APPENDIX A

Preliminary Hydrology and Hydraulics Report

Note: The Section 508 amendment of the Rehabilitation Act of 1973 requires that the information in federal documents be accessible to individuals with disabilities. The U.S. Army Corps of Engineers (Corps) has made every effort to ensure that the information in this appendix is accessible. However, this appendix is not fully compliant with Section 508, and readers with disabilities are encouraged to contact Mr. Jayson Hudson at the Corps at (409) 766-3108 or at SWG201601027@usace.army.mil if they would like access to the information.

Water Resources • Environmental • Green Infrastructure

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Preliminary Hydrology and Hydraulics Report

DCC Harris Reservoir Expansion EIS

2018-0568.0-TX

Prepared for:

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Table of Contents

Table of Tables

Table of Figures

Acronyms and Terminology

ac	acre
AEP	Annual Exceedance Probability (relates to floodplain flooding risk)
AF	acre feet
ARS	Agriculture Research Service, USDA
BFE	Base Flood Elevation
BRA	Brazos River Authority
BWA	Brazosport Water Authority
cfs	Cubic feet per second
DCC	Dow Chemical Company
Dow	Dow Chemical Company
EIS	Environmental Impact Statement
FEMA	Federal Emergency Management Agency
FIS	Flood Insurance Study
FPP	Floodplain Protection Planning Study
ft	feet
GCWA	Gulf Coast Water Authority
gpm	Gallons per minute
HEC-HMS	Hydraulic Engineering Center-Hydrologic Modeling System, USACE
HEC-RAS	Hydraulic Engineering Center-River Analysis System, USACE
HMG	Hydrologic Modeling Guidelines, USACE
HUC	Hydrologic Unit Code
MGD	Million gallons per day
mi^2	Miles squared
mph	Miles per hour
MSL	Mean sea level
NAVD88	North American Vertical Datum of 1988
NCDC	National Climatic Data Center, NOAA
NOAA	National Oceanic and Atmospheric Agency
NRCS	Natural Resource Conservation Service, USDA
NWS	National Weather Service, NOAA

Riverware™	River and Reservoir Modeling Software, University of Colorado Boulder
SCS	Soil Conservation Service (predecessor of the NRCS)
sq mi	Square miles
SSC	Suspended sediment concentration
TCEQ	Texas Commission on Environmental Quality
TDS	Total Dissolved Solids
TWDB	Texas Water Development Board
TX	Texas
TxRR	Texas Rainfall-Runoff Model
USACE	United States Army Corps of Engineers
USDA	United States Department of Agriculture
USGS	United States Geological Survey
WAM	Water Availability Model
WSEL	Water Surface Elevation

0 Executive Summary

The Dow Chemical Company (Dow) and Regional Water Planning Group identified at least as early as 2011 the need for Dow to undertake steps to ensure reliable water supply to their plant located in Freeport, Texas. For purposes of this analysis, the time horizon was at least 50 years into the future for resiliency and water supply needs.

0.1 Project Summary

A full detail of the project Purpose and Need is provided in the Dow Individual Permit application to the US Army Corps of Engineers (USACE). Dow currently operates two reservoirs, Harris and Brazoria Reservoirs, for a total effective storage of approximately 28,000 acre-foot (AF), which is no more than 68 days of storage based on current water use. The Texas Commission on Environmental Quality (TCEQ) recommendations for water suppliers to have at least 180 days of water storage or they are at risk for shortages during drought conditions.

Dow proposes to construct an approximately 50,000 AF off-channel impoundment reservoir adjacent and upstream of the existing Harris Reservoir, referred to in the permit application as the Harris Reservoir Expansion (Proposed Project). The proposed impoundment is located directly upstream and adjacent to the existing Harris Reservoir but will work independently. The proposed reservoir covers approximately 2,000 acres (ac). The proposed reservoir includes a pumped intake station on the Brazos River and gravity outfall to Oyster Creek via a new bypass channel.

Dow proposes to operate the three reservoirs in a manner similar to current operations with the Proposed Project increasing available storage from 68 days of water to 180 days. During periods of drought, the Proposed Project reservoir would be exhausted first, followed by the existing Harris Reservoir, and then the Brazoria Reservoir. The decision for emergency releases due to severe weather, such as tropical storms and hurricanes with wind speeds that can overtop the embankments, would remain unchanged.

0.2 Environmental Setting

The Brazos River is a major river system within the State of Texas with its headwaters located near Blackwater Draw, New Mexico and its mouth near Freeport, Texas. The river is highly managed through a series of dams and off-channel storage (reservoirs) throughout its length. This is due to the high variability of flows as the primary water source is rainfall to store water for dry season use but also for flood control. The proposed project is located within segment 1201, which is tidally influenced.

The general climate for the project area includes high potential rainfall events from tropical storms and hurricanes with long periods of drought. Future rainfall is predicted to trend towards lower rainfall levels and higher temperatures. Sea level is expected to rise by one to two feet in the next 50 years, which will tend to push the estuary farther upstream (referred to as the salt wedge) and storm surge could reach farther upstream from current conditions. The historic sediment load for the Brazos River has decreased for particles larger than sand but has increased overall for sand and smaller size particles.

Dow currently operates two reservoirs, Harris Reservoir located at River Mile 46 with effective storage capacity of 7,000 AF and Brazoria Reservoir located at River Mile 25 with effective storage capacity of 21,000 AF, to provide potable water to the Dow chemical plan and other users. Dow has reported periodic but not regularly scheduled maintenance dredging on the existing reservoirs, which has resulted in loss of storage by up to half of the original design volume. During drought conditions, Dow estimates the two-reservoir system provides 68 days or less of necessary water supplies. Texas Council on Environmental Quality (TCEQ) identified that facilities with less than 180 days of water storage are at risk during droughts.

0.3 Summary of Modeling and Analysis

Modeling included HEC-HMS, Riverware™, and HEC-RAS. HEC-HMS provides hydrologic modeling, Riverware™ provides reservoir operational modeling, and HEC-RAS provides hydraulic modeling. Using data provided by Dow and supplemented by various local, state, and federal data and reports, the modeling and analysis focused on drought conditions during the life of the project. The assumed project life is 50 years for analysis purposes although the current Dow plant has been in operation for more than 60 years. The assumed project life is not an indication of maximal life for the project and only used for modeling purposes.

0.4 Analysis of Potential Impacts

0.4.1 Floodplain Storage Loss

The Proposed Project site is approximately 2,000 acres in the shared Brazos River and Oyster Creek 100-year floodplain. The loss of floodplain storage for the Brazos River is negligible under current development conditions. However, there is a 316 AF loss of storage for Oyster Creek as a result of the proposed project. Credits for floodplain storage within the project footprint, namely the overflow channel, is approximately 199 AF, which results in a net loss of 117 AF of floodplain storage on Oyster Creek. While Dow presented modeling results for No Rise, meaning that the water surface level in Oyster Creek meets Federal Emergency Management Agency (FEMA) requirements for not creating impacts to the stream, the concern is that the excess water resulting from high flows such as a 100-year flood event (0.1-percent chance of occurring in any given year) that are no longer stored on the proposed project site will result in hydromodification downstream as that means the flows are typically faster past the site.

0.4.2 Hydromodification of Oyster Creek

Oyster Creek will be hydro-modified from 3,600 ft. north (Project 1) of the northeast of the proposed reservoir to the proposed reservoir outlet channel which is a length of 21,300 feet (ft). Project 2 follows the original Oyster creek for the first 12,860 ft. until the original channel flows east into an old oxbow before meeting up with the proposed reservoir outlet channel downstream. Project 3 is an overflow channel 8,440 ft. in length which parallels the proposed reservoir's eastern embankment until it joins with the proposed reservoir outlet channel. The overflow channel is designed to allow water to enter at the 25 yr. 24 hr. storm event. The hydromodification of Oyster Creek by channel benching will contribute to the overall stability of the channel.

The hydromodification of Oyster Creek does not alleviate the floodplain storage loss along Oyster Creek caused by the construction of the proposed reservoir embankment. In fact the construction of the embankment west of Oyster Creek will block the floodplain storage that was possible previously and the overflow channel will diminish the storage potential in the oxbow and shorten the waters flow path resulting in the peak storm discharge to flow downstream in a shorter time which could increase the amount of water at a given time period.

0.5 Conclusions

0.5.1 Near Term

Dow estimates that the current two-reservoir system can provide no more than 68 days of water supply to Dow's Freeport plant and other users Dow is under contract to supply with potable water. Based on TCEQ water storage recommendations, recent drought events, and loss of contract water availability, Dow estimates that they need at least 180 days of storage to provide the necessary water to the users during an extended drought. The existing reservoirs, even with maintenance dredging to original storage volumes, would not meet the stated water supply needs for the Dow Freeport plant and other users in the near term. The proposed reservoir would more than double the storage capacity and in the near term provide approximately 180 days of water supply storage at project completion.

The modeling and analysis support Dow's analysis that the current two-reservoir system provides less than 68 days of potable water to their Freeport plant and other water supply users. The analysis indicates that the proposed capacity (volume of 50,000 AF) is the minimum size to meet near term water supply needs. The effective storage capacity of the existing reservoirs is likely less than assumed by Dow (Dow assumes 28,000 AF and maybe actually as low as 18,000 AF). This means the proposed project likely does not meet the 180 days of water supply storage stated in Dow's need statement. Dow could conduct a new survey of the existing reservoirs to confirm actual effective capacity and this would confirm the actual total days of storage of the combined reservoir system.

The proposed design meets current reservoir standards for dam safety including considerations for wind and wave conditions, which are likely to increase due to more severe and frequent tropical storm and hurricane events.

0.5.2 Long-Term

Changes in rainfall patterns, anticipated increases to average air temperatures (resulting in increased evaporation), rising sea levels, and high fine sediment loads in the Brazos River are all considerations for a long-term outlook on the project. The existing reservoirs have been in operation for more than 50 years and shown a nearly 50% loss in storage capacity due to sedimentation. Using a similar projection of approximately 50 years, sedimentation presents the highest risk for long-term viability of the 180 days of total combined water storage. This is further put at risk as Dow proposes to capture high flow events to refill the proposed and existing reservoirs as part of their normal operations. Without planned and regularly executed maintenance removal of solids from all three reservoirs, the Proposed Project purpose and need of 180 days of storage cannot be maintained and will fall below that level.

0.5.3 Recommendations

1. The purpose and need of the project is to provide 180 days of water storage for drought conditions. The existing Harris and Brazoria Reservoirs have an estimated capacity of 28,000 AF, which may be overestimated by Dow and that could result in the total storage with the three-reservoir system being less than 180 days of water storage.
    a. A survey of the existing reservoirs should be conducted to confirm capacity.
    b. An Operation and Maintenance Plan should be required for the existing reservoirs, which have lost capacity due to sedimentation. The O&M Plan should require scheduled solids removal, which can be based on a number of different indicators such as a depth gage or probing.
2. Sustained discharge from the proposed new reservoir will likely result in significant downstream erosion of Oyster Creek. To address this, we recommend that a discharge operation plan (can be included in the overall O&M Plan) be developed for the new reservoir that minimizes the potential for downstream erosion of Oyster Creek.
    a. Dow should note that FEMA may require a floodplain amendment due to the changes in the Oyster Creek and floodplain from the restoration project. This determination would be made by the local Flood Plain Administrator.
    b. Erosion control is recommended at the inlet and outlet to the stream restoration section, especially for the Project 3 Overflow segment.
3. Repeated filling and draining to create wet then dry conditions over the short term can result in hydromodification to the reservoirs and the receiving waters, which is specifically a concern for Oyster Creek due to the low natural flow. The repeated wet/dry conditions can break down the soil structure and lead to erosion. Oyster Creek between the Proposed Project discharge point and the existing Harris Reservoir discharge point are at highest near-term risk due to the changed conditions and regular inspection should be required along with a management plan to minimize erosion.
4. Dow should consider additional water storage as the proposed project likely does not meet the 180-day storage recommendation by TCEQ.
    a. This could include maintenance dredging to original or deepening the existing reservoirs, assuming dam safety concerns can be addressed.
    b. Another option is to contract storage in an upstream reservoir.
    c. Other water saving and conservation measures at the Dow plant could be considered, including water reuse through systems such as reverse osmosis. However, these systems tend to have a high energy requirement.
5. This analysis assumes 100,000 gpm discharge rates. If Dow does increase their discharge to 175,000 gpm, which is possible if Dow exercises their full water right, the water storage would be insufficient to meet the 180 days of water storage.
    a. Of note is that the Proposed Project shifts the current discharge rate into Oyster Creek upstream of the adjacent existing Harris Reservoir. This is a minor change that did not result in a changed condition for Oyster Creek. However, nearly doubling the discharge could have an impact on Oyster Creek for both the

existing Harris Reservoir as well as the Proposed Project. This would represent a significant increase in flows in Oyster Creek and the periodic nature could make Oyster Creek more susceptible to hydromodification and erosion.

b. A change in withdrawal rate from Brazos River to 175,000 gpm, expect possibly at the lowest of river flows during drought, would not be anticipated to cause a change to the river due to the large natural flows through the project vicinity.

1 Introduction

The report describes the hydrologic and hydraulic analysis conducted to inform the US Army Corps of Engineers (USACE) determination if the proposed Dow Chemical Company (Dow) Harris Reservoir Expansion project meets hydrology requirements in Section 404 of the Clean Water Act (CWA). The analysis followed the guidance provided in the USACE Hydrology Modeling Guidelines (HMG) for conducting the hydrologic and hydraulic modeling. The USACE developed Hydrologic Modeling Guidelines to assign project managers and applicants in determining how to address hydrology and specifically how to approach hydrologic modeling for primary and secondary effects.

The purpose of the proposed Project is to expand Dow's water storage capacity at or near the existing Harris Reservoir to improve the long-term reliability of water supply during drought for the Texas Operations facilities in Freeport, Texas as well as other industrial, community and potable water users that rely on Dow's water supply. It is also planned to allow more efficient utilization of Dow's existing Brazos River surface water rights.

Dow currently manages the Brazoria and Harris reservoirs for water supply and water quality (at the Dow intake for industrial water supply), which has a reported combined effective storage capacity of 28,000 AF. This provides approximately 68 days or less of stored water. Texas Commission on Environmental Quality (TCEQ) recommendation for storage to meet drought preparedness and response standards is 180 days of storage. This recommendation is based on the Texas Administrative Code Title 30, Part 1, Chapter 290, Subchapter D, Rule §290.41, which under b.1 states that retail public utilities should report when they have less than 180 days of water supply storage and should develop a drought contingency plan (State of Texas, Revised 2013).

The proposed Harris Reservoir Expansion (Proposed Project) will include an approximately 2,000-acre off-channel impoundment facility that will increase Dow's storage capacity by about 50,000 AF. The facility will include an auxiliary spillway outlet from the reservoir and an intake and pump station to divert Brazos River water within Dow's existing water rights. The Proposed Project in conjunction with the existing two reservoirs, which Dow estimates to have approximately 28,000 AF of effective capacity, may result in 180 days of water storage when that reservoir comes online. There is uncertainty as to the existing reservoir capacities, which may be as low as a combined storage of 18,000 AF.

2 Environmental Setting

This section describes the general environmental conditions that define the setting of the Proposed Project. This includes the physical setting as well as other hazards that are considered when analyzing the Proposed Project.

2.1 Watershed

The Proposed Project is located along the Brazos River, one of the second largest watershed by area in Texas (see Figure 1) (TWDB, 2019). The watershed generally runs northwest to southeast with the headwaters in New Mexico and discharges to the Gulf of Mexico near Freeport, Texas. The Brazos River has the largest average annual flow of any river in the state.

The Brazos River flow is primarily supplied through precipitation with many creeks and streams along the main stem. The upper basin was historically underutilized for withdrawals for irrigation, livestock water, and other agricultural purposes until recently with the decline in groundwater supplies, in particular the overuse of the Ogallala Aquifer (TWDB, 2019). This has led to decreasing supplies farther downstream in the more populated areas of the basin, especially during low rainfall and drought years.

The Brazos River is a highly managed and regulated river system with three Brazos River Authority (BRA) reservoirs, eight USACE Flood Control Dams, and numerous other large to small impoundments (Figure 2). There are over 1,200 adjudicated water rights in the Lower Brazos River alone. In addition, Dow is also a potable water supplier for industries and municipal users near their plant in Freeport, Texas.

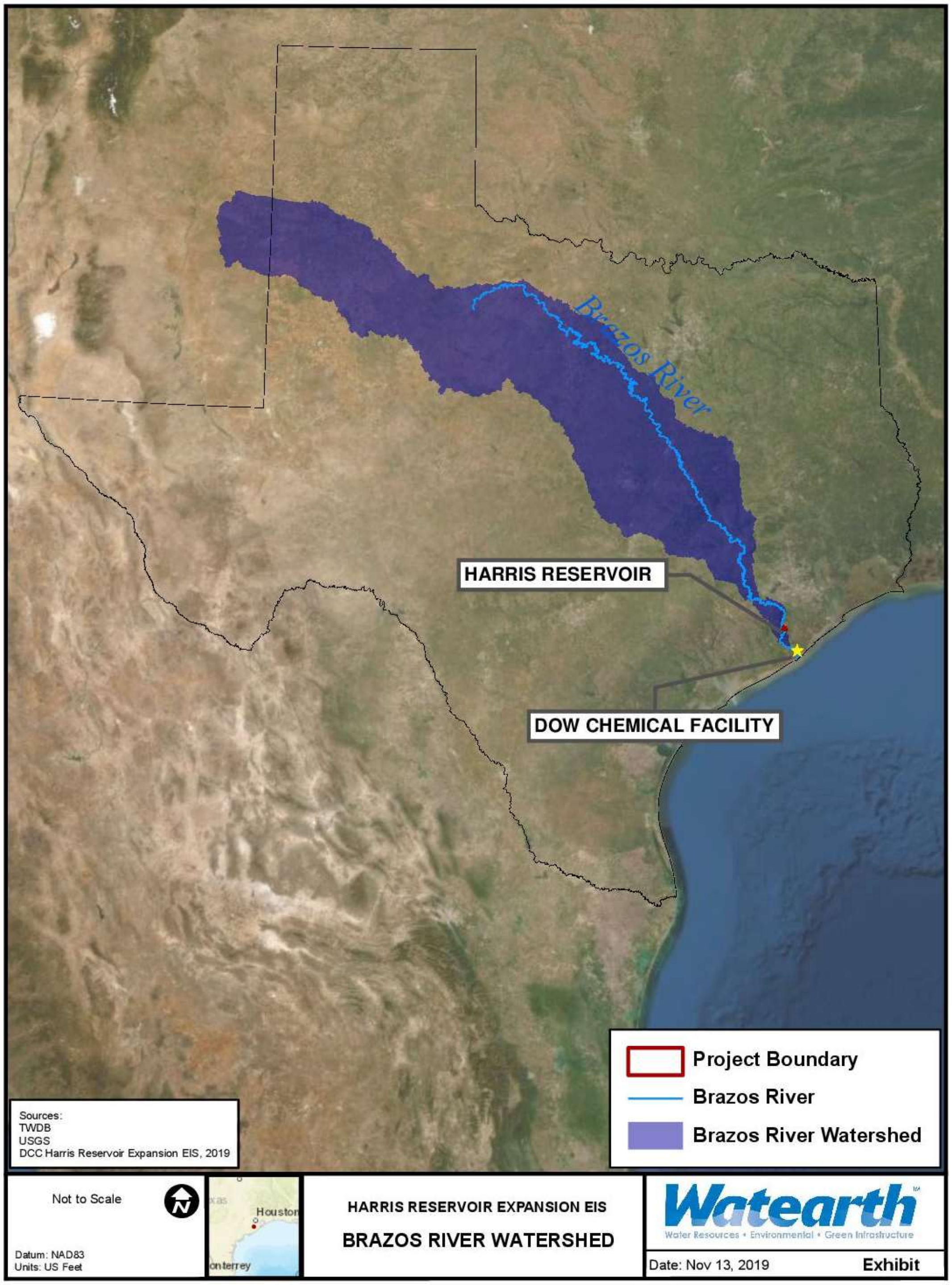


Figure 1: Brazos River Watershed

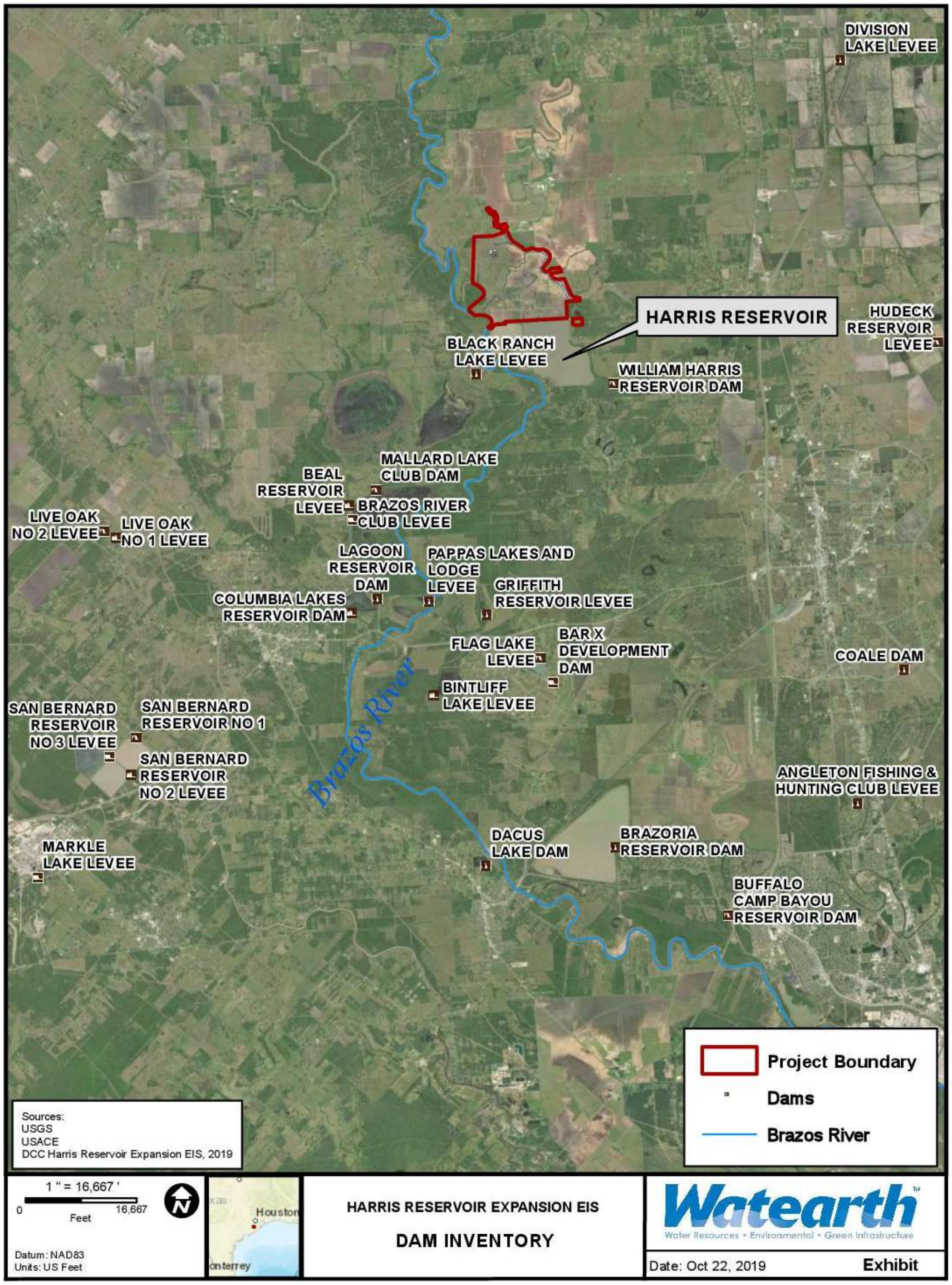


Figure 2: Dam Inventory for Lower Brazos River (Segment 1201)

2.2 Surface Waters and Local Hydrology

The Brazos River Basin is more than 820 miles long and crosses nearly every physiographic region in Texas (TWDB, 2019; BRA, 2019). The watershed is approximately 42,000 sq mi descends at a rate of three feet to one-half foot per river mile.

The Lower Brazos River sub-basin includes the area from Waco, Texas to the Gulf of Mexico (Halff, 2019). The focus of this report is the lowest portion of the Lower Brazos River and limited to Brazoria and Fort Bend Counties. Figure 3 shows the project area drainage areas in the Lower Brazos River sub-basin.

The topography in this area is level with minimal rise as shown by the height of the gages along the Brazos River in Table 1 (USGS, 2019; USGS, 2019). The gages along the Brazos River are reported in NGVD29 and NAVD88. The conversion factor for vertical datums in the project area is NAVD88 is equal to USGS gage elevation in NGVD29 minus 0.975 ft (Heitmuller & Greene, 2009). As Table 1 shows, there is minimal elevation change between the Freeport gage and the Rosharon gage. The thalweg of the Brazos River does not rise above mean sea level until above the Rosharon gage.

Table 1: Gage Elevations

Location	Brazos River Mile	Elevation (NAVD88)
Freeport Gage (08772440)	6	-4.51ft
Rosharaon Gage (08116650)	57	-0.98 ft
Richmond Gage (08114000)	92	+27.02 ft

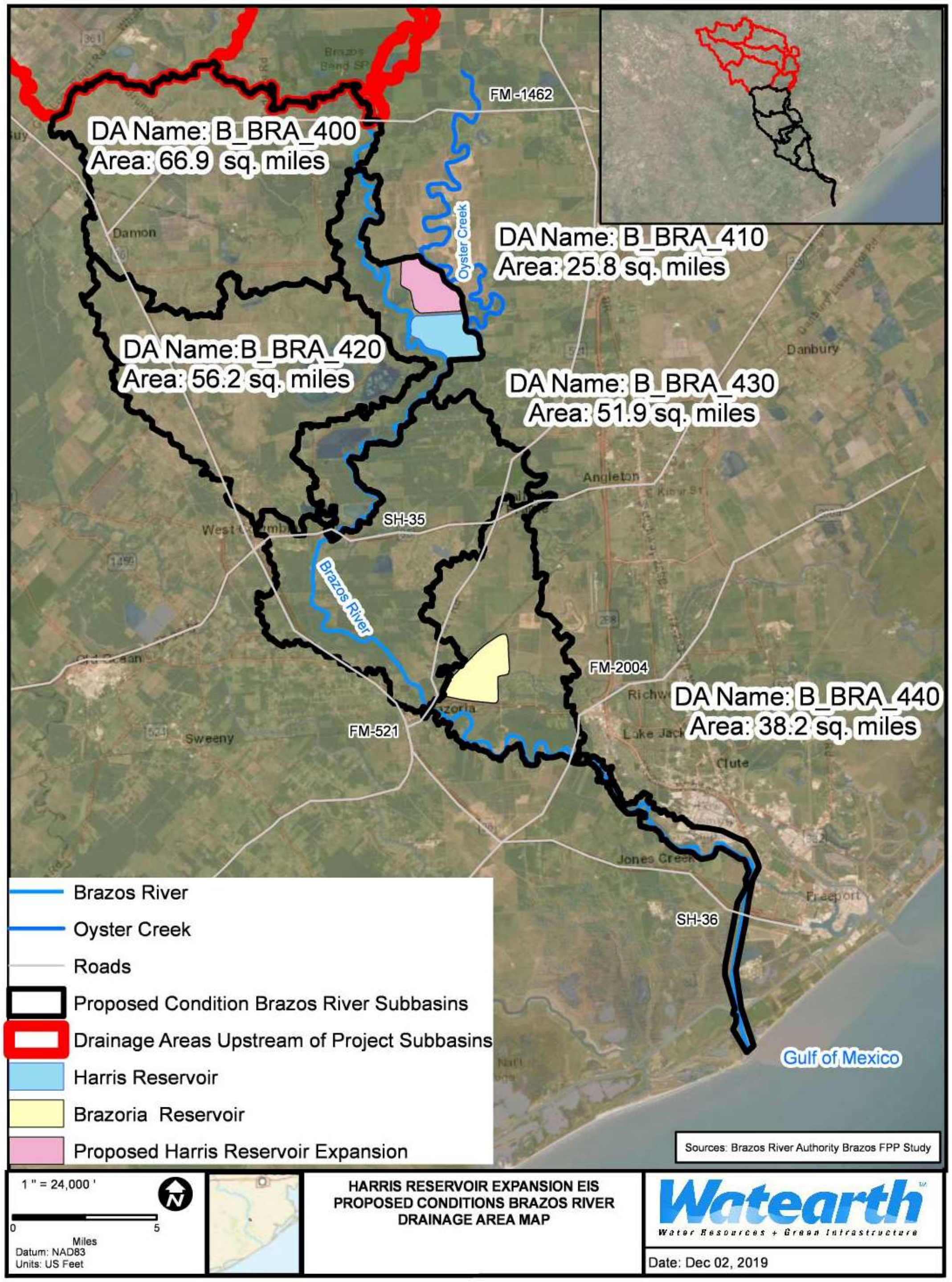


Figure 3 Lower Brazos River and Oyster Creek Sub-Basins in Project Vicinity

2.3 Rainfall and Temperature Change

The USACE has developed predictive models for changes in rainfall and temperature, among other climate predictors. The USACE Region 12 (Texas-Gulf Region) report summarizes current climate and hydrology literature for the general project area. Seasonal precipitation is expected to decrease slightly with warmer annual temperatures, although intense rainfall events may increase in frequency. This means that mean annual rainfall may decrease while the variance from year to year increases. Figure 4 shows projected seasonal precipitation changes in 2085 (USACE, 2015).

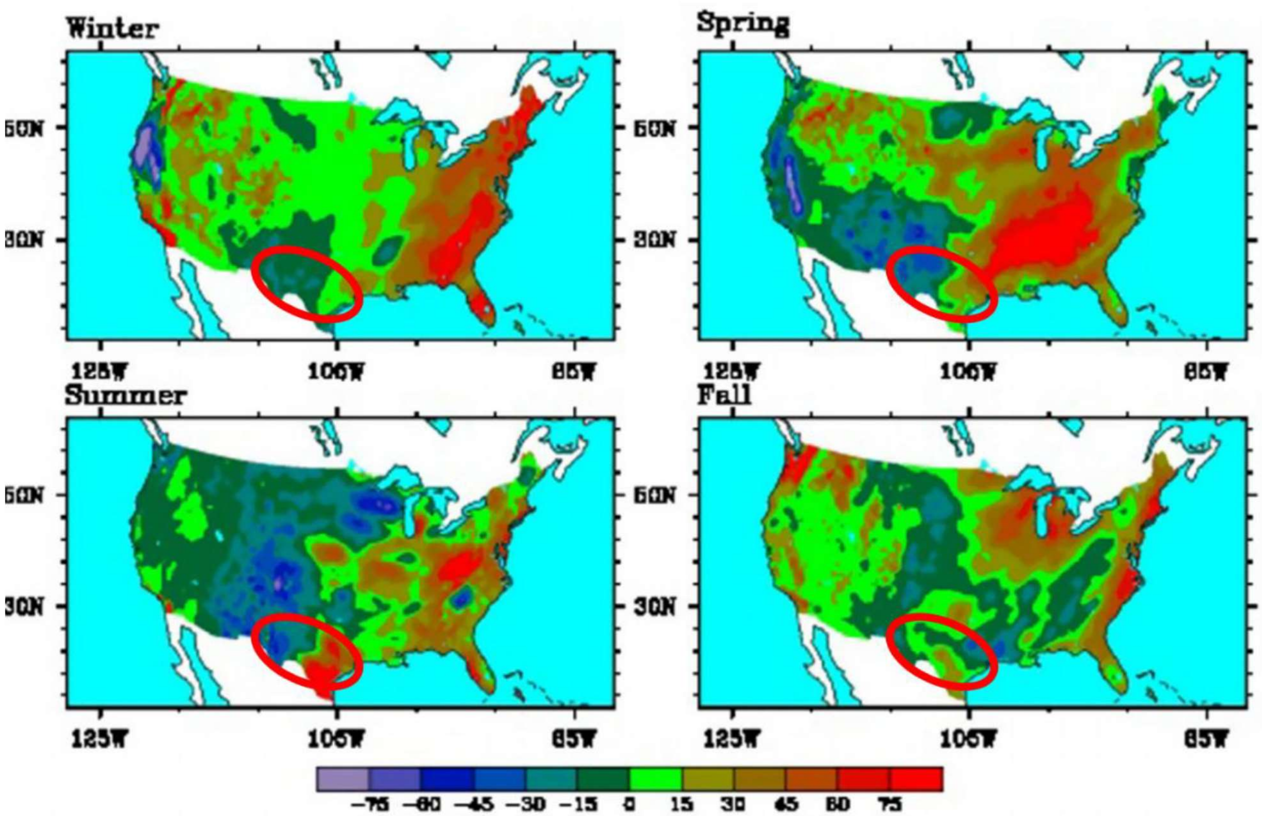


Figure 4: Projected changes in seasonal precipitation, 2085 vs. 1985 mm (from (USACE, 2015)). Texas region circled with red oval.

Although Figure 4 shows a slight decrease in precipitation in southern Texas, projections of future precipitation change are especially uncertain in this region because it is located in a transition zone between projected drier conditions to the south and projected wetter conditions to the north, which could have mixed effects on river flows at the project site. Due to these uncertainties, the assumption that future precipitation in the project area will be roughly similar to past precipitation appears to be justified.

2.4 Watershed Vulnerability and Hydrology Assessment

The project proponent, Dow, developed a Hydrology and Floodplain Analysis (Attachment J of the USACE Individual Permit Application). The focus of the Attachment J analysis was on flooding risk and high flow events and that full analysis is not repeated here. The USACE watershed vulnerability tool was used to screen the vulnerability of the project area to flooding under future conditions (USACE, 2019b). For the Brazos River Watershed (HUC 1207), the projected future risk is expected to be low for the dry scenario, and moderate for the wet scenario. Figure 5 shows the vulnerability of the Brazos River watershed for 2050 and 2085 conditions.

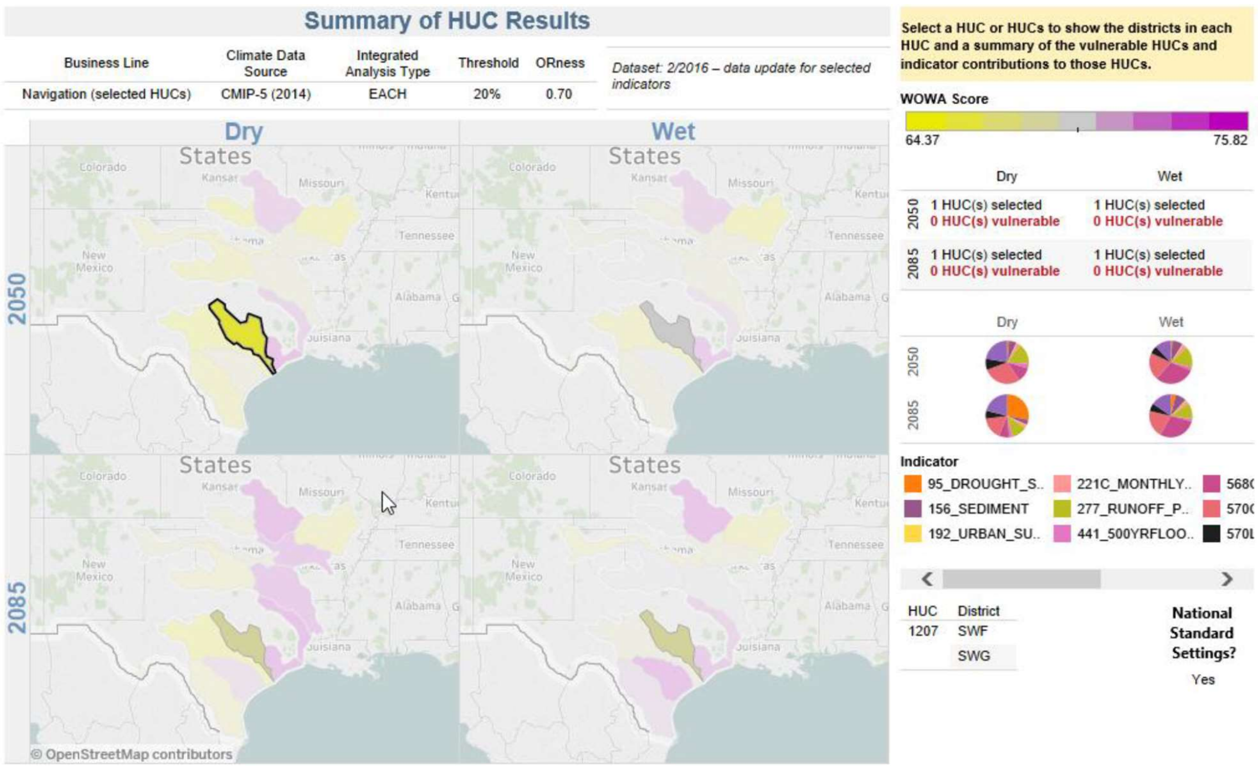


Figure 5: Watershed vulnerability for the Brazos River watershed (HUC 1207) from the USACE watershed vulnerability tool.

The climate hydrology assessment tool was also used to assess the predicted trends of the peak annual discharge for the Brazos River (USACE, 2019a). Figure 6 shows the trends in projected peak annual flowrate, which represent the mean of 93 projected future hydrology models for the Brazos River watershed (HUC-1207). The projected annual maximum monthly streamflow for the Brazos River is expected to remain relatively constant, with the potential for a very small increase in flow rates in the future based on the climate hydrology model results shown in Figure 6. However, there is considerable uncertainty in making such specific predictions of future peak annual discharges. It is important to note that this data is not to be used for quantitative analysis.

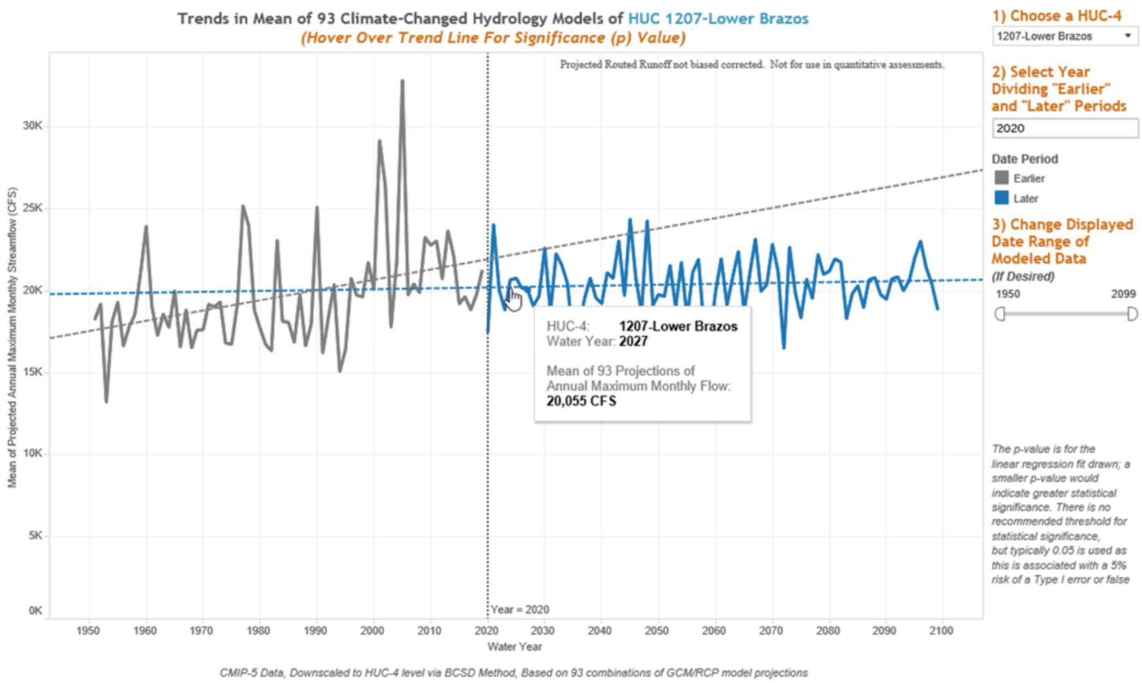


Figure 6: Trends in mean modeled annual maximum streamflow. The mean (dotted blue line) is the average of 93 Climate-Change Hydrology Models of HUC 1207.

The consensus in the recent literature points toward mild increases in annual precipitation and streamflow in the Texas-Gulf Region over the past century. In some studies, and some locations, statistically significant trends have been quantified, however, the trends at the Brazos project site remain insignificant or unclear. The discussion above should be used for qualitative analysis of the hydrology, precipitation, and temperature impacts for the Proposed Project.

2.5 Storm Surge

The Gulf Coast shoreline is susceptible to storm surge, which is an abnormal rise in seawater level during a storm as a result of on-shore high winds. Storm surge is measured as the height above the normal predicted astronomical tide. The distance on-shore that storm surge travels can be compounded if associated with high tides, especially unusually high tides called king tides. The increased sea level height means that the tidal influence area is extended upstream from normal conditions temporarily. Storm surge and associated winds can be damaging to human development and infrastructure farther upstream than under normal conditions. FEMA calibrates and validates storm surge using historic recorded storms in development of the Flood Insurance Study (FIS) for Texas Coastal Counties (FEMA, 1999). FEMA selected Carla (1961), Claudette (2003), Rita (2005), and Ike (2008) as potential validation storms due to their intensity and proximity to the project site (Figure 7). The storm tracks for these storms are shown in Figure 7. Due to the flat topography in the project area, inundation of brackish and saline water will reach farther upstream than under normal conditions. Based on sampling data provided by Dow, the salt wedge ranged from river mile 15 to 43 and could potentially reach river mile 49.

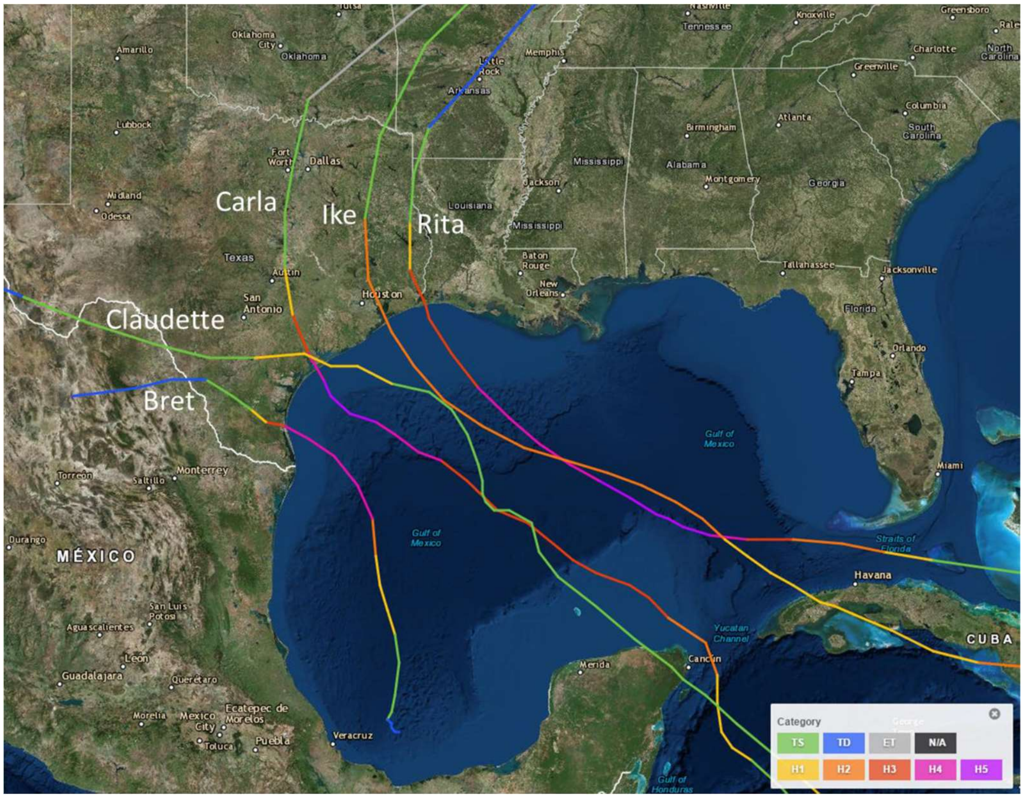


Figure 7: Historical Storm Tracks near the Project Site (FEMA, 1999).

2.6 Relative Sea Level Rise

The global sea level has been rising over the last century and current prediction models indicate that this will accelerate over the next century. Low lying and flat topography areas such as the project area are more likely to experience direct effects including inundation and extension of the brackish water upstream compared to past conditions. The Brazos River estuary extends above the Brazoria Reservoir located at river mile 25 periodically throughout the year. Dow monitors and tracks the location of the salt wedge, as defined as greater than 500 milligrams/liter of chloride. As discussed above, Dow provided the salt wedge position tracking data and found the salt wedge fluctuates between river mile 15 and 43 and could potentially reach river mile 49. The existing Harris Reservoir is located at river mile 46.

The USACE developed a relative sea level rise calculation and mapping tool (USACE, 2014). The tool uses USGS gage data, NOAA Atlas 14 rainfall rates, and other data to provide three scenarios for relative sea level change, which reflects different rates of sea level rise based on the scientific literature.

The assumed project start date (substantial completion of the Proposed Project) is 2022 with the planning horizon of 2072 (50 years). Data was obtained using the web tool from the closest available gage, 8772440 at Freeport, TX, which is located approximately six miles from the Brazos River mouth. Tool assumptions include a base flood elevation (BFE) of 12 feet (FEMA, 1999). Model predictions range from approximately one foot to four feet in 2070 and two feet to over eight feet in 2122.

Figure 8 shows the resulting relative sea level change over the planning horizon (until 2075) and 100 years from the project start date (2122). Figure 9 displays the resulting inundation from the USACE high sea level change scenario in 2122, which is 100 years from project start.

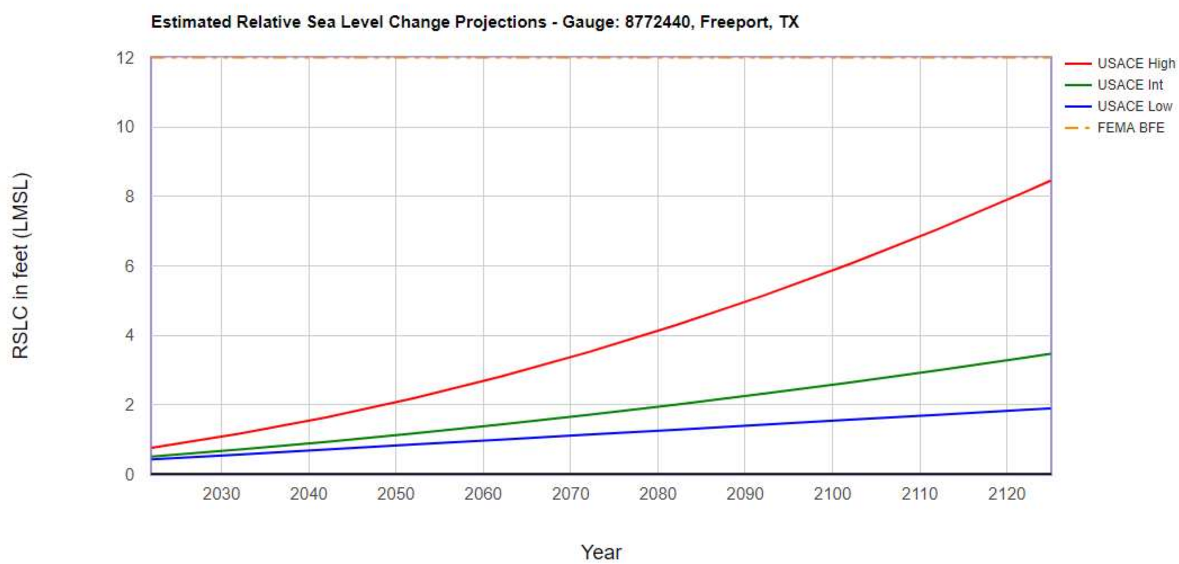


Figure 8: USACE projected RSLR, at NOAA gage 8772440, Freeport TX over 100-Year Period of Analysis (2022 Base Year, 2075 End of 50-Year Project Planning Horizon, 2122 End of 100-Year).

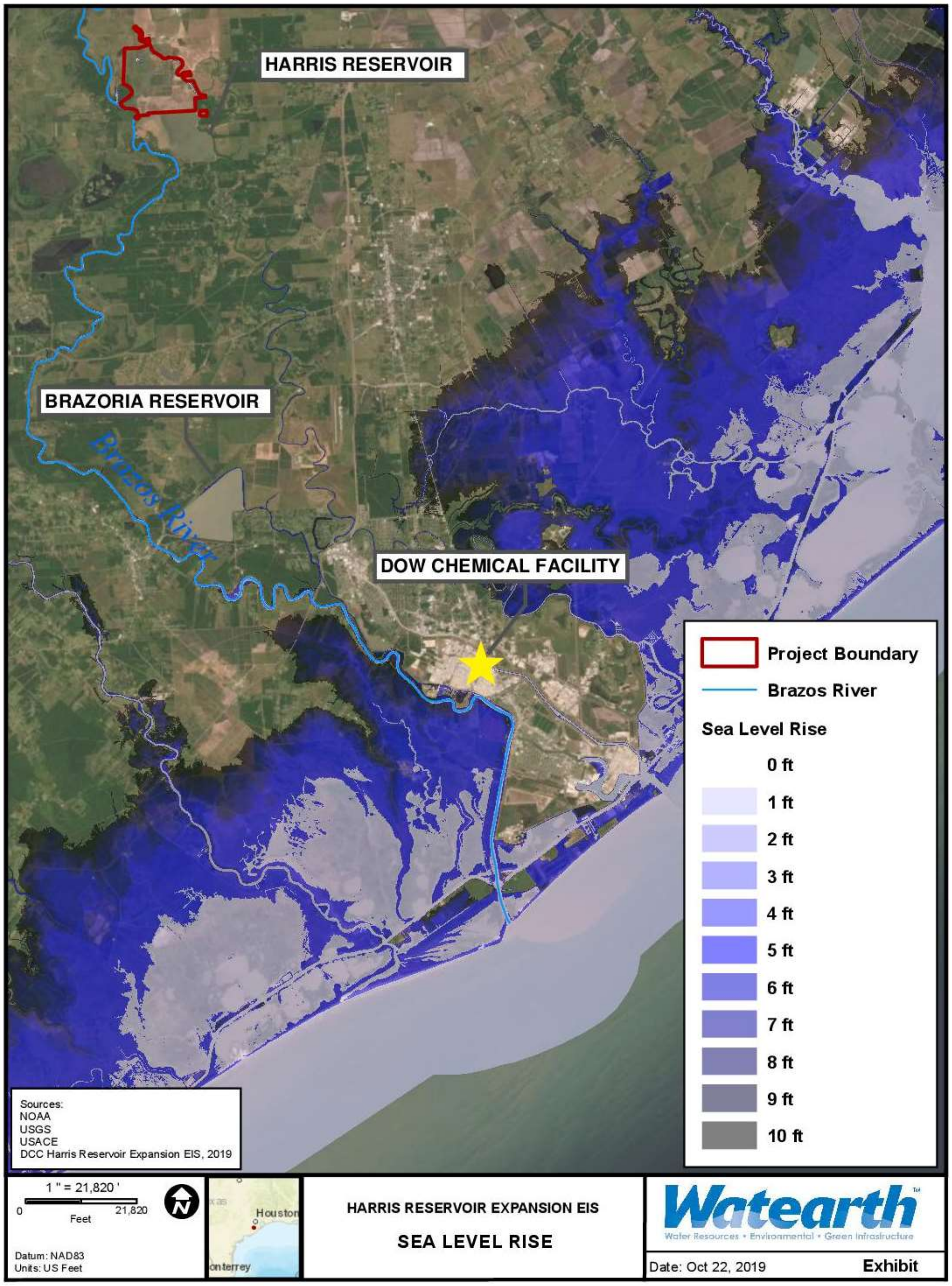


Figure 9: Gulf Coast inundation map for mean sea level in the year 2122 under the high sea level rise scenario.

3 Existing Site Conditions

This project provides a unique set of existing site conditions because the existing condition is comprised of a water supply system spanning over nearly 40 river miles of the Brazos River, cross basin interactions between the Brazos River and Oyster Creek, a series of canals, and multiple reservoirs.

3.1 Proposed Project Boundaries

The Proposed Project is development of an approximately 50,000 AF reservoir directly upstream of the existing Harris Reservoir. The proposed reservoir site land use is current agriculture. According to project information provided by Dow, the proposed reservoir site has wetlands and acts as the floodplain for both the Brazos River and Oyster Creek.

The Proposed Project must be considered in the context of the system it will contribute, specifically the water supply system that serves the Dow plant and other users in Freeport, Texas. For modeling purposes, the project boundaries include the Brazos River from the Rosharon USGS stream gage to the mouth of the Brazos River at the Gulf of Mexico and portions of Oyster Creek used for inter-basin transfers of water through the existing Harris and Brazoria Reservoirs.

As shown in Figure 10, Dow operates two off channel impoundments (information provided by Dow). The existing Harris Reservoir, located at river mile 46, lies between the Brazos River and Oyster Creek in their shared floodplain. The Brazoria Reservoir, located at river mile 25, is deeper than the existing Harris Reservoir and designed for three times the storage.

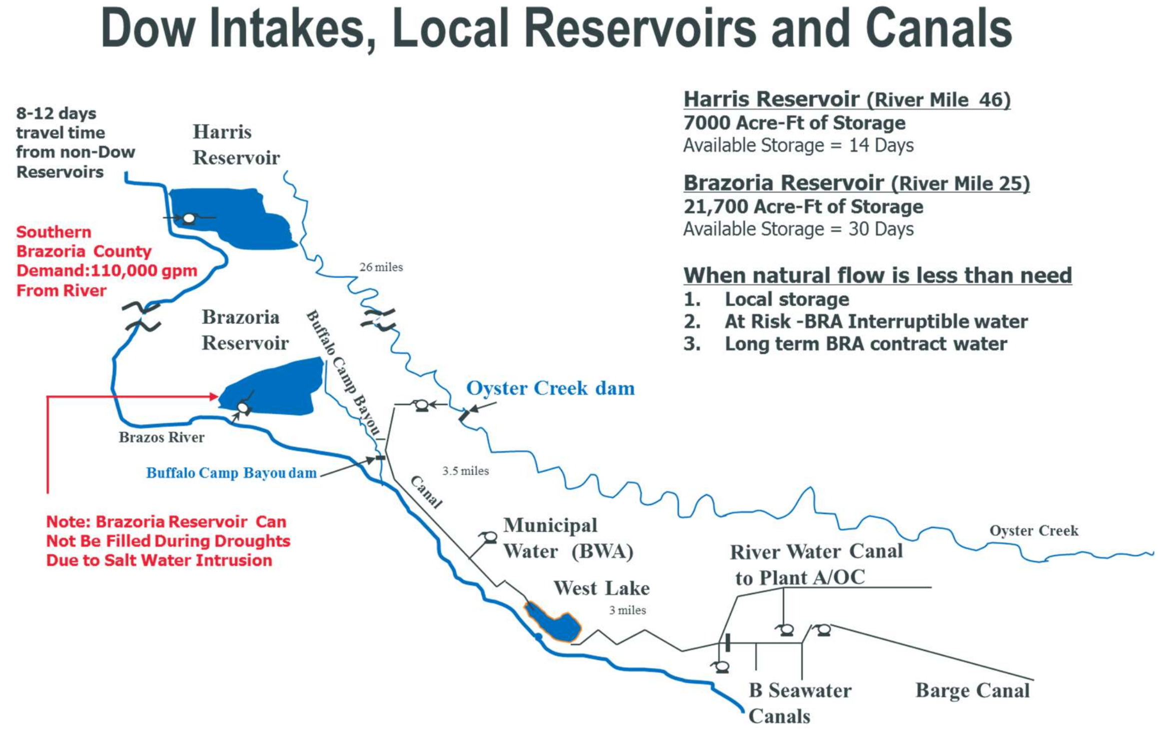


Figure 10: Dow Reservoir Water Supply Map (provided by Dow)

3.2 Dow Managed Water Storage

Dow's existing surface water intakes for the Brazoria and Harris Reservoirs are located in segment 1201 of the Brazos River, which are tidally influenced. During low flow conditions in the Brazos River, saline water moves up from the Gulf of Mexico to upstream locations on the river (saltwater wedge), ranging from river mile 15 to 43 per Dow provided data on chloride sampling. When flow conditions at the Brazos River pump station (river mile 25) are reduced to approximately 1,730 cfs or lower, Dow is unable to divert water into the Brazoria Reservoir due to saltwater intrusion from the Gulf and must rely on water delivered from the existing Harris Reservoir. When river flows are sufficient at the existing Harris pump station intake on the Brazos River, river water is transferred through the reservoir to Oyster Creek by pumping from the river into the reservoir and then discharging to the creek through a siphon system. When flow conditions limit pumping to the existing Harris Reservoir, water supply needs of Dow and others are met by withdrawing water stored in Harris and Brazoria Reservoirs.

3.2.1 Dow's Brazos River Water Rights

Dow has a Brazos River water right of 238,156 AF per year for industrial, municipal, domestic and livestock uses. In addition, they have an Oyster Creek water right for 60,000 AF per year for industrial and municipal uses and a Buffalo Bayou water right of 7,560 AF per year for industrial and municipal uses. There are no water rights holders with more senior rights compared to Dow in the river segment between the Rosharon USGS gage and the Gulf of Mexico. Dow's combined water rights allows a maximum diversion rate of 630 cubic feet per second (cfs) from the Brazos River.

3.2.2 Water Supply Needs

As discussed below in the Local Drought section, the Freeport, TX area, like much of Texas, experienced drought conditions that reduced the flows in many local rivers and streams. During this time there was significant population growth and corresponding demands for additional potable water. Portions of the Brazos River Watershed are undergoing significant development.

Dow undertook efforts to reduce potable water needs. Even with these demand reduction measures in place, the raw water use rate for Dow and water customers is about 3,000 AF per week (approximately 430 AF per day or 97,000 gpm). At this rate, and without any additional storage, the existing two reservoirs (when full) would provide a storage reserve of approximately 68 days or less, assuming all stored water could be accessed. This is significantly fewer days than drought preparedness and response standards established by the state. The Texas Commission on Environmental Quality considers water systems with 180 days or fewer of available water supply at risk during drought.

3.3 Recent Drought Conditions

A multi-year drought began throughout Texas in 2005 with 2011 being the driest year on record in Texas. By October 2011, 97-percent of the state was in extreme or exceptional drought conditions. During this drought period, flows in the river were significantly lower than during average conditions. Had such severe drought conditions continued, Dow may have had to reduce essential functions at their facility and curtail usage for the industries and municipal users that rely on its water supply system for a reliable source of water.

Additionally, WAM modeling provided by Dow indicates that Dow's run-of-the river rights in the Brazos River (the rights diverted into the existing reservoirs) may not be available for diversion from the River during a repeat of the drought of record observed during the period of record for the Brazos River. There are significant periods (multi-month) of time when water from the Brazos River would not be available during a repeat of the drought of record. Modeling indicates that when upstream junior water rights holders divert their full authorization, availability for diversion will be decreased.

During recent years, Dow has successfully reduced its freshwater consumption from the Brazos River by more than 20,000 AF per year for production at the Texas Operations through onsite recycling and water efficiency practices. Additional water conservation/water use efficiency measures are planned for implementation over time as technology and cost-effective approaches develop. It is anticipated that these future water savings in combination with savings already achieved would meet future water demands associated with operations and production growth during most climate conditions; however, these investments in water conservation do not provide the additional storage capacity required to sustain operations during extended drought.

3.4 Lower Brazos River Watershed

The drainage area of the entire Brazos River is approximately 45,560 sq mi (TWDB, 2011). The drainage area starts 50 miles west of the Texas – New Mexico border and runs approximately 1050 miles to the Gulf of Mexico (Figure 1). The Lower Brazos River drainage basin that includes the Proposed Project is approximately 9,766 sq mi. and has no major structures that control the river flow. The Lower Brazos River affects the southern Texas counties of Falls, Limestone, Robertson, Milam, Lee, Burleson, Grimes, Washington, Waller, Austin, Fort Bend and Brazoria. This area is one of the fastest growing areas in the country and this region has experienced substantial flooding over the last four years such as the Memorial Day Flood (2015), Tax Day Flood (2016) and Hurricane Harvey (2017).

3.4.1 Basin Hydrology

The following hydrologic data corresponds to the hydrologic studies completed by the Texas Water Development Board (TWDB) for Brazos River (TWDB, 2011). The Brazos River Estuary Hydrology Study covers the period of record from 1977 to 2009.

Hydrologic analysis results provided a volumetric runoff balance in AF, which includes the following contributions:

$$Balance = gaged + modeled - diversion + return - evaporation + precipitation$$

Note that there is no gaged data at the coastal sub-watershed (below the Rosharon Gage) that is not subject to tidal influences. Therefore, a rainfall-runoff hydrologic model is needed. Where gaged flows are obtained from USGS gages, modeled are rainfall-runoff values estimated using the Texas Rainfall-Runoff Model (TxRR) model, diversions and returns are flows associated with water rights and holders of discharge permits, and evaporation and precipitation include a contribution from each process on the surface area exclusively (TWDB, 2011). Note that the TxRR model results were obtained from the TWDB. The TxRR model is conceptually similar to the United States Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS; formerly the Soil Conservation Service (SCS)) curve number method, which was developed by research conducted by the USDA Agricultural Research Service (ARS).

Figure 11 shows over the study period, gaged inflow from the USGS station on the Brazos River near Rosharon accounted for approximately 86-percent of combined inflow, while modeled flows (rainfall-runoff) accounted for almost 3-percent of the balance. Hence, the river discharge on the Brazos River is significantly dominated by upstream riverine processes rather than precipitation-induced discharges in the coastal plain. Therefore, precipitation processes can be ignored in the analysis. Such behavior is expected due large drainage area. It is possible that heavy local rainfall between the Rosharon gage and the Harris Reservoir Project intersection could influence hydrodynamics at the project site. However long-term trends indicate that is an infrequent event, which would likely not alter the long-term hydrodynamics that river flows at the project site.

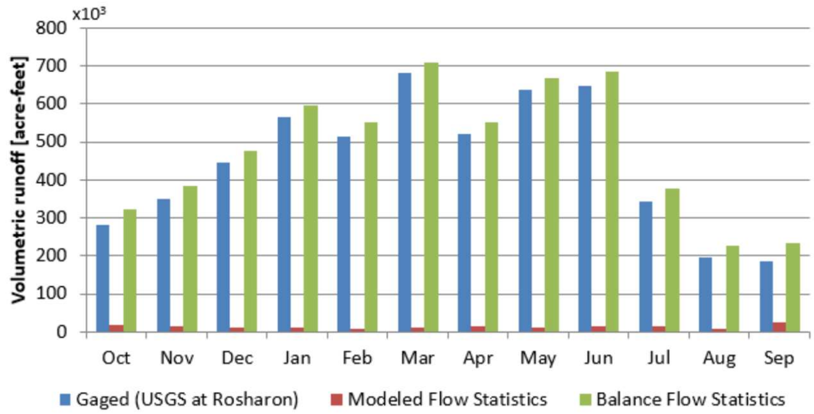


Figure 11: Brazos River long-term monthly mean freshwater inflow hydrology data over the period from 1977 to 2009. Data is shown in water year from October 1st to September 30th (TWDB, 2011).

3.4.2 Analysis of Flow Gage Data Trends

USGS maintains stream gages throughout the project watershed including on the mainstem Brazos River as well as tributaries (Figure 12). The nearest upstream gage to the project is located near Rosharon Texas. For purposes of modeling, this was selected as the upper limit of the project area for analysis. The Richmond Texas gage was used to confirm stream flow conditions. The West Columbia gage is subject to tidal and estuary conditions.

To evaluate the long-term trends of precipitation on river discharge, a trend analysis was conducted on the annual peak discharges at the Rosharon, Texas and Richmond, Texas USGS gages for the Brazos River. Figures showing the peak annual discharges are shown below in Figure 13 and Figure 14 for the Brazos Rosharon gage and Brazos Richmond gage, respectively.

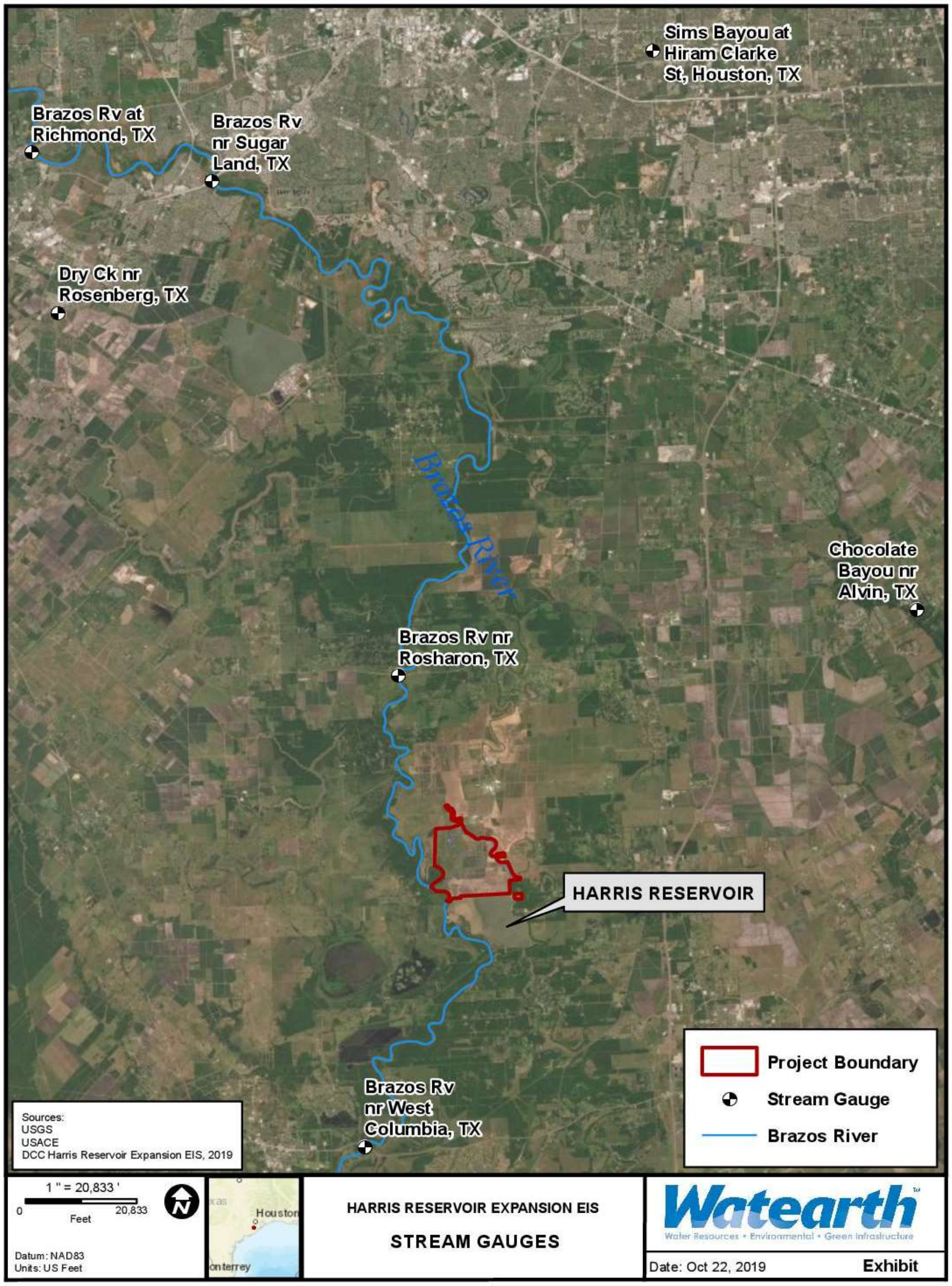


Figure 12: Stream Gages in Vicinity of Proposed Project

A USGS gauge upstream of the project site at Brazos River (USGS 08116650 Brazos River near Rosharon, TX) shows the flow time series fluctuates significantly in a relatively short period of time. Historical records show that daily flows within one month can go from 800 cfs to more than 100,000 cfs and back to low flows again within the next month.

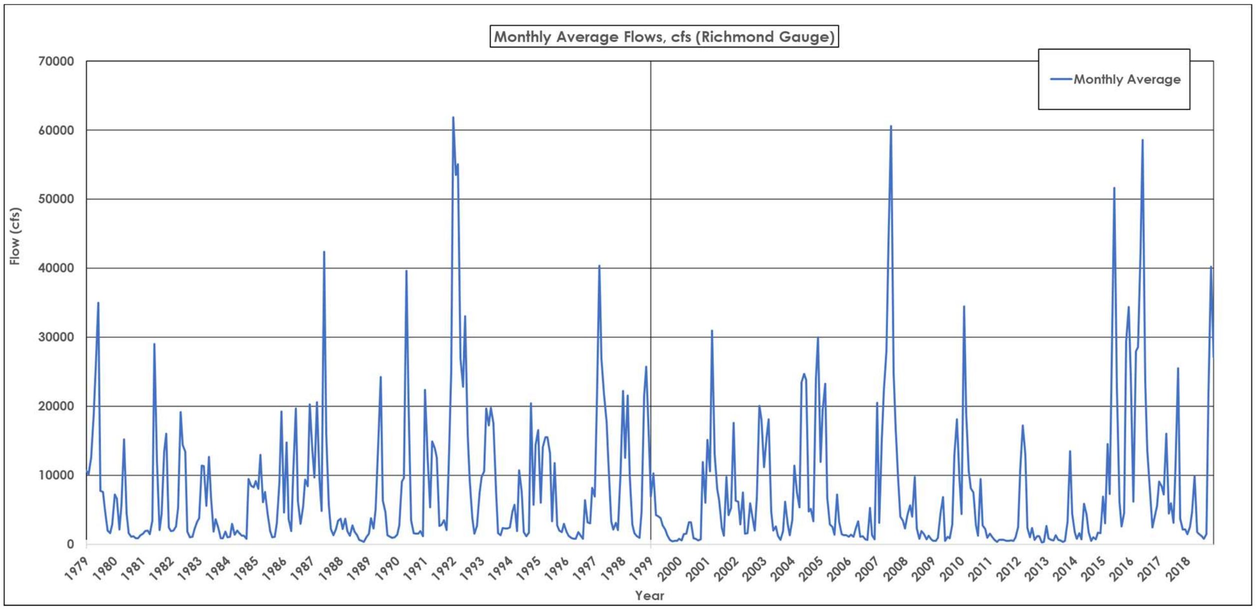


Figure 13: Monthly Average Flows, Richmond, TX Gage

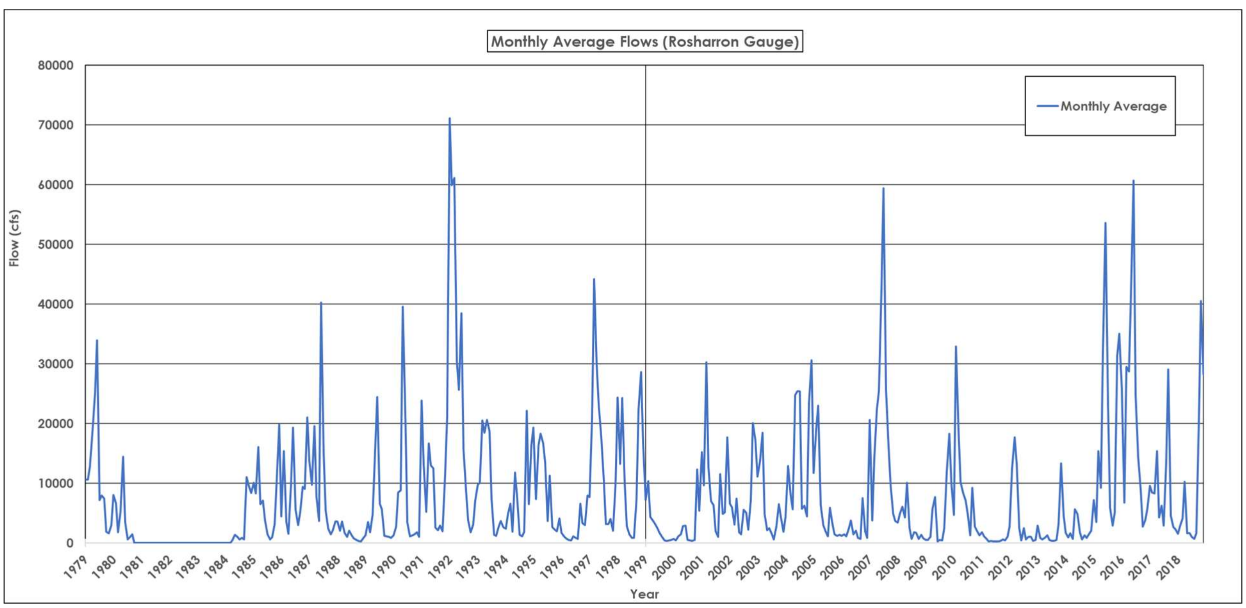


Figure 14: Monthly Average Flows, Rosharon, TX Gage

The comparison of this data shows that over the entire period of record, the monthly mean peak discharge attenuates in the downstream direction. The maximum monthly mean discharge drops from 14,200 cfs to 12,400 cfs in May. Such attenuation is expected in the lower sections of the

Brazos River, “as elevated flows enter storage in the low elevation terrain and are released over longer time periods” (USGS, undated). Conversely the lower flows seen during November, December, January, February, March, April, June, July, April, and September increase in the downstream reach. June is when the highest monthly average discharge occurs in the Brazos River.

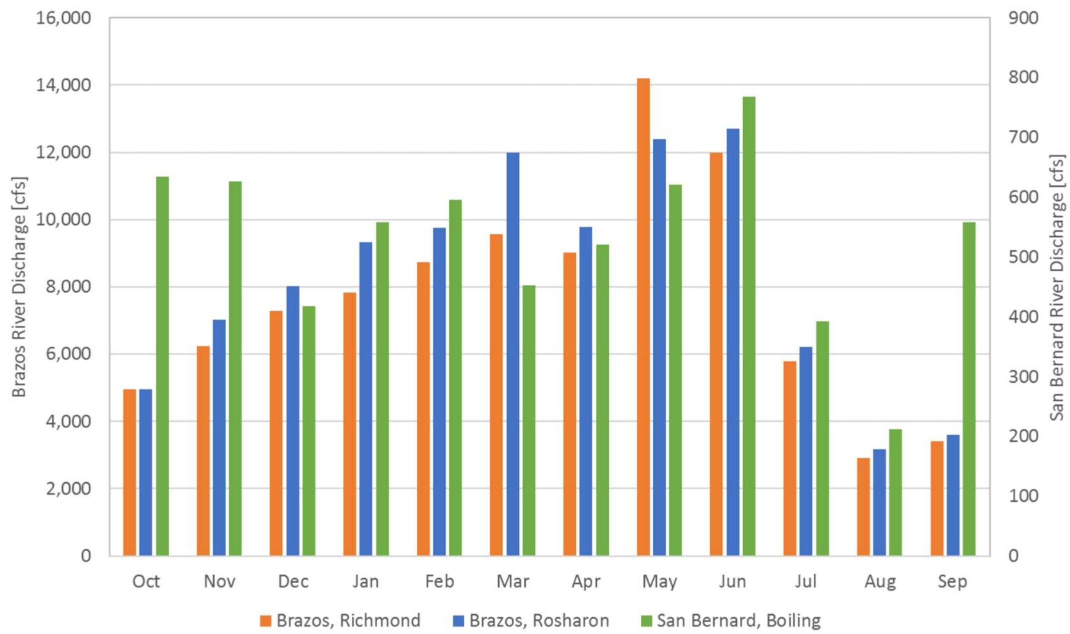


Figure 15: Long-term monthly mean streamflow discharge at USGS stations Brazos River near Richmond (upstream in blue), Brazos River near Rosharon (downstream in red) and San Bernard River near Boling. Data is shown in water year from October 1st to September 30th

3.5 Sedimentation Loads in Brazos River

3.5.1 Introduction

Sediment transport is a function of riverine systems. The velocity of flow determines sediment load and gradation size as higher velocities carry larger particle sizes and resist settling. Increases in velocities can also resuspend sediment of larger particle sizes as well.

3.5.2 Brazos River Sediment Load

Sand-sized sediment transport has been decreasing since measurements were taken starting in 1969, which is at least partially attributable to the effects of reservoirs placed into operation during the same time period (USGS, 2001). The reservoirs reduced high peak flows, which can transport larger particles for longer distances, and trapped sediment within their boundaries. The scatter plot in Figure 16 shows the relationship to discharge rates and concentration of sand particles with a Locally Weighted Scatterplot Smoothing (LOWESS) line providing graphical comparison between the two time periods shown without assigning a statistical significance to the difference (USGS, 2001). At similar discharge rates, the suspended-sand load is reduced during the latter period

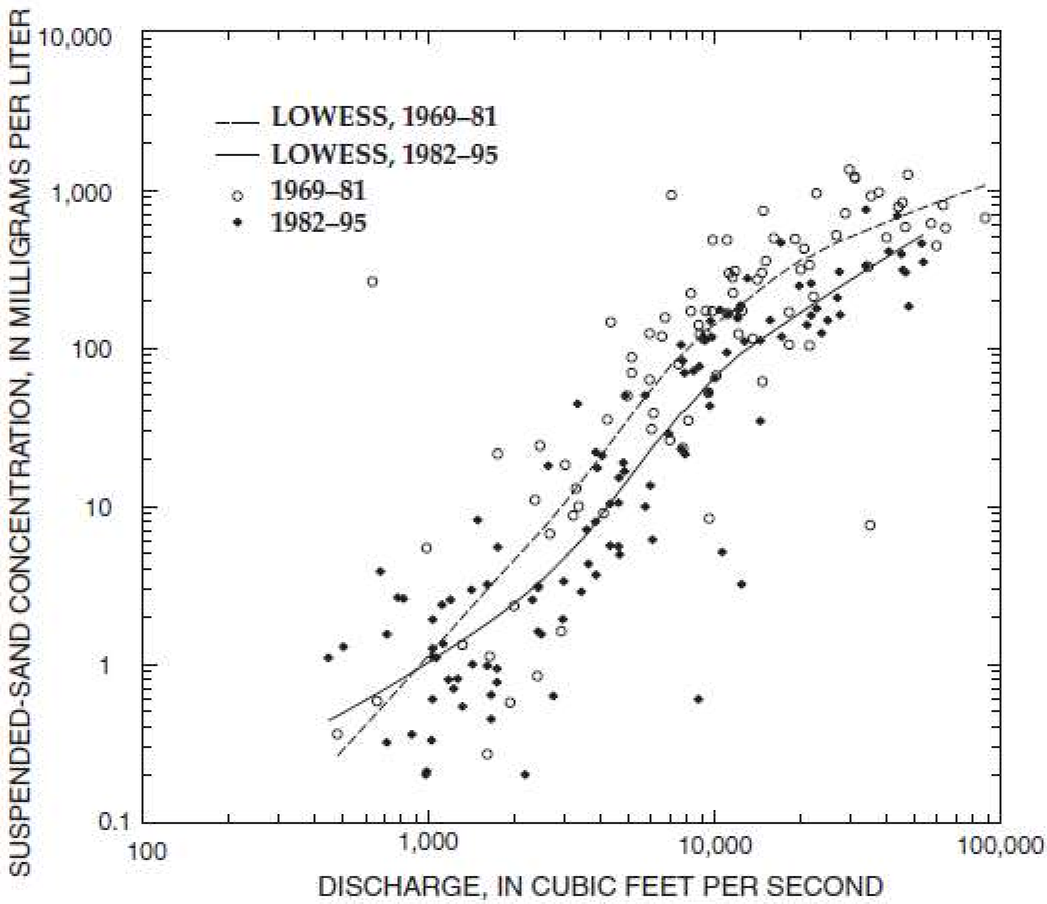


Figure 16: Relation of Suspended Sand Concentration to Discharge at Streamflow-Gaging Station 08114000 Brazos River at Richmond, Texas, 1969-1995 (USGS, 2001)

BRAZORIA RESERVOIR

AUTHORIZED			1990 SURVEY			ADJUSTED 1990 SURVEY		
Volume-Area-Depth			Volume-Area-Depth			Volume-Area-Depth		
Volume ac-ft	Area acres	Elevation feet	Volume ac-ft	Area acres	Elevation feet	Volume ac-ft	Area acres	Elevation feet
0	0	13.6	0	0	16.0	0	0	16.0
160	200	15.2	90	300	17.6	160	200	17.6
900	400	17.6	900	800	20.0	900	400	20.0
2,257	830	19.6	2,000	1,300	22.0	2,257	830	22.0
4,587	1,500	21.6	4,650	1,830	24.0	4,587	1,500	24.0
6,262	1,850	22.6	6,000	1,850	25.0	6,262	1,850	25.0
9,103	1,860	24.2	8,500	1,860	26.6	9,103	1,860	26.6
21,710	1,870	31.0	17,300	1,870	31.0	17,309	1,870	31.0

Authorized: 2.36 feet lower bottom than Adjusted 1990 Survey.

HARRIS RESERVOIR

AUTHORIZED				1990 SURVEY			ADJUSTED 1990 SURVEY		
Volume ac-ft	Area acres	Elevation feet		Volume ac-ft	Area acres	Elevation feet	Volume ac-ft	Area acres	Elevation feet
0	0	29.8		0	0	32.0	0	0	32.0
13	50	30.3	0.5	20	200	32.5	13	50	32.5
88	100	31.3	1.0	50	480	33.5	88	100	33.5
493	170	34.3	3.0	200	1,220	35.5	493	170	36.5
728	300	35.3	1.0	400	1,450	36.5	728	300	37.5
813	550	35.5	0.2	1,000	1,600	37.7	813	550	37.7
1,593	1,400	36.3	0.8	1,500	1,655	38.5	1,593	1,400	38.5
2,355	1,650	36.8	0.5	3,000	1,660	39.9	2,355	1,650	39.0
5,173	1,665	38.5	1.7	4,500	1,665	40.7	5,173	1,665	40.7
10,199	1,675	41.5	3.0	6,500	1,675	41.5	6,509	1,675	41.5

Authorized: 2.21 feet lower bottom than Adjusted 1990 Survey.

Figure 17: Effective Capacity of Brazoria and Harris Reservoirs

The amount and gradation of the sediment carried by the Brazos River is highly dependent on the velocity of the river. High flows carry sands, silt and clay but low flows carry mostly clay. The intake pump inlets for both existing reservoirs is below the natural stream bed and likely results in sediment intake at all flow conditions. The Proposed Project intake has a similar location compared to the natural stream bed.

Historical suspended sediment concentration (SSC) was recorded in the Brazos River at USGS Station 08116650 (Rosharon Gage) at an approximately monthly frequency between 1973 and 1981, and again between 2008 and 2015 (Figure 18).

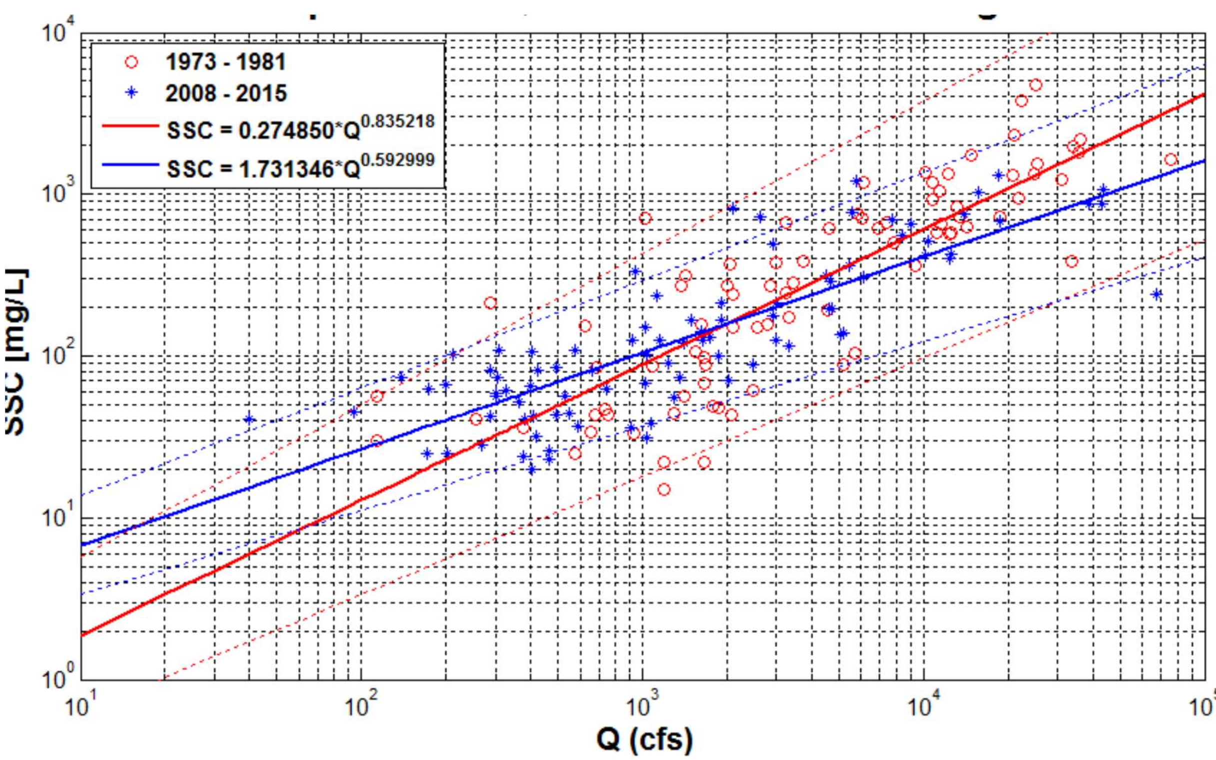


Figure 18: Sediment load curve at Brazos River, Rosharon gage based on measured data.

Dow reported periodic sediment removal by dewatering the existing Harris reservoir and removing sediment by a bulldozer however the frequency of past sediment removal and future maintenance at the two current reservoirs was not provided. They also reported in their reply to questions concerning the "Dow Water Rights and Supply – Fast Facts and Information" document that Dow has a permit authorizing dredging of solids from the reservoirs with specified, limited releases to the Brazos River under certain river flow conditions. Dow also indicated they have concerns with embankment stability if dredging was performed. But there is a possibility to dredge these reservoirs back to their original authorized capacity with the modern equipment that could be used with global positioning systems (GPS) that would control location and depth of dredging. Dredging to original or deeper contours could increase available water but would not increase reservoir surface area where the evaporation occurs.

As described in Figure 17 and show in Table 2, the historical reservoir capacity loss for Brazoria Reservoir was a 111 AF/yr from 1954 to 1990. The straight-line projection of 111 AF/yr storage loss by sediment for another 29 years to 2019 would mean that an addition storage loss of approximately 3,200 AF. This would reduce the 2019 Brazoria Reservoir storage volume to approximately 14,100 AF. However, as provided by Dow and shown in Figure 10, Dow is assuming an effective storage capacity of 21,000 AF, noting in other correspondence with Dow that 16,000 AF is available via the siphon outlet but that the remaining 5,000 AF would need to be pumped.

As described in Figure 17 and show in Table 2, the historical reservoir capacity loss for Harris Reservoir was 81 AF/yr from 1947 to 1990. The straight-line projection of 81 AF/yr storage loss by sediment for another 29 years to 2019 would mean that an addition storage loss of approximately 2,350 AF. This would reduce the 2019 Harris Reservoir storage volume to approximately 4,150 AF. However, as provided by Dow and shown in Figure 10, Dow is assuming an effective storage capacity of 7,000 AF, noting in other correspondence with Dow that 3,000 AF is available via the siphon outlet but that the remaining 4,000 AF would need to be pumped.

Table 2: Effective Storage Capacity for Harris and Brazoria Reservoirs

Year (Estimate by)	Harris Reservoir (AF)	Brazoria Reservoir (AF)	Total Effective Storage (AF)
1947	10,200	-	10,200
1954	-	22,000	32,200
1990 (Dow by survey)	6,500	17,300	22,800
2018 (Dow USACE Application)*	**7,000**	**21,000**	**28,000**
2019 (Watearth)	4,150	14,100	18,250

* Dow USACE application storage values are used for purposes of analysis and modeling. Other values, including Watearth estimates are shown for informational purposes.

Without a more recent survey of the existing reservoirs, the actual effective storage volume could range from 18,000 AF to 28,000 AF, as described above for different sedimentation rate calculations.

3.6 Other Hazards Considered

3.6.1 Wind

The proposed reservoir location is close to the Gulf of Mexico and can be subject to high winds from tropical storms and hurricanes. The preliminary design report supplied by ch2m was reviewed concerning their design approach to how wind may affect the proposed reservoir design. The design report indicates that in 2017 a wind speed of 185 miles per hour (mph) was report from a Hurricane Harvey.

These high winds traveling across open water in the reservoir (the fetch) can generate waves that could damage the embankment or even overtop the embankment. The preliminary design indicates that these concerns were taken into consideration and elements such as the soil-cement embankment protection, the wave wall at the intersection of the top and interior slope, and the operational drawdown prior to the forecasted storm events.

3.6.2 Wave

The preliminary proposed embankment design addresses the embankment slope protection from wave action by the placement of 8-inch stair stepped soil-cement lifts on the interior slope above elevation 60.93. Dow also prepares for large storm events by drawing down the reservoir pool elevation whenever a hurricane alert is issued for any magnitude hurricane that may make landfall near the reservoirs. This allows for more freeboard below the top of the embankment.

The preliminary design also addresses overtopping, which is the most common reason for an embankment breach and uncontrolled release of water. Anchored into the soil-cement is a three-foot tall bullnose (or parapet) wall at the interior edge of the embankment top to reduce overtopping of embankment. Using the USBR breach equation, Watearth estimated that approximately 12,500 cfs of water could be released into the Brazos River or Oyster Creek in the event of a breach. While this is a significant quantity of water, the downstream floodplain would quickly dissipate this volume and little to no long-term effects would be anticipated under current land use conditions.

3.6.3 Tidal Elevations

The lowest extent of the project is the confluence of Brazos River with the Gulf of Mexico near Freeport, Texas. In addition, nearly the entire project area is subject to estuarine conditions with one of the factors being tides. Tides are determined by the lunar cycle, distance and position of the moon in comparison to the sun, and gravitational forces. The lunar day is 24 hours and 50 minutes, this results in two high tides per lunar day every 12 hour and 25 minutes with the accompanying low tide occurring 6 hours and 12.5 minutes after the high tide. Due to the relationship between the moon and the position on Earth experiencing a tide, there will be a higher and lower high tide during the lunar day. With other influences such as the position to the sun, higher than normal tides can occur (sometimes referred to as king tides).

The Gulf of Mexico is tidally influenced with tidal conditions similar to an inland sea due to a large coastal shelf and relatively narrow entrance blocked by Cuba and other Caribbean islands. As such, tides can be highly influenced by storm conditions.

The tidal gauge at Freeport, Texas (gauge 8772447), located six miles northeast of the mouth of the Brazos River, measures tidal conditions near the project area (Figure 19) (NOAA, 2019). The average monthly high tide fluctuation is 1.67 ft (MSL) with the largest recorded fluctuation being 5.4 ft (MSL). The average fluctuation between the monthly lowest low tide and the highest high tide is 3.65 ft (MSL) with the largest recorded fluctuation being 7.25 ft (MSL). This is a relatively narrow band of water surface elevation changes related to tides but when taken in consideration with the low nearshore topography, can present design and inundation risks, especially during storm surge. The flat topography carries relatively far inland as the bottom of the Rosharon gauge is below MSL.

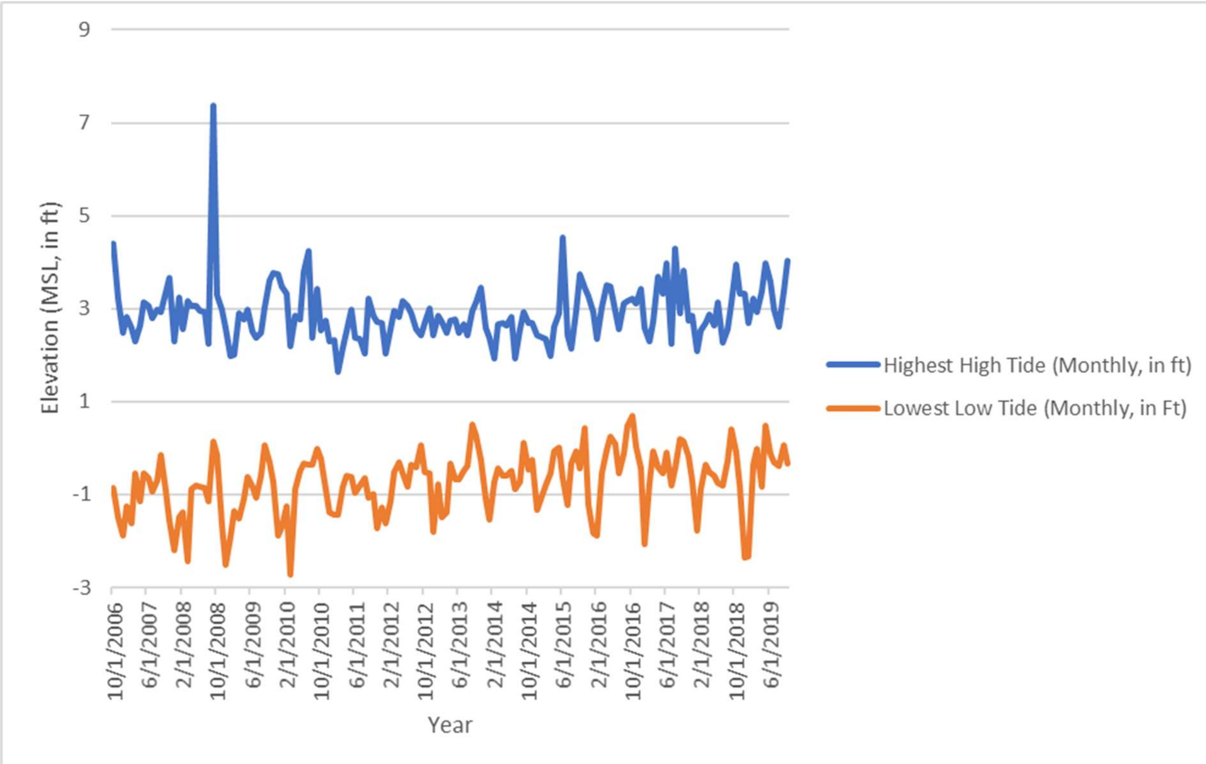


Figure 19: Highest High Tide and Lowest Low Tide (Monthly, in ft) for Freeport, TX gauge 8772447

4 Proposed Project

The Proposed Project, referred to as Harris Reservoir Expansion in the permit application to USACE Regulatory, is located immediately north of the existing Harris Reservoir site (Figure 20). The Proposed Project would include a 1,929-acre impoundment with a nominal storage capacity of 50,000 acre-feet, an intake and pump station to divert Dow's existing surface water rights from the Brazos River, an outlet to Oyster Creek and an emergency spillway. The Project also includes floodplain enhancements in Oyster Creek, stream restoration, and temporary construction staging and laydown areas.

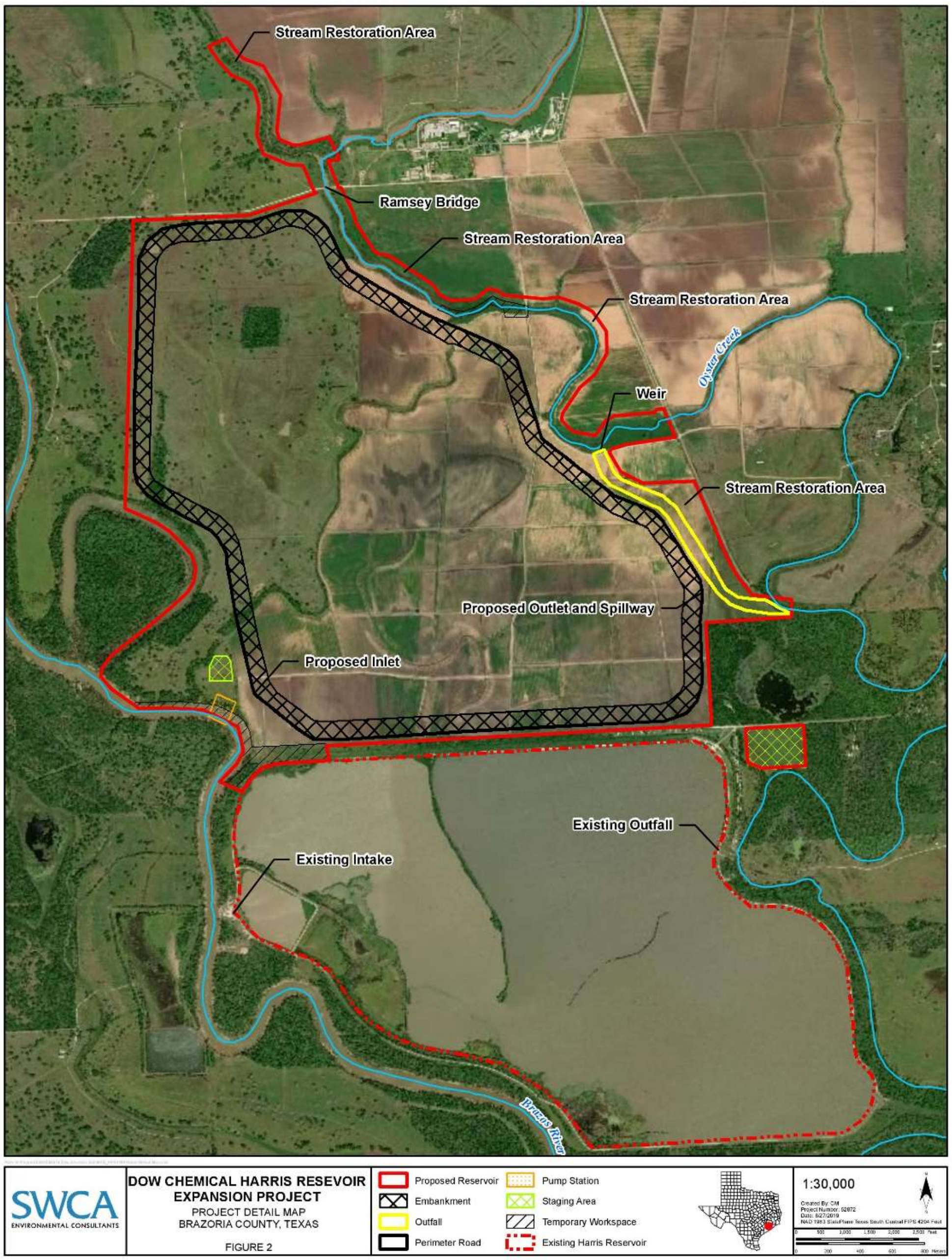


Figure 20: Project Elements for Hydrologic Analysis

4.1 Harris Reservoir Expansion

The embankment will be constructed to a nominal elevation of 72.7 feet with borrow material from the interior of the reservoir leaving 400 feet no borrow zone from the embankment toe (Figure 21). The embankment will have a three-foot-wide vertical chimney drain located five-feet downstream of embankment center line draining into a horizontal blanket drain which will exit into the embankment tow drain. The interior slope will have a sacrificial lower slope with an upper slope stepped soil-cement wave protection. Anchored into the soil-cement at the intersection of the interior embankment slope and the top of the embankment is a three-feet tall (top of wall is El. 75.7 feet) precast concrete wave wall.

A 2.5-foot-wide vertical seepage barrier wall is to be constructed 35 feet upstream from the embankment centerline. The seepage barrier is to be constructed under the entire embankment length of approximately 36,059 feet. The depth of the seepage barrier wall varies from approximately 17 feet below natural ground to approximately 55 feet below natural ground.

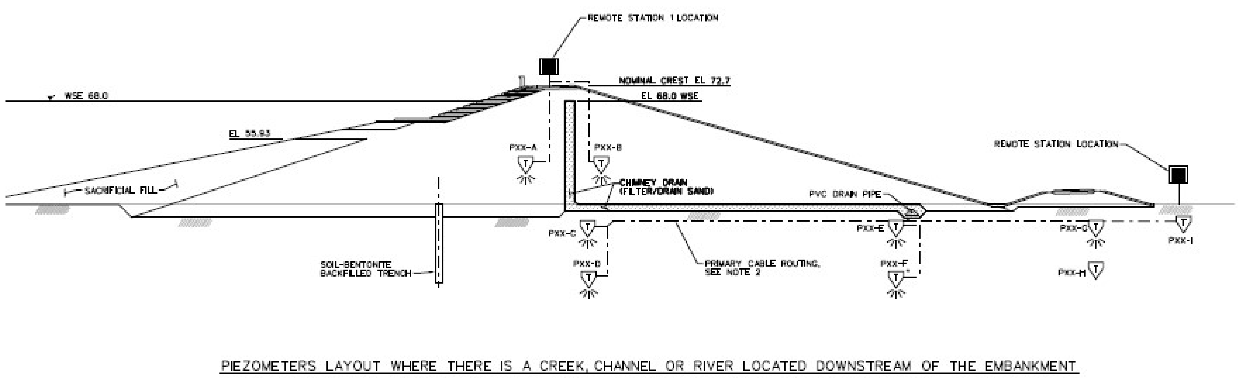


Figure 21: Embankment Cross Section

The proposed pump station in located near the southwest corner of the Proposed Project at embankment STA 113+89 and has a capacity of 150,000 gpm (334 cfs). The water in pumped from the Brazos River intake through the pump house up and over the embankment in a 72-inch pipe into the Project intake structure. The suction centerline elevation will be set at 8.5 feet NAV88, which will require a vacuum priming system to fill the pump suction lines. The pumps can be isolated for maintenance regardless of the river level. The 72-inch pipe will have a gooseneck air vent at the top of the embankment so that gravity flow down the interior of the reservoir embankment to an energy dissipation structure inside the reservoir at the end of the pipe. The combined gated outlet and auxiliary spillway structures are located on the southeast side of the reservoir at STA 227+29.88. The outlet structure has two 36” wide by 48’’ high sluice gates which allows water to flow in an outlet conduit through the embankment into a stilling basin at rates from 60 cfs to slightly over 1,000 cfs. The baffled drop inlet auxiliary spillway structure also flows into the outlet conduit. The baffled outlet structure will be designed to allow the reservoir to be lowered 3 feet (from normal maximum water surface elevation prior to storm events). A one foot per day draw down requires slightly more than 900 cfs release rate. The stilling basin outlets into the Oyster Creek flood mitigation channel.

The Northeast part of the Project includes enhancement of the Oyster Creek flood capacity and also provide riparian restoration. The enhancement starts on an unnamed tributary to Oyster Creek which flows into Oyster Creek where riparian restoration and flood plain benching is planned. A weir will be constructed that will allow large discharges to flow down the flood mitigation channel which parallels the Project embankment along the north side until it flows back into Oyster creek below the gated outlet and auxiliary spillway outlet.

There will also be a temporary staging area and temporary workspace located southeast of the Project and due north of the current Harris Reservoir. This area will be restored back to natural conditions after the Project is completed.

4.2 Oyster Creek Enhancements

As part of the proposed expansion project, Oyster Creek is planned to be enhanced with three projects. These projects are planned to improve the flood capacity and provide restoration and enrichment to the riparian habitat along the three project lengths. Geomorphic design principles were utilized to provide a bankfull benching creating floodplain storage, riparian habitat, and channel conveyance to accommodate the proposed reservoir outlet flow in to Oyster Creek.

Project 1 is approximately 3,600 feet long from STA 5+00 to STA 41+00 on an unnamed tributary north of the proposed project's northeast corner Figure 20. It flows into Oyster Creek a short distance north of the northeast corner which is the start of Project 2. Project 2 is approximately 12,860 feet long from STA 41+00 to STA 169+60 and is in the main channel of Oyster Creek. Project 3 is an improved flood overflow channel that flows along the east side of the proposed reservoir until the overflow channel intersects again at approximate STA 254+00 with the main Oyster Creek channel and the proposed reservoir outlet channel. Figure 22 shows a typical cross section of the Project 1 and 2 stream restoration to recreate the multiple level channel morphology.

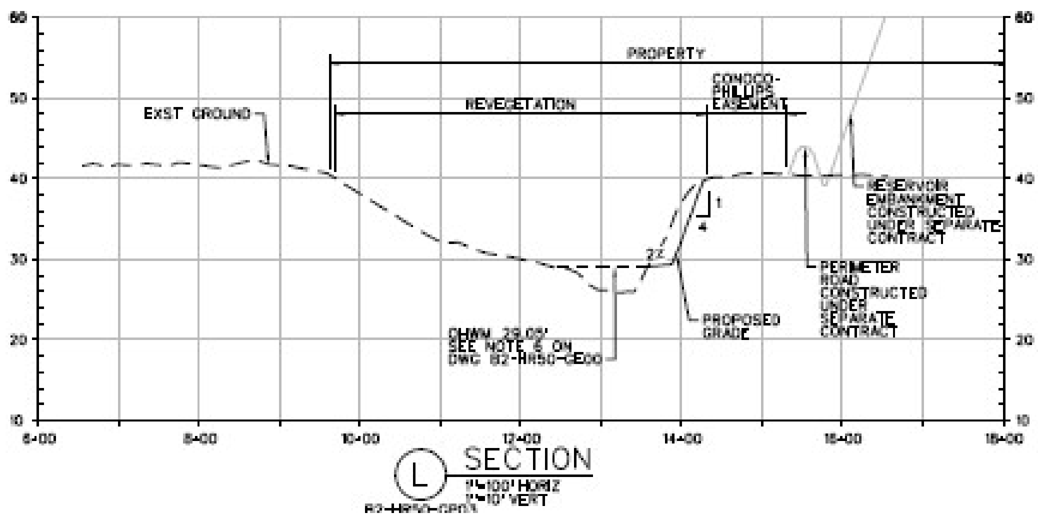


Figure 22 Cross Section of Oyster Creek Restoration in Area Adjacent to the Reservoir Embankment

4.3 Water Supply Needs

Dow conducted calculations and modeling, which were confirmed by Watearth, that indicate Dow needs a minimum of about 78,000 AF of water storage capacity to supply the Texas Operations for 180 days during an extended drought using their existing water supplies and water rights. Dow needs 430 AF/day of water supply to meet their daily water supply obligations including to BWA which supplies approximately 16,000 AF per year to their customers through the Dow water pumping and reservoir facilities. The current combined storage capacity in the existing Brazoria and Harris reservoirs is approximately 28,000 AF. Therefore, Dow will need to develop additional storage capacity of at least 49,000 AF to provide a reliable water supply during drought, which cannot be achieved by maintenance dredging or deepening Dow's existing reservoirs.

Use of Dow's existing water rights and storage facilities, existing pumping and conveyance system through Oyster Creek and Buffalo Camp Bayou, and existing industrial plant canal system supplemented with expanded storage at the Harris Reservoir site provides a cost-effective and financially viable means of meeting the storage requirements and increasing drought resilience at the Texas Operations, industries, and the BWA. Without additional storage capacity that would allow more efficient use of Dow's existing surface water rights from the Brazos River, production at the Dow Texas Operations and reliable public water supplies for the BWA customers would be at risk during extended drought conditions. Reduction of production would result in severe economic hardship for the local economy – potentially affecting the approximately 6,700 direct jobs at the Dow Texas Operations as well as the health and safety of the seven cities in Brazoria and Fort Bend counties who currently obtain approximately 16,000 AF per year of drinking water from Dow's water supply system through the BWA. Furthermore, interruption of production from the Texas Operations site would impact material supply across the state and the nation.

The recent drought conditions demonstrated the urgency for implementation of a project to provide additional storage and increase the reliability of water supply during drought in an environmentally responsible and financially viable manner. Without additional water storage to increase Dow's resilience to drought, essential functions at the Texas Operations site would be at risk during times of water shortage. The Proposed Project is intended to reduce the risk of water shortage during drought.

5 Hydrology, Operational, and Hydraulic Modeling

The purpose of this section is to provide methodologies for the three models developed to analyze the Proposed Project potential impacts and for compliance with the Hydrologic Modeling Guidelines (HMG). The models discussed in this section include HEC-HMS, Riverware™, and HEC-RAS.

5.1 Hydrologic Modeling Guidelines

US Army Corps of Engineers (USACE) developed the Hydrologic Modeling Guidelines (HMGs) checklist for use by USACE Regulatory project managers and Applicants to guide their daily data analysis and modeling process. Required information is presented in a form of a series of questions, grouped into three tiers of increasing complexity. Per the HMGs, the USACE permit decision will be based on whether enough information have been provided so that all required aspects of the project are appropriately addressed. From a modeling perspective, this documentation presents a general summary of three models selected for the project in terms of their capabilities on addressing related items in the HMGs checklist.

The models will provide answers to the following items:

1. Flow extent and water depth under both existing and post-project condition
2. Peak and low flow impacts on aquatic resources under both wet and dry hydrology periods

The USACE Regulatory uses the HMGs checklist in determining sufficiency for hydrologic evaluation but does not require the use of specific modeling software, which allows for flexibility in determining which suites of software to use based on the proposed project's potential impacts. In general, any project that includes an existing and/or proposed reservoir will require the use of the RiverWare modeling software due to its unique capabilities to model complex reservoir operations including input of water rights and water supply. As more fully discussed in the Hydrology and Hydraulic Modeling White Paper and the Environmental Modeling Approach prepared for this project, HEC-HMS has reservoir modeling capabilities but these are limited compared to RiverWare in that HEC-HMS uses a science-based hydrologic model whereas RiverWare models the type and ownership of the water in the system to identify the owner of water based on water rights priority is passing at any location. RiverWare also allows for prioritizing of different objectives, such as water diversion, flood control, environmental flow compliance, etc., making it possible to solve very complex water resources problems.

In addition to RiverWare, the USACE developed HEC-HMS and HEC-RAS models are necessary to fully address the HMGs checklist. The three models have different strengths in responding to the questions posed in the HMGs and need to be used collaboratively as none of them individually provide the full picture of potential impacts due to proposed project conditions.

5.2 Model Descriptions

This section describes several different models used in the analysis of the project with specific attention to the three models developed as part of this analysis; HEC-HMS, Riverware™, and HEC-RAS.

USACE **Hydraulic Engineering Center-Hydrologic Modeling System (HEC-HMS)** is designed to simulate the complete hydrologic processes of dendritic watershed systems. It can be applied to a wide range of geographic areas in solving a wide range of problems, including large river basin water supply, water withdrawal, flood hydrology, and small urban or natural watershed runoff. Flow time series produced by the model can be used in conjunction with other software for studies of water availability, urban drainage, flow forecasting, future urbanization impact, reservoir spillway design, flood damage reduction, floodplain regulation, and systems operation. The software includes many traditional hydrologic analysis procedures such as event infiltration including evapotranspiration, snowmelt, and soil moisture accounting (USACE, 2018). The primary purpose of this model for this analysis was to identify and process hydrologic data including instream flows and precipitation. Rainfall-runoff modeling with HEC-HMS based on gauged precipitation and upstream inflows provided results of river flows into and downstream of the Proposed Project. The results from HEC-HMS are flow hydrographs at points in the watershed where flows are not controlled by the Proposed Project operations.

Riverware™ is a reservoir and river basin modeling software decision support tool. Users can model the topology, physical processes and operating policies of river and reservoir systems, and make decisions on how to operate these systems by understanding and evaluating the trade-offs among the various basin operation and management objectives, in both simulation and forecast modes. The model's wide variety of applications range from short-term operations to long-term water resources planning, which includes hydropower optimization, reservoir operation optimization, water accounting, water quality, environmental flows and climate change assessments. The Bureau of Reclamation, the Tennessee Valley Authority, and the USACE sponsor ongoing RiverWare™ research and development. It is an ideal platform for operational decision-making, responsive forecasting, operational policy evaluation, system optimization, water accounting, water rights administration and long-term resource planning (University of Colorado at Boulder, 2019). For this analysis, the primary purpose was the prioritization tools for water rights and instream flows. Using outputs from HEC-HMS combined with user defined operating rules and scheduled withdrawals and releases, Riverware™ simulated reservoir operations for the pre-defined 50-year analysis horizon.

USACE **Hydraulic Engineering Center-River Analysis System (HEC-RAS)** is a computer program that models hydraulics of water flow through natural rivers, man-made channels, lakes and reservoirs. The model can perform one-dimensional steady flow, one and two-dimensional unsteady flow, sediment transport and water temperature/water quality modeling. The HEC-RAS model is being developed as a part of the Hydrologic Engineering Center's "Next Generation" (NexGen) of hydrologic engineering software, which will encompass several aspects of hydrologic engineering, including: rainfall-runoff analysis; river hydraulics; reservoir system simulation; flood damage analysis; and real-time river forecasting for reservoir operations (USACE, 2018). For this project, river hydraulics were performed with HEC-RAS using unsteady flow modeling for selected drought, average, and storm events. From the hydrographs produced by HEC-HMS, HEC-RAS computed water surface profiles, velocity and stage hydrographs. When used in conjunction with Habitat Suitability Criteria, weighted usable area for certain species habitat could be calculated.

5.2.1 Water Availability Model

The Texas Commission Environmental Quality (TCEQ) **Water Availability Model (WAM)** is a computer-based simulation predicting the amount of water that would be in a river or stream under a specified set of conditions. The model is used in the evaluating water rights applications to help determine if water would be available for a newly requested water right or amendment, or if an amendment might affect other water rights. The WAM model is used by Dow and TCEQ in predicting available flows for water rights in the Brazos River. However, the model cannot be calibrated against gauge records and therefore is insufficient for modeling and analysis needs for the Proposed Project.

5.3 Modeling Assumptions

Due to the conceptual, planning-level nature of the modeling performed for this study, several assumptions were made based on available data, synthesis of multiple data sources provided by Dow, and engineering judgement. Primary assumptions are noted below and where relevant further details are provided in Section 5.4 Modeling Methodology:

1. All elevations and project survey are based upon vertical datum NAVD88.

2. Modeling was performed in HEC-HMS version 4.3, HEC-RAS unsteady flow version 5.0.7, HEC-RAS steady flow version 5.0.7, and Riverware version 7.5.3.

3. HEC-RAS unsteady flow was used for routing flows along the Brazos River, whereas HEC-HMS was used to generate flow hydrographs for use in Riverware and HEC-RAS unsteady flow and was not used for hydrologic routing along the Brazos River in this study.

4. HEC-HMS and HEC-RAS models were not available downstream of the portion of the Oyster Creek watershed where existing and future discharges will occur from the Existing Harris Reservoir and Proposed Harris Reservoir Expansion. Therefore, this analysis is based on analysis of available data and modeling results related to discharges from the Harris Reservoirs at this time.

5. The following models were used as a basis for the modeling performed for this study:
    a. FPP HEC-HMS provided by Brazos River Authority;
    b. FPP HEC-RAS unsteady flow provided by Brazos River Authority;
    c. HEC-RAS steady flow Oyster Creek model by Baker and Lawson and provided by Dow as a HEC-2 model.
    d. HEC-HMS hydrologic model of Oyster Creek by Jacobs.
    e. HEC-RAS steady flow model of Oyster Creek by Jacobs.

6. In their USACE application, Dow estimated the existing reservoir storage capacity as 7,000 AF for Harris Reservoir and 21,000 AF for Brazoria Reservoir, for a combined total of 28,000 AF of existing water storage. The application values presented by Dow were used but as noted in Table 2, the effective storage volume could be as low as 18,000 AF. It was assumed that even if these storage volumes do not exist currently, routine maintenance operations to remove sediment could be performed to restore and/or maintain capacity at the 2018 values reported by Dow.

7. During initial HEC-HMS modeling, existing conditions operations were simulated with numerical relationships rather than with physical structures and pumps due to the manual adjustments regularly made by Dow's operators that override set operational parameters. While this type of manual operation provides "real time" operational control to Dow, it is impractical to capture each detailed nuance within static modeling relationships and conceptual operational protocols for the reservoir modeling and routing. During the initial modeling, the diversions into the existing Harris Reservoir and Brazoria Reservoir are simulated with an inflow-diversion relationship (i.e., flow diverted into the reservoirs is based on flow in the Brazos River). Discharge from the existing Harris Reservoir and Brazoria Reservoir was based on storage-discharge relationships (i.e., discharge from the reservoir into Oyster Creek and the Brazos River, respectively, based on storage in the reservoir at a given time step). Operations of the proposed Harris Reservoir expansion were similarly simulated. However, modeling results with this conceptual approach were not reflective of the actual reservoir operation, inflows, discharges, and water levels.

   As such, the modeling approach was changed to use historical operational data for the Existing Brazoria and Existing Harris Reservoirs, including diversions into the reservoirs and discharges out of the reservoirs. The Proposed Harris Reservoir Expansion was simulated with similar, but scaled up, operational parameters as the Existing Harris Reservoir.

8. Since detailed operational protocol and parameters were not available for the Proposed Harris Reservoir Expansion, the historical operation data (i.e., inflows from the Brazos River and discharges to Oyster Creek) for the Existing Harris Reservoir was scaled up proportionately based on the proposed storage volume versus the existing storage volume.

9. The elevation-volume relationship for the proposed Harris Reservoir expansion was estimated from available design details using the conic approximation method and did not account for detailed bottom grading, if any. It was then adjusted to match the total volume provided by Dow. Small changes to the total estimated volume or the elevation-volume relationship will not have a significant effect on results of this study.

10. Rainfall gage data was not available for the entire period of record for the analysis based on historical operational parameters. As such, precipitation in the very lower reach of the Brazos River below the Rosharon gage was neglected for part of the analysis as watershed processes in the Brazos River are driven by the large upstream watershed rather than by local rainfall.

11. HEC-RAS unsteady flow of the Brazos River was not stable with the negative (flow leaving) diversions into the existing and proposed reservoirs. To stabilize the model and provide a basis of comparison, the diversions into the Harris Reservoir and diversions into and discharges from the Brazoria Reservoir were excluded. The increased diversion into the Proposed Harris Reservoir Expansion was simulated by adding the diverted flows in existing conditions and removing them in proposed conditions.

12. Consistent with the project description, it was assumed that the entire Harris Reservoir expansion is constructed at once and not phased.

13. The objective of the analysis was to evaluate the operation and potential water resources impacts of the proposed Harris Reservoir expansion as designed. As such, the effects of changes in location, volume, or operations were not evaluated.

5.4 Modeling Methodology

This section describes the site-specific model development for the hydrologic, hydraulic, and reservoir operational models.

5.4.1 Brazos River HEC-HMS

The Brazos River HEC-HMS model utilized in this study was taken from the BRA Lower Brazos Flood Protection Planning Study (FPP) HEC-HMS hydrologic model that was approved by the BRA in March of 2019 (Halff, 2019). The original model was truncated upstream of the Richmond USGS gage to reduce run times and eliminate unnecessary data, as none of the sub-basins upstream of the gage are part of the area of study for this report (see Figure 23 Figure 24). While the study area extends from the Rosharon gage to the outlet of the Brazos River at the Gulf of Mexico, the reach upstream was extended to the Richmond gage to provide a more comprehensive model in the project vicinity.

The original FPP Study model did not include either of the existing Harris or Brazoria reservoirs that are operated by Dow. These two reservoirs and their corresponding diversions along the Brazos River were added to the Existing Conditions model along with applicable routing reaches to connect back downstream to the Brazos River and to account for discharge of flows from the existing and proposed Harris Reservoirs into Oyster Creek. The Proposed/Expansion Condition model included all of the aforementioned model elements, but additionally had a diversion added upstream of the existing Harris Reservoir to tie into the Proposed Project reservoir, which was also added to the HEC-HMS model based on the current CH2MHill design (Figure 25).

All hydrologic modeling was performed in HEC-HMS version 4.3 following standard modeling procedures for conceptual or planning-level analysis. The modeling simulations were run on daily time steps, which is appropriate for continuous simulation modeling covering this time-frame, and consistent with the original HEC-HMS model. Table 3 summarizes the HEC-HMS basin model names and the models are included in Appendix A.

Below in Figure 23 there is visual representations of the Drainage Areas, reservoirs, and subasins involved with the exsisting conditions project modeling. The polygons shown in red are part of the Brazos watershed and are upstream of the project area. The area highlighted in yellow is the original drainage area for B_BRA_410 called B_BRA_410_original. Next to B_BRA_410_original is BRA_410 which is the area used within the exsisting condition model and it includes the area within the exsisting Harris Reservoir.

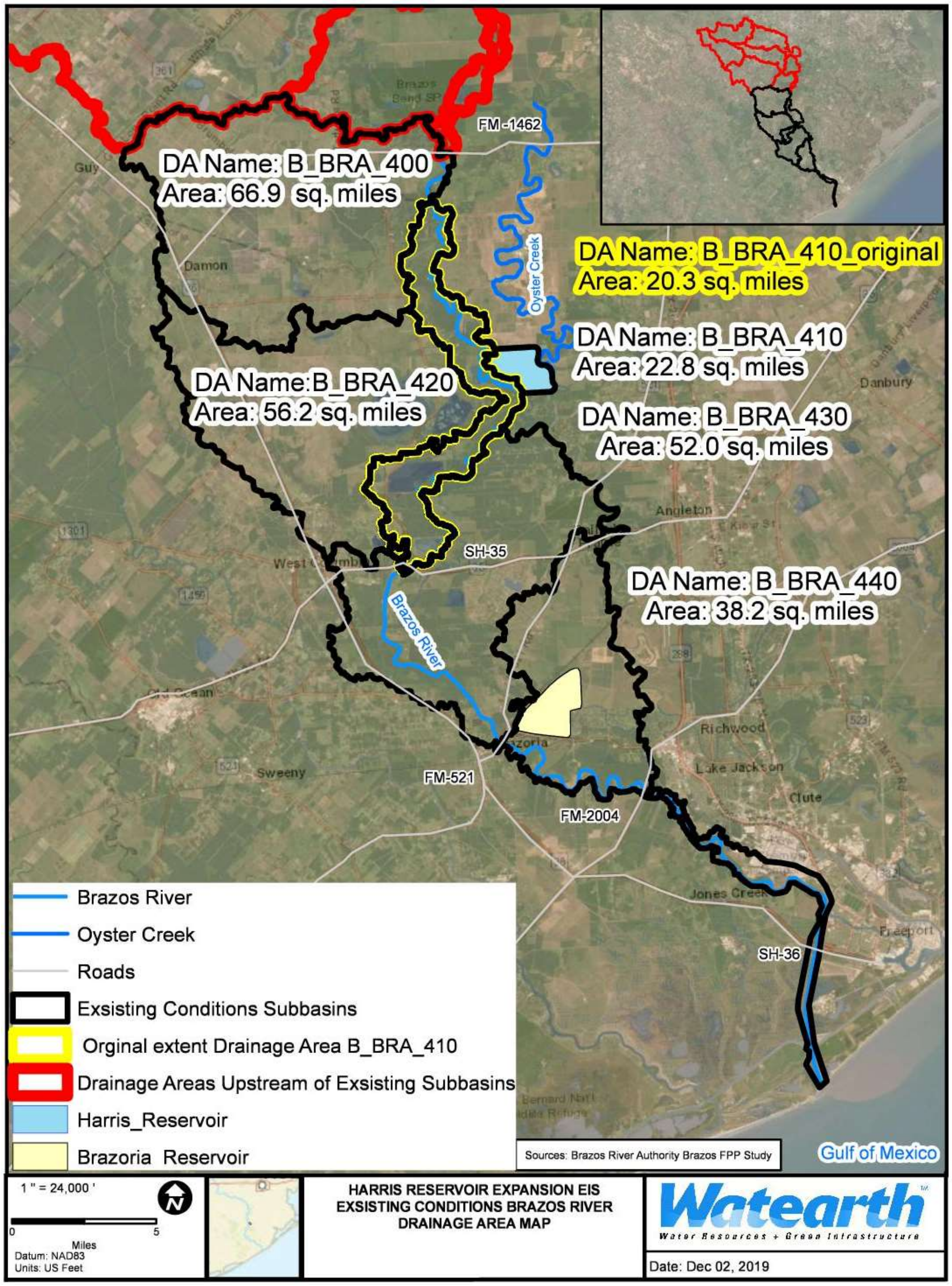


Figure 23 Brazos River Existing Conditions for HEC-HMS Model

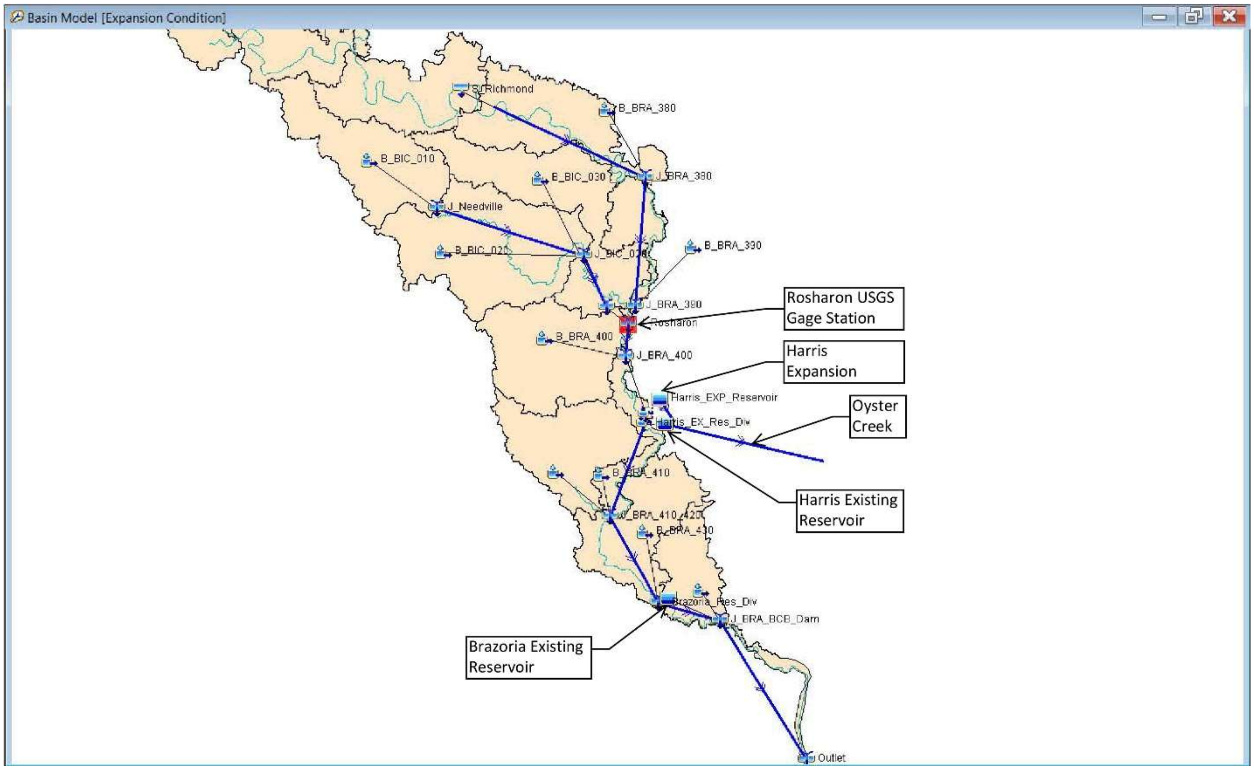


Figure 24: HEC-HMS Model for Harris Reservoir Expansion Project

Table 3: HEC-HMS Basin Model Names

Analysis Conditions	Model Name
Base Conditions[1]	HMS v4.0 B_BRA_410_original
Existing Conditions[2]	Harris_Reservoir_HMS_v4.3 BRA_410 Brazos_Model_Harris_Reservo.hms
Proposed Conditions[3]	Harris_Reservoir_HMS_v4.3 Brazos_Model_Harris_Reservo.hms

[1]Base conditions is the original model obtained from Brazos River Authority.
[2]The existing conditions model adds the existing Brazoria and Harris Reservoirs to the original model.
[3]The proposed conditions model adds the proposed Harris Reservoir expansion to the existing model.

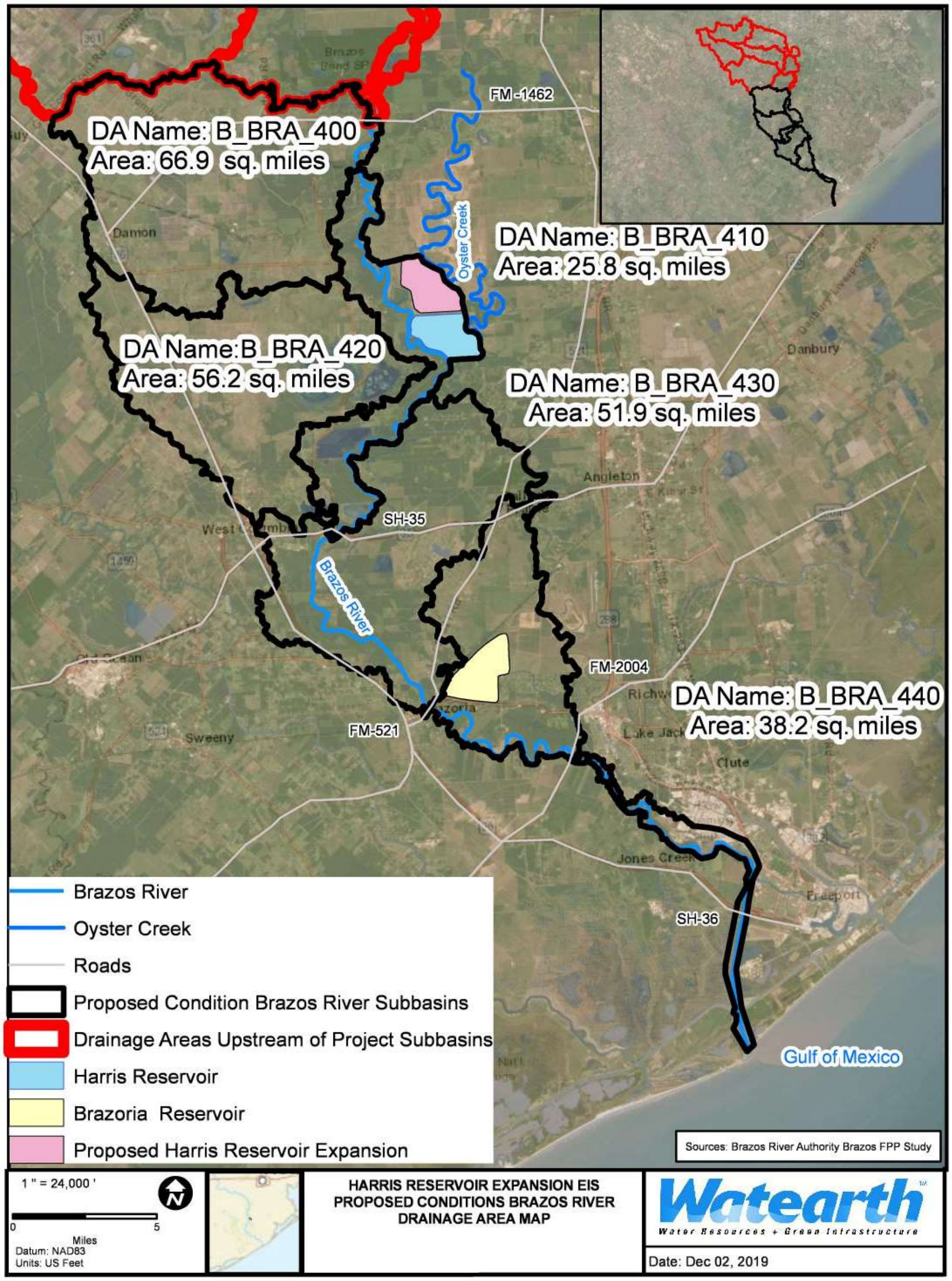


Figure 25 Brazos River Proposed Conditions in HEC-HMS Model

5.4.1.1 Meteorological and Rainfall Data

The meteorological and rainfall data used in the original FPP HEC-HMS model was unable to be maintained for this study. The NOAA National Climatic Data Center (NCDC) Richmond and

Thompson rainfall gages were used to capture hourly rainfall data and rainfall patterns for the 42-year period of record from January 1, 1979 through December 31, 2010. This 42-year record captures historical drought and high rainfall years. For the purposes of this analysis, the simulation was run for the period of record from January 1, 2009 through May 6, 2019 due to the availability of measured inflows and outflows from the existing reservoirs. New gage data was acquired for the study, however the data could not be utilized in the model, because there was missing data from the new set of acquired data. The meteorological model with missing data was preventing the HMS model from running stable, the data for the Richmond and Thompson gages was omitted from the model. Since the rainfall data has little effect on the Brazos River it was found appropriate to not include the meteorological data in the model for the entire simulation period.

Consistent with the original HEC-HMS model, the gage weights method was used to assign one gage for time weighting for each drainage sub-basin and percentages of each of the two gages for depth weighting for each drainage sub-basin. While a continuous simulation model, neither tree canopy interception nor evaporation were considered in the original HEC-HMS hydrology model or the existing or proposed conditions models modified for this study.

5.4.1.2 Gage Data

Historical gage data was used from the United States Geological Service (USGS) for daily maximum flows at the Richmond and Rosharon gages in the project vicinity for the 10-1/2 -year period of record from January 1, 2009 through May 6, 2019 (Figure 13 and Figure 14). The Richmond gage was placed at J_BRA_380 as a discharge gage representative of discharge from the entire Brazos River watershed upstream of this junction. The Rosharon gage was placed at the J_Rosharon junction as an observed flow gage. As discussed above, the simulation was run for the period of record from January 1, 2009 through May 6, 2019 due to the availability of measured inflows and outflows from the existing reservoirs. The data found in the original model did not cover the new analysis period. The Brazos river Rosharon gage data was acquired for the study. The data for the Rosharon gage extended through the full simulation period, however the data had a substantial amount of information gaps (missing river gage information) , thus results are reported for the period of available flow data for both gages. Gage data for the Richmond and Rosharon gages for this time period are provided in Figure 26 and Figure 27.

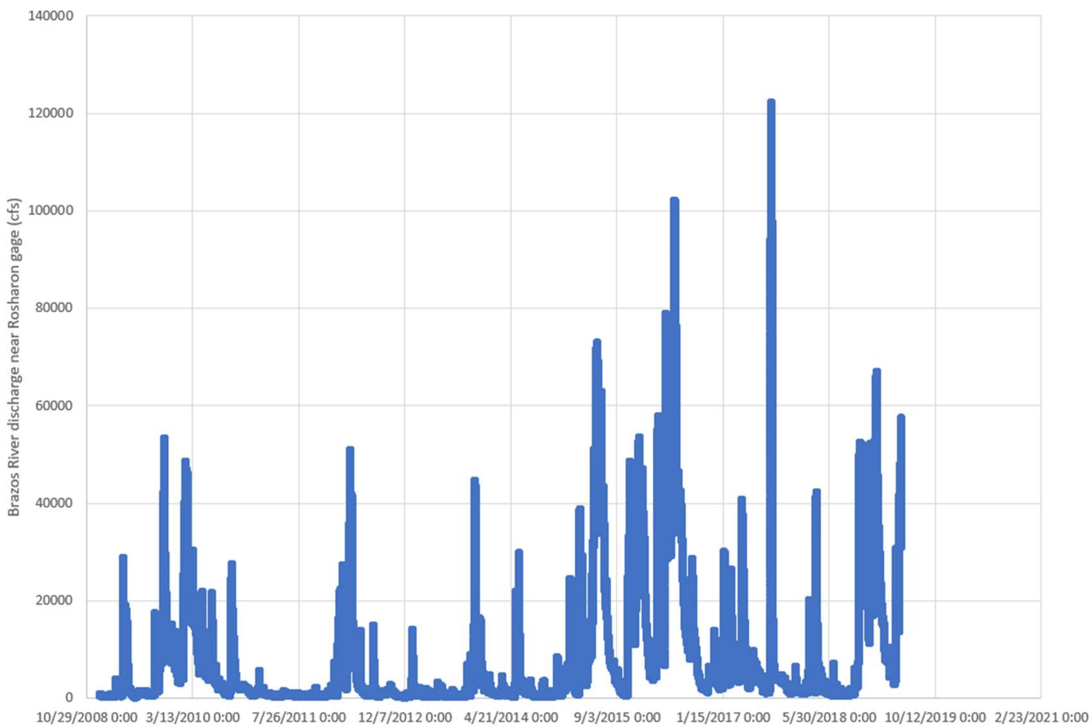


Figure 26 Flow for Brazos River for the USGS Richmond Gage from January 1 2009 through May 6, 2019

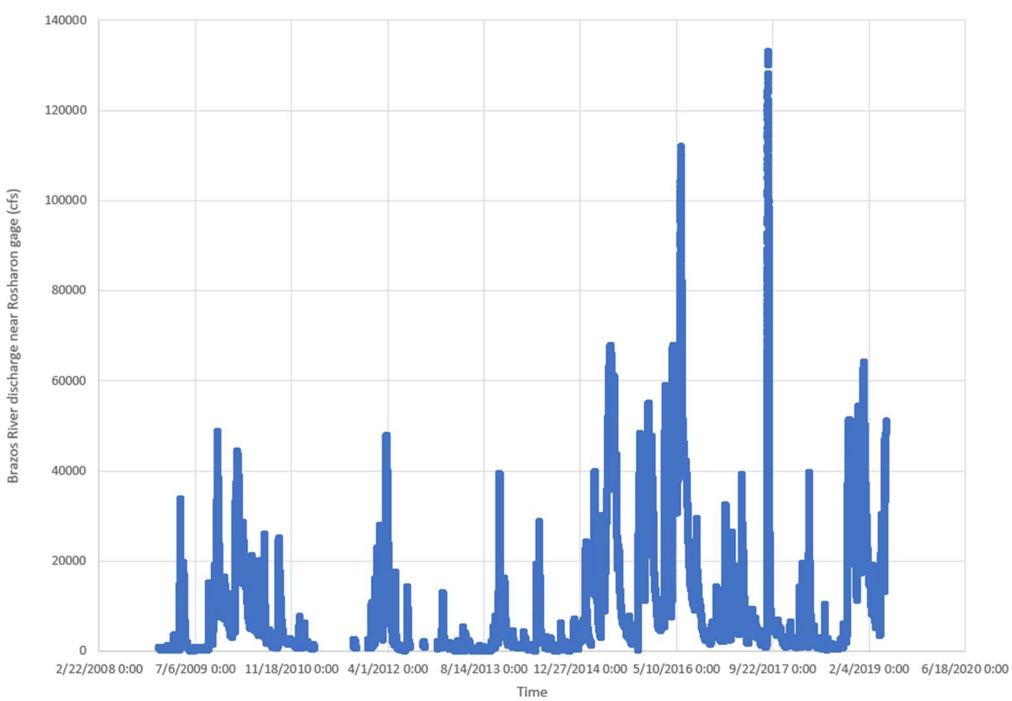


Figure 27 Flow for the Brazos River for the USGS Rosharon Gage from January 1, 2009 through May 6, 2019

5.4.1.3 Drainage Sub-Basins

Figure 23 and Figure 25 depict the portion of the Brazos River watershed included in the HEC-HMS model. As stated previously, both the Richmond and Rosharon gages are included in the model, although results reporting is focused from the Rosharon gage to the outlet at the Gulf of Mexico.

The existing approximately 1,675-acre (2.62-square mile) Brazoria Reservoir is located in the B_BRA_440 drainage sub-basin. The approximately 1,870-acre (2.92-square mile) existing Harris Reservoir Harris Reservoir and proposed approximately 1,776-acre (2.78-square mile) Harris Reservoir expansion are located adjacent to the B_BRA_410 drainage sub-basin, but are outside the drainage sub-basin boundary in the original model. For existing conditions, the B_BRA_410 drainage sub-basin boundary was expanded to include the existing Harris Reservoir and for proposed conditions further expanded to include the proposed Harris Reservoir expansion. As shown in Table 4, the B_BRA_410 drainage sub-basin area was increased from the original 20.3 square miles to 23.2 square miles and 26.0 square miles in existing and proposed conditions, respectively. Due to the planning-level nature of this analysis, sub-watersheds were not further subdivided.

Table 4: Original, Existing, and Proposed Brazos River Sub-Basin Area Parameters Downstream of Rosharon Gage, Texas

Drainage Sub-Basin Name	Original Area (mi^2)	Exist. Area (mi^2)	Prop. Area (mi^2)
B_BRA_400	66.9	66.9	66.9
B_BRA_410	20.3	23.2	26.0
B_BRA_420	56.2	56.2	56.2
B_BRA_430	52.0	52.0	52.0
B_BRA_440	38.2	38.2	38.2

5.4.1.4 Hydrologic Parameters

The FPP models use the Clark Unit Hydrograph Method, which is a commonly used method in the region, to generate unit hydrographs and transform them into runoff hydrographs. The specific unit hydrograph transformation parameters are the time of concentration (Tc) in hours (hrs) and the Clark's Storage Coefficient (R value) in hrs. The Exponential Loss Method is used to account for soil losses (i.e., infiltration) and is an appropriate loss method for continuous simulation analyses. Due to the planning-level nature of this analysis, all existing conditions hydrologic parameters were left unchanged with the exception of impervious cover.

Impervious cover is used to reflect the percent of each drainage sub-basin occupied by impervious cover that does not allow infiltration of rainfall (or create losses). Areas not occupied by impervious cover are referred to as pervious cover and include all permeable surfaces (i.e., lawns, fields, landscaped areas, etc.). Drainage sub-basins with lower impervious cover, such as the project area, are less developed and have higher potential for infiltration. More developed areas with higher impervious cover have less potential for infiltration and higher runoff from a given rainfall event.

Due to the underlying clay soils, infiltration from the existing Brazoria and Harris Reservoirs and proposed Harris Reservoir Expansion is expected to be minimal especially in saturated and prolonged rainfall conditions. As such, the reservoir surface areas were assumed to be 100% impervious consistent with local hydrology practices and the existing and proposed impervious cover values associated with the drainage areas containing the reservoirs were adjusted as these areas did not seem to be included as impervious cover in the original study.

The existing Harris Reservoir and proposed Harris Reservoir Expansion are generally located within drainage sub-basin B_BRA_410, which was expanded to include the Harris Reservoir. Accounting for the approximately 1,870-acre (2.92-square mile) existing Harris Reservoir increases the existing conditions impervious cover in the 232.2-square mile existing B_BRA_410 drainage sub-basin from 2.4-percent to 14.7-percent. The approximately 1,776-acre (2.78-square mile) reservoir expansion increases the total impervious cover in B_BRA_410 in proposed conditions to 6.19 square miles, resulting in an overall percent impervious cover of 23.8-percent in the 26.0-square mile drainage sub-basin in proposed conditions.

The existing approximately 1,675-acre (2.62-square mile) Brazoria Reservoir is located in the B_BRA_440 drainage sub-basin. Accounting for the reservoir surface area in the impervious cover, increases the existing impervious cover in B_BRA_440 from the 7.7-percent reported in the original study to 5.56 square miles, or 14.6-percent impervious cover. This value remains constant between existing and proposed conditions. Table 5 summarizes hydrologic parameters for the drainage sub-basins located between the Rosharon gauge and the downstream end of the HEC-HMS model or outlet into the Gulf of Mexico. The drainage sub-basins located between the Richmond and Rosharon gages are not included in this table for brevity.

Table 5: Original, Existing, and Proposed Brazos River Hydrologic Parameters Downstream of Rosharon Gage, Texas.

Drainage Sub-Basin Name	Original Area (mi^2)	Exist. Area (mi^2)	Prop. Area (mi^2)	Tc (hr)	Storage Coefficient (R-Value)	Original Impervious Cover	Existing Impervious Cover	Proposed Impervious Cover
B_BRA_400	66.9	66.9	66.9	9.13	31.74	3.4	3.4	3.4
B_BRA_410	20.3	23.2	26.0	13.62	837.35	2.4	14.7	23.8
B_BRA_420	56.2	56.2	56.2	13.25	31.25	3.8	3.8	3.8
B_BRA_430	52.0	52.0	52.0	6.83	51.87	6.0	6.0	6.0
B_BRA_440	38.2	38.2	38.2	3.19	54.65	7.7	14.6	14.6

5.4.1.5 Routing Reaches

Reach routing methods were not used in HEC-HMS for the reaches along the Brazos River as all hydrograph routing is performed in the HEC-RAS unsteady flow model for both this study and the original models. Hydrographs were computed in HEC-HMS and the reaches are simply used to spatially and geographically orient the model and to translate the hydrographs from an upstream junction to a downstream junction. While the hydrographs are translated, there is no real attenuation (dampening of flows) or lag (delay to account for travel time) as these affects of routing or accounted for in the dynamic, or unsteady flow hydraulic routing performed in HEC-RAS unsteady flow. Consistent with the original HEC-HMS model, the Muskingum Cunge reach routing method was maintained for the remaining tributary in the truncated model between the Richmond gage and the Rosharon gage (from Junction J_Needville to Junction J_Rosharon).

Routing reaches (without routing methodology) were added from the existing Harris Reservoir and the proposed Harris Reservoir expansion to simulate flows leaving the system and entering the Oyster Creek system and are named R_OC_Harris_EX and R_OC_Harris_PRO, respectively.

5.4.1.6 Reservoir Data

The elevation-volume relationship for the existing Harris Reservoir and Brazoria Reservoir are included in Table 6 and Table 7, respectively. The total effective storage is based on the 2018 Dow estimate of 7,000 ac-ft and 21,000 ac-ft for the existing Harris and Brazoria Reservoirs, respectively, with an existing total effective storage of 28,000 ac-ft. The elevation-volume relationships were developed using the conic approximation method and based on the existing reservoir surface area of 1,675 ac at the crest elevation of 41.50 ft and bottom area of 0 ac at the bottom elevation of 29.80 ft for the existing Harris Reservoir. For the existing Brazoria reservoir, the existing surface area of 1,870 ac at the crest elevation of 31.00 ft and 0 ac at the bottom elevation of 13.60 ft. These relationships were than multiplied by a factor of 98.4-percent at each elevation to match the 2018 Dow storage volume estimates.

The proposed Harris Reservoir expansion storage volume was estimated at 51,976 AF using the conic approximation method and based on the proposed reservoir surface area of 1,776 ac at the crest elevation of 68.00 ft and bottom area of 1,572 ac at the bottom elevation of 32.00. This volume and associated elevation-volume relationship were adjusted downward by applying a 98.4-percent factor to match the volume of 50,968 AF reported by Dow (Table 8).

Table 6: Existing Harris Reservoir Elevation-Volume Relationship

Existing Harris Reservoir Elevation-Volume Relationship					
Stage (ft)	Areas (sq ft)	Area (ac)	Incremental Storage Volume (AF)	Adjusted Storage Volume (AF)	Cumulative Storage Volume (AF)
29.80	0	0	0	0	0
30.30	2,178,009	50	13	13	13
31.30	4,356,017	100	88	85	98
34.30	7,405,229	170	493	477	574
35.30	13,068,051	300	728	704	1,278
35.50	23,958,094	550	813	786	2,065
36.30	60,984,238	1,400	1,593	1,540	3,605
36.80	71,874,281	1,650	2,355	2,277	5,882
38.50	72,527,683	1,665	5,173	5,002	10,885
41.50	72,963,285	1,675	10,199	9,862	***20,747***

Table 7: Brazoria Reservoir Elevation-Volume Relationship

Brazoria Reservoir Elevation-Volume Relationship					
Stage (ft)	Areas (sq ft)	Area (ac)	Incremental Storage Volume (AF)	Adjusted Storage Volume (AF)	Cumulative Storage Volume (AF)
13.60	0	0	0	0	0
15.20	8,712,034	200	160	110	110
17.60	17,424,068	400	900	617	727
19.60	36,154,941	830	2,257	1,548	2,275
21.60	65,340,255	1,500	4,587	3,147	5,422
22.60	80,856,315	1,850	6,262	4,296	9,718
24.20	81,021,916	1,860	9,103	6,245	15,963
31.00	81,457,518	1,870	21,710	14,893	***30,856***

Table 8: Proposed Harris Reservoir Expansion Elevation-Volume Relationship

Proposed Harris Reservoir Expansion **Conic Approximation Method**							
Stage (ft)	**Emb. Slope (1H:1V)**	**Area (SF)**	**Area (ac)**	**Incremental Storage Volume (ac-ft)**	**Incremental Storage Volume (ac-ft)**	**Cumulative Storage Volume (ac-ft)**	**Adjusted Storage Volume (ac-ft)**
32.00	3.5	68,479,108	1572	0.00	0	0	0
40.00	3.5	70,419,590	1617	12,754	4311	4311	4,242
45.00	3.5	71,642,397	1645	8,153	8153	12464	12,265
50.00	3.5	72,872,901	1673	8,294	8294	20758	20,426
55.00	3.5	74,111,101	1701	8,436	8436	29194	28,727
60.00	3.5	75,356,999	1730	8,578	8578	37772	37,168
65.00	3.5	76,610,594	1759	8,722	8722	46494	45,751
68.00	3.5	77,366,445	1776	5,302	5302	51796	50,968
				60,239	***51,796***	***51,796***	***50,968***

As discussed under assumptions, existing conditions operations were simulated using detailed operational data provided by Dow, including diversions into the reservoirs and discharges out of the reservoirs. The proposed Harris Reservoir Expansion was simulated with similar, but scaled up, operational parameters as the Existing Harris Reservoir given the adjacent location in the watershed and similar diversion locations from the Brazos River and discharge locations into Oyster Creek. The proposed 50,968 ac-ft Harris Reservoir Expansion is 7.28 times the Existing Harris Reservoir capacity of 7,000 ac-ft and thus the diversions and existing diversions and discharges were scaled up by a factor of 7.28 to estimate the future diversions and discharges into and out of the proposed Harris Reservoir Expansion.

Diversions from the Brazos River into the Brazoria Reservoir are simulated by the specified flow diversion placed at Brazoria_Res_Div and diversions from the Brazos River into the existing and proposed Harris Reservoir expansion are simulated by the specified flow diversion placed at Harris_Ex_Res_Div and Harris_Pro_Res_Div, respectively. Brazoria Reservoir discharges back into the Brazos River are simulated at J_BRA_BCB_Dam and discharges from the existing and proposed Harris Reservoir expansions are simulated to leave the Brazos River and enter Oyster Creek through reaches R_OC_Harris_EX and R_OC_Harris_PRO, respectively. Discharges from all three reservoirs are modeled with the specified discharge outflow structure method. Table 9, Figure 28, and Figure 29 illustrate the diversion into the reservoirs and discharges out of the reservoirs.

Table 9: Existing Brazoria Reservoir and Harris Reservoir Diversion and Discharges

Reservoir Name	Flow
Brazoria Reservoir	Diversion (Max Flow)
	500 cfs
	Reservoir (Max Discharge)
	521 cfs
Harris Reservoir	Diversion (Max Flow)
	290 cfs
	Reservoir (Max Discharge)
	278 cfs
Proposed Harris Reservoir Expansion	Diversion (Max Flow)
	2,109 cfs
	Reservoir (Max Discharge)
	2,027 cfs

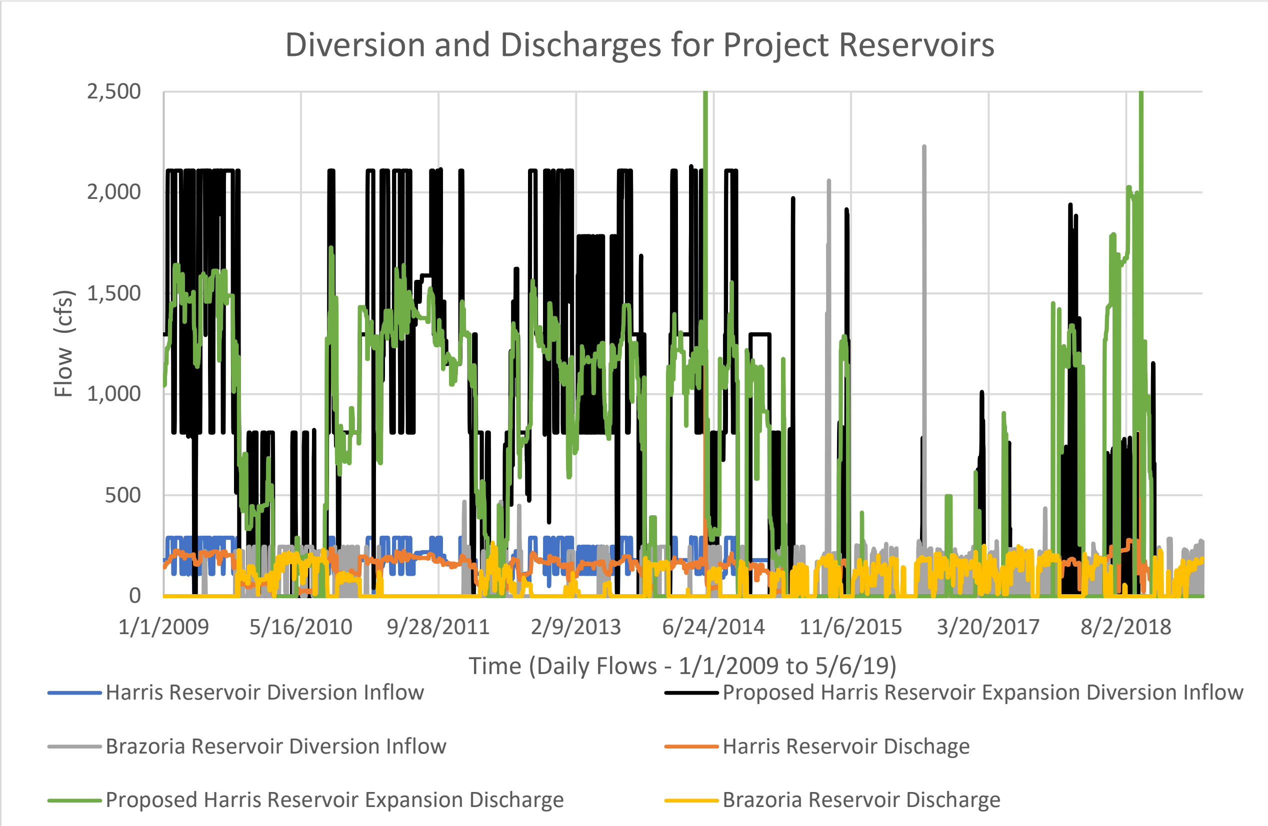


Figure 28 Existing Harris Reservoir, Proposed Harris Reservoir, and Brazoria Reservoir Diversions and Discharges

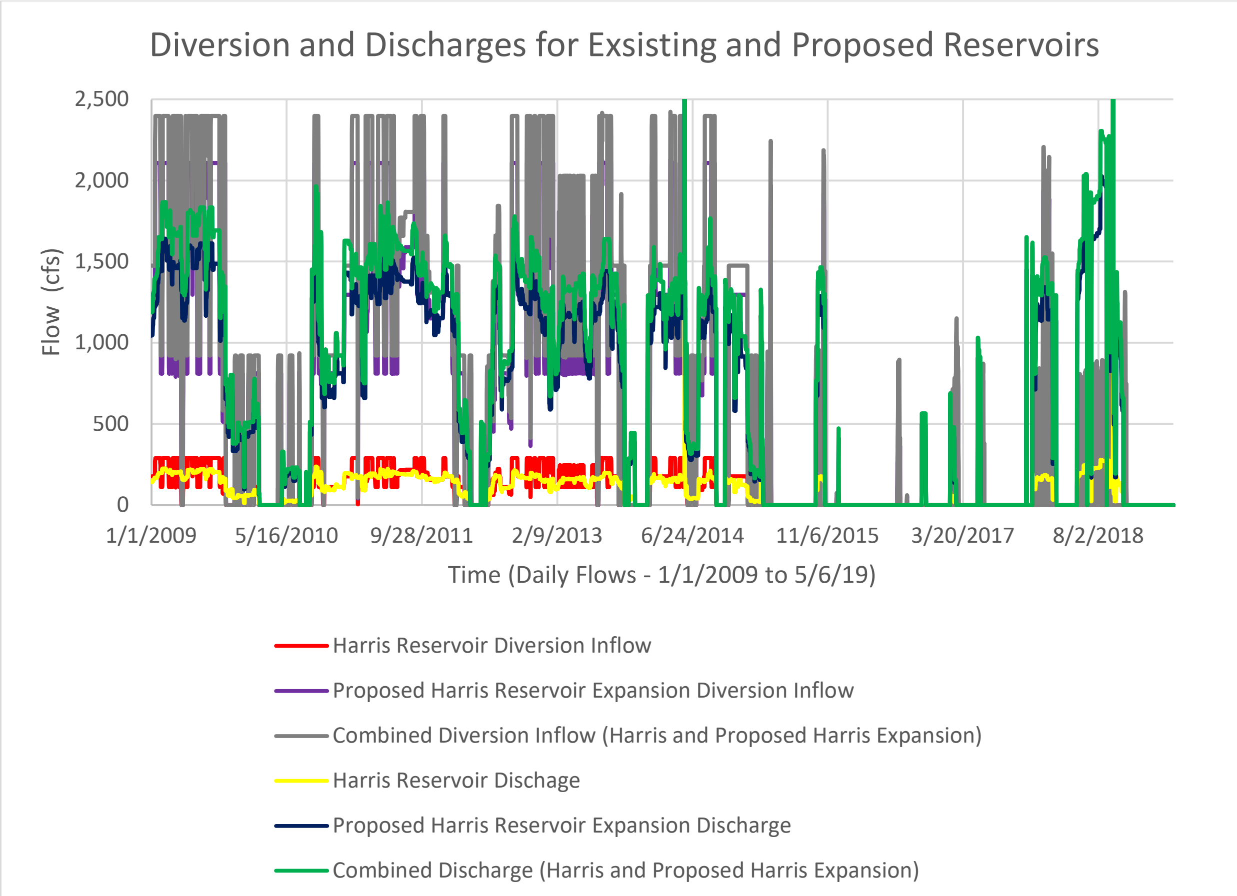


Figure 29 Combined Flows for Harris Reservoir and Proposed Harris Reservoir Expansion Compared to Existing Harris Reservoir Diversions and Discharges

5.4.1.7 HEC-HMS Results

Table 10 lists maximum flows over the 10-½-year simulation for each of the drainage sub-basins and junctions from the Rosharon gage at J_Rosharon to the outlet of the Brazos River at the Gulf of Mexico. Figure 30 through Figure 50 show diversions into each of the reservoirs and discharges out of the reservoirs over the 10-½-year simulation period.

These results and modeling assumptions show no significant changes to diversions into or discharges out of the Brazoria Reservoir into the Brazos River. Similarly, modeling assumptions and results show no significant changes to diversions into or discharges out of the Existing Harris Reservoir into Oyster Creek. The proposed diversion into the Proposed Harris Reservoir and associated discharge into Oyster Creek significantly increase peak flows out of the combined Harris Reservoir into Oyster Creek from an existing range of 0 to 278 cfs to a proposed range of 0 to 2,305 cfs.

Table 10: Table of Existing and Proposed Maximum Flows over the 10-½-Year Simulation Period

HEC HMS NODES	Existing Conditions Maximum Flows (cfs)	Proposed Conditions Maximum Flows (cfs)	Difference between both conditions (cfs)
J_ROSHARON	122,000	122,000	0
HARRIS_PR_RES_DIV	-	2,109	N/A
HARRIS_PR_RES	-	2,027	N/A
R_OC_HAR_PR	-	2,027	N/A
HARRIS_EX_RES_DIV	290	290	0
HARRIS_EX_RES	278	278	0
R_OC_HAR_EX	278	278	0
BRAZORIA_RES_DIV	500	500	0
BRAZORIA_EX RES	521	521	0
J_BRA_BCB_DAM	120,229	120,229	0
OUTLET	120,229	120,229	0

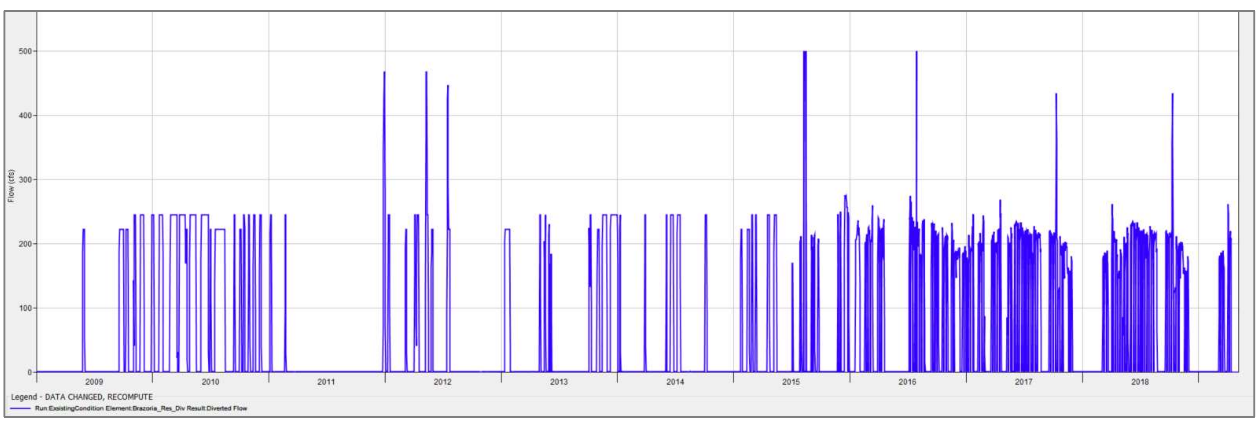


Figure 30 Existing Conditions Diversion into Existing Brazoria Reservoir Over 10- ½ -Year Simulation Period

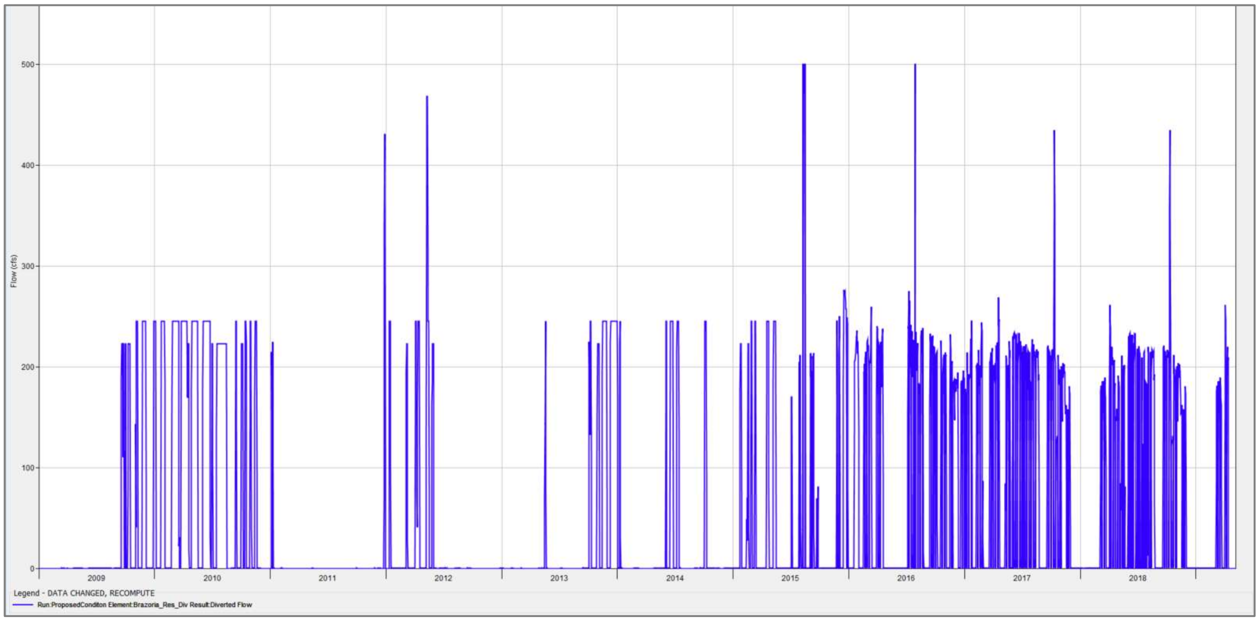


Figure 31 Proposed Conditions Diversion into Existing Brazoria Reservoir Over 10- ½ -Year Simulation Period

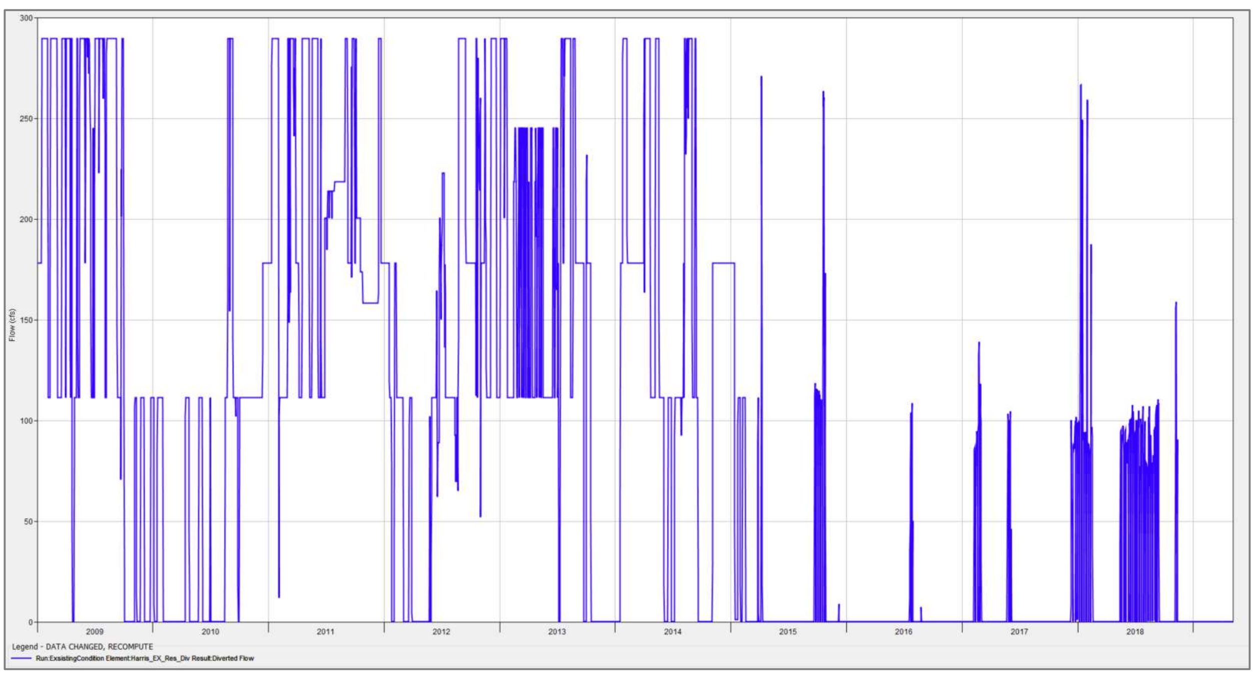


Figure 32 Existing Conditions Diversion into Existing Harris Reservoir Over 10- ½ -Year Simulation Period

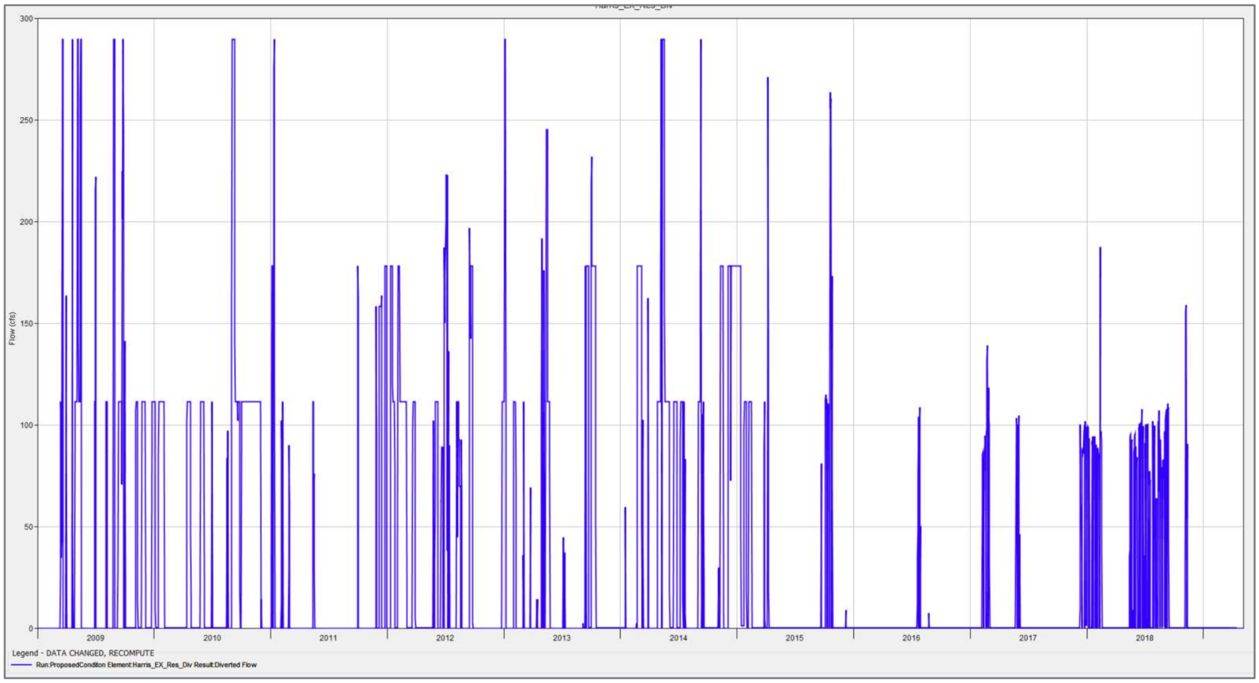


Figure 33 Proposed Conditions Diversion into Existing Harris Reservoir Over 10- ½ -Year Simulation Period

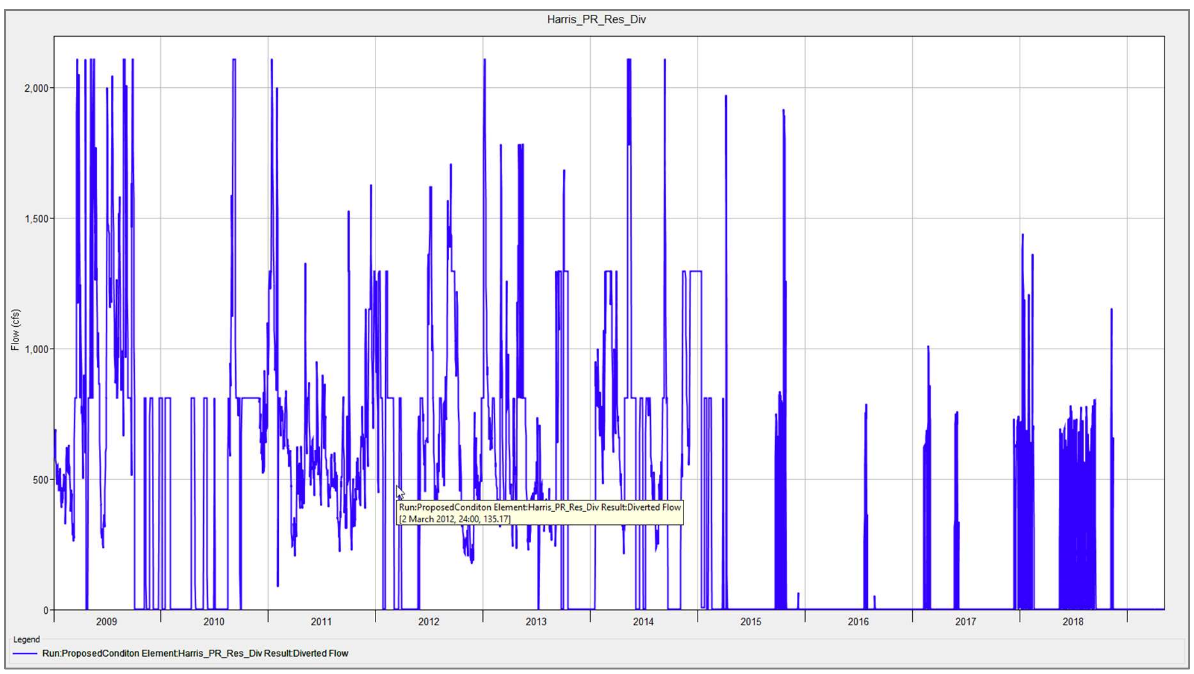


Figure 34: Proposed Conditions Diversion into Proposed Harris Reservoir During 10- ½ -Year Analysis Period

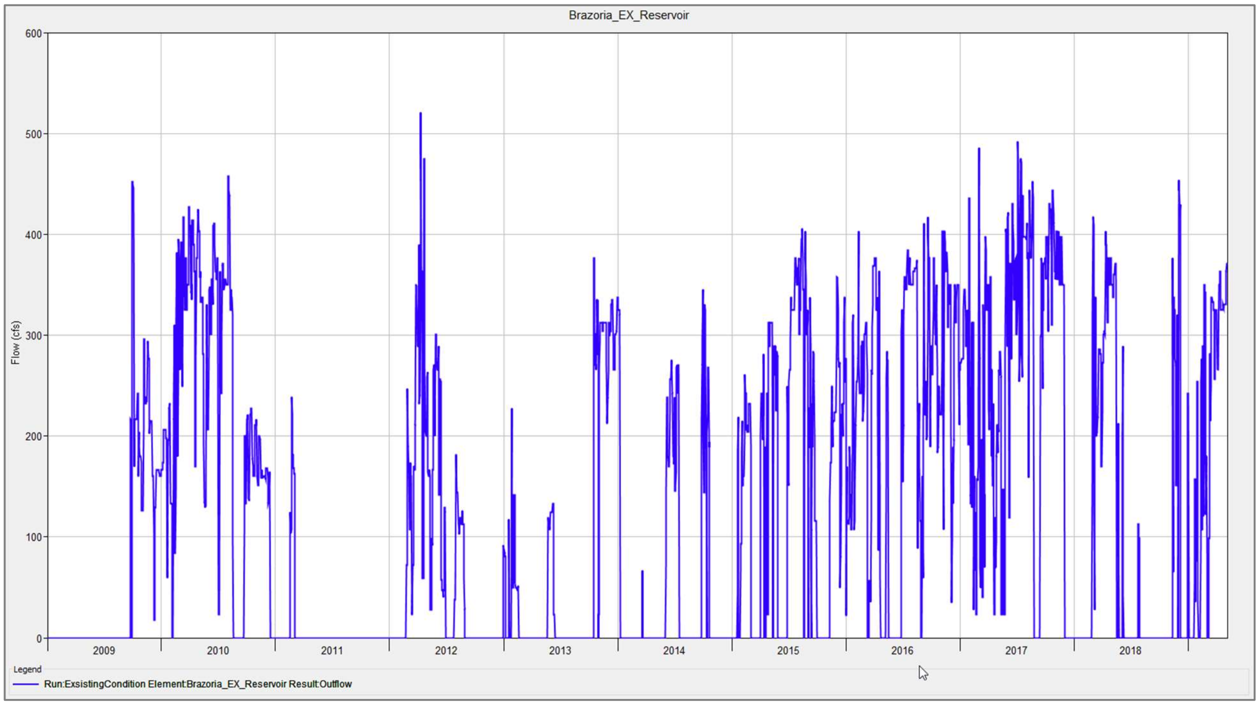


Figure 35: Existing Conditions Discharges from Existing Brazoria Reservoir Over 10-½ -Year Simulation Period

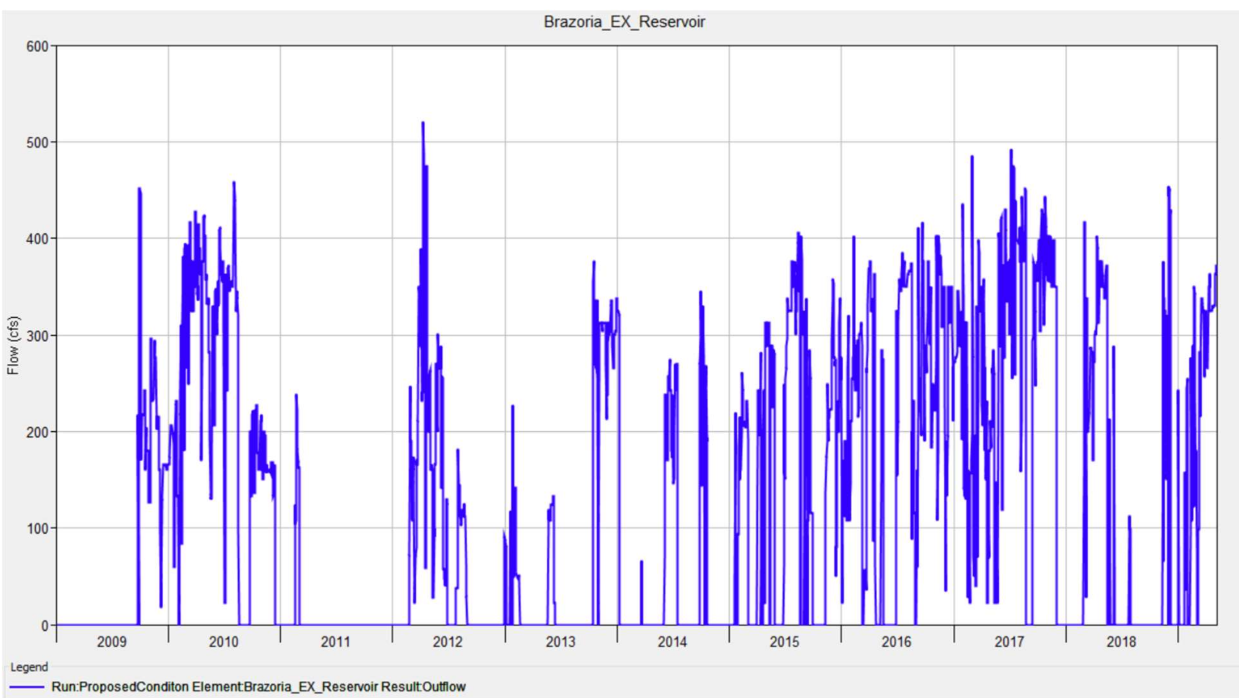


Figure 36: Proposed Conditions Discharges from Existing Brazoria Reservoir Over 10-½ -Year Simulation Period

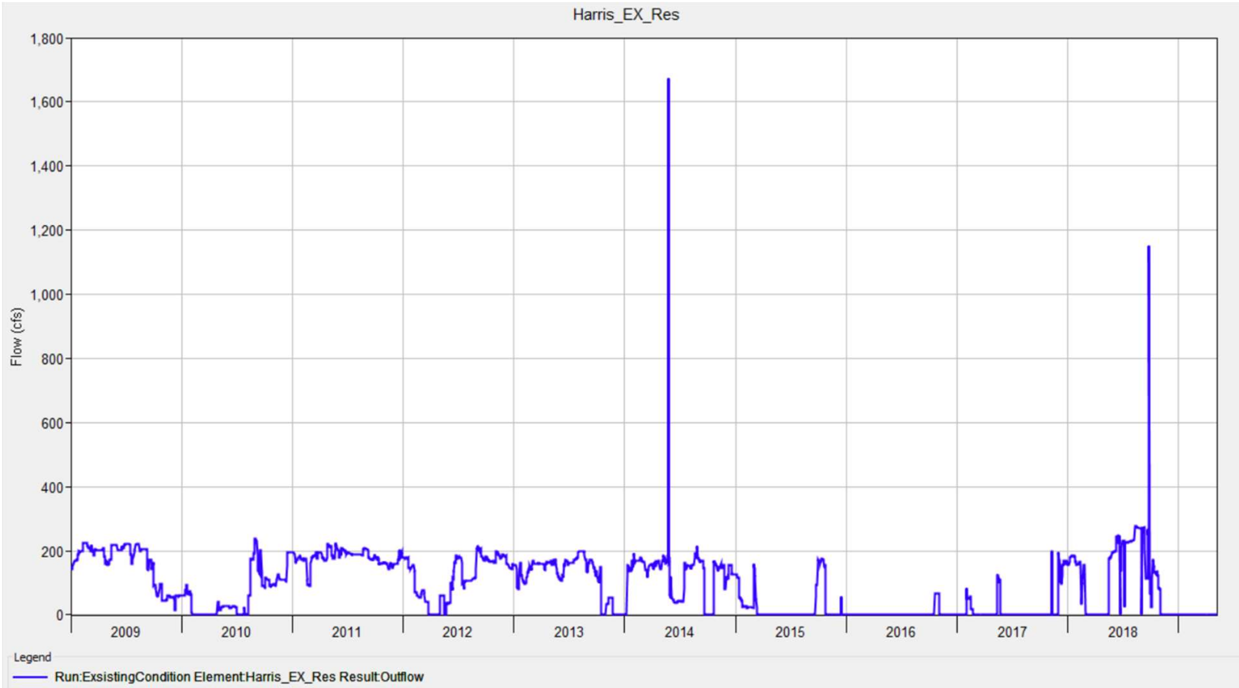


Figure 37: Existing Conditions Discharges from Existing Harris Reservoir Over 10- ½ -Year Simulation Period. Note: the large spikes in 2014 and 2018 data appear to be data outliers

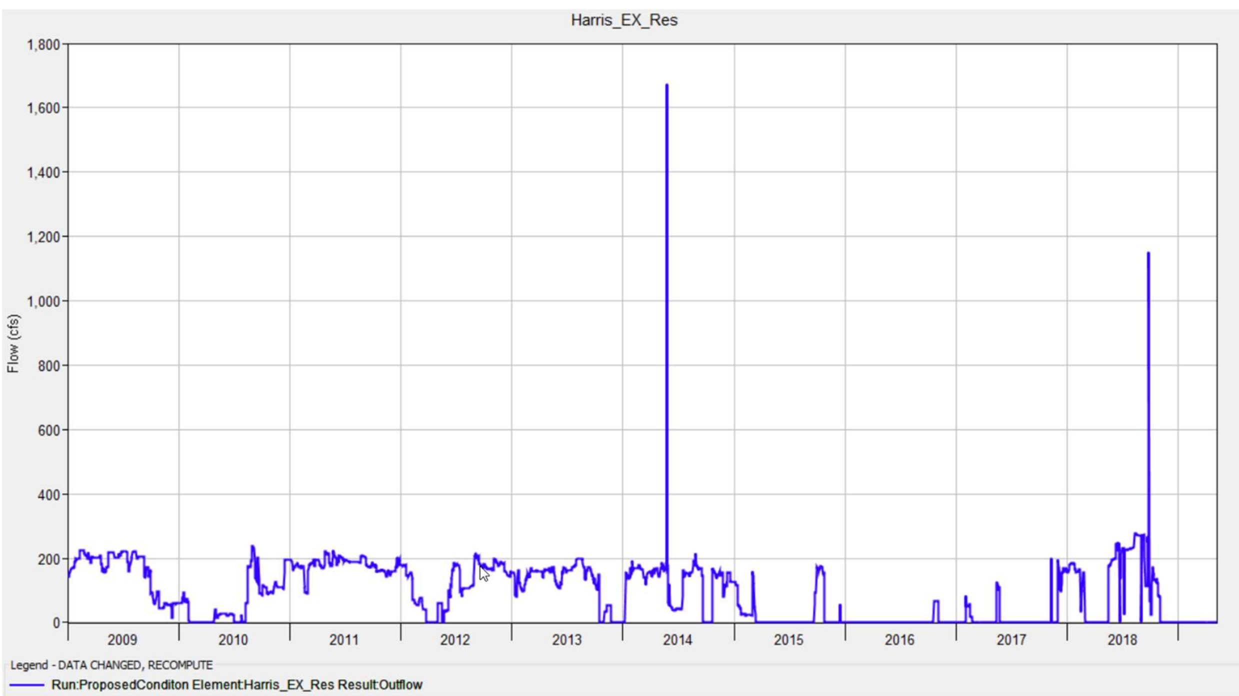


Figure 38: Proposed Conditions Discharges from Existing Harris Reservoir Over 10- ½ -Year Simulation Period

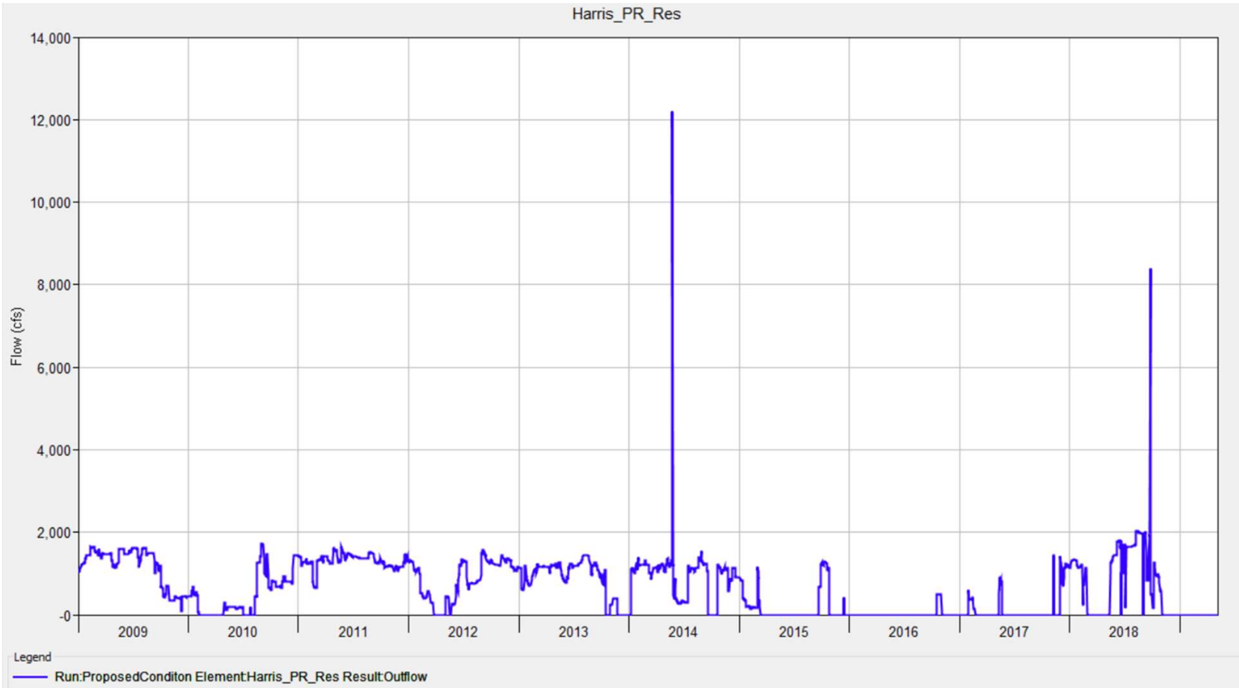


Figure 39: Proposed Conditions Discharges Outflow from Proposed Harris Reservoir Over 10- ½ -Year Simulation Period. Note that there are two outflows hat are outliers in the data)

Figure 40 through Figure 48 depict existing and proposed flow hydrographs at six key analysis points between the Rosharon gage and the outlet at the Gulf of Mexico. The key analysis points are listed in Table 11 and include the Rosharon gage, which is not expected to change between existing and proposed conditions as it is an observed flow condition in the model. While routing along the Brazos River is performed in HEC-RAS unsteady flow rather than HEC-HMS, this is a useful comparison at the outlet as hydrographs are combined along the Brazos River without attenuation or lagging. Downstream of the Rosharon gage, no significant changes in flow are shown in the Brazos River despite assumed increased diversions at peak river flows/stages to maintain the additional storage associated with the Proposed Harris Reservoir Expansion.

Table 11: Key Analysis Points for Results Reporting

Key Analysis Point	Location	HEC-HMS Name
1	Rosharon Gage	J_Rosharon
2	Proposed Harris Reservoir Expansion Diversion (Brazos River)	Harris_Pro_Res_Div
3	Existing Harris Reservoir Diversion (Brazos River)	Harris_Ex_Res_Di
4	Brazoria Reservoir Diversion (Brazos River)	Brazoria_Res_Div
5	Brazoria Discharge/Dow's Water Intake	J_BRA_BCB_Dam
6	Outlet (Mouth)	Outlet

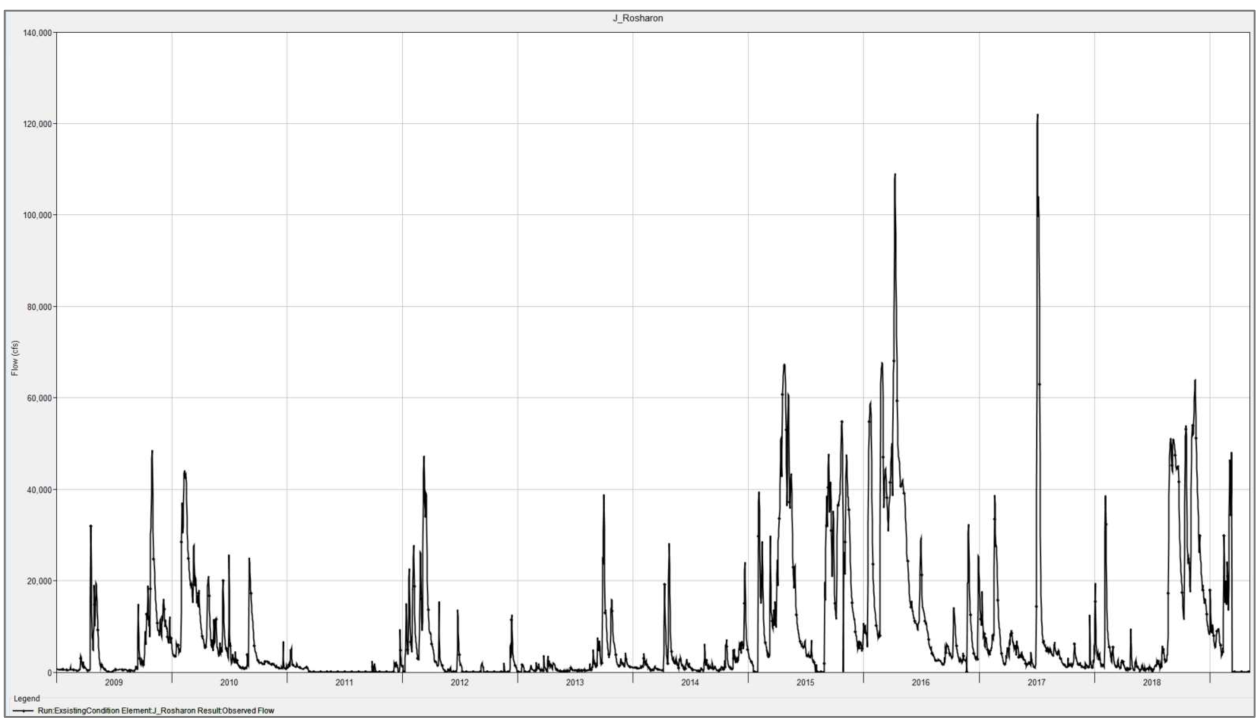


Figure 40: Existing Conditions Flow Hydrograph at Rosharon Gage During 10- ½ -Year Analysis Period

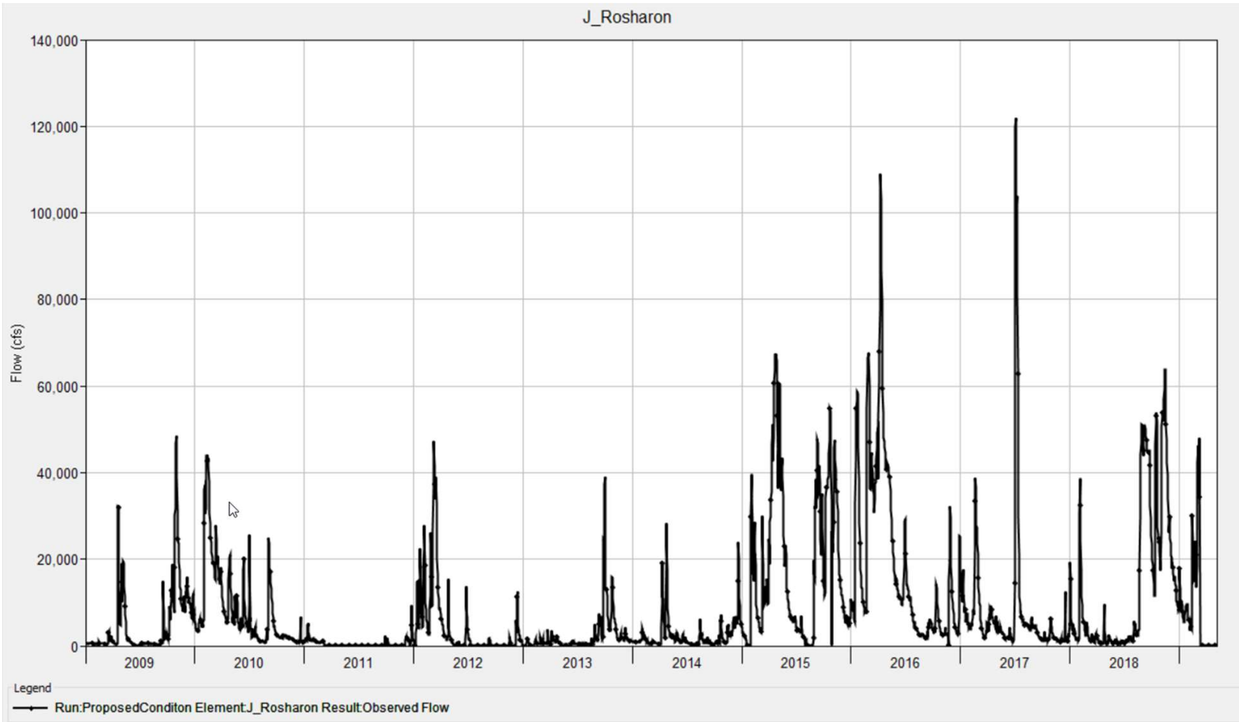


Figure 41: Proposed Conditions Flow Hydrograph at Rosharon Gage During 10- ½ -Year Analysis Period

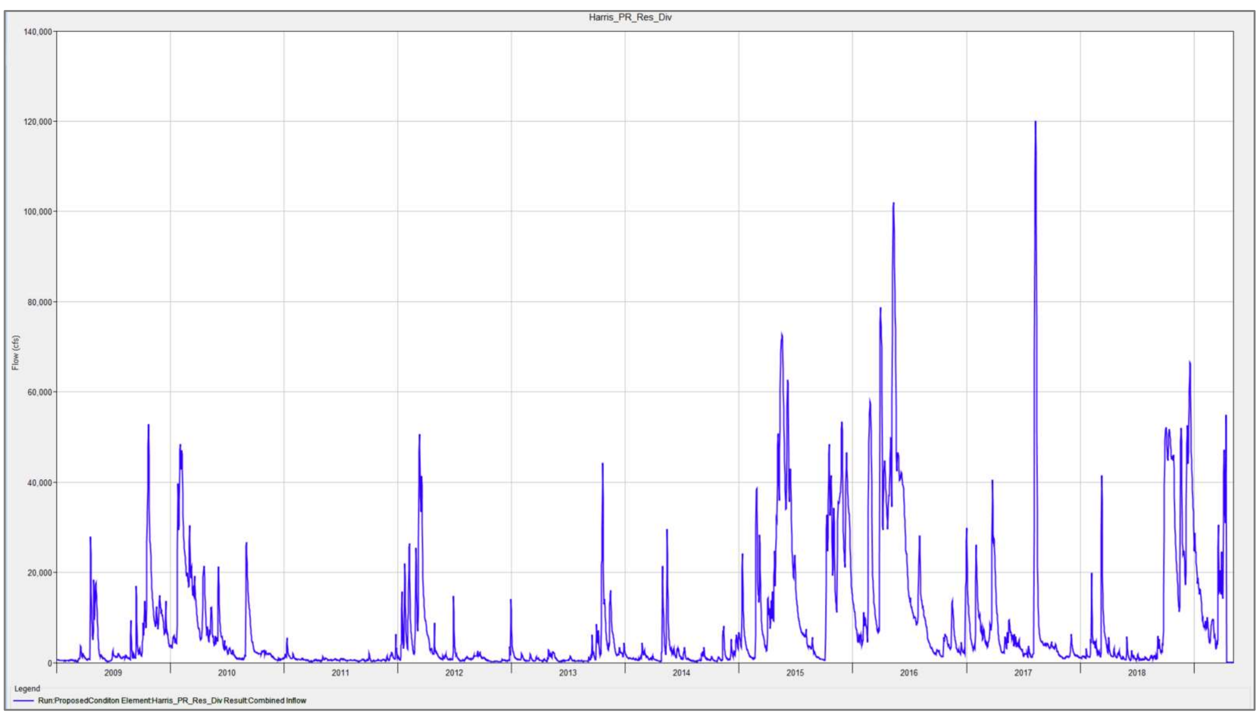


Figure 42: Proposed Conditions Flow Hydrograph at Proposed Harris Reservoir Expansion Diversion (Brazos River) During 10- ½ -Year Analysis Period

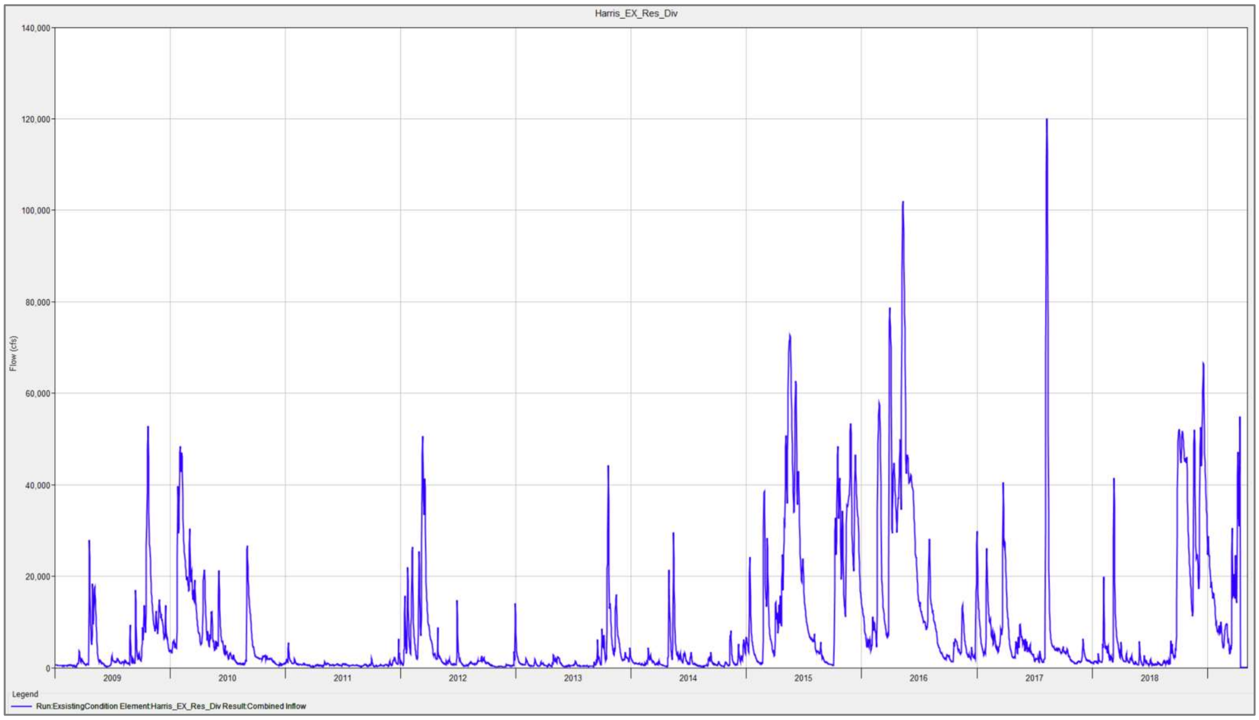


Figure 43: Existing Conditions Flow Hydrograph at Existing Harris Reservoir Diversion (Brazos River) During 10- ½ -Year Analysis Period

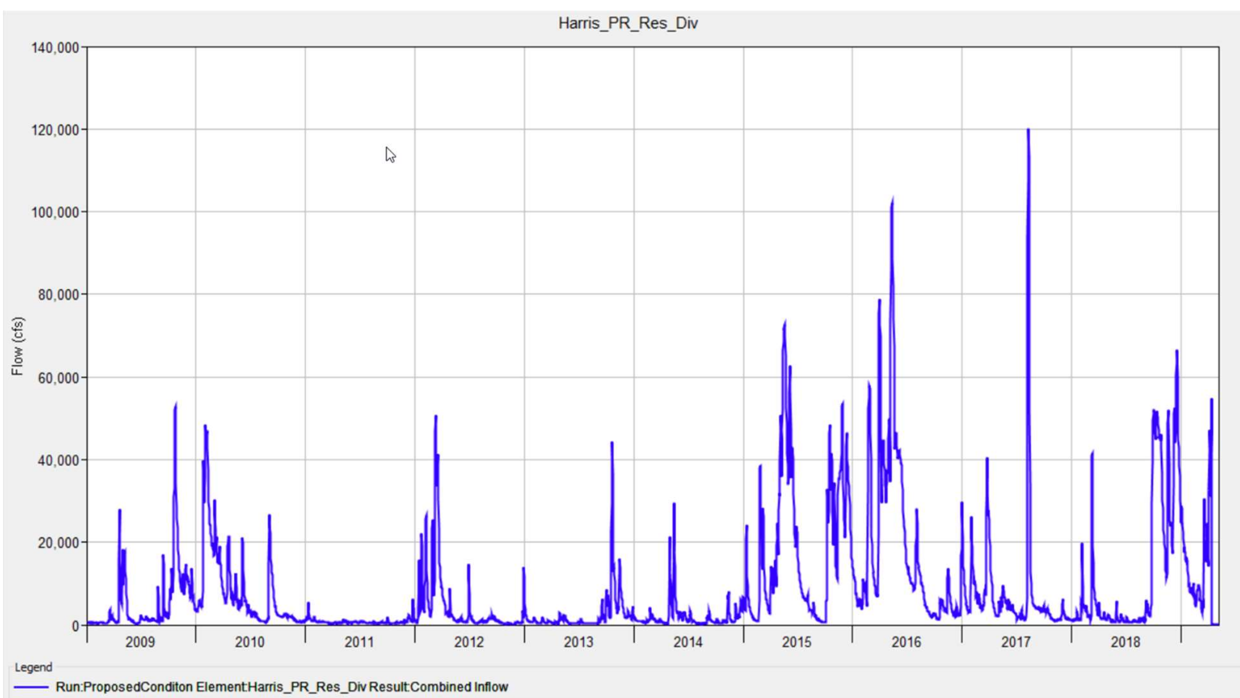


Figure 44: Proposed Conditions Flow Hydrograph at Existing Harris Reservoir Diversion (Brazos River) During 10- ½ -Year Analysis Period

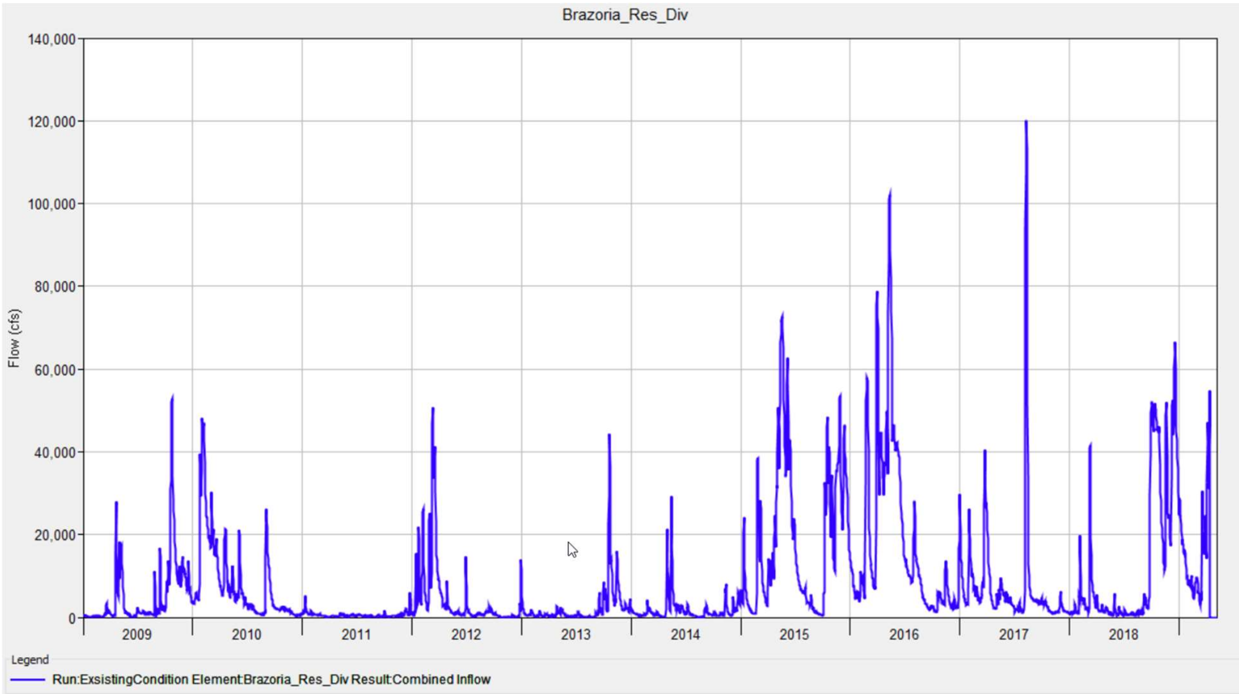


Figure 45: Existing Conditions Flow Hydrograph at Existing Brazoria Reservoir Diversion (Brazos River) During 10- ½ -Year Analysis Period

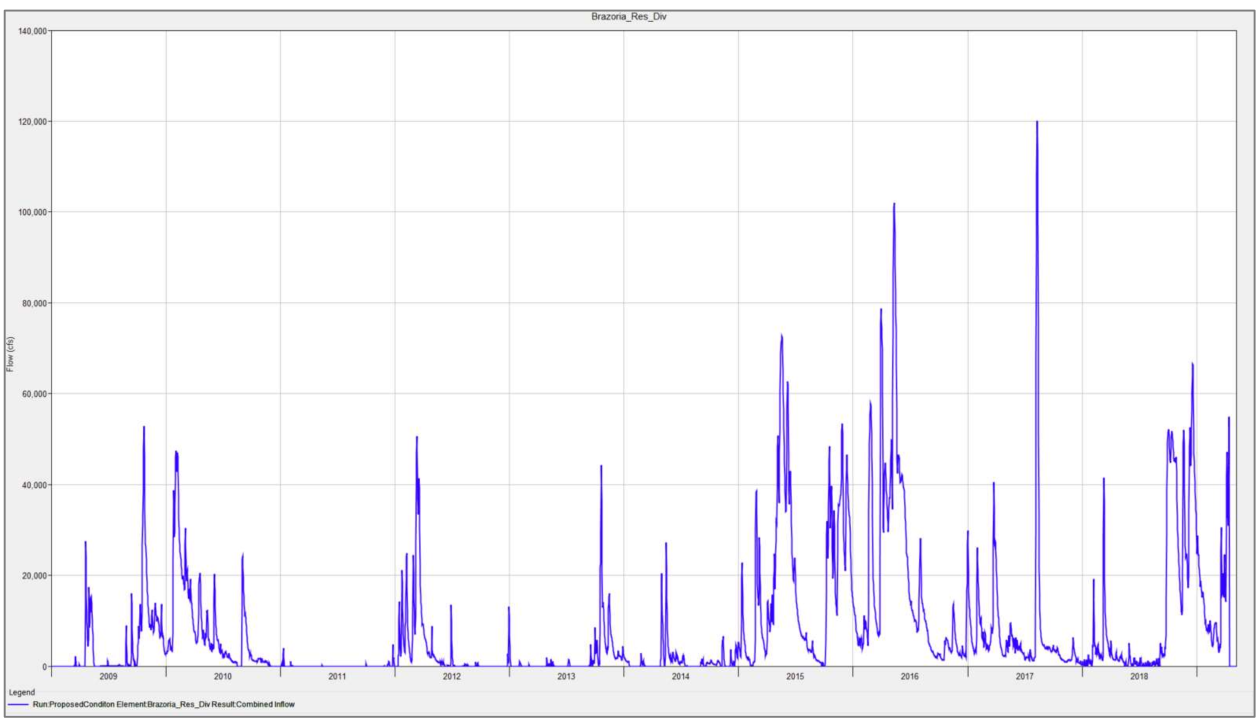


Figure 46: Proposed Conditions Flow Hydrograph at Existing Brazoria Reservoir Diversion (Brazos River) During 10- ½ -Year Analysis Period

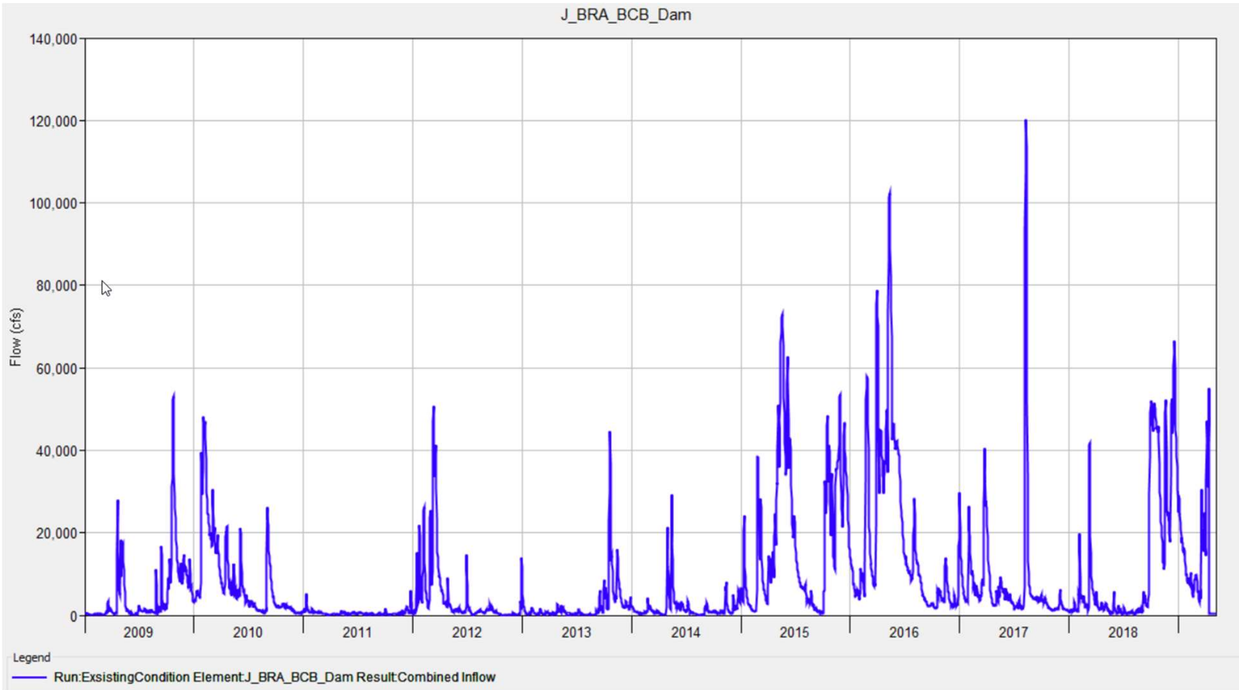


Figure 47: Existing Conditions Flow Hydrograph at Brazoria Discharge/Dow's Water Intake (Brazos River) During 10- ½ -Year Analysis Period

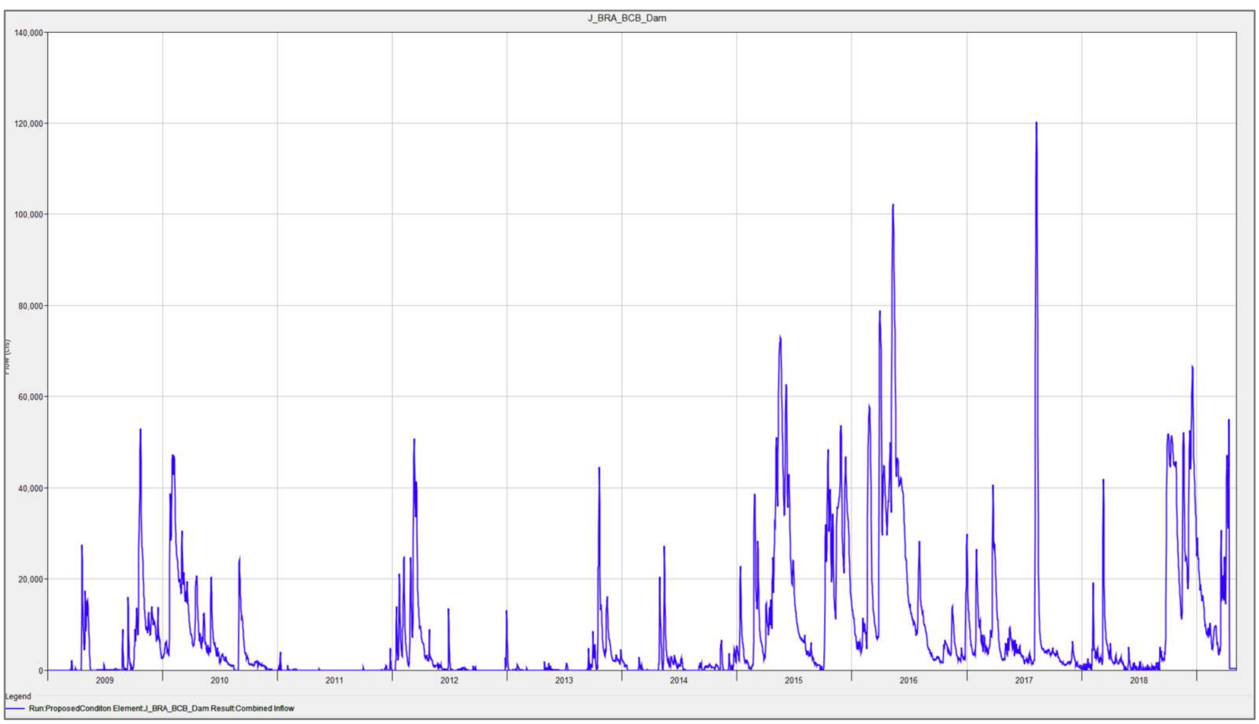


Figure 48: Proposed Conditions Flow Hydrograph at Brazoria Discharge/Dow's Water Intake (Brazos River) During 10- ½ -Year Analysis Period

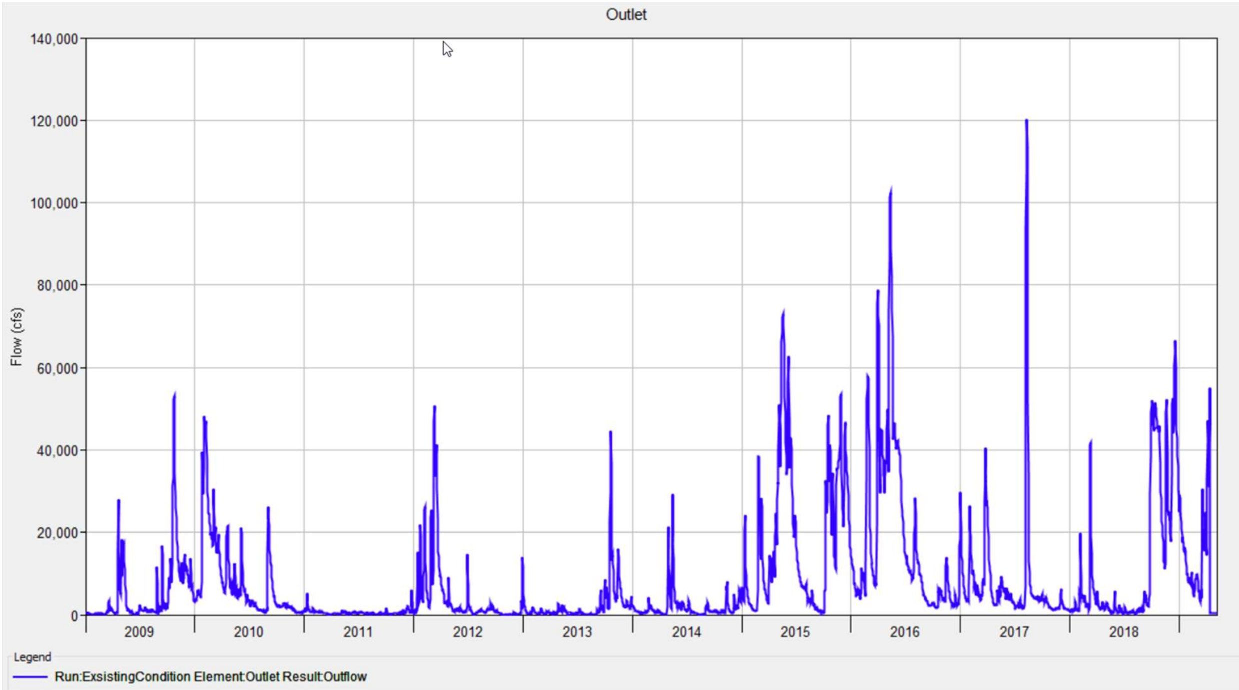


Figure 49: Existing Conditions Flow Hydrograph at Outlet (Brazos River) During 10- ½ -Year Analysis Period

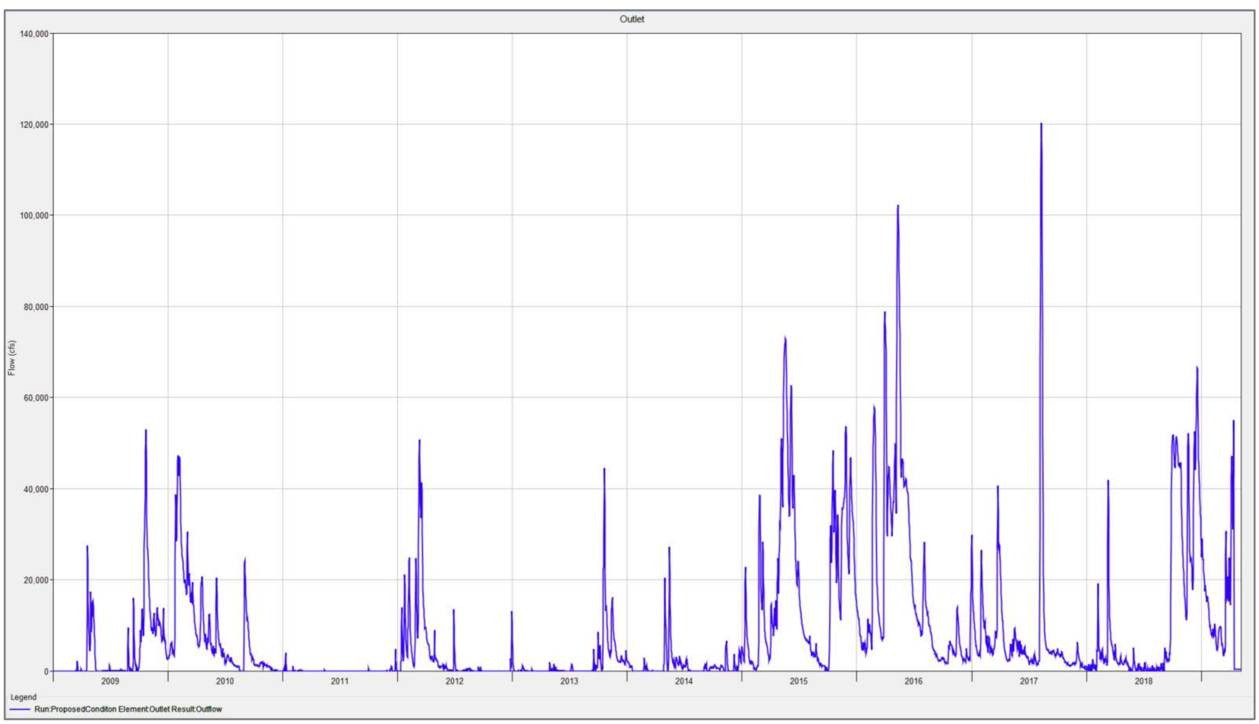


Figure 50: **Existing and Proposed Conditions Flow Hydrograph at Outlet (Brazos River) During 10- ½ -Year Analysis Period**

5.4.2 Riverware™

RiverWare uses **objects** to represent certain natural or man-made systems or structures (e.g., various types of reservoirs, diversions, reaches, stream gages, pumps, power plants, etc.) within a model, much like HEC-HMS does to create the elements within a flow model. However, it differs from HEC-HMS by using what are called **slots** as the primary "storage containers" for data, as well as the actual variables for object operations (e.g., stream inflow/outflow, diversion flow, reservoir stage-storage-discharge values, pump curve and operation information, etc.). RiverWare uses its **slot link** capabilities to couple two or more objects (and specific slots within each respective object) to perform operations within the model (e.g., routing outflow from an object upstream as inflow into a downstream linked object, etc.).

The Existing and Proposed Riverware™ models were built using the Richmond and Rosharon USGS flow gage historical hydrograph data (with a 40-year period of record) extracted from the same BRA FPP Study HEC-HMS model as described above. The Existing Conditions model includes the existing Harris and Brazoria reservoirs, respectively, along with their corresponding diversion elements in order to account for allowed pumping withdrawals along the Brazos River.

5.4.2.1 ***Existing Condition Model*** *(DowHarrisReservoirExisting.mdl.gz)*

The RiverWare model utilized the Existing Condition HEC-HMS Basin Model run's "Inflow" daily flow values from the "Harris_EX_Res_Div" diversion element, which utilized the previously mentioned ten-year period of record flow data from Dow as input, as the starting flow input for the RiverWare "Harris_EX_Res_Div" diversion object "Inflow" slot. Values for "Outflow" from the same HEC-HMS diversion element were likewise used as the input for the "Outflow" slot of the same "Harris_EX_Res_Div" diversion object in RiverWare. A "Diversion" flow data slot was also created to represent pumped outflows which were routed to the "Harris_EX_Res" pumped storage reservoir object, which was used to simulate the existing Harris Reservoir, which receives water from pumped inflows siphoned from the Brazos River at the "Harris_EX_Res_Div".

Historic reservoir plan and operational data received from Dow were used to build the "Harris_EX_Res_" reservoir "Storage", "Elevation Volume Table", and "Pool Elevation" slots. The "Inflow" slot was linked to the "Outflow" slot from the "Harris_EX_Res_Div" object. An "Outflow" slot was created to route discharge flows from the reservoir into the "Harris_EX_Res_Outlet_AP2" control slot, which was used as an analysis point (AP).

This same process was repeated using the flow summary values from the HEC-HMS "Brazoria_Res_Div" element and transferred into the appropriate "Brazoria_Res_Div" diversion object "Inflow" and "Outflow" slots.

Reach objects "R_BRA_410 R_BRA_430" and "R_BRA_440" and confluence object "J_BRA_BCB_Dam" were created to route the discharges from the Brazos River and return flows from the reservoir objects back into the Brazos River system and down to the ultimate outfall, which was the "Outlet_AP1" control object. See the model schematic in Figure 51.

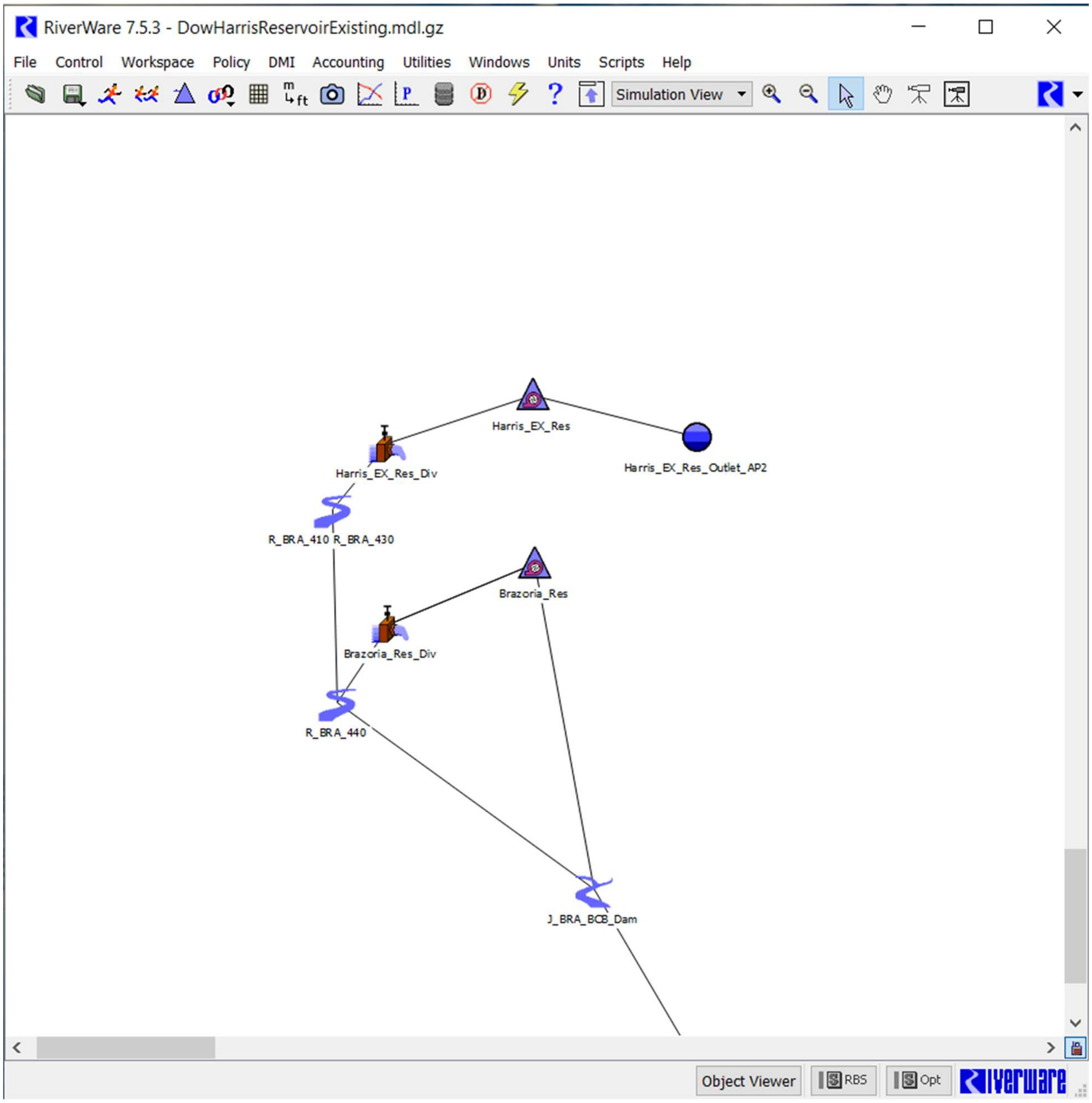


Figure 51: Riverware™ Existing Conditions Schematic

5.4.2.2 ***Proposed Condition Model*** *(DowHarrisReservoirProposed.mdl.gz)*

The Proposed Condition RiverWare model was built upon the Existing Condition model, as explained above. It was modified from the existing condition by the addition of the "Harris_PR_Res_Div" diversion object, the "Harris_PR_Res" pumped storage reservoir object, and the "Harris_PR_Res_Outlet_AP2" control object. The process for building the additional proposed Harris Reservoir and its accompanying diversion was the same as was described above for the Existing Condition Model, except the values were taken from the Proposed Condition Basin Model run of HEC-HMS for the "Harris_PR_Res_Div" and accompanying "Harris_PR_Res" pumped storage reservoir object.

The proposed Harris Reservoir expansion plans and proposed operational data received from Dow and its engineering consultants were used to create the “Harris_PR_Res” reservoir “Storage”, “Elevation Volume Table”, and “Pool Elevation” slots, just as for the Existing Condition model.

As was done previously for the existing Harris Reservoir, an “Outflow” slot was created to route discharge flows from the “Harris_PR_Res” reservoir into the “Harris_PR_Res_Outlet_AP3” control slot, which was used as another AP. A reach object “R_BRA_Harris_PR_Res_Div” was created, along with corresponding “Inflow” “Outflow” slots, to route undiverted flows from the “Harris_PR_Res_Div” back to the Brazos River System. See Figure 52 for the Proposed Project schematic.

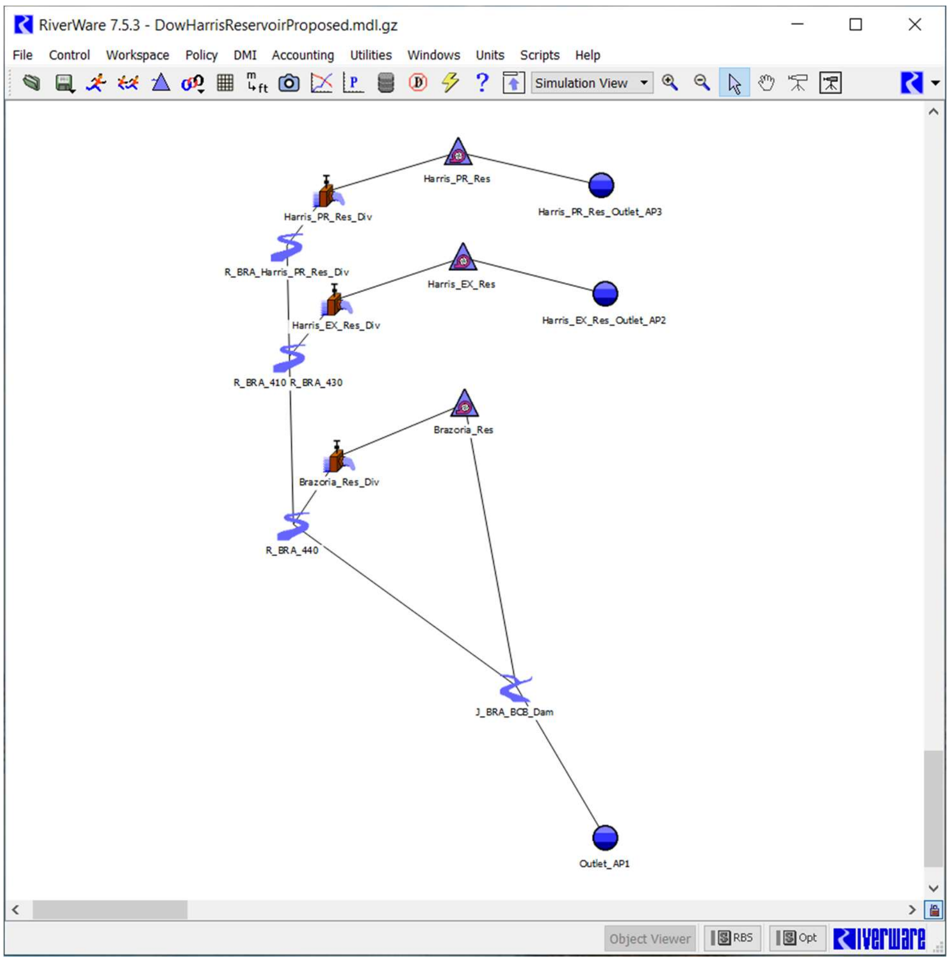
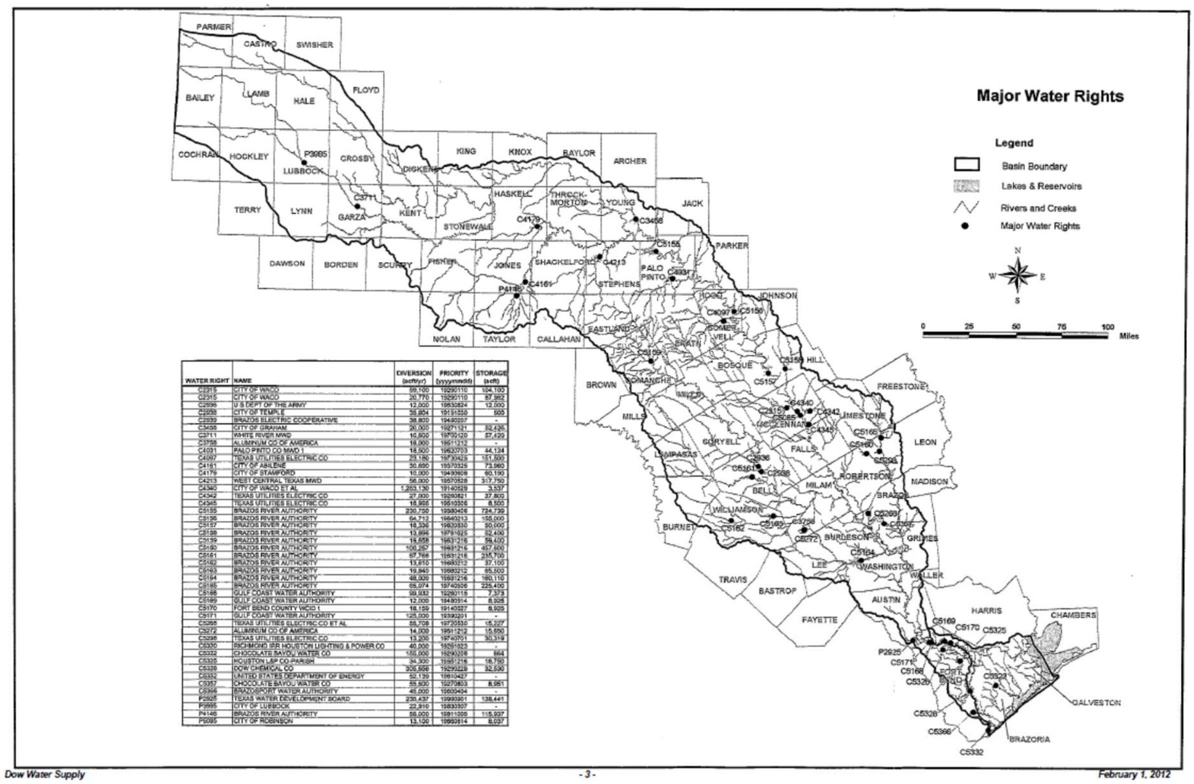


Figure 52: Riverware™ Proposed Conditions Schematic

5.4.2.3 Summary of Water Rights and Inputs to Models

This section provides the prioritization for model inputs for Riverware™. The information is based on documentation provided by Dow regarding their water rights and water supply methods and was confirmed through a review of TCEQ documentation (Texas Water Commission, 1985). Figure 53 provides a summary of the major water rights holders and Figure 54 provides a summary of the adjudicated water rights Dow holds, as confirmed by the Brazos River Watermaster.



WATER RIGHT	NAME	DIVERSION (acft/yr)	PRIORITY (yyyymmdd)	STORAGE (acft)
C2315	CITY OF WACO	59,100	19290110	104,100
C2315	CITY OF WACO	20,770	19290110	87,962
C2936	U S DEPT OF THE ARMY	12,000	19530824	12,000
C2938	CITY OF TEMPLE	35,804	19151030	500
C2939	BRAZOS ELECTRIC COOPERATIVE	38,800	19490207	-
C3458	CITY OF GRAHAM	20,000	19271121	52,426
C3711	WHITE RIVER MWD	10,600	19700120	57,420
C3758	ALUMINUM CO OF AMERICA	18,000	19511212	-
C4031	PALO PINTO CO MWD 1	18,500	19620703	44,124
C4097	TEXAS UTILITIES ELECTRIC CO	23,180	19730425	151,500
C4161	CITY OF ABILENE	30,690	19570325	73,960
C4179	CITY OF STAMFORD	10,000	19490608	60,190
C4213	WEST CENTRAL TEXAS MWD	56,000	19570528	317,750
C4340	CITY OF WACO ET AL	1,253,130	19140529	3,537
C4342	TEXAS UTILITIES ELECTRIC CO	27,000	19260821	37,800
C4345	TEXAS UTILITIES ELECTRIC CO	18,966	19510326	8,500
C5155	BRAZOS RIVER AUTHORITY	230,750	19380406	724,739
C5156	BRAZOS RIVER AUTHORITY	64,712	19640213	155,000
C5157	BRAZOS RIVER AUTHORITY	18,336	19820330	50,000
C5158	BRAZOS RIVER AUTHORITY	13,896	19761025	52,400
C5159	BRAZOS RIVER AUTHORITY	19,658	19631216	59,400
C5160	BRAZOS RIVER AUTHORITY	100,257	19631216	457,600
C5161	BRAZOS RIVER AUTHORITY	67,768	19631216	235,700
C5162	BRAZOS RIVER AUTHORITY	13,610	19680212	37,100
C5163	BRAZOS RIVER AUTHORITY	19,840	19680212	65,500
C5164	BRAZOS RIVER AUTHORITY	48,000	19631216	160,110
C5165	BRAZOS RIVER AUTHORITY	66,074	19740506	225,400
C5168	GULF COAST WATER AUTHORITY	99,932	19260115	7,373
C5169	GULF COAST WATER AUTHORITY	12,000	19480514	8,925
C5170	FORT BEND COUNTY WCID 1	18,159	19140327	8,925
C5171	GULF COAST WATER AUTHORITY	125,000	19390201	-
C5268	TEXAS UTILITIES ELECTRIC CO ET AL	55,708	19720530	15,227
C5272	ALUMINUM CO OF AMERICA	14,000	19511212	15,650
C5298	TEXAS UTILITIES ELECTRIC CO	13,200	19740701	30,319
C5320	RICHMOND IRR HOUSTON LIGHTING & POWER CO	40,000	19251023	-
C5322	CHOCOLATE BAYOU WATER CO	155,000	19290208	664
C5325	HOUSTON L&P CO-PARISH	34,300	19551216	18,750
C5328	DOW CHEMICAL CO	305,656	19290228	32,530
C5332	UNITED STATES DEPARTMENT OF ENERGY	52,139	19610427	-
C5357	CHOCOLATE BAYOU WATER CO	55,500	19270803	8,951
C5366	BRAZOSPORT WATER AUTHORITY	45,000	19600404	-
P2925	TEXAS WATER DEVELOPMENT BOARD	235,437	19990901	138,441
P3985	CITY OF LUBBOCK	22,910	19830307	-
P4146	BRAZOS RIVER AUTHORITY	56,000	19811005	115,937
P5085	CITY OF ROBINSON	13,100	19860814	8,037

Figure 53: Summary of Major Water Rights on the Brazos River in Texas (provided by Dow)

Dow Water Rights Summary

Controlling Legal Documents

Certificate of Adjudication # 12-5328 Granted January 14, 1988; Cover Brazos River, Oyster Creek and Buffalo Camp Bayou Water Rights

Certificate of Adjudication # 12-5328A Granted February 27, 1991; Oyster Creek Adjustment to #12-5328

Certificate of Adjudication # 12-5328B Granted December 4, 1991; Oyster Creek Adjustment to #12-5328

		Period Reliability (Month by Month Basis)	Volume Reliability	Minimum Diverted	Special Consideration
1929	20,000 Acre-ft	98.56 %	98.80%	14,679 Acre-ft	
1942	150,000 Acre-ft	94.25 %	95.78%	76,910 Acre-ft	
1942 OC	58,175 Acre-ft	37.64 %	47.11%	8,626	
1942 OC	1,800 Acre-ft	37.50 %	26.01%	13	
1951BCB	7,500 Acre-ft	55.46 %	67.86 %	1500	
1952	Constructed Brazoria Reservoir and Relocated Right				
1960	65,000 Acre-ft	88.22%	88.75%	18,738 Acre-ft	61,000 Acre-ft of Storage or Contract Water with BRA Req'd
1960	45,000 Acre-ft	BWA Water			
1976	3,136 Acre-ft	84.34 %	88.24%		
				121,205 Acre-ft	

Current TCEQ Water Rights Reliability Assessment
Based on KBR work in Sept, 2002
WAM Model Run 3 (=All Authorized Water Rights at Authorized Amounts, No Return Flows, Original Areas-Capacities)

DOW RESTRICTED - For internal use only

Figure 54: Summary of Dow Water Rights on the Brazos River, Texas DOW RESTRICTED - For Internal Use Only

Dow currently states that it plans to use approximately 100,000 gpm (222.2 cfs) at its plant. This would require a water right of 162,222 AF, which is less than the current Dow water right of approximately 284,000 AF from the Brazos River, Oyster Creek and Buffalo Bayou. If Dow could use all their water right they could increase the water use to 175,000 gpm or 388.9 cfs. The 388.89 cfs would be less than the 630 cfs maximum diversion rate from the water right.

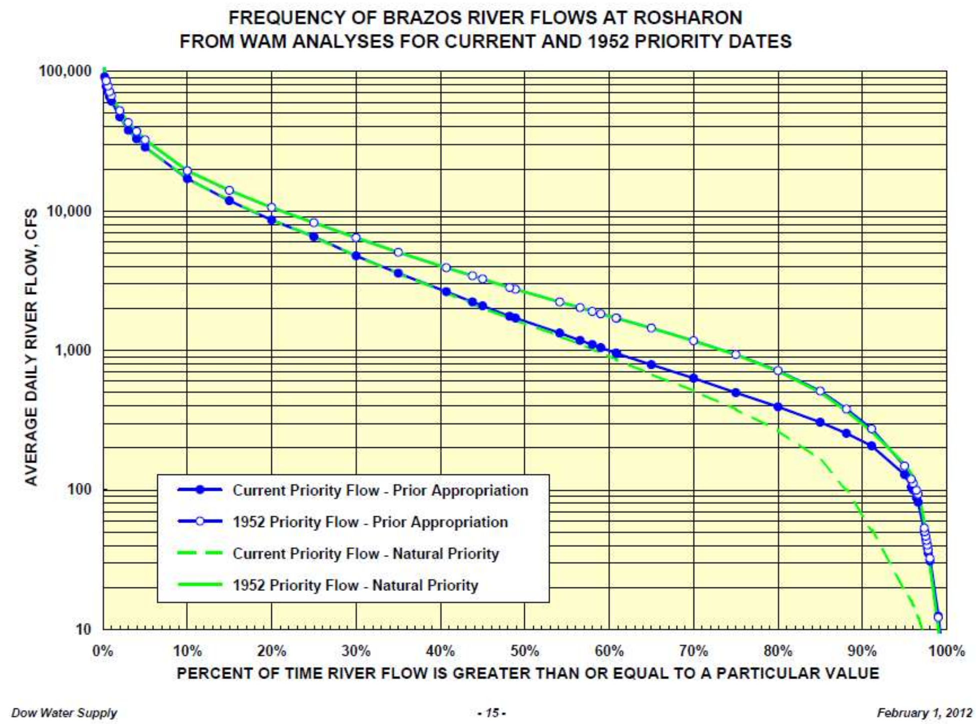


Figure 55: Frequency of Flows for Prior Appropriated and Natural Priority on the Brazos River, Texas

5.4.3 Brazos River HEC-RAS Unsteady Flow

The Brazos River HEC-RAS unsteady flow model used in this study was obtained from the BRA Lower Brazos Flood Protection Planning Study (FPP Study) HEC-RAS hydraulic model that was approved by the BRA in March of 2019 (Halff, 2019). The original model was truncated upstream of the Rosharon USGS gage to reduce extremely long run times and eliminate unnecessary data, as the stream segment and cross-sections upstream of the gage are not part of the area of study for this report. Additionally, any backwater effects associated with the existing and proposed reservoir are expected to be isolated to the area in the closer vicinity to the existing Brazoria and Harris reservoirs and proposed Harris reservoir expansion.

All hydraulic modeling of the Brazos River was performed in HEC-RAS unsteady flow version 5.0.7 following standard modeling procedures for conceptual or planning-level analysis. Model computation time steps of 30 minutes and reporting intervals of one-day were used and were held constant between existing and proposed conditions. Changes to the original model were limited to the following:

1. Truncating the model;
2. Revising the upstream boundary conditions and associated initial flows;
3. Incorporating lateral inflow hydrographs.

5.4.3.1 Geometry Data

With the exception of truncating the HEC-RAS unsteady flow model at cross-section 308,583.5, no changes were made to the geometry data from the original study. As with HEC-HMS, the original FPP Study model did not include either of the existing Harris or Brazoria reservoirs that are operated by Dow. These two reservoirs and their corresponding diversions along the Brazos River were not modeled in the traditional way existing conditions and proposed conditions are modeled in a HEC-RAS unsteady flow model. This usually is done by adding lateral inflow hydrograph along the main river. Diversions (negative flows out of the main river) are not easily modeled in HEC-RAS, as HEC RAS cannot appropriately handle negative flows or flows leaving the system. Negative flows would crash the HEC-RAS simulation. A different approach was used to model the existing Brazos River conditions, which was by inserting a lateral inflow hydrograph of the Proposed Harris reservoir back into the model were the flow was diverted into the Proposed Harris Reservoir. Then, the lateral flow hydrograph was removed and only the boundary conditions were kept in the model. This method gives you the ability to quantify the differences happening at the Brazos River between the existing and proposed project conditions without compromising mode stability.

These three reservoirs were not added to the geometry data as reservoirs. Reservoir routing was performed in HEC-HMS so that hydrographs could be readily imported into both HEC-RAS unsteady flow and Riverware and to avoid creating stability issues in HEC-RAS unsteady flow. Reservoir routing computations are performed using the Modified Puls routing method in both HEC-HMS and HEC-RAS unsteady flow, so results from reservoir routing in either model would be very similar. The two existing and one proposed reservoir were also not included in the cross-section geometry as including them and filling them with blocked obstructions would not significantly change the hydraulic modeling results.

5.4.3.2 Boundary Conditions

The Rosharon gage was input as a flow hydrograph for the upstream boundary condition at the upstream cross-section 308,583.5 (Figure 40). Details on this gage are discussed in Section 5.3. While the original model used a normal depth downstream boundary condition with a slope of 0.0003, this boundary condition did not produce expected backwater effects from the Gulf of Mexico related to mean, high, or low tide or any condition. Since the reach of the Brazoria River modeled for this study has bottom elevation nearly 20 ft below sea level and is tidally influenced, the downstream boundary condition was modified to a fixed WSEL of 0.511 ft, which his consistent with the current MSL reported by USGS (USGS, 2019). While MSL does not capture extreme tidal influence or storm surge, it is reflective of typical levels of tidal influence and backwater effects from the Gulf of Mexico on the study area. As shown in Figure 11, neither the existing Brazoria Reservoir or Harris Reservoir or proposed Harris Reservoir expansion are expected to be inundated from the effects of sea level rise.

5.4.3.3 Lateral Inflow Hydrographs

The rainfall data was omitted from the HMS model, due to the incompleteness of the data set. Therefore, the only river hydrograph utilized in the HEC-RAS model was the upstream boundary condition hydrograph (USGS Rosharon gage). No lateral inflow from drainage area sub-basins were included in the HEC-RAS model. Only the diversion for proposed Harris reservoir was modeled in HEC-RAS.

5.4.3.4 Reservoir Diversions and Discharges

As shown in Figure 56 and Table 12, the only diversion modeled was the proposed Harris Reservoir expansion. The diversion was input into HEC-RAS unsteady flow as a lateral inflow hydrograph at the representative cross-section. As mentioned above, the proposed Harris Reservoir expansion required an additional lateral inflow hydrograph in proposed conditions. There was an attempt to model the diversions in HEC-RAS for both the Existing Harris Reservoir and Brazoria Reservoir as positive discharges(flow entering into the Brazos) and negative discharges(flow exiting the Brazos), except that this methodology brought instability and errors to the model and it was unable to run. A simplified version of the model was the preferred method of analysis which only used one lateral inflow for the proposed Harris Reservoir which was chosen as the best way to represent the system, as the only difference between the existing and proposed conditions in the Brazos river system is the addition of the proposed Harris Reservoir diversion. In Table 12 below the location of the proposed Harris Reservoir Diversion within the HECRAS Model is shown.

Table 12: Reservoir Diversions and Discharges Lateral Inflow Hydrograph Input Locations

Reservoir	HEC-RAS Cross-Section
Existing Harris Discharge	Leaves to Oyster Creek
Proposed Harris Inflow	253,920.7
Proposed Harris Discharge	Leaves to Oyster Creek

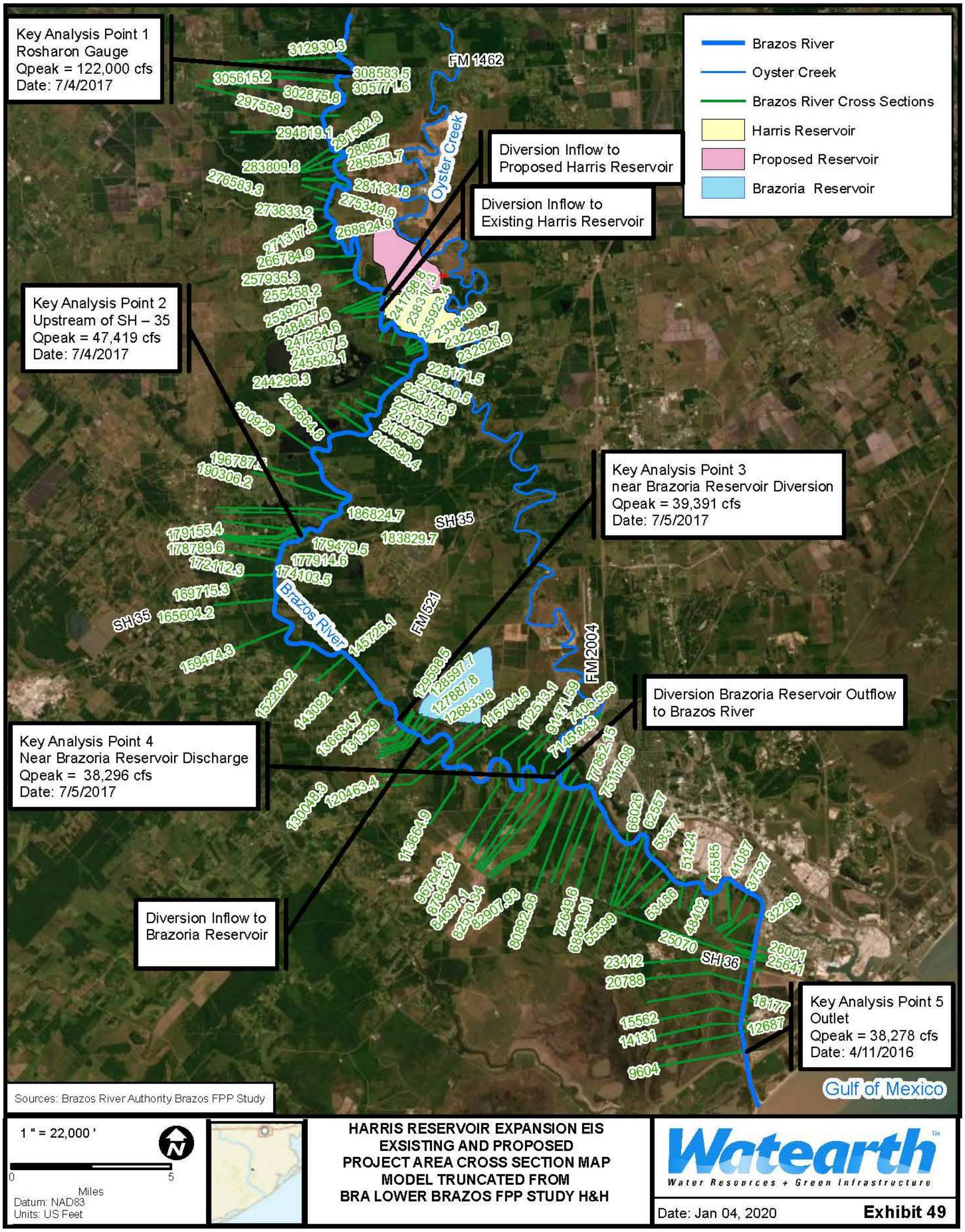


Figure 56: HEC-RAS Cross-Section Layout for Brazos River

5.4.3.5 HEC-RAS Unsteady Flow Results

Table 13 lists existing conditions and proposed conditions Peak Flows at Maximum Water Surface Elevation for the entire 10-1/2-year simulation period and shows the difference in maximum flow through the cross sections at each of the river stations.

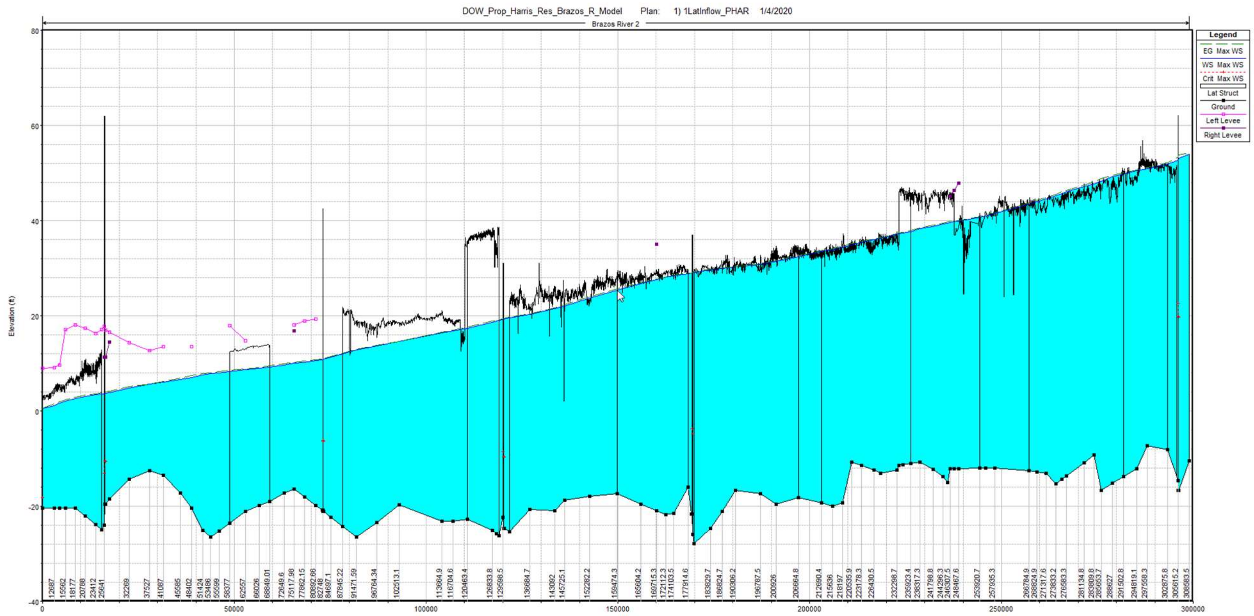


Figure 57 and Figure 58 provides a profile plot of existing and proposed conditions maximum water surface elevation (WSEL) along the Brazos River from the Rosharon gage to the outlet at the Gulf of Mexico. Similarly, Figure 60 through

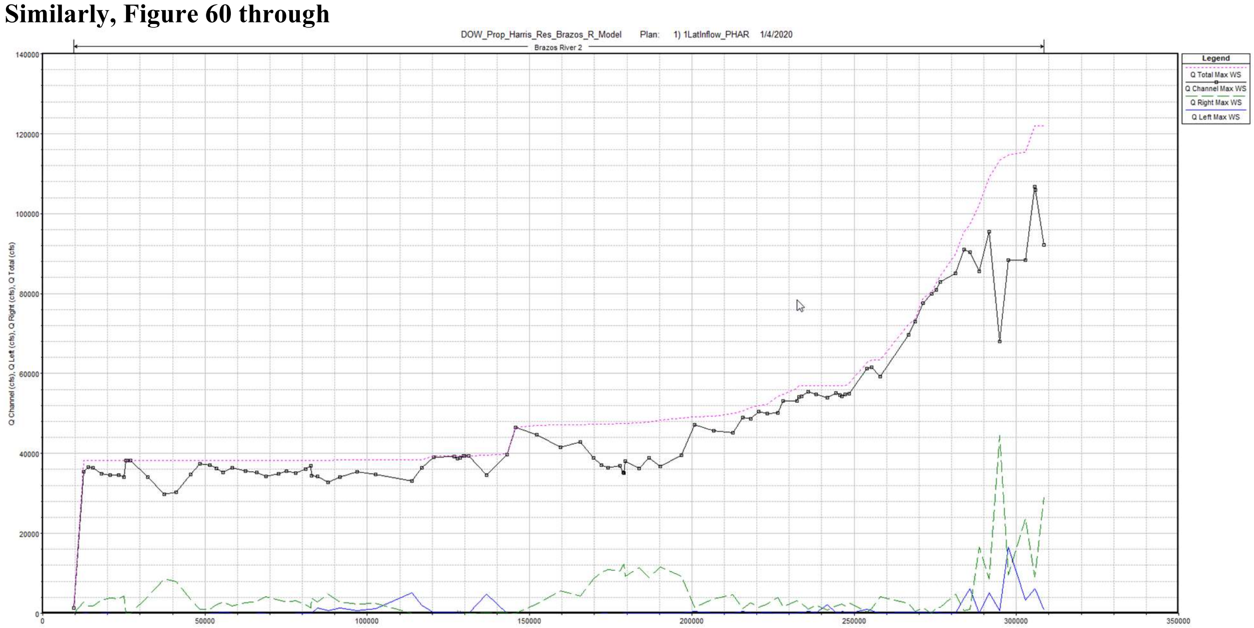


Figure 61 provide a profile plot of existing and proposed conditions maximum velocities and flows along the same analysis reach of the Brazos River, respectively. Most of the results between the existing and proposed conditions varied only slightly from the existing conditions, due to the relatively insignificant change of one diversion added in proposed conditions over a large watershed study area. The change in flow in the Brazos River caused by the Proposed Harris Reservoir Diversion is negligible and the results for both conditions are nearly identical.

Table 13: Comparison of Existing and Proposed Flows at Maximum Water Surface Elevation Over the 10-1/2 Year Simulation Period.

River Station	Existing Conditions Flow Total (cfs)	Proposed Conditions Flow Total (cfs)	Flow Δ (cfs)
308,583.5	122,000	122,000	0
305,771.6	121,974	121,974	0
305,615.2	121,974	121,974	0
302,875.8	115,267	115,267	0
297,558.3	114,603	114,603	0
294,819.1	113,349	113,349	0
291,502.8	109,004	109,004	0.1
288,627.0	102,202	102,202	0
285,653.7	97,362	97,362	-0.02
283,809.8	95,441	95,441	-0.01
281,134.8	89,821	89,821	0.01
276,583.3	84,367	84,367	0.01
275,349.9	82,810	82,810	0.01
273,833.2	80,262	80,262	0.01
271,317.6	79,008	79,008	0
268,824.9	73,715	73,715	0
266,784.9	72,342	72,342	0
257,935.3	63,398	63,398	0
255,458.2	63,302	63,302	-0.01
253,920.7	62,678	62,678	-0.01
248,467.6	57,526	57,526	-0.03
247,254.6	56,999	56,999	-0.02
246,307.5	56,999	56,999	-0.03
245,582.1	56,999	56,999	-0.03
244,296.3	56,999	56,999	-0.03
241,798.8	56,998	56,998	-0.01
238,317.3	56,997	56,997	0
235,923.4	56,995	56,995	-0.02
233,849.8	56,995	56,995	-0.01
232,926.9	56,995	56,995	-0.01

River Station	Existing Conditions Flow Total (cfs)	Proposed Conditions Flow Total (cfs)	Flow Δ (cfs)
232,298.7	56,222	56,222	-0.02
228,171.5	54,743	54,743	0
226,430.5	54,217	54,217	0.01
223,178.3	52,342	52,342	0
220,535.9	51,956	51,956	0.01
218,197.0	51,388	51,388	0.01
215,636.0	50,570	50,570	-0.01
212,690.4	49,959	49,959	0
206,664.8	49,271	49,271	0.01
200,926.0	49,219	49,219	0
196,787.5	48,811	48,811	0.01
190,306.2	48,277	48,280	-3.42
186,824.7	47,827	47,827	0.03
183,829.7	47,681	47,681	0.02
179,479.5	47,417	47,417	-0.01
179,155.4	47,417	47,417	0
178,789.6	47,415	47,415	0.01
177,914.6	47,415	47,415	0.01
174,103.5	47,389	47,389	-0.01
172,112.3	47,361	47,361	0
169,715.3	47,344	47,344	-0.01
165,604.2	47,190	47,190	0
159,474.3	47,167	47,167	0
152,282.2	47,079	47,079	0
145,725.1	46,471	46,471	0.01
143,092.0	39,801	39,801	0
136,684.7	39,498	39,498	0
131,329.0	39,400	39,400	0.01
130,048.3	39,399	39,399	0
129,598.5	39,399	39,399	0
128,597.7	39,399	39,399	0
127,887.8	39,399	39,399	-0.46
126,833.8	39,399	39,399	0
120,463.4	39,397	39,397	-0.01

River Station	Existing Conditions Flow Total (cfs)	Proposed Conditions Flow Total (cfs)	Flow Δ (cfs)
116,704**.6**	38,345	38,345	0
113,664**.9**	38,343	38,343	-0.01
102,513**.1**	38,334	38,334	0
96,764.3	38,329	38,329	0
91,471.6	38,315	38,315	0.18
87,845.2	38,285	38,285	0
84,697**.1**	38,284	38,284	0.01
82,907.9	38,284	38,284	-0.23
82,530.3	38,283	38,283	0
80,892.7	38,283	38,283	0.23
77,862.2	38,283	38,283	-0.2
75,118.0	38,283	38,283	0
72,649**.6**	38,282	38,282	0.01
68,849.0	38,282	38,282	-0.13
66,026.0	38,282	38,282	0.15
62,557.0	38,282	38,282	-0.13
58,377.0	38,282	38,282	0.11
55,599.0	38,282	38,282	0
53,486.0	38,282	38,282	0
51,424.0	38,282	38,282	0
48,402.0	38,282	38,282	0
45,585.0	38,281	38,281	0.01
41,087.0	38,281	38,281	0
37,527.0	38,281	38,281	0
32,269.0	38,281	38,281	0.05
27,098.0	38,281	38,281	0
26,001.0	38,281	38,281	0
25,641.0	38,281	38,281	0.01
25,070.0	38,281	38,281	0
23,412.0	38,281	38,281	0.01
20,788.0	38,281	38,281	0
18,177.0	38,281	38,281	0
15,562.0	38,281	38,281	0
14,131.0	38,281	38,281	0

River Station	Existing Conditions Flow Total (cfs)	Proposed Conditions Flow Total (cfs)	Flow Δ (cfs)
12,687.0	38,281	38,281	0
9,604.0	1,348	730	618

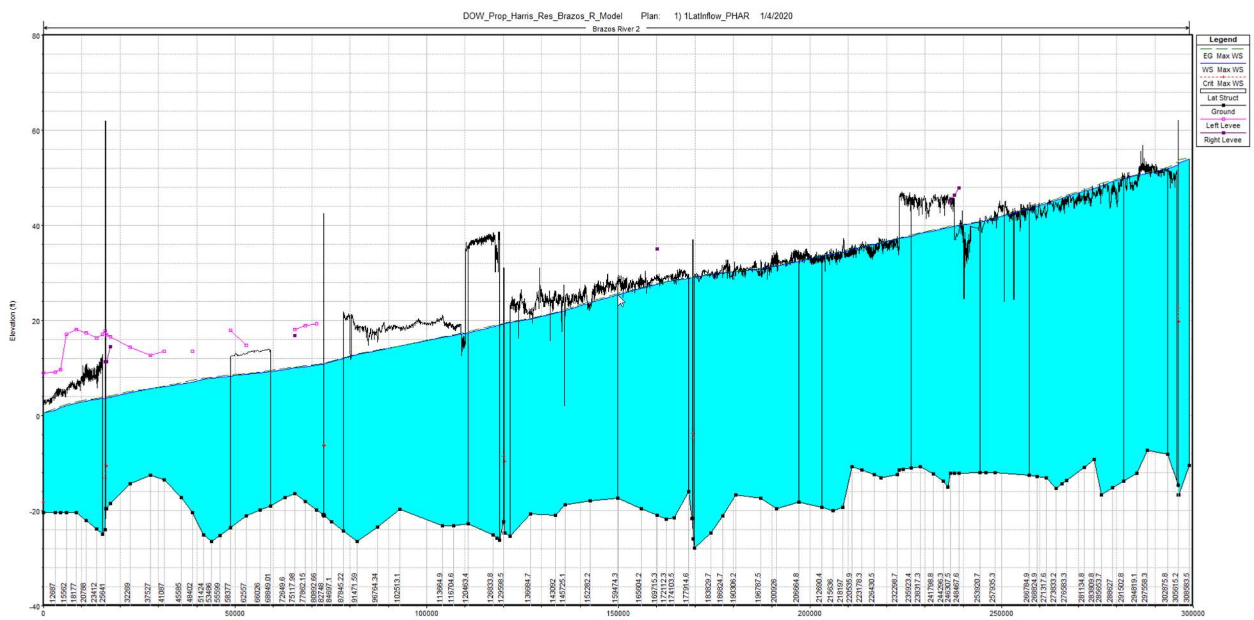


Figure 57 Existing Conditions Maximum WSEL Profile During 10-1/2 - Year Analysis Period Along the Brazos River Between Rosharon Gage and Outlet.

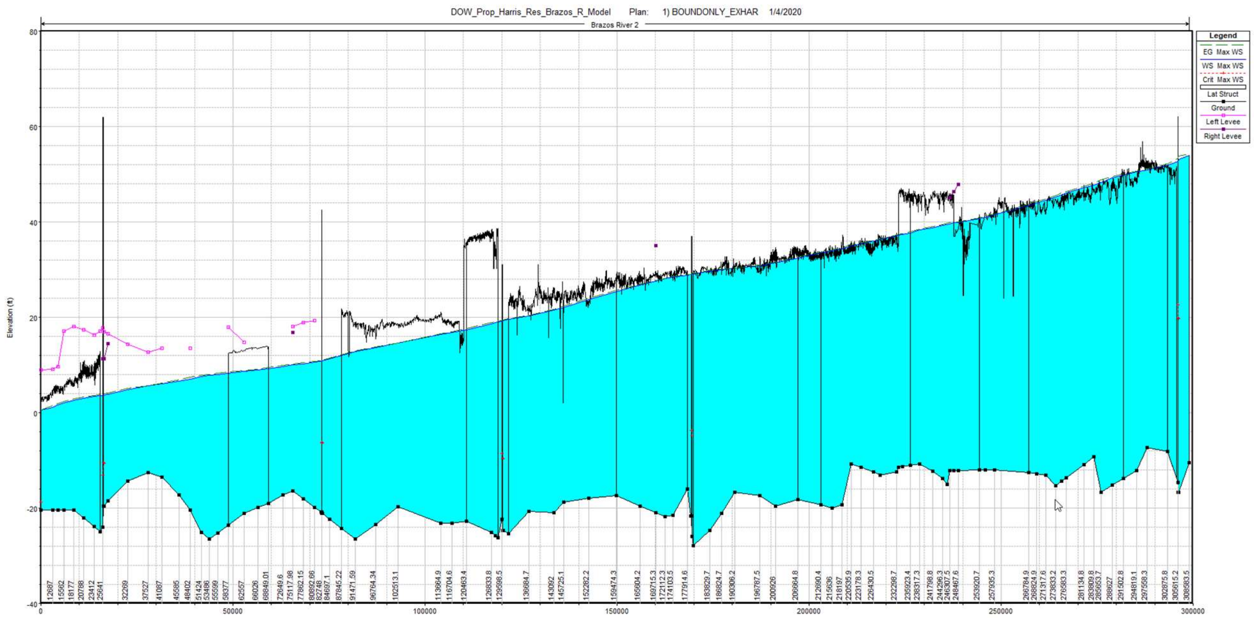


Figure 58 Proposed Conditions Maximum WSEL Profile During 10-1/2 - Year Analysis Period Along the Brazos River Between Rosharon Gage and Outlet.

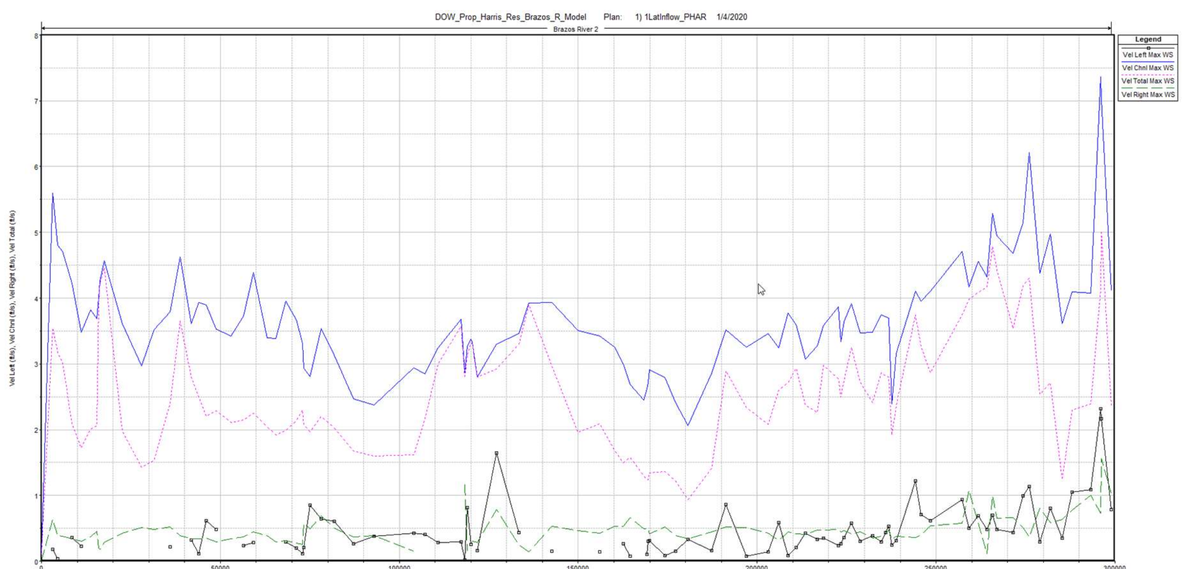


Figure 59: Existing Conditions Channel Flow Velocity, Left and Right Overbank Flow Velocity and Average Flow Velocity for the Peak Maximum WSEL During 10-1/2 - Year Analysis Period Along the Brazos River Between Rosharon Gage and Outlet

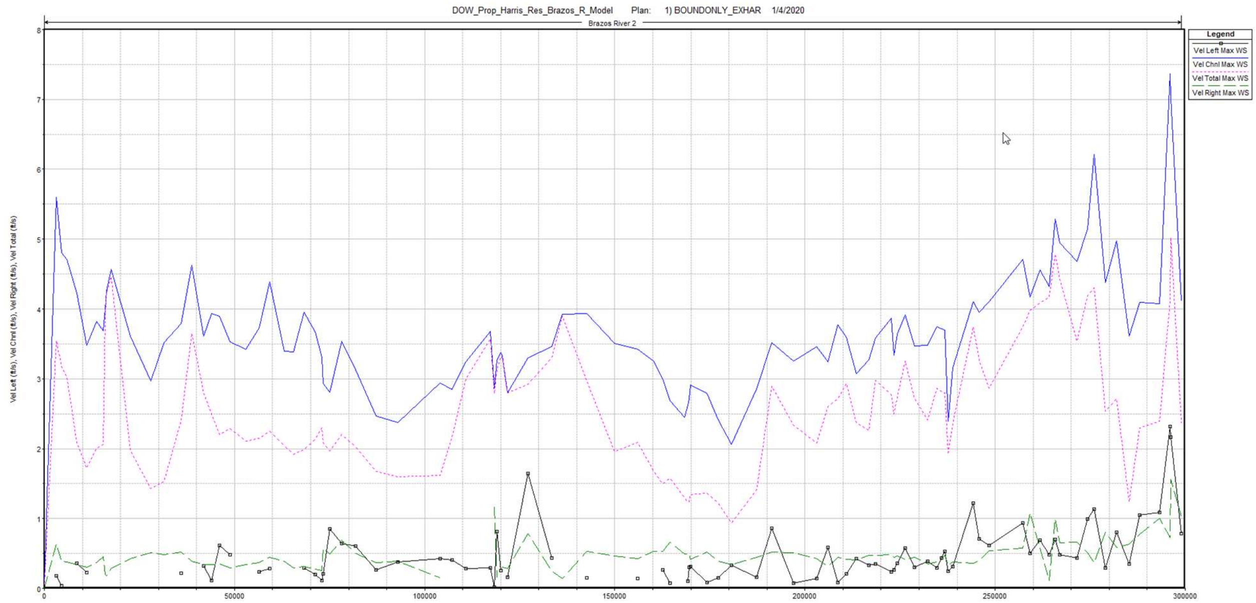


Figure 60: Proposed Conditions Channel Flow Velocity, Left and Right Overbank Flow Velocity and Average Flow Velocity for the Peak Maximum WSEL During 10-1/2 - Year Analysis Period Along the Brazos River Between Rosharon Gage and Outlet

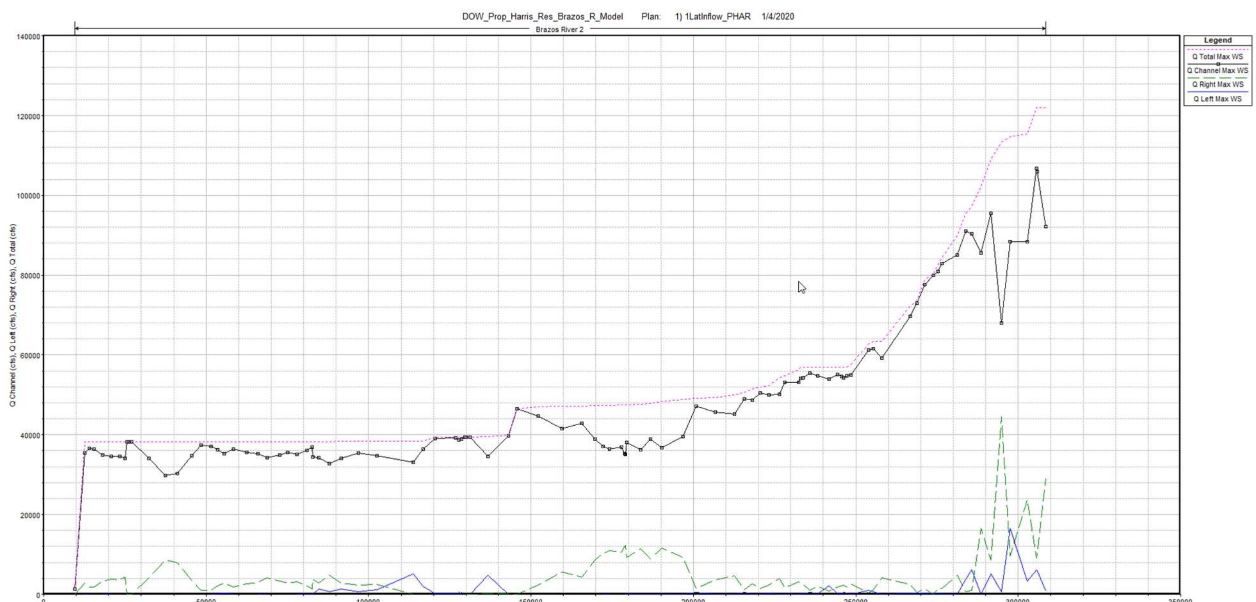


Figure 61: Existing Conditions Channel Flow, Left and Right Overbank Flow and Total Maximum Flow for the Peak Maximum WSEL During 10-1/2 - Year Analysis Period Along the Brazos River Between Rosharon Gage and Outlet

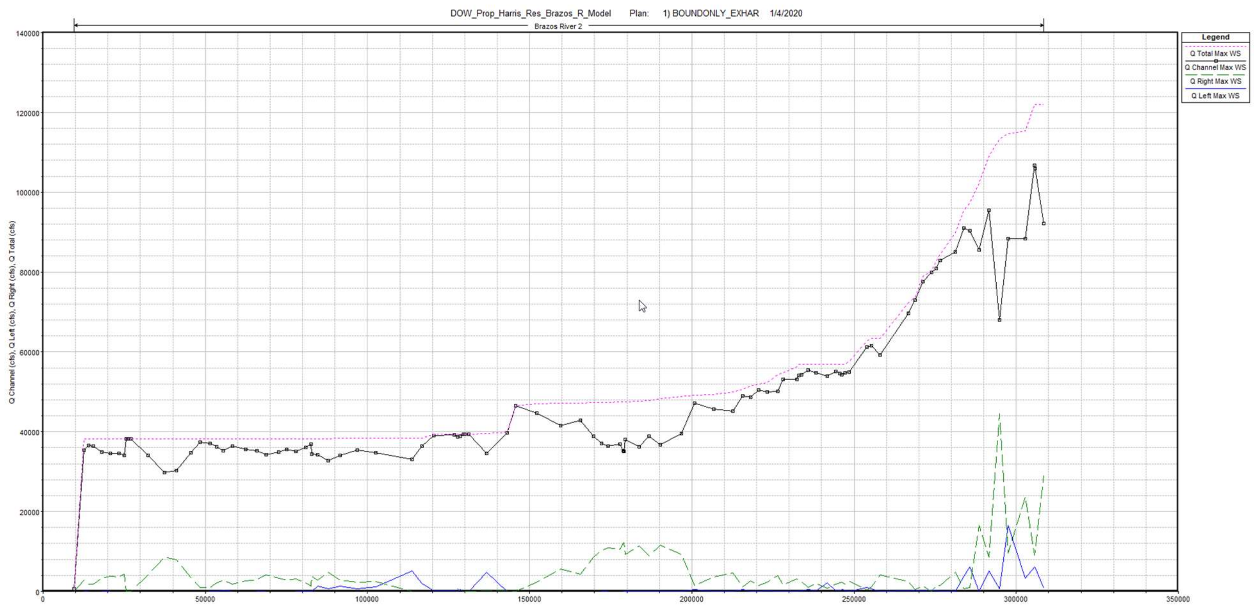


Figure 62: Proposed Conditions Channel Flow, Left and Right Overbank Flow and Total Maximum Flow for the Peak Maximum WSEL During 10-1/2 - Year Analysis Period Along the Brazos River Between Rosharon Gage and Outlet

Figure 65 through Figure 72 depict existing and proposed stage hydrographs and flow hydrographs, at five key analysis points between the Rosharon gage and the outlet at the Gulf of Mexico. Table 14 shows the HEC-RAS results showing the water surface elevations for all the cross sections within existing and proposed conditions model. Table 15 shows the HEC-RAS results showing the maximum channel velocities for all the cross sections within existing and proposed conditions model. The HEC-RAS model results did not show any difference in water surface elevation between the existing and proposed conditions model. The key analysis points are listed in Table 16 and include the Rosharon gage, which is not expected to change between existing and proposed conditions as it is an upstream boundary condition in the model. Most of the results between the existing and proposed conditions varied only slightly from the existing conditions, due to the model having one diversion added over a large watershed study area. Therefore, the change in flow in the Brazos River caused by the Proposed Harris Reservoir Diversion is negligible and the results for both conditions are identical.

Figure 73 and Figure 74 show the flood inundation mapping results of the Brazos HEC-RAS Model which includes cross-sections with maximum existing and proposed WSELs over the 10-1/2-year simulation.

Table 14: Comparison between Existing and Proposed Maximum Water Surface Elevations

River Station	Existing Conditions WSEL (ft.)	Proposed Conditions WSEL (ft.)	Δ WSEL (ft.)
308,583.5	53.95	53.95	0.0
305,771.6	53.06	53.06	0.0
305,615.2	52.65	52.65	0.0
302,875.8	51.88	51.88	0.0
297,558.3	50.96	50.96	0.0
294,819.1	50.5	50.5	0.0
291,502.8	49.74	49.74	0.0
288,627.0	49.21	49.21	0.0
285,653.7	48.21	48.21	0.0
283,809.8	47.73	47.73	0.0
281,134.8	47.18	47.18	0.0
276,583.3	46.02	46.02	0.0
275,349.9	45.59	45.59	0.0
273,833.2	45.25	45.25	0.0
271,317.6	44.57	44.57	0.0
268,824.9	44.02	44.02	0.0
266,784.9	43.43	43.43	0.0
257,935.3	41.47	41.47	0.0
255,458.2	40.94	40.94	0.0
253,920.7	40.63	40.63	0.0
248,467.6	39.91	39.91	0.0
247,254.6	39.84	39.84	0.0
246,307.5	39.64	39.64	0.0
308,583.5	53.95	53.95	0.0
245,582.1	39.51	39.51	0.0
244,296.3	39.28	39.28	0.0
241,798.8	38.81	38.81	0.0
238,317.3	38.32	38.32	0.0
235,923.4	37.67	37.67	0.0
233,849.8	37.33	37.33	0.0
232,926.9	37.21	37.21	0.0
232,298.7	37.06	37.06	0.0

River Station	Existing Conditions WSEL (ft.)	Proposed Conditions WSEL (ft.)	Δ WSEL (ft.)
228,171.5	36.28	36.28	0.0
226,430.5	35.99	35.99	0.0
223,178.3	35.46	35.46	0.0
220,535.9	34.92	34.92	0.0
218,197.0	34.38	34.38	0.0
215,636.0	33.94	33.94	0.0
212,690.4	33.49	33.49	0.0
206,664.8	32.47	32.47	0.0
200,926.0	31.43	31.43	0.0
196,787.5	30.77	30.77	0.0
190,306.2	30.28	30.28	0.0
186,824.7	29.98	29.98	0.0
183,829.7	29.7	29.7	0.0
179,479.5	29.12	29.12	0.0
179,155.4	29.05	29.05	0.0
178,789.6	28.93	28.93	0.0
177,914.6	28.84	28.84	0.0
174,103.5	28.44	28.44	0.0
172,112.3	28.09	28.09	0.0
169,715.3	27.59	27.59	0.0
165,604.2	26.72	26.72	0.0
159,474.3	25.43	25.43	0.0
152,282.2	23.74	23.74	0.0
308,583.5	53.95	53.95	0.0
145,725.1	22.04	22.04	0.0
143,092.0	21.53	21.53	0.0
136,684.7	20.32	20.32	0.0
131,329.0	19.54	19.54	0.0
130,048.3	19.29	19.29	0.0
129,598.5	19.19	19.19	0.0
128,597.7	19.02	19.02	0.0
127,887.8	18.94	18.94	0.0
126,833.8	18.67	18.67	0.0

River Station	Existing Conditions WSEL (ft.)	Proposed Conditions WSEL (ft.)	Δ WSEL (ft.)
120,463.4	17.43	17.43	0.0
116,704.6	16.89	16.89	0.0
113,664.9	16.39	16.39	0.0
102,513.1	14.56	14.56	0.0
96,764.3	13.68	13.68	0.0
91,471.6	12.88	12.88	0.0
87,845.2	12.01	12.01	0.0
84,697.1	11.33	11.33	0.0
82,907.9	10.95	10.95	0.0
82,530.3	10.77	10.77	0.0
80,892.7	10.59	10.59	0.0
77,862.2	10.26	10.26	0.0
75,118.0	10.02	10.02	0.0
72,649.6	9.71	9.71	0.0
68,849.0	9.24	9.24	0.0
66,026.0	8.93	8.93	0.0
62,557.0	8.66	8.66	0.0
58,377.0	8.33	8.33	0.0
55,599.0	8.06	8.06	0.0
53,486.0	7.83	7.83	0.0
51,424.0	7.62	7.62	0.0
48,402.0	7.09	7.09	0.0
45,585.0	6.66	6.66	0.0
41,087.0	6.01	6.01	0.0
37,527.0	5.59	5.59	0.0
32,269.0	4.87	4.87	0.0
27,098.0	3.85	3.85	0.0
26,001.0	3.68	3.68	0.0
25,641.0	3.65	3.65	0.0
25,070.0	3.64	3.64	0.0
23,412.0	3.42	3.42	0.0
20,788.0	3.09	3.09	0.0

River Station	Existing Conditions WSEL (ft.)	Proposed Conditions WSEL (ft.)	Δ WSEL (ft.)
18,177.0	2.65	2.65	0.0
15,562.0	2.02	2.02	0.0
14,131.0	1.61	1.61	0.0
12,687.0	1.11	1.11	0.0
9,604.0	0.51	0.51	0.0

Table 15: Comparison between Existing and Proposed Maximum Velocities

River Station	Existing Conditions Channel Velocity (ft/s)	Proposed Conditions Channel Velocity (ft/s)	Channel Velocity WSEL (ft/s)
308,583.50	4.11	4.11	0.00
305,771.60	7.02	7.02	0.00
305,615.20	7.36	7.36	0.00
302,875.80	4.07	4.07	0.00
297,558.30	4.09	4.09	0.00
294,819.10	3.61	3.61	0.00
291,502.80	4.97	4.97	0.00
288,627.00	4.38	4.38	0.00
281,134.80	4.68	4.68	0.00
276,583.30	4.95	4.95	0.00
275,349.90	5.29	5.29	0.00
273,833.20	4.32	4.32	0.00
271,317.60	4.56	4.56	0.00
268,824.90	4.17	4.17	0.00
266,784.90	4.71	4.71	0.00
257,935.30	4.11	4.11	0.00
255,458.20	3.95	3.95	0.00
253,920.70	4.1	4.1	0.00
248,467.60	3.16	3.16	0.00
247,254.60	2.4	2.4	0.00
246,307.50	3.7	3.7	0.00
245,582.10	3.71	3.71	0.00

River Station	Existing Conditions Channel Velocity (ft/s)	Proposed Conditions Channel Velocity (ft/s)	Channel Velocity WSEL (ft/s)
244,296.30	3.75	3.75	0.00
241,798.80	3.48	3.48	0.00
238,317.30	3.47	3.47	0.00
235,923.40	3.91	3.91	0.00
233,849.80	3.64	3.64	0.00
232,926.90	3.34	3.34	0.00
232,298.70	3.87	3.87	0.00
228,171.50	3.59	3.59	0.00
226,430.50	3.27	3.27	0.00
223,178.30	3.07	3.07	0.00
220,535.90	3.59	3.59	0.00
218,197.00	3.77	3.77	0.00
215,636.00	3.24	3.24	0.00
212,690.40	3.46	3.46	0.00
206,664.80	3.25	3.25	0.00
200,926.00	3.51	3.51	0.00
196,787.50	2.86	2.86	0.00
183,829.70	2.79	2.79	0.00
179,479.50	2.91	2.91	0.00
179,155.40	2.72	2.72	0.00
178,789.60	2.61	2.61	0.00
177,914.60	2.45	2.45	0.00
174,103.50	2.68	2.68	0.00
172,112.30	3	3	0.00
169,715.30	3.25	3.25	0.00
165,604.20	3.43	3.43	0.00
159,474.30	3.5	3.5	0.00
152,282.20	3.94	3.94	0.00
145,725.10	3.92	3.92	0.00
143,092.00	3.46	3.46	0.00
136,684.70	3.3	3.3	0.00
131,329.00	2.8	2.8	0.00

River Station	Existing Conditions Channel Velocity (ft/s)	Proposed Conditions Channel Velocity (ft/s)	Channel Velocity WSEL (ft/s)
130,048.30	3.33	3.33	0.00
129,598.50	3.38	3.38	0.00
128,597.70	3.27	3.27	0.00
127,887.80	2.86	2.86	0.00
126,833.80	3.68	3.68	0.00
120,463.40	3.24	3.24	0.00
116,704.60	2.85	2.85	0.00
113,664.90	2.94	2.94	0.00
102,513.10	2.37	2.37	0.00
96,764.34	2.47	2.47	0.00
91,471.59	3.13	3.13	0.00
87,845.22	3.53	3.53	0.00
84,697.10	2.81	2.81	0.00
82,907.93	2.93	2.93	0.00
82,530.34	3.31	3.31	0.00
80,892.66	3.67	3.67	0.00
72,649.60	3.39	3.39	0.00
68,849.01	4.39	4.39	0.00
66,026.00	3.72	3.72	0.00
62,557.00	3.42	3.42	0.00
58,377.00	3.53	3.53	0.00
55,599.00	3.9	3.9	0.00
53,486.00	3.94	3.94	0.00
51,424.00	3.61	3.61	0.00
48,402.00	4.62	4.62	0.00
45,585.00	3.79	3.79	0.00
41,087.00	3.52	3.52	0.00
37,527.00	2.96	2.96	0.00
32,269.00	3.61	3.61	0.00
27,098.00	4.56	4.56	0.00
26,001.00	4.25	4.25	0.00
25,641.00	4.00	4.00	0.00

River Station	Existing Conditions Channel Velocity (ft/s)	Proposed Conditions Channel Velocity (ft/s)	Channel Velocity WSEL (ft/s)
25,070.00	3.68	3.68	0.00
23,412.00	3.82	3.82	0.00
20,788.00	3.48	3.48	0.00
18,177.00	4.23	4.23	0.00
15,562.00	4.7	4.7	0.00
14,131.00	4.81	4.81	0.00
12,687.00	5.6	5.6	0.00
9,604.00	0.14	0.07	0.07

Table 16: Key Analysis Points for Results Reporting

Key Analysis Point	Location	HEC-RAS Cross-Section
1	Rosharon Gage	308,583.5
2	Upstream of State Road – 35, near West Columbia	179,155.4
3	Downstream of FM-521 (approximately 1,711 ft. upstream of Brazoria Reservoir Diversion [Inflow])	129,598.5
4	Brazoria Discharge upstream of FM-2004	82,907.9
5	Last RAS Cross Section (approximately 9,604 feet from the mouth of the Gulf of Mexico)	9,604.0

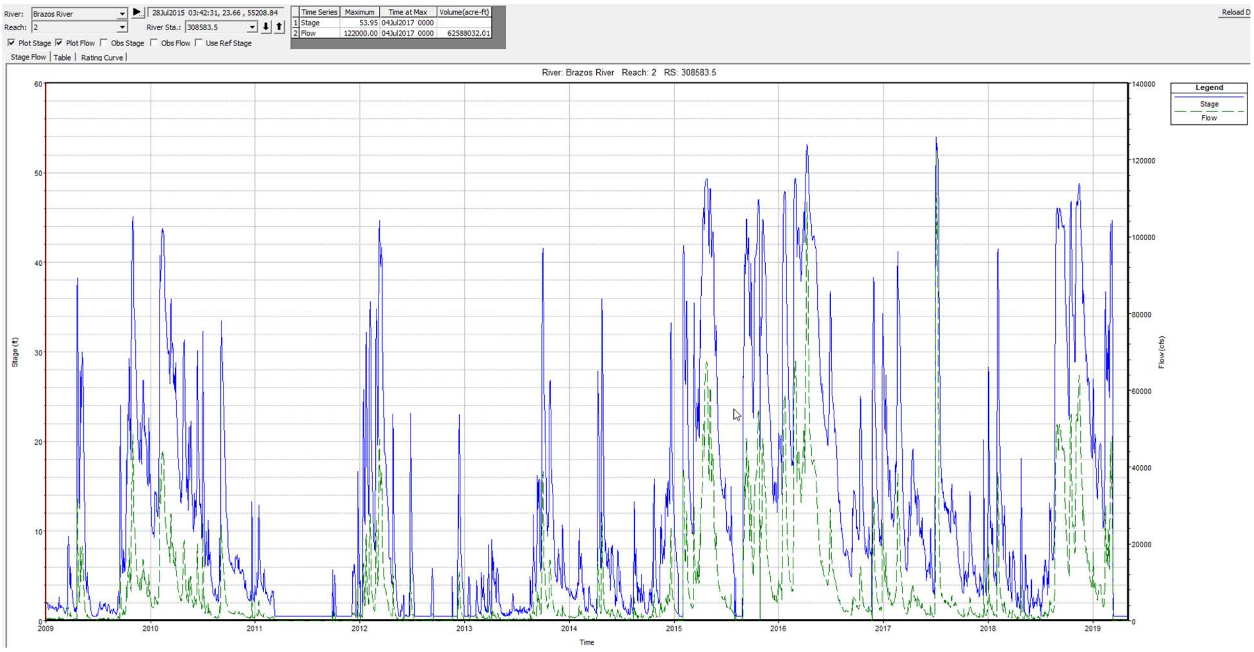


Figure 63 Proposed Stage and Flow Hydrographs at Rosharon Gage During 10-1/2 - Year Analysis Period

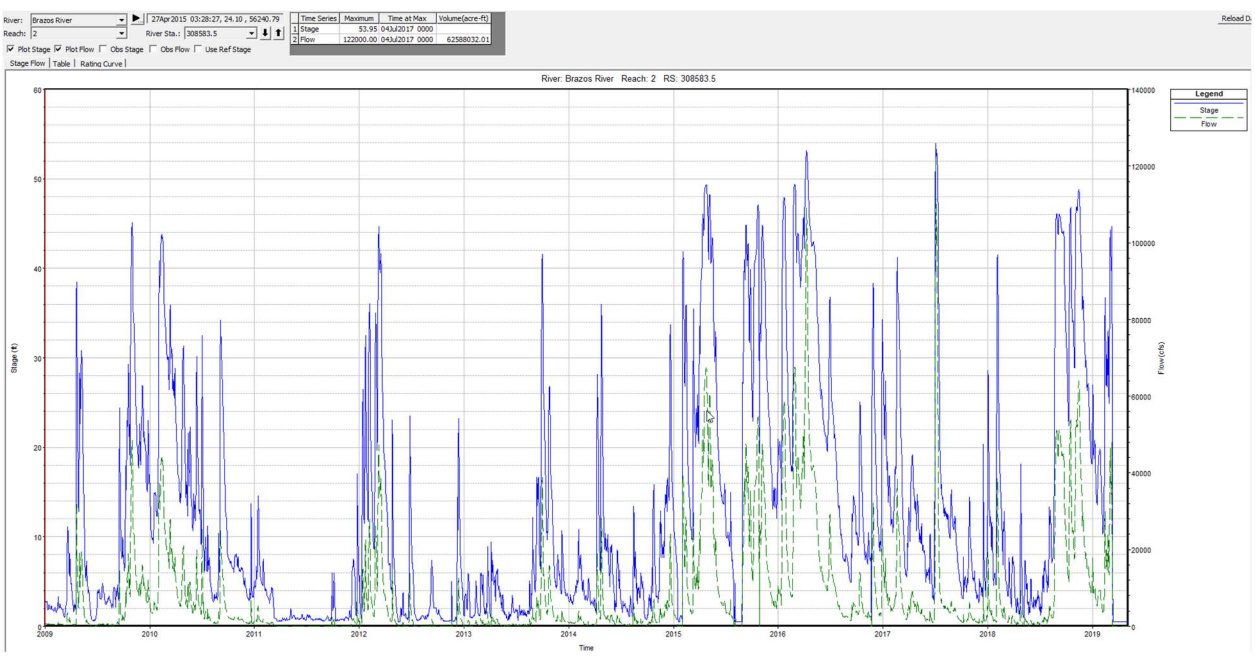


Figure 64 Existing Stage and Flow Hydrographs at Rosharon Gage During 10-1/2 - Year Analysis Period

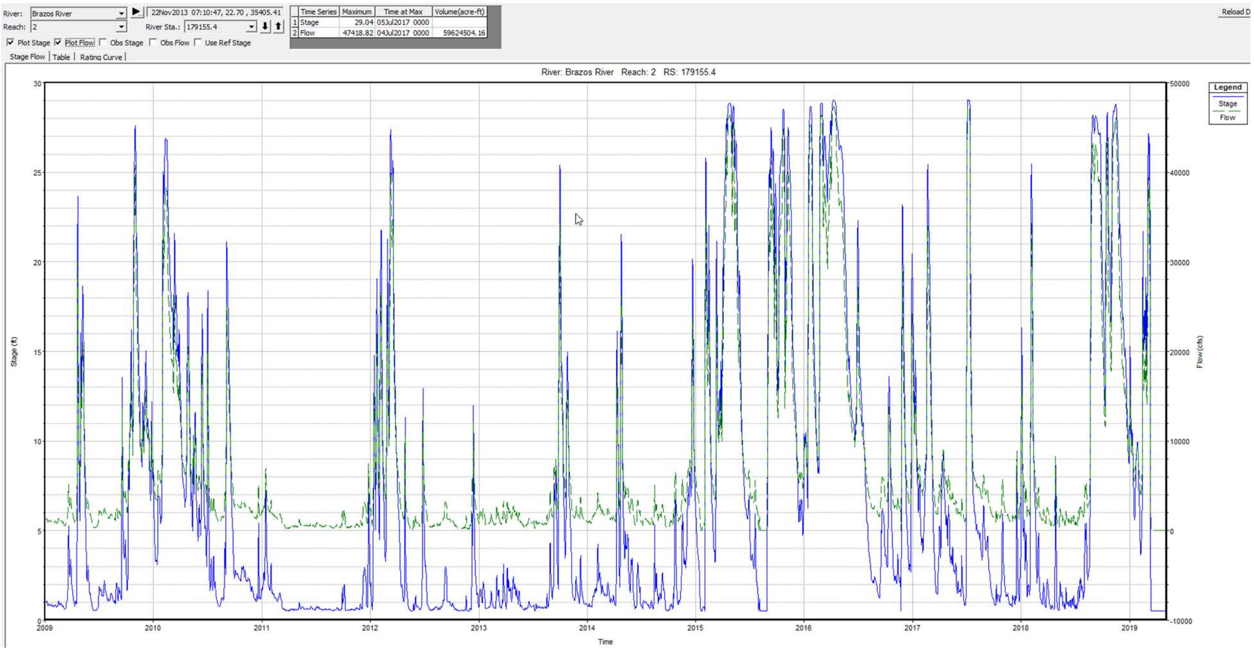


Figure 65: Proposed Stage and Flow Hydrographs upstream of State Road – 35, near West Columbia During 10-1/2 - Year Analysis Period

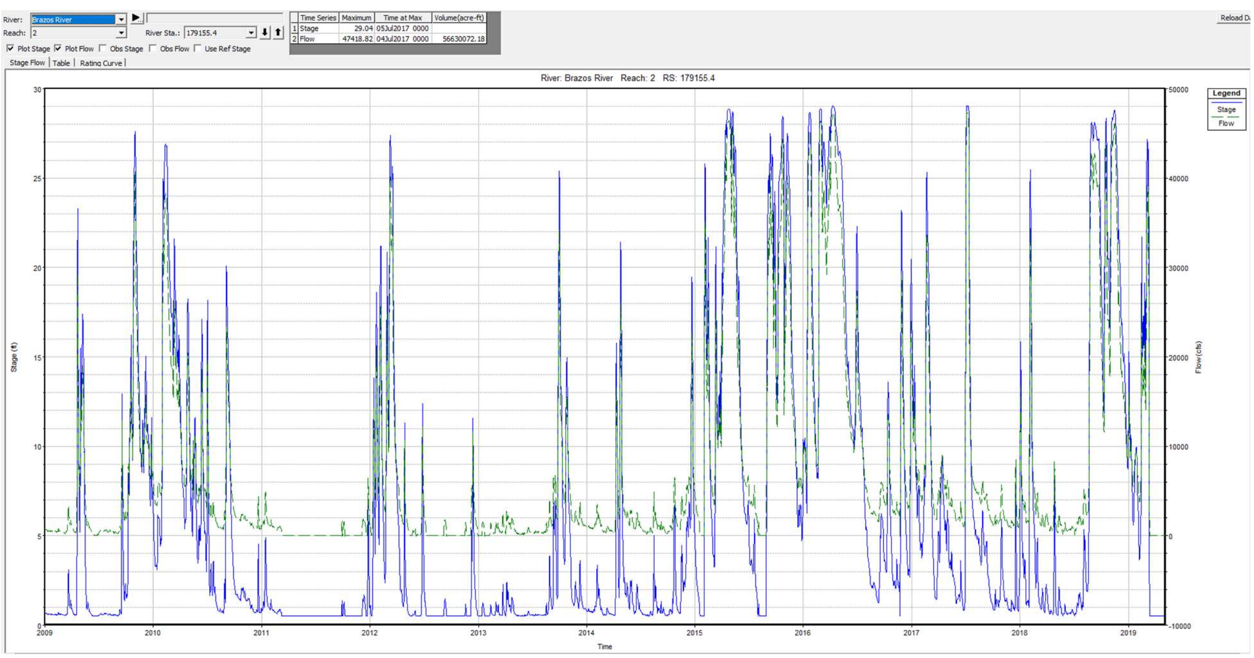


Figure 66: Existing Stage and Flow Hydrographs upstream of State Road – 35, near West Columbia During 10-1/2 - Year Analysis Period

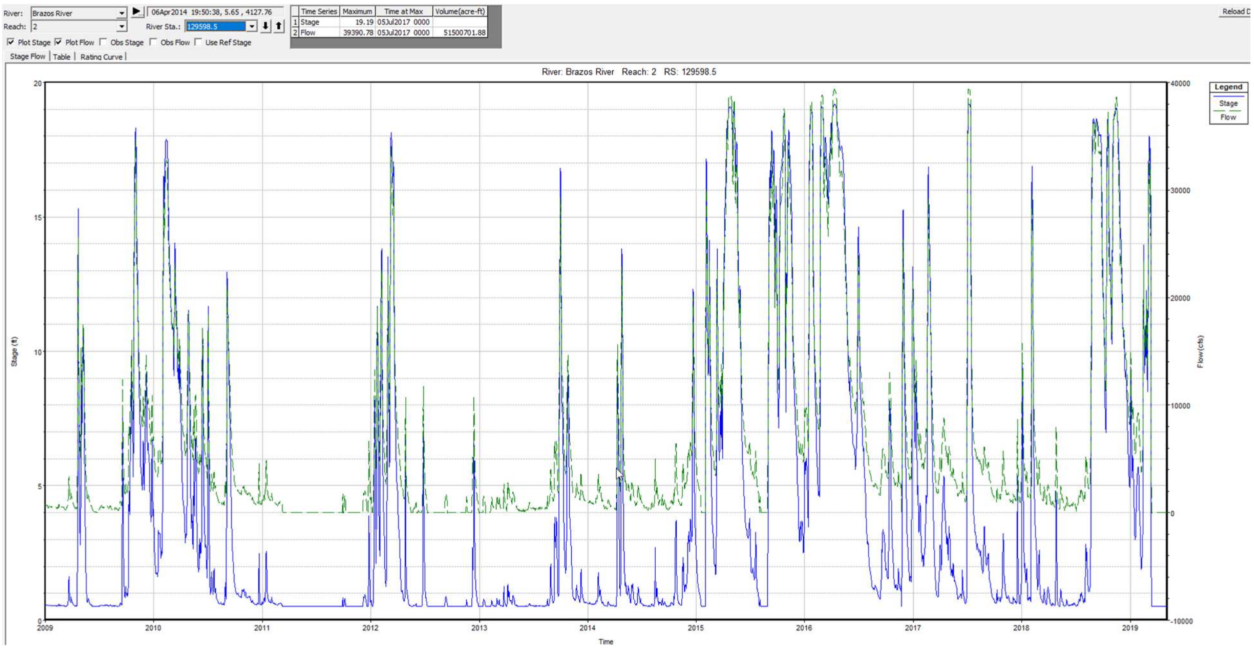


Figure 67 Proposed Stage and Flow Hydrographs Downstream of FM-521, During 10-1/2 - Year Analysis Period

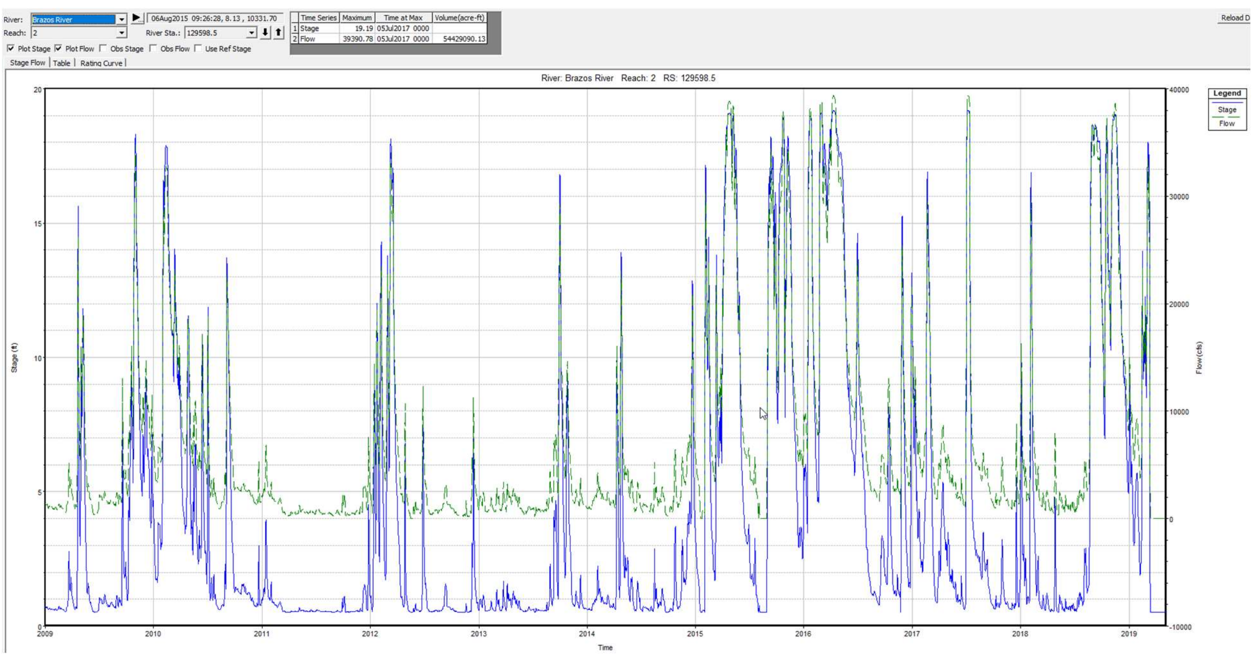


Figure 68: Existing Stage and Flow Hydrographs Downstream of FM-521, During 10-1/2 - Year Analysis Period

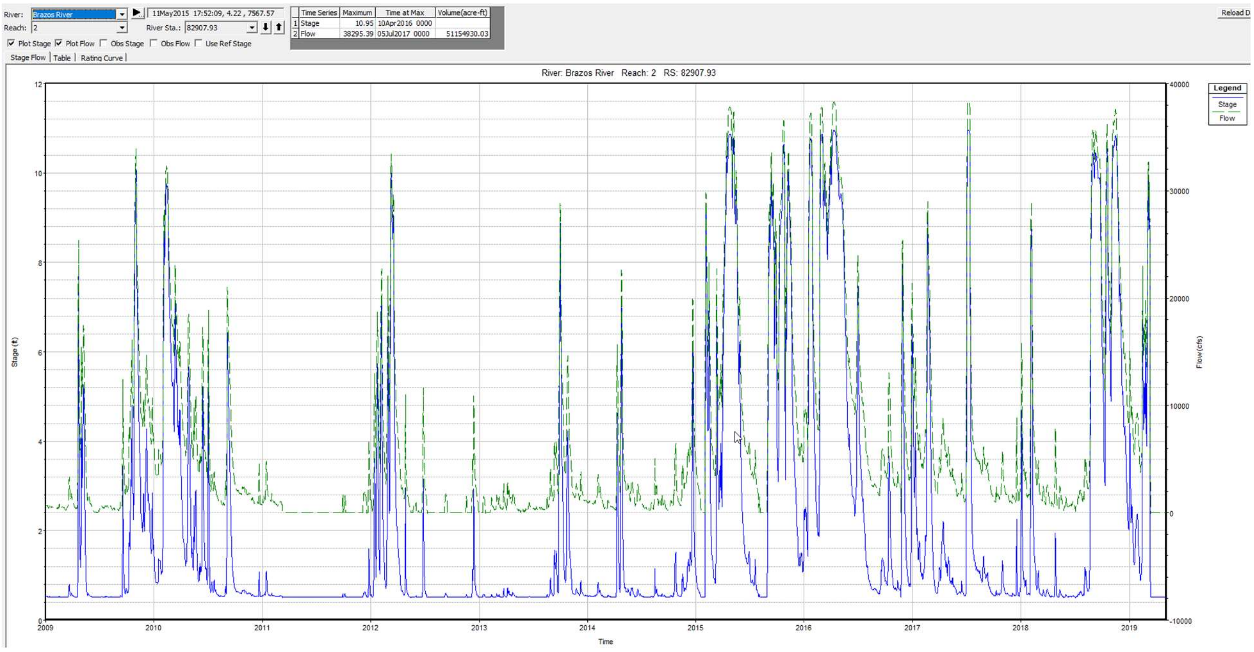


Figure 69: Proposed Stage and Flow Hydrographs Upstream of FM-2004, During 10-1/2 - Year Analysis Period

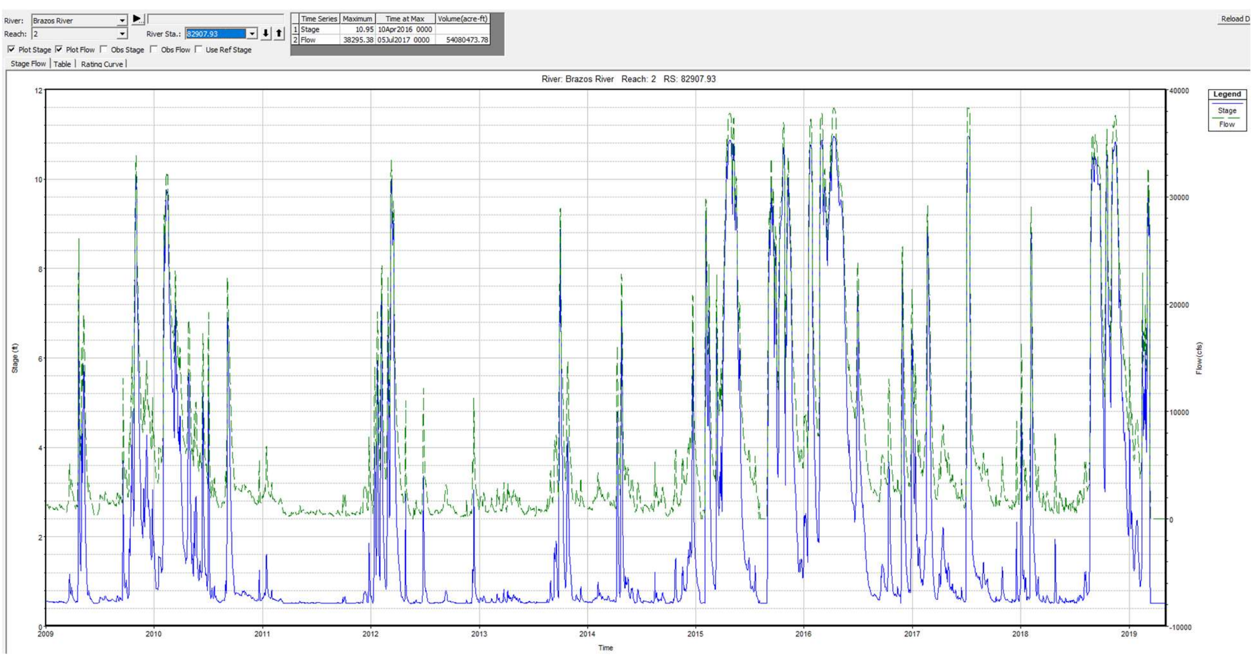


Figure 70: Existing Stage and Flow Hydrographs Upstream of FM-2004, During 10-1/2 - Year Analysis Period

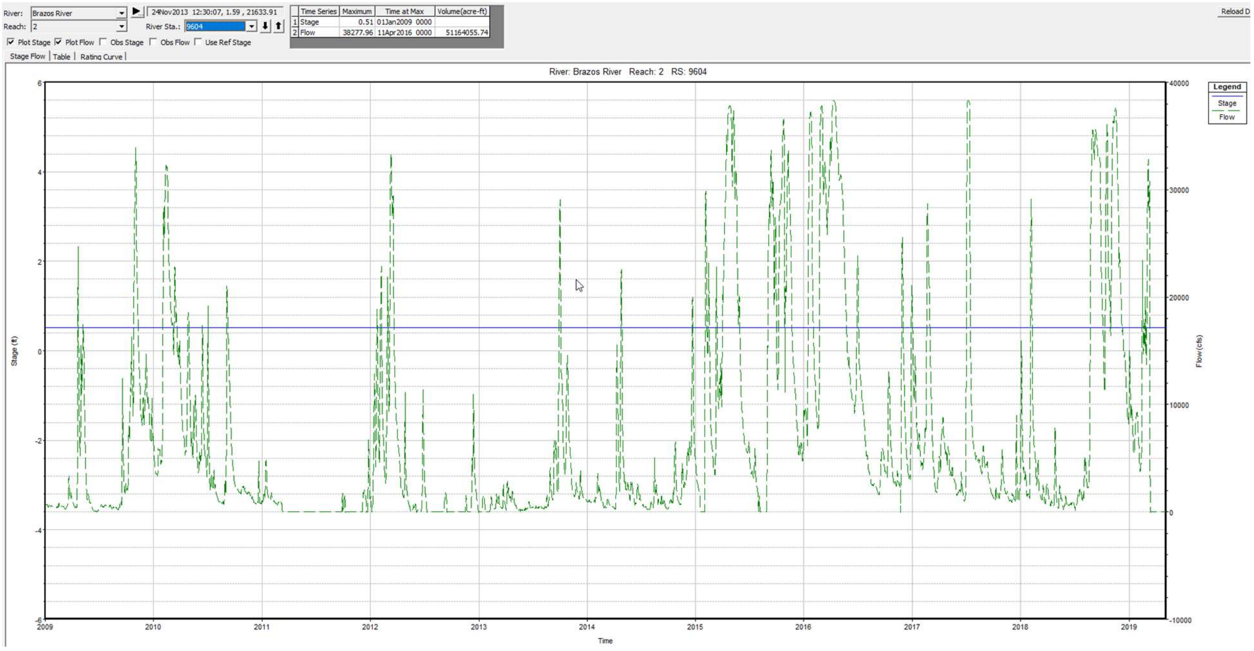


Figure 71: Proposed Stage and Flow Hydrographs at the Last RAS Cross Section approximately 9,604 ft. from the Gulf of Mexico, During 10-1/2 - Year Analysis Period

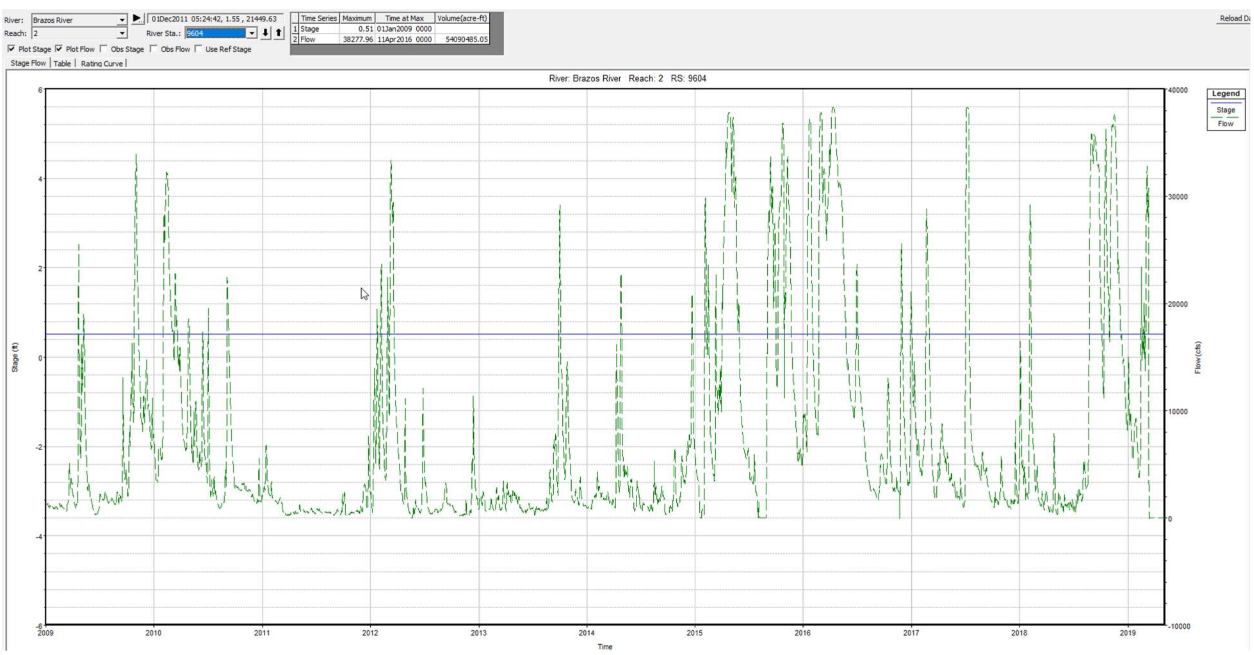


Figure 72: Existing Stage and Flow Hydrographs at the Last RAS Cross Section approximately 9,604 ft. from the Gulf of Mexico, During 10-1/2 - Year Analysis Period

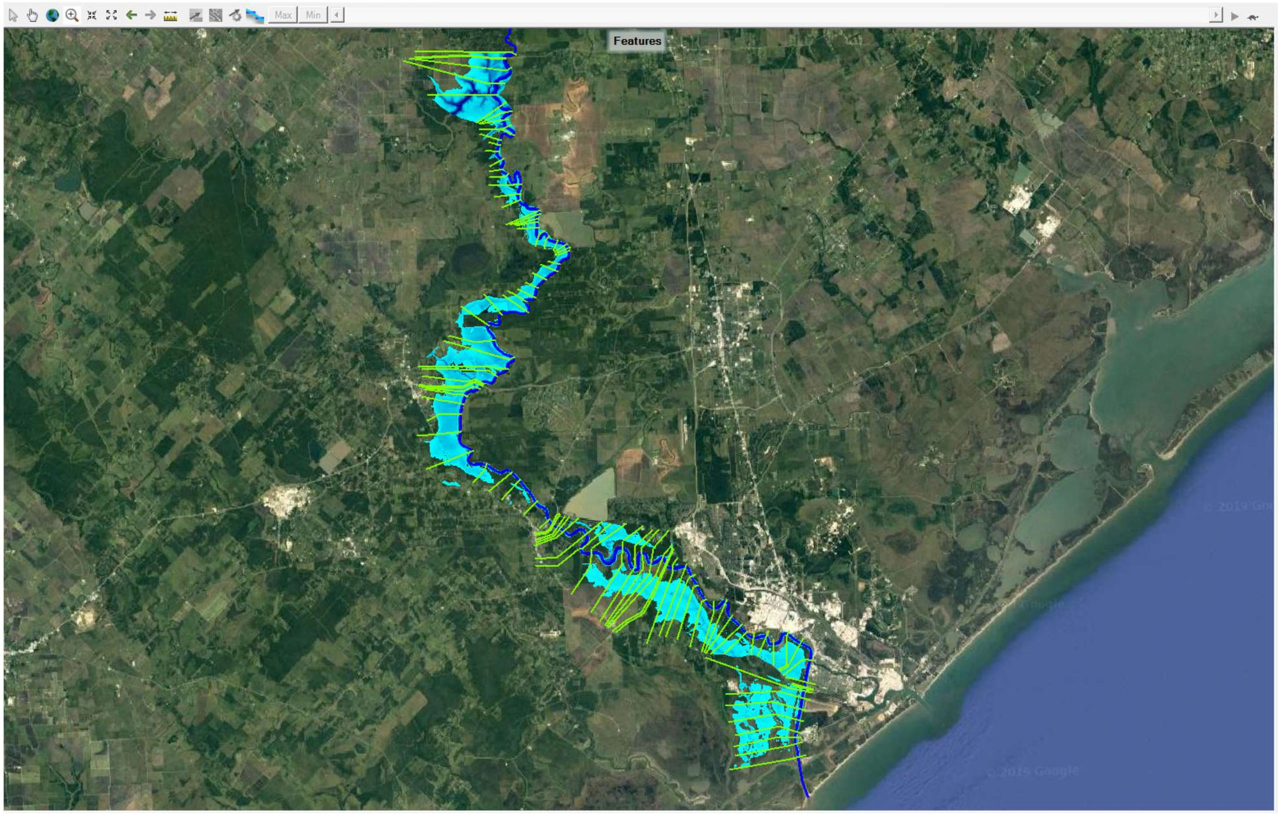


Figure 73: Maximum Flood Inundation Results of Proposed Conditions during the 10-1/2 Year Analysis Period

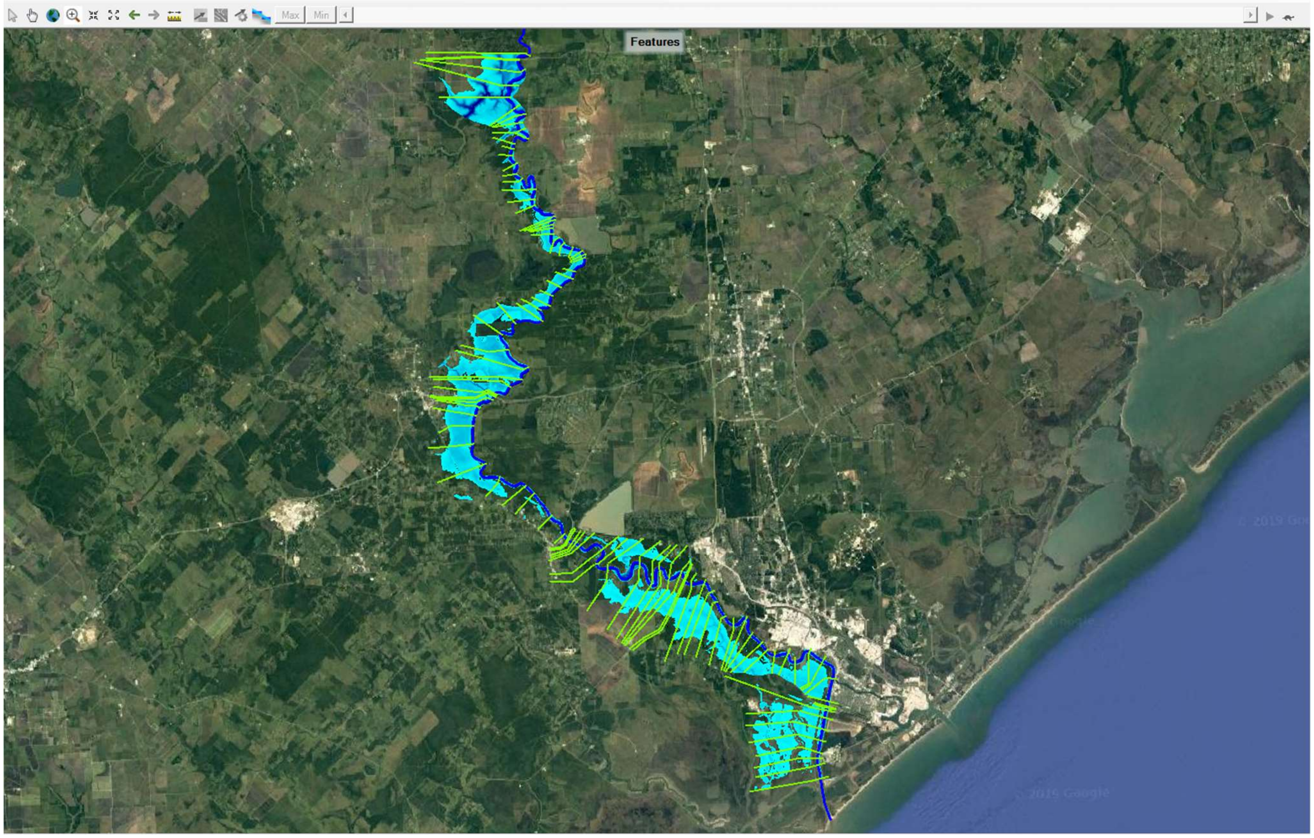


Figure 74: Maximum Flood Inundation Results of Existing Conditions during the 10-1/2 Year Analysis Period

5.4.4 Oyster Creek Hydrology

As shown on Figure 75 depicts the Oyster Creek watershed, which is located directly adjacent to and east of the portion of the Brazos River watershed modeled in this study. Discharges from the Existing Harris Reservoir and Proposed Harris Reservoir Expansion enter Oyster Creek through a series of outfalls discussed further in Section 5.4.5. Discharges from both of these reservoirs enters Oyster Creek near the middle of the watershed or lower portion of the 133.3-square mile Middle Oyster Creek drainage area. The Oyster Creek watershed near the project vicinity is generally flat and undeveloped and similarly to the Brazos River significantly affected by tidal influence and backwater. While an upstream hydrologic model of Oyster Creek was available, hydrologic models of the Oyster Creek watershed were not available for the project study area due to the undeveloped condition of this portion of the watershed.

Figure 29 illustrates historical discharges from the Existing Harris Reservoir, which are expected to remain similar under proposed project conditions, future discharges from the Proposed Harris Reservoir expansion, and the combined total proposed discharges from the Existing Harris Reservoir and Proposed Harris Reservoir expansion. These discharges are based on results of the 10-1/2-year HEC-HMS analysis described in Section 5.4. As shown, total combined discharges into Oyster Creek are expected to increase from a typical range of 0 to 278 cfs under existing conditions to a range of 0 to 2,305 cfs under proposed conditions.

This level of increase in combined flows potentially could create hydromodification issues downstream along Oyster Creek. However, the proposed Oyster Creek bypass/outfall channel/stream restoration segment shown in yellow on Figure 22, will provide buffering storage and partially ameliorate the range of higher peak discharges and associated higher velocities into Oyster Creek associated with the Proposed Harris Reservoir expansion. Additionally, the upstream stream restoration for the portion of Oyster Creek receiving the Existing Harris Reservoir discharge provides additional flood plain storage as compared to existing conditions. The lower velocities and increased storage associated with the upstream stream restoration will further reduce peak flows and velocities downstream on Oyster Creek. Potential for erosion exists at the inlet into the bypass/outfall channel/stream restoration segment shown in yellow on Figure 22 and at the outlet from this segment back into Oyster Creek. Additional stream restoration downstream of the point of discharge into Oyster Creek may be needed for discharges in the range of assumed operational parameters.

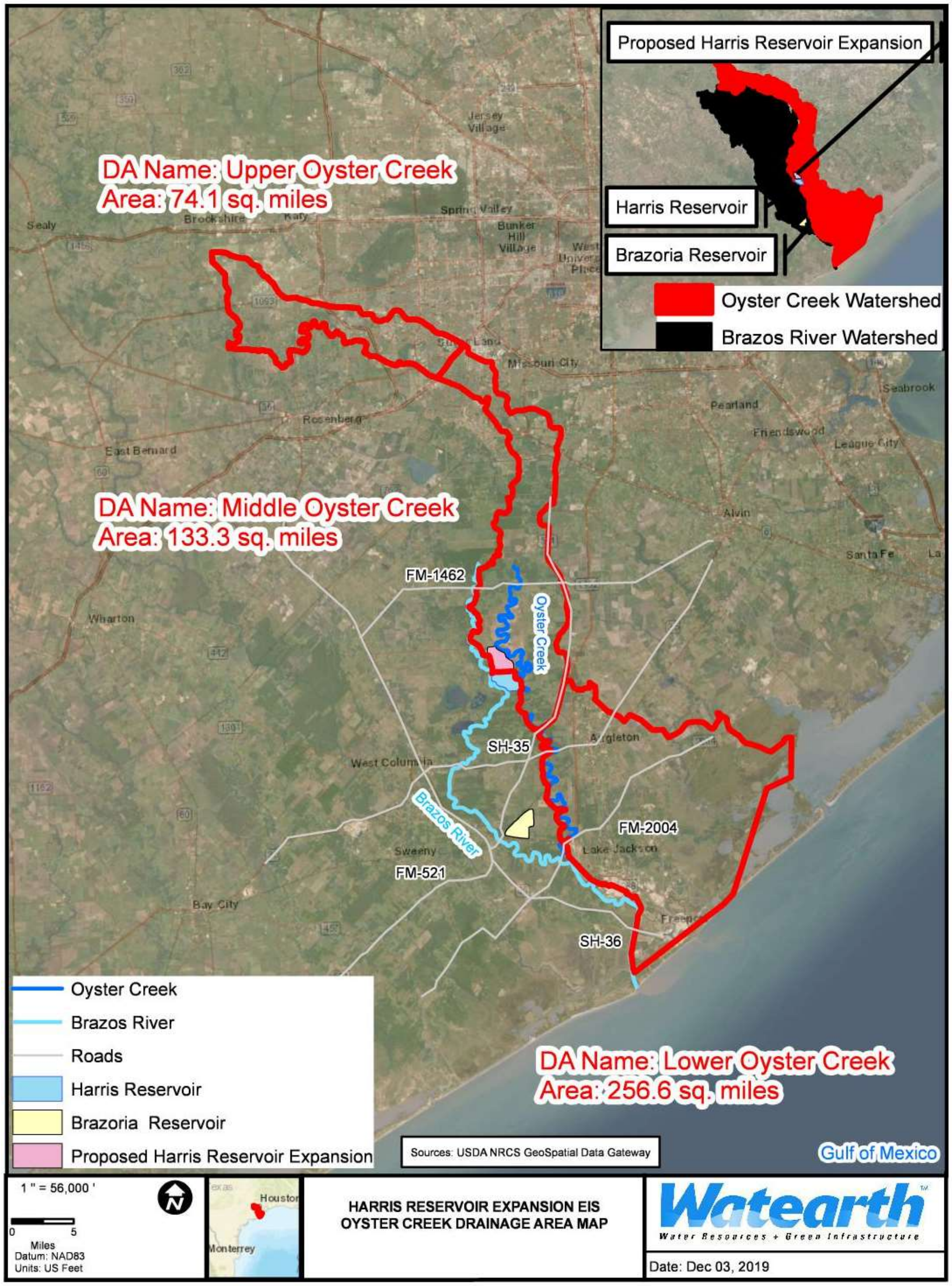


Figure 75 Oyster Creek Drainage Map for HEC-HMS

5.4.5 Oyster Creek Hydraulics

As part of the proposed expansion project, Oyster Creek is planned to be enhanced with three projects (Figure 76). These projects are planned to improve the flood capacity and provide restoration and enrichment to the riparian habitat along the three project lengths. Geomorphic design principles were utilized to provide a bankfull benching creating floodplain storage, riparian habitat, and channel conveyance to accommodate the proposed reservoir outlet flow in to Oyster Creek.

Project 1 is approximately 3,600 feet long from STA 5+00 to STA 41+00 on an unnamed tributary north of the proposed project's northeast corner. It flows into Oyster Creek a short distance north of the northeast corner which is the start of Project 2. Project 2 is approximately 12,860 feet long from STA 41+00 to STA 169+60 and is in the main channel of Oyster Creek. Project 3 is an improved flood overflow channel that flows along the east side of the proposed reservoir until the overflow channel intersects again at approximate STA 254+00 with the main Oyster Creek channel and the proposed reservoir outlet channel. Additional stream restoration downstream of the point of discharge into Oyster Creek may be needed for discharges in the range of assumed operational parameters.

The OCNoRiseUpdate20DEC2019 RAS Model provided by Dow and developed by Jacobs was executed without changes. The model contained two proposed scenarios, one scenario with the Proposed Harris Reservoir Expansion as a blocked obstruction (i.e., affecting conveyance and flood plain storage) and one scenario, which included stream restoration modifications and channel improvements. The corrected effective, the proposed and the proposed with stream restoration modifications conditions-RAS models results yielded the cumulative volume of water between the model cross sections or what is considered loss of flood plain storage between the corrected effective (pre-project, or existing) and proposed conditions. From evaluation of the HEC-RAS model output it was estimated that there is a loss of 316 ac-ft and 263 acre-ft. of floodplain storage for the Oyster Creek Floodplain for the proposed channel improvements and the proposed channel improvements with stream restoration, etc. The results from the HEC-RAS models are summarized below in Table 17. The largest reported loss in floodplain storage column is considered to be the loss of flood plain storage for the project.

Table 17: Comparison Between Change of Floodplain storage between Existing Conditions vs. Proposed Conditions and Existing Conditions vs. Proposed Conditions with Stream Restoration Modifications.

River Station	**Volume (acre/ft)** Existing Conditions	**Volume (acre/ft)** Proposed Conditions	**Volume (acre/ft)** Proposed Conditions + **Stream Restoration Modifications**	**Δ Floodplain Storage (acre/ft)** Existing Conditions vs. Proposed Conditions	**Δ Floodplain Storage (acre/ft)** Existing Conditions vs. Proposed Conditions + **Stream Restoration Modifications**
69.9	103,892	103,577	103,630	-315	-263
69.72	100,529	100,214	100,267	-315	-263
68.56	96,664	96,349	96,402	-315	-262
67.62	92,522	92,210	92,263	-312	-259

River Station	Volume (acre/ft) Existing Conditions	Volume (acre/ft) Proposed Conditions	Volume (acre/ft) Proposed Conditions + **Stream Restoration Modifications**	Δ Floodplain Storage (acre/ft) Existing Conditions vs. Proposed Conditions	Δ Floodplain Storage (acre/ft) Existing Conditions vs. Proposed Conditions + **Stream Restoration Modifications**
66.85	90,347	90,038	90,090	-309	-257
65.35	81,616	81,332	81,380	-284	-236
64.6	79,782	79,506	79,553	-276	-229
63.9	78,106	77,838	77,884	-268	-222
63.19	70,410	70,179	70,220	-231	-190
62.84	67,926	67,708	67,747	-218	-179
61.87	60,216	60,038	60,069	-178	-147
61.43	57,298	57,122	57,150	-176	-149
60.49	51,054	50,937	50,956	-117	-98
60.48	50,939	50,823	50,842	-116	-97
60.47	50,749	50,642	50,661	-107	-87
59.85	49,690	49,629	49,646	-61	-44
59.17	43,547	43,695	43,695	148	148
58.67	39,996	40,235	40,332	239	336
56.05	31,937	32,263	32,573	326	636
55.6	27,689	28,029	28,114	340	425
55.3	25,886	26,181	26,181	295	295
53.49	14,982	14,984	14,984	2	2
53.48	14,794	14,797	14,797	3	3
53.47	14,746	14,745	14,745	-1	-1
53.46	14,586	14,584	14,584	-2	-1
52.75	5,621	5,621	5,621	0	0
50.3					

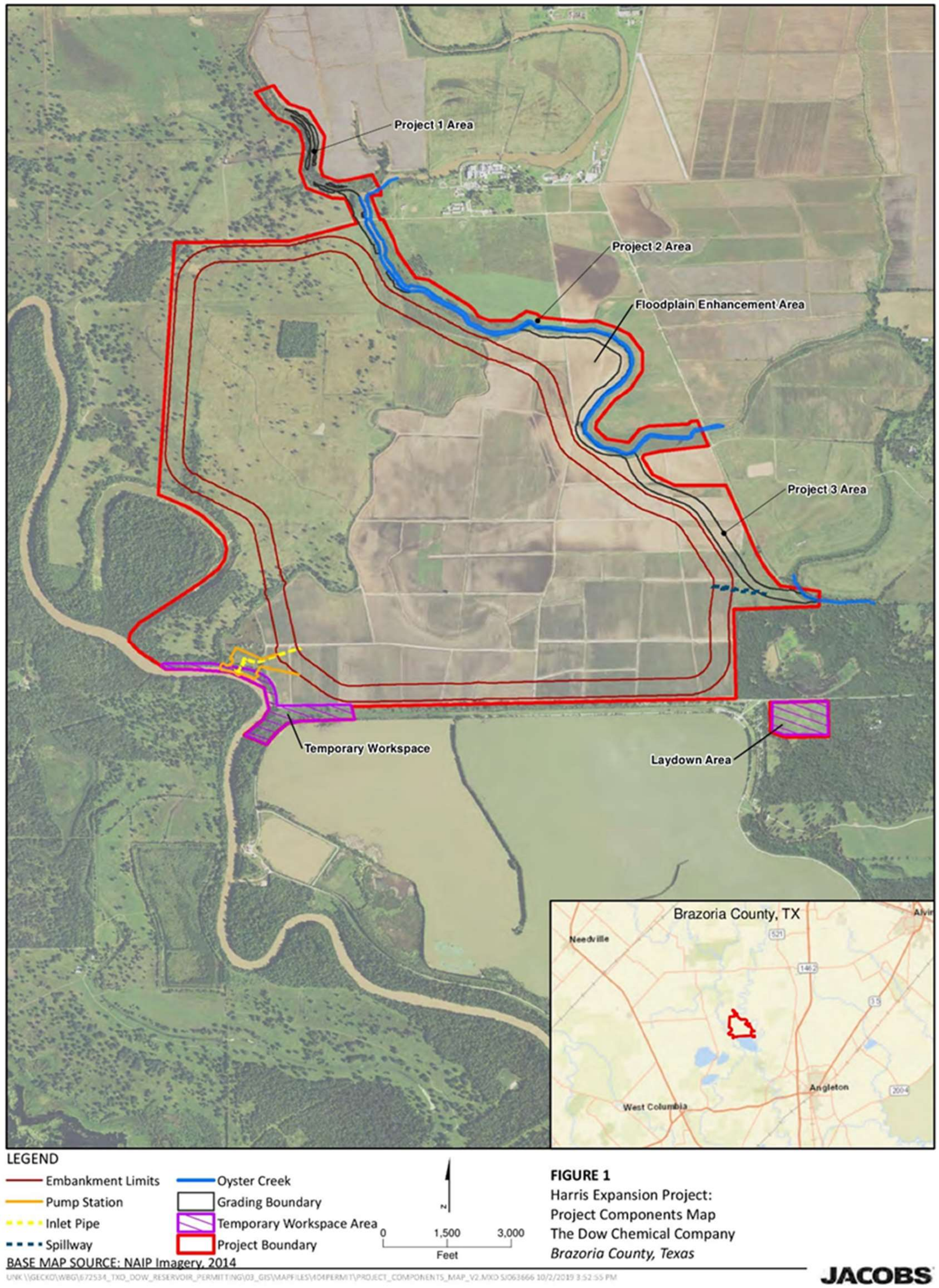


Figure 76 Oyster Creek Floodplain Enhancements

6 Analysis

This section is comprised of quantitative and qualitative analysis of the Proposed Project through the analysis horizon of 50 years (year 2072). The hydrologic, hydraulic, and reservoir operational models provide near term analysis of water supply needs and instream flow alternations. Analysis to long-term changes in the project vicinity to precipitation, temperature, and sea level rise are based on predictive models by agencies such as the USACE, NOAA, and USGS. The combination of these various analysis points is summarized in the Conclusions section below.

6.1 Evaporation Analysis

6.1.1 Introduction

The climatic process where moisture is removed from any water surface and transported as vapor away from the source by wind is called evaporation. Substantial amounts of water can be evaporated from lakes, reservoirs, rivers, streams, bayous, and canals. During wet periods when normal to above normal rainfall, climatic effects minimize evaporation. On the other hand, in dry periods evaporation rates are higher and the amount of evaporation loss becomes a very important item in a water supply analysis.

Evaporation rates in Texas vary during the year with approximately 86% of the evaporation occurring in the six-month period from May through October, which corresponds to lowest rainfall and full sun conditions (TWDB, 2018). Median gross evaporation for the project area is approximately 47.8 inches but can vary from 35 inches to 58 inches (Figure 78). The evaporation from the current and proposed storage reservoirs can present a substantial loss during a dry period.

6.1.2 Data Collection

The TWDB compiles water related data from a number of sources for water managers to estimate evaporation rates, one of the largest sources of water loss from Texas reservoirs (TWDB, 2018). The data in this set is from nearly 4,000 gauging stations and includes precipitation data primarily collected from NOAA's National Weather Service (NWS). In addition, TWDB collects data from pan evaporation sites throughout Texas and from surrounding states from the NOAA-NWS sites as well as other cooperators, which include lake owners and operators, government agencies, research institutions, and other public and private entities.

The Proposed Project generally falls within Quad 812 (Figure 77). Available data includes monthly precipitation from January 1940 through December 2018 and gross evaporation from January 1954 through December 2018 (Figure 78). The graph shows that the trend is towards higher evaporation and precipitation rates, however, the evaporation rate has a steeper trend line than precipitation, which indicates a potential for the evaporation rate to exceed the precipitation rate within the project horizon.

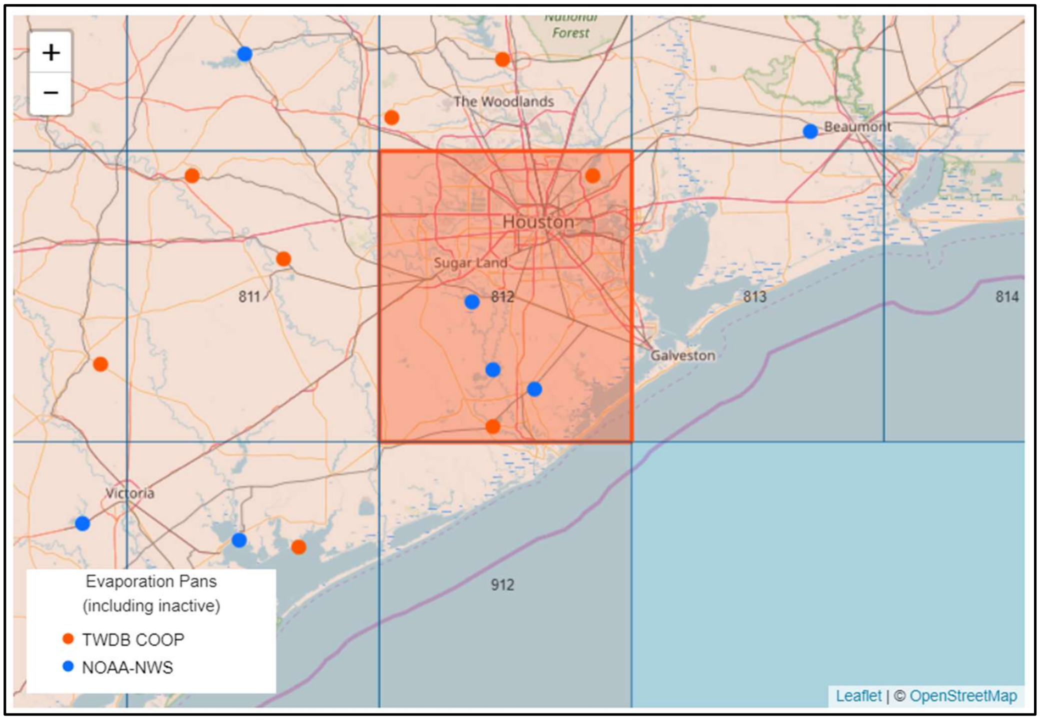


Figure 77: Quad 812 of the Texas Water Development Board Water Data

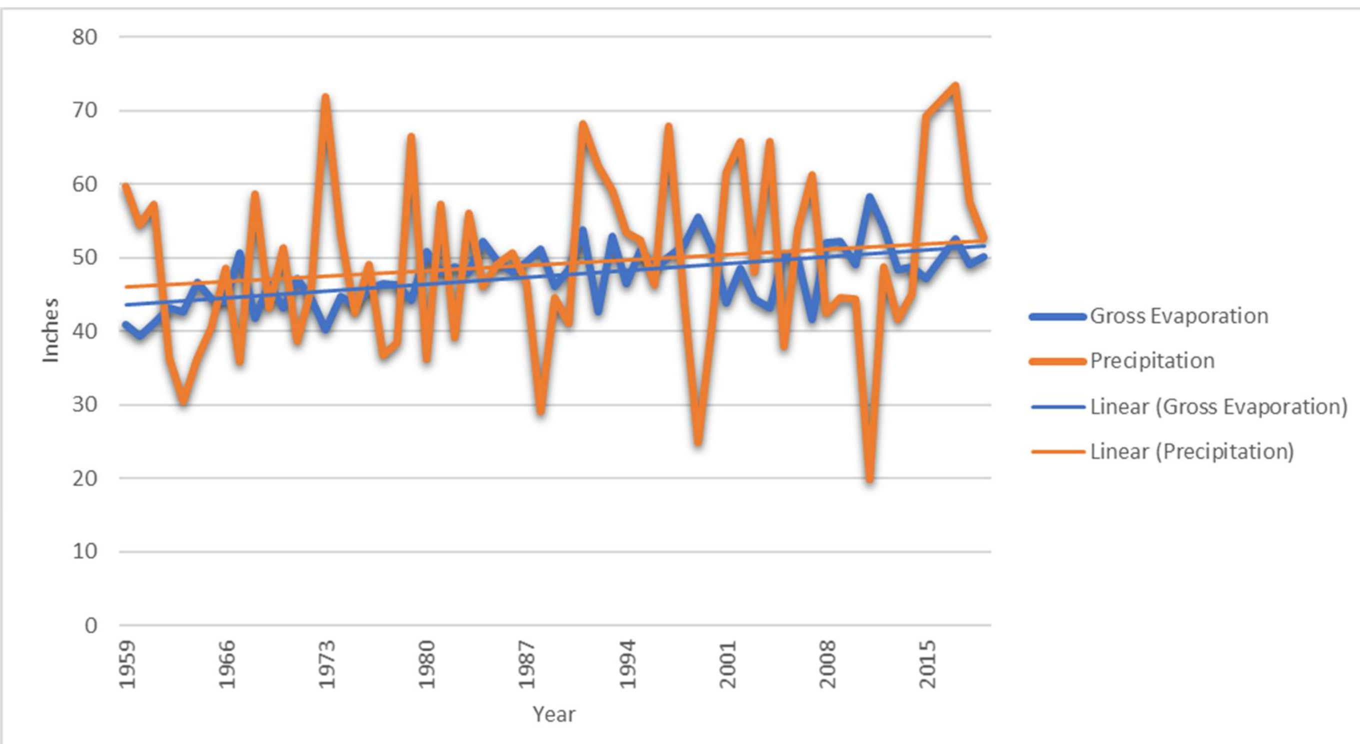


Figure 78: Quad 812 Gross Evaporation Versus Precipitation

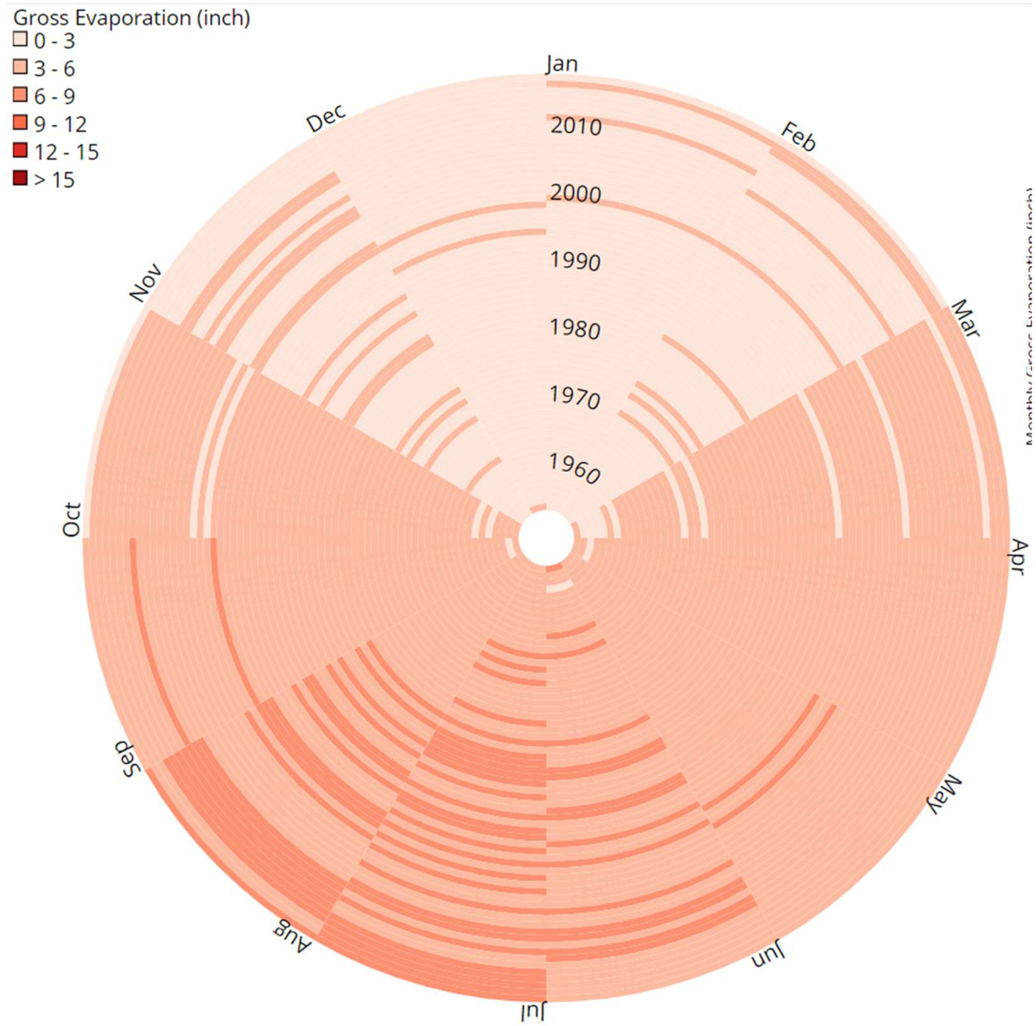


Figure 79: Annual Gross Evaporation Wheel

As shown in Figure 78, net evaporation (trend line) on average is slightly higher than annual precipitation (approximately 1.0 inches more evaporation than rainfall) (TWDB, 2018). In addition, the high variability from month to month and year to year makes long term planning more difficult. For example, the highest net evaporation occurred during August 2017, which corresponds with the majority of rainfall with Hurricane Harvey, when there was 33.5 inches of rain but only 5.3 inches of evaporation. In 1973, the yearly precipitation exceeded evaporation by 31.7 inches compared to in 2011 when there was a net evaporation of 38.4 inches. In 1973, the Freeport, Texas area experienced Tropical Storm Delia, which made landfall twice and dropped significant amounts of rainfall along the coastline during its erratic path in the Gulf of Mexico.

6.1.3 Analysis

Dow currently assumes an approximately 25-percent annual loss due to evaporation in the two-reservoir system. This may be underestimated as the current average annual rainfall for Freeport, TX is 52 inches; evaporation can vary from 35 inches to 58 inches, as described above. During wet conditions, precipitation and high humidity retard evaporation. During drought conditions evaporation rates increase and the lack of rainfall results in less natural make up water. Evaporation rates are a function of surface area versus depth/volume, which results in shallow reservoirs with large surface area being more susceptible to evaporation during drought periods than deep reservoirs with small surface area with the same volume of water.

Dow's existing two-reservoir system are typical of Gulf Coast reservoirs that are relatively shallow compared to surface area. Evaporation rates during normal weather patterns (average annual rainfall and median gross pond evaporation) are almost equal to rainfall rates so there would be negligible water loss during normal years. This is due in part to the natural refill by rainfall capture directly into the reservoir. The normal weather evaporation rate would balance with precipitation for the existing conditions and under the Proposed Project conditions.

Under drought conditions (lower than normal rainfall), the reservoirs would experience maximum evaporation and there would potentially not be makeup water depending on river conditions and precipitation within the watershed. Assuming half the normal precipitation and maximum evaporation, net evaporation (NE=E-R) would be approximately 31 inches. The existing and proposed reservoirs surface area being approximately 5,500 ac. That could result in over a 14,000 AF loss during the most critical periods.

Under wet weather conditions (higher than normal rainfall), the reservoirs would capture precipitation, experience reduced evaporation, and Dow would be able to refill the reservoirs from river pump stations. Capture would be limited to the total effective capacity of each of the reservoirs as well as considerations as discussed below such as sediment loads in the river and wind restrictions for embankment protections.

6.2 Hydromodification of Oyster Creek

Oyster Creek historically had a greater drainage area but 63-percent of the drainage area was diverted by a canal at the Sienna Plantation in Missouri City, Texas to the Brazos River (as measured at the downstream end of Project 2). The analysis of stream system is also limited by the fact that there is a lack of availability of existing hydraulic models for the project reaches but the Geomorphic Assessment approach using Rosgen Level I, II, and III stream assessment that was used to classify the stream is a proven process to establish a stable channel for the long term.

The proposed water storage/floodplain overflow feature near the end of Project 2 and the start of Project 3 is critical to the system. This allows large flows to bypass the oxbow in Oyster Creek and decreasing the velocities which could lead to increased erosion of the agricultural fields in the oxbow area. This and all the features must be maintained for the long-term viability of benefits created by the floodplain storage, riparian habitat and channel conveyance. A maintenance plan should be developed and implemented by Dow for the project reaches.

In coordination with SWCA, the following information and analysis is provided regarding geomorphic impacts of the reservoir operations on Oyster Creek from the Proposed Project (Forbes, 2020).

SWCA reviewed the referenced report with a focus on fluvial geomorphology and hydromodification. SWCA has concerns that the operational discharge from the new reservoir may have significant impacts to the stability and ecological integrity of the receiving and downstream reach of Oyster Creek. As stated in Section 5.4.4 of the Watearth report, "total combined discharges into Oyster Creek are expected to increase from a typical range of 0 to 278 cubic feet per second (cfs) under existing conditions to a range of 0 to 2,305 cfs under proposed conditions." According to Jacobs' Memorandum, the drainage area to Oyster Creek at the point of discharge from the proposed new reservoir expansion is 42.55 square miles (mi^2). According to the regional hydraulic geometry curves developed for the Texas Gulf Coastal Plains by the Harris County Flood Control District (AMEC, 2011), bankfull (channel-forming) discharge can be estimated from the drainage area using the following equation:

$$Q_{BKF} = 45.76 \times DA^{0.65}$$

where Q_{BKF} = bankfull discharge (cfs)

DA = drainage area (mi2)

A drainage area of 42.44 mi2 corresponds to a bankfull discharge of 524 cfs, which means that the maximum discharge from the reservoir would be approximately 4.4 times larger than the bankfull discharge. Sustained discharges to Oyster Creek at flows near or above than bankfull discharge are now known to increase the erosion of the receiving stream, as described below.

A study by (Bledsoe, 2002) suggests that sustained discharges from standard, peak-control (limiting discharge rates to pre-development peak flow – optimizes flood control) and erosion-control (much lower maximum detention discharges – supposedly optimizes erosion protection of downstream receiving streams) managed detention basins typically result in channel instability due to the an increase in frequency and duration of critical shear stress exceedance. Other studies examined the channel erosion from two-year (which is just slightly higher than bankfull discharge) control detention discharge management, which is the most common form of erosion-control detention discharge method currently in use (McCuen & Moglen, 1988; MacRae, 1993; MacRae, 1997). These studies similarly suggest that two-year control detention discharges does not reduce channel erosion and actually increases the amount of time the channel is exposed to erosive flows. The cause of this excessive channel erosion is described as follows: Two-year control often releases water above the critical discharge for effective work (Qcrt) for a longer period of time, which results in greater transport of sediment and bedload. MacRae also documented that two-year control causes channel expansion by as much as three times the predevelopment condition. In addition, many communities have provided anecdotal evidence that two-year control has failed to protect downstream channels from erosion. The primary reason is that while the magnitude of the peak discharge is unchanged from pre to post development under two-year control, the duration and frequency of erosive flows sharply increases. As a result, "effective work" on the channel is shifted to smaller runoff events that range from the half-year event up to the 1.5-year runoff event (MacRae, An alternative design approach for the control of stream erosion potential in urbanizing watersheds, 1993).

In conclusion, any traditional, sustained discharge from the proposed new reservoir will likely result in significant downstream erosion of Oyster Creek. SWCA recommends that a discharge operation plan be developed for the new reservoir that minimizes the potential for downstream erosion of Oyster Creek.

MacRae ((1993; 1997)) presented a promising framework for achieving receiving stream channel stability and water quality objectives in conjunction with reservoir discharge operations that might be appropriate for the proposed new reservoir. The framework, termed Distributed Runoff Control, includes designing detention discharge to emulate both the shape and magnitude of the pre-development hydrograph over a range of geomorphically important flows. It involves complex field assessments and modeling to determine the hydraulic stress and erosion potential of bank materials. The criteria states that channel erosion is minimized if the erosion potential of the channel boundary materials is maintained constant to predevelopment conditions over the range of available flows, such that the channel is just able to move the dominant particle size of the bedload. This Canadian method holds great promise but would require considerable field work at the site and it has yet to be tested on streams in the Texas Gulf Coastal region.

6.3 Sedimentation Analysis for Reservoirs, Brazos River, and Oyster Creek

6.3.1 Existing Reservoirs and Brazos River

Sediment loads and corresponding impacts on existing reservoir effective storage volumes is discussed in Section 3.5. Effective storage volumes for Harris and Brazoria Reservoirs is based on the Dow USACE application of 7,000 AF and 21,000 AF, respectively, for a combined existing effective water storage volume of 28,000 AF. This is at least a 4,000 AF loss of storage due to sedimentation during the nearly 60 years of operation of the two reservoirs. Based on a linear calculation of original design volume and surveyed volume in 1990, the effective combined existing storage could be as low as 18,250 AF. Dow reported periodic sediment removal by dewatering the existing Harris reservoir and removing sediment by a bulldozer however the frequency of past sediment removal and future maintenance at the two current reservoirs was not provided. They also reported in their reply to questions concerning the "Dow Water Rights and Supply – Fast Facts and Information" document that Dow has a permit authorizing dredging of solids from the reservoirs with specified, limited releases to the Brazos River under certain river flow conditions.

Dow also indicated they have concerns with embankment stability if dredging was performed. But there is a possibility to dredge these reservoirs back to their original authorized capacity with the modern equipment that could be used with global positioning systems (GPS) that would control location and depth of dredging. Dredging to original or deeper contours could increase available water but would not increase reservoir surface area where the evaporation occurs.

Without a more recent survey of the existing reservoirs, the actual effective storage volume could range from 18,000 AF to 28,000 AF, as described above for different sedimentation rate calculations. Due to the relatively high sands and fine sediment loads in the Brazos River, storage volume loss due to sedimentation for the Proposed Project as well as the existing reservoirs could be a significant issue during the 50-year planning horizon if not addressed by operation and maintenance plans and potentially results in less than the 180-day water storage volume which is the project purpose. Currently provided documentation does not indicate if there is an operational restriction on pumping high sediment load water from the Brazos River into any of the reservoirs and/or plans to remove accumulated sediments on a regular basis to maintain authorized reservoir volumes. A requirement to develop an O&M plan for these reservoirs could be a condition of the permit.

6.3.2 Proposed Project

The Proposed Project would be subject to the same sedimentation rates experienced by the existing Harris and Brazoria Reservoirs. Operational restrictions for pumping for high sediment load periods and regular removal of accumulated sediments on a regular basis are the most reasonable methods for maintaining authorized reservoir volumes. The O&M plan can be a condition of the permit.

6.3.3 Oyster Creek

Oyster Creek's natural flow has been significantly curtailed by a flood control project near Sienna Plantation, which has resulted in very low to no flow conditions throughout the project area. In addition, the channel is highly incised, which has disconnected the creek from it's floodplain and may at least be in part a result of the flood control project and farming practices creating hydromodification and erosion. Repeated wet and dry conditions are more likely to create a hydromodification condition due to breaking down the soil structure. The section of Oyster Creek between the proposed reservoir outfall through the overflow channel and the existing Harris Reservoir outfall are at highest near-term risk for hydromodification due to the current nearly dry conditions except during high rain events.

6.4 Watershed Vulnerability and Floodplain Storage

As addressed above in Section 3, previous floodplain impacts were addressed by analyzing water surface elevation (WSEL) changes in the Brazos River and Oyster Creek. While Dow found there was no rise in either system directly downstream of the proposed project, they did not address the loss of floodplain storage due to the 2,000-ac off-channel impoundment facility located between Brazos River and Oyster Creek and across the shared 100-year floodplain. It does not appear Dow previously completed calculations for floodplain storage loss for the reservoir and/or the channel revisions.

The proposed reservoir embankment will be built to elevation 72.88 ft. from the natural ground elevation of approximately 40 ft. The natural ground east of the Brazos River and west of Oyster Creek is relatively flat, so the water from high flows from either the Brazos River and Oyster Creek would have been able to flow across that area (shared 100-year floodplain) and be stored until the Brazos River or Oyster Creek receded to allow the flood plain storage to safely flow downstream.

Also, to be considered is the planned three phased Oyster Creek enhancement project to improve the flood capacity and provide restoration and enrichment to the riparian habitat. Although the enhancement is planned to revegetate and stabilize the main Oyster Creek channel as part of Phase 2, it will not totally make up the flood plain storage diminished by the proposed reservoir.

Phase 3 is an overflow channel that flows along the east side of the proposed reservoir which shortens the water flow path by cutting off an Oyster Creek main channel ox bow. The channel overflow weir is set at the 25-year discharge elevation. This will allow the higher peak discharges to flow into Phase 3, thus shorting the discharge travel distance (cutting off flow through the ox bow channel to the east) and timing of the water getting downstream.

6.4.1 Floodplain Storage Volume Loss Analysis

The volume of storage above natural ground eliminated by the originally proposed reservoir is 315 AF across the shared 100-year floodplain for both Brazos River and Oyster Creek. The revised proposed stream restoration and overflow channel results in 263 AF loss of floodplain storage across the shared 100-year floodplain. This loss of flood plain storage volume is due to volume taken up by reservoir and slight decreases in 100-year WSEL. This loss of flood plain storage volume could lead to increased peak flows downstream of the project. For purposes of this analysis, the revised proposed design is used with the 263 AF loss of floodplain storage.

The loss of this floodplain storage may or may not change the water elevations downstream of the reservoir (because of the relative flat floodplain) but will change the timing of that water arriving at downstream locations. Because the water cannot be stored in the proposed reservoir location, it will be forced to flow downstream arriving at the downstream locations earlier than it would have if the proposed reservoir had not been built. Additional analysis of the change in timing and impacts to Oyster Creek downstream of the proposed project are underway but not completed as part of this report.

6.5 Relative Sea Level Rise Analysis

An increase in the sea level water surface can have the same effect as the saltwater wedge moving upstream during a drought that is discussed in next section. As the sea level rises the river flow will have to be greater that the current 1,750 cfs now required to allow Dow to pump the fresh water from the river into Brazoria Reservoir at the maximum pump capacity. The sea level rise would also require a greater river flow than currently required at the existing Harris and proposed expansion. This could greatly limit the availability of Dow to get fresh water with their water rights.

6.6 Salinity Analysis

6.6.1 Introduction

Dow's Brazoria Reservoir intake pumps (river mile 25) cannot be operated when the water in Brazos River chloride concentration reaches or exceeds 500 mg/l. The interface between the fresh river water and the saltwater is referred to as the saltwater wedge and denotes the extent of the Brazos River estuary, which ranges from river mile 15 to 43 and potentially up to river mile 49 depending on river flow and tides. Dow reported efforts to correlate river flows at the USGS Rosharon gage with location of the salt wedge, which determines if withdrawals are restricted at the Brazoria Reservoir. They found that when river flows are greater than 1700 cfs at the USGS Rosharon gage, the salt wedge is downstream of the Brazoria Reservoirs pumps and there are no restrictions to filling the reservoir. River flow between 1700 cfs to 600 cfs at Rosharon gage may allow limited pumping at the Brazoria Reservoir intake. Below 600 cfs, the intakes cannot be used at all because of the saltwater wedge.

Dow's existing Harris Reservoir intake pumps (river mile 46) can be impacted by the salt wedge, which can extend up to river mile 49. Dow found they can operate the existing Harris Reservoir intake pumps at full capacity (approximately 290 cfs) as long as there is 400 cfs river flow at the Rosharon gage.

6.6.2 Saltwater Discharges

The inter-coastal barge canal crosses the Brazos River approximately 1.4 miles upstream of the current mouth of the River. The inter-coastal barge canal introduces saltwater into the Brazos River at that location.

Intermittent discharge of brine into the Brazos River from the Strategic Oil Reserve occurs at a location that is approximately 2.7 miles upstream of the mouth of the Brazos River.

Multiple discharges, containing elevated salts or seawater, are discharged to the Brazos River in an area are that is approximately 7 to 8 miles upstream of the mouth of the Brazos River. These discharge flows include:

- Discharge from the Dow Plant A storm water/wastewater canal at a location that is 7 miles upstream of the mouth of the Brazos River
- A Dow chemical discharge of approximately 40 MGD (61.7 cfs) of 7 to 8 % TDS wastewater at a location 8 miles upstream of the mouth of the Brazos River,
- Discharge of approximately 400,000 (888.9 cfs) to 500,000 (1,111.1 cfs) gpm of seawater used for one pass cooling at a location 8 miles upstream of the mouth of the Brazos River

Compared to the discharge of the Brazos River, 20,055 cfs as shown in Figure 6 and with tidal flows, the above process water discharges are unlikely to material impact the location of the salt wedge. The above volumes may contribute to increasing the localized salinity but not likely to materially impact the location of the salt wedge.

6.6.3 RSLR Salinity Analysis

The rising relative sea level is likely to result in long term viability of the Proposed Project due to low lying topography of the Gulf Coast. Due to variability of climate models, as shown in Figure 8 and Figure 9, the relative sea level is expected to rise from one to three feet over the next 50 years. With anticipated decreases in annual precipitation levels (Figure 4), although storm events are anticipated to be more frequent and higher intensity, natural stream flows could decrease and result in the regular position of the leading edge of the estuary being farther upstream compared to today.

6.7 Storm Surge Analysis

An increase in the local water surface and tide levels from tropical storms and hurricanes, referred to as storm surge, can have the same effect as the saltwater wedge moving upstream during a drought. Due to the estuary and associated salt wedge potentially reaching up to river mile 48, these storms could result in reduced water quality that exceeds the 500 mg/l of salts that Dow determined is in excess of the allowable for pumping into the plant near Freeport as well as pumping make up water into the existing Brazoria and Harris Reservoirs and the Proposed Project.

A recent example is during Hurricane Harvey the storm surge caused the water and tide levels over most of the Texas Coast to rise, with the highest storm tides observed at the Aransas National Wildlife Refuge where the storm surge levels were more than 12 feet above ground level. Storm surge in Port Lavaca was also more than 10 feet. Elsewhere across South Texas, storm tide levels ranged from near three to six feet above ground level at Seadrift, Port

O'Connor, Holiday Beach, Copano Bay, Port Aransas, and Bob Hall Pier (National Weather Service 2017).

Although storm surge may impede in Dow's ability to pump during the storm event, these storms are usually short in duration and Dow should be able to start utilizing their river water rights again as the storm surge recedes.

7 Conclusions

The purpose and need of the project is to provide 180 days of water storage for drought conditions as recommended by TCEQ for near term (assume 2022 for when Proposed Project reservoir could come online) and the long-term planning horizon (assumed to be 50 years, or year 2072). Dow currently needs 430 AF/day to meet their water supply needs, including the water supplied to others. Dow estimated the existing Harris and Brazoria Reservoirs as 28,000 AF. However, the estimate appears to be based on a survey conducted in 1990 and extrapolated with unknown assumptions. Dow reported that solids removal has occurred but the extent and frequency were unclear so under a worse-case scenario the existing reservoir capacity could be as low as 18,000 AF. When the proposed reservoir comes online in the near-term (e.g. 2022), the total storage capacity could meet the TCEQ recommendation for 180 days of storage is Dow's existing reservoirs do have a combined effective capacity of 28,000 AF per Dow's calculations.

Watearth has the following recommendations to confirm the project meets the Purpose and Need, as stated by Dow, for the near-term.

1. A survey of the existing reservoirs should be conducted to confirm capacity.
2. An Operation and Maintenance Plan should be required for the existing reservoirs, which have lost capacity due to sedimentation. The O&M Plan should require scheduled solids removal, which can be based on a number of different indicators such as a depth gage or probing.

Downstream of the Rosharon gage, no significant changes in flow are shown in the Brazos River despite assumed increased diversions at peak river flows/stages to maintain the additional storage associated with the Proposed Harris Reservoir Expansion.

These results and modeling assumptions show no significant changes to diversions into or discharges out of the Brazoria Reservoir into the Brazos River. Similarly, modeling assumptions and results show no significant changes to diversions into or discharges out of the Existing Harris Reservoir into Oyster Creek. The proposed diversion into the Proposed Harris Reservoir and associated discharge into Oyster Creek significantly increase peak flows out of the combined Harris Reservoir into Oyster Creek from an existing range of 0 to 278 cfs to a proposed range of 0 to 2,305 cfs.

Under the Proposed Project, Dow will conduct stream restoration of two segments upstream of the Proposed reservoir plus an overflow channel to receive the discharge. Watearth has the following recommendations.

1. Sustained discharge from the proposed new reservoir will likely result in significant downstream erosion of Oyster Creek. To address this, we recommend that a discharge operation plan (can be included in the overall O&M Plan) be developed for the new reservoir that minimizes the potential for downstream erosion of Oyster Creek.
2. Dow should note that FEMA may require a floodplain amendment due to the changes in the Oyster Creek and floodplain from the restoration project. This determination would be made by the local Flood Plain Administrator.

3. Erosion control is recommended at the inlet and outlet to the stream restoration section, especially for the Project 3 Overflow segment.
4. Additional stream restoration on Oyster Creek downstream of the point of discharge is recommended based on the assumed operational parameters of the Proposed Harris Reservoir Expansion.
5. Repeated filling and draining to create wet then dry conditions over the short term can result in hydromodification to the reservoirs and the receiving waters, which is specifically a concern for Oyster Creek due to the low natural flow. The repeated wet/dry conditions can break down the soil structure and lead to erosion. Oyster Creek between the Proposed Project discharge point and the existing Harris Reservoir discharge point are at highest near-term risk due to the changed conditions and regular inspection should be required along with a management plan to minimize erosion.

As mentioned above, Dow should consider additional water storage as the proposed project likely does not meet the 180-day storage recommendation by TCEQ.

1. This could include maintenance dredging to original or deepening the existing reservoirs, assuming dam safety concerns can be addressed.
2. Another option is to contract storage in an upstream reservoir.
3. Other water saving and conservation measures at the Dow plant could be considered, including water reuse through systems such as reverse osmosis. However, these systems tend to have a high energy requirement.

This analysis assumes 100,000 gpm discharge rates. If Dow does increase their discharge to 175,000 gpm, which is possible if Dow exercises their full water right, the water storage would be insufficient to meet the 180 days of water storage.

1. Of note is that the Proposed Project shifts the current discharge rate into Oyster Creek upstream of the adjacent existing Harris Reservoir. This is a minor change that did not result in a changed condition for Oyster Creek. However, nearly doubling the discharge could have an impact on Oyster Creek for both the existing Harris Reservoir as well as the Proposed Project. This would represent a significant increase in flows in Oyster Creek and the periodic nature could make Oyster Creek more susceptible to hydromodification and erosion.
2. A change in withdrawal rate from Brazos River to 175,000 gpm, expect possibly at the lowest of river flows during drought, would not be anticipated to cause a change to the river due to the large natural flows through the project vicinity.

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APPENDIX B

Brazos River Hydrology and Hydraulics Final Report

Note: The Section 508 amendment of the Rehabilitation Act of 1973 requires that the information in federal documents be accessible to individuals with disabilities. The U.S. Army Corps of Engineers (Corps) has made every effort to ensure that the information in this appendix is accessible. However, this appendix is not fully compliant with Section 508, and readers with disabilities are encouraged to contact Mr. Jayson Hudson at the Corps at (409) 766-3108 or at SWG201601027@usace.army.mil if they would like access to the information.

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Brazos River Hydrology and Hydraulics Final Report

DCC Harris Reservoir Expansion EIS

October 2021

Prepared for:

SWCA

ENVIRONMENTAL CONSULTANTS

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DRAFT MEMORANDUM RELEASED UNDER THE AUTHORITY OF **JENNIFER J. WALKER PE (85619), DWRE, CFM** ON 2021-10-08 AND SHOULD NOT BE USED FOR DESIGN OR CONSTRUCTION.

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ES-1.0 Executive Summary

The Dow Chemical Company (Dow) and Regional Water Planning Group identified at least as early as 2011 the need for Dow to undertake steps to ensure reliable water supply to their plant located in Freeport, Texas. For purposes of this analysis, the time horizon was at least 50 years into the future for resiliency and water supply needs. This Watearth report supersedes past reports, and details cited and referenced are the most recent information concerning the proposed Harris Reservoir expansion and the Brazos River. This report supplants all previous reports concerning the Brazos River.

ES-1.1 Project Summary

A full description of the project purpose is provided in the Dow Individual Permit application to the U.S. Army Corps of Engineers (USACE). Dow currently operates the existing Harris and Brazoria Reservoirs with a total effective storage of approximately 27,343 acre-feet (ac-ft), which is no more than 68 days of storage based on current water use. The Texas Commission on Environmental Quality (TCEQ) recommends water suppliers have at least 180 days of water storage or they are at risk of shortages during drought conditions.

Dow proposes to construct an approximate 50,968 ac-ft off-channel impoundment reservoir adjacent and upstream of the existing Harris Reservoir, referred to in the permit application as the Harris Reservoir expansion (proposed project). The proposed impoundment is located directly upstream and adjacent to the existing Harris Reservoir but will work independently. The proposed Harris Reservoir expansion would cover approximately 2,000 acres (ac). It includes a pumped intake station on the Brazos River and gravity outfall to Oyster Creek via a new bypass channel.

Dow proposes to operate the three reservoirs in a manner similar to current operations with the proposed project increasing available storage from 68 days to 180 days. During periods of drought, the proposed Harris Reservoir would be exhausted first, followed by the existing Harris Reservoir and then the Brazoria Reservoir. The decision for emergency releases due to severe weather, such as tropical storms and hurricanes with wind speeds that can overtop the embankments, would remain unchanged.

ES-1.2 Environmental Setting

The Brazos River is a major river system within Texas with headwaters located near Blackwater Draw, New Mexico, and its mouth near Freeport, Texas. The river is highly managed through a series of dams and off-channel storage reservoirs throughout its length. This is due to the high variability of flows as the primary water source is rainfall to store water for dry season use but also for flood control. The proposed project is located within segment 1201, which is tidally influenced.

The general climate for the project area includes high potential rainfall events from tropical storms and hurricanes with long periods of drought. Future rainfall is predicted to trend toward lower rainfall levels and higher temperatures. Sea level is expected to rise by 1 to 2 feet in the next 50 years, which will tend to push the estuary farther upstream (referred to as the salt wedge). Storm surge could reach farther upstream from current conditions. The historic sediment load of the Brazos River has decreased for particles larger than sand but has increased overall for sand and smaller size particles.

Harris Reservoir is located at River Mile 46 with an effective storage capacity of 9,136 ac-ft. Brazoria Reservoir is at River Mile 25 with an effective storage capacity of 18,207 ac-ft. The reservoirs provide potable water to the Dow chemical plant and other users. Dow has reported periodic but not regularly scheduled maintenance dredging on the existing reservoirs, which has resulted in loss of storage by up to half of the original design volume. During drought conditions, Dow estimates the two-reservoir system provides 68 days or less of necessary water supplies. TCEQ has determined that facilities with less than 180 days of water storage are at risk during droughts.

ES-1.3 Summary of Modeling and Analysis

Modeling included Hydrologic Engineering Center-Hydrologic Modeling System (HEC-HMS), RiverWare, and Hydraulic Engineering Center- River Analysis System (HEC-RAS). HEC-HMS provides hydrologic modeling, RiverWare provides reservoir operational modeling, and HEC-RAS provides hydraulic modeling. Using data provided by Dow and supplemented by various local, state, and federal data and reports, the modeling and analysis were focused on drought conditions during the life of the project. The assumed project life is 50 years for analysis purposes although the current Dow plant has been in operation for more than 60 years. The assumed project life is not an indication of maximal life for the project and only used for modeling purposes.

ES-1.4 Analysis of Potential Impacts

ES-1.4.1 Floodplain Storage Loss

The proposed project site is approximately 2,000 ac in the shared Brazos River and Oyster Creek 100-year floodplain. The loss of floodplain storage for the Brazos River is negligible under current development conditions. There would be a net loss of 1,028 ac-ft Oyster Creek floodplain storage when the proposed Harris Reservoir is constructed, as documented in the Jacobs HEC-RAS model dated May 27, 2020, between FM-1462 (cross-section 69.9) and Harris Reservoir Road (cross-section 50.3).

Dow presented modeling results that meet Federal Emergency Management Agency (FEMA) No Rise requirements, meaning that there will be no water surface elevation increases associated with the project. Nonetheless, there is a concern that loss of floodplain storage will cause flow, velocity, and water surface elevation increases downstream, particularly for a 100-year flood event (1.0% chance of occurring in any given year).

A more detailed analysis of the floodplain storage loss and effects are contained in the *Oyster Creek Downstream Hydrologic and Hydraulic Impacts Final Report (October 2021)*.

ES-1.4.2 Hydromodification of Oyster Creek

Hydromodification will occur on 21,300 feet (ft) of Oyster Creek (i.e., channel size increased) from 3,600 ft northeast of the proposed reservoir (Project 1) to the proposed reservoir outlet channel. Project 1 widens the existing unnamed tributary channel north of the confluence of Oyster Creek and FM 655. Project 2 starts immediately downstream of Project 1, 12,000 ft downstream from the confluence until the original channel flows east into an old oxbow before meeting the proposed reservoir outlet channel downstream. Project 3 is an overflow channel up to 15 ft deep with a 100-foot bottom width and 4H:1V side slopes starting downstream of Project 2, which is represented between cross-sections 56.05 and 55.3 in the HEC-RAS model. A complete description of the hydromodification of Oyster Creek is provided in section 5.2, Oyster Creek Enhancements.

The hydromodification of Oyster Creek does not alleviate the floodplain storage loss caused by the construction of the proposed Harris Reservoir embankment. Construction of the embankment west of Oyster Creek will block floodplain storage that was previously provided. The proposed Harris Reservoir will also block interbasin flows from entering Oyster Creek at current locations. These interbasin flows will be either transferred to Oyster Creek above the proposed reservoir or transferred downstream stream of the current entry location.

An aquatic assessment was completed on Oyster Creek to determine potential impacts on the biological resources of Oyster Creek. More details pertaining to these effects are found in the *Oyster Creek Downstream Hydrologic and Hydraulic Impacts Final Report (October 2021)*.

ES-1.5 Conclusions

ES-1.5.1 Near Term

Dow estimates that the current two-reservoir system can provide only 68days of water supply to Dow's Freeport plant and other users that Dow is under contract to supply with potable water. Based on TCEQ water storage recommendations, recent drought events, and loss of contract water availability, Dow estimates that it needs at least 180 days of storage to provide the necessary water to users during an extended drought.

The modeling and analysis support Dow's findings that the current two-reservoir system provides less than 68days of potable water to their Freeport plant and other water supply users. Due to sedimentation, the effective storage capacity of the existing reservoirs is 27,343 ac-ft based on a 2020 survey conducted by Doyle and Wachtsetter. This is slightly lower than the previous Dow estimate of 28,000 acre-ft. Modeling shows that the proposed Harris Reservoir expansion volume of 50,968 ac-ft, combined with existing reservoir effective storage of 27,343 ac-ft, will provide 180 days of storage at 78,311 ac-ft.

The proposed design meets current reservoir standards for dam safety, including wind and wave conditions, which are likely to increase due to more frequent and severe tropical storm events.

ES-1.5.2 Long-Term

Changes in rainfall patterns, anticipated increases to average air temperatures (resulting in increased evaporation), rising sea levels, and high fine sediment loads in the Brazos River are all considerations for a long-term outlook on the project. The existing reservoirs have been in operation for more than 50 years and have shown a nearly 30% loss in storage capacity due to sedimentation. Using a similar projection of approximately 50 years, sedimentation presents the highest risk for long-term viability of the 180 days of total combined water storage. This is further put at risk as Dow proposes to capture high flow events to refill the proposed and existing reservoirs as part of its normal operations. Without planned and regularly executed maintenance removal of solids from all three reservoirs, the proposed project purpose and need of 180 days of storage cannot be maintained and will fall below that level.

ES-1.5.3 Recommendations

1. Watearth recommends Dow proceeds with design and construction of the proposed Harris Reservoir to provide the required 180 days of water storage for drought conditions. An operation and maintenance (O&M) plan should be developed and implemented for the existing reservoirs and the proposed Harris Reservoir. The O&M Plan should require regularly scheduled solids removal based on radar surveys, depth gages, or probing.

2. Sustained discharge from the proposed Harris Reservoir will likely result in significant downstream erosion of Oyster Creek. To address this, we recommend that a discharge operation plan (can be included in the overall O&M plan) be developed for the new reservoir that minimizes the potential for downstream erosion of Oyster Creek.
    a. Dow should note that FEMA may require a floodplain amendment due to the changes in Oyster Creek and the floodplain from the restoration project. This determination would be made by the local Flood Plain Administrator.
    b. Erosion control is recommended at the inlet and outlet to the stream restoration section, especially for the Project 3 Overflow segment.
3. Repeated filling and draining to create wet, then dry conditions over the short term can result in hydromodification to the reservoirs and the receiving waters, which is specifically a concern for Oyster Creek due to the low natural flow. The repeated wet/dry conditions can break down the soil structure and lead to erosion. Oyster Creek between the proposed project discharge point and the existing Harris Reservoir discharge point are at highest near-term risk due to the changed conditions and regular inspection should be required along with a management plan to minimize erosion. The O&M plan that will be developed by Dow will address periodic inspections reservoir outlet work into Oyster Creek and the channel down to Lake Jackson.
4. Dow should consider additional water storage as the proposed project currently meets the 180-day storage recommendation by TCEQ but can incrementally lose storage over time due to sedimentation of the reservoirs.
    a. This could include maintenance dredging to the original or deepening the existing reservoirs, assuming dam safety concerns can be addressed.
    b. Another option is to contract storage in an upstream reservoir.
    c. Other water-saving and conservation measures at the Dow plant could be considered, including water reuse through systems such as reverse osmosis. However, these systems tend to have a high energy requirement.
5. If Dow discharges at 175,000 gpm, the equivalent of their full water right, the water storage would be insufficient to meet the 180 days of water storage.
    a. The proposed Harris Reservoir would shift the current discharge rate into Oyster Creek upstream of the adjacent existing Harris Reservoir. This is a minor change that did not result in a changed condition for Oyster Creek. However, nearly doubling the discharge could have an impact on Oyster Creek for both the existing Harris Reservoir and the proposed project. The impact of the proposed Harris Reservoir on Oyster Creek is analyzed in detail in the *Oyster Creek Downstream Hydrology and Hydraulic Impact Final Report (October 2021)*.
    b. A change in withdrawal rate from Brazos River to 175,000 gpm, except possibly at the lowest of river flows during drought, would not be anticipated to cause a change to the river due to the large natural flows through the project vicinity.

Table of Contents

List of Tables

List of Figures

Acronyms and Abbreviations

Acronym/Abbreviation	Full Form
ac	acre
ac-ft	acre-feet
AP	analysis point
BFE	Base Flood Elevation
BRA	Brazos River Authority
BWA	Brazosport Water Authority
cfs	cubic feet per second
DCC	Dow Chemical Company
Dow	Dow Chemical Company
EIS	environmental impact statement
FEMA	Federal Emergency Management Agency
FIS	Flood Insurance Study
FM	Farm to Market Road
FPP	Floodplain Protection Planning Study
ft	feet
gpm	gallons per minute
HEC-HMS	Hydraulic Engineering Center-Hydrologic Modeling System, USACE
HEC-RAS	Hydraulic Engineering Center-River Analysis System, USACE
HMG	Hydrologic Modeling Guidelines, USACE
hrs	hours

HUC	Hydrologic Unit Code
MGD	million gallons per day
mi²	miles squared
mph	miles per hour
MSL	mean sea level
NAVD88	North American Vertical Datum of 1988
NCDC	National Climatic Data Center, NOAA
NGVD29	National Geodetic Vertical Datum of 1929
NOAA	National Oceanic and Atmospheric Agency
NWS	National Weather Service, NOAA
O&M	Operations and maintenance
RiverWare	River and Reservoir Modeling Software, University of Colorado Boulder
sq-mi	square miles
SSC	suspended sediment concentration
TCEQ	Texas Commission on Environmental Quality
Tc	time of concentration
TWDB	Texas Water Development Board
TX	Texas
TxRR	Texas Rainfall-Runoff Model
USACE	U.S. Army Corps of Engineers
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey
WAM	Water Availability Model

HUC	Hydrologic Unit Code
WSEL	water surface elevation

Appendices

Appendix A – Brazos River HEC-HMS Model

1.0 Introduction

This report describes the hydrologic and hydraulic analysis conducted to inform the USACE determination if the proposed Dow Harris Reservoir Expansion project meets hydrology requirements in Section 404 of the Clean Water Act. The analysis followed the guidance provided in the USACE Hydrology Modeling Guidelines (HMG) for conducting the hydrologic and hydraulic modeling. The USACE developed HMG to assign project managers and applicants in determining how to address hydrology and specifically how to approach hydrologic modeling for primary and secondary effects.

The purpose of the proposed project is to expand Dow's water storage capacity at or near the existing Harris Reservoir to improve the long-term reliability of water supply during drought for the Texas Operations facilities in Freeport, Texas, as well as other industrial, community and potable water users that rely on Dow's water supply. It is also planned to allow more efficient use of Dow's existing Brazos River surface water rights.

Dow currently manages the Brazoria and Harris reservoirs for water supply and water quality (at the Dow intake for industrial water supply), which has a reported combined effective storage capacity of 27,343 ac-ft, providing approximately 63 days of stored water. The TCEQ recommendation for storage to meet drought preparedness and response standards is 180 days. This recommendation is based on the Texas Administrative Code Title 30, Part 1, Chapter 290, Subchapter D, Rule §290.41, which under b.1 states that retail public utilities should report when they have less than 180 days of water supply storage and therefore develop a drought contingency plan (State of Texas, Revised 2013).

The proposed Harris Reservoir will include a 2,000-ac off-channel impoundment facility that will increase Dow's storage capacity by 50,968 ac-ft. The facility will include an auxiliary spillway outlet from the reservoir and an intake and pump station to divert Brazos River water within Dow's existing water rights. The proposed project, in conjunction with the existing two reservoirs, will provide 78,311 ac-ft of effective capacity and have 180 days of water storage.

This report includes analysis of the impacts of proposed Harris Reservoir on the Brazos River. A thorough assessment of local hydrology, climate, existing site conditions, and hydrological and hydraulic modeling analysis are reported. An unsteady one-dimensional hydraulic model was used to determine if there is a floodplain storage loss, and a hydrologic model was used to determine if there is a change in peak flowrates in the Brazos River.

2.0 Environmental Setting

This section describes the general environmental conditions that define the setting of the proposed project. This includes the physical setting and other hazards that are considered when analyzing the proposed project.

2.1 Watershed

The proposed project is located along the Brazos River, one of the largest watersheds by area in Texas (

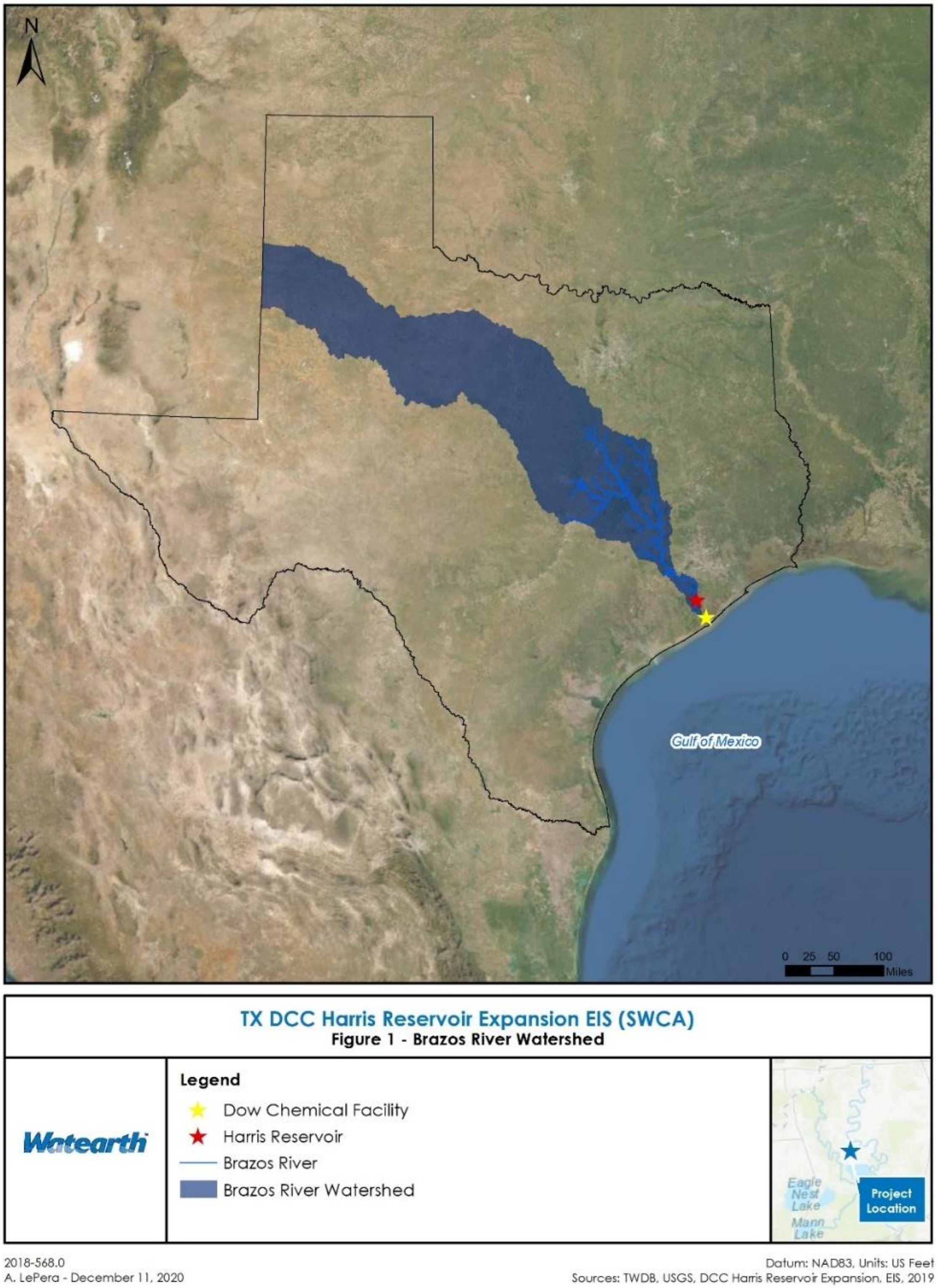


Figure 1 - Brazos River Watershed

Figure 1) (TWDB, 2019). The watershed generally runs northwest to southeast with the headwaters in New Mexico and discharges to the Gulf of Mexico near Freeport, Texas. The Brazos River has the largest average annual flow of any river in the state.

The Brazos River flow is primarily supplied through precipitation with many creeks and streams along the main stem. The upper basin was historically underutilized for withdrawals for irrigation, livestock water, and other agricultural purposes until recently with the decline in groundwater supplies, in particular the overuse of the Ogallala Aquifer (TWDB, 2019). This has led to decreasing supplies farther downstream in the more populated areas of the basin, especially during low rainfall and drought years.

The Brazos River is a highly managed and regulated river system with three Brazos River Authority (BRA) reservoirs, eight USACE flood control dams, and numerous other large-to-small impoundments (**Figure 2**). There are over 1,200 adjudicated water rights in the Lower Brazos River alone. In addition, Dow is also a potable water supplier for industries and municipal users near its plant in Freeport, Texas.

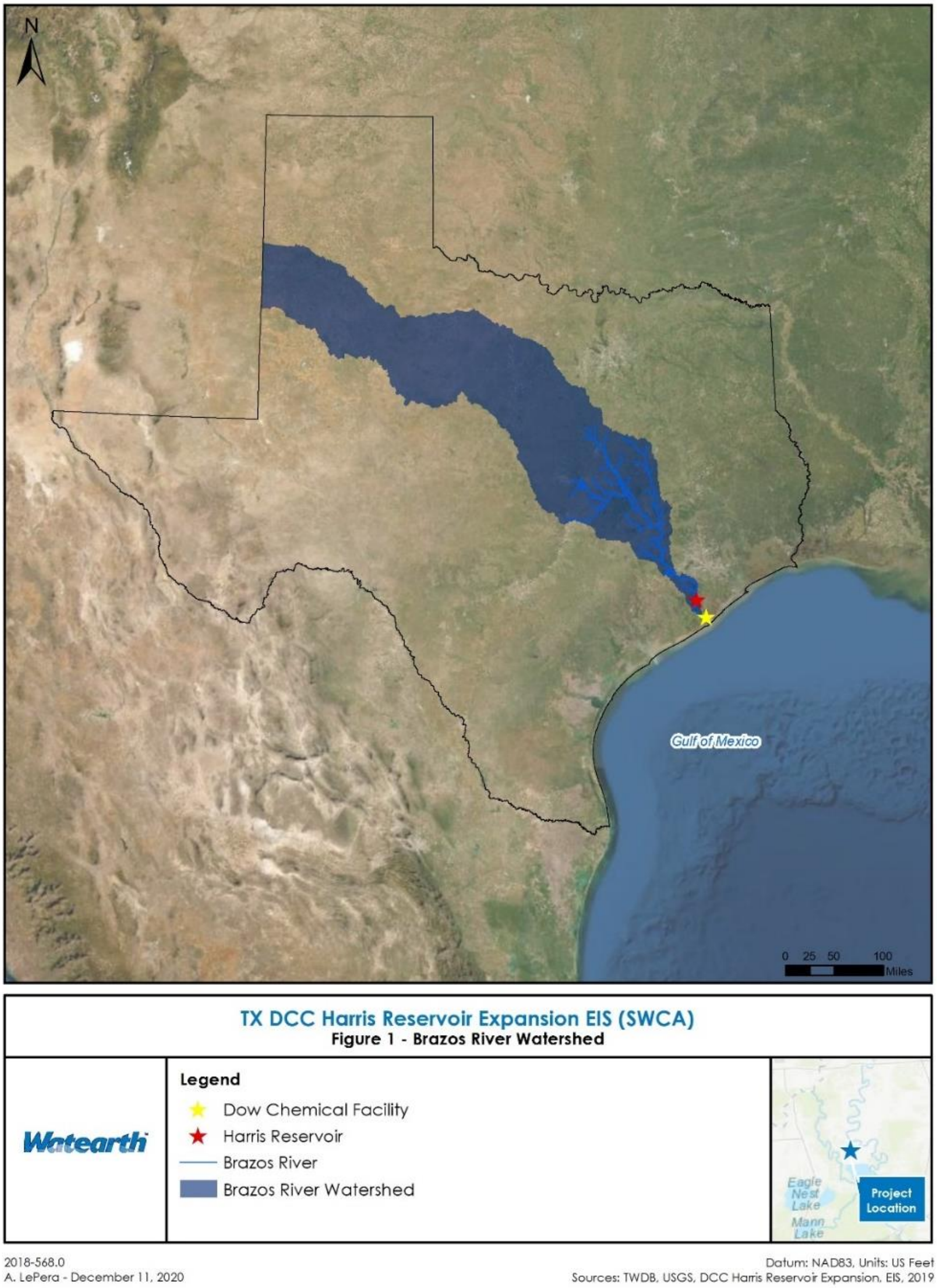


Figure 1: *Brazos River watershed.*

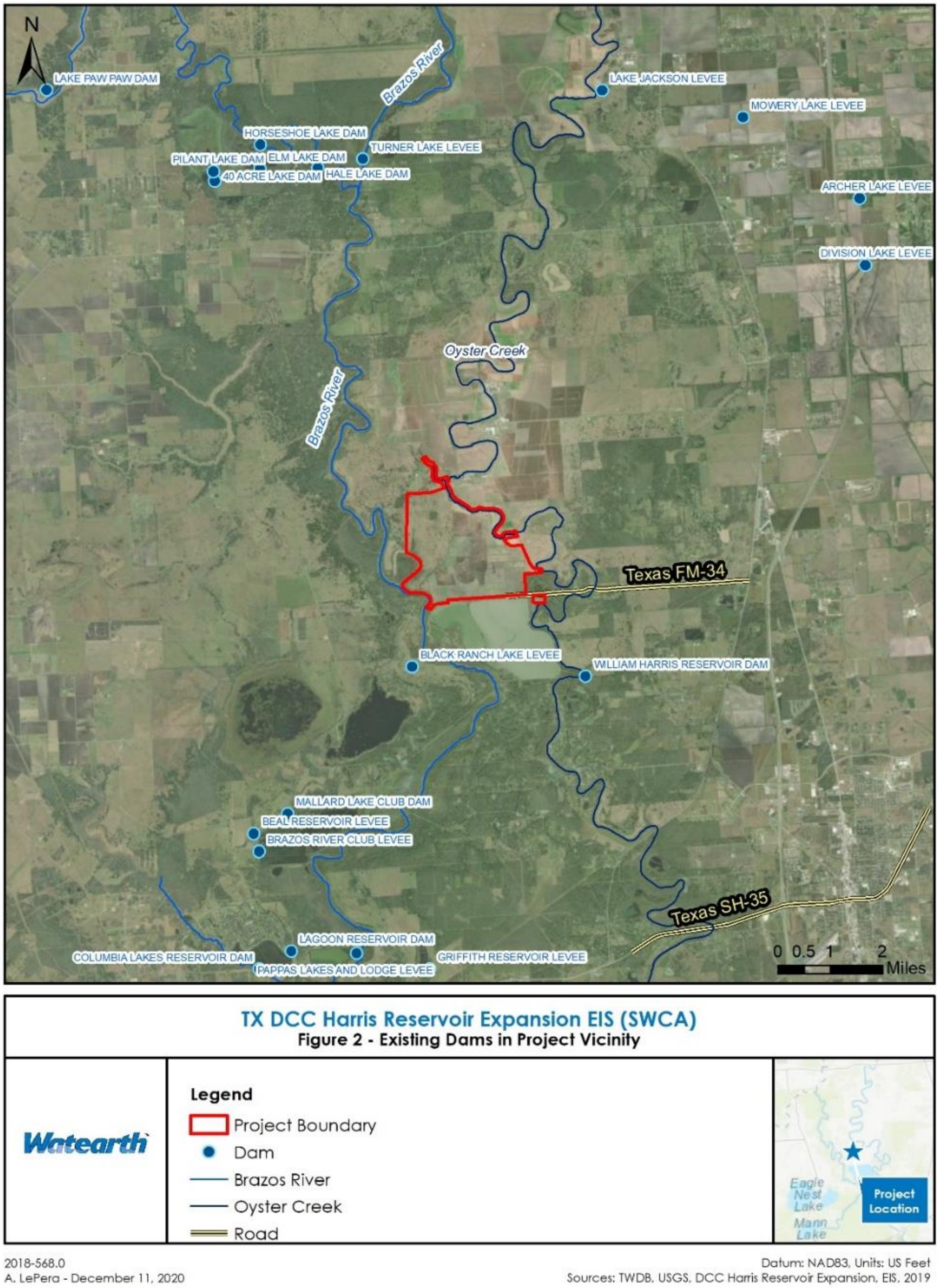


***Figure 2**: Dam inventory for Lower Brazos River (segment 1201).*

2.2 Surface Waters and Local Hydrology

The Brazos River Basin is more than 820 miles long and crosses nearly every physiographic region in Texas (TWDB, 2019; BRA, 2019). The watershed is approximately 42,000 square miles (sq-mi) and descends at a rate of 3 ft to 0.5 foot per river mile.

The Lower Brazos River sub-basin includes the area from Waco, Texas, to the Gulf of Mexico (Halff, 2019). The focus of this report is the lowest portion of the Lower Brazos River and is limited to Brazoria and Fort Bend Counties. Figure 3 shows the project area drainage areas in the Lower Brazos River sub-basin.

The topography in this area is level with minimal rise as shown by the height of the gages along the Brazos River in **Table 1** (USGS, 2019; USGS, 2019). The gages along the Brazos River are reported in National Geodetic Vertical Datum of 1929 (NGVD29) and North American Vertical Datum of 1988 (NAVD88). The conversion factor for vertical datums in the project area is NAVD88 is equal to U.S. Geological Survey (USGS) gage elevation in NGVD29 minus 0.975 ft (Heitmuller & Greene, 2009). As **Table 1** shows, there is minimal elevation change between the Freeport gage and the Rosharon gage. The thalweg of the Brazos River does not rise above mean sea level (MSL) until above the Rosharon gage.

Table 1: Gage Elevations

Location	Brazos River Mile	Elevation (NAVD88)
Freeport Gage (08772440)	6	-4.51ft
Rosharaon Gage (08116650)	57	-0.98 ft
Richmond Gage (08114000)	92	+27.02 ft

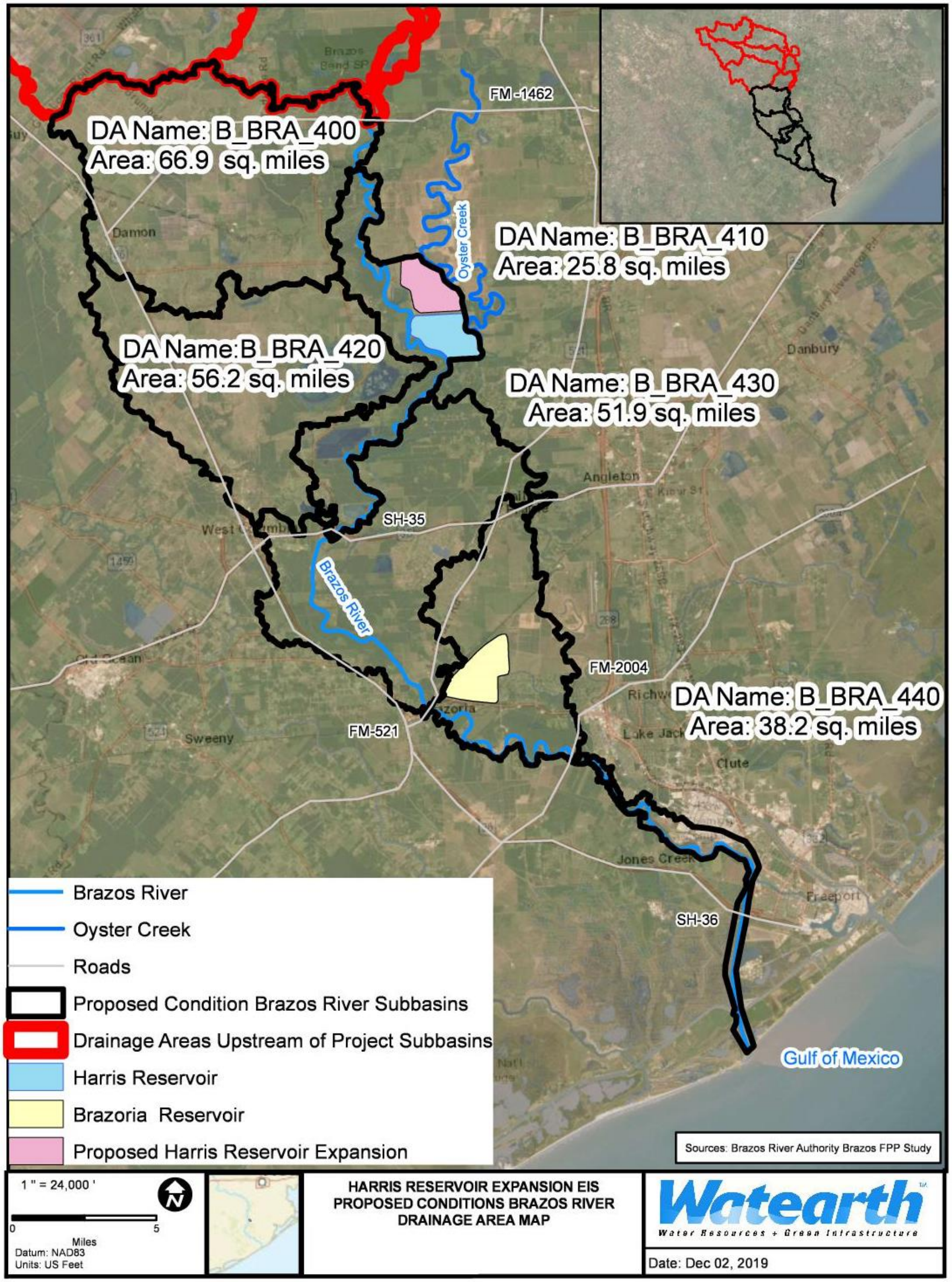


***Figure 3**: Lower Brazos River and Oyster Creek sub-basins in project vicinity.*

2.3 Rainfall and Temperature Change

The USACE developed predictive models for changes in rainfall and temperature, among other climate predictors. The USACE Region 12 (Texas-Gulf Region) report summarizes current climate and hydrology literature for the general project area. Seasonal precipitation is expected to decrease slightly with warmer annual temperatures, although intense rainfall events may increase in frequency. Consequently, the mean annual rainfall may decrease while the variance from year-to-year increases. **Figure 4** shows projected seasonal precipitation changes in 2085 (USACE, 2015).

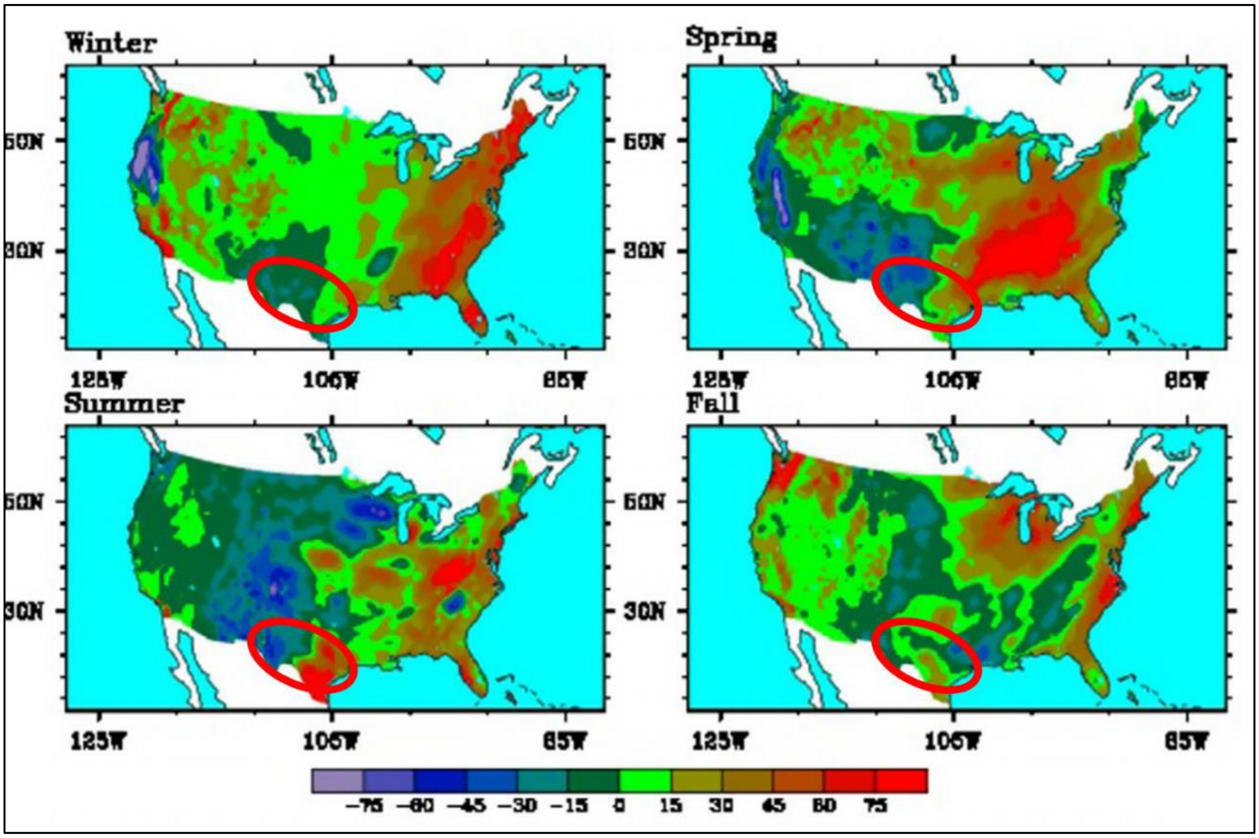


Figure 4: *Projected changes in seasonal precipitation, 2085 vs. 1985 mm (from (USACE, 2015)) Note: Texas region circled in red.*

Although **Figure 4** shows a slight decrease in precipitation in southern Texas, projections of future precipitation change are especially uncertain in this region because it is in a transition zone between projected drier conditions to the south and projected wetter conditions to the north, which could have mixed effects on river flows at the project site. Due to these uncertainties, the assumption that future precipitation in the project area will be roughly similar to past precipitation appears to be justified.

2.4 Watershed Vulnerability and Hydrology Assessment

The project proponent, Dow, developed a Hydrology and Floodplain Analysis (Attachment J of the USACE Individual Permit Application) with a focus on the flooding risk and high flow events. That full analysis is not repeated in this report. The USACE watershed vulnerability tool was used to screen the vulnerability of the project area to flooding under future conditions (USACE, 2019b). For the Brazos River watershed (HUC 1207), the projected future risk is expected to be low for the dry scenario and moderate for the wet scenario. **Figure 5** shows the vulnerability of the Brazos River watershed for 2050 and 2085 conditions.

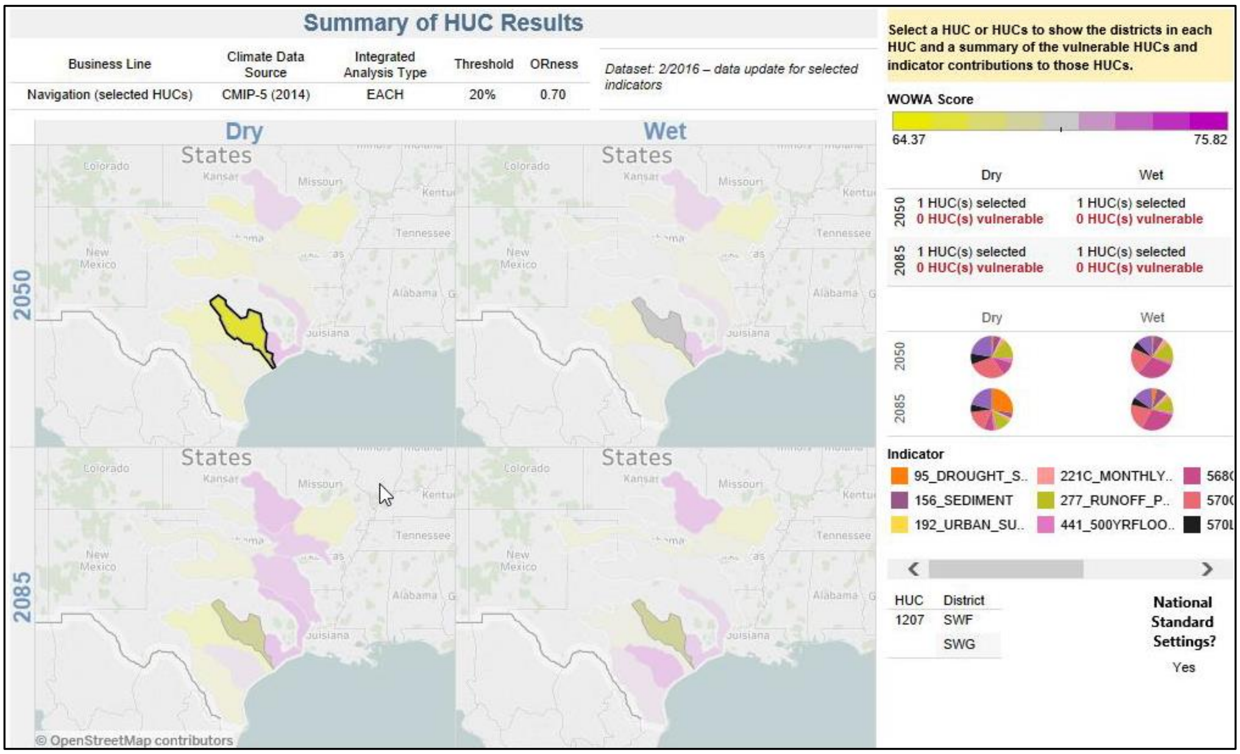


Figure 5: Watershed vulnerability for the Brazos River watershed (HUC 1207) from the USACE watershed vulnerability tool.

The climate hydrology assessment tool was also used to assess the predicted trends of the peak annual discharge for the Brazos River (USACE, 2019a). **Figure 6** shows the trends in projected peak annual flowrate, which represent the mean of 93 projected future hydrology models for the Brazos River watershed (HUC-1207). The projected annual maximum monthly streamflow for the Brazos River is expected to remain relatively constant, with the potential for a very small increase in flow rates in the future based on the climate hydrology model results shown in **Figure 6.** However, there is considerable uncertainty in making such specific predictions of future peak annual discharges. It is important to note that this data should not be used for quantitative analysis.

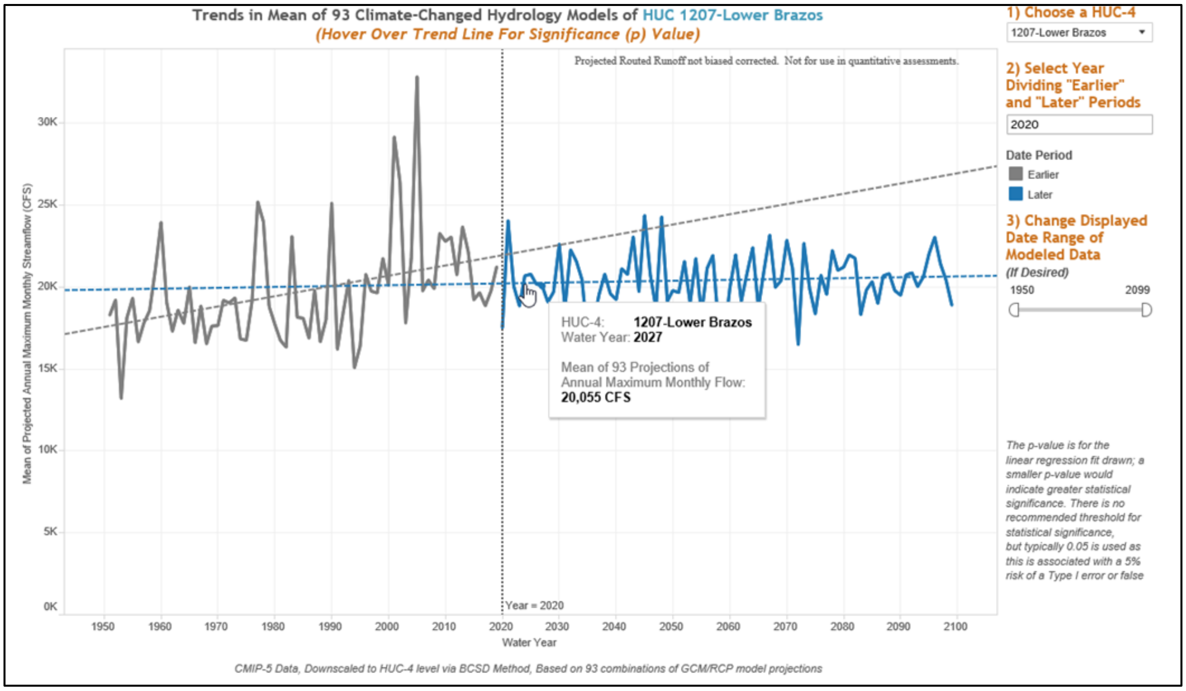


***Figure 6**: Trends in mean modeled annual maximum streamflow. The mean (dotted blue line) is the average of 93 climate-change hydrology models of HUC 1207.*

The consensus in recent literature points toward mild increases in annual precipitation and streamflow in the Texas-Gulf Region over the past century. In some studies and some locations, statistically significant trends have been quantified; however, the trends at the Brazos project site remain insignificant or unclear. The information in this section should be used for qualitative analysis of the hydrology, precipitation, and temperature impacts for the proposed project.

2.5 Storm Surge

The Gulf Coast shoreline is susceptible to storm surge, which is an abnormal rise in seawater level during a storm as a result of onshore high winds. Storm surge is measured as the height above the normal predicted astronomical tide. The distance onshore that storm surge travels can be compounded if associated with high tides, especially unusually high tides called king tides. The increased sea level height indicates that the tidal influence area is extended upstream from normal conditions temporarily. Storm surge and associated winds can damage human development and infrastructure farther upstream than under normal conditions. FEMA calibrates and validates storm surge using historical recorded storms in development of the Flood Insurance Study (FIS) for Texas coastal counties (FEMA, 1999). FEMA selected Carla (1961), Claudette (2003), Rita (2005), and Ike (2008) as potential validation storms due to their intensity and proximity to the project site (**Figure 7**). Due to the flat topography in the project area, inundation of brackish and saline water will reach farther upstream than under normal conditions. Based on sampling data provided by Dow, the salt wedge ranged between River Miles 15 and 43 and could potentially reach River Mile 49.

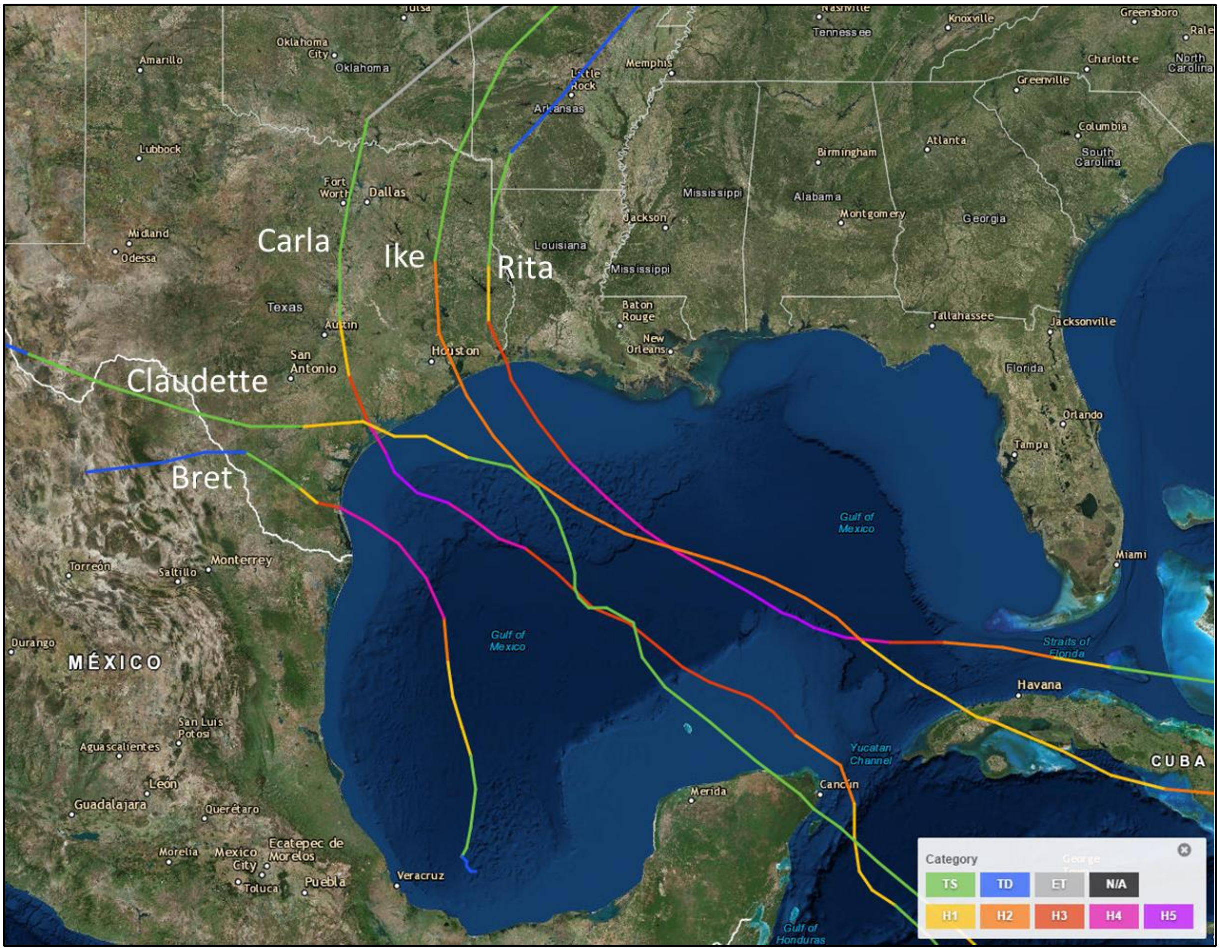


Figure 7: Historical storm tracks near the project site (FEMA, 1999).

2.6 Relative Sea Level Rise

The global sea level has been rising over the past century and current prediction models indicate sea level rise will accelerate over the next century. Low-lying and flat topography areas such as the project area are more likely to experience direct effects including inundation and extension of the brackish water upstream compared to past conditions. The Brazos River estuary extends above the Brazoria Reservoir located at River Mile 25 periodically throughout the year. Dow monitors and tracks the location of the salt wedge, which is defined as greater than 500 milligrams/liter of chloride. As discussed earlier, Dow provided the salt wedge position tracking data and found the salt wedge fluctuates between River Miles 15 and 43 and could potentially reach River Mile 49. The existing Harris Reservoir is located at River Mile 46.

The USACE developed a relative sea level rise calculation and mapping tool (USACE, 2014). The tool uses USGS gage data, National Oceanic and Atmospheric Agency (NOAA) Atlas 14 rainfall rates, and other data to provide three scenarios for relative sea level change, which reflects different rates of sea level rise based on the scientific literature.

The assumed project start date (substantial completion of the proposed project) is 2022 with the planning horizon of 2072 (50 years). Data were obtained using the web tool from the closest available gage, 8772440 at Freeport, Texas, which is located approximately 6 miles from the

Brazos River mouth. Tool assumptions include a base flood elevation (BFE) of 12 feet (FEMA, 1999). Model predictions range from approximately 1 foot to 4 feet in 2070 and 2 feet to over 8 feet in 2122.

Figure 8 shows the resulting relative sea level change over the planning horizon (until 2075) and 100 years from the project start date (2122). **Figure 9** shows the century of the resulting inundation from the USACE high sea level change scenario in 2122.

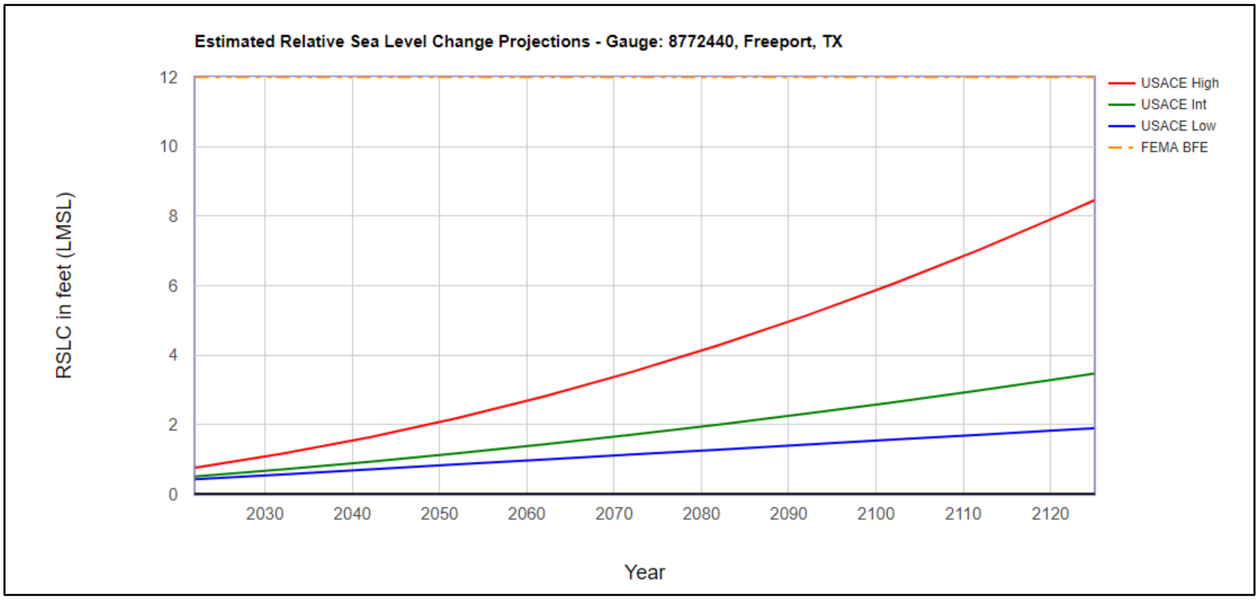


__Figure 8__: USACE projected RSLR, at NOAA gage 8772440, Freeport, Texas, over 100-year period of analysis (2022 base year, 2075 end-of-50-year project planning horizon, 2122 end-of-100-year).

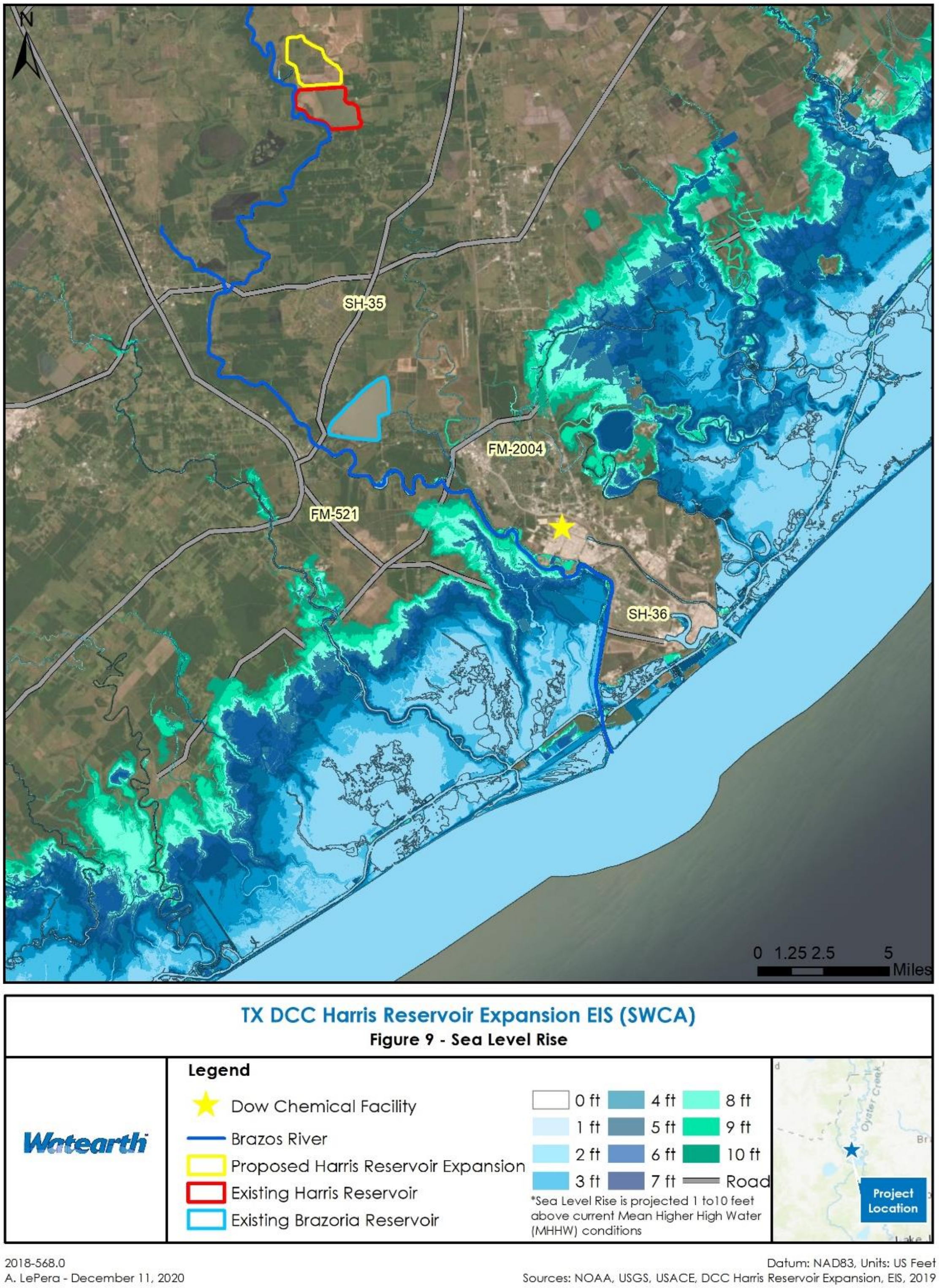


***Figure 9**: Gulf Coast inundation map for mean sea level in the year 2122 under the high sea level rise scenario.*

3.0 Existing Site Conditions

This project has a unique set of existing site conditions such as a water supply system spanning nearly 40 river miles of the Brazos River, cross basin interactions between the Brazos River and Oyster Creek, a series of canals, and multiple reservoirs.

3.1 Proposed Project Boundaries

The proposed project is development of a 50,968 ac-ft reservoir directly upstream from the existing Harris Reservoir. The proposed Harris Reservoir site is currently being used for agriculture. According to project information provided by Dow, the proposed Harris Reservoir site has wetlands and acts as the floodplain for both the Brazos River and Oyster Creek.

The proposed project must be considered in the context of the system it will contribute to, specifically the water supply system that serves the Dow plant and other users in Freeport, Texas. For modeling purposes, the project boundaries include the Brazos River from the Rosharon USGS stream gage to the mouth of the Brazos River at the Gulf of Mexico and portions of Oyster Creek used for inter-basin transfers of water through the existing Harris and Brazoria Reservoirs.

As shown in **Figure 10**, Dow operates two off-channel impoundments (information provided by Dow). The existing Harris Reservoir, located at River Mile 46, lies between the Brazos River and Oyster Creek in their shared floodplain. The Brazoria Reservoir, located at River Mile 25, is deeper than the existing Harris Reservoir and designed for three times the storage.

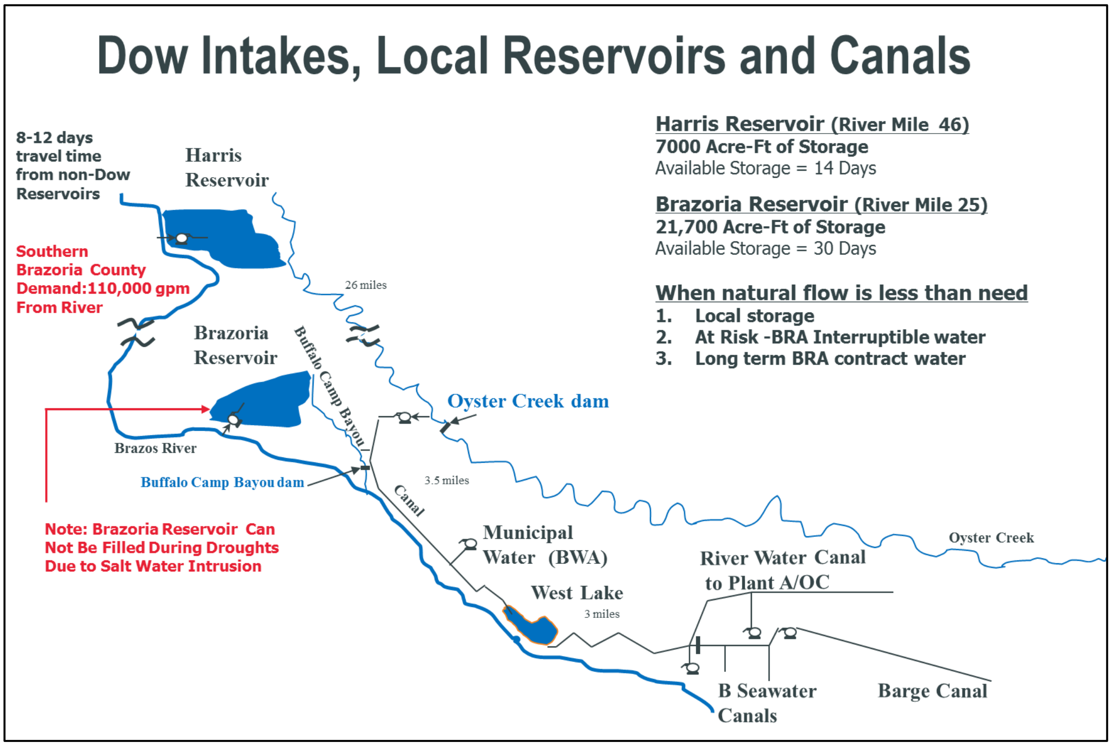


***Figure 10**: Dow Reservoir water supply map (provided by Dow).*

3.2 Dow Managed Water Storage

Dow's existing surface water intakes for the Brazoria and Harris Reservoirs are located in segment 1201 of the Brazos River, which is tidally influenced. During low flow conditions in the Brazos River, saline water moves up from the Gulf of Mexico to upstream locations on the river (saltwater wedge), ranging between River Miles 15 and 43, per data provided by Dow on chloride sampling. When flow conditions at the Brazos River pump station (River Mile 25) are reduced to approximately 1,730 cubic feet per second (cfs) or lower, Dow is unable to divert water into the Brazoria Reservoir due to saltwater intrusion from the Gulf and must rely on water delivered from the existing Harris Reservoir. When river flows are sufficient at the existing Harris pump station intake on the Brazos River, river water is transferred through the reservoir to Oyster Creek by pumping from the river into the reservoir and then discharging into the creek through a siphon system. When flow conditions limit pumping to the existing Harris Reservoir, water supply needs of Dow and others are met by withdrawing water stored in the Harris and Brazoria Reservoirs.

3.2.1 Dow's Brazos River Water Rights

Dow has a Brazos River water right of 238,156 ac-ft per year for industrial, municipal, domestic, and livestock uses. In addition, it has an Oyster Creek water right for 60,000 ac-ft per year for industrial and municipal uses, and a Buffalo Bayou water right of 7,560 ac-ft per year for industrial and municipal uses. There are no water rights holders with more senior rights compared to Dow in the river segment between the Rosharon USGS gage and the Gulf of Mexico. Dow's combined water rights allows a maximum diversion rate of 630 cfs from the Brazos River.

3.3 Water Supply Needs

As discussed in the Local Drought **Section 2.4**, the Freeport area, like much of Texas, experienced drought conditions that reduced the flows in many local rivers and streams. During the drought there was significant population growth and corresponding demands for additional potable water. Portions of the Brazos River watershed also saw significant development.

In response, Dow undertook efforts to reduce potable water needs. Even with demand reduction measures in place, the raw water use rate for Dow and water customers was about 3,000 ac-ft per week (approximately 430 ac-ft per day or 97,000 gpm). At this rate, and without any additional storage, the existing two reservoirs (when full) would provide a storage reserve of approximately 63 days or less, assuming all stored water could be accessed. The TCEQ considers water systems with 180 days or fewer of available water supply at risk during drought. A storage reserve of only 63 days is significantly below the drought preparedness and response standards established by the state.

3.3 Recent Drought Conditions

In 2005, a multi-year drought started in Texas. The year 2011 was the driest year on record and by that October, 97% of the state was in extreme or exceptional drought conditions. During the drought period, flows in the river were significantly lower than during average conditions. Had the severe drought conditions continued, Dow would have faced the possibility of reducing essential functions at its facility and curtailing use for the industries and municipal users that rely on its water supply system.

Additionally, the Water Availability Model (WAM) provided by Dow indicates there are significant multi-month periods when water from the Brazos River would not be available during a repeat of the drought of record. Modeling indicates if upstream junior water rights holders divert their full authorization, availability for diversion will be decreased.

During recent years, Dow has successfully reduced its freshwater consumption from the Brazos River by more than 20,000 ac-ft per year at its Texas Operations through on-site recycling and water efficiency practices. Additional water conservation/water use efficiency measures are planned for implementation as technology and cost-effective approaches are developed. It is projected that with future water savings and with savings already achieved, future water demands associated with operations and production growth during most climate conditions could be met. However, investments in water conservation do not provide the additional storage capacity required to sustain operations during extended drought.

3.4 Lower Brazos River Watershed

The drainage area of the entire Brazos River is approximately 45,560 sq-mi (TWDB, 2011). The drainage area starts 50 miles west of the Texas–New Mexico border and runs approximately

1,050 miles to the Gulf of Mexico (see

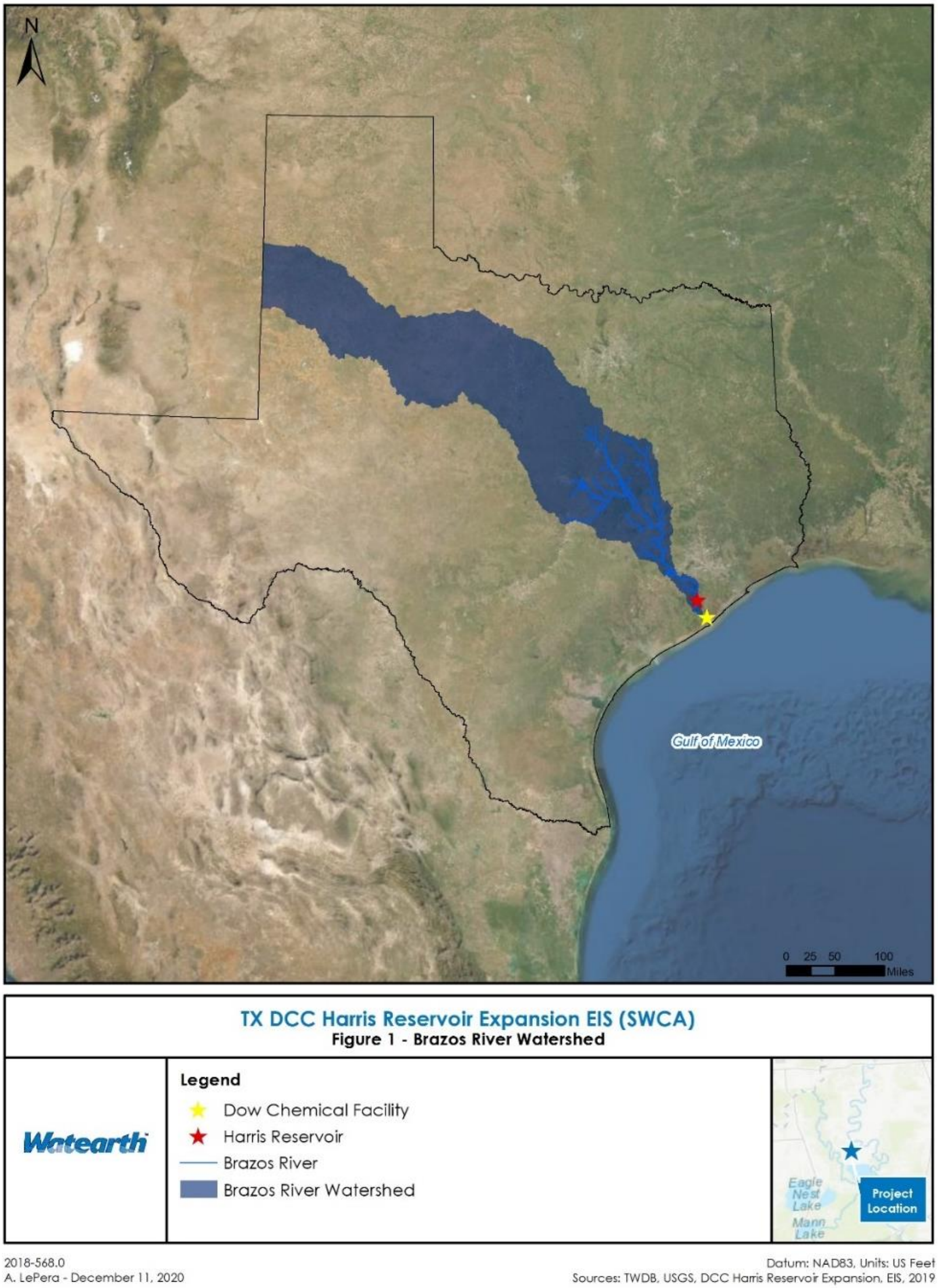


Figure 1 - Brazos River Watershed

Figure **1**). The Lower Brazos River drainage basin that includes the proposed project is approximately 9,766 sq-mi and has no major structures that control the river flow. The Lower Brazos River affects the southern Texas counties of Falls, Limestone, Robertson, Milam, Lee, Burleson, Grimes, Washington, Waller, Austin, Fort Bend, and Brazoria. This area is one of the fastest-growing areas in the country and has experienced substantial flooding over the last 4 years including the Memorial Day Flood (2015), Tax Day Flood (2016), and Hurricane Harvey (2017).

3.4.1 Basin Hydrology

The following hydrologic data corresponds to the hydrologic studies completed by the Texas Water Development Board (TWDB) for Brazos River (TWDB, 2011). The Brazos River Estuary Hydrology Study covers the period of record from 1977 to 2009.

Hydrologic analysis results provided a volumetric runoff balance in ac-ft, which includes the following contributions:

Balance = gaged + modeled - diversion + return - evaporation + precipitation

Note that there is no gaged data at the coastal sub-watershed (below the Rosharon gage) that is not subject to tidal influences. Therefore, a rainfall-runoff hydrologic model is needed; where gaged flows are obtained from USGS gages, modeled are rainfall-runoff values estimated using the Texas Rainfall-Runoff Model (TxRR), diversions and returns are flows associated with water rights and holders of discharge permits, and evaporation and precipitation include a contribution from each process on the surface area exclusively (TWDB, 2011). Note that the TxRR model results were obtained from the TWDB. The TxRR model is conceptually similar to the United States Department of Agriculture (USDA) Natural Resources Conservation Service; formerly the Soil Conservation Service curve number method, which was developed by research conducted by the USDA Agricultural Research Service.

Gaged inflow from the USGS station on the Brazos River near Rosharon accounted for approximately 86% of combined inflow, while modeled flows (rainfall-runoff) accounted for almost 3% of the balance over the study period as shown in **Figure 11**. Indicating the river discharge on the Brazos River is significantly dominated by upstream riverine processes rather than precipitation-induced discharges in the coastal plain. Therefore, precipitation processes can be ignored in the analysis. Such behavior is expected due to a large drainage area. It is possible that heavy local rainfall between the Rosharon gage and the Harris Reservoir project intersection could influence hydrodynamics at the project site. However, long-term trends indicate it is an infrequent event, which would not likely alter the long-term hydrodynamics.

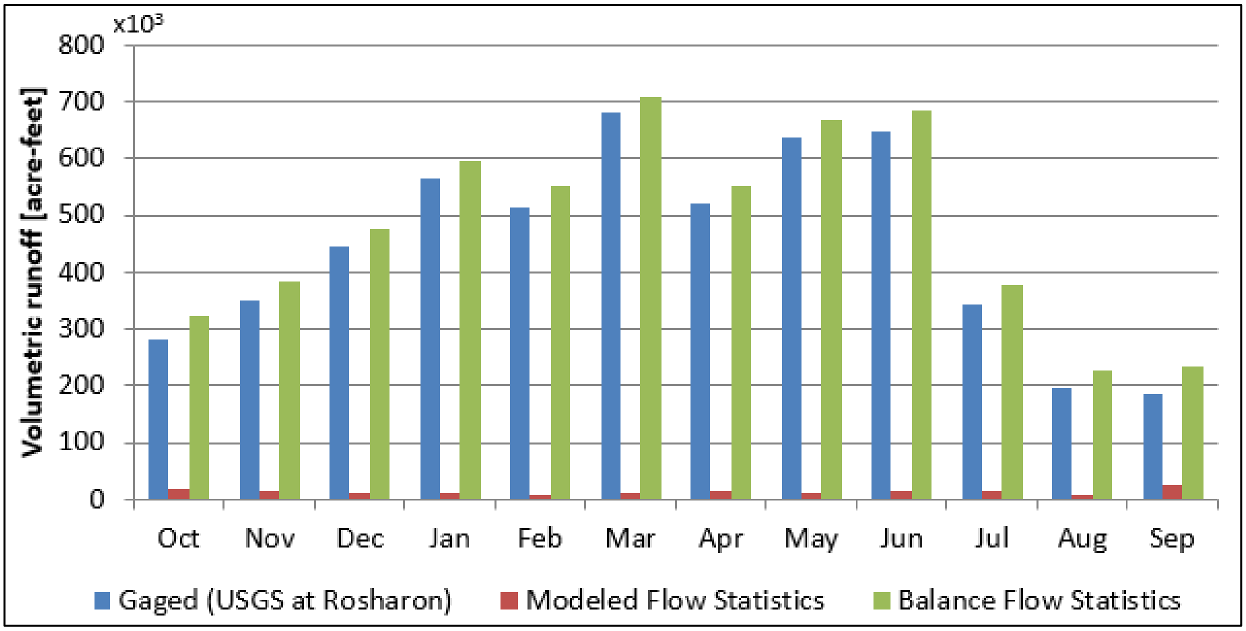


***Figure 11**: Brazos River long-term monthly mean freshwater inflow hydrology data over the period from 1977 to 2009. Data are shown in water year from October 1 to September 30 (TWDB, 2011).*

3.4.2 Analysis of Flow Gage Data Trends

USGS maintains stream gages throughout the project watershed including on the mainstem Brazos River as well as tributaries (**Figure 12**). The nearest upstream gage to the project is located near Rosharon, Texas. For purposes of modeling, this was selected as the upper limit of the project area for analysis. The Richmond, Texas gage was used to confirm stream flow conditions. The West Columbia gage is subject to tidal and estuary conditions.

To evaluate the long-term trends of precipitation on river discharge, a trend analysis was conducted on the annual peak discharges at the Rosharon, Texas and Richmond, Texas USGS gages for the Brazos River. **Figures 13** and **14** show the peak annual discharges for the Brazos Rosharon gage and Brazos Richmond gage, respectively.

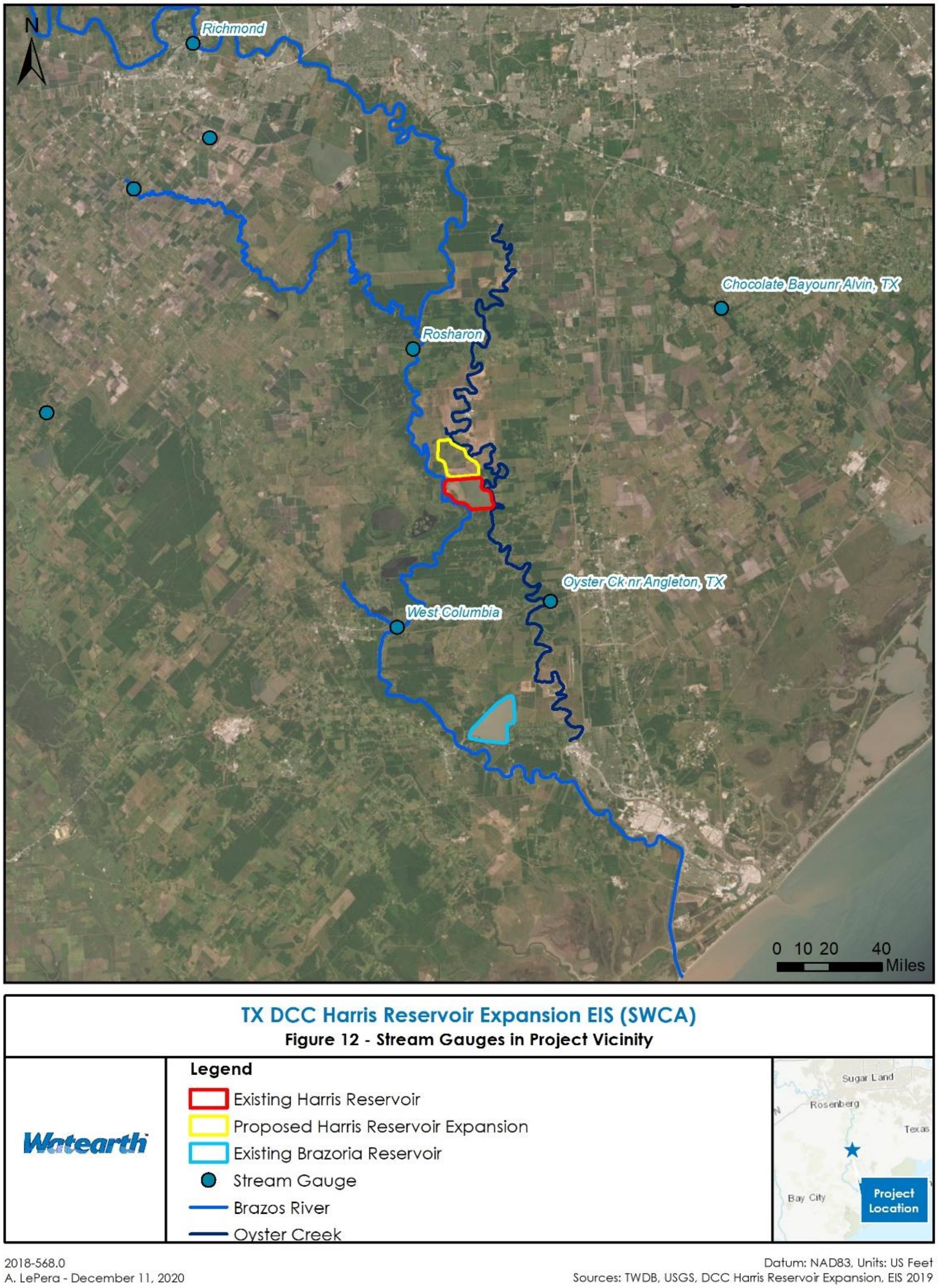


***Figure 12**: Stream gauges in vicinity of proposed project.*

A USGS gauge upstream of the project site at Brazos River (USGS 08116650 Brazos River near Rosharon, Texas) shows the flow time series fluctuates significantly in a relatively short period of time. Historical records show that daily flows within 1 month can go from 800 cfs to more than 100,000 cfs and back to low flows again within the next month.

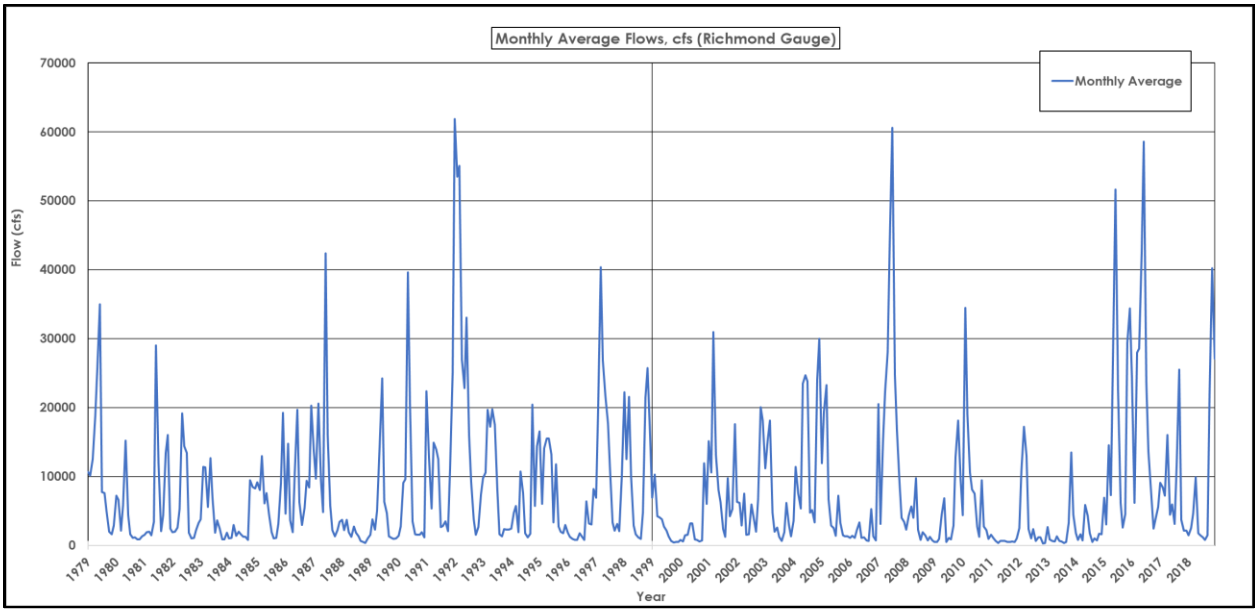


Figure 13*: Monthly average flows, Richmond, Texas, gage.*

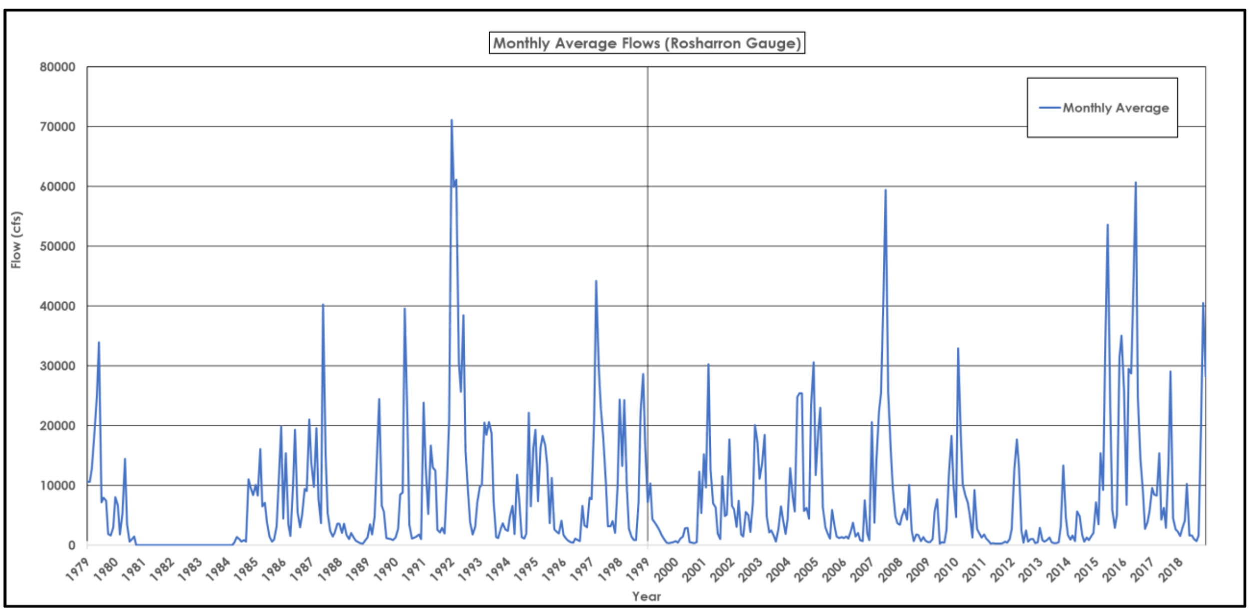


Figure 14*: Monthly average flows, Rosharon, Texas, gage.*

The comparison of the data shows over the entire period of record, the monthly mean peak discharge attenuates in the downstream direction. The maximum monthly mean discharge drops from 14,200 cfs to 12,400 cfs in May. Such attenuation is expected in the lower sections of the Brazos River, "as elevated flows enter storage in the low elevation terrain and are released over longer time periods" (USGS, undated). Conversely, the lower flows seen during November, December, January, February, March, April, June, July, August, and September increase in the downstream reach. The highest monthly average discharge in the Brazos River occurs in June as shown in **Figure 15**.

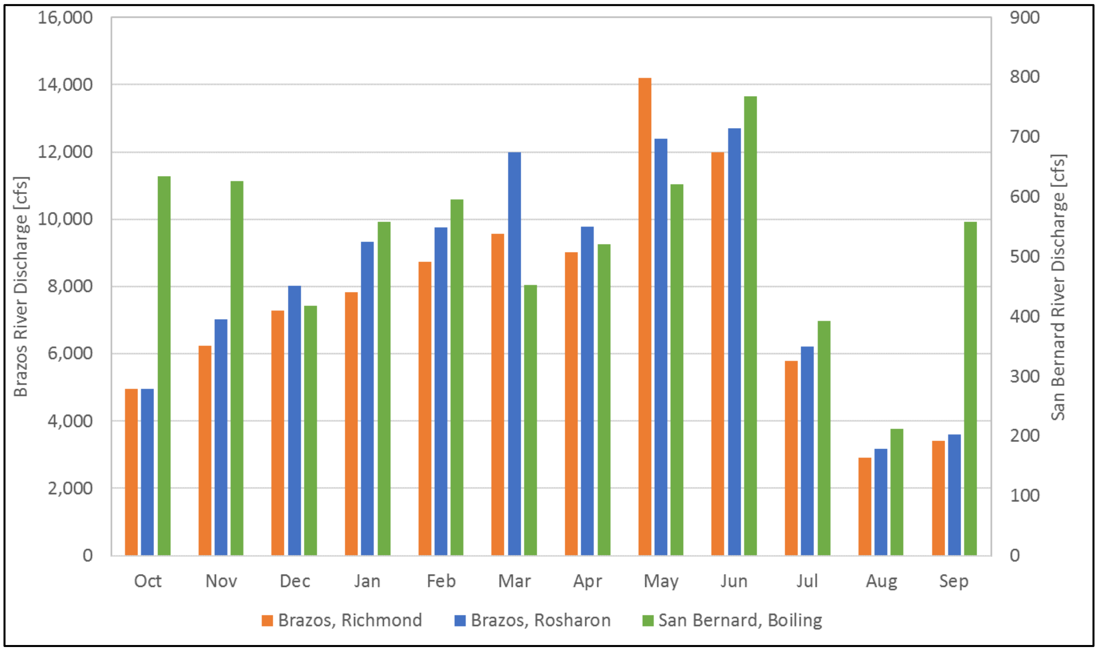


***Figure 15**: Long-Term monthly mean streamflow discharge at USGS Stations Brazos River near Richmond (upstream in blue), Brazos River near Rosharon (downstream in red) and San Bernard River near Boling. Data are shown in water year from October 1 to September 30.*

3.5 Sedimentation Loads in Brazos River

3.5.1 Introduction

Sediment transport is a function of riverine systems. The velocity of flow determines sediment load and gradation size as higher velocities carry larger particle sizes and resist settling. Increases in velocities can also resuspend larger particle size sediment.

3.5.2 Brazos River Sediment Load

Sand-sized sediment transport has decreased since measurements were taken starting in 1969. The decrease is at least partially attributable to the effects of the operation of new reservoirs during the time period (USGS, 2001). The reservoirs reduce high peak flows, which can transport larger particles for longer distances, and trap sediment within their boundaries. The scatter plot in **Figure 16** shows the relationship to discharge rates and concentration of sand particles with a Locally Weighted Scatterplot Smoothing (LOWESS) line. The plot provides a graphical comparison between the two time periods shown without assigning a statistical significance to the difference (USGS, 2001). At similar discharge rates, the suspended-sand load is reduced during the latter period. Tables 2 and 3 show the change in Brazos River based on surveys taken in 1990 and 2020.

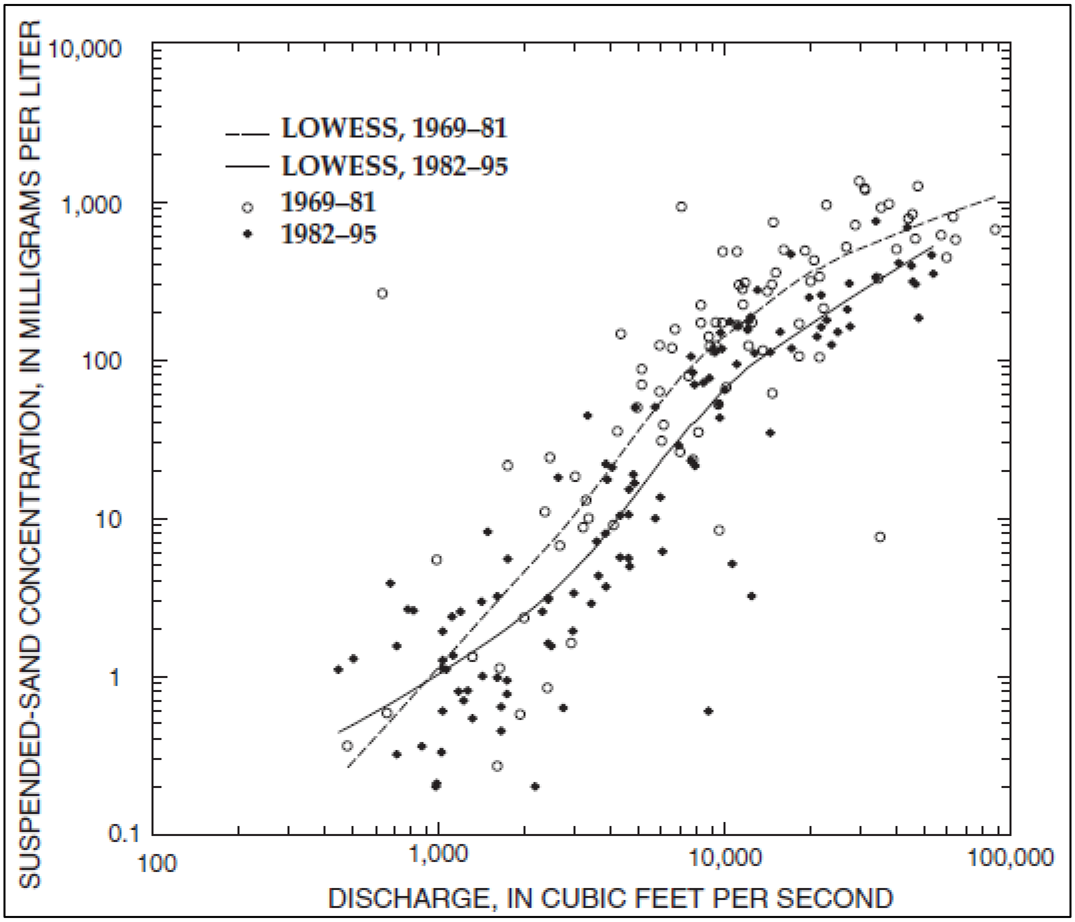


***Figure 16**: Relation of suspended sand concentration to discharge at Streamflow-Gaging Station 08114000 Brazos River at Richmond, Texas, 1969–1995 (USGS, 2001).*

Table 2: Brazoria Reservoir

Authorized			1990 Survey			Adjusted 1990 Survey			2020 Survey		
Volume-Area-Depth			Volume-Area-Depth			Volume-Area-Depth			Volume-Area-Depth		
Volume (ac-ft)	Area (acres)	Elevation (ft)	Volume (ac-ft)	Area (acres)	Elevation (ft)	Volume (ac-ft)	Area (acres)	Elevation ft)	Volume (ac-ft)	Area (acres)	Elevation (ft)
0	0	13.6	0	0	16.0	0	0	16.0	0.2	1	13.0
160	200	15.2	90	300	17.6	160	200	17.6	70	72	17.5
900	400	17.6	900	800	20.0	900	400	20.0	992	727	20.0
2,257	830	19.6	2,000	1,300	22.0	2,257	830	22.0	2,884	1,142	22.0
4,587	1,500	21.6	4,650	1,830	24.0	4,587	1,500	24.0	5,615	1,549	24.0
6,262	1,850	22.6	6,000	1,850	25.0	6,262	1,850	25.0	7,248	1,700	25.0
9,103	1,860	24.2	8,500	1,860,	26.6	9,103	1,860	26.6	9,875	1,787	26.5
21,710	1,870	31.0	17,300	1,870	31.0	17,309	1,870	31.0	18,115	1,851	31.0
N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	18,207	1,851	31.05
N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	21,883	1,858	33.0
N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	25,546	1,865	35.0
N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	29,283	1,872	37.0
N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	31,156	1,873	38.0
N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	32,092	1,873	38.5

Table 3: Existing Harris Reservoir

Authorized			1990 Survey			Adjusted 1990 Survey			2020 Survey		
Volume-Area-Depth			Volume-Area-Depth			Volume-Area-Depth			Volume-Area-Depth		
Volume (ac-ft)	Area (acres)	Elevation (ft)	Volume (ac-ft)	Area (acres)	Elevation (ft)	Volume (ac-ft)	Area (acres)	Elevation (ft)	Volume (ac-ft)	Area (acres)	Elevation (ft)
0	0	29.8	0	0	32.0	0	0	32.0	N/A	N/A	N/A
13	50	30.3	20	200	32.5	13	50	32.5	0.3	3	33.0
88	100	31.3	50	480	33.5	88	100	33.5	3.3	9	33.5
493	170	34.3	200	1,220	35.5	493	170	36.5	668.8	672	36.5
728	300	35.3	400	1,450	36.5	728	300	37.5	1,539.4	1,148	37.5
813	550	35.5	1,000	1,600	37.7	813	550	37.7	2,158.3	1,345	38.0
1,593	1,400	63.3	1,500	1,655	38.5	1,593	1,400	38.5	2,861.2	1,466	38.5
2,355	1,650	36.8	3,000	1,660	39.9	2,355	1,650	39.0	3,613.2	1,531	39.0
5,173	1,665	38.5	4,500	1,665	40.7	5,173	1,665	40.7	5,962.3	1,580	40.5
10,199	1,675	41.5	6,500	1,675	41.5	6,509	1,675	41.5	7,546.1	1,586	41.5
N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	13,102.5	1,605	45.0
N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	16,323.6	1,615	47.0
N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	17,131.6	1,616	47.5

The amount and gradation of the sediment carried by the Brazos River is highly dependent on the velocity of the river. High flows carry sand, silt, and clay, but low flows carry mostly clay. The intake pump inlets for both existing reservoirs are below the natural stream bed, which likely results in sediment intake at all flow conditions. The proposed project intake has a similar location compared to the natural stream bed.

Historical suspended sediment concentration (SSC) was recorded in the Brazos River at USGS Station 08116650 (Rosharon gage) monthly between 1973 and 1981, and again between 2008 and 2015 (**Figure 17**).

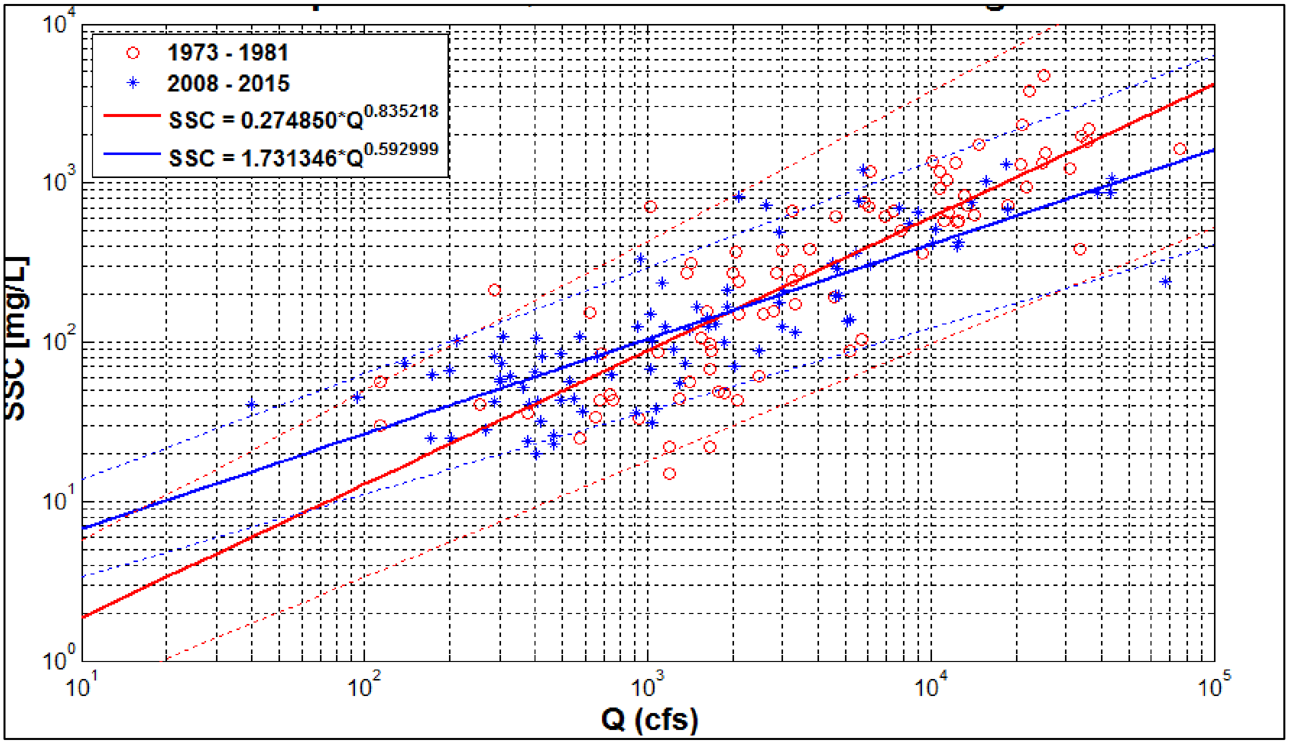


***Figure 17**: Sediment load curve at Brazos River, Rosharon gage, based on measured data.*

Dow reported periodic sediment removal of the existing Harris Reservoir through dewatering and bulldozer excavation, but documented frequency was not provided. Further, there is no current schedule of future maintenance for the existing reservoirs. Dow also reported in its *Dow Water Rights and Supply – Fast Facts and Information (June 2020)* document an existing permit authorizing dredging of solids from the reservoirs with specified, limited releases to the Brazos River under certain river flow conditions but indicated concerns with embankment stability. It is possible to dredge these reservoirs back to their original authorized capacity with modern equipment in conjunction with radar surveys or global positioning systems (GPS) that would control the location and depth of dredging. Dredging to original or deeper contours could increase available water but would not increase reservoir surface area where evaporation occurs.

The historical reservoir capacity loss for Brazoria Reservoir was 111 ac-ft per year (ac-ft/yr) from 1954 to 1990. The straight-line projection of 111 ac-ft /yr storage loss by sediment forecast the 2020 Brazoria Reservoir storage volume at approximately 14,877 ac-ft (**Table 4**). Survey data from 2020 show actual storage capacity of 18,207 ac-ft.

The historical reservoir capacity loss for Harris Reservoir was 81 ac-ft/yr from 1947 to 1990 (**Table 4**). The straight-line projection of 81 ac-ft/yr storage loss by sediment forecast the 2020 Harris Reservoir storage volume to approximately 6,706 ft. 2020 survey data show actual storage capacity of 9136 ac-ft.

Table 4: Effective Storage Capacity for Existing Harris and Brazoria Reservoirs

Year (Estimate by)	Harris Reservoir (ac-ft)	Brazoria Reservoir (ac-ft)	Total Effective Storage (ac-ft)
1947	10,200	-	10,200
1954	-	22,000	22,200
1990 (Dow by survey)	6,500	17,300	23,800
2018 (Dow USACE Application)*	7,000	21,000	28,000
2020 (by Doyle and Wachtstetter)	9,136	18,207	27,343

* Dow USACE application and 2020 Doyle and Wachtstetter storage values are used for purposes of analysis and modeling.

3.6 Other Hazards Considered

3.6.1 Wind

The proposed Harris Reservoir location is close to the Gulf of Mexico and can be subject to high winds from tropical storms and hurricanes. The preliminary design report supplied by CH2M was reviewed concerning their design approach and how wind may affect the proposed Harris Reservoir design. The design report indicates that in 2017, a wind speed of 185 miles per hour (mph) was reported from Hurricane Harvey.

The high winds traveling across open water in the reservoir (the fetch) generate waves that could damage the embankment or even overtop the embankment. The preliminary design indicates that these concerns were taken into consideration and addressed by elements such as the soil-cement embankment protection, the wave wall at the intersection of the top and interior slope, and the operational drawdown prior to the forecasted storm events.

3.6.2 Wave

The preliminary proposed embankment design addresses the embankment slope protection from wave action with the placement of 8-inch stair-stepped soil-cement lifts on the interior slope above elevation 60.93. Dow also prepares for large storm events by drawing down the reservoir pool elevation whenever a hurricane alert is issued for any substantial hurricane that may make landfall near the reservoirs, allowing for more freeboard below the top of the embankment.

The preliminary design also addresses overtopping, which is the most common cause of an embankment breach and uncontrolled release of water. A 3-foot tall bullnose (or parapet) wall at the interior edge of the embankment top would be anchored into the soil-cement to reduce overtopping of the embankment. Using the U.S. Bureau of Reclamation breach equation, Watearth estimates approximately 12,500 cfs of water could be released into the Brazos River or Oyster Creek in the event of a breach. While this is a significant quantity of water, the downstream floodplain would quickly dissipate this volume and little to no long-term effects would be anticipated under current land use conditions.

3.6.3 Tidal Elevations

The lowest extent of the project is the confluence of Brazos River with the Gulf of Mexico near Freeport, Texas. In addition, nearly the entire project area is subject to estuarine conditions with one of the factors being tides. Tides are determined by the lunar cycle, distance, and position of the moon in comparison to the sun, and gravitational forces. The lunar day is 24 hours and 50 minutes, resulting in two high tides per lunar day every 12 hours and 25 minutes, with the accompanying low tide occurring six hours and 12.5 minutes after the high tide. Due to the relationship between the moon and the position on Earth experiencing a tide, there will be a higher and lower high tide during the lunar day. With other influences, such as the position of the sun, higher than normal tides can occur (sometimes referred to as king tides).

The Gulf of Mexico is tidally influenced with tidal conditions similar to an inland sea due to a large coastal shelf and relatively narrow entrance blocked by Cuba and other Caribbean islands. As such, tides can be highly influenced by storm conditions.

The tidal gauge at Freeport, Texas (gauge 8772447), located 6 miles northeast of the mouth of the Brazos River, measures tidal conditions near the project area (**Figure18**) (NOAA, 2019). The average monthly high tide fluctuation is 1.67 ft (MSL) with the largest recorded fluctuation of 5.4 ft (MSL). The average fluctuation between the monthly lowest low tide and the highest high tide is 3.65 ft (MSL) with a largest recorded fluctuation of 7.25 ft (MSL). This is a relatively narrow band of water surface elevation changes related to tides, but when taken in consideration with the low nearshore topography, it can present design and inundation risks, especially during storm surge. The flat topography carries relatively far inland as the bottom of the Rosharon gauge is below MSL.

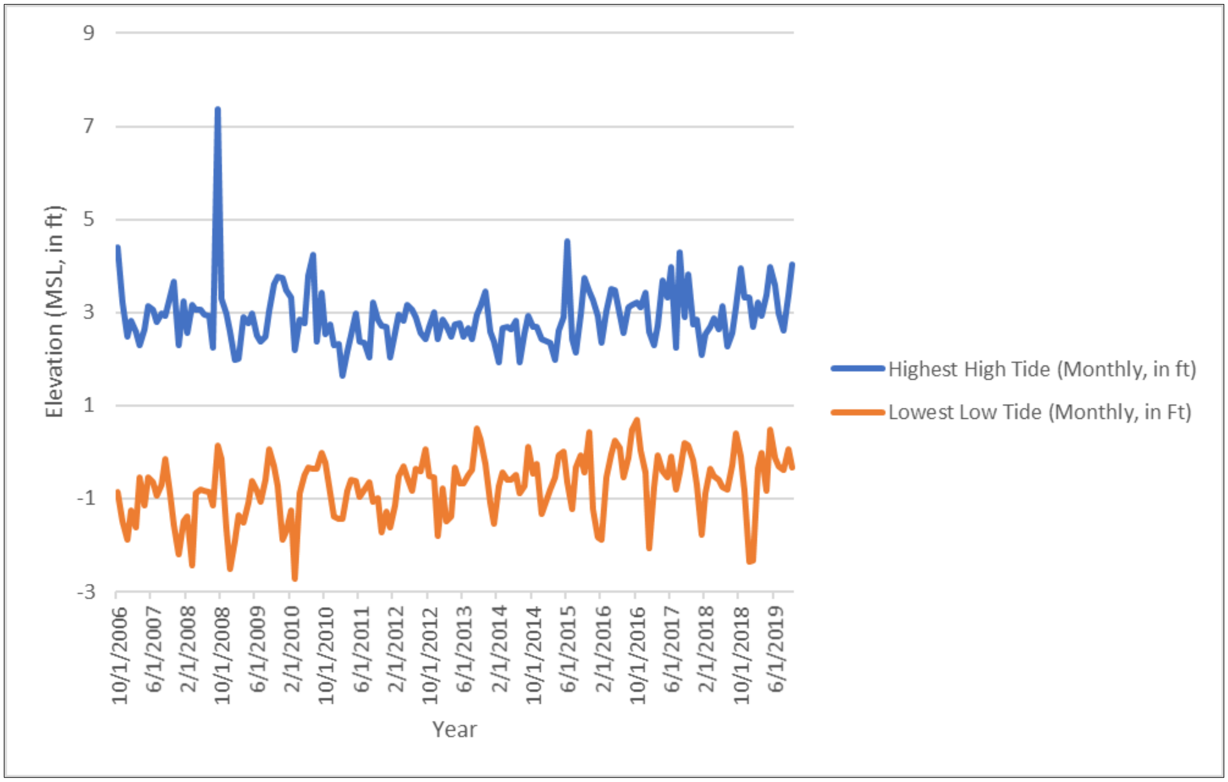


__Figure18:__ Highest high tide and lowest low tide (monthly, in ft) for Freeport, Texas, gauge 877244.

4.0 Proposed Project

The proposed project, referred to as Harris Reservoir expansion in the permit application to USACE Regulatory, is located immediately north of the existing Harris Reservoir (**Figure 19**). The proposed project includes a 2,000-ac impoundment with a nominal storage capacity of 50,968 ac-ft, an intake and pump station to divert Dow's existing surface water rights from the Brazos River, an outlet to Oyster Creek, and an auxiliary spillway. The proposed project will change the current interbasin flows from the Brazos River to Oyster Creek and the amount of floodplain storage. Recommendations will be added to the proposed O&M plan for the proposed project and operational flows in Oyster Creek. The project also includes floodplain enhancements to Oyster Creek, stream restoration, and temporary construction staging and laydown areas.

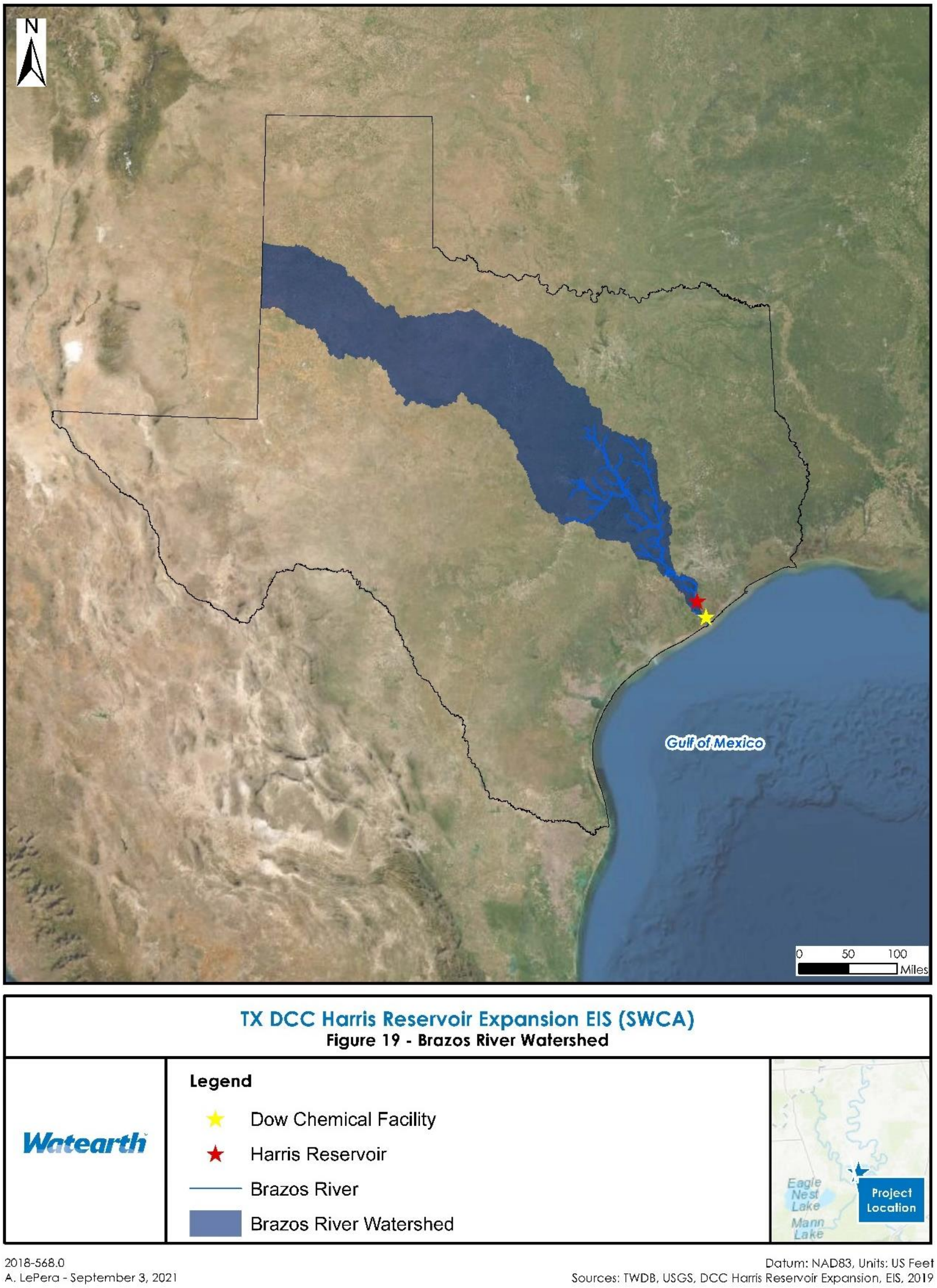


Figure 19*: Project elements for hydrologic analysis.*

4.1 Harris Reservoir Expansion

The embankment will be constructed to a nominal elevation of 72.7 ft with borrow material from the reservoir interior, leaving 400 feet of no borrow zone from the embankment toe (**Figure 20**). The embankment will have a 3-foot-wide vertical chimney drain located 5 feet downstream of the embankment center line. Drainage will continue into a horizontal blanket drain, which will exit into the embankment tow drain. The interior will have a sacrificial lower slope with a stepped soil-cement upper slope for wave protection. A 3-feet tall (top of wall is El. 75.7 ft) precast concrete wave wall will be anchored into the soil-cement at the intersection of the interior embankment slope and top of embankment.

A 2.5-foot-wide vertical seepage barrier wall will be constructed 35 ft upstream from the embankment centerline. The seepage barrier is under the entire embankment length of 36,059 ft. The depth of the seepage barrier wall varies from 17 ft below natural ground to 55 ft below natural ground.

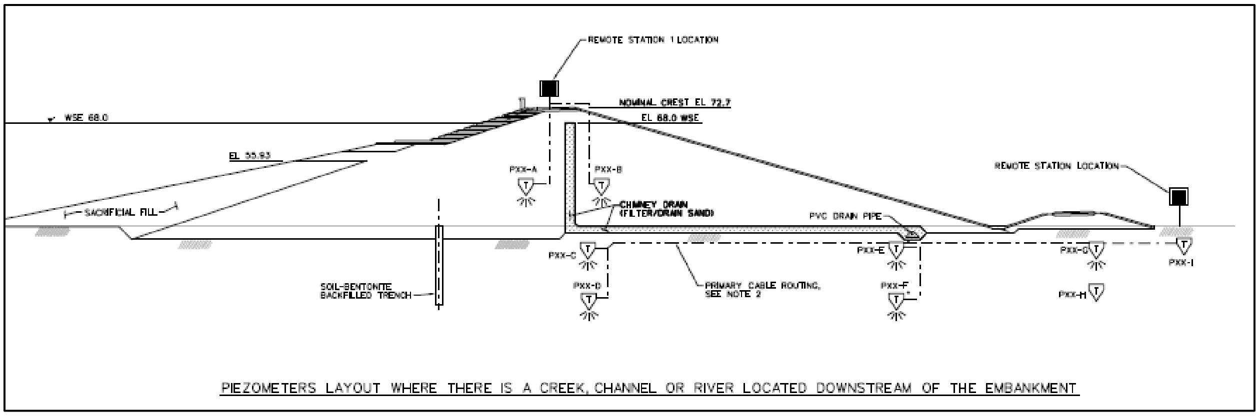


***Figure 20**: Embankment cross-section.*

The proposed pump station is located near the southwest corner of the proposed project at embankment STA 113+89 and has a capacity of 150,000 gpm (334 cfs). The water is pumped from the Brazos River intake through the pump house up and over the embankment in a 72-inch pipe into the project intake structure. The suction centerline elevation is set at 8.5 ft, which will require a vacuum priming system to fill the pump suction lines. The pumps can be isolated for maintenance regardless of the river level. The 72-inch pipe will have a gooseneck air vent at the top of the embankment for gravity flow down the interior of the reservoir embankment to an energy dissipation structure inside the reservoir at the end of the pipe. The combined gated outlet and auxiliary spillway structures are located on the southeast side of the reservoir at STA 227+29.88. The outlet structure has two 36-inch-wide × 48-inch-high sluice gates that allow water to flow in an outlet conduit through the embankment into a stilling basin at rates from 60 cfs to 1,000 cfs. The baffled drop inlet auxiliary spillway structure also flows into the outlet conduit. The baffled outlet structure is designed to allow the reservoir to be lowered 3 ft from normal maximum water surface elevation prior to storm events. A 1-foot per day draw down requires slightly more than a 900 cfs release rate. The stilling basin outlets into the constructed Oyster Creek flood channel.

The northeastern part of the proposed project includes enhancement of the Oyster Creek flood capacity and provides riparian restoration. The enhancement starts on an unnamed tributary, which flows into Oyster Creek where riparian restoration and flood plain benching is planned. A weir will be constructed that allows large discharges to flow down the flood channel, which parallels the project embankment along the north side until it flows back into Oyster Creek below the gated outlet and auxiliary spillway outlet.

There will also be a temporary staging area and temporary workspace located southeast of the project and due north of the existing Harris Reservoir. This area will be restored back to natural conditions after the project is completed.

4.2 Oyster Creek Enhancements

As part of the proposed expansion project, Oyster Creek will be enhanced with three projects. These projects are planned to improve the flood capacity and provide restoration and enrichment to the riparian habitat along the three project lengths. Geomorphic design principles were used to provide a bankfull benching creating floodplain storage, riparian habitat, and channel conveyance to accommodate the proposed Harris Reservoir outlet flow into Oyster Creek.

Project 1 is approximately 3,516 ft long from STA 5+15.90 to STA 40+00 on an unnamed tributary north of the proposed project's northeast corner. Project 1 widens the existing unnamed tributary channel to Oyster Creek north of the confluence of Oyster Creek and the unnamed tributary north of FM 655. The changes include providing a 70-foot bottom-width channel with 4H:1V side slopes and a widened floodplain bench, which are represented between cross-sections 61.87 and 61.43 of the HEC-RAS model. The channel flows into Oyster Creek a short distance north of the northeast corner, which is the start of Project 2.

Project 2 is approximately 12,960 ft long from STA 40+00 to STA 169+60 and is in the main channel of Oyster Creek. Widening of the Oyster Creek channel through this section will be predominantly on the western side of Oyster Creek and include an 80-foot bottom width channel with 4H:1V side slopes followed by a 150-foot flat buffer and channel with 4H:1V side slopes until tying to existing ground. This provides a 310-foot-wide top width for the section of channel represented between cross-sections 60.47 and 58.67 of the HEC-RAS model. Project 2 is intended to restore the natural function of the channel by planting riparian vegetation and providing a riparian buffer in conjunction with channel widening.

Project 3 is an improved flood overflow channel that flows along the east side of the proposed Harris Reservoir until the channel intersects downstream with the main Oyster Creek channel at STA 254+00, and also the proposed Harris Reservoir outlet channel. The Project 3 channel will extend 4,300 feet south, rejoining Oyster Creek 12,000 feet upstream of CR 34 (Harris Reservoir Road). A weir would prevent flows from the Oyster Creek main channel from spilling into the overflow channel until the existing Oyster Creek main channel exceeds its 25-year water surface elevation (WSEL); however, backwater flows will inundate the downstream end of the Project 3 channel at lower rates. Project 3 provides additional channel capacity for Oyster Creek during high flow events. A typical cross-section of the Project 1 through Project 3 stream restoration to recreate the multiple level channel morphology is shown in **Figure 21**.

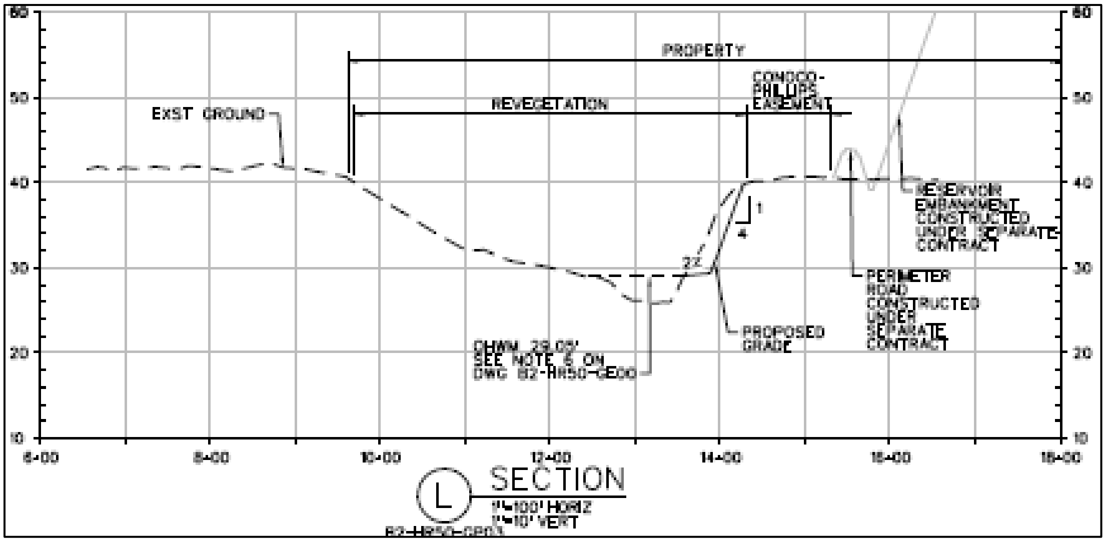


Figure 21*: Cross-section of Oyster Creek restoration in area adjacent to the reservoir embankment.*

4.3 Water Supply Needs

Modeling results show that 78,311 ac-ft of reservoir storage is needed to supply Dow's Texas Operations for 180 days during an extended drought using existing water rights. Dow needs 430 ac-ft per day of water supply to meet its daily water supply obligations, which include the Brazosport Water Authority (BWA), which supplies approximately 16,000 ac-ft per year to its customers through the Dow water pumping and reservoir facilities. The effective combined storage capacity in the existing Brazoria and Harris Reservoirs is approximately 27,343 ac-ft. Therefore, Dow will need to develop additional storage capacity of 50,968 ac-ft from a new reservoir to provide a reliable water supply during drought, which cannot be achieved by maintenance dredging or deepening Dow's existing reservoirs.

Use of Dow's existing water rights and storage facilities, existing pumping and conveyance system through Oyster Creek and Buffalo Camp Bayou, and existing industrial plant canal system supplemented with expanded storage at the Harris Reservoir site provides a cost-effective and financially viable means of meeting the storage requirements and increasing drought resilience for Dow's Texas Operations, industries, and the BWA. Without additional storage capacity that would allow more efficient use of Dow's existing surface water rights from the Brazos River, production at Dow's Texas Operations and reliable public water supplies for BWA customers would be at risk during extended drought conditions. Reduction of production would result in severe economic hardship for the local economy—potentially affecting approximately 6,700 direct jobs at Dow's Texas Operations and the health and safety of the seven cities in Brazoria and Fort Bend Counties that currently obtain approximately 16,000 ac-ft per year of drinking water from Dow's water supply system through the BWA. Furthermore, interruption of production would impact material supply across the state and the nation.

The recent drought conditions demonstrated the urgency for implementation of a project to provide additional storage and increase the reliability of water supply during drought in an environmentally responsible and financially viable manner. Without additional water storage to increase Dow's resilience to drought, essential functions at the Texas Operations site would be at risk during times of water shortage. The proposed project is intended to reduce the risk of water shortage during drought.

5.0 Hydrology, Operational, and Hydraulic Modeling

The purpose of this section is to describe the three models used to analyze the existing and proposed project and for compliance with the Hydrologic Modeling Guidelines (HMG). The models discussed in this section include Hydraulic Engineering Center-Hydrologic Modeling System (HEC-HMS), RiverWare, and Hydraulic Engineering Center-River Analysis System (HEC-RAS).

5.1 Hydrologic Modeling Guidelines

The USACE developed the HMGs checklist for use by USACE Regulatory project managers and applicants to guide their daily data analysis and modeling process. Required information is presented as a series of questions, grouped into three tiers of increasing complexity. Per the HMGs, the USACE permit decision is based on whether enough information have been provided so all required aspects of the project are appropriately addressed. From a modeling perspective, this documentation presents a general summary of three models selected for the project in terms of their capabilities to address related items in the HMGs checklist.

The models provide answers to the following items:

1. Flow extent and water depth under both existing and post-project condition
2. Peak and low flow impacts on aquatic resources under both wet and dry hydrology periods

The USACE Regulatory uses the HMGs checklist in determining sufficiency for hydrologic evaluation but does not require the use of specific modeling software, which allows for flexibility in determining which suites of software to use based on the proposed project's potential impacts. In general, any project that includes an existing and/or proposed Harris Reservoir will require the use of the RiverWare modeling software due to its unique capabilities to model complex reservoir operations including input of water rights and water supply. As more fully discussed in the *Hydrology and Hydraulic Modeling White Paper (2019)* and the *Environmental Modeling Approach (2019)* prepared for this project, HEC-HMS has reservoir modeling capabilities, but these are limited compared to RiverWare in that HEC-HMS uses a science-based hydrologic model while RiverWare models the type and ownership of the water in the system to identify the owner of water based on water rights priority at any location. RiverWare also allows for prioritizing of different objectives, such as water diversion, flood control, environmental flow compliance, etc., making it possible to solve very complex water resources problems.

In addition to RiverWare, the USACE-developed HEC-HMS and HEC-RAS models are necessary to fully address the HMGs checklist. The three models have different strengths in responding to the questions posed in the HMGs and need to be used collaboratively as none of them individually provide the full picture of potential impacts caused by proposed project conditions.

5.2 Model Descriptions

This section describes several different models used in the analysis of the project with specific attention to the three models developed as part of this analysis: HEC-HMS, RiverWare, and HEC-RAS.

1. **USACE-developed HEC-HMS** is designed to simulate the complete hydrologic processes of dendritic watershed systems. It can be applied to a wide range of geographic areas in solving a wide range of problems, including large river basin water supply, water withdrawal, flood hydrology, and small urban or natural watershed runoff. Flow time series produced by the model can be used in conjunction with other software for studies of water availability, urban drainage, flow forecasting, future urbanization impact, reservoir spillway design, flood damage reduction, floodplain regulation, and systems operation. The software includes many traditional hydrologic analysis procedures such as event infiltration including evapotranspiration, snowmelt, and soil moisture accounting (USACE, 2018).

   The primary purpose of the model for this analysis is to identify and process hydrologic data including instream flows and precipitation. Rainfall-runoff modeling with HEC-HMS based on gauged precipitation and upstream inflows provided results of river flows into and downstream of the proposed project. The results from HEC-HMS are flow hydrographs at points in the watershed where flows are not controlled by the proposed project operations.
2. **RiverWare** is a reservoir and river basin modeling software decision support tool. Users can model the topology, physical processes, and operating policies of river and reservoir systems to make decisions on how to operate these systems by understanding and evaluating the trade-offs among the various basin operation and management objectives, in both simulation and forecast modes. The model's wide variety of applications range from short-term operations to long-term water resources planning, which includes hydropower optimization, reservoir operation optimization, water accounting, water quality, environmental flows, and climate change assessments. The Bureau of Reclamation, the Tennessee Valley Authority, and the USACE sponsor ongoing RiverWare research and development. It is an ideal platform for operational decision-making, responsive forecasting, operational policy evaluation, system optimization, water accounting, water rights administration, and long-term resource planning (University of Colorado at Boulder, 2019).

   For this analysis, the primary purpose of this analysis is the prioritization tools for water rights and instream flows. Using outputs from HEC-HMS combined with user defined operating rules and scheduled withdrawals and releases, RiverWare simulated reservoir operations for the pre-defined 50-year analysis horizon.
3. **USACE HEC-RAS** is a computer program that models hydraulics of water flow through natural rivers, man-made channels, lakes, and reservoirs. The model can perform one-dimensional steady flow, one- and two-dimensional unsteady flow, sediment transport, and water temperature/water quality modeling. The HEC-RAS model is being developed as a part of the Hydrologic Engineering Center's "Next Generation" (NexGen) of hydrologic engineering software, which will encompass several aspects of hydrologic engineering, including rainfall-runoff analysis, river hydraulics, reservoir system simulation, flood damage analysis, and real-time river forecasting for reservoir operations (USACE, 2018).

For this project, river hydraulics were performed with HEC-RAS using unsteady flow modeling for selected drought, average, and storm events from the hydrographs produced by HEC-HMS, HEC-RAS–computed water surface profiles, velocity, and stage hydrographs. When used in conjunction with Habitat Suitability Criteria, weighted usable area for certain species habitat were calculated.

5.2.1 Water Availability Model

The TCEQ WAM is a computer-based simulation predicting the amount of water in a river or stream under a specified set of conditions. The model is used in evaluating water rights applications to help determine if water would be available for a newly requested water right or amendment, or if an amendment might affect other water rights. The WAM model is used by Dow and the TCEQ in predicting available flows for water rights in the Brazos River. However, the model cannot be calibrated against gauge records and therefore is insufficient for modeling and analysis needs for the proposed project.

5.3 Modeling Assumptions

Due to the conceptual, planning-level nature of the modeling performed for this study, several assumptions were made based on available data, synthesis of multiple data sources provided by Dow, and engineering judgement. Primary assumptions are noted below, and where relevant, further details are provided in **Section 5.4 Modeling Methodology**.

1. All elevations and project survey are based on vertical datum NAVD88.
2. Modeling was performed in HEC-HMS version 4.3, HEC-RAS unsteady flow version 5.0.7, HEC-RAS steady flow version 5.0.7, and RiverWare version 7.5.3.
3. HEC-RAS unsteady flow was used for routing flows along the Brazos River, whereas HEC-HMS was used to generate flow hydrographs for use in RiverWare and HEC-RAS unsteady flow and was not used for hydrologic routing along the Brazos River in this study.
4. HEC-HMS and HEC-RAS models were not available downstream of the portion of the Oyster Creek watershed where existing and future discharges will occur from the existing Harris Reservoir and proposed Harris Reservoir. Therefore, this analysis is based on analysis of available data and modeling results related to discharges from the Harris Reservoirs presently.
5. The following models were used as a basis for the modeling performed for this study:
   a. FPP HEC-HMS provided by Brazos River Authority
   b. FPP HEC-RAS unsteady flow provided by Brazos River Authority
   c. HEC-RAS steady flow Oyster Creek model by Baker and Lawson and provided by Dow as a HEC-2 model
   d. HEC-HMS hydrologic model of Oyster Creek by Jacobs
   e. HEC-RAS steady flow model of Oyster Creek by Jacobs
6. In its USACE application, Dow estimated the existing reservoir storage capacity at 7,000 ac-ft for the existing Harris Reservoir and 21,000 ac-ft for Brazoria Reservoir, providing a combined 28,000 ac-ft of existing water storage. A 2020 survey from Doyle and Wachtstetter provided an updated value of 27,343 ac-ft for effective storage that supersedes the application values presented by Dow. It is assumed that future, routine sediment removal maintenance operations will be performed to increase existing reservoir storage capacities.

7. During initial HEC-HMS modeling, existing conditions operations were simulated with numerical relationships rather than with physical structures and pumps due to the manual adjustments regularly made by Dow's operators that override set operational parameters. While this type of manual operation provides "real time" operational control to Dow, it is impractical to capture each detailed nuance within static modeling relationships and conceptual operational protocols for the reservoir modeling and routing. During the initial modeling, the diversions into the existing Harris Reservoir and Brazoria Reservoir are simulated with an inflow-diversion relationship (i.e., flow diverted into the reservoirs is based on flow in the Brazos River).

   Discharge from the existing Harris Reservoir and Brazoria Reservoir was based on storage-discharge relationships (i.e., discharge from the reservoir into Oyster Creek and the Brazos River, respectively, based on storage in the reservoir at a given time step). Operations of the proposed Harris Reservoir were similarly simulated. However, modeling results with this conceptual approach were not reflective of the actual reservoir operation, inflows, discharges, and water levels.

   As such, the modeling approach was changed to use historical operational data for the existing Brazoria and existing Harris Reservoirs, including diversions into the reservoirs and discharges out of the reservoirs. The proposed Harris Reservoir was simulated with similar, but scaled up, operational parameters as the existing Harris Reservoir.

8. Since detailed operational protocol and parameters were not available for the proposed Harris Reservoir, the historical operation data (i.e., inflows from the Brazos River and discharges to Oyster Creek) for the existing Harris Reservoir were scaled up proportionately based on the proposed storage volume versus the existing storage volume.

9. The elevation-volume relationship for the proposed Harris Reservoir was estimated from available design details using the conic approximation method and did not account for detailed bottom grading, if any. It was then adjusted to match the total volume provided by Dow. Small changes to the total estimated volume or the elevation-volume relationship will not have a significant effect on results of this study.

10. Rainfall gage data were not available for the entire period of record for the analysis based on historical operational parameters. As such, precipitation in the lower reach of the Brazos River below the Rosharon gage was neglected for part of the analysis as watershed processes in the Brazos River are driven by the large upstream watershed effects rather than by local rainfall.

11. HEC-RAS unsteady flow of the Brazos River was not stable with the negative (flow leaving) diversions into the existing and proposed Harris Reservoir. To stabilize the model and provide a basis of comparison, the diversions into the Harris Reservoir and diversions into and discharges from the Brazoria Reservoir were excluded. The increased diversion into the proposed Harris Reservoir was simulated by adding the diverted flows in existing conditions and removing them in proposed conditions.

12. Consistent with the project description, it was assumed that the entire Harris Reservoir expansion would be constructed at once and not phased.

13. The objective of the analysis was to evaluate the operation and potential water resources impacts of the proposed Harris Reservoir as designed. As such, the effects of changes in location, volume, or operations were not evaluated.

A detailed modeling was performed to determine the potential impacts of proposed Harris Reservoir on Oyster Creek. *Oyster Creek Downstream Hydrologic and Hydraulic Impacts Final Report (October 2021)* provides this study and its results.

5.4 Modeling Methodology

This section describes the site-specific model development for the hydrologic, hydraulic, and reservoir operational models.

5.4.1 Brazos River HEC-HMS

The Brazos River HEC-HMS model used in this study was taken from the BRA Lower Brazos Flood Protection Planning Study (FPP) HEC-HMS hydrologic model that was approved by the BRA in March 2019 (Halff, 2019). The original model was truncated upstream of the Richmond USGS gage to reduce run times and eliminate unnecessary data, as none of the sub-basins upstream of the gage are part of the area of study for this report (see **Figure 22** and **Figure 23**). While the study area extends from the Rosharon gage to the outlet of the Brazos River at the Gulf of Mexico, the reach upstream was extended to the Richmond gage to provide a more comprehensive model in the project vicinity.

The original FPP study model did not include either the existing Harris or Brazoria Reservoirs that are operated by Dow. These two reservoirs and their corresponding diversions along the Brazos River were added to the existing conditions model along with applicable routing reaches to connect back downstream to the Brazos River and to account for discharge of flows from the existing and proposed Harris Reservoir into Oyster Creek. The proposed/expansion condition model included all the aforementioned model elements, but a diversion was added upstream of the existing Harris Reservoir to tie into the proposed Harris Reservoir, which was also added to the HEC-HMS model based on the current CH2MHill design (**Figure 24**).

All hydrologic modeling was performed in HEC-HMS version 4.3 following standard modeling procedures for conceptual or planning-level analysis. The modeling simulations were run on daily time steps, which is appropriate for continuous simulation modeling covering this timeframe, and consistent with the original HEC-HMS model. Summarized HEC-HMS basin model names are in **Table 5,** and the models are included in **Appendix A**.

Figure 22 shows a visual representations of the drainage areas, reservoirs, and sub-basins involved with the exsisting conditions project modeling. The polygons shown in green are part of the Brazos River watershed and are upstream of the project area. The area highlighted in yellow is the original drainage area for B_BRA_410 called B_BRA_410_original. Next to B_BRA_410_original is BRA_410, which is the area used within the existing condition model and includes the area within the existing Harris Reservoir.

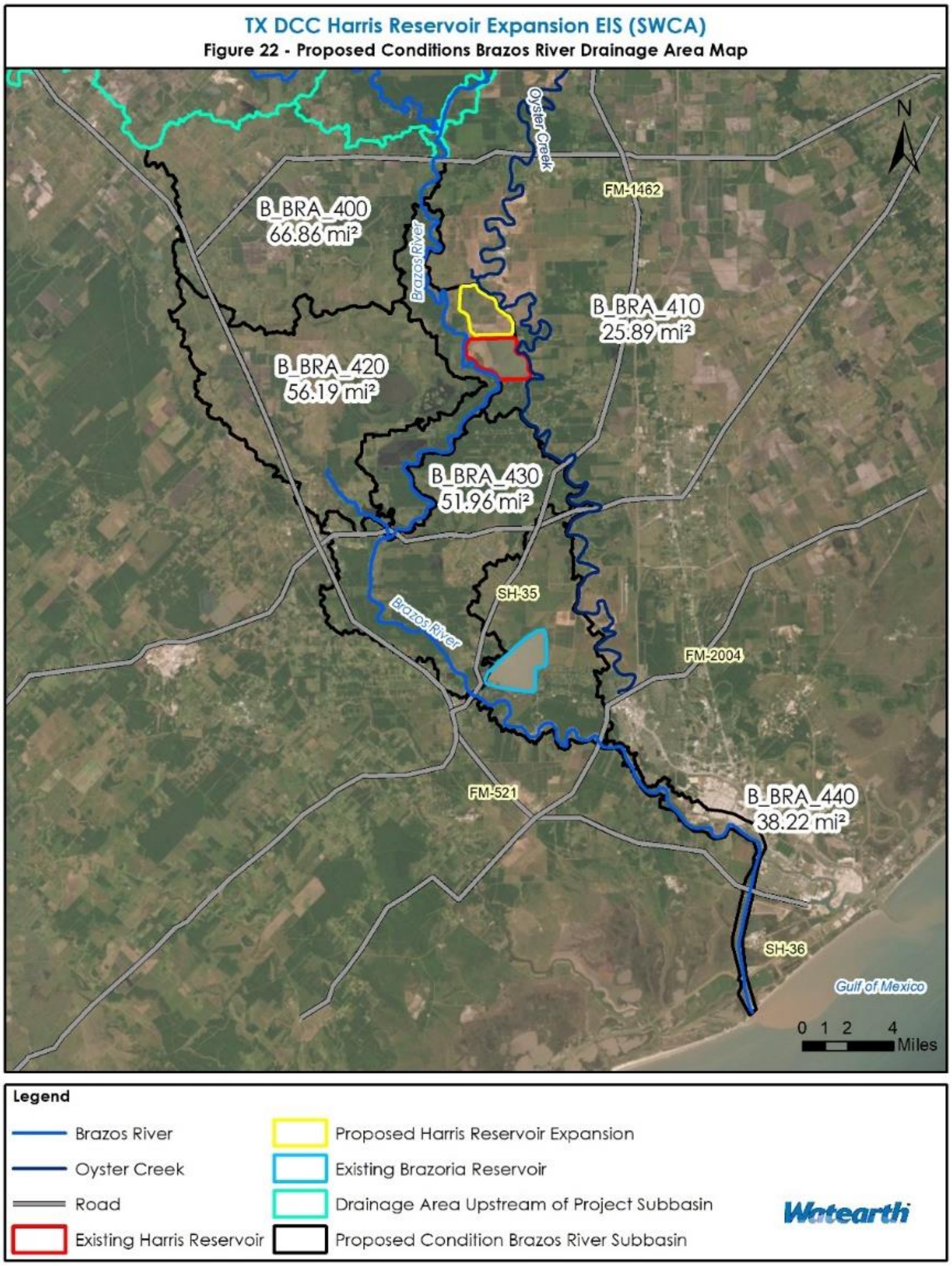


***Figure 22**: Brazos River existing conditions for HEC-HMS model.*

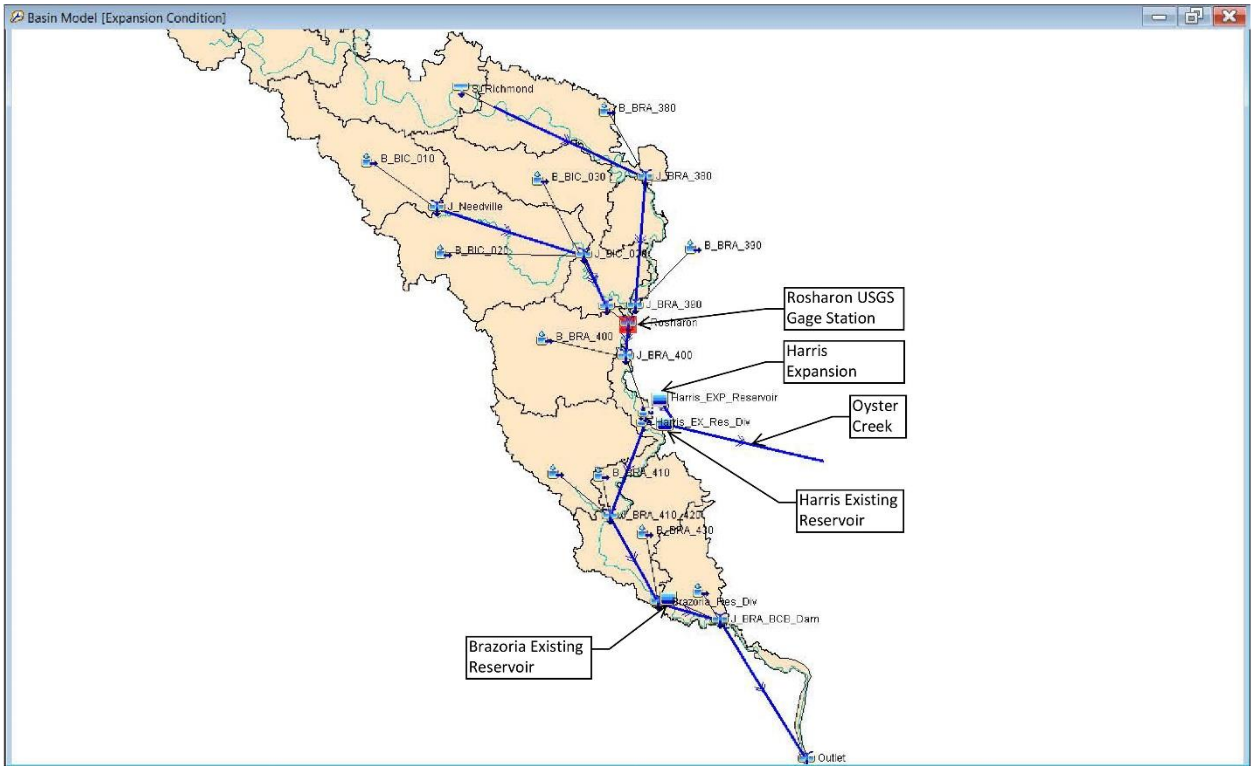


***Figure 23**: HEC-HMS model for Harris Reservoir Expansion Project.*

Table 5: HEC-HMS Basin Model Names

Analysis Conditions	Model Name
Base Conditions[1]	HMS v4.0 B_BRA_410_original
Existing Conditions[2]	Harris_Reservoir_HMS_v4.3 BRA_410 Brazos_Model_Harris_Res_1_6.hms
Proposed Conditions[3]	Harris_Reservoir_HMS_v4.3 Brazos_Model_Harris_Res_1_6.hms

[1]Base conditions are the original model obtained from Brazos River Authority.
[2]The existing conditions model adds the existing Brazoria and Harris Reservoirs to the original model.
[3]The proposed conditions model adds the proposed Harris Reservoir to the existing model.

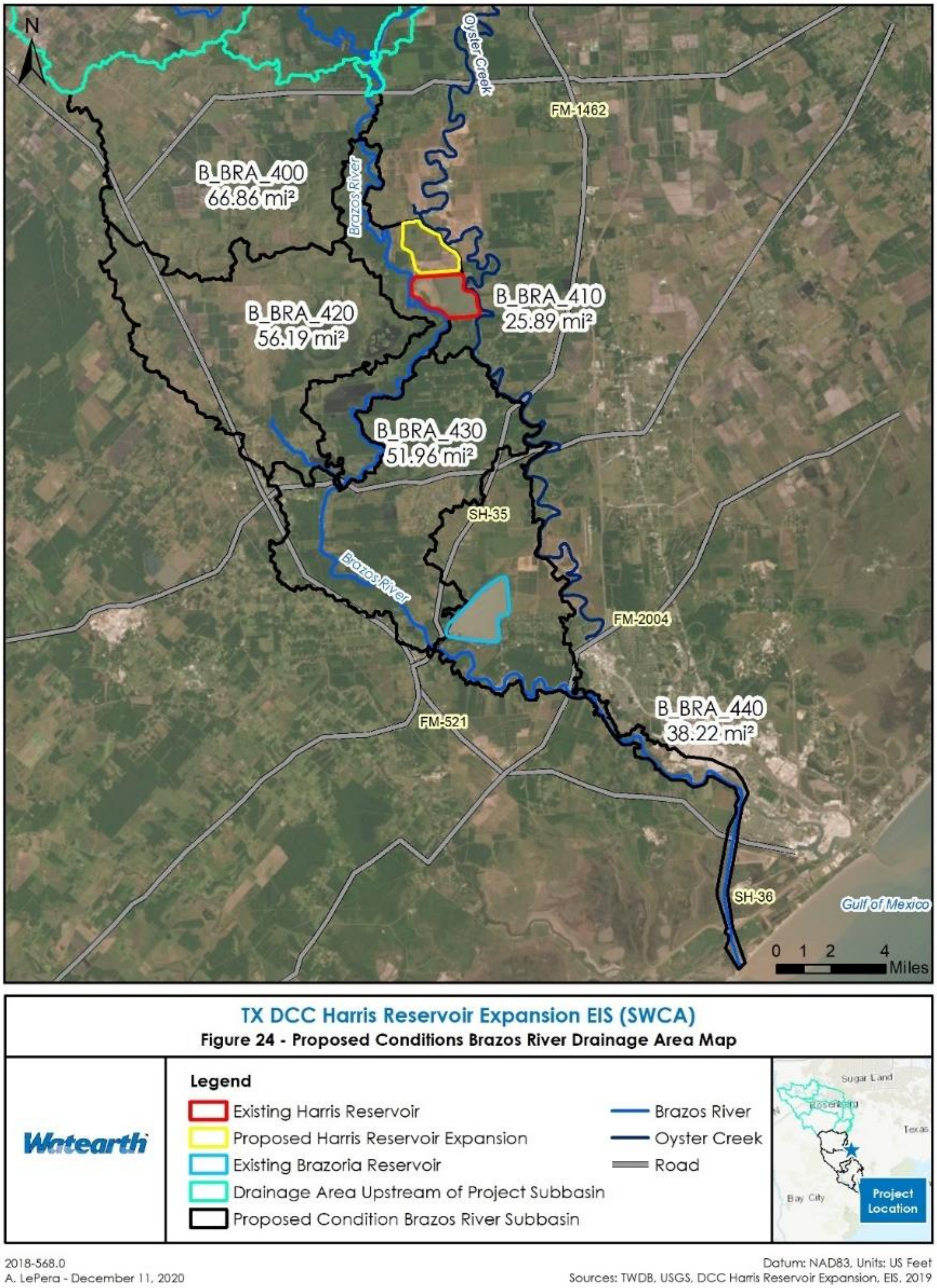


***Figure 24**: Brazos River proposed conditions in HEC-HMS model.*

5.4.1.1 Meteorological and Rainfall Data

The meteorological and rainfall data used in the original FPP HEC-HMS model were not maintained for this study. The NOAA National Climatic Data Center (NCDC) Richmond and Thompson rainfall gages were used to capture hourly rainfall data and rainfall patterns for the 42-year period of record from January 1, 1979, through December 31, 2010. The 42-year record captures historical drought and high rainfall years. For the purposes of this analysis, the simulation was run for the period of record from January 1, 2009, through May 6, 2019, due to the availability of measured inflows and outflows from the existing reservoirs. New gage data were acquired for the study; however, the data could not be used in the model because there was missing data from the new set of acquired data. The meteorological model with missing data prevented the HMS model from running stable, so the data for the Richmond and Thompson gages were omitted from the model. Since the rainfall data have little effect on the Brazos River, it was appropriate to exclude the meteorological data in the model for the entire simulation period.

Consistent with the original HEC-HMS model, the gage weights method was used to assign one gage for time weighting for each drainage sub-basin and percentages of each of the two gages for depth weighting for each drainage sub-basin. While a continuous simulation model, neither tree canopy interception nor evaporation were considered in the original HEC-HMS hydrology model, or the existing or proposed conditions models modified for this study.

5.4.1.2 Gage Data

Historical USGS daily maximum flows at the Richmond and Rosharon gages from January 1, 2009, through May 6, 2019, were used in the hydraulic analysis (see **Figure 13** and **Figure 14**). The Richmond gage was input at HEC-RAS junction J_BRA_380 to represent discharge from the entire Brazos River watershed upstream of this junction. The Rosharon gage was placed at HEC-RAS junction J_Rosharon as an observed flow gage. The gage data in the original HEC-RAS model did not cover the new analysis period. Furthermore, the data for the Rosharon gage extended through the full simulation period but contained data gaps. Gage data for the Richmond and Rosharon gages are provided in **Figure 25** and **Figure 26.**

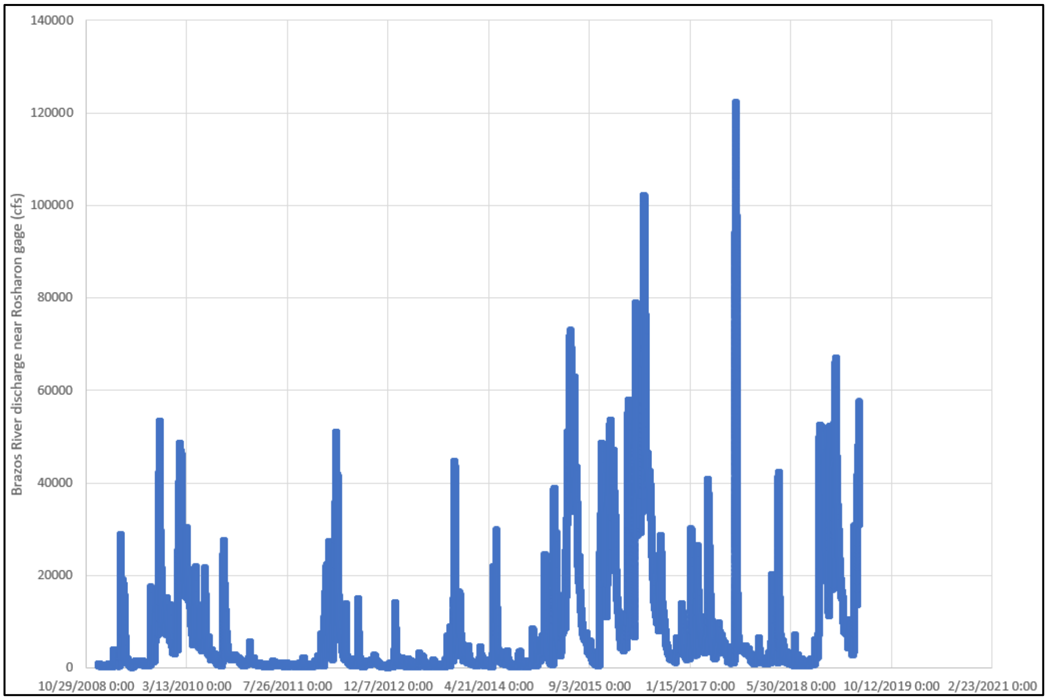


Figure 25*: Flow for Brazos River for the USGS Richmond gage from January 1, 2009, through May 6, 2019*

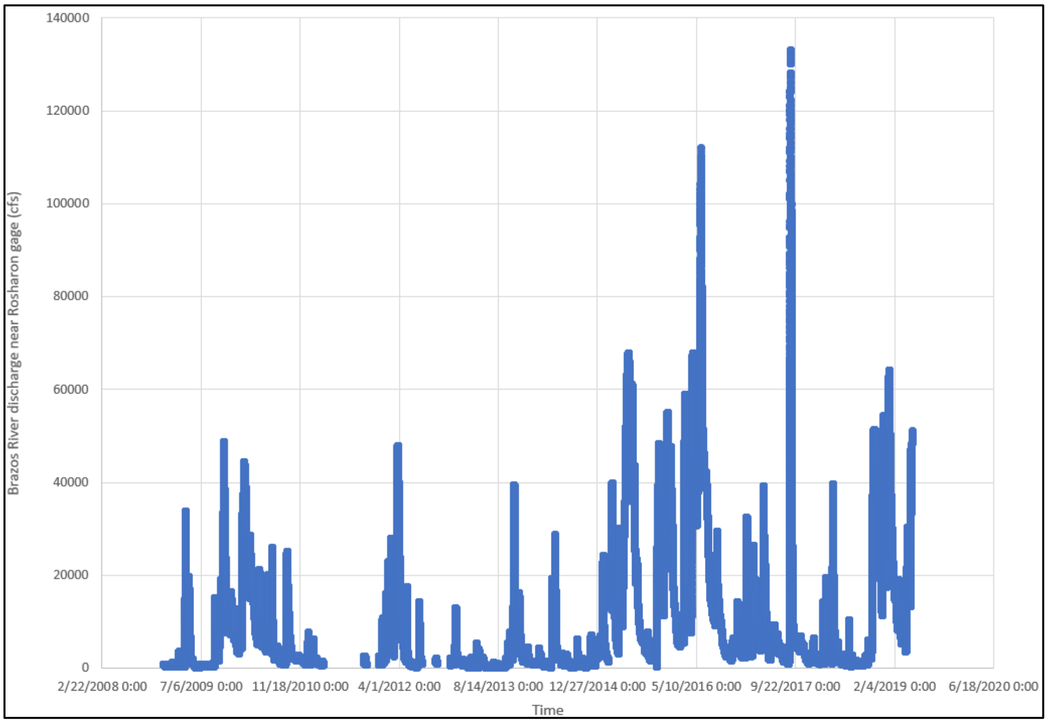


Figure 26*: Flow for the Brazos River for the USGS Rosharon gage from January 1, 2009, through May 6, 2019.*

5.4.1.3 Drainage Sub-Basins

The portions of the Brazos River watershed included in the HEC-HMS model are depicted in **Figure 22** and **Figure 24**. As stated previously, both the Richmond and Rosharon gages are included in the model, although results reporting are focused from the Rosharon gage to the outlet at the Gulf of Mexico.

The existing approximately 1,873-ac (2.93-sq mi) Brazoria Reservoir is located in the B_BRA_440 drainage sub-basin. The approximately 1,616-ac (2.53-sq mi) existing Harris Reservoir and approximately 1,776-ac (2.78-sq mi) proposed Harris Reservoir are located adjacent to the B_BRA_410 drainage sub-basin but are outside the drainage sub-basin boundary in the original model. For existing conditions, the B_BRA_410 drainage sub-basin boundary was expanded to include the existing Harris Reservoir, and for proposed conditions, the boundary was further expanded to include the proposed Harris Reservoir. As shown in **Table 6**, the B_BRA_410 drainage sub-basin area was increased from the original 20.3 sq-mi to 22.8 sq-mi and 25.6 sq-mi in existing and proposed conditions, respectively. Due to the planning level nature of this analysis, sub-watersheds were not further subdivided.

Table 6: Original, Existing, and Proposed Brazos River Sub-Basin Area Parameters Downstream of Rosharon Gage, Texas

Drainage Sub-Basin Name	Original Area (mi^2)	Exist. Area (mi^2)	Prop. Area (mi^2)
B_BRA_400	66.9	66.9	66.9
B_BRA_410	20.3	22.8	25.6
B_BRA_420	56.2	56.2	56.2
B_BRA_430	52.0	52.0	52.0
B_BRA_440	38.2	38.2	38.2

5.4.1.4 Hydrologic Parameters

The FPP models use the Clark Unit Hydrograph Method, which is a commonly used method in the region, to generate unit hydrographs and transform them into runoff hydrographs. The specific unit hydrograph transformation parameters are the time of concentration (Tc) in hours (hrs) and the Clark's Storage Coefficient (R value) in hours. The Exponential Loss Method is used to account for soil losses (i.e., infiltration) and is an appropriate loss method for continuous simulation analyses. Due to the planning-level nature of this analysis, all existing conditions hydrologic parameters were left unchanged with the exception of impervious cover.

Impervious cover is used to reflect the percent of each drainage sub-basin occupied by impervious cover that does not allow infiltration of rainfall (or create losses). Areas not occupied by impervious cover are referred to as pervious cover and include all permeable surfaces (i.e., lawns, fields, landscaped areas, etc.). Drainage sub-basins with lower impervious cover, such as the project area, are less developed and have higher potential for infiltration. More developed areas with higher impervious cover have less potential for infiltration and higher runoff from a given rainfall event.

Due to the underlying clay soils, infiltration from the existing Brazoria and Harris Reservoirs and proposed Harris Reservoir is expected to be minimal, especially in saturated and prolonged rainfall conditions. As such, the reservoir surface areas were assumed to be 100% impervious consistent with local hydrology practices and the existing and proposed impervious cover values associated with the drainage areas. The drainage areas containing the reservoirs were adjusted as these areas were not included as impervious cover in the original study.

The existing Harris Reservoir and proposed Harris Reservoir are generally located within drainage sub-basin B_BRA_410, which was expanded to include the proposed Harris Reservoir. Accounting for the approximately 1,616-acre (2.53 sq-mi) existing Harris Reservoir the expansion increases the existing conditions impervious cover in the 22.8 sq-mi existing B_BRA_410 drainage sub-basin from 2.4% to 11.1%. The approximately 1,776-acre (2.78 sq-mi) reservoir expansion increases the total impervious cover in B_BRA_410 in proposed conditions to 5.31 sq-mi, resulting in an overall 20.7% impervious cover in the 25.6 sq-mi drainage sub-basin in proposed conditions. The Tc and storage coefficient for proposed sub-basin B_BRA_410 was left unchanged in the model because the reservoirs are not located within the largest flow path in the drainage area, resulting in minimal impacts to modeling.

The existing approximately 1,873-acre (2.93-sq mi) Brazoria Reservoir is located in the B_BRA_440 drainage sub-basin. Accounting for the reservoir surface area in the impervious cover increases the existing impervious cover in B_BRA_440 from the 7.7% reported in the original study to 5.56 sq-mi, or 14.6% impervious cover. This value remains constant between existing and proposed conditions. Hydrologic parameters for the drainage sub-basins located between the Rosharon gauge and the downstream end of the HEC-HMS model or outlet into the Gulf of Mexico are summarized in **Table 7**. The drainage sub-basins located between the Richmond and Rosharon gages are not included in **Table 7** for brevity.

Table 7: Original, Existing, and Proposed Brazos River Hydrologic Parameters Downstream of Rosharon Gage, Texas

Drainage Sub-Basin Name	Original Area (mi^2)	Exist. Area (mi^2)	Prop. Area (mi^2)	Tc (hr)	Storage Co-efficient (R-Value)	Original Impervious Cover	Existing Impervious Cover	Proposed Impervious Cover
B_BRA_400	66.9	66.9	66.9	9.13	31.74	3.4	3.4	3.4
B_BRA_410	20.3	22.8	25.6	13.62	837.35	2.4	14.7	23.8
B_BRA_420	56.2	56.2	56.2	13.25	31.25	3.8	3.8	3.8
B_BRA_430	52.0	52.0	52.0	6.83	51.87	6.0	6.0	6.0
B_BRA_440	38.2	38.2	38.2	3.19	54.65	7.7	14.6	14.6

5.4.1.5 Routing Reaches

Reach routing methods were not used in HEC-HMS for the reaches along the Brazos River as all hydrograph routing is performed in the HEC-RAS unsteady flow model for both this study and the original models. Hydrographs were computed in HEC-HMS and the reaches are used to orient the model spatially and geographically and to translate the hydrographs from an upstream junction to a downstream junction. While the hydrographs are translated, there is no real attenuation (dampening of flows) or lag (delay to account for travel time) as these effects of routing or accounted for in the dynamic, or unsteady flow hydraulic routing performed in HEC-RAS unsteady flow. Consistent with the original HEC-HMS model, the Muskingum Cunge reach routing method was maintained for the remaining tributary in the truncated model between the Richmond gage and the Rosharon gage (from Junction J_Needville to Junction J_Rosharon).

Routing reaches (without routing methodology) were added from the existing Harris Reservoir and the proposed Harris Reservoir to simulate flows leaving the system and entering the Oyster Creek system and are named R_OC_Harris_EX and R_OC_Harris_PRO, respectively.

5.4.1.6 Reservoir Data

The elevation-volume relationship for the existing Harris and Brazoria Reservoirs are displayed in **Table 8** and **Table 9.** As previously discussed, total effective storage of 27,343 ac-ft is based on the 2020 Doyle and Wachtstetter survey, which is composed of existing Harris and Brazoria Reservoir volumes of 9,136 ac-ft and 18,207 ac-ft, respectively. The HEC-RAS modeling elevation-volume relationships were developed using the conic approximation method. For the Harris Reservoir, a surface area of 1,591 ac was used at top of overflow weir elevation 42.50 ft, and zero ac at the reservoir bottom 33 ft elevation. For the Brazoria Reservoir, a surface area of 1,850.7 ac was used at top of overflow weir elevation 31.05 ft, and zero ac at the reservoir bottom 13.0 ft elevation.

The 2020 Doyle and Wachtstetter survey reports that reservoir water surface elevations and volumes are higher than the top of the overflow weirs, which are summertime reservoir elevation target levels following Dow's freeboard management practices.

The proposed Harris Reservoir storage volume was estimated at 51,796 ac-ft using the conic approximation method. This volume and associated elevation-volume relationship were adjusted downward by applying a 98.4% factor to match the volume of 50,968 ac-ft reported by Dow (**Table 10**).

Table 8: Existing Harris Reservoir Elevation-Volume Relationship

Stage (ft)	Area (sq-ft)	Area (ac)	Incremental Storage Volume (ac-ft)	Cumulative Storage Volume (ac-ft)
33.00	113,256	2.6	0	0.3
33.50	387,684	8.9	3	3.3
34.00	675,180	15.5	5.9	9.2
34.50	1,454,904	33.4	11.6	20.8
35.00	5,566,968	127.8	34.2	55.0
35.50	13,895,640	319.0	112.9	167.9
36.00	21,993,444	504.9	205.8	373.7
36.50	29,276,676	672.1	295.1	668.8
37.00	36,908,388	847.3	377.6	1,046.4
37.50	50,011,236	1,148.1	493	1,539.4
38.00	58,570,776	1,344.6	618.9	2,158.3
38.50	63,867,672	1,466.2	702.9	2,861.2
39.00	66,694,716	1,531.1	752.0	3,613.2
39.50	68,092,992	1563.2	774.6	4,387.8
40.00	68,615,712	1575.2	785.4	5,173.2
40.50	68,829,156	1580.1	789.1	5,962.3
41.00	68,972,904	1583.4	791.1	6,753.4
41.50	69,099,228	1586.3	792.7	7,546.1
42.00	69,221,196	1589.1	794.1	8,340.2
42.50	69,312,672	1591.2	795.3	9,135.5
43.00	69,421,572	1593.7	768.2	9,903.7
43.50	69,547,896	1596.6	797.6	10,701.3

Stage (ft)	Area (sq-ft)	Area (ac)	Incremental Storage Volume (ac-ft)	Cumulative Storage Volume (ac-ft)
44.00	69,669,864	1599.4	799.0	11,500.3
44.50	69,783,120	1602	800.4	12,300.7
45.00	69,896,376	1604.6	801.8	13,102.5
45.50	70,009,632	1607.2	802.9	13,905.4
46.00	70,118,532	1609.7	804.3	14,709.7
46.50	70,310,196	1614.1	806.5	15,516.2
47.00	70,371,180	1615.5	807.4	16,323.6
47.50	70,410,384	1616.4	808.0	17,131.6

Table 9: Brazoria Reservoir Elevation-Volume Relationship

Stage (ft)	Areas (sq-ft)	Area (ac)	Incremental Storage Volume (ac-ft)	Cumulative Storage Volume (ac-ft)
13.0	30,492	0.7	0	0.2
13.5	69,696	1.6	0.60	0.8
14.0	08,900	2.5	1.10	1.9
14.5	12,460	3.5	1.40	3.3
15.0	248,292	5.7	2.20	5.5
15.5	422,532	9.7	3.80	9.3
16.0	701,316	16.1	6.40	5.7
16.5	1,075,932	24.7	10.00	25.7
17.0	1,794,672	41.2	16.00	41.7
17.5	3,145,032	72.2	27.80	69.5
18.0	5,841,396	134.1	49.20	118.7

Stage (ft)	Areas (sq-ft)	Area (ac)	Incremental Storage Volume (ac-ft)	Cumulative Storage Volume (ac-ft)
18.5	12,109,680	278.0	102.00	220.7
19.0	19,209,960	441.0	178.70	399.4
19.5	26,179,560	601.0	259.60	659.0
20.0	31,655,052	726.7	332.60	991.6
20.5	36,951,948	848.3	395.60	1,387.2
21.0	41,416,848	950.8	449.60	1,836.8
21.5	45,568,116	1,046.1	500.80	2,337.6
22.0	49,728,096	1,141.6	546.60	2,884.2
22.5	54,968,364	1,261.9	601.00	3,485.2
23.0	59,807,880	1,373.0	659.00	4,144.2
23.5	64,194,372	1,473.7	713.60	4,857.8
24.0	67,470,084	1,548.9	756.90	5,614.7
24.5	71,368,704	1,638.4	796.50	6,411.2
25.0	74,052,000	1,700.0	836.50	7,247.7
25.5	75,794,400	1,740.0	860.80	8,108.5
26.0	76,966,164	1,766.9	877.50	8,986.0
26.5	77,837,364	1,786.9	888.90	9,874.9
27.0	78,543,036	1,803.1	897.90	10,772.8
27.5	79,131,096	1,816.6	905.20	11,678.0
28.0	79,579,764	1,826.9	911.30	12,589.3
28.5	79,858,548	1,833.3	915.40	13,504.7
29.0	80,071,992	1,838.2	918.20	14,422.9

Stage (ft)	Areas (sq-ft)	Area (ac)	Incremental Storage Volume (ac-ft)	Cumulative Storage Volume (ac-ft)
29.5	80,241,876	1,842.1	920.30	15,343.2
30.0	80,411,760	1,846.0	922.30	16,265.5
30.5	80,538,084	1,848.9	924.10	17,189.6
31.0	80,607,780	1,850.5	925.10	18,114.7
31.05	80,616,492	1,850.7	92.50	18,207.2
31.5	80,694,900	1,852.5	833.40	19,040.6
32.0	80,760,240	1,854.0	926.60	19,967.2
32.5	80,829,936	1,855.6	927.40	20,894.6
33.0	80,912,700	1,857.5	988.30	21,882.9
33.5	80,995,464	1,859.4	869.20	22,752.1
34.0	81,082,584	1,861.4	930.30	23,682.4
34.5	81,160,992	1,863.2	931.10	24,613.5
35.0	81,252,468	1,865.3	932.10	25,545.6
35.5	81,252,468	1,865.3	933.20	26,478.8
36.0	81,417,996	1,869.1	934.10	27,412.9
36.5	81,483,336	1,870.6	935.00	28,347.9
37.0	81,526,896	1,871.6	935.50	29,283.4
37.5	81,557,388	1,872.3	935.90	30,219.3
38.0	81,570,456	1,872.6	937.30	31,156.6
38.5	81,579,168	1,872.8	935.4	32,092.0

Table 10: Proposed Harris Reservoir Elevation-Volume Relationship

Conic Approximation Method							
Stage (ft)	Embankment Slope (1H:1V)	Area (sq-ft)	Area (ac)	Incremental Storage Volume (ac-ft)	Incremental Storage Volume (ac-ft)	Cumulative Storage Volume (ac-ft)	Adjusted Storage Volume (ac-ft)
32.00	3.5	68,479,108	1572	0.00	0	0	0
40.00	3.5	70,419,590	1617	12,754	4311	4311	4,242
45.00	3.5	71,642,397	1645	8,153	8153	12464	12,265
50.00	3.5	72,872,901	1673	8,294	8294	20758	20,426
55.00	3.5	74,111,101	1701	8,436	8436	29194	28,727
60.00	3.5	75,356,999	1730	8,578	8578	37772	37,168
65.00	3.5	76,610,594	1759	8,722	8722	46494	45,751
68.00	3.5	77,366,445	1776	5,302	5302	51796	50,968
				60,239	51,796	51,796	50,968

As discussed earlier, existing conditions operations were simulated using detailed operational data provided by Dow, including diversions into the reservoirs and discharges out of the reservoirs. The proposed Harris Reservoir was simulated with similar operational parameters provided by Dow as the existing Harris Reservoir given the adjacent location in the watershed and similar diversion locations from the Brazos River and discharge locations into Oyster Creek. The proposed 50,968 ac-ft Harris Reservoir expansion is 5.58 times the existing Harris Reservoir capacity of 9,136 ac-ft. The maximum discharge capacity for the proposed Harris Reservoir is 978 cfs, and the maximum diversion from the Brazos River pump station into the proposed Harris Reservoir is 334 cfs, thus the diversion flows into the dataset were scaled up by a factor of 1.15 and reservoir discharges were scaled up by a factor of 3.51 to estimate the future diversions and discharges into and out of the proposed Harris Reservoir.

Diversions from the Brazos River into the Brazoria Reservoir were simulated by HEC-HMS model diversion Brazoria_Res_Div; diversions from the Brazos River into the existing and proposed Harris Reservoir were simulated by diversions placed at Harris_Ex_Res_Div and Harris_Pro_Res_Div, respectively. Brazoria Reservoir discharges back into the Brazos River were simulated at HEC-HMS node J_BRA_BCB_Dam, and discharges from the existing and proposed Harris Reservoirs were simulated to leave the Brazos River and enter Oyster Creek through reaches R_OC_Harris_EX and R_OC_Harris_PR, respectively. Discharges from all three reservoirs were modeled with the specified discharge outflow structure method. See **Table 11, Figure 27,** and **Figure 28** for illustrations of the diversions into and discharges out of the reservoirs.

Table 11: Existing Brazoria Reservoir and Harris Reservoir Diversion and Discharges

Reservoir Name	Flow
Brazoria Reservoir	Diversion (Max Flow)
	468 cfs
	Reservoir (Max Discharge)
	263 cfs
Harris Reservoir	Diversion (Max Flow)
	290 cfs
	Reservoir (Max Discharge)
	278 cfs
Proposed Harris Reservoir	Diversion (Max Flow)
	334 cfs
	Reservoir (Max Discharge)
	978 cfs

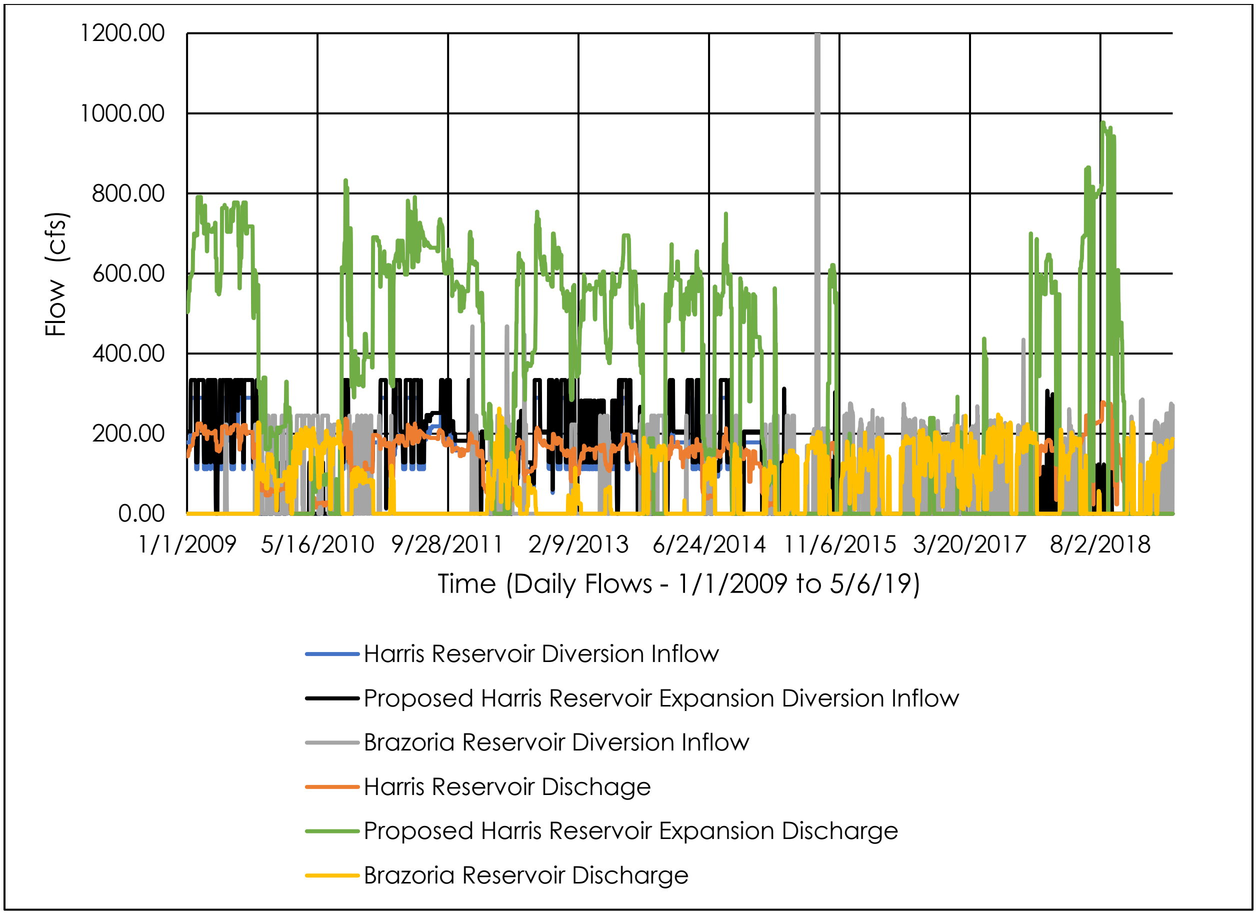


***Figure 27**: Existing Harris Reservoir, proposed Harris Reservoir, and Brazoria Reservoir diversions and discharges.*

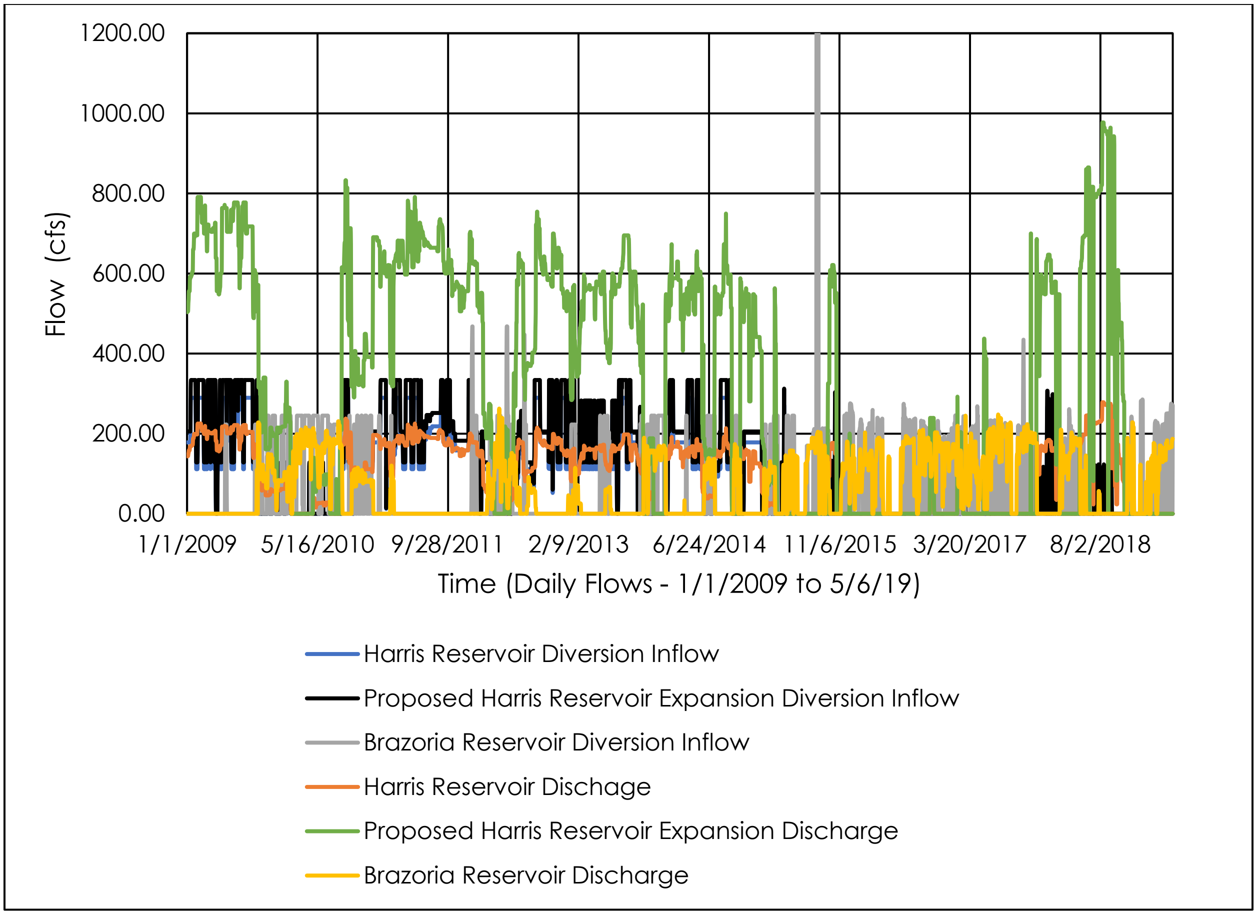


***Figure 28**: Combined flows for Harris Reservoir and proposed Harris Reservoir compared to existing Harris Reservoir diversions and discharges.*

5.4.1.7 HEC-HMS Results

Maximum flows over the 10.5-year simulation for each of the drainage sub-basins and junctions to the outlet of the Brazos River at the Gulf of Mexico based on Rosharan USGS gage data (HEC-RAS junction J_Rosharon) are listed in **Table 12**. Diversions into each of the reservoirs and discharges out of the reservoirs over the 10.5-year simulation period are shown in **Figures 29** through **49**. It should be noted that some outliers were found in the Harris Reservoir flow data (**Figure 27**, **Figure 28**, and **Figure 36** through **Figure 38**), which were normalized to the rest of the values on May 25, 2014, and September 24, 2018.

These results and modeling assumptions show no significant changes to diversions into or discharges out of the Brazoria Reservoir into the Brazos River. Similarly, modeling assumptions and results show no significant changes to diversions into or discharges out of the existing Harris Reservoir into Oyster Creek. The proposed diversion into the proposed Harris Reservoir and associated discharge into Oyster Creek significantly increase peak flows out of the combined Harris Reservoirs (existing and proposed Reservoirs) into Oyster Creek from an existing maximum of 278 cfs to a proposed maximum of 1,256 cfs.

Table 12: Table of Existing and Proposed Maximum Flows over the 10.5-Year Simulation Period

HEC HMS NODES	Existing Conditions Maximum Flows (cfs)	Proposed Conditions Maximum Flows (cfs)	Difference Between Both Conditions (cfs)
J_ROSHARON	120,000	120,000	0
HARRIS_PR_RES_DIV	-	334	N/A
HARRIS_PR_RES	-	334	N/A
R_OC_HAR_PR	-	334	N/A
HARRIS_EX_RES_DIV	290	290	0
HARRIS_EX_RES	278	278	0
R_OC_HAR_EX	278	278	0
BRAZORIA_RES_DIV	468	468	0
BRAZORIA_EX RES	263	263	0
J_BRA_BCB_DAM	119,892	119,892	0
OUTLET	119,892	119,882	0

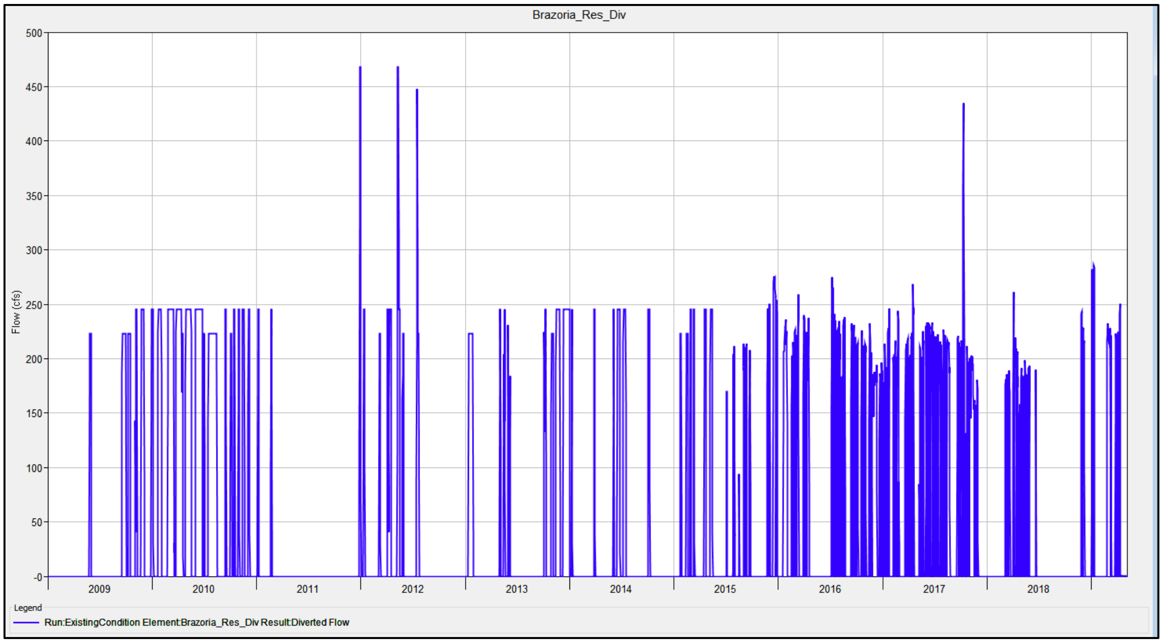


Figure 29: Existing conditions diversion into existing Brazoria Reservoir over 10.5-year simulation period.

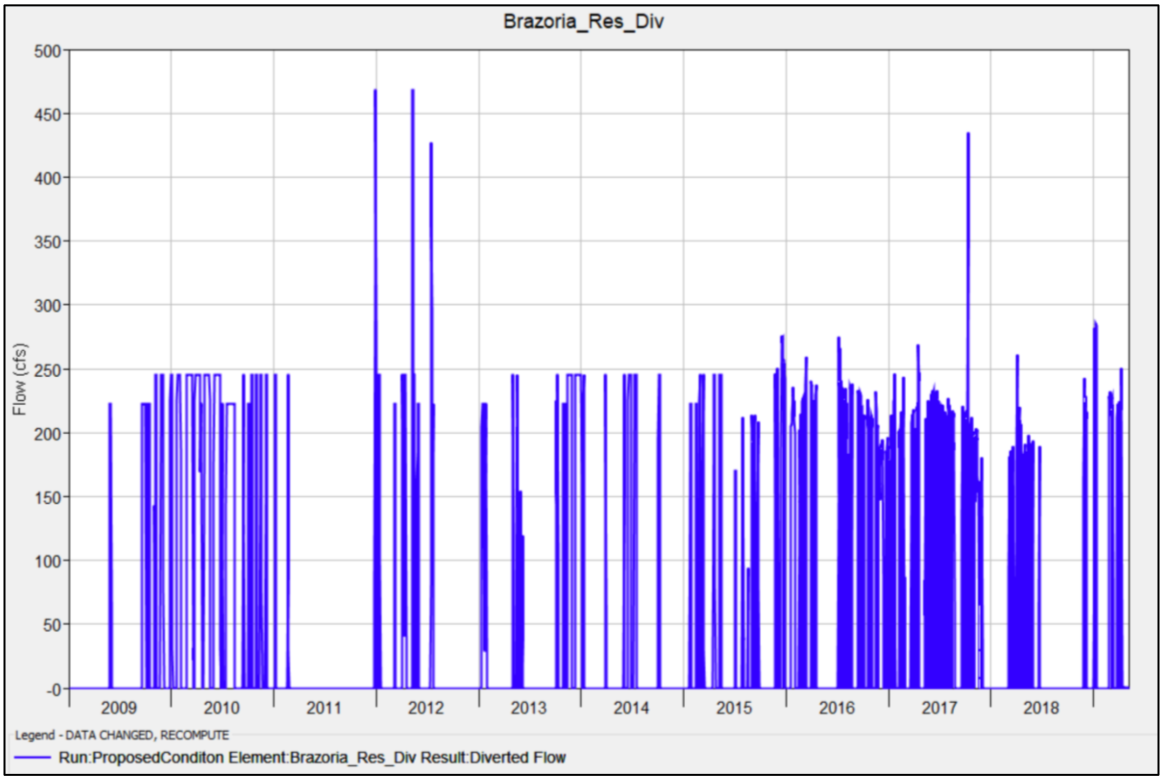


Figure 30: Proposed conditions diversion into existing Brazoria Reservoir over 10.5-year simulation period.

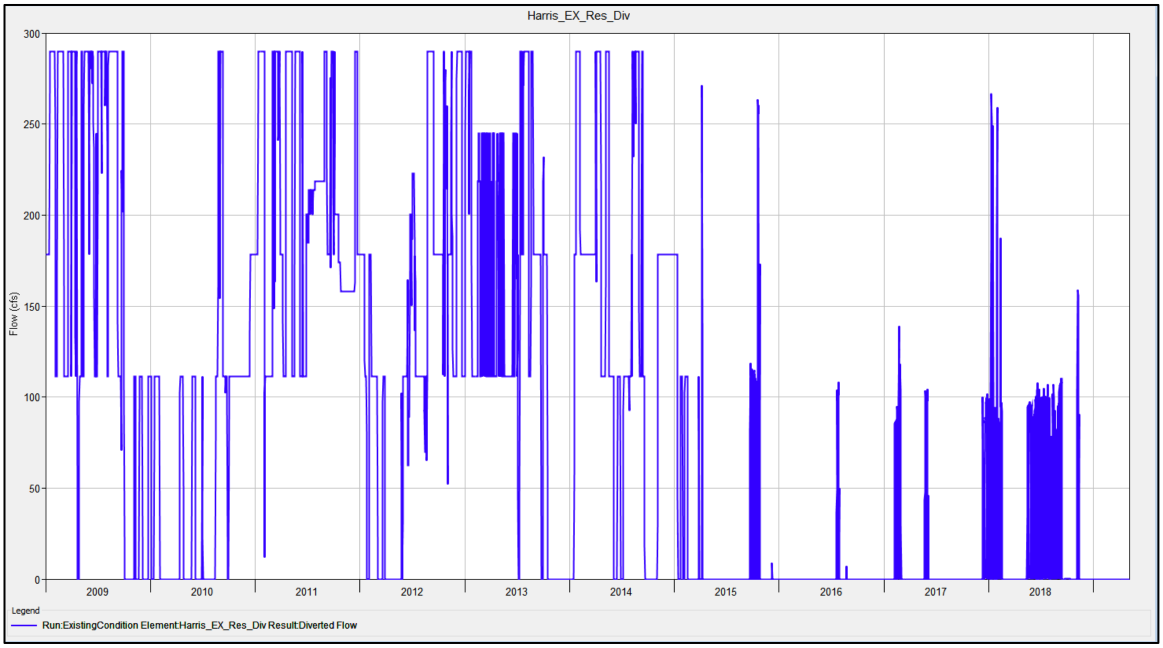


***Figure 31**: Existing conditions diversion into existing Harris Reservoir over 10.5-year simulation period.*

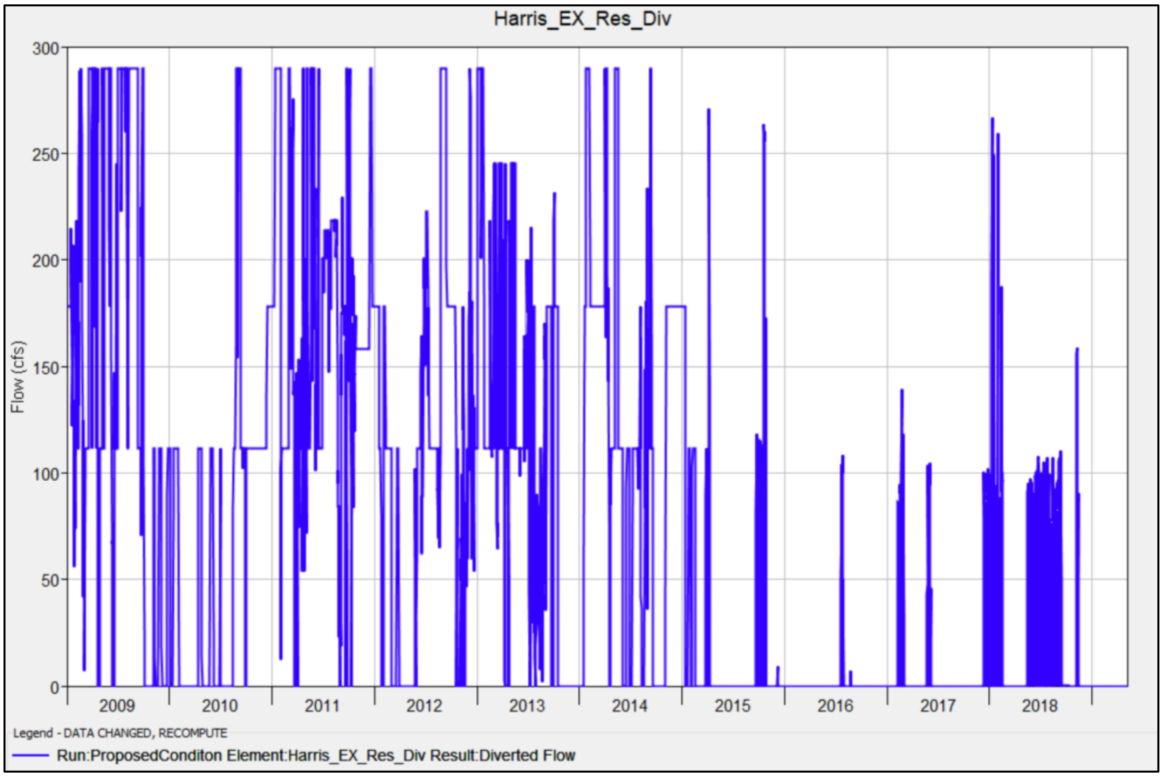


***Figure 32**: Proposed conditions diversion into existing Harris Reservoir over 10.5-year simulation period.*

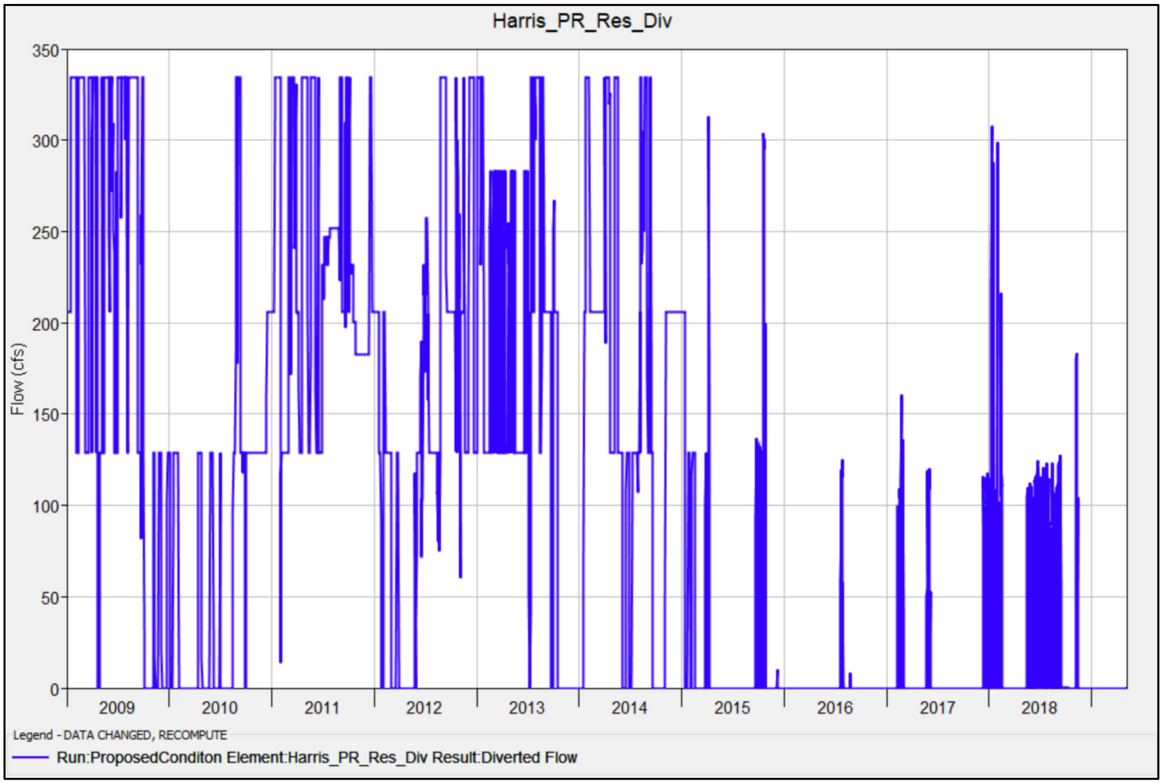


***Figure 33**: Proposed conditions diversion into proposed Harris Reservoir over 10.5-year simulation period.*

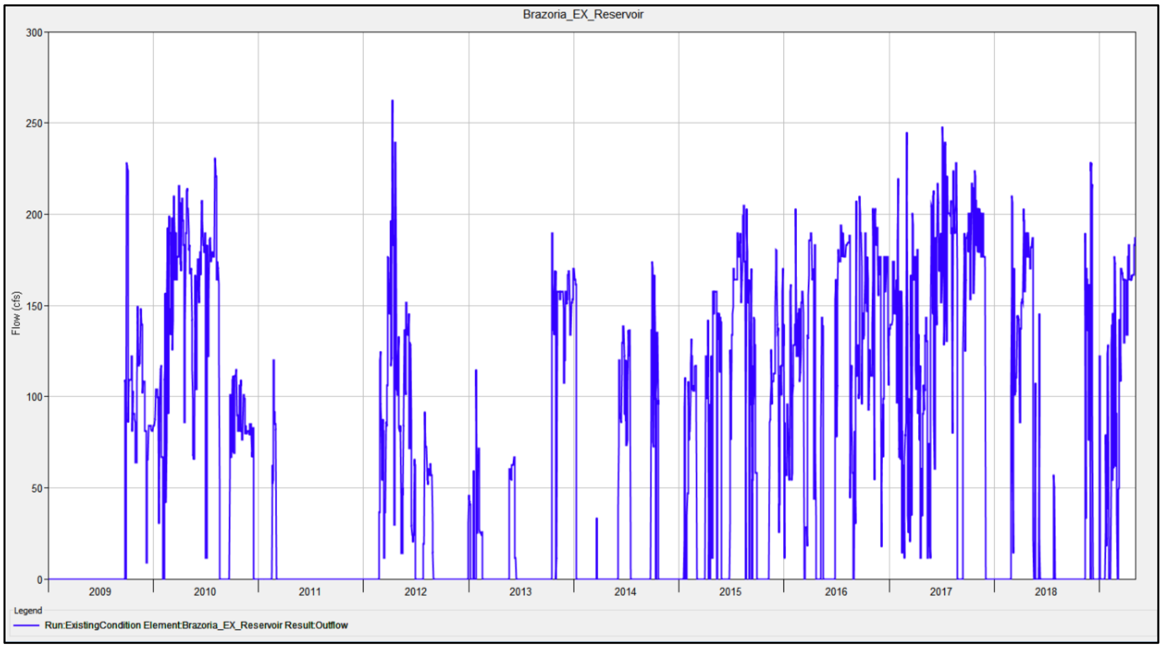


***Figure 34**: Existing conditions discharges from existing Brazoria Reservoir over 10.5-year simulation period.*

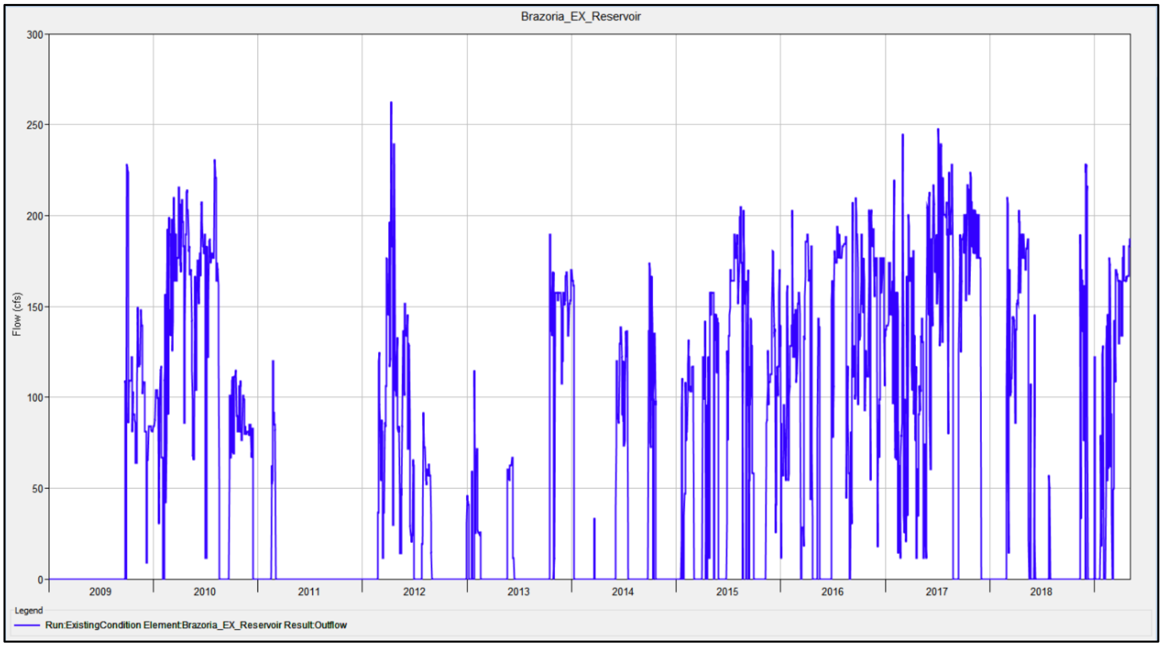


***Figure 35**: Proposed conditions discharges from existing Brazoria Reservoir over 10.5-year simulation period.*

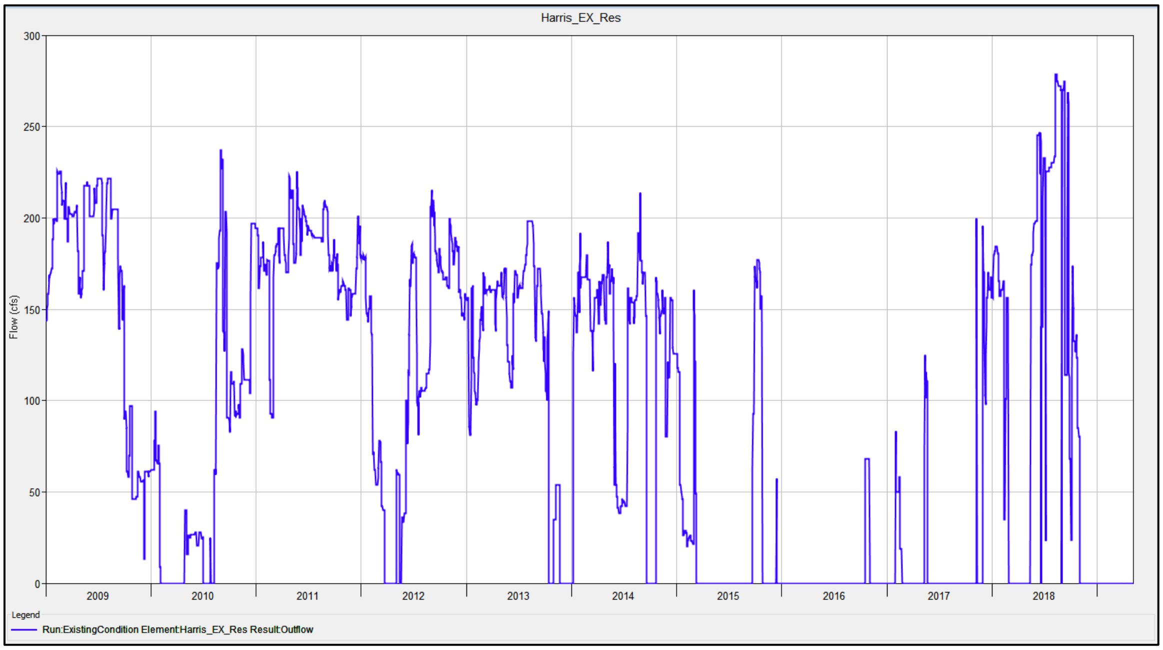


***Figure 36**: Existing conditions discharges from existing Harris Reservoir over 10.5-year simulation period. Note: Large spikes were noted in the May 25, 2014, and September 24, 2018, flow data (not shown in the hydrograph,) which appeared to be outliers. The flows on those dates were normalized to the rest of the data.*

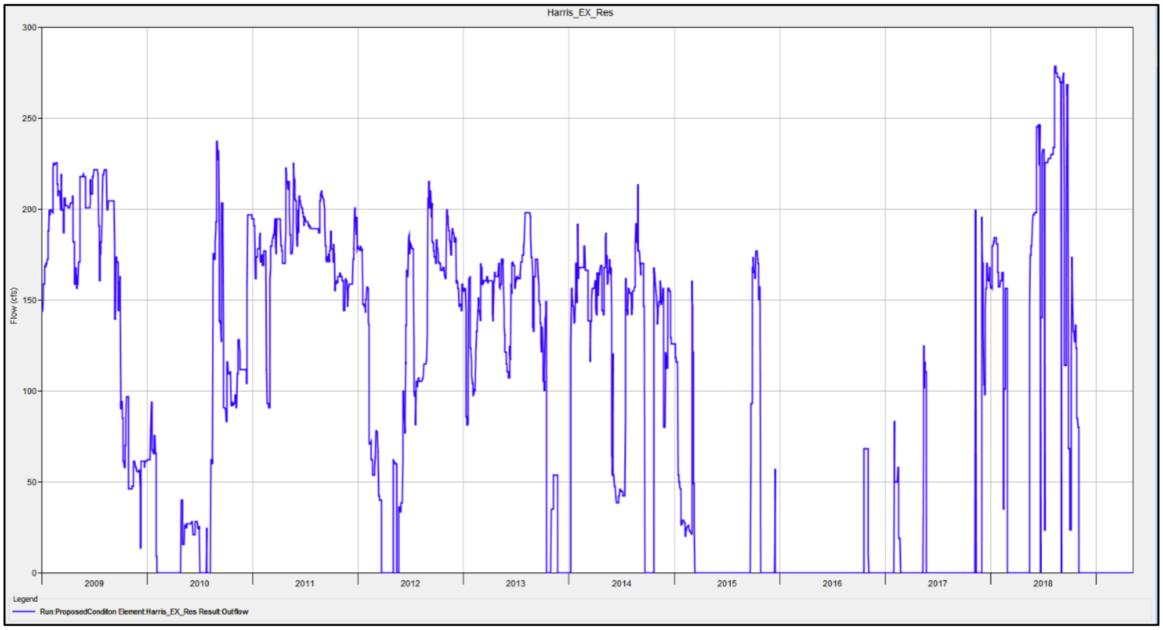


***Figure 37**: Proposed conditions discharges from existing Harris Reservoir over the 10.5-year simulation period. Note: Large spikes were noted in the May 25, 2014, and September 24, 2018, flow data (not shown in the hydrograph), which appeared to be outliers. The flows on those dates were normalized to the rest of the data.*

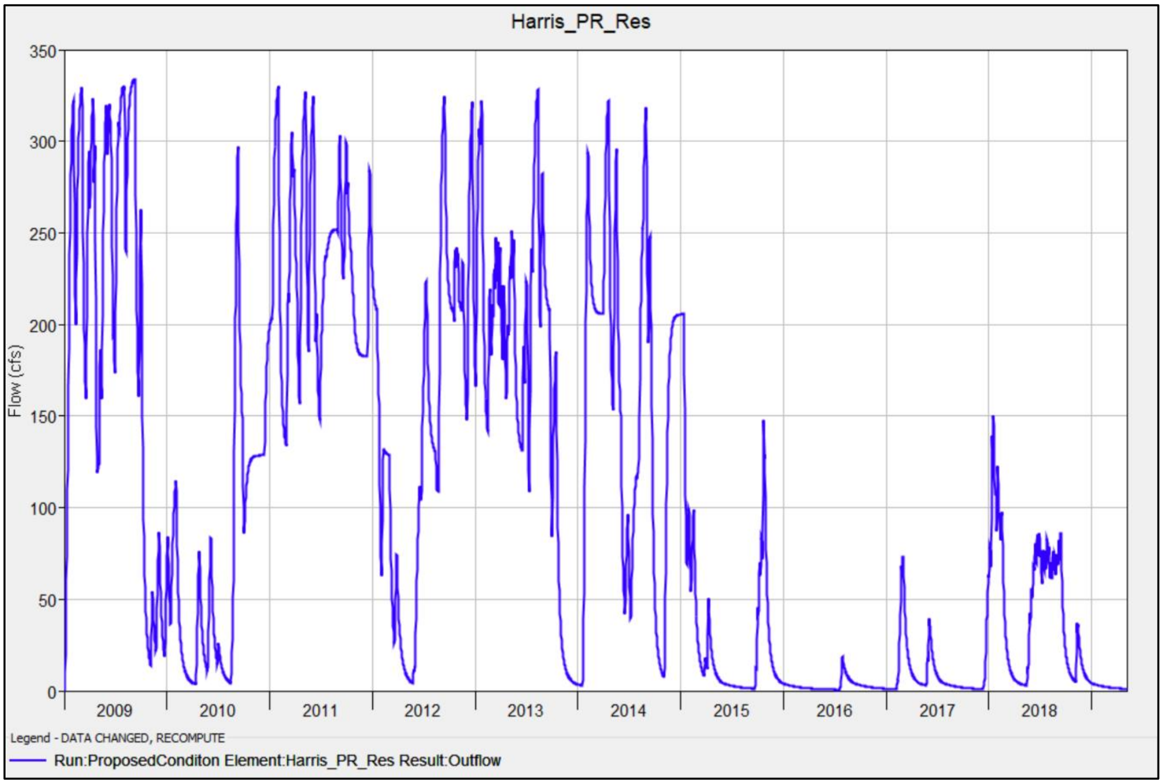


***Figure 38**: Proposed conditions discharges outflow from proposed Harris Reservoir over the 10.5-year simulation period.*

Shown in **Figures 39** through **49** are the existing and proposed flow hydrographs at six key analysis points between the Rosharon gage and the outlet at the Gulf of Mexico. The key analysis points are listed in **Table 13** and include the Rosharon gage, which is not expected to change between existing and proposed conditions as it is an observed flow condition in the model. While routing along the Brazos River is performed in HEC-RAS unsteady flow rather than HEC-HMS, this is a useful comparison at the outlet as hydrographs are combined along the Brazos River without attenuation or lagging. Downstream of the Rosharon gage, no significant changes in flow are shown in the Brazos River despite assumed increased diversions at peak river flows/stages to maintain the additional storage associated with the proposed Harris Reservoir.

Since detailed design and operational inflow or discharge rating curves were not available, multiple scenarios were modeled within HEC-HMS to estimate the proposed Harris Reservoir inflow and outflow through the spillway. Several multipliers were applied to the known existing Harris Reservoir daily peak flows provided by Dow to estimate possible peak flows that the proposed Harris Reservoir could discharge while in operation to develop a range of possible operating scenarios. Multipliers of 2.98, 5.57 (described in this report), and 7.28 (described in the January 8, 2020, report) were applied to the existing Harris Reservoir peak outflows and Brazos River diversion to the existing Harris Reservoir, which was used to forecast the diversion and outflow occurring in the proposed Harris Reservoir system. It was determined after observing several of these results with the different ranges of peak flows that the diversion occurring at the proposed Harris Reservoir had no change in the water surface elevation or peak flows in Brazos River based on the range of scenarios that were modeled. If actual operations result in significantly different inflows and discharges, then results may vary.

Table 13: Key Analysis Points for Results Reporting

Key Analysis Point	Location	HEC-HMS Name
1	Rosharon Gage	J_Rosharon
2	Proposed Harris Reservoir Diversion (Brazos River)	Harris_PR_Res_Div
3	Existing Harris Reservoir Diversion (Brazos River)	Harris_EX_Res_Div
4	Brazoria Reservoir Diversion (Brazos River)	Brazoria_Res_Div
5	Brazoria Discharge/Dow's Water Intake	J_BRA_BCB_Dam
6	Outlet (Mouth)	Outlet

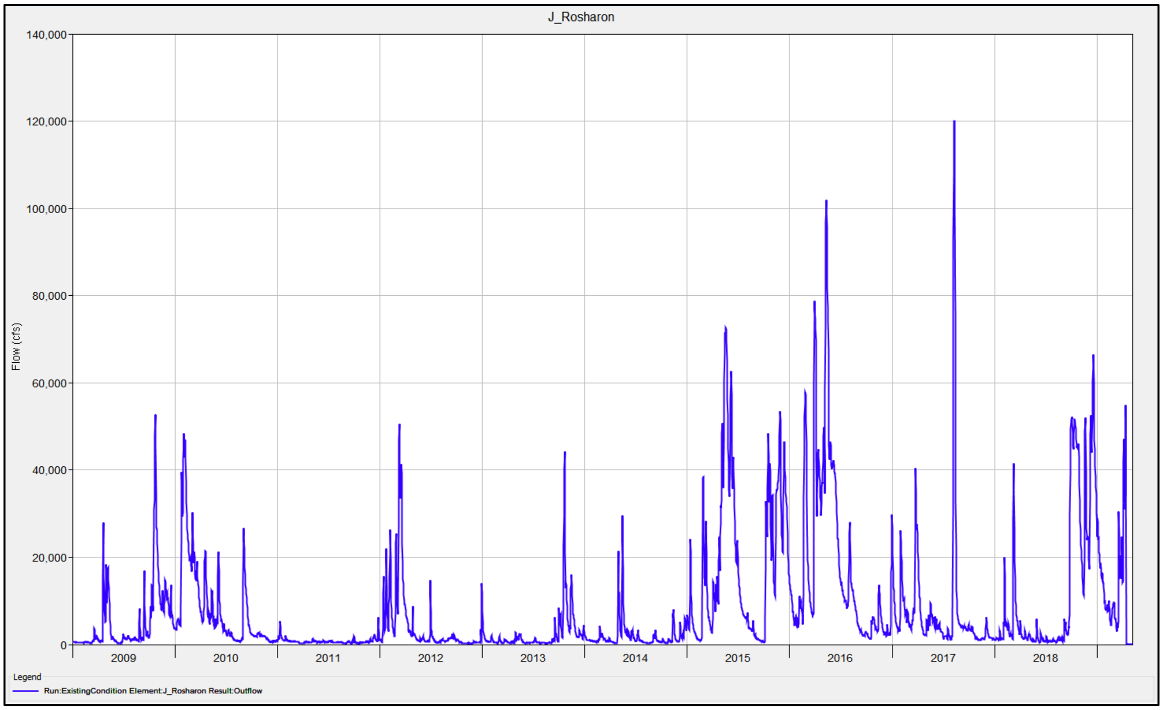


***Figure 39**: Existing conditions flow hydrograph at Rosharon gage over the 10.5-year simulation period.*

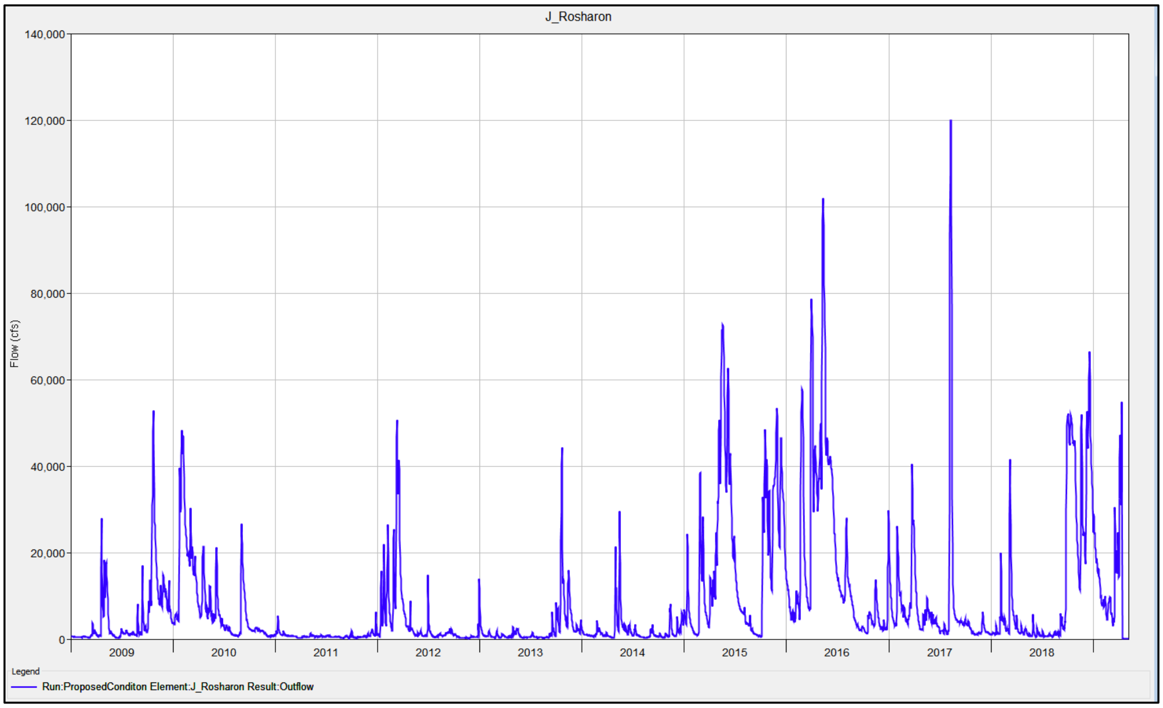


***Figure 40**: Proposed conditions flow hydrograph at Rosharon gage over the 10.5-year simulation period.*

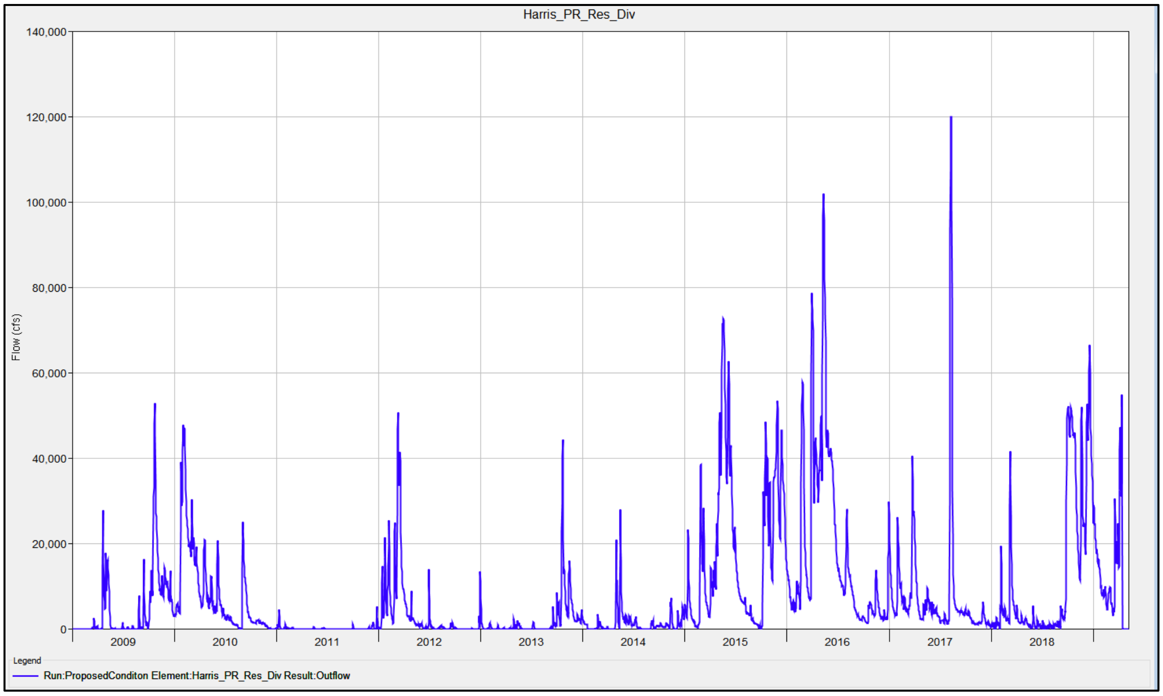


***Figure 41**: Proposed conditions flow hydrograph at proposed Harris Reservoir diversion (Brazos River) over the 10.5-year simulation period.*

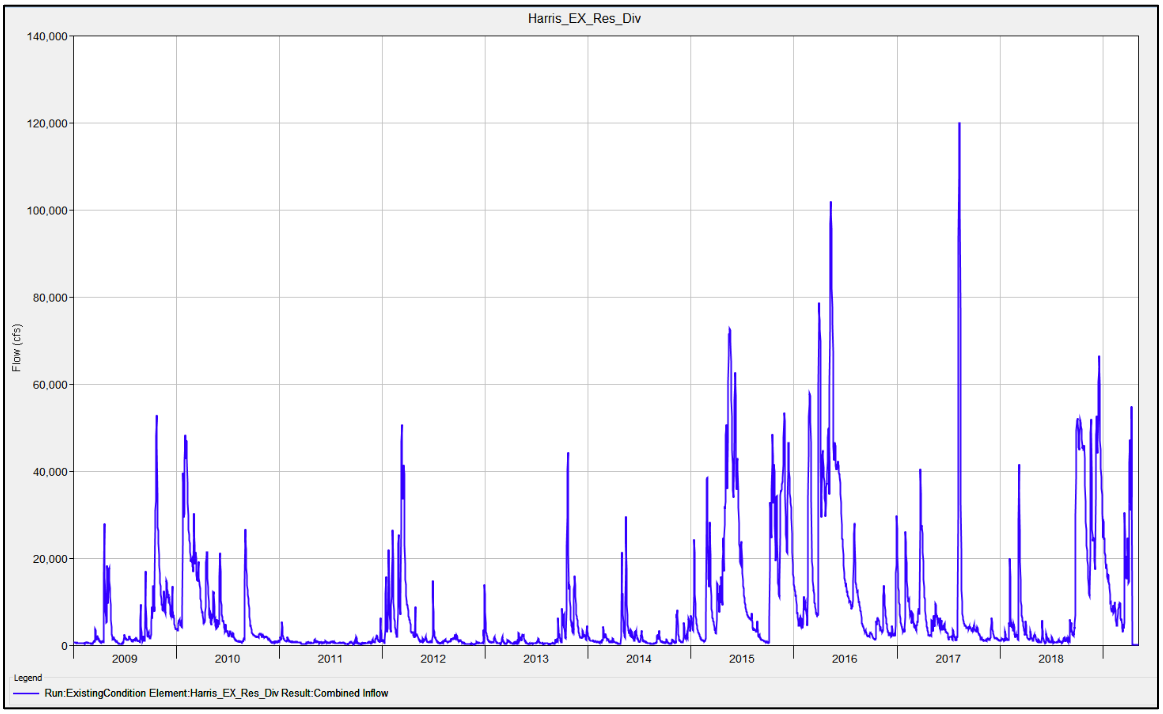


***Figure 42**: Existing conditions flow hydrograph at existing Harris Reservoir diversion (Brazos River) over the 10.5-year simulation period.*

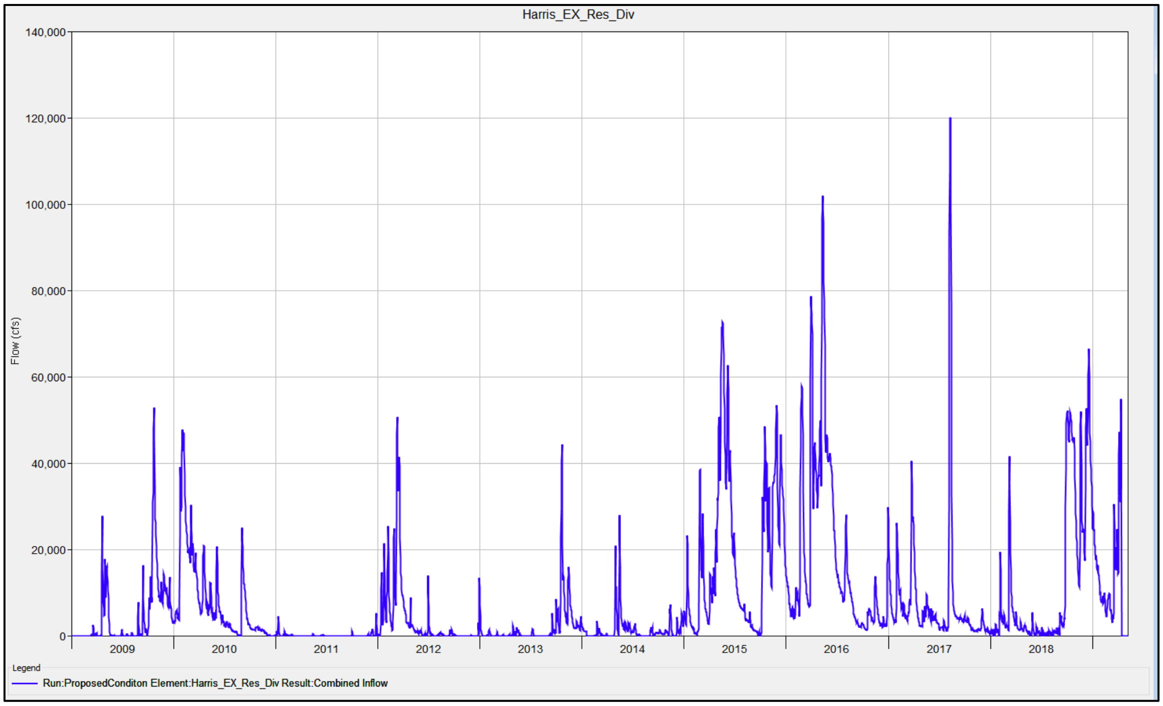


Figure 43: *Proposed conditions flow hydrograph at existing Harris Reservoir diversion (Brazos River) over the 10.5-year simulation period.*

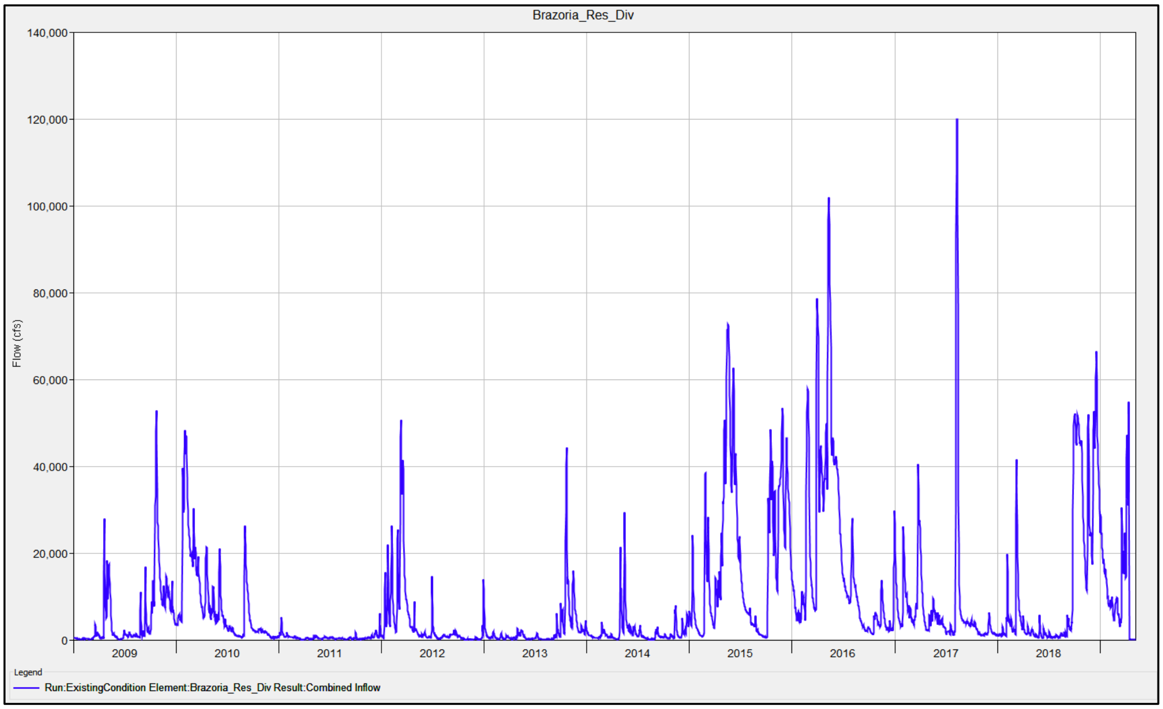


***Figure 44**: Existing conditions flow hydrograph at existing Brazoria Reservoir diversion (Brazos River) over the 10.5-year simulation period.*

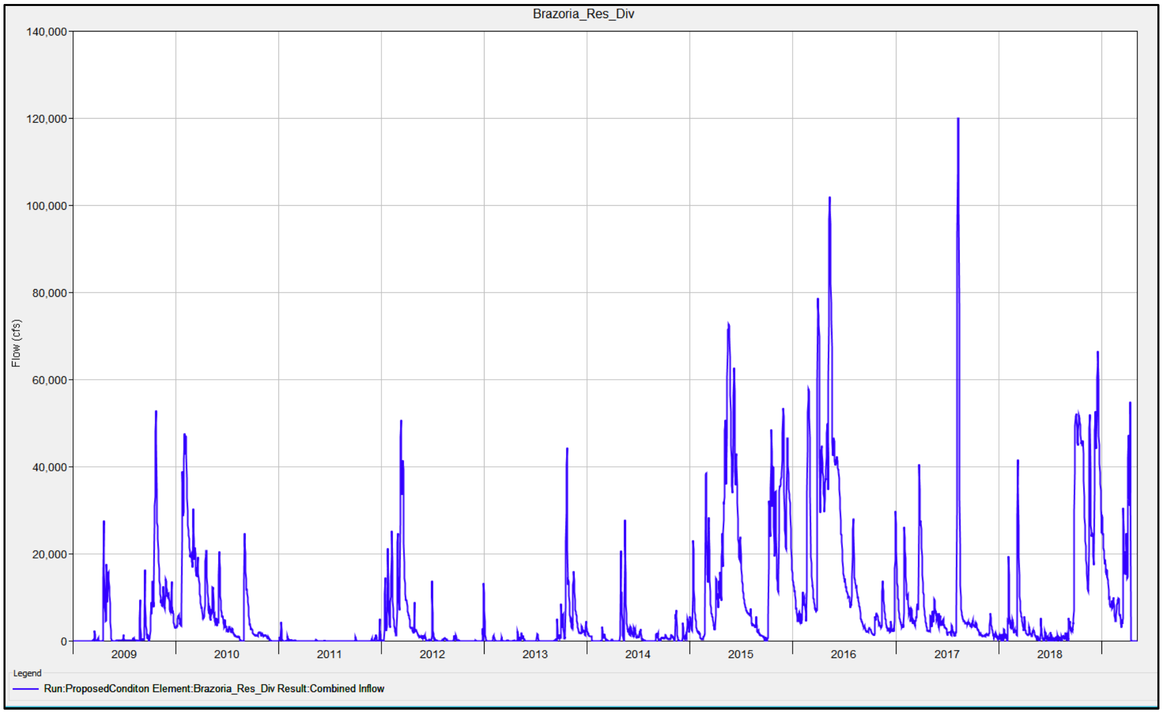


***Figure 45**: Proposed conditions flow hydrograph at existing Brazoria Reservoir diversion (Brazos River) over the 10.5-year simulation period.*

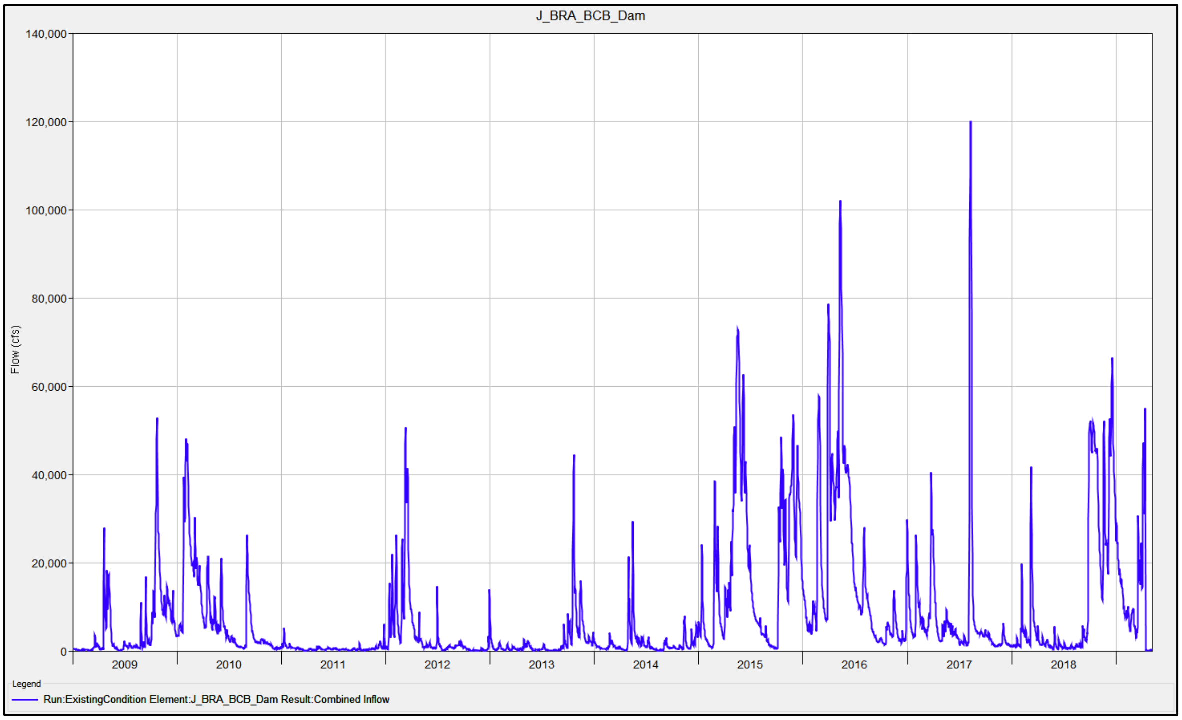


***Figure 46**: Existing conditions flow hydrograph at Brazoria discharge/Dow's water intake (Brazos River) over the 10.5-year simulation period.*

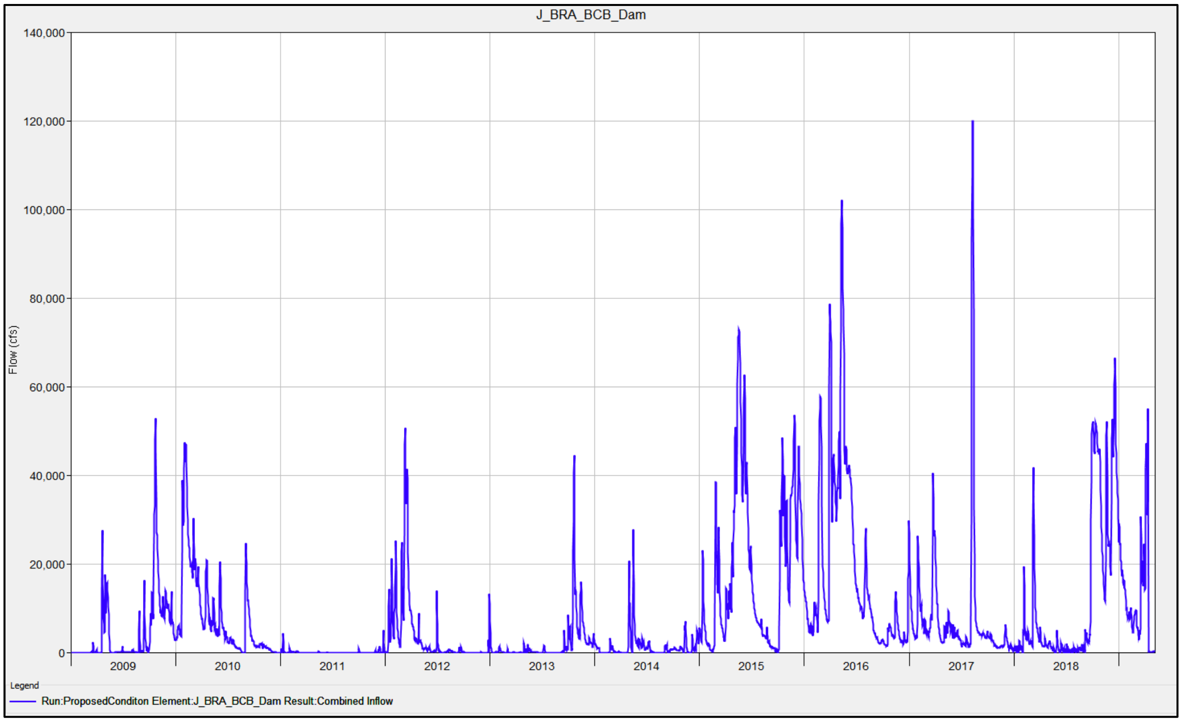


***Figure 47**: Proposed conditions flow hydrograph at Brazoria discharge/Dow's water intake (Brazos River) over the 10.5-year simulation period.*

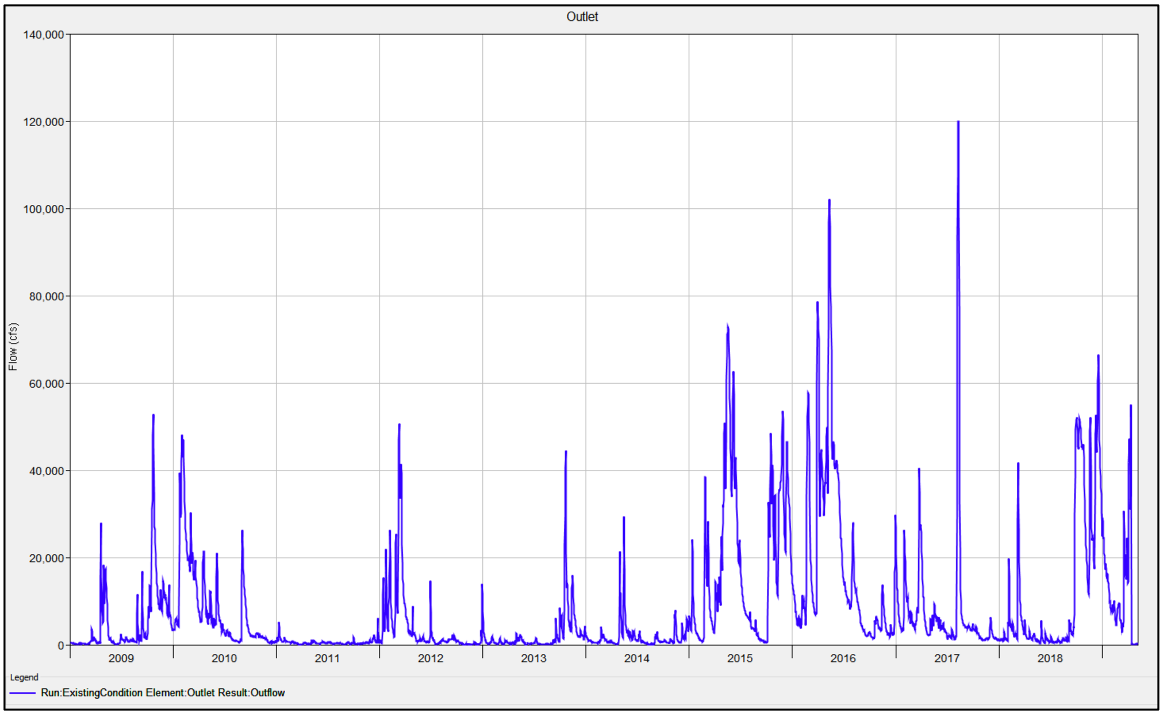


***Figure 48**: Existing conditions flow hydrograph at outlet (Brazos River) over the 10.5-year simulation period.*

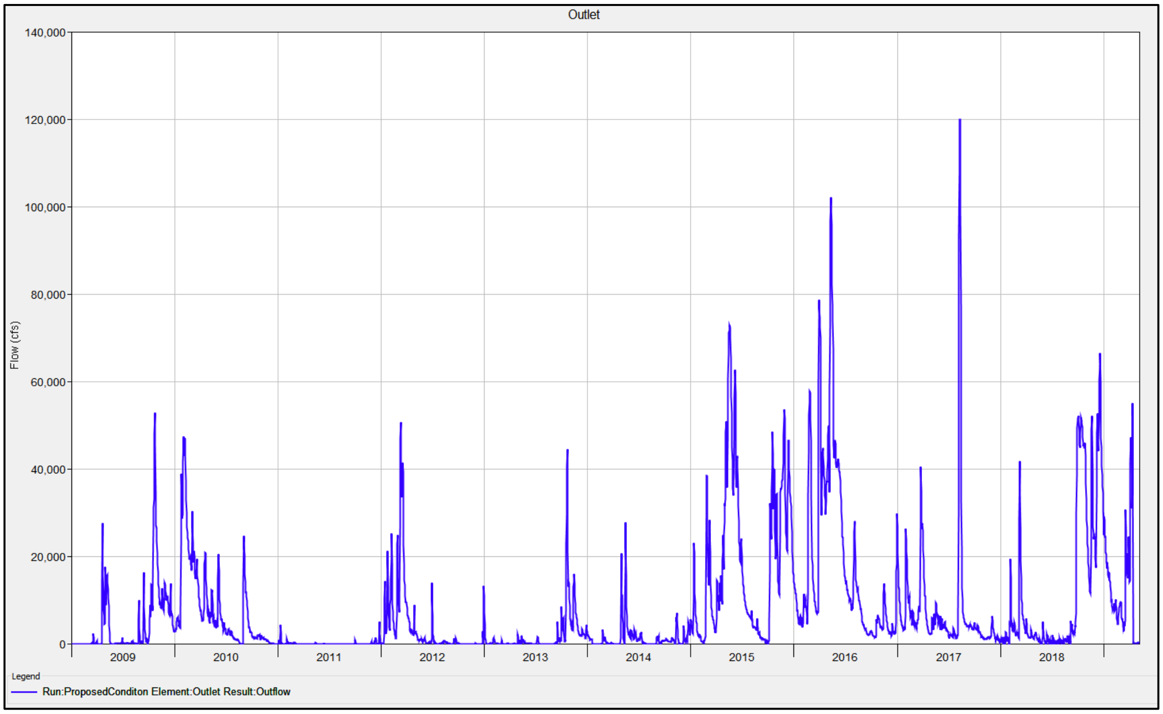


***Figure 49**: Proposed conditions flow hydrograph at outlet (Brazos River) over the 10.5-year simulation period.*

5.4.2 RiverWare

RiverWare uses objects to represent certain natural or man-made systems or structures (e.g., various types of reservoirs, diversions, reaches, stream gages, pumps, power plants, etc.) within a model, much like HEC-HMS does to create the elements within a flow model. However, it differs from HEC-HMS by using slots as the primary "storage containers" for data, as well as the actual variables for object operations (e.g., stream inflow/outflow, diversion flow, reservoir stage-storage-discharge values, pump curve and operation information, etc.). RiverWare uses its slot link capabilities to couple two or more objects (and specific slots within each respective object) to perform operations within the model (e.g., routing outflow from an object upstream as inflow into a downstream linked object, etc.).

The existing and proposed RiverWare models were built using the Richmond and Rosharon USGS flow gage historical hydrograph data (with a 40-year period of record) extracted from the same BRA FPP Study HEC-HMS model as described previously. The existing conditions model includes the existing Harris and Brazoria Reservoirs, respectively, along with their corresponding diversion elements in order to account for allowed pumping withdrawals along the Brazos River.

5.4.2.1 Existing Condition Model

The RiverWare model utilized the existing condition HEC-HMS basin model run's "Inflow" daily flow values from the "Harris_EX_Res_Div" diversion element, which utilized the previously mentioned 10-year period of record flow data from Dow as input, as the starting flow input for the RiverWare "Harris_EX_Res_Div" diversion object "Inflow" slot. Values for "Outflow" from the same HEC-HMS diversion element were likewise used as the input for the "Outflow" slot of the same "Harris_EX_Res_Div" diversion object in RiverWare. A "Diversion" flow data slot was also created to represent pumped outflows which were routed to the "Harris_EX_Res" pumped storage reservoir object, which was used to simulate the existing Harris Reservoir, which receives water from pumped inflows siphoned from the Brazos River at the "Harris_EX_Res_Div."

Historical reservoir plan and operational data received from Dow were used to build the "Harris_EX_Res_" reservoir "Storage," "Elevation Volume Table," and "Pool Elevation" slots. The "Inflow" slot was linked to the "Outflow" slot from the "Harris_EX_Res_Div" object. An "Outflow" slot was created to route discharge flows from the reservoir into the "Harris_EX_Res_Outlet_AP2" control slot, which was used as an analysis point (AP). This same process was repeated using the flow summary values from the HEC-HMS "Brazoria_Res_Div" element and transferred into the appropriate "Brazoria_Res_Div" diversion object "Inflow" and "Outflow" slots.

Reach objects "R_BRA_410 R_BRA_430" and "R_BRA_440" and confluence object "J_BRA_BCB_Dam" were created to route the discharges from the Brazos River and return flows from the reservoir objects back into the Brazos River system and down to the ultimate outfall, which was the "Outlet_AP1" control object. See the model schematic in **Figure 50**.

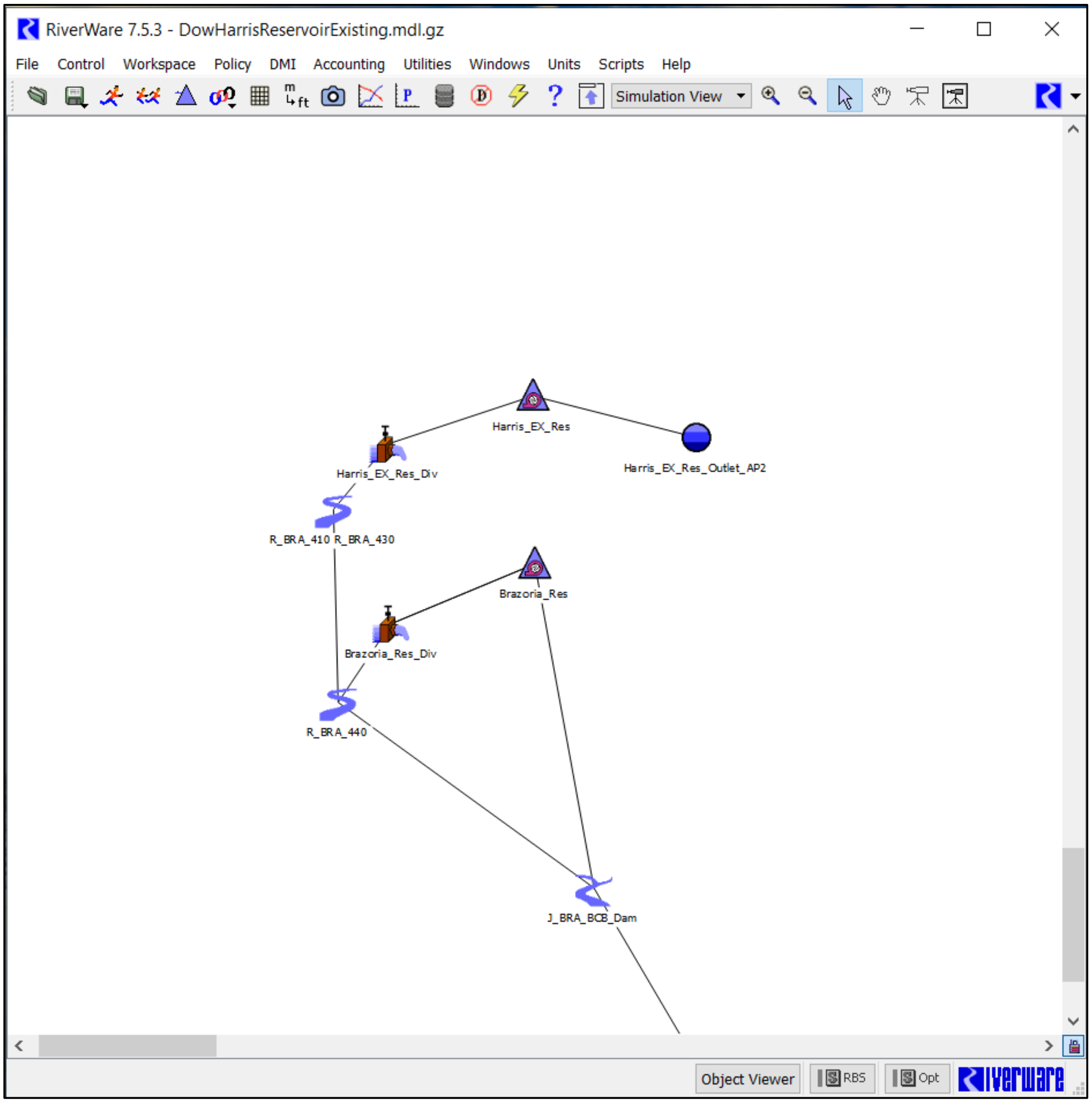


***Figure 50**: RiverWare existing conditions schematic.*

5.4.2.2 Proposed Condition Model

The proposed condition RiverWare model was built upon the existing condition model, as explained previously. It was modified from the existing condition by the addition of the "Harris_PR_Res_Div" diversion object, the "Harris_PR_Res" pumped storage reservoir object, and the "Harris_PR_Res_Outlet_AP2" control object. The process for building the additional proposed Harris Reservoir and its accompanying diversion was the same as was described above for the Existing Condition Model, except the values were taken from the Proposed Condition Basin Model run of HEC-HMS for the "Harris_PR_Res_Div" and accompanying "Harris_PR_Res" pumped storage reservoir object. The proposed Harris Reservoir expansion plans and proposed operational data received from Dow and its engineering consultants were used to create the "Harris_PR_Res" reservoir "Storage," "Elevation Volume Table, and "Pool Elevation" slots, just as for the existing condition model.

As was done previously for the existing Harris Reservoir, an "Outflow" slot was created to route discharge flows from the "Harris_PR_Res" reservoir into the "Harris_PR_Res_Outlet_AP3" control slot, which was used as another AP. A reach object "R_BRA_Harris_PR_Res_Div" was created, along with corresponding "Inflow" "Outflow" slots, to route undiverted flows from the "Harris_PR_Res_Div" back to the Brazos River System. See **Figure 51** for the proposed project schematic.

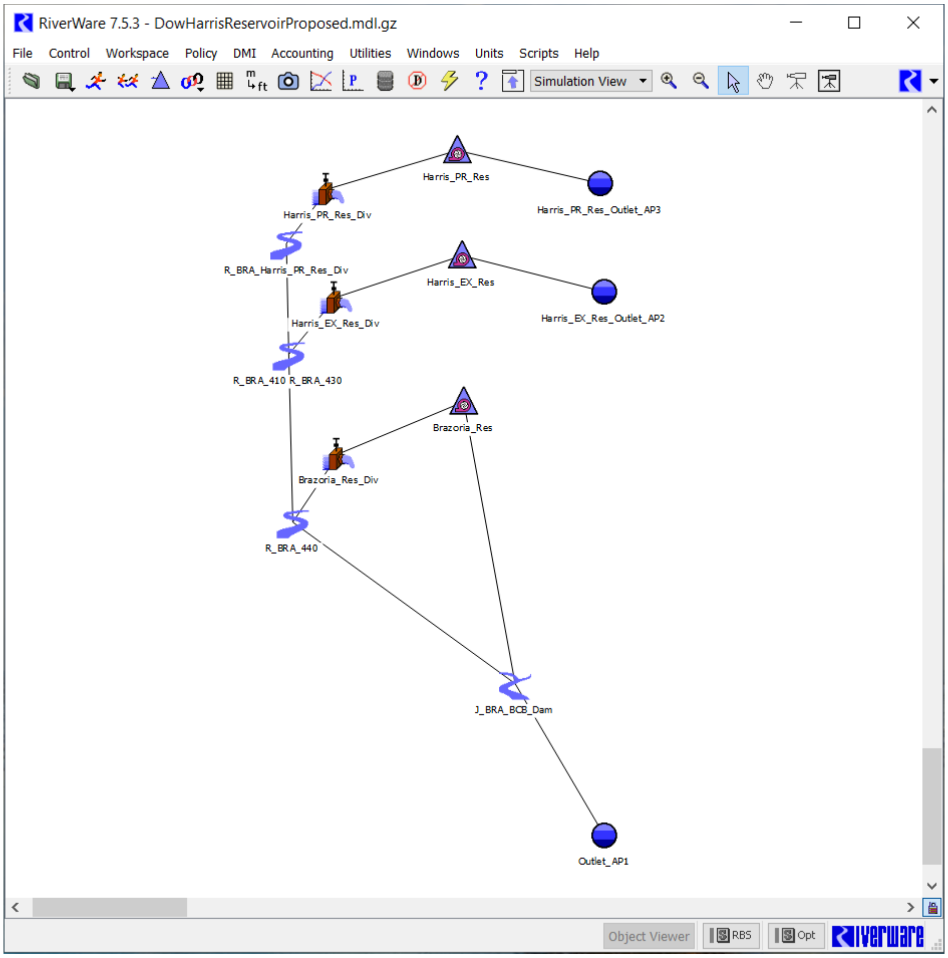
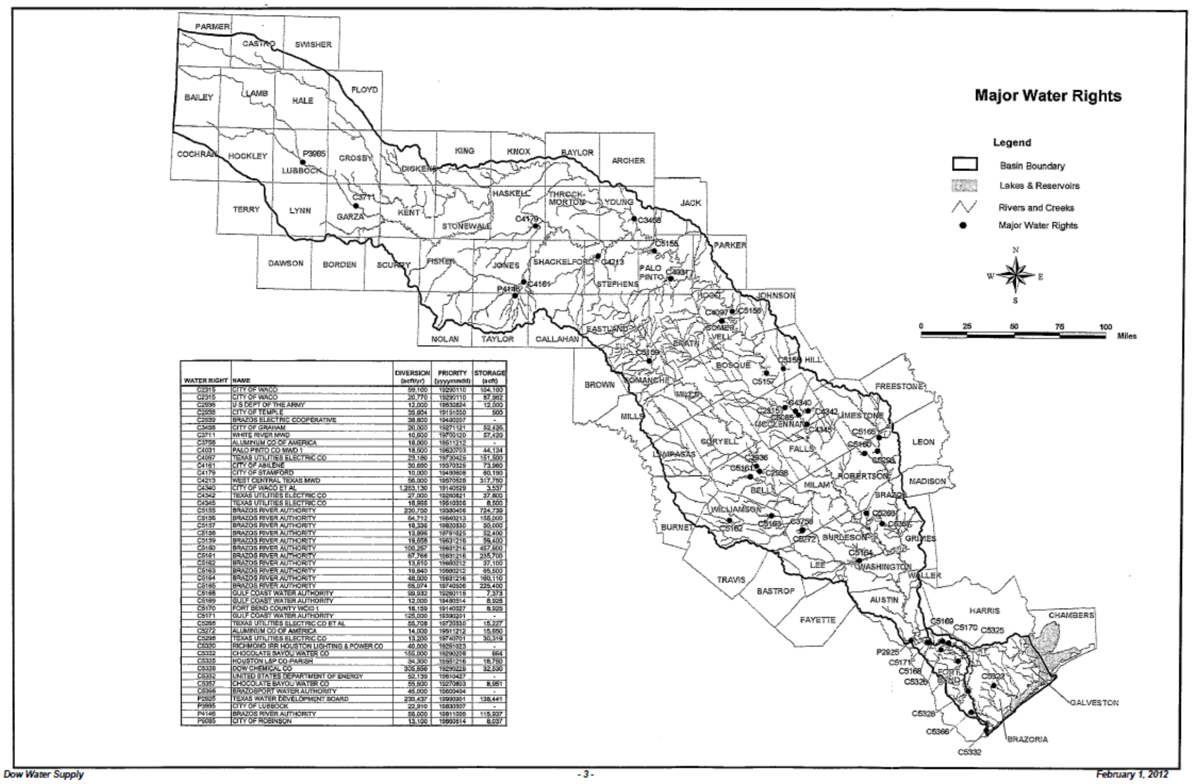


Figure 51: RiverWare proposed conditions schematic.

5.4.2.3 Summary of Water Rights and Inputs to Models

This section provides the prioritization for model inputs for RiverWare. The information is based on documentation provided by Dow regarding its water rights and water supply methods and was confirmed through a review of TCEQ documentation (Texas Water Commission, 1985). A summary of the major water rights holders is provided in **Figure 52. Figure 53** provides a summary of the adjudicated water rights Dow holds, as confirmed by the Brazos River Watermaster. Figure 54 shows the frequency of flows for prior appropriated and natural priority on the Brazos River.



WATER RIGHT	NAME	DIVERSION (acft/yr)	PRIORITY (yyyymmdd)	STORAGE (acft)
C2315	CITY OF WACO	59,100	19290110	104,100
C2315	CITY OF WACO	20,770	19290110	87,962
C2596	U S DEPT OF THE ARMY	12,000	19530824	12,000
C2938	CITY OF TEMPLE	35,804	19151030	500
C2939	BRAZOS ELECTRIC COOPERATIVE	38,800	19490207	-
C3458	CITY OF GRAHAM	20,000	19271121	52,425
C3711	WHITE RIVER MWD	10,600	19700120	57,420
C3758	ALUMINUM CO OF AMERICA	18,000	19511212	-
C4031	PALO PINTO CO MWD 1	18,500	19620703	44,124
C4097	TEXAS UTILITIES ELECTRIC CO	23,180	19730425	151,500
C4161	CITY OF ABILENE	30,690	19370325	73,960
C4179	CITY OF STAMFORD	10,000	19490608	60,190
C4213	WEST CENTRAL TEXAS MWD	56,000	19570528	317,750
C4340	CITY OF WACO ET AL	1,253,130	19140529	3,537
C4342	TEXAS UTILITIES ELECTRIC CO	27,000	19290821	37,800
C4345	TEXAS UTILITIES ELECTRIC CO	18,966	19510326	8,500
C5155	BRAZOS RIVER AUTHORITY	230,750	19380406	724,739
C5156	BRAZOS RIVER AUTHORITY	64,712	19640213	155,000
C5157	BRAZOS RIVER AUTHORITY	10,336	19620830	50,000
C5158	BRAZOS RIVER AUTHORITY	13,896	19761025	52,400
C5159	BRAZOS RIVER AUTHORITY	19,658	19631216	59,400
C5160	BRAZOS RIVER AUTHORITY	100,257	19631216	457,600
C5161	BRAZOS RIVER AUTHORITY	67,768	19631216	235,700
C5162	BRAZOS RIVER AUTHORITY	13,610	19680212	37,100
C5163	BRAZOS RIVER AUTHORITY	19,840	19680212	65,500
C5164	BRAZOS RIVER AUTHORITY	48,000	19631216	160,110
C5165	BRAZOS RIVER AUTHORITY	66,074	19740506	225,400
C5168	GULF COAST WATER AUTHORITY	99,932	19260115	7,373
C5169	GULF COAST WATER AUTHORITY	12,000	19480514	8,925
C5170	FORT BEND COUNTY WCID 1	18,159	19140327	8,925
C5171	GULF COAST WATER AUTHORITY	125,000	19390201	-
C5266	TEXAS UTILITIES ELECTRIC CO ET AL	55,708	19720530	15,227
C5272	ALUMINUM CO OF AMERICA	14,000	19511212	15,650
C5298	TEXAS UTILITIES ELECTRIC CO	13,200	19740701	30,319
C5320	RICHMOND IRR HOUSTON LIGHTING & POWER CO	40,000	19261023	-
C5322	CHOCOLATE BAYOU WATER CO	155,000	19290228	664
C5325	HOUSTON L&P CO-PARISH	34,300	19551216	18,750
C5328	DOW CHEMICAL CO	305,656	19290228	32,530
C5332	UNITED STATES DEPARTMENT OF ENERGY	52,139	19610427	-
C5357	CHOCOLATE BAYOU WATER CO	55,500	19270803	8,951
C5366	BRAZOSPORT WATER AUTHORITY	45,000	19600404	-
P2925	TEXAS WATER DEVELOPMENT BOARD	235,437	19990901	138,441
P3985	CITY OF LUBBOCK	22,910	19830307	-
P4146	BRAZOS RIVER AUTHORITY	56,000	19811006	115,937
P5085	CITY OF ROBINSON	13,100	19860514	8,037

***Figure 52**: Summary of major water rights on the Brazos River in Texas (provided by Dow).*

Dow Water Rights Summary

Controlling Legal Documents

Certificate of Adjudication # 12-5328 Granted January 14, 1988; Cover Brazos River, Oyster Creek and Buffalo Camp Bayou Water Rights

Certificate of Adjudication # 12-5328A Granted February 27, 1991; Oyster Creek Adjustment to #12-5328

Certificate of Adjudication # 12-5328B Granted December 4, 1991; Oyster Creek Adjustment to #12-5328

		Period Reliability (Month by Month Basis)	Volume Reliability	Minimum Diverted	Special Consideration
1929	20,000 Acre-ft	98.56 %	98.80%	14,679 Acre-ft	
1942	150,000 Acre-ft	94.25 %	95.78%	76,910 Acre-ft	
1942 OC	58,175 Acre-ft	37.64 %	47.11%	8,626	
1942 OC	1,800 Acre-ft	37.50 %	26.01%	13	
1951BCB	7,500 Acre-ft	55.46 %	67.86 %	1500	
1952	Constructed Brazoria Reservoir and Relocated Right				
1960	65,000 Acre-ft	88.22%	88.75%	18,738 Acre-ft	61,000 Acre-ft of Storage or Contract Water with BRA Req'd
1960	45,000 Acre-ft	BWA Water			
1976	3,136 Acre-ft	84.34 %	88.24%		
				121,205 Acre-ft	

Current TCEQ Water Rights Reliability Assessment
Based on KBR work in Sept, 2002
WAM Model Run 3 (=All Authorized Water Rights at Authorized Amounts, No Return Flows, Original Areas-Capacities)

DOW RESTRICTED - For internal use only

***Figure 53**: Summary of Dow water rights on the Brazos River, Texas. DOW RESTRICTED - For Internal Use Only.*

Dow has a water right up to 175,000 gpm (388.9 cfs), of which it plans to use about 100,000 gpm (222.2 cfs). Even if it uses all its water right, the water use would still be less than the maximum diversion rate of 630 cfs.

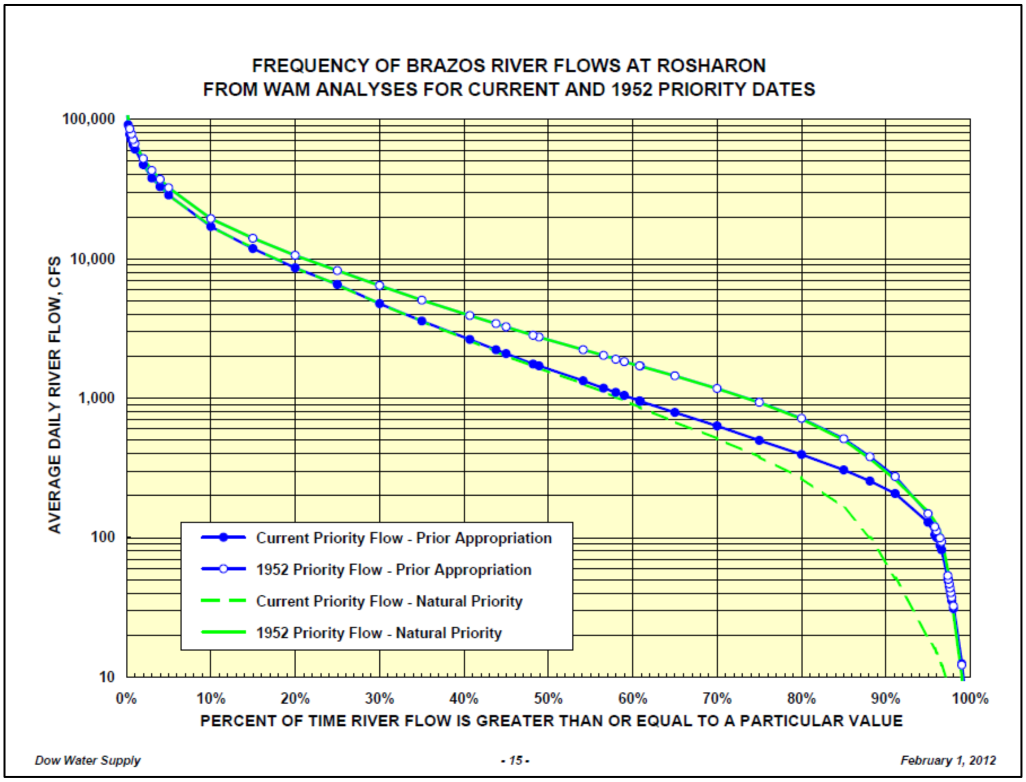


***Figure 54**: Frequency of flows for prior appropriated and natural priority on the Brazos River, Texas.*

5.4.3 Brazos River HEC-RAS Unsteady Flow

The Brazos River HEC-RAS unsteady flow model used in this study was obtained from the BRA Lower Brazos Flood Protection Planning Study (FPP Study) HEC-RAS hydraulic model approved by the BRA in March of 2019 (Halff, 2019). The original model was truncated upstream of the Rosharon USGS gage to reduce extremely long run times and eliminate unnecessary data; the stream segment and cross-sections upstream of the gage are not part of the area of study for this report. Additionally, any backwater effects associated with the existing and proposed Harris Reservoir are expected to be isolated to the area in the closer vicinity to the existing Brazoria and Harris Reservoirs and proposed Harris Reservoir.

All hydraulic modeling of the Brazos River was performed in HEC-RAS unsteady flow version 5.0.7(DOW_Prop_Harris_Res_Brazos.prj) following standard modeling procedures for conceptual or planning-level analysis. Model computation time steps of 30 minutes and reporting intervals of 1 day were used and were held constant between existing and proposed conditions. Changes to the original model were limited to the following:

1. Truncating the model
2. Revising the upstream boundary conditions and associated initial flows
3. Incorporating lateral inflow hydrographs

5.4.3.1 Geometry Data

The geometry data from the original HEC-RAS unsteady flow model were used with the only modification at cross-section 308,583.5. The original FPP study model did not include either of the existing Harris and Brazoria Reservoirs, which are operated by Dow. These reservoirs were not added to the HEC-RAS model; however, they were modeled in HEC-HMS using the reservoir routing method. The resulting hydrographs were then imported into both HEC-RAS and RiverWare models. The Modified Puls Routing Method was used in HEC-HMS reservoir routing.

5.4.3.2 Boundary Conditions

The Rosharon gage was input as a flow hydrograph for the upstream boundary condition at the upstream cross-section 308,583.5 (see **Figure 39**). Details on this gage are discussed in **Section 4.3.5** While the original model used a normal depth downstream boundary condition with a slope of 0.0003, this boundary condition did not produce expected backwater effects from the Gulf of Mexico related to mean, high, or low tide or any condition. Since the reach of the Brazoria River modeled for this study has bottom elevation nearly 20 ft below sea level and is tidally influenced, the downstream boundary condition was modified to a fixed WSEL of 0.511 ft, which is consistent with the current MSL reported by USGS (USGS, 2019). While MSL does not capture extreme tidal influence or storm surge, it is reflective of typical levels of tidal influence and backwater effects from the Gulf of Mexico on the study area. As shown in **Figure 11**, neither the Brazoria Reservoir, the existing Harris Reservoir, or the proposed Harris Reservoir are expected to be inundated from the effects of sea level rise.

5.4.3.3 Lateral Inflow Hydrographs

The only river hydrograph used in the HEC-RAS model was the upstream boundary condition hydrograph (USGS Rosharon gage). No lateral inflow from drainage area sub-basins were included in the HEC-RAS model. Only the diversion for proposed Harris reservoir was modeled in HEC-RAS.

5.4.3.4 Reservoir Diversions and Discharges

Figure 55 and **Table 14** show the only diversion which was modeled in HEC-RAS. This HEC-RAS model includes only Brazos River, not Oyster Creek. The modeling conventions do not allow for crossing cross-sections within the same floodplain. A detailed modeling analysis of Oyster Creek is located in the *Oyster Creek Downstream Hydrology and Hydraulic Impacts Final Report*. This diversion was added to the existing conditions model to represent the amount of water that would be removed from Brazos River when the proposed Harris Reservoir was added. This way, existing and proposed conditions can be compared to each other.

Table 12: Reservoir Diversions and Discharges Lateral Inflow Hydrograph Input Locations

Reservoir	HEC-RAS Cross-Section
Existing Harris Discharge	Leaves to Oyster Creek
Proposed Harris Inflow	253,920.7
Proposed Harris Discharge	Leaves to Oyster Creek

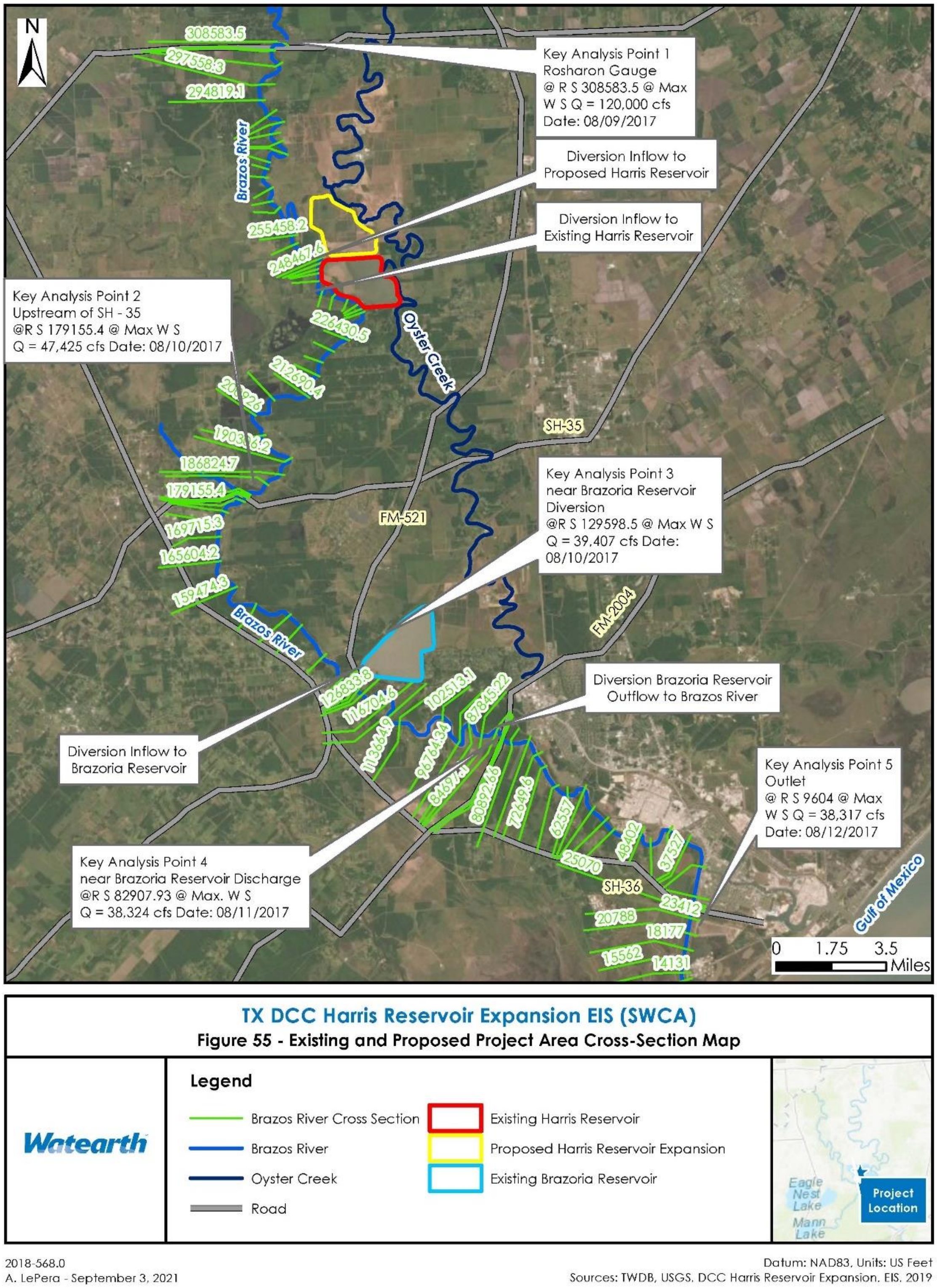


***Figure 55**: HEC-RAS cross-section layout for Brazos River.*

5.4.3.5 HEC-RAS Unsteady Flow Results

Listed in **Table 15** are the existing and proposed condition peak flows at maximum WSELs for the entire 10.5-year simulation period showing the difference in maximum flow through the cross-sections at each of the river stations. Provided in **Figure 56** and **Figure 57** are a profile plot of existing and proposed conditions maximum WSELs along the Brazos River from the Rosharon gage to the outlet at the Gulf of Mexico.

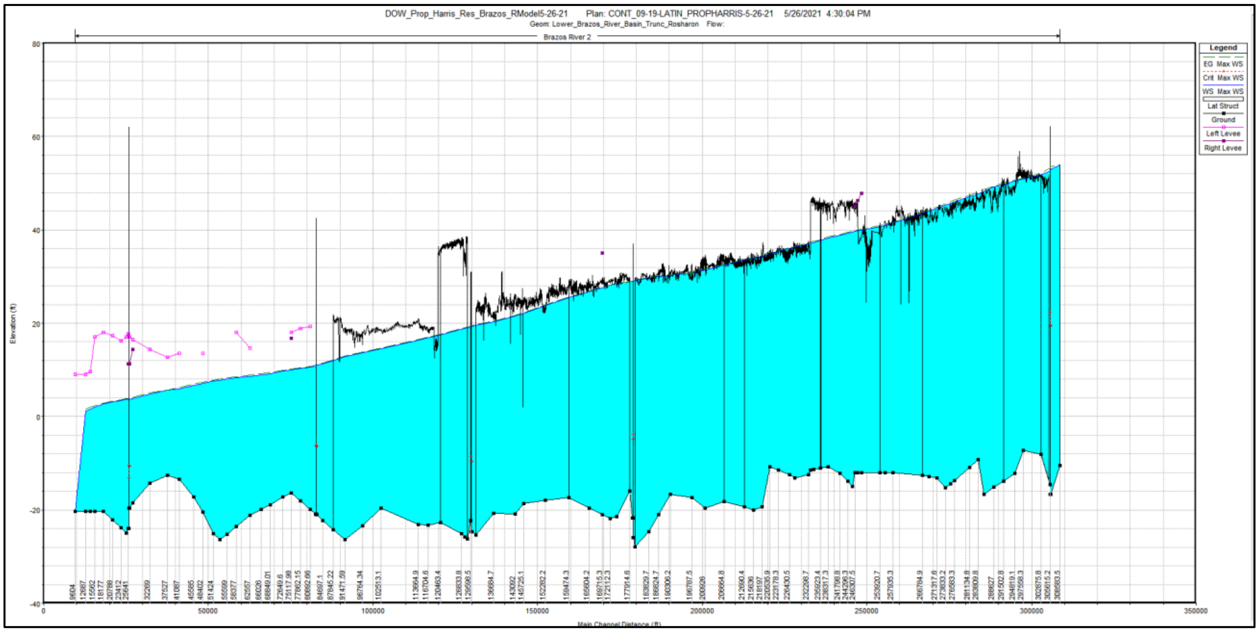


Figure 56: Existing conditions profile plot showing maximum water surface elevations along the Brazos River from the Rosharon gage to the outlet at the Gulf of Mexico.

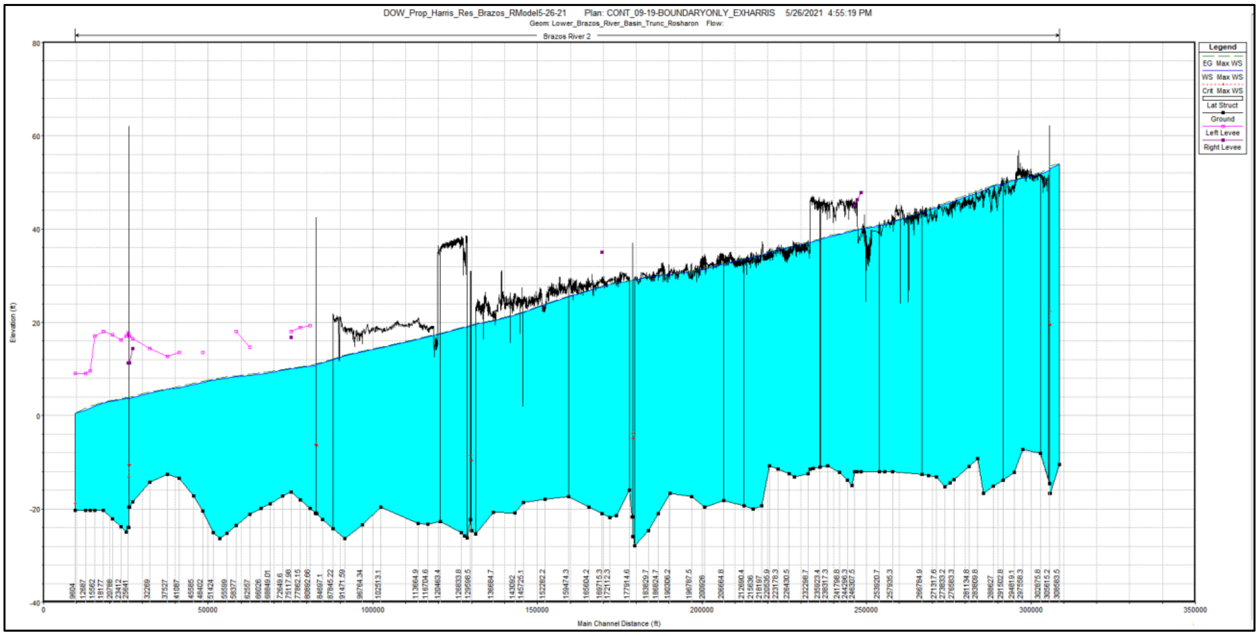


Figure 57: Proposed conditions profile plot showing maximum water surface elevations along the Brazos River from the Rosharon gage to the outlet at the Gulf of Mexico.

Similarly, **Figure 58** through **Figure 61** provide a profile plot of existing and proposed conditions maximum flows and velocities. Most of the proposed results varied only slightly from the existing conditions due to relatively insignificant diversion impacts compared to the large watershed study area. Accordingly, the change in flow in the Brazos River caused by the proposed Harris Reservoir diversion is negligible and the results for both conditions are nearly identical.

Table 15: Comparison of Existing and Proposed Flows at Maximum Water Surface Elevation Over the 10.5-Year Simulation Period

River Station	Existing Conditions Flow Total (cfs)	Proposed Conditions Flow Total (cfs)	Flow Δ (cfs)
308,583.50	120,000	120,000	0
305,771.60	120,000	120,000	0
305,615.20	120,000	120,000	0
302,875.80	113,694	113,694	0
297,558.30	113,184	113,184	0
294,819.10	112,072	112,072	0
291,502.80	107,921	107,921	0
288,627.00	101,320	101,320	0
285,653.70	96,609	96,609	0
283,809.80	94,770	94,770	0

River Station	Existing Conditions Flow Total (cfs)	Proposed Conditions Flow Total (cfs)	Flow Δ (cfs)
281,134.80	89,298	89,298	0
276,583.30	84,011	84,011	0
275,349.90	82,492	82,492	0
273,833.20	79,991	79,991	0
271,317.60	78,770	78,770	0
268,824.90	73,545	73,545	0
266,784.90	72,194	72,194	0
257,935.30	63,290	63,290	0
255,458.20	63,199	63,199	0
253,920.70	62,582	62,582	0
248,467.60	57,453	57,453	0
247,254.60	56,930	56,930	0
246,307.50	56,930	56,930	0
245,582.10	56,930	56,930	0
244,296.30	56,930	56,930	0
241,798.80	56,930	56,930	0
238,317.30	56,930	56,930	0
235,923.40	56,930	56,930	0
233,849.80	56,930	56,930	0
232,926.90	56,930	56,930	0
232,298.70	56,160	56,160	0
228,171.50	54,692	54,692	0
226,430.50	54,169	54,169	0
223,178.30	52,301	52,301	0
220,535.90	51,918	51,918	0
218,197.00	51,353	51,353	0
215,636.00	50,540	50,540	0
212,690.40	49,932	49,932	0
206,664.80	49,250	49,250	0
200,926.00	49,208	49,208	0

River Station	Existing Conditions Flow Total (cfs)	Proposed Conditions Flow Total (cfs)	Flow Δ (cfs)
196,787.50	48,811	48,811	0
190,306.20	48,284	48,284	0
186,824.70	47,835	47,835	0
183,829.70	47,687	47,687	0
179,479.50	47,425	47,425	0
179,155.40	47,425	47,425	0
178,789.60	47,425	47,425	0
177,914.60	47,425	47,425	0
174,103.50	47,400	47,400	0
172,112.30	47,373	47,373	0
169,715.30	47,358	47,358	0
165,604.20	47,203	47,204	0
159,474.30	47,183	47,183	0
152,282.20	47,095	47,095	0
145,725.10	46,484	46,484	0
143,092.00	39,811	39,811	0
136,684.70	39,508	39,508	0
131,329.00	39,410	39,410	0
130,048.30	39,410	39,410	0
129,598.50	39,410	39,410	0
128,597.70	39,410	39,410	0
127,887.80	39,410	39,410	0
126,833.80	39,410	39,410	0
120,463.40	39,410	39,410	0
116,704.60	38,357	38,357	0
113,664.90	38,357	38,357	0
102,513.10	38,356	38,356	0
96,764.34	38,356	38,356	0
91,471.59	38,355	38,355	0
87,845.22	38,324	38,324	0

River Station	Existing Conditions Flow Total (cfs)	Proposed Conditions Flow Total (cfs)	Flow Δ (cfs)
84,697.10	38,323	38,323	0
82,907.93	38,323	38,323	0
82,530.34	38,323	38,323	0
80,892.66	38,322	38,322	0
77,862.15	38,322	38,322	0
75,117.98	38,322	38,322	0
72,649.60	38,322	38,322	0
68,849.01	38,322	38,322	0
66,026.00	38,321	38,321	0
62,557.00	38,321	38,321	0
58,377.00	38,321	38,321	0
55,599.00	38,321	38,321	0
53,486.00	38,321	38,321	0
51,424.00	38,321	38,321	0
48,402.00	38,321	38,321	0
45,585.00	38,321	38,321	0
41,087.00	38,321	38,321	0
37,527.00	38,321	38,321	0
32,269.00	38,320	38,321	0
27,098.00	38,320	38,320	0
26,001.00	38,320	38,320	0
25,641.00	38,320	38,320	0
25,070.00	38,320	38,320	0
23,412.00	38,320	38,320	0
20,788.00	38,320	38,320	0
18,177.00	38,320	38,320	0
15,562.00	38,320	38,320	0
14,131.00	38,320	38,320	0
12,687.00	38,320	38,320	0
9,604.00	618	0	618

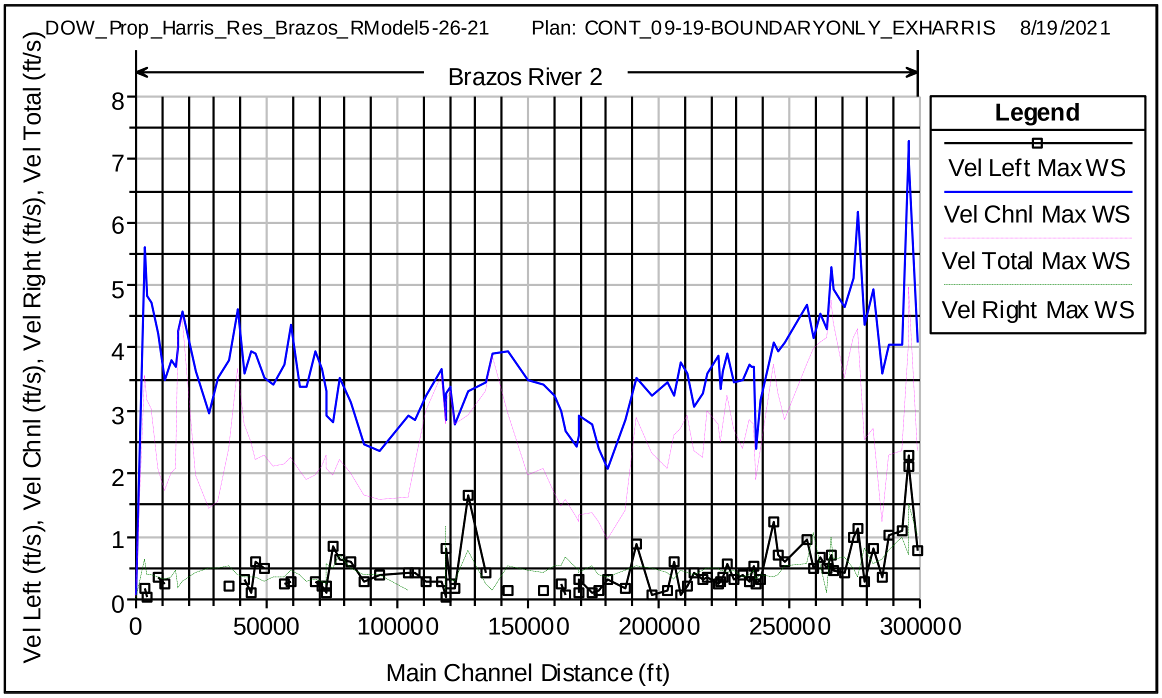


***Figure 58**: Existing conditions channel flow velocity, left and right overbank flow velocity, and average flow velocity for the peak maximum WSEL over the 10.5-year simulation period along the Brazos River between Rosharon gage and outlet.*

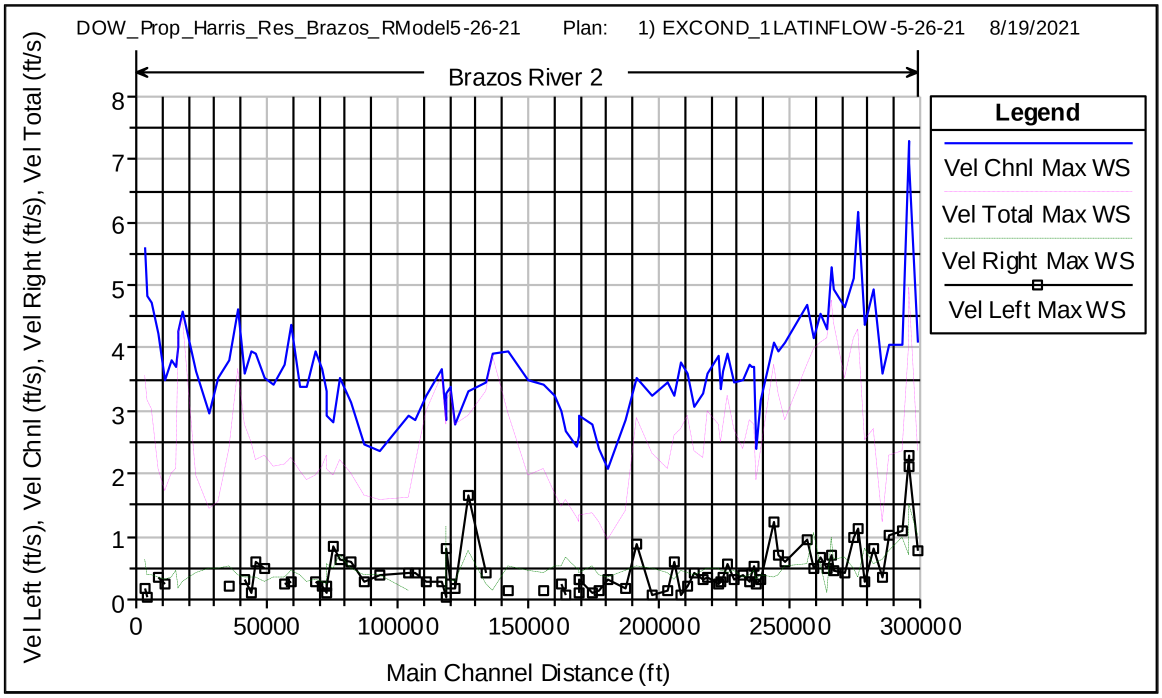


***Figure 59**: Proposed conditions channel flow velocity, left and right overbank flow velocity, and average flow velocity for the peak maximum WSEL over 10.5-year simulation period along the Brazos River between Rosharon gage and outlet.*

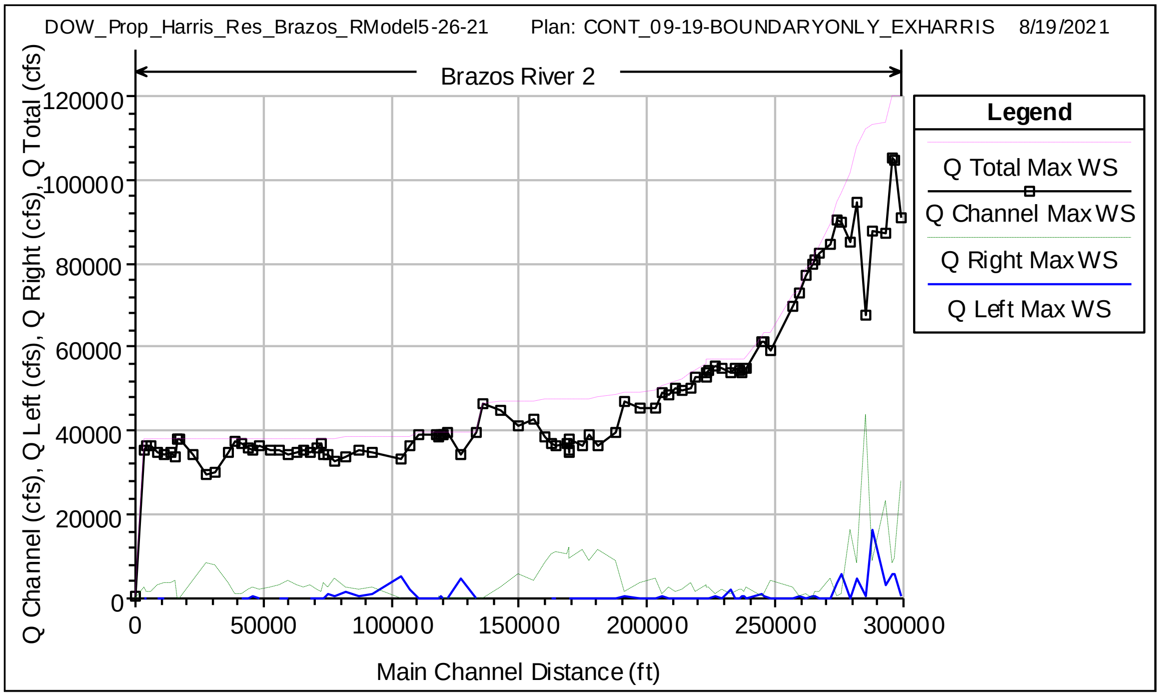


***Figure 60**: Existing conditions channel flow, left and right overbank flow, and total maximum flow for the peak maximum WSEL over the 10.5-year simulation period along the Brazos River between Rosharon gage and outlet.*

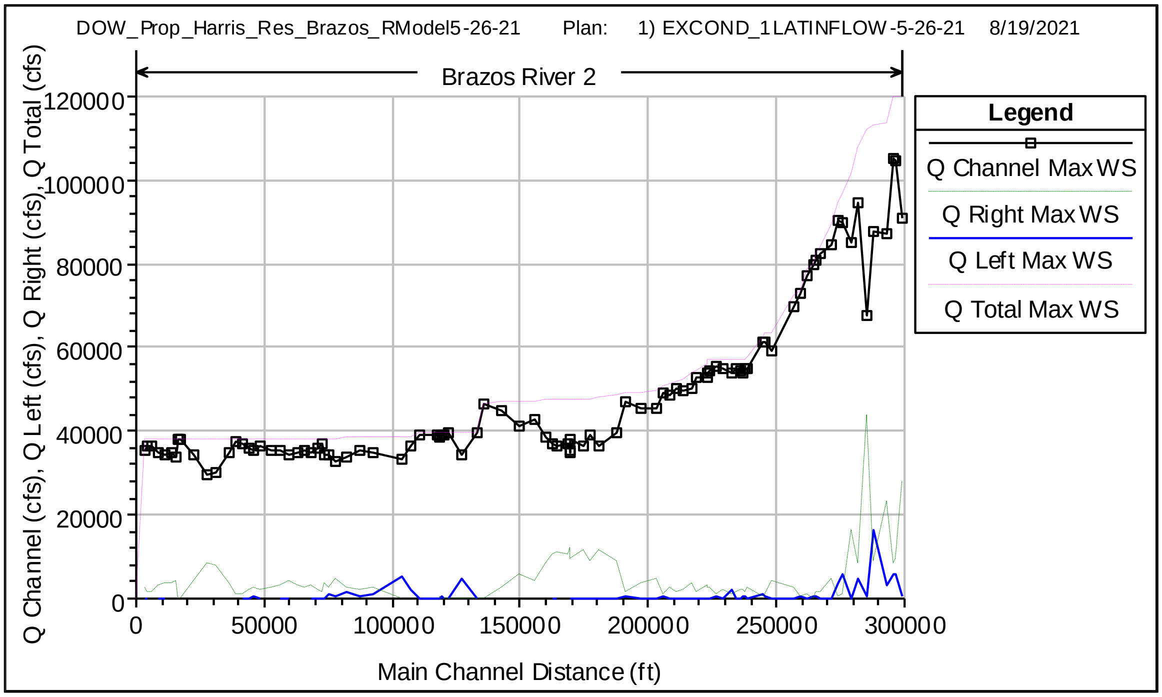


***Figure 61**: Proposed conditions channel flow, left and right overbank flow, and total maximum flow for the peak maximum WSEL during the 10.5-year simulation period along the Brazos River between Rosharon gage and outlet.*

Depicted in **Figure 62** through **Figure 71** are the existing and proposed stage hydrographs and flow hydrographs at five key analysis points between the Rosharon gage and the outlet at the Gulf of Mexico. **Table 16** shows the existing and proposed HEC-RAS unsteady flow water surface elevations for all cross-sections. **Table 17** shows the HEC-RAS existing and proposed unsteady flow maximum channel velocities for all cross-sections. The key analysis points are listed in **Table 18** and include the Rosharon gage, which is not expected to change between existing and proposed conditions as it is input as an upstream boundary condition in the model. Most of the results between the existing and proposed conditions varied only slightly from the existing conditions due to the model having one diversion added over a large watershed study area. Therefore, the change in flow in the Brazos River caused by the proposed Harris Reservoir diversion is negligible and the results for both conditions are identical.

Figure 72 shows the flood inundation mapping results of the Brazos HEC-RAS model, which includes cross-sections with maximum existing and proposed WSELs over the 10.5-year simulation. The red shade is used for proposed conditions model results and the blue shade is used for existing conditions model results. As there is no change in WSEL, when overlaid, the flood inundation map looks purple. **Figure 73** shows a close-up of the flood inundation map around the proposed Harris Reservoir.

Table 16: Comparison between Existing and Proposed Maximum Water Surface Elevations

River Station	Existing Conditions WSEL (ft)	Proposed Conditions WSEL (ft)	Change in WSEL (ft)
308,583.5	53.84	53.84	0.00
305,771.6	52.96	52.96	0.00
305,615.2	52.57	52.57	0.00
302,875.8	51.81	51.81	0.00
297,558.3	50.90	50.90	0.00
294,819.1	50.44	50.44	0.00
291,502.8	49.69	49.69	0.00
288,627.0	49.17	49.17	0.00
285,653.7	48.18	48.18	0.00
283,809.8	47.70	47.70	0.00
281,134.8	47.15	47.15	0.00
276,583.3	46.00	46.00	0.00
275,349.9	45.57	45.57	0.00
273,833.2	45.23	45.23	0.00
271,317.6	44.55	44.55	0.00
268,824.9	44.01	44.01	0.00
266,784.9	43.42	43.42	0.00

River Station	Existing Conditions WSEL (ft)	Proposed Conditions WSEL (ft)	Change in WSEL (ft)
257,935.3	41.45	41.45	0.00
255,458.2	40.93	40.93	0.00
253,920.7	40.62	40.62	0.00
248,467.6	39.90	39.90	0.00
247,254.6	39.83	39.83	0.00
246,307.5	39.63	39.63	0.00
245,582.1	39.50	39.50	0.00
244,296.3	39.27	39.27	0.00
241,798.8	38.81	38.81	0.00
238,317.3	38.31	38.31	0.00
235,923.4	37.67	37.67	0.00
233,849.8	37.32	37.32	0.00
232,926.9	37.20	37.20	0.00
232,298.7	37.06	37.06	0.00
228,171.5	36.28	36.28	0.00
226,430.5	35.99	35.99	0.00
223,178.3	35.46	35.46	0.00
220,535.9	34.92	34.92	0.00
218,197.0	34.38	34.38	0.00
215,636.0	33.94	33.94	0.00
212,690.4	33.49	33.49	0.00
206,664.8	32.47	32.47	0.00
200,926.0	31.44	31.44	0.00
196,787.5	30.77	30.77	0.00
190,306.2	30.28	30.28	0.00
186,824.7	29.98	29.98	0.00
183,829.7	29.70	29.70	0.00
179,479.5	29.13	29.13	0.00
179,155.4	29.05	29.05	0.00
178,789.6	28.94	28.94	0.00

River Station	Existing Conditions WSEL (ft)	Proposed Conditions WSEL (ft)	Change in WSEL (ft)
177,914.6	28.84	28.84	0.00
174,103.5	28.45	28.45	0.00
172,112.3	28.09	28.09	0.00
169,715.3	27.60	27.60	0.00
165,604.2	26.72	26.72	0.00
159,474.3	25.43	25.43	0.00
152,282.2	23.75	23.75	0.00
145,725.1	22.05	22.05	0.00
143,092.0	21.53	21.53	0.00
136,684.7	20.32	20.32	0.00
131,329.0	19.55	19.55	0.00
130,048.3	19.29	19.29	0.00
129,598.5	19.19	19.19	0.00
128,597.7	19.02	19.02	0.00
127,887.8	18.94	18.94	0.00
126,833.8	18.67	18.67	0.00
120,463.4	17.43	17.43	0.00
116,704.6	16.90	16.90	0.00
113,664.9	16.39	16.39	0.00
102,513.1	14.57	14.57	0.00
96,764.3	13.69	13.69	0.00
91,471.6	12.88	12.88	0.00
87,845.2	12.02	12.02	0.00
84,697.1	11.34	11.34	0.00
82,907.9	10.96	10.96	0.00
82,530.3	10.78	10.78	0.00
80,892.7	10.59	10.59	0.00
77,862.2	10.27	10.27	0.00
75,118.0	10.03	10.03	0.00
72,649.6	9.72	9.72	0.00

River Station	Existing Conditions WSEL (ft)	Proposed Conditions WSEL (ft)	Change in WSEL (ft)
68,849.0	9.25	9.25	0.00
66,026.0	8.93	8.93	0.00
62,557.0	8.66	8.66	0.00
58,377.0	8.33	8.33	0.00
55,599.0	8.07	8.07	0.00
53,486.0	7.84	7.84	0.00
51,424.0	7.63	7.63	0.00
48,402.0	7.09	7.09	0.00
45,585.0	6.67	6.67	0.00
41,087.0	6.02	6.02	0.00
37,527.0	5.60	5.60	0.00
32,269.0	4.87	4.87	0.00
27,098.0	3.85	3.85	0.00
26,001.0	3.69	3.69	0.00
25,641.0	3.66	3.66	0.00
25,070.0	3.64	3.64	0.00
23,412.0	3.42	3.42	0.00
20,788.0	3.10	3.10	0.00
18,177.0	2.66	2.66	0.00
15,562.0	2.02	2.02	0.00
14,131.0	1.62	1.62	0.00
12,687.0	1.11	1.11	0.00
9,604.0	0.51	-	0.51

Table 17: Comparison Between Existing and Proposed Maximum Velocities

River Station	Existing Conditions Channel Velocity (ft/s)	Proposed Conditions Channel Velocity (ft/s)	Change in Channel Velocity (ft/s)
308,583.5	4.08	4.08	0.00
305,771.6	6.95	6.95	0.00
305,615.2	7.28	7.28	0.00
302,875.8	4.04	4.04	0.00
297,558.3	4.07	4.07	0.00
294,819.1	3.60	3.60	0.00
291,502.8	4.94	4.94	0.00
288,627.0	4.36	4.36	0.00
285,653.7	6.18	6.18	0.00
283,809.8	5.11	5.11	0.00
281,134.8	4.66	4.66	0.00
276,583.3	4.93	4.93	0.00
275,349.9	5.27	5.27	0.00
273,833.2	4.31	4.31	0.00
271,317.6	4.55	4.55	0.00
268,824.9	4.16	4.16	0.00
266,784.9	4.70	4.70	0.00
257,935.3	4.10	4.10	0.00
255,458.2	3.95	3.95	0.00
253,920.7	4.10	4.10	0.00
248,467.6	3.15	3.15	0.00
247,254.6	2.39	2.39	0.00
246,307.5	3.70	3.70	0.00
245,582.1	3.71	3.71	0.00
244,296.3	3.74	3.74	0.00

River Station	Existing Conditions Channel Velocity (ft/s)	Proposed Conditions Channel Velocity (ft/s)	Change in Channel Velocity (ft/s)
241,798.8	3.48	3.48	0.00
238,317.3	3.47	3.47	0.00
235,923.4	3.91	3.91	0.00
233,849.8	3.63	3.63	0.00
232,926.9	3.34	3.34	0.00
232,298.7	3.87	3.87	0.00
228,171.5	3.58	3.58	0.00
226,430.5	3.27	3.27	0.00
223,178.3	3.07	3.07	0.00
220,535.9	3.59	3.59	0.00
218,197.0	3.77	3.77	0.00
215,636.0	3.24	3.24	0.00
212,690.4	3.46	3.46	0.00
206,664.8	3.25	3.25	0.00
200,926.0	3.51	3.51	0.00
196,787.5	2.85	2.85	0.00
190,306.2	2.07	2.07	0.00
186,824.7	2.41	2.41	0.00
183,829.7	2.79	2.79	0.00
179,479.5	2.91	2.91	0.00
179,155.4	2.71	2.71	0.00
178,789.6	2.61	2.61	0.00
177,914.6	2.45	2.45	0.00
174,103.5	2.68	2.68	0.00
172,112.3	3.00	3.00	0.00
169,715.3	3.25	3.25	0.00

River Station	Existing Conditions Channel Velocity (ft/s)	Proposed Conditions Channel Velocity (ft/s)	Change in Channel Velocity (ft/s)
165,604.2	3.43	3.43	0.00
159,474.3	3.50	3.50	0.00
152,282.2	3.94	3.94	0.00
145,725.1	3.92	3.92	0.00
143,092.0	3.46	3.46	0.00
136,684.7	3.30	3.30	0.00
131,329.0	2.80	2.80	0.00
130,048.3	3.33	3.33	0.00
129,598.5	3.38	3.38	0.00
128,597.7	3.27	3.27	0.00
127,887.8	2.86	2.86	0.00
126,833.8	3.68	3.68	0.00
120,463.4	3.24	3.24	0.00
116,704.6	2.85	2.85	0.00
113,664.9	2.94	2.94	0.00
102,513.1	2.37	2.37	0.00
96,764.3	2.47	2.47	0.00
91,471.6	3.13	3.13	0.00
87,845.2	3.53	3.53	0.00
84,697.1	2.81	2.81	0.00
82,907.9	2.93	2.93	0.00
82,530.3	3.31	3.31	0.00
80,892.7	3.67	3.67	0.00
77,862.2	3.95	3.95	0.00
75,118.0	3.39	3.39	0.00
72,649.6	3.39	3.39	0.00

River Station	Existing Conditions Channel Velocity (ft/s)	Proposed Conditions Channel Velocity (ft/s)	Change in Channel Velocity (ft/s)
68,849.0	4.39	4.39	0.00
66,026.0	3.72	3.72	0.00
62,557.0	3.42	3.42	0.00
58,377.0	3.53	3.53	0.00
55,599.0	3.90	3.90	0.00
53,486.0	3.94	3.94	0.00
51,424.0	3.61	3.61	0.00
48,402.0	4.63	4.63	0.00
45,585.0	3.79	3.79	0.00
41,087.0	3.52	3.52	0.00
37,527.0	2.97	2.97	0.00
32,269.0	3.61	3.61	0.00
27,098.0	4.57	4.57	0.00
26,001.0	4.26	4.26	0.00
25,641.0	4.01	4.01	0.00
25,070.0	3.69	3.69	0.00
23,412.0	3.82	3.82	0.00
20,788.0	3.48	3.48	0.00
18,177.0	4.23	4.23	0.00
15,562.0	4.71	4.71	0.00
14,131.0	4.81	4.81	0.00
12,687.0	5.60	5.60	0.00
9,604.0	0.06	-	0.10

Table 18: Key Analysis Points for Results Reporting

Key Analysis Point	Location	HEC-RAS Cross-Section
1	Rosharon Gage	308,583.5
2	Upstream of State Road – 35, near West Columbia	179,155.4
3	Downstream of FM-521 (approximately 1,711 ft. upstream of Brazoria Reservoir Diversion [Inflow])	129,598.5
4	Brazoria Discharge upstream of FM-2004	82,907.9
5	Last RAS Cross Section (approximately 9,604 feet from the mouth of the Gulf of Mexico)	9,604.0

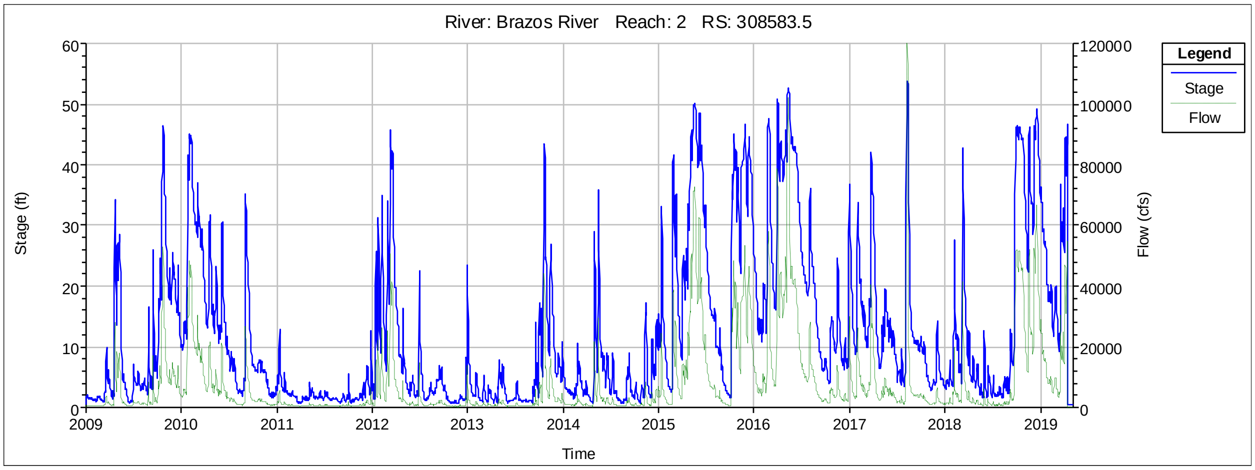


***Figure 62**: Proposed stage and flow hydrographs at Rosharon gage over the 10.5-year simulation period.*

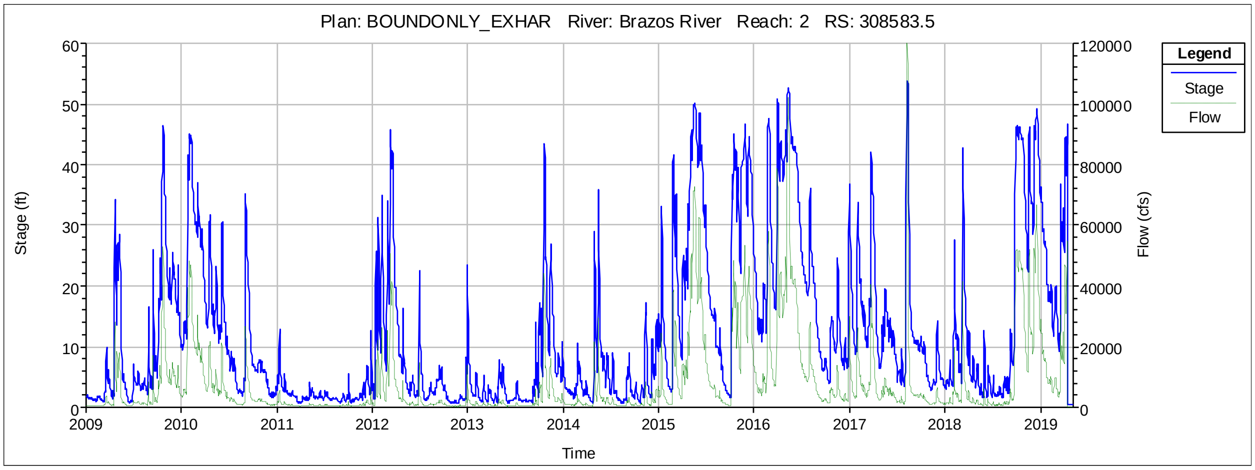


***Figure 63**: Existing stage and flow hydrographs at Rosharon gage over the 10.5-year simulation period.*

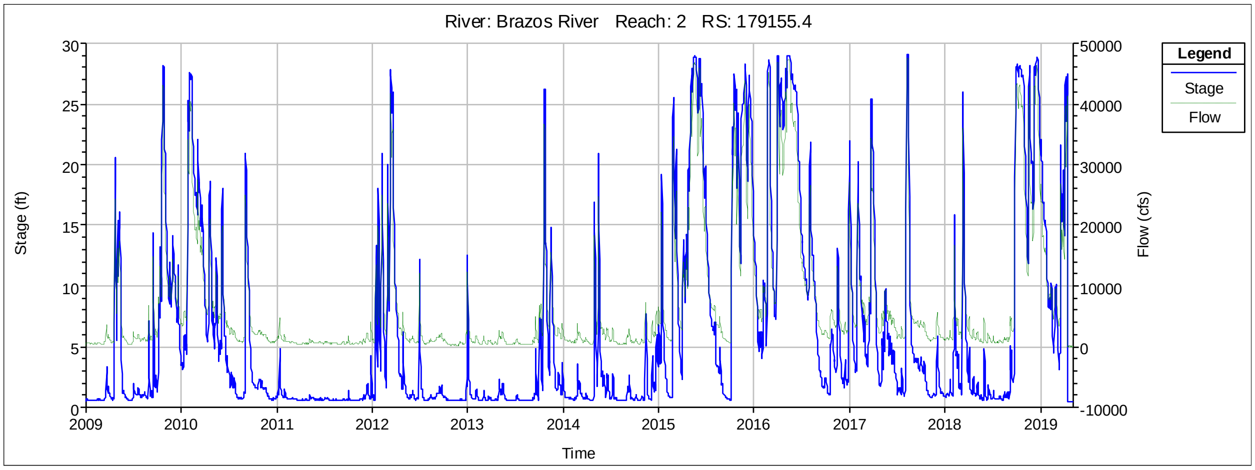


Figure 64: *Proposed stage and flow hydrographs upstream of State Road – 35, near West Columbia, over the 10.5-year simulation period.*

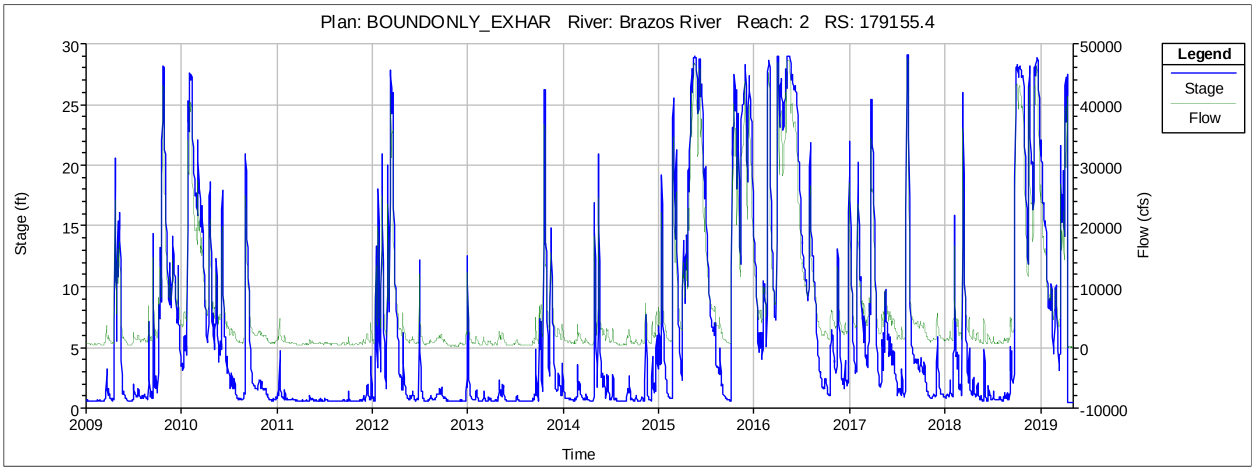


Figure 65: *Existing stage and flow hydrographs upstream of State Road – 35, near West Columbia, over the 10.5-year simulation period.*

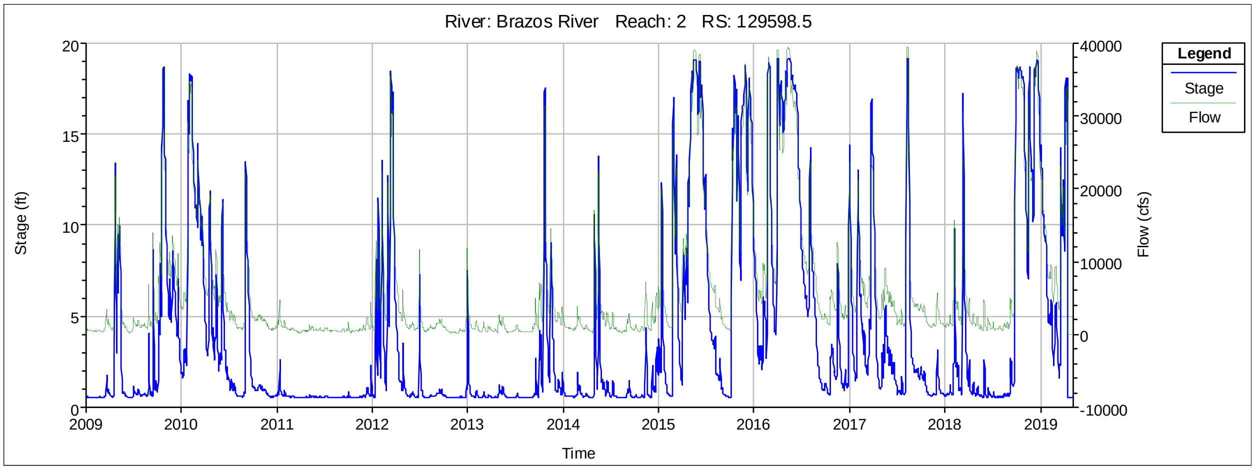


Figure 66: *Proposed stage and flow hydrographs downstream of FM-521 over the 10.5-year simulation period.*

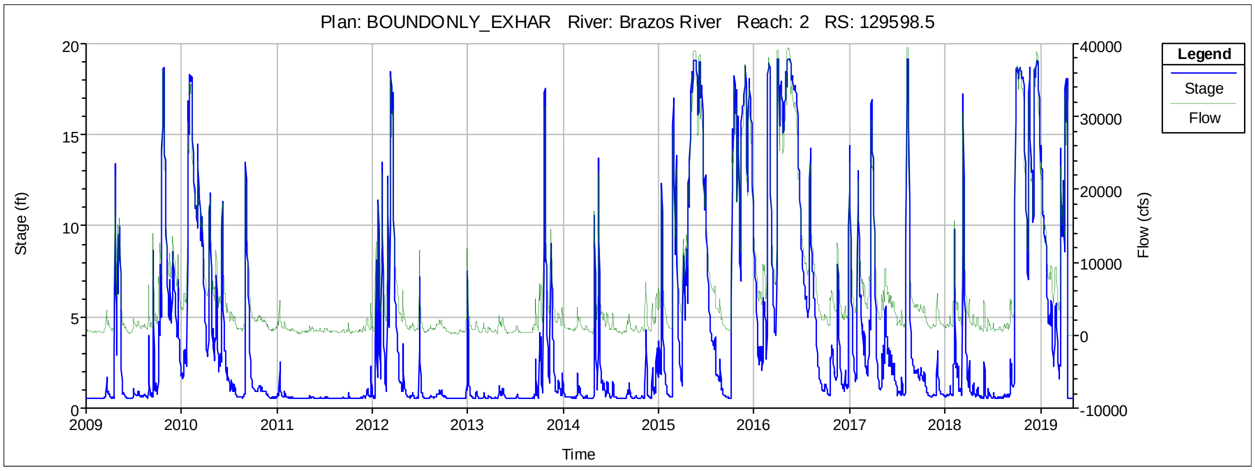


Figure 67: *Existing stage and flow hydrographs downstream of FM-521over the 10.5-year simulation period.*

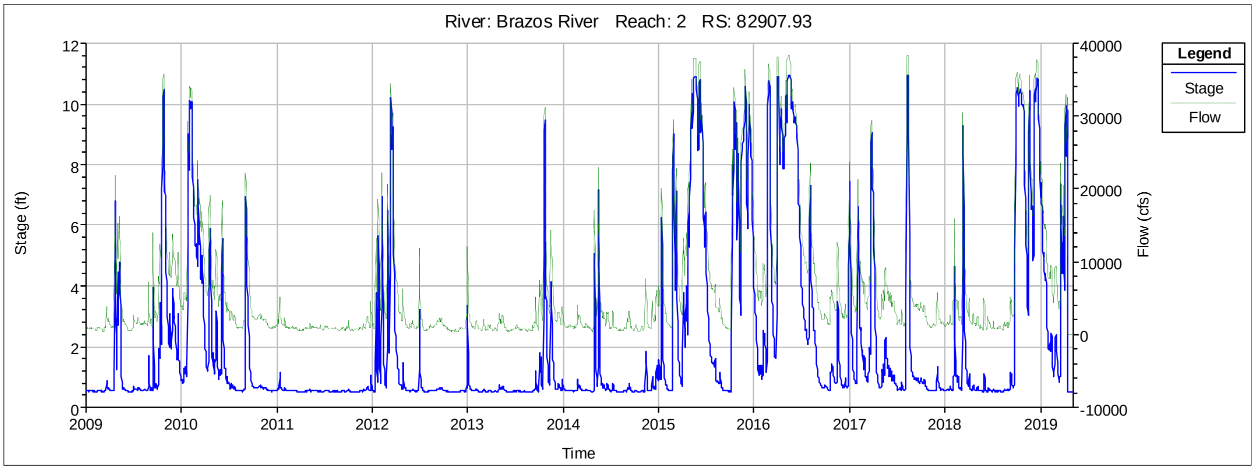


***Figure 68**: Proposed stage and flow hydrographs upstream of FM-2004 over the 10.5-year simulation period.*

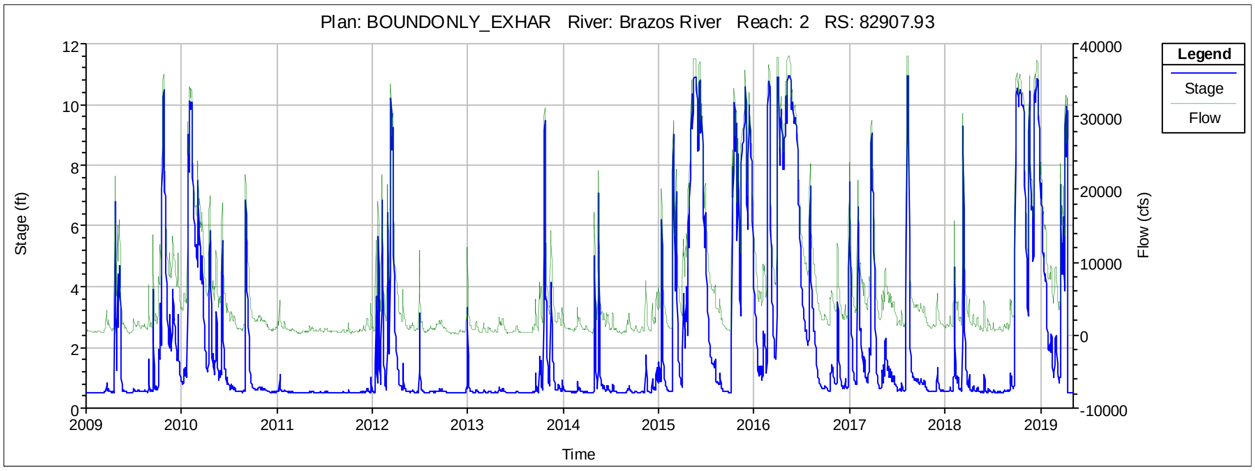


***Figure 69**: Existing stage and flow hydrographs upstream of FM-2004 over the 10.5-year simulation period.*

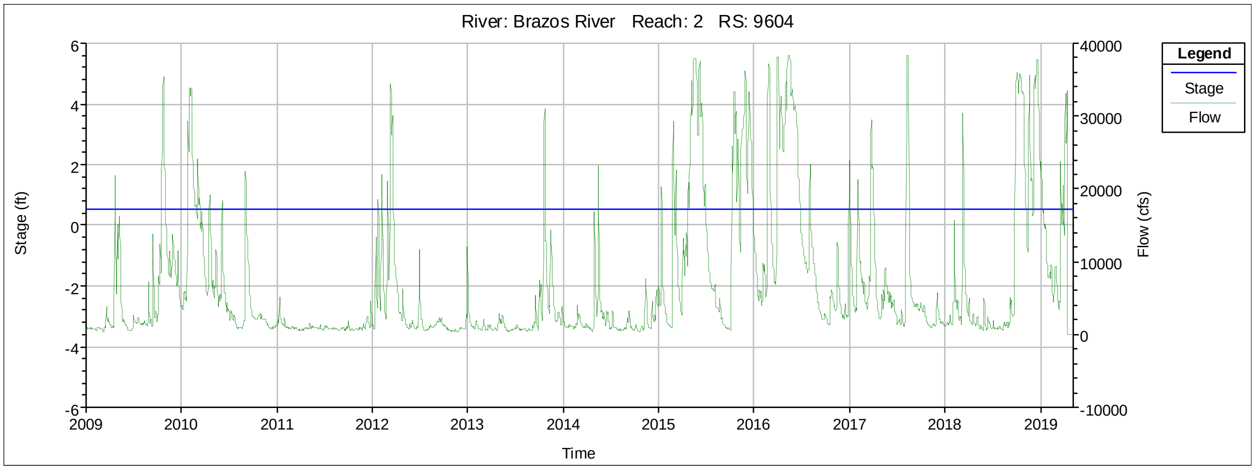


Figure 70: *Proposed stage and flow hydrographs at the last RAS cross-section approximately 9,604 ft from the Gulf of Mexico over the 10.5-year simulation period.*

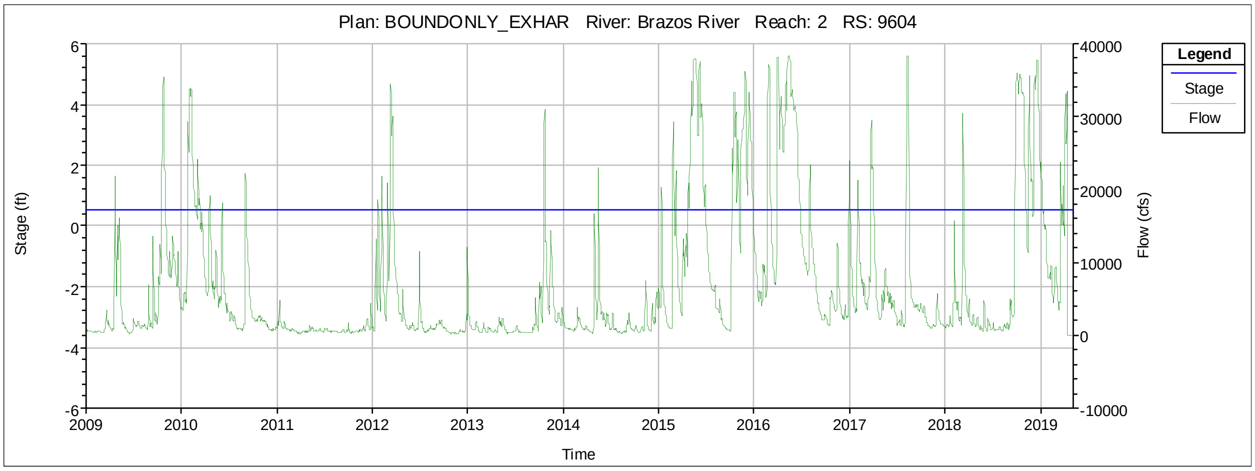


Figure 71*: Existing stage and flow hydrographs at the last RAS cross-section approximately 9,604 ft from the Gulf of Mexico over the 10.5-year simulation period.*

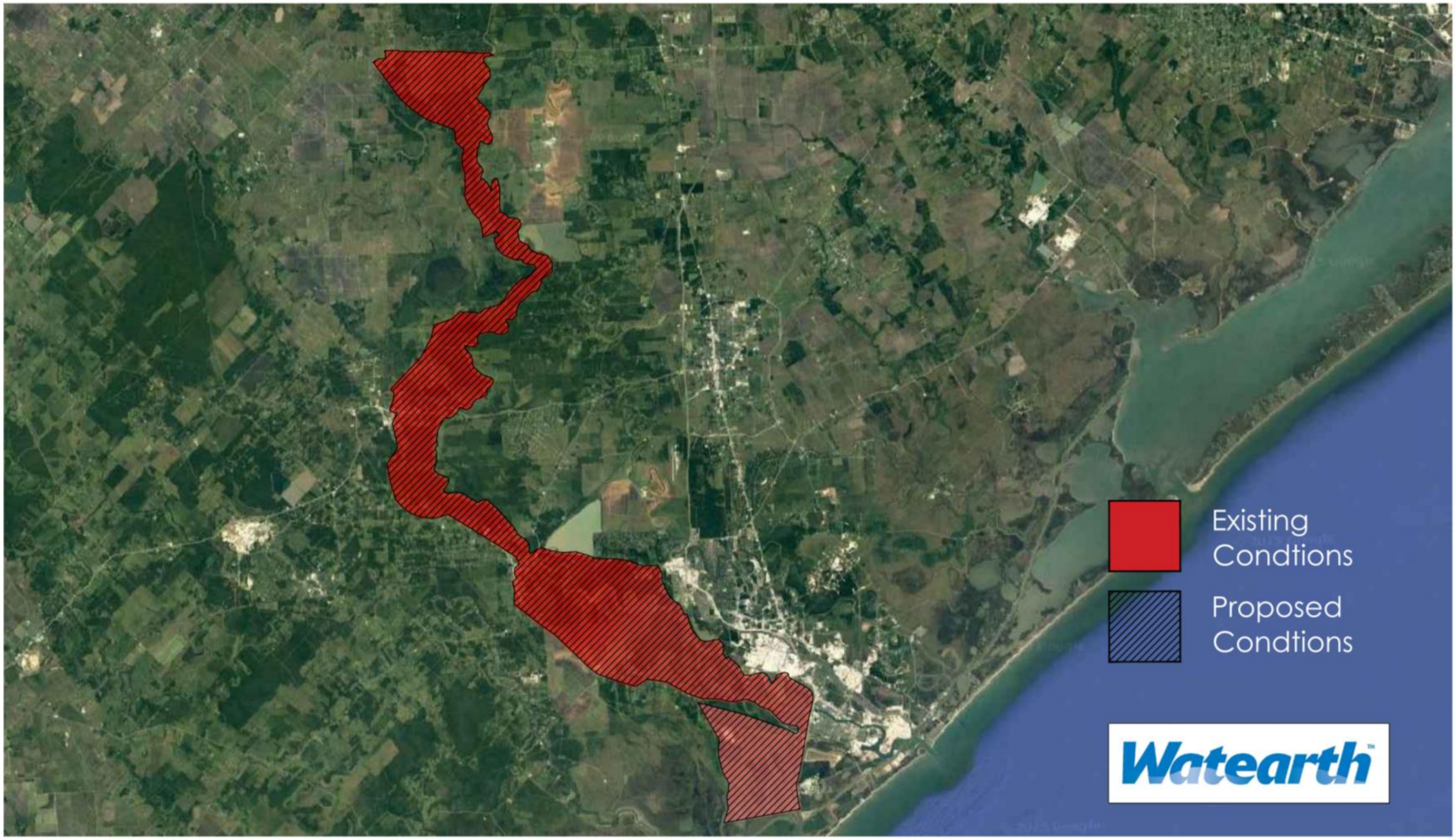


***Figure 72**: Maximum flood inundation results of both existing and proposed conditions over the 10.5-year simulation period.*

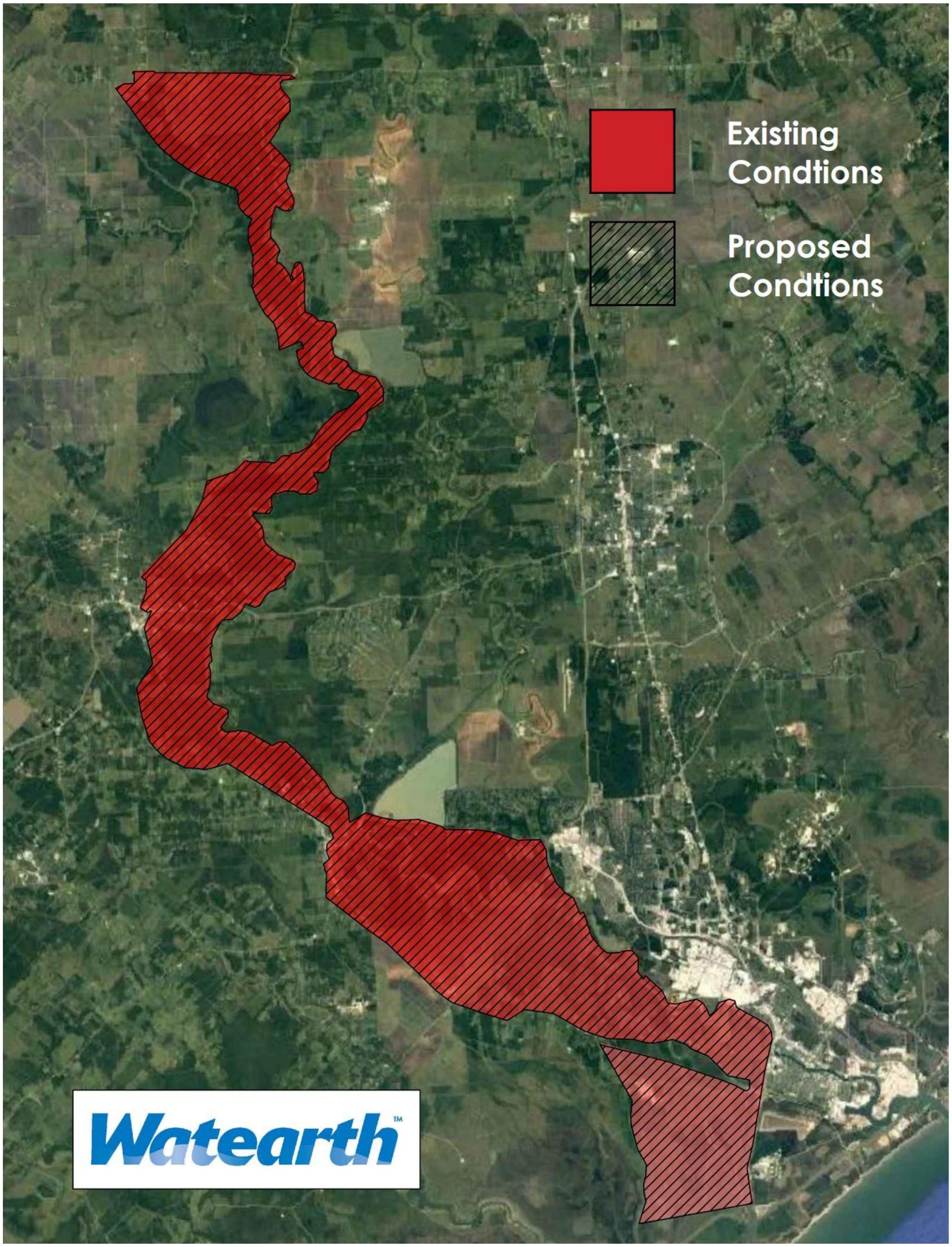


***Figure 73**: Close-up of proposed Harris Reservoir on maximum flood inundation results of existing and proposed conditions over the 10.5-year simulation period.*

5.4.4 Oyster Creek Hydrology

The Oyster Creek watershed located adjacent to and east of the Brazos River watershed modeled in this study is depicted in **Figure 74**. Discharges from the existing Harris Reservoir and proposed Harris Reservoir enter Oyster Creek through a series of outfalls as discussed in **Section 5.4.5**. Discharges from both reservoirs enter Oyster Creek near the middle of the watershed or lower portion of the 133.3 sq-mi Middle Oyster Creek drainage area. The drainage area of the proposed Harris Reservoir is in the Brazos River watershed; however, as the proposed Harris Reservoir discharges into Oyster Creek, it was also modified and moved into the Oyster Creek watershed for the hydrologic and hydraulic models for Oyster Creek, which are explained in detail in the *Oyster Creek Downstream Hydrologic and Hydraulic Impacts Final Report (October 2021)*.

The Oyster Creek watershed near the project vicinity is generally flat and undeveloped and, similar to the Brazos River, is significantly affected by tidal influence and backwater. While an upstream hydrologic model of Oyster Creek was available, hydrologic models of the Oyster Creek watershed were not available for the project study area due to the undeveloped condition of this portion of the watershed.

The historical discharges from the existing Harris Reservoir and the future discharges from the proposed Harris Reservoir are illustrated in **Figure 28.** This level of increase in combined flows potentially could create downstream hydromodification issues on Oyster Creek. These potential impacts are explained in detail in the *Oyster Creek Downstream Hydrologic and Hydraulic Impacts Final Report (October 2021)*.

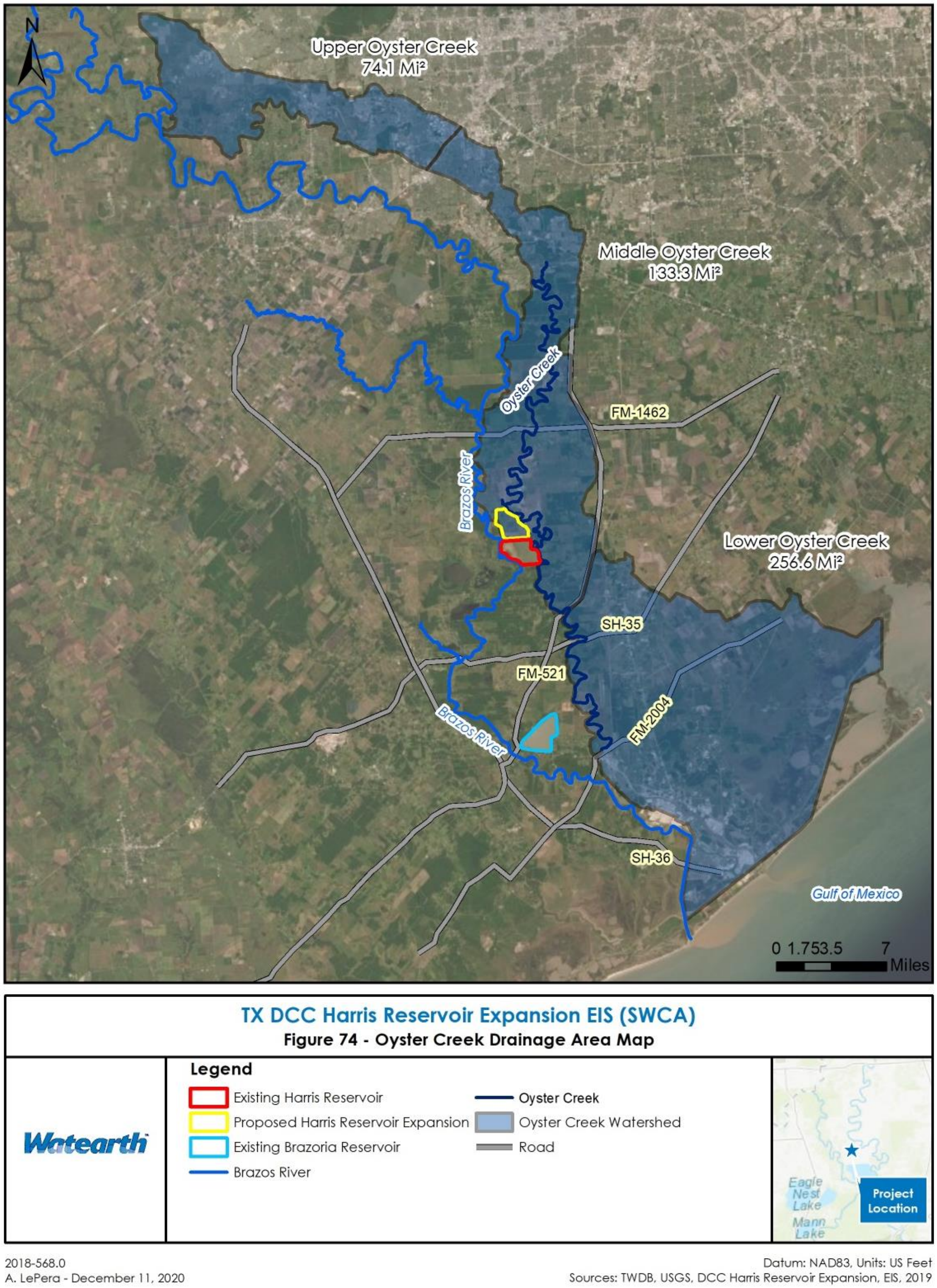


***Figure 74**: Oyster Creek drainage map for HEC-HMS.*

5.4.5 Oyster Creek Hydraulics

As part of the proposed expansion project, Oyster Creek will be enhanced with three projects to improve flood capacity and provide restoration and enrichment to the riparian habitat (**Figure 75**). Geomorphic design principles were used to provide bankfull benching creating floodplain storage, riparian habitat, and channel conveyance to accommodate the proposed Harris Reservoir outlet flow in to Oyster Creek.

A comparative analysis of the floodplain storage between existing and proposed conditions using the Brazos River HEC-RAS model is summarized in **Table 19A** and **Table19B**. A more detailed analysis of Oyster Creek hydraulics can be found in *Oyster Creek Downstream Hydrologic and Hydraulic Impacts Final Report (October 2021)*.

Table 19A: Comparison of Floodplain Storage Between Existing Conditions vs. Proposed Conditions

River Station	10-Year Flood			50-Year Flood		
	Existing (ac-ft)	Proposed (ac-ft)	Δ (ac-ft)	Existing (ac-ft)	Proposed (ac-ft)	Δ (ac-ft)
69.90	13,692	12,565	-1,127	75,207	74,682	-525
69.72	13,230	12,103	-1,127	73,160	72,635	-525
68.56	12,871	11,743	-1,127	70,772	70,247	-525
67.62	12,007	10,876	-1,131	67,643	67,118	-525
66.85	11,611	10,478	-1,133	65,990	65,465	-525
65.35	10,543	9,443	-1,100	59,684	59,199	-484
64.60	10,364	9,280	-1,084	58,377	57,910	-468
63.90	10,201	9,139	-1,061	57,149	56,697	-452
63.19	8,988	8,083	-905	51,336	50,958	-377
62.84	8,585	7,730	-855	49,463	49,115	-349
61.87	7,640	7,001	-640	43,753	43,542	-210
61.43	7,182	6,673	-508	41,539	41,384	-155
60.49	6,036	5,825	-211	36,715	36,694	-20
60.48	6,018	5,811	-207	36,627	36,608	-19
60.47	5,990	5,789	-201	36,483	36,472	-11
59.85	5,859	5,699	-160	35,694	35,731	37
59.17	4,960	5,022	62	31,066	31,349	283
58.67	4,407	4,583	176	28,497	28,944	447
56.05	3,249	3,518	269	22,931	23,458	527

River Station	10-Year Flood			50-Year Flood		
	Existing (ac-ft)	Proposed (ac-ft)	Δ (ac-ft)	Existing (ac-ft)	Proposed (ac-ft)	Δ (ac-ft)
55.60	2,649	2,757	108	19,917	20,185	268
55.30	2,395	2,442	47	18,619	18,813	194
53.49	846	847	0	10,629	10,638	9
53.48	825	825	0	10,494	10,497	3
53.47	822	821	0	10,465	10,464	-1
53.46	812	812	0	10,351	10,351	-1
52.75	232	232	0	4,149	4,149	0
50.30	0	0	0	0	0	0

Table 19B: Comparison of Floodplain Storage Between Existing Conditions vs. Proposed Conditions

River Station	100-Year Flood			500-Year Flood		
	Existing (ac-ft)	Proposed (ac-ft)	Δ (ac-ft)	Existing (ac-ft)	Proposed (ac-ft)	Δ (ac-ft)
69.90	103,892	102,865	-1,028	199,464	196,468	-2,996
69.72	100,529	99,502	-1,028	193,665	190,661	-3,004
68.56	96,664	95,637	-1,028	186,522	183,488	-3,034
67.62	92,522	91,494	-1,027	180,233	177,078	-3,145
66.85	90,347	89,320	-1,027	177,001	173,767	-3,235
65.35	81,616	80,589	-1,026	163,525	159,728	-3,797
64.60	79,782	78,756	-1,026	160,672	156,722	-3,950
63.90	78,106	77,081	-1,026	158,108	154,021	-4,087
63.19	70,410	69,387	-1,023	146,624	141,926	-4,698
62.84	67,926	66,903	-1,022	142,906	137,997	-4,909
61.87	60,216	59,239	-977	131,137	125,538	-5,598
61.43	57,298	56,337	-961	126,722	120,844	-5,878
60.49	51,054	50,173	-882	117,094	110,795	-6,299
60.48	50,939	50,059	-881	116,911	110,607	-6,304
60.47	50,749	49,879	-870	116,593	110,305	-6,287

River Station	100-Year Flood			500-Year Flood		
	Existing (ac-ft)	Proposed (ac-ft)	Δ (ac-ft)	Existing (ac-ft)	Proposed (ac-ft)	Δ (ac-ft)
59.85	49,690	48,867	-824	114,811	108,575	-6,236
59.17	43,547	42,891	-656	104,193	98,217	-5,976
58.67	39,996	93,489	-507	97,213	91,661	-5,552
56.05	31,937	31,736	-201	78,192	74,806	-3,386
55.60	27,689	27,443	-246	68,027	65,859	2,168
55.30	25,886	25,663	-223	63,777	62,135	-1,642
53.49	14,982	14,985	3	38,177	38,175	-1
53.48	14,794	14,797	3	37,724	37,722	-2
53.47	14,746	14,745	-1	37,563	37,556	-7
53.46	14,586	14,584	-1	37,143	37,136	-7
52.75	5,621	5,621	0	13,016	13,015	0
50.30	0	0	0	0	0	0

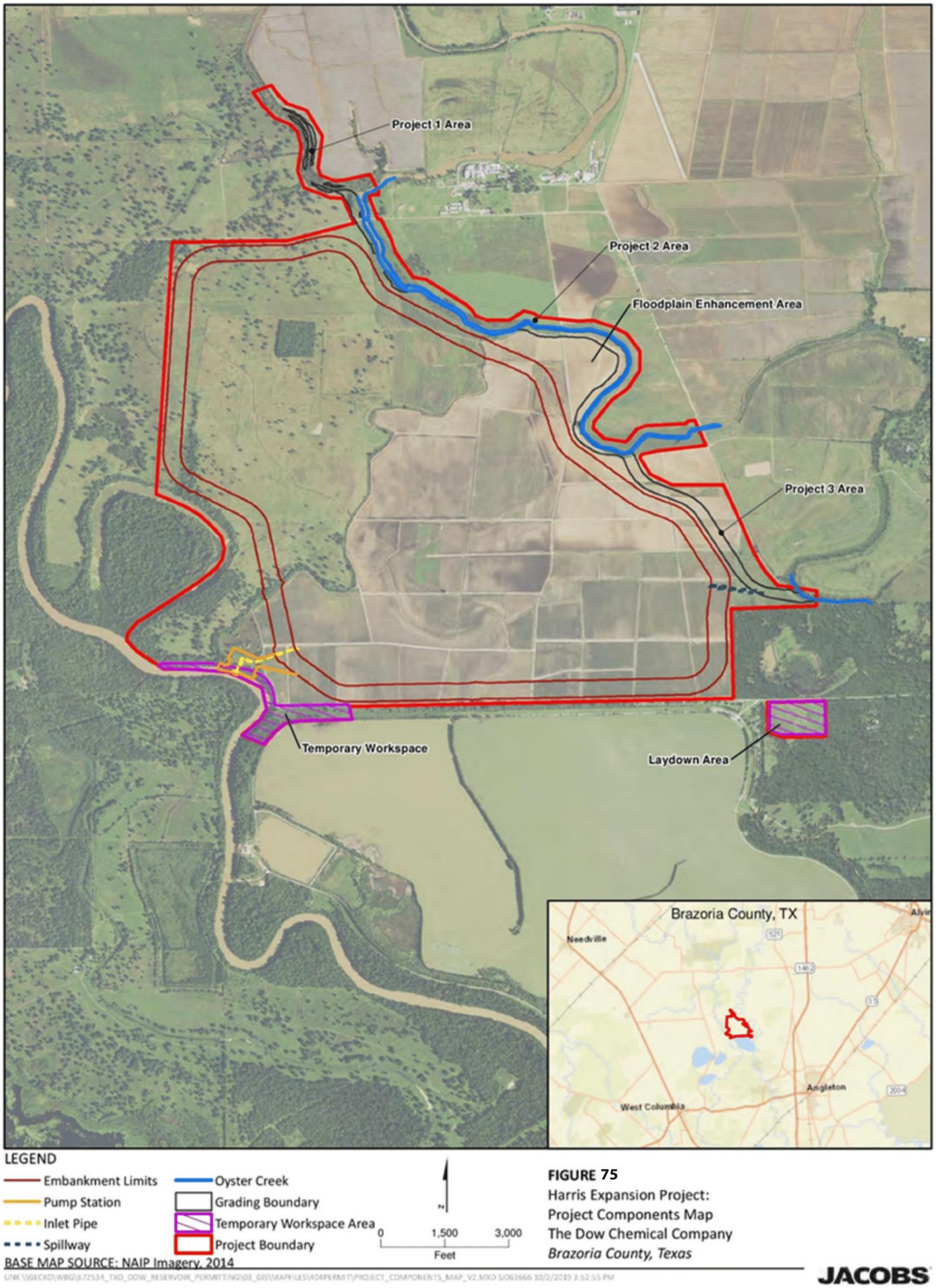


Figure 75: Oyster Creek floodplain enhancements.

6.0 Analysis

This section is comprised of quantitative and qualitative analysis of the proposed project through the analysis horizon of 50 years (year 2072). The hydrologic, hydraulic, and reservoir operational models provide near-term analysis of water supply needs and instream flow alternations. Analysis to long-term changes in the project vicinity such as precipitation, temperature, and sea level rise are based on predictive models by agencies such as the USACE, NOAA, and USGS. The combination of these various analysis points is summarized in the Conclusions and Recommendations section, **Section 7**.

6.1 Evaporation Analysis

6.1.1 Introduction

The climatic process, where moisture is removed from any water surface and transported as vapor away from the source by wind, is called evaporation. Substantial amounts of water can evaporate from lakes, reservoirs, rivers, streams, bayous, and canals. During wet periods with normal to above normal rainfall, climatic effects minimize evaporation. On the other hand, in dry periods, evaporation rates are higher and the amount of evaporation loss becomes a very important element in a water supply analysis.

Evaporation rates in Texas vary during the year with approximately 86% of the evaporation occurring in the 6-month period from May through October, which corresponds to the lowest rainfall and full sun conditions (TWDB, 2018). Median gross evaporation for the project area is approximately 47.8 inches but can vary from 35 inches to 58 inches (**Figure 76**). The evaporation from the current and proposed storage reservoirs can present a substantial loss during a dry period.

6.1.2 Data Collection

The TWDB compiles water related data from a number of sources for water managers to estimate evaporation rates because evaporation is one of the largest sources of water loss from Texas reservoirs (TWDB, 2018). The data in this set are from nearly 4,000 gauging stations and includes precipitation data primarily collected from NOAA's National Weather Service (NWS). In addition, TWDB collects data from pan evaporation sites throughout Texas and from surrounding states from the NOAA-NWS sites, as well as other cooperators, which include lake owners and operators, government agencies, research institutions, and other public and private entities.

The proposed project generally falls within Quad 812 (**Figure 76**). Available data include monthly precipitation from January 1940 through December 2018 and gross evaporation from January 1954 through December 2018 (**Figure 77 and Figure 78**). The graph shows the trend is toward higher evaporation and precipitation rates; however, the evaporation rate has a steeper trend line than precipitation, which indicates a potential for the evaporation rate to exceed the precipitation rate within the project horizon.

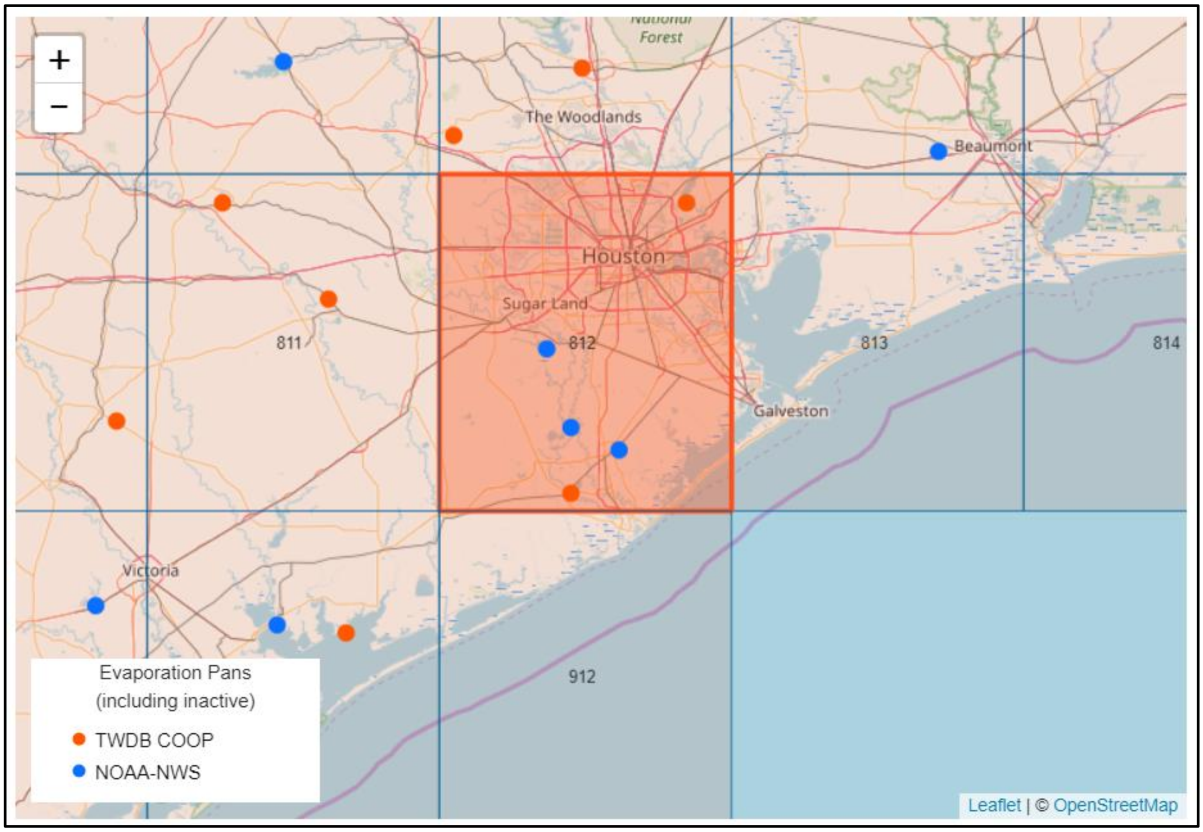


***Figure 76**: Quad 812 of the Texas Water Development Board water data.*

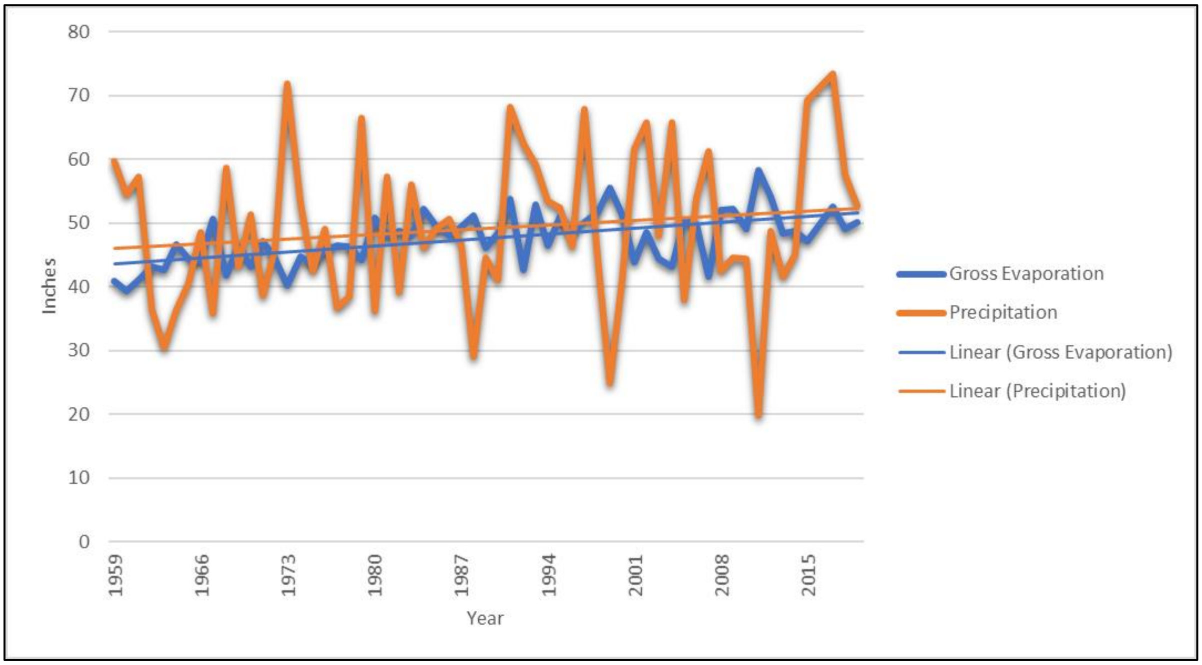


***Figure 77**: Quad 812 gross evaporation versus precipitation.*

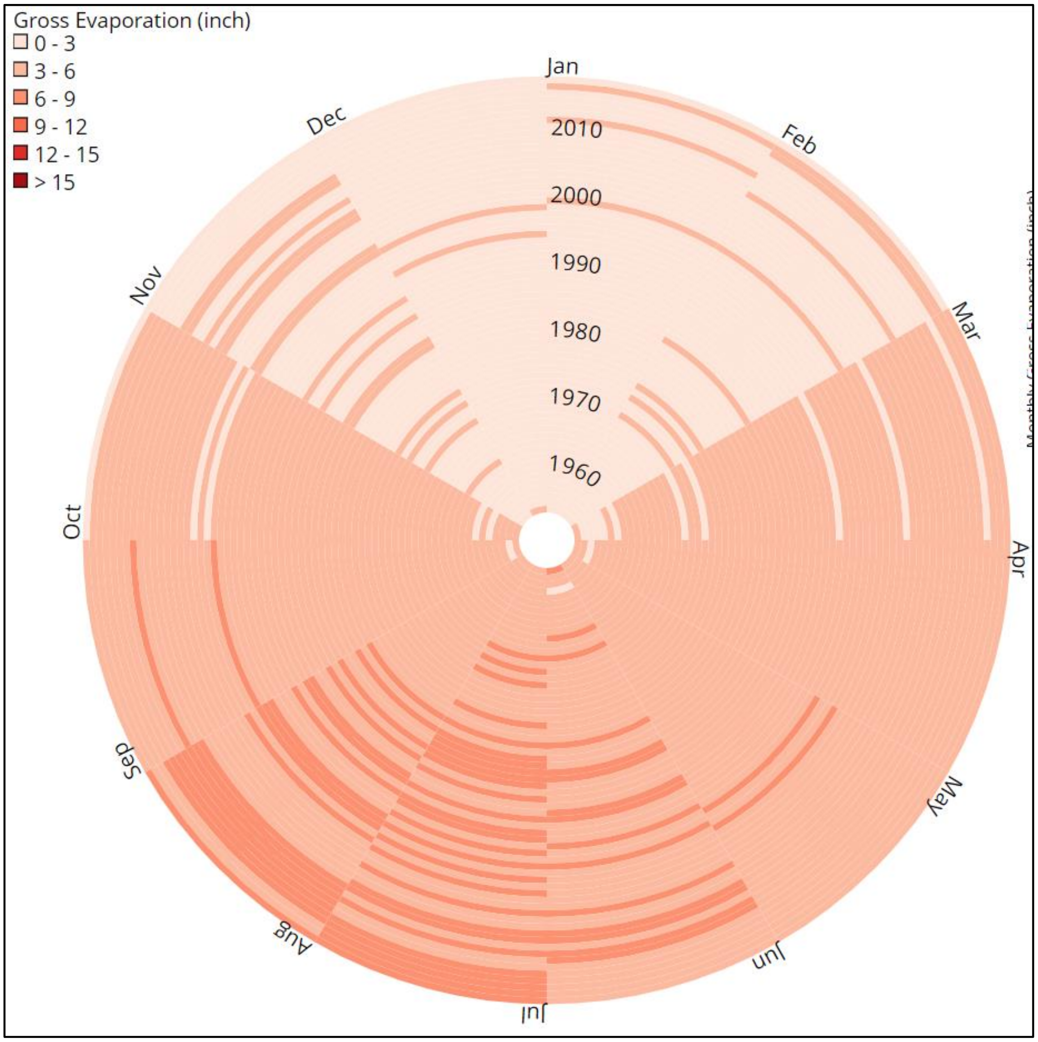


Figure 78: Annual gross evaporation wheel.

The net evaporation (trend line), as depicted in **Figure 77**, is on average slightly higher than annual precipitation (approximately 1 inch more evaporation than rainfall) (TWDB, 2018). In addition, the high variability from month-to-month and year-to-year makes long-term planning more difficult. For example, the highest net evaporation occurred during August 2017, which corresponds with the majority of rainfall from Hurricane Harvey, when there was 33.5 inches of rain but only 5.3 inches of evaporation. In 1973, the yearly precipitation exceeded evaporation by 31.7 inches compared to 2011 when there was a net evaporation of 38.4 inches. In 1973, the Freeport, Texas, area experienced Tropical Storm Delia, which made landfall twice and dropped significant amounts of rainfall along the coastline during its erratic path in the Gulf of Mexico.

6.1.3 Analysis

Dow currently assumes an approximately 25% annual loss due to evaporation in the two-reservoir system. This may be underestimated as the current average annual rainfall for Freeport, Texas, is 52 inches; evaporation can vary from 35 inches to 58 inches, as described previously. During wet conditions, precipitation and high humidity retard evaporation. During drought conditions, evaporation rates increase and the lack of rainfall results in less natural makeup water. Evaporation rates are a function of surface area versus depth/volume, which results in shallow reservoirs with large surface area being more susceptible to evaporation during drought periods than deep reservoirs with small surface area with the same volume of water.

Dow's existing two-reservoir system is typical of Gulf Coast reservoirs that are relatively shallow compared to surface area. Evaporation rates during normal weather patterns (average annual rainfall and median gross pond evaporation) are almost equal to rainfall rates so there would be negligible water loss during normal years. This is due in part to the natural refill by rainfall capture directly into the reservoir. The normal weather evaporation rate would balance with precipitation for the existing conditions and under the proposed project conditions.

Under drought conditions (lower than normal rainfall), the reservoirs would experience maximum evaporation and there would potentially not be makeup water depending on river conditions and precipitation within the watershed. Assuming half the normal precipitation and maximum evaporation, annual net evaporation (NE=E-R) would be approximately 31 inches. The existing and proposed Harris Reservoirs surface area is approximately 5,500 ac. That could result in a loss of over 14,000 ac-ft during the most critical periods.

Under wet weather conditions (higher than normal rainfall), the reservoirs would capture precipitation, experience reduced evaporation, and Dow would refill the reservoirs from river pump stations. Capture would be limited to the total effective capacity of each of the reservoirs, as well as considerations as discussed in the following section, such as sediment loads in the river and wind restrictions for embankment protections.

6.2 Hydromodification of Oyster Creek

Oyster Creek historically had a greater drainage area but 63% of the drainage area was diverted by a canal at the Sienna Plantation in Missouri City, Texas, to the Brazos River (as measured at the downstream end of Project 2). The analysis of the stream system is also limited because there is a lack of availability of existing hydraulic models for the project reaches but the geomorphic assessment approach using Rosgen Level I, II, and III stream assessment used to classify the stream is a proven process to establish a stable channel for the long term.

There is a proposed water storage/floodplain overflow feature near the end of Project 2 and the start of Project 3, which is critical to the system. This storage/floodplain overflow allows large flows to bypass the oxbow in Oyster Creek and avoid increased velocities in Oyster Creek. Increased velocities could lead to increased erosion of the agricultural fields in the oxbow area. All features of this overflow must be maintained for the long-term viability of benefits created by the floodplain storage, riparian habitat, and channel conveyance. A maintenance plan should be developed and implemented by Dow for the project reaches.

The hydromodification impacts of the proposed Harris Reservoir on Oyster Creek has been examined in detail and can be found in *Oyster Creek Downstream Hydrologic and Hydraulic Impacts Final Report (October 2021)*.

6.3 Sedimentation Analysis for Reservoirs, Brazos River, and Oyster Creek

6.3.1 Existing Reservoirs and Brazos River

Sediment loads and corresponding impacts on existing reservoir effective storage volumes were discussed in **Section 3.5.2**.

Due to the relatively high sands and fine sediment loads in the Brazos River, storage volume loss due to sedimentation for the proposed project and the existing reservoirs could be a significant issue during the 50-year planning horizon and will likely result in less than the required 180-day reservoir storage. Current information does not indicate if there is an operational restriction on pumping high sediment load water from the Brazos River into any of the reservoirs. As previously discussed, it is recommended that Dow develop and implement an O&M plan to provide regular reservoir sediment removal to ensure maintenance of required storage capacity.

6.3.2 Proposed Project

The proposed project would be subject to the same sedimentation rates experienced by the existing Harris and Brazoria Reservoirs. Operational restrictions for pumping for high sediment load periods and regular removal of accumulated sediments on a regular basis are the most reasonable methods for maintaining authorized reservoir volumes. The O&M plan can be a condition of the permit. A BASINS/HSPF model was used to analyze the sediment transport in Oyster Creek as a result of the construction of proposed Harris Reservoir and can be found in *Oyster Creek Downstream Hydrologic and Hydraulic Impacts Final Report (October 2021)*.

6.3.3 Oyster Creek

Oyster Creek's natural flow has been significantly curtailed by a flood control project near Sienna Plantation, which has resulted in very low to no flow conditions throughout the project area. In addition, the channel is highly incised, which has disconnected the creek from its floodplain and may at least be in part a result of the flood control project and farming practices creating hydromodification and erosion.

To examine the hydromodification process in Oyster Creek, Better Assessment Science Integrating Point and Nonpoint sources (BASINS) model is used together with Hydrologic Simulation Program Fortran (HSPF). The methodology and results are described in detail in the *Oyster Creek Downstream Hydrology and Hydraulics Impacts Final Report*. The results of the BASINS/HSPF model shows an increase in the erosion within Oyster Creek downstream of the proposed Harris Reservoir outflow and a slight increase in velocity in the channel.

6.4 Watershed Vulnerability and Floodplain Storage

As discussed in **Section 5.4**, floodplain flow, velocity, and WSEL changes were analyzed for the Brazos River and storage effects on Oyster Creek for the proposed Harris Reservoir project. While Dow found there was no rise in either system directly downstream of the proposed project, Dow did not address the loss of Oyster Creek floodplain storage due to the proposed Harris Reservoir between the Brazos River and Oyster Creek.

The proposed Harris reservoir embankment will be built to elevation 72.7 ft from the existing 40 ft natural ground elevation. The natural ground east of the Brazos River and west of Oyster Creek is relatively flat, so current flood flows from the shared 100-year floodplain are stored and peak flows are attenuated downstream.

The proposed three-phased Oyster Creek enhancement project will improve flood storage capacity and provide restoration and enrichment to the riparian habitat. Nonetheless, as previously discussed, there will be a net 1,028 acre-ft (1%) loss in floodplain storage as a result of the proposed Harris reservoir embankment encroaching the Oyster Creek 100-year floodplain.

Table 20A and **Table 20B** show the Jacobs HEC-RAS 5.07 (OCNoRiseUpdateMay2020) existing and proposed Oyster Creek WSELs upstream of the proposed flood channel projects to downstream of the proposed Harris Reservoir. **Table 20A** shows the HEC-RAS generated WSEL comparisons between existing and proposed conditions for the Oyster Creek floodplain between FM-1462 (cross-section 69.90) and Harris Reservoir Road (cross-section 50.30) during the 10- and 50-year flood events; **Table 20B** shows the HEC-RAS generated WSEL comparisons between existing and proposed conditions for the Oyster Creek floodplain between FM-1462 (cross-section 69.90) and Harris Reservoir Road (cross-section 50.30) during the 100- and 500-year flood events.

Table 20A: Comparison of Water Surface Elevations Between Existing Conditions vs. Proposed Conditions for Oyster Creek

River Station	10-Year Flood			50-Year Flood		
	Existing (ft)	Proposed (ft)	Δ	Existing (ft)	Proposed (ft)	Δ
69.90	41.05	41.05	0.00	44.13	44.13	0.00
69.72	40.93	40.93	0.00	43.78	43.78	0.00
68.56	40.12	40.13	0.01	42.07	42.07	0.00
67.62	39.87	39.88	0.01	41.58	41.58	0.00
66.85	39.78	39.78	0.00	41.44	41.44	0.00
65.35	38.49	38.44	-0.05	40.50	40.52	0.02
64.60	38.15	38.06	-0.09	40.39	40.41	0.02
63.90	38.02	37.89	-0.13	40.33	40.36	0.03
63.19	37.82	37.64	-0.18	40.16	40.19	0.03
62.84	37.75	37.55	-0.20	40.09	40.12	0.03
61.87	37.44	37.07	-0.37	39.82	39.86	0.04
61.43	37.37	36.97	-0.40	39.70	39.75	0.05
60.49	37.21	36.72	-0.49	39.38	39.46	0.08
60.48	37.20	36.71	-0.49	39.37	39.45	0.08
60.47	37.17	36.69	-0.48	39.35	39.43	0.08
59.85	37.09	36.60	-0.49	39.26	39.34	0.08
59.17	36.63	36.17	-0.46	38.73	38.84	0.11
58.67	36.13	35.77	-0.36	38.22	38.34	0.12
56.05	33.53	33.39	-0.14	36.39	36.39	0.00
55.60	33.14	33.19	0.05	36.14	36.10	-0.04
55.30	33.06	33.13	0.07	36.09	36.04	-0.05
53.49	32.23	32.24	0.01	35.53	35.44	-0.09
53.48	32.16	32.17	0.01	35.51	35.42	-0.09

River Station	10-Year Flood			50-Year Flood		
	Existing (ft)	Proposed (ft)	Δ	Existing (ft)	Proposed (ft)	Δ
53.47	32.02	32.02	0.00	35.40	35.40	0.00
53.46	31.99	31.99	0.00	35.38	35.38	0.00
52.75	29.59	29.58	-0.01	34.50	34.50	0.00
50.30	24.65	24.65	0.00	34.24	34.24	0.00

Table 20B: Comparison of Water Surface Elevations Between Existing Conditions vs. Proposed Conditions for Oyster Creek

River Station	100-Year Flood			500-Year Flood		
	Existing (ft)	Proposed (ft)	Δ	Existing (ft)	Proposed (ft)	Δ
69.90	44.70	44.70	0.00	45.54	45.55	0.01
69.72	44.39	44.39	0.00	45.25	45.25	0.00
68.56	42.70	42.70	0.00	43.71	43.74	0.03
67.62	42.11	42.11	0.00	43.02	43.08	0.06
66.85	41.95	41.95	0.00	42.86	42.93	0.07
65.35	41.15	41.15	0.00	42.22	42.37	0.15
64.60	41.06	41.06	0.00	42.16	42.32	0.16
63.90	41.02	41.02	0.00	42.13	42.29	0.16
63.19	40.85	40.85	0.00	41.99	42.17	0.18
62.84	40.78	40.78	0.00	41.94	42.13	0.19
61.87	40.54	40.54	0.00	41.76	41.97	0.21
61.43	40.41	40.41	0.00	41.65	41.88	0.23
60.49	40.07	40.07	0.00	41.38	41.64	0.26
60.48	40.06	40.06	0.00	41.37	41.63	0.26
60.47	40.05	40.04	-0.01	41.36	41.62	0.26
59.85	39.96	39.96	0.00	41.30	41.57	0.27
59.17	39.45	39.44	-0.01	41.00	41.27	0.27
58.67	38.95	38.94	-0.01	40.76	41.02	0.26
56.05	37.21	37.21	0.00	40.12	40.22	0.10
55.60	36.93	36.93	0.00	39.96	40.00	0.04

River Station	100-Year Flood			500-Year Flood		
	Existing (ft)	Proposed (ft)	Δ	Existing (ft)	Proposed (ft)	Δ
55.30	36.86	36.86	0.00	39.91	39.94	0.03
53.49	36.23	36.23	0.00	39.38	39.38	0.00
53.48	36.21	36.20	-0.01	39.36	39.36	0.00
53.47	36.13	36.13	0.00	39.34	39.34	0.00
53.46	36.12	36.12	0.00	39.33	39.33	0.00
52.75	35.29	35.29	0.00	38.81	38.81	0.00
50.30	35.05	35.05	0.00	38.69	38.69	0.00

6.4.1 Floodplain Storage Volume Loss Analysis

Per Watearth's analysis on January 23, 2020, titled *Preliminary Hydrology and Hydraulics Report DCC Harris Reservoir Expansion EIS (January, 2020)* the volume of storage above natural ground eliminated by the originally proposed Harris Reservoir across the shared Brazos River and Oyster Creek 100-year floodplain and the proposed Oyster Creek stream restoration and overflow channel results in 1,028 ac-ft (1%) loss of floodplain storage. This loss of flood plain storage volume could lead to increased peak flows downstream of the project.

The loss of this floodplain storage may change the timing of flood flows arriving downstream and increase WSELs. Additional analysis of downstream impacts to Oyster Creek are explained in detail in the *Oyster Creek Downstream Hydrologic and Hydraulics Impacts Final Report*.

6.5 Relative Sea Level Rise Analysis

An increase in the sea level water surface has the same effect as the saltwater wedge moving upstream during a drought that is discussed in next section. As the sea level rises, the river flow will have to be greater that the current 1,750 cfs now required to allow Dow to pump the fresh water from the river into Brazoria Reservoir at the maximum pump capacity. The sea level rise also requires a greater river flow than currently required at the existing Harris Reservoir and the proposed Harris Reservoir. This could greatly limit the availability of Dow to get fresh water with its water rights.

6.6 Salinity Analysis

6.6.1 Introduction

Dow's Brazoria Reservoir intake pumps (River Mile 25) cannot be operated when the chloride concentration in the Brazos River water reaches or exceeds 500 mg/l. The interface between the fresh river water and the saltwater is referred to as the saltwater wedge and denotes the extent of the Brazos River estuary, which ranges between River Miles 15 and 43 and potentially up to River Mile 49 depending on river flow and tides. Dow reported efforts to correlate river flows at the USGS Rosharon gage with location of the salt wedge, which determines if withdrawals are restricted at the Brazoria Reservoir. They found when river flows are greater than 1,700 cfs at the USGS Rosharon gage, the salt wedge is downstream of the Brazoria Reservoirs pumps and there are no restrictions to filling the reservoir. River flow between 1,700 cfs to 600 cfs at Rosharon gage may allow limited pumping at the Brazoria Reservoir intake. Below 600 cfs, the intakes cannot be used at all because of the saltwater wedge.

Dow's existing Harris Reservoir intake pumps (River Mile 46) can be impacted by the salt wedge, which can extend up to River Mile 49. Dow found it can operate the existing Harris Reservoir intake pumps at full capacity (approximately 290 cfs) as long as there is 400 cfs river flow at the Rosharon gage.

6.6.2 Saltwater Discharges

The inter-coastal barge canal crosses the Brazos River approximately 1.4 miles upstream of the current mouth of the river. The inter-coastal barge canal introduces saltwater into the Brazos River at that location. Intermittent discharge of brine into the Brazos River from the Strategic Oil Reserve occurs at a location that is approximately 2.7 miles upstream of the mouth of the Brazos River. Multiple discharges, containing elevated salts or seawater, are discharged to the Brazos River in an area are that is approximately 7 to 8 miles upstream of the mouth of the Brazos River. These discharge flows include the following:

1. Discharge from the Dow plant: A stormwater/wastewater canal at a location that is 7 miles upstream of the mouth of the Brazos River
2. A Dow chemical discharge of approximately 40 MGD (61.7 cfs) of 7% to 8% total dissolved solids wastewater at a location 8 miles upstream of the mouth of the Brazos River
3. Discharge of approximately 400,000 (888.9 cfs) to 500,000 (1,111.1 cfs) gpm of seawater used for one pass cooling at a location 8 miles upstream of the mouth of the Brazos River.

Compared to the discharge of the Brazos River, 20,055 cfs as shown in **Figure 6** and with tidal flows, the above process water discharges are unlikely to materially impact the location of the salt wedge. The above volumes may contribute to increasing the localized salinity but are not likely to materially impact the location of the salt wedge.

6.6.3 RSLR Salinity Analysis

The rising relative sea level is likely to result in long-term viability of the proposed project due to low lying topography of the Gulf Coast. Due to variability of climate models, (see **Figure 8** and **Figure 9**), the relative sea level is expected to rise from 1 to 3 feet over the next 50 years. Although storm events are anticipated to be more frequent and higher intensity, anticipated annual precipitation levels are expected to decline (see **Figure 4**). Natural stream flows could decrease and result in the regular position of the leading edge of the estuary being farther upstream compared to today.

6.7 Storm Surge Analysis

An increase in the local water surface and tide levels from tropical storms and hurricanes, referred to as storm surge, can have the same effect as the saltwater wedge moving upstream during a drought. Due to the estuary and associated salt wedge potentially reaching up to River Mile 48, these storms could result in reduced water quality that exceeds the 500 mg/l of salts that Dow determined is in excess of the allowable for pumping into the plant near Freeport, as well as pumping makeup water into the existing Brazoria and Harris Reservoirs and the proposed project.

A recent example is when the Hurricane Harvey storm surge caused the water and tide levels along most of the Texas Coast to rise. The highest storm tides were observed at the Aransas National Wildlife Refuge, where the storm surge levels were more than 12 feet above ground level. Storm surge in Port Lavaca was more than 10 feet. Elsewhere across southern Texas, storm tide levels ranged from near 3 to 6 feet above ground level at Seadrift, Port O'Connor, Holiday Beach, Copano Bay, Port Aransas, and Bob Hall Pier (National Weather Service 2017).

Although storm surge may impede Dow's ability to pump during the storm event, these storms are usually short and Dow should be able to start using its river water rights again as the storm surge recedes.

7.0 Conclusions and Recommendations

The purpose of the proposed Harris Reservoir project is to provide 180 days of water storage for drought conditions as recommended by TCEQ guidelines. The 2020 survey (by Doyle and Wachtstetter) estimated the existing Harris and Brazoria Reservoirs has 27,343 ac-ft acre feet of storage. The proposed Harris Reservoir would provide 50,968 ac-ft of storage, resulting in a combined effective capacity of 78,311 ac-ft and 180 days of storage. The potential impact of the proposed Harris Reservoir on Oyster Creek is examined using a long-term, 180-day, BASINS model. The results of this BASINS model is used to determine potential impacts on the biological resources of Oyster Creek. The details of the BASINS modeling methodology and results, together with the aquatic assessment report, are found in the *Oyster Creek Downstream Hydrologic and Hydraulic Impacts Final Report (October 2021)*.

The following conclusions and recommendations for the Brazos River are presented below.

Conclusions

1. **Discharge Rates**: This analysis assumes 100,000 gpm (222.8 cfs) reservoir discharge rates. If Dow does increase its discharges to 175,000 gpm (389.9 cfs), which is possible if Dow exercises its full water right, the water storage would be insufficient to meet the 180 days of water storage.

   A change in withdrawal rate from Brazos River to 175,000 gpm, except possibly at the lowest of river flows during drought, would not be anticipated to cause a change to the river due to the large natural flows through the project vicinity. The proposed project shifts the current discharge rate into Oyster Creek upstream of the adjacent existing Harris Reservoir and there will be additional discharges from the proposed Harris Reservoir. The potential impact from the increased discharges into Oyster Creek for 180 days of dry conditions is modeled using EPA BASINS model and the results are analyzed in the *Oyster Creek Downstream Hydrologic and Hydraulic Impacts Final Report (October 2021)* BASINS model results indicate that Oyster Creek will be more susceptible to hydromodification and erosion with increased discharges from the proposed Harris Reservoir.

2. **Modeling Results and Assumptions**: Based on the unsteady one-dimensional HEC-RAS hydraulic model described in Section 5.4.3, the addition of the proposed Harris Reservoir does not result in any changes in flow, velocities, and WSELs in the Brazos River downstream of the Rosharon gage despite increased diversions at peak river flows to maintain the additional storage associated with the proposed Harris Reservoir. The results from the unsteady one-dimensional hydraulic model presented in Section 5.4.3.5 exhibit no significant changes in diversions into or discharges out of the Brazoria Reservoir into the Brazos River. Similarly, modeling assumptions and results described in Sections 5.3 and 6.4 for the unsteady one-dimensional HEC-RAS model show no significant changes in diversions into or discharges out of the existing Harris Reservoir into Oyster Creek.

3. **Proposed Diversion**: The proposed diversion into the proposed Harris Reservoir and associated discharge into Oyster Creek significantly increase peak flows. The most significant increase occurs when both the existing and the proposed Harris Reservoirs discharge at the same time. The discharge out of the existing and proposed Harris Reservoirs into Oyster Creek increase from an existing maximum of 278 cfs to a maximum of 1,256 cfs.

4. **Stream Restoration**: Under the proposed project, Dow will conduct stream restoration of Oyster Creek on two segments upstream of the proposed Harris Reservoir plus an overflow channel to receive the discharge. The improvements will increase flood storage capacity and riparian habitat.
5. **Floodplain Storage**: Oyster Creek floodplain storage will decrease by a net 1,028 acre-feet (1%) for the 100-year event as a result of the proposed Harris Reservoir berm and Oyster Creek channel improvements. To counter the loss of floodplain storage, Dow plans to operate the reservoir to drawdown the proposed Harris Reservoir prior to 50-year and 100-year storm events and tropical storms and hold the rainfall falling on the proposed Harris Reservoir and any initial diverted flows from the Brazos River as floodplain storage prior to discharge. In the *Oyster Creek Downstream Hydrologic and Hydraulic Impacts Final Report*, a detailed analysis of this operational measure is included. For a 100-year design storm, with 18 inches of drawdown before a 100-year storm event, the proposed Harris Reservoir will store 807 ac-ft for 6 inches of depth, 1,309 ac-ft of gain for 9 inches of depth and a gain 0f 1,632 ac-ft for 12 inches of depth. Using 18 inches of drawdown before a 100-year storm event and storing various depths within the proposed Harris Reservoir before releasing flows into Oyster Creek results in a net loss of 221 ac-ft floodplain storage for 6 inches of storage depth while gaining a net floodplain storage of 281 ac-ft for 9 inches of storage depth and 604 ac-ft of floodplain storage for 12 inches of storage depth. The details of this analysis are in the *Oyster Creek Downstream Hydrologic and Hydraulic Impacts Final Report (October 2021)*.
6. **Interbasin Flows**: Due to the flat nature of their watersheds, a significant amount of water transfers between the Brazos River and Oyster Creek. These interbasin flows are modeled into Oyster Creek HEC-HMS model as sources and sinks. The proposed Harris Reservoir blocks some of the interbasin flows into Oyster Creek so that they enter Oyster Creek downstream of the proposed Harris Reservoir, increasing the magnitude and timing of peaks. The details of this modeling and its results are included in the *Oyster Creek Downstream Hydrologic and Hydraulic Impacts Final Report (October 2021)*.
7. **Aquatic Impacts on Oyster Creek**: A long-term, 180 days, BASINS/HSPF model is simulated for four separate constant discharge values from the proposed Harris Reservoir to examine the impacts of the proposed Harris Reservoir on Oyster Creek. The details of this model and analysis are included in the *Oyster Creek Downstream Hydrologic and Hydraulic Impacts Final Report (October 2021)*. The BASINS/HSPF model results indicate an increase in velocity and erosion in Oyster Creek downstream of the proposed Harris Reservoir, as well as a decrease in water temperatures.

   The increase in velocity could affect populations of fish that prefer stagnant or slow-moving water. In addition, the increase of velocity could cause increased sedimentation and turbidity downstream, as well as erosion and scour along the banks of Oyster Creek. The outflows from the proposed Harris Reservoir will cause an increase in sedimentation and turbidity in Oyster Creek downstream of the proposed Harris Reservoir due to increased erosion and scour. This increase in sedimentation could cause water quality issues and decrease clarity downstream. The sediment increases could potentially clog fish gills, bury eggs, cover food sources, kill off vegetation, and shade out the sun needed for aquatic life.

   The decrease in temperature could affect vegetative growth, decrease spawning and reproduction of some fish species, cause die-off of fish species, or cause species to move to other warmer waters. The decrease in temperature could cause extended overwintering for benthic species and could slow down reproduction. A detailed analysis of the aquatic impact of the proposed Harris Reservoir on the Oyster Creek is included in the *Oyster Creek Downstream Hydrologic and Hydraulic Impacts Final Report (October 2021)*.

Recommendations

1. **Additional Maintenance Measures**: Dow should consider additional measures to ensure maintenance of the 180-day storage recommendation by TCEQ.
    a. Develop and adopt an O&M plan for regular maintenance dredging of existing reservoirs and the proposed Harris Reservoir.
    b. Consider contract storage in an upstream reservoir.
    c. Consider plant water re-use through treatment systems such as reverse osmosis. However, note that these systems tend to have a high energy requirement.
2. **Discharge Optional Plan**: Sustained discharge from the proposed Harris Reservoir will likely result in significant downstream erosion of Oyster Creek. To address this concern, a discharge operation plan is recommended for the new reservoir.
    a. Erosion control is recommended at the inlet and outlet to the stream restoration section, especially for the Project 3 overflow segment.
    b. Additional stream restoration and erosion reduction measures on Oyster Creek downstream of the point of discharge are recommended based on the assumed increase in flows and velocities resulting from loss of floodplain storage.
    c. Repeated filling and draining to create wet then dry conditions over the short term can result in hydromodification to the reservoirs and the receiving waters, which is specifically a concern for Oyster Creek due to the low natural flow. The repeated wet/dry conditions can break down the soil structure and lead to erosion. Oyster Creek between the proposed project discharge point and the existing Harris Reservoir discharge point are at highest near-term risk due to the changed conditions. Accordingly, regular inspections should be performed along this section of Oyster Creek to address potential erosion.
3. **Letter of Map Revision**: Dow should note that FEMA may require a Letter of Map Revision due to the changes in the Oyster Creek floodplain from the restoration project. This determination would be made by the local Flood Plain Administrator.
4. **Operation and Maintenance Plan.** A comprehensive O&M plan should be developed that encompasses the water storage reservoirs and water delivery to Dow.

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Appendix A

Brazos River HEC-HMS Model

APPENDIX C

Oyster Creek Downstream Hydrologic and Hydraulic Impacts Final Report

Note: The Section 508 amendment of the Rehabilitation Act of 1973 requires that the information in federal documents be accessible to individuals with disabilities. The U.S. Army Corps of Engineers (Corps) has made every effort to ensure that the information in this appendix is accessible. However, this appendix is not fully compliant with Section 508, and readers with disabilities are encouraged to contact Mr. Jayson Hudson at the Corps at (409) 766-3108 or at SWG201601027@usace.army.mil if they would like access to the information.

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Oyster Creek Downstream Hydrologic and Hydraulic Impacts Final Report

DCC Harris Reservoir Expansion EIS

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ES-1.0 Executive Summary

The purpose of this technical report is to supplement Watearth, Inc.'s (Watearth's) *Preliminary Hydrology and Hydraulics Report for the DCC Harris Reservoir Expansion Environmental Impact Statement (EIS)* dated August 2021 (Watearth, Inc., 2021). The report details cited and referenced are the most recent information concerning the proposed Harris Reservoir expansion concerning the proposed Harris Reservoir expansion and the impacts to Oyster Creek. This report supplants all previous reports concerning Oyster Creek.

Specifically, this memorandum addresses hydrologic and hydraulic downstream impacts at a planning-level review for the proposed Harris Reservoir expansion as identified in the report in Section 6.2 *Hydromodification of Oyster Creek* and Section 6.4 *Watershed Vulnerability and Floodplain Storage*. This technical report provides a summary of the environmental setting, existing conditions, and proposed project conditions necessary for the planning-level analysis conducted in support of the EIS for Oyster Creek while further details for the entire project area and detailed models for Brazos River are described in the *Preliminary Hydrology and Hydraulics Report* for the DCC Harris Reservoir Expansion EIS (Watearth, Inc., 2020).

ES-1.1 Project Setting

The proposed project is located in south central Texas on the Gulf Coastal Plain near the town of Rosharon, Texas. The general climate for the project area includes high potential rainfall events from tropical storms and hurricanes with long periods of drought (Watearth, Inc., 2020). Future rainfall is predicted to trend toward lower rainfall levels and higher temperatures. Sea level is expected to rise by 1 to 2 feet in the next 50 years, which will tend to push the estuary farther upstream (referred to as the salt wedge). In addition, the storm surge could reach farther upstream from current conditions.

ES-1.2 Proposed Project

Dow Chemical (Dow) currently operates two reservoirs: Harris Reservoir, located at Brazos River Mile 46 with reported effective summer storage capacity of 9,135.5 acre-feet (ac-ft), and Brazoria Reservoir, located at Brazos River Mile 25 with reported effective summer storage capacity of 18,207.2 ac-ft, to provide potable water to the Dow Chemical plant and other users. Dow has reported periodic but not regularly scheduled maintenance dredging on the existing reservoirs, which has resulted in loss of storage by up to half of the original design volume. Storage will continue to be lost or water will be blocked from getting to the lowest outlet elevations, which can reduce the available water storage further.

During drought conditions, Dow estimates that the two-reservoir system provides 68 days or less of necessary water supplies. The Texas Commission on Environmental Quality (TCEQ) identified facilities with less than 180 days of water storage as being at risk during droughts. Dow's purpose and need statement identifies the minimum of 180 days of water storage as a primary project feature and justification.

The proposed project, called the Harris Reservoir Expansion project in the Clean Water Act Section 404 permit application, includes a 50,968 ac-ft reservoir adjacent and upstream of the existing Harris Reservoir. The proposed Harris Reservoir lies between the Brazos River and Oyster Creek on their shared floodplain. The hydromodification of Oyster Creek is displayed in **Figure 1**. The proposed Harris Reservoir discharges to a constructed overflow and conveyance channel, referred to as Project 3. In addition, Dow proposes to conduct stream restoration projects adjacent to the proposed Harris Reservoir, referred to as Projects 1 and 2.

ES-1.3 Summary of Modeling and Analysis

Modeling of Oyster Creek includes Hydrologic Engineering Center-Hydrologic Modeling System (HEC-HMS) for hydrology and Hydraulic Engineering Center-River Analysis System (HEC-RAS) for hydrologic flow routing (Modified Puls Method) to determine peak flows downstream of the proposed Harris Reservoir. The HEC-HMS hydrology model computes peak flows. The HEC-RAS steady state model (Watearth model) routes the peak flows determined by the HEC-HMS model through the reaches set in the hydrologic model. The upstream boundary includes the entire Oyster Creek watershed (headwaters), and the downstream boundary is the inlet to Lake Jackson. Overflow hydrographs from the Lower Brazos Flood Protection Planning Study were used in the HEC-HMS modeling of Oyster Creek because the Flood Insurance Study (FIS) for Brazoria County, Texas, (revised December 2020) and the Lower Brazos Flood Protection Planning Study (March 2019) demonstrated that interbasin flows are occurring between the Brazos River and Oyster Creek watersheds and should be represented in the current hydrologic model.

The Brazos/Oyster interbasin flows are represented in the HEC-HMS model as sources and sinks. The sources are considered positive inflows entering Oyster Creek and the sinks are considered negative outflows leaving Oyster Creek, which return to the Brazos River. After a thorough review of the Lower Brazos Flood Protection Planning Study, the flow hydrographs were adjusted to generate peak flow results at the same nodes/river mile stations similar to the Brazoria County FIS study. The lateral structure hydrographs from the Lower Brazos Flood Protection Planning Study were used to represent the interbasin flows; however the flow hydrographs were decreased by 75% to 80% to better match the results found in the Brazoria County FIS study.

The lateral structure hydrographs from the Lower Brazos Flood Protection Planning Study HEC-RAS model were entered at the centroid of the lateral structure weir length and transferred across to Oyster Creek. This method was used to place the interbasin flow sources and sinks into the appropriate locations in the HEC-HMS node diagram.

The proposed Harris Reservoir and the existing Harris Reservoir were both modeled as detention basins with inflows from the Brazos River pump stations. Small sub-basins were included for each reservoir, which represent the drainage area associated with rainfall occurring over the reservoirs. Current elevation-storage data and operational data for the proposed Harris Reservoir and the other reservoirs in the system were used in the HMS reservoir model. The 50-year and 100-year, 24-hour design storm events were modeled for both the existing and the proposed conditions. Several proposed conditions scenarios were modeled to simulate proposed Harris Reservoir operations before a tropical storm or extreme rainfall event. For the proposed condition models, 18 inches of pre-release design storm drawdown coupled with 6 inches, then 9 inches, and lastly 12 inches of floodplain storage was modeled along with a no-drawdown scenario. The post-project HEC-HMS hydrologic modeling consists of a total of four proposed conditions scenarios for each design storm event.

The construction of the proposed Harris Reservoir would affect the flow path of interbasin flows occurring in the area north of the existing Harris Reservoir where the proposed reservoir is located. There are several differences between the existing and proposed conditions HEC-HMS models. The existing conditions model only has the existing Harris Reservoir modeled while the proposed conditions model has both the existing and proposed Harris Reservoir modeled. The existing conditions model has additional sources and sinks added to represent interbasin flow where the proposed reservoir is located. The proposed conditions HEC-HMS model has a few interbasin flows that have been shifted downstream due to blocked flows from the proposed reservoir's embankment and were added to a downstream node below the existing Harris Reservoir.

The proposed conditions HEC-RAS geometry includes the stream restoration projects (revised Projects 1, 2, and 3 revised in May 2020) and the floodplain storage volume displacement by the proposed Harris Reservoir. The HEC-RAS hydraulic model calculates the 50- and 100-year design storage/discharge relationship for the reaches within the project area sub-basins. The upstream boundary starts near the town of Otey, Texas, (approximately 3,500 feet [(ft] downstream of Otey), and the downstream boundary ends approximately 1,000 ft downstream of the Lake Jackson inlet to allow the model to equalize. The HEC-RAS model includes the proposed stream restoration projects and the floodplain storage volume displacement by the proposed Harris Reservoir. The HEC-HMS model provides the peak flows to be hydraulically routed in the HEC-RAS model. The HEC-RAS model returns the amount of storage in a reach for the HEC-HMS calculated flowrate. The HEC-RAS model provides the storage/discharge parameters to conduct the Modified Puls hydrologic routing in HEC-HMS. Once the peak flows are within a 5% difference between what is entered in HEC-RAS and calculated in HEC-HMS, the peak flows determined in HEC-HMS are accurate for the storage/discharge capacity of the modeled reaches.

The Modified Puls Reservoir Routing Method was used as the hydrologic routing method for critical downstream reaches in HEC-HMS and is a commonly used method for flat watersheds within the Gulf Coast of Texas.

Hydrologic Simulation Program Fortran (HSPF) was used to examine the effects of the proposed reservoir during drought conditions. HSPF is a plug-in program within the U.S. Environmental Protection Agency's (EPA) BASINS (Better Assessment Science Integrating Point and Nonpoint Sources) model. BASINS is a multipurpose environmental analysis system developed by the EPA to assist in watershed management. A geographic information system (GIS) provides the integrating framework for BASINS by allowing users to efficiently access national environmental information. The BASINS model provides a core framework with various EPA- and third-party–supported model plug-ins. HSPF is an EPA-supported watershed model for estimating in stream concentrations of point and nonpoint sources.

Land use and meteorological data were accessed through BASINS framework, and HSPF has the capability to calculate sediment transport in overland runoff and streams, as well as water temperature in the streams based on heat exchange equations. By using BASINS and HSPF, Watearth was able to analyze the effects of the proposed Harris Reservoir under drought conditions and compare the results to the existing conditions.

ES-1.4 Analysis of Potential Impacts

The drainage area for the Oyster Creek watershed upstream of the proposed Harris Reservoir is 80.53 square miles (sq-mi), with a peak flow of 25,602 cubic feet per second (cfs) and a runoff volume of 544,834 ac-ft at Junction O-6 for the 100-year design storm event, this includes four interbasin flow locations upstream of the proposed Harris Reservoir.

As identified in Watearth's *Preliminary Hydrology and Hydraulics Report for the DCC Harris Reservoir Expansion EIS* (2020), the proposed project results in a floodplain storage loss. Under the originally submitted application, this was 309 ac-ft, but the revised stream restoration and improvements, provided in May 2020 (by Jacobs), result in a 1,028 ac-ft floodplain storage loss.

The 1,028 ac-ft floodplain storage loss is less than 1% of the volume of flow for the watershed above the proposed project.

Review of the flood peak flow hydrographs show the peak flows in the hydrologic model (HEC-HMS) for Oyster Creek are driven by a combination of the watershed runoff and the Brazos River interbasin flows.

The HEC-HMS model results for both 50- and 100- year 24-hour design storm events show two peak flow events. A smaller magnitude peak flow associated with the design storm rainfall (peak one) and a larger peak flow associated with the arrival of the interbasin flows to Oyster Creek (peak two). Model results point to an increase in the peak flows associated with the arrival of interbasin flows from Brazos River into Oyster Creek for the proposed conditions. This increase is especially pronounced in the locations just downstream of the proposed Harris Reservoir.

The increases in the peak flows of the proposed conditions hydrograph show the potential for erosion and hydromodification during larger events. While there are increases to peak flows downstream of the proposed Harris Reservoir during both the 50-year and 100-year, 24-hour design storm events, models for lesser storms do not contain interbasin flows and thus do not have peak flow increases. The 10-year storm event generally remains within the banks of Oyster Creek.

Both HEC-RAS and HEC-HMS models analyzed conditions during design storm events. To examine the impacts of the proposed Harris Reservoir on Oyster Creek during dry conditions, a BASINS/HSPF model was used. Four different constant outflows from the proposed Harris Reservoir into Oyster Creek during 180 days of drought conditions (spring and summer months) are modeled and compared to existing conditions. Using the HSPF model, the average velocity in Oyster Creek, sediment transport, and heat exchange between Oyster Creek and the atmosphere are modeled. Based on the HSPF model results, the velocity in Oyster Creek increases as the outflows from the proposed Harris Reservoir increases. The average velocity in Oyster Creek increases about 30% for the highest modeled outflow from the proposed Harris Reservoir, which is 334 cfs. For the environmental flows (Scenario Four, 22 cfs constant outflow), the increase in average velocity is 1.75%.

There is a very slight increase in shear velocity and bed shear stress in Oyster Creek with an increase in outflows from the proposed Harris Reservoir. The increase in velocity, shear velocity, and bed shear stress causes increased scouring in Oyster Creek, which results in higher erosion and sediment discharge downstream of the proposed Harris Reservoir. With more erosion and scouring, more sediment discharges from Oyster Creek downstream of the proposed Harris Reservoir. The outflow of sediment causes a decrease in total suspended sediment concentration in Oyster Creek immediately downstream of the proposed Harris Reservoir. The average total suspended sediment concentration decreases around 10% as the eroded sediments are transported farther downstream with increased velocities in Oyster Creek.

HSPF model results also indicate a decrease in water temperatures as more outflow from the proposed Harris Reservoir enters Oyster Creek. The HSPF model is run through spring and summer months to represent dry conditions. The water temperature is between 55 and 78 degrees Fahrenheit for existing conditions. However, with outflows from the proposed Harris Reservoir, the range of water temperature decreases to 41 to 62 degrees Fahrenheit for the highest outflow (334 cfs). Oyster Creek usually has low flows, based on U.S. Geological Survey (USGS) Gage 0807900 Oyster Creek Discharge Gage near Angleton, Texas. A baseflow of 2 cfs flows in the model for dry conditions. When the proposed Harris Reservoir discharges 334 cfs (in the highest discharge scenario), there is a significant increase in the amount of water in Oyster Creek. The heat exchange equation used in the HSPF model uses a simple heat balance between atmosphere and water. As the water volume increases, the time for all the volume of water to warm up to the atmospheric temperature also increases, causing a drop in water temperature.

The BASINS/HSPF model results, transect data for Oyster Creek collected in May and June of 2021, and the following reports have been evaluated to analyze the potential impacts of the proposed Harris Reservoir on the aquatic life in Oyster Creek:

1. Fisheries Use Attainability Study for Oyster Creek (Segment 1110). Written by Gordon W. Linam and Leroy J. Kleinsasser. July 1987.
2. Macroinvertebrate Assessment of Allens Creek and the Brazos River, Austin County, Texas. Written by Charles R. Wood, Thomas L. Arsuffi, and M. Katherine Cauble. Data collection in 1993. December 1994.
3. Fish Assemblage Changes in Three Western Gulf Slope Drainages. Written by Dr. Timothy Bonner and Dennis T. Runyan. July 2007.
4. Stream Condition Assessment Report for the Dow Harris Reservoir Expansion Project in Brazoria County, Texas. Written by SWCA Environmental Consultants. November 2019.

A detailed aquatic assessment of Oyster Creek was prepared by SWCA Environmental Consultants and is attached here to as Appendix A. Effects to aquatic species including fish and macroinvertebrates are discussed in that report..

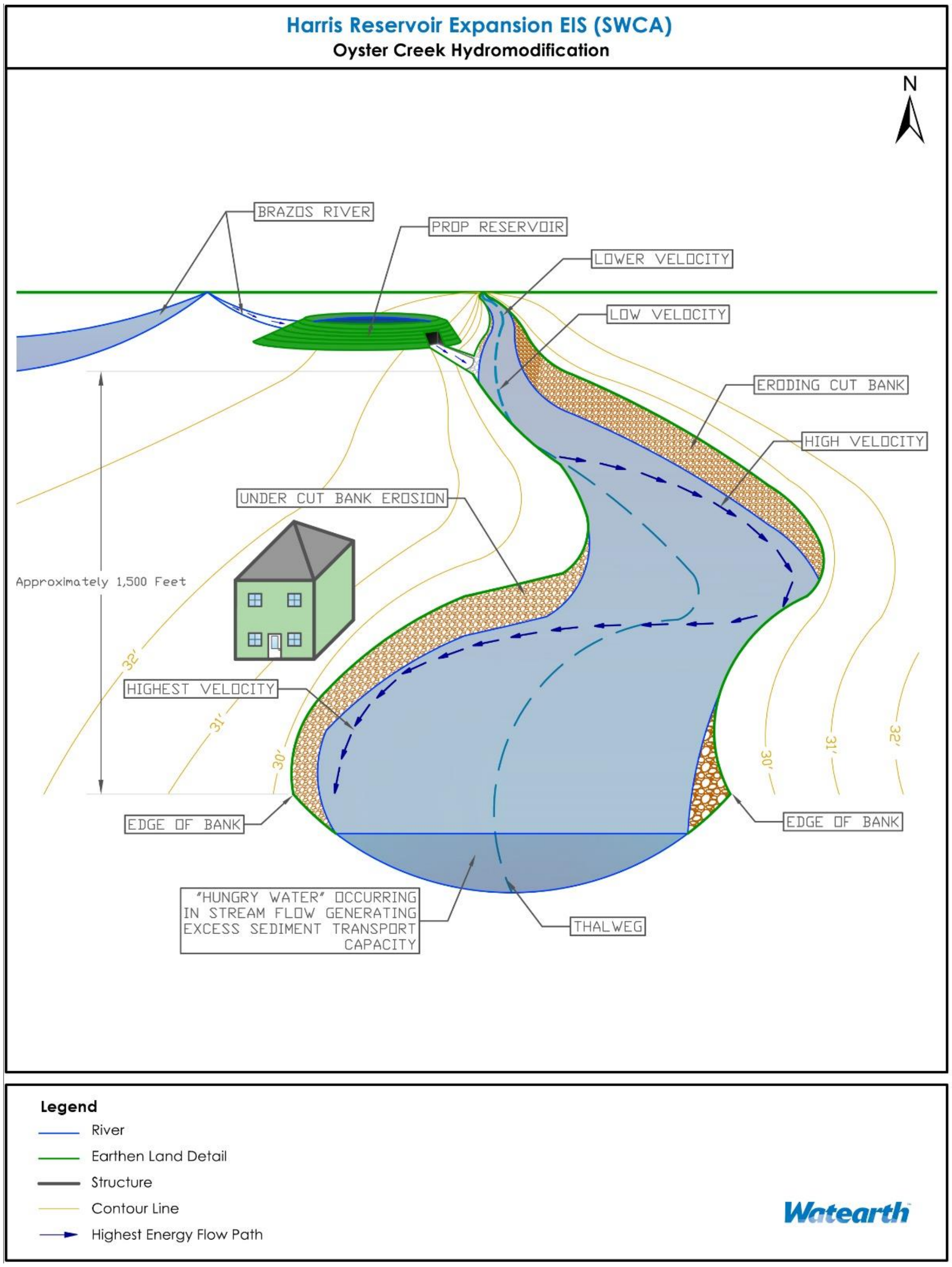

Figure 1: *Example of hydromodification occurring in Oyster Creek.*

ES-1.5 Conclusions

The purpose of this report was to identify if there were potential impacts to Oyster Creek downstream of the proposed Harris Reservoir. The analysis includes planning-level modeling and literature research to establish likely downstream impacts as a result of the project, specifically if there are impacts resulting from the loss of floodplain storage due to the proposed construction of a 2,000-acre (ac) reservoir in the shared Oyster Creek and Brazos River floodplain at the project site in conjunction with the proposed stream restoration (Projects 1 and 2) and overflow/conveyance channel (Project 3). Under the original in-stream design, there was an estimated 309 ac-ft loss of floodplain storage. Under the revised in-stream design, there was an estimated 1,028 ac-ft loss of floodplain storage.

In order to address the 1,028 ac-ft loss of floodplain storage, the proposed Harris Reservoir would be operated to counter the effects due to the loss of floodplain storage.

Several operational scenarios are modeled to analyze the possible floodplain gain or loss through operational measures. The scenarios modeled using a combination of HEC-HMS and HEC-RAS are as follows:

1. Existing conditions for 50-year, 24-hour design storm (no proposed Harris Reservoir expansion).
2. Proposed conditions and no drawdown prior to a storm event for 50-year, 24-hour design storm event.
3. Proposed conditions, 18 inches drawdown prior to a storm event, and holding 6 inches of floodplain storage in the reservoir before spillway discharge for 50-year, 24-hour design storm event.
4. Proposed conditions, 18 inches drawdown prior to a storm event, and holding 9 inches of floodplain storage in the reservoir before spillway discharge for 50-year 24-hour design storm event.
5. Proposed conditions, 18 inches drawdown prior to a storm event, and holding 12 inches of floodplain storage in the reservoir before spillway discharge for 50-year, 24-hour design storm event.
6. Existing conditions for 100-year, 24-hour design storm (no proposed Harris Reservoir expansion).
7. Proposed conditions and no drawdown prior to a storm event for 100-year, 24-hour design storm event.
8. Proposed conditions, 18 inches drawdown prior to a storm event, and holding 6 inches of floodplain storage in the reservoir before spillway discharge for 100-year, 24-hour design storm event.
9. Proposed conditions, 18 inches drawdown prior to a storm event, and holding 9 inches of floodplain storage in the reservoir before spillway discharge for 100-year, 24-hour design storm event.
10. Proposed conditions, 18 inches drawdown prior to a storm event, and holding 12 inches of floodplain storage in the reservoir before spillway discharge for 100-year, 24-hour design storm event.

These scenarios are depicted in **Figure 2**. **Table 1** shows a summary of model results for floodplain storage gain and loss.

Table 1: Operational Plan Scenarios to Offset Floodplain Storage Loss

	Loss of Floodplain Storage	50-Year Design Storm				100-Year Design Storm			
		Floodplain Storage (ac-ft)							
		Proposed No Drawdown	Proposed 18" Drawdown and 6" Floodplain Storage	Proposed 18" Drawdown and 9" Floodplain Storage	Proposed 18" Drawdown and 12" Floodplain Storage	Proposed No Drawdown	Proposed 18" Drawdown and 6" Floodplain Storage	Proposed 18" Drawdown and 9" Floodplain Storage	Proposed 18" Drawdown and 12" Floodplain Storage
50-year	-525	-525	+993	+1,371	+1,715	N/A	N/A	N/A	N/A
100-year	-1,028	N/A	N/A	N/A	N/A	-1,028	+807	+1,309	+1,632
Total		-525	+468	+846	+1,190	-1,028	-221	+281	+604

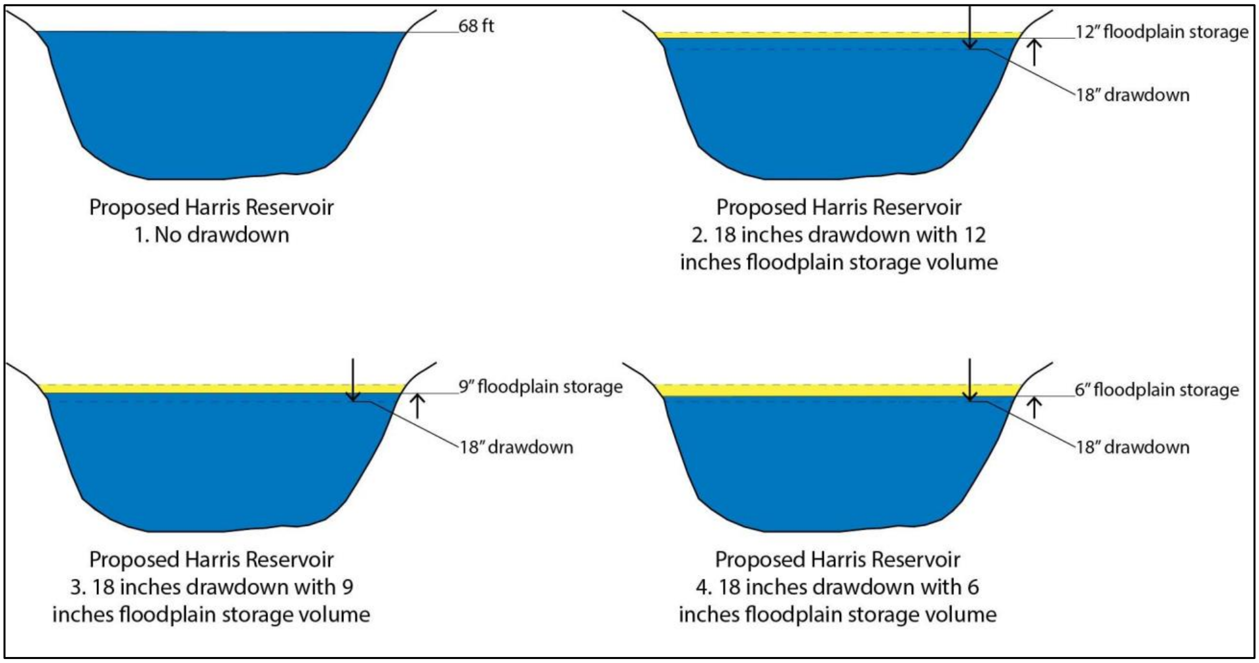

***Figure 2**: Operational measures for floodplain storage gain.*

The hydrologic and hydraulic model results also indicate a peak flow increase downstream of the proposed Harris Reservoir due to interbasin flows occurring between the Brazos River and Oyster Creek during 50- and 100-year design storms. The proposed Harris Reservoir blocks some of the interbasin flows into Oyster Creek, which causes the interbasin flows to enter Oyster Creek downstream of the proposed Harris Reservoir.

The HSPF model, which was applied to examine the impact of the proposed Harris Reservoir during long-term drought conditions, produced results indicating an increase in average channel velocity, shear velocity, and bed shear stress in Oyster Creek. These increases cause erosion, scouring, and an increase in sediment outflow downstream of the proposed Harris Reservoir.

HSPF model results also indicate a decrease in water temperatures as more outflow from the proposed Harris Reservoir enters Oyster Creek during spring and summer months simulation. The average water temperature decreases from 78 degrees Fahrenheit to 62 degrees Fahrenheit on the warmest end for the highest outflow (334 cfs). More water takes longer to warm, which might have an adverse effect on temperature-sensitive aquatic life.

The results of the models demonstrate that the higher flows in conjunction with the low-sediment reservoir discharge is highly likely to result in erosion downstream of the proposed Harris Reservoir. As stated above, the peak flows and water surface elevation (WSEL) increase; this is due to the large, flat nature of the Oyster Creek watershed. The increase in flows along with loss of sediment is likely to increase Oyster Creek erosion if operations and maintenance (O&M) of the three-reservoir water supply system does not follow a well-reasoned and updated O&M Plan.

The erosion and scour will increase the concentration of suspended sediments in Oyster Creek downstream of the proposed Harris Reservoir. The average velocity in Oyster Creek will also increase slightly. Model results indicate a decrease in water temperatures with outflows from the proposed Harris Reservoir into Oyster Creek, as well. These changes in velocity, temperature, sediment concentration, and scour will also have aquatic impacts, which are explained in more detail in the aquatic assessment in **Appendix A**.

Table of Contents

List of Tables

List of Figures

Acronyms and Abbreviations

Acronym/Abbreviation	Full Form
ac	acre
ac-ft	acre feet
ACE	Annual Chance Exceedance
BASINS	Better Assessment Science Integrating Point and Nonpoint Sources
BRA	Brazos River Authority
CF3R	Comprehensive Flood Risk Resources and Response
cfs	cubic feet per second
DEM	Digital Elevation Model
Dow	Dow Chemical
EIS	environmental impact statement
EPA	U.S. Environmental Protection Agency
FEMA	Federal Emergency Management Agency
FIS	Flood Insurance Study
FM	Farm to Market
ft	feet
GIS	geographic information system
H&H	hydrology and hydraulics
HEC-HMS	Hydraulic Engineering Center – Hydrologic Modeling System
HEC-RAS	Hydraulic Engineering Center – River Analysis System
HSPF	Hydraulic Engineering Center – River Analysis System
LBFPPS	Lower Brazos Flood Protection Planning Study
NHD	National Hydrography Dataset

NLCD	National Land Cover Database
NLDAS	North American Land Data Assimilation System
O&M	Operations and maintenance
sq-mi	square mile
TC	time of concentration
TCEQ	Texas Commission on Environmental Quality
TSARP	Tropical Storm Allison Recovery Project
TWDB	Texas Water Development Board
USACE	U.S. Army Corps of Engineers
USBR	U.S. Bureau of Reclamation
USGS	U.S. Geological Survey
WSEL	water surface elevation

Appendices

Appendix A – Oyster Creek Aquatic Assessment Report

Appendix B – Clark's Method Hydrologic Parameters

Appendix C – HCFCD Conveyance Discharge Curve

Appendix D – Locations of Effective Cross-Sections

Appendix E – Meteorological Gage (TX 722527) Data

Appendix F – USGS 0807900 Gage Discharge Data

Appendix G – Evapotranspiration Data from EPA Stormwater Calculator

Appendix H – Proposed Harris Reservoir Expansion Elevation-Volume Relationship

Appendix I – HSPF Model Results

1.0 Project Setting

The general climate for the project area includes high potential rainfall events from tropical storms and hurricanes with long periods of drought (Watearth, Inc., 2020). Future rainfall is predicted to trend toward lower rainfall levels and higher temperatures. Sea level is expected to rise by 1 to 2 ft in the next 50 years, which will tend to push the estuary farther upstream (referred to as the salt wedge). Storm surge could reach farther upstream from current conditions.

Dow currently operates two reservoirs: Harris Reservoir, located at Brazos River Mile 46 with reported effective storage capacity of 9,135.5 ac-ft, and Brazoria Reservoir, located at Brazos River Mile 25 with reported effective storage capacity of 18,207 ac-ft, to provide portable water to the Dow Chemical plant and other users. Dow has reported periodic but not regularly scheduled maintenance dredging on the existing reservoirs, which has resulted in loss of storage by up to half of the original design volume. Storage will continue to be lost or water will be blocked from getting to the lowest outlet elevations, which can reduce the available water storage further.

During drought conditions, Dow estimates that the two-reservoir system provides 68 days or less of necessary water supplies. TCEQ has identified facilities with less than 180 days of water storage as being at risk during droughts.

2.0 Proposed Project

The analysis in this report focuses on Oyster Creek modifications as fully described in (Watearth, Inc., 2020) Section 4.2. As part of the proposed Harris Reservoir expansion project, three projects are planned to enhance Oyster Creek. These projects are planned to improve the flood capacity and provide restoration and enrichment to the riparian habitat along the three project lengths. Geomorphic design principles were used to provide a bankfull benching creating floodplain storage, riparian habitat, and channel conveyance to accommodate the proposed Harris Reservoir outlet flow into Oyster Creek. For this analysis, the proposed project elements analyzed are described in detail below:

1. Proposed project (Harris Reservoir expansion) embankment, which restricts flows into the existing shared 100-year floodplain for Oyster Creek and the Brazos River (**Figure 3**).
2. Project 1 is approximately 3,600 ft long from STA 5+00 to STA 41+00 on an unnamed tributary north of the proposed project's northeast corner **Figure 3**. It flows into Oyster Creek a short distance north of the northeast corner, which is the start of Project 2.
3. Project 2 is approximately 12,860 ft long from STA 41+00 to STA 169+60 and is in the main channel of Oyster Creek running mostly parallel to the proposed Harris Reservoir embankment on the northeast side. Oyster Creek then turns east and enters an oxbow, which is approximately 15,550 ft long (almost 3 miles).
4. Project 3 is an improved flood overflow channel that flows along the east side of the proposed Harris Reservoir until the overflow channel intersects again at approximate STA 254+00 with the main Oyster Creek channel and the proposed Harris Reservoir outlet channel. It starts as Oyster Creek enters the oxbow. This project allows water flow greater than the 25-year storm to bypass the oxbow and flow along the east side of the proposed Harris Reservoir until the overflow channel intersects again with the main Oyster Creek channel and the proposed Harris Reservoir outlet channel.

   The overflow weir will take runoff discharge greater than the 25-year runoff discharge and allow the difference between the 25-year and the 100-year runoff discharge to flow a shorter distance of approximately 8,440 ft until it rejoins the main channel. This could affect the time to peak water surface elevation downstream; the loss of floodplain storage in the oxbow could affect the amount of water downstream at that peak water surface elevation. **Figure 4** shows a typical cross-section of the Project 1 and 2 stream restorations to recreate the multiple-level channel morphology. Additional details on Project 3 are explained in **Section 3.1**.

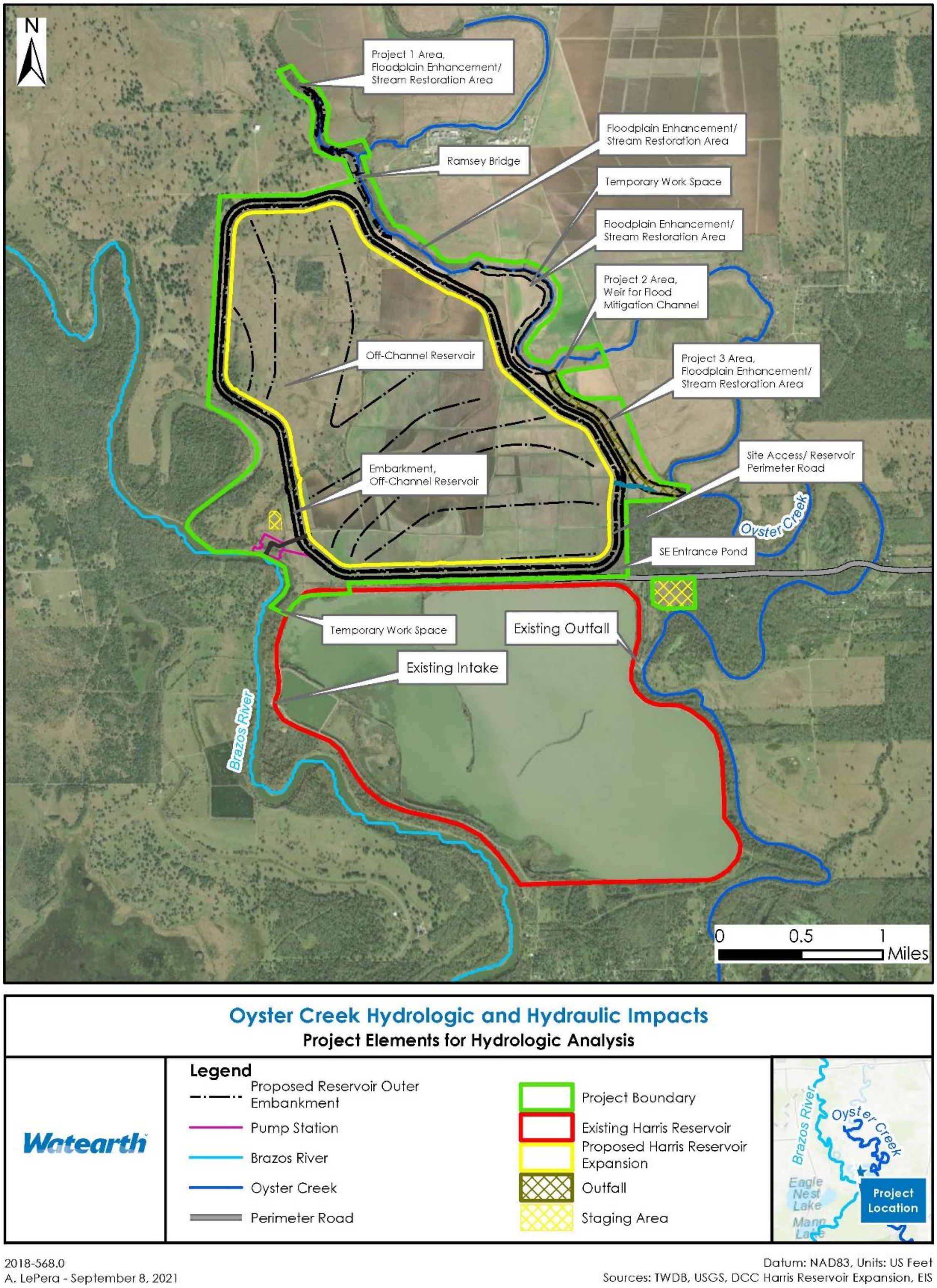

***Figure3**: Project elements for hydrologic analysis.*

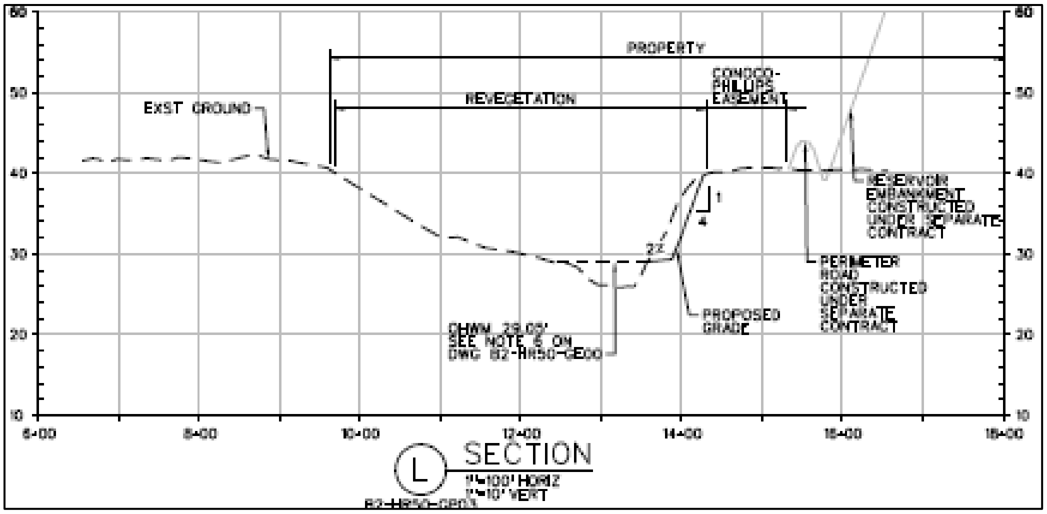

***Figure 4**: Cross section of Oyster Creek restoration in area adjacent to the reservoir embankment (Projects 1 and 2 only).*

2.1 Overflow and Conveyance Channel (Project 3)

The proposed Harris Reservoir has a rectangular concrete riser structure in the reservoir, which serves as the gated outlet and auxiliary (emergency) spillway (ch2m, 2018). The gated outlet has two sluice gates to provide a low-level flow release. Both sluice gates are 36 inches wide × 48 inches tall and are attached on the downstream side of the headwall.

The hydraulic capacity required of the gates varies from 60 cfs to slightly over 1,000 cfs. For normal operations, the maximum flow capacity is 300 cfs for the majority of water levels in the reservoir. A maximum of 450 cfs capacity is desired for the upper range of the pool elevations. For emergency flow releases at full or near full pool, the performance requirements determined for the 36-hour drawdown before a tropical storm might affect the reservoir and would need to be 978 cfs. This would allow a reservoir drawdown of approximately 1 foot per day so the reservoir would be ready for the tropical storm. The proposed gated outlet will provide the desired performance with the gates fully opened.

The rectangular concrete outlet riser structure can function effectively over a wide range of stream flows. There is no compromise in energy dissipation performance at flows less than the design flow. The structure can operate at any downstream tailwater level as submergence or no submergence is not a concern.

The 10-ft-wide × 5-ft-tall concrete outlet conduit conveys the released water through the embankment, which exits near where the flood overflow channel (Project 3) comes back into Oyster Creek. Before reaching Oyster Creek, the flow goes through different types of flow elements. The first transition increases the width from 10 ft to 20 ft to reduce the unit discharge entering the U.S. Bureau of Reclamation (USBR) Type III stilling basin where a hydraulic jump occurs, reducing the velocity. Then the flow is equalized by a wave suppressor before entering a rectangle flume below the stilling basin for the purpose of measuring the normal flow releases (less than 400 cfs). Normal flow releases from the gated outlet will occur only when flows in Oyster Creek are low or when the only flows in Oyster Creek are from the reservoir.

3.0 Summary of Modeling and Analysis

This section of the report shows details about prior studies used to develop the basis for the models in this report. It focuses on describing the methods and procedures used to develop the models associated with this report. All parameters and modeling extents used to set up the three different models used in this analysis are documented in this section of the report.

3.1 Prior Studies

Dow, the applicant, provided a revised conceptual design in May 2020 to increase hydraulic storage and hydraulic capacity for Oyster Creek (Jacobs, 2019). There were changes to the profile of the stream restoration projects (Projects 1 and 2), as well as a significant change to Project 3, the storage and conveyance channel that receives the proposed project discharge and flows higher than the 10-year event. The northern extent includes a weir that will split flow from Oyster Creek prior to the oxbow during the 25-year and higher event flows.

As part of the Individual Permit application to the U.S. Army Corps of Engineers (USACE), the applicant prepared a no-rise analysis of Oyster Creek to demonstrate that the project would not cause any rise in WSEL in Oyster Creek (Jacobs, 2018). Jacobs modeled elevated embankments by simulating the reservoir as a blocked obstruction, as is standard and appropriate. This model included all three channel projects (Projects 1, 2, and 3). The oxbow was included in their model and is shown in cross-section 53.49. The model and documentation did not calculate the loss of floodplain storage. Watearth reviewed both the original model with the original design submitted in February 2018 and the updated model with the updated restoration design provided in May 2020.

The Digital FIRM Update for Fort Bend County, Texas Part 1, Task 42 – Hydrology Oyster Creek and Lower Oyster Creek was prepared by Comprehensive Flood Risk Resources and Response (CF3R) (revised February 2007). The CF3R study was carried out to calculate the peak discharges for the 0.2%, 1%, 2%, and 10% annual chance events for Oyster Creek.

CF3R modeled three sections of Oyster Creek. The Lower Oyster Creek Model associated with their report was the most relevant item to review. The limits of the study for the Lower Oyster Creek Model started near the Flat Bank diversion channel to the Sienna Plantation levee diversion channel at McKeever Road. CF3R described the topography of Oyster Creek as gently sloping to flat with ground elevations at about 60 ft in the Lower Oyster Creek area. CF3R described the ground slopes in the watershed to be less than 10 ft per mile. The soils in the watershed were described as typically clayey or silt-loamy, which results in a high runoff potential. The land use varies from residential, commercial, to undeveloped areas. Most of the development consists of single-family, residential communities with curb-and-gutter streets and underground storm sewer drainage systems.

The CF3R report stated their parameters for the hydrologic analysis in their report as follows:

- Rainfall data were from the 1999 Fort Bend County *Drainage Criteria Manual*
- Land use data were developed based on county GIS data and 2005 aerial imagery
- Green-Ampt loss function was used to compute infiltration loss

- Clark Unit Hydrograph was used to calculate runoff volume with the time of concentration (TC) and storage coefficient R computed using the methodology from the Fort Bend *Drainage Criteria Manual*
- The Modified Puls Routing Method was used to route the hydrographs between model nodes

The Brazos River Authority (BRA) was awarded a Texas Water Development Board (TWDB) flood protection grant for the development of the Lower Brazos Flood Protection Planning Study that was completed in March 2019. Hydrology and hydraulics (H&H) of the lower basin were conducted with the goal of updating discharge rates and WSELs in the Brazos River for the 10%, 2%, 1%, and 0.2% Annual Chance Exceedance (ACE) storm events, a 1-D unsteady hydraulic model was developed from the Waller/Grimes County line to the Gulf of Mexico for the BRA study. The H&H analyses in the BRA study determined the peak discharges in the Brazos 1% ACE were generally lower than the discharges published in the current effective Federal Emergency Management Agency (FEMA) FIS.

For the Rosharon USGS gauge, the difference in WSEL between the BRA study versus the FEMA FIS study was 0.2 ft lower in the BRA study. This demonstrates that the BRA study and the FIS study have similar results due to the similar WSELs stated in the BRA study executive summary.

The Brazos 1-D unsteady state model was the newest hydraulic model that modeled interbasin flows entering the Oyster Creek watershed. The lateral outflow hydrographs for the Brazos River found in the BRA study's 1-D unsteady state model were used to quantify the Brazos basin overflows entering the Oyster Creek watershed. The hydrographs from the 1-D model were applied to the Lower Oyster Creek HMS model and inserted as sources and sinks to accurately represent the interbasin flows that occur in the Lower Oyster/Brazos watersheds.

The Brazoria County, Texas, and incorporated areas FIS (revised in 9-22-1999) was reviewed for this analysis. The discharges found in Oyster Creek (near the project area) were used as reference to calibrate the flows found in Oyster Creek for the 50- and 100-year events, which include the combination of Oyster Creek watershed peak discharges and the inclusion of interbasin flows that enter Oyster Creek from the Brazos River inundation events. The FIS mentions that a FLOW SIM 10 and a USACE 2-D model was used in analyzing the interbasin flows in low-lying areas. A combined 1D/2D approach was used in the FLOW SIM 10 model with the discharges entered into a HEC-2 model. The summary of flows for the discharges mentioned in this section is shown in Table 2 of the FIS report.

3.2 Modeling Methodology

H&H modeling conducted for this analysis included HEC-HMS unsteady flow hydrologic analysis and computation of peak flows of Oyster Creek to assess downstream impacts and HEC-RAS hydraulic analysis including computation of WSEL profiles, velocities, and storage. The Modified Puls Reservoir Routing Method was used because it is the best method for assessing flat watersheds, such as those in the Gulf Coast of Texas, and because it uses storage in the routing reach data. This method allows for the subtraction of lost floodplain storage, as well.

BASINS with HPSF plug-in was used to model the velocity and sediment erosion in the Oyster Creek under drought conditions to examine the hydromodification impact of the proposed reservoir. The HSPF model was also used to model the water temperature in Oyster Creek during drought conditions to determine any impact on aquatic life. The HSPF model has been successfully used to determine hydromodification effects in previous studies (EPA, 2009).

3.2.1 Existing Model Selection

After reviewing the CF3R HEC-HMS model and supporting documentation, it was determined that the previous model could be used as a basis for the Watearth model. However, the CF3R HEC-HMS model ends approximately 20.5 miles (linearly estimated) upstream of the Oyster Creek Project 1 restoration site. Two sub-basins and 10 reaches were delineated and inserted into the new model in order to close the gap between the CF3R model and the Watearth model. In addition, there were several references to paired data errors in the existing model that were resolved. The existing model was run to obtain the peak flows happening at the existing model's outlet. **Figure 5** contains the 1% annual reoccurrence run with the outflow hydrograph displayed in the lower left corner of the figure. **Figure 6** shows the results summary table for the model seen in **Figure 5**.

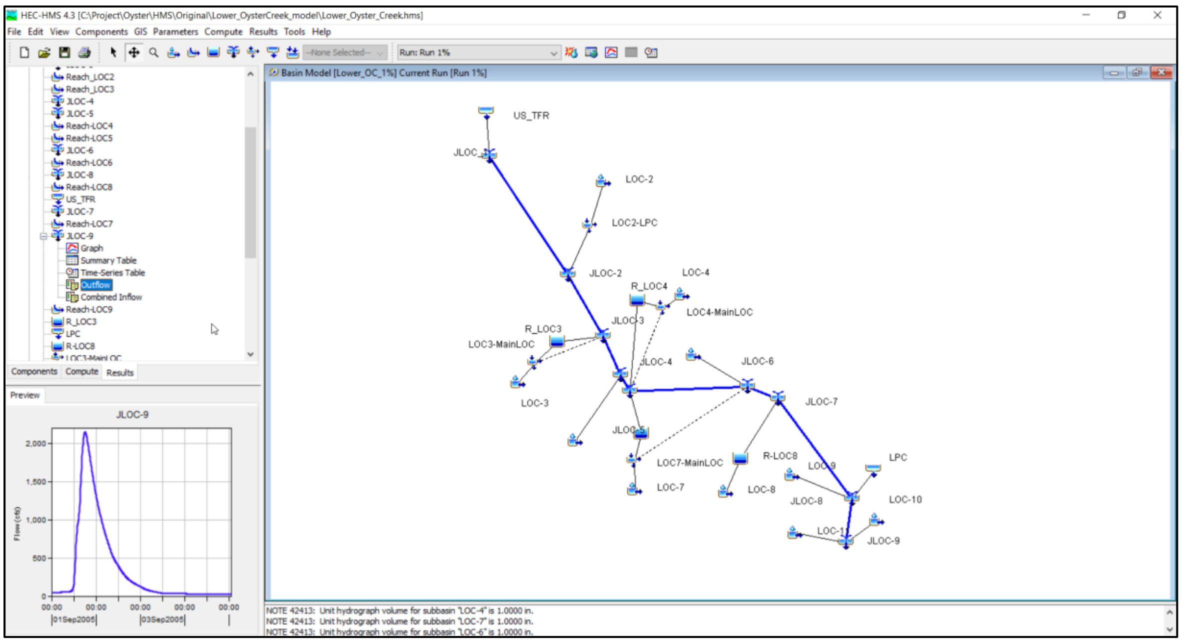

__Figure 5__: CF3R's existing model was ran to obtain peak flows for the Lower Oyster Creek Model as referenced by CF3R. The peak flow at the end of the model (JLOC-9) is 2,144 cfs.

Global Summary Results for Run "Run 1%"

Project: Lower_Oyster Creek Simulation Run: Run 1%

Start of Run: 01Sep2005, 00:00 Basin Model: Lower_OC_1%
End of Run: 05Sep2005, 01:00 Meteorologic Model: 1%
Compute Time: 21Jan2020, 09:47:34 Control Specifications: Control 1

Show Elements: All Elements Volume Units: IN AC-FT Sorting: Alphabetic

Hydrologic Element	Drainage Area (MI2)	Peak Discharge (CFS)	Time of Peak	Volume (AC-FT)
JLOC-2	5.78	219.5	01Sep2005, 15:20	278.3
JLOC-3	6.19	295.0	01Sep2005, 15:40	484.7
JLOC-4	6.30	349.7	01Sep2005, 15:00	528.9
JLOC-5	6.97	433.6	01Sep2005, 14:50	695.2
JLOC-6	7.11	622.4	01Sep2005, 15:10	828.2
JLOC-7	7.24	627.1	01Sep2005, 15:30	864.6
JLOC-8	14.46	2126.4	01Sep2005, 18:00	2619.2
JLOC-9	14.66	2144.2	01Sep2005, 18:10	2689.0
JLOC_1	5.32	69.4	02Sep2005, 03:20	124.1
LOC-10	0.11	138.5	01Sep2005, 13:40	38.7
LOC-11	0.09	161.6	01Sep2005, 13:00	30.8
LOC-2	0.46	303.6	01Sep2005, 15:20	175.5
LOC-3	0.41	428.7	01Sep2005, 13:40	169.3
LOC-4	0.30	307.7	01Sep2005, 13:40	112.0
LOC-5	0.11	155.7	01Sep2005, 13:10	42.0
LOC-6	0.14	156.3	01Sep2005, 13:40	54.1
LOC-7	0.37	402.7	01Sep2005, 13:40	149.7
LOC-8	0.13	161.6	01Sep2005, 13:40	46.6
LOC-9	0.16	200.4	01Sep2005, 13:30	56.8
LOC2-LPC	0.46	215.8	01Sep2005, 15:20	156.1
LOC3-MainLOC	0.41	278.7	01Sep2005, 13:40	110.0
LOC4-MainLOC	0.30	215.4	01Sep2005, 13:40	78.4
LOC7-MainLOC	0.37	201.4	01Sep2005, 13:40	74.9
LPC	7.06	1628.0	01Sep2005, 18:20	1696.7
Reach-LOC4	6.19	295.0	01Sep2005, 16:30	487.0
Reach-LOC5	6.30	349.7	01Sep2005, 15:10	529.7
Reach-LOC6	6.97	413.3	01Sep2005, 15:50	699.3
Reach-LOC7	7.11	621.9	01Sep2005, 15:30	828.8
Reach-LOC8	7.24	619.0	01Sep2005, 15:50	865.7
Reach-LOC9	14.46	2126.1	01Sep2005, 18:10	2619.5
Reach_LOC2	5.32	57.8	02Sep2005, 08:20	122.1
Reach_LOC3	5.78	183.0	01Sep2005, 18:10	277.6
R-LOC8	0.13	5.3	01Sep2005, 20:40	35.7
R_LOC3	0.41	56.1	01Sep2005, 18:50	147.8
R_LOC4	0.30	8.8	01Sep2005, 13:20	61.9
R_LOC7	0.37	8.8	01Sep2005, 00:00	70.0
US_TFR	5.32	69.4	02Sep2005, 03:20	124.1

***Figure 6**: CF3R's existing model summary table. The peak flow at the end of the model (JLOC-9) is 2,144 cfs.*

3.2.2 Lake Jackson Reservoir as Downstream Analysis Ending Point

The contributing drainage area for Oyster Creek has been altered by the Sienna Plantation Subdivision canal project, which rerouted the northern portion of Oyster Creek (north of the proposed Harris Reservoir) to the Brazos River. The contributing drainage area was reduced by 63%.

Oyster Creek continues to flow downstream approximately 26 miles without any further channel modification until it arrives near Lake Jackson, Texas, which is where the reservoir discharge or any natural stream flow is diverted into Dow's canal. The water from the Oyster Creek Dam (Keyway) is pumped into Dow's canal (Dow Chemical Company, 2019, p. 9). The canal takes the water to the Dow's plants for use.

Oyster Creek Dam near Lake Jackson, Texas, was selected as the end point of the modeling because it is where the water is diverted by Dow and any impacts due to the proposed project would naturally end due to the weir and Lake Jackson operations. Additionally, this distance downstream of the proposed project would allow changes in flows to attenuate back into natural conditions. The Oyster Creek Dam is approximately 12 miles linear distance from the Gulf of Mexico.

3.2.3 Reservoir Discharge Assumptions During a 50- and 100-Year Design Event for Oyster Creek Modeling

Dow has a 1942 water right that allows it to divert up to 60,000 ac-ft per year from Oyster Creek. Dow's operational philosophy is to maximize the use of storm flows in Oyster Creek so that it does not have not pump water into and release water from the existing and proposed reservoirs (Dow Chemical Company, 2019). This allows Dow to save pumping costs, which is one of its primary objectives according to their operation philosophy (Dow Chemical Company, 2019).

The current and proposed reservoirs can only be filled by water pumping from the Brazos River and natural rainfall on the reservoir surface. The reservoirs are operated at such a level that a localized 50- and 100-year storm event is contained in the reservoir without discharge. For larger storm events from tropical storms, Dow monitors tropical storm activity in the Gulf of Mexico and uses a site shutdown sequence that typically starts 96 hours or more ahead of landfall for larger tropical storms or hurricanes. This storm monitoring protocol needs to continue.

This would mean that if Dow is diverting Oyster Creek stream flow from storm events whenever possible, there would not be any water discharge from the existing or proposed Harris Reservoirs during the 50- and 100-year storm event. So only natural rainfall and runoff from the contributing drainage area will have to be considered in the modeling of the 50- and 100-year storm event on Oyster Creek.

3.2.4 Considerations for Proposed Oyster Creek Improvements and Oxbow Storage

The proposed project reservoir berm will prevent Oyster Creek overflow into the west floodplain of Oyster Creek for approximately 12,000 ft of the creek. The Dow proposed Oyster Creek improvement projects do not fully mitigate this floodplain storage loss, which was 309 ac-ft of loss under the original application and 1,028 ac-ft under the revised Project 3 design. Under the revised Project 3 design, all flows through the 25-year flow event will continue to enter the oxbow as it currently does. However, for events above the 25-year flow, the flow volume between the 25-year and 100-year storm flow will be diverted into the (Project 3) overflow channel. The Jacobs model contains one cross-section through this oxbow, which could better be represented with additional cross-sections in the existing and proposed conditions models. This would better simulate floodplain storage losses between the 25-year and 100-year design storm event. Watearth did not scope to add cross-sections or other modifications to the Jacobs model for this effort.

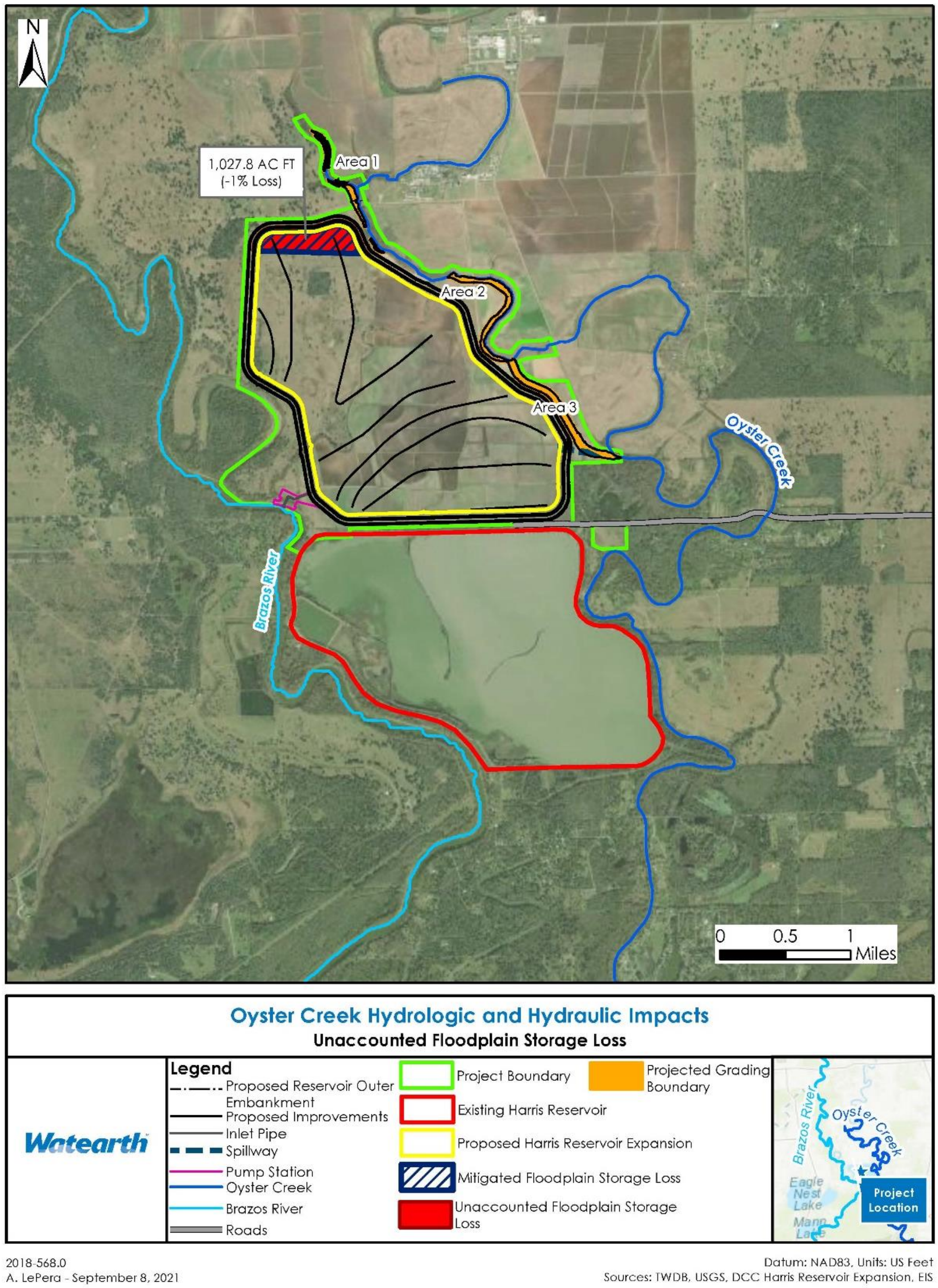

Figure 7: *Oyster Creek figure showing loss of floodplain storage due to the construction of the proposed Harris Reservoir expansion and stream restoration projects.*

3.2.5 Assumptions for Hydrologic and Hydraulic Models and Analysis

As described above, the model end points were established to include the proposed improvements and to assess the downstream impacts due to the proposed Harris Reservoir. Upstream impacts were not reviewed. The H&H model developed by Watearth starts junction JLOC-9 to the same location were the unnamed tributary being improved in stream restoration Project 1(Area 1 in the **Figure 7** above) converges with Oyster Creek near Otey, Texas, as seen in **Figure 8**. This will bridge the gap between the two models. The model ends at the Oyster Creek Dam, which serves as the Dow water supply diversion near Lake Jackson as seen in **Figure 8**.

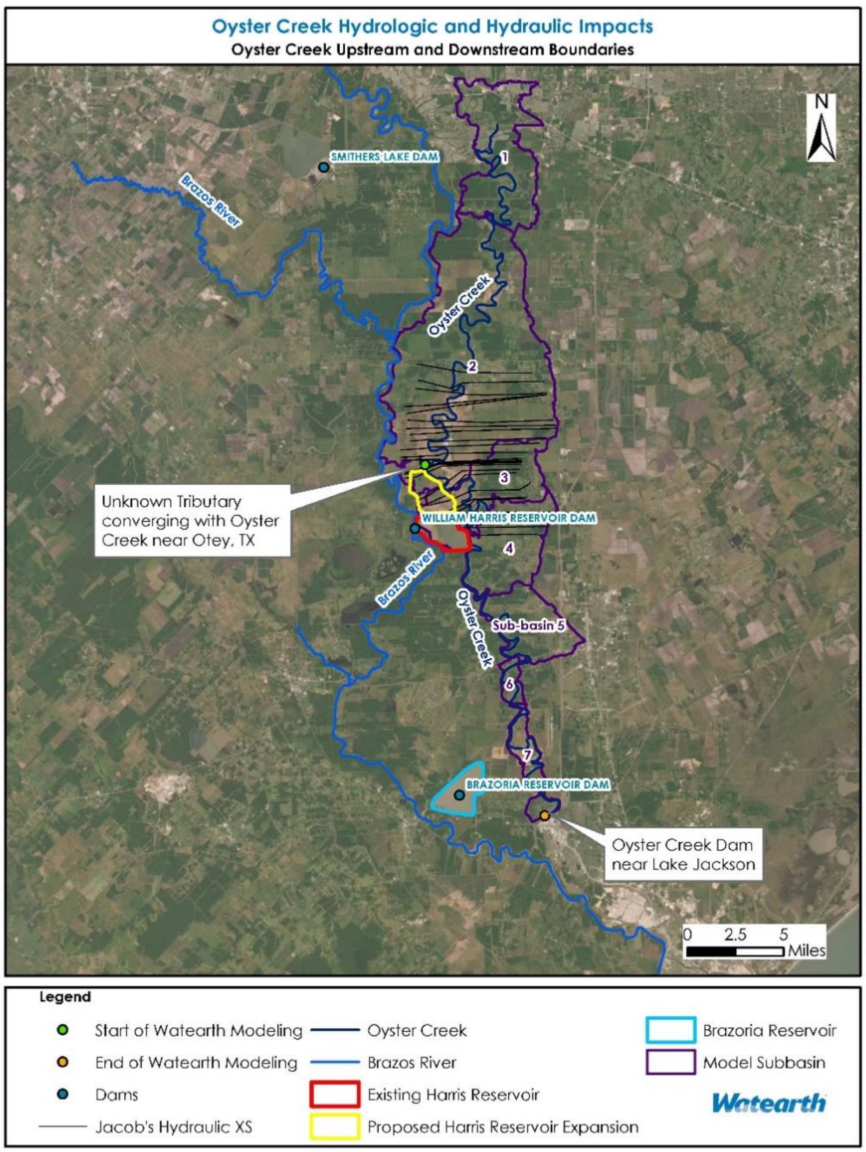

***Figure 8**: Modeling boundaries for the Watearth H&H model for Oyster Creek.*

As mentioned in previous sections, there is a gap between the existing model and Watearth's model. The first two sub-basins (O-1 and O-2) and the part of Oyster Creek drawn in dark blue (between O-1 and O-2) represented in the HEC-HMS model in the following reaches: R-O1, R-1.29, R-1.54, R-1.59, R-O1.61, R-1.65, R-1.70, R-1.72, R-1.73, R-1.75, and R-02. The reaches located in **Figure 9** was used to bridge the gap between the models.

The sub-basins for Oyster Creek were delineated using the Arc-Hydro 10.6 extension within Arc-GIS 10.6.1. First, the Digital Elevation Model (DEM) was obtained from the USGS TNM Download application for the project area. The DEM was obtained with the precision of one-third arc-second in ArcGrid format. The elevations for the DEM are in meters and were converted to feet by multiplying the values in the DEM by the conversion factor of 3.281 (meters to feet). The DEM was then clipped to a smaller area to lower the terrain preprocessing time.

After the catchments were created, the point delineation feature in Arc-Hydro 10.6 was used to assist in determining the extents of the watershed (area that includes all the sub-basins). The point delineation could not be used at the outlet point because there was not enough stream definition in that location. However, the point delineation was used at the sub-basin boundary for Sub-basin O6. Sub-basin O-7 is directly downstream of Sub-basin O-6 and was just added to the watershed. The watershed was divided into small catchments, then the hydrologic modeler merged the sub-basins by visual inspection into seven larger sub-basins for the watershed. The divisions were set so that one sub-basin would flow into the subsequent sub-basins until the flows reached the outlet point or end of the model. The first two sub-basins were created to close the gap between the existing model and Watearth's model. The subsequent sub-basins were created to model the watershed within the Watearth project area shown in **Figure 10**.

The hydrography for the rivers/streams in the area were also obtained within the National Hydrography Dataset (NHD) layer. This layer was clipped to obtain the Oyster_US_model shape file and the ClipNHD_STP shapefile.

An adjustment was made to the C3FR side of the model to run the model to completion due to the addition of new elements to the model downstream of the C3FR model, as well as having to extend the run time of the model to approximately 30 days instead of 7 days in the original version. This was done to see the effects of interbasin peak flow and sub-basin peak flow hydrographs in the HEC-HMS model. The model would not run to completion in its original version, and after troubleshooting the error messages within the RAS model, a couple changes were made to a few of the nodes in the C3FR side of the model (model upstream of J-LOC9).

Error messages popped up regarding reservoir R-LOC7 possibly running dry and having no outflow; this would cause the model to fail. R-LOC7 receives flow from sub-basin LOC-7, which is a small sub-basin of 0.37 square miles that feeds flow into R-LOC7. The issue was resolved by disconnecting the sub-basin LOC-7 and adding and connecting a source node (STEADYFLOW LOC-7) with a constant flow of 10 cfs in its place. This adjustment eliminated the errors caused by the empty reservoir. A flow of 10 cfs upstream in the model should have minimal effects to the results, especially because the Oyster Creek model is subject to large volume interbasin flows.

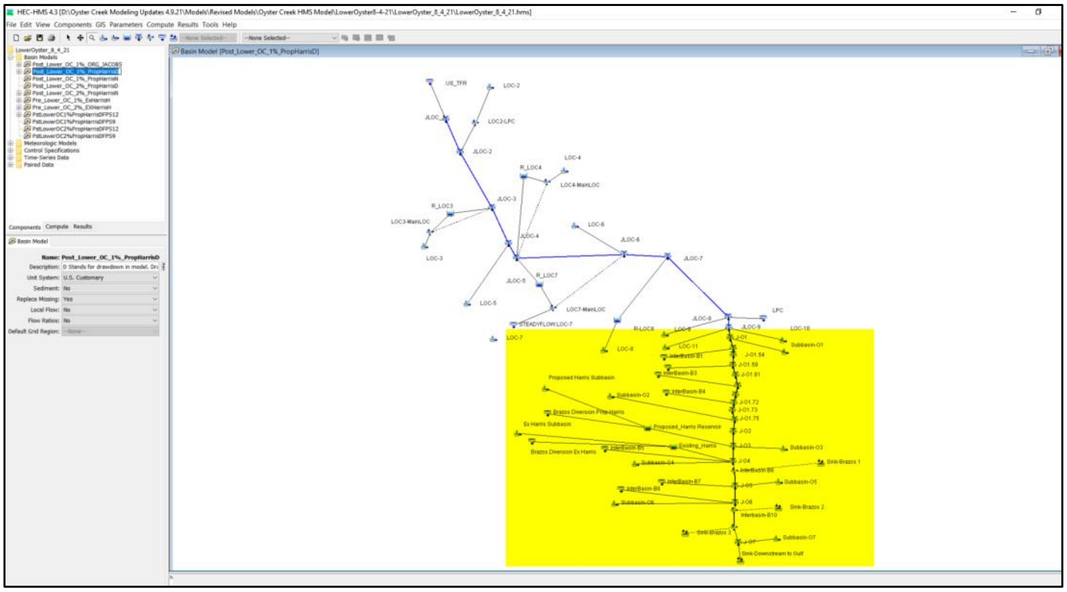

Figure 9: *Watearth's hydrologic model including a portion added to fill gap in existing models.*

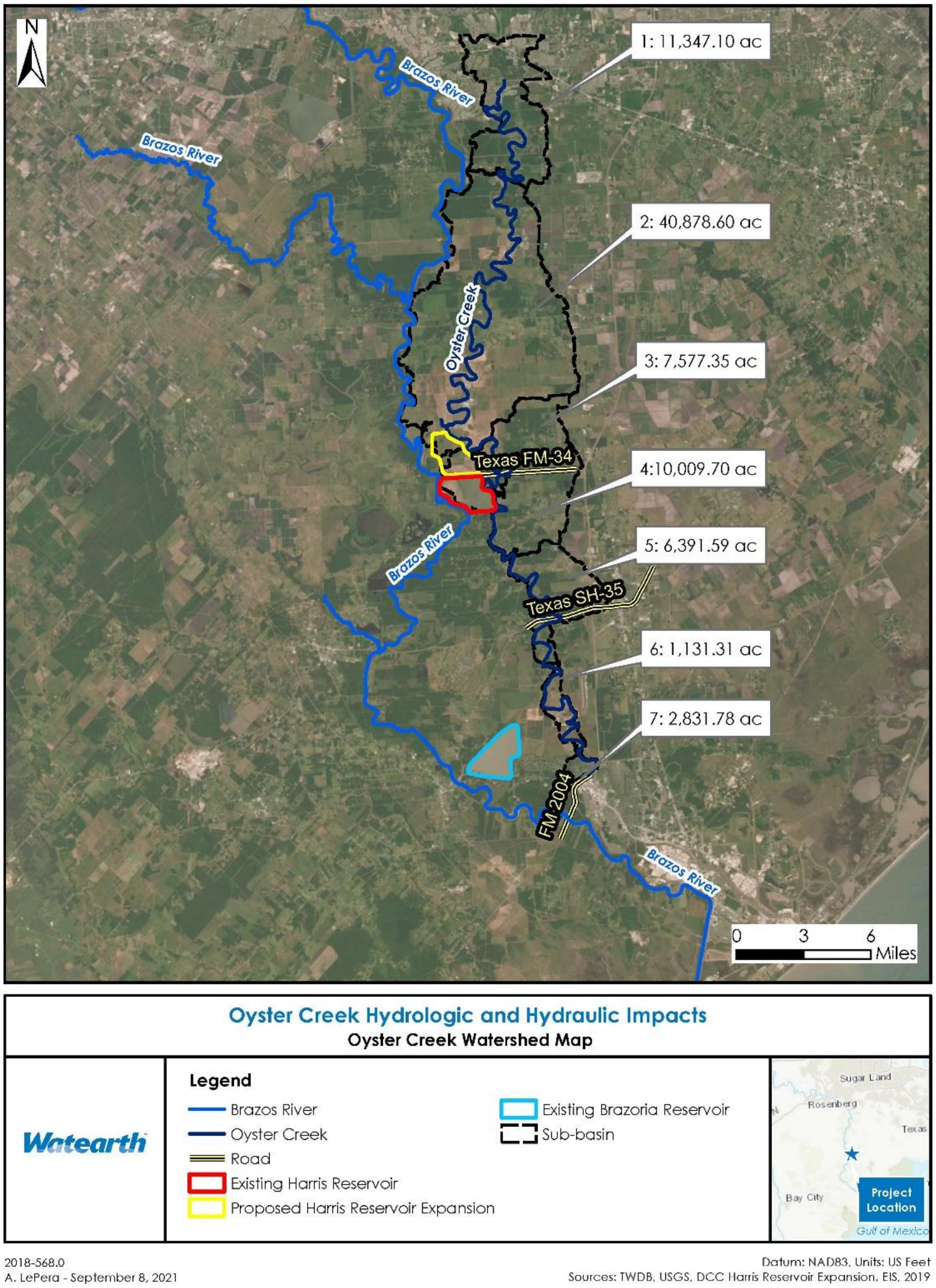

***Figure 10**: Oyster Creek watershed delineated in ARC-HYDRO 10.6. Watearth Oyster Creek modeling begins approximately where the blue stream begins and consists of Sub-basins O3 through O7.*

The next step in the construction of the hydrologic model was to include the sub-basins, reaches, and junctions established in ArcGIS into the existing HEC-HMS model. HEC-HMS version 4.3 was used to model Oyster Creek from the model boundary points seen in **Figure 8**. The items mentioned above were added to C3FR's model seen in **Figure 9,** which includes the sub-basins delineated and connected downstream by reaches and junctions down to the outlet point, Dow's intake diversion (a freshwater canal) at J-07, shown in yellow. Later, the interbasin flows were added to the model. **Figure 11** provides a closer look at all the nodes in Lower Oyster Creek hydrologic model as the **Figure 9** node diagram does not show all the nodes.

The hydrologic model was set up with the sub-basins, reaches, and junctions established in ArcGIS for the Lower Oyster Creek watershed and was combined into the existing HEC-HMS model. This model setup was not enough to model the effects of interbasin flows and the operation of the existing and proposed Harris Reservoirs during the storm events for Oyster Creek. Additional improvements had to be made for the HEC-HMS model to accurately model the interbasin flows entering and exiting the Oyster Creek watershed because of the flat slopes and interbasin flooding that occur in the Oyster/Brazos watershed during the 50- and 100-year storm events.

The existing and proposed Harris Reservoirs modeled in the HEC-HMS model included a sub-basin for each reservoir, which was added to account for rainfall occurring over the reservoir area, and a source node that was used to include the diversion inflows from the pumps that draw water from the Brazos River and fill up the reservoirs when necessary. Various operational scenarios were modeled for the proposed Harris Reservoir to determine whether impacts occur downstream and/or if overtopping of the dam's embankment could occur. These scenarios include the following:

1. 50-year and 100-year 24-hour design storms with no drawdown.
2. 50-year and 100-year 24-hour design storms with 18 inches of drawdown prior to the design storm event at a rate of 978 cfs for 6 hours prior to design storm rainfall and 6 inches of floodplain storage held during the design storm event within the reservoir prior to spillway discharge.
3. The same scenario as No. 2 above but with 9 inches of floodplain storage held during the design storm events.
4. The same scenario as Nos. 2 and 3, but with 12 inches of floodplain storage held in the reservoir during the storm event.

After the design storm rainfall concludes, the flow out of the proposed Harris Reservoir spillway is modeled as 11 cfs (half the environmental flow required in Oyster Creek). The other half or 11 cfs to complete the environmental flow required for Oyster Creek is provided by a release from the existing Harris Reservoir.

Interbasin flows B1 though B4 are modeled as sources in the HEC-HMS model. They occur upstream of the proposed Harris Reservoir within the O2 sub-basin. The incoming hydrographs used to represent the interbasin flows were obtained from the Lower Brazos Flood Protection Planning Study Hydraulic Analysis HEC-RAS model. The Lower Brazos Flood Protection Planning Study (LBFPPS) Hydraulic Analysis HEC-RAS model spans from Washington County to Brazoria County ending at the Gulf of Mexico, which includes the modeled area.

The LBFPPS has the Brazos River and Oyster Creek modeled side by side with lateral structure weirs set up between the Brazos River and Oyster Creek to transfer flow between the Brazos/Oyster watershed. **Figure 10** shows a lateral structure circled in magenta, which was used to represent Interbasin flow B1 in the HEC-HMS model. The flow hydrograph highlighted in red shown in the same figure represents the interbasin flow leaving the Brazos River and entering Oyster Creek.

The interbasin flow hydrograph is distributed through a long weir to Oyster Creek in the HEC-RAS model; however, HEC-HMS does not have the same capability as HEC-RAS to distribute flow along a weir length. HEC-HMS uses point sources or point diversions/sinks along the reaches to add or subtract flow from the modeled reaches. To resolve the different ways that the two models handle lateral inflows, the centroid of the lateral structure weir was measured in GIS and a junction node was placed in that location. A lateral structure hydrograph then was inserted in the lateral structure's centroid to best represent the most accurate location of where the flow hydrograph should enter Oyster Creek in the HEC-HMS model.

The reaches between J-O1 and J-O2 were broken up into smaller reaches where a junction node was added at the start, center, and end of each lateral structure section shown in the HEC-RAS model. This was done to accurately place the interbasin flows in the correct locations within the Oyster Creek reach in the HEC-HMS model. For example, for interbasin flow B1, a junction node was placed in J-O1 representing the start of the lateral flow weir location. Another node was then added at J-O1.29 where interbasin flow hydrograph B1 was applied to Oyster Creek, and then another junction node was entered at J-O1.54 representing the end of the lateral structure location. This same process was used for Interbasins-B2 through B4.

There are additional interbasin flows occurring downstream of the existing Harris Reservoir; these are labeled interbasin flow B5 through B10. Interbasin flow B7 is a source node with flow entering Oyster Creek. Interbasin flow B10 is a diversion/sink where flow is leaving Oyster Creek to return to the Brazos River. Interbasin flows B5-B6 and B8-B9 were represented slightly differently in the HMS model compared to B1 through B4. The reason is because below the existing Harris Reservoir, there are some areas where there is a combination of flows leaving Oyster Creek into the Brazos River. Flows entering Oyster Creek from the Brazos River at different sections of the hydrograph must be handled differently in the HEC-HMS model as shown in LBFPPS HEC-RAS model screenshot in **Figure 12**.

For example, there are flows entering and exiting Oyster Creek just downstream of the existing Harris Reservoir near Junction O4. The positive flows in the hydrograph are represented as flows entering Oyster Creek as a source node (InterBasin-B5) just upstream of J-O4. The negative flows in the hydrograph are represented as flow leaving Oyster Creek using a diversion and a sink node (Interbasin-B6/Sink Brazos 1) just downstream of J-O4.

All the interbasin flows seen in the in LBFPPS HEC-RAS model and the flows generated within the Oyster Creek watershed sub-basins are represented in the HEC-HMS model. The model results were reviewed and were compared to the peak flows reported in the Brazoria County FIS. The results in the HEC-HMS model appeared to be significantly higher than the peak discharges reported in the Brazoria County FIS. This prompted the calibration of the interbasin flow hydrographs that appeared to be too high of magnitude and were reduced in magnitude by multiplying the flows to a factor, so peak flow results match up better with the peak flow results reported in the FIS for Oyster Creek from that previous study.

A factor of 0.25 was multiplied to all the interbasin flows hydrographs in the 100-year model so the peak flows in the HMS model would be more realistic and correlate better to the values reported in the FIS. For the 50-year, interbasin flow hydrographs were multiplied by a factor of 0.21 for the same reason.

The hydrograph adjustments to the data yielded results similar to those reported in the FIS for peak flows, which included interbasin flows in the modeling approach.

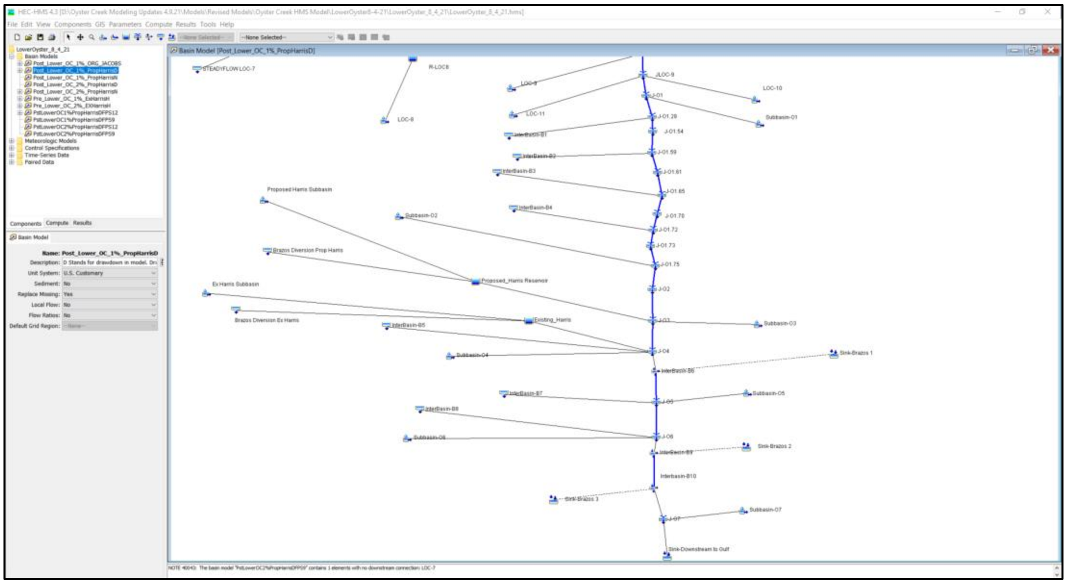

Figure 11: *Watearth's hydrologic model zoomed in showing all the nodes within the Lower Oyster Creek HMS model.*

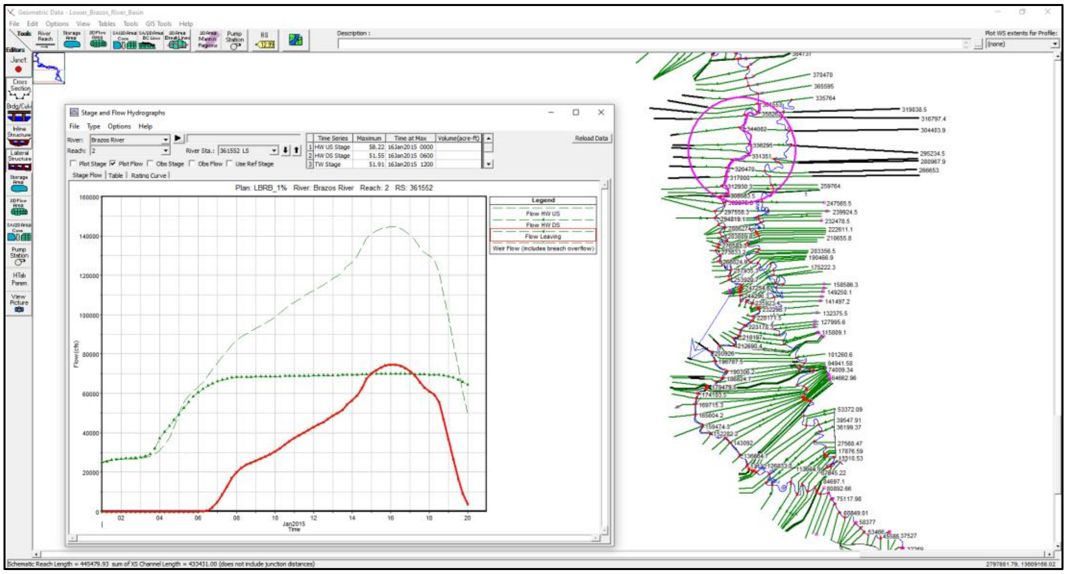

Figure 12: *Lower Brazos Flood Protection Planning Study Hydraulic Analysis HEC-RAS model showing a lateral inflow location (circled in magenta) and lateral inflow hydrograph (highlighted in red to the left of the cross section diagram,) which was entered into the HEC-HMS model as Interbasin flow-B1.*

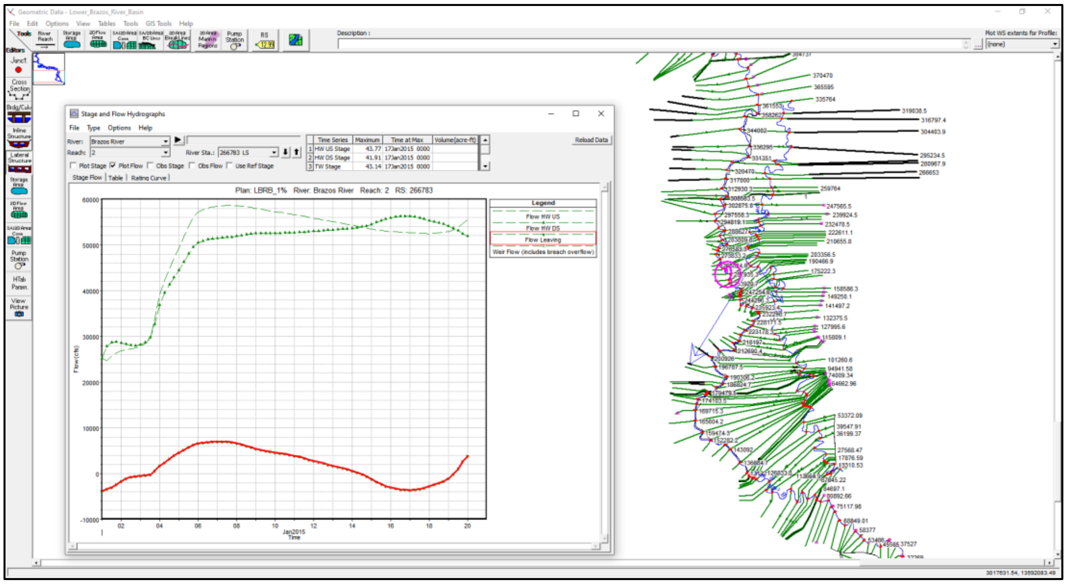

Figure 13: *Lower Brazos Flood Protection Planning Study Hydraulic Analysis HEC-RAS model showing a lateral inflow location (circled in magenta) and lateral inflow hydrograph (highlighted in red to the left of the cross section diagram) which was entered into the HEC-HMS model as Interbasin flow-B5(positive flows) and B6 (negative flows).*

3.2.6 Rainfall Data

The previous model used criteria established in the Fort Bend County *Drainage Criteria Manual*. However, the majority of the model is located in Brazoria County, therefore the methods established for determining hydrologic parameters used the 2003 Brazoria County *Drainage Criteria Manual* (Brazoria County, TX, 2003). The 1% Frequency Storm (100-year) was changed from what is shown in **Table 2** to the values stated to be used for Brazoria County found in the 2003 *Drainage Criteria Manual* as shown in **Table 3.** The same approach was applied to the 2% Frequency Storm (50-year) shown in **Table 3** through **Table 5.**

Table 2: Existing Conditions Model Frequency Storm Data for Fort Bend County

100-Year Storm Frequency Storm Data	
Met Name	1%
Annual-Partial Conversion	None
Annual-Partial Ratio	1.0000
Storm Duration	1 Day
Intensity Duration	5 Minutes
Intensity Position	50%

Area Reduction	TP40
Storm Area	0.01
Curve	Uniform for All Sub-basins
Depth/Duration Data	
Duration	Depth (Inches)
5 Minutes	0.91
15 Minutes	2.01
1 Hour	4.55
2 Hours	6.05
3 Hours	6.85
6 Hours	8.40
12 Hours	10.45
1 Day	12.50

Table 3: Proposed Conditions Revised Frequency Storm Data for Brazoria County as Required from *Drainage Criteria Manual*

100-Year Storm Frequency Storm Data	
Met Name	1%
Annual-Partial Conversion	None
Annual-Partial Ratio	1.0000
Storm Duration	1 Day
Intensity Duration	5 Minutes
Intensity Position	50%
Area Reduction	TP40
Storm Area	0.01
Curve	Uniform for All Sub-basins

100-Year Storm Frequency Storm Data	
Depth/Duration Data	
Duration	Depth (Inches)
5 Minutes	0.91
15 Minutes	2.02
1 Hour	4.62
2 Hours	6.20
3 Hours	7.15
6 Hours	8.75
12 Hours	10.75
1 Day	13.00

Table 4: Existing Conditions Model Frequency Storm Data for Fort Bend County

50-Year Storm Frequency Storm Data	
Met Name	2%
Annual-Partial Conversion	None
Annual-Partial Ratio	1.0000
Storm Duration	1 Day
Intensity Duration	5 Minutes
Intensity Position	50%
Area Reduction	TP40
Storm Area	0.01
Curve	Uniform for All Sub-basins
Depth/Duration Data	
Duration	Depth (Inches)
5 Minutes	0.83
15 Minutes	1.85
1 Hour	4.14

50-Year Storm Frequency Storm Data	
2 Hours	5.45
3 Hours	6.10
6 Hours	7.55
12 Hours	9.25
1 Day	11.00

Table 5: Proposed Conditions Model Frequency Storm Data for Brazoria County as Required from Drainage Criteria Manual

50-Year Storm Frequency Storm Data	
Met Name	2%
Annual-Partial Conversion	None
Annual-Partial Ratio	1.0000
Storm Duration	1 Day
Intensity Duration	5 Minutes
Intensity Position	50%
Area Reduction	TP40
Storm Area	0.01
Curve	Uniform for All Sub-basins
Depth/Duration Data	
Duration	Depth (Inches)
5 Minutes	0.84
15 Minutes	1.86
1 Hour	4.20
2 Hours	5.60
3 Hours	6.30

50-Year Storm Frequency Storm Data	
6 Hours	7.80
12 Hours	9.60
1 Day	11.50

3.2.7 Land Use Data and Soils Data

Land use data were obtained from the 2016 National Land Cover Database (NLCD 2016) and was used to estimate the percentage of impervious cover used in the Green Ampt Loss Method as reported in **Table 6**. The percentage of impervious cover was estimated visually using **Figure 14** and reported in **Table 7**. The soil classifications for the project area were similar to the existing model and the same parameters were kept for the use of Watearth's Hydrologic Model (**Figures 15–17**).

Table 6: Green Ampt Soil Characteristics

Green Ampt Soil Characteristics	HEC-HMS inputs (All Sub-basins)
Initial Content	0.075
Saturated Content	0.46
Suction (in.)	12.45
Conductivity (in/hr)	0.15

Table 7: Percent Impervious Values Used in Green Ampt Method within the HEC-HMS Model

Sub-basin Name	Percent Impervious (%)
O1	10.0
O2	5.0
O3	0.0
O4	5.0
O5	5.0
O6	0.0
O7	5.0

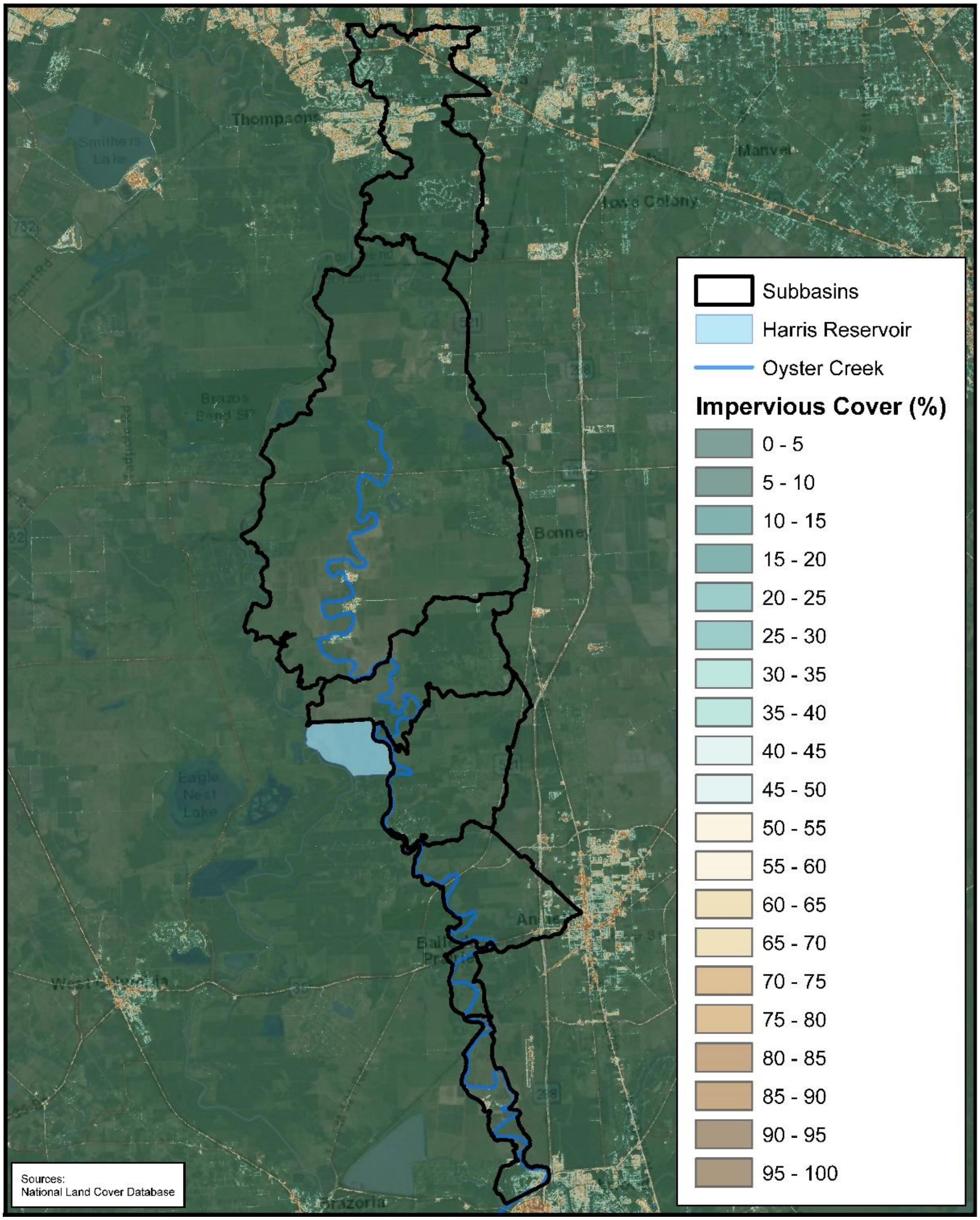

Figure 14: *Impervious cover for the Oyster Creek watershed.*

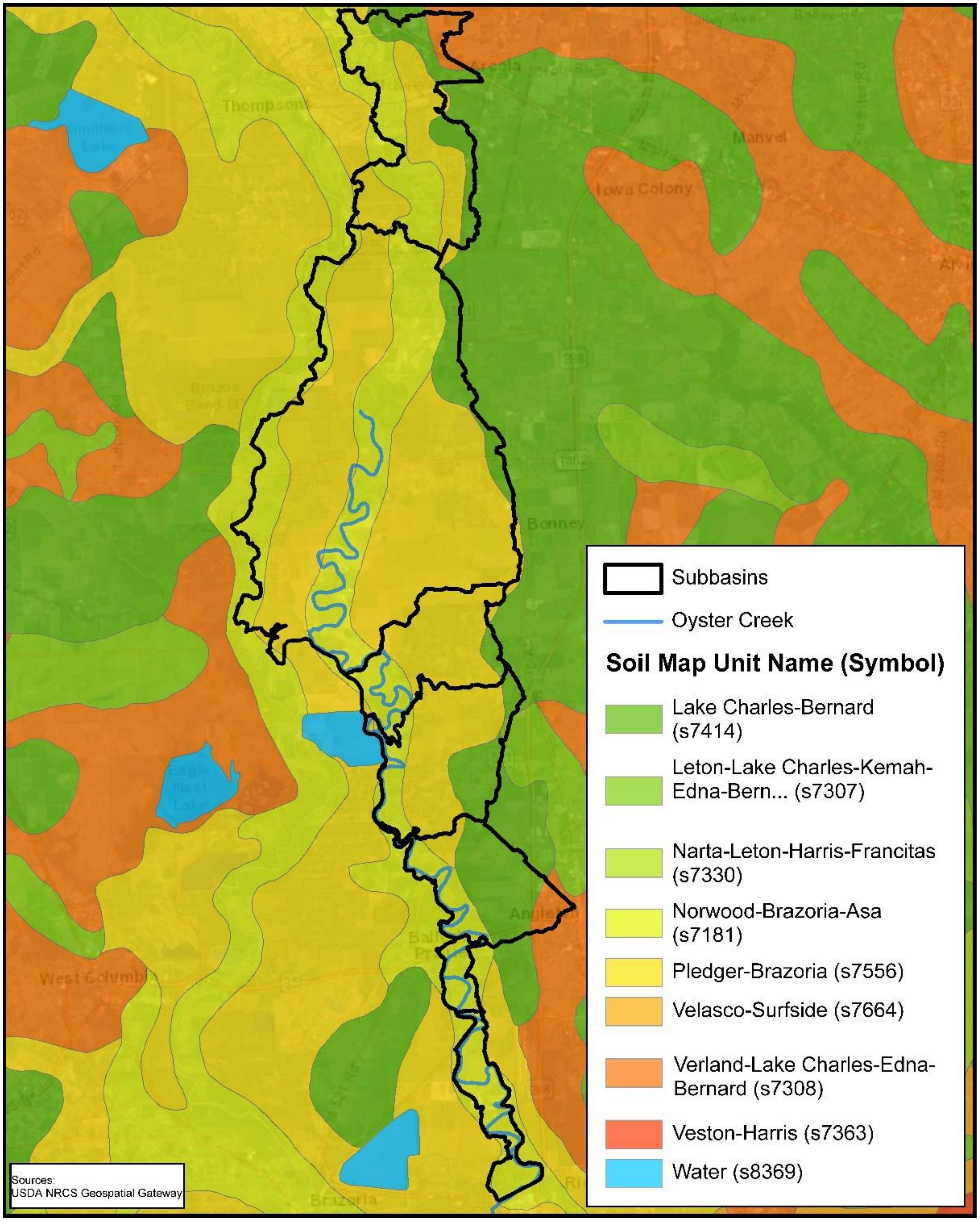

Figure 15: *Soils series for project study area.*

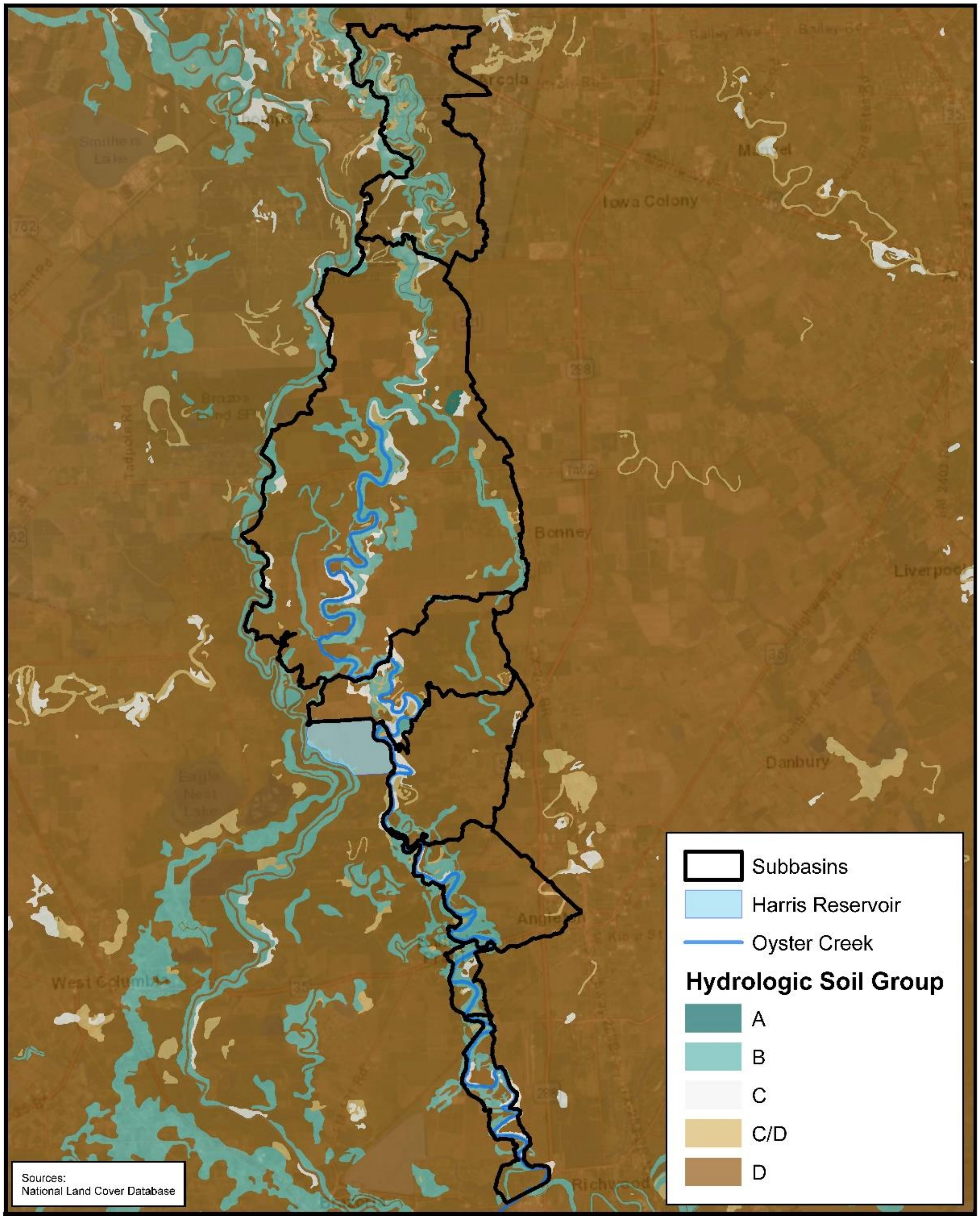

Figure 16: *Hydrologic soil group map for the Oyster Creek modeling sub-watershed.*

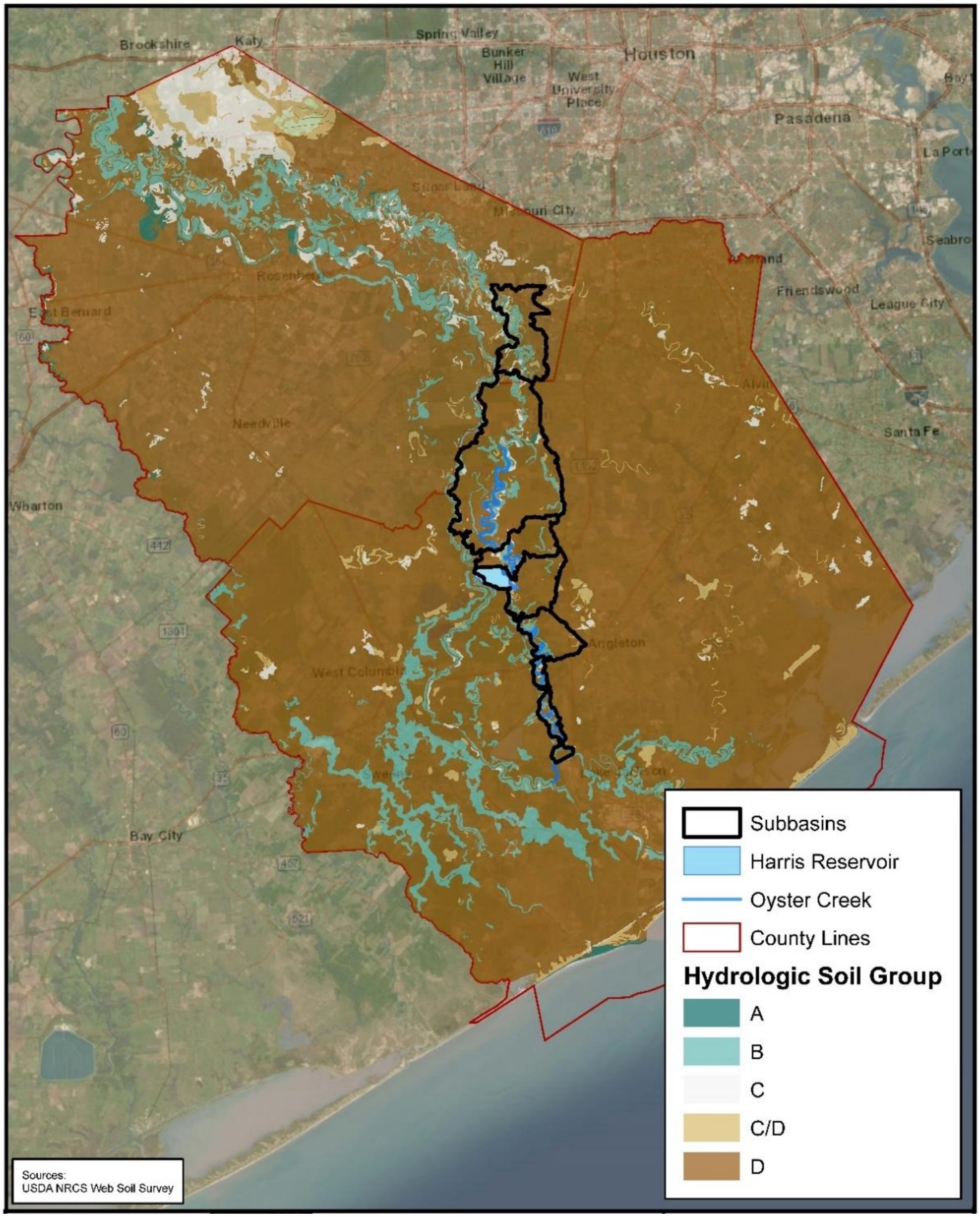

Figure 17: *Watershed view of the hydrologic soil group map for the Oyster Creek watershed.*

3.3 Hydrologic Model Methodology

The Clark Unit Hydrograph Method was selected to determine the design storm runoff in HEC-HMS. The Brazoria County Drainage Criteria determined that the equations from the *Harris County Hydrology Manual* dated March 1988 should be used to determine the variables to be used in the Clark Method (Brazoria County, TX, 2003). The process to obtain T_c (Time of Concentration) and R (Clark's Storage Coefficient) is to calculate T_c using Equation 1 and to calculate T_c + R by using Equation 2, then subtract Equation 1 from Equation 2 to obtain Clark's Storage Coefficient (R). Watearth determined that instead of using Equation 1, the Kerby-Kirpich Method would be applicable for calculating T_c for this planning level study. However, the T_c calculated by the Kerby-Kirpich Method was subtracted from Equation 2 to obtain the R.

T_c and R found in the Brazoria County *Drainage Manual* is calculated by using the following equations found in **Appendix B.** The Kerby-Kirpich Method was used to obtain T_c for this study. This method is applicable for estimating watershed time of concentration for drainage areas of 0.25 sq-mi up to watersheds less than 150 sq-mi. The T_c for this method is broken up into two components: an overland flow component (Kerby Method) and a channel flow component (Kirpich Method).

The results for the Kerby-Kirpich Method to determine T_c for all the sub-basins is located in **Appendix B**. Using the method described in the text above with the equations and T_c for each sub-basin in hours presented in **Appendix B**, the R coefficient for the Clark Method was obtained for each sub-basin and summarized in **Table 8**.

Table 8: Summary Calculations Used to Obtain Clark's Storage Coefficient (R)

Sub-basin Name	L (miles)	S (ft/mile)	Tc + R	Tc (Kirpich)	R
O3	5.8	1.55	21.43	5.77	15.66
O4	3.5	2.31	12.96	3.64	9.32
O5	5.2	1.14	22.29	5.57	16.72
O6	3.3	1.82	13.66	3.66	10.00
O7	8.6	0.47	43.14	8.74	34.40

3.3.1 Reach Routing

The flow through the sub-basins was routed using Muskingum-Cunge (O1 and O2) and Modified Puls Reservoir Routing Methods (O3 through O7).

3.3.2 Muskingum-Cunge Routing

O1(R-O1) through O2 (R-O1.75) was routed using the Muskingum-Cunge Method. Arc-GIS and Google Street View were used to assist in estimating the characteristics of the channels mentioned for the sub-basins where Muskingum-Cunge routing was used. The slope was obtained from the T_c calculations in the section above. The length of the reaches was obtained by tracing Oyster Creek in Arc-GIS between drainage area boundaries and junctions when necessary. Manning's n values were estimated from Chow's 1959 Manning's n for channels table. The main channel appeared to be winding; was mostly clean; contained pools, and shoals; weeds, and had a very shallow slope. Manning's n values range from 0.045 to 0.055 for these types of reaches. This was more typical for the reaches R-O1 through R-O1.75. The index flows used for R-O1 through R-O1.75 were obtained from the Harris County Flood Control District's Hydrology and Hydraulics Guidance Manual – Exhibit II.3-18 – Conveyance Discharge Curve for S = 1 foot/mile (which is very similar to Brazoria Counties Drainage Criteria). The graphical interpolation for the flows is in **Appendix C.**

The other reach parameters were estimated by cutting cross-sections in GIS and by using a USGS DEM as terrain background to assist in determining the channel width and depth. Google Street View images near relevant bridge crossings were also used to develop the average cross-section for the reaches. The Index Flow parameters were set in an early version of the HMS model where interbasin flows were not included in the modeling and only the sub-basin peak flows were expected in the Muskingum-Cunge reaches. A higher index flow was tested with the values elevated to the peak flow range expected with interbasin flows included.

Those modeling results were reviewed, and a higher index flow did not affect the model results. Therefore, the index flows set in the model shown in **Appendix C** were used in the model. Ten reaches and junctions were set in this location of the model to include interbasin flows in the hydrologic model. The reason for including all the reaches and junctions was to accurately place the interbasin flows entering along Oyster Creek in the correct locations in the HEC-HMS model. The locations and reach lengths of the interbasin flows were measured in ArcGIS and placed at the centroid of the lateral flow structure as described in Section 3.2.5 Assumptions for Hydrologic and Hydraulic Models and Analysis. The parameters used the Muskingum-Cunge routing are the same between existing and proposed conditions. **Table 9** and **Table 10** are a few examples of the Muskingum-Cunge reaches found in the model with many found in the HEC-HMS model.

3.3.3 Modified Puls Reservoir Routing

Part of the Jacobs HEC-RAS model was used as a basis for Watearth's HEC-RAS model, which was used to calculate the volume of the reaches for Modified Puls reservoir routing. Jacobs created a HEC-RAS model with cross sections representing the stream restoration channel improvements. The Watearth model contained Jacobs' model cross sections and HEC-2 effective model cross sections to show the effects of the stream restoration improvements downstream of the existing Harris Reservoir. The cross sections capture the upstream end of the proposed Harris Reservoir embankment and stream restoration Project 2 and end near the Lake Jackson diversion Dow freshwater canal. Watearth chose to use the Modified Puls reservoir routing method because it provides the best method for flat watersheds, such as along the Gulf Coast of Texas, and because it uses storage volume in the routing reach data.

First, initial peak flows were obtained by extracting the peak flow results from the Lower Oyster Creek HEC-HMS model. Interbasin flows from the Oyster/Brazos river watershed were included as sources and sinks that connect to junctions going along Oyster Creek. The 50- and 100-year peak flows found in the Modified Puls reaches (RO2 through RO7) are entered into the Watearth HEC-RAS model. The flow change locations/cross-sections within the steady flow data window match up with the reaches found within the Oyster Creek HEC-HMS sub-basins. In the HEC-RAS model, River Stations 147 through 142 correspond to reach (R-O2). In the HEC-HMS model, River Stations 142 through 134 correspond to reach (R-O3), River Stations 134 through 128 correspond to reach (R-O4), River Stations 128 through 111 correspond to reach (R-O5), River Stations 111 through 102 correspond to reach (R-O6), and River Station 102 through 72 correspond to reach (R-O7).

The Harris County Flood Control District *Hydrology and Hydraulics Guidance Manual* (Harris County Flood Control District, 2009) contains a procedure to determine the Modified Puls storage-outflow relationship for each reach. The procedure was used in this analysis and is summarized in the following paragraph.

The procedure states to hold the flows constant between routing reaches which were held constant until the last cross section where the flow change occurs for the next reach downstream. The interbasin flows exiting and entering the Oyster Creek system were added to the end of the reach in order to not affect the requirement of the Modified Puls procedure of keeping the flows between reaches constant.

The initial peak flows for the Modified Puls reaches determined in the HEC-HMS model were multiplied by several factors and entered into the HEC-RAS model. A downstream boundary condition of S = 0.00006 represented the slope at the downstream boundary of the model. The average reach travel time and the average flood wave travel time are calculated according to the procedure using results generated from the HEC-RAS model. The storage/discharge data for each reach were obtained from the HEC-RAS model results for areas between the reaches. Then, using the average flood wave travel time and the HEC-HMS model time step, the number of sub-reaches was calculated for each peak flow factor and the average sub-reach was entered as a parameter in the HEC-HMS model.

The average number of subreaches and the storage discharge data for each reach were then entered into the HMS model as Modified Puls parameters. All the hydrologic parameters for each drainage area were entered in the HEC-HMS model and routed through all the reaches. Peak flows were generated for each junction/reach, which represent a drainage area boundary in the HEC-HMS model or flow change location in the HEC-RAS model.

The HEC-HMS model results yielded the 50-year and 100-year design storm peak flows for each sub-basin, which were then reinserted into the HEC-RAS model. The HEC-RAS model yielded new storage/discharge data for the reaches dependent on the new peak flows, which were then entered into HEC-HMS, which resulted in an adjusted flow value for the 100-year storm. After seven iterations of the process described above, the difference in peak flow between the reaches (R-O2 through R-O7) was less than 3% when compared to the peak flows calculated for each reach in HEC-HMS and compared to the flows entered into the HEC-RAS model. Since the peak flows are similar between the HEC-RAS and HEC-HMS models, the storage/volume relationship for each reach has been determined by using the iterative method described above. The Modified Puls parameters are shown for each of the sub-basins in **Table 9** through **Table 16** for existing conditions and proposed conditions.

Table 9: Pre-Project Muskingum-Cunge Parameters for R-O1

Basin Name: Pre_Lower_OC_1%_ExHarrisH	
Element Name: R-O1	
Initial Type	Discharge = Inflow
Length (FT)	55,782
Slope (FT/FT)	0.0006
Manning's n	0.045
Space-Time Method	Auto DX Auto DT

Basin Name: Pre_Lower_OC_1%_ExHarrisH	
Index Method	Flow
Index Flow (CFS)	3,000
Shape	Triangle
Side Slope (xH: 1V)	3
Invert (FT)	1.5

Table 10: Post Project Muskingum-Cunge Parameters for R-O1.75

Basin Name: Post_Lower_OC_1%_PropHarrisD	
Element Name: R-O1.75	
Initial Type	Discharge = Inflow
Length (FT)	5,325
Slope (FT/FT)	0.006
Manning's n	0.055
Space-Time Method	Auto DX Auto DT
Index Method	Flow
Index Flow (CFS)	8,000
Shape	Trapezoid
Bottom Width (FT)	10
Side Slope (xH: 1V)	4
Invert (FT)	1.5

Table 11: Existing Conditions and Proposed Conditions Modified Puls Parameters for R-O2

Basin Name: Pre_Lower_OC_1%_ExHarrisH		Basin Name: Post_Lower_OC_1%_PropHarrisD	
Element Name: R-O2		Element Name: R-O2	
Initial Type	Discharge = Inflow	Initial Type	Discharge = Inflow
Stor-Dis Function	100YR R-O2 PreMod.Puls R4	Stor-Dis Function	100YR R-O2 PostMod.Puls R4
Subreaches	25	Subreaches	70
Elev-Dis Function	None	Elev-Dis Function	None
Invert (FT)	-	Invert (FT)	-
Basin Name: Pre_Lower_OC_1%_ExHarrisH		**Basin Name: Post_Lower_OC_1%__PropHarrisN**	
Element Name: R-2		Element Name: R-2	
Storage (ac-ft)	**Discharge (cfs)**	**Storage (ac-ft)**	**Discharge (CFS)**
0	0	0	0
2,478	4,568	2,094	4,569
5,090	9,136	4,705	9,137
7,287	13,704	7,030	13,706
9,201	18,272	9,068	18,275
10,934	22,840	10,904	22,844
12,691	27,409	12,657	27,412
15,072	34,259	15,159	34,265

Table 12: Existing Conditions and Proposed Conditions Modified Puls Parameters for R-O3

Basin Name: Pre_Lower_OC_1%_ExHarrisH		Basin Name: Post_Lower_OC_1%_PropHarrisD	
Element Name: R-O3		Element Name: R-O3	
Initial Type	Discharge = Inflow	Initial Type	Discharge = Inflow
Stor-Dis Function	100YR R-O3 PreMod.Puls R4	Stor-Dis Function	100YR R-O3 PostMod.Puls R4
Subreaches	70	Subreaches	70
Elev-Dis Function	None	Elev-Dis Function	None
Invert (FT)	-	Invert (FT)	-
Element Name: R-O3		Element Name: R-O3	
Storage (ac-ft)	Discharge (cfs)	Storage (ac-ft)	Discharge (cfs)
0	0	0	0
5,595	4,388	6,349	4,568
14,102	8,776	15,372	9,136
22,391	13,165	23,866	13,703
29,858	17,553	30,633	18,271
35,067	21,941	35,558	22,839
39,994	26,329	40,138	27,407
48,000	32,912	48,687	34,258

Table 13: Existing Conditions and Proposed Conditions Modified Puls Parameters for R-O4

Basin Name: Pre_Lower_OC_1%_ExHarrisH		Basin Name: Post_Lower_OC_1%_PropHarrisD	
Element Name: R-O4		Element Name: R-O4	
Initial Type	Discharge = Inflow	Initial Type	Discharge = Inflow
Stor-Dis Function	100YR R-O4 PreMod.Puls R4	Stor-Dis Function	100YR R-O4 PostMod.Puls R4
Subreaches	65	Subreaches	65
Elev-Dis Function	None	Elev-Dis Function	None
Invert (FT)	-	Invert (FT)	-
Basin Name: Pre_Lower_OC_1%_ExHarrisH		**Basin Name: Post_Lower_OC_1%__PropHarrisD**	
Element Name: R-O4		**Element Name: R-O4**	
Storage (ac-ft)	**Discharge (cfs)**	**Storage (ac-ft)**	**Discharge (cfs)**
0	0	0	0
3,505	4,227	3,772	4,568
10,778	8,455	11,294	9,136
17,410	12,682	18,278	13,705
25,393	16,910	26,411	18,273
31,474	21,137	32,743	22,841
36,843	25,365	38,546	27,409
46,931	31,706	51,167	34,261

Table 14: Existing Conditions and Proposed Conditions Modified Puls Parameters for R-O5

Basin Name: Pre_Lower_OC_1%_ExHarrisH		Basin Name: Post_Lower_OC_1%_PropHarrisD	
Element Name: R-O5		Element Name: R-O5	
Initial Type	Discharge = Inflow	Initial Type	Discharge = Inflow
Stor-Dis Function	100YR R-O5 PreMod.Puls R4	Stor-Dis Function	100YR R-O5 PostMod.Puls R4
Subreaches	65	Subreaches	65
Elev-Dis Function	None	Elev-Dis Function	None
Invert (FT)	-	Invert (FT)	-
Basin Name: Pre_Lower_OC_1%_ExHarrisH		**Basin Name: Post_Lower_OC_1%__PropHarrisD**	
Element Name: R-O5		**Element Name: R-O5**	
Storage (ac-ft)	**Discharge (cfs)**	**Storage (ac-ft)**	**Discharge (cfs)**
0	0	0	0
3,657	4,581	3,786	4,664
12,533	9,161	12,977	9,329
21,554	13,742	22,506	13,993
32,074	18,323	33,638	18,657
42,304	22,904	44,739	23,321
52,733	27,484	56,574	27,986
70,984	34,355	77,868	34,982

Table 15: Existing Conditions and Proposed Conditions Modified Puls Parameters for R-O6

Basin Name: Pre_Lower_OC_1%_ExHarrisH		Basin Name: Post_Lower_OC_1%_PropHarrisD	
Element Name: R-O6		Element Name: R-O6	
Initial Type	Discharge = Inflow	Initial Type	Discharge = Inflow
Stor-Dis Function	100YR R-O6 PreMod.Puls R4	Stor-Dis Function	100YR R-O6 PostMod.Puls R4
Subreaches	33	Subreaches	33
Elev-Dis Function	None	Elev-Dis Function	None
Invert (FT)	-	Invert (FT)	-
Basin Name: Pre_Lower_OC_1%_ExHarrisH		**Basin Name: Post_Lower_OC_1%__PropHarrisD**	
Element Name: R-O6		**Element Name: R-O6**	
Storage (ac-ft)	**Discharge (cfs)**	**Storage (ac-ft)**	**Discharge (cfs)**
0	0	0	0
780	4,932	818	5,078
3,524	9,863	4,384	10,157
11,191	14,795	12,880	15,235
19,099	19,727	21,352	20,313
26,787	24,659	29,629	25,392
34,301	29,590	37,663	30,470
45,184	36,988	49,219	38,088

Table 16: Existing Conditions and Proposed Conditions Modified Puls Parameters for R-O7

Basin Name: Pre_Lower_OC_1%_ExHarrisH		Basin Name: Post_Lower_OC_1%_PropHarrisD	
Element Name: R-O7		Element Name: R-O7	
Initial Type	Discharge = Inflow	Initial Type	Discharge = Inflow
Stor-Dis Function	100YR R-O7 PreMod.Puls R4	Stor-Dis Function	100YR R-O7 PostMod.Puls R4
Subreaches	30	Subreaches	30
Elev-Dis Function	None	Elev-Dis Function	None
Invert (FT)	-	Invert (FT)	-
Basin Name: Pre_Lower_OC_1%_ExHarrisH		Basin Name: Post_Lower_OC_1%__PropHarrisD	
Element Name: R-O7		Element Name: R-O7	
Storage (ac-ft)	Discharge (cfs)	Storage (ac-ft)	Discharge (cfs)
0	0	0	0
1,903	2,876	2,088	3,100
3,524	5,752	3,762	6,200
5,201	8,628	5,727	9,299
7,537	11,503	8,255	12,399
9,785	14,379	10,617	15,499
11,877	17,255	12,807	18,599
14,775	21,569	15,834	23,248

3.4 Hydraulic Methodology

The Oyster Creek FEMA effective model consisted of HEC-2 cross section data, which were imported into HEC RAS 5.0.7 along with the Jacobs model cross sections. A steady flow model was created for the affected reaches of Oyster Creek (FEMA, 1992). A QA/QC check was performed on the model and errors corrected accordingly as noted below in Section 3.4.1 Existing Model QA/QC Check. Further, in HEC-RAS version 5.0.7, a steady flow model was used to perform a floodplain storage analysis for Oyster Creek using the Modified Puls Routing Method (described above). All elevations presented in this report are based on the Tropical Storm Allison Recovery Project (TSARP) datum (NAVD88, 2001 adj.)

The HEC-RAS model upstream extent is just upstream of a bridge along Farm to Market (FM) Road 655 (Jacobs cross section 60.49/Watearth cross section 147) with a downstream extent at approximately 8,000 ft downstream of FM Road 2004 (Watearth cross section 65) as shown below in **Figure 18** and **Figure 19**. The modeling end point is at the Lake Jackson diversion Dow freshwater canal (Watearth cross section 72).

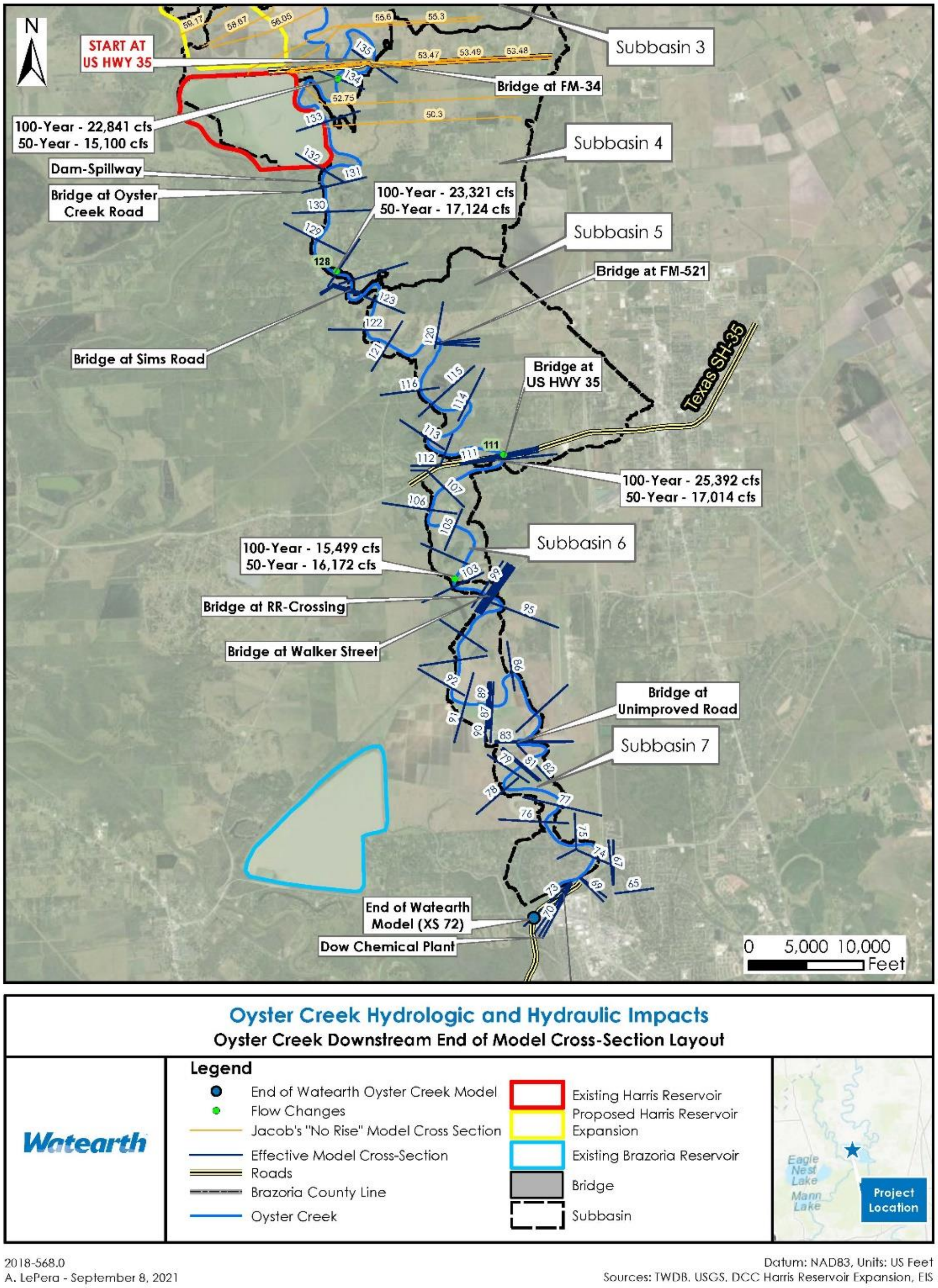

***Figure 18**: HEC-RAS model boundaries for Oyster Creek Including cross sections.*

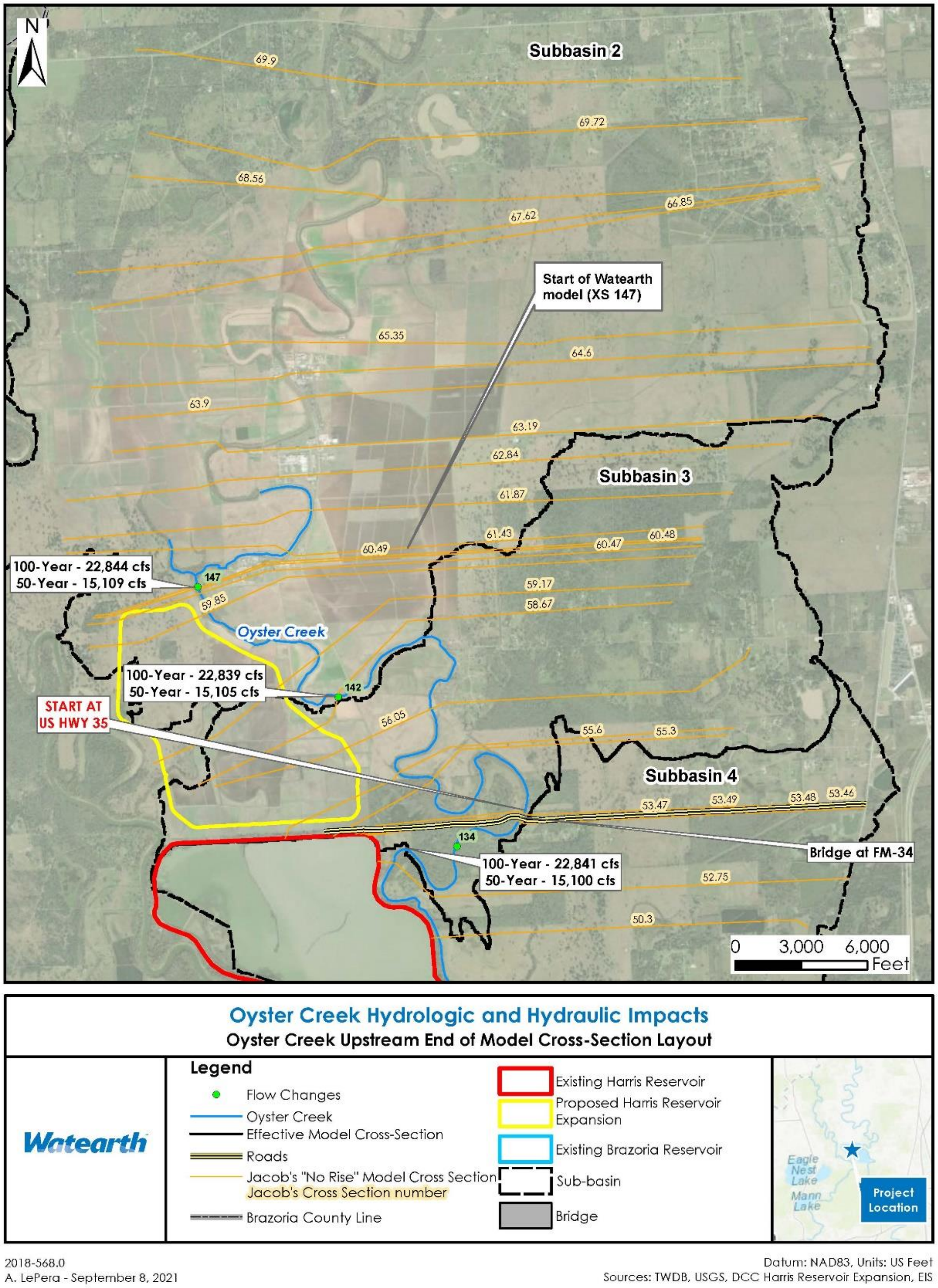

Figure 19: HEC-RAS model boundaries for Oyster Creek Including cross sections.

3.4.1 Existing Model QA/QC Check

The conversion of the HEC-2 model to run in the HEC-RAS software often results in errors that require correction. The most common errors were "No upstream or downstream cross sections" bridges. A review showed that several bridge decks were not attached to the piers within the model. To resolve this error, the bridge decks were deleted, re-input with upper and lower chords, and reattached to the piers. There were duplicate points in the cross sections, which were deleted to remove errors. There was one bottom-of-channel elevation input error that resulted in the channel being significantly below other data points. This data point was also corrected. All corrections made ensured model stability and accuracy. The following is the list of errors in the model and the corrections made, including a list of the cross sections and points.

Duplicate Points – Deleted duplicate points

1. CS: 178 At point(s): 35
2. CS: 173 At point(s): 33, 38
3. CS: 172 At point(s): 29, 34
4. CS: 171 At point(s): 25, 30
5. CS: 170 At point(s): 40, 45
6. CS: 169 At point(s): 30, 35
7. CS: 162 At point(s): 37, 43
8. CS: 157 At point(s): 5, 41, 46
9. CS: 155 At point(s): 33, 39
10. CS: 154 At point(s): 33, 38
11. CS: 153 At point(s): 29, 34
12. CS: 152 At point(s): 29, 34
13. CS: 151 At point(s): 33, 38
14. CS: 145 At point(s): 31
15. CS: 139 At point(s): 33
16. CS: 138 At point(s): 7, 10, 14, 16, 21
17. CS: 127 At point(s): 5
18. CS: 125 At point(s): 5

Bridge and/or crossing that had upstream distance of zero. The bridge was shortened by 2 feet, and then 1 foot was added to the upstream distance.

1. CS: 164.5
2. CS: 159.5
3. CS: 136.5
4. CS: 125.5
5. CS: 118.5
6. CS: 109.5
7. CS: 100.5
8. CS: 88.5
9. CS: 81.5
10. CS: 71.5
11. CS: 67.5
12. CS: 62.5
13. CS: 56.5
14. CS: 52.5
15. CS: 49.5
16. CS: 45.5
17. CS: 38.5
18. CS: 32.5
19. CS: 28.5
20. CS: 20.5
21. CS: 16.5
22. CS: 6.5

Bridge and/or crossing did not contain an opening on the upstream and/or downstream side. The bridge deck was moved to be over the stream opening. This assumed a 10-foot deck thickness.

1. CS: 136.5
2. CS: 125.5
3. CS: 118.5
4. CS: 109.5

Additional items modified (see notes below).

1. CS: 177 - Updated top of left bank
2. CS: 176 - Updated top of left bank
3. CS: 174 - Updated top of left and right bank
4. CS: 172 - Corrected Section 172 for low creek elevation point. See **Figure 20** below.

Appendix D illustrates the locations of effective cross-sections in the model, including the cross sections identified above with errors.

3.5 Methodology for BASINS/HSPF Modeling

HSPF model version 3.1 is used to examine the impact of the proposed Harris Reservoir during drought conditions. HSPF is a plug-in watershed quality model within the BASINS framework. BASINS version 4.5 is used to create the HSPF model. Oyster Creek is located within the Austin-Oyster watershed (HUC 12040205). The NHD, North American Land Data Assimilation System (NLDAS) land use data set, USGS gages, and meteorological data were downloaded for the selected HUC8 watershed using BASINS framework. To keep consistency between all modeling studies, the same watershed delineations used in HMS models were used in the BASINS model framework. **Figure 20** shows the four sub-basins in Oyster Creek. The shapefile for the same four sub-basins was imported into the BASINS model to create the background information for the HSPF model. **Figure 20** shows the watershed delineation used in the BASINS model. It must be noted that the model boundaries for the BASINS/HSPF models are slightly different than the HEC-HMS and HEC-RAS models. The downstream boundary ends sooner for the BASINS model. The upstream boundary is Reach 1 (R-O1 in the HMS model), which is the same in other models, but the downstream boundary is Reach 4 (R-O4), which ends at the downstream drainage basin boundary south of the existing Harris Reservoir.

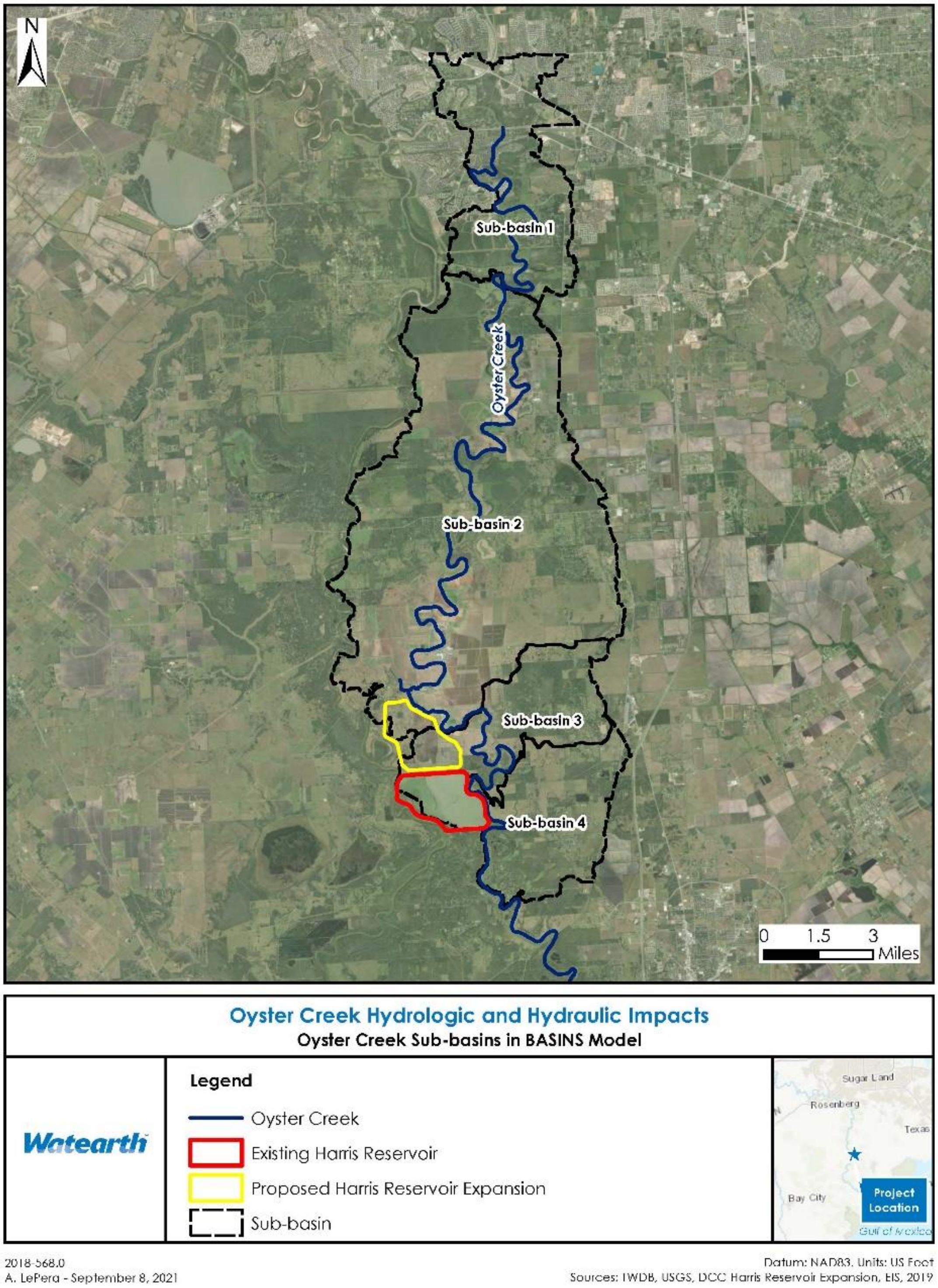

Figure 20: *Oyster Creek sub-basins in BASINS model.*

There are four sub-basins and four stream reaches in the Oyster Creek BASINS and HSPF models. HSPF treats the whole watershed as three components: pervious land, impervious land, and waterbodies (reaches and reservoirs). It has algorithms to calculate runoff from both pervious and impervious land, as well as one-directional water flow in streams. It uses water budget calculations to account for precipitation, evapotranspiration, infiltration, and runoff.

Land use information for both pervious and impervious land was downloaded within the BASINS framework. There are five land uses defined in the study area: urban (also called the build-up land in BASINS), agricultural land, forest land, wetlands/water, and barren land. The HSPF model uses different algorithms when calculating overland flow for each type of land use. **Figure 21** shows the land use information in the HSPF model for the four sub-basins of Oyster Creek.

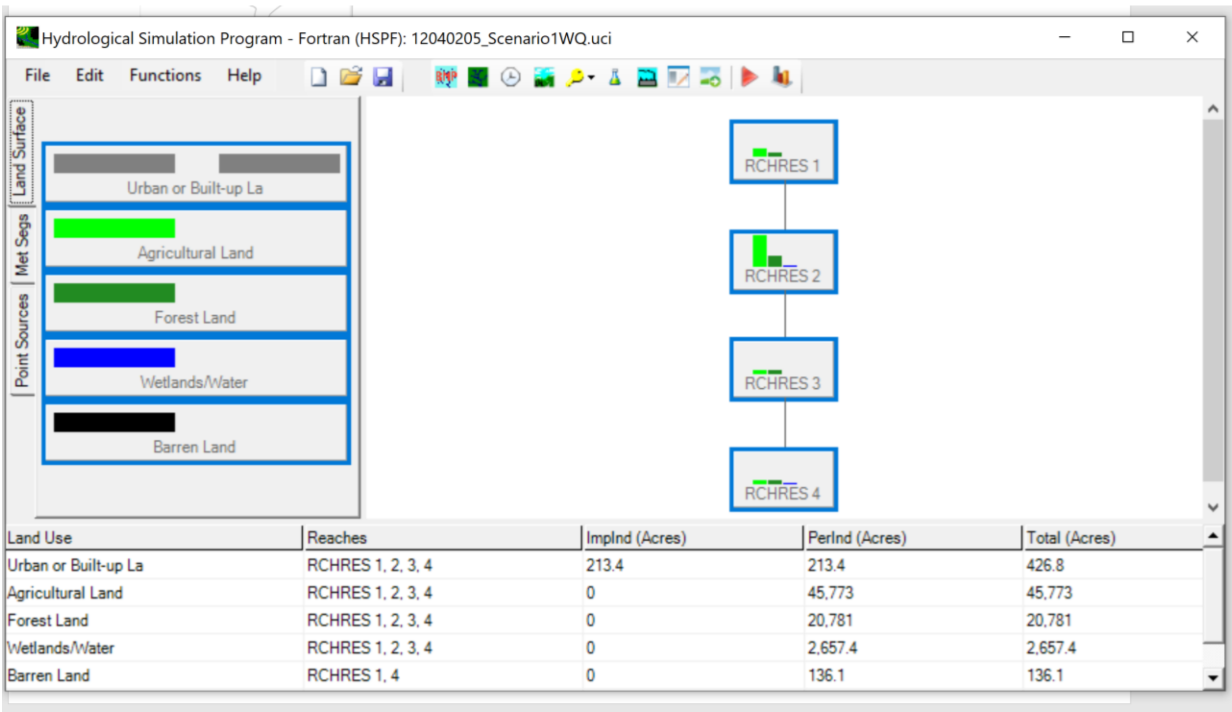

Figure 21: *The four sub-basins and five types of land use information in HPSF model.*

Data from the closest meteorological station to the study area, TX 418996, were downloaded. TX 418996 station has timeseries data for the duration of May 1, 1957, to March 31, 2006. The scenarios to be modeled required dry conditions where there was no precipitation at all. A dummy gage was created with no rain data but has air temperature and potential evaporation from meteorological gage TX 418996. However, this meteorological station did not record the parameters required to model heat exchange to obtain water temperature results such as solar radiation, cloud cover, dew point temperature, and wind speed. Another meteorological station, TX 722527, recorded all those parameters, so these parameters were imported into the same dummy gage, as well. **Appendix E** has the values used for the heat exchange calculations from station TX 722527. The locations of both meteorological stations are shown in **Figure 22** below.

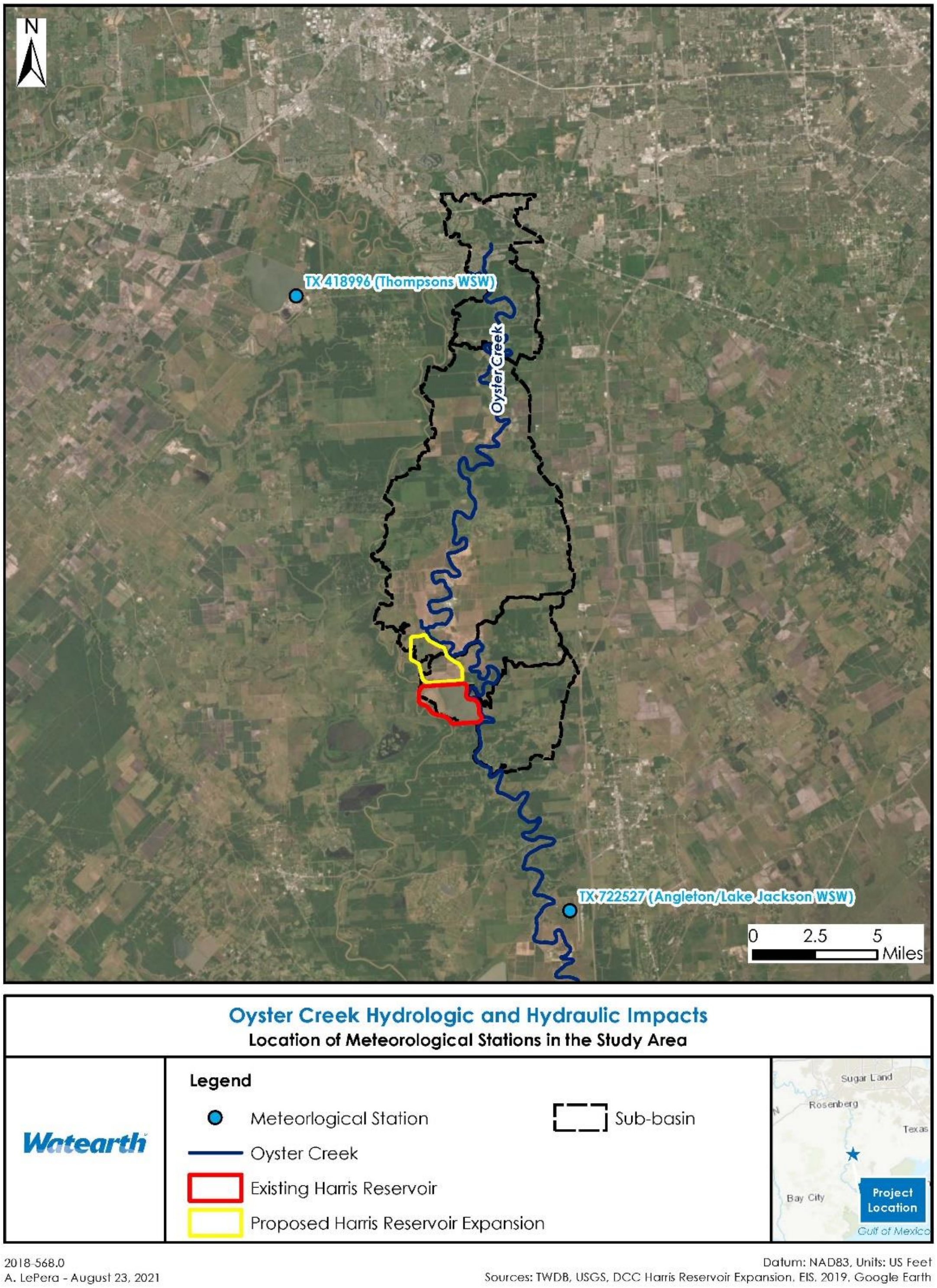

Figure 22: *Location of meteorological stations in the study area.*

Using HSPF, existing conditions without the proposed Harris Reservoir and proposed conditions (with the proposed Harris Reservoir) were compared under dry conditions. Four scenarios were modeled with the proposed conditions. These four scenarios were run continously for 180 days of simulation with no precipitation (total drought conditions). The four scenarios are:

1. Scenario 1: 334 cfs constant discharge for 180 days with no rain
2. Scenario 2: 216 cfs constant dischrage for 180 days with no rain
3. Scenario 3: 133 cfs constant discharge for 180 days with no rain
4. Scenario 4: 22 cfs constant discharge for 180 days with no rain

All these outflows from the proposed Harris Reservoir enter Oyster Creek in Sub-basin 3, which is downstream of the proposed reservoir.

As there was no precipitation during the simulation period, a baseflow was added to Oyster Creek to keep the model stable. USGS Gage 0807900 – Oyster Creek near Angleton shows discharge data for Oyster Creek. After a thorough examination of the discharge at this gage, a constant flow of 2 cfs was used as an upstream boundary condition in the model. The historical flowrates in Oyster Creek from USGS Gage 0807900 are in **Appendix F**. Both the 2 cfs baseflow and the outflows from the proposed reservoir were entered as external point sources into the HSPF model.

The areas of each sub-basin, flow lengths, Manning's n values, overland slope, and the length of each reach were calculated by BASINS framework and used in HSPF model. These values are given in **Table 17** below. The land use information created through BASINS and used in the HSPF model are given in **Table 18** below.

Table 17: Parameters Used in HSPF Model

Sub-basin Name	Area of Basin (Acres)	Overland Slope (ft/ft)	Length of Reach (mi)	Reach Slope (ft/ft)	Manning's N in Reach
Sub-basin-1	11,347.1	0.1899	10.54	0.00000329	0.04
Sub-basin-2	40,878.6	0.0957	27.34	0.0001566	0.04
Sub-basin-3	7,577.35	0.0892	5.55	0.00031	0.05
Sub-basin-4	10,009.7	0.0923	4.45	0.0004	0.05

Table 18: Land Use Areas in Sub-basins Used in HSPF Model

Sub-basin Name	Impervious Land (ac)	Pervious Land – Urban (ac)	Pervious Land – Agricultural (ac)	Pervious Land – Forest (ac)	Pervious Land – Wetland (ac)	Pervious Land – Barren (ac)
Sub-basin-1	0	0	7,714.2	3,416	156.9	62.2
Sub-basin-2	53.4	53.4	30,073.2	9,980.5	722	-
Sub-basin-3	14.3	14.3	3,851.7	3,636.4	54.9	-
Sub-basin-4	145.7	145.7	4,134.3	3,747.6	1,723.6	73.9

The model uses monthly average evapotranspiration values for the water budget calculations. The EPA Stormwater Calculator was used to get the evapotranspiration values; these values are shown in **Table 19**. The evaporation data downloaded from the EPA Stormwater Calculator are located in **Appendix G**. A constant value for monthly interception value of 0.1 was used for both the existing and the proposed models.

Table 19: Monthly Average Evapotranspiration Values

Month	Evapotranspiration (in)
January	0.12
February	0.15
March	0.23
April	0.27
May	0.30
June	0.33
July	0.33
August	0.32
September	0.26
October	0.21
November	0.19
December	0.12

HSPF calculates the flowrate in streams based on some depth-area-volume-discharge relationships called FTables. HSPF calculates those automatically using BASINS land use information. BASINS created some FTables using GIS-based land information when the HSPF model was created. The FTables generated by the BASINS model were less accurate than the data obtained in the latest survey transects. Therefore, the FTables were updated using the latest survey transects. Transect 1 was used to determine the FTable for Reach 1. Transect 1 is far away from Reach 1 but was used because it was the most accurate representation of an upstream reach currently available. Transects 2 and 3 were averaged to determine the FTable for Reach 2. Transects 2 and 3 fall within Reach 2 boundaries. Transects 4, 5, and 6 were averaged and then used to determine the FTable for Reach 3. Transects 4, 5, and 6 are with the Reach 3 boundary. Lastly, Transects 8, 9, and 10 were averaged and then used to determine the FTable for Reach 4. Transects 8, 9, and 10 fall within the Reach 4 boundaries. These transects are located in **Figure 23**. The updated FTables for each reach are given in **Table 20** through **Table 23.**

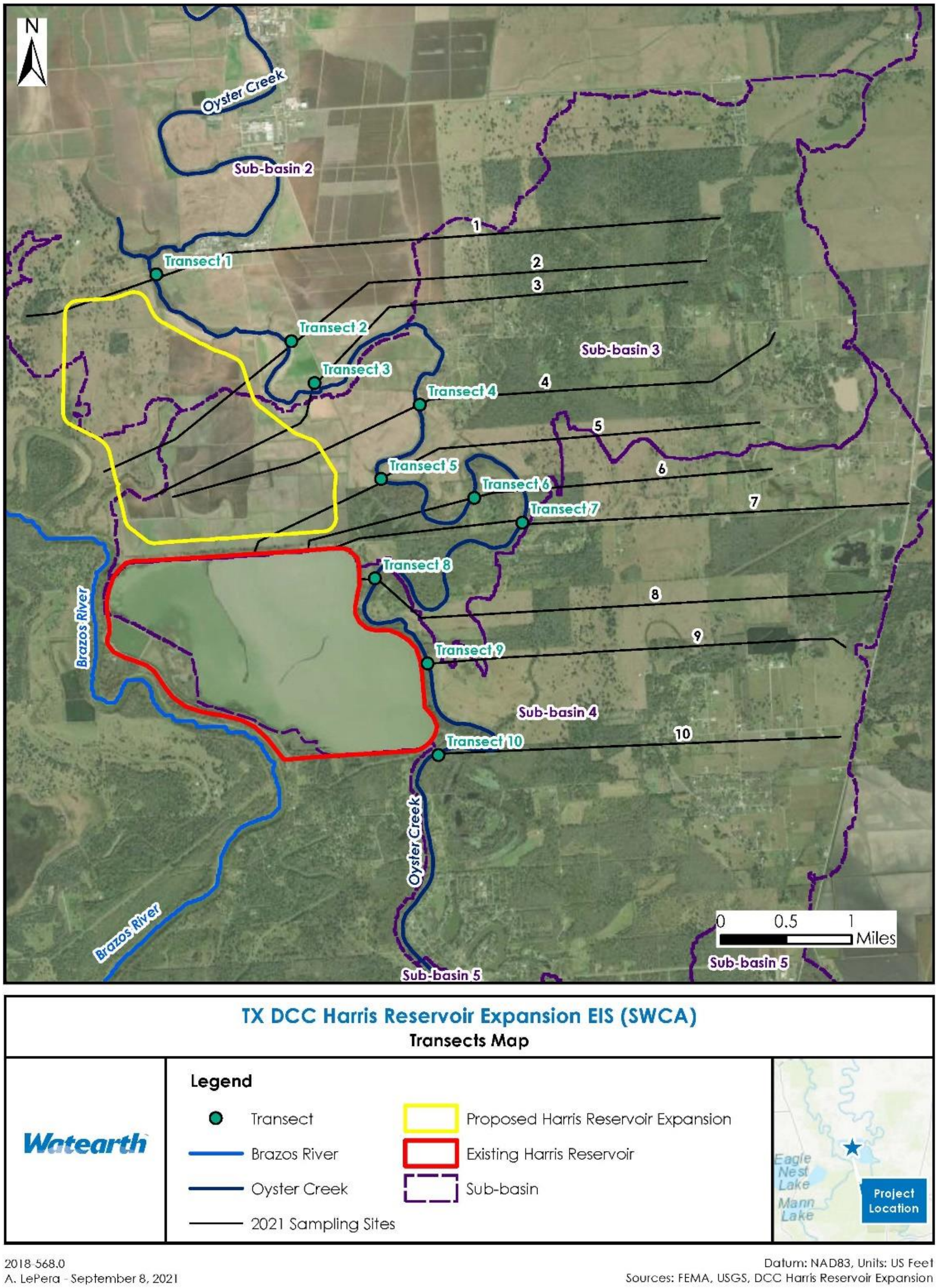

Figure 23: *Surveyed transects along Oyster Creek.*

Table 20: FTable for Reach 1 in Oyster Creek

Depth (ft)	Area (ac)	Volume (ac-ft)	Outflow (cfs)
0.5	44.5	57	30
2	178	22	120
4	408	521	301
6	675	862	532
8	974	1,244	809
10	1304	1,666	1,133
12	1714	2,190	1,583
14	2205	2,817	2,173
16	2836	3,623	3,024
30	7253	9,266	9,513
50	13563	17,328	19,207

Table 21: FTable for Reach 2 in Oyster Creek

Depth (ft)	Area (ac)	Volume (ac-ft)	Outflow (cfs)
0.5	5.8	19	7
2	23	76	27
4	68	225	105
6	157	520	323
8	307	1,017	814
10	556	1,843	1,888
12	994	3,294	4,402
14	1634	5,415	9,096
14.9	1995	6,611	12,170

Depth (ft)	Area (ac)	Volume (ac-ft)	Outflow (cfs)
15.7	2392	7,927	15,904
30	9,488.4	31,444	102,660
50	19,413.4	64,335	240,815

Table 22: FTable for Reach 3 in Oyster Creek

Depth (ft)	Area (ac)	Volume (ac-ft)	Outflow (cfs)
0.5	8.1	5	14
2	32.3	22	54
4	88	59	181
6	164.7	111	393
8	300	202	882
10	563.3	379	2,172
12	1,048	705	5,412
14	1,639.7	1,103	10,297
16	2,291.7	1,542	16,458
17.6	2,473	1,664	17,535
18	3,248	2,185	27,209
18.3	4,805	3,233	51,688
30	65,528	44,083	2,893,995
50	169,328	113,912	10,017,709

Table 23: FTable for Reach 4 in Oyster Creek

Depth (ft)	Area (ac)	Volume (ac-ft)	Outflow (cfs)
0.5	11.8	6	29
2	47.3	6	116
4	132	71	404
6	234.3	126	801
8	364	196	1,378
10	531.67	287	2,233
12	743	401	3,455
14	1,009.3	544	5,194
16	1,345.7	726	7,674
18	1,739.3	938	10,881
20	2,184.7	1,178	14,831
22	2,702.7	1,458	19,842
24	3,454.3	1,863	28,184
26	4,630	2,497	43,537
28	5,727.5	3,089	59,071
30	7,876	4,248	95,933
32	9,126	4,923	117,464
34	10,391	5,605	140,060
35.1	11,195	6,039	155,253
50	22,085.6	11,913	380,544

After the hydrology calculations were completed successfully, sediment erosion calculations were added. As in water budget calculations, HSPF again uses three separate algorithms to calculate sediment erosion and transportation for pervious land, impervious land, and water bodies. On pervious and impervious land, sediment particles get detached from the soil matrix during rainfall events and carried with surface runoff whereas in reaches, sediment is transported with the bulk movement of water in the stream (Briknell et al., 2001).

The sediment particles are modeled in three categories: sand, silt, and clay. A power function is used for sediment transport. The coefficient of the power function is 0.1 and the exponent of the power function is 2 (Briknell et al., 2001). Other parameters required for sediment transport are the physical properties of sand, silt, and clay, which are found in literature (Donigian and Crawford, 1976). Other parameters are TAUCD (critical bed shear stress for deposition) and TAUCS (critical bed shear stress for scour), which determine above which no deposition occurs and below which no scour occurs, respectively. **Table 24** below is a summary of the parameters used for sediment transport in the model.

Table 24: Sediment Physical Properties

Parameter	Sand	Silt	Clay
Diameter (in)	0.005	0.0004	0.0001
Fall velocity in still water (in/sec)	0.02	0.0003	0.00001
Density (gm/cm^3)	2.5	2.2	2.0
TAUCD (lb/ft^2) Critical bed shear stress for deposition	0.1	0.1	0.1
TAUCS (lb/ft^2) Critical bed shear stress for scour	0.3	0.3	0.3

After the sediment erosion/transportation portion of the modeling was successfully conducted, heat exchange calculations were completed to account for the effects of the proposed reservoir on the water temperature within Oyster Creek downstream of the outflows from the proposed reservoir. The results of the HSPF model and their potential implications are discussed in Section 5.3.

4.0 Analysis of Potential Impacts

Hydrologic, hydraulic, and environmental water quality analyses for Oyster Creek were conducted using three modeling software programs: HEC-HMS, HEC-RAS, and EPA-BASIN/HSPF. The results for the different models are presented in this section of the report and shown in various tables and graphs.

4.1 Analysis of Modeling Results

Modeling of Oyster Creek includes HEC-HMS for hydrology and HEC-RAS for hydrologic flow routing (Modified Puls Method) to determine peak flows downstream of the proposed Harris Reservoir. The HEC-HMS hydrology model computes peak flows. The HEC-RAS steady state model (Watearth model) routes the peak flows determined by the HEC-HMS model through the reaches set in the hydrologic model. The BASINS model was used to determine sediment transport and possible hydromodification of the proposed Harris Reservoir stepped spillway flows during drought conditions in the area between the proposed and existing Harris Reservoirs. The HEC-HMS hydrology model assessed peak flows. The upstream boundary includes the entire Oyster Creek watershed (headwaters). The downstream boundary was the Dow freshwater canal near Lake Jackson. The proposed site conditions included the stream restoration projects (revised Projects 1, 2, and 3 revised in May 2020) and the floodplain storage volume displacement by the proposed Harris Reservoir expansion.

Watearth modeled 10 scenarios in HEC-HMS to determine peak flows in Oyster Creek and quantify potential impacts. The HEC-HMS hydrology model contained 10 models which incorporated the current elevation-storage and operational data of the proposed Harris Reservoir. The proposed conditions modeling consisted of eight proposed conditions models: six proposed conditions models with drawdown containing different volumes of floodplain storage and two proposed conditions models without drawdown. The existing condition modeling consisted of two models.

The proposed conditions 50-year and 100-year events reservoir models both included 18 inches of drawdown. All models had a starting water surface elevation of 68 ft, which was drawn down at a flow rate of 978 cfs to an elevation of 66.5 ft, 6 hours prior to the design storm event's arrival. After the design storm arrives, the discharges were held in the reservoir to simulate 6 inches of floodplain storage volume before spillway discharges occur. The 9-inch and 12-inch floodplain storage volume scenarios were modeled for the 50-year and 100-year drawdown events, as well, to determine whether impacts were minimized with a higher floodplain storage volume retained prior to spillway discharge.

A no-drawdown scenario was developed for the 50-year and 100-year proposed conditions design storm events. The starting water surface elevation for the no-drawdown scenarios was 68 ft, and after the design storm rainfall event, it was concluded that the proposed Harris Reservoir rose to a water surface elevation of 69.1 ft (100-year rainfall event) and 68.9 ft (50-year rainfall event), which is lower than the proposed reservoir's nominal crest of 72.7 ft.

The Jacobs HEC-RAS hydraulic model assessed the 50-year and 100-year design storm WSEL changes downstream of the proposed Harris Reservoir. The upstream boundary starts 6.5 miles upstream of the town of Otey, Texas, and the downstream boundary ends approximately 1.0 mile upstream of the existing Harris Reservoir spillway channel at Oyster Creek. The model includes the stream restoration projects (revised Projects 1, 2, and 3) and the floodplain storage volume displacement by the proposed Harris Reservoir expansion.

The Modified Puls Reservoir Routing Method was used as the hydrologic routing method for critical downstream reaches in HEC-HMS and is a commonly used method for flat watersheds within the Gulf Coast.

BASINS and HSPF models together were used to examine the sediment erosion in Oyster Creek during drought conditions with and without the proposed Harris Reservoir. Four different constant outflows from the proposed Harris Reservoir were modeled and compared with the existing conditions, where there is no reservoir outflow into Oyster Creek. The modeled four scenarios represent Lake Jackson pump station capacity, normal river use, 180 days drawdown, and Dow's environmental flows. All models were run for 180 days with no precipitation (total drought). The same models were also used to model the water temperature in the Oyster Creek.

4.1.2 Peak Flows

Peak flows were calculated using HEC-HMS. HEC-HMS and HEC-RAS models were used in an iterative analysis to determine the peak flows for the modeled reaches. HEC-RAS was also used to determine the hydrologic routing for each reach (see next section). The peak flow for reach R-O1 was dependent on the flow incoming from the upstream watershed in Fort Bend County and the flows arriving from sub-basin O-1. The peak flows downstream of O-1 were subject to interbasin flows entering Oyster Creek, as well as flows arriving from the Lower Oyster Creek watershed sub-basins and flows entering Oyster Creek from the existing and proposed reservoirs that are located along Oyster Creek. The interbasin flows are the primary reason for the peak flows that elevate drastically between reach R-O1 and R-O2 and stay elevated until the lower portion of reach R-O7 where the interbasin flow stops. The Lower Oyster Creek model includes the interbasin flows that overflow from the Brazos River in the 50-year and 100-year events. **Table 25** and **Table 26** provide the results for the 50-year and 100-year existing peak flows. The purpose of the iterations was to converge on a peak flow using the HEC-HMS and HEC-RAS models for the existing and proposed conditions for the 50-year and 100-year design storm. This was achieved when the percent difference, as shown in **Table 27** through **Table 29**, was less than 5% between both models.

Table 25: Peak Flow Results for Existing Conditions (50-year event) HEC-HMS Reaches

Existing Conditions 50-year Event	HMS MODEL	RAS MODEL	Percent Difference (%)
Hydrologic Element	Peak Flow (cfs)		
R-O1	1,818	N/A	N/A
R-O2	15,109	15,109	0.00%
R-O3	15,003	15,003	0.00%
R-O4	14,588	14,588	0.00%
R-O5	16,029	16,024	0.00%
R-O6	17,027	16,909	0.70%
R-O7	13,732	14,026	2.10%

Table 26: Peak Flow Results for Existing Conditions (100-year event) HEC-HMS Reaches

Existing Conditions 100-year Event	HMS MODEL	RAS MODEL	Percent Difference (%)
Hydrologic Element	Peak Flow (cfs)		
R-O1	1,888	N/A	N/A
R-O2	22,844	22,839	0.02%
R-O3	21,970	21,941	0.13%
R-O4	21,183	21,137	0.22%
R-O5	23,184	22,904	1.22%
R-O6	25,364	24,659	2.82%
R-O7	14,277	14,379	0.71%

The existing model was modified to develop the proposed condition HEC-HMS model. The proposed conditions HEC-HMS model simulates the effect of interbasin flows becoming obstructed by the proposed reservoir embankment, and this effect results in interbasin flows being shifted farther downstream. The interbasin flows from the Brazos River enter downstream of the existing Harris Reservoir where the flows are unobstructed. This effect was modeled in HEC-HMS by moving the hydrograph connection downstream of the original entrance locations where the proposed Harris Reservoir expansion would be constructed and shifting the hydrograph connection downstream of the existing Harris Reservoir where the obstructed flows can enter the Oyster Creek watershed freely.

In the existing conditions model, interbasin source nodes B11 and B12 were added to the model linked to Junction J-O2 and J-O3 to represent flows entering Oyster Creek from the Brazos River at the locations where the proposed Harris Reservoir expansion would be constructed. In that same area, flows exit Oyster Creek and return to the Brazos River which is represented in interbasin sink flows B13 and B14. The location of interbasin flows is shown in **Figure 24.**

In the proposed conditions model, the interbasin flow hydrographs B11 through B14 were summed up and added to the flows entering Oyster Creek as interbasin B5 (or Junction J-O4). This represents the flow being obstructed by the proposed Harris Reservoir embankment and results in the flow being shifted downstream entering Oyster Creek where the flows are unobstructed by the floodplain's topography.

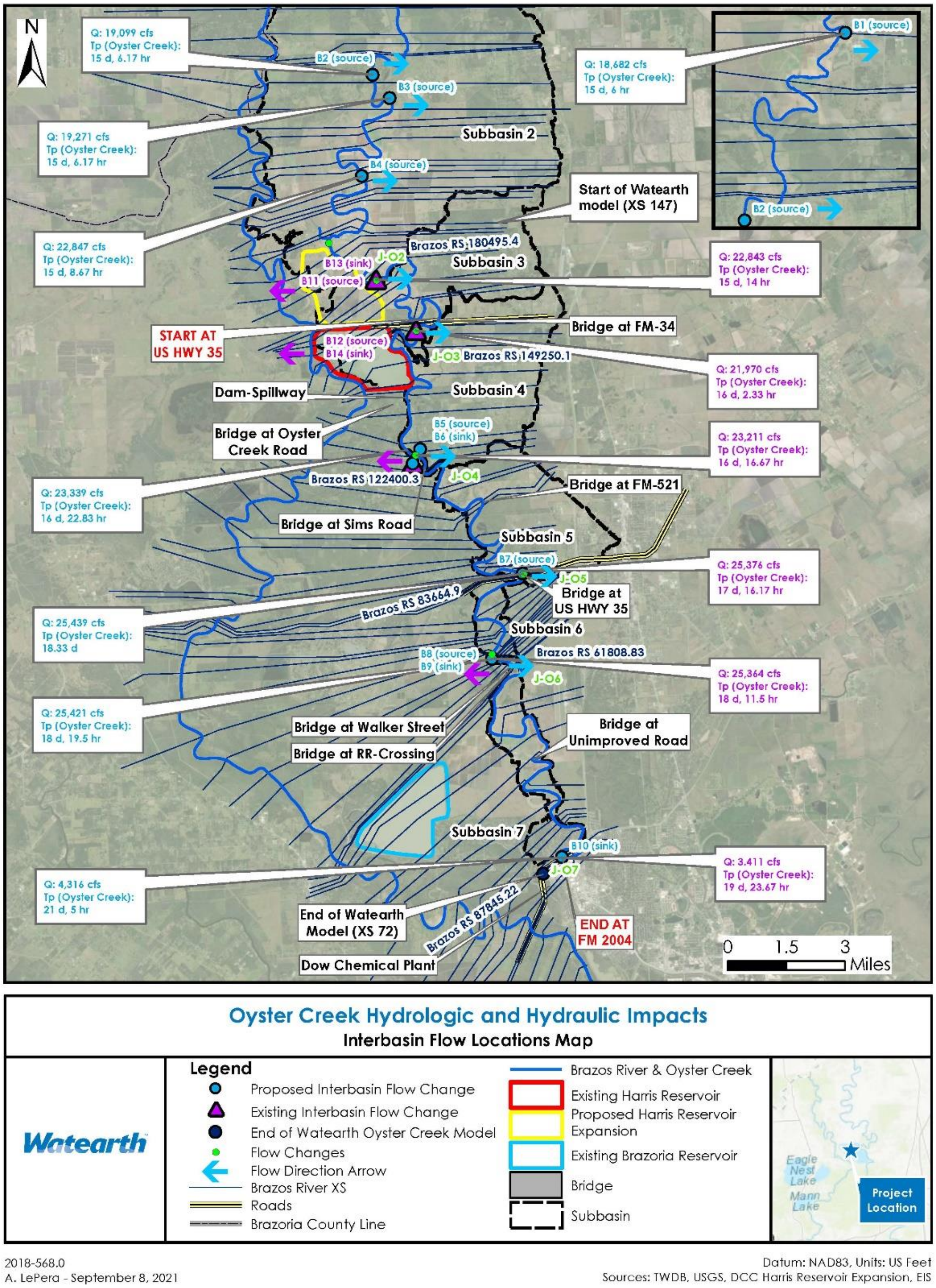

Figure 24: *Interbasin flow location map.*

Table 27: Peak Flow Results for Proposed Conditions (50-year event) HEC-HMS Reaches

Proposed Conditions 100-year Event	HMS MODEL	RAS MODEL	Percent Difference (%)
Hydrologic Element	Peak Flow (cfs)		
R-O1	1,818	N/A	N/A
R-O2	15,109	15,109	0.00%
R-O3	15,102	15,105	0.02%
R-O4	15,100	15,100	0.00%
R-O5	17,213	17,124	0.52%
R-O6	17,223	17,014	1.22%
R-O7	16,180	16,172	0.05%

Table 28: Peak Flow Results for Proposed Conditions (100-year event) HEC-HMS Reaches

Proposed Conditions 100-year Event	HMS MODEL	RAS MODEL	Percent Difference (%)
Hydrologic Element	Peak Flow (cfs)		
R-O1	1,888	N/A	N/A
R-O2	22,844	22,844	0.00%
R-O3	22,839	22,839	0.00%
R-O4	22,841	22,841	0.00%
R-O5	23,318	23,321	0.01%
R-O6	25,422	25,392	0.23%
R-O7	15,198	15,499	1.96%

For the proposed project conditions, the loss of floodplain storage was subtracted from Reaches R-O2 and R-O3 (within the Modified Puls model parameters) in order to display modeled results that factored the loss of floodplain storage within the HMS models. Reaches R-O2 and R-O3 were selected because the proposed Harris Reservoir expansion and the channel improvements occur within that sub-basin/reach location. The loss of floodplain storage was subtracted from the 60% of 100-year event in the storage volume/storage flow data within the Modified Puls Method level and above. This methodology was used because the 50-year event in the Jacobs model is visually where the loss in floodplain storage occurs, and the 50-year flow is 67% of the 100-year flow. This occurs for Jacobs' cross sections 60.49 (Watearth Model RS 147) through 55.3 (Watearth Model RS 134) and provide the results of subtraction of the floodplain storage in Reaches R-O2 and R-O3.

Table 29: Peak Flow Comparison Results Between Existing and Proposed Conditions for the 50-Year and 100-Year Design Storm Events Located in the HEC-HMS Model Reaches

Hydrologic Element	50-Year 24-Hour Storm			100-Year 24-Hour Storm		
	Existing Conditions	Proposed Conditions	Δ (Proposed – Existing Conditions)	Existing Conditions	Proposed Conditions	Δ (Proposed – Existing Conditions)
	Peak Flow (cfs)			Peak Flow (cfs)		
R-O1	1,818	1,818	0	1,888	1,888	0
R-O2	15,109	15,109	0	22,844	22,844	0
R-O3	15,003	15,102	+99	21,970	22,839	+869
R-O4	14,588	15,100	+512	21,183	22,841	+1,658
R-O5	16,029	17,213	+1,184	23,184	23,318	+134
R-O6	17,027	17,223	+196	25,364	25,422	+58
R-O7	13,732	16,180	+2,448	14,277	15,198	+921

In a previous version of this report, the maximum proposed conditions peak flow for the 100-year design storm event was reported to be 6,883 cfs occurring in Junction J-O1.75. The previous report showed proposed conditions with stream restoration improvements and proposed conditions without stream restoration improvements. The stream restoration improvements approximately decreased the peak flow by 52 cfs in comparison to the proposed conditions without the stream restoration improvements between J-03 and J-O4. The previous model and analysis were simpler than the current analysis. The existing and proposed Harris Reservoirs were not modeled in the previous version of the model. This analysis only included the flows being introduced to Oyster Creek from the sub-basins in the watershed.

In this report, interbasin flows were included in the analysis and the existing and proposed reservoirs were modeled, which greatly increased the flows occurring in Oyster Creek. The construction of the proposed Harris Reservoir also shifts flows farther downstream, which increases the peak flow occurring downstream at Junction J-O4. There are interbasin flows entering and exiting upstream and downstream of the existing and proposed reservoirs, which ultimately added flows into Oyster Creek. The hydrographs entering at J-O4 are combined with the hydrographs that would enter where the proposed Harris Reservoir is located. The results for the two conditions are seen in **Tables 29.**

The blockage of interbasin flows between the Brazos River and Oyster Creek changes both the magnitude and the timing of the peak flows in Oyster Creek between existing and proposed conditions models. The proposed Harris Reservoir blocks the interbasin flows from the Brazos River into Oyster Creek. These interbasin flows were modeled as lateral hydrographs in the unsteady HEC-RAS model, and as sources/sinks in HEC-HMS model. These hydrographs were not adjusted to account for routing or lagging in the watershed but assumed to have the same timing and shape as overflows from Brazos River.

The overflows blocked by the proposed Harris Reservoir were entered into the Oyster Creek downstream of the proposed reservoir (Junction J-O4), causing an increase in peak flowrate at this point in Oyster Creek; prior to this junction, peak flows in Oyster Creek were similar for both the proposed and existing conditions.

In the existing conditions model, there are 12 interbasin flows between the Brazos River and Oyster Creek. The addition of the proposed Harris Reservoir blocks three of these interbasin flows. As there is a higher elevation road between the existing and the proposed Harris Reservoirs, the interbasin flows enter Oyster Creek at a junction farther downstream. Two of these interbasin flows were modeled as sources (one entering the model at Junction J-O2, and one entering the model at Junction J-O3), and one was modeled as a sink (exiting the model at Junction J-O3).

The sources were added, and the sink was subtracted from the interbasin flow entering the proposed model at the junction downstream of the proposed Harris Reservoir (J-O4). When the three interbasin flows forming the existing conditions model were combined, time lag was not considered. **Figure 25** shows a plot of the existing interbasin flows into J-O4 (blue line) and proposed interbasin flows into J_O4 (orange line), which is the combination of the interbasin flows B11+B12-B6. The same interbasin flows enter the model in both cases, just at earlier junctions for existing conditions and as a combination for proposed conditions farther downstream. If the proposed Harris Reservoir was not blocking the interbasin flows from Brazos River into Oyster Creek, there would not be such a significant increase in the peak flows in Oyster Creek.

Table 30 shows the location, magnitude, and arrival time of peak flows for the 100-year design storm. **Table 31** and **Tabel 32** show the peak flows for all the interbasin flows for the 50- and 100-year design storms, respectively for various scenarios simulated.

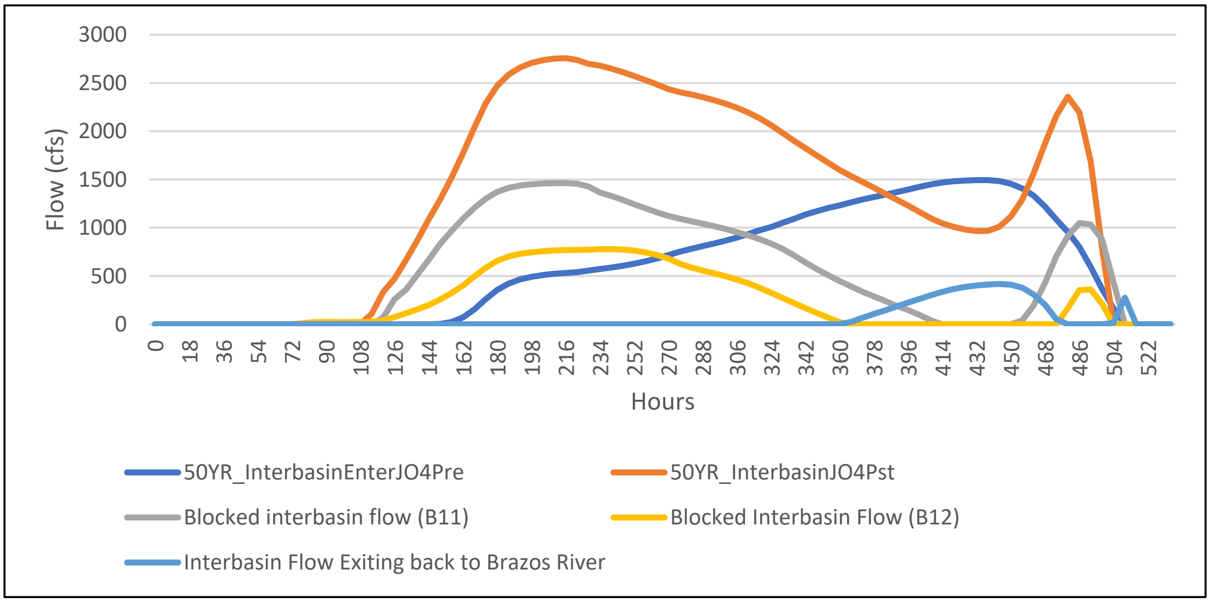

***Figure 25**: The interbasin FLOWS at the Junction (J-O4 downstream of the proposed Harris Reservoir for existing and proposed models).*

Table 30: Interbasin Peak Flows and Time to Peak Flow in Oyster Creek for the Existing and Proposed Conditions at Significant Junctions for the 100-Year Design Storm Event

Hydrologic Element	Peak Flows [Q_p] (cfs) and Time to Peak [T_p] (days)							
	Q_p Existing Conditions (cfs)	T_p Existing Conditions (days)	Q_p Proposed Conditions 18" Drawdown and 6" Floodplain Storage (cfs)	T_p Proposed Conditions 18" Drawdown and 6" Floodplain Storage (days)	Q_p Proposed Conditions 18" Drawdown and 12" Floodplain Storage (cfs)	T_p Proposed Conditions 18" Drawdown and 12" Floodplain Storage (days)	Q_p Proposed Conditions 18" No Drawdown (cfs)	T_p Proposed Conditions 18" No Drawdown (days)
J-O1	3,113	0.98	3,113	0.98	3,113	0.98	3,113	0.98
J-O1.29	18,682	15.25	18,682	15.25	18,682	15.25	18,682	15.25
J-O1.59	19,099	15.26	19,099	15.26	19,099	15.26	19,099	15.26
J-O1.72	22,847	15.26	22,847	15.26	22,847	15.26	22,847	15.26
J-O1.75	22,846	15.36	22,846	15.36	22,846	15.36	22,846	15.36
J-O2	22,844	15.58	22,844	15.58	22,844	15.58	22,844	15.58
J-O3	21,970	16.10	22,850	16.13	22,850	16.13	22,851	16.13
J-O4	23,211	16.69	23,339	16.95	23,303	16.80	22,339	16.95
J-O5	25,376	17.67	25,439	18.01	25,623	17.39	25,441	18.01
J-O6	25,364	18.48	25,421	18.81	25,602	18.19	25,423	18.81
J-O7	3,411	19.99	4,316	21.21	3,375	20.88	4,316	21.21

Table 31: HEC-HMS Model Results for the Existing and Proposed Conditions at Significant Junctions for the 50-Year Storm Event

Hydrologic Element	Peak Flows (cfs)								
	Existing Conditions (cfs)	Proposed Conditions No Drawdown (cfs)	Δ Proposed No Drawdown vs Existing Conditions	Proposed 18" Drawdown and 6" Floodplain Storage (cfs)	Δ Proposed 18" Drawdown and 6" Floodplain Storage vs Existing Conditions (cfs)	Proposed Conditions 18" Drawdown and 9" Floodplain Storage	Δ Proposed 18" Drawdown and 9" Floodplain Storage vs Existing Conditions	Proposed Conditions Outflow 18" Drawdown and 12" Floodplain Storage	Δ Proposed 18" Drawdown and 12" Floodplain Storage vs Existing Conditions
J-O1	2,822	2,822	0	2,822	0	2,822	0	2,822	0
J-O2	15,109	15,109	0	15,109	0	15,109	0	15,109	0
J-O3	15,003	15,118	+115	15,113	+110	15,113	+110	15,113	+110
J-O4	16,050	17,448	+1,398	17,445	+1,395	17,445	+1,395	17,445	+1,395
J-O5	17,070	17,266	+196	17,263	+193	17,263	+193	17,263	+193
J-O6	17,027	17,226	+199	17,223	+196	17,223	+196	17,223	+196
J-O7	6,312	8,053	+1,741	8,048	+1,736	8,048	+1,736	8,048	+1,736

Table 32: HEC-HMS Model Results for the Existing and Proposed Conditions at Significant Junctions for the 100-Year Storm Event

Hydrologic Element	Peak Flows (cfs)								
	Existing Conditions (cfs)	Proposed Conditions No Drawdown (cfs)	Δ Proposed No Drawdown vs Existing Conditions	Proposed Conditions 18" Drawdown and 6" Floodplain Storage (cfs)	Δ Proposed 18" Drawdown and 6" Floodplain Storage vs Existing Conditions (cfs)	Proposed Conditions 18" Drawdown and 9" Floodplain Storage (cfs)	Δ Proposed 18" Drawdown and 9" Floodplain Storage vs Existing Conditions (cfs)	Proposed Conditions 18" Drawdown and 12" Floodplain Storage (cfs)	Δ Proposed 18" Drawdown and 12" Floodplain Storage vs Existing Conditions (cfs
J-O1	3,133	3,133	0	3,133	0	3,133	0	3,133	0
J-O2	22,844	22,844	0	22,844	0	22,844	0	22,844	0
J-O3	21,970	22,851	+881	22,850	+880	22,850	+880	22,850	+880
J-O4	23,211	23,339	+128	23,338	+127	23,338	+127	23,303	+92
J-O5	25,376	25,441	+65	25,439	+63	25,439	+63	25,623	+247
J-O6	25,364	24,423	-941	25,422	+58	25,422	+58	25,602	+238
J-O7	3,411	4,316	+905	4,316	+905	4,316	+905	3,375	-36

The loss in floodplain storage has some effect in increasing peak flow impacts. In this model, there are two peak flow events: a smaller-magnitude peak flow associated with the design storm rainfall (peak one) and a larger peak flow associated with the arrival of the interbasin flows to Oyster Creek (peak two). In this brief analysis, the hydrographs for locations J-O3 and J-O4 were analyzed due to their proximity to the proposed Harris Reservoir project area. For the proposed conditions,100-year design storm event, the peak one flow occurs 3 days after the beginning of the design storm rainfall at a peak flow of 6,072 cfs at Junction J-O3. Arriving 21 hours later at Junction J-O4, the peak one flow increases to 7,137 cfs arriving at day 4. The second larger peak flow (peak two) resulting from the entrance of the large interbasin flows arrives at Junction J-O3 on day 17 at 22,850 cfs and travels downstream to Junction J-O4, arriving 14 hours later. The peak two flow at J-O4 increases from 22,850 to 23,338 cfs.

Due to the large, flat nature of the Oyster Creek watershed, there generally is an increase in peak flow occurring in the proposed conditions model when comparing it to the existing conditions scenarios.

The 100-year design storm flow event proposed conditions flows are generally higher (50 to 260 cfs) than the existing conditions flows on the rising limb of the peak one section of the hydrograph. The proposed conditions 100-year design storm peak flow is 6,072 cfs, which is 487 cfs higher than the existing conditions 100-year design storm peak flow of 5,584 cfs, related to the 100-year design storm event. The proposed conditions peak flow arrives 10 minutes sooner than the existing conditions peak flow.

The same hydrograph behavior occurs during the 50-year design storm event where two peak flow events occur: peak flow one, which related to the design storm event, and peak flow two, which is related to the interbasin flows arriving to Oyster Creek.

The 100-year proposed conditions results hydrograph shows there is a rise in peak flow in comparison to the existing condition hydrograph on the extremities of the hydrograph. For the middle portion of the hydrograph, the existing conditions flow is higher than the proposed conditions flow.

The 50-year results hydrograph shows there is a rise in peak flow for the proposed conditions after the second peak flow occurs and in the falling limb of the second peak flow in the hydrograph. Generally for the 50-year event, the existing conditions flow are higher than the proposed conditions flow for the majority of the hydrograph.

4.1.3 Loss of Floodplain Storage

In a prior version of the HEC-RAS model, an additional run of the model with proposed conditions was created to determine the proposed conditions for Oyster Creek without proposed channel improvements. The loss of floodplain storage estimated for this condition without the proposed channel improvements was 309 ac-ft, which corresponds with the original stream restoration design provided by Dow in their application. A second model run was set up to show the loss of floodplain storage with the revised stream restoration design, which had an estimated 263 ac-ft loss of floodplain storage. After reviewing the most up-to-date Jacobs HEC-RAS model, the results for the loss of floodplain storage for the 50-year and 100-year events demonstrate a loss of 525 ac-ft and 1,028 ac-ft in floodplain storage.

Oyster Creek floodplain storage will decrease by a net 1,028 acre-feet (1%) for the 100-year event as a result of the proposed Harris Reservoir berm and Oyster Creek channel improvements. To counter the loss of floodplain storage, Dow plans to operate the reservoir to draw down the proposed Harris Reservoir prior to 50-year and 100-year storm events and tropical storms and hold the rainfall falling on the proposed Harris Reservoir and any initial diverted flows from the

Brazos River as floodplain storage prior to discharge. In the *Oyster Creek Downstream Hydrologic and Hydraulic Impacts Draft Report,* a detailed analysis of this operational measure is included. For a 100-year design storm, with 18 inches of drawdown before a 100-year storm event, the proposed Harris Reservoir would store 807 ac-ft for 6 inches of depth, 1,309 ac-ft of gain for 9 inches of depth, and a gain of 1,632 ac-ft for 12 inches of depth. Using 18 inches of drawdown before a 100-year storm event and storing various depths within the proposed Harris Reservoir before releasing flows into Oyster Creek would result in a net loss of 221 ac-ft floodplain storage for 6 inches of storage depth while gaining a net floodplain storage of 281 ac-ft for 9 inches of storage depth and 604 ac-ft of floodplain storage for 12 inches of storage depth. **Table 33** below shows the gross and net floodplain storage gain with this operational measure.

Table 33: Operational Plan to Offset Floodplain Storage Loss

	50-Year Design Storm				100-Year Design Storm		
	Floodplain Storage (ac-ft)						
	Loss of Floodplain Storage	Proposed 18" Drawdown and 6" Floodplain Storage	Proposed 18" Drawdown and 9" Floodplain Storage	Proposed 18" Drawdown and 12" Floodplain Storage	Proposed 18" Drawdown and 6" Floodplain Storage	Proposed 18" Drawdown and 9" Floodplain Storage	Proposed 18" Drawdown and 12" Floodplain Storage
50-year	-525	+993	+1,371	+1,715	N/A	N/A	N/A
100-year	-1,028	N/A	N/A	N/A	+807	+1,309	+1,632
Total		+468	+846	+1,190	-221	+281	+604

4.1.4 Existing and Proposed Conditions Hydrographs

Below are the hydrographs for key junctions within the model for the two project conditions (existing and conditions) for the 50-year and 100-year design storm events, which include Brazos/Oyster interbasin flows as seen in **Figure 26** through **Figure 37.**

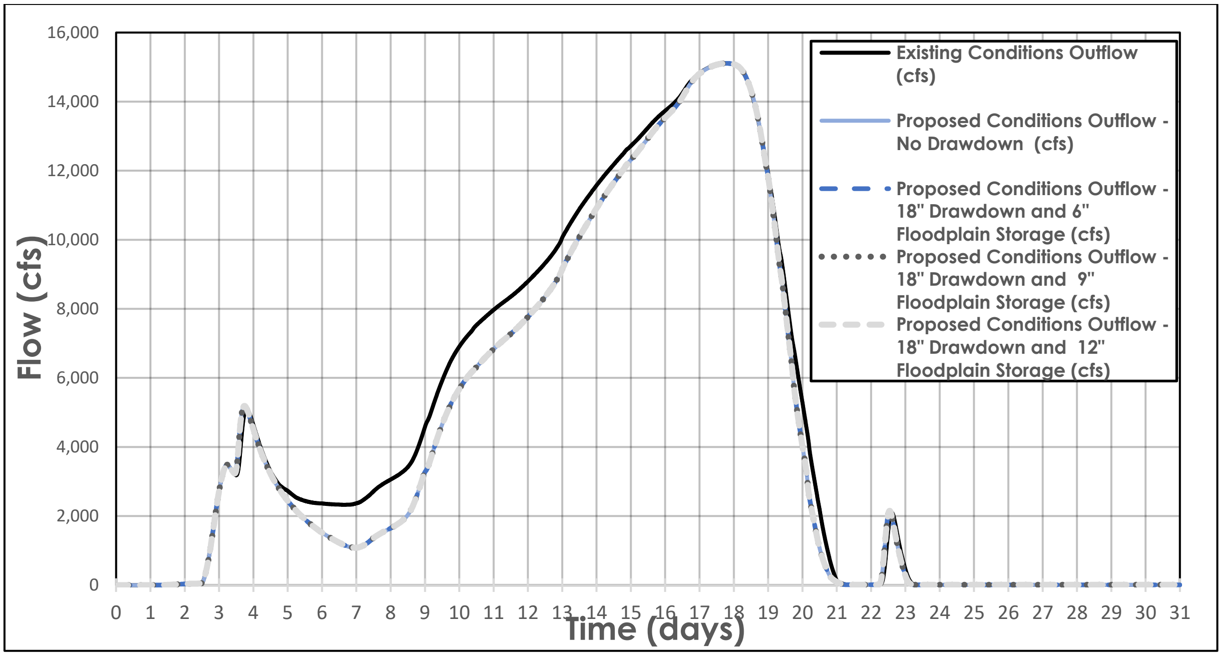

Figure 26: *50-Year existing and proposed conditions design storm hydrographs at Junction J-O2.*

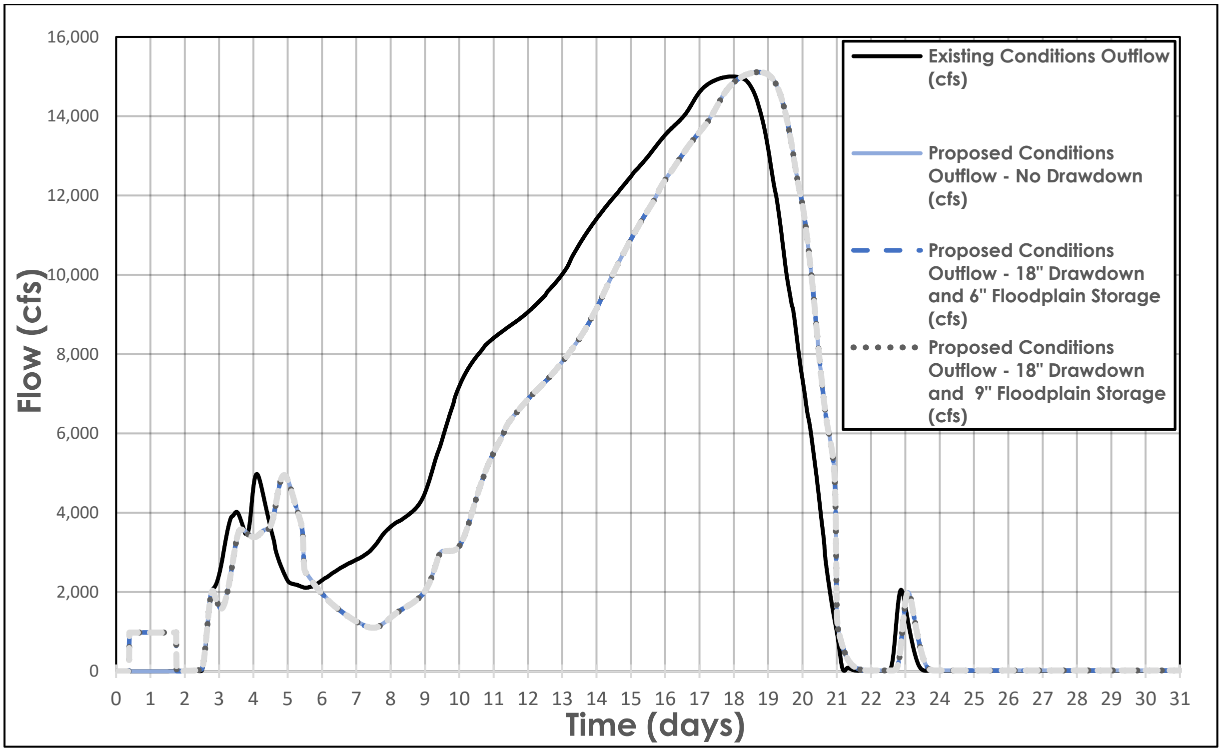

Figure 27*: 50-year existing and proposed conditions design storm hydrographs at Junction J-O3.*

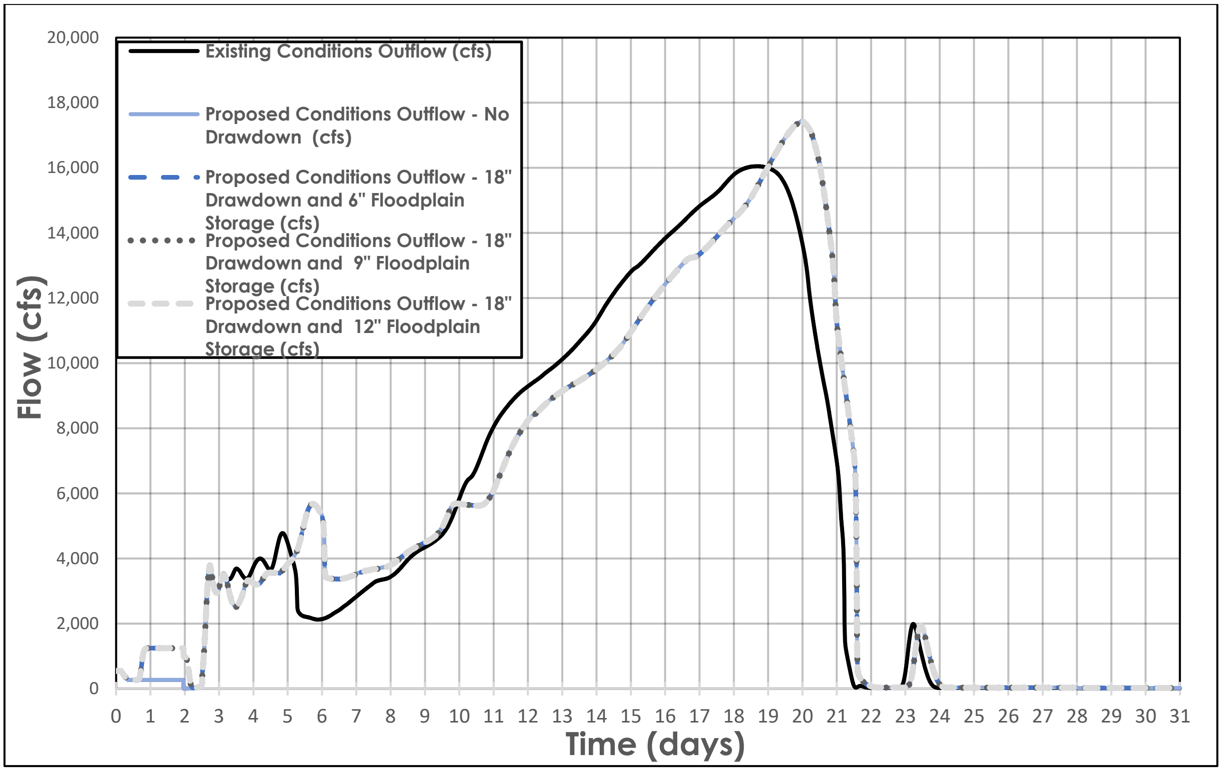

***Figure 28**: 50-year existing and proposed conditions design storm hydrographs at Junction J-O4.*

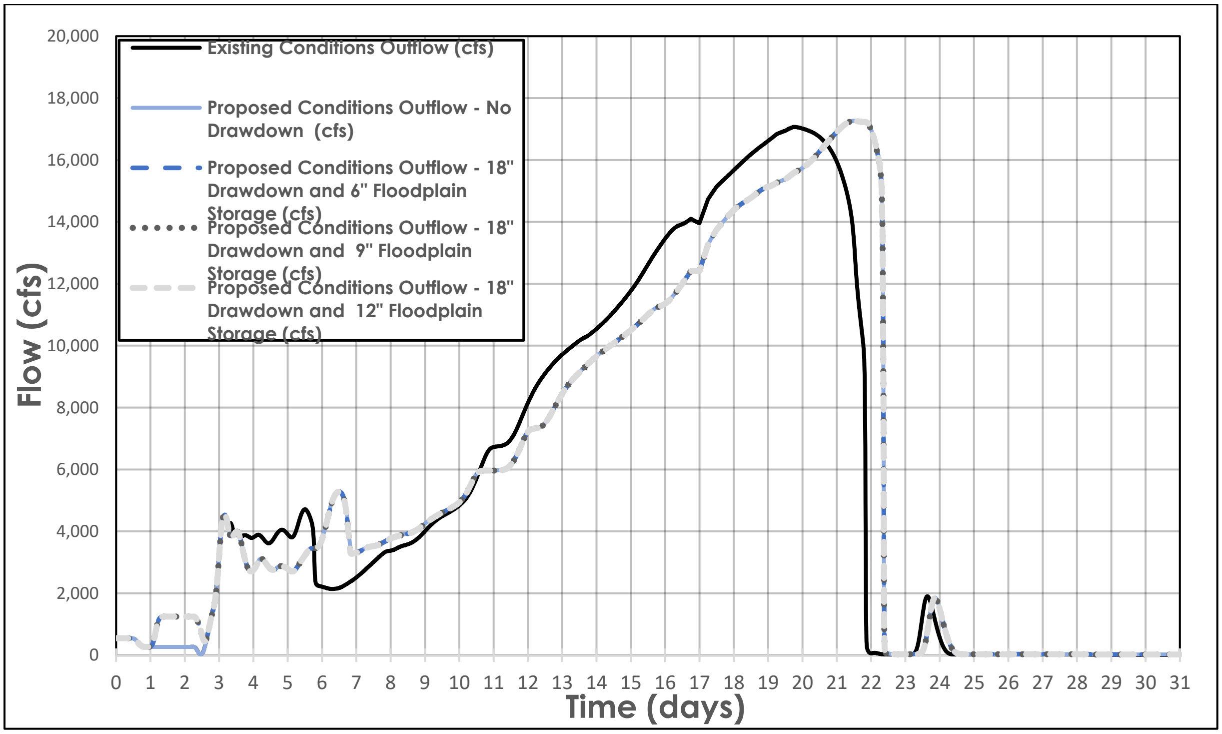

***Figure 29:** 50-year existing and proposed conditions design storm hydrographs at Junction J-O5.*

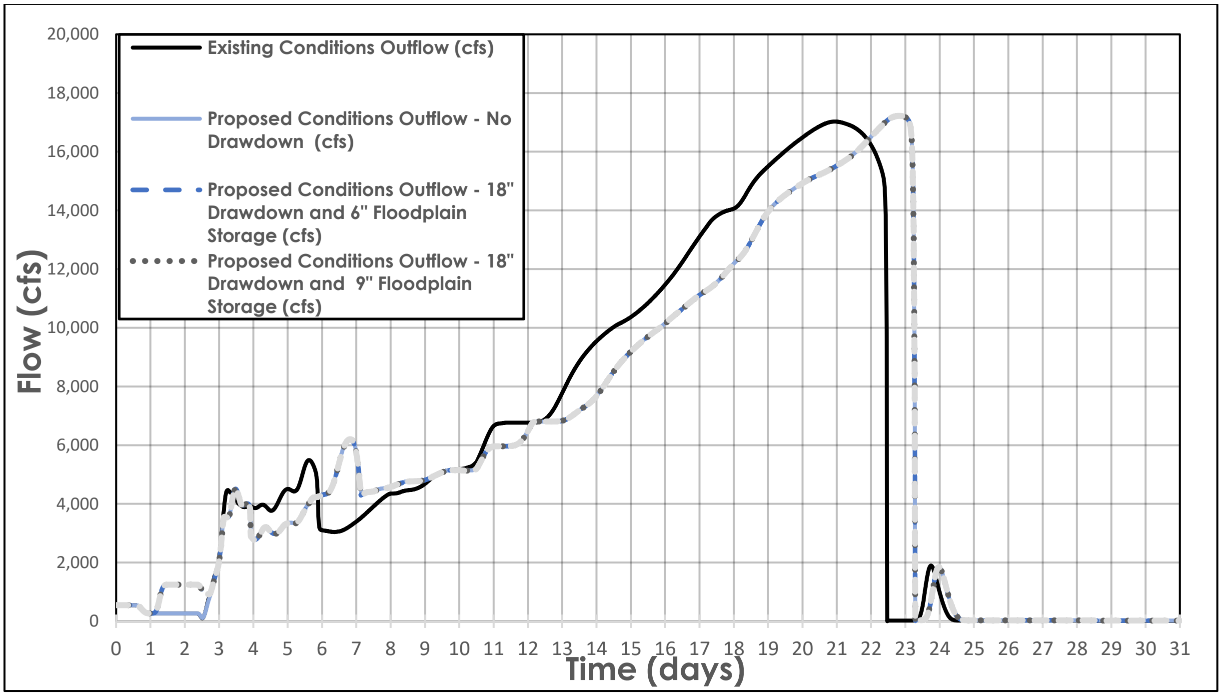

Figure 30: *50-year existing and proposed conditions design storm hydrographs at Junction J-O6.*

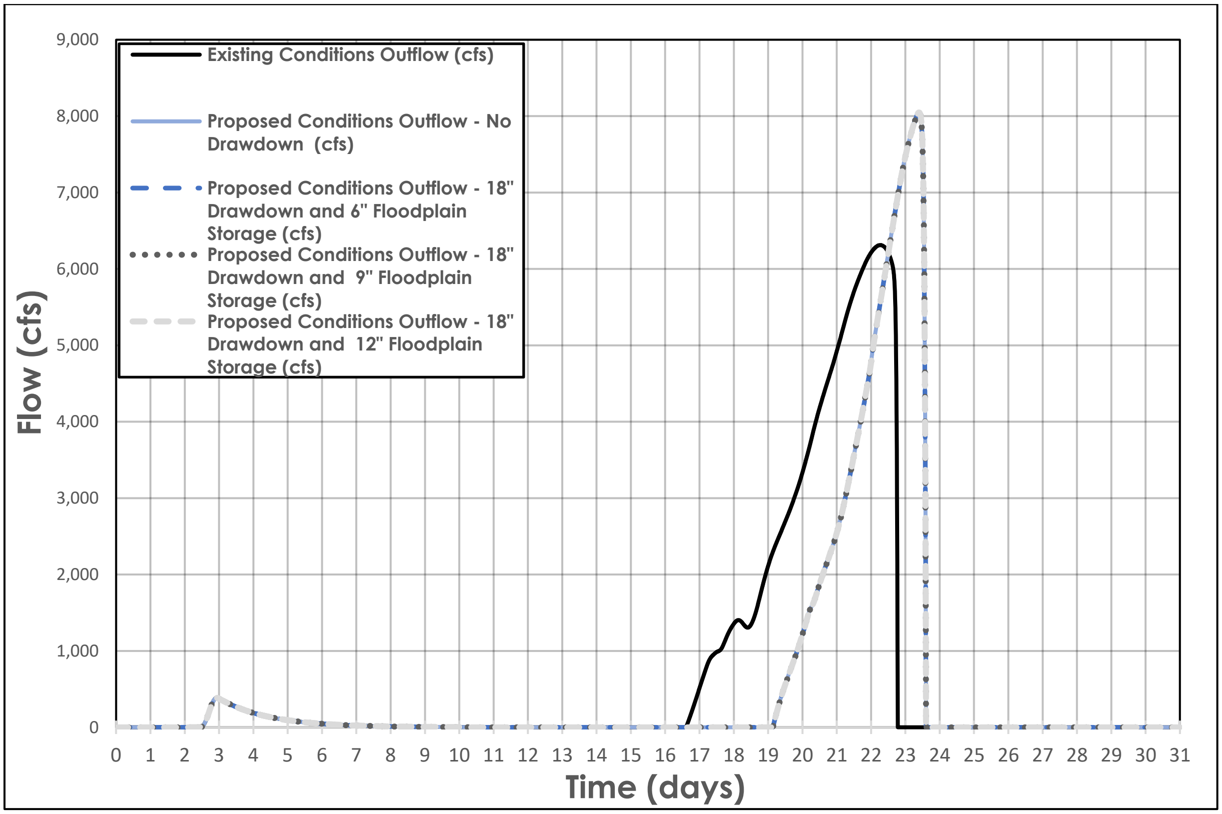

Figure 31: *50-year existing and proposed conditions design storm hydrographs at Junction J-O7.*

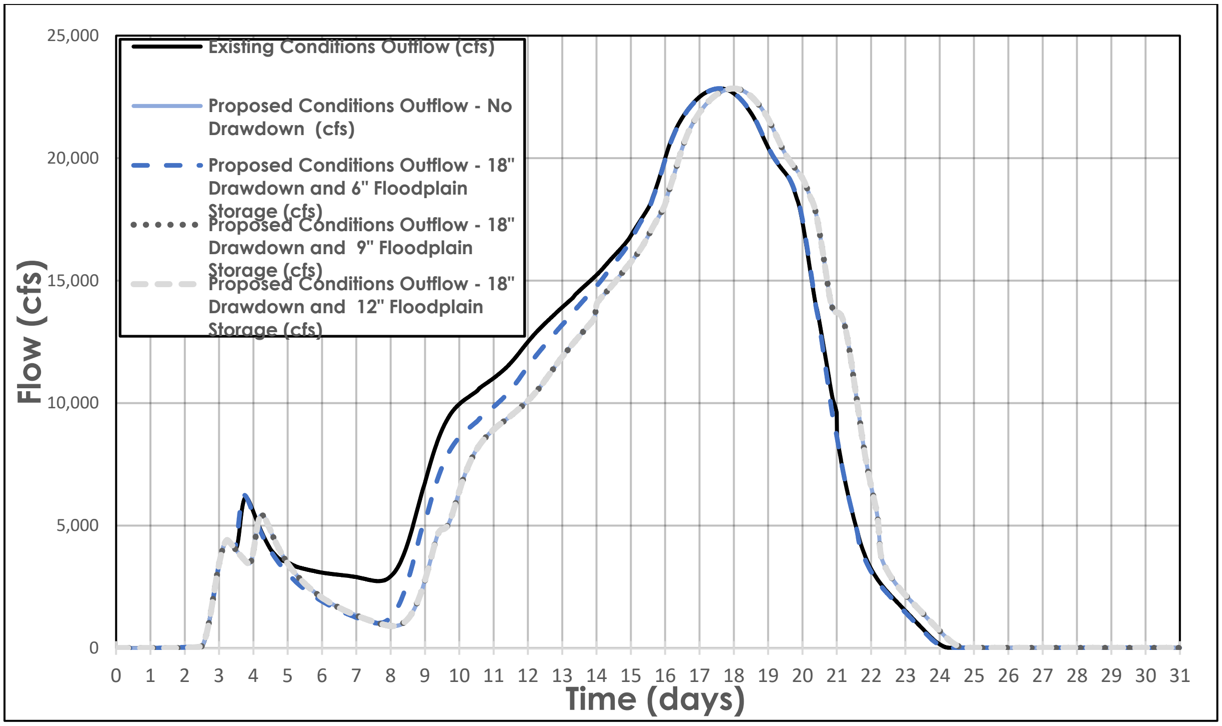

Figure 32: 100-year existing and proposed conditions design storm hydrographs at Junction J-O2.

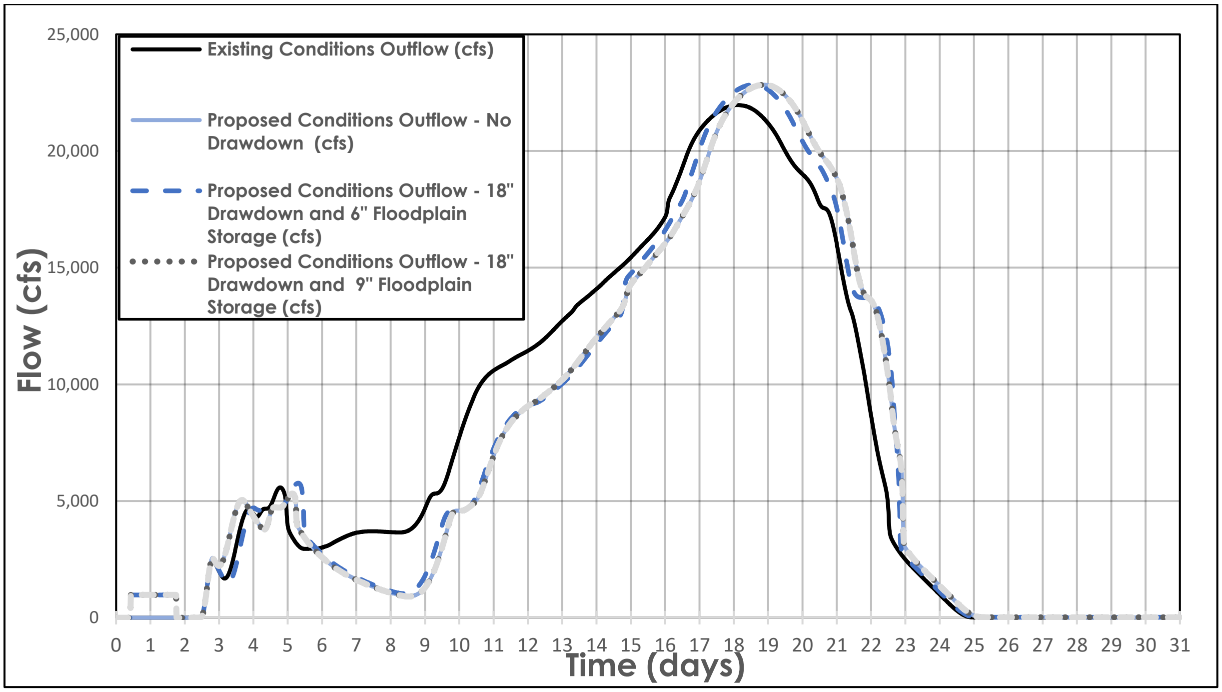

Figure 33: 100-year existing and proposed conditions design storm hydrographs at Junction J-O3.

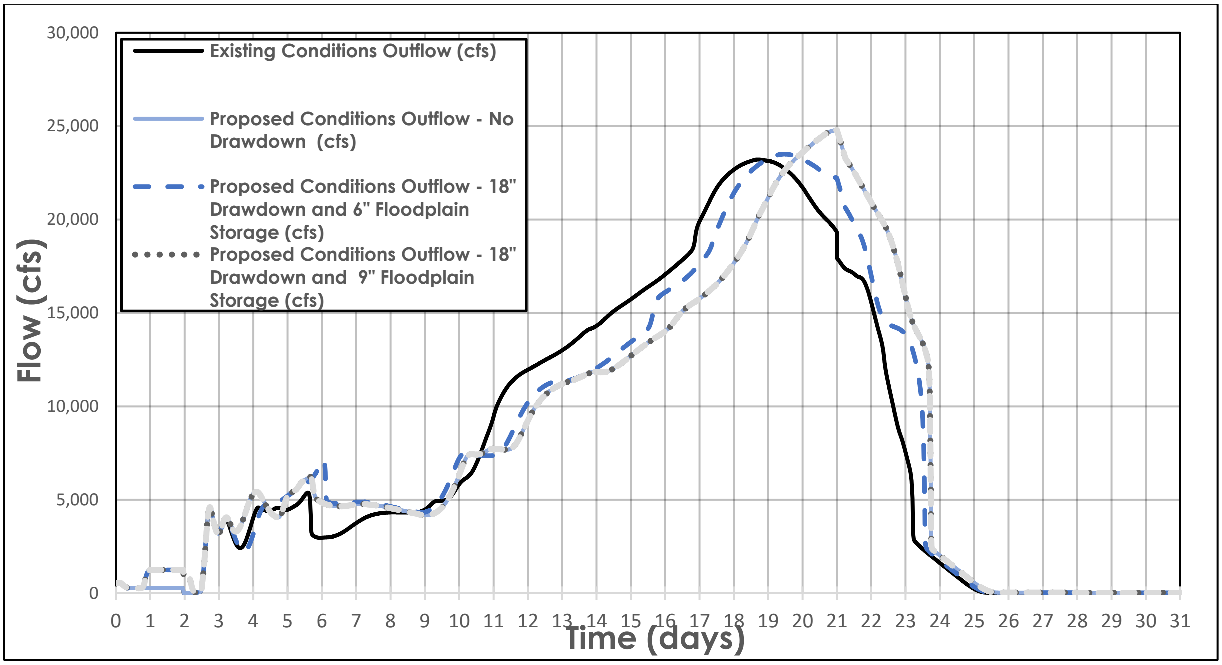

Figure 34: *100-year existing and proposed conditions design storm hydrographs at Junction J-O4.*

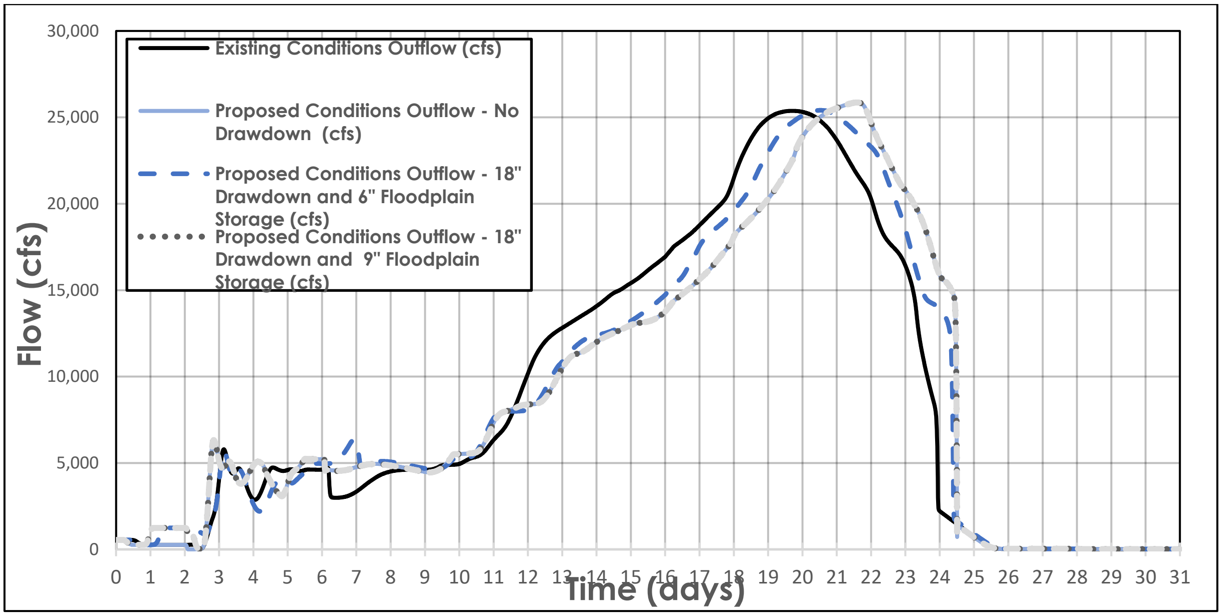

Figure 35: 100-year existing and proposed conditions design storm hydrographs at Junction J-O5.

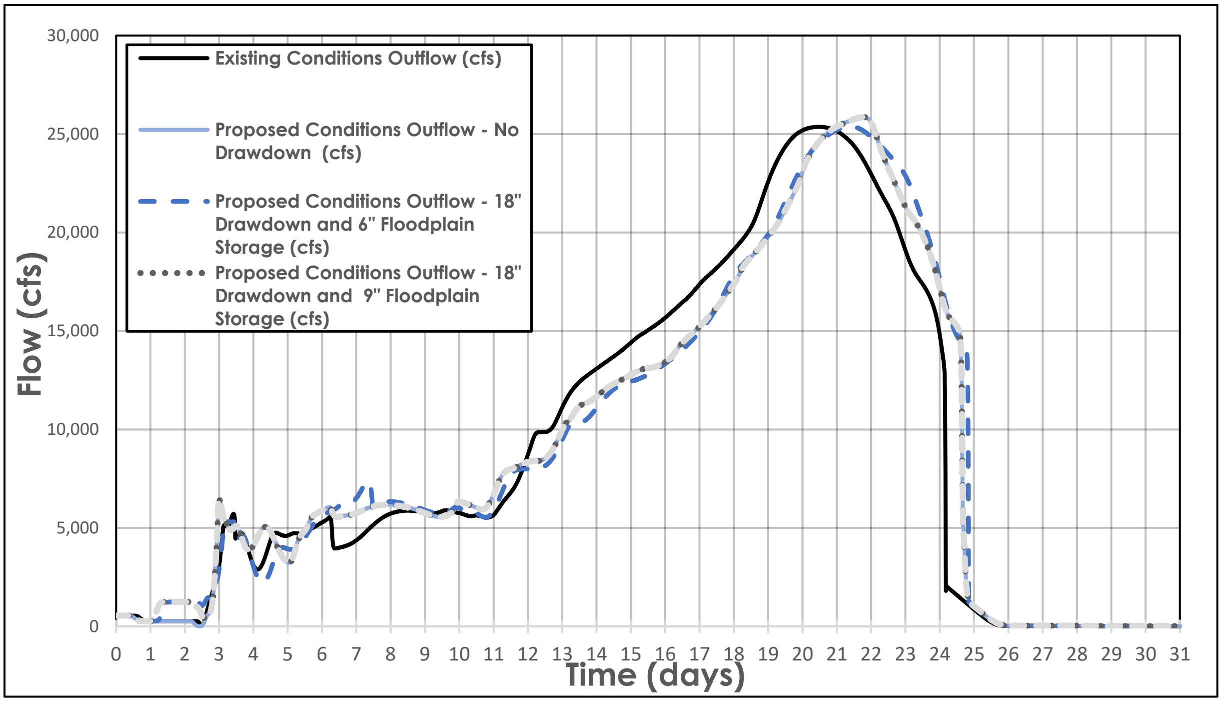

***Figure 36**: 100-Year Existing and Proposed Conditions Design Storm Hydrographs at Junction J-O6.*

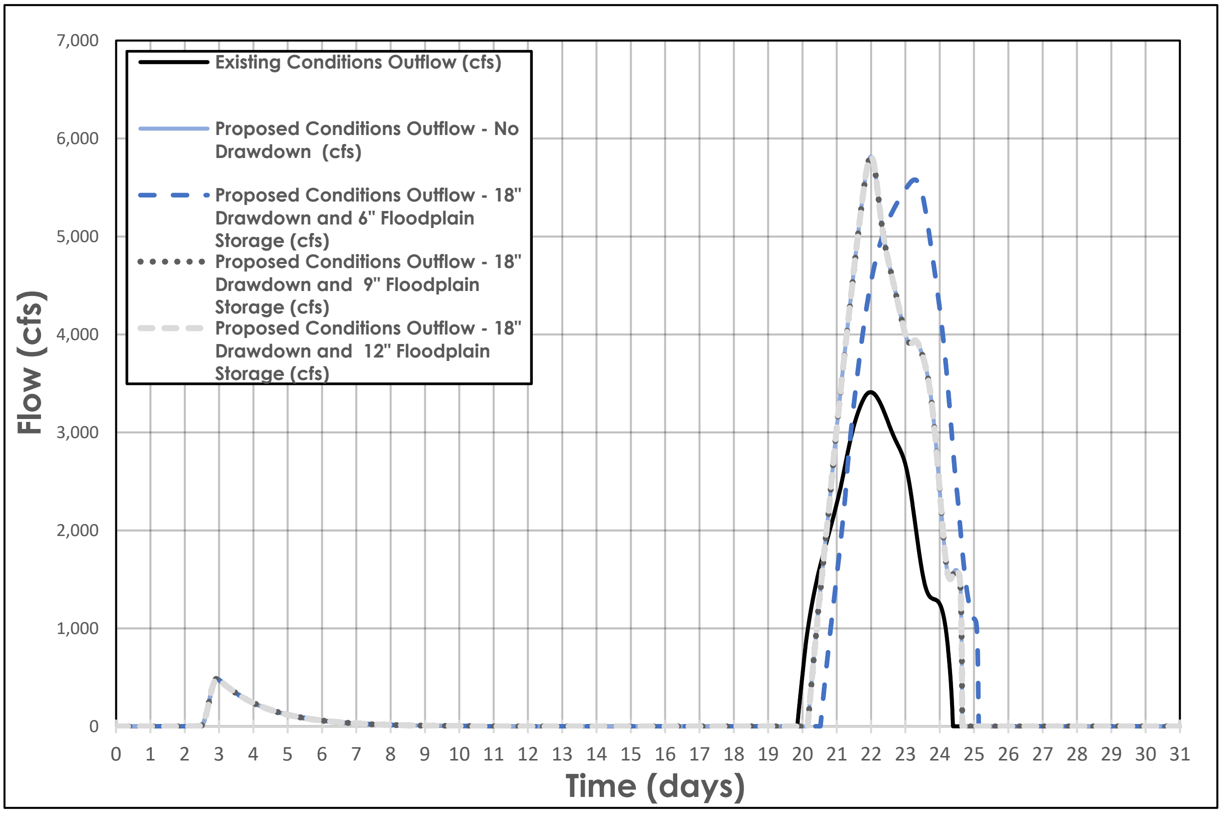

***Figure 37**: 100-Year Existing and Proposed Conditions Design Storm Hydrographs at Junction J-O7.*

4.1.5 Water Surface Elevation

Using HEC-RAS, WSELs were modeled for existing and proposed conditions for the revised channel improvements design as shown in **Table 34.** The results shown here were deterimined in the May 2020 Oyster Creek No Rise Model developed by Jacobs.

Table 34: Water Surface Elevations for Oyster Creek for the 50-Year and 100-Year Design Event

River Station	50-Year Design Storm WSEL (ft)			100-Year Design Storm WSEL (ft)		
	Existing Conditions	Proposed Conditions	Δ Existing Conditions vs Proposed Conditions	Existing Conditions	Proposed Conditions	Δ Existing Conditions vs Proposed Conditions
69.9	44.13	44.13	0.00	44.7	44.7	0.00
69.72	43.78	43.78	0.00	44.39	44.39	0.00
68.56	42.07	42.07	0.00	42.7	42.7	0.00
67.62	41.58	41.58	0.00	42.11	42.11	0.00
66.85	41.44	41.44	0.00	41.95	41.95	0.00
65.35	40.52	40.5	-0.02	41.15	41.15	0.00
64.6	40.41	40.39	-0.02	41.06	41.06	0.00
63.9	40.36	40.33	-0.03	41.02	41.02	0.00
63.19	40.19	40.16	-0.03	40.85	40.85	0.00
62.84	40.12	40.09	-0.03	40.78	40.78	0.00
61.87	39.86	39.82	-0.04	40.54	40.54	0.00
61.43	39.75	39.7	-0.05	40.41	40.41	0.00
60.49	39.46	39.38	-0.08	40.07	40.07	0.00
60.48	39.45	39.37	-0.08	40.06	40.06	0.00
60.47	39.43	39.35	-0.08	40.05	40.04	-0.01
59.85	39.34	39.26	-0.08	39.96	39.96	0.00
59.17	38.84	38.73	-0.11	39.45	39.44	-0.01
58.67	38.34	38.22	-0.12	38.95	38.94	-0.01
56.05	36.39	36.39	0.00	37.21	37.21	0.00
55.6	36.1	36.14	0.04	36.93	36.93	0.00
55.3	36.04	36.09	0.05	36.86	36.86	0.00
53.49	35.44	35.53	0.09	36.23	36.23	0.00
53.48	35.42	35.51	0.09	36.21	36.2	-0.01

River Station	50-Year Design Storm WSEL (ft)			100-Year Design Storm WSEL (ft)		
	Existing Conditions	Proposed Conditions	Δ Existing Conditions vs Proposed Conditions	Existing Conditions	Proposed Conditions	Δ Existing Conditions vs Proposed Conditions
53.47	35.4	35.4	0.00	36.13	36.13	0.00
53.46	35.38	35.38	0.00	36.12	36.12	0.00
52.75	34.5	34.5	0.00	35.29	35.29	0.00
50.3	34.24	34.24	0.00	35.05	35.05	0.00

4.2 Normal Flow Releases and Sediment Loss in Oyster Creek

Normal flow releases from the proposed Harris Reservoir only occur when flow in Oyster Creek is low or not flowing at all. Dow is currently using around 100 cfs but has a water right to use up to 176 cfs in its operation, which it could release from the proposed Harris Reservoir when built. These releases would flow downstream in Oyster Creek approximately 29 stream miles to the Oyster Creek Dam at Lake Jackson, Texas, where the water is pumped into a canal to be conveyed to the plants for use.

The normal release of reservoir water into Oyster Creek can become the source of erosion even though the flow is low (100 cfs to 176 cfs) compared to the bankfull stream flow of 476 cfs in Project 2 mentioned above. This erosion is caused because the reservoir water is deprived of sediment (Kondolf, 1997; Subcommittee on Sedimentation, 2017).

The approximate 900 cfs flow for lowering the reservoir for a tropical storm would equate to less than the 1.5-year storm in Project 2, which would make it part of the regular storm flow from the contributing watershed.

The sediment that was part of the Brazos River flow when it was pumped from the Brazos River into the reservoir has settled out. This is substantiated by looking at the change in available storage in the Brazoria Reservoir and the existing Harris Reservoir, which have lost substantial storage capacity to water-pumped sediment settling out in the reservoirs. This will continue to occur unless a regular scheduled operation and maintenance program is started to maintain storage capacity in all reservoirs.

Since the proposed Harris Reservoir will not be continually releasing water, there will also be a wetting and drying cycle that can increase the bed and bank erosion when the sediment-deprived reservoir water is released. This can cause channel incision and widening thus increasing the sediment load farther downstream.

The proposed reservoir is an off-channel storage structure, thus allowing storm events to flow downstream from the upstream Oyster Creek watershed as it has in the past. Although these flow events are being altered by the upstream projects, some of the sediment that was carried by Oyster Creek will still be feeding the stream, but it may not be enough to make up for the erosion caused by deprived water released from the reservoir.

Inspection of the downstream channel for erosion should be part of the proposed project O&M plan. If any excessive erosion is observed in the stream channel or banks, it should be restored.

4.3 Analysis BASINS/HSPF Modeling Results

The velocity, sediment transport, and water temperature were modeled using the BASINS framework and HSPF watershed model during 180 days of continuous simulation under drought conditions. Five scenarios were modeled: no reservoir, 334 cfs constant outflow, 216 cfs constant outflow, 133 cfs constant outflow, and 22 cfs constant outflow. The results are used to compare the existing conditions with proposed conditions (addition of proposed Harris Reservoir) under the four constant outflow conditions.

The drawdown time for the proposed reservoir was analyzed to have a better understanding of how long it would take to empty for each of the four scenarios modeled. For this analysis, the elevation-storage table for the proposed reservoir was used. The elevation-storage relationship for the proposed reservoir is given in **Appendix H**. According to this analysis, the proposed reservoir would empty as follows:

- Scenario 1 – 334 cfs outflow from proposed reservoir: reservoir would be empty at simulation day 72
- Scenario 2 – 216 cfs outflow from proposed reservoir: reservoir would be empty at simulation day 111
- Scenario 3 – 133 cfs outflow from proposed reservoir: reservoir would be empty at simulation day 180
- Scenario 4 – 22 cfs outflow from proposed reservoir: reservoir would still be between 60 ft and 65 ft at the end of 180 days of simulation

Using BASINS and HSPF, average velocity, shear velocity, bed shear stress, deposition/scour, sediment inflow and outfow, and water temperature at Reach 3 of Oyster Creek, which is immediately downstream of the proposed reservoir, are modeled and compared with the existing conditions. The tables showing all the results for the duration of 180 days are in **Appendix I. Table 35** below shows a summary of these results.

Table 35: Summary of HSPF Model Results

	No Reservoir	Scenario 1 (334 cfs discharge from proposed reservoir)	Scenario 2 (216 cfs discharge from proposed reservoir)	Scenario 3 (133 cfs discharge from proposed reservoir)	Scenario 4 (22 cfs discharge from proposed reservoir)
Average Velocity (ft/s)	1.68	2.36	2.20	2.03	1.71
Maximum Velocity (ft/s)	1.75	2.40	2.26	2.10	1.86
Average Shear Velocity (ft/s)	0.04	0.05	0.05	0.05	0.04

	No Reservoir	Scenario 1 (334 cfs discharge from proposed reservoir)	Scenario 2 (216 cfs discharge from proposed reservoir)	Scenario 3 (133 cfs discharge from proposed reservoir)	Scenario 4 (22 cfs discharge from proposed reservoir)
Maximum Shear Velocity (ft/s)	0.05	0.05	0.05	0.05	0.05
Average Bed Shear Stress (lb/ft²)	0.0032	0.0042	0.0041	0.0041	0.0032
Maximum Bed Shear Stress (lb/ft²)	0.0041	0.0043	0.0041	0.0042	0.0041
Average Deposition/scour	-0.0001	-0.0219	-0.0125	-0.0067	-0.0008
Maximum Deposition/Scour	0.0175	-0.0107	0.0004	0.0073	0.0162
Average Sediment Outflow Concentration (ton/ac-ft)	0.0021	0.0239	0.0145	0.0087	0.0029
Maximum Sediment Outflow Concentration (ton/ac-ft)	0.0508	0.0821	0.0706	0.0630	0.0530
Average Sediment Inflow Concentration (ton/ac-ft)	0.0020	0.0020	0.0020	0.0020	0.0020
Maximum Sediment Inflow Concentration (ton/ac-ft)	0.0808	0.0808	0.0808	0.0808	0.0808
Average Total Suspended Sediment Concentration (mg/L)	0.6466	0.5864	0.5279	0.4775	0.4784
Maximum Total Suspended Sediment Concentration (mg/L)	11.075	1.9078	2.38	3.1306	7.1945

	No Reservoir	Scenario 1 (334 cfs discharge from proposed reservoir)	Scenario 2 (216 cfs discharge from proposed reservoir)	Scenario 3 (133 cfs discharge from proposed reservoir)	Scenario 4 (22 cfs discharge from proposed reservoir)
Average Water Temperature (deg F)	71.86	52.00	53.78	55.52	63.56
Maximum Water Temperature (deg F)	78.29	62.25	64.36	65.88	73.40

The average velocity in Oyster Creek for each modeled scenario is plotted in **Figure 38** below. As observed in the plot, and based on the model results, the average velocity in Oyster Creek increases proportional to the amount of outflow from the proposed reservoir. The more outflow from the proposed reservoir, the higher the average velocity in Oyster Creek.

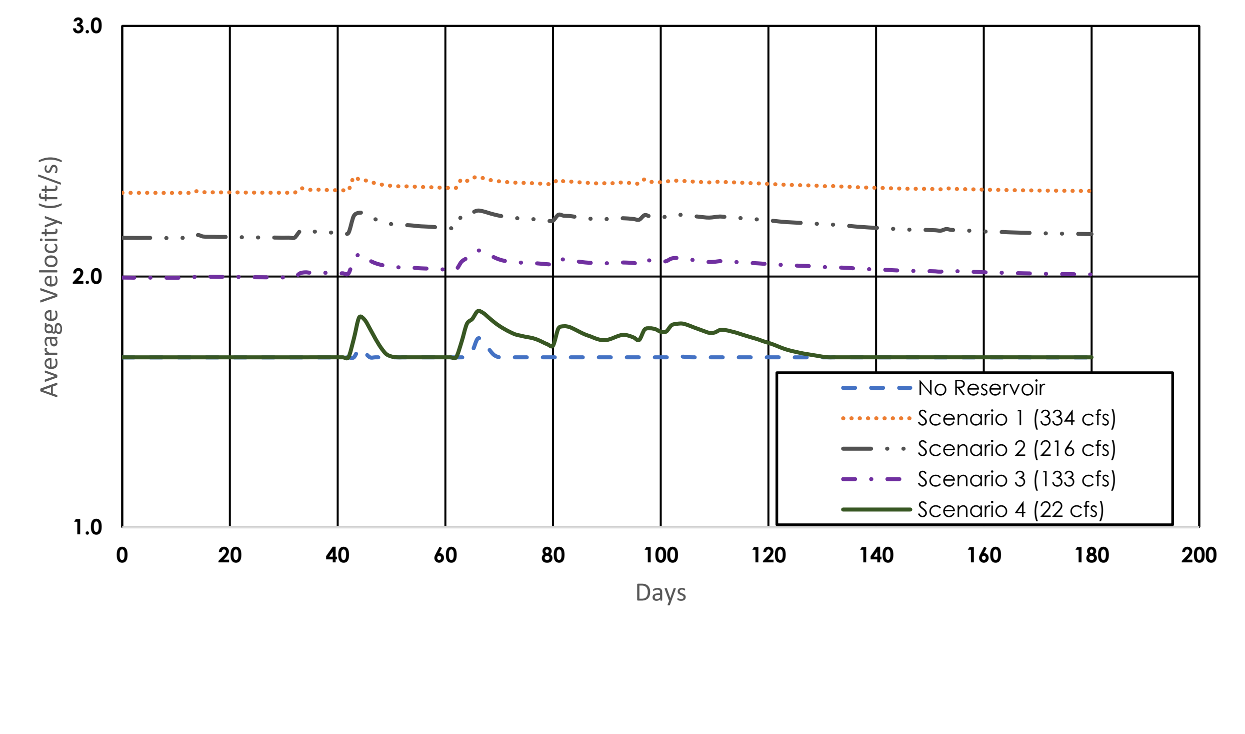

Figure 38: *Average velocities in Oyster Creek downstream of proposed dam.*

As the modeling aims to examine if there is any potential for hydromodification, shear velocity and bed shear stress are two other parameters used to compare the proposed conditions with the existing conditions. With constant outflows from the proposed Harris Reservoir, the results show a very slight increase in shear velocity in Oyster Creek compared to existing conditions. **Figure 39** below shows the difference in shear velocity between all modeled scenarios.

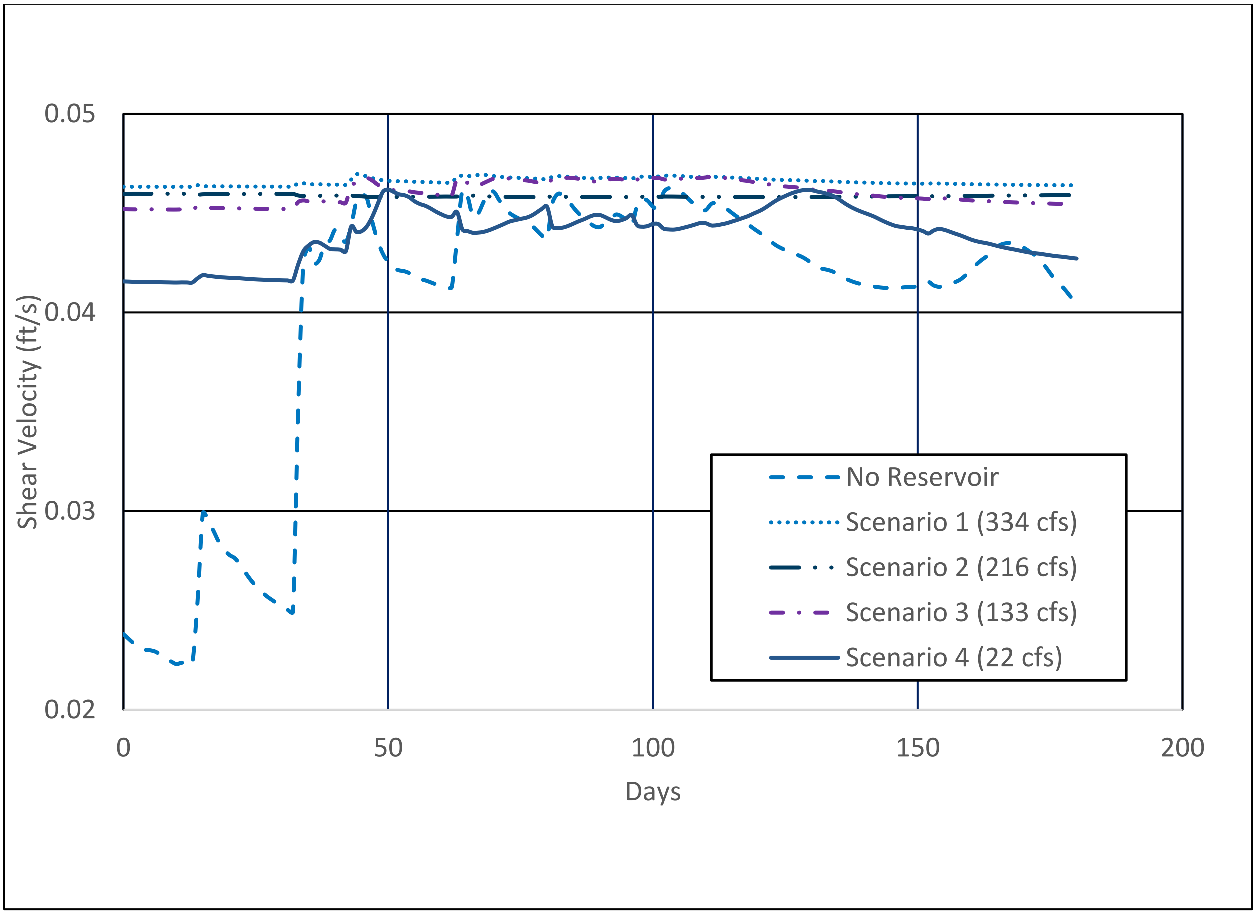

***Figure 39:** Shear velocity comparison in Oyster Creek downstream of the proposed reservoir.*

Bed shear stress in Oyster Creek becomes more stable as there is consistently higher flow in the creek as a result of proposed Harris Reservoir outflows. The value of the bed shear stress increases very slightly with higher velocities. **Figure 40** below shows the model results for bed shear stress.

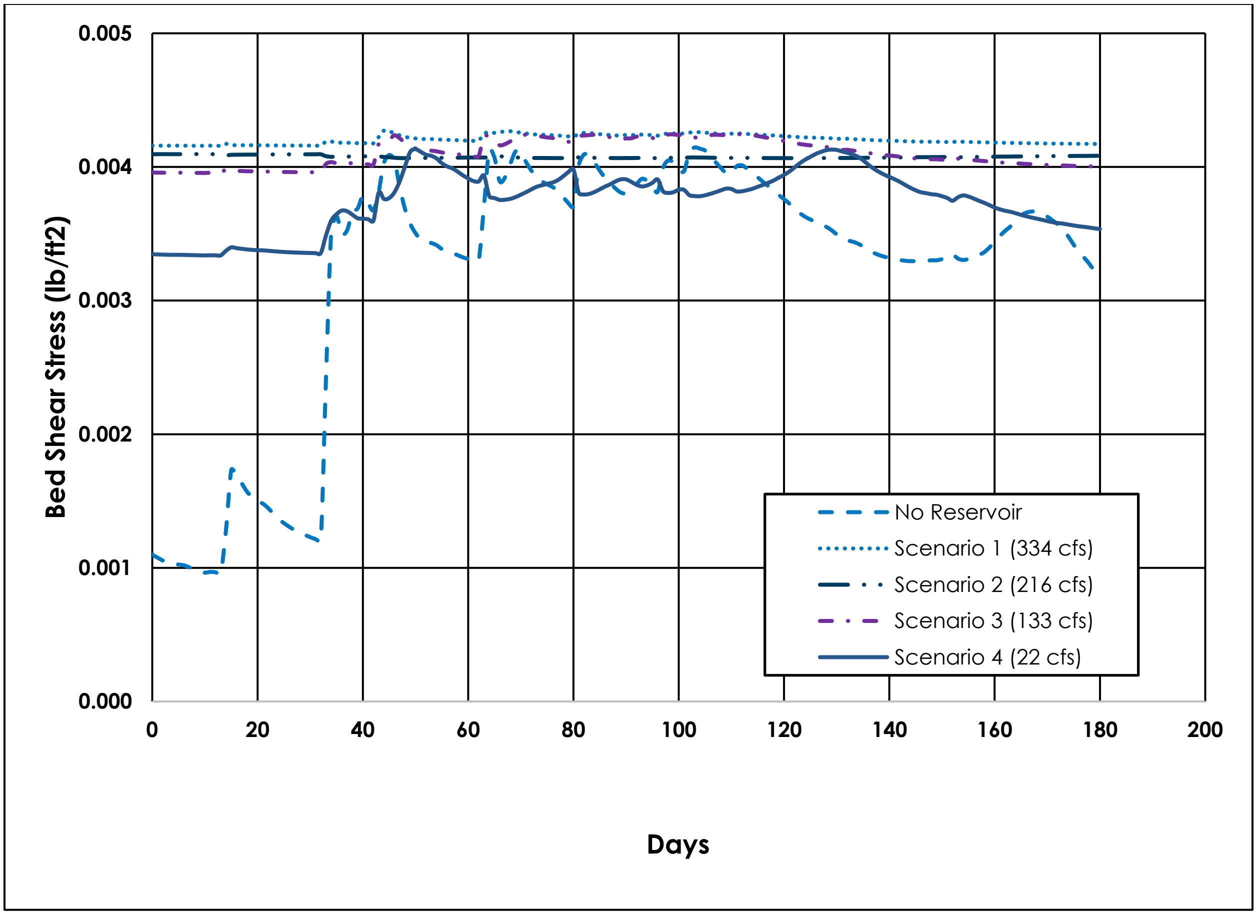

Figure 40: *Bed shear stress in Oyster Creek downstream of proposed reservoir.*

Another parameter used to examine the hydromodification in Oyster Creek is the deposition/scour term. If positive, this parameter indicates the occurrence of deposition in the channel, whereas a negative value indicates occurrence of scour in the channel. As expected with the major source of flow being the outflows from the proposed Harris Reservoir, scouring will be observed more than deposition with the construction of the proposed Harris Reservoir. **Figure 41** shows the change in deposition and scour terms for all modeled scenarios. The occurrence and amount of deposition decreases as the flow increases in Oyster Creek.

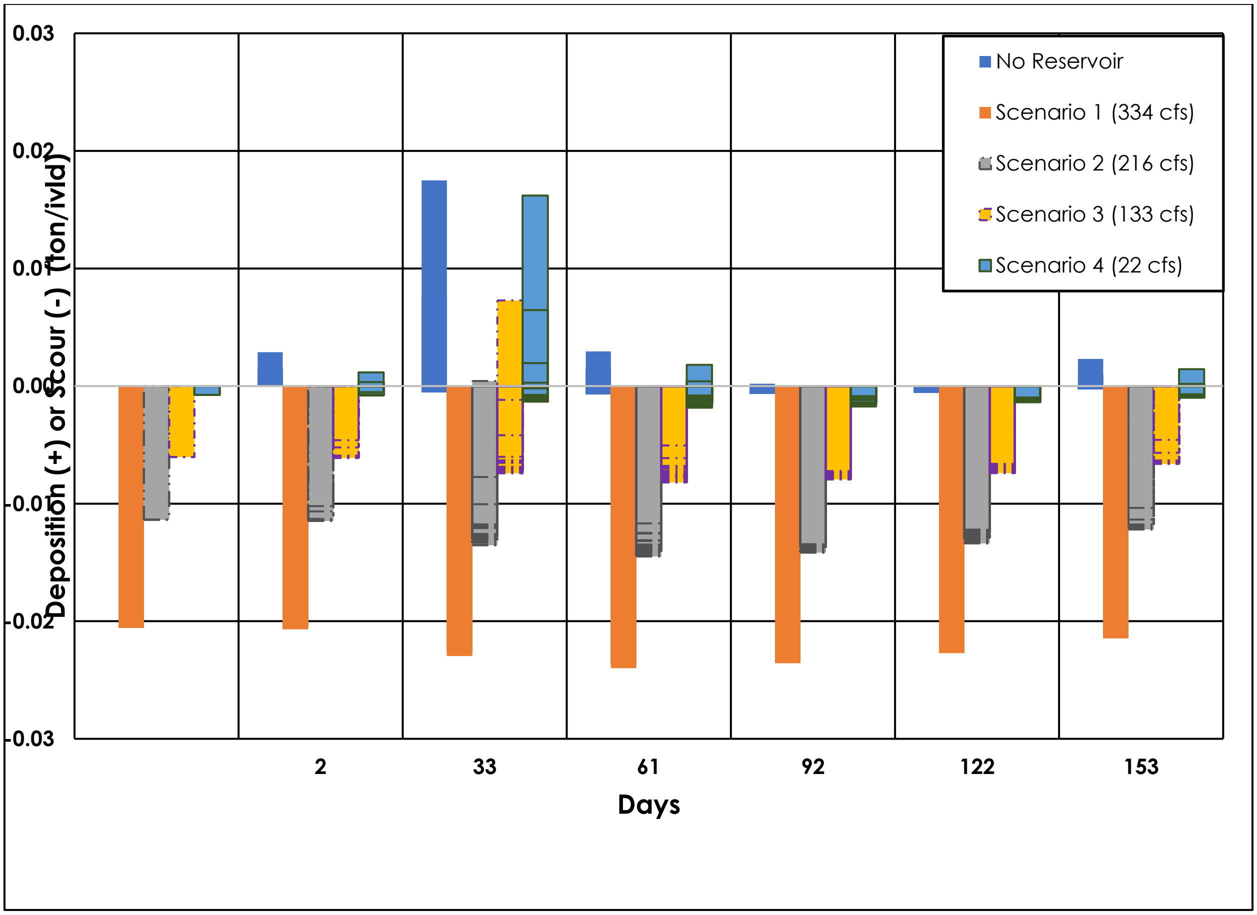

***Figure 41:** Deposition/scour in Oyster Creek downstream of proposed reservoir.*

With more water flowing in Oyster Creek, more sediment outflow is expected. The model agrees with this expectation. The increases in scour and velocity indicate more suspended sediment concentration in Oyster Creek. As the outflow from the proposed Harris Reservoir increases, the sediment outflow from Reach 3 in Oyster Creek also increases. The results are shown in **Figure 42**.

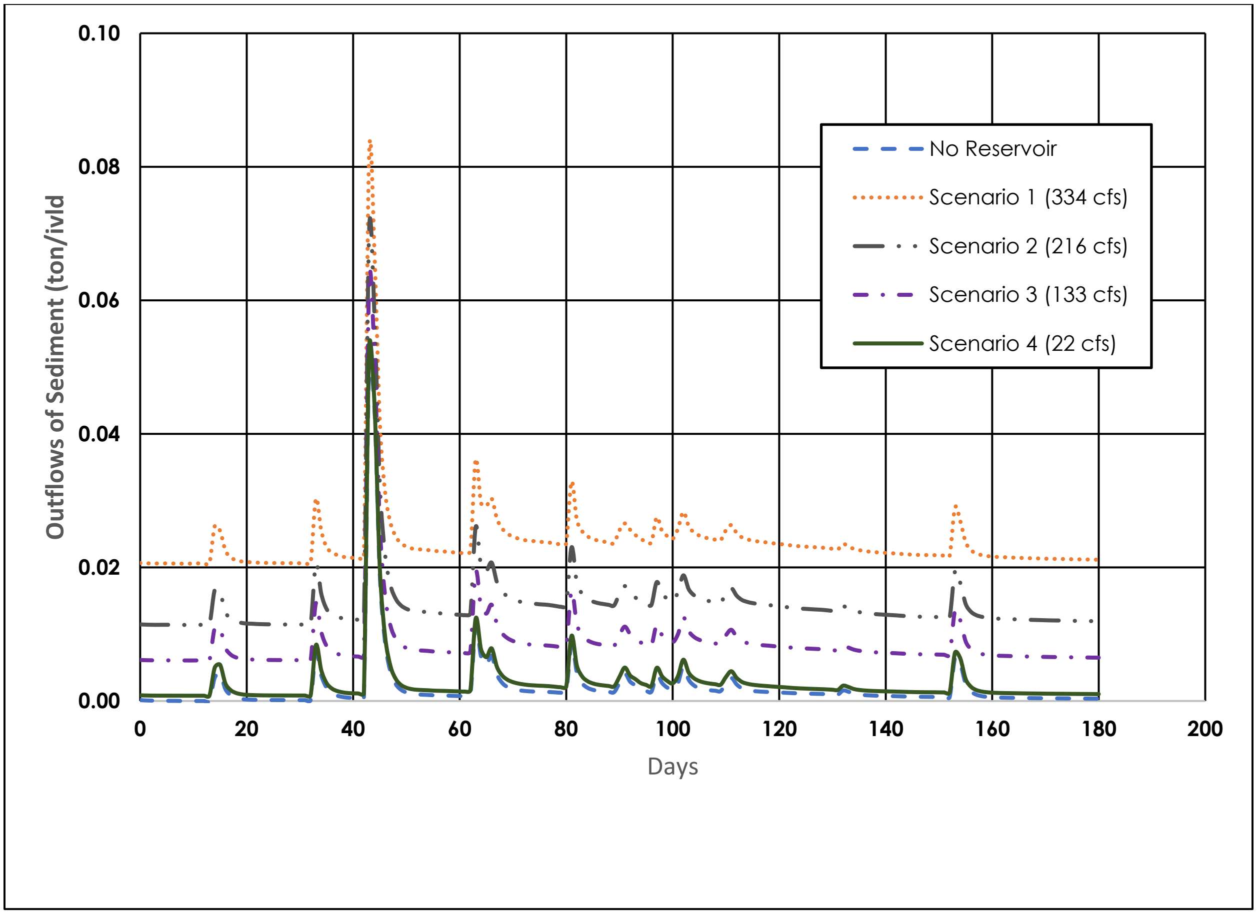

***Figure 42**: Sediment outflow from Oyster Creek downstream of proposed reservoir.*

As there is no sediment coming from the proposed Harris Reservoir, the inflow of sediment into Reach 3 of Oyster Creek is the same for all five scenarios, including the existing conditions. The outflows from the proposed Harris Reservoir are causing scour of sediment from Oyster Creek, increasing erosion. **Figure 43** shows that all five scenarios show the same results for the amount of sediment in the inflow into Oyster Creek Reach 3.

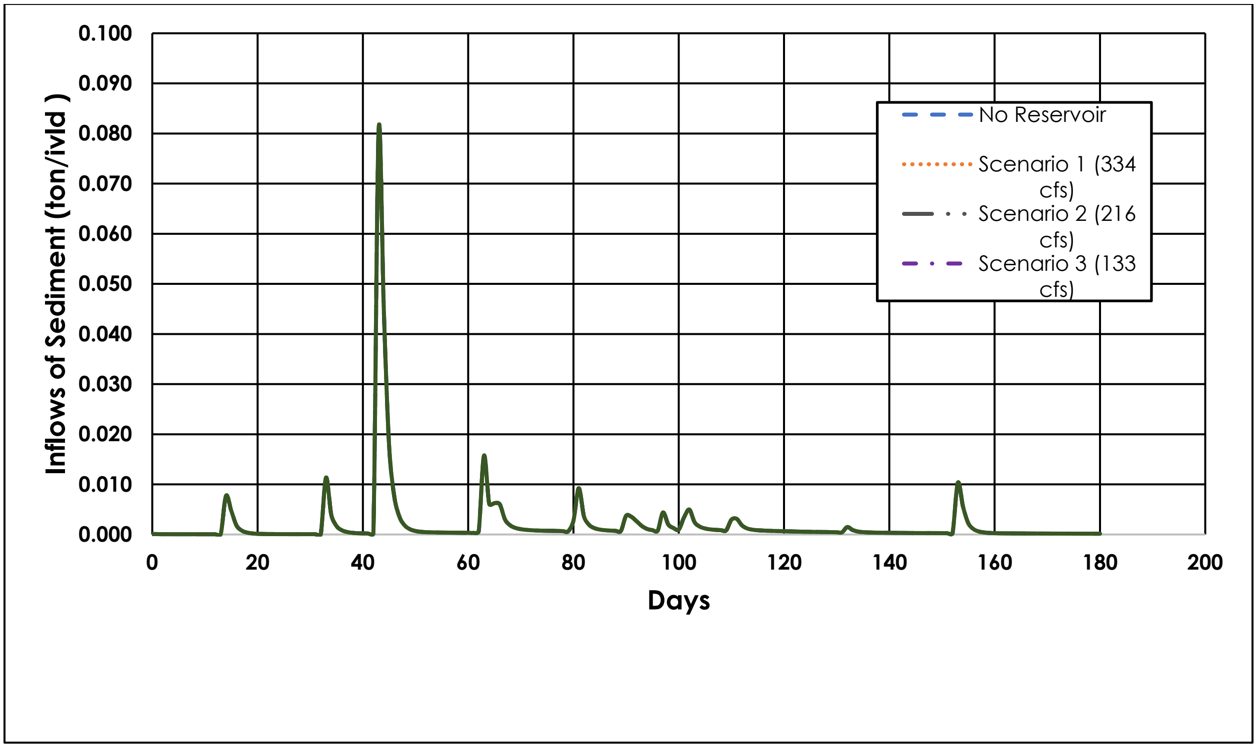

***Figure 43:** Sediment inflow into Oyster Creek downstream of proposed Harris Reservoir.*

The total suspended sediment concentration in Reach 3 of Oyster Creek is shown in **Figure 44** below. With the higher flows from the proposed reservoir, the concentration of suspended sediments decreases just downstream of the proposed Harris Reservoir in Oyster Creek. Higher flows in Oyster Creek transports the suspended sediments farther downstream, decreasing their concentration in Reach 3.

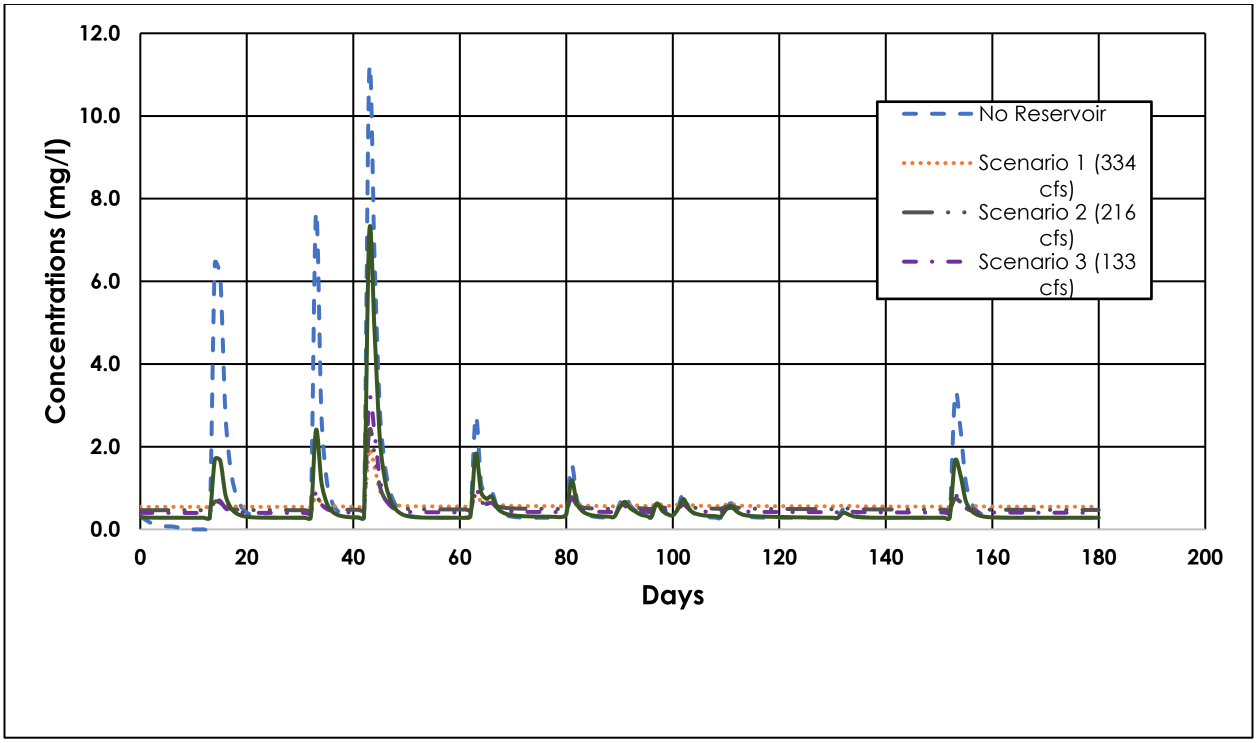

Figure 44: *Total suspended sediment concentration in Oyster Creek.*

One last model result examined was the water temperature in Oyster Creek downstream of proposed reservoir for all five scenarios. This parameter was used in aquatic assessment portion of this study (**Appendix A**). Water temperature in Oyster Creek decreases as the amount of outflow from the proposed Harris Reservoir increases. **Figure 45** shows the water temperature results from the HSPF model. The average water temperature in Oyster Creek before the proposed Harris Reservoir is 71.86 degrees Fahrenheit, whereas this value decreases by 19.87 degrees for Scenario 1, which has the highest constant flow out of the proposed Harris Reservoir into Oyster Creek. This scenario has an average water temperature of 52 degrees Fahrenheit. When there is more water, it takes longer for that water body to absorb heat from atmosphere.

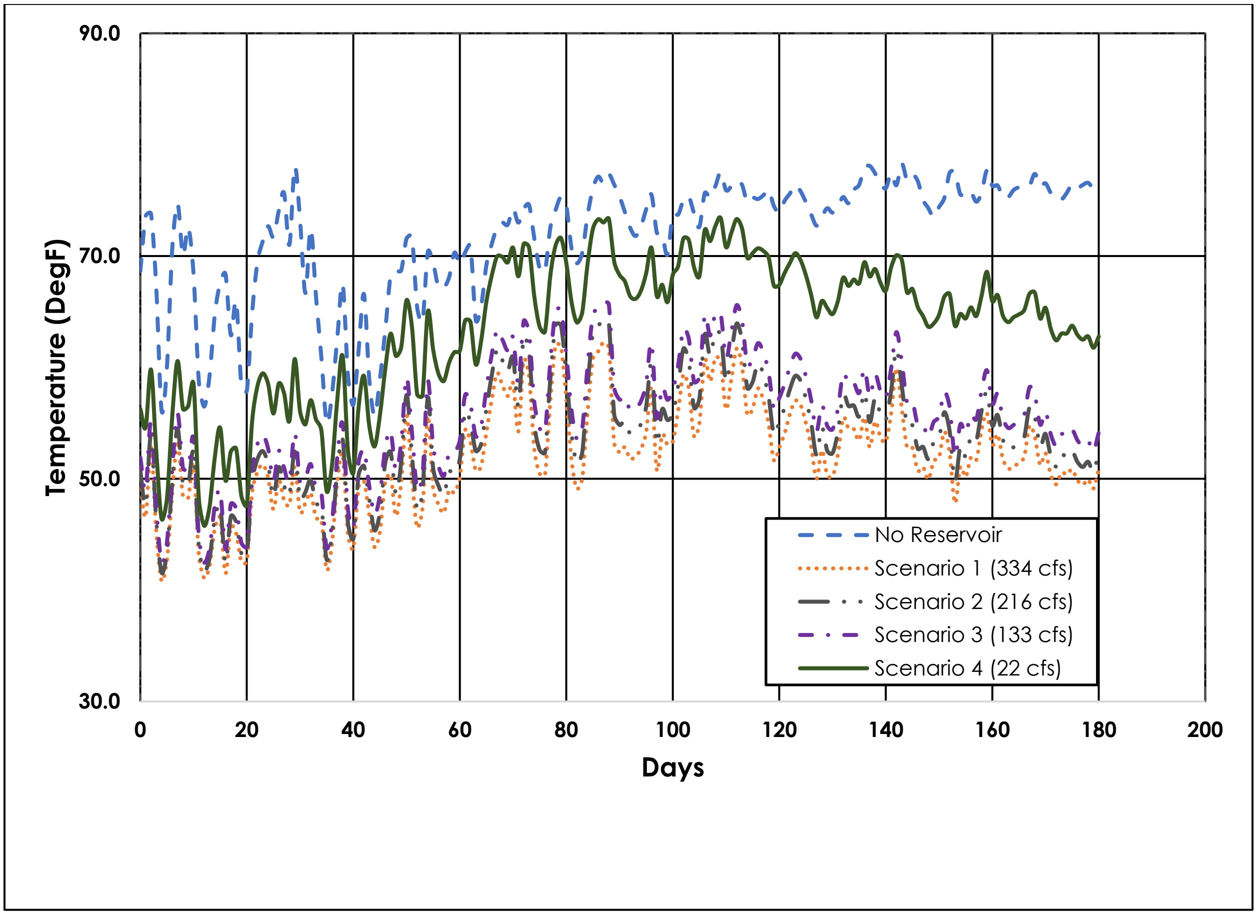

Figure 45: *Water temperature in Oyster Creek downstream of proposed reservoir.*

HSPF model results indicate that erosion and scour will increase as a result of construction of the proposed Harris Reservoir. Another effect would be on the water temperature. All these results are also used in the analysis of the proposed expansion on the aquatic environment, which is in **Appendix A**.

5.0 Conclusions

5.1 Downstream Impacts to Oyster Creek

The following conclusions can be drawn pertaining to downstream impacts of the proposed Harris Reservoir to Oyster Creek:

5.1.1. Hydrologic and Hydraulic Modeling for Design Storms

1. **Floodplain Storage Loss**
    a. Jacobs HEC-RAS model demonstrates no rise between existing and proposed conditions, but shows a loss of floodplain storage of 1,028 ac-ft .
    b. To address the 1,028 ac-ft loss of floodplain storage, the proposed Harris Reservoir will be operated to counter the effects due to the loss of floodplain storage. All of the results are summarized in **Table 36** and explained here in text. With no drawdown, there is no floodplain gain. With a 18-inch drawdown prior to a 100-year storm event and holding 6 inches of floodplain storage in the reservoir, there is a floodplain gain of 807 ac-ft. With a 1,028 ac-ft floodplain loss, this operational measure supplied a net loss of 221 ac-ft.
    c. The other operational measure modeled for 100-year design storm event is 18 inches of drawdown and 9 inches of storage held in the reservoir. This measure causes a gain of 1,309 ac-ft of floodplain, which results in a net gain of 281 ac-ft.
    d. The next operational measure for 100-year design storm event is 18 inches of drawdown before the storm and holding 12 inches of storage before spillway discharge. The model results for this measure show a floodplain gain of 1,632 ac-ft with a net gain of 604 ac-ft floodplain storage.
    e. The same operational measures were also modeled for 50-year design storm. The no-drawdown scenario for 50-year design storm shows no floodplain gain or loss.
    f. Drawing down the reservoir 18 inches prior to the storm event and holding 6 inches of storage for a 50-year storm event causes a floodplain gain of 993 ac-ft, which has a net floodplain gain of 468 ac-ft.
    g. For 50-year design storm, 18 inches of drawdown and holding 9 inches of storage causes a gross floodplain increase of 1,371 ac-ft and a net floodplain increase of 846 ac-ft.
    h. For 50-year design storm, drawing down the reservoir 18 inches before the storm event and holding 12 inches of storage results in a gross floodplain gain of 1,715 ac-ft and a net floodplain gain of 1,190 ac-ft.

Table 36: Floodplain Storage Gain/Loss with Operational Measures

	50-Year Design Storm					100-Year Design Storm			
	Floodplain Storage (ac-ft)								
	Loss of Floodplain Storage	No Draw-down	Proposed 18" Drawdown and 6" Floodplain Storage	Proposed 18" Drawdown and 9" Floodplain Storage	Proposed 18" Drawdown and 12" Floodplain Storage	No Draw-down	Proposed 18" Drawdown and 6" Floodplain Storage	Proposed 18" Drawdown and 9" Floodplain Storage	Proposed 18" Drawdown and 12" Floodplain Storage
50-year	-525	-525	+993	+1,371	+1,715	N/A	N/A	N/A	N/A
100-year	-1,028	N/A	N/A	N/A	N/A	-1,028	+807	+1,309	+1,632
Total		-525	+468	+846	+1,190	-1,028	-221	+281	+604

2. **Peak Flow Discharge**
    a. There are two peak flows in the HEC-RAS model results. A smaller magnitude peak flow associated with the design storm rainfall that arrives within days after the storm event has ceased. Later, there is a larger peak flow associated with the crossing of interbasin flows into Oyster Creek from the Brazos River that arrives weeks later and is larger in magnitude. The peak flows are generally higher in the proposed conditions model in comparison to the existing conditions model. This increase in flows increases the potential for erosion and hydromodification during larger storm events. All the reaches downstream of the proposed Harris Reservoir experience increases in peak flows. The reaches that experience peak flow impacts are reaches R-O3, R-O4, R-O5, R-O6, and R-O7.
    b. The peak flow increase is associated directly with the proposed Harris Reservoir blocking the interbasin flows from the Brazos River into Oyster Creek. The interbasin flows are modeled as lateral hydrographs in the unsteady HEC-RAS model and sources/sinks in the HEC-HMS. These hydrographs were not adjusted to account for routing or lagging in the watershed but were assumed to have the same timing and shape as overflows from Brazos River.
    c. As the interbasin flow hydrographs for both existing and proposed conditions are the same, the increase in peak is the result of the blockage of these interbasin flows by the proposed Harris Reservoir.
3. **Water Surface Elevations**
    a. The increase in peak flows shown in the HEC-HMS model demonstrates that there is potential for increases in the water surface elevations on the downstream reaches that are farther downstream than what was modeled in the Jacobs model. There is potential for water surface increases for R-O3, R-O4, R-O5, R-O6, and R-O7 between the existing Harris Reservoir (Junction J-O3) and the end of the model at Lake Jackson (Junction J-O7).

b. Watearth recommends the operation of proposed Harris Reservoir to include 18 inches of drawdown prior to a tropical storm event in combination with 12 inches of floodplain storage prior to discharge in order to lessen the peak flow impacts occurring at Junction J-O4, which experiences the highest increase of peak flow of all the modeled junctions. Further analysis is needed to either eliminate the WSEL increase and its potential effects on the floodplain and adjacent land structures.

5.1.2. Watershed Modeling for Drought Conditions

1. Based on modeling during 180 days of drought conditions, with the construction of the proposed Harris Reservoir, sediment erosion and scouring will increase downstream of the proposed in Oyster Creek. Among the four scenarios modeled in HSPF for drought conditions, the most scour occurs for Scenario 1, which has the highest constant outflow from the proposed Harris Reservoir. For this scenario, only scour happens. For Scenarios 3 and 4 (constant flows of 133 cfs and 22 cfs, respectively), deposition also occurs over the 180 days of simulation.

2. The erosion and scour will increase the concentration of suspended sediments in Oyster Creek downstream of the proposed Harris Reservoir. The amount of total sediment concentration flowing out of Reach 3, which is immediately downstream of the proposed Harris Reservoir, increases from 0.0508 tons/ac-ft for existing conditions to 0.0821 tons/ac-ft for Scenario 1, 0.0706 tons/ac-ft for Scenario 2, 0.0630 tons/ac-ft for Scenario 3, and 0.0530 tons/ac-ft for Scenario 4.

3. The average velocity in Oyster Creek will also increase as the discharge from the proposed Harris Reservoir increases. The average velocity in Oyster Creek for existing conditions is 1.68 ft/s. This value increases to 2.36 ft/s for Scenario 1 (334 cfs outflow from the proposed Harris Reservoir), 2.2 ft/s for Scenario 2 (216 cfs outflow from the proposed Harris Reservoir), 2.03 ft/s for Scenario 3 (133 cfs outflow from the proposed Harris Reservoir), and 1.71 cfs for Scenario 4 (22 cfs outflow from the proposed Harris Reservoir).

4. Model results indicate a decrease in water temperatures with outflows from the proposed Harris Reservoir into Oyster Creek, as well. The average water temperature in Oyster Creek for existing conditions is 78.29 degrees Fahrenheit. This value decreases to 62.25 degrees Fahrenheit for Scenario 1, 64.36 degrees Fahrenheit for Scenario 2, 65.88 degrees Fahrenheit for Scenario 3, 73.40 degrees Fahrenheit for Scenario 4.

5. Although not modeled, there will be some impact on Oyster Creek when constant discharge from the proposed Harris Reservoir stops after 180 days of operation. This could potentially impact bank erosion as velocity decreases and potentially impact vegetation on the banks. The wet bank soils would dry when the constant discharge stops causing erosion.

5.1.3. Aquatic Assessment

1. The outflows from the proposed Harris Reservoir will cause an increase in velocity in Oyster Creek that could cause increased sedimentation and turbidity downstream, as well as erosion and scour along the banks of Oyster Creek.

2. The outflows from the proposed Harris Reservoir will cause a decrease in temperature with increased outflows from proposed Harris Reservoir.

3. The outflows from the proposed Harris Reservoir will cause an increase in sedimentation and turbidity in Oyster Creek downstream of the proposed Harris Reservoir due to

increased erosion and scour. This increase in sedimentation could cause water quality issues and decrease clarity downstream.

4. With the increased velocity in Oyster Creek, there will be an environmental shift with less deposition and more scour. Sediments will be removed, therefore deepening the channel.
5. If vegetation is affected by increased velocity, lower temperatures, turbidity, and an influx of sedimentation, the protective measures that streambank vegetation provides will be lessened and could cause increased erosion on Oyster Creek.

5.2 Oyster Creek Flow Pattern Alteration

Oyster Creek is a highly modified drainage system. The Sienna Plantation diversion canal removes 67.28 sq mi of drainage (or 63-percent of drainage at the end of Project 2). This results in a lower peak flows and flow durations from the Sienna Plantation diversion to the Gulf of Mexico when taking into consideration the historical flow patterns before the diversion. This will result in a channel narrowing and a reduction in bankfull channel width over time. Oyster Creek will have more dry periods than it has historically, which can lead to a wetting/drying cycle that can enhance channel erosion.

The stream is being further modified by the geomorphic stream modification starting upstream of the proposed reservoir's northeast corner. The stream modification continues downstream with benching in Project 2 for enhanced riparian plant growth for overall channel stability. Project 3 is an overflow channel that eliminates the greater than 25-year flow from entering an approximately 2.95-mile oxbow in Oyster Creek before the overflow channel re-joins Oyster Creek again at the reservoir outlet channel. This geomorphic stream modification will stabilize the channel, allowing sediment deposited in the benched areas and more uniform velocities to transport sediment through the modified system, noting low sediment loads in reservoir discharges and possibly also natural flows from upstream of the proposed project. Reservoir releases will be from water deprived of sediment. This deprived water can cause stream channel incision and streambank erosion.

The reservoir outlet works will normally only operate when there is no natural/storm flow in Oyster Creek. The outlet sluice gates can operate over a wide range of discharges. These discharges can include emergency reservoir drawdown in preparation for a tropical storm, which may be at maximal allowable discharge during a short period of time due to period of warning provided. Since these releases may be made into a channel that is dry, the release rate needs to be such that the erosion potential of the deprived reservoir water is taken into consideration and is part of the operation plan.

5.3 Reservoir System

The new proposed reservoir will become part of the Dow water supply system, which consists of the following elements: the lower Brazos River, Oyster Creek, and three off-channel pump storage reservoirs. All elements of the system need to be and should be operated as a system.

The system should be operated by a fully functional plan called an operations plan. A comparable system could not be found with a similar plan for reference, but the operations plan needs to include the following:

1. When water will be pumped (what elevation in each reservoir will be the indicator); and
2. Water releases from each reservoir

a. Rate of release

 i. Initial or changes in release rates and duration to reduce channel and bank erosion because of wet and dry cycles

 ii. Controlled planned reductions in release rates. Sudden reduction can cause stream bank instability and bank sloughing.

 iii. The proposed Harris Reservoir causes blockage to interbasin flows from the Brazos River into Oyster Creek. This causes increases in peak flows following 50- and 100-year storm events. To address this, the design of the proposed reservoir can be modified to keep the natural overflow paths, or a conveyance route can be established for interbasin basin flows that are blocked by the proposed Harris Reservoir (especially B11 and B12 in the HEC-HMS model).

 iv. Another measure to address the blockage of interbasin flows from the proposed Harris Reservoir would be to have an additional detention storage to store 50- and 100- year storm events and mimic the current timing of overflows from the Brazos River into Oyster Creek. This would also help decrease the potential water surface elevation increases due to peak flow increases.

b. Water quality releases from all three reservoirs

 i. Visual indicators need to be listed

 ii. Chemical testing indicators need to be listed.

The system should also have a maintenance plan and program. A comparable system could not be found with a similar plan for reference, but the maintenance plan needs to include the following items that are to be inspected on at least an annual basis or more often, as necessary:

1. Reservoir embankments
    a. Adequately vegetated and mowed
    b. No trees or brush on embankment
    c. No embankment cracks, settlement, or bulges present
    d. No embankment erosion from rainfall or wave action
    e. No animal holes or burrows present
    f. Excessive seepage should be repaired
    g. Foundation and toe drains should be functional
2. Inlets and outlets
    a. Concrete deterioration
    b. Conduits structural sound
    c. Pumps maintained
    d. Gates and valves maintained
    e. Metal corrosion
    f. Fences and guardrails are secure

3. Channels
    a. Maintain channel dimensions and slope
    b. Maintain vegetation where applicable
    c. Remove undesired vegetation
    d. Remove debris and sediment when necessary
    e. Repair channel and bank erosion
4. Reservoirs
    a. Sediment should be removed on a rotational schedule from each of the three reservoirs to maintain reservoir storage capacity (i.e., every 10 years) and maintain a clear path to the outlet structures (siphons)
    b. Maintain good water quality in all three reservoirs at all times

These O&M plans should be reviewed annually to make any needed updates and changes. Training should be given to all employees who use the operation plans to manage the system so they understand the processes. The maintenance inspections should be completed by qualified individuals with knowledge of water resources concerning embankments, channels, and water resources. The maintenance inspection shall be documented with any items that need correction and then followed up with documentation when the corrective action is completed.

6.0 References

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Oyster Creek Downstream Hydrologic and Hydraulic Impacts Final Report

Appendix A

Aquatic Assessment Report

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Oyster Creek Hydrologic and Hydraulic Impacts

Draft Report

Appendix B

Clark's Method Hydrologic Parameters

Appendix C

HCFCD Conveyance Discharge Curve

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Appendix D

Locations of Effective Cross-Sections

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Appendix E

Meteorological Station (TX 722527) Data

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Appendix F

USGS 0807900 Gage Discharge Data

Appendix G

Evapotranspiration Data from EPA Storm Calculator

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Appendix H

Proposed Harris Reservoir Expansion Elevation-Volume Relationship

Appendix I

HSPF Model Results