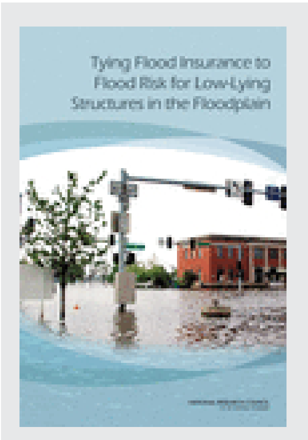

Tying Flood Insurance to Flood Risk for Low-Lying Structures in the Floodplain

DETAILS

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Cover Illustration: Photo of an inundated downtown riverfront in Davenport, Iowa, when the Mississippi River overflowed its banks on May 4, 2001. The building is a negatively elevated structure in the Special Flood Hazard Area. SOURCE: Photo by David Teska, FEMA.

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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 Gerald Galloway, University of Maryland, College Park, and Robin McGuire, Lettis Consultants International, Inc., Boulder, Colorado. 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 NRC.

Contents

Summary

Floods take a heavy toll on society, costing lives, damaging buildings and property, disrupting livelihoods, and sometimes necessitating federal disaster relief, which has risen to record levels in recent years. The National Flood Insurance Program (NFIP) was created in 1968 to reduce the flood risk to individuals and their reliance on federal disaster relief by making federal flood insurance available to residents and businesses if their community adopted floodplain management ordinances and minimum standards for new construction in floodprone areas. Insurance rates for structures built after a floodplain map was adopted by the community were intended to reflect the actual risk of flooding (i.e., risk-based rates), taking into account the likelihood of inundation, the elevation of the structure, and the relationship of inundation to damage to the structure. Charging higher premiums for structures expected to suffer greater flood damage would make people aware of their flood risk and would transfer the cost of losses from taxpayers to property owners. Rates for existing structures were subsidized to encourage insurance purchase and community participation in the NFIP. The NFIP designers anticipated that the need for such subsidies would diminish over time as aging structures left the portfolio.

Today, rates are subsidized for one-fifth of the NFIP's 5.5 million policies. Structure elevations are not known for most subsidized policies. However, the NFIP believes that most of these structures are negatively elevated, that is, the elevation of the lowest floor (including basement) is lower than the NFIP benchmark for construction standards and floodplain management ordinances—the water surface elevation with a 1 chance in 100 of being exceeded annually (called the 1 percent annual chance exceedance elevation or base flood elevation). Compared to structures built above the base flood elevation, negatively elevated structures are more likely to incur a loss because they are inundated more frequently, and the depths and durations of inundation are greater.

When subsidies are phased out to improve the fiscal health of the NFIP, as required by the Biggert-Waters Flood Insurance Reform Act of 2012 and subsequent legislation, premiums for negatively elevated structures will rise, in some cases substantially, to cover the expected losses. Consequently, it is important to ensure that NFIP methods used to calculate risk-based premiums for negatively elevated structures are credible, fair, and transparent. This report examines current NFIP methods for calculating risk-based rates for negatively elevated structures; identifies changes in analysis methods and data collection that are needed to support risk-based premiums; and discusses the feasibility, implementation, and cost of making these changes (Box S.1).

CURRENT NFIP METHODS

The first task of the committee was to review current NFIP methods for calculating risk-based premiums, including the floodplain analysis and mapping that support insurance rate setting (Box S.1). The NFIP expresses flood risk in terms of the expected economic loss due to inundation and the probability of that loss. Information about the flood hazard, determined through NFIP flood studies, the vulnerability of the

BOX S.1
Study Charge

An ad hoc committee will conduct a study of pricing negatively elevated structures in the National Flood Insurance Program. Specifically, the committee will

1. Review current NFIP methods for calculating risk-based premiums for negatively elevated structures, including risk analysis, flood maps, and engineering data.
2. Evaluate alternative approaches for calculating "full risk-based premiums" for negatively elevated structures, considering current actuarial principles and standards.
3. Discuss engineering, hydrologic, and property assessment data and analytical needs associated with fully implementing full risk-based premiums for negatively elevated structures.
4. Discuss approaches for keeping these engineering, hydrologic, or property assessment data updated to maintain full risk-based rates for negatively elevated structures.
5. Discuss feasibility, implementation, and cost of underwriting risk-based premiums for negatively elevated structures, including a comparison of factors used to set risk-based premiums.

structure being insured, and the performance of certain flood protection measures is incorporated into a flood risk assessment, which yields an estimate of the average annual loss. The insurance rate is determined from this loss after adjusting for expenses, deductibles, under-insurance, and other factors. This process is described in more detail below.

Flood Hazard Analysis and Mapping

In inland areas, NFIP flood studies focus on the expected behavior of a watershed, river channel, and adjacent floodplain where structures are located. In coastal areas, the studies also assess the effects of storm surge and wave action. Models of relevant physical processes are coupled with statistical models of weather events to compute flood depths and velocities, and their likelihood of occurring. The model prediction results are summarized in reports and portrayed on Flood Insurance Rate Maps, which show water surface elevations, floodplain boundaries, zones of flood severity, and other information. The maps are used to identify locations of high flood risk, to determine whether flood insurance is required, and, if so, to inform determination of a flood insurance premium.

Flood Risk Assessment

Flood risk assessments generally focus on four components:

1. Flood hazard—the probability and magnitude of flooding
2. Exposure—the economic value of assets subjected to flood hazard
3. Vulnerability—the relationship of flood hazard properties to economic loss
4. Performance—the effect of flood protection and damage mitigation measures in modifying the flood hazard, the exposure, or the vulnerability

The NFIP describes flood hazard using water surface elevation–exceedance probability functions, referred to as PELV curves. The curves, which were developed from flood studies in the early 1970s, represent natural watershed, channel, and tidal and wind behaviors throughout the range of possible flood events, and show the annual probability that flood waters will reach or exceed a given depth relative to the base flood elevation. Variations in flood hazard are described with 30 PELV curves, representing topographies ranging from broad, shallow floodplains to narrow, steep mountain valleys.

The NFIP describes vulnerability by relating expected damage to depth of inundation. A depth–

percent damage function, referred to as a DELV curve, expresses damage as a percentage of a structure's replacement value (the exposure) for a specified depth of water in the structure. The NFIP uses two models—damage functions derived from NFIP claims data and U.S. Army Corps of Engineers (USACE) damage functions—to develop a blended DELV curve.

The NFIP describes the performance of levees and flood storage and diversion by comparing the properties of these measures to design and operation standards. If a measure meets those standards, then it is considered to provide complete protection from the 1 percent annual chance exceedance flood as well as floods with lesser velocities, water surface elevations, and discharge rates.

Risk-Based Insurance Rates

The NFIP determines insurance rates for classes of structures that share similar characteristics, including flood zone, occupancy, type of construction, the location of contents in the structure, and the structure's elevation relative to the base flood elevation. The average annual loss is computed by summing the product of the DELV curve for a class of structures and each PELV curve, and then averaging the computed losses over the set of 30 PELV curves, weighted by the estimated fraction of structures in the various flood zones at various elevations. The average annual loss for the class of structures is converted to an insurance rate for that class by adjusting for expenses, the amount of underinsurance (because not all structures can be or are insured to their full value), the portion of the claim that will not be covered because of the policy deductible, and other factors.

NFIP methods for setting risk-based rates focus on rating structures that comply with NFIP construction standards, and their use has been optimized for structures with lowest floor elevations at or above the base flood elevation. However, the NFIP has applied risk-based methods to about 240,000 negatively elevated structures that have had an elevation survey. The NFIP uses the same method to calculate risk-based rates for negatively elevated structures, but requires additional information to be collected on building construction and contents value, a more detailed review of the policy application, and possibly verification of building construction details. The additional data are used to adjust the rate on a more individualized basis for negatively elevated structures.

Overall, the committee found that current NFIP methods for setting risk-based rates do not accurately and precisely describe critical hazard and vulnerability conditions that affect flood risk for negatively elevated structures, including very frequent flooding, a longer duration of flooding, and a higher proportion of damage from small flood events. In addition, the PELV and DELV curves have not been updated with modern data. Finally, many NFIP methods were developed decades ago and do not take full advantage of modern technological and analysis capabilities. Potential changes to NFIP methods to address these issues are summarized below.

ALTERNATIVE APPROACHES

The second task of the committee was to evaluate alternative approaches for calculating risk-based premiums for negatively elevated structures (Box S.1). The committee considered both incremental changes to current NFIP methods and different approaches, which would require research, development, and standardization; new data collection; and user training.

Incremental Changes to Current NFIP Methods

Conclusion 1. Careful representation of frequent floods in the NFIP PELV curves is important for assessing losses for negatively elevated structures. The shape of the PELV curve depends primarily on the difference between the 1 percent and 10 percent annual chance exceedance depths. However, a significant portion of potential losses to negatively elevated structures are caused by floods more frequent than those with a 10 percent annual chance of exceedance. A short-term solution is to use information from existing detailed flood studies to refine the PELV curves so that they define more accurately the water surface elevations for frequent floods. If a flood study developed the frequency information needed to determine the 1 percent annual chance exceedance elevation, it could be easily expanded to determine more frequent water surface elevations.

Conclusion 2. Averaging the average annual loss over a large set of PELV curves leads to rate classes that en-

compass high variability in flood hazard for negatively elevated structures, and thus the premiums charged are too high for some policyholders and too low for others. A short-term means to reduce the excessive variance in premiums is to calculate the average annual loss component of the flood insurance rate using a water surface elevation–exceedance probability function that represents the flood hazard at the structure's location, rather than basing the calculation on the 30 PELV curves that represent flood hazard nationally. The appropriate function might be an existing PELV curve, but it is more likely that new categories of water surface elevation–exceedance probability functions would have to be developed to capture important differences in flood hazard conditions. Local meteorological, watershed, and floodplain properties (e.g., terrain, presence of levees) could be used to guide the selection of the appropriate PELV curve or category of water surface elevation–exceedance probability functions.

Conclusion 3. NFIP claims data for a given depth of flooding are highly variable, suggesting that inundation depth is not the only driver of damage to structures or that the quality of the economic damage and inundation depth reports that support the insurance claims is poor. The NFIP calculates damage from inundation depth alone, but other drivers of damage (e.g., duration of inundation, flow velocity, water contamination, debris content) may also be important. For example, a negatively elevated structure will commonly be inundated longer than a structure built above the base flood elevation at the same location, and the prolonged wetting of material will increase damage. Research would be required to determine which drivers of flood damage are important and to develop the appropriate damage prediction function for use in the rate calculation.

Conclusion 4. When the sample of claims data is small, the NFIP credibility weighting scheme assumes that USACE damage estimates are better than NFIP claims data, which has not been proven. The DELV model uses both USACE damage estimates and NFIP claims data, weighted according to their credibility. NFIP claims data are used when the sample size is large enough to assign 100 percent credibility at a selected confidence level. When NFIP claims data are sparse, USACE damage estimates are weighted heavily, even though the quality of the damage estimates is unknown. With almost 50 years of NFIP claims data, it may no longer be necessary to incorporate USACE damage models of unknown origin and quality into NFIP damage estimates. Instead, the NFIP could build a large set of flood damage reports from relevant agencies (e.g., Federal Emergency Management Agency, USACE, National Weather Service, state and local agencies) and use it to adjust the DELV curves annually. Having multiple sources of damage data would also provide an independent check on NFIP data quality. Smaller improvements could be made by determining the quality of the USACE data—a difficult task given the lack of documentation—and revising the NFIP credibility scheme to weigh the two datasets appropriately.

Conclusion 5. Levees may reduce the flood risk for negatively elevated structures, even if they do not meet NFIP standards for protection against the 1 percent annual chance exceedance flood. The NFIP treats levees designed, constructed, and maintained to an acceptable standard as preventing damage from floods more frequent than those with a 1 percent annual chance of exceedance. Levees (or levee segments) that do not meet that standard are treated as providing lesser or no flood protection. However, these nonaccredited levees may provide some protection against the 50 percent and 10 percent annual chance exceedance floods, which contribute significantly to losses for negatively elevated structures. A short-term change is to modify the NFIP Levee Analysis and Mapping Procedure to assess the ability of nonaccredited levees to prevent inundation of negatively elevated structures by events more frequent than the 1 percent annual chance exceedance flood.

Conclusion 6. When risk-based rates for negatively elevated structures are implemented, premiums are likely to be higher than they are today, creating perverse incentives for policyholders to purchase too little or no insurance. As a result, the concept of recovering loss through pooling premiums breaks down, and the NFIP may not collect enough premiums to cover losses and underinsured policyholders may have inadequate financial protection. The NFIP encourages the purchase of sufficient flood insurance to cover the value of the structure, but the mandatory purchase statute requires only that the amount of insurance cover the outstanding balance of the federally backed mortgage, if any. (In addition, the statutory limit of $250,000 coverage for single family structures, unchanged since 1994, means that many structures cannot be insured to their full value). The NFIP could discourage the deliberate purchase of too little insurance, and fairly compensate for it, by tying the underinsurance adjustment to the ratio of the amount of insurance purchased to the replacement cost value of the structure, as is currently done for structures in high-hazard coastal zones. Alternatively, the NFIP could reduce loss payments or impose other penalties for severely underinsured structures, although public policy issues may also have to be considered.

Conclusion 7. Adjustments in deductible discounts could help reduce the high risk-based premiums expected for negatively elevated structures. The current NFIP minimum deductible ranges from $1,000 to $2,000 for structure and for contents coverages. The NFIP offers premium discounts based on the dollar amount of the deductible chosen and whether the structure was built before or after floodplain maps were adopted by the community. However, more refined PELV curves and more accurate replacement cost information in rating policies could be used to develop deductible discounts that are more appropriate to individual expected annual losses. Minimum deductibles could also be increased, which would reduce premiums as well as NFIP expected claims payouts overall.

New Approach: A Comprehensive Risk Assessment

Conclusion 8. Modern technologies, including analysis tools and improved data collection and management capabilities, enable the development and use of comprehensive risk assessment methods, which could improve NFIP estimates of flood loss. A comprehensive risk assessment would describe risk over the entire range of flood hazard conditions and flood events, including the large, infrequent floods that cause substantial losses to the NFIP portfolio, and the smaller, frequent floods that make up a significant portion of loss to negatively elevated structures. Major differences from current NFIP methods include the following:

- Rather than using a standard set of national PELV curves to describe flood hazard, water surface elevation–exceedance probability functions would be developed for a study area and used to determine the flood hazard for individual structures by modeling watershed, channel, and floodplain characteristics at fine spatial resolution.
- In addition to describing the effectiveness of levees and flood storage and diversion in protecting against the 1 percent annual chance exceedance flood, a comprehensive risk assessment would describe the various levels of protection offered by all elements of a flood protection system (e.g., reservoirs, levees, floodwalls, diversions and bypasses, channels, warning systems) and mitigation measures (e.g., elevating structures) through the entire range of flood events.
- A comprehensive risk analysis would account explicitly for all uncertainties—including uncertainties about current and future flood hazard; structure value, vulnerability, and elevation; and the current and future performance of flood protection measures—and account for them through the risk analysis.

These changes would improve both the accuracy and precision of flood loss estimates for structures or groups of structures, and thus, the accuracy and precision of rates based upon the loss estimates.

SUPPORTING DATA

The third and fourth tasks of the committee concern collecting and updating engineering, hydrologic, and property assessment data needed for implementing risk-based premiums for negatively elevated structures (Box S.1). The committee focused on near-term data issues, which have been documented or seem likely to arise.

Conclusion 9. Risk-based rating for negatively elevated structures requires, at a minimum, structure

elevation data, water surface elevations for frequent flood events, and new information on structure characteristics to support the assessment of structure damage and flood risk. For risk-based rating, the NFIP requires an Elevation Certificate, which records the elevation of the lowest floor of a structure, measured by a land survey. However, the accuracy of the data is difficult to confirm. Vehicle-mounted lidar could potentially be used to validate structure elevation data on Elevation Certificates or to collect structure elevation data at a much lower cost. Because lidar measures the highest adjacent grade elevation, some work would have to be done to convert the data to lowest floor elevations.

The NFIP collects basic information on structure characteristics, such as the number of floors and the type of supporting foundation, but additional information is needed to support models that predict damage from inundation, duration of flooding, or other drivers of damage at the structure level (see Conclusion 3). New data needs include the characteristics and usage of basements, the properties of the foundation, the type of structure or architecture, the type of interior and exterior finishes, and the quality of construction. Finally, water surface elevation predictions for frequent events can be extracted from existing or new flood studies. Structure elevations and, in some cases, flood studies would have to be updated following a major flood event or the accumulation of sufficient vertical land motion to change the rate class. Structure characteristics would have to be updated after a major renovation.

Conclusion 10. The lack of uniformity and control over the methods used to determine structure replacement cost values and the insufficient quality control of NFIP claims data undermine the accuracy of NFIP flood loss estimates and premium adjustments. The NFIP obtains replacement cost data from insurance companies and agents, who use their own methods to make estimates. Replacement cost values could potentially be improved by (1) requiring all insurance companies and agents to use a single cost estimation method or (2) purchasing data already collected by private companies that use consistent methods to estimate replacement costs across the nation. Having multiple sources of replacement cost data would enable the NFIP to assess data quality and to choose which source is best for rating purposes. Replacement cost values would have to be updated following a disaster, structural modification, or a major socioeconomic change in the community.

Inconsistent replacement cost data and inaccurate and incomplete damage data may contribute to the documented variability in NFIP claims data for a given depth of inundation (see Conclusion 3). Data quality could be improved by collecting more data in damage reports, implementing a more thorough quality control and review process, or strengthening requirements on how data are collected and reported.

FEASIBILITY, IMPLEMENTATION, AND COST

The fifth task of the committee was to discuss the feasibility, implementation, and cost of underwriting risk-based premiums for negatively elevated structures (Box S.1). Changes to the water surface elevation–exceedance probability functions and the flood damage functions would strengthen the scientific and technical foundation for setting risk-based rates for negatively elevated structures. The incremental changes to PELV, DELV, and levee performance summarized above could be implemented quickly and at low or moderate cost (e.g., a few person months to a few person years). However, over the longer term, implementing a comprehensive risk analysis methodology and developing site-specific flood hazard descriptions, models that predict damage from multiple drivers, and probabilistic models that describe the performance of flood risk reduction measures would yield a much improved assessment of flood losses, and thereby strengthen the foundation for rate setting. Work done by other agencies (e.g., USACE) demonstrates that these changes are feasible. Implementation could be done in stages, and the use of relevant information, models, and analysis methods developed by other government agencies (e.g., USACE data on structures and derived information on hazard and performance) would speed the work and stretch NFIP resources. The changes outlined above will improve the accuracy and precision of loss estimates for negatively elevated structures, which in turn will increase the credibility, fairness, and transparency of premiums for policyholders.

1

The National Flood Insurance Program and the Need for Accurate Rates

Floods take a heavy toll on society, costing lives, damaging homes and property, and disrupting businesses and livelihoods (e.g., Figure 1.1). Of all natural disasters, floods are the most costly (Miller et al., 2008) and affect the most people (Stromberg, 2007). Since 1953, nearly two-thirds of presidential disaster declarations—which trigger the release of federal funds for community recovery and relief—have been flood related. Moreover, the number of flood disaster declarations has increased over the past 60 years, from an average of about 8 per year in the 1950s to a record high of 51 in 2008 and 2010 (Figure 1.2). Flood losses are increasing because more people are living in harm's way; more expensive homes are being built in the floodplain (Michel-Kerjan, 2010); and development in watersheds and climate changes, such as sea level rise and more frequent heavy rainstorms (IPCC, 2012; Melillo et al., 2014), are increasing flood risk (the likelihood and consequence of flooding) in some areas.

The National Flood Insurance Program (NFIP) was created in 1968 to reduce the flood risk to individuals and their reliance on federal post-disaster aid. The program enabled residents and businesses to purchase federal flood insurance if their community adopted floodplain management ordinances and minimum standards for new construction in floodprone areas. Insurance rates for new structures were intended to reflect the risk of flooding (i.e., risk-based rates), with rates depending on structure elevation and other factors. Rates for existing structures were subsidized to keep property values from dropping immediately and to encourage communities to participate in the NFIP and manage development in the floodplain. Within NFIP participating communities, flood insurance is mandatory for homes and businesses with a federally backed or regulated mortgage in high flood risk areas (called Special Flood Hazard Areas), and is available for homes and businesses in moderate to low flood risk areas.

Today, about 20 percent of the NFIP's 5.5 million policies receive subsidized flood insurance rates. Subsidized structures are located across the nation, with the largest concentrations along the coasts (NRC, 2015). Rates for subsidized structures do not depend on elevation (although elevation affects risk), and so only a few of these structures have been surveyed to determine their elevation. However, most subsidized structures are thought to be negatively elevated (see Figure 7.2 in PWC, 1999),[1] that is, to have lowest floor elevations lower than the base flood elevation. This is the water surface elevation with 1 percent annual chance of being exceeded, and it is the NFIP benchmark for construction standards and floodplain management ordinances. Structures with lowest floor elevations equal to the base flood elevation have a 26 percent chance of flooding during the lifetime of a 30-year mortgage (compared with a 1–2 percent chance of catching fire; FEMA, 1998). Negatively elevated structures have a much higher chance of flooding over the same period and a greater potential for damage.

[1] Personal communication from Andy Neal, Federal Emergency Management Agency (FEMA), on July 9, 2014. The NFIP has elevation data for only 2.2 million policies, most of which are charged actuarial rates.

FIGURE 1.1 Flooding of homes and businesses in Minot, North Dakota, in July 2011, when the Souris River (also known as the Mouse River) overflowed its banks. SOURCE: Photo by Patsy Lynch, Federal Emergency Management Agency (FEMA). Available at http://www.fema.gov/media-library/assets/images/59875.

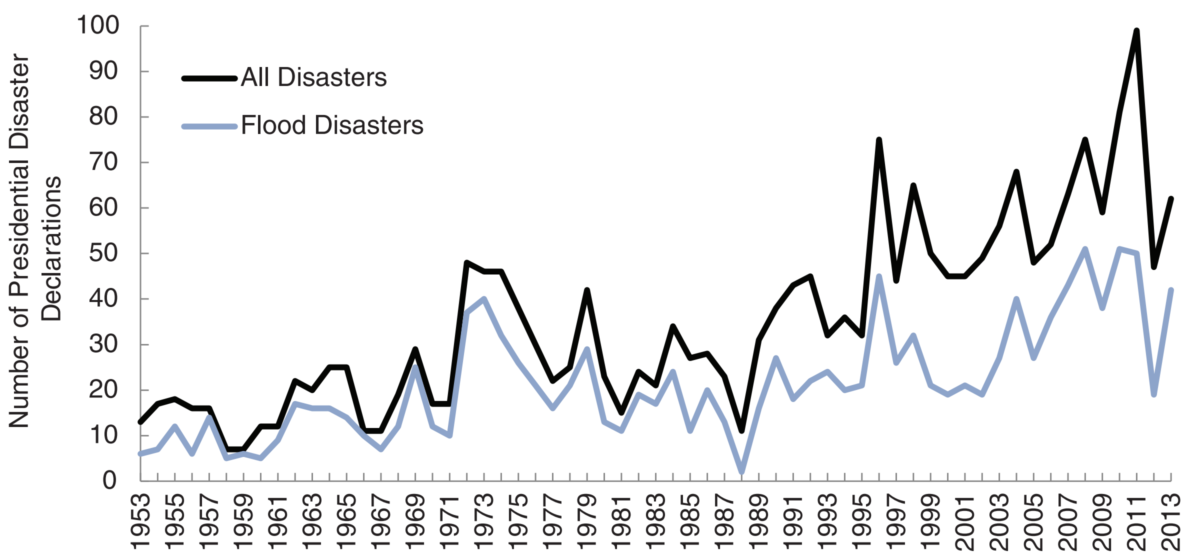

FIGURE 1.2 Number of presidential disaster declarations (black line) and declarations associated with flood-related events (blue line) from 1953 to 2013. SOURCE: Data from FEMA, http://www.fema.gov/disasters/grid/year.

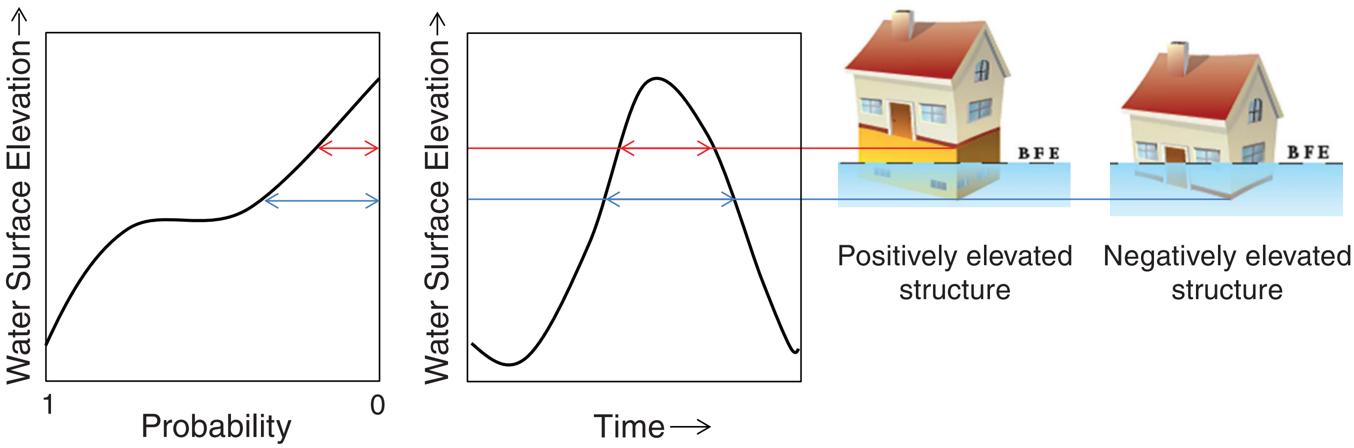

FIGURE 1.3 The flood risk to a structure depends in part on the elevation of the lowest floor of a structure (red and blue horizontal lines) relative to the base flood elevation (BFE). (Left) A typical water surface elevation–probability function. Compared to structures built above the base flood elevation, negatively elevated structures have a greater probability of inundation with shallower depths, and they are inundated to greater depths by lower probability events. (Center) A typical flood hydrograph for riverine flooding. Because negatively elevated structures are lower in the floodplain, a given flood will commonly inundate them for a longer period of time than structures above the base flood elevation.

With the passage of the Biggert-Waters Flood Insurance Reform Act of 2012[2] and subsequent legislation, subsidies are beginning to be phased out and premiums are expected to rise to levels that reflect the full risk of flooding (see "National Flood Insurance Program" below). Premium increases for those negatively elevated structures are likely to be substantial, given the high flood risk and loss of the large subsidy. The NFIP's current method for calculating risk-based rates was developed for structures built at or above the base flood elevation, but negatively elevated structures are susceptible to different flood conditions (e.g., more frequent flooding) and drivers of loss and damage (e.g., deeper and longer duration of flooding; Figure 1.3). Adjustments to account for these conditions in the rate setting method may be necessary to ensure that rates for negatively elevated structures are credible and fair.

This report evaluates methods for calculating risk-based premiums for negatively elevated structures and examines data and analysis needed to support risk-based premiums for these structures, as well as issues of feasibility, implementation, and cost of underwriting risk-based premiums for negatively elevated structures (Box 1.1). As specified in the charge, the focus is on the methods for calculating premiums, not on what those premiums should be. A separate report (NRC, 2015) addresses the affordability of NFIP insurance premiums. At the request of the NFIP, the analysis focused on single family homes, which make up the majority of NFIP policies.

NATIONAL FLOOD INSURANCE PROGRAM

Insurance provides a means for an individual or business to transfer the risk of potential losses to another entity in exchange for payment of a premium. In the early part of the 20th century, private flood insurance was offered in some areas, but was not widely available because of inadequate information for projecting the cost of future flood losses, the potential for catastrophic losses for insurers, and the expectation that only those at high risk of flooding would seek insurance, thus diminishing the ability to spread risk (Pasterick, 1988). State regulation of insurance prices and tax policies limiting the ability to build adequate reserves added further disincentives for private companies to offer flood insurance. Private insurance companies stopped covering flood losses in 1929, a few years after a Mississippi River flood inundated 13 million acres of land and left more than 700,000 people homeless (AIR, 2005).

[2] Public Law 112-141.

BOX 1.1
Study Charge

An ad hoc committee will conduct a study of pricing negatively elevated structures in the National Flood Insurance Program. Specifically, the committee will

1. Review current NFIP methods for calculating risk-based premiums for negatively elevated structures, including risk analysis, flood maps, and engineering data.
2. Evaluate alternative approaches for calculating "full risk-based premiums" for negatively elevated structures, considering current actuarial principles and standards.
3. Discuss engineering, hydrologic, and property assessment data and analytical needs associated with fully implementing full risk-based premiums for negatively elevated structures.
4. Discuss approaches for keeping these engineering, hydrologic, or property assessment data updated to maintain full risk-based rates for negatively elevated structures.
5. Discuss feasibility, implementation, and cost of underwriting risk-based premiums for negatively elevated structures, including a comparison of factors used to set risk-based premiums.

After devastating flooding from Hurricane Betsy triggered losses of more than $11 billion (in 2014 dollars; Michel-Kerjan, 2010) in 1965, the federal government began studying the feasibility of offering flood insurance (AIR, 2005). A few years later, Congress passed the National Flood Insurance Act of 1968,[3] which established the National Flood Insurance Program. The program set minimum standards for development in the floodplain (i.e., elevating structures to at least the base flood elevation, limiting development in designated floodways) and offered federal flood insurance to residents and businesses in communities that agreed to adopt and enforce ordinances that meet or exceed NFIP standards. Under the program, federally funded engineering studies and modeling would be used to assess and map flood hazards. This information would be used to promote better land use and construction decisions, and thereby reduce future flood losses as the vulnerability to inundation diminished over time. It would also be used to support insurance rate setting. The Federal Emergency Management Agency currently administers the NFIP, sets insurance rates commensurate with program guidelines, and carries out floodplain mapping and analysis to support rate setting and floodplain management.

The NFIP was modeled after personal lines of insurance (e.g., homeowners, automobile), with risks grouped into classes and limited use of individual risk ratings. However, NFIP insurance differed from private insurance in three key ways. First, the NFIP was not initially capitalized. Rather than hold sufficient funds for eventual heavy flood losses, the program would receive an infusion of funds from the federal treasury when necessary. Limited borrowing authority from the federal treasury would provide a short-term backstop to enable insured claims to be paid in cases of high losses. Second, the NFIP could not choose who would be insured. All residents and businesses in a participating community would have access to NFIP flood insurance, even the high risk policyholders. Third, owners of existing homes and businesses (the majority of policyholders) were charged premiums that were significantly lower than warranted by their risk of flooding. It was anticipated that over time, older floodprone construction would be removed from the policyholder base, and the new policyholders would pay risk-based rates. No provision was made to cover the premium shortfall, such as routinely infusing funds into the program or building additional charges into premiums for newer construction.

Over the years, Congress made a number of adjustments to the NFIP. A changing mix of incentives and penalties, coupled with periodic reminders of the adverse consequences of flooding, led to significant growth of the program. The number of policies issued rose from about 1.5 million in 1978 to 5.5 million at

[3] Public Law 90-448.

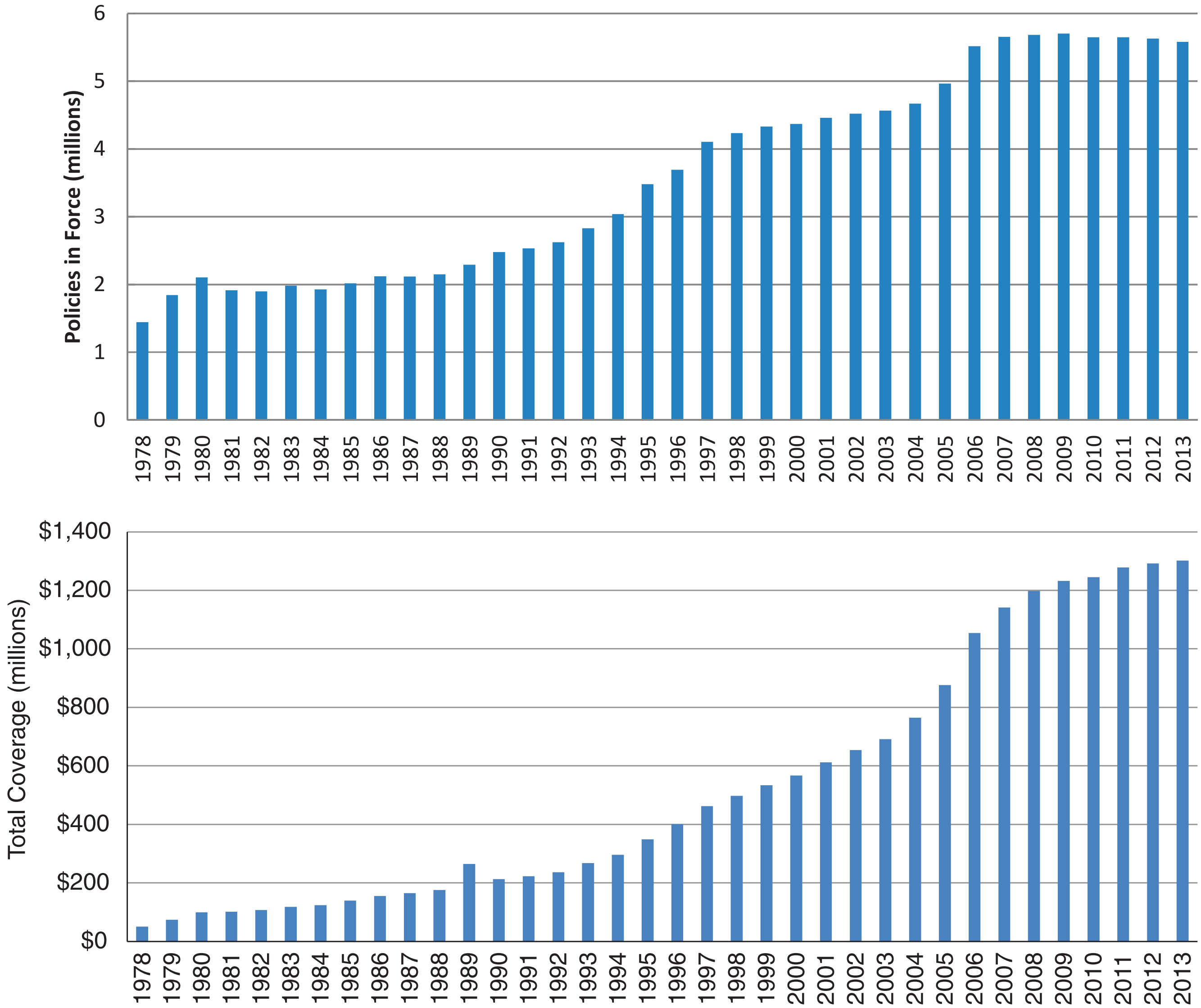

FIGURE 1.4 NFIP statistics by calendar year. (Top) Total number of policies in force. (Bottom) Total coverage of NFIP policies in millions, not adjusted to a common year. In 2012 dollars, coverage rose from $178 billion in 1978 to $1.3 trillion in 2013. SOURCE: FEMA, http://www.fema.gov/statistics-calendar-year.

the end of 2013 (Figure 1.4, top). In addition, the total value of property insured by the NFIP rose from $178 billion in 1978 (in 2012 prices) to $1.3 trillion in 2013 (Figure 1.4, bottom). The increase in insured value has been attributed to two factors: (1) policyholders purchase nearly twice as much flood insurance as they did 30 years ago[4] and (2) the population and number of policyholders has increased substantially in coastal states, which now account for a large portion of the NFIP portfolio (Michel-Kerjan, 2010). Some important changes to the NFIP over its history are summarized below.

[4] Homeowners can obtain coverage up to $250,000 for structures and $100,000 for contents. Inflation-corrected data show that the average quantity of insurance per policy almost doubled over 30 years, from $114,000 in 1978 to $217,000 in 2009 (Michel-Kerjan, 2010).

Evolution of the NFIP

The NFIP began operations in 1969, and a consortium of private companies (the National Flood Insurers Association) was established to sell and service NFIP flood insurance policies (AIR, 2005). At the time, the purchase of flood insurance was not required. In 1972, Hurricane Agnes revealed that few property owners had availed themselves of NFIP flood insurance. The Flood Disaster Protection Act of 1973[5] made insurance purchase mandatory for any resident with a federally backed mortgage in an NFIP-participating community. Lenders were responsible for ensuring that this requirement was carried out. To encourage acceptance of the new insurance purchase requirements, insurance subsidies were expanded to cover structures built after initial floodplain mapping, but before 1975, and the subsidized rates were substantially lowered. As a result, community and state participation in the NFIP greatly expanded and the number of policies increased.

Other public policy decisions made in the 1970s concerned changing flood risks. Development in the floodplain and other factors (e.g., climate change) might increase the flood risk for some structures that had been built in compliance with NFIP standards. To prevent large increases in premiums, these structures were allowed to retain their lower risk rating classification if conditions beyond the control of the property owner later increased the flood risk. This practice is often referred to as administrative grandfathering. It was anticipated that the rates for classes with grandfathered properties would have to be adjusted over time to reflect the mix of some higher risk properties.

In the 1970s, most of the properties in the NFIP were older construction and received subsidized insurance rates. Consequently, the premiums collected were insufficient to cover the annual costs of the program. From 1981 to 1988, rates were increased and coverage was changed to reduce premium subsidies and to improve the financial condition of the NFIP. Another major change concerned private insurance company participation in the NFIP. In 1977, the National Flood Insurers Association dissolved its relationship with the NFIP because of disagreements about authority, financial control, and other operational matters (AIR, 2005). In 1983, the Write Your Own Program reestablished a relationship with insurance companies, allowing them to sell and service the standard NFIP policies in their own names, without bearing any of the risk, in exchange for a fee. The objective was to use insurance industry knowledge and capabilities to increase the size and geographic distribution of the NFIP policy base and to improve service to NFIP policyholders.[6]

In the late 1980s, it became clear that older flood-prone construction was only slowly being removed from the policyholder base, and so mitigation began to be considered. The Robert T. Stafford Disaster Relief and Emergency Assistance Act of 1988[7] authorized funding for hazard mitigation projects aimed at reducing the risk of future flood damage or loss, such as elevating buildings, utilities, or roads; increasing the capacity of storm drainage systems; restoring wetlands or landforms that provide natural flood protection; or removing structures that are flooded repeatedly. In 1990, the NFIP implemented the Community Rating System, which rewarded community floodplain management efforts that go beyond minimum NFIP standards. Under the Community Rating System, communities receive points for taking additional actions related to flood hazard mapping and regulations, flood damage reduction, flood preparedness, and public education about flood risk in Special Flood Hazard Areas. These points are translated into discounts on insurance premiums for policyholders in that community.[8]

In 1993, record flooding in the upper Mississippi and lower Missouri River basins showed that only about 10 percent of properties eligible for flood insurance were insured (AIR, 2005). The NFIP Reform Act of 1994[9] introduced monetary penalties for lenders who do not enforce federal flood insurance requirements and denied future federal disaster assistance to property owners who allowed their flood insurance policy to lapse after receiving disaster assistance. In the late

[5] Public Law 93-234.

[6] See http://www.fema.gov/national-flood-insurance-program/what-write-your-own-program.

[7] Public Law 100-707.

[8] Currently about two-thirds of all NFIP insurance policies in force are in Community Rating System communities. Approximately 56 percent of participating communities take actions that earn premium discounts of 5–10 percent, and 43 percent of communities earn discounts of 15–25 percent. Only a few communities earn premium discounts of 30–45 percent. See the Community Rating Fact Sheet, http://www.fema.gov/media-library-data/20130726-1605-20490-0645/communityratingsystem_2012.pdf.

[9] Public Law 103-325.

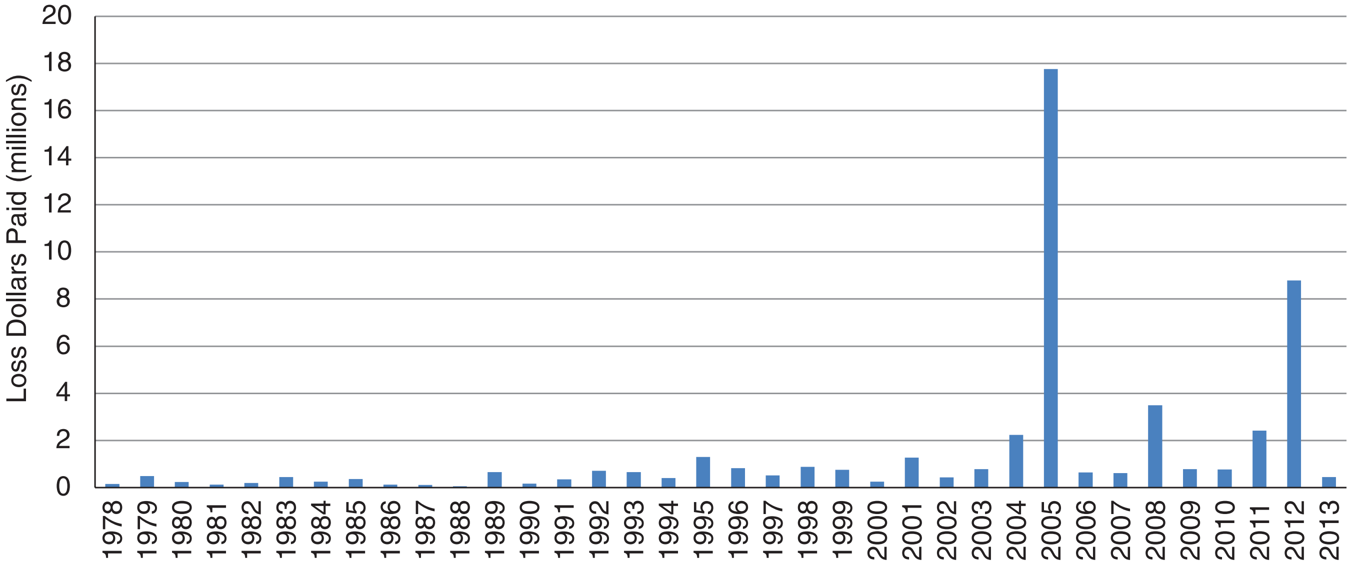

FIGURE 1.5 Annual insured claims paid by the NFIP, unadjusted to a common year. SOURCE: FEMA, http://www.fema.gov/statistics-calendar-year.

1990s and early 2000s, Congress turned its attention to properties that flooded repeatedly. The Flood Insurance Reform Act of 2004[10] targeted mitigation funding toward the worst repetitive loss properties and denied subsidized premiums to property owners who refused mitigation assistance.

From 1987 to 2005, the NFIP had been able to use premium income to repay funds it borrowed from the U.S. Treasury to cover insured flood losses. Premium income was set to cover the historical average loss year, from 1978 to present. In 2005, hurricanes Dennis, Katrina, Rita, and Wilma struck, causing the first truly catastrophic losses to the NFIP in its history (Figure 1.5). In fact, NFIP claims from these hurricanes, which were nearly $19 billion, exceeded the total losses of the program over its history (AIR, 2005). In December 2013, the NFIP owed the Treasury $24 billion, primarily to pay claims associated with hurricanes Katrina and Sandy (GAO, 2014).

A recent review of the NFIP concluded that "the NFIP is constructed using an actuarially sound formulaic approach for the full-risk classes of policies, but is financially unsound in the aggregate because of constraints (i.e., legislative mandates) that go beyond actuarial considerations" (NRC, 2013, p. 79). The Biggert-Waters Flood Insurance Reform Act of 2012 aimed to put the NFIP on sounder financial footing by authorizing higher premiums to build up program reserves in advance of heavy loss years. The act also phased out subsidized and grandfathered insurance rates over several years. However, if a policy lapsed or the structure was sold, then the owner would then be charged the risk-based rate based on the latest flood maps.[11] Premiums began increasing at the end of 2013, and some of these increases were large. The Homeowner Flood Insurance Affordability Act of 2014[12] rolled back these large, sudden increases and gave the NFIP the flexibility to set annual rate increases up to 18 percent for most policies.[13] Although the goal of phasing in risk-based rates has not changed, the annual rate increase that the NFIP chooses will determine how long it will take to reach this goal.

[10] Public Law 108-264.

[11] A recent analysis of the NFIP portfolio revealed that the average tenure of flood insurance is between 3 and 4 years, so this provision is likely to affect a significant number of homeowners (Michel-Kerjan et al., 2012).

[12] Public Law 113-89.

[13] See the overview of the Homeowner Flood Insurance Affordability Act, http://www.fema.gov/flood-insurance-reform.

ORGANIZATION OF THE REPORT

This report examines methods for calculating risk-based rates for negatively elevated structures in the NFIP. Chapter 2 provides an overview of current NFIP methods for calculating flood insurance rates, as well as the flood studies and mapping used to support rate setting. Setting risk-based insurance rates depends on an accurate assessment of flood risk—the magnitude of flood loss and the likelihood that losses of that magnitude will occur. Chapter 3 compares the NFIP and other methods for assessing flood risk and calculating flood losses. Chapter 4 identifies factors that affect negatively elevated structures and changes to NFIP methods that could address them. Finally, Chapter 5 presents the committee's conclusions and discusses data and implementation issues. Biographical sketches for the committee members (Appendix A), a glossary of technical terms used in this report (Appendix B), and a list of acronyms and abbreviations (Appendix C) appear at the end of the report.

2

NFIP Procedures for Analyzing Flood Hazard and Calculating Insurance Rates

Under the National Flood Insurance Program (NFIP), engineers carry out hydrologic and hydraulic analyses to describe flood hazard, calculate flood elevations, delineate floodplain boundaries, and designate flood zones for insurance rating. The results of the flood studies are summarized in reports and portrayed graphically on Flood Insurance Rate Maps (FIRMs). The NFIP, Write Your Own Companies, and insurance agencies use the maps to determine whether a structure being insured is located in a Special Flood Hazard Area, and, if so, its elevation relative to the base flood elevation. This information is combined with additional information about the flood hazard, exposure to the hazard, structure characteristics, expenses, and other factors to determine insurance rates. This chapter provides an overview of NFIP flood studies, Flood Insurance Rate Maps, and methods for calculating flood insurance rates.

FLOODPLAIN ANALYSIS AND MAPPING

NFIP flood study methods and maps were reviewed in detail in *Mapping the Zone: Improving Flood Map Accuracy* (NRC, 2009), and are summarized below.

Flood Studies

The type of flood study depends on the type of flood hazard, primarily riverine or coastal. Riverine flood studies focus on the river's watershed, precipitation, the topography along the river and adjacent floodplain, and the hydraulic characteristics of the river and floodplain. The studies involve the following steps, which are illustrated in Figure 2.1:

1. Hydrologic analyses are conducted to estimate the river discharge rate with 1 percent annual chance of exceedance. Depending on data availability, the discharge rate is estimated using (a) statistical analyses of historical annual maximum discharges measured at stream gages; (b) regression equations derived from observations at similar locations in the region to estimate the 1 percent annual chance exceedance discharge as a function of drainage area and other river basin characteristics; or (c) precipitation-runoff models, which convert rainfall and snowmelt to stream discharge rates. These calculations are based on past events and do not account for changing hydrologic conditions resulting from watershed development, increased storm intensity, or other factors.
2. Hydraulic modeling is carried out to determine the depths that correspond to the river discharge rates estimated in the hydrologic analyses. Software applications such as HEC-RAS are commonly used to model the movement of water. HEC-RAS simulates flow that is predominantly parallel to the channel, based on the geometry of the channel and floodplain, the slope of the channel and ground, the resistance to flow due to channel roughness and bridges and obstructions, and ponding and pooling of water in the channel and on the floodplain. In

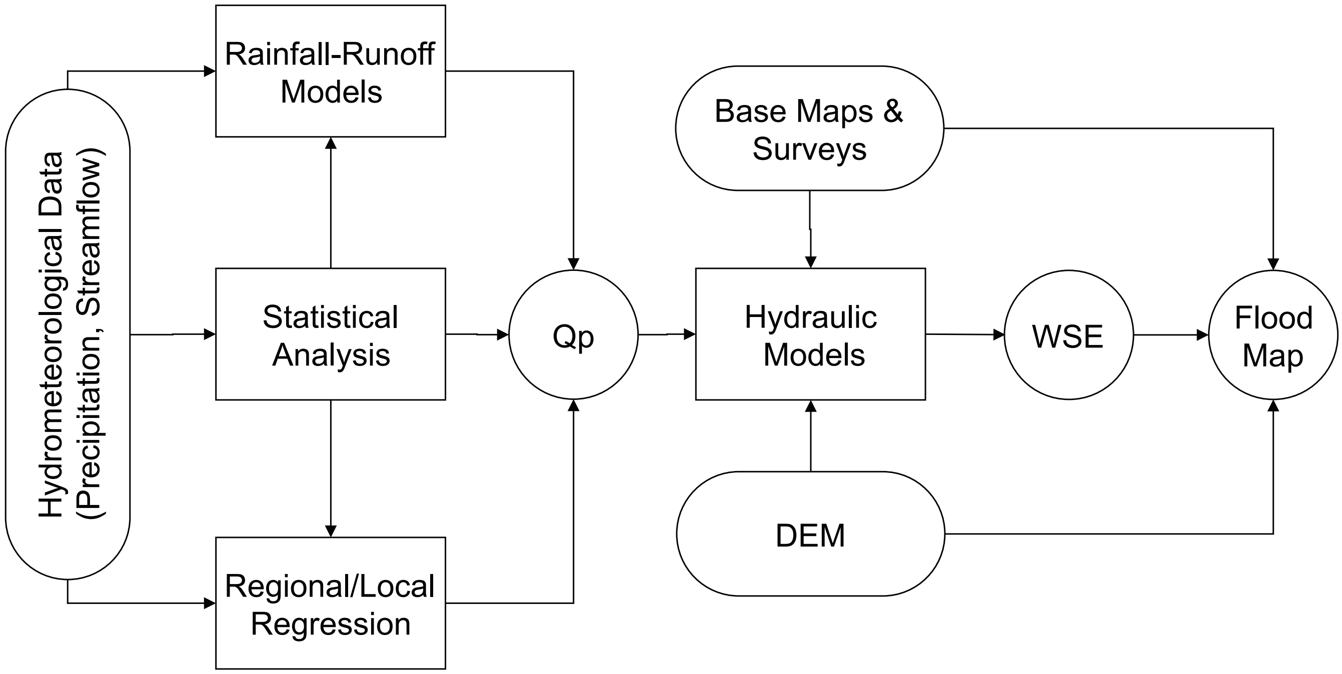

FIGURE 2.1 Schematic of an idealized riverine flood study showing the data inputs (rounded boxes), models and methods used in the hydrologic and hydraulic analysis (boxes), and outputs (circles), including the flood discharge (Qp) and the water surface elevation (WSE). Note: DEM = digital elevation model. SOURCE: NRC (2009).

the analysis, levees that meet NFIP standards are modeled as blocking flow onto the floodplain, and levees that do not meet the standard are modeled as if they fail to protect. This model accounts for the loss of natural water storage in the floodplain. The result of the computation is an estimated base flood elevation for a cross section of the channel and floodplain. When flow patterns are more spatially variable, a two-dimensional hydraulic model is used to compute the maximum water surface elevation for cells or polygons that represent the channel and floodplain geometry.

3. Comparisons of estimated water surface elevations at river cross sections (or cells or polygons) to the ground elevations along the river are made to define the extent and properties of the inundated floodplain. If the computed water surface elevation for a point or cell is greater than the ground elevation, then the point or cell will be inundated by the 1 percent annual chance exceedance flood and the difference between the two elevations is the inundation depth. Ground elevations are estimated using topographic data collected in field surveys or taken from digital elevation models derived from aerial surveying (photogrammetry) or, since the early 2000s, from remote sensing technologies, such as lidar (light detection and ranging).

The same process is followed for the 0.2 percent annual chance exceedance flood and delineation of the moderate flood hazard area. The studies also establish the floodway—the stream channel and adjacent part of the floodplain that must remain open to permit passage of the 1 percent annual chance exceedance discharge, and thus prevent an increase in flood levels.

Coastal flood studies are similar to riverine flood studies, but they also assess the effects of storm surge (water piled up against the shore during a storm) and tidal- and wind-driven wave action. The studies use data on fetch (the distance over water that the wind blows in a single direction), near-shore terrain and water depths, and wind speed to predict storm surge properties. Data on past storms from gages and historic high water marks are used with statistical and conceptual models to determine the storm surge elevations that have a 1 percent chance of being exceeded annually. Next, transects perpendicular to the shoreline are surveyed to determine onshore and offshore ground elevations. The elevations are then used to compute the height of wave crests and wave run-up (the rush of waves up a slope or structure). For coastal flooding, the base flood elevation is the stillwater elevation plus wave run-up, or the wave crest elevation, whichever is greater (FEMA, 2011).

Flood studies can be expensive (up to a few tens of thousands of dollars per stream mile; NRC, 2009), so the NFIP strategy is to carry out the detailed studies described above in densely populated areas. In relatively unpopulated areas, the NFIP generally conducts approximate studies, which use existing flood data and floodplain information (e.g., historic high water marks, aerial photographs of previous floods, empirical information on stream characteristics) to generate an approximate outline of the Special Flood Hazard Area. Because detailed hydraulic analyses are not performed, base flood elevations are generally not determined in approximate studies.

Flood Insurance Rate Maps

Results from flood studies are portrayed graphically on FIRMs, which show flood hazard areas and flood zones, and may also show base flood elevations, floodways, and other data. An example of a FIRM in a riverine area is shown in Figure 2.2. FIRMs are used for a variety of purposes, including rating flood insurance policies; regulating new development in floodprone areas; determining whether flood insurance must be purchased as a condition of a loan; and local flood mitigation planning, evacuation, and infrastructure design.

About one-third of the nation's 3.5 million miles of rivers and coasts has been mapped, covering more than 90 percent of the U.S. population (NRC, 2009). Only about half of those maps have flood elevations. Moreover, the age and quality of these maps vary. In 2008, half of the NFIP's map panels were more than 15 years old, and 8 percent were 10 to 15 years old (GAO, 2008; Michel-Kerjan, 2010). Flood study results are presumed representative of current flood hazard for 5 years, after which time they are examined and identified as representative and appropriate or in need of updating.[1] Current funding levels are sufficient to update existing flood studies, but not to map new areas or to increase the number of miles with base flood elevations.

FIRMs delineate areas of high, moderate, and minimal flood hazard. These areas are labeled as particular flood zones based on the type of flooding (e.g., riverine, coastal, shallow), whether detailed hydraulic analyses were performed (and thus whether base flood elevations were calculated), and the presence of flood protection measures. These zones, which are described in Table 2.1, are used in the insurance rate setting process. Some of the zones have been renamed (e.g., Zone X [shaded] has replaced Zone B) or grouped into larger categories (e.g., Zone AE has replaced zones A1–A30). Because it can take many years to carry out the engineering studies needed to create a new FIRM or revise an existing FIRM, the older zone designations are still found on some flood maps.

NFIP INSURANCE RATES

The National Flood Insurance Act of 1968 established two broad categories of insurance rates for the NFIP:[2]

1. risk-based rates (also called actuarial rates), based on flood risk and accepted actuarial principles (e.g., premium income covers losses and costs of providing insurance; rates are fair, reasonable, and not unfairly discriminatory; Mathewson et al., 2011); and
2. subsidized rates for certain older structures, based on considerations that would yield reasonable premiums while encouraging floodplain management and the widespread purchase of flood insurance.

An overview of how rates are determined for these two categories is presented below.

[1] Presentation to the committee by Doug Bellomo, Director, Risk Analysis Division, FEMA, on January 6, 2014.

[2] Public Law 90-448.

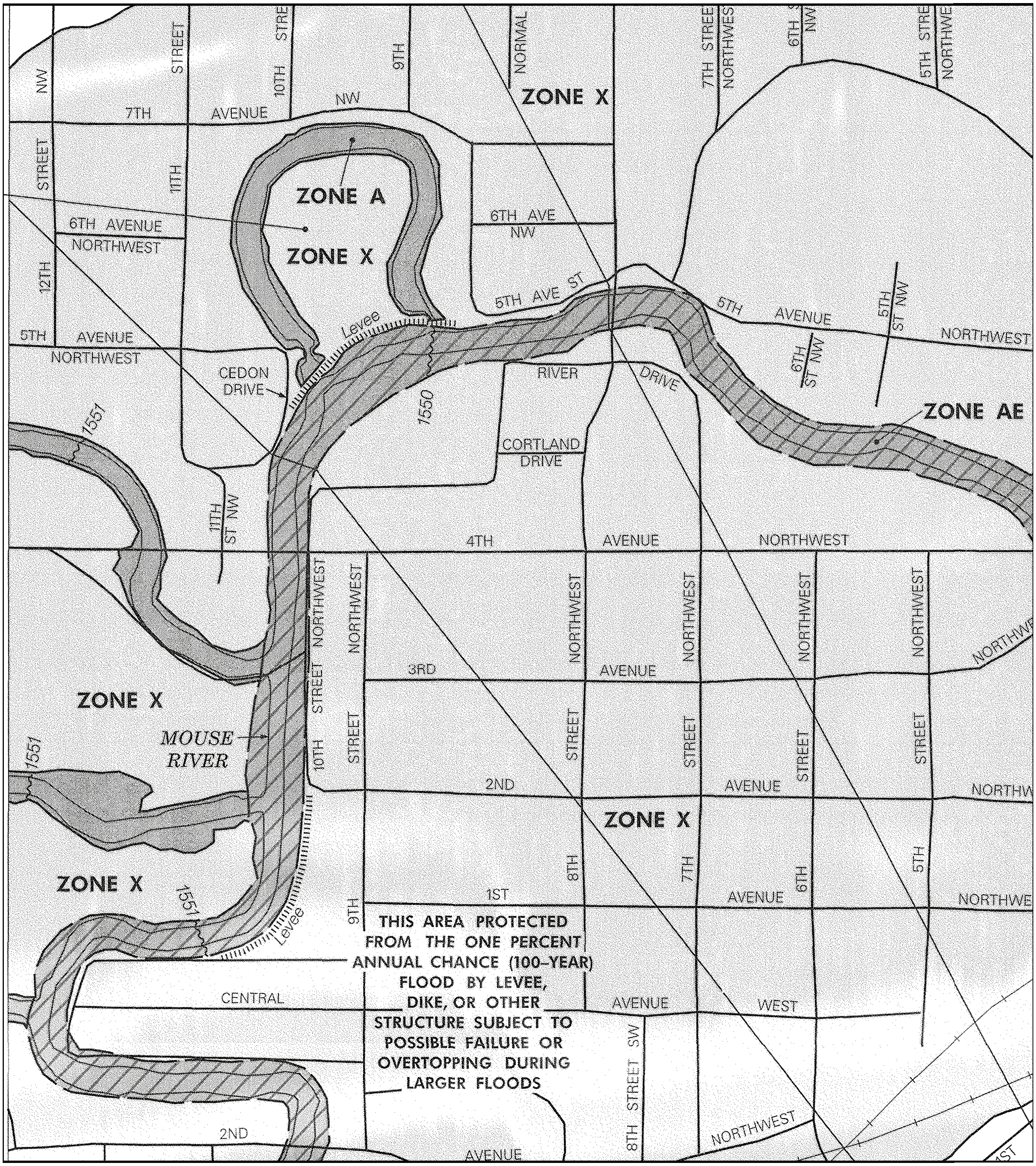

FIGURE 2.2 Portion of a Flood Insurance Rate Map of Ward County, North Dakota, which flooded in 2011 (see Figure 1.1). Dark gray areas denote the Special Flood Hazard Area (AE and A zones), and light gray denotes areas of moderate flood risk (shaded X zone). Levees along portions of the river (dotted lines) are credited as protecting areas from the 1 percent annual chance exceedance flood. Diagonal lines show where cross sections were taken. SOURCE: FEMA Map Service Center (map item ID 38101C0781D).

TABLE 2.1 NFIP Flood Zones

Hazard Level	Zone	Description
Special Flood Hazard Areas		
High	A	Areas subject to inundation by the 1 percent annual chance exceedance flood. Because detailed hydraulic analyses have not been performed, no base flood elevations (BFEs) or flood depths are shown.
	AE, A1–A30	Areas subject to inundation by the 1 percent annual chance exceedance flood determined by detailed methods. BFEs are shown within these zones. Zone AE is used on new and revised maps in place of zones A1–A30.
	AH	Areas subject to inundation by 1 percent annual chance exceedance flood (usually areas of ponding) where average depths are 1–3 feet (shallow flooding). BFEs derived from detailed hydraulic analyses are shown within this zone.
	AO	Areas subject to inundation by 1 percent annual chance exceedance flood (usually sheet flow on sloping terrain) where average depths are 1–3 feet (shallow flooding). Average flood depths derived from detailed hydraulic analyses are shown within this zone.
	AR	Areas that result from the decertification of a previously accredited flood protection system that is determined to be in the process of being restored to provide base flood protection.
	A99	Areas subject to inundation by the 1 percent annual chance exceedance flood, but which will ultimately be protected upon completion of an under-construction federal flood protection system. In these areas, enough progress has been made on the construction of a protection system, such as dikes, dams, and levees, to consider it complete for insurance rating purposes. Zone A99 may be used only when the flood protection system has reached specified statutory progress toward completion. No BFEs or flood depths are shown.
	V	Areas along coasts subject to inundation by the 1 percent annual chance exceedance flood with additional hazards associated with storm-induced waves. Because detailed coastal analyses have not been performed, no BFEs or flood depths are shown.
	VE, V1–V30	Areas along coasts subject to inundation by the 1 percent annual chance exceedance flood with additional hazards due to storm-induced velocity wave action. BFEs derived from detailed hydraulic coastal analyses are shown within these zones. Zone VE is used on new and revised maps in place of zones V1–V30.
Other Areas		
Moderate	B, X (shaded)	Moderate risk areas within the 0.2 percent annual chance exceedance floodplain, areas of 1 percent annual chance exceedance inundation where average depths are less than 1 foot, areas of 1 percent annual chance exceedance inundation where the contributing drainage area is less than 1 square mile, and areas protected from the 1 percent annual chance exceedance flood by a levee. No BFEs or flood depths are shown. Zone X (shaded) is used on new and revised maps in place of Zone B.
Minimal	C, X (unshaded)	Minimal risk areas outside the 1 percent and 0.2 percent annual chance exceedance floodplains. No BFEs or flood depths are shown. Zone X (unshaded) is used on new and revised maps in place of Zone C.
Undetermined	D	Unstudied areas where flood hazards are undetermined, but flooding is possible.

SOURCE: FEMA Map Service Center.

Risk-Based Rates

Risk-based rates are charged for post-FIRM structures in all flood zones and for pre-FIRM structures in areas of moderate and minimal flood hazard (Hayes and Neal, 2011). Rates are calculated by estimating the average annual loss (in dollars) from flooding, then adjusting for program costs (Box 2.1). NFIP estimates of average annual loss are made using the NFIP hydrologic method, which has two components (FEMA, 2013d):

BOX 2.1
NFIP Formula for Calculating Risk-Based Rates

The NFIP actuarial rate formula for calculating risk-based rates is as follows:

$$RATE = \left[\sum_{i=Min}^{Max} \left(PELV_i \times DELV_i \right) \right] \times \frac{LADJ \times DED \times UINS}{EXLOSS},$$

where

PELV is the annual probability that flood waters will reach or exceed a given depth relative to the base flood elevation
$PELV_i$ is the incremental probability that the flood water depths are in a certain interval
DELV is the damage to the property, expressed as a percentage of the total property value (replacement value for structure, actual cash value for contents), resulting from that level of flood water
$DELV_i$ is the average damage within a certain depth interval corresponding to $PELV_i$
Min is the minimum elevation relative to the lowest floor at which flood damage occurs
Max is the elevation relative to the lowest floor at which flood damage approaches a maximum
LADJ is a loading factor to account for loss adjustment expenses
DED is a factor to eliminate that portion of the loss that will be borne by the policyholder through his or her deductible
UINS is a factor to adjust for how much a policyholder has underinsured his or her property
EXLOSS is the expected loss ratio, which serves as a loading for underwriting expenses, a contingency factor, and other factors

SOURCE: FEMA (2013d).

1. a description of the hazard that estimates the probability of various depths of flood water in the structure (denoted PELV in the rate formula), based on selected NFIP hydrologic and hydraulic analyses; and
2. a description of exposure and vulnerability that estimates the damage that flood water depths would cause (denoted DELV), based on NFIP claims from similar inundation depths.

The average annual loss is calculated by summing the probability-weighted estimate of damage amounts for each possible inundation depth within the structure.

The average annual loss is converted into an insurance rate by adjusting for expenses and other factors (the second term of the formula in Box 2.1). Rates are adjusted upward (loaded) to account for loss adjuster fees and claims investigations costs (LADJ) as well as agent commissions and acquisition expenses and contingencies (EXLOSS). The rates are also adjusted upward to account for underinsurance (UINS; i.e., the insured value is less than the full value of the property). Rates are adjusted downward to account for the portion of the claim that will not be covered because of the policy deductible (DED). It should be noted that the rate formula presented here is a simplification useful for illustrating the concepts. The actual rate formula employed by the NFIP contains more complicated terms for adjusting for underinsurance and for computing rates for basic and additional limits of insurance coverage (see Hayes and Neal, 2011).

Application of the rate formula yields a price per unit of insurance for each $100 of property coverage. The rate is multiplied by the amount of insurance being purchased to determine the premium a policyholder pays. In Community Rating System communities, policyholders receive premium discounts for mitigation actions taken to reduce flood risk in the community, such as improving drainage systems (see Chapter 1, "National Flood Insurance Program"). Individual policyholders can also reduce their premiums through mitigation, for example, by elevating their home or business. In such cases, the average flood losses will be lower, and the insurance rating will be redone using the revised rating elements. The effect of most substantive mitigation actions can be accommodated in the current rate setting process. The impact on rates and the costs of mitigation actions, including those not covered in current rate setting and underwriting processes (e.g., residential floodproofing), are being investigated by the NFIP (FEMA, 2015).

The hydrologic method is used to determine risk-based rates in Special Flood Hazard Area zones, where the most detailed engineering studies are carried out and base flood elevations are established. About one-third of the risk-based insurance policies cover structures in other zones (e.g., Zone X; Hayes and Neal, 2011).[3] In these zones, the NFIP has determined that the costs to develop flood magnitude and probability functions are too high relative to the program's floodplain management benefits (Hayes and Neal, 2011). Consequently, risk-based rates in these zones are based on extrapolations of the hydrologic method, along with other actuarial and engineering judgments and underwriting experience.

The insurance premium paid by a flood insurance policyholder depends on the flood zone, occupancy (e.g., single family, nonresidential), construction (e.g., no basement), the location of contents (e.g., lowest floor, above the lowest floor), the number of floors, the type of supporting foundation, and the structure's elevation relative to the base flood elevation (FEMA, 2013b). The NFIP uses these factors to group structures into classes, then determines the average annual loss and insurance rates for each class, rather than for individual structures. Consequently, a policyholder will pay an amount averaged over the pool of all other policyholders in a given class of structures, which may be somewhat higher or lower than the premium would be if it were based on his or her individual flood risk (e.g., see Michel-Kerjan et al., 2015). Grouping insureds into classes is a standard industry practice.

Subsidized Rates

Subsidized rates are available by statute for older structures built before floodplain maps were issued and adopted by the community (pre-FIRM structures) as well as for certain newer (post-FIRM) structures, such as those with protective structural measures under construction. Pre-FIRM subsidized rates do not depend on the structure elevation. Rather, the insurance rate is based on the flood zone, occupancy, construction, and contents location (FEMA, 2013b). Pre-FIRM subsidized rates are employed primarily in Special Flood Hazard Areas where insurance purchase is mandatory. Subsidized rates for structures that are not primary residences or that suffer severe repetitive losses are beginning to be phased out (see "National Flood Insurance Program" in Chapter 1).

Subsidized rates are based both on subjective (e.g., political, public policy) considerations and objective processes, including comparisons with the amount needed to meet NFIP premium income targets. Prior to 2005, the NFIP total annual premium income was targeted so that the combination of subsidized and risk-based premiums would be at least sufficient for the historical average loss year, based on losses and associated expenses since 1978, and corrected for inflation and changes in coverage and mix of policy holders. However, catastrophic flood losses to the NFIP in 2005 (from hurricanes Katrina, Rita, and Wilma) raised the historical average loss year so much that using it to set NFIP premium income targets would have required the elimination of subsidized premiums. Consequently, the NFIP gives only partial weight to the 2005 losses in establishing the historical losses benchmark (Hayes and Neal, 2011), which reduces, but does not eliminate subsidies.

Pre-FIRM subsidized premiums are about 55–60 percent lower than warranted by their true flood risk (Hayes and Neal, 2011). However, the average subsidized premium being paid is still significantly higher than the average risk-based premium being paid, because the flood risk to pre-FIRM structures is generally so much higher than the flood risk to structures that comply with modern floodplain management ordinances.

Rating for Negatively Elevated Structures

The vast majority of negatively elevated structures in Special Flood Hazard Areas are pre-FIRM structures eligible for subsidized rates and post-FIRM structures grandfathered into rates that are lower than indicated by new mapping. Of the approximately 1 million negatively elevated structures in the NFIP portfolio, only about 240,000 have structure elevation data and have been actuarially rated.[4] These structures are mainly post-

[3] Personal communication from Andy Neal, FEMA, on March 3, 2014.

[4] Personal communication from Andy Neal, FEMA, on July 9, 2014.

TABLE 2.2 Comparison of Subsidized and Risk-Based Premiums for a Single Family Home in an AE Zone

		Premium for Type of Structure[a]	
Type of Rating	Difference between lowest floor elevation and base flood elevation	2 or more floors with basement, no machinery or equipment[b]	1 floor, non-elevated, no basement or crawlspace[c]
Subsidized rating	Not applicable	$4,203	$3,600
Risk-based rating	+4 feet	$553	$553
	+3 feet	$572	$591
	+2 feet	$604	$667
	+1 feet	$712	$931
	+0 feet	$1,090	$1,815
	−1 feet	$2,610	$5,642
	−2 feet	$2,764	$6,443
	−3 feet	$2,894	$8,589
	−4 feet	$3,035	$10,723
	−5 feet	$3,574	$13,081
	−6 feet	$4,169	$15,184
	−7 feet	$4,970	$17,215
	−8 feet	$5,977	$19,382
	−9 feet	$7,200	$21,467
	−10 feet	$8,814	$23,496

[a] Premium calculation includes coverage of $250,000 for the structure and $100,000 for its contents, a standard deductible, federal policy fee and reserve, and no Community Rating System discount.
[b] Limited basement coverage generally means lower premiums.
[c] All habitable space at ground level increases the premium.
SOURCE: Presentation to the committee by Joseph Cecil, Insurance Examiner, FEMA, on January 6, 2014.

FIRM construction built out of compliance with the base flood elevation standard. An example comparing subsidized and risk-based premiums for a single family home in an AE zone is given in Table 2.2. The premiums for negatively elevated structures are shaded gray.

The process for setting risk-based rates for negatively elevated structures is similar to that used for structures built at or above the base flood elevation, although additional underwriting procedures are required. In particular, the valuation of machinery, equipment, and appliances in basements, enclosures, and crawlspaces is factored into the rate; and additional information is collected on the construction and use of crawlspaces. Policy applications for structures that are more than 1 foot below the base flood elevation in an AE zone or more than 3 feet below the base flood elevation in a VE zone receive a more detailed review (FEMA, 2013c). In some cases, a local building official, engineer, or architect must validate assertions about the construction of the structure and enclosures below (e.g., crawlspaces, garage), as well as how a structure is elevated off the ground (e.g., foundation walls, piles). These additional procedures are intended to determine the vulnerability of negatively elevated structures to damage and how that vulnerability might affect the potential for damage to upper portions of the structure.

The additional underwriting procedures described above provide a means to set risk-based rates for negatively elevated structures without adjusting the terms of rate formula to accommodate the flood conditions and drivers of damage and loss that affect these structures. The following chapters examine the terms in the actuarial rate formula in more detail, and discuss how they can be adjusted to develop fair and credible rates for negatively elevated structures.

3

Methods for Assessing Flood Risk

A key to informed decision making on risk management and risk transfer (insurance) is an accurate assessment of risk. In the context of this report, flood risk refers to the magnitude of economic flood loss and the probability that losses of that magnitude will occur. Flood risk assessments focus on four main components:

1. Flood hazard—the probability and magnitude (e.g., depth, velocity, discharge) of flooding
2. Exposure—the economic value of assets subjected to flood hazard
3. Vulnerability—the relationship of flood hazard properties to economic loss
4. Performance—the effectiveness and behavior of flood protection and damage mitigation measures that modify the flood hazard, the exposure, or the vulnerability

This chapter describes how these four flood risk components are commonly assessed and discusses variations in assessment approaches used by government agencies and private companies to carry out their particular flood risk management or flood insurance responsibilities.

ASSESSING THE COMPONENTS OF FLOOD RISK

Assessing Flood Hazard

Flood hazard assessment estimates the probability of different magnitudes of damaging flood conditions, such as the depth of inundation, duration of inundation, velocity of moving water, quality of water, debris content of water, or the wave height in addition to still water level. For example, in many urban riverine settings, the most important flood condition is the annual maximum depth of inundation at the location of an insured structure. The depth of inundation is computed as the difference between the annual maximum water surface elevation and a reference elevation at the structure (commonly the lowest floor elevation of the structure, because this is the elevation above which water ponding will cause damage). The hazard in that location can be represented as a water surface elevation–exceedance probability function, as shown in Figure 3.1a. This function represents the probability that the annual maximum water surface elevation at a specified location will equal or exceed a specified magnitude.[1] Greater water surface elevations have lesser probability of exceedance. The magnitudes for the various probabilities depend on meteorological, hydrological, hydraulic, and topographic properties of the watershed, channels, and floodplains at and upstream of the location of interest. These magnitudes can be determined for current conditions or for future conditions (e.g., extreme precipitation as a result of climate change, urban growth in floodplains).

The water surface elevation–exceedance probability function may be derived through statistical analysis of observations of annual maximum water surface eleva-

[1] In this report, probability is expressed as a percent chance exceedance, which is probability × 100. For example, a 10 percent annual chance exceedance event has an annual exceedance probability of 0.10.

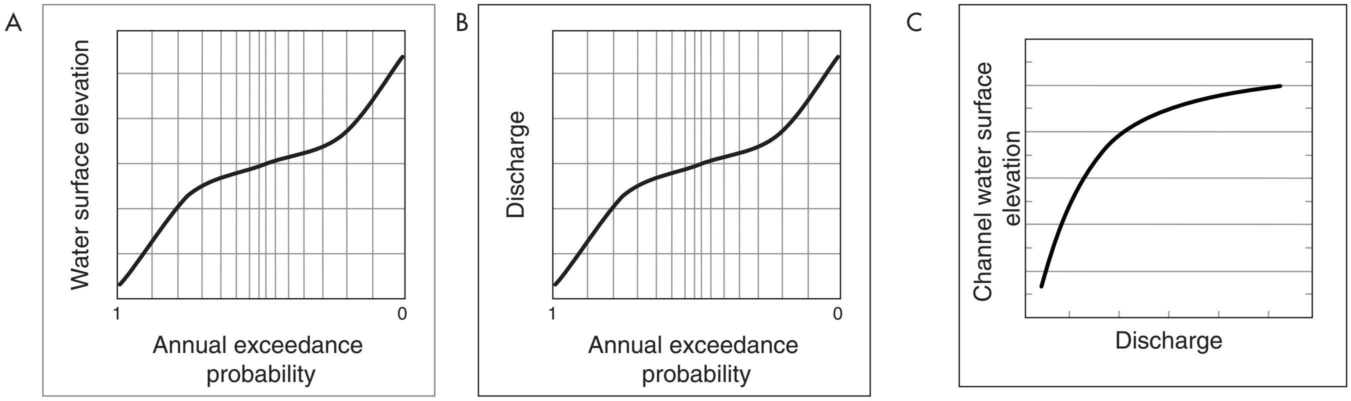

FIGURE 3.1 (a) Flood hazard for riverine systems may be represented with a water surface elevation–exceedance probability function, usually derived from flood studies. Alternatively, the function may be derived from a discharge–exceedance probability function (b), transformed with a discharge–water surface elevation function (c). The annual exceedance probability means the same thing as the annual chance of exceedance. SOURCE: Courtesy of David Ford, David Ford Consulting Engineers, Inc.

tions at a location if an appropriate sample of historical values is available from a stream gage at or near the insured structure. However, historical data are limited, and so the water surface elevation–exceedance probability function is usually derived using conceptual and empirical models of hydrologic and hydraulic processes. For riverine systems, analysts commonly develop a discharge–exceedance probability function (Figure 3.1b), then transform that with a discharge–water surface elevation function (Figure 3.1c) to derive the water surface elevation–exceedance probability function. The discharge–exceedance probability function for a stream may be developed by correcting for stream regulation then carrying out a statistical analysis of historical discharge observations or, if these data are not available, by using models of the watershed response to precipitation and channel behavior.

In floodplains with relatively uniform terrain, such as that shown in the cross section in Figure 3.2a, the water surface elevation at a structure in the floodplain is not significantly different from the water surface elevation in the channel. In such cases, a discharge–water surface elevation function (e.g., Figure 3.1c) is used to determine the channel water surface elevation, and a simple channel–floodplain water surface elevation function (e.g., Figure 3.2b), developed using an open-channel hydraulics model, is used to determine the floodplain water surface elevation.

If the terrain in the floodplain is complex—because of variable topography; flow entering and leaving the floodplain at different locations; or the presence of roadways, waterways, or impediments to flow—then inferring the floodplain water surface elevation from the channel water surface elevation may introduce significant error in the hazard description. In such cases, floodplain flow may be modeled with a two-dimensional hydraulics model. For example, the floodplain may be represented as a grid of linked cells, with the movement of water modeled from the channel to grid cells adjacent to the channel, then from cell to cell (e.g., Figure 3.3). The result is a unique water surface elevation–exceedance probability function that describes the hazard for each cell in the grid.

Assessing the Performance of Flood Protection and Damage Mitigation Measures

Flood hazard may be reduced through structural measures, such as building reservoirs, levees, or floodwalls. For example, reservoirs store water, altering the magnitude of downstream discharges, thus changing the form of the discharge–exceedance probability function (Figure 3.1b) and reducing the discharge rates for rarer events. The performance of the reservoir system during flood events is accounted for in the hazard analysis by adjusting the discharge– or water surface elevation–exceedance probability functions, although the potential for uncontrolled release of water (e.g., dam breach, gate failure) is commonly not considered.

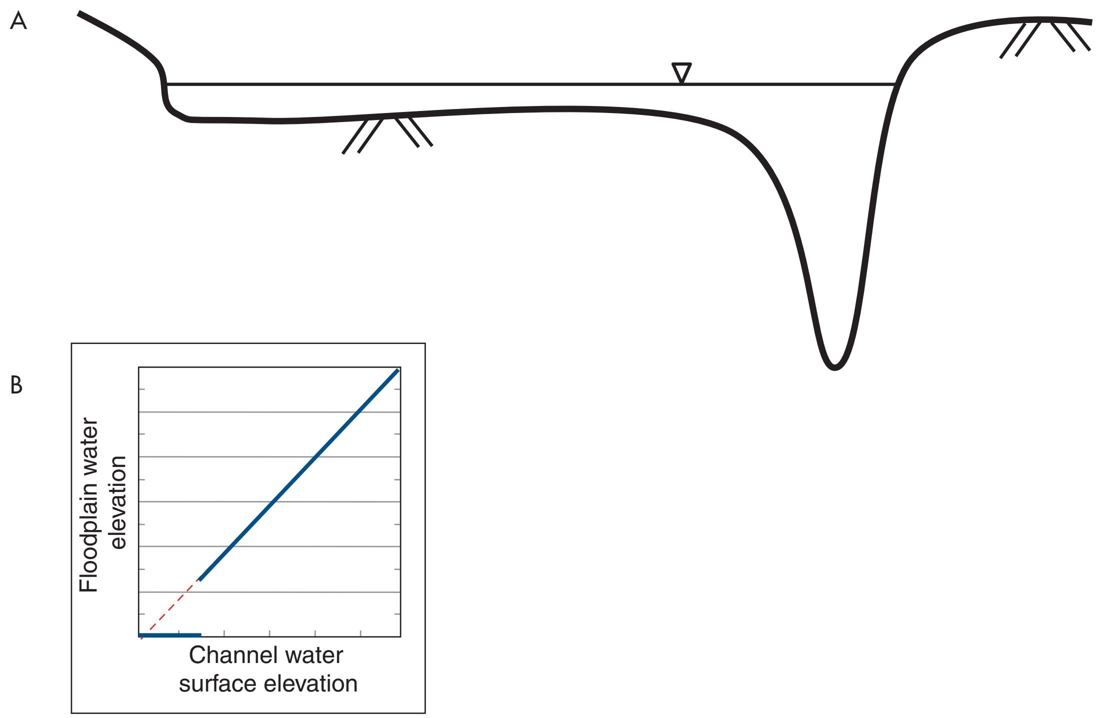

FIGURE 3.2 Water surface elevations on the floodplain adjacent to a river may be inferred from the elevation at a cross section of the river using a floodplain–channel water surface elevation function. (a) A cross section of the river and adjacent floodplain. In (b), the floodplain depth is zero until the capacity of the channel is exceeded and water moves onto the floodplain. SOURCE: Courtesy of David Ford, David Ford Consulting Engineers, Inc.

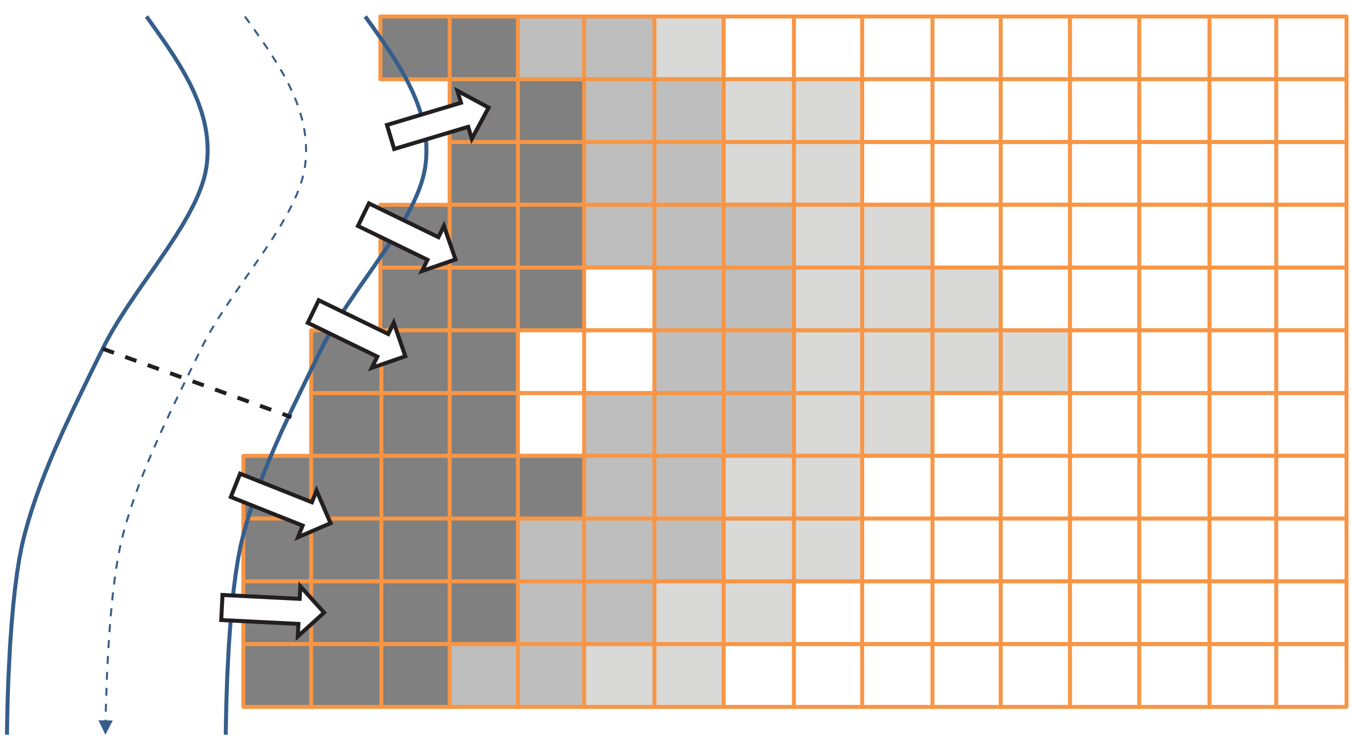

FIGURE 3.3 For complex floodplains, water surface elevations on the floodplain may be computed with a two-dimensional model. SOURCE: Courtesy of David Ford, David Ford Consulting Engineers, Inc.

A levee or floodwall constructed adjacent to a channel would also alter the relationship between the channel and the floodplain water surface elevation, and hence the floodplain water surface elevation–exceedance probability function. When the levee provides the anticipated protection, water will not inundate the floodplain and so the water depth will be zero. When the levee is overtopped by rising flood water or when it breaches as a result of structural instability, under- or through-seepage, or other factors, water will move onto the floodplain (i.e., the water depth will be greater than zero) and losses will result. This condition may be represented with a function such as Figure 3.1b, where the jump in floodplain water surface elevation coincides with levee overtopping or breaching.

To represent levee reliability (or the probability of failure of the levee to protect), a fragility function is developed to capture aleatory uncertainty (natural variability). Figure 3.4 shows the likelihood that a levee will fail to function as designed (breach), conditioned on channel water surface elevation. Similar functions can be developed to describe the likely performance of flood proofing or other local mitigation measures designed to reduce vulnerability. Fragility functions can be developed for each of the floodplain protection measures in place (e.g., levees, floodwalls, culverts, pumping stations) are included in the assessment.

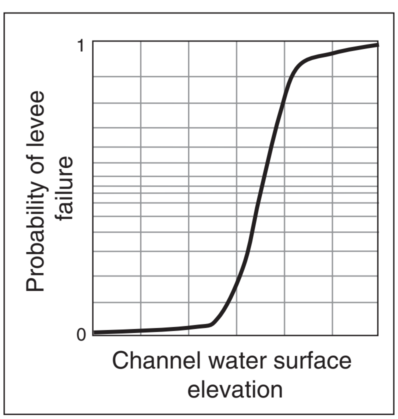

FIGURE 3.4 Variability in the performance of flood protection systems, such as levees, is represented with a fragility function, which is included in the risk assessment. SOURCE: Courtesy of David Ford, David Ford Consulting Engineers, Inc.

Assessing Exposure and Vulnerability

Exposure and vulnerability analysis examines the value of an asset and the relationship between the flood hazard and damage to the asset. This information may be represented with an inundation depth–damage function for the structure, as illustrated by Figure 3.5a. The inundation depth–damage function may be developed from a detailed valuation and investigation of the potential damage to the insured structure and/or statistical analysis of reports of damage and coincident inundation depths for similar structures. A typical approach is to determine the total value of the structure and its content; to categorize the structure according to its construction type, use, or other characteristics; and then to predict the damage corresponding to specific water depths. The damage predictor for the category is developed with a conceptual or empirical model,

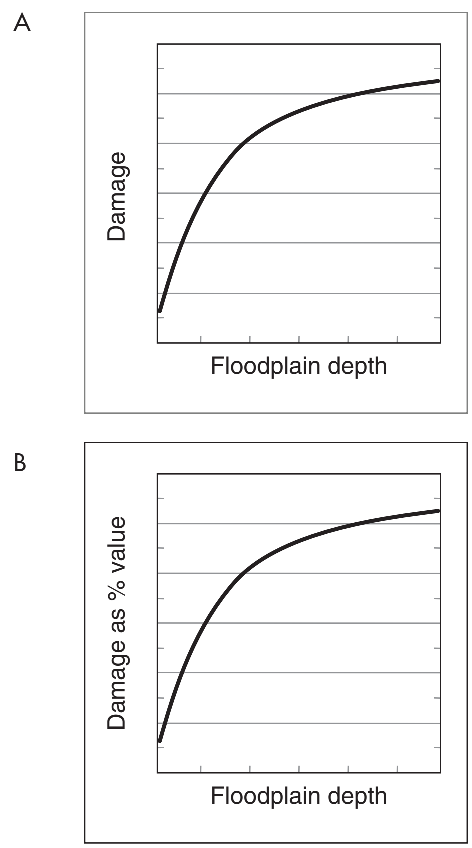

FIGURE 3.5 Exposure and vulnerability are represented with an inundation depth–damage function (a), which may be developed from a generic inundation depth–percent damage function, scaled by the total value of the asset (b). SOURCE: Courtesy of David Ford, David Ford Consulting Engineers, Inc.

and is expressed as a percentage of the total structure and content value. An inundation depth–percent damage function is illustrated in Figure 3.5b.

Assessing Risk

The consequence of flooding is assessed by transforming the water surface elevation–exceedance probability function (Figure 3.1a) with a channel–floodplain water surface elevation function (Figure 3.2b), a levee fragility function (Figure 3.4), and a floodplain inundation depth–damage function (Figure 3.5a). The result is a damage–exceedance probability function (Figure 3.6), which describes the risk. Common amounts of damage are near the center of the diagram, with probabilities near 0.50. Greater damage is less likely, with probabilities approaching zero.

The damage–exceedance probability function shown in Figure 3.6 represents the flood damage that can occur for each flood over the range of possible floods. This function can be developed for an individual structure category or for an entire portfolio of structures. The function is integrated to compute the expected annual damage for the full range of floods, also known as the average annual loss. The average annual loss is the basis for setting risk-based rates (see "NFIP Insurance Rates" in Chapter 2).

The following sections summarize risk assessment approaches used by organizations with responsibility for flood risk management or flood insurance.

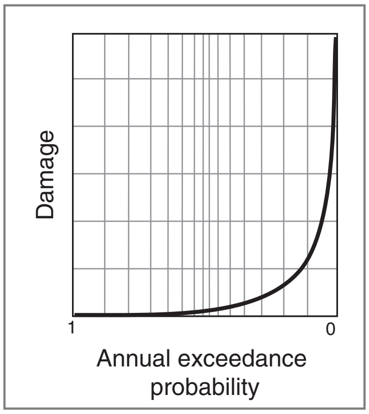

FIGURE 3.6 Flood risk is commonly represented with a damage–exceedance probability function. SOURCE: Courtesy of David Ford, David Ford Consulting Engineers, Inc.

NFIP HYDROLOGIC METHOD

The National Flood Insurance Program (NFIP) assesses flood risk for insurance purposes using a hydrologic method developed in the 1960s (HUD, 1966). The method derives a water surface elevation–exceedance probability function to describe the flood hazard in a geographical area, then transforms that function to an inundation damage–exceedance probability function using a model of damage as a function of depth of inundation (Box 2.1). The damage–exceedance probability function is then integrated to compute the average annual loss.

Flood Hazard Description: PELV Curves

The water surface elevation–exceedance probability function illustrated in Figure 3.1a, referred to in the NFIP hydrologic method as the PELV curve, represents the natural flood hazard as well as the performance of engineering measures designed to manage the hazard in Special Flood Hazard Areas. A PELV curve shows the relationship between annual exceedance probabilities and flood depths relative to the base flood elevation, representing implicitly all relevant meteorological, topographical, hydrologic, hydraulic, and performance conditions. Flood depths shown include stillwater and increases due to wind-driven and tidal-driven waves.

The PELV curves were derived in the early 1970s from a sample of water surface elevation–exceedance probability functions developed from detailed studies in communities nationwide. Analysts parameterized these water surface elevation–exceedance probability functions using the difference between the 1 percent annual chance exceedance elevation (100-year elevation) and the 10 percent annual chance exceedance elevation (10-year elevation) (MacFadyen, 1974). Next, the water surface elevation–exceedance probability functions were grouped, averaged, and smoothed to create 30 zones covering the range of hazard conditions. In each successively numbered A zone, the difference between the 1 percent and 10 percent annual chance exceedance water surface elevation increases, with differences ranging from 0.5 feet for Zone A1 (broad, shallow floodplains) to 20 feet for Zone A30 (narrow, steep mountainous valleys). Note that the classification by flood zone is not spatially or geographically oriented. Rather, it focuses on common hazard properties. Different locations in the United States will fall within the same zone if they have the same difference between the 1 percent and 10 percent annual chance exceedance water surface elevations without regard to the underlying causes of the hazard.

For each zone, a PELV curve is described with a fourth order polynomial of the form:

$$-\log_{10}[p(elev)] = C_1 + C_2 elev + C_3 elev^2 + C_4 elev^3 + C_5 elev^4,$$

where *elev* is the water surface elevation with exceedance probability p(*elev*), and C_1, C_2, C_3, C_4, C_5 are coefficients given in FEMA (2013d). The PELV curve is used in the rate formula in Box 2.1.[2] In application, NFIP analysts would determine the difference between the 1 percent and 10 percent annual chance exceedance water surface elevations for a structure from flood studies of an area, find the corresponding numbered A zone, and then derive the appropriate PELV curve with the appropriate equation for the zone.

Development and use of a nationwide set of 30 PELV curves, instead of site specific, unique water surface elevation–exceedance probability functions, allowed a workable nationwide set of rate tables to be developed. However, reviews of NFIP insurance loss experience in the early 1980s revealed inconsistencies in losses among the 30 flood zones, in part because of inherent uncertainties in the flood hazard analysis and variations in hazard conditions (e.g., a debris jam could increase local water surface elevations). At the same time, the complexity associated with determining the appropriate zone for a structure and then using that in the rate setting increased the likelihood of error by agents, who were using paper maps and rating manuals. Consequently, for rating purposes, the NFIP collapsed the 30 numbered flood zones into a smaller set of zones and weighted the resulting set in areas where NFIP policies were written (circa 1980s) for the computation of average annual loss.

Performance of Levees and Flood Storage and Diversion

The NFIP accounts for the reduction of flood hazard attributable to flood storage and diversion and to the presence of accredited levees. The impact of flood storage and diversion measures is simulated using detailed studies.[3] Reductions in inundation depth that are attributable to these measures are reflected conceptually in adjustments to the base flood elevation and, through that, to the PELV curve.

The NFIP does not set standards for building levees. However, if a levee is designed, constructed, and maintained according to U.S. Army Corps of Engineers (USACE) engineering criteria, the NFIP credits the levee with eliminating inundation and corresponding damage caused by events more frequent than the 1 percent annual chance exceedance flood. Until 2013, levees that fell short of the standard were considered "non-accredited" and assumed not to reduce flood hazard. However, under the Levee Analysis and Mapping Procedure (LAMP) for non-accredited levees, the NFIP is analyzing individual sections of levees (FEMA, 2013a). Sections that meet design, construction, and maintenance standards will be credited with providing protection and eliminating damage from the 1 percent annual chance exceedance flood and more frequent events. For sections that do not meet standards, floodplain depths will be computed using models appropriate for the relevant deficiency. For example, levees with structural deficiencies are analyzed as if they will breach in multiple locations, but will provide some hazard reduction.

Exposure and Vulnerability: DELV Curves

To assess exposure and vulnerability, the NFIP employs inundation depth–percent damage functions (referred to as DELV curves), such as the one illustrated in Figure 3.7a, based upon the type of occupancy, type of construction, and location of contents in the structure. The percent damage values are converted to monetary values by multiplying by the value of the structure (ideally the replacement value) in the final step of rate setting. The depth for assessing damage

[2] Note that p(*elev*) is the same as PELV, with rounding resulting from an imperfect polynomial fit.

[3] See http://www.fema.gov/guidelines-and-standards-flood-risk-analysis-and-mapping.

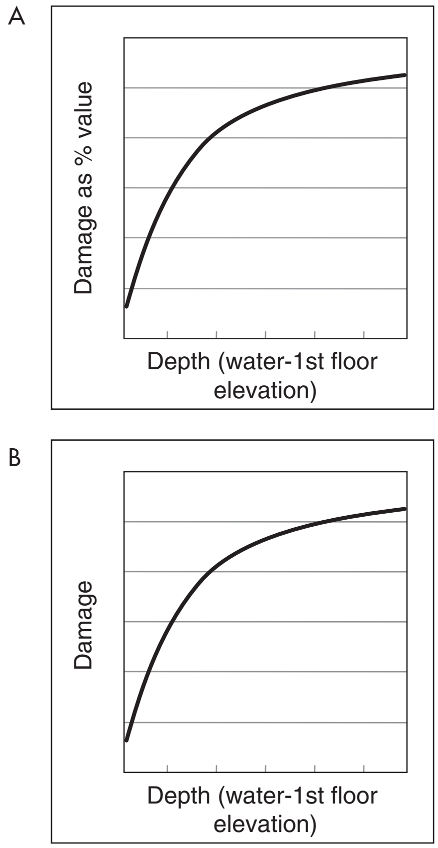

FIGURE 3.7 NFIP DELV curves predict damage as a function of depth of water relative to the lowest floor elevation of the structure. SOURCE: Courtesy of David Ford, David Ford Consulting Engineers, Inc.

is found by adjusting the inundation depth–damage function to correspond to the elevation of the structure.

Flood Risk

The NFIP expresses flood risk in terms of loss and corresponding probability. To assess risk, the DELV curve is matched with the PELV curve, which results in a damage–exceedance probability function. This damage–exceedance probability function is integrated to compute the average annual loss portion of the insurance rate (Box 2.1).

Calculations of average annual loss include the incremental contribution of losses due to the entire range of flood events, including floods less frequent than those with a 1 percent annual chance of exceedance. For the PELV curves currently used by the NFIP, the relationship between the exceedance probability and the water surface elevation is assumed to be a smooth, monotonically decreasing function.[4] Extrapolating these curves to estimate water surface elevations with less than 0.2 percent annual chance exceedance (500-year flood) is considered by the NFIP to be unreliable. Consequently, when deriving the tail of the damage–exceedance probability function, the NFIP doubles the 0.2 percent annual chance exceedance depth to estimate the associated damage from the DELV curve. For example, if the PELV curve shows a 0.2 percent annual chance exceedance depth of 1.8 feet, the NFIP will assign damage corresponding to 3.6 feet of inundation for all the depths less frequent than 0.2 percent annual chance exceedance, and will include the result in the average annual loss calculation.

U.S. ARMY CORPS OF ENGINEERS METHOD

The USACE assesses flood risk following analysis procedures laid out in Engineering Manual 1110-2-1619 (USACE, 1996). Flood damage reduction analysis software (HEC-FDA) uses methods from the engineering manual with results of traditional hydrologic engineering and economic analyses to assess flood risk.[5]

The USACE approach is similar to the NFIP's, but includes the results of site-specific flood hazard assessment and an evaluation of uncertainties in the assessment of flood hazard and levee fragility. The USACE method begins with deriving a discharge–exceedance probability function for a particular location using statistical analysis of available records or precipitation–runoff modeling of the contributing watershed. The function includes discharge values for a range of probabilities, commonly between 50 percent and 0.2 percent annual chance exceedance. The discharge–exceedance probability function is transformed to a water surface elevation–exceedance probability function using hydraulic model studies based on the best available bathymetric and topographic information. Applications are site specific, with hydraulic modeling methods selected as appropriate for the channel and floodplain properties. If levees or other water control features alter the hazard, then their performance is assessed, and uncertainty about their performance is represented with a fragility function.

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[4] Personal communication by Andy Neal, FEMA, on April 28, 2014.

[5] See http://www.hec.usace.army.mil/software/hec-fda/.

Vulnerability and exposure are assessed using the depreciated replacement value of assets and inundation depth–percent damage functions developed by the USACE (2000, 2003). The inundation depth–damage functions are consistent with, but not identical to, those used by the NFIP. Moreover, the NFIP uses the replacement value of the structure in its calculation of average annual loss, rather than the depreciated replacement value. The USACE estimates the depreciated replacement value by first estimating the replacement value, then reducing that value using the results of a site inspection to account for the condition and remaining useful life of the structure. The expected annual damage (average annual loss) is computed by integrating the damage–exceedance probability function.

The USACE risk analysis method considers the aleatory uncertainty in the assessment of flood hazard and levee performance, and in the estimation of water surface elevations from river discharges. Consideration is also given to selected sources of epistemic uncertainty. For example, the method uses probability distributions to describe the uncertainty about inputs, including uncertainties about (a) the discharge–exceedance probability function, (b) the discharge-to-water surface elevation transformation, (c) the lowest floor elevation of a structure, and (d) the values of assets. Monte Carlo sampling is used to develop the required damage–exceedance probability function and the uncertainty distributions. Results are reported with levels of significance attached.

CATASTROPHE MODELS

Many private insurers use catastrophe models to assess the risk of natural hazards, including wind, earthquakes, wildfire, and, more recently, floods (e.g., see Grossi and Kunreuther, 2005). These models are generally developed for large or geographically diverse insurance portfolios for which it is important to assess the likelihood of catastrophic losses. The models can be used to assess individual or aggregated risk (e.g., entire insurance portfolios).

Catastrophe models developed by private companies share common modules and characteristics (see Grossi and Kunreuther (2005), although details of the different models are proprietary (Czajkowski et al., 2013). In general, catastrophe models include the risk assessment components described above: a probabilistic description of flood hazard; a probabilistic description of how hazard is modified by mitigation and management measures, including a representation of the likelihood of success or failure of the measures; and a mathematical description of exposed assets and a model of their vulnerability to the hazard. As with other risk assessment methods, catastrophe models develop a representation of the likelihood of damage over time, which is analyzed statistically to compute an average annual loss.

Unlike the NFIP hydrologic method—which transforms a PELV curve with a DELV curve to derive a damage–exceedance probability function (as illustrated in Figure 3.8a–c)—catastrophe models develop and analyze long time series of flood events (Figure 3.8d), including historical events, extremely rare but physically possible events, and future flooding scenarios that account for global environmental changes. The models then use a function that relates damage to depth or other drivers (Figure 3.8e) to estimate the loss incurred with each flood event, creating a series of damage values (Figure 3.8f). The resulting series of hypothetical floods and associated damages are analyzed to compute average annual loss and other relevant metrics of hazard and consequence.

Private insurers often collect detailed construction and occupancy information to develop loss estimates for anticipated flood events. This information can then be used to develop site-specific predictors (similar to Figure 3.8e) for use in a catastrophe model. In the absence of site-specific information, classes of risk are determined and available information used to assign the structure to a class.

Catastrophe models are developed for and fitted to conditions for the floodplain of interest, and therefore do not need to average hazard, performance, exposure, or vulnerability over time or space. Instead, site-specific detailed meteorological, hydrological, hydraulic, and consequence models can be developed and applied. For example, the loss calculations (using a function such as shown in Figure 3.8e) may include one or more drivers of damage beyond water depth, such as duration, velocity, quality of flood waters, season of flooding, or other factors.

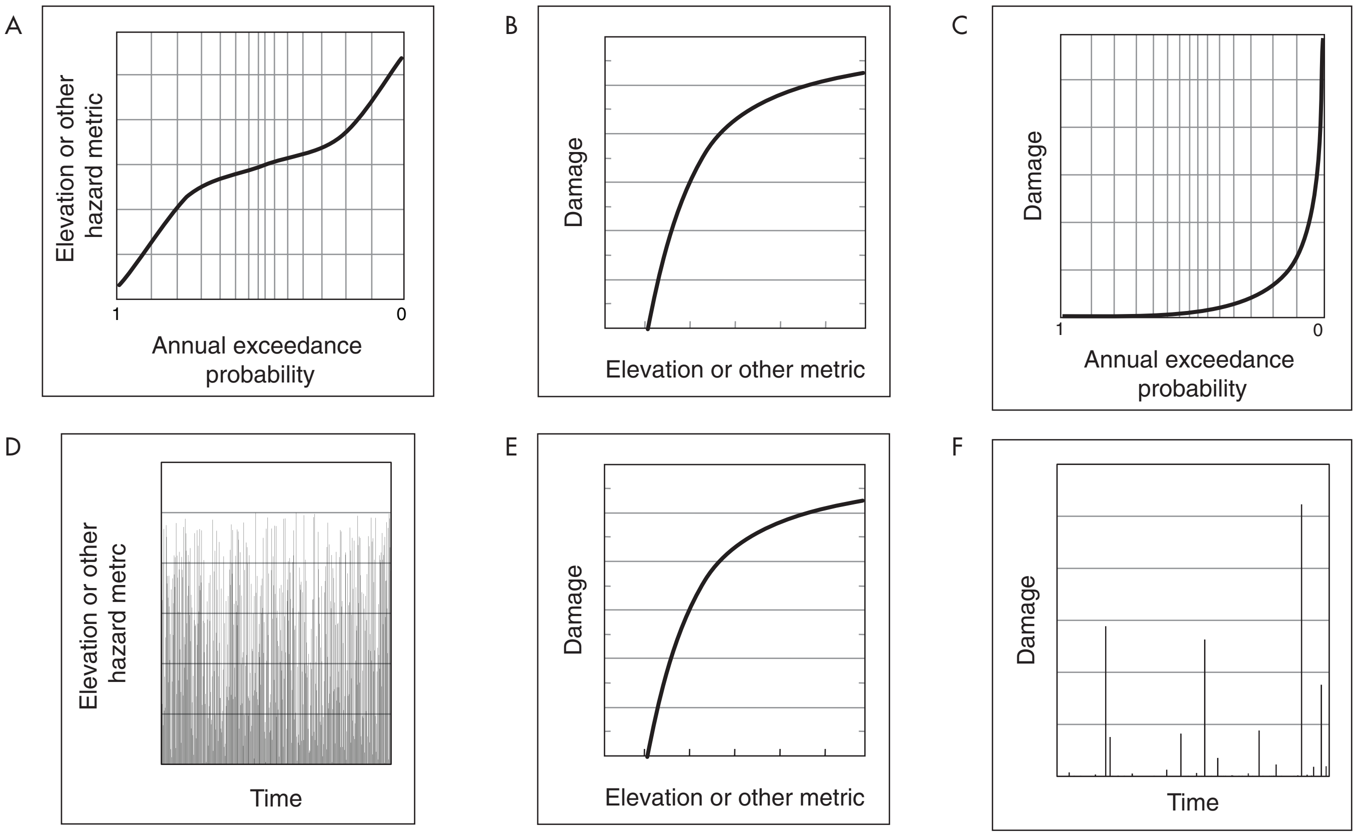


FIGURE 3.8 Comparison of the NFIP hydrologic method (a–c) with the event-based approach used in cat modeling (d–f), which creates a long history of flood events, then estimates and averages the damage associated with each to compute average annual loss. SOURCE: Courtesy of David Ford, David Ford Consulting Engineers, Inc.

REFINEMENTS TO CURRENT METHODS

North Carolina Flood Risk Information System

The North Carolina Floodplain Mapping Program is assessing certain components of flood risk as a part of a statewide program to provide seamless, accurate, statewide modeling and mapping of flood hazards.[6] To assess flood hazard, North Carolina developed site-specific water surface elevation–exceedance probability functions using hydrologic and hydraulic studies carried out by the state[7] and by the NFIP, and high-resolution airborne lidar terrain data. The state's 3 meter lidar data is being replaced with quality level 2 lidar data (see Dewberry, 2011, for a description), which is similar to high precision survey data. This information has been used to determine base flood elevations for more than 300,000 locations in the state. In addition, the state has determined water surface elevations and flood depths for five flood probabilities: 10 percent (10-year depth), 4 percent (25-year depth), 2 percent (50-year depth), 1 percent (100-year depth), and 0.2 percent (500-year depth) annual chance exceedance. The 1 percent annual chance exceedance depths along a portion of a North Carolina river are illustrated in Figure 3.9. North Carolina is the first state to have performed such an analysis and to acquire high-resolution lidar statewide.

North Carolina is currently computing the annual probability of any depth of flooding for every structure in the state using information collected on building footprints (identified using remote sensing, high-resolution aerial images, and geographic information system technology) and elevations of individual structures (determined using high-resolution lidar). The exposure and vulnerability of identified struc-

[6] See http://fris.nc.us/fris.

[7] North Carolina has generated and incorporated more than 300,000 base flood elevations on Flood Insurance Rate Maps for the state. See the presentation to the committee by John Dorman, North Carolina Floodplain Mapping Program, on May 12, 2014.

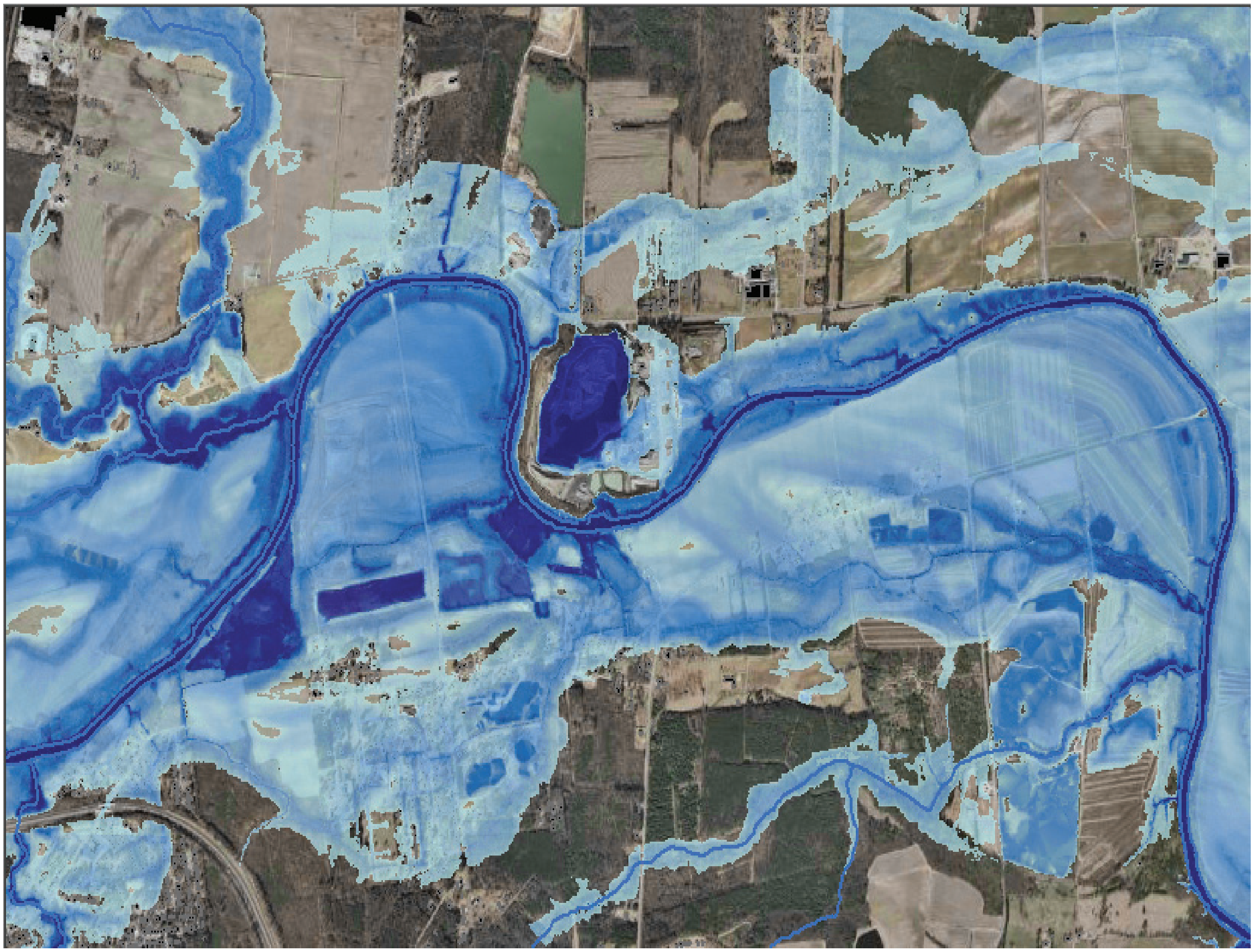


FIGURE 3.9 One percent annual chance exceedance depth grid along a reach of the Tar River in Rocky Mount, North Carolina. Darker blues represent greater flood depth between the base flood elevation and the terrain elevation. SOURCE: Courtesy of John Dorman, North Carolina Floodplain Mapping Program.

tures are quantified using tax records to establish the value and characteristics of the structures. Inundation depth–damage functions similar to the NFIP DELV curves are derived from the NFIP HAZUS software application (Scawthorn et al., 2006).[8] Average annual loss is computed for individual properties in floodplains statewide, and publicly available databases and visualization tools provide easy access to these estimates, as well as to the underlying reports of hazard, exposure, vulnerability, and consequence.

[8] See also http://www.fema.gov/hazus.

NFIP Multi-Frequency Depth Grids

The NFIP has been developing multi-frequency depth grids to analyze flood risk since 2009. The multi-frequency depth grids are intended to provide a platform for NFIP hydrologic and hydraulic analyses and to help individuals better understand and visualize their flood hazard. The NFIP analyzes flood depth at the same flood probabilities as North Carolina's (10 percent, 4 percent, 2 percent, 1 percent, and 0.2 percent annual chance exceedance), and uses similar methods for producing the depth grids (FEMA, 2014). Depths for the grids are currently determined using spatial interpolation schemes, which estimate grid cell water surface elevations from results of state-of-practice hydraulic models. The description and display of site-specific flood hazard at a relatively fine spatial scale are also similar to those of North Carolina. The depth grid datasets currently cover about 20 percent of the U.S. population.[9] This technology—if integrated with reliable structure elevation and replacement value information—will eventually permit great spatial resolution of flood risk, perhaps to a neighborhood or structure level nationwide, similar to what is done on a smaller scale in North Carolina.

COMPREHENSIVE RISK ASSESSMENT

The 2013 NRC report *Levees and the National Flood Insurance Program: Improving Policies and Practices* recommended and summarized the advantages of the NFIP moving toward a more comprehensive approach to risk analysis that builds on current USACE and catastrophe model methods. As described in the NRC report, a comprehensive risk assessment (1) derives a site-specific water surface elevation–exceedance probability function to represent hazard; (2) takes into account the performance and reliability of flood protection measured aimed at reducing inundation depths, as well as the effect that their failure may have on flooding and, ultimately, damages; (3) determines inundation depths throughout a floodplain with appropriate hydraulic analyses; (4) estimates the damage to exposed assets as a consequence of the inundation (or other relevant drivers), which is necessary for developing the damage–exceedance probability function; and (5) evaluates the aleatory and epistemic uncertainty (natural variability and knowledge uncertainty) in each of the elements of the analysis and propagates them through the estimate of risk. The elements of the flood risk model are combined to derive the frequency distribution of the flood damage for individual structures or for a community as well as the uncertainty in these estimates. From these results, the average annual loss can be computed for a structure or a group of structures. The comprehensive risk assessment method has been applied in at least two large-scale flood studies (see URS/JBA, 2008; IPET, 2009).

[9] Personal communication by Paul Rooney, FEMA, on May 13, 2014.

COMPARISON OF APPROACHES

All four of the flood risk assessment approaches described in this chapter (NFIP hydrologic method, USACE method, catastrophe models, and comprehensive risk assessment) address the main components of risk (i.e., flood hazard, the performance of flood protection measures, exposure, and vulnerability) using methods tailored to each organization's needs. Each of the flood risk assessment methods describes flood hazard using hydrologic and hydraulic models that represent the watershed, channel, and tidal behavior for the entire range of possible events. The NFIP hydrologic method, the USACE method, and the comprehensive risk assessment recommended in NRC (2013) use an inundation depth–exceedance probability function to describe flood hazard, whereas catastrophe models typically use Monte Carlo sampling to generate a long series of synthetic stream flows or ocean tides derived from a probability function. A critical difference among the methods is the extent to which the hazard description represents the unique conditions at a site. The NFIP PELV curves are spatial averages that do not represent unique weather, watershed, or channel features. Other methods capture those unique features.

The performance of flood protection measures is represented in all the methods, albeit in different ways. The USACE method, the comprehensive risk assessment, and catastrophe models explicitly account for uncertainty about levee performance with fragility functions. In contrast, the NFIP treats certified and accredited levees as preventing damage from floods more frequent than the 1 percent annual chance exceedance event, and treats nonaccredited levees (or levee segments) as providing lesser or no flood protection. Both the NFIP and USACE methods account for the performance of flood storage and diversion, although in a simplistic and somewhat optimistic manner. For example, both presume that reservoir water control manuals will be followed exactly; in practice such adherence is difficult.

All risk assessment methods described in this chapter model exposure and vulnerability in a similar manner. The methods predict damage as a function of inundation depth, typically using damage ratio models. All methods require estimates of the value of a structure and its contents to calculate damage, and these estimates are made in a variety of ways. The USACE commonly uses building unit cost information and structure type and size to estimate replacement value, which is then adjusted to account for depreciation. The NFIP uses replacement cost values. Detailed information about construction and occupancy collected by private insurers can be used to develop site-specific inundation depth–damage functions for use in a catastrophe model. If this detailed information is not available, then inundation depth–damage functions are developed for classes of structures.

A significant difference among the risk assessment methods is that the NFIP method was developed to assess flood losses for individual structures, whereas the USACE, comprehensive risk assessment, and catastrophe modeling methods can assess individual or aggregated risk (e.g., a community or an entire insurance portfolio). Assessing aggregated risk is useful for determining the financial soundness of the insurance portfolio.

Another significant difference among the methods is the treatment of aleatory and epistemic uncertainties about the hazard, performance, exposure, and vulnerability inputs to flood loss calculations. Although some aleatory uncertainties are considered in the NFIP hydrologic method, epistemic uncertainties are not explicitly considered or integrated into the risk assessment. Instead, in the average annual loss calculation, the NFIP relies on judgments and empirical adjustments to accommodate uncertainties in the flood risk analyses and underwriting process (Hayes and Neal, 2011). In contrast, the comprehensive risk assessment, catastrophe models, and, to a lesser extent, the USACE method account for both aleatory and epistemic uncertainty about the various inputs to the average annual loss calculation. For example, the NFIP mathematically treats the water surface elevation–exceedance probability function as if quantiles were known with certainty. In contrast, with the comprehensive risk assessment and, to a lesser degree, the USACE method, epistemic uncertainty about the water surface elevation–exceedance probability function is described with a probability distribution about the mean value of elevation predicted for a specified probability. Similarly, the NFIP rate formula mathematically treats the inundation depth–damage functions as known with certainty, whereas the USACE method, catastrophe models, and comprehensive risk assessment consider the impact of small samples and imperfect knowledge on relationships to predict damage associated with depth. These three methods then derive sample probability distributions that describe variations from the average values predicted in the hazard, performance, exposure, and vulnerability models.

The appropriate method for assessing risk depends on the application. Possible changes in methods for improving flood insurance rates are described in Chapters 4 and 5.

4

Factors That Affect Risk-Based Premiums for Negatively Elevated Structures

The National Flood Insurance Program (NFIP) method for calculating risk-based premiums was developed for rating post-FIRM (Flood Insurance Rate Map) structures, and its use has been tailored for structures with lowest floor elevations at or above the base flood elevation. However, negatively elevated structures are typically affected by different flood conditions (e.g., more frequent floods) and different drivers of damage and loss (e.g., longer duration of flooding) than structures above the base flood elevation. Moreover, risk-based insurance premiums for negatively elevated structures are expected to be high when subsidies are phased out, simply because flood risks are higher. This chapter identifies potential changes to the NFIP method for calculating risk-based rates for negatively elevated structures. Of particular interest are the water surface elevation–exceedance probability functions (PELV curves), the inundation depth–damage functions (DELV curves), underinsurance, and deductibles. Associated data issues are discussed in Chapter 5.

PELV

The NFIP develops rates for a class of structures by computing the average annual loss, accounting for the elevation of the structure relative to the base flood elevation, and then adjusting that value for expenses and other factors. Rates are computed by integrating the product of the DELV curve for a class of structures and each PELV curve to compute an average annual loss, and then averaging the computed losses over the set of PELV curves, weighted by the estimated fraction of structures in each PELV zone equivalent. This averaging step can result in premiums that are representative of the flood risk for the structure class as a whole, but not for individual structures within the class. In addition, the PELV curves were developed with a focus on the difference between the 1 percent and 10 percent annual chance exceedance elevations and may not adequately capture the loss potential from frequent flooding, which can be significant for negatively elevated structures. These issues and possible changes to the NFIP method are described below.

Averaging in the Rate Calculation

Averaging the average annual loss over a large set of PELV curves in the rate calculation affects premiums because it obscures variations in the water surface elevation–exceedance probability functions. This means that the magnitude of flood hazard will be overestimated (and premiums will be too high) in some areas and underestimated in others (and premiums will be too low), and thus to rate classes with excessive variance in premiums.

Variation in Flood Hazard. The PELV curves were derived to represent the wide variety of coastal and riverine flood hazard conditions that exist across the United States. The family of PELV curves range from those with a large water surface elevation difference between rarely exceeded and frequently exceeded flood events to those with small water surface elevation differences. The need for this differentiation of hazard is illustrated in Table 4.1, which shows the difference between water surface elevations for a rarer event (1 percent annual chance of exceedance) and a frequently exceeded event (10 percent annual chance of exceedance) relative to the base flood elevation at three locations. The water surface elevation difference is 13.9 feet for Fayette County, Texas; 6.7 feet for Boulder County, Colorado; and 2.1 feet for Suffolk County, New York (Table 4.1). These differences in water surface elevations reflect differences in the meteorological, hydrological, and hydraulic properties of the watersheds and floodplains. If the insurance rate for an identical structure were computed then averaged for these three cases, then that rate would not represent well the risk for any one of the cases.

As discussed below, negatively elevated structures are inundated by more frequent events than structures above the base flood elevation (see "Capturing the Loss Potential from Very Frequent Flooding"), and the depths of inundation for more rare events may be considerable. Those flood hazard conditions are obscured in the averaging, leading to rates that are correct in aggregate, but incorrect for individual cases.

***Premium Variance Within Rate Classes*.** Homogeneity of the insured properties within a rate class is desirable for calculating rates that are both precise and fair to the policyholders (Mathewson et al., 2011). Rate classes for negatively elevated structures appear to be heterogeneous, largely as a result of averaging the insurance rates produced from a wide range of PELV curves. Table 4.2 shows how premiums for a specific set of structural parameters vary for the different PELV curves. When the rate is averaged from the appropriate set of PELV curves in the average annual loss calculation, the variance around that average premium can be large. This means that while the rate (and resulting premium) computed may be appropriate as an average for all policyholders in a class ($9,142 in Table 4.2), rates may be far too high for some structures and far too low for others. For example, if insurance was priced differently for each of the 30 A zone equivalents, then a policyholder in Zone A30 would be charged only $4,228 in the Table 4.2 example. But because the 30 numbered A zones have been consolidated into a single AE zone, the rate represents an average across all 30 A zones, and the policyholder pays more than double that amount—$9,142. Although rate classes for positively elevated structures are also heterogeneous, the dollar amounts and, hence, the absolute magnitudes of the differences are much larger for negatively elevated structures.

Another issue is that computed rates for negatively elevated structures generally increase as the difference between the 1 percent and 10 percent annual chance exceedance depths decrease (PELV numbers decrease; see Table 4.2). The opposite is true for positively elevated structures. As discussed below, this trend can be attributed to the large contributions from more frequent floods to the total flood risk for negatively elevated structures, and thus there is great sensitivity to PELV values associated with floods of high annual probabilities (10 percent or greater annual chance exceedance).

***Potential Changes to the NFIP Method*.** Representing flood hazard variation more precisely and accurately in the average annual loss computation would reduce inequities that result when all policyholders with the same structure type and elevation pay a rate averaged over hazard conditions. Precise hazard representation requires structure elevations and site-specific water surface elevation–exceedance probability functions devel-

TABLE 4.1 Comparison of Water Surface Elevation Differences in Different Regions

	Difference Between the 1 Percent and 10 Percent Annual Chance Exceedance Water Surface Elevations (feet)		
Percent Chance Exceedance	Fayette County, TX	Boulder County, CO	Suffolk County, NY
0.2	4.3	3.4	1.7
1	0.0	0.0	0.0
2	−4.6	−2.5	−0.6
10	−13.9	−6.7	−2.1

SOURCES: Data from Flood Insurance Studies; see FEMA (2006, 2009, and 2012).

TABLE 4.2 Influence of PELV Curves on the Insurance Premium for a Structure With the Lowest Floor Elevation 4 Feet Below the Base Flood Elevation

PELV	Zone Equivalent	Zone Weight[a]	Zone Premium
25	A1	1%	$11,267.88
26	A2	1%	$11,267.88
27	A3	1%	$11,267.88
28	A4	3%	$11,267.88
29	A5	6%	$11,267.88
30	A6	8%	$11,267.88
31	A7	10%	$11,267.88
32	A8	11%	$11,911.69
33	A9	11%	$10,040.57
34	A10	11%	$8,561.74
35	A11	10%	$7,925.78
36	A12	9%	$7,101.71
37	A13	7%	$6,694.55
38	A14	6%	$6,299.23
39	A15	4%	$5,881.52
40	A16	3%	$5,544.08
41	A17	2%	$5,274.60
42	A18	1%	$5,151.74
43	A19	0%	$4,948.63
44	A20	0%	$4,853.87
46	A21	0%	$4,774.61
48	A22	0%	$4,691.30
50	A23	0%	$4,557.16
52	A24	0%	$4,462.78
54	A25	0%	$4,442.11
56	A26	0%	$4,382.93
58	A27	0%	$4,338.98
60	A28	0%	$4,254.83
62	A29	0%	$4,252.54
64	A30	0%	$4,228.72
Weighted Average			$9,142.03

[a] Weights are rounded.
NOTE: This example is for a one-story 1–4 family residential building with no basement and $250,000 of coverage on the structure.
SOURCE: Andy Neal, Federal Emergency Management Agency (FEMA).

oped from detailed flood studies. In some cases, local flood study reports may yield the required water surface elevation–exceedance probability functions. For example, the site-specific water surface elevation–exceedance probability functions developed and used by the U.S. Army Corps of Engineers (USACE) for planning studies and by North Carolina for risk communication define flood hazard with the necessary precision. The NFIP's multi-frequency depth grids represent a step toward site-specific hazard definition.

If deriving and using site-specific water surface elevation–exceedance probability functions is not practical, then the NFIP could group and average the functions to capture important differences in flood hazard conditions, and use the average function that best represents the hazard at a structure. This strategy

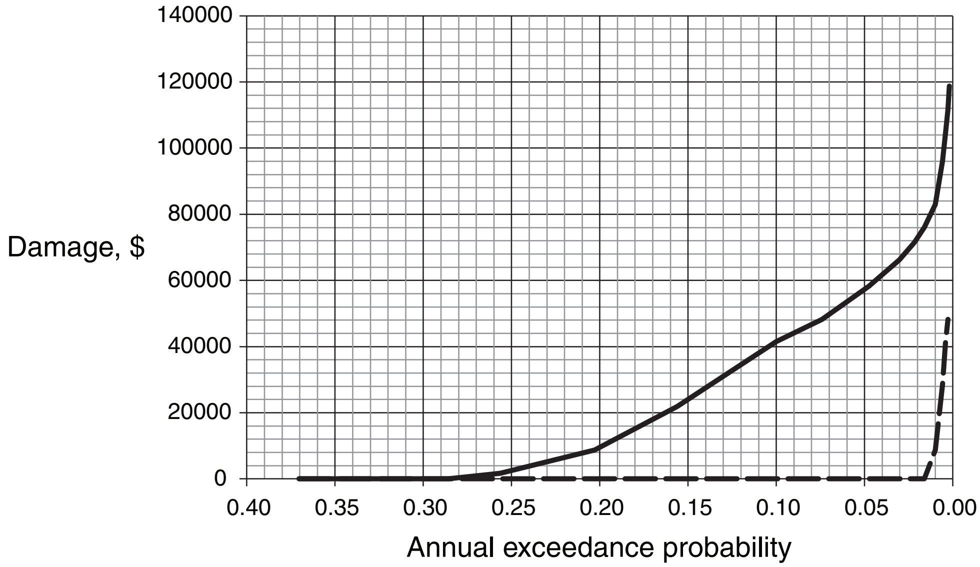


FIGURE 4.1 Illustration of a damage–exceedance probability function for the same structure at two elevations. (Solid line) Lowest floor elevation 4 feet below the base flood elevation (negatively elevated structure). (Dashed line) Lowest floor elevation equal to the base flood elevation.

is similar to the NFIP's now abandoned strategy of using numbered A zones (or V zones) for rate setting. Research, guided by the extent of the variance in premiums within rate classes, would be required to determine how many categories of water surface elevation–exceedance probability functions would be needed to create more homogeneous rate classes for negatively elevated structures, and thus to increase fairness to policyholders. Once the categories are determined, new flood studies and mapping would likely be required in regions with significant numbers of negatively elevated structures.

If new flood studies are not feasible, then alternative strategies could be developed to guide selection of the appropriate category of water surface elevation–exceedance probability function to use for rating a structure. For example, a strategy similar in concept to the U.S. Geological Survey's regional regression equations[1] for estimating flood flow discharges from selected meteorological, hydrologic, and hydraulic properties of the watershed, channel, and floodplain could be employed to guide selection of the appropriate water surface elevation–exceedance probability function. Such an approach would account for all drivers of rising water surface elevations, including coastal waves where appropriate.

[1] See http://water.usgs.gov/osw/programs/nss/pubs.html.

Capturing the Loss Potential from Very Frequent Flooding

The accuracy with which more frequently exceeded floods are represented in the water surface elevation–exceedance probability function is particularly important for assessing risk for negatively elevated structures. In the NFIP average annual loss calculation, the loss attributable to each depth of inundation is multiplied by the probability of that inundation, then summed over all possible probability values. Thus, higher probability events have a significant impact on the average annual loss. Depending on the inundation depth–exceedance probability function and the structure elevation, the threshold annual chance exceedance value for damage to negatively elevated structures may be as great as 50 percent (the 2-year flood), with a significant portion of the loss caused by floods with the value much greater than 1 percent (i.e., by floods more frequent than the 100-year flood).

Figure 4.1 shows the annual damage–exceedance probability function derived for a $250,000 structure located 4 feet below the 1 percent annual chance exceedance elevation. The structure in this example is in a floodplain for which the 10 percent annual chance exceedance water surface elevation is 3 feet less than the 1 percent annual chance exceedance water surface elevation (Zone A6). The average annual loss for the structure, computed by integrating the damage–exceedance probability function, is approximately \$8,880. For this negatively elevated structure, approximately 30 percent of that loss is attributable to events more frequent than the 10 percent annual chance exceedance (10-year) event, and 60 percent of the loss is attributable to events more frequent than the 5 percent annual chance exceedance (20-year) event. Only 11 percent of the average annual loss is attributable to events less frequent than the 1 percent annual chance exceedance event. By comparison, all of the loss to a structure with a first floor elevation equal to the base flood elevation is attributable to events less frequent than the 1 percent annual chance exceedance event (dashed line in Figure 4.1).

The contribution of small flood events to the average annual loss is greater in locations with smaller differences between the 1 percent and 10 percent annual chance exceedance water surface elevations. For example, if the water surface elevation difference is 0.5 feet (Zone A1), then 88 percent of the average annual loss is due to the 10 percent annual chance exceedance (10-year) event or to more frequent events. If the water surface elevation difference is 8 feet (Zone A16), then 49 percent of the average annual loss is due to events less frequent than the 1 percent annual chance exceedance (100-year) event, while events more frequent than the 5 percent annual chance exceedance (20-year) event contribute nothing to the loss.

Average annual loss calculations for negatively elevated structures are also sensitive to even small inaccuracies in inundation depth estimates at the lower end of the water surface elevation–exceedance probability function. For the example shown in Figure 4.1, if inundation depths for events more frequent than those with a 10 percent annual chance of exceedance are 0.3 feet greater than those shown in the PELV curve (a reasonable tolerance in hydrologic and hydraulic analysis model results), then the average annual loss increases from \$8,800 to approximately \$10,220 (a 15 percent increase). If the inundation depths are 0.3 feet less than shown in the PELV curve, then the average annual loss is approximately \$7,960 (a 10 percent decrease).

Potential Changes to the NFIP Method. The loss potential for negatively elevated structures is driven by losses from floods more frequent than those with 1 percent annual chance of exceedance. Careful definition of the water surface elevation–exceedance probability function throughout the entire range of floods would ensure that the PELV curves capture the most frequent flood events. Site-specific water surface elevation–exceedance probability functions would represent the full range of floods, including very frequent floods. If developing site-specific water surface elevation–exceedance probability functions is not practical, then the NFIP could develop categories of PELV curves, as described in the previous section, with special attention given to frequent events. The shape of the current PELV curves is dictated by the difference between the 1 percent and 10 percent annual chance exceedance depths. For negatively elevated structures, the PELV curves would also have to reflect the relative magnitude of more frequent events, such as the difference between the 1 percent, 10 percent, and 50 percent annual chance exceedance depths.

DELV

The NFIP predicts economic loss due to inundation using a DELV curve, which expresses damage as a percentage (damage ratio) of a structure's replacement value for a specified depth of water in the structure. The NFIP uses two models—the damage functions derived from the NFIP claims data and the U.S. Army Corps of Engineers (USACE) damage functions—to develop a blended DELV model. A standard actuarial technique (credibility weighting) is used to combine the two models. The more credible the NFIP claims data, the less weight is given to the USACE damage estimates. Different DELV curves are developed for different structure types and contents locations.

Three aspects of the inundation depth–damage function and its development affect premiums for structures in the NFIP portfolio, including negatively elevated structures. First, inundation depth–damage data are highly variable. Second, data quality problems may compromise the integrity of the DELV curves (see Chapter 5). Third, the NFIP credibility weighting method in many cases assigns greater weight to the USACE damage estimates for a selected inundation depth than the NFIP damage estimates for the same depth without considering whether the quality of the underlying USACE data is better than the NFIP data.

Variability of NFIP Damage Estimates

A reliable damage estimate is critical to the computation of the average annual loss. The NFIP frequently refines its inundation damage prediction functions using actual claims data. However, the claims data for a selected depth of inundation used in this refining are highly variable. For example, Figure 4.2 shows the distribution of damages reported for 2 feet of inundation depth in 2 years: 2005 and 2012. In these examples, damage ratios vary from zero to 100 percent. Figure 4.3 shows the coefficient of variation, which is the ratio of the standard deviation to the mean damage ratio, for one-story residential structures with no basement. The coefficient of variation is greater than 0.6 for water surface elevations -4 feet below to +4 feet above the lowest floor elevation, and is greater than 1.0 for some water surface elevations below the lowest floor elevation. In other types of structures, the coefficient of variation may be different.

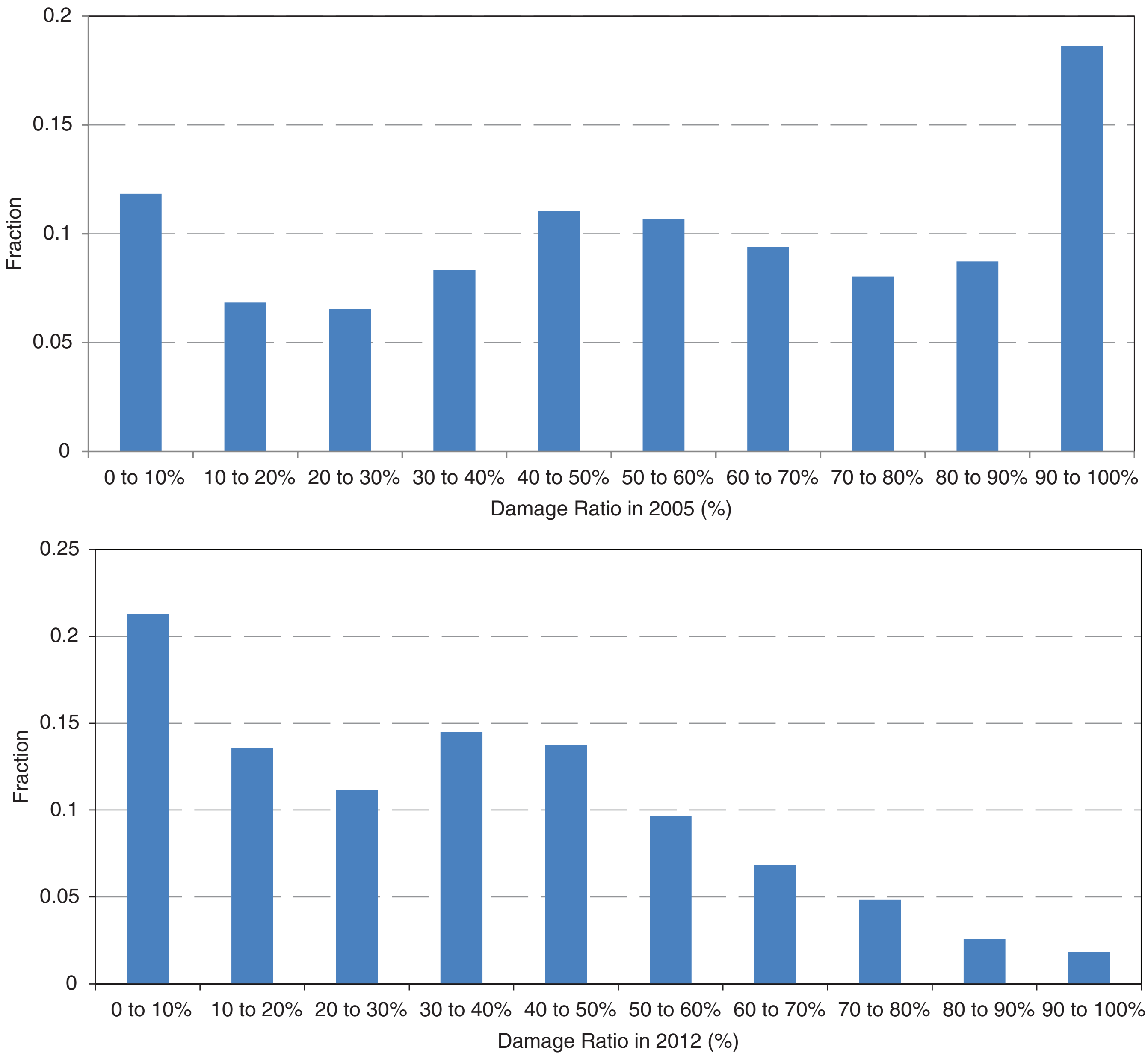


FIGURE 4.2 Distribution of NFIP flood damage data (assuming reported inundation depths are in feet) for 2 feet of flooding in 2005 (top) and 2012 (bottom). SOURCE: Data provided by Andy Neal, FEMA.

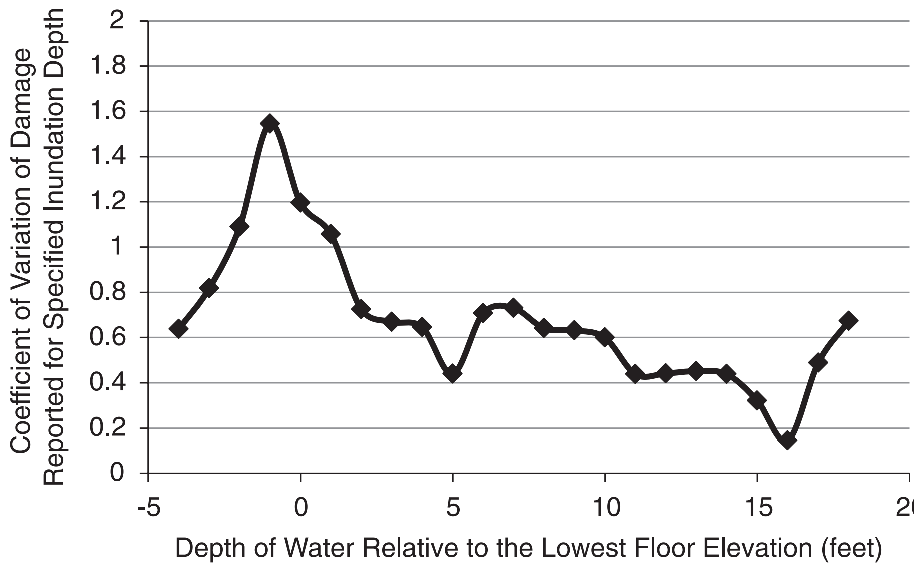


FIGURE 4.3 Coefficient of variation—the ratio of the standard deviation to the mean damage ratio—determined for one-story residential structures with no basement in the NFIP portfolio. Damage reports from 2005 are excluded to avoid biasing results with damage from extreme coastal flooding in that year. SOURCE: Data provided by Andy Neal, FEMA.

The variance observed in Figure 4.2 may be attributable to (1) a failure of inundation depth alone to adequately predict damage, (2) poor data quality (see Chapter 5), or (3) unrecognized variability within a structure class. Besides depth, characteristics of flood events that may influence the nature and extent of flood damage to a structure (and the observed variance in NFIP reported claims) include tidal- and wind-driven wave height, flow velocity, duration of inundation, debris and impact loads, sediment load, buoyancy, scour effects, erosion, and contamination (McBean et al., 1988; Thieken et al., 2005). As a result, floods with the same inundation depth may cause different damage. A suggestion that some of these factors contribute to damage is illustrated in Figure 4.4, which shows the mean flood damage ratio as a function of inundation depths for 2005 and 2012. The data for 2005 are dominated by Hurricane Katrina, which caused extensive damage in Louisiana and Mississippi. In New Orleans, where many structures behind levees are negatively elevated, some structures were inundated for an unusually long period of time, exacerbating damage, and others were near levee breaches where higher flow velocities increased forces on structures and caused more damage than predicted by depth alone. In Mississippi, which was not protected by coastal barriers, flood damage caused by high inundation depths and wind-driven waves extended many miles inland (Fritz et al., 2007). The difference between the 2005 and 2012 data could be interpreted as reflecting the effect of duration of inundation or to other factors, such as wave effects, scour at levee breaches, or the effects of debris.

The variance in damage reports may also be attributable to vulnerability differences among structures within a given category. For example, the NFIP develops a DELV curve for all one-story, no basement residential structures without regard to the replacement value of the structures. However, the higher quality materials and construction used in more expensive structures may suffer greater damage (have higher damage ratios) at lower inundation depths than the materials and construction used in less expensive structures.

Potential Changes to the NFIP Method. To better understand the large variance in damage data, additional data on flood hazard characteristics (e.g., depth and duration of flooding, flow velocity, sediment load) and structure vulnerability (e.g., properties of the foundation, quality of materials used in the construction and finish) would have to be collected in damage reports and analyzed. In addition, more classes of damage prediction functions may have to be developed to capture critical differences in drivers in the risk calculation. For

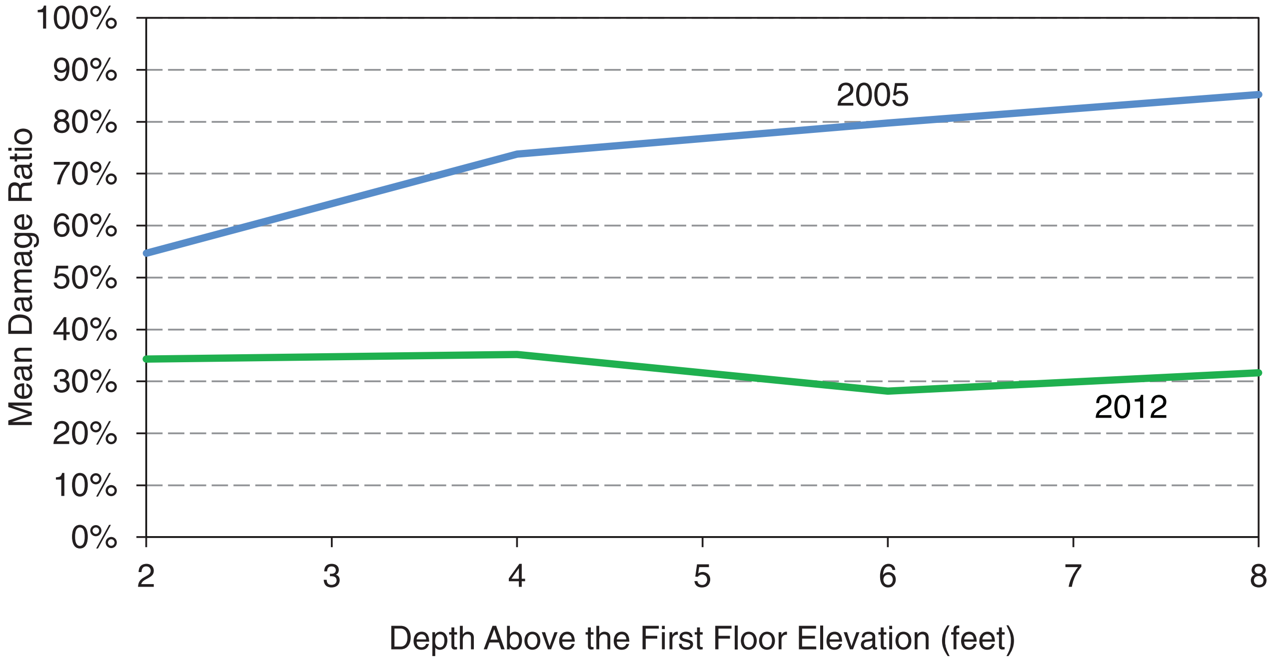


FIGURE 4.4 Variation in the mean damage as a function of the inundation depth (assumed to be in feet) for the NFIP for 2005 and 2012. SOURCE: Data provided by Andy Neal, FEMA.

example, functions might be developed to represent damage that is due primarily to inundation depth; damage that is due primarily due to inundation depth and duration (likely to be particularly important for negatively elevated structures); and so on. Developing these functions would require improved data collection (see Chapter 5) and research to establish reliable predictors of damage and their probabilities.

Weight Assigned to USACE Damage Estimates

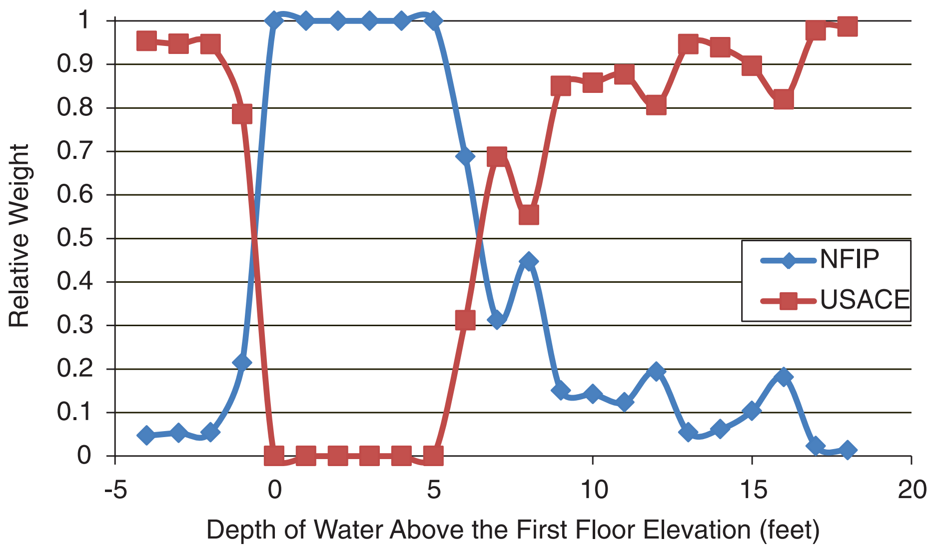
The NFIP credibility weighting procedure (FEMA, 2003) estimates damage for each specified inundation depth as follows:[2]

- If the NFIP claims sample is large enough to assign 100 percent credibility at a selected confidence level (e.g., 90 percent),[3] then the NFIP uses the damage estimate from claims reports.
- If NFIP claims data are not available, then the NFIP uses the USACE estimate of damage.
- If NFIP claims data are available, but not fully credible because of the small sample size, then the NFIP uses a weighted average of the NFIP claims data and the USACE damage estimates.

Figure 4.5 shows an example of the credibility analysis for 2005 loss data. The top figure shows the relative weights given to NFIP and USACE loss data from the credibility analysis. For inundation depths between zero and 5 feet, there are a sufficient number of NFIP claims data to assign full weight to the damages predicted with them; no weight is assigned to the USACE estimates for inundation depths in that range (Figure 4.5, top). For greater and lesser inundation depths, NFIP claims data are sparse, and the USACE damage estimates are weighted heavily. The bottom figure shows the damage ratio function derived from NFIP claims data, USACE damage estimates, and the blended result using the weights from the top figure. In this case, the blended DELV curve tracks

[2] Personal communication from Andy Neal, FEMA, on April 11, 2014.

[3] The number of claims needed for full credibility = $\left[\frac{Z \times S}{D \times X}\right]^2$, where Z is half the standard normal distribution value corresponding to a required confidence, S is the sample (collection of claims corresponding to a water depth category) standard deviation, D is the desired relative error of the estimated mean, and X is the sample mean (FEMA, 2003).



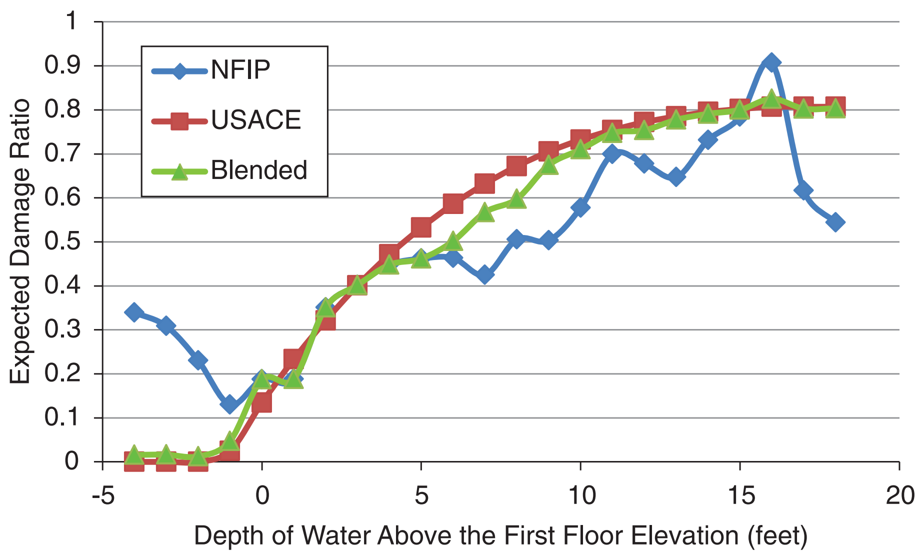


FIGURE 4.5 Illustration of the NFIP credibility analysis for 2005 loss data. (Top) Relative weights assigned to the NFIP data and the USACE data based on the credibility weighting methodology. (Bottom) Comparison of the NFIP claims data, USACE damage estimates, and the blended result using the credibility weighting methodology.

the USACE inundation depth–damage function (Figure 4.5, bottom).

The NFIP credibility analysis looks only at the size of the NFIP claims dataset (the number of data points required to produce a credible estimate) and the data variance. Other relevant factors are not included, such as the quality of the data (measurement and reporting errors), the diversity of the data (e.g., the number of flood events, variability among flood events), the number of damage observations associated with individual flood events, structure variability, or other drivers of damage. In addition, the credibility criteria (data variance and size of the claims dataset) are applied only to the NFIP data, not to the USACE inundation depth–damage function. Finally, the NFIP does not evaluate the quality of the USACE damage data. Thus, in some cases, unreliable estimates from the USACE will be given higher weight than high-quality but sparse NFIP claims data.

Potential Changes to the NFIP Method. The NFIP could improve estimates of potential damage due to inundation by developing new inundation depth–damage functions using long-term averages of NFIP claims data or data from other sources. A new credibility analysis could then be implemented to adjust values as newer claim data become available. Smaller improvements could be made using the current weighting procedure, incorporating an assessment of the sample size and quality of both NFIP claims data and USACE damage estimates. Such changes would enhance the weighting procedure, and thus improve estimates of potential damage due to inundation—or at least improve the confidence in those values. To incorporate the credibility of the USACE damage estimates into the weighting procedure, the NFIP would have to investigate and assess the quality and statistical significance of the USACE inundation depth–damage functions used. This may be straightforward with the new USACE damage functions being created (e.g., USACE, 2015), but would likely prove to be a challenge with the USACE inundation depth–damage functions used in the credibility analysis because little documentation of those functions is available.

UNDERINSURANCE

The NFIP computes flood loss by applying the damage ratio from the appropriate DELV curve to the replacement cost value of the structure. The objective is to set a rate that, when multiplied by an amount of insurance, will produce a premium that makes a sufficient contribution to the risk pool to cover the NFIP's expected losses. If the insurance limit of a policy is significantly less than the replacement value of the structure—a situation referred to as underinsurance—then the concept of recovering loss through pooling premiums can break down, and both the policyholder and the insurer are threatened financially. For the policyholder, underinsurance means a loss may not be covered fully if the loss exceeds the amount of insurance purchased. For the insurer, underinsurance means that premiums collected for the underinsured property may not adequately reflect the loss, unless adjustments are made.

Empirical evidence shows that homeowners are often reluctant to protect themselves against low-probability high-consequence events, such as floods, and so purchase too little or no insurance unless required to do so (e.g., Kunreuther, 1984). The NFIP encourages, but does not require, the purchase of "insurance to value," hence avoiding underinsurance, by providing replacement cost coverage if a single family structure is insured to at least 80 percent of its value at the time of loss (or to the full statutory limit of $250,000 for structures). Otherwise, the loss is settled on an actual cash value basis. The program also encourages the purchase of higher amounts of insurance by charging less for amounts of insurance purchased above the basic limits threshold, currently $60,000 for a single family building. The statutory mandatory flood insurance purchase requirement ties the amount of insurance to be purchased to the outstanding balance of the loan on the property for federally backed or regulated mortgages (if there is one). This balance may be less than the replacement value, and some lenders require insurance to value. In addition, the statutory limit of $250,000 on coverage for single family structures means that many structures cannot be covered to their full value. These statutory limitations may lead to underinsurance.

The NFIP method to compensate for underinsurance is to use a loading factor (UINS) in the rate formula. The loading factor adjusts the rate so that collectively the premiums reflect the amount of expected annual loss, thus protecting the NFIP from potential premium shortfalls as a result of underinsurance. To calculate underinsurance, the rate formula shown in Box 2.1 is expanded to account for losses that are not covered when the limits are lower than the property value (see Formula 3 in FEMA, 2013d). Application of the NFIP rate formula to the rate classes produces results that are consistent with the first loss scales approach (Box 4.1). The breadth of a rate class can be a factor in how effective either approach is in treating underinsurance and in pricing the different layers of risk.

In the VE zone (along coasts, with additional hazard due to wave velocity), where very high premiums and high building values can lead to underinsurance, the NFIP rate depends on how much insurance is being purchased as a percentage of the building value. In all other zones, the rate loadings reflect a broader average of the amounts of insurance purchased relative to the building values. This broader averaging may be problematic if properties within a rate class are underinsured by substantially different amounts, as may happen when

BOX 4.1
First Loss Scales

Financial risk in insurance can be treated as having three layers: the deductible, the insured limit, and the difference between the insured limit and the value of the property (if it exceeds the policy limit of liability). The standard private industry practice is to apply a rate to the total replacement value of the property to develop the pure premium (average annual loss) and then to modify this rate to take account of the uninsured layers. The relative price for each layer is determined by applying what is referred to as a first loss scale. Claims data are used to determine the frequency of loss relative to the insured amount, and this relationship is used to assign the relative price of each layer of risk. Generally, for any given property, the first dollars of coverage are more expensive to provide than the last. This is why increasing a deductible (the first layer of financial risk) can have a large impact on reducing the premium, whereas purchasing higher amounts of coverage (second layer of financial risk) may not increase the overall premium very much.

First loss scales are generally used in the insurance industry to rate individual properties. The NFIP rate formula is applied to classes of properties, but the resulting rates are consistent with those that would be developed for classes of properties using first loss scales.

negatively elevated structures are in the rate class. In such cases, the premiums paid for fully insured properties can end up subsidizing the underinsured properties.

The examples that follow illustrate how underinsurance may affect rates for negatively elevated structures. In the examples, the structure elevation (8 feet below the base flood elevation) and location (Zone A18) are constant, and the building value and the amount of insurance purchased vary (see Table 4.3). Examples 1 through 3 illustrate first loss scales principles in that (1) the required premium is not reduced much when the lower limits of coverage are purchased and (2) the rate for the amount of insurance being purchased must be increased, reflecting that it is a more expensive layer of coverage (see the first loss scales discussion in Box 4.1).

Example 1 is a building fully insured to its replacement cost of $200,000. The premium needed to cover the expected NFIP loss is $5,608, and the associated rate is $2.80 per $100 of coverage purchased. The DELV model of potential damage to this structure predicts maximum damage of $156,800 for inundation depths greater than 12.5 feet. In Example 2, the amount of insurance purchased for the same building is $170,000. Even though this is less than the replacement cost, in residential property coverage, this amount is generally still considered to be “insured to value.” As with Example 1, no loss greater than $156,800 is predicted for the $200,000 structure. All losses to the structure are covered, and so the premium needed to cover the expected annual loss is still $5,608. However, the rate needed to generate that premium increases to $3.30 per $100 of coverage purchased. If this degree of underinsurance was the average amount for the rate class, then the NFIP would charge the rate of $3.30, rather than $2.80.

In Example 3, the amount of insurance purchased for the $200,000 structure covers only half of the building value (Table 4.3). Some losses to the NFIP will be avoided; even though the maximum loss predicted by the DELV calculation is $156,800 for an inundation depth of 12.5 feet, only losses up to the insured value of $100,000 will be paid. The premium needed to cover the expected loss is slightly lower than in Examples 1 and 2 ($5,075, compared with $5,608). However, the rate needed to generate the required premium rises by 35–45 percent to $5.07 per $100 of coverage purchased. The policy will pay out for more frequent damaging events (such as those that affect negatively elevated structures) for which claims are less than the policy limit.

Examples 1 and 4 illustrate the impacts of underinsurance for a high valued building ($1 million) compared to a relatively low valued building ($200,000; Table 4.3). The current NFIP statutory limit on coverage is $250,000, and the high valued building is insured to that amount. Even though the NFIP will not pay for losses higher than that amount, the premium needed to cover the losses that will be paid is $17,800 and the rate is $7.12. If the high valued and low valued buildings are in the same rate class, the rate for the entire class must be raised to compensate, leading to a form of rate compression. Thus, losses to expensive houses can wind up being heavily subsidized by premiums paid on less expensive houses.

TABLE 4.3 Effect of Underinsurance on Premiums and Premium Rates for Structures with Lowest Floor Elevations 8 Feet Below the Base Flood Elevation

			Example 1		Example 2		Example 3		Example 4	
			Structure Value	$200,000	Structure Value	$200,000	Structure Value	$200,000	Structure Value	$1,000,000
			Insurance	$200,000	Insurance	$170,000	Insurance	$100,000	Insurance	$250,000
Inundation Depth	Percent Damage	Probability in Range	Damage Amount	Expected NFIP Loss	Damage Amount	Expected NFIP Loss	Damage Amount	Expected NFIP Loss	Damage Amount	Expected NFIP Loss
≥12.5 ft	78.4%	0.2%	$156,800	$313.60	$156,800	$313.60	$156,800	$200.00	$784,000	$500.00
12–12.5 ft	73.8%	0.1%	$147,600	$147.60	$147,600	$147.60	$147,600	$100.00	$738,000	$250.00
11–12 ft	73.1%	0.1%	$146,200	$146.20	$146,200	$146.20	$146,200	$100.00	$731,000	$250.00
10–11 ft	70.5%	0.2%	$141,000	$282.00	$141,000	$282.00	$141,000	$200.00	$705,000	$500.00
9–10 ft	68.0%	0.2%	$136,000	$272.00	$136,000	$272.00	$136,000	$200.00	$680,000	$500.00
8–9 ft	63.5%	0.3%	$127,000	$381.00	$127,000	$381.00	$127,000	$300.00	$635,000	$750.00
7–8 ft	59.6%	0.3%	$119,200	$357.60	$119,200	$357.60	$119,200	$300.00	$596,000	$750.00
6–7 ft	54.2%	0.4%	$108,400	$433.60	$108,400	$433.60	$108,400	$400.00	$542,000	$1,000.00
5–6 ft	48.9%	0.4%	$97,800	$391.20	$97,800	$391.20	$97,800	$391.20	$489,000	$1,000.00
4–5 ft	41.9%	0.7%	$83,800	$586.60	$83,800	$586.60	$83,800	$586.60	$419,000	$1,750.00
3–4 ft	33.2%	0.7%	$66,400	$464.80	$66,400	$464.80	$66,400	$464.80	$332,000	$1,750.00
2–3 ft	28.6%	1.0%	$57,200	$572.00	$57,200	$572.00	$57,200	$572.00	$286,000	$2,500.00
1–2 ft	23.3%	1.2%	$46,600	$559.20	$46,600	$559.20	$46,600	$559.20	$233,000	$2,796.00
0–1 ft	16.6%	1.9%	$33,200	$630.80	$33,200	$630.80	$33,200	$630.80	$166,000	$3,154.00
−0.5–0 ft	3.5%	1.0%	$7,000	$70.00	$7,000	$70.00	$7,000	$70.00	$35,000	$350.00
≤ −0.5 ft	0.0%	91.3%	$ —	$ —	$ —	$ —	$ —	$ —	$ —	$ —
Premium				$5,608.20		$5,608.20		$5,074.60		$17,800.00
Premium Rate				$2.80		$3.30		$5.07		$7.12

NOTE: Examples are for single family structures in Zone A18. Calculations use the NFIP actuarial rate formula to compute the average annual loss. The loss costs are based on the expected annual damage amounts and do not include consideration for deductibles, loss adjustment costs, or other loadings that would go into an actual insurance rate.
SOURCE: Data from FEMA (2013d).

***Potential Changes to the NFIP Method*.** Policyholders underinsure their property because they do not understand their flood risk, high premiums create an incentive to underinsure, or statutory limits prevent them from purchasing enough flood insurance. Better communication of flood hazard and flood risk could help policyholders understand their flood risk, which could lead them to purchase sufficient insurance. Possible solutions to the deliberate purchase of too little insurance include (1) raising premiums for policyholders who elect to purchase a lower amount of insurance than warranted by their risk, although this may not be cost effective for the NFIP; (2) reducing loss payments or charging penalties if it is discovered that the declared value of the property is too low, although heavy penalties may be hard to impose in practice because they would likely cause political problems; and (3) expanding the treatment of underinsurance for VE zone structures to all structures in the NFIP portfolio. The first two are practices used in the insurance industry. The third is used by the NFIP. Rather than making one overall adjustment in the rate for underinsurance in VE zones, the NFIP varies the rate based on the ratio of the amount of insurance purchased to the replacement cost value of the building. Three ratios are considered: less than 0.5; between 0.5 and 0.74; and 0.75 or more. A more refined classification scheme such as this could reduce the potential for cross subsidies.

Although outside the control of the NFIP, raising the statutory limits on federal flood insurance could lessen the underinsurance problem. The limits have not changed since 1994, even to correct for inflation ($250,000 in 1994 is equivalent to $402,000 in 2014). As a reference point, the average value of owner-occupied houses in California was $108,000 in 1994 and $233,600 in 2014.[4] These are only averages, meaning that many policyholders have a structure value above the current $250,000 limit. At a national level, the committee's analysis of the NFIP portfolio reveals that the proportion of single-family flood insurance policies at the $250,000 limit has increased from 11 percent in 2000 to 48 percent in 2012. As building replacement cost values increase over time, larger numbers of buildings may become underinsured, worsening the problem of cross subsidies illustrated above.

[4] Data from http://www.lincolninst.edu/subcenters/land-values/land-prices-by-state.asp.

Another issue that affects the treatment of underinsurance is data quality. In the NFIP, insurance companies and agents use their own methods to estimate replacement cost (e.g., property sales data, construction costs, maximum amount of insurance coverage), and so the estimates are often inconsistent. More consistent replacement cost values could improve the underinsurance adjustment as well as other terms in the NFIP actuarial rate formula, such as DELV. Potential ways to improve replacement cost values are discussed in Chapter 5.

DEDUCTIBLES

A deductible is the amount a policyholder pays for a loss before the insurance coverage is triggered. Deductibles can provide savings both to the insurer and the policyholder. For the insurer, deductibles reduce a portion of the loss or eliminate smaller claims and the associated claim handling expenses. For the policyholder, deductibles lower the insurance premium. In general, the higher the deductible, the lower the premium because the deductible reduces the predicted claim loss for the insurer. In addition, paying some part of the loss can encourage policyholders to take mitigation actions, thereby reducing the potential for losses to both policyholders and insurers.

Deductibles can be offered as a defined amount unrelated to the limits of liability or the insured asset value, as a percentage of the limits of liability, or as a percentage of the insured asset value. To address any potential underreporting of values, the deductible is most often expressed as a percentage of value at the time of loss. The NFIP offers deductible options as set dollar amounts, not as percentages of insurance purchased or property value. Because premiums for negatively elevated structures are expected to be high when risk-based rates are implemented, it is important for the NFIP to look for ways that policyholders can reduce their premiums and receive deductible discounts that are appropriate for the expected losses.

The current NFIP minimum deductibles for building and contents coverages range from $1,000 to $2,000 (Table 4.4), and the maximum deductible available for residential properties is $5,000 each for structure and contents coverage. Research shows that most people prefer low deductibles for all types of insurance, even

TABLE 4.4 Current Minimum Deductibles for all NFIP Policies

	Post-FIRM Rating		Pre-FIRM Rating	
Building Coverage	Building	Contents	Building	Contents
Below $100,000	$1,000	$1,000	$1,500	$1,500
Above $100,000	$1,250	$1,250	$2,000	$2,000

SOURCE: NFIP Insurance Agents Manual, June 2014, pp. 14-15.

though they will have to pay more for losses (Eldred, 1980; Cutler and Zeckhauser, 2004; Sydnor, 2006). In an analysis of flood insurance deductible choices of homeowners in Florida, Michel-Kerjan and Kousky (2010) found that nearly 80 percent of policyholders chose the lowest building deductible available, and about 18 percent chose the second lowest deductible available ($500 at the time). Such a low deductible has a significant financial impact on the NFIP. The committee's analysis of national claims data for single family residences insured by the NFIP shows that increasing the minimum deductible to $2,500 would have saved the NFIP $1.6 billion in claims payments over the 1985–2009 period, and that increasing the minimum deductible to $5,000 would have saved $3.4 billion in claims payments. Of course, NFIP savings from these higher deductibles would be partly offset by the larger premium discounts offered to policyholders.

Potential Changes to the NFIP Method. One way to reduce the anticipated premium increase for negatively elevated structures is to increase the minimum deductible. In addition, changes could be made in the way premium discounts are calculated. The current NFIP premium discounts for single family residences depend only on the dollar amount of the deductible selected and whether the insurance rating is for a pre-FIRM or post-FIRM structure. This simple approach averages the effect of different deductibles on losses, masking connections between deductible amounts, premium discounts for deductibles, and loss drivers, such as flood hazard and structure value. Refining the current NFIP approach to account for differences in flood risk and structure values would result in higher premium discounts and thus lower premiums for lower valued properties. These higher discounts could be meaningful with the high premiums anticipated for negatively elevated structures. The NFIP could also explore expressing deductibles as a percentage of the insured value, as is done in earthquake and hurricane insurance policies. This approach would more closely align the deductible discounts with the replacement values of the structures.

Regardless of which approach is taken, making the results widely available and as transparent as possible could promote policyholders' understanding of the effects of deductible choices. For example, tools like the price simulator applications found on some private insurance company websites show how premiums would change for different deductible amounts and coverage limits, helping policyholders make more informed decisions on purchasing insurance.

5

Alternative Approaches and Implementation

National Flood Insurance Program (NFIP) methods for calculating risk-based premiums balance statutory requirements, actuarial principals, and practical considerations, such as feasibility, cost, and ease of implementation. Much of this balancing was based on the data and technology that were available in the early years of the program. However, expected statutory changes (i.e., a shift from subsidized to risk-based rates for negatively elevated structures) and concerns raised in program reviews (e.g., GAO, 2014) are driving a change in NFIP methods. In addition, technological advances (e.g., increased computing power; availability of lidar and web-based mapping; new techniques for providing greater spatial resolution in hazard modeling) are enabling analyses that were not practical in the early 1970s, when NFIP methods were developed. This chapter presents the committee's primary conclusions about calculating risk-based rates for negatively elevated structures, organized around the study tasks (Box 1.1).

CURRENT NFIP METHODS

The first task of the committee was to review current NFIP methods for calculating risk-based premiums for negatively elevated structures, including risk analysis, flood maps, and engineering data (see Box 1.1). NFIP methods for setting risk-based rates were developed for rating post-FIRM structures (i.e., those complying with NFIP construction standards), and their use has been tailored for structures with lowest floor elevations at or above the base flood elevation. The methods have also been applied for setting rates for about one-quarter of the negatively elevated structures in the NFIP portfolio (see "NFIP Insurance Rates" in Chapter 2).

Overall, the committee found that current NFIP methods for setting risk-based rates do not accurately and precisely describe critical hazard and vulnerability conditions that affect negatively elevated structures, including very frequent flooding, a longer duration of flooding, and a higher proportion of damage from small flood events. In addition, many NFIP methods were developed decades ago and do not take full advantage of modern technological and analysis capabilities. Specific conclusions about NFIP methods are summarized below.

ALTERNATIVE APPROACHES

The second task of the committee was to evaluate alternative approaches for calculating risk-based premiums for negatively elevated structures. The committee considered both incremental changes to current NFIP methods and different approaches, which would require research, development, and standardization; new data collection; and user training.

Incremental Changes to Current NFIP Methods

Conclusion 1. Careful representation of frequent floods in the NFIP PELV curves is important for assessing losses for negatively elevated structures. The shape of the PELV curve depends primarily on the difference between the 1 percent and 10 percent annual chance exceedance depths. However, a significant portion of potential losses to negatively elevated structures are caused by depths exceeded more frequently than once in 10 years on average (those with a 10 percent annual chance of exceedance). A short-term step to address this problem is to use information from existing detailed flood studies to refine the PELV curves so that they define more accurately the water surface elevations for frequent floods. If a flood study developed the flow frequency information needed to determine a base flood elevation (1 percent annual chance exceedance elevation), then it could easily be expanded to determine more frequent water surface elevations. The incremental cost to extract this information from existing studies and to use it to refine the PELV curves is small compared to the cost of carrying out a new detailed flood study (typically $13,000 per mile in riverine areas and $9,300 per mile in coastal areas; see NRC, 2009).

Conclusion 2. Averaging the average annual loss over a large set of PELV curves leads to rate classes that encompass high variability in flood hazard for negatively elevated structures, and thus the premiums charged are too high for some policyholders and too low for others. An incremental change is to calculate the average annual flood loss component of the premium rate using a PELV curve that represents the flood hazard at the structure's location, rather than basing the calculation on the 30 PELV curves that represent flood hazard nationally. Local meteorological, watershed, and floodplain properties (e.g., terrain, presence of levees) could be used to guide the selection of the appropriate PELV curve or to develop new PELV curves using longer records and modern analysis techniques. This adjustment would lead to more narrowly defined rate classes and premiums that better reflect the local flood hazard.

Conclusion 3. NFIP claims data for a given depth of flooding are highly variable, suggesting that inundation depth is not the only driver of damage to structures or that the quality of the economic damage and inundation depth reports that support the insurance claims is poor. Investigating the relationship between claims and the depth and duration of inundation is particularly important for negatively elevated structures, which are inundated by a flood longer than structures above the base flood elevation. An incremental improvement is to develop new classes of damage prediction functions that capture key damage drivers (e.g., depth and duration of inundation, flow velocity, water contamination, debris content) and use the appropriate function in the rate calculation. Research and new data collection would be required to determine which drivers for estimating flood damage are important. The incremental costs for collecting additional data on structure characteristics is likely to be low, and the cost for carrying out the research is likely to be moderate. The contribution of data quality to the variability in claims data is discussed below (see "Supporting Data").

Conclusion 4. When the sample of claims data is small, the NFIP credibility weighting scheme assumes that U.S. Army Corps of Engineers (USACE) damage estimates are better than NFIP claims data, which has not been proven. With almost 50 years of NFIP claims data, it may no longer be necessary to incorporate USACE damage models of unknown origin and quality into NFIP damage estimates. Instead, the NFIP could rely on improved damage models (see Conclusion 3) and its own and other flood damage reports (including damage reports from USACE, the National Weather Service, and state and local agencies involved in post-flood damage assessments) to adjust the DELV curves annually. This approach would take advantage of better models, a larger dataset, and multiple sources of damage data, which would provide an independent check on NFIP data quality. Smaller improvements could be made by determining the quality of the USACE data—a difficult task given the lack of documentation—and revising the NFIP credibility scheme to weigh the two datasets appropriately.

Conclusion 5. Levees may reduce the flood risk for negatively elevated structures, even if they do not meet NFIP standards for protection against the 1 percent annual chance exceedance flood. An incremental step is to modify the Levee Analysis and Mapping Procedure (LAMP) to assess the ability of nonaccredited levees to prevent inundation of negatively elevated structures by events more frequent than the 1 percent annual chance exceedance flood. LAMP implementation has only recently begun, and so the cost of application is uncertain. Much of the effort focuses on developing and calibrating models that can be used for floods with various exceedance probabilities. The effort to modify the procedure and use the results in the average annual loss calculation is likely to be moderate. The procedure is already being applied for the 1 percent annual chance exceedance flood, and so the incremental cost to apply it for more frequent events will likely be low. However, the cost to collect the data necessary to assess the levee performance and reduction of flood risk may be high, especially for levees that have never been certified.

Conclusion 6. When risk-based rates for negatively elevated structures are implemented, premiums are likely to be higher than they are today, creating perverse incentives for policyholders to purchase too little or no insurance. As a result, the concept of recovering loss through pooling premiums breaks down, and the NFIP may not collect enough premiums to cover losses and underinsured policyholders may have inadequate financial protection. A short term solution for discouraging the deliberate purchase of too little insurance, and to fairly compensate for it, is to tie the underinsurance adjustment to the ratio of the amount of insurance purchased to the replacement cost value of the structure, as is currently done for structures in the VE zone. Alternatively, the NFIP could reduce loss payments or impose other penalties for severely underinsured structures, although public policy issues may also have to considered. The cost to implement these changes will likely be low.

Conclusion 7. Adjustments in deductible discounts could help reduce the high risk-based premiums expected for negatively elevated structures. Premium discounts are currently based on the dollar amount of the deductible chosen and whether the structure is pre- or post-FIRM. However, more refined PELV curves and more accurate replacement cost information in rating policies can be used to structure deductible discounts that are more appropriate to individual expected annual losses. Minimum deductibles could also be increased, which would reduce premiums as well as NFIP expected claims payouts overall. The costs to implement these changes are likely to be low.

New Approach: A Comprehensive Risk Assessment

Conclusion 8. Modern technologies, including analysis tools and improved data collection and management capabilities, enable the development and use of comprehensive risk assessment methods, which could improve NFIP estimates of flood loss. A comprehensive risk assessment would describe risk over the entire range of flood hazard conditions and flood events, including the large, infrequent floods that cause substantial losses to the NFIP portfolio, and the smaller, frequent floods that make up a significant portion of loss to negatively elevated structures. It would also describe the various levels of protection offered by all elements of a flood protection system (e.g., reservoirs, levees, floodwalls, diversions and bypasses, channels, warning systems) and mitigation measures (e.g., elevating structures) through the entire range of flood events. Finally, a comprehensive risk assessment would account explicitly for uncertainty and changing conditions. Epistemic and aleatory uncertainties are accounted for through the risk analysis, including uncertainty about current and future flood hazard; structure value, vulnerability, and elevation; and current and future performance of flood protection measures. The results of a comprehensive risk assessment would improve the accuracy, precision, and robustness of flood loss estimates. It would also provide additional information to support management of the NFIP portfolio.

The NFIP already has taken some steps toward a comprehensive risk assessment (e.g., by developing multi-frequency depth grids). In addition, the NFIP is collaborating with the USACE to align methods. For example, a joint USACE–Federal Emergency Management Agency (FEMA) task force recommended the following for the NFIP (USACE and FEMA, 2013, p. 14):

> Eliminate the concept of levee system accreditation and instead implement a risk-informed suite of NFIP actions. This involves a more holistic change within the NFIP from a single "in or out" boundary of 1 percent annual chance exceedance for insurance and floodplain management to graduated zones that reflect risk, including consequences. This could include insurance premiums scaled for each parcel/risk zone, whether leveed or not, and implementation of risk-informed floodplain management requirements scaled to the risk zones.

Key steps in implementing a comprehensive risk assessment include the following:

- Develop or adapt a framework and software for the analysis. The software would have to integrate descriptions of hazard, exposure, vulnerability, performance, and uncertainty about those components to compute the distribution of flood losses and the average annual loss and to assess risk for individual structures, communities, or the entire portfolio of insured structures. The procedures and software would have to be consistent and applicable for a broad user base. Developing the software and procedures, training users, and shifting operations from the current hydrologic method to a comprehensive risk assessment would likely be expensive. However, taking advantage of existing procedures and software tools developed by the USACE (USACE, 1996),[1] the NFIP,[2] or other government agencies and private companies involved in floodplain management could yield significant cost savings.
- Describe flood hazard for every structure by modeling watershed, channel, tidal, and riverine and coastal floodplain characteristics at fine spatial resolution. This description would replace the hazard information currently provided by the PELV curves. The NFIP's multi-frequency depth grids, which use available hydrologic and hydraulic analysis to describe site-specific flood hazard, are a step in this direction. In certain cases, information from existing flood studies completed by the NFIP, the USACE, or other agencies is adequate for this purpose. In other cases, new studies will have to be completed to define the water surface elevation–exceedance probability functions. Modeling costs will be consistent with those incurred by the NFIP today, although additional model applications will have to be developed to compute inundation depths for the full range of flood frequencies. Where the terrain and hydraulics are complex, multi-dimensional hydraulic models will have to be developed to capture the water movement. These come at a greater cost. However, the capabilities of readily available, commonly used software—notably HEC-RAS—are expanding, permitting multidimensional modeling to be carried out cheaper and faster than before (Brunner, 2014).
- Describe quantitatively the uncertainty about all of the components of the flood risk analysis. For example, it will be important to describe the distribution about the mean 50, 10, 1, and 0.2 percent annual chance exceedance inundation depths. This distribution will depend on how the inundation depth–exceedance probability function is defined, including the size of the historical sample used to fit the probability model. Integrating uncertainty analysis into the rate calculation would add costs, because it imposes two new requirements on the NFIP: (1) the development of probability distributions of key inputs and (2) numerous repetitions of calculations. For some inputs, the probability distributions could be estimated with little additional effort. For example, information about the distribution of damage incurred for a given inundation depth is currently reported and could be used to derive the distribution about the mean damage. Estimating uncertainty about other inputs would require more effort. In addition, training in methods for describing uncertainty of the various flood risk components will likely be required.
- Determine the elevation, replacement value, and relevant characteristics of insured structures. Structure elevation data are needed to develop a predictor of potential damage to the structure for all inundation depths. Replacement values are needed to identify the maximum potential damage and to develop more realistic damage models. Relevant structure characteristics need to be determined so that a proper predictor of damage can be used when structures are grouped for damage assessment. Low cost methods for obtaining structure elevation, replacement values, and structure characteristics are discussed below.
- Describe the performance of levees and other flood protection measures with probabilistic

[1] See http://www.hec.usace.army.mil/software/hec-fda/.
[2] See http://www.fema.gov/hazus.

models, which are not typically used in NFIP analyses. Developing these models is likely to be one of the more expensive elements of a comprehensive risk analysis framework. Some of the required input has been developed by the USACE, but the analysis would go further by capturing the system-wide performance of all elements of a flood protection system. In addition, the NFIP technical investigations and analyses for levee certification are similar to those that would be required to develop fragility functions for each flood protection measure. New standards for these analyses and models would have to be developed and promulgated to ensure they are applied consistently.

The greatest improvements in precision and accuracy and the fewest integration problems are likely if NFIP takes all steps, making the holistic change recommended by the USACE–FEMA interagency task force. However, these steps could be implemented independently, with some attention to their eventual inclusion in a comprehensive risk assessment.

SUPPORTING DATA

The third and fourth tasks of the committee concern data. Task 3 was to discuss engineering, hydrologic, and property assessment data needed for implementing risk-based premiums for negatively elevated structures, and Task 4 was to discuss approaches for keeping these data updated. The discussion below focuses on near-term data issues, which have been documented or seem likely to arise.

Data Collection

Conclusion 9. Risk-based rating for negatively elevated structures requires, at a minimum, structure elevation data, water surface elevations for frequent flood events, and new information on structure characteristics to support the assessment of structure damage and flood risk. Water surface elevation data can be extracted from existing flood studies (see Conclusion 2). Data on structure elevation and characteristics will have to be collected.

Structure Elevation. Structure elevations have not been determined for approximately three-quarters of the structures in the NFIP thought to be negatively elevated. The NFIP requires an Elevation Certificate for risk-based rating (FEMA, 2004). An Elevation Certificate records the elevation of the lowest floor of a structure and also includes information on the property, the Flood Insurance Rate Map for the community, and photographs and comments describing the building. Figure 5.1 shows an Elevation Certificate for a negatively elevated structure in Isleton, California. For this structure, the base flood elevation is 9 feet (item B9), and the top of bottom floor and the lowest adjacent grade are far below that (item C2).

For a given rate class, the lower the elevation of the structure, the higher the premium, with large premium increases every foot below the base flood elevation (e.g., see Table 2.2). Consequently, it is important to obtain accurate estimates of structure elevations, particularly for negatively elevated structures. Errors in the structure elevation used for risk-based rating can result in policyholders paying too much or too little for flood insurance. A Dewberry (2005) study found a significant number of errors in Elevation Certificates. For example, in Pinellas County, Florida, 12.5 percent of 1,524 certificates had either no lowest floor elevation or grossly erroneous elevations. Detecting and correcting errors and omissions in the forms is the responsibility of the communities that maintain the Elevation Certificates (FEMA, 2004). In practice, however, it is difficult for a community to confirm whether the information on an Elevation Certificate is accurate, and so audits tend to focus on whether the blanks are filled in. This raises important questions about the quality of the existing certificates.

An Elevation Certificate prepared by a licensed surveyor or engineer generally costs $500 to $1,000, and the cost is usually borne by policyholders. Substantial cost savings are possible if large groups of structures (e.g., a neighborhood) are surveyed with common land surveying methods. Obtaining commercial data may also be cost effective. In addition, new technologies have the potential to estimate structure elevation at a much lower cost. For example, vehicle-mounted lidar is being used in North Carolina to acquire highest adjacent grade elevations for approximately $25 per

U.S. DEPARTMENT OF HOMELAND SECURITY
FEDERAL EMERGENCY MANAGEMENT AGENCY
National Flood Insurance Program

ELEVATION CERTIFICATE

IMPORTANT: Follow the instructions on pages 1–9.

OMB No. 1660-0008
Expiration Date: July 31, 2015

SECTION A – PROPERTY INFORMATION

FOR INSURANCE COMPANY USE
Policy Number:
Company NAIC Number:

A1. Building Owner's Name [redacted]

A2. Building Street Address (including Apt., Unit, Suite, and/or Bldg. No.) or P.O. Route and Box No. [redacted]

City Isleton State CA ZIP Code 95641

A3. Property Description (Lot and Block Numbers, Tax Parcel Number, Legal Description, etc.)

A4. Building Use (e.g., Residential, Non-Residential, Addition, Accessory, etc.) Exist. SFD

A5. Latitude/Longitude: Lat. [redacted] Long. [redacted] Horizontal Datum: ☐ NAD 1927 ☑ NAD 1983

A6. Attach at least 2 photographs of the building if the Certificate is being used to obtain flood insurance.

A7. Building Diagram Number 1A

A8. For a building with a crawlspace or enclosure(s):
- a) Square footage of crawlspace or enclosure(s) 1134 sq ft
- b) No. of permanent flood openings in the crawlspace or enclosure(s) within 1.0 foot above adjacent grade 0
- c) Total net area of flood openings in A8.b 0 sq in
- d) Engineered flood openings? ☐ Yes ☑ No

A9. For a building with an attached garage:
- a) Square footage of attached garage 451 sq ft
- b) Number of permanent flood openings in the attached garage within 1.0 foot above adjacent grade
- c) Total net area of flood openings in A9.b sq in
- d) Engineered flood openings? ☐ Yes ☑ No

SECTION B – FLOOD INSURANCE RATE MAP (FIRM) INFORMATION

B1. NFIP Community Name & Community Number COUNTY OF SACRAMENTO - 060262

B2. County Name County of Sacramento

B3. State CA

B4. Map/Panel Number	B5. Suffix	B6. FIRM Index Date	B7. FIRM Panel Effective/ Revised Date	B8. Flood Zone(s)	B9. Base Flood Elevation(s) (Zone AO, use base flood depth)
06067C 0561	h	08/16/2012	8/16/2012	AE	9.0

B10. Indicate the source of the Base Flood Elevation (BFE) data or base flood depth entered in Item B9:
☐ FIS Profile ☑ FIRM ☐ Community Determined ☐ Other/Source:

B11. Indicate elevation datum used for BFE in Item B9: ☐ NGVD 1929 ☑ NAVD 1988 ☐ Other/Source:

B12. Is the building located in a Coastal Barrier Resources System (CBRS) area or Otherwise Protected Area (OPA)? ☐ Yes ☑ No

Designation Date: ___/___/___ ☐ CBRS ☐ OPA

SECTION C – BUILDING ELEVATION INFORMATION (SURVEY REQUIRED)

C1. Building elevations are based on: ☐ Construction Drawings* ☐ Building Under Construction* ☑ Finished Construction
*A new Elevation Certificate will be required when construction of the building is complete.

C2. Elevations – Zones A1–A30, AE, AH, A (with BFE), VE, V1–V30, V (with BFE), AR, AR/A, AR/AE, AR/A1–A30, AR/AH, AR/AO. Complete Items C2.a–h below according to the building diagram specified in Item A7. In Puerto Rico only, enter meters.

Benchmark Utilized: PRS26122610680 Vertical Datum: NAVD 1988

Indicate elevation datum used for the elevations in items a) through h) below. ☐ NGVD 1929 ☑ NAVD 1988 ☐ Other/Source:
Datum used for building elevations must be the same as that used for the BFE.

Check the measurement used.

a) Top of bottom floor (including basement, crawlspace, or enclosure floor)	3.43	☒ feet	☐ meters
b) Top of the next higher floor	NA	☒ feet	☐ meters
c) Bottom of the lowest horizontal structural member (V Zones only)	NA	☒ feet	☐ meters
d) Attached garage (top of slab)	3.03	☒ feet	☐ meters
e) Lowest elevation of machinery or equipment servicing the building (Describe type of equipment and location in Comments)	3.33	☒ feet	☐ meters
f) Lowest adjacent (finished) grade next to building (LAG)	2.57	☒ feet	☐ meters
g) Highest adjacent (finished) grade next to building (HAG)	3.18	☒ feet	☐ meters
h) Lowest adjacent grade at lowest elevation of deck or stairs, including structural support	NA	☒ feet	☐ meters

SECTION D – SURVEYOR, ENGINEER, OR ARCHITECT CERTIFICATION

This certification is to be signed and sealed by a land surveyor, engineer, or architect authorized by law to certify elevation information. *I certify that the information on this Certificate represents my best efforts to interpret the data available. I understand that any false statement may be punishable by fine or imprisonment under 18 U.S. Code, Section 1001.*

☑ Check here if comments are provided on back of form.
☐ Check here if attachments.

Were latitude and longitude in Section A provided by a licensed land surveyor? ☐ Yes ☐ No

PLACE SEAL HERE
REGISTERED PROFESSIONAL ENGINEER
JON E. MONEY
63966
CIVIL
STATE OF CALIFORNIA

Certifier's Name Jon E. Money		License Number 63966	
Title Associate Civil Engineer	Company Name County of Sacramento		
Address 827 7th St. Room 301	City Sacramento	State CA	ZIP Code 95814
Signature	Date 1/30/2014	Telephone (916) 874-6851	

FEMA Form 086-0-33 (7/12) See reverse side for continuation. Replaces all previous editions.

ID 4533 Exist. SFD

FIGURE 5.1 Example of an Elevation Certificate, with identifying features redacted, for a negatively elevated house built in 1970 in Isleton, California. SOURCE: Courtesy of George Booth, Senior Civil Engineer, Sacramento County, California.

ELEVATION CERTIFICATE, page 2

IMPORTANT: In these spaces, copy the corresponding information from Section A.			FOR INSURANCE COMPANY USE
Building Street Address (including Apt., Unit, Suite, and/or Bldg. No.) or P.O. Route and Box No. [redacted]			Policy Number:
City Isleton	State CA	ZIP Code 95641	Company NAIC Number:

SECTION D – SURVEYOR, ENGINEER, OR ARCHITECT CERTIFICATION (CONTINUED)

Copy both sides of this Elevation Certificate for (1) community official, (2) insurance agent/company, and (3) building owner.

Comments Low Equip. Servicing Building: Water heater = 3.33', AC is roof mounted

Gross area is used for venting of structure types 6, 7, 8 and 9.

Signature Date

SECTION E – BUILDING ELEVATION INFORMATION (SURVEY NOT REQUIRED) FOR ZONE AO AND ZONE A (WITHOUT BFE)

For Zones AO and A (without BFE), complete Items E1–E5. If the Certificate is intended to support a LOMA or LOMR-F request, complete Sections A, B, and C. For Items E1–E4, use natural grade, if available. Check the measurement used. In Puerto Rico only, enter meters.

E1. Provide elevation information for the following and check the appropriate boxes to show whether the elevation is above or below the highest adjacent grade (HAG) and the lowest adjacent grade (LAG).

a) Top of bottom floor (including basement, crawlspace, or enclosure) is ______.______ ☐ feet ☐ meters ☐ above or ☐ below the HAG.

b) Top of bottom floor (including basement, crawlspace, or enclosure) is ______.______ ☐ feet ☐ meters ☐ above or ☐ below the LAG.

E2. For Building Diagrams 6–9 with permanent flood openings provided in Section A Items 8 and/or 9 (see pages 8–9 of Instructions), the next higher floor (elevation C2.b in the diagrams) of the building is ______.______ ☐ feet ☐ meters ☐ above or ☐ below the HAG.

E3. Attached garage (top of slab) is ______.______ ☐ feet ☐ meters ☐ above or ☐ below the HAG.

E4. Top of platform of machinery and/or equipment servicing the building is ______.______ ☐ feet ☐ meters ☐ above or ☐ below the HAG.

E5. Zone AO only: If no flood depth number is available, is the top of the bottom floor elevated in accordance with the community's floodplain management ordinance? ☐ Yes ☐ No ☐ Unknown. The local official must certify this information in Section G.

SECTION F – PROPERTY OWNER (OR OWNER'S REPRESENTATIVE) CERTIFICATION

The property owner or owner's authorized representative who completes Sections A, B, and E for Zone A (without a FEMA-issued or community-issued BFE) or Zone AO must sign here. The statements in Sections A, B, and E are correct to the best of my knowledge.

Property Owner or Owner's Authorized Representative's Name

Address City State ZIP Code

Signature Date Telephone

Comments

NA

☐ Check here if attachments.

SECTION G – COMMUNITY INFORMATION (OPTIONAL)

The local official who is authorized by law or ordinance to administer the community's floodplain management ordinance can complete Sections A, B, C (or E), and G of this Elevation Certificate. Complete the applicable item(s) and sign below. Check the measurement used in Items G8–G10. In Puerto Rico only, enter meters.

G1. ☐ The information in Section C was taken from other documentation that has been signed and sealed by a licensed surveyor, engineer, or architect who is authorized by law to certify elevation information. (Indicate the source and date of the elevation data in the Comments area below.)

G2. ☐ A community official completed Section E for a building located in Zone A (without a FEMA-issued or community-issued BFE) or Zone AO.

G3. ☒ The following information (Items G4–G9) is provided for community floodplain management purposes.

G4. Permit Number	G5. Date Permit Issued	G6. Date Certificate Of Compliance/Occupancy Issued

G7. This permit has been issued for: ☐ New Construction ☐ Substantial Improvement ☐ Existing Structure

G8. Elevation of as-built lowest floor (including basement) of the building: ______.______ ☒ feet ☐ meters Datum ______

G9. BFE or (in Zone AO) depth of flooding at the building site: 9.0 ☐ feet ☐ meters Datum ______

G10. Community's design flood elevation: ______.______ ☒ feet ☐ meters Datum ______

Local Official's Name Title

Community Name COUNTY OF SACRAMENTO - 060262 Telephone 916-874-6851

Signature Date

Comments Building Sq. Ft. 1134 MFE:

Community determined BFE based on ☐ Check here if attachments.

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FIGURE 5.1 Continued

structure.[3] However, some work would have to be done to determine the extent to which these highest adjacent grade elevations can be translated to lowest floor elevations. For example, a Dewberry (2005) report found that lidar measurements would have to be supplemented with on-site precise survey measurements. Cross-checking structure elevations from vehicle-mounted lidar and from Elevation Certificates may offer a means of validating both measurements.

Structure elevations (and in some cases, flood studies) have to be updated following a major flood event or the accumulation of enough vertical land motion (e.g., uplift from tectonics, subsidence from sediment compaction or extraction of water or hydrocarbons) to change the rate class. These updates will maintain the accuracy of the flood hazard assessments. Vertical land motion is significant in some parts of the country. For example, the coasts of Oregon and Washington are rising about 1.5–3.0 mm per year due to tectonics, and parts of the Los Angeles Basin have risen or dropped by more than 10 mm per year due to hydrocarbon and groundwater withdrawal and faulting (NRC, 2012).

Structure Characteristics. Information on structure characteristics is used to understand the exposure and vulnerability of structures to damage from flooding. The NFIP collects some information on structures, including the construction characteristics (e.g., presence of a basement), the number of floors, and the type of supporting foundation. However, additional information would have to be collected to support the development and use of improved damage prediction models that consider flood duration, which is likely important for negatively elevated structures, as well as other possible drivers of flood damage. New data needs include the characteristics and usage of basements, the properties of the foundation, the type of structure or architecture, the type of interior and exterior finishes (e.g., brick vs. siding; wood vs. vinyl floors), and the quality of construction. These data would likely need to be updated only after a major renovation. The incremental cost for collecting additional data on structure characteristics is likely to be low.

[3] Presentation to the committee by John Dorman, Program Director, North Carolina Floodplain Mapping Program, on May 12, 2014.

Data Quality and Consistency

Conclusion 10. The lack of uniformity and control over the methods used to determine structure replacement cost values and the insufficient quality control of NFIP claims data undermine the accuracy of NFIP flood loss estimates and premium adjustments.

Replacement Cost. The NFIP obtains replacement cost data from insurance companies and agents, who use their own methods to estimate replacement cost (e.g., property sales data, construction costs, maximum amount of insurance coverage). Consequently, replacement cost estimates are often inconsistent. Replacement cost values could potentially be improved by (1) requiring all insurance companies and agents to use a single cost estimation method or (2) purchasing replacement cost data from commercial databases that use consistent methods to estimate replacement costs. A single method for estimating replacement costs, either developed or endorsed by the NFIP, would yield more consistent results and also be less liable to manipulation. The cost of obtaining more accurate estimates of replacement values from insurance companies need not exceed the current cost. An alternative is to purchase commercially available property replacement values estimated from regional and local property sales data, construction cost data, and other proprietary information, as is commonly done in the private insurance industry. Replacement cost estimates provided to this committee by two commercial data providers are in the range of $0.40 to $0.60 per property for the NFIP portfolio (about $2.5 million for all NFIP policies). Having multiple sources of replacement cost data would also enable the NFIP to assess the quality of replacement cost data and to choose which is best for rating purposes.

The value of a structure will change following a disaster (e.g., flood, fire, earthquake), structural modification, or socioeconomic factors (e.g., regional economic trends). Replacement cost data for affected properties could be purchased following these triggers. Increases in construction costs due to local demand surge in a post-disaster environment could be predicted with engineering and economic indices.

NFIP Claims Data. The variability in NFIP claims data for a given depth of inundation may partly reflect the inconsistent replacement cost data discussed above or the quality of damage reports. For example, the units for reporting inundation depths are not always specified consistently (e.g., 2 feet versus 2 inches), creating considerable uncertainty.[4] In addition, basic data that are used to estimate flood damages (e.g., base flood elevation, depth of flooding, losses above the amount of flood insurance carried) are not always accurate or complete (Galloway et al., 2006; GAO, 2008). While data needed for later analysis can be cleaned up by adjusting for what appear to be erroneous values or outliers, ongoing efforts to improve quality at the point of data collection are important to the NFIP ratemaking method.

Data quality could be improved by implementing a more thorough quality control and review process. A focused sampling of historical loss claims could reveal where data quality has compromised rate setting. For example, verifying historical inundation depths (e.g., by using stream gage data) and analyzing spatial statistics on a sample of structure elevations could show the extent to which unreported units of inundation depth are a problem. In addition, systemic changes in the manner data are collected and reported could improve data quality. For example, damage report forms could be revised to specify that inundation depths are reported in inches. Other changes could include more stringent requirements and standardized procedures for Write Your Own companies and contractors involved in NFIP insurance operations as well as targeted efforts in the ongoing operational reviews of those entities.

FEASIBILITY, IMPLEMENTATION, AND COST

The fifth task of the committee was to discuss feasibility, implementation, and cost of underwriting risk-based premiums for negatively elevated structures, including a comparison of factors used to set risk-based premiums. A detailed assessment of implementation options was beyond the capability of the committee because it requires detailed information on NFIP operations, costs, and plans, as well as the knowledge and experience of NFIP analysts. Consequently, the committee used its judgment, gained through experience with similar risk assessments, to discuss issues of timing, costs, and level of effort associated with adjusting NFIP methods. These issues are discussed below and summarized in Table 5.1.

Feasibility

Many of the analysis approaches identified by the committee are already being carried out by other organizations, and so should be feasible for the NFIP to implement. For example, the USACE analyzes risk on a site-specific basis for its planning studies, developing water surface elevation–exceedance probability functions and computing average annual loss for individual structures or groups of structures. This approach demonstrates that site-specific precision for risk analysis is feasible. The performance of levees in reducing flood risk has been described using probabilistic models by the USACE and others (URS/JBA, 2008; IPET, 2009). This approach was recommended by the USACE–FEMA task force and was expected to have a cost comparable to the cost of NFIP levee accreditation (USACE and FEMA, 2013). Modeling and analysis of site-specific information and future flood scenarios are already used in the private flood insurance market (see “Catastrophe Models” in Chapter 3), demonstrating that more refined rating models are feasible. Finally, the state of North Carolina has demonstrated that lidar mounted on vehicles can be used to determine individual structure elevations on a large scale and at low cost. It has also shown that a digital environment that displays information on flood hazard, structure vulnerability, and flood risk management options for individual structures can be created at relatively low cost ($3,000–$12,000 per county in North Carolina).[5]

Cost

As discussed above and summarized in Table 5.1, incremental changes to current NFIP methods can be accomplished at low or moderate cost. Implementing new approaches, such as those included in a comprehensive risk assessment, will carry higher costs. However, the use of relevant information, models, and analysis methods developed by other government agen-

[4] Personal communication from Andy Neal, FEMA, on July 7, 2014.

[5] Presentation to the committee by John Dorman, North Carolina Floodplain Mapping Program, on May 12, 2014.

TABLE 5.1 Summary of Potential Changes to NFIP Methods

Rate Component	Current NFIP Method	Incremental Changes to NFIP Methods			Shift to a Comprehensive Risk Assessment		
		Change	Level of Effort[a]	Data Needs	Change	Level of Effort[a]	Data Needs
Hazard	Described with PELV curves, which are fitted to a location using an estimate of the 1 percent annual chance exceedance depth. The rate setting process averages over PELV curves, and so the hazard description is not specific to the site	Use a water surface elevation–exceedance probability function that represents the hazard at the structure using information from existing flood studies. Select from existing PELV curves or create new categories of functions for various topographic, hydrologic, and hydraulic conditions	MEDIUM effort to extract data from existing flood studies and to analyze the flood frequency information to develop the categories LOW increase in effort once the categories have been identified	Estimates of water surface elevations more frequent than the 1 percent annual chance exceedance elevation to refine the development of PELV curves Meteorological, watershed, and floodplain properties to establish categories of water surface elevation–exceedance probability functions	Develop site-specific water surface elevation–exceedance probability functions	HIGH effort to overhaul assessment	Data for a complete hydrologic and hydraulic analysis, including watershed properties to estimate runoff, channel geometry to estimate water surface elevation in the channel, and floodplain geometry to estimate water surface elevation at structures
Vulnerability	Use a DELV curve for the structure type to predict the damage ratio as a function of depth of inundation. DELV curves are developed from NFIP data and USACE historical analyses. Structure elevations are determined using ground surveys	Continue using DELV curves, but review methods for averaging NFIP and USACE loss and damage information Investigate causes of great variability in damage, including other drivers, and expand damage predictors if appropriate Require property owners to obtain Elevation Certificates Investigate using commercial sources of structure elevation data Investigate using vehicle-mounted lidar to estimate lowest floor elevation	LOW effort to review and enhance the credibility weighting scheme MEDIUM effort to investigate additional damage drivers LOW effort to investigate commercial data on structure elevation HIGH effort to use lidar to estimate structure elevations	Historical damage data and information on floods and identified damage drivers Provenance of USACE inundation depth–damage functions if credibility weighting scheme is to be enhanced Data from vehicle-mounted lidar to validate or replace Elevation Certificates	Make use of enhanced post-flood damage reporting to develop dataset and establish inundation depth–damage functions independent of the USACE damage models Use a larger set of damage predictors to capture the relevant drivers of damage Investigate using vehicle-mounted lidar to estimate lowest floor elevation	HIGH effort to incorporate additional damage drivers into the analysis LOW effort to investigate commercial data on structure elevation HIGH effort to use lidar to estimate structure elevations	Historical damage data and information on floods and identified damage drivers Data from vehicle-mounted lidar to validate or replace Elevation Certificates
Exposure	Use structure replacement values reported by insurance agents	Obtain consistent structure replacement values by setting standards for insurance companies or purchasing commercial data	LOW effort to obtain accurate structure replacement values	Accurate and consistent structure replacement values	Same as incremental change	Same as incremental change	Same as incremental change

Performance	Credit levees and other flood protection measures with reducing risk from the 1 percent annual chance exceedance and more frequent events if the levee meets NFIP standards; ignore other levees in the risk analysis. Enhancements are proceeding under LAMP	Credit levees with providing full or partial protection, as determined with expanded application of LAMP for events more frequent than 1 percent annual chance exceedance	LOW effort to collect additional data on the performance of certified levees; HIGH effort to collect data on levees that have not been certified MEDIUM effort to adjust the LAMP analysis procedure and the average annual loss calculation to account for risk reduction attributable to nonaccredited levees	Additional information on levee performance for events more frequent and less frequent than the 1 percent annual chance exceedance flood	Use fragility functions to describe the performance of and uncertainty of all flood protection measures, attributing risk reduction as appropriate	HIGH effort to develop fragility functions for all flood protection measures affecting insured properties HIGH effort to adjust risk analysis procedures to include those fragility functions	Additional information on the performance of flood protection measures, including results of geotechnical engineering explorations and analyses
Underinsurance	Compensate for underinsurance using a loading factor to adjust rate so the collective premiums reflect the expected annual loss	Apply the treatment of underinsurance used for VE zone structures to all structures in portfolio Impose penalties (e.g., reduce loss payments) if the insured value is too low at the time of loss	LOW effort to make administrative changes	Accurate and consistent structure replacement values	Same as incremental change	Same as incremental change	Same as incremental change
Deductibles	Minimum and maximum deductibles are offered for structures and contents	Increase the minimum deductible Account for differences in flood risk and structure values when calculating premium discounts Express deductibles as a percentage of the insured value, rather than fixed value	LOW effort to make administrative changes	None	Same as incremental change	Same as incremental change	Same as incremental change

[a] A low level of effort means that existing resources can be reapplied to make the change (e.g., a few person months). Medium effort means that existing resources plus some additional resources would be required to make the change (e.g., a few person years). High effort means that substantial new resources would be required to make the change (e.g., a person decade).

cies would speed the work and stretch NFIP resources. For example, the USACE collects data on structure elevations, types, and replacement values in floodprone areas, and derives hazard and performance information for its planning studies. Similarly, California has collected information on flood hazard, performance, exposure, and vulnerability in the Central Valley.[6] Obtaining such information would enable the NFIP to move to a comprehensive risk analysis in some areas without incurring all costs associated with developing new models and gathering new data. Easy access to flood risk databases, such as those maintained by North Carolina, could also reduce costs for insurance companies and agents that write NFIP policies by reducing the need to collect information or interpret map data in some areas.

Implementation

This report identifies a menu of possible changes to NFIP methods, ranging from simple to complex. Ultimately, the NFIP needs methods that rest on a firm scientific and technical foundation, which is important for setting rates that are credible, fair, and transparent. Changes to the water surface elevation–exceedance probability functions and to the flood damage functions would strengthen the scientific and technical foundation for setting risk-based rates for negatively elevated structures. If immediate changes must be made (e.g., a congressionally mandated end to subsidies and shift to risk-based rates), then the NFIP could implement the incremental changes to PELV, DELV, and levee performance. Otherwise, taking the time and effort to implement a comprehensive risk analysis methodology and to develop site-specific flood hazard descriptions, models that predict damage from multiple drivers, and probabilistic models that describe the performance of risk reduction measures would yield a better assessment of flood losses, and thereby provide a firmer foundation for rate setting.

The challenge for the NFIP is to determine how to integrate the components of a comprehensive risk analysis into the rate-setting process. Although it is feasible to estimate the average annual loss for each structure, it may not be practical for a national insurance program to administer a program with potentially millions of structure-specific rates. For example, premium rates may vary by only a few cents per $1,000 among similar structures in a neighborhood, because of slight differences in the water surface elevation–exceedance probability functions. The accuracy achieved with these rates would not be worth the administrative burden. However, flood losses calculated for individual structures could be used to inform the assignment of those structures to rate classes.

Similarly, some evaluation will be required to balance the higher costs of data analysis and training against the benefits of a thorough uncertainty analysis. These benefits include a more reliable estimate of the expected loss, including losses from low-probability high-consequence events such as hurricanes Katrina and Sandy, and a clear statement of the limitations of the underlying analysis. In addition, the analysis would identify areas of high uncertainty, and thus where enhanced data collection or refinements to the rate model would be most productive. For example, if uncertainty analysis demonstrates that rates are most sensitive to variations about mean inundation depth, then the NFIP may choose not to invest in expanding the current depth–damage predictors to include flood duration, velocity, or other damage drivers.

[6] See http://www.water.ca.gov/cvfmp/2012cvfpp.cfm.

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Appendix A

Biographical Sketches of Committee Members

David T. Ford, *chair*, is president of David Ford Consulting Engineers in Sacramento, California. Dr. Ford is an internationally recognized expert in hydrologic, hydraulic, and water resources engineering, and flood and floodplain management. He has more than 35 years of project management experience, including 23 as owner and president of David Ford Consulting Engineers, Inc., and 12 as a senior hydraulic engineer at the U.S. Army Corps of Engineers' (USACE's) Hydrologic Engineering Center. He has served as a consultant to the USACE, the National Weather Service, U.S. Agency for International Development, state government agencies, the United Nations, the World Bank, and engineering firms worldwide. He has prior NRC committee experience, most recently with the Committee on Levees and the National Flood Insurance Program. He has served on the faculty of the University of California and California State University. Dr. Ford received his B.S., M.S., and Ph.D. degrees in civil engineering from the University of Texas. He is a registered professional engineer in 12 states.

Ross B. Corotis is the Denver Business Challenge Professor of Engineering at the University of Colorado, and former dean of the College of Engineering and Applied Science. With a background in structural mechanics, Dr. Corotis' primary research interests are in the application of probabilistic concepts to civil engineering problems, where he has expanded traditional studies of structural reliability into risk and decision modeling for the built environment. He has expanded reliability approaches to estimate seismic risk loss and prioritize mitigation, developed generalized methods of uncertainty to evaluate risk and reliability, and created regional decision models based on disaster data. Recent completed projects include a comparison of the differing damages in Haiti, Chile, and New Zealand after similar earthquakes; risk communication for seismic retrofit; and the development of a risk-based decision methodology for transportation facility design. Dr. Corotis is a member of the National Academy of Engineering. He received his B.S., M.S., and Ph.D., all in civil engineering, from the Massachusetts Institute of Technology, and is a registered professional engineer and structural engineer.

Wei Du is principal scientist and chief hydrologist at CoreLogic Spatial Solutions, where he has led research on flood risk and hazards and development of methods and analytic tools. He has more than 25 years of experience in hydrologic engineering, hazard risk assessment, and geospatial technology. During the past decade, he led a consulting team to work with the Federal Emergency Management Agency (FEMA) on many flood hazard-related projects (including FEMA Map Modernization and RiskMap) and on the production of Flood Insurance Rate Maps. He has developed analytical tools on classifying hazard risk and conducted research on flood risk associated with riverine flooding, coastal storm surge, flash flooding, and basement and sewer backup flooding. Under his leadership, CoreLogic has created the most detailed national hydrologic datasets available, including the national multiple direction flow accumulation dataset, the national catchment slope dataset, and the national flood elevation surface dataset. Working closely with Swiss Re, Dr. Du has provided catastrophic flood loss analyses for many insurance clients. He has a B.S. in hydrologic engineering, an M.S. in hydrologic and environmental science, and a Ph.D. in geography from Clark University.

Clive Q. Goodwin is assistant vice president and manager for natural hazard peril underwriting at FM Global Insurance Company. In this position, he manages worldwide underwriting of wind, flood, and collapse perils. The work capitalizes on FM Global's engineering knowledge of these hazards to improve clients' knowledge of risk and their insurance terms and conditions. Recently, Mr. Goodwin represented FM Global in a collaboration with the USACE, FEMA, and other agencies to highlight concerns about the aging inventory of levees and the importance of changing U.S. policy on levee risk. He is a chartered engineer, a member of the Institution of Mechanical Engineers, and a former member of the Industry Leaders Council of the American Society of Civil Engineers. Mr. Goodwin holds a B.S. in mechanical engineering and metallurgy from the University of Manchester, U.K., and a Certified Diploma in accounting and finance.

Larry Larson is director emeritus and senior policy advisor for the Association of State Floodplain Managers (ASFPM), where he coordinates national flood and water resources policy development with state and federal agencies, the Administration, and other policy groups and organizations. His 50+ year career has been devoted to flood hazard and water resources management. He is the codeveloper of ASFPM's No Adverse Impact approach to community development and has authored numerous white papers and articles. For decades, Mr. Larson has been a leader in developing national policy on the wise and sustainable use of floodplains. Prior to joining ASFPM, he spent 30 years with the Wisconsin Department of Natural Resources managing flood loss reduction, dam safety, wetlands, and other programs, and 5 years with the California Department of Water Resources on the design and construction of large dams, aqueducts, and other water projects. Mr. Larson holds a B.S. in civil engineering from the University of Wisconsin and is a registered professional engineer in Wisconsin and California.

Howard Leikin is retired after decades with the Federal Insurance Administration and FEMA. He served as chief actuary at FEMA beginning in 1994. In 1999, he was appointed deputy federal insurance administrator, providing executive leadership and direction for the insurance and floodplain management aspects of the National Flood Insurance Program (NFIP). He also coordinated insurance marketing, communication, and outreach strategies to reduce losses from flooding and other perils. In 2003, Mr. Leikin transferred to the Department of the Treasury, where he served as the deputy director for the newly enacted Terrorism Risk Insurance Program. His responsibilities included establishing a framework for the program, developing policies and procedures for administering claims and for sharing losses among the federal and private sectors, and developing program regulations. He was detailed back to FEMA for 5 months in 2005 to assist with policy and implementation of the NFIP in the aftermath of Hurricane Katrina. Mr. Leikin holds a B.S. in applied mathematics from SUNY Stony Brook, and an M.S. in operations research from George Washington University, and he was designated an associate in risk management by the Insurance Institute of America.

Martin W. McCann is president of Jack R. Benjamin and Associates, Inc., and is also a consulting professor of civil and environmental engineering at Stanford University. At Stanford, he is a former chair of the National Performance of Dams Program, which created a national network to report dam safety incidents and to archive this information for use by the geotechnical and seismic engineering communities. Dr. McCann's professional background and research have focused on probabilistic hazards analysis, including hydrologic events, risk assessment, reliability and uncertainty analysis, and systems analysis. He has been a consultant to several government and private sector groups in the United States and abroad, and he has served on three NRC committees, including the Committee on Integrating Dam and Levee Safety and Community Resilience. Dr. McCann received a B.S. from Villanova University and an M.S. and Ph.D. from Stanford University.

Laura A. McLay is an associate professor of industrial and systems engineering at the University of Wisconsin, Madison. Her research interests are in the field of operations research, with a particular focus on discrete optimization with application to homeland security and emergency response problems. She has authored or coauthored more than 40 publications in archival journals and refereed proceedings. Her research has been awarded several honors, including a National Science Foundation CAREER Award, a Young Investigator Award from the Army Research Office, and four best paper awards. Dr. McLay has recently served as president of Women in Operations Research and the Management Sciences, a forum of the Institute for Operations Research and the Management Sciences (INFORMS), and president of the INFORMS Section on Public Sector Operations Research. She is a department editor for *IIE Transactions*, and an associate editor for *Risk Analysis and International Transactions on Operational Research*. She received a B.S. and M.S. in general engineering, and a Ph.D. in industrial engineering, all from the University of Illinois at Urbana-Champaign.

Erwann Michel-Kerjan is the executive director of the Wharton Risk Management and Decision Processes Center at the Wharton School of the University of Pennsylvania. His research focuses on natural and manmade catastrophe risk management and disaster financing to strengthen resilience through business and policy innovation. Dr. Michel-Kerjan has published more than 100 journal articles on these topics and has (co)authored several books, including *Treatise on New Risks* (Gallimard), *Seeds of Disaster, Roots of Response: How Private Action Can Reduce Public Vulnerability* (Cambridge University Press), *The Irrational Economist: Making Decisions in a Dangerous World* (Public Affairs), *Leadership Dispatches* (Stanford University Press), and *At War with the Weather* (MIT Press), which received the prestigious Kulp-Wright award for the most influential book on risk management. He advises several heads of state and government agencies, businesses, and international organizations on risk management and has testified on several occasions before the U.S. Congress. He also serves on the board of the World Economic Forum initiative, which publishes the Global Risks Report every year, and chairs the Organisation for Economic Cooperation and Development Secretary-General Board on Financial Management of Catastrophes, which advises the 34 member countries on these issues. Dr. Michel-Kerjan studied mathematics, physics and finance at Ecole Polytechnique (France), McGill (Canada), and Harvard.

Lindene Patton is Global Head of Hazard Product Development at CoreLogic. Previously, she was chief climate product officer for Zurich Insurance Group, where she was responsible for policy and risk management related to climate change. Her research focuses on how risk management systems are affected by natural catastrophes, and on alternative financing models that reflect actual exposure as well as future climate change. She is a member of the World Economic Forum's Global Advisory Council on Measuring Sustainability and Advisory Board on Sustainability and Competitiveness. Ms. Patton serves on numerous government and nongovernmental advisory boards, including the Executive Secretariat of the U.S. National Climate Assessment Development and Advisory Committee. She recently coauthored the book *Climate Change and Insurance* (2012). She is an attorney licensed in California and the District of Columbia and an American Board of Industrial Hygiene Certified Industrial Hygienist. She holds a B.S. in biochemistry from the University of California, Davis, a master's of public health from the University of California, Berkeley, and a J.D. from Santa Clara University School of Law.

Patricia Templeton-Jones is chief operating officer of Wright National Flood Insurance Company, the largest provider of flood insurance in Florida and the United States. She is the current president of the Flood Insurance Servicing Companies Association of America and a member of the Write Your Own (WYO) Coalition. The Write Your Own Program of the NFIP allows participating property and casualty insurance companies to write and service the standard flood insurance policy in their own names. Ms. Templeton-Jones recently served as NFIP flood coordinator for Wright Flood, and chaired the Institute for Business and Home Safety and The WYO Marketing Committee. With more than 25 years of experience in the insurance industry, she is an outspoken advocate of the flood insurance program and of education about flood insurance.

Susan E. Voss is vice president/general counsel for American Enterprise Group, Inc. an insurance company specializing in health care insurance products and services. Prior to beginning her work at American Enterprise Group in November 2013, she was a consultant in the areas of life insurance and annuity regulation. From 2005 to 2013, she was the Iowa Insurance Commissioner, where she led efforts to coordinate work with state and federal emergency management teams to assist Iowans with flood-related property issues, including mitigation of homeowner damage and flood insurance issues. An integral member of the Iowa Insurance Division, she assisted on an "after action plan" committee formed by Governor Branstadin in 1993, which made recommendations on risk mitigation, insurance education and outreach, and state emergency management plans. She provided similar leadership services following the Iowa floods of 2008. She was a representative of the state of Iowa as well as president of the National Association of Insurance Commissioners. Ms. Voss has also represented the United States and Iowa in meetings with foreign regulators and officials regarding insurance operations in China, South Korea, Chile, Ecuador, and Germany. She received her B.A. from Simpson College and her J.D. from the Gonzaga University School of Law.

Appendix B

Glossary

1 percent annual chance [exceedance] flood—A flood that has a 1 percent chance of being equaled or exceeded in any given year; also known as the "100-year flood" or "base flood" (http://www.fema.gov/national-flood-insurance-program/definitions)

Average annual loss—Expected long-term loss, which is obtained by multiplying the probability of an event by its expected loss and summing over all possible events (GFDRR, 2009)

Base flood elevation (BFE)—The elevation of surface water resulting from a flood that has a 1 percent chance of being equaled or exceeded in any given year (http://www.fema.gov/national-flood-insurance-program/definitions)

Catastrophe model—A computer-based model that estimates losses from natural or manmade hazards, such as earthquakes, floods, hurricanes, and acts of terrorism (Grossi and Kunreuther, 2005)

Credibility weighting—A statistical analysis that combines theoretical damage with observed damage results. When sufficient claims exist to provide statistical confidence in observed results, the depth–damage relationship is based on the claims data. When claims data are insufficient, the claims data and theoretical damage are combined using a weighting process (http://www.fema.gov/media-library-data/20130726-1748-25045-4777/hazusmr5_fl_tm.pdf)

DED—A term in the NFIP actuarial rate formula to eliminate that portion of the loss that will be borne by the policyholder through his or her deductible (FEMA, 2013d)

DELV—A term in the NFIP actuarial rate formula that estimates damage to the property, expressed as a percentage of the total property (replacement) value, resulting from a specified depth of water (FEMA, 2013d)

Depth grid—A grid is a digital raster dataset that defines geographic space as an array of equally sized square cells arranged in rows and columns. The value in each cell represents the magnitude in that location of the flood depth represented by that particular grid (http://www.fema.gov/media-library-data/1406747117357-744b6bd203c18ada4806ad4e90c18b81/Flood_Depth_and_Analysis_Grids_Guidance_May_2014.pdf)

Detailed studies—Flood hazard mapping studies that are done use hydrologic and hydraulic methods that produce base flood elevations, floodways, and other pertinent flood data (https://www.fema.gov/pdf/floodplain/nfip_sg_appendix_d.pdf)

Elevation Certificate—A certificate that verifies the elevation data of a structure on a given property relative to the ground level. It is used by local communities and builders to ensure compliance with local floodplain management ordinances and is also used by insurance agents and companies in the rating of flood insurance policies (https://www.floodsmart.gov/floodsmart/pages/glossary_A-I.jsp)

Exceedance probability—Probability that a random event will exceed a specified magnitude in a given time period, usually 1 year unless otherwise indicated (http://www.fema.gov/media-library-data/20130726-1553-20490-8579/dl_flow_app2.pdf)

EXLOSS (expected loss ratio)—A term in the NFIP actuarial rate formula, which serves as a loading factor for underwriting expenses, a contingency factor, and other factors (FEMA, 2013d)

Exposure—The number of people and value of property that might be harmed by inundation (CDWR and USACE, 2013)

Flood depth—Height of flood waters above the surface of the ground at a given point (http://www.fema.gov/pdf/fima/pbuffd_appendix_b.pdf)

Flood duration—Amount of time between the initial rise of flood waters and their recession (http://www.fema.gov/pdf/fima/pbuffd_appendix_b.pdf)

Flood elevation—Height of flood waters above an elevation datum plane (also called water surface elevation; http://www.fema.gov/pdf/fima/pbuffd_appendix_b.pdf)

Flood hazard—Frequency of occurrence of excess water (large flow rates, high stages, or both) at a location. Commonly, this is represented with flow– or stage–frequency relationships (how severe and how often floods occur) at specific locations (CDWR and USACE, 2013)

Flood Insurance Rate Map (FIRM)—The official map of a community prepared by FEMA that shows the Special Flood Hazard Areas, the base flood elevations, and the flood risk zones applicable to the community. The following designations are made for insurance rating purposes:

- **Post-FIRM building—**A building constructed or substantially improved after December 31, 1974, or after the effective date of the initial Flood Insurance Rate Map of a community, whichever is later
- **Pre-FIRM building—**A building constructed or substantially improved on or before December 31, 1974, or before the effective date of the initial Flood Insurance Rate Map of the community, whichever is later (http://www.fema.gov/national-flood-insurance-program/definitions)

Flood protection measure—Those physical works for which funds have been authorized, appropriated, and expended and which have been constructed specifically to modify flooding in order to reduce the extent of the area subject to a “special flood hazard” and the extent of the depths of the associated flooding. These systems typically include hurricane tidal barriers, dams, reservoirs, levees, or dikes (http://www.fema.gov/media-library-data/20130726-1922-25045-4455/20130703_approachdocument_508.pdf)

Flood risk—Risk is the potential for an unwanted outcome. The flood risk to economic activity is the chance that individuals will lose property due to flooding. The risk is measured by economic metrics, such as direct and indirect costs (Traver et al., 2014)

Floodplain—Any land area susceptible to being inundated by flood waters from any source (http://www.fema.gov/national-flood-insurance-program/definitions)

Fragility curve (or function)—Describes the likelihood of flooding due to a levee breach, given the loading on the water side of the levee (CDWR and USACE, 2013)

Full-risk premium rate—A rate charged to a group of policies that results in aggregate premiums sufficient to pay anticipated losses and expenses for that group; also referred to as an actuarial rate (http://www.fema.gov/national-flood-insurance-program/definitions)

LADJ—A factor in the NFIP actuarial rate formula to account for loss adjustment expenses (FEMA, 2013d)

Lidar (light detection and ranging)—A remote sensing method that uses light in the form of a pulsed laser to measure ranges (variable distances) to Earth. These light pulses—combined with other data recorded by the airborne system—generate precise, three-dimensional information about the shape of Earth and its surface characteristics. Lidar terrain data are used in hydraulic models of the floodplain (http://oceanservice.noaa.gov/facts/lidar.html)

Lowest floor—The lowest floor of the lowest enclosed area (including basement) of a building (http://www.fema.gov/national-flood-insurance-program/definitions#L)

Negatively elevated structure—A structure in the Special Flood Hazard Area with the lowest floor elevation below the base flood elevation

PELV—A term in the NFIP actuarial rate formula that estimates the annual probability that flood waters will reach or exceed a given depth relative to the base flood elevation (FEMA, 2013d)

Performance—The effectiveness of flood or floodplain management measures (CDWR and USACE, 2013)

Replacement value—The current cost of a similar new item having the closest usage to the item being replaced. The item does not need to be replaced with an exact replica including all the item's deficiencies, superadequacies, or obsolescence (USACE, 1995)

Special Flood Hazard Area—Portion of the floodplain subject to inundation by a 1 percent annual chance [exceedance] flood (http://www.fema.gov/pdf/fima/pbuffd_appendix_b.pdf)

Subsidized premium rate—A rate charged to a group of policies that results in aggregate premiums insufficient to pay anticipated losses and expenses for that group (http://www.fema.gov/national-flood-insurance-program/definitions)

UINS—A term in the NFIP actuarial rate formula to adjust for how much policyholders have underinsured their property (FEMA, 2013d)

Vulnerability—The susceptibility of people and property to be harmed from the hazard (i.e., how flooding adversely affects people and property; CDWR and USACE, 2013)

Zone—A geographical area shown on a Flood Hazard Boundary Map or a Flood Insurance Rate Map that reflects the severity or type of flooding in the area (http://www.fema.gov/national-flood-insurance-program/definitions)

Appendix C

Acronyms and Abbreviations

BFE	base flood elevation
FEMA	Federal Emergency Management Agency
FIRM	Flood Insurance Rate Map
LAMP	Levee Analysis and Mapping Procedure
NFIP	National Flood Insurance Program
USACE	U.S. Army Corps of Engineers