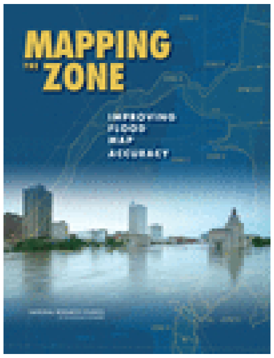
Free Executive Summary

Mapping the Zone: Improving Flood Map Accuracy



Committee on FEMA Flood Maps; Board on Earth Sciences and Resources/Mapping Science Committee; National Research Council

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Federal Emergency Management Agency (FEMA) Flood Insurance Rate Maps portray the height and extent to which flooding is expected to occur, and they form the basis for setting flood insurance premiums and regulating development in the floodplain. As such, they are an important tool for individuals, businesses, communities, and government agencies to understand and deal with flood hazard and flood risk. Improving map accuracy is therefore not an academic question--better maps help everyone. Making and maintaining an accurate flood map is neither simple nor inexpensive. Even after an investment of more than $1 billion to take flood maps into the digital world, only 21 percent of the population has maps that meet or exceed national flood hazard data quality thresholds. Even when floodplains are mapped with high accuracy, land development and natural changes to the landscape or hydrologic systems create the need for continuous map maintenance and updates.Mapping the Zone examines the factors that affect flood map accuracy, assesses the benefits and costs of more accurate flood maps, and recommends ways to improve flood mapping, communication, and management of flood-related data.

Summary

Floods are the leading cause of natural disaster losses in the United States, costing approximately $50 billion in property damage in the 1990s alone. To manage flood risk and minimize future disaster relief costs, the nation invests significant resources in mapping flood hazard areas and providing federal flood insurance to residents in communities that regulate future floodplain development. The Federal Emergency Management Agency's (FEMA's) Flood Insurance Rate Maps (FIRMs, hereafter referred to as flood maps) are used for setting flood insurance rates, regulating floodplain development, and communicating the 1 percent annual chance flood hazard to those who live in floodplains.

Making and maintaining an accurate flood map is neither simple nor inexpensive. FEMA's Map Modernization Program, funded for fiscal years 2003 to 2008, will result in flood maps in digital format for 92 percent of the continental U.S. population. Taking flood maps into the digital world was a great step forward because digital maps are more versatile for floodplain management and other uses and they are easier to update. Yet even after an investment of more than $1 billion, only 21 percent of the population has maps that meet or exceed national flood hazard data quality thresholds (Figure S.1). Even when floodplains are mapped with high accuracy, land development and natural changes to the landscape or hydrologic systems create the need for continuous map maintenance and updates.

FEMA and the National Oceanic and Atmospheric Administration (NOAA) sponsored this study to examine the factors that affect flood map accuracy, assess the benefits and costs of more accurate flood maps, and recommend ways to improve flood mapping, communication, and management of flood-related data. The charge to the committee is given in Box S.1.

The committee based its findings and recommendations on information gathered from presentations, publications, and case studies carried out by the committee and the North Carolina Floodplain Mapping Program, which has high-accuracy data and maps for nearly the entire state, enabling comparison of new and traditional data and techniques. The case studies focused on (1) uncertainties in hydrologic, hydraulic, and topographic data in and near selected streams in Florida and North Carolina, and (2) the economic costs and benefits of creating new digital flood maps in North Carolina. The North Carolina analyses were carried out in three physiographically distinct areas: mountains (city of Asheville), rolling hills (Mecklenburg County), and coastal plain (Pasquotank and Hertford Counties). For the economic analysis, two benefits were considered, based in part on the availability of geospatial data required to carry out the analysis: (1) avoiding flood losses to new buildings and avoiding repairs to infrastructure through accurate floodplain delineation, and (2) setting flood insurance premiums to better match estimates of actual risk.

FACTORS THAT AFFECT FLOOD MAP ACCURACY

The components of FEMA flood maps that are most relevant to the issues of accuracy discussed in this

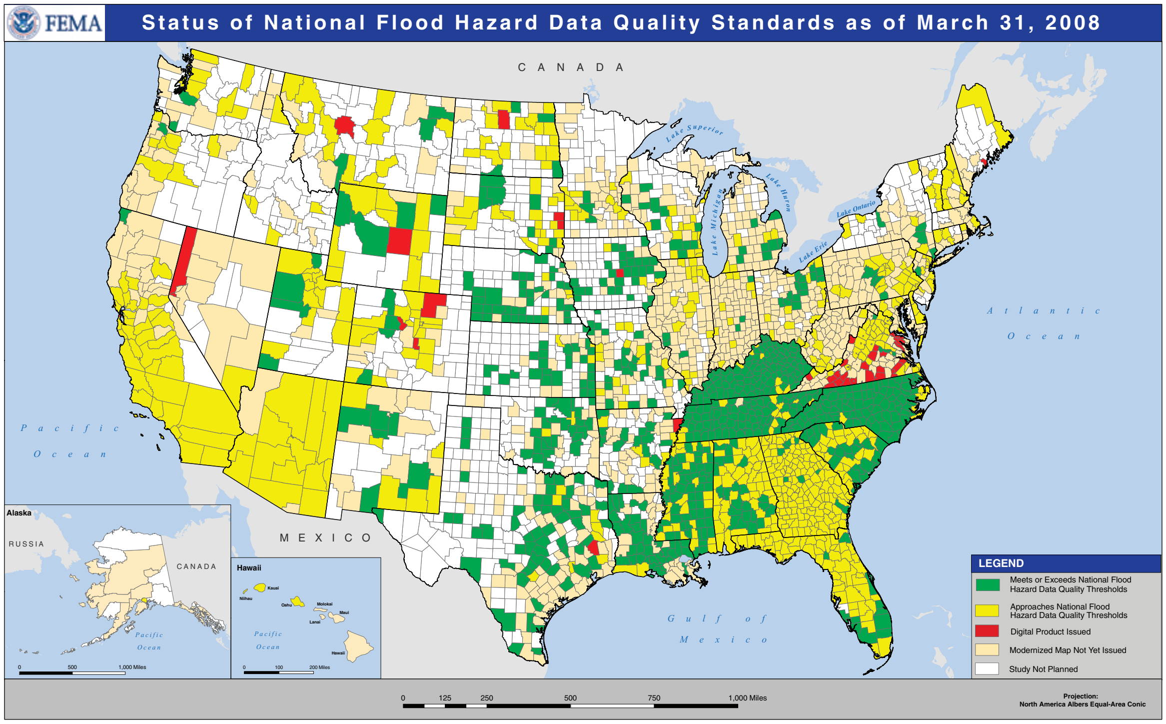

FIGURE S.1 Data quality standards achieved by individual counties as of March 31, 2008. Green counties meet or exceed national flood hazard data quality thresholds. Yellow counties meet some standards. In red counties, the maps have been updated digitally and a digital product has been issued. Compliance with data quality standards was not required for such digital conversions, although a limited FEMA audit suggests that some portions of these counties meet the standards. In beige counties, modernized maps have not yet been issued because the first phase of map production has not been completed or quality data do not exist. No study is planned in white counties. SOURCE: Paul Rooney, FEMA.

report are the floodplain boundaries and base flood elevations. Floodplains are low-lying, relatively flat areas adjoining inland and coastal waters. The most common floodplains mapped are those created by the 1 percent annual chance flood (also known as the 100-year flood) and the 0.2 percent annual chance flood (also known as the 500-year flood). The base flood elevation is the computed elevation to which floodwater is expected to rise or that it is expected to exceed during a 1 percent annual chance flood, and it forms the basis for setting flood insurance premiums and structure elevation regulations.

The extent of potential flood inundation must be predicted from statistical analyses and models. For riverine flooding, statistical estimates of flood discharges at U.S. Geological Survey (USGS) stream gages and digital representations of the land surface topography provide data for hydrologic and hydraulic models. The output is used in geographic information systems to delineate the predicted floodplain area. The process is similar for coastal flood mapping, except the existing repository of observational data (hurricane winds, topography, and bathymetry) is smaller and extreme events are more difficult to capture. As a result, coastal flood maps rely more heavily on modeling of wave and erosion processes and storm surge (water that is pushed toward the shore by the force of winds swirling around a storm) to predict coastal flood elevations. All of the inputs have uncertainties that affect the accuracy of the resulting flood map.

OVERARCHING FINDINGS

Finding 1. Topographic data are the most important factor in determining water surface elevations, base flood elevation, and the extent of flooding and, thus, the accuracy of flood maps in riverine areas.

BOX S.1 Committee Charge

The committee will

1. Examine the current methods of constructing FEMA flood maps and the relationship between the methods used to conduct a flood map study (detailed study, limited detailed study, automated approximate analysis, or redelineation of existing hazard information), the accuracy of the predicted flood elevations, and the accuracy of predicted flood inundation boundaries.
2. Examine the economic impacts of inaccuracies in the flood elevations and floodplain delineations in relation to the risk class of the area being mapped (based on the value of development and number of inhabitants in the risk zone).
3. Investigate the impact that various study components (i.e., variables) have on the mapping of flood inundation boundaries:
   a. Riverine flooding
      - The accuracy of digital terrain information
      - Hydrologic uncertainties in determining the flood discharge
      - Hydraulic uncertainties in converting the discharge into a floodwater surface elevation
   b. Coastal flooding
      - The accuracy of the digital terrain information
      - Uncertainties in the analysis of the coastal flood elevations
   c. Interconnected ponds (e.g., Florida)
      - The accuracy of the digital terrain information
      - Uncertainties in the analysis of flood elevations
4. Provide recommendations for cost-effective improvements to FEMA's flood study and mapping methods.
5. Provide recommendations as to how the accuracy of FEMA flood maps can be better quantified and communicated.
6. Provide recommendations on how to better manage the geospatial data produced by FEMA flood map studies and integrate these data with other national hydrologic information systems.

A study of sampling uncertainties in extreme stage heights at USGS stream gages in North Carolina and Florida found that for 30 of 31 gages, the average uncertainty is approximately 1 foot with a range of 0.3 feet to 2.4 feet. Uncertainties do not appear to vary with the size of the drainage basin or its topographic slope. It may thus be inferred that the lower bound on the uncertainty of the base flood elevation is approximately 1 foot. For the river reaches studied in North Carolina, a 1-foot change in flood elevation corresponds to a horizontal uncertainty in the floodplain boundary of 8 feet in the mountains, 10 feet in the rolling hills, and 40 feet in the coastal plain. This uncertainty has a significant impact on the delineation of inundated areas on flood maps.

The constriction of flood flow by bridges and culverts raises the base flood elevation in the three study areas. Such backwater effects are largest just upstream of the constriction and diminish progressively upstream. They are most pronounced in the coastal plain, extending an average of 1.1 miles and raising base flood elevations by up to 2.5 feet (average 0.9 foot). They are least pronounced in mountainous areas, raising the base flood elevation an average of 0.2 foot, which is not significant, given the sampling uncertainty noted above.

The largest effect by far on the accuracy of the base flood elevation is the accuracy of the topographic data. The USGS National Elevation Dataset (NED), developed from airborne and land surveys, is commonly used in flood map production, even though the elevation uncertainties of the NED are about 10 times greater than those defined by FEMA as acceptable for floodplain mapping. Data collected using high-resolution remote sensing methods such as lidar (light detection and ranging) can have absolute errors on the order of centimeters, consistent with FEMA requirements, but they are not available nationwide. A comparison of lidar data and the NED around three North Carolina streams revealed random and sometimes systematic differences in ground elevation of about 12 feet, which significantly affects predictions of the extent of flooding (e.g., Figure S.2). These large differences exceed FEMA's stated error tolerances for terrain data by an

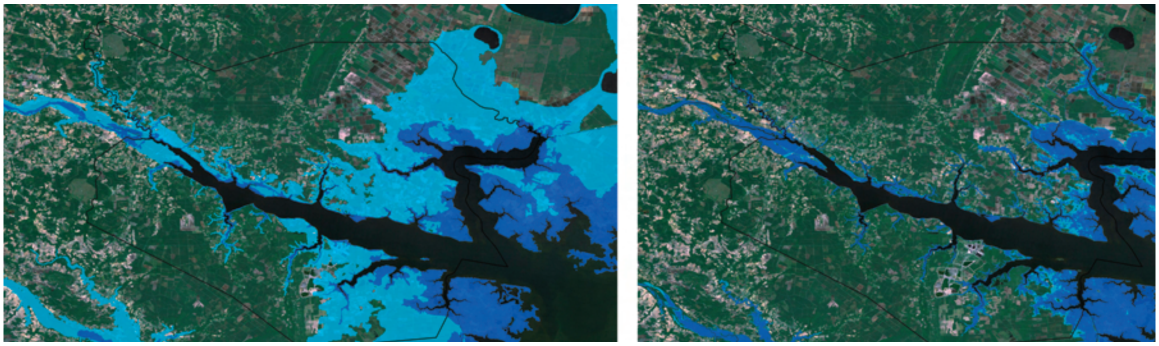

FIGURE S.2 Inundation maps of the area where the Tar-Pamlico River empties into Pamlico Sound of North Carolina. The figure on the left is based on a digital elevation model (DEM) with 30-meter post spacing created from the USGS NED. The figure on the right is based on a DEM with 3-meter post spacing created from North Carolina Floodplain Mapping Program lidar data. The dark blue tint represents land that would become inundated with 1 foot of storm surge or sea level rise. The light blue area represents uncertainty in the extent of inundation at the 95 percent confidence level. SOURCE: Gesch (2009).

order of magnitude and support the need for new topographic surveys, as called for in a National Research Council (NRC, 2007) report *Elevation Data for Floodplain Mapping*. In two of the study areas, random errors in topographic data produce inaccuracies in floodplain boundaries, but do not significantly alter the total area of the floodplain. In the other study area, in addition to random errors, there is a large systematic difference between the lidar and NED data that results from a misalignment of the stream location between the base map planimetric information and the topographic data. As a result, the total areas of the floodplains defined from lidar and from the NED differ by 20 percent. Because imagery is improving faster than elevation, the misalignment problem is growing more acute.

Finding 2. Coastal flood maps can be improved significantly through use of coupled two-dimensional storm surge and wave models and improved process models, which would yield more accurate base flood elevations.

The science of riverine flooding is reasonably well understood, and improvements to inland flood maps can focus on harnessing available technology. In contrast, advancing understanding of the complex dynamics of the coastal inundation process is necessary for improving the accuracy of coastal flood maps. Coastal flood models are evolving rapidly, but published results suggest that replacing FEMA's one-dimensional model for calculating wave heights (Wave Height Analysis for Flood Insurance Studies [WHAFIS]), which was introduced in the late 1970s, with a two-dimensional wave model would improve the accuracy of calculated base flood elevations. Coupled two-dimensional surge and wave models, as well as models that account for erosion processes, the effects of structures, and variations in topography, offer the potential for further improvements of coastal flood map accuracy. A comparison of available models, conducted by an independent external advisory group, would help quantify uncertainties and indicate which models should be incorporated into mapping practice.

Finding 3. Flood maps with base flood elevations yield greater net benefits than flood maps without.

Benefit-cost analyses have shown that the greatest benefits of more accurate flood maps are avoided flood losses to planned new buildings and avoided repairs to infrastructure through more accurate base flood elevations and depiction of floodplain boundaries. Producing a more accurate base flood elevation yields the greatest increment of benefits because it enables insurance premiums and building restrictions to be set commensurate with a more realistic profile of the horizontal and vertical extent of flooding. Only the more expensive of FEMA's flood study methods—detailed studies and most limited detailed studies—yield a base flood elevation. A comparison of study methods in the three case study areas by the North Carolina Floodplain Mapping Program showed that the use of detailed studies and limited detailed studies that generate base flood elevations results in net benefits to the state. In contrast, the use of approximate study methods, which do not yield base flood elevations, results in net costs. This is significant because detailed and limited detailed studies in North Carolina rely on lidar data, and even though lidar surveys are expensive, the costs to map the three study areas are outweighed by the benefits of more accurate maps.

Finding 4. The most appropriate flood study method to be used for a particular map depends on the accuracy of the topographic data and the overall flood risk, including flood probability, defined vulnerabilities, and consequences.

The North Carolina benefit-cost analysis showed that a combination of different study methods produces the greatest economic benefits to the state as a whole. The best study method depends on the characteristics of the area being mapped, such as the present and future potential of flooding, the potential for population growth, the availability of land for development, and the likely economic value of structures to be built. The quality of the topographic data is also important. Where accurate topographic data are available, an accurate base flood elevation can be calculated, a more accurate map can be produced, and thus better decisions can be made about appropriate use of the floodplain.

Finding 5. FEMA's transition to digital flood mapping during the Map Modernization Program creates opportunities for significant improvements in the communication of flood hazards and flood risks through maps and web-based products.

FEMA is moving from simply portraying flood hazard and flood insurance rate zones on maps to communicating and assessing risk, an ambitious goal that leverages the digital flood-related information and maps produced during the Map Modernization Program as well as FEMA tools for estimating flood damage and loss (i.e., Hazards U.S. Multi-Hazards software). To communicate risk, the maps and products must show not only where flood hazard areas are located, but also the likely consequences of flooding (e.g., damage to houses, coastal erosion). Inundation and risk maps beginning to be produced by U.S. federal and state government agencies and by other countries have attributes that merit FEMA's attention.

Maps that show only floodplain boundaries have the disadvantage of implying that every building in a designated flood zone may flood and that every building outside the zone is safe. Providing floodplain residents with the elevation of structures relative to the expected height of a number of floods offers a better way to define graduated risk (from low risk to high risk). Where the necessary data are available (e.g., structure elevation, base flood elevations, flood protection structure performance), a geographic information system could be used to personalize flood risk to individual addresses.

RECOMMENDATIONS

The body of the report contains focused recommendations on how to improve specific aspects of FEMA's flood data, models, and mapping. The following overarching recommendations address Tasks 4 through 6 and are based on the analysis of information presented throughout the report.

Cost-Effective Improvements to FEMA's Flood Study and Mapping Methods

Recommendation 1. FEMA should increase collaboration with federal (e.g., USGS, NOAA, U.S. Army Corps of Engineers), state, and local government agencies to acquire high-resolution, high-accuracy topographic and bathymetric data throughout the nation.

Riverine mapping methods are well established, although improvements could be made in calibrating rainfall-runoff models, updating regression equations (many of which are more than 10 years old) more frequently, and increasing the use of two-dimensional models developed by the research community. The greatest improvement, however, would come from use of high-accuracy, high-resolution topographic data. Improved measurements of channel, lake, estuarine, and near coastal bathymetry would augment the improved measurement of land surface topography enabled by lidar technology. As noted above, the use of lidar data to calculate more accurate base flood elevations and floodplain boundaries reduces future flood losses and produces net benefits to the State of North Carolina. Reducing future flood losses also benefits taxpayers throughout the nation. FEMA has recently begun to support collection of lidar data along the Gulf coast, but lidar data coverage over most inland areas is still sparse.

Recommendation 2. FEMA should work toward a capability to use coupled surge-wave-structure models to calculate base flood elevations, starting with incorporating coupled two-dimensional surge and wave models into mapping practice.

A significant improvement to coastal flood mapping can be made by improving the models. Currently, base flood elevations are calculated by combining storm surge models with wave models, and using the result in models that calculate erosion and wave effects. However, modeling has greatly advanced, and it is now possible to use coupled models that account for storm surge, waves, erosion, and topographic features simultaneously.

Recommendation 3. FEMA should commission a scientific review of the hydrology and hydraulics needed to produce guidelines for flood mapping in ponded landscapes.

Methods to map landscapes in which water tends to flow from one ponded area to the next (shallow flooding) are still being developed. The primary hurdle to progress is the lack of scientific studies and models on the interactions between ponds, the volume of water temporarily stored in the depressions, and the rate at which it percolates out. Commissioning a study would not be costly and is a necessary step toward improving shallow flood mapping.

Quantifying and Communicating the Accuracy of FEMA Flood Maps

Recommendation 4. FEMA should require that every flood study be accompanied by detailed metadata identifying how each stream and coastline reach was studied and what methods were used to identify the magnitude and extent of the flood hazard and to produce the map.

One of the most important ways to quantify and communicate flood map accuracy is to document the data and methods used to study each segment of stream or coastline. FEMA's current metadata reporting requirements do not include all the information needed to assess the quality and reliability of the data underlying the maps. For each stream or coastline mile studied, metadata should describe what input data, mapping, and modeling methods were used; the date of mapping; the contractor; and the starting and ending points.

Managing Geospatial Data

Recommendation 5. FEMA should reference all stream and coastal studies within its Mapping Information Platform to the USGS National Hydrography Dataset.

FEMA Map Modernization has produced a large amount of geospatial data and flood hydraulic models for the nation's streams and coastlines. The result is the most comprehensive digital description of the nation's streams and rivers that has ever been undertaken. These data are stored in the Mapping Information Platform (MIP) on a county-by-county basis. There is no requirement that map information such as stream centerlines be consistent from one county to the next. The USGS National Hydrography Dataset is a seamless, connected map of the nation's streams, rivers, and coastlines. Using a technique called linear referencing, it is feasible to link the FEMA stream and coastline data with the corresponding information in the National Hydrography Dataset. If this were done, FEMA flood data could become an integral part of the nation's hydrologic information infrastructure rather than existing as a separate database.

MAPPING THE ZONE

IMPROVING FLOOD MAP ACCURACY

Committee on FEMA Flood Maps

Board on Earth Sciences and Resources/Mapping Science Committee

Water Science and Technology Board

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Cover: June 2008 flooding in Cedar Rapids, Iowa (foreground), and a portion of the FEMA Flood Insurance Rate Map in the same region (background). This part of the downtown is within the Special Flood Hazard Area (zone A), which is subject to a 1 percent or greater chance of flooding in any given year. Photograph courtesy of Stephen Mally. Used with permission. Map extract from FEMA's Map Service Center. Cover design by Van Nguyen.

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Preface

Federal Emergency Management Agency (FEMA) Flood Insurance Rate Maps portray flood hazard areas, and they form the basis for setting flood insurance premiums and regulating development in the floodplain. As such, they are an important tool for individuals, businesses, communities, and government agencies to understand and deal with flood hazard and flood risk. Improving map accuracy is therefore not an academic question—better maps help everyone.

This study was requested by managers of FEMA's Risk Analysis Division and the National Oceanic and Atmospheric Administration's (NOAA's) Coastal Services Center, supported by NOAA's National Weather Service, National Geodetic Survey, and Coast Survey Development Laboratory. The Committee on FEMA Flood Maps was established to examine the factors that affect flood map accuracy, assess the economic benefits of more accurate flood maps, and identify ways to improve flood mapping, communication, and management of flood-related data. Committee members included academics and practitioners who collectively possessed expertise covering inland and coastal flood modeling and mapping, geospatial data management, flood hazard assessment, and economic and policy implications of flood map accuracy. Information on these topics was gathered from the literature, the Association of State Floodplain Managers, discussions with colleagues, and briefings at five committee meetings held between June 2007 and April 2008. In addition to these traditional means of gathering information, the committee conducted original analyses of variables that influence flood map accuracy, such as elevation and flood flow.

The committee would like to thank the individuals who briefed the committee or provided data, figures, or other input: Ken Ashe, Glenn Austin, Jerad Bales, Julio Cañon, Andy Carter, Tim Cohn, Todd Davison, David Divoky, Mary Erickson, Dean Gesch, Mike Godesky, Susan Greenlee, Ruth Haberman, Eric Halpin, Victor Hom, Marti Ikehara, Doo Sun Kang, Larry Larson, Kevin Long, Doug Marcy, Kate Marney, Robert Mason, Gordon McClung, Sally McConkey, Venkatesh Merwade, Mike Moya, Jim Nelson, Rick Neuherz, Edward Pasterick, Kernell Ries, Dan Roman, Paul Rooney, Rick Sacbibit, Brett Sanders, Eric Tate, Ronnie Taylor, Patty Templeton-Jones, Gary Thompson, D. Phil Turnipseed, Gordon Wells, Bruce Worstell, and Dave Zilkoski. Special thanks go to Thomas Langan, Stephanie Dunham, and Jerry Sparks, who carried out extensive hydrologic and economic case studies for the committee. Their efforts greatly expanded the pool of data from which to draw conclusions about improving the accuracy of flood maps. The committee also thanks the National Academies staff who worked on this report: Lauren Alexander Augustine, Tonya Fong Yee, Jared Eno, and particularly Anne Linn, the study director, who expertly guided the committee's activities and contributed significantly to synthesizing our results.

David R. Maidment
Chair

Acknowledgment of Reviewers

This report has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise, in accordance with 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 institution in making its published report as sound as possible and to ensure that the report meets 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 wish to thank the following individuals for their participation in the review of this report:

Gregory Baecher, University of Maryland, College Park
Richard Bernknopf, United States Geological Survey, Menlo Park, California
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Although the reviewers listed above have provided many constructive comments and suggestions, they were not asked to endorse the conclusions or recommendations nor did they see the final draft of the report before its release. The review of this report was overseen by Michael Goodchild, University of California, Santa Barbara, and Robert Dalrymple, Johns Hopkins University, Baltimore, Maryland. Appointed by the National Research Council, they were responsible for making certain that an independent examination of this report was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this report rests entirely with the authoring committee and the institution.

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