps water into Bayou Courtableau at a rate of 1040 ft^3/s (29.45 m^3/s) via a canal and assisted by a siphon with a gate providing protection against reverse flow. Additional canals and flow control structures move water from Bayou Teche to the Vermilion River. The Atchafalaya River at Krotz Springs USGS stream gauge, which is located upstream from the Teche-Vermilion Pumping Station, annual average rate of flow is 184,000 ft^3/s (5210 m^3/s) over the course of water years 1946-1964 (USGS Water Data server, 2024), so only approximately 0.0057% of the Atchafalaya River's average annual flow rate is received and shared by Bayou Teche and the Vermilion River.

There are two points along Bayou Teche where control structures distribute water to the Vermilion River: the intersection of Bayou Teche and Bayou Fuselier near Arnaudville and the Ruth Canal Diversion Structure. A weir at Bayou Fuselier limits the flow into Vermilion River at approximately 10% of the water pumped from the Atchafalaya. Farther downstream, the Ruth Canal Diversion diverts approximately 494 ft^3/s (14.0 m^3/s) of the water pumped from the Atchafalaya River into the Vermilion River, while ensuring a minimum flow of 100 ft^3/s (2.83 m^3/s) continues down Bayou Teche. During extreme flood conditions, the Ruth Canal Diversion is closed. Additionally, approximately 10% of the water pumped into Bayou Courtableau is diverted to the West Atchafalaya Basin Protection Levee borrow pit, a remnant of the levee construction process, to reduce stagnation that was occurring there (Teche-Vermilion Freshwater District, 2019). According to a USGS Water Resource Report, from April 1 to August 31, 70% of discharge in Bayou Teche is sent to the Vermilion River through Ruth Canal for rice irrigation. From September 1 to March 31, flow diverted to the Vermilion River is reduced to 30% of Bayou Teche (Baker, 1988) (Table 1)(Figure 5).

Table 1. Estimated water budget of Teche-Vermilion Pumping Station.

Structure	Flow Capacity	Receiving Stream(s)
Teche-Vermilion Pumping Station	1040 ft^3/s (29.45 m^3/s)	Bayou Teche, Vermilion River, and W. Atchafalaya Basin Protection Levee borrow pit
W. Atchafalaya Basin Protection Levee borrow pit weir	10% of water pumped from the Atchafalaya River before it reaches Bayou Teche (104 ft^3/s)	W. Atchafalaya Basin Protection Levee borrow pit
Bayou Fuselier weir	approximately 10% of water pumped from the Atchafalaya River to Bayou Teche	Vermilion River
Ruth Canal Diversion	494 ft^3/s (14.0 m^3/s), varies seasonally from 30% up to 70% of Bayou Teche discharge	Vermilion River

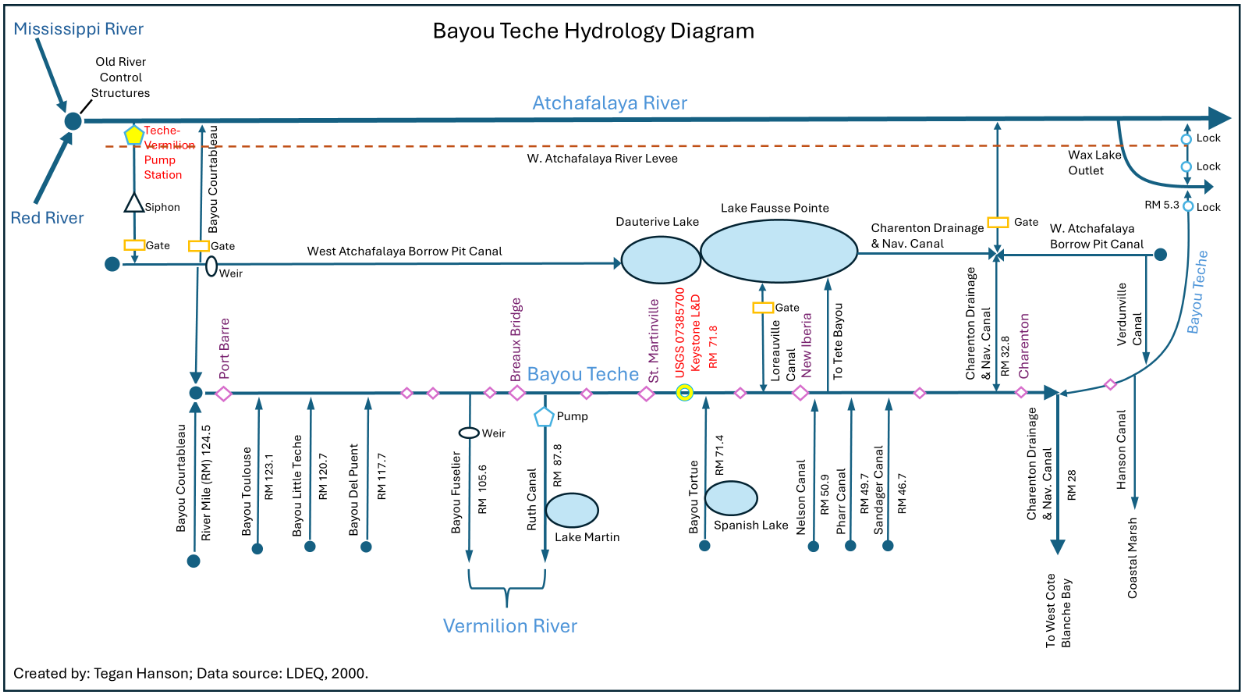

Figure 5. Diagram of Bayou Teche hydrology, connected systems and structures, and major towns. (See enlargement in Appendix C.)

Data Source

To determine the extent to which the Teche-Vermillion pump station altered the flow regime of Bayou Teche, I chose data from the USGS 07385700 Bayou Teche at Keystone L&D near St. Martinville, Louisiana stream gauge located in St. Martin Parish (see Figure 3). This gauge is located on Bayou Teche river mile 71, approximately 55 mi downstream from the headwaters and downstream from both the Ruth Canal diversion and the Bayou Fuselier weir, which are both outfalls that send water from Bayou Teche to the Vermilion River. Data include surface-water daily statistics of daily mean discharge measured in ft^3/s for water years 1974-1978 and 1984-1988. Water years between 1979 and 1983 were not included to ensure disturbance to the flow regime because of construction activity of the pump station did not affect the results. This gauge was chosen for its location on Bayou Teche, the characteristics of its associated watershed, and the availability of complete data in the date range required. Concerns about other factors affecting the flow regime were considered, such as changes in urbanization or agriculture over time or the addition of other hydrologic control structures, so water years further away in time from the date of installation and operation were avoided. Instantaneous values in this date range and stream gauge were not available. Water years 1974-1978 include data recorded after the completion of the Atchafalaya River levee system improvements but before the completion and implementation of the Teche-Vermilion pumping station and conveyance channel located north of Krotz Springs, Louisiana. Water years 1984-1988 include data recorded after the completion and implementation of the pumping station and conveyance channel.

Data Analysis

Microsoft Excel was used to create hydrograph charts and descriptive statistics table of all water years. Separate regression analysis of the pre-pump station mean annual discharge and post-pump station mean annual discharge years was performed to examine the relationship between year and flow. Pre- and post-pump station discharge values were compared using an ANOVA to determine statistical significance.

RESULTS

Hydrographic Data

The completion of the Teche-Vermilion Pump Station and Conveyance Channel was intended to increase flow in both Bayou Teche and the Vermilion River after flow from the Atchafalaya River was interrupted following the completion of the Atchafalaya River levee system in 1946 and subsequent improvements and expansion in 1973. Lower flows in these two basins reportedly caused saltwater to reverse flow into these waterways, impacting agriculture and the ecological health of these systems. Comparison of the pre-Teche-Vermilion pump station water year hydrographs (1974-1978) to the post-Teche-Vermilion pump station water year hydrographs (1984-1988) does not confirm an increase in flow following the completion of the pump station and conveyance channel. The pre-pump station hydrographs show lower flows in fall, a slight increase through winter and spring with a few extreme discharge events, and then inconsistent flows through summer. The post-pump station hydrographs show extreme events in October and consistently lower flows from April through September (Figure 6). Please see Appendix A for hydrographs displayed individually by year. The increased proportion of water pumped from Bayou Teche to the Vermilion River, as reported in Baker (1988), supports the lower flows displayed in the hydrograph from April through August.

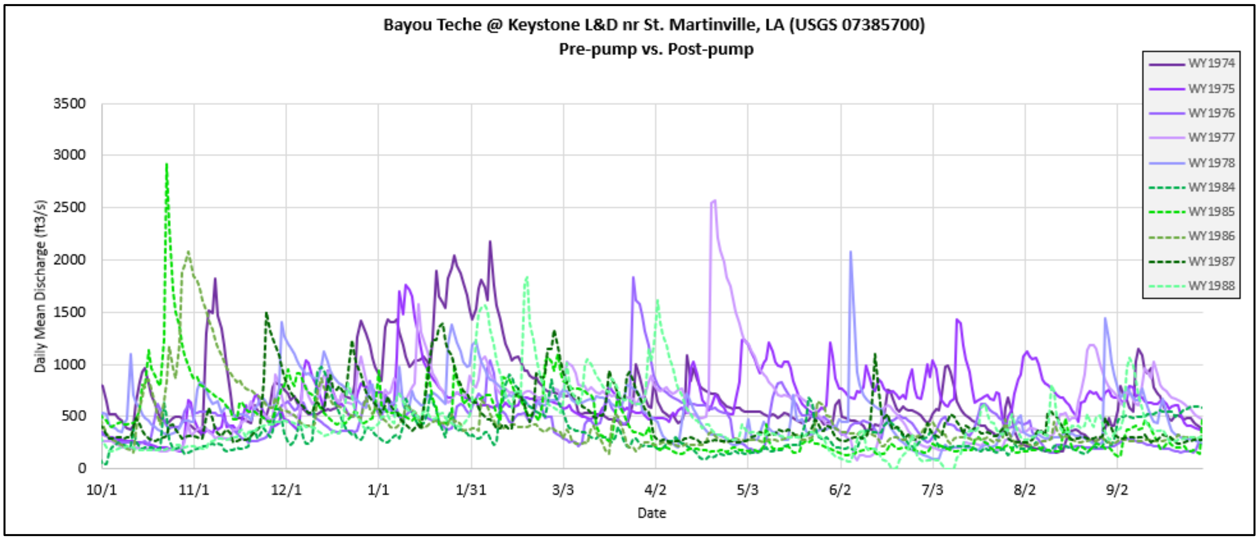

Figure 6. Comparison of pre-pumping station (purples) and post-pumping station (greens) daily mean discharge hydrographs.

Pre-pump station years held the highest average minimum overall, although post-pump station year 1988 had the lowest minimum value at 0 ft^3/s and the highest minimum value at 245 ft^3/s (6.94 m^3/s) (Table 2). The average maximum value was roughly the same, although post-pump station years held both the highest and lowest maximum values. Comparison of the average of each year's daily discharge shows the four of the five pre-pump station years were higher than the post-pump station years.

Table 2. Comparison of Pre- and Post-pumping station statistics in ft^3/s.

Water Year	1974	1975	1976	1977	1978	Avg	1984	1985	1986	1987	1988	Avg
Min	149	170	155	85	92	130	44	114	139	245	0	108
Max	2180	1760	1830	2570	2080	2084	971	2930	2080	1500	1830	1862
Mean	695	666	450	619	548		325	436	435	478	453	
Std Dev	382	256	217	355	276		174	320	298	257	307	

Regression Analysis

To further explore the pre- and post-pump station discharge regime, a regression analysis was run through Excel to determine the statistical significance separately in the years before and after the construction of the Teche-Vermilion pump station. A visual representation of this analysis initially seemed to suggest an overall reduction in flow pre-structure and an overall increase in flow post-structure year over year, but the statistical values did not support this finding (Figure 7).

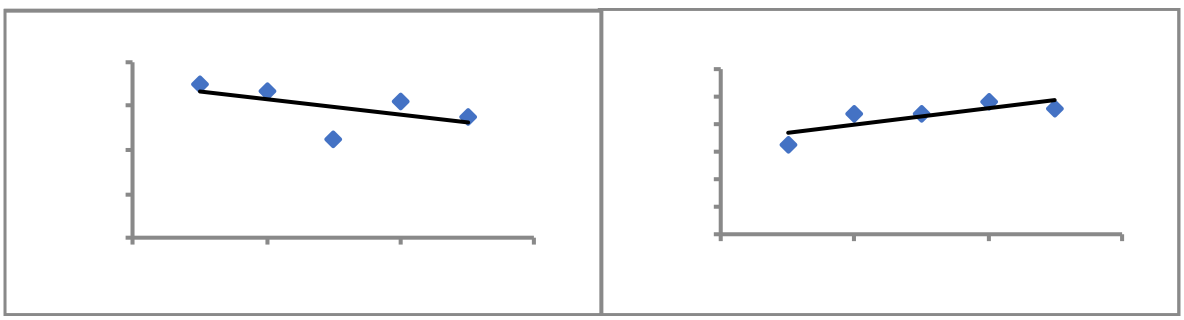

Figure 7. Linear regression graph of annual mean discharge of pre- and post-control structure with R-squared value.

The pre-control structure overall regression model is not statistically significant at the 5% level ($F_{1,3}$-=1.28, $p= 0.34$). The R-squared value is 0.2993, but the adjusted R-squared is 0.066, which adjusts for the number of predictors and indicates a very weak model fit. The post-control structure regression results R-squared value is 0.6429, and the adjusted R-squared is 0.524. However, the overall regression model is not statistically significant ($F_{1,3} = 5.40$, $p = 0.103$).

A multiple regression analysis was conducted to examine the relationship between the annual mean discharge of Bayou Teche pre- and post-control structure three independent variables: year, pre- or post-structure (using dummy values, where 0 represents pre-structure and 1 represents post-structure), and the interaction between year and control-structure. The dummy variables were included to test whether the slopes and intercepts between pre- and post-control structure periods differed significantly. The overall regression model was statistically significant ($F_{3,6}$ 5.78, $p = 0.033$), which suggests that at least one of the predictors is significantly related to mean annual discharge. The regression model included 10 observations and returned a multiple R of 0.862, indicating a strong linear relationship between the predictors and the annual mean discharge. The model explained 74.3% of the mean annual discharge variance, as shown by an R^2 of 0.743. The adjusted R^2 value was 0.614, indicating a moderate fit.

The intercept was significant ($b = 697.9$, $p < 0.0001$), indicating that when all predictors are zero, the expected value of the mean annual discharge is 697.9. The coefficient for year was -34.1, but it was not statistically significant ($p = 0.191$), suggesting that there is insufficient evidence to conclude that year has a meaningful effect on the dependent variable when considered alone.

The pre- and post-structure variable was statistically significant ($b = -361.9$, $t=3.33$, $p = 0.016$), indicating that transitioning from pre-structure to post-structure is associated with a decrease mean annual discharge and plays a significant role in explaining mean annual discharge (Figure 8).

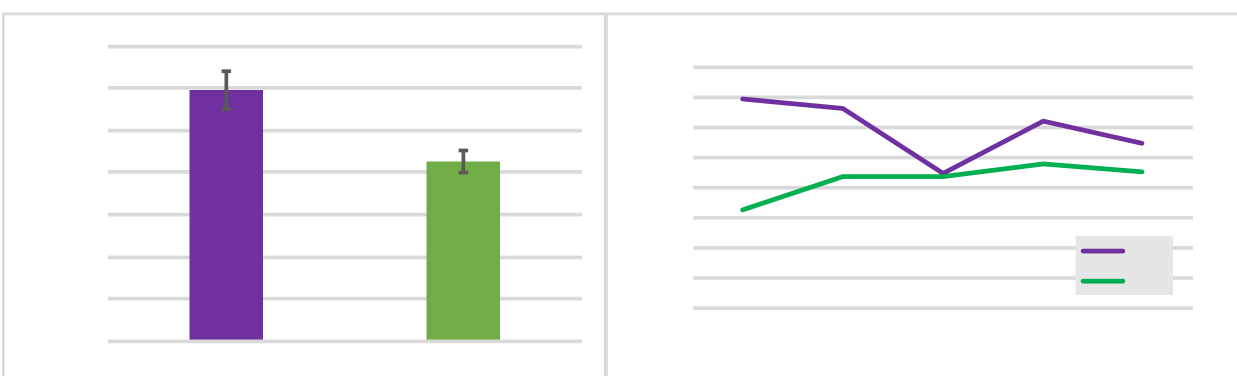

Figure 8. Pre- and post- control structure annual mean discharge with standard error.

The interaction between year and structure had a positive coefficient of 63.9, but was not significant ($t = 1.951$, $p = 0.099$), indicating that there is weak evidence against the null hypothesis that the rate of change (slope) in mean annual discharge pre- and post-structures is not different.

The standard error of the regression was 73.21, which indicates that the predicted values deviate from the observed values by an average of 73.21 ft^3/s (2.07 m^3/s). The 95% confidence interval for the intercept ranged from 510.03 to 885.77, reflecting the range within which the true intercept value is likely to fall.

DISCUSSION

Flood protection upstream, downstream, and along distributaries and tributaries frequently creates a domino effect of repeated mitigation, repair, and assessment. Bayou Teche, much like the rest of the hydrologic region, has undergone extensive modifications, improvements, and attempts to mitigate the detrimental effects of alterations to the watersheds discussed in this report. This complexity is reflected in the hydrographic analysis and review of discharge in this watershed.

Measures were taken to increase discharge and improve conditions in Bayou Teche, and its sister watershed of the Vermilion River, with the installation of the Teche-Vermilion Pumping Station. The post-pump station hydrographs and summary statistics did not reveal increased discharge at the location of the USGS stream gauge in Bayou Teche during the years of study. Findings indicated that flow diminished following the installation of the pump station. From year to year in both pre-control structure and post-control structure years, it did not appear to significantly affect the annual mean discharge. That is, time as a variable did not have a significant role in variation in discharge.

Pre- vs. post-structure as a variable did have a significant role in discharge, although not in the way one may expect, given the goal and function of the installation of the pumping station. Unexpectedly, flow significantly diminished post-control structure in the years studied. Potential factors that may have contributed to this outcome include increased water usage due to expectations of increased supply, precipitation rates, or other anthropogenic activities along associated waterways. Assuming stakeholders would be aware of the flow issues and plans for improvements, it may have been anticipated and acted upon once the pump-station came online.

The proportion of water that is pumped from the Atchafalaya River into Bayou Teche via Bayou Courtableau may be diminished along the way to such a degree that it is not measurable by the time it reaches the stream gauge located on Bayou Teche @ Keystone Lock & Dam near St. Martinville. Precipitation would be an interesting factor to investigate and could have a significant impact on flow rate (Biemans et al., 2009). Notably, a severe drought in the region began in 1988 and led to extreme low flows throughout the country (Trenberth et al., 1988).

CONCLUSION

The Bayou Teche Pump Station may not have solved the issues its installation intended to address when examining the evidence presented in my study. A hydrologic snapshot in a complex setting such as the Atchafalaya Basin nearly 50 years ago presents a certain set of challenges. Despite a lack of instantaneous data, a record drought during the period of interest, and continued anthropogenic activities limiting a wider-ranging time series, these results highlight the importance of accounting for other factors and considering the limitations of complex hydrogeomorphic settings. Policy and resource management goals may not have aligned with outcomes and implies a potential conflict. Improving stakeholder engagement may also improve sustainable water use. Future studies of this kind should keep in mind expectations and actualization in the planning phase and ensure goals are realistic and achievable by installing instrumentation in strategic locations, allowing for sufficient sampling time, and accounting for other factors before and after flow structures are put in place.

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APPENDICES

APPENDIX A

INDIVIDUAL HYDROGRAPHS

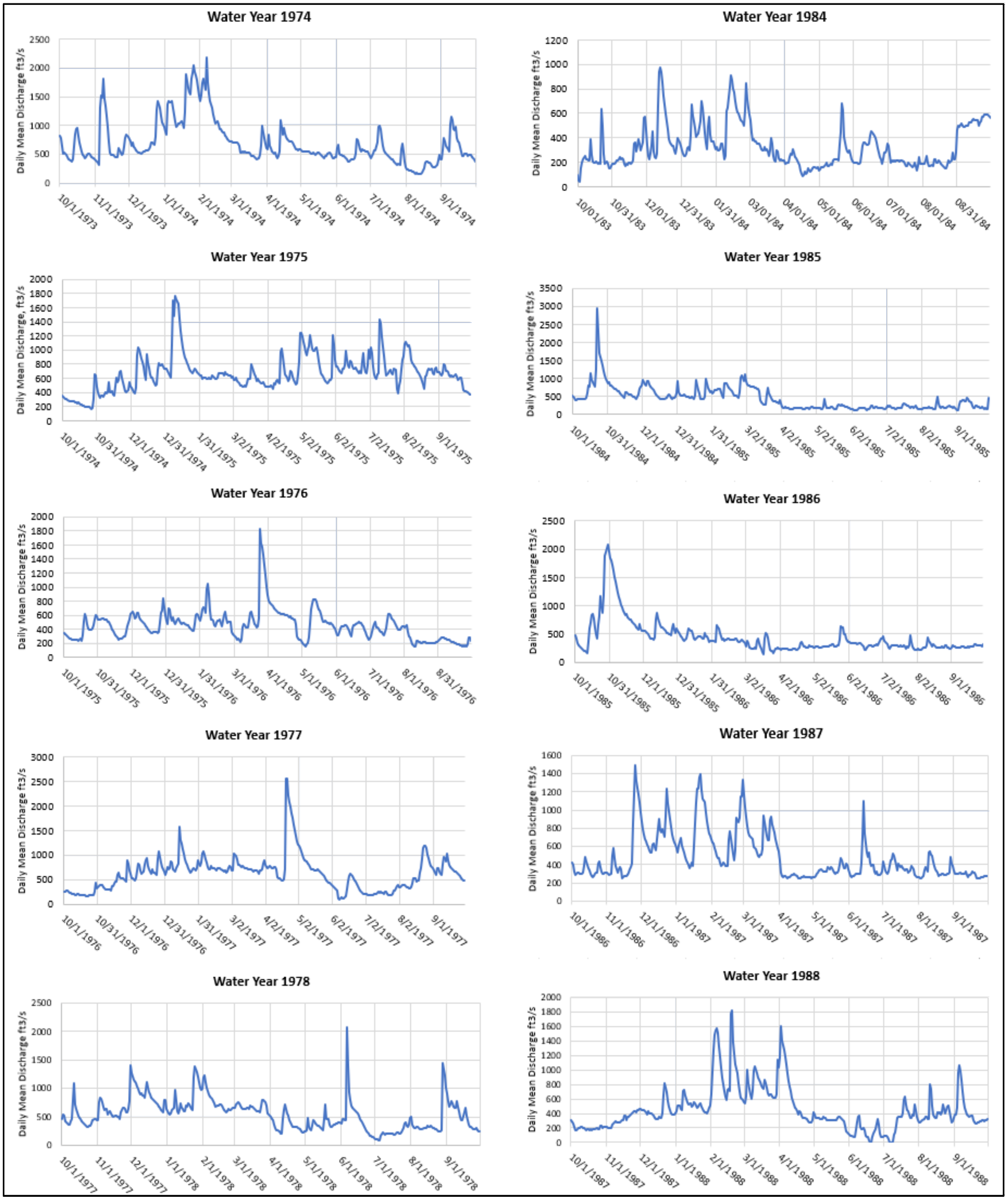

Figure A1. Bayou Teche @ Keystone L&D nr St. Martinville, LA (USGS 07385700) hydrographs of pre-pumping station (left column) and post-pumping station (right column).

APPENDIX B

RAW DATA OUTPUT

The following tables include the raw output from the Excel regression analysis used in this report.

Table B1. Summary output of linear regression analysis in Excel of pre-control structure.

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.547095747
R Square	0.299313757
Adjusted R Square	0.065751676
Standard Error	95.25597094
Observations	5

ANOVA

	df	SS	MS	F	Significance F
Regression	1	11628.1	11628.1	1.28151691	0.339921936
Residual	3	27221.1	9073.7		
Total	4	38849.2			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%
Intercept	663.8	73.78495782	8.996413627	0.00289918	428.9833336	898.6166664
Year	-34.1	30.12258289	-1.132041038	0.33992194	-129.9635026	61.76350263

RESIDUAL OUTPUT

Observation	Predicted Pre-control structure	Residuals	Standard Residuals
1	663.8	31.2	0.378208908
2	629.7	36.3	0.440031519
3	595.6	-145.6	-1.764974906
4	561.5	57.5	0.697019623
5	527.4	20.6	0.249714856

PROBABILITY OUTPUT

Percentile	Pre-control structure
10	450
30	548
50	619
70	666
90	695

Table B2. Summary output of linear regression analysis in Excel of post-control structure.

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.801805653
R Square	0.642892306
Adjusted R Square	0.523856408
Standard Error	40.54955816
Observations	5

ANOVA

	df	SS	MS	F	Significance F
Regression	1	8880.4	8880.4	5.400827	0.102711394
Residual	3	4932.8	1644.2667		
Total	4	13813.2			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%
Intercept	365.8	31.40955269	11.646138	0.00136	265.8407851	465.759215
Year	29.8	12.82289619	2.323968	0.102711	-11.0081786	70.6081786

RESIDUAL OUTPUT

Observation	Predicted Post-control structure	Residuals	Standard Residuals
1	365.8	-40.8	-1.161832
2	395.6	40.4	1.1504417
3	425.4	9.6	0.2733723
4	455.2	22.8	0.6492592
5	485	-32	-0.911241

PROBABILITY OUTPUT

Percentile	Post-control structure
10	325
30	435
50	436
70	453
90	478

Table B3. Summary output of multiple linear regression output in Excel

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.86193878
R Square	0.74293846
Adjusted R Square	0.61440769
Standard Error	73.2050772
Observations	10

ANOVA

	df	SS	MS	F	Significance F
Regression	3	92928.6	30976.2	5.780238167	0.033369466
Residual	6	32153.9	5358.98333		
Total	9	125082.5			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%
Intercept	697.9	76.77813274	9.08982773	9.95364E-05	510.0306771	885.769323
X (year)	-34.1	23.14947804	-1.4730354	0.191169058	-90.7447322	22.5447322
G (structure (0=pre, 1=post))	-361.9	108.5806766	-3.3330056	0.015747817	-627.587344	-96.212656
XG	63.9	32.7383058	1.95184199	0.098806322	-16.2077484	144.007748

APPENDIX C

BAYOU TECHE HYDROLOGY DIAGRAM

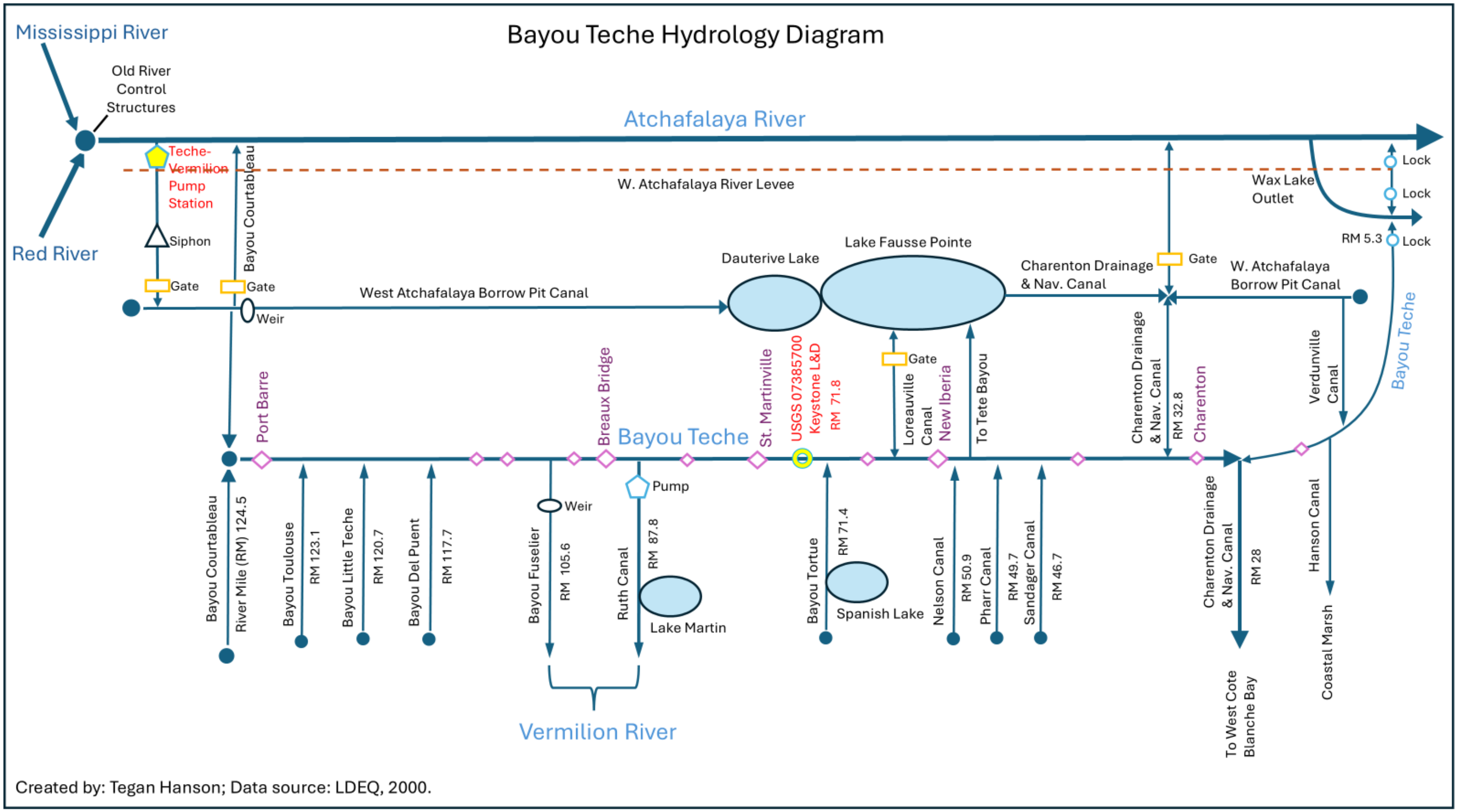

Figure C1. Enlarged diagram of Bayou Teche hydrology, connected systems and structures, and major towns.