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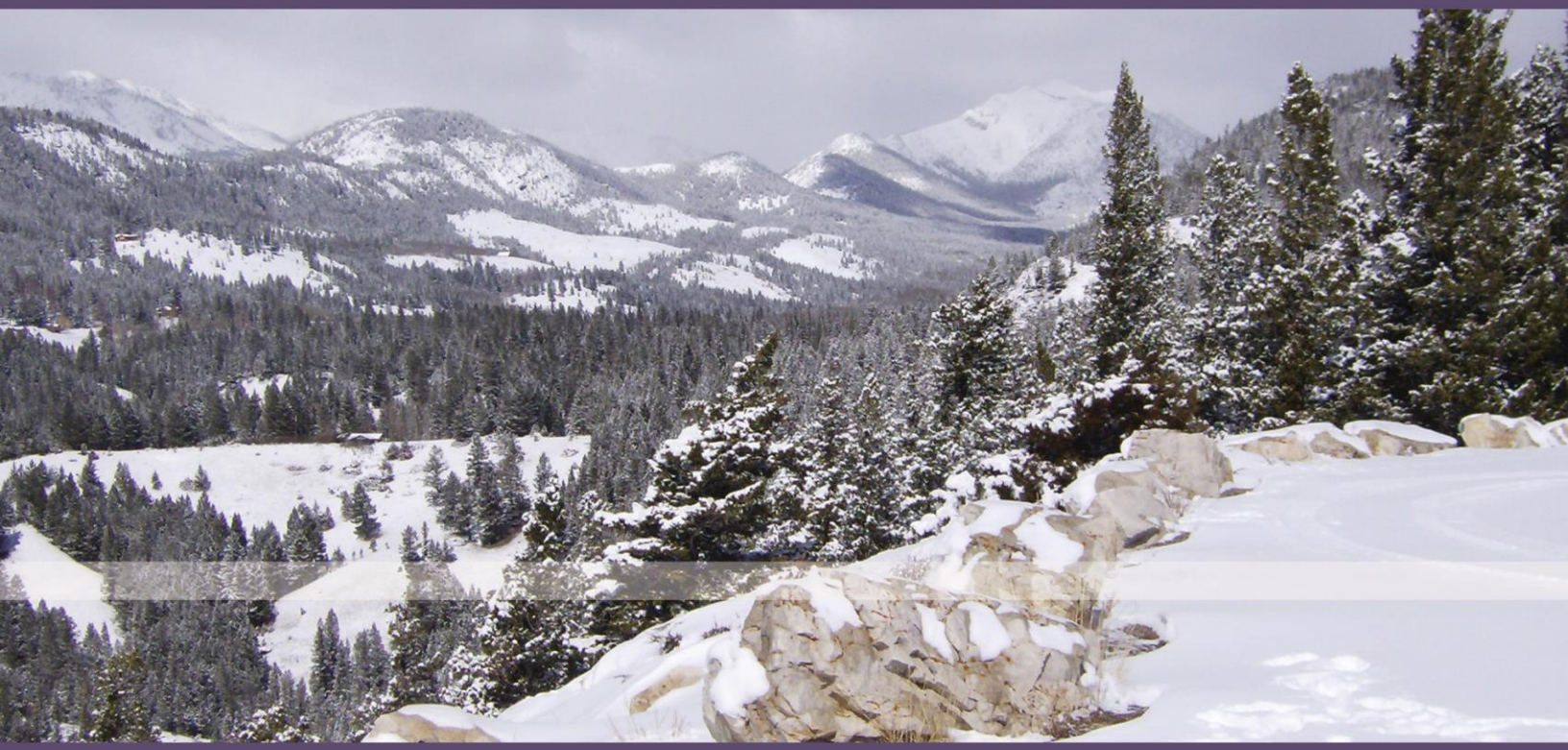
Report on Lessons Learned From USACE Climate Change Adaptation Pilot Projects Fiscal Years 2010-2015



Missouri River headwaters snowpack

USACE CLIMATE PREPAREDNESS AND RESILIENCE

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This report outlines the adaptation pilot projects funded under the Responses to Climate Change Program during fiscal years 2010-2015. These projects spanned the continental United States and Hawaii and represented a range of future climate impacts challenges to project planning, coastal ecosystem restoration and flood risk reduction, freshwater water supply, navigation, and flood risk management.

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Report on Lessons Learned from USACE Climate Change Adaptation Pilot Projects

Executive Summary

The U.S. Army Corps of Engineers (USACE) has a statutory responsibility to operate and maintain its programs and projects to provide their authorized services. Along with changing land use, land cover, and demographic changes, climate change is one of the major challenges of the 21st century, with impacts on all areas of our missions and operations. The Responses to Climate Change (RCC) Program develops methods, tools, policies, and technical guidance to support effective adaptation of USACE projects, systems, and programs to reduce vulnerabilities and improve resilience to the effects of climate change where necessary. Additional needs include improved capabilities to identify impacts and vulnerabilities, assess the effectiveness of climate change adaptation, and evaluate how alternative adaptation measures improve system performance flexibility over a wide range of future scenarios.

The RCC Program initiated an Adaptation Pilot Projects program that was designed to improve knowledge of climate change impacts and adaptation across all levels within USACE, from headquarters to the districts, in accordance with the Adaptation Roadmap. At the time of initiation of the pilot program in late calendar year 2009—fiscal year (FY) 2010—knowledge was quite limited. The pilot projects were thus designed to test new ideas, develop information necessary for policy and guidance, and assess the need for climate change information in decision making. This report outlines the adaptation pilot projects funded under the RCC Adaptation Pilot Projects program during FY2010–2015, which addressed approaches to project planning, coastal ecosystem restoration and flood risk reduction, freshwater water supply, navigation, and flood risk management. These projects, which spanned the continental United States and Hawaii and represented a range of future climate impacts challenges, included:

- Application of Sea Level Change Guidance to the C-111 Spreader Canal, Jacksonville District
- Climate Change Impact on the Operation of Coralville Lake, Iowa, Rock Island District
- Climate Change Associated Sediment Yield Impacts on the Rio Grande, Cochiti Dam and Lake, Albuquerque District
- Climate Change Associated Sediment Yield Impacts and Operation Evaluations at Garrison Dam, North Dakota, Omaha District
- East Rockaway Inlet to Rockaway Inlet, New York, Collaboration Framework Development, New York District

- Risk-Informed Decision Making for Potential Sea Level Rise Impacts on Wetland Restoration, Hamilton Wetland Restoration Project, California, San Francisco District
- Framework for Building Resiliency into Restoration Planning Case Study—Lower Columbia River Estuary, Portland District
- Upland Sediment Production and Delivery in the Great Lakes Region Under Climate Change, Detroit District
- Climate Change Impacts on Water Supply in the Marion Reservoir Watershed, Kansas, Tulsa District
- Missouri River Basin Mountain Snowpack—Accumulation and Runoff, Northwest Division
- Red River of the North Flooding at Fargo, North Dakota, St. Paul District
- Utilization of Regional Climate Science Programs in Reservoir and Watershed Risk-Based Assessments, Oologah Lake and Watershed, Tulsa District
- Climate Modeling and Stakeholder Engagement to Support Adaptation in the Iowa-Cedar Watershed, Rock Island District
- Formulating Mitigation/Adaptation Strategies Through Regional Collaboration with the Ohio River Basin Alliance, Huntington District
- Risk-Informed Decision Making for Integrated Water Resources Management Planning, West Maui Watershed Project, Hawaii District
- Climate Change Impact Evaluation: Impacts to Hurricane Storm Surge Inundation Resulting from Sea Level Change, Chesapeake Bay, Baltimore District
- Modern and Projected Peak Snowpack and Runoff in the Upper Missouri River Basin, Northwest Division
- Implementing a Climate Change Project Under a Regional Integrated Water Resources Management Plan: The Los Angeles Basin Stormwater Conservation Study, Los Angeles District
- Historical Trends and Future Projections of Climate and Streamflow in the Willamette Valley and Rogue River Basins, Portland District.

Key lessons learned from these studies include the following:

- Climate variability and change are already impacting projects planning and operations in varying ways and these impacts will continue in the future.
- Though key aspects of climate impacts may vary from site to site, the pilot projects have provided a body of knowledge and tested methods that support the development of policy and guidance and demonstrate methods that can be (or should not be) used by districts to improve climate change preparedness and resilience.
- Establishing a policy, no matter how broad, reduces the time and cost of adaptation because policy provides the legal and technical justification for action, narrows the range of potential alternative approaches, and guides planning and study approaches to support the desired decisions. Beginning with a broad policy will help minimize the effects of future refinements.

- Adaptation implementation for new projects over the 100-year planning horizon is less complex than for existing projects, many of which have been in place for 50 years or more. A phased screening approach with progressively more detailed evaluations can efficiently identify projects with the highest consequences from climate change or those requiring earlier adaptation.
- Costs and benefits are dynamic and will change over time, just as climate does. These may need to be considered at the regional scale or may need to be quantified or evaluated differently over time. Consideration of dynamic changes over time can guide alternatives formulation, plan selection, design, and adaptive management decisions.
- Accounting for lifecycle adaptation costs must be included in assessing project plans to avoid selecting plans resulting in Federal investments that need substantial reinvestment at a later date.
- Meaningful external collaboration can improve understanding of climate impacts and speed the development and implementation of innovative and effective approaches to climate preparedness and resilience.

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1. Introduction

The U.S. Army Corps of Engineers (USACE) is charged with providing engineering services in support of the general public (Civil Works [CW]) and the armed forces (Military Missions). The USACE CW missions relate to water resources management and the areas of navigation, inland and coastal flood risk management, ecosystem restoration, hydropower, recreation, regulatory, emergency response, and water supply. USACE has a statutory responsibility to operate and maintain its CW programs and projects to provide their authorized services now and in the future. These CW missions are all impacted by observed and projected climate change (Brekke et al. 2009, USACE 2012). To improve its climate preparedness and resilience, USACE has undertaken an active program to assess, develop, test, plan, and implement adaptation measures. Adaptation implementation improves the ability of projects to continue to provide their essential services despite future changes. Because USACE is a Federal agency serving the entire Nation, these adaptation measures need to be practical, cost effective, legally justifiable, and consistent across the Nation while still allowing individual districts to tailor their actions to differing regional conditions.

Significant, measurable climate change is already apparent across the country (Kunkel et al. 2013) (**Figure 1**). U.S. average temperature has increased approximately 1.5°F since 1900 (Karl et al. 2009). Over the next century, an additional 2°F to 11.5°F rise in average temperatures is expected, with greater warming at higher latitudes and in the western United States (Karl et al. 2009). Changes in total annual precipitation have not been observed, although changes in precipitation patterns are evidenced by observed increases in storm intensity; already, many portions of the U.S. have reported increases in very heavy precipitation events, particularly in the Northeast, Midwest, and Great Plains (Kunkel et al. 2013).

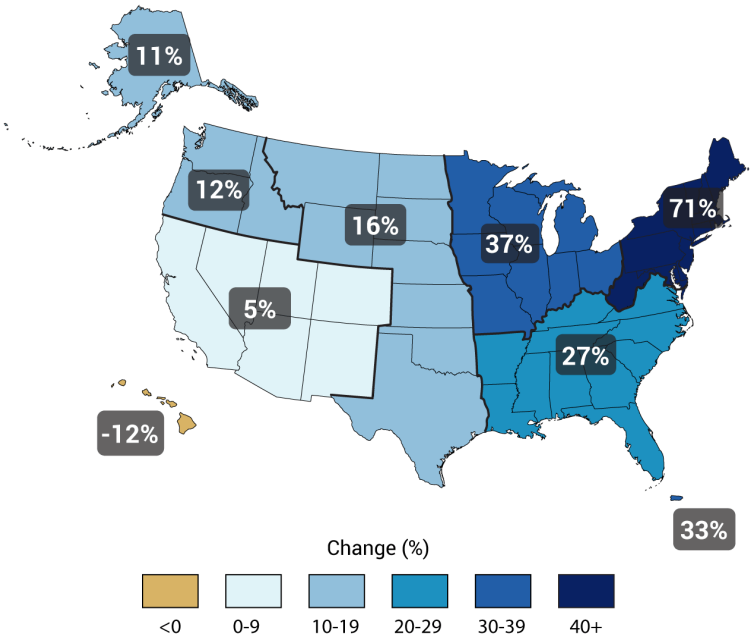


Figure 1: Map of change in the amount of precipitation falling in very heavy events (defined as the heaviest 1% of all daily events) from 1958 to 2012 for each region of the continental United States (Melillo et al. 2014).

Meanwhile, the arid southwestern United States has endured persistent drought in most of the years since the start of the millennium, and especially since 2012. Whether this drought is part of a natural cycle or the beginning of a shift to the more xeric climate anticipated in many climate models remains debated. In coastal areas, the combination of ongoing sea level rise with more intense storm events is leading to more flooding in both coastal and inland areas, with a measurable increase in nuisance flooding (Sweet et al. 2014).

Projected warming and changes in precipitation may significantly alter water resources in ways that will affect socioeconomic stability in the U.S. Changes in water availability for domestic, agricultural, industrial, hydropower, navigation, and ecosystem use; changes in the frequency and magnitude of flooding and drought; and effects of changing sea levels pose significant current and future challenges for Federal agencies charged with managing the United States' water resources. These challenges are compounded by a host of other environmental stressors affecting water quality and water quantity. These stressors include population growth and distribution, changing land use patterns, changing land cover types, decaying and aging infrastructure, economic challenges, declining biodiversity, and increasing globalization pressures (Stockton and White 2011).

1.1 Special Issues Facing Water Managers

Prior to about the mid-2000s, water resources managers generally assumed that the future mean and range of variation in temperature, precipitation, and other hydroclimate variables could reasonably be expected to fall within the range of observations. For example, a reasonably long observed flow record for a particular location was thought to accurately capture the average, maximum, and minimum flows for the foreseeable future. This assumption is termed **stationarity**, because the range of conditions is assumed to be unchanging over time (e.g., Vandaele 1983). Engineers were aware that this assumption oversimplified complex processes (e.g., Chow 1964) and tested the assumption for certain non-climate conditions, such as river regulation of large changes in land cover that impact runoff hydrographs.

By the mid-2000s, it became clear that past climate conditions could no longer be assumed to provide an accurate baseline for predicting the range of future conditions because the baseline was changing (Milly et al. 2008). **Nonstationarity** refers to the condition where the historical averages and ranges of variation may not accurately characterize future conditions in a project area because these conditions are evolving over time. Although cyclical change has been long recognized as important in natural systems (e.g., ecological succession, disturbance, stream channel avulsion), until recently water resources planners have typically not routinely considered long term directional changes in climate in the planning process. In this sense, climate change and its effects introduce a new element of nonstationarity into the planning process. The rate of

future climate change is unknown but it is likely to induce natural, water resources, and human systems to respond in novel ways.

1.2 USACE Responses to Climate Change Program

The Responses to Climate Change (RCC) Program was started in fiscal year (FY) 2010 with the objective to develop and implement practical, nationally consistent, and cost-effective policies, methods, and approaches for effective adaptation of USACE projects, systems, and programs to climate change (Darcy 2010):

> *The US Army Corps of Engineers (Corps) recognizes that the entire portfolio of our structural and nonstructural water resources projects will be affected by climate change, necessitating not only mitigation to climate change, but adaptation as well...[The] Corps is responding to water-related risks posed by climate change to water resources infrastructure, including risk and vulnerability assessments, identification of potential adaptation strategies, and collaborative efforts supporting climate change adaptation.*

These climate adaptation measures are required to ensure USACE water resources infrastructure (**Figure 2**) continues to perform and reliably provide the authorized services that enhance national economic development, national aquatic ecosystem restoration, and regional economic development and that address other social effects (USACE 2013b).

Figure 2: Cochiti Lake, New Mexico—one of the hundreds of reservoirs USACE owns and operates across the Nation.

The RCC Program represents a continuation of activities related to climate change and variability by the Institute for Water Resources (IWR) since the droughts of the late 1970s in support of the CW Program. At that time, IWR initiated studies to evaluate climate change and its implications for water resources planning, which resulted in a 1981 policy requiring all projects with controlled storage to develop a drought contingency plan (USACE 1981). In the mid-1980s, USACE supported the influential study by the National Research Council, *Responding to Changes in Sea Level: Engineering Implications*. The issues raised in this report were so compelling that even before the report's publication in 1987, USACE released a guidance letter requiring the consideration of changing sea levels in project planning and design (USACE 1986) and follow-on planning guidance to incorporate changing sea levels (USACE 1989). The IWR Economic Impacts of Climate Change research program supported the first national conference on climate change and water resources (Ballantine and Stakhiv 1994). This 1991 conference provided an early preview of climate impacts and adaptation measures.

Figure 3: Post-Hurricane Sandy beach nourishment, Rockaway Beach, New York. Beach nourishment has repeatedly proven to confer resilience to storm damage for coastal infrastructure, and nourishment is being undertaken here to reduce future storm damage to the community.

Climate-related work continued through the 1990s, largely led by Eugene Stakhiv, who in 1998 identified three approaches to adapt to the impacts of climate change: anticipatory, reactive, and adaptive (Stakhiv 1998). The anticipatory strategy encompasses preparedness measures to improve resilience and adaptive capacity before an event occurs (**Figure 3**). The reactive strategy is implemented as a response to an event, and therefore may be both risky and expensive, since

preparedness is usually far more cost effective than response and recovery. Adaptive management is a structured process where different solutions are tried and evaluated for their effectiveness, either simultaneously or sequentially. The lessons learned from these evaluations are incorporated in future decision making. Adaptive management can reduce risk by allowing planners to test solutions for cost effectiveness against a range of conditions that might occur in the future to identify the best potential solution given current knowledge. Ongoing monitoring reevaluates the effectiveness of the solution over time and enables changes to occur in response to more certain future information. These approaches are described more fully in USACE guidance (USACE 2014a), which notes that the approaches can be used singly or combined in various pathways over the life of a project or system of projects.

1.3 USGS Circular 1331: Climate Change and Water Resources Management: A Federal Perspective

Hurricane Katrina devastated New Orleans and much of the Gulf Coast in 2005, providing a wakeup call to Federal agencies and non-Federal organizations of the dangers posed by the combination of the Nation's aging infrastructure and new and changing conditions, including climate change and variability. In 2006, the USACE CW Program initiated the Western States Watershed Study to evaluate climate change impacts on water resources in the western U.S. The relationships developed in part through this effort led to interagency teaming that resulted in Circular 1331 and became the nucleus of the interagency Climate Change and Water Working Group (CCAWWG) in 2007. This group, initially made up of USACE, the U.S. Geological Survey (USGS), the Bureau of Reclamation (Reclamation), and the National Oceanic and Atmospheric Administration (NOAA), evaluated the state of knowledge of climate impacts and adaptation. The intent of a collaborative effort beginning in 2007 was to provide a preliminary framework and identify information needed to prepare for, reduce the effects of, and adapt to future climate change and variability. The resulting report, *Climate Change and Water Resources Management: A Federal Perspective* (Brekke et al. 2009: Circular 1331), emphasized the importance of accounting for climate change and variability in Federal decision making, as nonstationarity could impact the magnitude and frequency of floods, droughts, and other hydrologic events (e.g., **Figure 4**) and in turn alter the performance and reliability of existing infrastructure. The report outlined critical knowledge gaps that currently hinder Federal planning efforts, including lack of information on future climate changes and how these changes will impact natural, water, and human resources (termed **uncertainty**); gaps in the collection of weather and streamflow data that would help address the information lack; and a widespread misunderstanding and lack of incorporation of nonstationarity into Federal planning efforts.

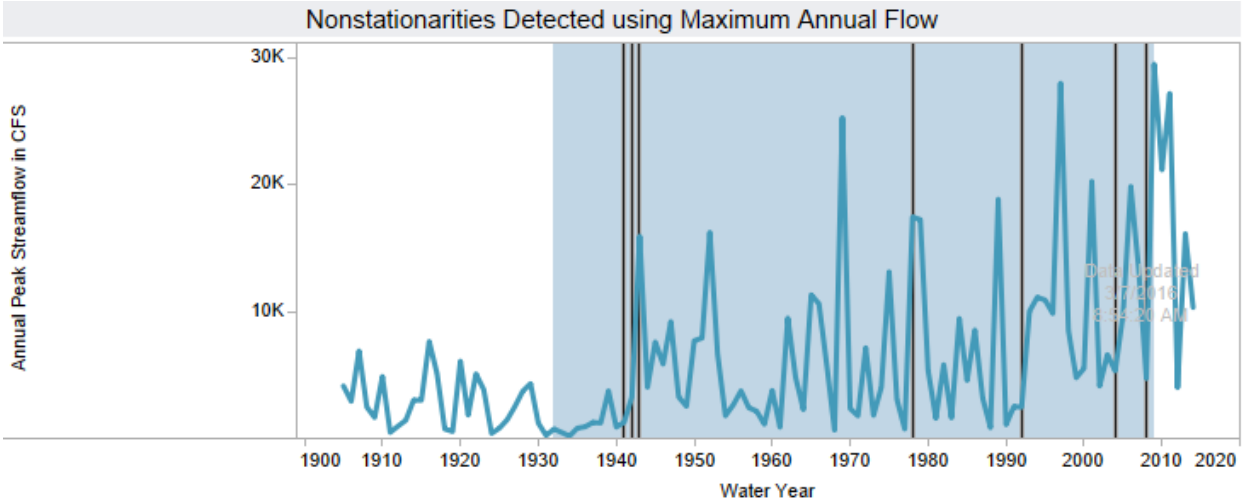


Figure 4: Nonstationarities in maximum annual flow at the Red River of the North at Fargo, North Dakota gage occur around 1940 and 1990. A significantly lower mean and variation in flows exist prior to 1940 compared to after, and a higher mean after 1990. Figure extracted from the USACE Climate Preparedness and Resilience Nonstationarity Tool.

The report outlined strategies for dealing with both uncertainty and nonstationarity. These approaches include **risk-informed decision making (RIDM)**, **adaptive management,** and **integrated water resources management (IWRM)**. RIDM is a process by which potential risks to a project are made explicit; those risks are evaluated for their impacts on the project; and, if the impact is significant, steps are identified to reduce the risk. For example, if a flood risk-reduction measure is being planned for a location where increased flooding is anticipated, then one risk could be that the project designed to provide risk reduction for past and current floods may not perform reliably for larger future floods. If in the future these large floods are anticipated to be very rare, it may not be cost effective to modify the design to accommodate them. However, if these large floods are anticipated to occur relatively frequently, it would probably be necessary to adjust the current design to ensure the project functions under plausible future flood conditions. One way to reduce this risk might be to design a project that can perform under the future conditions; another might be to alter regulation patterns upstream or alter the watershed to provide additional storage, either through nature-based methods or by constructing new water detention facilities. Our confidence in the likelihood of the future risk-causing event would factor into calculating the relative cost effectiveness of taking action now versus dealing with the consequences later. RIDM is a way of ensuring planners account for both nonstationarity (future conditions different from that of today) and uncertainty (how sure we are that an event is going to occur) when planning flood control, navigation, water supply, ecosystem restoration, and other long-term investments in the Nation's infrastructure. Consideration of residual risk at different stages of the project lifetime also helps inform decision making.

Circular 1331 also argued that to be effective, planning for climate change effects on projects requires consideration of the entire watershed in which a project occurs; changes in vegetation

and land use exert profound effects on how much rainwater runs off and therefore how large a flood occurs following a storm of a given size. IWRM is the preferred framework for partnering with Federal, state, local, and tribal entities to determine the effects of climate change on whole watersheds and to identify how actions taken at every level of government might interact to make the consequences larger or smaller (Interagency Climate Change Adaptation Task Force [ICCATF] 2011). IWRM is a process that encourages coordinated development and management of water, land, and related resources in a watershed so water is distributed fairly to users and the sustainability of vital ecosystems is not compromised.

Based on Circular 1331, USACE and Reclamation identified gaps in knowledge needed to incorporate climate change into long-term decision making (Brekke et al. 2011). This was followed by a second report by USACE, Reclamation, and the National Weather Service addressing other needs related to short-term decision making at a time scale from weather to climate (Raff et al. 2013).

1.4 Other Interagency Efforts

USACE participation in interagency groups addressing water resources and climate adaptation expanded with the establishment of the ICCATF by the Executive Office of the President in 2009. These working groups benefitted from the lessons learned during the earlier USACE work. By late 2009, an interagency working group under the auspices of the ICCATF had developed a flexible framework for adaptation planning to help agencies identify and address climate vulnerabilities and opportunities and build resilience to climate change. This framework identified evaluation and learning from adaptation implementation as a key step in improving adaptation planning (Council on Environmental Quality [CEQ] 2009). CEQ published guiding principles for climate change adaptation that include the following (CEQ 2011):

- Adopt integrated approaches, including coordination among Federal, state, local, and tribal governments to manage project work at the watershed level.
- Use best available science; don’t delay adaptation until better information is available.
- Build strong partnerships across multiple sectors, geographic scales, and levels of government.
- Apply risk management methods and tools.

1.5 Need for Pilots to Test and Evaluate Adaptation Approaches

The ICCATF Adaptation Processes Working Group identified the implementation of agency pilots to further and test the flexible framework for adaptation planning, suggesting that pilots to be conducted by different agencies span several scales (local to agency-wide) (CEQ 2010). The pilots were intended to test the effectiveness of the flexible framework. Lessons learned from the

pilots could be used to develop agency implementation guidance and identify key enabling investments. The Department of Homeland Security conducted agency-wide pilots. The Department of Transportation tested pilots at the agency component level on a statewide basis. The Environmental Protection Agency (EPA) conducted a community-level pilot, and the USACE tested the framework at project scale.

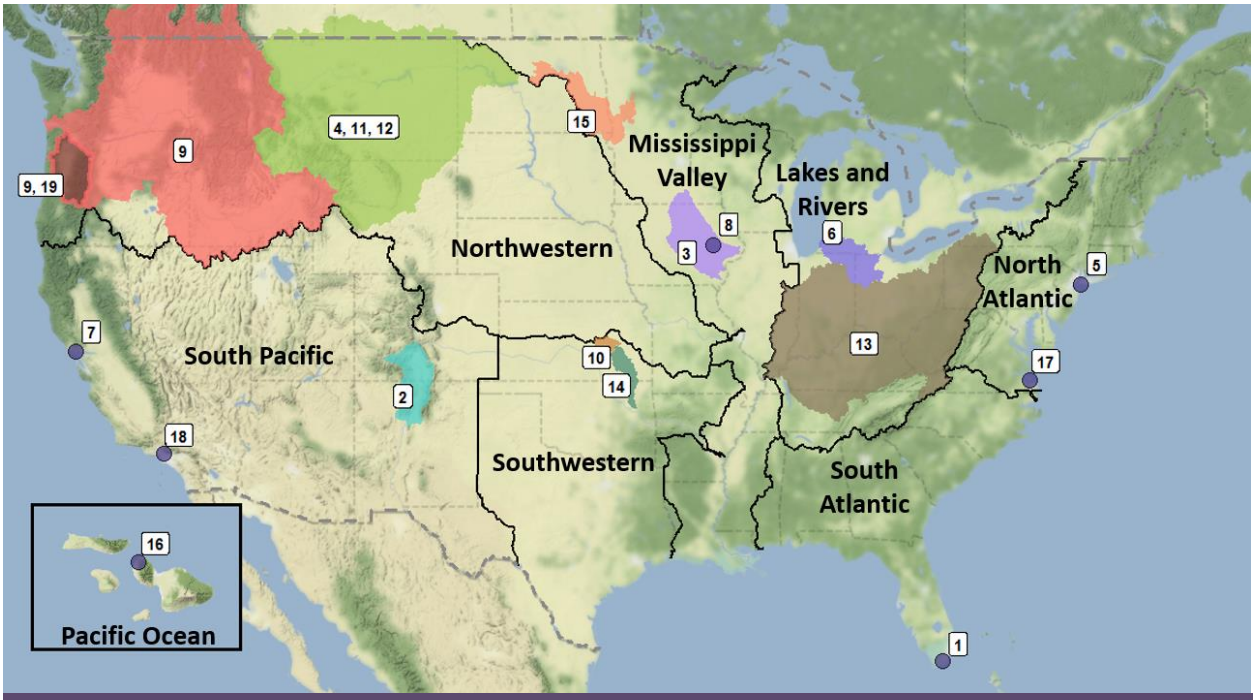
The RCC Adaptation Pilot Projects Program began in FY2010 with the first four pilots, with the goal of increasing internal agency understanding of how to prepare for climate change adaptation planning and implementation (USACE 2011c). They were also used to test the CEQ's flexible framework for adaptation at the project scale. This second objective fit nicely with the USACE desire to conduct climate change adaptation pilot studies spanning the project lifecycle and the USACE business lines in river basins, coastal regions, and aquatic ecosystem projects. The lessons learned from these projects are helping USACE to mainstream climate change adaptation, improve vulnerability assessment methods, develop an adaptive management strategy for climate change and variability, and improve water resources management and planning methodologies. The pilots are helping address eight primary gap areas identified by Brekke et al. (2009) (**Figure 5, Table 1**):

1. Summarize relevant literature.
2. Obtain climate change information.
3. Make decisions about how to use the climate change information.
4. Assess natural system response.
5. Assess socioeconomic and institutional response.
6. Assess system risks and evaluate alternatives.
7. Assess and characterize uncertainties.
8. Communicate results and uncertainties to decision makers.

1.6 Organization of this Report

The remainder of this report includes the following sections:

- Chapter 2 discusses the purpose and scope of each of the RCC Adaptation Pilot Projects undertaken between FY2010 and FY2015.
- Chapter 3 describes RCC Adaptation Pilot Project methodologies and approaches.
- Chapter 4 describes the results of the RCC Adaptation Pilot Projects, identifying lessons learned and remaining gaps.
- Appendix A provides copies of the RCC Adaptation Pilot Project fact sheets.



USACE RCC Adaptation Pilot Projects	
1	Application of Sea Level Change Guidance to the C-111 Spreader Canal, Jacksonville District
2	Climate Change Associated Sediment Yield Impacts on the Rio Grande, Cochiti Dam and Lake, Albuquerque District
3	Climate Change Impact on the Operation of Coralville Lake, Iowa, Rock Island District
4	Climate Change Associated Sediment Yield Impacts and Operation Evaluations at Garrison Dam North Dakota, Omaha District
5	East Rockaway Inlet to Rockaway Inlet, New York, Collaboration Framework Development, New York District
6	Upland Sediment Production and Delivery in the Great Lakes Region Under Climate Change, Detroit District
7	Risk-Informed Decision Making for Potential Sea Level Rise Impacts on Wetland Restoration, Hamilton Wetland Restoration Project, California, San Francisco District
8	Climate Modeling and Stakeholder Engagement to Support Adaptation in the Iowa-Cedar Watershed, Rock Island District
9	Framework for Building Resiliency into Restoration Planning Case Study—Lower Columbia River Estuary, Portland District
10	Climate Change Impacts on Water Supply in the Marion Reservoir Watershed, Kansas, Tulsa District
11	Missouri River Basin Mountain Snowpack—Accumulation and Runoff, Northwest Division
12	Modern and Projected Peak Snowpack and Runoff in the Upper Missouri River Basin, Northwest Division
13	Formulating Mitigation/Adaptation Strategies Through Regional Collaboration with the Ohio River Basin Alliance, Huntington District
14	Utilization of Regional Climate Science Programs in Reservoir and Watershed Risk-Based Assessments, Oologah Lake and Watershed, Tulsa District
15	Red River of the North Flooding at Fargo, North Dakota, St. Paul District
16	Risk-Informed Decision Making for Integrated Water Resources Management Planning, West Maui Watershed Project, Hawaii District
17	Climate Change Impact Evaluation: Impacts to Hurricane Storm Surge Inundation Resulting from Sea Level Change, Chesapeake Bay, Baltimore District
18	Implementing a Climate Change Project Under a Regional Integrated Water Resources Management Plan: The Los Angeles Basin Stormwater Conservation Study, Los Angeles District
19	Historical Trends and Future Projections of Climate and Streamflow in the Willamette Valley and Rogue River Basins, Portland District

Figure 5: Map showing the location of RCC Adaptation Pilot Projects with respect to USACE divisions; projects in small watersheds are represented as dots.

Table 1: USGS Circular 1331 Gaps Addressed by RCC Adaptation Pilot Projects.

USACE RCC Adaptation Pilot Project	USGS Circular 1331 Primary Gap(s) Addressed
1. Application of Sea Level Change Guidance to the C-111 Spreader Canal, Jacksonville District	4) Assess natural system responses 6) Assess system risks and evaluate alternatives 7) Assess and characterize uncertainties
2. Climate Change Associated Sediment Yield Impacts on the Rio Grande, Cochiti Dam and Lake, Albuquerque District	4) Assess natural system responses 6) Assess system risks and evaluate alternatives
3. Climate Change Impact on the Operation of Coralville Lake, Iowa, Rock Island District	4) Assess natural system responses
4. Climate Change Associated Sediment Yield Impacts and Operation Evaluations at Garrison Dam North Dakota, Omaha District	4) Assess natural system responses
5. East Rockaway Inlet to Rockaway Inlet, New York, Collaboration Framework Development, New York District	6) Assess system risks and evaluate alternatives 7) Assess and characterize uncertainties 8) Communicating results and uncertainties to decision makers
6. Upland Sediment Production and Delivery in the Great Lakes Region Under Climate Change, Detroit District	2) Obtain climate change information 4) Assess natural system responses
7. Risk-Informed Decision Making for Potential Sea Level Rise Impacts on Wetland Restoration, Hamilton Wetland Restoration Project, California, San Francisco District	6) Assess system risks and evaluate alternatives 7) Assess and characterize uncertainties
8. Climate Modeling and Stakeholder Engagement to Support Adaptation in the Iowa-Cedar Watershed, Rock Island District	7) Assess and characterize uncertainties 8) Communicating results and uncertainties to decision makers
9. Framework for Building Resiliency into Restoration Planning Case Study—Lower Columbia River Estuary, Portland District	7) Assess and characterize uncertainties 8) Communicating results and uncertainties to decision makers
10. Climate Change Impacts on Water Supply in the Marion Reservoir Watershed, Kansas, Tulsa District	3) Make decisions about how to use the climate change information 6) Assess system risks and evaluate alternatives 7) Assess and characterize uncertainties
11. Missouri River Basin Mountain Snowpack—Accumulation and Runoff, Northwest Division	2) Obtain climate change information 3) Make decisions about how to use the climate change information 4) Assess natural system responses
12. Modern and Projected Peak Snowpack and Runoff in the Upper Missouri River Basin, Northwest Division	2) Obtain climate change information 3) Make decisions about how to use the climate change information 4) Assess natural system responses 7) Assess and characterize uncertainties
13. Formulating Mitigation/Adaptation Strategies Through Regional Collaboration with the Ohio River Basin Alliance, Huntington District	6) Assess system risks and evaluate alternatives 8) Communicating results and uncertainties to decision makers
14. Utilization of Regional Climate Science Programs in Reservoir and Watershed Risk-Based Assessments, Oologah Lake and Watershed, Tulsa District	6) Assess system risks and evaluate alternatives

USACE RCC Adaptation Pilot Project	USGS Circular 1331 Primary Gap(s) Addressed
15. Red River of the North Flooding at Fargo, North Dakota, St. Paul District	2) Obtain climate change information 3) Make decisions about how to use the climate change information 7) Assess and characterize uncertainties
16. Risk-Informed Decision Making for Integrated Water Resources Management Planning, West Maui Watershed Project, Hawaii District	6) Assess system risks and evaluate alternatives 8) Communicating results and uncertainties to decision makers
17. Climate Change Impact Evaluation: Impacts to Hurricane Storm Surge Inundation Resulting from Sea Level Change, Chesapeake Bay, Baltimore District	4) Assess natural system responses 7) Assess and characterize uncertainties
18. Implementing a Climate Change Project Under a Regional Integrated Water Resources Management Plan: The Los Angeles Basin Stormwater Conservation Study, Los Angeles District	6) Assess system risks and evaluate alternatives 8) Communicating results and uncertainties to decision makers
19. Historical Trends and Future Projections of Climate and Streamflow in the Willamette Valley and Rogue River Basins, Portland District	2) Obtain climate change information 3) Make decisions about how to use the climate change information 4) Assess natural system responses 6) Assess system risks and evaluate alternatives 7) Assess and characterize uncertainties

2. Purpose and Scope of RCC Adaptation Pilot Projects

USGS Circular 1331 and subsequent publications outlined strategies for addressing climate change impacts on water resources. However, USACE had policy or guidance in place only for incorporating considerations related to changing sea levels (USACE 1986, 2000, 2009). Additional policy and guidance were required to enable district planners to address other aspects of climate change in planning and engineering. The initial series of four adaptation pilot projects begun in FY2010 (from October 1, 2009, through September 30, 2010) sought to (1) develop innovative methods, strategies, and technologies supporting climate preparedness and resilience for water resources management; and (2) test the concept of a flexible framework for climate adaptation proposed by the CEQ in 2010.

By the time the second round of 11 projects was competitively selected for FY2011 (from October 1, 2010, through September 30, 2011), lessons learned from the first pilot projects enabled testing of a more specific set of goals:

- Test the efficacy of the RIDM process with respect to climate change adaptation and uncertainty.
- Test the utility of integrated watershed management as a framework for identifying and working with partners and stakeholders.
- Continue to build district capacity in the professional and technical competencies important in climate change adaptation, including joint work across all levels of government and with non-governmental partners and stakeholders.

Finally, four projects were initiated over the period 2012–2015.

2.1 FY2010 Pilot Studies

Four studies were funded in FY2010 under the RCC Program (for additional information, see Appendix A):

- Application of Sea Level Change Guidance to the C-111 Spreader Canal, Jacksonville District
- Climate Change Impact on the Operation of Coralville Lake, Iowa, Rock Island District
- Climate Change Associated Sediment Yield Impacts on the Rio Grande, Cochiti Dam and Lake, Albuquerque District
- Climate Change Associated Sediment Yield Impacts and Operation Evaluations at Garrison Dam, North Dakota, Omaha District.

All four of these projects were completed by December 2012 and are described in more detail below.

2.1.1 Application of Sea Level Change Guidance to the C-111 Spreader Canal, Jacksonville District

This project sought to understand how changing sea levels would affect ecosystem restoration for a single component of the Everglades restoration project. Channelization of the area of Florida in and around Everglades National Park over a long period of time has disrupted the natural overland flow that historically sustained this wetland. Alterations to the flow in one of the channels, the C-111 Spreader Canal, were planned to prevent drainage of surface water from the Everglades into the canal, resulting in improved freshwater wetland function and improved water flow into Florida Bay. The improved flows into Florida Bay are anticipated to restore some of the coastal habitat lost when overland flows were channelized and diverted elsewhere and thus support increased numbers of birds and near-shore marine organisms. Observed increases in local relative sea level raised concerns that changing sea level could wipe out these gains by inundating the newly restored near-shore brackish habitat **(Figure 6).**

Figure 6: Sea level rise is projected to inundate freshwater meadows with saltwater, fundamentally changing their character and ecological function across the southern tip of Florida.

The C-111 Spreader Canal RCC Adaptation Pilot Project used the (then) recently issued USACE (2009) guidance on sea level rise, *Water Resources Policies and Authorities Incorporating Sea-Level Change Considerations in Civil Works Programs* (Engineer Circular [EC] 1165-2-211), to estimate the impact of global sea level rise on restored habitat in Florida Bay and the freshwater wetlands lying to the north. EC 1165-2-211 specified that projected local relative sea level change for a given area should account for both global (eustatic) sea level rise and local changes in the elevation of the land surface.[1] Under this (and subsequent) guidance, USACE is required to consider current trends as well as an intermediate and a high scenario of projected global sea level change for the project area. In Florida Bay, the range of future sea level change considered was 1 to 5 feet above current mean levels.

Analysis of sea level rise change showed that the restored near-shore low-salinity habitat would naturally relocate landward as sea levels rise, but freshwater habitats immediately inland of the coast are likely to be lost in proportion to the amount of sea level rise. Additional delivery of

[1] These included tectonic changes (uplift and down-dropping of the crust) and isostasy (the regional rise and fall of the Earth's crust in response to the addition [or removal] of sediment or ice).

freshwater not currently available to the system would be required to prevent such losses. The highest sea level change, 69 inches above mean sea level by 2100, is projected to lead to the gradual loss of all freshwater wetlands restored by this project.

2.1.2 Climate Change Impact on the Operation of Coralville Lake, Iowa, Rock Island District

Coralville Lake is a multipurpose reservoir in east-central Iowa located on the Iowa River just above Iowa City. In recent decades, inflow to the reservoir has been higher than the baseline observations that the project was designed to accommodate. Two of the largest floods since the dam was put into operation in 1958 occurred in 1993 and 2008, resulting in activation of the spillway (**Figure 7**) and downstream flooding of urban, rural, and agricultural areas. Both of these floods exceeded the largest historical event upon which the original dam and water control plan were developed.

Figure 7: Coralville Lake spilling water during the flood of 2008.

The Coralville Lake RCC Adaptation Pilot Project sought to understand the hydrologic changes to the Iowa River that could occur due to future climate conditions and how and whether these changes could be used to guide updates to reservoir operating policies that would be robust with respect to climate change.

Although the project team was able to simulate average hydrologic conditions in the Iowa River for future periods under a changing climate, the team was not successful in adequately capturing the range of variation in those conditions, including the magnitude of extreme high-flow events that could lead to overtopping of the spillway and downstream flooding. Though extremely useful in developing and testing methods to address hydrologic impacts of climate change, the pilot demonstrated that progress in actionable science would be required before 21st century climate scenarios would be appropriate for use in defining a new optimized release schedule for future major flood events. Therefore, as knowledge of climate-impacted hydrology improves, the results of this completed study should be revisited.

2.1.3 Climate Change Associated Sediment Yield Impacts on the Rio Grande, Cochiti Dam and Lake, Albuquerque District

The Cochiti Dam and Lake RCC Adaptation Pilot Project investigated the impacts of climate change on the hydrology and sediment yield of the Upper Rio Grande to determine whether climate change would affect sedimentation rates in the lake and therefore affect projected project lifetime. This was part of a paired basin study with Reclamation, which evaluated impacts on a USACE reservoir and a Reclamation reservoir in each of the Rio Grande Basin and the Upper Missouri Basin (described below).

These studies were deemed important because changes in hydrology impact river and reservoir sedimentation, which in turn impact reservoir storage, channel stability, and channel conveyance. Model projections of future climate conditions in much of the western U.S. show increased aridity is likely to occur, leading to vegetation loss. This vegetation loss can result in greater erosion during increasingly intense precipitation events. Increased erosion translates into increased stream sediment load, which has the potential to change sedimentation in reservoirs and affect estimated project lifetime (Graf et al. 2010). So an important question is, will stream sediment load increase in projected climate scenarios, and what effect will this have on the project lifetime of reservoirs and the dams that impound them?

Cochiti Dam is the only mainstem dam on the upper Rio Grande, providing flood risk management to the City of Albuquerque and numerous downstream communities. The Cochiti Dam and Lake RCC Adaptation Pilot Project addressed the question of whether climate change would increase the amount of sediment entering Cochiti Lake behind Cochiti Dam, impacting the capacity of the designated flood control storage and potentially shortening the project lifetime and impacting the flood control pool.

To answer this question, downscaled climate model projections of temperature and precipitation were input into hydrologic models that routed surface and groundwater flows to Cochiti Lake. The relationship between the amount water flowing into Cochiti Lake and the amount of sediment likely to settle out onto the lake floor (known as sediment yield) had been estimated by a prior Reclamation study (Kolk 2002). Consequently, sediment yield as the result of modeled inflows under future climate conditions could be estimated using current knowledge of inflow-sedimentation relationships. Under most future climate scenarios, sediment yield was found to decline due to decreased flow volumes in the Rio Grande under an increasingly arid climate (**Figure 8**).

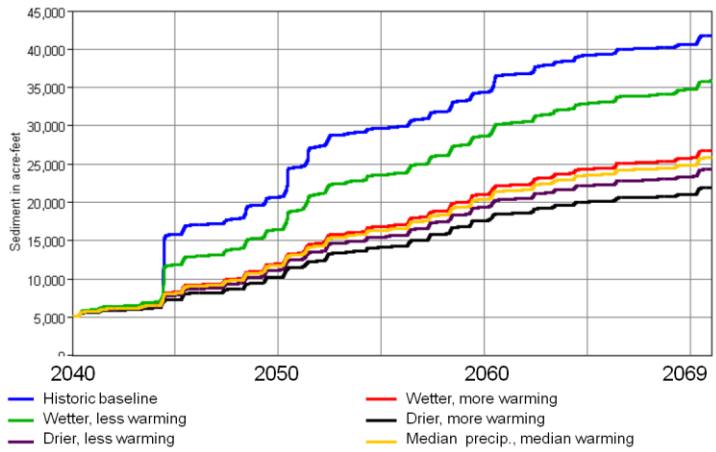


Figure 8: Projected reductions in sedimentation at Cochiti Lake, New Mexico, compared the historical baseline, resulting from projected reductions in inflow.

2.1.4 Climate Change Associated Sediment Yield Impacts and Operation Evaluations at Garrison Dam, North Dakota, Omaha District

The second paired basin study with Reclamation, the Garrison Dam RCC Adaptation Pilot Project, investigated the impacts of climate change on the hydrology and sediment yield of the Upper Missouri River to determine whether climate change would shorten the lifetime of the project through increased sedimentation or require a change of operations to manage changes in extreme flood events. As for the Cochiti Dam and Lake Pilot Study, for Garrison, downscaled climate model projections of temperature and precipitation were input into hydrologic models that routed surface and groundwater flows to Lake Sakakawea impounded behind Garrison Dam.

Climate model projections for the Upper Missouri Basin call for an increase in temperature of about 0.5°C and 2.5°C and precipitation changes of about -5% to +25%. Hydrologic models projected an increase in pool elevations and releases for all climate scenarios, with increased water inflow accounting for the majority of the rise (not sedimentation). Counterintuitively, drier future scenarios posed greater flood risk due to changes in the timing of spring runoff. Further study suggested that coordinated changes in the operation of the six mainstem Missouri Basin dams, including Garrison, would be able to accommodate the changes in projected flows.

2.2 FY2011 RCC Adaptation Pilot Projects

Eleven adaptation pilot projects were funded in FY2011 under the RCC Program (for additional information, see Appendix A):

- East Rockaway Inlet to Rockaway Inlet, New York, Collaboration Framework Development, New York District
- Risk-Informed Decision Making for Potential Sea Level Rise Impacts on Wetland Restoration, Hamilton Wetland Restoration Project, California, San Francisco District
- Framework for Building Resiliency into Restoration Planning Case Study—Lower Columbia River Estuary, Portland District
- Upland Sediment Production and Delivery in the Great Lakes Region Under Climate Change, Detroit District
- Climate Change Impacts on Water Supply in the Marion Reservoir Watershed, Kansas, Tulsa District
- Missouri River Basin Mountain Snowpack—Accumulation and Runoff, Northwest Division
- Red River of the North Flooding at Fargo, North Dakota, St. Paul District
- Utilization of Regional Climate Science Programs in Reservoir and Watershed Risk-Based Assessments, Oologah Lake and Watershed, Tulsa District
- Climate Modeling and Stakeholder Engagement to Support Adaptation in the Iowa-Cedar Watershed, Rock Island District
- Formulating Mitigation/Adaptation Strategies Through Regional Collaboration with the Ohio River Basin Alliance, Huntington District
- Risk-Informed Decision Making for Integrated Water Resources Management Planning, West Maui Watershed Project, Hawaii District.

2.2.1 East Rockaway Inlet to Rockaway Inlet, New York, Collaboration Framework Development, New York District

The East Rockaway Inlet to Rockaway Inlet RCC Adaptation Pilot Project sought to identify vulnerabilities to sea level rise of the Rockaway Peninsula, a barrier island formed at the mouth of Jamaica Bay on Long Island in the New York City Borough of Queens. Unlike many of the pilot studies, this study area is heavily urban, with more than 10,000 structures, including critical infrastructure such as a sewage treatment plant, a hospital, and numerous primary and secondary education facilities. As a low-lying barrier beach, the peninsula is subject to storm-induced recession and long-term erosion, problems likely to be exacerbated by sea level change and projected increases in storm surges associated with potentially larger storm events in the region. The study was designed to facilitate well-designed and inclusive multi-stakeholder collaboration with local decision makers for the purpose of identifying vulnerability to sea level change impacts, acceptable levels of risk, and the most acceptable alternatives over the project lifecycle.

A major component of this study was the development of a multidisciplinary team of decision makers who collaboratively identified, inventoried, and mapped vulnerable areas, infrastructure, and critical facilities at greatest risk for repetitive sea level impacts. This Sea Level Change Risk Reduction Team (SLRRT) also investigated ways to reduce future risk from sea level rise along the peninsula.

This adaptation pilot project was overcome by events in a dramatic manner when, just after the initial inundation maps were presented to the stakeholders in October 2012, Hurricane Sandy came ashore in the greater New York City metropolitan area. Moving slowly and merging with a large winter storm, Sandy produced a large storm surge that inundated most of the New Jersey and New York coastline, producing widespread flooding along the Jersey Shore, Staten Island, Manhattan, and Queens. As a low-lying barrier island, the Rockaway Peninsula sustained inundation consistent with the flooded areas identified by the study (**Figure 9**). USACE District staff and the SLRRT are now actively engaged in assisting with planning for future redevelopment of the peninsula as part of Sandy recovery. As a result, the pilot project merged into the larger post-Sandy effort.

Figure 9: Much of the Rockaway Peninsula was destroyed by Hurricane Sandy in 2012.

2.2.2 Risk-Informed Decision Making for Potential Sea Level Rise Impacts on Wetland Restoration, Hamilton Wetland Restoration Project, California, San Francisco District

The Hamilton Wetland RCC Adaptation Pilot Project was initiated to evaluate the RIDM framework as a tool for adapting to potential sea level change. Climate change and sea level variability increase uncertainty associated with wetland restoration planning and management. In the San Francisco Bay Area, wetland restoration projects are at risk of inundation as sea level

rises, particularly at sites where hardened perimeters, urbanization, levees, or other barriers exist at the inland boundaries of restoration sites. These barriers constrain or prevent the inland migration of seasonal or transitional wetland areas as sea level rises over time. With the exception of the higher tidal marsh, much of the Hamilton site will likely revert to subtidal and mud flat habitat under all three sea level change scenarios unless accretions of sediment occurs. Higher marsh areas will become tidal rather than seasonal, a tradeoff that planners and resource agencies have previously agreed would be acceptable at a landscape scale in this setting. RIDM uses a risk management framework to incorporate such uncertainties and tradeoffs into USACE decision-making processes (**Figure 10**).

The initial Hamilton Pilot Study proposed to evaluate the RIDM framework by testing a hypothetical wetland restoration planning scenario modeled on the actual planning scenarios used for the Hamilton Wetland Restoration Project. Unlike the actual planning scenarios, this hypothetical pilot planning scenario would consider sea level change as part of the future with- and without-project conditions. However, since the pilot study began in 2011, USACE has modified and updated both its planning policies and its sea level change guidance. Accordingly, the initial Hamilton Pilot Study methods were updated to reflect these changes. In the updated pilot study, the alternatives analysis will include the following steps:

Figure 10: Restoration of the Hamilton Wetlands provides an important addition to estuarine habitats in San Francisco Bay.

- Incorporate SMART planning principles and guidelines (which include many RIDM principles).
- Increase the design performance analysis period of the alternatives to 100 years.
- Incorporate all three standard sea level change scenarios into the design performance analysis of alternatives.
- Incorporate all three standard sea level change scenarios into the cost effectiveness/incremental cost analysis (CEICA) of alternatives.

The results of the pilot study will facilitate the evaluation of performance risk tradeoffs between plan alternatives that maintain seasonal wetlands versus those alternatives that allow for seasonal wetlands to be sacrificed as sea level rises. This pilot study is ongoing.

2.2.3 Framework for Building Resiliency into Restoration Planning Case Study—Lower Columbia River Estuary, Portland District

Changing sea levels are anticipated to have strong impacts on the Lower Columbia River Estuary, the 145-mile stretch of tidally influenced river between Bonneville Dam and the Pacific Ocean. USACE has committed $150 million in FY2009–2018 for ecosystem restoration, research monitoring, and evaluation efforts on the estuary. Climate change impacts such as changing sea level, changes in storm frequency and intensity, and altered Columbia River flows have the potential to significantly impact the long-term effectiveness of these restoration efforts, particularly those designed to historical baseline conditions. The objective of the Lower Columbia River Estuary RCC Adaptation Pilot Project is to develop and test a replicable framework for incorporating climate change and building resiliency into aquatic ecosystem restoration planning. This framework includes both RIDM and adaptive management components.

The first phase of the pilot included conducting two workshops with regional stakeholders and partners to establish consensus on the need for a planning process that accounts for climate change impacts, as well as consensus on how those impacts should be monitored and addressed. The vulnerabilities of restoration projects and of specific places on the landscape were identified, and project-specific risk assessments (risk registers) and thresholds that initiate particular management responses (adaptation measures) have been identified.

Phase 2 of this project, initiated in 2014, was a project-specific activity to demonstrate how to incorporate climate change in an estuarine ecosystem restoration project. This phase used detailed climate change information and conceptual models of the project estuary to determine potential alternative design features that might be implemented to make the project more resilient to climate change impacts. Six potential adaptation measures were developed, consisting primarily of modifications to existing project features, such as adjustments to levee setbacks, channel shapes, and habitat gradients. The pilot demonstrated that there are often straightforward opportunities to include adaptation measures to not only enhance existing aquatic ecosystem restoration but also increase the resilience of these projects with respect to climate change.

2.2.4 Upland Sediment Production and Delivery in the Great Lakes Region Under Climate Change, Detroit District

The Great Lakes Region RCC Adaptation Pilot Project focused on sediment deposition at the mouths of two rivers: the St. Joseph River (located in Michigan and Indiana), which enters Lake Michigan through Detroit District's St. Joseph Harbor (**Figure 11**), and the Maumee River (located in Ohio), which enters Lake Erie through Buffalo District's Toledo Harbor. Sediment deposition in the harbors creates sizeable annual dredging requirements to maintain commercial

navigation. The pilot study harbors are considered representative of significant sedimentation and dredging issues at most of the 139 harbors USACE manages on the Great Lakes, and climate change impacts are likely to be similar across the region.

Figure 11: St. Joseph Harbor, Michigan, is an important shipping channel maintained by the USACE Detroit District through an active dredging program. Future changes in harbor sedimentation may affect dredging costs.

This pilot study addresses the following central question: How will dredging cost requirements at Great Lakes harbors vary in the future as climate change affects precipitation regimes and stream runoff characteristics? To answer this question, the project team had to first determine the historical relationship between runoff volumes, storm event characteristics, and dredging costs. The outcome of this step was a determination of the types of precipitation events that cause the greatest impacts on sediment production at the harbor mouths. Projected future changes in precipitation were then modeled and the resulting surface water runoff and groundwater routed to streams. From these data, the future frequency of such precipitation events and associated sediment deposition were estimated, providing an initial estimate of future dredging needs and cost.

2.2.5 Climate Change Impacts on Water Supply in the Marion Reservoir Watershed, Kansas, Tulsa District

Marion Reservoir on the Cottonwood River in Kansas is a multipurpose project that is authorized for water supply, with 44,730 acre-feet (ac-ft) of reservoir water storage owned by the State of Kansas. The state in turn has water supply contracts with local communities, which will expire from 2021 to 2039. No allocation currently exists for future water supply storage. The current firm yield (the amount expected to be available even in drought years) is 33.5 ft^3/s (5,719 ac-ft/yr), is sufficient to satisfy the existing contract demand. However, it was unclear before this pilot whether firm yield in the future would be affected by climate change.

The Marion Reservoir RCC Adaptation Pilot Project explored how information about projected future climate conditions can best be incorporated into decision making about the future firm yield available for allocation to communities via existing and future water supply contracts. Model projections of average future climate in the region indicated that the streamflow conditions at the reservoir will remain relatively unaffected (**Figure 12**), leading to no major changes in firm yield. The results of this study suggest that stresses resulting from climate change at Marion Reservoir as characterized by changes in mean temperature and precipitation

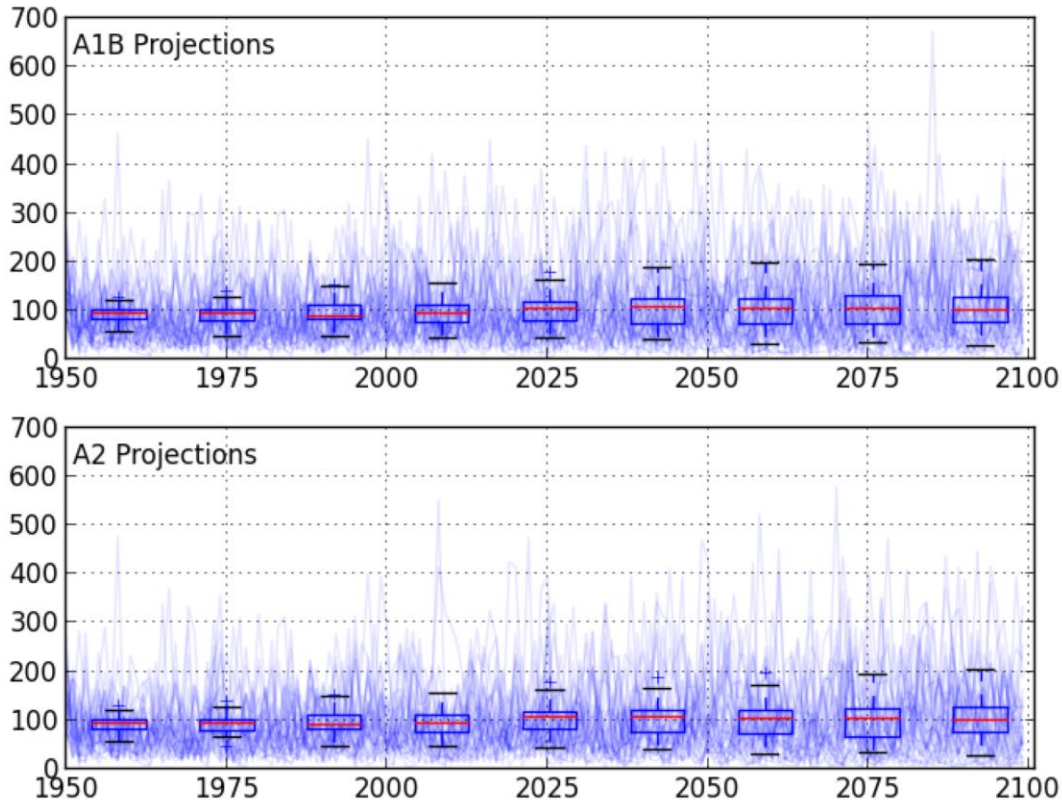


Figure 12: Changes to the inflow hydrograph at Marion Reservoir under moderate (A1B) and high (A2) future greenhouse gas emissions. The boxplots depict 30-year period averages.

will not negatively impact water supply capacity, and existing water supply contracts will continue to be met. However, extreme events influence firm yield, particularly extreme droughts, and considerably less certainty is associated with estimates of extremes than of means. As knowledge improves, the results of this completed study should be revisited.

2.2.6 Missouri River Basin Mountain Snowpack—Accumulation and Runoff, Northwest Division

Changes in snowpack in the western U.S. have been observed, and future changes are anticipated to significantly affect streamflow in western snow-dominated watersheds. Some regions are experiencing significant decline in snow pack volume, water content, and persistence into the spring. The Missouri River Basin gathers the snowmelt runoff from the eastern slopes of the Rocky Mountains in Montana and north central Wyoming and accumulates this runoff in the two uppermost Missouri River System reservoirs: Fort Peck and Garrison. During the 3-month period of spring runoff from May through July, nearly one-half the total annual runoff is introduced into the system. The size and volume of this runoff depends on the volume and snow water equivalent (SWE) of the prior winter's mountain snowpack.

The Missouri River Basin RCC Adaptation Pilot Project assessed whether mountain snowpack and spring runoff are currently changing in response to recent warming trends and whether these changes make the Missouri River Basin more susceptible to droughts and floods. Analysis of historical snowpack data, stream gage records, weather data, and information about broader scale drivers of western precipitation (such as El Niño-Southern Oscillation [ENSO] cycle) showed little or no change in the date snow begins to accumulate in both basins, in SWE of the snowpack, or in the timing of peak SWE. Fort Peck Reservoir does not show any trend for May-June-July (MJJ) runoff, but Garrison Reservoir (downstream of Fort Peck with a much larger watershed) shows a significant downward trend in MJJ runoff in the historical period.

Hydrologic projections indicate a future in which mountain snowpack in the Upper Missouri River Basin has reduced SWE, earlier peak SWE in the spring, shorter times from peak SWE to melt-out, and decreasing net MJJ runoff. Garrison Reservoir shows a significant trend toward increasing variance in runoff. However, the methods used and the decision to rely on only a limited number of models prevented a complete assessment of future extremes (droughts and floods) on streamflow. As knowledge of projected snow-related factors improves, the results of this completed study should be revisited. The pilot study did identify an immediate need to apply a similar analysis to plains snowpack, which can be quite different from mountain snowpack and is a significant contributor to inflow for a number of USACE reservoirs and projects. As a result, a follow-on study was conducted (see 2.3.2 Modern and Projected Peak Snowpack and Runoff in the Upper Missouri River Basin, Northwest Division.

2.2.7 Red River of the North Flooding at Fargo, North Dakota, St. Paul District

In recent years, flooding has been a significant problem for the City of Fargo, North Dakota, with three of the largest six floods in the last 100 years occurring in the last 10 years, including the largest flood on record in 2009. An expert opinion elicitation panel conducted by the St. Paul District in 2009 concluded that the flood record shows an abrupt shift in maximum annual flows in 1942, although the reasons for this change in flood behavior were not determined. An assessment of future flows in the nearby James River indicates that by 2071–2099, the discharge of the 100-year flood may be 83% greater than at present (Raff et al. 2009).

Given the recent increased flooding of the Red River of the North at Fargo, and given the projected increase in future flood discharge at the nearby James River, the Red River of the North RCC Adaptation Pilot Project is investigating whether tools and data exist for USACE to provide reliable estimates of future flooding in this river system. Because under a warming climate a greater share of the annual winter precipitation is likely to fall as rain, the study is attempting to assess how changes in precipitation patterns, form, and timing are likely to affect flood events in this historically snowmelt-dominated basin. Like other studies exploring future streamflow, the approach uses data from model projections of regional climate change to drive a

model of flow in the Red River of the North, simulating flood events in the watershed for historical and future time periods. This study is ongoing and has served as a test bed for climate hydrology tools under development.

2.2.8 Utilization of Regional Climate Science Programs in Reservoir and Watershed Risk-Based Assessments, Oologah Lake and Watershed, Tulsa District

Oologah Lake is a reservoir on the Verdigris River, approximately 27 miles north of Tulsa, Oklahoma. The Verdigris River arises in Kansas and flows roughly south to its confluence with the Arkansas River in Oklahoma. The Oologah Lake RCC Adaptation Pilot Project investigated how climate change analyses might proceed (e.g., **Figure 13**) when using a portfolio approach to evaluate impacts on the amount of water the reservoir can provide (its firm yield), as well as water quality and soil and water conditions in the watershed. The evaluation of analysis pathways included levels of effort for different stages in the planning process and hence could be of immediate value for other similar studies. The project also leveraged expertise from a range of institutions, including Reclamation, the University of Oklahoma, and NOAA's Southern Climate Impacts Planning Program. A related study (Qiao et al. 2014) compared the use of dynamically downscaled and statistically downscaled techniques in the watershed, based on Coupled Model Intercomparison Project 3 (CMIP3) data and a single emissions scenario.

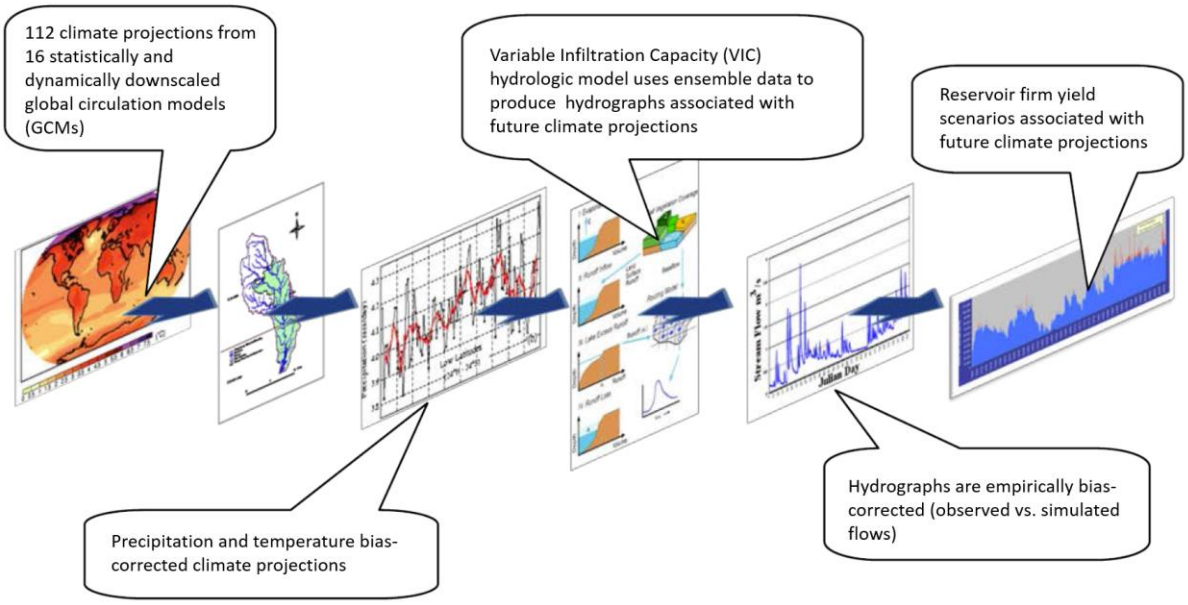


Figure 13: Depiction of possible climate analysis pathway developed in the Oologah Pilot Study.

As with the Marion Reservoir RCC Adaptation Pilot Project, also on a tributary of the Arkansas River, the results of this adaptation pilot showed that while temperature increases are anticipated in the study area, changes in precipitation are less certain. Consequently, there is little anticipated change in reservoir firm yield. Models show neither an increasing nor a decreasing trend in firm yield through the end of the study period; future firm yield will likely be similar to the historical firm yield if the assumptions hold. Demand, however, may go up as the City of Tulsa and several other growing municipalities obtain water from this lake.

The study used a Soil and Water Assessment Tool (SWAT [Arnold et al. 1998, Williams et al. 2008]) model of the Verdigris River, as well as a CE-QUAL-W2 (Cole and Wells 2001), a water quality model, to assess how climate change may impact water quality throughout the Verdigris River watershed. Throughout the Verdigris River watersheds, models project runoff decreases from 0.6% to 80.6%, accompanied by reductions in herbaceous biomass production. Decreases from baseline in lakewide dissolved oxygen and algae concentrations were observed in most simulations, while higher than baseline concentrations for nutrient concentration were observed. There was no trend in phosphorous and total suspended solids in the model simulations. Thus, warming is anticipated to reduce water quality, with likely impacts on the optimality of lake habitat for current fish populations. As knowledge of climate-impacted hydrology improves, the results of this completed study should be revisited.

2.2.9 Climate Modeling and Stakeholder Engagement to Support Adaptation in the Iowa-Cedar Watershed, Rock Island District

The Iowa-Cedar River Basin, located in north central Iowa, contains three urban areas that have seen large-scale flooding three times in recent years. Both changing precipitation patterns and land use changes have been implicated as causes of the flooding. Of particular concern have been the urban development of farmland, the shift from crop to biofuel production, and the conversion of pasture to row crops. These changes affect precipitation, runoff, and infiltration rates, which in turn affect how much precipitation enters local streams and at what rate, ultimately contributing higher flood volumes downstream.

The Iowa-Cedar RCC Adaptation Pilot Project incorporated shared vision planning (SVP) in an effort to help stakeholders identify common ground for understanding the economic, environmental, and social tradeoffs in the basin and to see how climate change scenarios affect these tradeoffs. In a series of five workshops focused on Indian Creek, a tributary of the Cedar River, stakeholders were guided through the watershed planning process to increase their understanding of, and to give definition to, the problems, objectives, adaptation strategies, and associated tradeoffs and uncertainties.

The second phase of the study assessed how land use and climate changes affect hydrology in the basin, including a comparison of multiple hydrology models (Hydrologic Engineering Center-

Hydrologic Modeling System [HEC-HMS] [USACE 2015a], SWAT, and Gridded Surface Subsurface Hydrologic Analysis [GSSHA] [Downer and Ogden 2003]). The analysis showed that one or more of these models may be appropriate depending on the questions to be answered. Because hydrologic models differ in complexity and required data, an important consideration in model selection is whether additional complexity is required to answer key. A more complicated model does not necessarily provide "better" results than a simple model, and more complex models require more time and data than simpler models. Therefore, a model should only be as complicated as is necessary to accurately model the system. In this case, the model results showed that tiled agricultural landscapes are more sensitive to changes in smaller, high-frequency precipitation events than to changes in larger events. The reason for this is that during larger events, soil saturation is usually achieved, whereas for smaller events, the degree of soil saturation is variable, exerting a greater effect on runoff generation under future climate change scenarios (when the initial soil moisture may be lower). The results were similar for anticipated future changes to land use in the basin. The potential for increased drought under future climate change scenarios suggests increasing vulnerability of the tiled agricultural land. This information was provided to stakeholders to begin a dialogue on what changes in land use in the floodplain will be needed to adapt to changes in precipitation patterns anticipated to lead to greater future flooding.

2.2.10 Formulating Mitigation/Adaptation Strategies Through Regional Collaboration with the Ohio River Basin Alliance, Huntington District

Existing river basin alliances provide an opportunity to initiate the discussion of climate change impacts on navigation, recreation, flood risk, hydropower, ecosystem restoration, and other actions within an existing collaborative framework. The Ohio River Basin Alliance consists of four USACE Districts (Huntington, Louisville, Nashville, and Pittsburgh) and other Federal, state, local, conservation, academic, and nonprofit agencies and organizations concerned with water resources problems in the ORB (**Figure 14**). Climate change has the potential to significantly increase flooding in the watershed through

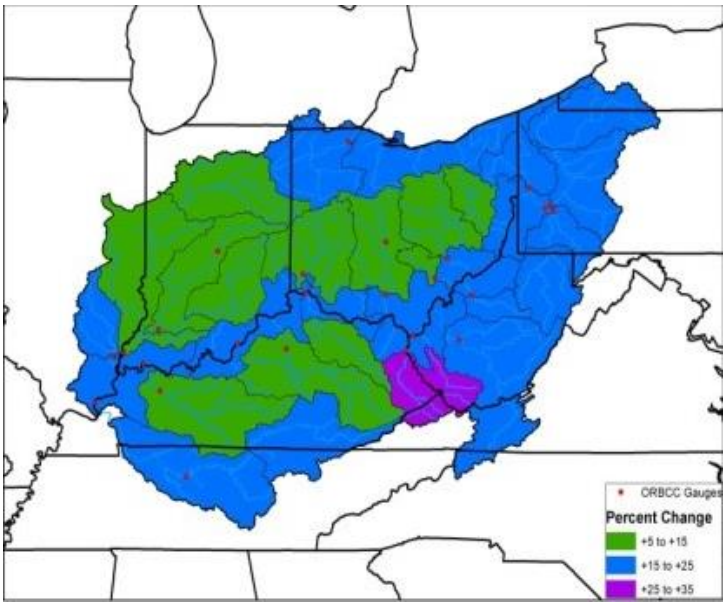


Figure 14: Projected change in average annual streamflow for the ORB for the period 2071–2099 compared to the historical period.

larger, more intense storms, increased precipitation, and changes in vegetation that affect rates of runoff and infiltration in the watershed.

The ORB RCC Adaptation Pilot Project pioneered the inclusion of climate change as an important focus of ORB Alliance activities. This adaptation pilot created a climate change working group within the ORB Alliance charged with refining and implementing a strategy for adapting to climate change using IWRM principles. The working group developed climate model projections for the basin and identified water resources, ecosystem resources, and infrastructure that are likely to be at risk under a changing climate. This effort is particularly timely as many flood storage facilities and local flood risk-reduction projects in the basin have reached sustained durations of operation (50–70 years). These facilities already require substantial rehabilitation, and it would be less costly to account for climate change during rehabilitation than later. Finally, the working group identified adaptation measures and strategies, including wetland restoration, floodplain reconnection, water consumption reductions, water harvesting, drought planning, increased management of acid mine drainage and nutrient inflow, adaptation of existing methods of power plant cooling to more recirculating facilities, expanded use of nonstructural flood damage reduction methods, additional monitoring for flow and water quality, better land use management, modification of reservoir control and management, and improved management of ecosystem stressors.

2.2.11 Risk-Informed Decision Making for Integrated Water Resources Management Planning, West Maui Watershed Project, Hawaii District

Despite popular perception that Hawaii is a moist tropical paradise, its location in the northern subtropics heightens its drought risk under a warming climate. Projected increases in aridity for the islands threaten native forests, streams, and wetlands and may increase land-based pollution in near-shore waters. Land-based pollution and rising ocean temperatures threaten Hawaii's coral reefs. Climate change impacts fall on already severely stressed ecosystems struggling with changes in land use, increased tourism, and introduction of a wide range of non-native species. The West Maui Watershed Ridge to Reef (R2R) Plan is an interagency planning process designed to implement a comprehensive management strategy to address impacts on coral reefs across multiple watersheds using an IWRM framework (**Figure 15**).

The West Maui RCC Adaptation Pilot Project leveraged the existing R2R planning process to address how a RIDM framework could be incorporated at the beginning of a collaborative planning process to create a place-based climate change adaptation strategy. The goal was to establish a process for including climate change in the early stages of a larger watershed planning process in West Maui and to ensure this process can be replicated elsewhere in Maui and the other Hawaiian Islands where similar watershed planning efforts are underway. Over the course of three planning workshops, the interagency team has identified climate threats and risks

Figure 15: Lance Gilliland discusses shoreline restoration and sustainable development approaches with participants in the decision framework workshop held in April 2012 at Honua Kai.

to the study area, incorporated climate change into key goals and objectives, developed a decision framework, and prioritized data gaps to guide future actions.

2.3 Pilot Projects Initiated 2012–2015

Four studies were undertaken in the period 2102–2015 under the RCC Program (for additional information, see Appendix A):

- Climate Change Impact Evaluation: Impacts to Hurricane Storm Surge Inundation Resulting from Sea Level Change, Chesapeake Bay, Baltimore District
- Modern and Projected Peak Snowpack and Runoff in the Upper Missouri River Basin, Northwest Division
- Implementing a Climate Change Project Under a Regional Integrated Water Resources Management Plan: The Los Angeles Basin Stormwater Conservation Study, Los Angeles District
- Historical Trends and Future Projections of Climate and Streamflow in the Willamette Valley and Rogue River Basins, Portland District.

2.3.1 Climate Change Impact Evaluation: Impacts to Hurricane Storm Surge Inundation Resulting from Sea Level Change, Chesapeake Bay, Baltimore District

This study assessed the impact of sea level rise on coastal flooding in Chesapeake Bay and the lower Delaware River during hurricanes of different magnitudes (Chesapeake Bay RCC Adaptation Pilot Project). The study relied on existing models of coastal storm surge, including NOAA's Norfolk Sea, Lake, and Overland Surge from Hurricanes (SLOSH) Basin "maximum of maximums" (MOM) model that NOAA uses to identify areas that have some risk of inundation from a hurricane of a given category. The team compared the effects of sea level rise alone (the "bathtub method") to sea level rise in combination with how water typically circulates within the study area during hurricanes (the "model method"). Following USACE EC 1165-2-212, *Sea-Level Change (SLC) Considerations for Civil Works Programs*, three scenarios of sea level rise (low, medium, and high) were considered. Each of these three sea level rises were considered for two different future periods centered on 2040 and 2100 for four different categories of hurricane strength (Categories 1–4 on the Saffir-Simpson hurricane wind scale).

The modeling showed that under Category 1 conditions, seashore areas facing the Atlantic were likely to exhibit storm surges above the average expected storm surge increase due to sea level rise, while other coastal regions were closer to average values. Under Category 4 conditions, areas at risk for higher storm surge are located more inland, away from the barrier beaches. Barrier beaches in the model had generally lower storm surges than expected. The reason for these differences was not clear and may be related to shoreline topography and bathymetry. Preliminary results suggested that the simplified bathtub method performed as well as the more complex, more detailed model method. The researchers suggested a repeat analysis in another SLOSH basin as a way to address some of these uncertainties.

2.3.2 Modern and Projected Peak Snowpack and Runoff in the Upper Missouri River Basin, Northwest Division

The Missouri River Basin RCC Adaptation Pilot Project led to a follow-up study of current and projected mountain snowpack in the upper reaches of the Missouri River Basin. The Modern and Projected Peak Snowpack and Runoff in the Upper Missouri River Basin Adaptation Pilot Project (Lake Sakakawea RCC Adaptation Pilot Project) was a collaboration between USACE Northwest Division and USGS. The study investigated historical (1992–2011) and projected (2012–2099) trends in peak snow depth and spring runoff in a pair of nested watersheds that combined form the watershed for Lake Sakakawea: the Fort Peck Reservoir watershed and the Lower Lake Sakakawea watershed. It also investigated the conditions that led to significant flooding in the area in 2011 and evaluated whether these same conditions were likely in the future. The study developed multivariable regression equations to relate precipitation data in Parameter-elevation Relationships on Independent Slopes Model (PRISM) runs of the historical

baseline period, calibrated the models, and applied these regression models to projected hydrometeorological model data for the watersheds separately and as a single unit. The project only considered future snowpack and runoff under the A2 and relative concentration pathway (RCP) 8.5 scenarios, both of which assume continued reliance on fossil fuels for energy and produce the largest gains in temperature by 2100 across scenarios considered. The projected data covered the period 2012–2099; however, because the precipitation, temperature, and other modeled independent variables for the regression models were outside the range of historical values for the period 2060–2099, these results for the second half of the 21st Century are considered less reliable than for the period 2012-2059.

The study found significant projected reductions in annual peak snowpack and runoff in the Fort Peck watershed but not in the Lower Sakakawea watershed in the historical period. The authors attributed this difference to the overall lower elevation of the Fort Peck watershed compared to the headwaters for the Lower Lake Sakakawea watershed, as warming in the Fort Peck watershed was more likely to raise temperatures above freezing. In addition, projected trends in runoff were projected to negatively impact hydropower production at Fort Peck Dam but not at Garrison Dam (which impounds Lake Sakakawea). Finally, the models produced two flood maxima as great as the 2011 flood, but none significantly larger. The results of this study have been published as a USGS Scientific Investigations Report (Stamm et al. 2015).

2.3.3 Implementing a Climate Change Project Under a Regional Integrated Water Resources Management Plan: The Los Angeles Basin Stormwater Conservation Study, Los Angeles District

The USACE Los Angeles District (SPL) partnered with the Department of the Interior, Reclamation, and the Los Angeles County Flood Control Department (LACFCD) to analyze future stormwater runoff through the region's extensive stormwater channel system (Los Angeles Basin RCC Adaptation Pilot Project). Given projected regional water supply and demand, the study used climate, land surface, and hydrologic models to evaluate how well the current system of stormwater capture and groundwater recharge will perform under expected increases in storm size and whether sufficient water could be captured to offset projected increases in drought and evapotranspiration, reductions in snowpack, and increases in population. The study was conducted as a specific investigation under the umbrella of the Greater Los Angeles County (GLAC) Regional Water Management Authority as part of its Integrated Regional Water Management Plan. The final outcome and recommendations of this study will serve as a guiding document for further local water supply development planning, financing strategy, and policy adoption at the LACFCD and other water supply organizations (Reclamation 2013).

As part of this project, a workshop was conducted at SPL to evaluate climate change vulnerabilities across USACE business lines. The workshop showed that while water supply was a concern, the major vulnerabilities are in the flood risk management and coastal storm damage reduction business lines. Both of these have the potential for significant increases in life safety and economic risk under future climate scenarios.

As a study in support of the GLAC Regional Water Management Authority's IWRM plan, this project highlighted the importance of long-term regional water resources management for addressing climate change impacts on regional hydrology. Regional water resources management organizations require long-term, local, and regional leadership and broad-based participation to be effective in this arena. Federal agencies can play significant supporting roles in addressing regional climate change impacts, adding significant technical capacity to support decision making. However, local and regional commitments are necessary to lead such efforts.

2.3.4 Historical Trends and Future Projections of Climate and Streamflow in the Willamette Valley and Rogue River Basins, Portland District

The USACE Portland District (NWP) partnered with the Oregon Climate Change Research Institute at Oregon State University to analyze the effects of future climate change on water management in the Willamette and Rogue River Basins (Willamette and Rogue RCC Adaptation Pilot Projects). NWP manages dams, reservoirs, and other projects such as fish facilities in the Willamette and Rogue River Basins. They must balance competing needs, including flood risk reduction, water supply storage, hydropower, and environmental objectives. This pilot study examined observed and projected changes in hydrologic variables to improve understanding of future management challenges.

The study found that minimum and maximum temperature increased between 1901 and 2013, with rates ranging from between 0.5°F and 3.9°F per century. Observed precipitation was variable but did exhibit increases in spring and summer for most stations and in winter and fall for about half of the stations. No significant trend was observed in SWE. In comparing streamflow hydrographs between two periods (1941–1970 and 1981–2010), the study found that runoff in rain-dominated basins changed between the two periods consistent with flood control management: winter streamflow decreased and summer streamflow increased. On the other hand, in snow-dominated basins, the study found a shift from winter and early summer streamflow peaks to a more stable runoff pattern from December through May.

The study projected increases in minimum, average, and maximum temperature and decreases in SWE. Projected precipitation was variable, without a consistent magnitude or direction of change across the study area. Streamflow projections exhibited seasonal changes, with winter (December-January-February) streamflow increasing and summer (June-July-August) streamflow decreasing. Peak flows are also projected to increase, especially for shorter return periods.

These results indicated that, like other pilot areas studied, the Willamette and Rogue River Basins are expected to experience both more floods and more droughts. These changes are expected to increase already existing stressors on water management in the study area. An additional study based on updated climate modeling is needed to better characterize future projected conditions and how these will impact water management within the study area. This pilot project provided a good foundation for developing such a follow-on study.

3. Methods and Approaches Used in RCC Adaptation Pilot Projects

All of the RCC Adaptation Pilot Projects rely on model projections of climate change that provide input into modeled sea level rise and modeled future average flows and flood flows through our Nation's streams. In addition, many of the studies, either explicitly or implicitly, employ the RIDM or IWRM framework or both in framing the study and managing the different kinds of collaborations involved. The successes in applying these methods and approaches have been mixed depending on the available data, its resolution, and the question being addressed.

This chapter reviews the methodologies and approaches used in the RCC Adaptation Pilot Projects. For each approach, the successes and failures as applied in the RCC Adaptation Pilot Projects are reviewed (**Table 2**). The projects are grouped as follows:

- Project planning: RIDM
- Project planning: IWRM and the SVP process
- Coastal ecosystem restoration and flood risk reduction: Sea level rise
- Water supply, navigation, flood risk management, and ecosystem restoration studies: Climate change impacts on inland hydrology.

Table 2: RCC Adaptation Pilot Study Status and Focus Areas.

Status	Adaptation Pilot Project Title	USACE Business Line	Functional Areas	Focus for Policy Guidance
Complete	1. Application of Sea Level Change Guidance to the C-111 Spreader Canal, Jacksonville District	Ecosystem Restoration	Operations & Management	Sea Level Change; Ecosystem Restoration
Complete	2. Climate Change Associated Sediment Yield Impacts on the Rio Grande, Cochiti Dam and Lake, Albuquerque District	Flood Damage Reduction	Operations & Management	Sediment Impacts
Complete	3. Climate Change Impact on the Operation of Coralville Lake, Iowa, Rock Island District	Flood Damage Reduction	Operations & Management	Reservoir Management
Complete	4. Climate Change Associated Sediment Yield Impacts and Operation Evaluations at Garrison Dam North Dakota, Omaha District	Flood Damage Reduction	Operations & Management	Sediment Impacts
Overcome by Events (Hurricane Sandy)	5. East Rockaway Inlet to Rockaway Inlet, New York, Collaboration Framework Development, New York District	Coastal Damage Reduction	Planning	Risk Adaptation; Flood Risk Reduction
Complete	6. Upland Sediment Production and Delivery in the Great Lakes Region Under Climate Change, Detroit District	Navigation	Operations	Sediment Impacts
Active	7. Risk-Informed Decision Making for Potential Sea Level Rise Impacts on Wetland Restoration, Hamilton Wetland Restoration Project, California, San Francisco District	Ecosystem Restoration	Planning	Coastal Wetland Restoration
Complete	8. Climate Modeling and Stakeholder Engagement to Support Adaptation in the Iowa-Cedar Watershed, Rock Island District	Multiple: Flood Damage Reduction; Ecosystem Restoration	Planning	Flood Risk Reduction
Complete	9. Framework for Building Resiliency into Restoration Planning Case Study—Lower Columbia River Estuary, Portland District	Flood Damage Reduction	Planning	Estuarine Habitat Restoration
Complete	10. Climate Change Impacts on Water Supply in the Marion Reservoir Watershed, Kansas, Tulsa District	Water Supply	Operations & Management	Water Supply
Complete	11. Missouri River Basin Mountain Snowpack—Accumulation and Runoff, Northwest Division	Flood Damage Reduction	Operations	Snowpack
Complete	12. Modern and Projected Peak Snowpack and Runoff in the Upper Missouri River Basin, Northwest Division	Water Supply	Operations	Snowpack
Complete	13. Formulating Mitigation/Adaptation Strategies Through Regional Collaboration with the Ohio River Basin Alliance, Huntington District	Navigation; Flood Damage Reduction	Planning	Multipurpose, Watershed Planning
Complete	14. Utilization of Regional Climate Science Programs in Reservoir and Watershed Risk-Based Assessments, Oologah Lake and Watershed, Tulsa District	Multiple	Operations & Management	Sediment Impacts

Status	Adaptation Pilot Project Title	USACE Business Line	Functional Areas	Focus for Policy Guidance
Complete	15. Red River of the North Flooding at Fargo, North Dakota, St. Paul District	Flood Damage Reduction	Operations	Flood Risk Reduction
Complete	16. Risk-Informed Decision Making for Integrated Water Resources Management Planning, West Maui Watershed Project, Hawaii District	Multiple	Planning	Risk Assessment
Complete	17. Climate Change Impact Evaluation: Impacts to Hurricane Storm Surge Inundation Resulting from Sea Level Change, Chesapeake Bay, Baltimore District	Flood Damage Reduction	Planning	Sea Level Change; Coastal Storm Damage Reduction
Complete	18. Implementing a Climate Change Project Under a Regional Integrated Water Resources Management Plan: The Los Angeles Basin Stormwater Conservation Study, Los Angeles District	Multiple	Planning	Water Supply; Flood Risk Reduction
Complete	19. Historical Trends and Future Projections of Climate and Streamflow in the Willamette Valley and Rogue River Basins, Portland District	Multiple	Operations	Flood Risk Reduction; Water Supply

3.1 Project Planning: RIDM

All USACE projects begin with an extensive planning phase that ascertains whether a problem exists that needs to be solved by the Federal Government and, if so, identifies the most cost-effective solution. Previously, an assumption of stationarity in hydrologic time series guided project planning (i.e., the past is indicative of the future). This assumption provided baseline conditions against which project designs could be compared. However, there has been increasing recognition that future conditions may in some cases be quite different that the baseline conditions representing the past, particularly given changes in land use and climate. Planning that takes nonstationarity into account represents a new direction for USACE planning practice—one that encourages collaboration and flexible decision making and acknowledges that the information available about the past, by itself, cannot be reliably used to forecast future conditions.

RIDM is a structured approach to planning a project that explicitly considers risks and uncertainties. A risk is the product of a particular event's likelihood of occurrence and its consequence. For example, given a rainfall event in which 2 inches of rain fall in an hour, what is the likelihood that streamflows will result that are large enough to overtop river banks and flood a community? Uncertainty refers to a lack of information about something, whether about the consequence (e.g., impact of flooding on a town) or the occurrence of an event (e.g., how likely it is for a storm to drop 2 inches of precipitation in an hour). As discussed previously, climate change increases uncertainty because (1) the rate of change itself appears to be changing; (2) feedbacks can enhance or reduce consequences in unexpected ways; and (3) our knowledge of the climate system, and models of that system, is incomplete.

RIDM is a process for describing and, to the extent possible, quantifying the risks from climate change so project planners can decide on cost-effective strategies for reducing the effects of climate change on their project or for adapting their project to projected consequences of climate change. The process involves identifying potential project risks due to climate change; assessing the likelihood of these risks and the likely magnitude of the consequences; and then developing cost-effective solutions that reduce risk while making a project more robust and more resilient (adapted) to climate change. Part of the goal of RIDM is to make climate change risks explicit to sponsors, stakeholders, and partners and to engage them in the process of determining how best to reduce these risks to a project since they bear part of the project cost and the impacts if a project fails due to a changed climate. Another goal is to assess collectively whether a risk is sufficiently high to warrant action (e.g., will the consequence have a big impact on the project and, if so, how likely is it to occur?).

3.1.1 RIDM in the RCC Adaptation Pilot Projects

A draft RIDM framework was issued in 2011 (USACE 2011b), and a number of the pilot projects include testing the RIDM framework as one of their goals. The framework is currently under revision based on the preliminary results of the pilot projects and internal review. The revised RIDM framework will be the foundation for developing strategies to incorporate climate change into decision making within USACE. RIDM application areas in RCC Adaptation Pilot Projects include ecosystem restoration, flood risk management, and water management.

The following pilot projects explicitly tested the RIDM framework:

- Hamilton Wetland RCC Adaptation Pilot Project
- West Maui RCC Adaptation Pilot Project
- Lower Columbia River Estuary RCC Adaptation Pilot Project
- Oologah Lake RCC Adaptation Pilot Project.

In addition, the Iowa-Cedar RCC Adaptation Pilot Project used a non-RIDM risk-based framework in multi-stakeholder discussions of climate change impacts on a small tributary creek within the Iowa-Cedar watershed. Finally, two projects examined climate change impacts as a component of regional RIDM-based analyses of sea level rise. These projects are discussed in Section 3.3.2.

The use of RIDM and the non-RIDM risk-based framework for each of these projects is described below.

3.1.1.1 Hamilton Wetland RCC Adaptation Pilot Project

The Hamilton Wetland RCC Adaptation Pilot Project tested the application of the RIDM framework to the project planning phase through the application of the SMART planning framework, including the use of a risk register. The project team applied the framework retrospectively, essentially asking whether project design would have been different had the RIDM and SMART planning frameworks and recent sea level rise guidance been applied to project design. The activity emphasized developing the USACE team’s familiarity with new planning processes and minimized the involvement of external stakeholders. For this project, the primary risk to wetlands development is from sea level rise. However, the overall risk to the project from sea level rise is limited by the absence of wetlands presently at the site and the assumption that the exact wetland composition was less important than the regeneration of any kind of wetland at the site.

3.1.1.2 West Maui RCC Adaptation Pilot Project

The West Maui RCC Adaptation Pilot Project tested the utility of the RIDM framework for collaboratively identifying climate risks and developing strategies for adapting to climate change in the context of a larger watershed assessment framework. The project leads worked closely with individuals from Federal and state agencies, the county of Maui, and key non-governmental organizations to develop a shared vision for the health and vitality of watersheds in West Maui as part of the West Maui R2R Initiative. Reaching a consensus on likely climate change impacts on the watersheds was a key outcome of a series of workshops conducted with stakeholders and partners. Workshop participants used the RIDM framework to identify climate risks and tracked these risks using a risk register. A risk register is a spreadsheet that identifies and describes each risk to a project; explicitly lists possible mitigation actions; and documents decisions made with respect to risk severity, project vulnerability, and mitigating actions taken. Although many of the climate threats to the watershed are less urgent than existing pollution and other problems, the project team felt that achieving awareness now is a necessary prelude to future action.

3.1.1.3 Lower Columbia River Estuary RCC Adaptation Pilot Project

The Lower Columbia River Estuary RCC Adaptation Pilot Project tested the utility of the RIDM framework as a means for collaboratively evaluating climate risks to ecosystem restoration projects and building resilience into restoration planning. This is critical because USACE has already committed $150 million for ecosystem restoration, research, and monitoring for FY2009–2018 without explicit consideration of climate change impacts that could significantly alter project benefits. Through two informational webinars and two workshops, participants collaboratively established a common understanding of current ecosystem restoration goals and priorities and discussed how climate change information could be used to inform current and future restoration planning efforts. Particular emphasis in Phase 2 was placed on the explicit integration of climate change risk into the standard USACE six-step planning process. The approach is bottom-up, considering first the vulnerabilities of restoration features to climate change and then identifying potential thresholds that, when crossed, may trigger changes in project function, operation, or design. An adaptive management approach, which continually assesses how well restoration features are functioning and recommends changes to maintain functionality, was identified as essential for responding flexibly to climate change over the long term. Computer modeling of estuary hydrology under changing climates was used to explore methods for including climate change in determining whether a project is feasible.

3.1.1.4 Iowa-Cedar RCC Adaptation Pilot Project

The Iowa-Cedar RCC Adaptation Pilot Project tested the appropriate integration of climate information to improve understanding of and adaptation to changing conditions within the watershed of Indian Creek, a tributary within the Iowa-Cedar basin. Because climate change has

the potential to exacerbate existing flooding problems in the basin, there is a significant need to identify common ground; understand economic, environmental, and social tradeoffs for proposed actions within the basin; and investigate how future climate change may affect these tradeoffs. Although a RIDM framework was not explicitly used, there was a similar emphasis on stakeholder engagement in a series of three workshops that addressed existing and future threats to the watershed, identified potential actions that could be taken, and identified ways to gauge the effectiveness of these actions (also known as metrics). Hydrologic models were then used to simulate future streamflow and flood conditions along Indian Creek and how changes in land use and other activities could alter these conditions. This information was used in a series of two additional workshops that discussed tradeoffs necessary to address climate change impacts and land use change issues and how to deal with uncertainty regarding future conditions. The final workshop consisted of a mock decision-making event that investigated how to effectively use all this information to create a robust climate-change-informed, basin-wide watershed plan.

3.1.1.5 Oologah Lake RCC Adaptation Pilot Project

In contrast to other RIDM projects, the Oologah Lake RCC Adaptation Pilot Project implemented a top-down approach leveraging existing relationships with the University of Oklahoma, NOAA's Southern Climate Impacts Planning Program, and the Department of the Interior's South-Central Climate Science Center. While model results provided insights into future conditions of the reservoir and watershed, there were challenges integrating this information into a RIDM framework in a manner compatible with the USACE CW planning process. Instead, the participants concluded that for reservoir operations projects, RIDM might be more effectively implemented in a step-wise process similar to dam and levee safety programs. This process might consist of an initial screening of reservoir status; prioritization of reservoirs at risk due to condition, capacity, or population served; and, for high-priority reservoirs, assessment of vulnerability to climate change using downscaled model projections of future climate and hydrologic changes.

3.1.2 Assessment of the Application of RIDM in the RCC Adaptation Pilot Projects

RIDM, whether using the RIDM framework or not, provided a successful means for project team members to understand the risks and uncertainties relating to climate change and convey this information to regional partners and stakeholders. Using a risk-informed approach allowed teams to better prioritize the threat from climate change relative to other problems and led to the recognition that pollution, habitat degradation, and land use change pose more immediate threats than climate change. Simultaneously, the effort also raised awareness of the potent long-term threat of climate change on the study areas, paving the way for integrating climate change impacts into the regional long-term planning process.

3.2 Climate Change, IWRM and the SVP Process

IWRM is a process for making decisions about and taking actions on the development and management of water, land, and related resources that takes the views and needs of all stakeholders into account. The goal is to maximize economic and social welfare in an equitable manner while preserving the sustainability of vital ecosystems. This holistic approach is very powerful in situations where water is limited and allocation tradeoffs must be made. Managing these tradeoffs among multiple stakeholders will become increasingly important over the next century because climate change is expected to cause or contribute to future water shortages in many areas of the United States (Melillo et al. 2014). The IWRM framework allows the impact of climate change to be considered in light of all existing and planned water resources projects, stressors, and changes in the basin so integrated solutions can be developed. This process avoids duplication of effort and facilitates identification of efficient, cost-effective solutions to water resources problems.

SVP is a collaborative approach to developing solutions to water management issues that combines traditional water resources planning with structured public participation and collaborative computer modeling. Because the goals of SVP are to improve the economic, environmental, and social outcomes of water management decisions, SVP provides a method for stakeholder collaboration under an IWRM framework. Through the SVP process, stakeholders converge on a common understanding of a natural resource system and are able to use a consensus-based forum to identify tradeoffs and new management options. User-friendly, understandable computer models of climate change impacts that are relevant to stakeholder interests and adaptable to changing conditions are essential tools made available to stakeholders to aid in their decision making.

3.2.1 Ohio River Basin RCC Adaptation Pilot Project

Within the existing structure of the ORB Alliance, the ORB RCC Adaptation Pilot Project seeks to expand the ORB Alliance scope to include consideration of climate change impacts on water resources availability. The IWRM framework was selected because water resources allocations are already a persistent problem in the basin and it is not clear whether this problem will worsen as climate changes. A diverse group of partners and stakeholders (including Federal agencies, non-Federal agencies, non-governmental organizations, and academic institutions) has been brought together to help develop a consensus on climate change impacts on the basin and how these impacts are likely to affect water resources allocations given existing and projected competing demands for water. The project established a climate change working group within the ORB Alliance, defined study objectives, modeled climate change impacts on streamflow in the Ohio River, and identified ecosystems and water resources infrastructure (e.g., dams, levees, locks, and irrigation ditches) that may be at risk due to climate change. The project also

identified adaptation measures and strategies together with stakeholders and prepared a report documenting the project. Next steps include sharing the information and lessons learned with basin communities.

3.2.2 Iowa-Cedar RCC Adaptation Pilot Project

The Iowa-Cedar RCC Adaptation Pilot Project implemented SVP as a way of getting stakeholders to reach consensus on the level of risk they are willing to take with respect to flooding in the Indian Creek watershed. Stakeholders were provided with computer models showing how flooding under future climate scenarios may impact the watershed and were guided through the process of determining whether the threshold of acceptable risk is likely to be exceeded in the future. Over a series of five workshops, they were guided through the planning process: (1) clarifying goals, objectives, and perceived problems; (2) describing existing conditions; (3) describing future streamflow conditions under a range of land use and climate change scenarios; and (4) identifying and evaluating actions to achieve their goals and objectives under future conditions. This process allowed stakeholders to organize their thinking in a way that facilitated effective decision making and helped frame what steps the group could take to reduce future risk from flood events resulting from changes to climate, land use, and other watershed conditions. The process enabled stakeholders to better understand current trends of more frequent and more extreme flood events and the combined roles that climate change, land use change, and other factors in the watershed play in determining flood risk. The participants understood that actions will likely require a combination of structural and nonstructural solutions, including moving out of the floodplain where possible and appropriate and changing floodplain zoning regulations.

3.2.3 West Maui RCC Adaptation Pilot Project

The West Maui RCC Adaptation Pilot Project used a combination of IWRM and SVP to guide stakeholders in employing RIDM in the assessment of climate change and other risks to the watershed. IWRM was critical for framing the project at the watershed level, identifying impacts on the watershed from current practices and climate change, and identifying potential stakeholders and partners. Over a series of workshops and meetings, the SVP process was used to create a sense of community engagement and stewardship and to help reach stakeholder consensus on objectives, problems, and potential solutions. SVP provided a collaborative process for selecting and adjusting the technical analysis tools to fit the unique needs of stakeholders as they wrestled with a breadth of technical, ecological, social, and economic issues.

3.2.4 Los Angeles Basin RCC Adaptation Pilot Project

The Los Angeles Basin RCC Adaptation Pilot Project was a collaboration among state and Federal partners to provide technical analysis in support of the GLAC Regional Water Management Authority. This project did not directly involve coordination and outreach (such as SVP and RIDM). However, the technical information is intended as a critical input to the GLAC's integrated regional watershed plan, and in that way supports the application of IWRM to watershed issues in the Los Angeles Basin.

3.2.5 Assessment of IWRM and SVP in the RCC Adaptation Pilot Projects

Pilot project participants felt that IWRM and SVP provided a good structure for sustaining the involvement of a range of stakeholders in the process of planning for climate change impacts on watersheds. Given the complexity and technical nature of the issues involved, these tools helped achieve consensus on the nature and gravity of future threats to the study areas, a sense of the limits of current understanding, and the potential broad scope of mitigation and adaptation actions. Such consensus among stakeholders is the necessary prelude to an effective response at the watershed scale.

Comparison of the RCC Adaptation Pilot Projects that evaluated aspects of IWRM planning shows the earliest steps in the USACE planning process (identify problems and opportunities; inventory existing conditions; and forecast future conditions) are the steps in which tools such as SVP and the discussion of risk due to climate change play a significant role. This is best shown by the West Maui and Iowa-Cedar RCC Adaptation Pilot Projects, both of which used a geographically constrained sub-basin of the original study area to facilitate stakeholder interactions. Both projects were effective at conveying climate change uncertainty and risk across a range of stakeholder groups. In contrast, the two studies focusing on larger watersheds (ORB and Los Angeles River Basin) relied on groups of experienced staff from local, state, and Federal agencies. While they did use consensus-building activities, they were also able to use sophisticated modeling tools to generate more data-rich assessments of specific impacts on natural, water, cultural, and economic resources (**Table 3**).

Table 3: Comparison of RCC Adaptation Pilot Studies That Focused on IWRM.

Attribute	West Maui	Iowa-Cedar	Ohio River Basin	LA Stormwater
Purpose	Sediment and pollution impacts on stream mouth coral reefs	Flood risk management	Regional climate change impacts	Water supply
Part of USACE planning cycle addressed	Problems and opportunities; inventory and forecast	Problems and opportunities; inventory and forecast; formulate alternative plans	Problems and opportunities; inventory and forecast; formulate alternative plans	Inventory and forecast; formulate alternative plans
Geographic scale	Tributary	Tributary	Major watershed	Major watershed
Partnering	Limited to watershed assessment partners	Geographically limited but inclusive within	ORBA members	LACFCD, Reclamation
Scenario planning		X		X
SVP	X	X		
RIDM	X	X	X	
Adaptive management	X			
Holistic—working across scales		X	X	
Success metrics		X		
Integrative across natural, cultural, and economic arenas	Focused on water quality and sediment	X	X	Focused on water supply
Outcome	Common awareness of problems and opportunities among stakeholders to inform watershed planning process	Support for Indian Creek Watershed Management Authority and its IWRM plan	Common awareness of problems and opportunities among stakeholders to inform watershed planning process; identified possible adaptation options	Water conservation alternatives

3.3 Coastal Ecosystem Restoration and Flood Risk Reduction: Changing Sea Levels

An important area of USACE concern is the condition of the Nation's coastlines and how these are being damaged by climate change and other human activities. Coastal ecosystems provide important protection from storm surges, help protect inland groundwater from contamination by saline seawater, filter pollutants from freshwater entering the sea, and provide habitat for endangered animals and plants. Changing sea levels pose numerous problems for coastal communities, including higher storm surges; intrusion of salty ocean water into coastal freshwater aquifers; flooding of homes, agricultural lands, roads, railroads, industrial infrastructure, and energy facilities; increased coastal erosion; loss of wetlands; and impacts on the depth of navigable channels.

3.3.1 USACE Sea Level Change Guidance and Policy

USACE recognized sea level rise as a potential problem for its coastal projects and for coastal ecosystems in the 1980s, with specific authority to address this problem given in Section 731 of the Water Resources Development Act (WRDA) of 1986 (PL 99-662). WRDA 1986 instructed Federal agencies to assess the probability and extent of coastal flooding and erosion and to develop strategies to adapt to or mitigate (minimize) the effects of global sea level rise. This language resulted in the 1987 publication of a National Research Council (NRC) report, *Responding to Changes in Sea Level: Engineering Implications.*

USACE efforts to respond to WRDA 1986 resulted in guidance for incorporating local relative sea level change in coastal planning in the form of a guidance letter issued in 1986. By 2000, USACE Engineer Regulation (ER) 1105-2-100, *Planning Guidance Notebook*, required the consideration of both the low and high sea level scenarios identified in NRC (1987). Following Hurricane Katrina, USACE placed a renewed emphasis on incorporating new and changing information in project planning and engineering, issuing EC 1165-2-211, *Water Resource Policies and Authorities Incorporating Sea-Level Change Considerations in Civil Works Programs in 2009* (USACE 2009). This was updated in 2011 by EC 1165-2-212, *Sea-Level Change Considerations for Civil Works Programs* (USACE 2011a), before being formalized as ER 1100-2-8162 in 2013 (USACE 2013a). The guidance stipulates that planning alternatives and engineering designs must be evaluated for the entire range of possible future rates of sea level change as specified within the regulation. Technical guidance for adaptation to sea level change is provided in Engineer Technical Letter (ETL) 1100-2-1, *Procedures to Evaluate Sea Level Change: Impacts, Responses, and Adaptation* (USACE 2014a).

Armed with these estimates, project planners can map areas of probable inundation given future amounts of sea level change. This information enables planners to evaluate the relative effects, if any, of sea level change on projects early in the planning process and adapt to or reduce the effects to the proposed project.

3.3.2 Sea Level Change in the RCC Adaptation Pilot Projects

Five projects addressed the issue of sea level change in the areas of ecosystem restoration and flood risk reduction: C-111 Spreader Canal RCC Adaptation Pilot Project, Hamilton Wetland RCC Adaptation Pilot Project, Lower Columbia River Estuary RCC Adaptation Pilot Project, East Rockaway Inlet to Rockaway Inlet RCC Adaptation Pilot Project, and Chesapeake Bay RCC Adaptation Pilot Project. In all five cases, planners solicited experts to determine project area-specific rates of sea level change.

3.3.2.1 C-111 Spreader Canal RCC Adaptation Pilot Project

The C-111 Spreader Canal RCC Adaptation Pilot Project tested the usefulness of implementing USACE sea level guidance during the latter stages of the planning process to determine whether sea level change is likely to negatively impact projected freshwater wetland and near-shore habitat gains. Local relative sea level change produced using EC 1165-2-211 provided projections of sea levels until the end of the projected project lifetime (100 years, see **Figure 16**). Using a geographic information system (GIS), maps were created using topographic data to show how far inland sea water is likely to penetrate in the future. The mean higher high water (MHHW) mark was found to be most effective at demarcating the boundary between freshwater and saltwater ecosystems. Higher sea level change translated into greater landward movement of the MHHW, and therefore greater loss of freshwater habitat. At the same time, the amount of near-shore habitat remained roughly constant but was pushed inland with the advancing tide. Mitigating projected freshwater habitat loss would require larger flows of freshwater through the Everglades, which in turn indicates a long-term need to reallocate water currently diverted from the Everglades for other uses if this objective is to be met.

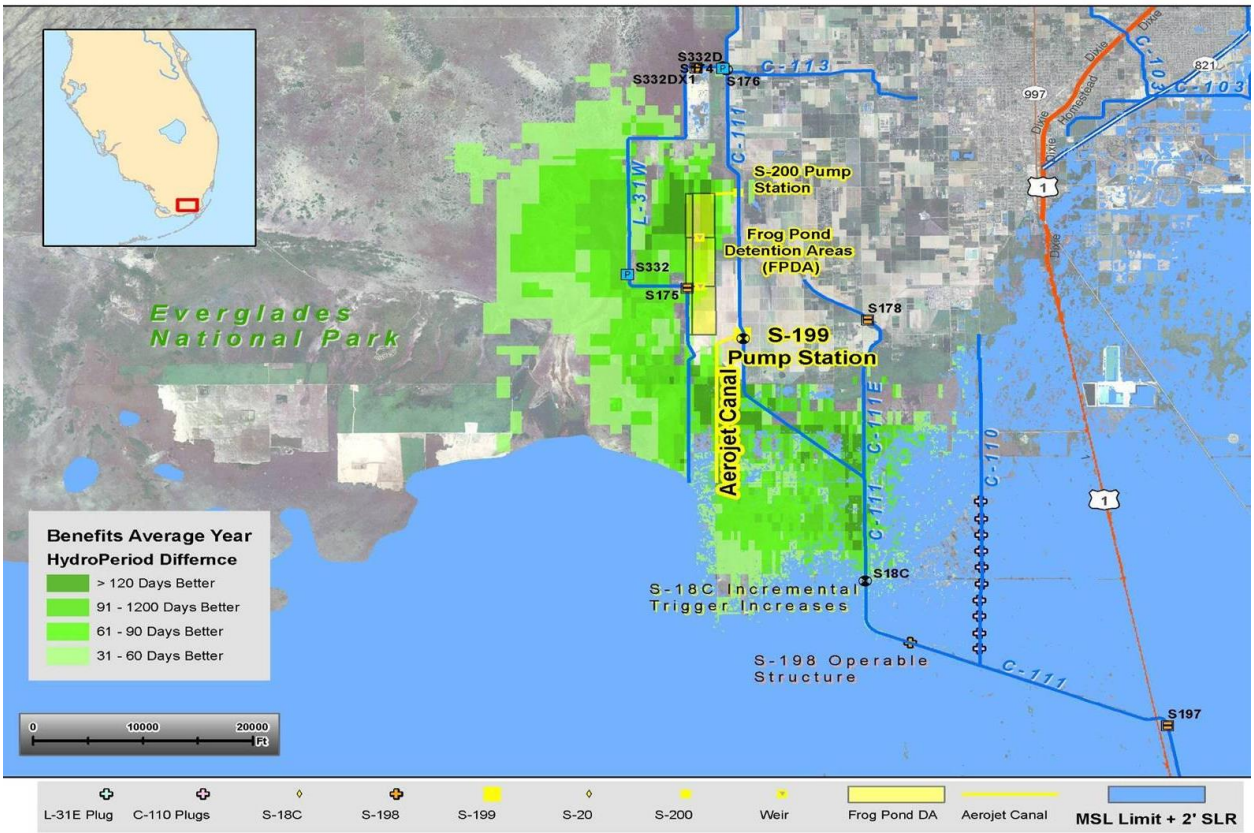


Figure 16: Map shows that sea level rise may inundate much of the southern tip of Florida, including project features, by the end of the century.

3.3.2.2 Hamilton Wetland RCC Adaptation Pilot Project

The Hamilton Wetland RCC Adaptation Pilot Project implemented the sea level change guidance to evaluate the impacts of sea level change on a freshwater and tidal wetlands restoration project along San Francisco Bay that was already in the construction phase. This was part of a larger effort to apply a RIDM framework in planning for sea level change. Sea levels in San Francisco Bay are currently rising at 0.1 in/yr, a rate faster than at any time in the last 5,000 years. Following the guidance, three sea level change curves were generated for the project area and used to assess how the projected three magnitudes of sea level change may affect habitat conversion based on the proposed restoration alternatives. The project seeks to initially create 20% freshwater and 80% tidal wetlands, and sea level change is projected to reduce freshwater wetlands over time in the project area. However, the study points out that there is currently no viable wetland habitat at the sites, so even if wetlands are established and later degraded by changing sea levels, there would still be a net gain in habitat in the project area.

3.3.2.3 Lower Columbia River Estuary RCC Adaptation Pilot Project

The Lower Columbia River Estuary extends 145 miles inland, with daily tidal cycles felt as far as immediately downstream of Bonneville Dam. Within the estuary, both water surface elevation and salinity will be affected by sea level change and upstream changes to snowmelt runoff patterns. These changes are anticipated to impact ecosystem restoration within the estuary, particularly with respect to restoration projects focused on salmon and steelhead populations. This project specifically incorporated planning under the USACE sea level guidance as one element in the application of a RIDM framework to long-term planning for the estuary. A key recommendation was the implementation of a more flexible planning process for ecosystem restoration studies to better account for increased future uncertainty under climate change.

3.3.2.4 East Rockaway Inlet to Rockaway Inlet RCC Adaptation Pilot Project

The East Rockaway Inlet to Rockaway Inlet RCC Adaptation Pilot Project was directly focused on sea level change impacts on urban development and ecosystem restoration efforts on this urbanized barrier island at the mouth of Jamaica Bay. The project sought to develop a collaborative framework under which vulnerability to sea level change impacts could be assessed and the risks from sea level change mitigated. The challenge was to develop a multi-stakeholder collaboration to address these issues. Implementation of the USACE sea level change guidance was a critical component in showing the extent of future inundation under future average high water and storm surge conditions.

As in other studies, the USACE sea level change scenarios were used as the basis for creating maps of areas likely to be inundated given future sea level change and storm surges. The sea level change analysis also enabled the identification, inventory, and mapping of areas,

infrastructure, and critical facilities likely to be impacted under different degrees of sea level change. This analysis enabled stakeholders to rapidly understand the extent of the problem and to move forward planning actions to mitigate the effects. Proposed measures included beach nourishment (adding sand to beaches to counteract erosion); dune creation and enhancement (to retain storm surge on the seaward side and prevent flooding); dredging; and construction of groins, breakwaters, and other features. A variety of nonstructural measures and actions such as raising roads were also under consideration.

The use of inundation maps to show potential future changes was found to be an effective way of communicating potential future risks due to changing sea levels. Following Hurricane Sandy, which damaged much of the study area in ways consistent with model projections soon after these were presented to local officials, the pilot was put on hold so local staffers could deal efficiently and effectively with response, recovery, planning, and engineering for near-term projects.

3.3.2.5 Chesapeake Bay RCC Adaptation Pilot Project

The Chesapeake Bay RCC Adaptation Pilot Project examined changes in the severity of coastal hurricane storm surge inundation at different degrees of future sea level change. Sea level change was estimated for six locations in the study area and then averaged to generate basin-wide increases in average sea levels in 2040 and 2100. Three scenarios at each time period (low, intermediate, and high sea level change) and two different methods for modeling storm surge were used. These methods were the simplified bathtub model and the more complex SLOSH model. The study examined storm surges for storms rated Categories 1–4 on the Saffir-Simpson hurricane wind scale. The two models showed non-linear increases in area of inundation relative to storm category reflective of bathymetry of the bay and adjoining coastal shelf and differences in specific areas inundated.

However, there was enough model agreement to suggest that in many scenarios, the bathtub method could be a reasonable low-risk, low-cost, and minimal effort approach to estimating the impact of sea level change on hurricane storm surge. Additional analysis is necessary to verify this suggestion before developing any guidance on what situations and scenarios would benefit from the use of the bathtub model. If the bathtub method were proven to be acceptable in some situations, it would likely reduce time and funding needed on some future feasibility studies, as the cost and time need for implementation of the full SLOSH model is much greater.

3.3.3 Assessment: Application of Sea Level Change Guidance

The sea level rise guidance was successful in all four pilot projects in providing scientifically sound projections of future impacts on projects. Developing the supporting information was relatively straightforward based on the method outlined in the USACE guidance initially, and

later through the use of the USACE sea level change calculator. Topographic mapping readily translated the projected rises to estimates of areas likely to be inundated in the future, and these maps proved to be effective in communicating future risks. Both the estimation of sea level change scenarios and the estimation of area inundated were readily communicated to sponsors, stakeholders, and other interested parties, resulting in broad public buy-in. Projects that focused on ecosystem restoration found mean high water or MHHW to better estimate where on the landscape the boundary between freshwater to saltwater is likely to be in the future.

3.4 Water Supply, Navigation, and Flood Risk Management: Climate Change Impacts on Inland Hydrology

The volume, quality, and availability of water in rivers affects four important USACE business lines:

- Flood risk management, or the construction and maintenance of dams, levees, and other structures that keep flood waters in the rivers rather than overbanking onto the floodplain and inundating towns, cities, infrastructure, and agricultural land
- Navigation, or ensuring the ability to transport people and goods along the Nation's inland and coastal waterways and harbors
- Hydropower, providing for continued efficient production of electricity generated from generating facilities at USACE projects
- Water supply, or the availability of freshwater for agricultural, industrial, municipal, ecological, and domestic use.

3.4.1 Modeling Projected Freshwater Streamflows

Estimating climate change impacts on freshwater streamflow is challenging because of the evolving nature of actionable science and the complexity of the processes involved. The challenges include the following:

- Model projections of precipitation change are much less certain than for temperature. For example:
    - The characteristics of a precipitation event, such as the intensity of rainfall, the period over which this rainfall occurs, and whether or not previous rainfall events have saturated the soil, determine how much water can sink into the ground and how much will run off into streams to cause flooding. Each river basin is unique, and even adjacent basins may respond differently to the same precipitation event.
    - The land cover and land use in the watershed also affect runoff, including the kind and density of vegetation, the soil type, surface permeability, whether the ground is sloped or flat, and the amount of urban development. Together, these determine how much precipitation can enter the soil and how much will run off.

  - With respect to snowfall and spring runoff, the amount of snow, how much water the snow holds (whether the snow is wet or dry), whether winter precipitation falls as rain instead of snow, and how early the snowpack begins to melt are also important considerations governing how large the spring runoff flow will be.
- Climate models and their results have evolved over the course of these adaptation studies, as have methods to downscale their results to the regional to local scales.
- Developing climate hydrology at the scale of these adaptation pilots has seen much progress between the earliest and later adaptation pilots.

To address climate change impacts on freshwater stream systems, teams undertook two basic steps:

- Obtained projections of future climate using primarily bias-corrected, statistically downscaled climate models, though some pilots did assess dynamically downscaled regional models
- Incorporated projected climate variables important to hydrology into hydrologic models to estimate projected future streamflow.

These steps are described below in Sections 3.4.1.1 and 3.4.1.2.

3.4.1.1 Project Future Climate Using Bias-Corrected, Spatially Downscaled Climate Model Data

The outputs of this step are model projections of temperature and precipitation events in a given future period. In addition, models are able to simulate changes in mountain snowpack and its persistence into spring. Projections of other climate variables, such as average monthly temperatures, are also output. In some cases, multiple models agree in the direction of change (gain or loss) and the relative amount; in others, models disagree about the direction and/or magnitude of change. It is the range of the plausible future conditions and how these affect the project that are the most important consideration.

3.4.1.2 Translating Climate Change into Changes in Streamflow

Deriving streamflow from precipitation requires a realistic model of a watershed that captures the different kinds of land surfaces and what happens to precipitation when it falls on those surfaces. The RCC Adaptation Pilot Projects used two basic modeling tools to construct climate-impacted hydrology models of the watersheds under study: the Variable Infiltration Capacity (VIC) model developed at the University of Washington (Gao et al. 2009, Wenger et al. 2010) and the U.S. Department of Agriculture's SWAT.

The VIC model represents the landscape as a grid of cells that are each 1 km^2 in area. Differences in land surface characteristics within each grid cell that affect runoff and infiltration are handled statistically. Surface runoff and groundwater flow can be transmitted from cell to

cell until a stream is reached, and then the water is routed downstream using a stream routing model. The SWAT model subdivides the landscape into smaller and smaller units based on the watersheds for smaller and smaller tributaries to create hydrologic response units. Hydrologic response units consist of sub-watersheds with homogeneous land use, management, and soil characteristics. Infiltration, evaporation, vegetation interception, and other factors that affect precipitation within the hydrologic response unit can then be modeled, and runoff from each unit calculated. Again, once this runoff reaches a stream, a routing model is used to calculate water movement downstream.

3.4.2 Climate Change Impacts on Inland Hydrology in RCC Adaptation Pilot Studies

Pilot projects focused on the following concerns in freshwater streams used the combination of downscaled climate models, the application of a VIC or SWAT model to translate precipitation into streamflow, and a routing model to transmit those flows downstream to the project area.

3.4.2.1 Flood Risk Management Pilot Studies: Reservoir and Lake Sedimentation

Three RCC Adaptation Pilot Projects used projected streamflows to understand how sediment could accumulate in the Nation's reservoirs and harbors, posing hazards to flood risk management, navigation, water supply storage, and other authorized purposes of USACE dams and reservoirs.

The Cochiti Dam and Lake RCC Adaptation Pilot Project investigated how the rate of sediment accumulation behind the dam might change under future climate conditions. This is a critical piece of information because any portion of the reservoir filled with sediment is a portion not available to store water for water supply or to retain streamflow during flood events. At Cochiti Dam and Lake, flows in the Rio Grande mainstem are projected to decrease, reducing the amount of sediment entering the reservoir. This sediment reduction is due to the projected decrease in the ability of the river to carry sediment in an area where much of the channel upstream is gravelly. By reducing sediment accumulation rates, climate change may slightly prolong the project lifetime. The Garrison Dam RCC Adaptation Pilot Project investigated both sedimentation and the impact of sedimentation on reservoir operations, including hydropower. Under projected climate change, the study estimated that there could be a small increase in sedimentation rate, but this could be offset by changes in reservoir operation to maintain the water elevation at desirable levels in the flood pool. However, modeling suggested that climate change may increase the magnitude of spring flood flows, potentially impacting the operation of all six Missouri River mainstem dams (**Figure 17**).

Figure 17: Flooding during the spring along the Missouri River may increase under a warmer future climate.

The Great Lakes Region RCC Adaptation Pilot Study investigated the potential for changes in sedimentation in harbors located at the mouths of two rivers entering the Great Lakes. Here, the primary issue is whether climate change will increase the rate of sediment deposition and, therefore, the annual cost of harbor dredging. The study looked at both the CMIP3 and CMIP5 climate model information, concluding that future studies should be aware that using older CMIP3 climate model data may produce results that differ from those obtained using newer, CMIP5 model data. The modeling results also indicated the presence of systematic bias in the projected streamflows compared to the hindcast period (1950–1999), which agrees with other analyses undertaken by the RCC Program. This does not prevent the results from being used in a qualitative sense to evaluate future changes, as was done in this pilot study. The study showed that results for the St. Joseph River and the Maumee River were quite different, despite similarities in basin size and regional setting. This result corroborated the finding of other sediment pilot studies that a one-size-fits-all approach is not sufficient, and that caution must be used when extrapolating results from one basin to adjacent watersheds. The study also compared the results of the VIC and SWAT models, but it reached no conclusion as to which would provide more accurate results. Further analysis is needed to better understand the difference between the two basins and the differences in estimated future dredging needs.

3.4.2.2 Flood Risk Management Pilot Studies: Flood Events

Three RCC Adaptation Pilot Projects used projected streamflows to evaluate changes in the magnitude and frequency of flooding. They used a similar methodology as the sedimentation studies discussed above.

The Coralville Lake RCC Adaptation Pilot Project evaluated whether projected changes in climate and streamflow would affect the operation of Coralville Reservoir on the Iowa River. Using a calibrated hydrologic model of the Iowa River Basin and regionally downscaled climate data, the risk to the reservoir system associated with future climate scenarios was analyzed. The robustness of the reservoir system to these changes was evaluated, and potential adaptation strategies were identified. The project team found that an effective approach is to determine how vulnerable the reservoir is to floods of different magnitudes.

The Iowa-Cedar RCC Adaptation Pilot Project was focused on collaborative decision making with respect to climate change impacts on flood magnitude and frequency. The modeling component of this study involved the comparison of three different hydrologic models: HEC-HMS, SWAT, and the GSSHA model. The models differ in complexity and the amount of data necessary. No one model emerged as capable of addressing all the issues on the river. It was concluded that the choice of model used in a watershed study has important consequences for a particular purpose, though it is difficult to gauge accuracy and there is not an ideal, one-size-fits all solution.

The Red River of the North RCC Adaptation Pilot Project examined how changes in winter precipitation—snowfall, snow water content, and the timing of snowmelt—affect spring flood flows in the vicinity of Fargo, North Dakota. The Missouri River Basin RCC Adaptation Pilot Project examined how changes in mountain snowpack and runoff would affect the frequency and magnitude of both droughts and floods in the Missouri River Basin.

3.4.2.3 Water Supply

Two RCC Adaptation Pilot Projects used projected streamflows to address issues related to water supply:

> The Marion Reservoir RCC Adaptation Pilot Project examines the vulnerability of the water supply to climate change, focusing on projected duration and magnitude of drought in the watershed. The modeling process is similar to that used in the sediment yield studies, with the output being water yield into the reservoir. The projections showed no pronounced change in average firm yield (the minimum annual quantity of water entering the reservoir). However, because firm yield is strongly influenced by extreme events, these results must be viewed with caution as the method is very poor at modeling extreme events.
>
> The Oologah Lake RCC Adaptation Pilot Project also examines the vulnerability of the water supply to climate change, focusing on projected duration and magnitude of drought in the watershed. The modeling process is similar to that used in the Marion Reservoir RCC Adaptation Pilot Project, with the output being water yield into the reservoir. Models showed no pronounced change in average firm yield under a warming climate given no directional change in precipitation. Expanding the study to include water quality indicates declines in dissolved oxygen and increases in water temperature that might affect some fish species in the reservoir.

3.4.2.4 Snowmelt and Spatial Variability

Three RCC Adaptation Pilot Projects used projected streamflows as they explored issues related to snowmelt and spatial variability.

Missouri River Basin RCC Adaptation Pilot Project examined the impact of climate change on Rocky Mountain snowpack accumulation and runoff. The models project a decrease in peak SWE, an earlier date for peak SWE, a faster melt-out, and decreasing spring runoff. By the second half of this century, there were significant increases in the frequency of low runoff years (relative to the historical long-term average), although the range of variability in runoff volumes showed no trend (high-runoff years will still occur) (**Figure 18**). The long-term impacts on water supply at the two reservoirs in the study were not modeled in this study but are likely to follow spring runoff trends.

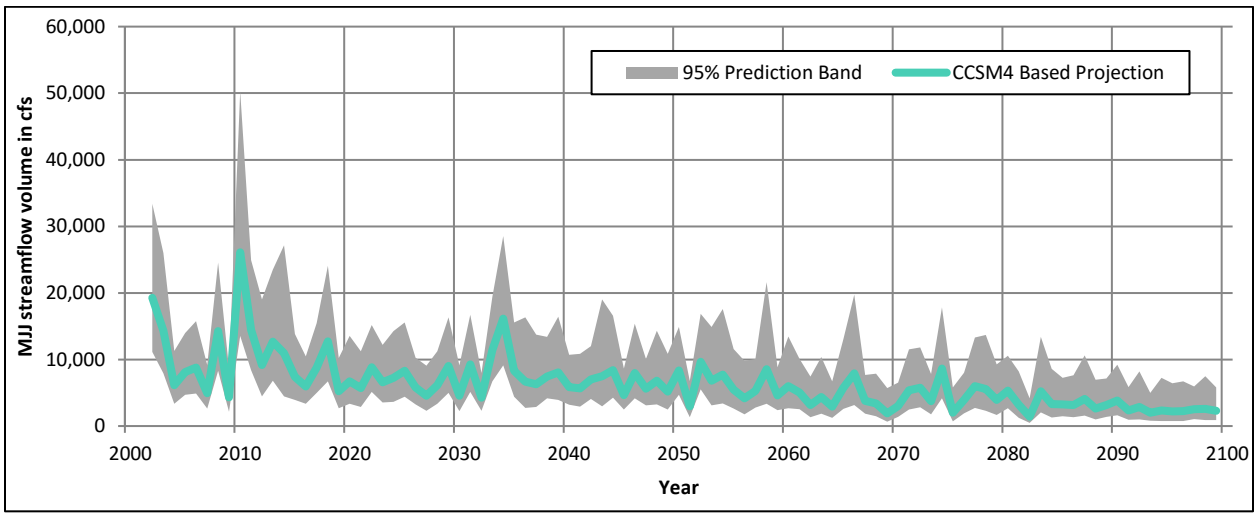


Figure 18: Projected changes in Missouri River streamflow near Landusky, Montana, above Ft. Peck, showing future reductions in flow due to loss of snowpack

The follow-on Lake Sakakawea RCC Adaptation Pilot Project showed that projected impacts could be different in different portions of a watershed, depending in part on elevation. The lower the elevation of the portion of the watershed where the snowpack accumulates, the greater the impact of temperature on the timing and magnitude of spring runoff.

Finally, the Willamette and Rogue RCC Adaptation Pilot Project also highlighted the spatial variability of watershed response to projected climate changes. In the historical record, rainfall-dominated watersheds showed a clear shift in streamflows from winter to summer, while runoff in snow-dominated basins became more stable. Models project variable future precipitation across the study area, with increases in winter streamflow and decreases in summer streamflow. More floods and more droughts are also anticipated. As in other pilot areas studied, these changes are anticipated to increase stressors to water management in the future.

3.4.3 Assessment: Climate Change Impacts on Inland Hydrology in RCC Adaptation Pilot Studies

Studies that examined annual or seasonal averages generally concluded that the existing data and tools were adequate and yielded useful results. Studies that focused on extreme flood and drought events concluded that the existing data and tools were inadequate for capturing future magnitudes, durations, and frequencies of such events. The reason for this dichotomy is primarily because the averages do not really change much; it is generally climate variability that is changing, and, with it, the extremes. Fortunately, updated climate information and hydrology in development by interagency and expert teams will address many of the climate hydrology issues identified in these studies.

4. Results

4.1 Lessons Learned from the Pilot Projects

Taken together, the pilot projects are providing a body of knowledge and tested methods that provide a foundation for successful water resources adaptation to climate change, thereby increasing our resilience to, and decreasing our vulnerability from, the effects of changing climate.

One of the most important lessons learned to date is that establishing a policy, no matter how broad, reduces the time and cost of adaptation. This is because policy not only provides legal and technical justification but also narrows the range of potential alternatives and guides planning and study approaches to support the desired decisions. Based on this lesson learned, USACE is working to develop both enabling (e.g., how we frame the approach) and implementing (e.g., how we adapt) policies and guidance for adaptation.

Overall, the pilot projects served as a good mechanism to develop in-house expertise and leverage expertise from other agencies, institutions, and partners through collaboration. Climate change is particularly challenging in this regard because the effects on watershed hydrology are diverse and complex, cutting across land ownership, land cover type, and disciplines. Although most of the pilot studies have involved collaborations and partnerships, these networks typically consist of a small handful of individuals from a few partnering agencies. Larger and more complex projects (e.g., ORB RCC Adaptation Pilot Project) demonstrated that these challenges could be overcome.

Lastly, an important factor identified in the pilot projects is that costs and benefits are dynamic and will change over time, just as climate does. These may need to be considered at the regional scale or may need to be quantified or evaluated differently over time. Consideration of dynamic changes over time can guide adaptive management decisions.

4.2 Additional Lessons Learned from Applying the Different Approaches

More specific lessons were learned from the efforts of individual teams to apply the four basic approaches used so far in the pilot studies.

4.2.1 RIDM Approaches

Most projects that implemented RIDM, either formally as RIDM or in a less structured manner, found that the conversations between stakeholders improved the understanding of the planning

process and were successful in elevating climate change as a long-term concern within the broader community. By considering climate change and risk early in the process, interagency teams more easily saw the key long-range issues and identified innovative solutions to these issues. Planners felt that the time spent designing and implementing the decision-making framework was as important as the time spent developing the scientific and engineering understanding of the physical process of climate change.

The consensus building central to RIDM had side benefits as well, including the following:

- RIDM led to better communication, which resulted in a better shared understanding of climate change impacts on the project area and led more rapidly to consensus about risk and solutions that mitigate and adapt to these impacts. Understanding was also more fine-grained, allowing participants to recognize heterogeneity within the project area and the need in some cases to customize adaptation and mitigation strategies to portions of the project area.
- Federal, state, and local agency participants and participants from non-governmental organizations gained a better understanding of the USACE planning process in general, and specifically the RIDM framework and the risk register (a listing of specific project risks and how they have been addressed). The risk register facilitated tracking of risks to individual project features, counteracting the tendency to lump risks into generic, one-solution-fits-all categories.
- Collaboration between Federal agencies promoted development of a Federal consensus about climate change and impacts on study areas. This collaboration enabled expertise and resources to be leveraged, improving project quality and impact.

Initially, lack of information and technical expertise at the district level was a cited concern among project team members. The resolution of climate projection and impacts data was also listed as a persistent concern. As the projects reached completion, these concerns were reduced because district staff improved technical competency through the process, and it became clear that the interagency consortium was making progress in improving resolution and confidence in climate data.

4.2.2 IWRM/SVP Process

Like RIDM, IWRM and the SVP process promote collaboration among stakeholders and the development of consensus over the nature of projected climate impacts and resulting infrastructure vulnerabilities. Activities that promoted group cohesion—such as a common logo, vision, process, and timeline—promoted local and community engagement and contributed to a feeling of stewardship for the project area. The IWRM framework is open with respect to the tools and methods used to achieve project ends, which allowed for collaborative, local decision making to guide the selection of tools and methods suitable to meet unique local needs.

4.2.3 Sea Level Change

The initial sea level rise guidance was evaluated by several projects, which found that overall the guidance was straightforward to apply for most situations. The translation of sea level change into inundation area was relatively easy to determine using existing topographic data in a GIS and provided data adequate for studies that needed to take into account substrate stability, erosion/sedimentation, and vegetation salinity tolerance, as well as more information on the density and infrastructure present in the built environment.

Sustaining the benefits of ecosystem restoration and shoreline infrastructure requires planning for long-term adaptation capacity, including coordination with other regional flood risk reduction planning efforts. At least one project team reported that USACE was ahead of the curve in addressing sea level change scenarios, risks, and consequences in its planning efforts; it was necessary to train local sponsors and stakeholders on USACE sea level change requirements at study initiation (**Figure 19**).

Figure 19: In the Norfolk, Virginia, region, significant shoreline infrastructure is at risk from sea level rise and increases in storm surge in a warmer future climate.

4.2.4 Climate Hydrology

Climate hydrology posed more difficult problems than changing sea levels, for which the scenario approach was a relatively standard way to deal with uncertain future conditions. Climate hydrology required analysis of climate data and translation of that data into water quantity on the landscape. All of the projects had to wrestle with large climate model projection datasets and the means to translate them into streamflow.

Planners and engineers reported that lack of existing USACE guidance made it difficult for them to decide how to proceed with their studies and to validate their choice of direction. Data for use in climate assessments can require significant processing quality assurance and quality checking prior to use in models. The early pilot studies resulted in the development of web tools to provide consistent, repeatable results that emphasized data analysis, and for which the data management was handled as a pre-processing step. Knowledge of local climate, climate trends, hydrology, and other conditions was fundamentally necessary to interpret model results.

The breadth of the analysis was also of concern in two ways. While projected streamflow averages seemed to provide usable data for determining variables such as average sedimentation rate, projects focused on extreme precipitation and drought events presented barriers that reduced confidence in the results. The second concern is that the methods used to translate climate projections into hydrologic conditions and impacts on watersheds did not adequately capture vegetation change, wildfire, land use change, and other factors.

Lastly, for some projects, the approach of starting with climate models and deriving streamflow and impacts was seen to be less useful than an approach that determined how large an impact would have to be to affect a planned or existing project, and then to assess whether projected climate change would be large enough to create an impact. In this approach, thresholds or trigger points could be identified where adaptation measures could be taken to reduce future impacts should climate change occur faster or slower than projected.

In spite of the projected climate hydrology shortfalls, many groups felt that stakeholder involvement with the models and climate projection data were useful for creating a broad understanding of the issues, knowledge, and knowledge gaps. Further, for studies where average monthly modeled streamflow provided usable information, this information was seen as both useful and actionable.

4.3 Responses to Lessons Learned

The adaptation pilot projects were key to developing professional and technical competence at the working level. By exploring ways in which districts can include climate impacts and adaptation in their planning and engineering processes, we not only fostered communication across all levels of government but also prompted development of methods, tools, and technical guidance. Summaries of relevant literature were developed (e.g., USACE 2015b) to assist districts in better identifying potential climate change impacts on their areas of responsibility.

For example, the early sediment pilot studies showed that changes in sediment influx may shorten the lifetime of some reservoirs, while extending the lifetime of others. As a result, the USACE developed a web portal to compile reservoir sediment information (RSI) nationwide and track past and current sedimentation rates. It built tools to translate sediment survey information

from newer data-rich methods for input into the portal. This portal is now operational and includes Reclamation and USGS as interagency partners to support IWRM approaches.

Similarly, the early water supply studies highlighted changing drought conditions as important climate impacts on USACE missions and operations. This knowledge led to the creation of a program component to compile water control information in a single web portal for use across USACE. The portal includes water control manuals, drought contingency plans, and deviation policies. This information, combined with records of past deviations, can be compared to the RSI data and information on water supply allocations to provide a comprehensive view of the past, current, and future states of reservoir operations. It also supports national prioritization of efforts to update reservoir surveys and drought contingency plans.

The lessons learned from coastal pilots have informed not only guidance in the form of USACE ETL 1100-2-1 and forthcoming guidance on procedures to evaluate the magnitudes and effects of total water levels at USACE projects but also extensive updates to the USACE sea level change calculator.

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6. Appendix A Pilot Study Fact Sheets

1 - APPLICATION OF SEA LEVEL CHANGE GUIDANCE TO C-111 SPREADER CANAL, FLORIDA

FACTS & INFORMATION | RESPONSES TO CLIMATE CHANGE (RCC) PILOT STUDY

FUNCTIONAL AREA: OPERATIONS AND MANAGEMENT — AUGUST 2017

BACKGROUND

Man-made drainage features have disrupted the hydrologic regime of the Everglades, causing a transition from a wetland system characterized by overland sheet flow, to one where water moves swiftly through conveyance features to point source discharge areas along Florida Bay. The altered hydroperiods have led to declines in prey bases for numerous macrofauna, including migratory birds. The changes in freshwater hydrology have also led to secondary effects on the estuarine and marine environments of Florida Bay. Damaging freshwater pulses from the Spreader Canal Western Project, located in Southern Miami-Dade County, Florida, southeast of Everglades National Park, disrupt flow patterns and create an unnatural salinity envelope along the shorelines and farther into the bay. These salinity changes adversely impact nursery areas for fish and invertebrate species. The C-111 Spreader Canal Western Project Recommended Plan includes the following major features: Frog Pond Detention Area (FPDA) with 225 cubic feet per second (cfs) pump station; Aerojet Canal with 225 cfs pump station; and ten plugs in the C-110 Canal. These features are shown below along with a depiction of the estimated zone of freshwater wetland rehydration. The FPDA and Aerojet Canal are intended to work in unison to create a 9-mile long hydraulic ridge adjacent to Everglades National Park. The ridge will serve to block groundwater flows from moving into the C-111 Canal from Everglades National Park, therefore retaining water in Taylor Slough to enhance freshwater wetland function and to improve the quantity, timing and distribution of flows into Florida Bay. Improved habitat conditions are expected to result in increased numbers of birds and nearshore marine organisms.

VULNERABLE BUSINESS LINES

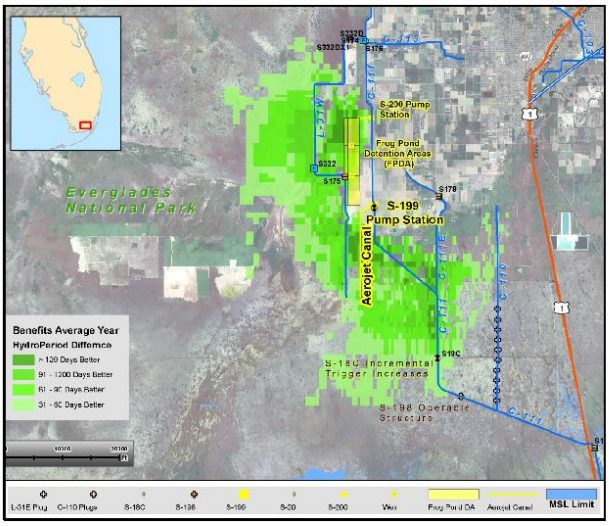
Flood Risk Management, Ecosystem Restoration, Water Supply

CENTRAL QUESTION ADDRESSED BY PILOT

How do we allow for shoreline retreat to preserve critical tidal and nearshore ecosystems in a long-term regional planning context?

APPROACH

This pilot tests the application of recent U.S. Army Corps of Engineers (USACE) sea-level change and datum guidance and policy. The Engineering Circular (EC) 1165-2-211 (and 212) evaluation was conducted during the later stages of the plan formulation process to estimate the impact of sea-level change on project benefits. Maps were created to show projections of the benefited freshwater wetland area and the shoreline. Impacts to freshwater wetland rehydration benefits were estimated by determining the fraction of benefit area inundated under increased mean sea level. Impacts to salinity benefits were estimated based on the availability and potential suitability of freshwater habitat for conversion to saltwater habitat.



MAP OF C-111 SPREADER CANAL WESTERN FEATURES PROJECT SHOWN WITH ESTIMATED ZONE OF AVERAGE INCREASE IN HYDROPERIOD.

APPLICATION OF SEA-LEVEL CHANGE GUIDANCE TO C-111 SPREADER CANAL

LESSONS LEARNED

- Enabling policy requiring the consideration of three scenarios of sea-level change guidance supported a fairly rapid analysis of sea level rise (depth) and salinity changes during the planning process.
- Mean higher high water (MHHW) is a better indicator than mean sea level (MSL) for the transition from freshwater to saltwater ecosystems.
- Allowing for shoreline retreat in environmental restoration areas can preserve critical tidal and nearshore ecosystems.
- Simple and quick GIS-created inundation maps with 1-foot increments are adequate for planning phase studies given the uncertainties of topographic information, water supply, and habitat response. When possible, more sophisticated evaluation tools could be used to take into account substrate stability, erosion/sedimentation, and vegetation salinity tolerance.
- Sustaining ecosystem restoration benefits requires planning for long-term adaptation capacity, including coordination with other regional flood protection planning efforts.

KEY RESULTS

- Establishing a policy that describes climate impacts to consider, no matter how broad, reduces the time and cost of adaptation planning.
- Both costs and benefits are dynamic over space and time.
- Long-term maintenance of nearshore salinity project benefits is feasible for this project under projected sea-level change, given few natural or man-made topographic obstructions to shoreline retreat.
- The ecological functions of transitioning habitat are likely to be limited for some period as the quality of the replacing habitat will be constrained initially.
- Long-term restoration and protection of freshwater wetland habitat upland of the MSL line is dependent upon sufficient delivery of freshwater supplies to protect salinity intolerant vegetation and peat soil substrate from infrequent higher tide events.
- Sufficient delivery of freshwater will require enhanced water supplies as provided by regional restoration efforts in addition to the water provided by this project.
- The study is complete.

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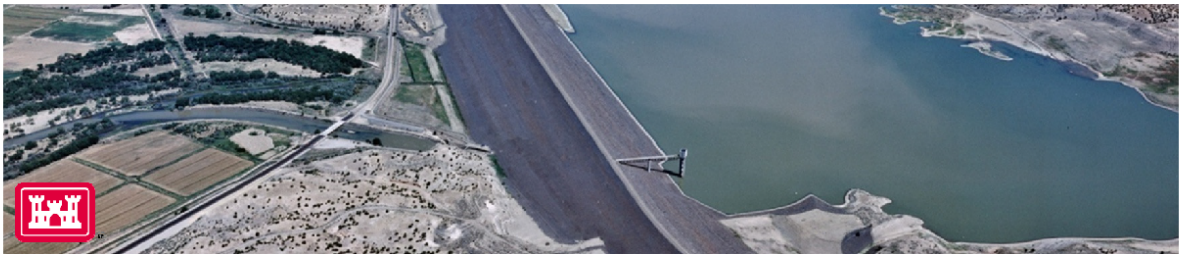
TAYLOR SLOUGH

U.S. ARMY CORPS OF ENGINEERS

2- CLIMAGE CHANGE ASSOCIATED SEDIMENT YIELD IMPACTS ON THE RIO GRANDE, COCHITI DAM & LAKE

FACTS & INFORMATION | RESPONSES TO CLIMATE CHANGE (RCC) PILOT STUDY



FUNCTIONAL AREA: OPERATIONS AND MANAGEMENT AUGUST 2017

BACKGROUND

Climate models for the Southwestern United States project average temperature increases that have the potential to lead to increasing aridity, decreasing soil moisture, and declines in headwaters mountain snowpacks. How such hydrologic changes might affect streamflow and sedimentation at the U.S. Army Corps of Engineers (USACE) Cochiti Dam and Lake Project is the topic of this pilot study. Cochiti Dam is located at the confluence of the Rio Grande and the Santa Fe River on Pueblo de Cochiti Land, approximately 50 river miles north of Albuquerque, NM. The dam, which was completed and operational in 1975, has a drainage area of approximately 11,685 square miles and serves as the primary flood control structure for snowmelt runoff control on the mainstem of the Rio Grande. Cochiti Lake storage includes approximately 500,000 acre-feet for flood control and another 105,000 acre-feet for sediment accumulation. As of 2009, approximately 73,517 acre-feet remained in the sediment reserve space.

VULNERABLE BUSINESS LINES

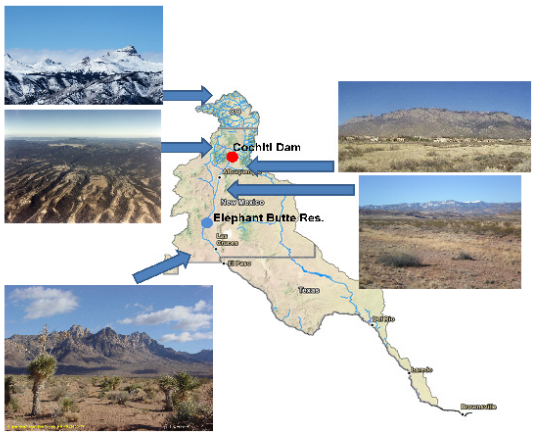
Flood Risk Management, Navigation, Hydropower, Recreation

CENTRAL QUESTION ADDRESSED BY PILOT

What is the relationship between changing climate conditions and reservoir sedimentation, and could this relationship shorten the lifetime of the infrastructure project or impact its flood control pool?

APPROACH

This pilot is part of a joint U.S. Bureau of Reclamation (Reclamation) and U.S. Army Corps of Engineers (USACE) study that examined climate change impacts at paired reservoirs, including Bighorn Lake in Montana and Wyoming, Elephant Butte Reservoir in New Mexico, Garrison Reservoir in North Dakota, and Cochiti Reservoir in New Mexico. Reclamation provided USACE with dynamically downscaled climate model ensembles with projections for monthly temperature and precipitation changes under five different climate scenarios for two different time periods: 2010 through 2039, and 2040 through 2069. Reclamation input these data into a variable infiltration capacity (VIC) model to derive values for runoff, infiltration, and contributions to groundwater from precipitation falling on a particular subset of the region. USACE put these data into its Upper Rio Grande water operations model to model changes of stream discharge into Cochiti Lake. Future sedimentation at Cochiti Lake was determined using monthly discharge as input to existing sediment transport equations.



LOCATION MAP SHOWING PAIRED STUDY DAMS ON THE RIO GRANDE AND THE TYPES OF TERRAIN IN THE WATERSHED

COCHITI DAM & LAKE RCC PILOT

LESSONS LEARNED

- Because climate change is only one of many factors that can affect sediment influx to reservoirs, an integrated watershed model would more effectively account for watershed changes that affect streamflow, sediment transport, and other hydrologic variables.
- Knowledge of local climate, climate trends, hydrology, and fluvial geomorphology are essential to make sense of model results.
- Expertise needs to be available within the district to evaluate information produced by others.

KEY RESULTS

- The projected changes in temperature and precipitation produced a decrease in streamflow volume along the Rio Grande mainstem, characterized by lower-volume, shorter-duration, earlier spring runoff pulses and decreases throughout the rest of the year.
- Overall reductions in inflow to Cochiti Lake were found, particularly in the period from 2040 to 2069 relative to the late 20th century baseline. These were driven by overall declines in runoff volume, particularly in winter and spring, and a shift in the hydrograph to an earlier, lower spring peak flow.
- Reservoir sedimentation rates are likely to decline, but sediment yield from tributary arroyos is expected to continue and possibly increase as climate warms. This may contribute to increasing rates of aggradations in the Rio Grande that, in turn, may increase the potential for overbank flows.
- The rate of sediment accumulation behind Cochiti Dam is expected to decline as a direct result of projected temperature and precipitation changes with no adverse effect on the lifetime of the project, and possibly extending the project life.
- Under climate scenarios for which peak and average inflows to Cochiti both decline, average and flood flows downstream are also expected to decrease. This is expected to have follow-on impacts on water allocations throughout the Rio Grande Basin, as well as conservation flows, groundwater recharge, groundwater contributions to surface flows, and other hydrologic relationships.
- The study is complete.

FOR MORE INFORMATION

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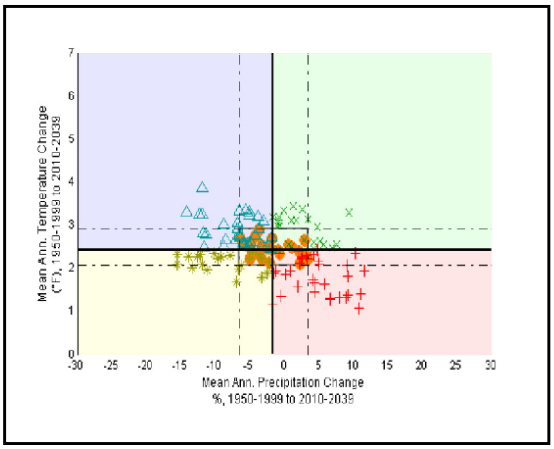
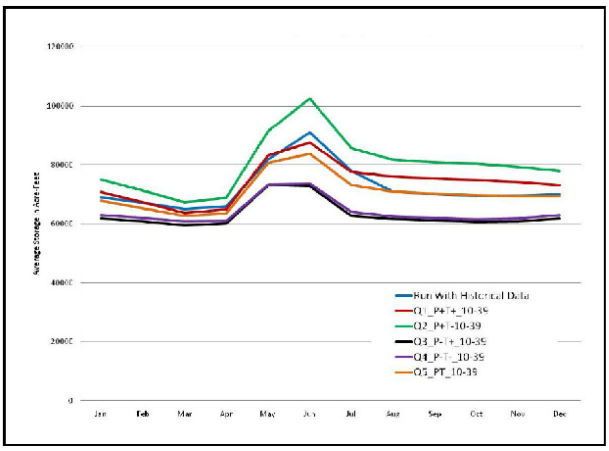


MODELED CHANGES IN TEMPERATURE AND PRECIPITATION IN THE NEAR FUTURE (2010-2039)



PROJECTED CHANGES IN COCHITI AVERAGE STORAGE (2010-2039)

U.S. ARMY CORPS OF ENGINEERS

3 - CLIMATE CHANGE IMPACTS ON THE OPERATION OF CORALVILLE LAKE, IOWA

FACTS & INFORMATION | RESPONSES TO CLIMATE CHANGE (RCC) PILOT STUDY

FUNCTIONAL AREA: OPERATIONS AND MANAGEMENT AUGUST 2017

BACKGROUND

The U.S. Army Corps of Engineers (USACE) owns or operates almost 700 U.S. dams and reservoirs. Climate change could potentially impact all of these projects, which must operate continuously to meet authorized purposes while balancing competing demands. Coralville Reservoir is a multipurpose USACE reservoir on the Iowa River with authorized purposes of flood risk reduction, fish and wildlife, water quality, low flow augmentation, and recreation. This pilot study is developing methods and plans to assess and improve the robustness of reservoir water control operations in the context of climate change. The pilot study is leveraging work from the USACE Watershed Study of the Iowa Cedar Rivers Basin, which is a participating United Nations Educational, Scientific and Cultural Organization (UNESCO) Hydrology for the Environment, Life and Policy (HELP) basin.

VULNERABLE BUSINESS LINES

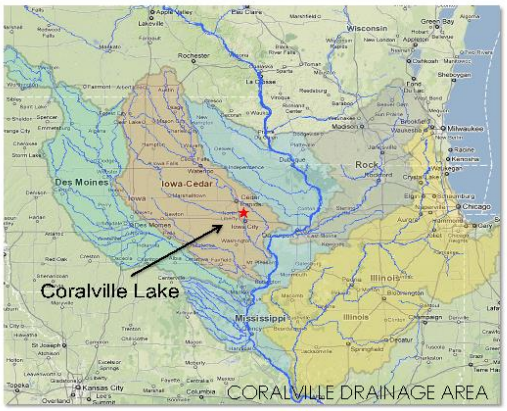
Flood Risk Management, Recreation

CENTRAL QUESTION ADDRESSED BY PILOT

How do we incorporate climate change considerations into reservoir operating policies that will be robust and adaptive to potential climate changes?

APPROACH

The approach used in this study first evaluated original project purposes and project design, the basis for storage allocation, the assumptions of sediment yield, frequency of uncontrolled releases, and the spillway design flood. At this phase, we also considered whether vulnerabilities exist because hydrologic conditions are different than originally assumed, and analyzed whether there have been observed changes to the original design parameters. Next, we used a risk-based approach to identify the most likely, highest consequence impacts that may result from climate change. We identified key performance questions and



CORALVILLE LAKE RCC PILOT

APPROACH continued

metrics (e.g., 15-day peak inflow, time until allocated sediment storage is fully utilized) for the highest risk of potential impacts from climate change on project performance. Based on quantitative analysis using downscaled climate projections, we developed potential adaptation strategies and are testing their effectiveness across a range of possible future climate scenarios. We will evaluate timing or triggers for implementation. During the second phase of the pilot study, Dr. Casey Brown, assistant professor at the University of Massachusetts Amherst, used a stochastic weather generator to conduct stress tests to determine what conditions would cause downstream flooding. This information could be used with observed data and climate model projections as part of a risk assessment.

LESSONS LEARNED

- We should attempt to avoid assumptions about what future climate data will indicate, and be open to revisiting questions/metrics.
- Vulnerability assessments need to consider all relevant factors–downstream development, land use change in watershed, etc.
- Managing expectations is important – and inability to definitively describe hydrologic response to climate change requires non-traditional decision making.
- Climate models may do a better job of modeling changes in the mean, but not necessarily the extreme, which may be of most interest.
- Climate data and downscaled models have limitations.
- It is better to define questions regarding climate vulnerabilities in a less specific way than was done in this pilot.
- The approach to analyzing the climate data would be determined best by first understanding the project's sensitivity and vulnerability to climatic variation, and then formulating alternatives to reduce the climate sensitivity (increase robustness) of the project.
- Downscaled climate data was unable to provide a basis for developing regulation procedures to reduce risk in future major flood events, and emphasizing the importance of short-term climate forecasts and the need to develop tools capable of informing water managers.

KEY RESULTS

- Operation of the Coralville Lake project provides flood control benefits for communities downstream, as well as along the Mississippi River below the confluence with the Iowa River.
- Low-flow release agreements have been reached between Iowa City Water Works and the State of Iowa to provide a minimum flow of 150 cubic feet per second (cfs) at Iowa City, Iowa. Also, a drought contingency plan constructively rations water during extreme drought periods.
- Upward trends in average annual temperature and total annual precipitation have been observed in Iowa between the early 20th and early 21st century, and at the tested gauges within the Iowa River Basin. These trends are statistically significant at 95 percent confidence.
- There is a larger increase in temperature over this time period than in precipitation. There is a strong cyclical component in both temperature and precipitation, and the endpoint of the trend is still within the historical, cyclical variability.
- There also has been an observed increase in the occurrence of the heaviest precipitation events (i.e., more days of heavy precipitation per year). Observations of the Iowa River indicated increased mean and variance of annual 15-day peak discharge between the design period (pre-reservoir), which was used to formulate assumptions, and actual operations (reservoir in operation-present).
- The study is complete.

FOR MORE INFORMATION

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U.S. ARMY CORPS OF ENGINEERS

4 - CLIMATE CHANGE SEDIMENT YIELD IMPACTS ON OPERATIONS EVALUATION AT GARRISON DAM, NORTH DAKOTA

FACTS & INFORMATION | RESPONSES TO CLIMATE CHANGE (RCC) PILOT STUDY

FUNCTIONAL AREA: OPERATIONS AND MANAGEMENT AUGUST 2017

BACKGROUND

Climate change is predicted to affect temperature and precipitation within the Missouri River Basin. Changes in temperature, the timing of snowpack runoff, and the amount of precipitation could significantly alter basin runoff. Runoff, vegetative cover and altering the timing of precipitation are all major factors for sediment yield. These combined changes could affect the Missouri River Reservoir System and dam operations. Garrison Dam, located on the Missouri River in central North Dakota, has a drainage area of over 180,000 square miles and a storage capacity of 23.8 million acre-feet. It is also the largest of the mainstem reservoirs located in the upper Missouri River Basin. Altered runoff and sedimentation due to climate change could affect the Missouri River reservoir system and dam operations.

VULNERABLE BUSINESS LINES

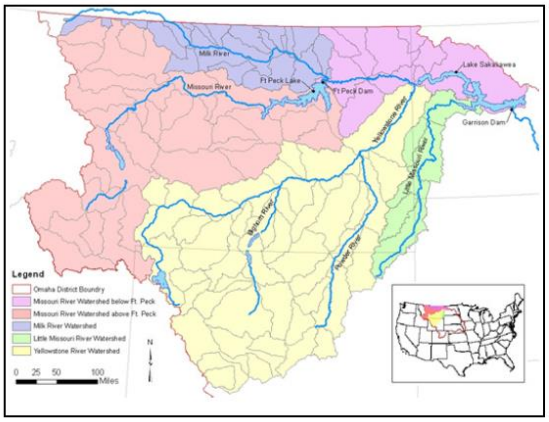
Flood Risk Management

CENTRAL QUESTION ADDRESSED BY PILOT

How will climate change affect basin runoff, sedimentation rates, and operations of the Garrison Dam?

APPROACH

This pilot is part of a joint U.S. Bureau of Reclamation (Reclamation) and U.S. Army Corps of Engineers (USACE) study that looked at paired reservoirs, including Bighorn Lake in Montana and Wyoming, Elephant Butte Reservoir in New Mexico, Garrison Reservoir in North Dakota, and Cochiti Reservoir in New Mexico. Under climate change conditions, hydrologic and land cover variation can be used to develop revised sediment load conditions. This study considers the potential impact of climate-induced hydrologic changes to the Garrison Dam Reservoir. The specific impact examined in this study is the relationship between changing climate and basin runoff that could affect reservoir sedimentation, or influence the flood control capabilities of the dam. A watershed sedimentation evaluation was performed with a range of parameters to examine climate change impacts. The study used statistically downscaled regional climate projections for five different climate scenarios: drier and cooler, drier and warmer, wetter and cooler, wetter and warmer, and a median future precipitation and temperature condition. The Variable Infiltration Capacity (VIC) model used the projected climate data to develop future inflows into the Garrison Reservoir. In-depth analysis of a potential method using climate forces to drive hydrologic models was performed. VIC outputs were applied to reservoir routing programs and streamflow-sediment relationships to evaluate future operations and inform management decisions. Measured stream gage data and historical reservoir survey data were used to develop sediment rating curves to define the streamflow-sediment relationship. The



MISSOURI RIVER DRAINAGE BASIN UPSTREAM OF GARRISON DAM

GARRISON DAM, NORTH DAKOTA, RCC PILOT

APPROACH continued

VIC flows were applied to this relationship to estimate the change in reservoir capacity. The six mainstem Missouri River dams were simulated as a system using the Daily Routing Model; as the pool elevations and releases increase at the Garrison Dam, the operations of the other five reservoirs can be adjusted to compensate. This helped reduce the overall effect of the increased flows into the system.

LESSONS LEARNED

- Because there were no policies supporting adaptation planning involving inland hydrology at the time of the study, it was not clear how to proceed. Fortunately, there are now several efforts (e.g., nonstationarity, portfolio of approaches) supporting development of enabling guidance (how to frame an approach) and implementation guidance.
- Even climate scenarios with less precipitation can result in increased reservoir inflows due to changes in timing.
- Sediment impact evaluations based on storage change and stream gage data as in this pilot do not reflect runoff timing and vegetation change, which can affect basin sediment yield.

KEY RESULTS

- Establishing a policy describing climate impacts to consider, no matter how broad, reduces the time and cost of adaptation planning.
- All climate change scenarios evaluated result in an increase in sediment loading and inflows.
- Impacts from changing sedimentation rates on flood regulation would be minor for this large mainstem reservoir, but hydrologic changes could potentially be significant.
- Changes in projected flow due to bias corrections are greater than changes due to future climate scenarios examined.
- The projected climate-adjusted sediment rates have no immediate impact on dam safety as long as the spillway design flood does not increase.
- Sedimentation rates can increase the frequency of non-normal reservoir releases.
- Climate-adjusted flows can have a large impact on pool elevations and releases for all climate scenarios evaluated.
- The Missouri River mainstem dams should be modeled as a system.
- Climate-adjusted runoff and sediment yield could increase the rate of storage depletion in Garrison Reservoir.
- Timing of precipitation plays an important role in reservoir inflows, which is important because the runoff to Garrison Dam is affected by snow volume and snowmelt.
- The study is complete.

FOR MORE INFORMATION

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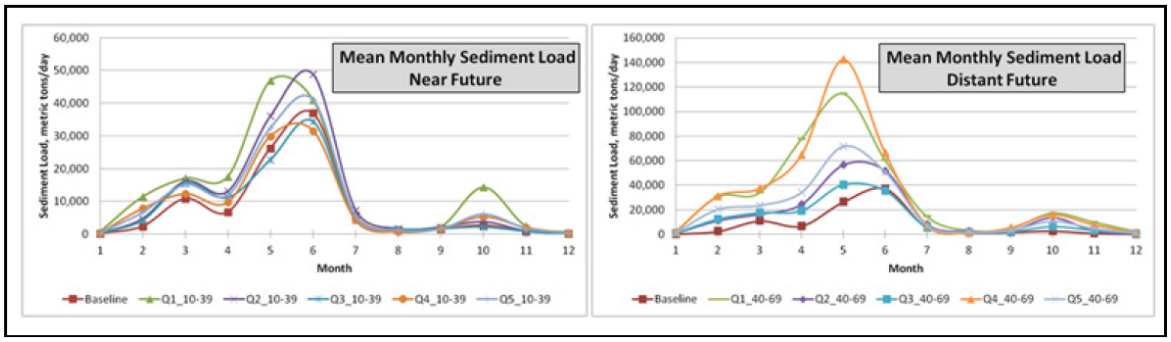

MEAN MONTHLY SEDIMENT LOAD AT THE WATERSHED OUTLET

U.S. ARMY CORPS OF ENGINEERS

5 - EAST ROCKAWAY INLET TO ROCKAWAY INLET, NEW YORK, COLLABORATION FRAMEWORK DEVELOPMENT

FACTS & INFORMATION | RESPONSES TO CLIMATE CHANGE (RCC) PILOT STUDY

FUNCTIONAL AREA: PLANNING AUGUST 2017

BACKGROUND

Considering sea level change impacts on highly populated and developed urban areas may require different approaches than for less developed areas. The East Rockaway Inlet to Rockaway Inlet, New York, Collaboration Framework Development RCC pilot study area is an urban, highly-developed, economically-diverse community, with over 10,000 structures, including critical infrastructure such as a sewage treatment plant, a hospital, and numerous primary and secondary education facilities. The pilot focuses on developing a collaborative framework to assess vulnerability to sea-level change impacts. The study also includes the development of lifecycle alternatives to reduce risk, with the recognition that solutions to address these problems can be implemented over time. The project study area is located on the Atlantic coast of New York City between East Rockaway Inlet and Rockaway Inlet. Rockaway Beach is located on a peninsula that separates the Atlantic Ocean to the south from Jamaica Bay to the north. The peninsula is entirely within the Borough of Queens, New York (Figure 1). The Atlantic coast shoreline of the Rockaway Peninsula is subject to storm-induced recession and long-term erosion. Erosion has significantly reduced the height and width of many beachfronts within the area. Low-lying areas are currently subject to frequent and severe damages from tidal inundation and wave run-up. The project area is exposed to increased risk due to sea-level change and storm surge inundation. Long-term Federal involvement in storm damage reduction for the project area remains an issue of concern and is undergoing investigation in the East Rockaway Inlet to Rockaway Inlet and Jamaica Bay, New York, Reformulation Study.

VULNERABLE BUSINESS LINES

Flood Risk Management

CENTRAL QUESTION ADDRESSED BY PILOT

How do we facilitate well-designed and inclusive multi-stakeholder collaboration with local decision makers for the purpose of identifying vulnerability to sea level change impacts, acceptable levels of risk, and the most acceptable alternatives over the project lifecycle?

Figure 1: The study area for the RCC Pilot East Rockaway Inlet to Rockaway Inlet, New York, Collaboration Framework Development is illustrated in the white box to the left and consists of the Rockaway Peninsula, between Beach 19th Street in the east, and Beach 149th Street to the west, from the Atlantic Ocean shoreline to the south, to the Jamaica Bay shoreline to the north in Queens, New York.

EAST ROCKAWAY INLET TO ROCKAWAY INLET, NEW YORK, RCC PILOT

APPROACH

This pilot climate change adaptation study includes a multidisciplinary team of decision makers to collaboratively identify, inventory, and map areas/infrastructure and critical facilities with the greatest risk for repetitive sea-level change impacts. The team is also working to collaboratively develop acceptable alternative lifecycle plans and strategies to reduce risk in those areas, both along the Atlantic Ocean and Jamaica Bay shorelines. This pilot study complements the Draft New York State Sea Level Rise Task Force Recommendations presented in the November 2010 document, and efforts by the New York City Panel on Climate Change. The lessons learned during this RCC pilot will be used to develop policy and guidance supporting collaborative coastal climate change adaptation planning. The successes and challenges of building a Sea-Level Change Risk Reduction Team (SLCRRT) for this project are being documented so that other similar projects will have an easier time establishing collaboration among stakeholders for sea-level change risk reduction alternative development across plan formulation, socio-economic, engineering, and environmental considerations.

LESSONS LEARNED

- The size, density and variation of structures in an urban coastal environment pose challenges to developing storm damage reduction alternatives. We need to improve our range of possible adaptable alternatives.
- The U.S. Army Corps of Engineers (USACE) is ahead of the curve in developing specific alternatives at Rockaway that address sea-level change projections, risks and consequences. We need to train local entities on USACE sea level change requirements at study initiation.

KEY RESULTS

- Our visualization of sea-level change projections based on Engineer Circular (EC) 1165-2-212, *Sea-Level Change Considerations for Civil Works Programs,* is similar to local science agency estimates.
- The projections provide a good tool for communicating with city and state agencies, as well as the private organizations (power, telecommunications) involved.
- The study was overcome by events (Hurricane Sandy).

FOR MORE INFORMATION

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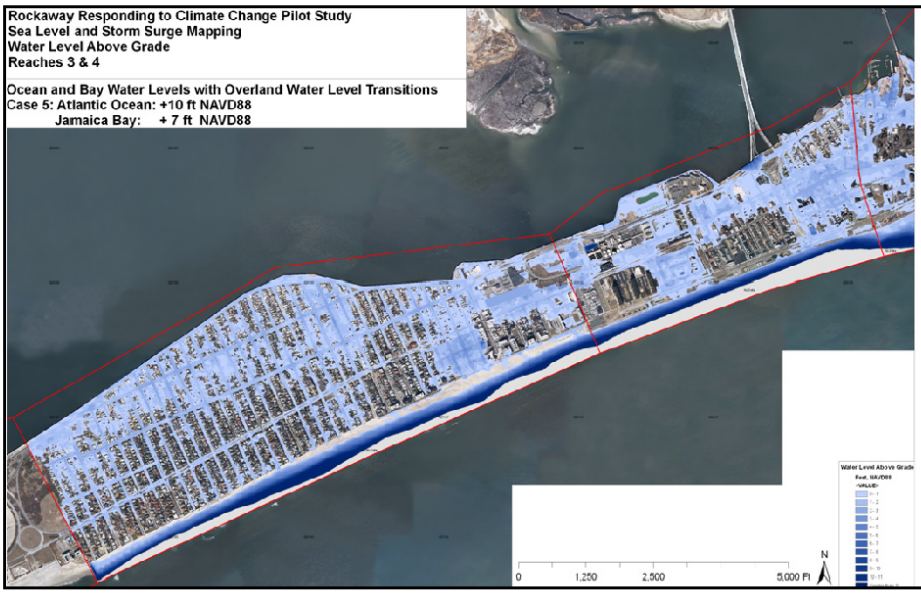

INNUNDATION MAPPING WITH SLC AND STORM SURGE EVENTS

- Year 2020, Intermediate SLC, 50-year Event
- Year 2030, Low SLC, 50-year Event
- Year 2050, High SLC, 10-year Event

U.S. ARMY CORPS OF ENGINEERS

6 - UPLAND SEDIMENT PRODUCTION & DELIVERY IN THE GREAT LAKES REGION UNDER CLIMATE CHANGE

FACTS & INFORMATION | RESPONSES TO CLIMATE CHANGE (RCC) PILOT STUDY

FUNCTIONAL AREA: OPERATIONS AUGUST 2017

BACKGROUND

The U.S. Army Corps of Engineers (USACE) has 139 harbors in the Great Lakes. Many of these harbors sit at the outlets of rivers that convey large amounts of sediment and create periodic dredging requirements. It is currently unknown how dredging costs vary with climate variability and future climate change. This study will examine the St. Joseph River and Maumee River watersheds to estimate the potential effects of climate change on dredging requirements. The project study area is focused on two characteristic areas within the Great Lakes region: St. Joseph River located in Michigan and Indiana, which enters Lake Michigan through St. Joseph Harbor in the Detroit District; and the Maumee River located in Ohio, which enters Lake Erie through Toledo Harbor in the Buffalo District. These harbors were selected because of their sizable dredging requirements and the existence of sediment production and transport models that can be updated with new climate scenarios.

VULNERABLE BUSINESS LINES

Navigation

CENTRAL QUESTION ADDRESSED BY PILOT

How will dredging cost requirements at Great Lakes harbors vary in the future as the climate potentially changes precipitation regimes and runoff characteristics?

APPROACH

Within each of the two study areas, the approach entailed two stages. The first stage analyzed historical data to determine the variability of dredging costs and the primary drivers, and then compared this information to the observed hydroclimate variability. Dredging costs were evaluated both for the frequency and the magnitude of each dredging operation. The observed hydroclimate data was evaluated to determine what characteristic storm events (e.g., 1, 3, 5, 7, and 15-day rainfall runoff events) produce significant sedimentation and the meteorological context (e.g., Gulf moisture, Great Lakes convection) that ultimately drives those events. This information was used to identify the primary drivers of dredging and highlight climate conditions that were evaluated in the second stage. The second stage explored projections of future climate variability to evaluate how the primary drivers of dredging costs may change. This was accomplished by working with two sets of Coupled Modeled Intercomparison Project (CMIP) Global Climate Model (GCM) data. The first dataset is the Bias Corrected Statistically Downscaled

GREAT LAKES REGION RCC PILOT

APPROACH continued

(BCSD) data. The second dataset is dynamically downscaled data developed with climate experts from the National Oceanic and Atmospheric Administration (NOAA) Great Lakes Environmental Research Lab (GLERL). The statistical and dynamically downscaled climate data were informative for different types of hydroclimate drivers, as well as for determining whether downscaling methodology provided a different system response. As necessary, the climate information as used within the Soil and Water Assessment Tool (SWAT) lumped parameter model and the Integrated Landscape Hydrology Model (ILHM) grid-based distributed parameters to produce numeric response metrics. The primary response metrics were evaluated and used to make statements the potential magnitude of future dredging costs based on those metrics determined as drivers from stage one.

LESSONS LEARNED

- Evaluations of potential impacts from climate change on dredging should use available observational data and to be tied to observed hydroclimatic variability.
- Hydrologic and hydraulic models need to be kept current.
- Data for use in climate assessments can require significant processing before use in models. The Regional Circulation Model (RCM) from NOAA has output at 6-hour intervals for a single climate change scenario. Use of this data will require programming to get the data into a useable format.
- Availability of experienced personnel is limited.

KEY RESULTS

- Communication and attribution of current climate events is a critical question with operations and maintenance personnel, and stakeholders.
- Anticipated results include the potential need for additional dredge disposal facilities and insights into the particular climatological changes that will most significantly impact dredging needs.
- The study is complete.

FOR MORE INFORMATION

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TOLEDO HARBOR LIGHTHOUSE

U.S. ARMY CORPS OF ENGINEERS

7 - RISK-INFORMED DECISION MAKING FOR POTENTIAL SEA LEVEL RISE IMPACTS ON THE HAMILTON WETLAND RESTORATION PROJECT, CALIFORNIA

FACTS & INFORMATION | RESPONSES TO CLIMATE CHANGE (RCC) PILOT STUDY

FUNCTIONAL AREA: PLANNING AUGUST 2017

BACKGROUND

Sea level change may negatively impact wetland resilience in the San Francisco Bay, thus affecting ecosystem outputs for wetland restoration projects. This pilot study tested the proposed risk-informed decision-making (RIDM) framework and evaluated its application to understanding the risks posed by sea level change in the U.S. Army Corps of Engineers (USACE) planning-feasibility phase. The Hamilton Wetland Restoration Project (HWRP) was authorized by Section 101 (b) (3) of the Water Resources Development Act (WRDA) 1999 and provides for wetland ecosystem restoration through beneficial reuse of dredged material. The project provides Federal and non-Federal navigation projects in the San Francisco Bay an opportunity for beneficial reuse of suitable dredge material to facilitate ecosystem restoration. The HWRP consists of constructing perimeter levees bordering the site along with internal berms and phase containment levees, which excavate one breach into San Pablo Bay. The HWRP also utilizes approximately 10,600,000 cubic yards of dredged material to restore approximately 990 acres of habitat.

VULNERABLE BUSINESS LINES

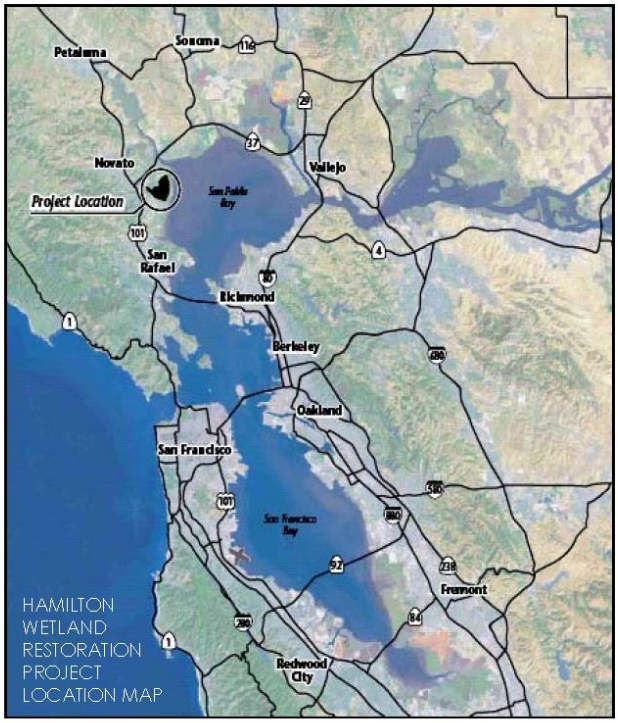
Ecosystem Restoration

CENTRAL QUESTION ADDRESSED BY PILOT

Given the potential effects of sea level change, how can we reduce the risk that the acres of seasonal wetlands planned for construction at the HWRP will not decrease over the study period?

APPROACH

The current project accepted the potential wetland habitat conversion from seasonal to tidal as sea level rises. The study introduced a hypothetical constraint to the HWRP, that requires the perpetuation of the wetland mosaic as designed (20 percent seasonal and 80 percent tidal wetlands), and particularly the perpetuation of seasonal wetlands, which may be the most vulnerable at the study site if sea level rises and upland migration is constrained. The pilot study used the RIDM framework to explore risk and uncertainty associated with multiple scenarios of sea-level change and different restoration measures. The RIDM matrix was used to facilitate communication about the feasibility of



HAMILTON WETLAND RESTORATION RCC PILOT

APPROACH continued

restoring seasonal wetlands that are resilient to sea level change for a project that touches three mission areas: navigation, ecosystem restoration, and flood risk management. The lessons learned during this RCC pilot will be used to develop policy and guidance supporting coastal climate change adaptation planning and, in particular, will inform national team efforts developing the RIDM framework and the sea level change adaptation guidance. Modeling was done to show the evolution of inundation frequency curves to evaluate current and future sea level rise scenarios on the future without project, and future with project condition. This enabled a more robust risk assessment. Graphs were also developed that display estimated critical thresholds where inundation and habitat conversion will occur.

LESSONS LEARNED

- Clear communication is facilitated by developing a group understanding of the terms used in discussions and any assumptions held by team members.
- Including a glossary of terms in the RIDM framework is useful.
- More detailed sea-level change information is necessary to thoroughly evaluate the application of the RIDM framework to assess the effects of climate change on a project in the feasibility study phase.

KEY RESULTS

- Through its use of the RIDM framework, the team is discovering the importance of testing each step of the RIDM process.
- The study team held a workshop to establish the decision context for the study and defined problems, opportunities, constraints, objectives, impacts of climate change on objectives, decision making criteria, evident uncertainties, and climate change data.
- A second workshop was held to begin identifying and assessing risks to the project.
- The team will continue to work on this critical step of the proposed RIDM framework.
- The study is ongoing.

FOR MORE INFORMATION

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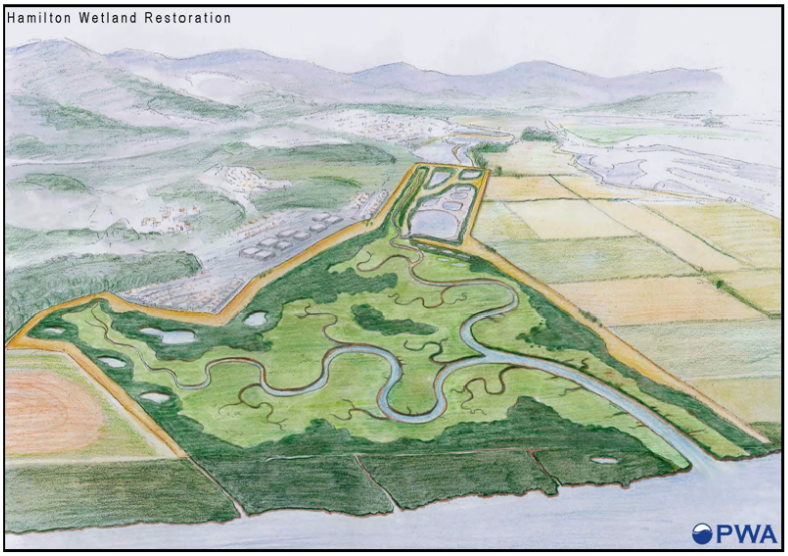


ARTIST'S RENDERING, BRAD EVANS, PWA-ESA, COASTAL CONSERVANCY WEBSITE 2012

U.S. ARMY CORPS OF ENGINEERS

8 - CLIMATE MODELING AND STAKEHOLDER ENGAGEMENT TO SUPPORT ADAPTATION IN THE IOWA-CEDAR WATERSHED

FACTS & INFORMATION | RESPONSES TO CLIMATE CHANGE (RCC) PILOT STUDY

FUNCTIONAL AREA: PLANNING AUGUST 2017

BACKGROUND

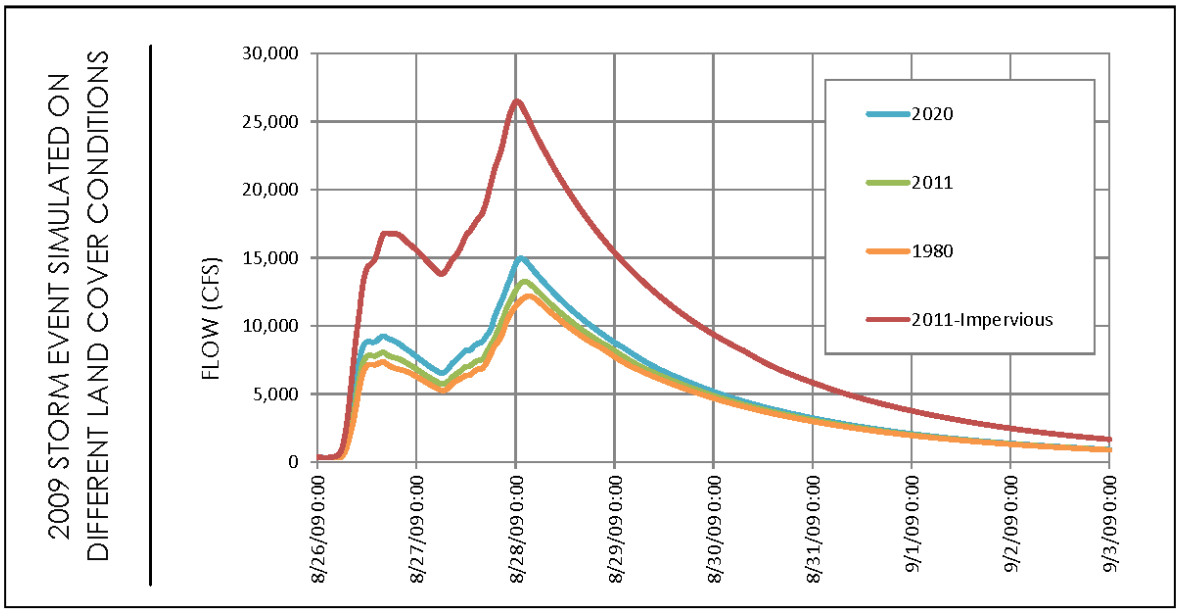
The Iowa-Cedar Rivers Basin includes some of the most fertile agricultural land in the country, as well as three large urban areas. However, in recent years, the region has declined in ecological integrity and experienced several monumental floods that well surpassed all previous records and the capacity of existing flood risk management systems. Questions have been raised about the role of climate change and how it might impact future floods. Current land uses may have also exacerbated the extent of flood damages. Stakeholders are motivated now to make changes to reduce impacts during future events. Additionally, an interagency team is advancing understanding, supporting local initiatives, and developing a comprehensive watershed plan.

VULNERABILITY

Flood Risk Management, Ecosystem Restoration

CENTRAL QUESTION ADDRESSED BY PILOT

How will climate and land use changes affect the state of the watershed; can land use changes and best management practices reduce flood risk significantly; and how can the community adapt to new climatic patterns, as recently experienced, as well as future variability and uncertainty?



IOWA-CEDAR WATERSHED RCC PILOT

APPROACH

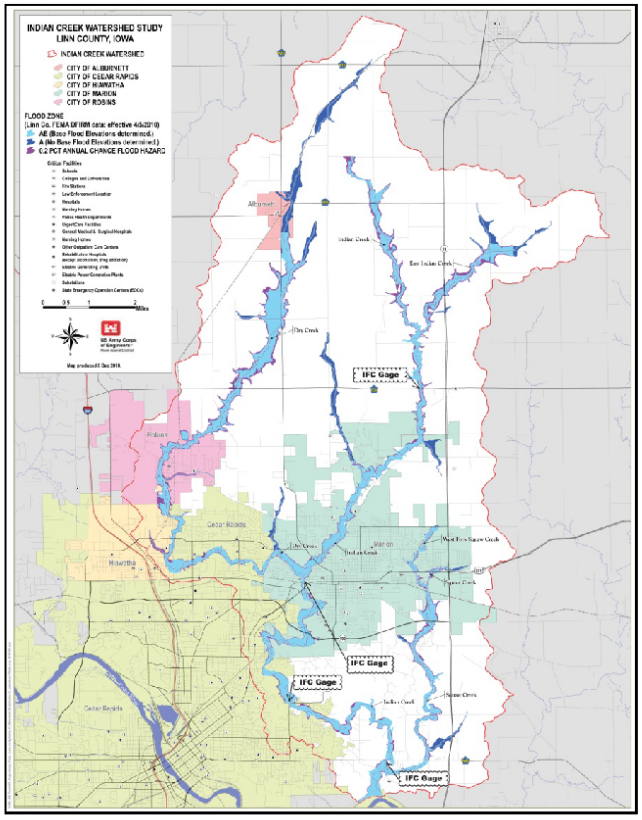
The pilot study focused on the Indian Creek watershed with three related efforts. The first effort included a series of five stakeholder dialogue workshops to increase understanding of, and to define, the problems, objectives, adaptation strategies, and their associated tradeoffs and uncertainties. The second effort was an assessment of how land use and climate changes affect hydrology, including a comparison of multiple hydrology models in order to better frame historical and existing conditions. The last effort included the development and comparison of climate data. This comparison included different downscaling methods, including the development of North American Regional Climate Change Assessment Program (NARCCAP) data for use in the Soil and Water Assessment Tool (SWAT) and the generation of statistically scaled historical rainfall observations at an existing rain gage for use within a Hydrologic Unit Code (HUC)-scale watershed.

LESSONS LEARNED

- Stakeholders were able to understand the climate change information when it focused on impacts, including the likelihood that extreme events will continue and that climate change presents an additional factor of uncertainty related to the floodplain.
- Collaboration is critical for leveraging resources and making a significant impact. In this study, numerous products and resources were leveraged to support this project, including partner team members and specialists and information from past and adjacent studies.
- It is important to adequately prepare for public engagement. With a widely diverse group of stakeholders, it is challenging to address the needs and concerns of everyone; clarifying the goals of each session and letting the stakeholders contribute to the content is most appropriate.

KEY RESULTS

- Land use and climate change both have significant impacts on streamflow regimes across a range of precipitation events. Thus, when planning in an urban watershed, both future development and precipitation trends may compound the impacts of storm intensity and frequency and, therefore, the impacts of flood events.
- The Indian Creek stakeholders now understand that they may continue to experience intense storms, there are actions they can take to reduce their risk, and they are able to access resources to enable them to do so.
- There is interest in making changes to land uses in the floodplain, but there is also a lack of consensus among policy makers and residents. Thus, a primary concern among stakeholders is in public education and rallying support for change.
- Additional results related to modeling and stakeholder dialogue.
- The study is complete.



FOR MORE INFORMATION

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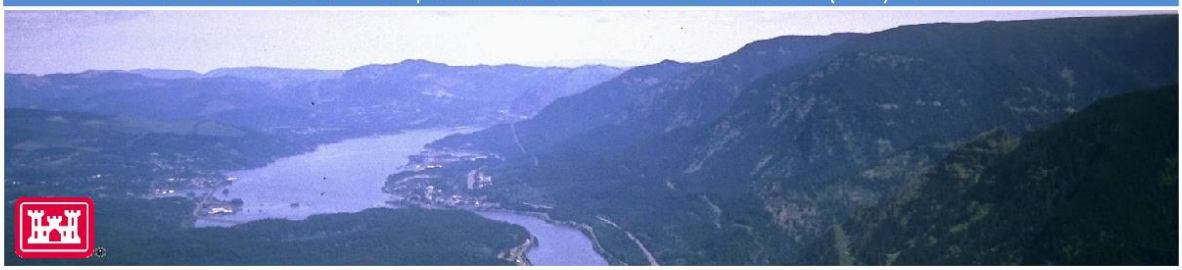
U.S. ARMY CORPS OF ENGINEERS

9 - FRAMEWORK FOR BUILDING RESILIENCY INTO RESTORATION PLANNING, LOWER COLUMBIA RIVER ESTUARY

FACTS & INFORMATION | RESPONSES TO CLIMATE CHANGE (RCC) PILOT STUDY



FUNCTIONAL AREA: PLANNING AUGUST 2017

BACKGROUND

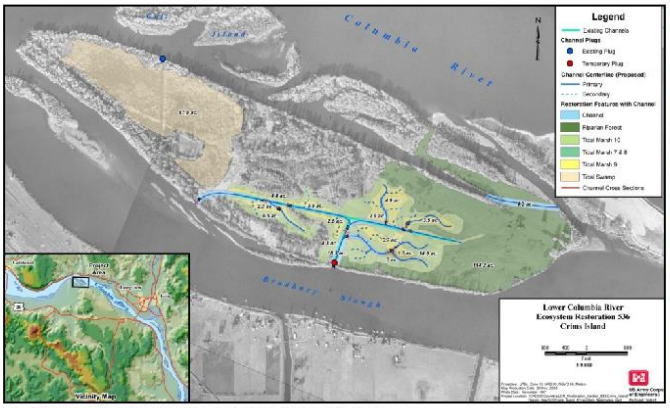
The physical characteristics of the Columbia River Estuary differ from most North American estuaries: river discharge is much greater, salinities are much lower, tidal forcing is greater, and bottom sediment is less stable. The Columbia River entrance is characterized by exceptionally strong wave-current interactions. As a consequence, the river entrance has been recognized as one of the most dangerous coastal inlets in the world for navigation. These factors also make it a difficult location for ecosystem restoration. Since the estuary provides rearing grounds for 12 Evolutionarily Significant Units (ESU) of salmon and steelhead, it provided a unique opportunity to test risk management and adaptive management planning tools for their ability to incorporate climate change into future restoration planning. The project study area is located in the Pacific Northwest, Lower Columbia River Estuary. The estuary extends from the mouth upstream to Bonneville Dam, a distance of about 145 miles, and is the largest human population center on the Columbia River. This well-informed population holds multiple perspectives on how water resources management could enhance ecosystem restoration, providing an ideal location to test ways to balance competing needs through collaboration and education.

VULNERABLE BUSINESS LINES

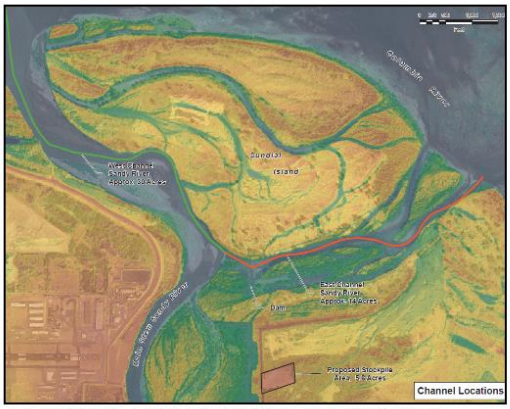
Ecosystem Restoration

CENTRAL QUESTION ADDRESSED BY PILOT

Can we develop a conceptual framework for how climate change information might be incorporated into ecosystem restoration projects?



CASE STUDY: CRIMS ISLAND (RIVER MILE 54)



CASE STUDY: SAND RIVER DELTA (RIVER MILE 122)

LOWER COLUMBIA RIVER ESTUARY RCC PILOT, WASHINGTON & OREGON

APPROACH

This pilot worked to establish a common understanding among stakeholders in regard to participants' ecosystem restoration project experiences, and how information on climate change impact could be utilized to develop a common ecosystem restoration project planning and feasibility framework. The project used three case studies, including Post Office Lake, Sandy River Delta, and Crims Island restoration projects, as starting points to investigate how climate change methodologies might be worked into the U.S. Army Corps of Engineers (USACE) six-step planning process. The lessons learned during this RCC pilot were used to aid in the development of policy and guidance supporting collaborative and risk-informed coastal climate change adaptation planning. The pilot addressed mainstreaming climate change adaptation so that it is treated as one of the numerous challenges facing the project area and receives similar attention as a risk element, with special consideration in defining the future conditions. This pilot project also tested vulnerability-based risk analysis decision making by identifying project vulnerabilities in the context of climate change. Potential adaption management options are triggered by predefined tipping points and thresholds. The lessons learned during this RCC pilot are being used to aid in the development of policy and guidance supporting risk-informed decision making (RIDM), collaborative processes, and coastal climate change adaptation planning. The team conducted two webinars. The first summarized climate change modeling and information available in the Pacific Northwest area, as well as descriptions of anthropogenic versus natural variability, hydrologic downscaling, and USACE-developed relative sea-level change estimates at the mouth of the Columbia River. The second webinar focused on RIDM, setting a context for dealing with climate change as another risk element to be considered in the ecosystem restoration study process.

LESSONS LEARNED

- In the first workshop, the list of vulnerabilities differed by location, such as being close to the mouth (characterized by strong tidal influence, complex sediment transport, and saline effected), mid-reach (transitional tidal, shallow floodplain lakes), or upstream (delta and terrestrial flow dominant).
- A comprehensive and consistent decision-making process (e.g., risk register or matrix) is necessary to consider unique features.
- Conceptual modeling is a key tool to develop a better picture of the pertinent processes, stressors, and vulnerabilities, and is vital to risk assessment. It also informs the model drivers (variables and metrics) used for quantifying risk impacts.
- Different teams develop quite different approaches to resolving the basic task of vulnerability determination. This has implications for adaptive management because the adaptive management process is an intensively social endeavor.
- Spending time to design a decision-making framework may be as important as the scientific and engineering understanding of the physical process in producing an optimal result because the human dimensions can be more complex and unpredictable and, thus, harder to manage.

KEY RESULTS

- Tidal changes have implications for the future habitat in narrow elevation bands, especially near the estuary mouth.
- The study is complete.

FOR MORE INFORMATION

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U.S. ARMY CORPS OF ENGINEERS

10 - CLIMATE CHANGE IMPACTS ON WATER SUPPLY IN MARION RESERVOIR WATERSHED, KANSAS

FACTS & INFORMATION | RESPONSES TO CLIMATE CHANGE (RCC) PILOT STUDY

FUNCTIONAL AREA: OPERATIONS AND MANAGEMENT AUGUST 2017

BACKGROUND

Water resources management is complicated by extremes of low and high precipitation and runoff, particularly when competing needs must be balanced. Marion Reservoir, located on the Cottonwood River in Marion County, Kansas, is a multipurpose reservoir with authorizations for flood control, water quality control, recreation, and water supply. The water supply in this reservoir (44,730 acre-feet) is owned by the State of Kansas. The Kansas Water Office, acting with legislative authority on behalf of the State of Kansas, currently has annual water marketing contracts totaling 1,834 ac-ft with the communities of Hillsboro, Marion, and Peabody, Kansas. These contracts have expiration dates ranging from 2021 to 2039. No allocation presently exists for future water supply storage. There have been three prolonged periods of drought recorded in the Cottonwood River Basin. The most prolonged and most severe occurred between 1952 and 1957. The average monthly inflow during this time period was 12 percent of the period average (1922-1988), and it included 6 months of zero inflow. The lowest Palmer Drought Severity Index (PDSI) value during this period was -6.06, which is considered to be an extreme drought. A firm yield of 8.1 million gallons per day (MGD) has been calculated based on this drought, which satisfies the demand for existing water supply contracts. It is unclear, however, if current contracts can be met in the context of future changes in climate.

VULNERABLE BUSINESS LINES

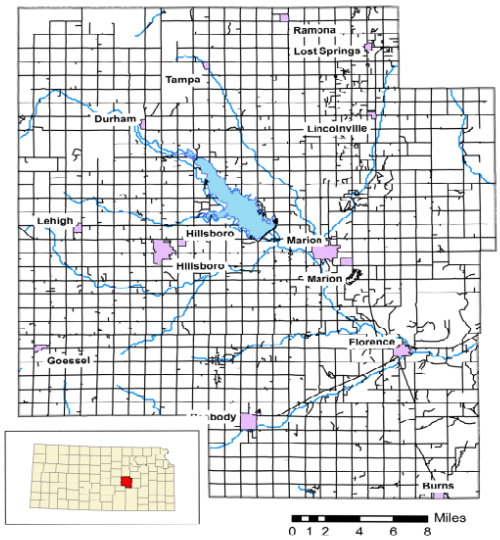
Water Supply, Flood Risk Management

CENTRAL QUESTION ADDRESSED BY PILOT

How can climate modeling be incorporated as a decision-making tool with respect to existing and future water supply contracts?

APPROACH

Our approach was to investigate if and how climate change projections could be used to develop a range of future conditions impacting firm yield. Firm yield can be quantitatively determined by simulating reservoir operations with hydrographs developed from climate projections. Uncertainties exist in both the climate projections and in the hydrologic modeling, which must be addressed in order to produce meaningful results. Therefore, a gridded dataset of bias-corrected, spatially disaggregated (BCSD), statistically downscaled climate data, customized for the Marion Reservoir watershed, was converted from a native greatest common measure (GCM) grid cell size and redistributed into 1/8° spacing. The resulting grid cells were superimposed across the Ma rion Reservoir watershed. Hydrographs were then



MARION RESERVOIR, KANSAS (COMPLEMENTS OF KANSAS WATER OFFICE)

MARION RESERVOIR, KANSAS, RCC PILOT

developed from the BCSD dataset by running simulations in the Variable Infiltration Capacity (VIC) model. Numerical routing was then used to project each of the hydrographs into a long-term simulation of pool elevations so that droughts could be identified. A mass balance approach was used and iteration proceeded automatically. Firm yield thresholds were identified at specific time intervals that can be used as indicators to reevaluate the viability of existing water supply contracts.

LESSONS LEARNED

- Unlike coastal or mountainous areas where changes in sea level or snowpack elevation may be more easily observed, climate impacts on water supply reservoirs in the Great Plains region are less obvious.
- The uncertainties associated with climate projections can be evaluated for decision making by identifying timelines and trigger points in which decisions can be made to avoid unintended consequences. This is best done by evaluating the spread of potential future outcomes.
- The process developed for this study can be applied to other water supply reservoirs as a predictive tool.

KEY RESULTS

- Changes in precipitation in conjunction with changes in evapotranspiration and hydrologic runoff produce ensembles that indicate no major changes in firm yield, although some extremes exist.
- Projected water supply yields will be evaluated as individual members of the model ensemble to determine which trajectories may lead to outcomes that may need to be managed differently than current contracts account for.
- Using this information, conclusions can be drawn about whether the project can meet existing water supply contracts, and whether additional water supply will be available in the future.
- Climate projection ensembles do not show pronounced uniformity in precipitation changes in this region, although the ensemble mean does trend toward more net precipitation.
- The study is complete.

FOR MORE INFORMATION

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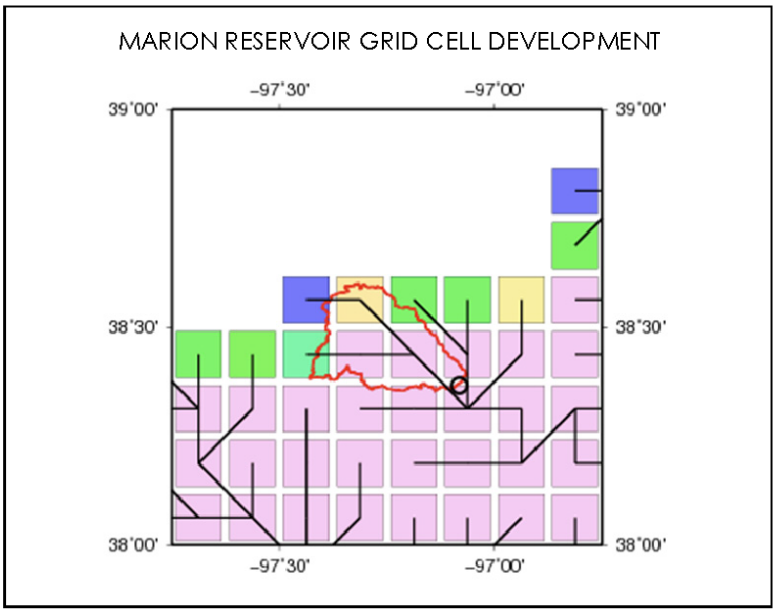
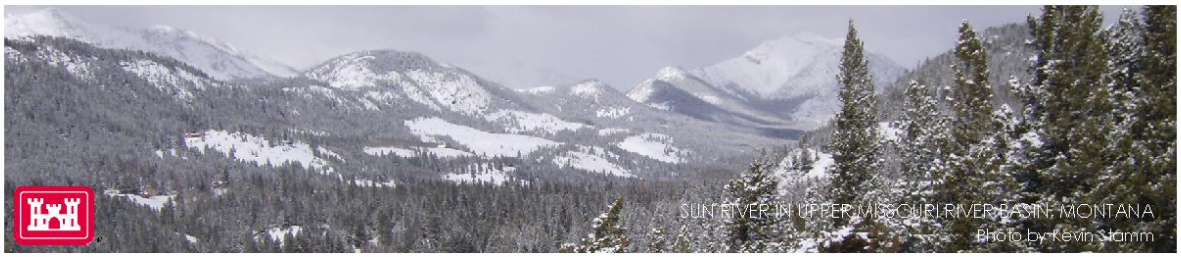


U.S. ARMY CORPS OF ENGINEERS

11 - MISSOURI RIVER BASIN MOUNTAIN SNOWPACK – ACCUMULATION AND RUNOFF

FACTS & INFORMATION | RESPONSES TO CLIMATE CHANGE (RCC) PILOT STUDY



FUNCTIONAL AREA: OPERATIONS AUGUST 2017

BACKGROUND

Mountain snowpack has a significant impact on runoff in the Missouri River Basin and can determine whether the basin is experiencing a normal, dry (2000), or wet (2011) year. This pilot focuses on the Missouri Mainstem Reservoir System, the largest reservoir storage system in the United States. Runoff from mountain snowpack generally occurs during the May through July period in the system. Mountain snowpack only affects two of the six mainstem projects: Fort Peck in Montana, and Garrison in North Dakota. However, runoff into these 2 reservoirs during the 3-month mountain snowmelt runoff season, between May and July, normally comprises nearly 40 percent of the total runoff in the upper Missouri River Basin (Missouri River above Sioux City, Iowa–248,000 square miles). During this 3-month period, almost half of the total annual runoff occurs in the Missouri River. The study is investigating the relationship between mountain snowpack accumulation and runoff versus overall basin conditions as it relates to drought and flood conditions. The U.S. Army Corps of Engineers (USACE), the National Oceanic and Atmospheric Administration (NOAA), the National Resources Conservation Service (NRCS), State of South Dakota (SD), and the U.S. Geological Survey (USGS) partnered for this study.

VULNERABLE BUSINESS LINES

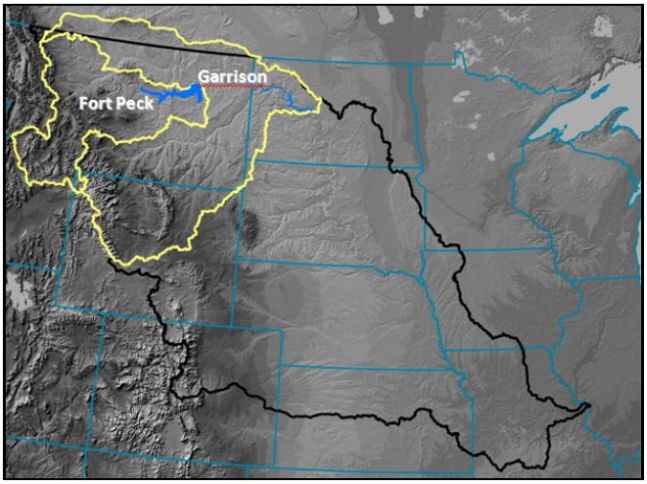
Flood Risk Management, Navigation, Hydropower, Recreation

CENTRAL QUESTION ADDRESSED BY PILOT

Are mountain snowpack and subsequent runoff changing due to changes in climate, and is the Missouri River Basin, therefore, more susceptible to droughts and floods?

APPROACH

The team followed a six-step process to answer the central question above: we acquired relevant driver data, conducted data analysis, consolidated the data analysis results, applied results to simulated real-time regulation, consider future effects due to climate change, and report results. Data was acquired from various sources and assembled into the three datasets covering 20-year epochs for this pilot. The data was then analyzed to determine whether climate change had affected factors such as precipitation and temperature, which determine the natural inflow to the reservoirs. Since the data analysis step produced a voluminous amount of results, it was necessary to conduct a critical review of the data analysis to sort out comparable and reasonable results before applying these results to any sort of real-time regulation scenarios. The end result was



GARRISON AND FORT PECK WATERSHEDS WITHIN THE OVERALL MISSOURI RIVER

MISSOURI RIVER BASIN MOUNTAIN SNOWPACK RCC PILOT

APPROACH

continued

a representative set of data adjusted for climate change that could be used in existing real-time reservoir regulation models. The boiled-down results, which were be 20-year continuous datasets, could then be applied to legacy inflow forecasting models and reservoir regulation models to determine impacts of climate change on existing real-time regulation practices. The current system master manual allows for some adjustment in short-term and long-term planning, as it pertains to forecasted runoff. The results from this study could lead to some adjustment in how monthly and annual regulation plans are developed. In order to continue meeting the authorized purposes of the Missouri River Mainstem Reservoir System, additional studies should be performed using the climate change datasets to determine changes needed to regulation and decision-making procedures. Additionally, long-term studies may include individual water control manual revisions, master manual revisions and re-allocation studies. Once results are reported, USACE will consider how they can be incorporated into regulation of the system.

LESSONS LEARNED

- Though partnering with agencies, academia, and other experts is necessary to perform climate-related projects, it has been very difficult and time consuming to develop the necessary agreements and financial mechanisms to complete related research with partners.
- The Missouri Basin has moved from an extreme flood year (2011) directly to an extreme drought year (2012). We are constantly asked whether we can attribute the extreme conditions to climate change, necessitating the need to develop processes supporting attribution and talking points.
- This work requires station-by-station analysis with snowpack (SNOTEL) and streamflow data, as well as careful evaluation of voluminous historical air temperature and precipitation records to ensure that all driver datasets are complete and accurate.

KEY RESULTS

- Developing overarching interagency agreements specifically addressing climate change issues allowed teams to quickly access expertise available in other agencies.
- Identification of trends and associated locations (e.g., stationarity) proved useful.
- The study is complete.

FOR MORE INFORMATION

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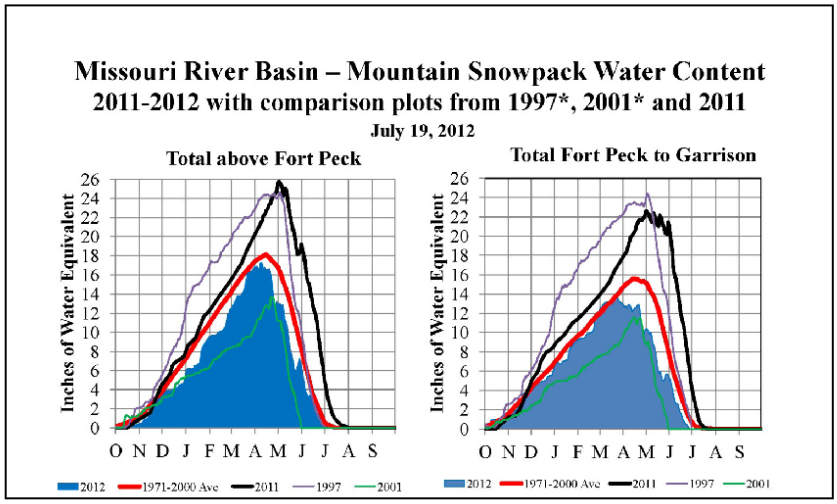
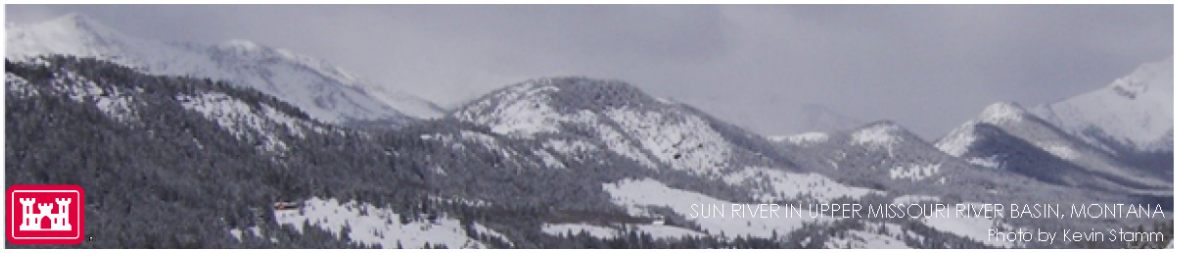


12 - MODERN AND PROJECTED PEAK SNOWPACK AND RUNOFF IN THE UPPER MISSOURI RIVER BASIN, MONTANA

FACTS & INFORMATION | RESPONSES TO CLIMATE CHANGE (RCC) PILOT STUDY



FUNCTIONAL AREA: OPERATIONS AUGUST 2017

BACKGROUND

The U.S. Army Corps of Engineers (USACE) Northwest Division partnered with the Department of the Interior, U.S. Geological Survey (USGS) to investigate current trends and projected changes in peak snowpack and May-July runoff for the Fort Peck Lake and Lake Sakakawea watersheds in the headwaters of the Missouri River in Montana. The study investigated historical (1992-2011) and projected (2012-2099) trends in peak snow depth and spring runoff in a pair of nested watersheds that combined to form the watershed for Lake Sakakawea: the Fort Peck Reservoir watershed and the Lower Lake Sakakawea watershed. It also investigated the conditions that led to significant flooding in 2011 in the area and evaluated whether these same conditions were likely in the future.

VULNERABILITY

Water Supply, Flood Risk Management, Hydropower

CENTRAL QUESTION ADDRESSED BY PILOT

How will climate change affect peak snowpack, and how will May-July runoff impact water levels at downstream reservoirs in the Upper Missouri River Basin; what impacts, if any, are likely for hydropower generation at Fort Peck and Garrison Dams?

APPROACH

The study developed multivariable regression equations to relate precipitation data in Parameter-elevation Relationships on Independent Slopes Model (PRISM) runs of the historical baseline period, calibrated the models, and applied these regression models to projected hydrometeorological model data for the watersheds separately and then as a single unit. The project only considered future snowpack and runoff under the A2 and RCP 8.5 scenarios, both of which assume continued reliance on fossil fuels for energy and produce the largest gains in temperature by 2100 across scenarios considered. The projected data covered the period 2012-2099, however, because the precipitation, temperature, and other modeled independent variables for the regression models were outside the range of historical values for the period 2060-2099, these results are considered less reliable.

FORT PECK DAM

MODERN AND PROJECTED PEAK SNOWPACK AND RUNOFF IN THE UPPER MISSOURI RIVER BASIN, MONTANA

LESSONS LEARNED

- Uncertainty in model projections increases over time, so there is lower confidence in projected peak snowpack and runoff after 2060 than before.
- The regressor variables for simulation years 2060-2099 fall outside of the range used for calibration in the historical period; consequently, model results for 2060-2099 must be interpreted with caution.

KEY RESULTS

- Projected trends in runoff indicate power production from the Fort Peck Dam watershed might be periodically affected by low runoff in upcoming decades; at Garrison Dam, downward trends in runoff are not projected to impact power production as much.
- Future years with high peak snowpack and high spring precipitation are not expected to produce runoff significantly greater than that experienced in 2011, the most recent major flood year.
- The study is complete.

FOR MORE INFORMATION

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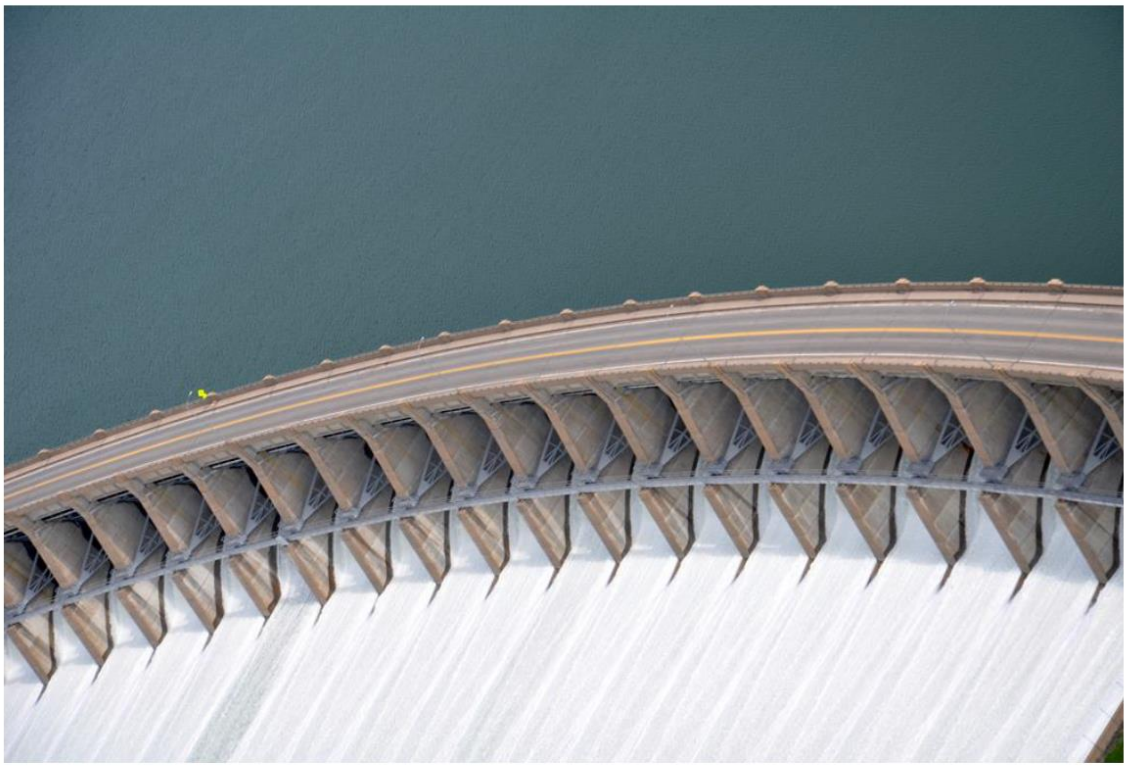

AERIAL VIEW OF GARRISON DAM

U.S. ARMY CORPS OF ENGINEERS

13 - FORMULATING MITIGATION/ADAPTATION STRATEGIES THROUGH REGIONAL COLLABORATION WITH THE OHIO RIVER BASIN ALLIANCE

FACTS & INFORMATION | RESPONSES TO CLIMATE CHANGE (RCC) PILOT STUDY

FUNCTIONAL AREA: PLANNING AUGUST 2017

BACKGROUND

The Ohio River Basin (ORB) contains a multitude of operating Federal reservoirs, navigation locks and dams, power generation plants, and other critical infrastructure that depends on informed management of sustainable water resources. Ecological resources in the Ohio River and its major tributaries include numerous Federally protected species that may be at risk from climate change. Climate change may impact all types of water resources management in the basin. The Great Lakes and Ohio River Division (LRD) Division Commander approved the Ohio River Basin Comprehensive Reconnaissance Report in December 2009. The report evaluated water resources problems across 204,000 square miles using a watershed approach for data collection and analysis, and it engaged numerous Federal and state agencies, local interests, and academia during the problem identification process. The four-district U.S. Army Corps of Engineers (USACE) team considered the potential effects of climate change on future management of water resources. As a result of study outreach efforts with stakeholders, a consortium of basin interests was assembled into what is now known as the ORB Alliance. This group of Federal, state, conservation, academic, non-profit and consultant professionals has evolved into a coalition addressing common interests in water resources and basin-wide climate change issues. The team is very diverse in its composition because of the size of the region being studied (which encompasses four USACE districts) and as a result of the diversity within the ORB Alliance, which comprises many non-USACE members. Two additional members from the U.S. Geological Survey (USGS) and National Oceanic and Atmospheric Administration (NOAA) were added to the pilot team in July because of their expertise in climatology and downscaling climatic changes.

VULNERABLE BUSINESS LINES

Navigation, Recreation, Flood Risk Management, Ecosystem Restoration, Hydropower

CENTRAL QUESTION ADDRESSED BY PILOT

Can regional climate change mitigation/ adaptation strategies, collaboratively developed with the ORB Alliance and formulated using integrated water resources management (IWRM) principles, be made operational within the ORB to counter the anticipated water resources, ecological, and infrastructure impacts of climate change?

OHIO RIVER BASIN RCC PILOT

APPROACH

The study approach consisted of nine tasks. The first was to establish a climate change working group within the alliance. The second was to define study objectives by refining study objectives included in the proposal. The third was to identify and agree on downscaled basin climate changes. The fourth was to identify ecosystem resources and infrastructure that are at risk from the effects of climate change in a GIS framework and characterize levels of risk that could be expected. The fifth was to identify primary water managers and their operating regulations for storing and discharging water under extreme weather conditions and determine the current state of infrastructure, institutional capability, and readiness to address climate change impacts (capability and readiness gaps were identified in the study). The sixth was to formulate structural and nonstructural mitigation/adaptation strategies using an IWRM approach that addresses gaps in current operations for climate change and future rehabilitation needs. Following these steps, the group prepared a draft report on the study process, findings, and recommended actions for USACE and ORB Alliance review. Steps eight and nine were preparing a final report and brochure for public use and compiling and sharing lessons learned through the USACE SharePoint site and ORB Alliance website.

LESSONS LEARNED

- Collaborative synergy inspires innovative approaches and ideas that should all be considered.
- The volume of climate change information on regional downscaling alone will challenge the pilot team to select appropriate information on climate change effects to serve as the foundation for forming adaptation and mitigation strategies.
- It is necessary to provide advice on how to select from among the portfolio of climate information.

KEY RESULTS

- Including climate expertise from USACE and other agencies is a key element, both in laying a foundation for a successful pilot and educating team members.
- The study is complete.

FOR MORE INFORMATION

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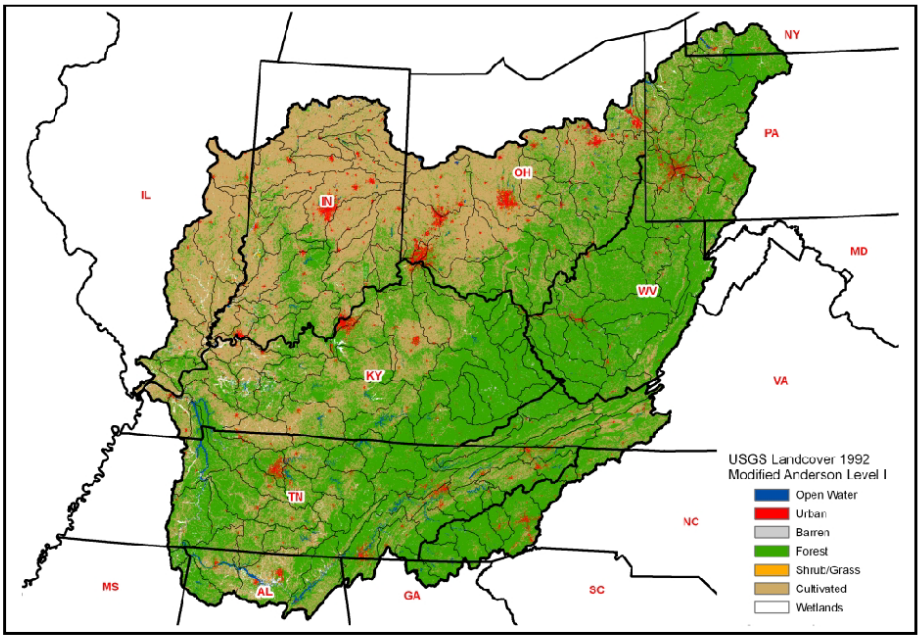


U.S. ARMY CORPS OF ENGINEERS

14 - UTILIZATION OF REGIONAL CLIMATE SCIENCE PROGRAMS IN RESEVOIR & WATERSHED RISK-BASED ASSESSMENTS, OOLOGAH LAKE & WATERSHED

FACTS & INFORMATION | RESPONSES TO CLIMATE CHANGE (RCC) PILOT STUDY

FUNCTIONAL AREA: OPERATIONS AND MANAGEMENT AUGUST 2017

BACKGROUND

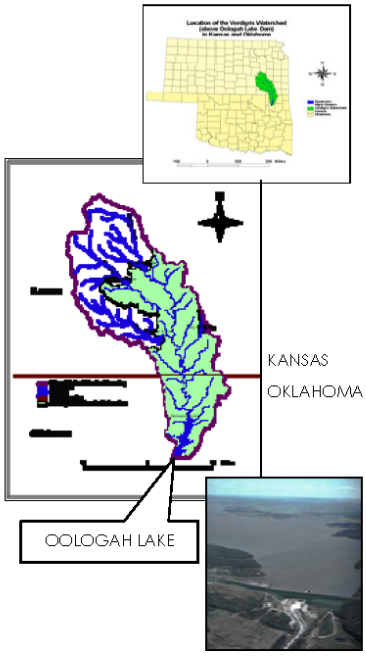
Of the more than 600 multipurpose U.S. Army Corps of Engineers (USACE) reservoir projects, 117 include storage for water supply. Collectively, they provide enough water to supply the average household needs of about 85 million Americans for a year. Our changing climate will increase the criticality of effectively managing these national water assets for future generations. The goal of this pilot study is to demonstrate a sustainable local, tribal, state, and Federal government risk management process associated with climate change impacts to evaluate future reservoir yield, water quality, and soil and water conditions in the watershed. Information generated during this process will help decision makers determine subsequent planning steps. This pilot study could serve as a template for other reservoirs and watersheds. The study area is the Oologah Lake and watershed located in northeast Oklahoma and southeast Kansas. An advantage of selecting this area is the existing reservoir/watershed models and baseline information developed from a recently completed general investigation study. Oologah Lake supplies approximately 50 percent of the potable water for the Tulsa, Oklahoma, metropolitan area, as well as to rural water supplies throughout northeast Oklahoma. The City of Tulsa and others are concerned about potential habitat, water quality, and additional impairments related to sedimentation of the reservoir, turbidity, and nutrient loading.

VULNERABLE BUSINESS LINES

Water Supply

CENTRAL QUESTION ADDRESSED BY PILOT

How can information from regional Federal climate science programs be used in water resources model assessments and associated risk management decision making by local, tribal, state, and Federal interests; and what is the value of information from a detailed assessment compared to a reconnaissance-level assessment?



APPROACH

The objective of the pilot study was to demonstrate a Western States Federal Agency Support Team (WestFAST)[1] field-level approach to applying climate science by leveraging regional Federal programs. Programs included the National Oceanic and Atmospheric Administration (NOAA) Southern Climate Impacts Planning Program (SCIPP) and the Department of Interior (DOI) South-Central Climate Science Center at the University of Oklahoma. The pilot study also included collaboration with additional local, tribal, state, Federal, and non-government stakeholders. This interactive study approach encouraged stakeholder input and information exchange. The first phase assessment of the pilot demonstrated a reconnaissance, or state water plan level of detail, for this pilot project, building on existing streamflow projections developed by the U.S. Bureau of Reclamation for Western states. The second phase of the pilot provided an example of a more detailed, or feasibility level, approach to evaluate climate change impacts to reservoir yield, water quality, and soil and water conditions in the watershed.

OOLOGAH LAKE & WATERSHED RCC PILOT, KANSAS & OKLAHOMA

APPROACH continued

Climate projection datasets were collected using a variety of global and regional climate models and statistical downscaling. Data for each climate model and statistically downscaled dataset was compared to observed conditions to develop ensembles of future projections. The Variable Infiltration Capacity (VIC)[2] model was benchmarked with a historical dataset, and the ensembles were run through VIC to provide output for incorporation into existing Lake Oologah and watershed models. Output included time-series hydrographs for a 50-year planning horizon that could be used for watershed and reservoir simulation and yield studies. The initial concept application of the USACE 5-step risk-informed decision-making (RIDM) process was integrated with these activities. Phase one and two results were compared to determine the value of the information added by investing additional time and money required for the feasibility-level approach. This comparison was useful for determining the level of effort necessary for incorporating climate change considerations into the USACE Specific, Measurable, Attainable, Risk-Informed, and Timely (SMART) planning guidelines.

LESSONS LEARNED

- Working with agencies such as the DOI, Department of Energy (DOE), Environmental Protection Agency (EPA), National Aeronautics and Space Administration (NASA), Natural Resources Conservation Service (NRCS), and others on water resources and climate change projects facilitates consistent Federal approaches.
- It can be difficult to transfer funds between agencies. Simplified processes are needed to more efficiently leverage the climate science and related resources associated with multiple Federal agencies.

KEY RESULTS

- A policy that provides for the efficient transfer of funds between agencies for climate change technical support would enable groups to leverage Federal technical resources and promote a national collaborative approach to the development and field application of climate science.
- The study is complete.

FOR MORE INFORMATION

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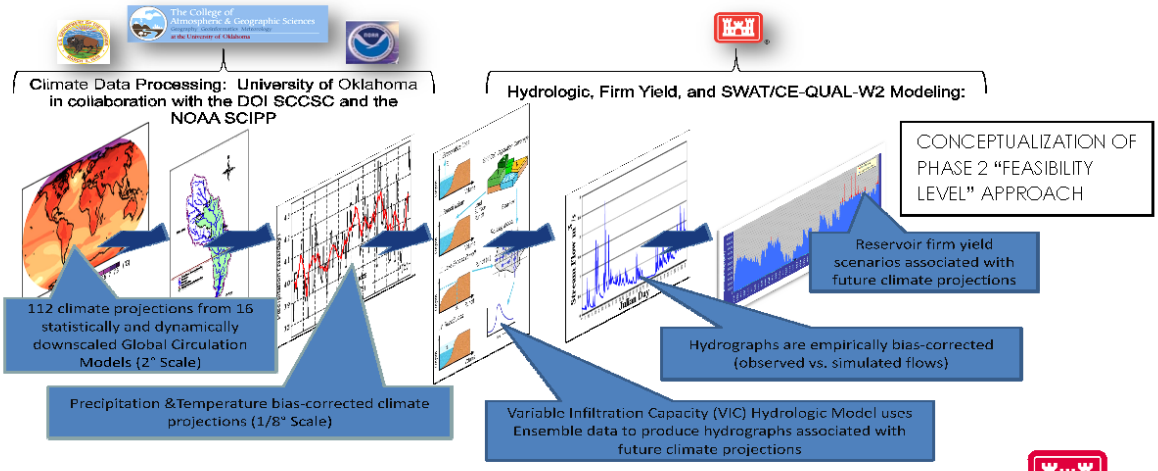
[1] WestFAST is a collaborative initiative between 11 Federal agencies with water management responsibilities in the West. WestFAST was established to support the Western States Water Council and the Western Governors Association in coordinating Federal efforts regarding water resources. Refer to: http://www.westgov.org/wswc/WestFAST.htm

[2] Refer to: http://www.hydro.washington.edu/Lettenmaier/Models/VIC/index.shtml



U.S. ARMY CORPS OF ENGINEERS

15 - RED RIVER OF THE NORTH FLOODING AT FARGO, NORTH DAKOTA

FACTS & INFORMATION | RESPONSES TO CLIMATE CHANGE (RCC) PILOT STUDY

FUNCTIONAL AREA: OPERATIONS AUGUST 2017

BACKGROUND

Northern snowmelt-dominated watersheds are particularly sensitive to changes in temperature. Basin topography (mountains, plains, or a combination of both) can play a role in mediating or enhancing changes in snow. The Red River of the North watershed is a large snow-dominated watershed whose topography is a factor in causing floods of relatively long durations. The basin is generally very flat and slopes gradually down from south to north. Snowmelt usually occurs first in the southern part of the basin, while the northern part of the river is still frozen. Flooding on the Red River of the North has increased in magnitude and frequency since 1942. The flood of record occurred in 2009. Currently, the U.S. Army Corps of Engineers (USACE) is designing a project worth approximately $2 billion to reduce flood risk for 200,000 residents of Fargo, North Dakota, and Moorhead, Minnesota. The future reliability of this project will depend on how climate change impacts future flooding.

VULNERABLE BUSINESS LINES

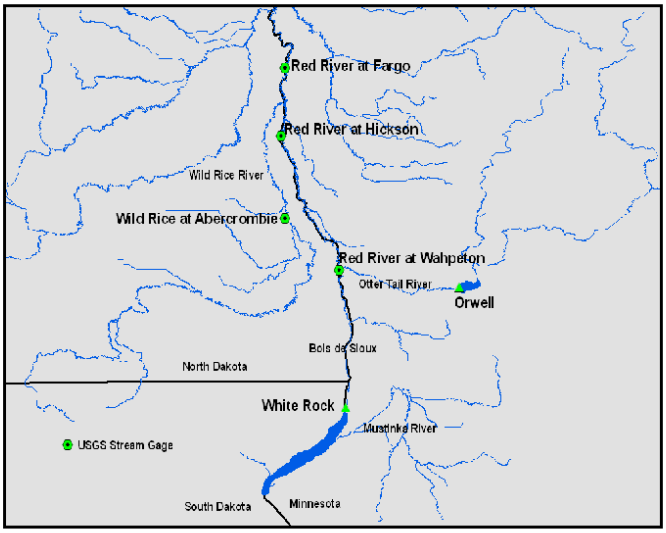
Flood Risk Management

CENTRAL QUESTION ADDRESSED BY PILOT

Are tools and data available for USACE to provide reliable estimates of future flooding using climate projections, including magnitude, frequency, and seasonality of precipitation? In the warming climate, how will changes in precipitation patterns for a historically snowmelt-dominated basin affect flood events?

APPROACH

The study used climate projections to develop and run a hydrologic model in order to evaluate future flood potential of the RRN upstream from the city of Fargo. The simulations created by the model used the Coupled Model Intercomparison Project (CMIP) Global Climate Model (GCM), developed for the Intergovernmental Panel on Climate Change. The simulations were used as coarse scale representations of future climate possibilities. Downscaled results of those simulations were considered from various leveraged sources, including the North American Regional Climate Change Assessment Program (NARCCAP) and the Statistically Downscaled WCRP CMIP3 Climate Projections archive. These climate projections were being evaluated to see how well they represent the critical aspects of historical flood events, including snowfall and rainfall timing



RED RIVER OF THE NORTH FLOODING AT FARGO, NORTH DAKOTA, RCC PILOT

APPROACH continued

and quantities, on a temporal basis consistent with flood events. The results of this evaluation helped characterize climate information for later use in the pilot. The climate information was applied to the Hydrologic Engineering Center's Hydrologic Modeling System (HEC-HMS) framework to simulate flood events within the watershed for historical and future time periods. The ability of the hydrologic modeling effort to simulate historically accurate distributions of floods was assessed and was used to characterize potential future flood events.

LESSONS LEARNED

- Using climate projections from NARCCAP and the CMIP3 statistical archive requires expertise in data acquisition, manipulation, and management beyond that typically required for hydraulic and hydrologic applications.
- NARCCAP climate simulations should be evaluated with respect to determining whether meteorological and climatological event types of interest are simulated reasonably prior to incorporation in hydrologic models.
- Developing trained experts within USACE through pilots such as this one will facilitate studies of this type in the future.

KEY RESULTS

- Building capacity to address climate change in hydraulic and hydrologic studies will speed the process of these studies.
- The study is complete.

FOR MORE INFORMATION

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STAGE 1 DIVERSION CHANNEL – INLET NEAR CITY OF BRECKENRIDGE, 11TH STREET BRIDGE OVER THE OTTERTAIL RIVER LOOKING NORTH

U.S. ARMY CORPS OF ENGINEERS

16 - RISK-INFORMED DECISION MAKING FOR INTEGRATED WATER RESOURCES MANAGEMENT PLANNING, WEST MAUI WATERSHED PLAN

FACTS & INFORMATION | RESPONSES TO CLIMATE CHANGE (RCC) PILOT STUDY

FUNCTIONAL AREA: PLANNING AUGUST 2017

BACKGROUND

Climate change impacts to Hawaii threaten native forests, streams, and wetlands and could increase land-based pollution in nearshore waters. Hawaii's coral reefs are at risk of climate change impacts associated with rising ocean temperatures that in turn increase coral bleaching and ocean acidification, threatening coral reefs' stability. Healthy reefs provide the best defense against future natural threats. In the last 13 years, nearly one-fourth of the corals in West Maui have been lost. Today, land-based pollution poses a significant threat to coral reef health as well. A watershed approach of addressing sediment, erosion, and pollutant inputs throughout the watershed is necessary. The West Maui watershed supports a diverse set of land uses, including conservation, tourism, agriculture, and urban areas. Each prospective area has a significantly different understanding of climate change risks and vulnerabilities and differing ideas about the types and importance of climate change adaptation measures. The West Maui Watershed Plan, authorized under §729 of the Water Resources Development Act (WRDA) 1986, is an interagency planning process supporting the West Maui Ridge to Reef Initiative, which is one of the first efforts in the State of Hawaii to implement a comprehensive management strategy to address impacts on coral reefs across multiple watersheds. The initiative aims to engage various Federal and state agencies and non-governmental organizations in order to implement a strategy to reduce the threats of land-based pollution to coral reefs in West Maui. The West Maui Ridge to Reef Initiative takes an action-oriented approach to integrated water resources management (IWRM). As an initial step, a number of Federal agencies and organizations are funding technical studies and public education efforts to support the state- and U.S. Army Corps of Engineers (USACE)-funded watershed plan. The State of Hawaii and other agencies will implement priority, on-the-ground actions as they are identified, while the state- and USACE-funded watershed plan is developing the associated comprehensive strategy.

VULNERABLE BUSINESS LINES

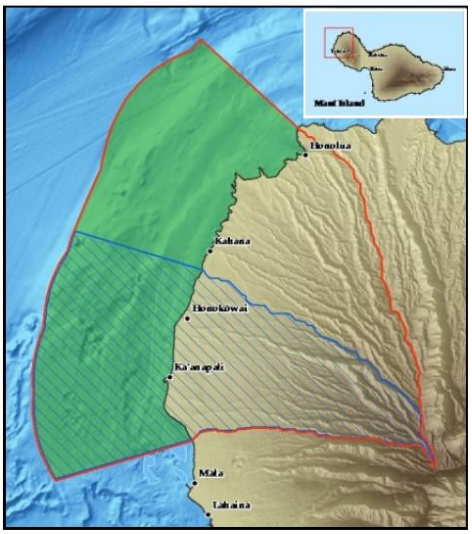
Ecosystem Restoration

CENTRAL QUESTION ADDRESSED BY PILOT

How can a risk-informed decision-making (RIDM) framework be incorporated at the beginning of a collaborative planning process for a place-based climate change adaptation strategy, and what are the challenges in implementing an IWRM framework?

APPROACH

Using a shared vision planning (SVP) process, the interagency team established a RIDM context and decision framework to guide development of the watershed plan. The lessons learned during this RCC Pilot were used to develop policy and guidance supporting collaborative coastal climate change adaptation planning. The West Maui Watershed Ridge to Reef Initiative is a prototype for integrated and collaborative planning and provides a process to coordinate Federal, non-federal, and



WEST MAUI WATERSHED PLAN RCC PILOT

APPROACH continued

non-governmental activities. The National Oceanic and Atmospheric Administration (NOAA) initiated the first phase of the initiative with the development of the Kahekili Watershed Assessment. Watershed assessment in the Wahikuli and Honokōwai watersheds follow the Environmental Protection Agency (EPA) nine elements of watershed planning. The National Resources Conservation Service (NRCS) assisted in the implementation of erosion and sediment control best management practices on agricultural lands. The National Fish and Wildlife Foundation (NFWF) funded an on-site watershed coordinator. Multiple state agencies and local non-governmental organizations led technical studies, monitoring programs, public outreach, and on-the-ground projects addressing fresh and marine water resources, native forest conservation, water quality, and water supply management. USACE provided strategic planning, climate adaptation strategy, multipurpose water management expertise, and facilitation to integrate all activities into an efficient and effective program in order to help build long-term capacity and promote community stewardship of the watershed.

LESSONS LEARNED

- A common logo, vision, process, and timeline promote local and community engagement and stewardship under IWRM.
- The RIDM concept and the USACE process are not easily understood, especially among natural resource managers. An increased shared understanding of decision frameworks and definitions facilitates increased integration of organizations and actions.
- By considering climate change and risk early in the process, interagency teams more easily see the key long-range issues and identify innovative solutions to these issues.
- Many non-Federal and Federal agency planning processes end at formulation of alternative strategies and have minimal specific requirements to long-term feasibility, sustainability, operations, maintenance, and climate change. USACE processes provide this additional analysis and technical assistance.
- There are a variety of tools across agencies and organizations that address risk and uncertainty, including climate change. The USACE SVP provides a collaborative process for selecting and adjusting the technical analysis tools to fit the unique needs of each IWRM initiative.

KEY RESULTS

- Through a series of three workshops, the interagency team has identified threats/risks to the study, identified a shared identity as the West Maui Ridge to Reef Initiative, incorporated climate change into key goals and objectives, developed a decision framework, and prioritized data gaps in a risk-informed context for immediate future actions.
- The study is complete.

FOR MORE INFORMATION

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U.S. ARMY CORPS OF ENGINEERS

17 - CLIMATE CHANGE IMPACT EVALUATION: IMPACTS TO HURRICANE STORM SURGE INUNDATION RESULTING FROM SEA LEVEL CHANGE, CHESAPEAKE BAY AND ADJOINING REGIONS, NEW JERSEY TO SOUTH CAROLINA

FACTS & INFORMATION | RESPONSES TO CLIMATE CHANGE (RCC) PILOT STUDY

FUNCTIONAL AREA: PLANNING AUGUST 2017

BACKGROUND

This investigation focused on an assessment of the impact of sea level change on the severity of hurricane storm surge inundation within the Norfolk SLOSH (Sea, Lake, and Overland Surge from Hurricanes) Basin. Flooding due to storm surge inundation is widely considered to be the hurricane hazard most likely to cause mass casualties and poses a major threat to critical infrastructure. Identification of the areas that are subject to storm surge inundation is a key component of hurricane readiness, evacuation, and response planning. Maps of storm surge inundation risk are used as the basis for Hurricane Evacuation Studies (HESs) for determining locations of hurricane shelters and are an important factor in the management of critical facilities and infrastructure. Storm surge inundation risk area maps can be used to determine which critical facilities and infrastructure (such as schools, police stations, fire stations, bridges, and emergency operations centers) may be in a surge risk area, and whether relocation or mitigation of this infrastructure should be considered. The maps are also an important resource to be used when making decisions on where to build new infrastructure.

VULNERABILITY

Flood Risk Management

CENTRAL QUESTION ADDRESSED BY PILOT

How will climate change and sea level rise affect hurricane storm surge in the Norfolk SLOSH Basin (coastal areas between approximately Cape Hatteras, North Carolina, and Atlantic City, New Jersey)?

APPROACH

The study relied on existing models of coastal storm surge, including National Oceanic and Atmospheric Administration's Norfolk SLOSH Basin maximums of maximums (MOM) model. The team compared the effects of sea level rise alone (the bathtub method) and sea level rise in combination with how water typically circulates within the study area during hurricanes (the model method). Following USACE Circular 1165-2-212, *Sea-Level Change Considerations for Civil Works Programs*, three scenarios of sea level rise (low, medium, and high) were considered. Each was examined for two future periods, centered on 2040 and 2100, using four categories of hurricane strength (Categories 1-4 on the Saffir-Simpson hurricane wind scale), resulting in 144 scenarios for each version of the SLOSH MOM model evaluated.

CLIMATE CHANGE IMPACT EVALUATION: IMPACTS TO HURRICANE STORM SURGE INUNDATION RESULTING FROM SEA LEVEL CHANGE, CHESAPEAKE BAY AND ADJOINING REGIONS, NEW JERSEY TO SOUTH CAROLINA

LESSONS LEARNED

- The study design did not account for the difference in model grid cell size between the bathtub method and the model method, which made it hard to compare the results to each other.
- Additional investigation is needed to determine the cause of the outliers (areas where surges are exceptionally high or low compared to the regional average).

KEY RESULTS

- Expected average additional sea level change due to storm surge was approximately 0.5 feet for a Category 1 storm and slightly over 5.5 feet for a Category 4 storm.
- Local geography influenced whether portions of the study area received more or less than the modeled estimate of storm surge increase. Possible factors include topography of the continental shelf and inland areas, the shape of the coastline, and the resolution of the SLOSH model grid cell.
- The project suggests that simple low-risk, low-cost, minimal effort models (such as the bathtub model) may be able to provide useful information relating to future hurricane storm surge.
- The study is complete.

FOR MORE INFORMATION

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INFRASTRUCTURE AT RISK – NORFOLK, VIRGINIA

U.S. ARMY CORPS OF ENGINEERS

18 - IMPLEMENTING A CLIMATE CHANGE PROJECT UNDER A REGIONAL INTEGRATED WATER RESOURCES MANAGEMENT PLAN IN THE LOS ANGELES BASIN, CALIFORNIA

FACTS & INFORMATION | RESPONSES TO CLIMATE CHANGE (RCC) PILOT STUDY

FUNCTIONAL AREA: PLANNING AUGUST 2017

BACKGROUND

The U.S. Army Corps of Engineers (USACE) Los Angeles District (SPL) partnered with the Department of the Interior, Bureau of Reclamation and the Los Angeles County Flood Control Department (LACFCD) to analyze future stormwater runoff through the region's extensive stormwater channel system (Los Angeles Basin RCC Pilot Project). Given projected regional water supply and demand, the study used climate, land surface, and hydrologic models to evaluate how well the current system of stormwater capture and groundwater recharge will perform under expected increases in storm size and whether sufficient water could be captured to offset projected increases in drought and evapotranspiration, reductions in snowpack, and increases in population. Results to date suggest that the existing system has sufficient capacity to meet future needs. The study was conducted as a specific investigation under the umbrella of the Greater Los Angeles County Regional Water Management Authority as part of its Integrated Regional Water Management Plan. The final outcome and recommendations of this study will serve as a guiding document for further local water supply development planning, financing strategy, and policy adoption at the LACFCD and other water supply organizations (Reclamation, 2013).

VULNERABILITY

Flood Risk Management, Water Supply

CENTRAL QUESTION ADDRESSED BY PILOT

How can information from regional Federal climate science programs be used in water resources model assessments, and how does this play out in an integrated water resources management (IWRM) planning environment?

WHITTIER NARROWS DAM AND RESERVOIR - CALIFORNIA

IMPLEMENTING A CLIMATE CHANGE PROJECT UNDER A REGIONAL INTEGRATED WATER RESOURCES MANAGEMENT PLAN IN THE LOS ANGELES BASIN, CALIFORNIA

APPROACH

USACE SP L worked closely with regional partners to investigate projected changes in regional precipitation and resulting runoff. These altered flows were routed through the complex, multi-agency system of projects that constitutes the LACFCD's stormwater management system in order to determine where in the system, and by approximately how much, flood flows might increase or decrease. Reclamation and LACFCD were interested in using this information to estimate the amount of stormwater that could be potentially captured at various dams and settling ponds and used to recharge local aquifers. SPL incorporated this information in a broader assessment of the vulnerabilities of all its business lines to climate change.

LESSONS LEARNED

- This project highlighted the importance of integrated regional water resources management for addressing climate change impacts on regional hydrology.
- Regional water resources management organizations require long-term, local, and regional leadership and broad-based participation to be effective in this arena.
- Federal agencies can play significant supporting roles in addressing regional climate change impacts, adding significant technical capacity to support decision making. However, local and regional commitments are necessary to lead such efforts.

KEY RESULTS

- With systemwide changes in stormwater capture and achievable reductions in regional water use, it may be possible to meet projected future regional water demand with projected future water supplies.
- While the Greater Los Angeles County Regional Water Management Authority's Integrated Regional Water Management Plan addresses a key regional climate change impact, vulnerabilities are present across all major SPL business lines. SPL's primary vulnerabilities are not in water supply, but in flood risk management and coastal storm damage reduction. Both of these primary vulnerabilities carry significant life safety, economic, and ecological risks that are only likely to increase in the future.
- While best available science does not currently support inclusion of highly detailed climate change projections such as those required for benefit-cost analyses, tools like adaptive management and risk-informed decision making, and the identification of thresholds and tipping points provide cost-effective ways to account for climate change in current decision making.
- Reductions in business line impacts could be obtained by reducing initial damage and enabling quicker recovery times by making SPL infrastructure more resilient and adaptive, employing a risk-based planning framework, and applying systemwide instead of component-based considerations and initiatives.
- The study is complete.

FOR MORE INFORMATION

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U.S. ARMY CORPS OF ENGINEERS

19 - HISTORICAL TRENDS AND FUTURE PROJECTIONS OF CLIMATE AND STREAMFLOW IN THE WILLAMETTE VALLEY AND ROGUE RIVER BASINS, OREGON

FACTS & INFORMATION | RESPONSES TO CLIMATE CHANGE (RCC) PILOT STUDY

FUNCTIONAL AREA: OPERATIONS AUGUST 2017

BACKGROUND

The U.S. Army Corps of Engineers (USACE) Portland District (NWP) partnered with the Oregon Climate Change Research Institute (OCCRI) at Oregon State University (OSU) to analyze the effects of future climate change on water management in the Willamette Valley and Rogue River Basins (Willamette and Rogue RCC Pilot Study). NWP manages dams, reservoirs, and other projects such as fish facilities in the Willamette and Rogue River Basins. They must balance competing needs, including flood damage reduction, water supply storage, hydropower, and environmental objectives. This pilot study examined observed and projected changes in hydrologic variables to improve understanding of future management challenges.

VULNERABILITY

Flood Risk Management, Navigation, Ecosystem Restoration

CENTRAL QUESTION ADDRESSED BY PILOT

USACE sought to better understand the potential implications of future climate change (2040s) on water management operations in the Willamette and Rogue Basins in the context of historical trends and variability in order to more effectively manage projects in the future.

APPROACH

OCCRI, in collaboration with USACE, evaluated historical hydrologic trends and future projections on interannual, annual, and seasonal scales. Primary variables of interest were temperature (T), precipitation (P), April 1 snow water equivalent (SWE), and daily streamflows for both the historical and projected future periods.

Historical T and P data were drawn from the U.S. Historical Climate Network (USHCN) stations, Natural Resources Conservation Service (NRCS) SNOTEL and Snow Course for April 1 SWE, and U.S. Geological Survey (USGS) streamflow gage sites in the Willamette and Rogue River Basins.

P and T data for 1901 through 2013 were examined for discernible trends. SWE records were examined for the period 1960-2014. Changes in streamflow using data from USGS gages in the Willamette and Rogue Basins were analyzed for two time periods: 1941-1970 and 1981-2010.

The values for these variables in the future were obtained from 20 global climate models (GCMs) from the Coupled Model Intercomparison Project 5 (CMIP5) archive driven by moderate and high future emissions scenarios (representative concentration pathways [RCP] 4.5 and 8.5, respectively). Changes in these variables were evaluated between the simulated historical (1970-1999) and future (2030-2059) periods. Streamflow projections were based on 10 GCMs from the Coupled Model Intercomparison Project 3 (CMIP3) archive driven by a low (B1) and high (A1B) future emissions scenario. Changes in mean annual and seasonal streamflow hydrographs, peak flows, and flow frequencies were examined to compare the simulated historical (1970- 1999) and future (2030-2059) periods.

Results of the OCCRI data analysis were shared with USACE water managers, including hydrologic engineers, regulators, and biologists. Internal discussions of these data were elicited to determine if there were implications to be inferred and lessons to be drawn.

HISTORICAL TRENDS AND FUTURE PROJECTIONS OF CLIMATE AND STREAMFLOW IN THE WILLAMETTE VALLEY AND ROGUE RIVER BASINS, OREGON

LESSONS LEARNED

- Overall , this study pointed to a warmer future for the Willamette and Rogue Basins with hydrologic pattern changes that could, on balance, stress future water management. Indications for greater wintertime precipitation in the Willamette and Rogue Basins hinted at added risk during future flood operations. Conversely, warmer temperatures are likely to store less of that winter precipitation as snowpack, which, coupled with an increased variability in spring precipitation, contributed to projections for lower summer base flows. It was also realized that adopting earlier reservoir refill dates to mitigate these reduced flows might not be feasible if future wintertime flood risk increased.
- It was difficult for USACE water management to identify potential vulnerability areas as well as identify the systems' resiliency to projected future climate changes. This pointed to the need for future studies to incorporate upfront elicitations of needs from potential end users and management interested in the subject.
- The USACE team was uncomfortable with the uncertainty and ambiguity in the projected climate data, and therefore they were uncomfortable embracing study results and implications. There is an opportunity to better communicate throughout a study and to better understand which metrics have the most relevance to the stakeholders.

KEY RESULTS

- Observed temperatures increased annually for 1901-2013, with warming rates ranging from 0.5°F to 3.9°F per century. Stations tended to warm less in winter and spring and more in summer and fall. Water year and seasonal precipitation exhibited large natural variability over the period 1901-2013. Historical SWE decreased at virtually all sites with a range of -3% to -60% over the period 1960-2014, with the largest decreases generally at lower elevations (2,500 to 5,000 feet) that hover near freezing during winter.
- By mid-century, climate models projected a temperature increase in all seasons, with greater warming in summer (June, July, August). Annual average increases in minimum and maximum temperature ranged from 0.8°F-5.3°F and 1.1°-5.5°F. In contrast, projections of precipitation change were variable. Those subbasins that historically received the most snow showed projected winter (December, January, February) declines of -27% to -67% in SWE. Sub-basins with little snow currently were projected to receive virtually no snow in the future. Future streamflow changes were driven primarily by warming-induced decreases in snow accumulation and secondarily by seasonal variation in precipitation change. All basins were projected to have increased mean flows in winter and decreased flows in summer. Annual peak flows of 1 to 5 days were projected to occur up to 5 days earlier in the water year at the majority of gages and up to 2 weeks earlier for the basins with larger snowmelt component.
- The study is complete.

FOR MORE INFORMATION

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DETROIT DAM - OREGON

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