VII. The Consequences

Executive Summary

In the IPET Final Report, this chapter will answer the questions pertaining to "The Consequences" as presented in IPET Report 1. The interim results on the societal-related consequences of the Katrina-related damage, the relationship of local consequences to the performance of individual components of the flood protection system, the consequences had the system not suffered catastrophic failure, and the consequences of Katrina that extend beyond New Orleans and vicinity are presented.

An important component in assessing interior drainage and related consequences are the pump stations. The pumping stations designed and constructed in the greater New Orleans area are not part of the flood and hurricane protection system. Their purpose is to evacuate accumulated precipitation occurring during storms since much of the area is below the level of Lake Pontchartrain, sea level, and the Mississippi River. Many pumps, particularly the larger ones, have horizontal shafts with the impeller located above the normal water surface of the suction side. Maximum water levels occurring during the Katrina storm exceeded the design discharge side water levels causing some pumps, particularly those in Jefferson Parish, to experience reverse flow during the time they were not operated. All of the pump stations were designed to be operated by personnel at the station. None can operate without operators present (i.e., none are remote operated or use automatic controls). None of the pump houses were designed to protect themselves from local flooding as happened during Hurricane Katrina. The pump station evaluations in this interim report include the condition assessment of components and record of pumping station performance during Katrina. The interim information to date for each parish and for each station is reported in the pump station technical and detailed report appendices.

To answer the questions regarding how the hurricane protection system would perform under various conditions, the interior drainage analysis focuses on the filling and unwatering of the separate areas protected by levees and pump stations. Interior drainage models will be developed for St. Charles, Jefferson, Orleans, St. Bernard and Placquemines Parishes that simulate water levels for what actually happened during Hurricane Katrina and what would have happened had all the hurricane protection facilities remained intact, functioned as designed, and operated as planned. Interior modeling data will be used in the Consequence and Risk and Reliability analyses to assess, measure, and report risks for various scenarios to help the public and officials make decisions. These models will also be useful to examine the degree of flooding that would result from any future scenarios.

Flooding and the level of destruction initiated by Hurricane Katrina are unprecedented from a natural disaster in U.S. history. The consequences from this event are both widespread and long-lasting. They can be described in economic, human health and safety, social and cultural, and environmental terms. The assessment of consequences has several purposes integral to understanding the dimensions of the event that happened. For instance, the economic impacts of the event went far beyond the direct impacts on the residents and businesses in New Orleans. Additionally, consequences are one of the dimensions of risk necessary to understand the level of safety provided by the hurricane protection system. Or, conversely, assessing consequences is part of estimating the residual risk borne by those who lived in the New Orleans area pre-Katrina and those who will live there after the protective system is restored. Therefore, the assessment of consequences will go beyond the grim accounting of destruction in people's lives, property, and the social fabric of New Orleans that actually happened. To provide a complete understanding of risk, consequences must be assessed under some "what if" scenarios. These losses, in turn, provide input for the IPET Risk and Reliability Assessment Team. Consequence assessment, in this mode, requires predictive approaches and frameworks. These approaches will be described and documented in detail in an Appendix to the final report.

Pumping Station Performance

Summary of Work Accomplished

To date this effort has obtained available documents through the contracted Architecture-Engineering firm (CH2M Hill), Task Force Guardian, Task Force Hope, and the USACE New Orleans District. The team has obtained documents and information from each of the parishes and responsible entities for pump station operations. The information includes configuration, capacity and location of each of the pump stations, photos of stations and components, pump performance curves, records of operation, fuel and/or power sources, backflow prevention devices, valves and gates for operations and the like. At this time approximately 90% of the work for St. Bernard Parish has been completed and submitted as a Technical Appendix (Appendix I, Pump Station Technical and Detailed Report) for this report. This appendix serves as the example of the complete pump station analysis that can be expected for all of the study areas for the final report.

Interim Results

St. Bernard Pump Stations

There are eight pump stations in St. Bernard Parish. All pumps are powered by diesel engines which are mechanically connected to the pumps. Five stations (representing 80% of total capacity) have operating floors approximately 12 feet above the natural ground surface which substantially reduced storm-induced damage. Three stations (#2, #3 and #5) were flooded to a depth of six to eight feet above the operating floor which destroyed the diesel engines, vacuum pumps, and many accessories. Until this equipment can be replaced, the stations cannot be operated. The metal framed & sided buildings suffered considerable damage while the structures built of concrete and brick experienced little damage. The three flooded stations accounted for 90% of the total estimated damage of $10.7 million.

The eight pump stations in St. Bernard Parish have a total discharge capacity of 6,960 cfs (cubic feet per second) to evacuate accumulated precipitation in a drainage area of 17,620 acres. If all pumps were to operate at rated capacity, they could keep up with a steady precipitation rate of 0.39 inches per hour. All stations use pumps directly connected to diesel engines.

Each pump station was visited to obtain operating logs of individual pump units. As can be seen in the performance chart (the white portion of each bar), a significant amount of operating information was lost or not available.
Figure VII-1 shows the daily operational status of the percentage of 28 main pumps from August 28th, through September 15th when continued pumping was no longer required. Although only three of the eight stations suffered substantial damage, these three accounted for nearly half (13) of the pump units.

Jefferson Parish Pump Stations

No Jefferson Parish pump station was flooded during Katrina and, as a result, none experienced significant damage. Primarily, the damage was to roofs, gutters, skylights, gutters, etc. A total estimated damage for all stations was $760,000. For their safety, the station operators were ordered to leave their stations prior to the arrival of Katrina. During this time when operators were absent, the pumps were not operated. The surface water level in Lake Pontchartrain exceeded the design level of the stations discharging to the lake thereby allowing reverse flow to occur.

Jefferson Parish has six pump stations on the East bank and twenty on the West bank. The East bank stations have a total capacity of 20,835 cfs to drain an area of 29,300 acres. If all pumps were to operate at rated capacity on the East bank, they could keep up with a steady precipitation rate of 0.70 inches per hour. The West bank stations have a total capacity of 23,354 cfs to drain an area of 44,200 acres. If all pumps were to operate at rated capacity, they could keep up with a steady precipitation rate of 0.52 inches per hour. All stations use pumps directly connected to diesel engines.

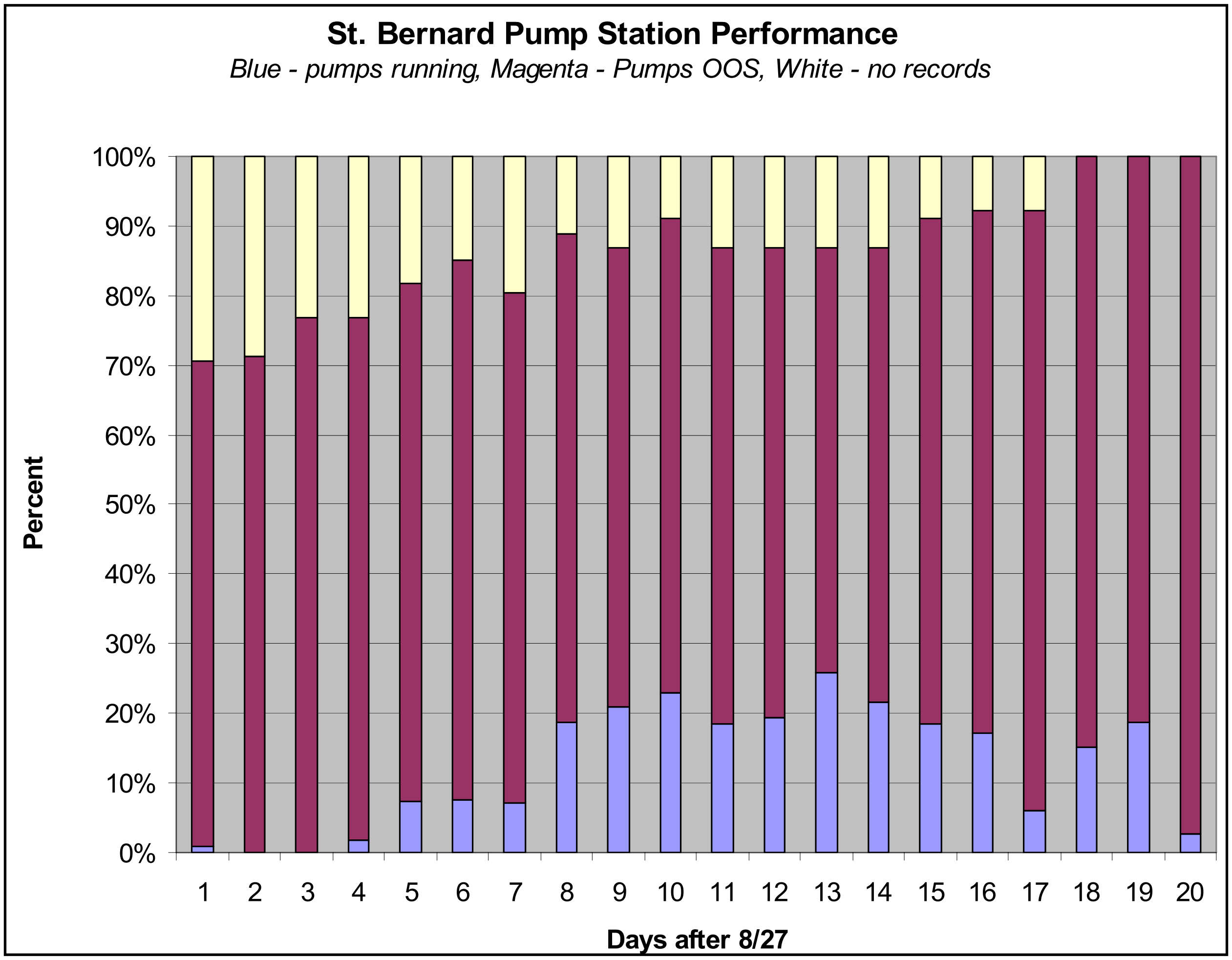

Figure VII-1. St. Bernard pump station performance

Plaquemines Parish Pump Stations

Nine stations suffered significant damage – principally from flooding. Total cost to restore the stations to pre-storm condition was estimated to be $8 million. One station (Belair) was so damaged, that a new pump house, including the foundation slab, is required. At stations where the diesel engines were destroyed due to flooding, new engines will be installed on an elevated platform or support which is now typical of newer construction. A hydraulic drive system will transmit power from the engine to the pump shaft.

There are 19 pump stations in Plaquemines Parish including two which are privately owned. These stations have a total discharge capacity of 13,680 cfs to evacuate accumulated precipitation in a drainage area of 55,000 acres. If all pumps were to operate at rated capacity, they could keep up with a steady precipitation rate of 0.25 inches per hour. All stations use pumps directly connected to diesel engines.

Orleans Parish Pump Stations

The pump stations and generating station in Orleans' metropolitan area suffered significant damage – principally due to flooding of the electrical motors, generators and switchgear. Pump stations in the Orleans east area also were significantly damaged from flooding. Many of the pump bearings were damaged from operating with dirty water. Some of the diesel engines were also destroyed. Neither of the west bank stations experienced any flooding. The contractor hired by the Corps estimated a total damage of more than $ 39 million in their damage survey report. When New Orleans District's Corps of Engineers completes their *Project Information Report*, the damage estimate is expected to be substantially less.

Orleans Parish has 22 pump stations on the East bank and two on the West bank. Twelve of the East bank stations are located in the metropolitan area as well with the remaining ten located east of the Inner Harbor Navigation channel (Orleans east). All stations in the metropolitan area have pumps which are electrically driven – most by direct-drive 25 Hz motors. A central diesel-electric generating station provides 25 Hz electricity for these stations. All stations in Orleans east and the two on the west bank have pumps which are diesel driven.

Status of Remaining Efforts

The remaining Parishes will be brought to the 90% level similarly to the work accomplished for St. Bernard Parish for the final report.

Interior Drainage Analysis

Summary

To help answer the questions regarding how the hurricane protection system would perform under various conditions, the interior drainage analysis focuses on the filling and unwatering of the separate areas protected by levees and pump stations. Interior drainage models are being developed for St. Charles, Jefferson, Orleans, St. Bernard and Placquemines Parishes that simulate water levels for what actually happened during Hurricane Katrina and what would have happened had all the hurricane protection facilities remained intact, functioned as designed, and operated as planned.

Other IPET task teams are providing data needed to estimate the flow into and out of the modeled parishes. Data provided includes storm surge and wave heights, levee breach geometry, and storm water pump station operation. Since these data are needed at many locations for the duration of the event itself, it is anticipated some of the data will be difficult to obtain due to the extent and severity of the hurricane and the resulting flooding.

Two scenarios are being modeled in this effort:

Pre-Katrina or As-Designed Scenario: Using the interior drainage models, simulate what would have happened during the Katrina event had all hurricane protection facilities remained intact, functioned as designed, and operated as planned. No levees will be failed for this scenario even where overtopping occurs. All water will be removed by the pumping stations.

Katrina or Actual Performance Scenario: Using the interior drainage models, simulate what happened during the Katrina with the hurricane protection facilities performing as actually occurred. All water will exit flooded areas through original breaches, man-made breaches, temporary pump stations and operating pumping stations.

Results from these scenarios will be used to provide input to answer the following specific questions that relate to the overall mission questions for IPET.

- How did the floodwalls, levees and drainage canals, acting as an integral system, perform during and after Hurricane Katrina?

- How did the pumping stations, canal gates and road closures, acting as an integral system, operate in preventing and evacuating the flooding due to Hurricane Katrina?

Interior modeling data will be used in the Consequence and Risk and Reliability analyses to assess, measure, and report risks for various scenarios to help the public and officials make decisions.

Background

Interior drainage/flooding models are not necessary to estimate water elevations in an interior leveed area for a catastrophic condition such as Hurricane Katrina where water levels rise rapidly until they reach the level of Lake Pontchartrain, the IHNC, or Lake Borgne. However, interior drainage/flooding models are essential for estimating the peak water elevation and extent of possible flooding, if any, when the hurricane protection system performs satisfactorily or without catastrophic failure. The models can also be used to estimate the time needed to unwater an area once it is flooded.

Many people will want to know the level of risk to which they are subjected on or before June 1, 2006 when the pre-Katrina level of protection will be achieved at the levee breach locations. The interior drainage/flooding models will be used to examine the resultant flooding for Hurricane Katrina rainfall, storm surge, wave heights, and pump station operations given the observed flood protection system performance and for the situation of no catastrophic structural failures. As such, the models will determine estimated peak water elevations and areas inundated within the protected areas for these two situations. These models will also be useful to examine the degree of flooding that would result from other storm or structural and pumping station performance scenarios.

The modeling for Katrina is being accomplished by four teams. Table VII-1 shows the modeling responsibilities.

Each area has been assigned a priority. The priority is based on flooding experienced during the Katrina event. Development is progressing on all models with the 2 and 3 priority areas not as far along as the priority 1 areas. Table VII-1 lists HEC-RAS and HEC-HMS. These refer to tools developed by the Corps of Engineers, Hydrologic Engineering Center. HEC-RAS refers to the River Analysis System software package. HEC-RAS is designed to perform one-dimensional hydraulic calculations for a full network of natural and constructed channels. HEC-HMS refers to the Hydrologic Modeling System software package. HEC-HMS is designed to simulate the precipitation-runoff processes. For this study, it is used to transform the precipitation, observed during Katrina, into runoff. This runoff is input to the HEC-RAS model and routed to the pump stations.

Table VII-1
Modeling Responsibilities

Leveed Area	Priority	Team	
		RAS	HMS
Jefferson East Bank	1	CTE	CTE
Jefferson West Bank	2	CTE	CTE
Orleans East Bank	1	MVK	MVK
New Orleans East	1	MVN	MVN
Orleans West Bank	2	MVN	MVN
St. Bernard	1	MVN	HEC
St. Charles East Bank	3	MVN	HEC
Plaquemines	1	HEC	HEC

CTE – CTE Consultants, Chicago, IL
MVK – Corps of Engineers, Vicksburg District
MVN – Corps of Engineers, New Orleans District
HEC – Corps of Engineers, Hydrologic Engineering Center, Davis, CA

Summary of Accomplished Work

The sequence of work for the interior drainage/flooding analysis is:

Develop HEC-RAS models using existing models, if available. Otherwise, construct new RAS models using current LIDAR data.

Develop HEC-HMS models using existing models, if available. Otherwise, construct new HMS models.

Conduct a sensitivity evaluation of critical model parameters.

Compute the Actual Performance Scenario (Task 3) results using Katrina data. Adjust model parameters, as appropriate.

Compute the As-Designed Scenario results.

The team is currently completing steps 1 and 2, developing the HEC-RAS and HEC-HMS models. The status of each leveed area is shown in Table VII-2.

Table VII-2

Leveed Area	Priority	Est. % Complete	
		RAS	HMS
Jefferson East Bank	1	60	75
Jefferson West Bank	2	50	75
Orleans East Bank	1	70	50
New Orleans East	1	50	35
Orleans West Bank	2	15	15
St. Bernard	1	75	33
St. Charles East Bank	3	15	15
Plaquemines	1	70	70

Interim Results

The interior drainage/flooding analysis require both field and analytical data from several tasks on the IPET team. This includes high water elevations, flooding and unwatering time sequence, levee and flood wall geometries, storm surge and wave heights, and stormwater pump station performance information. Consequently, interim results will not be available and steps 4 and 5 will be accomplished near the end of the IPET effort. However, a summary description of how the models are being developed and generic samples of input, parameters, and output is provided in the description.

RAS Interior Modeling

Method. The Corps of Engineers' Hydrologic Engineering Center's River Analysis System (HEC-RAS) will be used for this study. RAS models will be developed for each area and will be operated independently in accordance with the current drainage patterns within the greater New Orleans area. Each parish maintains their own drainage system and the models will reflect this operation. Figure VII-2 shows the model locations. Table VII-3 lists their names.

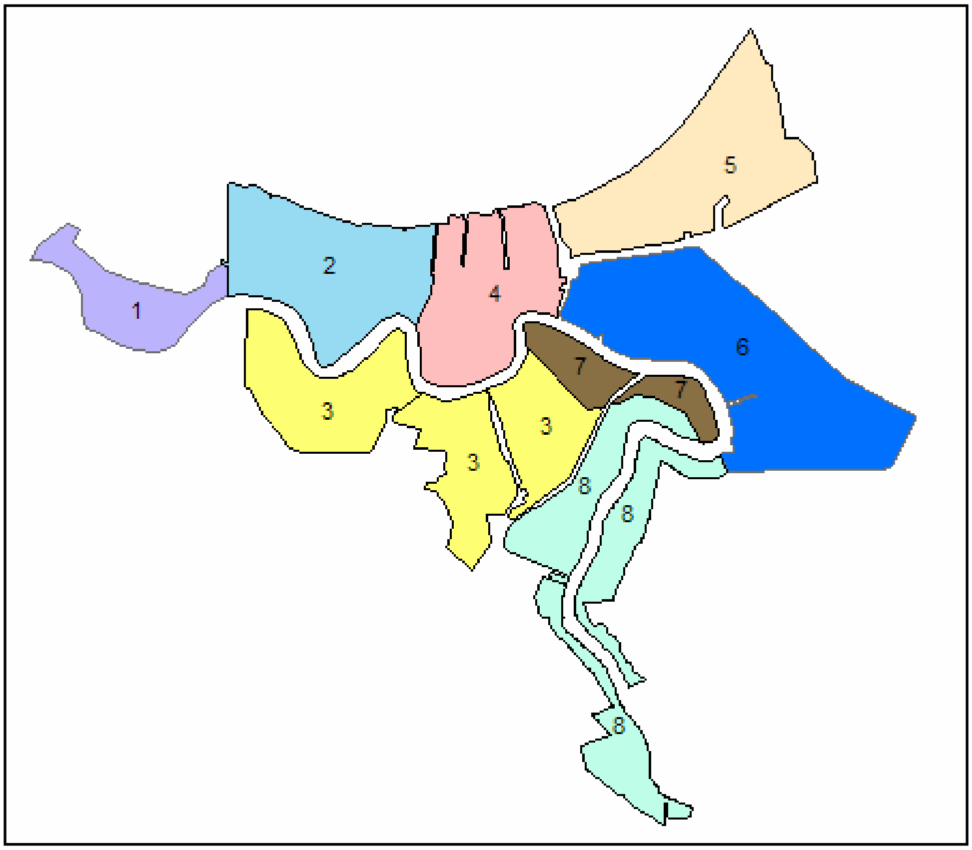

Figure VII-2. Model areas

Table VII-3 Model Areas	
Number	**Name**
1	St. Charles Parish
2	East Bank Jefferson Parish
3	West Bank Jefferson Parish (3 separate models make up this area)
4	Orleans Parish
5	New Orleans East (Part of Orleans Parish)
6	St. Bernard Parish (Includes Lower 9th Ward)
7	Algiers (Part of Orleans Parish)
8	Plaquemines Parish

The West Bank Jefferson Parish is actually broken into 3 separate models, thus the three divisions. The Algiers area is being developed as one model. The Plaquemines Parish model actually extends down river to Venice. The entire extend is not shown on this figure. HEC-RAS models existed for a few locations within the modeling area prior to Katrina. These models were adopted and updated to reflect conditions at the time of Katrina.

Terrain. All HEC-RAS models are based on 5 Meter Lidar data set. The datum of the LIDAR is NAVD88. The vertical accuracy for this data is

+/- 0.7 feet. The horizontal projection is Louisiana State Plane South 1983 feet. All models have been georeferenced to this projection. The basin boundaries for the HMS models are in the same projection.

RAS Storage Areas. The area between drainage canals were modeled as storage basins. These basins are delineated based on geographic features within each leveed area. Features used as divisions between storage areas are levees, railroads, roads, elevated areas, etc. The storage area elevation-volume data and the connection between the storage areas in the RAS models were developed using the Hydrologic Engineering Center's HEC-GeoRAS software. GeoRAS is an ArcMap extension. It provides the tools to draw a polygon representing the storage basin shape and then extract the volume-elevation data from the 5 meter grid. Additionally, it also provides the tools to draw a line which represents the connection between adjacent storage basins and then extract a profile of the connection that represents the elevations from the 5 meter grid. Each RAS model includes storage basins and storage area connections (flow diversions). Figure VII-3 is a sample which shows storage basin outlines for Orleans Parish.

Water can flow between storage areas through storage area connections. These connections are modeled hydraulically using either a weir equation or a linear routing method to transfer flow between the storage areas. Flow can go in either direction, and submergence on the weir is accounted for. Both the weir coefficients and the linear routing coefficients are used as calibration parameters to slow down or increase the spread of the water through the system.

Geometric Data. Cross section data is used to represent the canals and the enclosed storm drains. Terrain information for describing the cross sections has come from a range of sources. General terrain for the open canals is a combination of the terrain model and surveyed cross section data. In general, the terrain model does not provide enough detail to hydraulically describe the canals. Additionally, the terrain model does not include any elevation data below the water surface. Surveyed cross section data has come from previous studies as well as newly surveyed cross sections. At the time of writing this preliminary report, we had not received all of the detailed surveys needed for all of the models. Therefore, the incorporation of detailed surveys for canals is an ongoing process.

Storm Drain System. Storm drains are modeled in HEC-RAS as normal cross sections with lids to represent a pressurized pipe. HEC-RAS has a feature called the Priessmann Slot option that allows the open channel flow equations to mimic pressure flow equations for an enclosed cross section. The Priessmann slot option puts a small slot in the lid of the cross section to allow the water surface to rise to the hydraulic gradeline within the pipe. This slot is extremely small and the wetted perimeter of the slot is not included in the conveyance calculations for the storm drain. The width of the slot is calculated in order to get the open channel flow wave celerity to be equal to the pressure wave celerity. This capability allows the HEC-RAS model to handle both open channel flow and pressure flow within a storm drain using the same set of equations.

Figure VII-3. Storage areas for Orleans Parish

The dimensions and slopes of the main storm drains have been obtained from drainage system maps, as well as previous models of the storm drainage system. Sub collector storm drains were added by putting in lateral structures in HEC-RAS along the main reaches. The lateral structures were used to put in culverts that represent the secondary storm sewer pipes that flow into the main storm sewer pips. The culverts were directly connected to the surface by connecting them to the storage areas that are being used to represent the surface terrain. With this setup, any water that goes into a surface storage area can then get into the storm drains through the culverts that are connected to them. Additionally, water that backs up within any stormdrain can also flow out into the surface areas through these culverts.

Pump Plants. Pump station data is being collected for all of the pump plants in the 5 parishes. HEC-RAS uses an inline structure to represent the pump house within a canal (for example, the 17th street canal pumping station). A series of pumps are then added to pump water from the interior sump area to the exterior canal system on the other side of the structure. HEC-RAS has the capability to model pumps of different sizes, capacities, and different on and off elevations that represent the normal operations of the pumps. Additionally HEC-RAS has the ability to enter pump override rules. These rules are being used to mimic the stopping and starting of pumps due to power failures that occurred during the event.

Boundary and Initial Conditions. Initial conditions were modeled by putting a base flow in all of the storm sewers and canals. HEC-RAS then computes a backwater profile to get the initial water surface. Just upstream of the pump station, the water surface is actually much lower in the sump area than it is on the open canal side. To accommodate this, HEC-RAS has an option where you can input a water surface to be used in the backwater computations. Initially, all of the storage areas are dry. This is simulated by setting the starting water surface elevation to the minimum elevation in each of the storage areas.

Results from the ADCIRC model are used as the exterior boundary conditions to the HEC-RAS models. Stage-hydrographs are applied directly to the canals that are open to Lake Pontchartrain and the Mississippi river. To apply the ADCIRC results in areas that were not modeled as canals (for example, the levees along lake Pontchartrain and the back levees for New Orleans East and St. Bernard Parish), it was necessary to put in model reaches with cross sections representing the lake areas. Stage hydrographs from ADCIRC were applied to each of these model reaches. Figure VII-4 depicts an ADCIRC computed stage-hydrograph used as a boundary condition for the 17trh Street Canal at Lake Pontchartrain. Each reach is connected to the interior area by using the lateral structure option in HEC-RAS. These lateral structures represent the levees that separate the interior areas from the unprotected exterior areas. The lateral structure option in HEC-RAS allows the model to calculate overtopping flows, as well as any levee breaches that occurred along these levees.

Levee Failures. As mentioned previously, levees and levee breaches are modeled as lateral structures along the canals and lake areas. The top of the levee is the top of the lateral structure. Flow over this structure is modeled with the weir equation. A levee breach can be added to any lateral structure. The breach outflow hydrographs are directly connected to a storage area that represents the land surface inside the levee in that area. The breach can be triggered based on a water surface elevation, time, or elevation and duration above an elevation. HEC-RAS requires the modeler to enter the maximum breach size and duration of the breach development. Breach information has been collected by another IPET team. This information is being used to estimate the breach parameters for within HEC-RAS. Figure VII-5 shows a sample result for a levee breach with the corresponding flow through the breach and the resultant stage in the flooded area.

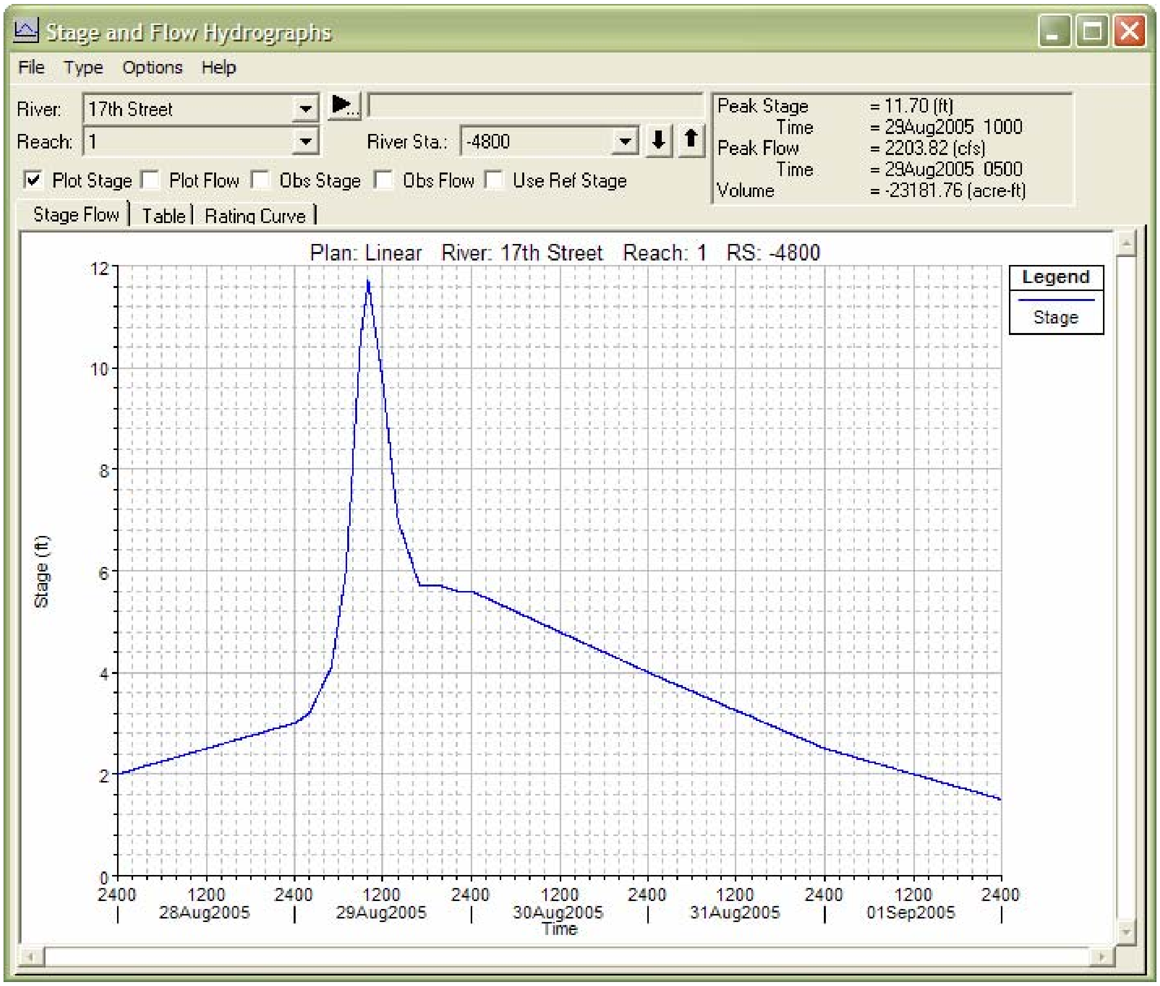

Figure VII-4. ADCIRC stage-hydrograph 17th Street Canal at Lake Pontchartrain

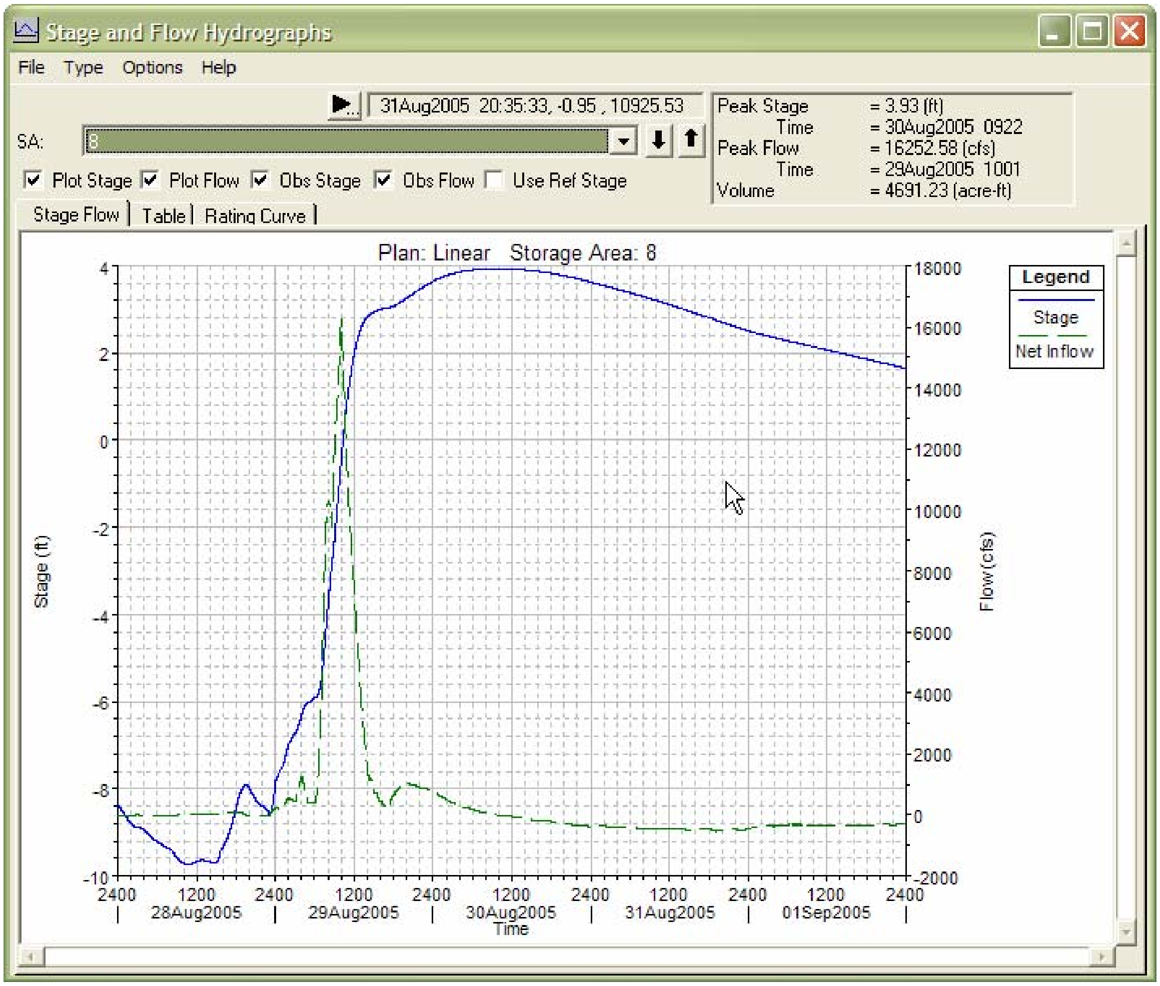

Figure VII-5. Levee breach hydrographs

Sample Results. Figure VII-6 depicts a sample result of the floodplain in Orleans Parish. This type of visual result is available for multiple time steps through the entire simulation. In this sample, the red locations show the actual failure locations during the Katrina event. The depth of water is indicated by the shade of blue with dark blue representing deeper water. Final products will have a legend which details information on the plots such as water depth. Additionally, animations of the flood progression can be produced.

HMS Interior Modeling

Method. The Corps of Engineers' Hydrologic Engineering Center's Hydrologic Modeling System (HEC-HMS) and will be used for this study.

Basin Models. The HMS models have been built to correspond directly to the RAS models. The HMS basin boundaries are a reflection of the RAS storage area boundaries. Applying this method allows the HMS model to transform the Katrina precipitation into runoff. The computed hydrograph is input to RAS as

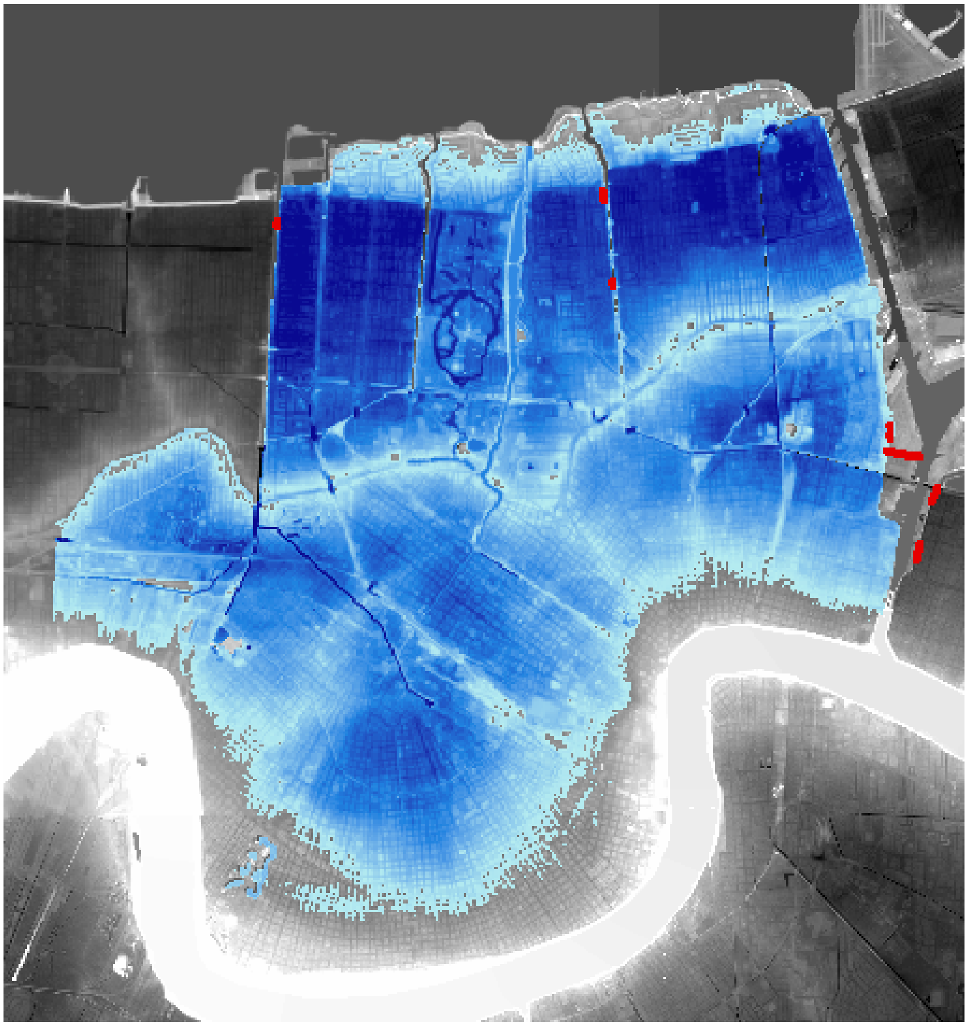

Figure VII-6. Sample result for Orleans parish

Inflow to a Storage Area. Figure VII-7 depicts an HMS basin model setup for the upper Plaquemines Parish area.

Rainfall. Radar rainfall data, referred to as Multisensor Precipitation Estimator (MPE), was used as a boundary condition in the hydrologic models to determine runoff hydrographs produced by the Hurricane Katrina event. MPE data from the Lower Mississippi River Forecast Center (LMRFC) was downloaded from the following website: *http://dipper.nws.noaa.gov/hdsb/data/nexrad/lmrfc_mpe.php*. Raw radar data is adjusted using rain gage measurements and possibly satellite data to produce the MPE product. Figure VII-8 shows the amount of precipitation estimated by the MPE product from August 29, 0600 – 0700.

The radar rainfall data was imported into a GIS where a precipitation hyetograph was computed for each subbasin in the different basin models. The individual hyetographs were imported into a DSS file where they were read by HEC-HMS.

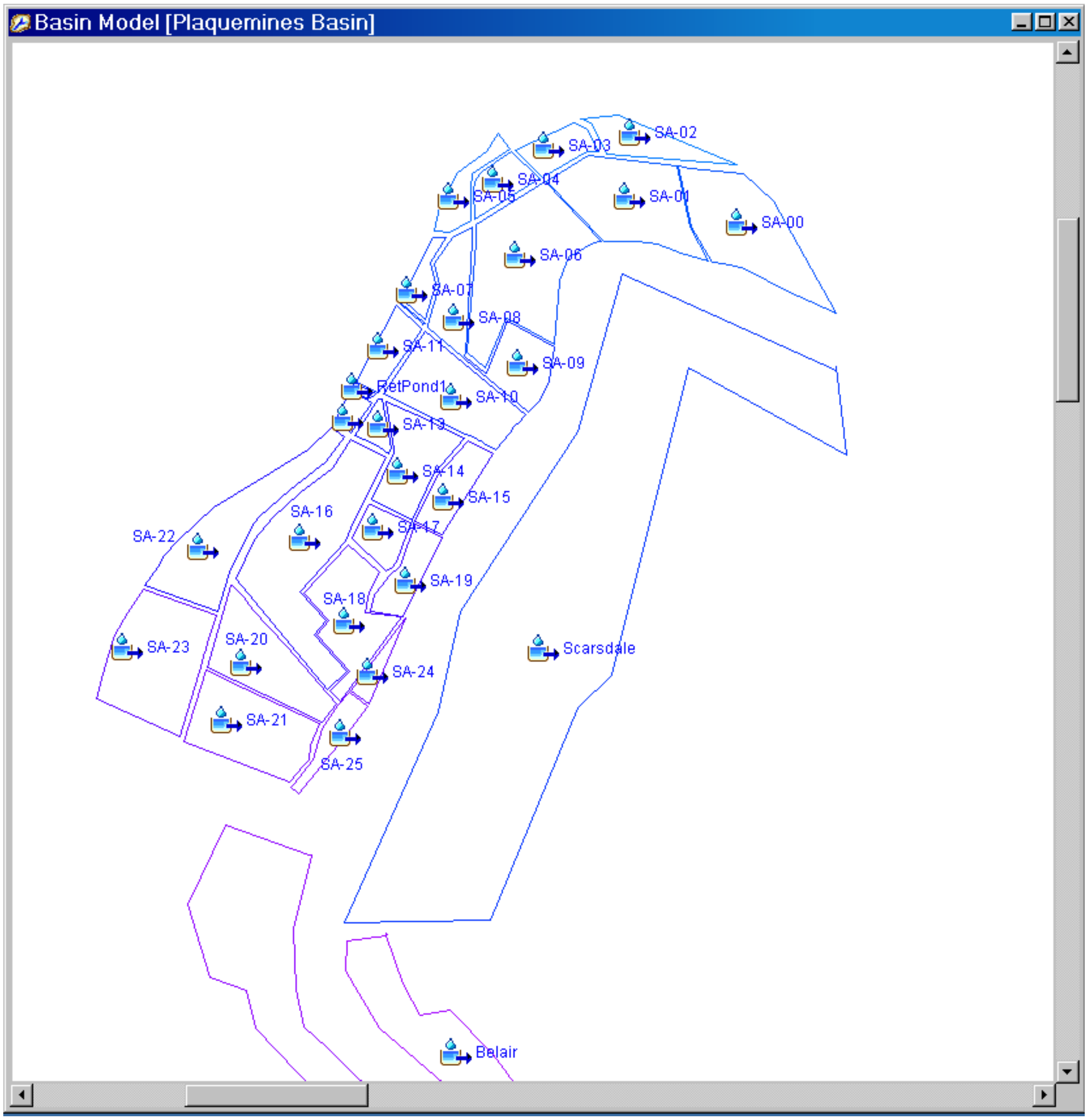

Figure VII-7. Sample HMS Basin model

Land Use and Soil Data. Land use and soil data were used to estimate SCS curve numbers. Land use data was obtained from the New Orleans District (MVN). The land use data was a raster coverage of 24 different land use types (Table VII-4). 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.

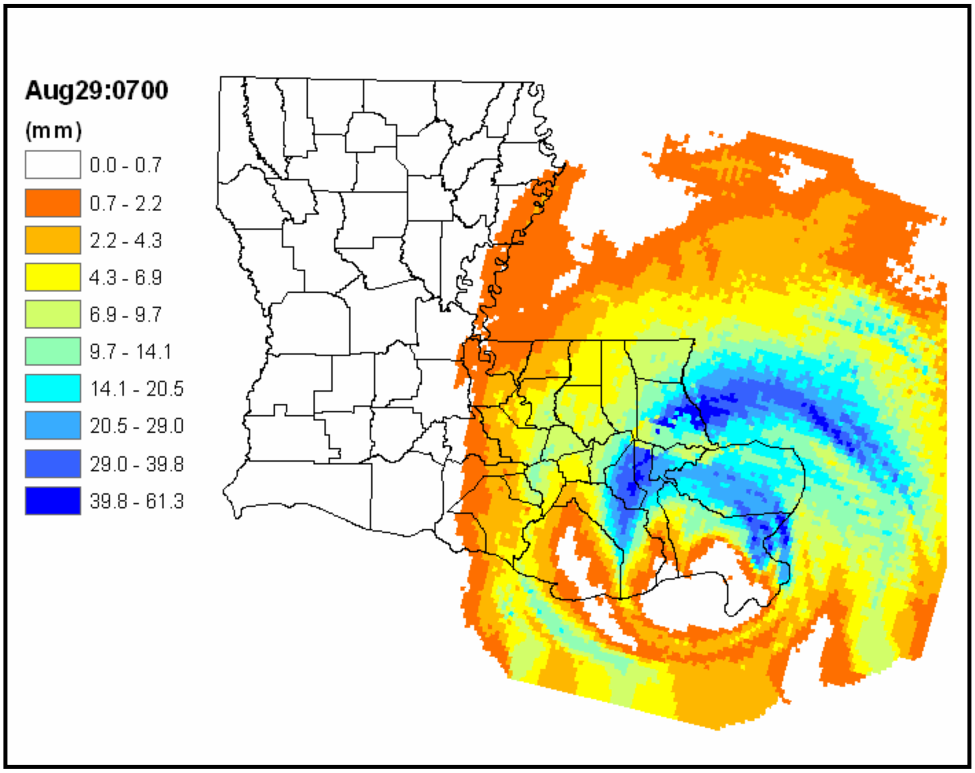

Figure VII-8. Katrina Precipitation

Table VII-4
Curve Numbers

	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 Soil Conservation Service (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 carried out to determine appropriate curve number values for combinations of landuse type and condition, soil type, and the moisture state of the watershed.

Table VII-4 was used to estimate a curve number value for each combination of land use and soil type in the study area. This table was supplied by the MVN office. 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 VII-4. More information about the background and use in the SCS curve number method can be found in Soil Conservation Service (1971, 1986).

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).

Drainage area was computed using GIS and input into HEC-HMS. Lag time was computed by using an estimate of travel time for the longest flow path.

Sample Results. Figure VII-9 depicts results for an HMS subbasin. The upper graph shows precipitation and the lower graph shows the runoff from the subbasin. This runoff hydrograph will be entered in the HEC-RAS model.

Status of Remaining Effort

- Step 3 – Sensitivity analysis of critical parameters. For the hydraulic modeling, factors that will be tested include breach opening widths, breach times, weir coefficients and roughness values. In the hydrologic modeling, the sensitivity of lag times and soil parameters will be tested.
- Steps 4 & 5 – Run the two scenarios.
- Determine if sediment and debris impact drainage efficiency.
- Complete the technical appendix to the final report.

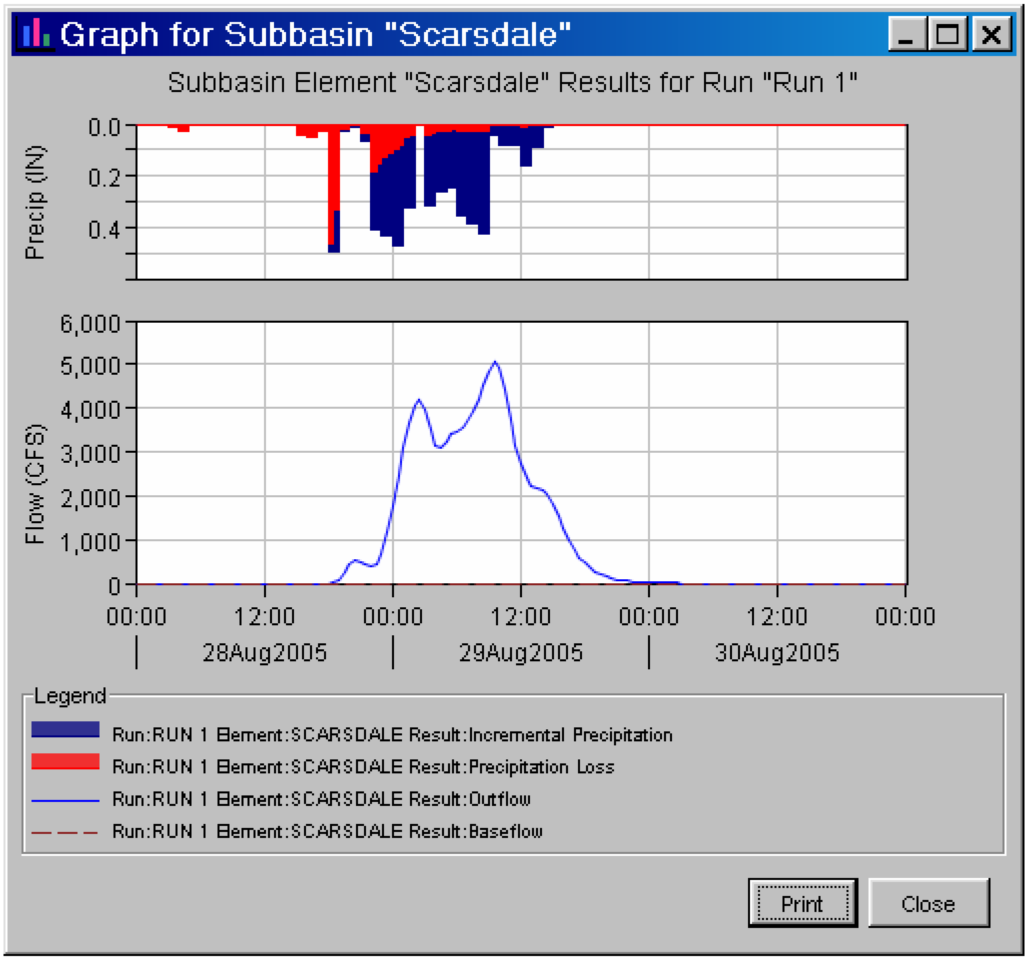

Figure VII-9. HMS Subbasin results

Final Report

The following output will be produced for both scenarios, as applicable.

Modeling Output

- Effective rainfall and runoff volume and distribution
- Flow hydrographs at breaches, overtopped areas, pump stations, and other entry and exit points
- Interior leveed area stage and volume hydrographs
- Filling and unwatering timeline

Visual Displays

- Cross-sections, alignments and storage basins
- Hydrologic basin delineations

- Radar and hyetographs
- Breach locations, volumes, and flow hydrographs
- Overtopping locations, volumes, and flow hydrographs
- Pump station locations, volumes, and flow hydrographs
- Computed and observed stage and volume hydrographs for interior leveed areas
- Inundation area maps
- Time lapse animation of water flowing into and out of interior leveed areas

Tables

- Event timeline
- Summary of volume of flood water from each source

Losses Analysis

Flooding and the level of destruction initiated by Hurricane Katrina are unprecedented from a natural disaster in U.S. history. The consequences from this event are both widespread and long-lasting. They can be described in economic, human health and safety, social and cultural, and environmental terms. The assessment of consequences has several purposes integral to understanding the dimensions of the event that happened. For instance, the economic impacts of the event went far beyond the direct impacts on the residents and businesses in New Orleans. Additionally, consequences are one of the dimensions of risk necessary to understand the level of safety provided by the hurricane protection system. Or, conversely, assessing consequences is part of estimating the residual risk borne by those who lived in the New Orleans area pre-Katrina and those who will live there after the protective system is restored. Therefore, the assessment of consequences will go beyond the grim accounting of destruction in people's lives, property, and the social fabric of New Orleans that actually happened.

To provide a complete understanding of risk, consequences must be assessed under some "what if" scenarios. These losses, in turn, provide input for the IPET Risk and Reliability Assessment Team. Consequence assessment, in this mode, requires predictive approaches and frameworks. These approaches will be described and documented in detail in an Appendix to the final report.

Table VII-6 explains overall logic of the analysis. The events we will analyze include:

- Katrina with the actual system performance along with a suite of consequences: economic (Econ-0), Social-Cultural (Soc-0), Human Health (Hum-0) and Environmental (Env-0) based on pre-Katrina New

Orleans (Orleans, Plaquemines, St. Bernard, St. Charles and Jefferson Parishes).

Table VII-6

Event	System Performance	Consequences	Conditions: Pre-Katrina New Orleans	Conditions: Post-Katrina New Orleans 1	Conditions: Post-Katrina New Orleans 2
Katrina	Actual	Economic	Econ-0	NA	NA
		Social-Cultural	Soc-0	NA	NA
		Human Health	Hum-0	NA	NA
		Environmental	Env-0	NA	NA
Katrina	System works as planned	Economic	Econ-1	NA	NA
		Social-Cultural	Soc-1	NA	NA
		Human Health	Hum-1	NA	NA
		Environmental	Env-1	NA	NA
Other	Probabilistic	Economic	NA	Econ-2	Econ-3
		Social-Cultural	NA	Soc-2	Soc-3
		Human Health	NA	Hum-2	Hum-3
		Environmental	NA	Env-2	NA

- Katrina, assuming that the floodwalls worked as planned with the same suite of consequences based on pre-Katrina New Orleans.
- Other probabilistic scenarios about the system (provided by the Risk and Reliability Team) based on Post Katrina New Orleans as of June 1, 2006 Post-Katrina New Orleans 1 is one such scenario. Economic consequences (Econ-2) will be limited to the direct economic impacts to the City of New Orleans). Human Health (Hum-2) will be limited to loss of life supplemented by qualitative analysis. Social consequences (Soc-2) will be discussed in qualitative terms. The analysis of environmental consequences (Env-2) will be symmetrical throughout the scenarios. The same approach does not apply to Post Katrina New Orleans 2, another scenario supplied by the Risk and Reliability Team.

Thus far, most of the work has been on conceptualizing the problem, writing contracts, coordinating with the other teams and collecting data. A sample of results is available for direct economic impacts and for social cultural; none are yet available for human health and safety.

The environmental impacts team, which has been functioning the longest, reported preliminary findings. Based on the existing data and its analysis to date, there is no evidence of significant impacts on fish or wildlife associated with levee failure or the dewatering of the flooded area by pumping on fish, macro-invertebrate, or shellfish populations of Lake Pontchartrain, Mississippi Sound, or the offshore waters of the Northern Gulf of Mexico. This conclusion is tentative and may need to be revised as additional evidence is accumulated. There is presently only enough information to suggest that benthic assemblages in the immediate proximity of active pumps were impacted by levee failure and dewatering. Information from a follow up study should clarify this issue. Impacts further afield (Lake Borgne and Lake Pontchartrain) will have to await the analyses from EPA's National Coastal Assessment program and from ERDC. However, wetlands within the flood protection system were impacted by high salinity associated with breached/overtopped levies within St. Bernard Parish. The degree of ecological impact is yet to be determined.

The sections below describe the efforts underway, provide some initial quantitative and qualitative results thus far, and outline the status of remaining efforts.

Summary of Work Accomplished

As generally defined for the IPET mission, the economic consequence analysis is being developed to investigate various scenarios associated with hurricane Katrina and the possible future occurrence of similar or more severe storms. Specific to occurrence of Katrina, two scenarios involve the assessment of flooding and inundation with subsequent physical and economic consequence for storm conditions as they transpired on 29 August, 2005. One scenario examines economic consequences due to physical levee or floodwall failure as it actually happened. Another scenario examines how consequences would have differed assuming performance of the levee and floodwall system commensurate with its intended level of protection. Additional scenarios involve assessment and evaluation of what will be at risk as of June 1st at the beginning of the 2006 hurricane season in relation to varying sets of conditions for possible future storms and potential for levee or floodwall failure in different reaches of the levee\floodwall system.

Requirements for consequence analysis involve estimation of direct, indirect, and induced economic impacts of storm effects with regard to flooding and inundation and related costs or damages associated with varying scenarios. Isolating the flooding and inundation related costs will require estimation of wind-driven damages so that the marginal economic costs or value of the levee\floodwall system can be determined.

To date, an extensive review of economic models available to assess indirect and induced market impacts produced a consensus agreement that none are available that is readily applicable to the circumstances of Katrina. This is due to the significant change or transformation of regional economic relationships. These changes have occurred due to widespread catastrophic loss or disruption of business sector activities and community\public activities combined with extensive displacement of households and workforce. It is also due to remaining uncertainties of residents, planners, officials, and investors on issues such as re-evaluation of risks, the pace and priorities of recovery, and numerous other issues fundamental to understanding and predicting market outcomes. Tentatively (and within the constraints of IPET), it has been determined that the approach for evaluating indirect impacts can be facilitated using a simplified economic base model approach possibly combined with adaptation of an economic impact model designed to address in-migration and out-migration or loss of workforce and physical capital assets. To be comprehensive, this will be done using a consistent multi-regional national modeling framework. Where practical, all modeling work will be calibrated using the detailed data to be provided by the Louisiana Department of Labor (described further below).

Interim Results

Some preliminary estimates of direct damages from inundation of structures and content have been assembled for primary areas of four parishes (Orleans, St. Bernard, Jefferson, and Plaquemines) based on availability of GIS grids topography and inundation. Presently available grids include areas of Central New Orleans, Mid-City, Old Metarie, New Orleans East, Lower 9th Ward and Plaquemines Parish communities. Figure VII-10 shows the spatial distribution for the preliminary estimates of residential damage in thousands of dollars by census block. These estimates will be cross-checked with other source data that is currently being processed. Updates will be made when more reliable estimates warrant changes.

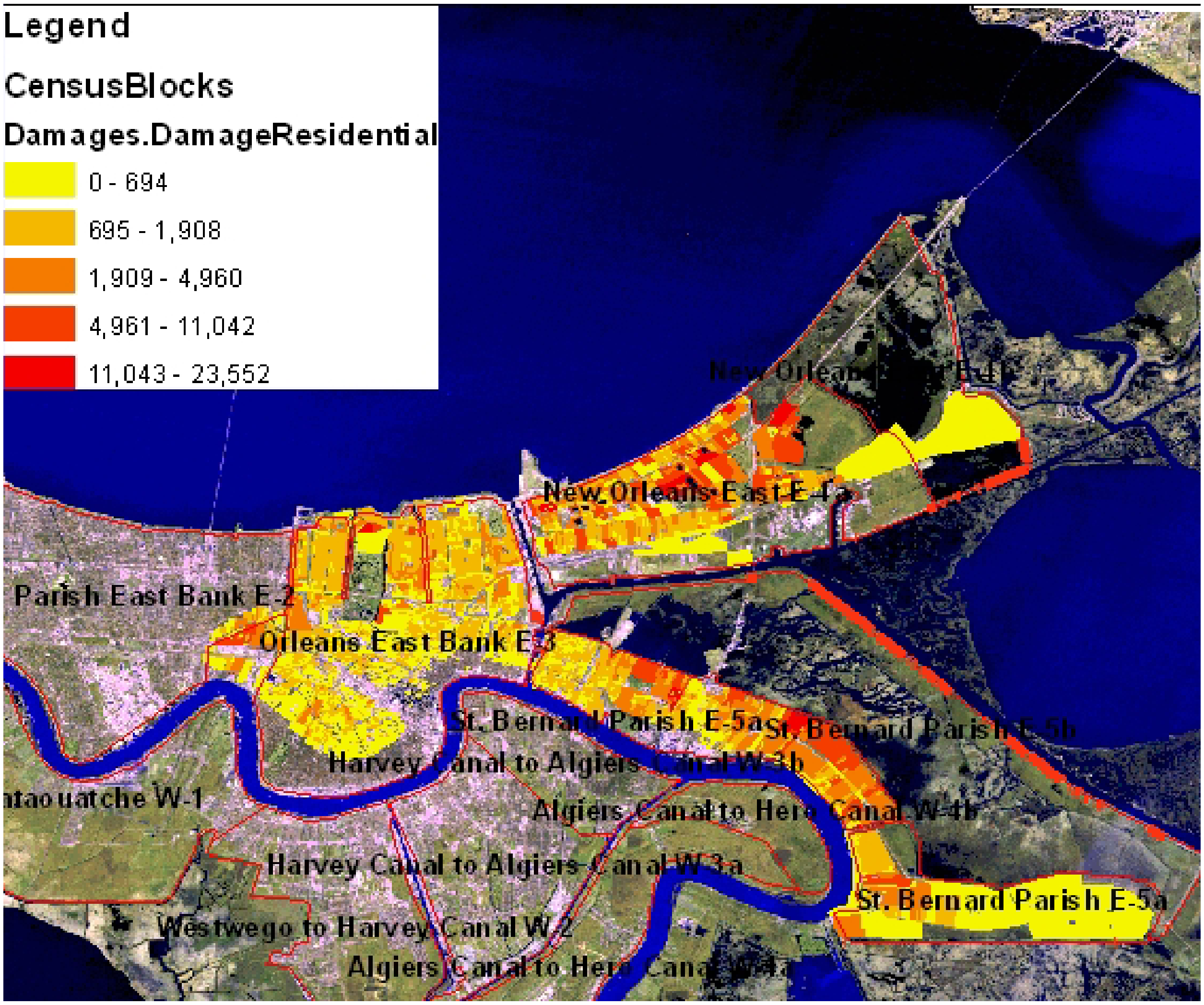

Figure VII-10. Preliminary Estimate of Residential Losses by Census Block

To date, flood damage estimates have been compiled according to aggregate categories of residential structures, commercial structures, and vehicles. Table VII-7 shows the preliminary estimate of total damage in thousands of dollars by parish and zip code for the areas shown in Figure VII-10. Because these values are preliminary and will be revised, a discussion of these figures at this stage would be pre-mature.

Table VII-7
Preliminary Estimate of Number and Damage (in millions of dollars) by Major Categories by Parish and Zip Code

Parish	Zip Code	Residential Damage	Number Housing Units	Non-residential Damage	Number Non-residential	Vehicle Damage	Number Vehicles
Jefferson	70001	$84,872	1,178	$7,757	54	$22,045	1,855
Jefferson	70005	$130,628	1,746	$7,432	190	$73,803	6,152
Jefferson	70121	$30,142	1,105	$7,586	107	$22,113	2,424
Parish Total		**$245,642**	**4,029**	**$22,775**	**351**	**$117,961**	**10,431**
Orleans	70112	$34,469	612	$296,314	644	$57,271	4,297
Orleans	70113	$68,653	2,074	$62,532	431	$99,376	9,272
Orleans	70115	$234,050	4,651	$47,038	772	$249,265	19,451
Orleans	70116	$119,777	3,177	$20,631	354	$100,223	8,007
Orleans	70117	$958,703	13,632	$61,583	680	$326,898	22,694
Orleans	70118	$384,094	7,227	$61,230	625	$259,985	19,302
Orleans	70119	$728,308	13,819	$197,688	1,612	$478,061	31,644
Orleans	70122	$1,349,469	16,408	$93,716	976	$487,073	32,769
Orleans	70124	$1,006,723	10,609	$56,183	504	$267,745	18,059
Orleans	70125	$419,207	6,556	$98,485	900	$313,229	20,202
Orleans	70126	$1,147,323	12,041	$226,037	1,092	$443,987	29,371
Orleans	70127	$858,781	8,001	$319,068	794	$305,107	19,954
Orleans	70128	$778,302	6,541	$113,513	480	$220,146	14,292
Orleans	70129	$293,981	2,613	$129,478	341	$101,267	6,545
Orleans	70130	$35	2	$412	134	$313	160
Parish Total		**$8,381,874**	**107,963**	**$1,783,909**	**10,339**	**$3,709,945**	**256,019**
Plaquemines	70041	$47,894	1,374	$11,074	61	$29,873	2,413
Plaquemines	70083	$6,510	233	$2,093	18	$7,105	675
Plaquemines	70091	$1,137	66	$1,141	2	$1,036	79
Parish Total		**$55,541**	**1,673**	**$14,308**	**81**	**$38,015**	**3,167**
St. Bernard	70032	$272,904	3,629	$67,242	300	$96,294	6,251
St. Bernard	70040	$7,014	109	$139	3	$1,757	126
St. Bernard	70043	$1,076,986	11,227	$139,754	762	$240,248	16,439
St. Bernard	70075	$421,454	3,274	$21,203	99	$69,937	4,565
St. Bernard	70085	$110,995	2,107	$12,338	50	$36,660	2,469
St. Bernard	70092	$378,715	3,983	$15,613	112	$70,376	4,652
Parish Total		**$2,268,068**	**24,329**	**$256,291**	**1,326**	**$515,273**	**34,502**
Grand Total		**$10,951,124**	**137,994**	**$2,077,283**	**12,097**	**$4,381,193**	**304,119**

Status

Compilation of data for more detailed estimates of commercial and public-sector damages is partially complete with some preliminary information becoming available for costs of repair and restoration of infrastructure such as distribution sub-grids for electrical services. Efforts are also in progress to facilitate the sharing of business sector data by the Louisiana Department of Labor (LDL). The LDL compiles data at the individual business level concerning physical location of business, type or classification of business, wages, and employment that is not disclosed publicly (due to requirements for confidentiality). This information is crucial to developing viable estimates of business sector inventory and estimation of direct economic impacts of Katrina within the schedules mandated for IPET. For this reason, the IPET has arranged an acceptable use of pre-Katrina LDL data that is consistent with the confidentiality restrictions (i.e., calendar year 2001 through the second Calendar year quarter of 2005) and post-Katrina, third and (time permitting)fourth quarter employment and wage data.

The USACE District Office in New Orleans has worked extensively to develop and apply GIS systems that enable economic analysis at the Census Tract and Block level and continues to integrate imagery and topographic data to refine economic analyses. This includes efforts to link the GIS product to hydraulics and hydrology modeling and analysis supported by other Tasks under IPET. It is anticipated that this methodology for tabulation of economic impacts of Katrina will be in place by late April and will facilitate scenario analysis conducted by the risk analysis team, task 10 of the IPET.

Activities to Complete

In addition to the completion and cross-checking of the activities already described, work will soon begin to investigate and compile data on the costs of Katrina to waterborne navigation. This includes estimation of damages to the waterway system and costs due to service loss caused by obstruction(s) and requirements for post storm dredging. Further, assessment of impacts on connecting inland waterway and deep-draft vessel services and port facilities will be carried out. It is anticipated these efforts will be largely completed by late March to early April.

Employment and wage data provided by the LDL will require tabulation of aggregates by location and business activity. As the 3rd and 4th quarter 2005 data becomes available, job loss and displacement statistics can be compiled. In addition, a review of the historical LDL data will be carried out to assist in the calibration of impact models and possible evaluation of trends or expected changes in economic relationships that will be analyzed via the Risk and Reliability Team.

Social, Cultural and Historic Consequences

The Social Problem and Objectives

The important consequences go beyond the event's physical damage. New Orleans is a unique community and this community has and will continue to experience unprecedented social and cultural change with regional and national implications. Social Consequences of the event, the impacts, the aftermath and the rebuilding is and will continue to be a key factor in decision making about future hurricane protection.

The objective is to address Social Cultural and Historic Consequences of Hurricane Katrina and the Levee Performance in New Orleans as follows:

- Quantify key parameters reflecting the social conditions in neighborhoods prior to the event; Include those parameters reflecting vulnerable populations (age, gender, income, disabilities, ethnic minorities, vulnerable groups)
- Quantify impact and consequences of the event on those neighborhoods, communities, and parishes
- Identify key institutions and changes in the functioning of those institutions as a consequence of the event
- Identify the cultural historic consequences of the event by social areas of the study region (neighborhood/significant sites)

Summary of Work Accomplished

A group of academic and other applied social scientists have been assembled to assist in developing a work plan. The group met in New Orleans for this purpose in January 2005, and a comprehensive work plan was finalized in early February. Working as a team, tasks outlined in the work plan have been delegated based on areas of team expertise. The plan adopts a conceptual framework for understanding the impacts of the event that is based on methods found in the current disaster research literature. Much of the current efforts are focused on compiling the relevant data sets. In addition, a number of other scholars and agencies are examining the Katrina event, and the team is reviewing methods, data and analysis that is being used in these efforts. Some preliminary information has assisted the team in directing its work.

Interim Results

Katrina was a unique event both in term of scale, response and the uncertainties of recovery. Some of the Parishes impacted by the Katrina event were in population decline between the U.S. Bureau of Census count in 2000 and Pre-Katrina 2005. Orleans Parish had a 5 percent decline in less than 5 years prior to Katrina while Plaquemines is estimated to have 2 percent decline over the same period. The Katrina event had the greatest impact on the Parishes in terms of the number of people. Orleans Parish had a pre-Katrina population of 485 thousand residents and a January 2006 estimated population of 171 thousand. Estimates indicate since the immediate impact (October 2005) 80 thousand residents have returned in interim recovery period (January 2006).

Researchers at Brown University indicated that the population of damaged areas was nearly half African American, living in rental housing and disproportionately below the poverty line. In the City of New Orleans, 75 percent of those living in impacted areas were African American, 29 percent poor and 52 percent renters. An estimated 5.7 percent of those residing in the New Orleans damaged area were over 65 years of age with one or more disabilities. In examining the mortality data made available by the State of Louisiana, the average age of those losing their life as result of the event was over 65 years old. These initial results indicate that the event hit areas that were highly vulnerable.

On an institutional level, the Brookings Institution indicates that only 32 percent of the New Orleans hospitals are open. Only 15 percent of the schools have reopened with over 9,000 students enrolled. Universities in the city are open, but have not fully regained pre-Katrina functionality. Electricity has been restored to about 95 percent of former customers, but only between 30-35 percent of the customers have either not returned or are unable to reconnect to the system. Based on this interim information, the institutions serving the city remain overwhelmed.

Status of Remaining Efforts

The team is evaluating data sources and developing more refined information of the social characteristics in the Parishes and neighborhoods. Data from the New Orleans Planning Department are being generated. Data on institutions will also be collected from a variety of existing sources based on the service areas of the institutions. Qualitative data on historic and significant cultural areas of the metropolitan region is being collected from community leaders and those experts in the cultural history of the areas. Data on institutions will also be collected from a variety of existing sources based on the service areas of the institutions. Field observations will begin in early March 2006, to collect indicators of residential and business reoccupation. All data will be organized within a Geographic Information System format.

The final analysis will be completed by June of 2006 with key parameters and summaries being made available in April 2006. The final report will be organized on a neighborhood by neighbor basis, providing both pre- and post-conditions with a discussion of social conditions in the one to five year time frame.

Human Health & Safety Consequences

Purpose

The human health and safety consequences assessment partially addresses the following IPET question included in the December 6, 2005 ASCE comments on the IPET detailed scope of work:

What were the societal-related consequences of the flooding and hurricane damage, and what are the future societal-related risks that will be faced in New Orleans following reconstruction?

To answer this question for human health and safety consequences, this subtask is proceeding on two somewhat independent tracks.

The first track is characterizing potential human health and safety impacts on New Orleans residents resulting from the actual Katrina event. This effort is largely descriptive and involves no original quantification of impacts. Rather, the effort seeks to identify and describe the most important actual and potential human health and safety impacts of Katrina, including susceptible population subgroups, timing of impacts (onset, duration), possible effects on others, and other relevant information. Hard data on fatalities is being gathered from original sources; however, it is not anticipated that quantitative estimates of morbidity cases will be available from external sources and no attempt will be made to estimate them by the study team. Rather, the study will identify external studies that are attempting to quantitatively estimate morbidity, and pull hard data from those studies to the extent that they are available and releasable.

The second track, which addresses the primary objective of this subtask, is to estimate potential flood-related mortality risks in greater New Orleans under different post Katrina risk scenarios (i.e., event-performance-flooding scenarios). This includes a scenario where the flood/hurricane system performed as designed as well as others developed by the Risk and Reliability Analysis Team.

The LIFESim dam/levee failure life loss model has been selected for modeling flood-related mortality. The main advantages of this model are 1) it can be run in uncertainty (probabilistic) mode that best facilitates mortality assessment due to flooding resulting from levee breaches and overtopping, 2) it includes a sophisticated warning and evacuation (including mobilization and transportation) module, and 3) it links to readily available data sources, including USGS topographic data (as adjusted based on IPET LIDAR controls), census tiger data on population and road network, and building data from HAZUS-MH database.

Summary of Work Accomplished

A conceptual framework for adapting and calibrating the LIFESim model to the New Orleans context has been developed. This calls for adding a rescue module to the model that draws on the actual experience in the Katrina event that will be used to account for escape/rescue of the population at risk (those who do evacuation prior to the event). The framework also identifies the need for flood routing input data that reflects not just maximum flood water elevations for Katrina flooding and post-Katrina risk scenarios, but also rates of inundation, and possibly velocities.

- Links with the social/cultural subtask have been developed for sharing of data on the Katrina rescue profile and pre- and post-Katrina demographic data.
- Links have been developed with the Risk and Reliability and Interior Drainage Team efforts to ensure flood routing data is developed in the required form.
- Publicly available data on flood-related fatalities, by parish, has been developed from numerous sources, some of which includes relevant

demographic data (e.g., age). Links have been established with the LSU Hurricane Center in an effort to improve the fatalities dataset with information developed by the Center.

- GIS data layers for pre-Katrina road network and buildings have been developed.
- Several external studies that are attempting to quantify morbidity impacts of Hurricane Katrina have been identified and preliminarily characterized.

Interim Results

At this time, no interim results have been generated.

Status of Remaining Efforts

- Adaptation of the LIFESim model to the New Orleans context is proceeding.
- Calibration of the LIFESim model awaits the availability of Katrina flood routing data in the appropriate hydrograph (time-dependent) format, as well as a more complete dataset on Katrina-related fatalities.
- Development of GIS data layers for post-Katrina demographics is nearing completion.
- Application of the LIFESim to estimate fatalities for post-Katrina risk scenarios awaits completion of adaptation and calibration of the GIS model, development of all relevant post-Katrina GIS data layers, and data on the provision of flood hydrographs for representative event cases for the risk and reliability analysis.

Environmental Subtask

Summary of Work Accomplished

The environmental subtask of the consequences effort examines the direct, intermediate and long-term environmental consequences (ecological resources degraded and environmental benefits lost) stemming from events associated with Hurricane Katrina; in particular, the local impacts from flooding within the hurricane protection system on ecological resources, including species of ecological and economic value, and pest species that might threaten human comfort, health and safety. It also examines impacts to the integrity of habitat and communities —the ecosystems—supporting resource and pest species. This was achieved primarily through assembly and analysis of data collected by other responsible federal and state agencies, universities, and other reputable organizations. Additional original data were collected on site and analyzed by personnel at the Engineer Research and Development Center of USACE at Vicksburg, MS. Based on subtask results, a forecast is to be made of the environmental consequences resulting from the same flooding, breaching , pumping and other Katrina-related events given the environmental conditions that are expected as of June 1, 2006.

Once the subtask problem was clearly defined, a concept model of the potentially impacted ecosystems and ecological resources were developed (Figure VII-11). The geographical boundaries of the potentially impacted ecosystems were defined at two primary levels: the "inner ecosystem" inside the flood-protection system in Orleans, Jefferson, Saint Bernard, Saint Charles and Plaquemines parishes and the "outer ecosystem" outside the flood-protection system and within reach of flood effects and flood-water management.

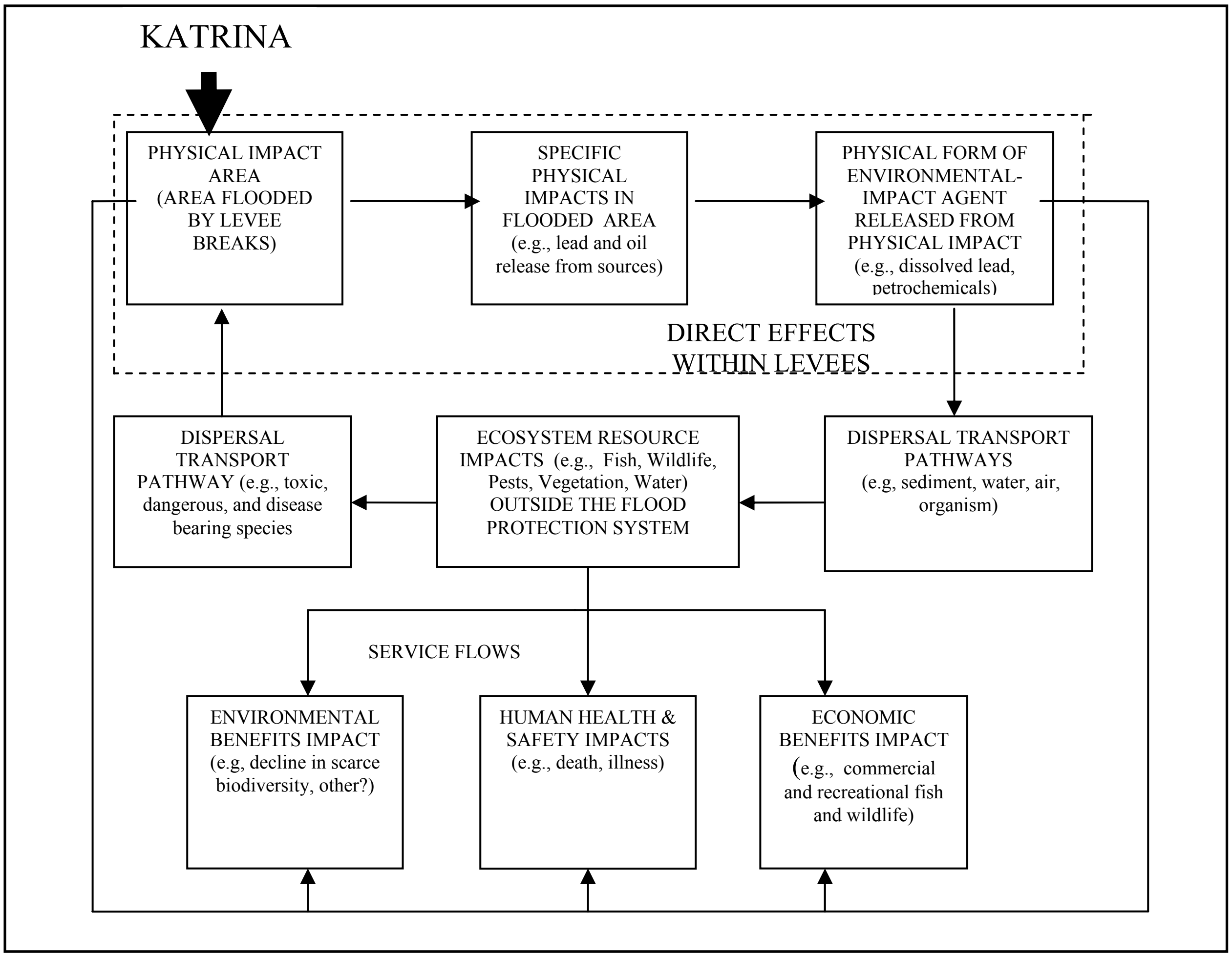

Figure VII-11. Conceptual model of the ecosystem area directly impacted by flooding and the area externally impacted outside the flood-protection system by indirect impacts

Because ecosystems are hierarchically organized, the inner and outer ecosystem includes a mix of smaller ecosystems defined by the biotic communities and their associated habitats. Marine, brackish and freshwater aquatic ecosystems and wetlands, as well as uplands are found in both inner and outer ecosystems. Critically important in determining the dimensions of the outer ecosystem and impacts from flooding and flood management, was identification of all hydrologic and other connection among ecosystems, including, primarily, levee overtopping and breaching, and flood water pumping. Aerial and overland connectivity was also considered to the extent it was related to flooding and flood-water management.

The inner ecosystem included all ecosystems within the flood-protection system, which included 13 sub-basins; i.e., polders (Figure VII-11). Within the flood protection system, the analysis concentrated on the direct effects of water level, water quality, and residual quality of soils after flood recession. It included the impact of salt-water intrusion by water pumping, levee overtopping, and levee breaching on wetlands and native species dependent on waters of lower salinity. From the perspective of total area, the most significant inner ecosystem wetlands existed in the Saint Bernard E-5b polder (Violet Marsh). Another important area, **Bayou Sauvage National Wildlife Refuge, is situated nearby; most of it in Polder E-3 (Orleans East Bank).** The subtask also addressed the impacts of possible insect, reptile, rodent and other pest species as vectors of threat to the comfort, health and safety of people within the area protected by system levees (information provided to the health and safety subtask leader).

Definition of the outer ecosystem focused on the possible transport of chemical and biological contaminants from within the flood-protection system and possible uptake in resource species including shrimp, oysters, fin-fishes, state threatened and endangered species, and supporting habitats. Areas that were breached and topped by storm surge were identified by maps and aerial photography, and by model results obtained from other IPET team efforts. The possible contaminants include toxic metals, organic synthetics, and indicators of fecal contamination considered a health threat by the Environmental Protection Agency at levels over posted standards of acceptability. Possible physical impacts were also considered. Within the outer ecosystems, lakes Pontchartrain and Borgne were separated from the more remote near-shore gulf and delta regions based on relative probability of impact from flood-protection system failure. Lastly, we considered the possible transport of pest species out of the inner ecosystem, including, especially, the invasive Formosa termite moved with debris from flooded areas.

While some of the lost environmental benefits considered here were confined to the region of direct impact in the inner and outer ecosystems, indirect loss of national benefits, primarily in the form of federal endangered and threatened species and their support ecosystem were also considered.

For each case, and to the extent data were available, pre-Katrina background information is provided to contrast with post-Katrina conditions occurring as if the flood-protection system performed as planned and occurring as a consequence of the flood protection system failures. These post-Katrina effects from wind, contaminants transport from other areas, and other general storm damage were sorted from the specific post-Katrina impacts of flooding and flood management in the flood protection system for the Greater New Orleans area.

Hydrologic pathways included the pumping of possibly contaminated flood waters into Lake Pontchartrain and other ecosystems adjacent to and within the flood protection system. Contaminants could possibly include metals, synthetic organics, nutrients, and pathogens indicating human fecal or other possible vectors of human health threat. Contamination is determined by concentrations greater than acceptable standards. Pumped flood waters or waters moving over top or through breaches in levees also may have been altered in other ways that could be stressful to communities in receiving ecosystems, such as different concentrations of salt and oxygen.

Within the flood protection system our concern for natural ecosystems was most focused on Violet Marsh, which occupies nearly all of Polder E5a in Saint Bernard Parish and one of the most important wetlands between the city of New Orleans and the Gulf. Changes in its composition were not only of environmental concern, but could influence future flood protection system performance. Of particular interest in that regard were possible effects of salinity on the vertical structure; i.e., the amount of forested wetland verses lower lying herbaceous wetland (e.g., grasses, rushes, sedges). The Bayou Sauvage National Wildlife Refuge nearby was also a concern.

Other environmental impacts may have also occurred through aerial and human-transport vectors. This included dust blown from the flooded impact site once the flood water receded and flying pest species, such as mosquitoes. In addition, some pests may have dispersed by land. These included the noxious invasive species, the Formosa termite, which could have been dispersed with debris among the flooded ecosystems and to outside terrestrial ecosystems. In addition, rodent vectors of disease and property damage move by land ahead of the rising waters, and may have colonized unflooded areas within the flood protection system.

In addition to undesirable connection, the management of flooding could conceivably cause physical barriers to natural movements of desirable species. This could occur from chemical alteration of connecting waters, for example, or temporary or permanent changes in levees or other physical structure.

In keeping with the boundaries of ecosystems defined in the concept model, the results are reported by ecological resource categories and pest species for near-shore gulf and delta ecosystems most remote from impacts, the exterior ecosystems most likely to be impacted outside the flood-protection system, which are lakes Pontchartrain and Borgne, and the interior ecosystems within the flood-protection system.

Interim Results

Outer Ecosystems

<u>Near-shore Gulf and Delta Ecosystems</u>

Fisheries. Fall of 2005 trawl surveys found no indication of reductions in offshore fish or shrimp populations or fish kills (SEAMAP program, *www.gsmf.org*). Details will be provided in final report.

Immediately following Hurricane Katrina, NOAA, EPA, USGS and Dauphin Island Marine Lab assessed potential contamination levels present in inshore and offshore water, sediment and fish and shellfish tissues. Bacterial contamination (E. coli, Enterococcus, or Vibrio cholera and other V. spp.) in water and sediments from Mississippi Sound and offshore areas did not exceed EPA standards for recreational waters (Peterson et al. 2005a and 2005b). Of other Vibrio species that were encountered, concentrations were not beyond those expected under normal (pre-Katrina) conditions.

Persistent organic compounds (PCB's and DDT's) and polycyclic aromatic compounds (PAC's) in fish tissues did not exceed FDA standards for consumption (Krahn et al. (2005a and 2005b).

Elevated bacterial concentrations in mussels consistent with a storm runoff event have been reported by NOAA's Status and Trends – Mussel Watch program immediately after Hurricane Katrina (*http://ccma.nos.noaa.gov/cit/katrina/prelim.html*). Subsequent sampling by the EPA and the Mississippi Department of Environmental Quality (EPA-DEQ 2005) found few instances of elevated bacterial concentrations or priority pollutants in Mississippi waters and the States of Mississippi and Louisiana and the Food and Drug Administration have all issued news releases indicating that seafood, including oysters are now safe to eat (*www.fda.gov/bbs/topics/NEWS/2005/NEW01271.html*). However, quantitative data has yet to be found.

Wildlife. The information so far discovered to evaluate potential impacts to wildlife populations is scarce and of limited utility. At least eight national wildlife refuges were closed as a consequence of the storm *http://www.fws.gov/southeast/news/2005/r05-098.html* but little information has been provided about wildlife impacts. Most areas of the refuges that were previously open to the public have reopened *http://www.fws.gov/southeastlouisiana/Katrina.htm*. The loss of sea turtle nesting sites along the Alabama coast, Alabama beach mouse dune habitat, and red cockaded woodpecker habitat in Noxubee National Wildlife Refuge (New Release Sept 9, 2005, *www.fws.gov/southeast*). These locations are remote from the flood-protection system and not likely to have been impacted by levee failure in any measurable way

Several threatened and endangered species have been observed in nearshore gulf and delta ecosystems. These include the West Indian Manatee Trichechus manatus, Atlantic Ridley Lepidochelys kempiisea (a sea turtle), piping plover Charadrius melodus, brown pelican (Pelecanus occidentalis), bald eagle (Haliaeetus leucocephalus), gulf sturgeon Acipenser oxyrinchus desotoi, and Louisian Quillwort Isoetes louisianensis. Little information on status of these species has been reported as yet.

Lakes Pontchartrain and Borgne

Fisheries. Information on fish and benthic invertebrate populations before Hurricane Katrina is available through the EPA's EMAP program (*http://www.epa.gov/emap/index.html*). Data from 2005 or 2006 are being analyzed (will be assembled in a Table for pre-Katrina assessments). Other information on the fish assemblages of Lake Pontchartrain, including a recent assessment of fish-habitat relationships, is summarized in O'Connell et al (2004) and in the University of New Orleans Vertebrate Museum's database of fish collections in Lake Pontchartrain (*http://www.nekton.uno.edu/about.htm*).

Both the Mississippi Department of Marine Resources (DMR) and the Louisiana Department of Wildlife and Fisheries report significant physical damage to oyster beds due to scouring, sedimentation, and debris deposition (*http://www.dmr.state.ms.us* and personal communication, Marti Bourgeois, LA DWF). However, quantitative data before and after the Hurricane have yet to be discovered.

Immediately after Hurricane Katrina, Louisiana Department of Environment Quality (LADEQ) (2005) found high bacterial counts in the water on the northern shore of Lake Pontchartrain; however, concentrations of organic contaminants were generally below water quality standards. In addition post-storm water quality assessments revealed significant low dissolved oxygen conditions and fish kills along the northern shore of the lake, but attributed these results to the storms and not to pumping of the floodwaters from the flood-protection system (*http://www.deq.louisiana.gov/portal/portals/0/news/ pdf/Post-KatrinaWaterQualityAssessment9-20-05.ppt*). LA DEQ (2005) also anecdotally noted there were "numerous bait fish and mullet" and live crabs in the lake following the Hurricane.

Additional post-storm benthic data is available from a one-time sampling of Lake Borgne conducted in late November 2005 by ERDC (Ray 2006, unpublished). The sampling effort collected sediment grain size, infaunal, and water quality data to assess foraging habitat of the endangered Gulf Sturgeon (Acipenser oxyrinchus desotoi). This information is presently being analyzed.

Many of the threatened and endangered species that occur in the near-shore gulf and delta region also occur in lakes Pontchartrain and Borgne. Of these, the gulf sturgeon population has been most closely monitored in the area. At the time of the storms most sturgeon were in their summer resting areas well away from the New Orleans in the Pearl and Bogue Chito Rivers. Of 40 fish carrying telemetry tags, none have been located since the storm. The other threatened and endangered species occur incidentally and seasonally, and there is no reported knowledge of their occurrence since Katrina in the region under study. The endangered Gulf Sturgeon may have been significantly impacted by the hurricanes, but probably not by the levee failure and dewatering process.

Development of a contaminants movement model out of the inner ecosystem to Lake Pontchartrain is nearly complete. Early evaluations of arsenic transport indicate that contaminants are quickly dispersed and diluted in Lake Pontchartrain to concentrations below EPA standards. Other contaminants, including indicators of human pathogens have yet to be analyzed with the model.

Inner Ecosystems

Contaminants. There are no important fish populations in inner ecosystem waters. However, there are important wetlands, which were sampled by ERDC and important associated wildlife populations. The central repository for Katrina-related water and sediment quality data is EPA's STORET Katrina Central Warehouse. Because of the availability of the data, only fecal coliform data are being supplied to the modeling team to evaluate pathogen transport out of the system into the surrounding ecosystem environment. Fecal coliform measurements in the flood water of New Orleans routinely exceeded water quality standards based on data obtained by EPA and LADEQ. Some metal concentrations were above standards set by EPA in the flood waters but do not differ substantially from typical storm-water runoff. Because of the volume of water pumped, however, these data raised some concerns about potential environmental impacts and public health threats resulting from the failure of the levees and were responsible in part for applying a contaminants transport and fate model to assess impacts outside the flood-protection system.

Sampling conducted by ERDC in Violet Marsh was designed to compliment and extend this fecal coliform data set. The data are providing a means to quantitatively evaluate the distribution of treated and untreated sewage in flood waters of St. Bernard Parish that were pumped into Violet Marsh from Polder E-5a. The flooded sewage treatment plant off Florida Avenue (at Dubreuil Street) and the oil spill from the Murphy Oil Company on Paris Road were selected as potential environmental contaminant sources (both in Polder E-5a of Saint Bernard Parish). Samples were then taken on transects some distance from these pumps into Violet marsh. Sediments from the top of each core were sampled to derive information on recently deposited material while deeper sediments were sampled to assess materials deposited prior to the storms. These have yet to be fully analyzed for fecal coliforms and ratio of coprostanol to cholesterol. Unlike water samples, sediment quality standards for microbes do not exist. Metal and organic contaminants are also being similarly analyzed.

Salinity changes and preliminary data on benthic invertebrates in Violet Marsh indicates that species composition of benthic assemblages in the immediate vicinity of active pumps suggest a history of recent disturbance consistent with higher salinities and other storm impacts probably associated with levee breaching along MRGO.

Wildlife. While no data on wildlife use has been described, undoubtedly Violet Marsh in Saint Bernard Parish gets similar wildlife use as a nearby refuge. Located within the City of New Orleans, Bayou Sauvage National Wildlife Refuge is the nations largest wildlife refuge (23,000 acres) and includes both fresh and brackish marshes. It includes "an enormous wading bird rookery from May until July… and tens of thousands of waterfowl winter in its…marshes" *http://www.fws.gov/bayousauvage/*. The Hurricane occurred during the interval between the seasons of greatest waterbird use. Damage, if any, to the freshwater wetlands has yet to be reported.

The condition of bald cypress is especially relevant to use as bird nesting areas (rookeries). Because it requires freshwater for survival, elevated salinities associated with levee failure may have stressed the cypress and perhaps killed trees. That condition is being monitored with the onset of the spring growing season along with impacts on marsh vegetation (mostly grasses, sedges, rushes).

No state or federal threatened and endangered species have been identified in Violet Marsh. However, bald eagle and brown pelicans occur in the Bayou Sauvage National Wildlife Refuge. Although other species might conceivably pass through the area, the probability of impact on the extant populations of all threatened and endangered species is likely to be small.

Pest Species. There has been considerable concern that the Formosa termite, Coptotermes formosanus, an invasive and destructive species, might be introduced to uninfected areas by rafting of the colonies on floodwaters or inadvertently with debris disposal. While much of the debris seems to have been retained in land fills within the flood-protection system, analysis of possible disposal outside the system and pre-Katrina range of the termite is underway. Other potential pest impacts are being sought out in useful data, but little has been found to date.

Status of Remaining Efforts

Analyses of sediment and water samples obtained by ERDC for ecosystems receiving flood waters are in the process of being completed. The contaminants model is being refined and used to simulate movements of metal, organic, and pathogen contaminants out of the inner ecosystem to Lake Pontchartrain. Additional unpublished data on wetland and wildlife condition and fisheries condition are being sought from responsible agencies. Assessment of existing ecosystem resource condition and impact by a June 1 hurricane event will follow upon compilation of all data.

Tables and Figures will be completed as all data becomes available. A preliminary list of Tables and Figures is listed below:

Tables.

1. Regional marine fish and sediment contamination results, pre- and post-Katrina
2. Wetland and barrier island area apparently lost after the storms—pre- and post- Katrina.
3. Areas and volumes of water in flood zone at observed flood peak in each Parish and in total, a performing flood system, Lake Pontchartrain, and Violet Marsh.
4. Pre- and post-Katrina live cypress and herbaceous plant cover and water salinity in violet marsh.
5. Differences in benthic invertebrates at pumped and un-pumped outfalls at violet marsh.

6. Lake Pontchartrain summary of pre- and post-Katrina fish, shellfish, water, and sediment pathogen and metal and organic contaminant concentrations.
7. Parish flood water summary of pathogen, metal, and organic contaminants.
8. Threatened and Endangered Species status summary for recent years including 2006.
9. Summary of likely impacts to ecosystems as of June 1, 2006 of an event like hurricane-Katrina.

Figures.

1. Conceptual model of the ecosystem.
2. Outer ecosystem potentially impacted defined by fisheries, contamination, and wetland data.
3. Inner ecosystem defined by the protection system structure around five parishes and the surrounding area.
4. Diagram showing ecosystem pathways of potential impacts through contamination of resources.
5. Contaminants model structure and 5 figures showing outer ecosystem distribution of pumped contaminants.
6. Debris dispersal to landfills, incinerators.