Fourth Report of the National Academy of Engineering/National Research Council Committee on New Orleans Regional Hurricane Protection Projects: Review of the IPET Volume VIII

Committee on New Orleans Regional Hurricane Protection Projects, National Academy of Engineering and National Research Council of the National Academies

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Committee on New Orleans Regional Hurricane Protection Projects

National Academy of Engineering
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INTRODUCTION

This is the fourth report from the National Academy of Engineering/National Research Council (NAE/NRC) Committee on New Orleans Regional Hurricane Protection Projects. This committee was appointed by the NAE and NRC in December, 2005 to provide advice to the Interagency Performance Evaluation Task Force, or IPET (Appendix A lists the committee's full statement of task). The IPET was established by the U.S. Army Corps of Engineers in October, 2005 to evaluate the performance of the New Orleans hurricane protection system during Hurricane Katrina. The IPET is conducting its evaluations in five areas:

1. design and status of the hurricane protection system pre-Katina;
2. storm surges and waves generated by Hurricane Katrina;
3. performance of the hurricane protection system during and after the event;
4. societal-related consequences of Katrina-related damage; and
5. risks to New Orleans and the region posed by future tropical storms.

As it has proceeded, the IPET has issued a series of draft reports. During 2006, the NAE/NRC committee issued three letter reports, each of which comments on an IPET draft report and provides recommendations for improvement.[1] Following this fourth report, the NAE/NRC committee will complete its charge by issuing a fifth and final report that will summarize its views of the lessons learned during and after the Hurricane Katrina experience (see Appendix A for more details on the committee's statement of task).

This report is a review of a single volume within the IPET report (Volume VIII), which is entitled "Engineering and Operational Risk and Reliability Analysis." Volume VIII is the final volume of the IPET report and it was presented a year after the rest of the report was issued (the report is available at the IPET website: https://ipet.wes.army.mil/; accessed January 8, 2008). It

[1] The first three reports from this NAE/NRC committee are available online at www.nap.edu.

assesses risks to life and property posed by hurricanes in New Orleans for both pre-Katrina conditions and for a reconstructed hurricane protection system as of June 2006. Volume VIII has taken on a unique importance to the IPET effort because the information contained in it will be central to understanding the likelihood of future flooding and inundation in New Orleans and the resulting loss of life and fiscal assets in New Orleans. These issues are critical to the ability of residents and businesses to obtain financing and insurance for rebuilding in the area and for making decisions about the safety of living in New Orleans in the future. The following report discusses the contents and main sections of Volume VIII and presents its findings and its recommendations for improvements in bold faced print.

The NAE/NRC committee received an interim draft of Volume VIII for review in October 2007, and met with members of the IPET staff in New Orleans on December 3, 2007 to discuss the interim draft. At that meeting, members of the IPET team provided several presentations. At the conclusion of those presentations, time was provided for members of the public to comment, a standard practice with NRC committee meetings. Five people, all citizens of New Orleans, spoke with the committee. Some of them spoke as individuals, while others represented organizations involved in reconstruction and hurricane protection.

The overall risk assessment method used by the IPET appears to be appropriate for evaluating risks associated with the New Orleans hurricane protection system, and in some cases they advance the state-of-the-art in this field. However, the interim draft Volume VIII does not provide sufficient presentation and explanation of the methods employed or results obtained to allow this to be clearly determined. Many of the technical aspects of Volume VIII presented by the IPET at the December 3, 2007 meeting are impressive. Nevertheless, the interim draft Volume VIII is incomplete. Further information will have to be provided to fully explain and validate the methodology that was used and the results that were obtained.

The IPET has put forth a strong effort in producing its previous reports. The team has faced many analytical and conceptual challenges, and they are conducting these studies in a politically charged and contentious setting. They deserve a great deal of credit for their work to date. Despite these efforts, Volume VIII and the IPET study are not complete. This letter report points out additional work that will be necessary to bring the report to a successful completion. These additional efforts will require time and resources. Successful and prompt completion of Volume VIII and the IPET report is important for several reasons: it is important for the credibility of the U.S. Army Corps of Engineers; it is important to life decisions and financial investments regarding rebuilding and relocation in the New Orleans metropolitan area, and; it is important to ongoing and future analyses of hurricane protection and coastal restoration in southern Louisiana. **The Corps of Engineers therefore is urged to provide the resources and support necessary for the prompt completion of Volume VIII.**

APPROACH TO AND COMPLETENESS OF THE IPET RISK ANALYSIS

Studies of the New Orleans hurricane protection system (HPS) are complicated by several factors. They include: (1) the size of the system, which covers hundreds of square miles

and five parishes of the greater New Orleans metropolitan region and includes many different reaches of protective structures of varying lengths and condition; (2) the varied nature of the protective structures, consisting of earthen levees, concrete walls, closure gates, pumping stations, and a mixture of I-wall and T-wall structures; (3) the region's dynamic physical character (for example, much of southeastern Louisiana is subsiding, at different rates, in different parts of the region), and; (4) the fragmented nature of the system, as the hurricane protection system was constructed under different congressional authorizations, at different times, and with different design standards and assumptions.

Key Strengths

In Volume VIII the IPET aims to present the risks to greater New Orleans posed by hurricanes for two different states of the hurricane protection system: a) a pre-Katrina condition, and b) the state of the system as of June 2006. The IPET has chosen to characterize and quantify these risks through a sophisticated risk analysis method. This approach employs a probabilistic framework that includes assumptions and computations regarding: hurricane intensity and frequency; storm surges and waves; performance of levees, floodwalls, closure gates, and pumping stations; and relationships between inundation depths and loss within the parishes of the greater New Orleans region.

The approach and methods employed by the IPET in this risk analysis appear to be appropriate for evaluating risks associated with the New Orleans hurricane protection system prior to and following Katrina, and in certain areas they advance the state-of-the-art. The approach allows additional information for specific aspects of the system (e.g., fragility of levees, or economic consequences of levee overtopping or failure) to be imported and used to update and improve future analyses. Thus, the risk analysis serves as a template that can be revised and enhanced over time. The development of the risk analysis in the IPET Volume VIII has required a detailed, system-wide description of the physical features of the hurricane protection system (e.g., actual levee heights, closure gates, the internal drainage system) that is likely the first evaluation of the system as a whole. Such system-wide thinking and analysis will be crucial for establishing and maintaining a coherent and robust hurricane protection system in the future.

Key Weaknesses

Although the risk analysis approach taken by the IPET is credible and potentially useful, the interim draft Volume VIII does not provide a complete presentation and explanation of the method or the interim findings and results. The value of this sophisticated risk analysis will be limited if it is not carefully explained so that readers of the report can adequately understand its underlying philosophy and logic, assumptions, and limitations. The draft Volume VIII unfortunately does not accomplish this goal of careful explanation, even for expert readers. It contains only limited information regarding interim calculations, which are important in helping

the reader understand the chain of logic in the risk analysis, and how model results compare with historical data. The main text of Volume VIII has a strong emphasis on the *process* that underlies the risk and reliability analysis, but it presents few *results*. The Executive Summary in Volume VIII poses five key questions to be addressed; however, Volume VIII does not present a clear set of answers and findings that addresses these five questions. In fact, the Executive Summary presents only a single statement that might be considered to be a finding. The document also contains numerous errors and in some instances is missing important information.

In the spirit of providing constructive advice to the IPET for the timely and successful completion of Volume VIII, the remainder of this report is divided into two sections: 1) gaps in information and analyses within the interim draft, and 2) recommendations for helping complete Volume VIII.

GAPS IN INFORMATION AND ANALYSES

Limited Explanation of Key Assumptions and Approach

Volume VIII is an important document of interest to many parties, as its results will directly affect resettlement, investment, and other major decisions of New Orleans citizens, businesses, and elected officials. It therefore is important to provide an unambiguous and complete accounting of the methodology and outputs of the analysis. The risk and reliability modeling within Volume VIII involves many engineering and physical assumptions, choices regarding data to be used, and choices of analytical methods and simulation software, all of which have advantages and disadvantages. Clear and complete exposition of these types of assumptions and choices is essential to good communication and, ultimately, to understanding findings and results. Volume VIII provides documentation but it is incomplete in some areas and difficult to follow in others.

Example: Joint Probability Model

The IPET bases its analysis of future hurricane threats on a modified version of the Joint Probability Model (JPM). Since this represents a new method for hurricane threat assessment, its explanation and validation are crucial parts of the report. Unfortunately, this explanation in Volume VIII is confusing and incomplete. A complete JPM involves Monte Carlo sampling of individual parameter distributions and could involve tens to hundreds of thousands of different storms. The modified JPM used by the IPET initially uses 152 storms and later reduces that number to 77. No validation is presented that the reduction from many thousands of storms to 152 storms then to 77 storms maintains the statistical characteristics or inundation response of a full JPM.

Some parts of the model are discussed in the main text of Volume VIII, while other parts are discussed in appendices, making this discussion difficult for the reader to follow. Additionally, specification of the joint probability is either incomplete or indecipherable. The

JPM is described in Appendix 8 as being dependent on five parameters—c_p, R_p, v_f, θ, and x. Distributions for each of those variables appear to be completely specified. In addition, another parameter—"B"—is introduced as a random variable. There is a discussion (see p. VIII-8-118-128) as to how that value is treated; but that discussion is difficult to follow and there is never an unambiguous statement of what relationship was used for calculating joint probabilities that include that variable (B). There is a statement on VIII-8-33 that a value of 1.27 was used for B and results were adjusted by adding a random dispersion about that value. That randomness somehow is introduced into an error term, but it is not clear how this was done.

Limited Presentation of Intermediate Results

The IPET risk analysis approach considers different risks and includes many models and calculations (e. g., Vol. VIII, P. 9, Figure 2). Given the complexities entailed by hurricanes in this region and by this approach, it is important to present and discuss intermediate results. Presentation of intermediate results will enhance understanding of the overall risk results, and independent testing and validation of the individual models and methods employed in the risk analysis. The interim draft Volume VIII, however, contains inadequate information about intermediate results and how these results impact the overall results.

Example: Hazard Analysis Model

The Hazard Analysis Model used in the risk analysis uses as input a set of six parameters for each of 77 hurricanes that determine wind fields at landfall. Those parameters are allowed to vary before and after the storms make landfall. Wind fields then are used to drive the surge models, and waves are added to the surge to get water levels. Analysis of parameters that determine wind fields are discussed in the main text of Volume VIII and in Appendix 8. The primary test of model validation is with some high water marks for a few historical storms.

Without any intermediate results of this modeling exercise, it is difficult to judge how well the wind speeds deriving from 77 hurricanes match historical probability distributions for wind speed (in presentations from the IPET at the December 2007 meeting in New Orleans, a figure of 76 storms was used; they may wish to clarify this exact number in future reports). Table 9 contains the input parameters for the storms, but it does not include wind speeds. Without that information and with no comparison of calculated wind speeds with historical data, it is difficult to critique the hurricane model. Furthermore, there is no explicit description of Table 9 that tells a reader what population of storms the table is supposed to represent (e.g., is it for all hurricanes of record? For major storms only?).

Further, there is no analysis indicating that 77 storms are adequate to represent the statistics of the full JPM analysis. Although this number of storms may adequately cover the domain of severe storms in the study area, Volume VIII presents no clear and convincing evidence to that effect. The report states (P. VIII-40):

> the approach was to first construct a response surface giving surge elevation as a function of storm parameters and location. This was done through simulation of 152 storms, as specified in Appendix D of R2007. Subsequently, this response surface was discretized through selection of a subset of storms adequately covering the surface. A set of 77 storms was selected, with a rate assigned to each (Resio, personal communication, 2007) so as to cover the entire space.

This statement is an assertion, however, and not a justification.

Incomplete Analysis and Discussion of Uncertainties

Estimates of storm surges and flooding associated with hurricanes along the U.S. Gulf coast always entail some degree of uncertainty. Changes in climate may affect recurrence intervals of large hurricanes in the future, for example, and large-scale changes in wetlands and coastal geomorphology may affect storm surges. Even without changes in these types of parameters, small differences in hurricane wind speed, direction, and size all may have significant effects on storm surge. The most credible estimates of future storm surge and flooding will contain uncertainties, and it is important to explain why such uncertainties exist and what they might imply for future development or construction activities.

The interim draft Volume VIII provides few quantitative estimates or qualitative explanation of uncertainties and their implications. Despite previous encouragement from this NAE/NRC committee in its 2006 reports to conduct this work, quantitative uncertainty analyses are in only early stages of development. When the uncertainty analysis is completed, it will be important to clearly and systematically present both the method and results.

Successful completion of the uncertainty analysis will present many challenges to the IPET. In particular, the uncertainties in the estimation of probabilities associated with inundation depths are likely to be significant—a result that may damage the credibility of the probability analysis if not properly managed.

For example, the estimation of central pressure deficit (pressure difference between the storm center and ambient pressure outside the storm) affects the wind field as well as the storm size. The distribution of central pressure deficit is assumed to be EV-1, a 2-parameter distribution. The parameters are assumed to vary across the Gulf of Mexico coastline from Florida to the Texas-Mexico border. Estimation of these spatially varying parameters is based on 22 historical storms, a very small sample. The IPET team has not presented an analysis of the uncertainty based on estimates of these parameters or the use of a limited set of storms, but it is likely that the uncertainty will be large. Better explanation of why these uncertainties are large and what they imply for estimates of risk and reliability would strengthen future versions of Volume VIII.

Limited Explanation of Soil and Related Geotechnical Factors

A key part of the reliability assessment is the formulation of fragility curves for elements of the hurricane protection system (HPS), including earthen levees, I-walls, and T-walls. The soils comprising these elements and the associated, underlying foundation conditions are subject to substantial variation in geometry and material properties, and subject to uncertainty arising from limitations in characterizing the system, choice of stability analyses, and laboratory test data to estimate undrained shear strength of the soil.

A key aspect of the HPS reliability assessment is the selection of lengths of levees and I-wall sections that are representative of uniform system conditions. This is a challenging and important aspect of the work that must balance the requirement for accurate representation against the need to simplify the complex assemblage of different HPS components into a rational and manageable model subject to gaps in information associated with widely spaced borings. The interim report describes how the HPS was divided into representative reaches that are on average 11,000 feet long, and describes statistical procedures for determining a representative auto-correlation distance in the horizontal direction on the order of 1,000 feet. Volume VIII, however, does not provide a clear explanation of the limitations of partitioning the system into such large reaches, nor does it clearly indicate how reaches exceeding 11 times the auto-covariance distance affect the results.

Furthermore, it is noted that the selection of reaches studied in the risk analysis is based on design memoranda and geotechnical considerations, and not on hydraulic loading considerations. For each reach, one specific location is chosen to represent the hydraulic load on that reach, and it is not clear that this location is representative of the hydrodynamic conditions for the entire reach. This is an especially important consideration for very long reaches, for example reach 75 along the Mississippi River Gulf Outlet (MRGO), which is more than 84,000 feet in length.

Other issues that need a more thorough and careful explanation include the bias and errors introduced by using stability analyses from the General Design Memoranda (GDM) that are based on the relatively simplistic and outdated method of planes (MOP) for safety factor determination, and how the MOP analyses were assessed and calibrated relative to the more comprehensive stability assessments by IPET for areas of I-wall failure, such as the 17th Street Canal failure site. The IPET stability analyses have been based largely on unconsolidated undrained (UU) soil tests that are known to be subject to variability and even can be inaccurate. The use of these test results, and the variability they entail, may introduce another source of uncertainty to the risk analysis.

Inadequate Presentation of Inundation Maps

Arguably the most important results to be produced within Volume VIII are inundation maps associated with varying hurricane storm surges. Not only do these results quantify the outcomes of the investments in design and construction to help reduce New Orleans's

vulnerability to storm surge, they will establish the basis for public safety decisions and future construction decisions and patterns.

Volume VIII presents numerous inundation maps in the main body of the report (Figures 28-46, P. 66-84). There is, however, little explanation or interpretation of these maps beyond the statement in the "Results" section that (P. 61):

> The risk analysis results show that moderate inundation reductions have been achieved for events of approximately 100-year return periods, but predicted inundation elevations are mostly unchanged for more frequent events (e.g., 50-year return periods) that depend mostly on rainfall, and there is still significant risk of inundation for stronger storms.

The reader then is referred to Appendix 13, where more maps are presented, for more explanation, but Appendix 13 provides little explanation beyond a statement that (App. 13, P. 16)

> While the HPS has been repaired and improved dramatically over the Pre- Katrina HPS, the risk associated with the Current HPS to the area is still considered to be high for extreme events.

At issue here is not the number of inundation maps, as Volume VIII provides a large number of them. Rather, the main limitation regarding these maps is inadequate explanation of their main points and what they imply for future resettlement and rebuilding. Citizens and entities that must make fundamental decisions about whether or not to (re)locate in New Orleans, what parts of the city are more or less vulnerable to storm surge, what types of structural and nonstructural flood protection measures they must adopt, and so on, will find this presentation limited and perhaps confusing. There is a great deal of important information within these inundation maps. But there is so little supporting explanation that the reader easily can be overwhelmed with information and technical detail without deriving an understanding of the maps' key points. Greater emphasis on the communication of the key features of these inundation maps would enhance future versions of Volume VIII.

Incomplete or Unclear Explanation, Inconsistencies, and Errors

Volume VIII contains instances in which the explanation and presentation of important and complex technical details are confusing or inadequate, and perhaps incorrect. There also are instances where graphics are confusing and perhaps incorrect. The following section presents examples of confusing information and presentation within Volume VIII.

Incomplete Explanation

The Executive Summary of Volume VIII (VIII-2) states:

> Risk-based inundation mapping and associated stage-frequency curves are intended for estimating relative risks for the purpose of identifying areas of vulnerability. These estimates should not be compared to inundation mapping conducted under the Federal Emergency Management Agency's (FEMA's) National Flood Insurance Program (NFIP) because the methods and purpose of the respective analyses are different.

Although factually correct, this statement does not explain the differences between the IPET and FEMA maps, why these differences exist, and how the public or the business community might decide which maps to use and what the implications of such a decision might be. These issues are of utmost importance in rebuilding and resettlement decisions in New Orleans, but the reader is provided little to no guidance on how to understand, resolve, and act upon these different maps.

Volume VIII ideally will present meaningful information with thorough description, but this is not done well in the interim draft. For example, Figures 24-27 (VIII, 62-65) contain important information on inundation estimates for different sub-basins, for storms of different recurrence intervals. However, the figures are presented with little explanation regarding their key messages, uncertainties that are included in these estimates, and implications of these results (e.g., how flood risk vulnerability varies across areas or sub-basins). Similar comments could be made of Figures 28, 29, 38, and 39 (VIII, p. 66, 67, 76, and 77, respectively). These figures contain information regarding overtopping of different sections of the hurricane protection system for pre-Katrina conditions and for current conditions. As in other cases, the figures are presented with little context or insufficient explanation, or both. It is crucial that more attention be devoted to presenting highly technical, and highly important, information with a well organized and easily understood structure, and as simply and completely as possible.

Figures, Graphics, Technical Editing

Volume VIII contains figures and graphs that do not consistently and clearly convey important information to the reader. The draft also contains some incorrectly numbered and referenced equations and figures, errant information in figures and captions, and technical errors and inconsistencies. Although a page-by-page editorial review of the draft Volume VIII was beyond the scope of this committee's charge, the following examples illustrate these points:

- Figure 2 (VIII-9) suggests that a portion of the uncertainty analysis is beyond the scope of the project;
- Figure 4 (VIII-12) includes an event tree that was not used in the analysis, but rather "was simplified to determine…" (VIII-14).
- There are multiple, inconsistent statements about backflow through pumps (VIII-15, 16, 55);
- Table 7 (VIII-29) is difficult to understand and could be more descriptive. One also wonders why such a detailed presentation is important to include in the report's main body

rather than in an appendix. Most readers will find the presentation of this type of complex detail to be a distraction from the main messages of the report.

- Central pressure is measured in millibars, not megabytes (VIII-38);
- Figure 17 (VIII-39) intends to represent Hurricanes Rita, Ivan, Camille, and Katrina—but the storm tracks are not labeled clearly on the map, and there are five tracks instead of four.
- The reliability analysis (VIII-49—VIII-51) is confusing and repetitive with previous discussion of fragility curves.
- Figure 22 (VIII-56) needs to be redrawn; it is confusing and presents little useful information;
- The y-axes in Figures 24-27 (VIII, 62-65) are not labeled with units. In appendix 13, similar figures are presented with y-axis units of elevation, with values ranging from -12 to 18 feet. This presentation could be misinterpreted. It might be easier to understand if presented in values of actual flooding depths (in feet).
- There appears to be an error in the 500-year curves presented in Figures 26 and 27 (VIII-64, 65). These curves are supposed to represent the mean condition plus additional water level due to uncertainty; however, these curves appear to be identical to the corresponding 500-year curves in Figures 24 and 25 (VIII-62, 63).
- Figure 10-2 (VIII-10-26) has a caption in the text, but no figure is present. Moreover, reference to Figure 10-12 (p. VIII-10-31) bears no resemblance to the apparent content of that figure as described by the caption and reference to it on p. VIII-10-26.

These examples illustrate portions of Volume VIII and select appendices that confuse and may mislead the reader. The sum of the errors and inconsistencies gives an impression of a document that was written quickly, with inadequate review and technical editorship.

RECOMMENDATIONS FOR STRENGTHENING VOLUME VIII

Careful analysis, thorough editing, and consideration of how information is to be presented are needed to improve the interim draft Volume VIII. This is necessary if the extensive and creative analytical efforts that have gone into Volume VIII are to be respected and appreciated. This also will bring the volume to a state where citizens and public officials can understand the results, the uncertainties, and the limitations of generating flood risk estimates. The following sections offer recommendations for improving Volume VIII.

A Clear, Thorough "Audit Trail" and Future Applications

More detailed discussion of assumptions, data, and models applied in the risk and reliability modeling will enhance the clarity and the credibility of a future version of Volume VIII. Methods employed in generating estimates of storm surge and other risks in Volume VIII will change over time, but this report should document the methods as they currently are used.

This "audit trail" is needed so that assumptions, limitations, and crucial analytical steps can be understood and checked, as well as to ensure that methods are being applied appropriately today in New Orleans.

Regarding future applications, the risk and reliability assessments used in Volume VIII will improve over time with advances in engineering and scientific procedures. This point should be emphasized and will serve two purposes. First, it draws attention to the growing evolution of risk and reliability models. The models employed in Volume VIII will be enhanced or replaced over time, and this needs to be understood. Second, it will encourage the development of models that will improve as new data are acquired. During the December 3, 2007 meeting, the IPET team explained that risk models for storm surge and wave effects had been structured to accept changes in the probability of hurricane occurrence and new knowledge about global warming's effects. Moreover, thorough and clear documentation of data, assumptions, and models will help future risk analyses to be better understood by the public and by experts alike. This aspect of Volume VIII therefore represents a welcome development that merits a stronger emphasis.

The IPET should more carefully document the data, assumptions, and models being used in its risk analysis. It also should present intermediate results from component models and emphasize more strongly the point that the component models being used in Volume VIII will evolve and improve over time.

Uncertainties in Storm and Flooding Estimates

There is only a limited degree of certainty in estimates of storm recurrence intervals and flood stages. The IPET intends to conduct an assessment of the uncertainties that stem from factors that affect flooding and inundation depths, including occurrence rates of hurricanes, surge and wave elevations, rainfall rates and amounts, and performance of the hurricane protection system. This is to be encouraged, as credible results from the uncertainty assessment will increase confidence levels in modeling results and applications.

The IPET should complete the assessment of uncertainties as soon as possible, while maintaining rigor within the assessment.

The uncertainty analysis will employ concepts and terminology that are not likely to be familiar to the non-expert. At the same time, it is important that the public, elected officials, and others understand the uncertainty analysis and how these results affect key outcomes (e.g., estimates of storm inundation depths).

The IPET should develop an effective strategy for communicating results that will entail large amounts of uncertainty, given that the total uncertainty in estimates of flooding for given storms is likely to be large. **In presenting this analysis, the IPET should ensure that the results are clearly and fully summarized and presented in terms that will be meaningful to citizens and elected officials. The responsibility for presenting important and complex concepts, and ensuring that they will be broadly understood by all parties who need to understand them, represents an important challenge to the IPET. It also suggests the value of producing a second, separate document for a more general audience.**

Strengthened Soil and Related Geotechnical Analyses

The IPET team should explain how unconsolidated undrained (UU) soil test results may introduce additional uncertainty into the risk analysis. The IPET team should discuss how the fragility curves could be improved through use of more reliable shear strength measurements either in laboratory or field tests.

Any steps that have been taken to validate I-wall fragility curves relative to full-scale I-wall tests performed by the Corps of Engineers at the Atchafalaya levees, or from back-calculated safety factors for the 17th Street and London Avenue Canal failure sites, should be described. The rationale, and possible limitations, of selecting single locations to represent reaches of the HPS, especially the longer reaches, also should be better explained.

Climate Change Effects

Volume VIII includes a short description of the issue of climate change, how that might affect the intensity and frequency of tropical storms, and how it is being addressed in the IPET report. In Volume VIII, p. 49 it is explained:

> Considering the general consensus and dissenting views on the effect of global warming on hurricane intensity, the historical mean pressure deficit is increased by 3% and an uncertainty factor of 5% is applied to the increased mean value.

Although this approach to accommodating the prospects of climate change may not be unreasonable, it is very difficult to judge the validity of these numbers without more explanation of how they were derived. Climate change is an issue that receives substantial attention around the world[2]. Given the potentially serious consequences that it may have for New Orleans and all coastal U.S. areas affected by hurricanes, it would be prudent and appropriate to provide detailed guidance for methods to account for climate change effects.

Volume VIII should explain more thoroughly the approach adopted to account for the prospect of climate change.

Flood Inundation Maps

Volume VIII contains a large set of inundation maps. These maps, along with some figures in the report, present meaningful and illustrative information about overtopping and inundation. Supporting discussion of the main points and implications of these inundation maps—and perhaps including a few of the most crucial maps in an Executive Summary—would enhance their presentation and meaning. For many parties, these maps will be the most

[2] For example, see reports from the Australian government on possible impacts of climate on coastal infrastructure: Available at: http://www.greenhouse.gov.au/impacts/settlements.htmland

important outputs of the IPET study. They should be presented prominently and with clear explanations of their key points, including information such as:

- Which inundation maps are the most important? Or are they all of equal importance?
- How do inundation levels compare with inundation levels associated with Hurricane Katrina?
- Do these maps differ from inundation maps being produced by FEMA? Why? And what are the implications of any differences?
- To what extent should the results from these maps be considered as final? Will further inundation estimates be made in the future, and when? What changes in inundation estimates might be expected, and why?

The IPET should issue a set of inundation maps that displays the current best estimates of inundation depths for the 50-year, 100-year, and 500-year event recurrence intervals. This presentation should include discussion and explanation of the implications of these estimates for rebuilding and reconstruction decisions across the New Orleans metropolitan region.

Other Technical Additions and Changes

Hurricanes used to conduct a risk analysis for the New Orleans region should be compared to those for which historical records are posted to the website of the National Hurricane Center (NHC). The NHC site includes the Saffir-Simpson scale for each hurricane of record. It is important that hurricanes in Volume VIII, Table 9 be related to NHC data for at least two reasons:

- To provide an intermediate validation of models of hurricanes against a well established and publicly available dataset; and
- To inform the public as to what combination of hurricane variables are likely to present the greatest hazard and informing them of the probability that those events will occur.

Wind speeds should be added to Table 9, and appropriate comparisons wind speeds and pressures that define categories of hurricanes on the Saffir-Simpson scale should be conducted. Frequencies of occurrence should be compared to the historical records. If there is an explanation as to why the hypothetical storms generated in the analysis do not have similar frequencies to historical storms, this explanation should be clearly stated.

The modified Joint Probability Model employed in Volume VIII should be fully and clearly explained in a single place within the report (as opposed to the partial explanation that is listed in several separate sections). When necessary and appropriate, detailed justification for various parts of the modified JPM can be relegated to an appendix. The use of an initial set of 152 storms that was then reduced to 77 storms in lieu of a complete

JPM, which might include 10,000 to 100,000 storms, should be fully explained and validated. The error introduced in the overall analysis due to this significant simplification also should be estimated and discussed.

A better explanation should be provided of how variable "B" was treated in the JPM. Justification for why it was not included as a sixth random variable and its distribution added to the joint probability function also should be given. This should include a concise statement explaining exactly which relationship or relationships for B were used in the model, and a discussion of how random variability in B was treated in the model.

Reporting to Multiple Audiences

The success of Volume VIII and the IPET report hinge upon not only the accuracy of data employed and the sophistication of methods and calculations, but also on how clearly the results are presented, and the extent to which the public, the business community, and government entities can use these results in making decisions. The IPET faces the challenge of having to write a report that is not only technically sound, but also is useful to the public and others impacted by its results. The IPET recognizes that its report must satisfy both technical experts and a more general audience of interested citizens and elected officials. Most of Volume VIII, especially its many appendixes, is written at a technical level for experts. Other parts of Volume VIII, especially the Executive Summary, are written for a more general audience. The IPET has developed a website to keep the public apprised of advances in its studies (http://nolarisk.usace.army.mil). The website is promising and potentially useful.

In addressing the issue of how best to communicate with these two distinct audiences, the IPET should consider a two-part strategy in which one document is prepared for technical experts and another document prepared for elected officials and the public. As an example, the first document could include data sets, assumptions, methods, validations, uncertainties, results, and all technical details, while the second document could be much shorter and focus on results and implications for reconstruction and resettlement.

Schedule for Completion

The IPET was established in October 2005 by the Chief of the Corps of Engineers. The IPET promptly addressed its task of evaluating the performance of the New Orleans hurricane protection system during Hurricane Katrina, with an initial goal of completing its final report by June 1, 2006. Despite concerted efforts by the IPET team, as of February 2008 its final report is not yet complete.

At the December 3, 2007 meeting in New Orleans, the IPET team explained its plans for future analyses within Volume VIII. These presentations identified ongoing and two new efforts: the first is an analysis of uncertainty in the parameters used in Volume VIII estimates,

the second relates to the analysis of a hurricane protection system that will protect greater New Orleans from flooding at the one percent (100-year recurrence) interval. Despite the importance and potential value of additional studies, they will require additional time. Many citizens, elected officials, and other decision makers have expressed frustrations with postponements in the IPET production schedule. This was reinforced in statements made by citizens in the public comment session at the December 3, 2007 meeting.

These issues are of concern because of the time that has elapsed (over 18 months) since the Volume VIII studies began in earnest, and because of the many elected officials, members of the business community, and citizens waiting for results of Volume VIII. The region and the nation are looking to the IPET for clear statements about hurricane and flood risks, and the IPET team may be losing an opportunity to issue an authoritative statement on these topics. Not only are people awaiting these results, but the IPET final report ideally will provide a platform for future analyses and policy decisions.

The credibility of the IPET and the Corps of Engineers will be affected by the length of time required to bring this study to a successful end. More time may indeed be required for further analyses. However, the IPET study is in the spotlight and delays in its timely completion are causing criticisms of the IPET—justified or not—to mount. Prompt completion of the IPET study is in the better interest of both the IPET and the many stakeholder groups in the New Orleans region.

The IPET should present a schedule for the timely completion of its study. Adequate resources should be provided to meet this schedule.

CLOSING COMMENTS

The risk and reliability analysis within the IPET interim draft Volume VIII are a crucial and challenging part of the IPET study. A great deal of intellectual energy and professional dedication has gone into developing the risk method that underpins this volume. As presented in October 2007, however, the interim draft Volume VIII is incomplete. There is not enough information in Volume VIII to allow for a complete review or a full validation of the method that was used.

Some of the efforts that have gone into Volume VIII, along with the plans for future evaluations, are impressive and promising, and this report is offered as advice on completing Volume VIII. The IPET is encouraged to use this advice as they see fit and with hopes that it is useful in helping the IPET complete its study. Not only are the methods developed and findings issued by the IPET important to people in New Orleans today, but the IPET study will be built upon and refined in the future as better data on storms and storm surge become available, as methods and models develop and improve, and as Gulf coastal and estuarine environments change. The IPET should strive to complete a study that provides its best estimates of storm surge and flooding risk and that explains the uncertainties that will attend those estimates, and to not be delayed by a quest for ever-greater precision. Clear explanation of these issues and prompt completion of the IPET final report will benefit the Corps of Engineers and the citizens

of New Orleans and southeastern Louisiana. This report is offered in the spirit of helping the IPET bring its study to a successful end.

The intense effort that resulted in volumes 1-7 of the IPET report has subsided such that the Volume VIII risk and reliability study has taken more than twice the length of time for the rest of the study, and remains incomplete. We encourage the Corps of Engineers to infuse this effort with the resources necessary to promptly complete the Volume VIII study, keeping in mind this NAE/NRC report's recommendations for improvement. This is especially urgent given that other analyses, such as the Corps's "100 year HPS" analysis for the New Orleans region, and the Corps's and State of Louisiana's Louisiana Coastal Protection and Restoration (LACPR) study, will depend greatly on Volume VIII and the IPET analyses and final report.

APPENDIX A
STATEMENT OF TASK
COMMITTEE ON NEW ORLEANS REGIONAL HURRICANE PROTECTION PROJECTS

Hurricane Katrina and the subsequent flooding of much of the New Orleans metro area prompted many questions about the geotechnical and hydraulic conditions and performance of the city's hurricane protection system. To help provide credible scientific and engineering answers regarding the performance of this system, an Interagency Performance Evaluation Task Force (IPET) has been convened. The IPET effort is being led by the U.S. Army Corps of Engineers. The IPET is also working with a review team from the American Society of Civil Engineers (ASCE). The IPET, which includes both federal and non-federal scientists and engineers, is divided into ten teams focusing on different topical areas*. The IPET is focusing its investigation on 3 primary topics: a) design capacity of the hurricane protection system, b) forces exerted against the system and system response, and c) factors that resulted in overtopping, breaching, or failure of levees and floodwalls. The IPET issued a draft final report on June 1, 2006. The IPET plans to issue its final report in 2008.

This NAE/NRC committee will focus its review on the following tasks:

1) review the data gathered by the IPET and the ASCE teams and provide recommendations regarding the adequacy of those data, as well as additional data that will be important to the IPET study and should be gathered;

2) review the analyses performed by the IPET and ASCE to ensure their consistency with accepted engineering approaches and practices;

3) review and comment upon the conclusions reached by the IPET and ASCE teams, and;

4) seek to determine lessons learned from the Katrina experience and identify ways that hurricane protection system performance can be improved in the future at the authorized level of protection.

The NAE/NRC committee will issue five reports:

1) a preliminary, letter report that comments on the adequacy of the nature of the data being collected by the IPET and ASCE teams (due in February 2006);

2) an interim report that represents the midpoint of the committee's evaluation and project (due June 1, 2006);

3) a report that reviews the IPET June 1, 2006 draft final report (due in September 2006);

4) a report that reviews the IPET draft "Volume VIII" on Engineering and Operational Risk and Reliability Analysis; and,

5) a final, comprehensive report that summarizes the committee's evaluation of the IPET final report.

The timeline for these five NAE/NRC reports conforms with plans regarding IPET report progress. The first two NRC/NAE reports will be drafted and issued following the review and evaluation of the IPET 30% and 60% completion reports, respectively. The third NAE/NRC report will review the IPET draft report (which was issued on June 1, 2006). The fourth NAE/NRC report will review the IPET Volume VIII on Risk and Reliability Analysis. The fifth NAE/NRC report will review the IPET final report.

*The committee's review will focus on the analysis of IPET teams in the areas of: data collection and management (perishable, systems data, and information management), interior drainage systems models, numerical models of the Hurricane Katrina surge and wave environment, storm surge and wave physical modeling of hydrodynamic forces and centrifuge breaching, geodetic vertical survey assessment, and the analysis of floodwall and levee performance.

APPENDIX B
COMMITTEE ON NEW ORLEANS REGIONAL HURRICANE PROTECTION PROJECTS

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APPENDIX C
ACKNOWLEDGEMENT OF REVIEWERS

This report was reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise in accordance with the procedures approved by the NRC's Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the NRC in making its published report as sound as possible, and to ensure that the report meets NRC institutional standards for objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process.

We thank the following for their review of this report: Rudolph Bonaparte, Geosyntec Consultants; Robert A. Dalrymple, Johns Hopkins University; David T. Ford, David Ford Consulting Engineers; Yacov Y. Haimes, University of Virginia; Daniel P. Loucks, Cornell University; Aurelio Mercado-Irizarry, University of Puerto Rico, Mayaguez; D. Warner North, NorthWorks, Inc., and, Robert V. Whitman, Massachusetts Institute of Technology.

Although these reviewers provided constructive comments and suggestions, they were not asked to endorse the report's conclusions and recommendations, nor did they see the final draft of the report before its release. The review of this report was overseen by Robert A. Frosch, Harvard University, who was appointed by the NRC's Report Review Committee, and by Paul H. Gilbert, Parsons Brinckerhoff Inc., who was appointed by the NRC's Division on Earth and Life Studies. Drs. Frosch and Gilbert were responsible for ensuring that an independent examination of this report was conducted in accordance with NRC institutional procedures and that all review comments received full consideration. Responsibility for this report's final contents rests entirely with the authoring committee and the NRC.