LOUISIANA COASTAL PROTECTION AND RESTORATION

Interior Flood Hydrology Study for Orleans East Bank

Introduction

Study Purpose

The numerical model investigation of flooding in Orleans East Bank for the Louisiana Coastal Protection and Restoration Project (LACPR) was conducted to help answer questions regarding the performance of alternative hurricane protection measures. Inundation sources included 10-year frequency rainfall and hurricane storm surge water that would overtop three alternative levee/floodwall designs along Lake Pontchartrain for three hypothetical storm surges. The LACPR model simulates flood protection improvements expected to be in place by 2010. These improvements include a barrier structure on the Mississippi River Gulf Outlet (MRGO) that prevents any significant overtopping of the Inner Harbor Navigation Canal (IHNC) floodwalls, increased pumping capacity at Pump Stations DPS 6 and DPS 7, and a new pump station across the London Avenue Canal from DPS 4. The LACPR numerical model included the proposed permanent pump stations at the downstream ends of the 17th Street, Orleans, and London Outlet Canals. The alternatives include increased levee heights along Lake Pontchartrain and a barrier structure between Lake Pontchartrain and the Gulf. The numerical model used in the LACPR study was developed from the Interagency Performance Evaluation Taskforce (IPET) model used to simulate flooding events during Hurricane Katrina.

The study investigated the impact of pumping stations and storm drains on flooding. In the LACPR study it was assumed that the pumping stations would continue to operate at full capacity during overtopping events. This is different from what happened during Hurricane Katrina when power was lost and most of the pump stations were flooded. The permanent pumping stations were assumed to operate at design capacity and the interior pumping station capacities were limited to the capacity of the proposed permanent pump stations. Potential surges in the outlet canals due to variable pump operations at either end of the canal were not addressed in this study, but were addressed in separate numerical model investigations for the Hurricane Protection Office (HPO). In the LACPR study, when significant overtopping occurred along Lake Pontchartrain, the storm drains became a source of flooding rather than a means of floodwater evacuation because of backflow.

Sections of the Orleans East Bank Basin are separated by ridges and elevated railroads. The Gentilly Ridge serves to contain some of the overtopping floodwaters from Lake Pontchartrain. In the numerical simulation, the high ground provided by I-10 and the lack of connecting storm drains served as a barrier to floodwaters, protecting the uptown area of New Orleans.

This report will provide details of the development of the Corps of Engineers Hydrologic Engineering Center's Hydrologic Modeling System (HEC-HMS) and the River Analysis System (HEC-RAS) models for the Orleans East Bank basin. In summary, an HEC-HMS model was developed to transform the 10-year precipitation into runoff for input to the HEC-RAS models. The New Orleans District provided unit discharge storm surge overflow hydrographs for each alternative. These unit discharge hydrographs were calculated using the ADCIRC model. The overflow surge hydrograph into each storage area adjacent to Lake Pontchartrain was calculated from the unit discharge hydrograph using the perimeter of the storage area adjacent to the lake.

Total HEC-RAS input was the sum of the overtopping hydrograph for each effected storage area and the discharge hydrograph from rainfall. HEC-RAS models were developed to simulate a "rainfall only" base condition and 6 alternative conditions discussed below.

Rainfall Only

Flood elevations were predicted for a 10-year rainfall event assuming no overtopping of any of the hurricane protection system and pump stations performing at capacity. Pump capacity was calculated using pump performance curves and calculated head differentials. For purposes of calculating pumping capacities, the 100-year surge elevations in Lake Pontchartrain and the IHNC were assumed.

2010 Base Condition

Flood elevations were predicted for a 10-year rainfall event assuming that a barrier structure on MRGO prevents overtopping of the floodwalls along the IHNC. Flooding for three alternative levee/floodwall designs with the 2010 Base Condition was calculated. Inflow over the Lake Pontchartrain levees/floodwalls was calculated for a 100-year design levee, a 400-year design levee, and a 1000-year design levee. Storm surge discharges were calculated at the 90-percent confidence level for the 100-, 400-, and 1000-year events. There were six HEC-RAS model runs for the 2010 Base Condition: for the 100-year design levee/floodwall the 100-, 400-, and 1000-yr storm surges were evaluated; for the 400-year design levee/floodwall the 400-, and 1000-yr storm surges were evaluated; and for the 1000-year design levee/floodwall the 1000-yr storm surge was evaluated. Pump stations were assumed to perform at capacity. Pump capacity was calculated using pump performance curves and calculated head differentials. For purposes of calculating pumping capacities, the 100-year storm surge elevations in Lake Pontchartrain and the IHNC were assumed.

2010 East Alternative B

Flood elevations were predicted for a 10-year rainfall event assuming that a barrier structure on MRGO prevents overtopping of the floodwalls along the IHNC and that a barrier structure between Lake Pontchartrain and the Gulf reduces the storm surge in Lake Pontchartrain. Inflow over the Lake Pontchartrain levees/floodwalls was calculated for a 100-year design levee, a 400-year design levee, and a 1000-year design levee. Storm surge discharges were calculated at the 90-percent confidence level for the 100-, 400-, and 1000-year events. There were six HEC-RAS model runs for the 2010 East Alternative B: for the 100-year design levee/floodwall the 100-, 400-, and 1000-yr storm surges were evaluated; for the 400-year design levee/floodwall the 400-, and 1000-yr storm surges were evaluated; and for the 1000-year design levee/floodwall the 1000-yr storm surge was evaluated. Pump stations were assumed to perform at capacity. Pump capacity was calculated using pump performance curves and calculated head differentials. For purposes of calculating pumping capacities, the 100-year storm surge elevations in Lake Pontchartrain and the IHNC were assumed.

Review of Existing Data

The HEC-RAS numerical model for the LACPR study was developed from the HEC-RAS model used in the IPET study. The IPET model was developed from data available at the time the study was conducted. This included topographic elevations of the Orleans East Bank area that were obtained from existing digital terrain models and dimensions of most of the storm drains and channels that were obtained from previously developed numerical models. Initially, dimensions of many geometric features were approximated with the anticipation that reliable data would eventually become available. Dimensions of several geometric features were estimated from photographs, rough field measurements, or inductive reasoning. Data on pump station operations, pump rating curves were developed during the IPET study. Some of the critical data were not available in a time frame that allowed incorporation into the IPET model. These include surveys of railroad grades and some channels. The IPET model was calibrated to simulate measured flood elevations during the Katrina event.

The LACPR HEC-RAS model incorporated additional data received after completion of the IPET study. Both operating schedules and pump capacities became available for three minor pumping stations and were incorporated into the model. These included the I-10, Monticello, and Prichard pumping stations. The 2010 design permanent pump stations at the downstream end of the 17th Street, Orleans, and London Outlet Canals were incorporated into the LACPR HEC-RAS model. Pumps were added to DPS 6 and DPS 7 to reflect 2010 design conditions. An additional pumping station was added across the London Canal from DPS 4 to reflect 2010 design conditions. Pump curves for the new pumps were provided by the New Orleans District. The geometry of the Outlet Canals in the LACPR HEC-RAS models was revised using channel and bridge survey information collected by New Orleans District and the HPO in late 2006 and early 2007. Additional storm drains and lateral structures were added to the LACPR HEC-RAS model to provide connections for additional storage areas that were added to the model. Corrections and additions to lateral storm drain dimensions were incorporated into the LACPR HEC-RAS model based on construction plans, surveys, and XP-SWMM data obtained for the Monticello Canal, Geisenheimer Drain, and Hoey Canal.

General Modeling Approach

The unsteady flow HEC-RAS program developed by the US Army Corps of Engineers Hydrologic Engineer Center was used to develop the hydraulic model for LACPR study of the Orleans East Bank. The modeling approach was to identify storage areas that were bounded by ridges and/or elevated roads and railroads and then calculate flow between the storage areas. Some of the storage areas from the IPET model were subdivided in the LACPR model in order to obtain better definition of flood elevations in storage areas with higher ground elevations. This was necessary because flooding elevations were lower in the LACPR simulations than during the Katrina event simulated in the IPET model. The LACPR HEC-RAS model consists of 37 storage areas connected by storm drains, open channels and overtopping ridges. External boundary conditions defined the inflow into the numerical model. Runoff hydrographs, developed from 10-year rainfall events, and overtopping hydrographs, calculated using the ADCIRC model, were used as the external boundaries to the model. The HEC-RAS model was not used to calculate flow over the levees/floodwalls. Therefore, it was not necessary for the HEC-RAS model to include the 2010 design elevations for any of the IHNC or Lake Pontchartrain levees or floodwalls. Rainfall runoff, captured in the storage areas, was calculated using the HEC-HMS rainfall-runoff program. Pump station discharges were also simulated in the HEC-RAS model to account for movement between storage areas and expulsion of flood waters from the Orleans East Bank Basin. Major storm drains and canals were modeled as a means to transfer flows between storage areas. Flow between these storm drains and the storage areas was simulated using only major tributary culverts. Minor storm drains and drop inlets were ignored. Storage areas were also connected by weirs defined by railroad grades, roads, underpasses and natural ridges. In this manner all the storage areas were interconnected for the matrix solution of the unsteady flow equations in HEC-RAS.

Hydrologic Model Development

Background

The purpose of the hydrologic modeling was to transform 10-yr frequency rainfall within the Orleans East Bank study area into runoff that was then applied to the unsteady flow (HEC-RAS model. The 10-yr frequency rainfall was determined using the Weather Bureau Technical Paper 40 (1961). The HEC-HMS model was used for this portion of the study.

Basin Model

The HEC-HMS model was constructed to correspond directly to the HEC-RAS model. The HEC-HMS sub-basin boundaries are a reflection of the HEC-RAS storage area boundaries. Applying this method allows the HEC-HMS model to transform the 10-yr frequency precipitation directly into runoff for each sub-basin. The computed flow hydrographs were input to HEC-RAS as storage area inflows. Figure 1 depicts the HMS basin model setup for the Orleans East Bank Basin.

Figure 1. Orleans East Bank HEC-HMS Basin Model

Rainfall

Based on Weather Bureau Technical Paper 40 (1961), the 10-year rainfall (24-hour duration) for New Orleans is 8.68 inches. The 10-yr frequency hyetograph in 5-minute increments is shown in Figure 2.

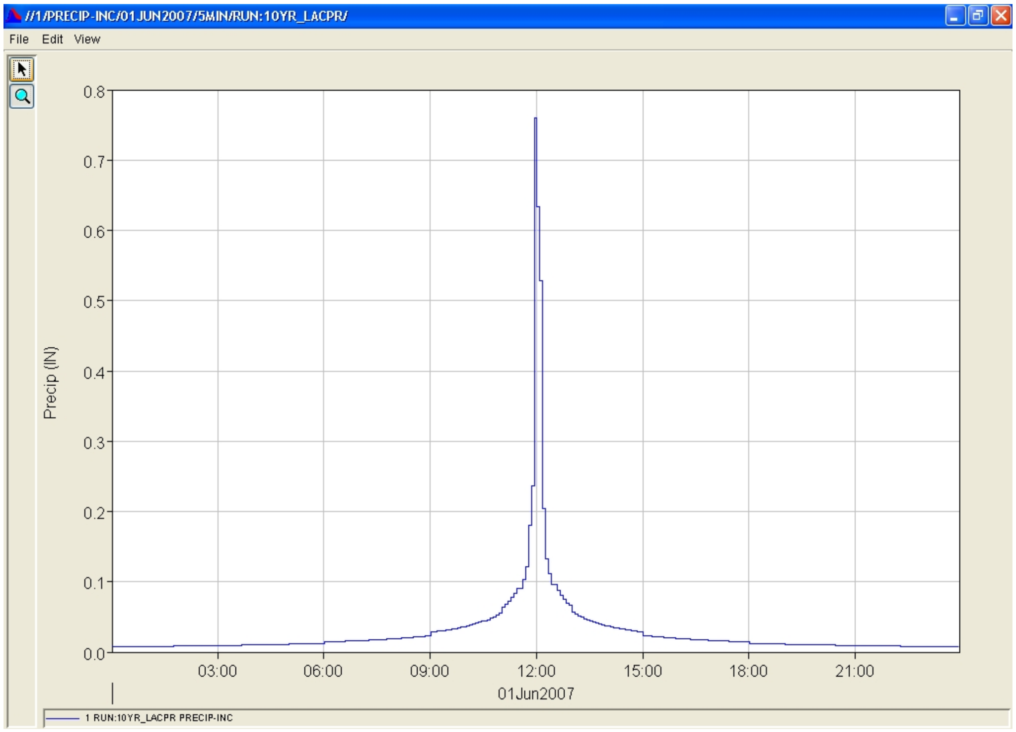

Figure 2. 10-yr Frequency Hyetograph for Orleans East Bank Storage Areas (5-minute increments)

Land Use and Soil Data

Land use and soil data were used to estimate the Soil Conservation Service (SCS) curve numbers. Land use data were obtained from the New Orleans District. The land use data consisted of raster coverage of 24 different land use types, as listed in Table 1. Soil data, contained in the Soil Survey Geographic (SSURGO) Database, was downloaded from the following National Resources Conservation Service (NRCS) website: http://www..ncgc.nrcs.usda.gov/products/datasets/ssurgo/. SSURGO is a digital copy of the original county soil survey maps and provides the most detailed soil maps from the NRCS.

Table 1
Curve Numbers by Land Use and Soil Type

	LAND USE	A	B	C	D
1	Fresh Marsh	39	61	74	80
2	Intermediate Marsh	39	61	74	80
3	Brackish Marsh	39	61	74	80
4	Saline Marsh	39	61	74	80
5	Wetland Forest-Deciduous	43	65	76	82
6	Wetland Forest- Evergreen	49	69	79	84
7	Wetland Forest- Mixed	39	61	74	80
8	Upland Forest- Deciduous	32	58	72	79
9	Upland Forest- Evergreen	43	65	76	82
10	Upland Forest- Mixed	39	61	74	80
11	Dense Pine Thicket	32	58	72	79
12	Wetland Scrub/shrub - deciduous	30	48	65	73
13	Wetland Scrub/Shrub - evergreen	35	56	70	77
14	Wetland Scrub/Shrub - Mixed	30	55	68	75
15	Upland Scrub/Shrub - Deciduous	30	48	65	73
16	Upland Scrub/Shrub - Evergreen	35	56	70	77
17	Upland Scrub/Shrub - Mixed	30	55	68	75
18	Agriculture-Cropland-Grassland	49	69	79	84
19	Vegetated Urban	49	69	79	84
20	Non-Vegetated Urban	71	80	87	91
21	Upland Barren	77	86	91	94
22	Wetland Barren	68	79	86	89
23	Wetland Complex	85	85	85	85
24	Water	100	100	100	100

Loss Rates

Loss rates were computed by determining the amount of precipitation intercepted by the canopy and depressions on the land surface and the amount of precipitation that infiltrated into the soil. Precipitation that is not lost to interception or infiltration is called “excess precipitation” and becomes direct runoff. The SCS Curve Number (CN) method was used to model interception and infiltration. The SCS CN method estimates precipitation loss and excess as a function of cumulative precipitation, soil cover, land use, and antecedent moisture. This method uses a single parameter, a curve number, to estimate the amount of precipitation excess/loss from a storm event. Studies have been conducted to determine appropriate curve number values for combinations of land use type and condition, soil type, and the moisture state of the watershed.

Table 1 was used to estimate a curve number value for each combination of land use and soil type in the study area. Each soil type in the SSURGO Database was assigned to one of the four hydrologic soil groups. (A, B, C or D). The percent impervious cover is already included in the curve number value in Table 1. More information about the background and use in the SCS curve number method can be found in SCS (1971, 1986).

By factoring in land use and soil type, curve numbers were developed for each of the 37 storage areas of the Orleans East Bank model, ranging in values from 84 to 89. A complete list of the curve numbers developed for each of the thirty-seven storage areas are as shown in Table 2.

Table 2
Storage Area Weighted Curve Numbers Orleans East Bank

Storage Area	Area in Acres	Curve Number
1	862	86
2	799	88
3	2162	86
4	834	86
5	1500	86
51	423	88
6	1240	85
7	1305	84
8	492	84
9	1061	85
101	790	87
102	623	89
111	445	85
112	519	85
113	63	86
114	765	84
122	554	84
123	172	86
124	662	84
125	190	85
126	168	85
127	84	85
131	982	86
132	1034	85
133	393	85
14	1385	86
142	84	88
151	1290	84
152	1200	86
153	278	85
16	877	85
171	729	85
172	997	85
18	1123	86
19	169	89
20	551	85
21	565	86

Transform

Excess precipitation was transformed to a runoff hydrograph using the SCS unit hydrograph method. The SCS developed a dimensionless unit hydrograph after analyzing unit hydrographs from a number of small, gaged watersheds. The dimensionless unit hydrograph is used to develop a unit hydrograph given drainage area and lag time. A detailed description of the SCS dimensionless unit hydrograph can be found in SCS Technical Report 55 (1986) and the National Engineering Handbook (1971).

Surface area in each of the 37 drainage areas (storage areas in HEC-RAS) was computed using GIS and then input into HEC-HMS. Lag time, shown in Table 3, was computed by using the curve number method described in the NRCS National Engineering Handbook, 1972.

Lag times for the SCS unit hydrograph method were estimated using the following equation:

$$Lag = (L^{0.8} * (S + 1)^{0.7}) / (1900 * Y^{0.5})$$

Where: Lag = basin lag time (hours)

L = hydraulic length of the basin (feet)

S = 1000/CN – 10 ; where CN is approximately equal to the curve number. CN values between 50 to 95 are appropriate to this equation.

Y = watershed slope (%)

Table 3 Computed Lag Times			
Sub-basin Name	**Hydraulic Length (ft)**	**Average Sub-basin Land Slope %**	**Lag Time (minutes)**
1	11444	0.04	524
2	4600	0.11	149
3	9960	0.10	310
4	6530	0.12	200
5	8530	0.12	253
51	3660	0.17	98
6	6600	0.14	198
7	7000	0.11	235
8	5620	0.14	176
9	6180	0.11	206
101	7700	0.16	195
102	5600	0.14	146
111	10950	.08	383
112	4140	.07	187
113	1980	.10	85
114	8040	.13	245
122	4120	.22	111
123	4500	.16	132
124	5120	.12	181
125	3480	.17	106
126	2870	.17	90
127	3110	.19	91
131	8980	.08	323
132	8080	.11	258
133	3060	.20	89
14	4210	.07	185
142	2320	.15	74
151	9880	.12	300
152	8080	.10	264
153	3870	.23	99
16	10560	.09	365
171	7470	.12	233
172	7920	.16	209
18	5210	.12	241
19	4240	.07	166
20	3060	.16	112
21	5340	.15	151

Model Results

Figures 3, 4, 5, 6, and 7 depict results for HEC-HMS sub-basins 8, 7, 6, 5, and 3 respectively. (These sub-basins are adjacent to Lake Pontchartrain where the overtopping hydrograph discharges from the various storm surge events were added to the rainfall runoff hydrograph.) The upper graphs show precipitation and precipitation loss. The lower graphs show the runoff from the sub-basin. These runoff hydrographs are entered in the HEC-RAS model in the corresponding storage areas. The same procedure is used for the other 32 storage areas. Complete summary results are shown in Table 4.

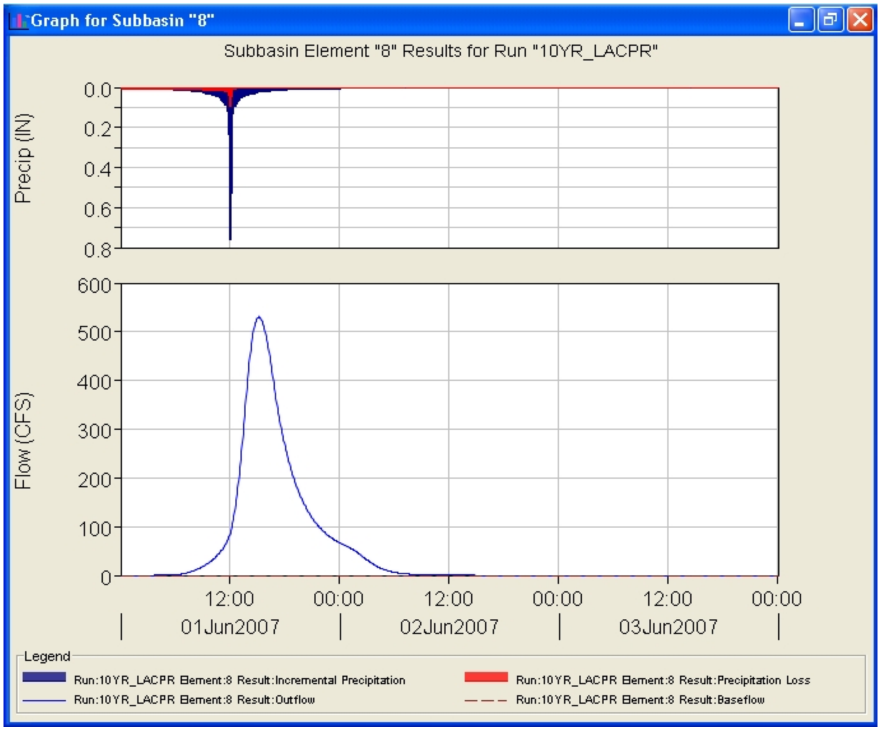

Figure 3. HEC-HMS Results for Sub-basin 8

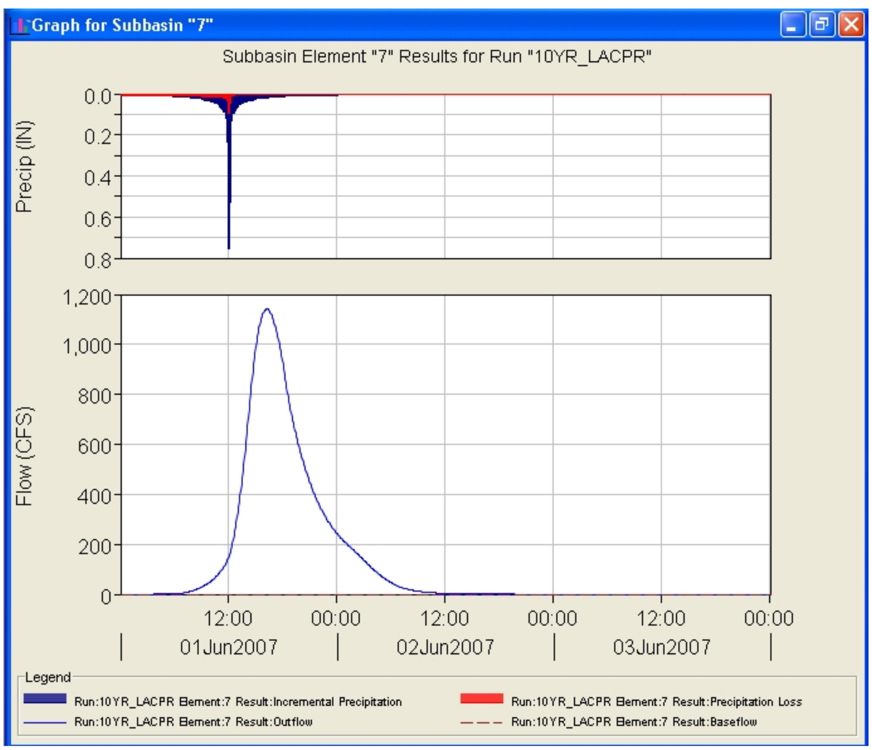

Figure 4. HEC-HMS Results for Sub-basin 7

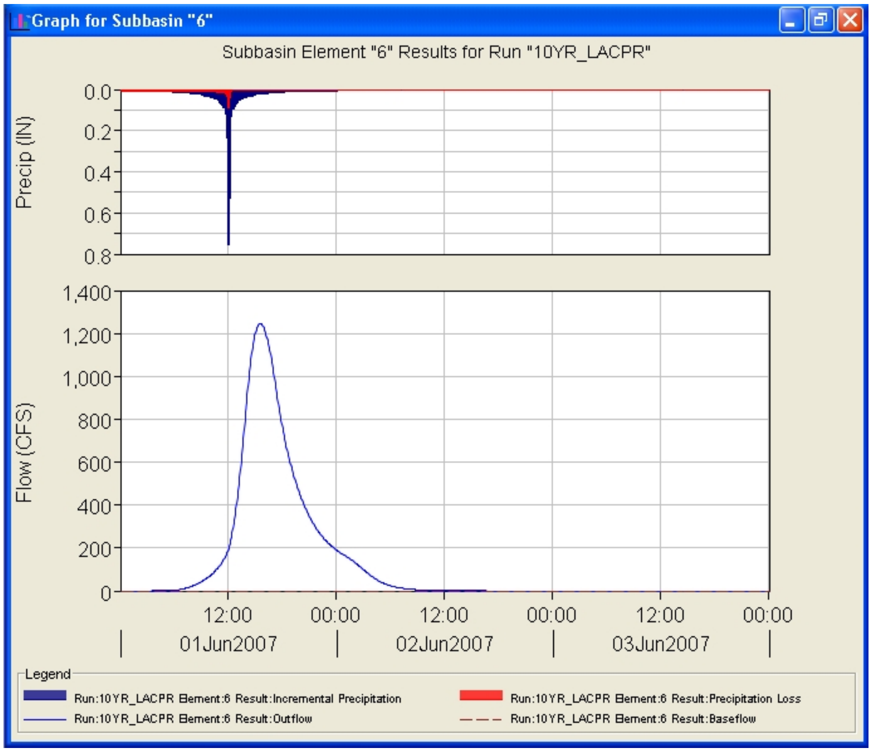

Figure 5. HEC-HMS Results for Sub-basin 6

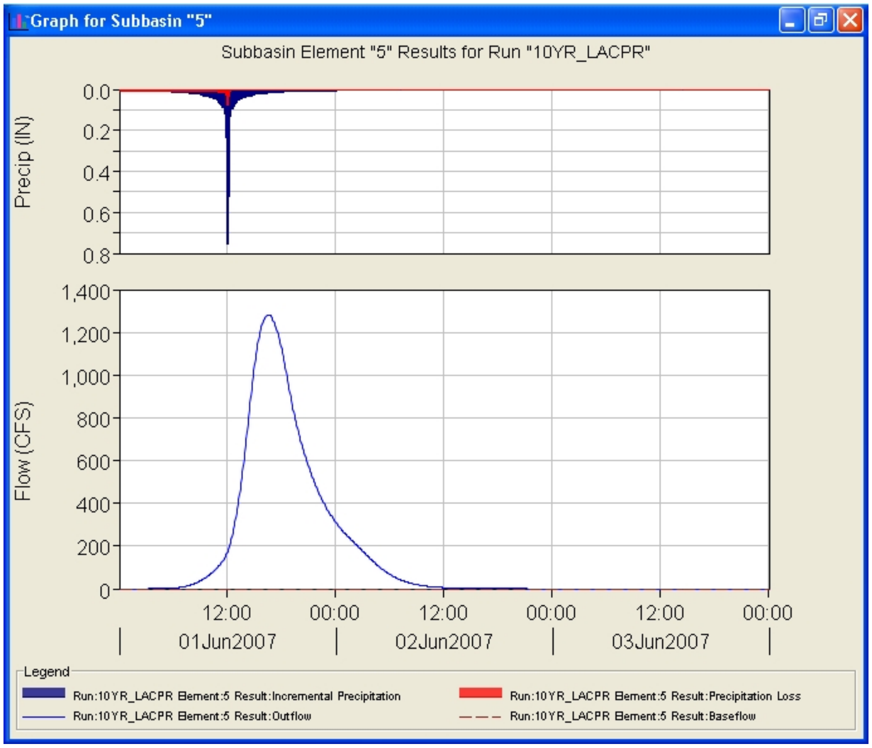

Figure 6. HEC-HMS Results for Sub-basin 5

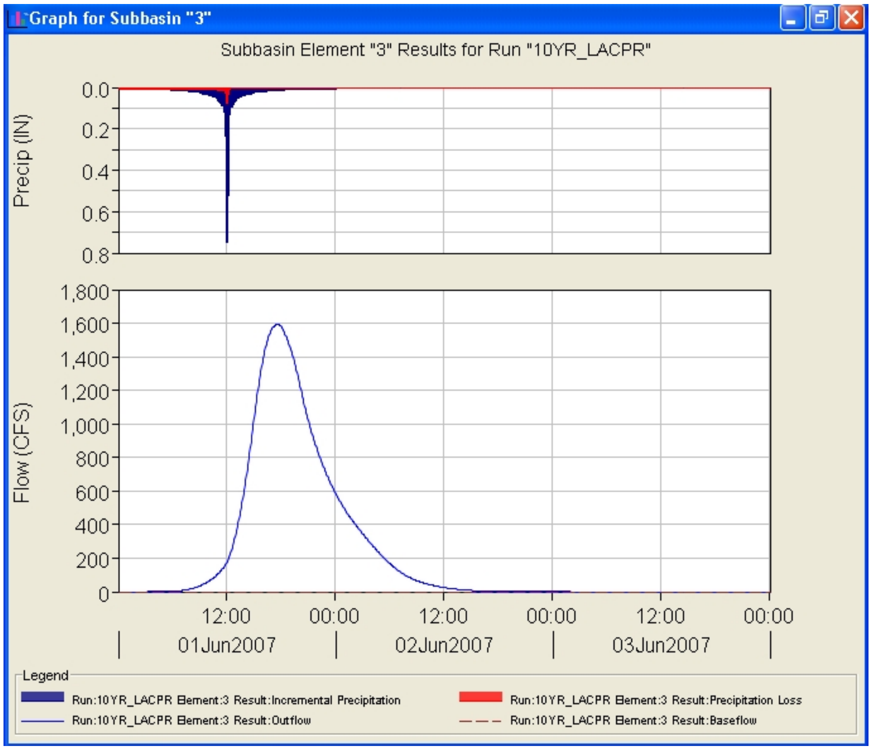

Figure 7. HEC-HMS Results for Sub-basin 3

Table 4
Summary of Hydrologic Analysis Results

Sub-basin Name	Drainage Area (mi2)	Peak Discharge (cfs)	Time of Peak	Runoff Volume (in)
1	1.35	430	21:36	6.98
2	1.25	1020	14:41	7.22
3	3.38	1594	17:36	6.95
4	1.30	843	15:36	6.98
5	2.34	1282	16:36	6.97
51	0.66	713	13:46	7.23
6	1.94	1246	15:36	6.85
7	2.04	1143	16:16	6.73
8	0.77	530	15:11	6.74
9	1.66	1038	15:46	6.85
101	1.23	824	15:31	7.10
102	0.97	823	14:36	7.34
111	0.69	275	19:01	6.86
112	0.81	543	15:21	6.86
113	0.10	116	13:31	6.99
114	1.19	648	16:26	6.74
122	0.86	809	14:01	6.74
123	0.27	233	14:21	6.99
124	1.03	695	15:16	6.74
125	0.30	296	13:56	6.87
126	0.26	285	13:36	6.87
127	0.13	142	13:36	6.87
131	1.53	703	17:51	6.97
132	1.62	863	16:41	6.85
133	0.61	674	13:36	6.86
14	2.16	1474	15:21	6.97
142	0.13	168	13:21	7.23
151	2.02	948	17:26	6.73
152	1.87	994	16:46	6.97
153	0.43	443	13:46	6.87
16	1.37	566	18:41	6.86
171	1.14	654	16:16	6.86
172	1.56	965	15:46	6.85
18	1.76	999	16:21	6.97
19	0.26	200	15:01	7.35
20	0.86	816	14:01	6.86
21	0.88	693	14:41	6.98

Hydraulic Model Development

Background

The Orleans East Bank HEC-RAS model consists of 37 storage areas connected by storm drains, open channels and overtopping ridges. The model limits are Lake Pontchartrain on the north, the Mississippi River on the south, the IHNC on the east and the 17th Street Canal, Fairmont Drive and Causeway Boulevard on the west. Potential flood waters enter the Orleans East Bank model as rainfall and levee/floodwall overtopping. Flood waters initially accumulate in storage areas until depths are sufficient for water to flow into the storm drains and open channels. This occurs immediately with the onset of rainfall. Storm waters are pumped from the local drainage system into either Lake Pontchartrain or the IHNC. Levee/floodwall overtopping can overwhelm the drainage system causing significant flooding. As water levels increase, flood flows move between storage areas across roads, railroads and ridges. These high water connections are treated as weirs in the HEC-RAS model.

Datum Reconciliation

Elevations reported herein are related to the NAVD88 (2004.65) datum. The digital terrain model used to define storage area elevations and ridge elevations in the HEC-RAS model are related to the NAVD88 (2004.65) datum. Elevations for the storm drains and pump stations were originally provided using the Cairo datum. Cairo elevations were adjusted to NAVD88 (2004.65) in the HEC-RAS model by subtracting 21.03 ft. Elevations in the IPET model were based on the NAVD88 (1994, 1996) datum. Calculated elevations from the IPET report can be compared to calculated elevations from the LACPR report by subtracting 0.4 ft from the IPET report elevations.

Terrain Model

Elevation data in the Orleans East Bank area were obtained through the use of the Louisiana Atlas website (http://atlas.lsu.edu). The LIDAR data used is a result of a statewide project started in 2000. The systems being used in the project are accurate to 15-30 cm RMSE, depending on land cover, and will support contours of 1ft to 2ft vertical map accuracy standards. The files are represented by quadrangle 5-meter DEM data files. These accuracies meet FEMA standards for floodplain reevaluation studies and map modernization programs designed to update the Flood Insurance Rate Maps.

Basic Geometric Data

Most of the storm drain and open channel dimensions used in the HEC-RAS model were extracted from XP-SWMM models developed by Brown Cunningham and Gannuch Engineers, Architects and Consultants, Inc (BCG). The XP-SWMM models were completed in 2005 for the USACE New Orleans District to simulate 10-year flooding conditions. Elevations in the XP-SWMM models were based on the Cairo datum. Model elevations were converted to NAVD88 (2004.65) datum for inclusion in the HEC-RAS model. The XP-SWMM model data was used to define dimensions for both the storm drains actually modeled in the HEC-RAS model and for the inlets that connected the storm drains to the storage areas.

BCG provided a HEC-RAS steady state model of the Palmetto Canal. This model was developed for the Sewerage and Water Board of New Orleans as part of a Master Drainage Study between 2002 and 2005. Bridges across the Palmetto Canal were included in the model. Elevations in the BCG HEC-RAS model were based on the Cairo datum. Model elevations were converted to NAVD88 (2004.65) datum for inclusion in the unsteady flow HEC-RAS model.

BCG provided survey data of the Monticello Canal between Claiborne Avenue and the Palmetto Canal. The survey data included surveys at the bridges crossing the canal. Cross sections for the Monticello reach in LACPR model were developed from these data. Elevations in the BCG survey were based on the NGVD datum. Model elevations were converted to NAVD88 (2004.65) datum for inclusion in the unsteady flow HEC-RAS model.

The New Orleans District and the HPO provided November 2006 hydrographic survey data for the 17th Street, Orleans and London Canals. These survey data were burned into the LIDAR data from which cross sections for the HEC-RAS model were cut. Additional channel survey data including bridge and pier dimensions were obtained in 2007. Survey data were provided in NAVD88 (2004.65) datum.

CTE, a Chicago based A-E firm, provided a steady state HEC-RAS model of the Geisenheimer Drain and Hoey Canal in the Hoey Basin. Elevations in the CTE model were based on the Cairo datum. Model elevations were converted to NAVD88 (2004.65) datum for inclusion in the HEC-RAS model. Dimensions of lateral inlets in the Geisenheimer Canal and Hoey Canal were obtained from a BCG XP-SWMM model.

Channels and storm drains included in the unsteady flow HEC-RAS model are shown in Figure 8. The names chosen for the model are based on nearby streets and do not necessarily reflect the appropriate local names.

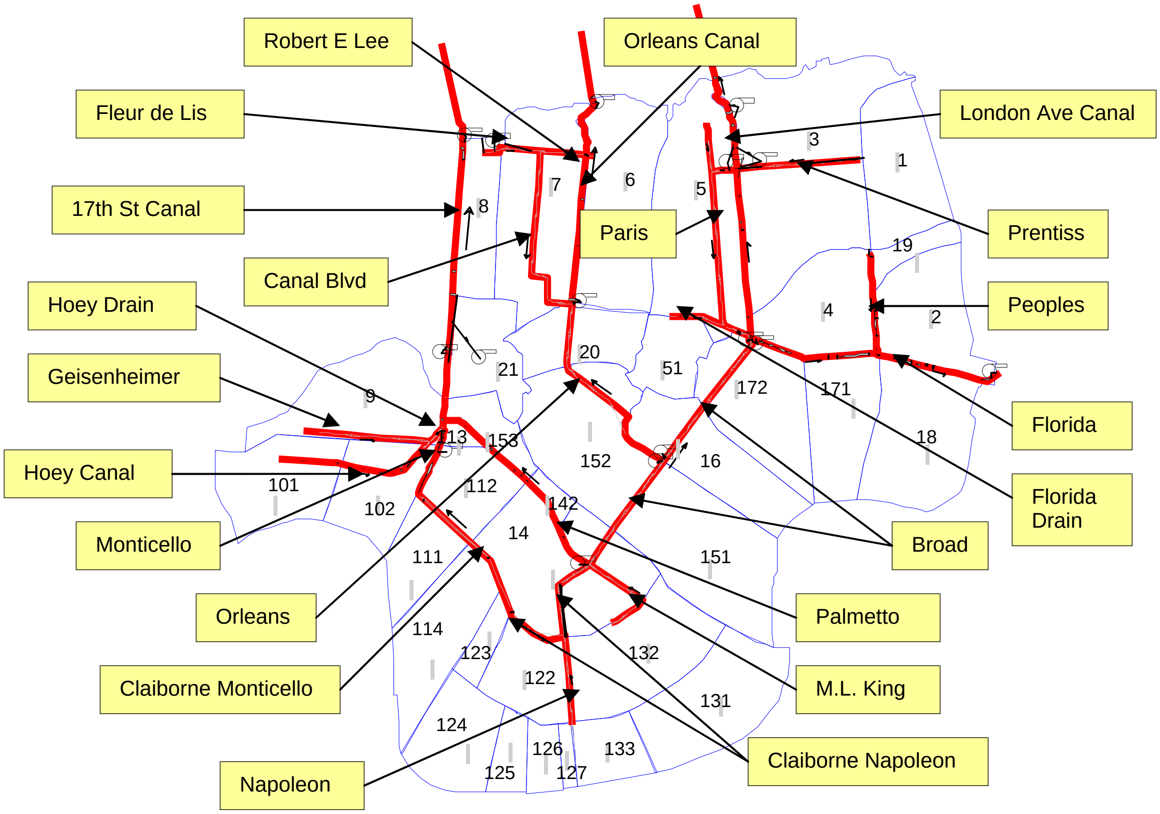

Figure 8. Channels and Storm Drains Modeled in HEC-RAS Model

Manning's n-Values

HEC-RAS uses Manning's equation to compute friction forces, which are then used in the unsteady flow equations in performing unsteady flow simulations. Manning's roughness coefficients, commonly called Manning's n values are assigned to each channel, bridge, culvert and storm drain in the geometry file used in the unsteady flow computations. The Manning's n values that were used in the model were obtained from the XP-SWMM model provided by BCG. These values were checked with the guidance furnished in HEC-RAS documentation. For earthen channels, values ranged from .024 to .04 depending on the condition of the main channel with overbank n values ranging from .03 to .05. The n value for concrete lined channels varied from 0.014 to 0.018 depending on the condition of the channel bottom and side slopes. The Manning's n values were also modified in reaches where the condition of the channel dictated the use of different values. The Manning's n values varied from 0.014 to 0.018 in the storm drain reaches depending on the shape and condition of the concrete.

Bridges

Bridges and box culverts were analyzed as part of the HEC-RAS model for the whole basin. HEC-RAS computes flow through the bridges or culverts using the Bernoulli or Energy Equation. Hydraulic losses in the large concrete box culverts and circular pipes were computed using entrance and exit loss coefficients recommended in the HEC-RAS Reference Manual. These were 0.3 to 0.5 and 0.5 to 1.0 respectively, depending on what local conditions require.

Storage Areas

Storage area elevation-volume curves were developed from the digital terrain model and from calculated storm drain volumes. In order to properly model the movement of floodwater from one sub-area to another in the Orleans East Bank Basin, the total area was subdivided into 37 sub-areas, as previously shown in Figure 1. These areas were selected based on the physical barriers that separated them such as natural high ground, railroads, levees, channel floodwalls and other barriers. The HEC-GeoRAS model was used with the digital terrain model to compute the elevation-storage data of each sub-area. Once the elevation-storage curves were computed, they were exported to the unsteady HEC-RAS model. Additional storage volume was added in some sub-areas to account for volume available in underground storm drains that were not simulated in the model. Dimensions and elevations for these storm drains were extracted from the XP-SWMM model input files.

Storage Area Connections

There are several underground storm drains and culverts that remove normal floodwater from the various storage areas; however, an overtopping flood event can overwhelm the drainage system and floodwaters will move overland from one storage area to another. In order to model the movement of floodwater from one storage area to another, HEC-RAS has an option that allows storage areas to be connected by a weir, culvert or a combination of the two. The majority of the 37 storage areas were connected using the weir flow option. Some of the storage areas were separated by railroads which had smooth crested weirs; however other areas were separated by natural high ground with streets acting as small channels between the areas. For the natural high ground cases, a cross section was taken using LIDAR data in ARC-MAP to determine the length-elevation rating curve of the weir section across the controlling high ground and streets between the storage areas. When HEC-RAS computes flow across a weir at low head conditions, it performs the computations more efficiently and with more stability if the weir length-elevation rating curve is smoothed out with the weir crest increasing from low to high elevations in a smooth transition. Therefore, in reaches where there were numerous changes in elevation due to the crossing streets, the data was computed in even horizontal increments then smoothed by sorting the elevations from low to high and inputting this data into the model as the weir crest. An example of the procedure is shown in Figure 9.

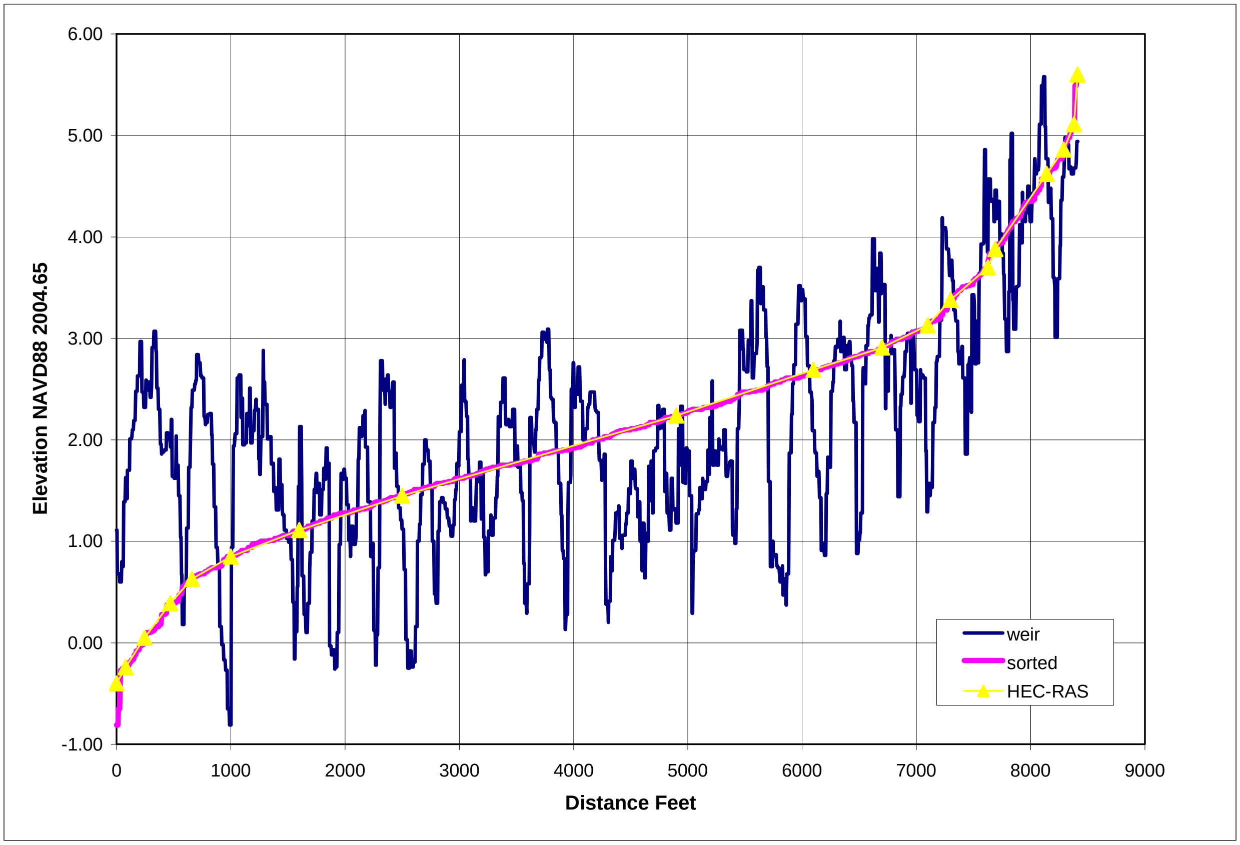

Figure 9. Digitized and Sorted Weir Profiles Between Storage Areas 16 and 172

Pump Stations

Fifteen pumping stations were included in the unsteady HEC-RAS model of Orleans East Bank. The Monticello and Prichard pump stations were treated as one in the LACPR model. A summary of pump station characteristics is shown in Table 5. Detailed pump data were collected by the U.S. Army Corps of Engineers Hydroelectric Design Center (HDC). These pump data can be found in Volume VI, Appendix 7 of the IPET report. Pump station locations are shown in Figure 10. If a pump station pumps water to more than one location, it is necessary to model the pump station as two pump stations in the numerical model. Hence, the figure shows Pump Station 2a and 2b, and 3a and 3b. Pump-on and pump-off elevations of the existing pumping stations were provided by the HDC. Pump-on and pump-off elevations for the new pumps proposed for 2010 were provided by the HPO. Pump station data included discharge-head rating curves for each pump at each pumping station. Some of these curves had to be extrapolated in the HEC-RAS model. There were very limited data regarding start-up elevations for individual pumps. Interviews with pump operators conducted by HDC suggest that operators are not held to a rigid schedule with respect to turning pumps on and off. Operations are based on existing sump elevations, downstream conditions, and weather forecasts. In the unsteady HEC-RAS model, start-up times for the pumps were set so that all pumps would be operating when the sump elevation reached -7.8 ft NAVD88 (2004.65). Start-up and shut-off times for individual pumps were set in the model to provide a smooth transition, over several minutes, from an estimated station start-up elevation to elevation -7.8 ft. The model does not simulate channel surges that might develop with instantaneous start-up or shut-down of the pump station.

Inflow into the 17th Street Canal from the Canal Street Pumping Station in Jefferson Parish was treated as a lateral inflow in the LACPR HEC-RAS model. Outflow from the Canal Street Pumping Station was approximated as a triangular-shaped hydrograph with a peak discharge of 160 cfs. An approximation was necessary because the only available data for the Canal Street Pumping Station was the maximum capacity.

Table 5
Pump Station Summary Data

Pump Station	Location/Name	Intake	Discharge	Rated 2010 Station Capacity CFS
1	Broad Street and Martin L. King Blvd.	Martin Luther King and Broad Street Drains	Palmetto Canal	6,825
2	Broad Street and St Louis Street	Broad Street Drain	Orleans Canal and Broad St Drain	3,150
3	London Ave Canal at Florida Avenue	Broad Street and Florida Avenue Drains	London Avenue Canal and Florida Avenue Canal	4,260
4	London Avenue Canal at Prentiss Avenue	Prentiss Avenue Drain on East side of Canal.	London Avenue Canal	3,720
6	17th Street Canal	17th Street Canal	17th Street Canal	11,480
7	Orleans Avenue Canal	Orleans Avenue Drain	Orleans Avenue Canal	3,390
12	Pontchartrain Blvd.	Fleur de Lis Drain	Lake Pontchartrain	1,000
19	Florida Avenue	Florida Avenue Canal	Inner Harbor Navigation Canal	3,650
I-10	Interstate 10 at Railroad	I-10 Underpass	17th Street Canal	860
Monticello	Oleander St at Monticello Canal	Carrollton Drainage	Monticello Canal	210
Prichard	Monticello Ave at Monticello Canal	Carrollton Drainage	Monticello Canal	250
Prentiss-West	London Avenue Canal at Prentiss Ave	Prentiss Avenue Drain on west side of Canal.	London Avenue Canal	1,000
17th Street	17th Street Canal downstream from Hammond Highway	17th Street Canal	Lake Pontchartrain	12,500
Orleans	Orleans Canal upstream from Lakeshore Dr	Orleans Canal	Lake Pontchartrain	3,390
London	London Canal downstream from Leon C. Simon Dr	London Canal	Lake Pontchartrain	8,980

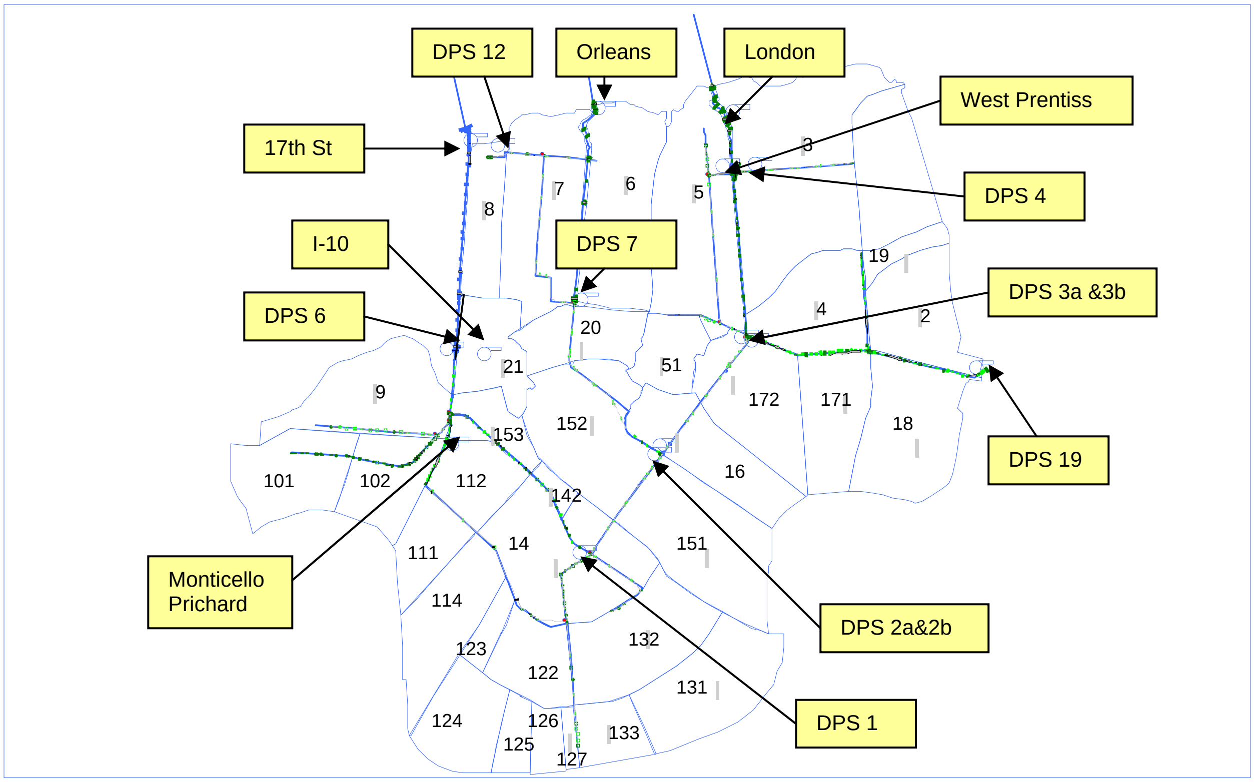

Figure 10. Pump Stations Modeled in HEC-RAS Model

Storm Drain System

The drainage system for Orleans East Bank area consists of many features that are typical of large urban cities in the United States, and some features that are unique because much of the area is below sea level. As in any urbanized area, catch basins and drop-inlets receive surface runoff from yards and streets, and excess runoff runs down slope in the streets and/or overland to areas of lower elevation. Runoff that can enter drop-inlets proceeds underground in small pipes, 21 inches or less in diameter, called the tertiary system that collect local flows and convey them to the secondary system, 21 inches to 30 inches in diameter, where several of these local flows combine. Generally pipes or box culverts that are larger than 30 inches in diameter are considered to be part of the secondary system. The primary drainage system is composed of enclosed culverts and man-made mainly prismatic open channels. The primary conveyances were modeled in the HEC-RAS unsteady model, along with drainage pump stations.

Flow Data and Boundary Conditions

The storm-surge elevation boundary conditions in Lake Pontchartrain and the IHNC were based on hypothetical stage-hydrographs for the 100-year storm surge obtained from ADCIRC simulations in the IPET study. A description of the ADCIRC model and results are discussed in Volume IV of the IPET report. The maximum stage for the 100-year storm surge was aligned with the time of the maximum storm outflow at the outfall canals. These stage-hydrograph boundaries were only used by the HEC-RAS model to calculate head differential and pump capacity for the pump performance curves. The 100-year storm surge elevations were used in the LACPR HEC-RAS model because the actual stage elevations in the lakes associated with the ADCIRC predictions for the LACPR studies were not provided.

Boundary conditions must also be set in the unsteady HEC-RAS model at the upstream end of storm drains and channels. Discharge boundaries in the model are shown in Table 6. A minimum discharge of 50 cfs was set at each upstream boundary. During the course of the study, inflow at some boundaries was increased to improve model stability. In order to account for the introduction of these arbitrary flows into the model, an equivalent volume of water was pumped out of the appropriate drainage basin throughout the model simulation.

Table 6
HEC-RAS Boundary Conditions at Upstream End of Storm Drains

Storm Drain	Station at Upstream End	Boundary Discharge CFS
Broad St Drain	164+60	150
Claiborne-Monticello Drain	146+00	50
Claiborne-Napoleon Drain	85+50	100
Fleur De Lis Drain	22+83	100
Florida Drain	50+00	50
Geisenheimer Drain	68+00	50
Hoey Channel	111+00	50
Martin Luther King Drain	118+61	100
Napoleon Drain	76+80	50
Orleans Channel	250+70	50
Paris Drain	120+80	50
Peoples Channel	61+50	50
Prentiss Drain	72+00	50
Robert E. Lee Drain	35+40	50
West Prentiss	13+00	50

Storm Surge Overtopping Hydrographs

The New Orleans District provided unit discharge storm surge hydrographs for the total length along Lake Ponchartrain for the alternatives evaluated. These unit discharge storm surge hydrographs were calculated using the ADCIRC model. For both conditions, 2010 Base and 2010 East Alternative B, the only sub-basins/storage areas receiving overtopping inflows were 8, 7, 6, 5, and 3. Figure 11 shows the sub-basins/storage areas affected and the overtopping reach lengths of each.

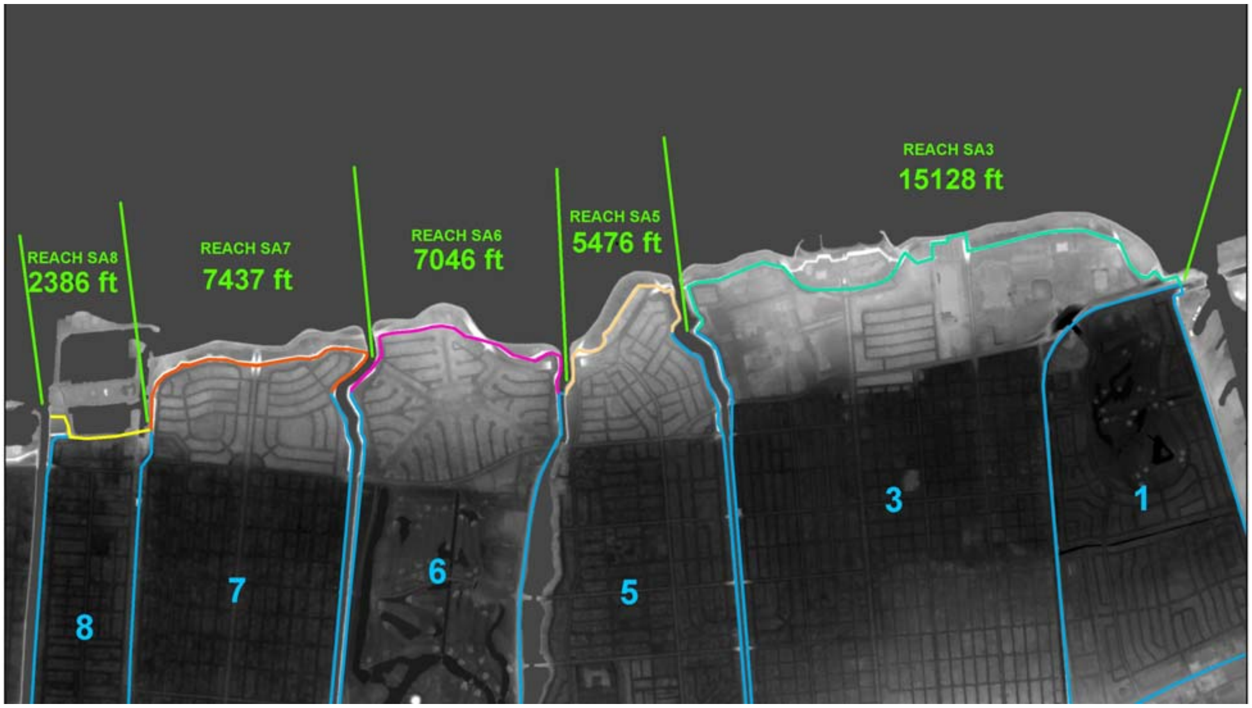

Figure 11. Orleans East Bank – Sub-basins/Storage Areas Affected by Overtopping from Storm Surges and Levee/Floodwall Reach Lengths

Figure 12 shows the unit discharge storm surge hydrographs for each levee design/storm surge alternative evaluated for the entire waterfront length along Lake Pontchartrain for the 2010 Base Condition. The individual discharge storm surge hydrographs for sub-basins/storage areas 8, 7, 6, 5, and 3 were determined by multiplying their respective boundary lengths (2386 ft, 7437 ft, 7046 ft, 5476 ft, and 15128 ft) along Lake Pontchartrain by the unit discharge values at the corresponding time increment. Figure 13 shows the results of this process for sub-basin/storage area 3 for the 2010 Base Condition. Also shown on Figure 13, for comparison, is the rainfall runoff hydrograph for the 10-yr 24-hr rainfall event in sub-basin/storage area 3. Figures 14 shows the unit discharge storm surge hydrographs for sub-basin/storage area 3 for the 2010 East Alternative B Condition. Figure 15 shows the individual discharge storm surge hydrographs for sub-basin/storage area 3 for the 2010 East Alternative B Condition.

The peak discharges of the individual discharge storm surge hydrographs for each alternative shown in Figures 13 and 15 were aligned with the peak discharges of the respective rainfall runoff hydrographs. The corresponding discharge values were added to obtain a combined inflow hydrograph for sub-basins/storage areas 8, 7, 6, 5, and 3.

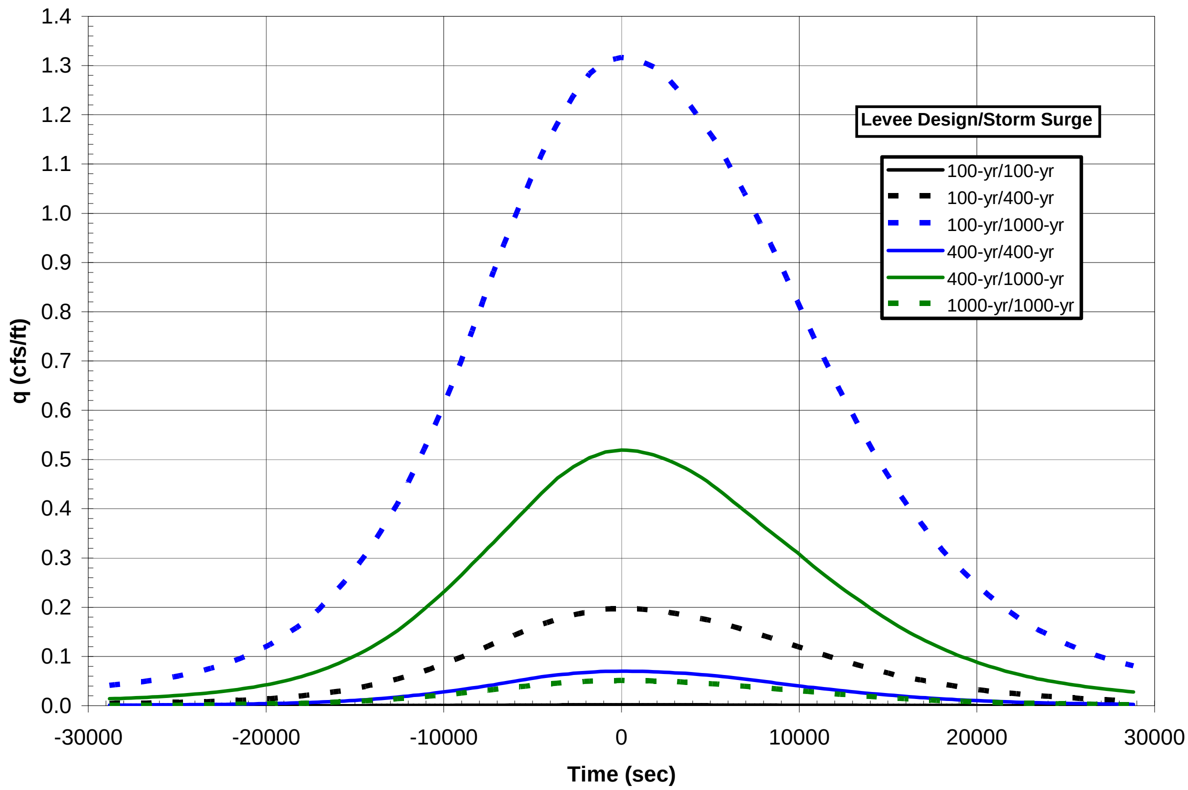

Figure 12. Orleans East Bank – 2010 Base Conditions, 90% Confidence Band Overtopping Unit Hydrographs Along Lake Pontchartrain (BS-0026)

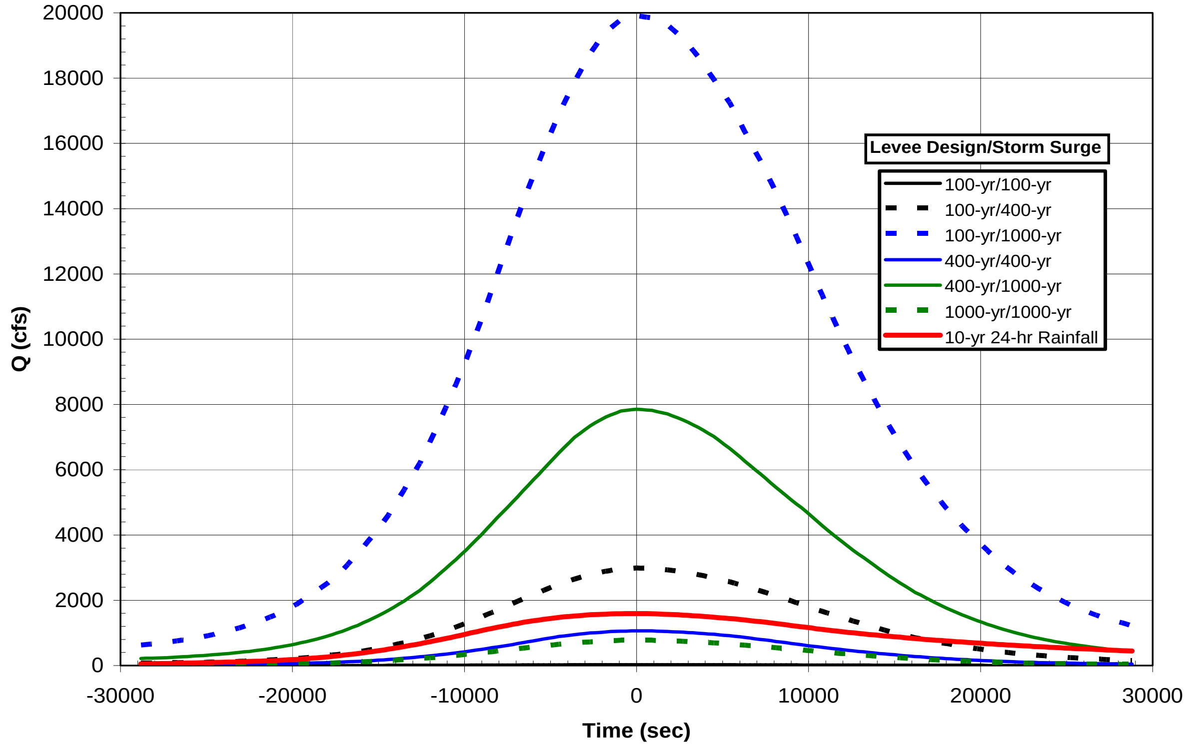

Figure 13. Orleans East Bank – Storage Area 3 (2010 Base Conditions), 90% Confidence Band Overtopping Hydrographs and the 10-yr 24-hr Rainfall Hydrograph

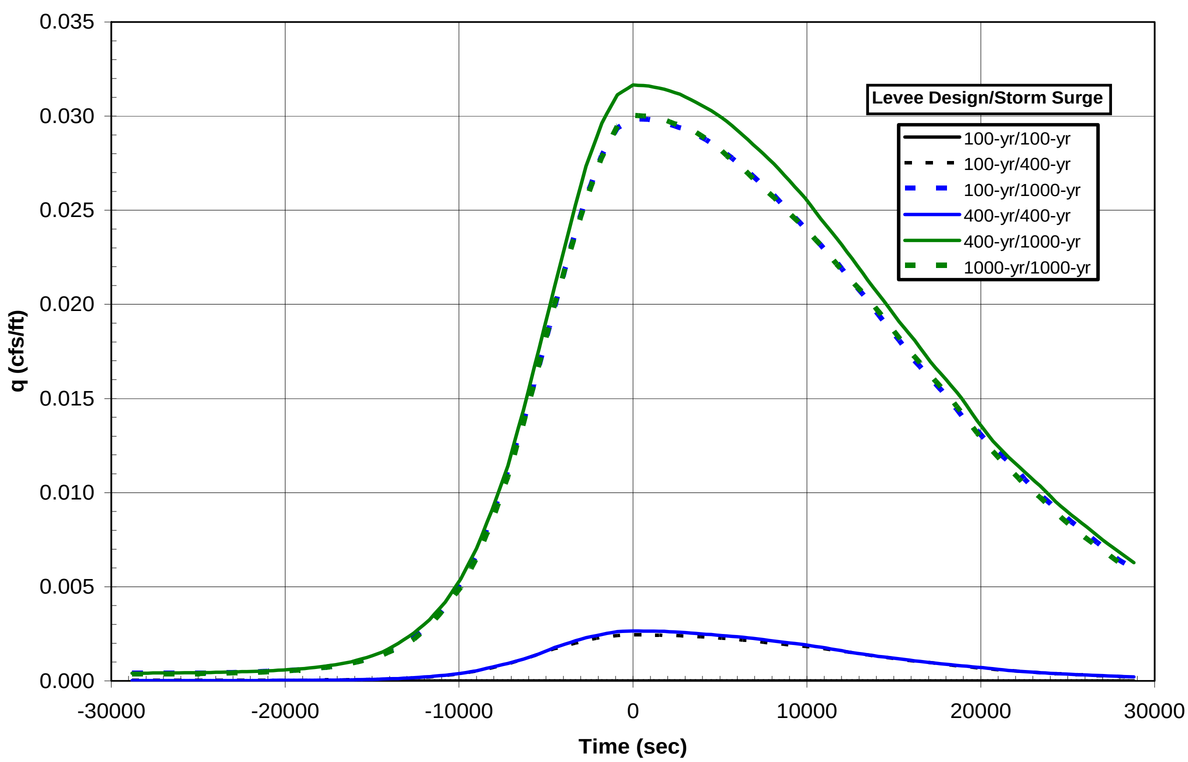

Figure 14. Orleans East Bank – 2010 East Alternative B, 90% Confidence Band Overtopping Unit Hydrographs Along Lake Pontchartrain (EB-0026)

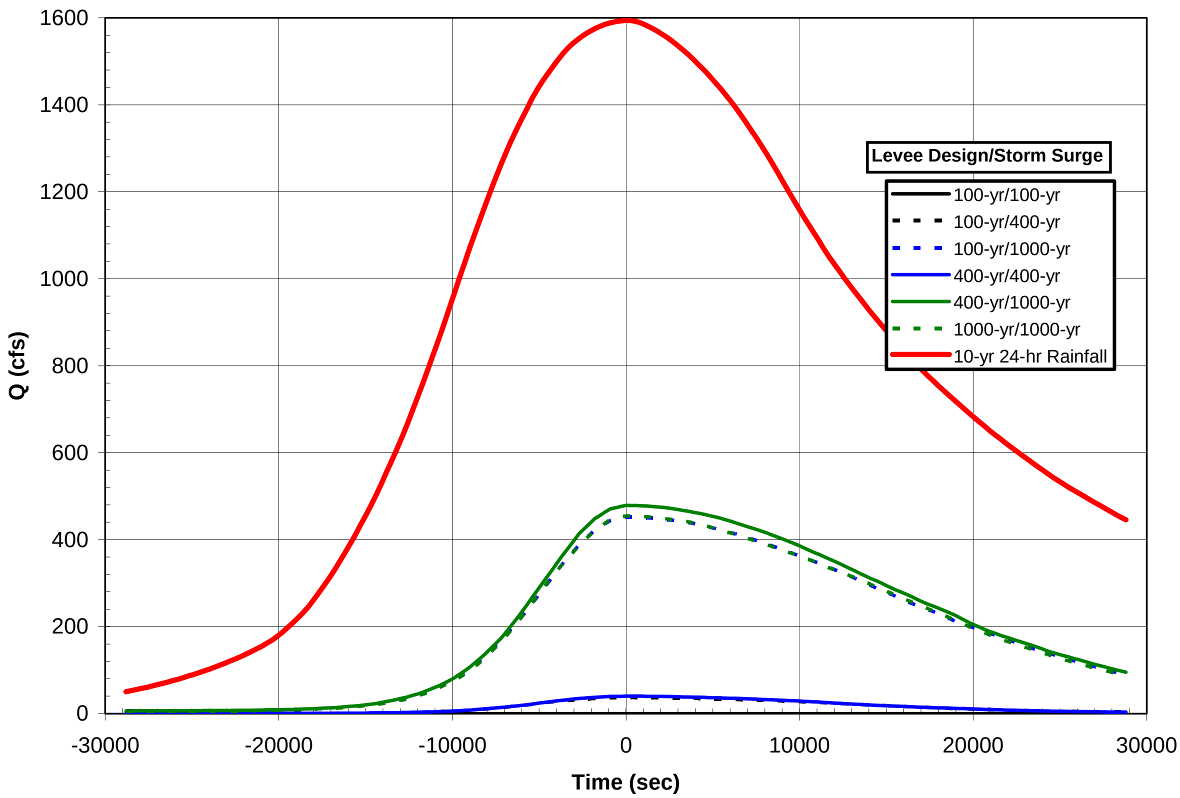

Figure 15. Orleans East Bank – Storage Area 3 (2010 East Alternative B), 90% Confidence Band Overtopping Hydrographs and the 10-yr 24-hr Rainfall Hydrograph

Model Results

Maximum calculated flood depths in Orleans East Bank, calculated for the "Rainfall Only" condition, the 2010 Base Condition, and the 2010 East Alternative B condition are tabulated in Tables 7 and 8.

As expected, the greatest flooding occurs with the 1000-year surge over the 100-year design levee for the 2010 Base Condition. For this alternative, the increase in flood depths due to overtopping ranged between 7.8 and 3.4 ft in storage areas adjacent to Lake Pontchartrain. The increase in flood depths due to overtopping was about 3 ft in other storage areas north of Gentilly Ridge. South of Gentilly Ridge, the increase in flood depths was one foot or less in all storage areas, with no increase in flooding in the Hoey Basin or in areas south of a line set by the Palmetto Canal, Broad Street, and Saint Bernard Avenue. Thus, the uptown area of New Orleans was not affected by any of the overtopping alternatives.

Overtopping was minor for 2010 East Alternative B. Consequently, maximum increases in flood depths due to 1000-year surge overtopping were less than 0.5 ft in the storage areas adjacent to Lake Pontchartrain. No increase in flooding was calculated south of Gentilly Ridge. According to the storm surge unit discharge hydrograph data provided by the New Orleans District, the levee designs did not significantly affect the overtopping hydrographs calculated by

ADCIRC. Therefore, calculated flood depths in HEC-RAS were essentially the same for each frequency storm surge event regardless of the levee design. It appears that the barrier structure at the entrance to Lake Pontchartrain significantly reduces the storm surge into Lake Pontchartrain for all frequency storm surge events analyzed for the 2010 East Alternative B.

These results should be considered approximate. Some bridges and channels had dimensions from old model studies that were unconfirmed by field checks. Other bridges and channels had dimensions assigned based on photographs or simply by knowledge of structures. More accurate geometric data that should be incorporated into the HEC-RAS model include: 1) storm drain elevations and dimensions on Broad Street between DPS 1 and DPS 2 and all primary drains to this reach, 2) surveys of the Florida Avenue canal between DPS 19 and DPS 3, 3) surveys on the Peoples Avenue Canal, 4) dimensions and elevations of storm drains entering the sump at DPS 7, and 5) dimensions and elevations of secondary storm drains. Results from the LACPR model are more uncertain than results from the IPET model used to simulate actual events during Hurricane Katrina. Issues related to exchange of flow between storm drains and storage areas at low elevations were not significant in the IPET model and therefore not addressed in sufficient detail for low elevation simulations. The additional storage areas and primary drainage structures added to the LACPR model improved flood elevation predictions in some of the storage areas with higher ground elevations. It should be noted that the LACPR model was not calibrated for small events, which increases the uncertainty of results.

Table 7
Calculated Maximum Water Surface Elevations Ft NAVD88 (2004.65)
LACPR 2010 Base Conditions
10-yr Rainfall – No overtopping of IHNC floodwalls
Lake Pontchartrain Levee Overtopping Rates for 90% Confidence Value

Storage Area	Base Test Rainfall Only	100-yr Design			400-yr Design		1000-yr Design
		100-yr Surge	400-yr Surge	1000-yr Surge	400-yr Surge	1000-yr Surge	1000-yr Surge
1	-7.0	-7.0	-6.2	-4.0	-6.7	-5.4	-6.8
2	-3.4	-3.4	-3.4	-3.4	-3.4	-3.4	-3.4
3	-7.8	-7.8	-6.2	0.0	-7.1	-4.2	-7.3
4	-4.5	-4.5	-4.4	-4.0	-4.4	-4.3	-4.4
5	-5.8	-5.8	-4.8	-1.4	-5.4	-3.7	-5.5
6	-4.6	-4.6	-3.1	0.7	-4.0	-1.6	-4.1
7	-7.4	-7.4	-6.1	-2.4	-6.8	-4.7	-7.0
8	-7.5	-7.5	-6.5	-2.4	-7.1	-5.4	-7.2
9	-3.3	-3.3	-3.3	-3.3	-3.3	-3.3	-3.3
14	-6.6	-6.6	-6.6	-6.6	-6.6	-6.6	-6.6
16	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5
18	-4.7	-4.7	-4.7	-4.4	-4.7	-4.6	-4.7
19	-4.1	-4.1	-4.1	-3.3	-4.1	-4.1	-4.1
20	-4.5	-4.5	-4.5	-1.0	-4.5	-4.4	-4.5
21	-12.1	-12.1	-12.1	-2.6	-12.1	-12.1	-12.1
51	-1.9	-1.9	-1.9	-1.9	-1.9	-1.9	-1.9
101	-0.7	-0.7	-0.7	-0.7	-0.7	-0.7	-0.7
102	-2.0	-2.0	-2.0	-2.0	-2.0	-2.0	-2.0
111	-4.5	-4.5	-4.5	-4.5	-4.5	-4.5	-4.5
112	-10.3	-10.3	-10.3	-10.3	-10.3	-10.3	-10.3
113	-5.4	-5.4	-5.4	-5.4	-5.4	-5.4	-5.4
114	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3
122	-2.8	-2.8	-2.8	-2.8	-2.8	-2.8	-2.8
123	-1.9	-1.9	-1.9	-1.9	-1.9	-1.9	-1.9
124	-3.1	-3.1	-3.1	-3.1	-3.1	-3.1	-3.1
125	-3.1	-3.1	-3.1	-3.1	-3.1	-3.1	-3.1
126	2.9	2.9	2.9	2.9	2.9	2.9	2.9
127	1.8	1.8	1.8	1.8	1.8	1.8	1.8
131	-1.3	-1.3	-1.3	-1.3	-1.3	-1.3	-1.3
132	-5.2	-5.2	-5.2	-5.2	-5.2	-5.2	-5.2
133	2.2	2.2	2.2	2.2	2.2	2.2	2.2
142	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5
151	-5.3	-5.3	-5.3	-5.3	-5.3	-5.3	-5.3
152	-6.7	-6.6	-6.6	-5.7	-6.6	-6.4	-6.6
153	-3.4	-3.4	-3.4	-3.4	-3.4	-3.4	-3.4
171	-4.8	-4.8	-4.6	-4.0	-4.8	-4.4	-4.8
172	-5.3	-5.3	-5.3	-5.3	-5.3	-5.3	-5.3

Table 8
Calculated Maximum Water Surface Elevations Ft NAVD88 (2004.65)
LACPR 2010 East Alternative B
10-yr Rainfall – No overtopping of IHNC floodwalls
Lake Pontchartrain Levee Overtopping Rates for 90% Confidence Value

Storage Area	Base Test Rainfall Only	100-yr Design			400-yr Design		1000-yr Design
		100-yr Surge	400-yr Surge	1000-yr Surge	400-yr Surge	1000-yr Surge	1000-yr Surge
1	-7.0	-7.0	-7.0	-6.8	-7.0	-6.8	-6.8
2	-3.4	-3.4	-3.4	-3.4	-3.4	-3.4	-3.4
3	-7.8	-7.8	-7.8	-7.4	-7.8	-7.4	-7.4
4	-4.5	-4.5	-4.5	-4.5	-4.5	-4.5	-4.5
5	-5.8	-5.8	-5.8	-5.6	-5.8	-5.6	-5.6
6	-4.6	-4.6	-4.6	-4.3	-4.6	-4.3	-4.3
7	-7.4	-7.4	-7.4	-7.1	-7.4	-7.1	-7.1
8	-7.5	-7.5	-7.5	-7.3	-7.5	-7.3	-7.3
9	-3.3	-3.3	-3.3	-3.3	-3.3	-3.3	-3.3
14	-6.6	-6.6	-6.6	-6.6	-6.6	-6.6	-6.6
16	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5
18	-4.7	-4.7	-4.7	-4.7	-4.7	-4.7	-4.7
19	-4.1	-4.1	-4.1	-4.1	-4.1	-4.1	-4.1
20	-4.5	-4.5	-4.5	-4.5	-4.5	-4.5	-4.5
21	-12.1	-12.1	-12.1	-12.1	-12.1	-12.1	-12.1
51	-1.9	-1.9	-1.9	-1.9	-1.9	-1.9	-1.9
101	-0.7	-0.7	-0.7	-0.7	-0.7	-0.7	-0.7
102	-2.0	-2.0	-2.0	-2.0	-2.0	-2.0	-2.0
111	-4.5	-4.5	-4.5	-4.5	-4.5	-4.5	-4.5
112	-10.3	-10.3	-10.3	-10.3	-10.3	-10.3	-10.3
113	-5.4	-5.4	-5.4	-5.4	-5.4	-5.4	-5.4
114	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3
122	-2.8	-2.8	-2.8	-2.8	-2.8	-2.8	-2.8
123	-1.9	-1.9	-1.9	-1.9	-1.9	-1.9	-1.9
124	-3.1	-3.1	-3.1	-3.1	-3.1	-3.1	-3.1
125	-3.1	-3.1	-3.1	-3.1	-3.1	-3.1	-3.1
126	2.9	2.9	2.9	2.9	2.9	2.9	2.9
127	1.8	1.8	1.8	1.8	1.8	1.8	1.8
131	-1.3	-1.3	-1.3	-1.3	-1.3	-1.3	-1.3
132	-5.2	-5.2	-5.2	-5.2	-5.2	-5.2	-5.2
133	2.2	2.2	2.2	2.2	2.2	2.2	2.2
142	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5	-2.5
151	-5.3	-5.3	-5.3	-5.3	-5.3	-5.3	-5.3
152	-6.7	-6.7	-6.6	-6.6	-6.6	-6.6	-6.6
153	-3.4	-3.4	-3.4	-3.4	-3.4	-3.4	-3.4
171	-4.8	-4.8	-4.8	-4.8	-4.8	-4.8	-4.8
172	-5.3	-5.3	-5.3	-5.3	-5.3	-5.3	-5.3

Conclusions

The unsteady flow HEC-RAS model was used to simulate flooding in Orleans East Bank for a 10-year frequency rainfall event and for 12 combinations of storm surge overflow and alternative protection measures. The calculated flood elevations should be considered approximate. However, results are reliable for relative design alternative comparisons and selection of alternatives for further evaluation. Additional data, including drainage network dimensions, surveys, storage area delineations, and calibration data are required to improve model reliability. A more detailed and calibrated model would provide more confidence in alternative condition simulations. It is recommended that additional analyses be conducted when more detailed data becomes available in order to verify and/or refine the results presented in this report.