False River
Watershed Council

An Annual Report to the Louisiana Legislature

April 2021

To the Distinguished Members of the House Committee on Natural Resources and Environment and Senate Committee on Environmental Quality of the Louisiana Legislature. and the People of the Great State of Louisiana

April 30, 2021

Dear Members:

We, the members of the False River Watershed Council, have completed this Annual report in accordance with House Concurrent Resolution No. 35 of Regular Session 2020. The original May, 2013 report was completed in accordance with House Concurrent Resolution No. 123 of Regular Session 2012 and updated in April 2018 in accordance with House Concurrent Resolution No. 52 of Regular Session 2017

Specifically, the False River Watershed Council has assembled and prepared this document, which presents the activities undertaken by the Council during the previous year, and lists the priorities for the upcoming year. It is the intent of this Council, interested stakeholders, and all those involved in the project to preserve, protect, and enhance the quality of False River, located in Pointe Coupee Parish, now and for generations to come.

The report includes the results of the completed False River Aquatic Resources Ecosystem Restoration Project - Phase II Project. We look forward to any further guidance or feedback as we press forward with the False River Aquatic Resources Ecosystem Restoration Project.

We appreciate the support of the Louisiana Legislature as we move forward with this plan of action.

Sincerely yours,

The Members of the False River Watershed Council

False River Watershed Fact Sheet

False River Watershed:

- Pointe Coupee Parish
- Total area: ~35,000 acres
- Area of "The Island": ~18,400 acres (53%)
  (defined herein as east of False River, South of False Bayou, north of the Chenal and west of the Mississippi River)
- Discharge Bayou drainage area (M-1 and associated canals): ~17,600 acres (50%)
- M-2 Canal and False Bayou drainage area: ~9,500 acres (27%)
- Cultivated area (2011): ~2,300 acres (7%)
- Developed area (2011): ~1,700 acres (5%)

False River (lake)

- Owned by the State of Louisiana
- Oxbow/horseshoe lake – abandoned (~1722) meander of the Mississippi River
- Area: ~3,100 acres (3,200 acres with associated wetlands)
- Shoreline: 117,000 feet (22 miles)
- Developed shoreline: 110,000 feet (21 miles)
- Pool stage: 16 feet above mean sea level (NGVD)
- Volume (pool stage): 67,300 acre-feet (22 billion gallons)
- Maximum depth: 65 feet
- Average depth: 21 feet
- Highest water level recorded: 23.2 feet (1983)
- Lowest water level recorded: 10.6 feet (2016)
- Primary Outfall - Lighthouse Canal Structure maximum capacity: 1,400 cfs (three roller gates)
- Lighthouse Canal Structure owned by LDOTD and operated by PCPJ
- Secondary Outfall - Bayou Sere invert eight: 15 feet (outflow start at 16.5 ft).
- Estimated sediment influx (2011 - NRCS RUSLE2 model): 21,000 tons
- South Flats Island: 16.5 acres (3,500 feet of shoreline)

Sources: LDNR, 2012 & 2017; NRCS, 2011 & 2017; USGS, 1999; LDWF, 2011 & 2016; USACE, 2011

Note: Front cover picture of the North Flats is courtesy of Professional Engineering Consultants Corporation.

Members of the False River Watershed Council

Richard Moses - Chairman
Director, Inland Fisheries Section
Louisiana Department of Wildlife & Fisheries
P.O. Box 98000, 2000 Quail Drive
Baton Rouge, LA 70898
Phone: (225) 765-2331/Email: rmoses@wlf.la.gov

Thomas Van Biersel, PhD - Vice Chairman
Senior Coastal Resources Scientist
Louisiana Department of Natural Resources
P.O. Box 44487, 617 North Third Street
Baton Rouge, Louisiana 70804-4487
Phone: (225) 342-1813/Email: thomas.vanbiersel@LA.GOV

Arthur Ewing
Appointed by the Pointe Coupee Parish Police Jury
P.O. Box 290, New Roads, La. 70760
Phone: (225) /Email: aoewing@gmail.com

Joey Breaux
Assistant Commissioner, Soil and Water Conservation
Louisiana Department of Agriculture and Forestry
5825 Florida Blvd.
Baton Rouge, LA 70821
Phone: (225) 922-1269/Email: joey_b@ldaf.state.la.us

Jacob Haffner, PE
District 2 Engineer, Office of Public Health
Louisiana Department of Health
P. O. Box 629, 628 N. 4th Street
Baton Rouge, LA 70821-0629
Phone: (225) 342-7395/Email: Jacob.Haffner@la.gov

Jimmy Chustz, PLS
Appointed by the representative from House District 18
Chustz Surveying, Inc.
211 Richy Street, New Roads, LA 70760
Phone: (225) 638-5949/Email: jchustz@chustz.com

Cy Daquila
Selected by the senator from Senate District 17
P.O. Box 866, New Roads, LA 70760
Phone: (225) 718-0506/Email: Cjdjr80@bellsouth.net

Jerry Hix
Appointed by the mayor of the city of New Roads
Phone: (225) 618-8867/Email: jdhix@aol.com

Mark Ward
Director
Pointe Coupee Parish Office of Emergency Preparedness
P.O. Box 248, East Main Street
New Roads, LA 70760
Phone: (225) 638-5400/Email: Mward@pcpso.org

Stephen Chustz
Appointed by the representative from House District 18
Phone: (225) /Email: chustz@msn.com

Bijan Sharafkhani, PE
Confidential Advisor to the Secretary
Louisiana Department of Environmental Quality
P.O. Box 4301
Baton Rouge, LA 70821-4301
Phone: (225) 219-3953/Email: Bijan.Sharafkhani@la.gov

Major Thibaut
Parish President
2004 False River Drive
New Roads, LA 70760
Phone: (225) 638-3811/Email: mthibaut@pcparish.org

Ron Pourciau
Selected by the senator from Senate District 17
President- Pointe Coupee B.A.S.S. Chapter
9512 Mary Louise St, Livonia, La 70755
Phone: (225) 240-9892/Email: ron.pouriau@wbrsheriff.org

Jeremy LaCombe
Representative – District 18
P. O. Box 370
Livonia, LA 70755
Phone: (225) 6378-3803/Email: hse018@legis.la.gov TVB Phone

Rick Ward, III
Senator – District 17
3741 Highway 1
Port Allen, LA 70767
Phone: (225) 246-8838/Email: wardr@legis.la.gov

Other Contributors to the Report

Brian Heimann
Biologist Manager, Inland Fisheries Section
Louisiana Department of Wildlife & Fisheries
P.O. Box 98000, 2000 Quail Drive
Baton Rouge, LA 70898
Phone: (225) 765-2337/Email: bheimann@wlf.la.gov

Gerald W. Babin Jr., P.E., Principal
Professional Engineering Consultants Corporation
7600 Innovation Park Drive
Baton Rouge, LA 70820
Phone: (225) 769-2810 / Email: gbabin@pecla.com

This report update is submitted to the Louisiana Legislature, specifically the House Committee on Natural Resources, and Environment and the Senate Committee on Environmental Quality, in accordance with HCR 35 of 2020.

Recent (since the May 2018 report to the legislature), and ongoing activities, concerns and maintenance issues by the False River Watershed Council (FRWC) are as follows:

1. *Dredging of the North Flats*

On January 23, 2020, the Pointe Coupee Parish Government completed Phase II of the False River Ecosystem Restoration project in the North Flats of False River (Figure 1). The project consisted of hydraulic dredging of the lake bottom (Figure 2) and pumping of the dredged sediment to a dewatering site 2 miles to the south (Figures 1 and 2). At the dewatering site, the dredged sediment was pumped into geotextile tubes where it was allowed to dewater, resulting in clear effluent flowing back into the lake (Figures 3 and 4).

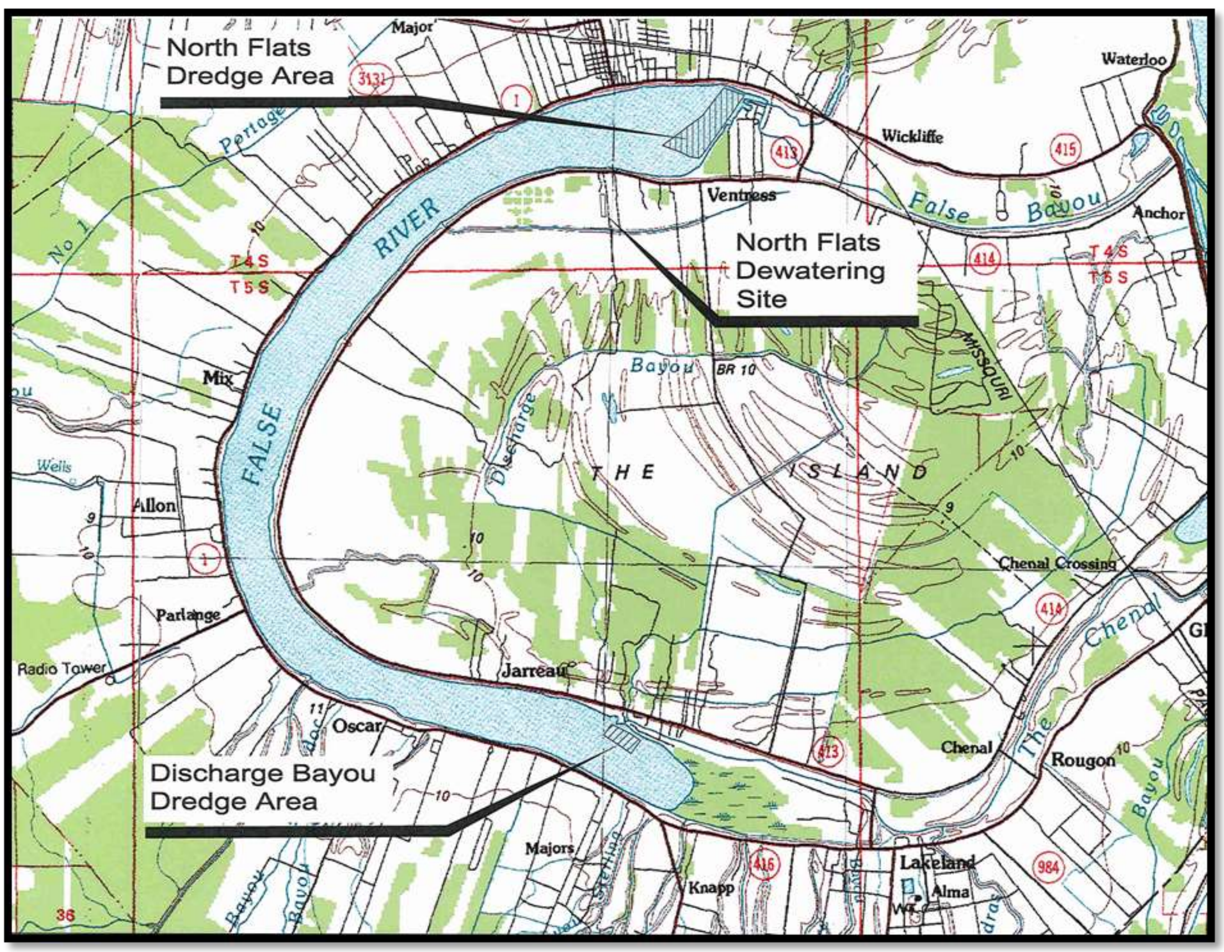

Figure 1: Location Map, False River Ecosystem Restoration, Phase II

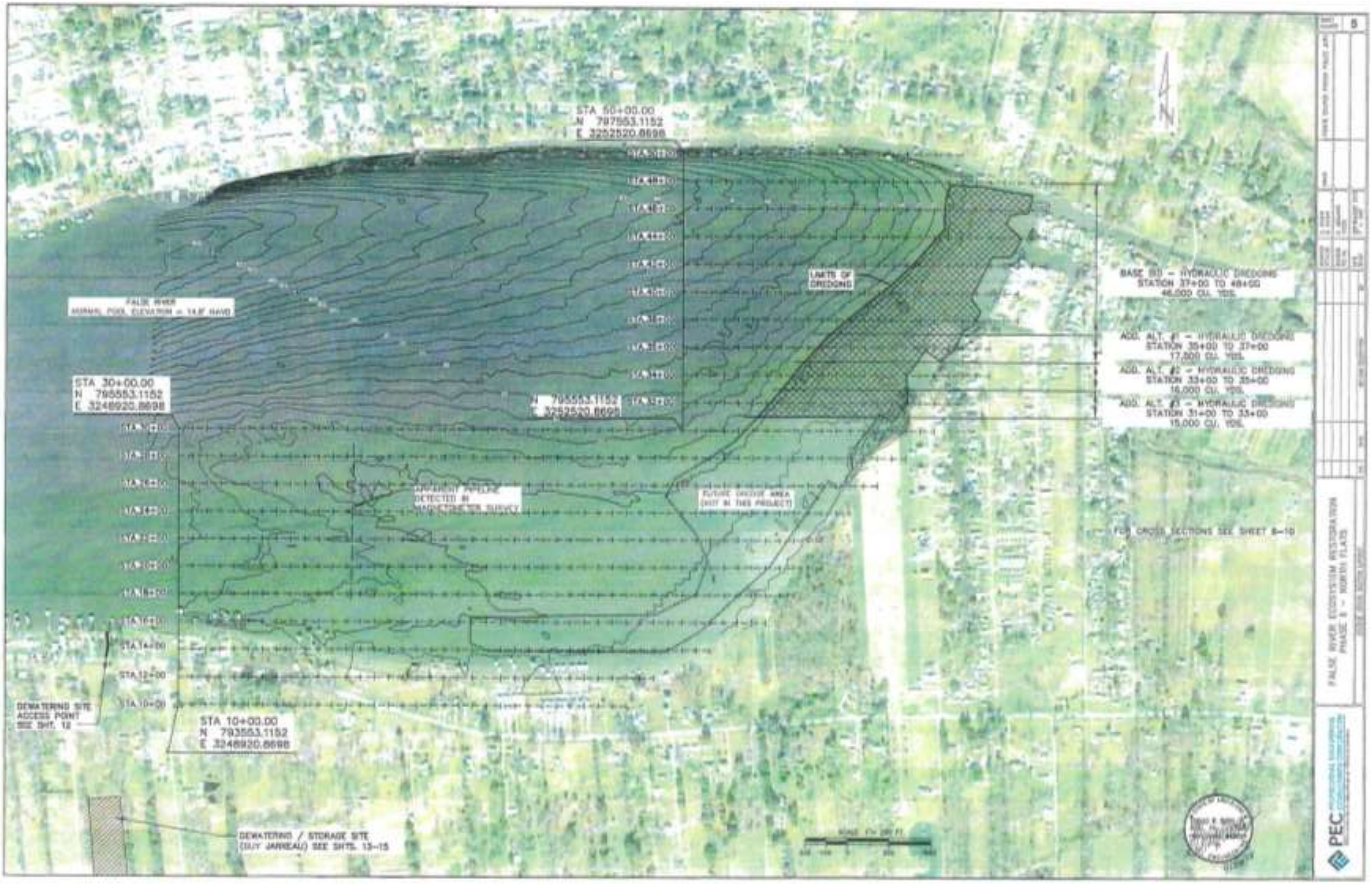

Figure 2: Map showing the limit of dredging in the North Flats and the dewatering site.

Figure 3: Location of the dredge material dewatering and storage site.

The project, which was awarded to Bertucci Contracting Company, LLC, began on January 28, 2019 with the construction of the dewatering berms and collection basins on a 12-acre site approximately 2 miles south of the dredge area. Within the constructed basins, geotextile dewatering tubes were laid out in rows with pipe headers attached to receive the dredged material (Figure 4). Ten-inch HDPE dredge piping was run from the dredge site along False River to the river exit point adjacent to the dewatering site and then under LA Hwy 413 to the basins (Figure 3).

Figure 4: Photographs of the dredge pipe header (left) and geotextile dewatering tube (right) at the dewatering site.

Hydraulic dredging of the North Flats of False River began on March 26, 2019. The dredging was performed by use of a 10” suction dredge with cutter head inlet (see cover page and Figure 5). The GPS control of the cutter head allowed dredging precision in the area outlined on the plans. Shallow areas of the North Flats, which ranged from 2 to 5 feet in depth, were deepened by the dredging to a minimum of 6 feet throughout the dredged area (Figure 2). From March through September of 2019, 66,000 cubic yards of bottom sediments in the North Flats were dredged, transported and dewatered through the geotextile tube dewatering system process. Approximately 22 acres of the North Flats were deepened by the dredging. The resulting sediment held within the geotextile tubes was allowed to dry and will be used as fill by the storage site owner (Figures 5 and 6).

Figure 5: Photographs of the dredge operations, the suction dredge in False River (top left) geotextile dewatering tubes being filled (top right) and an aerial view of the dewatering site (bottom).

By the end of September 2019, the storage basin had reached its capacity to hold additional dredged material. With project funds remaining, the Division of Administration, Office of Facility Planning approved the additional dredging at the mouth of Discharge Bayou in the South Flats. This area was not dredged during Phase I due to funding limitation at the time. In December 2019 and January 2020, the contractor removed 24,000 cubic yards of bottom sediment and placed this dredged material inside the existing sediment basin/island created in Phase I. The False River Ecosystem Restoration - Phase II project was completed on January 23, 2020 at a total cost of $1,730,915.15

Figure 6: Photographs of the dewatering tubes (left) and dried sediment (right) at the dewatering site.

2. Ongoing repair to the lake and Discharge Bayou shoreline

Discharge Bayou and M-1 Canal drains approximately 50 percent of the 35,000-acre watershed that enters False River. Several projects throughout the past 20 years have focused on the reduction of erosion of this important waterway. In 2019, after several rain events, the headwall at the outlet into False River failed (Figure 7), prompting the Parish to take emergency measures in order to prevent loss of land and structures to the flowing waters of Discharge Bayou.

Figure 7: Photograph of the headwall Failure in Discharge Bayou

False River Ecosystem Restoration - Phase III consists of replacing 325 linear feet of aged/failing headwall with a new steel sheet pile wall. The project has been designed and has received approval from the Division of Administration, Office of Facility Planning to proceed with procurement of a construction contract. Bids have been received and are scheduled to be opened on April, 28, 2021. The Engineer's Estimate on the headwall replacement is $1.65 million, which will be funded by Capital Outlay Appropriations of $ 1,210,123, as well as a Line Item Appropriation of $750,000 from Act 1 of the 2020 First Extraordinary Legislative Session. Construction is expected to be completed by Fall 2021.

3. Louisiana Watershed Initiative

The Pointe Coupee Parish government has been actively participating in the Louisiana Watershed Initiative (LWI). The initial phases of the initiative have been focused on modeling, governance structure, and data collection. Numerous stage and flow gage locations (data collection points) were submitted to LWI for consideration, however, none of the Pointe Coupee locations made the final cut of 100 gages throughout the state (Appendix A).

Currently, the process is turning toward more infrastructural projects. Through input from local stakeholders, numerous projects have been submitted or at least entered into the project inventory that would impact the False River watershed. Proposed projects submitted consisted of improvements to the False River Outfall Structure (aka Lighthouse Control Structure), False River Outfall Channel (aka Lighthouse Canal), and the South Pointe Coupee Pump Station. In addition, projects were submitted through Iberville Parish to improve the flow of Bayou Maringouin, which could help alleviate some flow issues occurring in the drainage of False River.

The Pointe Coupee Parish government has been working closely with the Upper Delta Soils and Conservation District on some of these major projects. They have procured the services of GIS, Inc. to assist with the engineering and application process. To date, no projects/funding which include the False River Watershed have been chosen.

Region 6 Project Inventory can be viewed on the following website: https://csrs-gis.maps.arcgis.com/apps/webappviewer/index.html?id=05f87e7dca9d4a37936de16cf775f500&extent=-10360353.3625%2C3354343.4624%2C-9790133.1315%2C3620038.5727%2C102100

4. Lake Habitat and Fisheries Update

Since 2018, the Louisiana Department of Wildlife and Fisheries (LDWF) Inland Fisheries has continued their sampling and stocking activities at False River. False River continues to be stocked annually with Florida strain Largemouth Bass (Table 1, and Figures 8 and 9). Other species are also stocked, although not on an annual basis. For a complete history of LDWF management of False River, please see the LDWF Waterbody Management Series for False River, parts MP-A and MP-B, accessible at: https://www.wlf.louisiana.gov/resources/category/freshwater-inland-fish/inland-waterbody-management-plans.

Table 1: Stocking efforts by species by year for False River, LA 2018 – 2021.

	Florida Largemouth Bass	Hybrid Striped Bass	Bluegill Sunfish	Channel Catfish	Black Crappie
2018	8,916	5,025	4,682		16,838
2019	6,090	16,430		7,240	
2020	6,080				
2021 (requested)	6,000				

Figure 8: Photographs of the stocking in False River

LDWF Inland Fisheries continues to sample the fishery of False River, utilizing a variety of gears and methods. All samples are performed per LDWF Inland Fisheries standardized sampling protocol. A summary of samples collected since 2018 is included in Table 2. Data collected from standardized sampling are utilized to analyze various characteristics of the fishery of False River. Figure 9 shows the catch-per-unit-effort (CPUE) of Largemouth Bass, captured by electrofishing. Since 2015, following regular water level reductions, dredging, and other improvements, CPUE of stock-size, quality-size and preferred-size Largemouth Bass have been increasing in standardized samples (Figure 10).

Table 2: LDWF sampling on False River, LA from 2018 – 2021.

	GEAR
2018	Electrofishing, 8 stations, spring & fall / Lead nets – 6 stations / Gill nets – 6 stations / Seine – 5 stations
2019	Electrofishing, 8 stations, spring only / Seine – 5 stations
2020	Electrofishing, 8 stations, spring & fall / Lead nets – 6 stations / Gill nets – 6 stations
2021 (scheduled)	Electrofishing, 8 stations, spring only

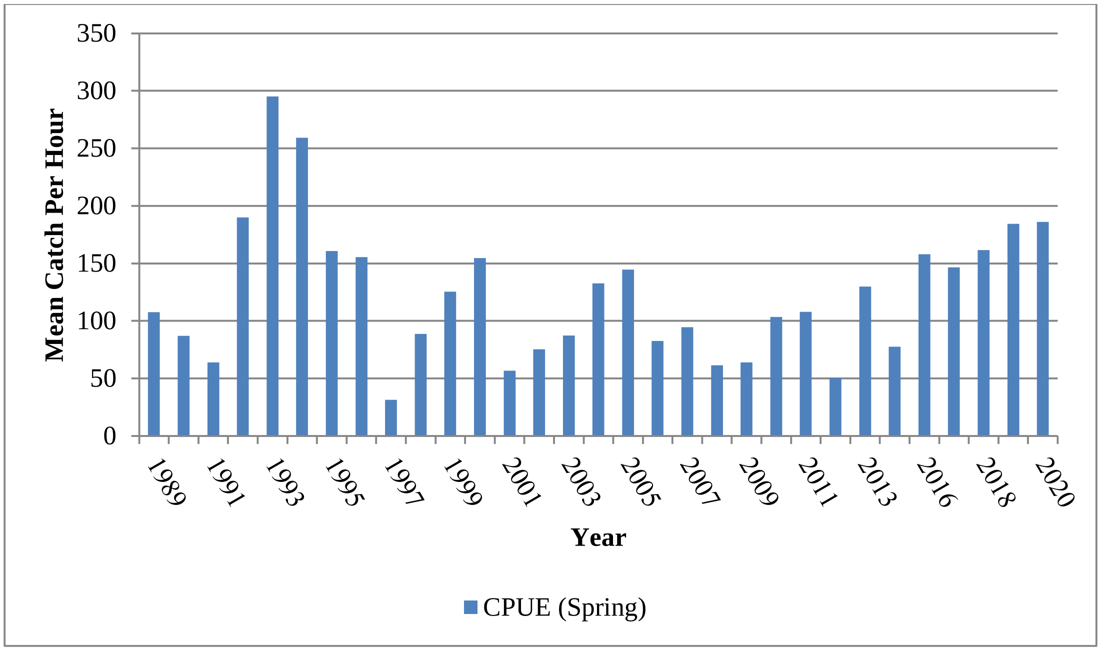

Figure 9: The mean CPUE in number per hour for Largemouth Bass collected from False River, LA, during spring electrofishing from 1989 to 2020.

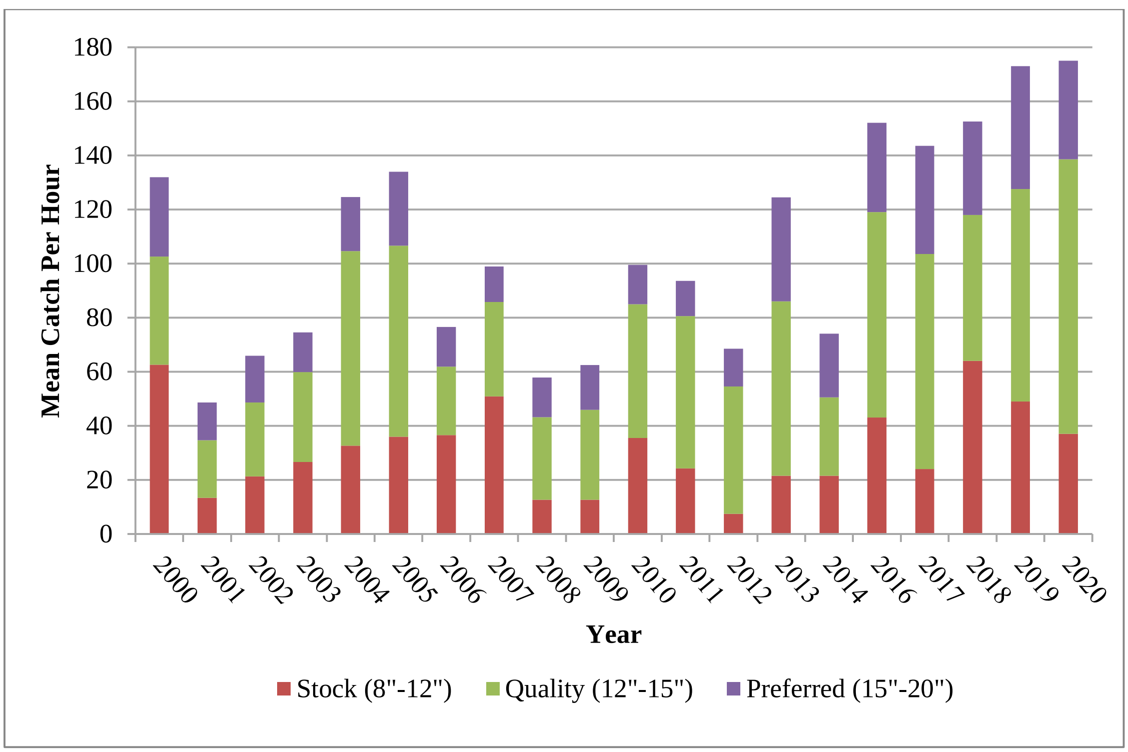

Figure 10: The mean CPUE for stock- (8”-12”), quality- (12”-15”) and preferred-size (15”-20”) largemouth bass collected from False River, LA during spring electrofishing from 2000 to 2020.

LDWF Inland Fisheries is responsible for managing freshwater fisheries resources through a variety of methods, including habitat improvement. One means of habitat improvement is the addition of complex cover for fish. It is known that anglers often enjoy increased success when they target objects that provide cover. In the spring of 2019 and 2020, LDWF Inland Fisheries staff hinge-cut approximately 500 yards of willow trees along the east bank of the island in the South Flats of False River. The trees were cut near-shore, along the bank, and allowed to fall into the water perpendicular to the shoreline. In the summer of 2019, LDWF Inland Fisheries created an artificial reef made of 120 structures in False River. The structures were constructed from scrap polyethylene pipe, and were placed in 6-9 foot depths in an area of the North Flats (Figure 11). Dense areas of cover can provide nursery habitat for young fish and ambush points for feeding fish. These downed trees and artificial structures will also be colonized by periphyton, which in turn is a food source for macroinvertebrates.

Figure 11: Photographs of the location (top) and material used (bottom) to create the artificial reef.

In 2019/2020, a drawdown was conducted for habitat improvement and sediment consolidation. The drawdown began on September 3, 2019 and ended on January 15, 2020. The lake reached a low level of 10.25' MSL in late November 2019, and remained below 12' MSL for the majority of the drawdown (Figure 12). The lake returned to pool stage by March 1, 2020.

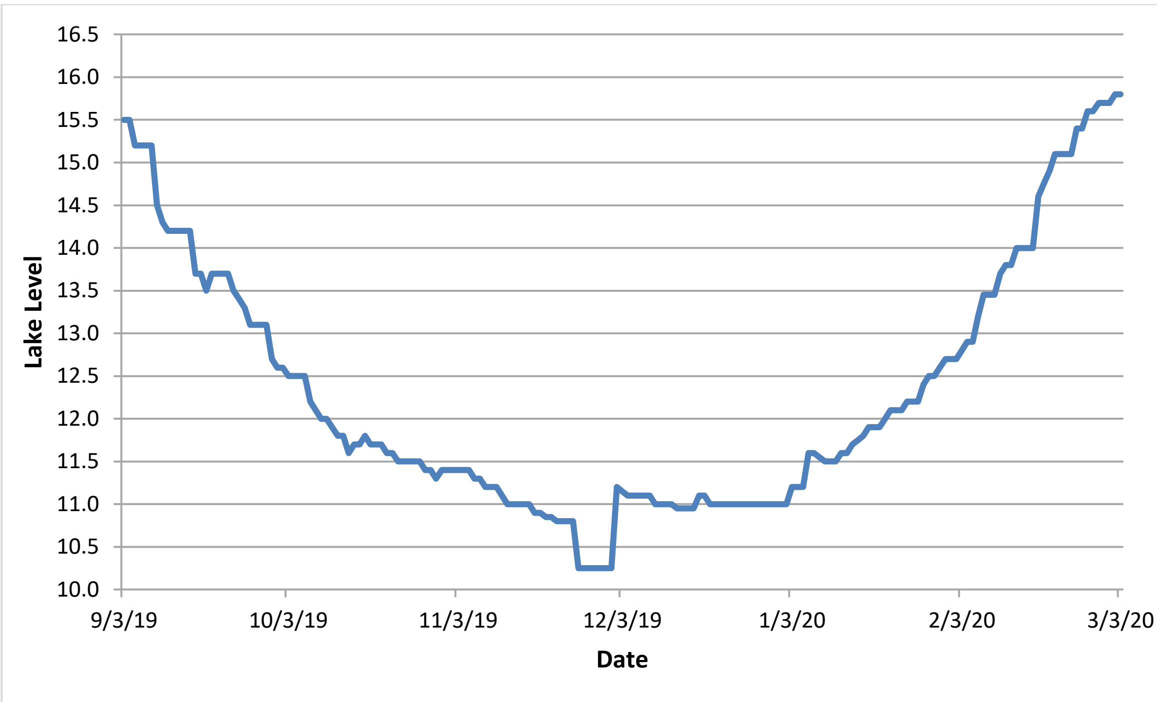

Figure 12: False River water level during 2019/2020 drawdown.

5. Lake Water Quality

Based on the 2020 Water Quality Integrated Report (IR), False River is currently impaired due to low dissolved oxygen (DO) and non-native aquatic plants. Low DO was first reported as an impairment in the 2018 IR. The following observations were made:

- The occasional low DO condition is thought to be caused due to the lake being relatively shallow and warm which can lead to occasional low DO conditions;
- There were only 2 criterion failures among 11 samples during the past two ambient monitoring cycles; 2015/2016 and 2019/2020 cycles. This results in a criterion exceedance rate of 18.2%, which is greater than the allowed 10.0% criterion exceedance rate. However, low DO is generally not a significant problem in False River
- DO concentrations have been stable and mostly above the criterion since at least 2020 (Figure 13).

Fecal coliform bacteria, a potential impairment to swimming and boating, has not been reported as an impairment since at least 2002; however, it will be impaired in the upcoming 2022 Integrated Report based on data collected during the 2019/2020 ambient monitoring cycle (Figure 14). The monitoring site for False River moved for the 2019/2020 monitoring cycle from the Pelican Yacht Club dock to The Sandbar restaurant dock, so it may be helpful to investigate if the new location is closer to sources of fecal coliforms.

Non-native aquatic plants have been reported as an impairment since at least 2002. This impairment is relatively common around Louisiana and may be exacerbated by elevated nutrient levels.

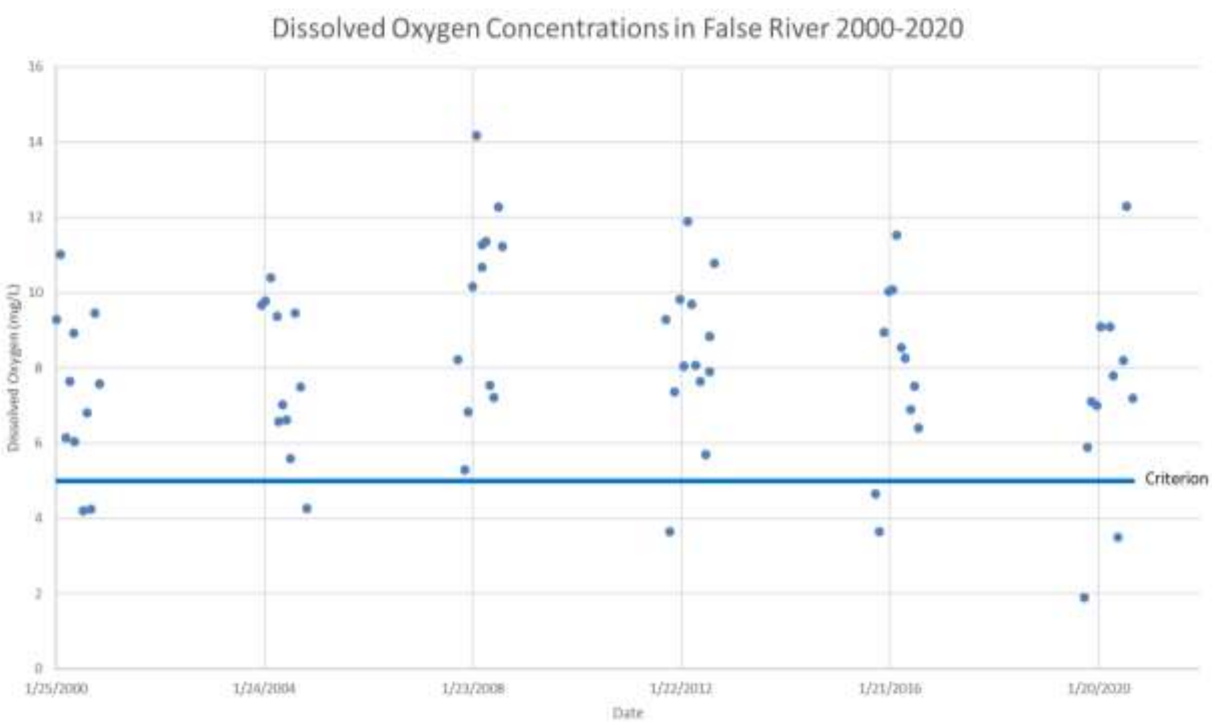

Figure 13: Dissolved Oxygen concentrations in water samples collected from False River between 2000-2020.

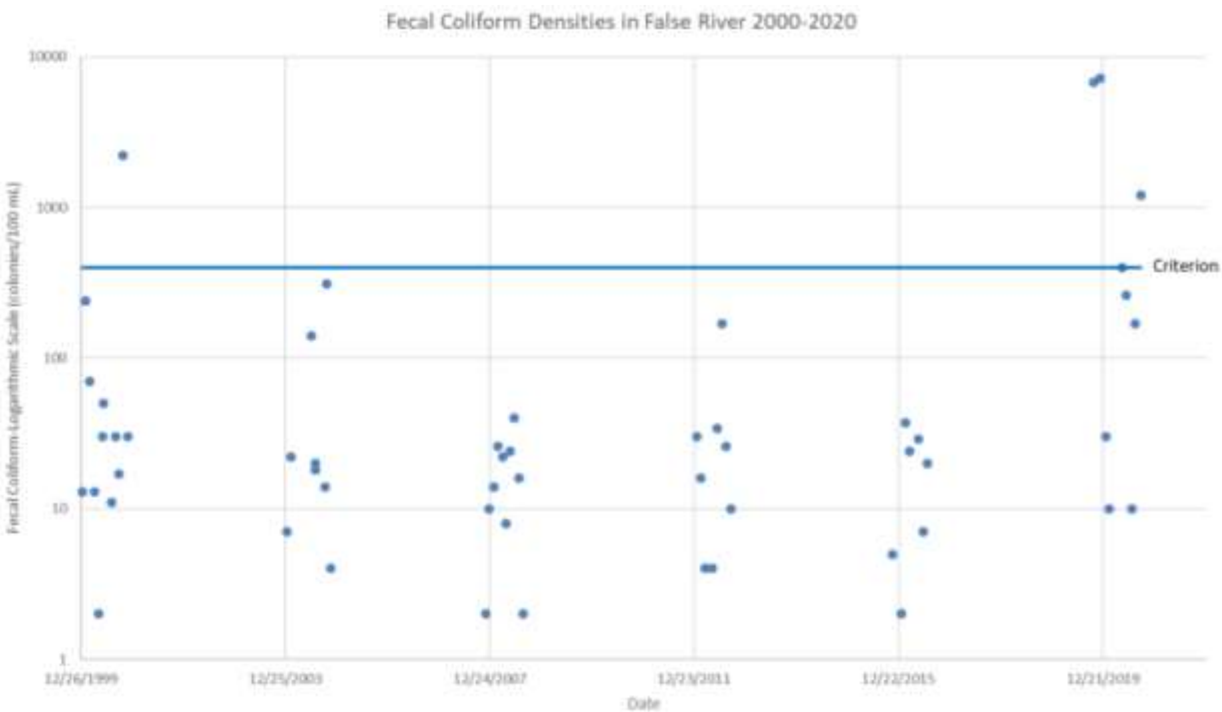

Figure 14: Fecal Coliform densities in water samples collected from False River between 2000-2020.

6. Lighthouse Canal Control Structure

The Parish Government has been in communication with the Louisiana Department of Development and Transportation (LDOTD) to discuss the condition of the Lighthouse Canal outfall structure. The structure condition has been steadily deteriorating the past few years although repairs have been made by the parish. The current structure was constructed by DOTD between 1947 and 1948, and modified in the early 1990s. The LDOTD is currently completing a study evaluating the control structure condition and what should be done to it.

The last major repair to the structure's gate was performed in 2015. Since then, portions of the bulkheads in the approach channel have been repaired. Currently, the structure has erosional issues along the approach and the structure (Figure 15), the bulkhead lining the approach channel to the structure are old and are continuing to fail, and, finally, one of the three gates has become for all practical purposes inoperable.

Figure 15: Photograph showing the erosion issues along the side of the control structure.

References:

False River Watershed Council, 2013. An Interim Report on HCR 123 of 2012 Regular Legislative Session: report submitted to the House Committee on Natural Resources and Environment and the Senate Committee on Environmental Quality, pp. 125.

False River Watershed Council, 2018. False River Watershed Interim Report on HCR 52 of 2017 Regular Legislative Session: : report submitted to the House Committee on Natural Resources and Environment and the Senate Committee on Environmental Quality, pp. 165.

Appendix A

DESIGN OF LWI RIVER AND RAIN GAGE NETWORK

LOUISIANA
WATERSHED
INITIATIVE

DESIGN OF LWI RIVER AND RAIN GAUGE NETWORK

TECHNICAL MEMORANDUM ON NETWORK DESIGN

November 2020

Authors: Emad Habib, Brian Miles, Mohamed Elsaadani and Robert Miller (University of Louisiana at Lafayette) & Ehab Meselhe, Mead Allisson and Kelin Hu (Tulane University)

With contributions from: Todd Baumann and Rodney Knight (USGS) & Jeff Graschel and David Welch (NWS)

LWI RIVER AND RAIN GAUGE NETWORK

TECHNICAL MEMORANDUM ON NETWORK DESIGN

INTRODUCTION

River and rain gauges are crucial assets for local communities and statewide decision-makers to understand where water flows and how it can lead to flooding. Many of Louisiana's watersheds do not have adequate gauge coverage (Figure 1), which can lead to a severe informational gap for mitigating future flood risk and responding to heavy or sustained rain events. Therefore, there is a need to enhance the existing monitoring network in Louisiana and support ongoing and future watershed management activities.

OBJECTIVES OF THE LWI RIVER AND RAIN GAUGE PROGRAM

The overall goal of the LWI River and Rain gauge program is to inform waterway and watershed management and improve the quality of life in and around the state. The following are two specific objectives of this gauge program:

1. *To support the calibration and verification of the LWI models that are currently under development:*

   The data generated from this network will support the calibration and verification of the LWI hydrologic and hydraulic flood models that are under development for all the state's watersheds. The network will provide near-term and long-term datasets and ensure that the models will be refined and maintained with up-to-date information that captures ever-changing environmental and meteorological conditions. Ultimately, this will help guide more accurate flood mitigation and adaptation policies, project evaluation and prioritization, and science-based watershed management.

2. *To support future development of flood warning and forecasting systems:*

   When fully developed, the gauge network will provide enhanced levels of statewide coverage for monitoring riverine and rainfall information in real time. Local communities will have information to respond more effectively to flood-related hazards, while the state's watershed regions can design and implement more effective mitigation strategies.

STUDY OBJECTIVES

The objective of this study is to develop a design for the LWI River and Rain Gauge network. The design of the network will focus on meeting the watershed-centered objectives of the LWI gauge program, while maintaining programmatic considerations. A primary constraint is the maximum number of gauges that can be afforded by the program from budgetary and logistical perspectives. The LWI and its partners have determined that the network design should recommend ~100 sites for new stream and rainfall monitoring gauges. The ~100 target sites will be dedicated to monitor three primary variables: stage, flow rates and rainfall. All 100 sites will contain a rain gauge; however, and due to resource constraints, only ~80 of these will be gauges that monitor streamflow rates, and ~20 will monitor stream stages only. To allow for possible site accessibility and logistic complications, the design analysis will identify an additional set of contingency gauges (~20). The new sites, when added to the existing network in the state, would result in a backbone network that addresses existing hydrologic monitoring gaps across the state and fulfils the needs of the LWI modeling and watershed management programs. Further enhancements to the state monitoring program will continue in the future according to new gaps that get identified by the LWI and its stakeholders.

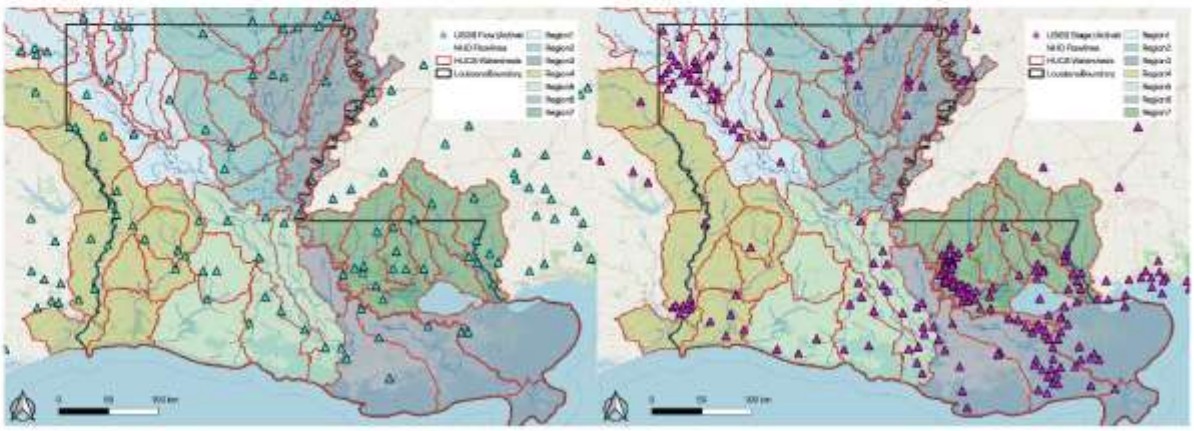

Figure 1. Distribution of existing USGS flow (left) and stage (right) gauges across Louisiana.

METHODOLOGY

SOLICITATION OF SUGGESTIONS FOR NEW GAUGE SITES

Gauge suggestions by LWI stakeholders and LWI Modeling Consultants

Regional and local experts, such as floodplain managers and engineers, have first-hand knowledge of their watersheds and where gauges are most needed to aid in mitigation and response efforts. It is important to incorporate existing expertise into the network's design and gauge placement. Therefore, the LWI launched web-based geospatial apps in February 2020 with the purpose of allowing local stakeholders and residents, state and regional partners, and LWI modeling consultants to suggest locations for new monitoring sites across Louisiana. Each of the seven LWI modeling regions were assigned two ArcGIS online web-based apps. The first type of apps was a crowdsource polling app that allowed users to provide their opinion on gauge locations that were initially proposed by the LWI program. The second app was a Geoform survey, which allowed stakeholders to propose new monitoring locations based on local and regional needs. The apps were disseminated to the LWI stakeholders and presented at several technical and public meetings. A webinar was also held to formally introduce the LWI stakeholders to the web-aps and encourage submission of gauge suggestions. The deadline for submissions was extended to allow further submissions from regions that initially showed a lower rate of suggestions (e.g., regions 1, 2 and 3). The LWI modeling consultants were also approached via the LA DOTD to solicit suggestions for new gauge locations based on future modeling needs.

Stakeholders who provided gauge suggestions and feedback to the web apps constituted a diverse population of backgrounds and affiliations, including the following:

- City and parish local governments and engineers (e.g., St. Tammany Parish, Tangipahoa Parish, and West Baton Rouge Parish Governments and city of Covington and city of Alexandria, City of West Monroe)
- Engineering consultants (e.g., Atkins North America, Freese and Nichols, C.H. Fenstermaker, Bluewing civil consulting, LLC, Michael Baker International)
- Police Juries (e.g., Calcasieu parish, Cameron parish, Bossier Parish, Ouachita parish police juries)
- Local drainage offices and city engineers (e.g., Amite River Basin Drainage & Water Conservation District, Teche-Vermilion Fresh Water District, Sabine River Authority, Iberville Parish Council Office, Caddo Levee District, and Lafayette Consolidated Government)
- State government agencies (e.g., Catahoula Parish OHSEP, LDWF)
- Federal government agencies (e.g., U.S. Fish & Wildlife Service)
- General public and individuals

A significant amount of feedback was received from various stakeholders through the web-based apps. A summary of the feedback received for each region via the crowdsource polling app and the Geoform surveys is provided in Table 1. Roughly a total of 100 stakeholders provided a total of 494 suggestions for new gauges (Figure 2). Regions 2, 4, 5, 6 and 7 received a considerable number of suggestions, with a fewer number submitted in regions 1 and 3.

Users who submitted feedback for the Geoform surveys were required to fill in the following fields:

- Name and contact information
- Affiliation
- Justification for the proposed location
- Level of need for the proposed location (critical, moderate, not critical)

Table 1. Summary of stakeholders' suggestions for new gauges and feedback on proposed locations received through the web apps.

Region	Number of Suggested Locations	Number of Likes	Number of Comments
1	32	35	31
2	78	10	0

3	32	0	0
4	70	24	3
5	114	16	16
6	104	5	16
7	64	17	2
Total	**494**	**107**	**68**

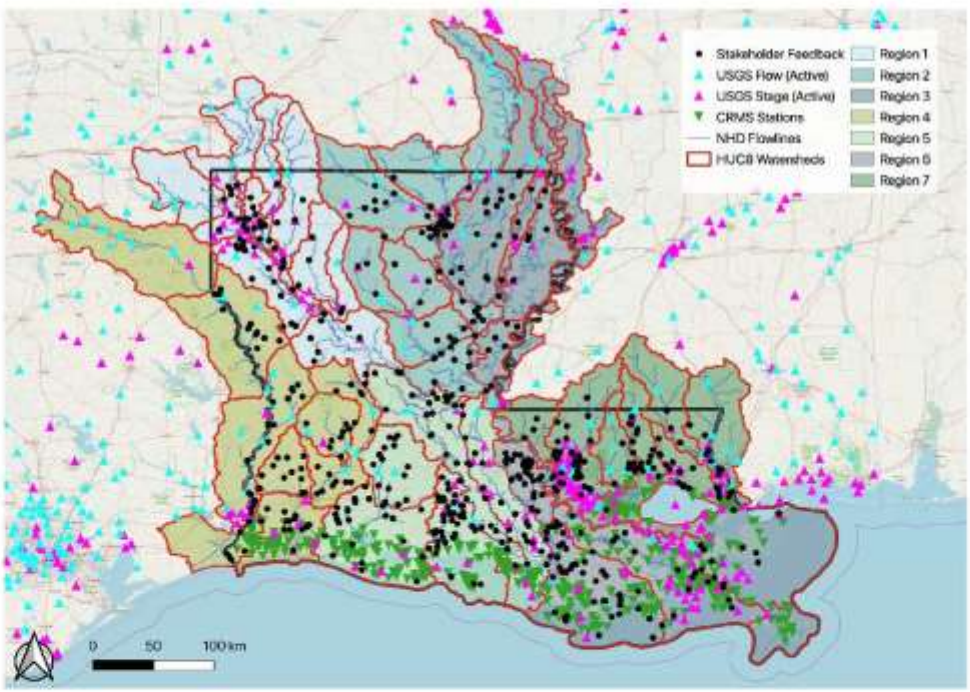

Figure 2. Suggested gauge locations (black) for all LWI regions mapped on top of existing USGS flow (cyan) and stage gauges (magenta) as well as Coastwide Reference Monitoring System (CRMS) stations (green).

Gauge suggestions by USGS and NWS

In addition to gauge suggestions from stakeholders, a list of locations (Table 2) in need of additional gauges was also submitted by the USGS (Figure 3) and the NWS (Figure 4) Lower Mississippi River Forecasting Center (LMRFC). The USGS identified and prioritized locations of historical gauges that have been discontinued. Discontinued gauges were classified based on recency of end date of their historical record. Accordingly, a total of 147 gauges with a record ending in 1970 or later were included in the gauge prioritization analysis (Figure 3). The USGS also suggested an additional set of 22 locations based on a multi-model statistical analysis that identifies possible gaps in areas with complex hydrologic regimes. The level of importance of these locations was described by the USGS on a scale from 0 to 4. Only gauges scoring 3 or 4 (red symbols in Figure 3) will be considered in the design of the LWI network. A similar map also shows gauge locations that were recommended by the NWS LMRFC (Figure 4). The NWS provided a total of 42 streamflow gauge locations that were classified into two categories based on forecasting needs. The first category represents locations where NWS issues river forecasts but currently lack gauges. The second category provided by the NWS is for non-forecast locations where stage-only gauges currently exist, but river forecasts would greatly benefit from additional information if flow observations were made available.

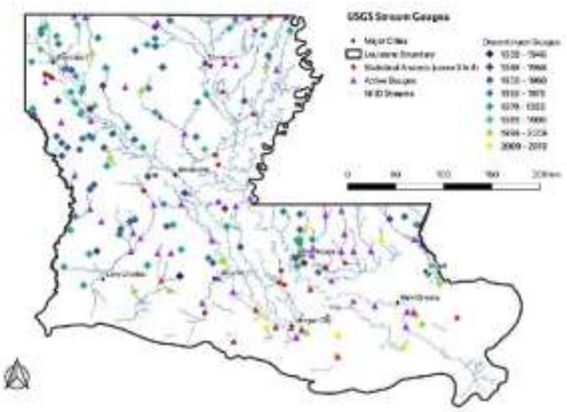

Figure 3. Locations of gauge suggestions provided by USGS, including discontinued sites, and sites based on multi-model statistical analysis. Locations of active USGS gauges are also shown for reference.

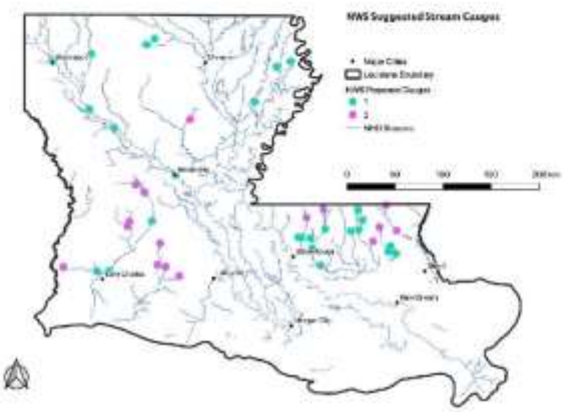

Figure 4. Locations of gauges recommended by the NWS classified into two categories, 1 and 2, that reflect different forecasting needs.

Table 2. Summary of suggestions for new gauges provided by USGS and NWS.

	USGS: discontinued gauges (1970 and later)	USGS: suggested based on multi-model analysis	NWS	Total
Number of suggested gauges	147	22	42	211

GAUGE SITE PRIORITIZATION

The total number of gauges suggested by the stakeholders is 494; however, upon further examination of these submissions, only 485 locations were deemed relevant. The other 9 gauges were excluded from any further analysis because they were either erroneous entries, redundant requests, requests for rain-gauges only, or requests for gauges on extremely small streams. Along with the gauge locations suggested by the NWS and the USGS (Table 2), there is now a total of 669 suggestions for new gauge locations throughout the state. To further narrow down the number of gauges that will be recommended for actual deployment by the LWI gauge monitoring program, additional site prioritization criteria are needed. In the next sections we provide a description of the selection methodology that were implemented to prioritize potential monitoring sites and produce a final design for the LWI network.

HUC8 watersheds lacking gauges

The first criterion used to select potential gauge sites was to identify HUC8s that are not currently monitored by any flow gauges. Figure 1 shows the distribution of existing flow and stage gauges across Louisiana; HUC8 watersheds that are not currently monitored by flow or stage gauges can clearly be seen. Given that the LWI modeling program plans to build coupled hydrologic and hydraulic models for nearly all HUC8 watersheds in the state, it is critical to model calibration and validation that each modeled watershed be monitored by at least one streamflow gauge. This set of gauged will labeled as "Tier 1" gauges.

Criteria-based automated gauge site scoring

Additional gauge selection, beyond Tier 1 gauges, will be performed using automated gauge prioritization criteria. The automated scoring is based on a set of quantitative hydrologic and geomorphic criteria that are relevant to watershed modeling flood risk. The automated criteria-based gauge site scoring is not designed to be the final word on gauge selection. Rather, it is intended to: (1) help focus expert evaluation of high-value gauging sites by filtering out lower-value gauges; and (2) help prioritize selection of gauges of seemingly identical value. All stakeholder-suggested gauges (except those that were not selected as Tier 1 gauges), as well as all USGS discontinued, USGS suggested, and NWS suggested gauges, were assigned a combined gauge score, GS, that represents a weighted average of a set of individual score elements, GS_j, as defined by equation (1):

$$GS = \frac{\sum_{j=1}^{n} w_j GS_j}{\sum_{j=1}^{n} w_j} * 100 \qquad (1)$$

Where w_j is the weight for gauge score element GS_j. Each score element represents a different watershed criterion as described in the following sections. For the current analysis, all weights were equal and assigned a value of 1; however, this formulation allows for further prioritization between the different scoring criteria. The weighted arithmetic mean of gauge scores was multiplied by 100 to yield possible gauge scores ranging from 0-100.

MEAN IMPERVIOUS PERCENT

GS_i is the gauge score that takes into account the extent of urbanization, using impervious percentage to prioritize gauge placement. Impervious surfaces can increase flood potential by reducing infiltration and increasing runoff. NLCD 2016 (Horner et al. 2016) percent impervious data were used to calculate the ratio of mean impervious percentage (Figure 5) in the HUC12 that the proposed gauge is located to the maximum impervious percentage for all proposed gauges in the parent HUC8 watershed. GS_i is defined in equation (2):

$$GS_i = \begin{cases} 0, & i < 1 \\ log\,(i)/log\,(max(i)), & i \geq 1 \end{cases} \qquad (2)$$

where i is mean NLCD 2016 impervious percentage in the HUC-12 that the proposed gauge is located in, and $max(i)$ is the maximum such impervious percentage for all proposed gauges in the HUC8 where the proposed gauge is located.

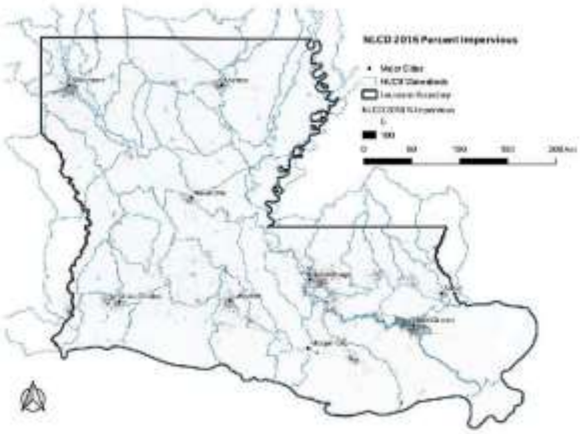

Figure 5. Percent impervious based on NLCD 2016

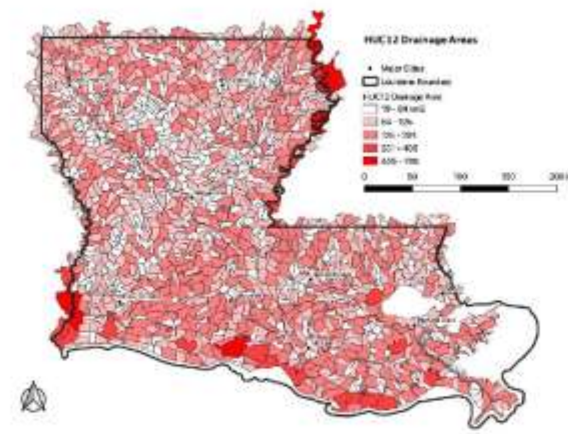

Figure 6. HUC12 drainage areas

CUMULATIVE DRAINAGE AREA

GS_a is the gauge score that takes into account the size of the drainage area (i.e., flow contribution) served by the proposed gauge location (Figure 6). The score is calculated as the cumulative drainage area of the NHD reach that the proposed gauge is located on scaled by the maximum cumulative drainage area for all proposed gauges in the HUC8 where the proposed gauge is located. GS_a is defined in equation (3):

$$GS_a = \frac{log\,(A_d)}{log\,(max(A_d))} \qquad (3)$$

where $max(A_d)$ is the maximum cumulative drainage area for all proposed gauges in the HUC8 where the proposed gauge is located. For reference HUC-12 drainage areas are mapped in Figure 6.

CHANNEL SLOPE

GS_{slp} is the gauge score due to NHD reach slope. Areas with flat slopes exhibit more complex flow regimes (e.g., reverse flows and backwater effects) and should be prioritized in gauge placement. Figure 7 shows the channel slopes across the state where low slopes are predominant in the northeast (i.e. Mississippi alluvial valley) and the coastal zone. The gauge score GS_{slp} was calculated as the slope of the NHD reach that the proposed gauge is located on scaled by the maximum such slope for all proposed gauges in the HUC8 where the proposed gauge is located. GS_{slp} is defined in equation (4):

$$GS_{slp} = \begin{cases} 0, \; slp \leq 0 \\ 1 - (log\ (slp * 1{,}000{,}000)/log\ (max(slp * 1{,}000{,}000))), \; slp > 0 \end{cases} \tag{4}$$

where slp is the slope of the NHD reach that the proposed gauge is located on, and $max(slp * 1{,}000{,}000)$ is the maximum such slope for all proposed gauges in the HUC8 where the proposed gauge is located. Note that some of the suggested gauges do not lie on the NHD flowline network. This meant that channel slope information was not readily available for these gauges, thus the score due to stream reach slope GS_{slp} was not factored in the calculation of the overall GS for these gauges.

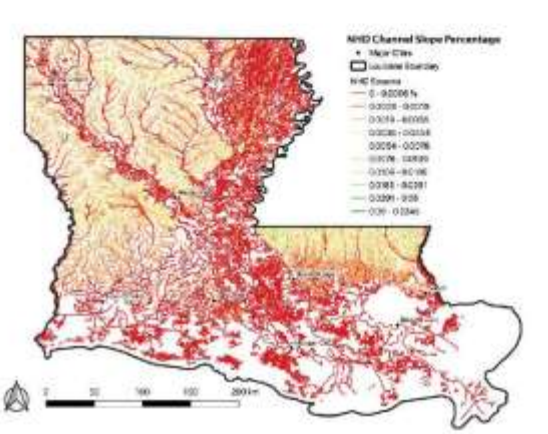

Figure 7. Spatial distribution of percent channel slope across the state.

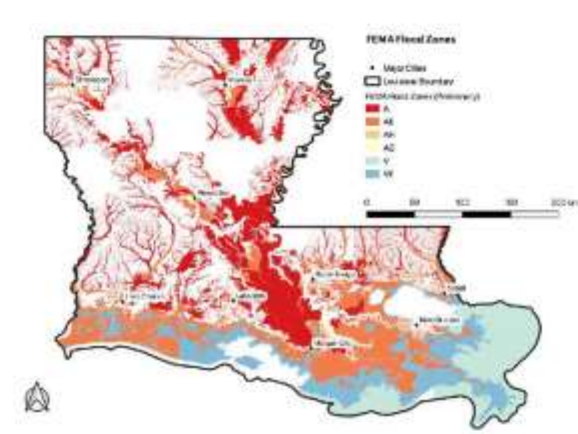

Figure 8. FEMA flood zones in Louisiana.

FLOOD ZONE

GS_{fz} is the gauge score due to being in a FEMA flood zone. Watersheds that have been prone to floods in the past will have higher priority for additional gauge placement. We identified such watersheds using FEMA flood zone maps. Figure 8 shows FEMA flood zones in Louisiana. GS_{fz} was based on whether a suggested gauge is in zone A, AE, flood way, or other FEMA flood zones and is defined in equation (5):

$$GS_{fz} = \begin{cases} 0, \; fz =' X' \; or \; fz = 'OPEN\ WATER' \; or \; fz = 'AREA\ NOT\ INCLUDED' \\ 1.0, \; fz = 'A' or \; (fz =' AE' and \; fst =' FLOODWAY') \\ 0.5, for\ all\ other\ floodzones \end{cases} \tag{5}$$

where fz is the FEMA flood zone, and fst is the FEMA flood zone subtitle. The rationale for giving gauges in flood zone "A" a score of 1.0 is that these gauges lack base flood elevations and as such these areas would benefit most from the additional information provided by a new flow gauging site. Likewise, gauges in flood zone "AE" that are also within floodways were also assigned a score of 1.0 to reflect the increased sensitivity to flood risk due to changes in land use within these areas.

HYDRAULIC CONTROL STRUCTURES

Hydraulic structures that play a significant role in controlling stream flow (e.g., gates, dams, flow diversions) should be prioritized when allocating additional streamflow gauges as they can plan critical role in flood response and mitigation. GS_{dam} is the gauge score due to proximity to hydraulic control structures is based on structures listed in the USACE structure database (Figure 9). Gauges close to USACE-listed structures and monitoring the same hydrologic features were given a score of 1.0. All other gauges were given a score of 0.

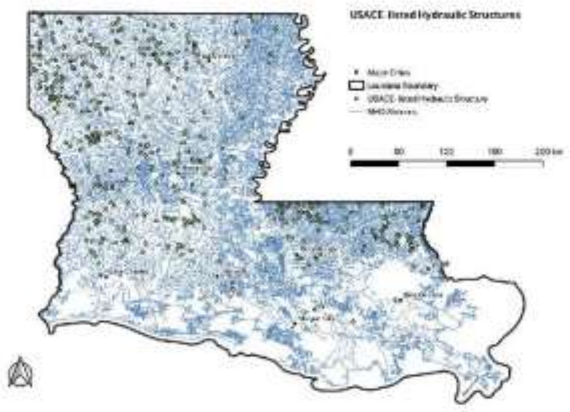

Figure 9. Hydraulic structures listed in the USACE hydraulic structure database.

FORMER USGS GAUGE SITES

GS_{USGS} is the gauge score due to being a former (discontinued) USGS stage or streamflow gauge site (Figure 3). Proposed gauges that monitor the same hydrologic features as a discontinued USGS were assigned a score of 1.0, all other proposed gauges were assigned a score of 0.0. The intent of this score is to build on the already available historical record at discontinued gauges as well as to take advantage of existing gauge infrastructure.

PROXIMITY BETWEEN GAUGES SUGGESTED BY USGS, NWS AND STAKEHOLDERS

$GS_{stakeholder}$ is the gauge score due to proximity to stakeholder suggested gauges (Figure 2). This criterion is intended to give USGS (discontinued or suggested; Figure 3) or NWS suggested gauges (Figure 4) more weight if they are close to and monitoring the same hydrologic features as those suggested by stakeholders. Such USGS and NWS gauges were given a score of 1.0, other gauges not proximal to stakeholder suggested gauges were given a score of 0.0. Stakeholder-suggested gauges that would monitor the same hydrologic features (e.g. NHD reach) as these USGS or NWS suggested sites were removed from further prioritization analysis. This was done to avoid repetition between similar gauge locations, build on prior work and analyses done by USGS and NWS, while also making sure that stakeholder feedback receives due consideration.

INUNDATION FREQUENCY

GS_{if} is the gauge score due to inundation frequency based on Gulf Coastal Plans and Ozarks (GCPO) LCC inundation frequency mosaic dataset (Allen, 2017; Figure 10). The GCPO inundation frequency value (0-100) at the site of the proposed gauges was scaled by the maximum such value for all proposed gauges in the HUC8 where the proposed gauge is located. GS_{if} is defined in equation (6):

$$GS_{if} = \begin{cases} 0, \ max\,(if) = 0 \\ if/max\,(if), \ max(if) > 0 \end{cases} \tag{6}$$

where if is the GCPO inundation frequency value (0-100) at the site of the proposed gauge, and $max\,(if)$ is the maximum such value for all proposed gauges in the HUC8 where the proposed gauge is located.

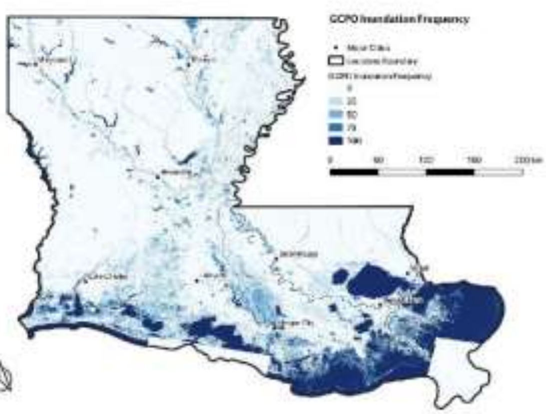

Figure 10. Inundation frequency mosaic created by Gulf Coastal Plains and Ozarks LCC

VALIDATION OF GAUGE SELECTION USING MANUAL INSPECTION AND QUALITY ASSURANCE

After completing the automated criteria-based gauge site scoring was complete, additional validation and manual inspection was performed for all scored gauges to add a quality assurance to the automated scoring process described above. This validation and quality assurance steps incorporate expert-level hydrologic and hydraulic analysis to ensure that the following aspects were considered in the selection process and the recommended design of the LWI network:

- Flood risk to surrounding populations or facilities;
- Detection of duplicate scored gauges in the dataset;
- Whether new information would be provided (relative to proximal gauges, both existing and proposed);
- Presence of regulating water control structures or inflow/out of into managed water bodies (e.g. reservoirs, river reaches);

- Estimated value for hydrologic model calibration;
- Geographic gaps in the distribution of existing and proposed new gauging site across and within LWI modeling regions; and
- Site access and logistics.

As a result of considering these manual quality assurance aspects some highly scored gauges were removed from selection, while other moderately scored gauges were selected. For example, one gauge along the Ouachita River suggested by Catahoula Parish OHSEP (Figure 11) received a low to average score due to little to no impervious surfaces nearby, not being in a flood zone, and not being close to discontinued USGS gauges. However, after inspecting the location, the gauge was found to be near the outlet of a HUC8 watershed, and would monitor a large ungauged area, therefore the gauge was selected for inclusion.

Another example of a low-scoring gauge was along Bayou Teche just downstream from Bayou Courtableau near Port Barre (Figure 12). This gauge will provide new information on a reach that is a source of major local flooding but where there is no current flow information (though USACE appears to have activated a stage gage nearby on US-190). This gauge would allow quantification of how much flow enters Bayou Teche at its headwaters and will be beneficial for both HMS and RAS models and would assist the regulation of the Teche-Vermilion Flow augmentation program.

Figure 11. Example of manual quality assurance of automated scoring: Ouachita River

Figure 12. Example of manual quality assurance of automated scoring: Bayou Teche

CRITERIA FOR COASTAL STATION SELECTION

For the purpose of selecting coastal monitoring locations, the coastal zone of Louisiana is defined as low elevation land area proximal to the land-ocean interface where the principal source of flooding will be astronomical and meteorological tides, storm surges, and even seiches or tsunamis, rather than riverine flooding. As such, extreme precipitation events can generally be expected to generate less severe flooding in the coastal zone than in upland areas. However, given that many extreme precipitation events are associated with tropical storms that can generate additional flooding risks from storm surge, these areas cannot be overlooked for gauging and flood risk modeling. Further, this compound flooding (runoff and storm surge) can also worsen flooding risks further inland by funneling storm surge upriver and stream channels, slowing and even reversing runoff from upland watersheds.

The inland extent of the coastal zone can be defined by different boundaries (e.g., mean salinity concentration, tides, storm surge runup, elevation, vegetation, etc.). We have chosen to follow two definitions (Figure 13). The first is the portion of Louisiana that FEMA defines as the coastal zone and is used by the LA Department of Natural Resources (green-shaded area Figure 13). This encompasses all or a portion of 20 Louisiana parishes and four of seven LWI modeling regions. The second coastal zone definition is the inland boundary of ADCIRC storm surge model domain, which is the beige-shaded area that extends slightly further inland than the FEMA boundary as shown in Figure 13.

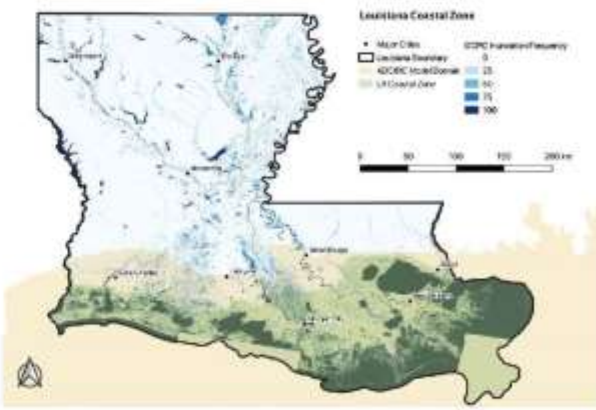

Figure 13. Definition of the coastal zone land area in Louisiana utilized by Louisiana Department of Natural Resources from FEMA maps (blue polygon) and the inland domain limit of the ADCIRC storm surge modeling performed by Louisiana CPRA for the State Master Plan

Three primary criteria were followed in identifying new gauge locations in the coastal region:

(1) The point at which HUC8 trunk channels, or larger HUC12 tributary channels to the trunk channel, cross into the coastal zone as defined by the FEMA/ADCIRC boundary. Outlets of major (HUC12) tributaries will be selected when their convergence to a HUC8 trunk channel occurs within the coastal zone. These key points will serve as funnels for storm surge into upland parts of coastally connected HUC8 watersheds, and their gaging will allow models to better predict compound flood risk.

(2) Larger cross-section channelized locations where storm surge enters the coastal zone at the land-sea interface, and at confined exchange points between large coastal zone water bodies (e.g. estuaries and lakes) as the surge proceeds inland. Calibrating storm surge models such as ADCIRC requires gauging at these locations of bi-directional discharge as well as monitoring water level to quantify volumes and pathways of surge, and ebb surge compounded by runoff from associated storm precipitation.

(3) Hurricane floodgates in bayous and nav channels, some of which are associated with levee protection systems like Morganza-to-the-Gulf, as well as Gulf Intracoastal Water Way (GIWW) gates. These provide possible monitoring points to assess surge (immediately outside) or backup (immediately inside).

In addition to these three over-arching criteria, the following factors were considered to further identify the highest priority stations locations in the coastal zone: (1) proximal to stakeholder suggested gauges; (2) are discontinued USGS gauging sites; (3) are sites presently gauged for water level but not discharge by the USGS; or (4) are located near key water control structures operated by the USACE or other state and federal agencies.

CRITERIA FOR STAGE-ONLY SITES

As explained earlier, the 100 LWI new gauging sites will monitor three primary variables: stage, flow rates and rainfall. However, and due to resource constraints, only ~80 of these will be gauges that monitor streamflow rates, and ~20 will monitor stream stages only. Therefore, it necessary to identify which sites where stage-only measurements could be adequate from a hydrological perspective. To do so, a manual analysis will be conducted to identify gauges which could function as stage-only out of the full gauge network. The main criteria for making the identification will be based the following factors:

a) Proximity to active USGS flow gauges

b) Potential ability to infer flow from a combination of nearby active or proposed flow gauges in the network

c) Potential ability to infer flow from reservoir/spillway rating curves

d) Stakeholder feedback specifically requesting stage-only

In cases lacking a clear justification for a stage-only designation based on the above criteria, we conservatively assumed a flow gauge would be required. The analysis will be performed on each of the selected inland gauge locations. Note that all coastal-designated sites will not be subject to this stage-only identification process, simply due to the availability of numerous coastal CRMS sites that already measure stage.

RESULTS

GAUGE SELECTIONS IN UNMONITOERED HUC8 WATERSHEDS

A total of eight HUC8 watersheds that are not currently monitored by any gauges within their domain were assigned gauges at their respective outlets (Figure 14). These gauges are referred to as Tier 1 gauges. However, if stakeholders, USGS or NWS suggested a location within the upstream vicinity of an unmonitored HUC8 outlet, that location was included as part of Tier 1, instead of the HUC8 outlet.

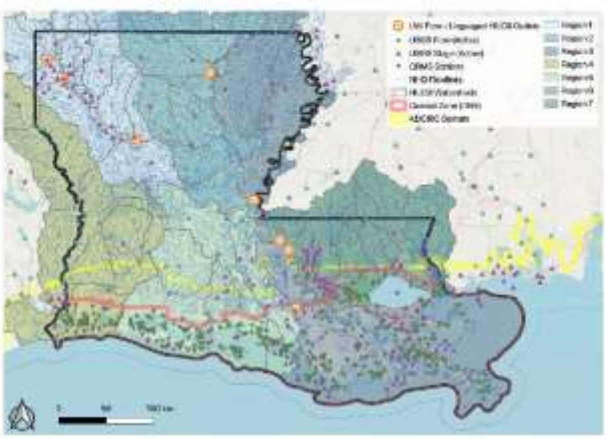

Figure 14. Proposed LWI flow gauges for ungauged HUC8 watersheds

AUTOMATED GAUGE SCORING OF INLAND GAUGES

Results of automated gauge site scoring are summarized in Table 3 and displayed in Figure 15. The automated scores were grouped into five rankings, with the highest rank, Rank 1, corresponding to gauge scores ranging from 47 to 75, Rank 2 scores ranging from 34 to 47, and so on down to Rank 5 (Table 3). Automated gauge scores were classified into the five ranks using Jenks natural breaks optimization. The Jenks natural breaks method groups data into classes that minimize variance within classes and that maximize variance between classes. There was a total of 40 gauges with the highest ranking. Nineteen (19) of these were gauges suggested by stakeholders, fourteen (14) were recent (post-1970) discontinued USGS gauges, three (3) were from USGS statistical analysis, and four (4) were from NWS suggested gauges.

Table 3. Cross tabulation of scored potential gauges by categories: Stakeholder gauges, USGS discontinued gauges (post-1970), USGS statistical analysis, and NWS suggested gauges.

Automated score ranking	Stakeholder gauges	USGS discontinued (post-1970)	USGS statistical analysis	NWS suggested gauges	Total
Rank 1	19	14	3	4	40
Rank 2	83	7	3	14	107
Rank 3	135	3	3	12	153
Rank 4	98	1	6	10	115
Rank 5	44	0	1	2	47
Total	**379**	**25**	**16**	**42**	**462**

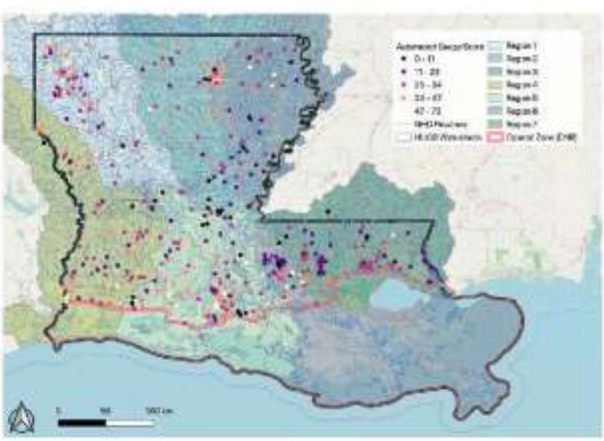

Figure 15. Intermediate results of criteria-based gauge site score for inland sites

GAUGE SELECTIONS IN COASTAL REGION

In total, there were 34 coastal gauge sites selected using the criteria for coastal station prioritization described earlier. These coastal sites are displayed in Figure 16. The 34 sites were further classified into three main groups (Figure 17) that reflect varying prioritization levels within the coastal zone. The three groups are as follows: 10-priority 1 (upland-coastal interface) sites, 18-priotiy 2 (gulf interface) sites, and six-priority 3 (coastal exchanges) sites.

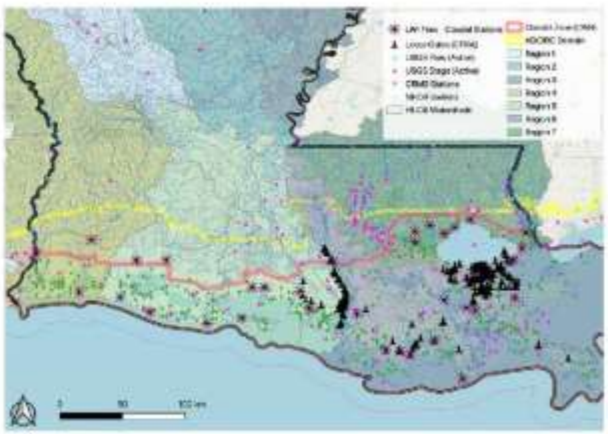

Figure 16. Proposed coastal stations selected using three primary criteria

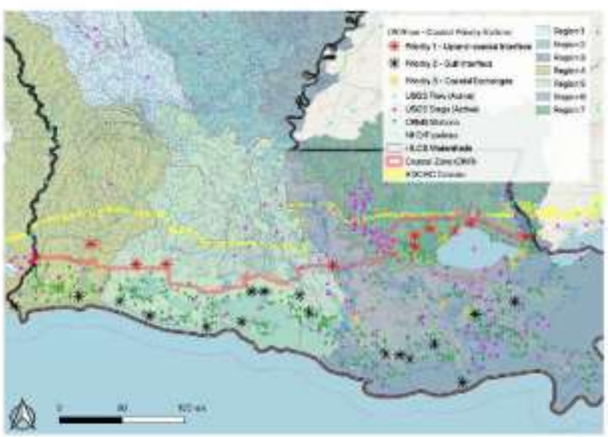

Figure 17. Proposed coastal prioritized stations

COMBINED GAUGE SELECTIONS FOR LWI NETWORK

This section presents the combined results on gauge selections using the process described above. While the target goal of the analysis is to produce a network design with ~100 gauges across the state, it is desirable to identify more than 100 gauges in the network design, given the likelihood that some proposed gauge sites may prove to be infeasible for logistical reasons and budget availability. As such, a total of 123 new sites are included in the final set of gauge selections. These sites were initially comprised of: (1) eight locations that were identified in HUC8 watersheds that lack gauges; (2) 40 locations identified as Rank 1 in the automated site scoring analysis for inland flow gauges; and (3) 34 locations identified as priority sites for coastal flow gauges. The manual expert-based quality assurance and validation analysis revised the selections to remove some of the 40 Rank-1 locations, and promote some of the Rank 2 and 3 locations, resulting in the final 123 sites shown in Figure 19. For reference purposes, the existing USGS streamflow and stage gauges as well as Coastwide Reference Monitoring System (CRMS) monitoring stations are first shown in Figure 18.

A summary of the 123 gauges by source and LWI modeling region is provided in Table 4. For comparison, a summary of existing USGS and CRMS gauges can be found in Table 5. As described earlier, detailed prioritization of the 123 gauges is possible as needed using the automated scoring results for inland gauges, and the internal prioritization criteria within the coastal region. An interactive ArcGIS Online Map showing the selected gauges for LWI network and their scoring is available here http://arcg.is/1G1vyK.

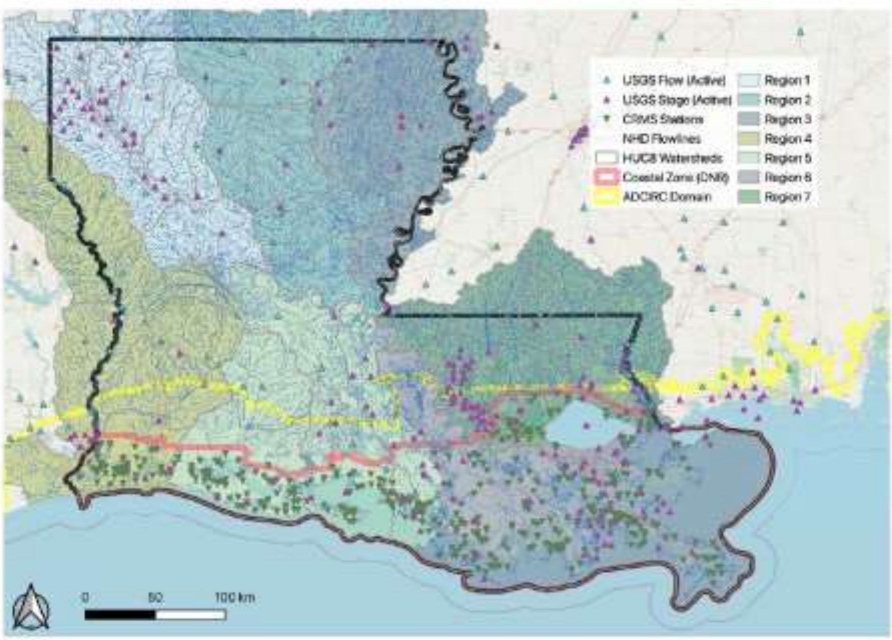

Figure 18. Current USGS (streamflow and stage) and CRMS monitoring stations.

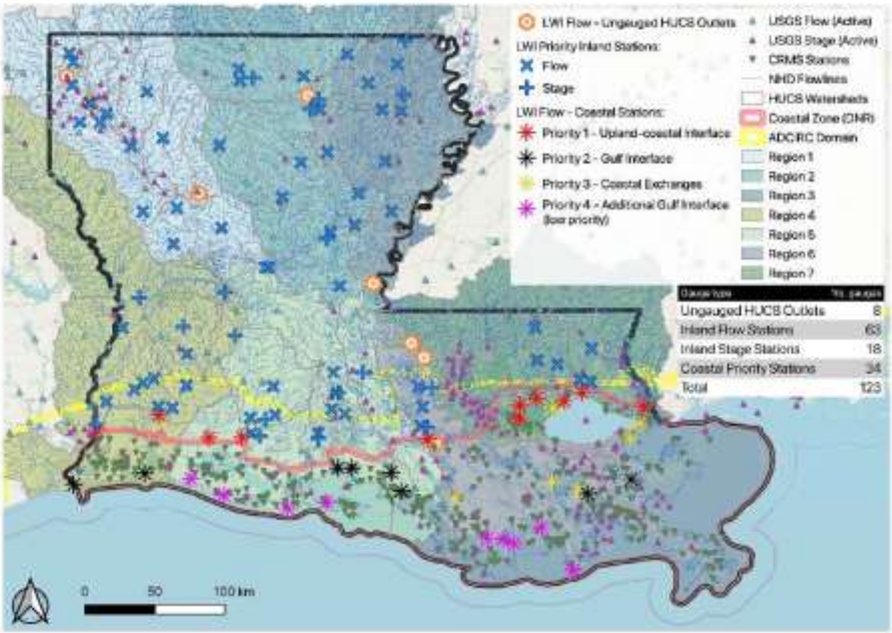

Figure 19. Combined results of gauge selection criteria showing: (1) LWI streamflow gages in ungauged HUC8 watersheds; (2) priority sites for inland gauges; and (3) priority sites for coastal flow gauges. Existing USGS (streamflow and stage) as well as CRMS stations are shown for comparison.

Table 4. Distribution of the 123 gauge locations selected for the LWI network grouped by type and LWI modeling region

Region	Flow gauges in ungauged HUC8 watersheds	Priority sites for coastal flow gauges	Stakeholder gauges	USGS discontinued (post-1970)	USGS statistical analysis	NWS suggested gauges	Total gauges per region
1	3	n/a	5	10	0	0	18
2	2	n/a	8	6	1	0	17
3	0	n/a	5	4	1	1	11
4	0	4	8	4	0	2	18
5	0	11	9	6	0	0	26
6	3	12	2	1	2	0	20
7	0	7	2	0	0	4	13
Total gauges	**8**	**34**	**39**	**31**	**4**	**7**	**123**

Table 5. Summary of existing USGS and CRMS gauges by LWI modeling region

Region	USGS active flow gauges	USGS active stage gauges	CRMS gauges	Total existing gauges per region
1	11	24	n/a	45
2	13	9	n/a	22
3	7	12	n/a	19
4	24	16	45	85
5	13	24	114	151
6	8	49	193	250
7	21	62	38	121
Total gauges	97	196	390	693

IDENTIFICATION OF 100 STREAMFLOW AND STAGE SITES

As described earlier, the LWI network design will be comprised of 100 sites for new stream monitoring gauges. The analysis presented thus far resulted in 123 gauges, allowing for additional 23 contingency sites. However, to allow immediate implementation of the LWI network, a further prioritization was conducted to narrow the 123 sites down to 100 locations. This prioritization was based on the numerically-ranked scores of the potential inland locations, and also by selecting the "priority 1" coastal locations (Figure 17). The results are shown in Figure 20. However, it should be noted that the specific selection of the final 100 sites might be further refined based on additional factors such as site accessibility and local considerations.

To meet the LWI requirements of 80 streamflow sites and 20 stage-only sites, the 100 sites were subject to further analysis to identify ~20 sites for stage-only monitoring. This was done based on examining factors such as: proximity to active USGS streamflow gauges, potential ability to infer flow from a combination of nearby active or proposed streamflow gauges, potential ability to infer flow from reservoir/spillway rating curves, and stakeholder feedback specifically requesting stage-only gauges. An example of this analysis is shown in Figure 21. The specific locations of the sites identified for stage-only gauges are shown in Figure 20.

The final set of 100 sites recommended for the LWI network is shown in Figure 20. A summary of the 100 gauges by type (streamflow and stage) and LWI modeling region is provided in Table 6. An interactive ArcGIS Online Map showing the selected 100 gauges recommended for the LWI network and their type classification is available at http://arcg.is/0mr54f (Table 7).

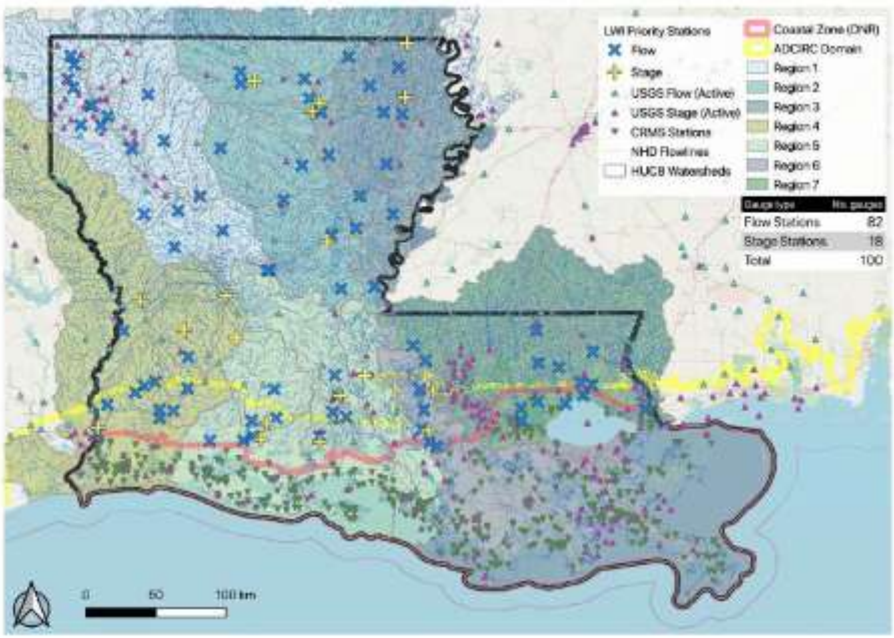

Figure 20: Locations of the 100 gauges sites for the new LWI network grouped into streamflow and stage-only sites. Existing USGS and CRMS sites are also shown

Figure 21: Example of stage only identification procedure. The stage-only determination was based on stakeholder request to support operations of the Black Bayou Pump Station and Outfall Structure. The region shown is the Ouachita watershed located

Table 6: Distribution of 100 gauge locations recommended for the LWI network grouped by type (streamflow and stage) and modeling region

Region	Priority sites: flow gauges	Priority sites: stage-only gauges	Total gauges per region
1	18	0	18
2	13	4	17
3	9	2	11
4	11	5	16
5	13	5	18
6	6	2	8
7	12	0	12
Total	**82**	**18**	**100**

Table 7: Weblinks to ArcGIS Online interactive showing the locations of gauges recommended for the LWI network

Description	Weblink

Locations of top 123 gauges (100 + 23 for contingency) with detailed scoring attributes and inland/coastal designation; a data dictionary is available as a data table in the online map	http://arcg.is/1G1vyK
Locations of proposed LWI 100 gauges classified by type: stage-only and streamflow gauges	http://arcg.is/0mrS4f

IDENTIFICATION OF NEW RAIN GAUGE SITES

Enhancing rainfall monitoring is another goal of the LWI network. Therefore, in addition to identifying potential sites of new streamflow gauges, we also analyzed locations where the addition of rain gauges would be beneficial to flood modeling, forecasting, and watershed management. Current rainfall monitoring over Louisiana is available through two main sources: in-situ rain gauges distributed across the state, and four NEXRAD weather radars located near Lake Charles, Slidell, Fort Polk and Shreveport, with partial coverage from a radar site in Jackson, MS (Figure 20). Rain gauges are primarily operated by agencies such as USGS and NOAA and have varying data collection frequencies. Some of these rain gauges have 15-minute reporting frequency, while others are registered with the Hydrometeorological Automated Data System (HADS) network and report mostly hourly data (Figure 20). Hourly or sub-hourly precipitation data is often required to calibrate hydrologic models (note: daily-reporting rain gauges over Louisiana are not shown). The spatial distribution of hourly (or sub-hourly) rainfall gauges shows clear coverage gaps over many regions in the state. Similarly, there are some areas that are not adequately covered by the radar domains. Therefore, there is a need to enhance the existing rainfall monitoring in the state by identifying locations where new gauges should be added as part of the LWI network. In this study, the following two criteria were used to identify such locations:

(a) Adding rain gauges to all of the new LWI network sites: Given the significant investments expected in installing the new LWI streamflow gauge sites, the LWI network will add a rain gauge to each of the new streamflow sites. This will increase the number of rain gauges over the state by ~100 new LWI sites. The spatial distribution of the new rain gauges will be the same as that of the streamflow sites shown earlier in Figure 19 and Table 4.

(b) Adding rain gauges in regions that don't have adequate radar coverage: Louisiana is covered by four radar sites (Figure 22) that provide rainfall observations with high temporal and spatial resolutions. Radar-rainfall measurements are processed by the NWS regional River Forecasting Centers (the Lower Mississippi River Forecasting Center in Louisiana) and are merged to produced national-scale rainfall products such as the Stage IV product (Eldardiry et al., 2015; Habib et al., 2009). The resolution of the Stage IV is ~1.54x1.54 mi^2 (4x4 km^2) spatially and 1-hour temporally. Another recent radar rainfall product is the NOAA's NSSL MRMS (Sharif et al., 2020). MRMS has a spatial resolution of 0.386 x 0.386x mi^2 (1x1 km^2) and hourly temporal resolution. The Stage IV product has a longer historical data record than MRMS. These products provide valuable data to the LWI modeling program and other related efforts. An NWS radar has a typical coverage of about 126 miles (203 km) measured radially from its sites (Figure 22); however, the quality of radar retrievals is known to deteriorate with the increase of distance away from the radar site. This is simply because the radar beam becomes too high into the atmosphere and starts to lose resolution and doesn't become representative of surface conditions. When the lowest radar beam (0.5° elevation angle) reaches a height of 2-km or higher into the atmosphere over a certain location, the radar retrievals become of considerably lower quality. Examining Figure 22, and based on the locations of the NEXRAD sites, regions with sub-optimal radar coverage are mostly within the southcentral and northcentral/northeastern areas of the state. However, the placement of a new rain gauge to each of the new 100 LWI monitoring sites (Figure 20) seems to address gaps over most of the areas that have sub-optimal radar coverage, except areas that are in the most southcentral and southeaster coastal areas of the state. Therefore, it is recommended that current USGS sites that are located in these areas and don't monitor rainfall should be upgraded to include a rain gauge (Figure 22). Adding rain gauges to some of the existing USGS sites will support the radar-rainfall estimation process at the Lower Mississippi River Forecasting Center (e.g., by bias-correction of radar estimates), but will also enhance the quality of rainfall information overall by adding more in-situ monitoring resources.

The addition of rain gauges to each of the new stream sites of the LWI network (~100 sites), as well as to a sub-set of the existing USGS sites that currently don't have rain gauges in the most southcentral and southeaster coastal areas of the state with inadequate radar coverage, will significantly enhance rainfall monitoring over the entire state and will provide comprehensive rainfall datasets needed for watershed modeling and management activities.

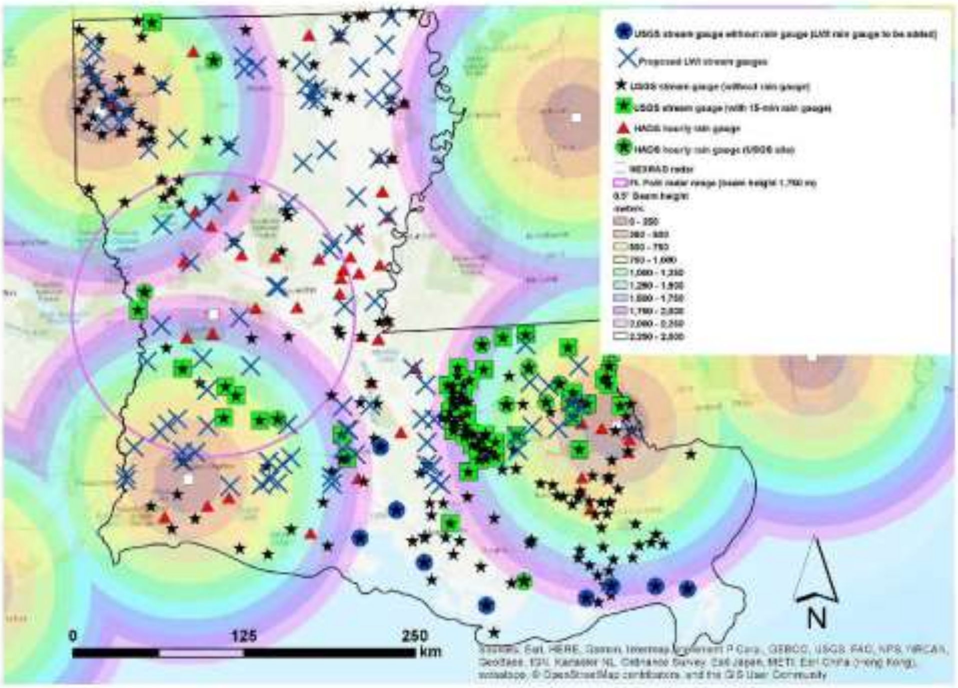

Figure 22. New rain gauges to be added to existing USGS sites that don't currently monitor rainfall, especially in the southcentral and southeaster coastal areas of the state where radar coverage is not optimal. Other areas in the state will benefit from rainfall monitoring as part of the new LWI 100 stream sites where rain gauges will also be deployed.

REFERENCES

Eldardiry, H., Habib, E., Zhang, Y., and Graschel, J. (2015). Artifacts in Stage IV NWS Real-Time Multisensor Precipitation Estimates and Impacts on Identification of Maximum Series. Journal of Hydrologic Engineering, 10.1061/(ASCE) HE.1943-5584.0001291, E4015003.

Habib, E., Larson, B., and J. Graschel (2009) "Validation of NEXRAD multisensor precipitation estimates using an experimental dense rain gauge network in south Louisiana." Journal of Hydrology, (2009), doi:10.1016/j.jhydrol.2009.05.010

Homer, Collin G., Dewitz, Jon A., Jin, Suming, Xian, George, Costello, C., Danielson, Patrick, Gass, L., Funk, M., Wickham, J., Stehman, S., Auch, Roger F., Riitters, K. H., Conterminous United States land cover change patterns 2001–2016 from the 2016 National Land Cover Database: ISPRS Journal of Photogrammetry and Remote Sensing, v. 162, p. 184–199, at https://doi.org/10.1016/j.isprsjprs.2020.02.019

Yvonne C Allen, Gulf Coastal Plains and Ozarks Landscape Conservation Cooperative (administrator), 2015-10-09(creation), 2017-11-15 (last Update), GCPO Inundation Frequency Mosaic. https://gcpolcc.databasin.org/datasets/0d0c5fb9d42f45d3a0a23872eda23543

Soil Survey Staff, Natural Resources Conservation Service, United States Department of Agriculture. Web Soil Survey. Available online at http://websoilsurvey.nrcs.usda.gov/. Accessed 03/25/2016.

APPENDIX: SOURCES OF DATA USED IN SELECTION CRITERIA

This section describes the datasets that were used to develop the above-mentioned gauge selection criteria. Table 7 shows description of the datasets and their sources.

Table 8. Dataset sources for the gauge selection criteria.

Criterion	Dataset	Source/Link
HUC8s lacking gauges	Existing Gauge Locations	Available via USGS, NWS, NOAA, and USACE
Proximity to discontinued USGS gauges and NWS recommended gauges	Discontinued USGS gauges and NWS suggested gauges	Data provided by USGS and NWS gauges
Percent imperviousness	National Land Cover Database (NLCD) 2016 percent impervious	https://www.mrlc.gov/national-land-cover-database-nlcd-2016
Drainage Area	National Hydrography Dataset (NHD); NHDPlus dataset attributes	https://www.epa.gov/waterdata/nhdplus-national-hydrography-dataset-plus
Flood Zones	Flood zones	https://hazards.fema.gov/gis/nfhl/rest/services/public/NFHL/MapServer/
Hydraulic Structures	Databases of hydraulic structures	• National Inventory of Dams (NID) – Available at http://nid.usace.army.mil or through the State Dam Safety Engineer, Louisiana DOTD • National Bridge Inventory (NBI) – Available at https://www.fhwa.dot.gov/bridge/nbi/ascii.cfm
Stream slope	NHDPlus dataset	https://www.epa.gov/waterdata/nhdplus-national-hydrography-dataset-plus
Frequency of Inundation	GCPO Inundation Frequency Mosaic	https://gcpolcc.databasin.org/datasets/0d0c5fb9d42f45d3a0a23872eda23543