I. Executive Summary

Report 2, Performance Evaluation Status and Interim Results, is the second in a series concerning the in-depth analysis of the New Orleans and Southeast Louisiana Hurricane Protection System being conducted by the Interagency Performance Evaluation Task Force (IPET). It provides a status report on the conduct of the scope of work outlined in Report 1, Performance Evaluation Plan and Interim Status, as well as preliminary results emerging from the analysis. The frequent professional interaction and review comments provided by the ASCE External Review Panel have been a substantial asset to the IPET in the conduct of the analysis and development of the results described in this report.

It is important to stress that this report provides a snapshot of a large multi-disciplinary analysis that is ongoing. Every effort has been made to properly qualify the level of development of the individual activities and the emerging results presented herein. The information is being provided at earliest possible time to allow broad exposure, external evaluation and feedback and application as appropriate. The work remaining is substantial and may result in some modifications and changes to the information presented, as well as substantial new results and findings. The information provided in this report should be considered a working draft and subject to revision prior to the completion and release of the IPET final report.

The key objective of the IPET is to understand the behavior of the New Orleans Hurricane Protection System in response to Hurricane Katrina and assist in the application of that knowledge to the reconstitution of a more resilient and capable system. As such the IPET analysis is geared toward determining why certain sections and structures breached, and using that understanding to both assess the integrity of the remaining portions of the system and to assist in designing more resilient protection measures. IPET is also conducting a risk and reliability assessment of the entire system to aid in understanding the levels of protection that will exist for the future. To do this the IPET Teams have been conducting an integrated set of analyses designed to provide a balanced assessment of the performance of all aspects of the physical system. The IPET is not addressing the issues of organizational and jurisdictional complexities that can impact the effectiveness of the physical system. These issues are being addressed in a separate activity.

This report is not intended as a final expression of the findings or conclusions of the United States Army Corps of Engineers, nor has it been adopted by

the Corps as such. Rather, this is a preliminary report summarizing data and interim conclusions compiled to date. It is intended to provide information necessary for the future decisions that will be made regarding the status of the New Orleans Hurricane Protection System. As a preliminary report, this document and the information contained therein are subject to revisions and changes as additional information is obtained.

The architecture of this report is aligned with the five major questions that comprise the IPET mission. Those questions involve 1) The System: documenting the pre-Katrina characteristics of the hurricane protection system (HPS) components and contrasting them to the original design intent, 2) The Storm: understanding the surge and wave environment created by the storm and the forces incident on the levees and floodwalls, 3) The Performance: understanding the performance of the levees and floodwalls and assessing the residual capability of the reconstituted HPS, 4) The Consequences: understanding the resultant flooding (including the role of the pump stations) and the losses due to flooding from Katrina and assessing the extend of flooding and losses if no catastrophic breaching had occurred and 5) The Risk: determining the risk and reliability of the HPS prior to Katrina and after planned repairs and improvements. All of these efforts are underpinned by the development of an accurate geodetic reference datum to ensure that all geospatial aspects of the analyses and results are accurately related.

A number of major tasks are nearly complete, including the Geodetic Vertical and Water Level Datum and the Storm Surge and Wave Analysis. Others, such as the structural performance analysis, have completed a prototype of the final analysis for a component of the overall HPS, providing useful results but relevant to only that portion of the HPS. Still other tasks, such as the consequence analysis and the risk and reliability analysis present samples of their work and examples of the types of products that are being generated, but do not provide results at this time.

The Datum: Because of the complex and variable subsidence in Southeast Louisiana, establishing an accurate vertical reference for measurements has been a constant challenge. By accelerating an effort already underway by the Corps of Engineers and the NOAA National Geodetic Survey, a new Datum was established using GPS technology. Additional surveys were accomplished to accurately determine the elevation of all critical features and structures that comprise the hurricane protection system as well as perishable data such as high water marks resulting from Katrina. These efforts documented that many sections of the levees and floodwalls were substantially below their original design elevations, an effective loss in protection. For example, the structures associated with the Inner Harbor Navigation Canal were originally constructed to an elevation of 15 feet (relative to mean sea level) but are now just over 12 feet, a typical loss of approximately 2.7 feet in elevation over the lifetime of the project.

The System: A major effort has been ongoing to characterize the HPS components to include geotechnical information relevant to their design. This report presents a reach by reach description of the physical characteristics of the hurricane protection structures and their pre-Katrina condition. The condition

information includes the actual elevations of the structures relevant to their original design elevations, indicating the impact of subsidence and settling. Contrast of the design and as built conditions are made in the performance analysis section of this report.

The Storm: The characterization of storm surge and waves has two components, a regional modeling effort to determine the time history of surge and wave conditions experienced by the entire HPS and a high resolution modeling effort to create more refined definition of water levels and conditions in the drainage and navigation canals. The regional surge and wave work is nearly completed and provides a clear picture of the hydrodynamic conditions that existed during Katrina. The results presented herein show highly variable wave and surge levels depending on location. Along the South Shore of Lake Pontchartrain, surge levels were slightly below the design levels but significant wave heights were higher than the design assumptions by around one foot. In the Gulf Intra-Coastal Waterway and along the Mississippi River Gulf Outlet, design water levels were exceeded by 1 to 5 feet, but significant wave heights were about equal to the design assumptions. However, wave periods, closely correlated to wave runup, were three times greater for Katrina than the design assumptions. The east facing levees in Plaquemines Parish experienced water levels approximately 6 feet greater than the design criteria, along with wave heights that exceeded design waves by up to 4 feet and wave periods much greater than the design assumptions.

The high resolution hydrodynamic analysis is developing detailed information on the interaction of the surge and waves and structures. For example, Boussinesq simulations at four specific levee transects along the Mississippi River Gulf Outlet (MRGO) provide time histories of combined wave and surge water levels, overtopping rates, and flow velocities along the back and front sides of the levees. The simulations predict continuous overtopping from 0630 to 0900 hr. Work ongoing in the drainage and navigation canals will determine the water and wave conditions in the canals prior to and at the time of the breaches and estimate the hydrographs of canal water flowing into the protected areas as an input to the interior drainage and flooding analysis. This will also provide the static and dynamic forces experienced by the levees and floodwalls.

The Performance: A key objective of the performance analysis is to assess the residual performance of the entire HPS. The strategy for accomplishing this assessment is to understand why breaching occurred in specific locations, augment that with an understanding of why breaching did not occur along reaches with similar characteristics and develop appropriate assessment methodologies to apply to the remainder of the system. This report provides a detailed analysis of the 17th Street Drainage Canal breach, including the most likely failure mechanism and a discussion of the site and structural conditions that led to that failure. Similar analyses are ongoing for the London Avenue, IHNC, GIWW/MRGO and Plaquemines breaches and will be presented in the IPET final report. The analysis of 17th Street breach provides a perspective of the information, analysis approaches and types of results that can be expected from the other analyses.

Our preliminary analysis identified the failure on the 17th Street canal to be initiated by a deflection of the floodwall that allowed application of full hydrostatic pressure vertically along the floodwall/sheet pile. This force coupled with relatively weak shear strengths in the clay layer under the inboard toe of the levee allowed the lateral translation of the levee from the floodwall back along a failure plane in the clay layer. The peat layer above the clay did not initiate the failure. This failure mechanism was not anticipated by the design criteria used. Our early evaluations indicate that in the absence of the observed failure mechanism, the floodwalls would likely have maintained a safety factor greater than one to the design elevation. Additional analysis is ongoing to develop a clear picture of the water environment in the canal at the time of the breach to better understand any role that wave action may have had in the initiation of the deflection of the wall. Lessons learned in this analysis are being used to shape the assessment of other I-wall sections around the HPS.

The Consequences: The development of interior drainage and flooding models has progressed and analysis is underway for all parishes. This report provides sample outputs from the process for Orleans Parish that demonstrate the information, methodologies and the types of results that will be available for the entire study area. The pump station performance analysis is in advanced stages. This report presents a general description of the pump stations for each parish and more in-depth information for the pump stations and their performance in St. Bernard Parish as an example of the types of results that will be available for all parishes. The analysis of losses is also ongoing but no prototype products are yet available to illustrate the expected final products. 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. 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. Based on the existing data and its analysis to date, there is no evidence of significant impacts on fish or wildlife associated with levee breaching or the dewatering of the flooded areas of metropolitan New Orleans by pumping on fish, macroinvertebrate, or shellfish populations of Lake Pontchartrain, Mississippi Sound, or the offshore waters of the Northern Gulf of Mexico. However, wetlands within the flood protection system were impacted by high salinity associated with breached/overtopped levies within St. Bernard Parish.

Risk: A risk and reliability model has been developed to allow a system-wide assessment of the risk inherent in the HPS prior to Katrina and flowing planned repairs and upgrades to the HPS. The model is being applied to Orleans East Parish to demonstrate the types of information used, how the model is applied and the results of this type of modeling. The focus of the model is to be able to consider uncertainties in geotechnical conditions and information, structural conditions and performance, types and levels of forces created by storms and the character and path of the storms themselves. The information in this report should be considered as preliminary examples of this methodology, not results to be used for analysis or application. The nature of the risk products and their relationship to consequence analysis is discussed.