Changing Climatic Conditions Affect Surface Water Quality in Southwestern Louisiana in the United States

Katherine Eddings[1], Durga D. Poudel[1,*], Timothy W. Duex[2],
Robert Miller[3] and J. Calvin Berry[4]

[1]*Environmental Science Program, School of Geosciences, University of Louisiana at Lafayette, Lafayette, Louisiana, USA*
[2]*Geology, School of Geosciences, University of Louisiana at Lafayette, Lafayette, Louisiana, USA*
[3]*Department of Civil Engineering, University of Louisiana at Lafayette, Lafayette, Louisiana, USA*
[4]*Department of Mathematics, University of Louisiana at Lafayette, Lafayette, Louisiana, USA*
E-mail: durga.poudel@louisiana.edu
[*]*Corresponding Author*

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Abstract

Climate change impacts on rising temperatures, changes on rainfall patterns, drought, flooding, sea level rise, glacier melts, and incidence of diseases and parasites are reported worldwide in recent decades. This study investigates the effects of changing climatic conditions – particularly air temperature and precipitation, on surface water temperatures and other water quality parameters, such as the conductivity, dissolved oxygen (DO), pH, and turbidity. A statistical analysis was performed on air temperature and precipitation data from 1980 to 2005 to determine the changing climatic conditions. The water quality data for four waterbodies in southwestern Louisiana was also

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analyzed to examine trends between the air temperature and surface water temperatures, precipitation and surface water temperatures, and precipitation and water quality parameters. There was an unexpected increase in surface water temperature with an increase in precipitation. As the precipitation and air temperature increased, so did the surface water temperature. This increase in surface water temperature was correlated with decrease in DO levels. The increase in precipitation also correlated with an increase in pH and turbidity in Bayou Plaquemine Brule. This study's findings could be utilized in a dynamic climate modeling system to provide more accurate predictions of climate change in southwestern Louisiana.

Keywords: Climate change, Louisiana, precipitation, temperature.

Introduction

Many watersheds in the United States are polluted due to nonpoint source pollution**.** This can be from numerous sources such as soil erosion, fertilizer and pesticide application, surface runoff, wildlife, and algal blooms (Poudel et al., 2020). The Environmental Protection Agency (EPA) created the Clean Water Act (CWA) in 1972 to reduce the pollution in the nation's water systems through Total Daily Maximum Loads (TDMLs). TDMLs are the total amount of each pollutant allowed to be discharged into a waterbody and is unique to each waterbody. Surface water quality is important because of the numerous uses it has including drinking water, recreation, agriculture, hydroelectric power plants, and transportation (Dunca, 2018). It also infiltrates down through soil and becomes groundwater, which is also used as a drinking water source and for agriculture irrigation (Essaid and Caldwell, 2017). However, the more use water has, the more substances enter the water, altering the physical, chemical and biological properties of the water (Yildirim and Balas, 2019). Surface water quality is heavily impacted by two major factors: climate change and human activity or management (Kundzewicz et al., 2007).

The Earth's climate changes regularly based on shifts in the Earth's orbit, solar activity and radiation and volcanic activity. Climate change is also significantly affected by human activity (Oreskes, 2004). The combination of an increase in burning fossil carbon, or coal, hydrocarbons and increased deforestation has resulted in increased amounts of carbon dioxide (CO_2) in the atmosphere. This in turn causes a greenhouse effect, leading to global warming (Kundzewicz, 2008). The warming temperatures due to climate change have major impacts on the hydrological cycle. The hydrological cycle is expected to accelerate, enhancing evapotranspiration, precipitation and intense precipitation (Kundzewicz, 2008). These changes in the regional water budgets can severely alter a region's ecology. For example, increasing precipitation on a grassland can develop that grassland into a forest. Increased precipitation in an arid region can lead to severe soil erosion (Kundzewicz, 2008). The deleterious effects from climate change can be further exacerbated by manmade infrastructure since water resources management has only recently begun to take possible climate changes into account (Kundzewicz et al., 2007). The effects, or relationships, between storm events and water temperatures are not fully understood and few studies regarding this topic focus on streams (Brown and Hannah, 2007). There has been a link made however, between precipitation events and an increase in pathogens in the water due to lower amounts of oxygen, which can be used in biodegeneration, the decay of organic matter by microorganisms (Kundzewicz et al., 2007).

Rising temperatures, both in air and on the surfaces of different water bodies, are commonly associated with climate change. Elevated temperatures can induce long term, far-reaching effects on rainfall, sea levels, and diversity in ecosystems (Blanchfield, 2019). It is well established in the literature that there is a direct relationship between the air temperature and surface water temperature because the surface water and air exchange heat (Minns et al., 2018). Matuszek and Shuter (1996) included an equation explaining this direct empirical relationship, which was used by Ngai et al. (2013) predicting the surface water temperature of Lake Tahoe, in California and Nevada, USA. Remote sensing is used in some studies to estimate surface water temperature of lakes and was used by Minns et al. (2018) to explain the influences of different lake and climate metrics to improve empirical models for predicting surface water temperatures of large lakes. These models are meant to enable more detailed regional assessments of climate change impacts on freshwater resources (Minns et al., 2018).

Temperature has been documented to greatly impact other water quality parameters, dissolved oxygen (DO) in particular. Increasing the surface water temperature leads to a reduction in the amount of oxygen that can be dissolved (Kundzewicz et al., 2007). DO is vital for aquatic ecosystems and must be maintained within an acceptable range for living organisms to survive. DO is often used as an indicator of water quality because it is a direct indicator of an aquatic resource's ability to support aquatic life. Water bodies with DO levels below 3 milligrams per liter (mg/L) are areas of concern and waters with levels below 2 mg/L are considered hypoxic, usually devoid of life (Collins et al., 2019). DO levels can fluctuate seasonally due to its inverse relation with temperature (Indicators: Dissolved Oxygen, 2016). An increase in surface temperature is also associated with algae blooms. The increase in surface water temperature is often due to an increase in sunlight and photosynthesis. This paired with excess nutrients leads to algal blooms and eutrophication. Eutrophication is especially common in agricultural watersheds because the canopy is cut for crops and the runoff typically carries nutrients from fertilizers (Nebgen and Herrman, 2019).

The effect of rainstorms on stream temperatures is a research focus that at times is contradictive. As cited by Brown and Hannah (2007), a study by Smith and Lavis (1975) in England and a study by Pluhowski (1972) in Virginia, found that rainstorms and heavy snowfall in the headwater stream were associated with decreased river and stream temperatures, respectively. Similarly, Chutter (1970) reported sharp decrease in stream temperature during summer hailstorms in the Vaal Dam basin, South Africa. In contrast, Shanley and Peters (1988) reported increase in streamwater temperatures following storm event in June 1987 in the Georgia Piedmont. Brown and Hannah (2007) addressed this in their research and found that about 75% of their sampled events showed a decline in temperature after storm events. They were not able to explain the other 25% of the sample which showed an increase in temperature after storm events.

While there are several studies about climate change relating to air and surface water temperature, the majority focus on lakes or oceans, such as Ngai et al. (2013). There are few studies regarding this topic on streams – particularly in subtropical coastal regions such as in southwestern Louisiana. This region has unique hydrological characteristics, such as an extremely low topographic gradient and numerous waterbodies, that prevent other studies or models from representing its impact on climate change effectively or accurately. This study will address three questions: (1) how the air temperatures and surface water temperatures related in southwestern Louisiana, (2) how the increase in precipitation may impact the surface water temperatures in this region, and (3) how the water bodies in this region would respond to precipitation events with regards to surface water quality. The hypothesis of this study is that the air and surface water temperatures will be positively correlated, increased rainfall due to climate change will lead to a slight decrease in surface water temperature, and that storm events will result in temporary and sudden decreases in surface water temperatures.

Materials and Methods

Study Area

Southwestern Louisiana has a subtropical climate which is primarily influenced by its subtropical latitude and proximity to the Gulf of Mexico. The Gulf of Mexico's average water temperature along the shoreline ranges from 64°F to 84°F. During the summer, the prevailing southerly winds bring moist, subtropical weather from the gulf which leads to thunderstorms. During the winter, there are occasional polar winds that bring cold continental air, resulting in sudden temperature drops. In 2018, the average monthly temperature in southwestern Louisiana ranged from 42°F to 92°F, and high temperatures averaged 83°F in the summer and 63°F in the winter months. The average monthly precipitation ranged from approximately 3.3 in. to 6.9 in, with an annual precipitation of 57.53 inches (Weather averages Lake Charles, 2020). Heavy rains cause flooding events annually, but flood control systems usually prevent major damages. Occasionally this region is in the path of tropical storms or hurricanes.

The four sampling sites that monitored water quality parameters were located on the Vermilion River in the Vermilion-Teche Basin within Lafayette parish, Louisiana (Figure 1). Monitoring data was taken at one meter depth from the surface when the water depth was more than two meter deep and at 50% of the depth from the surface when water depth was less than two meter deep with the YSI Sonde model 6820 with 650 MDS weekly and after storm events from October 2019 to February 2020. The YSI Sonde is a water quality monitoring instrument that can measure a number of parameters depending on which probes are attached. The instrument used in this study was capable of measuring the temperature, conductivity, turbidity, pH, and dissolved oxygen (DO). Calibration of the YSI Sonde was performed in the lab as needed. Table 1 shows the specific geographic locations of the sampling sites in Vermilion River.

Pre-Existing Data. The water quality data from Bayou Plaquemine Brule was collected weekly from April 2002 to March 2005. The data from Bayou Chene was collected weekly from August 2012 to October 2016 and the data from Lacassine Bayou was collected weekly from August 2012 to March 2015. The locations of the bayous are given in Figure 2. All three data sets were collected by the School of Geoscience at the University of Louisiana at Lafayette. Bayou Plaquemine Brule is an agricultural watershed used to grow rice, soybeans, cotton, cattle, and crawfish (Poudel, 2006). Bayou Chene and Lacassine Bayou are listed as impaired water bodies under the Clean Water

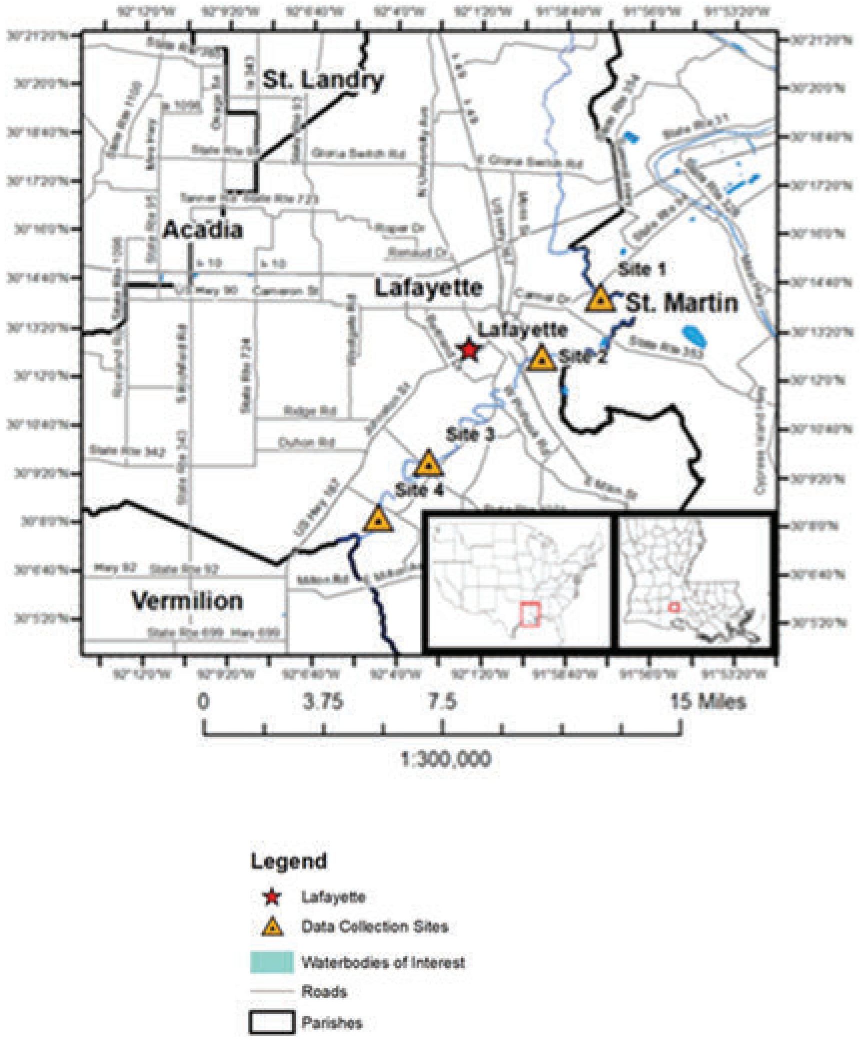

Figure 1 Map of the monitoring sites along the Vermilion River in southwestern Louisiana.

Act. In both bayous, one reason they were on the list of impairment was their low DO levels (Moore et al., 2014). The temperature and precipitation data for the Vermilion River was collected from the weather station at the Lafayette Regional Airport located on Surry St. The temperature and precipitation data for Bayou Plaquemine Brule, Bayou Chene and Lacassine Bayou for the years 1980 to 2001 were collected from the weather stations in

Table 1 The geographic locations of the four sampling sites in Vermillion River in southwestern Louisiana

Site	Longitude	Latitude
Beaver Park	30°12′53″ North	91°59′48″ West
Carmel Dr.	30°14′21″ North	91° 57′45″ West
Ambassador Caffery	30°09′46″ North	92°03′18″ West
South Side Park	30°08′21″ North	92°04′41″ West

Jennings and Welsh, Louisiana, and the data for the years 2002 to 2017 were collected from the H. Rouse Caffey Rice Research Station located on Caffey Rd. in Crowley, Louisiana.

Statistical Analysis

The weather data for the Vermilion River, Bayou Chene, Lacassine Bayou, and Bayou Plaquemine Brule was analyzed using Excel to determine trends and frequency of precipitation events. The DO, surface water temperature, conductivity, pH, and turbidity of each of the four waterbodies along with the air temperature and precipitation data from October through February were analyzed with Statistical Analysis Software (SAS). The trends and impacts of precipitation on the surface water temperature in this region were investigated with General Linear Models (GLM) to include different regression analyses and the CORR procedure to calculate the Pearson Correlation Coefficients and p values.

Results and Discussion

Storm Events

In Southwestern Louisiana flooding events are common given the extremely flat topography. Over the course of 25 years, 1980 to 2005, there were 61 precipitation events recorded at H. Rouse Caffey Rice Research Station that were more than 3 inches of rain fall in a single day, and nine days with 5 inches. There were also 18 hurricanes in Louisiana within this time period (Roth, 2010). The highest amount of precipitation in this time was 7.88 inches recorded on May 16th, 1980. The five highest precipitations events recorded include two hurricane events, Rita in 2005 (6.67 inches rainfall) and Juan 1985 (5.95 inches rainfall). The other three storm events were one in 1980 (7.88 inches rainfall), another in 1989 (6.92 inches rainfall), and the third

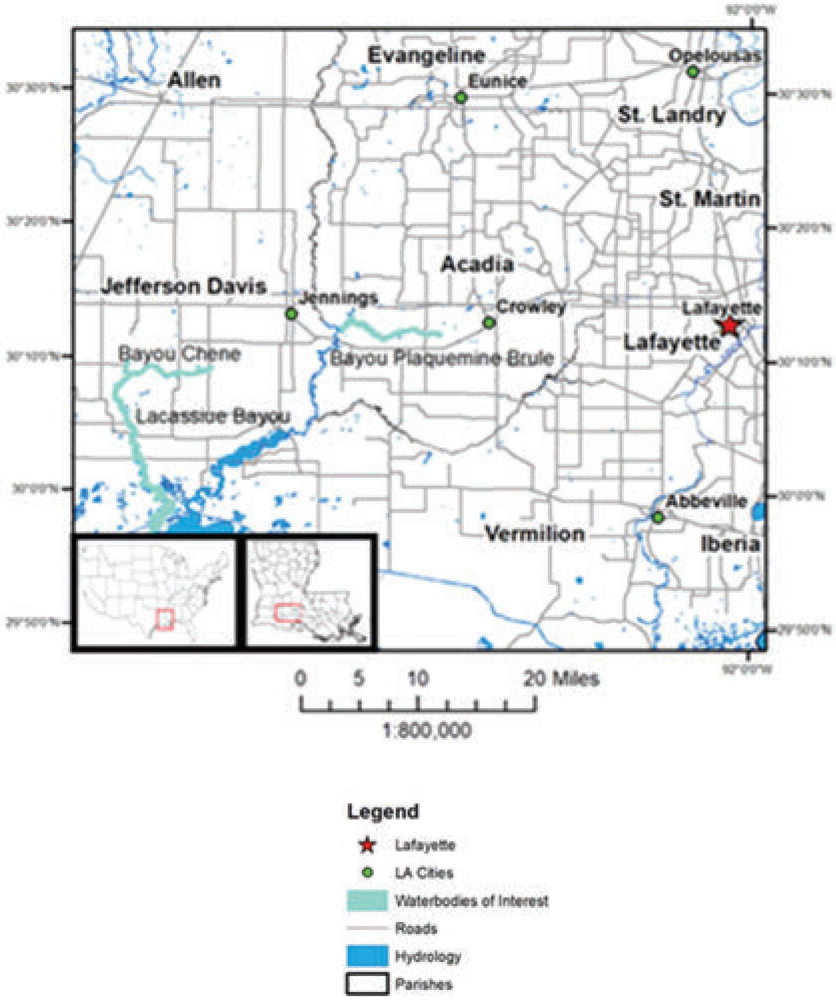

Figure 2 Map showing the locations of Bayou Chene, Lacassine Bayou, and Bayou Plaquemine Brule in Southwestern Louisiana.

one in 1996 (6.41 inches rainfall). An increase in the frequency and intensity of large storms such as hurricanes have been documented and attributed to climate change. Extreme weather events were rare in historic terms, but the United States experienced 14 in 2011 and 11 in 2012. An increase in tropical storms is predicted to continue as Earth's temperature and the ocean's temperature continues to increase each year (DiMento and Doughman, 2014).

Waterbody Water Quality

The water quality of Vermilion River, Bayou Chene, Lacassine Bayou, and Bayou Plaquemine Brule differed in certain water quality parameters (Table 2). The mean of the surface water temperatures of these waterbodies were all near 15°C with low ranges, standard deviations, and interquartile ranges. This suggests most of the surface water temperature readings were near 15°C. The conductivity of the Vermilion River, Bayou Chene and Lacassine Bayou had comparable means, medians, modes, ranges and interquartile ranges, which describes the distribution of the data. The mean and median of the conductivity of Bayou Plaquemine Brule, 478.77 μS/cm^3 and 395.00 μS/cm^3 respectively, were higher than the other waterbodies' mean and medians but the mode, 110.00 μS/cm^3, was not. This suggesting there were lower conductivity readings, but the higher readings were significantly higher. The large standard deviation of 657.49 μS/cm^3 suggests there was a wide spread of conductivity measurements. The mean, median, and modes of the pH of all the waterbodies were consistent near 7, with low interquartile ranges suggesting the measurements were rather consistent. The Vermilion River's pH had a relatively large range and standard deviation however, this suggests there were outliers. The mean value of the Vermilion River's DO was 9.09 mg/L with a relatively high standard deviation and range. The median and mode were lower than the mean, 7.53 mg/L and 7.10 mg/L respectively, suggesting most of the measurements were lower than the mean and there were a few high readings. The turbidity of all the waterbodies, except the Vermilion, had high ranges and interquartile ranges due to outliers. The Vermilion River's turbidity had a low standard deviation and the median, 46 NTU, was near the mean, 54.08 NTU, suggesting there was little spread in the measurements. The differences in the temperature, conductivity, DO, and pH may be due to differences in land use. The Plaquemine Brule, Bayou Chene, and Lacassine Bayou watershed are agricultural watersheds used to grow rice, soybeans, cotton, cattle, and crawfish (Poudel, 2006 and Moore et al. 2014). High runoff and soil erosion are common in agricultural watersheds (Pathak et al., 2016), and this erosion not only impairs water quality, but also harms wildlife and livestock, degrades aquatic habitats, and reduces reservoir storage. The monitored section of the Vermilion River is in an urban area. The turbidity spikes may be due to elevated suspended sediment concentrations from urbanized and agricultural tributaries, or sudden bank collapse or streambank erosion which can be caused by erosion undercutting stream banks (Zaimes et al., 2019).

Table 2 Mean, median, mode, range and interquartile range of the temperature, conductivity, DO, pH, and turbidity for the months from October through February of each the Vermilion River, Bayou Chene, Lacassine Bayou, and Bayou Plaquemine Brule in southwestern Louisiana

Waterbody	Water Quality Parameter	Mean	Median	Mode	Range	Interquartile Range
Vermilion River	Temperature (°C)	15.78 (+/−2.91)	15.31	11.64	11.31	4.19
	Conductivity (microS/cm^3)	219.54 (+/−93.05)	195.00	131.00	380.00	185.00
	DO (mg/L)	9.09(+/−4.14)	7.53	7.10	15.85	4.53
	pH	7.74 (+/−4.01)	7.26	7.40	31.64	0.41
	Turbidity (NTU)	54.08 (+/−33.75)	46.00	9.20	121.60	57.20
Bayou Chene	Temperature (°C)	15.6 (+/−5.53)	14.75	11.63	23.83	9.34
	Conductivity (microS/cm^3)	181.24 (+/−70.38)	169.50	143.00	416.00	93.00
	DO (mg/L)	5.67 (+/−2.74)	5.47	3.15	13.66	4.13
	pH	7.01 (+/−0.21)	7.02	7.00	1.55	0.25
	Turbidity (NTU)	166.14 (+/−126.39)	134.15	126.90	1170.00	101.00
Lacassine Bayou	Temperature (°C)	14.65 (+/−5.43)	13.89	12.20	24.13	8.02
	Conductivity (microS/cm^3)	172.38 (+/−80.22)	161.00	156.00	464.00	92.00
	DO (mg/L)	5.19 (+/−2.71)	4.97	3.60	12.96	3.68
	pH	6.98 (+/−0.31)	6.96	6.90	2.02	0.37
	Turbidity (NTU)	107.48 (+/−120.59)	72.00	65.70	1246.00	99.00
Bayou Plaquemine Brule	Temperature (°C)	14.86 (+/−4.70)	14.54	9.44	20.68	6.78
	Conductivity (microS/cm^3)	478.77 (+/−657.49)	395.00	110.00	1802.50	437.00
	DO (mg/L)	7.73 (+/−2.27)	7.88	6.46	12.16	3.07
	pH	7.57 (+/−0.59)	7.64	7.93	3.16	0.75
	Turbidity (NTU)	165.02 (+/−235.12)	89.95	21.40	2645.00	165.57

Air Temperature and Surface Water Temperature

Over the course of 21 years, the average air temperature in Southeastern Louisiana has remained consistent with seasonal variabilities (Figure 3). The average daily temperatures have a range of 106.78°F and the mean and median are relatively close at 19.56°F and 21.11°F respectively. This and the low standard deviation of 7.69°F suggests that variations in the data are consistent and closely grouped. Climate change has been documented to increase air temperature and increase the frequency and intensity of hurricanes, however the direct effects on average air temperature often take decades to show noticeable trends (DiMento and Doughman, 2014). The surface water temperatures of the waterbodies in the region showed mixed trends. The surface water temperatures of Bayou Chene had increasing trend (Figure 4) while that of Bayou Plaquemine Brule had a decreasing trend (Figure 5). These results indicate that it is possible that the stream temperature response to climate change is influenced by agriculture and other local activities in the watershed. As expected, the surface water temperatures of the waterbodies in the region had consistent seasonal fluctuations.

Bayou Chene, Lacassine Bayou, Bayou Plaquemine Brule, and Vermilion River all have positive correlations between the surface water temperatures and average air temperatures. Bayou Chene and Lacassine Bayou had the

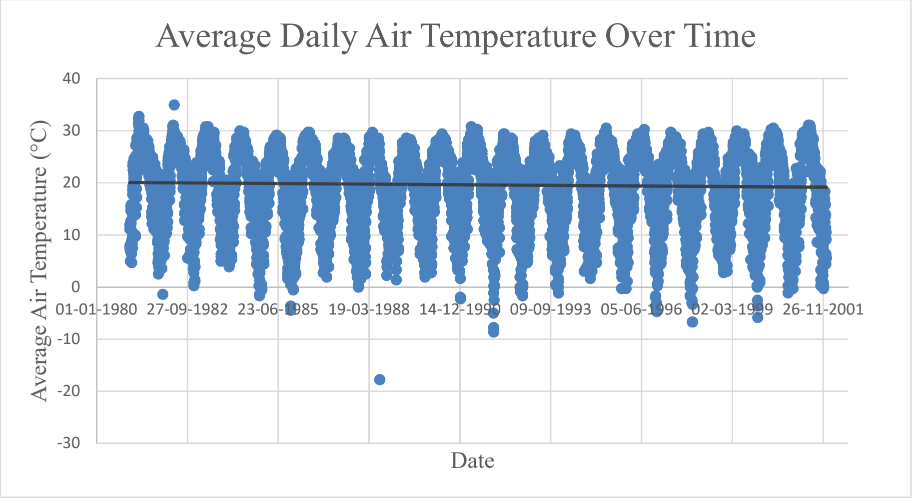

Figure 3 A scatterplot with a fitted line showing the daily average temperatures from January 1, 1984 to December 31, 2005 in southwestern Louisiana.

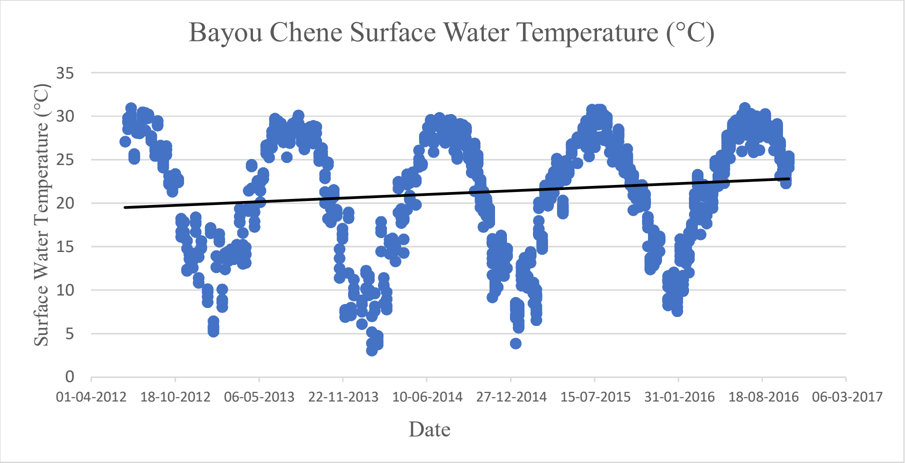

Figure 4 A scatterplot with a fitted line showing the surface water temperature in Celsius of Bayou Chene from June 2012 to July 2016 in southwestern Louisiana.

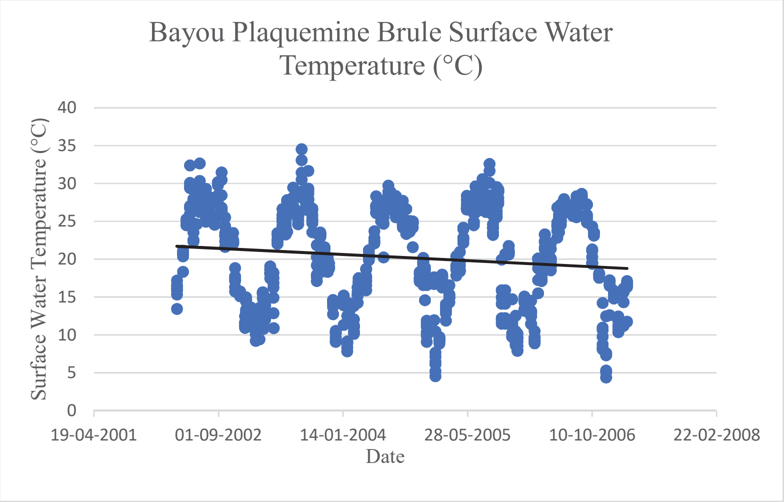

Figure 5 A scatterplot with a fitted line showing the surface water temperature in Celsius of Bayou Plaquemine Brule from March 2002 to March 2007 in southwestern Louisiana.

same slopes and intercept, and a large p- value of 0.1569, therefore are depicted by the same line in the model. The standard error, t-values, and 95% confidence levels are shown in Table 3. The low standard errors and narrow 95% confidence intervals support the accuracy of this analysis. The

Table 3 Parameter estimates (intercepts and slopes of the fitted lines), standard errors, y-value, and 95% confidence limits of the fitted lines of average air temperatures and surface water temperatures of the Vermilion River, Bayou Chene, Lacassine Bayou, and Bayou Plaquemine Brule in southwestern Louisiana

	Estimate	Standard Error	t Value	95% Confidence Limits	
Vermillion River	11.63	2.42	4.81	6.88	16.37
Bayou Chene and Lacassine Bayou	−6.56	0.35	−18.86	−7.25	−5.88
Bayou Plaquemine Brule	−5.34	0.82	−6.54	−6.94	−3.74
Vermillion River Slope	0.06	0.04	1.5	−0.02	0.15
Bayou Chene and Lacassine Bayou Slope	0.38	0.01	64.38	0.37	0.39
Bayou Plaquemine Brule Slope	0.34	0.04	23.93	0.31	0.36

*Vermilion River Slope, Bayou Chene and Lacassine Bayou Slope, and Bayou Plaquemine Brule Slope are the slopes of the fitted line showing the average temperature and surface water temperatures of the Vermilion River, Bayou Chene and Lacassine Bayou, and Bayou Plaquemine Brule, respectively in Figure 6.

mean of the surface water temperature in all events was 15°C and the R-Square for this model is 0.98. This suggests the surface water temperature is strongly dependent on the air temperature and they are positively correlated. The Vermilion River surface water temperature's correlation with the air temperature is weaker than the other waterbodies' relationships. This could be because there was less data collected from the Vermilion River. While the Vermilion River's data covered four months; all the other waterbodies had year-round data spanning multiple years.

The relationships between average air temperature and the surface water temperature for each waterbody is given by the regression equations 1, 2 and 3 given below. Equation (1) refers to the fitted line for Bayou Chene and Lacassine Bayou on Figure 6. The fitted lines on the graph were close enough for the slope and intercepts to be the same.

$$y = 0.38x - 6.56 \tag{1}$$

$$y = 0.34x - 5.34 \tag{2}$$

$$y = 0.06x + 11.63 \tag{3}$$

Equation (2) refers to the fitted line for Bayou Plaquemine Brule and Equation (3) refers to the fitted line for the Vermilion River on Figure 6.

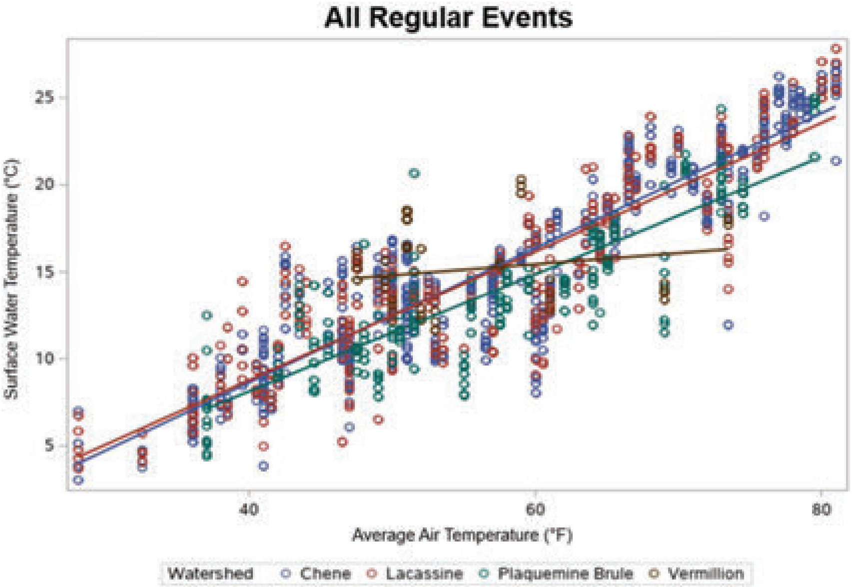

Figure 6 A scatterplot with a fitted line showing the average air temperature (°F) and surface water temperatures (°C) from October through February of the four waterbodies in southwestern Louisiana.

The x refers to the average air temperature and the y refers to the surface water temperature. This equation can be used to estimate the surface water temperature if the air temperature is given, or vice versa. The analysis of the average air temperatures and surface water temperatres in the precipitation events was seperated into two catigories inorder to include the precipitation events that were monitored the day after the event itself. On those events, the precipitation measurement was 0 dispite it being a precipitation monitoring event. Table 4 shows the regression equations assosiated with the fitted lines in Figures 7 and 8. The x values in these equations refer to the average air temperatures and the y values refer to the surface water temperatures in their resective waterbodies.

Precipitation Impacts Surface Water Temperature

The precipitation and surface water temperatures were analyzed with the precipitation measured greater than 0, and between 0 to 7 inches to demonstrate how unusually large precipitation events effect the analysis. The precipitation means of all the waterbodies in both the >0 and the >0 and <7 categories

Table 4 The regression equations of the fitted lines depict the correlation between the average air temperatures and the surface water temperatures of the Vermilion River, Bayou Chene, Lacassine Bayou, and Bayou Plaquemine Brule when the data was taken on the day of the precipitation event and when it was taken the day after the event

Waterbody	Data Taken	Regression Equation
Vermilion River	On the Day of Rain Event	$y = 0.13x + 9.53$
	Day After	$y = 0.09x + 9.87$
Bayou Chene	On the Day of Rain Event	$y = 0.36x - 5.62$
	Day After	$y = 0.40x - 7.26$
Lacassine Bayou	On the Day of Rain Event	$y = 0.37x - 6.10$
	Day After	$y = 0.37x - 5.79$
Bayou Plaquemine Brule	On the Day of Rain Event	$y = 0.43x - 9.80$
	Day After	$y = 0.33x - 4.52$

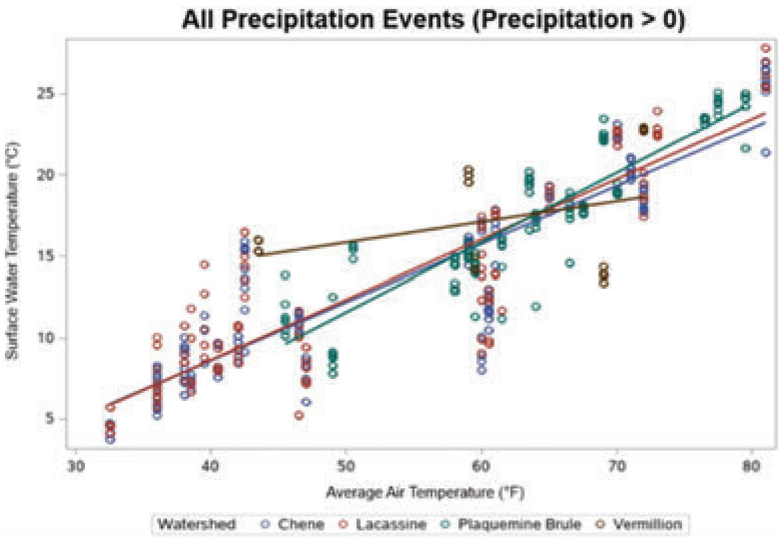

Figure 7 A scatterplot with a fitted line of the average air temperature and the surface water temperature of every precipitation monitoring event when the monitoring occurred on the day of the precipitation event from October through February.

were less than one inch with low standard deviations. Bayou Chene's and Lacassine Bayou's precipitation and temperature had the highest ranges in the >0 categories at 8.63 in, 8.63 in and 23.12°C and 12.73°C. The nearness of these bayous and the fact that the means and ranges are similar suggests there may have been one large precipitation event that occurred at both bayous

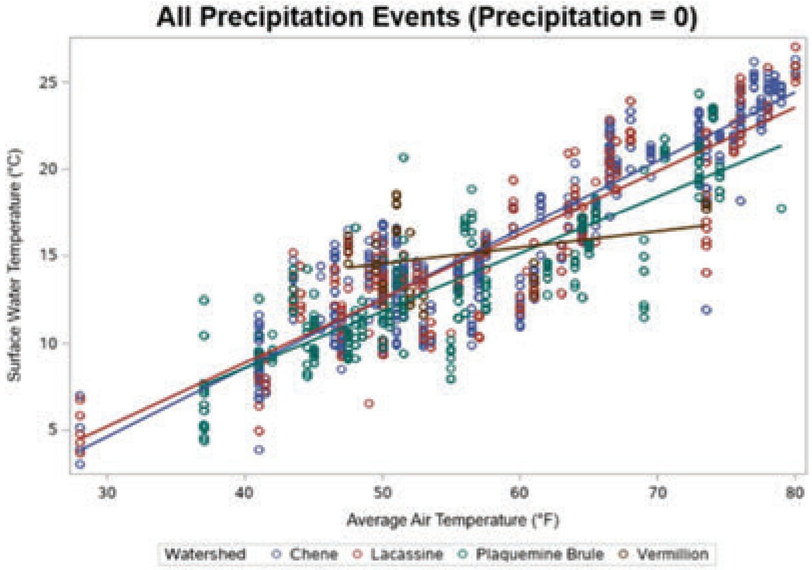

Figure 8 A scatterplot of the surface water temperature and average air temperature of every precipitation monitoring event when the monitoring event occurred directly after a precipitation event, resulting in the precipitation reading 0 inches from October through February.

Table 5 The Pearson Correlation Coefficients and p values of the surface water temperature and precipitation of the Vermilion River, Bayou Chene, Lacassine Bayou, and Bayou Plaquemine Brule in southwestern Louisiana

Waterbody	Precipitation (in)	N	Pearson Correlation Coefficients	p Value
Vermilion River	>0	19	0.874	<0.01
	>0 and <7	19	0.874	<0.01
Bayou Chene	>0	135	0.098	0.26
	>0 and <7	132	0.069	0.43
Lacassine Bayou	>0	100	0.181	0.07
	>0 and <7	95	0.387	<0.01
Bayou Plaquemine Brule	>0	110	0.119	0.22
	>0 and <7	110	0.119	0.22

and may have had similar effects on the temperature. There was little if any difference in the mean, standard deviations, and ranges of the precipitation and temperatures in the >0 inches and between 0 and 7 inches categories of Vermillion River and Bayou Plaquemine Brule. The precipitation and

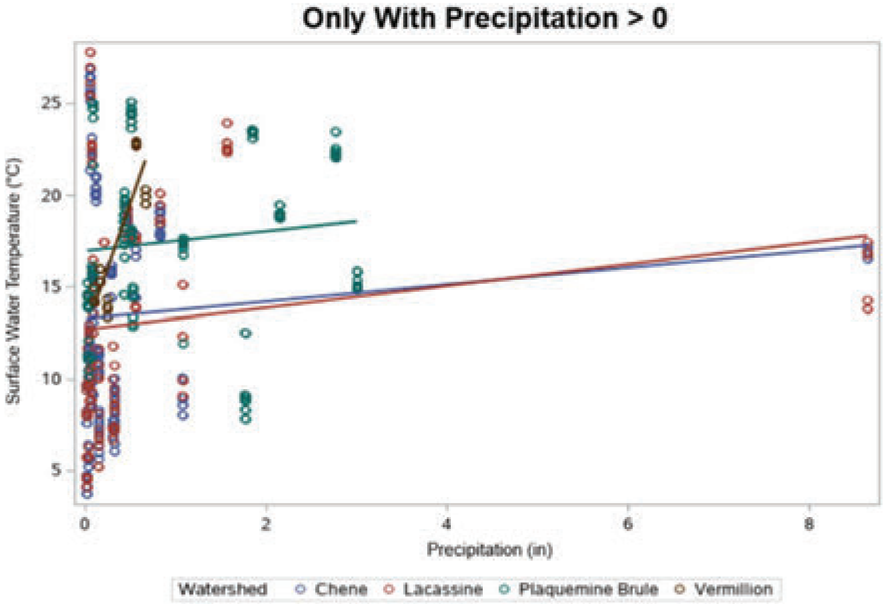

Figure 9 A scatterplot showing the surface water temperature of each waterbody in relation to the amount of precipitation during precipitation events from October through February.

surface water temperature of all the waterbodies were positively correlated (Table 5). The correlation from the Vermilion sites were stronger than the other waterbodies' in the analysis of sites with a precipitation greater than 0 inches, and between 0 and 7 inches with Pearson Correlation Coefficient values of 0.87 and 0.87, respectively. This may be because urban runoff tends to be at a slightly higher temperature than in rural areas due to the urban heat island effect (Kaplan, 2019). Figure 9 shows the relationships between the precipitation and surface water temperatures of each waterbody in all precipitation events and Figure 10 shows the relationships between the precipitation and surface water temperatures of each waterbody in precipitation events that had less than 7 inches of precipitation. The p values, shown in Table 5 of the Vermilion River in both the >0 and >0 and <7 categories and the >0 and <7 category of Lacassine Bayou were significant suggesting the correlation between the precipitation and surface water temperature was not due to random chance. However, the p values of Bayou Chene and Bayou Plaquemine Brule and the >0 category of Lacassine Bayou were not significant enough at 0.05 probability level to support the correlations between precipitation and surface water temperature.

Precipitation Impacts on Other Water Quality Parameters

Correlation analysis between the precipitation and conductivity values of the surface water showed a negative relationship between precipitation and conductivity values for Bayou Plaquemine Brule for both rain event categories and Lacassine Bayou for >0 in rain category at 0.05 probability level suggesting that an increase in rainfall amount results in the decrease in conductivity measure. This is likely due to the dilution effect. The conductivity of water is based on the ions present in it therefore, if the volume of water increases through precipitation and there is not much inflow in the amount of ions such as nitrate and phosphate through runoff water the conductivity would decrease. The correlations between the precipitation and conductivity values for other water bodies were either not significant or very weak. Similarly, the DO of Vermilion River for both categories of rain event and that of Lacassine Bayous for >0 to <7 inches rain category had significant negetive correlation at 0.05 probability level. The Vermilion River's DO had a steep negetive correlation with precipitation in both situations. The negetive correlation is believed to be due to the indirect relationship with temperature. As stated before, the surface water temperature was observed to rise with the precipitation which would result in a reduction in the DO levels. There could

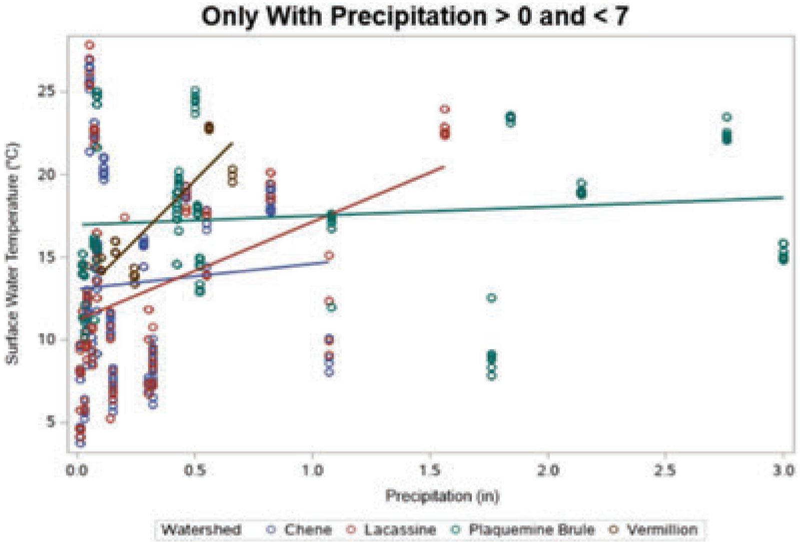

Figure 10 A scatterplot of the surface water temperature of each waterbody in relation to the amount of precipitation during precipitation events that had less than seven inches from October through February.

be several other factors, however, that may have influenced DO levels, which could not be identified in this study. This may include substances increasing the biological oxygen demand (BOD) entering the waterbodies though runoff resulting in lower DO levels. There was a significant negative correlation between the turbidity and precipitation for Vermilion River and Bayou Plaquemine Brule for both precipitation categories at 0.05 probability level. This means an increase in precipitation makes the water less turbid which is possibly due to the dilution effect. However, in most situations an increase in precipitation is expected to bring more sediments to waterbodies causing elevated turbidity levels. It is also possible that when swamps flood following storm events and the swamp water, which is low in DO primarily due to an accumulation of leaf litters and other organic materials coupled with high surface water temperature, mixes with the river water results in the reduction of DO levels. The p values of the Vermilion River and Bayou Plaquemine Brule were significant at 0.05 probability level suggesting the correlation between the percipitation and turbidity was not due to randomness. In case of pH, precipitation had a variable impact. While Bayou Plaquemine Brule showed significant positive correlation between precipitation and pH for both categories of precipitation, Bayou Chene showed sigficant negetive corelation between precipitation and pH at >0 category of precipitation. This may indicate that the effects of precicitation on the pH of surface water varies across the landscape. These watersheds are heavily in agriculture where the use of chemicals, such as nitrogen and phosphorous fertilizers would affect the pH (Elrashidi et al., 2008). This is likely the reason that Bayou Plaqumine Brule watershed which receives a large amount of fertilizer and the correlation is possitive.

The positive correlations between the air temperatures and surface water temperatures of all the waterbodies monitored in this study supports the fact that the global warming and changing climate is causing the stream temperatures to increase. The increase in surface water temperatures impacts several other aspects of water quality. The increase in surface water temperatures and turbidity and, decrease in DO levels in all studied waterbodies suggest that the aquatic ecosystems in this region will be detrimentally impacted by the changes in climatic conditions including precipitation and air temperature over time. These changes can lead to fish kills, impaired drinking water, an increase in algae blooms, and health risks in the form of an increase in pathogens (Kundzewicz et al., 2007). The changes in pH in some waterbodies can also lead to the death of aquatic species (Elrashidi et al., 2008). Those changes can also impact groundwater in the area.

Groundwater is commonly used for irrigation in agricultural areas and if the water entering the groundwater is a higher temperature, it can cause the stream surface water temperature to rise. This results in a positive feedback loop since the stream water often seeps back into the groundwater as recharge at an even higher temperature due to interactions with the air and precipitation (Essaid, and Caldwell, 2017).

Conclusions

The management of waterbodies in Southwestern Louisiana is important for the continued use of water as a resource in changing climatic conditions. Increased frequency and intensity of storms is just one of the many effects that climate change has on the ecosystem. As the precipitation and air temperature increased, so did the surface water temperature in the Southwestern region of Louisiana. This increase correlated with a decrease in DO levels. The increase in precipitation also correlated with the increase in turbidity. All four waterbodies showed a positive correlation between the air temperatures and surface water temperatures as well as precipitation and surface water temperature, supporting the hypothesis that the air and surface water temperatures would be positively correlated, however, the increase in surface water temperature with an increase in precipitation was not expected. Louisiana will need to implement water policies and adapt land use policies to help mitigate this decrease in water quality. In future studies, it would not be necessary to categorize precipitation events based on the amount of precipitation because it did not show significant results. This study could be used in a computer simulation dynamic modeling systems to better understand how increasing air temperatures can impact storm-induced stream temperature response and to predict how future changes in precipitation events may impact the ecosystem in this region. Accurate simulations on how the ecosystem is affected by climate change could reduce the time spent on adapting policies, promote sustainability, and help avoid adverse environmental impacts of land use change, urbanization, and flood mitigation practices.

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Biographies

Katherine Eddings earned her Master's of Science degree in Environmental Resource Science from the University of Louisiana at Lafayette, LA, USA, and Bachelor's of Science degree from Western Carolina University in Cullowhee, NC, USA. She currently teaches undergraduate Environmental Science classes for the University of Louisiana at Lafayette and taught previously at Horry-Georgetown Technical College. Her areas of interest are water quality, environmental restoration, and climatology. She has one four-legged, furry child named Cinna and enjoys hiking, traveling, reading, and spending time with Cinna.

Durga D. Poudel is a Professor of Environmental Science at University of Louisiana at Lafayette, Lafayette, USA. He received his B.Sc. degree in Agriculture from University of Agriculture, Faisalabad, Pakistan, M.Sc. in Natural Resource Development and Management from Asian Institute of Technology, Bangkok, Thailand, and Ph.D. in Soil Science from the University of Georgia, Athens, GA, USA. Dr. Poudel's professional experience consists of Research Fellow at Asian Vegetable Research and Development Center, Taiwan; Graduate Research Assistant in Sustainable Agricultural and Natural Resource Management Collaborative Research Support Program, University of Georgia, Athens, GA, USA; and Visiting Research Scholar, University of California Davis, USA. Dr. Poudel joined the University of Louisiana at Lafayette, USA, as an Assistant Professor of Soil Science in August 2000. Dr. Poudel is a Board of Regents Professor in Applied Life Sciences at the University of Louisiana at Lafayette, Louisiana, USA. As an Associate Editor, Dr. Poudel has been serving the *Strategic Planning for Energy and the Environment* journal since 2020. He is the Founder of Asta-Ja Framework and the Founding President of Asta-Ja Research and Development Center (Asta-Ja RDC) Kathmandu, Nepal, and Asta-Ja USA.

Timothy W. Duex has been at the University of Louisiana at Lafayette since 1984 where he is Associate Professor in the School Geosciences. He is a member of several professional societies, including the Lafayette Geological Society, in which he served as President, the American Association of Petroleum Geology, Division of Environmental Geology, where he is Secretary-Treasurer, the Geological Society of America, and the Baton Rouge Geological Society. He is also the University of Louisiana representative since 2001 on the Water Advisory Task Force of the Louisiana Department of Natural Resources. He teaches courses in Hydrology, Environmental Geology, Mineralogy, Petrology, and Field investigations.

Robert Miller is an assistant professor in the civil engineering department at the University of Louisiana at Lafayette, Lafayette, LA, USA. Dr. Miller's research focuses on numerical modeling in hydraulics and hydrology, coastal water quality, and mathematical biology. Prior to joining academia, Dr. Miller worked in the private sector for 11 years as a water resources engineer and project manager on numerous projects including site drainage design, FEMA flood zone mapping and floodplain management, environmental impact assessments, watershed master plans, and coastal restoration. Dr. Miller obtained his PhD in applied mathematics with an emphasis in structured population dynamics in 2015 from the University of Louisiana at Lafayette and is a registered professional engineer in Louisiana.

J. Calvin Berry is an associate professor of statistics in the Mathematics Department at University of Louisiana at Lafayette, Lafayette, Louisiana, USA. Dr. Berry received his Bachelor of Science (1978) and Master of Arts (1980) degrees in mathematics from the University of North Carolina at Greensboro, NC, USA. He received his PhD in statistics (1985) from Cornell University. After graduating from Cornell, he joined the faculty in the mathematics department at Northern Arizona University in Flagstaff, USA. In 1990, he relocated to Lafayette to join the statistics department at UL Lafayette, then University of Southwestern Louisiana. He teaches statistics at all levels, provides statistical advice to students and faculty, and conducts research in statistics.