VIII. The Risk

Executive Summary

The mission of the IPET risk and reliability analysis is to examine the risks to life and property posed by the New Orleans hurricane protection system that was in place prior to Katrina and by the system as it is expected to exist at the start of the next hurricane season (1 June 2006). The risk analysis will consider the expected performance of the various elements of the system and the consequences associated with that performance. All engineered systems impose risks that result from humans using technology to create conditions or activities that are not produced by nature. For instance, the hurricane protection system in New Orleans has been designed to control interior flooding within New Orleans and protection to the city from storm induced surges and waves. The hurricane protection system (HPS) project is designed to perform this function without imposing unacceptable risks to public safety, property and welfare.

The risk analysis covers four states that represent the condition of the New Orleans hurricane protection system.

- The system as it existed before the arrival of Hurricane Katrina. Knowledge gained from IPET studies will be considered in the analysis.

- After Hurricane Katrina with repairs that have been completed prior to the 2006 hurricane season. Some projects may be ongoing after 1 June 2006.

- After Hurricane Katrina with all repair and improvement projects complete, but prior to longer-term increases in the authorized level of protection.

- The system as authorized before the arrival of Hurricane Katrina. All authorized components of the HPS are constructed and knowledge gained from IPET studies will be considered in the analysis.

The difference in relative risks among the three states will be a unified measure for fully evaluating the performance of the integrated system before Hurricane Katrina, after Hurricane Katrina, and during the interim recovery period.

Two groups of questions concerning the performance of the hurricane protection system (HPS) are addressed by the risk and reliability analyses:

Pre-Katrina: The system as it existed before the arrival of Hurricane Katrina. This state is the baseline for estimating risk, and includes the following:

1. What was the reliability of the hurricane protection system to prevent flooding of protected areas of the HPS that was in existence before the arrival of Katrina, for the standard project hurricane? Note that some components of the authorized projects had not been constructed prior to Katrina.

2. What was the reliability of the hurricane protection system to prevent flooding of protected areas with all of the authorization projects completed, for the standard project hurricane?

3. What is the estimated annual rate of occurrence of system failure due to hurricane events?

4. What are the probability distributions and annual rates of consequences that would result from failure of the hurricane protection system as defined in terms of life loss and economic impact?

5. What is the uncertainty in these estimates?

The pre-Katrina analysis does not attempt to recreate the design intent or knowledge that the designers used to determine the configuration of the HPS. Engineering parameters, foundation conditions and operational information gained by IPET through exploration and testing since the hurricane are used. This allows for an assessment of the actual risks that existed pre-Katrina. An additional analysis was conducted on the authorized HPS that includes all features in the original design that were not completed prior to Katrina.

Post-Katrina: After Hurricane Katrina with repairs made prior to the 2006 hurricane season, and during the interim recovery period after the hurricane protection system has been strengthened and improved, but prior to longer-term increases in the authorized level of protection. This group includes:

1. What is the reliability of the HPS to prevent flooding of protected areas for the authorized standard project hurricane with the system repairs and improvements in place as of June 1, 2006?

2. What is the frequency of flooding due to the range of expected hurricane events with the system repairs and improvements in place as of June 1, 2006?

3. What are the probability distributions and annual rates of consequences that would result from failure of the hurricane protection system as defined in terms of life loss and economic impact?

4. What is the uncertainty in these estimates?

The condition of the system has been degraded by the effects of hurricane Katrina. Flood walls and levees may have been overtopped, damaged by impacts from debris, saturated, submerged and/or breached. Permanent repairs on these elements have been accomplished since the hurricane that may have different material strength parameters than the original feature. This difference in strengths is considered in the analyses of component reliability. The pumping system was also damaged and shut down or submerged. The post Katrina reliability of the levees, flood walls and pumping stations will be considered in the risk assessment. The reliability of the various elements of the protection system will be determined using analytical and expert elicitation methods.

The term reliability is intended to mean the conditional probability of a component or system performing intended function. This result can also be used to determine the conditional probability of failure. System failure refers to the failure of the HPS to provide protection from flooding in one or more protected areas and can also be thought of as the occurrence of flood inundation. The effectiveness of the protection system is also dependent upon how well the operational elements of the system performed. Elements such as road closure structures, gate operations and pumping plants, etc. that requires human operation and proper installation during a flood fight can dramatically impact flood levels. The lessons learned concerning the performance of these elements during Katrina will be considered in the analysis.

The changed demographics of the local areas protected by the system will be considered when determining the consequences. In some areas, many homes and much of the infrastructure were destroyed by the hurricane and some may not be rebuilt. Therefore the pre-Katrina populations and property values will be impacted and must be considered in the post-Katrina analysis.

Risk is generally calculated by combining the probability of system failure with the consequences associated with that failure. For New Orleans, the post Katrina risks will be lower primarily due to reduced population at risk and lower economic activity. Consequences in terms of loss of life, however, are greatly dependent upon warning time and the effectiveness of the implementation of the evacuation plans. While recommendations may be made concerning evacuation planning, the effectiveness of plan implementation is beyond the control of USACE. In order to better compare the adequacy of pre and post Katrina HPS, probability of failure and inundation mapping will be used as the primary metric by which to measure the effectiveness of repairs and improvements. Coordination is ongoing with the consequence team to determine the manner by which loss of life calculations will be made.

Summary of Work Accomplished

Risk Model

Work accomplished to date has focused on development and testing of a spreadsheet template to be used for all polders and the associated mathematical relationships required to incorporate hurricane, reliability and consequence inputs. The risk model for the New Orleans East polder has been completed and will be used as the template for the remaining polders. All polder models are based upon the same basic event tree with some alterations to consider any unique features of the polder.

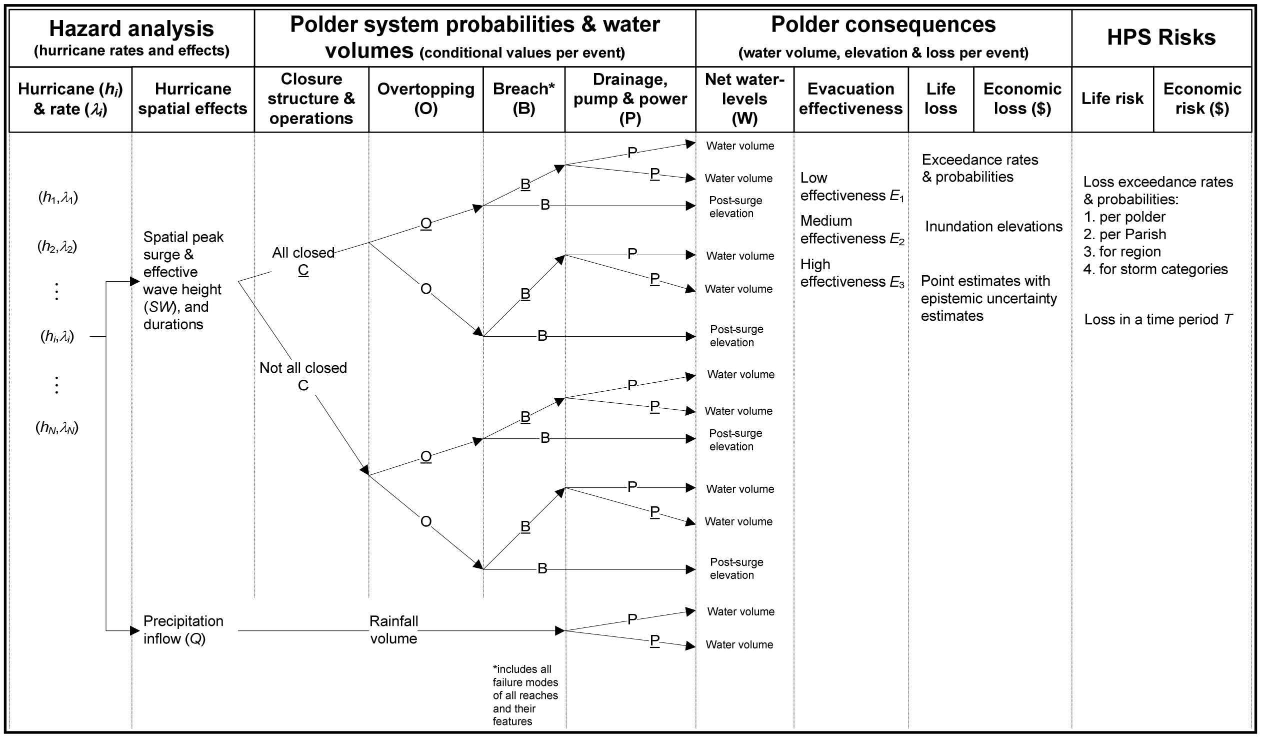

Figure VIII-1. Risk Model Event Tree. Underlined events (i.e., *C*, *P*, *O*, and *B*) are the complements of the respective events (i.e., *C*, *P*, *O*, and *B*).

System/Polder definitions

The physical characteristics of each polder must be accurately modeled in the risk model. The polder perimeter is separated into reaches that have similar levee cross-sections, foundation conditions and engineering parameters. The interior of each polder has been separated into sub-polders that are defined by the interior drainage and pumping systems.

The field work required to develop the system model for the New Orleans East polder has been completed and much work has been done on the other polders. A standard format for the collection of polder data was used to assemble the physical characteristic of the polder. Design Memorandums (DM) for each project were used to develop maps of each polder showing the location of critical features, stationing and elevations. Field trips were made to verify these maps and to note any changes made since construction. Team members traveled the entire perimeter of the polder and documented all critical features by taking GPS coordinates, photographing areas of interest and noting deviations from DM maps. A sample map for the New Orleans East polder is shown in the appendix.

The system consists of polders, sub-polders and reaches. The definition of these polders, sub-polders and reaches are based on the following considerations:

- Local jurisdiction,
- Floodwall type and cross section,
- Levee type and cross section,
- Engineering parameters defining structural performance,
- Soil strength parameters,
- Foundations parameters, and
- Surge and wave levels.

A sample of the spreadsheet model for a specific reach of the New Orleans East polder that has been developed based on the event tree is shown in Figure VIII-2. The figure shows the case of overtopping (OT) for a reach using several storms. Note inflow volumes are calculated for each hurricane run.

The primary goal of the risk model is to determine the volume of water entering each polder due to surge and wave overtopping, breaches and precipitation for each hurricane event. The perimeter of each polder is segmented into reaches that have similar characteristics as defined in Section 2.2. below. Since polders are made up of sub-polders based on interior drainage and pumping systems, the model must take into account the interflow between sub-polders. Inflow volume calculations are made for each reach and sub-polder and then aggregated to determine the total volume of water in each polder due to the hurricane event. Volumes will be post-processed with the topography of the interior of each polder to determine water elevations within the polder, and frequencies associated with each elevation. Water elevations within polders are determined using stage-storage relationships provided by the interior drainage modeling done by other IPET teams. A typical stage-storage curve is shown in Figure VIII-3.

Reach Number	1
Reach start-end stations	To be provided
Reach coordinates	To be provided
Equal allocation to Sub-Polder(s)	1
Reach length (ft)	2000
Reach elevation (ft)	16
Mean (Weir Coeff.)[1]	3
COV (Weir Coeff.)	0.2
[1]Use 3.0 for floodwalls, 2.6 for levees, and 2.0 for gates	

Hurricane Runs			1								
Run	Rate (R)		Surge+Waves		Duration		OT Length		OT Probability	OT Volume (Weir Eq)	
i	Mean	StD*	Hs		T		L		P(OT)	V|OT	
			Mean	StD*	Mean	StD*	Mean	StD*		Mean	StD
ID	event/yr	event/yr	ft	ft	sec	sec	ft	ft		ft^3	ft^3
1	5.00E-04	0.00E+00	25	0	5400	0	2000	0	1.00E+00	8.748E+08	1.750E+08
2	5.00E-04	0.00E+00	25	0	5400	0	2000	0	1.00E+00	8.748E+08	1.750E+08
3	7.50E-04	0.00E+00	24	0	5400	0	2000	0	1.00E+00	7.331E+08	1.466E+08
4	1.00E-03	0.00E+00	23	0	5400	0	2000	0	1.00E+00	6.001E+08	1.200E+08
5	1.00E-03	0.00E+00	22	0	5400	0	2000	0	1.00E+00	4.762E+08	9.524E+07
6	1.50E-03	0.00E+00	21	0	5400	0	2000	0	1.00E+00	3.622E+08	7.245E+07
7	2.00E-03	0.00E+00	20	0	5400	0	2000	0	1.00E+00	2.592E+08	5.184E+07
8	2.00E-03	0.00E+00	19	0	5400	0	2000	0	1.00E+00	1.684E+08	3.367E+07
9	2.00E-03	0.00E+00	18	0	5400	0	2000	0	1.00E+00	9.164E+07	1.833E+07
10	2.00E-03	0.00E+00	17	0	5400	0	2000	0	1.00E+00	3.240E+07	6.480E+06
11	3.50E-03	0.00E+00	16	0	5400	0	0	0	0.00E+00	0.000E+00	0.000E+00
12	5.00E-03	0.00E+00	15	0	4320	0	0	0	0.00E+00	0.000E+00	0.000E+00
13	5.00E-03	0.00E+00	14	0	3600	0	0	0	0.00E+00	0.000E+00	0.000E+00
14	5.00E-03	0.00E+00	13	0	3600	0	0	0	0.00E+00	0.000E+00	0.000E+00
15	5.00E-03	0.00E+00	12	0	3600	0	0	0	0.00E+00	0.000E+00	0.000E+00
16	5.00E-03	0.00E+00	11	0	3600	0	0	0	0.00E+00	0.000E+00	0.000E+00
17	5.00E-03	0.00E+00	10	0	3600	0	0	0	0.00E+00	0.000E+00	0.000E+00
* Reserved for future epistemic uncertainty analysis											

Figure VIII-2. New Orleans East Polder Model

Figure VIII-3. Stage-Storage Curve for Citrus

The spreadsheet includes tabs for various braches of the tree provided in Figure VIII-1. The results from all the simulated hurricanes are used to evaluate Eq. 8-1 with results illustrated in Figures VIII-4 and VIII-5.

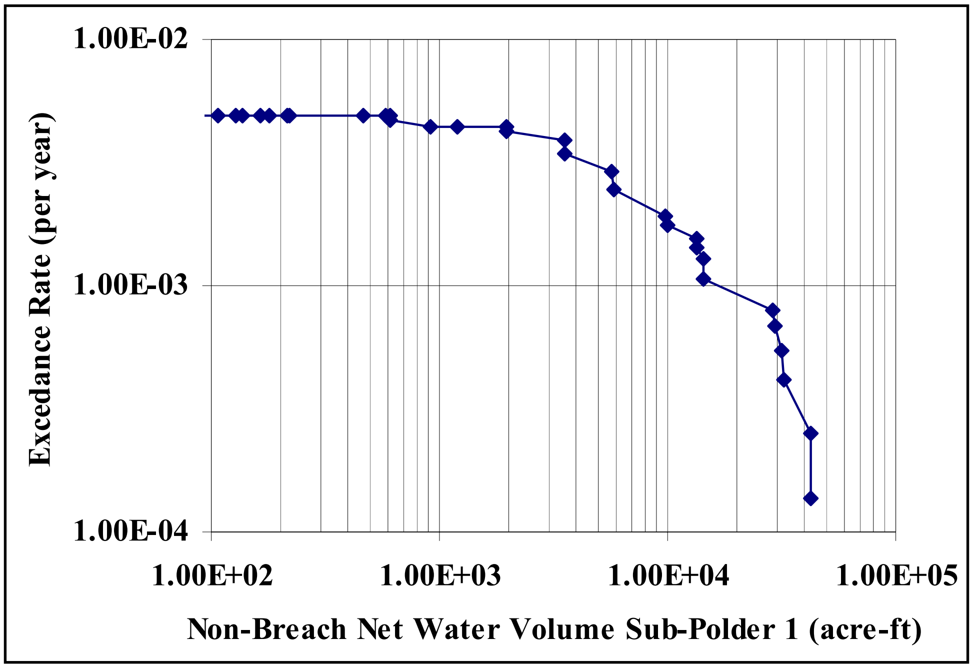

Figure VIII-4. Overtopping Risk Profile for Sub-Polder 1

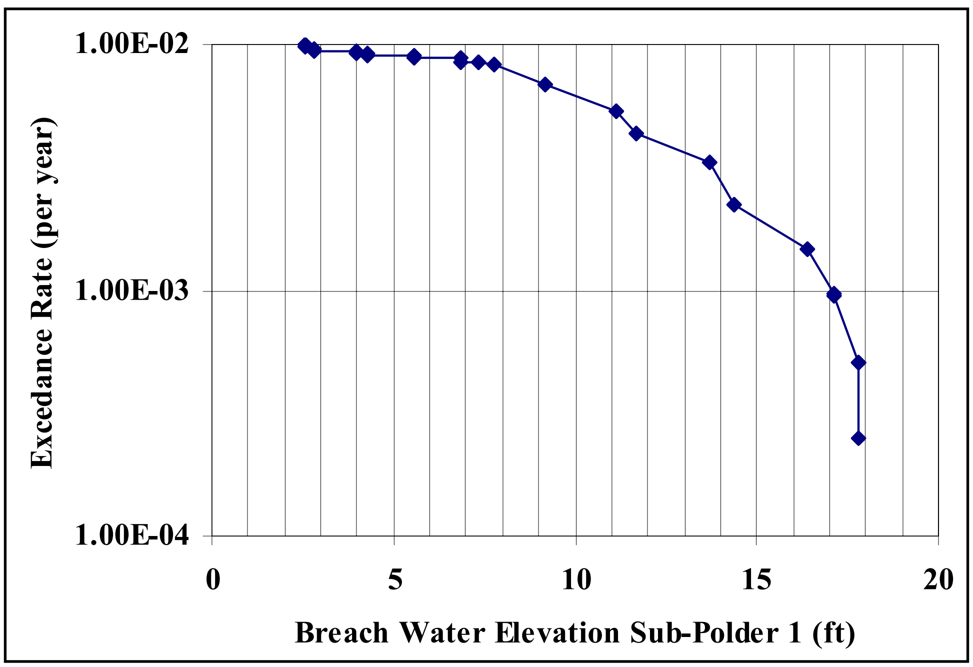

Figure VIII-5. Breach Risk Profile for Sub-Polder 1

Polder Geotechnical Subsurface Information

Geotechnical subsurface information has been collected from numerous borings and undisturbed samples found in the GDMs and from other USACE subsurface investigations. Polder maps will show the boring locations and data is presented in the forms of strip logs for each borings, profile cross sections under each levee section and laboratory test results for the continuous undisturbed samples. The laboratory test results include unconfined compression, triaxial (Q, R, and S) testing, Atterberg Limits and consolidation. This information has been carefully extracted and processed and incorporated into the reliability modeling. For each polder the subsurface geotechnical information will be interpreted from the test data to estimate statistical parameters and distributions and the spatial variability of the foundation materials. Appendix B includes a description of the geotechnical information gathered for the New Orleans East polder and similar information will be collected for the remaining polders.

Hurricane Hazard Modeling

Hurricane hazard is quantified using a joint-probability approach. This approach requires three main components: a hurricane parameterization scheme, a hurricane recurrence model, and a system load model. The standard hurricane parameterization at landfall in terms of landfall location, track direction, speed, central pressure drop, radius to maximum winds, and Holland's B shape parameter is used. In addition, the variation of mean track with landfall direction and the pre-landfall variation of central pressure and storm speed is also considered. After landfall, the central pressure is filled using the standard exponential model.

The recurrence rate for different hurricane parameters at and before landfall is obtained through statistical analysis of FEMA's HURDAT data set and various published results. While the model resembles others proposed in the literature, the specific form of distributions, dependencies and parameter values have been adjusted to best fit the historical record.

The loads of interest are surge levels and wave characteristics along the hurricane protection system and the rain rates inside the polders. The surge levels are the most critical loads. The main tool to estimate surges is the numerical code ADCIRC. Significant effort has been devoted to devise a computationally efficient scheme to accurately evaluate surges for about 40,000 different hurricane scenarios. The strategy makes combined use of preliminary runs with a very coarse spatial grid to determine the nature of the dependence of the surge on different parameters and the presence or lack of interaction among different parameters. Taking advantage of these characteristics, the number of needed ADCIRC runs has been reduced to about 1000. Not all 1000 runs are made with a high-resolution (HR) grid. The bulk of the runs use a mid-resolution (MR) grid. The MR results are then calibrated using about 40 HR runs.

The combinations of the parameter values listed in Table VIII-1 are considered in the ADCIRC modeling and the process used to select the parameter sets is described in Appendix J.

Table VIII-1 Mid-Resolution Runs		
Parameter	**Factorial 1**	**Factorial 2**
ΔP (mb)	41, 80, 115	80
V (km/h)	8, 21, 36	21
$X\cos(\theta)$ (km)	-130, -90, -50, -10, 30, 70, 110	-130, -90, -50, -10, 30, 70, 110
θ	-60, -30, 0, 30, 60	-60, -30, 0, 30, 60
R_{max}	10%, 50%, 90% quantile from Eq. J-20	10%, 50%, 90% quantile from Eq. J-20
B	50% quantile from Eq. J-21	5%, 95% quantiles from Eq. J-21
$\Delta P_R(t)$	$\Delta P_{R,0.5}(t)$ from Figure J-21	$\Delta P_{R,0.5}(t)$ from Figure J-21
$V_R(t)$	$V_{R,0.5}(t)$ from Figure J-22	$V_{R,0.5}(t)$ from Figure J-22
$R_{max}(t)$	From Eq. J-23	From Eq. J-23
$B(t)$	From Eq. J-24	From Eq. J-24
α	0.035 + 0.0005 ΔP	0.035 + 0.0005 ΔP
No. of runs	**945**	**210**
Total runs	**1155**	

For the HR runs, the subset of 36 hurricanes in Table VIII-2 is retained. In general, the levels in Table VIII-2 have been chosen to maximize the accuracy of calibration of the MR results.

For the waves, a parameterization scheme based on previous analyses is used. While the details of this approach are still being developed, it is expected that the wave contribution to the water level and other wave characteristics like HS and T will be related directly to the surge values.

Rainfall inside the polders is estimated based on statistics from NASA's Tropical Rainfall Measuring Mission (TRMM) experiment. Since rainfall is not a primary input variable for the performance of the hurricane protection system, the model needs not be very sophisticated. The variation of the symmetric component of rainfall with distance and central pressure is accounted for, but the effect of asymmetry due to storm motion and shear and the assessment of uncertainty is simplified.

Uncertainty on the elements that constitute the hazard model (recurrence rate, parameter distribution, loads) is assessed considering the limitations of the data to which the models are fitted, uncertainty on the future hurricane climate in the Gulf of Mexico, and errors in the load models.

Table VIII-2 High-resolution runs	
Parameter	**High-resolution model runs**
ΔP (mb) V (km/h) $Xcos(\theta)$ (km) θ R_{max} B -----------------	80, 115 21 -90, -10, 70 -60, 0, 60 10%, 90% quantiles from Eq. J-20 50% quantile from Eq. J-21 ---
$\Delta P_R(t)$	$\Delta P_{R,0.5}(t)$ from Figure J-21
$V_R(t)$	$V_{R,0.5}(t)$ from Figure J-22
$R_{\max}(t)$	from $R_{\max}$, $\Delta P(t)$ and $Lat(t)$; see Eq. J-23
$B(t)$ α	from B, $R_{\max}$ and $Lat(t)$; see Eq. J-24 0.035 + 0.0005 ΔP
No. of cases	**36**

For the 36 cases in Table VIII-2, the water levels *H* and the wave characteristics *W* are directly extracted from the HR runs. For the remainder of the cases run only with the MR grid, corrections must be made to reflect the bias of that coarser discretization. The bias is site-specific, as it depends on the local geometry of the coast, the topography, and the different local land coverage of the MR and HR grids. The correction further depends on the hurricane parameters. For example, the correction at a given location generally depends on landfall position, direction, and possibly storm intensity. The approach used to calibrate the MR runs is included in the appendices.

Reliability Modeling

System Reliability Model. The reliability of the hurricane protection system (HPS) under potential water surge and wave loadings is quantified using structural and geotechnical reliability models integrated within a larger systems description of each polder. We use standard reliability models that combine uncertainties in structural material properties, geotechnical engineering properties, subsurface soil profile conditions, and engineering performance models of levees, floodwalls, and transition points. Uncertainties due to spatial and temporal variation (aleatory uncertainty) and due to limited knowledge (epistemic uncertainty) are tracked separately in the analysis, to provide a best estimate of frequency of failures along with a measure of the uncertainty in that frequency.

To date, the reliability model has been developed for the Orleans East (NOE) polder as a means of exercising the approach. The perimeter protection system comprises levees, flood walls, levees with floodwalls on top, and various points of transition or localized facilities such as pumping stations, drainage works, pipes penetrating the HPS, or gates. This perimeter has been divided into reaches that are deemed to be homogeneous in three aspects: structural cross-section, elevation, and geotechnical cross-section. Approximately 20 such reaches have been identified for NOE.

Geometric and engineering properties have been identified for each reach of NOE and summarized in flat-file data tables. Structural cross-sections were initially identified by review of as-build drawings, aerial photographs, and GIS overlays; and were confirmed by on-the-ground reconnaissance by Team 10 members. Elevations were initially assessed in the same reconnaissance, and were later supplemented by LIDAR data and field surveys provided to the Team. Geotechnical cross-sections and corresponding soil engineering properties were derived from the original Design Memoranda for the respective project areas of the polder, supplemented by site characterization data collected post-Katrina at levee flood wall failure sites (cone penetrometer and laboratory measurements).

Reliability assessments are performed for individual reaches of the HPS for given water levels and loadings. This results in fragility curves for each reach by mode of failure. For each reach and mode of failure, the fragility curve gives the conditional frequency at which a failure state is exceeded. As a first step, engineering performance models and calculations have been adapted from original Design Memoranda. Engineering parameter and model uncertainties are propagated through those calculations to obtain approximate fragility curves as a function of water height on the HPS. These results will later be calibrated against the ongoing work the by the performance analysis team, which is applying more sophisticated analysis techniques to similar structural and geotechnical profiles in the vicinity of failures. Failure modes identified by the performance analysis Team will be incorporated into the reliability analyses as those results become available.

Systems risk model. The reliability assessments for individual reaches of the polder perimeter (and possibly of interior levees or walls) are combined in a systems model which brings together the uncertainties in hurricane hazard and HPS fragility to calculate frequencies of volume and duration of flooding within the polder. The systems risk model, embedded in a software application, is structured around an event-tree description of the occurrence of hurricane events, corresponding water and wave heights, and resulting response of the HPS. This model separately tracks aleatory and epistemic uncertainties from both the hurricane hazard and the structural and geotechnical response, producing a best estimate of frequency and duration of flooding, along with measures of uncertainty in those frequencies.

Events Studied. The events of interest that have been selected to predict component performance are overtopping (O), breach (B), and pumping (U). Shown below are the branch segments analyzed. Where an event is underlined, the event is the complement of the event (for example: O indicates a non-overtopping event). The branch segments from the event tree are:

O, B, U	O, B, U
O, B, U	O, B, U
O, B	O, B

The probability of failure for the levees and floodwalls when subjected to combinations of overtopping and breaching (O, B; O, B; O, B) are evaluated separately from the performance of the pumping stations.

Failure of a component has been defined as an event that allows flood waters to enter the polder beyond that expected without failure. Only a complete breach of a levee or floodwall is considered; partial breaching is not included. The expression for determining the probability of failure has been included where known in order to identify the information required. All probabilities are conditional upon the flood elevation (and associated hazards, such as wave forces, where applicable).

Component Hazards. The following hazards are considered as component loads in the risk analysis:

- Flood elevation - storm surge plus wave setup
- Breaking waves
- Flood flow rate and duration for scour and erosion

Polder Components. The reliability examines the performance of the following components of the HPS system in the risk analysis:

- I-wall with sheetpile embedded in levees
- T-wall on levee
- Transitions and closures
- Levees

Structures or components not included. The following structures in the HPS system were not independently evaluated for their failure modes. Both structures can be addressed with the failure modes developed for I-walls.

- Concrete apron with some I-walls (treated as an I-wall with improved erosion resistance)
- Sheetpile with a 3 to 4 ft concrete cap (treated as an I-wall)

Failure Modes and Factors Contributing to Failure Modes Not Included. Some potential factors that may contribute to failure of a component have not been considered. These factors were screened prior to elimination from the risk analysis and it was determined that there was either little evidence that they occurred during Katrina, or they would have minimal potential for failure. Some of these factors may, however, be considered in future refinements of the risk model.

Settlement of levees and floodwalls over time. The time-varying nature of levee crest elevations are not considered. For these analyses, the crest elevations at the time of Hurricane Katrina will be used. The crest elevations were established from LIDAR surveys or surveys.

Piping soil failures under levees. In surveys conducted after Hurricane Katrina, piping was only observed in the canals where there were sand beds under the levee. Boils were sometimes found on the protected side of the levee, but the levee did not fail at these locations. The available geotechnical data used for levee designs, and that obtained under IPET, is not sufficiently detailed to determine localized weaknesses in the soil (i.e. local sand pockets) that may exist along the levees.

Maintenance of levees and floodwalls. The effects of maintenance on the HPS capacity over time are not included. Improper maintenance or neglect can lead to reduced capacity of the levees in particular; gates and other moving components also require maintenance. Trees, landscaping, and pools were observed on the protected (landside) embankments after Hurricane Katrina, indicating a lack of enforcement and maintenance of the levees. However, there is insufficient information about maintenance activities, or lack thereof, to include this factor in the risk analysis.

Barge or tree impact. Impact by a barge or floating tree, or other large object, on the floodwalls or levees are a possibility during a hurricane. However, during Hurricane Katrina there was no clear evidence of a component failure due to impact from a barge or tree. The barge found inside the New Orleans East polder near the ninth ward was reported to have floated over the levees and floodwalls during overtopping, or after the levee breach. Such an impact may cause local damage, but the flooding due to a single breach of a floodwall is not considered in these analyses. Flooding from a single breach caused by an impact during overtopping and breaching over miles of the HPS system is too small of an event to consider within the uncertainty that exists for the system analysis.

Blast events. Several statements raised the issue of some component failures being caused by blast events. Review of photographs and witness accounts and inspection of the HPS after Hurricane Katrina by multiple independent groups has not found any evidence of blast events. However, the failures of the levees and concrete floodwalls that did occur were sometimes so sudden that they may have sounded or appeared to be 'explosive' with the immense force that swept cars and homes along with the incoming surge waters.

Consequences Modeling

The primary output of the risk and reliability modeling of Team 10 will be an estimate of the probability of life loss and physical damage relating to the performance of the hurricane protection system in southeastern Louisiana. The three scenario cases which are being considered: 1) the pre-Katrina (August 28, 2005) risk, 2) the actual Katrina experience, and 3) the risk associated with conditions as of June 1, 2006. A probabilistic estimate of losses (life and property) will be provided.

IPET is working in close collaboration with the Consequence Team (Consequences) to ascertain appropriate relationships of inundation, impact and life and property loss. The consequence team is considering consequences in four areas: 1) economic consequences, including direct damage and indirect losses, at local, regional and national level; 2) environmental consequences; 3) social, cultural and historical consequences, and; 4) life safety and health consequences.

As of mid-February, the work of the consequence team has been initiated, but limited data has been collected and no firm inputs are available to the modeling effort of the Risk and Reliability Team. Liaison with the Consequence Team has contributed to the refinement of the flood life loss model (lifesim) and have established contact with the Louisiana State University Hurricane Center and Team Louisiana which have been tasked with the State of Louisiana to carry out forensic evaluation of the Katrina event.

Issues of interface between team activities remain a major concern. Attempts are underway to clarify the necessary input to the consequence team modeling of consequences in the categories mentioned above. It had earlier been assumed that a maximum flood elevation in each sub-folder would provide sufficient characterization of the event to generate consequence estimates. In further discussion with subgroups of the Consequence Team, it is evident that for the case of life loss several factors are considered of critical importance including rate of inundation, duration of inundation, and velocity of flow. These factors relate to the feasibility of evacuation and rescue to prevent life loss. For physical damage, it is also possible that these characteristics will be desirable for the refinement of loss estimates. Social and demographic data is also required for the life loss estimation. This data is currently being collected by other IPET Teams but has not been analyzed to develop useful relationships for the risk model. Detailed analysis of fatality data is still required to relate socio-economic demographic information to specific risk factors for fatality. The application of the flood life loss model (lifesim) requires more detailed consideration of both evacuation and rescue procedures. The work of other IPET teams has primarily been dedicated to documentation and forensic analysis of the Katrina event. This analysis is developing risk and reliability models which will be calibrated by earlier events including Katrina, but will be useful in evaluating potential variation in design, management and other risk-related factors for future events and future modification of the hurricane protection system. The establishment of valid general relationships between measurable event impacts and measurable event consequences is critical to the completion of the risk model. Currently, the consequence team has committed to focusing its attention on two specific quantitative characterizations of consequences: 1) life loss (rather than injury, health status, mental health, etc.) and, 2) the dollar value of direct physical damage to buildings and infrastructure (rather than indirect costs such as business interruption, loss of revenue, etc.). These simplifications are necessary because of difficulties in data collection and because of time limitations imposed on the preparation of the IPET report. It should be borne in mind, that these are only representative consequences and not comprehensive. The full social, economic and culture impact of the event will be considerably greater than that represented than the two selected factors.

Liaison with Louisiana State University Hurricane Center. Liaison with the Louisiana State University Hurricane Center has provided valuable input to the understanding of Katrina consequences. The Hurricane Center at LSU has been deeply involved in assessment of previous hurricane losses and modeling of expected losses due to future hurricanes for a number of years. Of specific relevance to the consequences evaluation, the LSU hurricane center is now working with the Louisiana State Coroner's Office to analyze fatality data on the roughly 1200 confirmed fatalities (bodies recovered). Of these, approximately 700 have been identified, and circumstances and location of death have been established. LSU is currently carrying out detailed studies of fatality circumstances and has developed a GIS for the location of victims recovered and their home addresses. This material is not currently available to IPET because of privacy concerns and further negotiation will be necessary to obtain data relevant to the IPET consequences study. The LSU Hurricane Center has collaborated with the FEMA mitigation assessment team which has carried out an analysis of building damage in the affected area and this data will be available from FEMA. The work is carried out under a FEMA contract with URS. The LSU Hurricane Center includes LSU faculty members with experience and expertise in a range of relevant areas: evacuation, experts in transportation, planning and traffic management have been directly involved in the development of state evacuation policy and have played a major role in the successful evacuation of over 1 million people from New Orleans. Members of the Sociology Faculty have worked on the analysis of behavioral aspects of warning and evacuation response in various neighborhoods and populations of New Orleans. Regional economists from LSU have developed input-output modeling for the region which will provide perspective on indirect losses at the regional level. The Hurricane Center also participated in the PAM exercise organized by FEMA in advance of Katrina and documentation of the PAM exercise should provide a useful input for the consequence calculation. The FEMA contractor for the PAM exercise was Innovative Emergency Management of Louisiana.

The Hurricane Center has developed its own models for the impact of hurricanes in the New Orleans region. It has calibrated ADCIRC for Betsy (1965) experience and it provided model results of Katrina impact to the Louisiana Department of Emergency Preparedness and the Times-Picayune in advance of Katrina landfall (these model results did not include breaching of the levee and floodwall system). Data sources identified by the LSU Hurricane Center have been communicated to the consequence team for follow-up. Risk Team liaison members met with the Life Safety and Health subgroup of the consequence team on February 22nd to clarify needed inputs for the consequence team and expected outputs from the consequence team which will contribute to the risk modeling effort. The clarification of required inputs and expected outputs of the consequence team represents a major step forward. It is now necessary to communicate those input needs to other relevant IPET teams and to incorporate those expected outputs into the risk model.

Risk Communication

A preliminary plan for communicating the results of the risk analyses to the USACE leadership and the public has been developed. This plan is not a part of this document but will be available for the ERP review meeting. The intent of this plan is to provide guidance concerning the types of questions that USACE can be expected to be asked from many different sources. The questions will encompass areas that are outside the IPET scope and beyond the responsibilities of USACE.

Status of Remaining Efforts

System Definition

Resources have been added that will assist in completing the field and geotechnical work required to define the remaining polders. Two teams will be used to supplement the field work already started on the polders using the completed New Orleans East polder as a template. This work is expected to be completed by the end of March.

Risk Model

The New Orleans East model will be refined using the experience gained during initial testing. Development of the risk models for the remaining polders will also use the New Orleans East polder as a template. These models should be developed rapidly once the system definitions are complete. It is expected that model testing and revisions will be complete by the end of March and that production runs will begin at that time.

Hurricane Modeling

The surge models using the ADCIRC MR have been started and initial runs will be used in testing of the risk model. The MR surge runs are expected to be complete by the end of March. Wave modeling continues to lag behind the surge modeling and additional assistance from ERDC CHL has been requested. This effort must be completed prior to initiating the risk model production runs.

Reliability Modeling

Reliability models have been developed for the New Orleans East polder that will be used as templates for the remaining polders. Changes in loading and material parameters will be made in the models to account for local conditions. Reliability model will follow closely polder development and is expected to be completed by early April.

Consequences

As of mid-February, the work of the consequence team has been initiated, but limited data has been collected and no firm inputs are available for the risk model. Team members providing liaison with the Consequence Team have contributed to the refinement of the flood life loss model (lifesim) and have established contact with the Louisiana State University Hurricane Center and Team Louisiana which have been tasked with the State of Louisiana to carry out forensic evaluation of the Katrina event.

Issues of interface between team activities remain a major concern. Attempts are underway to clarify the input required from other IPET teams for the Consequence Team to use in modeling of consequences. This is not expected to delay work since the primary risk model results will be in terms of the extent of inundation and the probability of system and component failure. Neither of these parameters requires input of consequences. The final determination of expected loss of life and economic losses however will require consequence input.