TECHNICAL MAPPING ADVISORY COUNCIL

TMAC

FUTURE CONDITIONS RISK ASSESSMENT AND MODELING

December 2015


Indian Creek East Tributary 7
ZONE A
LIMIT OF DETAILED STUDY
717
716
715
Culvert
B
ZONE X
ZONE X
723
719
717
716
C
713
712
A
714
B
ZONE AE
711
710
706
PAWNEE TRAIL
CAYUGA TRAIL
711
712
B
709
708
707
ZONE X
ZONE AE
(EL 705)
706
706
219
LIMIT OF FLOODWAY
2112
KIOWA DRIVE NORTH
224
MAHAVE DRIVE
Indian Creek (Upper Reach)
Tributary Kiowa 1
NAVAJO TRAIL
BLACKFOOT TRAIL
ZONE AE
LIMIT OF DETAILED STUDY
713
712
B
MODOC TRAIL
Culvert
706
C
ZONE X
711
Culvert
A
HURON TRAIL
LIMIT OF FLOODWAY
ZONE AE
(EL 705)
ZONE X
FM ROAD 3496
M
ZONE AE
COCOPA DRIVE W.
Indian Creek East Tributary No. 2
Lake Kiowa
ZONE X
C
721
295
717
DRIVE
LIMIT OF DETAILED STUDY
724
COCOPA
K
295
L

TECHNICAL MAPPING ADVISORY COUNCIL

TMAC
Future Conditions Risk Assessment and Modeling

December 2015

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Table of Contents

Flooding in Minot, ND, 2011.

Summary of the Future Conditions Risk Assessment and Modeling Report

FLOODING IS THE most common and costly natural disaster in the United States, and flood damages are increasing due to sea level changes, changing climatological patterns, and increased development in floodplains. While a few communities have worked with the Federal Emergency Management Agency (FEMA) to include future conditions flood hazards as an informational layer on their Flood Insurance Rate Maps, and voluntary programs like the Community Rating System encourage communities to plan for future conditions, most of the flood hazard maps that are used nationwide to determine minimum building design and other floodplain development standards are a snapshot in time, showing only the current flood risk. Meeting our National Preparedness Goal of a "secure and resilient Nation with the capabilities required across the whole community to prevent, protect against, mitigate, respond to, and recover from the threats and hazards that pose the greatest risk"[1] can only be achieved if we first identify the threats and hazards we face as we move into the future.

The availability of future conditions flood risk products, tools, and information will help communities make more informed development decisions that mitigate the loss of life and property by lessening the impact of future disasters. This information will also enable current local property owners to become more resilient. Risk information supported by future conditions data can save lives; protect property and the environment; and allow for focused, planned recovery when keeping future conditions flood hazards in mind.

The recommendations outlined in this report are intended to counsel FEMA on the utilization and incorporation of best available climate science and methodology to assess possible future flood risk.

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[1] Department of Homeland Security, 2011.

Flooded house following a severe storm. Location unknown.

BIGGERT-WATERS
2012 MANDATE
Section 100215(d)

FUTURE CONDITIONS RISK ASSESSMENT AND MODELING REPORT.—

(1) IN GENERAL.—The Council shall consult with scientists and technical experts, other Federal agencies, States, and local communities to—

(A) develop recommendations on how to—

(i) ensure that flood insurance rate maps incorporate the best available climate science to assess flood risks; and

(ii) ensure that the Federal Emergency Management Agency uses the best available methodology to consider the impact of—

(I) the rise in the sea level; and

(II) future development on flood risk; and

(B) not later than 1 year after the date of enactment of this Act, prepare written recommendations in a future conditions risk assessment and modeling report and to submit such recommendations to the Administrator.

CREATION AND AUTHORITY OF TMAC

The Technical Mapping Advisory Council (TMAC) is a Federal advisory committee established to review and make recommendations to FEMA on matters related to the national flood mapping program.

The TMAC provides advice and recommendations to the Administrator of FEMA to improve the preparation of Flood Insurance Rate Maps and flood hazard information. Among its specified statutory responsibilities, the TMAC examines performance metrics, standards and guidelines, map maintenance activities, delegation of mapping activities to State and local mapping partners, interagency coordination and leveraging, and other requirements mandated by the authorizing Biggert-Waters Flood Insurance Reform Act of 2012 legislation.

CONGRESSIONAL MANDATE FOR FUTURE CONDITIONS RISK ASSESSMENT AND MODELING

Per the Biggert-Waters Flood Insurance Reform Act of 2012, the TMAC must also develop recommendations for incorporating the best available climate science in flood insurance studies and maps and using the best available methodology when considering the impacts of sea level rise and future development on flood risk. This is the focus of this report.

IMPORTANCE FOR THE NATION

The identification and broad availability of future conditions hazard and risk information is of utmost importance to our Nation's citizens and economy as development and population growth occur in areas that are at risk now, or will be in the future. Several recent directives, pieces of legislation, reports, and initiatives also support this assertion. These are further described in Section 7 of this report.

Planning, zoning, land use, and other development decisions made by communities today will impact the buildings and infrastructure that will be in existence for decades to come. The recommendations provided here support the assertion that in order to become a more resilient Nation, elected officials, community planners, engineers, architects, emergency management officials, and decision-makers will need the tools necessary to plan, prepare for, and mitigate against future risks from natural and manmade hazards.

Water rescue team in Moorhead, MN, 2009.

The TMAC believes that future conditions flood hazard products, tools, and information can be developed and provided to communities via policy change alone, and that regulatory or legislative changes are not necessary at this time.

TMAC RECOMMENDATIONS AND SUB-RECOMMENDATIONS

The seven primary recommendations from the TMAC as well as sub-recommendations that support these primary recommendations are outlined on the following pages. Sub-recommendations are shown throughout the report in blue boxes with white text.

The sub-recommendations are numbered according to the section of the Future Conditions report in which they appear, and reflect the numerical order in which they appear in that section. For example, Sub-Recommendation 3-1 is the first sub-recommendation in Section 3, Sub-Recommendation 3-2 is the second, and so on. The sub-recommendations estimate the amount of time required to achieve the recommended action. "Short-term" means up to 2 years to accomplish and "long-term" means greater than 2 years to achieve. The TMAC believes that future conditions flood hazard products, tools, and information can be developed and provided to communities via policy change alone, and that regulatory or legislative changes are not necessary at this time.

Though many of the recommendations and sub-recommendations outlined in this report are specific to FEMA, many of them should be undertaken with mapping partners and other relevant stakeholders, including the private sector.

RECOMMENDATION 1

Provide future conditions flood risk products, tools, and information for coastal, Great Lakes, and riverine areas. The projected future conditions should use standardized timeframes and methodologies wherever possible to encourage consistency and should be adapted as actionable science evolves.

Coastal Coalition Meeting in Ventor City, NJ, 2013.

RECOMMENDATION 1 : SUB-RECOMMENDATIONS

Sub-Recommendation 3-2	FEMA should use future risk assessments to take into account the likelihood of events occurring and their impacts, as well as the associated uncertainties surrounding these estimates. Timing: SHORT TERM
Sub-Recommendation 3-4	FEMA should define a future population metric that uses a standard future population database along with various budget scenarios for keeping the data current to predict the percent of the population covered at various points in the future. Timing: SHORT TERM
Sub-Recommendation 3-5	FEMA should take into account future development (excluding proposed flood control structures for the base condition/scenario) for future conditions mapping. An additional scenario can be generated that does include future flood control structures. Timing: SHORT TERM
Sub-Recommendation 3-6	FEMA should use population growth as an indicator of areas with increased potential flood risk. Timing: SHORT TERM
Sub-Recommendation 4-4	FEMA should develop guidance for how local zoning and land use planning can be used to identify where and how land use will change in the future, and incorporate that into local hazard and risk modeling. Timing: SHORT TERM
Sub-Recommendation 4-11	FEMA should develop a policy and standards on how to consider and determine erosion zones that are outside of the Special Flood Hazard Area (SFHA), as they ultimately affect flooding and environmental conditions within the SFHA. Timing: SHORT TERM

RECOMMENDATION 1 : SUB-RECOMMENDATIONS

Sub-Recommendation
5-2

FEMA should use a scenario approach for future conditions flood hazards calculation and mapping that will allow users to evaluate the robustness of proposed solutions to a range of plausible future conditions, including uncertain land use and climate change impacts.

Timing: LONG TERM

Flood damage in Sea Bright, NJ, 2012.

RECOMMENDATION 1 DISCUSSION

THE IDENTIFICATION AND BROAD availability of future conditions hazard and risk information is of utmost importance to our Nation's citizens and economy as development and population growth occur in areas that are at risk now, or will be in the future. Therefore, the TMAC recommends that FEMA provide future conditions flood hazard products, tools, and information for coastal, Great Lakes, and riverine areas. In this report, the term "riverine" encompasses flood risk from inland flooding sources, such as rivers, streams, and lakes; shallow flooding, such as sheet flow and ponding; and special hazards, such as areas subject to ice jams, alluvial fans, and other special flood hazards.

The TMAC recommends that all future conditions flood risk information be non-regulatory (advisory at the Federal level of National Flood Insurance Program [NFIP] administration). However, communities should be allowed—and encouraged—to adopt the future conditions flood hazard products, tools, and information for local regulatory purposes and decision-making on the local level.

In order to encourage national consistency and allow for accurate comparisons, the flood risk products, tools, and information provided should use standardized timeframes and methodologies wherever possible. These timeframes and methodologies should be adapted as the actionable science in this area evolves.

FEMA should use a scenario approach to future conditions flood hazard products, tools, and information. While future development should be taken into account for future conditions flood risk products, tools, and information (perhaps using population growth as an indicator of future urbanization), the TMAC believes that the base future scenario should not include proposed flood control structures. If proposed flood control structures are taken into account, their impacts should be incorporated into a second scenario. By using a scenario approach, users can evaluate the robustness of proposed solutions to a range of plausible future conditions, including uncertain land use and climate change impacts.

FEMA should develop companion future conditions flood risk product guidance, including information about how local zoning and land use planning can be used to identify where and how land use will change in the future, and how that information can be incorporated into local hazard and risk modeling. FEMA should also develop a policy and supporting standards on how to consider and determine erosion zones that are outside of the SFHA as they ultimately affect flooding and environmental conditions within the 1-percent-annual-chance flood hazard area.

When measuring coverage for future conditions flood risk products, tools, and information, FEMA should define a future population metric that uses a standard future population database along with various budget scenarios for keeping the data current to predict the percent of the population covered by future conditions flood risk products, tools, and information at various points in the future.

RECOMMENDATION 2

Identify and quantify accuracy and uncertainty of data and analyses used to produce future conditions flood risk products, tools, and information.

Flooded roadway and bridge in Marshall County, KS, 2015.

RECOMMENDATION 2 : SUB-RECOMMENDATIONS

Sub-Recommendation 3-2	FEMA should use future risk assessments to take into account the likelihood of events occurring and their impacts, as well as the associated uncertainties surrounding these estimates. Timing: SHORT TERM
Sub-Recommendation 3-7	FEMA should publish multiple future conditions flood elevation layers that incorporate uncertainty so as to provide a basis for building designs that lower flood risk. Timing: SHORT TERM

RECOMMENDATION 2 DISCUSSION

GIVEN UNCERTAINTY ABOUT predicted rainfall and temperatures, historical averages, and recent trends are generally used to identify flood hazards and make flood risk management decisions. This is problematic because past averages and trends may not always be accurate indicators of the future, especially if there are large changes or disruptions in our natural or manmade systems. Also, the observations and data for the past are incomplete and can be inaccurate. While the flood mapping community is accustomed to relying on observations of past floods to estimate the extent and depth of future floods, there has always been uncertainty associated with these estimates, whether that uncertainty has been acknowledged or not.

In the case of future conditions (e.g., changes in precipitation patterns, land alteration by nature or man, changes in stream flow, sea level rise, long-term coastal erosion, riverine erosion), projected trends and variabilities will be based on some combination of data and modeling, both of which magnify uncertainty. Uncertainties will be even greater for future conditions than those associated with modeling and mapping existing conditions, particularly as projections are made over a longer timeframe.

To date, the accuracies, degree of precision, and uncertainties associated with respect to currently-issued flood studies and mapping products have not been quantified or published. This information is needed both for improved risk identification and risk communication, and can serve as a baseline for characterizing future conditions. Therefore, as part of the future conditions flood hazard products, tools, and information recommended by the TMAC, FEMA should publish multiple future conditions flood elevation layers that incorporate identification of uncertainty so as to provide a basis for building designs that lower flood risk. In addition, risk assessments provided by FEMA should take into account the likelihood of events occurring and their impacts, as well as the associated uncertainties surrounding these estimates.

RECOMMENDATION 3

Provide flood hazard products and information for coastal and Great Lakes areas that include the future effects of long-term erosion and sea/lake level rise. Major elements are:

- **Provide guidance and standards for the development of future conditions coastal flood risk products.**
- **Incorporate local relative sea/lake level rise scenarios and long-term coastal erosion into coastal flood hazard analyses.**
- **Consider the range of potential future natural and man-made coastal changes, such as inundation and coastal erosion.**

Sand berm construction in Long Beach, NY, 2015.

RECOMMENDATION 3 : SUB-RECOMMENDATIONS

Sub-Recommendation **4-1**	FEMA should use a scenario approach when considering shoreline location for the estimation of future conditions flood hazards. At least two scenarios should be evaluated, one in which the shoreline is held at its present location, and another in which the shoreline is eroded according to the best available shoreline erosion data. Timing: SHORT TERM
Sub-Recommendation **4-6**	FEMA should develop guidance for incorporating future conditions into coastal inundation and wave analyses. Timing: SHORT TERM
Sub-Recommendation **4-8**	FEMA should develop consistent methods and models for long-term coastal erosion hazard mapping. Timing: SHORT TERM
Sub-Recommendation **5-4**	FEMA should use Parris et. al, 2012,[2] or similar global mean sea level scenarios, adjusted to reflect local conditions, including any regional effects (Local Relative Sea Level) to determine future coastal flood hazard estimates. Communities should be consulted to determine which scenarios and time horizons to map based on risk tolerance and criticality. Timing: SHORT TERM
Sub-Recommendation **5-5**	FEMA should work with other Federal agencies (e.g., National Oceanic and Atmospheric Administration, U.S. Army Corps of Engineers, U.S. Geological Survey), the U.S. Global Change Research Program, and the National Ocean Council to provide a set of regional sea-level rise scenarios, based on the Parris et al, 2012[3] scenarios, for the coastal regions of the United States out to the year 2100 that can be used for future coastal flood hazard estimation. Timing: SHORT TERM

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[2] Parris, et. al., 2012.
[3] Ibid.

RECOMMENDATION 3 : SUB-RECOMMENDATIONS

Sub-Recommendation
5-7

FEMA should prepare map layers displaying the location and extent of areas subject to long-term erosion and make the information publicly available. Elements include:

- Establishing the minimum standards for long-term erosion mapping that will be used by FEMA that must be met by partners/communities if it is to be incorporated into the FEMA products
- Working with Federal, State, and local stakeholders to develop these minimum standards via pilot studies
- Securing funding that can support sustained long-term erosion monitoring and mapping by allowing for periodic updates

Timing: LONG TERM

Sub-Recommendation
5-9

FEMA should support additional research to characterize how a changing climate will result in changes in Great Lakes and ocean wave conditions, especially along the Pacific Coast. The relative importance of waves on this coast makes this an important consideration.

Timing: LONG TERM

Sub-Recommendation
5-10

For the Great Lakes, the addition or subtraction of future lake level elevations associated with a changing climate is not recommended at this time due to current uncertainty in projections of future lake levels.

Timing: SHORT TERM

Sub-Recommendation
5-11

FEMA should build upon the existing current conditions flood hazard analyses prepared by FEMA for the NFIP to determine future coastal flood hazards.

Timing: SHORT TERM

Fast-moving floodwaters in Texas, undated.

RECOMMENDATION 3 : SUB-RECOMMENDATIONS

Sub-Recommendation
5-12

FEMA should incorporate Local Relative Sea Level Rise scenarios into the existing FEMA coastal flood insurance study process in one of the following ways:

- Direct Analysis – Incorporate sea level rise directly into process modeling (i.e., surge, wave setup, wave runup, overtopping, and erosion) for regions where additional sea level is determined to impact the Base Flood Elevation non-linearly (for example, where a 1-foot sea level rise equals a two-foot or more increase in the base flood).
- Linear Superposition – Add sea level to the final calculated total water level and redefine the Base Flood Elevation for regions where additional sea level is determined to impact the base flood linearly (for example, 1 foot of sea level rise equals a 1-foot increase in the base flood).

Wave effects should be calculated based on the higher Stillwater, including sea level rise.

Timing: SHORT TERM

Sub-Recommendation
5-13

Maps displaying the location and extent of areas subject to long-term coastal erosion and future sea level rise scenarios should be advisory (non-regulatory) for Federal purposes. Individuals and jurisdictions can use the information for decision-making and regulatory purposes if they deem appropriate.

Timing: SHORT TERM


Washed-out landing in Tipton County, TN, 2011.


North Carolina coastline, undated.

RECOMMENDATION 3 DISCUSSION

NON-REGULATORY FUTURE CONDITIONS flood hazard products, tools, and information for coastal and Great Lakes areas should include the effects of long-term erosion and sea level rise (lake level rise, if appropriate, for the Great Lakes).

It is important to understand existing hazards in order to begin to understand how those hazards may change in the future. Therefore, the TMAC recommends that the analyses for future coastal flood hazards be built from existing current conditions flood hazard analyses, such as those prepared by FEMA for the National Flood Insurance Program. This consistency will facilitate comparisons between current and future projections of extreme water levels and will also enable compatibility with existing programs and uses.

Defining future coastal flood hazards will require an assessment of how sea level change will influence the frequency and magnitude of future extreme water level events. Future storm tides and waves may reach higher elevations than during past storms and may do so with more frequency in most areas of the country, increasing the area impacted by future coastal flood hazards. Because local relative sea level is variable along the coast, some areas are actually experiencing relative sea level fall, while other localized areas exhibit a more dramatic relative sea level rise trend than generally observed globally. Therefore, regionalization of existing global sea level projections is needed for mapping future conditions. Ideally, these regional scenarios would be vetted by regional and local stakeholders and used for consistent future flood hazard assessment. These decisions should be documented as part of the final product.

Because of the uncertainty about future changes in climate, it is necessary to examine a range of scenarios that reflect complete, coherent, and internally consistent descriptions of plausible future states. This allows an examination of cases for exposure to extreme events and performance for the project alternatives. The TMAC recommends that FEMA work with other Federal agencies (e.g., National Oceanic and Atmospheric Administration, U.S. Army Corps of Engineers, U.S. Geological Survey), the U.S. Global Change Research Program, and the National Ocean Council to provide a set of regional sea-level rise scenarios, based on the Parris et al, 2012[4] scenarios, for the coastal regions of the U.S. out to the year 2100 that can be used for future coastal flood hazard estimation. In addition, Parris et. al, 2012, or similar global mean sea level scenarios, adjusted to reflect local conditions, including any regional effects, should be used to determine future coastal flood hazard estimates. Communities should be consulted to determine which scenarios and time horizons to map based on risk tolerance and criticality.

When incorporating these scenarios into the existing FEMA coastal flood insurance study process, FEMA should use a direct analysis approach that incorporates sea level rise directly into process modeling (e.g., surge, wave setup,

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[4] Ibid.

wave runup, overtopping, and erosion) for regions where additional sea level increase is determined to impact the Base Flood Elevation non-linearly (e.g., a 1-foot sea level rise equaling a 2-foot or more increase in the base flood). For regions where additional sea level is determined to impact the Base Flood Elevation linearly (where a 1-foot rise in sea level causes a 1-foot increase in the base flood), a linear superposition approach should be used; that is, adding the sea level change to the final calculated total water level and redefining the elevation of the base flood in that manner. In either case, wave effects should be calculated based on the higher stillwater elevation, including sea level rise.

For the Great Lakes, the addition or subtraction of future lake level elevations associated with a changing climate is not recommended at this time due to current uncertainty in projections of future lake levels.

Turbulent water on a beach. Location unknown.

When considering shoreline location for the estimation of future conditions flood hazards, the TMAC recommends that at least two scenarios be evaluated—one in which the shoreline is held at its present location, and another in which the shoreline is eroded according to the best available shoreline erosion data.

FEMA should develop consistent methods and models for long-term coastal erosion hazard mapping. The TMAC also recommends that FEMA work with Federal, State, tribal, and local stakeholders via pilot studies to establish the minimum standards for long-term erosion mapping if the information is to be incorporated into the regulatory FEMA products. FEMA should secure funding that can support sustained long-term erosion monitoring and mapping by allowing for periodic updates.

In support of future conditions coastal flood hazard products, tools, and information, FEMA should develop guidance for incorporating future conditions into coastal inundation and wave analyses, and support additional research to characterize how a changing climate will result in changes in Great Lakes and ocean wave conditions, especially along the Pacific Coast. The relative importance of waves on the Pacific Coast makes this an important consideration.

RECOMMENDATION 4

Provide future conditions flood risk products and information for riverine areas that include the impacts of: future development, land use change, erosion, and climate change, as actionable science becomes available.

Major elements are:

- Provide guidance and standards for the development of future conditions riverine flood risk products.
- Future land use change impacts on hydrology and hydraulics can and should be modeled with land use plans and projections, using current science and build upon existing model study methods where data are available and possible.
- Future land use should assume built-out floodplain fringe and take into account the decrease of storage and increase in discharge.
- No actionable science exists at the current time to address climate change impacts to watershed hydrology and hydraulics. If undertaken, interim efforts to incorporate climate change impacts in flood risk products and information should be based on existing methods, informed by historical trends, and incorporate uncertainty based upon sensitivity analyses.
- Where sufficient data and knowledge exist, incorporate future riverine erosion (channel migration) into flood risk products and information.

Recovery efforts in Sea Bright, NJ, 2013.

RECOMMENDATION 4 : SUB-RECOMMENDATIONS

Sub-Recommendation 4-7	FEMA should evaluate previously-issued guidance for future conditions land use and hydrology to incorporate best practices and lessons learned from communities that have implemented the guidance since 2001. Timing: SHORT TERM
Sub-Recommendation 4-9	FEMA should determine long-term riverine erosion hazard areas for areas subject to high erosion and provided to the public in a digital layer. Timing: SHORT TERM
Sub-Recommendation 4-10	FEMA should utilize a national standard for riverine erosion zone delineations that reflects geographic variability. Timing: SHORT TERM
Sub-Recommendation 5-6	FEMA should take the impacts of future development and land use change on future conditions hydrology into account when computing future conditions for riverine areas. Timing: SHORT TERM

RECOMMENDATION 4 : SUB-RECOMMENDATIONS

Sub-Recommendation 5-8	FEMA should implement riverine erosion hazard mapping (channel migration zones), leveraging existing data, models, and approaches that reflect site-specific processes and conditions. Timing: LONG TERM
Sub-Recommendation 5-15	FEMA should use observed riverine trends to help estimate what future conditions might look like. In watersheds where floods of interest may decrease in magnitude and frequency, then use existing riverine study results as the basis for flood hazard mapping. In watersheds where floods exhibit increase in magnitude or frequency, then use best available science to determine future hydrology and flood hazards. Timing: SHORT TERM
Sub-Recommendation 5-16	FEMA should work with other Federal agencies via the Advisory Committee on Water Information’s Subcommittee on Hydrology to produce a new method to estimate future riverine flood flow frequencies. This method should contain ways to consistently estimate future climate-impacted riverine floods and address the appropriate range of flood frequencies needed by the NFIP. Timing: LONG TERM
Sub-Recommendation 5-17	FEMA should produce, and should encourage communities to adopt, future conditions products to reduce flood risk. Timing: SHORT TERM

Flood dame in Nags Head, NC, 1999.

At the current time, available and actionable science does not support the development of a single, nationwide method for determining future riverine flood risk boundaries based on projected future changes to the watershed due to geomorphological or climate changes.

RECOMMENDATION 4 DISCUSSION

NON-REGULATORY FUTURE CONDITIONS flood risk products, tools, and information for riverine areas should include the impacts of future development, land use change, erosion, and climate change. This includes rivers that are influenced by coastal effects; Great Lakes tributaries; inland flooding sources, such as rivers, streams, and lakes; shallow flooding, such as sheet flow and ponding; and special hazards, such as areas subject to ice jams, alluvial fans, and other non-coastal special flood hazards. FEMA should encourage the adoption of future conditions products by communities to reduce flood risk. Changes in river morphology can impact future conditions flood hazard identification. Expansion of the floodplain, meandering, erosion and sedimentation, shifting riverbank stability, altered sediment supply, and underlying geologic influence can all have a significant impact on riverine flood levels and lateral migration. Therefore, FEMA should implement riverine erosion hazard mapping (channel migration zones), leveraging existing data, models, and approaches that reflect site-specific processes and conditions. For consistency, channel migration zones should conform to a national standard that allows for them to reflect regional variability.

The TMAC is aware that, at the current time, available and actionable science does not support the development of a single, nationwide method for determining future riverine flood risk boundaries based on projected future changes to the watershed due to geomorphological or climate changes. Therefore, as outlined in Recommendations 6 and 7, FEMA should build on the current science, support research and innovation, and inform the process with best practices and lessons learned from demonstration projects.

Initially, FEMA should use observed riverine trends to help estimate what future conditions might look like: In watersheds where floods of interest may decrease in magnitude and frequency, then use existing riverine study results as the basis for flood hazard mapping; in watersheds where floods exhibit increase in magnitude or frequency, then use best available science to determine future hydrology and flood hazards.

In order to further the needed research in this area of science, FEMA should work with other Federal agencies via the Advisory Committee on Water Information’s Subcommittee on Hydrology to produce a new method to estimate future riverine flood flow frequencies. This method should contain ways to consistently estimate future climate-impacted riverine floods and address the appropriate range of flood frequencies needed by the NFIP.

Before implementing new future flood risk products, tools, and information for riverine areas, FEMA should evaluate previously-issued guidance for future conditions land use and hydrology to incorporate best practices and lessons learned from communities that have implemented that guidance since 2001.

RECOMMENDATION 5

Generate future conditions data and information such that it may frame and communicate flood risk messages to more accurately reflect the future hazard in ways that are meaningful to and understandable by stakeholders. This should enable users to make better-informed decisions about reducing future flood-related losses.

Coastal Flood Recovery Project Meeting, Pensacola, FL, 2004.

RECOMMENDATION 5 : SUB-RECOMMENDATION

Sub-Recommendation 3-3	FEMA should frame future risk messages for future conditions data and information such that individuals will pay attention to the future flood risk. Messages may be tailored to different stakeholders as a function of their needs and concerns. Timing: LONG TERM

RECOMMENDATION 5 DISCUSSION

ANY FUTURE CONDITIONS flood hazard products, tools, or information that FEMA generates are inherently risk communication products, because they will seek to communicate the risk associated with future conditions to stakeholders. Risk communication is a critical aspect of risk management. All concerned stakeholder groups, including the public, require accurate, easy-to understand information on the risks that communities face.

To illustrate this point, consider a flood with a 100-year return period. If property owners in a flood-prone area are told that there is a 1 in 100 chance of their home flooding in the coming year, they are likely to assume it will not occur and will treat the event as below their threshold level of concern. Had they been told that there is a greater than 1 in 5 chance of their home flooding over the next 25 years (the same probability with an extended time horizon to match a typical 30-year mortgage), they may have been more likely to pay attention and considered undertaking protective measures. Such framing of information on or with future conditions flood hazard products, tools, and information can help assure that individuals who are in harm's way recognize the hazards they face and their associated risks.

When designing products, tools, and information that are meant to communicate future flood hazards, FEMA should seek to recognize the systematic biases and simplified decision rules that individuals utilize in making choices under uncertainty. This recognition will allow FEMA to design better and more effective ways to illustrate and communicate future conditions flood hazard information.

Risk communication is a critical aspect of risk management with all stakeholder groups requiring accurate, easy-to understand information.

Informing residents that there is a greater than 1 in 5 chance of at least one flood occurring in their area over the next 25 years is more likely to get their attention than communicating this as a 1 in 100 chance in the coming year (the same probability).

Hurricane damage, Mississippi, 2005.

RECOMMENDATION 6

Perform demonstration projects to develop future conditions data for representative coastal and riverine areas across the Nation to evaluate the costs and benefits of different methodologies or identify/ address methodological gaps that affect the creation of future conditions data.

RECOMMENDATION 6 : SUB-RECOMMENDATIONS

Sub-Recommendation 3-1	FEMA should perform a study to quantify the accuracies, degree of precision, and uncertainties associated with respect to flood studies and mapping products for existing and future conditions. This should include the costs and benefits associated with any recommendation leading to additional requirements for creating flood-related products. Timing: SHORT TERM
Sub-Recommendation 5-3	FEMA should conduct future conditions mapping pilots to continue to refine a process and methods for mapping and calculating future flood hazards, and capture and document best practices and lessons learned for each. Timing: SHORT TERM
Sub-Recommendation 5-14	FEMA should support research for future conditions coastal hazard mapping pilots and case studies using the latest published methods to determine the best means to balance the costs and benefits of increasing accuracy and decreasing uncertainty. Timing: SHORT TERM

RECOMMENDATION 6 DISCUSSION

FUTURE ADJUSTMENTS AND refinements will be needed in the estimation of future flood risk and the corresponding uncertainties as the population, land surface, and actionable science evolve.

Approximate or simplified methods to estimate future flood changes may be needed due to limitations in our ability to project land use and land cover changes, as well as other changes impacting future hydrologic conditions, such as climate change.

Therefore, the TMAC recommends that FEMA conduct future conditions mapping pilots or demonstration projects in order to continue to refine a process and methods for calculating and mapping future conditions flood hazards. FEMA should also capture and document best practices and lessons learned for each project as these should inform changes to the process, methodologies, and assumptions.

In addition, the cost of improving the accuracy and reducing uncertainties of the future conditions flood hazard products, tools, and information needs to be compared with the benefits so that future studies can be budgeted and prioritized appropriately. Therefore, FEMA should support research for future conditions coastal hazard mapping pilots and case studies using the latest published methods to determine the best means to achieve this balance between costs and benefits.

Flood risk education in Wimberley, TX, undated.

Urban Search and Rescue Team in Virginia, 2015.

RECOMMENDATION 7

Data and analysis used for future conditions flood risk information and products should be consistent with standardized data and analysis used to determine existing conditions flood risk, but also should include additional future conditions data, such as climate data, sea level rise information, long-term erosion data; and develop scenarios that consider land use plans, planned restoration projects, and planned civil works projects, as appropriate, that would impact future flood risk.

Elevated homes in Stratford, CT, 2012.

RECOMMENDATION 7 : SUB-RECOMMENDATIONS

Sub-Recommendation 4-2	FEMA should support expanded research and innovation for water data collection, for example using Doppler radar. Timing: SHORT TERM
Sub-Recommendation 4-3	FEMA should use a scenario approach to evaluate the impacts of future flood control projects on future conditions flood hazards. Timing: SHORT TERM
Sub-Recommendation 4-5	FEMA should support research on future conditions land use effects on future conditions hydrology and hydraulics. Timing: SHORT TERM
Sub-Recommendation 4-12	FEMA should develop guidance for evaluating locally-developed data from States and communities to determine if it is an improvement over similarly-available national datasets and could be used for future conditions flood hazard analyses. Timing: SHORT TERM
Sub-Recommendation 4-13	FEMA should develop better flood risk assessment tools to evaluate future risk, both population-driven and climate-driven. Improve integration of hazard and loss estimation models (such as Hazus) with land use planning software designed to analyze and visualize development alternatives, scenarios, and potential impacts to increase use in local land use planning. Timing: LONG TERM
Sub-Recommendation 5-1	Future flood hazard calculation and mapping methods and standards should be updated periodically as we learn more through observations and modeling of land surface and climate change, and as actionable science evolves. Timing: SHORT TERM

RECOMMENDATION 7 DISCUSSION

THE TMAC RECOMMENDS that FEMA build on the current flood hazard identification process and methods as a starting point for providing future conditions flood hazard products, tools, and information. Calculating and mapping future conditions can be accomplished by using the existing FEMA modeling framework, but requires additional information and data about future natural and manmade changes. Using future conditions data requires a different approach that must account for a potential future that is not based on the past. In other words, the rules of stationarity (i.e., the assumption that data and processes do not change over time), upon which existing conditions mapping is based, will no longer be valid. Non-stationarity (i.e., the assumption that data and processes will change over time) must be taken into account. Incorporating non-stationarity into the existing modeling framework requires different approaches that deal with future uncertainty (e.g., future manmade actions and changing natural systems, such as climate change and sea level rise).

In addition, FEMA should support and utilize research and technology that will assist in our understanding of future conditions flood hazards, and develop a process and associated guidance for evaluating locally-developed data from States, tribes, and communities to determine if it is an improvement over similarly-available national datasets and could be, therefore, be used for future conditions flood hazard analyses.

FEMA should develop better flood risk assessment tools to evaluate future risk, both population-driven and climate-driven. Improve integration of hazard and loss estimation models (such as Hazus) with land use planning software designed to analyze and visualize development alternatives, scenarios, and potential impacts to increase use in local land use planning.

As noted in Recommendation 1, FEMA should use a scenario approach to future conditions flood hazard products, tools, and information. A scenario approach allows users to evaluate land use plans, planned restoration projects, and planned civil works projects (e.g., transportation, navigation, infrastructure, flood control), as appropriate, that could impact future flood risk.

Finally, future conditions flood hazard calculation and mapping methods and standards should also be updated periodically as we learn more through observations and modeling of land surface and climate change, as actionable science evolves, and through the pilot projects outlined in Recommendation 6.

Damage caused by storm surge, Jersey City, NJ, 2012.

CONSIDERATIONS FOR FUTURE STUDY

The scope of the report is to identify how future conditions should be incorporated into the floodplain analysis from a technical basis. The following are some of the issues that need to be considered if future conditions data (or components) are added nationally to the program. These are further explored in Section 6.

Issue	Description
1. Risk-based information	People will be more accurately informed if they are provided with information on the insurance premium that reflects their flood-related risk.
2. Base regulatory conditions	Consider whether and how future conditions information could be used for regulatory purposes.
3. Properties impacted by coastal shoreline change and riverine erosion	Develop a more complete understanding of the impact of future conditions if future conditions become regulatory products at the Federal level.
4. Rate of Future Change Implications	Consider rates of future conditions changes and determine appropriate planning time horizons.
5. Maintenance of Future Conditions Maps	Consider the cost of adding and maintaining future conditions maps.
6. Future Conditions Implication to Mitigation Grants	Consider how future conditions should be linked to mitigation grants in order to reduce future losses.
7. Future Conditions Roll-Out	Consider how future conditions data will be released to stakeholders.
8. Public's Perception of Safety	Can future conditions data be used to improve the public's understanding of flood risk?
9. Flood Control Structures	Consider how flood control structures should be incorporated into future conditions hazard data and information.
10. Implications of the Federal Flood Risk Management Standard	Changes in future conditions mapping should be consistent with the options for meeting the Federal Flood Risk Management Standard.
11. Types of Future Condition Changes	Should land development changes be separated from climate changes in future conditions data and information?
12. Floodplain Management and Community Rating System Modifications to Support Future Conditions	How might floodplain management regulations and the Community Rating System be modified to support future conditions?

Table of Contents

List of Figures

List of Tables

1 Introduction

The Technical Mapping Advisory Council (TMAC or Council) is a Federal advisory committee established to review and make recommendations to the Federal Emergency Management Agency (FEMA) on matters related to the national flood mapping program. Section 1 provides the TMAC's statutory authorization and requirements, a description of the TMAC, and the 2015 members.

1.1 Purpose

The purpose of this report is to provide FEMA recommendations for incorporating the best available climate science and using the best available methodologies when considering the impacts of sea level rise and future development on flood risk.

1.2 Congressional Charter

Pursuant to the *Biggert-Waters Flood Insurance Reform Act of 2012*, as amended (BW-12) (42 U.S.C. §§ 4001–4130), the charter filed with Congress on July 29, 2013, formally established the TMAC. The TMAC was established in accordance with and operates under the provisions of the *Federal Advisory Committee Act of 1972*, as amended (FACA) (5 U.S.C. App 2).

The TMAC Charter outlines the principles and functions of the Council, including the objectives and scope of TMAC activities, description of duties, member composition, frequency of meetings, and other pertinent items relating to the Council's establishment and operation (see Appendix A).

1.3 TMAC Responsibilities

The TMAC provides advice and recommendations to the Administrator of FEMA to improve the preparation of Flood Insurance Rate Maps (FIRM) and flood hazard information. Among its specified statutory responsibilities, the TMAC examines performance metrics, standards and guidelines, map maintenance activities, delegation of mapping activities to State and local mapping partners, interagency coordination and leveraging, and other requirements mandated by the authorizing BW-12 legislation.

The TMAC Bylaws establish and describe rules of conduct, regulations, and procedures regarding Council membership and operation (see Appendix B).

1.4 TMAC Duties

The TMAC's duties as mandated by BW-12 are as follows:

(1) Recommend to the Administrator how to improve in a cost-effective manner the:

- (A) accuracy, general quality, ease of use, and distribution and dissemination of flood insurance rate maps and risk data; and
- (B) performance metrics and milestones required to effectively and efficiently map flood risk areas in the United States;

(2) Recommend to the Administrator mapping standards and guidelines for:

  (A) flood insurance rate maps; and

  (B) data accuracy, data quality, data currency, and data eligibility;

(3) Recommend to the Administrator how to maintain, on an ongoing basis, FIRMs and flood risk identification;

(4) Recommend procedures for delegating mapping activities to State and local mapping partners;

(5) Recommend to the Administrator and other Federal agencies participating in the Council:

  (A) methods for improving interagency and intergovernmental coordination on flood mapping and flood risk determination; and

  (B) a funding strategy to leverage and coordinate budgets and expenditures across Federal agencies; and

(6) Submit an annual report to the Administrator that contains:

  (A) a description of the activities of the Council;

  (B) an evaluation of the status and performance of flood insurance rate maps and mapping activities to revise and update flood insurance rate maps, as required under section 4101b of this title; and

  (C) a summary of recommendations made by the Council to the Administrator (42 U.S.C. § 4101a(c))

**BIGGERT-WATERS 2012 MANDATE
SECTION 100215(d)**

The Council shall consult with scientists and technical experts, other Federal agencies, States, and local communities to—

(A) Develop recommendations on how to—

  (i) Ensure that flood insurance rate maps incorporate the best available climate science to assess flood risks; and

  (ii) Ensure that the Federal Emergency Management Agency uses the best available methodology to consider the impact of—

    (I) The rise in the sea level; and

    (II) Future development on flood risk; and

(B) Not later than 1 year after the date of enactment of this Act, prepare written recommendations in a future conditions risk assessment and modeling report and to submit such recommendations to the Administrator.

The TMAC is also required by BW-12 to provide recommendations to FEMA on incorporating the best available climate science in flood insurance studies and maps, and using the best available methodology when considering the impacts of sea level rise (SLR) and future development on flood risk (the legislative language is located in the text box to the left). This is the focus of this report.

1.5 TMAC Creation and Composition

Since the National Flood Insurance Program's (NFIP's) inception in 1968 under the *National Flood Insurance Act of 1968*, as amended (42 U.S.C. §§ 4001–4129), Congress has enacted additional legislation to encourage community participation in the national flood mapping program, strengthen the flood insurance purchase requirement, and address other priorities. BW-12 sought to make the program more financially sound, directing FEMA to raise flood insurance rates to reflect true flood risk and implement other changes. The TMAC was originally established under the *National Flood Insurance Reform Act of 1994,* as amended (42 U.S.C. §§ 4001 et seq.), for a term of 5 years. In 2012, BW-12 directed FEMA to re-establish the TMAC.

Current TMAC members were appointed based on their demonstrated knowledge and competence regarding surveying, cartography, remote sensing, Geographic Information Systems (GIS), or the technical aspects of preparing and using FIRMs. In addition, the legislation requires that the TMAC's membership have to the maximum extent practicable a balance of Federal, State, local, tribal, and private members, and include geographic diversity, including representation from areas with coastline on the Gulf of Mexico and other States containing areas identified by the Administrator as at high risk for flooding or as areas having special flood hazards.

Per FACA requirements, FEMA solicitedTMAC nominations through various professional organizations and a public submission process that was published in the *Federal Register*. To establish the TMAC as a Federal advisory committee, the FEMA Administrator selected the most qualified candidates in each membership category, ensuring that, together, the nominees provided a balance of geographically diverse professional opinions from a mix of State, local, and private- sector organizations. Following a rigorous vetting process, FEMA announced the membership and establishment of the Council in July 2014.

TMAC members serve 1- or 2-year terms, at the discretion of the Administrator, to allow refresh and ensure that the required expertise is represented. The FEMA Administrator or designee may reappoint serving members for additional 1- or 2-year periods. When new members must be appointed, the same process that was used to appoint members in 2014 will be followed. When the TMAC terminates, all TMAC appointments will also terminate.

The 2015 TMAC members, subcommittee members, and Designated Federal Officers are listed below. See Section 1.8 for information on the TMAC subcommittees.

2015 TMAC Members

Mr. John Dorman, CFM, Chair

Assistant State Emergency Management Director for Risk Management, North Carolina Emergency Management

BW-12 TMAC Membership Requirement
State Cooperating Technical Partner Representative

TMAC Member Role
Chair; Annual Report Subcommittee Member

Mr. Scott Edelman, P.E., Vice-Chair
Senior Vice President, North America AECOM Water Resources

BW-12 TMAC Membership Requirement
Mapping Member (recommended by Management Association for Private Photogrammetric Surveyors)

TMAC Member Role
Vice-Chair; Future Conditions Subcommittee Chair

Mr. Doug Bellomo, P.E., CFM
Senior Technical Advisor, U.S. Army Corps of Engineers

BW-12 TMAC Membership Requirement
Federal Emergency Management Agency Designee

TMAC Member Role
Member through May 2015; Annual Report Subcommittee Member

Ms. Juliana Blackwell
Director, National Geodetic Survey, National Oceanic and Atmospheric Administration

BW-12 TMAC Membership Requirement
National Oceanic and Atmospheric Administration / Commerce for Oceans and Atmosphere Designee

TMAC Member Role
Annual Report Subcommittee Member; Future Conditions Subcommittee Member

Ms. Nancy Blyler
Lead, Geospatial Community of Practice, U.S. Army Corps of Engineers

BW-12 TMAC Membership Requirement
U.S. Army Corps of Engineers Designee

TMAC Member Role
Annual Report Subcommittee Member; Future Conditions Subcommittee Member

Mr. Richard Butgereit, GISP
GIS Administrator, Florida Division of Emergency Management

BW-12 TMAC Membership Requirement
State Geographic Information System Representative

TMAC Member Role
Annual Report Subcommittee Member

Mr. Mark DeMulder
Director, U.S. Geological Survey National Geospatial Program (Ret.)

BW-12 TMAC Membership Requirement
U.S. Geological Survey Representative

TMAC Member Role
Annual Report Subcommittee Member

Ms. Leslie Durham, P.E.
Floodplain Management Branch Chief, Office of Water Resources, Alabama Department of Economic and Community Affairs

BW-12 TMAC Membership Requirement
State Cooperating Technical Partner Representative

TMAC Member Role
Annual Report Subcommittee Chair

Mr. Steve Ferryman, CFM
Mitigation and Recovery Branch Chief, Ohio Emergency Management Agency

BW-12 TMAC Membership Requirement
State Mitigation Officer

TMAC Member Role
Future Conditions Subcommittee Member

Mr. Gale Wm. Fraser, II, P.E.
General Manager and Chief Engineer, Clark County (Nevada) Regional Flood Control District

BW-12 TMAC Membership Requirement
Regional Flood and Stormwater Member (recommended by National Association of Flood and Stormwater Management Agencies)

TMAC Member Role
Annual Report Subcommittee Member

Ms. Carrie Grassi
Deputy Director for Planning, New York City Mayor's Office of Recovery and Resiliency

BW-12 TMAC Membership Requirement
Local Cooperating Technical Partner Representative

TMAC Member Role
Future Conditions Subcommittee Member

Mr. Christopher P. Jones, P.E.
Registered Professional Engineer

BW-12 TMAC Membership Requirement
Engineering Member (recommended by the American Society of Civil Engineers)

TMAC Member Role
Annual Report Subcommittee Member; Future Conditions Subcommittee Member

2015 TMAC Members (cont.)

Dr. Howard Kunreuther

James G. Dinan Professor of Decision Sciences and Public Policy, Wharton School, University of Pennsylvania

BW-12 TMAC Membership Requirement
Risk Management Member (recommended by the Society for Risk Analysis)

TMAC Member Role
Future Conditions Subcommittee Member

Ms. Wendy Lathrop, PLS, CFM
President and Owner, Cadastral Consulting, LLC

BW-12 TMAC Membership Requirement
Surveying Member (recommended by the National Society of Professional Surveyors)

TMAC Member Role
Annual Report Subcommittee Member

Mr. David Mallory, P.E., CFM
Program Manager, Floodplain Management Program, Urban Drainage and Flood Control District, Denver, Colorado

BW-12 TMAC Membership Requirement
Local Cooperating Technical Partner Representative

TMAC Member Role
Future Conditions Subcommittee Member

Mr. Robert Mason
Chief, Office of Surface Water, Department of Interior, U.S. Geological Survey

BW-12 TMAC Membership Requirement
Department of the Interior Designee

TMAC Member Role
Annual Report Subcommittee Member

Ms. Sally Ann McConkey, P.E., CFM, D. WRE
Illinois State Water Survey Prairie Research Institute, University of Illinois

BW-12 TMAC Membership Requirement
State Floodplain Management Member (recommended by Association of State Floodplain Managers)

TMAC Member Role
Annual Report Subcommittee Member

Mr. Luis Rodriguez, P.E.
Branch Chief, Engineering Management Branch, Federal Insurance and Mitigation Administration, FEMA

BW-12 TMAC Membership Requirement
Federal Emergency Management Agency Designee

TMAC Member Role
TMAC Member (beginning May 2015); Annual Report Subcommittee Member

Mr. Javier E. Ruiz
Acting Director, National Geospatial Center of Excellence, Natural Resources Conservation Service

BW-12 TMAC Membership Requirement
U.S. Department of Agriculture Designee

TMAC Member Role
Future Conditions Subcommittee Member

Ms. Christine Shirley, CFM
National Flood Insurance Program Coordinator, Oregon Department of Land Conservation and Development

BW-12 TMAC Membership Requirement
National Flood Insurance Coordination Office Representative

TMAC Member Role
Future Conditions Subcommittee Member

Ms. Cheryl Small
President, Small Consulting LLC

BW-12 TMAC Membership Requirement
Flood Hazard Determination Firm Member (Recommended by National Flood Hazard Determination Association)

TMAC Member Role
Annual Report Subcommittee Member

Additional 2015 TMAC Subcommittee Members

Ms. Laura Algeo, P.E., CFM

Program Specialist, FEMA

TMAC Member Role
Annual Report Subcommittee Member

Mr. Kenneth W. Ashe, P.E., PMP, CFM

Senior Associate Engineer, Amec Foster Wheeler Environment & Infrastructure, Inc.

TMAC Member Role
Annual Report Subcommittee Member

Mr. Dwayne Bourgeois, P.E.

Executive Director, North Lafourche Conservation, Levee and Drainage District

TMAC Member Role
Annual Report Subcommittee Member

Dr. Maria Honeycutt, CFM

Coastal Hazards Specialist, National Oceanic and Atmospheric Administration

TMAC Member Role
Annual Report Subcommittee Member

Mr. Douglas Marcy

Coastal Hazards Specialist, National Oceanic and Atmospheric Administration

TMAC Member Role
Future Conditions Subcommittee Member

Additional 2015 TMAC Subcommittee Members (cont.)

Mr. Andy Neal

Actuary, FEMA

TMAC Member Role
Future Conditions Subcommittee Member

Mr. Patrick Sacbibit, P.E.

Program Specialist, Federal Emergency Management Agency

TMAC Member Role
Annual Report Subcommittee Member

Mr. Jonathan Westcott, P.E.

Coastal Hazards Specialist, Federal Emergency Management Agency

TMAC Member Role
Future Conditions Subcommittee Member

Dr. Kathleen D. White, P.E.

Lead, Climate Preparedness and Resilience, Community of Practice, U.S. Army Corps of Engineers, Institute for Water Resources

TMAC Member Role
Future Conditions Subcommittee Member

TMAC Designated Federal Officers

Mr. Mark Crowell

Physical Scientist, FEMA

TMAC Member Role
TMAC Designated Federal Officer
Future Conditions Subcommittee Member

Ms. Kathleen Boyer

Program Specialist, FEMA

TMAC Member Role
TMAC Alternate Designated Federal Officer

Mr. Michael Godesky, P.E.

Physical Scientist, FEMA

TMAC Member Role
TMAC Alternate Designated Federal Officer

1.6 TMAC Mission and Guiding Principles

The TMAC's mission is to provide counsel to FEMA on strategies and actions that will efficiently and effectively advance the identification, assessment, and management of flood hazards and risk.

The TMAC believes the following guiding principles should underpin the future of the national flood mapping program:

- Credible products
- Efficient implementation
- Stakeholder acceptance
- Effective leveraging
- Financial stability

1.7 TMAC Program Vision and Goals

The TMAC believes the following statement reflects an appropriate end-state vision for the national flood mapping program:

> *A Nation more resilient to flood hazards through the effective identification and communication of flood hazards and risk.*

Toward this end-state vision, the TMAC believes the following goals and subsequent recommendations should be established and monitored:

Goal 1 Accurate, comprehensive data, models, displays, and risk assessments associated with present and future flood hazards

Goal 2 Time- and cost-efficient generation and process management of flood hazard risk data, models, assessments, and displays

Goal 3 Effective utilization of efficient technologies for the acquisition, storage, generation, display, and communication of data, models, displays, and risk

Goal 4 Integrated flood risk management framework of hazard identification, risk assessment, mitigation, and monitoring

Goal 5 Strong confidence, understanding, awareness, and acceptance of flood hazard and risk data, models, displays, assessments, and process by the public and program stakeholders

Goal 6 Robust added-value coordination, leveraging and partnering with local, State, Federal, and private sector organizations

Goal 7 Permanent, substantial funding that supports all program resource requirements

1.8 Activities of the TMAC

As a Federal advisory committee, the TMAC open business meetings are announced to the public in a notice published in the *Federal Register* (https://www.federalregister.gov/). The notices included meeting details, the agenda, general information, and direction to the public website (www.fema.gov/tmac) where interested parties can obtain certified public meeting summaries. These materials are made available for the public comment period 15 days prior to each TMAC meeting.

To facilitate public participation, members of the public were invited to provide written comments on the issues to be considered by the TMAC prior to the meetings. In addition, the public was given an opportunity to provide oral comments during designated public comment periods at each meeting.

The TMAC conducted seven in-person public meetings and two virtual public meetings between September 2014 and October 2015 that were guided by the TMAC's mission (see Section 1.5) and vision (see Section 1.6) and were in accordance with the requirements mandated under BW-12 and the *Homeowner Flood Insurance Affordability Act of 2014* (HFIAA) (Public Law 113–89, 128 Stat. 1021–22).

The business objectives that were achieved in the TMAC meetings from September 2014 through October 2015 were as follows:

- Nominate, deliberate, and vote on the TMAC Chair
- Develop the TMAC vision and mission statement
- Form the subcommittees
- Research topics in the form of subject matter expert (SME) briefings
- Produce two reports required by BW-12 and HFIAA:
  - *Future Conditions Flood Risk Assessment and Modeling Report* containing recommendations for future conditions risk assessment and modeling
  - *2015 Annual Report* containing recommendations to improve the effectiveness of the national flood mapping program and products

The TMAC also established three subcommittees: the Future Conditions Subcommittee; Flood Hazard and Risk Generation Subcommittee; and Operations, Coordination, and Leveraging Subcommittee. In March 2015, the Flood Hazard and Risk Generation Subcommittee and the Operations, Coordination, and Leveraging Subcommittee were combined into the Annual Report Subcommittee. The subcommittees presented their work at TMAC meetings.

The purpose of the subcommittees was as follows:

- Future Conditions Subcommittee – Consult with scientists, technical experts, other Federal agencies, States, and local communities to develop recommendations on how to ensure that FIRMs incorporate the best available climate science to assess flood risks and that FEMA uses the best available methodology to consider the impacts of the rise in sea level and future development on flood risk.
- Flood Hazard and Risk Generation Subcommittee – Recommend the following to the Administrator:
  - How to improve in a cost-effective manner the accuracy, general quality, ease of use, and distribution and dissemination of FIRMs and risk data
  - Improve in a cost-effective manner the performance metrics and milestones required to effectively and efficiently map flood risk areas in the United States
  - Map standards and guidelines for FIRMs
  - Map standards and guidelines for data accuracy, data quality, and data eligibility
- Operations, Coordination, and Leveraging Subcommittee:

- Recommend to the Administrator how to maintain FIRMs and flood risk identification on an ongoing basis
- Recommend to the Administrator and other Federal agencies a funding strategy to leverage and coordinate budgets and expenditures across Federal agencies
- Recommend to the Administrator and other Federal agencies how to delegate mapping activities to State and local mapping partners
- Recommend to the Administrator and other Federal agencies participating on the Council methods for improving interagency and intergovernmental coordination on flood mapping and flood risk assessment

A summary of the TMAC meetings and meeting activities is shown in Appendix D.

1.9 Presentations/Research/Subject Matter Experts

As part of the TMAC and subcommittee agendas, SMEs were invited to TMAC and subcommittee meetings to present information that was critical to achieving the TMAC's objectives and producing the required reports. Although some presentations were organized by subcommittees, they were all open to all TMAC members. The presentations are listed in Appendix E.

2 Background

Section 2 provides background information on the NFIP, Flood Insurance Studies (FIS) and maps, flood zones, and current policies and practices regarding future conditions flood risk and mapping. This section also provides a brief history of SLR and how long-term erosion is accounted for in the program.

1.1 National Flood Insurance Program

FEMA administers the NFIP through the Federal Insurance and Mitigation Administration (FIMA). Created with the passage of the *National Flood Insurance Act of 1968*, the NFIP is an insurance, mapping, and floodplain management program that makes Federally-backed flood insurance available to home and business owners and renters in the more than 22,000 communities that participate in the program.

The NFIP comprises three central interconnected activities:

- **Flood insurance** – Making flood insurance available to help property owners recover following a flood
- **Floodplain management** – Minimizing the economic impact of flood events using a combination of mitigation efforts and community-adopted floodplain ordinances
- **Floodplain identification and mapping** – Identifying and mapping community areas that are subject to flooding

These activities are supported by the production of FISs and FIRMs based on engineering evaluations of the flood hazards in each community.

2.1 Flood Insurance Studies and Maps

FISs are prepared to determine the elevation and spatial extent of the 1-percent-annual-chance flood, which defines the water surface elevations that have a 1-percent chance of being equaled or exceeded during any given year, as well as other frequency events. The 1-percent-annual-chance water surface elevations are termed Base Flood Elevations (BFE) and are referenced to the National Geodetic Vertical Datum of 1929 (NGVD29), the North American Vertical Datum of 1988 (NAVD88), or a local datum where NGVD29 and NAVD88 are not available.[1]

Areas subject to 1-percent-annual chance flooding are termed Special Flood Hazard Areas (SFHAs). If a structure is located in an SFHA, owners carrying Federally-backed mortgages and owners receiving FEMA grant funding are required to purchase flood insurance if the community participates in the NFIP. The boundaries and lateral extent of the SFHAs and other flood zones are established when the BFEs are overlain on topographic data. This information is then used to produce FIRMs, which depict the horizontal extent of SFHAs (and other flood hazard boundaries) and associated BFEs.

In 1997, FEMA developed a plan to modernize the mapping inventory from paper maps to a digital product. As part of a map modernization effort, FEMA has been producing updated FIRMs using digital methods. These georeferenced, modernized and, generally, more accurate FIRMs are published as cartographic map products and as digital geospatial data in the National Flood Hazard Layer.[2]

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[1] FEMA's current policy is to ensure that all new updated maps are referenced to NAVD88 where it is available.

[2] Crowell, et al., 2013.

2.1.1.1 Flood Zones

FIRMs depict various flood hazard areas, or flood zones, that are determined in a variety of ways. It is important to understand that flood risk and, therefore, the flood zones depicted on a FIRM, can change over time due to manmade and natural changes in floodplains that impact the flood hazard. The flood zones are described below.

2.1.1.2 High Flood Risk Areas

In communities that participate in the NFIP, mandatory flood insurance requirements apply to all flood zones in high flood risk areas. These flood zones are known as SFHAs. Riverine SFHAs are defined in Table 2-1, and coastal SFHAs are defined in Table 2-2.

Table 2-1: Flood Zones in High Flood Risk Riverine Areas (Riverine SFHAs)

Zone(s)	Description
A	Areas subject to inundation by the 1-percent-annual-chance flood event generally determined using approximate methodologies. Because detailed hydraulic analyses have not been performed, no BFEs or flood depths are shown. Mandatory flood insurance purchase requirements and floodplain management standards apply.
AE, A1-30	Areas subject to inundation by the 1-percent-annual-chance flood event determined by detailed methods. BFEs are shown. Mandatory flood insurance requirements and floodplain management standards apply. In general, AE is used on newer FIRMs, whereas Zones A1–30 were used on older Flood Insurance Rate Maps (approximately 1989 and older).
AH	Areas subject to inundation by 1-percent-annual-chance shallow flooding (usually areas of ponding) where average depths are between 1 and 3 feet. BFEs derived from detailed hydraulic analyses are shown. Mandatory flood insurance purchase requirements and floodplain management standards apply.
AO	Areas subject to inundation by 1-percent-annual-chance shallow flooding (usually sheet flow on sloping terrain) where average depths are between 1 and 3 feet. Average flood depths derived from detailed hydraulic analyses are shown. Mandatory flood insurance purchase requirements and floodplain management standards apply. Some Zone AO areas have been designated in areas with high flood velocities, such as alluvial fans and washes. Communities are encouraged to adopt more restrictive requirements for these areas.
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. Mandatory flood insurance purchase requirements and floodplain management standards apply.
A99	Areas subject to inundation by the 1-percent-annual-chance flood event but that will ultimately be protected upon completion of an under-construction Federal flood protection system. These are areas of special flood hazard where 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 only be used when the flood protection system has reached specified statutory progress toward completion. No BFEs or depths are shown. Mandatory flood insurance purchase requirements and floodplain management standards apply.

Table 2-2: Flood Zones in High Flood Risk Coastal Areas (Coastal SFHAs)

Zone(s)	Description
V	Areas along coasts subject to inundation by the 1-percent-annual-chance flood event with additional hazards associated with storm-induced waves. Because detailed hydraulic analyses have not been performed, no BFEs or flood depths are shown. Mandatory flood insurance purchase requirements and floodplain management standards apply.

Zone(s)	Description
VE, V1-30	Areas subject to inundation by the 1-percent-annual-chance flood event with additional hazards due to storm-induced velocity wave action. BFEs derived from detailed hydraulic analyses are shown. Mandatory flood insurance purchase requirements and floodplain management standards apply. In general, Zone VE is used on newer FIRMs, whereas Zones V1–30 were used on older FIRMs (approximately 1989 and older).
A	Areas subject to inundation by the 1-percent-annual-chance flood event generally determined using approximate coastal flood methods. Because detailed hydraulic analyses have not been performed, no BFEs or flood depths are shown. Mandatory flood insurance purchase requirements and floodplain management standards apply.
AE, A1-30	Areas subject to inundation by the 1-percent-annual-chance flood event generally determined using detail coastal flood models. BFEs are shown. Mandatory flood insurance requirements and floodplain management standards apply.
AO	Areas subject to inundation by 1-percent-annual-chance shallow flooding (usually sheet flow on the landward side of a dune or barrier subject to wave overtopping). Average depths in coastal A zones are between 1 and 3 feet. Mandatory flood insurance purchase requirements and floodplain management standards apply.

Most riverine SFHAs are categorized as Zone AE, Zones A1–30, or Zone A and are determined using hydrologic and hydraulic models or analysis procedures designed for riverine flood analyses. Storm surge or tide gauge analyses and wave studies are used to determine Zone As in coastal areas. Collectively, these zones are referred to as Zone As.[3]

COASTAL A ZONE

The term “Coastal A Zone” has been used to refer to both (1) Zone A_S determined using coastal flood models and (2) the area between the landward extent of Zone VE and the Limit of Moderate Wave Action (LiMWA), commonly referred to as CAZ.

Coastal A Zone (CAZ) is not a regulatory flood zone, but a specific term tied to the LiMWA and referenced by FEMA building science and building codes and standards. Building codes and standards apply Zone V design and construction requirements in the CAZ. CAZ also is recognized by the CRS program.

Coastal SFHAs categorized as Zone VE, Zones V1–30, or Zone V indicate flood hazard areas that are subject to high velocity wave action.

Coastal high flood risk areas are more hazardous than riverine high flood risk areas because wave effects can cause structural damage to buildings that would otherwise remain intact following inundation only.

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[3] In this report, the term “Zone As” refers to any zone that begins with the letter A (A, A1–30, AE, AH, AO, AR, A99).

Consequently, NFIP floodplain management and construction requirements are more stringent (see Figure 2-1) and flood insurance premium rates are much higher in Zone Vs.[4] Building codes and standards extend Zone V design and construction requirements to Coastal A Zones subject to wave heights between 1.5 and 3 feet (see Figure 2-2).

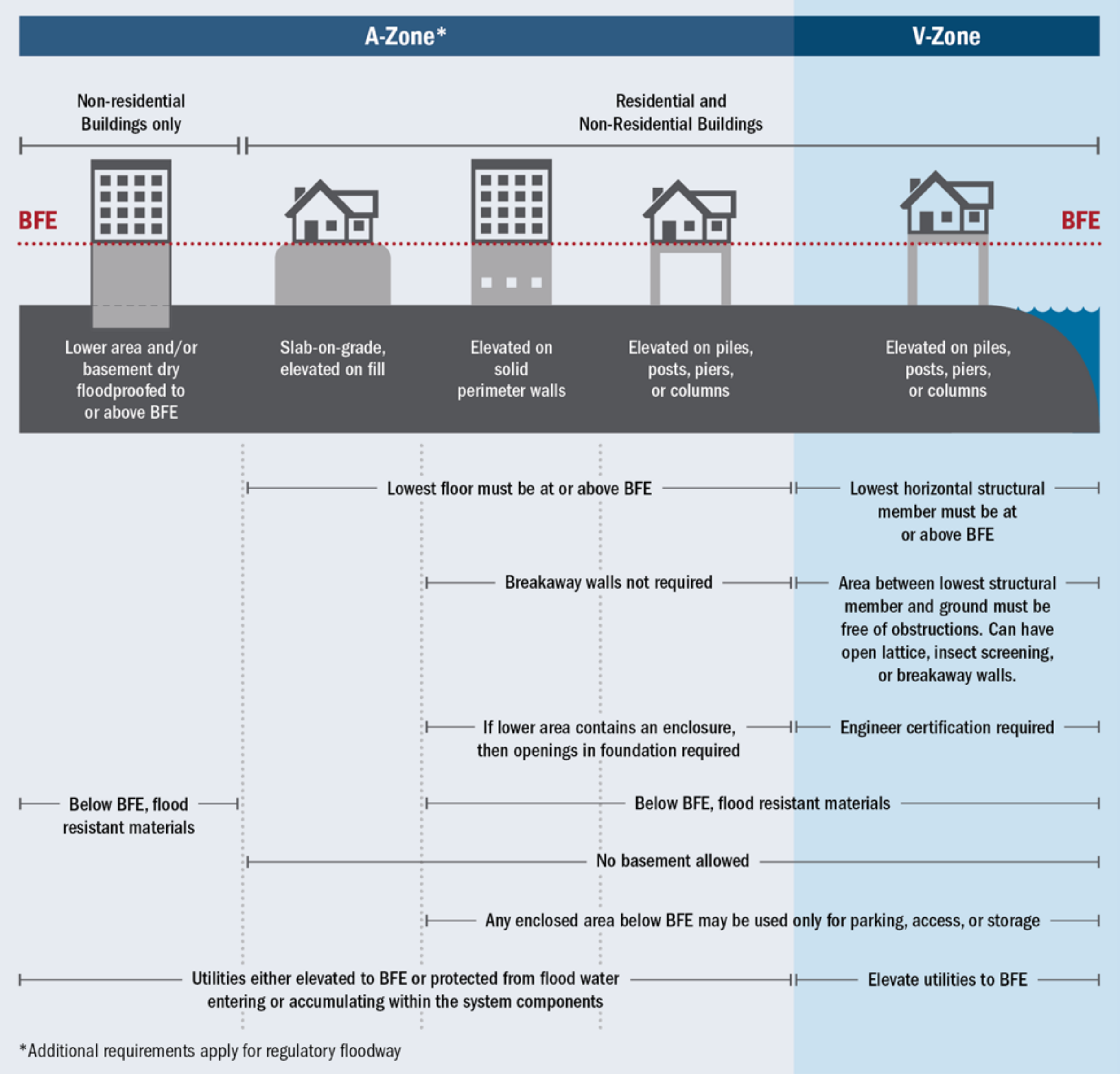

Figure 2-1: Summary of current minimum NFIP building requirements[5]

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[4] In this report, the term "Zone Vs" refers to any zone that begins with the letter V (V, V1–30, VE).

[5] Crowell, et al., 2013

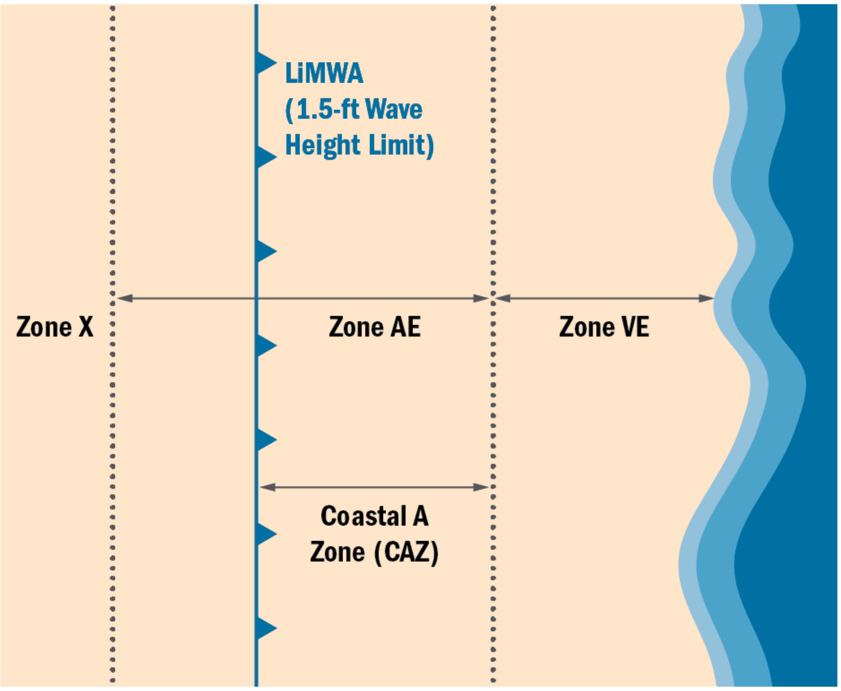

Figure 2-2: Coastal A Zone relationship to flood zones[6]

2.1.1.3 Moderate-to-Low Flood Risk Areas

In communities that participate in the NFIP, flood insurance is available to all property owners and renters in moderate-to-low flood risk areas. Moderate-to-low flood risk areas are not considered to be within the SFHA because the area has less than a 1-percent-annual-chance flood hazard or the 1-percent-annual-chance flood depth is less than 1 foot. While purchasing flood insurance in these areas is encouraged, there is no Federally-mandated requirement to do so. The flood zones in the moderate-to-low flood risk area are defined in Table 2-3.

Table 2-3: Flood Zones in Moderate-to-Low Flood Risk Areas

Zone(s)	Description
B and X (shaded)	Areas subject to inundation by the 0.2-percent-annual-chance flood event; areas subject to inundation by the 1-percent-annual-chance flood event with average depths of less than 1 foot or with drainage areas less than 1 square mile; and areas protected by accredited levees. Flood insurance is not Federally mandated, but lenders can require the purchase of flood insurance in these areas. No minimum Federal floodplain management standards apply.
C and X (unshaded)	Areas determined to be outside the 1-percent-annual-chance and 0.2-percent-annual-chance floodplains. Flood insurance is not Federally mandated, but lenders can require the purchase of flood insurance in these areas. No minimum Federal floodplain management standards apply.

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[6] Crowell et al., 2013.

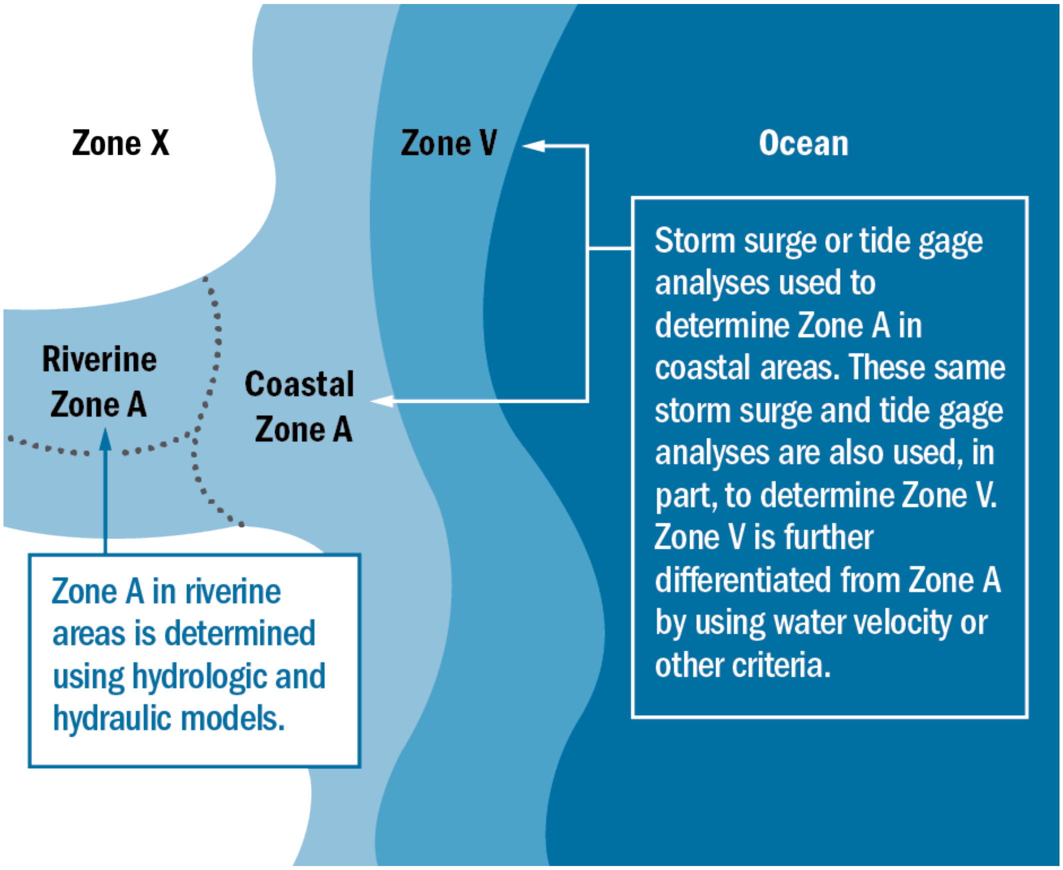

Figure 2-3: Relationship between riverine Zone A, coastal Zone A, Zone V, and Zone X7

2.1.1.4 Undetermined Flood Risk Areas

In communities that participate in the NFIP, flood insurance is available to all property owners and renters in undermined flood risk areas. While purchasing flood insurance in these areas is encouraged, there is no Federally mandated requirement to do so. The flood zone used for areas of undetermined flood risk is defined in Table 2-4.

Table 2-4: Flood Zone for Undetermined Flood Risk Areas

Zone	Description
D	Areas where there are possible but undetermined flood hazards. This zone designation is used for areas where no analysis of flood hazards have been conducted, in sparsely populated areas, and some areas protected by non-accredited levees. Flood insurance is not Federally mandated, but lenders can require the purchase of flood insurance in these areas. No minimum Federal floodplain management standards apply.

2.2 Future Conditions: Current Policy

The NFIP generally does not consider future conditions hydrology or hydraulics for the identification of SFHAs, where the minimum development standards of the program apply. Current mapping practice is to

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7 Adapted from Crowell, et al., 2013.

apply historical climate information to existing topography and development conditions. Minor adjustments can be made to the application of historical data, but current FIRMs do not predict or project future flood hazards based on future climate and sea level.

At present, the most direct consideration of future conditions in the NFIP involves: (1) the Community Rating System (CRS), a voluntary floodplain management incentive program that recognizes and encourages community floodplain management activities that exceed the minimum NFIP requirements; (2) insurance premiums, where flood insurance premium rate setting considers future conditions-based actuarial loading; and (3) mapping future conditions for informational purposes, where communities may use future conditions hydrology, resulting from land use development, for (with respect to the NFIP) non-regulatory mapping purposes.

2.2.1 Community Rating System

The CRS was implemented as a voluntary program for recognizing and encouraging community floodplain management activities exceeding the minimum NFIP standards. Communities can accrue points to improve its CRS rating and receive increasingly higher insurance discounts for property owners. In particular, points can be accrued for certain future conditions activities undertaken by local communities. For example, credit points can be provided for communities that demonstrate that:

- They have programs that minimize increases in future flooding
- They use regulatory flood elevations in the Zone V, VE, V1-30, and coastal Zone A areas that reflect future conditions, including SLR
- The community's regulatory map is based on future conditions hydrology, including SLR;
- The community's stormwater program regulates runoff from future development
- They have flood hazard assessment and problem analyses that address areas likely to flood, and flood problems that are likely to get worse in the future, including: (1) changes in floodplain development and demographics, (2) development in the watershed, and (3) climate change or SLR

2.2.2 Insurance Premiums

Fundamental insurance principals dictate that actuarially-based insurance policies should be priced to account for all of the expected costs associated with the transfer of risk. Most NFIP policies, as with most homeowner's policies, have a one-year policy term; thus, the premium is based on the current risk within that term and is not be based on expected increases or decreases in risk beyond the policy term.[8] Nonetheless, NFIP insurance premiums include an explicit load for long-term erosion, while other climate conditions, including SLR, and future development are addressed minimally as one of many uncertainties in a general contingency load.

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[8] Because NFIP policies are only for a one-year term, an understanding of current conditions risk would be necessary for setting current rates. However, estimates of future conditions risk could also be necessary if analyses of current risk do not adequately capture the effect of future changes in risk. For example, if mean sea level relative to ground elevation is increasing, risk analyses based on the current sea level may become out of date soon after the analyses are complete. Incorporating estimates of future conditions risk into premiums could be required to maintain estimates of current risk between analyses. Furthermore, estimates of future premiums based on estimates of future conditions risk could be one of the most useful tools to communicate the magnitude of expected increases or decreases in risk.

It should be noted that flood insurance premium rates can be lower for structures elevated above minimum NFIP requirements if an elevation certificate is provided. The higher a structure is elevated above the BFE, the more insurance premium rates decrease. This provides an incentive for mitigation above minimum standards, which can help a structure's resiliency when future conditions result in increased risk. The opposite is true as well. If a new structure is built below the BFE, then the insurance premium rates will be higher to reflect the increased risk of flooding.

2.2.2.1 General Contingency Load

FEMA currently accounts for SLR, future development, and other future conditions in rate-setting through an actuarial contingency loading.[9] The contingency load is not rigorously developed, and there is no explicit allocation of the load that is specifically due to future conditions. The contingency load accounts for the cost of bearing risk, including the cost of uncertainty. The portion of the contingency load for the risk of uncertainty can be divided into two components: (1) process risk, which is the inherent uncertainty of actual events modeled by a given loss distribution, and (2) parameter risk, which is the risk for which the model does not adequately model the loss. The modeled rate is based on current hazard parameters that describe the probability of flooding relative to a structure, such as the BFE and other depth exceedance probabilities.

To the extent future conditions change the estimates of the frequency of flooding, the modeled loss distribution may not adequately describe the actual loss distribution, resulting in the need for parameter risk contingency. In addition to parameter risk, the NFIP also faces considerable process risk, in that actual aggregate losses will be very different from the expected mean in any given year. The contingency load is currently 10 percent for most policies in Zone As. The load is 20 percent for policies in Zone Vs, 20 percent for policies in Zone As with a reference level below the BFE, and 25 percent for policies in Zone Vs with a reference level below the BFE.

2.2.2.2 Long-term Erosion Load

The increased risk of flooding brought about by erosion has long been an area of concern for the NFIP. In recognition of this, Section 577 of the *National Flood Insurance Reform Act of 1994* mandated that FEMA oversee a study on the economic impact of erosion on the NFIP. The Heinz Center for Science, Economics, and the Environment was contracted to perform the study and released its report, *Evaluation of Erosion Hazards*, in 2000 (see Section 2.5.9 of this report).

The study results demonstrated that the risk of flooding in Zone Vs susceptible to erosion will dramatically increase over the next 30 to 60 years. As a result of this finding, the NFIP began a multi-year plan to increase rates for all policies in Zone Vs in 2001. The Heinz study also contributed to the development of the erosion load for policies in Zone Vs. The load accounts for the increasing hazard of flooding resulting from ongoing erosion. Consequently, insurance rates have increased faster in Zone Vs than they would have if based strictly

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[9] To better understand the concept of the contingency load, two resources are a World Bank article (World Bank, 2015) about catastrophic risk pricing and a Casualty Actuary Society (Feldblum, 1991) article on risk loads for insurers. The World Bank article delineates the contingency load into the cost of equity capital, the cost of risk transfer, frictional costs, and uncertainty loads. The uncertainty load is defined as “a margin to compensate the insurer for limited information or uncertainty associated with writing a specific insurance line. For those lines covering large, infrequent events, and even more frequent events in countries where the quality of data is poor, the uncertainty load can be a significant component of the premium.” The Casualty Actuary Society article delineates the contingency load into process risk and parameter risk, where parameter risk is defined as “uncertainty in estimating the expected loss; this is the major risk for the insurer.”

on FEMA's flood risk models. It should be pointed out that FEMA does not have the authority to charge higher premiums in areas of higher erosion; as such, the erosion loading applies equally to all Zone Vs, regardless of whether a particular area has a high or low erosion rate (or even an accretion rate).

2.2.3 Future Land-Use Conditions Hydrology

In 2001, FEMA issued a rule that allows communities to use future conditions hydrology, resulting from land use development, for mapping purposes. From the perspective of FEMA, showing a future conditions boundary is for informational purposes only, and carries with it no additional regulatory requirements for floodplain management, nor would insurance be rated using a future conditions boundary. The 2001 ruling modified shaded Zone X (and Zone B) designations to indicate that they represented "Areas of moderate flood hazards or areas of future conditions flood hazard." Showing the future conditions floodplain as shaded Zone X attempts to avoid confusion regarding the mandatory flood insurance requirement. Section 2.3.5 provides additional information regarding mapping implications of future land use conditions hydrology.

2.3 Future Conditions: Flood Hazard Mapping

The projected impacts of future conditions (long-term) erosion and SLR are not considered by FEMA in mapping and managing coastal SFHAs. For riverine SFHAs, neither storm-event-driven erosion, nor future conditions erosion is considered. However, future land development is considered for informational, non-regulatory mapping purposes as explained below.

2.3.1 Coastal Erosion

With regard to coastal flood mapping, there are two categories of erosion: (1) storm- or event-driven erosion, and (2) long-term erosion.

2.3.1.1 Storm- or event-driven erosion

Storm- or event-driven erosion is the erosion that occurs during a storm event (e.g., dune erosion). This type of erosion is considered in mapping coastal flood hazards along open-coast shorelines backed by dunes; however, such erosion is not considered in flood hazard mapping for coastal bluffs on the open coast, or along any shoreline in bay and estuary areas. Further, storm- or event-driven erosion does not consider the long-term movement of shorelines in response to several factors, such as interruption/fluctuation in sediment supply, tidal inlets, and SLR, among others.

2.3.1.2 Long-term, future conditions erosion

Long-term erosion (more properly, long-term recession) as used in this report is the erosion that occurs over a period of decades, and that can be projected into the future based on historical erosion trends and/or modeling. This type of erosion is not considered in determining SFHAs. It is common for States to establish coastal setback lines or erosion hazard areas based on predicted shoreline locations 30, 60, or 100 years into the future. This method for determining long-term erosion rates and future shoreline locations is known as historical shoreline mapping and erosion rate analysis. As implemented by most States, this method generally assumes stationarity; that is, the predicted rate of shoreline change is assumed to be the same as the historical rate of shoreline change, and does not consider potential acceleration or deceleration caused by geophysical processes, such as changes in the rate of relative SLR.[10]

2.3.2 Riverine Erosion

Riverine erosion is a complex physical process that involves the interaction of numerous factors, including: fluvial hydraulics, geotechnical stability, sediment transport, and watershed characteristics, including hydrology and sediment yield; past and future land use; and vegetation; among others.[11] As stated above, FEMA does not consider storm- or event-driven erosion, nor long-term erosion, when mapping riverine flood hazard areas. Nonetheless, there are many communities that have used various methods to calculate riverine erosion hazard areas and incorporate the data and information into their respective floodplain management programs.

2.3.3 Special Note on E Zones

The Code of Federal Regulations (CFR) that govern the NFIP (44 CFR) contains language regarding a Zone E. Specifically, *44 CFR 59.1 Definitions*, associates Zone E with flood-related erosion, not long-term, gradual erosion. For example, an area of special flood-related erosion hazard is defined as "…the land within a community which is most likely to be subject to severe flood-related erosion losses. The area may be designated as Zone E on the Flood Hazard Boundary Map."[12]

While Zone E is clearly associated with "flood-related erosion," the definition goes on to state that, "After the detailed evaluation of the special flood-related erosion hazard area in preparation for publication of the FIRM, Zone E may be further refined." This may imply that, in the future, Zone E may be refined to include long-term, gradual erosion. Note that additional changes would need to be made to 44CFR to clarify and recognize long-term (gradual) erosion as a peril covered under the NFIP. As an example, *44 CFR 59.1* defines erosion as, "…the process of gradual wearing away of land masses. This peril is not per se covered under the Program." The current map inventory does not contain any areas with a Zone E designation. The designation was authorized, but never implemented.

2.3.4 Sea Level Rise

As with long-term erosion, FEMA does not consider SLR in a prospective manner (future conditions) in flood hazard mapping. However, as with the case of coastal and riverine erosion, SLR is considered in a retrospective manner. For example, after a period of years, when an area is to be restudied and remapped, the past cumulative effects of SLR and erosion will be reflected in revised and relocated positions of flood zones and revised BFEs.

2.3.5 Future Land Use Development

Historically, flood hazard information presented on NFIP flood maps has been based on the existing conditions of the floodplain and watershed, with no consideration given to future development and its impact on hydrology. As such, FEMA's guidelines for study contractors had specified that flood hazard

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[10] Long-term SLR is an "enabler" of long-term coastal erosion; thus, both are linked geophysically.

[11] FEMA, 1999.

[12] FHBM.

determinations should be based on conditions that are planned to exist in the community within 12 months following completion of the draft FIS. In 2001, FEMA issued a rule that allows communities to use future conditions hydrology, resulting from land use development, for mapping purposes. Specifically, Section 64.3 of *44 CFR* states that "FIRM[s] also may indicate, at the request of the community, zones to identify areas of future-conditions flood hazards." The Zone B and shaded Zone X designation was also modified to indicate that they represented "areas of moderate flood hazards or areas of future-conditions flood hazard."

Definitions were added to Section 59.1 of *44 CFR* to provide clarification in what is meant by future conditions. Specifically, the term "area of future-conditions flood hazard" was defined as "the land area that would be inundated by the 1-percent-annual-chance (100-year) flood based on future conditions hydrology." Moreover, the term "future-conditions hydrology" is defined as "the flood discharges associated with projected land-use conditions based on a community's zoning maps and/or comprehensive land-use plans and without consideration of projected future construction of flood detention structures or projected future hydraulic modifications within a stream or other waterway, such as bridge and culvert construction, fill, and excavation." Note that the definition referred to manmade, and not natural changes to future conditions hydrology.

FEMA's Modernizing FEMA's Flood Hazard Mapping Program: Recommendations for Using Future-Conditions Hydrology for the National Flood Insurance Program[13] report provides a detailed summary of FEMA's evaluation of future conditions hydrology. As a result of the evaluation, FEMA concluded, in part, the following:[14]

- The local community should determine the future-conditions land-use and hydrology.
- If the community requests that FEMA do so, the future-conditions 1-percent-annual-chance (100-year) floodplain should be shown on the printed FIRM and be designated as shaded Zone X with no BFEs shown. The future boundaries are also prepared and are delivered in a digital format for the community to use in their GIS and Web-based systems.
- BFEs should be shown on the FIRM only for the existing-conditions 1-percent-annual-chance (100-year) floodplain. The future conditions BFEs should be included in the FIS report (on the Flood Profiles and in the Floodway Data Table), thus providing necessary information to the community to meet its local floodplain management needs. The existing conditions 0.2-percent-annual-chance (500-year) flood elevations should also be shown on the Flood Profiles in the FIS report to help Federal agencies meet the requirements of Executive Order 11988 and to provide Federal agencies with information to evaluate the potential effects of any actions they may take in a floodplain.
- From a floodplain management standpoint, FEMA should continue to require regulation of floodplain development based on the existing conditions data, while local floodplain managers can regulate development based on the future conditions data.

2.4 Federal Flood Risk Management Standard

In 2013, the Hurricane Sandy Rebuilding Task Force adopted a higher flood standard for the Sandy-affected region to ensure that Federally-funded buildings, roads, and other projects were rebuilt stronger to withstand future storms. The strengthened standard is similar to flood risk standards in place in the States of New York and New Jersey. The Sandy Task Force also recommended that the Federal Government create a national

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[13] FEMA, 2001.

[14] A full list of conclusions can be found at: http://www.fema.gov/media-library/assets/documents/7287?id=2219.

flood risk standard for Federally-funded projects beyond the Sandy-affected region. *The President's Climate Action Plan* directed Federal agencies to update their flood risk reduction standard to ensure that Federally-funded projects across the country last as long as they are intended. Federal agencies collaborated on this update in 2014. The new Federal Flood Risk Management Standard (FFRMS), issued in January of 2015, gives agencies the flexibility to select one of three approaches for establishing the flood elevation and associated hazard area they use in siting, design, and construction.

Compliance with FFRMS is mandatory when FEMA grants are involved (e.g., Hazard Mitigation Assistance grants, Public Assistance grants, any other FEMA grants funding construction activities in or affecting a floodplain).The FFRMS requires one of the following three approaches to be used to determine the level of resilience needed:

- The Climate-Informed Science Approach – Use data and methods informed by best-available, actionable climate science;
- The Freeboard Value Approach – Use 2 feet above the 1-percent-annual-chance (also referred to as the base flood) elevation for standard projects and 3 feet above the 1-percent-annual-chance elevation for critical buildings, like hospitals and evacuation centers; or
- The 0.2-percent-annual-chance flood Approach – Use the 0.2-percent-annual-chance floodplain and elevation.

The FFRMS is focused on all Federal actions and does not impact operation of the NFIP, but may have positive effect on insurance rates for structures covered by NFIP policies via the CRS. While elevation of the lowest floor per the freeboard approach or the 0.2-percent-annual-chance elevation approach may be used by many projects to satisfy FFRMS, other options may be available. The climate-informed science approach outlined in the standard and the agency implementation guidelines[15] recommend future conditions mapping approaches consistent with the TMAC report's recommendations.

2.5 Sea Level Rise and Long-Term Erosion: A Brief History

FIMA and its predecessor directorates have a long history of investigating and planning for certain aspects of climate change and its impact on the NFIP. The main focus has been on long-term coastal erosion (and occasionally riverine erosion), and to a lesser extent, long-term SLR. Within the context of the NFIP, both SLR and long-term erosion have been politically controversial, and the NFIP has examined both to varying degrees as a result of congressional mandates. It wasn't until passage of BW-12 that FEMA was authorized to incorporate SLR and long-term coastal erosion into flood mapping.

Following is a summary of legislation, reports, and other significant events concerning FEMA and future conditions erosion and SLR.

2.5.1 National Flood Insurance Act (1968)

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[15] FEMA, 2015.

The *National Flood Insurance Act of 1968 (NFIA)*, which was responsible for the creation of the NFIP, did not contain language regarding the peril of erosion. Losses were covered by flood insurance only if the direct cause was a flood event, with the term "flood" being defined as:

"A general and temporary condition of partial or complete inundation of normally dry land areas from:

- The overflow of inland or tidal waters;
- The unusual and rapid accumulation of runoff of surface waters from any source;" or
- "Mudslides."

Note that this definition was revised during modifications to the NFIP in 1973 (see Section 2.5.2). In practice, however, event-driven erosion-related claims were (and still are) paid when a flood, as defined above, was determined to be the cause of the loss.

2.5.2 Flood Disaster Protection Act (1973)

The *Flood Disaster Protection Act of 1973* added a new dimension to insurance coverage under the NFIP by including losses caused by extraordinary erosion, absent the existence of other, typical flooding conditions at the time of the loss. The Act amended the NFIA by expanding the definition of flood to include "the collapse or subsidence of land along the shore of a lake or other body of water as a result of erosion or undermining caused by waves or currents of water exceeding anticipated cyclical levels…"

Importantly, long-term, gradual, erosion was not considered in the 1973 Act.

2.5.3 National Conference on Coastal Erosion, Cape May, NJ (1977)

Following the *Flood Disaster Protection Act of 1973*, a National Conference on Coastal Erosion convened in Cape May, New Jersey, in 1977. A primary goal of the conference was to determine how to deal with long-term erosion within the context of the NFIP. Unfortunately, the outcome was inconclusive and did not provide a clear direction for the future.[16]

2.5.4 Upton/Jones Amendment (1988-1995)

In 1987, as a result of high water levels in the Great Lakes, the U.S. Congress became concerned about buildings threatened by erosion caused by abnormally high lake levels. Numerous structures were being undermined and collapsing into the lakes. Similar problems were occurring in North Carolina, where every year more beach cottages were sustaining structural damage or being lost completely as a result of coastal erosion.

To reduce these losses, Congressman Fred Upton (R-Michigan) and Walter Jones (D-North Carolina) proposed the Upton/Jones Amendment to the *National Flood Insurance Reform Act*. The Upton/Jones Amendment, which was enacted into law in 1988, provided demolition and relocation benefits to insureds whose structures were located within a "zone of imminent collapse," an area defined as five times the long-term erosion rate at a site plus ten horizontal feet.

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[16] Buckley, 1999.

Insureds whose structures were found to be located in a zone of imminent collapse could receive benefits of up to 40-percent of the value of the structure, with the requirement that the structure be relocated landward of a 30- or 60-year setback line. Insureds opting for demolition benefits could receive up to 110 percent of the value of the structure for demolition expenses.

The zones of imminent collapse for site-specific areas (both coastal and riverine) were determined on a case-by-case basis either by FEMA or a certified State agency. Zones of imminent collapse and setback lines were not mapped by FEMA. The Upton/Jones Amendment marked the first time that long-term erosion was considered under the NFIP, albeit briefly. The Upton/Jones program was an underutilized program,[17] and was terminated in 1995 by the *National Flood Insurance Reform Act of 1994*.

2.5.5 National Research Council Report: Managing Coastal Erosion (1990)[18]

In an effort to evaluate and determine how FEMA should treat long-term erosion through the NFIP, FEMA commissioned the National Research Council (NRC) in the late 1980s to examine public policy and scientific issues related to the potential consideration of long-term erosion in the flood insurance program. In 1990, the NRC issued the *Managing Coastal Erosion* report, which recommended including mapping, land-use management, and insurance requirements under the NFIP.

The NRC report stimulated congressional interest and, beginning in 1990, several bills were introduced to amend the NFIP. Still, questions continued regarding the scientific methods and the economic impacts of erosion on the NFIP and possible impacts on coastal real estate valuations. Without clear qualitative answers, Congress settled on a mandate for FEMA to conduct an economic impact study of erosion under a provision in the *National Flood Insurance Reform Act of 1994* (see Section 2.5.7).

2.5.6 FEMA Sea Level Rise Report: Projected Impacts of Relative Sea Level Rise on the National Flood Insurance Program (1991)[19]

FEMA completed a congressionally-mandated report in 1991 on the impact of SLR on NFIP.[20] The report, titled *Projected Impacts of Relative Sea Level Rise on the National Flood Insurance Program*, concluded that the NFIP would not be significantly affected by a 1-foot rise in sea levels by the year 2100 because "the aspects of flood insurance ratemaking [contingency loading—see Section 2.2.2.1] already account for the possibility of increasing risk, and the tendency of new construction to be built more than 1 foot above [the] BFE."

The study also concluded that, "given the high projection of a 3-foot rise, the incremental increase of the first foot would not be expected until the year 2050." Given this 60-year timeframe for the first foot of SLR, the study concluded that there would be "ample opportunity for the NFIP to consider alternative approaches to the loss control and insurance mechanisms of the NFIP and to implement those changes that are both effective and based on sound scientific evidence."

Nonetheless, the study noted that because of uncertainties in projected SLR and the ability of the insurance rating system to easily respond to a 1-foot rise, the possibility exists for significant SLR impacts in the long term and, therefore, FEMA should: (1) continue to monitor progress in the scientific community about SLR

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[17] Crowell, Leikin, and Buckley, 1999.

[18] National Research Council, 1990.

[19] FEMA, 1991.

[20] Ibid.

and consider future studies that provide more detailed information on potential impacts of SLR on the NFIP, (2) consider the formulation and implementation of measures that would reduce the impact of relative SLR along the Louisiana coast, and (3) strengthen efforts to monitor development trends and incentives of FEMA's CRS that encourage measures that mitigate the impacts of SLR.

2.5.7 National Flood Insurance Reform Act (1994)

Between 1990 and 1994, a number of legislative proposals were introduced that would have established long-term erosion mapping, management, and insurance provisions under the NFIP. Many of these proposals were based on recommendations from the 1990 NRC report. The proposals were controversial and vigorously debated in Congress; in the end, none of these proposed bills were enacted.

However, a compromise was included in the *National Flood Insurance Act of 1994*. Section 577 of the Act, entitled "Evaluation of Erosion Hazards," required FEMA to study the socio-economic and insurance implications of long-term coastal erosion mapping through the NFIP (and conduct a riverine erosion mapping feasibility study, discussed below in Section 2.6.8), rather than mandate immediate change to the NFIP. The Act also specified that FEMA submit a report to Congress, but that the report should be conducted by a "private independent entity." Additionally, the Act stated that "the [FEMA] Director may map a statistically valid and representative number of communities with erosion hazard areas throughout the U.S., including coastal, Great Lakes, and, if technologically feasible, riverine areas."

Ultimately, two reports were prepared, including: (1) FEMA's *Riverine Erosion Hazards Mapping Feasibility Study* report, which focuses on riverine issues; and (2) *Evaluation of Erosion Hazards*, which focuses on coastal issues. These reports are described in the following sections.

2.5.8 FEMA's Riverine Erosion Hazards Mapping Feasibility Study Report (1999)[21]

In 1995, FEMA initiated a *Riverine Erosion Hazards Mapping Feasibility Study*. The study was advised by a project working group of experts in the field of riverine erosion. In 1999, the *Riverine Erosion Hazard Areas Mapping Feasibility Study* report was released. The study developed cost estimates for mapping riverine erosion hazard areas and concluded that it was technologically feasible to map the hazard areas.

2.5.9 Heinz Center Report: Evaluation of Erosion Hazards (2000)[22]

Beginning in 1995, FEMA oversaw the first technical phase of the coastal erosion study and contracted with 18 coastal and Great Lakes states (or their designees) to conduct long-term coastal erosion hazard mapping for a total of 26 counties. In 1997, the H. John Heinz III Center for Science, Economics and the Environment, initiated the second, economic/insurance phase of the study, which utilized the erosion hazard mapping conducted during the first phase.

The Heinz Center's *Evaluation of Erosion Hazards* (Heinz Center report), was delivered to Congress in April 2000. The report made two recommendations: (1) Congress should instruct FEMA to map long-term coastal erosion hazard areas, and (2) "Congress should require FEMA to include the cost of expected erosion losses when setting flood insurance rates along the coast." Congress did not act on these recommendations;

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[21] FEMA, 1999.

[22] Heinz Center, 2000.

however, FEMA developed and began implementing a long-term erosion contingency loading model based on data from the Heinz Center report.

2.5.10 Climate Change: Financial Risks to Federal and Private Insurers in Coming Decades are Potentially Significant (2007)[23]

In 2007, the Government Accountability Office (GAO) published a report, *Climate Change: Financial Risks to Federal and Private Insurers in Coming Decades are Potentially Significant*, recommending that FEMA analyze the potential long-term implications of climate change on the NFIP and report its findings to Congress. In response to this recommendation, FEMA contracted with AECOM to conduct a climate change study (see Section 2.5.12).

2.5.11 Biggert-Waters Flood Insurance Reform Act (2012)

In 2012, Congress passed BW-12, which requires that FEMA make several policy changes to the NFIP. Key provisions of the legislation require the NFIP to raise rates to reflect true flood risk, make the program more financially stable, and change how FIRM updates will impact policyholders. BW-12 also mandated the creation of the current TMAC.

2.5.12 Impact of Climate Change and Population Growth on the NFIP (2013)[24]

In 2013, AECOM released a report, *Impact of Climate Change and Population Growth on the National Flood Insurance Program*.

The report investigated various aspects of climate change and their impacts on the NFIP. These aspects of climate change include changes in: (1) precipitation patterns, (2) frequency and intensity of coastal storms, and (3) sea levels. The report's findings include:

- By 2100, the 1-percent-annual-chance flood depth and flood hazard areas are expected to increase on average by about 45 percent in riverine areas. In the populated areas of most interest to the NFIP, about 30 percent may be attributed to increased runoff caused by growth of impervious land area caused by population growth/development, while the remaining 70 percent represents the influence of climate change. This means that even if future climate change is minimal, future flooding will increase anyway because of population growth, increase in development, and increased surface impermeability.
- By 2100, coastal SFHAs may increase anywhere from zero percent to 55 percent depending on type and scale of shore protection measures.
- By 2100, the total number of NFIP insurance policies is likely to increase by approximately 80 percent to 100 percent, with 70 percent of this increase attributable to growth of floodplains caused by climate change and 30 percent attributable to population growth.
- Individual premiums per policy are projected to increase by 10 percent to 70 percent in 2010 dollars by 2100 in order to offset the projected increase in flood losses.

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[23] US GAO, 2007.

[24] AECOM, 2013.

2.5.13 The Homeowner Flood Insurance Affordability Act (2014)

In 2014, the HFIAA was passed into law. This law repeals and modifies certain provisions of BW-12 and makes additional changes to other aspects of the program not covered by that Act. Many provisions of BW-12 remain and are still being implemented. In addition, HFIAA requires the TMAC to review the new national flood mapping program authorized under the 2012 and 2014 flood insurance reform laws.

3 Future Conditions and Changes in the Floodplain

The phrase, "future conditions and changes in the floodplain," encompasses both natural changes (e.g., SLR, erosion, rainfall patterns), as well as human impacts (e.g., population changes, land use policies, development). There are several challenges in developing a set of recommendations for incorporating future conditions into FISs and maps and using the best available methodology when considering both the impacts of natural processes and human policies on flood risk.

First, uncertainty about future conditions is inherent in any approach to develop flood hazard data. Regarding expected natural changes in floodprone areas, the direction (increasing or decreasing) of future trends may be uncertain for any particular location. Even in cases where there is a definable trend in historical data, the degree of uncertainty increases substantially the farther into the future we project. Yet, ignoring uncertain or as-yet-unquantified trends is hazardous in itself, particularly for mapping products that attempt to quantify future hazards beyond the next century.

There are several other sources of uncertainty, including the impacts of future laws, regulations, and policies—or even changes to the NFIP itself—that may impact the way development is planned and implemented, where and whether future population will increase or decrease, how future development will impact the environment, and a host of other unknowns that are difficult to predict.

All of these uncertainties create challenges in how best to communicate future risk in an understandable and usable way, particularly when communicating even *current* flood risk is a challenge for many practitioners. Mapping future risk also brings up connected issues that need to be explored, such as the use of future conditions in risk assessments, flood insurance rating, land use regulations, building design and construction, and floodplain management regulations. This section explores these issues and the scientific and social considerations involved with mapping flood hazard areas based on future conditions.

3.1 Future Conditions Impacts and Uncertainty

In making decisions, there is always some degree of uncertainty about the future, whether it be an investment strategy for financial markets, determining what weather to expect for a planned vacation, or what types of seeds to purchase now for planting next year's crops. Given uncertainty about predicted rainfall and temperatures, we tend to use historical averages and recent trends to make decisions, and we assume these simple measures provide us with the information we need.

There are two potential problems with this approach: (1) past averages and trends may not always be accurate indicators of the future, especially if there are large changes or disruptions in our natural or manmade systems; and (2) our observations and data for the past are incomplete and can be inaccurate. Thus, while we are accustomed to relying on observations of past floods to estimate the extent and depth of future floods, there has always been uncertainty associated with our estimates, whether we have acknowledged it or not. When that uncertainty is combined with additional uncertainty related to future land use, topographic changes, hydrology, and hydraulics, the confidence in our estimates diminishes.

This is obvious when considering future climate-related changes impacting flooding. Even in cases where there is a definable trend in historical data, we would expect the degree of uncertainty to increase substantially as we predict flooding decades into the future.

Changes can happen slowly, as in the case where urban areas gradually expand into agricultural or forested land, thereby altering runoff patterns over time; or they can happen rapidly, like the kinds of river channel changes, erosion, and deposition that occurred during Hurricane Irene in Vermont (2011) or in the 2013 fall floods in Colorado (see Figure 3-1).

Uncertainties will be greater for future conditions than those associated with modeling and mapping existing conditions, particularly as projections are made over longer time frames.

Figure 3-1: Channel Changes, Erosion, and Deposition. Left shows channel changes on Vermont Route 107 resulting from Hurricane Irene (Photo: Vermont Agency of Transportation). Right shows changes after flash flooding at the in Colorado (Photo: Cliff Grassmick, AP).

It is helpful to consider how uncertainty can be characterized and the likelihood of uncertain events taking place. Uncertainty guidelines from the Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC)[25] are useful in this regard.

3.1.1 IPCC AR5 Uncertainty Guidelines

The AR5 rely on two metrics for communicating the degree of certainty in key findings:

- Confidence in the validity of a finding, based on the type, amount, quality, and consistency of evidence (e.g., mechanistic understanding, theory, data, models, expert judgment) and the degree of agreement as detailed in Figure 3-2
- Quantified measures of uncertainty in a finding expressed probabilistically (based on statistical analysis of observations or model results, or expert judgment) as depicted by the Likelihood Scale in Table 3-1

These two metrics defined a common approach and calibrated language that can be used broadly for developing expert judgments and for evaluating and communicating the degree of certainty in findings of the assessment process.

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[25] IPCC, 2010.

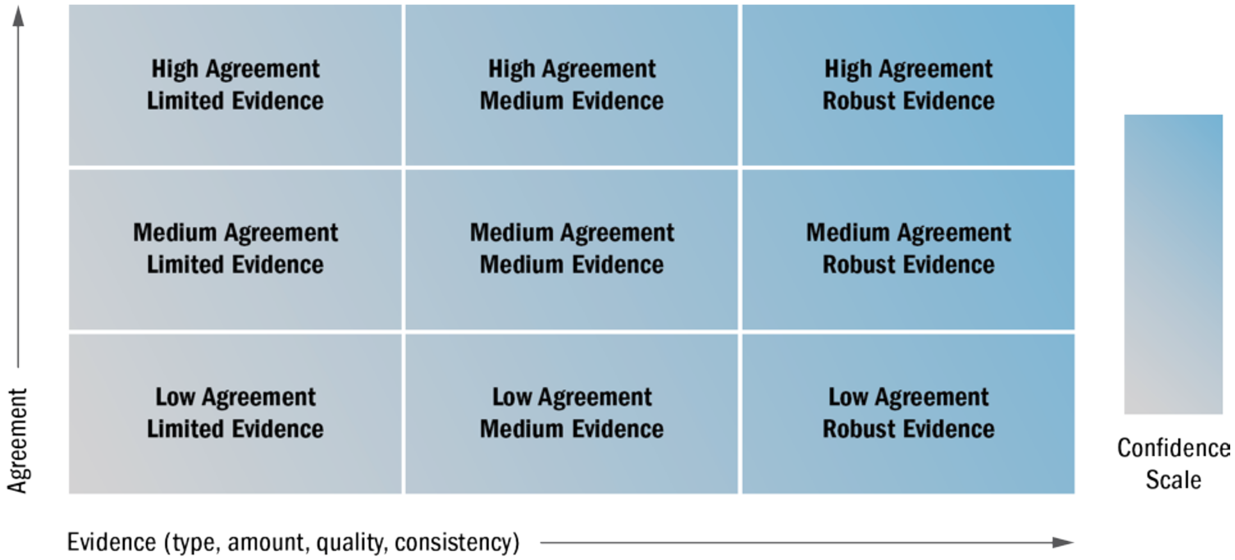

Figure 3-2: Evidence and Agreement Relationship.
Evidence and agreement statements and their relationship to confidence.

Confidence in the validity of a finding is based on the type, amount, quality, and consistency of evidence and the degree of agreement among experts. Confidence is expressed qualitatively as shown in Figure 3-2, with the degree of confidence in an estimate increasing moving from the least amount of confidence in the lower left to the highest amount of confidence in the upper right.

Table 3-1: Likelihood Scale

Term	Likelihood of the Outcome
Very Certain	99-100 percent probability
Very Likely	90-100 percent probability
Likely	66-100 percent probability
About as likely as not	33-66 percent probability
Unlikely	0-33 percent probability
Very Unlikely	010 percent probability
Exceptionally Unlikely	0-1 percent probability

3.1.2 Flood Map Accuracy and Uncertainty

Current flood hazard studies and maps are not perfect. They are estimates of complex hydrologic and hydraulic processes, and graphical depictions of the resulting flood hazards. Some of those estimates are based on detailed studies using recent data, well-established calculation procedures, and modern mapping techniques; others are more approximate, relying on less and/or older data, simplified assumptions, and simplified calculations/mapping.

Flood hazard studies and maps can be characterized by two types of uncertainty.

- **Natural Variability (Aleatory Uncertainty)** – Variability in the physical world; uncertainty arising from variations inherent in the behavior of natural phenomena that are viewed as random rather than systematic
- **Knowledge Uncertainty (Epistemic Uncertainty)** – Uncertainty arising from imprecision in analysis methods and data. Arises from a lack of understanding of events and processes, or from a lack of data; such lack of knowledge is reducible with additional measurements, observations, and scientific analysis

To date, the accuracies, degree of precision, and uncertainties associated with respect to flood studies and mapping products have not been quantified or published. This information is needed, both for improved risk identification and risk communications and can serve as a baseline for characterizing future conditions. The cost of improving the accuracy and reducing uncertainties of the flood hazard studies and maps needs to be compared with their expected benefits with respect to prioritizing and undertaking future flood studies for existing and future conditions.

Some sources of uncertainty that exist in flood hazard identification include the precision and accuracy associated with measurements of the physical environment. Topographic and bathymetric data are the most important factors in the accuracy of FEMA's flood maps.[26] Climatology data for the physical process being simulated are also a factor. For coastal areas, this relates primarily to wind and pressure fields; for riverine areas, this mostly covers historical rainfall and stage/discharge data. The data that will be used to validate the results (i.e., the measured wave and water level data, the wave information studies, and surveyed high water marks) are also a factor.

Uncertainty also lies in the calculation methods used to identify flood hazards, including the skill of models used in the computation of the physical parameters. All models, both physical and empirical models, include some uncertainty; and this uncertainty is additive. While care is exercised to identify and reduce uncertainty and bias in the results, no strict standards exist with respect to the acceptable amounts of uncertainty in flood hazard identification. FEMA relies on model validation, engineering judgment, and rigorous review to ensure the results are high-quality and reasonable representations of historical flood conditions.

The variability in the physical processes being simulated (both climate-driven and anthropomorphic adaption) is also a source of uncertainty. A long period of climatological record may provide an account of what has happened in the past, but it does not necessarily represent what could happen in the future. Therefore, climatic factors, such as increases in the frequency and severity of coastal storms and SLR are sources of uncertainty. Variability inherent in the storm track is also a factor; slight changes in storm track can result in very different flooding locations and impacts. Also, development and/or construction of flood conveyance, retention, or protection structures can also impact the flood hazard being identified.

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[26] NRC, 2009.

In the case of future conditions (such as changes in precipitation patterns, land alteration by nature or man, changes in stream flow, SLR, long-term coastal erosion, and riverine erosion), projected trends and variabilities are based on some combination of data and modeling, both of which magnify uncertainty. Uncertainties will be greater for future conditions than those associated with modeling and mapping existing conditions, particularly as projections are made over a longer time frame.

Sub-Recommendation 3-1. FEMA should perform a study to quantify the accuracies, degree of precision, and uncertainties associated with respect to flood studies and mapping products for existing and future conditions. This should include the costs and benefits associated with any recommendation leading to additional requirements for creating flood related products.

3.1.3 Hazard Identification, Risk Assessment, and Risk Communication

The process of hazard identification requires the determination of the types and characteristics of potential disasters facing a community or region. The risk to the community is characterized by the likelihood of disasters of different magnitudes and intensities and their resulting impacts to individuals, property, and the environment. Assessing the likelihood of a future flood is typically based on analysis of the historical record, as well as knowledge of the physical processes leading to the occurrence of a disaster.

RISK COMMUNICATION

- Risk communication is a critical aspect of risk management with all stakeholder groups requiring easy-to-understand information.
- informing residents that there is a greater than 1-in-5 chance of at least one flood occurring in their area over the next 25 years is more likely to get their attention than communicating this as a 1-in-100-chance in the coming year (the same probability).

Although historical records are important, they need to be combined with scientific studies to attempt to project future physical phenomena. For example, expected changes in climate bring into question how to interpret historical data in characterizing the intensity and magnitude of future hurricanes and floods[27] and may increase the costs and losses associated with severe hurricanes and floods in the years to come.[28]

The risk assessment process (see Figure 3-3) combines the potential hazards obtained from hazard identification with data on vulnerability (taking into account exposure and mitigation). Risk assessment encompasses studies that estimate the chances of a specific set of events occurring, their potential consequences, and the uncertainties surrounding these estimates.

Figure 3-3: Risk Assessment

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[27] Milly, et al., 2008.
[28] IPCC, 2015.

UNCERTAINTY

- Climate change adds uncertainty to flood loss predictions.
- Risk assessments take into account the likelihood of events occurring and their impacts, as well as the associated uncertainties.

Risk assessment was greatly improved by the confluence of two developments in the last several decades: scientifically-based probabilistic hazard models (i.e., quantifying the rate of occurrence and magnitude of hazard events and their impact)[29] and advances in information technology and GIS for mapping risk and measuring the hazard.[30] Computer-based models were developed for assessing probabilistic catastrophic risk and loss potential at different return periods. Maps can indicate the likelihood of specific events, and damage models can determine their impacts. Together, these tools can be used in catastrophe models to determine premiums for insurance protection against floods and other natural hazards.[31]

Risk communication is a critical aspect of risk management. All concerned stakeholder groups including the public require accurate, easy-to-understand information on the risks that residents and communities face. When designing risk communication strategies, there is a need to recognize the systematic biases and simplified decision rules that individuals utilize in making choices under uncertainty. To illustrate this point, consider a flood with a 1-percent-annual-chance (often termed “100-year”) return period. If a property owner in a floodprone area is told that there is a 1-in-100 chance of their home flooding in the coming year, they are likely to assume it will not occur and will treat the event as below their threshold level of concern. Had they been told that there is a greater than 1-in-5 chance of their home flooding over the next 25 years (the same probability with an extended time horizon to match a typical 30-year mortgage), they may have been more likely to pay attention and considered undertaking protective measures.[32] Such framing of information on risk maps can be employed to communicate information on the risk so that individuals in harm’s way recognize the hazards they face and their associated risks.

Sub-Recommendation 3-2. Future risk assessments should take into account the likelihood of events occurring and their impacts, as well as the associated uncertainties surrounding these estimates.

Sub-Recommendation 3-3. FEMA should frame future risk messages for future conditions data and information such that individuals will pay attention to the future flood risk. Messages may be tailored to different stakeholders as a function of their needs and concerns.

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[29] Cornell, 1968.

[30] NRC, 2007.

[31] Grossi and Kunreuther, 2005.

[32] Kunreuther, 2015.

3.2 Population Growth and Development Changes

For centuries, mankind has lived and worked around waterways and the coast. Waterways provide transportation, food, water, and a desirable environment. Many of our population centers are located near major water features of the coast or large rivers. It's far too simplistic to say, "Get out of harm's way," when there are established communities and critical infrastructure (energy, transportation, water and wastewater, etc.) that aren't easy to move and have historical (health, survival, technology, industry) reasons for their geographic location.

As the Nation grows, additional land becomes developed, which in turn increases the runoff from rainfall (see Figure 3-4). In an undeveloped state, water that does not run off is stored in natural depressions until such time it either evaporates or moves to the groundwater table. The impacts of development can be very significant—especially for watersheds under 100 square miles, with discharges more than doubling.[33] This development can lead to the water surface elevations in streams increasing by many feet in elevation. Use of the national urban equations in the U.S. Geological Survey (USGS) Water-Supply Paper 2207, *Flood Characteristics of Urban Watersheds in the U.S.* (WSP 2207),[34] shows that a percent impervious area of as little as 20 percent can double flow.

Many communities have stormwater regulations that include the provision that post-development discharges must be equal to or less than the pre-development discharges; however, this typically applies only to the frequent storm events, such as the 10-year frequency. These regulations typically have no or very little impact on infrequent events, such as the 100-year frequency event (1-percent-annual-chance flood event). It should be noted that not all development results in increased water surface elevations. Water surface elevations can be decreased by implementing projects that improve rainfall infiltration and retention, such as re-forestation and wetland restoration.

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[33] Sauer, et al., 1983.

[34] Ibid.

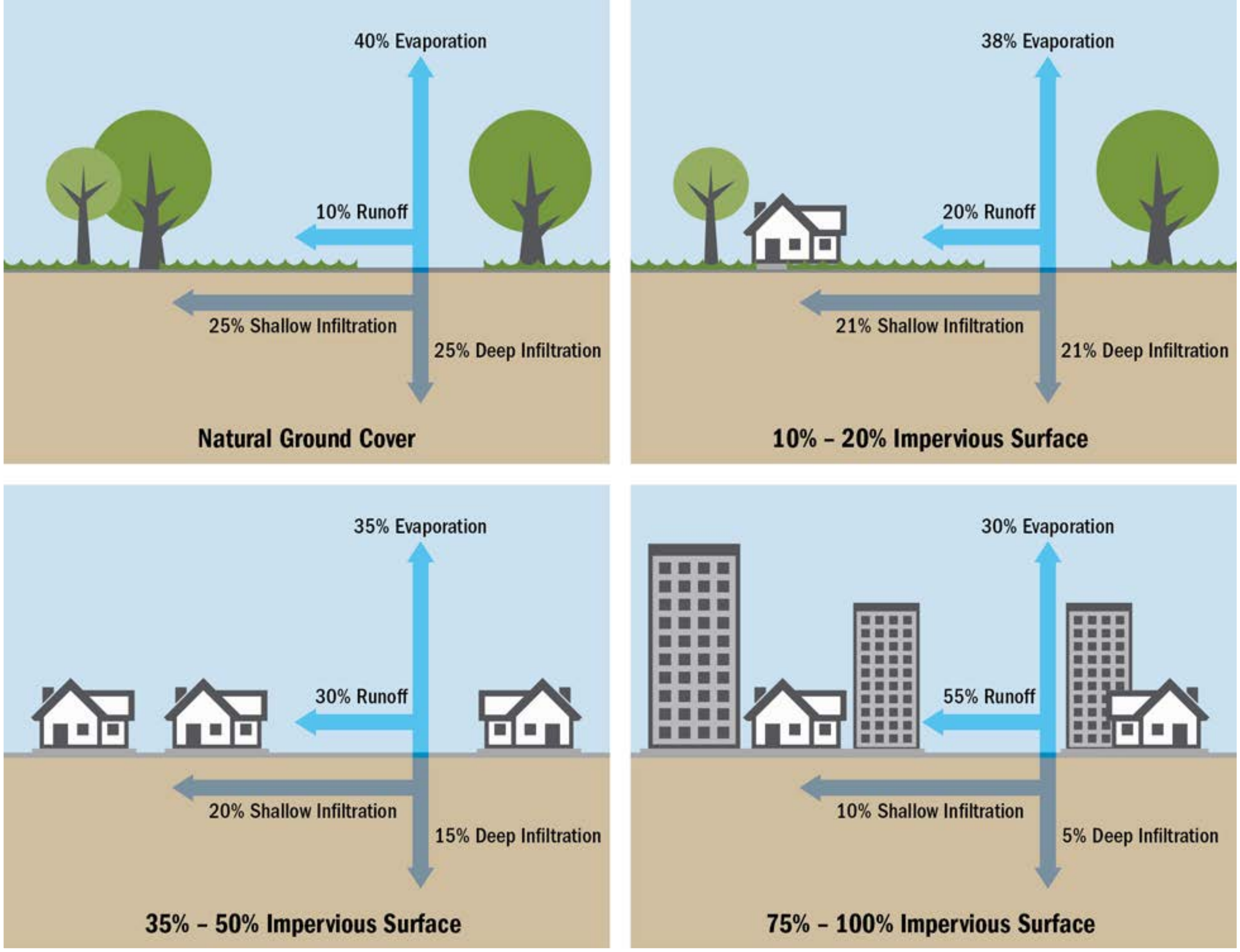


Figure 3-4: Impacts of Development.
Manmade development can increase flood discharge by a factor of five.

Population—particularly population growth—is a significant indicator of development. As the population increases, the infrastructure required to support housing, utilities, and businesses increases as well. Population increase can also increase the density of people in certain geographic areas. Therefore, population growth over time as well as by geographic location should be evaluated when assessing future conditions and changes to the floodplain. For the large majority of areas across the United States, population and development increases have occurred over the time, and this population growth is expected to continue (see Figure 3-5 and Figure 3-6).

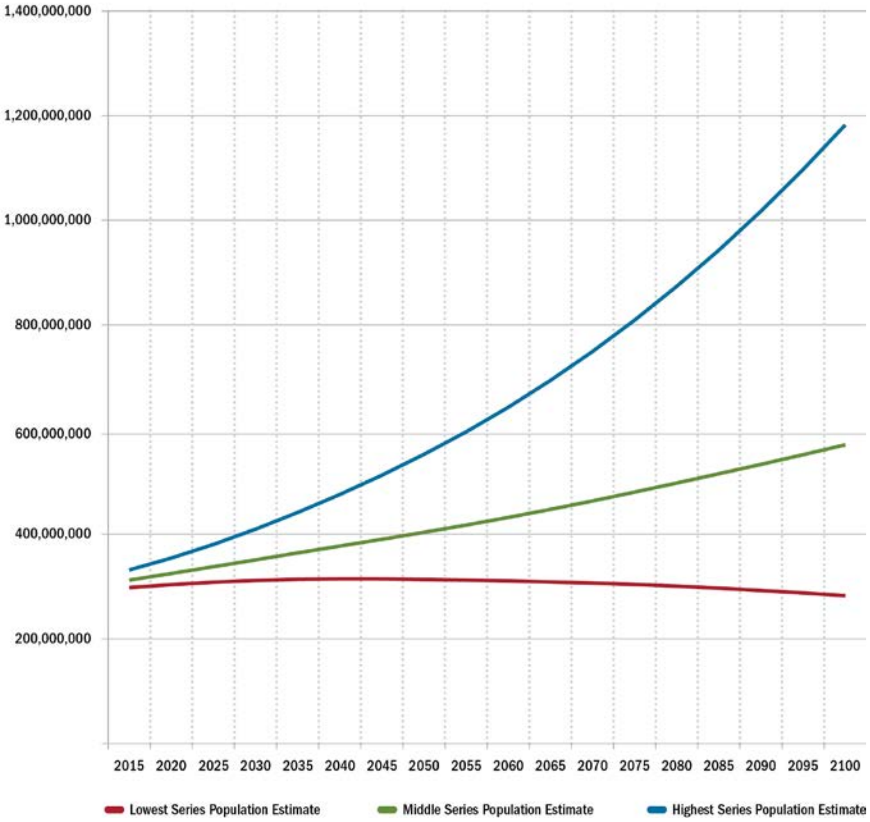


Figure 3-5: Population Growth Estimates.

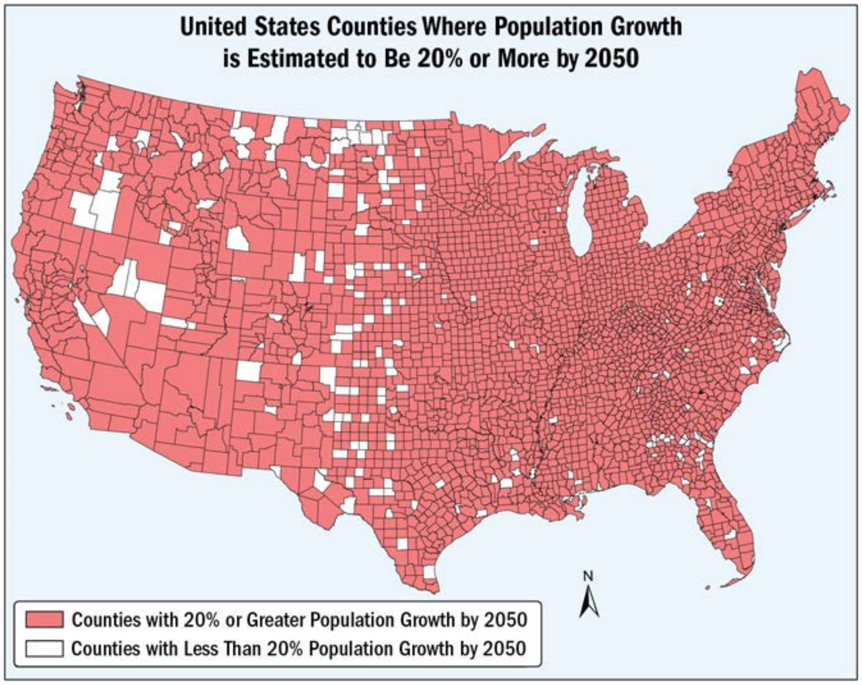


Figure 3-6: Population Growth Estimates by County.

Surges in population have been most significant in coastal region of the county. The trend of people moving towards the coasts is illustrated in Figure 3-7.

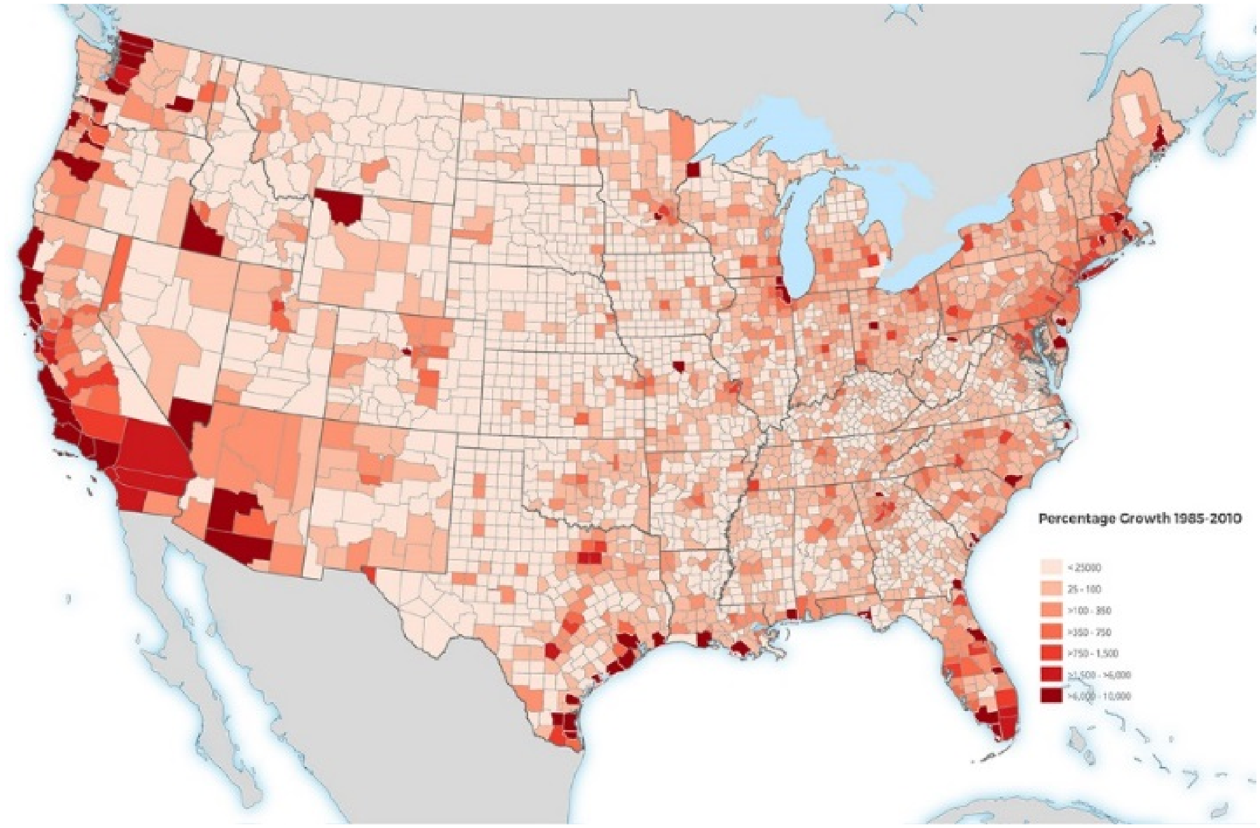


Figure 3-7: Population Changes: 1985-2010.
The mid-Atlantic, the Atlantic, the Gulf Coasts of Texas and Florida,
and the California Coast have incurred the most change from 1985 to 2010.

3.2.1 Land Use Changes

A Hydrologic Unit Code by County (HUCCO) is a geographic area that represents counties and hydrologic units that have been combined together. Figure 3-8 illustrates the development increases that have occurred over time. Significant changes on a percent basis are seen in the mid-Atlantic area of the United States. This trend can be seen in more recent land use and land change evaluations as well. Figure 3-9 illustrates the land use change by looking at impervious areas.

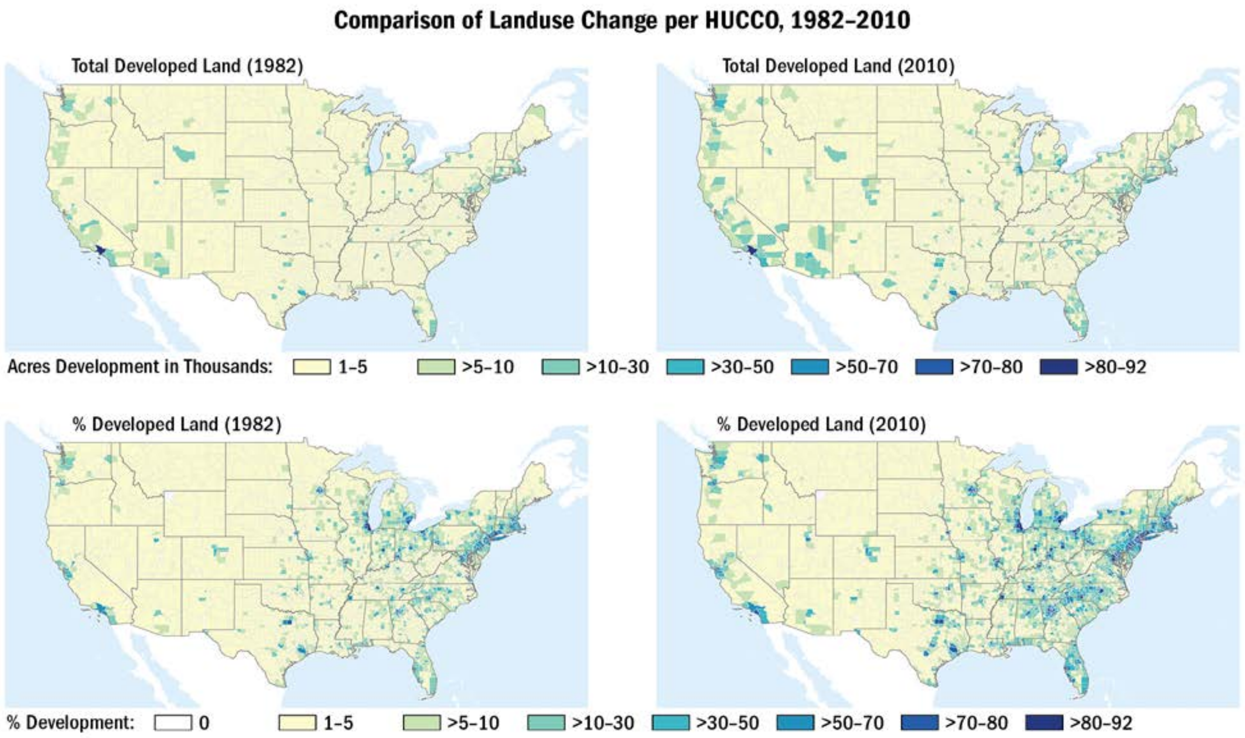
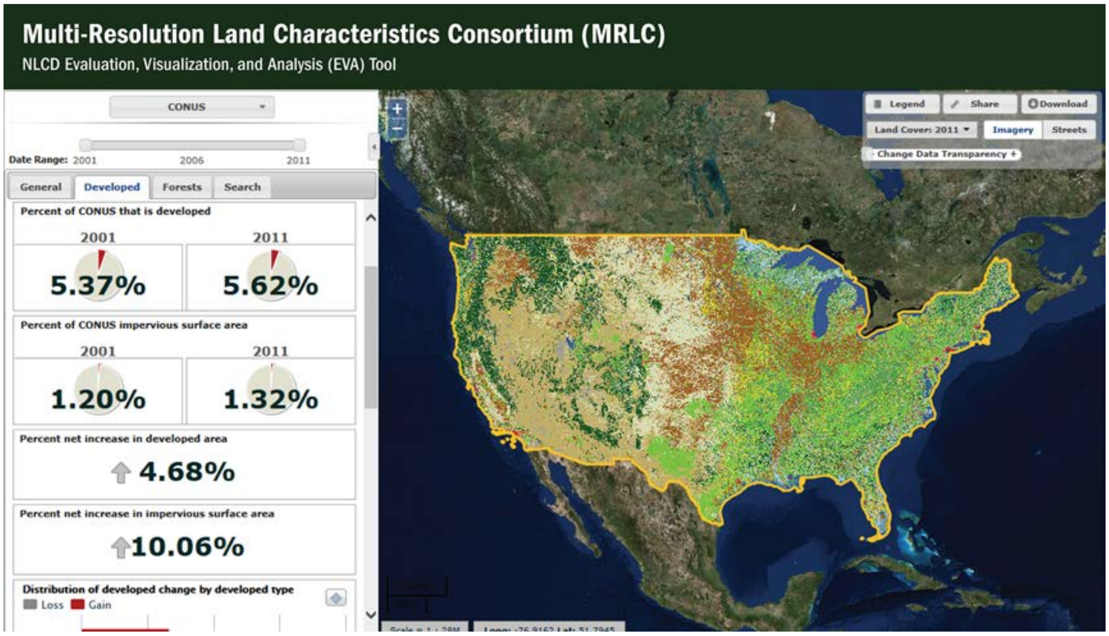


Figure 3-8: Changes in Development between 1982 and 2010.



Date Range: 2001 2006 2011

Percent of CONUS that is developed

2001	2011
5.37%	5.62%

Percent of CONUS impervious surface area

2001	2011
1.20%	1.32%

Percent net increase in developed area: 4.68%

Percent net increase in impervious surface area: 10.06%

Distribution of developed change by developed type

Figure 3-9: Changes in Land Development between 2001 and 2011.

3.2.2 Measuring Population Covered by Modernized Maps

The Map Modernization Program used a metric that reported on the percent of population covered by modernized maps. As of 2015, the program has exceeded the goal of 92 percent of the population being covered by a modernized map. This computation used the logic that if any part of a stream that had a defined floodplain intersected a census block group, then the entire population of the census block group was considered to be covered by a modernized map. This included maps that were just converted to a digital format with no updated flood modeling. There are currently 220,818 census block groups that cover the Nation, with each block group typically representing between 600 and 3,000 people. This metric worked well for the mass conversion of the inventory from paper to digital format, and allowed tracking of progress since the inception of the program.

However, this population metric has two challenges for moving forward. First, the metric over-predicts the population covered by a modernized map. FEMA generally studies streams that drain a drainage area of greater than one square mile. If a census block group has 10 miles of stream and only 1 mile is studied, the current metric will count 100 percent of the population within the census block group as being covered by a modernized map, as opposed to the 10 percent that may actually be covered. Therefore, the current metric can lead to a significant over-prediction of the population covered by a modernized map. This could lead policy makers to believe that flood hazards have been more widely identified than the reality. If the metric is changed to be more reflective of the streams studied within a census block group, then it may more realistically illustrate that the country has flood hazard areas defined for only somewhere between 16 percent and 22 percent of all streams.

The second challenge is that the metric does not predict the future. In predicting the future, two aspects must be considered. The first aspect is in knowing where the population will grow and where in the country emigration will occur. The second aspect is that the mapped floodplains degrade with time due to changes in land use, and better data and science becoming available. FEMA currently addresses this second aspect with a quality metric that predicts the degradation of the floodplain data over time.

Sub-Recommendation 3-4. FEMA should define a future population metric that uses a standard future population database, along with various budget scenarios, for keeping the data current to predict the percent of the population covered at various points in the future.

3.2.3 Population Impacts for Riverine Areas

At the request of the GAO (see Section 2.5.10), FEMA funded a study in November 2008 on the effects of climate change and population growth on the NFIP (see Section 2.5.12). Through the study, FEMA hoped to understand the potential impact of climate change on the financial strength of the NFIP and recommend options to increase the NFIP's viability. FEMA contracted with AECOM, in partnership with Michael Baker Jr., Inc. and Deloitte Consulting, LLP, to conduct an independent study and present the findings and recommendations to FEMA.

The primary conclusions of the study are:[35]

> *"For the riverine environment, the typical 1-percent-annual-chance floodplain area nationally is projected to grow by about 45 percent, with very large regional variations. The 45 percent growth rate is a median estimate implying there is a 50 percent chance of this occurring.*

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[35] AECOM, 2013.

> *Floodplain areas in the Northwest and around the Great Lakes region may increase more, while areas through the central portions of the country and along the Gulf of Mexico are expected to increase somewhat less. No significant decreases in floodplain depth or area are anticipated for any region of the Nation at the median estimates; median flood flows may increase even in areas that are expected to become drier on average. Within typical developed areas of primary interest for the NFIP, approximately 30 percent of these increases in flood discharge, SFHA, and base floodplain depth may be attributed to normal population growth, while approximately 70 percent of the changes may be attributed to the influence of climate change. The implication is that on a national basis approximately 30 percent of the 45 percent (or 13.5 percent) growth in the 1-percent-annual-chance floodplain is due solely to population growth and would occur even if there is no climate change. Conversely, approximately 70 percent of the 45 percent (or 31.5 percent) growth in the 1-percent-annual-chance floodplain is due solely to climate change and would occur even if there is no population growth. The split is highly variable from place to place, and so should not be taken as a definitive value; the relative importance of population growth will be much less in undeveloped areas, but will be greater than the national average in densely populated centers."*

3.2.3.1 Population Demographics

In 2010, the total U.S. population was 309 million, which was almost a 10 percent increase from the population in 2000.[36]

- The five most populous states were: (1) California; (2) Texas; (3) New York; (4) Florida; and (5) Illinois.
- The five most populous cities were: (1) New York City; (2) Los Angeles; (3) Chicago; (4) Houston; and (5) Philadelphia.

According to the Census Bureau, there were on average 87.4 people per square mile in the U.S. in 2010. In general, the population density is highest along the Atlantic and Pacific coasts.

- The areas of the U.S. with the greatest population densities in 2010 were: (1) District of Columbia; (2) New Jersey; (3) Puerto Rico; (4) Rhode Island; and (5) Massachusetts. It should be noted that each of these States/territories include coastal areas.
- The Census Bureau predicts that the U.S. population will reach 400 million by the year 2051. See Figure 3-10 for estimated population growth by county.

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[36] U.S. Department of Commerce, 2010.

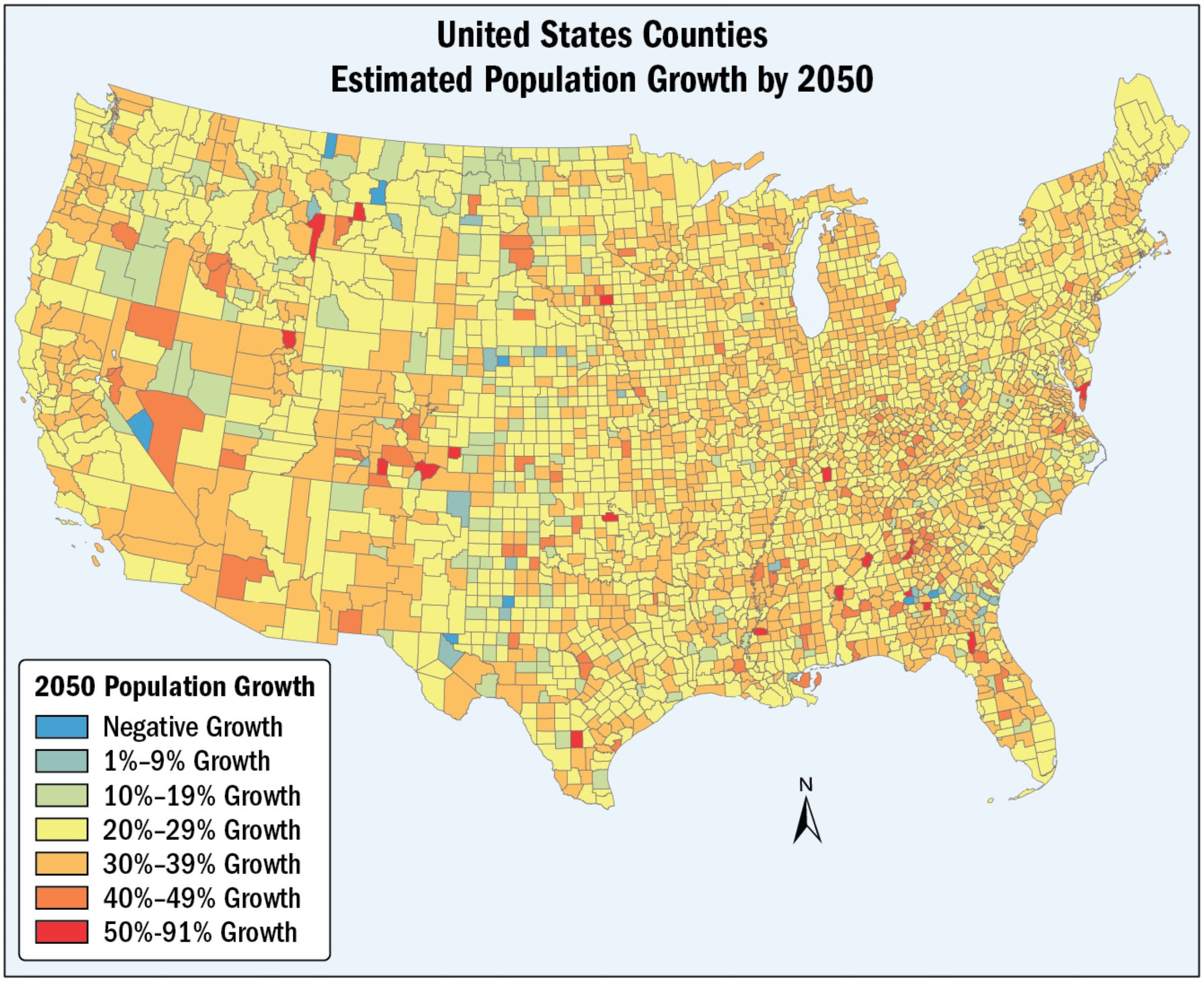

Figure 3-10: Estimated U.S. Population Growth by 2050.

3.2.3.2 Effects of Watershed Hardening

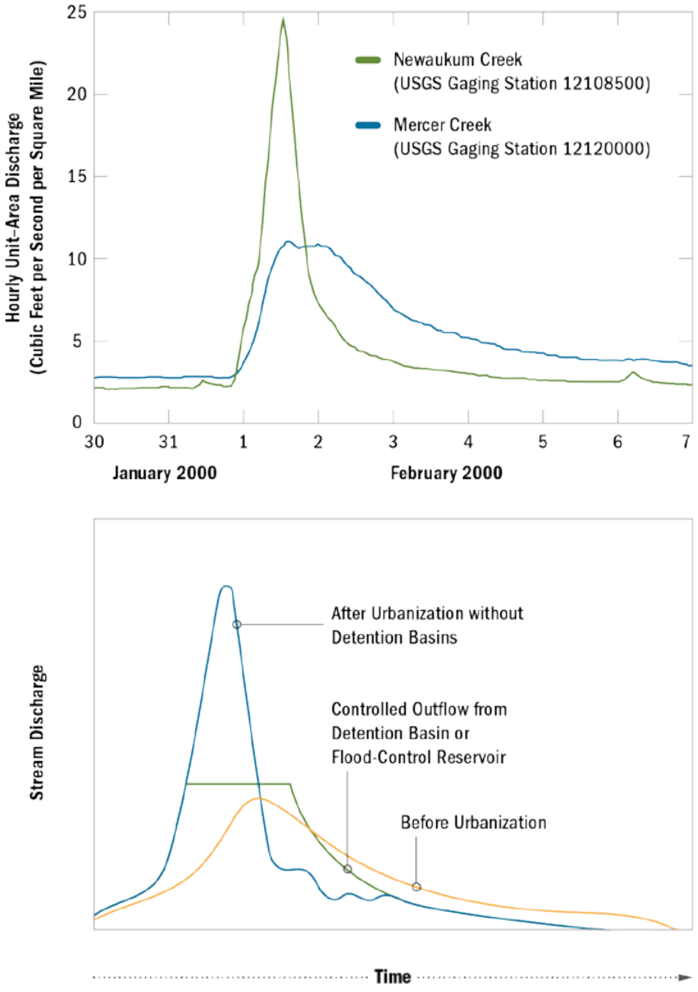

Figure 3-11: Impacts of Urbanization. Urbanization can lead to increased peak flow and total runoff volume, as well as decreased time to peak. Increased peak flows can be mitigated by stormwater detention, but increase in volume remains an issue.

As shown in , manmade development has a significant impact on discharges. Watershed hardening occurs when a watershed experiences development. When a watershed is hardened, water tends to runoff with greater volume and it runs off the surface much greater speed than in the natural state. The impacts on floodplains can be dramatic with increases in water surface elevations of a foot or more common. The increase in peak flow in response to urbanization can vary from 1.5 to 5 times. In general, the increase in peak flow resulting from urbanization will be larger for the lower magnitude, higher frequency events.

Levees and dams impact our floodplains in both positive and negative ways. On the positive side, a levee will keep the water contained to a channel and a dam will reduce flooding downstream. But there are negative impacts as well. A dam will increase flooding upstream and both levees and dams are designed for a certain flood level that, if exceeded, may result in the structure failing, potentially causing serious damage. Another example may be a levee that currently meets protection guidelines but, due to land development, climate change, and subsidence, would not allow the levee to meet flood protection criteria in the future.

Stormwater management facilities provide effective control for frequent floods of up to the 25-year event (see Figure 3-12). However, when less frequent events occur, such as the 1-percent-annual-chance (100-year) event, the stormwater feature is generally filled and has no flood-reducing impact on downstream areas. Therefore, stormwater facilities generally do not need to be considered in future conditions modeling.

Figure 3-12: Stormwater Facilities.
Most stormwater facilities are designed for less than the 25-year event and have nearly no impact on the 100-year event. This creates significant problems for those downstream.

3.2.3.3 Life of Structure

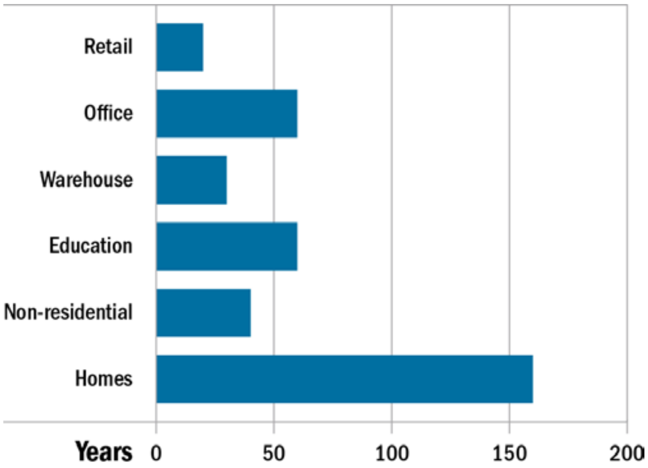

Figure 3-13: Life of Structure.
Residential structures built today will be tomorrow's problems unless life of structure is taken into account.

The design criteria and flood elevations that are established today will have impacts that can range from a couple of decades to future generations. Dr. Arthur C. Nelson, FAICP, has studied the probable life of facilities built today, and determined that a typical residential house built today will have a useful life of over 150 years.[37] One estimate of damage from Superstorm Sandy counted over 650,000 houses that were damaged or destroyed. How the Nation rebuilds after a disaster and how development occurs in the future will impact the health, safety, and welfare of future generations.

When examining future conditions, the future state may be different for different types of structures (see Figure 3-13[38]). If a structure has a service life of 20 years, the design event may be different than a structure that has a service life of over 100 years. For example, a typical shopping center will have a major upgrade once every 20 years while, for a home, it may be over 150 years before a renovation

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[37] Nelson, "Human Factors in 2050."
[38] Nelson, "Human Factors in 2050."

significant enough to trigger the NFIP floodplain management standards (50 percent of market value). If the science improves our future predictions for the near-term future, a correction can more easily be made for some types of structures than others.

If people are not better informed of their future flood risk, and if structures are built or rebuilt to the current 1-percent-annual-chance flood elevation, we could see similar or worse damages in the decades to come, placing a heavy financial burden on future generations.

3.2.3.4 Impact of Future Conditions on Mitigating Flood Damage

Mapping future conditions could have a positive impact on reducing flood damage in the future if this information is adopted by local communities and used to regulate current and future development. As discussed in Section 3.2.3.3, homes built today may be in use, without major changes, for the next 100 years. If these homes are built with their low floors to or above the water surface elevation of the future conditions 1-percent-annual-chance flood, these structures and their occupants will be better protected, property values will be less likely to degrade over time, and public investment in post-flood damage assistance programs will be reduced.

Future conditions mapping could also be used to help the public understand and local officials plan for the flood risk they and future generations are likely to face. This information could help guide planning and zoning decisions at the local level; help the public better understand the changing dynamics of flood risk; and help encourage mitigation actions, such as the purchase of flood insurance and safer construction practices. Knowing future conditions flood levels will help the public understand how a slight investment in elevating a few more feet during the construction of a home can pay dividends when you consider the resulting reduction in annual flood insurance premiums. In addition, the CRS program currently allows communities to accrue points to improve its CRS rating for implementing future conditions requirements, which will have a positive effect on mitigating flood damage and reducing flood insurance premiums for residents and business owners in that community.

3.2.4 Population Impacts for Coastal Areas

FEMA defines coastal high hazard areas (Zone V, VE, and V1-30) as those areas of special flood hazard extending from offshore to the inland limit of a primary frontal dune along an open coast and any other area subject to high velocity wave action from storms or seismic sources. Special floodplain management requirements apply in these areas, including the requirement that all buildings be elevated on piles or columns. Other coastal hazard areas include the Coastal A Zone and Shaded Zone X (see Figure 3-14).

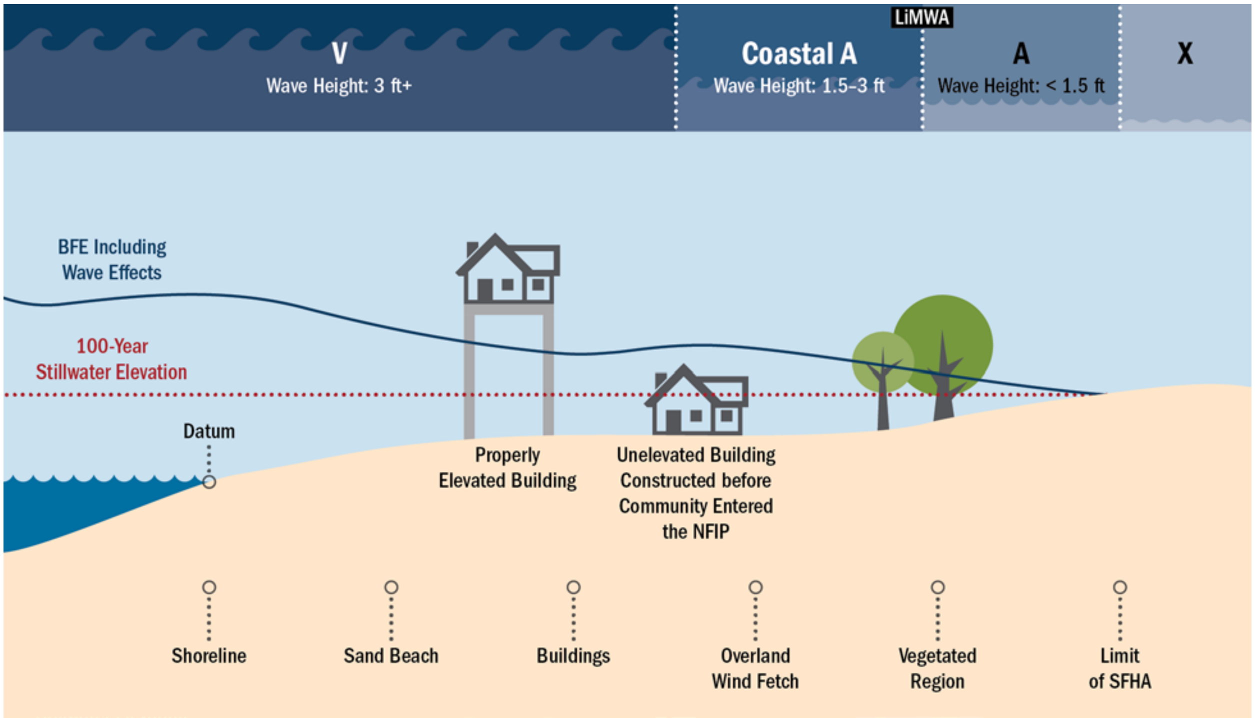

Figure 3-14: Coastal Flood Zones.

3.2.4.1 Coastal Population Demographics

There are 31 States with population in the coastal floodplain (see Table 3-2). In 2010, approximately 11 million people, or 3 percent of the U.S. population, resided in the coastal floodplain. The average population density in the coastal floodplain (excluding Alaska), was 292 people per square mile. This is about three times higher than the average density in the United States. For the population residing in the coastal floodplain (excluding U.S. territories):

- 12 percent are below the poverty level
- 23 percent are under 5 years old or are 65 years old and older

The population density is growing along the coast. In 2010, population density in coastal counties (i.e., counties with a coastal shoreline, but excluding Alaska) was 446 people per square mile (the U.S. average is 87.4 people per square mile). The same year, approximately 123.3 million people, or 39 percent of the U.S. population, resided in a coastal county, which is defined as any county that abuts the ocean or Great Lakes coastline, and or contains a V-zone or coastal A-zones. This number was a 39 percent increase in population of coastal counties from 1970 (the U.S. average during this same time was a 52 percent increase). The expected population change from 2010 to 2020 in coastal counties is 8 percent. This means an additional 10 million people are expected to live in counties with a coastal shoreline in 2020.

Table 3-2: Coastal Population.

Coastal State	2010 Population in Coastal A Zones	2010 Population in Coastal V Zones	2010 Population in Coastal Shaded X Zones	2010 Population in all Coastal A, V, and Shaded X Zones	Total Coastal State 2010 Population
Alabama	40,209	14,202	8,966	63,377	4,779,736
Alaska	26,986	2,258	2,843	32,086	710,231
California	241,304	24,821	144,136	410,261	37,253,956
Connecticut	101,845	21,469	17,391	140,705	3,574,097
Delaware	53,691	1,440	10,892	66,022	897,934
D.C.	7,471	0	2,062	9,533	601,723
Florida	4,205,413	249,907	582,144	5,037,464	18,801,310
Georgia	132,448	46,843	42,926	222,217	9,687,653
Hawaii	59,666	10,460	3,116	73,242	1,360,301
Illinois	10,260	0	5	10,265	12,830,632
Indiana	779	0	19	798	6,483,802
Louisiana	1,033,646	99,711	379,740	1,513,097	4,533,372
Maine	26,714	5,501	1,958	34,173	1,328,361
Maryland	155,694	6,677	40,063	202,434	5,773,552
Massachusetts	145,618	39,428	38,792	223,837	6,547,629
Michigan	85,981	0	27,323	113,304	9,883,640
Minnesota	4,165	0	150	4,315	5,303,925
Mississippi	90,242	27,001	49,998	167,241	2,967,297
New Hampshire	11,921	385	707	13,013	1,316,470
New Jersey	581,659	32,493	130,999	745,150	8,791,894
New York	648,475	32,935	287,676	969,086	19,378,102
North Carolina	166,914	17,960	34,948	219,822	9,535,483
Ohio	23,447	0	3,393	26,841	11,536,504
Oregon	14,981	2,355	1,754	19,090	3,831,074
Pennsylvania	25,060	0	9,176	34,236	12,702,379
Puerto Rico	119,900	16,124	39,250	175,274	3,725,789
Rhode Island	33,417	19,291	17,041	69,748	1,052,567
South Carolina	275,876	69,238	32,391	377,504	4,625,364
Texas	175,212	65,407	177,080	417,700	25,145,561
Virginia	329,021	16,080	87,439	432,540	8,001,024
Washington	55,377	5,011	5,879	66,268	6,724,540
Wisconsin	18,935	0	671	19,606	5,686,986
TOTALS:	**8,902,328**	**826,997**	**2,180,926**	**11,910,250**	**255,372,888**
	2010 Total U.S. Population (All States, including non-coastal)				**312,471,327**

3.2.4.2 Effects of Shoreline Hardening

Coastal flood hazards arise from waves and storm surge that originate in the ocean and then interact with the ocean bottom and the land. Therefore, when the ocean bottom or land is modified, it impacts the flood hazard. Future conditions modeling needs to incorporate expected changes to the shoreline.

The shoreline, including the ocean bottom and land, is constantly in motion. The natural processes that change the shoreline include the following example scenarios:

- Breaking waves that move sand along the coast, eroding sand in one area and depositing it on an adjacent beach
- Tidal cycles that bring sand onto the beach and carry it back into the surf
- Rivers that carry sediment to the coast and build deltas into the open water
- Storms that cause deep erosion in one area and leave thick overwash deposits in another
- Plants that retain sediment in wetlands and impede movement of coastal dunes [39]

These natural processes are very complex, and when manmade actions alter any of these items, it affects the coastal flood hazard (see Figure 3-15).

Figure 3-15: Seawall. This seawall on New Smyrna Beach, Florida, was mostly hidden by sand prior to the arrival of Hurricane Jeanne in 2004. FEMA Photo/Mark Wolf.

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[39] USGS, 2008.

Shoreline Hardening

Seawalls or other shoreline hardening constructed to protect property along retreating beaches often exacerbate beach erosion. As shown in Figure 3-16, as the coast naturally erodes, undisturbed beaches can keep their natural width. When seawalls or other hardening is constructed, it confines the wave energy. This concentrates the sediment transport processes into an increasingly narrow area; thereby increasing erosion. Eventually, the beach disappears, leaving the seawall. For example, a massive seawall built to protect a highway and beach houses along the northern New Jersey coast has resulted in the complete disappearance of the beach itself.

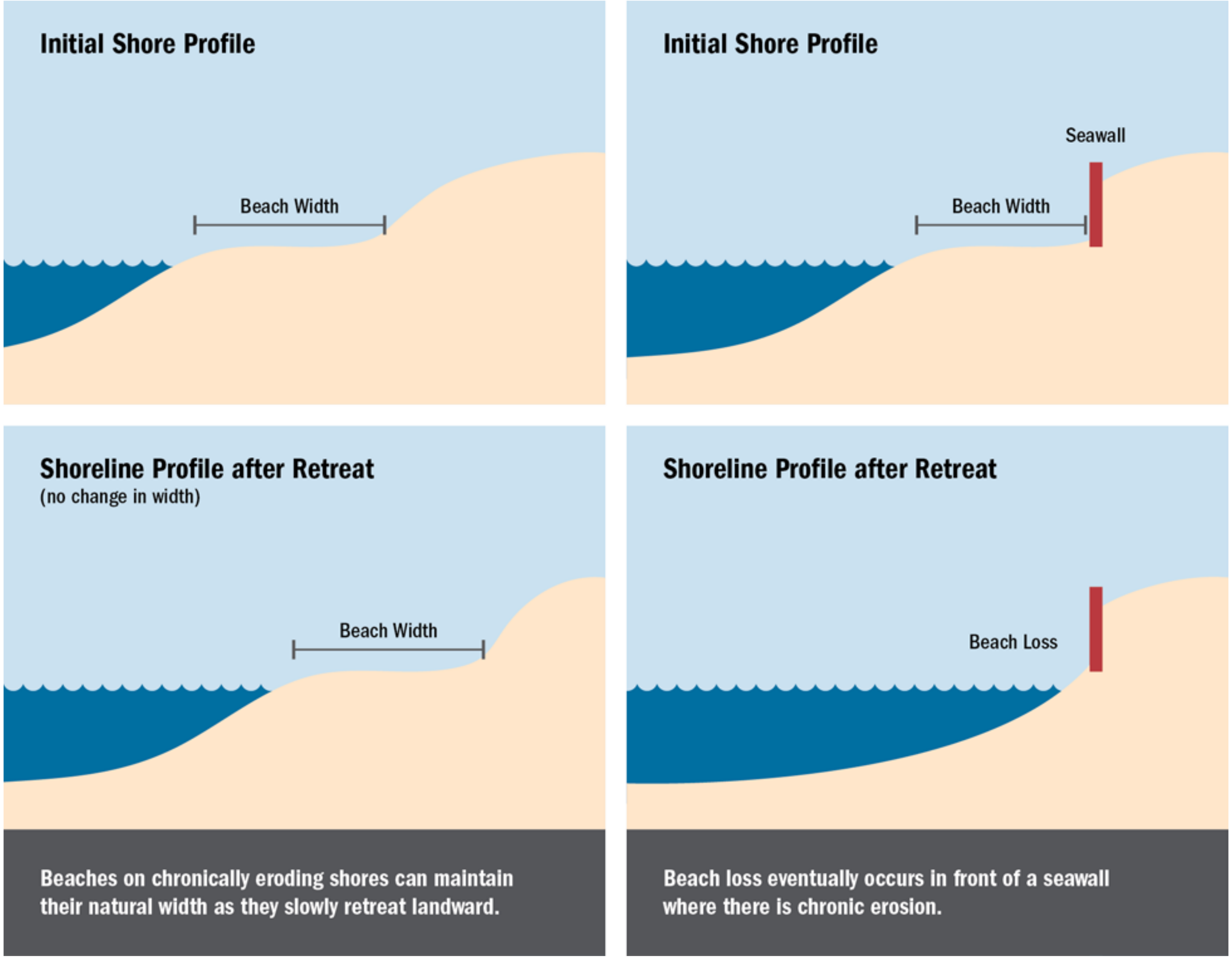

Figure 3-16: Shoreline Hardening. Shoreline hardening can result in beach loss.

Groins or Jetties

To prevent beach loss, groins or jetties are often constructed into the water. These solid structures impede the natural cross-beach transfer of sand that is caused by currents along the shoreline. Small groins may have little effect on sand movement along the entire beach. Larger groins or jetties can cause a significant retention of sand on the updrift side of the groin, which expands the beach in this area. However, the groin will also impede the ability of the sand to move downdrift of the groin, which increases downdrift erosion and reduces the beach area. Sand carried out past the jetty may be deposited as shoals offshore in deeper water. This removes the sand from the coastal system, thereby further increasing downdrift erosion and reducing the beach area.[40]

Sand Removal

Dredging navigation channels and tidal inlets and discharging the materials into deep water also removes sand from the coastal system. For some coastal regions, such as the Pacific Coast, a large part of their sand budget is supplied by rivers.

According to the USGS, dams "built for flood control and water catchment along the rivers leading to these coasts inhibit the transport of large-grained sediment. Lacking new material, the sediment-starved coasts erode and migrate inland. Damming of tributary rivers to the Mississippi River over the past 60 years has also reduced the movement of sediment. Studies by the USGS in recent years demonstrate that the amount of sediment carried by the Mississippi has been cut in half, aggravating the deterioration of Louisiana's wetlands."[41]

All of these manmade actions along our coast can dramatically alter the shoreline. These changes will then affect the flood hazards along the coast.

Sub-Recommendation 3-5. FEMA should take into account future development (excluding proposed flood control structures for the base condition/scenario) for future conditions mapping. An additional scenario can be generated that does include future flood control structures.

Sub-Recommendation 3-6. FEMA should use population growth as an indicator of areas with increased potential flood risk.

3.3 Natural Changes

3.3.1 Overview of Climate Change

The Global Change Research Act of 1990 (Public Law 101-606)[42] requires a report to Congress and the President every four years on the environmental, economic, health, and safety consequences of climate change. The Third National Climate Assessment (NCA)[43] was conducted as part of this requirement. It was released by the United State Global Climate Change Research Program in May 2014. It summarizes the current and future potential impacts of climate change on the United States on a regional and sector basis. A team of more than 300 experts, guided by a 60-member Federal Advisory Committee, produced the report, which was extensively reviewed by the public and subject matter experts, including Federal agencies and the National Academy of Sciences.

Flood-related issues are covered in nearly every chapter of the NCA, and are addressed specifically in the separate chapters for water and coasts in addition to the chapter on "Our Changing Climate." This section summarizes salient points in the NCA and elsewhere related to flooding and projected climate information

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[40] USGS, 2008.
[41] USGS, 2008.
[42] Global Change Research Act of 1990, 1990.
[43] Georgakakos, 2014.

that may be of interest to decision-makers. For the purpose of this report, we will first address observed changes, and then projected changes.

3.3.2 Observed Climate Change

The Third NCA noted that all of the trends identified in the Second National Assessment[44] have continued in the intervening 5 years. These include a continuation of the trends in the 10 indicators of a warming world (see 3-17). These 10 indicators are all important to understanding floods and flood risk because they affect aspects of the hydrologic cycle and contribute to changing sea levels and storm patterns.

Figure 3-17: Ten Indicators of a Warming World

The NCA was very clear in stating that the climate is changing, will continue to change for the foreseeable future, and may accelerate in the future if global greenhouse gas emissions continue. These changes are evident in many places, and are becoming increasingly disruptive. Observed changes that directly impact flood risks are outlined below.

3.3.2.1 Observed Precipitation Trends

Generally, it is both the long-term trend and the variability that are important in understanding how precipitation patterns have changed over time. Average annual precipitation is one commonly used measure of how precipitation has changed. But the amount of precipitation that falls in different seasons is also important, as is the amount of precipitation that falls during heavy precipitation events. Chapter 25[45] of the NCA reports that since 1991, average annual precipitation has increased 9 percent in the Midwest and 8 percent in the Northeast and southern Great Plains, compared to the period 1901-1960. No definitive trends were reported for the Southeast, Southwest, and Caribbean (Chapter 17),[46] where some locations had increases and some had decreases. No trends were reported for Alaska (Chapter 22).[47] In the Pacific,

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[44] Karl, et al., 2009.
[45] Moser, et al., 2014.
[46] Carter, et al., 2014.
[47] Chapin, et al., 2014.

western islands are experiencing slight increases in precipitation, while those in the east (e.g., Hawaii) are experiencing decreases (Chapter 23).[48]

Heavy rainfall that contributes to both local and regional flooding has been observed to increase just about everywhere except Hawaii in the past several decades (see Chapter 2).[49] The greatest increase in very heavy events (the heaviest 1 percent of all events) between 1958 and 2012 (see Figure 3-18) was observed in the Northeast (71 percent) and Midwest (37 percent). No significant changes were observed in the Southwest, Northwest, and Hawaii.

3.3.2.2 Observed Sea Level Trends

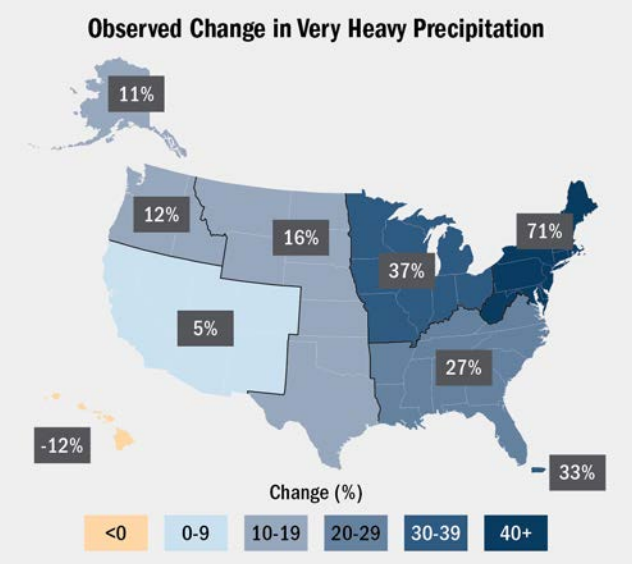

Figure 3-18: Change in Heaviest Precipitation. Percent change from 1958 to 2012 in the amount of precipitation falling in very heavy events (the heaviest 1 percent).

There are a number of factors that impact sea level. Important factors include local land movement (e.g., uplift, subsidence); glacial and ice cap conditions; ocean circulation; and ocean properties, such as the temperature of the water, which is closely related to its volume, salinity, and density. Both global sea level and local relative sea level (LRSL) vary by location, depending on local, regional, and global processes (see Figure 3-19).

Records from various sources show that there has been a long-term trend in rising global sea levels, with an increasing rate of change since the 1800's.[50] The National Oceanic and Atmospheric Administration (NOAA) maintains tide gauges, which measure local relative sea level, and also reports on current trends (see Figure 3-20). For most of the United States, LRSLs are increasing. In some areas of the Pacific Northwest and Alaska, SRSLs are falling, primarily due to tectonic activity. Increasing LRSLs are already resulting in increased nuisance or recurrent flooding for the continental United States.[51]

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[48] Leong, et al., 2014.

[49] Walsh, et al., 2014.

[50] NRC, 2012.

[51] Sweet, et al., 2014.

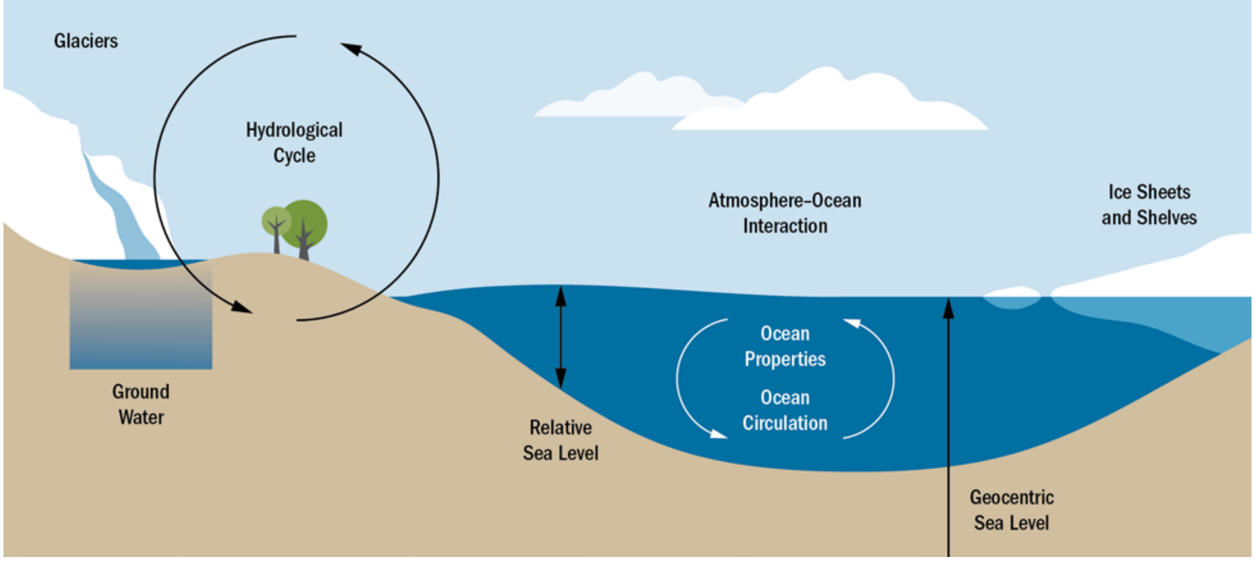

Figure 3-19: Some Components of Global Sea Level Rise.[52]
Note that both global sea level and relative sea level vary by location.

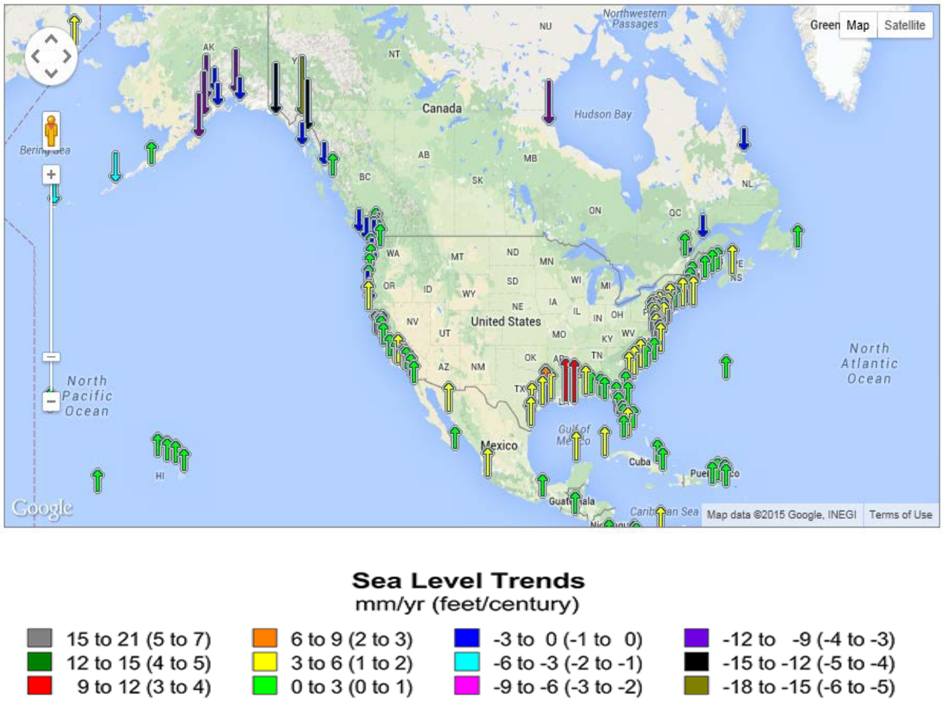

Figure 3-20: NOAA Regional Sea Level Trends for the United States, April 2015.[53]

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[52] Church, et al., 2013.

[53] NOAA, 2013.

3.3.2.3 Observed Storm Trends

While the NCA reports that Northeast and Northwest coastlines have experienced increasing storm activity since about 1980, when high-quality satellite data became available, it is possible that this apparent increase may also be a factor of improved detection capabilities.[54] Some reports suggest that it is not possible at this time to identify robust trends in tropical cyclone activity for the Atlantic and western North Pacific for a variety of reasons.[55]

3.3.2.4 Observed Great Lakes Water Level Trends

Great Lakes water levels have been observed since the mid-1800s to fluctuate above and below average.[56] For example, decreasing water level trends across the Great Lakes in the 1960s were followed by above-average water levels in the 1970s and 1980s, after which period water levels dropped in the 1990s, leveling off (Ontario and Erie) in the 2000s. This natural variability in lake levels has been observed even more recently. For example, in January 2013, monthly-average water levels on Lake Michigan and Lake Huron dropped to their lowest levels in recorded history.[57] In early 2015, the Great Lakes water levels increased to near record levels in some of the lakes. The Great Lakes Water Level Dashboard[58] provides visualization and access to the long-term average water level observations for the Great Lakes going back to 1918 (see Figure 3-21).

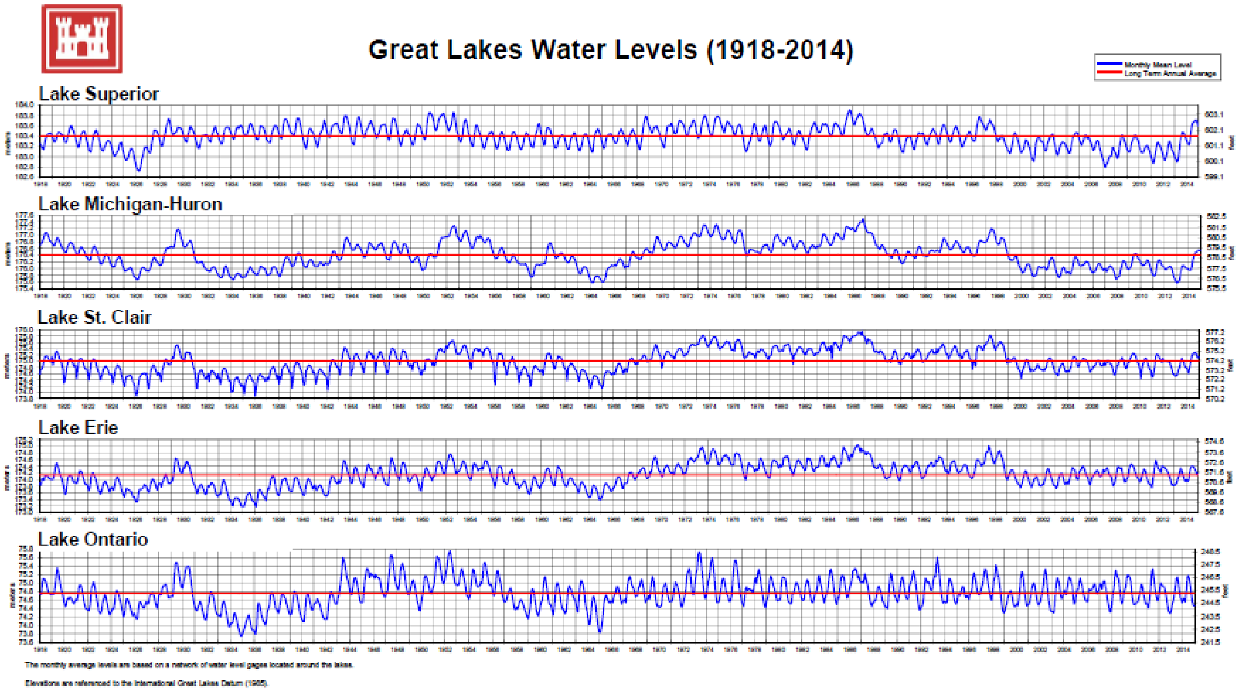

Figure 3-21: Great Lakes Water Levels. Great Lakes Water Levels have historically fluctuated seasonally and interannually. Some lakes are controlled and thus have less fluctuation (ex. Superior and Ontario).[59]

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[54] Landsea, et al., 2010.
[55] Kunkel, et al., 2013.
[56] Angel and Kunkel, 2010.
[57] Clites, et al., 2014.
[58] Gronewold, et al., 2013.
[59] USACE, 2015a.

3.3.2.5 Observed Wildfire Trends

Wildfires leave the ground charred, barren, and unable to absorb water, creating conditions conducive for flash flooding and mudflow. Until a watershed impacted by a major wildfire can restore vegetation—which may take up to 5 years after the wildfire—flood risk remains significantly higher when compared with the risk prior to the event.[60] Areas directly affected by fires and those located below or downstream of burn areas are at greatest risk for flooding. In the U.S. Southwest, increases in heat, drought, and insect outbreaks that are linked to climate change has increased wildfires. Between 1970 and 2003, warmer and drier conditions increased burned areas in the western U.S. mid-elevation conifer forests by 650 percent.[61]

3.3.3 Future Climate Change

The NCA states that global climate is projected to continue to change over this century and beyond. The magnitude of climate change beyond the next few decades depends on the amount of heat-trapped gasses emitted globally and how sensitive the earth's climate is to those emissions.

Choices made now and in the next few decades will determine the amount of additional future warming. Beyond mid-century, lower emission levels will lead to noticeably less future warming. Higher emissions levels will result in more warming and, thus, more severe impacts on human society and the natural world. Figure 3-22[62] shows different greenhouse gas scenarios projected out to 2100. Lowering emissions now will reduce future temperature increases.

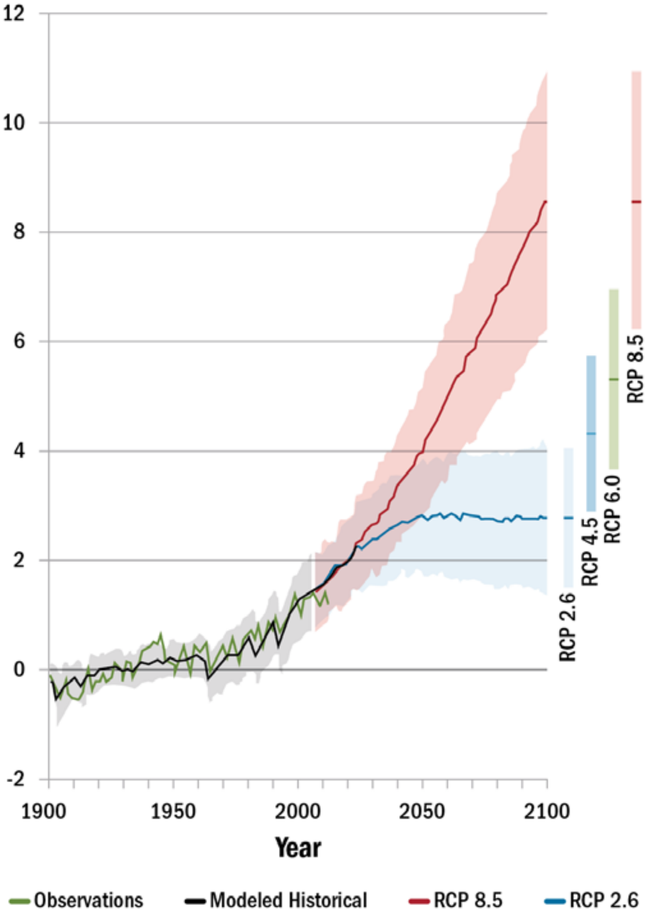

Figure 3-22: Heat-Trapping Gasses and Temperature. Different amounts of heat-trapping gases released into the atmosphere by human activities produce different projected increases in Earth's temperature. This plot shows temperature observations vs modeled historical trends on the left, and future projected trends based on a lower and higher emissions pathways (also known as Representative Concentration Pathways [RCPs]) on the right.

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[60] FEMA FloodSmart, 2015.

[61] Westerling, et al., 2011.

[62] NCA, 2014.

3.3.3.1 Projected Precipitation Trends

Warmer air contains more water vapor than cooler air. Global analyses show that the amount of water vapor in the atmosphere has, in fact, increased over both land and oceans. Climate change also alters dynamic characteristics of the atmosphere that, in turn, affect weather patterns and storms. In the mid-latitudes, where most of the continental United States is located, there is an upward trend in extreme precipitation in the vicinity of fronts associated with mid-latitude storms. Locally, natural variations can also be important.

Projections of future changes in precipitation show small increases in the global average, but substantial shifts in where and how precipitation falls. Generally, areas closest to the poles are projected to receive more precipitation, while the dry subtropics expand toward the poles and receive less rain. Increases in tropical precipitation are projected during rainy seasons, especially over the tropical Pacific. Certain regions, including the western United States (especially the Southwest) and the Mediterranean, are presently dry and are expected to become drier.

The widespread trend of increasing heavy downpours is expected to continue, with precipitation becoming less frequent, but more intense. The patterns of the projected changes of precipitation do not contain the spatial details that characterize observed precipitation, especially in mountainous terrain, because the projections are averages from multiple models and because the effective resolution of global climate models is roughly 100 to 200 miles. Figure 3-23 shows globally where precipitation is expected to increase and decrease.

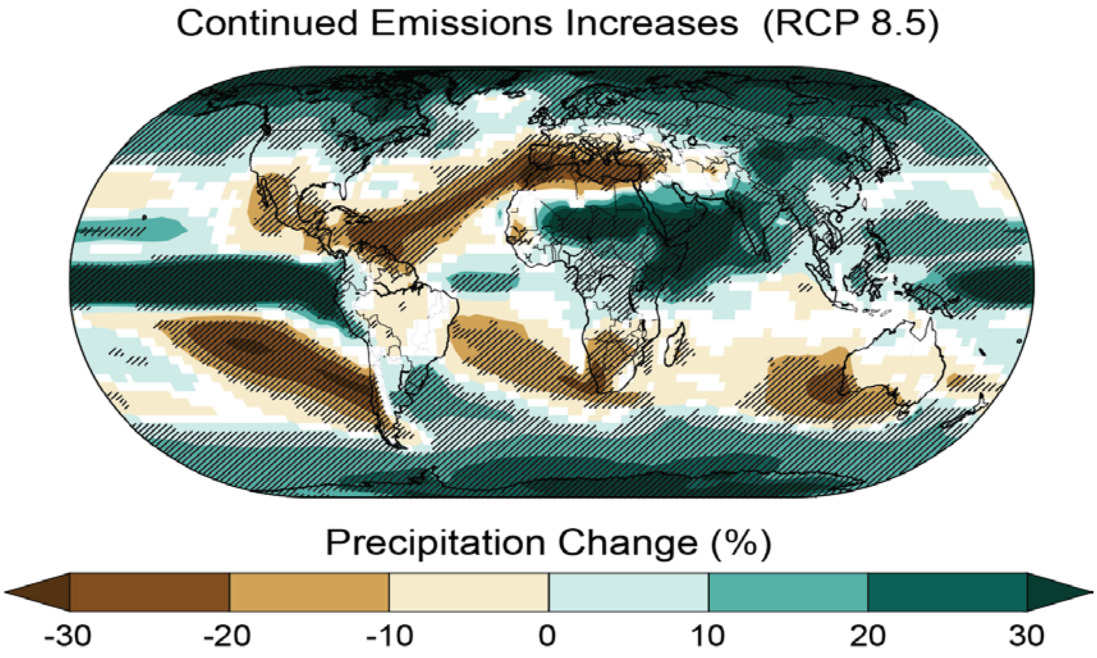

Figure 3-23: Emissions Increases and Precipitation Change.
Projected change in average annual precipitation over the period 2071-2099 (compared to the period 1970-1999) under a high scenario that assumes continued increases in emissions (RCP 8.5). In general,

northern parts of the United States (especially the Northeast and Alaska) are projected to receive more precipitation, while southern parts (especially the Southwest) are projected to receive less.[63]

3.3.3.2 Projected Storm Trends

Projected storm trends include trends in heavy precipitation and hurricanes.

Heavy Precipitation Events

Flooding may intensify in many U.S. regions, even in areas where precipitation is projected to decline (see Figure 3-24). Floods are caused or amplified by both weather- and human-related factors. Major weather factors include heavy or prolonged precipitation, snowmelt, thunderstorms, storm surges from hurricanes, and ice or debris jams. Human factors include structural failures of dams and levees, altered drainage, and land-cover alterations (e.g., pavement). The risks from future floods are significant, given expanded development in coastal areas and floodplains, unabated urbanization, land-use changes, and human-induced climate change.[64]

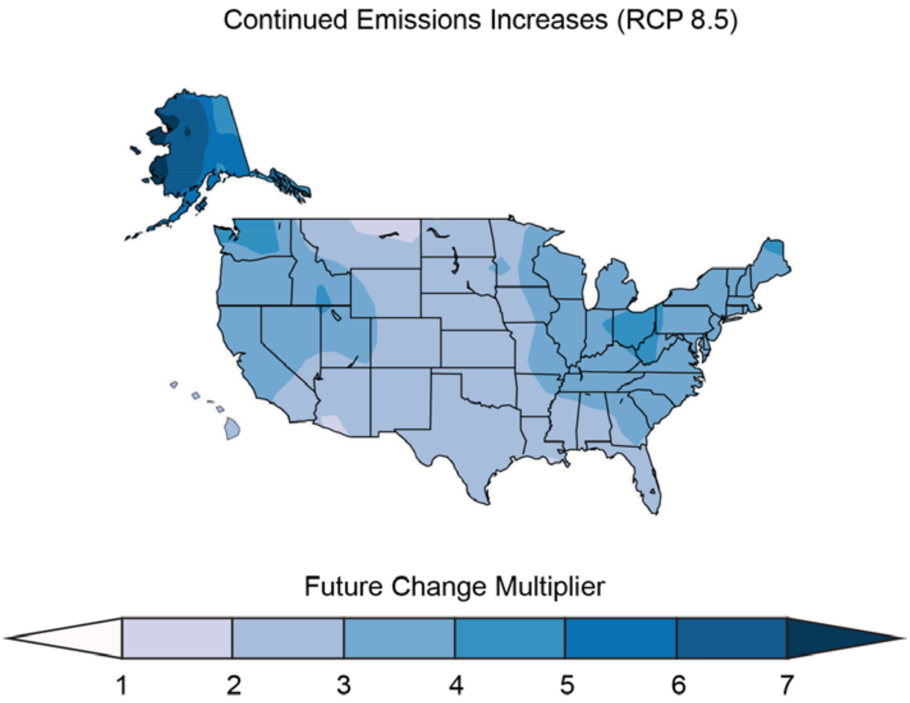

Figure 3-24: Extreme Daily Precipitation events. Map shows the increase in frequency of extreme daily precipitation events (a daily amount that now occurs once in 20 years) by the later part of this century (2081-2100) compared to the later part of last century (1981-2000). Such extreme events are projected to occur more frequently everywhere in the United States For the scenario assuming continued increases in emissions (RCP 8.5), these events would occur more often (noted by the darker blue regions).[65]

Hurricanes

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[63] NCA, 2014.

[64] Doocy, et al., 2013.

[65] Walsh, et al., 2014.

By late this century, models, on average, project a slight decrease in the annual number of tropical cyclones, but an increase in the number of the strongest (Category 4 and 5) hurricanes. Models also project greater rainfall rates in hurricanes in a warmer climate, with increases of about 20 percent averaged near the center of hurricanes. It is important to note, however, that there is still some uncertainty in the climate models when it comes to future tropical cyclone activity.

Severe Storms

Tornadoes and other severe thunderstorm phenomena frequently cause as much annual property damage in the United States as do hurricanes, and often cause more deaths. Recent research has yielded insights into the connections between global warming and the factors that cause tornadoes and severe thunderstorms (e.g., atmospheric instability, increases in wind speed with altitude). Although these relationships are still being explored, a recent study suggests a projected increase in the frequency of conditions favorable for severe thunderstorms.[66]

3.3.3.3 Projected Sea Level Trends

Projecting future rates of sea level rise (SLR) is challenging. Even the most sophisticated climate models, which explicitly represent Earth's physical processes, cannot simulate rapid changes in ice sheet dynamics and, thus, are likely to underestimate future sea level rise. In recent years, "semi-empirical" methods have been developed to project future rates of SLR based on a simple statistical relationship between past rates of globally-averaged temperature change and SLR. These models suggest a range of additional SLR from about 2 feet to as much as 6 feet by 2100, depending on the emissions scenario. It is not clear, however, whether these statistical relationships will hold in the future, or that they fully explain historical behavior. Regardless of the amount of change by 2100, however, SLR is expected to continue well beyond this century as a result of both past and future emissions from human activities.

Scientists are working to narrow the range of SLR projections for this century. Recent projections show that, for even the lowest emissions scenarios, thermal expansion of ocean waters and the melting of small mountain glaciers will result in 11 inches of SLR by 2100, even without any contribution from the ice sheets in Greenland and Antarctica. This projection suggests that about 1 foot of global SLR by 2100 is probably a realistic low end. On the high end, recent work suggests that 4 feet or more is plausible, including significant ice contribution from Greenland and Antarctica. In the context of risk-based analysis, some decision makers may wish to use a wider range of scenarios, from 8 inches to 6.6 feet by 2100[67] (see Figure 3-25). In particular, the high end of these scenarios may be useful for decision makers with a low tolerance for risk. Although scientists cannot yet assign likelihood to any particular scenario, in general, higher emissions scenarios that lead to more warming would be expected to lead to higher amounts of SLR.

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[66] Diffenbaugh, et al., 2013.

[67] Parris, et al., 2012.

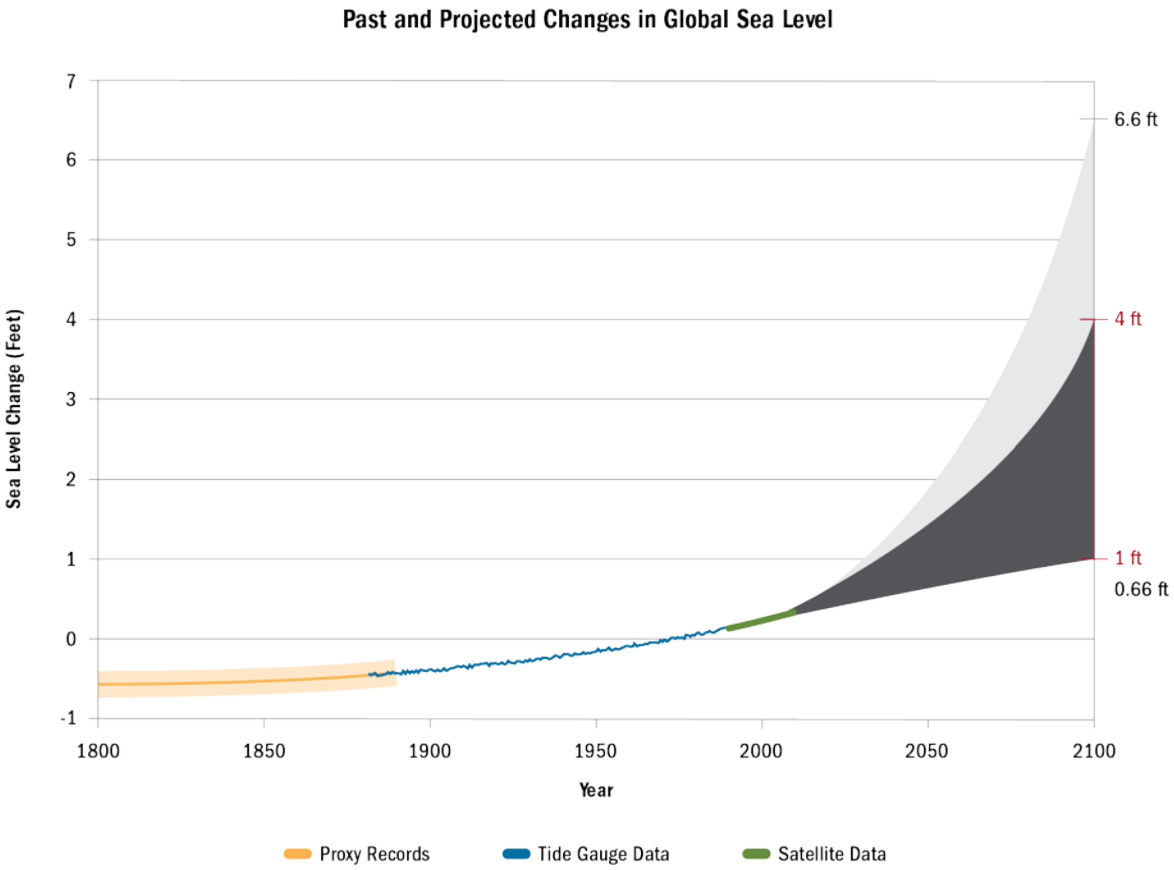

Figure 3-25: Past and Projected Changes in Global Sea Level. Estimated, observed, and possible future amounts of global sea level rise from 1800 to 2100, relative to the year 2000, based on possible scenarios based on science consensus.[68]

3.3.3.4 Great Lakes Level Trends

Future flood risk in the Great Lakes area will be determined by future fluctuations in lake levels, as well as storm frequency and magnitudes. Great Lakes water levels represent evolving research and are still subject to considerable uncertainty. For example, water level projections for the individual lakes vary by several feet among the available climate models. One area of research is to improve techniques to estimate evapotranspiration because previous estimates from temperature data may have overestimated evaporation losses.[69, 70, 71]

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[68] Adapted from Parris et al., 2012, with input from NASA Jet Propulsion Laboratory.
[69] Pryor, et al., 2012.
[70] MacKay and Seglenieks, 2012.
[71] Angel and Kunkel, 2010.

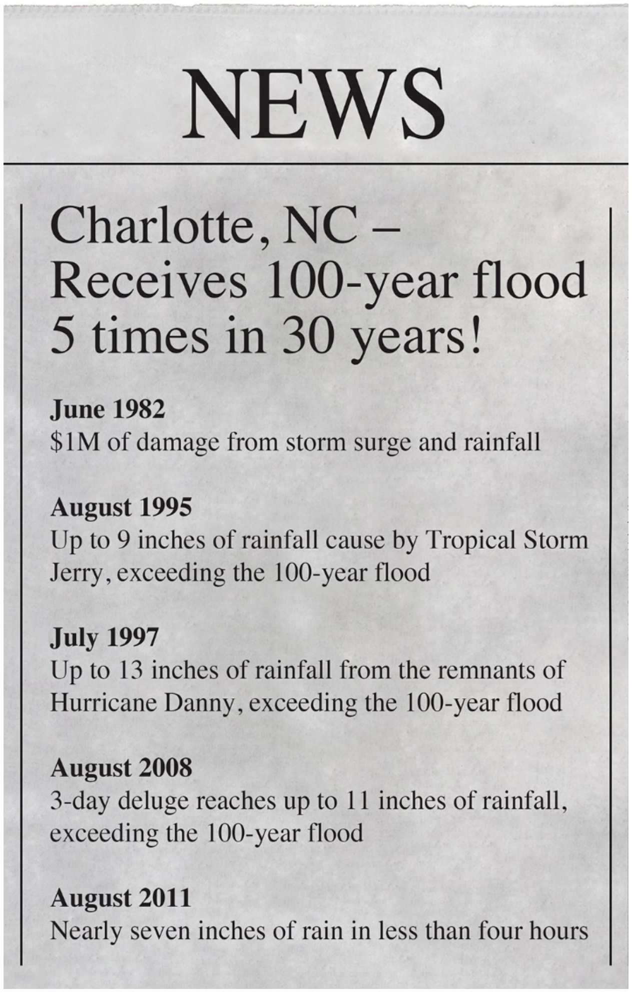
3.3.3.5 Projected Wildfire Trends

Numerous fire models project more wildfires as climate change continues. For example, models project a doubling of burned area in the Southern Rockies and up to a 74 percent increase in burned areas in California, with northern California potentially experiencing a doubling under a high emission scenario toward 2100.[72]

3.4 Design Elevations for Future Conditions

The Nation is projected to grow from a population of 310 million to a population of 450 million by the year 2050. This will result in a large number of new structures and significant infrastructure being built. If responsible design decisions are made, the Nation will be better prepared for future disasters. Conversely, if this new development is not planned and implemented in a responsible manner, the consequences of these poor decisions will last for many generations.

Due to the relative young age of the United States, there is limited historic data on flood elevations, which presents a challenge when predicting future flood elevations. Many of the predictions for the 1-percent-annual-chance flood (100-year flood) are based on a period of historical record that is significantly less than 100 years. In the United States, there are very few gages with greater than 100 years of record. By contrast, the Nile River has perhaps nearly 3,000 years of record. Predicting a 1-percent-annual-chance storm for the Nile River would have a narrower band of uncertainly than any flooding source in North America. The uncertainty of flood predictions for existing conditions is generally greater than 40 percent in the United States. Couple this with the unknowns of future development and climate change and the uncertainty of the flood predictions increases.



NEWS

Charlotte, NC –
Receives 100-year flood
5 times in 30 years!

June 1982
$1M of damage from storm surge and rainfall

August 1995
Up to 9 inches of rainfall cause by Tropical Storm Jerry, exceeding the 100-year flood

July 1997
Up to 13 inches of rainfall from the remnants of Hurricane Danny, exceeding the 100-year flood

August 2008
3-day deluge reaches up to 11 inches of rainfall, exceeding the 100-year flood

August 2011
Nearly seven inches of rain in less than four hours

Figure 3-26. Newspaper Headlines

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[72] Westerling, et al., 2006.

EXPECTATIONS OF SAFETY

FEMA's Top Two Goals

Goal 1: Reduce loss of life and property
Goal 2: Minimize suffering and disruption caused by disasters

Code of Ethics for Engineers

1. Hold paramount the safety, health, and welfare of the public

Planners, engineers, and designers deal with all types of uncertainty by applying a factor of safety to keep the public safe. This is illustrated by FEMA's top two goals of reducing loss of life and property and minimizing the suffering and disruption caused by disasters (see text box). In addition, the code of ethics for engineers is to hold paramount the safety, health, and welfare of the public.

If the United States is to become a resilient and sustainable Nation, then we need to encourage the construction of infrastructure that takes into account the same level of safety that is expected in all other aspects of engineering with a factor of safety applied to designs.

3.4.1 Ranges and Averages

Riverine and coastal hydrologic and hydraulic analyses and numerical flood modeling are fundamentally based on statistics. These statistical results are often reported as the median storm at a certain recurrence interval.

In addition, the USGS definition of the 1-percent-annual chance flood, upon which FEMA bases its FIRMs, is based on the average number of occurrences over a long period of time: *"the 1-percent flood has a 1 in 100 chance of being equaled or exceeded in any 1 year, and it has an* ***average*** *recurrence interval of 100 years, it often is referred to as the '100-year flood.'"*[73] However, the past 100 years proves that averages are not the norm, and "average" flooding can be exceeded many times, sometimes even within a single calendar year.

The use of the 1-percent-annual-chance flood as the design flood (with regard to building codes) has led to the existence of structures that are designed to withstand a median 1-percent- or perhaps 0.2-percent storm. However, the reality is that 50 percent of the time, the 1-percent-annual-chance flood will be higher than predicted and structures built to the minimum NFIP requirements will be damaged.

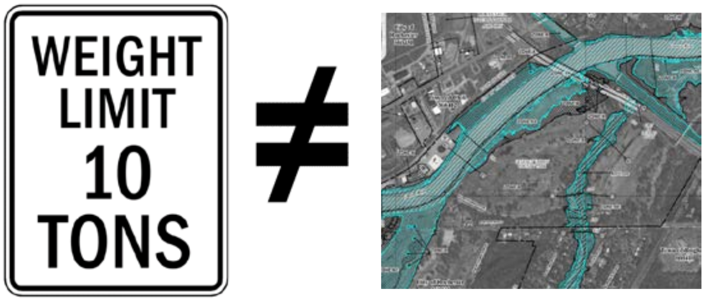

Figure 3-27: Public Expectations of Safety. When an engineer reports a number, the public expects that they will be safe if they follow the engineer's advice. This is not true if the owner wants to be safe from the 1-percent-annual-chance event.

Catastrophic damage from events that exceed the 1-percent-annual-chance flood will also occur and damage buildings and structures that were designed or protected to the NFIP minimum standard.

Defining flood risk based on a median storm confuses the public and policy makers (as well as many architects, engineers, and planners). Since the

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[73] USGS, 2010.

message that the FIRMs are intended to convey is confusing, efforts to communicate the risk and take actions to reduce risk are also affected.

The public trusts engineers to keep them safe in many ways, and when engineers provide information about our safety or risk, the public tends to rely on them. For example, if a driver sees a sign on a bridge that states the safe rating of the bridge is 10 tons, the driver expects to be able to drive a 10-ton truck over the bridge once, twice, or a thousand times without the bridge failing. As design professionals, we have conditioned the public to trust without exception the safety limits we set, whether it is the number of people that should be in an elevator, or the maximum weight limit of a bridge.

However, when it comes to flooding, it is more difficult to draw a line between an area that is floodprone and an area that is not. Flood elevations and floodplain boundaries on a FIRM are not based on absolute values, nor do they include an associated factor of safety. Instead, these numbers are the statistical medians developed using averages. While the insurance industry needs the statistical medians to generate flood insurance rate tables, these medians are not building design criteria.

Calculations of flood risk for planning and building/infrastructure design does not include any factor of safety. Factors of safety are applied in every other engineering field to take into account the uncertainty of the science and protect the safety of the public. Many people believe that if they build to an elevation that is reported on the FIRM or outside of an SFHA, they will be safe from flooding. This simply is not the case.

Figure 3-28 and Figure 3-29 show graphs of flood elevations statistical “median,” along with the with 5 percent and 95 percent confidence limits. As shown, the uncertainty of the numbers is large. For example, for the riverine flooding in the Ramapo River near Pompton Lakes, New Jersey, the 1-percent-annual-chance elevation could be 3.8 feet higher or 2.4 feet lower than the average shown. For the coastal flooding at the NOAA Battery, New York, Tidal Station, the 1-percent-annual chance flood elevation could be 1.6 feet higher or 2.3 feet lower than the average, depending upon the data source.

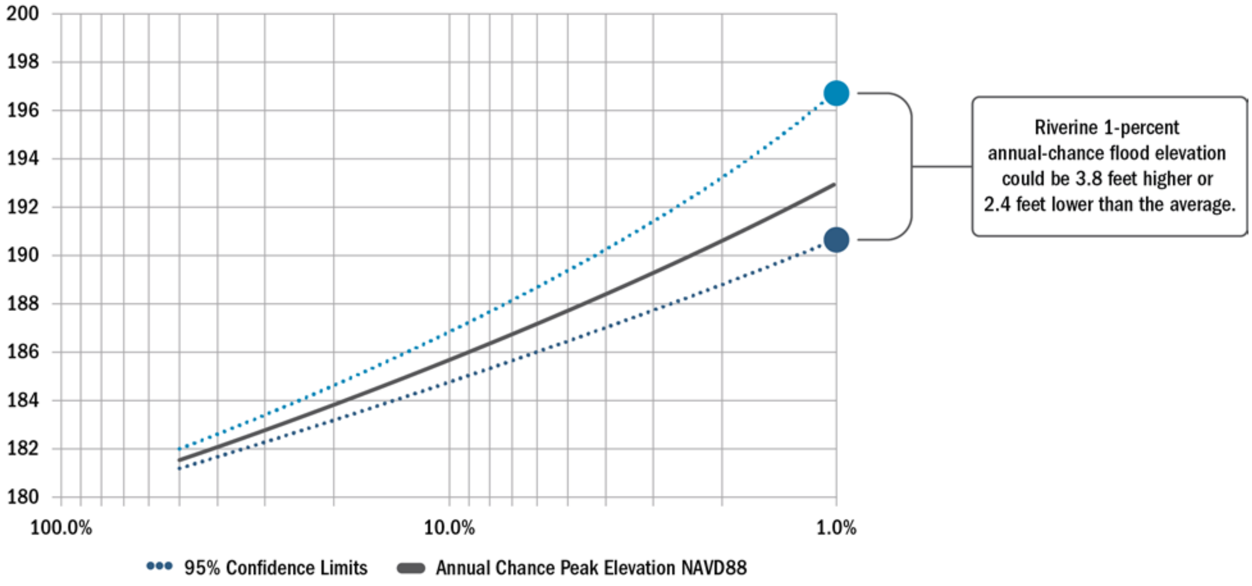


Figure 3-28: Confidence Limits for Ramapo River near Pompton Lakes, New Jersey

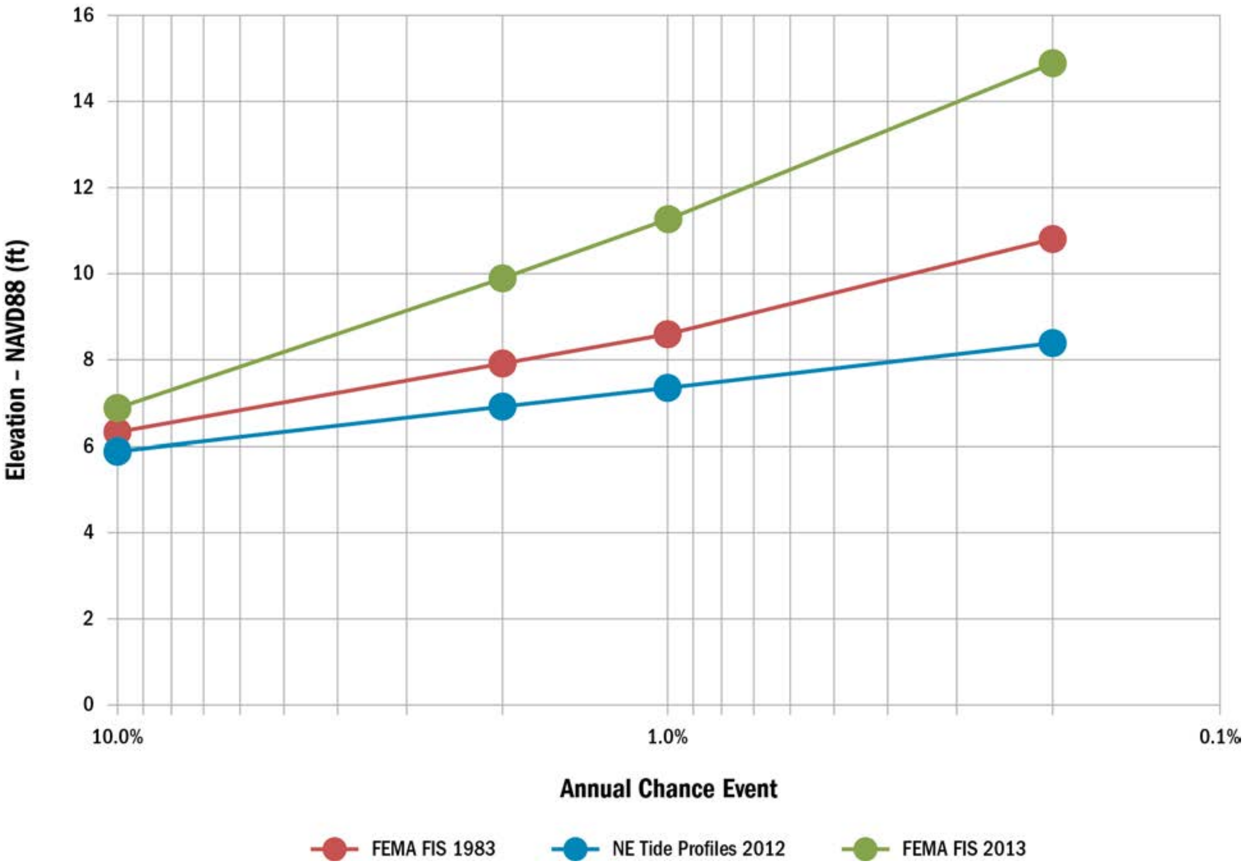


Figure 3-29: NOAA Battery, New York Tidal Station

3.4.2 Design versus Insurance

A design standard is typically an agreed-upon method that will result in a safe condition for the user if that particular situation is encountered. For example, if a structure were to be designed to withstand the 1-percent-annual-chance flood, the design elevation would take into account the uncertainties of the flood prediction in the design. The 1-percent-annual-chance flood elevation shown on the FIRM is more of an average or median elevation with almost no factor of safety. The problem with this approach is that the public and some designers use the BFEs on the FIRM as design elevations when, in reality, they are average or median elevations with no factor of safety.

To illustrate the impact of the flood elevation on design criteria, Figure 3-30 shows that the 1-percent-annual-chance flood elevation of 193.0 feet is equivalent to the 2-percent-annual-chance flood elevation (50-year flood) at the 95 percent confidence limit.

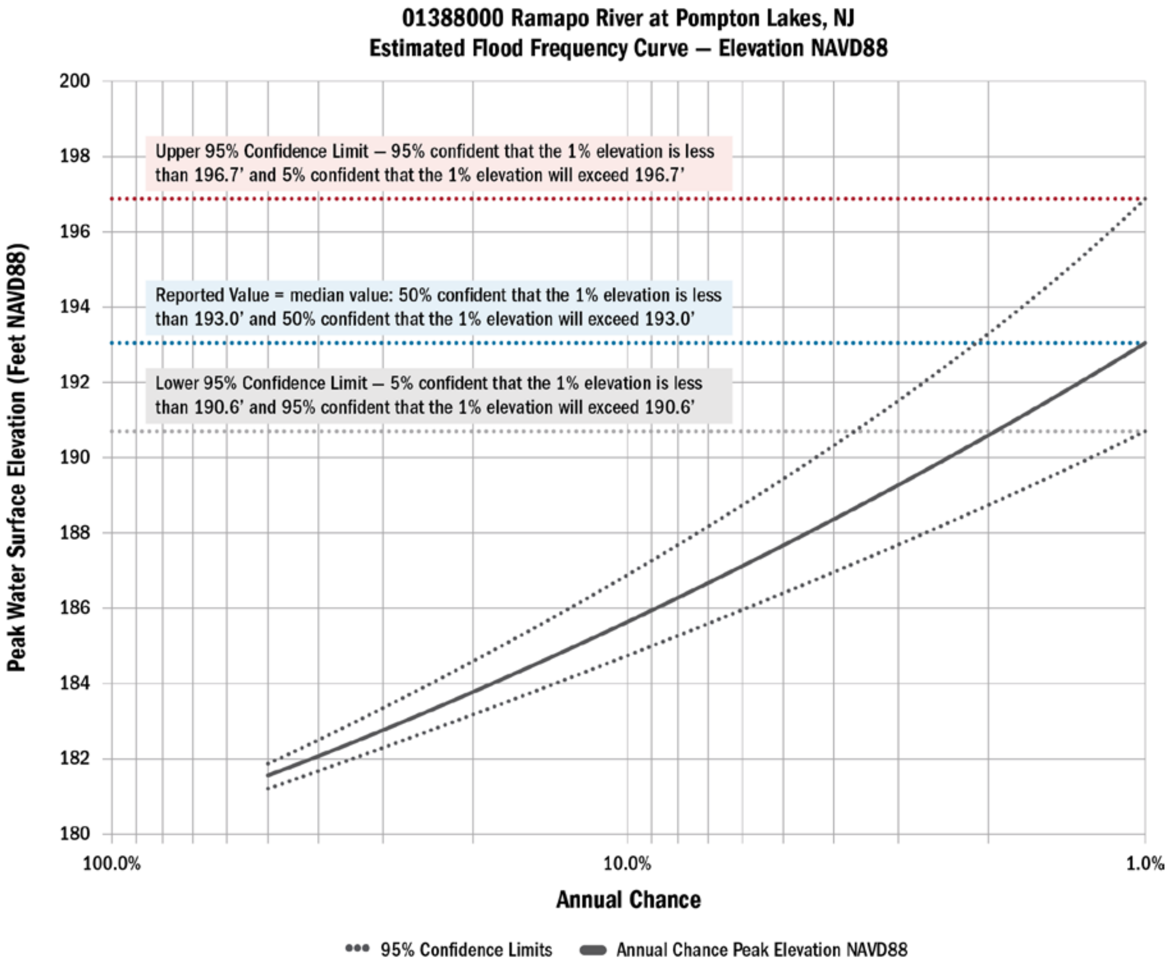


Figure 3-30. Base Flood and Confidence Limits

3.4.3 Additional Design Considerations

The calculations underlying the flood hazard information shown on existing FIRMs have three basic assumptions. These are:

1. All protective flood structures will operate correctly and will never fail.
2. No debris or ice jams will impact flood elevations.
3. Only existing land use can be considered.

Figure 3-31: Failed Levee

The Nation has experienced floods resulting from structures that do fail, such as dams, levees, and floodwalls (see Figure 3-31). These structures are not 100 percent reliable and this residual risk should be taken into account in design considerations for buildings and infrastructure.

Figure 3-32: Debris on a Bridge

Debris has a major impact on flood elevations (see Figure 3-32). Major riverine floods generate large amounts of debris that clogs bridges and culverts and increases flooding. This effect should also be considered in design criteria.

Future land use development also needs to be considered (see Figure 3-33). Many communities have zoning maps that identify future areas of development and its density. Where available, this information can be used to determine where the watershed may be hardened, which will result in flooding that is potentially more frequent, deeper, and with less warning time.

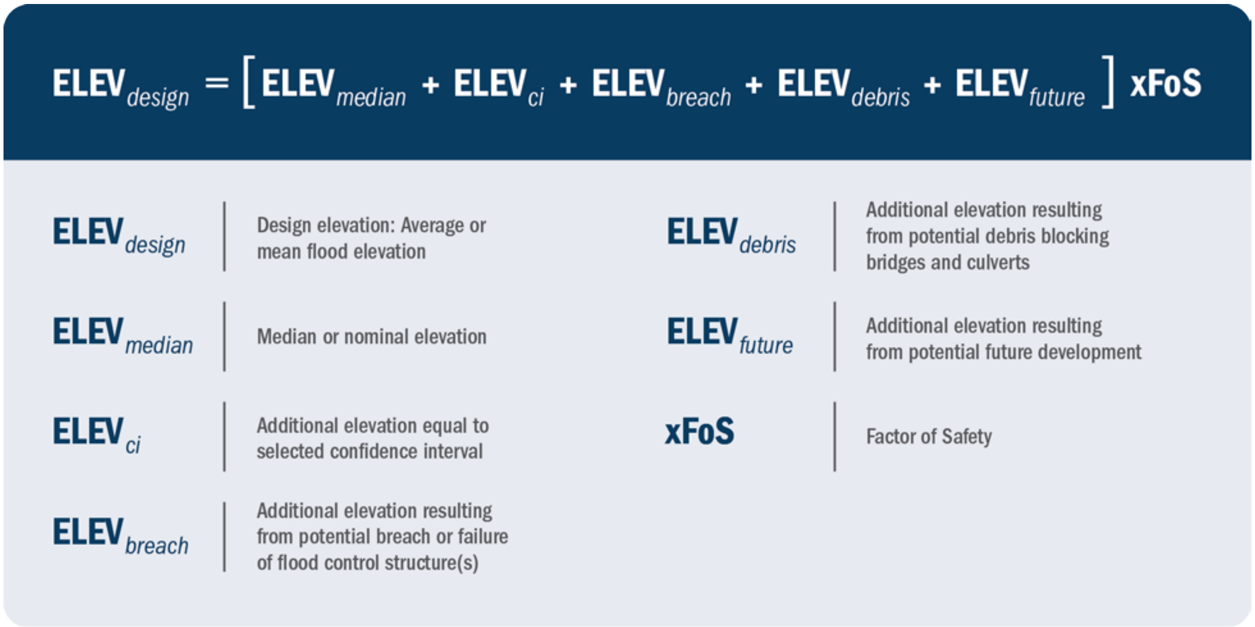
Figure 3-33: Massive Land Development

Many local stormwater regulations limit the post-development discharge condition to the pre-development condition, but only for frequent flood events. These structures have almost no impact on the 1-percent-annual-chance flood event.

Planned flood control infrastructure designed to mitigate larger floods should not be accounted for in future conditions mapping for several reasons. The main reason is that many large projects are studied for years, but are never actually constructed for multiple reasons.

3.4.4 Establishment of a Future Conditions Design Elevation Criteria

The public needs to have a design elevation that is similar to every other number an engineer provides to the public. The design elevation should include the unknowns and uncertainties to keep the individual safe during times when the design storm is encountered. Figure 3-34 shows the elements that should be incorporated into a future design elevation.



$$ELEV_{design} = \left[ELEV_{median} + ELEV_{ci} + ELEV_{breach} + ELEV_{debris} + ELEV_{future}\right] xFoS$$

$ELEV_{design}$	Design elevation: Average or mean flood elevation
$ELEV_{median}$	Median or nominal elevation
$ELEV_{ci}$	Additional elevation equal to selected confidence interval
$ELEV_{breach}$	Additional elevation resulting from potential breach or failure of flood control structure(s)
$ELEV_{debris}$	Additional elevation resulting from potential debris blocking bridges and culverts
$ELEV_{future}$	Additional elevation resulting from potential future development
xFoS	Factor of Safety

Figure 3-34: Design Elevation Equation.

Sub-Recommendation 3-7. FEMA should publish multiple future conditions flood elevation layers that incorporate uncertainty so as to provide a basis for building designs that lower flood risk.

4 Information Needed to Incorporate Future Conditions

Significant changes in weather patterns are now the new normal; the frequency, severity, and intensity of the full range of calamities are resulting in unprecedented destruction, misery, and loss of life, and disasters are becoming more interrelated. For instance, severe drought can lead to widespread wildfires, and the burn scars are then at increased risk of flooding and landslides. Severe rainfall is increasing (seeFigure 4-1) and can also involve tornadoes and lightning, in addition to flooding. Calls to build back stronger, increase resiliency, and reduce risk are often heard. Flood mitigation and floodplain management efforts are aimed at reducing loss of life and reducing annualized losses.

The number of organizations working on natural hazard mitigation, climate adaptation, and resilience has mushroomed in recent years.[74] Climate adaptation is an emerging field that closely resembles the work of natural hazard mitigation.

One significant difference is the perspective. While flood hazard mitigation relies on information from the past years of record, climate adaptation looks into the future.

This section explores these issues, and includes recommendations for FEMA's consideration regarding the information and data needed in order to better identify and map future flood risk.

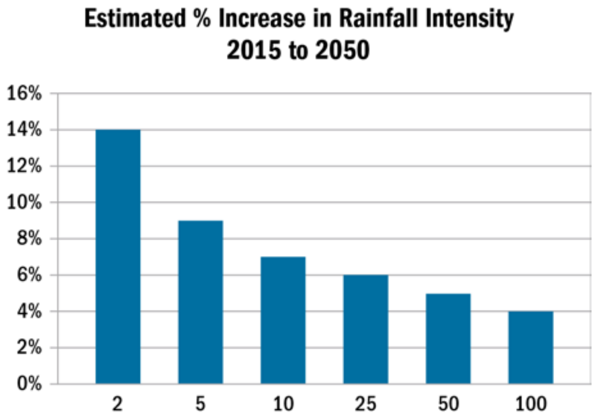


Figure 4-1: Percent Increase in Rainfall Intensity versus Return Interval

4.1 Topographic Data Needs

The accuracy of the NFIP flood hazard maps, as well as the accuracy of all underlying core datasets, like topographic or bathymetric Light Detection and Ranging (LiDAR), Digital Elevation Models (DEMs), and hydrologic and hydraulic models, is of paramount importance to all stakeholders who use maps for insurance, floodplain management, emergency management, hazard mitigation, and other uses.

One way to evaluate the accuracy of measurements and maps is to compare new or existing information to a known reference system, such as the National Spatial Reference System (NSRS). The NSRS is the most up-to-date version of positional truth available in the United States, so data referenced to the NSRS inherently gain the built-in accuracy of that system. For this reason, LiDAR data collection must include tying to the NSRS as part of the quality assurance and quality control procedures.

FEMA is heavily invested in the USGS-led 3D Elevation Program (3DEP) program. FEMA should continue to assure that topographic and bathymetric LiDAR acquisition is consistent with 3DEP and Interagency Working Group on Ocean and Coastal Mapping standards and that all geospatial data for the flood mapping program is referenced to current national datums and the NSRS.

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[74] Watson, 2015.

4.1.1 Riverine Topographic & Bathymetric Needs

There are several aspects of current flood data collection and mapping processes that need improvement:

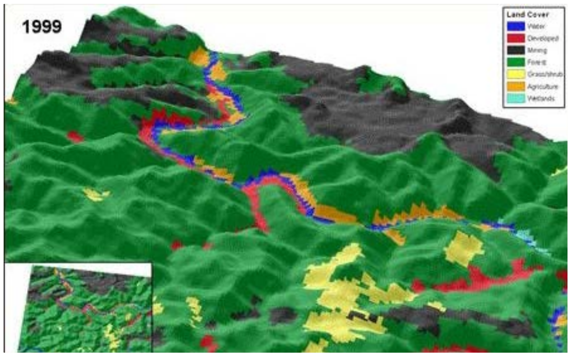

Figure 4-2: Topographic Change

- Structure footprints should be a standard derivative of raw LiDAR data. Accurate footprints on the same geospatial platform as the DEM will eliminate a source of incorrect flood risk determination.
- Ground LiDAR should be used to supplement aerial LiDAR collection for stream channel areas. Current aerial LiDAR does an inadequate job in confined areas and considerable extra effort is needed to correct hydraulic models, which also introduces a risk of error.
- Bathymetric information is important for hydraulic analysis of perennial streams. If the underwater topography is unknown, an informed estimate is often applied, introducing another source of error.
- The raw data or point cloud data should be protected in order to reprocess the data for future requirements.

4.1.2 Refresh requirements

Topographic and bathymetric data should be regularly refreshed due to land cover changes. The rate of land cover change will determine the refresh rate.

4.1.3 Hydrography and Watershed Boundaries Datasets

The USGS National Hydrography Dataset (NHD) and Watershed Boundary Dataset (WBD) are used to portray surface water on The National Map. The NHD represents the drainage network with features like rivers, streams, canals, lakes, ponds, coastline, dams, and stream gages. The WBD represents drainage basins as enclosed areas in eight different size categories.

Future conditions floodplain mapping could leverage these datasets in order to maintain consistency across Federal initiatives and watershed studies.

4.2 Coastal Bathymetric Data Needs

Bathymetric data describes the elevation of the land under water. These data are used by FEMA in the development of stillwater elevations and BFEs for the NFIP. Bathymetric data are used in large-scale, regional storm surge modeling and also in more localized wave setup and runup modeling. This section discusses the availability and currency of bathymetric data as context for a discussion of adjustments to those data to represent future conditions. In coastal areas where relative sea levels are rising, today's topography may become tomorrow's bathymetry so, lastly, this section includes a discussion of future conditions shorelines.

4.2.1 Data Availability

Coastal bathymetric data are not collected as frequently or to the same standards that topographic data are. Other than in ports, shipping lanes, and other areas where there is an economic interest, bathymetric data are typically sparse and can be very outdated, and future conditions bathymetry are practically non-existent.

Bathymetric data collection is improving and likely to continue doing so. Improvements in LiDAR and other topographic data collection technologies allow for the collection of bathymetry in nearshore areas when water conditions are ideal. As this technology continues to advance, bathymetric data are likely to improve in quality and availability. Therefore, guidance for use of bathymetric data in determining future conditions flood hazards should acknowledge the evolution of technologies that will allow for better bathymetric data available more widely in the future.

4.2.2 Adjustments to Approximate Future Conditions

In some cases, it may be necessary to make adjustments to bathymetric data when estimating future conditions flood hazards; however, any adjustments should be made with caution and are likely to introduce significant uncertainty into the estimates. For the most part, open ocean (deep water) bathymetry, such as that typically incorporated into FEMA's regional storm surge modeling, is not likely to change so substantially that it will have significant impacts on storm surge estimates overland. Therefore, it is not unreasonable to use existing open ocean (deep water) bathymetric data as-is when estimating future storm surge hazards. Nearshore bathymetry is likely to change over time and the impacts of bathymetry on coastal flood hazards are increased in shallower water.

Therefore, it may be reasonable to make some adjustments to bathymetric data in the nearshore to account for future conditions that are likely to occur; however, doing so increases the uncertainty of the results. Alternatively, it may be useful to have the ability to evaluate proposed future projects, such as widening and deepening of dredged inlets and shipping channels, thereby identifying their impacts on flood hazards in a fashion similar to the Conditional Letter of Map Revision process. This process would establish a "base" future conditions model that incorporates existing, non-adjusted bathymetry (and topography for that matter), and could facilitate the development of different project scenarios.

4.2.3 Future Conditions Shoreline

The discussion of a future conditions shoreline is germane to several different subsections within this section of the report. The location of the shoreline is related to the topographic and bathymetric data, as well as the shoreline erosion rate data. This discussion is intended to complement these other sections and provide some background on the importance of selecting an appropriate shoreline or shorelines when estimating future conditions.

Human response to rising sea levels likely will have a significant impact on future coastal flood hazards. Local shoreline decisions or policies to maintain the current shoreline location through beach nourishment and/or shoreline hardening, for example, versus a managed retreat from the most highly-erodible areas will have major impacts on the extent of the future conditions floodplain. Figure 4-3[75] provides a good

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[75] Adapted from AECOM, 2013.

discussion of why this is the case. In addition to open coasts, there are extensive bay, estuary, and other lower-wave-energy shoreline miles that will also be impacted by rising sea levels. It may be anticipated that communities will increasingly turn to hardening of their shorelines as sea levels continue to rise, but evaluating the likelihood of when and where this hardening may occur is difficult. Unfortunately, predicting human response to future climate impacts is highly uncertain and likely to vary significantly from one location to another.

Given that local shoreline policies will have a large impact on future flooding and that predicting these policies may introduce significant uncertainty, it is recommended that a scenario approach be taken when considering shoreline location for the estimation of future conditions flood hazards. At least two scenarios should be evaluated: one where the shoreline is held at its present location, and another in which the shoreline is eroded according to the best available shoreline erosion data. Additional scenarios based on an understanding of local conditions could also be incorporated. This approach will enable communities to evaluate impacts and make informed shoreline decisions and policies.

Sub-Recommendation 4-1: FEMA should use a scenario approach when considering shoreline location for the estimation of future conditions flood hazards. At least two scenarios should be evaluated: one in which the shoreline is held at its present location, and another in which the shoreline is eroded according to the best available shoreline erosion data.

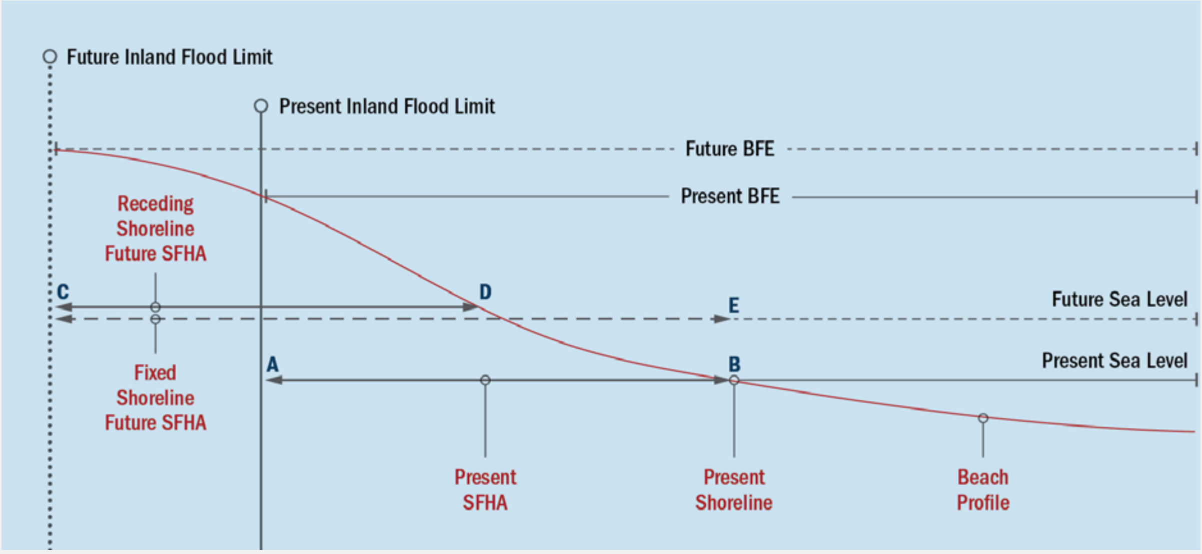
Receding vs. Stabilized Shorelines

Rising sea level and changes in storm intensity and frequency will cause the inland limit of coastal flooding to move landward over time. On a simple beach slope, the action of sea level rise would also cause the SFHA to migrate landward without much change of size, as long as the shoreline was allowed to move freely in a corresponding way. This receding shoreline assumption was adopted in the 1991 FEMA Sea level Rise Study.

It must be expected, however, that many communities will take steps to hold their shorelines in place through stabilization measures of various sorts. In such cases, the SFHA must grow since the inland limit moves landward while the seaward limit does not. Consequently, the area with exposure to the 1-percent-annual-chance flooding would grow, representing enhanced chronic risk to the NFIP.

No attempt has been made in this study to predict how individual communities might respond over time; some will allow shoreline regression, while others will take steps to stabilize and hold their existing shorelines. It is worth noting, however, that as a general trend, densely developed, urban areas could represent the stabilization case, while rural coastal communities could represent the recession case. The financial implications of these two limiting cases are evaluated elsewhere. These alternate assumptions are discussed and illustrated in more detail below.

The following sketch illustrates the concepts discussed above. Note that the sketch is idealized and not to scale, perhaps spanning 10 or 20 feet vertically, but spanning thousands of feet horizontally. Possible changes to the beach profile caused by erosion or stabilization are not shown.



The lowest horizontal line represents present sea level, while the dashed line immediately above it represents future sea level. The upper two horizontal lines show present and future BFEs extending landward to the present and future inland flood limits. Point B is at the present shoreline, with the segment AB representing the present SFHA. Point D is a possible future position of the shoreline after landward migration caused by submergence and erosion; the segment CD represents the future SFHA for that receding shoreline case. Point E represents the future location of the shoreline if held near its present position at B. In this case, the future SFHA extends from C to E exceeding the receding shoreline case CD. The sketch does not show the future beach profile, which could be stabilized (fixed) by seawalls, levees, beach fill, etc.

Since SFHA CE is larger than SFHA CD, it follows that there would be greater chronic exposure to flood losses in the fixed-shoreline case than in the migrating case, unless the fixed-shoreline case were exceptional, such as the Galveston Seawall or the Miami Beach nourishment. The encroachment area between D and E would be on an area of transient losses as storms and sea level rise caused the shoreline to retreat from Point B to Point D; the costs of those transient losses are estimated separately.

Discussion by David Divoky and Robert Dean

Figure 4-3. Receding versus Stabilized Shorelines.

4.3 Water Data

FEMA’s process for flood hazard identification requires estimating the potential magnitude and frequency of major flooding.

- For coastal communities, flood frequency is determined from analysis of annual flood peak water-level data acquired at tide gauges or synthesized water levels generated from application of advanced hydrodynamic models driven by tide, storm-track, and wind records.
- For riverine communities, flood frequency is determined from direct analysis of observed annual flood peak flows, or analysis of flood flows synthesized from the application of observed rainfall records or rainfall-depth-duration-frequency estimates to hydrologic and hydraulic models.

Understanding and mapping future flood risk conditions will require more abundant sources and innovative uses of these hydrologic data.

4.3.1 Tide Gauges

The NOAA National Water Level Observation Network (NWLON) provides the foundation of a comprehensive system for observing, communicating, and assessing the impact of changing ocean and Great Lakes water levels nationwide, including U.S. territories. The network consists of 210 long-term, continuously-operating water level stations (tide/water level gauges) and is considered the primary source for commercial sector navigation, recreation, and coastal ecosystem management. The NWLON also provides the national standards for tide and water level reference datums used for nautical charting, coastal engineering, international treaty regulation, and boundary determination.

Originally established to support safe navigation through tide predictions and nautical charts, the gauge network now contributes to NOAA’s forecast models, which provide tsunami and storm surge warnings. The NWLON provides historical, as well as present-day water level information. For example, the long-term records from the NWLON are used to compute local relative sea level trends and to understand the patterns of high tide events and extreme water levels from storm events. Sea level trend information is used to develop local relative sea level trends and future sea level projections.

Historical data from NOAA tide gauges are used to verify storm surge modeling for FEMA’s coastal FISs and for developing flood-frequency estimates. This is the preferred approach for communities that have data of adequate length and aerial coverage. However, many communities lack the tide gauge data needed for either direct water-level analysis or model verification.

The USGS has pioneered the development of new, mobile storm-tide networks that can supplement traditional tide gauge networks. These mobile networks consist of a few hundred small, self-contained water-level sensors that can be temporarily deployed to an expected hurricane landfall location in the days and hours just prior to the landfall. When coupled with wind and storm-observations, the resulting storm-tide data can be used to calibrate a storm surge model that can subsequently be used to model future storm-driven flooding.

4.3.2 Rainfall Gages

Rain gages provide essential precipitation data needed for the development of flood hazard maps for some communities. In the absence of stream gage-derived flood-flow records, rainfall can be fed into rainfall-runoff models to generate a series of synthetic flood peaks that are then subjected to frequency analysis.

Alternatively, rainfall depth-duration-frequency curves based on rain gage data are commonly used as the basis of a design storm for a unit hydrograph rainfall-runoff model. However, long records of many decades are needed to acquire observations of the storms that produce the large floods needed to model the 1-percent-annual-chance flood and create the flood hazard map.

4.3.3 Stream Gages

The USGS stream gage network is the primary source of observed peak-flow data. Using data from 8,400 currently operational stream gages and about 15,000 stream gages that it once operated, the USGS has compiled the National "Peak Flow File." This file lists the dates and magnitudes of approximately 750,000 observed annual peak flows at more than 24,000 "gaged" locations for dates extending back, for some sites, to the mid-1800s. For most sites the data are limited to only a few decades in the 20th Century. However, the quality and reliability of a flood-frequency estimate depends on the length of the record; the precision, accuracy, and representativeness of the observations; and the suitability of the analytical tools to the hydrologic conditions prevailing in the community. Despite the size of the USGS peak-flow file, observed flood data—particularly data representing long periods of record—are sparse, hindering the detection and analysis of the changes in the flood hazard that results from urbanization and climate change. Expansion of the dataset by continuing to collect flood data at current stream gages and supplementing these observations with flood measurements at historic, discontinued stream gages, and miscellaneous locations is needed to provide the data required to manage and map future flood risks.

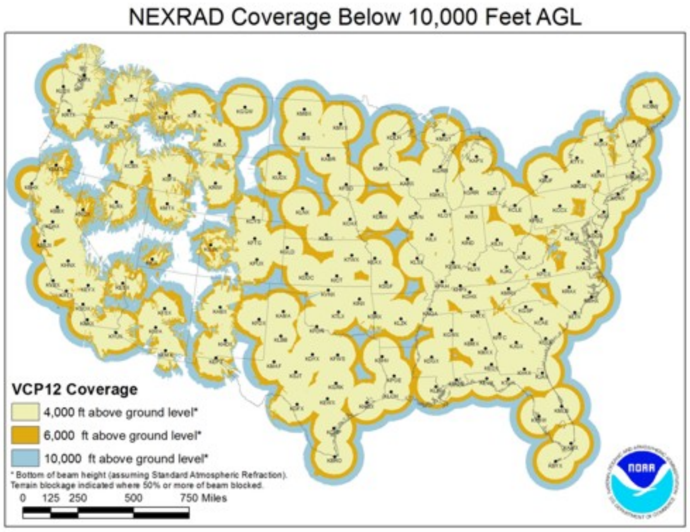


Figure 4-4: Doppler Radar Coverage of the United States.[76]

4.3.4 Doppler Radar

Doppler radar is a tracking system that can determine the location and velocity of storm clouds and precipitation. Doppler radar is calibrated with rainfall gaging stations to predict the distribution of rainfall over a continuous area. Nexrad is an implementation of Doppler radar that stands for Next Generation Radar. The use of Nexrad can help with understanding of storm rainfall and be used to develop better rainfall runoff models.

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[76] NOAA, 2015c.

Sub-Recommendation 4-2: FEMA should support expanded research and encourage innovation for water data collection, for example using Doppler radar.

4.3.5 Estimating Future Conditions Riverine Hydrology and Hydraulics

Aspects of land cover, such as the extent of impervious surface and vegetation type, and land use, such as residential or open space, impact both the amount of water and the speed of that water entering the system (hydrology), as well as how that water moves through the system (hydraulics). As open space is converted to developed areas, impervious surface generally increases, which decreases infiltration and leads to more runoff during rain events. In addition, the runoff occurs more quickly. The presence of storm sewers further increases these impacts as runoff is more quickly collected and conveyed.

The impacts to hydraulics are not as easy to generalize, but as land converts from undeveloped to developed, watercourses are often relocated, and culverts and bridges are added. In some cases, detention basins or other flood control works are implemented. As land cover and land use change in the future, it is expected that flood hazards will also change.

There is precedent within the NFIP for evaluating potential future land cover and its impact on hydrology. In 2001, FEMA issued regulations recommending that local communities determine their future conditions land use and use that information to determine future condition hydrology. It was acknowledged that land use is an inherently local issue and, therefore, the most reasonable assumptions on where and how development would occur would be made locally.

Since then, guidance has been developed and implemented by FEMA, Denver Urban Drainage and Flood Control District (UDFCD), and Mecklenburg County (Charlotte), North Carolina, for using local zoning and land use planning to identify where and how development would occur and revising hydrologic predictions based on this expected future development condition. It is recommended that this guidance be reviewed and considered a best practice by FEMA for implementing similar efforts nationwide. It is also important to note that experience in the communities previously noted has indicated that land use projections tend to under-predict the actual changes over time.

In terms of hydraulics, there is no precedent for considering the impacts of future land use. Since there is no precedence, there is also no existing guidance available for doing so within the NFIP. Community land use planning provides a reasonable set of assumptions for where development is likely to occur, but there is no corresponding uniform dataset that can be used to accurately identify when and where individual projects are likely to occur that would impact the hydraulics of watercourses. Estimating where these projects are likely to occur would introduce significant uncertainties in flood predictions.

This shortcoming was noted by FEMA when developing the aforementioned regulations and guidance. Therefore, it is recommended that a scenario approach be used to evaluate the impacts of future flood control projects on future flood predictions. In addition to reducing uncertainty, this will allow users of the data to run scenarios in which proposed projects are incorporated to evaluate the effects of proposed projects on future hazards.

Sub-Recommendation 4-3: FEMA should use a scenario approach to evaluate the impacts of future flood control projects on future conditions flood hazards.

4.3.6 Estimating Future Conditions Coastal Analyses

Coastal flood hazard analyses differ significantly from riverine flood hazard analyses. Coastal flooding is not typically the result of rainfall runoff and does not typically follow well-defined water courses. Thus, the hydrology and hydraulic considerations discussed in the preceding section do not apply to coastal flood hazard identification. However, land use and development can impact coastal flooding.

It may not be necessary to consider future conditions land use when determining future coastal storm surge elevations, including wave setup, because these analyses are typically performed at a large scale or are evaluated at gauges and incremental changes in land use over time are unlikely to impact the results significantly.

Local coastal hazards, such as erosion, wave runup, and overtopping, and the overland propagation of waves are impacted by land use, sometimes significantly. These analyses are typically performed using 1D transect models that account for detailed characteristics of the land, such as vegetation, dunes, houses, and other structures. As these characteristics change over time, so will the hazards at the site. It is likely possible to utilize local zoning and land use planning to identify where and how land use will change in the future and incorporate that information into the local coastal hazard modeling process, but there is no precedence or any guidance for doing so within the NFIP.

4.3.7 Community Land Use Plans

There is no national requirement that communities develop comprehensive land use plans. Some States do mandate long-range planning; however, this is not uniform across the Nation. Many communities also develop a comprehensive land use plan because it guides the land entitlement process, provides community focus and branding, and supports subdivision and zoning regulations. The planning process usually includes stakeholder and citizen collaboration in order to understand the community vision and support neighborhood vitality.

Land use changes land cover over time, which in turn changes the nature of the watershed. Thus, flood risk changes over time. In order to adapt to future flood hazards, communities must look forward to predict and respond to changes in hazards. Many communities are engaged in watershed planning studies and hazard mitigation efforts.

Most NFIP communities have hazard mitigation plans as a pre-condition for FEMA grants. Each State and FEMA regional office has planning specialists to assist communities with plan creation and updating. Hazard mitigation plans can also be cross-referenced with CRS requirements for additional CRS points.

4.3.8 Plan Integration

One shortcoming of comprehensive land use plans is the exclusion of hazard and risk identification. Land use planning should include hazard mitigation planning, watershed master planning, and risk analysis (see Section 4.8). FEMA should provide guidance and incentivize the integration of local planning efforts.

Sub-Recommendation 4-4: FEMA should develop guidance for how local zoning and land use planning can be used to identify where and how land use will change in the future, and incorporate that into local hazard and risk modeling.

Sub-Recommendation 4-5: FEMA should support research on future conditions land use effects on future conditions hydrology and hydraulics.

Sub-Recommendation 4-6: FEMA should develop guidance for incorporating future conditions into coastal inundation and wave analyses.

Sub-Recommendation 4-7: FEMA should evaluate previously-issued guidance for future conditions land use and hydrology to incorporate best practices and lessons learned from communities that have implemented the guidance since 2001.

4.4 Shoreline Erosion Data Needs

Shoreline erosion data needs are mostly dependent on determining the long-term erosion rate.

4.4.1 Determination of long-term erosion rate

Many States establish coastal setback lines or erosion hazard areas (EHA) to use for State-based regulatory or non-regulatory purposes. The EHAs are normally based on an erosion rate determined by analyzing the positions of two or more known historical and recent shorelines (known as shoreline change reference features [SCRFs]) that are plotted on historical shoreline change maps. These maps are produced by digitizing SCRFs from various sources, such as historical maps (especially National Ocean Service T-sheets, which in some locations date back to the mid-1800s), aerial photographs, Global Positioning Systems, and LiDAR. This process is followed by combining and overlaying shorelines onto a common coordinate system. Most regional studies for low-relief, sandy beaches use the high water line as the SCRF, although the berm crest, vegetation line, or erosion scarp is sometimes used. In coastal regions characterized by high topographic relief, the top edge of bluffs or cliffs is commonly used as a reference point.[77]

Historical shoreline change maps for the United States often contain four to eight or more digitally-plotted shorelines and can span up to 150 or more years. Erosion rates are typically calculated from the digital maps by digitizing or plotting a line approximately perpendicular to the multiple shorelines and measuring the amount of movement over a period of time, which is defined and constrained by the dates of the digital shorelines. In many cases, subsets of the historical shorelines are used, particularly in areas where prolonged and perhaps permanent physical changes to the beach system have occurred (e.g., inlet openings), or where construction of man-made structures (e.g., groins, jetties, sea walls) makes older data unrepresentative of the long-term trend.[78] Various empirically-based statistical methods have been used to calculate long-term erosion rates, but because of the scarcity and uneven sampling of historical and recent shorelines, it is questionable whether higher-order statistical methods are better at predicting future shoreline positions than “simple” methods, such as linear regression.[79]

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[77] Crowell, Honeycutt, and Hatheway, 1999.

[78] Crowell, Leatherman, and Douglas, 2005.

[79] Crowell, Douglas, and Leatherman, 1997.

Once a historical erosion rate is determined for a particular area, this rate is then multiplied by a timespan (e.g., 30- , 60-, or 100-years) to define an EHA. The inland extents of EHAs are measured landward from an erosion reference feature (ERF), such as a vegetation line, dune line, or top edge of bluff. Note that regional geomorphologies determine both the SCRF and ERF, and for any given stretch of shoreline, the SCRF and ERF may not necessarily be the same feature.

The above-described empirical method for determining long-term erosion rates and future shoreline locations typically assumes stationarity; that is, the predicted rate of shoreline change is assumed to be linear and equal to the historical linear rate of shoreline change. As such, the method does not consider potential acceleration or deceleration caused by geophysical processes, such as changes in the rate of relative sea level rise. Long-term sea level rise, however, is an "enabler" of long-term coastal erosion; thus, both processes are linked geophysically. As sea levels rise, land is inundated by the rising waters and higher water levels allow increasing erosion. As such, the location of a receding shoreline is dependent on both SLR-induced inundation combined with dynamic erosion. If SLR is projected to accelerate, then long-term erosion rates should also be projected to accelerate.

One of the best known models to link SLR with erosion is the Bruun Rule. The Bruun Rule is a two-dimensional model that predicts a landward and upward displacement of the beach profile in response to sea level rise.[80] The Bruun rule, however, has long been controversial and while it may be suitable for regional scale assessments, it is generally recognized as unsuitable for localized studies which require reliable estimates of shoreline retreat.[81]

Recent studies have used other methods for predicting future shoreline locations. For example, one study[82] used a Bayesian Network to produce probabilistic forecasts of future shoreline locations assuming accelerated SLR. A more recent study[83] employed a combination of historical erosion rates with a Bruun-derivative model that incorporates projected acceleration in SLR.

Sub-Recommendation 4-8: FEMA should develop consistent methods and models for long-term coastal erosion hazard mapping.

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[80] Ranasinghe, et al., 2012.

[81] Ibid.

[82] Gutierrez, et al., 2011.

[83] Anderson, et al., 2015.

4.5 Riverine Erosion Data Needs

Riverine systems change over time, both laterally and vertically. Changes in river morphology over longer time periods can affect the potential flood risk at any specific location. A significant amount of research and practical experience has occurred in the field of geomorphology and stream restoration.[84]

An additional recognition of these natural processes is the Make Room for the River project.[85] Sufficient data and analytical tools currently exist to map riverine erosion and migration zones.

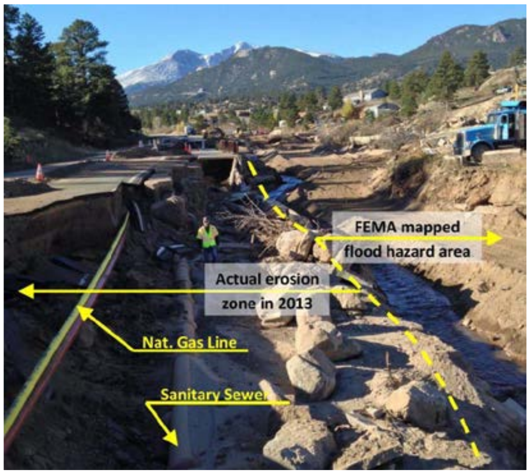

Figure 4-5: Fish Creek in Estes Park, Colorado

Riverine systems can also change in very short time periods as was seen in the Vermont during Hurricane Irene in 2011 and Colorado flooding in 2013 (seeFigure 4-5[86]). In both these events, considerable losses occurred outside of the SFHA. Hundreds of miles of State and Federal highways were destroyed and in Boulder Colorado, thousands of structures were lost resulting nearly $260 million in private property destruction. See Figure 4-6 for an assessment of EHZ and SFHAs, showing that EHZs are not confined to the SFHA.

Event-driven erosion is not as well understood and is not mapped in the context of flood hazard identification. The current FEMA policy of assuming clearwater and rigid boundary conditions for flood hazard mapping can significant under-identify flood hazards and, thus, convey a false sense of flood risk. This is especially true for mountainous terrain and alluvial fans as was seen in the Vermont and Colorado flooding. Massive debris flows contributed to the destruction in Boulder.

The States of Vermont and Washington have developed erosion zone mapping and regulatory frameworks[87] Planning-level channel migration zones (pCMZ) methodologies are currently underway in Colorado based on the Vermont and Washington work. These pCMZs are based on the space the river system requires for lateral adjustment. Regulatory standards typically take the form of required setbacks from the channel based on the pCMZ.

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[84] FEMA, 1999.

[85] Dutch Room for the River Programme, 2015.

[86] Image by Brian Varrella, City of Fort Collins, and Terry Martin, ICON Engineering, 2013.

[87] Vermont Agency of Natural Resources, 2008.

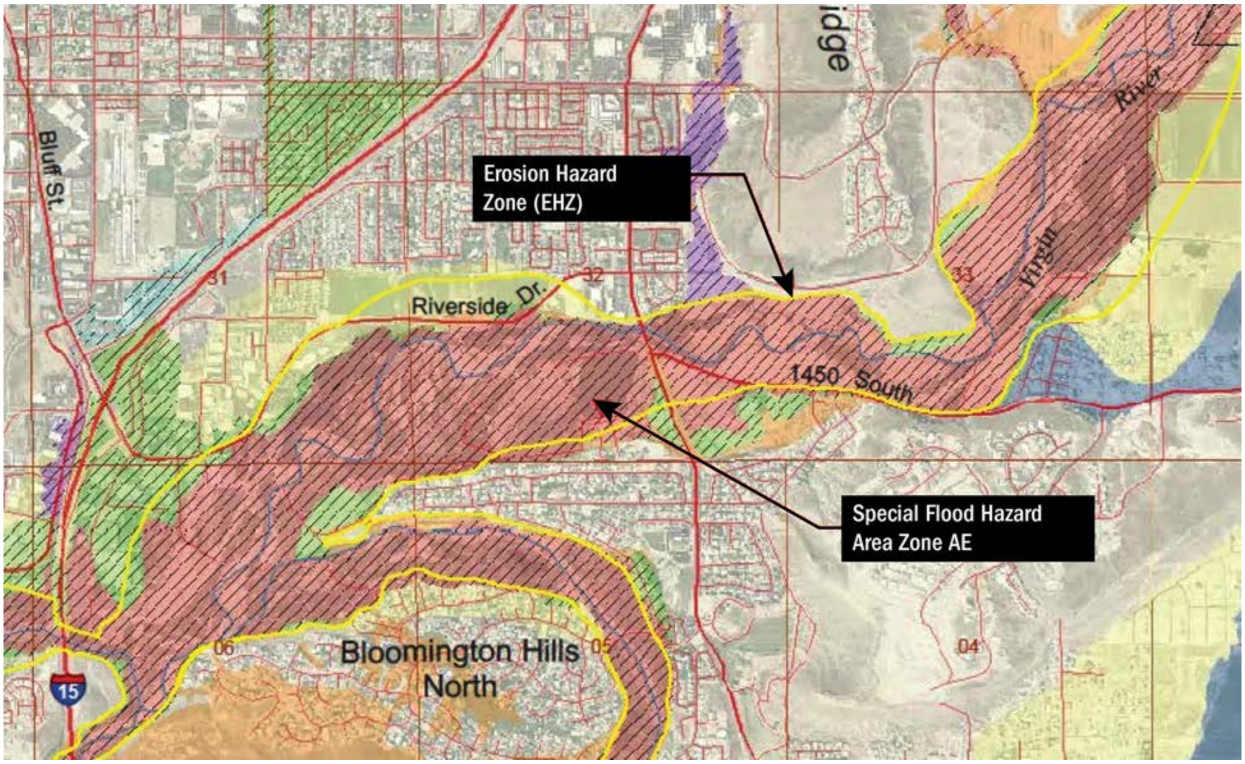

Figure 4-6: Portion of the Flood-Hazard Map for the St. George-Hurricane Metropolitan Area in Utah.[88] Notice the Erosion Hazard Zone is both inside and outside of the Special Flood Hazard Area.

The information needed to establish pCMZs includes topographic and bathymetric mapping (LiDAR), soil data, and aerial photography. Acquisition of historical photography is very useful in erosion zone and river meander evaluation, and so is aerial photography going forward. Historic and new, geo-referenced aerial photography housed in a database would the most useful tool for erosion hazard identification.

Alluvial fans are a subset of riverine erosion. Alluvial fan hazard identification is especially difficult because of the geology (groundwater and subsurface activity) and geomorphology (small channel formation that belies the risk). Erosion and avulsion activity is more pronounced in the context of alluvial fans. Alluvial fans also react more dramatically to anthropogenic changes. The recent advent of two-dimensional hydraulic modeling has proven to be very useful in improved hazard identification.[89] One downside of two-dimensional models is the regulatory context.[90] The current practice is to convert the two-dimensional model to a traditional one-dimensional model for flood hazard mapping and regulatory purposes. FEMA should develop guidance for the use of two-dimensional models for flood hazard mapping and floodplain development regulation purposes.

Sub-Recommendation 4-9: FEMA should determine long-term riverine erosion hazard areas for areas subject to high erosion and provided to the public in a digital layer.

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[88] Utah Geological Survey, 2008.
[89] Icon Engineering, Inc., 2014.
[90] ASFPM, 2014.

Sub-Recommendation 4-10: FEMA should utilize a national standard for riverine erosion zone delineations that reflects geographic variability.

Sub-Recommendation 4-11: FEMA should develop a policy and standards on how to consider and determine erosion zones that are outside of the SFHA as they ultimately affect flooding and environmental conditions within the SFHA.

4.6 Demographic Data Needs

The U.S. population is expected to grow by nearly 100 million from 2010 to 2050. Past experience suggests that population and population densities will be greatest in close proximity to coastal or riverine areas. Living near the water has always been and will continue to be desirable. Population management is not a FEMA directive; however, a framework for managing growth that is based on a clear and accurate description of current and future risk is necessary in order to get ahead of the curve.

4.6.1 Existing demographic data

The U.S. Constitution mandates a national census every 10 years. The Census Bureau conducts the national census once every decade. The national census is an enormous task involving scores of field workers, analysis, and reporting. However, this information may not be adequate to inform future conditions flood hazard analysis.

4.6.2 Projected demographic data

The decennial census may be too infrequent for flood hazard identification and floodplain management response. For this, real-time demographic data are required. Information will also be needed regarding how the built environment evolving, how we will safely accommodate the next 100 million Americans, what our neighborhoods will look like, how 21st century land use and zoning will differ from past practices, and how our transportation and transit systems will react to increasing flood risk. These and many other questions should be considered in the context of future flood risk.

Micro demographic trends and future projections are fundamental in deploying the Whole Community Approach to mitigation, preparation, response, and recovery. Understanding communities at the community level is also essential for getting better market penetration for flood insurance.

4.7 Consistency of Data

A large amount of data is required to evaluate both current and future flood hazards. The sections that follow provide details of many of them and this section is intended to provide a brief discussion related to the consistency of the data necessary to evaluate future conditions.

Required datasets for flood hazard analyses, for both current and future conditions, are typically collected from a variety of sources and range from global-, to national-, State-, and local-scales. In some cases, even property-specific data may be available. Given the wide variety of data and the lack of consistency, careful attention should be paid to selecting the best available, actionable data for analyses. In all cases, an understanding of the quality, resolution, coverage, time horizon, and other important metrics is needed to assess the end product and should be documented.

There is a tendency for national programs to rely on national datasets, but national datasets may not be the best available data for use when there are more local datasets available. With respect to climate data, there are global and national datasets available that provide insight into how the climate is expected to change in the future, but in many cases these datasets do not down-scale well and can lead to unrealistic estimates at a local level. For example, global SLR estimates do not provide a good estimate of relative sea level change in areas where local effects such as subsidence play a major role. When local-scale data have been developed that provide an improvement over similarly-available national datasets, the local data should be evaluated and utilized if possible and appropriate.

Maintaining consistency with respect to land use data may be more challenging. Section 4.3.7 highlights the importance of community-developed land use projections when determining future conditions. Unfortunately, community-developed datasets are likely to vary significantly from one community to another, unless standards for the development of these data are put in place. Even then, it would likely be decades before consistent data become available. However, local land use projections are an integral dataset for future conditions flood hazard analyses and should be used. Achieving consistency across community-supplied land use and zoning datasets is unlikely, but FEMA should strive to achieve consistency with respect to how those datasets are used to estimate future conditions flood hazards.

Another aspect of consistency to consider is with respect to the methods used to evaluate current and future hazards. Employing similar methods consistently will enable meaningful comparisons of results from one area to another and also between current and future conditions. There are also likely to be efficiencies gained by employing similar methods of analyses when estimating current and future flood hazards. Finally, using consistent methods will also help to drive consistency with existing products and usages. Therefore, when current projections of flood hazards already exist, such as NFIP flood hazard studies, future projections should rely on those current projections as a starting point for evaluating future hazards.

Sub-Recommendation 4-12: FEMA should develop guidance for evaluating locally-developed data from States and communities to determine if it is an improvement over similarly-available national datasets and could be used for future condition flood hazard analyses.

4.8 Risk Assessment

Risk assessment represents the "A" in Risk Mapping, Assessment, and Planning (Risk MAP). Assessment is part of the mitigation cycle of first identifying the hazard, then assessing the consequences, and then planning around the assessed risk.

An excellent example of Federal/regional partnership is the work FEMA Region VIII has done with the UDFCD. The regional staff commissioned a Risk MAP alignment study between UDFCD floodplain mapping and master planning products and the Risk MAP regulatory and non-regulatory outputs. The study concluded that the UDFCD products lacked only a risk assessment. Regional staff have worked closely with the local communities within the UDFCD service area, leveraging community-supplied parcel and structure data to achieve very detailed risk assessments.

4.8.1 Service Life Considerations of Structures

The decisions a community makes today will have long-term impacts in terms of the community's risk profile. New structures built in harm's way will be in harm's way for decades to come. See Section 3 for a deeper discussion of structure service life, including the life expectancy of various structure classes.

4.8.2 Flood Risk Assessment

Risk assessment is the product or process that collects information and assigns values to risks for the purpose of informing priorities, developing or comparing courses of action, and informing decision making.[91] Risk assessment is fundamental to hazard mitigation planning and long-term risk reduction.

Risk assessment that addresses future conditions will require the combination of community-developed land use and development projections and the hazard data needs described in this section.

To understand how risk may change and how vulnerability may increase or decrease, an analysis of how communities may look and grow in the future with the expected characteristics (i.e., frequency, intensity) of hazards in the future is required. Improvements in data and methods are needed in each.

The outputs of this risk analysis must be in terms that planners, policy makers, and citizens can use in making decisions about future investments, allocation of resources, and when and where to adopt stronger regulatory approaches. A primary goal is to build overall capacity at all levels of government to engage in useful risk assessments by:

- Designing outputs of models and assessments to have real application for planning and decision making; and
- Improving accessibility and usability of tools and software, such as Hazus, for end users and providing training and outreach to build skills.

4.8.3 FEMA's Hazus Program

FEMA's Hazus program is a nationally-applicable, standardized methodology that contains models for estimating potential losses from earthquakes, floods, and hurricanes. Hazus uses GIS technology to estimate physical, economic, and social impacts of disasters. It graphically illustrates the limits of identified high-risk locations due to earthquake, flood, and hurricane. Users can then visualize the spatial relationships between populations and other more permanently-fixed geographic assets or resources for the specific hazard being modeled, which is a crucial function in the pre-disaster planning process.

The input data for Hazus analysis ranges from very generalized to very detailed. Level 1 Hazus analysis uses national datasets for population, building stock, and hazards. Level 1 is considered too coarse at the community scale. Level 2 data can include effective floodplains and other local hazard conditions, as well as community-supplied building, facilities, and infrastructure data. Community-supplied building datasets currently come in all forms. FEMA can assist communities by developing standardized protocols for organizing and serving up the data.

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[91] FEMA, 2013.

Hazus output should be in a format that is useful to community planners, emergency managers, floodplain managers, and policy makers. FEMA should focus on improving the utility of Hazus for local users to build greater capacity in risk assessment. A key focus should be an update to the flood module to analyze future development, mitigation, and climate adaptation scenarios. Risk assessment information can be used by communities to consider the consequences of land use decisions, planned infrastructure investment, and resiliency. The goal is to encourage safe development that reduces a community's overall risk profile.

The Hazus community of users includes all levels of government and the private sector. FEMA supports a variety of user forums and a national conference. FEMA should support more training and outreach in order to enlarge both the size and skill of Hazus practitioners.

Sub-Recommendation 4-13: FEMA should develop better flood risk assessment tools to evaluate future risk, both population-driven and climate-driven. Improve integration of hazard and loss estimation models (such as Hazus) with land use planning software designed to analyze and visualize development alternatives, scenarios, and potential impacts to increase use in local land use planning.

5 Approaches for Future Conditions Calculation and Mapping

For the purposes of addressing how to calculate and map future conditions, the TMAC has organized the discussion and recommendations in this section by primary flooding source type: coastal and riverine. Coastal areas are determined by the extent of the current and future tidal influence as well as Great Lake shorelines. Riverine areas include all inland or non-coastal flooding sources (e.g., alluvial fans, major rivers, tributaries, and rivers that are influenced by coastal effects as applicable).

Section 3 discusses the uncertainty associated with future conditions information, including natural and manmade changes, and Section 4 details the types of data currently available for determining current flood risk, data needed to project future outcomes, and current data gaps. FEMA's current flood hazard identification methods for both coastal and riverine areas rely on historical trend data (i.e., streamflow statistics and coastal water levels) and existing ground conditions as data inputs. Modeling the current flood risk involves determining how much water will be in the riverine or coastal system from a statistically-derived 1-percent-annual-chance flood event (hydrology), and how that water flows overland and through channels and structures (hydraulics). Simply put, hydrology determines how much water and hydraulics determine how high the water will rise. Both analyses are needed to identify flood hazards and both require data inputs that can affect the model outcome.

Calculating and mapping future conditions can be accomplished by using the existing FEMA modeling framework, but requires additional information and data about future natural and manmade changes. Using future conditions data requires a different approach that must account for a potential future that is not based on the past. In other words, the rules of stationarity (i.e., the assumption that data and processes do not change over time), upon which existing conditions mapping is based, will no longer be valid. Non-stationarity (i.e., the assumption that data and processes will change over time) must be taken into account. Incorporating non-stationarity into the existing modeling framework requires different approaches that deal with future uncertainty (e.g., future manmade actions; changing natural systems, such as climate change and SLR).

This section describes a new flood risk management philosophy that uses a scenario approach to address this uncertainty, discusses the current state of coastal and riverine science, addresses future geomorphology changes that could impact future flood risk, describes current and recommended future study methods, and provides case studies.

5.1 Flood Risk Management Philosophy

Managing flood risk is only possible when the types of future risks that may occur in a particular location in addition to those that have occurred in the past are understood. For example, methods to accommodate some types of observed changes in riverine flooding (e.g., land use change, regulation) are addressed in the *Guidelines for Determining Flood Flow Frequency*.[92]

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[92] Interagency Committee on Water Data, 1982.

Figure 5-1: Risk MAP Process

Incorporating uncertain future conditions that affect flood-related processes into standard methods for estimating future flood risk requires a risk management framework. The ultimate goal for estimating future flood risk is to provide unbiased estimates of future flood risk at any location, as well as to quantify the corresponding uncertainties. These estimates should account for the various authorized purposes and agency operations and missions, and should allow for future adjustments and refinements as the land surface and actionable science evolve.

The current Risk MAP conceptual process (seeFigure 5-1) addresses future risk at the risk assessment phase (Phase 2). Identifying and mapping future flood hazards is needed as part of Phase 1 (Mapping Risk Data), but may require approximate or simplified methods to estimate future flood changes due to limitations in the ability to project development and agricultural uses and their related changes in land use and land cover, as well as other changes impacting future hydrologic conditions, such as climate change.

5.1.1 Challenges of Flood Risk Estimation

While the theory behind risk-based flood management is well established and sound, as a practical matter, it is not always easy to estimate flood risk given limited data[93]and is especially difficult when attempting to detect changes in the frequency of rare events. Recently, additional complications have emerged associated with changes in climate and weather, combined with other changes, such as land use and land cover. The Third NCA[94] reported several trends, including rising global sea levels and increases in the frequency of heavy precipitation events in some regions of the United States (see Section 3.3).

Conversely, local sea levels are falling relative to land movement in some areas, such as Alaska. In some places in the southwestern United States, there is an observed trend toward decreased flood magnitude, where nearby locations are experiencing an increasing trend.[95] To date, uncertainties remain an important factor in assessing both observed records and projected changes. These uncertainties, and the possibility of substantial shifts in flood frequencies over the coming decades, require us to expand beyond traditional approaches, which assume that flood processes are stable and "vary within an unchanging envelope of natural variability," so that the past represents the future.[96] This assumption of stationarity has been challenged, and scientists and engineers now recognize and account for non-stationary processes[97,98] using a variety of methods.[99]

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[93] Federal Interagency Floodplain Management Task Force, 1987.
[94] National Climate Assessment, 2014.
[95] Hirsch and Ryberg, 2012.
[96] Milly, et al., 2008.
[97] Chow, 1964.
[98] Hirsch, 2011
[99] Kiang, et al., 2011.

5.1.2 Deterministic/Probabilistic or Scenario Approaches

Scenario approaches are often used to analyze problems that are characterized by large uncertainties with large potential consequences. For example, due to the complexity of the physical processes involved in changing sea levels and limitations in our understanding of important interactions and feedback cycles, the use of SLR scenarios[100,101] is a common method to deal with uncertainties.

The reason for selection of this method is not only because of the uncertainty related to climate, but also because of uncertainty due to vertical land movement that can result from many factors. This uncertainty is magnified when considering: (1) the variability in responses of coastal systems and processes, and (2) the combined effects of SLR and altered storm frequency or intensity.[102] For riverine systems, uncertainty related to future hydrology and hydraulics caused by many factors, including land use changes, climate change, and channel configurations, can be dealt with by using various future outcomes employing scenario approaches as well.

Probabilistic approaches, such as those proposed for SLR,[103] are generally based on knowledge about the probability distributions of different factors (e.g., ocean dynamics, isostacy, mass redistribution), thus explicitly incorporating uncertainty. Conversely, deterministic approaches are used when a great deal is known about the process in question. That is why deterministic approaches are so common in evaluating past events—because methods are based on observations and enable best-guess estimates of important factors. The difficulty in taking a deterministic approach to future conditions arises in part because the concentration of atmospheric greenhouse gas is greater than in recent past history (see Section 3).

The resultant increase in global average temperature and its impact, particularly on ice masses in Greenland and Antarctica, is thus difficult to project. Commonly-employed scenarios encompass a wide variety of deterministic projections and those based on the observed record. Though deterministic approaches have been proposed, they cannot be proven or otherwise validated until the future comes to pass. Thus, selection now of one particular deterministic approach entails the risk of false precision and decision-making based on a single future that may not materialize. Scenario analysis allows the user to test the robustness of future choices against a range of plausible futures. A broader risk-management approach enables a range of possible outcomes to be examined, as well as the uncertainty surrounding their likelihoods.[104]

Figure 5-2[105] illustrates the relationship between deterministic, probabilistic, and scenario approaches. Scenario approaches can be used together with an analysis of risk tolerance to determine the best scenarios for mitigating future flood risk (see Section 5.2.2.1).

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[100] Parris, et al., 2012.
[101] USACE, 2013.
[102] Woodriff, et al., 2013.
[103] Kopp et al., 2014.
[104] Kunreuther, et al., 2013.
[105] Slingo and Palmer, 2011.

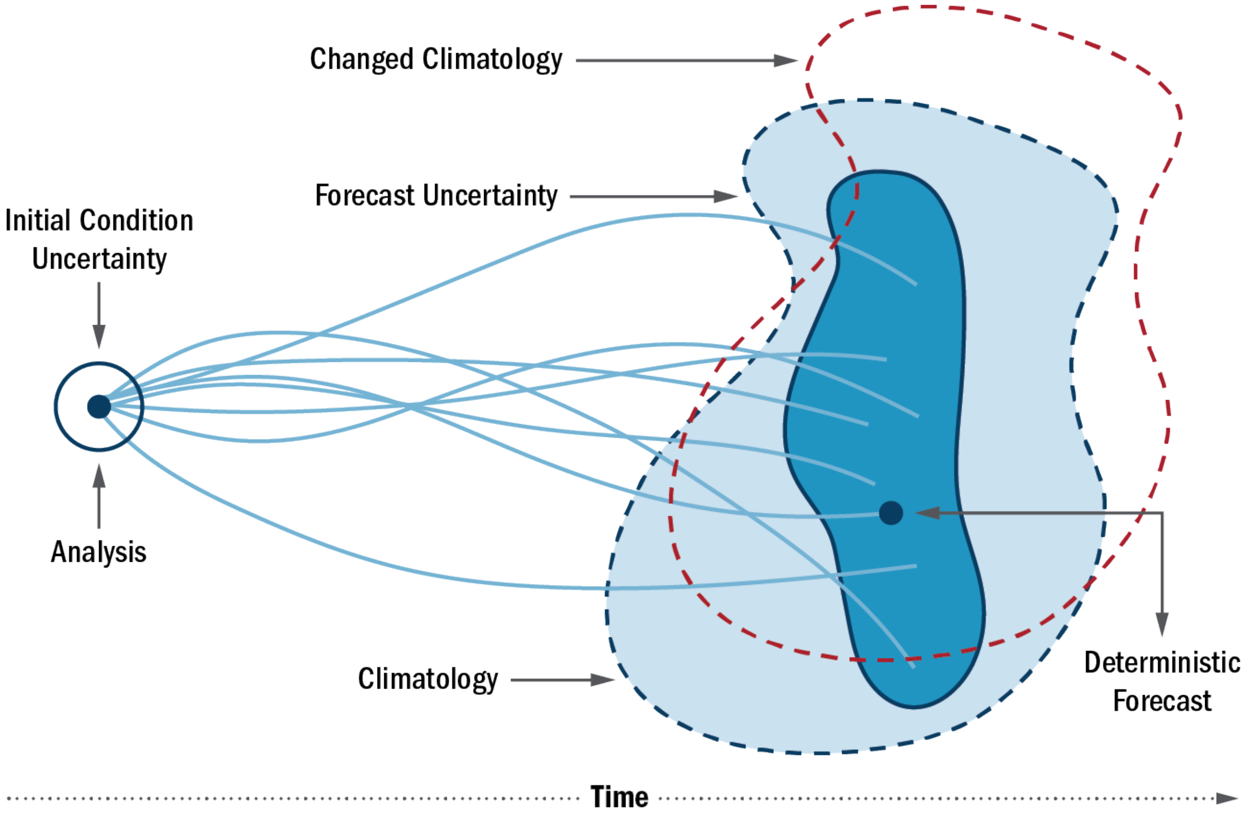

Figure 5-2: Graphical Depiction of Deterministic versus Scenario versus Probabilistic Forecasts. This shows one future outcome (blue dot) vs. scenario forecasts showing many future possible future outcomes (blue curves) vs. probabilistic forecast showing a distribution (light and dark blue areas) of future outcome. Red dashed line shows how future climate change may completely shift future outcomes due to non-stationarity.

Sub-Recommendation 5-1: Future flood hazard calculation and mapping methods and standards should be updated periodically as we learn more through observations and modeling of land surface and climate change, and as actionable science evolves.

Sub-Recommendation 5-2: FEMA should use a scenario approach for future conditions flood hazards calculation and mapping that will allow users to evaluate the robustness of proposed solutions to a range of plausible future conditions, including uncertain land use and climate change impacts.

Sub-Recommendation 5-3: FEMA should conduct future conditions mapping pilots to continue to refine a process and methods for mapping and calculating future flood hazards and capture and document best practices and lessons learned for each.

5.2 Best Available Coastal Science

Defining future coastal flood hazards requires an assessment of how sea level change will influence the frequency and magnitude of future extreme water level events. Future storm tides and waves may reach higher elevations than past storms and may do so with more frequency in most areas of the country, increasing the area impacted by future coastal flood hazards.

5.2.1 Sea Level Change Trend Data

Global sea level, also sometimes referred to as global mean sea level (GMSL), is the average height of all the world's oceans. Global (eustatic) SLR is caused by the global change in the volume of water in the world's oceans in response to three primary processes: (1) ocean mass change associated with long-term forcing of the ice ages, ultimately caused by small variations in the orbit of the earth around the sun; (2) density changes related to total salinity; and, most recently, (3) changes in the heat content—and, therefore, the volume—of the world's oceans, which recent literature suggests may be accelerating due to a warming climate. Global SLR can also be affected by basin changes, through such processes as seafloor spreading.

At any location, changes in local relative sea level (LRSL) reflect the integrated effects of GMSL change plus local or regional changes of geologic, oceanographic, or atmospheric origin. Atmospheric origin refers to the effects of the climate oscillations, such as the El Niño-Southern Oscillation and North Atlantic Oscillation, which in turn impact LRSL at decadal time scales. Section 3.3 discusses current and future climate trends and the impacts on global SLR.

5.2.1.1 Past Sea Level History

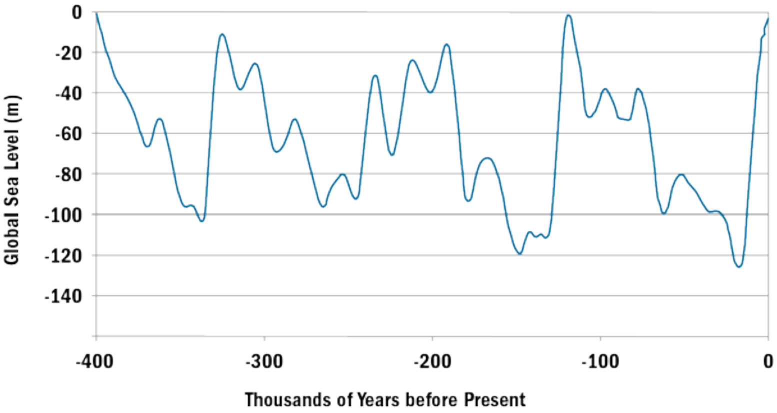

**Figure 5-3: Global Sea Level Change.
Global sea level change from 400,000 years ago to the present**

Figure 5-3[106] shows large variations in GMSL elevation over the last 400,000 years resulting from four natural glacial and interglacial cycles. GMSL was approximately 4 to 6 meters (m) higher than present during the last interglacial warm period 125,000 years ago and 120 m lower than present during the last ice age, approximately 21,000 years ago.[107] Figure 5-4[108] illustrates the rise in GMSL at variable rates over the last 18,000 years as the earth moved from a glacial period to the present interglacial warm period. The rise was rapid but highly variable, slowing about 3,000 years ago. Recent acceleration is not noticeable at this scale.

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[106] Climate Change Science Program, 2009.
[107] Ibid.
[108] Ibid.

5.2.1.2 Global Sea Level Rise and Future Projections

The average annual GMSL change in millimeters (mm) is shown in Figure 5-5.[109,110,111,112] The estimated trend over the past century, based on analyses of tide gauge records around the globe, is 1.7–1.8 mm/yr. Recent research has addressed the potential ranges of GMSL rise by year 2100[113,114,115,116,117,118,119,120] (see Figure 5-6[121,122]).

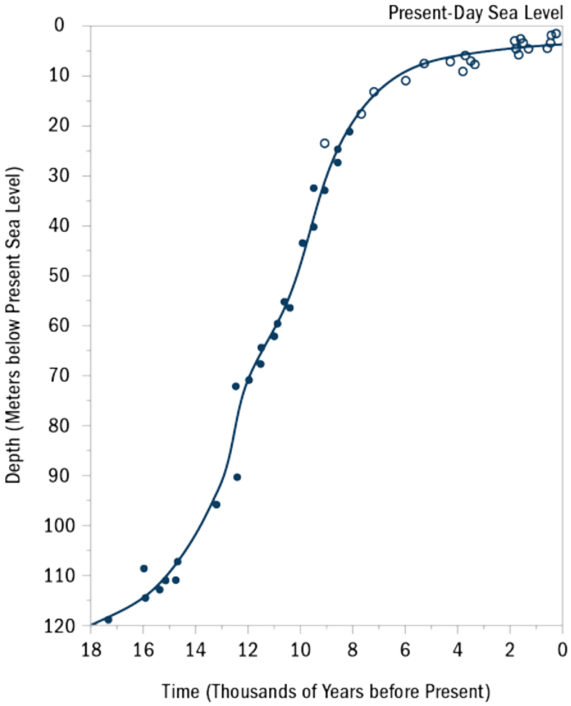

Figure 5-4: Global Mean Sea Level Rise. Rise in global mean sea level over the last 18,000 years.

The most recent NRC report[123] projects an upper bound of approximately 1.4 m, which is very close to the upper bound of 1.5 m used in U.S. Army Corps of Engineers (USACE) guidance. The 2012 report by NOAA[124] states that "…we have very high confidence (>9 in 10 chance) that global mean sea level will rise at least 0.2 meters (8 inches) and no more than 2.0 meters (6.6 feet) by 2100." A credible upper bound for 21st century GMSL is about 2 m.[125] There are other research papers that suggest the upper bound may be larger than 2.0 m.[126] However, consensus reports[127,128] conclude that exceeding 2.0 m by 2100 is not likely. An additional study[129] produced probabilistic sea-level rise projections out to 2100 and 2200 (see Figure 5-7[130]).

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[109] National Research Council, 2012.
[110] Rahmstorf, 2007.
[111] Holgate and Woodworth, 2004.
[112] Leuliette, et al., 2004.
[113] National Research Council, 1987.
[114] National Research Council, 2012.
[115] Rahmstorf, 2007
[116] Horton, et al., 2008.
[117] Pfeffer, et al., 2008
[118] Vermeer and Rahmstorf, 2009.
[119] Jevrejeva, et al., 2010.
[120] Katsman, et al., 2011.
[121] USACE, 2014.
[122] The red bar to the right on Figure 5-6 represents the guidance in the USACE Engineer Regulation 1100-2-8162 and the 2009 and 2011 Engineering Circular guidance it supersedes.
[123] National Research Council, 2012.
[124] Parris, et al., 2012.
[125] USACE, 2013.
[126] Grinsted, et al., 2010.
[127] Bindoff, et al., 2007
[128] Parris, 2012.
[129] Kopp, et al., 2014.
[130] Ibid.

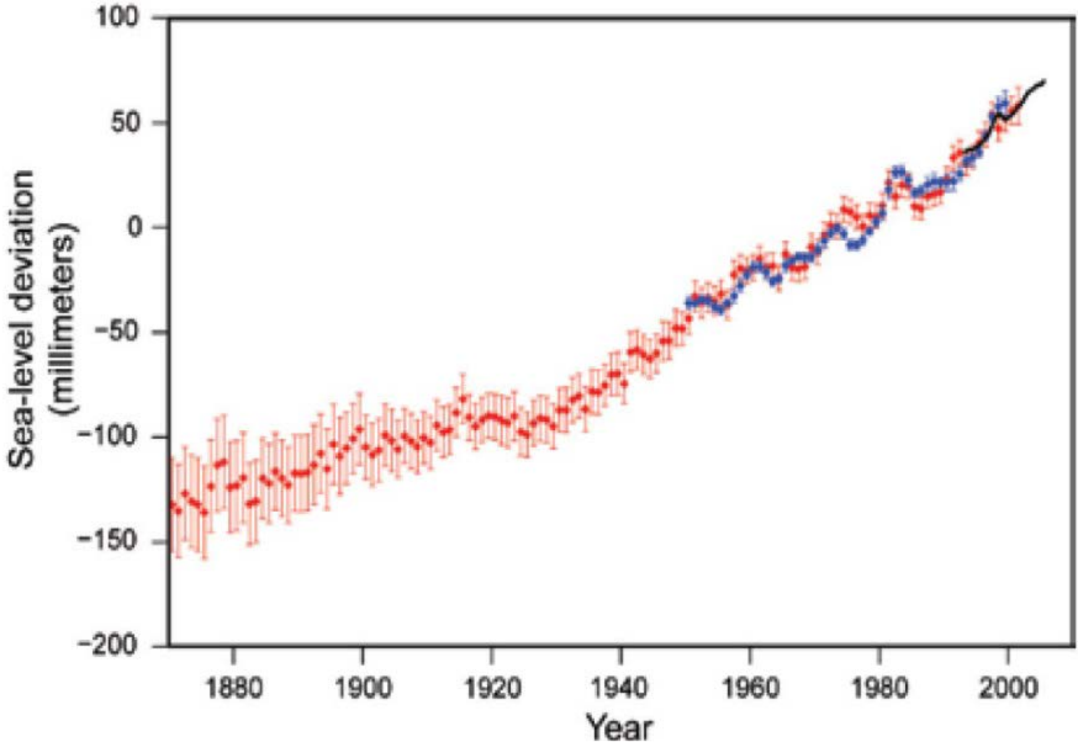


Figure 5-5: GMSL change since 1870. The red curve shows sea level variation from tide gauge observations since 1870. The blue curve displays adjusted tide gauge data and the black curve is based on satellite observations.

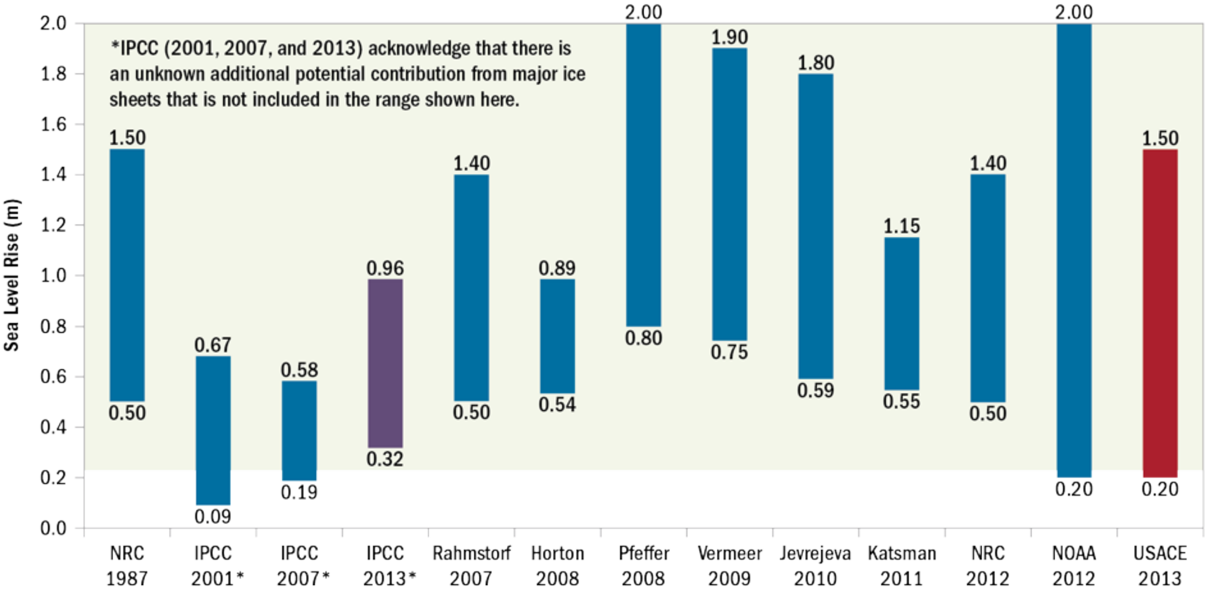
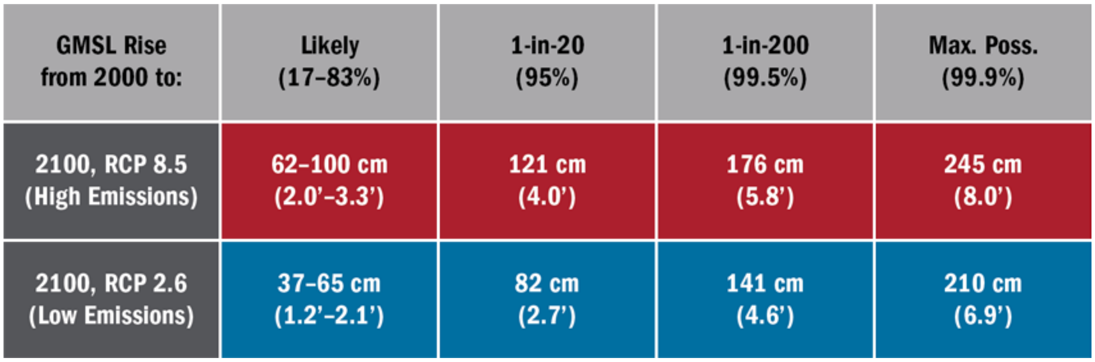


Figure 5-6: Comparison of Peer-Reviewed Research Estimates for Global SLR by 2100. The red column on the right hand side of the plot shows the USACE range of global SLR consideration at USACE projects, although higher estimates can be considered. As shown in this figure, IPCC scenarios give a lower range of SLR but at the high end they acknowledge that there is an unknown additional potential contribution from major ice sheets. The other estimates shown in the figure do not have this limitation.



GMSL Rise from 2000 to:	Likely (17–83%)	1-in-20 (95%)	1-in-200 (99.5%)	Max. Poss. (99.9%)
2100, RCP 8.5 (High Emissions)	62–100 cm (2.0'–3.3')	121 cm (4.0')	176 cm (5.8')	245 cm (8.0')
2100, RCP 2.6 (Low Emissions)	37–65 cm (1.2'–2.1')	82 cm (2.7')	141 cm (4.6')	210 cm (6.9')

Figure 5-7: Global Mean Sea Level Rise Probabilities. Global mean SLR probabilities from 2000 to 2100 under low and high emission scenarios (Subsection 3.3).

Tide Gauge Information

The term "tide" is used to define the alternating rise and fall of the oceans with respect to the land produced by differential variations in the gravitational attraction of the moon and sun. Non-astronomical factors, such as the configuration of the coastline, local depth of the water, ocean-floor topography, and other hydrographic and meteorological influences, play an important role in determining the range of tide, delay times of the tide, and the time interval between high and low waters.

Although the astronomical influences of the moon and sun upon the earth would seem to imply a uniformity in the tide, the type of tide can vary both with time at a single location and in distance along the coast. As the tides travel through ocean basins, the frequency and amplitude can be either amplified or damped by the oceanic bathymetry (see Figure 5-8).

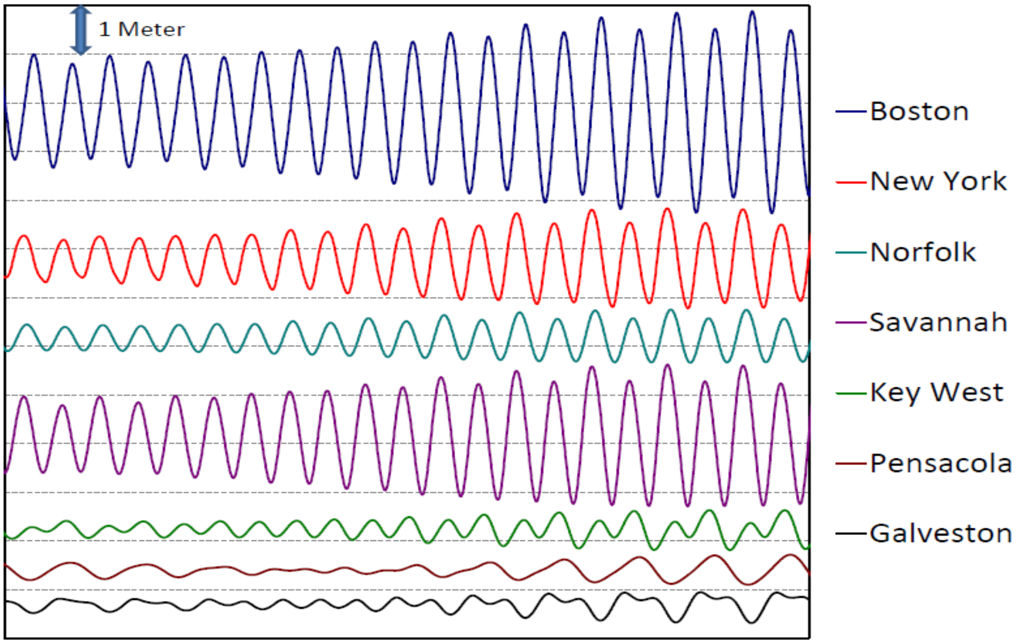


Figure 5-8: Characteristic Tide Curves. Characteristic tide curves near port facilities along the U.S. East and Gulf Coasts showing the variations of tidal amplitudes and frequencies.

LRSL is best determined using trend data from established tide gauges (see Section 4.3.1). The length of the tide gauge record impacts the robustness of the estimated historical relative mean sea level change. Interannual, decadal, and multi-decadal variations in sea level are sufficiently large that misleading or erroneous sea level trends can be derived from periods of record that are too short.[131] Tide gauge records with a length of two tidal epochs (an epoch is 18.6 years) or 38 years is suggested. Closure on 18.6 years takes into account variations in the range of tide due to a slowly varying orientation of the lunar orbit. NOAA does not publish sea level trends from tide gauge records unless they are at least 30 years in length.[132] NOAA does not publish sea level trends from tide gauge records unless they are at least 30 years in length because the error in the trends increases exponentially with decreasing series length.

The question of the required proximity of a tide gauge to be used in estimating trends is heavily influenced by regional factors, such as vertical land movement, and local factors, such as the exposure of the tide gauge (see Figure 5-9[133]).

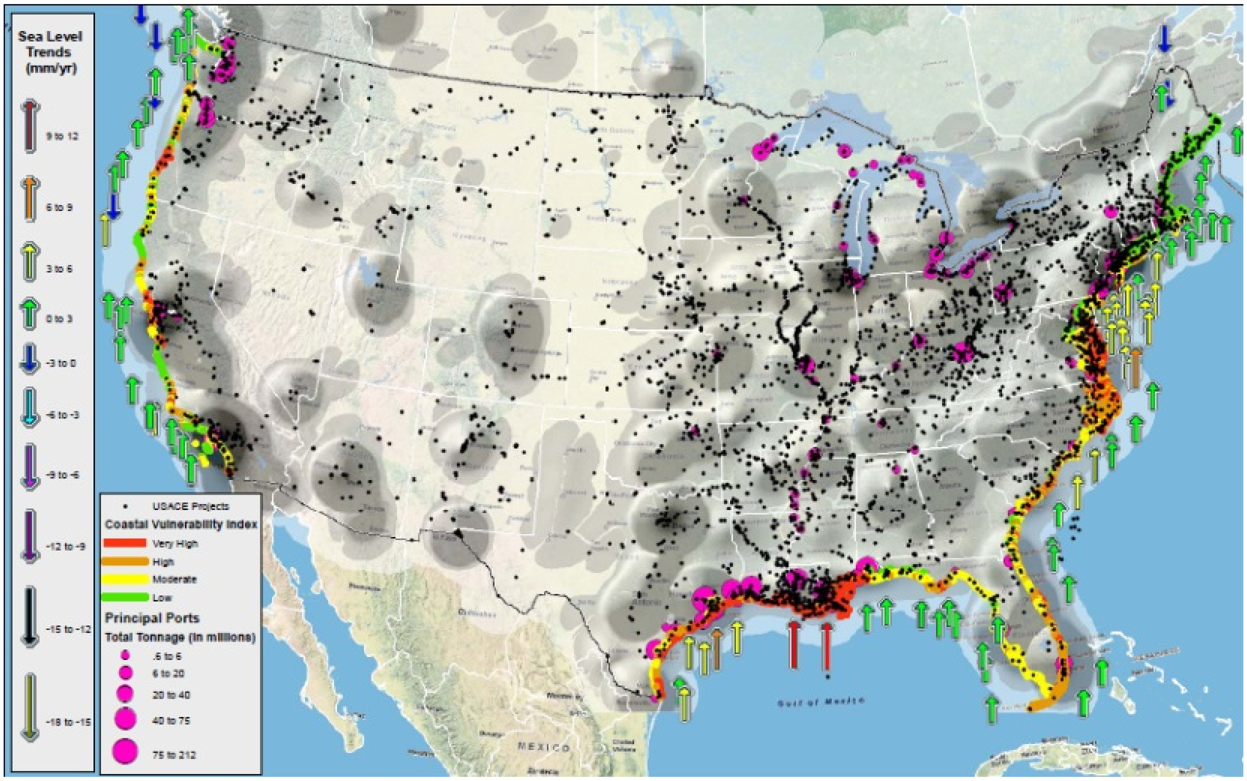


Figure 5-9: Changing Sea Levels at Tide Gauges.
Changing sea levels at tide gauges in the U.S. are illustrated by color, length, and direction (NOAA), Coastal Vulnerability Index (USGS), USACE Projects, and Port Tonnage on map of Population Density.

Over time, sea level variations are tracked relative to a fixed station datum maintained by the benchmark network. As a result, it is critical to consider vertical datums, including past and potential future shifts in datum, when estimating future LRSL.

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[131] Zervas, 2009.
[132] Ibid.
[133] USACE, 2014.

Global Mean Sea Level over the Period of Record from Satellite Altimetry

Since 1992, satellite altimetry has provided an additional method to estimate sea level changes. An estimate of the present trend in global SLR based on a series of overlapping satellite altimeter missions, capturing a rate of 2.9 mm/year for the global oceans. This relatively short period of record is not sufficient to determine a sea level change trend.

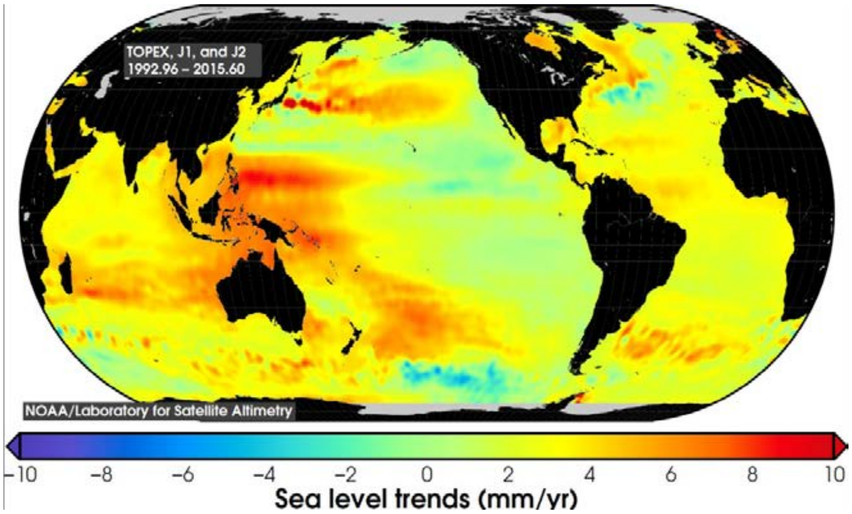

Figure 5-10: Local Sea Level Rise. LRSL is a combination of global, regional, and local sea level changes caused by estuarine and shelf hydrodynamics, regional oceanographic circulation patterns (often caused by changes in regional atmospheric patterns), hydrologic cycles (river flow), and local and/or regional vertical land motion (subsidence or uplift).

5.2.1.3 Local Sea Level Rise

LRSL is the local change in sea level relative to the elevation of the land at a specific point on the coast. LRSL is a combination of global, regional, and local sea level changes caused by estuarine and shelf hydrodynamics, regional oceanographic circulation patterns (often caused by changes in regional atmospheric patterns), hydrologic cycles (river flow), and local and/or regional vertical land motion (subsidence or uplift) (see Figure 5-10). Thus, LRSL is variable along the coast. LRSL is a specific type of sea level change that affects many applications, since the contribution to the local relative rate of rise from global SLR is expected to increase. Some areas are experiencing relative sea level fall, which can also have ecological and societal impacts. Additionally, some localized areas exhibit a more dramatic relative sea level trend than the generally observed globally, unless data are filtered to account for local geophysical anomalies (e.g., Southern Louisiana).

AlthoughFigure 5-11[134] suggests a global average sea level trend of 2.9 mm/year, the altimeter data show a wide range of regional sea level trends which make up the global average. Some trends are positive and some are negative since 1993. Tide gauge records show similar regional variability.

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[134] NOAA, Center for Satellite Applications and Research, 2015a.

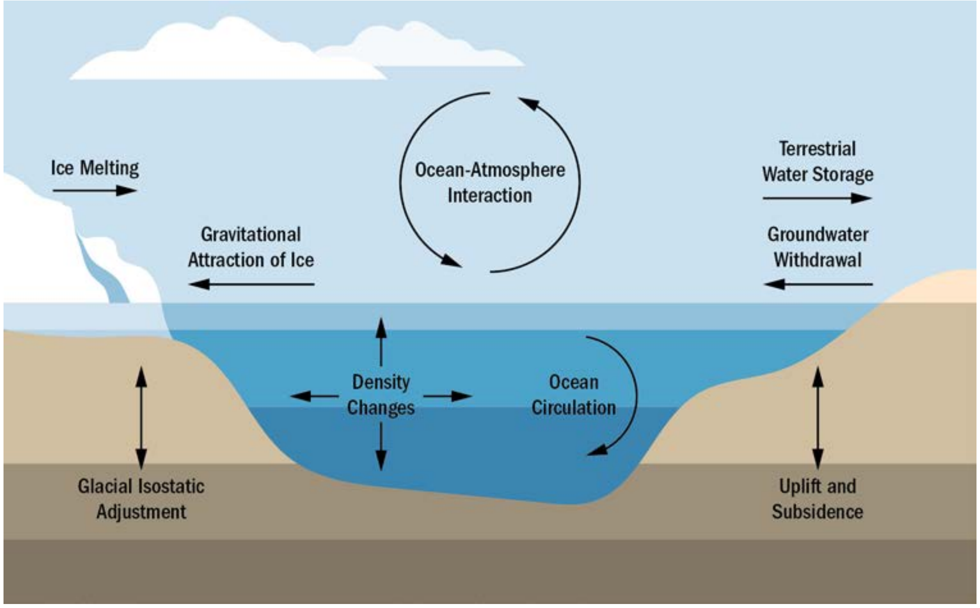

Figure 5-11: Sea Level Trends. Regional rates of sea level change from overlapping satellite altimeter missions.

When GMSL information is applied to a particular location, it must be adjusted due to regional and site-specific effects. Most significant among these are vertical land movement (either uplift or subsidence) and ocean/atmospheric conditions at the project site. The long-term data obtained from tidal records capture these effects as they are represented by historical conditions, but they do not capture potential changes into the future.

Some new research[135] provides sea level projections at a global network of tide gages. This approach starts to regionalize the global projections and captures subsidence and other impacts. Regionalization of existing global sea level projections is needed for mapping future conditions flood hazards. Ideally, these regional scenarios would be vetted by regional and local stakeholders and used for consistent future flood hazard assessment.

Subsidence Trends

Vertical land movement (VLM) is a primary component of local relative SLR. VLM can be caused by many factors, such as regional tectonic movement, regional vertical land subsidence or uplift, compaction of sedimentary strata, crustal rebound in formerly-glaciated areas, and subsidence due to local withdrawal of subsurface fluids (water or hydrocarbons). In many locations, direct estimates of local vertical land uplift or subsidence can be obtained from Continuously Operating Reference Stations (CORS). The CORS allows for centimeter-level accuracy of vertical change.

Rates of vertical land motion can be factored into local SLR projections by co-location of CORS with tide gauges.[136] For example, the USACE Sea Level Calculator uses information at NOAA tide gauges to add vertical land motion to global sea level projections to make the projections relative to what is happening locally (LRSL). Extrapolation or interpolation of VLM should also be performed with caution, as many areas have large gradients in VLM rates of short geographic distances (e.g., coastal Louisiana and Texas). VLM rates are often assumed to be linear for long time periods; however, in some tectonically-active areas or in

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[135] Kopp, et al., 2014.

[136] NOAA, 2015b.

areas where groundwater and hydrocarbon fluid withdrawal is stopped or mitigated, the trends will change over shorter time periods.

Variability of Components of Water Level

The primary components of coastal water level predictions are: sea-level rise, tidal variation, seasonal effects, storm surge, wave set-up, and wave runup. The relative importance of the magnitude of components of total water along coastlines can be illustrated by a wide range of non-tidal residuals as well as storm climates. Figure illustrates potential components from a representative extreme event over wide-varying coastlines.

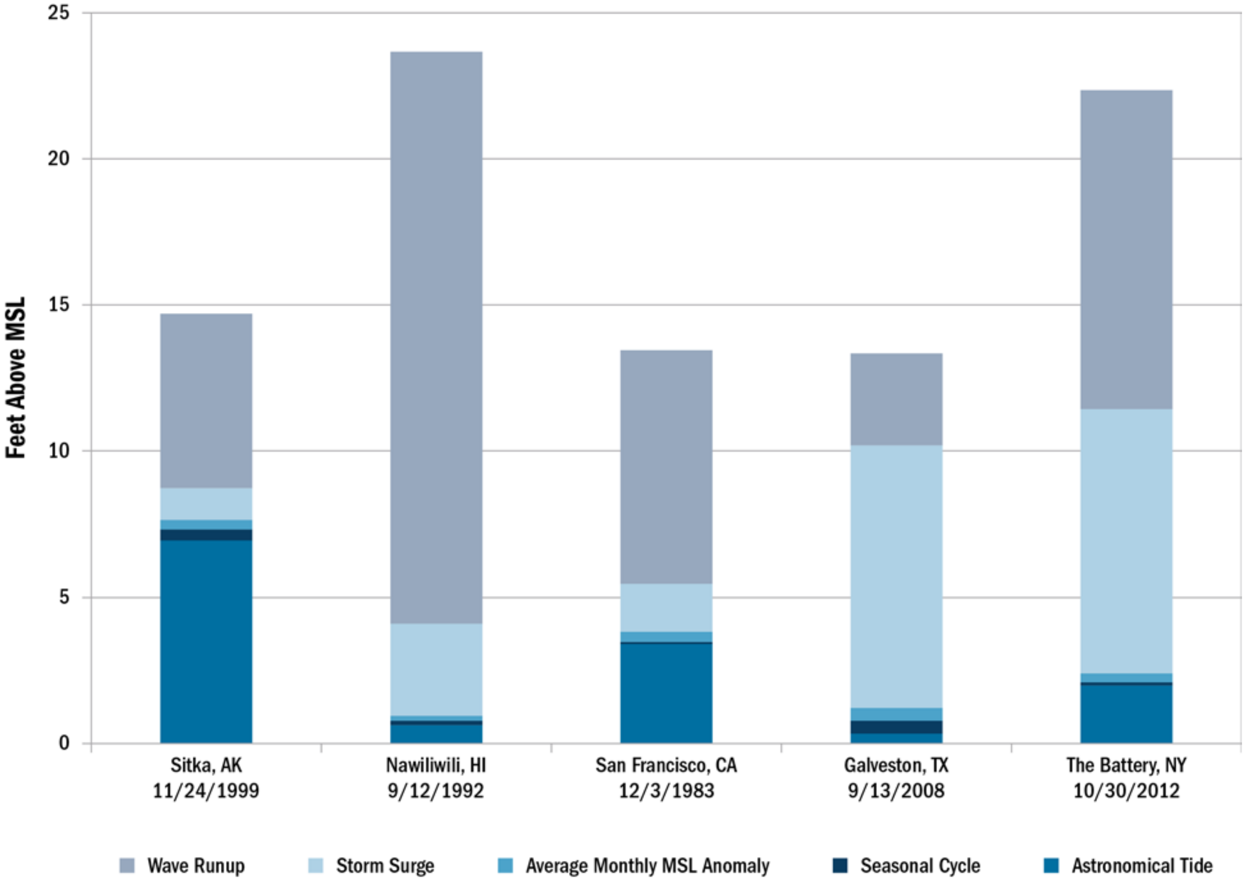

Figure 5-12: Components of Water Level. Relative importance of Total Water Level (TWL) Components for Different Coastlines and Example Extreme Events.

At any given time, the elevation of the SWL, relative to a fixed datum, is comprised of mean sea level, the deterministic astronomical tide, and non-tidal residual. The non-tidal residual is defined as any elevation change in the SWL not related to the astronomical tide, including the seasonal cycle. This non-tidal residual can be substantial (on the order of tens of centimeters) due to low frequency cyclical changes in water temperature, currents, and other forcing mechanisms (e.g., processes associated with El Nino Southern Oscillation), as well as relatively high frequency water level changes due to the presence of winds and low atmospheric pressure (e.g., storm surge).

In sheltered environments, precipitation and river discharge also contribute significantly to non-tidal residual. The dynamic still water level (DSWL) (see Figure 5-13[137]) combines the SWL wave-induced changes to the mean sea surface and wave-induced water level fluctuations on the order of minutes. DSWL includes the mean water level in the presence of waves, including wave setup (a superelevation of the water level due to wave breaking, which reaches its maximum at the shoreline) and setdown. DWSL also includes additional low-frequency water level fluctuations due to waves caused by processes like bound long waves and wave groups.

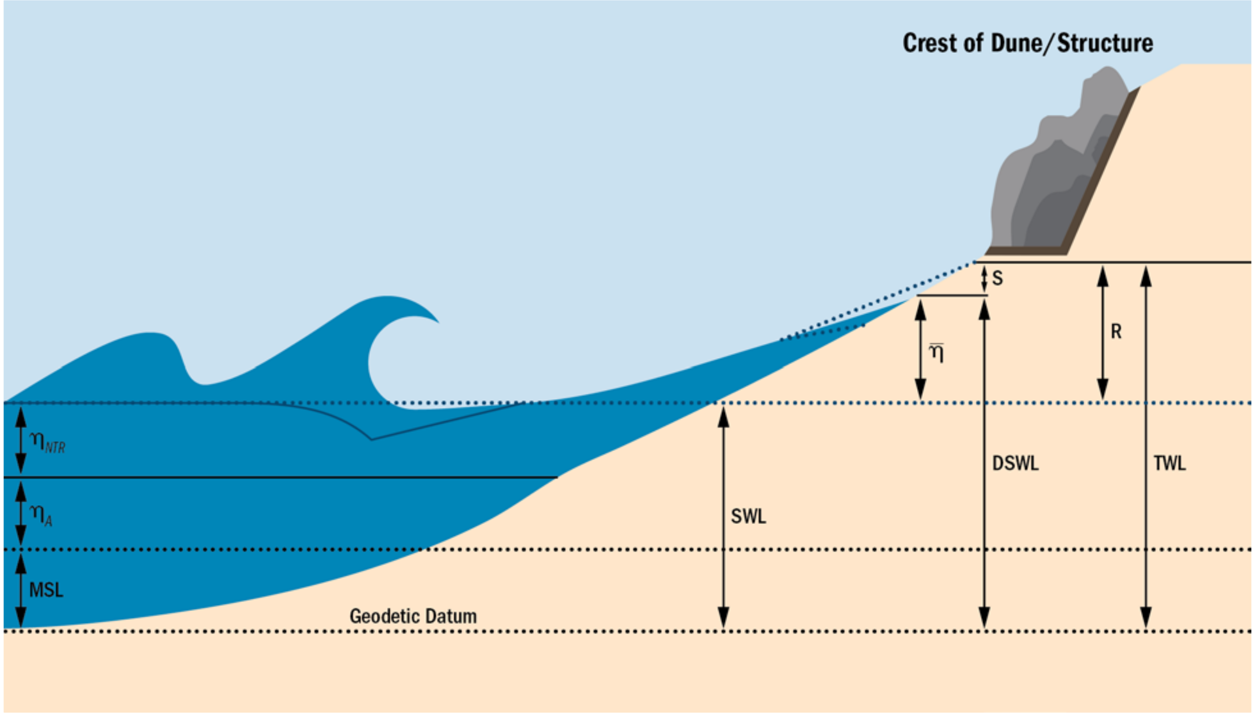

Figure 5-13: Profile View of Total Water Level Components.
Generic profile view schematic of the components of total water levels (TWL), including Stillwater level (SWL) and dynamic Stillwater level (DSWL) relative to a geodetic datum.

5.2.2 Uncertain Future Conditions

Section 3.3 discusses future projected sea level trends from the NCA and that there is a wide range of SLR based on uncertainty of the future contribution of ice melt to SLR and which emission scenario used in global climate models ends up being reality. Due to this uncertainty, a scenario approach has been adopted by many agencies for future project planning. The USACE sea level change adaptation process[138] explains the need for a multiple scenario approach.

5.2.2.1 Use of Scenarios

The dynamic nature of climate change as it affects coastal and hydrologic processes requires us to fully explore whether plans, designs, operations, and maintenance based on the principle of stationarity are still

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[137] Ibid.
[138] USACE, 2013.

valid.[139] For example, USACE sea level change (SLC) adaptation addresses the potential for nonstationary conditions through the use of a multiple scenario approach, which includes a range of future potential SLC rates. Due to the uncertainty and variability of future SLC, social, economic, and ecological changes, as well as their associated interactions, USACE employs a robust framework for project performance that is flexible and adaptable to multiple future scenarios.

Emphasis should be placed on both how the project operates within a larger system and how project decisions made today can influence future system responses to perturbations through adjustments, feedbacks, or cascading impacts. Robustness here is considered to be the ability of a project or system of projects, or their adaptation strategies, to continue to perform satisfactorily under changing conditions and over a wide range of conditions.[140]

Because of the uncertainty about future changes in climate, it is necessary to examine a range of scenarios that reflect complete, coherent, and internally-consistent descriptions of plausible future states. This approach allows an examination of cases for exposure to extreme events and performance for the project alternatives. As one study[141] pointed out, "Rather than focus on a single without project condition as the base, scenario planning acknowledges uncertainty by considering an array of futures based on different potential values of key uncertainties. In this context, plans are formulated that both address each of the possible futures but also are robust in achieving the desired objectives regardless of the future."

5.2.2.2 Risk Framing

Risk cannot be eliminated entirely. Evaluation of SLR scenarios and flood levels is guided by the risk inherent in planning, designing, and implementing particular types of projects and by their location. For example, projects with high consequences from failure may be more risk-averse than projects with lower consequences of failure. It is recommended, therefore, that scenarios be communicated in the context of risk tolerance (see Figure 5-14) to improve transparency and credibility.

Figure 5-14: Risk Tolerance. We have a high tolerance for things like a path in a public park (left), and low tolerance for things like air safety (right).

The four interagency scenarios presented in *Global Sea Level Rise Scenarios for the United States National Climate Assessment*[142] (see Figure 5-15) have been framed as such and the Federal community and partners have begun using the information for future planning (see FFRMS in Section 2.5). This framing offers several

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[139] Milly, et al., 2008.

[140] Moser, et al., 2008.

[141] Ibid.

[142] Parris, et al., 2012.

points (see bulleted list below) worth considering in the development and application of sea level change scenarios for mapping future coastal flood hazards.

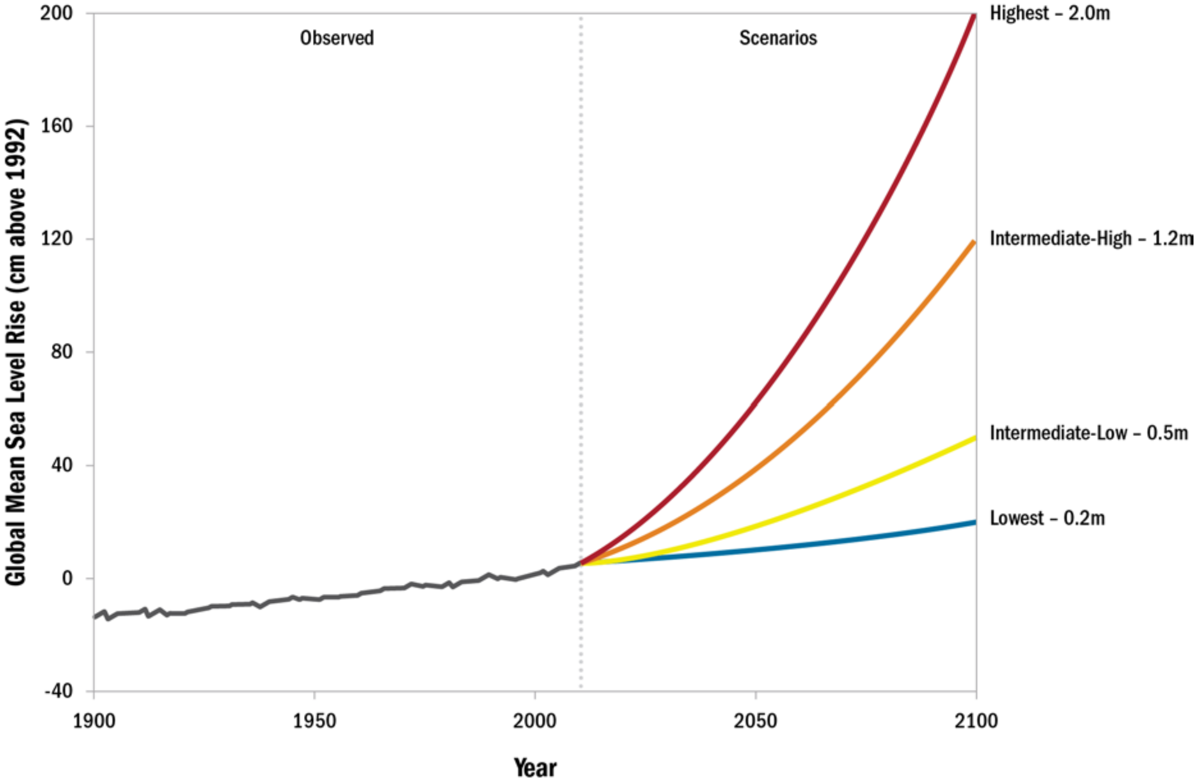

Figure 5-15: Global Mean Sea Level Rise Scenarios from Parris et al., 2012.

Table 5-1: Global Mean Sea Level Rise Scenarios from Parris et al., 2012, for 2100 in Table Form.

Scenario	SLR by 2100 (m)*	SLR by 2100 (ft.)*
Highest	2.0	6.6
Intermediate-High	1.2	3.9
Intermediate-Low	0.5	1.6
Lowest	0.2	0.7
* Using mean sea level in 1992 as a starting point.		

- The low and intermediate low scenarios, or comparable data, may be appropriate where there is a high tolerance for risk (e.g., projects with a short lifespan or planning areas with flexibility to make alternative choices within the near-term). These scenarios primarily address ocean warming.
- Where LRSL is falling, the use of the lowest scenario may be appropriate.

- The intermediate-low scenario has been recommended as the minimum scenario where LRSL is rising because it includes ocean expansion, whereas the lowest scenario is simply an extrapolation of the existing sea level trend into the future.
- The intermediate high and high scenarios, or comparable data, should be considered in situations where there is little tolerance for risk. These situations include projects with a long lifespan, where losses would be catastrophic, where there is limited flexibility to adapt in the near- or long-term, and those that serve critical economic and ecological function (e.g., ports or endangered species refuges). These scenarios primarily address both ocean warming and contributions from ice sheets.
- If more refined or recent regional sea level rise projections are available that are based on credible and salient climate science (e.g., information developed from highly resolved numerical models), they can be used instead of the *Global Sea Level Rise Scenarios for the United States National Climate Assessment* interagency scenarios.[143]

Communities Could Decide Their Own Future Risk Tolerance

Much like the current guidance for future riverine conditions hydrology[144] a coastal community could determine which SLR scenarios to use in future conditions mapping. These scenarios would be based on a community's risk tolerance and desired future planning horizons (2020, 2050, and 2100). The community would then be able to evaluate consequences of future risk and begin to adapt and mitigate for them.

At the national level, FEMA could provide guidance on defining a minimum risk tolerance that communities would have to meet. The end mapping product could be a non-regulatory product, much like the existing coastal +1, +2, and +3, maps that are options as part of the current Risk MAP program (see Section 5.5.1.5).

Sub-Recommendation 5-4: FEMA should use Parris et al., 2012, or similar global mean sea level scenarios, adjusted to reflect local conditions, including any regional effects (Local Relative Sea Level) to determine future coastal flood hazard estimates. Communities should be consulted to determine which scenarios and time horizons to map based on risk tolerance and criticality.

Sub-Recommendation 5-5: FEMA should work with other Federal agencies (NOAA, USACE, USGS), the U.S. Global Change Research Program (USGCRP), and the National Ocean Council to provide a set of regional sea-level rise scenarios, based on the Parris et al., 2012, scenarios, for the coastal regions of the United States out to the year 2100 that can be used for future coastal flood hazard estimation.

5.3 Best Available Riverine Science

Defining future riverine flood hazards requires an assessment of future hydrologic and land use change that will influence the frequency and magnitude of extreme precipitation events. Future river discharges may increase, causing higher flood elevations than during past events, and may do so with more frequency in some areas of the country, thereby increasing the area impacted by future riverine flood hazards.

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[143] Parris, et al., 2012.

[144] FEMA, 2001.

5.3.1 Land use Impacts on Future Riverine Conditions

Urban development and other changes in land use influence the magnitude of flood flows by modifying how rainfall and snowmelt are stored and run off the land surface into streams. Where much of the land surface is impermeable (e.g., covered by roads, parking lots, and buildings), watersheds have less capacity to store and retain rainfall and snowmelt, which leads to more rapid runoff and higher peak flows.

Many FIRMs have been issued for communities in watersheds undergoing rapid urbanization. For such basins, there is a need to account for the urbanization in flood-frequency estimates. Regression relations have been developed[145] for converting flood-frequency estimates derived from evaluation of flood-frequency relations for rural areas into estimates of flood-frequency for urban watersheds.

These equations employ seven parameters, including drainage area; basin slope; a measurement of the two-hour, two-year rainfall; and a basin development factor. These and other equations are implemented in USGS StreamStats,[146] whose estimates assume natural flow conditions and should be adjusted for trends in urban development or other impactful human activities. However, the equations are dated and may not reflect new trends in urban development that attempt to mitigate stormwater runoff through flood detention and enhanced infiltration.

Flood flows for 78 USGS gauged streams subject to varying degrees of urbanization over the last three decades were studied[147] to develop a peak discharge adjustment methodology that accounts for progressive urbanization. Flood frequency analysis, coupled with nonlinear regression techniques, were used to generate a set of equations for converting peak discharge estimates determined from rural regression equations to a set of peak discharge estimates that represent known urbanization.

Two sets of equations—one set based on imperviousness and one based on population density—were developed by the USGS. Both sets of equations are dependent on rural peak discharges, a measure of development (average percentage of imperviousness or average population density), and a measure of homogeneity of development within a watershed. Average imperviousness was readily determined by using GIS methods and commonly-available land cover data. Similarly, average population density was determined from census data. A key advantage to these equations is that they do not require field measurements of watershed characteristics as did the USGS urban equations developed earlier.[148]

5.3.2 Climate Impacts on Future Riverine Conditions

A warmer climate will result in two outcomes: (1) increased evaporation from oceans and other water bodies, thus leading to increased precipitation intensities and correspondingly more rapid runoff; or (2) increased evaporation from arid lands, leading to reduced runoff in arid regions and correspondingly lower river discharges. According to the Clausius-Clapeyron equation, air can hold about 7 percent more moisture for each 1 degree Celsius increase in temperature,[149] thus allowing back-of-the-envelope predictions of how higher global temperatures would affect annual global runoff. Droughts and floods, however, result from complicated interactions involving the timing, duration, and magnitude of multiple meteorological,

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[145] Sauer, et al., 1983.

[146] USGS, StreamStats, 2015.

[147] Moglen and Shivers, 2005.

[148] Sauer, et al., 1983.

[149] Held and Soden, 2006.

watershed, channel, and other local and regional factors. Predicting precisely how flood risk will change due to increased global temperatures, specifically in a given watershed, is not currently possible using simple physics.

In addition to temperature, there are other systematic changes that are important in altering riverine hydrology. Future development in the floodplain, land use changes in the watershed, regulation and deregulation of flow by addition or removal of flood control structures, increases in carbon dioxide (CO_2) in the atmosphere, and changes in other critical atmospheric components (e.g., the future availability and distribution of water vapor) will affect the statistical characteristics of flood flows. Such changes, or non-stationarities, can affect the mean, maximum, variability, and timing of flood peaks.

As physical processes change, flood risk changes as well. The goal in flood frequency analysis is to characterize the population of future floods taking into account knowledge of non-stationarities and their likely impact on flood hydrology. This characterization represents a change in how flood frequency estimates are computed. The previous assumption of stationarity implied that information about past floods could be relied upon to characterize future floods, and this may no longer be the case. Figure 5-16 illustrates processes that can cause non-stationarity.

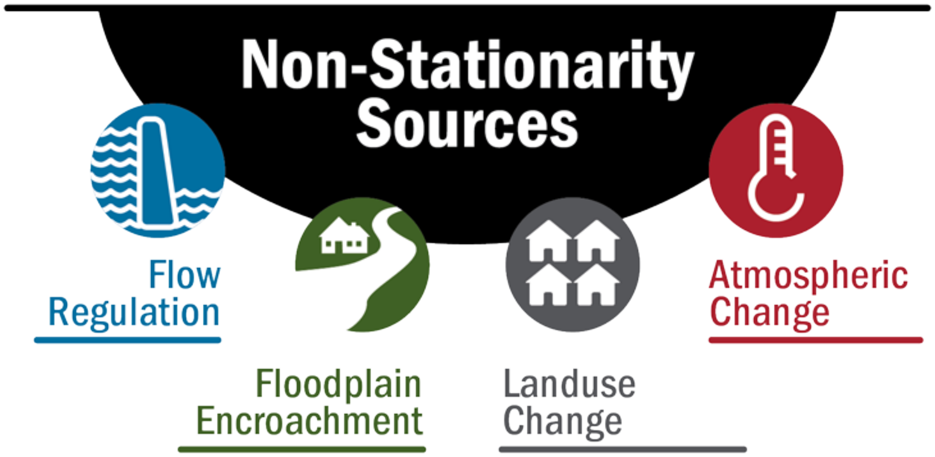

Figure 5-16: Sources of Non-Stationarity

Section 3.3 discusses observed precipitation changes from the NCA that show that, although long-term trends in average annual precipitation are variable and significant increases across the country were not pronounced, heavy rainfall has been increasing just about everywhere. However, extreme precipitation such as the 1-percent-annual-chance event does not appear to be increasing.

Similarly, analysis of USGS long-term streamflow records indicates many highly-significant trends for very low and moderate (non-flood) flows, such as those corresponding to the 90th-percentile through median flows.[150] Moving to higher flows, the examination of the partial-duration flood series (all of the peak flows above a stated threshold) reveals some significant trends.[151]

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[150] Lins and Slack, 1998.

[151] Villarini, et al., 2011.

However, study of annual peak flows (the base observations on which flood-frequency analysis is generally based) reveals few significant trends and no consistent national pattern. This finding is because peak-flow data are typically noisy, flood records are short, and major floods are rare. Even where trends have been detected in annual floods, there is no strong association with climate indicators. For example, a study of trends in flood magnitude versus global CO_2 levels[152] noted that none of the four regions of the country showed strong statistical evidence for flood magnitudes increasing with increasing CO_2. Changes in flood magnitude are more likely influenced by other factors, including future land use changes, because flood data records are typically noisy and rare, and are therefore they difficult to detect (see Figure 5-17[153]).

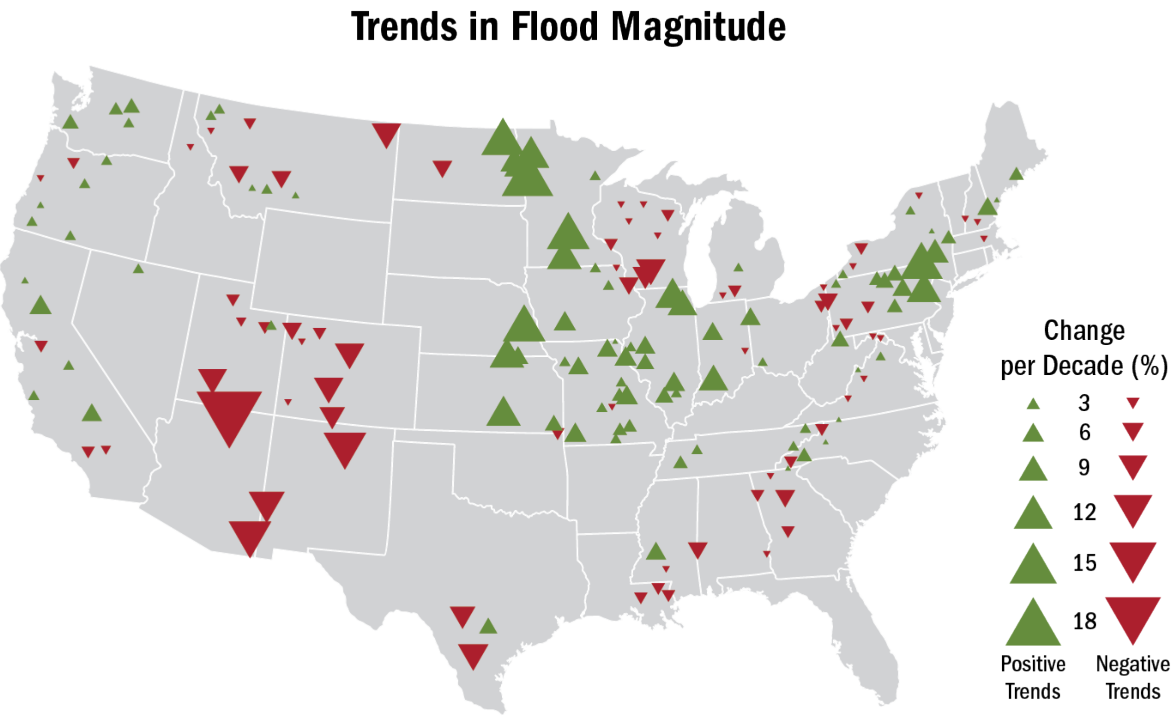

Figure 5-17: Trends in Flood Magnitude.
River flood magnitudes (from the 1920s through 2008) have decreased in the Southwest and increased in the eastern Great Plains, parts of the Midwest, and from the northern Appalachians into New England. The map shows increasing trends in floods in green and decreasing trends in brown. The magnitude of these trends is illustrated by the size of the triangles.

5.3.3 Climate Projections

Projecting climate conditions relies on different storylines, or narratives, that describe the future conditions. An example of a storyline includes the different representative concentration pathways that describe how greenhouse gas concentrations change over time.[154]

Due to the complexity of hydrologic processes, developing narratives of climate change for the water sector must encompass the full suite of uncertainties associated with: (1) global climate modeling; (2) climate

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[152] Hirsch, et al., 2012
[153] Melillo, et al., 2014.
[154] Van Vuuren, et al., 2011.

downscaling; and (3) hydrologic modeling. The process of defining climate change narratives for the water sector is an active area of research, with two major challenges.

- First, the models available were not specifically designed to capture uncertainties and, thus, may provide a biased and incomplete sampling of the range of possible climate futures.
- Second, all models are not created equal (i.e., some models are better than others).

The selection and/or weighting of climate models is also an active area of research, where many groups are experimenting with alternative methods to combine output from multiple climate models.[155,156,157,158] Moving forward, it is important to comprehensively characterize uncertainties in global climate modeling,[159,160] climate downscaling,[161] and hydrologic modeling,[162] and to carefully select climate change narratives that reflect these myriad of uncertainties[163,164,165] (see Figure 5-18).

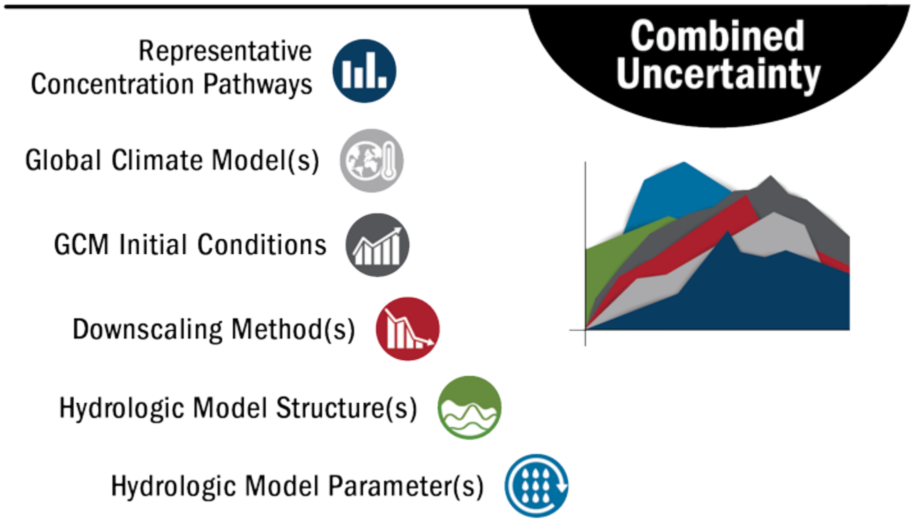

Figure 5-18: Sources of Uncertainty. Projecting climate hydrology involves a number of steps, each of which introduced uncertainty into the final result.

5.3.3.1 Climate Downscaling

Different types of downscaling have revealed a number of uncertainties that should be considered. From a dynamical downscaling perspective, the results from the coarse-resolution North American Regional Climate Change Assessment Program reveal that regional climate model simulations can have very different climate change signals compared to the parent global model.[166] From a statistical downscaling

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[155] Knutti, et al., 2010.
[156] Mote, et al., 2011.
[157] Bishop and Abramowitz, 2013.
[158] Evans, et al., 2013.
[159] Deser, et al., 2012a.
[160] Deser, et al., 2012b.
[161] Gutmann, et al., 2015.
[162] Clark, et al., 2015.
[163] Knutti, 2010.
[164] Knutti and Sedláček, 2013.
[165] Addor, et al., 2014.
[166] Mearns, et al., 2013.

perspective, a comprehensive assessment reveals substantial biases, inadequate representation of extremes, inadequate representation of the spatial scaling characteristics that are important for hydrology,[167] and often a complete (and unjustified) reliance on the precipitation change signals from global climate models.

It is possible to select among a range of downscaling methods based on their capability to produce unbiased information,[168] and to adequately represent extremes and the spatial scaling characteristics that are important for hydrology.[169] As with global climate modeling, the selection of downscaling methods must proceed with caution, as there can be unintended consequences of over-correcting the noise in climate model simulations (e.g., interpreting internal variability as a model bias), over-confidence in the change signal from the global models, and reliance on downscaling methods that are unable to represent non-stationarity.[170,171] It is important to note that any model downscaling can result in missing a potential realization in the future due to uncertainty.

5.3.3.2 Hydrologic Modeling

The opportunities to reduce uncertainty in hydrologic modeling relate to the selection and configuration or calibration of hydrologic models. In terms of model selection, the challenge is to use models that appropriately represent the dominant hydrologic processes, because neglecting processes (e.g., groundwater-surface water interactions) or over-simplifying the process representations (e.g., temperature index snow models) leads to unreliable portrayal of climate change impacts.[172,173] In terms of model parameters, the objective is to avoid problems associated with parameter interactions and parameter non-uniqueness and reduce model uncertainty by selecting smaller subsets of behavioral model parameters.

Sub-Recommendation 5-6: FEMA should take the impacts of future development and land use change on future conditions hydrology into account when computing future conditions for riverine areas.

5.4 Future Geomorphology Changes

Section 3 discusses both manmade and natural changes that will likely occur in the future and how those changes will impact current floodplains. Riverine and coastal floodplains are dynamic systems, with constantly-changing geomorphologies in response to physical phenomena operating over a wide range of

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[167] Gutmann, et al., 2014.
[168] Teutschbein and Seibert, 2012.
[169] Gutmann, et al., 2014.
[170] Ehret, et al., 2012.
[171] Gutmann, et al., 2014.
[172] Milly and Dunne, 2011.
[173] Lofgren, et al., 2013.

spatial and temporal scales (see Figure 5-19).

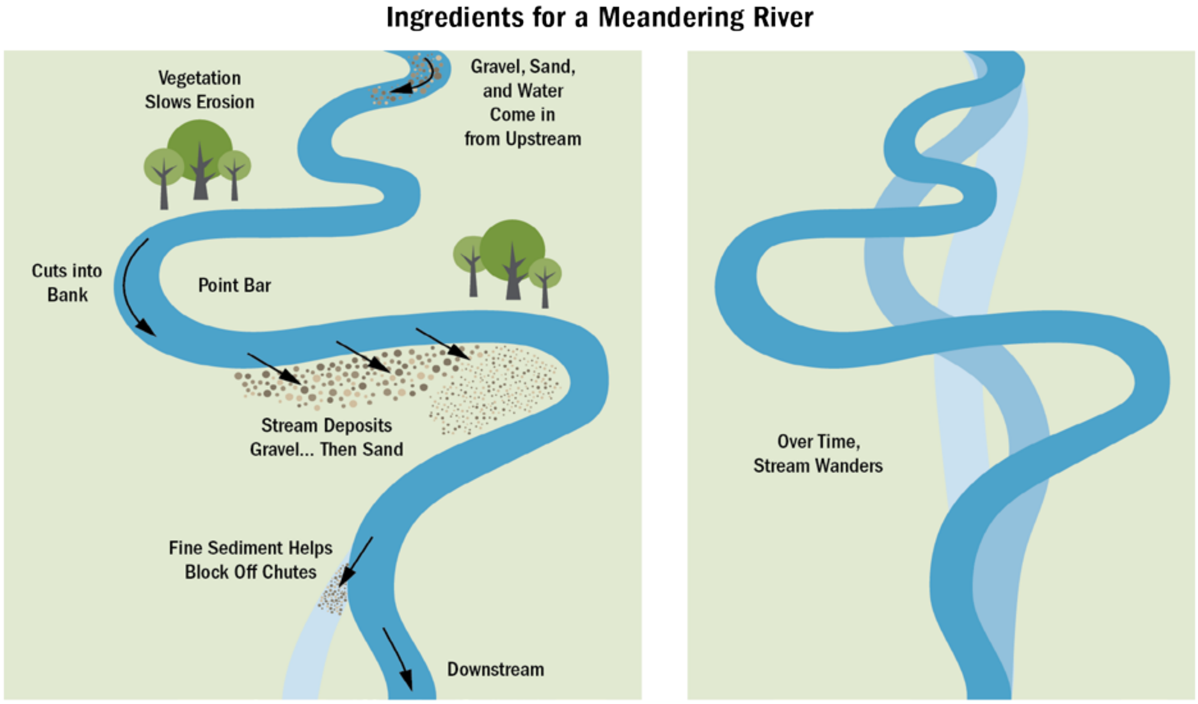

Figure 5-19: Riverine Floodplain.
Floodplains are dynamic systems, with constantly-changing geomorphologies in response to physical phenomena operating over a wide range of spatial and temporal scales

Coastlines and beaches evolve over time, transgressing or regressing in response to variations in storminess (surge and waves), water levels (SLR or fall), sediment volume, and underlying geology (see Figure 5-20[174]). Coastal inlets will migrate (some cyclically) in response to these same drivers. Riverine floodplains meander and expand or contract based on flow, sediment regimes, and underlying geology. Changes in riverine geomorphology and in sedimentation can cause channel degradation (lowering the bed) in some locations and aggradation (elevating the bed) in others.

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[174] Maine SeaGrant, 2015.

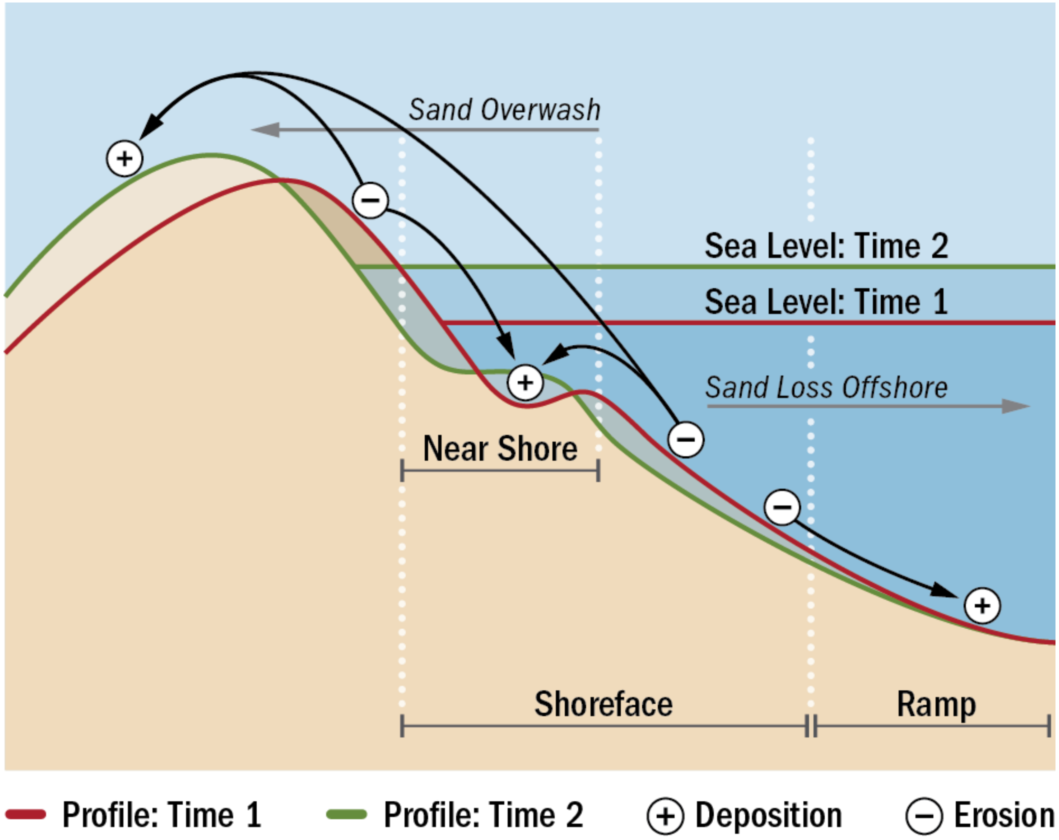

Figure 5-20: Coastline Change. Coastlines subject to a combination of storms, sea level rise, and erosion can change dramatically over time. A typical existing conditions beach profile is shown as the curvy red line. Over time, the profile will migrate landward as seen by the curvy green line. Sand is deposited (+) offshore or inland as overwash and eroded (-) from the nearshore and active drive beach. Sea level rise (horizontal red and green line) can exacerbate long-term coastal erosion.

5.4.1 Coastal Erosion

Shorelines erode and prograde in response to a complex set of forcing phenomena, as noted above. Owing to their importance to navigation, commerce, and defense, U.S. shorelines have been mapped for more than a century by the U.S. Coast Survey and successor agencies.

As mapping technologies have evolved, shoreline data have been collected more frequently and with greater accuracy by the Federal Government and other entities. Most coastal reaches of the United States have sufficient data to support calculation of long-term rates of change, information that is vital to government agencies and other coastal stakeholders concerned with managing coastal hazards.[175]

Although shoreline change can have a significant impact on the geographic distribution and severity of coastal flooding, FIRMs do not incorporate long-term erosion into the underlying flood modeling or depict erosion information separately. The *National Flood Insurance Reform Act of 1994* required the Director of FEMA to submit a report to Congress that evaluated the economic impact of erosion and erosion mapping on coastal communities and the NFIP. FEMA contracted with the Heinz Center to prepare the report, which

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[175] For example, see the USGS's National Assessment of Coastal Change Hazards, or one of the many State-based coastal erosion mapping programs.

was delivered to Congress in April 2000, and which recommended that Congress: (1) instruct FEMA to map coastal erosion hazard areas, and (2) require FEMA to include the cost of expected erosion losses when setting flood insurance rates along the coast. While FEMA has taken steps to address losses stemming from long-term erosion in the NFIP's insurance premium rate structure, FIRMs do not include any erosion hazard information. See Section 2.6 for more information on this and other attempts to map long-term erosion in the NFIP.

While the research community is making advances in the modeling of coastal geomorphic response to storms and sea level rise,[176] consensus models are not currently available to determine detailed future flood hazards. In the interim, resources are available to assess the severity of long-term erosion hazards along U.S. shorelines; however, the granularity (or resolution) may or may not be sufficiently detailed to support detailed (i.e., parcel-scale) assessment.

Coastal scientists can combine analyses of SLR and erosion based on simplified methods with tools like the USGS's Coastal Vulnerability Index (CVI)[177] to identify vulnerable coastal reaches where a more detailed analysis may be required to more fully capture risks. The CVI provides national maps with an index of vulnerability and probabilities of high shoreline loss. The CVI was recently updated using probabilistic shoreline change data to predict long-term shoreline change associated with SLR through the use of a Bayesian Network[178] (see USGS Coastal Vulnerability and Shoreline Change in Section 5.5.1.5).

5.4.1.1 Impact with Coastal Erosion and Sea Level Rise

As sea levels rise, the increase in water depth allows higher energy waves and currents to impact the active beach profile, thereby increasing the probability of potential erosion due to sediment redistribution landward and seaward.[179] Beach recession is caused by a combination of static inundation from rising sea levels and dynamic sediment lost caused by erosion. Because of this combination of factors, simplified methods of expressing impacts of SLR, such as linear superposition (i.e., the bathtub approach), which, among other things, ignore erosion, may underestimate long-term risk to structures and other infrastructure located along the coast.

5.4.1.2 Implementation Challenges (National vs. State)

The biggest challenge for including long-term erosion hazard information on future flood risk products is using consistent shoreline erosion data and calculation methods. Though there is a national dataset provided by the USGS, as mentioned above, there is not a guaranteed funding source to keep that product updated in the future.

Many coastal States have beach monitoring programs in which to develop their own long-term erosion rates to establish erosion and building setback lines in which they multiply the long-term rates (e.g., x feet/year) by a certain number of years (e.g., 30 or 40). These data could be used by FEMA to map future erosion areas; however, States collect data and calculate rates using slightly different methods, which would cause inconsistency between States for a national mapping program. Developing national standards

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[176] Holman, et al., 2015.

[177] Thieler and Hammar-Klose, 1999.

[178] Gutierrez, et al., 2014.

[179] National Research Council, 2012.

for erosion rate calculation and mapping would need to take into account the current State standards so States would be able to use these data for beachfront management. It is recognized also that FEMA does not currently provide a long-term erosion product, and that additional funding would be needed if this aspect were added to their hazard assessment procedures to accommodate the additional effort and resources needed.

Sub-Recommendation 5-7: FEMA should prepare map layers displaying the location and extent of areas subject to long-term erosion and make the information publicly available. Elements include:

- **Establishing the minimum standards for long-term erosion mapping that will be used by FEMA that must be met by partners/communities if it is to be incorporated into the FEMA products.**
- **Working with Federal, State, and local stakeholders to develop these minimum standards via pilot studies.**

5.4.2 Riverine Erosion

Practitioners have long recognized that being able to predict the effects and magnitude of future human activities is a necessary constituent in properly considering riverine erosion.[180] As described by Lagasse,[181] practitioners typically consider geomorphic and hydraulic factors as affecting stream stability and riverine erosion.

In 1999, FEMA concluded that it was technologically feasible to determine and map riverine erosion hazard areas,[182] and that, to address site-specific conditions, flexibility in the choice of analysis techniques is needed. Changes in river morphology can impact future conditions mapping. Expansion of the floodplain, meandering, erosion and sedimentation, shifting riverbank stability, and altered sediment supply and underlying geologic influence (e.g., Mount St. Helens eruption): all these factors can have a significant impact on riverine flood levels and lateral migration. FEMA provided a solid foundation for evaluating Riverine Erosion Hazard Areas, where erosion hazard areas are defined as locations where potential "erosion or avulsion [lateral migration] is likely to result in damage to or loss of buildings and infrastructure within a 60-year period.[183]

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[180] Richardson, et al., 1975.

[181] Lagasse, et al., 2012.

[182] FEMA, 1999.

[183] Ibid.

These determinations could be made based on erosion rate information and other historical data, or riverine erosion studies such as geomorphic analyses, engineering analyses, and mathematical modeling. FEMA noted that, while riverine erosion involves highly complex and interacting physical processes (see Figure 5-21), "it is entirely feasible to analyze channel history and infer trends in the stream alignment and average migration rates."

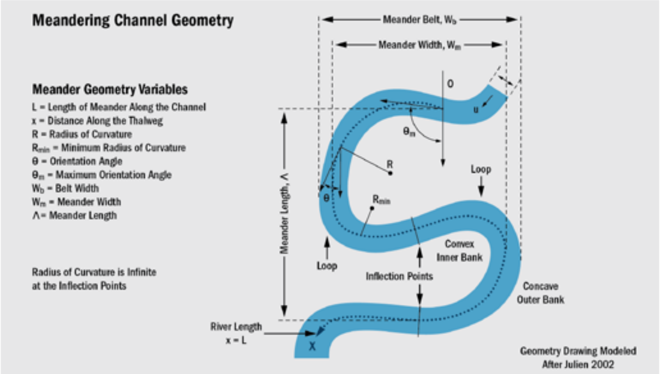

Figure 5-21: Meandering Channel Geometry. Illustration of the complex processes in channel meandering; other river morphology processes have similar levels of complexity.

Since 1999, a large amount of research and numerous river engineering studies have been focused on geomorphological changes as they relate to riverine erosion and potential flood hazards. In particular, there have been improvements in understanding the important processes in bank stability and seasonal effects on stability, channel migration, and other natural and anthropogenic effects on river morphology. There have been substantial advances in analytical and numerical modeling and GIS techniques that support decision-making with varied levels of complexity, from field screening approaches[184] to very detailed 2-D and 3-D computer models.[185] Riverine erosion zones in areas identified by Federal, State, local, or tribal entities as having channel migration risk are candidates for future mapping.

Sub-Recommendation 5-8: FEMA should implement riverine erosion hazard mapping (E Zones that define channel migration zones), leveraging existing data, models, and approaches that reflect site-specific processes and conditions.

5.5 Calculating and Mapping Future Coastal Flood Hazards

5.5.1 Geographic Coastal Approaches

It is important to understand existing hazards in order to begin to understand how those hazards may change in the future. Therefore, it is recommended that analyses of future coastal flood hazards build off existing current conditions flood hazard analyses, such as those prepared by FEMA for the NFIP. This consistency will facilitate comparisons between current and future projections of extreme water levels and will also enable compatibility with existing programs and uses.

This section describes the primary drivers of existing coastal flood hazards and provides recommendations on how to account for changes to these hazards in the future. More detailed discussions and guidance on these topics are found in FEMA's guidelines and standards for coastal flood hazard identification for each of these coasts and also in FEMA's Coastal Construction Manual.[186]

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[184] Bledsoe, et al., 2012.
[185] Duan and Julien, 2010.
[186] FEMA, 2011.

COMPARISON OF IMPORTANT FLOOD HAZARD FACTORS BY COAST

Atlantic and Gulf Coasts

- Hurricanes and Nor'easters
- Large storm surges
- Concurrent waves and water levels

Pacific Coasts

- Longer period swell
- Wave setup, runup, and overtopping
- Tsunami

Great Lakes Coasts

- Concurrent waves and water levels
- Lake-level changes
- Ice cover
- Water level regulation

Flood hazards vary significantly from coast to coast as illustrated in Figure 5-22[187] below and the text box to the left. Therefore, it is important to begin an analysis of flood hazards by identifying the principal flood hazards (e.g., storm surge or erosion) and forcing functions (e.g., hurricanes or tsunamis) affecting the area of interest.

It may not be necessary to account for every flood hazard in every study (erosion hazards may not be significant in a low wave energy environment) or every forcing function (the impacts of Nor'easters along the Gulf of Mexico are minimal), but the principal aspects and causes of flooding should be addressed. A thorough understanding of the current hazards impacting an area will help to prioritize and focus the evaluation of future hazards. The sections below provide a generalized description for each coast (Pacific, Atlantic, Gulf, and Great Lakes); however, a detailed site-specific assessment of principal flood hazards is recommended.

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[187] FEMA, 2002.

Figure 5-22: Flood Hazards Impacting Different Coastlines. This is an excerpt from FEMA's guidelines and standards highlighting some different aspects of flooding from coast-to-coast.

Long-term erosion is another important consideration when determining future conditions and is not discussed here. Section 5.4.1 of this report contains a detailed discussion of long-term erosion and future hazards.

Another important consideration impacting nearly all U.S. coasts except the Great Lakes is tides. Tides vary significantly from coast to coast and can play an important role in determining extreme water levels. Tides can be expected to change slightly as basins change in shape, depth, and size as a result of changing sea levels. NOAA incorporates these incremental changes as they update tidal epochs. These changes are generally small and may be negligible for short-term predictions of future hazards; however, they may become important when making longer-term predictions.

5.5.1.1 Atlantic and Gulf Coasts

The Atlantic and Gulf Coasts of the United States span a large geographic area, include a wide range of different settings and characteristics, and are impacted by a variety of flood hazards from various types of forcing functions. Still, there are commonalities generally shared across these areas and specific aspects that differentiate them from other coasts.

Elevated water levels and waves associated with tropical and extra-tropical storms (hurricanes and Nor'easters, respectively), are the primary coastal flood hazard forcing functions along the Atlantic and Gulf Coasts. The presence of a relatively wide continental shelf and a generally submerging coastline results in significant storm surges that propagate into bays and estuaries and inundate normally dry areas where development is likely.

In the future, storm surges will generally increase as local sea levels rise. Other climate change impacts, such as changes in the frequency and intensity of coastal storms, will also affect future storm surge levels.

Another defining aspect of coastal flood hazards on the Atlantic and Gulf Coasts is the coincidence of wind-driven waves with storm surges from the same event. There are some areas where this is not the case, such as embayments with inefficient connectivity to the open coast or areas sheltered from high winds; however, even in these cases, there is likely to be wave impacts associated with high storm surges. Additionally, since the storms which produce these impacts generally occur near to the coast, the wave periods associated with these storms are typically shorter than those experienced on the Pacific Coast.

As with other coasts, the impacts of storm-driven waves are generally dependent on the characteristics of the shoreline they are acting on. For example, wave runup will be a dominant factor along steep shorelines or those armored with seawalls and revetments, whereas in low-lying areas, the presence of waves over land that is normally dry is likely to be the dominant flood hazard factor, and sandy shorelines typically experience erosion during flood events. Many of these impacts are not specific to the Atlantic and Gulf Coasts, but their occurrence during periods of high water (i.e., storm surge) is an important consideration in assessing coastal flood hazards. Rising sea levels will result in deeper flooding, which makes the presence of larger waves possible. Changes in the frequency and intensity of coastal storms will also have impacts on wave hazards in the future. Lastly, as shoreline characteristics change as a result of adaptation to rising sea levels, the impacts of the wave hazards are also likely to change.

5.5.1.2 Pacific Coast

The basic coastal hazards (e.g., elevated water levels, waves, shoreline responses) that impact the Atlantic and Gulf Coasts also impact the Pacific Coast, but these processes interact in different ways and to different levels of magnitude. In contrast with other coasts, the overall geology of the Pacific Coast is determined by the existence of tectonic activity throughout and a narrow and steep continental shelf. In addition, the Pacific Coast is not as heavily impacted by tropical cyclones or other nearshore storm surge events. These conditions result in hazards that differ in frequency and magnitude along the Pacific Coast from those on the Atlantic and Gulf coasts. Whereas the dominant source of coastal hazards on the Atlantic and Gulf coasts is associated with large storm surge and coincident waves, the narrow continental shelves of the Pacific Coast preclude surges greater than a few feet. The relative importance of these individual components of coastal flood hazards is not expected to change significantly in the future.

The Pacific Coast is on the eastern rim of a very long wave-generating fetch; both near- and far-field wind events produce waves that impact the Pacific Coast. Far-field wind events result in waves with very long periods—greater than 20 seconds in major storms impacting the coast. This exposure to long waves generated anywhere in the Pacific Ocean also yields the potential for tsunami impacts along the Pacific Coast. The exposure of the Pacific Coast to waves and the relative influence of waves versus storm surge mean that wave impacts, such as wave setup, runup, and overtopping are also of greater relative importance along these coasts. The steep shorelines generally found on the Pacific Coast reduce the importance of overland waves here, although low-lying areas where these impacts are prevalent do exist.

Additional research is needed to characterize how a changing climate will result in changes in wave conditions along all of the U.S. coasts, particularly the Pacific Coast, where the wave action is the dominant flooding source. In addition, wave impacts are not highly correlated with sea levels; changes in sea level are likely to have a non-linear response to wave impacts.

5.5.1.3 Great Lakes

Similar to other coasts, hazards along the Great Lakes result from storm surge and/or storm waves. These impacts do not always occur concurrently. However, the most significant impacts typically occur when they do, and so this concurrence is of particular concern. Notable differences in Great Lakes hazards are the lack of tides and the presence of seiches. The Great Lakes are not directly connected to the Atlantic Ocean and are therefore not impacted by global sea level changes. Locally, however, lake levels are changing primarily as a result of isostatic rebound, where the land is rising with respect to the lake levels.

The magnitude of historic lake level changes make lake levels an important aspect of coastal flood hazards along the Great Lakes; and this is expected to remain an important aspect in the future. The lake levels change over many distinct time scales (e.g., hourly, daily, monthly, yearly, and long-term).[188]

GREAT LAKES CONSIDERATIONS

Accounting for future Great lake level changes as a result of climate change is not recommended at this time.

The other two drivers of water-level change are seasonal-scale changes and storm event-scale changes. FEMA's Great Lakes study process accounts for all three of these lake level changes when determining current flood hazards. Climate changes will impact lake levels at all three of these time scales, but the magnitude, timing, and other important considerations of these changes are currently not well understood. Therefore, accounting for future lake level changes as a result of climate change is not recommended at this time.

Ice cover can also play an important role in coastal hazards along Great Lakes coastlines. Current FEMA methodologies incorporate considerations of how shore-fast ice impedes wave action. An understanding of how ice cover on the Great Lakes could change in a changing climate is likely to be an important consideration for determining future hazards.

The Great Lakes are heavily regulated on a lake-by-lake and a system-wide basis. Lake-level regulation and navigation structures, such as dams and locks, are present on most lakes as illustrated in Figure 5-23.[189] Changes in how the lakes and system are regulated to account for water needs, navigation, environmental considerations, and other considerations will impact lake levels in the future, but projecting future regulation regimes entails a high level of uncertainty.

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[188] A more detailed discussion of long-term lake level changes is included in Section 3 of this report.

[189] Michigan SeaGrant, 2015.

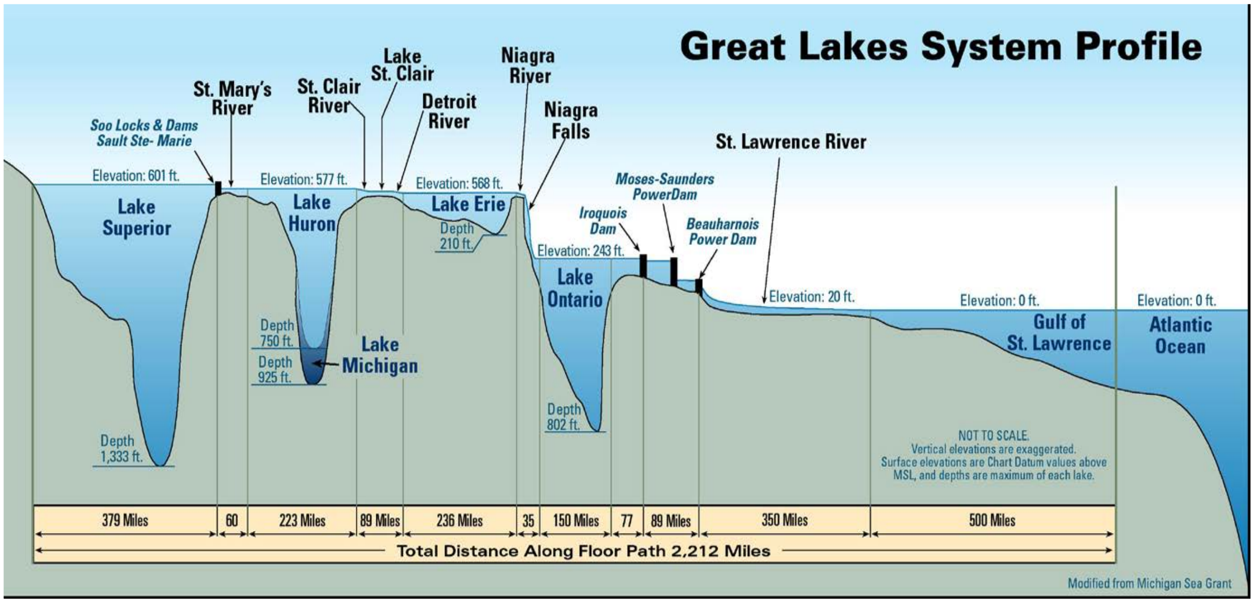

Figure 5-23: Great Lakes System Profile. This excerpt from FEMA's guidelines and standards shows the interconnectedness of the Great Lakes and control structures.

5.5.1.4 Linear vs. Non-Linear Reponses to Sea Level Rise

The different coastal geomorphologies and dominant processes highlighted in the above coastal modeling approaches also cause different responses that impact the BFE when sea level is introduced. The response with either be linear (e.g., 1, 2, and 3 feet of SLR causes 1, 2, and 3 feet of increase to the BFE) or non-linear (e.g., 1, 2, and 3 feet of SLR does not correspond to same increase to the BFE).

There are 2 ways to include future sea level rise into the existing coastal study modeling and mapping process: (1) dynamic (direct) analysis or (2) static (linear superposition/bathtub) analysis:

- Dynamic coastal flood modeling can be defined as using physics-based computer simulation techniques that include the effects of factors such as wind, atmospheric pressure, waves, and friction in calculation of coastal flood elevations (i.e., hydrodynamic modeling).
- Linear superposition or bathtub analysis is a common technique for mapping flood extents whereby a flood elevation increase is extrapolated landward until it reaches the equivalent contour height on land. Topographic elevations at or lower than this height are considered flooded. The method is also often used to add sea level rise onto existing BFEs, then spread further onto the floodplain using hydrologic connectivity rules.

On steeper, wave-dominated coasts like most of the west coast, wave run-up is the dominant flooding process. Because of this, adding sea level at the end of the modeling process via linear superposition underestimates the BFE (see case study in Section 5.5.1.5). On shallower, tide-dominated coasts like most of the east and gulf coasts, storm surge is the dominant flooding process. Due to this reason, adding sea level via linear superposition may be a good proxy for the future BFEs in open coast areas. The North Atlantic Coast Comprehensive Study (NACCS) also used this approach to add 3 feet of SLR to the 1-percent-annual-chance flood for the year 2068 to determine vulnerability.

Two pilot studies, one in New York and one in Puerto Rico, showed that there were some differences between dynamic and linear superposition analyses, but the differences in the stillwater BFEs were minimal except in some areas.

- The New York study pointed out that some locations in New York Harbor saw differences between the two. These differences can be more pronounced in back bay and estuary areas versus open coasts. Stillwater elevations calculated by storm surge hydrodynamic models appear to respond fairly linearly on open coasts; however, wave impacts do not seem to behave in the same manner.
- In the Puerto Rico study, depth-limited wave analysis showed that increases in sea level caused higher BFEs due to the increased water depths impacting wave heights. Wave impacts from SLR seem to behave non-linearly and, thus, may need to be estimated to determine future coastal high hazard area locations.

In other situations, when modeled dynamically, back-bay areas behave non-linearly when sea level is added to the stillwater analysis as well.

The State of North Carolina conducted a pilot SLR study[190] that showed that when sea level increased, it changed the flow dynamics of the estuaries and ultimately the land separating Albemarle and Pamlico sounds was inundated, causing the storm surge characteristics to change (see Figure 5-24[191]). This change in characteristics impacted the BFE in a non-linear fashion.

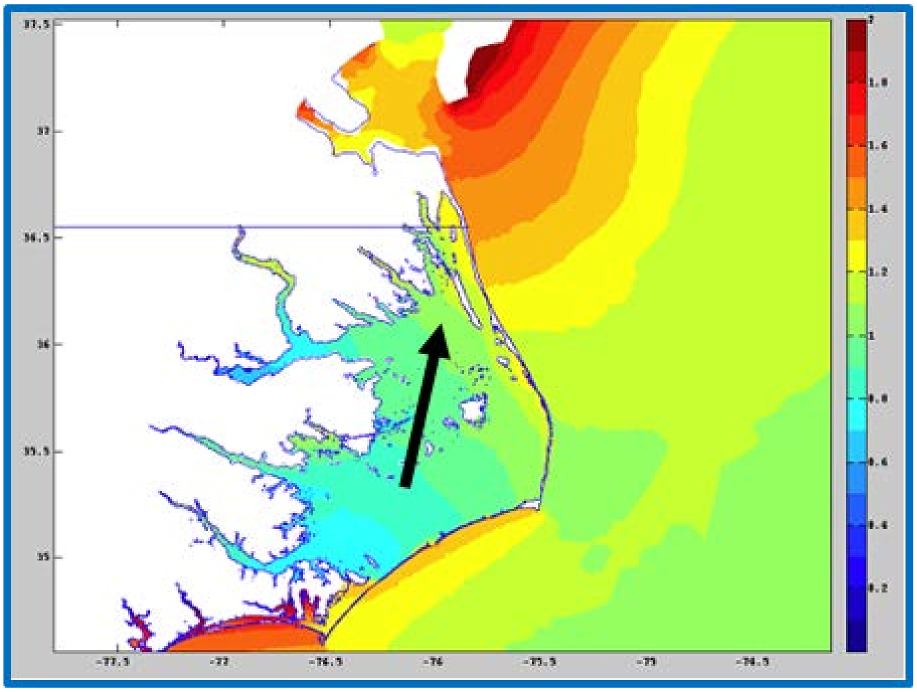

Figure 5-24: Non-Linear Response to Sea Level Rise.
Increased sea level causes Pamlico and Albemarle sounds to become connected in a storm surge event, making the BFEs response to sea level rise non-linear.

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[190] North Carolina Coastal Resources Commission Science Panel, 2015.
[191] Ibid.

5.5.1.5 Example Case studies

Many case studies and pilot projects have attempted to estimate future conditions coastal hazards. Adding future conditions in the form of SLR, coastal erosion, and other factors is a developing discipline in both science and engineering. Currently, there is not consensus on a single standard method. Some studies employ a more simplistic approach that costs less and others are much more detailed and costly. This section briefly captures some of the recent efforts to estimate future conditions coastal hazards and provides example products to communicate this risk to the public and decision-makers.

New York Panel on Climate Change Scenarios and Maps, New York City Panel on Climate Change

The New York City Panel on Climate Change (NPCC) was first convened by New York City in 2008 as a body of leading climate and social scientists charged with developing local climate projections. The panel released climate and SLR projections in a 2009 report.[192]

In September 2012, New York City formally codified the NPCC by writing the entity into law that requires the NPCC meet twice a year, advise the city on the latest scientific developments, and update climate projections at least every 3 years.

In the wake of Superstorm Sandy, the city reconvened the NPCC on an emergency basis to update its projections to inform planning for rebuilding and resiliency. The updated projections were released in a June 2013 report entitled, *Climate Risk Information 2013*. This report presented information about future climate hazards for the 2020s and 2050s, including SLR, and provided future coastal flood risk maps.

The 2015 NPCC report extended the projections to the 2080s and 2100 for sea level rise, and presented new future coastal flood risk maps for those time slices. It also reported on a study comparing the dynamic modeling of SLR on storm surge with linear superposition (or bathtub) modeling for New York City.

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[192] New York City Panel on Climate Change, 2009.

For all time-slices, SLR was presented at the low estimate (10th percentile), the middle range (25th to 75th percentile), and the high estimate (90th percentile). See Figure 5-25[193] for an example of a high-estimate map.

The presentation of SLR projections in the reports was designed to help New York City decision-makers better understand climate science and the potential consequences for city infrastructure. For example, the high estimate is presented as a more extreme outcome and would be appropriate for those with lower risk tolerances such as critical infrastructure operators.

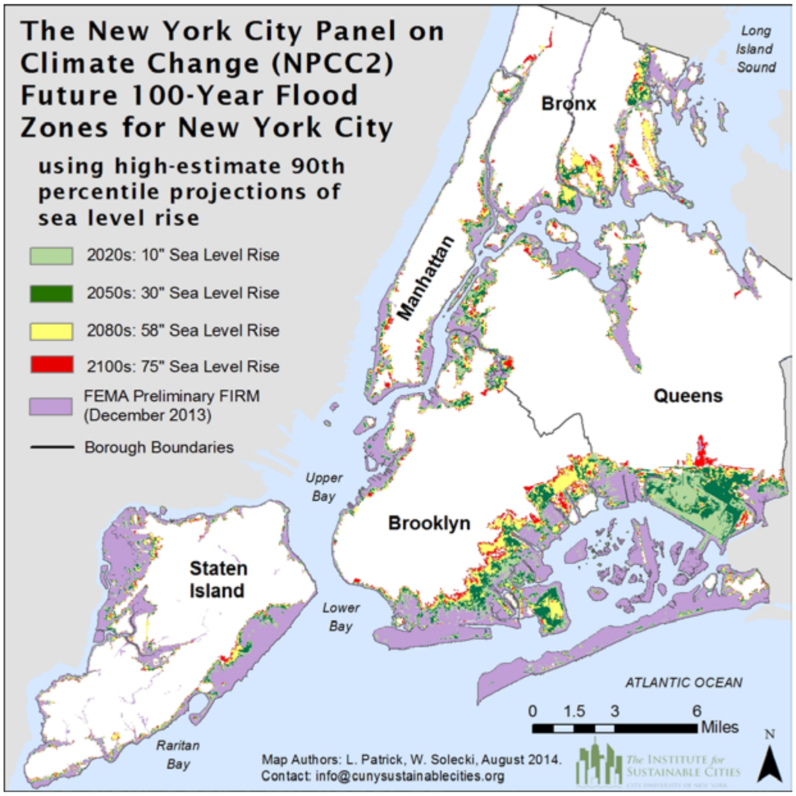

Figure 5-25: New York City Panel on Climate Change Future 100-Year Flood Zones for New York City

The NPCC used the FIRM as the base dataset for New York City because the FIRM is used for Building Code regulations and floodplain management practices. The linear superposition (bathtub) approach utilized the 90th percentile for the time slices, added those values to the flood elevations in the FIS report, and then used GIS to spread the floodwater landward until reaching a corresponding topographical elevation.

The NPCC also conducted a study to explore whether there were differences between dynamic modeling of SLR and linear superposition mapping approaches (see Figure 5-26[194]). For New York City, they found that in most cases dynamic and static approaches produce very similar results (plus or minus two inches). There were some exceptions. For the New York City region, future flood uncertainties are much larger than the differences between the dynamic and static flood-mapping methods.

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[193] Patrick, et al., 2015.
[194] Orton, "Hydrodynamic Modeling".

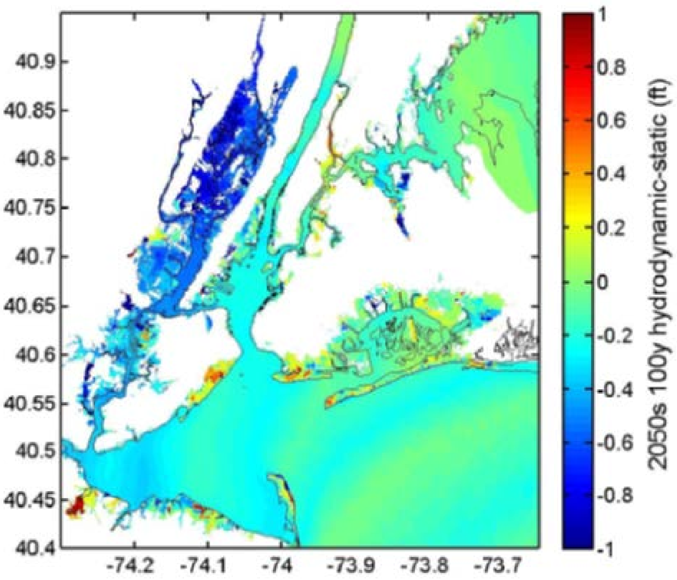

Figure 5-26: Dynamic versus Linear Superposition Mapping Approaches. Map with shading representing the difference—dynamic minus static—mapping results for 1-percent-annual-chance flood elevations (2050's 90th-percentile sea level rise). Results for the combined assessment results (extra-tropical cyclones and tropical cyclones) are shown.

Sandy Sea Level Rise Tool

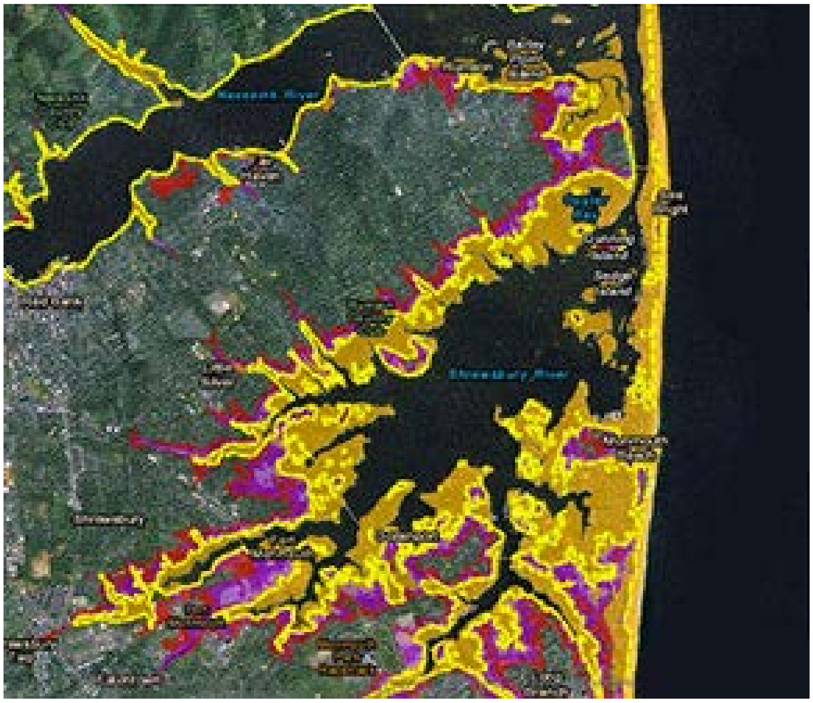

Figure 5-27: Sandy Sea Level Rise Map Tool. Sample map in New Jersey showing future 1-percent floodplain boundaries for various SLR Scenarios.

In the aftermath of Superstorm Sandy, FEMA partnered with the NOAA, the USACE, and the USGCRP to develop a Sea Level Rise Tool (SLR Tool). The SLR Tool used linear superposition methods to add SLR elevations to best available 1-percent-annual-chance flood elevations as developed by FEMA.

The SLR Tool consists of two components: a map tool, and an elevation calculator. The map tool (see Figure 5-27) is an interactive ARC-GIS map developed by NOAA's Office for Coastal Management that allows one to use NOAA SLR curves, or NPCC SLR scenarios, to visualize the future horizontal expansion of the existing floodplain over broad spatial scales and long range (up to 100 years) planning horizons.

The NOAA maps do not denote future site-specific flood depths or elevations within this horizontal extent. They also do not calculate wave effects and denote the future coastal high hazard areas.

The elevation calculator, developed by USACE, complements the map tool in that it calculates site-specific projected flood depths based on current conditions BFEs combined with projected rise in sea levels, out to 100 years (see Figure 5-28).

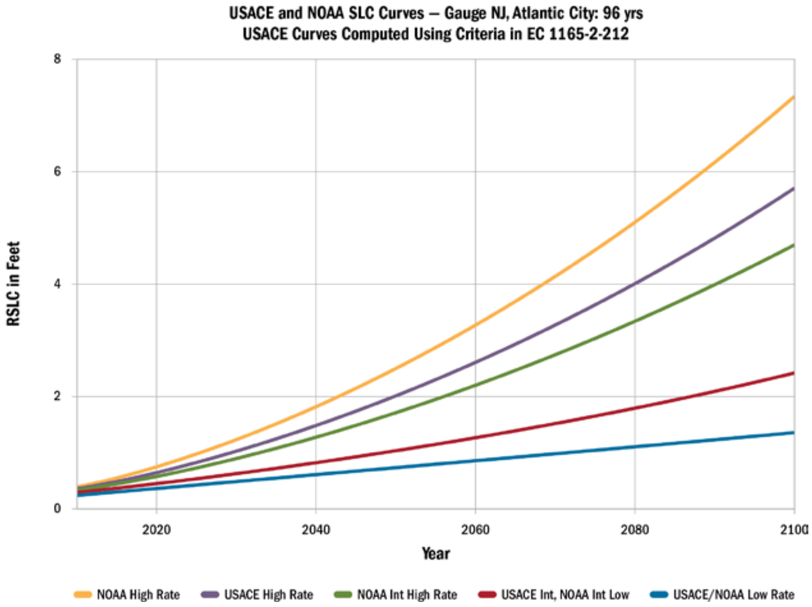

Figure 5-28: Sandy Sea Level Rise Calculator Tool. The calculator tool generates curves of relative sea level change projected through the year 2100 for coastal U.S. locations (above: Atlantic City, NJ).

The SLR Tool has many uses, chief among them to: (1) provide siting and elevation guidance for post-Sandy planning and rebuilding, (2) support scenario planning that may help decision makers prepare for and adapt to uncertainties surrounding the future risks posed by SLR, and (3) help make transparent the level of risk accepted under different scientific assumptions underlying the expected rate of sea level rise in the 21st century.

San Francisco Sea Level Rise Pilot

Following the development of the SLR Tool for Hurricane Sandy, FEMA initiated pilot studies designed to further test and refine methods for projecting future 1-percent-annual-chance flood elevations.

Pilot studies were initiated for sections of Pinellas and Hillsborough Counties, Florida; San Francisco County, California; and parts of the Washington, D.C. metropolitan area. The first two studies are intended, in part, to test whether linear superposition is an adequate alternative for the more costly and time-consuming methods where SLR elevations are included as input into storm surge and wave models (hereafter, the “direct” approach). Of these pilot studies, only the San Francisco County study has neared completion.

San Francisco County, like almost the entirety of the Pacific Coast, is an area where coastal flooding is dominated by wave runup, rather than storm surge. Whereas some studies in certain storm surge-dominated coastal areas have shown that using super linear position methods may be an adequate first approximation of projected future flood elevations, results from the San Francisco County study indicate that linear superposition, compared to the direct approach, can significantly underestimate future flood elevations in wave runup dominated areas.

Results show that direct analysis better captures the physical processes of waver runup in response to SLR. This was especially true at steep shorelines, such as rocky bluffs and areas of coastal armoring, where the increase in total water level was found to exceed the amount of SLR by a factor of two to four in some instances.

At natural sandy beach and dune areas, the total water level increase was found to be more linear and equal to the amount of SLR. This pilot study also evaluated the impact of long-term erosion based on increased sea level and extrapolating long-term trends. When long-term coastal erosion is taken into account, the effect of SLR on wave runup lessens. Highly-erodible areas will keep a relatively consistent profile (no steepening); thus, wave runup will be less of a factor. Here, linear superposition shows a 1:1 relationship with SLR and BFEs. Less erodible areas will produce steeper beach profiles in the future, thus causing wave runup to increase, leading to almost a 2:1 SLR to BFE ratio (see Figure 5-29).

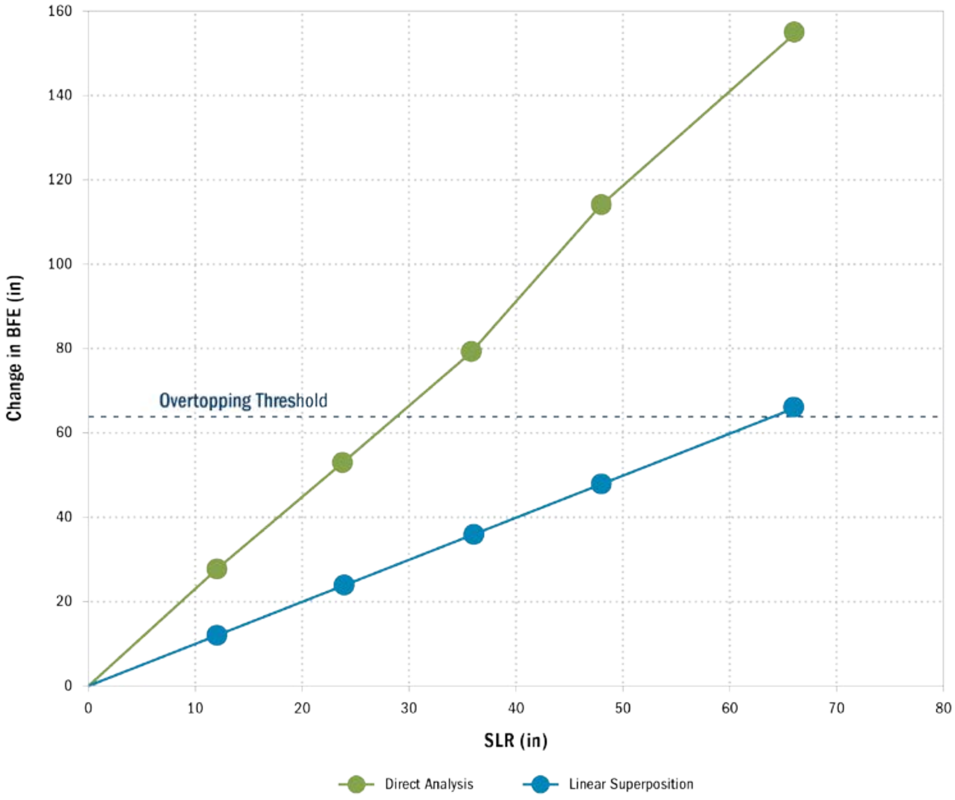

Figure 5-29: Linear Superposition vs. Dynamic (Direct) Analysis. Dynamic BFEs greatly exceed the linear BFEs by a factor of two.

The pilot study found that for natural sandy beach and dune shorelines, SLR may increase the rate of shoreline retreat by a factor of 3 to 6 through 2050 and 6 to 10.5 from 2050 to 2100. SLR may increase the rate of shoreline retreat by a factor of 1.7 to 2.4 through 2050 and by a factor of 2.4 to 3.2 from 2050 to 2100 for bluffed shorelines. This finding indicates that future special flood hazard areas will increase, not only due to the vertical increase in SLR, but also due to horizontal increase in landward extend due to shoreline retreat.

This study noted that national historical shoreline change data were used and that future studies may wish to refine the shoreline change methods using local or State shoreline change data, where available, for more site specific projections.

North Atlantic Coast Comprehensive Study

The USACE NACCS was a 2-year study to address coastal storm and flood risk to vulnerable populations, property, ecosystems, and infrastructure affected by Superstorm Sandy in the U.S. Northeast. It was designed to help local communities better understand changing flood risks associated with climate change and to provide tools to help those communities better prepare for future flood risks.

The study builds on lessons learned from Superstorm Sandy and attempts to bring to bear the latest scientific information available for State, local, and tribal planners. As part of the study, one of the process steps was to analyze risk and vulnerability by mapping inundation and exposure, assess vulnerability and resilience, and determine areas of high risk. The study mapped inundation areas impacted by future sea level using the USACE low, intermediate, and high scenarios, and the NOAA High scenario[195,196] for 26 NOAA gauge locations across the study area at 2018, 2068, and 2100 (based on 5 years following appropriations for construction by 2018, 50 years post-construction, and the commonly-presented sea level change endpoint used in scientific literature (see Figure 5-30[197]).

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[195] USACE, 2013.

[196] Parris, et al., 2012.

[197] USACE, 2015b.

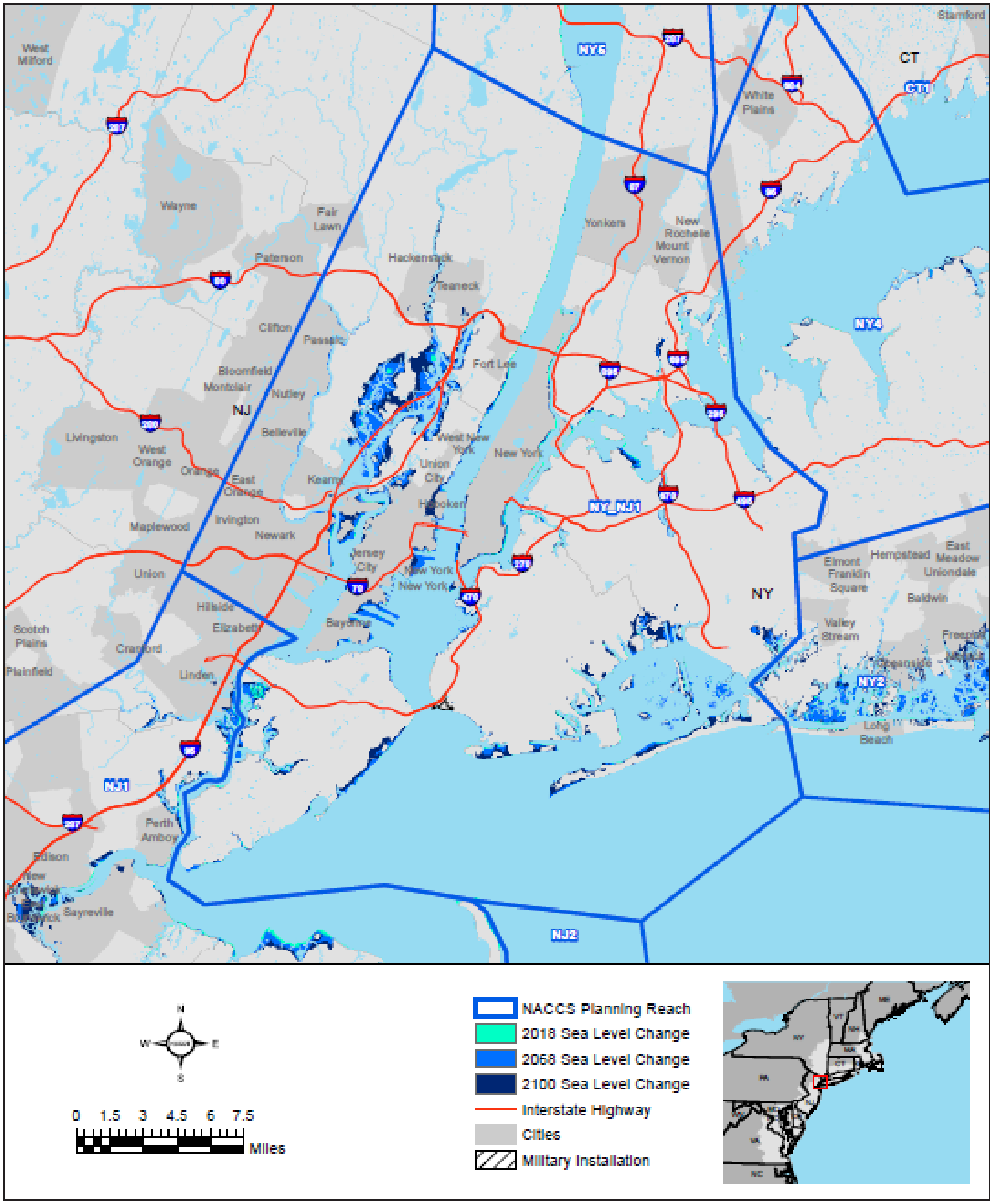

Figure 5-30: USACE High Scenario Future Mean Sea Level Mapping for New York City

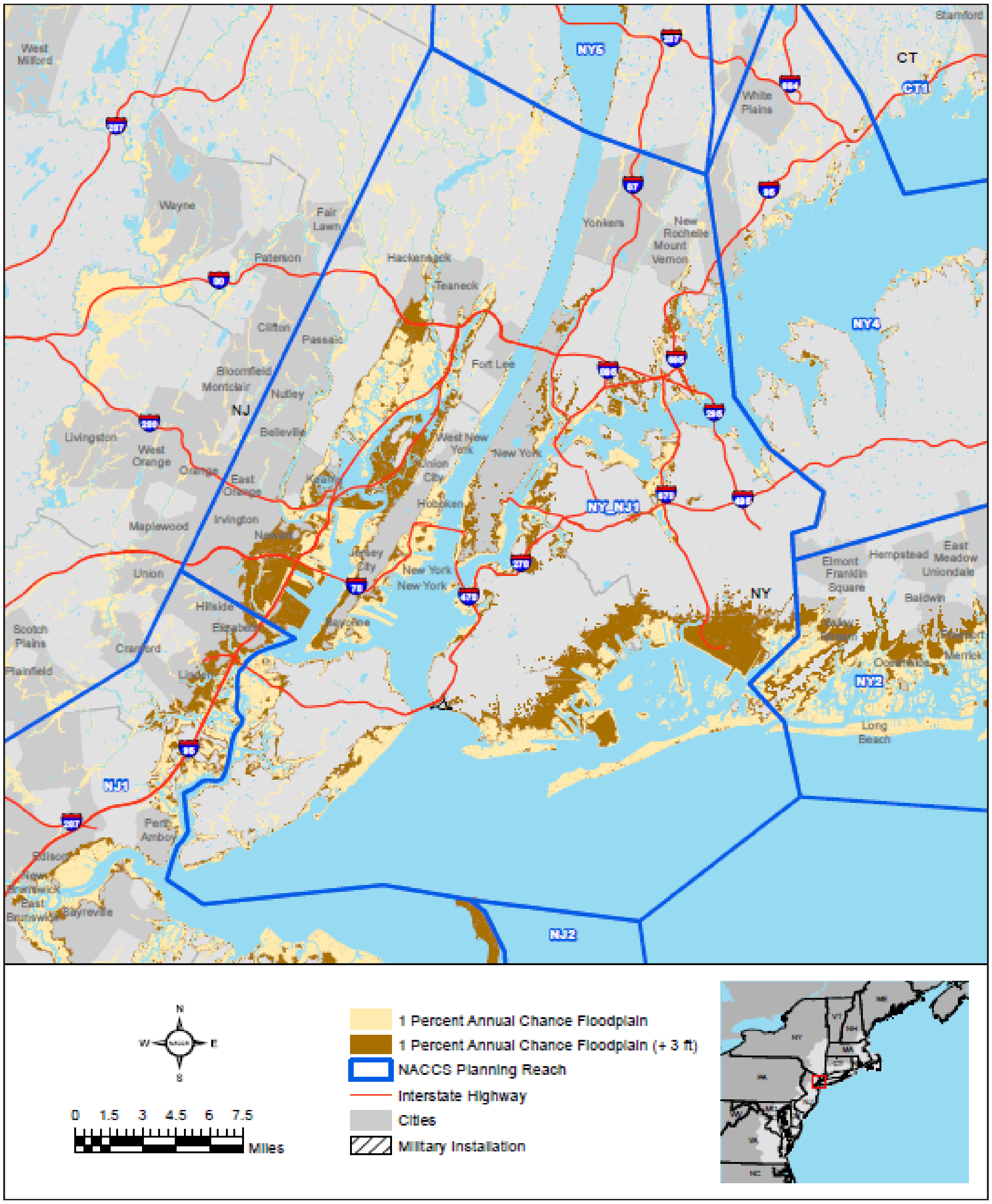

Figure 5-31: Base Flood Elevation plus 3 Feet. Map showing current annual 1-percent chance floodplain plus 3 feet for potential sea level rise by 2068 (USACE an NOAA high scenarios).

The NACCS also mapped areas exposed to the current 1-percent-annual-chance flood plus a 3-foot relative sea level change allowance (see Figure 5-31[198]). The 3-foot allowance was closely aligned with the USACE/NOAA high scenario for project relative SLR by year 2068, as well as New York City's recent recommendations.

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[198] USACE, 2015b.

USGS Coastal Vulnerability and Shoreline Change

The USGS has developed two methods to describe the vulnerability of coastal regions: a Coastal Vulnerability Index (CVI), [199] and probabilistic assessment of shoreline change that uses a Bayesian Network approach. [200]

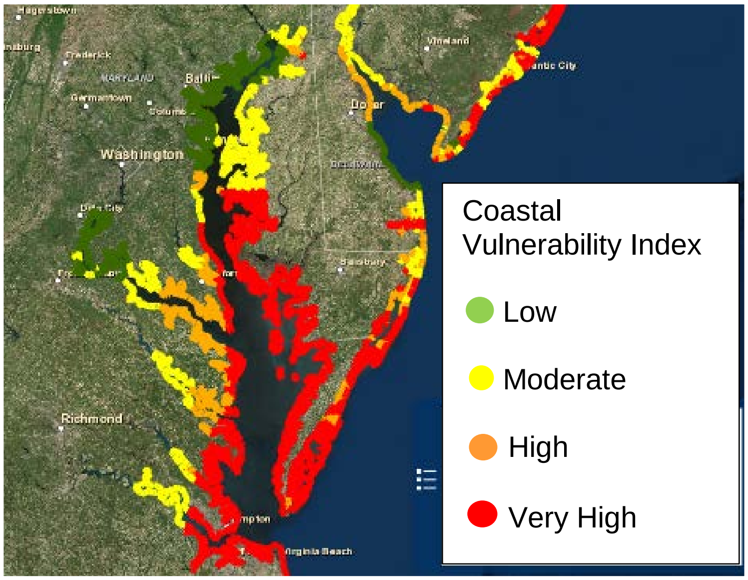

Figure 5-32: Coastal Vulnerability Index for the Atlantic Coast

The CVI (see Figure 5-32) provides a preliminary overview, at a national scale, of the relative susceptibility of the Nation's coast to SLR. This classification is based upon the following variables: geomorphology, regional coastal slope, tide range, wave height, relative SLR, and shoreline erosion and accretion rates.

The combination of these variables and the association of these variables to each other furnish a broad overview of regions where physical changes are likely to occur due to SLR.

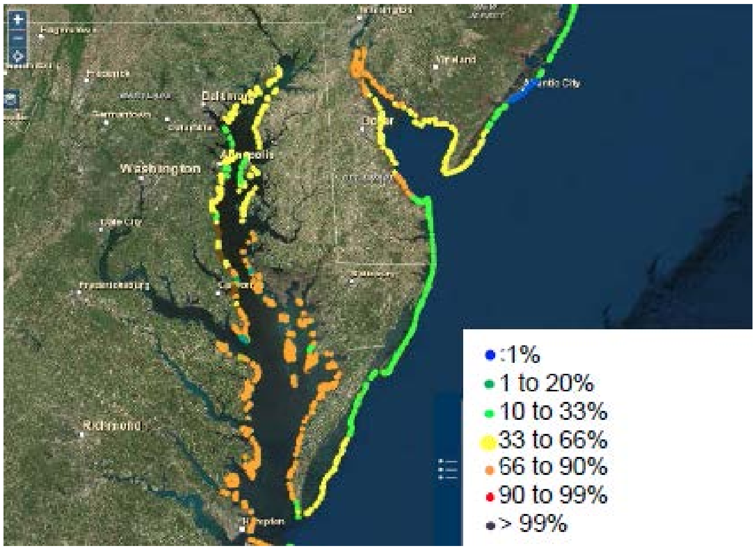

Figure 5-33: Probabilities of High Shoreline Loss

Probabilistic shoreline change data were used to develop and evaluate the performance of a Bayesian Network that predicts long-term shoreline change associated with SLR. The Bayesian Network is used to define relationships between driving forces, geologic constraints, and coastal response, which includes observations of local rates of relative SLR, wave height, tide range, geomorphology, coastal slope, and rate of shoreline change. Using this information, the Bayesian Network is used to make probabilistic predictions of shoreline change in response to different future SLR scenarios (see Figure 5-33).

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[199] Thieler and Hammar-Klose 1999.

[200] Gutierrez, et al., 2014.

Puerto Rico Pilot and Prototype Sea Level Advisory Maps

FEMA conducted a pilot study in Puerto Rico to assess the feasibility of producing an SLR prototype advisory layer that could be added to a FIRM. The study examined different modeling approaches (e.g., Advanced Circulation and Storm Surge model or ADCIRC, Sea, Lake, and Overland Surges from Hurricanes model or SLOSH, and linear superposition). FEMA compared the results to conclude that linear superposition was a fairly good approximation of SLR impacts on the stillwater elevations, but that wave effects to determine future coastal high hazard areas required at least a depth-limited wave approximate approach if not a full-blown wave analysis (see Table 5-2[201]).

One output of the study was "proof of concept" maps that illustrated the impacts of future flood extents from SLR as advisory maps. These maps were presented as non-regulatory (advisory) products that could be developed as add-on products to Risk MAP studies (see Figure 5-34). The maps convey the future changes to the coastal flood hazard and can be used to guide long-term planning and adaption. Proactive communities could include this product for a fairly low incremental production cost. Uncertainty could also be shown on the maps indicating the imprecise nature of future conditions mapping (see Figure 5-35).

Table 5-2: Puerto Rico Pilot Study Results.
Wave effects increase the BFE non-linearly in this Puerto Rico case study. Linear superposition with depth-limited wave calculations may provide an effective estimate for a lower cost.

Parameter, all units in feet	Baseline Case	SLR Scenarios		

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[201] Batten, Brian, "Case Studies of SLR and Floodplain Mapping".

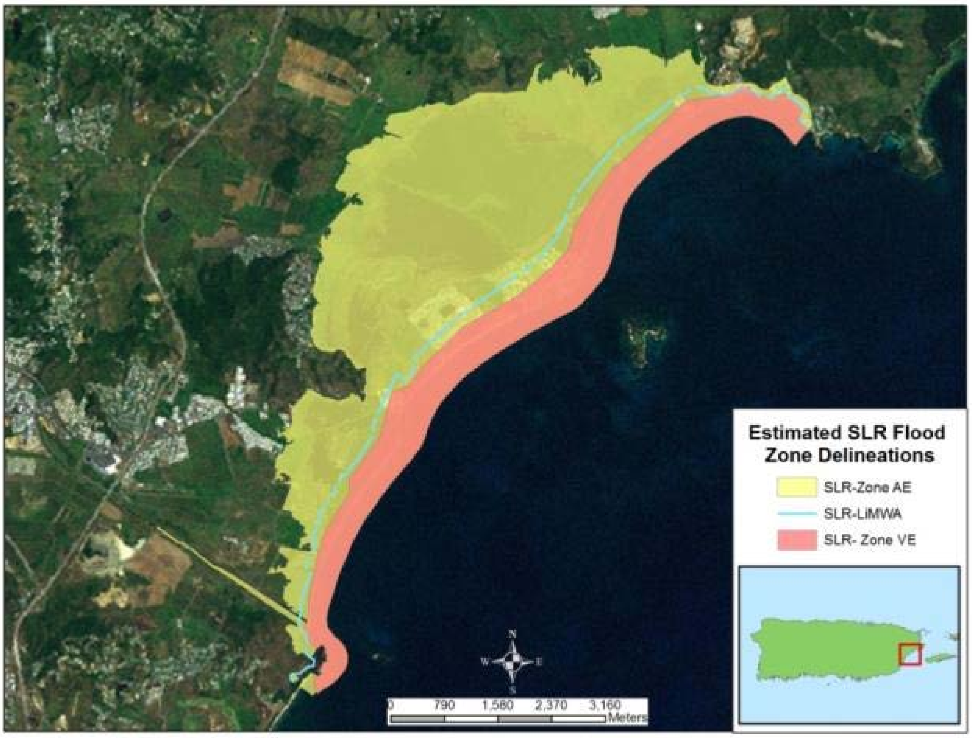

Figure 5-34: Example Sea Level Rise Advisory Layer.
This example shows future Zone AE, Limit of Moderate Wave Action, and Zone VE.

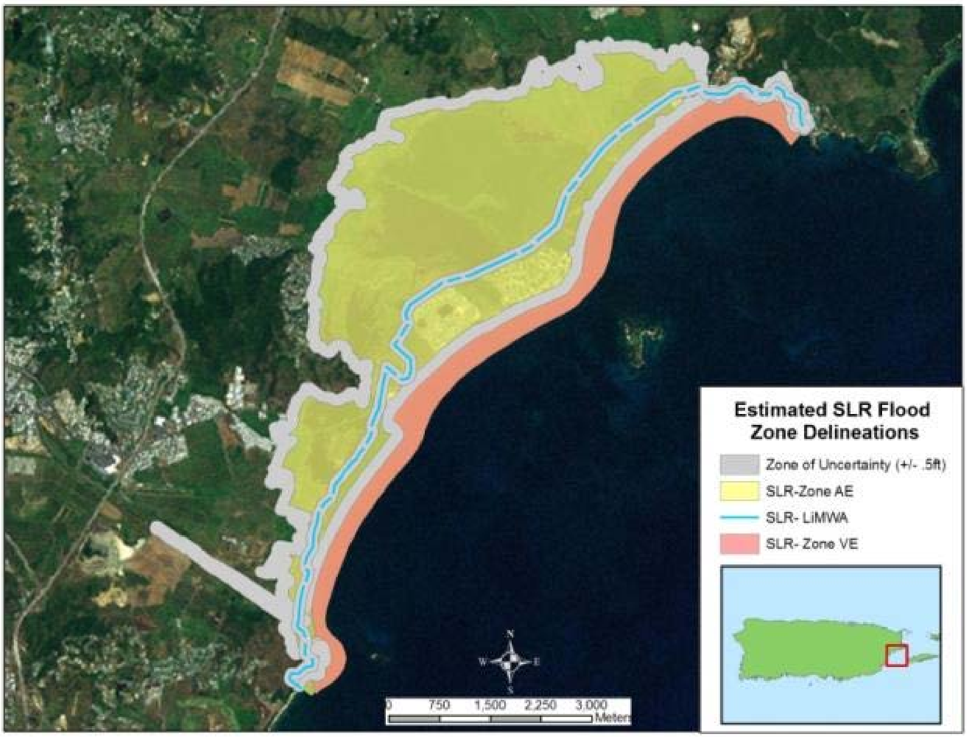

Figure 5-35: Illustrating Uncertainty. Uncertainty bands could also be included.

Probabilistic Maps to Show Future Coastal Flood Hazards

Another method of displaying future coastal flood hazards is in a probabilistic sense. If probabilistic analyses are performed either for long-term coastal erosion or for SLR, the resulting map products could be shown in terms of confidence intervals. The USGS shoreline loss estimates discussed in the USGS case study above show probabilities of high shoreline loss. One study[202] provide a good example of a conceptual map based on probability of exceedance for predicted coastal erosion distances based on SLR, other factors including changing wave climate, and frequency of El Nino events (see Figure 5-36).

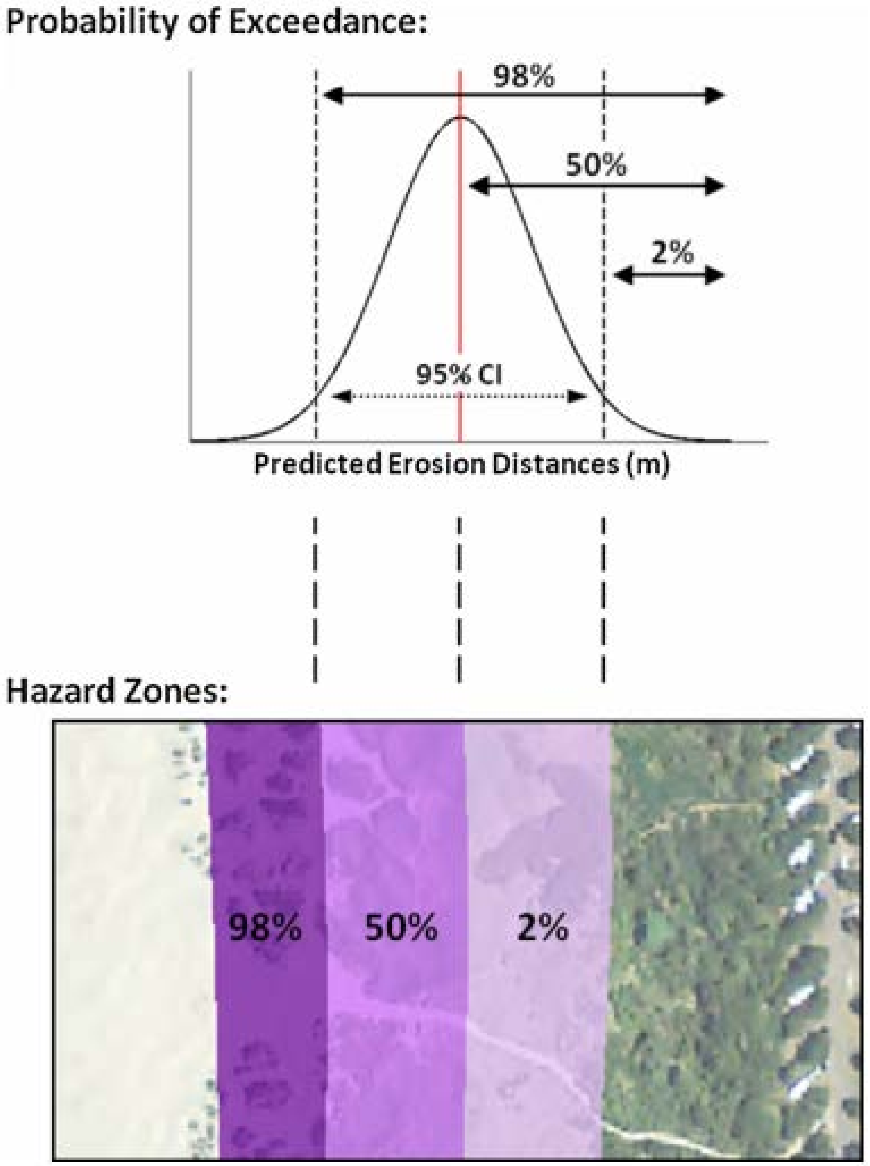

Figure 5-36: Probabilistic Mapping.
Example of mapping hazard zones based on probability of exceedance.

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[202] Baron, et al., 2015.

Sub-Recommendation 5-9: FEMA should support additional research to characterize how a changing climate will result in changes in Great Lakes and ocean wave conditions, especially along the Pacific Coast. The relative importance of waves on this coast makes this an important consideration.

Sub-Recommendation 5-10: For the Great Lakes, the addition or subtraction of future lake level elevations associated with a changing climate is not recommended at this time due to current uncertainty in projections of future lake levels.

Sub-Recommendation 5-11: Maps displaying the location and extent of areas subject to long-term coastal erosion and future sea level rise scenarios should be advisory (non-regulatory) for Federal purposes. Individuals and jurisdictions can use the information for decision-making and regulatory purposes if they deem appropriate.

Sub-Recommendation 5-12: FEMA should build upon the existing current conditions flood hazard analyses prepared by FEMA for the NFIP to determine future coastal flood hazards.

Sub-Recommendation 5-13: FEMA should incorporate local Relative Sea Level Rise scenarios into the existing FEMA coastal flood insurance study process in one of the following ways:

- **Direct Analysis – Incorporate sea level rise directly into process modeling (ex. surge, wave setup, wave runup, overtopping, and erosion) for regions where additional sea level is determined to impact the BFE non-linearly (ex. 1FT SLR = 2FT or more BFE increase).**
- **Linear Superposition – Add sea level to the final calculated total water level and redefine base flood elevation for regions where additional sea level is determined to impact the BFE linearly (ex. 1FT SLR = 1FT BFE increase).**

Wave effects should be calculated based on the higher Stillwater including sea level rise.

Sub-Recommendation 5-14: FEMA should support research for future conditions coastal hazard mapping pilots and case studies using the latest published methods to determine the best means to balance the costs and benefits of increasing accuracy and decreasing uncertainty.

5.6 Calculating and Mapping Future Riverine Flood Hazards

5.6.1 Recommended Approaches for Calculation

Actionable science supporting the future impacts of climate change on hydrology is still evolving. A number of large uncertainties remain to be revealed about downscaling methods, hydrologic model structures, and hydrologic model parameters. The information available today, from the large number of general circulation models (GCMs) and the various projections of greenhouse gas emissions that drive these models, provides a hint of the uncertainties, though all of the sources of uncertainty cannot be known at this time. Therefore, approaches that are tied to a single GCM or a single representative concentration pathway (RCP) are certain to underestimate uncertainty. Currently, available and actionable science does not support the development of a single, nationwide method for determining future riverine flood risk boundaries based on projected future changes to the watershed due to a combination of land use, geomorphological, climate, or other changes.

ACTIONABLE SCIENCE IN RIVERINE AREAS

Currently, available and actionable science does not support the development of a single, nationwide method for determining future riverine flood risk boundaries based on projected future changes to the watershed due to a combination of land use, geomorphological, climate, or other changes.

There are major uncertainties in quantitative projections of changes in the hydrological characteristics for a drainage basin. Precipitation, a principal input signal to water systems, is not reliably simulated in present climate models. However, it is well established that precipitation variability increases due to climate change, and projections of future temperatures, which affect snowmelt, are more consistent, such that useful conclusions are possible for snow-dominated basins.

Uncertainty has two implications. First, adaptation procedures need to be developed that do not rely on precise projections of changes in river discharge, groundwater, etc. Second, based on the studies completed so far, it is difficult to assess in a reliable way the water-related consequences of climate policies and emission pathways. Research on methods of adaptation in the face of these uncertainties is needed.[203] On the other hand, observed trends can be explored to help estimate what future conditions might look like. For example, if past records of runoff exhibit non-stationary behavior that can be attributed to a factor that is expected to continue into the future (e.g., land use change, agricultural practices that hinder or speed runoff, climate-induced changes in snowmelt), then a decision about using only a part of the historical record on which to base future projections could then be made. If non-stationary behavior is detected in the observed runoff, and there is no clear consensus in the peer-reviewed climate literature or in an analysis of multi-model behavior about the direction and/or magnitude of projected trends for the future, then the analysis could reasonably continue using the standard methods available today. The flow chart below (see Figure 5-37) provides an example of the decision process.

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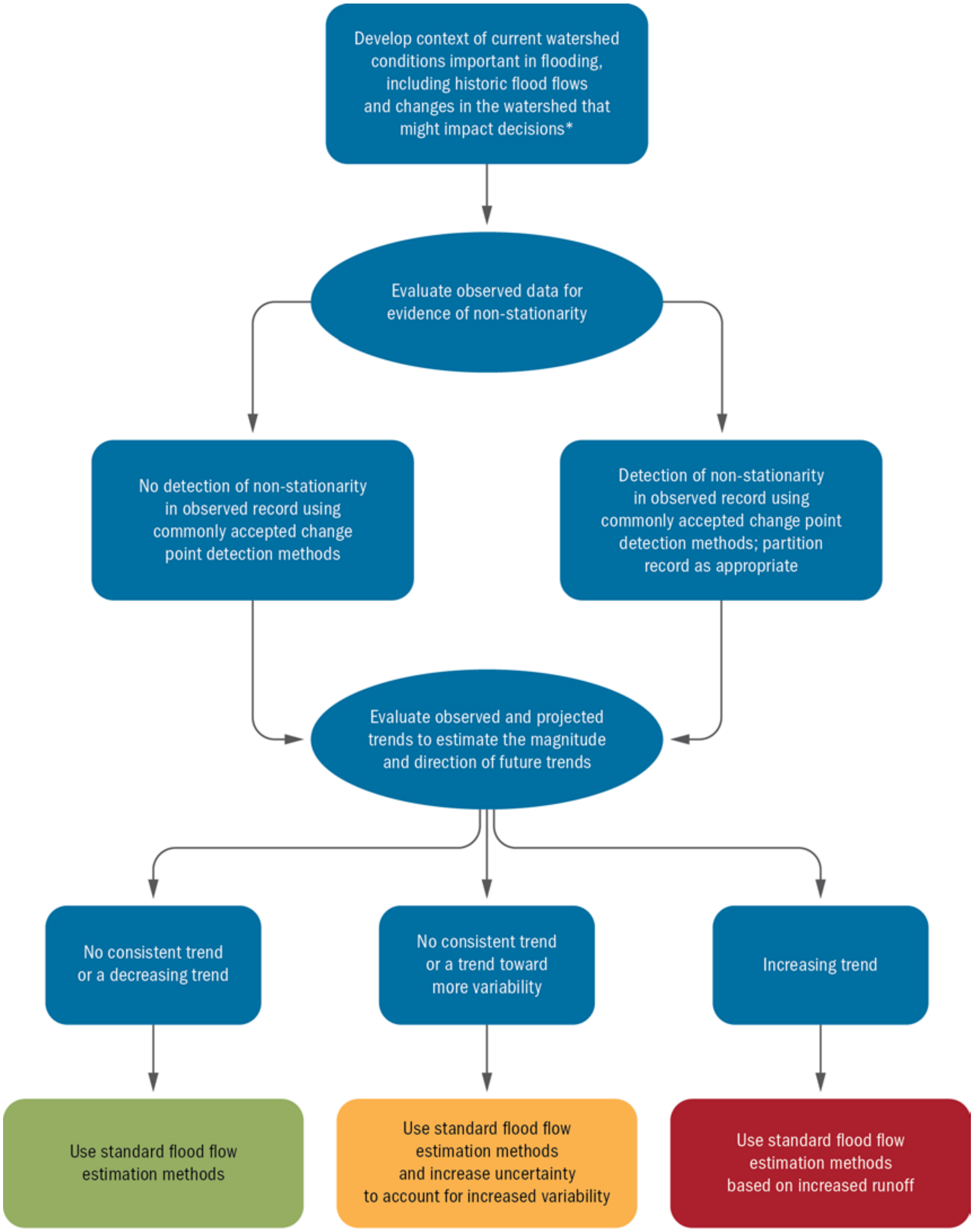
[203] Intergovernmental Panel on Climate Change, 2007.



*Changes include but not limited to: land use, agricultural practices, construction or removal of dams, and observed climate trends from NCA 3 or other reputable sources.

Figure 5-37: Decision Process.
Example decision process for calculating future flood flow based on climate-informed science.

5.6.2 Case Studies

5.6.2.1 Charlotte-Mecklenburg

In 1997, Charlotte-Mecklenburg Storm Water Services (CMSWS) developed and adopted a *Floodplain Management Guidance Document* that contained a series of strategies to more effectively management floodplains throughout the county.

Charlotte-Mecklenburg
STORM
WATER
Services

Figure 5-38: Charlotte-Mecklenburg Stormwater Services logo.

One of the key strategies identified in the document was that "new development should be managed so flood problems are not increased."[204] The evaluation of this strategy identified the ongoing challenge that FEMA studies were based on existing land use conditions at the time a study was initiated. As a result, new development was occurring in areas that could be subject to flooding in the future as growth continued to increase in each watershed. Working extensively with the development and environmental communities, CMSWS then commissioned the *Mallard Creek Floodplain Analysis and Floodplain Fill Assessment*[205] in 1998 to quantify potential increases in flood levels based on future land use changes, the impact of allowing fill to occur in the flood fringe areas, and flood height reductions through the adoption of local water quality buffer regulations.

The results of the study showed that future land use changes in the subject watershed could result in increased flood levels of 4 feet or more in some areas. The report included several recommendations based on these findings including:

- A future conditions floodplain boundary should be developed and used as a regulatory boundary and all new construction should be required to have a finished floor elevation based on the future conditions 1-percent-annual-chance elevation plus some required freeboard, and
- There should be limits on fill placed in the floodplain fringe areas.

CMSWS then initiated a countywide restudy of all streams, including both existing (FEMA floodplain for insurance purposes) and future conditions (Community floodplain) 1-percent-annual-chance flood elevations and floodplain boundaries (see Figure 5-39. In addition, CMSWS developed higher regulatory standards regarding the regulatory floodway to be used on their FIRMs.

CMSWS worked with FEMA regarding the mapping specification changes required to effectively show both the existing and future 1-percent-annual-chance floodplain boundaries and reflect the corresponding flood elevations on the FIRM and in the FIS report effectively. In 2000, Mecklenburg County produced the first FIRM in the United States to show both existing and future conditions flood elevation information. In May 2000, CMSWS adopted the Community Floodplain and flood elevations for regulating development, and the FIRMs have an initial effective date of February 4, 2004.

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[204] Charlotte-Mecklenburg Storm Water Services (CMSWS), 1997.
[205] CMSWS, 1998.

Since the initial May 2000 local adoption of the maps, CMSWS has been able to demonstrate significant reduction in potential flood losses by requiring new development be built in areas outside of mapped future floodplain areas. Some of the studies that have been completed to date estimate the following impacts:

- 1300+ structures will have avoided insured flood losses as a result of the new future flood elevation regulation.
- Losses avoided of > $160 million for a single 1-percent-annual-chance flood event.

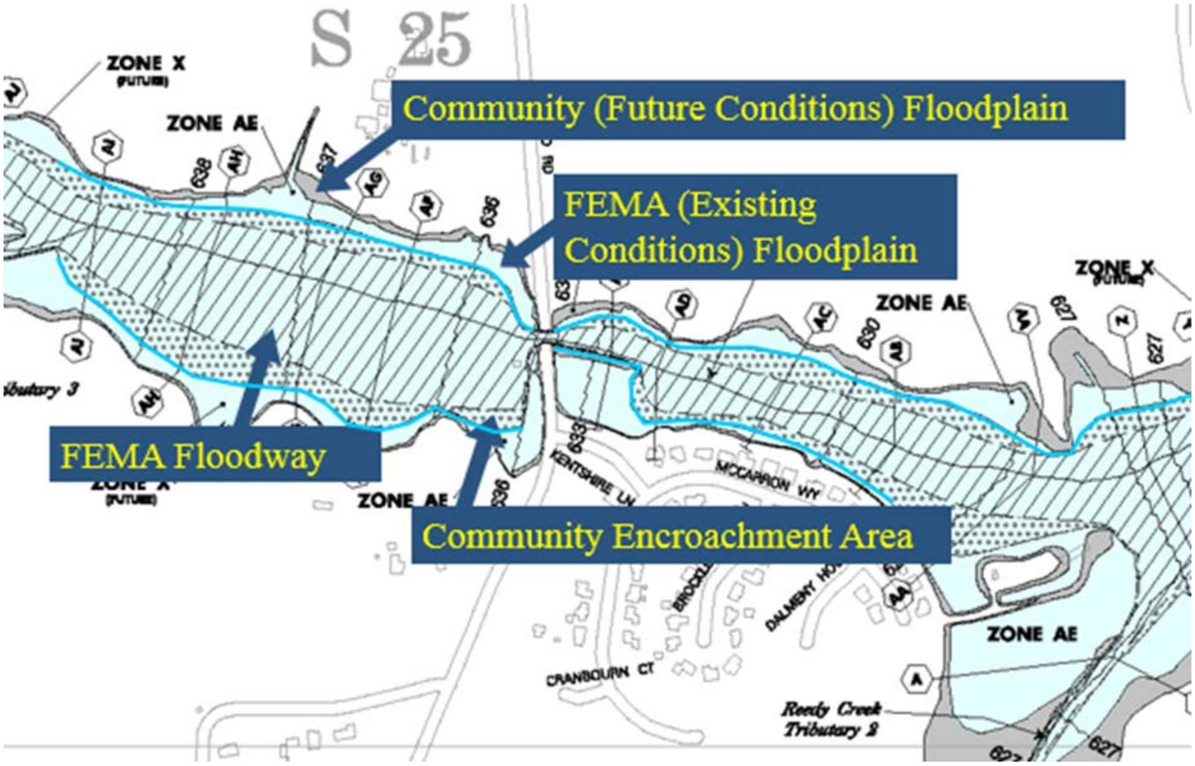

Figure 5-39: Comparison of Existing and Future Conditions Floodplains. Portion of comparison developed by CMSWS.

5.6.2.2 Licking County, Ohio

Licking County is located in central Ohio, just northwest of the City of Columbus metropolitan area. The west side of Licking County is mostly headwater streams that converge in the City of Newark, which is the centrally-located county seat. These headwater streams form the Licking River, which drains the east side of the county on its way to the Muskingum River. The first permanent settlement in the county occurred in 1798, when there was a need to locate near water bodies for transportation and sanitary reasons. Since this time, the county has experienced significant growth due to its close proximity to the State capital, extensive transportation system and abundant resources.

In 2003, FEMA initiated a FIRM and FIS update for Licking County. Early in the process, it was decided that the updated maps would incorporate future conditions hydrology. In addition to mapping the 1-percent-annual-chance floodplain, FEMA also mapped the future 1-percent-annual-chance stream discharges based on projected land use conditions identified in local zoning maps and comprehensive plans.

There are 25 townships in Licking County, including 19 townships that have zoning plans and 18 townships that have a comprehensive plan. The future condition 1-percent-annual-chance floodplain was mapped as a Shaded Zone X on the FIRM and the flood elevations at particular cross sections were published in the corresponding FIS.

In order to make the data more publically accessible, the information was added to the county's online and searchable GIS and Floodplain Map Viewer. Licking County and 12 of the incorporated communities have adopted local flood damage reduction regulations that utilize the future conditions data to eliminate or reduce damage to proposed development. This objective is accomplished by applying the same regulatory standards that are applied to the 1-percent-annual-chance floodplain to the future 1-percent-annual-chance floodplain.

As a participant in the CRS, Licking County earns points for identifying future condition flood hazard areas. These points improve the county's ranking in the program, and result in reduced flood insurance premiums for property owners and businesses.

5.6.3 Plausible Path Forward for Incorporating Future Climate Impacts into Riverine Studies

Currently, it is very difficult to predict extreme climate impacts in riverine environments. This does not mean that stakeholders should not plan for changes in climate change in the riverine environment. Stakeholders should examine locally-available information and make decisions based on the type of development proposed, the expected occupancy of proposed buildings, and the expected life of the structure. In addition, riverine climate science should be monitored closely for applicability to the NFIP and future conditions flood hazard identification.

Sub-Recommendation 5-15: FEMA should use observed riverine trends to help estimate what future conditions might look like. In watersheds where floods of interest may decrease in magnitude and frequency then use existing riverine study results as the basis for flood hazard mapping. In watersheds where floods exhibit increase in magnitude or frequency then use best available science to determine future hydrology and flood hazards.

Sub-Recommendation 5-16: FEMA should work with other Federal agencies via the Advisory Committee on Water Information's Subcommittee on Hydrology to produce a new method to estimate future riverine flood flow frequencies. This method should contain ways to consistently estimate future climate-impacted riverine floods and address the appropriate range of flood frequencies needed by the NFIP.

Sub-Recommendation 5-17: FEMA should produce, and should encourage communities to adopt, future conditions products to reduce flood risk.

6 Considerations for Future Conditions Mapping Impacts

The previous sections of this report outline the best available methodologies for considering the impacts of sea level rise and future development on flood risk. This section focuses on items to consider before all or some of the future conditions are integrated into FEMA's flood hazard mapping program. During the course of generating this report, several issues were raised concerning future conditions that are important considerations for future conditions implementation, but were not the focus of this report because they were not specifically requested by Congress. What follows is a list of 12 issues that may need to be considered when future conditions are incorporated into flood data collection and analysis and into community floodplain management practices:

1. What future risk-based information should be provided to communities?
2. What is the "base" regulatory condition? Will future conditions information be used for regulatory purposes? If so, how?
3. What is the impact to properties located in riverine and coastal environments if future conditions information become regulatory?
4. How will the rate of future change impact the implementation of future conditions products, tools, and information?
5. How will maintenance of future conditions data be performed?
6. What is the impact of future conditions on mitigation grants?
7. How should future conditions products, tools, and information be released to communities and the public?
8. Can future conditions data be used to improve the public's understanding of flood risk?
9. How should flood control structures be incorporated into future conditions hazard data and information?
10. What are the implications of FFRMS?
11. Should land development changes be separated from climate changes in future conditions data and information?
12. How might floodplain management regulations and the CRS be modified to support future conditions?

6.1 What future risk-based information should be provided to communities?

As discussed in Section 2.3.2.1, SLR, future development, and other future conditions are currently accounted for in flood insurance rate-setting through an actuarial contingency loading. However, the contingency load is not rigorously developed, and there is no explicit allocation of the load that is specifically due to future conditions.

All NFIP policies have a 1-year policy term and, thus, the actuarial premium is based on the current risk and not the expected increases or decreases in risk. However, due to continually changing conditions, the data from flood hazard maps used to set the premium may be out of date soon after the analysis is completed.

Insurance premiums are designed to provide residents with a signal as to the risk they face. By providing residents in floodprone areas with information on the insurance premium that reflects their flood-related risk next year and how it is likely to change in future years, individuals may then recognize how hazardous the area is in which they are living or working. They may be more likely to adopt cost-effective mitigation measures for reducing the damage to their property from future floods. Therefore, future conditions studies could provide a more accurate assessment of risks for years after the flood hazard analysis is conducted.

A method may need to be developed to estimate the risk between the time of the flood risk analysis and the future conditions period of time. For example, using the methodologies discussed in Section 5, a hazard analysis could be completed based on conditions today and future conditions expected in 2050. However, a method still needs to be developed to estimate the flood hazard just five years from now, so that risk-based premiums can be developed.

Equity and affordability are issues that are now being considered in determining how much a property owner will actually pay for flood insurance. Since a risk-based premium is an important source of information, there are ways to address affordability other than by subsidizing premiums. A subsidized premium implies that the property is safer than it actually is. Means-tested vouchers or mitigation funding through public sector grants or low interest loans are examples of measures that could be used to deal with affordability concerns.[206]

6.2 What is the "base" regulatory condition? Will future conditions information be used for regulatory purposes? If so, how?

The BW-12 mandate for this report directs the TMAC to outline the best available methodologies for considering the impacts of sea level rise and future development on flood risk, not to dictate how that information is used. For example, should the future conditions flood hazard information replace the existing conditions BFEs or should they be included in a non-regulatory product that communities can adopt as higher standards?

Currently, future conditions are not part of FEMA's regulatory program, although some communities map future conditions for informational or local floodplain development purposes. If future conditions information becomes regulatory, additional guidance may need to be developed and existing guidance may need to be updated. In addition, the impact on the NFIP and the needed resources may need to be considered.

Non-regulatory products cannot be appealed. If future conditions information becomes regulatory, appeals may become more prevalent. An appeal period is available for all new or modified flood hazard information on a FIRM that is regulatory, including additions or modifications of the BFE, base flood depth, SFHA boundary or zone designation, or regulatory floodway. As discussed in Section 3, future conditions modeling introduces additional uncertainty to calculations and the potential for additional appeals should be considered.

If future conditions considerations become regulatory, this could also increase the number of Letters of Map Revision (LOMRs). Incorporating future conditions requires an approach that deals with future uncertainty, including future manmade actions and changing natural systems. As time passes, items that were estimated in the distant future become the short-term future or current conditions, which can be estimated better or defined. Therefore, the estimated parameters for future conditions may frequently change. This could result in significantly more LOMRs as over time the uncertain parameters are better known.

6.3 What is the impact to properties located in riverine and coastal environments if future conditions information become regulatory?

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[206] National Research Council, 2015

If future conditions become linked to mandatory insurance requirements, an analysis of the impact to property owners may need to be conducted. Issues of equity and affordability associated with insurance premiums need to be considered. This should not be addressed through subsidized insurance premiums; other measures can be used, such as means-tested vouchers or mitigation funding.

6.4 How will the rate of future change impact the implementation of future conditions products, tools, and information?

Before implementing a policy on future conditions, the date of the "future" may need to be defined, such as 2020, 2050, 2100, or perhaps a full build-out scenario. If future conditions information becomes a regulatory aspect of the NFIP, this needs to be defined nationwide. Some possible considerations for setting a nationwide "future" date is the average life of structures, expected rate of change, and increases in uncertainty for longer time periods. Impacts on property values may also need to be considered.

If future conditions are implemented as non-regulatory products and information, then the "future" date could be defined based on the community's risk tolerance and their desired future planning horizons.

6.5 How will maintenance of future conditions data be performed?

After the initial future conditions studies are conducted, they will need to be periodically updated based on new information. This new information could include improvements to our current methodologies and technology for predicting climate change conditions. For example, in 2014, the U.S. Global Change Research Program released the Third NCA with climate change estimates. This report updated the 2009 NCA estimates and future updates are expected. Once a new NCA is issued, a statistical analysis for different regions of the Nation could be conducted to determine if new future conditions flood studies are warranted based on the new information in the NCA.

New information triggering the need for an updated future conditions study could also include new data regarding watershed land use or other changes in the watershed. If a community has a significant change to its zoning, comprehensive, or other land use plans, or if a community has incurred development that is significantly different than expected, it may require updates to its future conditions study.

6.6 What is the impact of future conditions on mitigation grants?

Use of future conditions data could have several impacts to the mitigation grant programs. For example, currently, many projects do not qualify for mitigation grants because they cannot meet the requirement that the benefit-cost ratio be equal to 1.0 or higher. If the increased risk from future conditions is considered, many more projects will meet the benefit-cost ratio requirement. It should be noted that FEMA's benefit-cost software currently allows SLR to be considered in the benefit-cost analysis.

FEMA's Hazard Mitigation Assistance Guidance may also need to be evaluated for impacts resulting from future conditions analysis. For example, the current guidance requires that elevating or retrofitting an existing structure must be done in accordance with ASCE 24-14 (BFE plus freeboard) or higher. FEMA may need to determine how the ASCE 24-14 requirements may relate to BFEs that include future conditions.

6.7 How should future conditions products, tools, and information be released to communities and the public?

Including future conditions in the NFIP may require an implementation plan. This plan may need to address how new studies are prioritized and how the new information is communicated to floodplain managers and the public.

6.8 Can future conditions data be used to improve the public's understanding of flood risk?

Changing the public's perception of safety will be an important component of the future conditions studies. Currently, members of the public may believe that they are not at risk of flooding if they are outside the SFHA. However, the current SFHAs do not consider the true hazards since they are based only on the conditions at the time of the study. Including future conditions in flood hazard identification and mapping will increase people's understanding of the real risk. However, if future conditions mapping is based on the 1-percent-annual-chance event, it will continue to demark a line that shows properties are either "in" or "out" of the floodplain.

Estimating future premiums based on estimates of future conditions risk could be a very useful tool to communicate to the public regarding the magnitude of expected increases or decreases in risk. Based on this, the public may better understand the importance of taking protective measures before the next disaster.

6.9 How should planned flood control structures be incorporated into future conditions hazard data and information?

The inclusion of the impact of planned flood control structures may need to be considered. In this report, it is recommended that the base condition be modeled without these impacts, but that a second scenario that includes the impacts of planned flood control structures and other man-made plans or impacts be an option for communities that wish to see the impacts of these structures on flood risk.

6.10 What are the implications of FFRMS?

As discussed in Section 2, FFRMS is mandatory for Federally-funded projects, including projects funded through FEMA's grant programs. The FFRMS provides three options for meeting the requirements, including:

- Use data and methods informed by best-available, actionable climate science (climate-informed science approach);
- Build the lowest floor two feet above the 100-year (1-percent-annual-chance) BFE for standard projects, and three feet above for critical buildings like hospitals and evacuation centers; or
- Build to the 500-year (0.2-percent-annual-chance) flood elevation.

Therefore, changes in future conditions mapping should be consistent with the options for meeting the FFRMS.

6.11 Should land development changes be separated from climate changes in future conditions data and information?

Future conditions changes to the floodplain can be the result of two types of changes: (1) those changes that are a result of actions within the watershed (e.g., changes in land use, filling in floodplains); and (2) those changes that are related to global climate change (e.g., SLR, rainfall pattern changes). Communities can make decisions that have a measurable effect on the first type of change, but not the second. Therefore, it may be beneficial to analyze and map these two types of future conditions changes separately. This distinction would allow communities and the public to better understand the root cause of the changes in risk over time.

6.12 How might floodplain management regulations and the CRS be modified to support future conditions?

The current CRS program allows communities to accrue points to improve their CRS ratings by implementing future conditions requirements. Therefore, communities that implement certain future conditions programs can receive higher insurance discounts (see Section 2.2.1). This program could be updated to further encourage communities to implement additional future conditions requirements. This program may also need to be re-evaluated based on future conditions implementation.

The implications of future conditions risks on floodplain management may also need to be considered. There are existing examples of future conditions mapping being used as an effective floodplain management tool, such as in Charlotte-Mecklenburg, North Carolina. Instead of the current 1-percent-annual-chance floodplain, Charlotte-Mecklenburg manages to the "Community Floodplain," which includes future "ultimate" land use conditions. The county has estimated that their future conditions floodplain mapping may help prevent $16 million in future flood damage.[207]

However, potential negative implications to floodplain management for communities that are not pro-active like Charlotte-Mecklenburg may also need to be considered. For example, No Adverse Impact floodplain management is an approach by which actions on any property are not allowed to adversely affect the property or rights of others. If a community uses future conditions mapping that shows an increased elevation due to actions in the watershed, it may be more challenging for some communities to prohibit some actions that increase the flood elevations.

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[207] Louisiana Resiliency Assistance Program, 2013.

7 Summary and Recommendations

1.1 Purpose

The focus of this report is to detail how future conditions flood hazards should be calculated. The TMAC recommends that all future conditions flood hazard information be non-regulatory for Federal purposes, but be created in such a manner that that it can be adopted by local communities for local regulatory and decision-making uses. Communities should be allowed—and encouraged—to adopt the future conditions flood hazard products, tools, and information for local floodplain management purposes on the local level.

7.1 Importance for the Nation

The identification and broad availability of future conditions flood hazard and risk information is of utmost importance to our Nation's citizens and economy as development and population growth occur in areas that are at risk now, or will be in the future. Several recent directives, pieces of legislation, reports, and initiatives support this assertion:

- Since its inception in 1968, the National Flood Insurance Program has undergone numerous changes and reforms, including the option of using future conditions hydrology based on projected development as an informational layer on FIRMs in communities requesting that option in 2001. The 2012 NFIP Reform legislation provides the impetus for this report.
- Recent GAO reports, such as the 2014 report titled, *Better Management of Exposure to Potential Future Losses Is Needed for Federal Flood and Crop Insurance*,[208] call for the need to take future risks into account.
- Signed by the President on March 30, 2011, Presidential Policy Directive 8 seeks to strengthen the Nation's security and resilience to manmade and natural disasters through preparedness by all levels of government, the private and nonprofit sectors, and individual citizens. The National Mitigation Framework includes climate adaptation as an important planning consideration.
- The new FFRMS, issued in January 2015, gives Federal agencies the flexibility to select one of three approaches for establishing the flood elevation and hazard area they use in siting, design, and construction. The approach options include using data and methods informed by the best-available, actionable climate science.

The planning, zoning, land use, and other development decisions made by communities today will impact the buildings and infrastructure that will be in existence for decades to come. The recommendations provided here support the assertion that, to become a more resilient Nation, elected officials, community planners, engineers, architects, emergency management officials, and decision-makers will need the tools necessary to plan, prepare for, and mitigate against future flood hazards.

7.2 Summary of Recommendations

The tables below show the seven primary Future Conditions recommendations from the TMAC as well as sub-recommendations that support the primary recommendations.

The sub-recommendations are numbered according to the section of this report in which they appear, and reflect the numerical order in which they appear in that section. For example, Sub-Recommendation 3-1 is the first sub-recommendation in Section 3, Sub-Recommendation 3-2 is the second, and so on. The sub-

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[208] GAO, 2014.

recommendations also include estimates of the amount of time required to achieve the recommended action. "Short-term" means up to 2 years to accomplish and "long-term" means greater than 2 years to achieve.

The TMAC believes that future conditions flood hazard products, tools, and information can be developed and provided to communities via policy change alone, and that regulatory or legislative changes are not necessary at this time. Though many of the recommendations and sub-recommendations outlined in this report are specific to FEMA, many of them should be undertaken with mapping partners and other relevant stakeholders, including the private sector.

Table 7-1: Recommendation 1 and Sub-Recommendations

Recommendation 1: Provide future conditions flood risk products, tools, and information for coastal, Great Lakes, and riverine areas. The projected future conditions should use standardized timeframes and methodologies wherever possible to encourage consistency and should be adapted as actionable science evolves.		
Sub-Recommendation		
	FEMA should use future risk assessments to take into account the likelihood of events occurring and their impacts, as well as the associated uncertainties surrounding these estimates.	Short-term
	FEMA should define a future population metric that uses a standard future population database along with various budget scenarios for keeping the data current to predict the percent of the population covered at various points in the future.	Short-term
	FEMA should take into account future development (excluding proposed flood control structures for the base condition/scenario) for future conditions mapping. An additional scenario can be generated that does include future flood control structures.	Short-term
	FEMA should use population growth as an indicator of areas with increased potential flood risk.	Short-term
	FEMA should develop guidance for how local zoning and land use planning can be used to identify where and how land use will change in the future, and incorporate that into local hazard and risk modeling.	Short-term

Recommendation 1, continued		
Sub-Recommendation		**Timing**
4-11	FEMA should develop a policy and standards on how to consider and determine erosion zones that are outside of the SFHA as they ultimately affect flooding and environmental conditions within the SFHA.	Short-term
5-2	FEMA should use a scenario approach for future conditions flood hazards calculation and mapping that will allow users to evaluate the robustness of proposed solutions to a range of plausible future conditions including uncertain land use and climate change impacts.	Long-term

Table 7-2: Recommendation 2 and Sub-Recommendations

Recommendation 2: Identify and quantify accuracy and uncertainty of data and analyses used to produce future conditions flood risk products, tools, and information.		
Sub-Recommendation		**Timing**
	FEMA should use future risk assessments to take into account the likelihood of events occurring and their impacts, as well as the associated uncertainties surrounding these estimates.	Short-term
	FEMA should publish multiple future conditions flood elevation layers that incorporate uncertainty so as to provide a basis for building designs that lower flood risk.	Short-term

Table 7-3: Recommendation 3 and Sub-Recommendations

Recommendation 3: Provide flood hazard products and information for coastal and Great Lakes areas that include the future effects of long-term erosion and sea/lake level rise. **Major elements are:** ▪ **Provide guidance and standards for the development of future conditions coastal flood hazard and risk products.** ▪ **Incorporate local relative sea/lake level rise scenarios and long-term coastal erosion into coastal flood hazard analyses.** ▪ **Consider the range of potential future natural and manmade coastal changes, such as inundation and coastal erosion.**		
Sub-Recommendation		**Timing**
4-1	FEMA should use a scenario approach when considering shoreline location for the estimation of future conditions flood hazards. At least two scenarios should be evaluated: one in which the shoreline is held at its present location, and another in which the shoreline is eroded according to the best available shoreline erosion data.	Short-term
4-6	FEMA should develop guidance for incorporating future conditions into coastal inundation and wave analyses.	Short-term

Recommendation 3: Provide flood hazard products and information for coastal and Great Lakes areas that include the future effects of long-term erosion and sea/lake level rise.
Major elements are:

- **Provide guidance and standards for the development of future conditions coastal flood hazard and risk products.**
- **Incorporate local relative sea/lake level rise scenarios and long-term coastal erosion into coastal flood hazard analyses.**
- **Consider the range of potential future natural and manmade coastal changes, such as inundation and coastal erosion.**

Sub-Recommendation		**Timing**
Recommendation 3, continued		
Sub-Recommendation		**Timing**
4-8	FEMA should develop consistent methods and models for long-term coastal erosion hazard mapping.	Short-term
5-4	FEMA should use Parris, et. al., 2012, or similar global mean sea level scenarios, adjusted to reflect local conditions, including any regional effects (Local Relative Sea Level) to determine future coastal flood hazard estimates. Communities should be consulted to determine which scenarios and time horizons to map based on risk tolerance and criticality.	Short-term
5-5	FEMA should work with other Federal agencies (e.g., NOAA, USACE, USGS), the U.S. Global Change Research Program (USGCRP), and the National Ocean Council to provide a set of regional sea-level rise scenarios, based on the Parris, et al., 2012 scenarios, for the coastal regions of the United States out to the year 2100 that can be used for future coastal flood hazard estimation.	Short-term
5-7	FEMA should prepare map layers displaying the location and extent of areas subject to long-term erosion and make the information publicly available. Elements include: Establishing the minimum standards for long-term erosion mapping that will be used by FEMA that must be met by partners/communities if it is to be incorporated into the FEMA products. Working with Federal, State, and local stakeholders to develop these minimum standards via pilot studies. Securing funding that can support sustained long-term erosion monitoring and mapping by allowing for periodic updates.	Long-term
5-9	FEMA should support additional research to characterize how a changing climate will result in changes in Great Lakes and ocean wave conditions, especially along the Pacific Coast. The relative importance of waves on this coast makes this an important consideration.	Long-term
5-10	For the Great Lakes, the addition or subtraction of future lake level elevations associated with a changing climate is not recommended at this time due to current uncertainty in projections of future lake levels.	Short-term
5-11	FEMA should build upon the existing current conditions flood hazard analyses prepared by FEMA for the NFIP to determine future coastal flood hazards.	Short-term

Recommendation 3: Provide flood hazard products and information for coastal and Great Lakes areas that include the future effects of long-term erosion and sea/lake level rise.
Major elements are:

- **Provide guidance and standards for the development of future conditions coastal flood hazard and risk products.**
- **Incorporate local relative sea/lake level rise scenarios and long-term coastal erosion into coastal flood hazard analyses.**
- **Consider the range of potential future natural and manmade coastal changes, such as inundation and coastal erosion.**

Sub-Recommendation		**Timing**
5-12	FEMA should incorporate local Relative Sea Level Rise scenarios into the existing FEMA coastal flood insurance study process in one of the following ways: Direct Analysis – Incorporate sea level rise directly into process modeling (ex. surge, wave setup, wave runup, overtopping, and erosion) for regions where additional sea level is determined to impact the BFE non-linearly (ex. 1FT SLR = 2FT or more BFE increase). Linear Superposition – Add sea level to the final calculated total water level and redefine BFE for regions where additional sea level is determined to impact the BFE linearly (ex. 1FT SLR = 1FT BFE increase). Wave effects should be calculated based on the higher Stillwater, including sea level rise.	Short-term
5-13	Maps displaying the location and extent of areas subject to long-term coastal erosion and future sea level rise scenarios should be advisory (non-regulatory) for Federal purposes. Individuals and jurisdictions can use the information for decision-making and regulatory purposes if they deem appropriate.	Short-term

Table 7-4: Recommendation 4 and Sub-Recommendations

Recommendation 4: Provide future conditions flood risk products and information for riverine areas that include the impacts of: future development, land use change, erosion, and climate change, as actionable science becomes available. Major elements are:

- **Provide guidance and standards for the development of future conditions riverine flood risk products.**
- **Future land use change impacts on hydrology and hydraulics can and should be modeled with land use plans and projections, using current science and build upon existing model study methods where data are available and possible.**
- **Future land use should assume built-out floodplain fringe and take into account the decrease of storage and increase in discharge.**
- **No actionable science exists at the current time to address climate change impacts to watershed hydrology and hydraulics. If undertaken, interim efforts to incorporate climate change impacts in flood risk products and information should be based on existing methods, informed by historical trends, and incorporate uncertainty based upon sensitivity analyses.**

Where sufficient data and knowledge exist, incorporate future riverine erosion (channel migration) into flood risk products and information.

Sub-Recommendation		Timing
4-7	FEMA should evaluate previously-issued guidance for future conditions land use and hydrology to incorporate best practices and lessons learned from communities that have implemented the guidance since 2001.	Short-term
4-9	FEMA should determine long-term riverine erosion hazard areas for areas subject to high erosion and provided to the public in a digital layer.	Short-term
4-10	FEMA should utilize a national standard for riverine erosion zone delineations that reflects geographic variability.	Short-term
5-6	FEMA should take the impacts of future development and land use change on future conditions hydrology into account when computing future conditions for riverine areas.	Short-term
5-8	FEMA should implement riverine erosion hazard mapping (E Zones that define channel migration zones), leveraging existing data, models, and approaches that reflect site-specific processes and conditions.	Long-term

Recommendation 4, continued		
Sub-Recommendation		**Timing**
5-15	FEMA should use observed riverine trends to help estimate what future conditions might look like. In watersheds where floods of interest may decrease in magnitude and frequency then use existing riverine study results as the basis for flood hazard mapping. In watersheds where floods exhibit increase in magnitude or frequency then use best available science to determine future hydrology and flood hazards.	Short-term
5-16	FEMA should work with other Federal agencies via the Advisory Committee on Water Information's Subcommittee on Hydrology to produce a new method to estimate future riverine flood flow frequencies. This method should contain ways to consistently estimate future climate-impacted riverine floods and address the appropriate range of flood frequencies needed by the NFIP.	Long-term
5-17	FEMA should produce, and should encourage communities to adopt, future conditions products to reduce flood risk.	Short-term

Table 7-5: Recommendation 5 and Sub-Recommendation

Recommendation 5: Generate future conditions data and information such that it may frame and communicate flood risk messages to more accurately reflect the future hazard in ways that are meaningful to and understandable by stakeholders. This should enable users to make better-informed decisions about reducing future flood-related losses.		
Sub-Recommendation		**Timing**
3-3	FEMA should frame future risk messages for future conditions data and information such that individuals will pay attention to the future flood risk. Messages may be tailored to different stakeholders as a function of their needs and concerns.	Long-term

Table 7-6: Recommendation 6 and Sub-Recommendations

Recommendation 6: Perform demonstration projects to develop future conditions data for representative coastal and riverine areas across the nation to evaluate the costs and benefits of different methodologies or identify/address methodological gaps that affect the creation of future conditions data.		
Sub-Recommendation		**Timing**
3-1	FEMA should perform a study to quantify the accuracies, degree of precision, and uncertainties associated with respect to flood studies and mapping products for existing and future conditions. This should include the costs and benefits associated with any recommendation leading to additional requirements for creating flood related products.	Short-term

Recommendation 6: Perform demonstration projects to develop future conditions data for representative coastal and riverine areas across the nation to evaluate the costs and benefits of different methodologies or identify/address methodological gaps that affect the creation of future conditions data.		
5-3	FEMA should conduct future conditions mapping pilots to continue to refine a process and methods for mapping and calculating future flood hazards and capture and document best practices and lessons learned for each.	Short-term
5-14	FEMA should support research for future conditions coastal hazard mapping pilots and case studies using the latest published methods to determine the best means to balance the costs and benefits of increasing accuracy and decreasing uncertainty.	Short-term

Table 7-7: Recommendation 7 and Sub-Recommendations

Recommendation 7: Data and analysis used for future conditions flood risk information and products should be consistent with standardized data and analysis used to determine existing conditions flood risk, but also should include additional future conditions data, such as climate data, sea level rise information, long-term erosion data; and develop scenarios that consider land use plans, planned restoration projects, and planned civil works projects, as appropriate, that would impact future flood risk.		
Sub-Recommendation		**Timing**
	FEMA should support expanded research innovation for water data collection, for example using Doppler radar.	Short-term
	FEMA should use a scenario approach to evaluate the impacts of future flood control projects on future conditions flood hazards.	Short-term
	FEMA should support research on future conditions land use effects on future conditions hydrology and hydraulics.	Short-term
	FEMA should develop guidance for evaluating locally developed data from States and communities to determine if it is an improvement over similarly-available national datasets and could be used for future condition flood hazard analyses.	Short-term
	FEMA should develop better flood risk assessment tools to evaluate future risk, both population-driven and climate-driven. Improve integration of hazard and loss estimation models (such as Hazus) with land use planning software designed to analyze and visualize development alternatives, scenarios, and potential impacts to increase use in local land use planning.	Long-term
	Future flood hazard calculation and mapping methods and standards should be updated periodically as we learn more through observations and modeling of land surface and climate change, and as actionable science evolves.	Short-term

8 Glossary[209]

0.2-Percent-Annual-Chance Flood – The flood that has a 0.2-percent chance of being equaled or exceeded in any given year.

1-Percent-Annual-Chance Flood – The flood that has a 1-percent chance of being equaled or exceeded in any given year.

2-Percent-Annual-Chance Flood – The flood that has a 2-percent chance of being equaled or exceeded in any given year.

3D Elevation Program (3DEP) – The primary goal of 3DEP is to systematically collect enhanced elevation data in the form of high-quality light detection and ranging (LiDAR) data over the conterminous United States, Hawaii, and the U.S. territories.

Aleatory Uncertainty – Variability in the physical world; uncertainty arising from variations inherent in the behavior of natural phenomena that are viewed as random rather than systematic.

Approximate Study – A flood hazard study that results in the delineation of floodplain boundaries for the 1-percent-annual-chance (100-year) flood, but does not include the determination of BFEs or flood depths.

Base Flood – The flood that has a 1-percent chance of being equaled or exceeded in any given year.

Base Flood Elevation (BFE) – The elevation of a flood having a 1-percent chance of being equaled or exceeded in any given year.

Bayesian Network, The – Used to define relationships between driving forces, geologic constraints, and coastal response, which includes observations of local rates of relative sea level rise, wave height, tide range, geomorphology, coastal slope, and rate of shoreline change.

Biggert-Waters Flood Insurance Reform Act of 2012 (BW-12) – Legislation that was later revised by the *Homeowner Flood Insurance Affordability Act of 2014* requiring the Federal Emergency Management Agency and other agencies to make a number of changes to the way the National Flood Insurance Program is run. Key provisions of the legislation required the program to raise rates to reflect true flood risk and make the program more financially stable. The legislation also authorized the Technical Mapping Advisory Council to re-convene.

Climate-Informed Science Approach – The use of data and methods informed by best-available, actionable climate science.

Coastal Flooding – Flooding that occurs along the Great Lakes, the Atlantic and Pacific Oceans, and the Gulf of Mexico.

Coastal High Hazard Area – An area of special flood hazard extending from offshore to the inland limit of a primary frontal dune along an open coast and any other area subject to high-velocity wave actions from storms or seismic sources.

Coastal Vulnerability Index (CVI) Allows six physical variables to be related in a quantifiable manner, which yields numerical data that cannot be directly equated with particular physical effects, but can highlight those regions where the various effects of sea level rise may be the greatest.

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[209] Except for those definitions with specific references noted, all definitions provided below have been obtained from FEMA, other Federal agencies, or from the body of this report.

Code of Federal Regulations (CFR) – The codification of the general and permanent rules published in the Federal Register by the Executive Departments and agencies of the Federal Government. National Flood Insurance Program regulations are printed in Parts 59 through 77 of Title 44 of the CFR.

Community – Any State or area or political subdivision thereof, or any Indian tribe or authorized tribal organization, or Alaska Native village or authorized native organization, which has the authority to adopt and enforce floodplain management regulations for the areas within its jurisdiction.

Community Rating System (CRS) – A FEMA initiative, established under the National Flood Insurance Program, to recognize and reward communities that have implemented floodplain management measures beyond the minimum required by National Flood Insurance Program regulations. Under the CRS, those communities that choose to participate voluntarily may reduce the flood insurance premium rates for property owners in the community by taking these additional actions.

Conditional Letter of Map Revision (CLOMR) – The FEMA response to a community request for FEMA's comment on proposed alterations to the floodplain conditions within that community. The CLOMR describes the effect of the proposed project, if constructed as proposed, on the effective FIRM, FBFM, and/or FIS report. A CLOMR often contains detailed information on conditions that must be met by a requester before FEMA will issue a final determination regarding revising the FIRM, FBFM, and/or FIS report.

Cooperating Technical Partners (CTP) Program – A program to create partnerships between FEMA and participating National Flood Insurance Program communities, regional agencies, State agencies, and non-governmental organizations that have the interest and capability to become more active participants in the FEMA Flood Hazard Mapping Program.

Digital Elevation Model (DEM) – A gridded array of elevations.

Epistemic Uncertainty (Knowledge Uncertainty) – Uncertainty arising from imprecision in analysis methods and data. Arises from a lack of understanding of events and processes, or from a lack of data; such lack of knowledge is reducible with additional measurements, observations, and scientific analysis.

Executive Order 11988 – Requires Federal agencies to avoid to the extent possible the long and short-term adverse impacts associated with the occupancy and modification of flood plains and to avoid direct and indirect support of floodplain development wherever there is a practicable alternative.

Federal Advisory Committee Act (FACA) – A Federal law that governs the establishment and operation of advisory committees. It is implemented government-wide by the General Services Administration (GSA), which has issued regulations and guidance.

Flood – A general and temporary condition of partial or complete inundation of 2 or more acres of normally dry land area or of 2 or more properties (at least 1 of which is the policyholder's property) from: (1) overflow of inland or tidal waters; or (2) unusual and rapid accumulation or runoff of surface waters from any source; or (3) mudflow; or (4) collapse or subsidence of land along the shore of a lake or similar body of water as a result of erosion or undermining caused by waves or currents of water exceeding anticipated cyclical levels that result in a flood as defined above.

Flood Boundary and Floodway Map (FBFM) – The floodplain management map issued by FEMA that depicts, based on detailed flood hazard analyses, the boundaries of the 1-percent-annual-chance (100-year) and the 0.2-percent-annual-chance (500-year) floodplains and, when appropriate, the regulatory floodway. The FBFM does not show flood insurance risk zones or BFEs.

Flood hazard – Flood conditions (e.g., depth, wind, velocity, duration, waves, erosion, and debris) that have the potential to cause fatalities, injuries, property damage, infrastructure damage, agricultural loss, damage to the environment, interruption of business, or other types of harm or loss.[210]

Flood Hazard Boundary Map (FHBM) – Official map of a community issued by FEMA, where the boundaries of the flood, mudflow, and related erosion areas having special hazards have been designated.

Flood risk – Expected flood losses, based on the likelihood and severity of flooding, the natural and manmade assets at risk, and the consequences to those assets.[211]

Freeboard Value Approach – The use of two feet above the 1-percent-annual-chance flood (also referred to as the base flood) as the elevation for standard projects and three feet above the 1-percent-annual-chance elevation for critical buildings, like hospitals and evacuation centers.

Frequency Curve – A graph showing the number of times per year on the average that floods of certain magnitudes are equaled or exceeded.

Flood Insurance Rate Map (FIRM) – The insurance and floodplain management map produced by FEMA that identifies, based on detailed or approximate analyses, the areas subject to flooding during a 1-percent-annual-chance (100-year) flood event in a community. Flood insurance risk zones, which are used to compute actuarial flood insurance rates, also are shown. In areas studied by detailed analyses, the FIRM shows BFEs to reflect the elevations of the 1-percent-annual-chance flood. For many communities, when detailed analyses are performed, the FIRM also may show areas inundated by 0.2-percent-annual-chance (500-year) flood and regulatory floodway areas.

Flood Insurance Study (FIS) – A Flood Insurance Survey (FIS) is a compilation and presentation of flood risk data for specific watercourses, lakes, and coastal flood hazard areas within a community. When a flood study is completed for the NFIP, the information and maps are assembled into an FIS. The FIS report contains detailed flood elevation data in flood profiles and data tables.

Flood Profile – A graph showing the relationship of water-surface elevation to location, with the latter generally expressed as distance above the mouth for a stream of water flowing in an open channel.

Floodplain – Any land area that is susceptible to being inundated by water from any source.

Floodway – See Regulatory Floodway.

Freeboard – A factor of safety usually expressed in feet above a flood level for purposes of floodplain management.

Future Conditions – For the purposes of this report, future conditions encompasses both natural changes (e.g., sea level rise, erosion, rainfall patterns) as well as human impacts (e.g., population changes, land use policies, development).

Geographic Information System (GIS) – A system of computer hardware, software, and procedures designed to support the capture, management, manipulation, analysis, modeling, and display of spatially referenced data for solving complex planning and management problems.

Global sea level – The average height of all the world's oceans. Also sometimes referred to as global mean sea level (GMSL).

Hazard – An event or physical condition that has the potential to cause fatalities, injuries, property damage, infrastructure damage, agricultural loss, damage to the environment, interruption of business, and other types of loss or harm.

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[210] FEMA, 1997.

[211] Schwab, et al., 1998.

Hazus – A nationally-applicable standardized methodology that contains models for estimating potential losses from earthquakes, floods, and hurricanes. HAZUS uses GIS technology to estimate physical, economic, and social impacts of disasters.

Hydraulic Analysis – An engineering analysis of a flooding source carried out to provide estimates of the elevations of floods of selected recurrence intervals.

Hydraulic Computer Model – A computer program that uses flood discharge values and floodplain characteristic data to simulate flow conditions and determine flood elevations.

Hydraulic Methodology – Analytical methodology used for assessing the movement and behavior of floodwaters and determining flood elevations and regulatory floodway data.

Hydrograph – A graph showing stage, flow, velocity, or other properties of water with respect to time.

Hydrologic Analysis – An engineering analysis of a flooding source carried out to establish peak flood discharges and their frequencies of occurrence.

Hydrology – The science encompassing the behavior of water as it occurs in the atmosphere, on the surface of the ground, and underground.

Letter of Map Revision (LOMR) – A letter issued by FEMA to revise the FIRM, FBFM, and/or FIS report for a community to change in BFEs, floodplain and floodway boundary delineations, and coastal high hazard areas.

Levee – A manmade structure, usually an earthen embankment, designed and constructed in accordance with sound engineering practices to contain, control, or divert the flow of water so as to provide protection from temporary flooding.

Light Detection and Ranging (LIDAR) System – An airborne laser system, flown aboard rotary or fixed-wing aircraft, that is used to acquire x, y, and z coordinates of terrain and terrain features that are both manmade and naturally occurring. LIDAR systems consist of an airborne Global Positioning System with attendant base station(s), Inertial Measuring Unit, and light-emitting scanning laser.

Local Relative Sea Level (LRSL) – The local change in sea level relative to the elevation of the land at a specific point on the coast.

Long-Term Erosion – Erosion that occurs over a period of decades, and that can be projected into the future based on historical erosion trends and/or modeling.

Mitigation – A sustained action taken to reduce or eliminate long-term risk to people and property from flood hazards and their effects. Mitigation distinguishes actions that have a long-term impact from those are more closely associated with preparedness for, immediate response to, and short-term recovery from specific events.

National Climate Assessment – Summarizes the impacts of climate change on the United States, now and in the future.

National Flood Hazard Layer (NFHL) – A digital database that contains flood hazard mapping data from FEMA's NFIP. The map data are derived from Flood Insurance Rate Map (FIRM) databases and Letters of Map Revision (LOMRs).

National Flood Insurance Program (NFIP) – Federal Program under which flood-prone areas are identified and flood insurance is made available to the owners of the property in participating communities.

National Hydrography Dataset (NHD) – The surface water component of The National Map that represents the drainage network with features like rivers, streams, canals, lakes, ponds, coastline, dams, and stream gages.

National Map, The – A collaborative effort of the United States Geological Survey (USGS) and other Federal, State, and local agencies to improve and deliver topographic information for the United States.

National Spatial Reference System (NSRS) – A consistent coordinate system that defined latitude, longitude, height, scale, gravity, and orientation throughout the United States The National Oceanic and Atmospheric Administration's (NOAA's) National Geodetic Survey defines, maintains, and provides access to the NSRS.

Non-regulatory – Unlike regulatory flood hazard products (FIRM, FIS Report, FIRM Database), non-regulatory products are not intended to be used as the basis for official actions required under the National Flood Insurance Program, such as determining mandatory insurance purchase requirements for a property. Non-regulatory flood risk products work alongside regulatory products and can be adopted by local communities wishing to regulate floodplain development to a higher standard.

Non-stationarity – The assumption that data and processes will change over time.

North American Regional Climate Change Assessment Program (NARCCP) – An international program that serves the high resolution climate scenario needs of the United States, Canada, and northern Mexico, using regional climate model, coupled global climate model, and time-slice experiments.

North Atlantic Coast Comprehensive Study (NACCS) – A U.S. Army Corps of Engineers (USACE) study detailing the results of a 2-year study to address coastal storm and flood risk to vulnerable populations, property, ecosystems, and infrastructure affected by Hurricane Sandy in the United States' North Atlantic region.

Point – A level of spatial measurement that refers to an object that has no dimension.

Point Data – In a vector structure, the data that consist of a single, distinct X, Y coordinate. In a raster structure, the data that consist of single cells.

Regulatory Floodway – A floodplain management tool that is the regulatory area defined as the channel of a stream, plus any adjacent floodplain areas that must be kept free of encroachment so that the base flood discharge can be conveyed without increasing the BFEs more than a specified amount. The regulatory floodway is not an insurance rating factor.

Risk – The potential losses associated with a hazard, defined in terms of expected intensity and frequency of an event coupled with its exposure and consequences to the natural and built environments.[212]

Riverine – For the purposes of this report, all inland or non-coastal flooding sources (e.g., alluvial fans, major rivers, tributaries, and rivers that are influenced by coastal effects as applicable).

Special Flood Hazard Area (SFHA) – The area delineated on a National Flood Insurance Program map as being subject to inundation by the base flood. SFHAs are determined using statistical analyses of records of riverflow, storm tides, and rainfall; information obtained through consultation with a community; floodplain topographic surveys; and hydrologic and hydraulic analyses.

Stationarity – The assumption that data and processes do not change over time.

Stillwater Flood Elevation (SWEL) – Projected elevation that flood waters would assume, referenced to National Geodetic Vertical Datum of 1929, North American Vertical Datum of 1988, or other datum, in the absence of waves resulting from wind or seismic effects.

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[212] Schwab, et al., 1998.

Structure – For floodplain management purposes, a walled and roofed building, including a gas or liquid storage tank that is principally above ground, as well as a manufactured home. For flood insurance purposes, a walled and roofed building, other than a gas or liquid storage tank, that is principally above ground and affixed to a permanent site, as well as a manufactured home on a permanent foundation.

Technical Mapping Advisory Council (TMAC) – A Federal advisory committee established to review and make recommendations to the Federal Emergency Management Agency (FEMA) on matters related to the national flood mapping program.

Vertical Datum – The National Geodetic Vertical Datum of 1929 (NGVD 29) or North American Vertical Datum of 1988 (NAVD 88) for which the property elevations are referenced. If the datum being referenced is different than the datum used to produce the effective FIRM, provide the datum conversion.

Watershed – An area of land that drains into a single outlet and is separated from other drainage basins by a divide.

Zone A – The flood insurance rate zone that corresponds to the 100-year floodplains that are determined in the FIS by approximate methods. Because detailed hydraulic analyses are not performed for such areas, no BFEs or depths are shown within this zone.

Zone AE – The flood insurance rate zone that corresponds to the 100-year floodplains that are determined in the FIS by detailed methods. In most instances, whole-foot BFEs derived from the detailed hydraulic analyses are shown at selected intervals within this zone.

Zone AH – The flood insurance rate zone that corresponds to the 100-year shallow flooding (usually areas of ponding) where average depths are between 1 and 3 feet. Whole-foot BFEs derived from detailed hydraulic analyses are shown at selected intervals within this zone.

Zone AR – The flood insurance rate zone used to depict areas protected from flood hazards by flood control structures, such as a levee, that are being restored. FEMA will consider using the Zone AR designation for a community if the flood protection system has been deemed restorable by a Federal agency in consultation with a local project sponsor; a minimum level of flood protection is still provided to the community by the system; and restoration of the flood protection system is scheduled to begin within a designated time period and in accordance with a progress plan negotiated between the community and FEMA. Mandatory purchase requirements for flood insurance will apply in Zone AR, but the rate will not exceed the rate for unnumbered A zones if the structure is built in compliance with Zone AR floodplain management regulations. For floodplain management in Zone AR areas, elevation is not required for improvements to existing structures. However, for new construction, the structure must be elevated (or floodproofed for non-residential structures) such that the lowest floor, including basement, is a maximum of 3 feet above the highest adjacent existing grade if the depth of the BFE does not exceed 5 feet at the proposed development site. For infill sites, rehabilitation of existing structures, or redevelopment of previously developed areas, there is a 3 foot elevation requirement regardless of the depth of the BFE at the project site. The Zone AR designation will be removed and the restored flood control system shown as providing protection from the 1-percent-annual chance flood on the NFIP map upon completion of the restoration project and submittal of all the necessary data to FEMA.

Zone AO – The flood insurance rate zone that corresponds to the 100-year shallow flooding (usually sheet flow on sloping terrain) where average depths are between 1 and 3 feet. Average whole-foot depths derived from the detailed hydraulic analyses. The highest top of curb elevation adjacent to the lowest adjacent grade (LAG) must be submitted if the request lies within this zone.

Zone A99 – The flood insurance rate zone that corresponds to areas of the 100-year floodplain what will be protected by a Federal flood protection system where construction has reached specified statutory milestones. No BFEs or depths are shown within this zone.

Zone D – The flood insurance rate zone that corresponds to unstudied areas where flood hazards are undetermined but possible.

Zone E – An area of flood-related erosion hazards, defined by the National Flood Insurance Program, but as yet unused on Flood Insurance Rate Maps.

Zone V – The flood insurance rate zone that corresponds to the 100-year costal floodplains that have additional hazards associated with storm waves. Because approximate hydraulic analyses are performed for such areas, no BFEs are shown within this zone. Mandatory flood insurance purchase requirements apply.

Zone VE, V1-30 – The flood insurance rate zone that corresponds to the 100-year coastal floodplains that have additional hazards associated with storm waves. BFEs derived from the detailed hydraulic analyses are shown at selected intervals within this zone. Mandatory flood insurance purchase requirements apply.

Zone X (shaded), Zone B – The flood insurance rate zone that corresponds to areas outside the 500-year floodplain, areas within the 500- year floodplain, and areas of 100-year flooding where average depths are less than 1 foot, areas of 100-year flooding where the contributing drainage area is less than 1 square mile, and areas protected from 100-year flood by levees. No BFEs or depths are shown within this zone.

Zone X (unshaded), Zone C – Areas determined to be outside the 1-percent-annual-chance and 0.2-percent-annual-chance floodplains. Flood insurance is not Federally-mandated, but lenders can require the purchase of flood insurance in these areas. No minimum Federal floodplain management standards apply.

9 Acronyms and Abbreviations

1D	1 dimensional
3DEP	3 Dimensional Elevation Program
ADCIRC	Advanced Circulation and Storm Surge model
AR5	Fifth Assessment Report of the Intergovernmental Panel on Climate Change
BFE	Base Flood Elevation
BW-12	*Biggert-Waters Flood Insurance Reform Act of 2012*
CAZ	Coastal A Zone
CFM	Certified Floodplain Manager
CFR	Code of Federal Regulations
CLOMR	Conditional Letter of Map Revision
CMSWS	Charlotte-Mecklenburg Storm Water Services
CO_2	Carbon Dioxide
CORS	Continuously Operating Reference Stations
CRS	Community Rating System
CTP	Cooperating Technical Partner
CVI	Coastal Vulnerability Index
DEM	Digital Elevation Model
DSWL	dynamic Stillwater level
EHA	erosion hazard area
ERF	erosion reference feature
FACA	Federal Advisory Committee Act
FEMA	Federal Emergency Management Agency
FFRMS	Federal Flood Risk Management Standard
FHBM	Flood Hazard Boundary Map
FIMA	Federal Insurance and Mitigation Administration
FIRM	Flood Insurance Rate Map
FIS	Flood Insurance Study
GAO	Government Accountability Office
GCM	General circulation model
GIS	Geographic Information System
GISP	Geographic Information System Professional
GMSL	Global mean sea level
HFIAA	*Homeowner Flood Insurance Affordability Act of 2014*
HUCCO	Hydrologic Unit Code by County
IPCC	Intergovernmental Panel on Climate Change

LiDAR	Light Detection and Ranging
LiMWA	Limit of Moderate Wave Action
LOMR	Letter of Map Revision
LRSL	Local relative sea level
m	meters
mm	millimeters
NACCS	North Atlantic Coast Comprehensive Study
NAVD88	North American Vertical Datum of 1988
NCA	National Climate Assessment
Nexrad	Next Generation Radar
NFHL	National Flood Hazard Layer
NFIA	*National Flood Insurance Act of 1968*
NFIP	National Flood Insurance Program
NGVD29	National Geodetic Vertical Datum of 1929
NHD	National Hydrography Dataset
NOAA	National Oceanic and Atmospheric Administration
NPCC	New York City Panel on Climate Change
NRC	National Research Council
NSRS	National Spatial Reference System
NWLON	National Water Level Observation Network
pCMZ	Planning-level channel migration zone
RCP	Representative concentration pathway
Risk MAP	Risk Mapping, Assessment, and Planning
SCRF	shoreline change reference features
SFHA	Special Flood Hazard Area
SLC	Sea Level Change
SLOSH	Sea, Lake, and Overland Surges from Hurricanes model
SLR	Sea Level Rise
SME	Subject Matter Expert
SWL	Stillwater level
TMAC	Technical Mapping Advisory Council
TWL	total water level
UDFCD	Urban Drainage and Flood Control District (Denver, Colorado)
USACE	U.S. Army Corps of Engineers
USGCRP	U.S. Global Change Research Program
USGS	U.S. Geological Survey

VLM	Vertical land movement
WBD	Watershed Boundary Dataset
WSP 2207	U.S. Geological Survey Water-Supply Paper 2207

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10.1.1.1.1.1 TMAC Charter[213]

Department of Homeland Security
Federal Emergency Management Agency
Technical Mapping Advisory Council

1. Committee's Official Designation:

Technical Mapping Advisory Council

2. Authority:

Pursuant to section 100215 of the *Biggert-Waters Flood Insurance Reform Act of 2012*, Public Law 112-141, 126 Stat. 924, 42 U.S.C. § 4101a ("the Act"), this charter establishes the Technical Mapping Advisory Council (TMAC or Council). This committee is established in accordance with and operates under the provisions of the *Federal Advisory Committee Act* (FACA) (Title 5, United States Code, Appendix).

3. Objectives and Scope of Activities:

The TMAC advises the Administrator of the Federal Emergency Management Agency (FEMA) on certain aspects of FEMA's flood Risk MAPping activities.

The TMAC recommends to the Administrator:

A. How to improve in a cost-effective manner the:
    1. Accuracy, general quality, ease of use, and distribution and dissemination of flood insurance rate maps and risk data; and
    2. Performance metrics and milestones required to effectively and efficiently map flood risk areas in the U.S.
B. Mapping standards and guidelines for:
    1. Flood Insurance Rate Maps (FIRMs); and
    2. Data accuracy, data quality, data currency, and data eligibility;
C. How to maintain, on an ongoing basis, FIRMs and flood risk identification; and
D. Procedures for delegating mapping activities to State and local mapping partners.

The TMAC recommends to the Administrator and other Federal agencies participating in the Council:

A. Methods for improving interagency and intergovernmental coordination on flood mapping and flood risk determination; and
B. A funding strategy to leverage and coordinate budgets and expenditures across Federal agencies.

The TMAC submits an annual report to the Administrator that contains a description of the activities of the Council, an evaluation of the status and performance of FIRMs and mapping activities to revise and update FIRMs as required by the Act, and a summary of the activities of the Council. In addition, the TMAC must prepare written recommendations in a future conditions risk assessment and modeling report and submit the recommendations to the Administrator.

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[213] The TMAC Charter in Appendix A is the renewed charter, effective July 29, 2015. The original TMAC Charter was effective July 29, 2013.

Further, the Homeowner Flood Insurance Affordability Act (HFIAA) of 2014 requires additional flood mapping review requirements for the TMAC.

4. Description of Duties:

The duties of the TMAC are solely advisory in nature.

5. Official to Whom the Committee Reports:

The TMAC provides advice and recommendations to the Administrator of FEMA.

6. Support:

FEMA shall be responsible for providing financial and administrative support to the Council. Within FEMA, the Risk Analysis Division of the Federal Insurance and Mitigation Administration provides this support.

7. Estimated Annual Operating Costs and Staff Years:

The estimated annual operating cost associated with supporting TMAC's functions is estimated to be $1,100,000 for FY2015 and $800,000 for FY2016. This includes surge support for all direct and indirect expenses and 2.0 FTE of staff support. Adequate staffing within the annual operating cost estimate is required to support the TMAC.

8. Designated Federal Officer:

A full-time or permanent part-time employee of FEMA is appointed by the Administrator as the TMAC Designated Federal Officer (DFO). The DFO or an Alternate DFO approves or calls TMAC meetings, approves meeting agendas, attends all committee and subcommittee meetings, adjourns any meeting when the DFO determines adjournment to be in the public interest, and chairs meetings when requested in the absence of the Chair.

9. Estimated Number and Frequency of Meetings:

Meetings of the TMAC may be held with the approval of the DFO. The Council shall meet a minimum of two times each year at the request of the Chairperson or a majority of its members, and may take action by a vote of the majority of the members.

Council meetings are open to the public unless a determination is made by the appropriate DHS official in accordance with DHS policy and directives that the meeting should be closed in accordance with Title 5, United States Code, subsection (c) of section 552b.

10. Duration:

Continuing

11. Termination:

This charter is in effect for two years from the date it is filed with Congress unless sooner terminated. The charter may be renewed at the end of this two-year period in accordance with section 14 of FACA.

12. Member Composition:

Members of the Council are defined by Section 100215(b)(1), and include four designated members and sixteen appointed members.

The four designated members of the Council serve as Regular Government Employees and consist of:

The FEMA Administrator or the designee thereof;
The Secretary of the Interior or the designee thereof;
The Secretary of Agriculture or the designee thereof; and
The Under Secretary of Commerce for Oceans and Atmosphere or the designee thereof.

The sixteen additional members of the Council are appointed by the Administrator or designee. These members are appointed based on their demonstrated knowledge and competence regarding surveying, cartography, remote sensing, geographic information systems, or the technical aspects of preparing and using FIRMs.

To the maximum extent practicable, the membership of the Council will have a balance of Federal, State, local, tribal and private members, and include geographic diversity including representation from areas with coastline on the Gulf of Mexico and other States containing areas identified by the Administrator as at high risk for flooding or as areas having special flood hazard areas.

These members are selected from among the following professional associations or organizations:

a. One member of a recognized professional surveying association or organization;
b. One member of a recognized professional mapping association or organization;
c. One member of a recognized professional engineering association or organization;
d. One member of a recognized professional association or organization representing flood hazard determination firms;
e. One representative of the United States Geological Survey;
f. One representative of a recognized professional association or organization representing State geographic information;
g. One representative of State national flood insurance coordination offices;
h. One representative of the Corps of Engineers;
i. One member of a recognized regional flood and storm water management organization;
j. Two representatives of different State government agencies that have entered into cooperating technical partnerships with the Administrator and have demonstrated the capability to produce FIRMs;
k. Two representatives of different local government agencies that have entered into cooperating technical partnerships with the Administrator and have demonstrated the capability to produce flood insurance maps;
l. One member of a recognized floodplain management association or organization;
m. One member of a recognized risk management association or organization; and
n. One State mitigation officer.

The non-Federal members in a., b., c., d., i., l., m., and n. serve as Special Government Employees as defined in Title 18, United States Code, section 202(a). The members in e., and h., serve as Regular Government Employees. The non-Federal members in f., g., j., and k. serve as representatives of their respective associations or organizations and are not Special Government Employees as defined in Title 18 of United States Code, section 202(a).

The sixteen appointed members serve terms of office of two years. However, up to half (eight) of those initially appointed to the Council may serve one-year terms to allow for staggered turnover. Appointments may be renewed by the FEMA Administrator for an additional one- or two-year period. A member appointed to fill an unexpired term shall serve the remainder of that term and may be reappointed for an additional one- or two-year term. The Administrator has the authority to extend reappoints for an additional one- or two-year period as deemed necessary. In the event the Council terminates, all appointments to the Council will terminate.

13. Officers:

The Council membership shall elect any one member to serve as Chairperson of the Council. The Chairperson shall preside over Council meetings in addition to specific responsibilities authorized under the Act.

14. Subcommittees:

The DFO may establish subcommittees for any purpose consistent with this charter. Such subcommittees may not work independently of the chartered committee and must present their work to the TMAC for full deliberation and discussion. Subcommittees have no authority to make decisions on behalf of the TMAC and may not report directly to the Federal government or any other entity.

15. Recordkeeping:

The records of the TMAC, formally and informally established subcommittees, or other subgroups of the Council, shall be maintained and handled in accordance with General Records Schedule 26, Item 2 or other approved agency records disposition schedule.

16. Filing Date:

July 20, 2015
Department Approval Date

July 29, 2015
CMS Consultation Date

July 29, 2015
Date Filed with Congress

10.1.1.1.1.2 FEMA TMAC Bylaws[214]

04/29/15

Federal Emergency Management Agency
Technical Mapping Advisory Council
Bylaws

ARTICLE I AUTHORITY

As required by the *Biggert-Waters Flood Insurance Reform Act of 2012* (BW-12), codified at 42 United States Code Section 4101a, the Federal Emergency Management Agency (FEMA) Technical Mapping Advisory Council (TMAC) is established. The TMAC shall operate in accordance with the provisions of the *Federal Advisory Committee Act* (FACA), as amended (Title 5, U.S.C., Appendix).

ARTICLE II PURPOSE

The TMAC provides advice and recommendations to the Administrator of FEMA to improve the preparation of flood insurance rate maps (FIRM). Among its specified statutory responsibilities, TMAC will examine performance metrics, standards and guidelines, map maintenance, delegation of mapping activities to State and local mapping partners, interagency coordination and leveraging, and other requirements mandated by the authorizing BW-12 legislation. In addition, TMAC provides advice and recommendations to the FEMA Administrator on future risks from climate change, rising sea levels, and FIRM development, as mandated by BW-12. Further, the Homeowner Flood Insurance Affordability Act (HFIAA) of 2014 requires additional flood mapping review requirements for the TMAC.

ARTICLE III MEMBERSHIP AND MEMBER RESPONSIBILITIES

Section 1. Composition.

Members of the Council include designated members and additional members appointed by the FEMA Administrator or his designee. See 42 U.S.C. § 4101a.

The designated members of the Council are:

- The FEMA Administrator or the designee thereof;
- The Secretary of the Interior or the designee thereof;
- The Secretary of Agriculture or the designee thereof; and,
- The Under Secretary of Commerce for Oceans and Atmosphere or the designee thereof.

The appointed members may be selected from among the following professional associations or organizations:

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[214] The FEMA TMAC Bylaws in Appendix B are the updated bylaws, effective April 29, 2015. The original FEMA TMAC Bylaws were effective July 29, 2013.

- A member of a recognized professional surveying association or organization;
- A member of a recognized professional mapping association or organization;
- A member of a recognized professional engineering association or organization;
- A member of a recognized professional association or organization representing flood hazard determination firms;
- A representative of the United States Geological Survey;
- A representative of a recognized professional association or organization representing State geographic information;
- A representative of State national flood insurance coordination offices;
- A representative of the Corps of Engineers;
- A member of a recognized regional flood and storm water management organization;
- Two representatives of different State government agencies that have entered into cooperating technical partnerships with the Administrator and have demonstrated the capability to produce FIRMs;
- Two representatives of different local government agencies that have entered into cooperating technical partnerships with the Administrator and have demonstrated the capability to produce flood insurance maps;
- A member of a recognized floodplain management association or organization;
- A member of a recognized risk management association or organization;
- A State mitigation officer.

Subject Matter Experts/Technical Advisors: The TMAC may hear from subject matter experts/technical advisors (“SMEs”) who will be asked to provide specialized information or assistance as appropriate and approved by the Designated Federal Officer (DFO). Individual TMAC members may request SMEs, by expertise or skillset, to appear before the TMAC, as needed. Member requests will be made to the Chair for consideration and consultation with the TMAC Designated Federal Officer (DFO). FEMA will not compensate SMEs for their services but they may be reimbursed for travel and lodging expenses.

Section 2. Appointment.

With the exception of the Secretary of the Interior, Secretary of Agriculture, and Under Secretary of Commerce for Oceans and Atmosphere, members of TMAC are appointed by and serve at the pleasure of the FEMA Administrator in an advisory role. Membership is voluntary and members are not compensated for their services. Appointments are personal to the member and cannot be transferred to another individual. Members may not designate someone to attend in their stead, participate in discussions, or vote. In compliance with FACA, members, while engaged in the performance of their duties away from their home or regular places of business, may be allowed travel expenses, including per diem in lieu of subsistence, as authorized by section 5703 of title 5, United States Code.

Section 3. Terms of Office.

Members of the TMAC may serve terms of office of two years; however, up to half of those initially appointed TMAC members may be appointed to serve one-year terms to allow for staggered turnover. The FEMA Administrator or his designee may reappoint serving members for additional terms. When the TMAC terminates, all appointments to the TMAC shall terminate.

Section 4. Certification of Non-Lobbyist Status.

All members of the TMAC must annually self-certify that they are not registered lobbyists under the *Lobbying Disclosure Act*, Title 2 U.S.C., Section 1603, and must advise the Department of Homeland Security (DHS) through the Federal Emergency Management Agency if they register as a lobbyist while serving on the TMAC. Members who register as a lobbyist after their appointment or re-appointment will be replaced on the Council.

Section 5. Members' Responsibilities.

Because the TMAC's membership is constructed to balance as many perspectives on floodplain mapping and future risk assessment as possible, member attendance and participation at meetings is vital to the TMAC's mission. Members are expected to personally attend and participate in Council, subcommittee meetings, and conference calls. Members will also be expected to provide written input to any final reports or deliverables.

The DFO or Chair may recommend to the FEMA Administrator that any appointed member unable to fulfill their responsibility be replaced on the Council or subcommittee. Members of the TMAC may be recommended for removal for reasons such as, but not limited to:

a) Missing two consecutive meetings, including teleconference calls;
b) Registering as a lobbyist after appointment; or,
c) Engaging in activities that are illegal or violate the restrictions on members' activities as outlined below.

Section 6. Restriction on Members' Activities.

a) Members may not use their access to the Federal Government as a member of this Council for the purpose of soliciting business or otherwise seeking economic advantage for themselves or their companies. Members may not use any non-public information obtained in the course of their duties as a member for personal gain or for that of their company or employer. Members must hold any non-public information in confidence.

b) The Council as a whole may advise FEMA on legislation or recommend legislative action. In their capacities as members of the TMAC, individual members may not petition or lobby Congress for or against particular legislation or encourage others to do so.

c) Members of the TMAC are advisors to the agency and have no authority to speak for the Council, FEMA, or for the Department outside the Council structure.

d) Members may not testify before Congress in their capacity as a member of the TMAC. If requested to testify before Congress, members of the TMAC:

    1. Cannot represent or speak for the Council, DHS, any agency, or the Administration in their testimony;
    2. Cannot provide information or comment on Council recommendations that are not yet publicly available;
    3. May state they are a member of the Council; and,
    4. May speak to their personal observations as to their service on the Council.

e) If speaking outside the Council structure at other forums or meetings, the restrictions in Section (d) also apply.

ARTICLE IV OFFICIALS

Section 1. TMAC Leadership.

TMAC members will elect a Chair through a nomination and formal vote. (The FEMA Administrator, or his designee, shall serve in this capacity until a Chair is elected.) The Chair will be responsible for appointing one or more Vice Chairs. The Chair and Vice Chairs will serve for either a one or two year term, based on their initial appointment. Appointments may be renewed for an additional one-year term. No Chair or Vice Chair shall serve longer than three years. The Chair will select chairs for any subcommittee established. Only voting members can serve as subcommittee chairs.

Chair Responsibilities:

a. Appoints officers to assist in carrying out the duties of the TMAC;
b. Works with the DFO to develop meeting agendas;
c. Sets and maintains a schedule for TMAC activities (e.g., report development);
d. Works with the TMAC membership to develop the draft annual report;
e. Signs the final reports addressed to the FEMA Administrator;

f. Coordinates with the DFO to form subcommittees with assigned areas of consideration;
g. Selects subcommittee chairs and vice chairs;
h. Resolves member conflicts.

Vice Chair Responsibilities:

a. Works with subcommittee chairs to ensure work is being completed;
b. Coordinates member engagement;
c. Assists Chair in conducting review of meeting minutes and recommendation reports;
d. Elevates any unresolved issues to the Chair;
e. Serves as Chair in absence of the Chair.

Subcommittee Chair Responsibilities:

a. Works with the DFO to develop subcommittee meeting agendas;
b. Facilitates subcommittee discussions;
c. Reports to the Chair and Vice Chair; and
d. Reports out subcommittee work at quarterly TMAC meetings.

Section 2. Designated Federal Officer.

The DFO serves as FEMA’s agent for all matters related to the TMAC and is appointed by the FEMA Administrator. In accordance with the provisions of the FACA, the DFO must:

a. Approve or call meetings of the Council and its subcommittees;
b. Approve agendas for Council and subcommittee meetings;
c. Attend all meetings;
d. Adjourn meetings when such adjournment is in the public interest; and,
e. Chair meetings of the Council when directed to do so by the FEMA Administrator.

In addition, the DFO is responsible for assuring administrative support functions are performed, including the following:

a. Notifying members of the time and place of each meeting;
b. Tracking all recommendations of the Council;
c. Maintaining the record of members’ attendance;
d. Preparing the minutes of all meetings of the Council’s deliberations, including subcommittee and working group activities;
e. Attending to official correspondence;

f. Maintaining official records and filing all papers and submissions prepared for or by the Council, including those items generated by subcommittees and working groups;
g. Reviewing and updating information on Council activities in the Shared Management System (i.e., FACA database) on a monthly basis;
h. Acting as the Council's agent to collect, validate and pay all vouchers for pre-approved expenditures; and
i. Preparing and handling all reports, including the annual report as required by FACA.

ARTICLE V MEETING PROCEDURES

Section 1. Meeting Schedule and Call of Meetings.

TMAC will meet in plenary sessions approximately once or twice per quarter, with additional virtual meetings as needed, at the discretion of the DFO. The Council may hold hearings, receive evidence and assistance, provide information, and conduct research, as it considers appropriate, subject to resources being made available. With respect to the meetings, it is anticipated that some may be held via teleconference, with public call-in lines. TMAC meetings will be open to the public unless a determination is made by the appropriate FEMA official that the meeting should be closed in accordance with subsection (c) of section 552b of title 5, U.S.C.

Section 2. Agenda.

Meeting agendas are developed by the DFO in coordination with the TMAC chair. In accordance with the responsibilities under FACA, the DFO approves the agenda for all Council and subcommittee meetings, distributes the agenda to members prior to the meeting, and publishes the agenda in the Federal Register.

FEMA will publish the meeting notice and agenda in the Federal Register at least 15 calendar days prior to each TMAC meeting or official public conference call. Once published in the Federal Register, the agenda items cannot be changed prior to or during a meeting.

Section 3. Quorum.

A quorum of the TMAC is the presence of fifty percent plus one of the Council members currently appointed. In the event a quorum is not present, the TMAC may conduct business that does not require a vote or decision among members. Votes will be deferred until such time as a quorum is present.

Section 4. Voting Procedures.

When a decision or recommendation of the TMAC is required, the Chair will request a motion for a vote. A motion is considered to have been adopted if agreed to by a simple majority of a quorum of TMAC members. Members vote on draft reports and recommendations in open meetings through a resolution recorded in the meeting minutes. Only members present at the meeting—either in person or by teleconference—may vote on an item under consideration. No proxy votes or votes by email will be allowed.

Section 5. Minutes.

The DFO will prepare the minutes of each meeting and distribute copies to each Council member. Minutes of open meetings will be available to the public on the TMAC website at http://www.fema.gov/TMAC. The minutes will include a record of:

a. The time, date, and place of the meeting;
b. A list of all attendees including Council members, staff, agency employees and members of the public who presented or oral or written statements;
c. An accurate description of each matter discussed and the resolution, if any, made by the Council;
d. Copies of reports or other documents received, issued, or approved by the Council; and
e. An accurate description of public participation, including oral and written statements provided.

The DFO ensures that the Chair certifies the minutes within 90 calendar days of the meeting to which they relate and prior to the next TMAC meeting.

Minutes of closed meetings will also be available to the public upon request subject to the withholding of matters about which public disclosure would be harmful to the interests of the Government, industry, or others, and which are exempt from disclosure under the *Freedom of Information Act* (FOIA) (5 U.S.C., section 552).

Section 6. Open Meetings.

TMAC meetings shall be open and announced to the public in a notice published in the Federal Register at least fifteen calendar days before the meeting. Members of the public may attend any meeting or portion of a meeting that is not closed to the public and, at the determination of the Chair and DFO, may offer oral comment at such meeting. Meetings will include a period for oral comments unless it is clearly inappropriate to do so. Members of the public may submit written statements to the TMAC at any time. All materials provided to the Council shall be available to the public when they are provided to the members.

Such materials, including any submissions by members of the public, are part of the meeting record.

Section 7. Closed Meetings.

All or parts of TMAC meetings may be closed in limited circumstances and in accordance with applicable law. No meeting may be partially or fully closed unless the component head issues a written determination that there is justification for closure under the provisions of subsection (c) of 5 United States Code 552b, the *Government in the Sunshine Act*. Where the DFO has determined in advance that discussions during a Council meeting will involve matters about which public disclosure would be harmful to the interests of the government, industry, or others, an advance notice of a closed meeting, citing the applicable exemptions of the *Government in the Sunshine Act*, will be published in the Federal Register.

The notice may announce the closing of all or just part of a meeting. If, during the course of an open meeting, matters inappropriate for public disclosure arise during discussions, the DFO or Chair will order such discussion to cease and will schedule it for a future meeting of the Council that will be approved for closure. No meeting or portion of a meeting may be closed without prior approval and notice published in the Federal Register at least 15 calendar days in advance. Closed meetings can only be attended by DFO, Council members, and necessary agency staff members. Presenters must leave immediately after giving their presentations and answering any questions.

Section 8. Other Meetings, No Public Notice Required.

Public notice is not required for meetings of administrative or preparatory work. Administrative work is a meeting of two or more TMAC or subcommittee members convened solely to discuss administrative matters or to receive administrative information from a Federal officer or agency. Preparatory work is a meeting of two or more TMAC or subcommittee members convened solely to gather information, conduct research, or analyze relevant issues and facts in preparation for a TMAC meeting or to draft position papers for consideration by the TMAC.

ARTICLE VI EXPENSES AND REIMBURSEMENTS

Expenses related to the operation of the TMAC will be paid by the Federal Insurance and Mitigation Administration. Expenditures of any kind must be approved in advance by the DFO. All such expense reports will be sent to the DFO for action and reimbursement. The DFO will be responsible for handling the payment of expenses. Members are responsible for submitting expense reports by the deadlines set by the DFO or they may not be reimbursed. The DFO will be responsible for developing the procedures for expense reimbursement.

ARTICLE VII ADMINISTRATION

The Federal Insurance and Mitigation Administration shall be responsible for providing financial and administrative support to the TMAC subject to the availability of appropriations.

ARTICLE VIII SUBCOMMITTEES

Section 1. Establishment of subcommittees.

The DFO may establish standing subcommittees with an overarching mission to work on specific focus areas and provide advice to the TMAC on a continuing basis. The DFO may also establish ad-hoc subcommittees to work and report on specific focus areas. The number, designation, mission, scope, and membership of subcommittees are determined by the DFO in consultation with the Chair and Vice Chairs. The Chair may also request of the DFO to establish (or reorganize) a subcommittee. The creation and operation of the subcommittees must be approved by the DFO on behalf of FEMA.

Subcommittee Members: TMAC subcommittees may consist of TMAC members and non-TMAC members as limited below. TMAC members will be named to serve on a specific subcommittee and may contribute to others as requested. It is mandatory that each TMAC member participate on at least one subcommittee and be a full and active participant in subcommittee deliberations.

Subcommittees will not function independently of the TMAC or provide advice or recommendations directly to FEMA. Subcommittees (standing and ad-hoc) must present all advice, recommendations, and reports to the full TMAC during a public meeting or teleconference for discussion, deliberation, and final approval. Each Subcommittee must be comprised of a majority of TMAC members.

In general, the requirements of FACA do not apply to subcommittees of advisory committees that report a parent advisory committee and not directly to a Federal officer or agency. However, minutes must be maintained for the public record and the DFO and/or ADFO must participate in all subcommittee proceedings.

Section 2. Membership.

Subcommittee membership should be balanced in relation to the subcommittee's mission and focus areas. The DFO and the Chair, with input from Council members, identify and determine the membership for the subcommittee, including a chair (and vice chair if deemed necessary). As noted above, each Subcommittee must be comprised of a majority of TMAC members.

Subcommittee chairs may request the DFO to invite non-TMAC individuals to serve on the subcommittee, as necessary. Only TMAC members may serve as the chair or vice chair of a subcommittee (standing or ad-hoc). The subcommittee chair can also advise the DFO that briefings from external subject matter experts are needed to provide pertinent and vital information not available among the current TMAC membership or from Federal staff. All such requests shall be made to the DFO who will facilitate the process to obtain subject matter expertise.

Section 3 Subcommittee Quorum

A Subcommittee quorum consists of: (1) the presence (either in person or by teleconference) of fifty percent plus one of TMAC members currently appointed to the Subcommittee; and (2) TMAC members make up more than half of the Subcommittee members present. In the event a Subcommittee quorum is not present, the Subcommittee may conduct business that does not require a vote or decision among members. Votes will be deferred until such time as a quorum is present.

Section 4 Subcommittee Voting Procedures

When a decision or recommendation of the Subcommittee is required, and a Subcommittee Quorum as defined above is present, the Subcommittee Chair will request a motion for a vote. A motion is considered to have been adopted if agreed to by a simple majority of the TMAC Subcommittee members present. Members vote on draft reports and recommendations that will be presented to the full TMAC. Only members present at the meeting—either in person or by teleconference—may vote on an item under consideration. No proxy votes or votes by email will be allowed.

Section 5. Focus Areas

Focus Areas are identified areas of consideration for the Council to review, either via subcommittee or by the TMAC through discussion as an entire body. The DFO will determine focus areas in consultation with the TMAC Chair. The DFO will then work with the Chair and Vice Chair to identify whether the focus area should be assigned to a standing subcommittee, an ad hoc subcommittee; or submitted to the TMAC for discussion and review.

Section 6. Workload and meetings.

Subcommittees may have more than one focus area to address. Subcommittee chairs will recommend the appropriate number of conference calls necessary to address focus areas, working in coordination with the DFO.

The subcommittee chair determines what materials are needed to prepare a response and develop a report to the TMAC. The DFO will supply the requested materials to the TMAC subcommittee upon request and resource availability.

ARTICLE IX RECOMMENDATIONS AND REPORTING

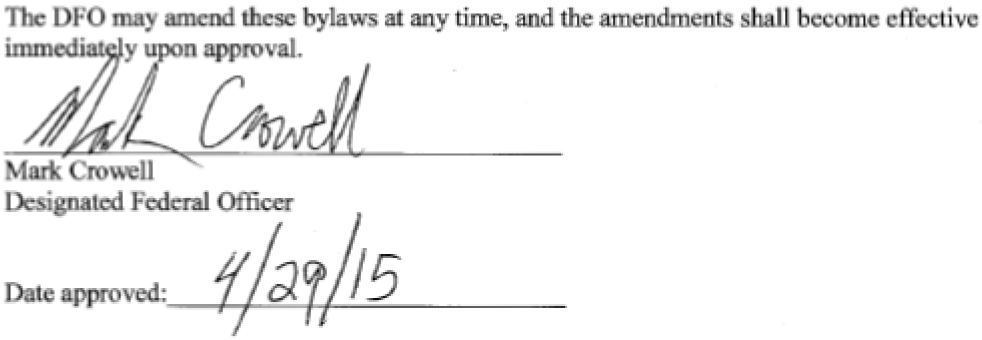
P.L. 112-141 directs TMAC to submit an annual report to the Administrator that contains a description of the activities of the Council; an evaluation of the status and performance of flood insurance rate maps and mapping activities to revise and update flood insurance rate maps; and a summary of recommendations made by the Council to the Administrator.

Once the TMAC achieves consensus on a report and recommendations, the TMAC Chair is responsible for providing a final version of the report to the FEMA Administrator. The final report and any accompanying memoranda will be posted on the TMAC website.

ARTICLE X RECORDKEEPING

The DFO maintains all records of the advisory Council in accordance with FACA and FEMA policies and procedures. All documents, reports, or other materials presented to, or prepared by or for the Council, constitute official government records and are available to the public upon request.

ARTICLE XI BYLAWS APPROVAL AND AMENDMENTS



The DFO may amend these bylaws at any time, and the amendments shall become effective immediately upon approval.

Mark Crowell

Mark Crowell
Designated Federal Officer

Date approved: 4/29/15

10.1.1.1.1.3 2014–2015 TMAC Meetings

Table C-1: 2014–2015 TMAC Meetings

Meeting Date	Location	Business Purpose
September 10, 2014	Virtual (closed to the public)	The TMAC conducted an administrative meeting to kick off future efforts by informing the TMAC members of requirements under authorizing legislation, member roles and responsibilities, legal and ethical statutes governing member activities, and next steps for the first in-person meeting.
September 30-October 1, 2014	USGS, Reston, Virginia	The TMAC voted, elected, and announced their Chair, Mr. John Dorman. TMAC members also discussed legislative requirements and received subject matter expert (SME) briefings that helped establish the TMAC's baseline understanding of the current status of the mapping program.
December 4-5, 2014	FEMA, Arlington, Virginia	The TMAC deliberated and voted upon its vision, mission and guiding principles and received SME briefings such as overall flood management process and components, data acquisition, maintenance, and dissemination, and future conditions risk to insurance rating.
March 10-11, 2015	USGS, Reston, Virginia	The TMAC deliberated and voted upon topics to be included in the 2015 Annual Report and the Future Conditions Report. TMAC members also received SME briefings such as how FEMA uses flood risk to calculate insurance ratings, floodplain management and the Flood Insurance Advocate, and State and local cooperating technical partner methods.
May 12-13, 2015	USGS, Reston, Virginia	The TMAC deliberated and voted to adopt outlines/table of contents for the 2015 Annual Report and the Future Conditions Report.
June 23-24, 2015	NOAA, Silver Spring, Maryland	The TMAC deliberated and voted upon the annotated outlines for the 2015 Annual Report and the Future Conditions Report. TMAC members also received SME briefings such as progress on the FEMA Flood Insurance Reform Flood Mapping Integrated Project Team and a tribal perspective.
August 4-5, 2015	USGS, Reston, Virginia	The TMAC deliberated on draft recommendations and narratives for potential infusion in the 2015 Annual Report and the Future Conditions Report.
September 9, 2015	Virtual	The TMAC reviewed, commented, and deliberated on draft recommendations and narratives for incorporation into the 2015 Annual Report and the Future Conditions Report.
September 29, 2015	Virtual	The TMAC reviewed, commented, and deliberated draft recommendations and narratives for incorporation into the 2015 Annual Report and the Future Conditions Report.

Meeting Date	Location	Business Purpose
October 20-21, 2015	USGS, Reston, Virginia	The TMAC reviewed, commented, and deliberated draft recommendations and narratives for incorporation into the 2015 Annual Report and the Future Conditions Report.

10.1.1.1.1.4 Future Conditions Subcommittee Meetings

Table D-1: Future Conditions Subcommittee Meetings

Meeting Date	Business Purpose
January 20, 2015	To discuss the legislative background, schedules, and requirements of the future conditions report
February 13,2015	To determine the SME briefings required and schedule
February 27, 2015	To receive SME briefings on the United States Army Corps of Engineers' (USACE) Perspective, guidance, and policies on SLR (sea level rise) and how they inform USACE's approaches and activities; proof on concept studies of SLR and floodplain mapping, and; the goals of the FEMA West Coast SLR pilot study.
March 10-11, 2015	To review the table of contents and assignments
March 20, 2015	To receive SME briefings on the effects of climate change on riverine hydrology
March 26, 2015	To review the table of contents and assignments
April 3, 2015	To receive SME briefings on the uncertainties and risks of regional sea-level change
April 6, 2015	To discuss draft report outline
April 23, 2015	To review feedback on the TOC
May 28, 2015	To provide an update on progress and recent changes
August 19, 2015	To discuss the subcommittee's draft recommendations
August 24, 2015	To discuss the subcommittee's draft recommendations
September 28, 2015	To discuss the draft report

10.1.1.1.1.5 Subject Matter Expert Presentations

Table E-1: Subject-Matter Expert Presentations

Date	Presenter	Presented to	Title
September 30, 2014	Mr. David Bascom Program Specialist, Risk Analysis Division, FEMA	TMAC	TMAC Priorities, Duties, and Reports
September 30, 2014	Mr. Joshua Smith Program Specialist, Business Analysis Branch, FEMA Ms. Kelly Bronowicz Program Specialist, Data and Dissemination Management Branch, FEMA Mr. Luis Rodriguez, P.E. Branch Chief, Engineering Management Branch, Federal Insurance and Mitigation Administration, FEMA	TMAC	Performance Metrics and Milestones Required to Effectively and Efficiently Map Flood Risk Areas
September 30, 2014	Mr. Michael Godesky Physical Scientist, FEMA	TMAC	FIRM Accuracy, Quality, Ease of Use, Distribution, and Dissemination
September 30, 2014	Mr. Paul Rooney Mapping Technology Specialist, FEMA	TMAC	Data Accuracy, Data Quality, Data Currency, and Data Eligibility
October 1, 2014	Mr. Mark Crowell Physical Scientist, FEMA Mr. Andy Neal Actuary, Risk Insurance Division, FEMA Ms. Rachel Sears Senior Policy Advisor, FEMA	TMAC	Future Conditions Risk Assessment and Modeling

Date	Presenter	Presented to	Title
October 1, 2014	Mr. Rick Sacbibit, P.E. Program Specialist, FEMA	TMAC	Maintaining, on an Ongoing Basis, Flood Insurance Rate Maps and Flood Risk Identification
October 1, 2014	Ms. Laura Algeo, P.E., CFM Senior Civil Engineer, FEMA Region IV	TMAC	Delegating Mapping Activities to State and Local Mapping Partners
December 4, 2014	Mr. Andy Read, CFM, EIT Program Specialist, FEMA	TMAC	Risk MAP: Flood Map Production
December 4, 2014	Ms. Vicki Lukas Chief, Topographic Data Services, USGS	TMAC	Data Acquisitions; Maintenance and Dissemination
December 4, 2014	Mr. Amar Nayegandhi, CP, CMS (RS), GISP Director of Remote Sensing, Dewberry	TMAC	Data Acquisitions; Maintenance and Dissemination
December 4, 2014	Mr. Jerad Bales Chief Scientist for Water, USGS	TMAC	Information for Understanding Current and Future Streamflow Conditions
December 4, 2014	Mr. Douglas Marcy Coastal Hazards Specialist, National Oceanic and Atmospheric Administration Mr. Steve Gill Chief Scientist, Center for Operational Products and Services, NOAA Mr. Adam Parris Division Chief, Climate Assessment and Services Division, NOAA	TMAC	NOAA Sea Level Change Measurement and Future Sea Level Rise Scenarios

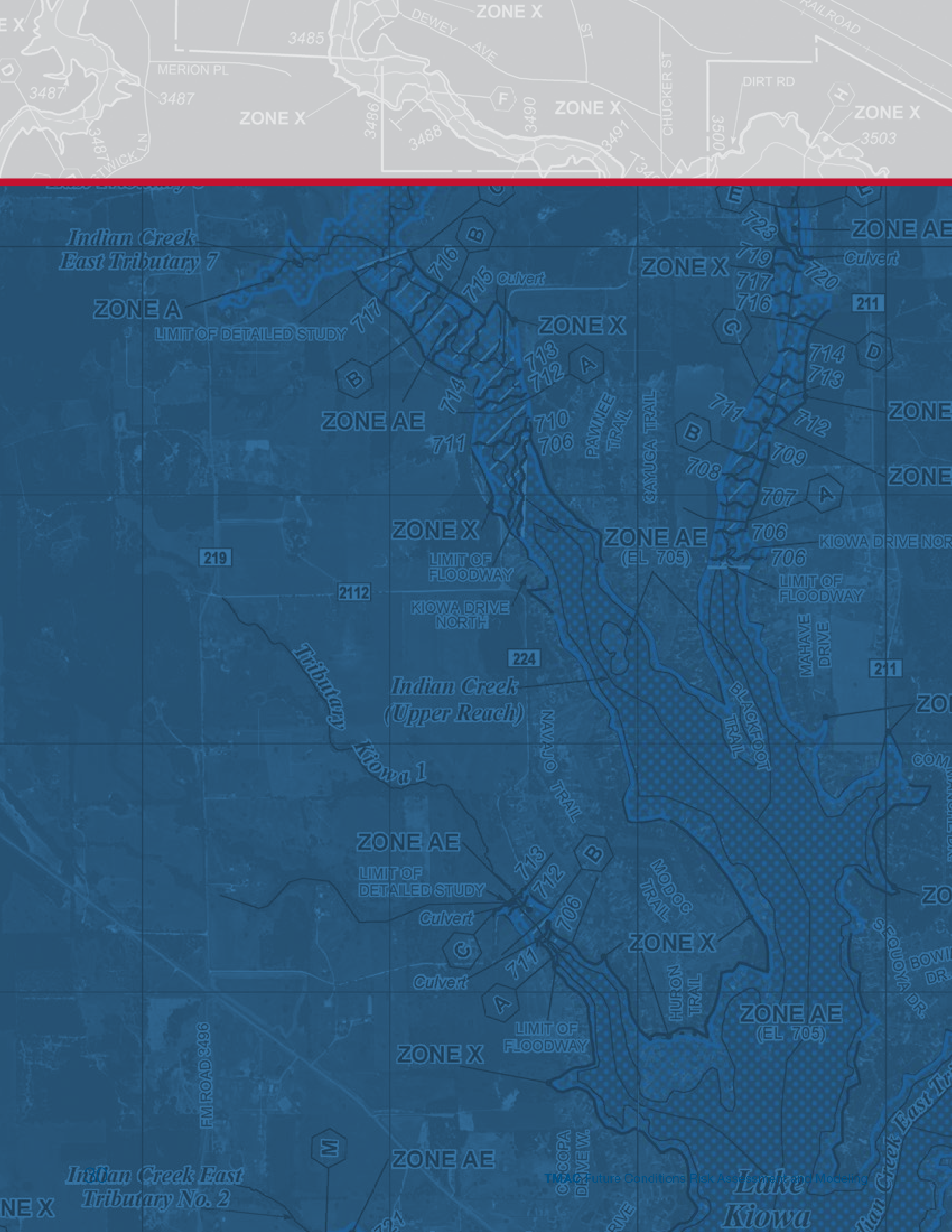
Date	Presenter	Presented to	Title
December 4, 2014	Mr. Paul Kovacs Executive Director, Institute for Catastrophic Loss Reduction, Western University	TMAC	Risk to Insurance Rating
December 4, 2014	Mr. Richard Fogleman Technical Director, Geographic Information Systems, AECOM	TMAC	Database, Mapping, and Digital Display
December 4, 2014	Mr. Eric Berman, GISP Hazus Program Manager, FEMA	TMAC	Risk Assessment and Mapping
December 4, 2014	Mr. David Key, PE, CFM Director, Water Resources, GIS and Applications ESP Associates, P.A.	TMAC	Risk Assessment Processes
December 4, 2014	Ms. Tucker Mahoney Coastal Program Specialist, FEMA	TMAC	Key Decision Points
December 5, 2014	Dr. Ty Wamsley Division Chief, Flood & Storm Protection Division, US Army Engineer Research & Development Center, Coastal & Hydraulics Laboratory, ERDC	TMAC	USACE R&D: Development of Tools for the Future of Flood Inundation Prediction
December 5, 2014	Ms. Erin Cobb, CFM Program Specialist, FEMA	TMAC	Current and Future Possibilities: Delegation
December 5, 2014	Mr. Chad Berginnis Executive Director, Association of State Floodplain Managers (ASFPM)	TMAC	Current and Future Possibilities: Delegation

Date	Presenter	Presented to	Title
December 5, 2014	Ms. Sally Ann McConkey, P.E., CFM, D. WRE Illinois State Water Survey Prairie Research Institute, University of Illinois	TMAC	Examples of Next Generation Flood Risk Management
December 5, 2014	Ms. Carrie Grassi Deputy Director for Planning, New York City Mayor’s Office of Recovery and Resiliency	TMAC	New York City Resiliency Briefing
December 5, 2014	Mr. Ken Ashe, P.E., PMP, CFM Assistant Director, North Carolina Floodplain Mapping Program	TMAC	Examples of Next Generation Flood Risk Management
February 27, 2015	Mr. Ed Curtis, P.E., CFM FEMA Region IX Mr. Darryl Hatheway, CFM Baker AECOM	Future Conditions Subcommittee	FEMA West Coast Sea Level Rise Pilot Study
February 27, 2015	Ms. Heidi Moritz, P.E. Coastal Engineer, Climate Preparedness and Resilience Community of Practice, USACE	Future Conditions Subcommittee	Tiered Approach to the Assessment of Sea Level Change at USACE Projects and the Development of Adaptation Measures for the Future
February 27, 2015	Dr. Brian K. Batten, CFM Senior Coastal Scientist/ Project Manager, Coastal and Resiliency Services, Dewberry	Future Conditions Subcommittee	Case Studies of SLR and Floodplain Mapping
March 3, 2015	Mr. Jonathan Westcott, P.E. Coastal Hazards Specialist, Federal Emergency Management Agency	Flood Hazard Subcommittee Operations, Coordination and Leveraging Subcommittee	NFIP Coastal Analyses and Mapping Overview for the TMAC Subcommittee Meeting

Date	Presenter	Presented to	Title
March 10, 2015	Mr. Andy Neal Actuary, Risk Insurance Division, FEMA	TMAC	Flood Risk to Insurance Rating
March 10, 2015	Mr. David Stearrett Interim Flood Insurance Advocate, FEMA	TMAC	Floodplain Management and the Federal Flood Risk Management Standard
March 10, 2015	Mr. Michael Talbott, P.E., D.WRE Executive Director, Harris County Flood Control District	TMAC	Cooperating Technical Partners (CTP) Presentation
March 10, 2015	Ms. Leslie Durham, P.E. Floodplain Management Branch Chief, Office of Water Resources, Alabama Department of Economic and Community Affairs	TMAC	National Flood Mapping Program: A State CTP Perspective
March 10, 2015	Mr. David Mallory, P.E., CFM Program Manager, Floodplain Management Program, Urban Drainage and Flood Control District, Denver, CO	TMAC	Cooperating Technical Partnership Presentation, UDFCD
March 20, 2015	Dr. Timothy Cohn Hydrologist, USGS Office of Surface Water	Future Conditions Subcommittee	Effects of Climate Change on Riverine Hydrology
March 20, 2015	Dr. Martyn Clark Scientist III, Hydrometeorological Applications Program at the National Center for Atmospheric Research (NCAR)	Future Conditions Subcommittee	Effects of Climate Change on Riverine Hydrology

Date	Presenter	Presented to	Title
March 26, 2015	Dr. Philip Orton Research Assistant Professor, Stevens Institute of Technology	Future Conditions Subcommittee	Hydrodynamic Modeling of Future Coastal Flood Hazards for New York City
April 3, 2015	Dr. Robert Kopp Earth System Science & Policy Research Group, Rutgers University	Future Conditions Subcommittee	Uncertainties and risks of regional sea-level change
April 8, 2015	Mr. Stephen R. Kalaf, CFM Special Mapping and Quality Services Department Manager, Dewberry LLC	Annual Report Subcommittee	Quality Management in Risk MAP
April 27, 2015	Mr. Michael Bremer, CFM NFDA Director, Technical Mapping Committee Chair, Director of Operations CoreLogic Flood Services	Annual Report Subcommittee	Use of FEMA Flood Map Data to Make Flood Determinations
April 27, 2015	Mr. Jason Stoker Physical Scientist and Elevation Products and Services Manager, USGS National Geospatial Program	Annual Report Subcommittee	LIDAR Technology
May 12, 2015	Mr. Paul Rooney Program Specialist, FEMA	TMAC	Database-Driven/ All Digital Display – Status/ Transition
May 12, 2015	Mr. Michael Bremer, CFM NFDA Director, Technical Mapping Committee Chair, Director of Operations CoreLogic Flood Services	TMAC	Lending and Insurance Perspective

Date	Presenter	Presented to	Title
May 13, 2015	Mr. Michael DePue, P.E., CFM Principal Technical Professional, STARR II, Atkins Global	TMAC	Map Generation: Workflow Process
June 23, 2015	Ms. March Runner Tribal Administrator, Louden Tribal Council	TMAC	Tribal Perspective
June 23, 2015	Mr. David Bascom Program Specialist, FEMA Mr. Paul Rooney Program Specialist, FEMA	TMAC	FEMA Flood Insurance Reform Flood Mapping Program Integrated Project Team Progress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NAVAJO TRAIL
BLACKFOOT TRAIL
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LIMIT OF FLOODWAY
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FM ROAD 3496
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ZONE AE
COCOPA DRIVE W.
Indian Creek East Tributary No. 2
Lake Kiowa
Indian Creek East Tributary