Design & Consultancy for natural and built assets

INTEGRATING STORM SURGE AND RAINFALL EFFECTS

A case study in Louisiana

International Workshop on Wave Hindcasting and Forecasting/Coastal Hazards Symposium

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Report:

Upper Barataria Basin Risk Reduction Modeling Phase 2 – Rainfall and Storm Surge Combined Effects Modeling, July 2015

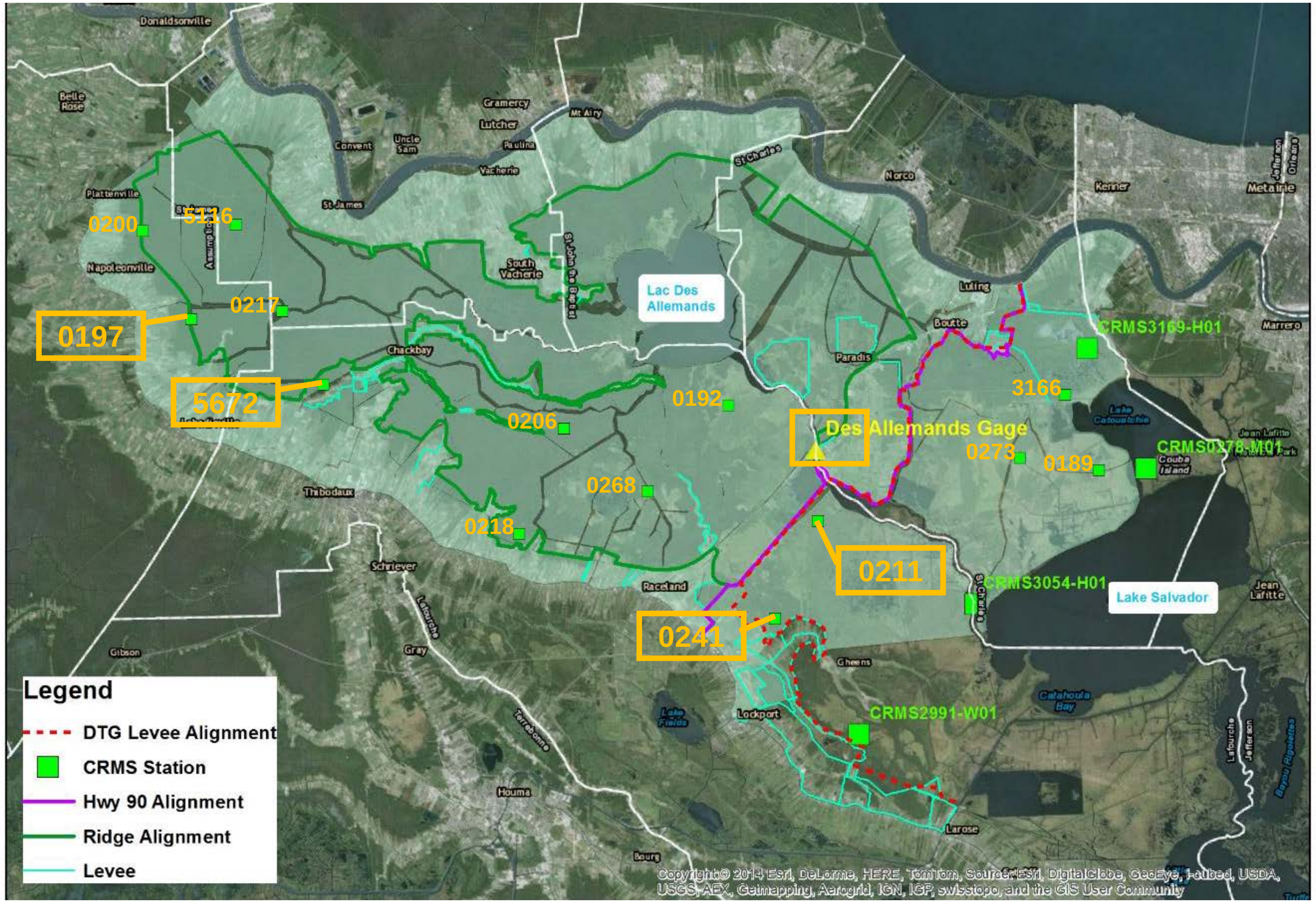
http://coastal.la.gov/resources/library/

Outline

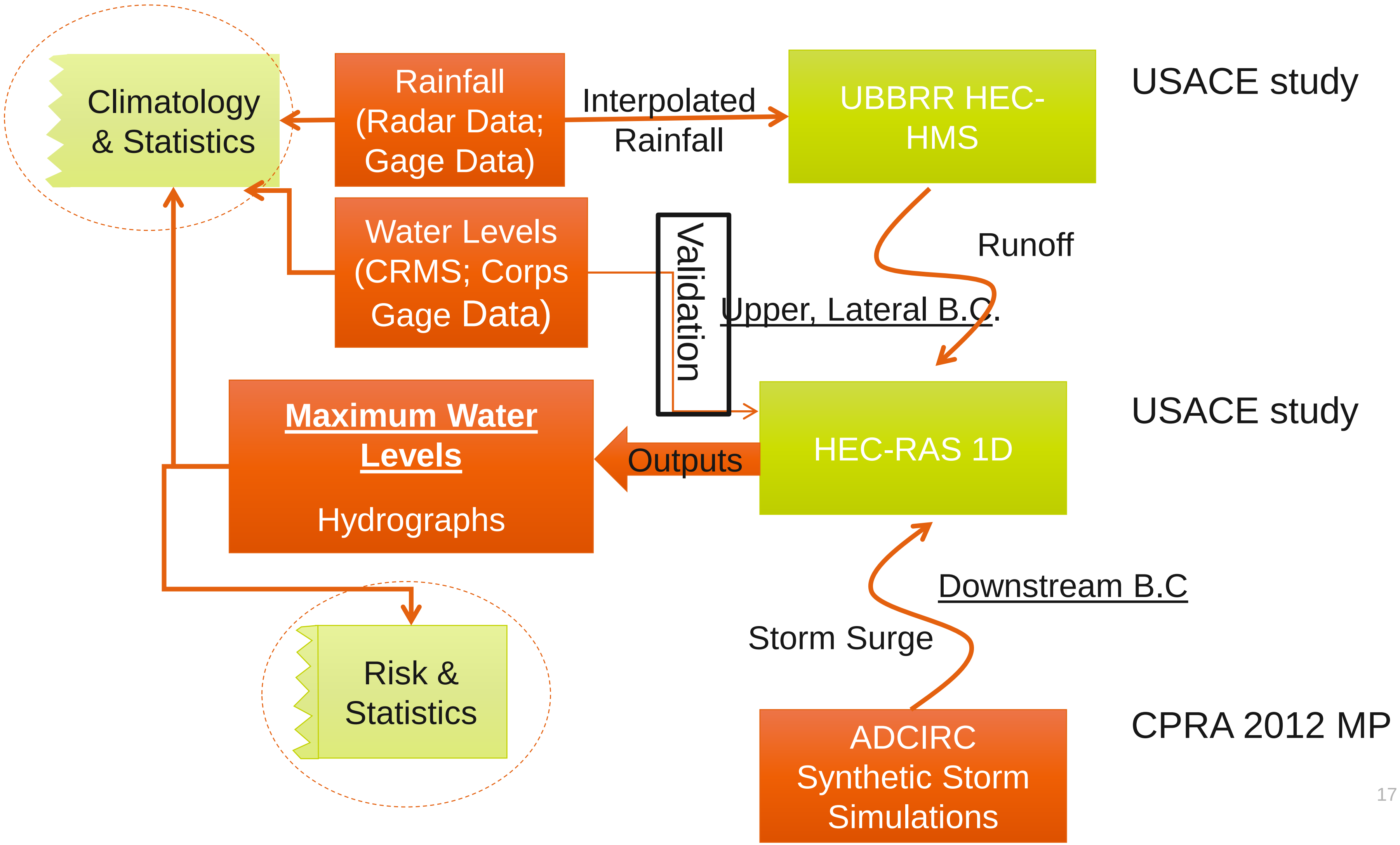
- Storm climatology and statistics
- Synthetic storm selection
- Hydraulic modeling
- Joint probability method development used to determine the flood frequency for the basin
- Conclusions

Upper Barataria Basin

- Rural and suburban
- 50 mi inland from coast
- Hurricane impacts extend inland
- Embankments, levees and ridges affect surge propagation and rainfall evacuation



Framework

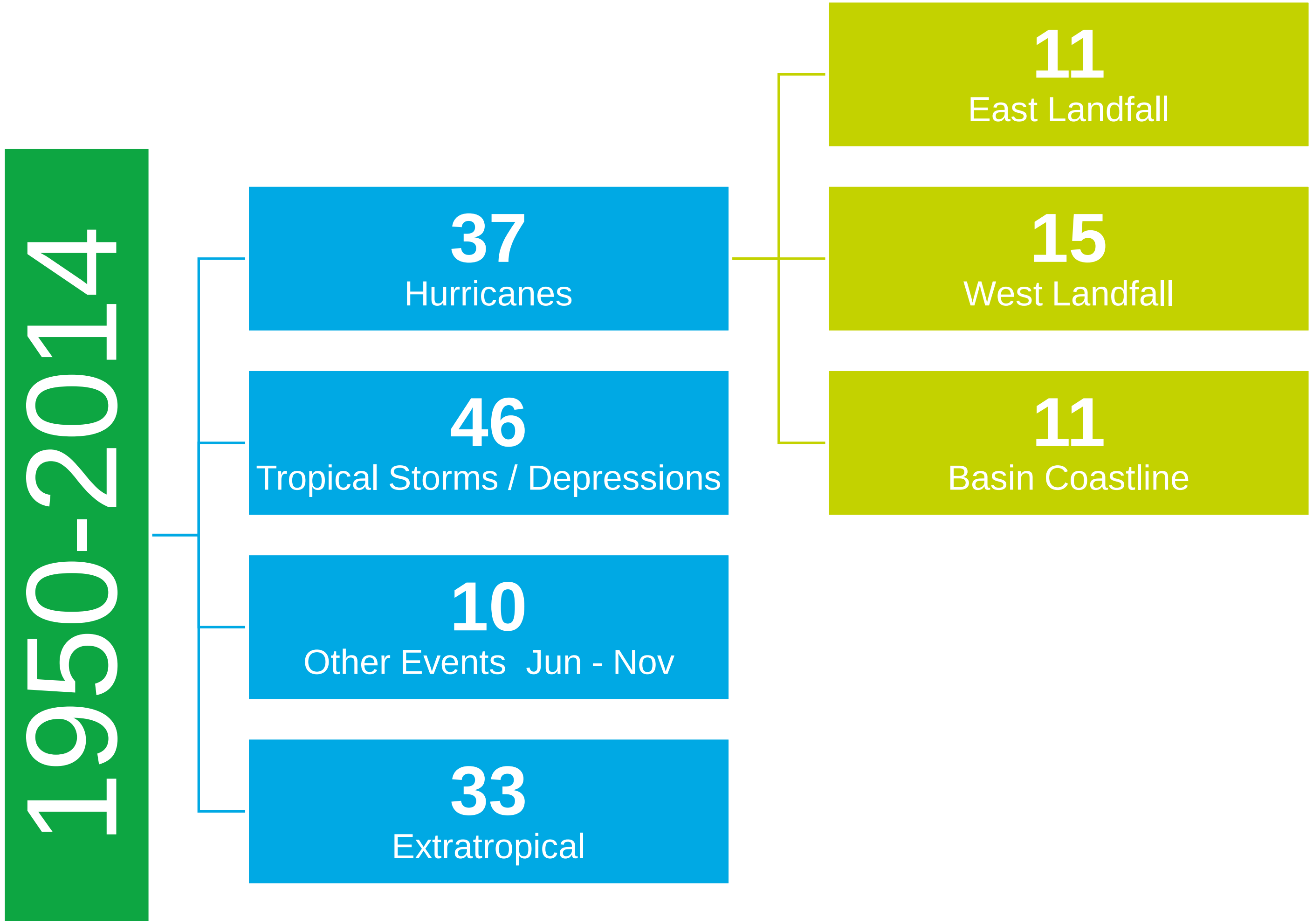

Climatology & Statistics
Rainfall (Radar Data; Gage Data)
Interpolated Rainfall
UBBRR HEC-HMS
USACE study
Water Levels (CRMS; Corps Gage Data)
Validation
Runoff
Upper, Lateral B.C.
Maximum Water Levels
Hydrographs
Outputs
HEC-RAS 1D
USACE study
Downstream B.C
Storm Surge
Risk & Statistics
ADCIRC Synthetic Storm Simulations
CPRA 2012 MP

Climatology & Statistics

Background

- Initial JPM-OS developed for coastal flooding from 152 storms
  - Subsequent work showed significant effects of river discharge and combined rainfall and surges
- Persistent hurricane activity in Gulf of Mexico region
  - Multiple storms during a hurricane season
  - Threat of extreme flooding in slow draining, shallow-slope coastal areas such as the upper Barataria Basin

Storm Events affecting Water Levels



Water Levels

Corps Gages

Des Allemands Gage

Gage record 1950-present

Hourly data available 1999-present

CRMS Gages

Water levels at 18 gages

Hourly data since 2007

Rainfall

Gage Rainfall

- 11 hourly rainfall gages
- 14 daily rainfall gages
- Data coverage varies

Gridded Rainfall

- Stage III Gridded Hourly NEXRAD radar rainfall (2001~2010)
- QA/QC processed using local rainfall gages by NOAA-NWS River Forecast Center

Barataria Basin Lag

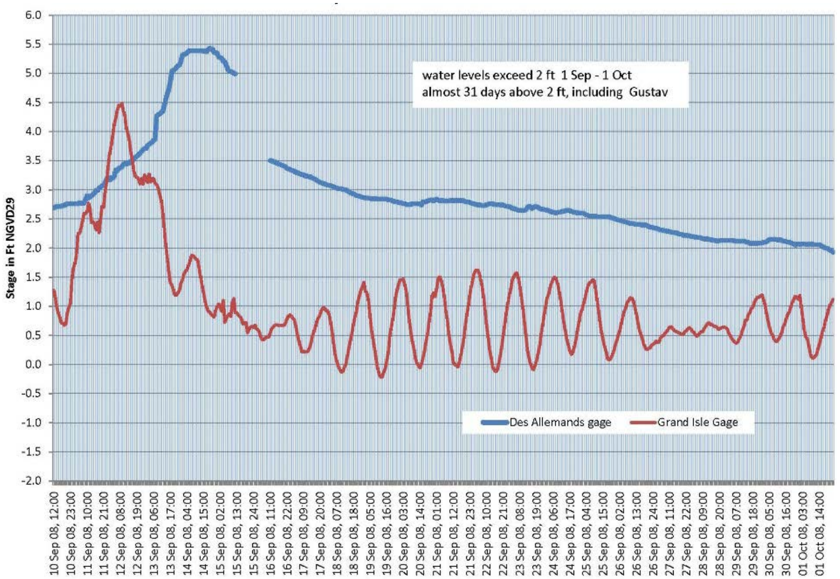
- Significant lag among storm winds, rainfall, peak stages
  - Storm quadrant, forward speed, landfall location affect event peaks

Event	Year	Peak (ft gage)	Landfall	Rainfall (in)
Hurricane Ike	2008	5.43	West	0.0 – 2.3
Hurricane Isaac	2012	4.28	Basin Coastline	8.2 – 12.6
Hurricane Juan	1985	3.92	West & East	>10
Tropical Storm Lee	2011	3.86	West	9.0 – 13.1

Barataria Basin Lag

Hurricane Ike

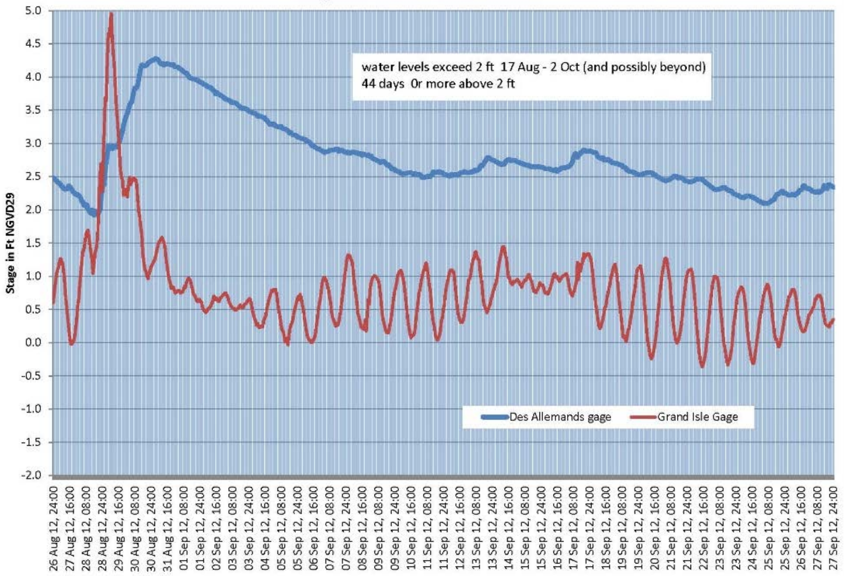
2008



58 hour lag

Hurricane Isaac

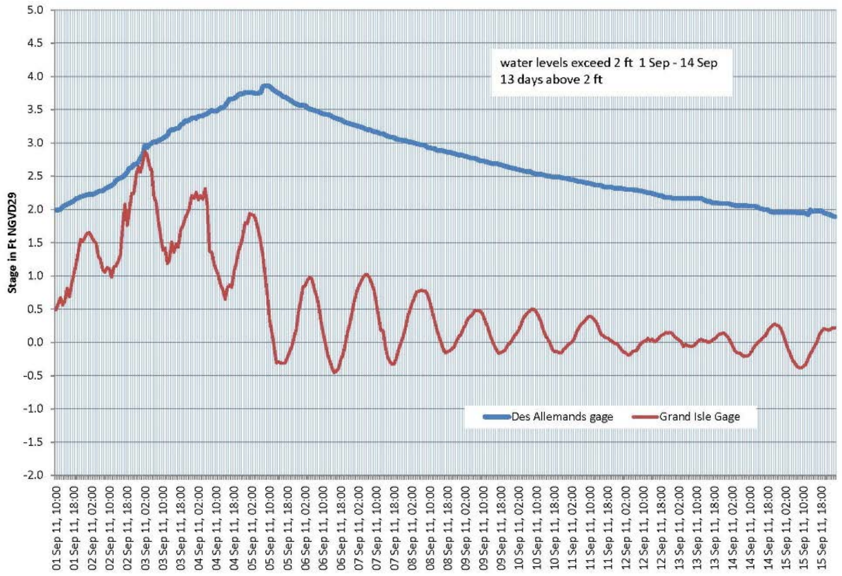
2012



44 hour lag

Tropical Storm Lee

2011

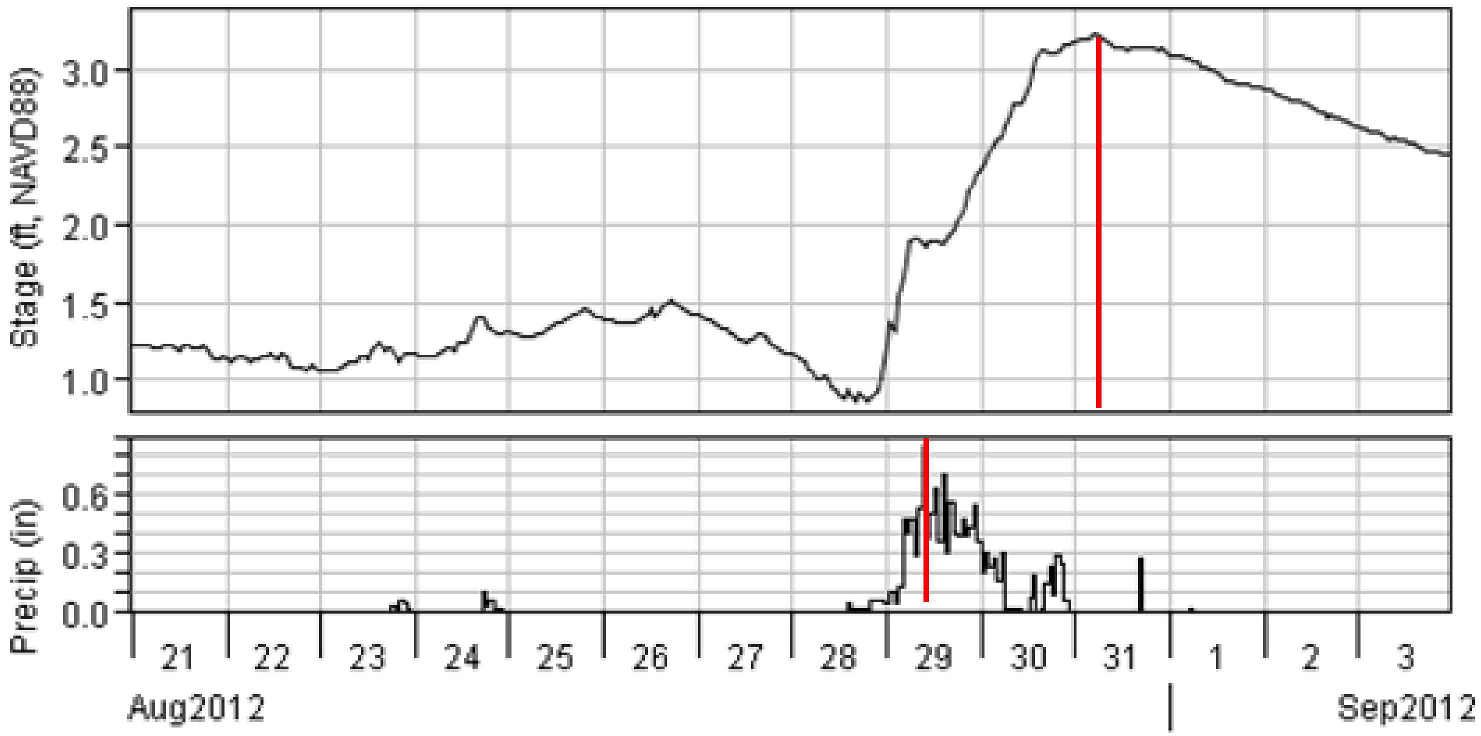


52 hour lag

Barataria Basin Lag

Hurricane Isaac

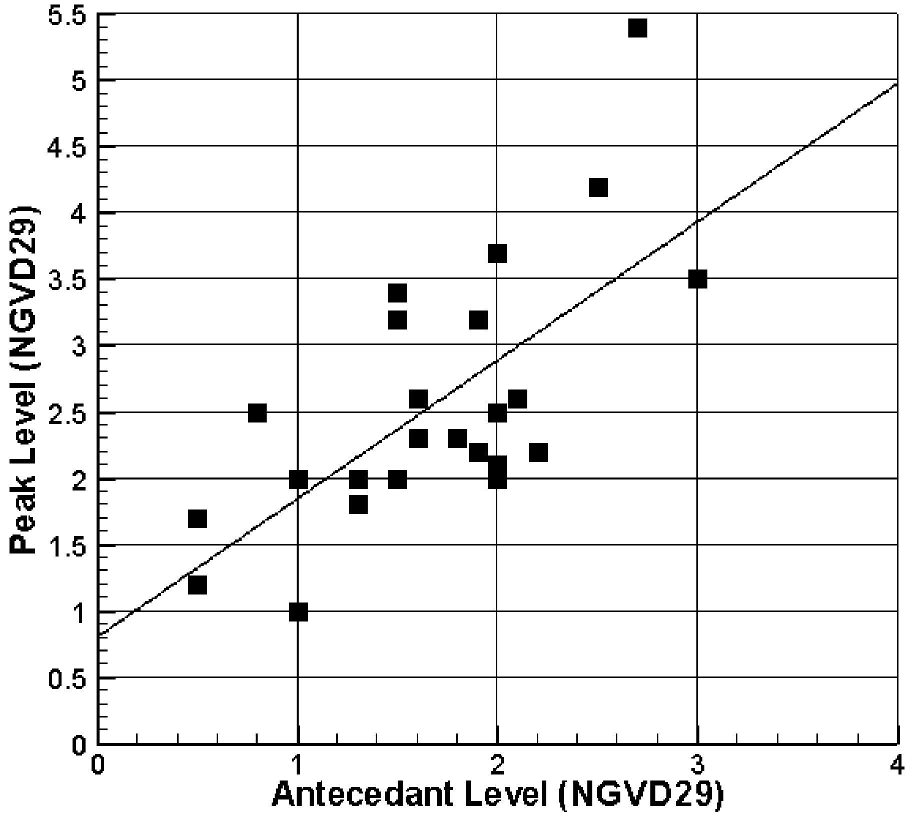
2012



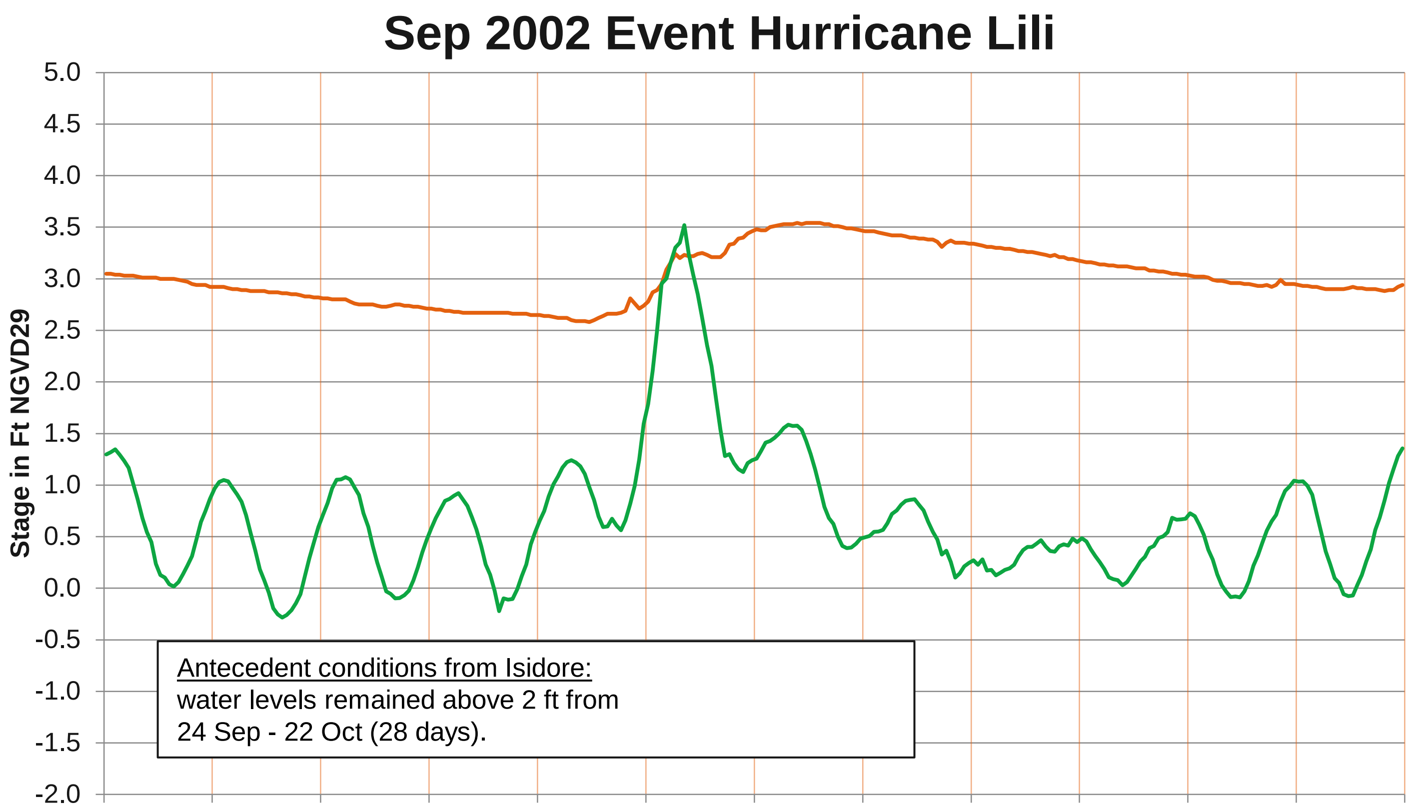
Special Tropic: Antecedent Conditions

Clustering of storms in time and relatively slow drainage result in pronounced effect of antecedent conditions

Neglect leads to lower flooding estimates than what should occur



Special Tropic: Antecedent Conditions



Synthetic Storm Selection

Storm Selection

To keep number of model runs manageable, made simplifying assumptions.

Tropical storms - consider larger probability masses for storm parameters to cover probability range 10-year to 500-year and use fitted extrapolation to extend to rarer events

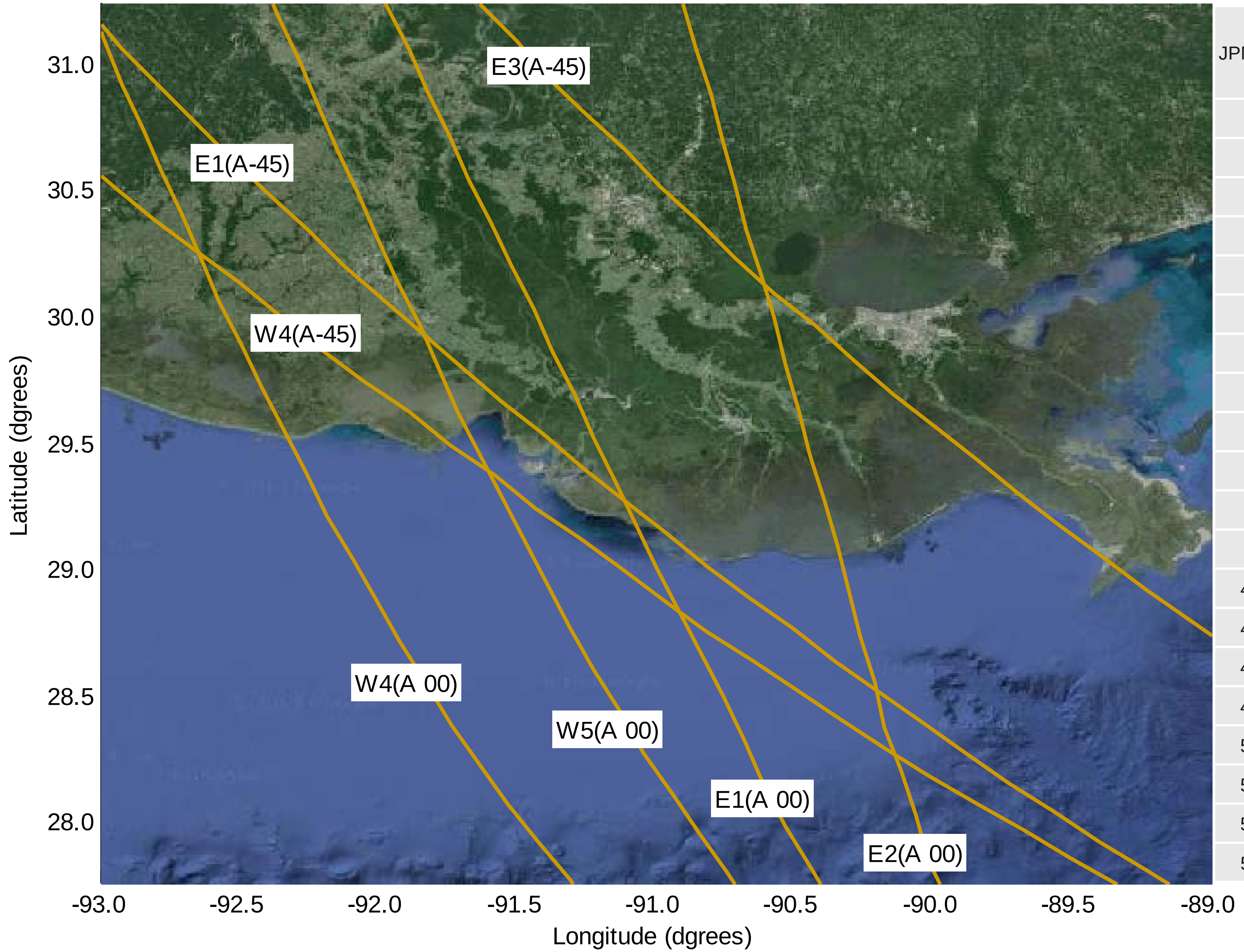
Surge from extratropical events does not contribute to flooding

Number of tropical events considered = 20 from set of storms used n 2012 MP

Rainfall only events - use 24-hour rainfall to categorize flood potential and distribute the rainfall over time based on a Gaussian distribution of rain over time

Number of rainfall events = 9

Tropical Event Selection

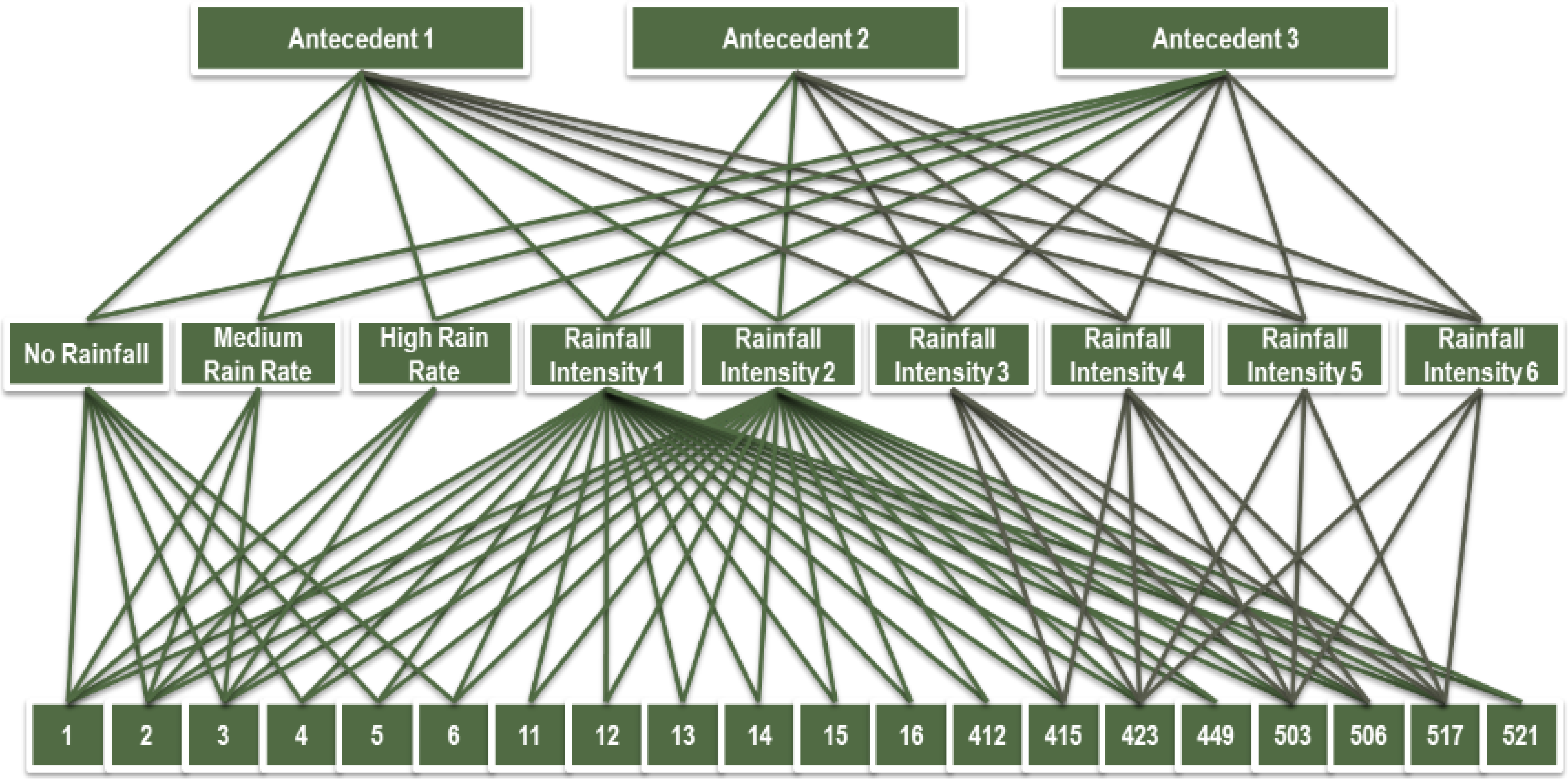


JPMOS#	Parameters			
	Cp	Radius	track	Vf
1	960	11	E1(A 00)	11
2	960	21	E1(A 00)	11
3	960	35.6	E1(A 00)	11
4	930	8	E1(A 00)	11
5	930	17.7	E1(A 00)	11
6	930	25.8	E1(A 00)	11
11	960	21	E2(A 00)	11
12	960	35.6	E2(A 00)	11
13	930	8	E2(A 00)	11
14	930	17.7	E2(A 00)	11
15	930	25.8	E2(A 00)	11
16	900	6	E2(A 00)	11
412	975	35.6	W4(A 00)	11
415	975	35.6	W5(A 00)	11
423	975	24.6	W4(A-45)	11
449	975	17.7	W5(A 00)	17
503	975	35.6	E1(A 00)	11
506	975	35.6	E2(A 00)	11
517	975	24.6	E1(A-45)	11
521	975	24.6	E3(A-45)	11

Rainfall Event Selection

Rainfall	Definition
No Rainfall	
Medium Rainfall	4 inches of rain distributed according to Gaussian form
High Rainfall	8 inches of rain distributed according to Gaussian form
Rainfall Intensity 1	4 inches of rain distributed at a constant rate
Rainfall Intensity 2	8 inches of rain distributed at a constant rate
Rainfall Intensity 3	8 inches of rain distributed with rate 3 times higher before landfall
Rainfall Intensity 4	12 inches of rain distributed with rate 3 times higher before landfall
Rainfall Intensity 5	8 inches of rain distributed with rate 3 times higher before landfall
Rainfall Intensity 6	12 inches of rain distributed with rate 3 times higher before landfall

Production Runs



168 HEC-RAS model runs

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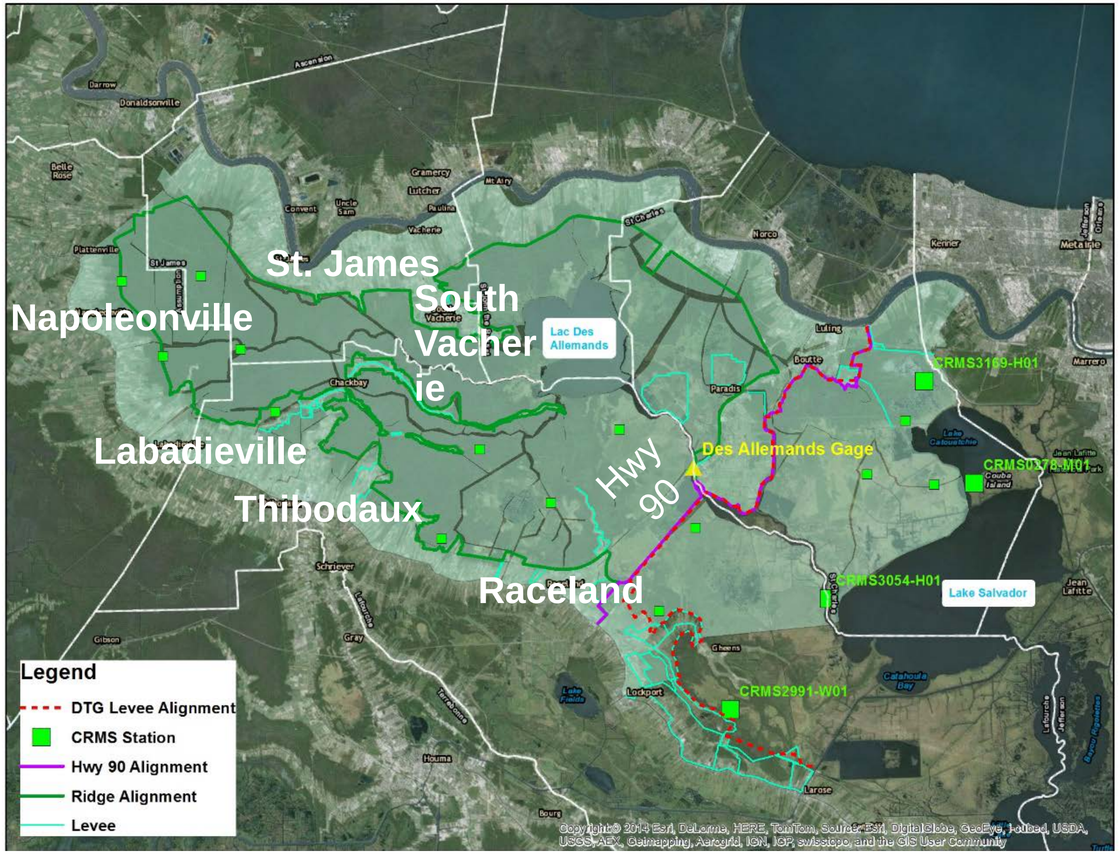
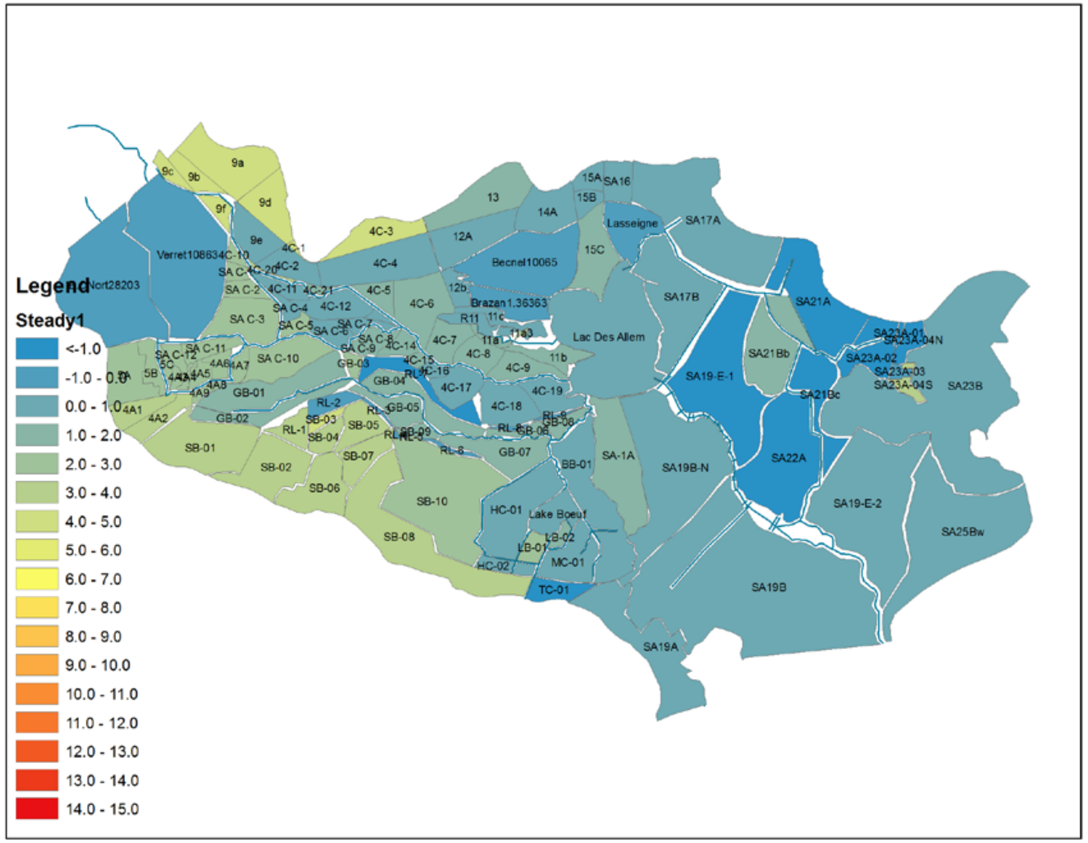
Hydraulic Analysis

HEC-RAS 1-D Model Domain





Model Validation

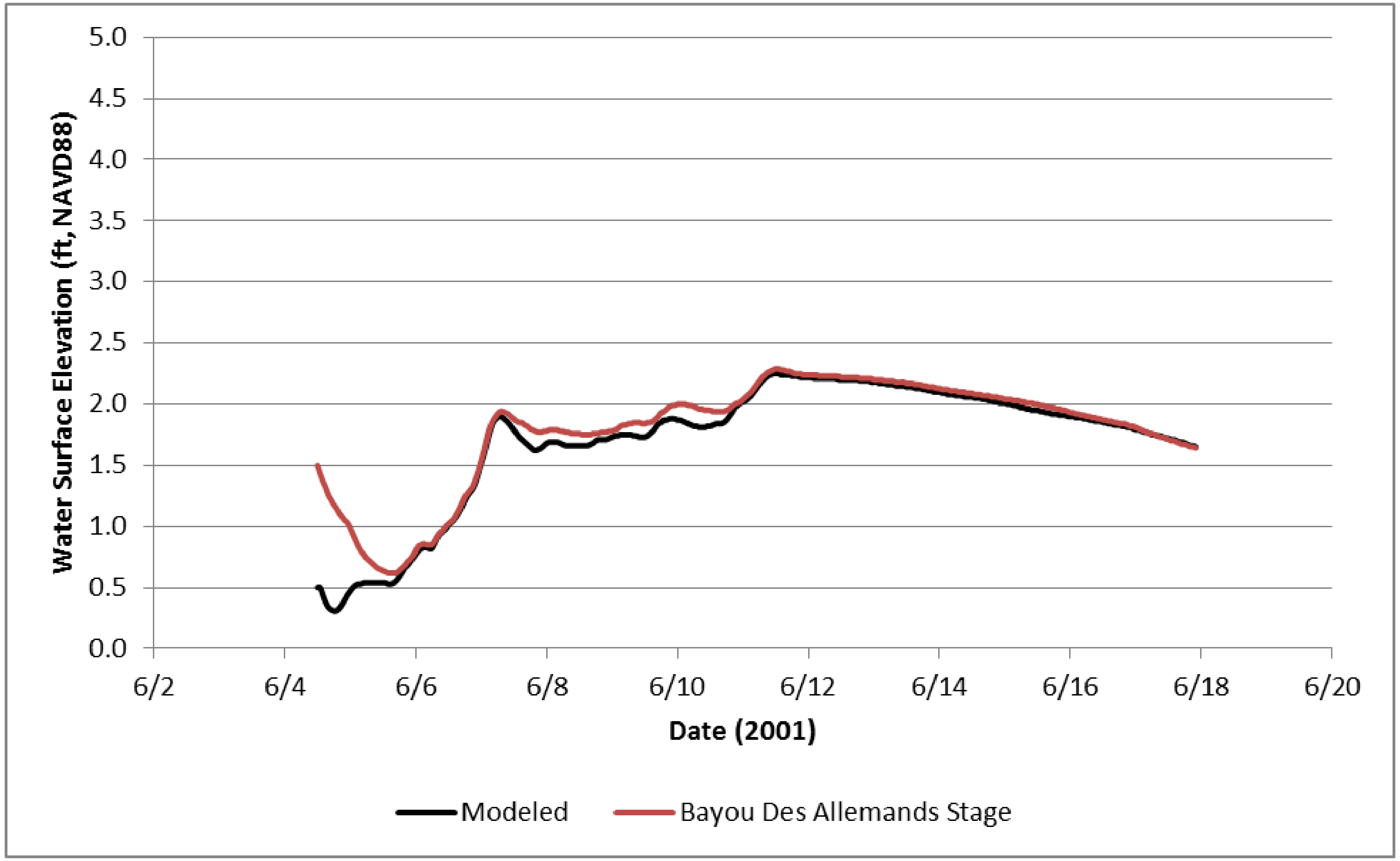
Events

- Allison 2001
- Gustav-Ike 2008
- Winter Storm 2009
- Isaac 2012

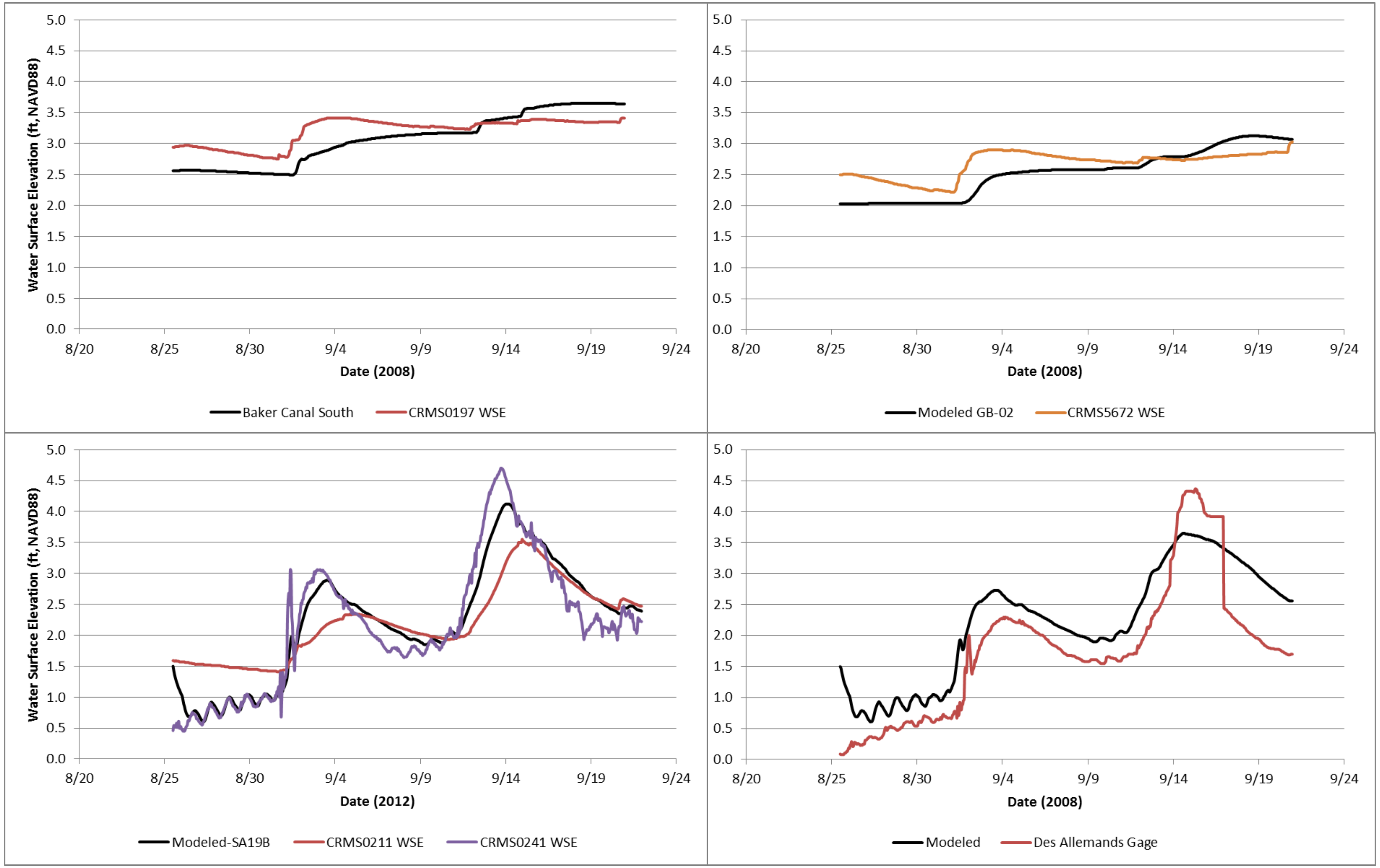
Hydrographs Comparison

- 14 CRMS stations
- One USACE gage (Des Allemands)

Allison 2001

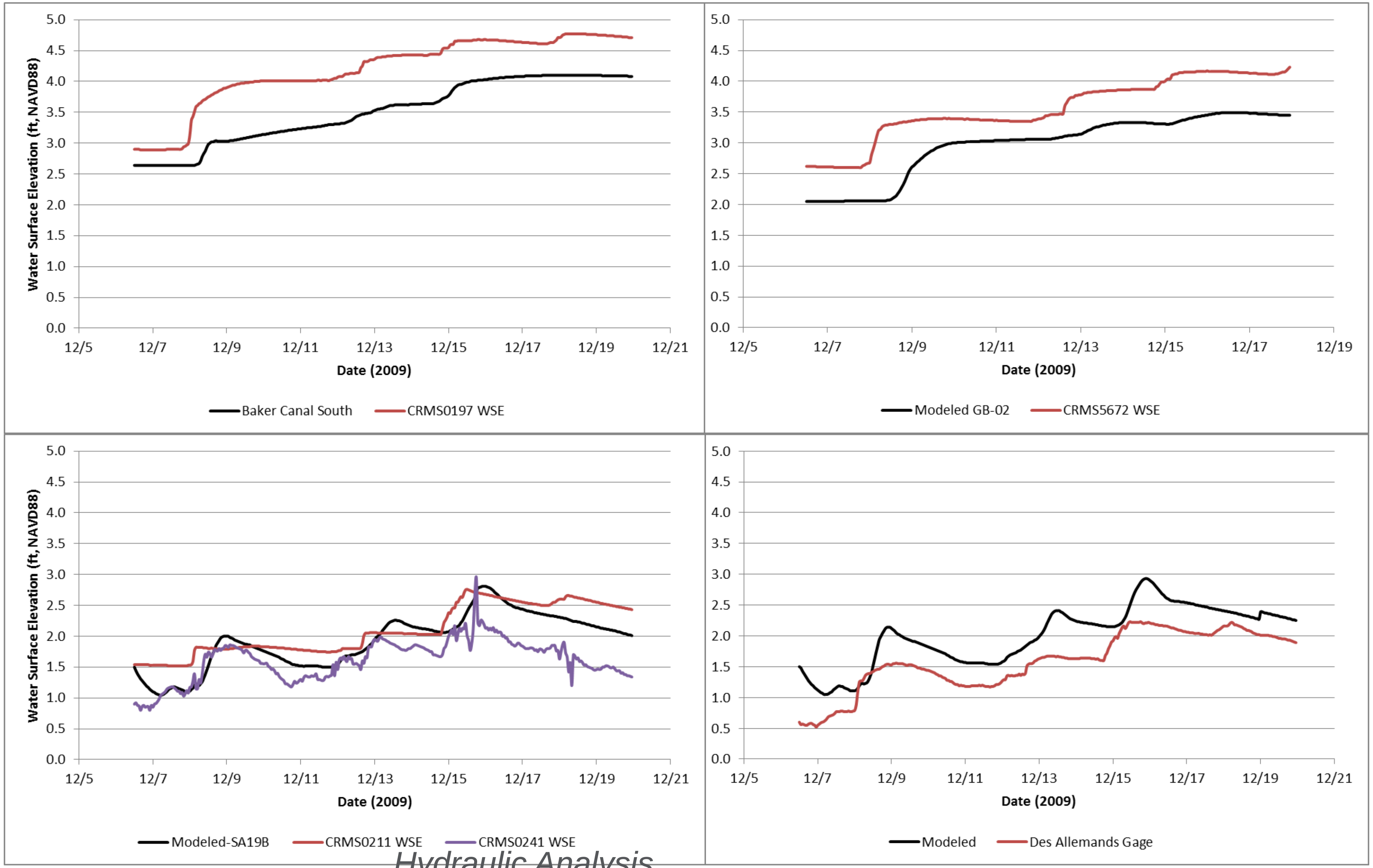


Gustav-Ike 2008

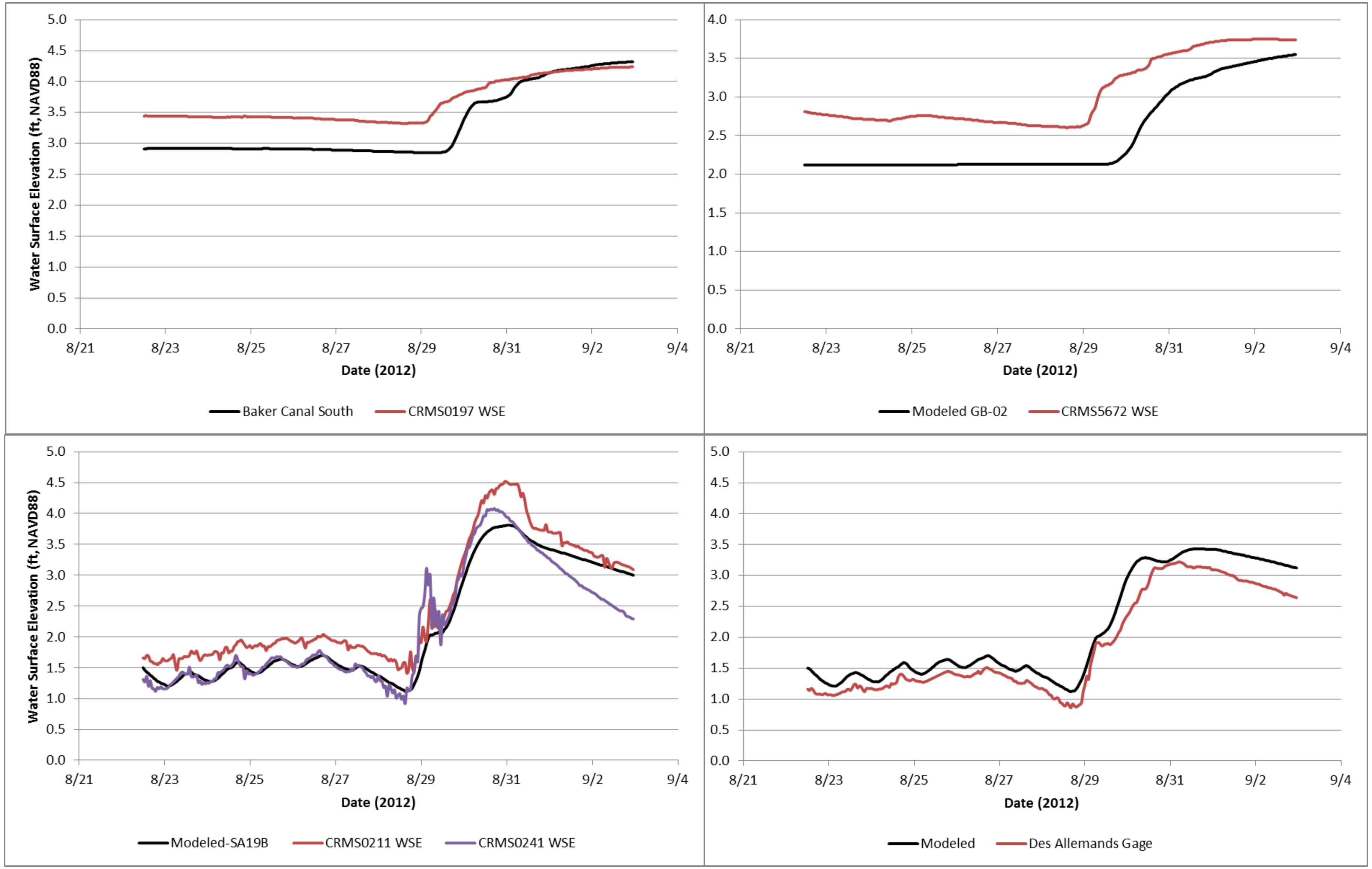


Hydraulic Analysis

Winter Storm 2009

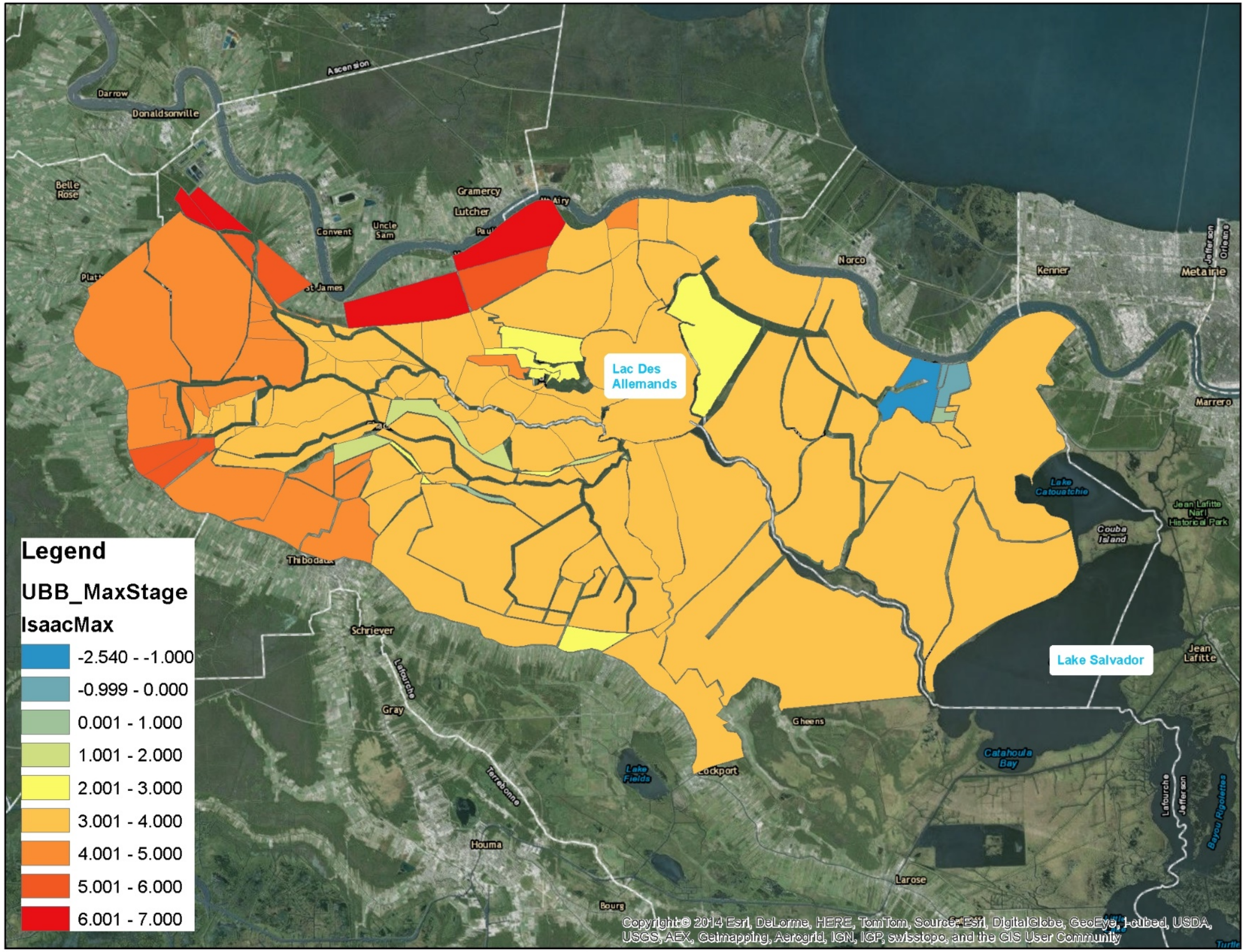


Isaac 2012



Hydraulic Analysis

Isaac 2012



Legend
UBB_MaxStage
IsaacMax
-2.540 - -1.000
-0.999 - 0.000
0.001 - 1.000
1.001 - 2.000
2.001 - 3.000
3.001 - 4.000
4.001 - 5.000
5.001 - 6.000
6.001 - 7.000
Lac Des Allemands
Lake Salvador
Donaldsonville
Darrow
Ascension
Belle Rose
Gramercy
Lutcher
Convent
Uncle Sam
St James
Norco
Kenner
Metairie
Marrero
Thibodaux
Schriever
Gray
Houma
Lockport
Gheens
Larose
Bourg
Catahoula Bay
Lake Catouatchie
Couba Island
Jean Lafitte
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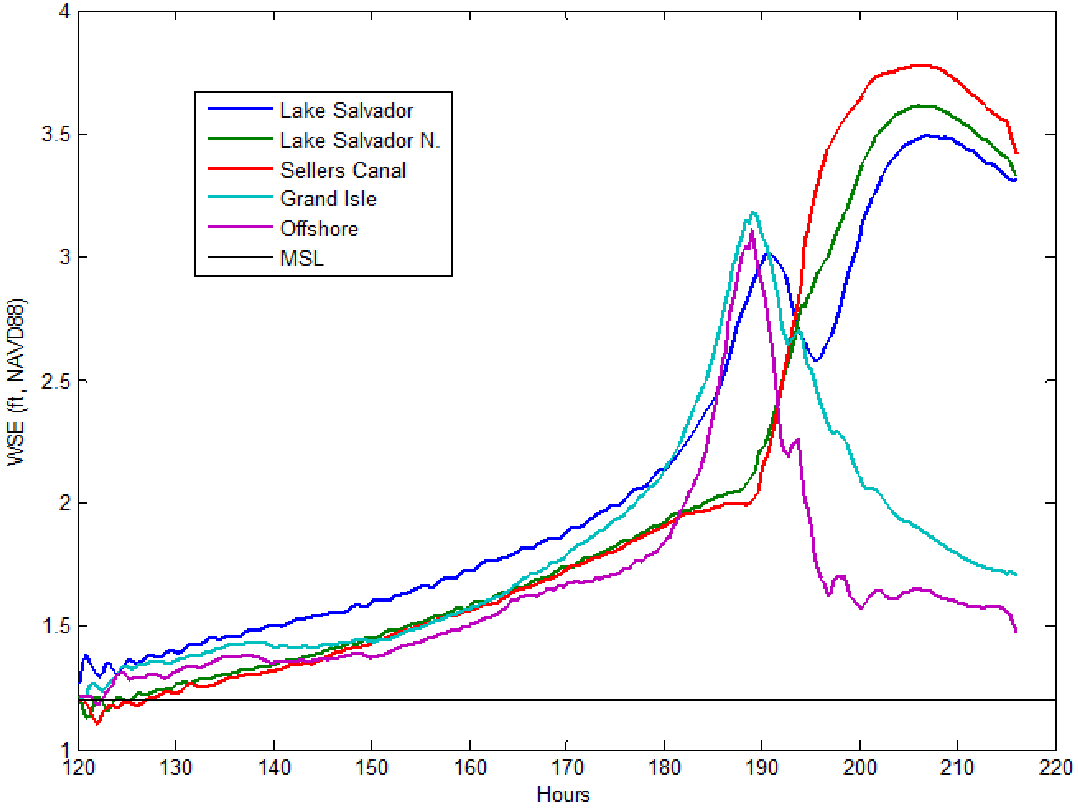
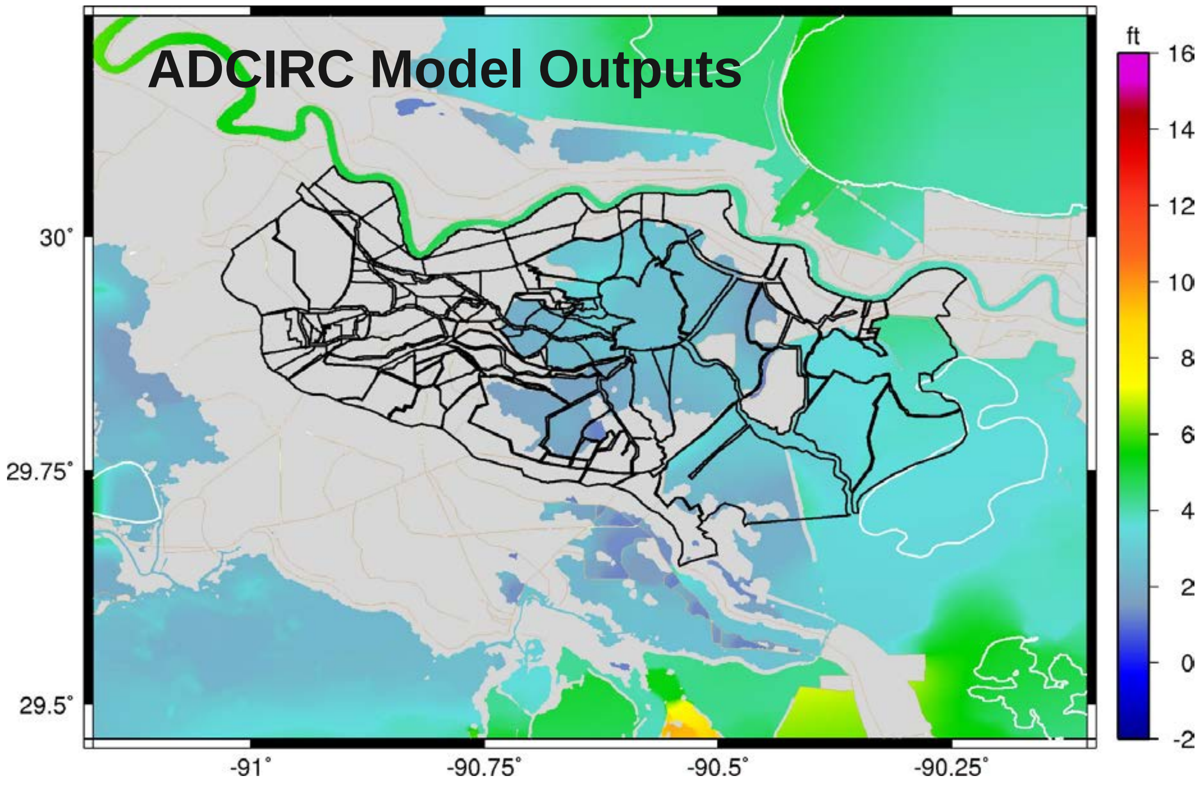
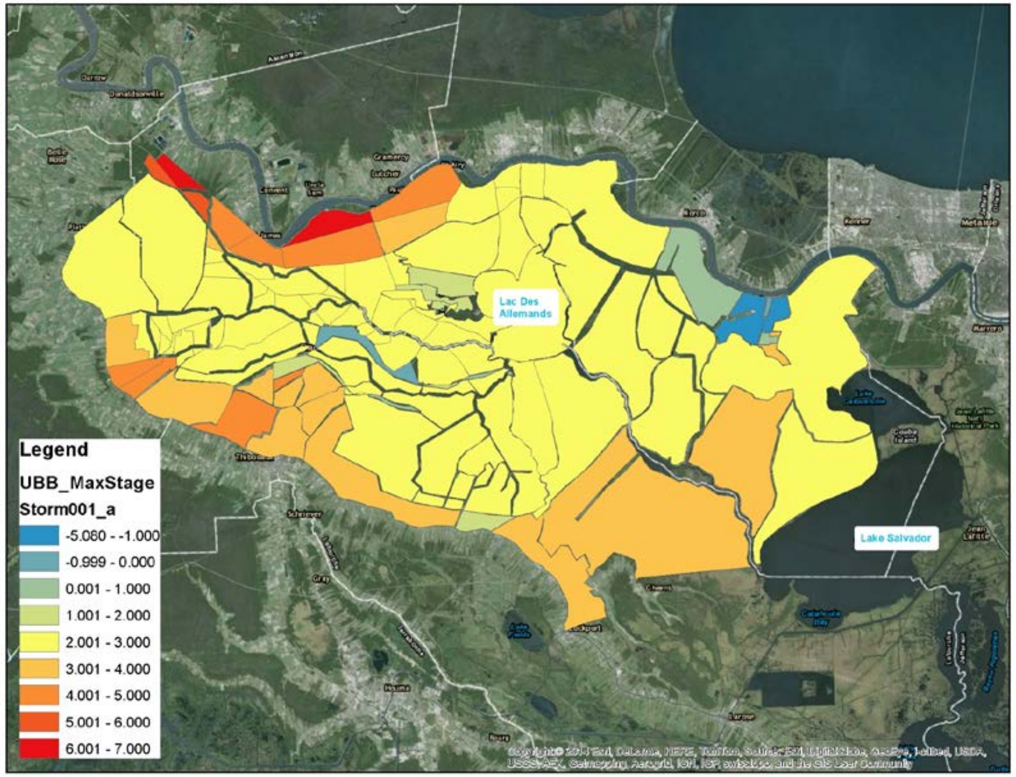
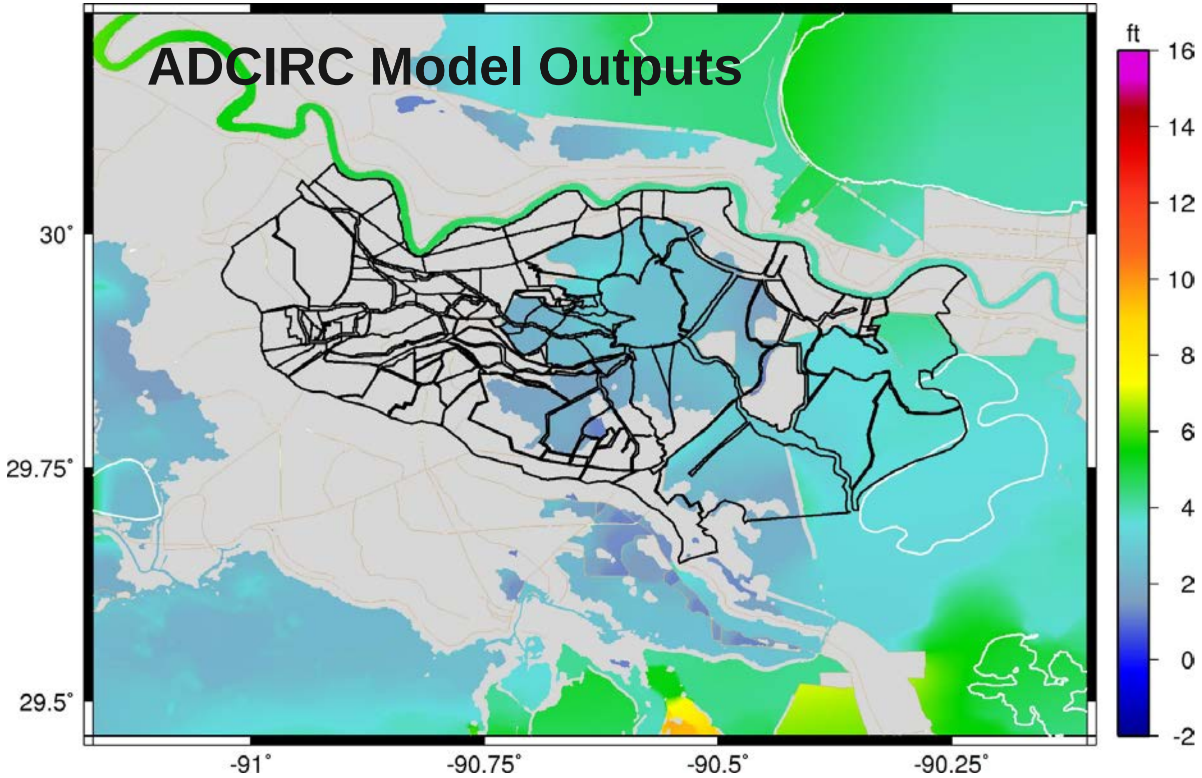
Synthetic Storm 001





Synthetic Storm 001

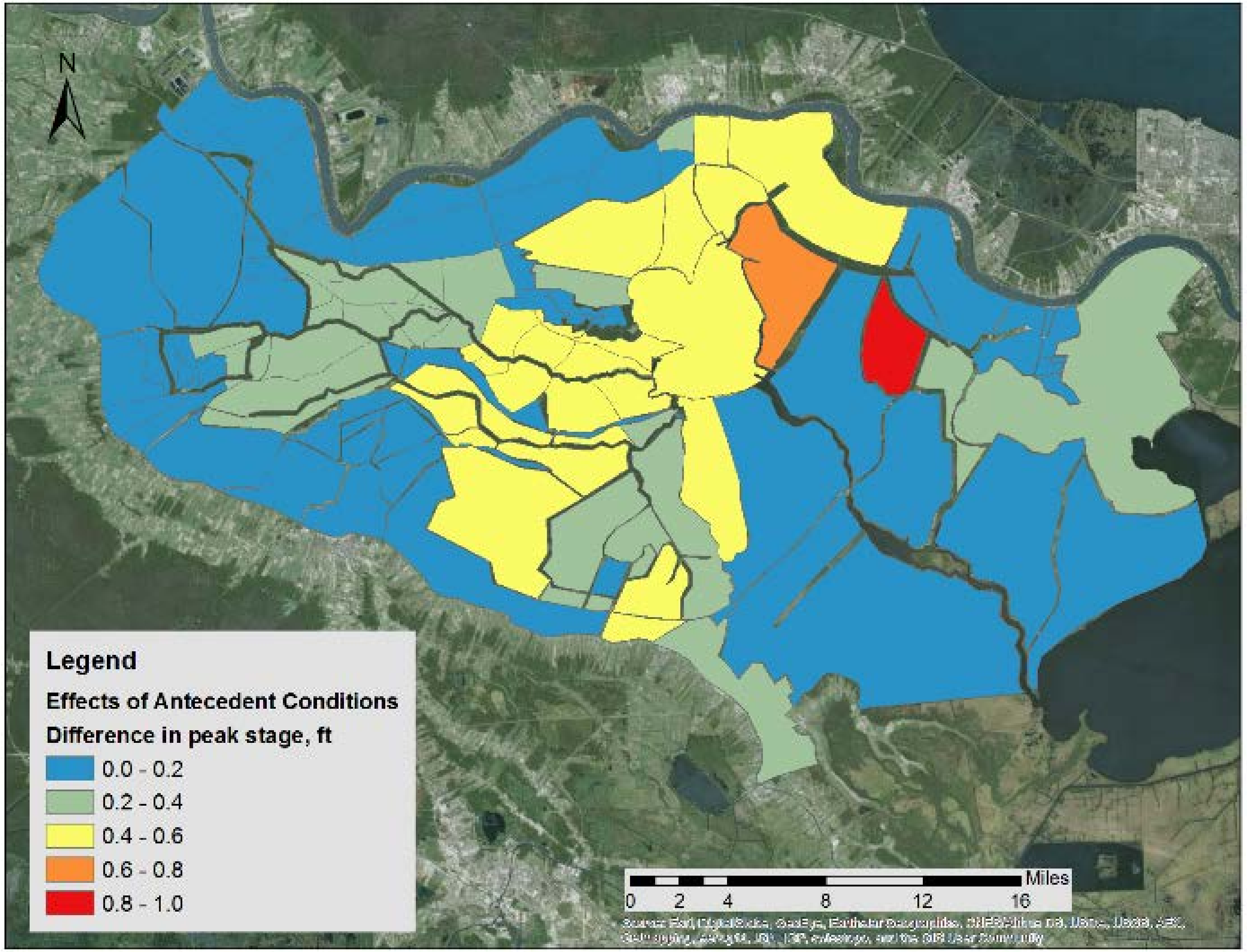




Effects of Antecedent Conditions

Approx. 0.5 feet in middle of study area

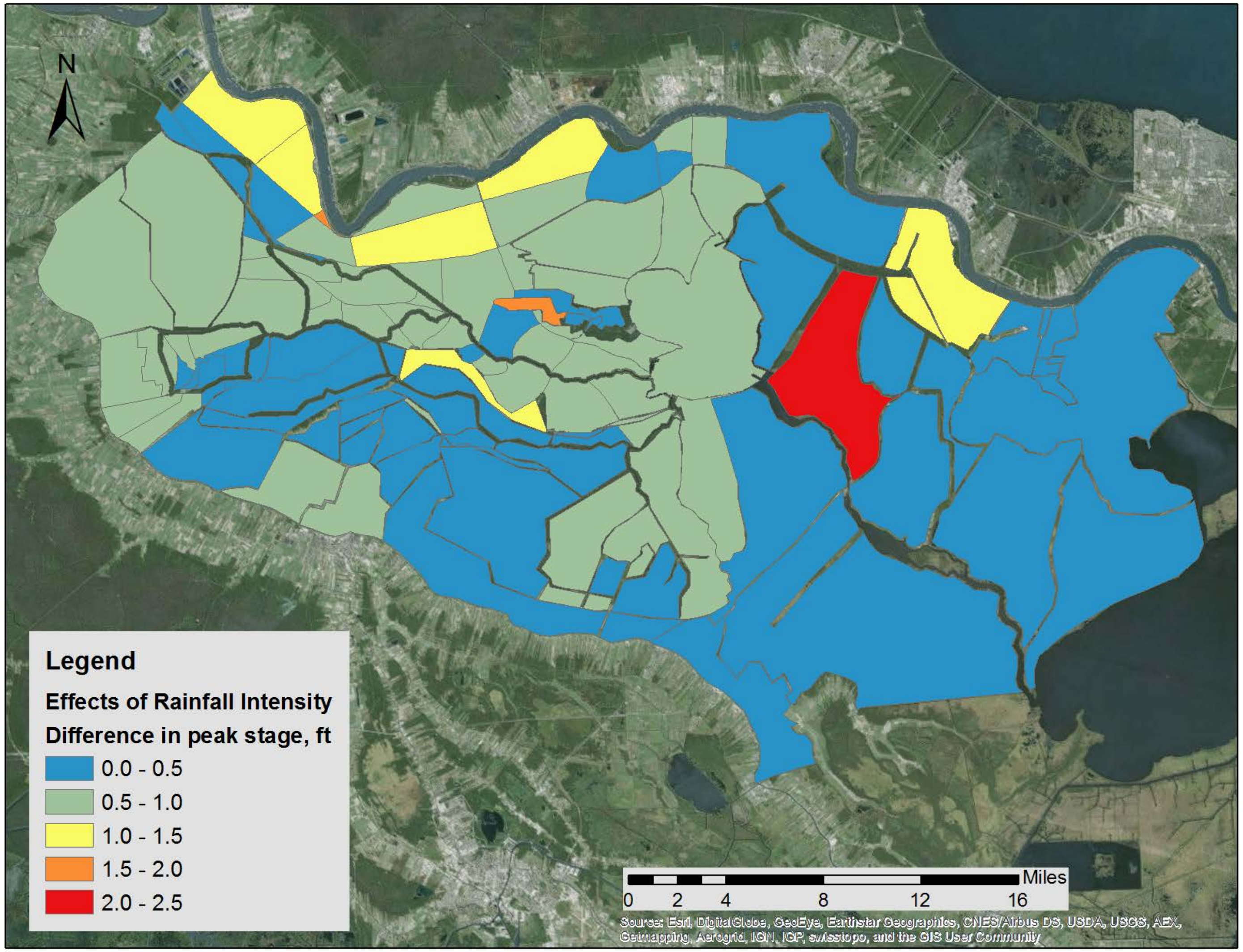
Illustrated by Storm 001-Rainfall1: Peak stage with antecedent of 2.0 ft (NAVD) minus peak stage with antecedent of 1.0 ft (NAVD)



Effects of Rainfall Intensity

Approx. 0.5-1.5 feet in middle of study area

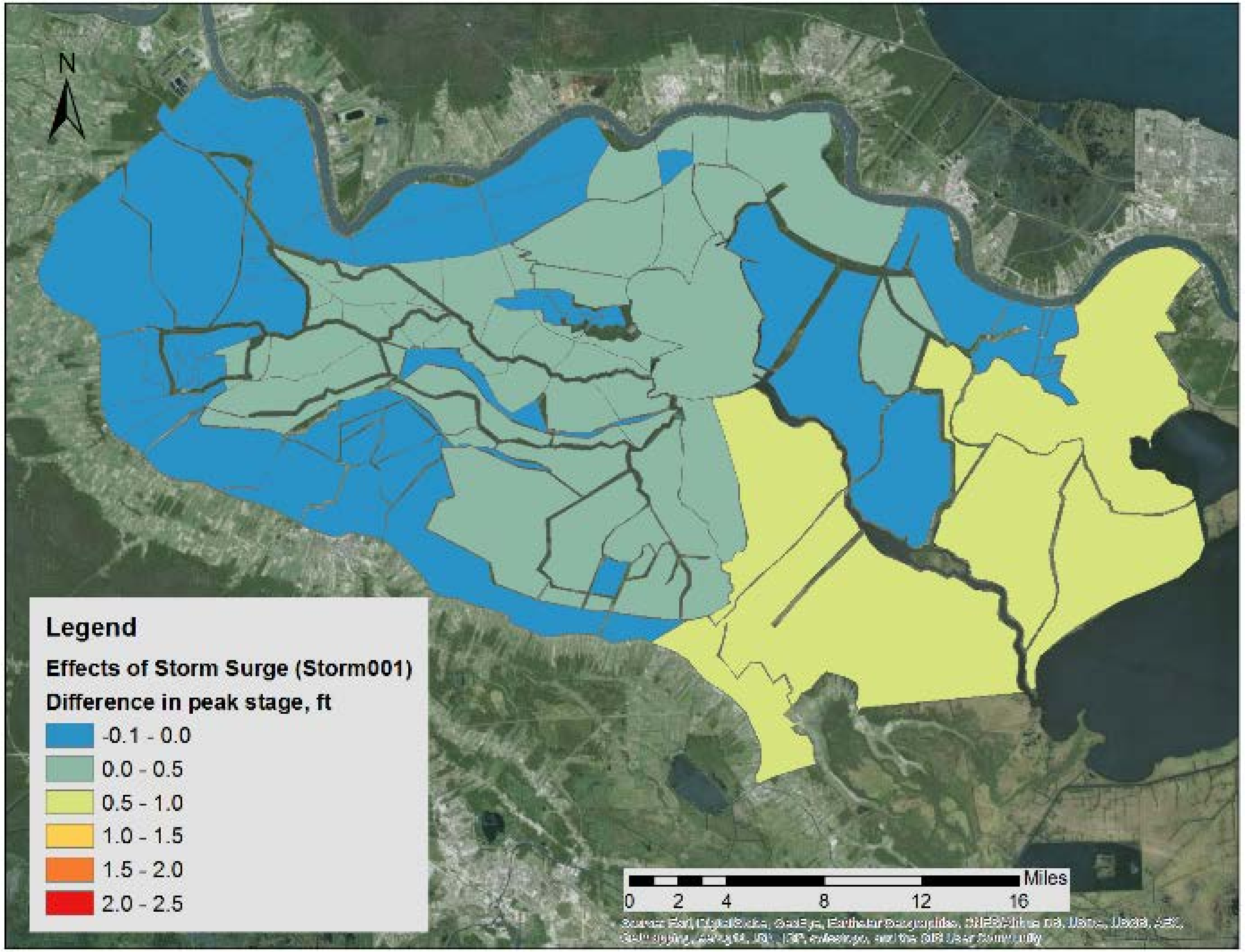
Illustrated by Storm 001-A3: peak stage due to coastal surge and R2 minus peak stage due to coastal surge and R1



Effects of Surge

Approx. 0.5-1.0 feet in lower part of study area

Illustrated by Storm 001-A3: peak stage due to storm surge and high rainfall minus peak stage due to high rainfall only



Joint Probability

Joint Probability

$$F(\eta_{\max})_{surge} = \sum_{k=1}^{20} \int_0^{15} \int_0^{3} p(\eta_{\max} \mid R_{24}) p(R_{24}, \vec{\eta}_{surge}, z_a) p(R_{24}, \vec{\eta}_{surge}, z_a) H[\Lambda(\bullet) - \eta_{\max}) dR_{24} dz_1 \delta\vec{\eta}_{surge,k}$$

where

$F(\eta_{\max})_{surge}$ is the cumulative distribution function of flooding when surges are significant

$H(x)$ is the Heaviside function of x

$\Lambda(\bullet)$ is the numerical model used to convert parameters to flood levels

z_a is the antecedent water level at the start of an event

$\delta\eta_{surge,k}$ is the increment of complementary probability of the k[th] event.

Joint Probability

The June through November rainfall data was very well fit by a Gumbel distribution:

$$F(R_{24}) = e^{-e^{\hat{R}}} \text{ with } \hat{R} = \frac{R_{24} - a_0}{b}, \text{ where } a_0 = 4.3757 \text{ and } b = 1.635$$

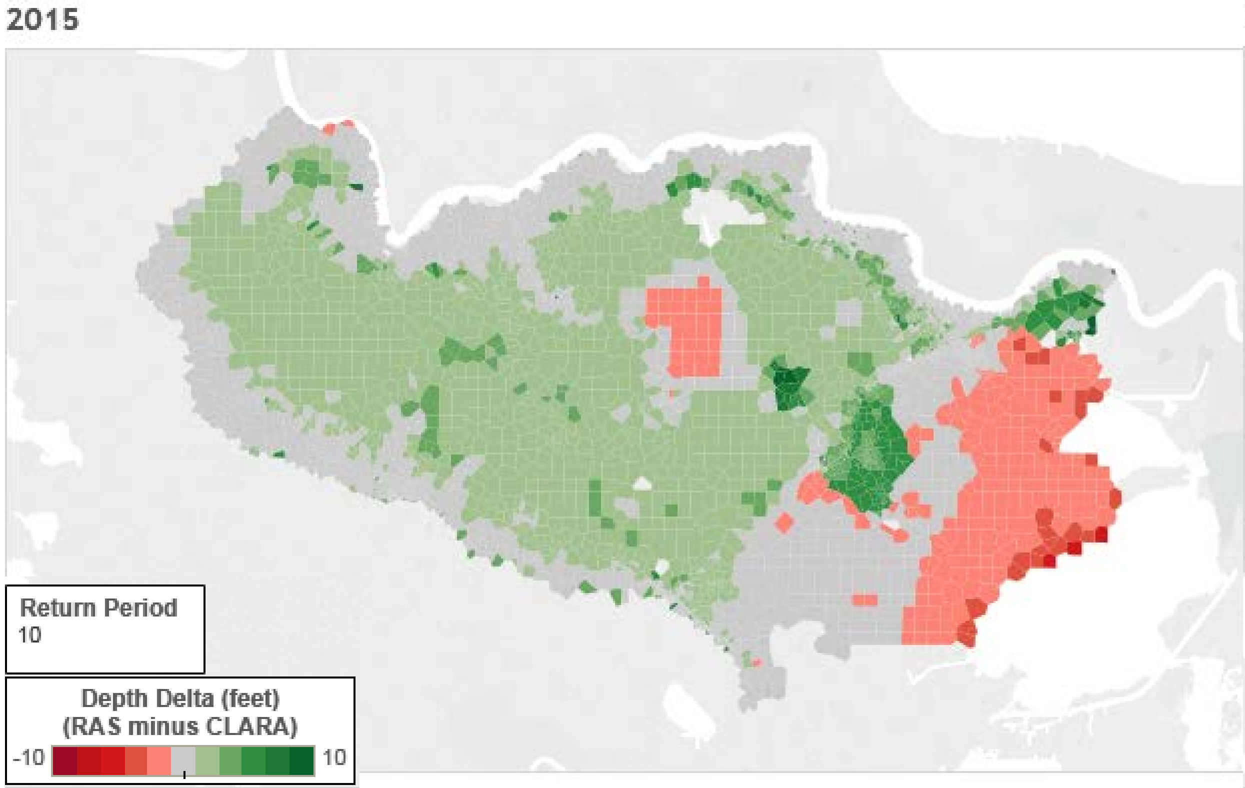
Return Period (years)	Estimated Rainfall (inches)
25	9.61
50	10.76
100	11.90
500	14.53

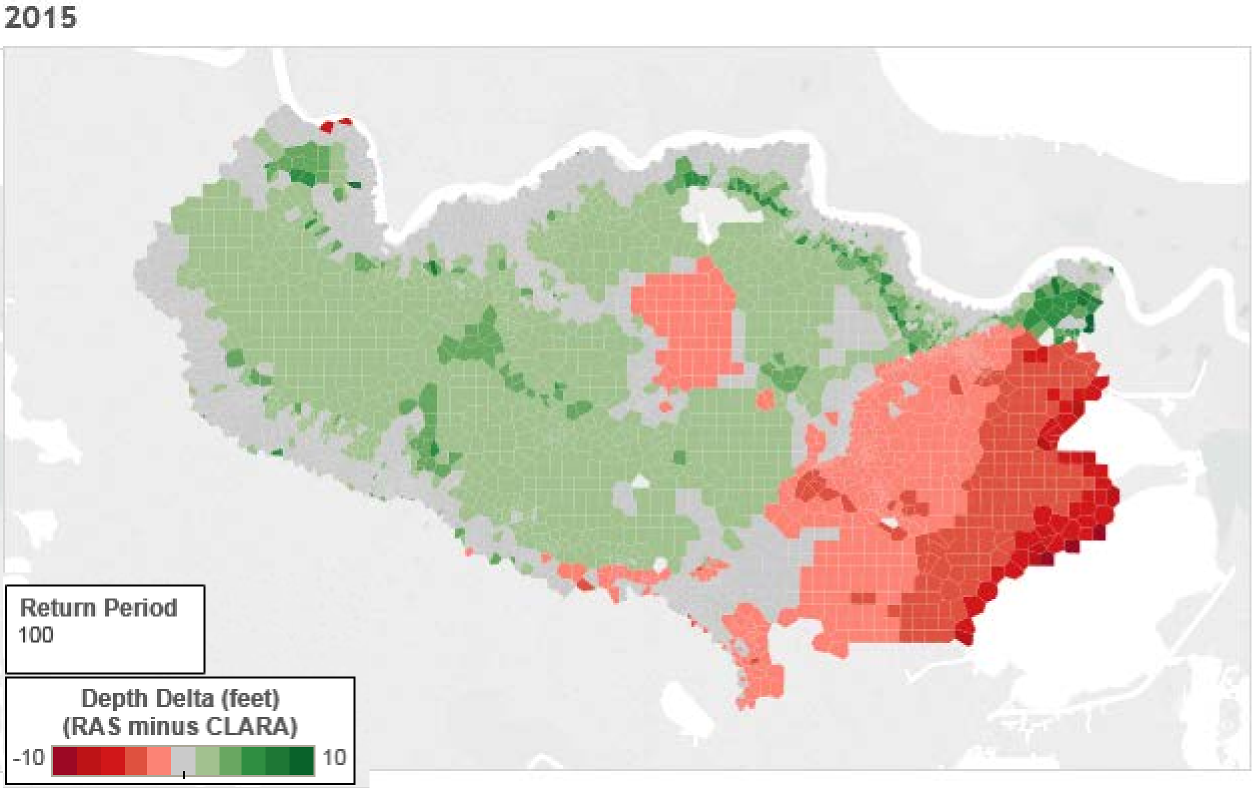
The December through May data was very well fit by a Gumbel distribution:

$$F(R_{24}) = e^{-e^{\hat{R}}} \text{ with } \hat{R} = \frac{R_{24} - a_0}{b}, \text{ where } a_0 = 3.4011 \text{ and } b = 1.6062$$

Return Period (years)	Estimated Rainfall (inches)
25	8.54
50	9.67
100	10.79
500	13.38

Comparison of Results





Addition of rainfall produces higher flood depth exceedances over most of the basin

Conclusions

Conclusions

The study shows that rainfall can be incorporated into a joint probability method analysis to define the flood hazard for geographic areas affected by both storm surge and rainfall

ADCIRC with HEC-HMS and HEC-RAS is a potential interim model framework that can be used while a robust coupled ADCIRC-runoff model is developed

Storm selection is an important step in the process that can affect JPM results

Storm climatology databases need to include information on rainfall intensity and spatial and temporal patterns as well as storm history after landfall. This information will aid in developing a probabilistic characterization of rainfall patterns of tropical events

Thank You!