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2017 Coastal Master Plan

Attachment C3-26: Hydrology and Water Quality Boundary Conditions

Report: Final

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Coastal Protection and Restoration Authority

This document was prepared in support of the 2017 Coastal Master Plan being prepared by the Coastal Protection and Restoration Authority (CPRA). CPRA was established by the Louisiana Legislature in response to Hurricanes Katrina and Rita through Act 8 of the First Extraordinary Session of 2005. Act 8 of the First Extraordinary Session of 2005 expanded the membership, duties and responsibilities of CPRA and charged the new authority to develop and implement a comprehensive coastal protection plan, consisting of a master plan (revised every five years) and annual plans. CPRA's mandate is to develop, implement and enforce a comprehensive coastal protection and restoration master plan.

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Executive Summary

The Coastal Protection and Restoration Authority of Louisiana (CPRA) has refined existing modeling tools and developed new tools for use in the 2017 Coastal Master Plan. Considering the effort to update the technical tools for the master plan, it is critical to ensure that the most up-to-date data were used to drive the newly developed Integrated Compartment Model (ICM) calibration and validation. As part of the task to improve input datasets and boundary conditions, a list of the data collection stations used in the 2012 Coastal Master Plan was assembled and newly available stations and sources of data to support improvements were added. The final list of data sources and stations was reviewed and approved by the broader modeling team.

Similar to the 2012 Coastal Master Plan, daily riverine inflow, hourly tidal stage, daily and discrete water quality, and daily precipitation and evapotranspiration data used to drive the ICM were collected from the following:

- United States Geological Survey (USGS);
- United States Army Corps of Engineers (USACE);
- National Oceanic and Atmospheric Administration (NOAA);
- National Oceanographic Data Center (NODC);
- Louisiana Department of Environmental Quality (LDEQ);
- Texas Commission on Environmental Quality (TCEQ); and
- National Climatic Data Center (NCDC).

Missing data in the time-series were addressed using fitted relationships and linear interpolation where appropriate.

To inform the offshore stage boundary, water levels from four NOAA stations and one USGS station along the coast were used at the model offshore boundary. These stations, however, did not provide reliable datum conversions to the datum used by the ICM (North American Vertical Datum of 1988 Geiod12A (NAVD88 12A)) nor did they correct for subsidence and eustatic sea level rise (ESLR). The USACE Southwest Pass gage was used to convert to the NAVD88 Geoid12A datum and correct for subsidence and ESLR. Additionally, further datum adjustments were made to minimize differences between the modeled stages and measured stages from CPRA's Coastwide Reference Monitoring System (CRMS) stations which provided a consistent reference water level across the Louisiana coast near the Gulf of Mexico.

To obtain a better representation of the salinity in the offshore area, hourly salinity data from near-shore stations (as used in the 2012 Coastal Master Plan) were replaced with data from the National Oceanographic Data Center's (NODC) World Ocean Database (WOD). WOD is a database of Gulf of Mexico measurements including salinity. These data were used to inform spatially varying but temporally constant salinity concentrations at the model offshore boundaries.

Wind data which was not originally used in the 2012 Coastal Master Plan were collected from National Climatic Data Center's (NCDC) North American Regional Reanalysis (NARR) Model. The 'reanalysis' incorporates observations from instruments and then assigns this output onto a regularly spaced grid of data (approximately 32 km x 32 km).

The updated and improved datasets will be used as input data for the 2017 Coastal Master Plan models. These up-to-date and improved sources of data, the refinement of existing modeling

tools, and the development of new tools will improve the quality of the 2017 Coastal Master Plan models.

All raw and post-processed datasets are located in the 2017 Coastal Master Plan Data Repository.

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List of Abbreviations

AUV	Autonomous Underwater Vehicles
CPRA	Coastal Protection and Restoration Authority
CRMS	Coastwide Reference Monitoring System
CTD	Conductivity-Temperature-Depth
ESLR	Eustatic Sea Level Rise
GLD	Glider
ICM	Integrated Compartment Model
Institute	The Water Institute of the Gulf
LDEQ	Louisiana Department of Environmental Quality
M&N	Moffatt & Nichol
MSL	Mean Sea Level
NARR	North American Regional Reanalysis
NAVD88	North American Vertical Datum (of 1988)
NCDC	National Climatic Data Center
NOAA	National Oceanic and Atmospheric Administration
NODC	National Oceanographic Data Center
OSD	Ocean Station Data
ppt	Parts per Thousand
PFL	Profiling Float
STD	Salinity-Temperature-Depth
TCEQ	Texas Commission on Environmental Quality
USACE	United States Army Corps of Engineers
USGS	United States Geological Survey
WAVCIS	Wave-Current-Surge Information System
WOD	World Ocean Database

1.0 Introduction

The Coastal Protection and Restoration Authority of Louisiana (CPRA) refined a number of existing modeling tools and developed new tools for use in the 2017 Coastal Master Plan. One aspect of these improvements was to update the hydrology and water quality boundary conditions datasets. This document details this effort; the scope of work included:

- Gather updated tidal water level, tidal salinity, riverine inflow, wind, wave, and water quality input data sets needed to set the boundary conditions for model calibration and validation;
- Assess the data sets for completeness and consistency and fill any data gaps using correlations or other filling techniques;
- Prepare the files for use by other team members; and
- Submit the files for archiving.

During the data collection campaign the following changes were made to the scope of work:

- Precipitation and evapotranspiration datasets were added to the list of data to be collected and processed as they are needed for model calibration and validation; and
- Wave datasets were collected but not processed as they are not needed as a boundary condition for model calibration and validation.
- The National Oceanic and Atmospheric Administration (NOAA) station 8735180 at Dauphin Island, Mobile Bay, AL water level dataset was added to the list of data to be collected to represent the eastern portion of the offshore boundary.

1.1 Final Stations List

A list and map of the original stations used from the 2012 Coastal Master Plan and newly available stations were distributed to the modeling teams for input on the adequacy of the stations to generate the ICM boundary conditions. Taking the responses into consideration, Table 1 in Attachment C3-26.1: Monitoring Station List identifies the final list of stations from which data was collected.

The following sections detail the collection and processing of this data.

2.0 Hydrologic Data

2.1 Riverine Inflow

2.1.1 Data Collection

Daily averaged riverine inflow or discharge data from January 2006 to May 2014 was downloaded from the United States Geological Survey (USGS)[1] website and United States Army

[1] http://www.usgs.gov/water/

Corps of Engineers (USACE)[2] using the dssvue software. Figure 1 shows the location of discharge stations and Table 1 provides stations' information.

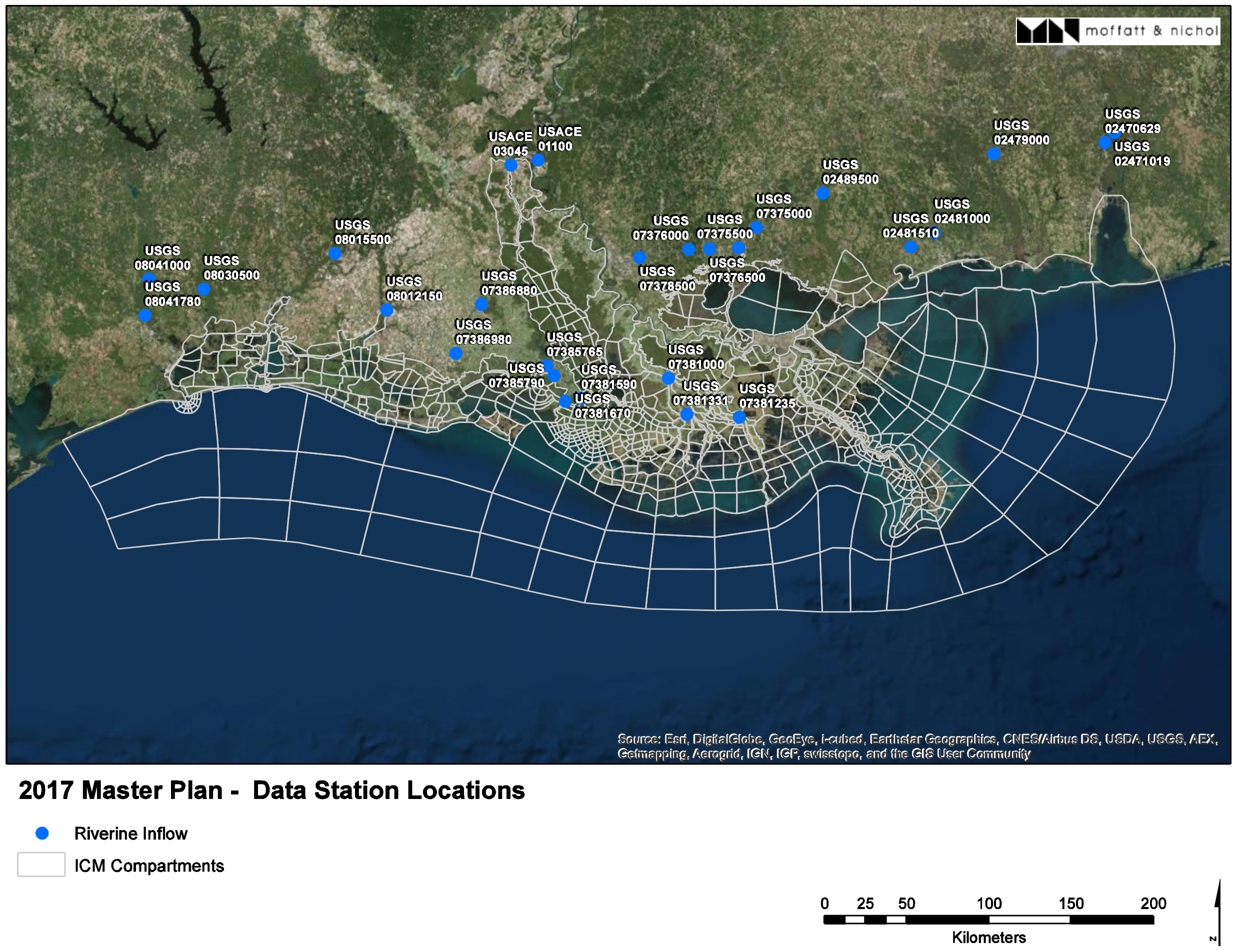

Figure 1: Riverine Inflow Station Locations.

Table 1: Riverine Inflow Station.

Agency	Station ID	Station Name	Latitude	Longitude
USACE	01100	Mississippi River at Tarbert Landing, MS	31.008083	-91.623611
USACE	03045	Atchafalaya River at Simmesport, LA	30.982500	-91.798333
USACE	MorgSpwy	Morganza Spillway	30.778700	-91.622600
USGS	02470629	Mobile River at River Mile 31 at Bucks, AL	31.015736	-88.020832

[2] http://www.hec.usace.army.mil/software/hec-dssvue/

Agency	Station ID	Station Name	Latitude	Longitude
USGS	02471019	Tensaw River near Mount Vernon, AL	31.067123	-87.958609
USGS	02479000	Pascagoula River at Merrill, MS	30.978056	-88.726944
USGS	02481000	Biloxi River at Wortham, MS	30.558611	-89.121944
USGS	02481510	Wolf River near Landon, MS	30.483611	-89.274444
USGS	02489500	Pearl River near Bogalusa, LA	30.793243	-89.820907
USGS	07375000	Tchefuncte River near Folsom, LA	30.616022	-90.248695
USGS	07375500	Tangipahoa River at Robert, LA	30.506580	-90.361752
USGS	07376000	Tickfaw River at Holden, LA	30.503802	-90.677316
USGS	07376500	Natalbany River at Baptist, LA	30.504358	-90.545924
USGS	07378500	Amite River near Denham Springs, LA	30.464079	-90.990380
USGS	07381000	Bayou Lafourche at Thibodeaux, LA	29.797985	-90.822593
USGS	07381235	GIWW West of Bayou Lafourche at Larose, LA	29.577222	-90.380833
USGS	07381331	GIWW at Houma, LA	29.598056	-90.710000
USGS	07381590	Wax Lake Outlet at Calumet, LA	29.697986	-91.372885
USGS	07381670	GIWW at Bayou Sale Ridge near Franklin, LA	29.680833	-91.470556
USGS	07385765	Bayou Teche at Adeline Bridge near Jeanerette, LA	29.879372	-91.586225
USGS	07385790	Charenton Drainage Canal at Baldwin, LA	29.823056	-91.541667
USGS	07386880	Vermilion River at Surrey St. at Lafayette, LA	30.217423	-91.992897
USGS	07386980	Vermilion River at Perry, LA	29.951111	-92.156361
USGS	08012150	Mermentau River at Mermentau, LA	30.190000	-92.590556
USGS	08012470	Bayou Lacassine near Lake Arthur, LA	30.070000	-92.878861
USGS	08015500	Calcasieu River near Kinder, LA	30.502556	-92.915417
USGS	08030500	Sabine River at Ruliff, TX	30.303817	-93.743778

Agency	Station ID	Station Name	Latitude	Longitude
USGS	08041000	Neches Rv at Evadale, TX	30.355764	-94.093237
USGS	08041780	Neches River at Beaumont, TX	30.156878	-94.114347

2.1.2 Data Processing

A data gap analysis was performed on the raw data from each station identifying the data gap locations and durations. The following rules were used for addressing data gaps:

(1) Data gaps for stations with a maximum data gap duration less than 3 days were filled using linear interpolation;
(2) Data gaps for stations with a maximum data gap duration greater than 3 days were filled using a rating curve (described below).

For stations with a maximum data gap duration greater than 3 days, stage-discharge (Q-H) rating curves and discharge-discharge (Q-Q) rating curves were developed and used to fill the data gaps. A stage-discharge rating curve is a relationship between the stage (independent data) and discharge (dependent data) of the target station in which the discharge can be estimated for a given stage. A discharge-discharge rating curve is a relationship between the discharge of the target station (dependent station) and the discharge of a separate station (independent station). The target station's discharge can be estimated for a given discharge of the independent station. The strength of these relationships can be quantified by the correlation coefficient between the two data sets calculated using the following equation:

$$R = \frac{\sum_{i=1}^{n}(X_i - \bar{X})\,(Y_i - \bar{Y})}{\sqrt{\sum_{i=1}^{n}(X_i - \bar{X})^2}\,\sqrt{\sum_{i=1}^{n}(Y_i - \bar{Y})^2}} \tag{1}$$

where X and Y are the independent and dependent data, respectively, and a "bar" denotes the sample mean. The values of *R* range from +1 to -1 where values close to +1 and -1 represent a strong positive and negative correlation, respectively, and values close to zero represent a weak or no correlation. The strongest relationship among all correlations was selected and used as the first iteration to address the data gaps. Due to data gaps also occurring in the independent data, not all data gaps were addressed. The remaining data gaps in the dependent data were filled using linear interpolation. Table 2 identifies the station agency and ID, corresponding percent complete of the data between January 2006 to May 2014 and maximum data gap duration, correlation type and station used for data gap filling, and corresponding correlation coefficient.

Table 2: Riverine Inflow Station Data Gap Analysis and Filling Information.

Agency	Station ID	% Complete	Maximum Gap Duration (days)	Correlation		
				Type	Station	R value
USACE	01100	99%	2	Linear	--	--
USACE	03045	99%	4	Q-Q	USACE 01100	1.00
USGS	02470629	96%	27	Q-H	USGS 02470629	0.92[3]
USGS	02471019	96%	27	Q-Q	USGS 02470629	1.00
USGS	02479000	99%	5	Q-Q	USGS 02489500	0.82
USGS	02481000	100%	0	--	--	--
USGS	02481510	100%	0	--	--	--
USGS	02489500	100%	0	--	--	--
USGS	07375000	100%	0	--	--	--
USGS	07375500	100%	0	--	--	--
USGS	07376000	99%	2	Linear	--	--
USGS	07376500	99%	2	Linear	--	--
USGS	07378500	100%	0	--	--	--
USGS	07381000	91%	45	Q-H	USGS 07381000	0.46
USGS	07381235	84%	77	Q-Q	USGS 07381331	0.63
USGS	07381670	85%	120	Q-Q	USGS 07381590	0.97
USGS	07385790	91%	57	Q-Q	USGS 07385765	0.68[4]
USGS	07386980	90%	72	Q-Q	USGS 07386880	0.49
USGS	08012150	91%	74	Q-H	USGS 08012150	0.83
USGS	08012470	0%	3,470	Q-Q	USGS 08012150	0.69
USGS	08015500	100%	0	--	--	--
USGS	08030500	100%	0	--	--	--
USGS	08041780	87%	365	Q-Q	USGS 08041000	0.90

The correlation between the discharge and stage for USGS station 02470629 was truncated to exclude stages above 2.5 m (gage datum) due to an unknown abrupt shift in the relationship for stages above 2.5 m (see Figure 2). Data gaps corresponding to stages above 2.5 m were filled using linear interpolation.

The correlation between the discharge of USGS station 07385790 and USGS station 07385765 was truncated to exclude discharge above 60 m^3/s due to an unknown downward shift in the relationship (see Figure 3). Data gaps corresponding to discharge above 60 m^3/s for USGS 07385765 were filled using linear interpolation.

[3] Truncated correlation for H below 2.5 m gage datum

[4] Truncated correlation for USGS 07385765 Q below 60 m^3/s

The USGS station 08012470 was decommissioned in 2005. Data from 1987 to 2005 was used to generate a correlation to USGS station 08012150. This was the best relationship available to generate the 2006 – 2014 time-series for USGS 08012470.

Two of the eleven stations' correlation coefficients for which correlations were developed fell below 0.60. The stage-discharge correlation coefficient used for USGS station 07381000 of 0.46 was the strongest correlation developed including discharge-discharge correlations to upstream and downstream stations. The discharge-discharge correlation coefficient used for USGS stations 07386980 (Perry) and 07386880 (Surrey) of 0.49 (see Figure 4) was a surprisingly low value for the apparent linearity of the plot. It is likely the higher positive flows at the Perry station corresponding to negative flows at the Surrey station negatively impacted the correlation. The stage-discharge correlation coefficient for USGS station 07386980 was calculated to be 0.53 (see Figure 5). It is important to note, however, that the high stage and high flow events made the relationship appear stronger than it was. Excluding these much lower frequency events of water levels above 2 m produced a correlation coefficient of only 0.31 (see Figure 6), which was much weaker than the 0.49. Therefore the strongest relationship (correlation coefficient of 0.49) to the discharge of USGS station 07386880 was used.

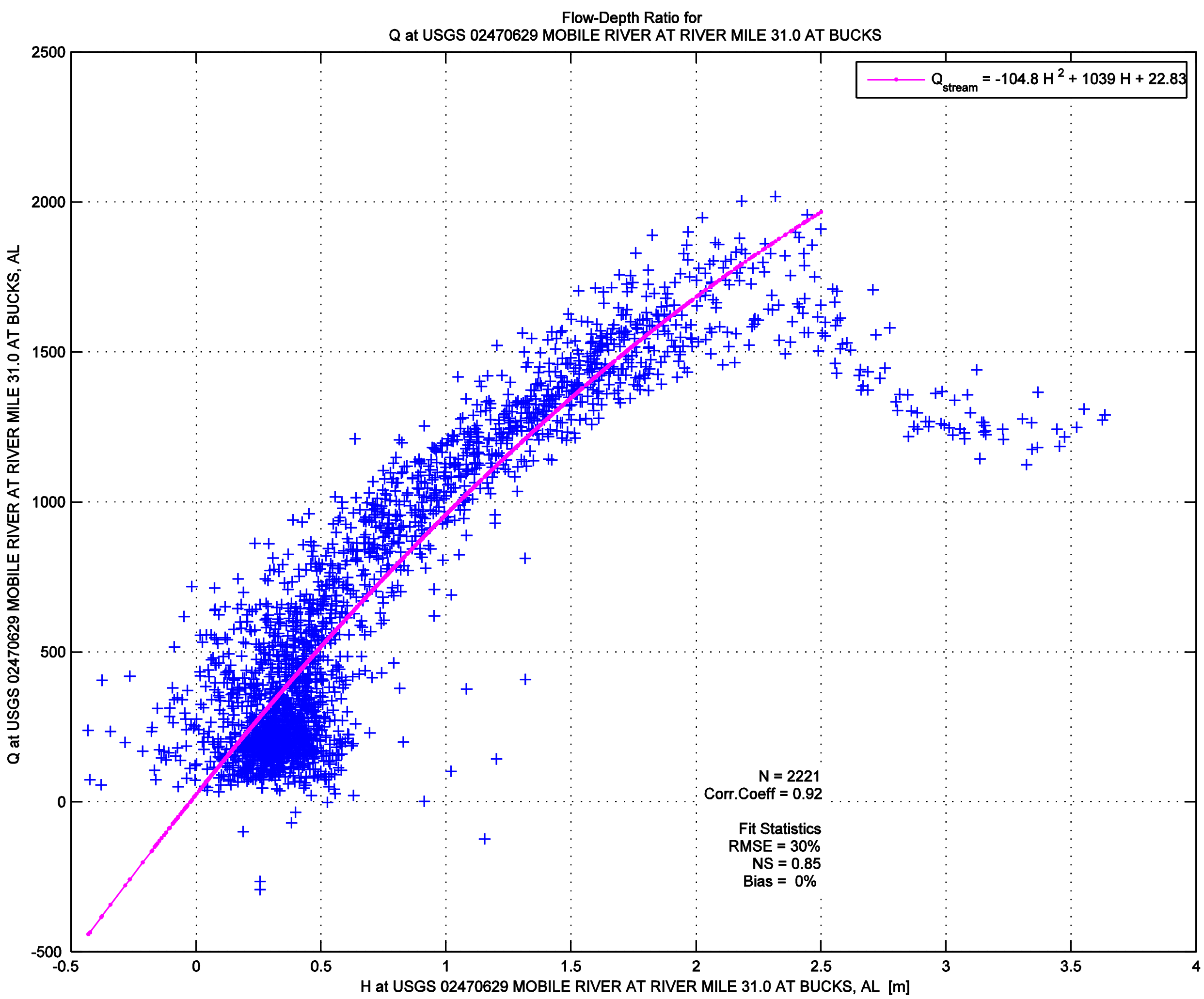

Figure 2: Truncated Correlation between USGS 0270629 Discharge and Stage.

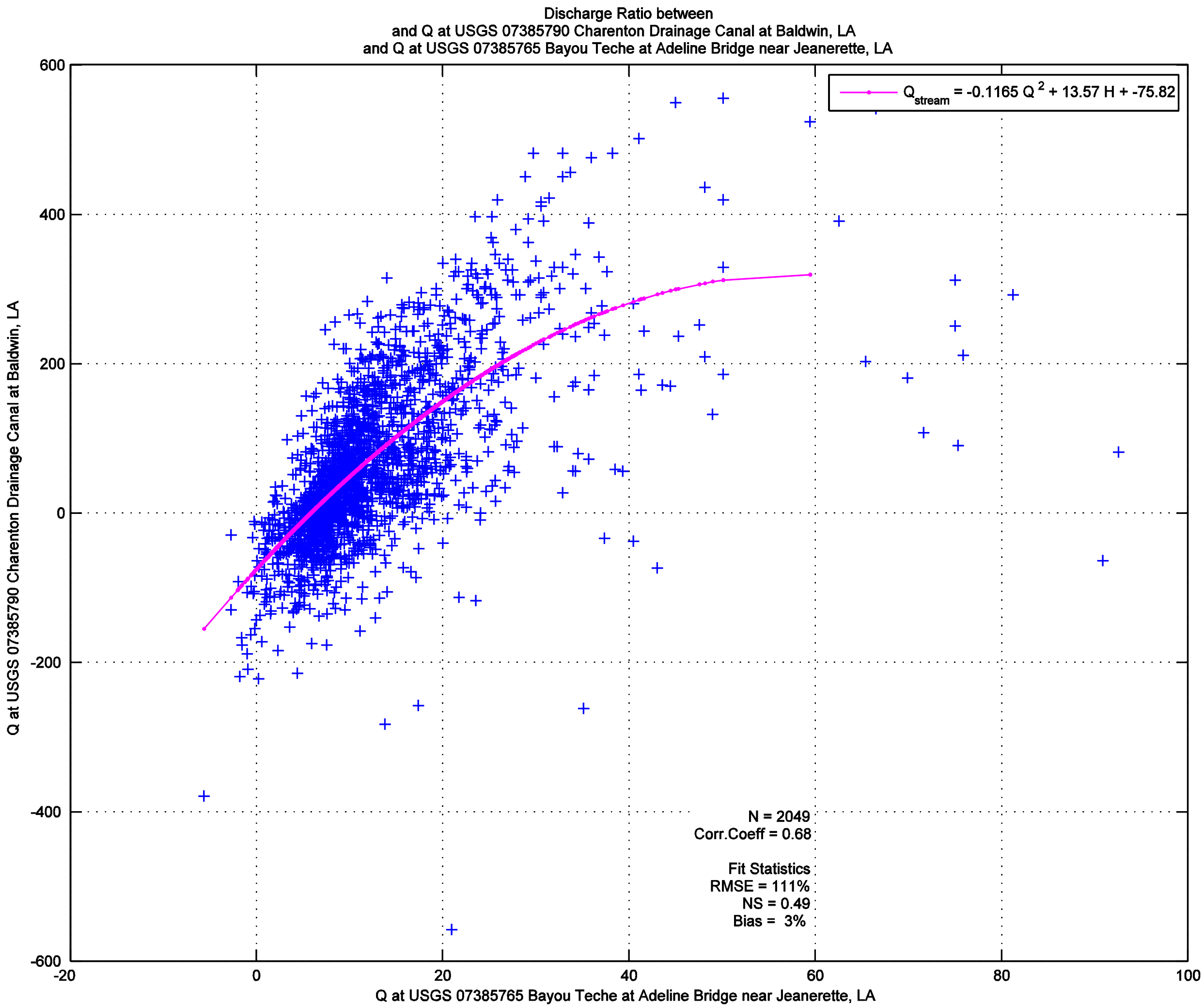

Figure 3: Truncated Correlation between Discharge of USGS 07385790 and USGS 07385765.

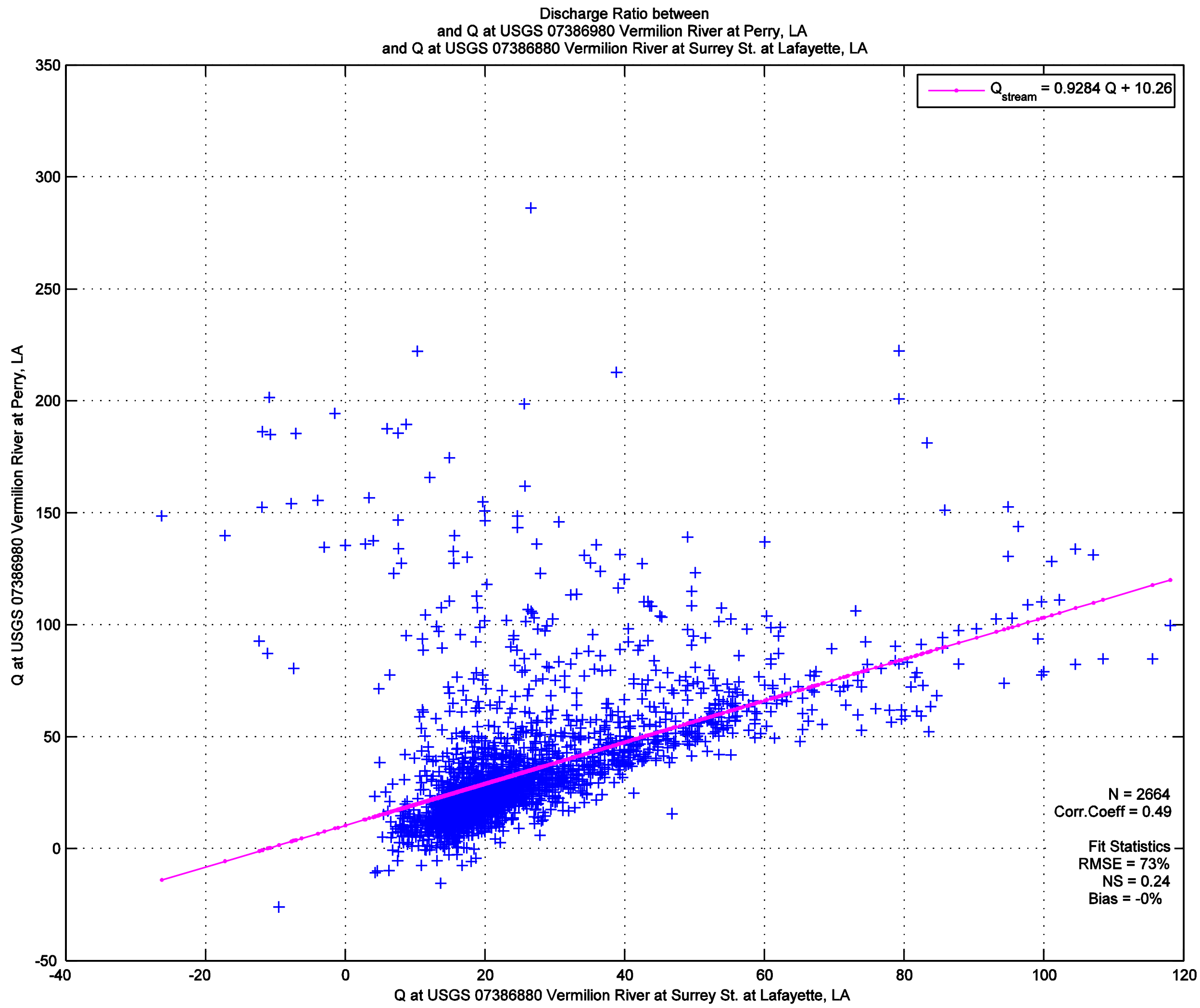

Figure 4: Correlation between USGS 07286980 Discharge and USGS 07386880.

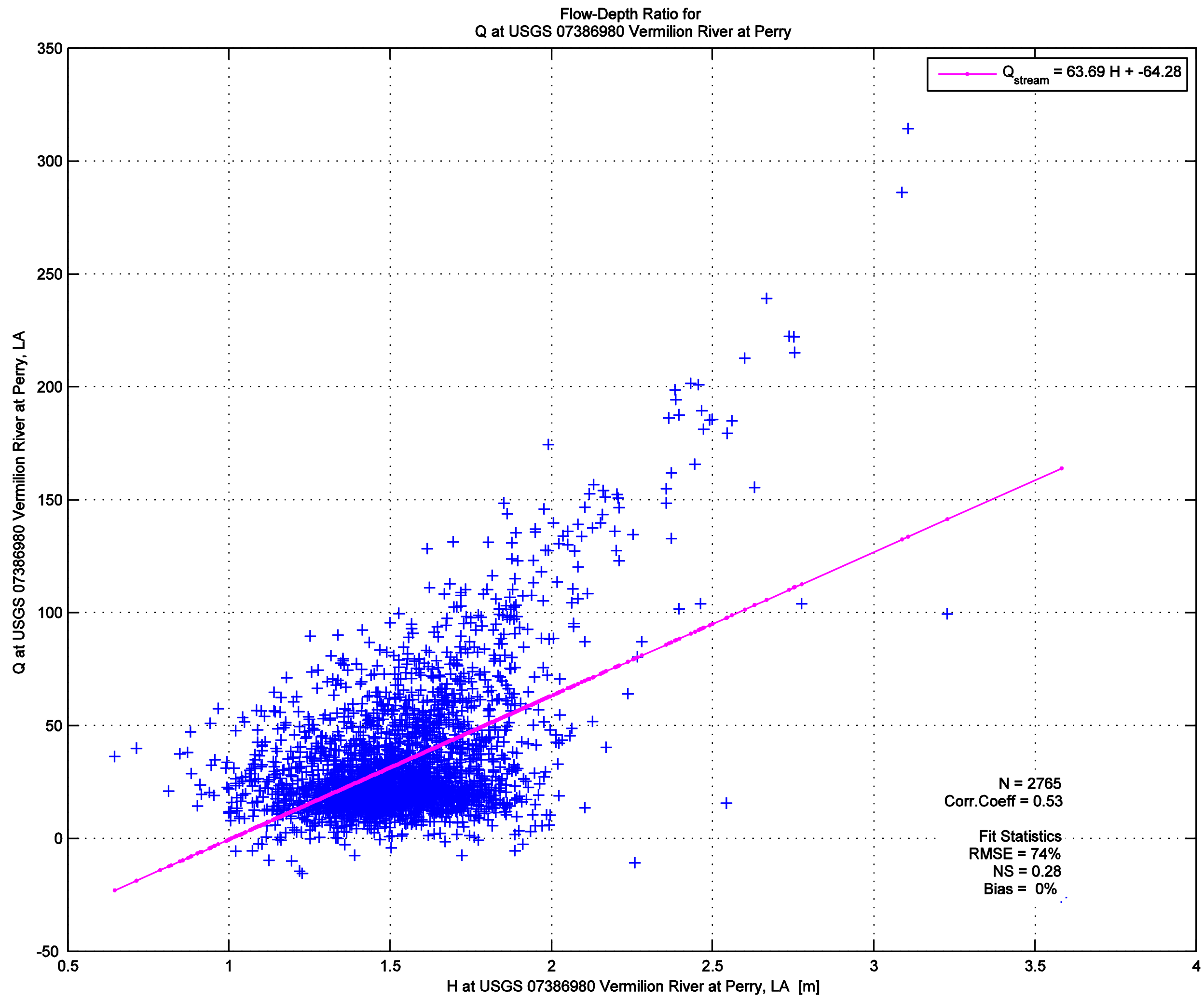

Figure 5: Correlation between USGS 07286980 Discharge and Stage.

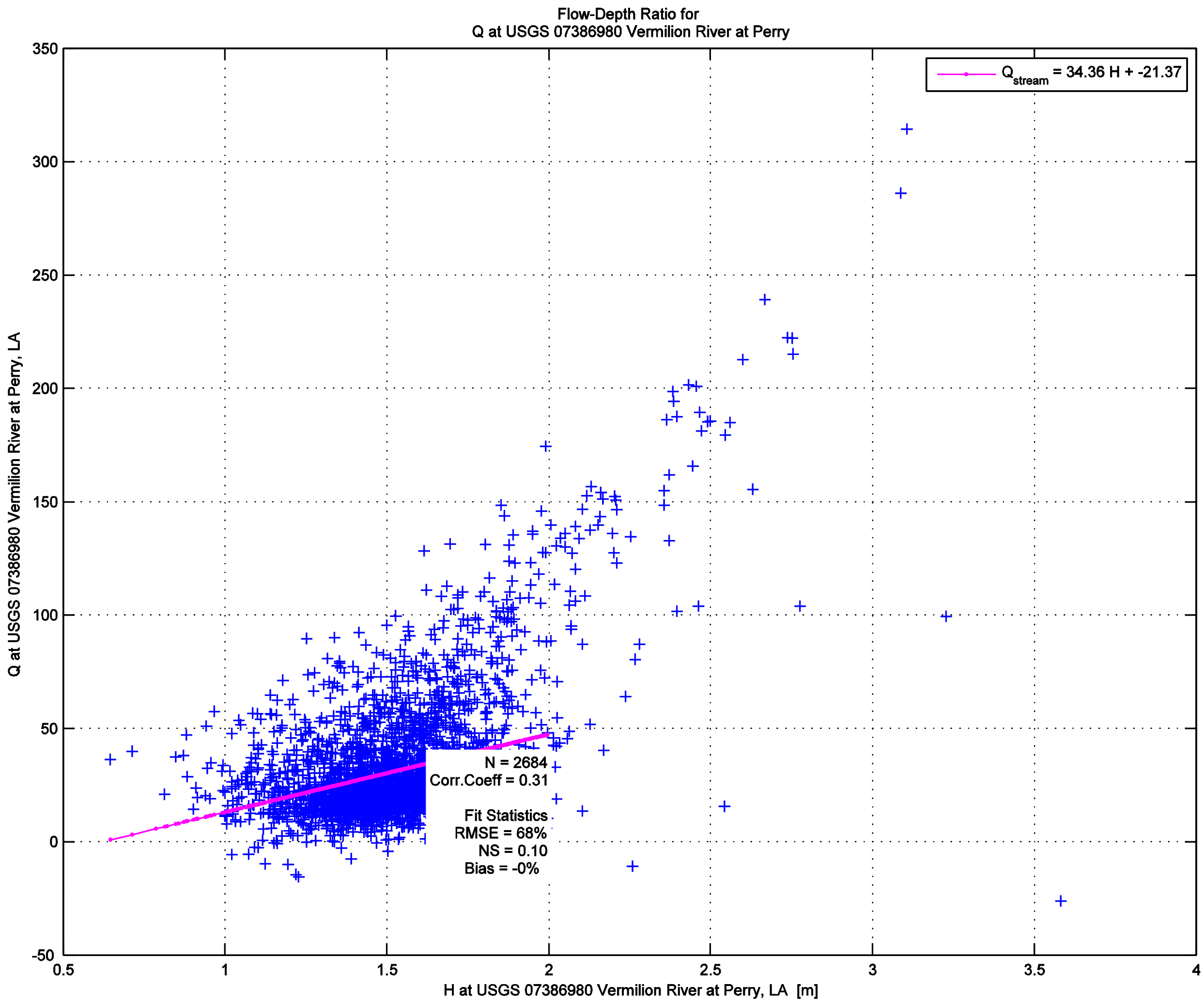

Figure 6: Truncated Correlation between USGS 07286980 Discharge and Stage.

Attachment C3-26.2: Flow Data contains figures and information for the data gap analyses. The following are included for each station:

(1) Data gap analysis;
(2) Selected correlation;
(3) Data gaps filled using correlation (top) and linear interpolation (bottom); and
(4) Filled time-series (top), raw time-series (middle), and correlated time-series (bottom).

All raw and post-processed data time-series are located in the 2017 Coastal Master Plan Data Repository.

2.1.3 Model Implementation

When using gages north of the project domain, the amount of interception/overflow storage and runoff is unknown. Therefore, a 'Qmult' factor is applied to the discharge record to increase or reduce the observed flow. The 'Qmult' factors were adjusted as part of model calibration to provide a better fit to the observed stages.

2.2 Tidal Water Level

2.2.1 Data Collection

Hourly averaged tidal water level data from January 2006 to May 2014 was downloaded from the National Oceanic and Atmospheric Administration (NOAA)[5], USACE, and USGS websites. Figure 7 shows water level station locations and Table 3 provides information for the stations that data was collected from and used.

The NOAA 8764227 Lawma, Amerada Pass, LA station is located in the Atchafalaya River Delta and as such, the water levels become elevated above those offshore. During initial model calibration, applying these elevated water levels offshore caused an artificial elevation in water levels throughout the central portion of the model domain. To alleviate this issue, water levels from USGS 073813498 in Caillou Bay, located offshore of Caillou Lake far from any riverine influence, were used in place of the NOAA 8764227 water levels.

[5] http://tidesandcurrents.noaa.gov/

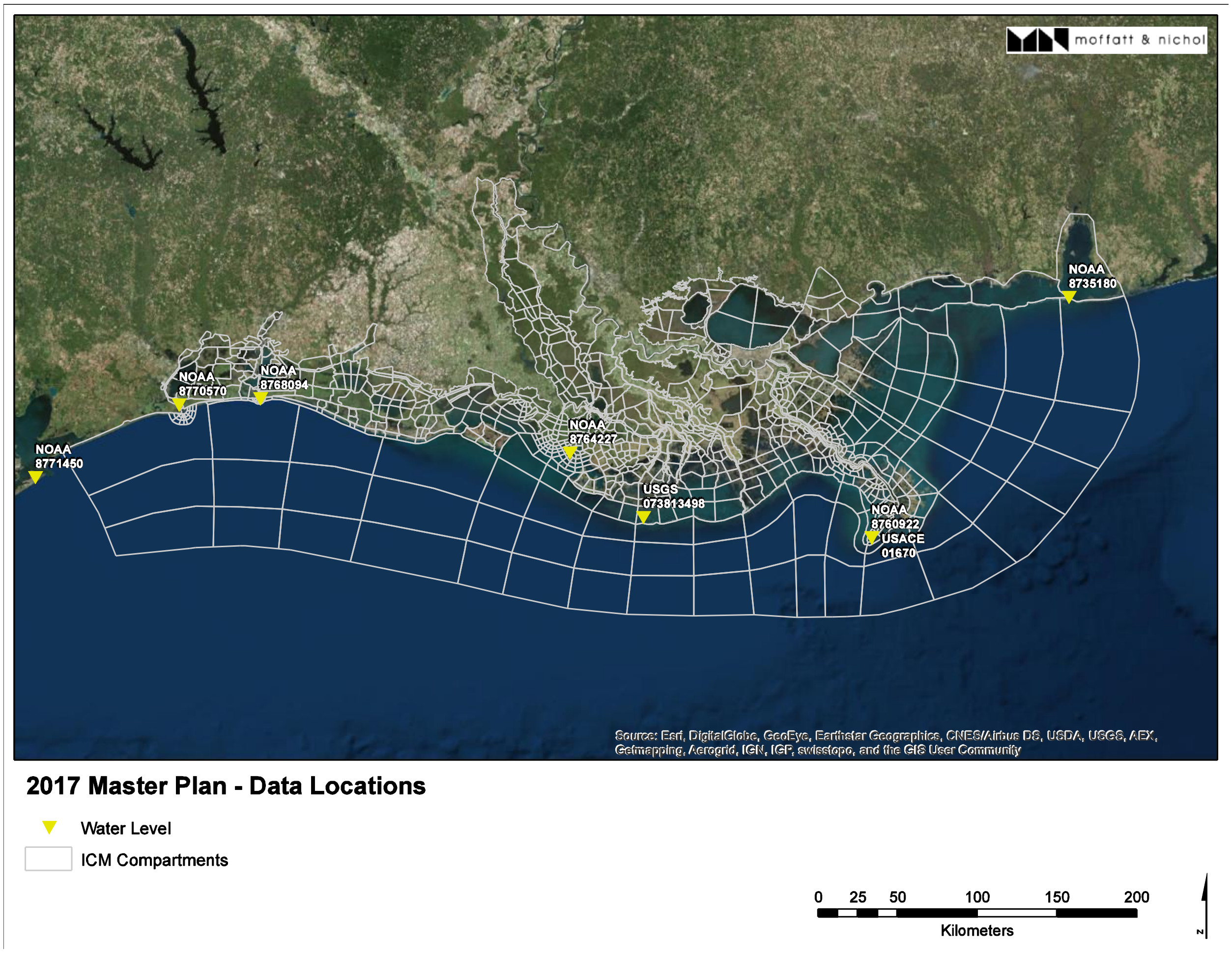

Figure 7: Tidal Water Level Station Locations.

Table 3: Tidal Water Level Stations.

Agency	Station ID	Station Name	Latitude	Longitude
NOAA	8735180	Dauphin Island, Mobile Bay, AL	30.250000	-88.075000
NOAA	8760922	Pilots Station East, Southwest Pass, LA	28.931667	-89.406667
NOAA	8764227	Lawma, Amerada Pass	29.450000	-91.340000
NOAA	8768094	Calcasieu Pass	29.768000	-93.340000
NOAA	8770570	Sabine Pass North	29.730000	-93.870000
NOAA	8771450	Galveston Pier 21, Texas	29.310000	-94.793333
USACE	01670	Southwest Pass Gauge	28.932305	-89.407111
USGS	073813498	Caillou Bay SW of Cocodrie	29.078056	-90.871389

2.2.2 Data Processing

A data gap analysis was performed on the raw data from each station identifying the data gap locations and durations. The following rules were used for addressing data gaps:

(1) Data gaps for stations with a maximum data gap duration less than 3 hours were filled using linear interpolation;
(2) Data gaps for stations with a maximum data gap duration greater than 3 hours were filled using a rating curve (described below).

For stations with a maximum data gap duration greater than 3 hours, stage-stage (H-H) rating curves were developed. A stage-stage rating curve is a relationship between the stage of the target station (dependent station) and the stage of a separate station (independent station). The stage of the target station can be estimated for a given stage of the independent station. The strength of the relationships can be quantified by the correlation coefficient (defined in Section 2.1.2). The strongest relationship among all correlations was selected and used as the first iteration to address the data gaps. Due to data gaps also occurring in the independent data, not all data gaps were addressed. The remaining data gaps were filled using linear interpolation. Table 4 identifies the station agency and ID, corresponding percent complete of the data between January 2006 to May 2014 and maximum data gap duration, correlation station used for data gap filling, and corresponding correlation coefficient.

Table 4: Tidal Water Level Station Gap Analysis and Filling Information.

Agency	Station ID	% Complete	Maximum Gap Duration (hours)	Correlation Station	R
NOAA	8735180	98%	1123	NOAA 8760922	0.84
NOAA	8760922	97%	359	USACE 01670	0.95
NOAA	8768094	97%	616	NOAA 8770570	0.96
NOAA	8770570	99%	74	NOAA 8771450	0.96
USGS	073813498	73%	15317[1]	NOAA 8764227	0.76

[1]occurs at the beginning of the time-series as the record does not start until October 2007

Attachment C3-26.3: Water Level Data contains figures and information for each station. The following are included for each station:

(1) Data gap analysis;
(2) Selected correlation;
(3) Data gaps filled using correlation (top) and linear interpolation (bottom); and
(4) Filled time-series (top), raw time-series (middle), and correlated time-series (bottom).

2.2.1 Model Implementation

The near-shore measured water levels were applied to the compartments furthest offshore of each station's' location. Since the water levels were not applied at the same location they were measured, a time-lag or temporal shift is needed such that when the model propagated the water levels from offshore to near-shore, the tidal signal from the modeled near-shore compartment would be in sync with the tidal signal measured in the observed data. All time-series were shifted by one hour with the except of NOAA 8735180 Dauphin Island in Mobile Bay, Alabama, which was not shifted as it was already located near the furthest offshore compartment.

To calculate this temporal shift, a simulation was performed applying the measured data to the boundary compartment. The temporal difference between the modeled low tide of the offshore and near-shore compartments was used as the temporal shift. Figure 8 shows how the temporal shift was estimated for NOAA 8768094 at offshore ICM compartment 943. The ICM resultant water level from the boundary compartment, ICM 943, is shown in black, the near-shore compartment, ICM 880, which NOAA 8768094 is located in, is shown in blue, and the measured data from NOAA 8768094 is shown as the red dashed line. The temporal difference between the low tide of ICM 943 and ICM 880 was one hour which was used as the temporal shift for this station.

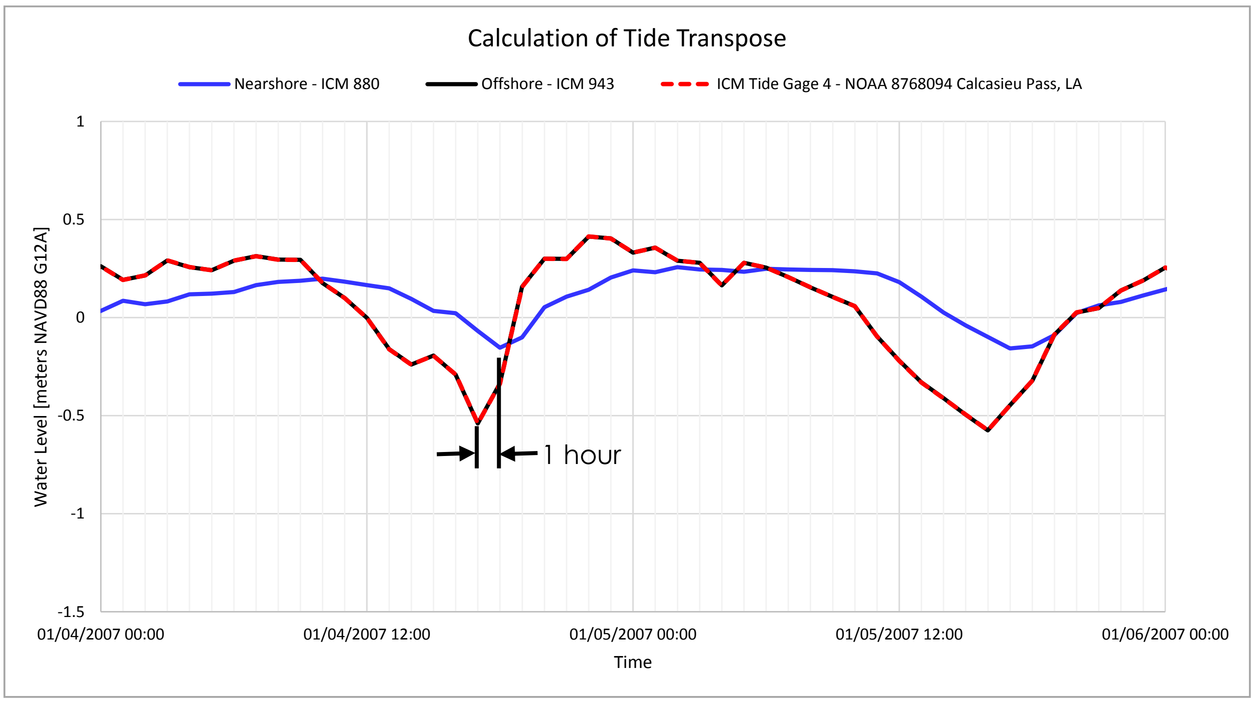

Figure 8: Tide Transpose Example for NOAA.

The station did not provide reliable datum conversions to the datum used by the ICM (North American Vertical Datum of 1988 Geiod12A (NAVD88 G12A)) nor were they corrected for subsidence and ESLR. The USACE Southwest Pass gage was used to convert to the NAVD88 G12A datum and correct for subsidence and ESLR. Additionally, further datum adjustments were made to minimize differences between the modeled stages and measured stages from CPRA's Coastwide Reference Monitoring System (CRMS) stations which provided a consistent reference water level across the Louisiana coast near the Gulf of Mexico.

The following explains how the observed data were corrected for ESLR and subsidence and shifted to the NAVD88 G12A datum. Table 5 provides the values. The annual increase in stage for each station was calculated using the slope of the trend line through the data. This slope includes both ESLR and subsidence. Assuming an ESLR of approximately two millimeters per year, the subsidence rate per year at each station was calculated as the slope less the ESLR. The mean sea level (MSL) in meters NAVD88 G12A for 2008 was adjusted to produce adequate water level comparisons between the ICM and CRMS stations in 2012. The year 2012 was chosen for comparison because of its low peak in river stage resulting in a greater tidal influence in the coastal zone. The comparison was only performed on the CRMS stations as they are spread throughout the coast and using stations from the same agency increases consistencies in surveying of the datum. Further adjustments were made to correct the direction of the long-shore tidal currents in the ICM offshore of Atchafalaya Bay and Marsh Island which push freshwater from the Atchafalaya River into East and West Cote Blanche Bays and Marsh Island. The MSL for 2008 in meters NAVD88 G12A were converted to MSL for 2006 after adjusting for ESLR. The shift for each station was determined as the difference between the 2006 MSL in meters NAVD88 G12A and the mean water level of the measured data in 2006. Each time-series was adjusted to NAVD88 G12A by applying the shift and corrected for subsidence by subtracting the fraction of the yearly rate per hourly time step. Additionally, for model stability, a minimum allowed water level of -0.6 meters was applied to all time-series.

Table 5: Calculation of Corrections for ESLR, Subsidence, and Shift to NAVD88 Geoid12A.

	NOAA 8735180	**NOAA 8760922**	**USGS 073813498**	**NOAA 8768094**	**NOAA 8770570**
Slope [m/yr]	0.015	0.037	0.013	0.007	0.009
ESLR [m/yr]	0.002	0.002	0.002	0.002	0.002
Subsidence [m/yr]	0.013	0.035	0.011	0.005	0.007
2008 MSL [m NAVD88 G12A]	0.200	0.100	0.100	0.100	0.100
2006 MSL [m NAVD88 G12A]	0.195	0.095	0.095	0.095	0.095
2006 MSL [m gage]	0.013	-0.227	0.196	-0.051	0.026
Shift to NAVD88 G12A	0.182	0.322	-0.101	0.146	0.069

3.0 Water Quality Data

3.1 Offshore Salinity

3.1.1 Data Collection

Hourly averaged salinity data from January 2006 to May 2014 was downloaded from the USGS website.[6] The stations that collect salinity data were primarily near-shore and did not give an accurate representation of the salinity along the model's offshore boundary. To obtain a better representation of the salinity in the offshore region, data was downloaded from the National

[6] http://www.usgs.gov/water/

Oceanographic Data Center's (NODC) World Ocean Database (WOD).[7] The WOD is a quality-controlled database which contains salinity data that was collected by the following methods:

- Ocean Station Data (OSD) measurements from stationary research ships including bottle data, low-resolution Conductivity-Temperature-Depth (CTD) data, and Salinity-Temperature-Depth (STD) data;
- High-resolution Conductivity-Temperature-Depth (CTD) data from stationary research ships;
- Profiling Float (PFL) data from drifting profiling floats mainly from The Argo Project;[8] and
- Glider (GLD) data from reusable autonomous underwater vehicles (AUV).

The salinity data in the WOD was unitless (Boyer 2013). Although unitless, one unit can be approximated as one parts per thousand (ppt). All processed salinity data was reported in ppt. Table 6 provides information on the extent of the data collected.

Table 6: Tidal Salinity Stations.

Agency	Station ID	Station Name	Latitude	Longitude
NODC	WOD	Grid: 85 – 97 West; 25 – 31 North	--	--

3.1.2 Data Processing

Most locations where data was collected from the WOD contained measurements at various depths. To obtain a single depth-averaged salinity value, the data for each location was averaged over all depths. These depth-averaged salinity values are shown in Figure 9.

Figure 10 shows the data points located inside of the furthest offshore compartments along the ICM boundary. The average of the data points within each of the compartments was calculated and is displayed in Figure 11. Figure 12 shows a plot of the average salinity with +/- 1 standard deviation along the model offshore boundary starting from Galveston, Texas to the west and ending at Mobile Bay, Alabama to the east. The standard deviations in salinity along the boundary are approximately 2.5 ppt for most of the compartments with a minimum standard deviation of 0.5 ppt in the compartment over the deep part of the Gulf of Mexico and maximum of 3.0 ppt in the compartment just offshore Mobile Bay.

The average salinities along the ICM boundary are nearly 32 ppt or greater with the standard deviation not reaching below 30 ppt for the majority of the boundary.

[7] http://www.nodc.noaa.gov/OC5/SELECT/dbsearch/dbsearch.html
[8] http://www.nodc.noaa.gov/argo/

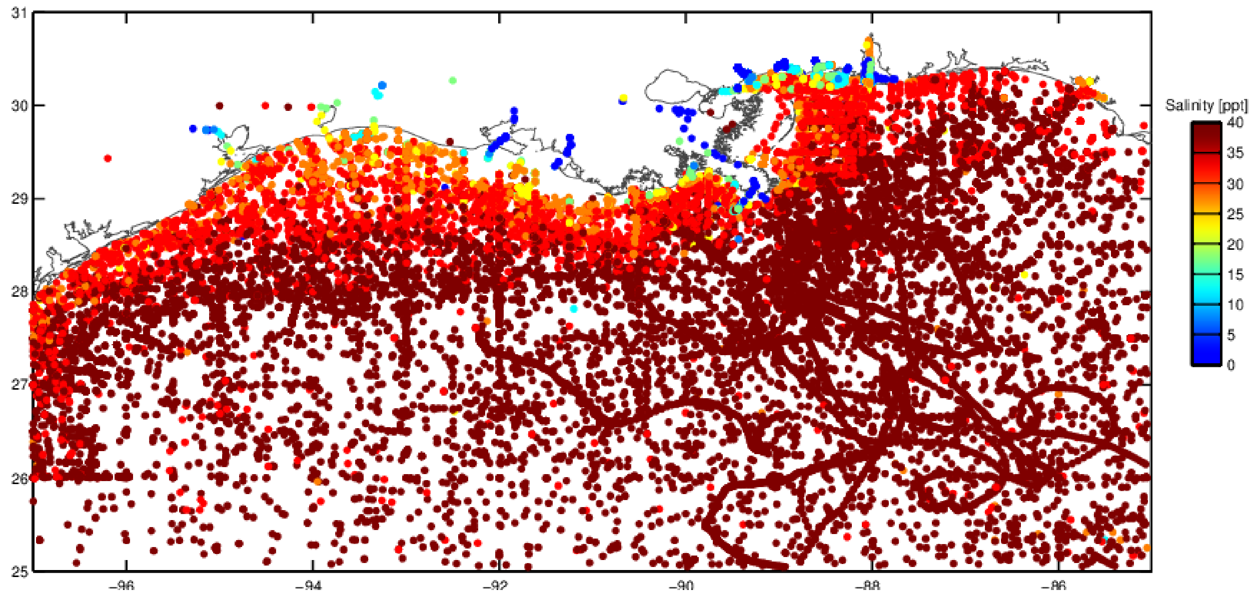

Figure 9: WOD Salinity Data.

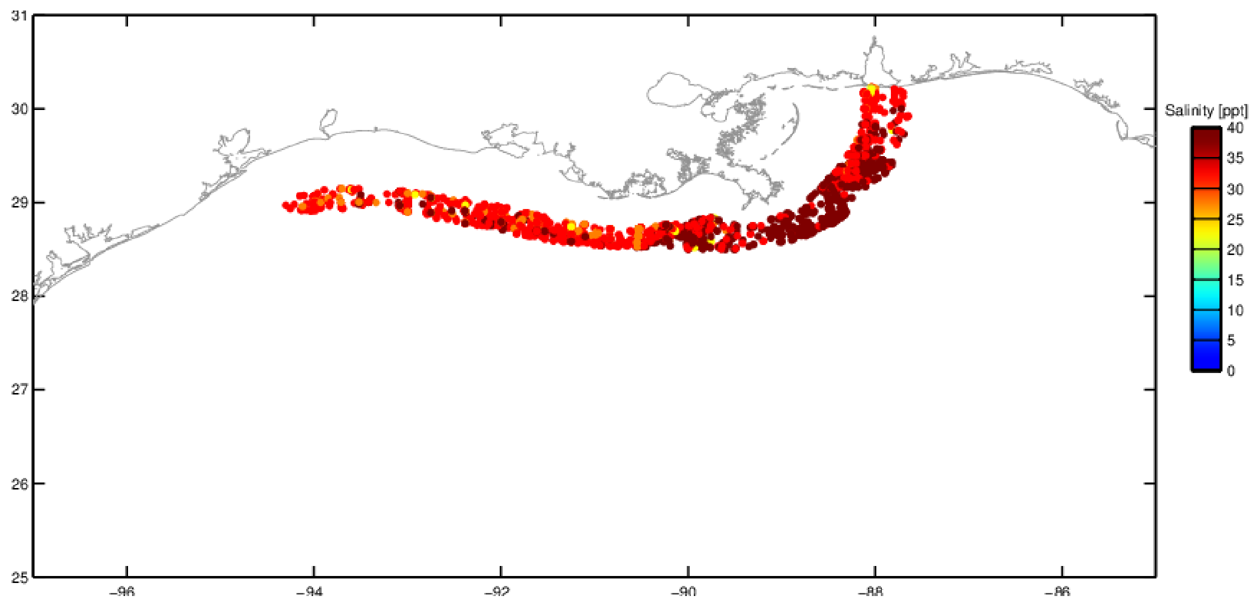

Figure 10: WOD Salinity Data inside ICM Boundary Compartments.

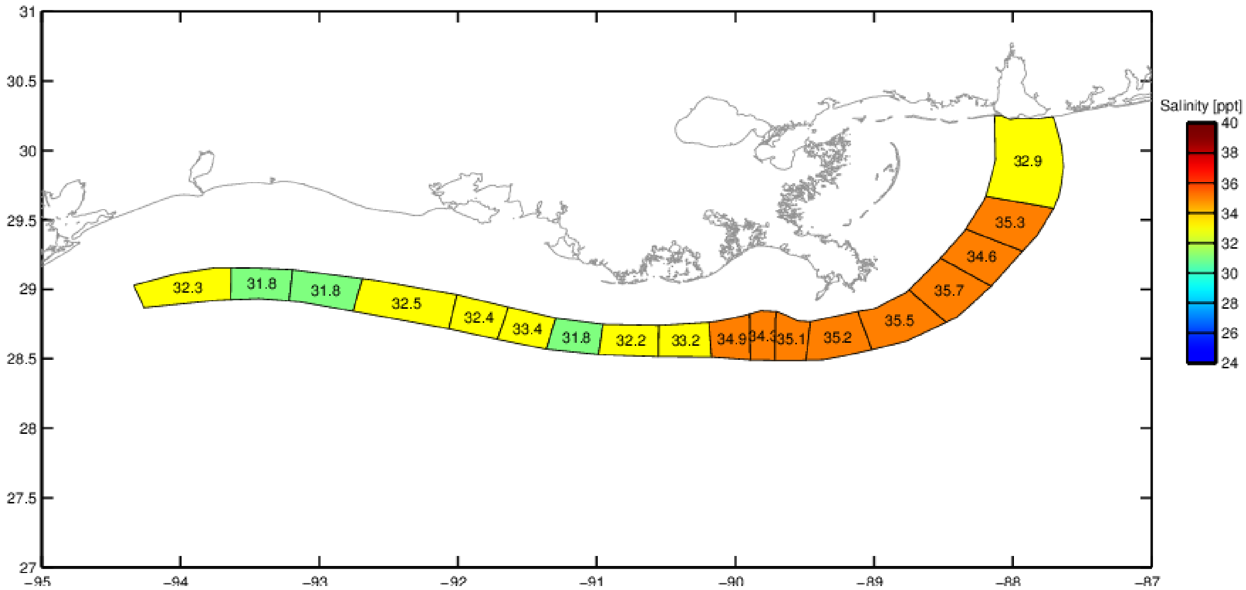

Figure 11: Average Salinity of ICM Boundary Compartments.

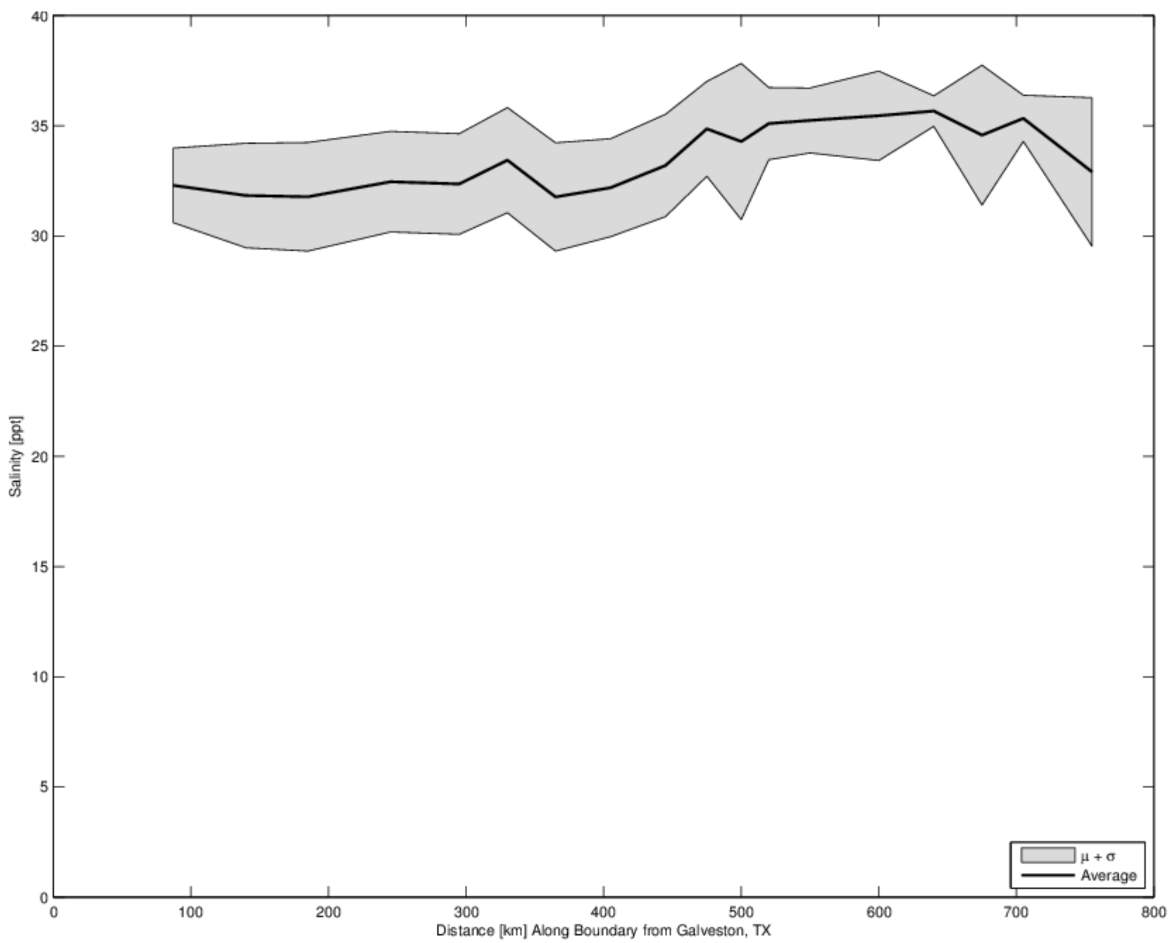

Figure 12: Average and Standard Deviation of ICM Boundary Compartment Salinity.

3.1.3 Model Implementation

Figure 13 identifies the salinity values implemented at the ICM offshore boundary compartments.

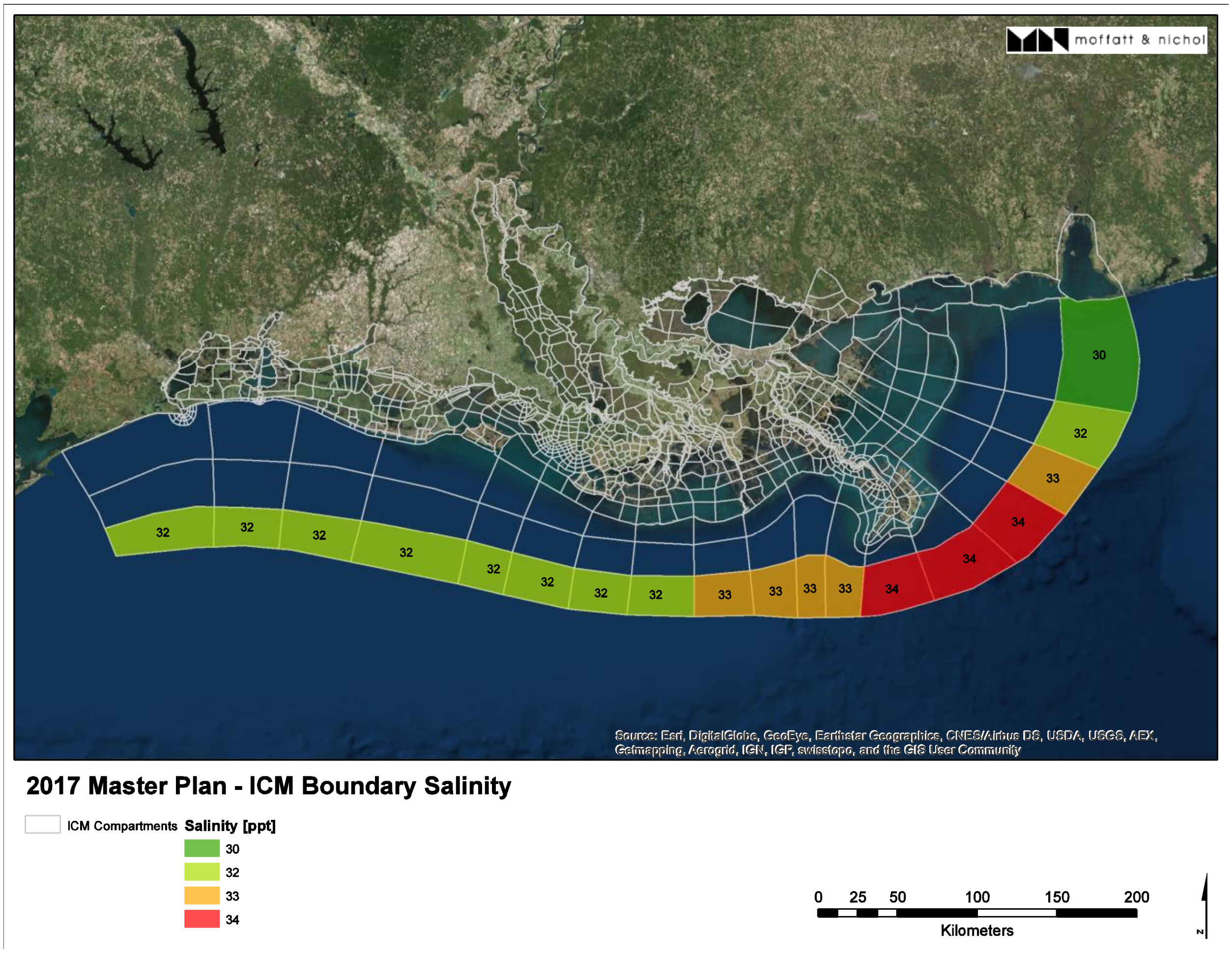

Figure 13: ICM Boundary Compartment Salinity.

3.2 Riverine and Offshore Water Quality

3.2.1 Data Collection

Water quality constituents including temperature, total suspended solid, nitrate+nitrite (NO_3), ammonium (NH_4), total phosphorus (TPH), and total organic nitrogen (ON) were used at the model boundary. Other water quality constituents were estimated based on equations in the eco-hydrology model technical report.

Discrete riverine and offshore water quality data from January 2006 to May 2014 was downloaded from the Louisiana Department of Environmental Quality (LDEQ),[9] the Texas

[9] http://www.deq.louisiana.gov

Commission on Environmental Quality (TCEQ),[10] and the United States Geological Survey (USGS)[11] websites. Attachment C3-26.4: Water Quality Data identifies the stations and locations from which data for each constituent was collected.

Data collected at stations LDEQ0962, LDEQ1170, and LDEQ1204 were averaged and used as the offshore boundary condition for the model.

3.2.2 Data Processing

Most water quality constituents were collected on average once a month. Due to the lack of continuous data, long-term monthly average values were calculated and used in the model. If a month had no measurements, the value from the closest previous month was used. For rivers that have no data available, the model-wise monthly average value was used.

The long-term averages, long-term monthly averages, and long-term seasonal averages were calculated for each of the stations and parameters. The results of these statistics can be found in in the 2017 Coastal Master Plan Data Repository.

3.2.3 Model Implementation

Table 7 summarized the water quality constituent values implemented at the ICM offshore boundary compartments.

Table 7: Offshore Water Quality Constituent Boundary Condition.

water quality constituent	Value
Total Suspended Solid	0 (g/m^3)
Nitrate+Nitrite	0.051 (g/m^3)
Ammonium	0.25 (g/m^3)
Total Organic Nitrogen	0.4 (g/m^3)
Total Phosphorus	0.3 (g/m^3)
Dissolved Oxygen	6 (g/m^3)
Total Organic Carbon	1 (g/m^3)
Green Algae	0.005 (mg/m^3)
Detritus	1(g/m^3)

4.0 Meteorological Data

4.1 Precipitation and Evapotranspiration

Daily accumulated precipitation and evapotranspiration data from January 2006 to May 2014 was downloaded from the National Climatic Data Center (NCDC) website. [12] Figure 14 shows

[10] www.tceq.texas.gov
[11] water.usgs.gov
[12] http://www.ncdc.noaa.gov/data-access

the precipitation and evapotranspiration station locations and Table 8 and Table 9 provide information for these stations.

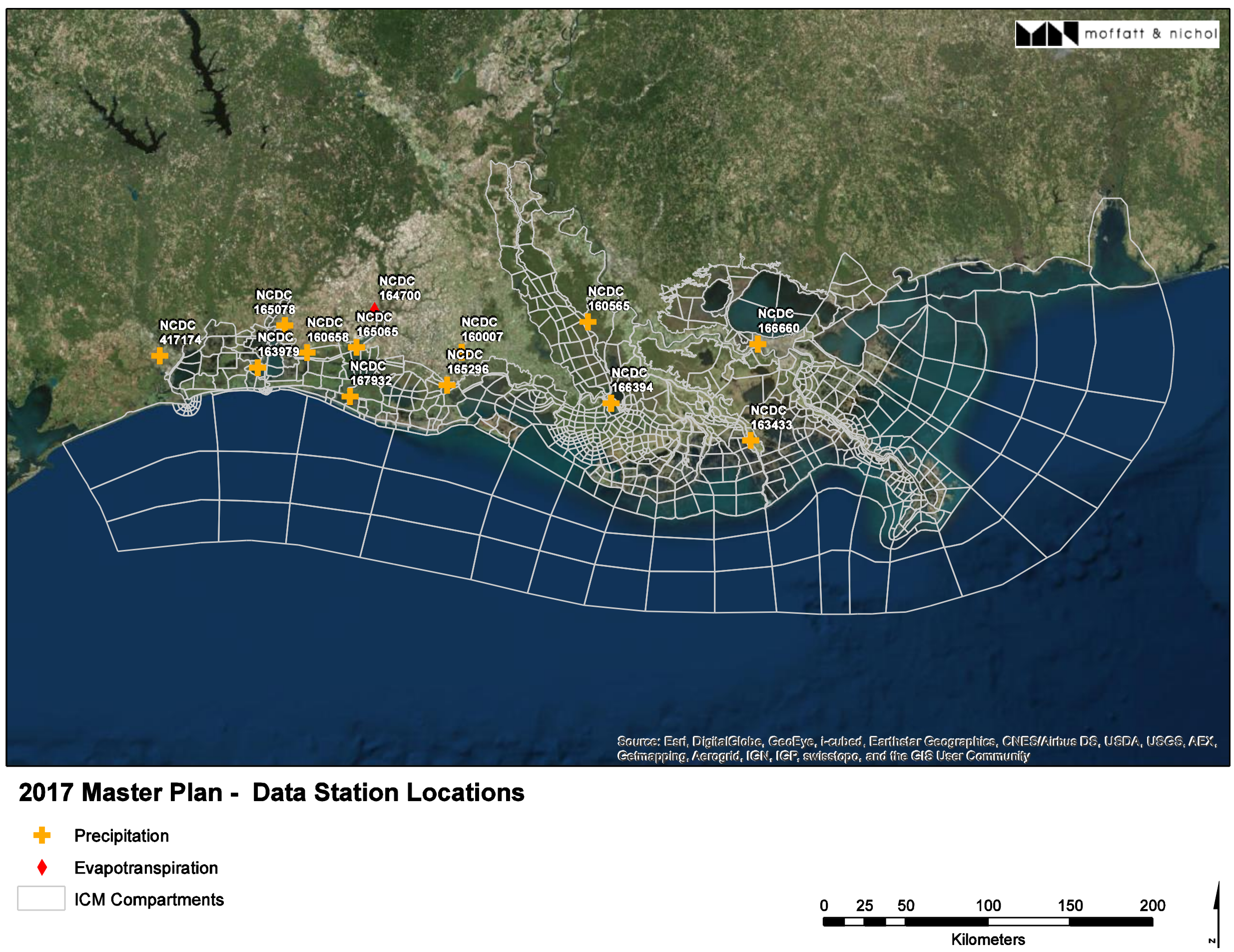

Figure 14: Precipitation and Evapotranspiration Station Locations.

Table 8: Precipitation Station Information.

Agency	Station ID	Station Name	Latitude	Longitude
NCDC	160007	Abbeville	29.969000	-92.117000
NCDC	160565	Bayou Sorrel Lock	30.130000	-91.320000
NCDC	160658	Bell City 13 SW	29.970000	-93.090000
NCDC	163433	Galliano	29.460000	-90.310000
NCDC	163979	Hackberry 8 SSW	29.889000	-93.402000
NCDC	165065	Lake Arthur 10 SW	30.000000	-92.780000
NCDC	165078	Lake Charles RGNL AP	30.120000	-93.230000

Agency	Station ID	Station Name	Latitude	Longitude
NCDC	165296	Leland Bowman Lock	29.790000	-92.210000
NCDC	166394	Morgan City	29.680000	-91.180000
NCDC	166660	New Orleans International Airport	29.990000	-90.250000
NCDC	167932	Rockefeller Wildlife Refuge	29.730000	-92.820000
NCDC	417174	Port Arthur SE TX AP	29.950000	-94.020000

Table 9: Evapotranspiration Station Information.

Agency	Station ID	Station Name	Latitude	Longitude
NCDC	164700	Jennings, LA	30.200000	-92.664000

Data gaps in the precipitation time-series were filled using inverse distance weighting. This method calculates the average of precipitation values among the other stations weighted based on their distance from the target station. Values from stations closer in proximity to the target station have a greater influence on the average while values from stations further away have less of an influence on the average.

Data gaps in the evapotranspiration time-series were filled using the long-term monthly averages of NCDC station 164700 (see Table 10). For example, a data gap occurring in March of any year is filled with a value of 39 tenths of a millimeter.

Table 10: Long-Term Monthly Averaged Evapotranspiration from NCDC 164700.

Month	ET [tenths mm]
January	23
February	26
March	39
April	51
May	60
June	67
July	59
August	63
September	49
October	39
November	26
December	21

All raw and filled data time-series are located in the 2017 Coastal Master Plan Data Repository.

4.1.1 Model Implementation

Precipitation and evapotranspiration for each compartment is assigned to be the same as the measurement at the nearest monitoring station using the Thiessen polygons method in the ArcGIS software suite.

4.2 Air Temperature

Daily air temperature data from January 2006 to May 2014 was downloaded from the National Climatic Data Center (NCDC)[13] website. Figure 15 shows the air temperature station locations and Table 7 and Table 11 provide station information.

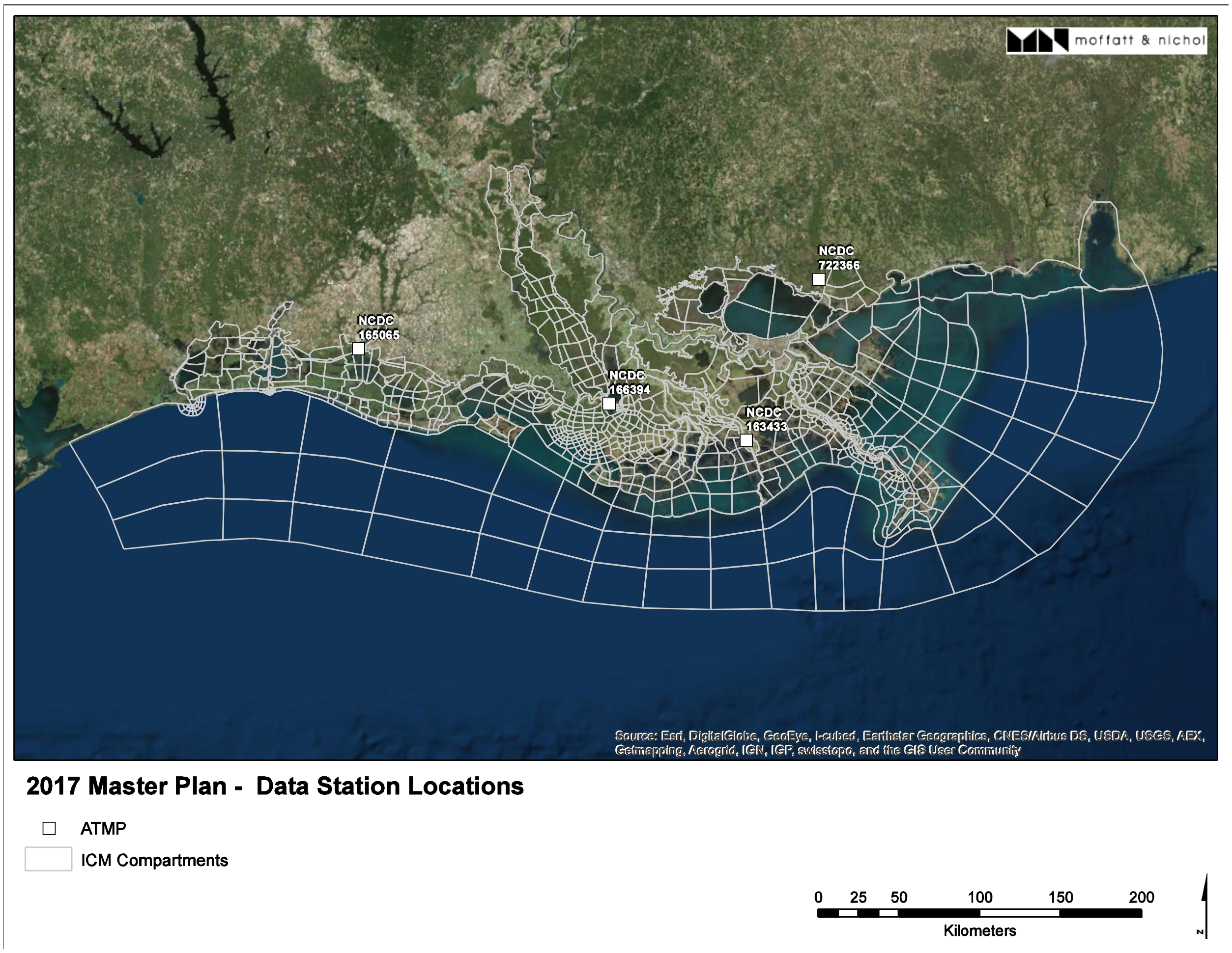

Figure 15: Air Temperature Station Locations.

[13] http://www.ncdc.noaa.gov/data-access

Table 11: Air Temperature Station Information.

Agency	Station ID	Station Name	Latitude	Longitude
NCDC	163433	Galliano	29.460000	-90.310000
NCDC	165065	Lake Arthur 10 SW	30.000000	-92.780000
NCDC	166394	Morgan City	29.680000	-91.180000
NCDC	722366	Slidell	30.350000	-89.820000

Data gaps in the air temperature time-series were filled using the inverse distance weighting as described in the precipitation section above.

All raw and filled data time-series are located in the 2017 Coastal Master Plan Data Repository.

4.2.1 Model Implementation

Air temperature for each compartment is assigned to be the same as the measurement at the nearest monitoring station using the Thiessen polygons method in the ArcGIS software suite.

4.3 Wind Velocity

Gridded wind data was downloaded from NCDC's North American Regional Reanalysis (NARR) Model's[14] output. The 'reanalysis' incorporates observations from instruments and then assigns this output onto a regularly spaced grid of data (approximately 32 km x 32 km). The u and v direction wind speeds in meters per second (m/s) at 10 meters above the ground were output from the NARR model at 3 hour intervals. Data between longitude 86 and 96 west and latitude 27 and 32 north was collected from January 2006 through June 2014. Figure 16 shows the NARR grid which data was downloaded for.

[14] http://www.ncdc.noaa.gov/data-access/model-data/model-datasets/north-american-regional-reanalysis-narr

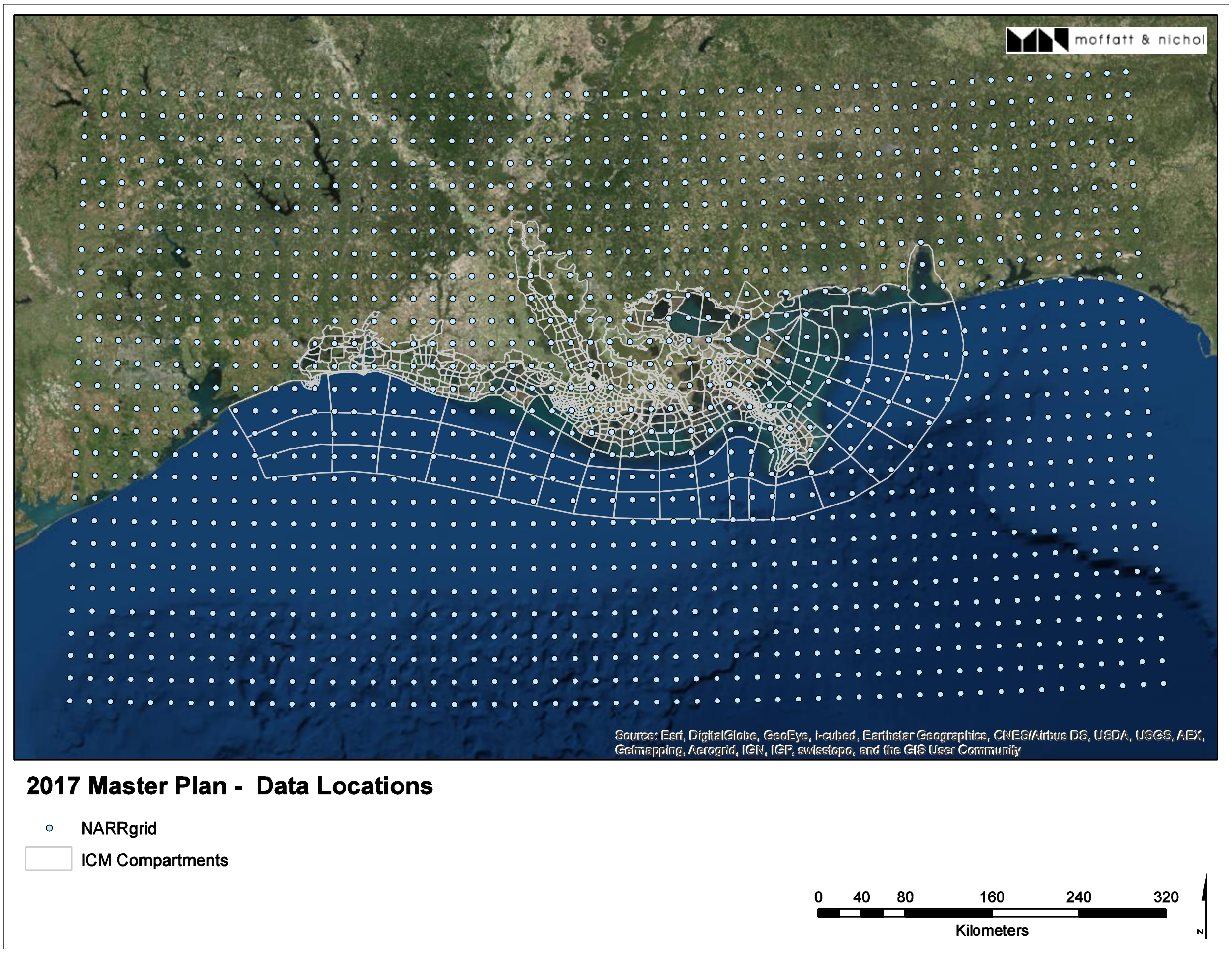

Figure 16: NCDC North American Regional Reanalysis Model Grid Points.

This immense amount of data was downloaded and processed from nearly 50,000 files (two files (u and v velocity) per 3 hour interval) into two files (u and v velocities) with each grid point as a column and 3 hour interval as a row.

All data is located in the 2017 Coastal Master Plan Data Repository.

4.3.1 Model Implementation

Wind velocity for each compartment is assigned to be the same as the measurement at the nearest monitoring station using the Thiessen polygons method in the ArcGIS software suite.

5.0 Boundary Conditions for 50-Year Simulations

Boundary conditions were prepared for various 50-year simulations for the 2017 Coastal Master Plan modeling effort. Detail descriptions for data source, data process, and model implementation can be found in Chapter 2 – Future Scenarios. A brief description of these data inputs and their difference compared to calibration/validation boundary conditions is provided in this section.

5.1 Hydrologic Data

5.1.1 Riverine Input

Daily averaged riverine inflow data was collected from monitoring stations. The observed Mississippi River discharge between years 1964 to 2014 was used as the Mississippi River hydrograph for the 50-year simulation (Figure 17). The historic record at Tarbert's Landing was used; however, the flow is truncated at 35,400 cms (1.25 million cfs), which is the flowrate at which the Bonnet Carre Spillway has traditionally been opened. Throughout the 50-year hydrograph, any observed Mississippi River flow in excess of this threshold was treated as a separate flow input into the model domain at the location of the Bonnet Carre Spillway.

Observed data for all non-Mississippi River tributaries in the model domain was obtained for the same 1964-2014 period. Any missing data were filled using a simple proportional rating curve, where the rating coefficient is the ratio of the mean flow in the tributary to the mean flow in the reference river. Rating coefficients and reference rivers for each of the riverine inputs are provided in Table 12.

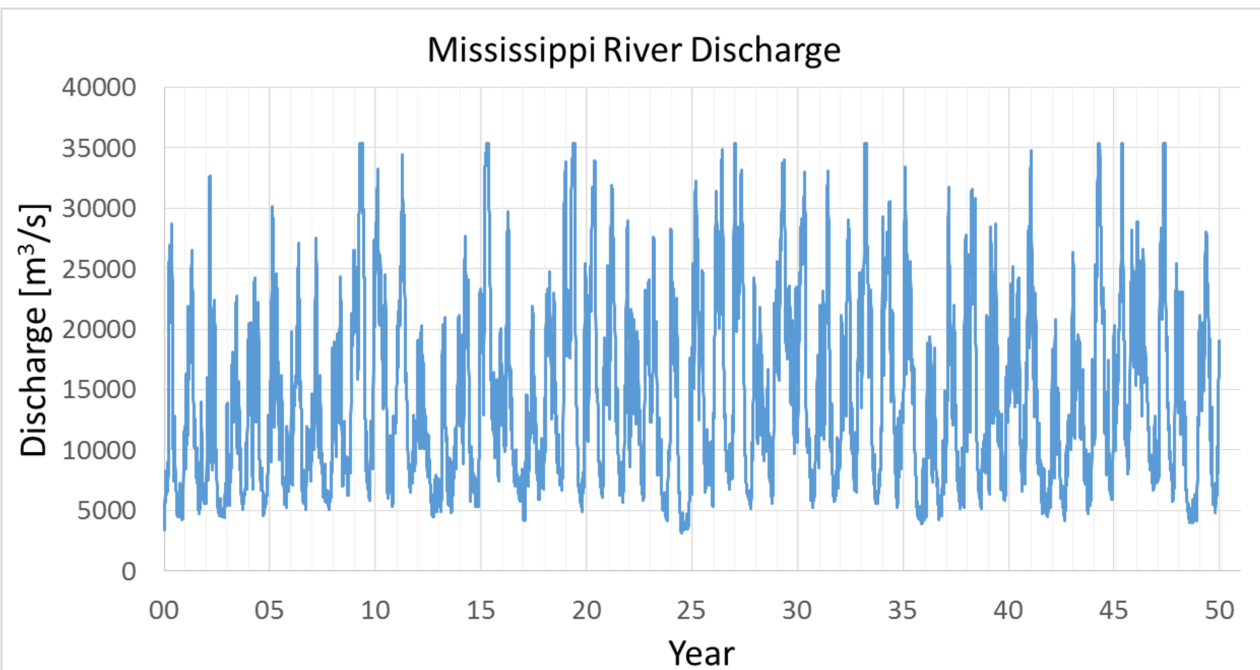

Figure 17: Mississippi River Hydrograph for 50-Year Simulations.

Table 12: Rating Curve References and Coefficients for Riverine Inputs.

Tributary Number in ICM input files	Tributary Name	Mean Observed Fowrate, 1990-2014 (cms)	$Q_{Trib}/Q_{Reference}$	Reference River
1	Neches River	212	0.0140	*Mississippi River*
2	Sabine River	254	0.0168	*Mississippi River*
4	Calcasieu River	75	0.0050	*Mississippi River*
5	Bayou Lacassine	11	0.0008	*Mississippi River*
6	Mermentau River	62	0.0041	*Mississippi River*
7	Vermilion River	30	0.0020	*Mississippi River*
8	Charenton Canal	69	0.0045	*Mississippi River*
9	GIWW at Franklin	220	0.0146	*Mississippi River*
10	Atchafalaya River	6,336	0.4199	*Mississippi River*
11	Mississippi River	15,089	-	-
12	GIWW at Larose	37	0.0025	*Mississippi River*
13	Bayou Lafourche	6	0.0004	*Mississippi River*
14	Amite River	62	0.0041	*Mississippi River*
15	Natalbany River	3	0.0002	*Mississippi River*
16	Tickfaw River	11	0.0008	*Mississippi River*
17	Tangipahoa River	34	0.0022	*Mississippi River*
18	Tchefuncte River	5	0.0003	*Mississippi River*
19	Pearl River	300	0.0199	*Mississippi River*
20	Wolf River	16	0.0011	*Mississippi River*
21	Biloxi River	6	0.0004	*Mississippi River*
22	Pascagoula River	284	0.0188	*Mississippi River*
23	Tensaw River	591	0.0391	*Mississippi River*
24	Mobile River	668	0.0443	*Mississippi River*

Tributary Number in ICM input files	Tributary Name	Mean Observed Fowrate, 1990-2014 (cms)	$Q_{Trib}/Q_{Reference}$	Reference River
25[1]	Mobile1	-	0.33	*Pascagoula River*
26[1]	Mobile 2	-	0.38	*Pascagoula River*
27[1]	Jourdan	-	1.00	*Wolf River*
28[2]	Violet Runoff	-	0.350	*Average of flows in: Amite, Natalbany, Tickfaw, Tangipahoa, Tchefuncte, and Pearl Rivers (rating developed to be consistent with)*
29[1]	NE Lake Pontchartrain ungaged drainage (Bayou Bonfouca)	-	2.70	*Tangipahoa River*
30[1]	SE Lake Pontchartrain ungaged drainage (Orleans Parish)	-	4.05	*Tangipahoa River*
31[1]	S Lake Pontchartrain ungaged drainage (Jefferson Parish)	-	4.05	*Tangipahoa River*
32[1]	SW Lake Pontchartrain ungaged drainage	-	4.05	*Tangipahoa River*
33[1]	S Lake Maurepas ungaged drainage	-	1.01	*Tangipahoa River*
34[1]	NE Lake Pontchartrain ungaged drainage (Bayou LaCombe)	-	2.70	*Tangipahoa River*
35[3]	Morganza Spillway	-	-	-
36[3]	Bonnet Carre	-	-	-

Tributary Number in ICM input files	Tributary Name	Mean Observed Fowrate, 1990-2014 (cms)	$Q_{Trib}/Q_{Reference}$	Reference River
	Spillway			
[1] Ungaged tributaries and urban drainage areas in the Pontchartrain region are weighted using the relationships developed for the 2012 Coastal Master Plan model (2012 Coastal Master Plan, Appendix D) [2] Runoff in the vicinity of Violet is calculated from an areally-weighted method developed for the 2012 Coastal Master Plan and subsequent modeling efforts [3] Morganza and Bonnet Carre flows are not filled with rating curves – only observed flows are used for Morganza, and Bonnet Carre flowrate is equal to any flow in the Mississippi River at Tarbert's Landing greater than 35,400 cms (1.25 million cfs)				

In addition to the riverine inputs, freshwater from the Mississippi River is also an input to the estuary in numerous locations directly adjacent to the river. The 50-year simulation flowrates for these existing freshwater diversions were developed from the flowrates used during the calibration and validation period. The mean flow of each freshwater diversion during the 2006-2013 calibration and validation period was compared to the mean Mississippi River flow during this same period. This produces a simple, proportional rating curve for each existing freshwater diversion as a function of Mississippi River flow (Table 13).

Table 13: Rating Curve Coefficients for Existing Freshwater Diversions off of the Mississippi River.

Diversion Number in ICM input files	Diversion Name	$Q_{Div}/Q_{Mississippi}$
4	Caernarvon	0.002691
5	Bohemia Downstream	0.002694
7	Davis Pond	0.005007
10	Inner Harbor Navigational Canal	0.00032
11	Bohemia Upstream & Intermediate	0.004387
15	West Point a la Hache	0.000712
22	Revised Residual[1]	0.987332
[1]The Mississippi River is not within the ICM model domain, therefore riverine inputs from the Mississippi flow are modeled as freshwater diversions at these known locations. All flow residual downstream of these locations is then distributed throughout the model compartments within the Bird's Foot Delta region.		

5.1.2 Mississippi River Suspended Sediment Concentrations

Suspended sediment rating curves developed for the Mississippi River at Belle Chase were used to calculate suspended sediment loads within the river for the 50-year boundary conditions. The sediment rating curves developed by Allison et al. (2012) from 2008-2010 were updated with data up to the end of 2012. Separate rating curves were developed for sand and fine sediments:

$$Load_{sand} = 7.716 \times 10^{7}\left(1 - e^{Q(-2.485\times10^{-7})}\right) - 5.748 \times 10^{7}\left(1 - e^{Q(-4.122\times10^{-5})}\right) \quad (2)$$

$$Load_{fines} = 2.0 \times 10^{-3} Q^{1.8589} \quad (3)$$

where $Load_{sand}$ is the sediment load of sand particles in tonnes/day, $Load_{fines}$ is the load of clay and silt particles in tonnes/day, and Q is the average daily flowrate in cubic meters/second. Mississippi River flow rates at Tarbert Landing were applied to these rating curves to develop the 50-year time-series for boundary condition suspended sediment concentrations within the Mississippi River.

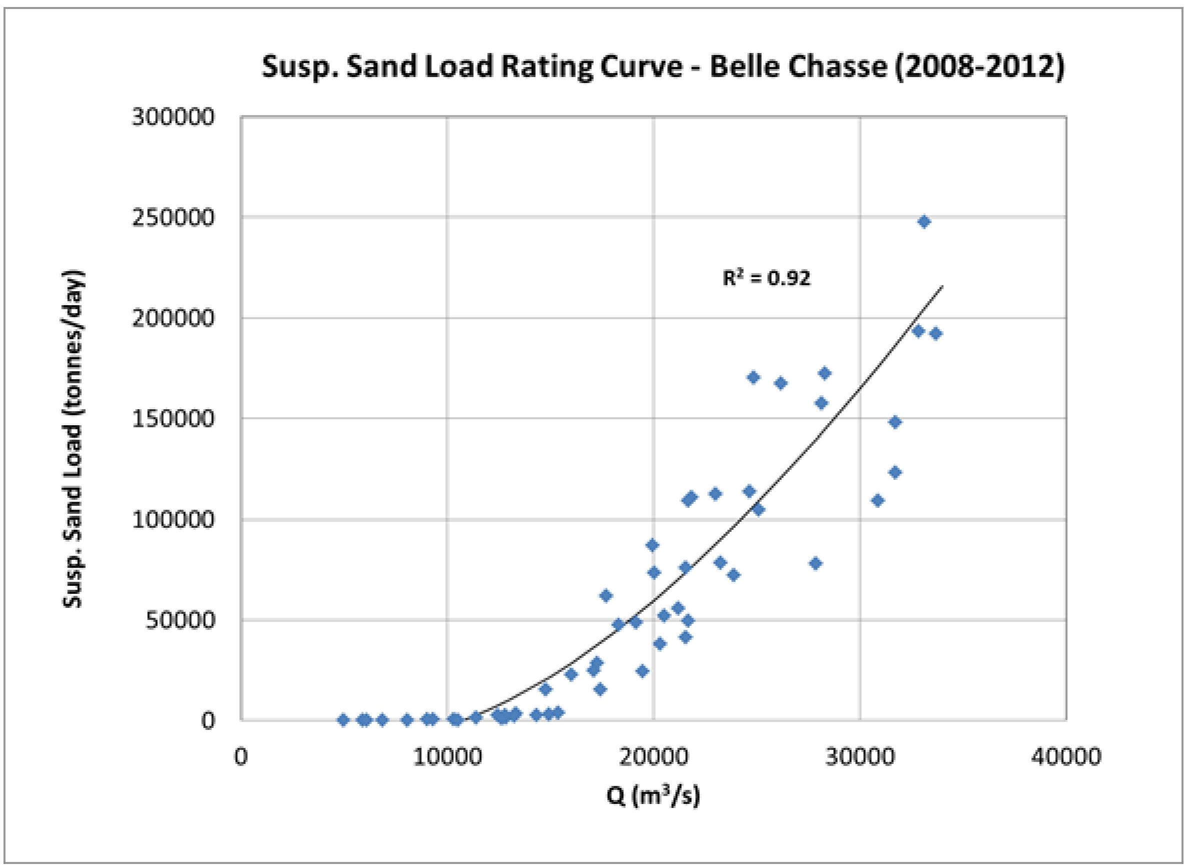

Figure 18: Rating Curve at Belle Chase for Mississippi River Suspended Sand Concentrations.

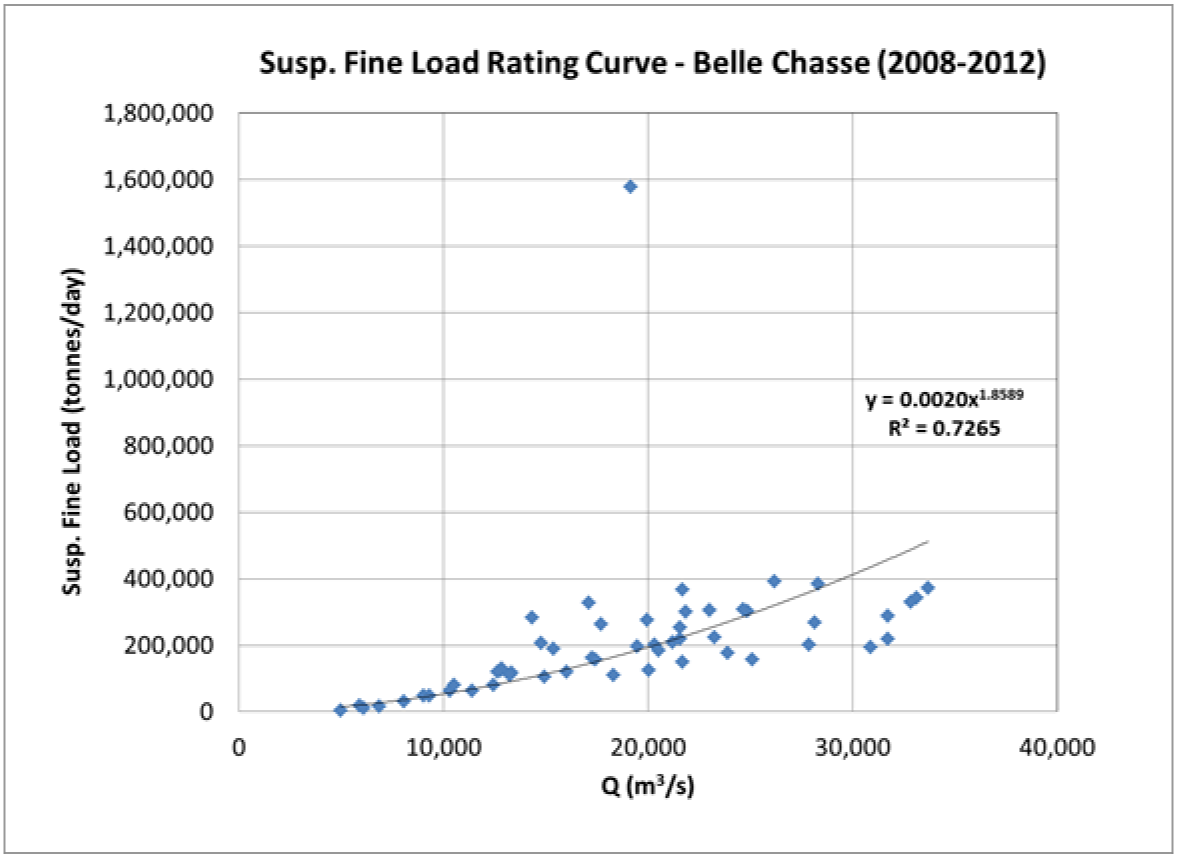

Figure 19: Rating Curve at Belle Chase for Mississippi River Suspended Silt and Clay Concentrations.

The sediment entering the model domain was calculated at each tributary or diversion location along the model boundary. All suspended sand in the boundary inflow was assigned to the sand particle class; 50% of the fines were assumed to be silt, 25% of the fines were assumed to be flocculated clay, and 25% of the fines were assumed to be un-flocculated clay.

All existing distributaries off of the Mississippi River (those listed in Table 133, excluding the Revised Residual) were assumed to have a suspended sand concentration equal to 5% of the suspended sand concentration within the Mississippi River (sediment-water-ratio of 0.05). These existing distributaries were assumed to have a suspended fines concentration equal to 97% of the suspended fines concentration within the Mississippi River (sediment-water-ratio of 0.97). These values are consistent with existing freshwater diversions that carry suspended fine particles but are not particularly efficient at diverting suspended sand particles. When active, the Bonnet Carre Spillway utilized the same assumption regarding fines, however the sediment-water-ratio for sand was assumed to be 0.5 (suspended sand concentration in Bonnet Carre flow is 50% of the suspended sand concentration in the Mississippi River).

As described in Chapter 4, all sediment diversion projects were implemented in the model assuming a sediment-water-ratio of 1.0 for all particle classes.

5.1.3 Tidal Water Level

Hourly predicted tidal water level data was developed by applying assumed rates of sea level rise to a predicted harmonic tidal signal. A full discussion of the sea level rise scenarios is provided in Chapter 2 – Future Scenarios as well as Attachment C2-1: Eustatic Sea Level Rise.

Predicted harmonic tidal signals for five NOAA tidal stations (Table 14) were downloaded for a 50-year period, dating from May 2015 through May 2064 via NOAA's Tide Predictions site (http://tidesandcurrents.noaa.gov/api/).

In addition to the harmonic tidal signal and sea level rise rates, storm surge conditions were also added to the offshore water level. As described in Attachment C3-3: Storms in the ICM Boundary Conditions, a set of synthetic tropical storm events were chosen to represent historical hurricanes that have impacted coastal Louisiana. Storm surge heights (defined as height above mean Gulf water level) were extracted from ADCIRC model runs at the centroid location of each offshore boundary compartment in the ICM. During each storm in the 50-year simulation, these surge levels are added to the Gulf water level that had been calculated from the harmonic tidal prediction with the additional sea level rise component.

Table 14: Tidal Stations used in 50-Year Future Boundary.

Agency	Station ID	Station Name	Latitude	Longitude
NOAA	8735180	Dauphin Island, Mobile Bay, AL	30.250000	-88.075000
NOAA	8760922	Pilots Station East, Southwest Pass, LA	28.931667	-89.406667
NOAA	8764227	Lawma, Amerada Pass	29.450000	-91.340000
NOAA	8768094	Calcasieu Pass	29.768000	-93.340000
NOAA	8770570	Sabine Pass North	29.730000	-93.870000
NOAA	8771450	Galveston Pier 21, Texas	29.310000	-94.793333

5.2 Water Quality Data

River inflow water quality constituent concentrations calculated for the calibration and validation simulations were repeated for the 50 years simulations. The values developed for and used in calibration and validation runs were used (Table 7) for these parameters at offshore boundary compartments as well.

5.3 Meteorological Data

5.3.1 Precipitation and Evapotranspiration

Precipitation and evapotranspiration predictions from different regional climate model datasets were used for the 50 years simulations (Chapter 2 – Future Scenarios). Gridded data from these projected datasets were mapped to the corresponding compartments by determining which climate model grid cell was closest to the centroid of each ICM compartment.

Rainfall during tropical storm events was also included. Rainfall depths, associated with each of the synthetic storms modeled, were added to the 50-year input precipitation time-series. For each day in which a storm was simulated, storm-associated rainfall was used in place of the regional climate model projected rainfall.

5.3.2 Air Temperature

Air temperature data compiled for the calibration and validation effort was repeated for the 50-year simulation.

5.3.1 Wind velocity

Wind velocity data compiled for the calibration and validation effort was repeated for the 50-year simulation. Wind fields associated with each of the modeled synthetic tropical storm events was used in place of the repeated historical data on days in which a storm was simulated.

6.0 References

Allison, M.A., Demas, C.R., Ebersole, B.A., Kleiss,B.A., Little, C.D., Meselhe, E.A., Powell, N.J., Pratt, T.C., and Vosburg, B.M. (2012). A water and sediment budget for the lower Mississippi-Atchafalaya River in flood years 2008-2010: Implications for sediment discharge to the oceans and coastal restoration in Louisiana. Journal of Hydrology. 432-433(2012) 84-97. doi:10.1016/j.jhydrol.2012.02.020.

Boyer, T.P., Antonov, J.I., Baranova, O.K., Coleman, C., Garcia, H.E., Grodsky, A., Johnson, D.R., Paver, C.R., Locarnini, R.A., Mishonov, A.V., O'Brien, T.D., Reagan, J.R., Seidov, D., Smolyar, I.V., & Zweng, M.M. (2013). World Ocean Database 2013. S. Levitus, Ed., A. Mishonov Technical Editor, NOAA Atlas NESDIS 72.