CWTS report 2017-01, May 2017

OHIO RIVER BASIN–

Formulating Climate Change Mitigation/Adaptation Strategies through Regional Collaboration with the ORB Alliance

U.S. Army Corps of Engineers and Ohio River Basin Alliance
Institute for Water Resources, Responses to Climate Change Program

Sunrise on the Ohio River. January, 2014.

US Army Corps of Engineers®

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*
05/30/2017

2. REPORT TYPE
Civil Works Technical Series

3. DATES COVERED *(From - To)*
2011-2017

4. TITLE AND SUBTITLE
Ohio River Basin - Formulating Climate Change Mitigation/Adaptation Strategies through Regional Collaboration with the ORB Alliance

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Institute for Water Resources, Responses to Climate Change Program

5d. PROJECT NUMBER
329421

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Directorate of Civil Works
US Army Corps of Engineers
Washington, DC

8. PERFORMING ORGANIZATION REPORT NUMBER
CWTS 2017-01

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Institute for Water Resources
7701 Telegraph Road (Casey Building)
Alexandria, VA 22315

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)
CWTS 2017-01

12. DISTRIBUTION/AVAILABILITY STATEMENT
Available through National Technical Information Service, Operations Division
5285 Port Royal Road
Springfield, VA 22161

13. SUPPLEMENTARY NOTES

14. ABSTRACT
This report encapsulates the research of numerous professionals in the fields of climatology, meteorology, biology, ecology, geology, hydrology, geographic information technology, engineering, water resources planning, economics, and landscape architecture. The report provides downscaled climate modeling information for the entire basin with forecasts of future precipitation and temperature changes as well as forecasts of future streamflow at numerous gaging points throughout the basin.

15. SUBJECT TERMS
Climate, Climate Change, Ohio River Basin, Systems Approach, Climate Change Impacts, Ecosystem, Navigation, Projected Hydrology

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	c. THIS PAGE	17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON / 19b. TELEPHONE NUMBER *(Include area code)*
U	U	U	UU		Dr. Kathleen White / 202-761-4163

Standard Form 298 (Rev. 8/98)
Prescribed by ANSI Std. Z39.18

Ohio River Basin Climate Change Pilot Study Report

ABSTRACT

The Huntington District of the U.S. Army Corps of Engineers, in collaboration with the Ohio River Basin Alliance, the Institute for Water Resources, the Great Lakes and Ohio River Division, and numerous other Federal agencies, non-governmental organizations, research institutions, and academic institutions, has prepared the Ohio River Basin Climate Change Pilot Report. Sponsored and supported by the Institute for Water Resources through its Responses to Climate Change program, this report encapsulates the research of numerous professionals in climatology, meteorology, biology, ecology, geology, hydrology, geographic information technology, engineering, water resources planning, economics, and landscape architecture. The report provides downscaled climate modeling information for the entire basin with forecasts of future precipitation and temperature changes as well as forecasts of future streamflow at numerous gaging points throughout the basin. These forecasts are presented at the Hydrologic Unit Code-4 sub-basin level through three 30-year time periods between 2011 and 2099. The report includes the results of preliminary investigations into the various impacts that forecasted climate changes may have on both aquatic and terrestrial ecosystems and operating water resources infrastructure. In addition, the report presents a menu of potential mitigation and adaptation strategies that could be instituted by Federal, state, regional, municipal, and county jurisdictions as well as individual and corporate land owners to attenuate the anticipated impacts of a changing climate. Among these strategies is a proposal that the current policies guiding the operation of basin water resources infrastructure be reviewed in light of the challenges that a new hydrologic regimen may present. The report concludes with a series of lessons learned from the research and study processes, which hopefully will assist others during future investigations of this timely and pressing issue.

Preface

This document is a result of a proposal by the Huntington District of the U.S. Army Corps of Engineers (USACE) to conduct a pilot study through the Responses to Climate Change Program (RCC) being administered by the Institute for Water Resources (IWR). The primary purpose of the pilot study was to investigate climate change effects that could adversely impact the operations, maintenance, and rehabilitation of Civil Works Water Resources infrastructure in the Ohio River Basin (ORB), and thereby jeopardize the authorized missions of those facilities. A secondary purpose of the pilot study was to investigate the potential effects of climate change on those basin ecosystems that can be influenced by the operation and rehabilitation of USACE infrastructure and associated Federal lands. Storage and release of surface waters at 83 USACE reservoirs and lakes provides a multitude of opportunities to attenuate climate change effects on downstream and lake aquatic communities and riparian habitat in watersheds where those facilities are located.

The collaborative aspect of the study involved extensive coordination and team building among the four USACE districts in the basin and members within the Ohio River Basin Alliance. Altogether, 18 professionals from USACE, IWR, U.S. Environmental Protection Agency (USEPA), U.S. Geological Survey (USGS), National Oceanic and Atmospheric Administration (NOAA)/National Weather Service (NWS), The Nature Conservatory (TNC), Battelle Memorial Institute (Battelle), and several universities collaborated in compiling data, downscaled modeling, basin outreach, and climate change investigations for the basin. This document has no fewer than 12 authors involved in its writing. Those authors include Dr. Paul Kirshen of the University of New Hampshire, Dr. Elly Best of the USEPA, Dr. Harry Stone of Battelle, Dr. Jeffery Kovatch of Marshall University, Dr. Lilit Yeghiazarian of the University of Cincinnati, Mr. Jim Noel of the Ohio River Forecast Center (OHRFC), Mr. John Stark of TNC, Mr. Erich Emery of the Ohio River and Great Lakes Division office, Mr. Joseph Trimboli of the Huntington District, Dr. David Raff and Dr. Jeff Arnold of the IWR, and R. Gus Drum of the Huntington District.

This team would like to acknowledge the contributions to the study by Mr. Kurt Buchanan of the Huntington District, Mr. Dick Bartz and Mr. Jim Morris of the USGS, Ms. Deborah Lee of the Great Lakes and Ohio River Division office, Ms. Joy Broach of the Nashville District, Mr. Juan Barrios of Marshall University, Mr. David Moore and members of his staff at Tetra Tech, and Mr. Doug Kluck of NOAA. The team also acknowledges the work of Mr. Tom Maier of the Pittsburgh District, Ms. Ramune Morales of the Nashville District, and Dr. Beth Hall of NOAA in reviewing and revising the draft document. Mr. Mark Kessinger was the USACE project manager (now retired) for the study and watched over the schedule and funding throughout the journey. Last but surely not least, the entire team wishes to thank Dr. Kate White from the IWR for her guidance, patience, and wisdom in championing this effort through the study and document preparation process.

In Memory of Dr. Jeffrey Kovatch

Dr. Jeffrey Kovatch, Marshall University Associate Professor of Biological Sciences and beloved husband and father, passed away on November 5, 2016 after a short illness. A graduate of the University of Pittsburgh (B.S., 1995) and Syracuse University (Ph.D., 2008), he specialized in aquatic ecology and was active as an executive committee member for the Ohio River Basin Consortium for Research and Education and the West Virginia Chapter of the American Fisheries Society. The Ohio River Basin Climate Change Pilot Study Team appreciates his willingness to share his research and expertise regarding the potential impacts of climate change on valuable Ohio River aquatic ecosystems and his contributions of precise text that added credibility and value to the pilot study report. We will miss our good friend and dedicated colleague.

Please cite this document as: *Drum, R. G., J. Noel, J. Kovatch, L. Yeghiazarian, H. Stone, J. Stark, P. Kirshen, E. Best, E. Emery, J. Trimboli, J. Arnold, and D. Raff (2017), Ohio River Basin–Formulating Climate Change Mitigation/Adaptation Strategies Through Regional Collaboration with the ORB Alliance, May 2017. Civil Works Technical Report, CWTS 2017-01, U.S. Army Corps of Engineers, Institute for Water Resources: Alexandria, VA*

Table of Contents

List of Tables

Table of Figures

Executive Summary

The USACE Huntington District in cooperation with the Pittsburgh, Louisville, and Nashville Districts, and the Great Lakes and Ohio River Division office, has prepared an adaptation pilot study to address the effects of climate change (CC) within the ORB through a collaborative effort with member agencies and organizations of the Ohio River Basin Alliance (the Alliance). This pilot study has investigated potential CC impacts to basin infrastructure, including Federal facilities operated for reduction of flood damages, navigation, local protection, water supply, and hydroelectric power production, as well as the potential impacts on terrestrial and aquatic ecosystems that are influenced by operation of these infrastructure components.

As caveat, the modeling results, impacts analyses, and formulated strategies in this pilot study are not intended to contribute to the international debate on causes of CC, nor does this study intend to present information in such manner as to elicit injudicious reactions to projected changes in temperatures and flow discharge. In fact, the modeling data suggest that the more rapid changes in temperature, precipitation, and streamflows due to changes in regional climate may not begin within the ORB until 2040. As such, this lead time can be used by state and Federal agencies and other organizations to (1) evaluate existing water resources policies and project operational procedures in light of expected changes, (2) identify and reduce current ecosystem stressors that limit the ability of natural systems to adapt to future climate-induced changes, (3) expand modeling capability for CC, and (4) expand the current streamflow and water quality monitoring network so that early signs of impending change may be detected.

This pilot study is based upon Global Circulation Models (GCM) produced by the International Panel on Climate Change Fourth Assessment in 2007. Specifically, the models archived by an interagency water resources group (NOAA, Bureau of Reclamation [BOR], USACE, and USGS) as Coupled Model Intercomparison Project-Phase 3 (CMIP3) Climate and Hydrology Projections were used as the basis for downscaled modeling for the ORB, with downscaled modeling of temperature and precipitation changes performed by the IWR staff using archived model ensembles from CMIP3. Three 30-year time periods were established (i.e., 2011–2040, 2041–2070, and 2071–2099; respectively *F1, F2,* and *F3*) within which both precipitation and temperatures were modeled. The results of that GCM modeling exercise were used by the Ohio River Forecast Center (NOAA) to model annual mean and seasonal flow discharge amounts for 25 forecast points within the basin and to forecast a range of temperature changes (annual mean, annual maximum, and annual minimum) for those same points.

Generally, modeling results indicate a gradual increase in annual mean temperatures between 2011 and 2040 amounting to one-half degree per decade, with greater increases between 2041 and 2099 of one full degree per decade. Hydrologic flow changes show substantial variability across the ORB through the three time periods, with Hydrologic Unit Code (HUC)-4 sub-basins located northeast, east, and south of the Ohio River expected to experience greater precipitation and thus higher stream flows—up to 50% greater—during most of the three 30-year periods. Conversely, those HUC-4s located north and west of the Ohio River are expected to experience ever-decreasing precipitation (especially during the autumn season) resulting in decreased in-stream flows—up to 50% less—during the same periods.

The potential impacts to infrastructure, energy production, and both aquatic and terrestrial ecosystems over the three 30-year time periods range from minimal in some HUC-4 sub-basins to

dramatic and potentially devastating in others. For example, Federal water resources infrastructure is designed using factors of safety (including hydrologic factors) that allow facilities, such as dams, reservoirs, and levees, to absorb and withstand many impacts through annual or seasonal operational modifications. However, other infrastructure that is dependent upon a reliable flow of water (i.e., hydropower and water supply) may be challenged in sustaining supplies during *F2* and *F3* periods without impacting other uses. Of special concern are the large numbers of thermoelectric power plants in the ORB that rely on sustained supplies of cooling water to meet national energy demand.

Concerns are also expressed in this report for the sustainability of certain fish and mussel communities in watersheds where annual mean and October Mean streamflow discharges may be reduced significantly during *F2* and *F3* periods. Coupled with the prospect of rising air temperatures that can result in higher water temperatures, some aquatic species may be at risk of extirpation in impacted watersheds; yet seasonal management of reservoir discharge volumes and water temperature may offset some of these anticipated impacts. Similar impacts may also be experienced by terrestrial and plant species that are accustomed to cooler basin temperatures. This pilot study identifies numerous data gaps that limit the identification of connections between streamflows and water temperatures and their effects on the basin's aquatic ecosystems, potentially guiding future research and investigations.

The pilot study addresses the formulation of potential adaptation themes or strategies that could decrease the impacts associated with changes in precipitation, streamflow discharge, and temperatures across the basin. Although not prescriptive in nature, these strategies suggest potential paths forward that can be integrated into near-term and long-term infrastructure planning, structure rehabilitation, water policy analysis, and operational changes.

Strategies included for addressing ecosystem impacts are based on an understanding of the current stressors that weaken ecosystems' resiliency to new disruptions, such as CC. Ecosystem adaptation strategies include reducing those stressors before the end of the *F1* period. The report also addresses key water resources policy issues that may need modification by state and Federal agencies so that necessary strategic actions can be undertaken to offset impacts that may occur after *F1*. The report suggests a number of follow-up actions to the adaptation pilot study that would affirm the modeling results on a decadal schedule and further refine the strategies based upon new information.

In conclusion, of the several objectives identified for the adaptation pilot study, the creation of a CC Working Group within the Alliance has been realized, with institution of a subgroup within the Sustainability and Competitiveness Working Group currently chaired by Dr. Harry Stone (Battelle). That subgroup first met during the fall of 2013 and discussed initial basin downscaled modeling results and a framework for impacts analyses. During the fall 2014 Alliance meeting, the preliminary results of the draft pilot study were shared with enthusiastic members of the working group and general Alliance membership. Hopefully, a fully functional, standalone working group that addresses CC impacts and adaptation strategies specifically can be established once the Ohio River Basin Pilot Study Report has been published for general consumption and specific adaptation strategies have been solidified for consideration by Alliance members. The Alliance may provide one of the best organizational structures for disseminating climate change information, supporting further research on CC and promoting adaptation strategies within the 13-state region.

1. Introduction

The USACE IWR administers a USACE-wide program entitled "Responses to Climate Change" (RCC). This program is dedicated to identifying those components of USACE water resources management infrastructure and associated programs that could be at risk from the effects of CC, and formulating adaptation and mitigation strategies that could reduce those effects. One component of the RCC program entails the development of pilot studies throughout the USACE's district and division offices that address various aspects of Federal Water Resources development and management. The results of these pilot projects form a database of CC effects potentially affecting the infrastructure and resources managed by the USACE, thereby providing an effects database that could inform future water resources policy and program changes.

The impetus behind IWR's RCC was the Intergovernmental Panel on Climate Change's (IPCC) Fourth Assessment (IPCC 2007), which stated that CC was occurring at that time and mostly as a result of human activities. While controversial, that report illustrated the impacts of global warming already under way and those to be expected in future, and described the potential for adaptation by society to reduce its vulnerability to these anticipated impacts. The report concluded with an analysis of the costs, policies, and technologies intended to limit the extent of future changes in the climate system. The global circulation models and emissions scenarios used to support the findings in the Fourth IPCC Assessment were used in the analysis of projected future climate change for this ORB CC pilot study.

As stated in the Executive Summary, the information presented herein does not intend to contribute to the ongoing debate over causes of CC, nor does it present material in such a way as to assert pressure on agencies, departments, municipal or county jurisdictions, or the public to initiate preemptive actions to combat CC. The mitigation strategies discussed in Section 10 are generally in line with generic strategies voiced by global and national scientific communities. The numerical model projections of potential future climates and the techniques for post-processing them to drive the numerical hydrology models used as part of this study have been reviewed, evaluated, and used in many other similar studies by several Federal agencies (e.g., USACE, USGS, BOR, and NOAA) and found to be reasonable, prudent, and reliable. The NOAA models used to translate the precipitation and temperature changes into hydrologic outputs have been used historically to forecast river conditions in the ORB.

The NOAA model used to forecast future basin conditions was evaluated through a back-casting process that matched modeled data to observed data for 25 gage points from 1952 until 2001. That modeled data was found to be within 2% of the observed data for all 25 forecast points. Those involved directly in the modeling phase cautioned the team about the levels of uncertainty associated with the model data, not only because of the considerable period being forecast (2011–2099), but also for applying the forecasted flow discharge outputs upstream of the forecast points. The downscaling process was relatively fine-grained, but not sufficient to apply a high level of certainty regarding precipitation and discharges to the upstream reaches of each HUC-4 within the basin. The NOAA forecast points, basin HUC-4s, and forecast groups are displayed in numerous maps throughout the report and appendices.

2. Background

2.1 Study Area

The ORB covers 204,430 square miles within 14 states and is populated by more than 27 million people residing within 548 counties and more than 2,400 municipal jurisdictions. Figure 2-1 depicts the geographic extent of the basin (bordered in blue) and its location in relation to state boundaries. The basin extends 570 miles from north to south, from southwestern New York State to northern Mississippi, Alabama, and Georgia, and 622 miles from east to west, from Illinois to Pennsylvania. Surface elevations vary from less than 300 feet at the mouth of the Ohio River in Cairo, IL, to more than 2,200 feet at the uppermost reaches of the Allegheny River.

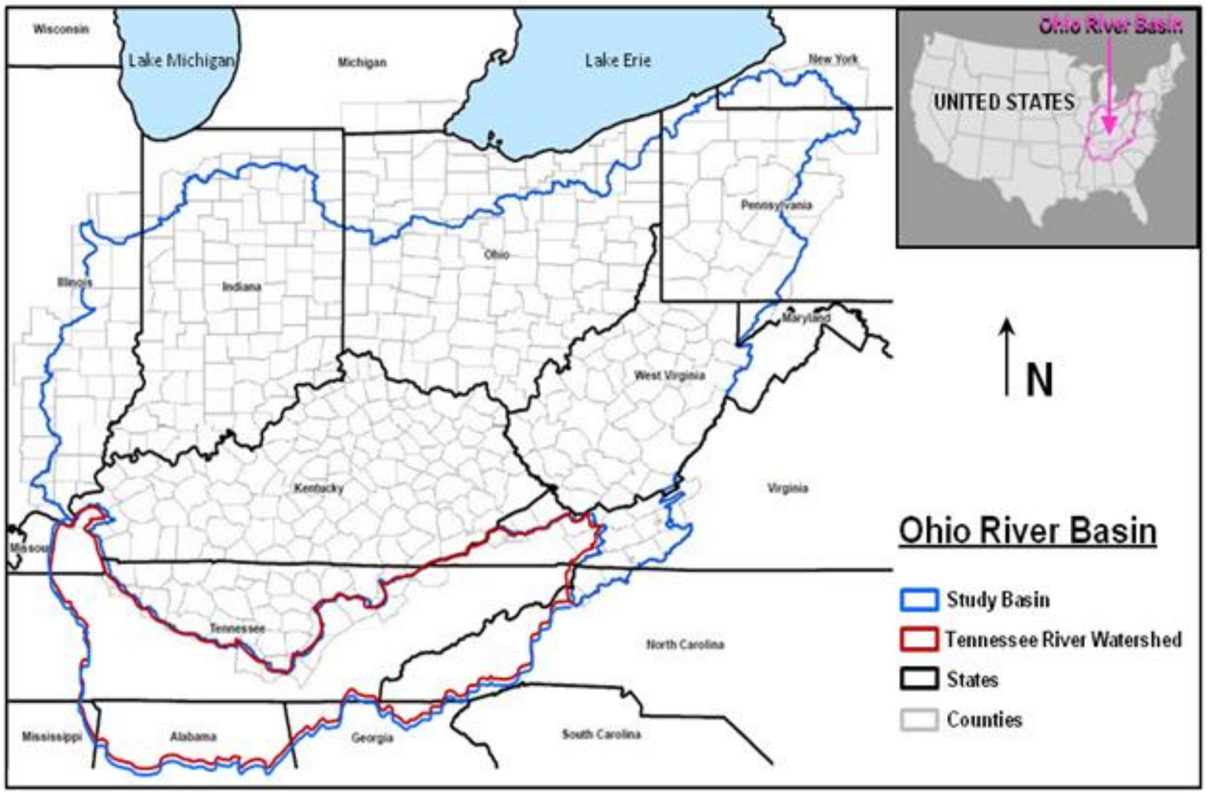


Figure 2-1: Ohio River Basin

This study covers the entire ORB; climate change data was not available for the Tennessee River watershed (bordered in red) and is not included in this study, although detailed information may be available for future climate change studies. Nonetheless, human and natural resources in the Tennessee River watershed are included in this study and the information is presented in the applicable sections.

More than 5 million people rely solely on the Ohio River mainstem for municipal water supplies. Numerous thermoelectric power plants use the rivers for cooling (providing electricity within and beyond the basin) and movements of freight, commodities, and manufactured goods by commercial navigation valued at more than $41 billion transit the Ohio River system annually.

The USACE system of flood risk reduction infrastructure includes 83 reservoirs and more than 100 local protection projects (levees and floodwalls). Seventy-eight of the dams are multipurpose structures that store and discharge quantities of water supporting human activities and ecological systems. Five of the reservoirs are single-purpose flood risk reduction structures and normally operate as run-of-river (i.e., maintain no year-round conservation pool). Multipurpose projects provide flood risk reduction, water supply, hydropower, low-flow augmentation that supports downstream water quality and aquatic ecosystem purposes, recreation, fish and wildlife management, and other authorized purposes. Some aquatic, terrestrial, and plant species both on Federal lands and in rivers downstream of operating reservoirs are protected by the Endangered Species Act. Many USACE multipurpose dams feature multiple port intake structures that allow mixing lake waters of varying depths, temperatures, and oxygen levels to meet downstream water quality targets and aquatic species needs.

Associated with these lakes and reservoirs are thousands of acres of Federal lands purchased by USACE to provide for various project purposes and protect the water resources at the project. Numerous acres of this Federal land are managed for fish, wildlife, and timber resources by state natural resources agencies, other Federal agencies (e.g., U.S. Forest Service), non-governmental organizations (NGO), and academic institutions through leases and licenses. Leases and licenses are also managed by USACE for energy production in limited federal lands. Annually, millions of public visitors use project lands for recreational pursuits, including fishing, boating, water skiing, camping, picnicking, hiking, and other passive and active recreation activities.

Two other major water managers operate water resources projects in the ORB. The Tennessee Valley Authority (TVA) operates 49 reservoirs in the Tennessee River watershed for flood control, water supply, hydropower, and recreation. TVA also manages hundreds of acres of land for various recreational purposes. The Natural Resources Conservation Service (NRCS) also manages numerous single-purpose and multipurpose watershed retention structures for public purposes, including water supply, flood control, and recreation.

2.2 Current Climate

Several factors influence ORB climate including latitude, elevation differences, large bodies of water (the Great Lakes, Gulf of Mexico, and Atlantic Ocean), prevailing winds, the jet stream, topography, and land cover. Prevailing winds are from the west, with most rain-producing storms moving into the basin from the west and southwest, with the exception of occasional tropical storms and hurricane remnants that enter the lower basin from the Gulf or enter the upper basin (i.e., Virginia, West Virginia, Maryland, and Pennsylvania) from the Atlantic.

The ORB has four distinct climatic zones (James 1922), but the two most prevalent zones relevant to CC issues are the humid continental region, lying across the upper half of the basin, and the humid subtropical region, lying across the lower half of the basin. The dividing line between the two prevalent climatic zones generally extends through the lower third of Kentucky. Precipitation and temperature data collected by NOAA for the ORB since 1952 indicates that there has been a slight general warming trend in the basin and a slight increase in annual precipitation, the latter mainly occurring during the early fall season.

A key factor in the variability of ORB weather is the constant meandering of the Northern Hemisphere polar jet stream that frequently crosses the basin and can fluctuate from the highest to lowest latitudes in a matter of days. Many high and low pressure systems follow this jet stream, including dry, cold frontal systems from Canada or warm, humid fronts from the Gulf, which are drawn into and through the basin by these high-altitude atmospheric currents.

2.3 Current Problem/Concern

The basin is considered to be "water-rich" (Adler et al. 2003) with its numerous major rivers and impoundments operated by Federal and state agencies. Annual rainfall amounts for regions of the basin range between 39 and 58 inches. There have been past episodes of drought (1988, 2002, 2007) and major flooding events (1997, 2010, 2011) within the basin that have tested the water management system, but these have been isolated, infrequent events. The primary water resources operating agencies (USACE, TVA, and NRCS) have developed facility management plans that address these periodic events and have consistently adjusted operations within the authorized limits of the existing infrastructure to minimize the impacts of these extreme weather events on the infrastructure and downstream development.

The primary concern to water management agencies is the threat of extreme episodes becoming more prevalent (a new "normal") and perhaps becoming even more extreme in duration and potency. The potential for components of climate/weather (e.g., temperature, precipitation, winds, humidity, evaporation) to become less predictable (which are forecasting issues) and for extreme changes (drought and floods) to become more prevalent suggests a need for review studies of the existing operating schemes for water management and whether the current infrastructure design can accommodate potential future operational changes. Issues of public acceptance to these future changes raise other concerns of equity, equality, public services, and social and economic impacts.

3. Study Purpose and Scope

3.1 Central Question Being Addressed and/or Method Tested

Each IWR RCC Program pilot study is based upon a central question that relates potential CC scenarios to basin-specific water resources development and management. For the ORB pilot study, the following central question was formulated:

> *"Can regional mitigation/adaptation strategies that are collaboratively developed with the ORB Alliance and formulated using Integrated Water Resources Management principles be implemented successfully within the ORB to counter the anticipated water resources, ecological and infrastructure impacts of climate change?"*

Based on this question, the primary purpose of this study is to identify those components of the ORB infrastructure and ecosystem resources that may be at risk from future changes in precipitation and temperature, and to formulate mitigation and adaptation strategies that may be implemented to reduce those effects. The ORB Alliance provided the opportunity for extensive collaboration among various Federal, state, and local agencies, NGOs, academia, and institutions, allowing this pilot study to incorporate the most knowledgeable CC information from a diversity of regional resources and jointly formulate feasible adaptation strategies.

This study scope addresses almost the entire ORB (excluding the Tennessee River watershed) and includes an extensive system of operating reservoirs that store and release water for various authorized purposes. Each system component is maintained by various agency operating procedures and manuals that address normal conditions and extreme conditions (e.g., drought or flood). While some operating manuals are not crafted to address future operating extremes, future adaptation strategies that address changed hydrologic and temperature regimes could be incorporated into the manuals and procedures to heighten operational readiness.

In addition, the basin's infrastructure was constructed during a time when the potential effects of CC were not part of the planning, design, and construction process. As this infrastructure ages and concerns for dams, locks, and levee safety arise, or opportunities arise for rehabilitation of such structures due to changed conditions, design options for adapting to CC conditions (e.g., higher annual flows or drought conditions) may be able to be incorporated as a part of that rehabilitation process.

3.2 Previous studies

In December 2009, four USACE districts completed the Ohio River Basin Comprehensive Reconnaissance Report[1] that addressed water resources issues in the ORB. Following a similar USACE basin report in 1969 (before CC concerns), the 2009 study evaluated current water resources issues with the threat of CC impacts identified as a significant and impending issue by agencies and the public. Despite the complexities of downscaling impacts to the basin level, research of CC scientific literature and North American modeling results during development of

[1] Huntington District U.S. Army Corps of Engineers, December 2009, "Ohio River Basin Comprehensive Reconnaissance Report and Appendices".

the 2009 report unveiled potential threats to the USACE's ability to manage the infrastructure system for its authorized purposes.

The 2009 reconnaissance report included specific recommendations that a CC impacts study with alternatives that addressed anticipated impacts of CC be initiated pending the availability of funding. That report was approved by the LRD Division Commander. USACE basin-wide drought contingency plans had been prepared, but required updating to address current and future CC issues. Basin-wide water management plans and infrastructure reinvestment plans were also recommended in the 2009 basin report—plans that could incorporate the results of any CC modeling and adaptation strategies recommended in this pilot study.

4. Pilot Study Methodology/Approach

4.1 Study Methodology

Pilot study proposals in the collaboration category were to be collaborative with various stakeholders from a specified region. Opportunities for collaboration were realized in the ORB through a timely set of circumstances related to the development of the Comprehensive Basin Plan. Following a timeline paralleling the development of the 2009 reconnaissance report, the USACE's Great Lakes and Ohio River Division fostered development of a basin coalition of Federal, state, regional, and local agencies; NGOs, industry, and academia (the Ohio River Basin Alliance). Numerous regional Alliance conferences have been held since its formation and the Alliance has created four working groups that are actively pursuing water resources topics, including water management and availability, enterprise and infrastructure, ecosystem restoration and protection, and sustainable growth and regional competitiveness. While the threats posed by CC were recognized by the four working groups in their ongoing deliberations to resolve basin issues, none of the four groups were specifically dedicated to the potential effects of CC on the basin's water resources, ecosystems, or critical public infrastructure. Establishing a dedicated CC working group within the Alliance would focus the expertise of qualified professionals on CC problems and plausible solutions. Addition of such a dedicated group to the Alliance framework was added as an objective of this pilot study.

4.2 Study Approach

The pilot study approach was structured as a series of individual work-tasks that would (a) identify the appropriate downscaled modeling data for the basin, (b) identify the potential impacts of changes in hydrology and temperature on the basin infrastructure and ecosystems, (c) identify what actions other non-USACE water managers may be taking to combat CC, and (d) formulate logical and reasonable adaptation and mitigation strategies to attenuate those anticipated impacts. All these separate activities would be combined into a single report that would document the study activities, results, and conclusions.

Team members (USACE staff and Alliance members) were assigned to single or multiple tasks, with team leaders appointed per task to ensure that the knowledge base of the Alliance would be appropriately applied to the technical and policy aspects of the study. Given the broad range of technical skills, experience, and study perspective with Federal, state, academia, NGOs, and private laboratory participation, these teams provided a sound collaborative base from which to study a subject of such broad interest and importance.

5. Study Objectives

An initial set of objectives were presented in the pilot study proposal. Afterward, USACE and Alliance team members would further refine the study objectives based upon available CC research data, information, and input from the entire Alliance membership. The Alliance Fall Conference in September 2011 at Marshall University, WV, provided an open forum and excellent opportunity to engage the members on the following CC objectives:

1. Through widely vetted global climate and hydrologic models, develop downscaled modeling results that describe the potential changes in temperature, precipitation, and streamflow within the ORB
2. Engage members of the Alliance in a productive dialogue on the potential effects of CC and work with the Alliance to identify implementable adaptation strategies
3. Establish a CC working group within the Alliance
4. Identify and document basin water resources, ecosystems, and infrastructure systems that are at risk from CC, and the scope and severity of those risks
5. Formulate mitigation/adaptation strategies that could be integrated into agency operations at multiple levels (basin-wide, sub-basin level) of water resources management
6. Apply Integrated Water Resources Management (IWRM) principles during the formulation of mitigation and adaptation strategies
7. Identify and document gaps in CC data, information, modeling, and monitoring that require additional resources for further study and development
8. Identify and document examples of USACE infrastructure operations policies whose future revision might enable USACE water managers within the ORB to attenuate or minimize the adverse effects of CC on USACE missions and threatened ecosystems.

6. Establish a Climate Change Working Group in the ORB Alliance

6.1 Initial Efforts

One of the initial objectives of the pilot study was the formation of a CC working group within the Alliance to foster the levels of collaboration needed to engage the stakeholders within the 13-state basin area. The initial plan was to establish a permanent CC working group using Alliance members with representation from Federal agencies (e.g., USACE, NOAA/NWS, USGS, NRCS), regional organizations (e.g., the Ohio River Valley Sanitation Commission [ORSANCO], TVA), state agencies (e.g., Department of Environmental Protection, Department of Natural Resources [DNR]), NGOs (e.g., TNC), and universities (e.g., Marshall, Carnegie Mellon, Ohio State). That working group would share common objectives with the pilot study team, with necessary adjustments as opportunities presented themselves during the study.

During formation of the pilot study team and refinement of study objectives, USACE team members frequently briefed the Alliance on the progression of the study and anticipated outputs. Once the pilot study was initiated, efforts to establish a standalone CC working group within the Alliance intensified between the Huntington District and the Alliance leadership.

6.2 Current Status

In 2013, the Alliance's Executive Board decided that CC issues in the ORB would be incorporated into the existing Sustainable Growth and Competitiveness Working Group as a part of that group's responsibilities. The current chairman of that working group, Dr. Harry Stone of Battelle, is also a key member of this pilot study. As the full spectrum of CC issues and impacts was being solidified during the pilot study, and definitive adaptation and mitigation strategies were formulated in the final study report, the decision to form a standalone working group would be revisited by the Alliance leadership. At that time, the purpose and objectives of a new CC working group would be established and their role(s) in assisting implementation of the recommended strategies would be documented and agreed to by the Alliance membership.

6.3 Alliance Working Group Activities

The August 2013 meeting of the Alliance in Louisville, KY, was the initial meeting of the Sustainability and Competitiveness Working Group, wherein members of the ORB CC pilot study were present. Members of the four USACE districts on the CC study team and members from USEPA, NOAA/NWS, USGS, the University of New Hampshire, and Marshall University were in attendance. Most of the working group meeting was devoted to detailed descriptions of the modeling process, output format, and anticipated results from the modeling analyses being accomplished by the OHRFC (NOAA) at that time. Also discussed in detail was the anticipated use of the modeling results by the CC Infrastructure and Ecosystem Impacts and Adaptation/Mitigation Strategies groups. The initial meeting of this expanded Alliance group signaled the accomplishment of Study Objective # 3, described as follows.

7. Downscale Modeling for the Ohio River Basin

7.1 Introduction

This section of the pilot study addresses a key study task—development of downscaled climate change data for the ORB. All other study components, such as impact analyses and formulation of adaptation strategies, were based on the modeling results. This task was undertaken through a joint effort between IWR climatologists and hydrologists, and hydrologists from NOAA's OHRFC, located in Wilmington, OH. To maintain consistency among the various nationwide RCC pilot studies, IWR recommended that the archived CMIP3 and Phase 5 (CMIP5) Climate and Hydrology Projections be used as the basis for the downscaling work in the ORB. These datasets were developed jointly by and vetted through the USACE, BOR, USGS, the National Center for Atmospheric Research, and various academic institutions and national laboratories. The study used the World Climate Research Program CMIP 3 modeling outputs as input into OHRFC hydrologic river model. The web site link for the data used is:

http://gdodcp.ucllnl.org/downscaled_cmip_projections/dcpInterface.html.

7.2 Downscale Modeling Procedures

To help ensure that the downscaled CC basin data used here would be consistent with other pilot studies in the RCC pilot program, IWR staff performed the initial model runs for the basin using an ensemble of 9 carefully selected combinations of Atmospheric Ocean Global Climate Models out of 77 available combinations of models and driving emissions scenarios in the archived set. Selection was made to represent a significant cross-section of the climate uncertainty space with a parsimonious set of model outputs. The technique was the same used by the USACE in the Red River of the North CC pilot study web site:

http://www.corpsclimate.us/docs/RCC_Pilots_Sept_2012_highres.pdf).

The model runs were performed using two greenhouse gas (GHG) emissions scenarios from the Intergovernmental Panel on Climate Change-Special Report on Emissions Scenarios (IPCC 2000), with emission scenarios "A1B" and "A2" (medium-range emissions scenarios that project GHG emissions rates already exceeded by actual global emissions), selected to ensure that measurable changes in temperature and precipitation would be encountered during analyses.

By early 2013, the nine ensemble runs were completed for the three time periods (*F1*, *F2*, *F3*) across a prescribed grid pattern covering 698 sub-watersheds in the ORB. The translation of that modeling data by the OHRFC (NOAA) into monthly data for river discharge and temperature changes did not include the Tennessee River; however, modeling forecasts for that portion of the ORB are handled through the Lower Mississippi Forecast Center and the necessary arrangements to acquire forecasts for the Tennessee River were outside of the purview of the ORB pilot study.

The OHRFC used the Community Hydrologic Prediction System along with the Sacramento Soil Moisture Accounting Hydrologic Model (SAC-SMA) to generate the hydrologic response in an unnatural state using a reservoir modeling system (RES-J and RES-SNGL). The output includes streamflow, temperatures, precipitation, and snow water equivalent (in CSV format for easy use). The hydrologic model output is at the confluence for each tributary along with the Ohio River and

Great Lakes Lake Erie drainage areas defined by 25 NOAA forecast gage points. Those stream gage points extend from Sharpsburg, PA (Allegheny River) to Golconda, IL (Lower Ohio River) and are displayed in Figure 7-1. The forecast gaging points are displayed graphically as red dots on the basin map, and four-letter acronyms signifying the forecast group names are explained in Table 7-1.

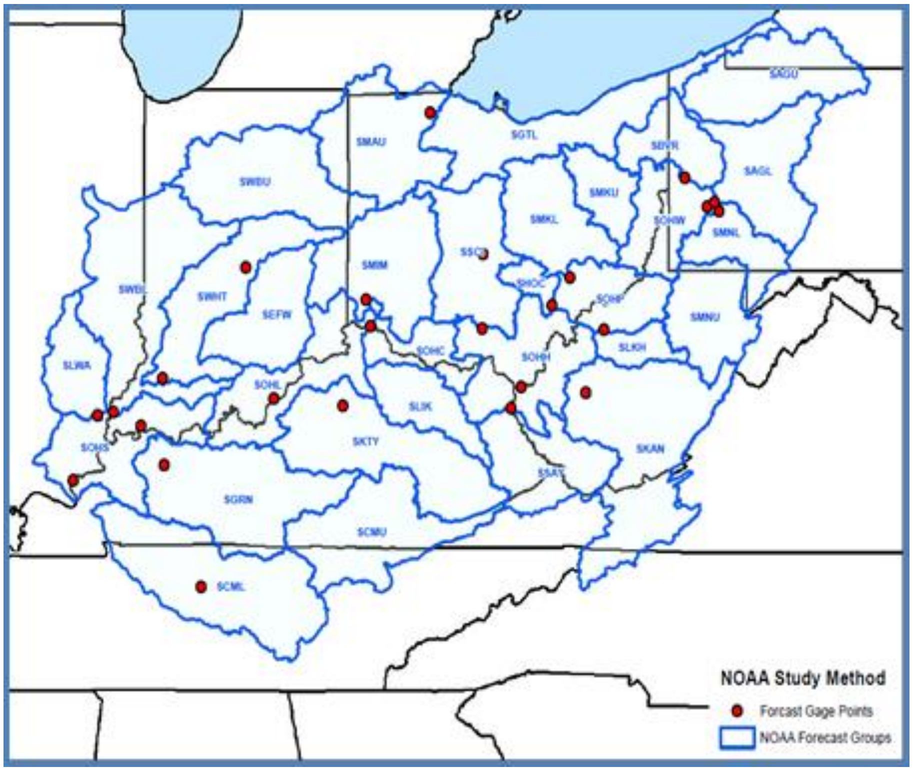


Figure 7-1: NOAA Forecast Points and Forecast Groups

A comparison of the models' retrospective period of 1952–2001 to actual historical flows showed how well the climate model inputs with hydrologic outputs of streamflow simulated the past to establish confidence in the model's abilities to simulate the future. The results showed flows were within 2% on the mainstem Ohio River and 5% on tributaries. The hydrologic model output is retained at the same time-scale (monthly) as the input climate grids produced by IWR. OHRFC (NOAA) produced streamflow outputs for the following nine measures: (1) annual percent change mean flow, (2) annual percent change maximum flow, (3) annual percent change minimum flow, (4) March percent change mean flow, (5) March percent change maximum mean flow, (6) March percent change minimum mean flow, (7) October percent change mean flow, (8) October percent change maximum mean flow, and (9) October percent change minimum mean flow. (Graphics were formulated to view both ORB spring peak flood season during March and autumn low-flow season during October.)

Table 7-1: Forecast Groups Symbols

Forecast Group Symbol	Forecast Group Name	Forecast Group Symbol	Forecast Group Name
SAGU	Allegheny River Upper	SKTY	Kentucky River
SAGL	Allegheny River Lower	SWBU	Wabash River Upper
SBCR	Beaver River	SWBL	Wabash River Lower
SMKU	Muskingum River Upper	SWHT	White River
SMKL	Muskingum River Lower	SGRN	Green River
SMNL	Monongahela River Lower	SCMU	Cumberland River Upper
SMNU	Monongahela River Upper	SCML	Cumberland River Lower
SSCI	Scioto River	SLWA	Little Wabash River
SLKH	Little Kanawha River	SHOW	Ohio River
SKAN	Kanawha River	SOHP	Ohio River
SHOC	Hocking River	SOHH	Ohio River
SSAY	Big Sandy River	SOHC	Ohio River
SMIM	Miami River	SOHL	Ohio River
SLIK	Licking River	SOHS	Ohio River
SEFW	East Fork White River		

7.3 Downscaled Modeling Results

Data were translated into thematic basin maps highlighting the percent changes from the 1952–2001 base condition within each watershed that contributes streamflow to the NOAA forecast points. The three 30-year periods are referenced in the following descriptions as *F1* (2011–2040), *F2* (2041–2070) and *F3* (2071–099). R1 represents the base years' modeling run (1952–2001) from which the percent changes were calculated. The forecasted annual mean percent change from the base years (1952–2001) is shown in the following subsection. Additional forecast data results (text description and graphics) for percent flow changes for Annual Minimum flows, Annual Maximum flows, March Mean flows, March Maximum flows, March Minimum flows, October Mean flows, October Minimum flows, and October Maximum flows for the three forecast periods (*F1*, 2011–2040; *F2*, 2041–207; and *F3*, 2071–2099) are included in Appendix A.

7.3.1 Percent Change in Mean Annual Streamflow (from Base 1952–2001)

Annual percentage change in the mean annual streamflow remains largely unchanged from 1952–2001 (the base period) through 2011–2040 (*F1*) with slight increases in the Kanawha and Big Sandy river watersheds (Figure 7-2, southeastern ORB respectively SKAN and SSAY). During *F2*, the eastern portion of the basin (NY, PA and WV) experiences slightly more rainfall with higher steam flow discharges (Figure 7-3). During *F3*, the eastern portion of the basin and the Cumberland River watershed (Figure 7-4, SCML and SCMU) experience slightly higher streamflow discharges with the greatest increases in the Big Sandy River watershed (Figure 7-4, SSAY). Forecasted ranges in mean annual streamflow are shown in the following three figures.

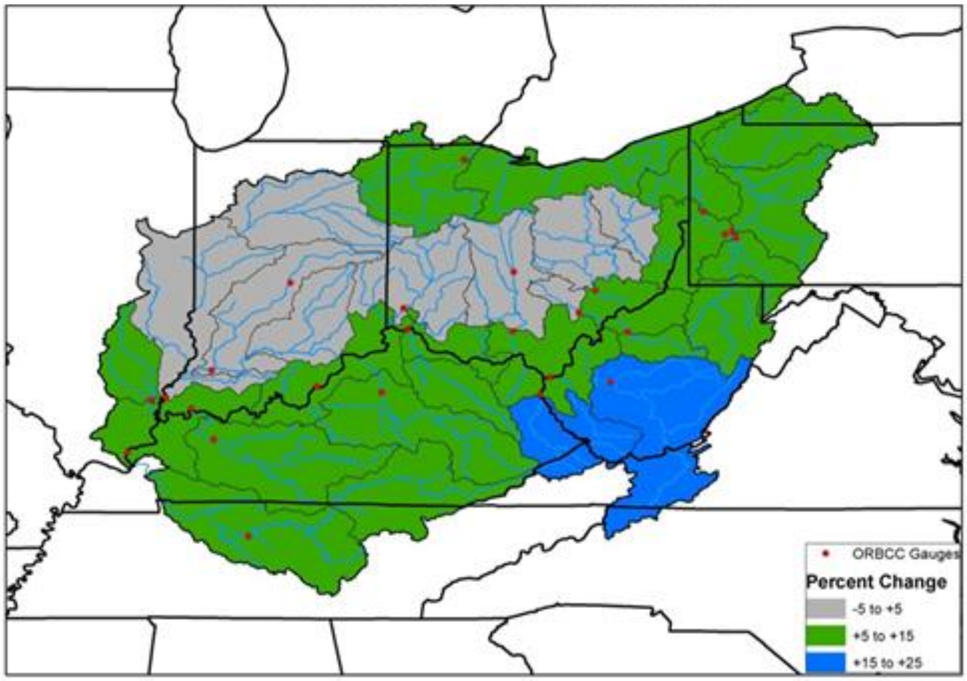


Figure 7-2: Forecasted Percent Change in Annual Mean Streamflow (2011–2040)

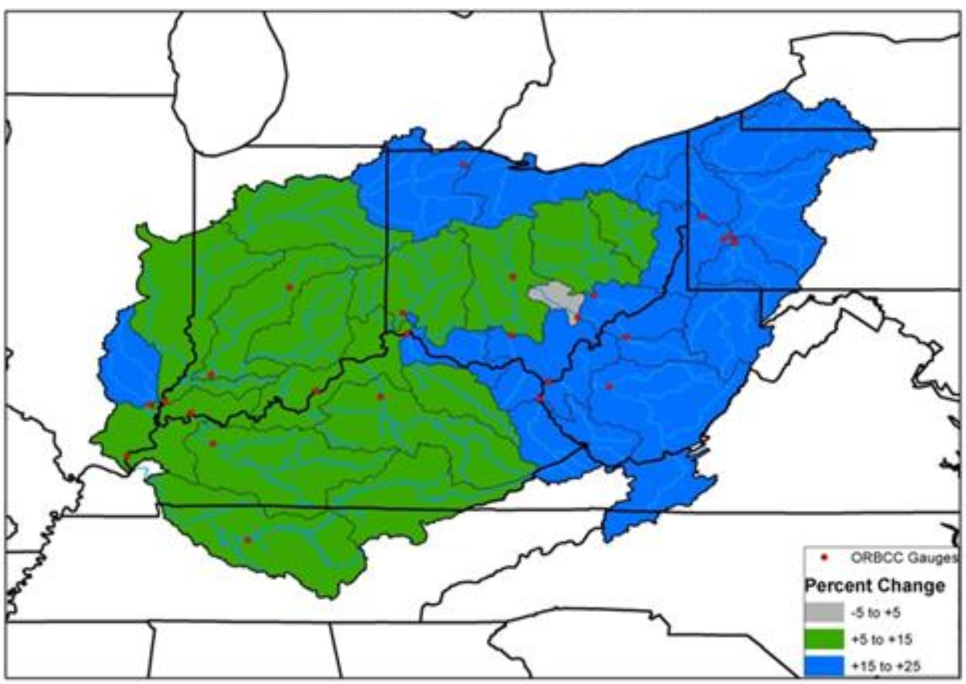


Figure 7-3: Forecasted Percent Change in Annual Mean Streamflow (2041–2070)

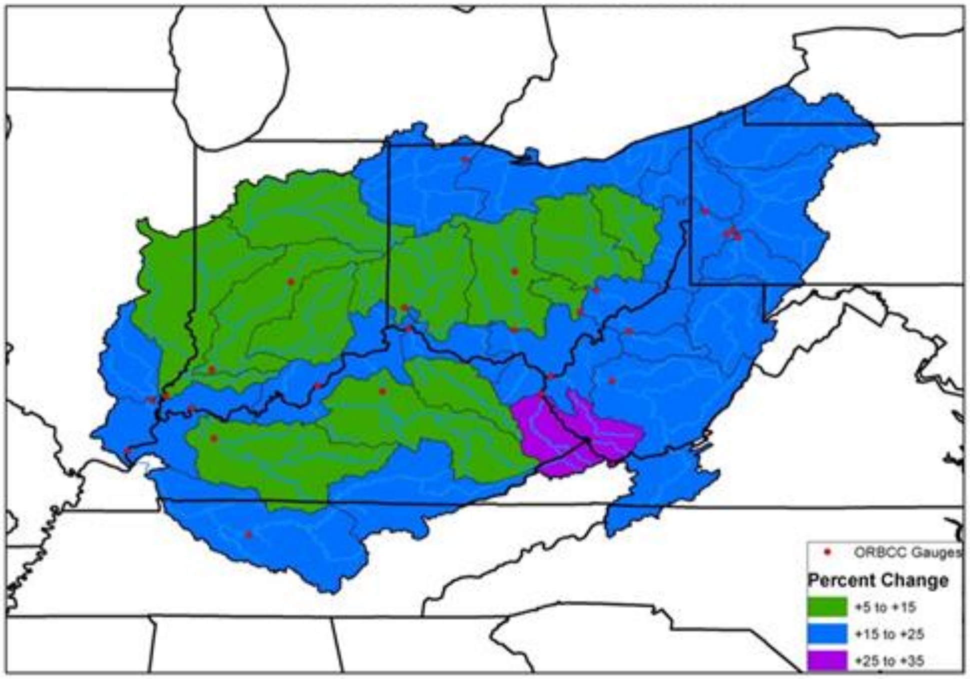


Figure 7-4: Forecasted Annual Mean Percent Change in Streamflow (2071–2099)

7.3.2 Projected Temperature Changes Periods F1, F2 and F3 (Base 1952–2001)

Temperature changes across the Ohio River Basin over the three equivalent time periods (*F1, F2, F3*) show a slight increase (0.5°F) in the annual monthly mean temperature per decade through 2040 and then increases in the annual monthly mean of 1°F per decade between 2040 and 2099. These projected changes are presented for the Pittsburgh, PA (PTTP1) and Golconda, IL (GOL12) forecast points between 1950 and 2100 in Figure 7-5. Table A-1 in Appendix A shows the progression of annual monthly mean temperature changes for all of the basin forecast points between 2001 and 2099, and the percent change for each forecast point in that time period.

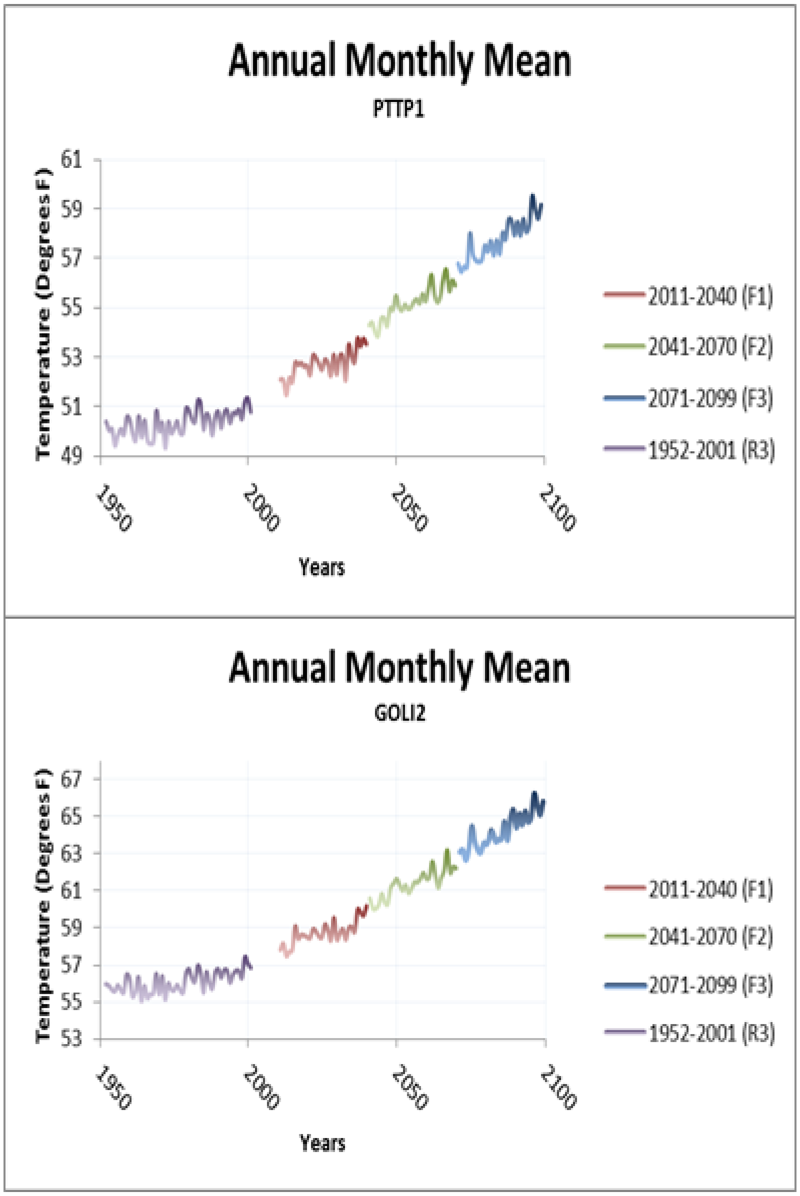


Figure 7-5: Observed and Projected Annual Monthly Mean Temperature Changes for Pittsburgh, PA, and Golconda, IL, Between 1950 and 2100

7.4 Modeling Summary

In summary, the ensemble climate models suggest the following:

- Mean, mean maximum, and mean minimum streamflows will generally be within the range of historic base conditions through 2040, except during autumn when reductions (5% to 15%) in flow will be experienced in some forecast groups.
- Beyond 2040 through 2099, increases occur in the mean and mean maximum flows, generally in the 10–40% range, with some higher flows, especially in the northern and eastern ORB, especially during autumn.

- Mean minimum flows decrease in most periods beyond 2040.
- Peak spring flood season sees mean maximum flows increase, especially beyond 2040. The autumn season experiences the greatest variability with mean minimum flows decreasing over time and mean maximum flows increasing with time (influenced by lower overall typical flows).
- Climate model inputs indicate that trends in temperatures and rainfall since 1976 will persist through 2040.
- The autumn season increases in maximum flows may enhance flood events in late autumn/early winter.
- The spring mean maximum streamflows increase beyond 2040 during peak flood season, with spring flooding conditions likely more problematic in some parts of the basin.
- Drying will occur beyond 2040 in the ORB, especially beyond 2070.
- Variability is projected to increase, especially beyond 2040.

7.5 Relevancy of Forecast Periods to USACE Planning

The USACE's water resources development process, as described in various Federal policies and regulations, requires that the planning process consider what future conditions may exist within a basin, watershed, or community in the absence of any Federal action. This "future without project condition" requires a realistic, credible, and logical description of social, economic, and environmental conditions for a period extending at least 50 years beyond the planned first operation of the proposed project. These future conditions are then used as a yardstick against which any proposed project's future outputs and impacts are compared.

The three time periods used in the downscaled modeling process provide a glimpse at various temperature and hydrologic regimes that may exist, whether or not a proposed water resources project would be implemented. For example, the initial modeling period *F1* (2011–2040) provides a near-term assessment of what hydrologic and atmospheric conditions may be like during the planning, design, construction, and initial years of operation of a water resources project started in 2014. The second modeling period *F2* (2041–2070) provides a projection of future conditions that would include the required time period for the "future without project condition" analysis. For any water resources project being initiated in 2014, that 50-year period of analysis would end in 2064, nearly the end of the second modeling period.

Although only presented as a forecast, the percent increases or decreases in flow discharge and temperature over the base years (1952–2001) indicated by the modeling provides a hydrologic and atmospheric background against which the performance of a proposed project can be measured. Concerns for project sustainability and reliability, and the capability to fulfill project purposes can be measured against the climate conditions forecasted in this study. For operating and planned water resources projects in the ORB, the modeling-based forecasts in this pilot study provide a background of climatic conditions that may prevail in the future, with increasing levels of uncertainty associated with each 30-year period.

8. Potential Impacts to Ecosystem Resources/ Services and Infrastructure

8.1 Introduction

This section of the pilot study addresses the potential impacts to basin ecosystems and infrastructure as may occur due to changes in precipitation/runoff and temperature increases discussed previously in Section 7. The study team was composed of a cross section of USACE staff from the four river districts and members of agencies associated with the Alliance. Alliance members included representatives from USEPA, Battelle, TNC, Marshall University, and the University of Cincinnati.

This team was further divided into two sub-teams whose tasks were to identify and describe the categories of basin resources that may be impacted by CCs and to what extent these resources could be impacted by the modeling results described previously in Section 7. Those two sub-teams addressed (1) ecosystem resources and services and (2) operating and future infrastructure. The following text describes the types of ecosystem resources and infrastructure that can be found in the basin and to what extent changes in temperature and river discharge could affect their operation and sustainability.

The amount and quality of information gathered during research by the team to describe the range and extent of impacts of CC on basin ecosystems is voluminous. To compress this main report into a reasonable length for ease in reading, several sub-sections of Section 8 containing the background research on potential CC effects on various ecosystems types (rivers, lakes, and wetlands) are located in the CC study appendices (Appendix B), with a number of explanatory tables and figures.

8.1.1 General Concerns

Healthy aquatic ecosystems provide many goods and services required to sustain human societies. The health of aquatic ecosystems strongly relies on the landscape of which they are a part; most ecosystems are managed and/or affected by humans, and CC affects aquatic as well as terrestrial ecosystems, species, and humans.

The most important ecosystem services in the ORB in terms of their estimated monetary value are:

1. Freshwater-related source of drinking water, power generation, and goods transport infrastructure
2. Agricultural land-associated food production
3. Near-stream land and wetlands-related flood control
4. Forested land-related timber production for fuel
5. Freshwater- and forested land-related recreation

Under low-flow conditions, withdrawal of water for human use removes much of the available streamflow in some localities of the ORB. Under these specific conditions, water to meet the in-stream needs of aquatic ecosystems is often limited, and the competition between the needs of people and natural systems is likely to increase with CC. As early as the 1970s, the ratio between in-stream use and total use of streamflow was 97 to 99% in the water resources regions of the Great Lakes, Ohio, and Tennessee, covering a large part of the ORB. Recently (2005), freshwater water use based on water withdrawal only, without taking available streamflow into account, was estimated at 43,817 Mgal/d, of which the largest portion (79%) was used for thermoelectric and the smallest portions (<1%) for domestic water supply, irrigation, livestock, and mining, respectively. It would be important to evaluate how much streamflow would be available under current low-flow conditions to meet in-stream needs of aquatic ecosystems.

Groundwater in the ORB originates from four aquifers, notably the Pennsylvania/Mississippian aquifers, the Glacial Aquifer, the Mississippi Embayment aquifer, and the Ozark Aquifer. Regional groundwater (GW) studies are ongoing since 2010, prompted by the depletion of GW and the compounding effects of recent droughts, emphasizing the need for updating the information on the availability of the Nation's GW resources. The results of these studies are expected to become available by 2016–17. The management of water quality and quantity within the ORB fulfilling legal requirements has to take CC-related effects into account and develop/adopt strategies that mitigate or adapt to these impacts.

8.1.2 Provisioning of Aquatic Ecosystem Services

Human societies require the goods and services of healthy aquatic ecosystems, which are sustainable, maintain ecological structure and function over time, and continue to meet societal needs and expectations. Important goods and services such as clean water and fish protein depend on basic ecosystem processes such as nutrient cycling, primary and secondary production, decomposition, and food web interactions. Rates of these vital processes are impacted by water temperature and by the range and temporal regime of discharge, all of which may be altered by CC. Freshwater habitats are rich in biological diversity, and a large part of the fauna is threatened with extinction by human activities (Naiman et al. 1995). A changing climate may intensify these threats (e.g., enabling the spread of aquatic nuisance species, further fragmenting native aquatic communities because of thermal or flow constraints, and altering human responses to a changing climate). Thus, the impacts of CC should be viewed in the broader context of intensifying human disturbance of the landscape.

8.1.3 Identification of Ecosystem Services and Estimates of At-Risk Monetary Values

In this section, a preliminary assessment is made of the major ecosystem services within the ORB, roughly following the conceptual framework used by the Millennium Ecosystem Assessment (MA) (MA 2005) for documenting, analyzing, and understanding the effects of environmental change on ecosystems and human wellbeing. The MA viewed ecosystems through the lens of the services that they provide to society, how these services in turn benefit humanity, and how human activities alter ecosystems and the services they provide. The focus on ecosystem services has been adopted widely among the scientific and policy communities and has resulted in new approaches for research, conservation, and development (Daily and Matson 2008; Carpenter et al. 2009).

Ecosystem services were divided into three categories—provisioning, regulating, and cultural services. Ecosystem condition is affected by human use of the services that any particular ecosystem provides. The MA findings showed that human use of ecosystem services is expanding with growth in earth's human population and the expansion of consumption. Human use is increasing for all ecosystem services studied, least for wood fuel, agricultural fibers, wild terrestrial foods, wild-caught fish, and some recreational use. Human efforts have increased food production to some extent to alleviate hunger and poverty (crops, livestock, and cultured fish). Most other services have decreased over the past 50 years worldwide. The decline of regulating services is of particular concern, since it forebodes future declines in other ecosystem services unless society takes action to combat adverse trends. All major drivers, such as CC, land use change, human population growth, and over-exploitation continue to increase, and these trends have exceeded the bounds of human experience (MA 2005). Therefore, society faces a challenge of unprecedented proportions.

For this assessment of major ecosystem services within the ORB, the following approach was followed. A literature search was conducted, using combinations of the relevant geography and keywords: for geography, the names of the states in which the ORB is located; for ecosystem service, economic, the names of the ecosystem service categories (see previous), and the names of their components (after Carpenter et al. 2009). This literature was explored to identify ecosystem service categories and their components, assess their monetary value, and identify their risk to CC (after Ranganathan et al. 2008.

In this section, an overview is provided of ecosystem services in the ORB within the categories modified from those established in the MA, with Table B-8 in Appendix B summarizing, the following tables supporting the assumption and calculations, and Table B-7 in Appendix B listing the major ecosystem services currently perceived as being associated with the greatest monetary values. This assessment may serve to increase the awareness for the great importance of ecosystem services for the economy and human wellbeing in the ORB, and provide the basis for sustainable basin-wide watershed management in the future to conserve and strengthen resilience within the basin when facing CC.

8.1.3.1 Provisioning Ecosystem Services

1. Provisioning a source of fresh water, and water purification and waste treatment services. The provisioning of drinking water, water purification and waste treatment, and abundant water for industrial manufacturing and power generation, along with transportation of goods over water, led to the growth of river cities and industries along the Ohio River. More than 5 million people use drinking water from the Ohio River, supplied via 32 source water intakes, according to ORSANCO (ORSANCO 2012).

   As indicators of the value of the first three ecosystem services, data for water supply and wastewater treatment of two cities in the ORB are provided: Pittsburgh and Cincinnati.

   An average of 70 million gallons of drinking water/d is produced in Pittsburgh (Pittsburgh Water and Sewer Authority [PWSA] 2013), and 250 million gallons of wastewater/d from Pittsburgh and 82 other communities is treated (Allegheny County Sanitary Authority [ALCOSAN] n.d.).

   A total of 131 million gallons of drinking water/y is provided to 235,000 accounts in Cincinnati by the Greater Cincinnati Water Works (GCWW) (City of Cincinnati n.d.), and about 167 million gallons of wastewater/d from Cincinnati and Hamilton County was treated in 2009 (Cincinnati Metropolitan Sewer District of Greater Cincinnati [MSD o.G.] 2005).

The water and sewer rates vary based on volume used, locations, surcharges, and other factors. Representative rates are shown in Table 8-1. The combined water and sewer rate ranges from $0.008 to 0.012/gallon in Pittsburgh, and from $ 0.015 to 0.017/gallon in Cincinnati.

Table 8-1: Water & Sewer Rates, ($/gallon) for Cities of Pittsburgh, PA and Cincinnati, OH

City	Water	Sewer	Combined
Pittsburgh, 2014			
Industrial	0.005	0.003	0.008
Residential	0.006	0.004	0.012
Cincinnati, 2012			
High volume use in city	0.002	0.015	0.017
Low volume use in Butler County	0.004	0.011	0.015

The revenues of the PWSA in 2010 were $89 million for metered water and $49 million for sewerage treatment (PWSA 2011). The revenues of the GCWW were $114 million for metered water in 2010 (GCWW 2011) and of the MSD o.G. $156 million for sewerage treatment in 2009 (Cincinnati MSD o.G. 2005).

A major withdrawal of water from the Ohio River occurs via 33 public water supplies, for the production of drinking water for 5 million residents within the ORB (USEPA reporting to ORSANCO). Public water supplies withdraw 257.4 Mgal/d from navigation pools (USACE 2009). Municipalities are estimated to represent only 2.4% of all water withdrawals. There are 394 intakes with maximum allowable withdrawals of about 40 billion gallons/d. No water withdrawals for irrigation purposes have been reported until very recently (ORSANCO 2013a).

Based on this information, the estimated value of water withdrawals, using a $0.08/gal proxy to the cost of water, is $36 billion/y (Frechione 2011). Based on more recent information on freshwater use within the ORB, public water supply amounts to 3,584 Mgal/d (ORSANCO 2013a). Daily withdrawal of 3,584 Mgal would amount to annual withdrawal of 1,308,160 Mgal/y, and at $0.08/gal would generate a value of $104.6 billion. A large amount of freshwater withdrawal within the ORB is for thermoelectric use; i.e., 34,452 Mgal/d (79% of total freshwater withdrawal; ORSANCO 2013a). This withdrawal would amount to an annual withdrawal of 12,574,980 Mgal/y, generate 17,513,900 x 10^6 kWh, and at a value of $0.0611/kWh generate a value of $1,070 billion/y (Table B-8 in Appendix B).

For this calculation the following information was used (Table 8-2). The average rate of power to residents in the five ORB states of Ohio, Kentucky, Indiana, Pennsylvania, West Virginia, and Tennessee was calculated using data on rates available from the U.S. Energy Information Administration (USEIA) (2013).

Table 8-2: Water Consumption per kWh of Energy2 and Power Rate in $/kWh3

State	Thermoel. Site Power (kWh/y)	Hydroel. Site Power a (kWh/y)	Thermoel. Site Water (gal/kWh)	Hydroel. Site Water (gal/kWh)	Power Rate to Consumer ($/kWh)
Ohio	129,316	0	0.95	N/A	0.0620
Kentucky	67,627	892	1.10	154.34	0.0532
Indiana	100,579	0	0.41	N/A	
Pennsylvan ia	160,926	0	0.54	N/A	0.0687
West Virginia	75,769	0	0.59	N/A	0.0603
Tennessee	70,693	3,261	0.0	43.35	
Average			0.718	98.8	0.0611

[a]: The hydroelectric power production reported in the table is not the net production for the state over the year; the values reported are only for the analyzed hydroelectric dams.

The overall power rate for these five states was $0.088/kWh (the national average is $0.119/kWh). The amount of water used to produce one kWh thermoelectrically of 0.718gal/kWh was derived from the study on consumptive water use for the U.S., power production by Torcellini et al. (2003). Water use for hydropower generation can be far greater (i.e., in the order of 99 gal/kWh, Torcellini et al. 2003). The use of hydropower is growing within the ORB and with it the water withdrawal and value of the latter power category. Hydroelectric power generation facilities are in place at five Ohio River navigation dams. The Federal Energy Regulatory Commission has granted licenses for hydropower at an additional seven dams and is reviewing applications for projects at five more (ORSANCO 2013b).

2. Goods transport infrastructure. The Ohio River is called a "working river" because of its economic role. Seventy-two counties along the river enjoy a total of 358,000 jobs related to the waterborne commerce in 72 corridor counties (ORSANCO, U.S. National Park Service [USNPS], and ORBC 1994).

   The ORB and its tributaries provide about 2,800 miles of navigable waterways over which goods are transported valued at $29 billion (Table B-9 in Appendix B). A large part of the water-borne commerce (i.e., coal) is used to generate electricity at power plants along the river. The availability of coal and low-cost transportation over water are the basis for low-cost power generation along the river, ranging from $0.0532/kWh in Kentucky to $0.0603/kWh in West Virginia, with Ohio ($0.0620/kWh) and Pennsylvania ($0.0687/kWh) in between. Costs are higher in other regions; e.g., New England (11.50/kWh) and Pacific Contiguous (8.70/kWh) (USEIA 2013). Increased temperatures, changed river dynamics, droughts, floods, stormwater dynamics, and fire regimes due to CC would affect all freshwater-related provisioning and regulating ecosystem services.

3. Agricultural land. Agricultural land provides food from crop, livestock, and poultry production. Agricultural land values capture the net present value of all goods and services

[2] From Torcellini et al. 2003
[3] From USEIA 2014

provided by the land, with market and non-market values by owner. The value includes the contribution of numerous ecosystem services that support the ability of the land to produce the valued goods and services—growing season, precipitation patterns or water for irrigation, soil, and the regulating ecosystem services of pollination, pest regulation, and nutrient control. Farmers receive great benefits from natural pollination services provided by honey bees and other natural pollinators. In Ohio, more than 70 crops depend on bees, including apples, peaches, strawberries, and pumpkins. Soybean is also a key crop and scientists have estimated that 10% of the latter crop depends on insect pollination (half of which is provided by honey bees). Thus, based on the market price of soybeans, it was estimated that honey bee pollination provides approximately a $13/y value per soybean crop-acre, amounting to a statewide total of about $59.2 million/y or $118 million/y with all insect pollinators considered (Trust for Public Land 2013).

The agricultural land value also captures a development and a non-development value component (Plantinga et al. 2002). A rough estimate of the non-development land value was made by using the 2013 land value estimates from the U.S. Department of Agriculture (USDA) (USDA 2013) and calculating the non-development value by subtracting the estimated development component based on results of a study by Plantinga et al. (2002). The non-development value was approximately $4,200/acre of crop land and $2,500/acre of pasture in 2013 across the basin (based on mean crop land and pasture land values in Ohio, Kentucky, Indiana, Pennsylvania, West Virginia, and Tennessee (USDA 2013), with a mean of $3,983/acre (Table 8-3). With 34.7% of land within the ORB or 71,000 mi^2 being in agricultural land use (USACE 2009), the total value of the ecosystem services reflected in agricultural land values within the ORB is therefore about 181 billion U.S. $ (Table B-8 in Appendix B).

Table 8-3: Calculation of Ecosystem Services Value of Agricultural Land[4]

State	Mean land value			Mean Ecosystem Services Value
	($/acre)a	Development component (%)b	Non-development component (%)	($/acre)
Ohio	5,600	11	89	4,984
Kentucky	3,300	7	93	3,069
Indiana	6,900	8	92	6,348
Pennsylvania	5,300	24	76	4,028
West Virginia	2,750	13	87	2,393
Tennessee	3,800	19	81	3,078
Mean				3,983

a: USDA 2013; b: Plantinga et al. 2002

[4] Corrected for development

The value of agricultural land depends on a variety of ecosystem services that could be impacted by CC. Increases in temperature, CO_2, and precipitation patterns could impact agricultural production rates, practice categories, and costs. (For potential impacts on production see Q2.1 and Q2.3, this report.) Heavier rains could increase erosion, thereby reducing the fertility of the soil. Increased incidences of disease or the introduction of new diseases tolerant of the CC could likewise impact the value of agricultural lands.

4. Forested land. Forested land produces timber, biomass for fuel, and wood fiber. Forested ("timber") land values capture the net present value of all the goods and services (market and non-market) provided by the land. The value includes the contribution of numerous ecosystem services that support the ability of the land to produce the valued goods and services—growing season, precipitation patterns, soil, and the regulating ecosystem services of pest regulation and nutrient control. Forested land also stabilizes the local and regional climate by carbon and air pollutant capture, and cooling energy provision, thus contributing to climate regulation.

   The value of timberland was estimated at about \$600/acre in Lake States and \$1,500/acre in the South by the National Council of Real Estate Investment Fiduciaries (Havsy 2013). A rough estimate of the value of forested land was about \$1,000/acre across the ORB in 2013 (USDA 2013). A median value of \$1,000/acre was used for calculations of the ORB-wide value of forested land. With 50.6% of land within the ORB or 103,500 mi^2 being forested land (USACE 2009), the total value of the ecosystem service values reflected in forested land use values within the ORB is about 66 billion U.S. \$ (Table B-8 in Appendix B).

   Historically, Ohio has transformed from prairie to forest as a result of changes in precipitation patterns. Remnant prairie lands are still present in the Edge of Appalachia areas. This trend could be reversed by changing precipitation patterns. CC may also impact fire regimes and diseases forest (Handler et al. 2012), leading to temporary destruction of forest and affecting local and regional climate, runoff patterns, and river and stream dynamics.

5. Fisheries. Fish production can be valued using capture fisheries as a measure (catch value). Commercial harvest of fish is allowed and regulated in some, but not all, ORB states. The harvest weight of 1.4 million pounds, consisted by weight of 38% of catfish (channel, flathead, and blue) accounts for only 17% of the economic value of the harvest (American Herbal Plants Association [AHPA] 2007). The fish harvest in 2005, worth \$3.2 million, consisted of 88% of paddlefish and paddlefish roe. The average fish harvest level within the ORB from 2001 through 2005, including the following rivers—Ohio, Wabash, Cumberland, Kentucky, and Salt—was estimated at approximately 1.4 million pounds with an associated ex-vessel value of \$2.0 million in 2010 (Great Lakes and Mississippi River Interbasin Study [GLMRIS] Team 2012; Table B-8 in Appendix B). Increased temperature, precipitation, and changes in flow regimes caused by CC may impact both the health of the ecosystem and harvest conditions. Reduced harvest levels and values have been attributed to the long periods of high river levels and flows restricting the number of fishing days (AHPA 2007).

6. Wild harvest production. The harvest of non-wood forest products includes medicinal herbs, food and forage crops, furs, pine cones, maple sap, and Christmas trees, which are collected and sold. Quantitative data and analysis of these ecosystem services are lacking. However, representative data are presented here indicating the magnitude of the value of both market and non-market non-wood forest products. The market value of medicinal herbs within the U.S. was estimated at \$600 million in 1998 (Robbins 1999).

Information on the wild-harvested herb mass in North America is reported by the AHPA (AHPA 2007). Most medicinal plants are harvested from temperate forests within the U.S. (Robbins 1999). Top commodities by volume include slippery elm (*Ulmus rubra*), black cohosh (*Actaea racemosa*), Echinacea species, goldenseal (*Hydrastis canadensis*), and wild yam (*Dioscorea villosa*) (U.S. Forest Service 2013). Harvests of natural products occur under permit in the National Forests. In 2007, this harvest represented 622,000 tons (U.S. Forest Service 2013). In the same year, permits to harvest 1.6 million pounds for food and forage, and 250 bushels of nuts, berries, and fruit were issued; and 1.3 million gallons of maple sap, Christmas trees, pine cones, and other materials for arts and crafts were also harvested.

All these data are aggregated at the national level, making estimates of harvests in the ORB difficult. However, the available information suggests that wild harvest is a relatively small, but possibly culturally significant, ecosystem service within the ORB.

CC impacts may cause changes in forest communities directly and/or indirectly by increased invasive species, pests, and diseases.

8.1.3.2 Regulating Ecosystem Services

1. Near-stream land value. Near-stream natural land areas regulate surface water flow by reducing volume and runoff flashiness into streams, thereby preventing and reducing flooding. These ecosystem services are expected to be associated with a high monetary value since they greatly reduce the risk of flooding for the human population and livelihoods in the ambient landscape. However, it proved to be difficult to assign a value to these services.

   Man-made structures, located partly or completely within a floodplain, near a stream or river prone to periodic flooding, are considered as being within a "flood zone." Residential properties within flood zones have lower values than comparable homes outside flood zones. The difference in value reflects the difference in flood risk. For example, in a recent study it was found that a flood zone home value was 7.5% less than the average home value, with the reduction reflecting the difference between locations within a 100-year floodplain versus locations within a 500-year floodplain (Bin et al. 2008). In Ohio, 15% of the land area is designated as Special Flood Hazard Area by the Federal Emergency Management Agency (FEMA) and this area supports man-made structures valued at $11 billion (Ohio Department of Natural Resources [ODNR] n.d.).

   Flood damage in Ohio to property was estimated at $1.46 billion and to crops at $64.2 million in the period 2003 to 2007. This is a conservative estimate, since flood damage often exceeds insured losses; in addition, 26% of the damage claims in Ohio were outside the Special Flood Hazard Areas (Hazards and Vulnerability Research Institute [HVRI] n.d.). For the entire ORB, the value of insured man-made structures at risk to flooding was estimated at $70 billion and of uninsured structures at $6 billion (USACE 2009). The value of $76 billion represents a conservative value of the flood control services provided by near-stream land (Table B-8 in Appendix B).

2. Wetlands. Wetlands provide a great variety of ecosystem services. They provide regulating services as surge capacity for floodwaters, regulate flow and purify water by the retention and/or destruction of excess nutrients and pollutants, provide habitat to wildlife, and are used by humans for recreation. There are 1,500 square miles of wetlands within the ORB (USACE 2009).

Wetlands ecosystem services in general, including swamps and floodplains, have been valued at $48,384/acre per year ($19,580/ha), a factor of 24 times greater than the value of crop land $2267.3/acre in the past ($92/ha; Costanza et al. 1997). Following the same line of reasoning, the wetlands within the ORB may have an annual non-market value of $7.6 billion.

Three specific ecosystem services of wetlands (i.e., GHG mitigation, nitrogen mitigation, and waterfowl habitat) included within a study on wetlands in the Mississippi Alluvial Valley were valued at $3,699.2/acre per year ($1,497/ha; Murray et al. 2009). Assuming that these services are similar for wetlands in the Mississippi Alluvial Valley and the ORB, a value of $582 million per year is estimated for wetlands within the ORB (Table B-8 in Appendix B).

3. Urban ecosystem services. Urban areas essentially "import" products of ecosystem services both from surrounding areas and far-flung localities within the ORB. Urban ecosystem services include provisioning and regulating services in the form of reduced costs of drinking water production and wastewater treatment, stormwater drainage, energy (through microclimate regulation), and noise reduction, as well as cultural services from recreation, all of which positively impact the human quality of life in an urban environment (Bolund and Hunhammar 1999, Gómez-Baggethun et al. 2013). There are also direct ecosystem services within the urban area itself which have not been fully captured in the previous ecosystem services, including air purification, microclimate regulation, and water flow regulation and water quality purification by single, or groups of, urban trees, and urban ponds, lakes, and wetlands. Awareness of these urban ecosystem services is growing, and research incorporated in the recently started Macrosystems Ecology Research Program of the National Science Foundation (NSF) (Groffman et al. 2014). Selected examples of urban ecosystem service values are provided in Table 8-4.

Table 8-4: Urban Ecosystem Service Values

Urban Ecosystem Service	Value		Reference
	Quantity/y	$/y	
Regulating			
Air quality regulation: air pollution removal by urban trees (Chicago, IL)	5,500 tons/city	9 million/city	McPherson et al. 1997
Water regulation: runoff reduction by urban trees (Modesto, CA)	845 gallon/tree	7/tree	McPherson et al. 1999
Climate regulation: cooling energy provision by urban trees (Chicago, IL)	0.48 GJ/tree	15/tree	McPherson et al. 1992

8.1.3.3 Cultural Ecosystem Services

1. Recreation. The ORB provides significant cultural ecosystem services largely in the form of recreation, including boating, swimming, hunting, fishing, and enjoying the beaches of lakes, streams, and rivers. Recent data on overall recreational benefits were not identified, but several examples of recreational trends are provided in the following paragraphs.

In 1994, one million passengers per year went on riverboat cruises and riverboat casinos had a $12 million payroll; 200 marinas existed, employing 1,500 people with an annual payroll of $3 million. More recent data show that the Pittsburgh District locks alone accommodated about 30,000 recreational boats per year (ORSANCO, USNPS, and ORBC 1994).

Outdoor recreation—hunting, fishing, hiking, skiing, and camping—is enjoyed in extensive undeveloped natural areas of the ORB. Outfitters, lodging, dining, and resorts businesses in the thousands are enabled by the ecosystem services of the region. There are 215 state parks and state natural resource areas and 83 USACE reservoirs in the basin, which draw in millions of visitors annually. Benefits from the reservoirs alone have an estimated value of more than $4 million per year. Tens of millions of tourists enjoy "two National Parks, two Wild and Scenic River Segments, thirty-three National Forests, nine National Parkways, seven National Recreation Areas, twenty-two National Wildlife Refuges, and thirty-six National Wilderness Areas" (USACE 2009).

The value of expenditures for hunting, fishing, and wildlife-related recreation in selected states within the ORB was used as an indication of the value of outdoor recreation. That total amounts to $13.3 billion year for Ohio, Kentucky, Pennsylvania, West Virginia, and Tennessee (Table 8-5). It has to be noted, though, that the actual recreational value may equal or exceed the amount that consumers are willing to pay to enjoy the ecosystem service.

Table 8-5: Annual Expenditures on Recreation (Hunting, Fishing, and Wildlife-Associated) Within the ORB[5]

State	Annual Expenditure (billion $/y)
Ohio	3.5
Kentucky	2.9
Pennsylvania	2.8
West Virginia	1.2
Tennessee	2.9
Total	13.3

8.1.3.4 Summary of Major ORB Ecosystem Services at Risk From CC

The ecosystem services within the ORB, to which currently the greatest monetary values are assigned, are in decreasing order: (1) freshwater, related source of drinking water source, power generation, and goods transport infrastructure, (2) agricultural-land associated food production, (3) flood control by near-stream land and wetlands, (4) forested land-related timber production for fuel, and (5) freshwater- and forested land-related recreation. These service categories are listed in Table 8-6, along with their main potential risks to CC.

Table 8-6: Major ORB Ecosystem Services Potentially at Risk from CC

Ecosystem Service	Value At Risk (billion U.S. $/y)	Risk to CC
Freshwater- related source of drinking water, power generation, goods transport infrastructure	36-104.6 1,070 29	Increased temperature, CO_2, precipitation (river dynamics, droughts, floods, storm water dynamics; changed fire regimes
Agricultural land-associated food production	181	Increased temperature and CO_2 level, changed precipitation pattern (water shortage, droughts,

[5] From USDOI, USFWS et al. 2011

Ecosystem Service	Value At Risk (billion U.S. $/y)	Risk to CC
		extreme precipitation, flooding, erosion); insects, animal diseases, feed shortage for livestock
Near-stream land-Wetlands-related flood control	76 0.582-7.6	Increased flooding; extended low flows during high water demand in hot-weather periods for power generation
Forested land-related timber production for fuel	66	Increased temperature and CO_2 level, changed precipitation pattern (see above); insects, animal diseases; changed fire regimes; conversion to prairie
Freshwater- and forested land-related recreation	13	Increased temperature, CO_2 levels, and changed river dynamics; droughts, fire regimes, changed forest communities

8.1.4 Water Use and Availability

In some basin localities, withdrawal of water for human use removes much of the available streamflow during low-flow conditions. During these low-flow periods, water to meet in-stream needs of aquatic ecosystems is often limited and competition between the needs of people and natural systems is likely to be increased by CC. Published estimates of the ratio between in-stream use and total use of streamflow indicate that in the Water Resources Regions of the Great Lakes, Ohio, and Tennessee, 97 to 99% was already used in the seventies (Meyer et al. 1999; total streamflow calculated as 1975 streamflow + 1975 "consumption"–1975 overdraft).

More recent data on water use within the ORB are being compiled by ORSANCO, and are summarized as follows (ORSANCO n.d.; ORSANCO 2013a). Data on water use within the U.S. are currently estimated at 5-year time intervals by the USGS. The water use data used in the 2005 USGS report (Kenny et al. 2009) are available for public use at http://water.usgs.gov/watuse/. Water use is defined here as water withdrawal; all of this water is not necessarily consumed, and available streamflow is not taken into account. Total freshwater use within the ORB is estimated at 43,817 Mgal/d, which is about 12.5% of the Nation's total freshwater use (349,418 Mgal/d). The ORB houses 9.5% of the total population (U.S. Census 2010), and covers 5% of the U.S. land surface area. Current water availability in Mgal/d on average within the ORB is unknown at this time. Of the total amount of freshwater within the ORB, 2,137 Mgal/d (4.9%) was withdrawn from GW sources, and the rest originated from surface water. Water withdrawals varied from 79% for thermoelectric use (34,452 Mgal/d) to <1% for irrigation, livestock, mining, and domestic water supply, respectively (Table 8-7).

Table 8-7: Estimated ORB Freshwater Use During 2005[6]

Freshwater User Category	Water Use (Mgal/d)	Water Use (% total)
Total use	43,817	100
Thermo-electric	34,452	79
Public water supply	3,584	8
Industrial	3,639	8
Aquaculture	1,086	3

[6] From ORSANCO 2013a

Freshwater User Category	Water Use (Mgal/d)	Water Use (% total)
Irrigation	217	<1
Livestock	155	<1
Mining	324	<1
Domestic water supply	359	<1

The ORB overlays three aquifers that serve as GW sources, including the Pennsylvania/Mississippian aquifers in the northeast (approximately 86,000 square miles in the Appalachian Plateaus region of Pennsylvania, Ohio, Maryland, Virginia, West Virginia, Kentucky, Tennessee, Georgia, and Alabama), the Glacial Aquifer in the north and northwest (underlying Ohio, Indiana, and Illinois), and the Mississippi Embayment aquifer in the south (underlying portions of seven states, including Arkansas, Louisiana, Mississippi, Tennessee, Alabama, Missouri, and Kentucky (http://water.usgs.gov/ogw/gwrp/activities/regional.html).

Regional GW studies are ongoing since 2010, prompted by the depletion of GW and the compounding effects of recent droughts emphasizing the need for updating the information on the availability of the Nation's GW resources. These studies are conducted by the USGS within the Groundwater Resources Program (GWRP), and use quantitative information previously collected within the Regional Aquifer System Analysis, and historical information on aquifers at higher spatial resolution (county) collected by states. For example, statewide aquifer mapping data for Ohio can be retrieved and visualized via the web (htpps://ohiodnr.com/water/samp/default/tabid/4218/Default.aspx). The GWRP studies include an assessment of how GW resources have changed over time, and development of tools to forecast regional responses to human and environmental stressors to assist answering questions about the Nation's ability to meet current and future demand for GW. Recognition by water managers and municipalities is growing that GW resources could be managed on an aquifer-wide spatial scale. Among the regional studies on the four abovementioned aquifers, the study on the Mississippi Embayment aquifer is complete and studies on the remaining three other aquifers are ongoing (expected to be completed in 2016–17). See hyperlink for more information: http://water.usgs.gov/ogw/gwrp/activities/regional.html

8.1.5 Management Authorities

Changes in climate affect ecosystems and, therefore, their management. Sustainable water management safeguarding the goods and services of healthy aquatic ecosystems, and meeting future human water "consumption" needs would greatly benefit from an ability to accurately (1) assess the goods, services, and associated water needs of aquatic ecosystems, and human water "consumption," (2) predict how these may be altered by CC, and (3) evaluate management options. Water management programs fulfilling legal requirements must take CC-related effects into account and adopt strategies that mitigate and/or adapt to these impacts.

8.1.5.1 Water Quality

In the United States, the main legislation for the assessment and prevention of water pollution is based on the Clean Water Act (CWA) of 1972, Air Pollution Prevention and Control Act of 1977, Coastal Zone Management Act of 1972, Harmful Algal Bloom and Hypoxia Research and Control Act of 1998, and the Oceans Act of 2000. Responsibility for monitoring and assessment of water quality is shared by Federal agencies, primarily the USEPA and NOAA. The USEPA is charged with regulating most aspects of water quality under the Federal CWA (USEPA 2003). This establishes that, wherever possible, water quality must provide for the protection and propagation of fish, shellfish, and wildlife; for recreation in and on the water, and protection of the physical, chemical, and biological integrity of those waters. States and tribes designate uses for their waters in consideration of CWA goals and establish water quality criteria to protect integrity and uses.

The CWA Sections 305(b) and 303(d) state reporting requirements that entail regular monitoring designed to identify water bodies that do not meet criteria for designated uses. These water bodies are included on the Section 303(d) list of impaired waters, which establishes protocols that must be followed to mitigate pollution induced impacts (USEPA 2003). Responsibility for implementing standards and criteria, and for monitoring to assess attainment, is generally delegated by USEPA to state water management authorities. Within the ORB, this responsibility has been delegated to multiple states, with responsibility of the Ohio River mainstem delegated to ORSANCO. (See Section 8.3 for additional information on water quality impacts from climate change.)

8.1.5.2 Water Quantity

Water quantity in major river systems is managed through flood control and multipurpose reservoirs and through the operation of navigation locks and dams by the USACE. Most laws governing water quantity management are of state rather than Federal origin, but there is an important Federal presence. Important Federal programs include FEMA, which is responsible for administering the National Flood Insurance Program (NFIP) and Disaster Assistance. Furthermore, there are State Flood Control and Drainage laws, and State Water Deficiency legislation.

The ORB spreads over 13 different states and has many more political, physical, and jurisdictional boundaries, each with their own differing water use rules. The ORB meets the demands of all water needs and, therefore, the water within the basin has many designated uses. Among the many uses, the major ones include drinking water, thermoelectric power supply, industrial, commercial, recreation, and navigation. A central authoritative agency governing water use within the ORB does not exist and, therefore, regulations of various governing entities are employed to regulate water use. Water resource laws and regulations within the ORB were recently reviewed by ORSANCO (ORSANCO 2012).

8.2 Environmental/Ecosystem Concerns to be Addressed

To identify aquatic environmental resources at risk to the impacts of CC, the following concerns serve as waypoints in the analysis:

1. What are important climatic change related effects on, and threats to, aquatic ecosystems?
2. How do climatic change effects manifest themselves in aquatic ecosystems?
3. Which aquatic ecosystems have been identified in the Ohio River Basin; which of these systems are at risk to climatic change?
4. What do relative vulnerability, resilience, and sensitivity of an aquatic ecosystem mean; how can these characteristics be measured and mapped?

5. What patterns of predicted climatic change on a regional scale have been confirmed; and how may management in the Ohio River Basin be altered to protect and maintain aquatic ecosystem goods and services in a changing climate?

The goal of this report is to provide managers and scientists working on sustainable water management with available, published information regarding the abovementioned concerns 1, 2, 3 and 4 in general, and more specifically relating to the ORB, with identification of published and unpublished information regarding concern 5. This information may serve as the basis for follow-up studies that address the information needs in support of developing a sustainable management strategy of the ORB.

8.2.1 General Effects of CC on Aquatic Ecosystems

The major changes in climate include increased atmospheric carbon dioxide concentration, increased air temperature, and altered precipitation regime. These changes by themselves have multiple effects, including increased water temperature, altered evapotranspiration, altered water chemistry, altered flow, reduced ice cover, increased carbon dioxide in waters, increased snowmelt, increased sea levels, and altered stratification regime. These effects in turn impact ecosystems at the levels of the ecosystem itself, community, population, and individual. Ecosystem-specific organisms integrate the impacts of changes in environmental and biotic factors on the ecosystem in which they live, and their presence and condition can, therefore, be used as a measurable parameter for ecosystem health (Figure 8-1; USEPA 2008a).

Aquatic and terrestrial ecosystems are situated in the same landscape, significant interactions between them occur, and both are greatly affected by anthropogenic influences. Because of this, the impacts of CC on the goods and services provided by freshwater ecosystems in the U.S. should be considered in the context of large overall anthropogenic changes in water quantity and quality stemming from altered patterns of land use, water withdrawal, and species invasions, since the latter altered patterns may mask or increase climate-induced changes. Multiple lines of independent evidence confirm that human activities are the primary cause of the global warming over the past 50 years (Melillo et al. 2014).

Because human-induced warming is superimposed on a background of natural variations in climate, warming is not uniform over time. Temperatures are projected to raise 2–4^{o}F in most areas of the United States over the next few decades. The amount of warming projected beyond the next few decades is directly linked to the cumulative global emissions of heat trapping gases (GHG), among which carbon dioxide contributes most, and particles. By the end of this century, a roughly 3–5^{o}F rise is projected under a lower emission scenario, which would require substantial reductions in emissions, and a 5–10^{o}F rise for a higher emission scenario assuming continued increases in emissions, predominantly from fossil fuel combustion.

The amount of future CC will largely be determined by choices society makes about emissions. Lower GHG emissions lead to less future warming and less sever impacts, while higher emissions lead to more warming and more sever impacts. Efforts to limit emissions or to increase carbon uptake, reducing the rate of future CC, fall into a category of response options called “mitigation.” A major other category of response options, called “adaptation,” refers to actions to prepare for and adjust to new conditions, thereby reducing harm or taking advantage of new opportunities. Both are essential parts of a comprehensive CC response strategy.

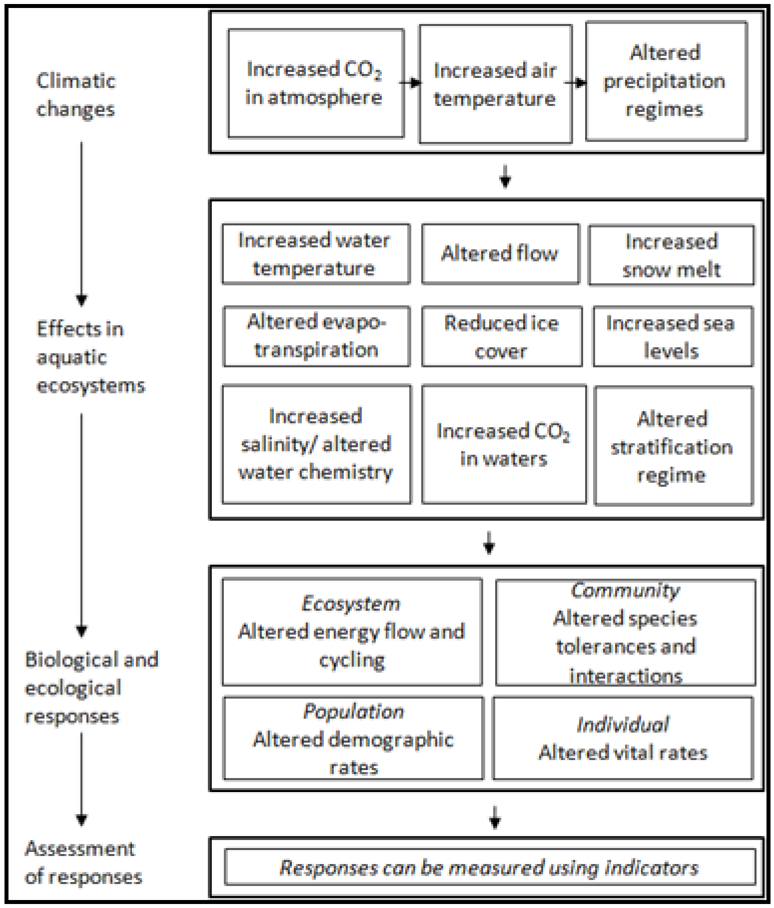


Figure 8-1: Conceptual Diagram of CC Effects on Aquatic Ecosystems and Possible Ecosystem Responses that Can Be Measured Using Biological or Ecological Indicators[7]

Climate change is a process that is already occurring, and it may be difficult to separate the historic anthropogenic influences from climate change in general (Allan 2004; Woodward et al. 2010), including within the ORB. Solar and long-wave radiations are the dominant components of heat flux to aquatic systems (Cassie 2006). Even with the consideration of natural thermal mitigations, human practices tend to increase freshwater temperatures (Hester and Doyle 2011), with the exception of waters downstream of some hypolimnetic release dams. Thus, changes that reduce riparian cover and modify lotic system flow (i.e., damming) are likely contributing to increased freshwater temperatures, independent of CC.

8.2.2 Management Needs for Information and Knowledge in Support of Management Strategies to Adapt Aquatic Ecosystems To CC

1. Management. Water managers face important questions concerning the implications of long-term CC for water resources. Potential concerns include the risk to water management goals, including the provision of safe, sustainable water supplies, compliance with water quality standards, urban drainage and flood control, and the protection and restoration of aquatic

[7] From USEPA 2008

ecosystems. Large negative effects of CC on sensitive ecosystems and humans are expected. CC, together with other ongoing stresses, may impede the ability of water resource managers as well as natural resource managers to maintain established goals for ecosystems, species, and humans.

Effective management of resources and ecosystems was based in the past on an expected set of climate conditions, but in the future would have to be more flexible to face the variability and uncertainty of CC. Management for adaptation to CC will have to allow natural and managed systems to adjust to the range in potential variations in future climate change, while building on sustainable management, conservation, and restoration practices.

Sustainable management of waters in river basins would greatly benefit from a holistic approach targeting a "good status" for the entire basin, including surface waters, ground waters, ecological protection, chemical quality protection, and other use protection (the latter in specific areas; http://www.iksr.org/index.php?id=171&L=3), as called for in the management of all waters in the European Union according to the Water Framework Directive (http://ec.europa.eu/environment/water/water-framework/). Besides setting and planning distinct goals, such management would require major coordination and collaboration efforts because of the involvement of multiple states, Federal agencies, and other entities. CC adaptation could be incorporated systematically into a holistic, sustainable management framework planning cycle, via the eight steps commonly followed and outlined (Julius et al. 2013; Stein et al. 2014):

a. Define area of interest
b. Conduct an adaptation plan based on vulnerability of management objectives to CC, on at least local and regional scales
c. Address uncertainty by analysis of the effects of the primary sources of uncertainty, including CC, on adaptation options
d. Modify existing management practices to include addressing temporal and spatial CC effects and ecological responses
e. Increase flexibility by coordinating with other managing entities at various spatial scales to attain management goals
f. Implement management and research efforts, coordinate, integrate, and disseminate information across jurisdictional borders to increase the scale at which adaptation management can be applied
g. Monitor and evaluate CC impacts and ecological responses to management actions
h. Reassess.

2. Needs for improved information and knowledge in support of management strategies to adapt to CC. Improvements in measuring, modeling, and understanding CC relevant to the hydrologic cycle, water quality, and aquatic ecosystems are needed, and management strategies of the past may not be adequate given the increased awareness of stressors including CC and land use change.

   Scenario analysis using computer simulation models is a useful and common approach to assess the vulnerability/risk to plausible, but uncertain, future conditions. However, the results of watershed assessments through modeling approaches are influenced by the characteristics of the watershed model that serves to translate climate forcing into hydrologic and water quality responses. These model results are also influenced by the characteristics of the CC scenarios forcing the watershed models.

3. Models. Models to examine the impact on aquatic systems of alterations in those properties identified as sensitive to CC can be important tools contributing to our understanding of complex interactions in watersheds at various temporal and spatial scales.

   At least the following model categories should be considered:

   a. In-streamflow models
   b. Models of nutrient uptake related to hydrodynamic properties
   c. Models of bioenergetic response
   d. Models relating riverine food web structure to climate and hydrologic regime.

   Both model categories a and b may be combined in watershed models enabling estimates of in-streamflow and nutrient uptake related to hydrodynamic properties. Model categories c and d remain distinct categories.

   At the national level, a relatively large body of literature exists on the potential CC effects on water quantity; far less is known about the potential CC effects on water quality and aquatic ecosystems, but progress is being made (Whitehead et al. 2009). Despite progress in our understanding of climate science and modeling, we currently have a limited ability to project long-term (multi-decadal) future climate at the local and regional scales needed by decision makers (Sarewitz et al. 2000).

4. Watershed models usage. A watershed model is a useful tool to provide a quantitative linkage between external forcing and in-stream response. It is essentially a series of algorithms applied to watershed characteristics and meteorological data to simulate naturally occurring land-based processes over an extended period of time, including hydrology and pollutant transport. Many watershed models are also capable of simulating in-stream processes.

   a. Water quantity. The SAC-SMA model is a conceptually based rainfall-runoff model with spatially lumped parameters; it models only water quantity. It is currently routinely used by NOAA/NWS for hydrological modeling purposes, including dam safety hydrologic hazards. The model is ideal for large-scale (>1000 km2) drainage basins, uses mean precipitation, evaporation, and air temperature as inputs, and uses multiple years of records for calibration. Important characteristics are that the model distinguishes two soil zones: an upper zone with pervious and impervious options (short-term storage capacity) and a lower zone for the bulk of the soil moisture and longer GW storage. The model is generally run at a 6-hour time step, but can be run at any time step (Burnash et al. 1973; Burnash and Ferral 2002; BOR 2003). The SAC-SMA model was used to evaluate effects of CC on streamflow in the ORB as part of the current USACE Pilot Project. For this activity, the CMIP3and CMIP5 CC data sets were used as basis for CC input generation for the SAC-SMA model, calibrated for the main stem of the Ohio River.

   b. Water quantity and quality. Two watershed models are of particular interest where the goals are to model the effects of CC on water quantity as well as quality, both important characteristics of water resources: Hydrological Simulation Program-Fortran (HSPF) and Soil and Water Assessment Tool (SWAT). Both models are available in the public domain and have a long history of application. They differ in the way they represent infiltration and plant-climate interactions. HSPF simulates rainfall-runoff processes using Green-Ampt infiltration, in which infiltration into the soil is simulated first, with the remainder available for direct runoff or surface storage. HSPF is typically run at a sub-daily time step, usually hourly for large watersheds, and has a more sophisticated representation of runoff, infiltration, and channel transport processes than SWAT. In contrast, SWAT simulates rainfall-runoff processes using a Curve Number approach, operating at a daily time step. The Curve Number approach first partitions incoming moisture into direct runoff and the remainder is available for infiltration. SWAT's advantage is that it incorporates a plant growth model and can, therefore, simulate some of the important feedbacks between plant growth and hydrologic response (water uptake, growth, and plant respiration) and account for fertilizing effects of increased CO2. SWAT's disadvantage is that it uses the Curve Number approach, which limits application to daily time steps and can, therefore, not be used to model hydrological events over periods shorter than 1 day.

c. Twenty watersheds study. A watershed model approach to assessment of CC and land use change effects on water quantity and quality was explored. Both HSPF and SWAT models were used in a study with goals to evaluate watershed response to CC and land use change in 20 drainage basins throughout the contiguous U.S. (USEPA 2013b). CC inputs served six dynamically downscaled scenarios available from the North American Regional Climate Change Assessment Program (NARCCAP), as described in the following paragraphs.

   NARCCAP–Six dynamically downscaled scenarios, available from NARCCAP (http://www.narccap.ucar.edu/), served to force the HSPF and SWAT models used by USEPA to simulate watershed response in 20 watersheds, in terms of temperature, PET (actual ET-SWAT only), streamflow (annual, peak-flow, dry-period flow) flashiness, TSS, TP, TN. These scenarios were: (1) GCCM3/CRCM, (2) Had/HRM3, (3) GFDL/RCM3, (4) GDFL/GFDL hi res, (5) CGCM3/RCM3, (6) CCSM/WRFP.

   i. Results of this study. Among the 20 watersheds evaluated, the Lake Erie Drainages and Illinois River Basin appear to be most similar to the ORB and, therefore, simulation results may provide information that can be used in support of our understanding of CC effects on the aquatic resources of the ORB. The results indicated that "the variability in watershed response resulting from a single GCM downscaled using different RCMs can be of the same order of magnitude as the ensemble variability between the different GCMs evaluated. Watershed simulations using different models with different structures and methods for representing watershed processes also resulted in increased variability of outcomes. SWAT simulations accounting for the influence of increased atmospheric CO2 on evapotranspiration significantly affected results. One notable insight from these results is, that in many watersheds, increases in precipitation amount and/or intensity, urban development, and atmospheric CO2 can have similar or additive effects on streamflow and pollutant loading (e.g., a flashier runoff process with higher high and lower low flows)."

   ii. Recommendations of this study. Recommendations for follow-up activities in watershed modeling included the following:

      - Use for future studies on watershed response to CC, with CC scenarios that contain data on all following parameters to enable proper inputs for modeling assessments of water quantity and quality, since both are important for water resources presence and condition. Parameters: temperature, precipitation, dew point temperature, solar radiation, wind speed, minimum temperature, maximum temperature, and precipitation bin data.

- Quantify the variability in model results, conduct sensitivity studies evaluating the implications of different methodological choices, and build the capacity of the water management community to understand and respond to CC.

5. Models of bioenergetic response. Models that predict ecological changes due to CC have common tendencies and broadly fall into two categories (Sipkay et al. 2009). In general, models provide hypotheses of general effects on biota based on abiotic changes to the aquatic system. These biotic effects are then extended to communities. Typically, the models are for specific habitats and environments and do not work well as models as "general ecosystem" models of climate change, and models that link species-specific impacts and ecosystem impacts of CC are rare (Mooij et al. 2009). Given this, models take one of two approaches:

   a. Model type-1. Model type-1 considers predicted physical changes (e.g., temperature, hydrology) first and changes to communities, for example, follow.

   The metabolic theory of ecology (Brown et al. 2004) offers a solid basis for the building of multi-scale bioenergetic models because it theorizes that most variation in an organism's metabolic rate is explained by temperature and body mass. A theoretical non-linear bioenergetics model that considers allometric body size and temperature dependencies was developed for a three-species food chain (Binzer et al. 2012). The model describes changes in biomass (B) for a basal species (B_B), an intermediate species (B_I), and a top species (B_T) with the following differential equations (Eq.),

$$B_B = x_B G_B B_B – B_I f_{IB}, \qquad (1)$$

$$B_I = \square_{IB}(BI f_{IB}) – B_T f_{TI} – x_I B_I, \qquad (2)$$

$$B_T = \square_{TI}(B_T f_{TI}) - x_T B_{T,} \qquad (3)$$

   where x_B (s^{-1}) is basal species mass and temperature-specific growth rate, G_B is the basal species' logistic growth term, and B_B is the basal species population biomass density. f_{IB} and f_{TI} are functional responses for feeding dynamics in the food chain for intermediate consuming basal and top consuming intermediate species, respectively. $\square_{IB}$ and $\square_{TI}$ are assimilation efficiencies of energy transfer between trophic levels, assumed by Binzer et al. to be 0.85. The mass and temperature dependent metabolisms of the intermediate and top species are x_I and x_T, respectively. The mass and temperature dependent metabolic rates are based on metabolic scaling derived equations based on first principles (West et al. 2001, Gillooly et al. 2001),

$$x_i = \varepsilon^I \ m_i^s \ e^{\left(\bar{E}/kT_0\right)\left((T-T_0)/T\right)} \qquad (4)$$

   where ε^I is the rate specific constant, m_i is organismal mass (g), and s is a scaling coefficient (theoretically 0.75, but can vary). The third term that includes the base of the natural log is the Arrhenius equation that describes the temperature dependency on rates of reaction, where $\overline{E}$ is the average energy of activation (West et al. 2001), k is the Boltzmann constant, and T_0 is a reference temperature (K) and T is observational temperature. Further intermediate and supporting equations for Eq. 1–3 are found in Binzer et al. (2012).

A few general predictions are derived from the models (Eq. 1–3). First, warming stabilizes the effects of nutrient enrichment in systems and then upper trophic level consumers show increased body mass with warming, which increases system tolerance to increased fertilization. In low fertilized systems, the model predicts large-bodied consumers will starve. This model can be used as a basis for both lotic and lentic system.

A number of models are bottom-up models designed for lentic systems. These models predict the dynamics of planktonic algae, the basal lentic trophic level, and then develop predictions about other aspects of the system based on changes in phytoplankton. One such model is PCLake (Janse 2005; Mooij et al. 2009), which puts equivalent emphasis on both abiotic and biotic factors and accounts for multiple lentic trophic levels. The function for abiotic processes (i) is given by c_i,

$$f_i(T) = c_i(T - T_0), \tag{5}$$

where T is temperature and T_0 is a reference temperature. The function for biotic processes (j) is a Gaussian function component,

$$f_j(T) = \exp(-0.5((T - T_{opt,j})^2 - (T_0 - T_{opt,j})^2)\,(T^2_{sig,j})^{-1}, \tag{6}$$

where $T_{opt,j}$ is the optimal temperature for the species and $T_{sig,j}$ is the width around $T_{opt,j}$. In PCLake, the temperature coefficient Q_{10} is used to account differential effects on rates as a function of temperature for macrophytes. The model can incorporate numerous abiotic and biotic factors, i and j, into a food web-detailed path-analysis form.

Simple models can also be incorporated into somewhat more complex models, such as PCLake. For example, a simple model for lake phosphorous dynamics (Carpenter et al. 1999) shows changes in phosphorus mass in algae (P) over time (t),

$$\frac{dP}{dt} = l - sP + r\frac{P^q}{m^q + P^q} \tag{7}$$

where s is a dilution rate, l is a fixed term of nutrient loading, r is a rate of internal recycling through biological processes, m is the threshold density, and q is a scaling coefficient (Mooij et al. 2009). Then sP is a proportional loss term and $r(Pq/(mq + Pq))$ is the gain term. This model does not work for riverine systems in which phytoplankton are assumed to be light-limited, not phosphorus-limited.

b. Model type-2. Model type-2 changes in populations or aspects of communities. The latter is often developed based on long-term biological data sets and CC effects are inferred based on accompanying abiotic data. Model type-2 considers changes to populations of some aspects of communities. Models that have predictive application may be preferable, and any biological interpretation of mathematical procedures is of secondary importance (Sipkay et al. 2009). This is counter to biological models based on first principles, such as those based on the metabolic theory of ecology.

Because no model will explain all variation in a system, Sipkay et al. (2009) questioned whether temperature as the primary model variable is effective enough, knowing that temperature changes will have hidden dynamics at multiple levels not explicitly accounted for in a model. Although the models in question were for plankton seasonal changes, the approach may extend well to other aquatic ecosystem levels as a general approach. This approach supports the use of developing statistical models based on patterns in empirical data from long-term data sets.

6. Models relating food web structure to climate and hydrologic regime. This model category could be a hybrid of watershed models, models on bioenergetic response, CC, and management. The management category dealing with reservoir operation and its relationship with upstream and downstream water levels, water quality, and air quality (GHG) would fit here. According to this approach, riverine macrosystems are described as watershed-scale networks of connected and interacting riverine and upland habitat patches. Such systems are driven by variable responses of nutrients and organisms to a suite of global and regional factors (e.g., climate, human social systems) interacting with finer-scale variations in geology, topography, and human modifications (McCluney et al. 2014).

7. Information and modeling needs.

    a. Monitoring data: additional data on streamflow and ecological elements; data on physical and chemical properties of water bodies; all with attention for annual as well as short-term variations. Water data portals accessible to the public include (a) National Water Quality Data web portal: http://www.waterqualitydata.us; and (b) Consortium of Universities for the Advancement of Hydrologic Science, Inc. Water Data Center: http://wdc.cuahsi.org.

    b. Studies linking hydrological regime with ecological processes, interactions, and water quality; in this context, focus on terrestrial-aquatic linkages is particularly important.

    c. Studies on development of indicators for stresses, including CC, to aquatic ecosystems under various land-use regimes.

    d. Studies on the degree of interconnectedness and integrity of floodplains and watersheds.

    e. Studies at increasing geographical scales. Macrosystems ecological studies are expected to fill this need (Soranno and Schimel 2014; Groffman et al. 2014).

    f. Studies on migratory species, the migration ranges of which may surpass basin boundaries, such as migratory fish, sensitive fish (e.g., paddlefish) and water-dependent birds (migrating via the Mississippi and Central Flyways).

    g. Modeling activities linking climate variability with ecological processes at the population, community, and ecosystem level. Sensitivity analyses examining thresholds (relevant to ecological processes and management targets) might be a more direct way of identifying management options to mitigate/adapt.

    h. Integrated assessments of potential impacts and viable response options for alternative futures (under changes in land use and climate).

Based on our improved knowledge and understanding of the multiple complex interactions within the ORB, CC effects on the component watersheds and feedbacks of watershed elements and organisms, current management in the ORB may be altered by adopting a strategy that includes adaptation/mitigation measures to CC effects on aquatic ecosystems in the basin and beyond, thereby contributing to solutions of water resources issues downstream of the ORB, including coastal waters such as the Gulf of Mexico.

8.2.3 Identification of Aquatic Ecosystems Within the ORB Potentially at Risk to CC Format This Section Too

1. General impacts of projected climate changes. Although the modeled climatic predictions vary across the ORB and are somewhat uncertain (especially in the latter portion of the 21st century), much of the basin appears likely to experience significantly higher high-flow events and in some cases, lowered low-flow events. In the face of changing land use and energy development, and where these projected air temperature and flow changes deviate more than 25% from the current levels, it is likely that fish and mussel populations, wetland complexes, reservoir fisheries, trans-boundary organisms such as migratory fish and water body-dependent birds, and human use and safety will also be noticeably impacted.

   The ORB is rich with stream systems of national ecological and recreational significance but does not have many natural lakes or large isolated wetland complexes. However, a number of aquatic systems in the basin have headwater wetland areas or periodically connected wetland features in floodplains, and stream networks with tributary flood control/hydropower projects that create large, artificial reservoirs. The projected climatic changes in the current study can accelerate or "drive" the dynamics of each of these components of a stream system as outlined in the following paragraphs.

   a. Streams. Generally, spring streamflow increases are expected in much of the basin while summer/fall low flows may decrease in periodically droughty areas in western Ohio, Indiana, and parts of northern Kentucky. In the eastern and portions of the southern ORB, increases in late summer and early fall flows are projected. In the context of higher spring flows, it is important to understand that 2- to 5-year floods (frequent mild flooding) are important to create and shape in-stream channel features (MacBroom 2008). However, without connected floodplains, higher flows and increased flooding can be devastating to stream habitat because stream power is confined and increased stream bank and bed scouring occurs (Shankman and Sampson 1991).

      The projected high flows across the basin in spring are often beneficial for fish reproduction because they act as a stimulus and provide access to unique types of habitat niches and spawning substrates (Firehammer and Scarnecchia 2007; Rankin et al. 2012). However, very high flows for mussels and fish are detrimental if streambed scouring occurs (Bowen et al. 1998; Mion et al. 1998). Lower flows in summer/fall often limit fish populations but could bring fish into closer contact with mussels during their reproductive cycle if they do not fall to critical levels (Morales et al. 2006; Haag and Warren 2008). Likewise, higher flows during this period may increase fish diversity and carrying capacity, but higher turbidities may lead to lower reproductive success for mussels as they depend on the proper host being able to see visual lures in order to achieve glochidia (larval mussels) attachment (Hartfield and Hartfield 1996).

      The projected trends in streamflow also have important positive and negative water quality impacts and human use implications. Torrential rainfall events not only lead to increased flooding, but also increased sediment and nutrient transport (Dolan and Richards 2008) that may require additional municipal and industrial water supply treatment and associated costs. Sediment and nutrients can also essentially be "exported" downstream to large river pools and ultimately into the Gulf of Mexico. This contribution creates extreme diurnal dissolved oxygen swings in river reaches and pools (ORSANCO 2012) and drives the size of the anoxic zone in the Gulf of Mexico.

Conversely, lowered, low streamflows during summer and fall have important implications to wastewater assimilation and levels of treatment needed to attain permitted discharge conditions and may result in downstream user conflicts. An additional important human usage change may occur in agricultural western Ohio and Indiana, where potentially hotter and drier summers may result in increased use of ground or surface water for irrigation of row crops. Where local GW drawdowns occur, wetland and baseflow impacts are likely to occur.

b. Reservoirs. Higher spring inflows and reservoir levels throughout much of the basin will benefit fish spawning, but in many cases increased air and associated water temperatures combined with increased nutrient and sediment runoff will also result in increased spatial and temporal extent of anoxic areas within larger reservoirs. When warmer water in the epilimnion of reservoirs occurs in conjunction with expanded anoxic conditions below and at the thermocline, the temperature/oxygen "squeeze" can result in decreased habitat suitability for important cool water sport fishes such as walleye, smallmouth bass, or striped bass (Cheek et al. 1985).

   Anoxic water that is withdrawn in late summer/early fall for human use or is released to streams often contains high levels of hydrogen sulfides and heavy metals that result in acute and chronic impacts (e.g., mortality, decreased growth and vitality) to aquatic organisms (Ligon et al. 1995). These tailwater releases may require longer travel times for atmospheric exposure to volatize or strip these substances and thereby decrease the amount of suitable stream habitat. Likewise, anoxic water withdrawn for human consumption requires greater treatment and associated costs and often retains residual tastes and odors even after conventional municipal treatment regimes.

c. Wetlands. Essentially, naturally functioning and functionally restored wetlands can be viewed as a form of green infrastructure that slow and infiltrate flood events, remove nutrients and sediments (Mitsch and Gosselink 2007), and provide important reproductive and rearing habitat for fish and waterfowl. Increased precipitation and high spring flows could generally restore greater connectivity to this part of aquatic ecosystems and expand areal extent as long as human engineers allow natural "flexing" in the frequency and duration of connectivity rather than undertaking further hydrologic alterations designed to minimize these changes. However, with current land management practices increased nutrients in storm runoff during torrential rain events may occur (Dolan and Richards 2008). An increase in nutrient input combined with air and associated water temperature increases may also increase the rate of eutrophication and eventual filling of wetlands, and shorten the lifespan of these valuable habitat features and the level of ecosystem benefits that they provide.

8.2.4 Projected CC Effects on Hydrologic Patterns, and Potential Impacts on Aquatic Ecosystems and Infrastructure by Hydrologic Unit Code

A list of all Ohio River Sub-basin HUC-4s and the Tennessee Sub-basin HUC-2 are shown in Table 8-8 and Figure 8-2. Capsule summaries of ORB HUCs are presented in Table B-11 in Appendix B, and as major departures from current trends are generally not projected until about mid-century and beyond, include probable climatic changes starting at 2041. Increasing air and associated water temperatures are assumed across all HUCs as outlined in the long-term basin forecast. The probable impacts of these changes on aquatic organisms and human uses are then listed. Potential green or gray water infrastructure types in each HUC that could be investigated as management avenues for climate change adaptation are also shown.

Table 8-8: Ohio and Tennessee Sub-basin HUCs

HUC Unit Name	States Drained	Watershed Area (mi ^{2})
Allegheny (HUC-4)	NY and PA	11,600
Upper Ohio (HUC-4)	PA, WV, and OH	13,200
Muskingum (HUC-4)	OH	7,980
Kanawha (HUC-4\)	NC, VA, and WV	12,200
Scioto (HUC-4)	OH	6,440
Cumberland (HUC-4)	TN and KY	17,848
Middle Ohio (HUC-4)	WV, OH, KY, IN	8,850
Kentucky-Licking (HUC-4)	KY	10,500
Green (HUC-4)	TN and KY	9,140
Wabash (HUC-4)	OH, IN and IL	32,600
Lower Ohio (HUC-4)	KY, IN, and IL	12,500
Tennessee (HUC-2)	VA, NC, AL, GA, MS, TN, KY	40,908

Figure 8-2: Ohio River Sub-Basin HUC-4s and the Tennessee Sub-basin (HUC-2)

1. Importance of spatial scale for management, processes and sensitive species. Defining at-risk environmental resources within the ORB is challenging, but general approaches to incorporate CC adaptation into a management cycle have been developed, in which assessment of relative vulnerability plays an important role (as outlined under Q5.4.1.) (Julius et al. 2013; USEPA 2011). According to a similar approach, vulnerability of watersheds in forested areas was assessed by Furniss et al. (2013) using six steps, including the (1) identification of water resource values and scales, (2) assessment of exposure, (3) evaluation of watershed sensitivity, (4) category of vulnerability, (5) identification of adaptive management responses, and (6) evaluation of the assessment. Their conclusions indicate that (1) the HUC-6 scale currently is the best scale for analysis and reporting, and possibly also for the planning and implementation of management alterations to sustain or improve watershed condition, (2) local and/or regional climate data at the appropriate spatial scale should be used to provide context, (3) historical and current hydrological changes within the watershed should be recorded and compiled, and (4) of the three related elements—vulnerability, exposure and sensitivity—exposure has to be considered first, with a listing of hydrologic changes in the water resource, then sensitivity elements that strongly modify these hydrologic changes have to be identified and selected, followed by elements that are strongly negatively influenced by these hydrologic changes (i.e., sensitive species).

   The Furniss et al. (2013) conclusions were used as a guideline for an initial vulnerability assessment of watersheds within the ORB. Within the ORB, predictive climate data is available only at very large spatial scales (> HUC-4), depending on which data source is accessed/used. Stream gage predictions exist on a HUC-4 spatial scale, or for the Tennessee River only at the HUC-2 scale and, therefore, hydrological monitoring is most reliable on these spatial scales rather than on a HUC-6 scale. Therefore, in the ORB the HUC-4 spatial scale may be the most useful scale for management in general, and particularly advantageous for larger-scale processes and management of migratory species.

   The ORB is a globally important area for freshwater mussel and fish diversity with a number of endemic fish species and federally listed mussels. Fish and freshwater mussel diversity and abundance are inextricably linked as mussels rely on the glochidial (larval form) infestation of varied fish hosts and their subsequent movement throughout stream systems to provide for the maturation and distribution of young mussels (Schwalb et al. 2011). In some cases, rarer mussels are known to be reliant on the presence of a single species of fish (e.g., snuffbox and logperch) or just a few possible fish host alternatives when the glochidia need to be dispersed. As a result, even within the ORB numerous mussels have recently been listed or are being considered for Federal listing.

   There is a strong positive correlation between stream base flow and the presence of sensitive mussel species (Martin et al. 2012), and negative correlations between “flashy” stream conditions (lowered, low flows and bed/bank scouring during extreme flood events). Flashiness can be caused by altered stream hydrology due to local and network impervious surface cover (Martin et al. 2012; Rankin and Yoder 2009), and ditching and agricultural tile drainage (Blann et al. 2009). In smaller streams, many suitable host fish species for mussels are either flow dependent or flow specialists. Therefore, suitable habitat for these species is dependent on certain flow conditions, particularly during critical reproductive periods (Rankin et al. 2012; Dephilip and Moberg 2013). In addition, some of the great river fish thought to be hosts for some of the rarest big-river mussels rely on the environmental stimulus of large increases in streamflow to move upstream and select spawning sites (Firehammer and Scarnecchia 2007).

However, projected climatic changes and trends have the potential to aggravate or intensify the current challenges for rarer, environmentally sensitive fish and mussels whose existence is often driven by short-term exposure to extremes in climate rather than the means experienced over a longer time period (Armstrong et al. 2011). Therefore, application of the framework developed by Furniss et al. (2013) in the ORB in the current study was applied in the following manner: (1) important or sensitive watershed elements must include environmentally sensitive fish and mussels; (2) examination, planning, and implementation of strategies to lessen climatic impacts will by necessity occur within HUC-4 or HUC-2 (Tennessee) accounting units; (3) significant changes in flow from climatic and potential runoff and temperature changes that drive sensitive fish and mussel abundance and distribution and impact current human uses must be examined; and (4) loss of sensitive organisms often indicates the beginning stages of decline in overall watershed health. Therefore, how to lessen any manifested extremes for key stream systems and their most sensitive indicators is also an important consideration in developing a list of at-risk resources and appropriate adaptation strategies.

2. Ohio River Basin Fish Habitat Partnership. Fortunately, the Ohio River Basin Fish Habitat Partnership (ORBFHP) recently developed a list of priority HUC-6s (Figure 8-3) from predictive models based in part on the highest probability of a broad range of important fish and mussel community elements, including the most sensitive aquatic organisms (Martin et al. 2012).

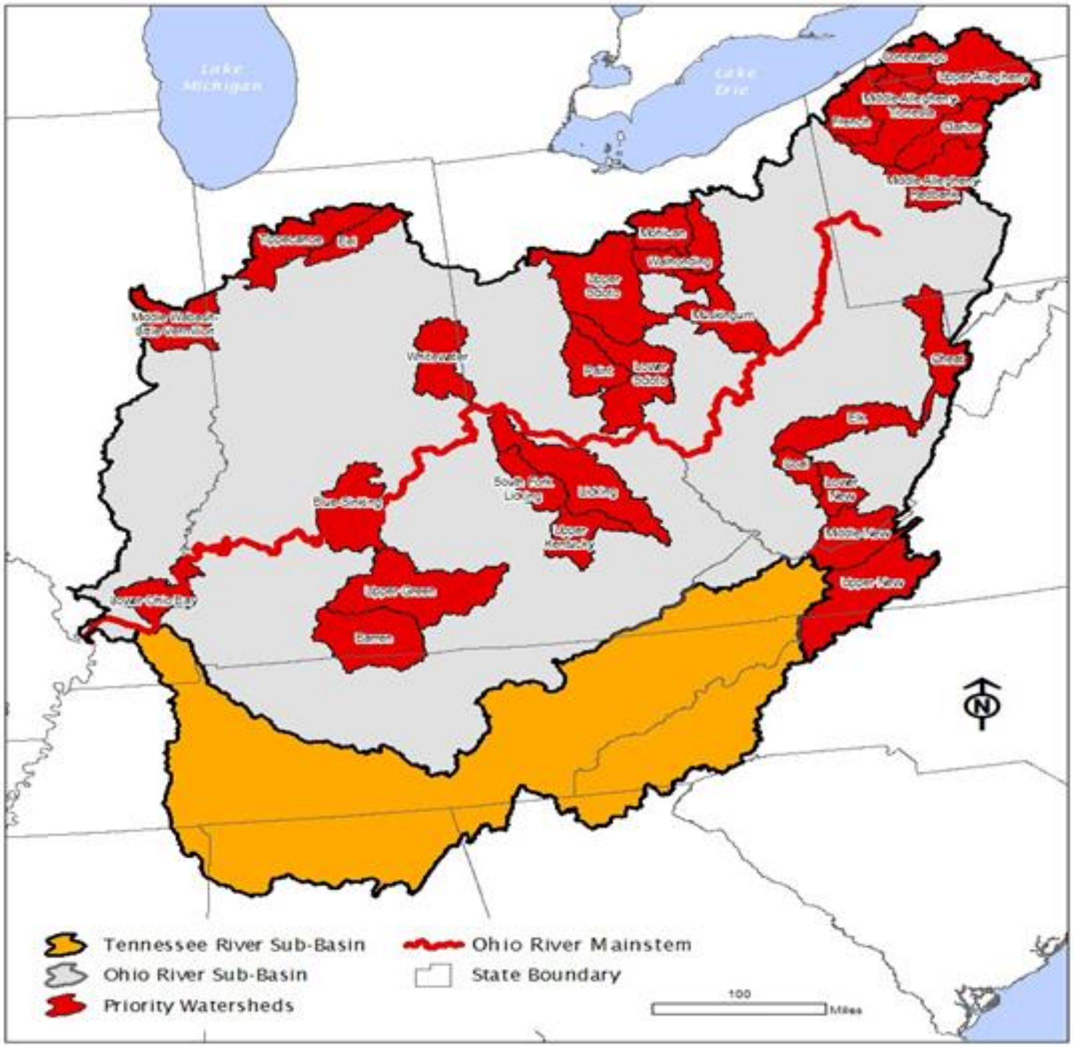


Figure 8-3: Ohio River Basin Fish Habitat Partnership (HUC-6 Priority Areas)

These HUC-6s can also be grouped into priority HUC-4s that contain gaged sites at which flows were calculated during the current climatic modeling. The ORBFHP network of priority HUCs covers about two-thirds of the ORBFHP. The same predictive modeling exists for HUCs in the southern portion of the ORB, although the Southeastern Aquatic Resources Partnership to date has not used this information to select priority watersheds. In any case, these assessments are an excellent indicator of which watersheds likely have widely distributed sensitive resource elements and were used as one filter to consider impacts to different watersheds. Impacts to key human uses were also examined to determine which ORB HUCs are at the greatest risk from climate change.

Although a case can be made that most of the ORB HUCs (Table 8-8) will experience some level of sensitive fish and mussel and human impacts from the projected climatic changes, a subset of these are likely at *greatest risk* due to the (1) severity of changes projected, (2) breadth and severity of the impacts of these changes to both human communities and sensitive aquatic organisms, and (3) current or anticipated watershed land use and functioning that would prevent or limit the ability of these areas to accommodate changes. Based on these criteria, the Allegheny, Kanawha, Kentucky-Licking, Middle Ohio, and Wabash HUC-4s appear to be at greatest risk (Figure 8-4). All these watersheds contain significant distributions of sensitive aquatic organisms.

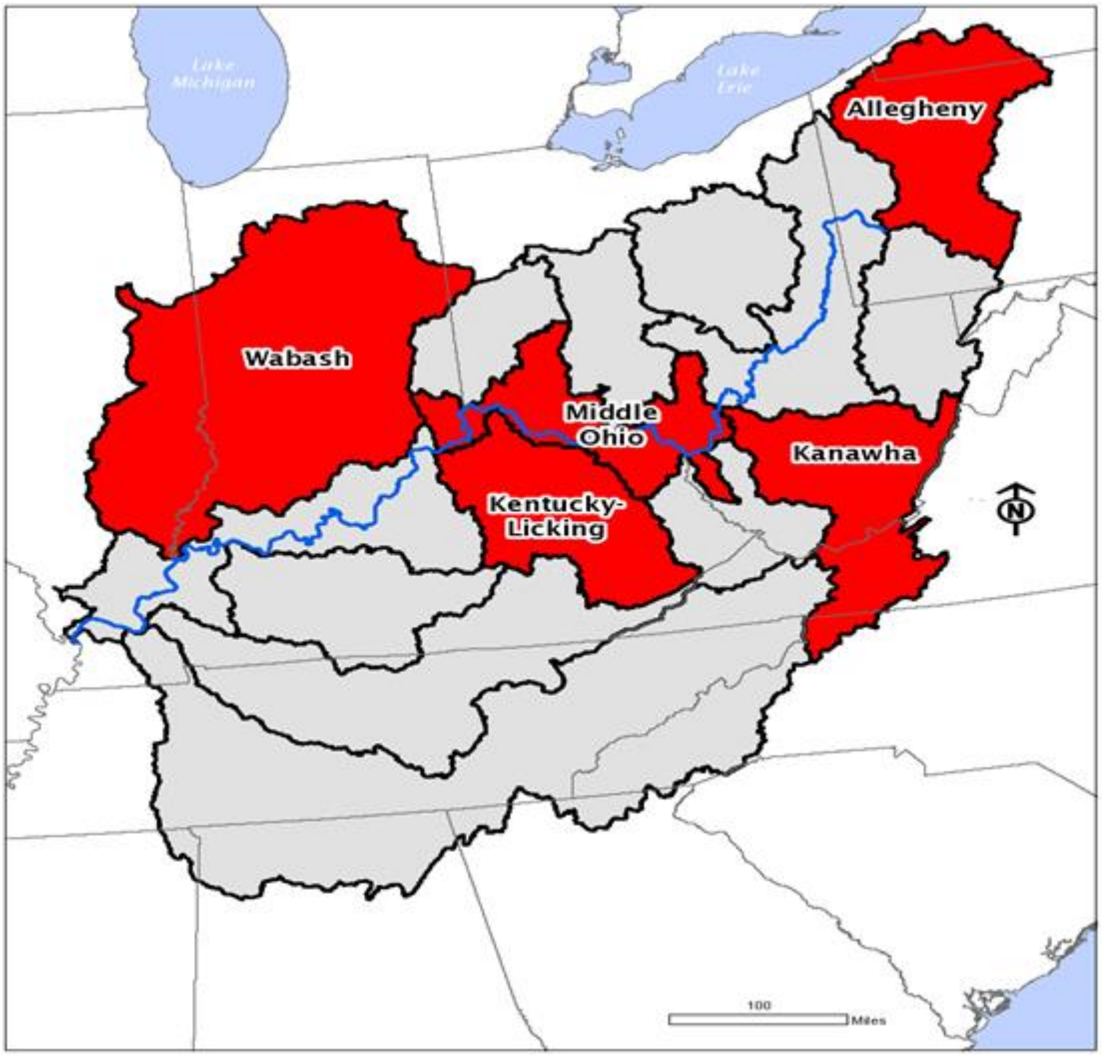


Figure 8-4: Most At-Risk Ohio River Basin HUCs

The Allegheny and Kanawha are likely to experience considerably greater streamflows (means 15–25% and maximums 15–50% more) and elevated flows generally during the summer and fall periods. In both HUCs, many floodplains are relatively narrow due to the mountainous topographies (USACE 2009). Therefore, it is reasonable to project increased flood impacts to human communities, and in-stream “scouring.” It is likely that freshwater mussel reproduction will also be impacted due to the elevated water levels that will likely exist during most of the summer reproductive period. As air and water temperatures will also be increasing, it is likely that larger reservoirs will have increased likelihood of earlier onset and spatial extent of anoxia.

As noted previously in this document and Appendix B, anoxic conditions reduce reservoir and stream habitat suitability for many aquatic organisms including fish and mussels. The same degraded water quality can also lead to significantly increased treatment cost to provide suitable water for drinking and industrial processes.

The Ohio River HUC-4s as a whole will experience significant changes in annual streamflows (15–25%), spring maximums (15–35%), and slightly elevated fall minimum flows (5–15%). However, as significantly less flood plain connectivity (USACE 2006) is present in the middle Ohio HUC versus the upper and lower HUCs, the detrimental ecological impacts of scour from increased streamflows during flood events may be manifested to a greater degree. Increased late summer-fall minimum flows may also reduce mussel reproductive success. Increased frequency and magnitude of flooding will also likely further degrade rare island habitats in this part of the river that are already at risk due to navigation impoundment impacts. Although greater maximum flows should improve wastewater dilution, increased turbidity in the projected spring high-flow events will likely lead to increased treatment costs for municipal and industrial water supplies as well.

The Kentucky-Licking HUC is projected to experience moderate flow increases over all (15–25%) and in the spring maximum flows (5–15%). Conversely, the late summer-fall low-flow period will become droughty (mean -5 to -15%, lows -15 to -50%), particularly toward the end of the century. The most likely impacts of these changes could be manifest in a variety of ways, including increased stream habitat scouring and flood damage to human communities during the spring, and lowered fish and mussel carrying capacity. The overall trend of decreased flows in late summer-fall and rising temperature could also trigger user conflicts from increased consumptive uses such as irrigation and wastewater dilution/permitting.

Finally, the Wabash HUC is likely at a greater risk due to the intensifying impacts of CC on the existing threats of significant nutrient enrichment and modified hydrology (impervious surface, ditching, and tile drainage). Annual mean flow is projected to increase just 5–15%, but spring maximum flow increases of 15–35% imply more intense precipitation and runoff events that likely will increase sediment and nutrient runoff from agricultural areas and storm water impacts from urban centers. It is therefore likely that where there is a lack of connected floodplains and wetlands that increased habitat destruction (scouring) and degradation (sediment and nutrient impacts) will take place.

The upper Wabash flood control projects are already experiencing significant harmful algal blooms indicative of nutrient enrichment and would likely see further intensification of algal blooms and anoxia with the projected streamflow and temperatures that would not only impact reservoir use and fish habitat, but also further degrade downstream habitat suitability. Therefore, it is likely that in a large part of the HUC municipal and industrial water withdrawals will require additional treatment costs. Degraded water quality, bed scouring, and generally elevated water levels during the summer and early fall will likely further impact declining mussel diversity and density in the Wabash.

Conversely, October (late summer-early fall) minimum flows are projected to decline, particularly during the late century period. As a result, periodic low flows in late summer-fall and rising temperature could also trigger user conflicts from increased consumptive uses such as irrigation and wastewater dilution/permitting.

Discussion of the relative impact of climatic change and development of appropriate adaptation strategies for ORB HUCs and the watersheds of greatest risk in the previous discussion will rely on further analysis of current ecosystem function and its indicators. While not an extensive discussion, these important considerations that will drive future water infrastructure (whether it be gray or green) adaptive management strategies are discussed in the following sections.

8.2.5 Healthy Watershed Functional Characteristics and Indicators

1. Properly functioning watersheds have five important characteristics (Williams et al. 2007).
    a. Provision of high biotic integrity, including habitats that support adaptive animal and plant communities and reflect natural processes
    b. Being resilient and recovering rapidly from natural and human disturbances
    c. Exhibiting a high degree of connectivity longitudinally along the stream, laterally across the floodplain and valley bottom, and vertically between surface and subsurface flows
    d. Provision of important ecosystem services, such as high-quality water, recharge of streams and aquifers, maintenance of riparian communities, and moderation of climate variability and change
    e. Maintaining long-term soil productivity. As the converse of these criteria would indicate an unhealthy watershed, they offer important avenues for investigation into qualitative (descriptive) or quantitative tipping points.
2. Indicators of ecosystem resilience and ability to moderate climate change effects could include the following, although not representing an exhaustive or complete list.

    In land-use and system connectivity-related context:

    a. Floodplains. Percentage of the 2- to 5-year flood zone with appropriate return frequency connection. Important for channel forming/in-stream habitat features (MacBroom 2008).
    b. Floodplains. Percentage of the modeled 100-year flood storage laterally accessible by streams. Important indicator of flood assimilation capacity/human safety.
    c. Wetlands. One of the most significant features indicative of sensitive fish and mussel abundance in ORB watersheds. ORBFHP modeling (Martin et al. 2012) suggests that Network Wetland Cover of at least 10% is a potential threshold.
    d. Watershed impervious surface area. At 3–5% impervious cover many sensitive fish species are lost (Rankin and Yoder 2009). By 20% impervious surface cover, fish communities (as evidenced by Index of Biotic Integrity scores) are severely compromised (Rankin et al. 2012).
    e. Longitudinal connectivity. Percentage of watershed stream system length without barriers to aquatic organism movement.

3. In hydrologic context.
   a. Baseflow Index (BFI). Indicative of ground and surface water connectivity. Low baseflows limit aquatic organism carrying capacity. ORBFHP stream habitat modeling (Martin et al. 2012) indicates a BFI of less than 50% is a point at which flow sensitive fish and mussel probability of presence declines.
   b. Key reproductive and rearing temporal “windows” and instances of discharge exceedance are presented as an example in Figures 8-5 and 8-6 from the Pennsylvania portion of the ORB (Dephilip and Moberg 2013). Key conditions often include flow magnitude during reproductive and rearing periods. Deviation of flows from baseline conditions can then be selected using Indicators of Hydrologic Alteration or similar analysis (Richter et al. 1996).
   c. Richards-Baker Flashiness Index. Developed by Heidelberg University (Baker et al. 2004) to quantify the impacts of various degrees of watershed hydrologic alteration.

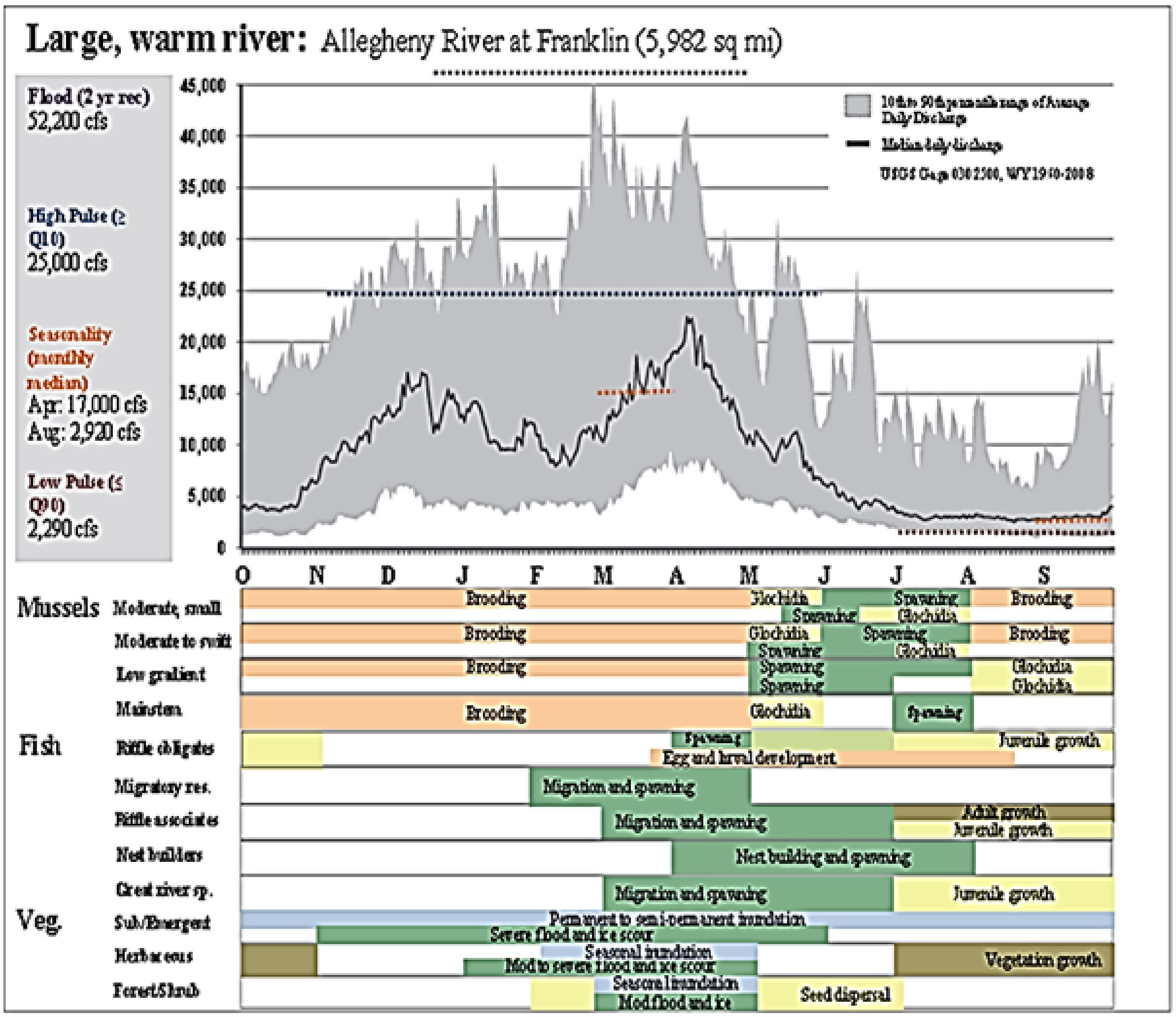


Figure 8-5: Critical Life History Stages and Flow for Stream Biota[8]

[8] From Dephilip and Moberg 2013

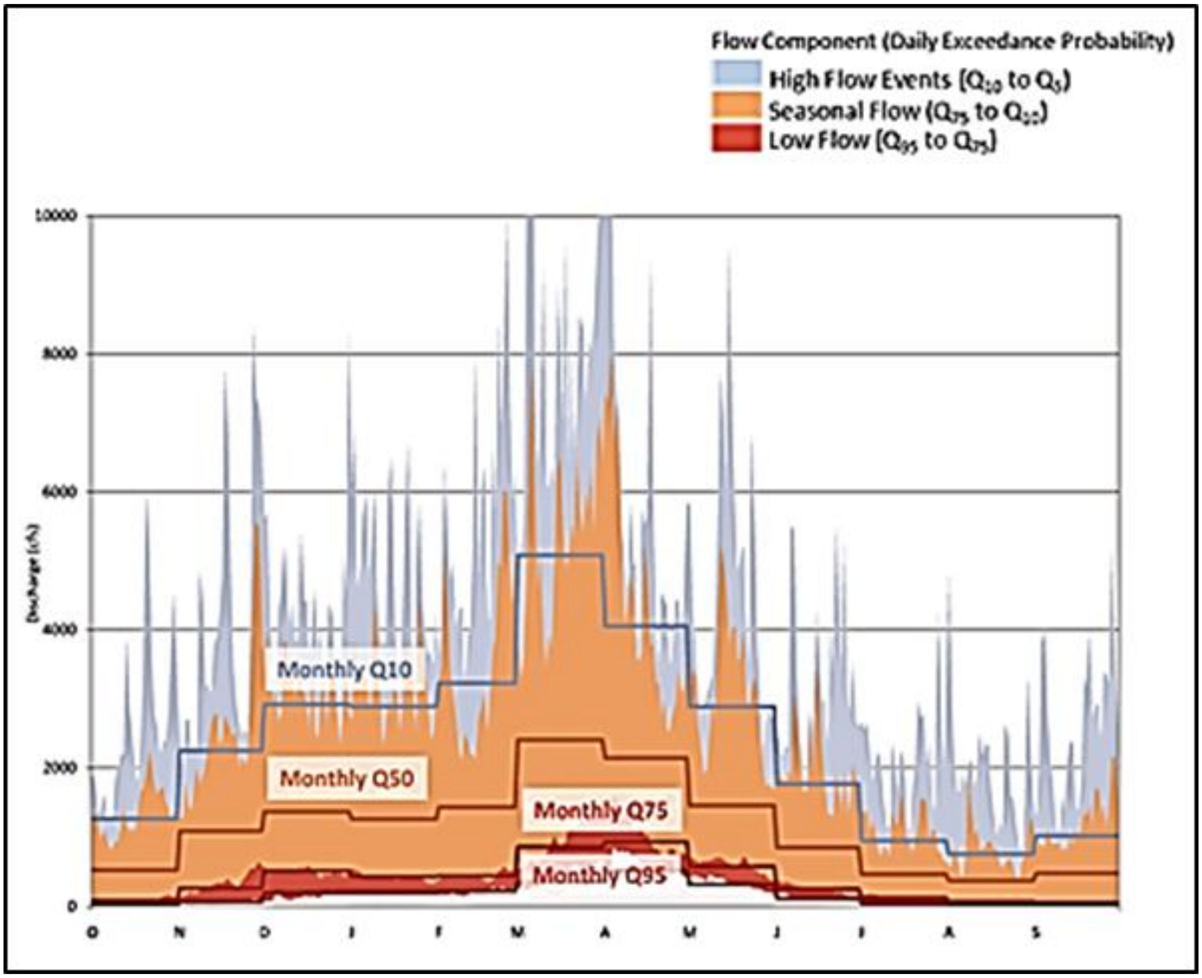


Figure 8-6: Important Flow Components for Stream Habitat[9]

8.3 Potential Water Quality Impacts from CC

8.3.1 Water Quality (WQ) Analysis Background

This analysis aims to evaluate changes in the risk of water contamination in the ORB associated with projected CC. The contaminant examined in this study was total nitrogen (TN), selected due to the significance of its potential impact on a wide range of ecosystem services (Compton et al. 2011).

Data from various sources have been compiled for this analysis. Watershed boundaries, lake locations, and the stream network have been retrieved from the National Hydrologic Dataset. Historical land use data for 1973–1985 were obtained from the USGS Enhanced Historical Land-Use and Land-Cover Data Sets and for 1986–1993 from the National Land Cover Database NLCD92. For consistency with downscaled hydrologic results, projected land use under emission

[9] From Dephilip and Moberg 2013

scenario "A1B" was selected (see IPCC Fourth Assessment Report and Section 7b of the Ohio River Basin Climate Change report). Historical nutrient data were obtained from the USGS National Stream Water-Quality Monitoring Networks Digital Data Series DDS-37, spanning years 1973–1995 at 36 monitoring stations. Point source contributions were determined from National Pollutant Discharge Elimination System permits.

Projected annual mean streamflow data were obtained from OHRFC computations discussed in detail in Section 7 of the Ohio River Basin Climate Change (ORBCC) report. These projections were made at 25 locations, only 7 of which (Carmi, IL; New Harmony, IN; Fuller Station, KY; Braddock, PA; Beaver Falls, PA; Elizabeth, WV; and McConnellsville, OH) overlapped with monitoring locations used in the USGS water quality dataset. The overlap determined the selection of these locations for water contamination risk projections. TN fate and transport in surface water including streams, lakes, and reservoirs was modeled on annual basis, and the risk of water contamination was computed as the probability of TN load exceeding the capacity of the system. Results indicate low to moderate risk (15–42%, with an average of 32%); however, it can be attributed to smoothing of TN spikes due to coarse temporal resolution of the analysis. Implementation of a 15% reduction in non-point source TN loading resulted in typically a 2–6% reduction in risk. Future research should focus on risk projection based on higher spatial and temporal resolution, and a wider range of Best Management Practices.

8.3.2 WQ Data Sources

Data from various sources have been compiled for this analysis, described in the following paragraphs.

8.3.2.1 Hydraulic Network

The hydraulic network of the basin was modeled using the NHDPlus dataset (http://www.horizon-systems.com/nhdplus). NHDPlus is an integrated suite of geospatial datasets that includes data from the National Hydrologic Dataset (NHD), Watershed Boundary Dataset, and National Elevation Dataset. NHD includes Geographic Information System (GIS)-ready shapefiles for the flow lines that represent the hydraulic network. These flow lines come with the necessary network connectivity and flow direction already defined. Catchment shapefiles delineate the area draining to each hydraulic feature. Lakes and other water bodies are also included as part of the NHD. The Watershed Boundary Dataset is used to define the hydrologic boundaries of sub-basins, designated by 4-digit HUCs (HUC-4).

8.3.2.2 Streamflow Data and Projections

Projected streamflows for the years 2011–2099 were based on archived CMIP3 and CMIP5 climate and hydrology projections developed collaboratively by several Federal organizations, national laboratories, and academic institutions. The OHRFC used these data, IPCC emission scenarios (A1b and A2), and dam project simulations in the SAC-SMA. Model output included annual flows and standard deviations at 25 points located at the end of major tributaries and other key points in the ORB. Retrospective models were also created to compare historical trends (1952–2001) with the projected values at each of the 25 sites. Data from these retrospective models were in general agreement (<2% deviation) with actual measurements.

8.3.2.3 Land Use Data and Projections

Relevant historical land use data for the years 1973–1985 were obtained from USGS Enhanced Historical Land-Use and Land-Cover Data Sets (http://water.usgs.gov/GIS/dsdl/ds240/index.html). Land use from 1986–1993 is based on the National Land Cover Dataset 1992 (http://www.mrlc.gov/nlcd1992.php). The USGS Earth Resources Observation Systems Center used the FORE-SCE (FOREcasting SCEnarios of land use change) modeling framework to project land use and land cover data for future scenarios. These projections include every year in the range of 2006–2100. The primary land use projections used for the water quality study were generated using the IPCC-SRES A1b scenario to ensure consistency with downscaled hydrologic results (Figure 8-7). This scenario emphasizes strong economic and technological growth and features moderate population growth (http://landcover-modeling.cr.usgs.gov/projects.php).

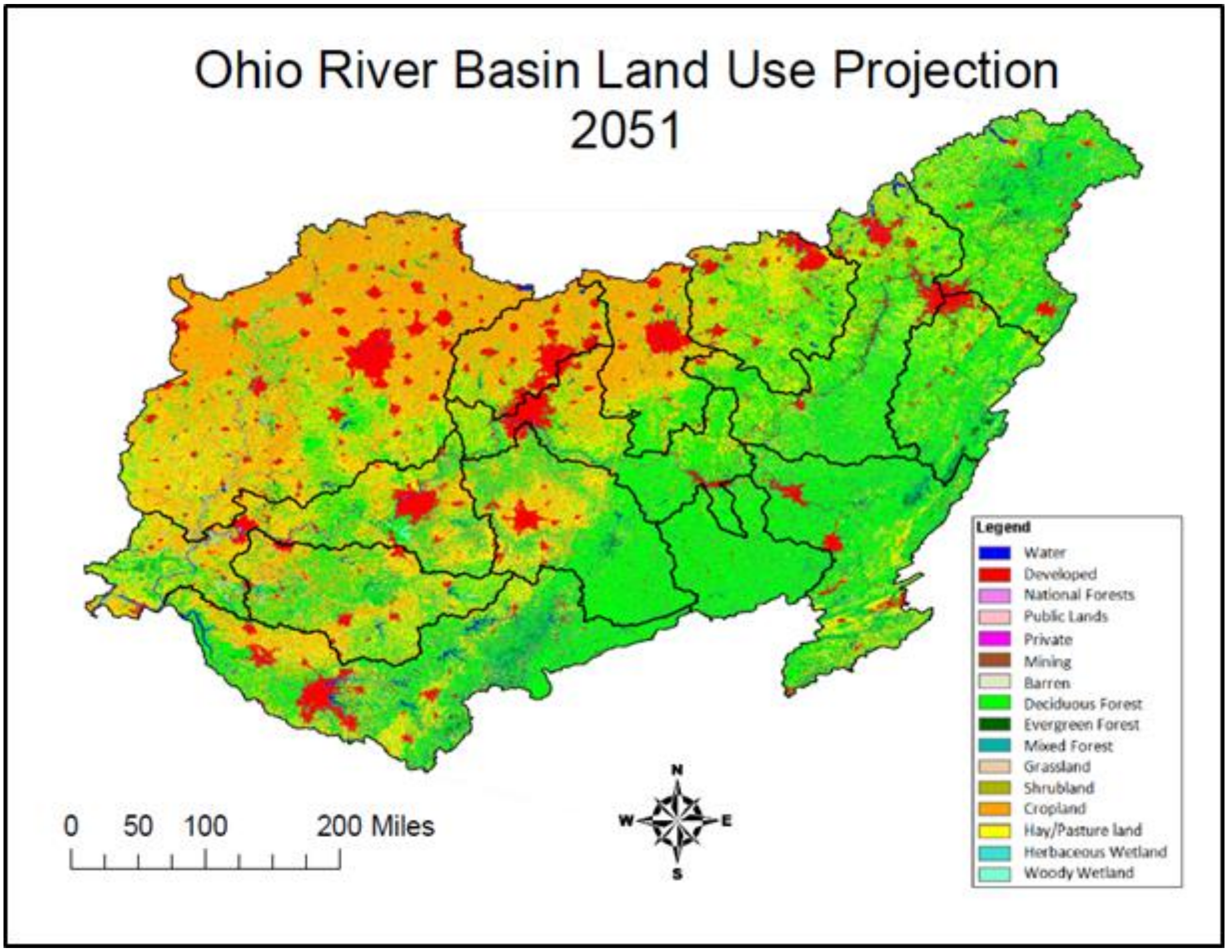


Figure 8-7: Ohio River Basin Land Use Projection Map for Year 2051

8.3.2.4 Nutrient Data

TN measurements were obtained from USGS DDS-37 Selected U.S. Geological Survey National Stream Water-Quality Monitoring Networks. That information can be found at: (http://pubs.usgs.gov/dds/wqn96cd/html/wqn/wq/region05.htm). These data span from 1973–1995 and include 36 monitoring stations across the ORB. Only the seven stations proximal to streamflow gage points, shown in Figure 8-8, were used in the risk analysis (Carmi, IL; New Harmony, IN; Fuller Station, KY; Braddock, PA; Beaver Falls, PA; Elizabeth, WV; and McConnellsville, OH). They were selected since both USGS historical nutrient data and projected flow data were available for these specific locations. Additional information is included in Appendix B.

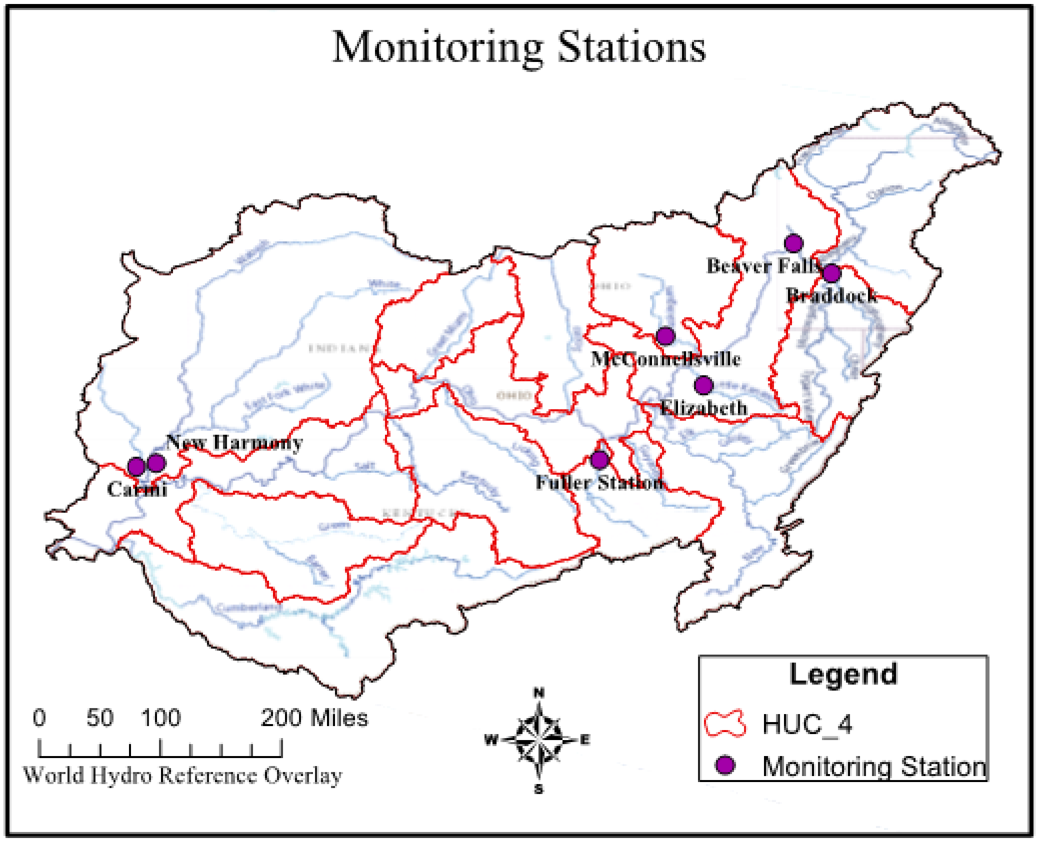


Figure 8-8: Locations Selected for Water Quality Analysis

8.4 Summary of Potential Environmental Resources Impacts

The following sections summarize the potential impacts of CC on environmental resources based on the aquatic ecosystem categories and current conditions. These potential impacts may be revised in the future because actionable climate science is rapidly evolving; they do provide a reasonable foundation for this adaptation pilot study.

8.4.1 CC Related Effects On, and Threats To, Aquatic Ecosystems

There are two primary Level II ecoregions in the basin study area[10]. They are the Temperate Plains ecoregion and the Southern Appalachian ecoregion.

[10] U.S. Environmental Protection Agency (USEPA). Ecoregions of North America (2016) https://www.epa.gov/eco-research/ecoregions-north-america

In the Temperate Plains ecoregion, rivers are inhabited by many fish species. Large parts of this ecoregion are cultivated land used for arable crops and livestock production. This dominant land use is consistent with observed poor or fair riparian vegetative cover and poor or fair streamed sediment in half of the assessed stream miles. It is also consistent with observation of pesticides in streams and rivers.[11] Lakes in the ecoregion are mostly natural (75%). The majority of the lakes are smaller than 100 hectares.[12] Diatom biodiversity, an indicator of biological condition, is low. Cyanbacteria and cyanotoxin exposure risk, impacting recreational use, is moderate. Most lakes are rated as "Good" for chlorophyll a levels, turbidity, dissolved oxygen, and acid neutralizing capacity. Anthropogenic lakeshore disturbance is an important stressor for 60% of the lakes in the ecoregion.[13]

Aquatic biodiversity in the Southern Appalachian region is among the highest in North America. Human modifications and use are stressing the ecosystem through habitat fragmentation, pollution, and changes to the natural flow.[14] In the Southern Appalachian region, virtually all of the lakes are manmade. Diatom diversity is generally high. About half of the lakes are mesotrophic (45.8%); 42.2% are eutrophic or hypereutrophic. Recreational chlorophyll risk is low in most lakes (58%); it is high in only 17% of the lakes. Cyanobacteria risk is low in 73.1% of the lakes. Most lakes (72%–100%) are rated as "Good" for chlorophyll a levels, turbidity, dissolved oxygen, and acid neutralizing capacity. Anthropogenic lakeshore disturbance is an important stressor for 90% of the lakes in the ecoregion.[15]

8.4.2 Aquatic Ecosystem Categories Within the ORB and Their Condition

The key stressors to aquatic ecosystems that arise from climate change are changes in water temperature and changes in precipitation patterns and flow regimes. Higher temperature will decrease dissolved oxygen and will increase the uptake of toxins by some fish. Higher temperature and changing precipitation patterns are expected to impact the size of waterbodies and pollutant levels within the waterbody.[16] With these changes, the biotic communities will change as limits of tolerance for some species are exceeded, and the changed conditions become acceptable to

[11]U.S. Environmental Protection Agency. Office of Water and Office of Research and Development. National Rivers and Streams Assessment 2008-2009: A Collaborative Survey (EPA/841/R-16/007). Washington, DC. pp.69-70 and pp. 78-80

[12] U.S. Environmental Protection Agency (USEPA), 2009. National Lakes Assessment: A Collaborative Survey of the Nation's Lakes. EPA 841-R-09-001. U.S. Environmental Protection Agency, Office of Water and Office of Research and Development, Washington, D.C., P 60.

[13] U.S. Environmental Protection Agency. Office of Water and Office of Research and Development. National Rivers and Streams Assessment 2008-2009: A Collaborative Survey (EPA/841/R-16/007). Washington, DC., P.61

[14].[14] U.S. Environmental Protection Agency (USEPA), 2009. National Lakes Assessment: A Collaborative Survey of the Nation's Lakes. EPA 841-R-09-001. U.S. Environmental Protection Agency, Office of Water and Office of Research and Development, Washington, D.C., P. 71

[15] Ibid., P. 54-55

[16] Adams, S. B. 2011. Climate Change and Warmwater Aquatic Fauna. (November 2nd, 2011). U.S. Department of Agriculture, Forest Service, Climate Change Resource Center. http://www.fs.fed.us/ccrc/topics/climate-change-and-warmwater-fauna

invading species. Wetland communities, such as vernal pools and wetlands in pothole depressions, may particularly lose function as a result of climate change on GW levels.[17]

8.4.3 Relative Vulnerability, Resilience, Sensitivity, Indicators of Risk to CC, and Main CC-Related Threats of Aquatic Ecosystems Within the ORB

Information on relative vulnerabilities is very desirable for decision making in support of management strategies of aquatic ecosystems that alleviate their vulnerabilities. However, because information on the relative vulnerability of watersheds itself was not readily available, indicators that reflect the three components of relative vulnerability were explored (i.e., sensitivity, exposure to stressors, including CC, and adaptive capacity). The line of reasoning is that existing stressors reduce resilience and increase vulnerability to additional stressors, including CC. This discussion relies on the authors' professional experience and knowledge of the basin ecosystems and were not derived from other sources. Table B-11 in Appendix B displays a listing of the current stressors to aquatic ecosystems by ecoregion. Study results pertaining to the ORB indicate that aquatic ecosystem indicators of risk to CC include freshwater plant communities, native freshwater species, and wetland and freshwater species. The largest CC-related threats are the ratio snowmelt/total precipitation and human water use/availability.

8.4.4 Patterns of Projected CC Within the ORB on a Regional Scale, Management and Approaches to Increase Knowledge

1. Regionally-downscaled CC patterns within the ORB indicate the following.
    a. Projected temperatures increase by 0.5°F per annual monthly mean per decade through 2040, followed by a 1°F increase per decade between 2040 and 2099.
    b. Projected streamflow characteristics, including mean, maximum, and minimum flows will generally be within the historical range through 2040 except during autumn, and may subsequently increase by 20–40% with some being greater in the northern and eastern Ohio Valley (particularly in autumn). Minimum flows may decrease, particularly from 2040 and beyond. Peak spring floods may increase, particularly beyond 2040. Autumn flow may show large increases in flow variability (lower minimum and greater peak flows).
2. Management and approaches to increase knowledge as basis for management alterations needed to protect and maintain aquatic ecosystem goods and services in a changing climate. Water managers face important questions concerning the implications of long-term CC for water resources. The potential concerns include risk to water management goals, including the provision of safe, sustainable water supplies, compliance with water quality standards, urban drainage and flood control, and the protection and restoration of aquatic ecosystems. Large negative effects of CC on sensitive ecosystems and humans are expected. CC, together with other ongoing stresses, may impede the ability of water resource managers as well as natural resource managers to maintain established goals for ecosystems, species, and humans.

    Effective management of resources and ecosystems was based in the past on an expected set of climate conditions, but in the future would have to be more flexible to face the variability

[17] Poff, Leroy, Mark Brinson, John Day, Jr. 2002. Aquatic ecosystems & Global Climate Change: Potential Impacts on Inland Freshwater and Coastal Wetland Ecosystems in the United States. Report prepared for the Pew Center on Global Climate Change.

and uncertainty of CC. Management for adaptation to CC will have to allow natural and managed systems to adjust to the range in potential variations in future CC, while building on sustainable management, conservation, and restoration practices.

Sustainable management of waters in river basins would greatly benefit from a holistic approach targeting a "good status" for the entire basin, including surface waters, ground waters, ecological protection, chemical quality protection, and other use protection (the latter in specific areas), as called for in management of all waters in the European Union according to the Water Framework Directive. Besides setting and planning distinct goals, such management would require major coordination and collaboration efforts because of the involvement of multiple states, Federal agencies, and other entities. CC adaptation could be incorporated systematically into a holistic sustainable management framework planning cycle, via the eight steps described on page 34.

Improvements in measuring, modeling, and understanding CC relevant to the hydrologic cycle, water quality, and aquatic ecosystems are needed, and management strategies of the past may not be adequate given the increased awareness of stressors including CC and land use change.

3. Modeling. Scenario analysis using computer simulation models is a useful and common approach to assess vulnerability/risk to plausible, but uncertain, future conditions. However, the results of watershed assessments through modeling approaches are influenced by the characteristics of the watershed model that serves to translate climate forcing into hydrologic and water quality responses. These model results are also influenced by the characteristics of the CC scenarios forcing the watershed models.

   Models to examine the impact on aquatic systems of alterations in those properties identified as sensitive to CC can be important tools contributing to our understanding of complex interactions in watersheds at various temporal and spatial scales.

   At least four model categories should be considered:

   a. In-streamflow models
   b. Models of nutrient uptake related to hydrodynamic properties
   c. Models of bioenergetic response
   d. Models relating riverine food web structure to climate and hydrologic regime
      iii. Information and modeling needs
      iv. Monitoring data: additional data on streamflow and ecological elements; data on temperature, dissolved oxygen, and nutrients of water bodies of various sizes; all with attention for annual as well as short-term variations
      v. Studies linking hydrological regime with ecological processes, interactions, and water quality; in this context, focus on terrestrial-aquatic linkages is particularly important
      vi. Studies on development of indicators for stresses, including CC, to aquatic ecosystems under various land use regimes
      vii. Studies on the degree of interconnectedness and integrity of floodplains and watersheds
      viii. Studies at increasing geographical scales

ix. Studies on migratory species, the migration ranges of which may surpass basin boundaries, such as migratory fish, sensitive fish (e.g., paddlefish), and water-dependent birds (migrating via the Mississippi and Central Flyways)

x. Modeling activities linking climate variability with ecological processes at the population, community, and ecosystem level. Sensitivity analyses examining thresholds (relevant to ecological processes and management targets) might be a more direct way of identifying management options to mitigate/adapt

xi. Integrated assessments of potential impacts and viable response options of watersheds for alternative futures (under changes in land use and climate).

4. Initial identification of watersheds within the ORB most at risk to CC at spatial scales amenable to management.

   a. Based on the available information, management of the ORB sub-basins at HUC-4 and of the Tennessee sub-basin at HUC-2 spatial scales would provide the best scale for analysis and reporting, and possibly also for planning and implementation of management alterations to sustain or improve watershed condition.

   b. Defining at-risk environmental resources within the ORB is challenging, but general approaches to incorporate CC adaptation into a management cycle have been developed, in which the assessment of relative vulnerability plays an important role. Indicators of ecosystem resilience and ability to moderate CC effects to be explored and assessed within these riverine systems include (1) floodplain storage capacity, appropriate return frequency, and lateral accessibility by streams; (2) watershed longitudinal connectivity; and (3) sufficient network wetland cover. In addition, the following hydrologic indicator ranges typical for sensitive species should be evaluated: (1) BFI, (2) key reproductive flow windows, and (3) Richards-Baker Flashiness Index.

      Most of the 15 ORB HUCs will experience some level of projected CC impacts on sensitive fish, mussels, and humans, but a subset of these are likely at *greatest risk* due to the (1) severity of changes projected, (2) breadth and severity of the impacts of these changes to both human communities and sensitive aquatic organisms, and (3) current or anticipated watershed land use and functioning that would prevent or limit the ability of these areas to accommodate changes. Based on these criteria, the Allegheny, Kanawha, Kentucky-Licking, Middle Ohio. and Wabash HUC-4s appear to be at greatest risk. All these watersheds contain significant distributions of sensitive aquatic organisms.

8.4.4.1 Watersheds Most at Risk

Initial identification of watersheds within the ORB most at risk to CC was made at spatial scales amenable to management approaches. Based on the available information, management of the ORB sub-basins at HUC-4 and of the Tennessee sub-basin at HUC-2 spatial scales would provide the best scale for analysis and reporting, and possibly also for planning and implementation of management alterations to sustain or improve watershed condition.

Most of the 15 ORB HUC-4 watersheds are expected to experience some level of projected CC impacts on sensitive fish, mussels, and humans, but a subset of these are likely at greatest risk due to the (1) severity of changes projected; (2) breadth and severity of the impacts of these changes to both human communities and sensitive aquatic organisms; and (3) current or anticipated watershed land-use and functioning that would prevent or limit the ability of these areas to accommodate changes. Based on these criteria, the Allegheny, Kanawha, Kentucky-Licking, Middle Ohio and Wabash HUC-4s appear to be at greatest risk. All these watersheds contain significant distributions of sensitive aquatic organisms.

8.5 Potential CC Impacts to At-risk Infrastructure and Regulatory Systems

8.5.1 Basin Infrastructure and Potential Impacts

The ORB encompasses a land area of 204,000 square miles covering 13 states. This area is home to more than 27 million people living in approximately 2,600 municipal jurisdictions and 548 counties. This population is served by physical infrastructure and social systems dedicated to flood protection, transportation, public safety and security, public health, commerce, communications, water supply, waste collection and treatment, or long-term storage and energy generation and distribution.

The growth of public, corporate, and private infrastructure has progressed to a point where every county within the basin contains some component of/or complete infrastructure system. Many components of this complex infrastructure or "system of systems" are related to, dependent upon, or geographically located near water features such as streams, rivers, or lakes. Convenient access to water for transportation of raw materials, energy resources, and finished products; water supply for municipal uses, processing, and cooling; water that generates electricity through hydropower facilities and water resources that support diverse ecosystems and recreation activities is the very basis for their location and heretofore success in the basin.

Figure 7-1 in this report delineates the forecast groups and gaging points used by OHRFC to forecast future streamflow. The basin maps that follow show distribution of infrastructure components that are sensitive to either excessive flow discharge or prolonged low flows (drought conditions) overlaying those same OHRFC forecast groups. Appendix B includes tabular listings that identify, by name, infrastructure components shown on the map as dots of various colors within each forecast group.

For the purpose of identifying the potential impacts of increased flow discharge on operating projects (dams, levee/floodwalls, and storm water drainage/pumping systems), the forecasted Annual Maximum, March Mean, and March Maximum percent increase parameters were used for the background mapping. Although the majority of multipurpose dams and reservoirs has been designed and constructed to adjust to a wide variety of conditions, these facilities are vulnerable to extremely high incoming flows requiring more frequent and higher levels of retention that can adversely affect project recreation facilities and ecological resources surrounding the lake environment. Adaptation strategies can include increasing fall drawdown to enable additional storage for higher spring inflows. In situations where a single purpose dam functions solely for flood control and has a relatively large catchment area, higher incoming flows that exceed outlet works (usually a perforated standpipe) could lead to uncontrolled discharges through an emergency spillway or overtopping the dam. Either of these two overflow scenarios can lead to damages downstream and potential life loss at larger projects.

Those same forecast parameters were used to evaluate impacts of higher flow discharge on existing levees and floodwalls. Such increases not only jeopardize the levee or floodwall level of protection through overtopping, but also challenge interior drainage pumping capacity and ponding area storage. The same parameters were used to evaluate the potential impacts of higher flow discharge on dams and reservoirs identified in the national dam database that show poor or unsatisfactory performance in the Dam Safety Program. In some cases, these facilities are being operated under an Interim Operating Plan (IOP) that may limit the amount of flood control storage at the project. Significantly higher incoming flows entering poor performing projects could jeopardize the integrity of the dam structure itself or result in uncontrolled spillway discharges in an effort to protect the dam. Under an IOP, higher incoming flows may be passed through the dam with little attenuation, resulting in downstream damages and potential life loss.

For the purpose of identifying potential impacts of decreased flow discharge changes on projects operated for hydroelectric power and water supply, Annual Minimum, October Mean, and October Minimum percent decrease parameters were used to evaluate potential impacts of decreases in flow discharge. Other than single-purpose projects operated for hydropower or water supply, multiple purpose projects must manage lake/reservoir supplies for other uses like recreation and lacustrine aquatic resources. The same low-flow forecast parameters were used to identify the potential impacts on navigation through locks and dams in reduced river channel depths and to assess impacts on thermoelectric power plants dependent upon sufficient flows for plant cooling. Concurrent higher air temperatures during later forecast periods may increase cooling water temperatures to levels above which power plants can efficiently operate.

8.5.1.1 Dams and Reservoirs

There are approximately 109 operating dams and reservoirs within the basin having storage capacities of more than 3,000 acre-feet.[18] Figure 8-9 displays the approximate locations of those structures and Table B-13 in Appendix B identifies dams by name, authorized purpose, ownership, current condition, and location on the river.

The USACE operates 83 dams in the basin, of which 78 are multipurpose with a permanent summer pool/lake and 5 are single-stream/watershed location. Of the total number of basin dams, 392 are classified as multipurpose reservoirs or those more likely having a year-round lake. The lake storage is used to support various authorized project purposes. These purposes (e.g., water supply, hydropower, flood control, low-flow augmentation, recreation, fish and wildlife enhancement) are supported in the reservoir through reservation of water storage volumes (expressed in acre feet of storage). The volume of storage for each purpose is based upon a forecasted need (i.e., municipal and industrial [M&I] water supply) and supported by annual benefits generated by each purpose. Also, within each reservoir is an increment of storage for incoming sedimentation from upstream sources throughout the anticipated life of the structure.

[18] Acre-feet is a term used to describe the volume of water being one foot deep that would cover one acre (43,560 square feet) of a flat surface.

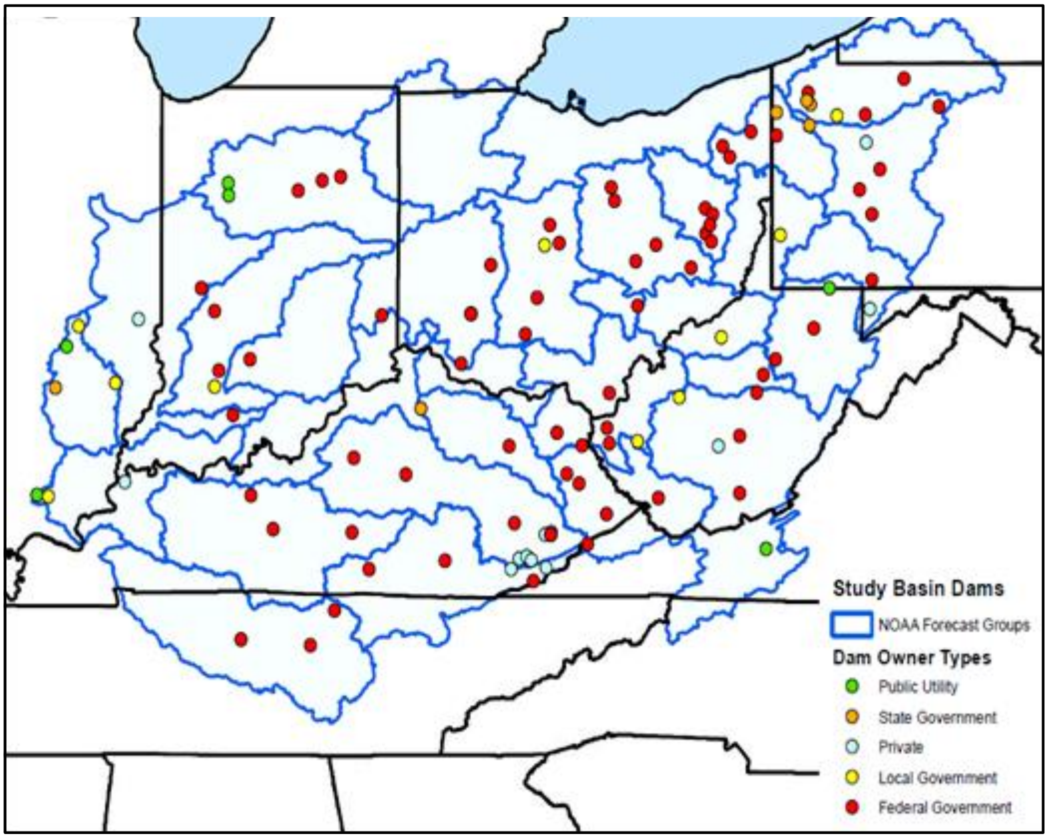


Figure 8-9: Operating Dams in the Basin by Ownership Type

Other reservoirs are classified as single purpose and store and discharge water for one purpose such as water supply, hydropower, recreation, or flood control. Single-purpose reservoirs for flood control can be operated as "dry dams" having no permanent pool or lake and store water temporarily during high flows to reduce downstream flood damages. There are five "dry dams" in the basin, all contained within the Muskingum River watershed.

1. Flood Damage Reduction Dams. Figure 8-10 shows the distribution of single- and multipurpose dams that have a flood control or stormwater management purpose. Table B-15 in Appendix B identifies the dams with a flood control or stormwater management purpose by river and forecast group. Table B-21 in Appendix B shows forecasted increases in flow discharge for various forecast groups in terms of percent increase over base years and projects within those forecast groups. Based on forecasts, 12 dams operated for flood control and stormwater management in the Allegheny River watershed during the 2040 to 2099 forecast period may experience much greater incoming flows in the range of 25% to 50% higher during spring (March) season. Likewise, seven dams in Big Sandy River watershed, which includes Levisa Fork River and Russell Fork River sub-watersheds, could experience incoming flows in the range of 25% to 50% during that same spring season. These flows may result in higher pools being retained with damages sustained to lakeside recreation facilities and shoreline ecosystems. Other watersheds including the Wabash, Green, Beaver, Cumberland, Monongahela, and Muskingum could experience higher spring season incoming flows between 25% and 35% during the 2040 to 2099 forecast period. A total of 36 dam and reservoir

structures are located within these six watersheds that could be affected by forecasted higher flows.

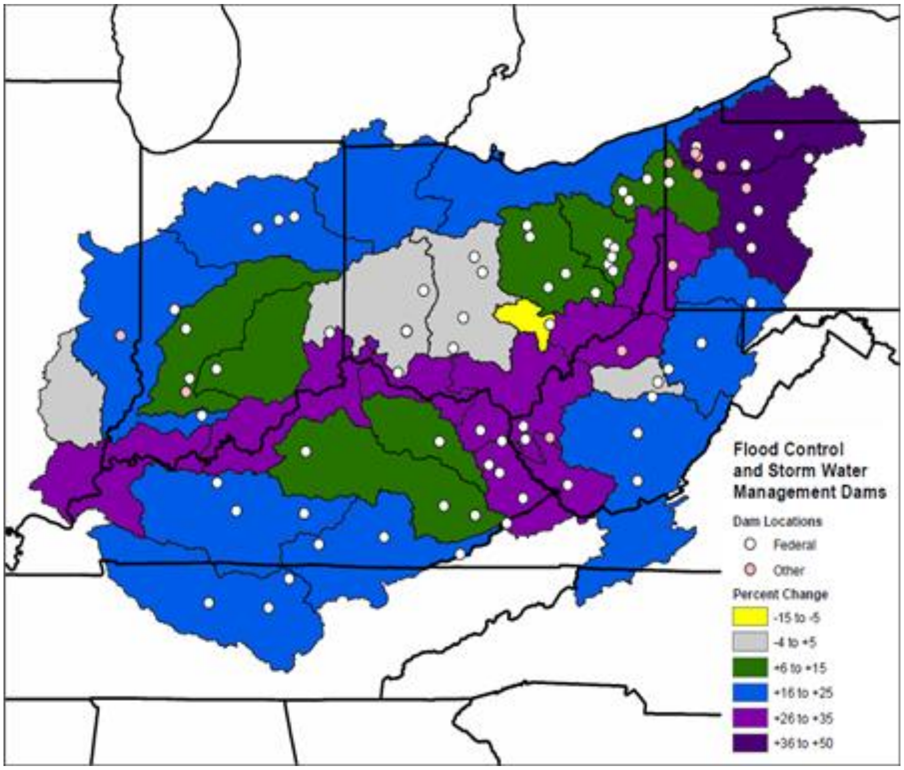


Figure 8-10: Single-Purpose and Multipurpose Dams w/Flood Control or Stormwater Purposes

2. Water Supply and Hydropower Dams. Single and multiple purpose dams that maintain storage for water supply or hydropower could suffer significant effects under conditions of prolonged low flow. The amount of runoff generated in the upstream watershed is balanced by discharges from the reservoir to maintain a stable pool and to serve downstream needs and authorized purposes such as water supply and/or hydropower. Gaging stations located above and below the reservoir provide necessary data to monitor both inflow and outflow at the facility. In extreme drought conditions, operating regulations (low-flow augmentation) and/or contractual agreements (i.e., water supply or hydropower) may require substantial pool drawdown. The flexibility to attain downstream water quality needs is achieved in part through use of multi-port intake towers facilitating the mixing of differing temperatures and oxygen levels from the lake. Such mixing capability could be advantageous where water temperatures increase over time. A number of reservoirs in the basin have single-port intakes that do not allow such flexibility.

   Figure 8-11 shows the distribution of multipurpose and single-purpose dams that feature water supply and hydropower as authorized purposes and could be affected by prolonged low flow or drought conditions. These projects are arrayed upon the October Minimum forecast map for the2070–2099 time periods. Additional maps and tabular data showing these structures arrayed across the Annual Minimum, October Mean, and October Minimum forecast maps for the forecast period 2070–2099 are included in Table B-22 in Appendix B.

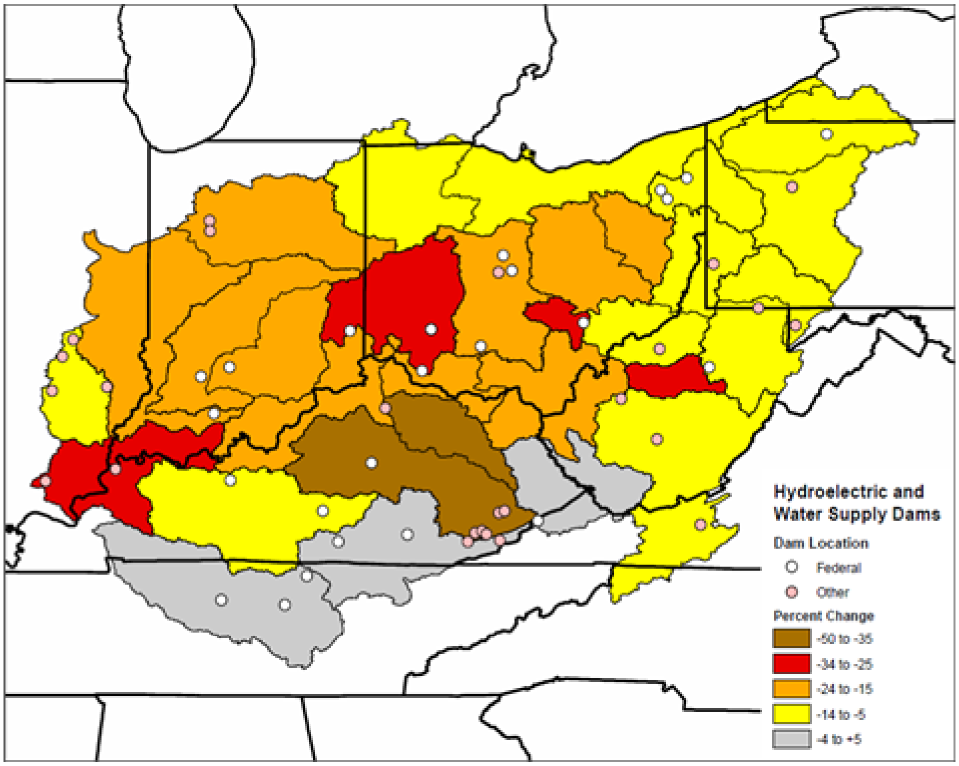


Figure 8-11: Single-Purpose and Multipurpose Dams w/Water Supply and Hydropower Purposes

3. Dams Exhibiting Poor Performance. Several USACE dams in the basin have been classified as having significant performance issues. These dams have been assigned ratings under the USACE Dam Safety Action Category (DSAC) rating system. Dams classified as having DSAC ratings of 1 or 2 have compelling performance issues worthy of immediate attention. A number of these dams have been found to exhibit either hydraulic or geotechnical deficiencies or both, and many are undergoing rehabilitation measures currently while others are in the queue for future rehabilitation. Numerous non-USACE dams have been inspected under the National Dam Safety Program and have been categorized (with USACE dams) in the NID under a condition assessment layer that includes ratings of "poor or unsatisfactory."

   Figure 8-12 shows the location of dams classified as having "poor or unsatisfactory" performance in the NID database by ownership category (Federal and other). Table B-23 in Appendix B identifies these dams by name and stream location within NOAA forecast groups. Forecasted increases in the maximum inflow into these dams could represent a significant threat to downstream development as a result of higher than usual sluice gate discharges or unregulated spillway flows designed to protect the dam's structural integrity. Those structures located in watersheds with forecasted higher flow discharges could experience greater risks before scheduled dam modification work is completed.

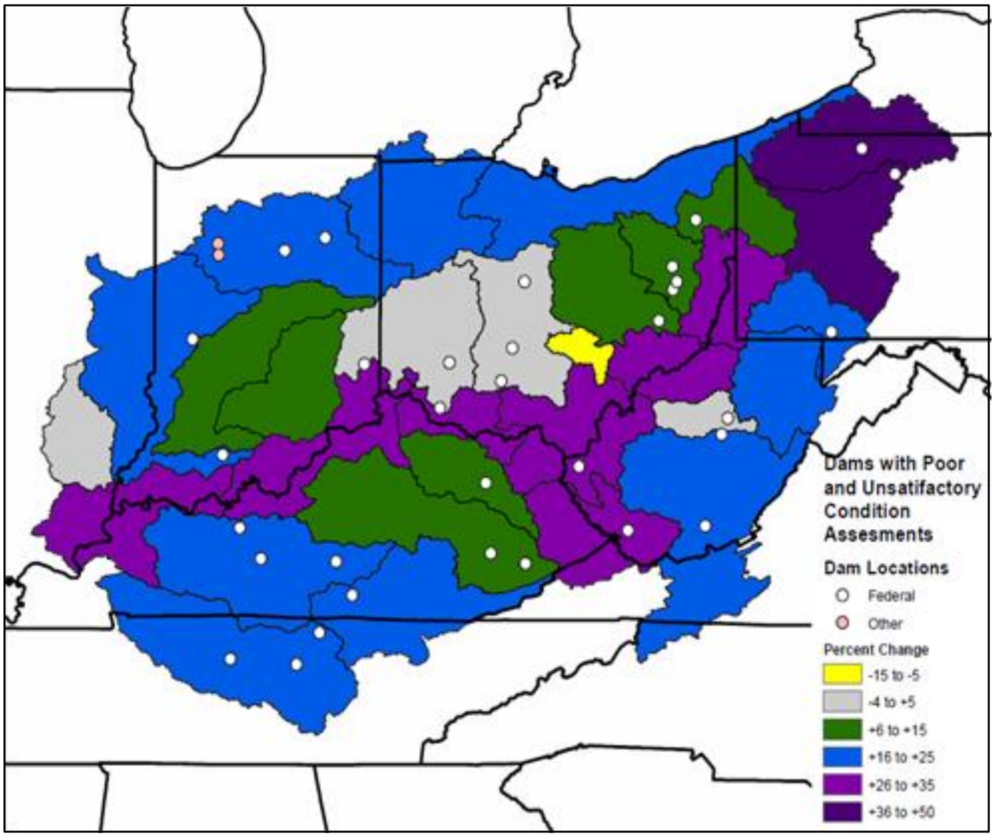


Figure 8-12: Dams with Poor or Unsatisfactory Performance Ratings

Table B-23 in Appendix B shows the forecasted percent increases in flow discharges above the base years and those projects that have been identified as having poor or unsatisfactory performance. Two dams in the Allegheny River watershed and one dam in the Big Sandy River forecast group may experience higher incoming flows between 2040 and 2099 in the range of 25% to 50% greater than the base years' annual mean maximum and spring (March) maximum flows. Twenty-two dams in the Cumberland River, Kanawha River, Kentucky River, Miami River, Muskingum River, Wabash River, and Big Sandy River watersheds that indicate poor or unsatisfactory performance may be subjected to higher incoming flows that range between 15% and 35% greater than the base years during the period between 2040 and 2070. This trend of higher incoming flows (15%–35%) will persist for most of those 22 dams into the period between 2070 and 2099.

8.5.1.2 Local Protection Projects (LPP)–Floodwalls and Levees

There is an extensive system of LPPs in the form of floodwalls and levees in the basin that provide flood protection for communities, industrial and commercial centers, and institutional complexes. USACE has constructed more than 100 of these structures and the majority has been turned over to municipal and county sponsors for future operation and maintenance. In some cases, an LPP has been constructed as an appurtenance to a dam or reservoir and protects facilities or communities within the flowage easement of a downstream dam. Figure 8-13 shows the approximate location of basin LPPs. Table B-17 in Appendix B identifies LPPs and their river locations.

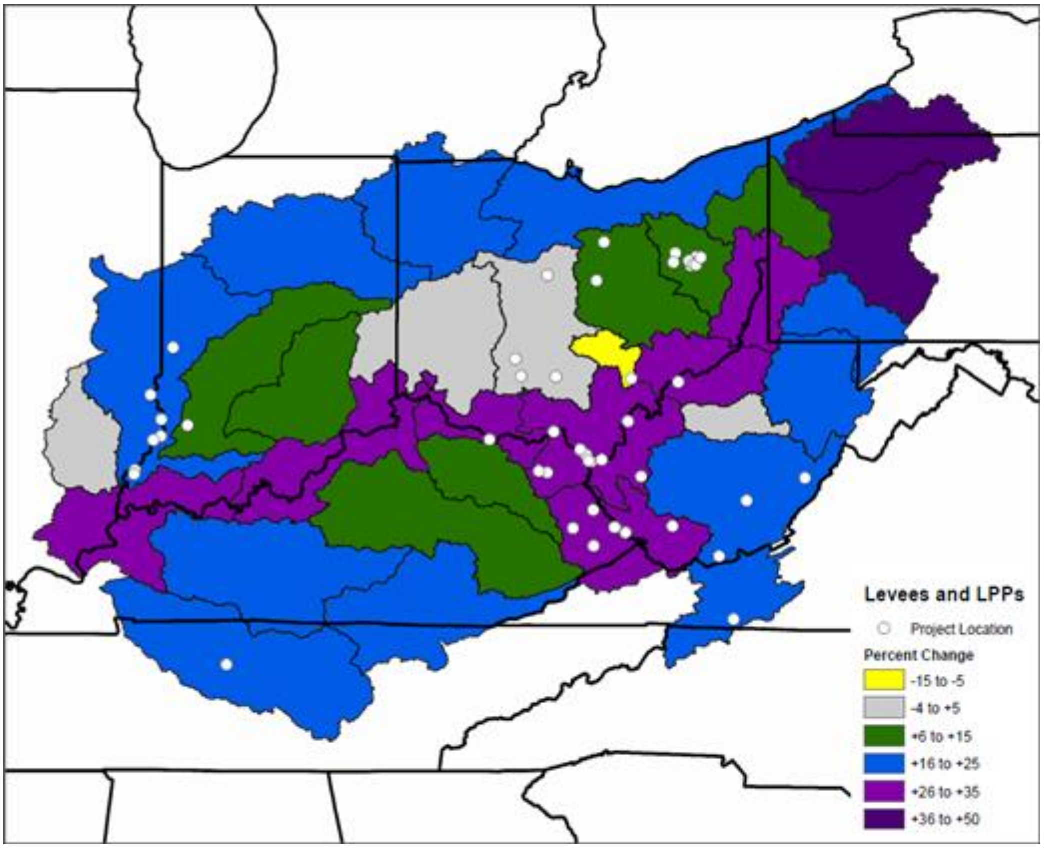


Figure 8-13: Location of Levees/Floodwalls and LPPs

These facilities are planned, designed, and constructed using historic hydrologic data for that particular river location. Generally, the crest height of the levee or floodwall was established to protect against a known record flood height (a historic flood event) or a theoretical flood such as the 1% annual chance event or the probable maximum flood (PMF). More recent LPP design calculations have incorporated elements of risk and uncertainty in establishing the crest height of floodwalls and levees. Considerations for future changes in precipitation rates due to CC that may affect flow discharges and levee crest heights were not part of the design process when most of the current LPPs were constructed.

Forecasts that indicate greater maximum river flows appear to increase risks that a floodwall or levee could be overtopped, resulting in potential life loss and economic damages to protected development. In addition to concerns about levee overtopping, the potential exists for greater precipitation intensity resulting in interior stormwater drainage, ponding areas, and pumping systems being overwhelmed. A combination of these changed conditions could result in existing local protection projects being identified as having unsatisfactory performance characteristics, thus jeopardizing their accreditation at the 1% chance flood event level under NFIP guidelines.

Table B-24 in Appendix B displays forecasted flow discharge increases for various forecast groups in terms of percent increase over base years and LPPs that are located within those forecast groups. The forecast data indicates that increases in Annual Maximum flow discharge and spring season maximum flows (March Maximum) between 2011 and 2040 could range between 15% and 35% higher at LPPs in the Kanawha River, Big Sandy River, Wabash River sub-basins, and at seven

LPPs on the Ohio River corridor between Parkersburg, WV, and Portsmouth, OH. This trend of higher flow discharges is pervasive in the period between 2040 and 2070 in these same watersheds, and flows ranging from 35% to 50% greater (annual maximum) than baseline years are forecast for nine LPPs in the Big Sandy River watershed between 2070 and 2099. Newer LPPs in the Big Sandy River watershed and Cumberland River watershed have been designed and constructed to the PMF level, but older projects like the Appalachian Regional Hospital LPP in South Williamson, KY, do not have that high level of protection and could be susceptible to overtopping under higher flow conditions.

8.5.1.3 Flood Protection Channels and Diversion Facilities

Unlike levees and floodwalls, these flood protection facilities provide either an increased hydraulic cross section within an existing river channel (or adjacent to the existing channel) that enables passing higher flows, or an alternate channel that carries excessive river flows away from at-risk development. As is the case with floodwalls and levees, the design calculations performed during design of these structures is based largely on historic river flows such as record flood events or a theoretical event (i.e., the 1% chance event). Although flows in excess of designed flow do not result in a catastrophic overtopping event (one that can lead to structure failure) such as the case of a levee or floodwall, the capacity of channels and diversions can be exceeded leading to flood damages to adjacent development and potential life loss. Awareness of the potential for future flows that could exceed designed channel flow can facilitate successful adaptation measures (i.e., small levee, floodproofing, flood warning system, or further channel modification) to be implemented by at-risk populations.

8.5.1.4 Navigation Locks and Dams

The USACE operates a system of locks and dams that supports commercial navigation on the Ohio River and its major tributaries. Altogether, there are 40 operating navigation dams in the system. Figure 8-14 shows the location of these structures on the Ohio River and its major tributaries and Table B-18 of Appendix B identifies each by name and river location.

These facilities are authorized to maintain a specific draft for commercial barge traffic through maintenance of relatively stable, linear pools. These pools are similar in operation to reservoirs that maintain a permanent pool, but navigation dams generally have no flood control purpose. The locks allow passage by tows (tow boats and commercial barges) and recreation craft between pools. Navigation dams control river flow through multiple gates that can be operated independently. Navigation dams with associated hydropower stations can control navigation pool depths through cooperative operation of hydropower plant flow alone. Under high river flow conditions, navigation dam gates are opened to allow passage of high flows without any consideration for storage of flows to address downstream damages; tributary flood damage reduction dams and LPPs fulfill that flood damage reduction responsibility within the system.

Byproducts of this navigation purpose are stable pools for water-based recreation, M&I water supply, hydropower, commercial fishing, effluent attenuation, marine-related businesses (i.e., floating dry docks), and sustaining aquatic habitat for federally protected and non-protected species.

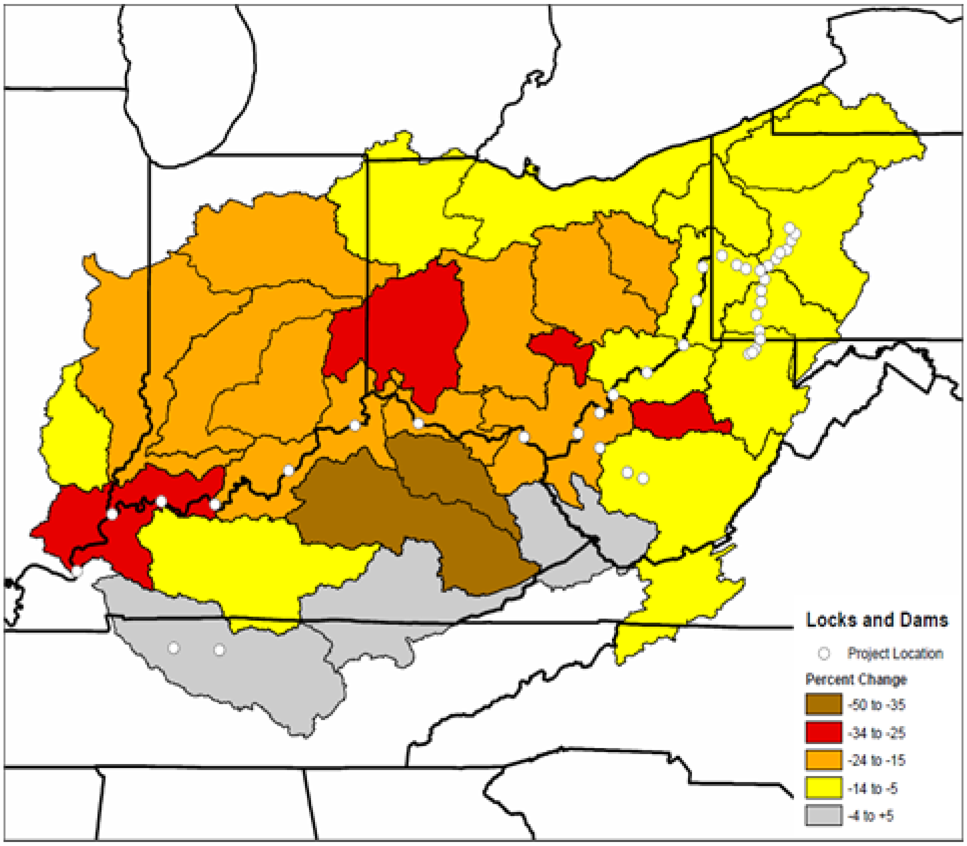


Figure 8-14: Location of Navigation Locks and Dams

A significant drop in river flow that dewaters municipal, industrial, or corporate water intakes can result in serious economic losses and emergency water supply conditions. ORSANCO data indicates that more than 5 million people depend upon Ohio River mainstem flow alone for potable water supply[19]. Withdrawals for cooling facilities at thermoelectric power plants along the Ohio River and its major tributaries can be sharply reduced in drought conditions, resulting in plant shutdowns and loss of regional energy supplies. Likewise, increased water temperatures can adversely impact the efficiency of "once through" thermoelectric power plants. Both "cool-water" and "cold-water" aquatic resources can be adversely affected by rising water temperatures. Forecasted lower flows could impact the capability of rivers to dilute/assimilate permitted effluent discharges under Total Maximum Daily Load (TMDL) guidelines.

Past episodes of persistent drought have jeopardized agencies' ability to maintain authorized draft of several navigation pools, thereby ceasing navigation on the river system. As the Ohio River navigation system feeds commercial traffic into the Mississippi River, any losses could translate into that lower system as well. Some flow relief can be provided by upstream reservoirs, but long-term attenuation of a navigation pool loss comes at the concurrent loss of economic benefits at basin reservoirs. Other options are available, such as channel dredging to maintain authorized draft for navigation, but that solution is limited by the water depth over the sill elevation of the lock

[19] Ohio River Sanitary Commission (ORSANCO) Annual Report, 2010

chambers—an elevation that cannot be modified without additional authorization and considerable investment.

Table B-25 in Appendix B shows forecasted changes (percent change from the base year) in flow discharge for three forecast periods by forecast group watershed. Forecasted data indicate that there would be sufficient flow in all parts of the Ohio River mainstem to maintain commercial navigation between Pittsburgh, PA and Cairo, IL during all forecast periods except for the fall season (October Minimum) during the 2070 to 2099 period. Forecasted flows in the Ohio River between Winfield Lock and Dam (L&D) and Cannelton L&D are forecasted to be between 15% and 25% lower than base years for the fall season during that 30-year period. More significant decreases in mainstem flow are forecasted for lower Ohio River between 2070 and 2099, when discharges may be between 25% and 35% lower than base years flow. This major decrease in fall season flow would be largely confined to the Ohio River reach that includes Newburgh L&D, John T. Myers L&D, Smithland L&D, and Olmstead L&D. These significantly lower fall season flows could limit commercial traffic or cause shippers to lighter their barge loads to avoid grounding in shallow depths or at the lock sill. Adaptation measures could include increasing releases from upstream reservoirs to sustain sufficient draft through that section of the Ohio River.

Conversely, excessive river flows jeopardize traffic flow due to unsafe navigation conditions at locks and dams. Higher flow discharge can result in unsafe navigation conditions on navigable reaches causing a stoppage of river traffic and more frequent accidents. Stoppages and accidents result in extremely high daily economic costs to shippers and barge operators. Conditions of higher mean flows and peak flows could jeopardize navigation on tributary navigation reaches or the entire Ohio River system.

Forecasted data indicate that spring season (March Maximum) flow discharge along the Ohio River mainstem between 2070 and 2099 may be 25% to 35% higher than the base years (1952–2011) flow. Personnel at each navigation dam are able to individually adjust pool elevations through gate operations and cooperative gate operations at adjacent hydroelectric power plants. Communications with downstream navigation facilities allow system adaptation to higher flows via orchestrated changes in gate operations. It is likely that enhanced coordination of gage data at forecast points between the OHRFC and USACE lock and dam projects could enable closer monitoring of incoming tributary flows and preemptive gate adjustments to maintain stable pools for navigation, thereby reducing accidents and outages.

8.5.1.5 Public Waterfront Parks, Marinas, and Commercial Cargo Terminals

There has been an expansion in the number of waterfront parks along waterways in the ORB over the last 30 years. With exception of a few public boat launching ramps and day-use parks, there were no formal urban waterfront parks. The 1980s spurred growth in basin waterfront park development that continues even today. These facilities feature paved esplanades for walking, fishing and boat mooring, amphitheaters, playgrounds, restrooms, picnic shelters, and other riverside amenities. Many of these facilities are located within a few feet of the normal navigation pool elevation and within feet of summer flow elevations in free-flowing streams, resulting in recurring maintenance after high flood flows. This close physical association with the water surface places these hard-edged, fixed-elevation facilities at risk from future increases in flow. More frequent and longer duration inundation ensures that annual operation and maintenance costs will rise and usage will be reduced. Future reductions in flow due to prolonged drought and evaporation could result in mooring areas being dewatered and requiring further dredging to facilitate their use.

There are numerous marinas located along the Ohio River. These floating facilities are capable of adjusting to changes in water surface elevation, but the effects of long duration drought conditions can result in grounded docks. Conversely, high-velocity flows on rivers can damage floating docks and watercraft docked there. In either case, owners of expensive craft will avoid using at-risk facilities over longer periods of time, reducing rental revenues and threatening continuing recreation use of river amenities. In contrast to threatening high flow conditions, warmer seasonal water temperatures could result an extended season of marina use and reduced river ice for marina owners and barge operators to contend with.

There are hundreds of commercial terminals located along the Ohio River and its navigable tributaries. These facilities accounted for transloading nearly 239 million tons of cargo in 2013 worth an estimated $41 billion (Planning Center of Expertise Inland Navigation 2013 data) to local, state, and regional economies. As is the case with waterfront recreation facilities, the elevation of the docks above the normal pool surface is fixed based on historic water surface profile information at that river location. One major difference between the commercial and recreation dock facility is the deeper draft needed at a mooring berth for commercial barges and tow boats to operate. Without adequate draft, barges cannot be filled to capacity, thus losing efficiency and the financial benefits of shipping by waterways. Major changes in draft along navigable waterways reduce the ability to service existing terminals that may be too shallow to allow barges and tow boats to dock safely. Adaptation to these potential changes involves expensive dock modifications, additional dredging, and/or relocation of terminals.

8.5.1.6 Stormwater Retention and Detention Infrastructure and Conveyance Systems

There are a number of large municipal and county-wide stormwater management systems within the basin. Major urban areas such as Pittsburgh, PA; Cincinnati, OH; Huntington, WV; and Louisville, KY, operate systems under the provisions of the CWA and oversight by ORSANCO and USEPA. These complex systems are constructed, operated, and maintained to address urban and suburban stormwater flooding issues. Normally, these facilities are designed to handle higher frequency, short duration precipitation events (i.e., 5- to 25-year frequency events) that cause urban street flooding and damages to homes and businesses.

Design calculations for these systems are founded upon rainfall intensity and duration from historic records within each catchment or watershed area. Changes in annual mean and maximum precipitation, catchment runoff, and stream discharge could significantly challenge the storage capacity and hydraulic efficiency of these facilities. Ongoing basin efforts by USEPA and states to reduce impervious surfaces in new development and placing more emphasis on low-tech rainwater capture, green infrastructure, and less reliance on direct conveyance to streams are good preemptive adaptation measures. However, current stormwater facilities designed to historic hydrologic regimes may be under-designed to meet future forecasted precipitation rates. Adaptation measures to retrofit these facilities (increase surface or underground storage) will be needed to maintain their effectiveness under forecasted precipitation conditions.

8.5.1.7 Federal and State Fish Hatcheries

Basin fish hatcheries are operated to accomplish a number of state and Federal goals in fishery management. In addition to maintaining adequate stocks to support sport fishing—a valuable resource-based sector of the economy for states—both state and Federal agencies use hatcheries to re-establish extirpated species from their natural habitat. In West Virginia, some state hatcheries are rearing sturgeon and paddlefish to re-establish those species in the Ohio River, the Kanawha River, and major tributaries. Infrastructure contained within the National Fish Hatchery System operated through the U.S. Fish and Wildlife Service has a total asset value of $2.2 billion, and represents complex water control and treatment technologies, as well as aquaculture systems that have value for rearing a myriad of aquatic species including mussels[20]. This system has a number of programs from spawning certified disease-free salmonoid eggs (National Broodstock Program) to rearing large river fishes (sturgeon and paddlefish) for repopulating major rivers.

There are five national fish hatcheries operated by the U.S. Fish and Wildlife Service and approximately 13 state fish hatcheries within the basin. Millions of walleye, musky, tiger musky, channel catfish, hybrid striped bass, saugeye, sunfish, and largemouth and smallmouth bass have been raised at these hatcheries. Hatcheries use ponds, indoor tanks, and raceways circulating fresh water at specific temperatures to sustain planned growth rates for aquatic species. Changes in water temperature outside of specific norms for each species can lead to disease, loss of appetite, loss of productivity, and/or reduced growth. These facilities are dependent upon reliable sources of fresh water that varies in temperature from warm to cold depending upon the species being reared. Hatcheries located along major rivers or below reservoirs are primarily warm water facilities used to supply production for those particular river and lakes.

There are a number of trout hatcheries scattered around the region supporting stocking programs for sport fishermen. These hatcheries require reliable cold water supplies that are GW pumped, spring fed, or provided by cold headwater tributaries. These facilities raise supplies of various aged trout species from fingerlings to breeders. Fish reared at these facilities bring in millions of dollars in license fees, tourism, and recreational use for the 13 basin states and their closures would be a significant economic loss to the region.

8.5.1.8 Wastewater Collection Systems and Treatment Plants

There are an indeterminate number of municipal, public service, county, corporate, and community-level wastewater collection and treatment facilities across the basin. Other than those residences and businesses using septic or aerator systems, all other habitable structures and commercial enterprises are on a sewerage collection system (at least that would be the preferable situation). Following prescribed levels of sewage treatment at a central or package plant, the resulting effluent is discharged into streams or rivers under strict CWA permit requirements. Generally, the state-issued permits for effluent discharge are based in part on the anticipated volume of flow in the receiving stream during any season of the year. Under severe drought conditions, the normal dilution capabilities of the receiving stream or river are reduced, resulting in higher concentrations of pollutants and decreased water quality.

[20] National Fish Hatchery System–Strategic Hatchery and Workforce Planning Report; March 2013, US Fish and Wildlife Service

Authorized low-flow augmentation (a.k.a. water quality) at some reservoirs provides a downstream minimum flow volume that maintains the dilution rate required for effluent permits. Where such augmentation does not exist, water quality can be an issue during extreme drought conditions. This situation becomes a health and safety issue when communities withdraw water from those same rivers downstream of effluent discharge points. Should future changes in precipitation and runoff decrease dramatically in tributaries the ability of streams and rivers to dilute effluent discharges will be decreased, resulting in degraded water quality, increased costs for potable water treatment, and additional stress on aquatic species.

Many older wastewater systems in the basin were constructed as combined sewer and stormwater systems. During heavy rainfall events these overwhelmed conveyance systems bypass wastewater treatment plants, resulting in a mixture of stormwater and untreated sewage entering streams and rivers. These Combined System Overflows (CSO) are detrimental to water quality and aquatic species. ORSANCO data indicate that there may be as many as 1,100 of these CSO systems entering the Ohio River mainstem. USEPA and ORSANCO monitor these systems and many municipal areas are under Federal court mandates to separate these systems and reduce CSO effluent streams. Should future annual mean and annual maximum precipitation/runoff increase substantially, CSO events could increase to the detriment of basin water quality and aquatic species health.

8.5.1.9 Water Extraction, Treatment, and Distribution Systems

As is the case of wastewater treatment systems, there are an indeterminate number of water supply systems in the basin. These systems range from massive municipal systems that serve major urban areas (i.e., Pittsburgh, PA; Huntington, WV; Cincinnati, OH; and Louisville, KY), to suburban or rural community systems dependent upon well fields and individual wells at single residences. These systems are dependent upon either surface or ground water supplies or a combination of the two sources to meet existing public and industrial demand.

Surface water supplies range from dependence upon natural river flows to contracted withdrawals from existing single-purpose or multiple-purpose impoundments. There are 40 reservoirs in the basin that include water supply as a purpose. Those reservoirs (both single- and multiple-purpose) include facilities constructed by NRCS, TVA, USACE, and larger municipalities. Many USACE impoundments provide water supplies to regional or local water districts through contractual arrangements according to the Water Supply Act of 1958. USACE data show that 135 USACE reservoirs have roughly 11 million acre-feet of storage designated for M&I water supply nationally[21]. Within the ORB, USACE operates 18 reservoirs that have M&I water supply as an authorized purpose. Within the Muskingum River watershed where the Muskingum Watershed Conservancy District (MWCD) controls the use and distribution of impounded water at 13 lakes constructed by USACE, MWCD has water supply contracts with several municipal and county systems as well as contracts with industrial users.

Other primary sources for water supply include natural river flows, controlled river flows, and ground water. Numerous communities in the basin extract municipal water supplies from naturally flowing rivers due to insufficient ground water resources (areas of karst topography). During past drought situations, some of these communities have required emergency water supplies (trucked in) provided by state agencies. Future drought episodes projected by the current modeling could

[21] Congressional Research Report for Congress (7-5700), Nicole T. Carter, January 2010

result in continuing emergency situations for these communities. Other communities extract water from rivers that have upstream impoundments providing some level of minimum downstream releases in support of purposes (low flow augmentation, fish and wildlife enhancement, or recreation) other than water supply. So long as sufficient water is impounded to support these authorized releases, these downstream communities will have access to reliable water supplies. More importantly to these communities would be the location and depth (invert elevation) of their water intakes in flowing rivers should future drought episodes persist under changing climate conditions.

A number of municipalities and counties in the basin depend upon ground water resources for water supply. The basin is underlain by a number of extensive aquifers that have been tapped by numerous communities for residential, commercial, and industrial use and crop irrigation. Water use by basin county can be found at: http://water.usgs.gov/watuse/data/2010/. Generally, these jurisdictions have constructed extensive well fields to meet their demands. Depending upon the size and capacity of the aquifer being tapped and the regenerative abilities of that resource, these communities can be sustained during drought periods. However, where urban communities withdraw large daily amounts of ground water, local surface water resources (creeks, ponds, and streams) and the aquatic species they support are adversely impacted. Future periods of decreased precipitation and runoff forecast by CC modeling portend significant water supply issues for many of these ground water dependent communities and local surface water resources that support aquatic species in the future.

8.5.1.10 Transportation Infrastructure

Transportation infrastructure includes highways, airports, railways, pipelines, waterways, bridges, tunnels, etc. The basin is laced with transportation corridors connecting towns and cities and major industrial centers within its borders. In addition, interstate highways, Class 1 railways, and interstate pipelines cross the basin connecting with major urban and industrial centers and port locations outside of the basin. Many of these transportation lines either cross the Ohio River and its major tributaries, or follow the gentle grades they offer within that corridor, making them susceptible to inundation through overbank flooding or inoperable due to lack of river flow. The nodes served (terminals, stations, urban and industrial centers and ports) by these transportation corridors are normally located within those same stream or river corridors.

Infrastructure associated with transportation systems includes the roadways, trackage, pipelines, runways and waterways themselves, the right-of-ways, bridges, navigation locks, tunnels, signaling system, stations, classification yards, terminals, hangers, pumping stations, interchanges, and both flow monitoring and communications systems that are integral to the safe and efficient operation of the modes. In addition to basic infrastructure components and control/monitoring systems, the current freight transportation network has begun the transition to an intermodal system composed of many integrated parts including highway and rail, and perhaps waterways in the future. The Heartland Corridor railway extends from Norfolk, VA to Columbus, OH and on to Chicago, IL, providing double-stack container service from the Atlantic coast through the basin to a Great Lakes connection. This national freight corridor follows several major river valleys and may be subject to disruption by future flooding.

Some key components of the transportation system (electronic monitoring, avionics, railway and highway signaling, materials expansion and contraction, etc.) could be affected by higher air temperatures and higher maximum spring discharges leading to overbank flooding—flooding that could inundate facilities or overwhelm the protection limits of key system components. Significant reductions in river flow could limit loadings (reduced draft) or stop waterway traffic altogether. Significant thermal expansion and contraction can affect component materials (e.g., steel rails, expansion joints at bridges, and pipeline fittings) leading to materials and equipment failures, higher operations and maintenance (O&M) costs, and potentially catastrophic accidents. Higher temperatures can adversely affect roadway surfaces (concrete and asphalt) leading to higher maintenance and repair costs and higher accident rates. Warmer, more humid air in the basin could affect passenger and air freight traffic take-off distance requirements leading to insufficient runway lengths and inadequate safety zones at major airports.

8.5.1.11 Energy Infrastructure

The ORB is home to approximately 400 electric energy producing power plants. Those plants include coal-fired, gas-fired; oil-fired and nuclear fueled thermoelectric plants as well as hydropower, wind turbine, solar, and bio-fuels plants. A listing of those plants using water for cooling the plant is shown in Table B-19 in Appendix B. Table B-20 in Appendix B shows those power plants located along the Ohio River mainstem with the cooling type and estimated water withdrawal in million gallons per day.

Thermoelectric power plants require substantial amounts of fresh cool water to maintain their operating efficiency. These plants use one of several types of water cooling systems including "once-through," "recirculating," and "air-circulating". Once-through systems pull in cool water, boil it for steam to run the turbines and send the warm water back into the river or lake, while recirculating (off-steam) systems use condensation or "cooling towers" to cool the water and then reuse the cooled water for re-boiling. Air-circulating systems use air to cool the recirculated water. Although the once-through systems extract more water overall (small losses through condensation), they return most of the warmer water to the river. The returned water results in thermal pollution issues (adverse impacts on aquatic species) in the receiving stream. Operation of these systems can be threatened by higher temperature water being pulled from lakes and rivers. At certain temperature thresholds the once-through system becomes less efficient and could be taken offline.

The recirculating units also require cool water, but use much less water (due to minimal losses in condensation), and are less susceptible to shutdowns. Air-circulating units can be threatened by higher air temperatures and high humidity that reduce the efficiency of water cooling through outdoor air condensers. Future changes in air and water temperatures could threaten the capability of some thermoelectric plants in the basin. A substantial number of residential customers in the basin (current population of 27 million) as well as much of the basin's industrial and commercial production would be placed at risk in the event of multiple thermoelectric plant shutdowns. Figure 8-15 shows the distribution of thermoelectric power plants that report using cooling water from a surface source (stream or river) or a well/GW source. Once-through and recirculating plants are shown. Those plant locations are arrayed upon the forecasted changes in flow discharge for the October Minimum values during the 2071–2099 (*F3*) period of analysis.

Table B-26 in Appendix B shows the array of these power plants associated with each forecast group in the basin and the forecasted percent change of flow discharge in that group for the three 30-year periods. The Annual Minimum, October Mean, and October Minimum values are shown in the table to reflect periods when flow discharge will likely be lowest at the cooling water source or when competing water demands (M&I water supply) would conflict with the power plant use.

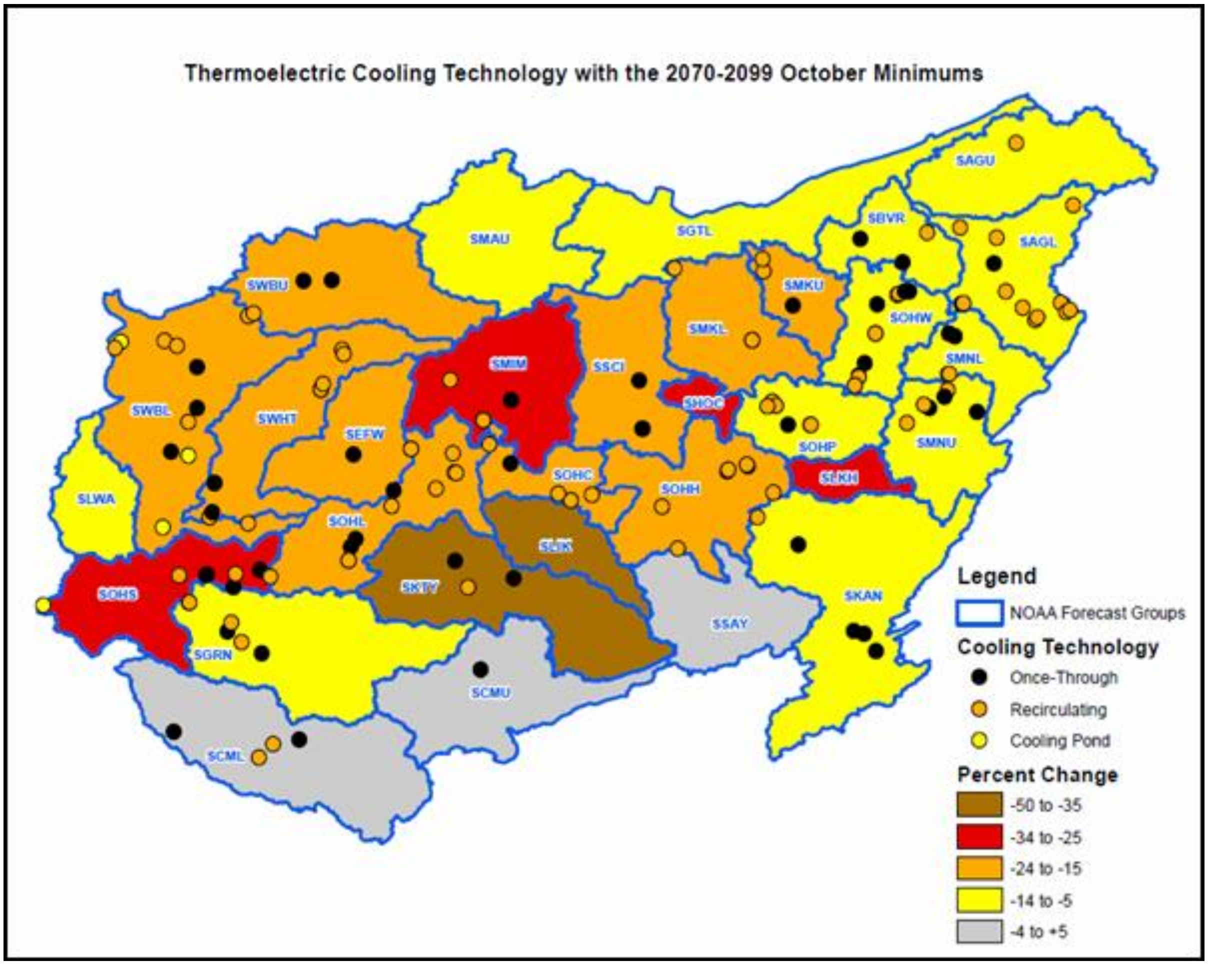


Figure 8-15: Thermoelectric Power Plants Extracting Surface Water for Cooling

The forecast data indicate that three power plants on the Kentucky River may face decreased flow discharge of 35% to 50% under the October Minimum flow season between 2070 and 2099. In addition, the forecast data show that five power plants on the Miami River may face decreased river flows between 5% and 15% under the October Minimum flow season between 2011 and 2040 with greater decreased flows of 15% to 25% during the same season between 2040 and 2070 and further decreases in flow 35% to 50% between 2070 and 2099. Also, the forecast data show that six power plants in the Muskingum River area may face deceased flows of 15% to 25% under the October Minimum flow season between 2070 and 2099. Additional decreased flows of 15% to 25% during the October Minimum flow season may occur for about 21 power plants along the Ohio River between 2070 and 2099. Other decreased flows in the range of 15% to 25% may occur in the Wabash River forecast group (lower and upper and White River) during the October Minimum flow season between 2070 and 2099.

There are 53 operating hydroelectric power plants that rely directly on the discharge/flow of those rivers to produce electricity. The USACE has 34 reservoirs and navigation dams in the basin that either are authorized for hydropower and store water specifically for hydroelectric power generation or maintain a stable pool (navigation dams) that supports run-of-river hydroelectric power generation. Figure 8-11 displays the location of the dams that generate hydroelectric power in the basin. Changes in the river flow (a historic flow rate that was used to justify construction of the power plant) could dramatically affect the future capability and reliability of those plants to produce power. Especially critical would be lower seasonal flow rates during heavy summer (air conditioning) demand periods. Competing water demands during this same period would require agencies to prioritize their operations according to policy or regulations that may not be updated to address CC conditions.

In addition to the plants themselves, the energy infrastructure system includes a network of distribution lines and substations throughout the basin that likewise intersect the Ohio River and its tributaries. Where these distribution networks and substations are located in floodplains, future changes in river discharges that may result in overbank flooding could threaten these facilities. Higher air temperatures could affect the efficiency of high-voltage aerial transmission lines that require cooler air temperatures to dissipate heat buildup. Likewise, high energy demands driven by higher summer temperatures (air conditioning) could result in substation failures due to the warmer air's inability to dissipate heat buildup in transformers. Should higher temperatures result in more frequent thunderstorm activities, lightning strikes at critical transmission facilities could result in more frequent power outages and higher repair costs.

8.5.1.12 Communications Infrastructure, Distribution Lines, and Towers

The basin supports a dense system of communications facilities including microwave, television, cellular telephone, emergency response, and supporting computer networks that rely on transmission towers, repeaters, and ground lines to serve customers throughout the basin. Due to the basin's rugged terrain, most communications towers are located on high ground where future over-bank flooding would not be a threat, but some transmission and receiving stations and supporting power facilities are still subject to effects of over-bank flooding. Similar to energy transmission lines, communication lines (telephone land lines) can be affected by high winds and lightning strikes that could become more frequent as a result of more frequent, intense rain events.

8.5.2 Summary of Potential Infrastructure Impacts

As discussed previously, the basin infrastructure for flood damage reduction, water supply, hydropower, energy production and distribution, wastewater collection and treatment, commerce, and transportation is vast and complex and features broad integration between the systems. The scope of the various systems extends geographically from local community services to regional networks, which are operated by public service districts, municipal and county governments, states, and Federal agencies. Each level of system management and financing for O&M carries with it policies, regulations, and objectives that direct actions to be taken in response to changing conditions.

Extreme conditions of drought threaten those facilities that depend largely upon a reliable flow of fresh water for navigation, industrial processing or thermoelectric cooling, municipal water supply and irrigation, dilution of effluents, and/or recreation. At the far extreme of this hydrologic régime are episodes of extremely high flows that would threaten infrastructure designed to reduce life loss and flood damages such as dams, levees, and floodwalls, diversion channels, and stormwater retention basins. In situations when discharge flows exceed the designed holding capacity of these facilities, risks to life, flood damages to property, and destruction of heritage/cultural resources can ensue.

Changes in climate that result in higher air temperatures and associated higher water temperatures in lakes and rivers can threaten certain industrial processes and energy production cooling. Increased evaporation from lakes and rivers can reduce the capability to store sufficient water to meet contracted water supply volumes and hydropower generation. In addition, thermal expansion/contraction and associated warping and deterioration of materials, flooding, or inadequate flow can affect many components of the transportation infrastructure including highway surfaces, runways, trackage, bridges, and pipeline crossings.

Although not directly related to the flow discharge requirements needed by hydropower dams or the cooling water needs of thermoelectric power plants, the hydraulic fracturing process being used for natural gas development represents a potential issue with regard to basin water needs. Figure B-9 in Appendix B shows the approximate extent of the Marcellus and Utica shale complex that underlies the basin. Estimates of water use to hydraulically fracture a gas well range from 2 to 4 million gallons. The quality of the resulting drill water generally falls short of any CWA standards for return to a nearby stream or river. The cocktail of chemicals and sand used to fracture the gas shale layers remains sealed within the well or is hauled away to safe disposal facilities, resulting in a net basin loss of that extracted water.

Where adequate water resources are available, such as the Ohio River and its main tributaries or large reservoirs with surplus storage, extraction from those sources does not appear to be a significant water availability issue from a basin perspective in the near future (2011–2040 [*F1*]). However, the extraction of 2 to 4 million gallons of water multiplied by hundreds or thousands of future wells may become a significant water availability issue within several of the forecast groups during the October Minimum period between 2041 and 2099. Adaptation strategies that address this competing use may require new onsite processing of drill water that would meet CWA standards for disposal into receiving streams, or regulatory actions requiring water extraction for hydraulic fracturing be limited to rivers with sufficient flow discharge or reservoirs with surplus storage to meet needs.

8.5.3 Impacts to Regulatory and Infrastructure Rehabilitation Programs

In addition to basin infrastructure systems that support commercial production, economic growth, and stability, there are regulatory systems and infrastructure rehabilitation programs in place that reduce the economic effects of flooding and life loss and either provide local control of floodplain development through ordinances or rehabilitate aging flood retention structures. Chief among regulatory systems is the NFIP. This program is active within a majority of municipal, county, and township jurisdictions and enables communities to exert some control on floodplain development through a vetted permitting process.

This permitting program is administered by local authorities and is based upon the Flood Insurance Rate Map (FIRM) program that identifies flood hazard zones and in some cases specific flood depth information. Historically, this hazard information has been developed based on the flood history of the local stream or river and a series of modeled theoretical floods including floods with recurrence intervals of 20 years, 50 years, 100 years (base flood elevation), and 500 years. Also shown on many FIRMs is the regulatory floodway whose location and extent are based largely upon flows associated with the 1% annual chance flood event.

The anticipated climate-induced increases in the Annual Mean flows, Annual Maximum flows, and March Maximum flows indicate a potential change in the recurrence probability of several mapped flood events as well as areal coverage of those floods. Since the basis for actuarial rates that determine annual flood insurance premiums depend upon depths of flooding at the structure and recurrence interval, potential future increases in stream discharge may indicate higher risk of damages and therefore higher insurance costs for landowners.

Flow increases may also modify the extent of a regulatory floodway, thus decreasing that portion of the floodplain in which development can safely occur without affecting the base flood elevation. More importantly, past Federal and state nonstructural projects that featured elevation of structures (raising the first floor elevation above the 1% annual chance event elevation) to reduce flood damages may have located first floors of raised structures too low should future river/stream discharges increase the 1% annual chance flood elevation.

From a rehabilitation program perspective, the National Dam Safety and National Levee Safety programs would be challenged by potentially higher river flows that may exceed historic hydrologic/hydraulic data being used as a basis for addressing performance issues at those facilities. Justification for adjusting design parameters during a Dam Safety Modification Study to account for forecasted future flows may be problematic, as would be additional construction costs to address forecasted flows. Facilities currently listed as being at risk from poor performance during flood conditions could be further threatened by significant future discharges before the scheduled dam or levee modifications have been completed.

9. Basin Water Managers and CC Activities/Readiness

9.1 Introduction

This section of the pilot study addresses an outreach effort undertaken by the team to (1) identify the basin water managers (Federal, state, local, private), (2) assess their current regulations for storing and discharging water under extreme weather/climatic conditions (primarily flood and drought conditions), (3) ascertain their current agency/organization activities for addressing CC effects, and (4) determine their willingness for future collaboration in CC activities. The purpose of this investigation was to determine the current state of infrastructure and institutional capability and readiness of USACE and other Federal and state agencies to address CC impacts primarily from a hydrologic perspective. The results of this outreach program would help place the USACE's concerns for CC impacts and adaptation strategy development into context with actions of other Federal, state, local, and private water managers.

9.2 Outreach Process

The Project Delivery Team (PDT) conducted an outreach program to determine what levels of awareness; planning and readiness might be present for the larger water managers in the basin. The term "larger" in this context was used to differentiate among a multitude of basin water managers as those public or private water managers that controlled either single-purpose or multiple-purpose reservoirs or that controlled extensive systems of stormwater retention facilities (i.e., municipal stormwater authorities) that could be affected by significant changes in river/stream discharges or precipitation.

A sub-group of PDT members conducted this outreach effort in three phases. Those phases included an extensive search of existing water managers including Federal, state, and local/municipal water managers in the basin, resulting in an extensive list. The list was evaluated and scaled down (constrained by study time and resources) by the team and a brief questionnaire (see the following) was developed and used to gather basic information on CC awareness, current activities, current agency regulations regarding CC, status of any climate modeling activities, and basic information on project authorities and operations.

The second phase was an invitation to the water managers for a webinar presented by Jim Noel of the OHRFC on the results of the downscaled CCs being used by the pilot study team. The OHRFC webinar was held on January 14, 2014 and was attended by 38 participants from USACE, NRCS, USEPA, and several state agencies. Questions were addressed by Mr. Noel (NOAA) after the webinar and participants were again encouraged by team members to respond to the questionnaire. A copy of the slides presented during the webinar is attached in Appendix C. Following the webinar, each participant was encouraged to respond to the questionnaire (third phase) and to provide feedback on the CC modeling and whether the participants may be willing to partner with the USACE in future CC modeling and implementation of adaptation strategies. Those individual agency responses are included in Appendix C and are summarized in the following paragraphs.

All four USACE districts (LRH, LRN, LRP, and LRL) were engaged in the outreach program as well as the PA, AL, KY, NY, and WV state offices of the NRCS, and the USEPA (TMDL

Specialist). All together the five participating NRCS state offices have constructed 286 structures through the Public Law (P.L.) 83-566 or P.L.78-534 flood protection and watershed protection authorities and the Resource Conservation and Development program in the basin and have summarily turned those structures over to local sponsors (state, county, or city) for O&M. Their responses to the questions are based on the construction authorities provided by these legislative acts and the subsequent O&M arrangements with local sponsors.

9.3 Questionnaire

The questionnaire was composed of seven questions aimed at discovering what types of water management systems were being used by the various managers and to what extent, if any, the various managers had been incorporating CC into their future operating systems. The seven questions are listed below. A summary of the answers to each question and the actual agency/company responses are provided in Appendix D.

1. What type of current operating management system do you employ for your system? (Individual plans? Integrated plan? Operations based upon system models?)

2. What water resources objectives or missions are your facilities authorized for?

3. Who are your major users?

4. Do your current operating plans account for any reactive measures or adaptation schemes for addressing anticipated CC effects?

5. If so, what CC scenarios did you use (national models, downscaled datasets, etc.) to develop your adaptation plans?

6. If you haven't developed particular adaptation actions in anticipation of CC effects, what components of your operating plans deal directly with the extremes of drought or flooding and could these be modified to address new changes in climate that may affect operating flows and water temperatures?

7. Are you interested in working with the USACE and other partners to develop a basin-wide response plan for CC that would integrate the systems?

10. Mitigation/Adaptation Strategies and Measures

10.1 Introduction

This section of the pilot study concentrated on formulating an array of mitigation and adaptation strategies that could be deployed by water managers and water users at all levels of government, private or corporate ownership to address the anticipated CC impacts identified in Section 8, and other effects cited in the research literature. Strategies for addressing unavoidable, residual impacts of CC were also developed, along with objective assessments of the likelihood of success. Team members included representation from USEPA, TNC, Battelle Memorial Institute, USACE, and both the University of New Hampshire and Marshall University.

The formulated mitigation/adaptation strategies and measures herein support the overall vision of the ORB Alliance stated as: *"To support and implement integrated management of the Basin's resources to achieve sustainable economic growth, ecological integrity, and public safety."* This basin vision, formulated and adopted by the Alliance members, provides a metric for determining the success or failure of the measures and strategies discussed in the following paragraphs in attenuating the potential impacts of forecasted conditions across the three periods *F1*, *F2*, and *F3*. Achieving sustained growth, ecological integrity, and public safety under the forecasted CC conditions outlined in this report will take a concerted effort on the part of Federal, state, local, and regional agencies, NGOs, corporate interests, and the general public.

The IWR RCCP website includes this statement on adaptation: "In mainstreaming adaptation, our goal is to develop practical, nationally consistent, legally justifiable, and cost effective measures, both structural and nonstructural, to reduce vulnerabilities and improve the resilience of our water resources infrastructure impacted by climate change and other global changes."

The recently published 3rd National Assessment for North America (based upon the 5th IPCC Assessment document) defines both mitigation and adaptation measures. Mitigation is thereby defined as *"response efforts to limit emissions or increase carbon uptake: reducing the amount and speed of future climate change by reducing emissions of heat trapping gases or removing carbon dioxide from the atmosphere. The threat of irreversible impacts makes the timing of mitigation efforts particularly critical."* The definition of adaptation in that publication is *"actions to prepare for and adjust to new conditions, thereby reducing harm or taking advantage of new opportunities."* The following sections describe the analytical process used in formulating strategies and measures that could be applied to basin infrastructure and ecosystem components, and a possible timetable for action based upon the forecast data.

10.2 Basin Mitigation Strategies

As expressed in the previous definition, the reduction of CO_2 emissions and other noxious gases in the atmosphere and increasing carbon sequestration through various means is a primary mitigation strategy being promoted throughout the Nation. Currently there are a number of mitigation strategies being implemented within the basin as responses to CC concerns, regulatory actions, or responses to market forces. Two of the primary generators of CO_2 gases in the basin are fossil-fuel power plants and transportation modes.

The basin is home to several hundred electric power generation plants. Although a percentage of these facilities use renewable fuel sources (wind, solar, biomass, and hydropower), the predominant fuels used are coal, oil, and gas. Recent environmental regulations and increased availability of natural gas within the region have resulted in a number of power plants switching from coal and oil to natural gas as their primary fuel. This switch to cleaner burning fuels has likely resulted in reductions in CO_2 emissions. Six low-head hydroelectric power plants operate at Ohio River mainstem navigation dams, providing a consistent, non-fossil fuel energy source in the basin. An additional four hydropower plants are under construction at other mainstem Ohio River navigation dams and Federal Energy Regulatory Commission license applications are being considered for additional USACE facilities in the Ohio River system. An additional five hydroelectric power plants are operating at other multipurpose dams in the basin. Each of these hydroelectric power plants (operating and under construction) further reduces reliance on fossil fuels and CO_2 emissions.

Basin transportation modes include highways, railways, airports, waterways, and pipelines. The majority of these modes (except pipelines) use fossil fuels as their primary energy source and emissions from these modes contribute to the total basin's output. These modes are the lifeblood network of the region's economy; therefore, sustaining their future capabilities while reducing their emissions supports the Alliance vision for the basin. Mitigation measures for transportation modes include efforts by basin states, counties, and municipal jurisdictions and their agencies to conserve the use of electricity and expand municipal and rural transit opportunities, thus reducing reliance on private vehicles for work and school-related trips. Some basin transit services and municipal service vehicles have changed to electric, propane, or natural gas fuels. All these local actions reduce CO_2 emissions. The current efforts to promote intermodal freight movements (truck, rail, and waterway) in the basin are being supported through investments by the WV Department of Transportation, Norfolk Southern Railroad, and CSX Railroad.

The Sustainable Rivers Program—a USACE and TNC partnership, based on a national Memorandum of Understanding—is an ongoing effort to modify operations at USACE dams to achieve more ecologically sustainable flows (e-flows), while maintaining or enhancing specific project benefits. Based on input from state and Federal natural resource managers, measurable e-flow goals are developed for USACE multipurpose reservoirs and the downstream river reaches they control, including (1) enhanced native fish passage, (2) water quality improvement/nutrient management, (3) threatened and endangered species protection (e.g., mussels), (4) reservoir pool elevation management to support fish spawning, (5) natural streamflow and sediment transport, (6) riparian habitat enhancement, and (7) maintenance of water temperature regimes. As previously stated in Section 8, reducing the current stressors on aquatic species is considered a preemptive adaptation strategy that enables these at-risk species to better adjust to forecasted changes in river flow and temperatures brought about by climate change.

10.3 Adaptation Strategy Plan Formulation

An adaptation plan is a comprehensive strategy to adjust to changed climate conditions. It consists of sets of public and private, local, and regional actions over time and space for an area. Actions can be dynamic, flexible, and adaptive or robust (a robust action works acceptably well over all climate change conditions). They should include "co-benefits" and "no-regrets" actions and be integrated with mitigation of GHG and other sustainability planning goals. The basic adaptation actions for both the built and natural environment include (1) taking no action, (2) protection, (3) accommodation, and (4) retreat. Actions can include those taken now for developing new systems to make them CC resilient or for modifying existing vulnerable systems (referred to as "Here and Now" actions), and those taken to protect existing or planned systems where actions do not have to be taken now but plans are developed, options to take action preserved, and the climate and other conditions monitored so that action can be taken when necessary (referred to as "Prepare and Monitor" actions). Adaptation planning starts with a vulnerability assessment of systems to present and future climates and then management strategies are developed to manage the impacts.

Strategies for adaptive management of current operating infrastructure and ecosystems can be formulated for several levels of implementation. USACE infrastructure (especially dams and reservoirs) are operated as independent facilities during "normal" operations and are guided by water control plans (codified in water control manuals) that dictate the levels of lake storage and daily releases to accomplish authorized missions and meet interagency agreements. Similar control/operation plans are prepared for navigation locks and dams operated by USACE and local protection projects (levees and floodwalls) operated by third parties. During emergency conditions (flooding or droughts), basin dams and reservoirs can be operated as an integrated system (also addressed in water control manuals) to limit life loss and flood damages at key centers, or to provide sufficient flows to enable waterway navigation or provide critical water supply.

For this reason, some strategies are formulated to be locally applied as responses to climate-induced variable flow discharge rates between the sub-basins (Allegheny River versus Wabash River), and some strategies would be applied basin-wide to meet climate-induced regional flow discharge challenges (i.e., regional flood emergency or drought conditions). Of paramount importance to successfully adapting this integrated system to forecasted changes would be the development of a basin water management plan that could incorporate downscaled CC modeling outputs (from this pilot study and future updates) into a basin-wide hydrologic model. This model must be capable of predicting individual facility operational changes in the HUC-4 sub-basins to balance water flows and storage capacities to meet flow targets at key points in the basin and to facilitate distribution of future water resources on an equitable basis.

Strategies range from adjusting seasonal and annual reservoir operations and possible future modification of structures to allow more flexibility in adjusting downstream flows to installing additional CC and flow monitoring stations, further modeling, and establishing a central repository for CC data storage. These adaptation strategies would require changes in reservoir water control manuals and agency readiness procedures. The strategies would also require use of predictive modeling methods to forecast climate-induced changes in hydrologic flows as a basis for design of reservoir dams and intake/outlet works and navigation dams scheduled for rehabilitation through the Dam Safety Program or other programs. Private/corporate landowner and municipal/county jurisdiction strategies for water harvesting onsite and other water conservation methods are included.

10.4 Basin Analysis Process

The process is organized through the framework of system vulnerability being defined by exposure (the present and future climates), sensitivity (the impacts of the climates on systems performance), and adaptive capacity of systems (how well systems can manage the impacts) (IPCC 2014). The flow discharge modeling results displayed in Chapter 7 were presented using the OHRFC forecast groups and forecast points (see Figure 7-1). As Figure 10-1 illustrates, the HUC-4 sub-basins (in various colors) within the ORB are geographically aligned with the OHRFC forecast groups (delineated by blue lines and abbreviated names). Many of the USACE dams and reservoirs are clustered within the HUC 4 sub-basins, and aquatic ecosystems have developed uniquely within the HUC 4 sub-basins; therefore, the HUC 4 sub-basins were used in this section as the geographic basis for the formulated strategies.

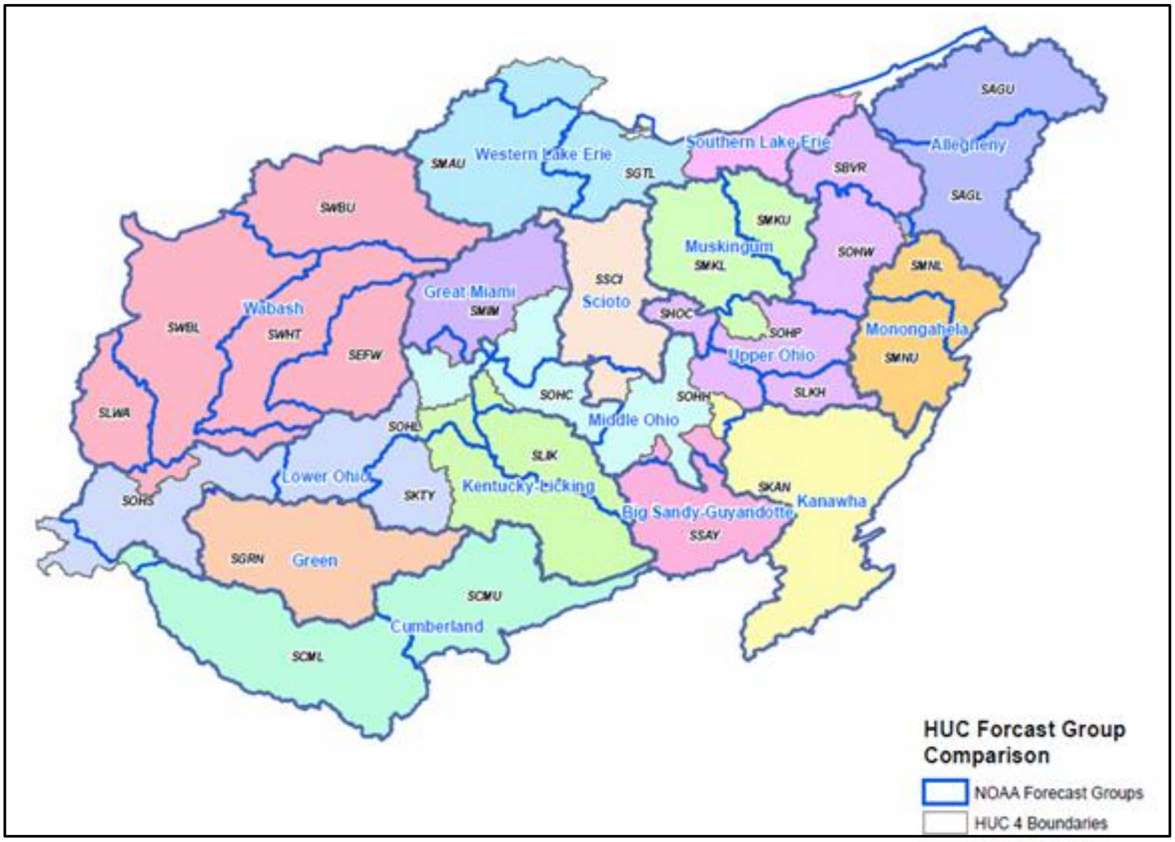


Figure 10-1: Adaptation Planning HUC-4 Sub-basins (HUC-4 in One Color)

The Tennessee River sub-basin flow discharges were not specifically modeled by OHRFC but presumed to be similar to the Cumberland River results (due to their adjacency) for the purpose of identifying adaptation strategies. Adjustments for the connectivity and interactions of the sub-basins by streamflow and land were carried out after the sub-basin analyses. The present and future climates and resulting streamflow conditions to which systems in sub-basins would be exposed are from Chapter 3. In addition, mean July precipitation rates and flow discharges by sub-basin for the periods 2011–2040 and 2041–2070 were also used to analyze the impacts to fish and mussels and their symbiotic reproductive exploits during summer low flows (see Appendix B). Since the major climate changes compared to the base years (1952–2001) occur after 2040, the adaptation analysis focused on impacts for the periods before 2040 and after 2040 in the period 2041–2070. The sensitivity or impacts to present conditions and then changes in flow and temperature were defined by a set of multi-criteria indicators reflecting social, environmental, infrastructure, and economic concerns according to the principles of IWRM. The following systems were analyzed:

1. Ecosystem services (drinking water extraction, agriculture [corn, soybean, wheat], forests, herbaceous wetlands, and nearby stream lands)

2. In-stream mussels and fish
3. Aquatic vegetation
4. Water quality
5. Infrastructure (wastewater treatment, navigation, flooding and stormwater management, hydropower, water supply, cooling water for thermoelectric power plants, reservoirs, locks and dams, transportation, waterfront parks, and marine terminals).

Where possible, given information and time resource constraints, these were analyzed in terms of the consistent format of present stresses, future exposure after 2040, impacts on the system, possible adaptation options, and positive and negative aspects of the adaptation options. Full descriptions of the impacts to systems are given in Chapter 8 and further text and tables in Appendix B. Table 10-1 shows that mapped adaptation themes applied to each sub-basin.

Table 10-1: Mapped Adaptation Themes

Adaptation Theme	Map or List	Figure Number
Restore wetlands	Wetlands in relationship to hydric soils	10-2
Reconnect floodplains	No map available	none
Consumptive use of water	No map available	none
Floodwaters capture	No map available	none
Drought planning	Indicators of past droughts by county	10-3
Nutrient & AMD stressed areas	Map of AMD sites	10-4
Thermoelectric power plant cooling system changeover	Map the plants and type of cooling system	10-5
Flooding effects	Flood declarations by FEMA	10-6
More WQ and discharge monitoring	Map current USGS and EPA sites	10-7
Land use management	Maps of land cover change	10-8
Reservoir ops modification	Map of reservoirs	8-18
Stressed ecosystems	Map of forest types	10-10

10.5 Adaptation Themes/Strategies

As described in the preceding chapters, CC has the potential to derail efforts in the basin to achieve the ORB Alliance's vision of *"sustainable economic growth, ecological integrity, and public safety."* A review of the adaptation options described in the tables in Appendix B found the common themes displayed in Table 10-2 and described in more detail as follows. The themes are displayed at the basin level or on several sub-basins described in more detail as follows. Many of the adaptation strategies will serve to sustain valuable ecosystem services and supporting infrastructure and contribute to attaining the basin vision.

Table 10-2: Adaptation Themes

Adaptation Themes	Basin Purposes Supported							
	Flood Risk Management	Wastewater Management	Water Supply	Navigation	Hydropower	Recreation	Aquatic Ecosystem	Land Ecosystem
Restore Wetlands	X	X				X	X	X
Reconnect Floodplains	X					X	X	X
Reduce Consumptive Uses of Water			X	X	X	X	X	X
Water Harvesting	X		X					
Drought Planning			X	X	X	X	X	
Increase Nutrient and AMD Management		X	X			X	X	
Thermoelectric Power Plant Cooling Changes[22]		X	X				X	
Nonstructural Flood Risk Management	X	X	X			X	X	X
More Water Quality and Discharge Monitoring	X	X	X	X	X	X	X	X
Land Use Management	X	X	X			X	X	X
Reservoir Operation and Structure Modifications	X	X	X	X	X	X	X	X
Managing Ecosystem Stress	X	X	X	X	X	X	X	X

10.5.1 Displaying Themes

Due to the vast size of the basin and its many HUC-4 sub-basins and the further division of the basin into forecast groups by the OHRFC for modeling purposes, the formulation team selected five of the HUC-4 sub-basin areas as examples for formulation and application of the adaptation strategies and measures. Those five HUC-4 sub-basin areas are the Allegheny River primarily in Pennsylvania, the Kanawha River divided between Virginia and West Virginia, the Great Miami River divided between Ohio and Indiana, the Wabash River divided between Indiana and Illinois, and the combined Kentucky/Licking Rivers in Kentucky. The five HUC-4 sub-basins were selected for their geographic distribution, ranges of size, distribution of climate change impacts due to differences in forecasted rainfall and river discharges, and forecasted range of air temperatures (and therefore water temperatures) in the future. Table 10-3 shows these five sub-basins and key physical/demographic data.

[22] Changing from Once-through systems to Re-circulating systems

Table 10-3: Selected HUC-4 Sub-basins

HUC-4 Sub-basin Name	State(s) Location	Land & Water Area in Square Miles	Estimated 2012 Population	Acres per Person	Dams and Reservoirs	Power Plants
Allegheny River	PA	11,666	1,261,154	6	12	14
Kanawha River	WV,VA	12,236	819,386	10	6	5
Great Miami River	OH, IN	4,277	2,121,582	1	6	5
Kentucky/Licking River	KY	9,300	1,263,810	5	15	3
Wabash River	IN, IL	39,950	4,348,010	6	11	26
Totals		77,429	9,813,942		50	53

10.5.2 Restore Wetlands

As noted in Chapter 8 and Appendix B, wetlands presently cover 1,500 square miles of the ORB. This is approximately 0.7% of the entire basin surface area. Historically, based on a USGS map of hydric soils in the basin, wetlands may have covered approximately 20% of the basin. Wetlands store and regulate flood waters, purify flow, provide wildlife habitat, facilitate aquifer recharge, and are locations of human recreation. Assuming that most current wetlands are federally protected, then restoration of once-existing wetlands would help manage some of the present and future climate-related stresses in the basin, such as flooding, poor water quality, and stressed ecosystems. Preemptive implementation for this strategy could be to concentrate on restoring and/or expanding existing wetlands lying within or adjacent to (intersecting with) hydric soils. In addition, new wetlands within hydric soil areas could be established by removing existing drainage systems (i.e., cutting drainage tile fields in abandoned farmland). As can be seen in Table 10-4, the potential for wetland restoration or expansion, as indicated by the intersection of existing wetlands and hydric soils, is well distributed among the five example HUC-4s, with the Wabash having the greatest number of opportunities for expansion. Figure 10-2 depicts this interrelationship graphically.

Table 10-4: Intersections Between Hydric Soils and Existing Wetlands by Sub-basin

Sub-basin Name	Acres in Sub-basin	Number of Intersections	Acres of Wetlands Intersecting Hydric Soils
Allegheny River	7,503,331	44,336	159,356
Kanawha River	7,833,246	10,232	14,862
Great Miami River	3,439,728	35,298	28,661
Kentucky/Licking Rivers	6,836,120	5,181	3,947
Wabash River	21,208,702	144,572	334,051

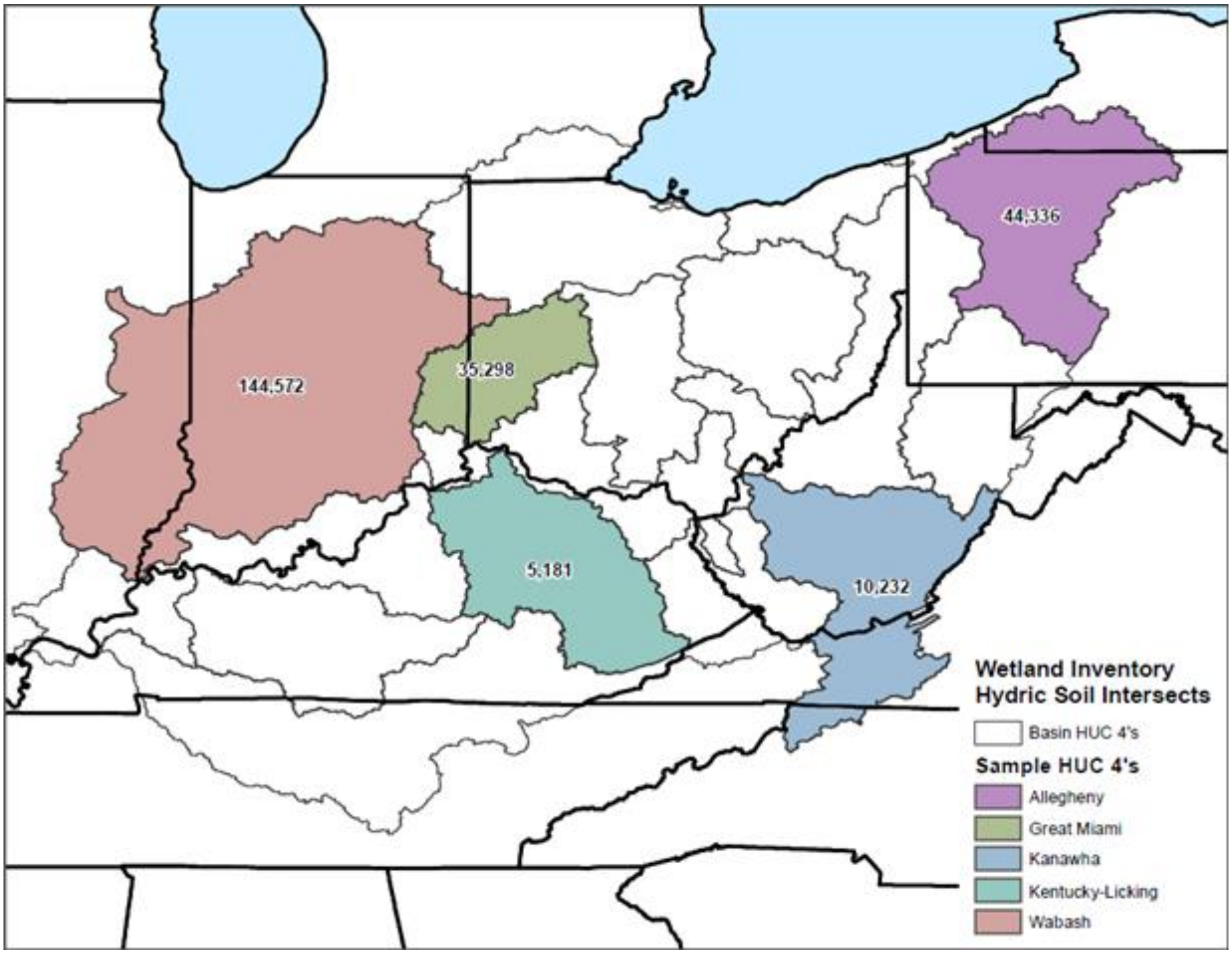


Figure 10-2: Wetland and Hydric Soils Intersections in Selected Sub-basins

10.5.3 Reconnect Floodplains

Many of the original floodplains are no longer connected to their parent streams, which has decreased the natural storage of floodwater and probably increased flood discharges and velocities. Disconnection has occurred, in part, because of construction of local protection projects (i.e., levees and floodwalls). Although numerous levees and floodwalls have been constructed to protect major urban centers and industrial complexes, there are many levees constructed to protect farmland in the lower reaches of the Ohio River. With increasing flooding projected for parts of the basin, removal or relocation of some agricultural levees may increase natural flood storage, reducing the flood risk in urban areas and reconnecting the floodplain to the stream channel. Further study of the locations of these agricultural levees and the acres of floodplain that could be reconnected should be undertaken when additional funding is available.

10.5.4 Reduce Consumptive Uses of Water

With lower flows forecasted in some months for the western portions of the basin, there is a potential for increased irrigation of cultivated crops and subsequent increase in water consumption. Assuming that most present and future water withdrawals are returned to the basin after use (non-consumptive), permanent reduction in present and future consumption of all water uses must be considered. For example, drip irrigation may be required for all future agricultural irrigation and other water conservation practices may be required around the major urban centers where future precipitation and flow discharges are forecast to decrease significantly in the future.

10.5.5 Harvest Precipitation and Flood Flows

With the potential increase in precipitation and flood discharges under CC, consideration should be given to capturing excess storm-water runoff on individual sites or at larger retention scales for areas of concentrated development during precipitation events and floods. The retained water could be used to recharge basin aquifers and for water supply. Given the forecast for substantially dryer conditions in parts of the basin, harvesting precipitation in all forms to recharge GW supplies (used extensively for municipal supplies and irrigation) is a sustainability strategy applicable for all basin counties and communities. Use of green infrastructure to capture storm-water can be applied throughout the basin. Reducing the future placement of impervious pavement surfaces (asphalt and concrete) where pervious pavement types can be used (parking lots) would further support GW recharge. These harvesting techniques are especially important in those portions of the basin where forecasted precipitation may be significantly decreased and in larger urban areas where storm-water runoff is an ongoing problem.

10.5.6 Drought Contingency Planning

As illustrated in Figure 10-3, the basin is sensitive to drought impacts and these are expected to grow in the future for certain areas of the basin. The 2012 data show that nearly every county in the basin had one drought declaration either from USDA or FEMA during that year. The most serious drought conditions were associated with the Kanawha River sub-basin in counties adjacent to the Greenbrier River, a tributary of the New River having no upstream storage to address the low flow river conditions. Past drought conditions in that area have resulted in emergency measures, including hauling water to communities in tanker trucks. Having in-place drought management strategies that take preemptive measures to store excess inflow in reservoirs and to gradually reduce the nonessential uses of water during droughts are useful adaptation strategies that will help meet essential water supply purposes during future events and also may partially maintain some off-stream water uses.

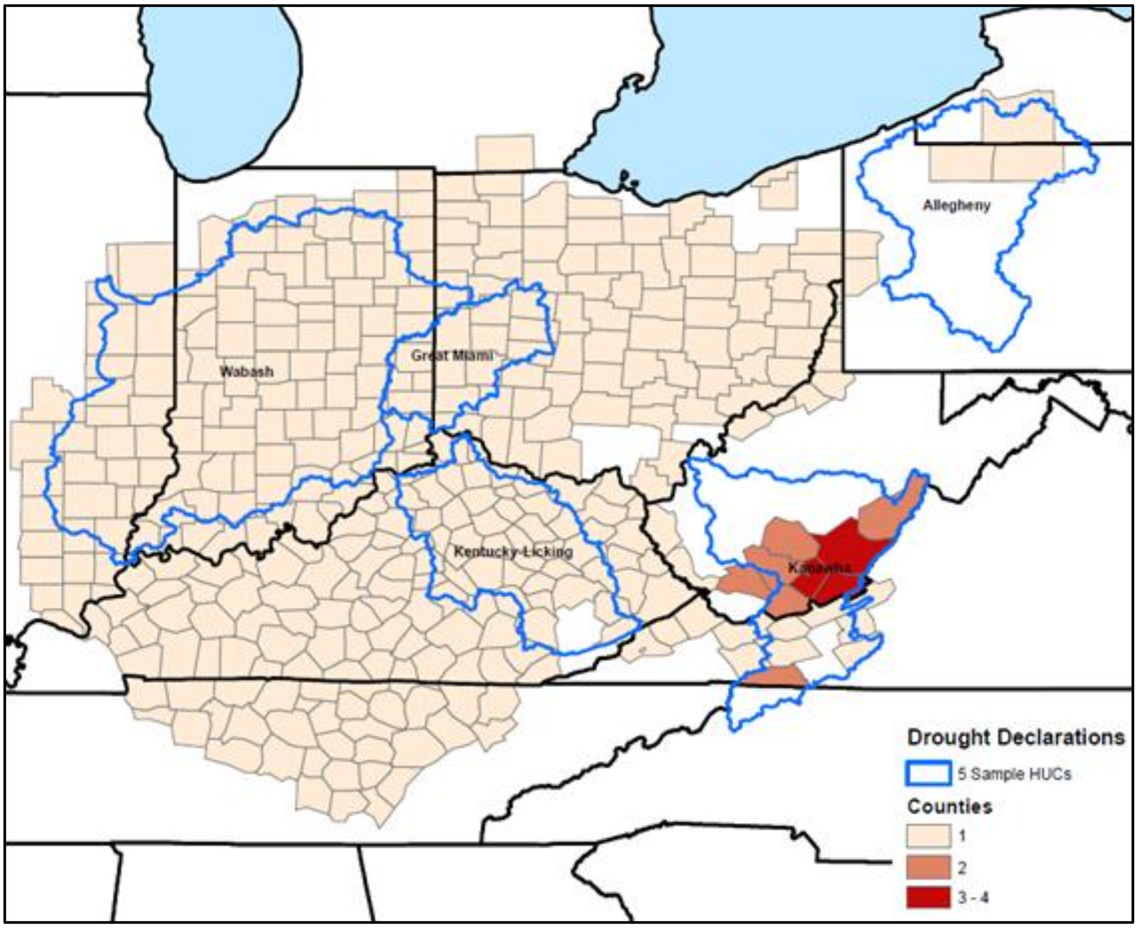


Figure 10-3: USDA/FEMA Drought Declarations in the Basin (2012)

Figure 10-4 depicts the current geographic relationship between cultivated crop land and water supply reservoirs (<3,000 acre feet of storage–NID 2014) that have irrigation listed as a project purpose. The yellow shading on the map denotes the areas of cultivated crop land based on USDA GIS data. The relative lack of water supply reservoirs in that cultivated area indicates a high potential for significant agricultural production impacts in the future, should forecasts for reduced precipitation be realized. A component of this strategy would be development of a basin-wide water management plan through a collaborative effort of the USACE, other basin water managers (i.e., NRCS and TVA) and water management agencies in the 13 basin states. Such a comprehensive plan could identify opportunities for reallocation of storage among basin reservoirs to meet future regional water supply/irrigation needs. Other adaptation strategies may include assessing the storage capacities of existing multipurpose reservoirs in this region for the purpose of including water supply and irrigation as a future authorized purpose, as well as increasing the capacity of existing smaller watershed impoundments that have storage capacities less than 3,000 acre feet.

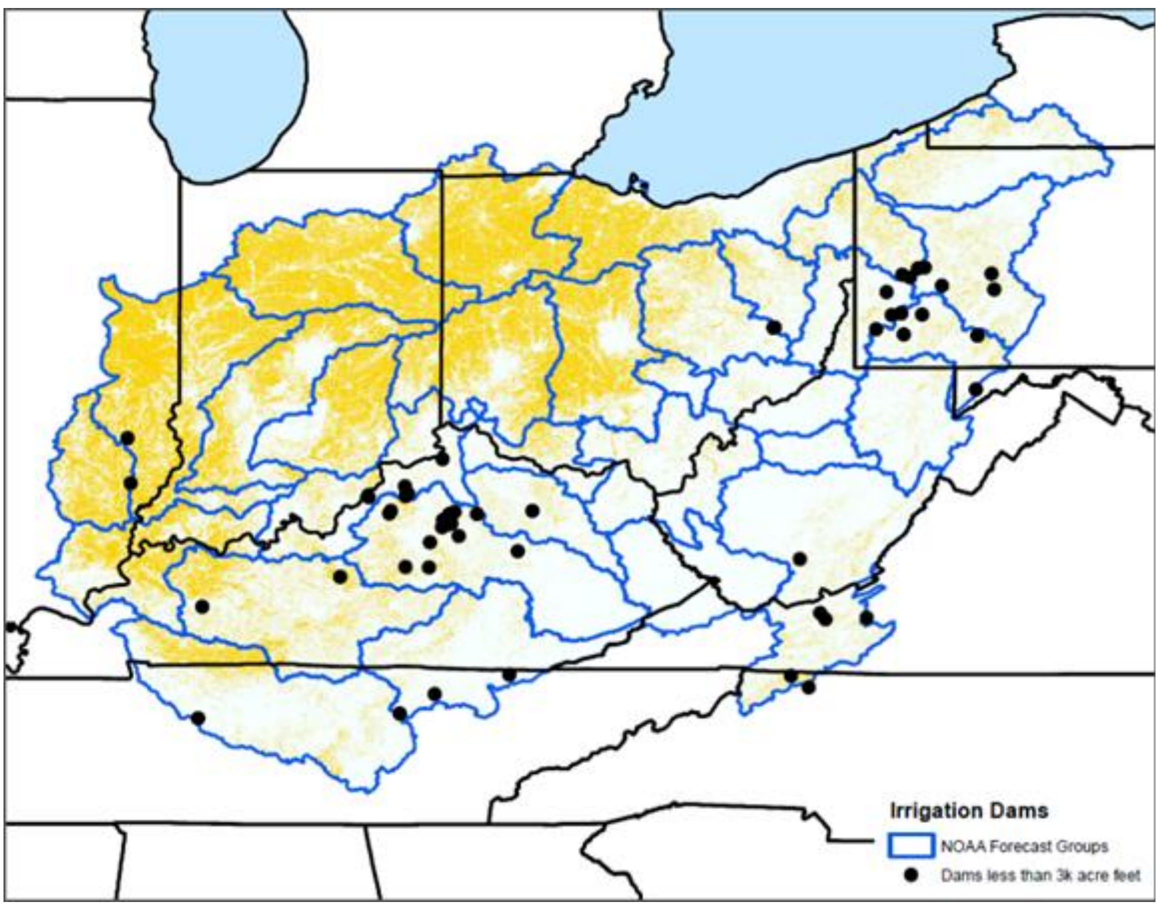


Figure 10-4: Distribution of Current Water Supply Reservoirs in Cultivated Crop Areas

10.5.7 Increase Nutrient and Abandoned Mine Drainage Management

Aquatic ecosystems in some sub-basins are already strained by these stressors. Figure 10-5 illustrates the distribution of abandoned mine land (AML) across the basin and the five selected watersheds. Many AMLs still contribute acid-mine drainage and heavy metals associated with past mining sites. Heaviest AML areas in the Allegheny and Kanawha sub-basins coincide with significant increases in forecasted precipitation (March Maximum flows in *F2* and *F3*). Areas where high rates of nutrient-laden fertilizers are likely applied coincide with the cultivate crops (in yellow shading) were depicted previously on Figure 10-4. With more nonpoint source runoff due to forecasted greater amounts of precipitation, higher peak flows and lower seasonal flows (less dilution) possible during some months (e.g., October), additional nutrients and abandoned mine drainage (AMD) may result in deteriorated water quality and loss of aquatic species. Increased agricultural lands management through reduced fertilizer usage, construction of onsite bio-retention systems (i.e., bio-swales), and additional AMD remediation will be necessary.

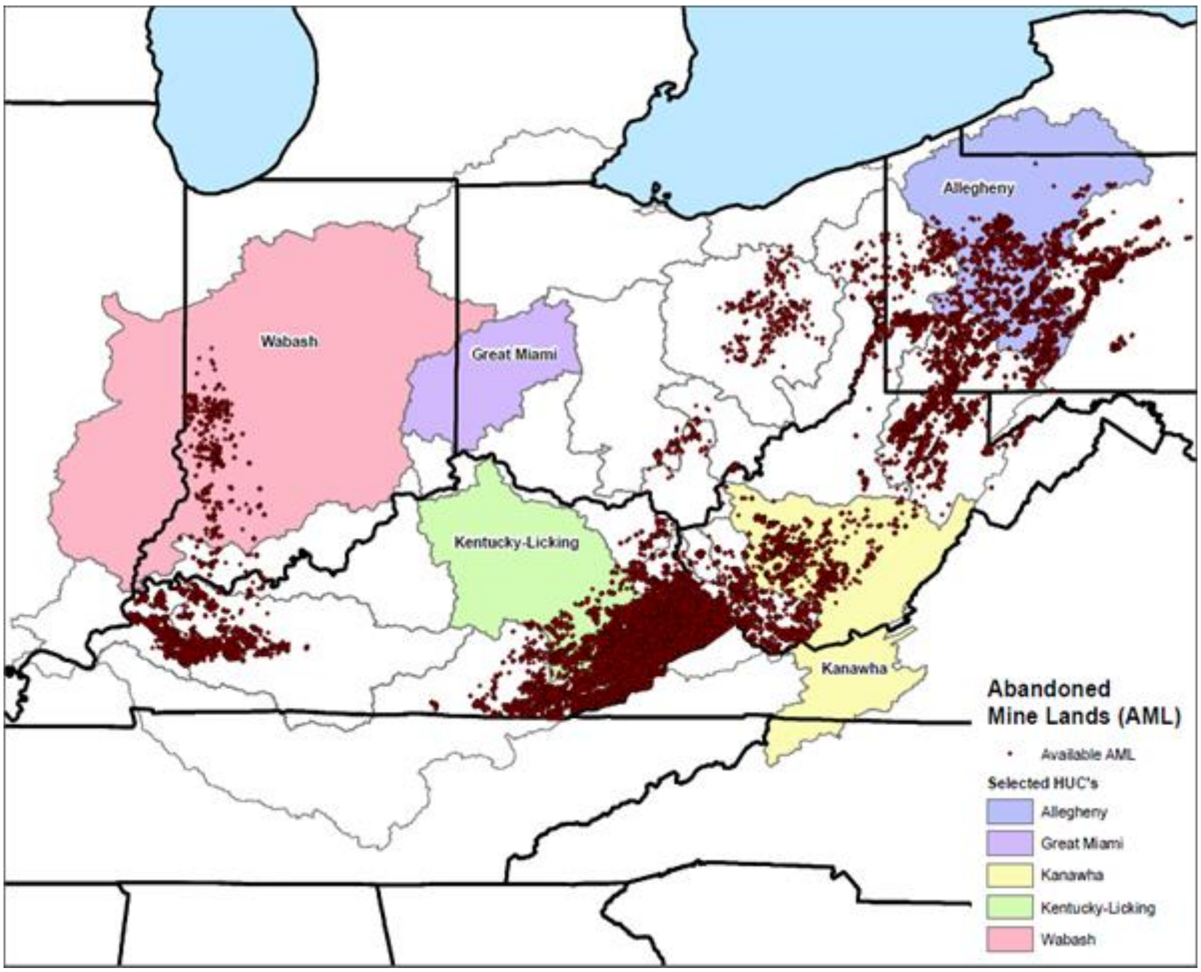


Figure 10-5: Occurrences of AML in Selected Sub-basins

10.5.8 Modify Thermoelectric Power Plant Cooling Systems

With more than 75 % of the water withdrawals in the basin being used for cooling thermoelectric power plants and with a large portion of these plants being once-through systems, there is the potential to reduce the inherent large cooling-water withdrawals by replacing the once-through systems with recirculating systems. Figure 10-6 depicts the distribution of these facilities across the basin arrayed across the forecasted 2040–2070 October streamflow amounts. The once-through circulation systems shown as black dots would be at risk from significantly reduced streamflow and warmer water brought about by increasing air temperatures. Modifying these once-through systems would also reduce thermal water pollution, a threat to sensitive aquatic species, and perhaps allow more plants to operate during extremely warm periods when in-stream ambient water temperatures are too high to provide sufficient cooling.

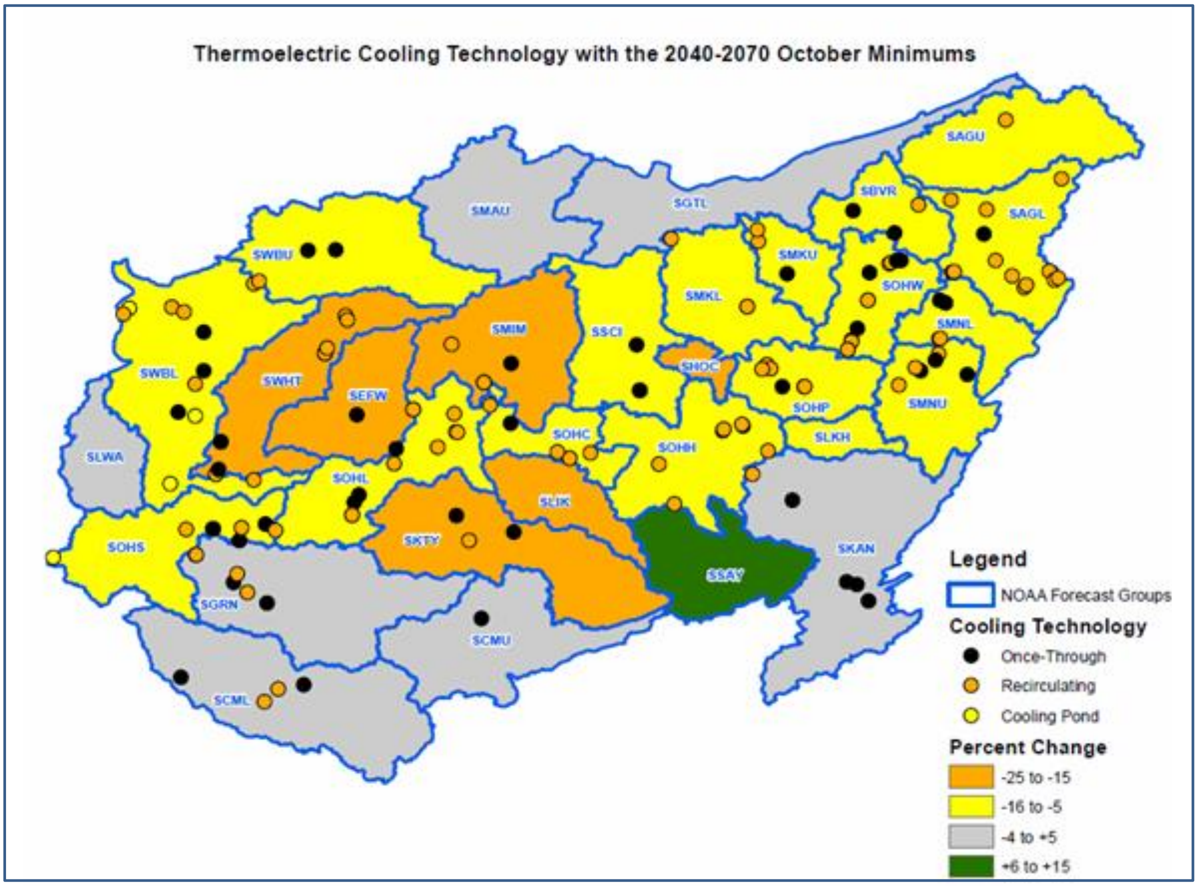


Figure 10-6: Thermoelectric Power Plants Shown by Cooling Technology

10.5.9 Reduce Flood Damages Through Nonstructural Measures

As noted previously, the basin already suffers from flooding and these recurring events are expected to increase in several sub-basins under future climate and land use changes. Figure 10-7 displays the numbers of FEMA flood and storm declarations across the basin that resulted in flooding damages for 2012. Construction of additional flood damage reduction dams and local protection projects (levees and floodwalls) in the future are likely constrained by economic and environmental realities. Therefore, increased emphasis should be placed on the use of proven nonstructural measures, such as floodplain zoning/insurance, floodplain retreat (acquisition), relocation of critical land uses, and both structure elevation and wet and dry flood proofing to address damages at small communities and rural settlements. Programs offered through the NFIP and congressionally authorized USACE programs can assist communities and rural development in reducing future flood damages through nonstructural measures.

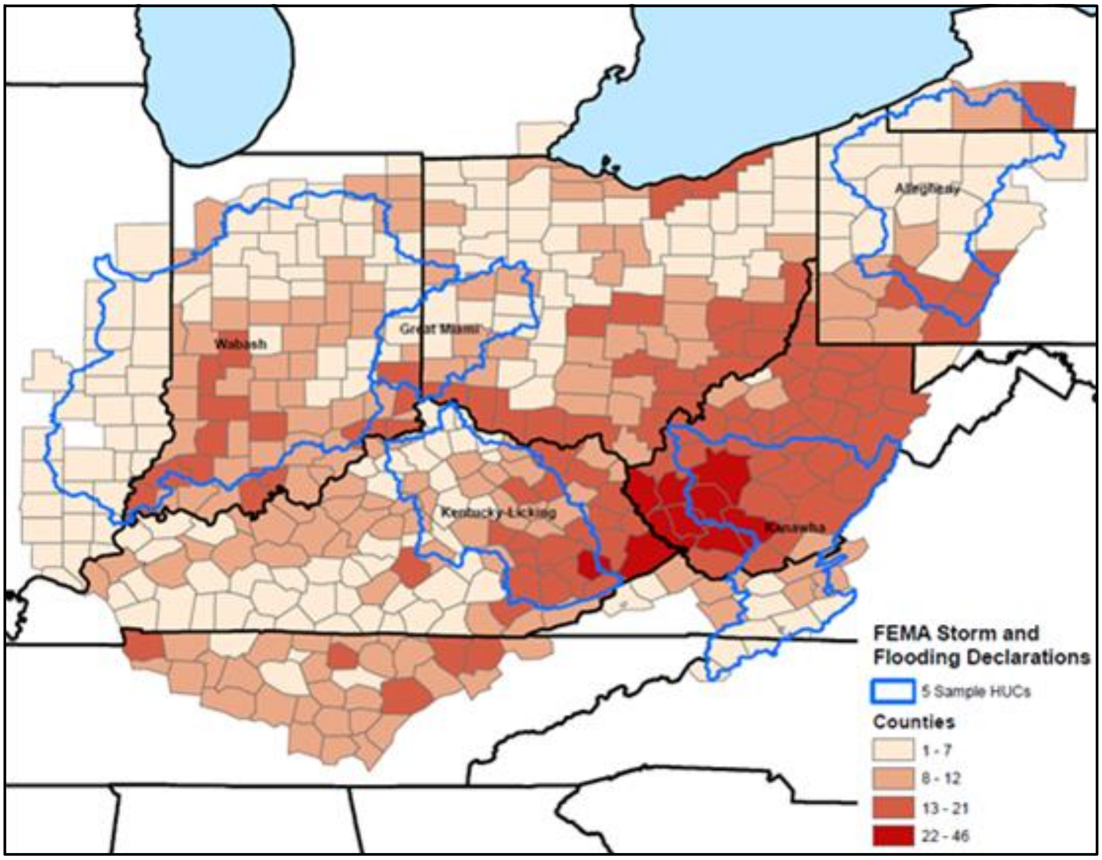


Figure 10-7: FEMA Flood Declarations by County and Selected Sub-basins

10.5.10 Increase Water Quality and Flow Discharge Monitoring

Many of the basin streams and rivers are not meeting Section 303 (established in CWA 1972) water quality standards due to nutrient loading and drainage from abandoned mine areas. Given the extent of the water quality stressors, there is a relative lack of regularly sampled water quality stations to monitor pollution levels. Figure 10-8 depicts the current numbers of water quality monitoring stations in the basin. More monitoring locations would enable the basin to implement improved spill management and to better track basin water quality changes. Related to the water quality monitoring issues is the relative lack of flow discharge measuring stations in the basin (also in Figure 10-8). A greater number of such stations, strategically placed, would allow for better management and forecasting of high and low flows and better monitoring of the actual flows in different parts of the basin.

10.5.11 Promote Wise Land Use Management

Population projections from the U.S. Census indicate that there could be 30 million people in the basin by 2030. That 11% increase from the current population would present certain challenges to the current land and water resources of the basin. Many parts of the basin would experience further urbanization through sprawl (an ongoing problem in the basin affecting natural buffers) regardless of forecasted CC. Increased placement of impervious surfaces (a key characteristic of urbanization) will exacerbate storm-water runoff and reduce infiltration so needed to replenish

GW supplies. Changes in land cover (2010 through 2013) depicted in Figure 10-9 for the five selected HUC-4s indicate trends already occurring in the selected sub-basins over a relatively short period of time. Each of the five basins shows a relative increase in the “developed” land cover category (red bar) with four of the five showing losses to grasslands and croplands (yellow bar). There will not only be a need to consider restoring previously lost natural features of the basin such as wetlands, but also the need to manage the expected changes in land cover types to encourage characteristics in new development, such as use of more pervious surfaces for parking and intensive use areas and sound management of floodplains. Related to land use management is the need to better manage storm water, which can also be improved by reducing impervious cover and using construction techniques such as low impact development (LID).

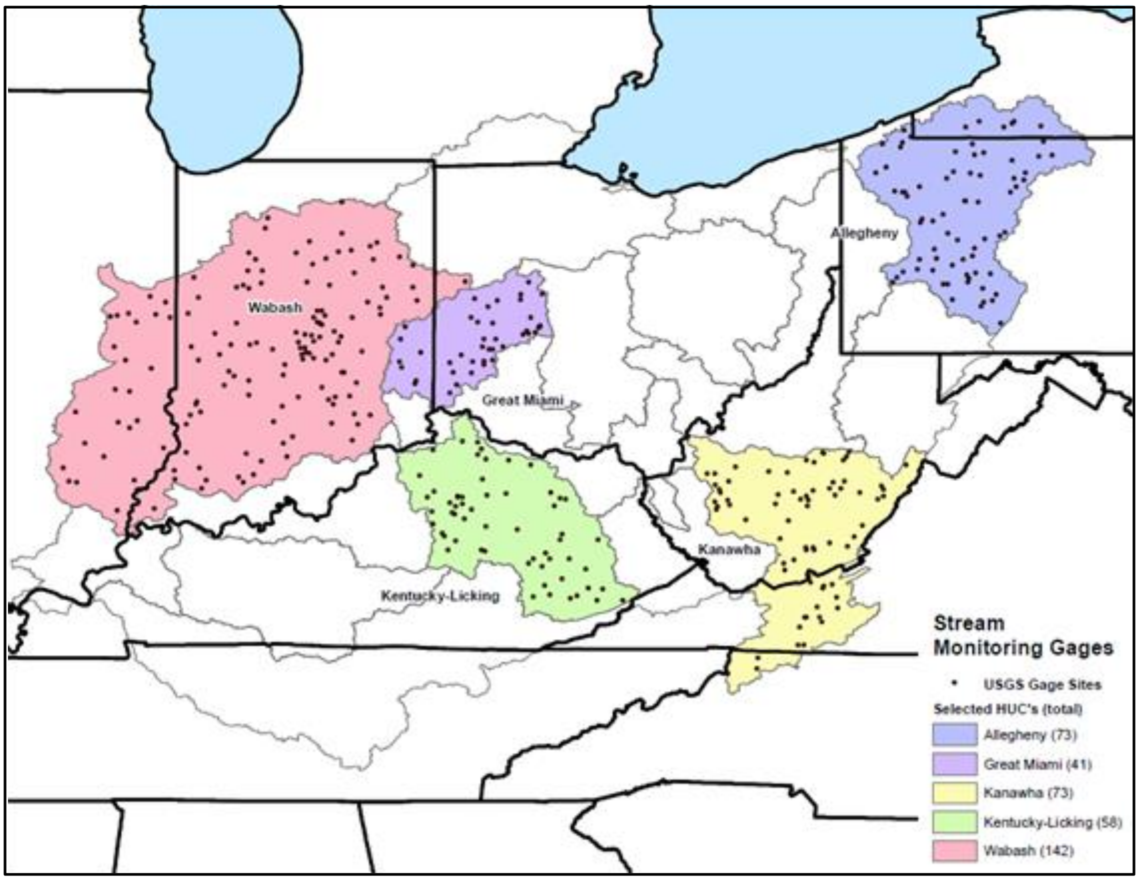


Figure 10-8: Current Stream Monitoring Stations by Selected Sub-basins

10.5.12 Modify Reservoir Operations, Policies and Structures

One of the pillars of the basins’ economic health has been physical regulation of the waterways. This regulation has supported inland waterway navigation, flood control, municipal water supply, hydroelectric energy production, industrial plant cooling, and water-borne recreation. This regulation has been achieved by the development and operation of dams and reservoirs (see Figure 8-9). In view of the forecasted CC in precipitation, changes that would modify hydrologic characteristics and water needs of the basin, it is highly likely that operations at many reservoirs may need to be modified to address these new challenges. Traditional reservoir pool drawdown in the fall/winter season to accommodate higher spring inflows may need to be either increased (to accommodate even greater forecasted inflows) or decreased (to store additional water to offset forecasted decreased inflow) depending on the changes in flow discharge at each of the forecast groups. Current operating policies and regulations for dams and reservoirs may require modification to successfully meet these challenges. While complex to achieve institutionally, strategic policy modifications may result in more equitable water allocations that support the economic health, public health and welfare, and environmental integrity of the basin. Structural modifications to reservoir intake and outlet works would enable more effective mixing of lake water that improves downstream water quality (O2 and water temperatures) for aquatic ecosystems. Opportunities to modify existing infrastructure to achieve necessary changes may occur as dams and reservoirs and associated facilities, such as locks, water intakes, and turbines are scheduled for rehabilitation due to performance issues or antiquated equipment.

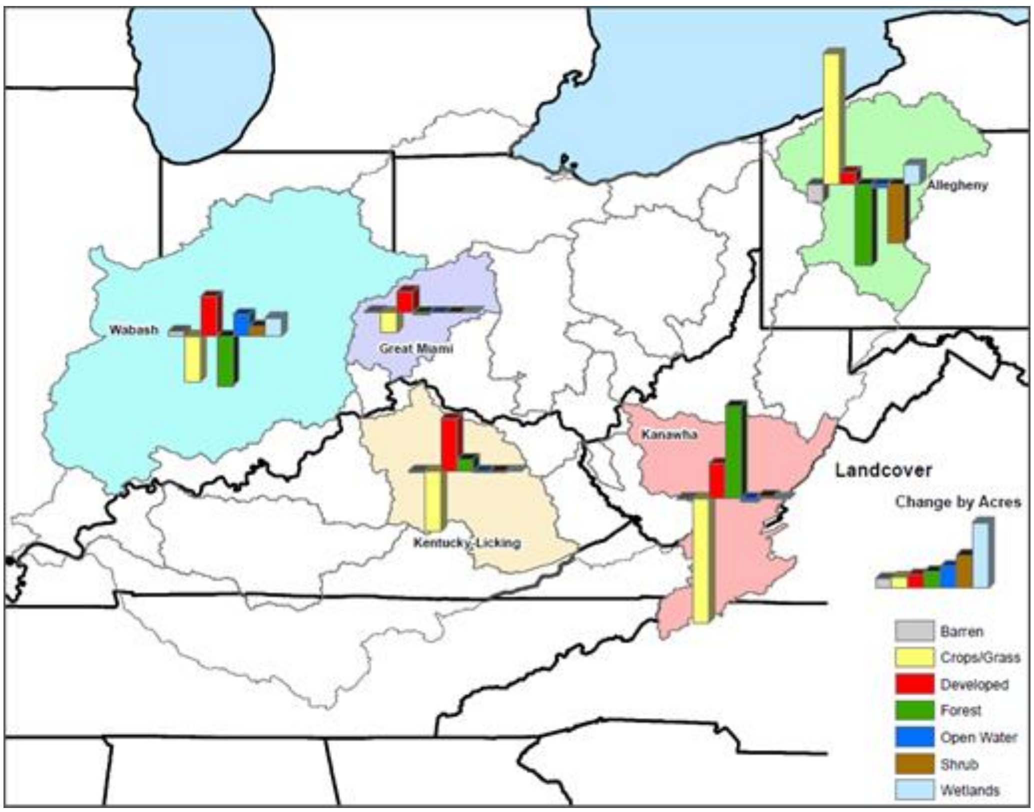


Figure 10-9: Land Cover Change Map for Selected Sub-basins (2010–2014)

10.5.13 Manage Ecosystem Stress

As noted in Chapter 8, the basin produces a high value of ecosystem services and faces many present and future aquatic and land-based ecosystem stresses (Table B-11 in Appendix B). While many of the actions described previously can help alleviate the stressors, there are additional actions that can be considered. For example, barge traffic can be diverted around known mussel beds during critical flow periods, regulated releases from reservoirs can be decreased during certain mussel reproduction periods, irrigation can be employed for croplands as well the increased use of low water consuming crops, tree replanting programs can be implemented with tree species expected to dominate the basin under future precipitation and temperature regimes, and wetlands can similarly be expanded into areas of hydric soils to take advantage of future conditions. Figure 10-10 displays the distribution of the existing predominantly deciduous and evergreen forest communities and location of mixed forest complexes within the selected sub-basins where preemptive plantings of warmer climate species could be initiated. Additional modeling can also be used by public laboratories and both private and academic institutions to better predict ecosystem response to climate changes.

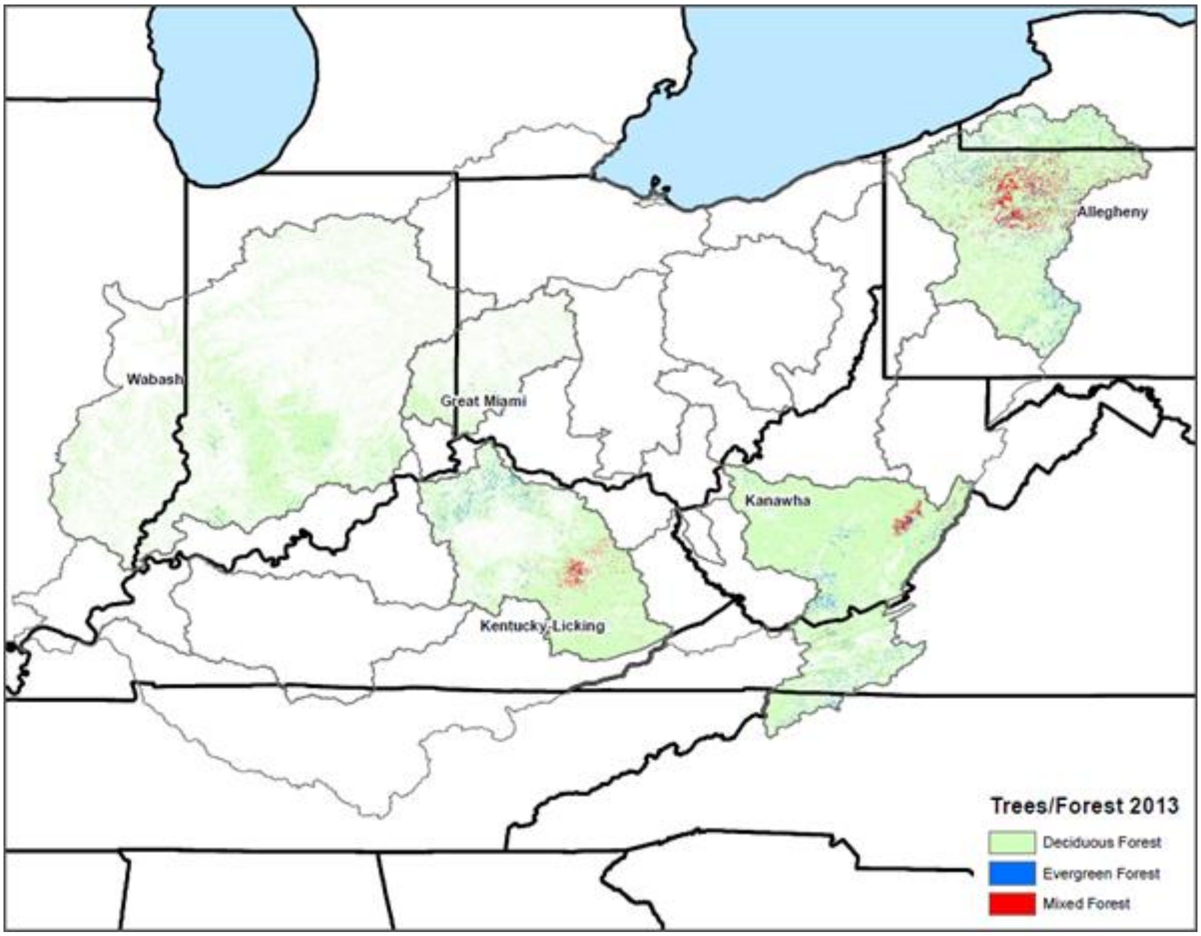


Figure 10-10: Location of Deciduous, Evergreen, and Mixed Forest Communities

10.5.14 Temporal Staging

Many of these recommended management activities do not have to be implemented at the present time; rather, they can be implemented as CC (changes in precipitation and temperature) manifest themselves and as infrastructure is rehabilitated to meet current performance standards or renovated due to age. Many of these activities can also be incrementally implemented by incorporating flexibility and adjustable features into their planning and designs. The present emphasis should focus on developing an integrated strategy built on these approaches, making necessary policy changes in water resources development and management where appropriate and then preserving the options to implement these management activities when opportunities arise or changes in climate begin to occur. Such opportunities may include initiation of Federal, state, or private programs and associated funding for support of "no-regrets" adaptation actions as watershed demonstration projects and/or funding for rehabilitation of existing infrastructure (reservoir dams, local protection projects, navigation dams, and other water-related facilities) where structural or operational modifications can be made in recognition of future CC threats or to reduce stressors on existing ecosystems.

10.6 Application of the Adaptation Themes to Five Selected Sub-basins

10.6.1 Allegheny River

The Allegheny sub-basin is the eastern headwaters of the ORB and has an area of 11,666 square miles. It is moderately sloped compared to the rest of the basin with only a small portion of its land area cultivated. It contains the major urban area of Pittsburgh, PA with a substantial amount of public water withdrawal volume. It is also a center of mineral extraction and manufacturing with a relatively large amount of industrial water use and moderate amount of mining use (ORSANCO 2013a). This sub-basin may have the largest total freshwater (ground and surface) withdrawals in the ORB. Its annual precipitation is on the order of 40 inches (USACE 2009). As seen in Figures 8-9 and 8-15, there are 12 dams/reservoirs and 14 thermal power plants in the sub-basin.

As shown in Table B-11 in Appendix B, this sub-basin is presently stressed and these stresses will increase under a changing climate. Table 10-5 summarizes possible adaptation options for each system.

Table 10-5: Adaptation Options for Allegheny River Sub-basin

Adaptation Options	
Ecosystem Resources and Services	**Operating Infrastructure**
Reconnect floodplains to river channels where opportunities exist to remove or realign impediments	Investigate options to modify fall/winter drawdown for additional seasonal storage at seven affected reservoir sites
Reduce stressors on aquatic ecosystems through water quality improvements	Modify interior drainage and pumping systems at LPPs
Increase emphasis on nutrient and AMD management programs	Implement nonstructural measures through multiple programs to reduce flood damages
Modify release schedules at storage reservoirs to meet seasonal aquatic needs during high flow periods	Consider increased discharges from storage reservoirs to support navigation in future drought situations
Encourage more wise use and development of floodplains and land resources including use of LID concepts	Ensure that flood control dams showing poor or unsatisfactory performance are rehabilitated before increased flows are forecasted
Install additional water quality and quantity monitoring stations	Consider relocation of flood sensitive infrastructure from high hazard floodplains

Allegheny Adaptation Discussion: Table 10-5 suggests that one adaptation measure could be to modify project releases to maintain flows, generally increasing in low flow season except during mussel mating season when less flow is desirable. Reservoir outflows could be decreased during mussel mating season if coordinated with other river purposes. Increasing dry season flows will require some combination of less reservoir storage for floods and less water for recreation. The loss of reservoir flood control storage—even with flood mitigation techniques such as reconnecting floodplains, LID, and GW recharge of peak river flows—may not be sufficient to manage the expected higher peak flows. Thus, more local techniques may be needed to protect infrastructure. Water supply demands may increase due to crop irrigation requirements, thus increasing the need for more water reuse and recycling. More water quality management will be necessary to deal with expected poorer water quality and lower flows. A major point of conflict is between the need to maintain more flow during low flow periods and having increased flood storage during the flood season (generally late winter and early spring).

10.6.2 Wabash River

The sub-basin has the largest amount of present irrigation in the basin (Figure 11, ORSANCO 2013a) and a relatively large amount of mining-related water withdrawals. There is a moderate amount of publicly supplied freshwater and relatively low industrial water use. The sub-basin appears to be the third largest withdrawer of freshwater in the basin (Figure 1, ORSANCO 2013a). It is relatively low in elevation and flat compared to rest of the basin. Most of the land area is cultivated. The majority of the water supply and irrigation comes from GW. Absence of connected floodplains and wetlands is likely increasing habitat destruction (scouring) and degradation (sediment and nutrient impacts). The sub-basin already has significant nutrient enrichment and is generally considered to be a stressed basin.

Wabash Adaptation Discussion: With more storage reservoirs than Allegheny, the Wabash sub-basin may have more flexibility to meet future water demands. More nutrient management is needed than in the Allegheny sub-basin. It will need more ecological restoration than the Allegheny sub-basin if water supply, water quality, and flood management goals are to be met. Table 10-6 shows the array of adaptation options that may be applicable for the Wabash River sub-basin.

Table 10-6: Adaptation Options for the Wabash River Sub-basin

Adaptation Options	
Ecosystem Resources and Services	Operating Infrastructure
Reconnect floodplains to river channels where opportunities exist to remove or realign impediments	Investigate options to modify fall/winter drawdown for additional seasonal storage at eight affected reservoir sites
Reduce stressors on aquatic ecosystems through water quality improvements	Modify interior drainage and pumping systems at eight LPP sites
Increase emphasis on nutrient and AMD management programs	Implement nonstructural measures through multiple programs to reduce flood damages
Modify release schedules at storage reservoirs to meet seasonal aquatic needs during high flow periods	Consider increased discharges from storage reservoirs to support navigation in future drought situations
Encourage more wise use and development of floodplains and land resources including use of LID concepts	Assure that flood control dams showing poor or unsatisfactory performance are rehabilitated before increased flows are forecasted
Install additional water quality and quantity monitoring stations	Consider relocation of flood sensitive infrastructure from high hazard floodplains

10.6.3 Great Miami River

The Great Miami River is relatively flat compared to the rest of the study area, with a large portion of its land surface cultivated and irrigated. As shown in Table 10-3, the Great Miami sub-basin is by far the most densely populated of the five sample sub-basins containing the Dayton, OH urban center (population 141,359 [2012 estimate]). The sub-basin has a number of multipurpose flood control dams and levees as part of the comprehensive strategy resulting from the 1913 floods. It also has many multipurpose water supply dams. There are no navigation locks and only three thermoelectric power plants. Table 10-7 shows the array of adaptation strategies that may be applicable for this sub-basin.

Table 10-7: Adaptation Options for the Great Miami River Sub-basin

Adaptation Options	
Ecosystem Resources and Services	**Operating Infrastructure**
Reduce stressors on ecosystems through improvements to water quality	Investigate options for decreasing seasonal drawdown at four storage reservoirs to increase water availability under low flow conditions
Encourage and fund programs for reduction of consumptive uses of water	Investigate installing multi-port intakes at storage reservoirs (currently with one intake port) for flexibility in meeting downstream water quality targets under low flow conditions
Install additional water quality and discharge monitoring stations	Encourage transition of power plant cooling systems at one once-through plant to re-circulating methods
Encourage and fund programs that emphasize water harvesting and reduce placement of impervious surfaces including LID	Consider potential for increased discharges from storage reservoirs to support navigation in the lower Ohio River during seasonal low flow conditions
Restore and expand existing wetlands in areas of hydric soils	Consider options for increased storage (at existing or new facilities) to address agricultural irrigation needs
Reconnect floodplains to river channels where opportunities exist to remove or realign impediments	

10.6.4 Kanawha River

This sub-basin contains the main watercourse Kanawha River plus four main tributaries—New River, Elk River, Greenbrier River, and Gauley River. The Gauley River and New River meet at Gauley Bridge, WV to form the Kanawha River. Flood control dams are located on the New River (Bluestone Dam), the Gauley (Summersville Dam), and the Elk (Sutton Dam). Two hydropower dams are located on the New River including Claytor Lake (in Virginia) and the Hawks Nest hydropower dam in West Virginia. The Greenbrier River drainage is uncontrolled and meets the New River just below Bluestone Dam.

With the exception of urban centers at Boone, NC and Blacksburg, VA, the headwaters area is composed largely of forested and agricultural/livestock land uses. Bluestone Dam is undergoing a major rehabilitation project through the USACE Dam Safety Program and is identified on the list of "poor or unsatisfactory performance dams" (Table B-14 in Appendix B). There are no local protection projects along the New, Gauley, Elk, or Kanawha Rivers due to the presence of the dams. The middle and lower reaches of the Kanawha sub-basin have substantial urban development including Charleston, WV; St. Albans, WV; Nitro, WV; and South Charleston, WV. Most of these urban centers draw public water from the Kanawha River. The lower Kanawha is also characterized by heavy industry, including chemical production and storage facilities. These facilities have numerous permitted effluent streams into the Kanawha River. A storage facility released hazardous chemicals into the Kanawha River (2014) that resulted in loss of drinking water for more than 300,000 residents.

There are three locks and dams in the lower Kanawha River (London, Marmet, and Winfield L&Ds) that pass approximately 17.7 million tons of commodities (primarily coal and chemicals) annually to the Ohio River waterway at Point Pleasant, WV. Aquatic ecosystems in the sub-basin are diverse extending from cold-water fisheries (trout and smallmouth bass) on NC, VA, and WV tributaries to warm water fisheries in the lower Kanawha River reaches (largemouth bass, carp, and catfish). Summersville Dam on the Gauley River provides an excellent downstream cold-water fishery due to the extreme depth of the reservoir and a single submerged intake. The New River reach immediately below Bluestone Dam is regionally significant for its aquatic species diversity and productivity. Table 10-8 shows the array of adaptation strategies that may be applicable for this sub-basin.

Table 10-8: Adaptation Options for the Kanawha River Sub-basin

Adaptation Options	
Ecosystem Resources and Services	**Operating Infrastructure**
Reconnect floodplains to river channels where opportunities exist to remove or realign impediments	Investigate options to modify fall/winter drawdown for additional seasonal storage at three reservoir sites on the New, Gauley, and Elk rivers
Restore wetlands by targeting the 10,232 occurrences where existing wetlands intersect hydric soils	Encourage transition of cooling systems at four once-through power plants to use re-circulating methods
Reduce stressors on aquatic ecosystems through water quality improvements	Implement nonstructural measures through multiple programs to reduce flood damages
Increase emphasis on nutrient and AMD management programs	Consider increased discharges from storage reservoirs to support navigation in future drought situations on the Kanawha River and Ohio River
Modify release schedules at storage reservoirs to meet seasonal aquatic needs during high flow periods	Ensure that flood control dams showing poor or unsatisfactory performance are rehabilitated before increased flows are forecasted
Encourage more wise use and development of floodplains and land resources including use of LID concepts	Consider relocation of flood sensitive infrastructure from high hazard floodplains
Install additional water quality and quantity monitoring stations	

10.6.5 Kentucky-Licking

This sub-basin is relatively high in elevation with a large average gradient. It is relatively un-urban compared to the rest of the basin. There is considerable mining activity in the southern portion of the sub-basin. The northern part of the basin has significant urban and agricultural land, which results in water withdrawals for public water supply and irrigation—a serious issue for aquatic ecosystems. No levees are included in this sub-basin and there is only one navigation dam. There is a relatively large number of multipurpose flood control and water supply dams. Three major thermoelectric power plants are in this sub-basin. Table 10-9 shows the array of possible adaptation strategies that may be applicable for this sub-basin.

Table 10-9: Adaptation Options for the Kentucky/Licking River Sub-basin

Adaptation Options	
Ecosystem Resources and Services	**Operating Infrastructure**
Reconnect floodplains to river channels where opportunities exist to remove or realign impediments	Investigate options to modify fall/winter drawdown for additional seasonal storage at four affected reservoir sites
Reduce stressors on aquatic ecosystems through water quality improvements	Implement nonstructural measures through multiple programs to reduce flood damages
Increase emphasis on nutrient and AMD management programs	Consider increased discharges from storage reservoirs to support navigation in future drought situations
Modify release schedules at storage reservoirs to meet seasonal aquatic needs during high flow periods	Ensure that flood control dams showing poor or unsatisfactory performance are rehabilitated before increased flows are forecasted
Encourage more wise use and development of floodplains and land resources including use of LID concepts	Consider relocation of flood sensitive infrastructure from high hazard floodplains
Install additional water quality and quantity monitoring stations	
Restore and expand wetlands targeting the 5,181 intersections of existing wetlands with hydric soils	

10.7 Summary of Adaptation Themes for the Basin

In summary, the mitigation and adaptation measures and strategies described previously (Table 10-2) include restoring wetlands, reconnecting floodplains, reducing water consumption, harvesting water, drought planning, increased management of AMD and nutrient inflow, changing 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 managing ecosystem stressors. All the above may be applied to the five example sub-basins in the ORB and display the wide array of alternative actions available for implementation by Federal, state, and local agencies, by corporate and private owners of infrastructure, and by ecosystem managers. This is not cast as an exhaustive list of options, but shows the range and extent of actions that could be taken over a period of time to reduce the effects of forecasted climate-induced changes.

10.8 Conclusions and Next Steps

Formulation of these mitigation and adaptation measures and their application to portions of the basin is the culmination of the work tasks originally envisioned for the ORB Pilot Study. The central question upon which the pilot study was based is:

> *"Can regional mitigation/adaptation strategies that are collaboratively developed with the ORB Alliance, and formulated using IWRM principles be implemented successfully within the Ohio River basin to counter the anticipated water resources, ecological and infrastructure impacts of CC?"*

That question remains unanswered, but the foundation for answering that question (documented mitigation and adaptation strategies collaboratively developed) exists now within these pages and the initiation of the Climate Change sub-committee in the ORB Alliance provides a vehicle for additional modeling and implementation of formulated strategies. The collaboration theme for the pilot study was founded on the belief that agencies, NGOs, academia, and members of the ORB Alliance could combine their forces to develop a strategic plan for addressing potential climate change impacts and making those strategies and measures operational through coordinated efforts. Generally, this original purpose has been accomplished and the eight objectives in Section 5 have been fulfilled.

An early "next-step" following publication of this report will be the dissemination of the report information to the basin's residents through various media, NGO activities, ongoing academic studies, and stakeholder meetings. Incorporating qualitative information from this pilot study into USACE decision documents and coordinating those documents with potential project sponsors will further disseminate the importance of CC readiness and adaptation strategies.

Additional "next-steps" include filling in numerous the data gaps identified during the study process. Many gaps in knowledge, understanding, and modeling need to be filled and much more investment will be required to assure ourselves that (1) the downscaled modeling results displayed in this pilot study are updated on a regular basis (at least decadal), (2) the mitigation and adaptation measures identified remain current based on new strategies and the documented successes or failures of applied strategies by others, and (3) the USACE accept an Army Strong role in leading basin water managers toward a comprehensive plan for basin water planning that can offset the potential effects of CC on infrastructure and the ecosystems that are dependent upon operation of those facilities.

11. Water Resources Policies

11.1 Current USACE Water Resources Development and Operation Policies

The current water resources policies that guide the activities of the USACE in the basin are prescribed through congressional legislation, Presidential Executive Orders, the office of the Assistant Secretary of the Army for Civil Works (ASACW) and the U.S. Army Corps of Engineers General Command and are documented in numerous documents such as the Economic and Environmental Principles and Guidelines for Water and Related Land Resources Implementation Studies and numerous ASACW policy statements, and are echoed in USACE regulations.

Those policies describe the application and implementation of legislative acts with regard to water resources jurisdiction and development in the United States and further address the fundamental missions of the USACE's Civil Works Program. Those policies also dictate the basic jurisdictional and economic relationships between the USACE and other levels of government and the public during water resources development and operation and maintenance. In addition, policies address the USACE's adherence to national environmental legislation such as the CWA, National Environmental Policy Act of 1969, and Clean Air Act as well as provisioning for disabled users through the Rehabilitation Act of 1973. In application, the policies establish water resources priorities for flood risk management, life safety, dam and levee safety, navigation, water supply, hydropower, ecosystem restoration, and recreation at existing and planned USACE projects.

11.2 Forecasted CC Threats to Infrastructure Operation Under Current Policies

Current policies for the planning, development, and operation of water resources projects emphasize the distribution of reservoir storage based on the anticipated streams of benefits attributable to each project purpose. Past policy has directed that reduction of flood damages (life loss was assumed as being a part of that damage) would be the primary benefit stream in justifying the construction of civil works infrastructure, and therefore flood storage capacity was a primary component of any "dry" or "wet" reservoir. More recently, reduction of life loss has been identified as being of paramount importance in the formulation of Civil Works Water Resources protection strategies. Assuming that life loss will remain a high priority in Civil Works project development and operations, adaptation strategies will emphasize the maintenance of existing or the expansion of current storage in the future to address potentially higher seasonal flows. Increases in reservoir drawdown could be considered, but impacts on lake fishing and other off-season recreation uses must be considered.

However, that being said, neither the distribution of reservoir storage nor the benefits assigned to that distribution fully consider the social or economic value or benefits of the continued existence of downstream resources (some federally protected) that may be at risk of extirpation under changing climatic conditions. Current policies support a continuing Federal interest in various authorized uses so long as the benefit streams remain intact. Only during severe droughts or extreme flooding conditions that pose a life loss risk or to the infrastructure itself are these policies exceeded. Under future CC scenarios, extreme flow conditions may become the norm over extended periods of time. During periods of extended drought conditions, the economic value of recreation days for boaters, fishermen, or water skiers may be weighed against the continued existence of one or more federally protected species dependent upon downstream flows. Whatever policies now exist during times of abundant water supply may need revisiting under future hydrologic regimes.

Similar to reservoirs, local projection projects that were constructed to a design flood elevation based on historic data may be increasingly threatened by overtopping (a life loss issue) or increased scour (a higher maintenance or failure mode issue) due to much greater flows in some watersheds. As important will be strategies to address interior storm-water collection and pumping capacity for protected areas that may experience much greater and intensive rainfall events.

On a basin-wide scale, the future availability and distribution of potable water from rivers, streams, and reservoirs may become problematic. Forecasts indicate a very dry future during late summer and fall months for western regions of the basin (OH, IN, and IL), where both municipal and industrial demand and crop irrigation needs would compete for limited amounts of precipitation and streamflow. Policies that consider distribution of water from "wetter" portions of the basin to drier areas may need to be considered. State water rights issues are likely to become more important and interstate agreements for water distribution may be required to maintain a healthy basin economy.

11.3 Opportunities for Modifying Policies to Address CC Effects

Recent policy statements by the ASACW office regarding the potential effects of CC on Federal infrastructure and formulating adaptation plans to meet those threats are quite clear. Quoting a portion of that policy statement delivered by the Assistant Secretary of the Army in 2011, "Mainstreaming climate change adaptation means that it will be considered at every step in the project life cycle for all USACE projects, both existing and planned… to reduce vulnerabilities and enhance the resilience of our water-resource infrastructure" provides support to the adaptation strategies formulated herein for the basin infrastructure. As steps in a project's lifecycle include ongoing O&M and structure rehabilitation, potential CC effects such as increased hydrologic flows will have to be considered during those phases, incorporating adaptation strategies described as follow for future operational and project structure changes.

The forecasted changes in precipitation, streamflow discharge, and temperatures do not appear to result in significant impacts until the end of *F1*. Between 2011 and 2030, there is sufficient time to intermittently reaffirm the pilot study downscale modeling data based on future refinements of the global climate models (5^{th} IPCC Assessment and following assessments) and actual observations of CC. At each reaffirmation stage, current water resources policies that may contradict what sound environmental science and past experience demonstrate to be in the best interests of the at-risk public and protected species will need to be reconsidered. The findings and conclusions of the Responses to Climate Change Program (RCCP) pilot studies should provide a basis for those deliberations.

12. Lessons Learned for USACE Communities of Practice and ORB Alliance

The pilot study team has identified a number of lessons learned that will be shared through this document with USACE Communities of Practice and the Alliance members using the ORB Alliance website and the USACE's various Communities of Practice websites.

12.1 On Physical System/Climate Findings

12.1.1 Ecosystem Findings

The existing ecosystems and infrastructure have demonstrated resiliency to environmental changes in streamflow and temperature changes over the past 60 years, but there have been some notable losses to aquatic species during that period. Numerous fish and mussel species in the basin have been extirpated from some watersheds due mainly to the introduction of anthropogenic stressors. Addition of pollutants through point and non-point discharges has reduced species diversity and productivity in many stream reaches. Changes in natural flow due to the operation of dams for hydropower, flood control, and water supply have impacted many aquatic species. Loss of wetlands and vegetation in riparian corridors due to urban growth and cultivation practices has impacted lotic ecosystems.

These environmental stressors are problematic for current species that may be confronted at a later date with yet again another stressor—climate changes that disrupt streamflow and introduce warmer water temperatures. Reduction of existing stressors to these systems could greatly increase the survivability and sustainability of the basin aquatic ecosystems before changes in river discharge and temperature are forecasted to begin.

12.1.2 Infrastructure Findings

Infrastructure—at least infrastructure that has been designed using conservative, hydrologic, and hydraulic factors of safety—can adapt to anticipated CC through operational changes and physical modification (intake structures) to better control reservoir discharge and maintain water quality for downstream aquatic species. Other infrastructure that has been constructed with somewhat less stringent safety factors may encounter future conditions resulting in loss of services or catastrophic consequences. In addition, storm-water management facilities that are designed for smaller, more frequent storm events may confront more intensive rainfall events that exceed their capacity. Also of concern are energy production facilities dependent upon a sustained and adequate supply of cool water for cooling power plant units. Since modifications to those facilities are costly and time consuming, plans for their future modification in preparation for these changes must be considered in the near future based on the forecasts.

12.1.3 Climate Change Findings

Section 7 includes a summary of the CC findings, but those are repeated here for emphasis. The modeling results indicate that climatic conditions will remain largely within the mean ranges of precipitation and temperatures, with the exception of a gradual warming that has been experienced between 1952 and 2001. Summer highs and winter lows between 2011 and 2040 will remain generally within what has been observed over that historic period but record temperatures, rainfall, or drought cannot be ruled out.

After 2040, temperatures may rise at one degree per decade through 2099, resulting in the forecasted mean annual temperatures shown in Table A-1 in Appendix A for the 25 forecast points. Likewise, there may be significant changes in precipitation with associated increases or decreases in river flow on an annual mean basis and a seasonal maximum and minimum basis for the 25 forecast points. Generally, the northeastern and eastern portion of the basin will experience greater rainfall and river discharges between 2040 and 2099 amounting to as much as 35% to 50% greater during spring flows within the Allegheny, Monongahela, Kanawha, and Big Sandy River sub-basins.

The northwest and western portions of the basin will experience some increases in precipitation and river flow in the spring season, but the fall season will bring significant reductions in rainfall and thus decreased river flows of as much as 25% to 35% less than the base years during the 2040 to 2099 time period. Of concern will be the Great Miami River, the Wabash River, the White River, the East Fork of the Wabash, and both the Scioto River and the Muskingum River sub-basins. During this same time period, the Kentucky and Licking River sub-basin drainages could experience reductions in rainfall and river flow of 35% to 50% below the base years. Of course the uncertainty of the modeling results increases in the latter periods of the analysis and at points further upstream from the forecast points, but the forecasted trends are troubling in the later years of the analysis.

12.1.4 Water Resources Policy Findings

Another lesson learned relates to the existing policies for water resources development and operation. The current policies were formulated upon a history of sufficient water supply and mean annual temperatures that had remained stationary since the initial development of water resources infrastructure in the basin. The forecasts in this pilot study suggest that current policies may need to be revisited and perhaps modified to allow changes in the operation of dams and reservoirs and other Federal infrastructure to maintain a high level of performance and meet mission requirements. Starting that policy dialogue in the basin with stakeholders, water managers, the Alliance, and congressional interests in the short term would be beneficial to all concerned.

12.2 On Method or Process Used

12.2.1 Study Method

The study method relied upon a sequence of defined tasks that built on each other, culminating in the formulation of adaptation strategies that address ecosystems and water resources-related infrastructure. Although the method is sound and commonly used in studies, it does have its shortfalls. First and foremost is the impact on the study schedule, as each succeeding task must wait until preceding work is complete and vetted before starting the following tasks.

In this study, the temperature and river flow forecasts accomplished by NOAA were dependent upon the completion and vetting of the IWR modeling of the CMIP3 data. Also, identification of the impacts to ecosystems and infrastructure was largely dependent upon the NOAA forecasts of future river flow discharge and temperatures over the three periods of analysis. Neither of the succeeding tasks could be effectively started without outputs from the previous tasks. The water managers outreach task was initiated following completion of the NOAA forecasts while the ecosystem and infrastructure impacts analyses were likewise underway, and writing of the draft report sections regarding the downscaled modeling processes was ongoing while these two tasks (impact assessments and outreach) proceeded, but these were exceptions to the norm.

Second, a sequential study process relies on the accuracy of preceding outputs to reduce the introduction of damaging errors into the study. Scientific, mathematical, and statistical errors can be compounded throughout the study leading to many unwanted and unexpected results. Much time was spent during the early modeling tasks to ensure that outputs were accurate and would provide sound data upon which to build succeeding tasks. The successful back-casting of the NOAA runoff/discharge model into the 1952–2001 time period and comparison with observed data at the 25 gages provided a measure of reliability that forecasted data would be reasonably accurate.

12.2.2 Outreach Findings

Another lesson learned was the virtual absence of ongoing CC studies or development of adaptation strategies by other agencies or water managers that responded to the survey questionnaire. This is not surprising given the relatively high cost of modeling and impact analyses and the general lack of public concern for events that either may never happen or may happen decades in the future. In some cases, the responsibility for ongoing operation and maintenance of Federal projects has been turned over to local interests that have neither the funds nor the expertise to address CC effects. It is likely that many jurisdictions in the basin are relying on either academic institutions or private/corporate research facilities to perform these modeling/impact assessment functions and provide recommendations for action. It appears at this time, that the USACE through the RCCP Pilot Study program, along with offices of NOAA and the USEPA are the primary basin agencies looking at potential effects of CC and formulating strategies to reduce future threats to its operating infrastructure.

12.2.3 Positive Collaboration Benefits

A positive lesson learned was collaboration with member organizations of the Ohio River Basin Alliance during the study. The array of resources made available to the study team, some provided without charge, were instrumental in the success of the study. Gratis work provided by the IWR staff (not officially members of the Alliance) for modeling temperature and precipitation data from the GCM archived models was the foundation to the entire study. NOAA, an Alliance member, provided gratis work for modeling the runoff and river flow discharge data for the entire basin as a part of its ongoing agency programs. Other team members were either recommended by the Alliance or were already members of the Alliance, including working group leaders from Battelle and TNC and both physical and environmental scientists from USEPA and USGS. Collaboration through the Alliance was a positive lesson learned and may return dividends as a method for disseminating CC data and operating as a vehicle for implementing strategies identified in the study.

12.2.4 Adaptation Strategies and Measures

An important lesson learned was the potential application of common adaptation themes (ecosystem and infrastructure) across many of the sub-basin areas. As much as the sub-basin areas are uniquely different, certain of their characteristics are very similar indicating that many of the adaptation strategies can be applied basin wide.

13. Conclusions

13.1 On physical System/Climate Findings

The ORB is a vast land area (204,000 square miles) spanning three major climatic zones. There are significant climate variations in annual mean temperatures and rainfall across the basin due to its longitudinal and latitudinal extent. Recent meteorological records show both significant drought conditions resulting in water supply emergencies, and extreme precipitation events resulting in major flood events. Past tropical incursions from the Atlantic and Gulf coasts have resulted in record rainfall events and damaging floods. The system of Federal, quasi-Federal, state, and local infrastructure dedicated to reducing flood damages has been in place since the 1930s and continues to fulfill that mission today, although many structures are in need of rehabilitation for performance issues.

Further information supplied by the OHRFC indicates that there has been a gradual warming trend throughout the basin since the late 1970s and precipitation has increased during the latter summer and early fall months during that time period as well. Also according to the OHRFC, the influence of the jet stream across the basin latitudes increases the variability of the weather and further complicates forecasting future climatic conditions.

Based on the study forecasts, it appears that significant changes in river flow discharges and mean annual air temperatures will not be occurring before 2040. Generally, with a few minor exceptions for precipitation increases in some watersheds during *F1*, the climate will not vary substantially from what has been experienced between 1952 and 2001. After 2040, precipitation may increase or decrease substantially across the basin depending on one's location. Generally, the northeastern, eastern, and southern parts of the basin will experience greater amounts of precipitation and thus higher flow discharges. The western and southwestern portions of the basin will experience decreased precipitation resulting in less runoff and lower flow discharges in those streams. The entire basin will experience temperature increases of at least one-half degree per decade between 2011 and 2040 and one full degree per decade between 2041 and 2099.

Basin ecosystems have endured significant losses of habitat and numerous aquatic species have been extirpated from several watersheds due to flow modifications, deteriorating water quality, and competition with other water uses (hydropower and M&I water supply). Due to the efforts of USEPA, TNC, ORSANCO, and state water quality departments, there have been water quality improvements for some tributary rivers and the Ohio River itself. However, tributaries still suffer from AMD, nutrient loading, and point and non-point source water quality impairments.

Forecasted changes in precipitation may exacerbate some of these conditions as increased rainfall washes pollutants into streams and exposes past mining areas to further erosion and subsequent stream degradation. Warming of streams and rivers may result in complete extirpation of some species or migration of some species from existing habitat. Similar movements or losses may occur to terrestrial species provided that there aren't significant barriers (dams or multilane highways) to both aquatic and terrestrial migrations. Additional threats to ecosystems will include incursions by invasive species more accustomed to warmer waters and the threat of water-borne and air-borne diseases and infestations of pests. Ecosystem services, a substantial component of the regional economy, will be placed at risk by the forecasted CC. Documented information in this study indicates potential economic losses due to CC in the basin could be orders of magnitude greater than any other economic threat faced by the basin's resources in the past.

Existing infrastructure including dams, LPPs, navigation locks and dams, power plants, transportation modes and communications systems, and both wastewater treatment and public water supplies will be challenged by forecasted changes in precipitation rates and temperature increases. Some infrastructure has been designed using engineering factors of safety that enable the facilities to operate under extreme conditions including flood flows and droughts. Changes in project operations, policies, and regulations that recognize the threat of CC and its impact on fulfillment of authorized missions may be necessary and warranted.

13.2 On Method or Process Used

Future IWR-funded pilot studies of the basin or components of the basin led by a USACE district should identify simpler methods of distributing program funds in the event that collaboration with non-USACE entities is deemed necessary and those entities require study funds to participate. Opportunities to collaborate on large-scale studies with basin-wide or regional entities, NGOs, and academia that have a vested interest in the social, economic, and environmental aspects of a region should be pursued by the USACE. Access to historic information and trends, geospatial databases, basic physical sciences research findings, modeling capabilities, and regional repositories of information can be greatly enhanced through these collaborations. Working closely with the ORB Alliance and its members has greatly increased the quality and breath of this pilot study. Should the findings and recommendations from this pilot study be embraced by the Alliance and its members, future implementation of adaptation measures could be realized at the lowest organizational and watershed levels of the basin.

14. Acknowledgements and References

14.1 Acknowledgements

Dr. S. Lehmann (USEPA, Office of Wetlands, Oceans, and Watersheds), Dr. S. Paulsen, and Dr. M. Kentula (USEPA/ORD) provided information about the National Aquatic Resources Survey (NARS) that proved to be extremely valuable for this report. Dr. M. Weber (USEPA/ORD) provided original NARS-related GIS layers from which ORB-specific cutouts were prepared for this report. Dr. C. Weaver (USEPA/ORD) provided information on the current activities within the USEPA's Global Change Research Program, which build on the results of the vulnerability indicator study and 20 watersheds study referenced in this report.

Dr. Kate White, Dr. David Raff, and Dr. Jeff Arnold at IWR for their knowledge, guidance, patience, and encouragement in furthering this pilot study to its completion, and to Dr. Raff and his team for downscaling basin data out of the GCM models from the 4th IPCC Assessment. To Mr. James Noel and his staff at the Ohio River Forecast Center in Wilmington, Ohio for their extensive runoff modeling work, team education, graphic skills, and guidance in interpreting the model outputs, as well as the very informative webinars provided by Mr. Noel to USACE staff and basin water managers. To Mr. Richard Bartz at USGS for his study guidance and his gracious provision of a meeting space in Columbus, Ohio from whence the pilot study essentially launched.

Dr. Paul Kirshen (University of New Hampshire), Dr. Harry Stone (Battelle Memorial Institute), Dr. Jeff Kovatch (Marshall University), Dr. Lilit Yeghiazarian (University of Cincinnati), and Dr. Elly Best (USEPA) for their extensive knowledge in ecosystem resources, surface and GW systems, water quality, ecosystem services, climate changes, and the growing art and science of climate adaptation. A special thanks to Dr. Elly Best from USEPA for her dogged determination as the ecosystem impacts team leader and best wishes from the pilot team to Dr. Best during her recovery. Mr. John Stark (TNC) for his working knowledge of the creatures large and small in the Ohio River and its tributaries and the challenges they face now and in the future. Also for Mr. Stark's connection with the Ohio River Fish Habitat Partnership and his knowledge of their future rehabilitation strategies that may align with climate adaptation strategies. Dr. Chuck Summerville (Ohio River Basin Alliance Director) and the Executive Committee of the Alliance for their support to this study and successful absorption of the climate change team members into an existing working group within the Alliance, thus accomplishing an important objective of the pilot study.

Finally, our thanks to the many contributing USACE staff at the four Ohio River districts including Mr. Tom Maier (LRP), Ms. Ramune Morales (LRN), Mr. Joe Trimboli (GIS-LRH), Mr. Chip Hall (LRN), Ms. Deborah Lee (LRD), Mr. Erich Emery (LRD), Mr. Kurt Buchanan (LRH), Mr. Juan Barrios (MU), and the project manager, Mr. Mark Kessinger (LRH).

14.2 References

Due to the extensive nature of the references used in various sections of the report, the references section has been moved to the accompanying report Appendices.

Ohio River Basin Climate Change Pilot Study–Abbreviations and Acronyms

(listed as they occur in the report)

USACE	United State Army Corps of Engineers
RCCP	Responses to Climate Change Program
IWR	Institute for Water Resources
ORB	Ohio River Basin
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
NOAA	National Oceanic and Atmospheric Administration
NWS	National Weather Service
TNC	The Nature Conservancy
Battelle	Battelle Memorial Institute
OHRFC	Ohio River Forecast Center
CC	Climate Change
Alliance	Ohio River Basin Alliance (13 states, Federal and state agencies, NGOs and Academia)
GCM	Global Circulation Model
BOR	Bureau of Reclamation
CMIP3/CMIP5	Coupled Model Intercomparison Project Phase 3 and Phase 5 Climate and Hydrology Projections
F1, F2, F3	**Future** Climate Forecast Periods (F1, 2011–2040), (F2, 2041–2070), (F3, 2071–2099)
HUC	Hydrologic Unit Code (used by USGS to categorize US watersheds)
RCC	Responses to Climate Change Program
IPCC	Intergovernmental Panel on Climate Change
NGO	Non-Governmental Organization
TVA	Tennessee Valley Authority
NRCS	Natural Resources Conservation Service
IWRM	Integrated Water Resources Management
R1	Base Years Data Period for Forecast Comparison (1952-2001)
PTTP1/GOL12	Pittsburgh, PA and Golconda, IL (see Table A-3 in the Appendix)
ORSANCO	Ohio River Valley Sanitation Commission
DNR	Department of Natural Resources
A1B/A2	Two specific CO_2 emissions scenarios developed by the International Panel on Climate Change
GHG	Greenhouse Gas
SAC-SMA	Sacramento Soil Moisture Accounting Hydrologic Model
RES-J/RES-SNGL	Reservoir simulation models used by NOAA
SKAN, SSAY	Kanawha Watershed, Big Sandy Watershed (see Table 7-1 for definitions)

SCML, SCMU	Cumberland River Lower, Cumberland River Upper
SSAY	Big Sandy River
Mgal/d	Million Gallons/day
GW	Groundwater
MA	Millennium Ecosystem Assessment
PWSA	Pittsburgh Water and Sewer Authority
ALCOSAN	Allegheny County Sanitary Authority
GCWW	Greater Cincinnati Water Works
MSD	Metropolitan Sewer District
USEIA	United States Energy Information Administration
kWh	Kilowatt-Hour
USNPS	United States National Park Service
ORBC	Ohio River Basin Commission
USDA	U.S. Department of Agriculture
AHPA	American Herbal Plants Association
FEMA	Federal Emergency Management Agency
GWRP	Groundwater Resources Program
CWA	Clean Water Act of 1972
NFIP	National Flood Insurance Program
HSFP	Hydrological Simulation Program-Fortran
SWAT	Soil and Water Assessment Tool
NARCCAP	North American Regional Climate Change Assessment Program
Eq.	Equation
ORBFHP	Ohio River Basin Fish Habitat Partnership
BFI	Baseflow Index
WQ	Water Quality
TN	Total Nitrogen
NHD	National Hydrologic Database
GIS	Geographic Information System
IOP	Interim Operating Plan
NID	National Inventory of Dams
M&I	Municipal and Industrial
NCA	National Climate Assessment
DSAC	Dam Safety Action Category
LPP	Local Protection Project
PMF	Probable Maximum Flood
L&D	Lock and Dam
TMDL	Total Maximum Daily Load
CSO	Combined Sewer Overflow

MWCD	Muskingum Watershed Conservancy District
O&M	Operations and Maintenance
FIRM	Flood Insurance Rate Map
PDT	Project Delivery Team
P.L.	Public Law
AML	Abandoned Mine Land
AMD	Abandoned Mine Drainage
LID	Low Impact Development
ASACW	Assistance Secretary of the Army for Civil Works
NARS	National Aquatic Resources Survey

CWTS report 2017-01, May 2017

OHIO RIVER BASIN– **APPENDICES**

U.S. Army Corps of Engineers and Ohio River Basin Alliance
Institute for Water Resources, Responses to Climate Change Program

Sunrise on the Ohio River. January, 2014.

US Army Corps of Engineers®

Table of Contents

List of Tables

Table of Figures

15. Appendix A: Downscaled Climate Change Modeling Backup Material

This information represents the backup data regarding the modeling process and graphics produced by the pilot study team members in the Institute for Water Resources (IWR) and National Oceanic and Atmospheric Administration. Additional data in the form of specific computer outputs are available and can be provided by request.

15.1 A.1 Percent Change in Mean Annual Minimum Streamflow (Base 1952–2001)

Annual % change to the mean annual minimum flow from the base period through 2011–2040 (*F1*) shows a slightly increased minimum flow in the Kanawha and Big Sandy rivers (Figure A.1-F1, respectively SKAN & SSAY). Period *F2* shows little change in the annual % change in the minimum stream flows in the basin (Figure A.1-F2), and period *F3* shows slightly drier conditions in the upper portions of OH, IN, and eastern IL (Figure A.1-F3). These drying conditions are illustrated in the three figures immediately following.

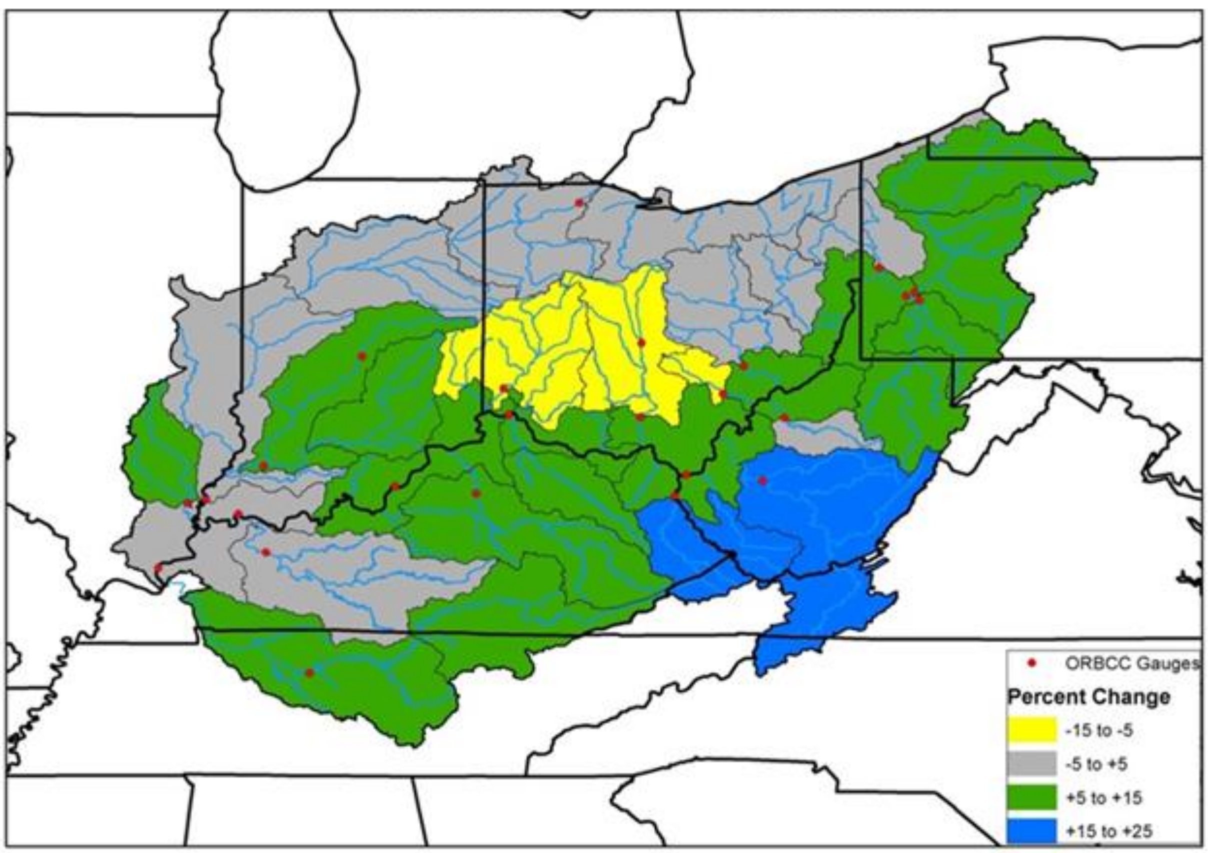


Figure A.1-F1: Annual Minimum Streamflow

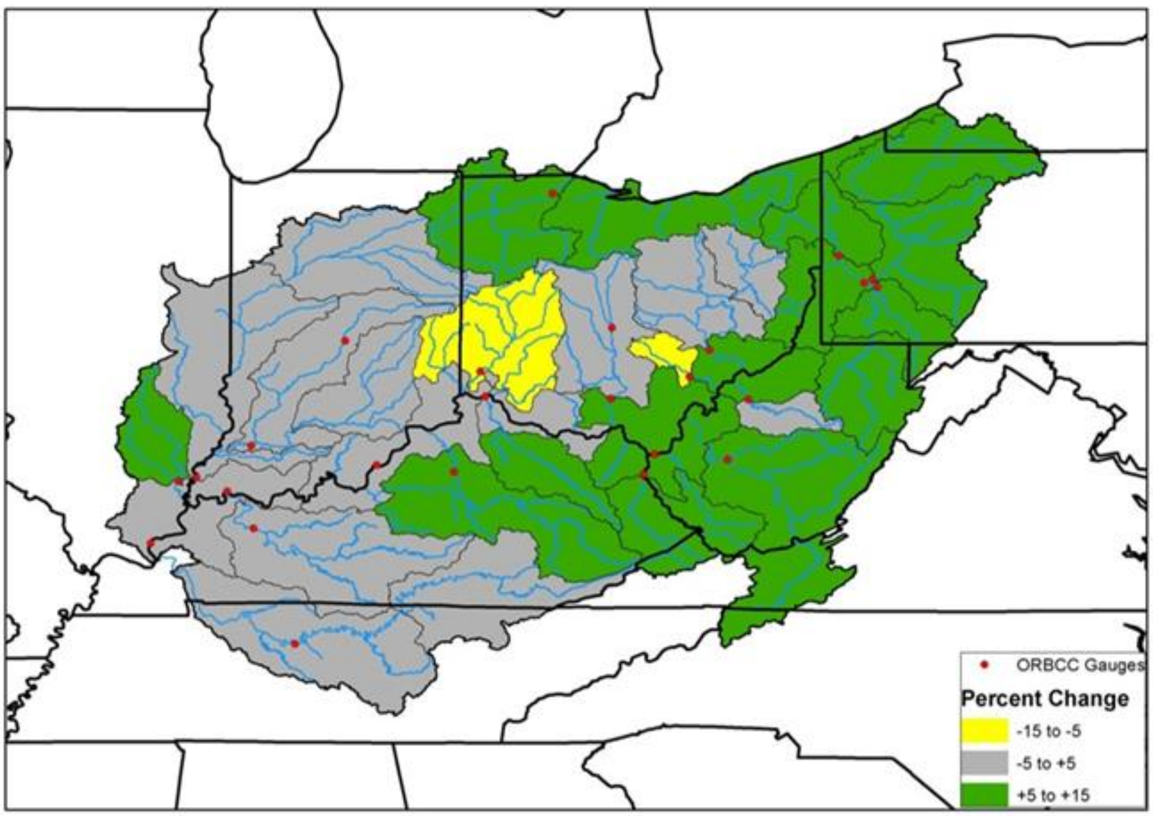


Figure A.1-F2: Annual Minimum Streamflow

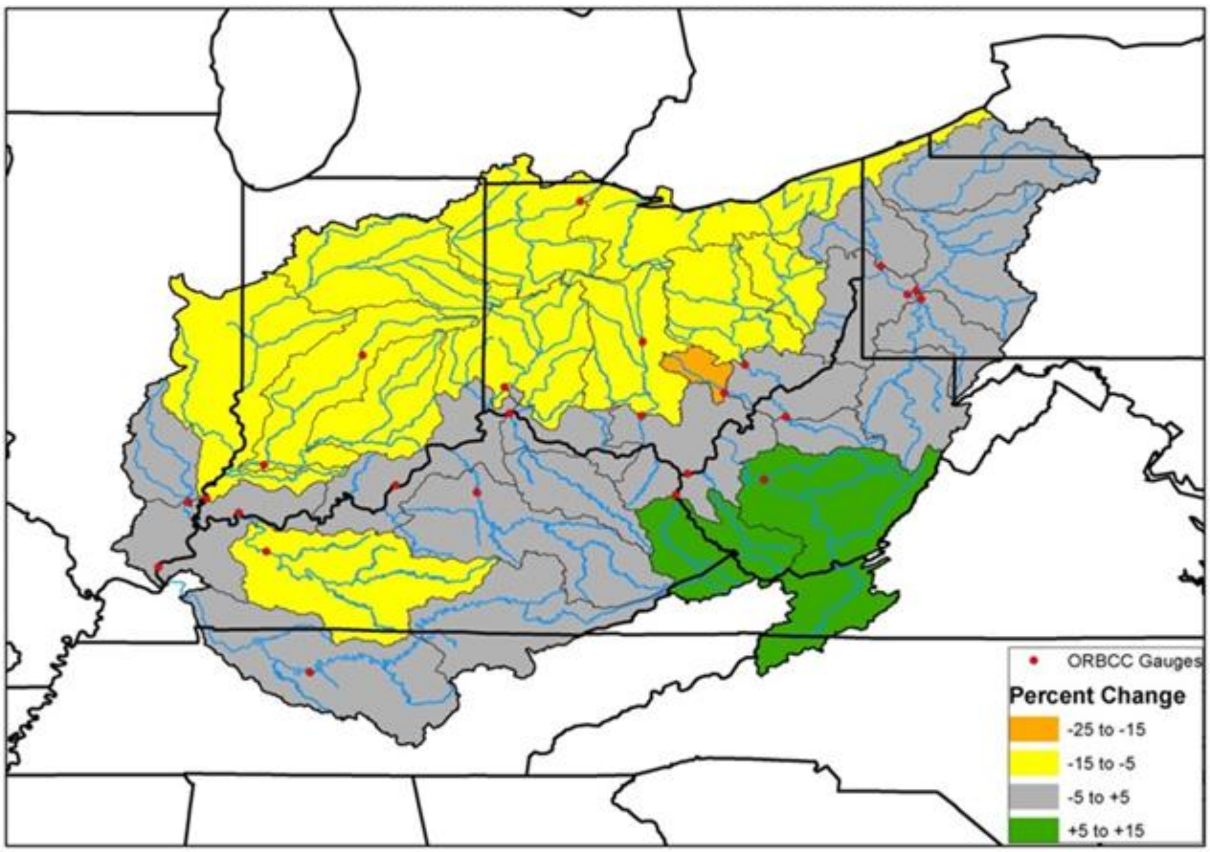


Figure A.1-F3: Annual Minimum Streamflow

15.2 A.2 Percent Change in Mean Annual Maximum Streamflow (Base 1952–2001)

Annual % change in the mean annual maximum stream flows from the base period through 2011–2040 (*F1*) show an increase in the maximum flows across portions of PA and WV. During *F2*, this higher maximum discharge extends into OH, IN, and the Cumberland River watershed (Figure A.2-F1, SCML & SCMU), with the maximum streamflow increasing markedly in the Kanawha and Big Sandy River watersheds (Figure A.2-F2, respectively SKAN & SSAY). During *F3*, the annual % change in maximum streamflow increases substantially across PA, WV, OH, IN, and IL, with significant changes in maximum flow in the Big Sandy River watershed (Figure A.2-F3, SSAY). These increases in mean annual maximum streamflow are illustrated in the three figures immediately following.

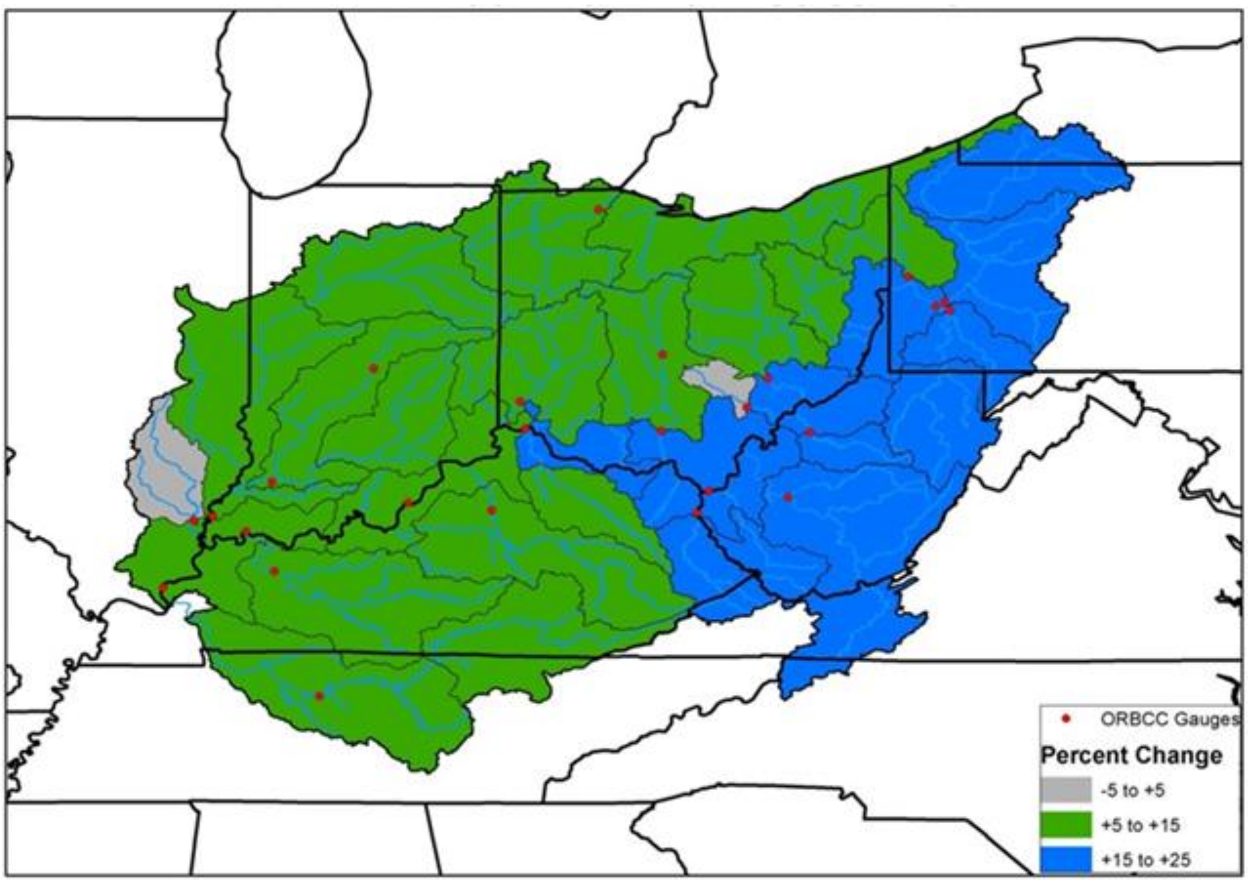


Figure A.2-F1: Annual Maximum Streamflow

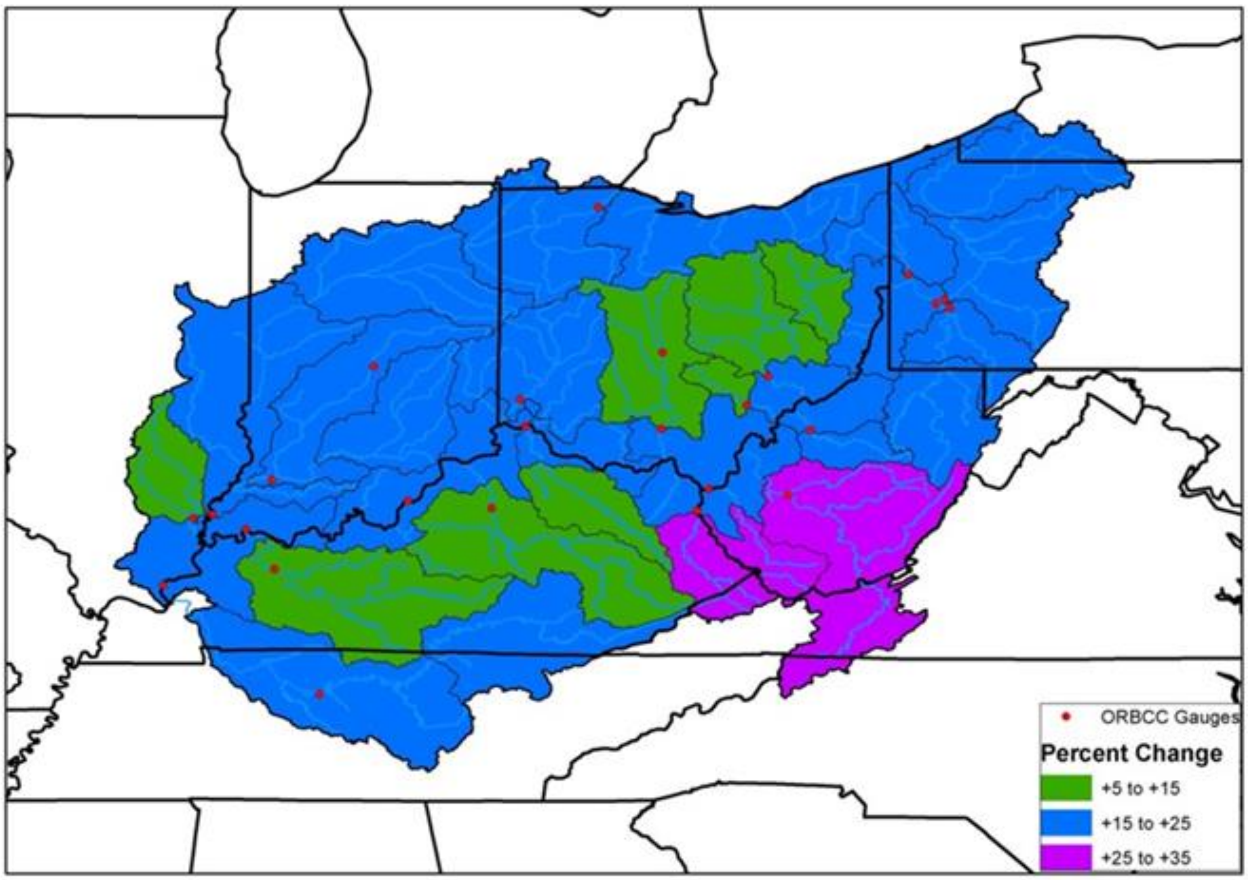


Figure A.2-F2: Annual Maximum Streamflow

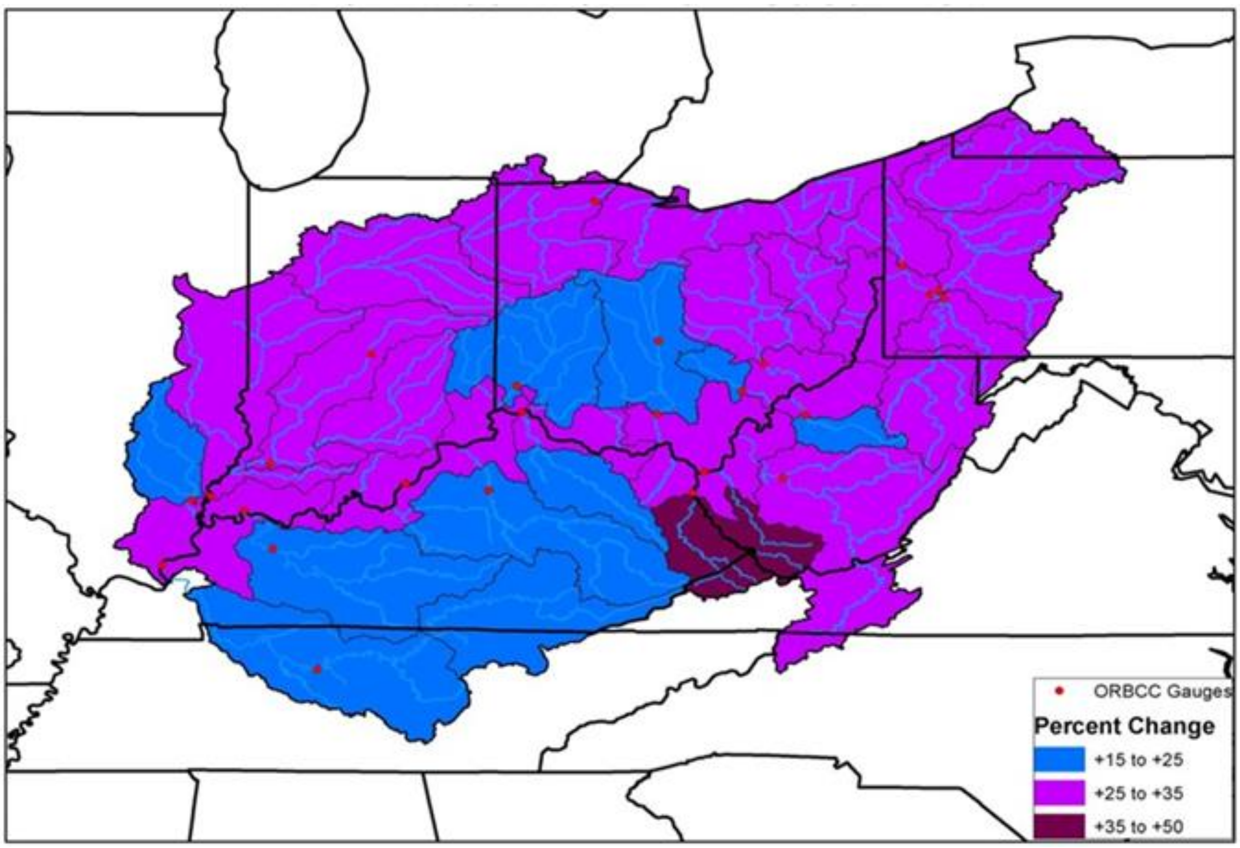


Figure A.2-F3: Annual Maximum Streamflow

15.3 A.3 Percent Change in March Mean Streamflow (Base 1952–2001)

March % changes in mean streamflow show minor increases from the base period through 2011–2040 (*F1*), with the largest increase within the Allegheny River watershed (Figure A.3-F1, SAGL & SAGU). Period *F2* shows increasing March mean flows throughout the upper basin (Figure A.3-F2 Allegheny River watershed and northern portions of OH, IN, and IL). Period *F3* shows a marked % increase in March mean flows within the Allegheny River watershed and results for northern OH, IN, and IL similar to the second period (Figure A.3-F3). These seasonal changes in mean streamflow during March are illustrated in the three figures immediately following.

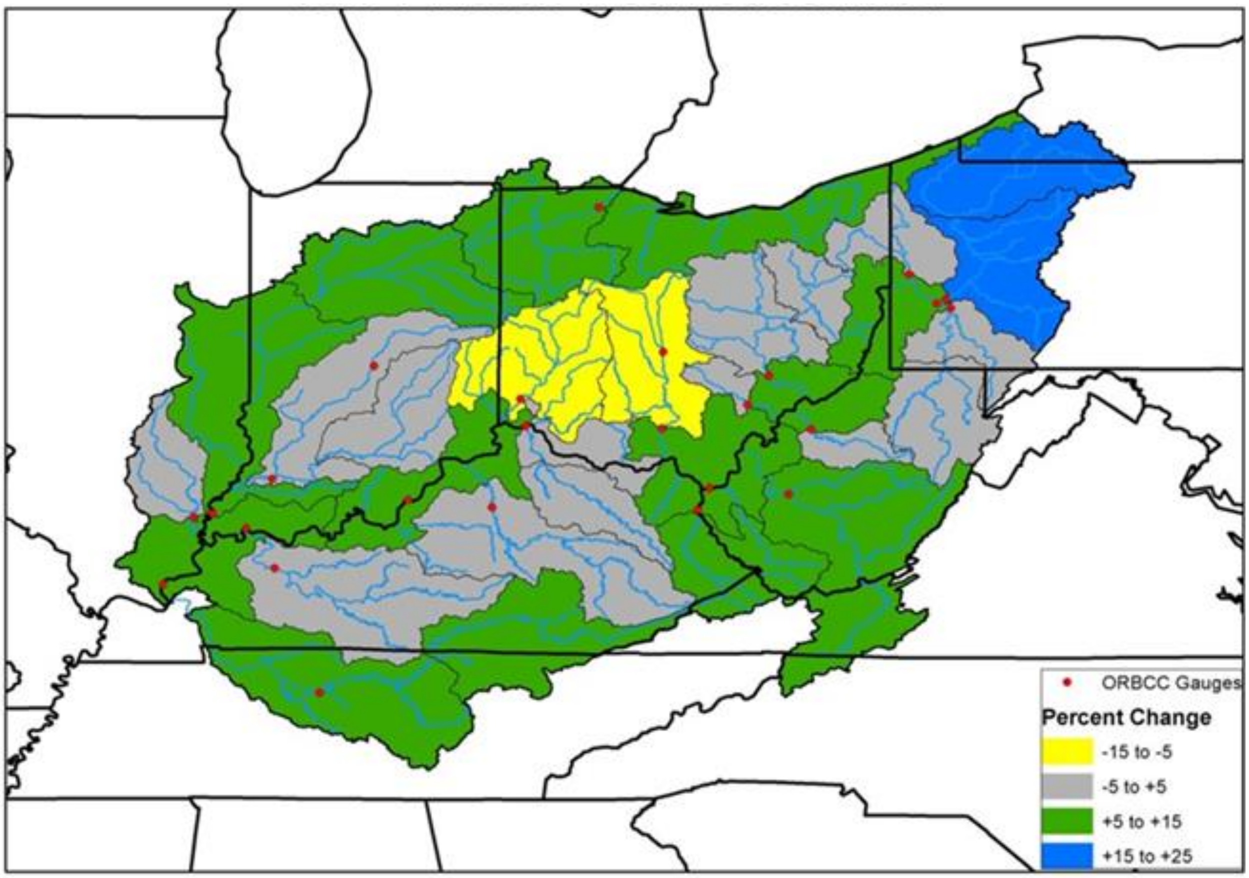


Figure A.3-F1: March Mean Streamflow

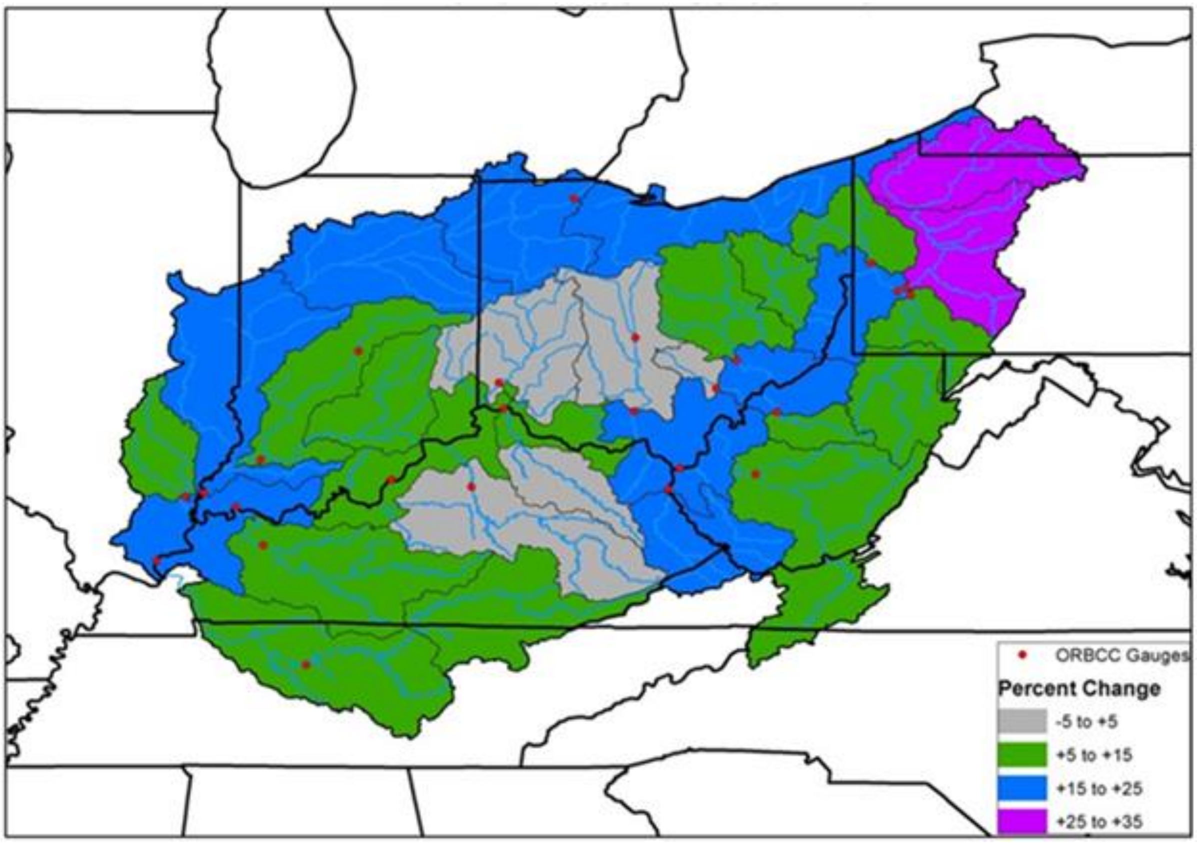


Figure A.3-F2: March Mean Streamflow

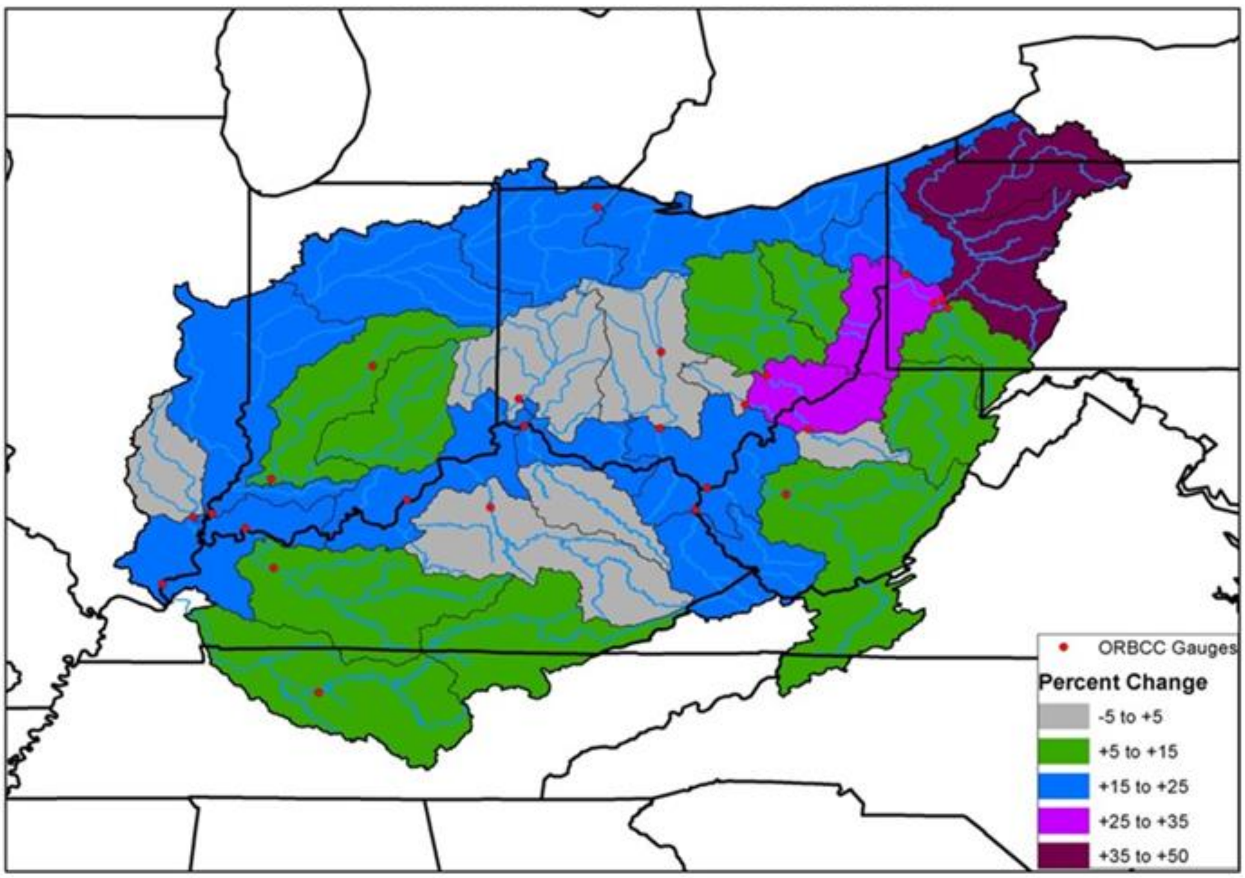


Figure A.3-F3: March Mean Streamflow

15.4 A.4 Percent Change in March Mean Maximum Streamflow (Base 1952–2001)

March % changes in mean maximum streamflow from the base period through 2011–2040 (*F1*) show little change other than moderate increases in the Wabash River watershed (Figure A.4-F1, SWBL, SWBU, SWHT, SEFW). Period *F2* shows some increases in March Maximum flows across most portions of the basin, with more substantial increases in the Wabash and Allegheny River watersheds (Figure A.4-F2, SAGL & SAGU). Period *F3* shows marked increases in March maximum flows in the Allegheny River watershed and other portions of the basin (Figure A.4-F3). These seasonal changes in mean maximum streamflow during March are illustrated in the three figures immediately following.

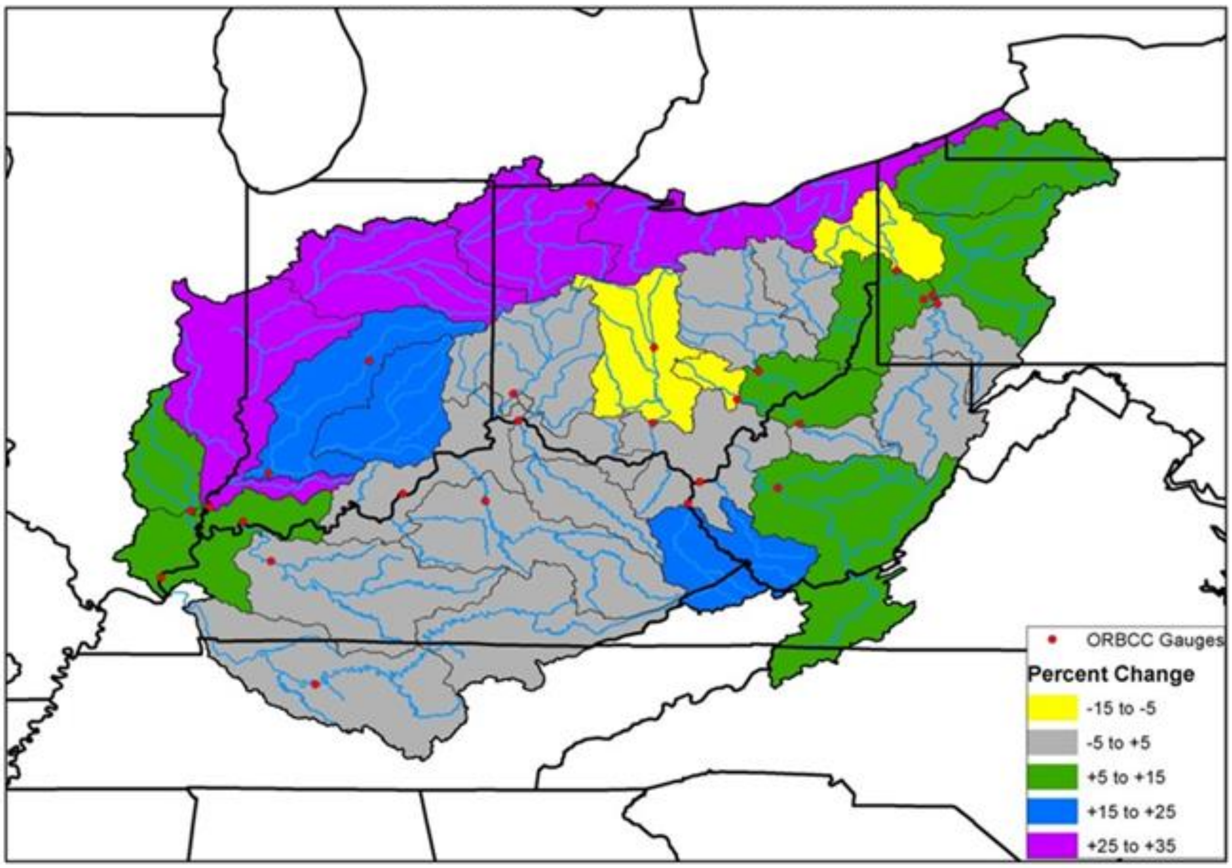


Figure A.4-F1: March Maximum Streamflow

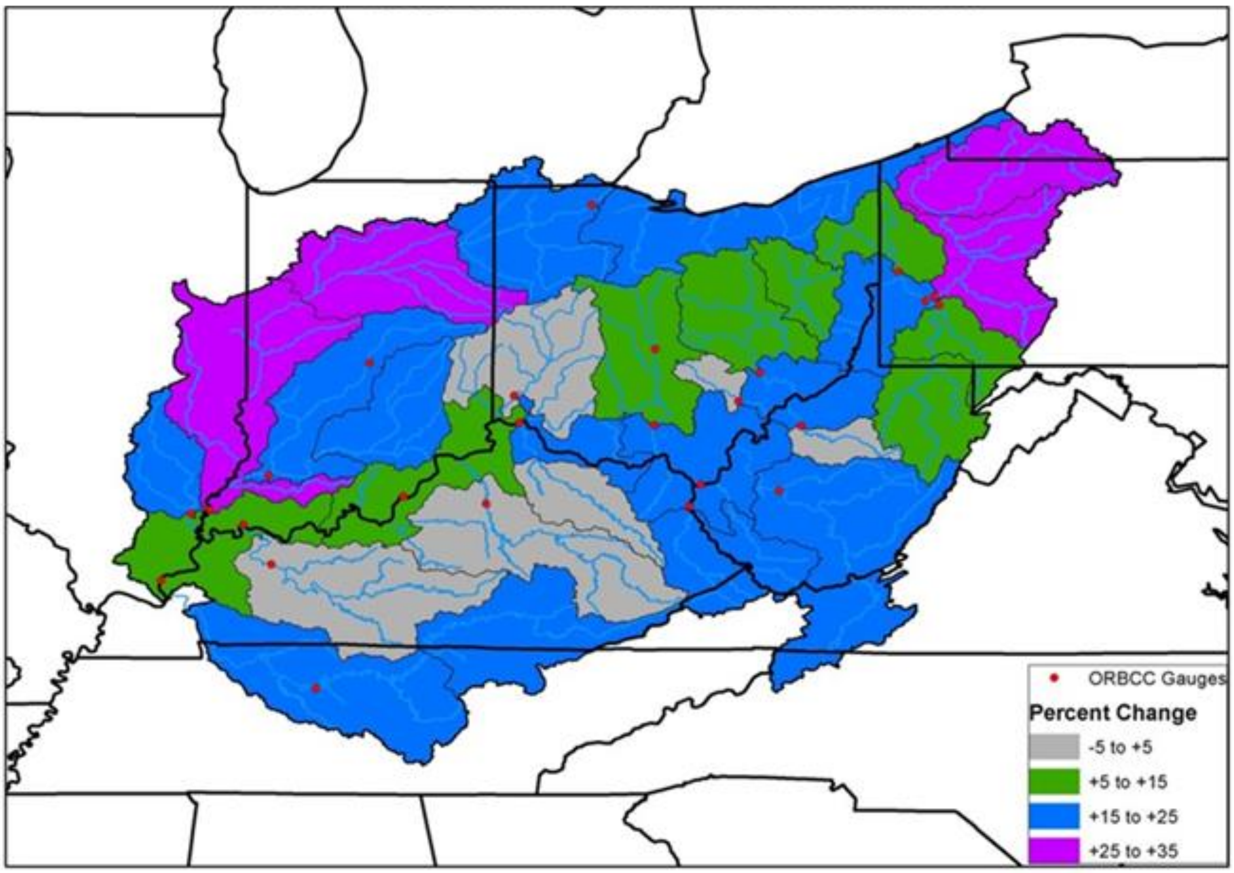


Figure A.4-F2: March Maximum Streamflow

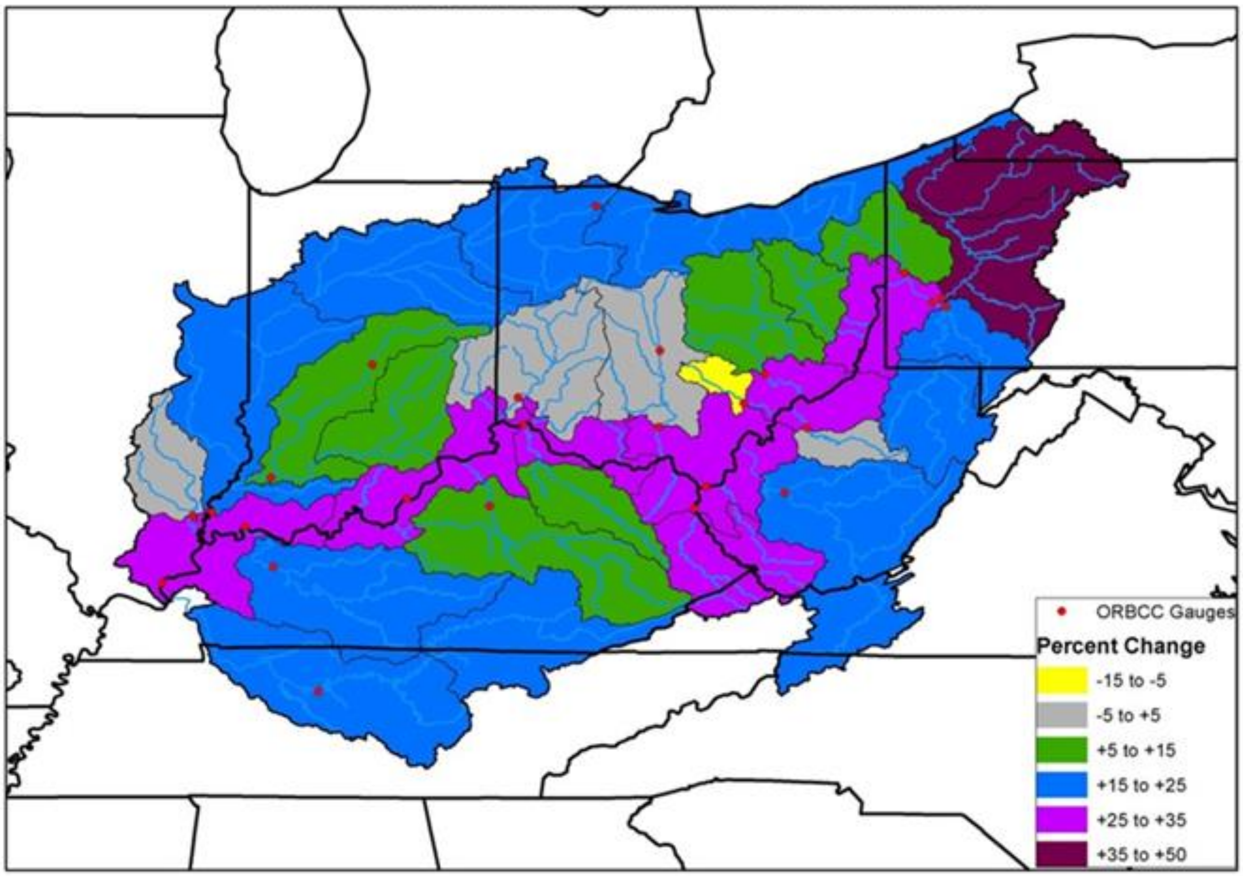


Figure A.4-F3: March Maximum Streamflow

15.5 A.5 Percent Change in March Mean Minimum Streamflow (Base 1952–2001)

March % changes in mean minimum streamflow from the base period through 2011–2040 (*F1*) show little change except for higher seasonal minimum flows in the Cumberland River and Allegheny River watersheds (Figure A.5-F1, respectively, SCML & SCMU and SAGL & SAGU). Period *F2* shows little % change except for higher minimum flows in the Allegheny River watershed and lower minimum flows in watersheds in central OH, IN, and KY (Figure A.5-F2). Period *F3* shows more variability across the basin with higher minimum flows in the Allegheny River watershed and lower minimum flows in central OH and IN (Figure A.5-F3). These seasonal changes in mean minimum streamflow during March are illustrated in the three figures immediately following.

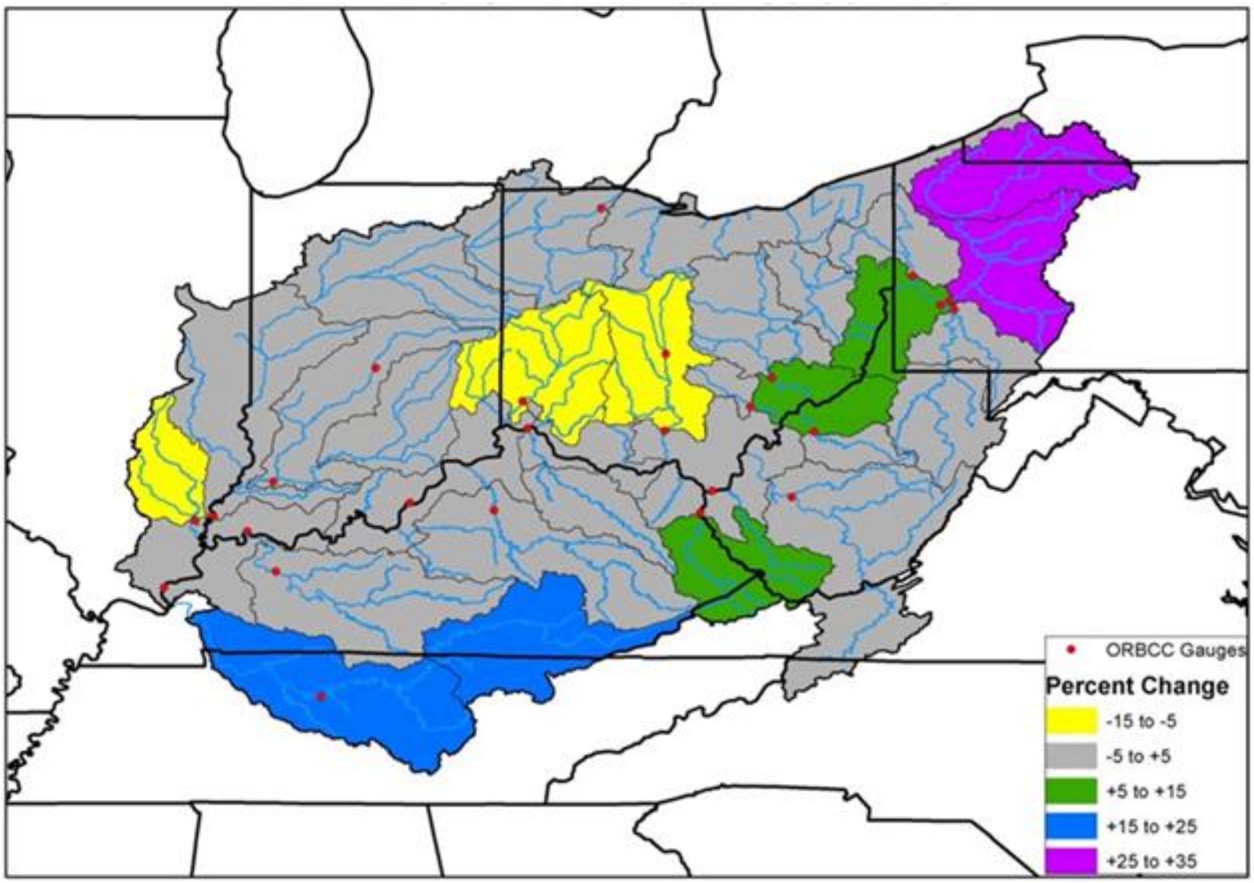


Figure A.5-F1: March Minimum Streamflow

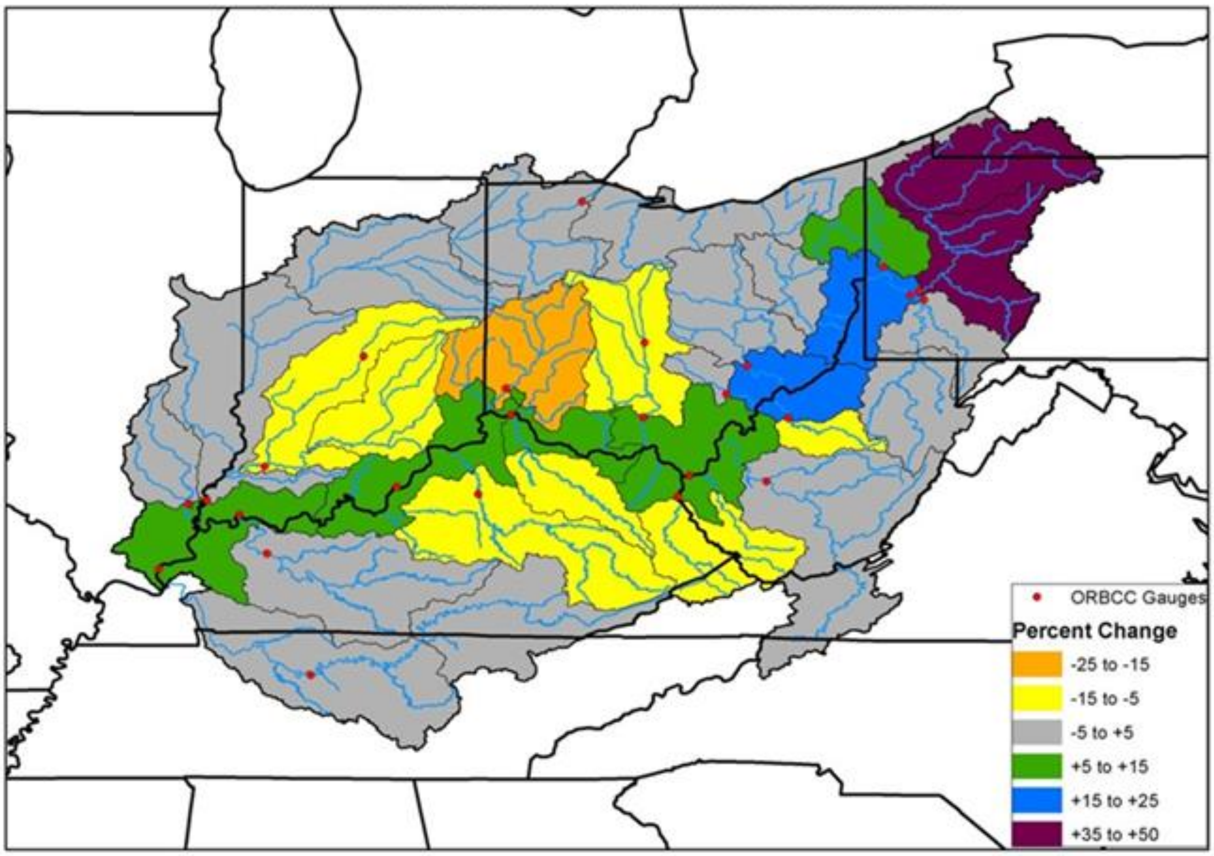


Figure A.5-F2: March Minimum Streamflow

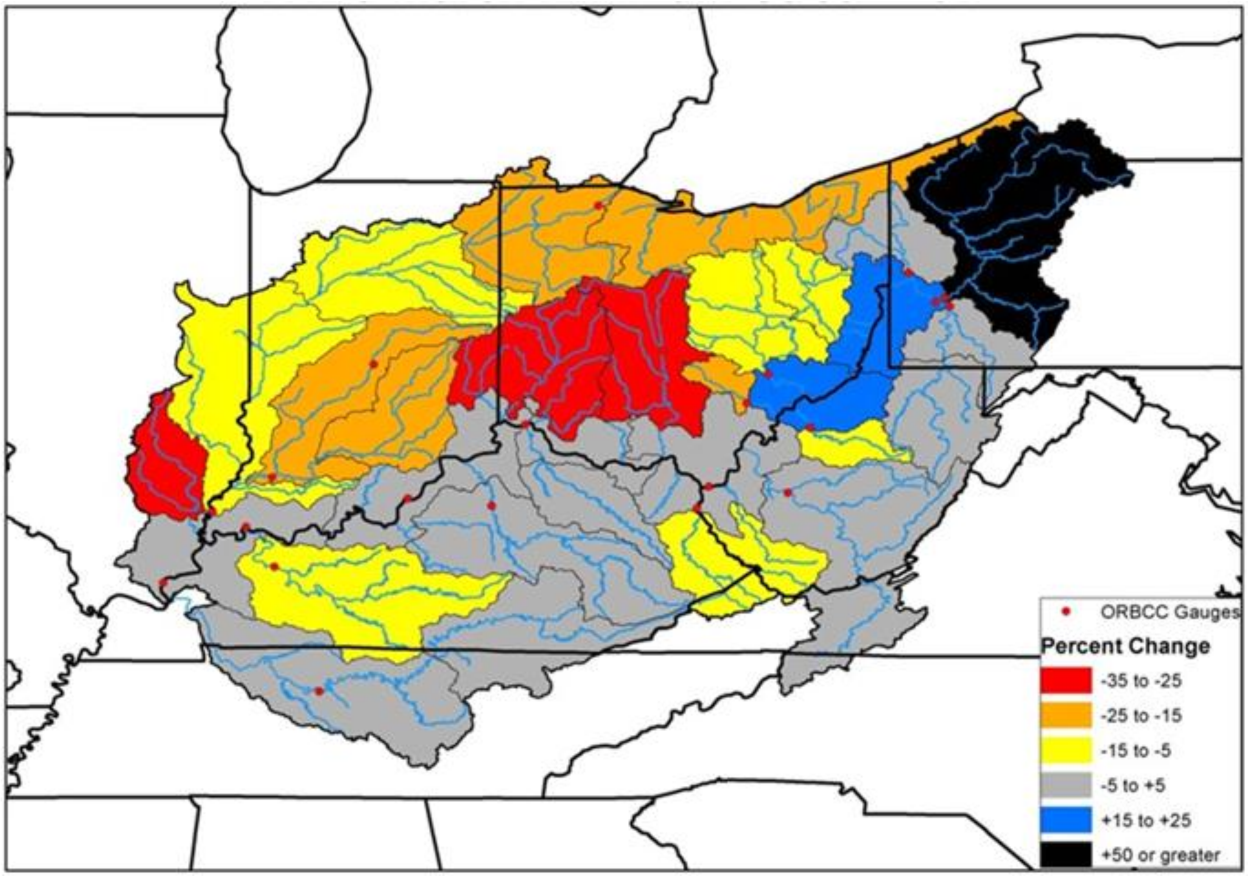


Figure A.5-F3: March Minimum Streamflow

15.6 A.6 Percent Change in October Mean Streamflow (Base 1952–2001)

October % changes in mean streamflow from the base period through 2011–2040 (*F1*) show much wetter conditions across much of the basin with increases in mean October flow in the Allegheny River, Monongahela River (Figure A.6-F1, SMNL & SMNU), and Kanawha River (Figure A.6-F2, SKAN) watersheds and substantial flow increases in the Little Wabash River watershed (Figure A.6-F3, SLWA). During period *F2*, October flows decrease resulting in dryer conditions in central OH, but higher flows occur in the Kanawha River watershed and the Little Wabash River watershed. During period *F3*, the October changes in mean streamflow increase across the basin with the exception of watersheds in both central OH and KY that are dryer. October mean streamflow % change in the Little Wabash River watershed remains substantially higher. These seasonal changes in mean streamflow during October are illustrated in the three figures immediately following.

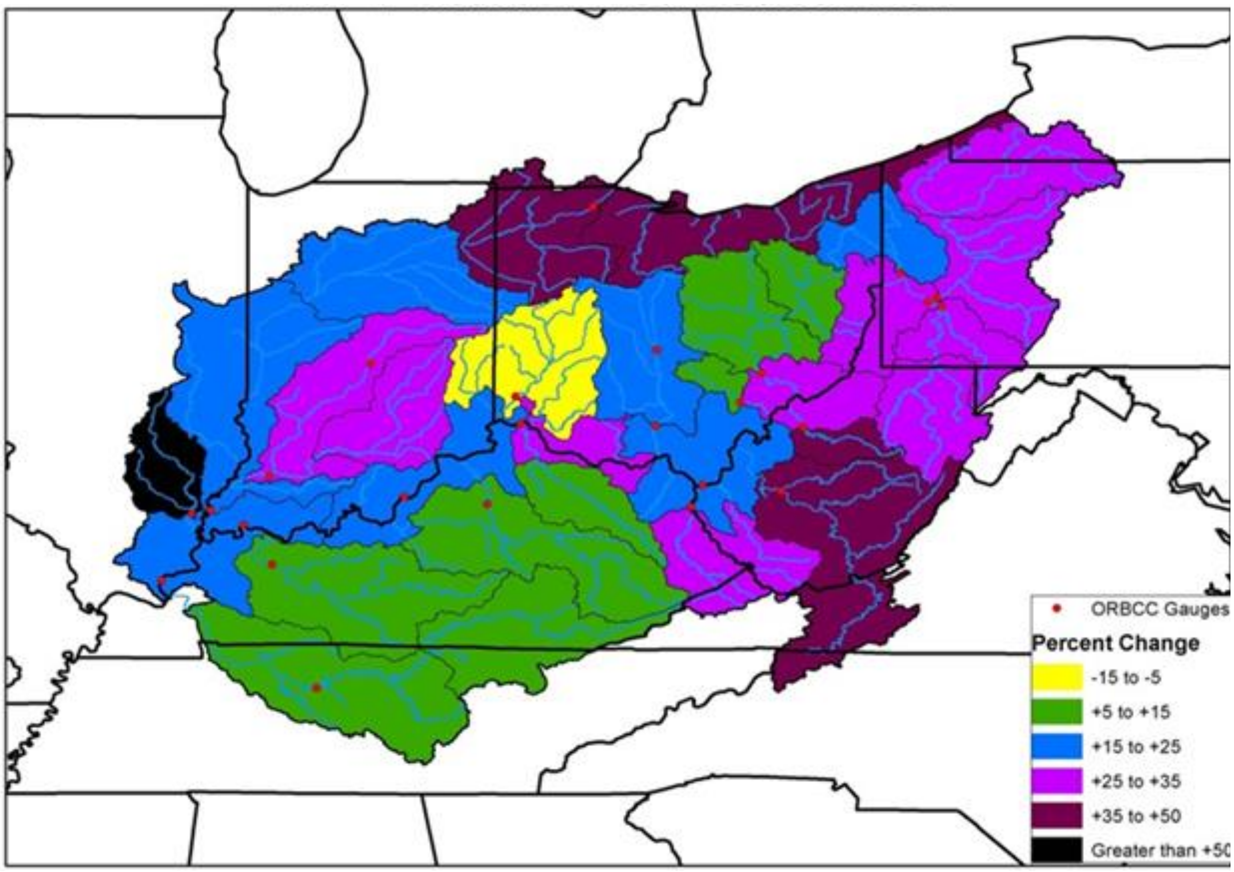


Figure A.6-F1: October Mean Streamflow

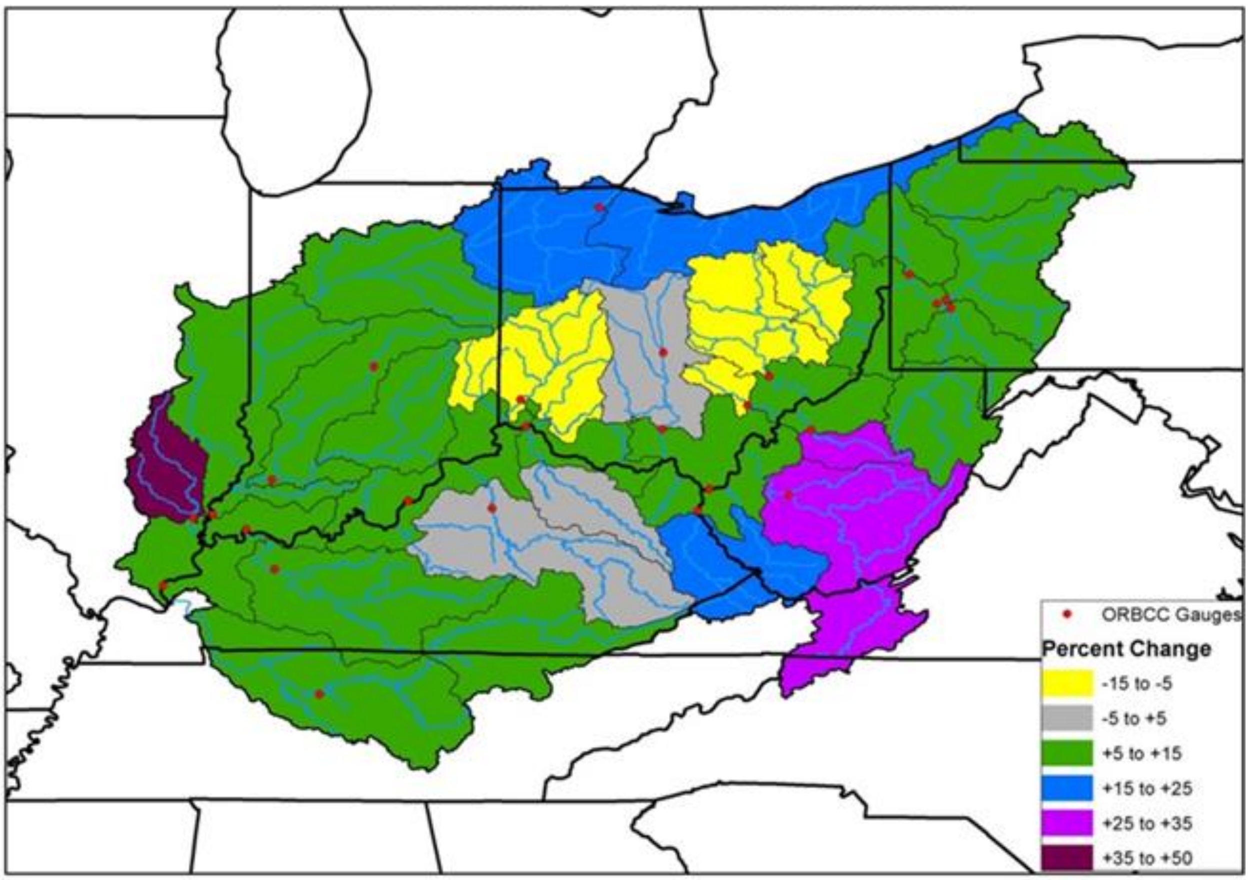


Figure A.6-F2: October Mean Streamflow

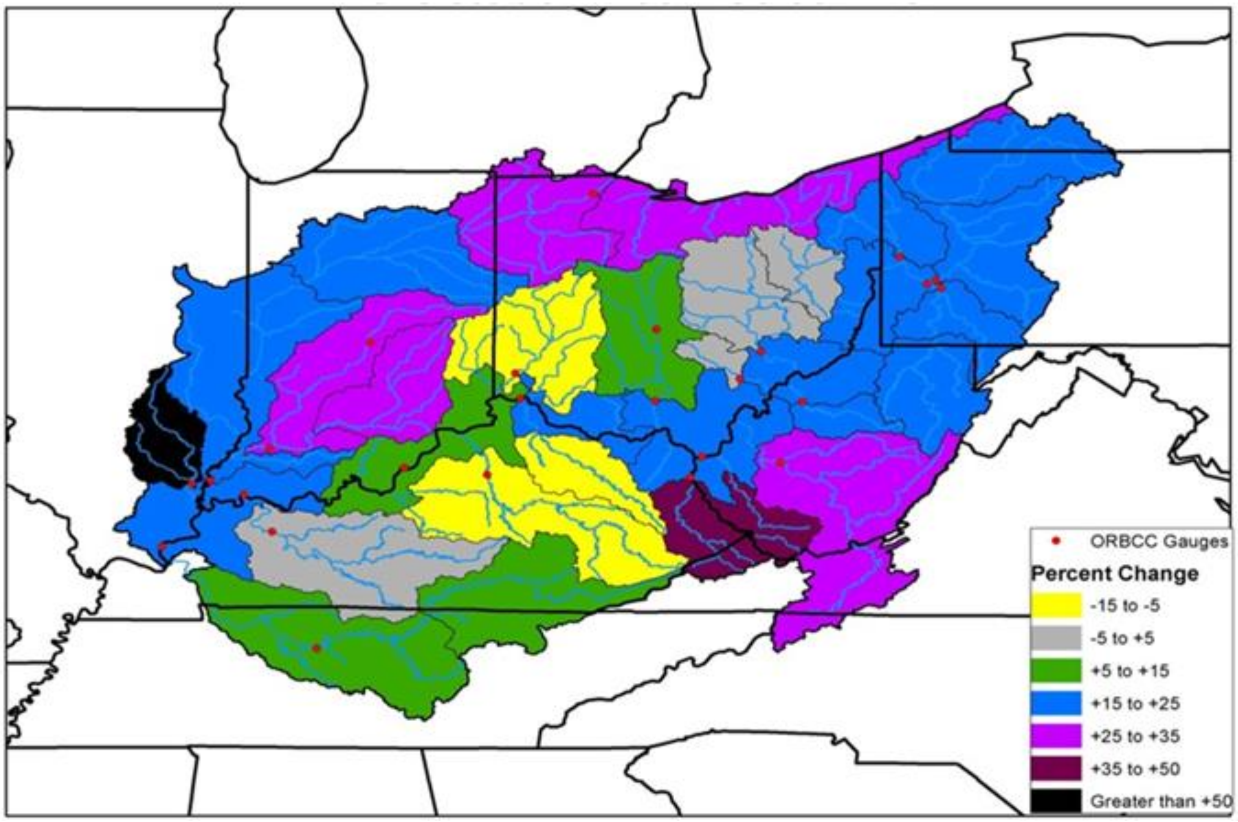


Figure A.6-F3: October Mean Streamflow

15.7 A.7 Percent Change in October Mean Maximum Streamflow (Base 1952–2001)

Changes in seasonal October mean maximum streamflow from the base period through 2011–2040 (*F1*) show increases in maximum flow over much of the basin and substantially higher maximum flows in the Allegheny River and Little Wabash River watersheds and significant increases in the Kanawha, Scioto, Big Sandy, and White River watersheds (Figure. A.7-F1 respectively, SKAN, SSCI, SSAY, SWHT, and SEFW). Period *F2* shows some relaxing of the wetter October conditions, but the Kanawha, White River, and Little Wabash maximum flows remain higher (Figure A.7-F2). Period *F3* shows a return to higher October maximum flows across the basin, with the exception of central OH and KY, with substantial increases during this period in the Big Sandy River, White River, and Wabash River watersheds (Figure A.7-F3). These seasonal changes in mean maximum streamflow during October are illustrated in the three figures immediately following.

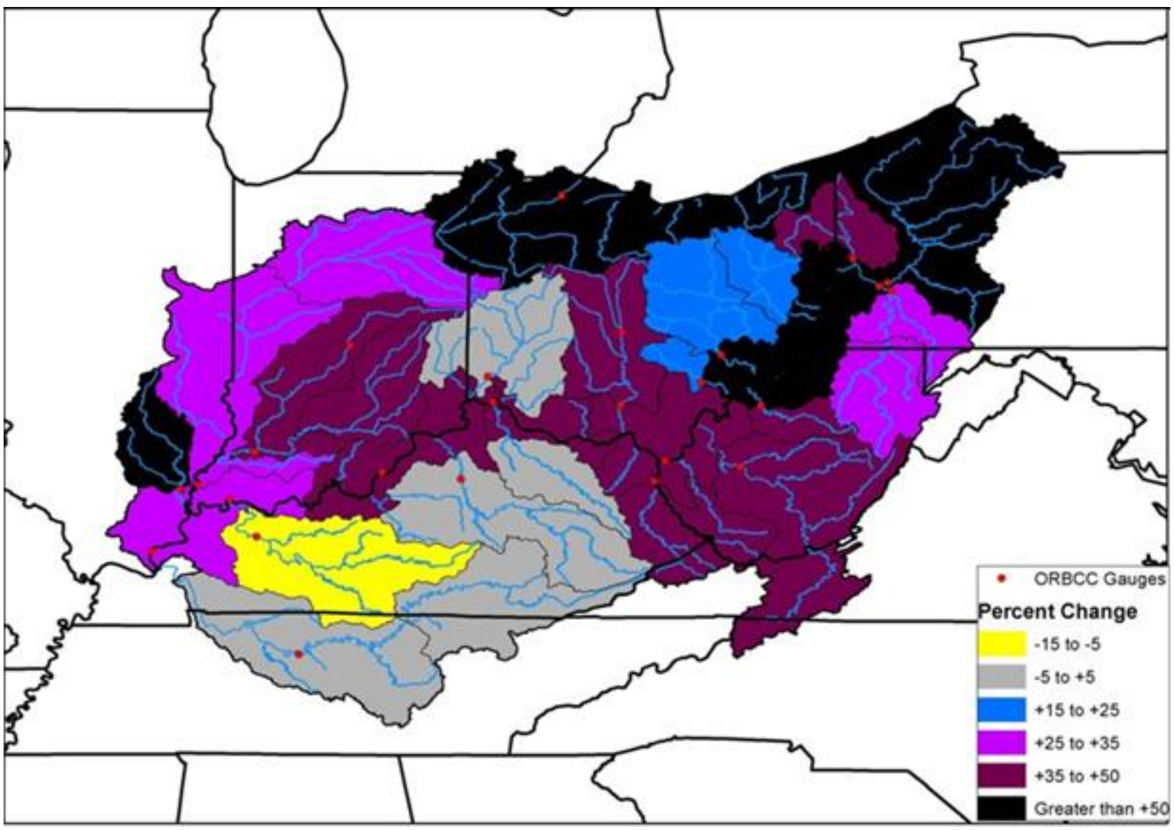


Figure A.7-F1: October Maximum Streamflow

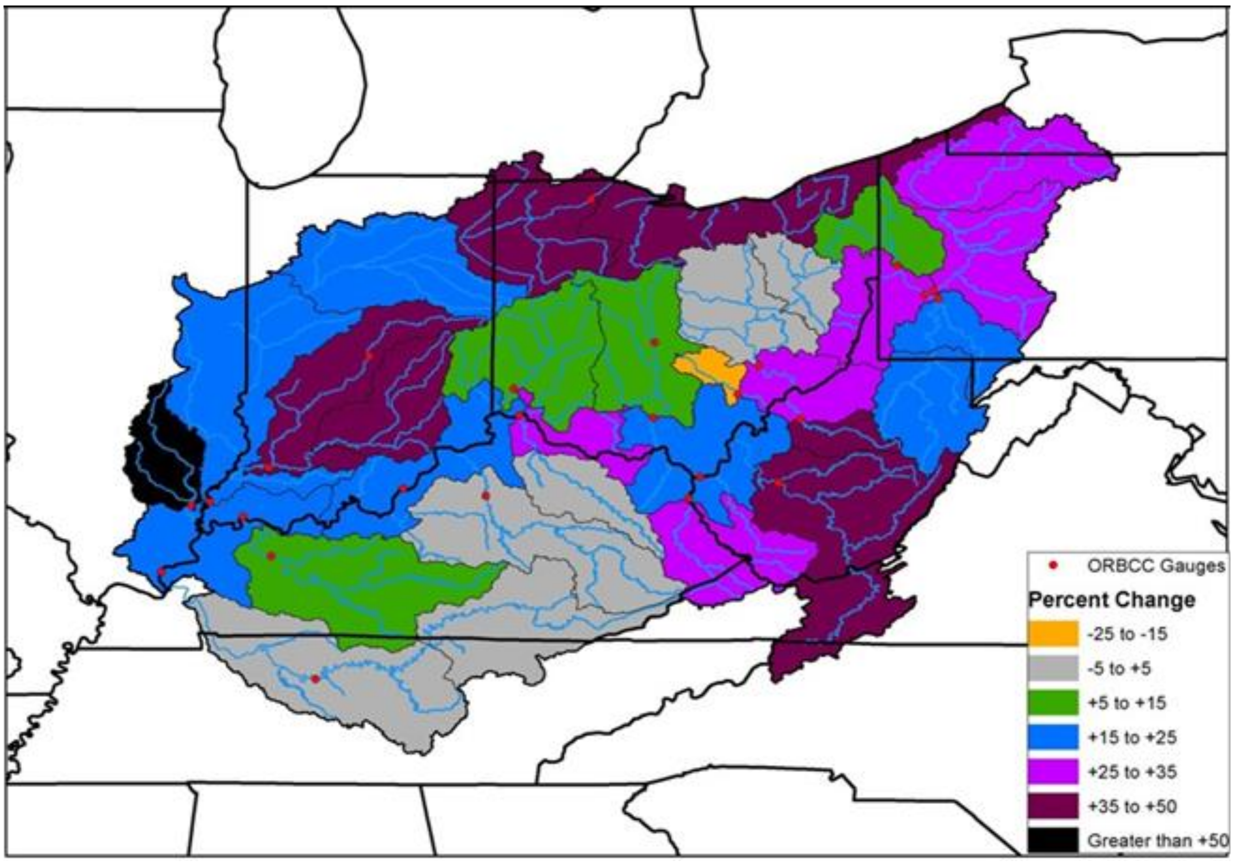


Figure A.7-F2: October Maximum Streamflow

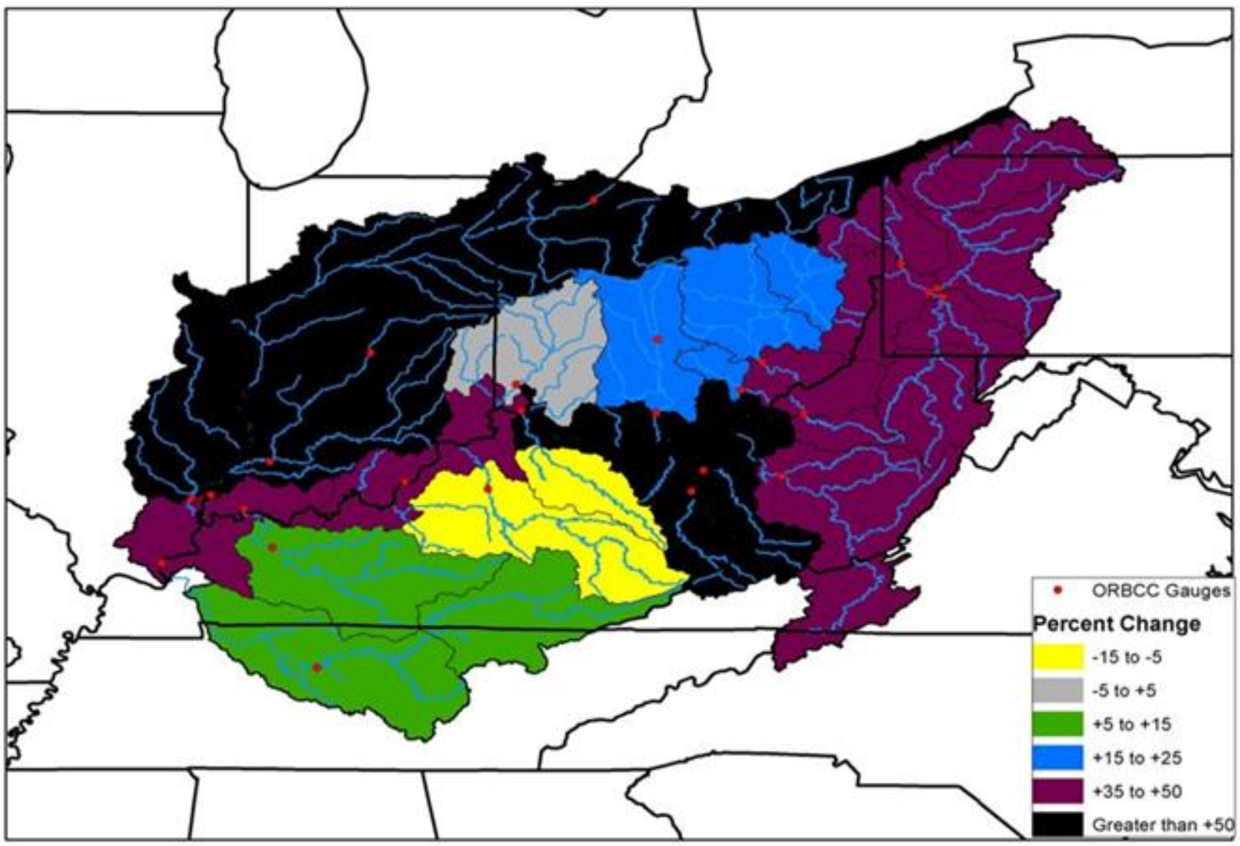


Figure A.7-F3: October Maximum Streamflow

15.8 A.8 Percent Change in October Mean Minimum Streamflow (Base 1952–2001)

Changes in seasonal October mean minimum streamflow from the base period through 2011–2040 (*F1*) show some % increase south of the Ohio River with moderate increases in the Big Sandy and Little Wabash River watersheds (Figure A.8-F1, respectively, SSAY and SLWA), while the region north of the Ohio River in OH, IN, and IL show little change. Period *F2* shows a decrease in October minimum flows through much of the basin, with the exception of the Big Sandy River watershed (Figure A.8-F2). Period *F3* shows significantly lower October minimum flows in central Ohio, most of IN, and IL. Substantially lower October minimum streamflows are indicated in the Little Kanawha, Miami, and both the Licking and Kentucky River watersheds in KY (Figure A.8-F3), respectively, SLKH, SMIM, SHOC, SKTY, and SLIK). These seasonal changes in mean minimum streamflow during October are illustrated in the three figures immediately following.

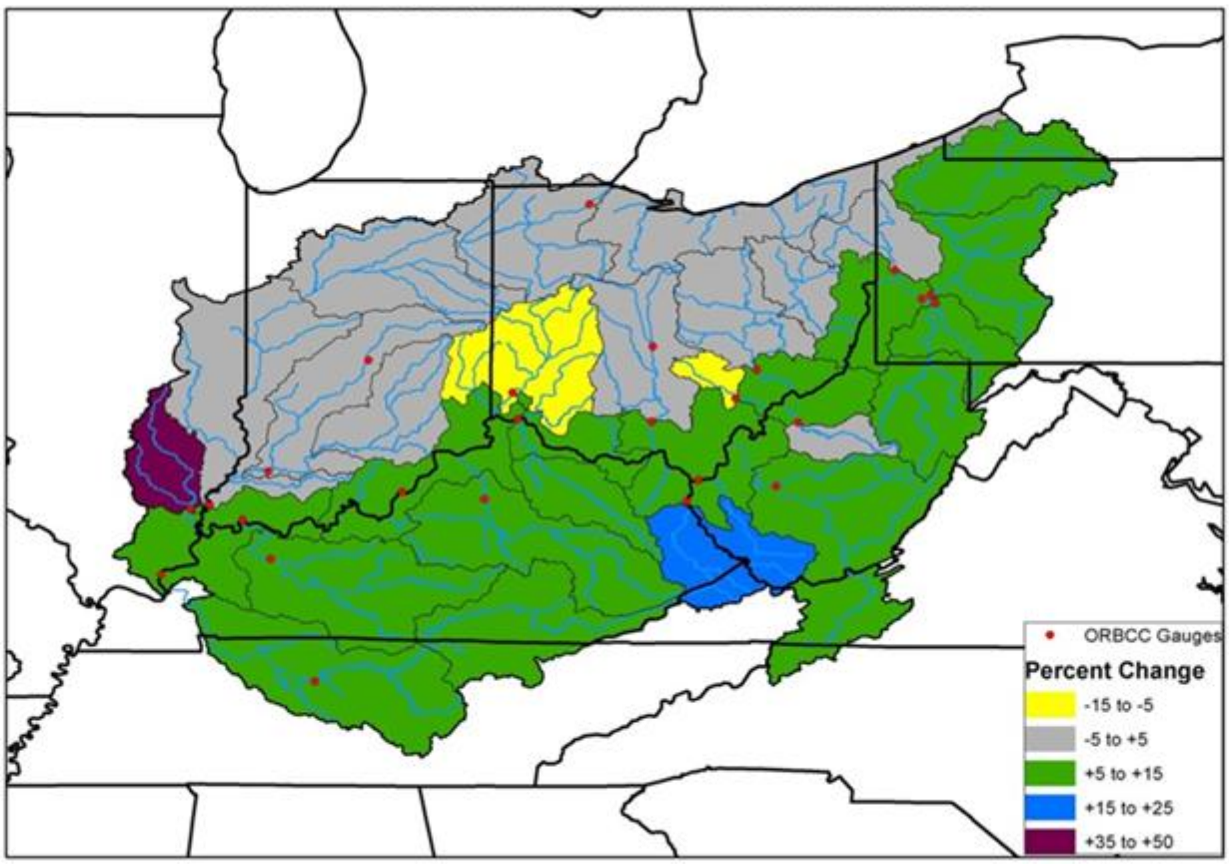


Figure A.8-F1: October Minimum Streamflow

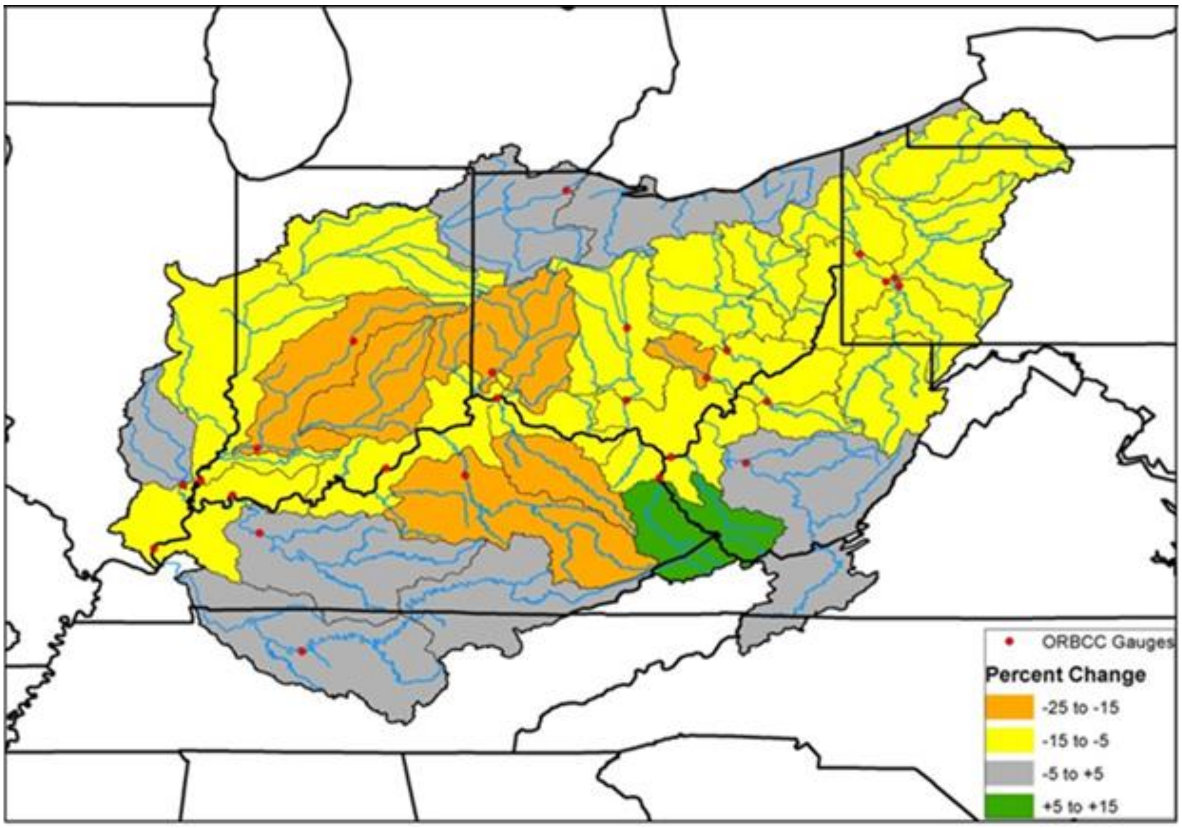


Figure A.8-F2: October Minimum Streamflow

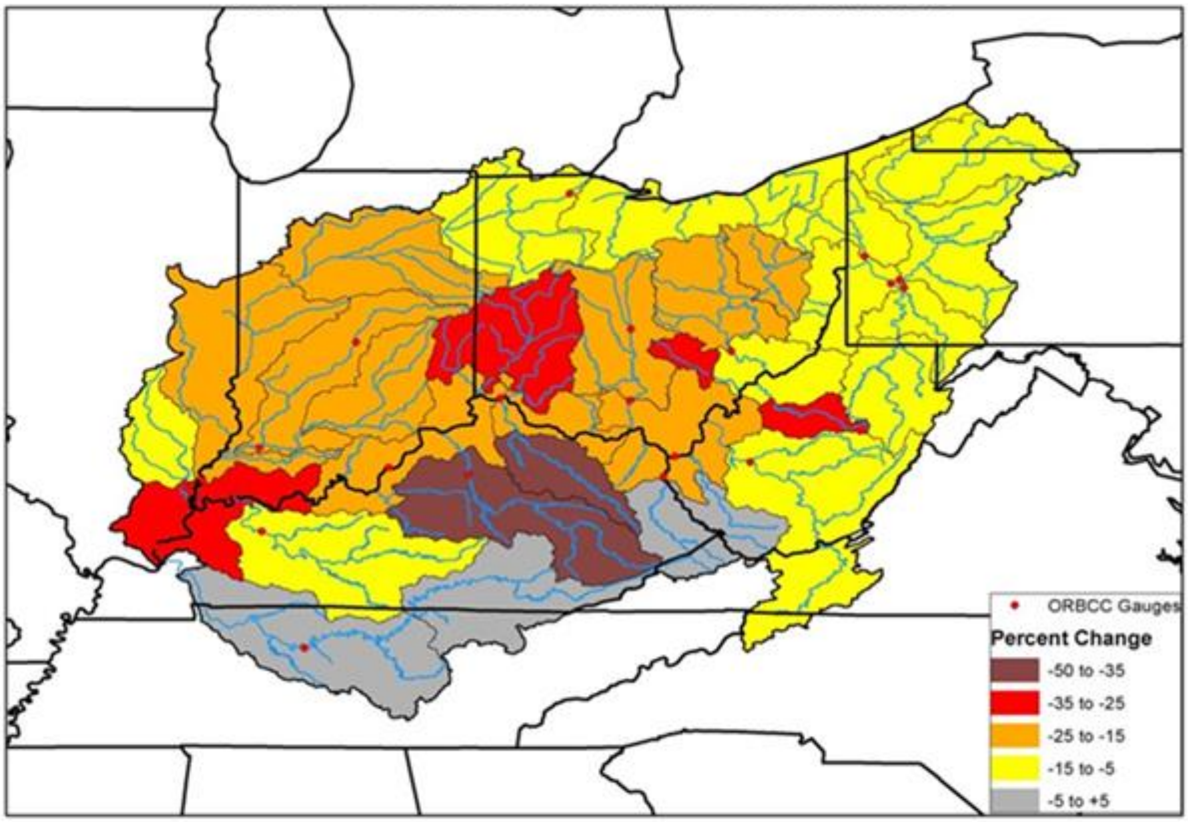


Figure A.8-F3: October Minimum Streamflow

Table A-8: Forecasted Temperature Changes Between 2001 and 2099 by Basin Forecast Point

Forecast Points	Point Location and River	Decades											% Increase from 2001 to 2099
		2001	2011	2020	2030	2040	2050	2060	2070	2080	2090	2099	
SHRP1	Sharpsburg, PA–Allegheny	49.5	50.6	50.9	50.7	51.6	53.5	53.5	54.2	55.6	56.0	57.4	15.9%
BDDP1	Braddock, PA–Monongahela	50.2	51.2	51.7	51.5	52.5	54.4	54.3	55.0	56.4	56.9	58.1	15.8%
BEAP1	Beaver Falls, PA–Beaver	49.8	50.9	51.3	51.0	52.2	54.1	53.8	54.5	56.1	56.4	57.7	16.0%
MCCO1	McConnellsville, OH–Muskingum	51.5	52.6	53.1	52.9	54.3	56.1	55.8	56.5	58.0	58.7	59.8	16.1%
ATHO1	Athens, OH–Muskingum	52.3	53.1	53.6	53.5	54.7	56.5	56.4	57.2	58.6	59.2	60.4	15.5%
ELZW2	Elizabeth, WV–Little Kanawha	53.1	53.9	54.5	54.3	55.7	57.4	57.5	57.9	59.6	60.1	61.4	15.6%
CRSW2	Charleston, WV–Kanawha	53.8	54.7	55.3	55.3	56.7	58.4	58.3	58.9	60.5	61.2	62.3	15.7%
FLRK2	Fuller Station, KY–Big Sandy	55.1	56.0	56.7	56.6	58.2	59.9	59.8	60.4	62.0	62.7	63.9	16.1%
PKTO1	Piketon, OH–Scioto	52.7	53.7	54.1	54.0	55.2	57.0	56.9	57.5	59.1	59.7	61.0	15.8%
HAMO1	Hamilton, OH–Great Miami	52.8	54.1	54.5	54.4	55.6	57.6	57.3	58.0	59.5	60.2	61.2	15.9%
FFTK2	Frankfort, KY–Kentucky	54.4	55.4	55.9	55.9	57.3	59.0	58.9	59.6	61.1	61.7	63.0	15.8%
INDI3	Indianapolis, IN–White	51.8	53.0	53.6	53.5	54.5	56.4	56.3	56.5	58.1	58.9	59.9	15.6%
PTRI3	Petersburg, IN–White/East Fork	54.2	55.5	55.7	55.7	56.9	58.7	58.6	59.3	60.7	61.5	62.8	15.9%
NHRI3	New Harmony, IN–Wabash	55.4	56.7	57.0	57.0	58.3	60.2	60.1	60.9	62.1	63.1	64.3	16.0%
CALK2	Calhoun, KY–Green	56.3	57.7	58.3	58.2	59.6	61.3	61.4	62.0	63.4	64.0	65.5	16.3%
CARI2	Carmi, IL–Little Wabash	55.8	57.1	57.4	57.4	58.7	60.6	60.6	61.3	62.6	63.5	64.7	16.0%
WTVO1	Waterville, OH–Maumee	49.9	51.1	51.3	51.2	52.3	54.4	53.9	54.8	56.1	56.7	57.9	16.0%
NAST1	Nashville, TN–Cumberland	58.4	59.5	60.4	60.2	61.9	63.5	63.4	64.1	65.7	66.4	67.8	16.1%
PTTP1	Pittsburgh, PA–Upper Ohio	50.8	52.1	52.7	52.3	53.6	55.5	55.3	55.9	57.5	57.9	59.1	16.3%
HNTW2	Huntington, WV–Upper Ohio	54.6	55.6	56.4	56.3	57.7	59.4	59.4	60.0	61.5	62.3	63.3	16.0%
CCNO1	Cincinnati, OH–Middle Ohio	53.7	54.9	55.5	55.3	56.6	58.5	58.3	59.0	60.5	61.2	62.3	16.0%
MLPK2	McAlpine, KY–Middle Ohio	55.1	56.2	56.9	56.7	58.3	60.0	59.8	60.6	61.9	62.7	64.0	16.2%
EVVI3	Evansville, IN–Lower Ohio	56.5	57.8	58.3	58.2	59.7	61.5	61.4	62.0	63.4	64.3	65.6	16.0%
GOLI2	Golconda, IL–Lower Ohio	56.6	57.8	58.5	58.4	60.1	61.7	61.7	62.2	63.6	64.5	65.8	16.4%
COLO1	Columbus, OH–Scioto	52.0	53.2	53.6	53.4	54.8	56.7	56.3	57.1	58.6	59.3	60.3	16.0%

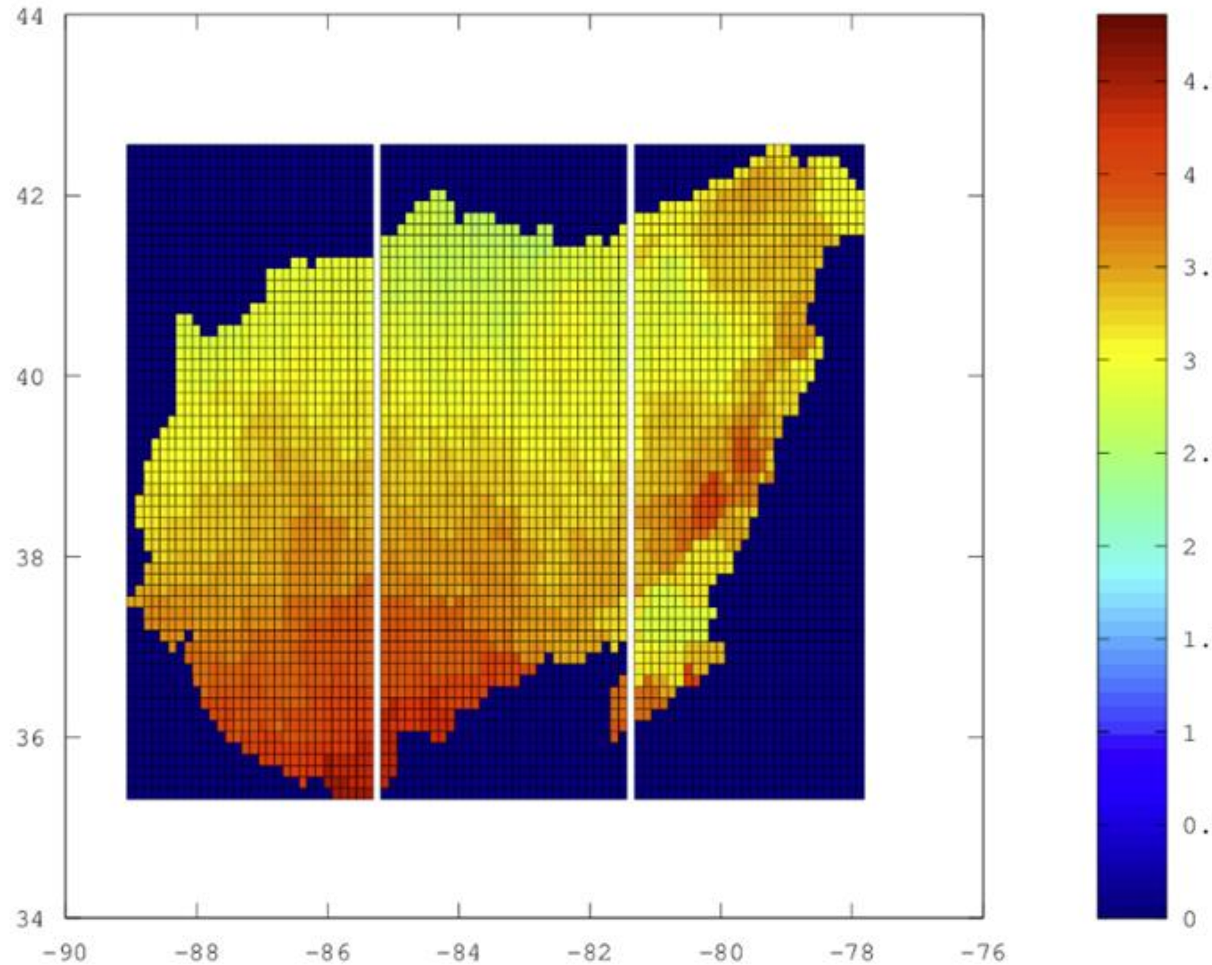


Figure A-9: Graphic Display of 2011–2040 Precipitation Model Results (IWR)

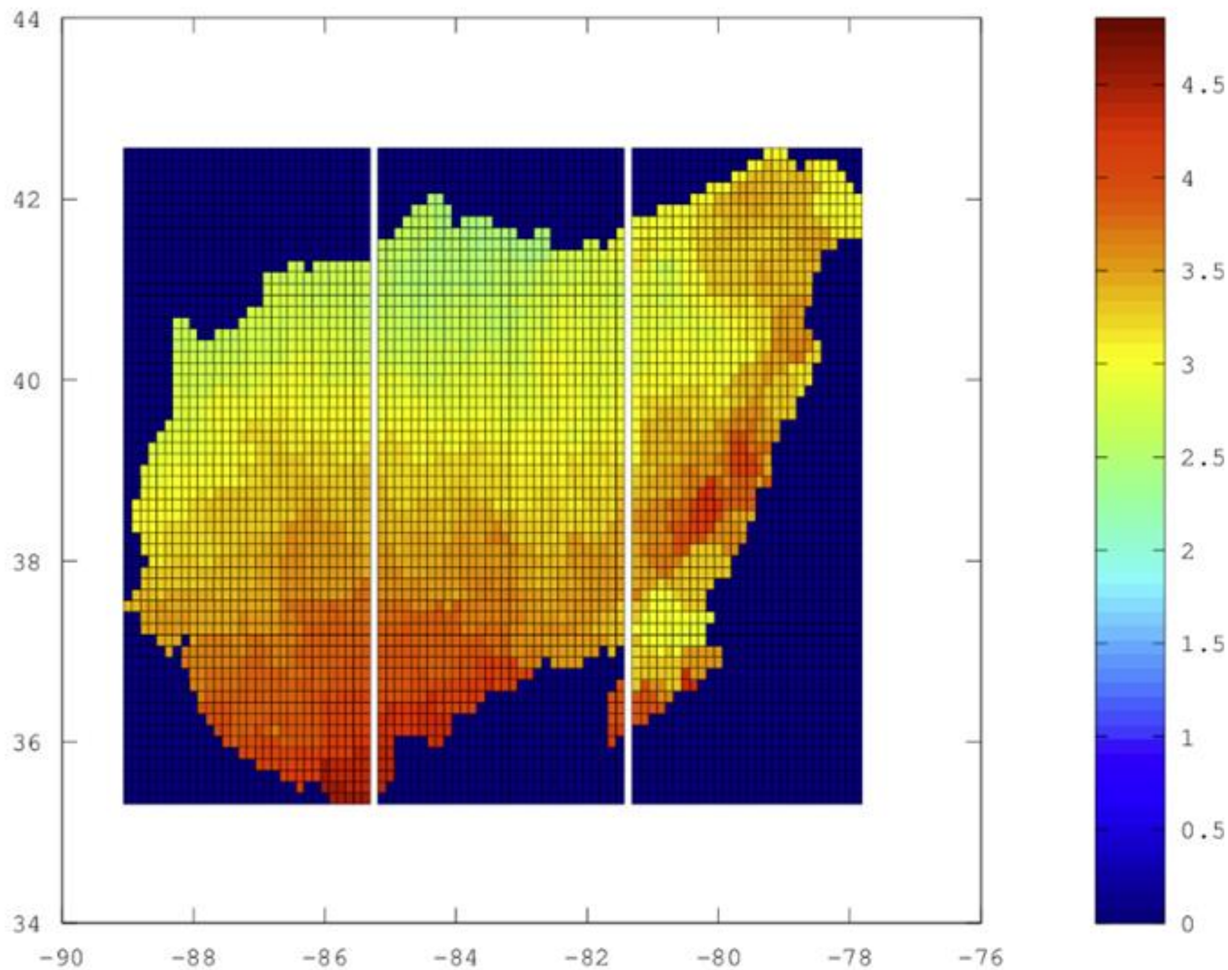


Figure A-10: Graphic Display of 2041–2070 Precipitation Model Results (IWR)

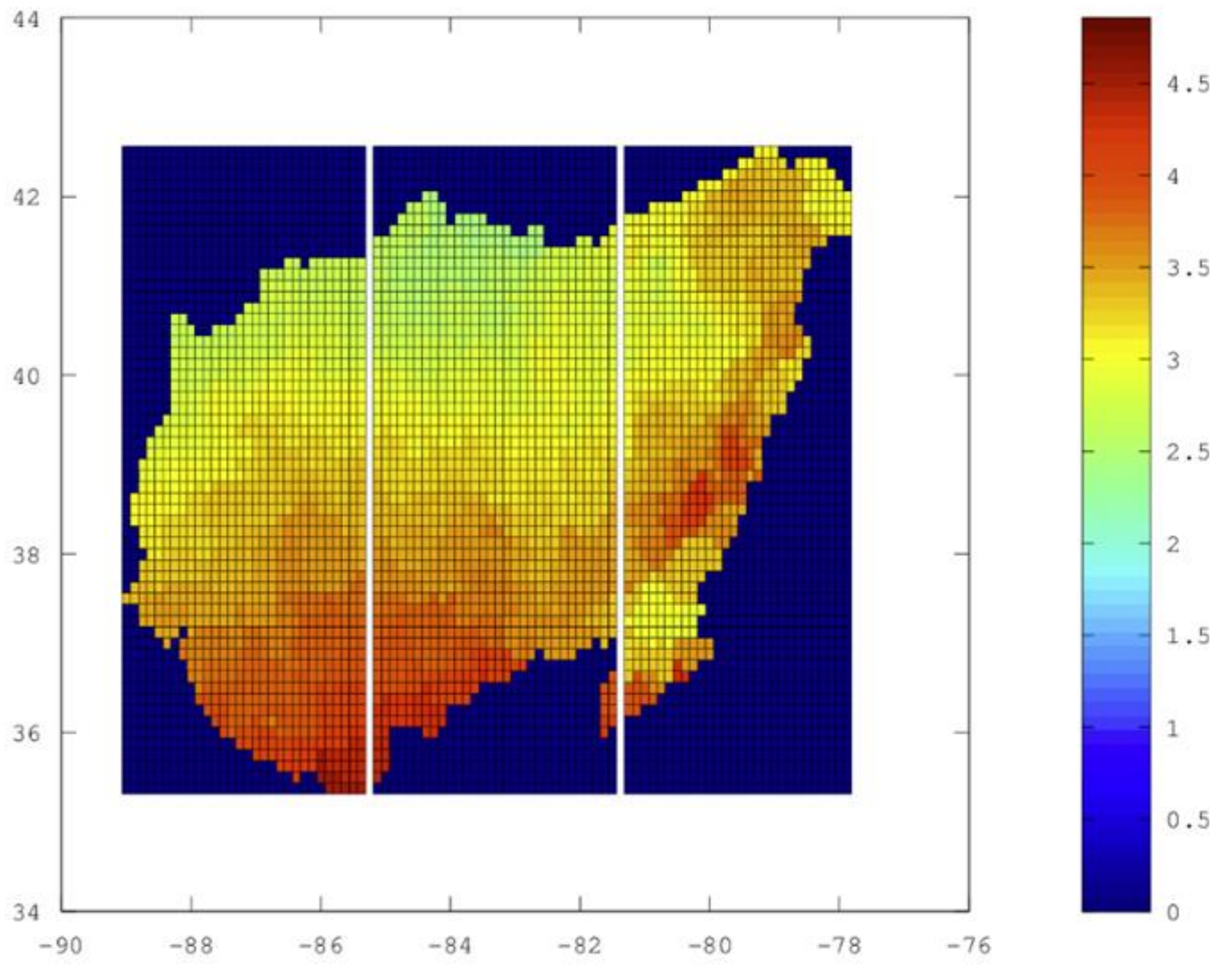


Figure A-11: Graphic Display of 2071–2099 Precipitation Model Results (IWR)

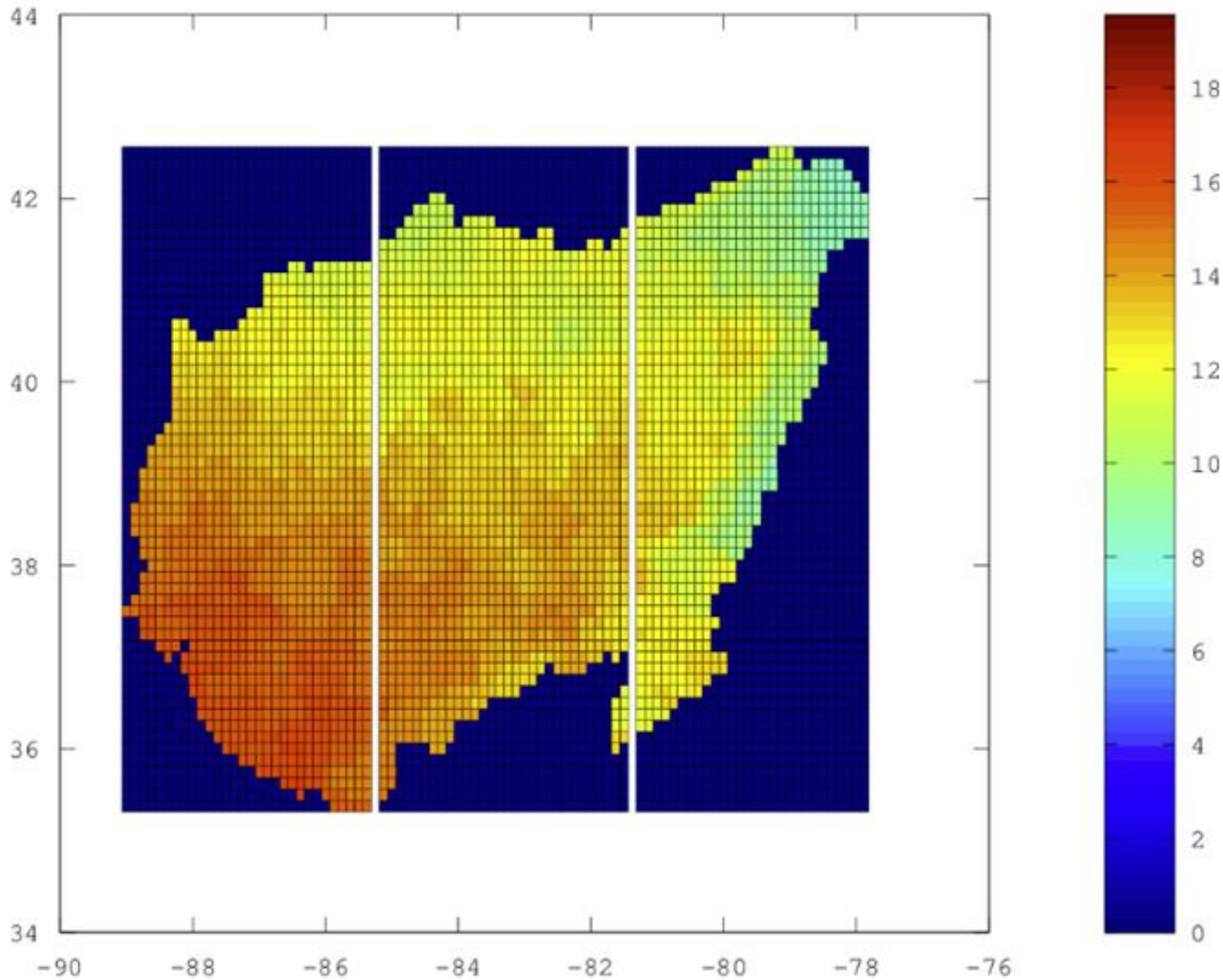


Figure A-12: Graphic Display of 2011–2040 Temperature Model Results (IWR)

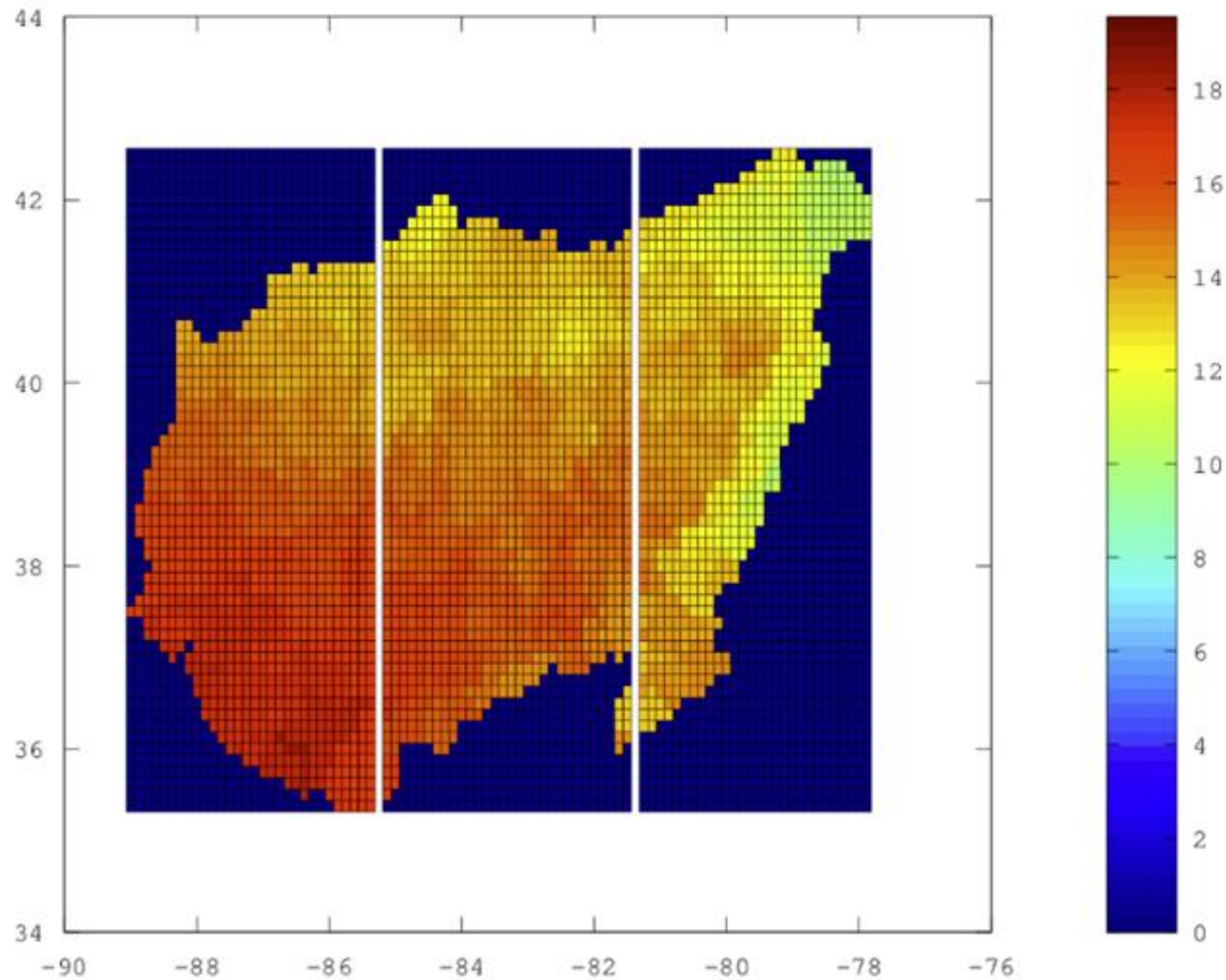


Figure A-13: Graphic Display of 2041–2070 Temperature Model Results (IWR)

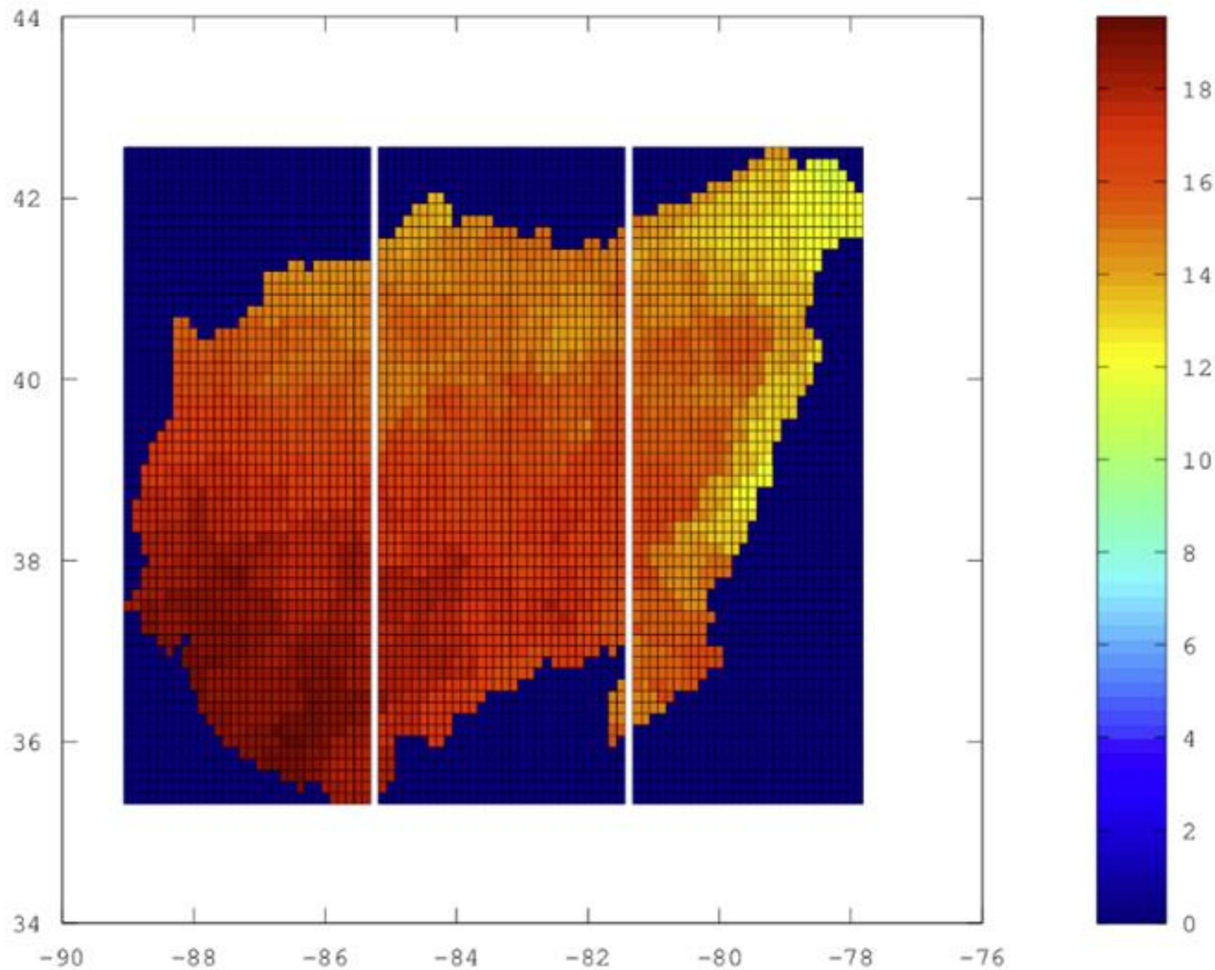


Figure A-14: Graphic Display of 2071–2099 Temperature Model Results (IWR)

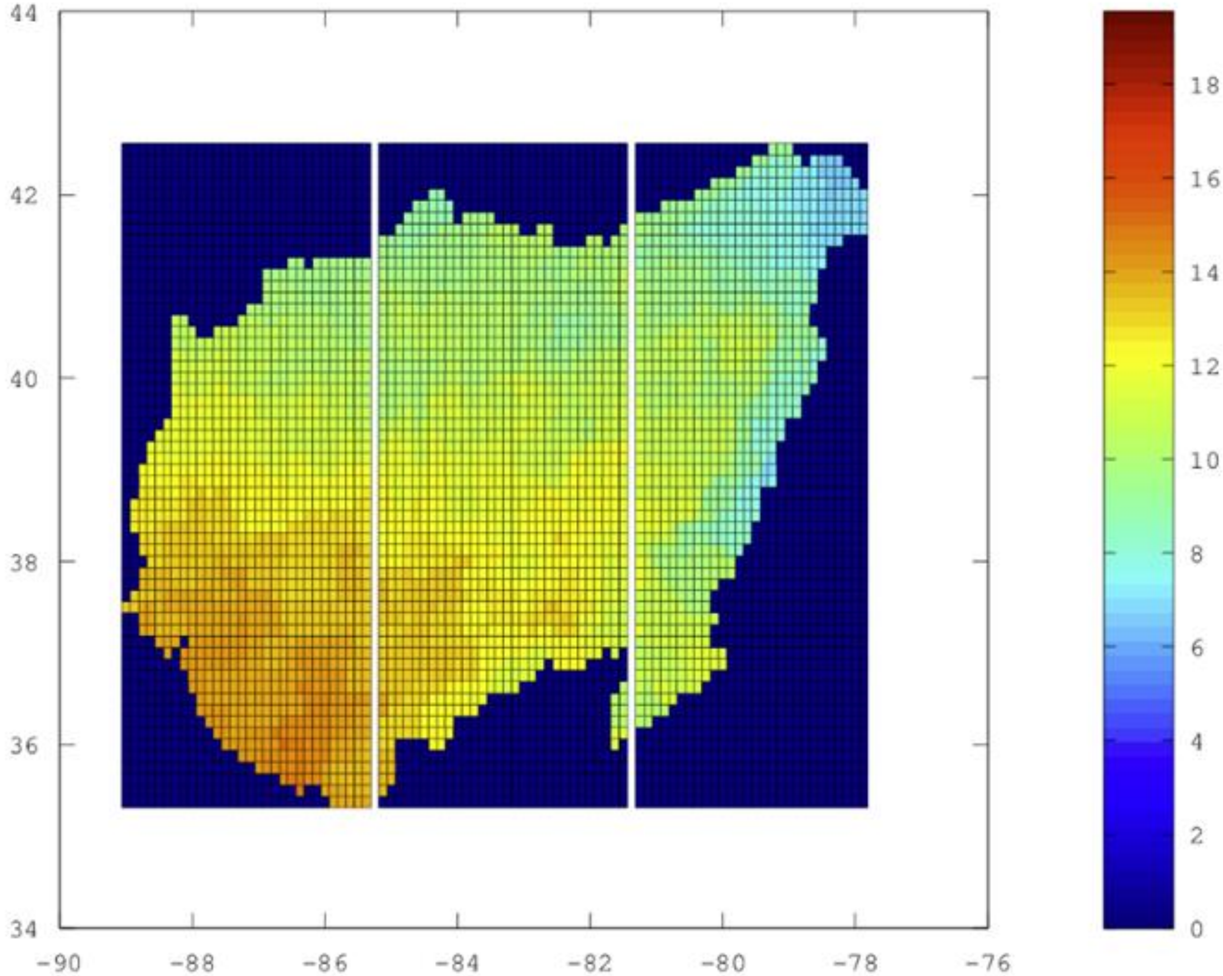


Figure A-15: Graphic Display of Temperature Base Model Results (1952–2000)–IWR

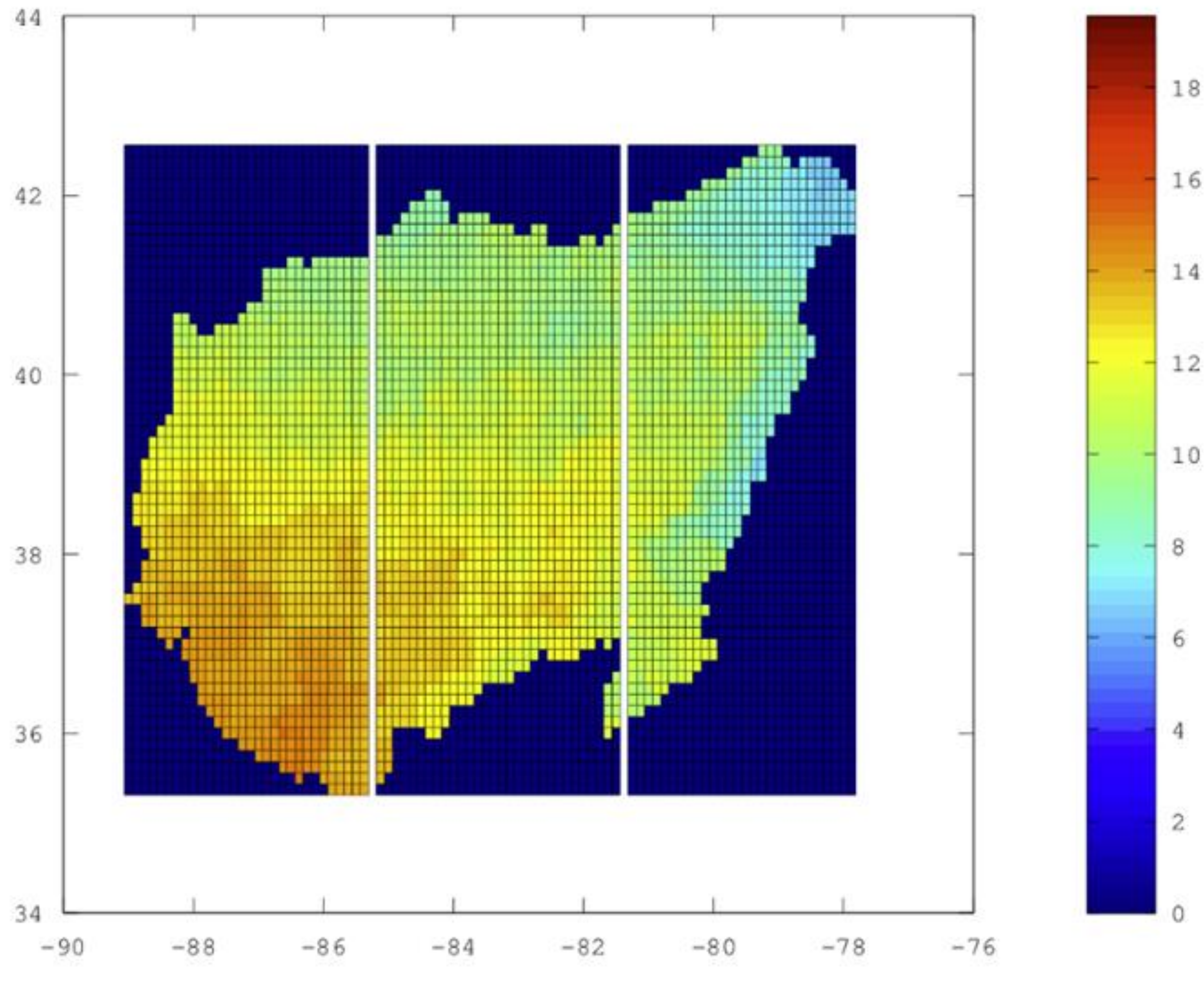


Figure A-16: Graphic Display of Precipitation Base Model Results (1950–2000)–IWR

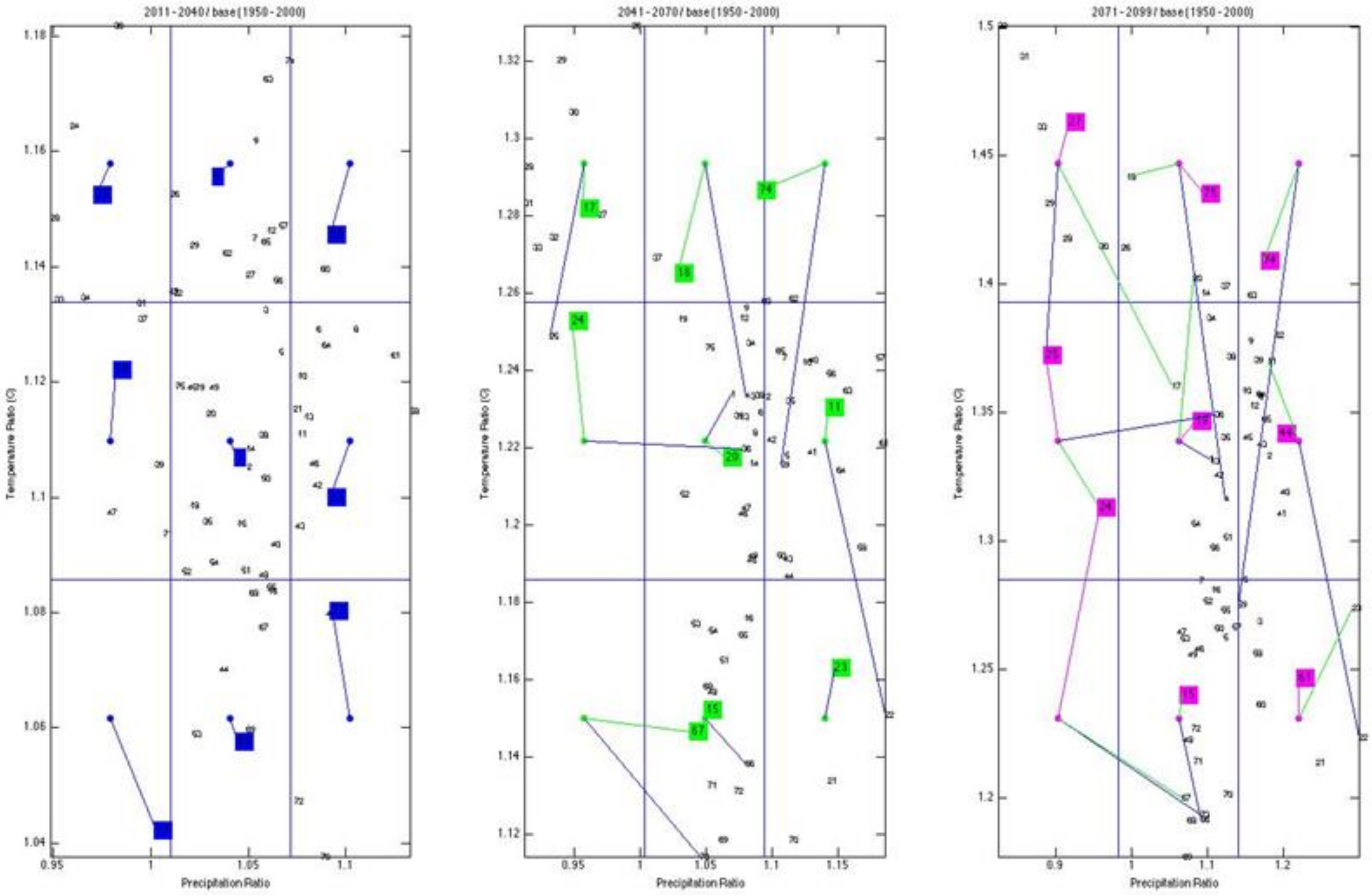


Figure A-16: Distribution of Selected Models over Three Analysis Periods (*F1*, *F2* and *F3*)

Table A-9: Selected Climate Change Model Ensembles for ORB Pilot Study

Time Periods	Period F1 (2011–2040)	Period F2 (2041–2070)	Period F3 (2071–2099)
Models	ncar_ccsm3_0.5.sres - a1b'	ukmo_hadcm3.1.sres - a1b'	ukmo_hadcm3.1.sres - a1b'
	giss_model_e_r.4.sres - a1b'	cccma_cgcm3_1.4.sres - a2'	mpi_echam5.2.sres - a2'
	giss_model_e_r.1.sres - a2'	giss_model_e_r.1.sres - a2'	ncar_ccsm3_0.7.sres - a1b'
	cccma_cgcm3_1.2.sres - a1b'	gfdl_cm2_0.1.sres - a2'	ukmo_hadcm3.1.sres - a2'
	bccr_bcm2_0.1.sres - a1b'	gfdl_cm2_1.1.sres - a2'	gfdl_cm2_1.1.sres - a1b'
	ncar_pcm1.1.sres - a1b'	csiro_mk3_0.1.sres - a1b'	csiro_mk3_0.1.sres - a1b'
	inmcm3_0.1.sres - a2'	gfdl_cm2_0.1.sres - a1b'	ipsl_cm4.1.sres - a2'
	miub_echo_g.3.sres - a1b'	inmcm3_0.1.sres - a1b'	inmcm3_0.1.sres - a2'
	ncar_pcm1.4.sres - a2'	ncar_pcm1.2.sres - a1b'	inmcm3_0.1.sres - a1b'

Model Origins

NCAR = National Center for Atmospheric Research (USA)

GISS = Goddard Institute for Space Studies (USA)

CCCMA = Canadian Center for Climate Modeling and Analysis (Canada)

BCCR = Bjerknes Center for Climate Research (Norway)

INMCM = Institute for Numerical Mathematics (Russia)

MIUB = Meteorological Institute of the University of Bonn (Germany)

UKMO = UK Meteorological Office (Britain)

GFDL = Geophysical Fluid Dynamics Laboratory (USA)

CSIRO = CSIRO Atmospheric Research (Australia)

IPSL = Institute Pierre Simon Laplace (France)

MPI = Max Planck Institute for Meteorology (Germany)

Note:

sres = Special Report on Emissions Scenarios

Emission Scenarios are A1B and A2

Historic time period climate base is 1950-2011

Table A-10: Forecast Points and Forecast Group Symbols

Forecast Point Symbol	Point Name and River	Forecast Group Symbol	Forecast Group Name
SHRP1	Sharpsburg, PA–Allegheny	SBCR	Beaver River
BDDP1	Braddock, PA–Monongahela	SMKU	Muskingum River Upper
BEAP1	Beaver Falls, PA–Beaver	SMKL	Muskingum River Lower
MCCO1	McConnellsville, OH–Muskingum	SMNL	Monongahela River Lower
ATHO1	Athens, OH–Muskingum	SMNU	Monongahela River Upper
ELZW2	Elizabeth, WV–Little Kanawha	SSCI	Scioto River
CRSW2	Charleston, WV–Kanawha	SLKH	Little Kanawha River
FLRK2	Fuller Station, KY–Big Sandy	SKAN	Kanawha River
PKTO1	Piketon, OH–Scioto	SHOC	Hocking River
HAMO1	Hamilton, OH–Great Miami	SSAY	Big Sandy River
FFTK2	Frankfort, KY–Kentucky	SMIM	Miami River
INDI3	Indianapolis, IN–White	SLIK	Licking River
PTRI3	Petersburg, IN–White/East Fork	SEFW	East Fork White River
NHRI3	New Harmony, IN–Wabash	SKTY	Kentucky River
CALK2	Calhoun, KY–Green	SWBU	Wabash River Upper
CARI2	Carmi, IL–Little Wabash	SWBL	Wabash River Lower
WTVO1	Waterville, OH–Maumee	SWHT	White River
NAST1	Nashville, TN–Cumberland	SGRN	Green River
PTTP1	Pittsburgh, PA–Upper Ohio	SCMU	Cumberland River Upper
HNTW2	Huntington, WV–Upper Ohio	SCML	Cumberland River Lower
CCNO1	Cincinnati, OH–Middle Ohio	SLWA	Little Wabash River
MLPK2	McAlpine, KY–Middle Ohio	SHOW	Ohio River
EVVI3	Evansville, IN–Lower Ohio	SOHP	Ohio River
GOLI2	Golconda, IL–Lower Ohio	SOHH	Ohio River
COLO1	Columbus, OH–Scioto	SOHC	Ohio River
SAGU	Allegheny River Upper	SOHL	Ohio River
SAGL	Allegheny River Lower	SOHS	Ohio River

16. Appendix B. Ecosystems/Ecosystem Services and Infrastructure Impacts Information

This backup data and additional information developed by the ecosystem team supports and enlarges the text and graphics in the main report.

16.1 B.1 Aquatic Biota Responses to CC Effects

16.1.1 B.1.1 Aquatic Biota Responses to Temperature

Although effects of climate change (CC) are complex across ecological levels of organization, three ecological principles of climate change have been identified (Daufresne et al. 2009):

6. An organismal range shift is expected with rising temperatures. Organisms that seek to optimize their physiologies (see the following) are expected to move with the CC gradient to either higher elevations or to higher latitudes.
7. A phenological shift is expected for many organisms. Warming temperatures are predicted to cause earlier annual onsets of lifecycle events. Because different organisms in any trophic cascade are likely to have slightly different temperature influences on phenologies, seasonal food web dynamics may become disconnected (Brose et al. 2012).
8. A reduced body size is predicted to occur with global warming (see the following). The effect of reduced body size is expected to occur at multiple levels (Daufresne et al. 2009; Lurgi et al. 2012). At the community level, a reduction in the proportion of larger bodied organisms is predicted. Size classes in a population should tend toward a smaller average size, and age structures will likewise tend toward a younger average. Related, size at age is expected to decrease.

The effects of changes in temperature on physiological aspects of animals including metabolic rates (Gillooly et al. 2001; Brown et al. 2004) and rates of growth and development (Gillooly et al. 2001) are generally well understood. Across many orders of magnitude of mass, metabolic rates of animals scaled to the ¾-power of organismal mass when normalized for temperature. Temperature influences on metabolic rates and growth can be approximated with either the temperature coefficient, Q_{10}, or using the Arrhenius equations (see Gillooly et al. 2001 for comparison). Briefly, metabolically dependent rates will increase with temperature up to some species-specific thermal maximum. The success of any organism at a higher temperature then depends on the availability of resources (e.g., O_2, CO_2, metabolizable energy) and the proportional allocation of those resources to mutually exclusive processes of tissue maintenance, growth, and reproduction (see West et al. 2001).

As metabolic rate increases, organismal maintenance costs increase and flux of resources, such as food and oxygen for a heterotroph, will be required at higher rates in order to maintain mass. If resources are limited, an inadequate amount of resources may be available for organismal growth and reproduction. Although the Metabolic Theory of Ecology (MTE) considers the influence of organismal size and temperature on energetic needs of organisms (Brown et al. 2004), it does not account for variation in different organisms' abilities to cope with the temperature changes that might accompany CC, but nevertheless can serve as a good basis for general models of organismal interaction with temperature change (see the following modeling section).

Knowing the species-specific thermal responses of organisms in an ecosystem might influence food web dynamics, but species-specific thermal response data are lacking for most freshwater taxa. A recent review by Hester and Doyle (2011) on the thermal performance of 48 river animals suggested that sensitivities to higher temperature are not equal among coexisting fauna. On average, fish are more sensitive than invertebrates to increased temperatures. The majority of studies on fishes have focused on economically important taxa, such as salmonids, which comprise 59% of the fish in Hester and Doyle's review. Studies of thermal response for macroinvertebrates were equally biased as all studies were comprised of only eight invertebrate orders, primarily insects and crustaceans (Hester and Doyle 2011). Many macroinvertebrate groups such as freshwater mussels (Unionidae), a highly diverse and sensitive family, comprise a dominant proportion of benthic biomass in many lotic systems (Strayer 2008). Despite patchy data, survival and growth of many fishes are expected to decline with increased water temperatures (Hester and Doyle 2011).

Because the concentration of dissolved oxygen in water changes inversely with water temperature, organisms in increasingly warmer water may experience a physiological oxygen bottleneck. As previously mentioned, metabolic rates will increase with water temperature for aquatic ectotherms. Increasing oxygen demand will accompany the increased metabolic demand for heterotrophs. The oxygen bottleneck will occur when metabolic oxygen demand is higher than concentrations of dissolved oxygen in the water, even if the water is saturated with oxygen. Suffocation or starvation can occur for organisms that cannot move to cooler water or water with higher O_2 concentrations. Starvation in heterotrophs comes in the form of using energy stores or tissue breakdown to fuel anaerobic metabolic pathways.

Starvation can occur, especially in larger-bodied consumers at higher trophic levels, when energetic efficiencies decrease (Binzer et al. 2012). Energetic efficiencies are the species-specific ratios of ingestion rate to metabolic rate. As temperature-induced increases in metabolic rate occur, an animal will require nutrient intake rates to increase concurrently. However, evidence for many species indicates that food handling time rates, including rates of digestion, do not increase at the same rate with temperature as metabolic needs. The result can be reduced predator biomass in a system, which can have top-down effects.

16.1.2 B.1.2 Aquatic Biotic Community Response to CC

The physiologies of aquatic animals have presumably evolved for specific hydrologic regimes that include temperature and oxygen specifics. CC studies are often species-focused rather than at high levels of organization such as ecosystems (Woodward et al. 2010). However, the collective responses and behaviors of individual organisms will drive changes in ecosystem dynamics.

As CC effects of altered hydrologies and temperatures take effect, mobile aquatic animals such as fishes may shift their ranges in an attempt to optimize their physiologies (Ficke and Myrick 2007). Such range shifts may result in altered community compositions because different fishes presumably have different tolerances to temperatures and thus different physiological optima. Organismal range shifts may not occur because a particular animal, for example, cannot handle the change in temperature, but the organisms it relies on may not be able to handle the shift. Thus, a food web approach does need to be considered when predicting organismal and community responses and changes.

The ability of a species to disperse may reduce its likelihood of extinction following extirpation from a locale (Eklöf et al. 2012). This may especially be the case for fishes in lotic systems in which populations may evolve on the leading edge of migration (Ficke and Myrick 2007). As dispersal rates for a population increase, mortality rates for that species will also increase, as a distance-dependent mortality effect (Eklöf et al. 2012). Counter to the idea that larger animals have the ability to move longer distances (Jetz et al. 2004), and should thus be able to disperse to preferable habitats more successfully, the greater proportion of time spent dispersing by larger animals is suggested to increase, rather than decrease, rates of dispersal-related mortality (Eklöf et al. 2012). Coupled with long generational times, large-bodied animals at high trophic levels may be at greater risk of extinction.

When thermal induced dispersal for a species is global, as might be the case for a latitudinal temperature shift causing northern dispersal of a fish, dispersal will likely be successful for populations in north-south oriented lotic systems (Ficke and Myrick 2007). Populations in isolated lentic system and east-west oriented lotic systems, however, will be thermally trapped. Any dispersal, whether altitudinal or latitudinal, will be possible only if suitable conduits for dispersal exist. Patchiness of suitable environments will influence the successfulness of climate-induced migrations. As patchiness increases or migration corridors decrease, dispersal-related mortality is expected to increase (Eklöf et al. 2012). For riverine species, migrations to cooler headwater streams may result in populations becoming divided and then isolated, which could increase the risk of both extirpation and extinction. In addition, species' dispersal patterns are related to body size (Jetz et al. 2004), and dispersal-related mortalities are likely higher for larger organisms (Eklöf et al. 2012). Preferential loss of organisms from upper trophic levels can affect top-down control and result in altered community structure.

Without dispersal, top-down effects on community structure may occur with warming. For example, thermal-induced reduction in foraging behavior by a herbivorous fish at higher temperatures may result in increased periphyton biomass (Kishi et al. 2005). Although metabolic rates for all organisms increase with temperature, limited oxygen availability for predators can influence their behavioral decisions, thereby reducing their consumption rates and altering the top-down control of community structure. Furthermore, with increasing temperature, metabolic inefficiencies of predators at higher trophic levels may lead to starvation of larger bodied species in the ecosystem (Binzer et al. 2012). Thus, relative relationships and magnitudes of interactions between organisms from a food web perspective may not change in a parallel manner, making general prediction from scaling theory (e.g., MTE) less reliable (Brose et al. 2012).

Effects on community structure can also be driven by bottom-up effects. Changes in lower trophic levels can negatively affect larger secondary consumers through bottom-up mechanisms (Eklöf et al. 2012). For example, with warming temperatures, competition among macrophytes and planktonic primary producers is likely to make nutrients limiting in lakes. Such scenarios may favor cyanobacteria that can fix nitrogen. In the absence of fertilization, this warming and nutrient limitation is expected to result in the loss of larger bodied top predators, followed by intermediate trophic-level consumers (Daufresne et al. 2009; Lurgi et al. 2012; Binzer et al. 2012).

16.1.3 B.1.3 Aquatic Biota Response to Hydrology

Water pulses into lotic systems are variable but follow seasonal pattern in the Ohio River Basin. Climate change, which is predicted to have less frequent but more concentrated precipitation events, may alter the seasonal influence of historic discharge events on aquatic biota. Large pulses can dislocate adult and juvenile animals resulting in an atypical change to community composition. Periods of low flow or reduced pulses can negatively affect fish community abundance and diversity (Ficke and Myrick 2007), and climate and human impacts tend to be highest in lower velocity and backwater areas (Hester and Doyle 2011).

16.2 B.2 CC Effects on Terrestrial Ecosystems in General

Many of the projected changes in aquatic ecosystems are caused by CC effects on the largely terrestrial landscapes of which they are a part, and terrestrial-aquatic system transition zones, where shifts in riparian vegetation and hydrology occur, are particularly critical. Shifts in riparian vegetation greatly affect bank stability, erosion, and water quality.

Global CC has the potential to both positively and negatively impact the location, timing, and productivity of crop, livestock, fishery, and forested systems at local, national, and global scales (Climate Change Science Program [CCSP] 2008b; Melillo et al. 2014).

16.2.1 B.2.1 Scaling from Higher Plant Physiology to Global Processes

Physiological differences among species have important predictable consequences for ecosystem and global processes (Lambers et al. 1998). Environments with favorable climate and high resource (e.g., light, water, nutrients) availability support growth forms that are highly productive due to either large size or high relative growth rate, depending on time since disturbance (“change”). In contrast, unfavorable environments support slowly growing plants, plants whose well-developed chemical defenses minimize rates of herbivory and decomposition. Rapidly growing plants have high rates of photosynthesis, transpiration (on a mass basis), tissue turnover, herbivory, and decomposition. Plant size is one of the major determinants of exchanges of carbon, nutrients, energy, and water. Vegetation differences in size and growth feedback to reinforce natural environmental differences, largely because large plants reduce soil moisture, and rapidly growing plants produce litter that enhances nutrient availability. At regional scales, large size and high stomatal conductance promote evapotranspiration, and therefore precipitation, whereas small size or sparse vegetative cover dissipates more energy as sensible heat, which leads to higher temperatures. There is an increasing recognition of the importance of plant traits in influencing ecosystem processes and climate (Chapin 1993).

B.2.2 Response of Higher Plants to Carbon Dioxide

Results of modeling studies conducted in the 1990s indicate that the yield enhancing effect of increased atmospheric CO_2 and associated products export would generally have a positive economic effect on U.S. agriculture; however, potentially associated effects (seasonal shortages) on water resources were not taken into account in this study (Adams et al. 1995). Water management would have to mitigate and adapt to the impacts of these changes on water resources, and would benefit from a continuation in the trend toward increased water use efficiency (CCSP 2008b).

B.2.3 Response of Higher Plants to Temperature

Temperature is a major environmental factor that determines plant distribution in terrestrial and aquatic systems (Lambers et al. 1998). Temperature affects virtually all higher plant processes, ranging from enzymatically catalyzed reactions and membrane transport to physical processes such as transpiration and the volatilization of specific compounds. Species differ in the activation energy of particular reactions, and consequently, in the temperature responses of most physiological processes, such as photosynthesis, respiration, and biosynthesis determining yield. Since plants respond to their habitat temperature, which may differ from "standard" air temperature, the physiological responses of plants to their thermal environment can only be understood through study of microclimate and plant energy budgets. Higher plants have a variety of mechanisms to deal with radiation and temperature that determine the plants' energy budget. Under hot and dry conditions most plants have small leaves because they cannot support high transpiration rates.

16.2.2 B.2.4 Ecosystem Energy Exchange and the Hydrologic Cycle

Vegetation effects on energy exchange. Energy exchange at the ecosystem level is influenced by the properties of individual aboveground plant parts (surface reflectance, i.e., albedo, and the partitioning of dissipated energy between sensible and latent heat), as well as by any contrasts between plant properties and the underlying surface.

9. Albedo. Air temperature at local to global scales is determined by the amount of energy absorbed and dissipated by the earth's surface. The influence of vegetation on albedo can have a substantial effect on climate. Snow and sand reflect more light than vegetation. In contrast, tall vegetation on a snow-covered landscape reduces albedo more than short vegetation. According to model simulations, conversion of boreal forest to snow-covered tundra would reduce annual average air temperature in the boreal zone by 6ºC, and this temperature effect would be large enough to extend into the tropics (Bonan et al. 1992, 1995). Vegetation effects on albedo may also influence regional climate in arid areas, as illustrated by an example from the Middle East, where overgrazing reduced plant density and ultimately led to a permanent drying of the regional climate (Charney et al. 1977).

10. Energy partitioning. Differences in energy partitioning between latent and sensible heat can have large-scale consequences. The leaf area index (LAI; m^2 leaf surface/m^2 soil surface) is the strongest determinant of evapotranspiration because it determines (1) the amount of precipitation that is intercepted by the plant canopy and rapidly evaporates after rain, and (2) the size of the transpiring surface. Plant biomass indirectly influences evapotranspiration because of its correlation with the quantity of litter on the soil surface, which strongly influences the partitioning of water between surface runoff and infiltration into the soil. In most ecosystems, there is a close correlation of evapotranspiration with gross photosynthesis because a large leaf area and high stomatal conductance promote both processes. In low-resource communities, however, canopies are sparse, and the soil surface contributes substantially to evapotranspiration (Chapin et al. 1997). Results of a model study on the relationship between LAI, evapotranspiration, transpiration, and runoff in a Florida forest indicated that over the LAI range of 3 to 9 tested, evaporation remained relatively constant at 120 mm water/y, transpiration increased linearly from 270 to 850 mm/y, and runoff decreased

from 600 to 200 mm/y, with transpiration exceeding runoff at an LAI≥5 (an LAI of 5 is a closed canopy; Chapin 1993).

11. Vegetation effects on the hydrologic cycle. If vegetation affects evapotranspiration, it also affects stream runoff, which is the difference between precipitation and evapotranspiration. Very dramatic vegetation effects are illustrated by the increased runoff observed following forest harvests (Bormann and Likens 1979). The same plant traits that influence evapotranspiration also influence soil moisture and runoff. Thus, high rates of evapotranspiration dry the soil and reduce the amount of water entering streams. Grasslands generally promote greater runoff than forest in the same climate zone.

16.3 B.3 Manifestation of CC Effects in Aquatic Ecosystems

16.3.1 B.3.1 Manifestation of CC Effects in Aquatic Ecosystems in North America

Information of CC on a national scale has been greatly expanded recently by the publication of the U.S. National Climate Assessment (Melillo et al. 2014) and information of these changes on a regional scale is growing (Meyer et al. 1999; Jones et al. 2013). A small part of this information is summarized here to form a basis for follow-up research. For effective contemporary and future water management recent, dependable regional information on CC is needed, as are assessments of expected effects of these changes. Part of these studies could be done using various modeling approaches (see Question 5).

The impacts of CC on North American water resources have been assessed at a regional level by the Intergovernmental Panel on Climate Change (IPCC; summarized by Mulholland and Sale 1998) and by a group of limnologists, hydrologists, and climatologists for the eight physiographic regions in North America based on an analysis of historical trends and CC predictions for each region (referenced in Meyer et al. 1999). In addition, a range in projected changes in temperature and precipitation caused by increased greenhouse gasses (GHG) was used as the basis to model suitable thermal habitat for fish guilds within the conterminous U.S. (Jones et al. 2013). Results of all these analyses generally indicate the following:

12. Climatic Warming. Climatic warming may produce a shift in biogeographic species distribution northward, with extinctions of cold-water species at lower latitudes and range expansion of warm-water and cool-water species into higher latitudes. The suitable habitat for cold-water fish species would be reduced by approximately 50% in streams and coldwater fisheries would be largely confined to mountainous areas in the western U.S. and to very limited areas of New England and the Appalachians (Eaton and Scheller 1996; Jones et al. 2013). In contrast, a 4^{o}C increase in mean air temperature is projected to push the ranges of smallmouth bass and yellow perch northward across Canada by about 500 km (Shuter and Post 1990). In addition, many aquatic nuisance species may benefit from warmer winter temperatures, e.g., hydrilla (an aquatic macrophyte) and zebra mussels.

13. Human Water Demands. Human water demands are expected to increase in a warmer climate, exacerbating current management problems. Increasing demands for irrigation and industrial cooling water would conflict with the increasing demands for municipal water supplies resulting from urban growth. Higher water temperatures would reduce the efficiency of cooling systems and make it increasingly difficult to meet regulatory requirements for downstream

water temperatures, particularly during summer heat waves (Miller et al. 1993). Improved management of water infrastructure, pricing policies, and demand-side management of supply have the potential to mitigate some of the impacts of increasing water demand (Frederick and Gleick 1989).

14. Precipitation and Streamflow. Precipitation and streamflow have increased over the past 50 years for the eastern part of the U.S., particularly in autumn and winter. Coupled with these climate-related changes, loss of wetlands from agriculture and urban expansion are producing changes in the characteristics in many drainage basins. These include increases in maximum river discharges resulting from reduced storage capacity for flood waters and reductions in groundwater recharge and minimum discharges.

15. Greater Hydrologic Variability. Greater hydrologic variability could pose large problems for the management of water resources in populated regions in terms of both quantity (e.g., flood control, water allocations during droughts) and quality (e.g., increases in sediment and contaminant loading during floods, reduction in assimilation, dilution, capacity of effluents during droughts).

16. Manifestation of Historic CC effects in Aquatic Ecosystems of the Ohio River Basin (ORB). The ORB is subject to two hydroclimatic regions out of the eight North American regions analyzed for historical trends and CC predictions by McKnight and Covich (1997) and Leavesley et al. 1997. The northern part of the ORB is part of the Great Plains region, and the Ohio River valley itself is part of the Lower Mississippi–Ohio River valley-New England region (Mid-Atlantic and New England) (Meyer et al. 1999).

    c. In the *Great Plains region* there is a strong east-west gradient in precipitation and temperatures, a historical record of major droughts, and considerable human alteration of aquatic ecosystems (dams, dikes, and channelization). The timing of winter/spring snowmelt is changing, and river and reservoir systems that rely on snowmelt during spring and summer periods of high agricultural and municipal demand and low precipitation may have critical supply-demand mismatches. Lake levels and wetlands are highly sensitive to changes in precipitation and evaporation. Lakes in dry evaporative drainage basins and semi-permanent prairie sloughs in the north-central U.S., fed primarily by groundwater, precipitation, and snowmelt, are among the most sensitive to changes in climate that produce drier conditions. This is expected to have substantial negative effects on the waterfowl since prairie wetlands produce 50–80% of the total North American duck population (Covich et al. 1997), and play an important role in bird migration along the Central Flyway (for priority bird species, such as Redhead, Ruddy Turnstone, Sanderling, Sandhill Crane, and others, www.conservation.audubon.org/priority-birds, accessed 28 July 2014; McIntyre et al. 2014; see also Q3 “Wetlands”). Warming of surface water may lead to loss of cold-water species (fish and invertebrates). Increased human demands and higher groundwater temperatures can alter the fauna of the springs and greatly reduce the area of wetted channel in ephemeral streams (Covich et al. 1997).

    d. In the *Mid-Atlantic region*, the climate is expected to become warmer and drier in a region characterized by dense human populations, extensive land use alterations, and abundant freshwater ecosystems. Thus, in this region the impacts of CC must be considered in the context of existing human stressors. Negative and positive CC impacts may occur in aquatic ecosystems, with bioaccumulation of contaminants increasing, but episodic acidification decreasing during snowmelt (Moore et al. 1997). Bog ecosystems that entirely depend on precipitation are most vulnerable; these systems are relatively rare, are found around Kettle Hole lakes that remain from the Wisconsin Glacier, and occur in Ohio and Indiana within the ORB.

16.3.2 B.3.2 Manifestation of CC Effects on Agricultural and Forested Lands Impacting Aquatic Ecosystems of the ORB

The ORB includes parts of several regions distinguished within the National Climate Assessment (Melillo et al. 2014); i.e., the southern part of the Midwest (Ohio, Indiana, and Illinois), the northern part of the Southeast (Kentucky, Tennessee), and the southern part of the Northeast (West Virginia, Pennsylvania), and extent of agricultural and forested land uses differ by region.

Changes in agriculture may greatly affect aquatic ecosystems in the ORB. Results may include altered hydrological regime (AHR), increased erosion (E), water pollution by sediments and nutrients (WP-SN), water pollution by herbicides (WP-H), and water pollution by algal blooms (AB) (CCSP 2008b).

17. Grain and oilseed crops may mature more rapidly, but increasing temperatures may increase the risk of crop failures, particularly if seasonal precipitation decreases or becomes more variable. Results: AHR, E, WP-SN, AB.
18. Weeds may grow more rapidly under elevated CO_2. Noxious weeds may migrate northward and are less sensitive to herbicide applications. This may result in more weeds, more herbicides, and negatively impacted crop yield. Result: WP-H.
19. Horticultural crops (tomato, onion, and fruit) are more sensitive to CC than grains and oilseed crops. Results: AHR, E, WP-SN, AB.
20. The growing season has increased by 10 to 14 days over the last 19 years across the temperate latitudes. Species distributions have also shifted. Results: AHR, E, WP-SN, AB.
21. Livestock may be negatively affected by higher temperatures. Mortality may be reduced by warmer winters, but this may be more than offset by greater mortality in hotter summers. Productivity of livestock and dairy animals may also be reduced by hotter temperatures. Results: AHR, WP-SN, AB.
22. A large part of the U.S. has experienced higher precipitation and streamflow, with decreased drought severity and duration over the 20th century. The West and Southwest, however, are notable exceptions, and increased drought conditions have occurred in these regions. Results: AHR, E, WP-SN, AB.
23. Invasion by exotic grass species into arid lands may result from CC, causing an increased fire frequency. Rivers and riparian systems may be negatively impacted directly by this phenomenon. Results: AHR, E, WP-SN, AB.

Changes in forested land use may also affect aquatic ecosystems, with impact depending on forest age. Young forests on fertile soils may achieve higher productivity from elevated CO_2 concentrations. Nitrogen deposition and warmer temperatures may increase productivity in other types of forests where water is available. Results: AHR, WP-SN. Forests could be affected by CC with increases in the size and frequency of forest fires, insect outbreak, and tree mortality, as already reported for the interior West, the Southwest, and Alaska (CCSP 2008b). Forests provide opportunities to reduce future CC by capturing and storing carbon, as well as providing resources for bioenergy production (biofuel). Management aimed at increasing forested land use would contribute to mitigating CC. Forested land use within the ORB is expected to increase between 2001 and 2050, particularly in the south-eastern part (Pijanowski and Doucette 2014).

In the Northeast, heat waves, coastal flooding, and river flooding are expected to greatly increase. Agriculture and other ecosystems are projected to be increasingly negatively affected by intense precipitation events (Melillo et al. 2014).

In the Midwest, increased heat wave intensity and frequency, increased humidity, degraded air quality, and reduced water quality are projected to occur and increase public health risks. This region has a highly energy-intensive economy with per capita emissions of GHG >20% higher than the national average. The region also has a large and increasingly utilized potential for mitigation by reducing GHG emissions that cause CC. The Midwest forests are projected to change in composition with rising temperatures. The role of these forests as carbon absorber, mitigating CC, is at risk from disruptions in forest ecosystem functioning, partly due to CC (Melillo et al. 2014).

In the Southeast, sea level rise, increasing temperatures, and the associated increase in the frequency, intensity, and duration of heat waves, as well as decreased water availability are projected to increasingly affect public health and ecosystems. This region is a major energy producer from fossil fuels and is the highest energy user of all NCA regions (Melillo et al. 2014).

16.3.3 B.3.3 Projected Basin Land Use Changes Until 2050–Potential Impacts on Water Quality and Riparian Areas

A study was conducted to develop a set of backcast and forecast land use maps for the ORB that could be used to assess spatial-temporal patterns of land use change within this basin (Pijanowski and Doucette 2014). The Land Transformation Model, an artificial neural network and GIS-based tool, was used to simulate land use patterns historically and in the future. In this study, the year 2001 (NLCD) was used as the base year for which the model was calibrated, and backcast and forecast simulations were conducted relative to this base year. Land uses were determined using county-based historical data on (1) agriculture from the National Agriculture Statistics Service–Land-in-Farms database and data from the U.S. Census Bureau Housing Data–Year Built statistic; Census 2000; http://dataferrett.census.gov/), following procedures described by Ray and Pijanowski (2010) and Tayyebi et al. (2012). According to the forecasts, in general, agricultural land use is expected to decrease between 2001 and 2050, transitioning into urban and forest land uses—even without taking CC into account:

24. More specifically, an analysis of all 152 eight-digit hydrological unit codes (HUC-8) in the ORB showed that many of these watersheds currently (2010) have surpassed thresholds for stream water quality health. These thresholds are >10% urban or >38% agricultural use, indicating that urban land use has a greater impact on stream water quality health than agricultural land use. The distribution of HUC-8s that exceeds either threshold is similar.
25. Large parts of the northern areas of the ORB exceed urban or agriculture intensity use that might lead to decreased stream health. Currently, 32% of the HUC-8s exceed 10% urban use, and by 2050 more than half may surpass this threshold. It is expected that by 2050, 11.38% of the ORB land area may be in urban use, a 32% increase from 8.98% in 2001.

26. A more detailed analysis was done in selected watersheds in Indiana to examine the potential impact of historical land use change on sensitive areas of these watersheds—in particular, areas that potentially recharge streams; i.e., riparian zones of permanent streams and rivers. Results indicated that land use persistence, i.e., no change in land use, was high (between 83 and 93%) within the entirety of these watersheds but slightly less within riparian zones (74 to 88%), suggesting that riparian zones have a greater potential for land use legacies than the upland areas of watersheds.

16.3.4 B.3.4 Aquatic Ecosystem Categories Identified in the Orb That Are At Risk

Water resources encompass water bodies (e.g., rivers and streams, lakes, wetlands, coastal waters, groundwater) and their associated ecosystems. They sustain many plants and animals and provide for drinking water, irrigation, fishing, recreation, and other human needs. The ability of water resources to support these functions depends on their extent and condition. The extent of a water resource refers to its depth, flow, volume, and area. Condition reflects the ability of the water resource to sustain ecological needs and human uses. The extent and condition of water resources may affect the health and well-being of people, ecosystems, and critical environmental processes (USEPA 2008b), and CC may pose a significant risk to these water resources. Information on condition and threats of aquatic ecosystems can form the basis for evaluating the potential risks posed by CC. The contents of this section will be limited to the surface water resources that frequently occur in the ORB. Information on groundwater resources is provided in the Introduction under "Water use and availability."

Data on the extent of surface water resources are contained in the National Hydrography Dataset (NHD) (Dewald 2006), which represents the best electronic database available. The NHD is widely used as the basis for estimating stream length (Olsen and Peck 2008) and has been used to estimate the number and surface area of lakes and reservoirs (Olsen et al. 2009). The NHD can be used as the sample frame for large-scale aquatic resources assessments, and within the U.S. the NHD is being used as such from 2006 onwards for the National Aquatic Resources Surveys (http://water.epa.gov/type/watersheds/monitoring/aquaticsurvey_index.cfm).

16.3.4.1 B.3.4.1 Aquatic Ecosystem Categories

The National Aquatic Resources Surveys (NARS), conducted by United States Environmental Protection Agency (USEPA) and its partners, are conducted to provide an overview of the presence and recent condition of the major aquatic ecosystem categories in the predominant ecoregions within the continental U.S. In this paper, we will use information generated by the NARS for the predominant ecoregions within the ORB. Ecoregions are areas that contain similar environmental characteristics and are defined by common natural characteristics such as climate, vegetation, soil type, and geology. By looking at aquatic resource conditions in these smaller ecoregions, managers and decision makers can gain an understanding of patterns based on morphology and geography, and whether problems are isolated in one or two adjacent regions, or are widespread. The nine ecoregions distinguished in the NARS are aggregations of the Level III ecoregions delineated by USEPA for the continental U.S. These nine ecoregions are: Northern Appalachians, Southern Appalachians, Coastal Plains, Upper Midwest, Temperate Plains, Southern Plains, Northern Plains, Western Mountains, and Xeric. The ORB is situated largely into the Temperate Plains and Southern Appalachians (USEPA 2006, Figure B.1).

The NARS include assessments of four aquatic ecosystem categories: (1) streams and rivers, (2) lakes, ponds and reservoirs, (3) coastal waters, and (4) wetlands, among which the categories 1, 2, and 4 frequently occur in the ORB. The NARS use randomized sampling designs, core indicators, and consistent monitoring methods and laboratory protocols to provide statistically defensible assessments of water quality at the national scale. The NARS results assess the ecological (biological, chemical, and physical) condition of the system by comparison of biological, chemical, and physical characteristics of sampled sites to a benchmark or estimate of what would be expected to find in a least disturbed (reference) condition. Condition was evaluated as: *Poor*, if up to a 5th percentile of the reference distribution of that indicator was identified in the site sample; *Fair*, if between 5th and 25th percentile of the reference distribution of that indicator was identified in the site sample; *Good*, if between 25th and 75th percentile of the reference distribution of that indicator, or better, was identified in the site sample. The results of the NARS are reported on national and ecoregional spatial scales (Figure B-1).

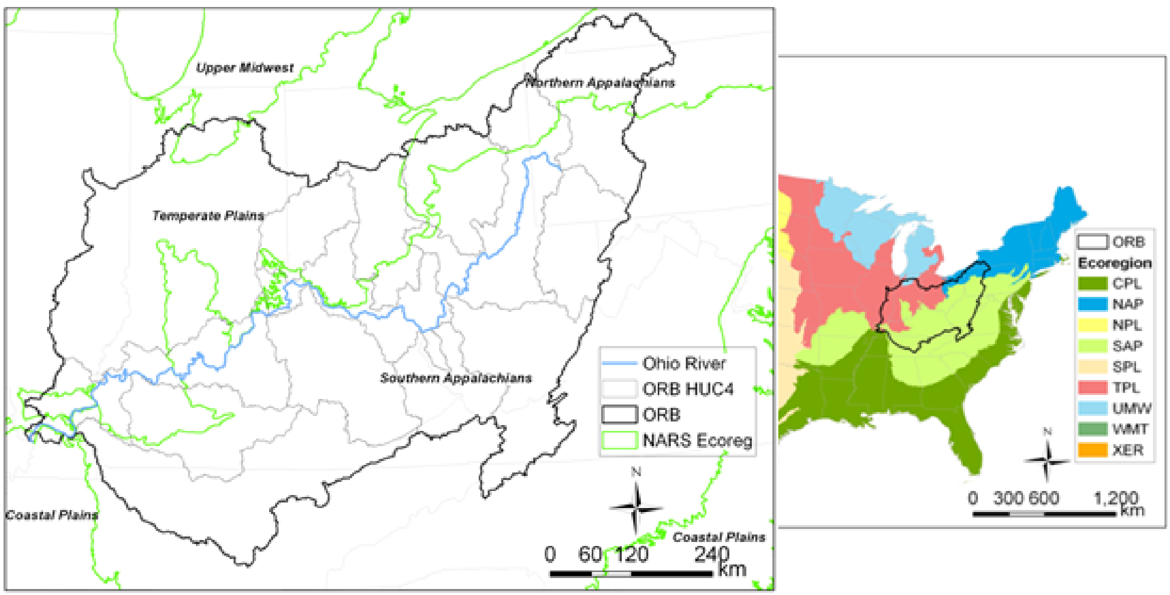


Figure B-1: ORB Location in Ecoregions Used as Part of the National Aquatic Resources Surveys Conducted by the USEPA Within the Conterminous United States[23] (USEPA 2014)

The NARS were initiated in 2006, and each survey is planned to be implemented on a 5-year rotation basis. Streams and rivers were assessed from 2006–2012 (sampled in 2008–2009), with a draft report available in 2013 (USEPA 2013a); lakes from 2006–2014 (sampled in 2007 and 2012), with a report available in 2007 (USEPA 2009); coastal waters from 2006–2012 (sampled in 2010), with reporting planned in 2014; and wetlands from 2006–2013 (sampled in 2011), with reporting planned at the end of 2014. A National Wadeable Streams Assessment (WSA) was completed in 2004 prior to the initiation of the NARS, with results reported on a coarser spatial scale than the results of the NARS assessment; i.e., for three major regions corresponding to major climate and

[23] Abbreviations: CPL-Coastal Plains; NAP-Northern Appalachians; NPL-Northern Plains; SAP-Southern Appalachians; SPL-Southern Plains; TPL-Temperate Plains; UMW-Upper Midwest; WMT-Western Mountains; XER-Xeric. Lower: Ecoregions within the Ohio River Basin boundary. NARS: National Aquatic Resources Surveys

landform patterns across the U.S., being (1) the Eastern Highlands, (2) the Plains and lowlands region, and (3) the West region (USEPA 2006). Since the latter survey is the first statistically defensible national assessment of stream condition, its results provide valuable information for comparing trends in condition over time with later assessments.

Currently available information from the NARS pertains to (1) streams and rivers, and (2) lakes. Reports and data of the NARS as well as the preceding WSA are available and accessible via the web after the specific NARS Report has been presented to Congress. Subsets of the national data can be selected and used to further explore them for any aquatic ecosystem characteristics and geographical area of interest. The availability of these data and further exploration of them for the ORB are expected to provide more detailed information than provided in this report (http://water.epa.gov/type/watersheds/monitoring/aquaticsurvey_index.cfm).

Raw data and information on the sampled sites is uploaded to USEPA's STOrage and RETrieval (STORET) warehouse at http://www.epa.gov/STORET. The National Wetlands Condition Assessment (NWCA) is ongoing and because assessment data are not available yet, information on wetlands has been derived largely from the National Wetlands Inventory of the U.S. Fish and Wildlife Service, which documents geographical distribution but does not assess condition (www.fws.gov/wetlands/Status-And-Trends-2009/index.html).

27. Rivers and Streams. The National Rivers and Streams Assessment (NRSA) provides information on the ecological condition of the Nation's rivers and streams and the key stressors that affect them, both on a national and ecoregional scale. It also discusses change in water quality conditions in streams sampled for the earlier WSA of 2004.

    During the summers of 2008 and 2009, a total of 1,924 river and stream sites were sampled across the country, representative of flowing waters included in NHDPlus, following a random probabilistic design. The sampled sites included 359 sites also included in the WSA. The following indicators were included: (1) Biological: fish, benthic invertebrates, and algae; (2) Chemical: phosphorus, nitrogen, salinity, acidity; (3) Physical: streambed sediment, in-stream fish habitat, riparian vegetative cover, riparian disturbance; (4) Human health: enterococci, mercury in fish tissue. A map of the rivers and stream sites sampled during the 2008–2009 NRSA, located within the ORB, is provided in Figure B-2. A subset of the NRSA results is provided in Table B-1.

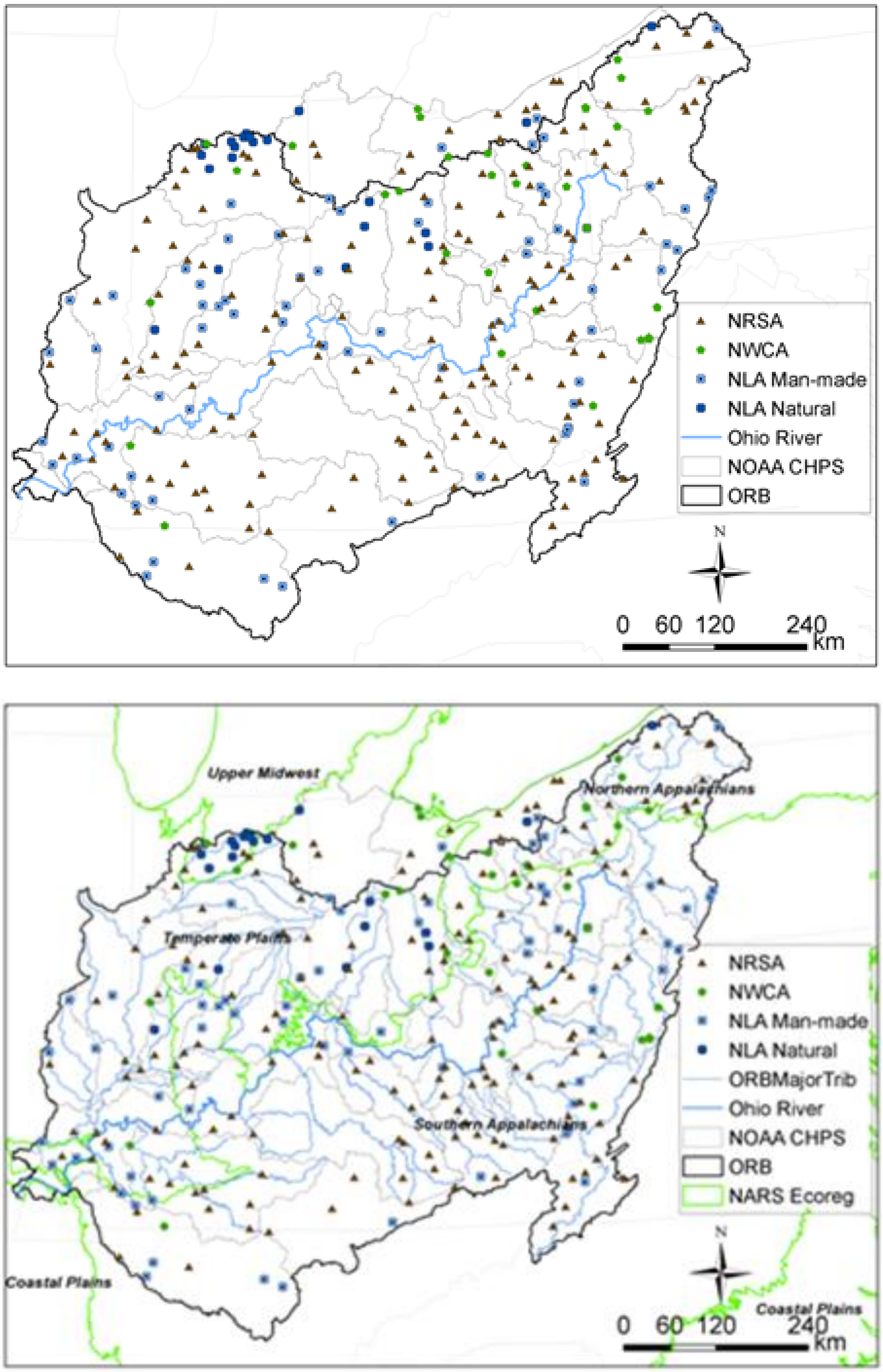


Figure B-2: Sites Sampled as Part of the NARS Conducted by the USEPA Within the Conterminous United States Within the ORB[24] (USEPA 2014). Upper: Sites within the ORB and NOAA CHPS boundaries with Ohio River. Lower: Sites within the OR, ecoregions and NOAA CHPS boundaries with Ohio River and tributaries.

e. Temperate Plains Ecoregion. This ecoregion extends across several plains states. The far eastern section of the ecoregion includes portions of the ORB in Ohio, Indiana, Kentucky, and Illinois. The streams and rivers in this area are inhabited with a broad array of fish species including minnows, darters, catfishes, black bass, and sunfishes. Cultivation dominates the land cover type in this portion of the ORB. These intensive land disturbances have resulted in loss of riparian habitat and increased streambed sediment in this ecoregion. These physical stressors were combined with high levels of chemical stressors (nitrogen, phosphorus, pesticides, and herbicides). Other land uses such as forest (10%), developed land (9%), and other uses (12%)[25] cover this region, which features a temperate climate of cold winters and hot summers with moderate rainfall and mean annual temperatures ranging from 36 to 55^{o}F.[26]

Table B-1 shows the biological conditions of the streams in the Temperate Plains and Southern Appalachians ecoregions. Most notable are the statistics for benthic invertebrates in which 55% of the stream reaches surveyed were listed as *Poor* and 30% *Fair*, and stream reaches where the complex food association of algae, cyanobacteria, heterotrophic microbes, and detritus found in streams (periphyton) were identified as 29% *Poor* and 51% *Good*. Perhaps related to the abundance of periphyton in the stream, the biological conditions of fish were found to be *Good* in 52% of the steam reaches and *Poor* in only 35% of the reaches surveyed.

Table B-1: Biological, Chemical, and Physical Habitat Conditions

Indicator	Conditions	Temperate Plains			Southern Appalachians		
		Poor	Fair	Good	Poor	Fair	Good
Biological							
	Benthic Invertebrates	55	30	15	65	18	17
	Periphyton	29	18	51	68	10	21
	Fish	35	8	52	37	16	36
Chemical							
	Total–P	31	24	46	40	30	30
	Total–N	58	13	29	17	12	71
	Salinity	1	7	92	2	13	85
	Acidification	0	0	100	1	0	99
Physical Habitat							
	Streambed Sediment	14	36	50	13	28	58
	In-Stream Fish Habitat	8	27	65	9	18	73
	Riparian Vegetative Cover	24	26	50	26	25	49
	Riparian Disturbance	16	56	29	26	43	31

f. Southern Appalachian Ecoregion. This region covers a considerable portion of the ORB including parts of West Virginia, Virginia, Kentucky, North Carolina, Pennsylvania,

[24] NRSA–rivers and streams; NWCA–wetlands; NLA–lakes; NOAA CHPS–NOAA Climate and Hydrology Projection Scenario
[25] USGS 2006. National Land Cover Data
[26] Ibid. P. 71

Alabama, Georgia, and Tennessee. The ecoregion is also the headwaters of most of the tributaries of the Ohio River. Total stream/river lengths in this region exceed 315,000 miles and are generally highly sinuous in steep channels.[27] Climatic characteristics of this region feature precipitation between 49 and 80 inches with annual mean temperatures that vary between 55 and 65°F, which suggests a temperate wet climate type.[28] This topography and climate type provides support for a nationally significant diversity of aquatic-related species including amphibians, fishes, mussels, insects, and crustaceans.

The ecoregion is overlaid predominantly by forest cover (60%) with segments of agricultural uses (23%), developed uses (9%), and other uses (8%).[29] Development, cultivation, streamflow modifications, and pollution are broadly observed stressors for streams in the ecoregion. As a result of these stressors, biological conditions found within surveyed reaches indicate that 52% of the reaches were *Poor* for macroinvertebrates and only 23% were given a *Fair* rating. Condition of fish species within these reaches was similarly meager (59% either in *Poor* or *Fair* condition). [30]

Based on a comparison of the NRSA (2008–2009) and WSA (2004) data, there have been significant changes in stream quality and aquatic species health in the Eastern Highlands climatic region that includes the ORB. There have been significant increases in lengths of stream where riparian vegetation cover rated as *Good* rose from 35.0% to 49.2% and where riparian disturbances rated as *Good* rose from (21.5% to 33.4%). On the negative side, the percentage of lengths of stream rated *Good* for total phosphorus loadings have significantly decreased (41.8% to 26.7%).[31]

28. *Lakes, Ponds, and Reservoir*. The National Lakes Assessment (NLA) is the first statistical survey of the condition of the Nation's lakes, ponds, and reservoirs (USEPA 2009). The survey results represent the state of almost 50,000 natural and manmade lakes >10 acres (4 hectares [ha]) in area and >1 meter depth. More than 1,000 lakes across the country were sampled for their water quality, biological condition, habitat conditions, and recreational suitability in the summer of 2007. A map of the lakes sampled during the 2007 NLA, located within the ORB, is provided in Figure B-5. A subset of the NLA results is provided in Table B-2. A map of the ORB and its ecoregions is provided in Figure B-4.

   g. Temperate Plains Ecoregion. A total of 6,327 lakes of this region are represented in the NLA, of which 75% are of natural origin. Lakes are generally small, with >60% of lakes being smaller than 100 ha in size. A total of 137 of the selected NLA sites was sampled for stress indicators per stress category and in the order of *Poor*, *Fair*, and *Good*.

   h. Biological condition (base-unit is natural or manmade lake>10 acres in area and >1 m depth). Planktonic observed/expected (O/E) taxa: *Poor* 35%, *Good* 24%; diatoms: *Poor* 52%, *Good* 17%; chlorophyll-a: 45% hypertrophic, 32% mesotrophic, 2% oligotrophic.

[27] Ibid. P. 70-71
[28] Ibid. P. 71
[29] USGS 2006. National Land Cover Data
[30] U.S. Environmental Protection Agency. Office of Water and Office of Research and Development. National Rivers and Streams Assessment 2008-2009: A Collaborative Survey (EPA/841/R-16/007). Washington, DC. March 2016. P 71
[31] U.S. Environmental Protection Agency. Office of Water and Office of Research and Development. National Rivers and Streams Assessment 2008-2009: A Collaborative Survey (EPA/841/R-16/007). Washington, DC. pp.69-70 and pp.55-57

Recreational suitability: moderate risk of exposure to cyanobacteria and associated cyanotoxins; cyanobacterial counts: 48% of lakes with low exposure risk; microcystin presence: 67% of lakes (Table B-2).

i. Chemical. Total phosphorus: *Poor* in 30%, *Good* in 38% of lakes; total nitrogen: *Poor* in 40%, *Good* in 27% of lakes; chlorophyll-a: *Good* in 56%, turbidity level *Good* in 84% of lakes; acid neutralizing capacity (CAN) and surface dissolved oxygen (DO) generally *Good*.

j. Physical. Lakeshore habitat *Good* in 8.9% of lakes. High levels of lakeshore disturbance.

29. Southern Appalachian ecoregion. Natural lakes are almost nonexistent in this region, and the 4,690 lakes in the NLA are all manmade. The configuration of the Southern Appalachian valleys has proven ideal for the construction of manmade lakes, and some of the largest hydropower developments reside in the Tennessee River Valley. A total of 116 of the selected NLA sites were sampled in 2007.

Table B-2: National Lakes Assessment Results for Two Ecoregions in which the ORB Is Largely Situated. Percentage of lakes within a condition class for a given indicator (USEPA 2013a)

Indicator	Condition [b]	Temperate Plains			Southern Appalachians		
		Poor	Fair	Good	Poor	Fair	Good
Biological							
	Planktonic O/E	34.7	39.5	24.2	31.0	27.4	41.7
	Diatom IBI	51.5	27.6	16.6	13.3	22.4	63.0
	Trophic-state-chlorophyll-a	44.8	21.1	32.4	25.5	16.6	45.8
Recreational Suitability							
	Chlorophyll-risk	31.8	28.0	40.1	17.2	24.5	55.4
	Cyanobacteria risk	20.7	21.1	48.1	1.7	25.2	73.1
	Microcystin risk	0.2	5.5	94.3	0	0	100
	Microcystin presence	66.7	0	33.3	24.7	0	75.3
Chemical							
	Total-P	30.1	31.8	38.0	12.9	20.7	66.4
	Total-N	39.7	33.6	26.7	12.1	20.1	67.8
	Chlorophyll	29.3	14.2	56.4	21.8	6.5	71.7
	Turbidity	5.5	10.2	84.2	16.7	1.1	80.2
	Acid Neutralizing Capacity	0	0	100	0	0	100
	Dissolved oxygen	0.8	12.2	89.1	9.2a	1.4	72.4
Physical habitat							
	18.2	41.8	38.7	24.3	66.2	7.7	18.2
	40.0	2.7	56.1	28.8	27.5	41.8	40.0
	20.8	18.0	61.9	16.0	20.2	62.0	20.8
	30.5	7.4	80.7	48.2	6.2	43.8	30.5

[a] 17% NA; [b] percents may not add up to 100% due to rounding.

k. Stress indicators. Biological condition. Planktonic (O/E): *Good* 42%; diatoms: *Poor* 13.3%, *Fair* 22.4%, *Good* 63%; chlorophyll-a: 26% hypertrophic, 46% eutrophic, 12% oligotrophic. Recreational suitability: low risk of exposure to cyanobacteria and associated cyanotoxins, a moderate 25% risk based on chlorophyll-a and cyanobacteria counts; mycrocystin presence: in 25% of lakes (Table B-2).

l. Chemical. Total phosphorus: *Good* in 66% of lakes; total nitrogen: *Good* in 68%; chlorophyll-a and turbidity level: *Good* in 72% of lakes; CAN and surface DO generally *Good*.

m. Physical. Lakeshore habitat: *Good* in 42%. Considerable levels of lakeshore development pressure.

30. Wetlands. The NWCA is a statistical survey that will provide information on the ecological integrity of wetlands, and include an integrated evaluation of the cumulative effects of actions that either degrade wetlands or protect and restore their ecological condition. Key questions for which the NWCA will provide information include the following: (1) What is the extent of wetland acreage that supports healthy ecosystems (2) How widespread are the most significant problems affecting wetland quality; (3) What is the nature of gains and losses in wetlands acreage; (4) What are the characteristics of wetlands soils; and (5) To what extent do buffers mitigate the effects of stressors on wetland condition? The survey results represent the state of wetlands across the conterminous U.S. and Alaska, with samples collected at approximately 1,250 sites in 2011 (USEPA 2008c), and reporting released in 2016 (USEPA 2016). A map of the wetlands sampled during the 2011 NWCA, and located within the ORB, is provided in Figure B-5.

The most recent available information on wetlands resources at the national scale is the Status and Trends 2004–2009 Report, which documents wetland acreage gains and losses (USFWS 2009). In the following summary, an outline of the survey approach is given. To monitor changes in wetland area, the 48 conterminous states were stratified or divided by state boundaries and 85 physiographical subdivisions. Habitats were identified primarily by the analysis of imagery, and wetlands were identified based on vegetation, visible hydrology, and geography. The minimum targeted delineation size for wetlands was 1 acre (0.40 ha). Created freshwater ponds were included in the survey for the first time. The area analyzed was composed of 5,042 sample plots (total area equal to 20,192 mi^2 or 51,893 km^2). Field verification was accomplished for 898 (18%) of the sample plots.

The results of the latter Status and Trends Study indicated the following (Table B-3). There were an estimated 110.1 million acres (44.6 million ha) of wetlands in the conterminous U.S. in 2009. About 95% of all wetlands were freshwater and 5% marine or estuarine. The overall wetland area and representation by freshwater and saltwater components remained the same. In contrast, freshwater wetlands slightly increased in area between 2004 and 2009, and freshwater ponds have continued their increase from previous reporting periods—creating uncertainty over the controversy between both results.

Table B-3: Status and Trends Survey Results Showing Changes in Wetland Area for Selected Wetland and Deepwater Categories in the Conterminous U.S. from 2004 to 2009 (USFWS 2009)

Wetland/Deepwater Category	Area (Thousands of Acres)			Relative Change (%)
	Estimated Area 2004	Estimated Area 2009	Change 2004-2009	
Freshwater ponds	6,502.1	6,709.3	207.2	3.2
Freshwater vegetated	97,750.6	97,565.3	-185.3	-0.2
Freshwater emergent	27,162.7	27,430.5	267.8	1.0
Freshwater shrub	18,331.4	18,511.5	180.1	1.0
Freshwater forested	52,256.5	51,623.3	-633.1	-1.2
All Freshwater Wetlands	104,252.7	104.274.6	21.9	0.0
Marine intertidal	219.2	227.8	8.5	3.9
Estuarine intertidal non-vegetated	999.4	1,017.7	18.3	1.8
Estuarine intertidal vegetated	4,650.7	4,539.7	-110.9	-2.4
All Intertidal wetlands	5,869.3	5,785.2	-84.1	-1.4
ALL WETLANDS	110,122.1	110,059.8	-62.3	-0.1
Lacustrine	16,786.0	16,859.6	73.6	0.4
Riverine	7,517.9	7,510.5	-7.4	-0.1
Estuarine subtidal	18,695.4	18,776.5	81.1	0.4
All Deepwater Habitats	42,999.4	43,146.6	147.2	0.3
ALL WETLANDS AND DEEPWATER HABITATS	153,121.4	153,206.4	85.0	0.1

Among the freshwater wetlands, forested wetlands made up the largest category (49.5%), followed by freshwater emergents with 26.3%, shrub wetlands with 17.8%, and freshwater ponds with 6.4%. Estuarine emergent, salt marsh wetland was the largest category among the estuarine and marine intertidal wetlands, covering 66.7% of the entire estuarine and marine wetland area.

Freshwater vegetated wetlands continued to decline, but with a slower rate compared with the previous reporting period. Declines in forested wetland area (633,100 acres or 256,300 ha) offset area gains in freshwater emergent and shrub categories. Forested wetlands showed their largest losses since the 1974–1985 period. Freshwater wetland losses continued in regions of the country where there is a potential for wetlands to get into conflict with competing land and resource development interests. Within the ORB, these regions cover the northeast corner of Ohio and the mid to northern half of Indiana. Between 2004 and 2009, 489,600 acres (198,230 ha) of former upland were reclassified as wetland. These increases were attributed to wetland re-establishment and creation on agricultural lands and other uplands with undetermined land use, including undeveloped land, lands in conservation programs, or idle lands. The rate of wetland re-establishment increased by approximately 17% from the previous survey, and the estimated wetland loss increased 140% during the same time period, resulting in net wetland loss at the national scale. Marine and estuarine intertidal wetlands declined by approximately 84,100 acres (34,050 ha) or 1.4% between 2004 and 2009. Losses were attributed to impacts of coastal storms and relative sea level rise along the coastlines of the Atlantic Ocean and Gulf of Mexico.

Wetland types identified as potentially vulnerable because exhibiting change in size or distribution due to changing climate conditions are the following:

n. Freshwater:
   - xii. Drier-end emergent depressions including playas of the high plains, vernal pools, small shallow pothole like depressions, and saturated swales; Geography: interior freshwater wetlands of the conterminous U.S.
   - xiii. Emergent marshes with direct hydrologic connection to the Great Lakes; Geography: emergent marshes contiguous with the Great Lakes.

o. Marine and estuarine:
   - xiv. Marine and estuarine tidal shores, sand bars, flats and small barrier islands; Geography: South Atlantic, Gulf of Mexico.
   - xv. Estuarine forests adjacent to coastlines; Geography: Mid and South Atlantic.
   - xvi. Mangrove forests; Geography: Gulf of Mexico.

16.4 B.4 Measuring/Mapping Relative Vulnerability, Resilience, and Sensitivity of an Aquatic Ecosystem

Improvements to measuring, modeling, and understanding CC relevant to the hydrologic cycle, water quality, and aquatic ecosystems are needed for effective water resources management (e.g., Bates et al. 2008; Lettenmaier et al. 2008; Kundzewicz et al. 2008; Poff et al. 2002), but the management strategies of the past will not necessarily be adequate given increased awareness of stressors such as CC and land use change.

16.4.1 B.4.1 Understanding, Information Use, and Decision Making in Support of Aquatic Resource Management Under CC and Land Use Change

An understanding of the current condition of, and threats to, the environment can form the basis for evaluating the potential risks posed by CC. This can be achieved through systematic, quantitative planning frameworks that help us understand and evaluate various management strategies across a wide range of plausible futures. The results of such planning should be the selection of management strategies that alleviate, or at least do not exacerbate, existing and anticipated vulnerabilities of water quality and aquatic ecosystems. Thus, we should search for strategies that are robust with respect to the inherent uncertainties of the problem (Lempert et al. 2006; Brown et al. 2011).

Effective decision support is expected to start with a commitment to understand the systems we manage or aim to protect, and a willingness to use what we currently know for decision making, while increasing our knowledge. Comparing relative vulnerabilities fits well with this line of reasoning, because evaluation of the absolute effects of CC on water quality and aquatic systems is not possible at this time under the current state of the science for many of our vulnerability indicators. However, decisions have to be made even if a large part of the relevant information is not yet available.

Model results-based assessments of the interactions between CC and hydrologic systems, ecosystems, and human communities may be of limited usefulness for local decision making. This is because of the current and foreseeable limits on reducing climate uncertainties, and because these types of assessments may not be compatible with conclusions from the social sciences about how information is used in decision making (Dessai et al. 2009; Johnson and Weaver 2009; Sarewitz et al. 2000).

USEPA has developed and is implementing a research effort to improve national-scale understanding of the complex interactions between CC and the Nation's waters. Part of this work is an effort devoted to the development of scenarios of future climate, land use, and hydrologic change; and conducting hydrologic modeling in 20 large U.S. watersheds to provide broad, national-scale scenarios of streamflow and nutrient/sediment loading across a wide range of potential climate and land-use changes, to improve our understanding of the plausible range of hydrologic sensitivity to CC (USEPA 2013b). Scenarios like these can be used to investigate the potential negative water quality and aquatic ecosystem impacts that we must prepare to mitigate at large spatial scales in view of existing and likely future vulnerabilities of our aquatic ecosystems. The question remains what these existing vulnerabilities are (USEPA 2001, 2011). It turned out to be very difficult to assess and map the relative vulnerability of watersheds, across a number of dimensions, for the entire U.S. in a meaningful way. To measure relative vulnerability, indicators were identified that reflect the three components of vulnerability as identified by the IPCC (2007): sensitivity, exposure, and adaptive capacity. Sensitivity is the extent to which a system responds either positively or negatively to external stimuli; exposure is the degree to which a system is exposed to stressors (including specific climatic variations); and adaptive capacity is the ability of a system to cope with stress. Most vulnerability indicators identified measure the exposure or sensitivity of water quality and aquatic ecosystems to stressors.

16.4.2 B.4.2 Study on Indicators of Current Condition of Aquatic Ecosystems

Based on the assumption that an understanding of exposure and sensitivity may facilitate the development of an understanding of adaptive capacity within a system, a nationwide study was conducted on the relative effects of existing stressors other than CC, and their potential to reduce overall resilience, or increase overall sensitivity of aquatic ecosystems, to CC within North America (USEPA 2011). The idea that existing stressors reduce resilience and increase vulnerability is an established one and incorporated into recent large CC assessment efforts. According to the IPCC 4th Assessment Working Group II report, "vulnerability of ecosystems and species is partly a function of the expected rapid rate of CC relative to the resilience of many such systems." However, multiple stressors are significant in this system, as vulnerability is also a function of human development, which has already substantially reduced the resilience of ecosystems and makes many ecosystems and species more vulnerable to CC through blocked migration routes, fragmented habitats, reduced populations, introduction of alien species, and stresses related to pollution (IPCC 2007).

According to a preliminary review by the U.S. CC Science Program (CCSP 2008a) aimed at identifying adaptation approaches to maximize ecosystem resilience to CC for six Federal management systems within the U.S., including National Forests, National Parks, National Wildlife Refuges, National Estuaries, Marine Protected Areas, and Wild and Scenic Rivers, decreasing current anthropogenic stresses was the adaptation approach considered most likely to lead to good outcomes in view of CC uncertainties. The idea that existing stressors reduce resilience and increase vulnerability to CC informs both the definition of "vulnerability" used here, and the selection of individual indicators examined in this study. It is key to providing the link between what these indicators measure and an understanding of the ecological and watershed impacts of CC. The recently published Climate-Smart Conservation guide (Stein et al. 2014) goes further in that it recommends to (1) adopt forward-looking goals and (2) implement strategies specifically designed to (3) prepare for and adjust to current and future CC, and the associated impacts on natural systems and human communities—an emerging discipline known as "climate change adaptation."

16.4.3 B.4.3 Indicator Information

Based on the assumption that a systematic evaluation of the impacts of existing stressors would be a key input to any comprehensive global change vulnerability assessment, as the impacts of global change will be expressed via often complex interactions with such stressors: through their potential to reduce overall resilience, or increase overall sensitivity, to CC. The study included an extensive literature search to identify projects related to the monitoring and evaluation of water quality and ecosystem conditions, local and international, published in journal articles and reports, over the period 1998–2008. From this literature review, which included the National Aquatic Resource Surveys conducted by USEPA (NARS; see Question 4), indicators of water quality and aquatic ecosystem condition were identified, indicators of vulnerability were classified, data availability for the individual indicators was verified, and data were analyzed to enable map creation for mappable indicators. Spatial distribution of indicator information was mapped on the basis of nine predominant ecoregions within the continental U.S. Indicator mapping can also be done on HUC-4, HUC-8, HUC-12, or state spatial scales. The ORB is situated largely into the Temperate Plains and Southern Appalachians.

Results of this study indicate that out of the 623 vulnerability indicators considered among the 24 indicators that actually could be used to map vulnerability, only 10 were directly related to CC, 6 related to pesticides, and the remainder related to habitat and biota. Results of a principal component analysis indicated that the largest loadings to the first principal component (PC1) of the nationwide dataset originated from at-risk native freshwater species, at-risk wetland species, and ratio of snow/total precipitation (in this order), and to the second principal component (PC2) from ratio of water withdrawal/annual streamflow, water availability/streamflow per capita, and total use/total streamflow. Thus, at-risk native freshwater species and at-risk wetland species are very powerful indicators for relative vulnerability of aquatic ecosystems, and the ratio of snow/total precipitation and anthropogenic water use/availability are important vulnerability impacting factors.

For the ORB, these indicator categories fall in the following relative risk classes:

31. At-risk freshwater plant communities (2006): 55.6-71.1, 51.9-55.5, and 45.8-51.8% (majority basin); classes rank top-3 out of 5 national classes
32. At-risk native freshwater species (2006): 15.4-22.7, 9.4-10.6, and 4.7-9.3% (majority basin)
33. At-risk wetland and freshwater species (2006): 64-572 (majority basin), and 34-63 (species number); classes rank top-2 out of 5 national classes
34. Ratio of snow/total precipitation (1998-2007): 0.004-0.031, 0.032-0.112 (majority basin), 0.113-0.174; classes rank 2, 3, and 4 out 5 national classes
35. Ratio of water withdrawal/annual streamflow (1995): 0-0.03, 0.04-0.18 (majority basin), and 0.19-0.43
36. Ratio water availability/streamflow per capita (gpd/gpd): 5,800-24,000 (majority basin), 2,800-5,700, and 1,000-2,700; classes rank 2, 3, and 4 out 5 national classes
37. Total water use/total streamflow: 0.601-1.000; class ranks bottom-1 out of 2 national classes.

Maps of the spatial distributions of these vulnerability indicators at the national scale are provided in the report of this study (USEPA 2011). Maps of the spatial distribution may be prepared for the ORB once the pertinent GIS information has been retrieved (vulnerability indicators maps No. 1 through 7). Follow-up research on urban resilience indicators is ongoing.

16.5 B.5 Patterns of CC Forecasted and How Management May Be Altered to Protect and Maintain Aquatic Ecosystem Goods and Services

16.5.1 B.5.1 Projected CC Patterns and Vulnerable Regions Within North America

38. Several common historic CC patterns have been identified for the eight physiographic regions in the U.S., referenced in Meyer et al. (1999). Among all regions, the Great Lakes and Great Plains regions are particularly vulnerable:
    p. All regions are projected to experience warmer temperatures, with the extent of temperature change varying per region. Expected changes in precipitation are more variable, with the Great Lakes region being wetter and the New England region being drier.
    q. Climate-induced changes occur in the context of large anthropogenic alterations of water quantity, quality, sediment and nutrient loads, and exotic species. CC effects may be dwarfed or exacerbated by these other forces of change. In addition, direct CC effects are complicated by indirect effects of human actions in response to changing climate (construction of flood control or water supply reservoirs).
    r. Water to meet in-stream needs of aquatic ecosystems is competing with other uses of water, and competition will intensify by CC.
    s. Changes in hydrologic variability (frequency and magnitude of extreme events) and seasonality are likely to have a greater impact on aquatic ecosystems than changes in mean annual condition.

t. Many of the projected changes in aquatic ecosystems (e.g., Dissolved Organic Carbon, nutrient loading) are caused by the effects of CC on terrestrial ecosystems. Therefore, *assessing changes in terrestrial-aquatic linkages is a very important component of a CC effects assessment, with shifts in vegetation composition and hydrology of riparian zones being critical.*

39. Characteristic CC impact patterns listed in the NCA (2014) for the three regions distinguished and referenced in the latter assessment, which emphasizes the impacts on human communities more than documented by Meyer et al. (1999), and does not specifically ranks regions in order of vulnerability, are the following:

u. Northeast. Communities are affected by heat waves, more extreme precipitation events; and coastal flooding due to sea level rise and storm surge.

v. Midwest. Longer growing seasons and rising carbon dioxide levels increase yields of some crops, although these benefits have already been offset in some instances by occurrence of extreme events such as heat waves, droughts, and floods.

w. Southeast. Decreased water availability, exacerbated by population growth and land use change, causes increased competition for water. There are increased risks associated with extreme events (such as hurricanes in coastal areas).

16.5.2 B.5.2 Basin-Level Downscaled CC Patterns Generated by OHRFC Modeling

Results of the basin downscaled modeling study conducted under Section 7 of the pilot study are summarized in the following paragraphs for comparison with the CC expected based on the older IPCC report mentioned previously. For the pilot study, the archived CMIP3 and CMIP5 Climate and Hydrology Projections were used as the basic sources for precipitation and air temperature values, and the Sacramento Soil Moisture Accounting (SAC-SMA) Model to generate future streamflows for 25 forecast points along the main stem of the Ohio River and up in tributary HUCs as well.

Forecasts were generated on streamflow and temperature over three 30-year time periods, (i.e., 2011–2040 (R1F1), 2041–2070 (R1F2), and 2071–2099 (R1F3) relative to a base condition. Base condition pertained to the period 1952–2001, with streamflow backcasted from the nine CC ensembles by SAC-SMA for the forecast points. A map of the ORB with its' NOAA Climate Hydrology Projection Scenario units and ecoregions is provided in Figure B-4.

40. Projected temperature changes in the ORB show a small (0.5^{o}F) increase in the annual monthly mean per decade through 2040 (*1.5^{o}F total*), followed by a larger (1^{o}F) increase per decade between 2040 and 2099 (*5^{o}F total*).

41. Projected streamflow changes are expected to exhibit the following characteristics in the ORB. Mean, maximum, and minimum flows will generally be within the historical range through 2040 except during autumn, and subsequently may increase by 20–40% with some being higher in the northern and eastern Ohio Valley (particularly in autumn). Minimum flows may decrease, particularly from 2040 and beyond. Peak spring floods may increase particularly beyond 2040. Autumn flow may show a large increase in flow variability (lower minimum and higher peak flows).

16.5.2.1 B.5.2.1 Patterns of Aquatic Ecosystem Properties Sensitive to CC

Patterns in aquatic ecosystem properties sensitive to CC have been identified, and vary with ecosystem category. The six most important properties, listed by ecosystem category (i.e., streams, lakes, and wetlands) are presented in Table B-4.

Table B-4: Aquatic Ecosystems Properties Sensitive to CC. Changed properties could alter aquatic ecosystem functioning and health (Meyer et al. 1999).

Streams	Lakes	Wetlands
Flow regime	Mixing regime	Altered water balance leading to wetland losses
Sediment transport/channel alterations	Nutrient and DOC inputs	Fire frequency
Nutrient loading and rates of nutrient cycling	Habitats meeting temperature and oxygen requirements	Altered rates of exchange of greenhouse gases
Fragmentation and isolation of cold water habitats	Productivity	Vegetation species composition
Altered exchange with the riparian zone	Top predator changes leading to trophic cascades	Reproductive success of many animal species
Life history characteristics of many aquatic insects	Abundance of cold-water and warm-water fish species	Sensitivity to invasion by tropical exotic species

16.6 B.6 Water Quality Analysis Methods

16.6.1 B.6.1 Watershed Representation

The modeling environment selected for the analysis is the Schematic Processor (SP), a suite of geo-processing ArcGIS tools (Whiteaker 2006). SP operates on a schematic, link-and-node network model of the watershed. NHD was used as the basis for this representation, as it provides the stream network, lakes, and catchment definitions. Nodes were placed at the centroid and the outlet of each catchment, as well as at the start of every reach. Two basic types of links were used, representing streams and surface runoff from the catchment. Given the schematic network of the watershed, SP adds the capability to perform mathematical computations along the links and at the nodes (Johnson et al. 2013). This enables modeling fate and transport of any entity over the network.

16.6.1.1 B.6.1.1 Nitrogen Source and Transport

At any desired location in the watershed, SP calculates the total contaminant load as the sum of point- (L^{PS}), non-point source (L^{NPS}) and upstream contributions (L^{U}):

$$L_{input} = L^{NPS} + L^{PS} + L^{U} \quad (1)$$

National Pollutant Discharge Elimination System permits were used to incorporate point sources into the model. These were assumed to stay constant for all future projections.

Non-point source pollution can be estimated using export coefficients, which represent expected runoff of a particular pollutant for a particular land use (Lin 2004). Export coefficient ranges for various land uses are shown in Table B-5. For each catchment, the total load from non-point sources L^{NPS} is calculated as:

$$L^{NPS} = \sum_{j=1}^{n} \epsilon_j A_j \quad (2)$$

where ϵ_j is the export coefficient for the respective land use of area A_j, $j = 1, \ldots, n$, and n is the number of land uses.

Table B-5: Total Nitrogen (TN) Export Coefficients Per Land Use

Land Use	Calibrated Mean Export Coefficient (kg of TN/ha/year)	Range of Export Coefficients (kg of TN/ha/year)
Developed	2.7	1.9–14.0 (Loehr et al. 1989)
Forested	5.5	1.38–6.26 (Reckhow et al. 1980)
Barren	9.6	1.48–38.48 (Reckhow et al. 1980)
Grassland	8	1.48–38.48 (Reckhow et al. 1980)
Shrubland	4	1.48–38.48 (Reckhow et al. 1980)
Cropland	16.3	2.10–79.60 (Reckhow et al. 1980)
Mixed Agriculture	10	2.82–41.50 (Reckhow et al. 1980)

Contaminant removal during transport along links is modeled using a continuous loss function as (Schwarz et al. 2009):

$$L = L_{input} \exp(\lambda_Q T) \quad (3)$$

where L is the load at a given location, T is the mean travel time, and λ_Q is the nitrogen removal rate for the given flow (Table B-6). Travel times were obtained from NHD plus.

Table B-6: In-Stream TN Removal Rate

Mean Annual Streamflow (ft^3/s)	In-Stream TN Removal Rate λ_Q (day^{-1}) (Schwarz et al. 2009)
0-10	1.2
10-400	0.55
400-10000	0.1
10,000+	0.05

Lakes and reservoirs often have longer residence times than streams and rivers, and thus also have an increased amount of particle settling (Wetzel 2001). This results in areas where extensive denitrification can occur. These areas are modeled by including a nitrogen load reduction function that accounts for nitrogen removal via denitrification and burial in sediments. The fraction of nitrogen removal (*R)* in each lake is calculated as (Harrison et al. 2009):

$$R = 1 - e^{\left(\frac{V_f * A_S}{Q}\right)} \tag{4}$$

where V_f is the settling velocity, A_s the surface area of a given lake, and Q the inflow rate to the lake. A characteristic settling velocity of 9.92 m/year for nitrogen is used for V_f (Harrison et al. 2009). Within SP, nitrogen reduction is calculated as the received nitrogen load multiplied by the removal fraction. The remaining nitrogen load is then delivered to the next downstream feature.

16.6.1.2 B.6.1.2 Model Calibration

Model calibration was performed to ensure the best possible fit between historical U.S. Geological Survey (USGS) TN data and the model output. Export coefficients were used as calibration parameters. The goodness of fit was evaluated using the root-mean-square error (RMSE)-observations standard deviation ratio (RSR). RSR has been selected because it incorporates the benefits of error index statistics and includes a scaling factor to manage data with large variance (Moriasi et al. 2007). RSR is defined as:

$$RSR = \frac{RMSE}{Stdev_{obs}} = \frac{\sqrt{\sum_{i=1}^{n}\left(Y_i^{obs} - Y_i^{sim}\right)^2}}{\sqrt{\sum_{i=1}^{n}\left(Y_i^{obs} - Y_i^{mean}\right)^2}} \tag{5}$$

where Y_i^{obs} is the ith observation, Y_i^{sim} is the ith simulated value, and Y_i^{mean} is the mean of observed data. Values of RSR between zero and 0.5 indicate a very good model fit, between 0.5 and 0.6 good, between 0.6 and 0.7 satisfactory, and above 0.7 unsatisfactory.

16.6.1.3 B.6.1.3 Risk Assessment

Risk is defined as the probability that TN load exceeds system capacity, which is the amount of contaminant loading that a water system is able to safely contain. The event of such exceedance is called *failure*, and is formulated as (Haldar and Mahadevan 1999):

$$Z = \frac{C}{L} < 1 \tag{6}$$

where C is capacity; and L is load. Load describes the actual amount of contaminant loading at a given location, and is a random variable defined by Eq (3). Assuming that both load and capacity are lognormally distributed (Limpert et al. 2001), eq (6) can be rewritten as

$$Ln(Z) = Ln(C) - Ln(L) \tag{7}$$

where the *Ln*(*C*) and *Ln(L*) are normally distributed. The probability distribution of *Z* is

$$Z \sim N\left(\xi_C - \xi_L, \sqrt{\phi_C + \phi_L}\right) \quad (8)$$

where ξ is the scale parameter and ϕ is the shape parameter for the lognormal distribution; index *C* stands for capacity, and *L* for load.

Probability of failure, or the probability of TN load exceeding the capacity, is represented as:

$$p_f = P(\mathrm{Ln}(Z) < 0) \quad (9)$$

or

$$p_f = 1 - \Phi\left[\frac{\xi_C - \xi_L}{\sqrt{\phi_C^2 + \phi_L^2}}\right] \quad (10)$$

The relation of the scale and shape parameters to the mean and coefficient of variation leads to the following equation:

$$p_f = 1 - \Phi\left(\frac{Ln\left[\left(\frac{\mu_C}{\mu_L}\right)\sqrt{\frac{1+\delta_L^2}{1+\delta_C^2}}\right]}{\sqrt{Ln(1+\delta_C^2)(1+\delta_L^2)}}\right) \quad (11)$$

where μ_C is the mean TN capacity, μ_L is the mean TN load, δ_C the coefficient of variation of the system capacity, and δ_L is the coefficient of variation of the TN load. Probability p_f can be computed for any link in SP.

Risk analysis was conducted both for historical and projected TN values. The capacity for TN concentration is set at 1.68 mg/L (Morgan and Kline 2011). To calculate the mean capacity (μ_C), the mean annual flow was multiplied by factor of 1.68 converted to kilograms. The capacity variance for historical years is calculated from the flow data; and for future predictions, from the projected standard deviation obtained from the downscaled climate model. Mean and variance of the load are calculated using first order approximation methods applied to eq (3) (Haldar and Mahadevan 1999) within the schematic processor.

16.6.2 B.6.2 BMP Implementation

Best Management Practices (BMP) may be effective in decreasing nitrogen loading. The schematic processor allows the user quickly assess how different scenarios will impact nitrogen loading. A reduction of 15% in nitrogen runoff was applied to all areas (Cho et al. 2010a; Cho et al. 2010b). This reduction changes both mean and variance values in total loading. These new values are then used to compute the risk associated with the BMP scenario. To simulate BMP application, eq (2) was modified as:

$$L^{NPS} = \beta \sum_{j=1}^{n} \epsilon_j A_j \quad (12)$$

where β is the percent TN exported from respective area A_j after BMP implementation, in this case $\beta = 0.85$.

16.6.3 B.6.3 Results and Discussion

Model calibration parameter values fall within the range reported in the literature (Table B-7). The model fit measured with the RSR statistic is shown in Table B-7 for individual HUC-4s, as well as across all analyzed locations. All RSR values fall between zero and 0.5, indicating a very good model fit (Moriasi et al. 2007).

Table B-7: Model Fit Statistic

HUC 4	RSR
Wabash	0.19
Big Sandy- Guyandotte	0.13
Monongahela	0.28
Upper Ohio	0.44
Muskingum	0.30
All Locations	0.18

TN mean load and capacity trends are shown in Figure B-6. For each monitoring location, annual historical trends have been plotted for each year for which data were available, typically from 1974 to the early 1990s. Future projections have been computed with decadal increments starting in 2011 to 2091. Future projections are in line with historical observations and demonstrate TN loads less than capacity. Projected probabilities of exceeding TN capacity are shown in Figure B-7. The values across all projected years and all locations fall between 15% and 42%, indicating low to moderate risk of TN contamination. It is important to emphasize, however, that the analysis was implemented for annual aggregated data, and therefore was likely to smooth out any transient spikes in TN amounts.

The average risk is 32% across all years and stations, with many of the higher values occurring in 2011. The small difference between 2011 and subsequent years is likely due to the differences in land use interpretation and categorization. The 2011 data come from NLCD, and the 2021–2091 from the FORE-SCE land cover modeling; the two use different land cover classification schemes. Similar land use categories across these two schemes were treated as the same in the TN risk analysis. BMPs in the form of 15% reduction in TN loads from non-point sources have been implemented throughout the areas of analysis. They resulted in risk reductions generally around 2–4%, with up to 9% reduction (Figure B-8). New Harmony, IN, appears to have the highest reduction in risk among the stations, likely due to having a larger contributing area than others.

Future investigations include risk projections at a higher spatial and temporal resolution, as well as investigation of effects of additional BMP types.

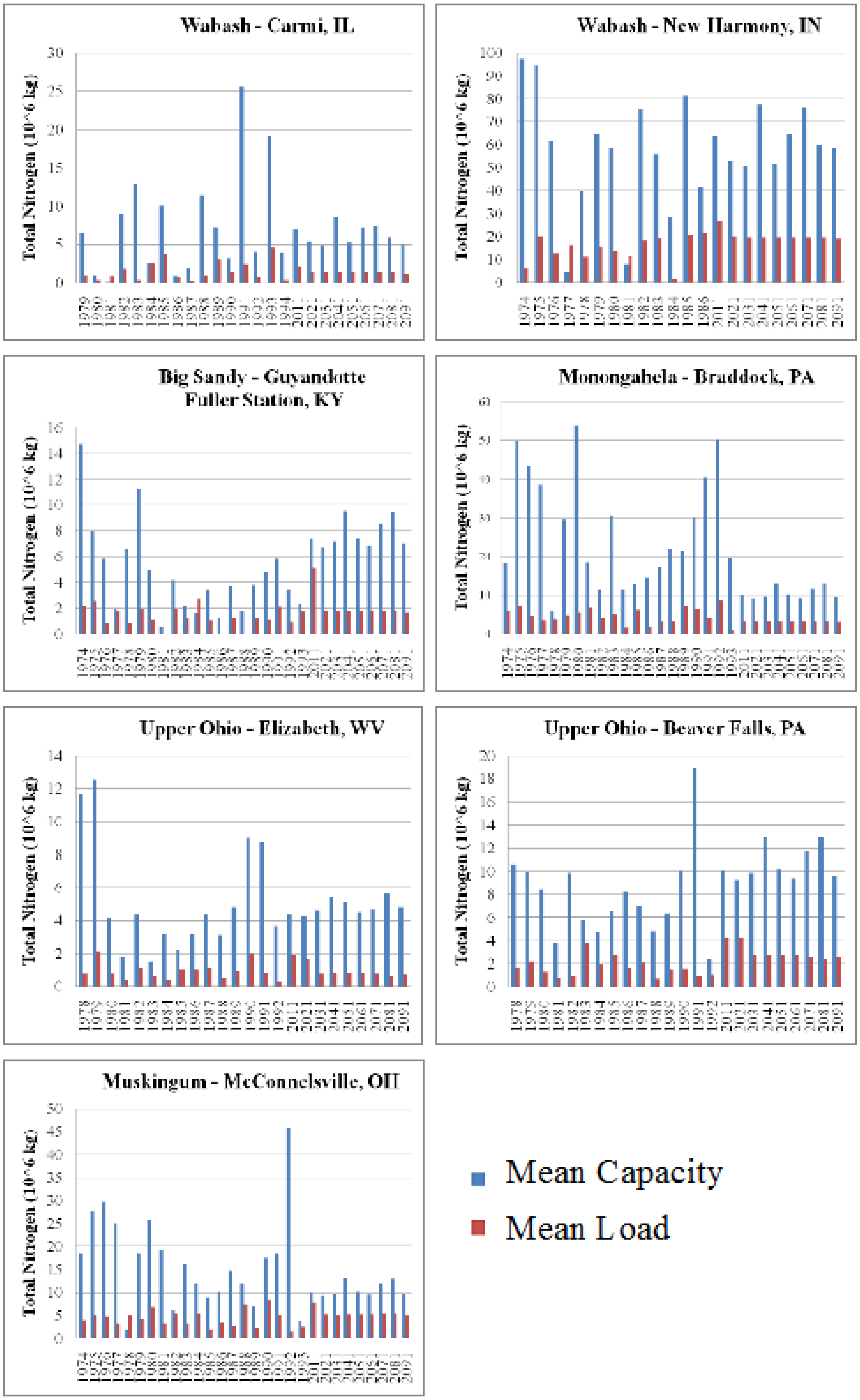


Figure B-6: Mean Load and Capacity for TN for Historic and Projected Years

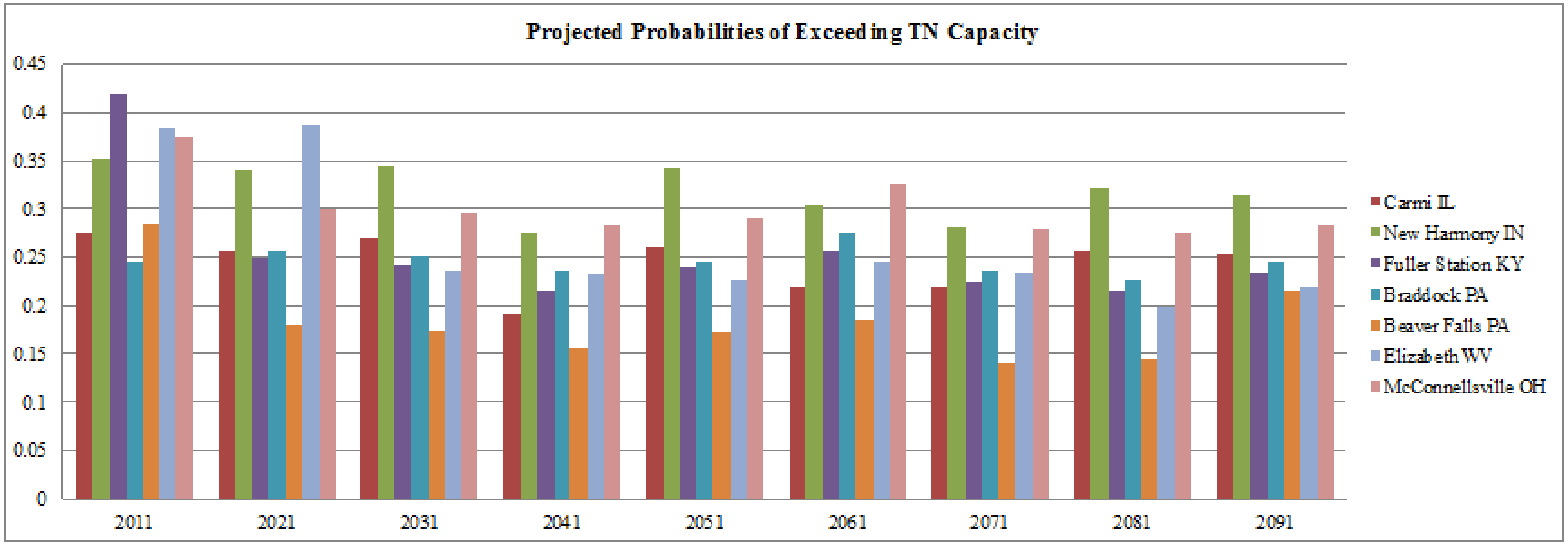


Figure B-7: Projected Probabilities of Exceeding TN Capacity

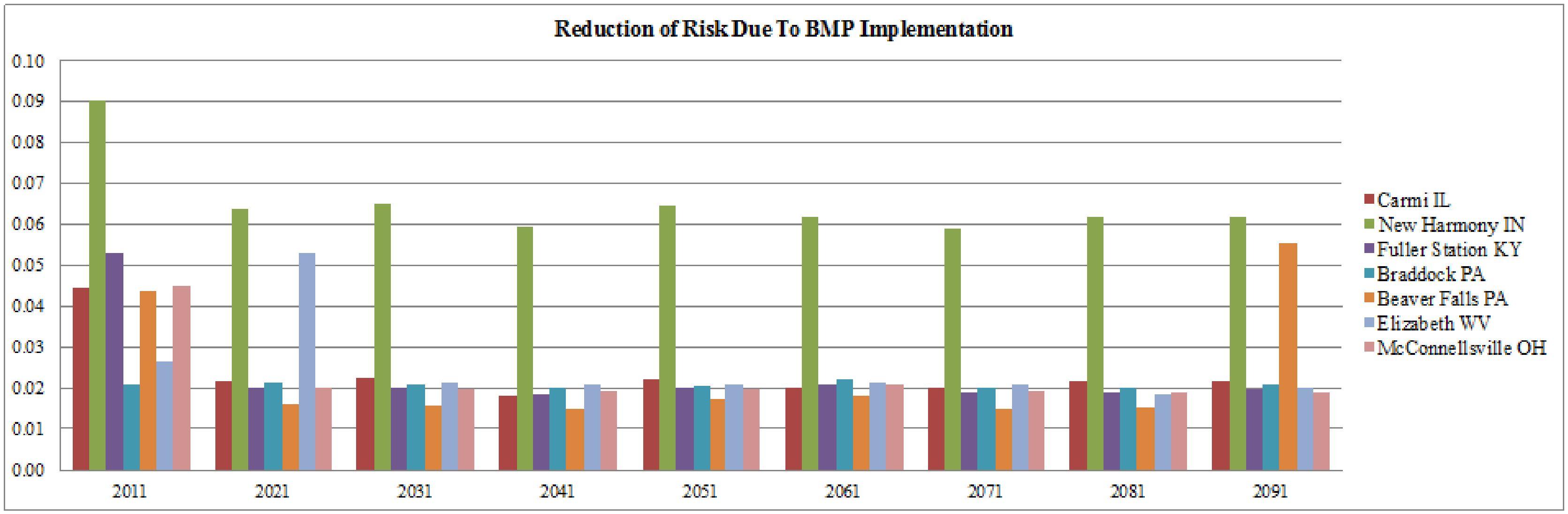


Figure B-8: Reduction of Risk Due to BMP Implementation

Table B-8: Ecosystem Services Identified Within the Basin, Their Values, and Potential Risks from CC

Ecosystem Service	Land Surface Area (mi^2)	Value ($/acre)	Value (Billion $)/y	Risk to CC	References
Provisioning					
Freshwater: water withdrawal for drinking water production; waste 'treatment'; power generation; goods transport infrastructure			36[1]-104.6[1,2] 0.2[3,4,5] (Pittsburgh, Cincinnati) 1,070[6] 29[7]	Incr. temperature, and CO_2 levels, precipitation (river dynamics, droughts, floods, storm water dynamics; changed fire regimes	1 Frechione 2011 2 ORSANCO 2013a 3 ALCOSAN n.d. 4 City of Cincinnati n.d. 5 Cincinnati MDS o G. 2005 6 Torcellini et al. 2003 7 Waterways Council n.d.
Food: Crop, livestock, poultry production agricultural land	71,100[8]	3,983[9]	181	Incr. temperature and CO_2 levels, changed precipitation pattern (water shortage, droughts, extreme precipitation, flooding, erosion); insects, animal diseases, feed shortage for livestock[10]	8 USACE 2009 9 From Table 2, this Q2.6 10 Doering et al. 2002
Timber: Timber, biomass for fuel and wood fiber production forested land	103,500[8]	600-1,500[11] (1,000 incl. in estim.[12])	66	Incr. temperature and CO_2 level, changed precipitation pattern (see above); insects, animal diseases; changed fire regimes; conversion to prairie	11 Havsy 2013 12 USDA 2013
Fisheries: Fish production (catch value)			0.002[13]	Incr. temperature, changed precipitation pattern (see above), river dynamics	13 GLMRIS Team 2012
Wild harvest production (medicinal herbs)			0.600 (U.S.)[14]	Incr. temperature and CO_2 level, changed precipitation pattern (see above); change in forest communities; increased invasive species, pests, diseases	14 Robbins 1999
Regulating					
Climate stability: Terrestrial vegetation stabilizes local/regional climate				Changed temperature, CO_2, precipitation and fire regimes may cause vegetation shifts	See Q2.1 (this report)
Flood control: a. Near-stream land (value);	157	3,699[15] 48,384[16]	76 [8] 0.582–7.6	Incremental flooding; extended low flows during high water demand in hot-weather periods for power generation	

Ecosystem Service	Land Surface Area (mi^2)	Value		Risk to CC	References
		($/acre)	(Billion $)/y		
b. Wetlands: Flood control, water purification (wildlife habitat; recreation)					15 Murray et al. 2009 16 Costanza et al. 1997
Pollination			0.059 (OH; [17])	Incr. temperature and CO_2 level, changed precipitation pattern (water shortage, droughts, extreme precipitation, flooding, erosion); insects, animal diseases; changed fire regimes; vegetation shifts	17 Trust for Public land 2013
Cultural					
Freshwater- and forested land-related recreation			13[8]	Incr. temperature, CO_2 levels, and changed river dynamics; droughts, fire regimes, changed forest communities	

Table B-9: Waterborne Commerce Within the ORB in 2011 (from Waterways Council, n.d.)

Commodity	Total Tonnage (Thousands)	Value (Million $)
Coal	142,363	5,182
Petroleum products	13,371	8,755
Crude petroleum	138	146
Aggregates	38,886	373
Grains	12,413	2,367
Chemicals	10,430	7,384
Ores/minerals	7,334	1,377
Iron/steel	7,952	2,583
Other	6,711	635
Total	239,598	28,800

Table B-10: Current Riparian/Aquatic Vegetation Stress by Aggregated Ecoregion

Subarea	Present Stress by Ecoregion							
	Southern Appalachians				Temperate Plains			
	%Total area	Rivers/ Streams	Lakes/ Reservoirs*	Wetlands	%Total Area	Rivers/ Streams	Lakes/ Reservoirs*	Wetlands
Allegheny (0501)	50	rip. veg.	*; rip. veg.	NA	0			
Monongahela (0502)	100	rip. veg.	*; rip. veg.	NA	0			
Upper Ohio (0503)	70	rip. veg.	*; rip. veg.	NA	0			
Muskingum (0504)	60	rip. veg.	*; rip. veg.	severe loss to ag.	0			
Kanawha (0505)	100	rip. veg.	*; rip. veg.	NA	0			
Scioto (0506)	30	rip. veg.	*; rip. veg.	severe loss to ag.	70	rip. veg.	rip. veg	severe loss to ag.
Big Sandy-Guyandotte (0507)	100	rip. veg.	*; rip. veg.	NA	0			
Great Miami (0508)	0				100	rip. veg.	rip. veg.	severe loss to ag.
Middle Ohio (0509)	10	rip. veg.	*; rip. veg.	NA	90	rip. veg.	rip. veg.	NA
Kentucky-Licking (0510)	100	rip. veg.	*; rip. veg.	NA	0			
Green (0511)	50	rip. veg.	*; rip. veg.	NA	50	rip. veg.	rip. veg.	NA
Wabash (0512)	15	rip. veg.	*; rip. veg.	severe loss to ag.	80	rip. veg.	rip. veg.	severe loss to ag.
Cumberland (0513)	100	rip. veg.	*; rip. veg.	NA	0			
Lower Ohio (0514)	100	rip. veg.	*; rip. veg.	NA	0			
Tennessee (06)	100	rip. veg.	*; rip. veg.	NA	0			

Table B-11: ORB HUC-4s and At-Risk Resource Summaries

Aquatic Ecosystem Adaptation Strategies for HUC4's								
Subarea	**System**	**Present Stress**	**2041-2070 Future Exposure or Climate Change**	**Sensitivity or Impacts on System**	**Adaptive Capacity**	**Possible Adaptation Options**	**Adaptation Pros**	**Adaptation Cons**
Allegheny (0501)	Fish & Mussels	Already increases in flows, esp. in fall	More water overall (mean 15-25%)	Increased scouring from floods	Fish & Mussels-low	Rejoin floodplains/ restore wetland	Scour relief, lowered turbidity and sediment, fish spawning and rearing habitat	
		Water use/ contamination-energy dev.	Higher spring maximums (25-50%), potentially torrential events	Elevated water levels during mussel reproductive cycle		Modified project releases	Improved fish and mussel reproduction and rearing	
		Channel connectivity	Increased fall mean (15-25%) but periodic lowered, low flows (-15 to -5%)	Increased risk of hypoxia/AMD in reservoirs/ tailwaters		Nutrient/ AMD source control	Lessened HABs & hypoxia in reservoirs and downstream water bodies	
				Periodically lowered baseflows				
Monongahela (0502)	Fish & Mussels	Already increases in flows, esp. in fall	More water overall (mean 15-25%)	Increased scouring from floods	Fish-moderate, Mussels- low	Rejoin floodplains/ restore wetlands	Scour relief, lowered turbidity and sediment, fish spawning and rearing habitat	
		Water use/ contamination-energy dev.	Higher spring maximums particularly late century (15-25%), potentially torrential events	Elevated water levels during mussel reproductive cycle		Modified project releases	Improved fish and mussel reproduction and rearing	
		Mod-high imperv. surface already	More water overall in late summer-early fall (15-25%) but periodic lowered low flows (-5 to -15%)	Risk of COD hypoxia/AMD in reservoirs/ tailwaters		Nutrient/ AMD source control	Lessened HABs & hypoxia in reservoirs and downstream water bodies	
		Channel connectivity		Periodically lowered baseflows				
Upper Ohio (0503)	Fish & Mussels	Already increases in flows, esp. in fall.	More water overall (mean 15-25%)	Increased scouring from floods	Fish-moderate, Mussels- low	Rejoin floodplains/ restore wetlands	Scour relief, lowered turbidity and sediment, fish spawning and rearing habitat	
		High imperv. surface already	Higher spring maximums (15-35%); potentially torrential events)	Elevated water levels during mussel reproductive cycle		Modified project releases	Improved fish and mussel reproduction and rearing	
		Water use/ contamination-energy dev.	Not droughty; although occasional low inflows	Increased wetland area?		AMD control	Lessened hypoxia/direct mortality	
		Loss of island habitat		Further loss of island habitat		Island dikes	Protection of rare habitat, potential spawning	
		Channel connectivity		Increased turbidity/water supply		Reoperation of nav. structures	Improved fish and mussel reproduction, rearing, and dist.	
Muskingum (0504)	Fish & Mussels	Water use/ contamination-energy dev?	Slightly more water overall (mean 5-15%)	Increased scouring/ from higher flows in downstream reaches?	Fish-moderate, Mussels- low	Restore wetlands/storm water handling	Reduced stream scour, nutrient assimilation, improved baseflow	
		Res. & stream hypoxia	Slightly higher spring maximum flows (5-15%). Downstream end of HUC tracks higher (15-35%)	Increased extent and duration of hypoxia		Modified project releases/ drought planning	Improved reproduction and rearing, habitat conservation	
		Mod-high imperv. surface already	Somewhat droughty (-15 to -5% mean) with lowered low flows (up to -25%) until late century. Wetter conditions return in late century?	Wastewater dilution impacts in midcentury period?		Nutrient/ AMD source control	Lessened HABs & hypoxia in reservoirs and downstream water bodies	
		Channel connectivity				Reoperation/ removal of obs. nav. structures	Improved fish and mussel reproduction, rearing, and dist.	
Kanawha (0505)	Fish & Mussels	Already sig. increases in flows, esp. in upstream reaches and fall.	Increased scouring from floods (naturally narrow flood plains)	Significantly more water overall (mean 25-35%)	Fish & Mussels-low	Rejoin floodplains/ restore wetlands	Scour relief, lowered turbidity and sediment, fish spawning and rearing habitat	
		Water use/ contamination-energy dev.	Elevated water levels during mussel reproductive cycle	Mod higher spring maximums in upper reaches (15-25%)		Modified project releases	Improved fish and mussel reproduction and rearing	
		Rel. high number of leveed areas already	Risk of COD hypoxia in reservoirs/AMD	Higher fall mean flows (35-50%)		Nutrient/ AMD source control	Lessened HABs & hypoxia in downstream water bodies	
		Reserv. & stream hypoxia	Increased turbidity/water supply			Reoperation/ removal of obs. nav. structures	Improved fish and mussel reproduction, rearing, and dist.	
		Channel connectivity						

Aquatic Ecosystem Adaptation Strategies for HUC4's								
Subarea	**System**	**Present Stress**	**2041-2070 Future Exposure or Climate Change**	**Sensitivity or Impacts on System**	**Adaptive Capacity**	**Possible Adaptation Options**	**Adaptation Pros**	**Adaptation Cons**
Scioto (0506)	Fish & Mussels	Already increases in downstream and fall flows	Increased flashiness/ from storm-water run-off in Columbus Metro area	Slightly more water overall (mean 5-15%)	Fish-moderate, Mussels-low	Rejoin floodplains/ restore wetlands	Scour relief, lowered turbidity and sediment, fish spawning and rearing habitat	
		High imperv. surface already	Increased scouring in downstream reaches?	Moderately higher spring maximums (15-25%) in downstream reaches		Nutrient/ AMD source control	Lessened HABs & hypoxia in downstream water bodies	
		Nutrient/HABs		Periodic, lowered low flows in fall but generally higher flows especially in downstream reaches				
Big Sandy–Guyandotte (0507)	Fish & Mussels	Already very significant increases in flows, esp. in fall.	Increased scouring from floods	More water overall (mean 15-25%)	Fish-high, Mussels-low	Rejoin floodplains/ restore wetlands	Scour relief, lowered turbidity and sediment, fish spawning and rearing habitat	
		Water contamination	Elevated water levels during mussel reproductive cycle	Higher spring mean flows (15-25%) and maximums (25-35%) by late century		Nutrient/ AMD source control	Lessened HABs & hypoxia in downstream water bodies	
			Increased flood potential	Higher fall mean flows (15-50%), particularly late century				
Great Miami (0508)	Fish & Mussels	Already altered flows (spring and fall lower)	Lowered sensitive fish and mussel carrying capacity	At most, slightly more water overall (mean -5 to 15%)	Fish & Mussels-moderate	Restore wetlands	Reduced stream scour, nutrients, & improved baseflow	
		High imperv. surface	Wastewater dilution/permitting	Little change in spring maximum flows (-5 to 5%)		Nutrient source control	Lessened HABs & hypoxia in downstream water bodies	
		Nutrient/HABs	Increased irrigation?	Droughty in fall (mean -15 to -5%) and lowered low flows (-15 to -35%)		Removal of obs dams	Improved fish and mussel reproduction, rearing, and dist.	
		Channel connectivity	Municipal water supply impacts in fall					
Middle Ohio (0509)	Fish & Mussels	Already increases in flows, esp. in fall.	Increased scouring from floods	More water overall (mean 15-25%)	Fish & Mussels-low	Rejoin floodplains/restore wetlands	Scour relief, lessened sediment, spawning & rearing	
		Rel. high imperv. surface	Elevated water levels during mussel reproductive cycle	Higher spring maximums (15-35%); potentially torrential events)		Nutrient/ AMD source control	Lessened HABs & hypoxia in downstream water bodies	
		Elevated Nutrient	Increased wetland area?	Slightly higher late summer-early fall mean flows (5-15%) although occasional low inflows		Reoperation of nav. structures	Improved fish and mussel reproduction, rearing, and dist.	
		Channel connectivity	Increased diurnal D.O. swings			Island dikes	Protection of rare habitat, potential spawning	
		Rel. high number of leveed areas already	Further loss of island habitat					
			Increased turbidity/water supply					
Kentucky-Licking (0510)	Fish & Mussels	Already increases in flows	Increased mussel bed scouring?	Moderately more water overall (mean 15-25%)	Fish & Mussels-low	Restore wetlands	Reduced stream scour, nutrients, & improved baseflow	
		Water use/ contamination-energy dev.	Lowered sensitive fish and mussel carrying capacity	Slightly higher spring maximums (5-15%) toward end of century		Nutrient/ AMD source control	Lessened HABs & hypoxia in downstream water bodies	
			Increased irrigation?	Droughty in late summer-fall (means -5 to -15%, lows -15% to -50%) by late century		Modified flood control releases/ drought planning	Improved reproduction and rearing, habitat conservation	
			Wastewater dilution/permitting by late century					
Green (0511)	Fish & Mussels	Already increases in flows, esp. in fall.	Increased mussel bed scouring?	Slightly more water overall (mean 5-15%)	Fish-low, Mussels-moderate	Restore wetlands	Reduced stream scour, nutrients, & improved baseflow	
		Water contamination-lower reaches	Wastewater dilution/permitting by late century	Slightly higher spring maximums (5-15%) with greater increases in downstream reaches toward end of century		Nutrient control	Lessened HABs & hypoxia in downstream water bodies	
		Channel connectivity	Increased risk and extent of COD hypoxia in reservoirs	Periodically droughty in late summer-fall (means -5 to 5%, lows -5% to -15%) by late century		Modified proj releases	Improved reproduction and rearing	

Aquatic Ecosystem Adaptation Strategies for HUC4's								
Subarea	System	Present Stress	2041-2070 Future Exposure or Climate Change	Sensitivity or Impacts on System	Adaptive Capacity	Possible Adaptation Options	Adaptation Pros	Adaptation Cons
			Irrigation increase?			drought planning	Habitat conservation	
			Lowered sensitive fish and mussel carrying capacity			Removal/ reoperation of dcs. navigation structures.	Improved fish and mussel reproduction, rearing, and dist.	
Wabash (0512)	Fish & Mussels	Already increases in flows, esp. in fall	Increased flashiness/ from storm-water run-off in Indianapolis Metropolitan and other developed areas, converted wetlands	Slightly more water overall (mean 5-15%)	Fish & Mussels-low in parts of extensive HUC4	Restore wetlands	Reduced stream scour, nutrients, & improved baseflow	
		Already altered hydrology (flood control/wetland conversion, urban impervious surface)	Increased scouring in upper reaches?	Higher spring maximums (15-35%) in most of the HUC.	Moderate in connected floodplain reaches	Nutrient control	Lessened HABs & hypoxia in downstream water bodies	
		Nutrient/HABs	Increased Ag nutrient runoff/diurnal D.O. swings	Torrential rain events possible.		Modified proj releases/	Improved reproduction and rearing	
			Increased risk and extent of reservoir hypoxia in upper system	Mean flows higher in late summer-fall (means 15-25%), but periodic low flow events (-15% to -25%) by late century		drought planning	Habitat conservation	
			Increased turbidity					
Cumberland (0513)	Fish & Mussels	Already some increases in fall flow	Increased scouring?	More water overall (mean 15-25%)	Fish&Mussels-moderate	Rejoin floodplains/ restore wetlands	Scour relief, lessened sediment, spawning & rearing	
		Mod. imperv. surface	Elevated water levels during mussel reproductive cycle	Little change in spring maximums until slightly higher in late century (5-15%)		Nutrient source control	Lessened HABS & hypoxia in downstream water bodies	
		Nutrient enrichment	Increased risk and extent of hypoxia in reservoirs?	Slight increase in late summer-early fall mean and minimum flows (5 to 15%)		Modified project releases	Improved reproduction and rearing	
		Current reservoir and stream hypoxia						
		Growing water demand						
Lower Ohio (0514)	Fish and Mussels	Already increases in flows, esp. in fall.	Increased scouring from floods	More water overall (mean 15-25%)	Fish & Mussels-moderate	Restore wetlands	Reduced stream scour, nutrients, & improved baseflow	
		Elevated Nutrient	Elevated water levels during mussel reproductive cycle	Higher spring maximums (15-35%); potentially torrential events)		Nutrient source control	Lessened HABS & hypoxia in downstream water bodies	
			Increased wetland area?	Slightly higher late summer-early fall mean flows (5-15%) although occasional low inflows		Island dikes?	Protection of rare habitat, potential spawning	
			Further loss of island habitat					
			Increased turbidity					
			Increased diurnal D.O. swings					
Tennessee (06)	Fish and Mussels	Already increases in spring and fall flows	Increased mussel bed scouring from floods	More water overall (mean 15-25%)	Fish-moderate, Mussels-low	Rejoin floodplains/ restore wetlands	Scour relief, lessened sediment, spawning & rearing	
		Mod. imperv. surface	Elevated water levels during mussel reproductive cycle	Moderately higher spring maximums (15-25%); potentially torrential events)		Nutrient source control	Lessened HABS & hypoxia in downstream water bodies	
		Nutrient enrichment	Increased Ag nutrient runoff/diurnal D.O. swings	Moderately higher late summer-early fall mean flows (15-25%)		Modified project releases	Improved reproduction and rearing	
		Current reservoir and stream hypoxia	Increased risk and extent of reservoir hypoxia					
		Growing water demand						

Table B-12: Dam and Reservoir Project Purposes

Purpose Symbol	Purpose
C	Flood Control
S	Water Supply
H	Hydropower
R	Recreation
F	Fish and Wildlife
T	Tailings
N	Navigation
O	Other

Table B-13: Dams/Reservoirs in the Ohio River Basin by Forecast Group

Dams/Reservoirs in the Ohio River Basin by Forecast Group					
NIDID	Forecast Group	DAM Name	River	Owner	Purposes
PA00101	SAGL	CONEMAUGH DAM	CONEMAUGH RIVER	F	CR
PA00102	SAGL	CROOKED CREEK DAM	CROOKED CREEK	F	CR
PA00107	SAGL	MAHONING CREEK DAM	MAHONING CREEK	F	RC
PA00514	SAGL	PINEY	CLARION RIVER	P	HRSC
PA00900	SAGL	LAKE WILHELM (PA-475)	SANDY CREEK	S	CR
PA00104	SAGL	EAST BRANCH DAM	CLARION RIVER	F	OCR
PA00254	SAGU	TWO MILE RUN	TWO MILE RUN	L	CR
PA00110	SAGU	TIONESTA DAM	TIONESTA CREEK	F	CR
PA00746	SAGU	TAMARACK LAKE B (PA-461B)	MUD RUN	S	CR
PA00181	SAGU	TAMARACK LAKE A (PA-461A)	MILL RUN	S	CR
PA00108	SAGU	WOODCOCK CREEK DAM	WOODCOCK CREEK	F	OCR
PA00105	SAGU	KINZUA DAM	ALLEGHENY RIVER	F	CHNR
OH00032	SBVR	BERLIN DAM	MAHONING RIVER	F	CRSO
OH00030	SBVR	MICHAEL J KIRWAN DAM AND RESERVOIR	WEST BRANCH OF THE MAHONING	F	CRSO
PA00111	SBVR	SHENANGO DAM	SHENANGO RIVER	F	CR
OH00031	SBVR	MOSQUITO CREEK DAM	MOSQUITO CREEK	F	CRSO
PA00176	SBVR	PYMATUNING	SHENANGO RIVER	S	CR
TN04102	SCML	CENTER HILL DAM	CANEY FORK RIVER	F	CHR
TN03701	SCML	J PERCY PRIEST DAM	STONES RIVER	F	CRH
TN02702	SCML	DALE HOLLOW DAM	OBEY RIVER	F	HCR
KY03061	SCMU	MARTINS FORK DAM	MARTINS FORK OF CUMBERLAND R.	F	CRO
KY83587	SCMU	STONEY FORK SLURRY DAM		P	ST
KY83509	SCMU	ABNER FORK DAM		P	ST
KY03010	SCMU	WOLF CREEK	CUMBERLAND	F	HCR
KY03046	SCMU	LAUREL DAM	LAUREL	F	CHR
IN03001	SEFW	MONROE LAKE DAM	SALT CREEK	F	CRS
KY03007	SGRN	GREEN RIVER LAKE DAM	GREEN RIVER	F	CRSO
KY03011	SGRN	NOLIN LAKE DAM	NOLIN RIVER	F	CR

Dams/Reservoirs in the Ohio River Basin by Forecast Group					
NIDID	Forecast Group	DAM Name	River	Owner	Purposes
KY03012	SGRN	ROUGH RIVER LAKE DAM	ROUGH RIVER	F	CRS
OH00018	SHOC	TOM JENKINS DAM	EAST BR OF SUNDAY CK	F	CRS
VA15502	SKAN	CLAYTOR	NEW RIVER	U	HSRN
WV08902	SKAN	BLUESTONE DAM	NEW RIVER	F	CRF
WV01901	SKAN	HAWKS NEST	NEW RIVER	P	HR
WV06702	SKAN	SUMMERSVILLE DAM	GAULEY RIVER	F	OCRF
WV03526	SKAN	POCATALICO STRUCTURE NO.28	MIDDLE FORK	L	RS
WV00701	SKAN	SUTTON DAM	ELK RIVER	F	CROF
KY83582	SKTY	LOVELY BRANCH SLURRY DAM		P	ST
KY83527	SKTY	HALF MILE DAM		P	ST
KY83530	SKTY	ADAMS FORK SLURRY DAM		P	ST
KY83526	SKTY	BRITTON BRANCH REFUSE DAM		P	ST
KY03056	SKTY	CARR CREEK LAKE–SEDIMENT DAM 1	CARR CREEK	F	CRO
KY03056	SKTY	CARR CREEK LAKE–SEDIMENT DAM 2	LITTCARR CREEK	F	CRO
KY03056	SKTY	CARR CREEK LAKE DAM	CARR CREEK	F	CRO
KY03056	SKTY	CARR CREEK LAKE–SEDIMENT DAM 3	CARR CREEK	F	ROC
KY83518	SKTY	BUCKEYE CREEK DAM		P	ST
KY83581	SKTY	BRUSHY FORK SLURRY DAM		P	ST
KY03027	SKTY	BUCKHORN LAKE DAM	MIDDLEFORK KENTUCKY RIVER	F	CR
KY01200	SKTY	MOTHER ANN LEE HYDROELECTRIC STATION	KENTUCKY RIVER	F	NH
KY00051	SKTY	TAYLORSVILLE LAKE DAM	SALT RIVER	F	CRO
KY03055	SLIK	CAVE RUN LAKE DAM	LICKING RIVER	F	CRO
KY01167	SLIK	CEDAR CREEK DAM	CEDAR CREEK	S	RS
WV00707	SLKH	BURNSVILLE LAKE DAM	LITTLE KANAWHA RIVER	F	RCOF
IL00230	SLWA	STEPHEN A. FORBES STATE PARK LAKE DAM	LOST FORK CREEK	S	RS

Dams/Reservoirs in the Ohio River Basin by Forecast Group					
NIDID	Forecast Group	DAM Name	River	Owner	Purposes
IL00334	SLWA	EAST FORK LAKE DAM	EAST FORK FOX RIVER	L	SR
IL00607	SLWA	LAKE SARA DAM	BLUE POINT CREEK	U	SR
IL00141	SLWA	LAKE MATTOON DAM	LITTLE WABASH RIVER	L	SR
OH00929	SMIM	WILLIAM H. HARSHA LAKE DAM	EAST FORK OF LITTLE MIAMI	F	CRSO
OH00927	SMIM	CAESAR CREEK LAKE SADDLE DAM #2	CAESAR CREEK	F	CRSO
OH00927	SMIM	CAESAR CREEK LAKE SADDLE DAM #3	CAESAR CREEK	F	CRSO
OH00927	SMIM	CAESAR CREEK LAKE DAM AND SADDLE DAMS #1 AND #4	CAESAR CREEK	F	CRSO
IN03017	SMIM	BROOKVILLE LAKE DAM–DUNLAPSVILLE LEVEE	EAST FORK OF WHITEWATER RIVER	F	CRS
OH00028	SMIM	CLARENCE J BROWN DAM	BUCK CREEK	F	CRO
OH00013	SMKL	SENECAVILLE DAM	SENECA FORK OF WILLS CREEK	F	CROF
OH00007	SMKL	DILLON DAM	LICKING RIVER	F	CROF
OH00002	SMKL	WILLS CREEK DAM	WILLS CREEK	F	CROF
OH00001	SMKL	PLEASANT HILL DAM	CLEAR FORK OF MOHICAN RIVER	F	CROF
OH00020	SMKL	CHARLES MILL DAM	BLACK FORK OF MOHICAN RIVER	F	CRF
OH00011	SMKU	PIEDMONT DAM	STILLWATER CREEK	F	CROF
OH00012	SMKU	CLENDENING DAM	BRUSHY FK OF STILLWATER CK	F	CROF
OH00010	SMKU	TAPPAN DAM	LITTLE STILLWATER CREEK	F	CROF
OH00014	SMKU	LEESVILLE DAM	MCGUIRE CREEK	F	CROF
OH00006	SMKU	ATWOOD DAM	INDIAN FORK OF CONOTTON CREEK	F	CROF
MD00004	SMNL	DEEP CREEK DAM	DEEP CREEK	P	HR
PA00109	SMNL	YOUGHIOGHENY DAM	YOUGHIOGHENY RIVER	F	OCR
WV04114	SMNU	STONEWALL JACKSON DAM, WV	WEST FORK	F	CRS
WV09101	SMNU	TYGART DAM	TYGART RIVER	F	NC
WV06128	SMNU	LAKE LYNN	CHEAT RIVER	U	HR

Dams/Reservoirs in the Ohio River Basin by Forecast Group					
NIDID	Forecast Group	DAM Name	River	Owner	Purposes
WV09901	SOHH	EAST LYNN DAM	EAST FK TWELVEPOLE CREEK	F	CRF
WV04307	SOHH	UPPER MUD RIVER NO.2A	MUD RIVER	L	CR
KY03030	SOHH	GRAYSON DAM	LITTLE SANDY RIVER	F	CROF
WV09903	SOHH	BEECH FORK LAKE DAM	BEECH FORK OF TWELVE POLE CK.	F	CRF
OH82421	SOHH	TIMBRE RIDGE DAM	TRIB TO SAND FORK	F	ORF
WV08512	SOHP	NORTH FORK HUGHES RIVER SITE 21C DAM	NORTH FORK	L	CRS
IL50169	SOHS	MARION NEW LAKE DAM–N/C	SUGAR CREEK	L	SR
IL00015	SOHS	LAKE OF EGYPT DAM	SOUTH FORK SALINE RIVER	U	OR
KY83486	SOHS	RIVER VIEW IMPOUNDMENT “SLURRY”		P	OS
PA00911	SOHW	CROSS CREEK (PA-661)	CROSS CREEK	L	CRS
VA19501	SSAY	N. FORK OF POUND DAM	NORTH FORK OF POUND RIVER	F	CRSF
KY03028	SSAY	FISHTRAP DAM	LEVISA FORK OF BIG SANDY RIVER	F	CROF
WV10924	SSAY	R D BAILEY DAM	GUYANDOT RIVER	F	CROF
KY03029	SSAY	DEWEY DAM	JOHNS CREEK OF LEVISA FORK	F	CROF
KY82202	SSAY	PAINTSVILLE DAM	PAINT CREEK	F	CROF
KY82201	SSAY	YATESVILLE DAM	BLAINE CREEK	F	CROF
OH00017	SSCI	PAINT CREEK DAM	PAINT CREEK	F	CSROF
OH00008	SSCI	DEER CREEK DAM	DEER CREEK	F	CROF
OH00751	SSCI	O’SHAUGHNESSY	SCIOTO RIVER	L	SRH
OH00931	SSCI	ALUM CREEK DAM	ALUM CREEK OF BIG WALNUT CRK.	F	CSRF
OH00015	SSCI	DELAWARE DAM	OLENTANGY RIVER	F	CRSOF
IN03018	SWBL	PATOKA LAKE DAM	PATOKA RIVER	F	CSRO
IL01233	SWBL	MILL CREEK STRUCTURE 1 DAM	MILL CREEK	P	CR
IN03003	SWBL	CECIL M HARDEN LAKE DAM	RACCOON CREEK	F	CR

Dams/Reservoirs in the Ohio River Basin by Forecast Group					
NIDID	Forecast Group	DAM Name	River	Owner	Purposes
IN00451	SWBU	OAKDALE	TIPPECANOE RIVER	U	RH
IN03004	SWBU	MISSISSINEWA LAKE DAM	MISSISSINEWA RIVER	F	RC
IN03005	SWBU	LANCASTER LEVEE AND DIKE	SALAMONIE RIVER	F	CR
IN00452	SWBU	NORWAY	TIPPECANOE RIVER	U	RH
IN03006	SWBU	J. EDWARD ROUSH LAKE DAM	WABASH RIVER	F	CR
IN00213	SWHT	WEST BOGGS CREEK STRUCTURE NO. 1	WEST BOGGS CREEK	L	
IN03007	SWHT	GREENWOOD LAKE DAM	FIRST CREEK	F	CSR
IN03002	SWHT	CAGLES MILL LAKE DAM	MILL CREEK	F	CR

Table B-14: Ohio River Basin Dams Condition Assessment (Performance) by Forecast Group

Ohio River Basin Dams Condition Assessment (Performance) by Forecast Group					
Forecast Group	Dam Name	River	Condition Assessment	Owner	Purposes
SAGL	EAST BRANCH DAM	CLARION RIVER	UNSATISFACTORY	F	OCR
SAGU	KINZUA DAM	ALLEGHENY RIVER	POOR	F	CHNR
SBVR	BERLIN DAM	MAHONING RIVER	POOR	F	CRSO
SCML	CENTER HILL DAM	CANEY FORK RIVER	UNSATISFACTORY	F	CHR
SCML	J PERCY PRIEST DAM	STONES RIVER	POOR	F	CRH
SCML	DALE HOLLOW DAM	OBEY RIVER	POOR	F	HCR
SCMU	WOLF CREEK	CUMBERLAND	UNSATISFACTORY	F	HCR
SGRN	GREEN RIVER LAKE DAM	GREEN RIVER	POOR	F	CRSO
SGRN	NOLIN LAKE DAM	NOLIN RIVER	POOR	F	CR
SGRN	ROUGH RIVER LAKE DAM	ROUGH RIVER	POOR	F	CRS
SKAN	BLUESTONE DAM	NEW RIVER	POOR	F	CRF
SKAN	SUTTON DAM	ELK RIVER	POOR	F	CROF
SKTY	CARR CREEK LAKE–SEDIMENT DAM 1	CARR CREEK	POOR	F	CRO
SKTY	CARR CREEK LAKE–SEDIMENT DAM 2	LITTCARR CREEK	POOR	F	CRO
SKTY	CARR CREEK LAKE–SEDIMENT DAM 3	CARR CREEK	POOR	F	ROC
SKTY	BUCKHORN LAKE DAM	MIDDLEFORK KENTUCKY RIVER	POOR	F	CR
SLIK	CAVE RUN LAKE DAM	LICKING RIVER	POOR	F	CRO
SLKH	BURNSVILLE LAKE DAM	LITTLE KANAWHA RIVER	POOR	F	RCOF
SMIM	WILLIAM H. HARSHA LAKE DAM	EAST FORK OF LITTLE MIAMI	POOR	F	CRSO

Ohio River Basin Dams Condition Assessment (Performance) by Forecast Group					
Forecast Group	Dam Name	River	Condition Assessment	Owner	Purposes
SMIM	CAESAR CREEK LAKE DAM AND SADDLE DAMS #1 AND #4	CAESAR CREEK	POOR	F	CRSO
SMIM	BROOKVILLE LAKE DAM–DUNLAPSVILLE LEVEE	EAST FORK OF WHITEWATER RIVER	POOR	F	CRS
SMKL	SENECAVILLE DAM	SENECA FORK OF WILLS CREEK	POOR	F	CROF
SMKU	CLENDENING DAM	BRUSHY FK OF STILLWATER CK	POOR	F	CROF
SMKU	TAPPAN DAM	LITTLE STILLWATER CREEK	POOR	F	CROF
SMKU	ATWOOD DAM	INDIAN FORK OF CONOTTON CREEK	POOR	F	CROF
SMNL	YOUGHIOGHENY DAM	YOUGHIOGHENY RIVER	POOR	F	OCR
SOHH	BEECH FORK LAKE DAM	BEECH FORK OF TWELVE POLE CK.	POOR	F	CRF
SSAY	R D BAILEY DAM	GUYANDOT RIVER	POOR	F	CROF
SSCI	PAINT CREEK DAM	PAINT CREEK	UNSATISFACTORY	F	CSROF
SSCI	DEER CREEK DAM	DEER CREEK	POOR	F	CROF
SSCI	DELAWARE DAM	OLENTANGY RIVER	POOR	F	CRSOF
SWBL	PATOKA LAKE DAM	PATOKA RIVER	POOR	F	CSRO
SWBL	CECIL M HARDEN LAKE DAM	RACCOON CREEK	POOR	F	CR
SWBU	OAKDALE	TIPPECANOE RIVER	POOR	U	RH
SWBU	MISSISSINEWA LAKE DAM	MISSISSINEWA RIVER	POOR	F	RC
SWBU	NORWAY	TIPPECANOE RIVER	POOR	U	RH
SWBU	J. EDWARD ROUSH LAKE DAM	WABASH RIVER	POOR	F	CR

Table B-15: Ohio River Basin Dams w/Flood Control or Stormwater Purpose by Forecast Group

Ohio River Basin Dams with a Flood Control or Stormwater Purpose by Forecast Group			
Forecast group	Dam Name	River	Purposes
SAGL	CONEMAUGH DAM	CONEMAUGH RIVER	CR
SAGL	CROOKED CREEK DAM	CROOKED CREEK	CR
SAGL	MAHONING CREEK DAM	MAHONING CREEK	RC
SAGL	PINEY	CLARION RIVER	HRSC
SAGL	LAKE WILHELM (PA-475)	SANDY CREEK	CR
SAGL	EAST BRANCH DAM	CLARION RIVER	OCR
SAGU	TWO MILE RUN	TWO MILE RUN	CR
SAGU	TIONESTA DAM	TIONESTA CREEK	CR
SAGU	TAMARACK LAKE B (PA-461B)	MUD RUN	CR
SAGU	TAMARACK LAKE A (PA-461A)	MILL RUN	CR
SAGU	WOODCOCK CREEK DAM	WOODCOCK CREEK	OCR
SAGU	KINZUA DAM	ALLEGHENY RIVER	CHNR
SBVR	BERLIN DAM	MAHONING RIVER	CRSO
SBVR	MICHAEL J KIRWAN DAM AND RESERVOIR	WEST BRANCH OF THE MAHONING	CRSO
SBVR	SHENANGO DAM	SHENANGO RIVER	CR
SBVR	MOSQUITO CREEK DAM	MOSQUITO CREEK	CRSO
SBVR	PYMATUNING	SHENANGO RIVER	CR
SCML	CENTER HILL DAM	CANEY FORK RIVER	CHR
SCML	J PERCY PRIEST DAM	STONES RIVER	CRH
SCML	DALE HOLLOW DAM	OBEY RIVER	HCR
SCMU	MARTINS FORK DAM	MARTINS FORK OF CUMBERLAND R.	CRO
SCMU	WOLF CREEK	CUMBERLAND	HCR
SCMU	LAUREL DAM	LAUREL	CHR
SEFW	MONROE LAKE DAM	SALT CREEK	CRS
SGRN	GREEN RIVER LAKE DAM	GREEN RIVER	CRSO
SGRN	NOLIN LAKE DAM	NOLIN RIVER	CR
SGRN	ROUGH RIVER LAKE DAM	ROUGH RIVER	CRS
SHOC	TOM JENKINS DAM	EAST BR OF SUNDAY CK	CRS

Ohio River Basin Dams with a Flood Control or Stormwater Purpose by Forecast Group			
Forecast group	Dam Name	River	Purposes
SKAN	BLUESTONE DAM	NEW RIVER	CRF
SKAN	SUMMERSVILLE DAM	GAULEY RIVER	OCRF
SKAN	SUTTON DAM	ELK RIVER	CROF
SKTY	CARR CREEK LAKE–SEDIMENT DAM 1	CARR CREEK	CRO
SKTY	CARR CREEK LAKE–SEDIMENT DAM 2	LITTCARR CREEK	CRO
SKTY	CARR CREEK LAKE DAM	CARR CREEK	CRO
SKTY	CARR CREEK LAKE–SEDIMENT DAM 3	CARR CREEK	ROC
SKTY	BUCKHORN LAKE DAM	MIDDLEFORK KENTUCKY RIVER	CR
SKTY	TAYLORSVILLE LAKE DAM	SALT RIVER	CRO
SLIK	CAVE RUN LAKE DAM	LICKING RIVER	CRO
SLKH	BURNSVILLE LAKE DAM	LITTLE KANAWHA RIVER	RCOF
SMIM	WILLIAM H. HARSHA LAKE DAM	EAST FORK OF LITTLE MIAMI	CRSO
SMIM	CAESAR CREEK LAKE SADDLE DAM #2	CAESAR CREEK	CRSO
SMIM	CAESAR CREEK LAKE SADDLE DAM #3	CAESAR CREEK	CRSO
SMIM	CAESAR CREEK LAKE DAM AND SADDLE DAMS #1 AND #4	CAESAR CREEK	CRSO
SMIM	BROOKVILLE LAKE DAM–DUNLAPSVILLE LEVEE	EAST FORK OF WHITEWATER RIVER	CRS
SMIM	CLARENCE J BROWN DAM	BUCK CREEK	CRO
SMKL	SENECAVILLE DAM	SENECA FORK OF WILLS CREEK	CROF
SMKL	DILLON DAM	LICKING RIVER	CROF
SMKL	WILLS CREEK DAM	WILLS CREEK	CROF
SMKL	PLEASANT HILL DAM	CLEAR FORK OF MOHICAN RIVER	CROF
SMKL	CHARLES MILL DAM	BLACK FORK OF MOHICAN RIVER	CRF
SMKU	PIEDMONT DAM	STILLWATER CREEK	CROF
SMKU	CLENDENING DAM	BRUSHY FK OF STILLWATER CK	CROF
SMKU	TAPPAN DAM	LITTLE STILLWATER CREEK	CROF
SMKU	LEESVILLE DAM	MCGUIRE CREEK	CROF
SMKU	ATWOOD DAM	INDIAN FORK OF CONOTTON CREEK	CROF
SMNL	YOUGHIOGHENY DAM	YOUGHIOGHENY RIVER	OCR

Ohio River Basin Dams with a Flood Control or Stormwater Purpose by Forecast Group			
Forecast group	Dam Name	River	Purposes
SMNU	STONEWALL JACKSON DAM, WV	WEST FORK	CRS
SMNU	TYGART DAM	TYGART RIVER	NC
SOHH	EAST LYNN DAM	EAST FK TWELVEPOLE CREEK	CRF
SOHH	UPPER MUD RIVER NO.2A	MUD RIVER	CR
SOHH	GRAYSON DAM	LITTLE SANDY RIVER	CROF
SOHH	BEECH FORK LAKE DAM	BEECH FORK OF TWELVE POLE CK.	CRF
SOHP	NORTH FORK HUGHES RIVER SITE 21C DAM	NORTH FORK	CRS
SOHW	CROSS CREEK (PA-661)	CROSS CREEK	CRS
SSAY	N. FORK OF POUND DAM	NORTH FORK OF POUND RIVER	CRSF
SSAY	FISHTRAP DAM	LEVISA FORK OF BIG SANDY RIVER	CROF
SSAY	R D BAILEY DAM	GUYANDOT RIVER	CROF
SSAY	DEWEY DAM	JOHNS CREEK OF LEVISA FORK	CROF
SSAY	PAINTSVILLE DAM	PAINT CREEK	CROF
SSAY	YATESVILLE DAM	BLAINE CREEK	CROF
SSCI	PAINT CREEK DAM	PAINT CREEK	CSROF
SSCI	DEER CREEK DAM	DEER CREEK	CROF
SSCI	ALUM CREEK DAM	ALUM CREEK OF BIG WALNUT CRK.	CSRF
SSCI	DELAWARE DAM	OLENTANGY RIVER	CRSOF
SWBL	PATOKA LAKE DAM	PATOKA RIVER	CSRO
SWBL	MILL CREEK STRUCTURE 1 DAM	MILL CREEK	CR
SWBL	CECIL M HARDEN LAKE DAM	RACCOON CREEK	CR
SWBU	MISSISSINEWA LAKE DAM	MISSISSINEWA RIVER	RC
SWBU	LANCASTER LEVEE AND DIKE	SALAMONIE RIVER	CR
SWBU	J. EDWARD ROUSH LAKE DAM	WABASH RIVER	CR
SWHT	WEST BOGGS CREEK STRUCTURE NO. 1	WEST BOGGS CREEK	CR
SWHT	GREENWOOD LAKE DAM	FIRST CREEK	CSR
SWHT	CAGLES MILL LAKE DAM	MILL CREEK	CR

Table B-16: Ohio River Basin Dams w/Hydropower and/or Water Supply Purpose by Forecast Group

Ohio River Basin Dams with Hydropower and/or Water Supply Purpose by Forecast Group			
Forecast Group	**Dam Name**	**River**	**Purposes**
SAGL	PINEY	CLARION RIVER	HRSC
SAGU	KINZUA DAM	ALLEGHENY RIVER	CHNR
SBVR	BERLIN DAM	MAHONING RIVER	CRSO
SBVR	MICHAEL J KIRWAN DAM AND RESERVOIR	WEST BRANCH OF THE MAHONING	CRSO
SBVR	MOSQUITO CREEK DAM	MOSQUITO CREEK	CRSO
SCML	CENTER HILL DAM	CANEY FORK RIVER	CHR
SCML	J PERCY PRIEST DAM	STONES RIVER	CRH
SCML	DALE HOLLOW DAM	OBEY RIVER	HCR
SCMU	STONEY FORK SLURRY DAM	NA	ST
SCMU	ABNER FORK DAM	NA	ST
SCMU	WOLF CREEK	CUMBERLAND	HCR
SCMU	LAUREL DAM	LAUREL	CHR
SEFW	MONROE LAKE DAM	SALT CREEK	CRS
SGRN	GREEN RIVER LAKE DAM	GREEN RIVER	CRSO
SGRN	ROUGH RIVER LAKE DAM	ROUGH RIVER	CRS
SHOC	TOM JENKINS DAM	EAST BR OF SUNDAY CK	CRS
SKAN	CLAYTOR	NEW RIVER	HSRN
SKAN	HAWKS NEST	NEW RIVER	HR
SKAN	POCATALICO STRUCTURE NO.28	MIDDLE FORK	RS
SKTY	LOVELY BRANCH SLURRY DAM	NA	ST
SKTY	HALF MILE DAM	NA	ST
SKTY	ADAMS FORK SLURRY DAM	NA	ST
SKTY	BRITTON BRANCH REFUSE DAM	NA	ST

Ohio River Basin Dams with Hydropower and/or Water Supply Purpose by Forecast Group			
Forecast Group	Dam Name	River	Purposes
SKTY	BUCKEYE CREEK DAM	NA	ST
SKTY	BRUSHY FORK SLURRY DAM	NA	ST
SKTY	MOTHER ANN LEE HYDROELECTRIC STATION	KENTUCKY RIVER	NH
SLIK	CEDAR CREEK DAM	CEDAR CREEK	RS
SLWA	STEPHEN A. FORBES STATE PARK LAKE DAM	LOST FORK CREEK	RS
SLWA	EAST FORK LAKE DAM	EAST FORK FOX RIVER	SR
SLWA	LAKE SARA DAM	BLUE POINT CREEK	SR
SLWA	LAKE MATTOON DAM	LITTLE WABASH RIVER	SR
SMIM	WILLIAM H. HARSHA LAKE DAM	EAST FORK OF LITTLE MIAMI	CRSO
SMIM	CAESAR CREEK LAKE SADDLE DAM #2	CAESAR CREEK	CRSO
SMIM	CAESAR CREEK LAKE SADDLE DAM #3	CAESAR CREEK	CRSO
SMIM	CAESAR CREEK LAKE DAM AND SADDLE DAMS #1 AND #4	CAESAR CREEK	CRSO
SMIM	BROOKVILLE LAKE DAM–DUNLAPSVILLE LEVEE	EAST FORK OF WHITEWATER RIVER	CRS
SMNL	DEEP CREEK DAM	DEEP CREEK	HR
SMNU	STONEWALL JACKSON DAM, WV	WEST FORK	CRS
SMNU	LAKE LYNN	CHEAT RIVER	HR
SOHP	NORTH FORK HUGHES RIVER SITE 21C DAM	NORTH FORK	CRS
SOHS	MARION NEW LAKE DAM–N/C	SUGAR CREEK	SR
SOHS	RIVER VIEW IMPOUNDMENT “SLURRY”	NA	OS
SOHW	CROSS CREEK (PA-661)	CROSS CREEK	CRS
SSAY	N. FORK OF POUND DAM	NORTH FORK OF POUND RIVER	CRSF

Ohio River Basin Dams with Hydropower and/or Water Supply Purpose by Forecast Group			
Forecast Group	Dam Name	River	Purposes
SSCI	PAINT CREEK DAM	PAINT CREEK	CSROF
SSCI	O'SHAUGHNESSY	SCIOTO RIVER	SRH
SSCI	ALUM CREEK DAM	ALUM CREEK OF BIG WALNUT CRK.	CSRF
SSCI	DELAWARE DAM	OLENTANGY RIVER	CRSOF
SWBL	PATOKA LAKE DAM	PATOKA RIVER	CSRO
SWBU	OAKDALE	TIPPECANOE RIVER	RH
SWBU	NORWAY	TIPPECANOE RIVER	RH
SWHT	GREENWOOD LAKE DAM	FIRST CREEK	CSR

Table B-17: Ohio River Basin Local Protection Projects by Forecast Group

Ohio River Basin Local Protection Projects by Forecast Group		
Project ID#	**Forecast Group**	**LPP Name–LEVEE/Floodwall**
8195	SCML	METRO CENTER LEVEE, DAVIDSON COUNTY, TN
361	SHOC	ATHENS, OH, LPP
163	SKAN	GALAX, VA, LPP
262	SKAN	PRINCETON, WV, LPP
265	SKAN	RAINELLE, WV, LPP
3497	SKAN	MARLINTON, WV LPP
245	SMKL	MOUNT VERNON, OH, LPP
3281	SMKL	PAVONIA LEVEE, CHARLES MILL LAKE, OH
3279	SMKU	SOMERDALE LEVEE, DOVER DAM, OH
3277	SMKU	FAIRFIELD LEVEE, DOVER DAM, OH
3274	SMKU	SILICA SAND LEVEE, BEACH CITY LAKE, OH
3278	SMKU	NORTON LEVEE, DOVER DAM, OH
3280	SMKU	ZOAR LEVEE, DOVER DAM, OH
3276	SMKU	CORUNDITE LEVEE, DOVER DAM, OH
3273	SMKU	MAGNOLIA LEVEE, BOLIVAR DAM, OH
3275	SMKU	EAST SPARTA LEVEE, BOLIVAR DAM, OH
3272	SMKU	BREWSTER LEVEE, BEACH CITY LAKE, OH
240	SOHC	MAYSVILLE, KY, LPP
167	SOHH	GRIFFITHSVILLE-YAWKEY, WV, LPP
164	SOHH	GRAHN, KY, LPP
252	SOHH	OLIVE HILL, KY, LPP
150	SOHH	CEREDO-KENOVA, WV, LPP
149	SOHH	CATLETTSBURG, KY, LPP
3323	SOHH	HUNTINGTON, WV, LPP
360	SOHH	ASHLAND, KY, LPP
169	SOHH	IRONTON, OH, LPP
268	SOHH	RUSSELL, KY, LPP
260	SOHH	PORTSMOUTH-NEW BOSTON, OH, LPP
259	SOHH	POINT PLEASANT, WV, LPP

Ohio River Basin Local Protection Projects by Forecast Group		
Project ID#	Forecast Group	LPP Name–LEVEE/Floodwall
255	SOHP	PARKERSBURG, WV, LPP
3388	SSAY	PIKEVILLE, KY, LPP
3351	SSAY	MATEWAN, WV, LPP
3349	SSAY	WEST WILLIAMSON, WV, LPP
3348	SSAY	WILLIAMSON, WV, CBD LPP
3350	SSAY	SOUTH WILLIAMSON, KY, LPP
261	SSAY	PRESTONSBURG, KY, LPP
270	SSAY	SOUTH WILLIAMSON, KY, ARH LPP
6547	SSAY	OCEANA LPP, WV
168	SSAY	INEZ, KY, LPP
152	SSCI	CHILLICOTHE, OH, LPP
3875	SSCI	GREENFIELD LEVEE, PAINT CREEK LAKE, OH
277	SSCI	WASHINGTON COURT HOUSE, OH, LPP
3288	SSCI	WALDO LEVEE, DELAWARE LAKE, OH
192	SWBL	LEVEE UNIT 5, IN
225	SWBL	ROCHESTER AND MCCLEARY'S BLUFF LEVEE, IL
172	SWBL	ENGLAND POND LEVEE, IL
230	SWBL	RUSSELL & ALLISON LEVEE, IL
218	SWBL	NIBLACK LEVEE, IN
186	SWBL	ISLAND LEVEE, IN
203	SWBL	LYFORD LEVEE, IN
193	SWHT	LEVEE UNIT 8, IN

Table B-18: Ohio River Basin Navigation Locks and Dams by Forecast Group

Ohio River Basin Navigation Locks and Dams by Forecast Group			
Project ID#	Forecast Group	Project Name	2013 Tonnage In (1,000's)
9458	SAGL	LOCK AND DAM #3–ALLEGHENY RIVER	1,886
9490	SAGL	LOCK AND DAM #4–ALLEGHENY RIVER	2,259
9519	SAGL	LOCK AND DAM #5–ALLEGHENY RIVER	1,748
9544	SAGL	LOCK AND DAM #6–ALLEGHENY RIVER	110
9600	SAGL	LOCK AND DAM #7–ALLEGHENY RIVER	593
9625	SAGL	LOCKAND DAM #8–ALLEGHENY RIVER	NA
9655	SAGL	LOCK AND DAM #9–ALLEGHENY RIVER	NA
8212	SCML	OLD HICKORY LOCK AND DAM–CUMBERLAND RIVER	4,463
8216	SCML	CHEATHAM LOCK AND DAM–CUMBERLAND RIVER	9,016
8698	SKAN	LONDON LOCK AND DAM–KANAWHA RIVER	1,172
8728	SKAN	MARMET LOCK AN DAM–KANAWHA RIVER	8,130
9339	SMNL	MAXWELL LOCK AND DAM–MONONGAHELA RIVER	10,696
9362	SMNL	LOCK AND DAM #4–MONONGAHELA RIVER	11,303
9377	SMNL	LOCK AND DAM #3–MONONGAHELA RIVER	10,880
9397	SMNL	LOCK AND DAM #2–MONONGAHELA RIVER	16,681
9222	SMNU	OPEKISKA LOCK AND DAM–MONONGAHELA RIVER	1
9229	SMNU	HILDEBRAND LOCK AND DAM–MONONGAHELA RIVER	1
9235	SMNU	MORGANTOWN LOCK AND DAM–MONONGAHELA RIVER	137
9262	SMNU	PT. MARION LOCK AND DAM–MONONGAHELA RIVER	4,795
9296	SMNU	GRAYS LANDING LOCK AND DAM–MONONGAHELA RIVER	4,761
8951	SOHC	CAPTAIN ANTHONY MELDAHL LOCK AND DAM–OHIO RIVER	48,272
8830	SOHH	WINFIELD LOCK AND DAM–KANAWHA RIVER	12,736
8873	SOHH	GREENUP LOCK AND DAM–OHIO RIVER	43,522
8902	SOHH	ROBERT C BYRD LOCK AND DAM–OHIO RIVER	43,676
8987	SOHH	RACINE LOCK AND DAM–OHIO RIVER	42,135
8749	SOHL	MCALPINE LOCK AND DAM–OHIO RIVER	67,837
8936	SOHL	MARKLAND LOCK AND DAM–OHIO RIVER	52,411
8580	SOHL	CANNELTON LOCK AND DAM–OHIO RIVER	64,713

Ohio River Basin Navigation Locks and Dams by Forecast Group			
Project ID#	Forecast Group	Project Name	2013 Tonnage In (1,000's)
9077	SOHP	BELLEVILLE LOCK AND DAM–OHIO RIVER	40,854
9158	SOHP	WILLOW ISLAND LOCK AND DAM–OHIO RIVER	37,438
8391	SOHS	SMITHLAND LOCK AND DAM–OHIO RIVER	68,016
8547	SOHS	JOHN T. MYERS LOCK AND DAM–OHIO RIVER	60,664
8599	SOHS	NEWBURGH LOCK AND DAM–OHIO RIVER	74,447
9251	SOHW	HANNIBAL LOCK AND DAM–OHIO RIVER	33,767
9364	SOHW	PIKE ISLAND LOCK AND DAM–OHIO RIVER	31,552
9437	SOHW	LOCK AND DAM #2–ALLEGHENY RIVER	6,276
9440	SOHW	EMSWORTH LOCK AND DAM–OHIO RIVER	19,320
9457	SOHW	NEW CUMBERLAND LOCK AND DAM–OHIO RIVER	31,286
9463	SOHW	DASHIELDS LOCK AND DAM–OHIO RIVER	20,778
9503	SOHW	MONTGOMERY LOCK AND DAM–OHIO RIVER	21,448

Table B-19: Ohio River Basin Thermoelectric Power Plants by Forecast Group

Ohio River Basin Thermoelectric Power Plants by Forecast Group							
Forecast Group	Plant Name	Plant ID	State	Cooling Process	Fuel Type	Cooling Water Source	Water Extraction in MG/Y
SAGL	Conemaugh	3118	PA	Re-circulating	Coal	Conemaugh River	11,531
SAGL	Seward	3130	PA	Re-circulating	Coal	Conemaugh River	3,801
SAGL	Ebensburg Power	10603	PA	Re-circulating	Coal	Wilmore Dam	430
SAGL	Cambria Cogen	10641	PA	Re-circulating	Coal	Wilmore Reservoir	667
SAGL	Homer City Station	3122	PA	Re-circulating	Coal	Twolick Creek	11,364
SAGL	Cheswick Power Plant	8226	PA	Once-Through	Coal	Allegheny River	88,934
SAGL	Allegheny Energy Units 3 4 & 5	55710	PA	Re-circulating	Natural Gas	Allegheny River	29
SAGL	Colver Power Project	10143	PA	Re-circulating	Coal	Vetera Reservoir	867
SAGL	Keystone	3136	PA	Re-circulating	Coal	Crooked Creek	14,215
SAGL	Armstrong Power Station	3178	PA	Once-Through	Coal	Allegheny River	52,188
SAGL	Piney Creek Project	54144	PA	Re-circulating	Coal	Clarion River	268
SAGL	Scrubgrass Generating Company LP	50974	PA	Re-circulating	Coal	Allegheny River	681
SAGL	Johnsonburg Mill	54638	PA	Re-circulating	Biomass	East Branch Clarion River	213
SAGU	S A Carlson	2682	NY	Re-circulating	Coal	Chadakoin River	6
SBVR	New Castle Plant	3138	PA	Once-Through	Coal	Beaver River	45,825
SBVR	Niles	2861	OH	Once-Through	Coal	Mahoning River	32,037
SBVR	WCI Steel	54207	OH	Re-circulating	Natural Gas	Mahoning River	85
SCML	Vanderbilt University Power Plant	52048	TN	Re-circulating	Coal	Municipality	2
SCML	Old Hickory Plant	10797	TN	Re-circulating	Coal	Old Hickory Lake	5
SCML	Gallatin	3403	TN	Once-Through	Coal	Cumberland River	285,998
SCML	Cumberland	3399	TN	Once-Through	Coal	Cumberland River	592,314
SCMU	Cooper	1384	KY	Once-Through	Coal	Cumberland Lake	75,761
SEFW	Tanners Creek	988	IN	Once-Through	Coal	Ohio River	170,412
SGRN	Shawnee	1379	KY	Once-Through	Coal	Ohio River	352,613
SGRN	Paradise	1378	KY	Re-circulating	Coal	Green River	15,404
SGRN	Green River	1357	KY	Once-Through	Coal	Green River	34,974

Ohio River Basin Thermoelectric Power Plants by Forecast Group							
Forecast Group	Plant Name	Plant ID	State	Cooling Process	Fuel Type	Cooling Water Source	Water Extraction in MG/Y
SGRN	D B Wilson	6823	KY	Re-circulating	Coal	Green River	3,010
SGRN	Robert A Reid	1383	KY	Re-circulating	Coal	Green River	110
SGRN	R D Green	6639	KY	Re-circulating	Coal	Green River	3,652
SGRN	HMP&L Station Two Henderson	1382	KY	Re-circulating	Coal	Green River	1,508
SKAN	Radford Army Ammunition Plant	52072	VA	Once-Through	Coal	New River	1,052
SKAN	DEGS of Narrows LLC	52089	VA	Once-Through	Coal	New River	6,786
SKAN	Glen Lyn	3776	VA	Once-Through	Coal	New River	51,001
SKAN	Kanawha River	3936	WV	Once-Through	Coal	Kanawha River	89,731
SKAN	John E Amos	3935	WV	Re-circulating	Coal	Kanawha River	16,231
SKTY	E W Brown	1355	KY	Re-circulating	Coal	Herrington Lake	4,144
SKTY	Dale	1385	KY	Once-Through	Coal	Kentucky River	38,050
SKTY	Tyrone	1361	KY	Once-Through	Coal	Kentucky River	12,927
SMIM	Hamilton	2917	OH	Once-Through	Coal	Great Miami River	11,730
SMIM	Hamilton	2917	OH	Once-Through	Natural Gas	Great Miami River	311
SMIM	Smart Papers LLC	50247	OH	Re-circulating	Coal	Great Miami River	71
SMIM	O H Hutchings	2848	OH	Once-Through	Coal	Great Miami River	13,606
SMIM	Whitewater Valley	1040	IN	Re-circulating	Coal	East Fork of Whitewater River	400
SMKL	Conesville	2840	OH	Once-Through	Coal	Muskingum River	29,116
SMKL	Conesville	2840	OH	Re-circulating	Coal	Muskingum River	8,706
SMKL	Shelby Municipal Light Plant	2943	OH	Re-circulating	Coal	Municipality	83
SMKU	Dover	2914	OH	Once-Through	Coal	Tuscarawas River	2,935
SMKU	Orrville	2935	OH	Re-circulating	Coal	Municipality	365
SMKU	Morton Salt Rittman	54335	OH	Re-circulating	Coal	Wells	7
SMNL	Hatfields Ferry Power Station	3179	PA	Re-circulating	Coal	Monongahela River	11,150
SMNL	Fayette Energy Facility	55516	PA	Re-circulating	Natural Gas	Monongahela River	104
SMNL	Mitchell Power Station	3181	PA	Once-Through	Coal	Monongahela River	55,073
SMNL	Elrama Power Plant	3098	PA	Once-Through	Coal	Monongahela River	41,498

Ohio River Basin Thermoelectric Power Plants by Forecast Group							
Forecast Group	Plant Name	Plant ID	State	Cooling Process	Fuel Type	Cooling Water Source	Water Extraction in MG/Y
SMNU	Harrison Power Station	3944	WV	Re-circulating	Coal	West Fork River	13,345
SMNU	Albright	3942	WV	Once-Through	Coal	Cheat River	30,221
SMNU	Rivesville	3945	WV	Once-Through	Coal	Monongahela River	2,860
SMNU	Grant Town Power Plant	10151	WV	Re-circulating	Coal	Monongahela River	634
SMNU	Morgantown Energy Facility	10743	WV	Once-Through	Coal	Monongahela River	14,955
SMNU	Fort Martin Power Station	3943	WV	Re-circulating	Coal	Monongahela River	6,832
SOHC	J M Stuart	2850	OH	Once-Through	Coal	Ohio River	392,486
SOHC	J M Stuart	2850	OH	Re-circulating	Coal	Ohio River	3,258
SOHC	Killen Station	6031	OH	Re-circulating	Coal	Ohio River	3,533
SOHC	H L Spurlock	6041	KY	Re-circulating	Coal	Wells/Ohio River	7,017
SOHC	Walter C Beckjord	2830	OH	Once-Through	Coal	Ohio River	119,885
SOHH	Big Sandy	1353	KY	Re-circulating	Coal	Big Sandy River	6,051
SOHH	Hanging Rock Energy Facility	55736	OH	Re-circulating	Natural Gas	Ohio River	337
SOHH	Union Carbide South Charleston	50151	WV	Re-circulating	Coal	Kanawha River	28
SOHH	Kyger Creek	2876	OH	Once-Through	Coal	Ohio River	248,837
SOHH	General James M Gavin	8102	OH	Re-circulating	Coal	Ohio River	21,208
SOHH	Philip Sporn	3938	WV	Once-Through	Coal	Ohio River	179,586
SOHH	Mountaineer	6264	WV	Re-circulating	Coal	Ohio River	9,868
SOHL	Kentucky Mills	55429	KY	Re-circulating	Biomass	Wells	307
SOHL	Mill Creek	1364	KY	Once-Through	Coal	Ohio River	72,487
SOHL	Mill Creek	1364	KY	Re-circulating	Coal	Ohio River	8,464
SOHL	Cane Run	1363	KY	Once-Through	Coal	Ohio River	124,049
SOHL	R Gallagher	1008	IN	Once-Through	Coal	Ohio River	99,158
SOHL	Trimble County	6071	KY	Re-circulating	Coal	Ohio River	4,142
SOHL	Clifty Creek	983	IN	Once-Through	Coal	Ohio River	305,902
SOHL	Ghent	1356	KY	Re-circulating	Coal	Ohio River	12,568
SOHL	W H Zimmer	6019	OH	Re-circulating	Coal	Ohio River	9,433
SOHL	East Bend	6018	KY	Re-circulating	Coal	Ohio River	4,263
SOHL	Lawrenceburg Energy Facility	55502	IN	Re-circulating	Natural Gas	Tanners Creek	171

Ohio River Basin Thermoelectric Power Plants by Forecast Group							
Forecast Group	Plant Name	Plant ID	State	Cooling Process	Fuel Type	Cooling Water Source	Water Extraction in MG/Y
SOHL	Miami Fort	2832	OH	Once-Through	Coal	Ohio River	39,229
SOHL	Miami Fort	2832	OH	Re-circulating	Coal	Ohio River	6,397
SOHL	Procter & Gamble Cincinnati Plant	50456	OH	Re-circulating	Coal	Wells	46
SOHP	Richard Gorsuch	7286	OH	Once-Through	Coal	Ohio River	43,235
SOHP	Pleasants Power Station	6004	WV	Re-circulating	Coal	Ohio River	8,421
SOHP	Willow Island	3946	WV	Once-Through	Coal	Ohio River	17,902
SOHP	AEP Waterford Facility	55503	OH	Re-circulating	Natural Gas	Muskingum River	70
SOHP	Washington Energy Facility	55397	OH	Re-circulating	Natural Gas	Muskingum River	77
SOHP	Muskingum River	2872	OH	Once-Through	Coal	Muskingum River	170,047
SOHP	Muskingum River	2872	OH	Re-circulating	Coal	Muskingum River	4,471
SOHS	Marion	976	IL	Cooling Pond	Coal	Lake of Egypt	18,504
SOHS	Elmer Smith	1374	KY	Once-Through	Coal	Ohio River	74,445
SOHS	A B Brown	6137	IN	Re-circulating	Coal	Ohio River	3,325
SOHS	F B Culley	1012	IN	Once-Through	Coal	Ohio River	88,941
SOHS	Warrick	6705	IN	Once-Through	Coal	Ohio River	140,944
SOHS	Rockport	6166	IN	Re-circulating	Coal	Ohio River	20,000
SOHS	Kenneth C Coleman	1381	KY	Once-Through	Coal	Ohio River	107,358
SOHW	PPG Natrium Plant	50491	WV	Once-Through	Coal	Ohio River	8,428
SOHW	PPG Natrium Plant	50491	WV	Re-circulating	Coal	Ohio River	221
SOHW	Mitchell	3948	WV	Re-circulating	Coal	Ohio River	10,692
SOHW	Kammer	3947	WV	Once-Through	Coal	Ohio River	113,240
SOHW	R E Burger	2864	OH	Once-Through	Coal	Ohio River	52,048
SOHW	Cardinal	2828	OH	Once-Through	Coal	Ohio River	254,564
SOHW	Cardinal	2828	OH	Re-circulating	Coal	Ohio River	3,400
SOHW	W H Sammis	2866	OH	Once-Through	Coal	Ohio River	535,362
SOHW	Beaver Valley	6040	PA	Re-circulating	Nuclear	Ohio River	16,153
SOHW	Bruce Mansfield	6094	PA	Re-circulating	Coal	Ohio River	18,650
SOHW	AES Beaver Valley Partners Beaver Valley	10676	PA	Once-Through	Coal	Nova Chemical Co	30,715
SOHW	G F Weaton Power Station	50130	PA	Once-Through	Coal	Ohio River	18,439

Ohio River Basin Thermoelectric Power Plants by Forecast Group							
Forecast Group	**Plant Name**	**Plant ID**	**State**	**Cooling Process**	**Fuel Type**	**Cooling Water Source**	**Water Extraction in MG/Y**
SSCI	P H Glatfelter Co - Chillicothe Facility	10244	OH	Once-Through	Biomass	Wells and Surface Water	12,696
SSCI	P H Glatfelter Co - Chillicothe Facility	10244	OH	Once-Through	Coal	Wells and Surface Water	6,811
SSCI	Picway	2843	OH	Once-Through	Coal	Scioto River	11,971
SWBL	Gibson	6113	IN	Cooling Pond	Coal	Gibson Lake	267,769
SWBL	Jasper 2	6225	IN	Re-circulating	Coal	Municipality	56
SWBL	Merom	6213	IN	Cooling Pond	Coal	Turtle Creek Reservoir Cooling	79,499
SWBL	Hutsonville	863	IL	Once-Through	Coal	Wabash River	34,821
SWBL	Sugar Creek Power	55364	IN	Re-circulating	Natural Gas	Collector Well	39
SWBL	Wabash River	1010	IN	Once-Through	Coal	Wabash River	174,100
SWBL	Cayuga	1001	IN	Once-Through	Coal	Wabash River	225,082
SWBL	University of Illinois Abbott Power Plt	54780	IL	Re-circulating	Coal	Illinois American Water	83
SWBL	Bunge Milling Cogen	51000	IL	Re-circulating	Coal	Wells	93
SWBL	Clinton Power Station	204	IL	Cooling Pond	Nuclear	Salt Creek	60,277
SWBL	Vermilion	897	IL	Re-circulating	Coal	Vermilion Reservoir	939
SWBL	Purdue University	50240	IN	Re-circulating	Coal	Wells	95
SWBU	Sagamore Plant Cogeneration	50903	IN	Re-circulating	Coal	Wells	35
SWBU	Logansport	1032	IN	Once-Through	Coal	Eel River	5,759
SWBU	Peru	1037	IN	Once-Through	Coal	Wabash River	1,990
SWHT	AES Petersburg	994	IN	Once-Through	Coal	River	173,140
SWHT	AES Petersburg	994	IN	Re-circulating	Coal	River	6,960
SWHT	Frank E Ratts	1043	IN	Once-Through	Coal	White River Cooling	62,160
SWHT	Edwardsport	1004	IN	Once-Through	Coal	White River	9,648
SWHT	Edwardsport	1004	IN	Once-Through	Oil	White River	10
SWHT	Harding Street	990	IN	Once-Through	Coal	River	41,425
SWHT	Harding Street	990	IN	Once-Through	Oil	River	7
SWHT	Harding Street	990	IN	Re-circulating	Coal	River	2,250
SWHT	CC Perry K	992	IN	Re-circulating	Coal	W. Fork, White River	1
SWHT	Crawfordsville	1024	IN	Re-circulating	Coal	Wells	26
SWHT	Noblesville	1007	IN	Re-circulating	Natural Gas	White River	104

Table B-20: Power Plants Withdrawing Cooling Water from the Mainstem Ohio River

Mile Point	Station Name	Fuel Type	Capacity (MW)	Cooling Type	Water Withdrawal (MGD)
15.3	F. R. Phillips	Coal	365	Once Through	234
34.0	Bruce Mansfield	Coal	2,505	Off Steam*	45
34.9	Beaver Valley (1&2)	Nuclear	1,643	Off Steam*	58
53.0	W.H. Sammis	Coal	2,303	Once Through	1,094
76.5	Cardinal (1&2)	Coal	1,200	Once Through	1,165
77.3	Cardinal (Unit 3)	Coal	630	Off Steam*	In above
102.0	R.E. Burger	Coal	544	Once Through	651
111.0	Kammer	Coal	713	Once Through	655
112.5	Mitchell	Coal	1,632	Off Steam*	35
119.5	New Martinsville	Coal	124	Once Through	NA
160.0	Pleasants	Coal	1,300	Off Steam*	15
160.5	Willow Island	Coal	243	Once Through	121
176.8	Marietta	Coal	213	Once Through	Inactive
241.6	Phillip Sporn	Coal	1,050	Once Through	1,058
242.5	Mountaineer	Coal	1,300	Off Steam*	22
258.0	Gen. J.M. Gavin	Coal	2,600	Off Steam*	173
260.0	Kyger Creek	Coal	1,086	Once Through	1,109
390.0	Killen	Coal	666	Off Steam*	8
404.7	J.M.Stuart (1,2,3 &4)	Coal	1,830	Once Through	839
414.0	H.L. Spurlock	Coal	800	Off Steam*	4
443.5	Zimmer	Coal	1,300	Off Steam*	41
453.0	W. C. Beckjord	Coal	1,125	Once Through	619
490.0	Miami Fort	Coal	163	Once Through	184
490.0		Coal	1,000	Off Steam*	NA
495.5	Tanners Creek	Coal	995	Once Through	1,093
510.0	East Bend	Coal	600	Off Steam*	15
536.0	Ghent	Coal	2,200	Off Steam*	69
560.0	Clifty Creek	Coal	1,304	Once Through	1,267
571.8	Trimble County	Coal	500	Off Steam*	6
610.0	Gallagher	Coal	600	Once Through	244
616.8	Cane Run	Coal	608	Once Through	498
		Gas	140	Once Through	108
625.9	Mill Creek	Coal	321	Once Through	242
		Coal	1,241	Off Steam*	20
728.4	Coleman	Coal	485	Once Through	258
745.0	Rockport	Coal	2,600	Off Steam*	43
753.5	Elmer Smith	Coal	416	Once Through	204

Mile Point	Station Name	Fuel Type	Capacity (MW)	Cooling Type	Water Withdrawal (MGD)
773.0	F.B. Culley	Coal	389	Once Through	284
773.5	Warrick	Coal	720	Once Through	409
803.6	Henderson	Coal	38	Once Through	15
817.0	A.B. Brown	Coal	530	Off Steam*	4
946.0	Shawnee	Coal	1,750	Once Through	1,490
952.3	Joppa	Coal	1,086	Once Through	467

** Off Steam refers to a re-circulation system using cooling towers.*

Table B-21: Potential Impacts to Ohio River Basin Dams w/Flood Control and Stormwater Purposes

Potential Flow Discharge Impacts to Ohio River Basin Dams w/Flood Control and Stormwater Purposes										
Forecast Group	Project Name	2011-2040			2041-2070			2071-2099		
		Annual Max	March Mean	March Max	Annual Max	March Mean	March Max	Annual Max	March Mean	March Max
SAGL	CONEMAUGH DAM	+15 to +25	+15 to +25	+25 to +35	+15 to +25	+25 to +35	+25 to +35	+25 to +35	+35 to +50	+35 to +50
SAGL	CROOKED CREEK DAM	+15 to +25	+15 to +25	+25 to +35	+15 to +25	+25 to +35	+25 to +35	+25 to +35	+35 to +50	+35 to +50
SAGL	MAHONING CREEK DAM	+15 to +25	+15 to +25	+25 to +35	+15 to +25	+25 to +35	+25 to +35	+25 to +35	+35 to +50	+35 to +50
SAGL	PINEY	+15 to +25	+15 to +25	+25 to +35	+15 to +25	+25 to +35	+25 to +35	+25 to +35	+35 to +50	+35 to +50
SAGL	LAKE WILHELM (PA-475)	+15 to +25	+15 to +25	+25 to +35	+15 to +25	+25 to +35	+25 to +35	+25 to +35	+35 to +50	+35 to +50
SAGL	EAST BRANCH DAM	+15 to +25	+15 to +25	+25 to +35	+15 to +25	+25 to +35	+25 to +35	+25 to +35	+35 to +50	+35 to +50
SAGU	TWO MILE RUN	+15 to +25	+15 to +25	+25 to +35	+15 to +25	+25 to +35	+25 to +35	+25 to +35	+35 to +50	+35 to +50
SAGU	TIONESTA DAM	+15 to +25	+15 to +25	+25 to +35	+15 to +25	+25 to +35	+25 to +35	+25 to +35	+35 to +50	+35 to +50
SAGU	TAMARACK LAKE B (PA-461B)	+15 to +25	+15 to +25	+25 to +35	+15 to +25	+25 to +35	+25 to +35	+25 to +35	+35 to +50	+35 to +50
SAGU	TAMARACK LAKE A (PA-461A)	+15 to +25	+15 to +25	+25 to +35	+15 to +25	+25 to +35	+25 to +35	+25 to +35	+35 to +50	+35 to +50
SAGU	WOODCOCK CREEK DAM	+15 to +25	+15 to +25	+25 to +35	+15 to +25	+25 to +35	+25 to +35	+25 to +35	+35 to +50	+35 to +50
SAGU	KINZUA DAM	+15 to +25	+15 to +25	+25 to +35	+15 to +25	+25 to +35	+25 to +35	+25 to +35	+35 to +50	+35 to +50
SBVR	BERLIN DAM				+15 to +25			+25 to +35	+15 to +25	
SBVR	MICHAEL J KIRWAN DAM AND RESERVOIR				+15 to +25			+25 to +35	+15 to +25	
SBVR	SHENANGO DAM				+15 to +25			+25 to +35	+15 to +25	
SBVR	MOSQUITO CREEK DAM				+15 to +25			+25 to +35	+15 to +25	
SBVR	PYMATUNING				+15 to +25			+25 to +35	+15 to +25	
SCML	CENTER HILL DAM	+15 to +25			+15 to +25		+15 to +25	+15 to +25		+15 to +25
SCML	J PERCY PRIEST DAM	+15 to +25			+15 to +25		+15 to +25	+15 to +25		+15 to +25

Potential Flow Discharge Impacts to Ohio River Basin Dams w/Flood Control and Stormwater Purposes										
Forecast Group	Project Name	2011-2040			2041-2070			2071-2099		
		Annual Max	March Mean	March Max	Annual Max	March Mean	March Max	Annual Max	March Mean	March Max
SCML	DALE HOLLOW DAM	+15 to +25			+15 to +25		+15 to +25	+15 to +25		+15 to +25
SCMU	MARTINS FORK DAM	+15 to +25			+15 to +25		+15 to +25	+15 to +25		+15 to +25
SCMU	WOLF CREEK	+15 to +25			+15 to +25		+15 to +25	+15 to +25		+15 to +25
SCMU	LAUREL DAM	+15 to +25			+15 to +25		+15 to +25	+15 to +25		+15 to +25
SEFW	MONROE LAKE DAM			+15 to +25			+15 to +25	+25 to +35		
SGRN	GREEN RIVER LAKE DAM							+15 to +25		+15 to +25
SGRN	NOLIN LAKE DAM							+15 to +25		+15 to +25
SGRN	ROUGH RIVER LAKE DAM							+15 to +25		+15 to +25
SHOC	TOM JENKINS DAM				+5 to +15			+15 to +25		
SKAN	BLUESTONE DAM	+15 to +25			+25 to +35		+15 to +25	+25 to +35		+15 to +25
SKAN	SUMMERSVILLE DAM	+15 to +25			+25 to +35		+15 to +25	+25 to +35		+15 to +25
SKAN	SUTTON DAM	+15 to +25			+25 to +35		+15 to +25	+25 to +35		+15 to +25
SKTY	CARR CREEK LAKE–SEDIMENT DAM 1							+15 to +25		
SKTY	CARR CREEK LAKE–SEDIMENT DAM 2							+15 to +25		
SKTY	CARR CREEK LAKE DAM							+15 to +25		
SKTY	CARR CREEK LAKE–SEDIMENT DAM 3							+15 to +25		
SKTY	BUCKHORN LAKE DAM							+15 to +25		
SKTY	TAYLORSVILLE LAKE DAM							+15 to +25		

Potential Flow Discharge Impacts to Ohio River Basin Dams w/Flood Control and Stormwater Purposes										
Forecast Group	Project Name	2011-2040			2041-2070			2071-2099		
		Annual Max	March Mean	March Max	Annual Max	March Mean	March Max	Annual Max	March Mean	March Max
SLIK	CAVE RUN LAKE DAM							+15 to +25		
SLKH	BURNSVILLE LAKE DAM				+15 to +25			+15 to +25		
SMIM	WILLIAM H. HARSHA LAKE DAM				+15 to +25			+15 to +25		
SMIM	CAESAR CREEK LAKE SADDLE DAM #2				+15 to +25			+15 to +25		
SMIM	CAESAR CREEK LAKE SADDLE DAM #3				+15 to +25			+15 to +25		
SMIM	CAESAR CREEK LAKE DAM AND SADDLE DAMS #1 AND #4				+15 to +25			+15 to +25		
SMIM	BROOKVILLE LAKE DAM–DUNLAPSVILLE LEVEE				+15 to +25			+15 to +25		
SMIM	CLARENCE J BROWN DAM				+15 to +25			+15 to +25		
SMKL	SENECAVILLE DAM							+25 to +35		
SMKL	DILLON DAM							+25 to +35		
SMKL	WILLS CREEK DAM							+25 to +35		
SMKL	PLEASANT HILL DAM							+25 to +35		
SMKL	CHARLES MILL DAM							+25 to +35		
SMKU	PIEDMONT DAM							+25 to +35		
SMKU	CLENDENING DAM							+25 to +35		
SMKU	TAPPAN DAM							+25 to +35		
SMKU	LEESVILLE DAM							+25 to +35		
SMKU	ATWOOD DAM							+25 to +35		

Potential Flow Discharge Impacts to Ohio River Basin Dams w/Flood Control and Stormwater Purposes										
Forecast Group	Project Name	2011-2040			2041-2070			2071-2099		
		Annual Max	March Mean	March Max	Annual Max	March Mean	March Max	Annual Max	March Mean	March Max
SMNL	YOUGHIOGHENY DAM	+15 to +25			+15 to +25			+25 to +35		+15 to +25
SMNU	STONEWALL JACKSON DAM, WV	+15 to +25			+15 to +25			+25 to +35		+15 to +25
SMNU	TYGART DAM	+15 to +25			+15 to +25			+25 to +35		+15 to +25
SOHH	EAST LYNN DAM	+15 to +25			+15 to +25	+15 to +25	+15 to +25	+25 to +35	+15 to +25	+25 to +35
SOHH	UPPER MUD RIVER NO.2A	+15 to +25			+15 to +25	+15 to +25	+15 to +25	+25 to +35	+15 to +25	+25 to +35
SOHH	GRAYSON DAM	+15 to +25			+15 to +25	+15 to +25	+15 to +25	+25 to +35	+15 to +25	+25 to +35
SOHH	BEECH FORK LAKE DAM	+15 to +25			+15 to +25	+15 to +25	+15 to +25	+25 to +35	+15 to +25	+25 to +35
SOHP	NORTH FORK HUGHES RIVER SITE 21C DAM	+15 to +25			+15 to +25	+15 to +25	+15 to +25	+25 to +35	+25 to +35	+25 to +35
SOHW	CROSS CREEK (PA-661)	+15 to +25			+15 to +25	+15 to +25	+15 to +25	+25 to +35	+25 to +35	+25 to +35
SSAY	N. FORK OF POUND DAM	+15 to +25		+15 to +25	+25 to +35	+15 to +25	+15 to +25	+35 to +50		+25 to +35
SSAY	FISHTRAP DAM	+15 to +25		+15 to +25	+25 to +35	+15 to +25	+15 to +25	+35 to +50		+25 to +35
SSAY	R D BAILEY DAM	+15 to +25		+15 to +25	+25 to +35	+15 to +25	+15 to +25	+35 to +50		+25 to +35
SSAY	DEWEY DAM	+15 to +25		+15 to +25	+25 to +35	+15 to +25	+15 to +25	+35 to +50		+25 to +35
SSAY	PAINTSVILLE DAM	+15 to +25		+15 to +25	+25 to +35	+15 to +25	+15 to +25	+35 to +50		+25 to +35
SSAY	YATESVILLE DAM	+15 to +25		+15 to +25	+25 to +35	+15 to +25	+15 to +25	+35 to +50		+25 to +35
SSAY	JOHN W. FLANNAGAN DAM & RES.	+15 to +25		+15 to +25	+25 to +35	+15 to +25	+15 to +25	+35 to +50		+25 to +35
SSCI	PAINT CREEK DAM							+15 to +25		

Potential Flow Discharge Impacts to Ohio River Basin Dams w/Flood Control and Stormwater Purposes										
Forecast Group	Project Name	2011-2040			2041-2070			2071-2099		
		Annual Max	March Mean	March Max	Annual Max	March Mean	March Max	Annual Max	March Mean	March Max
SSCI	DEER CREEK DAM							+15 to +25		
SSCI	ALUM CREEK DAM							+15 to +25		
SSCI	DELAWARE DAM							+15 to +25		
SWBL	PATOKA LAKE DAM			+25 to +35	+15 to +25	+15 to +25	+25 to +35	+25 to +35	+15 to +25	+15 to +25
SWBL	MILL CREEK STRUCTURE 1 DAM			+25 to +35	+15 to +25	+15 to +25	+25 to +35	+25 to +35	+15 to +25	+15 to +25
SWBL	CECIL M HARDEN LAKE DAM			+25 to +35	+15 to +25	+15 to +25	+25 to +35	+25 to +35	+15 to +25	+15 to +25
SWBU	MISSISSINEWA LAKE DAM			+25 to +35	+15 to +25	+15 to +25	+25 to +35	+25 to +35	+15 to +25	+15 to +25
SWBU	LANCASTER LEVEE AND DIKE			+25 to +35	+15 to +25	+15 to +25	+25 to +35	+25 to +35	+15 to +25	+15 to +25
SWBU	J. EDWARD ROUSH LAKE DAM			+25 to +35	+15 to +25	+15 to +25	+25 to +35	+25 to +35	+15 to +25	+15 to +25
SWHT	WEST BOGGS CREEK STRUCTURE NO. 1			+15 to +25	+15 to +25		+15 to +25	+25 to +35		
SWHT	GREENWOOD LAKE DAM			+15 to +25	+15 to +25		+15 to +25	+25 to +35		
SWHT	CAGLES MILL LAKE DAM			+15 to +25	+15 to +25		+15 to +25	+25 to +35		

Table B-22: Potential Impacts to Ohio River Basin Dams w/Hydropower and Water Supply Purposes

Potential Discharge Impacts to Ohio River Basin Dams w/Hydropower and Water Supply Purposes										
Forecast Group	Project Name	2011-2040			2041-2070			2071-2099		
		Annual Min	October Mean	October Min	Annual Min	October Mean	October Min	Annual Min	October Mean	October Min
SAGL	PINEY						-5 to -15			-5 to -15
SAGU	KINZUA DAM						-5 to -15			-5 to -15
SBVR	BERLIN DAM						-5 to -15			-5 to -15
SBVR	MICHAEL J KIRWAN DAM AND RESERVOIR						-5 to -15			-5 to -15
SBVR	MOSQUITO CREEK DAM						-5 to -15			-5 to -15
SCML	CENTER HILL DAM									
SCML	J PERCY PRIEST DAM									
SCML	DALE HOLLOW DAM									
SCMU	STONEY FORK SLURRY DAM									
SCMU	ABNER FORK DAM									
SCMU	WOLF CREEK									
SCMU	LAUREL DAM									
SEFW	MONROE LAKE DAM						-15 to -25	-5 to -15		-15 to -25
SGRN	GREEN RIVER LAKE DAM									-5 to -15
SGRN	ROUGH RIVER LAKE DAM									-5 to -15

Potential Discharge Impacts to Ohio River Basin Dams w/Hydropower and Water Supply Purposes										
Forecast Group	Project Name	2011-2040			2041-2070			2071-2099		
		Annual Min	October Mean	October Min	Annual Min	October Mean	October Min	Annual Min	October Mean	October Min
SHOC	TOM JENKINS DAM	-5 to -15		-5 to -15	-5 to -15	-5 to -15	-15 to -25	-15 to -25		-25 to -35
SKAN	CLAYTOR									-5 to -15
SKAN	HAWKS NEST									-5 to -15
SKAN	POCATALICO STRUCTURE NO.28									-5 to -15
SKTY	LOVELY BRANCH SLURRY DAM						-15 to -25	-5 to -15	-5 to -15	-35 to -50
SKTY	HALF MILE DAM						-15 to -25	-5 to -15	-5 to -15	-35 to -50
SKTY	ADAMS FORK SLURRY DAM						-15 to -25	-5 to -15	-5 to -15	-35 to -50
SKTY	BRITTON BRANCH REFUSE DAM						-15 to -25	-5 to -15	-5 to -15	-35 to -50
SKTY	BUCKEYE CREEK DAM						-15 to -25	-5 to -15	-5 to -15	-35 to -50
SKTY	BRUSHY FORK SLURRY DAM						-15 to -25	-5 to -15	-5 to -15	-35 to -50
SKTY	MOTHER ANN LEE HYDROELECTRIC STATION						-15 to -25	-5 to -15	-5 to -15	-35 to -50
SLIK	CEDAR CREEK DAM						-15 to -25		-5 to -15	-35 to -50
SLWA	STEPHEN A. FORBES STATE PARK LAKE DAM									-5 to -15
SLWA	EAST FORK LAKE DAM									-5 to -15
SLWA	LAKE SARA DAM									-5 to -15
SLWA	LAKE MATTOON DAM									-5 to -15
SMIM	WILLIAM H. HARSHA LAKE DAM	-5 to -15	-5 to -15	-5 to -15	-5 to -15	-5 to -15	-15 to -25	-5 to -15	-5 to -15	-25 to -35

Potential Discharge Impacts to Ohio River Basin Dams w/Hydropower and Water Supply Purposes										
Forecast Group	Project Name	2011-2040			2041-2070			2071-2099		
		Annual Min	October Mean	October Min	Annual Min	October Mean	October Min	Annual Min	October Mean	October Min
SMIM	CAESAR CREEK LAKE SADDLE DAM #2	-5 to -15	-5 to -15	-5 to -15	-5 to -15	-5 to -15	-15 to -25	-5 to -15	-5 to -15	-25 to -35
SMIM	CAESAR CREEK LAKE SADDLE DAM #3	-5 to -15	-5 to -15	-5 to -15	-5 to -15	-5 to -15	-15 to -25	-5 to -15	-5 to -15	-25 to -35
SMIM	CAESAR CREEK LAKE DAM AND SADDLE DAMS #1 AND #4	-5 to -15	-5 to -15	-5 to -15	-5 to -15	-5 to -15	-15 to -25	-5 to -15	-5 to -15	-25 to -35
SMIM	BROOKVILLE LAKE DAM–DUNLAPSVILLE LEVEE	-5 to -15	-5 to -15	-5 to -15	-5 to -15	-5 to -15	-15 to -25	-5 to -15	-5 to -15	-25 to -35
SMNL	DEEP CREEK DAM									-5 to -15
SMNU	STONEWALL JACKSON DAM, WV									-5 to -15
SMNU	LAKE LYNN									-5 to -15
SOHP	NORTH FORK HUGHES RIVER SITE 21C DAM						-5 to -15			-5 to -15
SOHS	MARION NEW LAKE DAM–N/C						-5 to -15			-25 to -35
SOHS	RIVER VIEW IMPOUNDMENT "SLURRY"						-5 to -15			-25 to -35
SOHW	CROSS CREEK (PA-661)						-5 to -15			-5 to -15
SSAY	N. FORK OF POUND DAM									
SSAY	JOHN W. FLANNAGAN DAM & RES.									

Potential Discharge Impacts to Ohio River Basin Dams w/Hydropower and Water Supply Purposes										
Forecast Group	Project Name	2011-2040			2041-2070			2071-2099		
		Annual Min	October Mean	October Min	Annual Min	October Mean	October Min	Annual Min	October Mean	October Min
SSCI	PAINT CREEK DAM	-5 to -15						-5 to -15		-15 to -25
SSCI	O'SHAUGHNESSY	-5 to -15						-5 to -15		-15 to -25
SSCI	ALUM CREEK DAM	-5 to -15						-5 to -15		-15 to -25
SSCI	DELAWARE DAM	-5 to -15						-5 to -15		-15 to -25
SWBL	PATOKA LAKE DAM							-5 to -15		-15 to -25
SWBU	OAKDALE							-5 to -15		-15 to -25
SWBU	NORWAY							-5 to -15		-15 to -25
SWHT	GREENWOOD LAKE DAM						-15 to -25	-5 to -15		-15 to -25

Table B-23: Potential Impacts to Ohio River Basin Dams w/Poor or Unsatisfactory Performance

Potential Discharge Impacts to Ohio River Basin Dams w/Hydropower and Water Supply Purposes										
Forecast Group	Project Name	2011-2040			2041-2070			2071-2099		
		Annual Min	March Mean	March Max	Annual Max	March Mean	March Max	Annual Max	March Mean	March Max
SAGL	EAST BRANCH DAM	+15 to +25	+15 to +25	+25 to +35	+15 to +25	+25 to +35	+25 to +35	+25 to +35	+35 to +50	+35 to +50
SAGU	KINZUA DAM	+15 to +25	+15 to +25	+25 to +35	+15 to +25	+25 to +35	+25 to +35	+25 to +35	+35 to +50	+35 to +50
SBVR	BERLIN DAM				+15 to +25			+25 to +35	+15 to +25	
SCML	CENTER HILL DAM	+15 to +25			+15 to +25		+15 to +25	+15 to +25		+15 to +25
SCML	J PERCY PRIEST DAM	+15 to +25			+15 to +25		+15 to +25	+15 to +25		+15 to +25
SCML	DALE HOLLOW DAM	+15 to +25			+15 to +25		+15 to +25	+15 to +25		+15 to +25
SCMU	WOLF CREEK	+15 to +25			+15 to +25		+15 to +25	+15 to +25		+15 to +25
SGRN	GREEN RIVER LAKE DAM							+15 to +25		+15 to +25
SGRN	NOLIN LAKE DAM							+15 to +25		+15 to +25
SGRN	ROUGH RIVER LAKE DAM							+15 to +25		+15 to +25
SKAN	BLUESTONE DAM	+15 to +25			+25 to +35		+15 to +25	+25 to +35		+15 to +25
SKAN	SUTTON DAM	+15 to +25			+25 to +35		+15 to +25	+25 to +35		+15 to +25
SKTY	CARR CREEK LAKE–SEDIMENT DAM 1							+15 to +25		
SKTY	CARR CREEK LAKE–SEDIMENT DAM 2							+15 to +25		

Potential Discharge Impacts to Ohio River Basin Dams w/Hydropower and Water Supply Purposes										
Forecast Group	Project Name	2011-2040			2041-2070			2071-2099		
		Annual Min	March Mean	March Max	Annual Max	March Mean	March Max	Annual Max	March Mean	March Max
SKTY	CARR CREEK LAKE–SEDIMENT DAM 3							+15 to +25		
SKTY	BUCKHORN LAKE DAM							+15 to +25		
SLIK	CAVE RUN LAKE DAM							+15 to +25		
SLKH	BURNSVILLE LAKE DAM				+15 to +25			+15 to +25		
SMIM	WILLIAM H. HARSHA LAKE DAM				+15 to +25			+15 to +25		
SMIM	CAESAR CREEK LAKE DAM AND SADDLE DAMS #1 AND #4				+15 to +25			+15 to +25		
SMIM	BROOKVILLE LAKE DAM–DUNLAPSVILLE LEVEE				+15 to +25			+15 to +25		
SMKL	SENECAVILLE DAM							+25 to +35		
SMKU	CLENDENING DAM							+25 to +35		
SMKU	TAPPAN DAM							+25 to +35		
SMKU	ATWOOD DAM							+25 to +35		
SMNL	YOUGHIOGHENY DAM	+15 to +25			+15 to +25			+25 to +35		+15 to +25
SOHH	BEECH FORK LAKE DAM	+15 to +25			+15 to +25	+15 to +25	+15 to +25	+25 to +35	+15 to +25	+25 to +35
SSAY	R D BAILEY DAM	+15 to +25		+15 to +25	+25 to +35	+15 to +25	+15 to +25	+35 to +50		+25 to +35

Potential Discharge Impacts to Ohio River Basin Dams w/Hydropower and Water Supply Purposes										
Forecast Group	Project Name	2011-2040			2041-2070			2071-2099		
		Annual Min	March Mean	March Max	Annual Max	March Mean	March Max	Annual Max	March Mean	March Max
SSCI	PAINT CREEK DAM							+15 to +25		
SSCI	DEER CREEK DAM							+15 to +25		
SSCI	DELAWARE DAM							+15 to +25		
SWBL	PATOKA LAKE DAM			+25 to +35	+15 to +25	+15 to +25	+25 to +35	+25 to +35	+15 to +25	+15 to +25
SWBL	CECIL M HARDEN LAKE DAM			+25 to +35	+15 to +25	+15 to +25	+25 to +35	+25 to +35	+15 to +25	+15 to +25
SWBU	OAKDALE			+25 to +35	+15 to +25	+15 to +25	+25 to +35	+25 to +35	+15 to +25	+15 to +25
SWBU	MISSISSINEWA LAKE DAM			+25 to +35	+15 to +25	+15 to +25	+25 to +35	+25 to +35	+15 to +25	+15 to +25
SWBU	NORWAY			+25 to +35	+15 to +25	+15 to +25	+25 to +35	+25 to +35	+15 to +25	+15 to +25
SWBU	J. EDWARD ROUSH LAKE DAM			+25 to +35	+15 to +25	+15 to +25	+25 to +35	+25 to +35	+15 to +25	+15 to +25

Table B-24: Potential Impacts to Ohio River Basin Levees and Floodwalls (LPPs)

Potential Flow Discharge Impacts to Ohio River Basin Levees and Floodwalls (LPP's)										
Forecast Group	Project Name	2011-2040			2041-2070			2071-2099		
		Annual Max	March Mean	March Max	Annual Max	March Mean	March Max	Annual Max	March Mean	March Max
SCML	METRO CENTER LEVEE, DAVIDSON COUNTY, TN	+15 to +25			+15 to +25		+15 to +25	+15 to +25		+15 to +25
SHOC	ATHENS, OH, LPP				+5 to +15			+15 to +25		
SKAN	GALAX, VA, LPP	+15 to +25			+25 to +35		+15 to +25	+25 to +35		+15 to +25
SKAN	PRINCETON, WV, LPP	+15 to +25			+25 to +35		+15 to +25	+25 to +35		+15 to +25
SKAN	RAINELLE, WV, LPP	+15 to +25			+25 to +35		+15 to +25	+25 to +35		+15 to +25
SKAN	MARLINTON, WV LPP	+15 to +25			+25 to +35		+15 to +25	+25 to +35		+15 to +25
SMKL	MOUNT VERNON, OH, LPP							+25 to +35		
SMKL	PAVONIA LEVEE, CHARLES MILL LAKE, OH							+25 to +35		
SMKU	SOMERDALE LEVEE, DOVER DAM, OH							+25 to +35		
SMKU	FAIRFIELD LEVEE, DOVER DAM, OH							+25 to +35		
SMKU	SILICA SAND LEVEE, BEACH CITY LAKE, OH							+25 to +35		
SMKU	NORTON LEVEE, DOVER DAM, OH							+25 to +35		
SMKU	ZOAR LEVEE, DOVER DAM, OH							+25 to +35		
SMKU	CORUNDITE LEVEE, DOVER DAM, OH							+25 to +35		
SMKU	MAGNOLIA LEVEE, BOLIVAR DAM, OH							+25 to +35		

Potential Flow Discharge Impacts to Ohio River Basin Levees and Floodwalls (LPP's)										
Forecast Group	Project Name	2011-2040			2041-2070			2071-2099		
		Annual Max	March Mean	March Max	Annual Max	March Mean	March Max	Annual Max	March Mean	March Max
SMKU	EAST SPARTA LEVEE, BOLIVAR DAM, OH							+25 to +35		
SMKU	BREWSTER LEVEE, BEACH CITY LAKE, OH							+25 to +35		
SOHC	MAYSVILLE, KY, LPP	+15 to +25			+15 to +25		+15 to +25	+25 to +35	+15 to +25	+25 to +35
SOHH	GRIFFITHSVILLE-YAWKEY, WV, LPP	+15 to +25			+15 to +25	+15 to +25	+15 to +25	+25 to +35	+15 to +25	+25 to +35
SOHH	GRAHN, KY, LPP	+15 to +25			+15 to +25	+15 to +25	+15 to +25	+25 to +35	+15 to +25	+25 to +35
SOHH	OLIVE HILL, KY, LPP	+15 to +25			+15 to +25	+15 to +25	+15 to +25	+25 to +35	+15 to +25	+25 to +35
SOHH	CEREDO-KENOVA, WV, LPP	+15 to +25			+15 to +25	+15 to +25	+15 to +25	+25 to +35	+15 to +25	+25 to +35
SOHH	CATLETTSBURG, KY, LPP	+15 to +25			+15 to +25	+15 to +25	+15 to +25	+25 to +35	+15 to +25	+25 to +35
SOHH	HUNTINGTON, WV, LPP	+15 to +25			+15 to +25	+15 to +25	+15 to +25	+25 to +35	+15 to +25	+25 to +35
SOHH	ASHLAND, KY, LPP	+15 to +25			+15 to +25	+15 to +25	+15 to +25	+25 to +35	+15 to +25	+25 to +35
SOHH	IRONTON, OH, LPP	+15 to +25			+15 to +25	+15 to +25	+15 to +25	+25 to +35	+15 to +25	+25 to +35
SOHH	RUSSELL, KY, LPP	+15 to +25			+15 to +25	+15 to +25	+15 to +25	+25 to +35	+15 to +25	+25 to +35
SOHH	PORTSMOUTH-NEW BOSTON, OH, LPP	+15 to +25			+15 to +25	+15 to +25	+15 to +25	+25 to +35	+15 to +25	+25 to +35
SOHH	POINT PLEASANT, WV, LPP	+15 to +25			+15 to +25	+15 to +25	+15 to +25	+25 to +35	+15 to +25	+25 to +35
SOHP	PARKERSBURG, WV, LPP	+15 to +25			+15 to +25	+15 to +25	+15 to +25	+25 to +35	+25 to +35	+25 to +35
SSAY	PIKEVILLE, KY, LPP	+15 to +25		+15 to +25	+25 to +35	+15 to +25	+15 to +25	+35 to +50		+25 to +35
SSAY	MATEWAN, WV, LPP	+15 to +25		+15 to +25	+25 to +35	+15 to +25	+15 to +25	+35 to +50		+25 to +35
SSAY	WEST WILLIAMSON, WV, LPP	+15 to +25		+15 to +25	+25 to +35	+15 to +25	+15 to +25	+35 to +50		+25 to +35
SSAY	WILLIAMSON, WV, CBD LPP	+15 to +25		+15 to +25	+25 to +35	+15 to +25	+15 to +25	+35 to +50		+25 to +35

Potential Flow Discharge Impacts to Ohio River Basin Levees and Floodwalls (LPP's)										
Forecast Group	Project Name	2011-2040			2041-2070			2071-2099		
		Annual Max	March Mean	March Max	Annual Max	March Mean	March Max	Annual Max	March Mean	March Max
SSAY	SOUTH WILLIAMSON, KY, LPP	+15 to +25		+15 to +25	+25 to +35	+15 to +25	+15 to +25	+35 to +50		+25 to +35
SSAY	PRESTONSBURG, KY, LPP	+15 to +25		+15 to +25	+25 to +35	+15 to +25	+15 to +25	+35 to +50		+25 to +35
SSAY	SOUTH WILLIAMSON, KY, ARH LPP	+15 to +25		+15 to +25	+25 to +35	+15 to +25	+15 to +25	+35 to +50		+25 to +35
SSAY	OCEANA LPP, WV	+15 to +25		+15 to +25	+25 to +35	+15 to +25	+15 to +25	+35 to +50		+25 to +35
SSAY	INEZ, KY, LPP	+15 to +25		+15 to +25	+25 to +35	+15 to +25	+15 to +25	+35 to +50		+25 to +35
SSCI	CHILLICOTHE, OH, LPP							+15 to +25		
SSCI	GREENFIELD LEVEE, PAINT CREEK LAKE, OH							+15 to +25		
SSCI	WASHINGTON COURT HOUSE, OH, LPP							+15 to +25		
SSCI	WALDO LEVEE, DELAWARE LAKE, OH							+15 to +25		
SWBL	LEVEE UNIT 5, IN			+25 to +35	+15 to +25	+15 to +25	+25 to +35	+25 to +35	+15 to +25	+15 to +25
SWBL	ROCHESTER AND MCCLEARY'S BLUFF LEVEE, IL			+25 to +35	+15 to +25	+15 to +25	+25 to +35	+25 to +35	+15 to +25	+15 to +25
SWBL	ENGLAND POND LEVEE, IL			+25 to +35	+15 to +25	+15 to +25	+25 to +35	+25 to +35	+15 to +25	+15 to +25
SWBL	RUSSELL & ALLISON LEVEE, IL			+25 to +35	+15 to +25	+15 to +25	+25 to +35	+25 to +35	+15 to +25	+15 to +25
SWBL	NIBLACK LEVEE, IN			+25 to +35	+15 to +25	+15 to +25	+25 to +35	+25 to +35	+15 to +25	+15 to +25
SWBL	ISLAND LEVEE, IN			+25 to +35	+15 to +25	+15 to +25	+25 to +35	+25 to +35	+15 to +25	+15 to +25
SWBL	LYFORD LEVEE, IN			+25 to +35	+15 to +25	+15 to +25	+25 to +35	+25 to +35	+15 to +25	+15 to +25
SWHT	LEVEE UNIT 8, IN			+15 to +25	+15 to +25		+15 to +25	+25 to +35		

Table B-25: Potential Impacts to Ohio River Basin Navigation Locks and Dams

Potential Flow Discharge Impacts to Ohio River Basin Navigation Locks and Dams										
Forecast Group	Project Name	2011-2040			2041-2070			2071-2099		
		Annual Min	October Mean	October Min	Annual Min	October Mean	October Min	Annual Min	October Mean	October Min
SAGL	LOCK AND DAM #3–ALLEGHENY RIVER						-5 to -15			-5 to -15
SAGL	LOCK AND DAM #4–ALLEGHENY RIVER						-5 to -15			-5 to -15
SAGL	LOCK AND DAM #5–ALLEGHENY RIVER						-5 to -15			-5 to -15
SAGL	LOCK AND DAM #6–ALLEGHENY RIVER						-5 to -15			-5 to -15
SAGL	LOCK AND DAM #7–ALLEGHENY RIVER						-5 to -15			-5 to -15
SAGL	LOCKAND DAM #8–ALLEGHENY RIVER						-5 to -15			-5 to -15
SAGL	LOCK AND DAM #9–ALLEGHENY RIVER						-5 to -15			-5 to -15
SCML	OLD HICKORY LOCK AND DAM–CUMBERLAND RIVER									
SCML	CHEATHAM LOCK AND DAM–CUMBERLAND RIVER									
SKAN	LONDON LOCK AND DAM–KANAWHA RIVER									-5 to -15
SKAN	MARMET LOCK AN DAM–KANAWHA RIVER									-5 to -15
SMNL	MAXWELL LOCK AND DAM–MONONGAHELA RIVER									-5 to -15

Potential Flow Discharge Impacts to Ohio River Basin Navigation Locks and Dams										
Forecast Group	Project Name	2011-2040			2041-2070			2071-2099		
		Annual Min	October Mean	October Min	Annual Min	October Mean	October Min	Annual Min	October Mean	October Min
SMNL	LOCK AND DAM #4–MONONGAHELA RIVER									-5 to -15
SMNL	LOCK AND DAM #3–MONONGAHELA RIVER									-5 to -15
SMNL	LOCK AND DAM #2–MONONGAHELA RIVER									-5 to -15
SMNU	OPEKISKA LOCK AND DAM–MONONGAHELA RIVER									-5 to -15
SMNU	HILDEBRAND LOCK AND DAM–MONONGAHELA RIVER									-5 to -15
SMNU	MORGANTOWN LOCK AND DAM–MONONGAHELA RIVER									-5 to -15
SMNU	PT. MARION LOCK AND DAM–MONONGAHELA RIVER									-5 to -15
SMNU	GRAYS LANDING LOCK AND DAM–MONONGAHELA RIVER									-5 to -15
SOHC	CAPTAIN ANTHONY MELDAHL LOCK AND DAM–OHIO RIVER						-5 to -15			-15 to -25
SOHH	WINFIELD LOCK AND DAM–KANAWHA RIVER						-5 to -15			-15 to -25
SOHH	GREENUP LOCK AND DAM–OHIO RIVER						-5 to -15			-15 to -25
SOHH	ROBERT C BYRD LOCK AND DAM–OHIO RIVER						-5 to -15			-15 to -25

Potential Flow Discharge Impacts to Ohio River Basin Navigation Locks and Dams										
Forecast Group	Project Name	2011-2040			2041-2070			2071-2099		
		Annual Min	October Mean	October Min	Annual Min	October Mean	October Min	Annual Min	October Mean	October Min
SOHH	RACINE LOCK AND DAM–OHIO RIVER						-5 to -15			-15 to -25
SOHL	MCALPINE LOCK AND DAM–OHIO RIVER						-5 to -15			-15 to -25
SOHL	MARKLAND LOCK AND DAM–OHIO RIVER						-5 to -15			-15 to -25
SOHL	CANNELTON LOCK AND DAM–OHIO RIVER						-5 to -15			-15 to -25
SOHP	BELLEVILLE LOCK AND DAM–OHIO RIVER						-5 to -15			-5 to -15
SOHP	WILLOW ISLAND LOCK AND DAM–OHIO RIVER						-5 to -15			-5 to -15
SOHS	SMITHLAND LOCK AND DAM–OHIO RIVER						-5 to -15			-25 to -35
SOHS	JOHN T. MYERS LOCK AND DAM–OHIO RIVER						-5 to -15			-25 to -35
SOHS	NEWBURGH LOCK AND DAM–OHIO RIVER						-5 to -15			-25 to -35
SOHW	HANNIBAL LOCK AND DAM–OHIO RIVER						-5 to -15			-5 to -15
SOHW	PIKE ISLAND LOCK AND DAM–OHIO RIVER						-5 to -15			-5 to -15

Potential Flow Discharge Impacts to Ohio River Basin Navigation Locks and Dams										
Forecast Group	Project Name	2011-2040			2041-2070			2071-2099		
		Annual Min	October Mean	October Min	Annual Min	October Mean	October Min	Annual Min	October Mean	October Min
SOHW	LOCK AND DAM #2–ALLEGHENY RIVER						-5 to -15			-5 to -15
SOHW	EMSWORTH LOCK AND DAM–OHIO RIVER						-5 to -15			-5 to -15
SOHW	NEW CUMBERLAND LOCK AND DAM–OHIO RIVER						-5 to -15			-5 to -15
SOHW	DASHIELDS LOCK AND DAM–OHIO RIVER						-5 to -15			-5 to -15
SOHW	MONTGOMERY LOCK AND DAM–OHIO RIVER						-5 to -15			-5 to -15

Table B-26: Potential Impacts to Ohio River Basin Thermoelectric Power Plants Using River/Stream Coolant Water

Potential Discharge Impacts to Ohio River Basin Thermoelectric Power Plants using River/Stream Coolant Water											
Forecast Group	Power Plant Name	Cooling Process	2011-2040			2041-2070			2071-2099		
			Annual Max	March Mean	March Max	Annual Max	March Mean	March Max	Annual Max	March Mean	March Max
SAGL	Conemaugh	Re-circulating						-5 to -15			-5 to -15
SAGL	Seward	Re-circulating						-5 to -15			-5 to -15
SAGL	Ebensburg Power	Re-circulating						-5 to -15			-5 to -15
SAGL	Cambria Cogen	Re-circulating						-5 to -15			-5 to -15
SAGL	Homer City Station	Re-circulating						-5 to -15			-5 to -15
SAGL	Cheswick Power Plant	Once-Through						-5 to -15			-5 to -15
SAGL	Allegheny Energy Units 3 4 & 5	Re-circulating						-5 to -15			-5 to -15
SAGL	Colver Power Project	Re-circulating						-5 to -15			-5 to -15
SAGL	Keystone	Re-circulating						-5 to -15			-5 to -15
SAGL	Armstrong Power Station	Once-Through						-5 to -15			-5 to -15
SAGL	Piney Creek Project	Re-circulating						-5 to -15			-5 to -15
SAGL	Scrubgrass Generating Company LP	Re-circulating						-5 to -15			-5 to -15
SAGL	Johnsonburg Mill	Re-circulating						-5 to -15			-5 to -15
SAGU	S A Carlson	Re-circulating						-5 to -15			-5 to -15
SBVR	New Castle Plant	Once-Through						-5 to -15			-5 to -15
SBVR	Niles	Once-Through						-5 to -15			-5 to -15
SBVR	WCI Steel	Re-circulating						-5 to -15			-5 to -15
SCML	Vanderbilt University Power Plant	Re-circulating									
SCML	Old Hickory Plant	Re-circulating									

Potential Discharge Impacts to Ohio River Basin Thermoelectric Power Plants using River/Stream Coolant Water											
Forecast Group	Power Plant Name	Cooling Process	2011-2040			2041-2070			2071-2099		
			Annual Max	March Mean	March Max	Annual Max	March Mean	March Max	Annual Max	March Mean	March Max
SCML	Gallatin	Once-Through									
SCML	Cumberland	Once-Through									
SCMU	Cooper	Once-Through									
SEFW	Tanners Creek	Once-Through						-15 to -25	-5 to -15		-15 to -25
SGRN	Shawnee	Once-Through									-5 to -15
SGRN	Paradise	Re-circulating									-5 to -15
SGRN	Green River	Once-Through									-5 to -15
SGRN	D B Wilson	Re-circulating									-5 to -15
SGRN	Robert A Reid	Re-circulating									-5 to -15
SGRN	R D Green	Re-circulating									-5 to -15
SGRN	HMP&L Station Two Henderson	Re-circulating									-5 to -15
SKAN	Radford Army Ammunition Plant	Once-Through									-5 to -15
SKAN	DEGS of Narrows LLC	Once-Through									-5 to -15
SKAN	Glen Lyn	Once-Through									-5 to -15
SKAN	Kanawha River	Once-Through									-5 to -15
SKAN	John E Amos	Re-circulating									-5 to -15
SKTY	E W Brown	Re-circulating						-15 to -25	-5 to -15	-5 to -15	-35 to -50
SKTY	Dale	Once-Through						-15 to -25	-5 to -15	-5 to -15	-35 to -50
SKTY	Tyrone	Once-Through						-15 to -25	-5 to -15	-5 to -15	-35 to -50

Potential Discharge Impacts to Ohio River Basin Thermoelectric Power Plants using River/Stream Coolant Water											
Forecast Group	Power Plant Name	Cooling Process	2011-2040			2041-2070			2071-2099		
			Annual Max	March Mean	March Max	Annual Max	March Mean	March Max	Annual Max	March Mean	March Max
SMIM	Hamilton	Once-Through	-5 to -15	-5 to -15	-5 to -15	-5 to -15	-5 to -15	-15 to -25	-5 to -15	-5 to -15	-25 to -35
SMIM	Hamilton	Once-Through	-5 to -15	-5 to -15	-5 to -15	-5 to -15	-5 to -15	-15 to -25	-5 to -15	-5 to -15	-25 to -35
SMIM	Smart Papers LLC	Re-circulating	-5 to -15	-5 to -15	-5 to -15	-5 to -15	-5 to -15	-15 to -25	-5 to -15	-5 to -15	-25 to -35
SMIM	O H Hutchings	Once-Through	-5 to -15	-5 to -15	-5 to -15	-5 to -15	-5 to -15	-15 to -25	-5 to -15	-5 to -15	-25 to -35
SMIM	Whitewater Valley	Re-circulating	-5 to -15	-5 to -15	-5 to -15	-5 to -15	-5 to -15	-15 to -25	-5 to -15	-5 to -15	-25 to -35
SMKL	Conesville	Once-Through					-5 to -15	-5 to -15	-5 to -15		-15 to -25
SMKL	Conesville	Re-circulating					-5 to -15	-5 to -15	-5 to -15		-15 to -25
SMKL	Shelby Municipal Light Plant	Re-circulating					-5 to -15	-5 to -15	-5 to -15		-15 to -25
SMKU	Dover	Once-Through					-5 to -15	-5 to -15	-5 to -15		-15 to -25
SMKU	Orrville	Re-circulating					-5 to -15	-5 to -15	-5 to -15		-15 to -25
SMKU	Morton Salt Rittman	Re-circulating					-5 to -15	-5 to -15	-5 to -15		-15 to -25
SMNL	Hatfields Ferry Power Station	Re-circulating									-5 to -15
SMNL	Fayette Energy Facility	Re-circulating									-5 to -15
SMNL	Mitchell Power Station	Once-Through									-5 to -15
SMNL	Elrama Power Plant	Once-Through									-5 to -15
SMNU	Harrison Power Station	Re-circulating									-5 to -15
SMNU	Albright	Once-Through									-5 to -15
SMNU	Rivesville	Once-Through									-5 to -15
SMNU	Grant Town Power Plant	Re-circulating									-5 to -15
SMNU	Morgantown Energy Facility	Once-Through									-5 to -15

Potential Discharge Impacts to Ohio River Basin Thermoelectric Power Plants using River/Stream Coolant Water											
Forecast Group	Power Plant Name	Cooling Process	2011-2040			2041-2070			2071-2099		
			Annual Max	March Mean	March Max	Annual Max	March Mean	March Max	Annual Max	March Mean	March Max
SMNU	Fort Martin Power Station	Re-circulating									-5 to -15
SOHC	J M Stuart	Once-Through									
SOHC	J M Stuart	Re-circulating									
SOHC	Killen Station	Re-circulating									
SOHC	H L Spurlock	Re-circulating									
SOHC	Walter C Beckjord	Once-Through									
SOHH	Big Sandy	Re-circulating						-5 to -15			-15 to -25
SOHH	Hanging Rock Energy Facility	Re-circulating						-5 to -15			-15 to -25
SOHH	Union Carbide South Charleston	Re-circulating						-5 to -15			-15 to -25
SOHH	Kyger Creek	Once-Through						-5 to -15			-15 to -25
SOHH	General James M Gavin	Re-circulating						-5 to -15			-15 to -25
SOHH	Philip Sporn	Once-Through						-5 to -15			-15 to -25
SOHH	Mountaineer	Re-circulating						-5 to -15			-15 to -25
SOHL	Kentucky Mills	Re-circulating						-5 to -15			-15 to -25
SOHL	Mill Creek	Once-Through						-5 to -15			-15 to -25
SOHL	Mill Creek	Re-circulating						-5 to -15			-15 to -25
SOHL	Cane Run	Once-Through						-5 to -15			-15 to -25
SOHL	R Gallagher	Once-Through						-5 to -15			-15 to -25
SOHL	Trimble County	Re-circulating						-5 to -15			-15 to -25
SOHL	Clifty Creek	Once-Through						-5 to -15			-15 to -25
SOHL	Ghent	Re-circulating						-5 to -15			-15 to -25

Potential Discharge Impacts to Ohio River Basin Thermoelectric Power Plants using River/Stream Coolant Water											
Forecast Group	Power Plant Name	Cooling Process	2011-2040			2041-2070			2071-2099		
			Annual Max	March Mean	March Max	Annual Max	March Mean	March Max	Annual Max	March Mean	March Max
SOHL	W H Zimmer	Re-circulating						-5 to -15			-15 to -25
SOHL	East Bend	Re-circulating						-5 to -15			-15 to -25
SOHL	Lawrenceburg Energy Facility	Re-circulating						-5 to -15			-15 to -25
SOHL	Miami Fort	Once-Through						-5 to -15			-15 to -25
SOHL	Miami Fort	Re-circulating						-5 to -15			-15 to -25
SOHL	Procter & Gamble Cincinnati Plant	Re-circulating						-5 to -15			-15 to -25
SOHP	Richard Gorsuch	Once-Through						-5 to -15			-5 to -15
SOHP	Pleasants Power Station	Re-circulating						-5 to -15			-5 to -15
SOHP	Willow Island	Once-Through						-5 to -15			-5 to -15
SOHP	AEP Waterford Facility	Re-circulating						-5 to -15			-5 to -15
SOHP	Washington Energy Facility	Re-circulating						-5 to -15			-5 to -15
SOHP	Muskingum River	Once-Through						-5 to -15			-5 to -15
SOHP	Muskingum River	Re-circulating						-5 to -15			-5 to -15
SOHS	Marion	Cooling Pond						-5 to -15			-25 to -35
SOHS	Elmer Smith	Once-Through						-5 to -15			-25 to -35
SOHS	A B Brown	Re-circulating						-5 to -15			-25 to -35
SOHS	F B Culley	Once-Through						-5 to -15			-25 to -35
SOHS	Warrick	Once-Through						-5 to -15			-25 to -35
SOHS	Rockport	Re-circulating						-5 to -15			-25 to -35
SOHS	Kenneth C Coleman	Once-Through						-5 to -15			-25 to -35
SOHW	PPG Natrium Plant	Once-Through						-5 to -15			-5 to -15

Potential Discharge Impacts to Ohio River Basin Thermoelectric Power Plants using River/Stream Coolant Water											
Forecast Group	Power Plant Name	Cooling Process	2011-2040			2041-2070			2071-2099		
			Annual Max	March Mean	March Max	Annual Max	March Mean	March Max	Annual Max	March Mean	March Max
SOHW	PPG Natrium Plant	Re-circulating						-5 to -15			-5 to -15
SOHW	Mitchell	Re-circulating						-5 to -15			-5 to -15
SOHW	Kammer	Once-Through						-5 to -15			-5 to -15
SOHW	R E Burger	Once-Through						-5 to -15			-5 to -15
SOHW	Cardinal	Once-Through						-5 to -15			-5 to -15
SOHW	Cardinal	Re-circulating						-5 to -15			-5 to -15
SOHW	W H Sammis	Once-Through						-5 to -15			-5 to -15
SOHW	Beaver Valley	Re-circulating						-5 to -15			-5 to -15
SOHW	Bruce Mansfield	Re-circulating						-5 to -15			-5 to -15
SOHW	AES Beaver Valley Partners Beaver Valley	Once-Through						-5 to -15			-5 to -15
SOHW	G F Weaton Power Station	Once-Through						-5 to -15			-5 to -15
SSCI	P H Glatfelter Co -Chillicothe Facility	Once-Through	-5 to -15						-5 to -15		-15 to -25
SSCI	P H Glatfelter Co -Chillicothe Facility	Once-Through	-5 to -15						-5 to -15		-15 to -25
SSCI	Picway	Once-Through	-5 to -15						-5 to -15		-15 to -25
SWBL	Gibson	Cooling Pond							-5 to -15		-15 to -25
SWBL	Jasper 2	Re-circulating							-5 to -15		-15 to -25
SWBL	Merom	Cooling Pond							-5 to -15		-15 to -25
SWBL	Hutsonville	Once-Through							-5 to -15		-15 to -25
SWBL	Sugar Creek Power	Re-circulating							-5 to -15		-15 to -25
SWBL	Wabash River	Once-Through							-5 to -15		-15 to -25
SWBL	Cayuga	Once-Through							-5 to -15		-15 to -25

Potential Discharge Impacts to Ohio River Basin Thermoelectric Power Plants using River/Stream Coolant Water											
Forecast Group	Power Plant Name	Cooling Process	2011-2040			2041-2070			2071-2099		
			Annual Max	March Mean	March Max	Annual Max	March Mean	March Max	Annual Max	March Mean	March Max
SWBL	University of Illinois Abbott Power Plt	Re-circulating							-5 to -15		-15 to -25
SWBL	Bunge Milling Cogen	Re-circulating							-5 to -15		-15 to -25
SWBL	Clinton Power Station	Cooling Pond							-5 to -15		-15 to -25
SWBL	Vermilion	Re-circulating							-5 to -15		-15 to -25
SWBL	Purdue University	Re-circulating							-5 to -15		-15 to -25
SWBU	Sagamore Plant Cogeneration	Re-circulating							-5 to -15		-15 to -25
SWBU	Logansport	Once-Through							-5 to -15		-15 to -25
SWBU	Peru	Once-Through							-5 to -15		-15 to -25
SWHT	AES Petersburg	Once-Through						-15 to -25	-5 to -15		-15 to -25
SWHT	AES Petersburg	Re-circulating						-15 to -25	-5 to -15		-15 to -25
SWHT	Frank E Ratts	Once-Through						-15 to -25	-5 to -15		-15 to -25
SWHT	Edwardsport	Once-Through						-15 to -25	-5 to -15		-15 to -25
SWHT	Edwardsport	Once-Through						-15 to -25	-5 to -15		-15 to -25
SWHT	Harding Street	Once-Through						-15 to -25	-5 to -15		-15 to -25
SWHT	Harding Street	Once-Through						-15 to -25	-5 to -15		-15 to -25
SWHT	Harding Street	Re-circulating						-15 to -25	-5 to -15		-15 to -25
SWHT	CC Perry K	Re-circulating						-15 to -25	-5 to -15		-15 to -25
SWHT	Crawfordsville	Re-circulating						-15 to -25	-5 to -15		-15 to -25
SWHT	Noblesville	Re-circulating						-15 to -25	-5 to -15		-15 to -25

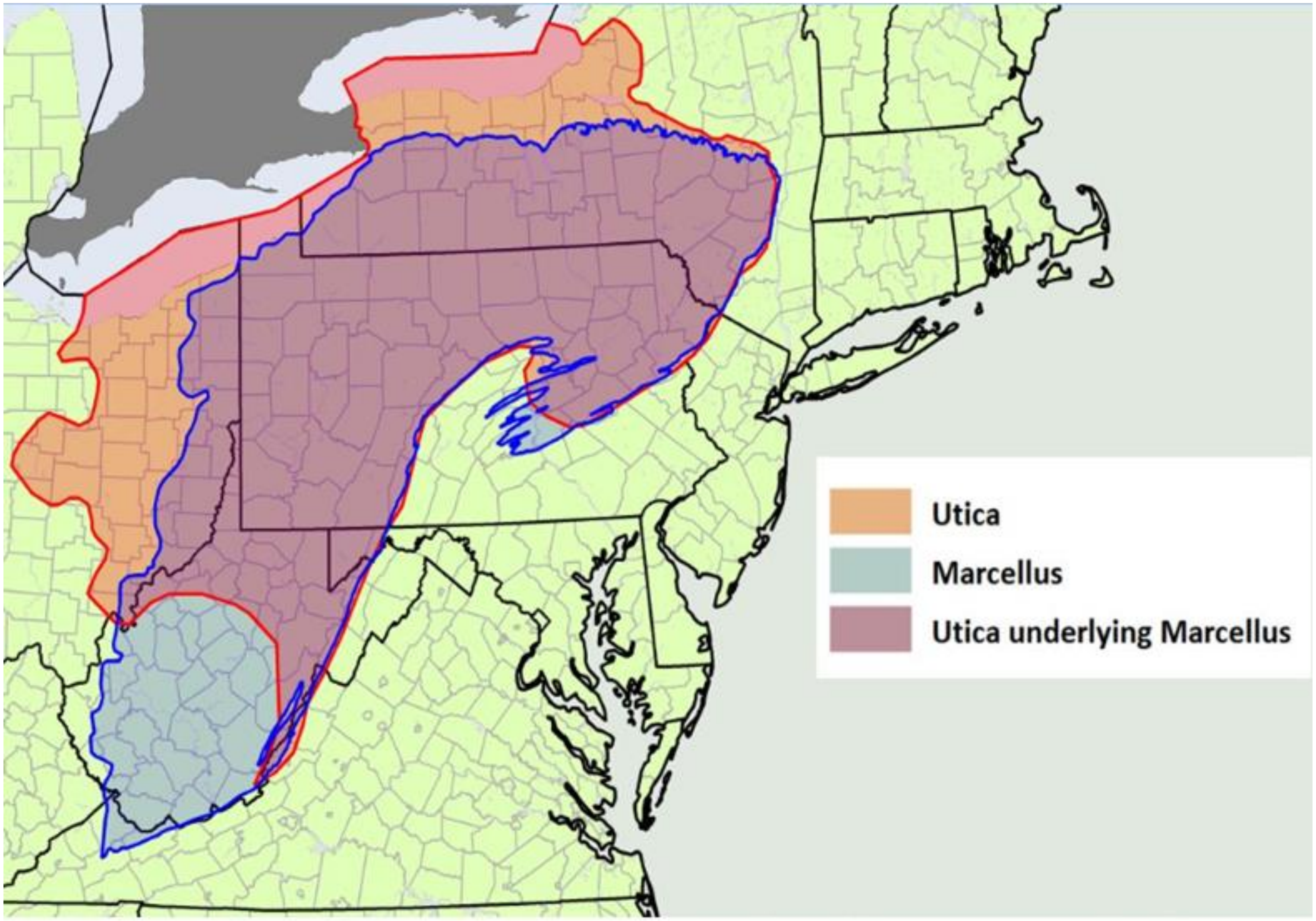
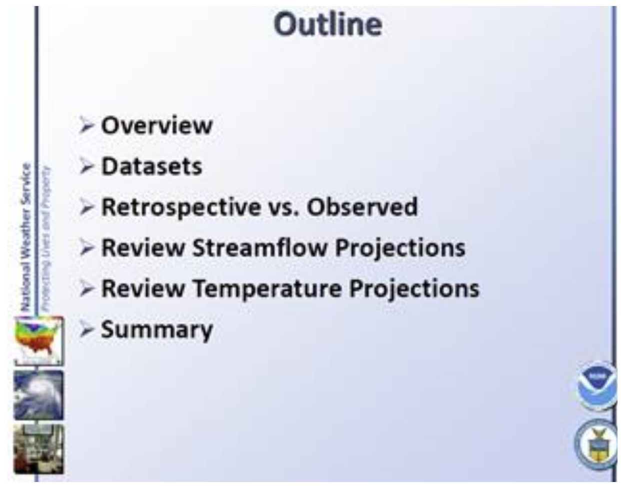
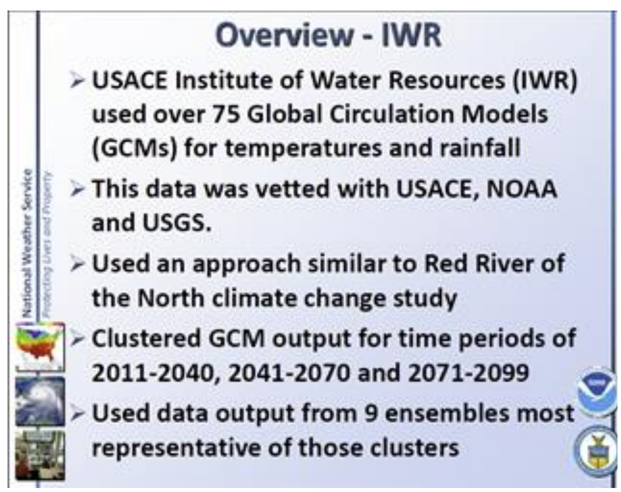


Figure B-9: Extent of the Marcellus and Utica Shale Complex in Areas of the ORB

17. Appendix C: Outreach to Basin Water Managers

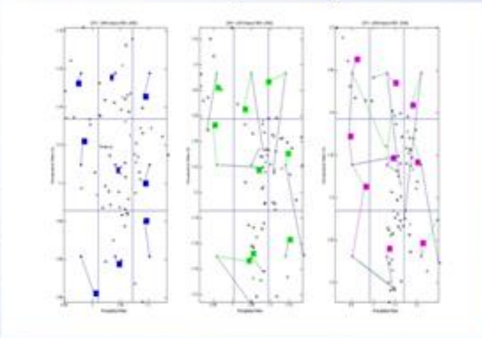
During the second phase of the outreach task, Mr. Jim Noel of the Ohio River Forecast Center (OHRFC) presented a PowerPoint of the modeling results for the basin upon which other aspects of the study (i.e., impact analyses and formulation of adaptation strategies) are based. The OHRFC webinar was held on January 14, 2014 and was attended by 38 participants from USACE, NRCS, USEPA, and several state agencies. Those PowerPoint slides are displayed as follows:





Overview - IWR

- How 9 ensembles were chosen for each future period. Rainfall increase 5%, then another 5% then another 5-10% by the last period.



Overview - OHRFC

- OHRFC used the Sacramento Soil Moisture Accounting Hydrologic Model (SAC-SMA) to generate the output
- OHRFC actually has output streamflow, temperatures, precipitation and snow water equivalent.
- OHRFC ran the hydrologic model and output the bottom end of the tributaries as well as the Ohio River.

Datasets

- SHRP1 (Sharpsburg, PA — lower Allegheny)
- BDDP1 (Braddock, PA — lower Monongahela)
- BEAP1 (Beaver Falls, PA — Beaver)
- MCCO1 (McConnellsville, OH — Muskingum)
- ATHO1 (Athens, OH — Muskingum)
- ELZW2 (Elizabeth, WV — Little Kanawha)
- CRSW2 (Charleston, WV — Kanawha)
- FLRK2 (Fuller Station, KY — Sandy)
- PKTO1 (Piketon, OH — Scioto)
- HAMO1 (Hamilton, OH — Great Miami)
- FFTK2 (Frankfort, KT — Kentucky)
- INDI3 (Indianapolis, IN — White)
- PTRI3 (Petersburg, IN — White/East Fork of White)
- NHRI3 (New Harmony, IN — Wabash)
- CALK2 (Calhoun, KY — Green)
- CARI2 (Carmi, IL — Little Wabash)
- WTVO1 (Waterville, OH — Maumee)
- NAST1 (Nashville, TN — Cumberland)
- PTTP1 (Pittsburgh, PA — Upper Ohio)
- HNTW2 (Huntington, WV — Upper Ohio)
- CCNO1 (Cincinnati, OH — Mid Ohio)
- MLPK2 (McAlpine, KY — Mid Ohio)
- EVVI3 (Evansville, IN — Lower Ohio)
- GOLI2 (Golconda, IL — Lower Ohio)
- COLO1 (Columbus, OH — Upper Scioto)

Datasets

- F1 = 2011-2040
- F2 = 2041-2070
- F3 = 2071-2099
- R1 = Restrospective models used for 2011-2040 run back in time from 1952-2001.
- R2 = Restrospective models used for 2041-2070 run back in time from 1952-2001.
- R3 = Restrospective models used for 2071-2099 run back in time from 1952-2001.

Retrospective vs. Observed

For Pittsburgh:

Time	March Mean (cfs)	October Mean (cfs)	Annual Mean (cfs)
Historical	55,000	17,000	33,000
Retrospective	50,000	13,000	33,000

Annual is within 0%

For Cincinnati:

Time	March Mean (cfs)	October Mean (cfs)	Annual Mean (cfs)
Historical	183,000	36,000	104,000
Retrospective	181,000	34,000	106,000

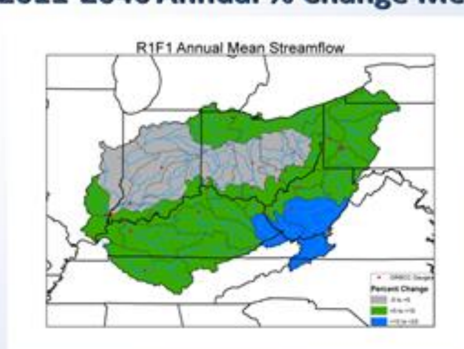
Annual is within 2%

For Golconda/Smithland:

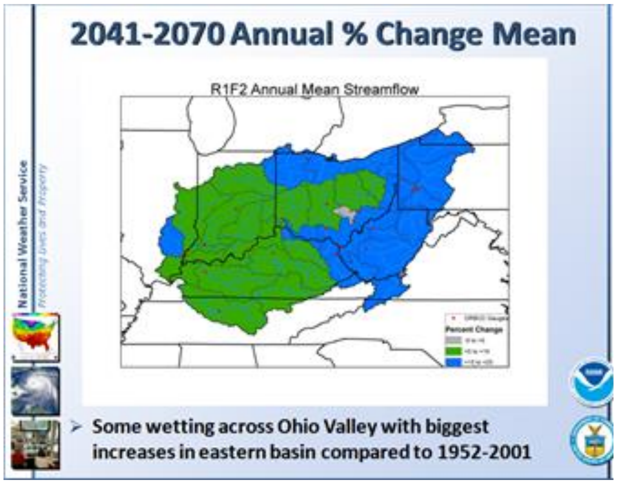
Time	March Mean (cfs)	October Mean (cfs)	Annual Mean (cfs)
Historical	340,000	75,000	185,000
Retrospective	310,000	53,000	182,000
2011_2040 sim	334,000	65,000	196,000

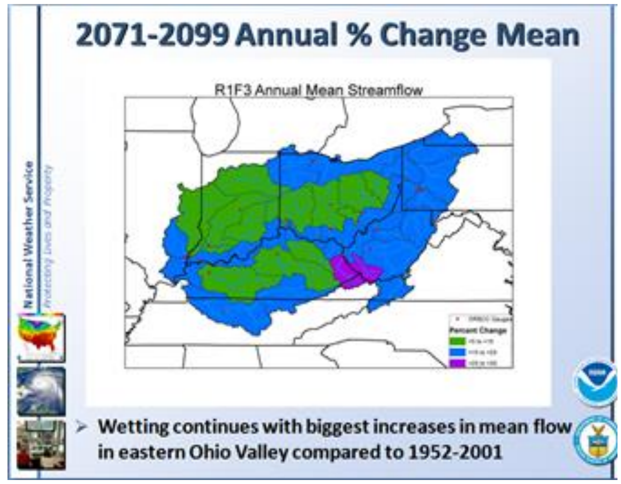
Annual is within 1.7%

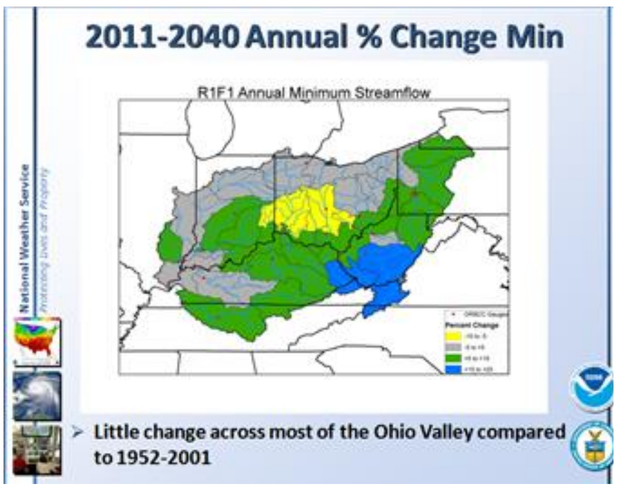
2011-2040 Annual % Change Mean

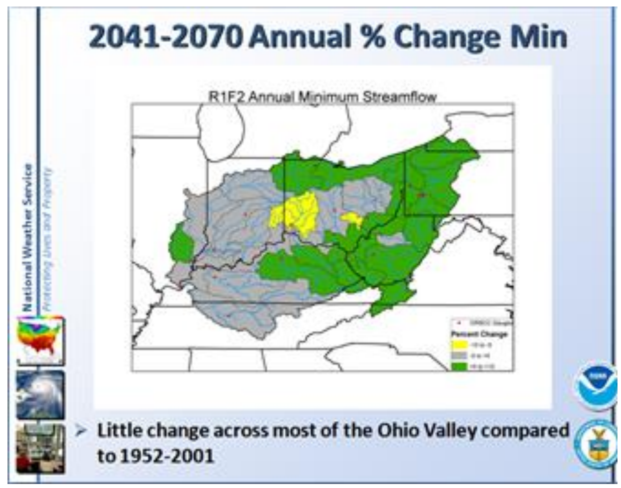


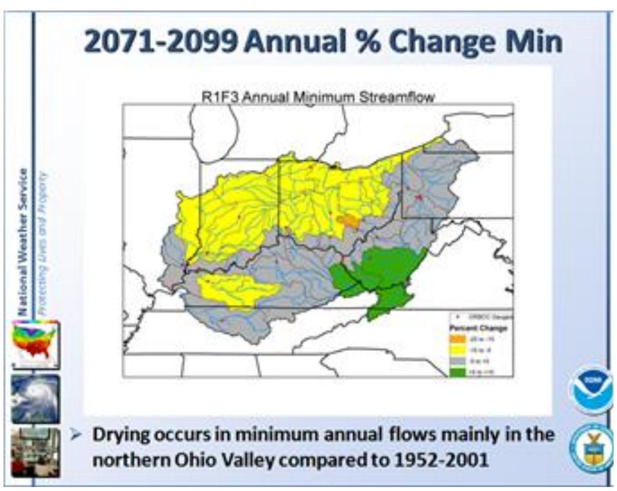
- Insignificant changes to slight wetting across most of the basin compared to 1952-2001

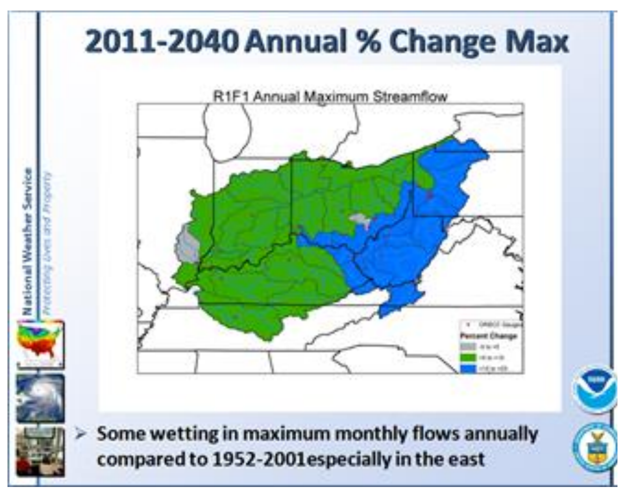

2041-2070 Annual % Change Mean
R1F2 Annual Mean Streamflow
National Weather Service
Some wetting across Ohio Valley with biggest increases in eastern basin compared to 1952-2001

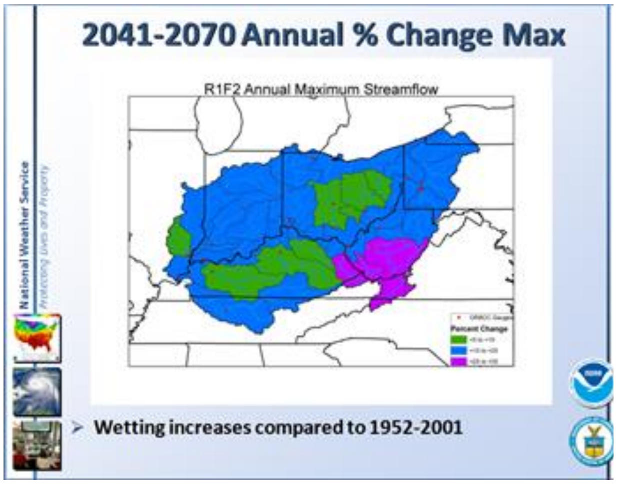

2071-2099 Annual % Change Mean
R1F3 Annual Mean Streamflow
National Weather Service
Wetting continues with biggest increases in mean flow in eastern Ohio Valley compared to 1952-2001

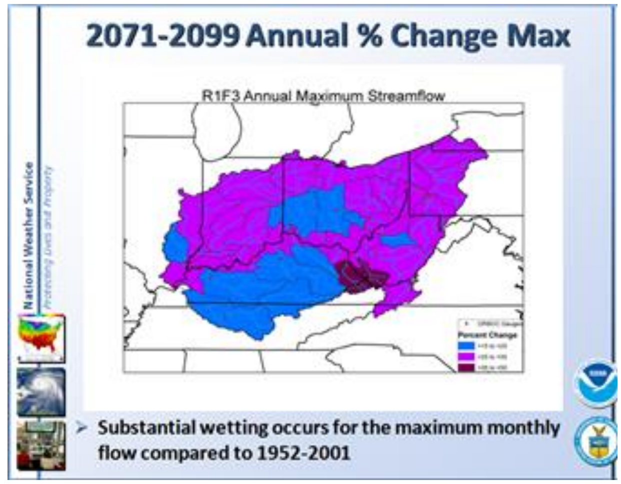

2011-2040 Annual % Change Min
R1F1 Annual Minimum Streamflow
National Weather Service
Little change across most of the Ohio Valley compared to 1952-2001

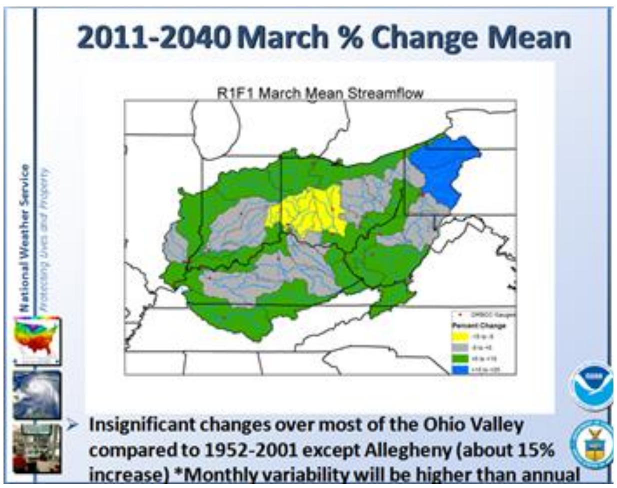

2041-2070 Annual % Change Min
R1F2 Annual Minimum Streamflow
National Weather Service
Little change across most of the Ohio Valley compared to 1952-2001

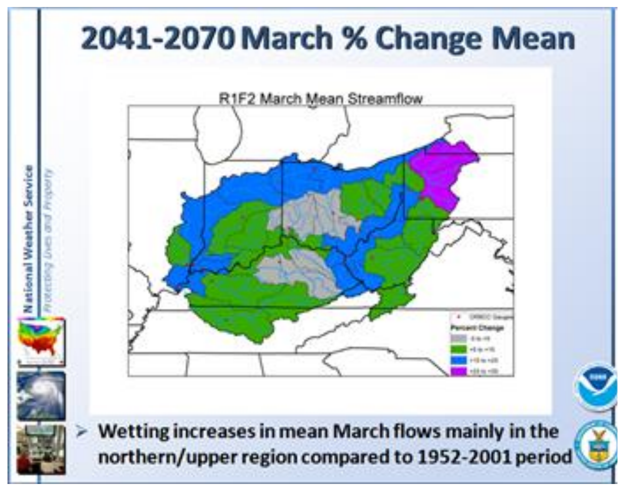

2071-2099 Annual % Change Min
R1F3 Annual Minimum Streamflow
National Weather Service
Drying occurs in minimum annual flows mainly in the northern Ohio Valley compared to 1952-2001

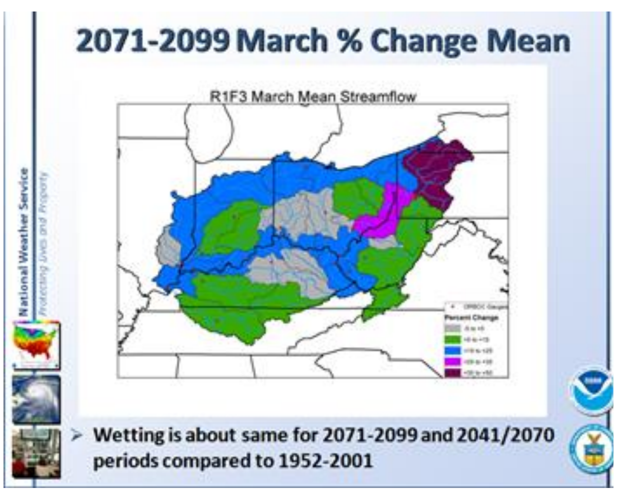

2011-2040 Annual % Change Max
R1F1 Annual Maximum Streamflow
National Weather Service
Some wetting in maximum monthly flows annually compared to 1952-2001especially in the east

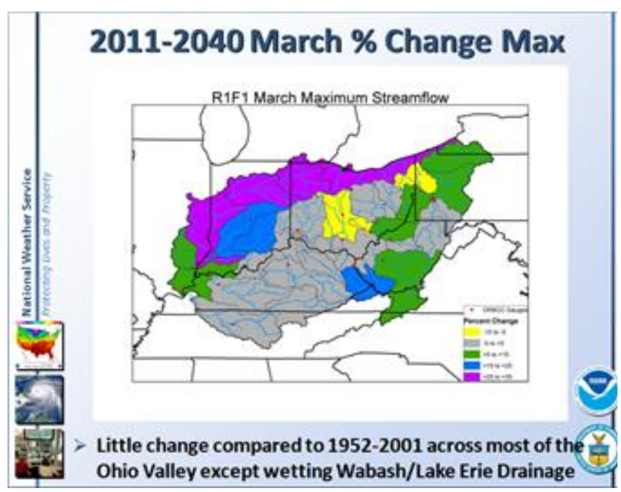

2041-2070 Annual % Change Max
R1F2 Annual Maximum Streamflow
National Weather Service
Wetting increases compared to 1952-2001

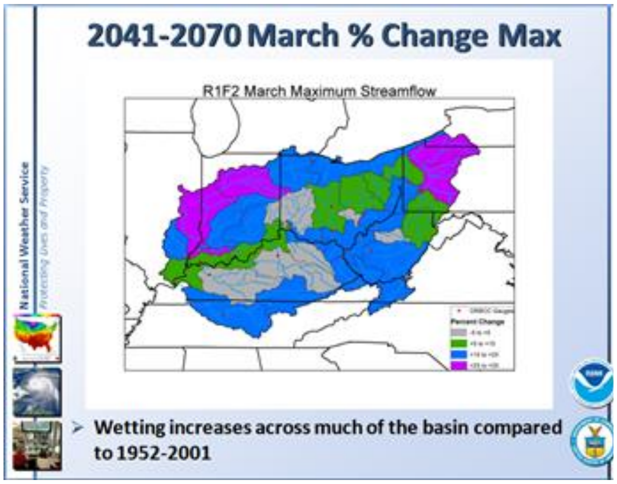

2071-2099 Annual % Change Max
R1F3 Annual Maximum Streamflow
National Weather Service
Substantial wetting occurs for the maximum monthly flow compared to 1952-2001

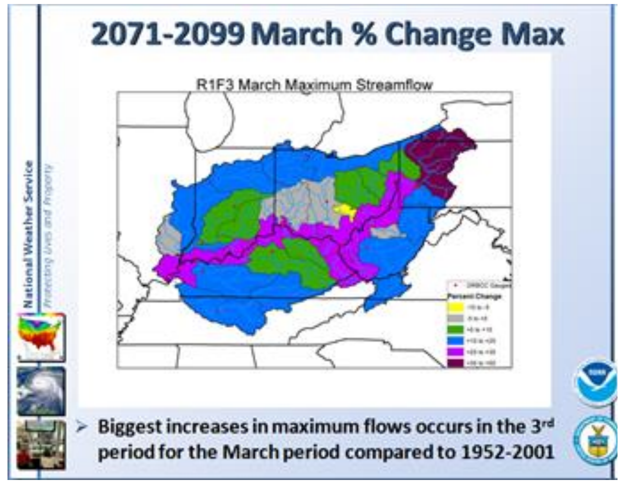

2011-2040 March % Change Mean
R1F1 March Mean Streamflow
National Weather Service
Insignificant changes over most of the Ohio Valley compared to 1952-2001 except Allegheny (about 15% increase) *Monthly variability will be higher than annual

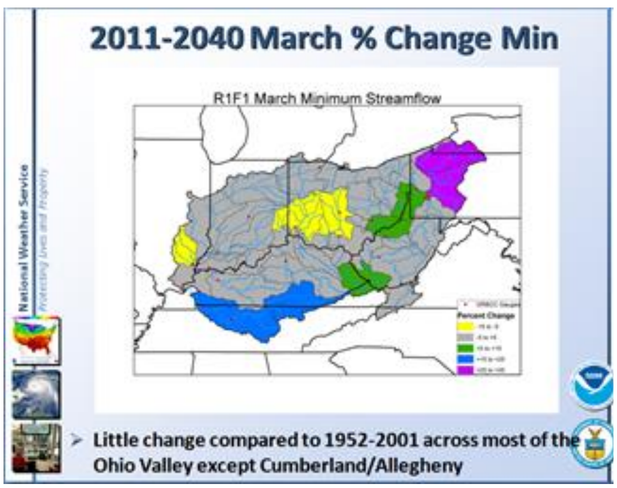

2041-2070 March % Change Mean
R1F2 March Mean Streamflow
National Weather Service
Wetting increases in mean March flows mainly in the northern/upper region compared to 1952-2001 period

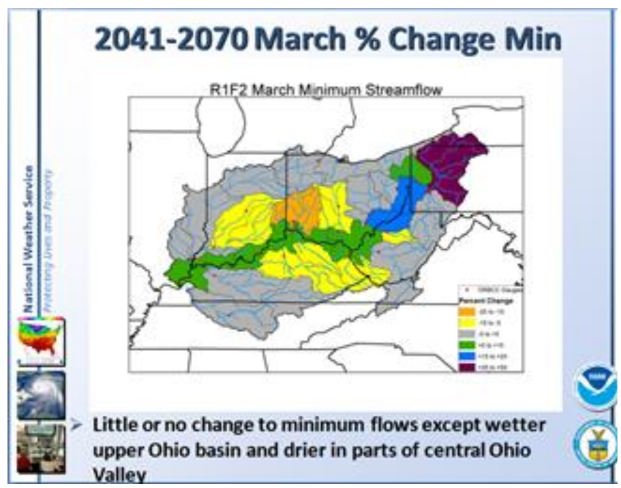

2071-2099 March % Change Mean
R1F3 March Mean Streamflow
National Weather Service
Wetting is about same for 2071-2099 and 2041/2070 periods compared to 1952-2001

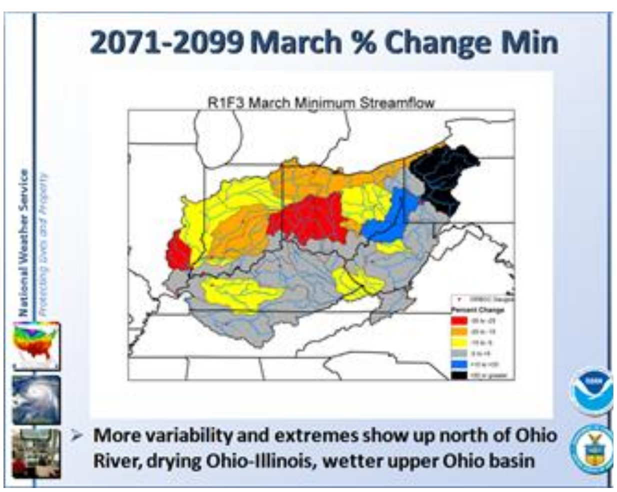

2011-2040 March % Change Max
R1F1 March Maximum Streamflow
National Weather Service
Little change compared to 1952-2001 across most of the Ohio Valley except wetting Wabash/Lake Erie Drainage

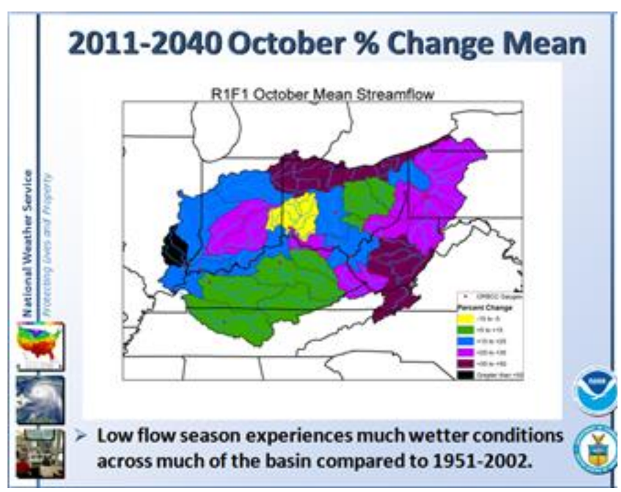

2041-2070 March % Change Max
R1F2 March Maximum Streamflow
National Weather Service
Wetting increases across much of the basin compared to 1952-2001

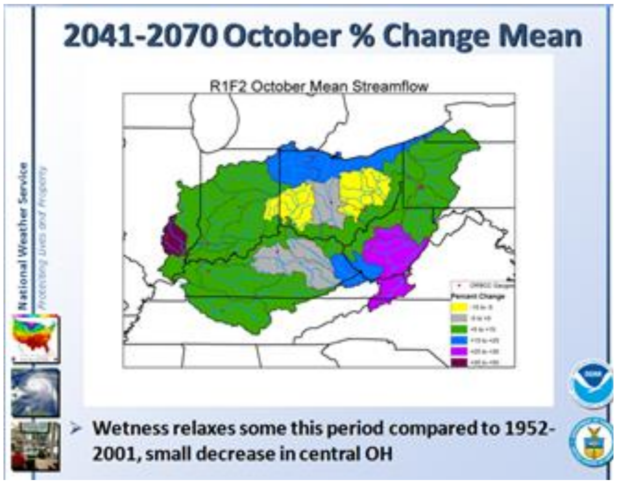

2071-2099 March % Change Max
R1F3 March Maximum Streamflow
National Weather Service
Biggest increases in maximum flows occurs in the 3rd period for the March period compared to 1952-2001

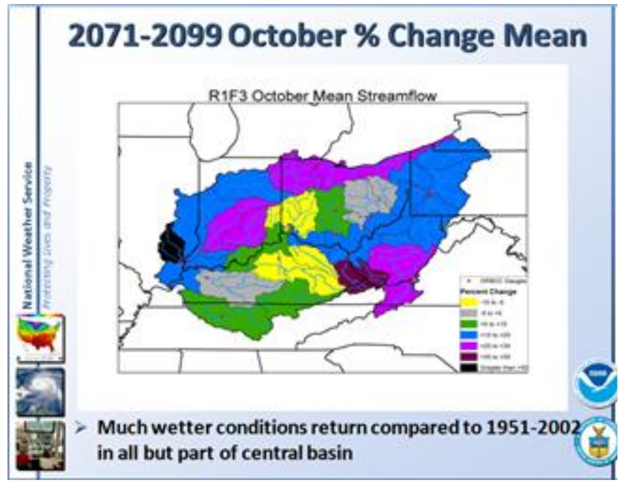

2011-2040 March % Change Min
R1F1 March Minimum Streamflow
National Weather Service
Little change compared to 1952-2001 across most of the Ohio Valley except Cumberland/Allegheny

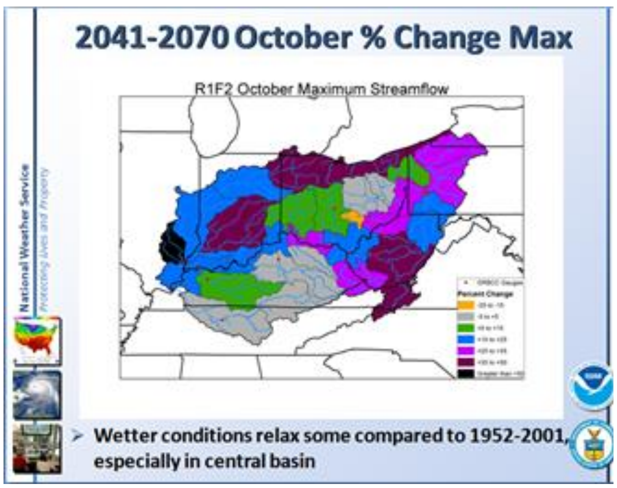

2041-2070 March % Change Min
R1F2 March Minimum Streamflow
National Weather Service
Little or no change to minimum flows except wetter upper Ohio basin and drier in parts of central Ohio Valley

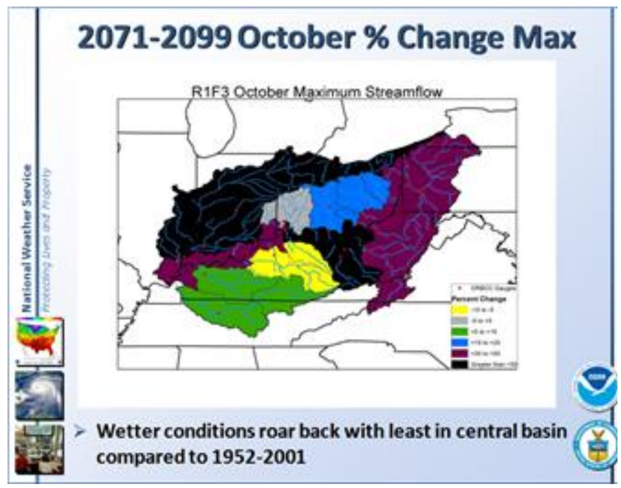

2071-2099 March % Change Min
R1F3 March Minimum Streamflow
National Weather Service
More variability and extremes show up north of Ohio River, drying Ohio-Illinois, wetter upper Ohio basin

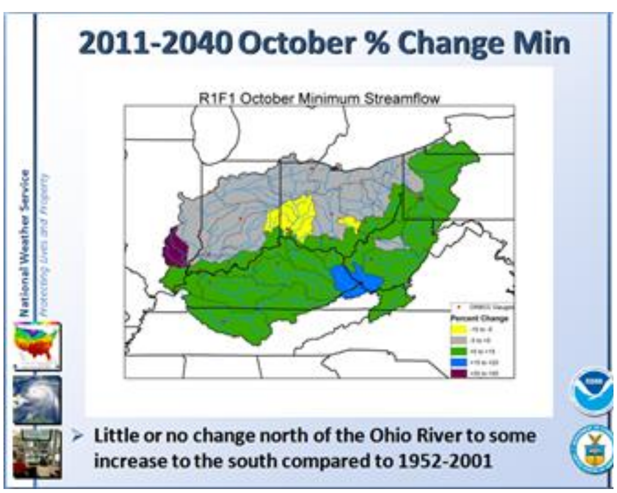

2011-2040 October % Change Mean
R1F1 October Mean Streamflow
National Weather Service
Low flow season experiences much wetter conditions across much of the basin compared to 1951-2002.

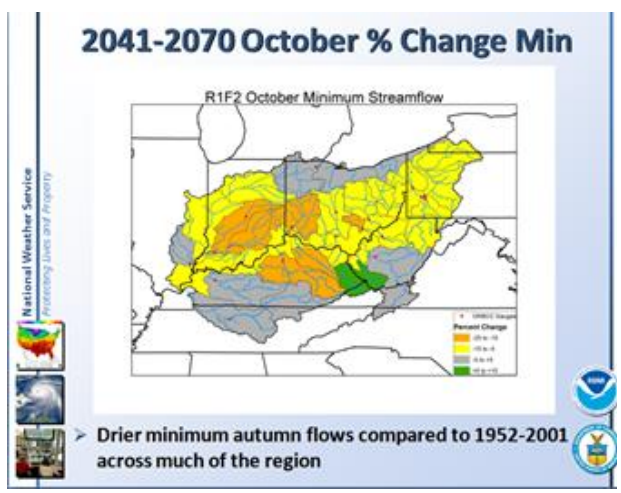

2041-2070 October % Change Mean
R1F2 October Mean Streamflow
National Weather Service
Wetness relaxes some this period compared to 1952-2001, small decrease in central OH

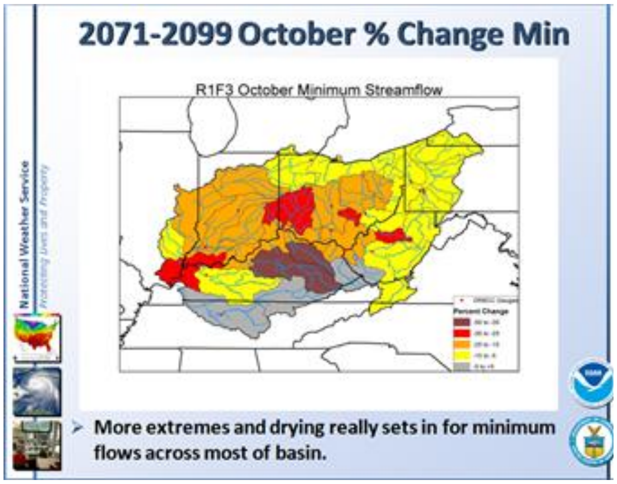

2071-2099 October % Change Mean
R1F3 October Mean Streamflow
National Weather Service
Much wetter conditions return compared to 1951-2002 in all but part of central basin

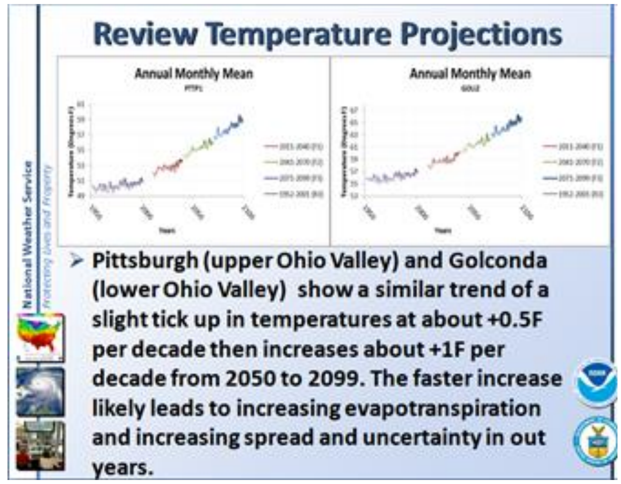

2041-2070 October % Change Max
R1F2 October Maximum Streamflow
National Weather Service
Wetter conditions relax some compared to 1952-2001, especially in central basin


2071-2099 October % Change Max
R1F3 October Maximum Streamflow
National Weather Service
Wetter conditions roar back with least in central basin compared to 1952-2001

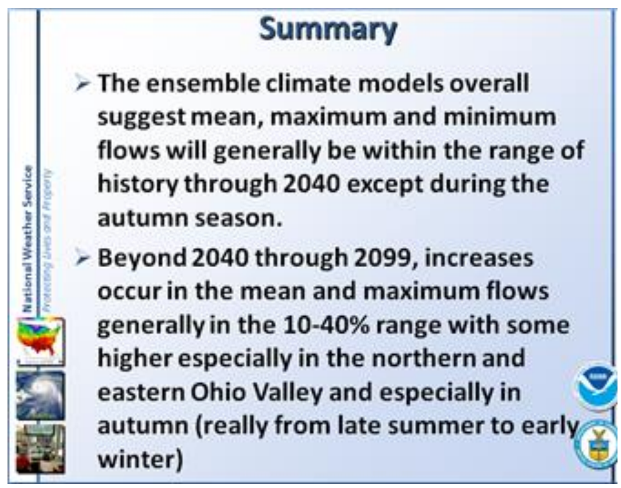

2011-2040 October % Change Min
R1F1 October Minimum Streamflow
National Weather Service
Little or no change north of the Ohio River to some increase to the south compared to 1952-2001

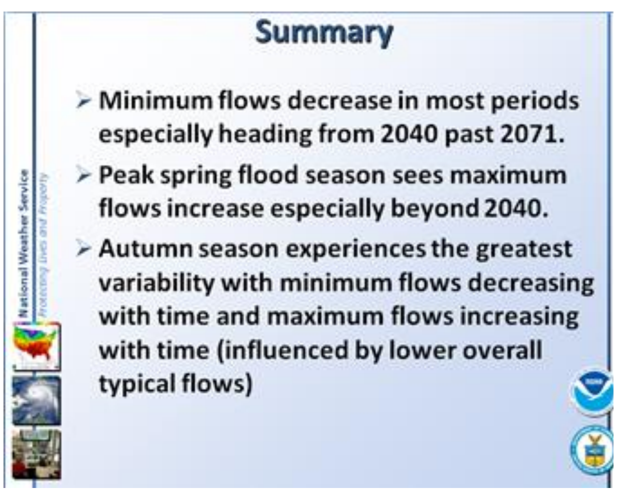

2041-2070 October % Change Min
R1F2 October Minimum Streamflow
National Weather Service
Drier minimum autumn flows compared to 1952-2001 across much of the region

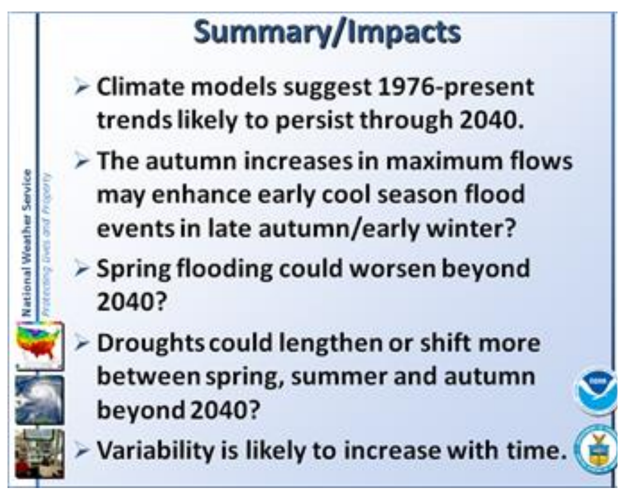

2071-2099 October % Change Min
R1F3 October Minimum Streamflow
National Weather Service
Protecting Lives and Property
More extremes and drying really sets in for minimum flows across most of basin.


Review Temperature Projections
Annual Monthly Mean
Annual Monthly Mean
National Weather Service
Protecting Lives and Property
Pittsburgh (upper Ohio Valley) and Golconda (lower Ohio Valley) show a similar trend of a slight tick up in temperatures at about +0.5F per decade then increases about +1F per decade from 2050 to 2099. The faster increase likely leads to increasing evapotranspiration and increasing spread and uncertainty in out years.


Summary/Trends Since 1976
National Weather Service
Protecting Lives and Property
Observed trends show most observed warming is in winter in the region.
Observed trends show most wetting is occurring from late summer into autumn and early winter.
Observed trends show peak floods remain within the historical record.
Observed trends show no change in droughts.


Summary
National Weather Service
Protecting Lives and Property
The ensemble climate models overall suggest mean, maximum and minimum flows will generally be within the range of history through 2040 except during the autumn season.
Beyond 2040 through 2099, increases occur in the mean and maximum flows generally in the 10-40% range with some higher especially in the northern and eastern Ohio Valley and especially in autumn (really from late summer to early winter)


Summary
National Weather Service
Protecting Lives and Property
Minimum flows decrease in most periods especially heading from 2040 past 2071.
Peak spring flood season sees maximum flows increase especially beyond 2040.
Autumn season experiences the greatest variability with minimum flows decreasing with time and maximum flows increasing with time (influenced by lower overall typical flows)


Summary/Impacts
National Weather Service
Protecting Lives and Property
Climate models suggest 1976-present trends likely to persist through 2040.
The autumn increases in maximum flows may enhance early cool season flood events in late autumn/early winter?
Spring flooding could worsen beyond 2040?
Droughts could lengthen or shift more between spring, summer and autumn beyond 2040?
Variability is likely to increase with time.

18. Appendix D: Agencies' Responses to Climate Change Questionnaire

The following information provides a summary of the outreach findings and specific responses to the questionnaire delivered to the various water managers contacted during the outreach process.

Summary of Outreach Findings: Based on the interagency information sharing, email communications, teleconferences, and feedback during the webinar and responses to the questionnaire, it appears that there is limited to no advanced planning for mitigation or adaptation strategies or measures to offset potential climate change (CC) effects on the part of basin water managers that participated in the outreach program. Although not surprising given the relative infancy of CC science and its warnings that are raising public concern, the lack of any current activity does open up opportunities for collaboration in developing basin-wide interagency strategies for addressing these effects as a system response.

This situation also opens up opportunities for the Ohio River Basin (ORB) Alliance (the Alliance) and any newly formed CC working group to act as the collaboration leader whereby participants from every governmental level, the member states, industry, academia, non-governmental organizations, research laboratories, and private institutions within the ORB can contribute to further CC studies, and development and implementation of mitigation and adaptation strategies.

The United States Army Corps of Engineers (USACE) operations and readiness offices have long relied upon individual water control manuals for individual projects from which operating plans have been developed for daily operations. The plans are subject to contractual and interagency agreements (lake storage or flow discharge for water supply or hydropower) or agreed-to water quality/quantity targets during formulation of the project and coordination with natural resources agencies during the National Environmental Policy Act process.

The National Resource Conservation Service (NRCS) water resources development and management activities through the Watershed Protection and Flood Prevention Act PL-566 and the Resource Conservation and Development Program (RC&D) are generally turned over to a sponsor that may be a local unit of government such as a city, county, or state agency for operation and maintenance. The sponsor is responsible for operating (drain gate) and maintaining (mow grass, remove woody debris, and repair/control rodent damage) the structure(s) and annual (or every 5 years) inspections, which are attended by the NRCS. Generally, once the projects are planned, designed, and constructed by the NRCS, any further operations and maintenance are the responsibility of the local sponsor. Under that process, local sponsors (states, cities, counties) would bear the responsibility for deciding whether and how CC effects might be incorporated into the future operation and maintenance of specific reservoir projects. NRCS as the Federal partner and developer of this infrastructure has developed certain programs such as DamWatch that can assist local sponsors in safely operating their dams and NRCS attends the dam inspections (at least the 5-year inspection action), which may open up opportunities on site to discuss the application of new operational procedures that address CC effects (increased flooding or increased droughts).

Responses to the brief questionnaire were received from several of those who attended the webinar presentation. The questions and general results of that feedback by agency are summarized as follows. The actual responses text follows the summary.

1. What type of current operating management system do you employ for your system? (Individual plans? Integrated plan? Operations based upon system models?)

USACE: Generally speaking, the four USACE districts responded in similar fashion regarding the operations of their reservoirs/lakes and their reliance upon individual water control manuals specifically prepared for each project. In some cases, several reservoir projects within a single sub-basin were operated in an integrated fashion through a master control plan or a system scheduling model to meet specific flow requirements within that sub-basin (i.e., Green River, Upper Wabash River, and Cumberland River sub-basins).
NRCS: Responses from the five state offices of NRCS were identical with respect to this question. The NRCS water resources development and management activities through the Watershed Protection and Flood Prevention Act PL-566 and the RC&D are generally turned over to a sponsor that may be a local unit of government such as a city, county, or state agency for operation and maintenance. The sponsor is responsible for operating (drain gate) and maintaining (mow grass, remove woody debris, and repair/control rodent damage) the structure(s) and annual (or every 5 years) inspections, which are attended by the NRCS.
United States Environmental Protection Agency (USEPA): The USEPA response indicated that the Total Maximum Daily Load (TMDL) plans are individual documents for controlling the level of pollutants that enter the river(s), and public domain models may or may not be used to prepare those plans. Further integration of these diverse plans is being contemplated for the bacterial TMDL in the Ohio River.

2. What water resources objectives or missions are your facilities authorized for?

USACE: Generally, the USACE districts responded with a litany of authorized missions for their reservoirs including flood risk management, navigation support, hydropower, recreation, water supply, fish and wildlife enhancement, water quality, and environmental stewardship.

NRCS: Generally, the responses from the five state NRCS offices stated that the primary purpose of the PL-566 and RC&D programs was flood control/protection of cropland and rural communities with secondary purposes for some reservoirs being municipal water supply, recreation, and fish and wildlife enhancement. Some of the watershed dams are dry projects without any seasonal pool and mainly store excess runoff that is released over time through the riser.

USEPA: The USEPA response emphasized the water quality mission of that agency and explained further that reducing contaminants and restoring impaired waters to designated uses were components of that basic mission. They included water supply as being affected as well.

3. Who are your major users?

USACE: USACE district offices responded with a number of public and corporate users including downstream communities, recreationists, water supply customers, hydroelectric power customers, navigation industry, general public, states, Tennessee Valley Authority, Southeastern Power Administration (SEPA), and specific municipalities.

NRCS: The five state NRCS offices responded that the users or beneficiaries of their projects were divided between flood protection for farm and pasture owners and rural communities, municipal, industrial, and irrigation water supply users; and lake recreation users at various percentages for each group of the 286 reservoirs in the basin.

USEPA: The USEPA assists states with funding or contracts for TMDLs and their major stakeholders are the public at large and watershed groups.

4. Do your current operating plans account for any reactive measures or adaptation schemes for addressing anticipated CC effects?

USACE: USACE district offices generally responded that no specific reactive measures or adaptation schemes were incorporated in operations plans to address CC per se, but responses cited specific operating plans for drought contingency operations and management of flood flows to avoid downstream damages. The Cumberland River Drought Contingency Plan included a prioritization of purposes that would be served during drought conditions based on public health and safety including, in order of importance, water supply, water quality, navigation, hydropower, and recreation. Other drought and flood contingency plans were cited addressing navigation needs, water management, and water quality and power plant water supplies.

NRCS: The NRCS offices generally responded that operation and maintenance of the reservoirs had been handed over to the states. Any future assessments of or modifications to the operation of those projects to address changed conditions such as CC would be the responsibility of the sponsors. The projects are operated mainly as storage for flood control, and water levels are not adjusted (except in cases of municipal water supply) during the year and discharge rates are determined by the riser elevation. The NY office indicated that at the 5-year scheduled formal inspections of the projects by the sponsors and NRCS, flood control capacity is evaluated with best available climate data using various models (NOAA Atlas 14, HMR-51, HMR 52, and NRCC Extreme Precipitation Data) for dam safety purposes.

USEPA: USEPA responded that with respect to meeting TMDL limits, they implicitly make adjustments that address not meeting water quality standards 100% of the time due to variable conditions. Their goal is using a percentile of all available data to account for any variations. Therefore, short of having specific data on water quality changes or effects due to CC, using the percentile method for determining TMDL allows for some variability in conditions over time.

5. If so, what CC scenarios did you use (national models, downscaled datasets, etc.) to develop your adaptation plans?

USACE: USACE district offices generally replied that they were not using any national or downscaled CC models to inform their current operating plans, but daily forecasts by the National Weather Service and real-time data from regional rain and stream gages do inform daily operations.

NRCS: NRCS generally responded that since responsibility for operating and maintaining the projects lays with the local sponsors, any future considerations for CC that would result in a change to the project or its operation would be the responsibility of that local sponsor. Thus, as an agency NRCS would not bear any responsibility for using or selecting CC scenarios as a basis for making changes to the projects. The NY NRCS office did list the use of the NOAA Atlas 14, HMR-51, HMR 52, and NRCC Extreme Precipitation Data as current models used to justify any changes for dam safety considerations.

USEPA: USEPA responded that their use of the percentile method for accounting of changed conditions allows sufficient variability in meeting TMDL parameters.

6. If you haven't developed particular adaptation actions in anticipation of CC effects, what components of your operating plans deal directly with the extremes of drought or flooding and could these be modified to address new changes in climate that may affect operating flows and water temperatures?

USACE: USACE district offices responded that current operating plans and water control manuals provide sufficient guidance for operating under extreme conditions of flooding, and drought contingency plans are appended to the manuals to address operations during extreme low-flow conditions. All districts indicated that should studies of CC effects indicate more extreme future conditions (flooding or drought), the operating plans and water control manuals can be revised to account for these changed conditions to allow projects to accomplish authorized missions.

NRCS: The NRCS state offices responded that a new program, DamWatch, would be available for NRCS and sponsors to facilitate real-time monitoring of potential threats to dam safety, including rainfall events. DamWatch also provides a repository for project documents and geospatial data that can be accessed by the sponsor through an interactive web interface. Also expressed was the fact that several sponsors have drafted water use plans due to past drought conditions. Those plans address use of the draw down gates at the dam to allow additional water releases for downstream users (cattle and irrigation) or storing water for irrigation withdrawals from the pool itself. The NY NRCS office indicated that New York-based operating plans do not address drought or flood frequency.

USEPA: USEPA responded that they use the 95th or 92nd percentile of the data distribution to assure they have captured a range of annual or seasonal variations that may occur in water flows and temperatures that could affect the TMDL measurements. They adjust the percentile of data used to account for the anticipated variations.

7. Are you interested in working with the Corps of Engineers and other partners to develop a basin-wide response plan for CC that would integrate the systems?

USACE: USACE district offices generally responded favorably to working with USACE personnel and other partners in developing a basin-wide response plan for CC to provide for an integrated system.

NRCS: Generally, the NRCS state offices responded favorably to working with USACE and other partners to address a wide range of water resources issues in the basin including CC concerns (i.e., more intense rainfall events, larger flood flows, more intense droughts, threats to water supply, and more wildfires).

USEPA: The USEPA respondent reacted favorably to working with the USACE and other partners on CC issues provided that USEPA management would approve of such collaboration. USEPA responses to the questionnaire were generated by one individual working on development and implementation of TMDL studies in the basin and her responses reflect that scope of her involvement with CC effects and the TMDL process.

Opportunities for collaboration with USEPA on CC adaptation strategies with regard to water quality in the Ohio River and its tributaries could be substantial, and the Alliance working group provides a good platform for coordination between the State water quality offices and USEPA on these issues.

Pittsburgh District:

Questions for Regional Water Managers and Specific Agency Responses

What type of current operating management system do you employ for your system? (Individual plans? Integrated plan? based upon system models?)

The Pittsburgh District currently has individual plans with some projects combining to operate for a single control point.

What water resources objectives or missions are your facilities authorized for? (Ex: flood control, hydropower, water supply, navigation etc.)

Flood control, low water regulation for navigation, low water regulation for water quality control, water supply, recreation (including whitewater rafting), fish and wildlife enhancement, endangered species protection, and hydropower.

Who are your major users?

General public, navigation industry, City of Warren, OH, and the hydropower industry

Do your current operating plans account for any reactive measures or adaptation schemes for addressing anticipated climate change effects?

No

If so what climate change scenarios did you use (national models, downscaled datasets, etc.) to develop your adaptation plans?

N/A

If you haven't developed particular adaptation actions in anticipation of climate change effects, what components of your operating plans deal specifically with the extremes of drought or flooding and could those be modified to address new changes in climate that may affect operating flows and water temperatures?

Storage and release schedule. They can be modified, but it has been our experience that any change to the schedule has resulted in major stakeholder resistance.

Are you interested in working with the Corps and other partners to develop a basin-wide response plan for climate change that would integrate the systems?

Yes

Huntington District

What type of current operating management system do you employ for your system?

The Huntington District has 35 multi-purpose flood control reservoirs. Each reservoir has an individual water control plan, these plans are integrated to for operation within each basin and within the Ohio River basin. There is a master water control manual for each basin. The Huntington

District has 9 navigation locks and dams on the Ohio and Kanawha Rivers. These projects have operation plans but as they are run-of-river projects they do not have a water control manual.

What water resources objectives or missions are your facilities authorized for?

The multi-purpose projects are for flood control, general recreation, fish and wildlife conservation. In addition, some of the projects have project purpose of water supply, water quality, and enhanced recreation

The navigation locks and dams are solely for navigation.

Who are your major users?

The nation, downstream communities, recreation users, and upstream communities in some water supply instances.

Do your current operating plans account for any reactive measures or adaptation schemes for addressing anticipated climate change effects?

No.

If so what climate change scenarios did you use (national models, downscaled datasets, etc.) to develop your adaptation plans?

N/A

If you haven't developed particular adaptation actions in anticipation of climate change effects, what components of your operating plans deal specifically with the extremes of drought or flooding and could those be modified to address new changes in climate that may affect operating flows and water temperatures?

The water control manuals detail how the project is to be operated during floods. In addition, each manual has a drought contingency plan as an appendix. These parts of the plan can be modified after a study indicates a better operating plan after an environmental review and a public meeting.

Are you interested in working with the Corps and other partners to develop a basin-wide response plan for climate change that would integrate the systems?

Yes.

Louisville District

Questions for Regional Water Managers

What type of current operating management system do you employ for your system? (Individual plans? Integrated plan? based upon system models?)

We utilize a basin wide plan for the Green River basin and Upper Wabash River projects in addition to individual water control plans (WCPs) for all 20 LRL multipurpose flood control projects.

What water resources objectives or missions are your facilities authorized for? (Ex: flood control, hydropower, water supply, navigation etc.)

We have sent this to you in the past. No changes. (FC, WS, WQ, F&W, Recreation)

Who are your major users?

Public, State and local municipalities.

Do your current operating plans account for any reactive measures or adaptation schemes for addressing anticipated climate change effects?

No.

If so what climate change scenarios did you use (national models, downscaled datasets, etc.) to develop your adaptation plans?

N/A.

If you haven't developed particular adaptation actions in anticipation of climate change effects, what components of your operating plans deal specifically with the extremes of drought or flooding and could those be modified to address new changes in climate that may affect operating flows and water temperatures?

Drought Contingency Plans approved by LRD exist for all 20 projects and are utilized during periods of drought. Extreme floods are covered in the respective WCPs.

Are you interested in working with the Corps and other partners to develop a basin-wide response plan for climate change that would integrate the systems?

No. LRN–Climate Change Considerations for Missions 1

Nashville District

Questions for Regional Water Managers:

What type of current operating management system do you employ for your system? (Individual plans? Integrated plan? based upon system models?)

LRN Water Management Section (Robert Sneed, Chief) has master plans for the entire Cumberland River system, and individual plans for each of the 10 projects.

- Lock and Dam: Barkley, Cheatham, Old Hickory, Cordell Hull
- High Dam: J. Percy Priest, Center Hill, Dale Hollow, Wolf Creek, Laurel & Martins Fork

  Volume I–Cumberland River Basin, Master Water Control Reference Manual

  Volume II–Master Water Control Operating Plan

  Volumes III–XII are Water Control Manuals and Instructions for Reservoir Regulation for each specific project.

What water resources objectives or missions are your facilities authorized for? (Ex: flood control, hydropower, water supply, navigation etc.)

Flood Damage Reduction (High Dams), Navigation (Lock and Dams), Hydropower, Recreation, Fish and Wildlife, Water Quality, and Water Supply

Who are your major users?

Southeastern Power Administration (SEPA), Municipalities, and the General Public.

Do your current operating plans account for any reactive measures or adaptation schemes for addressing anticipated climate change effects?

Yes. The District has a Cumberland River Drought Contingency Plan. Flood Damage Reduction is not an issue during drought. The Plan prioritizes purposes where public health and safety is the overall guiding principle:

1. Water Supply
2. Water Quality
3. Navigation
4. Hydropower
5. Recreation

Water Management Initiatives during Drought Conditions:

High Dams

- Reduce hydropower generation
  - Minimize water releases
- Implement sluice/orifice gate to maintain DO and cold temperature for trout
- J. Percy Priest has a Howell-Bunger valve to supply low flow/DO when cannot spill
- Low reservoir pool
- Low reservoir pool
  - Extend boat ramps and relocate marinas to deeper water
- LRN–Climate Change Considerations for Missions 4
  - Extend water intakes/floating water intakes in the reservoir
- Lock and Dams
  - Continuous flow to water intakes
  - Ensure minimum flow for waste water assimilation
  - Ensure minimum flow releases to support fossil fuel plants
  - Spill instead of hydropower generation to water quality (DO)
  - Maintain some commercial navigation capacity:
    - Create 4-6 hour windows to lock through (conserve pool)
    - Recommend light loading (less than 11 ft draft) to ensure clearance floods

LRN Water Management Section (Robert Sneed, Chief) has master plans for the entire Cumberland River system, and individual plans for each of the 10 projects.

- Cheatham Lock and Dam is designed to be over-topped during a flood (little damage)

Navigation

The District has a Cumberland River and Tennessee River Waterway Management Plan to address commercial navigation operations during emergencies including climate effects (drought and floods). River flows and depth are used as triggers.

If so what climate change scenarios did you use (national models, downscaled datasets, etc.) to develop your adaptation plans?

NWS forecast data is initially used. Real-time data is collected at rain and stream gauge stations used to refine forecasts

If you haven't developed particular adaptation actions in anticipation of climate change effects, what components of your operating plans deal specifically with the extremes of drought or flooding and could those be modified to address new changes in climate that may affect operating flows and water temperatures?

N/S

Are you interested in working with the Corps and other partners to develop a basin-wide response plan for climate change that would integrate the systems?

N/A LRN–Climate Change Considerations for Missions 5

The Cumberland and Tennessee River Basins are regulated systems that have high water storage capacity in many high dams. The below article provides a sense of how much. Lower Mississippi River would be four feet less mighty without Twin Rivers

Posted 8/23/2012

By Lee Roberts, Nashville District Public Affairs

NASHVILLE, Tenn. (Aug. 23, 2012)–The lower Mississippi River would be four feet less mighty today if not for the water storage reservoirs along the Tennessee and Cumberland rivers and their tributaries that provide a stream of water management benefits.

In support of current drought conditions on the lower Ohio and Mississippi Rivers, water is being released at a rate of 41,000 cubic feet per second from the Tennessee River and 12,000 cfs from the Cumberland River.

According to water managers in the U.S. Army Corps of Engineers Nashville and Memphis Districts, the Tennessee and Cumberland River Basins represent about six percent of the drainage area above Memphis. However, the basins are currently providing one half of the water flowing in the lower Ohio River, and one third of the water flowing in the Mississippi River at Memphis, Tenn.

David Berretta, chief of the Memphis District Hydraulics and Hydrology Branch, said contributions from the Tennessee and Cumberland Rivers are very important to the Lower Mississippi River. He reports that currently there are no navigation issues in the Memphis District, although the towing industry in conjunction with the U.S. Coast Guard is limiting tow sizes and are "light loading" barges.

"The level on the Mississippi River would absolutely be at a historical low if it were not for the water from the Tennessee and Cumberland rivers," Berretta said.

Water managers in the Nashville District said the system of dams and reservoirs were built to provide water resources during months of limited rainfall, which is proving its worth now during a drought throughout the middle of the country.

"The ability of our reservoir system projects to store water has made it possible for the Cumberland River to play a big role in supporting water levels on the lower Ohio and Mississippi Rivers" said Bob Sneed, Nashville District Water Management Section chief.

The Nashville District operates Barkley Dam in Grand Rivers, Ky., which is the last downstream dam on the Cumberland River. The Tennessee Valley Authority operates Kentucky Dam, also in Grand Rivers, Ky., which is the last downstream dam on the Tennessee River. Working in conjunction with the dams upstream, the two dams on the Twin Rivers can either hold water or pass water as necessary in support of water management requirements that support the nation's overall system of waterways. LRN–*Climate Change Considerations for Missions* 6 TVA and Corps water managers have been coordinating and working hard this year to manage the reservoir systems and the purposes of the projects, which include flood risk reduction, commercial navigation, water supply, water quality, hydropower, recreation and environmental benefits.

"TVA's river operations staff has worked all summer to keep TVA reservoirs and river levels as high as possible despite below average rain and runoff. This has allowed TVA to provide minimum flows that are having a significant contribution to the Ohio and Mississippi rivers. This illustrates the regional and national benefits of TVA's integrated and balanced river management approach," said John McCormick, TVA senior vice president, River Operations and Renewables.

The Mississippi River in Memphis is at its fourth lowest level since record keeping began in the 1920s. The levels of the Mississippi River and Ohio River at their confluence in Cairo, Ill., are at the 12th lowest level since record keeping began in the 1870s and sixth lowest level since the system of modern dams was constructed.

Berretta said that as of this morning, the Cairo gage at the confluence of the Ohio and Mississippi rivers is 8.1 feet. The average for August and September is about 17 feet on this gage. He also said the Memphis gage is at -9.3 feet. The record low at this location was -10.7 feet in 1988.

The public can obtain news, updates and information from the U.S. Army Corps of Engineers Nashville District on the district's website at www.lrn.usace.army.mil, on Facebook at http://www.facebook.com/nashvillecorps and on Twitter at http://www.twitter.com/nashvillecorps. The public can also visit the Memphis District at http://www.mvm.usace.army.mil/ and the Tennessee Valley Authority at http://www.tva.gov/.

Nashville

Water Management

Q–What type of current operating management system do you employ for your system? (Individual plans? Integrated plan? based upon system models?)

A–The Cumberland River system of dams is generally operated as an integrated system using a system scheduling model. On occasion an individual dam, typically a flood control project, may be scheduled based on looking at that particular project, however the releases are then integrated into the overall scheduling plan.

Q–What water resource objectives or missions are your facilities authorized for? (Ex: flood control, hydropower, water supply, navigation etc.)

A–All of our projects are multipurpose in nature. Our primary objectives are flood damage reduction, navigation and hydropower. In addition to those purposes listed in the question some of our other objectives include recreation, environmental stewardship and fish and wildlife.

Q–Who are your major users?

A–The general public benefits from our flood damage reduction efforts. Commercial navigation and recreational craft benefit from our navigational levels and flows. TVA, SEPA and others from our hydropower generated. TVA also benefits from minimum flows we provide for the two thermoelectric plants on the Cumberland River. The general public also benefits from our other multipurpose benefits we provide.

Q–Do your current operating plans account for any reactive measures or adaptation schemes for addressing anticipated climate change effects?

A–The short answer is no, but we do have operating plans in place for flood damage reduction and drought based on historical experiences.

Q–If so what climate change scenarios did you use (national models, downscaled datasets, etc.) to develop your adaptation plans?

A–NA, see above.

Q–If you haven't developed particular adaptation actions in anticipation of climate change effects, what components of your operating plans deal specifically with the extremes of drought or flooding and could those be modified to address new changes in climate that may affect operating flows and water temperatures?

A–Our operating plans to handle both floods and drought are extensive in nature and have proven effective over time. If conditions due to climate change do occur, we are confident our current plans will either prove effective or can be modified if needed.

Q–Are you interested in working with the Corps and other partners to develop a basin-wide response plan for climate change that would integrate the systems?

A–Yes.

February 19, 2014

NRCS-Pennsylvania Response

What type of current operating management system do you employ for your system? (Individual plans? Integrated plan? based upon system models?)

For NRCS assisted dams built through the Watershed Protection and Flood Prevention Act

(PL-566) and the Resource Conservation & Development Program (RC&D), NRCS has entered into operation and maintenance agreements with a sponsor for each dam. A sponsor could be a local unit of government such as city, county or a state agency such as PA DCNR, PA

Fish & Boat Commission, and PA Game Commission. The sponsor is responsible for yearly inspections, filing of an annual state dam safety report and any maintenance items. Generally, operation of the drain gate, mowing of vegetation, removal of woody trees and debris, and repair/control of rodent damage are the primary annual maintenance requirements.

What water resources objectives or missions are your facilities authorized for? (Ex: flood control, hydropower, water supply, navigation etc.)

The primary purpose for NRCS assisted dams built through the PL-566 and RC&D Programs is flood control. Secondary purposes include sediment control, water supply, recreation, fish & wildlife enhancement.

For your state: please list the number of PL-566/534 dams in the ORBA watershed area and provide a rough percentage of the primary and secondary use e.g. 65% provide flood protection; 20% provide water supply; 15% provide sediment storage (can exceed 100%).

	Number	Percentage
Total Structures in ORBA:	33	
Rural Community	33	100%
Municipal Protection/Use:	33	100%
Farm/Pasture Flood Protection/Use:	33	100%

	Number	Percentage
Total Structures in ORBA:	33	
Provide Sediment Storage:	33	100%
Provide Flood Protection:	33	100%
Provide Water Supply:	0	0%
Provide Recreational	10	30%
Provide Fish and Wildlife Enhancement	33	100%

Who are your major users?

Pennsylvania

Do your current operating plans account

for any reactive measures or adaptation schemes for addressing anticipated climate change effects?

NRCS-Pennsylvania does not operate or maintain these dams. The local sponsor has operation responsibilities and would need to reassess a dam's need and purpose to determine if anticipated climate change effects should be included.

If so what climate change scenarios did you use (national models, downscaled datasets, etc.) to develop your adaptation plans?

N/A

If you haven't developed particular adaptation actions in anticipation of climate change effects, what components of your operating plans deal specifically with the extremes of drought or flooding and could those be modified to address new changes in climate that may affect operating flows and water temperatures?

NRCS dams are built to meet a specific local purpose and need. Some dams are built to have a pool area and some are built to be "dry" dams, that is, no water except to provide temporary storage of excess runoff water from the upstream watershed. Propose changes to the current purpose and need would require review as well as the engineering design and calculations to ensure the dam would be able to safely handle any new requirements.

NRCS is currently instituting a new program called DamWatch to help the sponsors of NRCS assisted flood control dams and other key local community leader. DamWatch will provide advance notification of potential high rainfall amounts that could threaten the safely of these dams when high rainfall amounts occur.

Are you interested in working with the Corps and other partners to develop a basin-wide response plan for climate change that would integrate the systems?

It is NRCS's mission "To Help People Help the Land". NRCS would be interested in working with the Corps and other partners to develop a response plan for climate change.

Applicable NRCS Program

The Watershed and Flood Prevention Operations (WFPO) Program–

- The Watershed Protection and Flood Prevention Act (PL-566) provides for cooperation between the Federal government and the States and their political subdivisions in a program to prevent erosion, floodwater, and sediment damage; to further the conservation, development, utilization, and disposal of water; and to further the conservation and proper utilization of land in authorized watersheds.
- The Watershed Rehabilitation Amendments of 2000 which amended the Watershed Protection and Flood Prevention Act and authorized the Natural Resources Conservation Service to provide technical and financial assistance to watershed project sponsors in rehabilitating their aging dams. The purpose of rehabilitation is to extend the service life

of the dams and bring them into compliance with applicable safety and performance standards or to decommission the dams so they no longer pose a threat to life and property.

- The DamWatch Project is a new dam monitoring tool that will be available for sponsors and NRCS to monitor NRCS assisted flood control dams. DamWatch will provide real-time monitoring of potential threats to dam safety including rainfall events. DamWatch also provides a "one-stop" source for critical documents, databases, and geospatial information through an interactive Web interface. This will allow NRCS and watershed project sponsors to more efficiently manage and access important dam information such as as-built plans, operation and maintenance agreements, emergency action plans, inspection reports, photos, videos, assessment reports, etc. on a DamWatch Web site.

NRCS ALABAMA

Questions for Regional Water Managers:

What type of current operating management system do you employ for your system? (Individual plans? Integrated plan? based upon system models?).

For watershed dams under Pl-566/534, NRCS has entered into individual operation and maintenance agreements with the sponsor (a sponsor is a local unit of government such as city, county, conservation district, or watershed conservancy district) for each dam. While NRCS may inspect the dam every year, or once every five years, the sponsors bear the cost and responsibility for maintenance. Generally, operation of drain gate, mowing of vegetation, removal of woody trees and debris, and repair/control of rodent damage are the primary annual maintenance requirements.

What water resources objectives or missions are your facilities authorized for? (Ex: flood control, hydropower, water supply, navigation etc.).

The primary purpose for most dams built under 566/534 is flood control, predominantly protecting cropland and pastureland, but many provide flood protection to rural houses and municipal communities. Some serve as municipal water supply.

For your state: please list the number of PL-566/534 dams in the ORBA watershed area and provide a rough percentage of the primary and secondary use e.g. 65% provide flood protection; 20% provide water supply; 15% provide sediment storage (can exceed 100%).

Alabama: Total Structure TRB* = 9	Number	Percentage
Provide Sediment Storage	9	100%
Provide Flood Protection	9	100%
Provide Water Supply	0	0%
Provide Recreational Supply	0	0%

Who are your major users?

List rough percent of farm/ranch/pasture protection; rural community; or municipal protection/uses.

Total Structures: TRB* = 9	Number	Percentage
Industrial Use	0	0%
Municipal Use	0	0%
Recreational Use	0	0%
Irrigation	1**	11%
Farm/Pasture Flood Protection Use	8	89%

Watersheds within Alabama which are included in these figures are: Big Nance Creek (1 structure), Cypress Creek (1 structure), Hurricane Creek (1 structure), Little Paint Creek (1 structure) and Town Creek (5 structures).

Do your current operating plans account for any reactive measures or adaptation schemes for addressing anticipated climate change effects?

NRCS does not operate these dams. Instead the local sponsor has operation responsibilities. Generally, unless used for municipal water, the water level is not adjusted over the course of the year, with the riser elevation controlling the discharge rate.

If so what climate change scenarios did you use (national models, downscaled datasets, etc.) to develop your adaptation plans?

NA

If you haven't developed particular adaptation actions in anticipation of climate change effects, what components of your operating plans deal specifically with the extremes of drought or flooding and could those be modified to address new changes in climate that may affect operating flows and water temperatures?

Past drought events have resulted in some sponsors having to draft water use plans. As an example, some downstream water users may request the dam owner to release water through the draw down gate so that water can be used downstream for cattle and/or irrigation. Additionally, landowners that own land adjacent or under the pool may request water for irrigation purposes. Who owns the impounded water will vary from state to state and can be dependent on who owns the land under the lake or who owns the dam. Often this is established by agreement and in limited instances, “case law”.

Are you interested in working with the Corps and other partners to develop a basin-wide response plan for climate change that would integrate the systems?

NRCS is interested in working with the Corps and other partners to integrate systems within the ORB for several reasons:

- PL 566/534 Dams;
  - Are critical infrastructure that communities depend upon for flood protection & water supply
  - More people are at risk living downstream from the dams than ever before
  - Dams are getting older and do not meet current safety standards
  - Climate change will increase precipitation intensity, will produce larger and more frequent floods, will increase drought severity, will dangerously reduce critical water supplies, and more result in more frequent and widespread wildfires.
  - Limited funds are available for maintenance and rehabilitation to keep the dams safe
  - Fewer experienced people are available to address operation and maintenance issues and effectively respond to emergency conditions.

Very few plans are in place to deal with any of the items listed above. Any exposure to the benefits of the dams, the issues faced when dealing with the aging infrastructure of the dams, impacts on climate change to the structures would benefit communities across the Commonwealth.

Watershed and Flood Prevention Operations Program

Watershed Rehabilitation

Local communities, with USDA Natural Resources Conservation Service (NRCS) assistance, have constructed over 11,000 dams in 47 states since 1948. Many of these dams are nearing the end of their 50-year design life. Rehabilitation of these dams is needed to address critical public health and safety issues in these communities.

Background. The Watershed and Flood Prevention Operations (WFPO) Program (Watershed Operations) includes the Flood Prevention Operations Program authorized by the Flood Control Act of 1944 (P.L. 78-534) and the provisions of the Watershed Protection and Flood Prevention Act of 1954 (P.L. 83-566). The Flood Control Act originally authorizes the Secretary of Agriculture to install watershed improvement measures to reduce flood, sedimentation, and erosion damage; improve the conservation, development, utilization, and disposal of water; and advance the conservation and proper utilization of land. The Watershed Protection and Flood Prevention Act provides for cooperation between the Federal government and the States and their political subdivisions in a program to prevent erosion, floodwater, and sediment damage; to further the conservation, development, utilization, and disposal of water; and to further the conservation and proper utilization of land in authorized watersheds.

Introduction

There are over 1,300 active or completed watershed projects. Assistance may be provided in authorized watershed projects to install conservation practices and project measures (works of improvement) throughout the watershed project area. The planned works of improvement are described in watershed project plans and are normally scheduled to be installed over multiple years.

All works of improvement, including floodwater retarding dams and reservoirs, are owned and operated by the sponsoring local organizations and participating individuals.

The Watershed and Flood Prevention Operations (WFPO) Program provides technical and financial assistance to States, local governments and Tribes (project sponsors) to plan and implement authorized watershed project plans for the purposes of:

- Watershed protection
- Flood mitigation
- Water quality improvements
- Soil erosion reduction
- Rural, municipal and industrial water supply
- Irrigation
- Water management
- Sediment control
- Fish and wildlife enhancement
- Hydropower

Watershed Rehabilitation

Local communities, with USDA Natural Resources Conservation Service (NRCS) assistance, have constructed over 11,000 dams in 47 states since 1948. Many of these dams are nearing the end of their 50-year design life. Rehabilitation of these dams is needed to address critical public health and safety issues in these communities.

NRCS Kentucky

Questions for Regional Water Managers

What type of current operating management system do you employ for your system? (Individual plans? Integrated plan? based upon system models?).

For watershed dams under Pl-566/534, NRCS has entered into individual operation and maintenance agreements with the sponsor (a sponsor is a local unit of government such as city, county, conservation district, or watershed conservancy district) for each dam. While NRCS may inspect the dam every year, or once every five years, the sponsors bear the cost and responsibility for maintenance. Generally, operation of drain gate, mowing of vegetation, removal of woody trees and debris, and repair/control of rodent damage are the primary annual maintenance requirements.

What water resources objectives or missions are your facilities authorized for? (Ex: flood control, hydropower, water supply, navigation etc.)

The primary purpose for most dams built under 566/534 is flood control, predominantly protecting cropland and pastureland, but many provide flood protection to rural houses and municipal communities. Some serve as municipal water supply.

For your state: please list the number of PL-566/534 dams in the ORBA watershed area and provide a rough percentage of the primary and secondary use e.g. 65% provide flood protection; 20% provide water supply; 15% provide sediment storage (can exceed 100%).

Total Structures ORBA:	Number	Percentage
Provide Sediment Storage:	137	
Provide Flood Protection:	137	100%
Provide Water Supply:	137	100%
Provide Recreational Supply:	9	7%

All PL-566 dams were built with the primary purpose of flood and sediment control.

Who are your major users?

List rough percent of farm/ranch/pasture protection; rural community; or municipal protection/uses.

	Number	Percentage
Total	137	
Industrial Use:	1	.1%
Municipal Use:	9	6.5%
Recreational Use:	10	7.3%
Farm/Pasture Flood Protection Use:	117	85.4%

Do your current operating plans account for any reactive measures or adaptation schemes for addressing anticipated climate change effects? NRCS does not operate these dams. Instead the local sponsor has operation responsibilities. Generally, unless used for municipal water, the water level is not adjusted over the course of the year, with the riser elevation controlling the discharge rate.

If so what climate change scenarios did you use (national models, downscaled datasets, etc.) to develop your adaptation plans?

Kentucky: N/A

If you haven't developed particular adaptation actions in anticipation of climate change effects, what components of your operating plans deal specifically with the extremes of drought or flooding and could those be modified to address new changes in climate that may affect operating flows and water temperatures?

Past drought events have resulted in some sponsors having to draft water use plans. As an example, some downstream water users may request the dam owner to release water through the draw down gate so that water can be used downstream for cattle and/or irrigation. Additionally, landowners that own land adjacent or under the pool may request water for irrigation purposes. Who owns the impounded water will vary from state to state and can be dependent on who owns the land under the lake or who owns the dam. Often this is established by agreement and in limited instances, “case law”.

Are you interested in working with the Corps and other partners to develop a basin-wide response plan for climate change that would integrate the systems?

NRCS is interested in working with the Corps and other partners to integrate systems within the ORB for several reasons:

PL 566/534 Dams

Are critical infrastructure that communities depend upon for flood protection & water supply

- More people are at risk living downstream from the dams than ever before
- Dams are getting older and do not meet current safety standards
- Climate change will increase precipitation intensity, will produce larger and more frequent floods, will increase drought severity, will dangerously reduce critical water supplies, and more result in more frequent and widespread wildfires.
- Limited funds are available for maintenance and rehabilitation to keep the dams safe
- Fewer experienced people are available to address operation and maintenance issues and effectively respond to emergency conditions.

Very few plans are in place to deal with any of the items listed above. Any exposure to the benefits of the dams, the issues faced when dealing with the aging infrastructure of the dams, impacts on climate change to the structures would benefit communities across the Commonwealth.

NRCS NEW YORK

Questions for Regional Water Managers

What type of current operating management system do you employ for your system? (Individual plans? Integrated plan? based upon system models?).

For watershed dams under Pl-566/534, NRCS has entered into individual operation and maintenance agreements and plans with the sponsor (a sponsor is a local unit of government such as city, county, conservation district, or watershed conservancy district) for each dam. The sponsors inspect the dam every year. NRCS attends annual inspections as the technical advisors. Every five years, the sponsors conduct more detailed inspections (Formal inspection) evaluating all physical and designed dam flood control criteria. The sponsors bear the cost and responsibility for maintenance. Generally, operation of drain gate, mowing of vegetation, removal of woody trees and debris, and repair/control of rodent damage are the primary annual maintenance requirements.

What water resources objectives or missions are your facilities authorized for? (Ex: flood control, hydropower, water supply, navigation etc.)

The primary purpose for all dams built under 566/534 is flood control, predominantly protecting cropland and pastureland, but many provide flood protection to rural houses and municipal communities. None serve as municipal water supply or supply hydropower or navigation.

For your state: please list the number of PL-566/534 dams in the ORBA watershed area and provide a rough percentage of the primary and secondary use e.g. 65% provide flood protection; 20% provide water supply; 15% provide sediment storage (can exceed 100%).

	Number	Percentage
Total Structures in ORBA:	18	
Provide Sediment Storage:	17	94%
Provide Flood Protection:	17	94%
Provide Water Supply:	0	0%
Provide Recreational Supply:	5	28%

All PL-566 dams were built with the primary purpose of flood and sediment control

Who are your major users?

List rough percent of farm/ranch/pasture protection; rural community; or municipal protection/uses.

	Number	Percentage
Total Structures in ORBA:	18	
Industrial Use:	0	0%
Municipal Use:	0	0%
Recreational Use:	5	28%
Flood Protection Use	17	94%

New York

Do your current operating plans account for any reactive measures or adaptation schemes for addressing anticipated climate change effects?

The 5-year formal inspection conducted by the sponsors as a component of the sponsors operating plan evaluates flood control capacity with best available climatic data (NOAA Atlas 14, HMR-51, HMR 52 and NRCC Extreme Precipitation Data) for dam safety. The water level is not adjusted over the course of the year, with the riser elevation controlling the discharge rate.

If so what climate change scenarios did you use (national models, downscaled datasets, etc.) to develop your adaptation plans?

New York: Sponsors are using NOAA Atlas 14, HMR-51, HMR 52 and NRCC Extreme Precipitation Data

If you haven't developed particular adaptation actions in anticipation of climate change effects, what components of your operating plans deal specifically with the extremes of drought or flooding and could those be modified to address new changes in climate that may affect operating flows and water temperatures?

New York based operating plans do not address drought or flooding frequency.

Are you interested in working with the Corps and other partners to develop a basin-wide response plan for climate change that would integrate the systems?

NRCS is interested in working with the Corps and other partners to integrate systems within the ORB for several reasons:

PL 566/534 Dams;

- More people are at risk living downstream from the dams than ever before
- Dams are getting older and do not meet current NCRS safety criteria
- Climate change will change precipitation intensity, may produce larger and more frequent flood.
- Limited funds are available for maintenance and rehabilitation to keep the dams safe
- Fewer experienced people are available to address operation and maintenance issues and effectively respond to emergency conditions.

Very few plans are in place to deal with any of the items listed above. Any exposure to the benefits of the dams, the issues faced when dealing with the aging infrastructure of the dams, impacts on climate change to the structures would benefit communities across the Commonwealth.

NRCS West Virginia

Questions for Regional Water Managers

What type of current operating management system do you employ for your system? (Individual plans? Integrated plan? based upon system models?).

For watershed dams under Pl-566/534, NRCS has entered into individual operation and maintenance agreements with the sponsor (a sponsor is a local unit of government such as city, county, conservation district, or the state) for each dam. While NRCS may inspect the dam every year, or once every five years, the sponsors bear the cost and responsibility for maintenance. Generally, operation of drain gate, mowing of vegetation, removal of woody trees and debris, and repair/control of rodent damage are the primary annual maintenance requirements.

What water resources objectives or missions are your facilities authorized for? (Ex: flood control, hydropower, water supply, navigation etc.).

The primary purpose for most dams built under 566/534 is flood control, predominantly protecting cropland and pastureland, but many provide flood protection to rural houses and municipal communities. Some serve as municipal water supply.

For your state: please list the number of PL-566/534 dams in the ORBA watershed area and provide a rough percentage of the primary and secondary use e.g. 65% provide flood protection; 20% provide water supply; 15% provide sediment storage (can exceed 100%). All dams include incidental or planned recreation.

West Virginia

	Number	Percentage
Total Structures in ORBA:	89	
Provide Sediment Storage:	88	98%
Provide Flood Protection:	88	98%
Provide Water Supply:	7	8%
Provide Recreational Supply	89	100%

All PL-566 dams were built with the primary purpose of flood and sediment control.

Who are your major users?

List rough percent of farm/ranch/pasture protection; rural community; or municipal protection/uses. Municipal includes estimate of rural com munities.

West Virginia

	Number	Percentage
Total Structures in ORBA:	89	
Industrial Use:	7	8%
Municipal Use:	50	56%
Recreational Use:	89	100%
Farm/Pasture Flood Protection Use:	89	100%

Do your current operating plans account for any reactive measures or adaptation schemes for addressing anticipated climate change effects?

NRCS does not operate these dams. Instead the local sponsor has operation responsibilities. Generally, unless used for municipal water, the water level is not adjusted over the course of the year, with the riser elevation controlling the discharge rate.

If so what climate change scenarios did you use (national models, downscaled datasets, etc.) to develop your adaptation plans?

WEST VIRGINIA: N/A

If you haven't developed particular adaptation actions in anticipation of climate change effects, what components of your operating plans deal specifically with the extremes of drought or flooding and could those be modified to address new changes in climate that may affect operating flows and water temperatures?

Past drought events have resulted in some sponsors having to draft water use plans. As an example, some downstream water users may request the dam owner to release water through the draw down gate so that water can be used downstream for cattle and/or irrigation. Additionally, landowners that own land adjacent or under the pool may request water for irrigation purposes. Who owns the impounded water will vary from state to state and can be dependent on who owns the land under the lake or who owns the dam. Often this is established by agreement.

Are you interested in working with the Corps and other partners to develop a basin-wide response plan for climate change that would integrate the systems?

NRCS is interested in working with the Corps and other partners to integrate systems within the ORB for several reasons:

PL 566/534 Dams;

- Are critical infrastructure that communities depend upon for flood protection & water supply
- More people are at risk living downstream from the dams than ever before
- Dams are getting older and do not meet current safety standards
- Climate change will increase precipitation intensity, will produce larger and more frequent floods, will increase drought severity, will dangerously reduce critical water supplies, and more result in more frequent and widespread wildfires.
- Limited funds are available for maintenance and rehabilitation to keep the dams safe
- Fewer experienced people are available to address operation and maintenance issues and effectively respond to emergency conditions.

Very few plans are in place to deal with any of the items listed above. Any exposure to the benefits of the dams, the issues faced when dealing with the aging infrastructure of the dams, impacts on climate change to the structures would benefit communities across the Commonwealth.

USEPA Responses–Jean Chruscicki

Hope my responses make sense, if not let me know and I can clarify I am speaking for myself as a TMDL specialist and contract manager, not a program manager, with my focus mostly on the Ohio River, as you know.

What type of current operating management system do you employ for your system? (Individual plans? Integrated plan? based upon system models?)

There are mostly individual plans (TMDLs, implementation plans, etc.) Models (public domain) may or may not be used. We are trying to integrate more, especially in the case of the Ohio River Bacteria TMDL.

What water resources objectives or missions are your facilities authorized for? (Ex: flood control, hydropower, water supply, navigation etc.)

Water Quality, reducing contaminants and restoring impaired waters (from the 303(d) list) to designated uses. Sometimes water supply may be affected.

Who are your major users?

We either assist the states with funding or contracts for TMDLs, and rare situations a third party may submit a TMDL but with a lot of input from the state and US EPA. Stakeholders are the public and may be watershed groups.

Do your current operating plans account for any reactive measures or adaptation schemes for addressing anticipated climate change effects?

From the TMDL standpoint, we have been implicitly making some adjustments to not expect meeting WQ standards 100% of the time. Usually a goal is using a percentile of all available data.

If so what climate change scenarios did you use (national models, downscaled datasets, etc.) to develop your adaptation plans?

(They were not specifically identified as climate change scenarios.) Downscaled datasets, or other probability based statistical analysis, were used. From the Chesapeake Bay TMDL: "Both the Chesapeake Bay TMDL annually-based maximum daily load and seasonally based maximum daily load represents the 95th percentile of the distribution to protect against the presence of anomalous outliers. That expression implies a 5 percent probability that an annually-based daily or seasonal-based daily maximum load will exceed the specified value under the TMDL condition."

If you haven't developed particular adaptation actions in anticipation of climate change effects, what components of your operating plans deal specifically with the extremes of drought or flooding and could those be modified to address new changes in climate that may affect operating flows and water temperatures?

Mostly we approach the data as above, using the 95th or 92nd percentile in two cases that I can recall. Also, we used to consider some data more as outliers, but now not as much, we may adjust our choice of the percentile used instead.

Are you interested in working with the Corps and other partners to develop a basin-wide response plan for climate change that would integrate the systems?

Yes, but based on my management approval. I don't know what I could contribute but would hope to gain better approaches for my projects.

19. Appendix E: Formulation of Adaptation Strategies Backup Data

Table E-1: Allegheny River Sub-Basin

Allegheny Sub-basin				
System	**Adaptive Capacity**	**Possible Adaptation Options**	**Adaptation Pros**	**Adaptation Cons**
Fish & Mussels	Low	Rejoin floodplains/ restore wetlands	Scour relief, lowered turbidity and sediment, fish spawning and rearing habitat	
		Modified project releases	Improved fish and mussel reproduction and rearing	
		Nutrient/ AMD source control	Lessened HABs & hypoxia in reservoirs and downstream water bodies	
Agriculture (C= corn, S=soybean, W=wheat)	C: Moderate; S: High: W: High	C, S, W: Use of irrigation, use of longer season cultivars, changing planting dates	C, S, W: maintains ecosystem service, enables farming to continue; soybean and wheat productivity may increase, corn yields may decrease	C, S, W: People–Farmers may have to adapt to alternative crops and management methods, costs for irrigation and stress on other water uses
Forests (F)	F: Low ability to adapt naturally	F: Increased fire-fighting capacity; physical transplant/seeding of plant types farther north to support migration to appropriate climate	F: Reduces forest loss and corresponding increases in TSS	F: Increased cost for firefighting and migration support
Herbaceous Wetlands (HW)	HW: High	HW: Hydrologic modeling of the wetland ecosystems, coupled with monitoring of changes in wetlands, is needed to better anticipate climate change effects. Expanding wetlands to serve as flood storage has potential to mitigate losses	HW: Multiple benefits; like high benefit cost ratio	HW: Takes land from development
Near Stream Land (L)	L: High	L: Develop dynamic flood plain maps reflecting the impact of climate change. Restrict development in advance of increased flood risk. Add flood protection infrastructure Timely adaptation of bridges for increased peak flows	L: Timely restriction on land use and/or building of flood protection infrastructure prevents costly losses. High potential benefit due to large population	L: Takes land before threat is "real" to land owners
Aquatic Vegetation	Low	"Reduce shore disturbance and development, protect riparian areas, restore wetlands" (from Elly). Also, manage invasive species by more variable flows in the sub-basin.		
Drinking (DW) Extraction and Distribution Systems	DW: Moderate	DW: Use agricultural BMPs to reduce erosion; increase fire-fighting capability; relocate water intakes; water reuse and recycling; water conservation. Increase groundwater recharge–perhaps conjunctive use systems with flood skimming. Locally protect facilities from flooding.	DW: Protects and increases supply	DW: Increases agricultural costs and water supply costs
Wastewater	Low	Protect with floodwalls, decrease wastewater volume, decrease infiltration and inflow, augment low flows during low flow periods. Use low impact development techniques to help decrease drainage volume entering CSO systems. Separate sewer systems in CSO areas. Use other CSO methods.	Protects WWTP	May increase WWTP costs
Hydropower	Low	Store more water in flood season	More flexible hydropower supply	Lowers flood protection
Thermal Power generation (PG, 12 in basin)	PG: Moderate	PG: Retrofit with re-circulating systems, adopting dry cooling systems, or enable use of municipal wastewater. Also use non-cooling water forms of energy production, short- and long-term demand management.	PG: Reduces or eliminates impact of higher water temperatures	PG: Raises costs for power generation
Single and Multi-Purpose Dams Supporting Water Supply and Hydropower (2 in basin, one rated as having poor or unsatisfactory condition assessment.	Moderate	When dam modified to address poor performance, adapt to climate change. Modify ports to meet downstream water quality goals. Take advantage of storage to meet critical needs in times of drought (note; with 2 dams, limited opportunity for this). If not already implemented, implement seasonal and real-time flow forecasting.	Opportunity to help increase water supply. NOTE: With both the mean and maximum October streamflows increasing and the minimum October flow decreasing, changing reservoir operation may be able to augment the October minimum flows.	Loss of hydropower and recreational opportunities if more storage and flexibility allocated to water supply. Any reservoir regulation must consider downstream impacts.

Allegheny Sub-basin				
System	**Adaptive Capacity**	**Possible Adaptation Options**	**Adaptation Pros**	**Adaptation Cons**
Single and Multi-Purpose Dams Supporting Flood or Stormwater Management (12 in basin, one rated as having poor or unsatisfactory condition assessment.	Moderate	When dam modified to address poor performance, adapt to climate change. Modify ports to meet downstream water quality goals. Take advantage of storage to meet critical water supply needs in times of drought (note; with 12 dams, reasonable opportunity for this). Undertake other flood control measures such as flood proofing, retreating from floodplains, and local floodwalls in urban areas. Implement user-pay based flood insurance policies. If not already implemented, implement seasonal and real-time flow forecasting.	Trade-off with storage based flood management vs. water supply, recreation, and water quality purposes. May be able to meet flood management goals with assistance of other methods. NOTE: With both the mean and maximum October streamflows increasing and the minimum October flow decreasing, changing reservoir operation may be able to augment the October minimum flows.	Any reservoir regulation must consider downstream impacts
Local Flood Protection Projects such as floodwalls	moderate (can be designed to be increased in height over time as needed)	There are presently none on the Allegheny. Consider building if for increased local risks in urban areas if less flood control storage available in the future.		
Navigation Locks and Dams	Low as purpose is to maintain a level pool	Improve coordination with other water storage systems. Curtail navigation operations if necessary. Remove relatively un-used locks and dams from sub-basin.		
Waterfront Parks and Marine Terminals	Moderate	Use floating docks, locally flood proof facilities.		
Local Stormwater drainage management	Low	Consider more use of low impact development (LID) techniques to keep water out of the forma drainage system as well as recharge groundwater and other beneficial purposes. Develop local management methods such as flood proofing.		
Transportation	Moderate	As systems are renewed, make climate change resilient. Utilize regional approaches and local flood proofing as necessary.		

Table E-2: Wabash Sub-basin

Wabash Sub-basin				
System	**Adaptive Capacity**	**Possible Adaptation Options**	**Adaptation Pros**	**Adaptation Cons**
Fish & Mussels	Low in parts of extensive HUC-4. Moderate in connected floodplain reaches.	Restore wetlands	Reduced stream scour, nutrients, & improved baseflow	
		Nutrient control	Lessened HABs & hypoxia in downstream water bodies	
		Modified project releases	Improved reproduction and rearing	
		drought planning	Habitat conservation	
Agriculture (C= corn, S=soybean, W=wheat)	C: Moderate, S: High, W: High	C, S, W: Expanded irrigation, use of longer season cultivars, changing planting dates	C, S, W: Maintains ecosystem service, enables farming to continue; soybean and wheat productivity may increase	C, S, W: People–Farmers may have to adapt to alternative crops and management methods; Economic–C: Lower corn yields and increased irrigation costs; S&W: Costs for irrigation.
Forests (F)	F: Low ability to adapt naturally	F: Increased fire-fighting capacity; physical transplant/seeding of plant types farther north to support migration to appropriate climate	F: Reduces forest loss and corresponding increases in TSS	F: Increased cost for firefighting and migration support
Herbaceous Wetlands (HW)	HW: Moderate	HW: Hydrologic modeling of the wetland ecosystems, coupled with monitoring of changes in wetlands, is needed to better anticipate climate change effects. Expanding wetlands to serve as flood storage has potential to mitigate losses	HW: Multiple benefits; like high benefit cost ratio	HW: Takes land from development
Near Stream Land (L)	L: High	L: Develop dynamic flood plain maps reflecting the impact of climate change. Restrict development in advance of increased flood risk. Add flood protection infrastructure. Timely adaptation of bridges for increased peak flows	L: Timely restriction on land use and/or building of flood protection infrastructure prevents costly losses	L: Takes land before threat is “real” to land owners
Riparian/Aquatic Vegetation	Low (and large loss to agriculture)	“Reduce shore disturbance and development, protect riparian areas, restore wetlands” (from Elly). Also, manage invasive species by more variable flows in the sub-basin.		
Drinking (DW) Extraction and Distribution Systems	DW: Moderate	DW: Use agricultural BMPs to reduce erosion; increase fire-fighting capability; relocate water intakes; water reuse and recycling; water conservation. Increase groundwater recharge–perhaps conjunctive use systems with flood skimming. Locally protect facilities from flooding.	DW: Protects and increases supply	DW: Increases agricultural costs and water supply costs
Wastewater	Low	Protect with floodwalls, decrease wastewater volume, decrease infiltration and inflow, augment low flows during low flow periods. Use low impact development techniques to help decrease drainage volume entering CSO systems. Separate sewer systems in CSO areas. Use other CSO methods.	Protects WWTP	May increase WWTP costs
Hydropower	Low	Store more water in flood season	More flexible hydropower supply	Lowers flood protection
Thermal Power generation (PG, 26 in basin)	PG: Moderate	PG: Retrofit with re-circulating systems, adopting dry cooling systems, or enable use of municipal wastewater. Also use non-cooling water forms of energy production, short- and long-term demand management.	PG: Reduces or eliminates impact of higher water temperatures	PG: Raises costs for power generation
Single and Multi-Purpose Dams Supporting Water Supply and Hydropower (8 in basin, several possibly rated as having poor or unsatisfactory condition assessment.	Moderate	When dam modified to address poor performance, adapt to climate change. Modify ports to meet downstream water quality goals. Take advantage of storage to meet critical needs in times of drought (note; with 2 dams, limited opportunity for this). If not already implemented, implement seasonal and real-time flow forecasting.	Opportunity to help increase water supply. NOTE: With both the mean and maximum October streamflows increasing and the minimum October flow decreasing, changing reservoir operation may be able to augment the October minimum flows.	Loss of hydropower and recreational opportunities if more storage and flexibility allocated to water supply. Any reservoir regulation must consider downstream impacts.

Wabash Sub-basin				
System	**Adaptive Capacity**	**Possible Adaptation Options**	**Adaptation Pros**	**Adaptation Cons**
Single and Multi-Purpose Dams Supporting Flood or Stormwater Management (10 in basin, several possibly rated as having poor or unsatisfactory condition assessment.	Moderate	When dam modified to address poor performance, adapt to climate change. Modify ports to meet downstream water quality goals. Take advantage of storage to meet critical water supply needs in times of drought (note; with 12 dams, reasonable opportunity for this). Undertake other flood control measures such as flood proofing, retreating from floodplains, and local floodwalls in urban areas. Implement user-pay based flood insurance policies. If not already implemented, implement seasonal and real-time flow forecasting.	Trade-off with storage based flood management vs. water supply, recreation, and water quality purposes. May be able to meet flood management goals with assistance of other methods. NOTE: With both the mean and maximum October streamflows increasing and the minimum October flow decreasing, changing reservoir operation may be able to augment the October minimum flows.	Any reservoir regulation must consider downstream impacts.
Local Flood Protection Projects such as floodwalls (8 in sub-basin)	Moderate (can be designed to be increased in height over time as needed)			
Navigation Locks and Dams (none on sub-basin)				
Waterfront Parks and Marine Terminals (unknown number)	Moderate	Use floating docks, locally flood proof facilities.		
Local Stormwater drainage management	Low	Consider more use of low impact development (LID) techniques to keep water out of the forma drainage system as well as recharge groundwater and other beneficial purposes. Develop local management methods such as flood proofing.		
Transportation	Moderate	As systems are renewed, make climate change resilient. Utilize regional approaches and local flood proofing as necessary.		

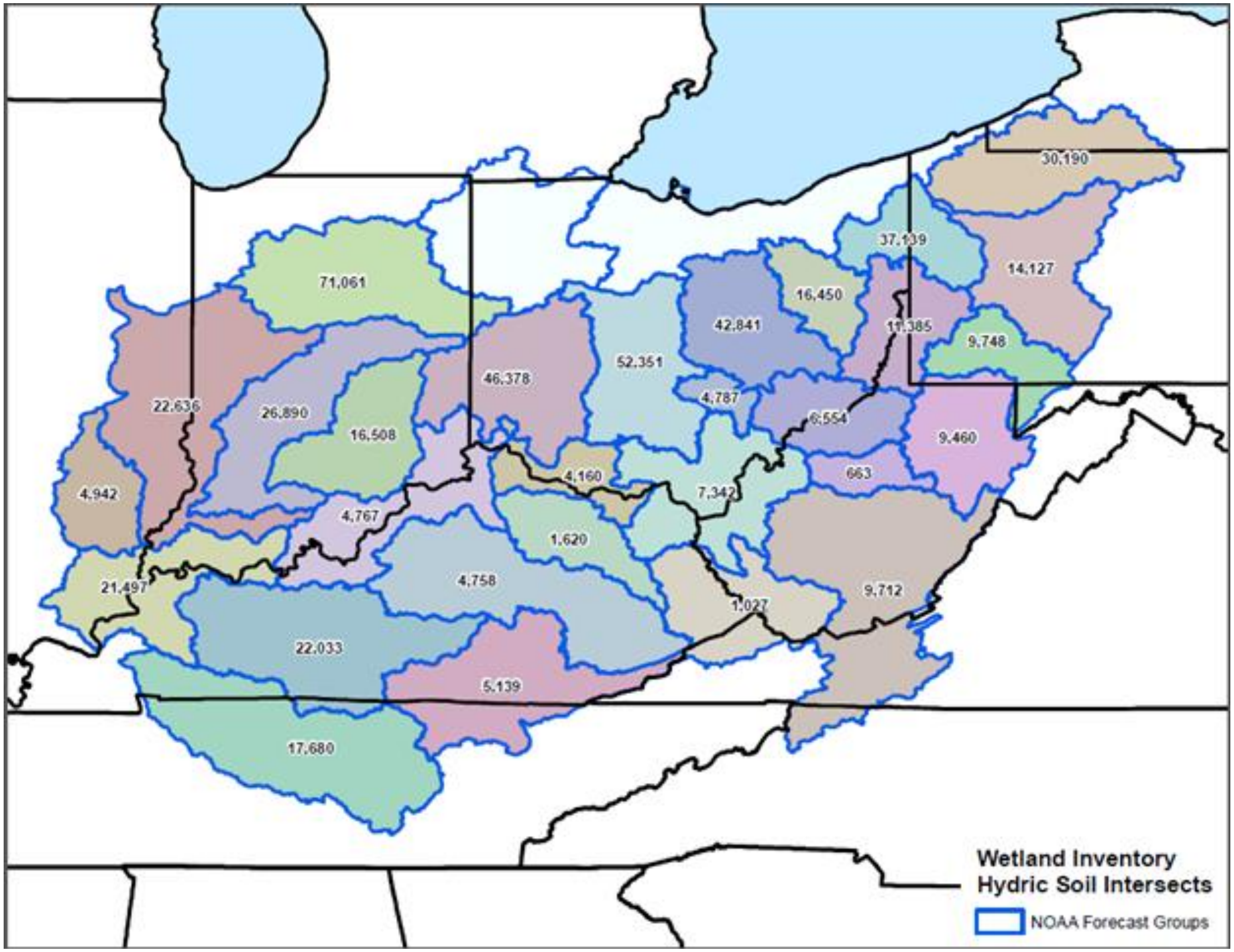


Figure E-1: Numbers of Intersections Between Hydric Soils and Existing Wetlands Basin-Wide

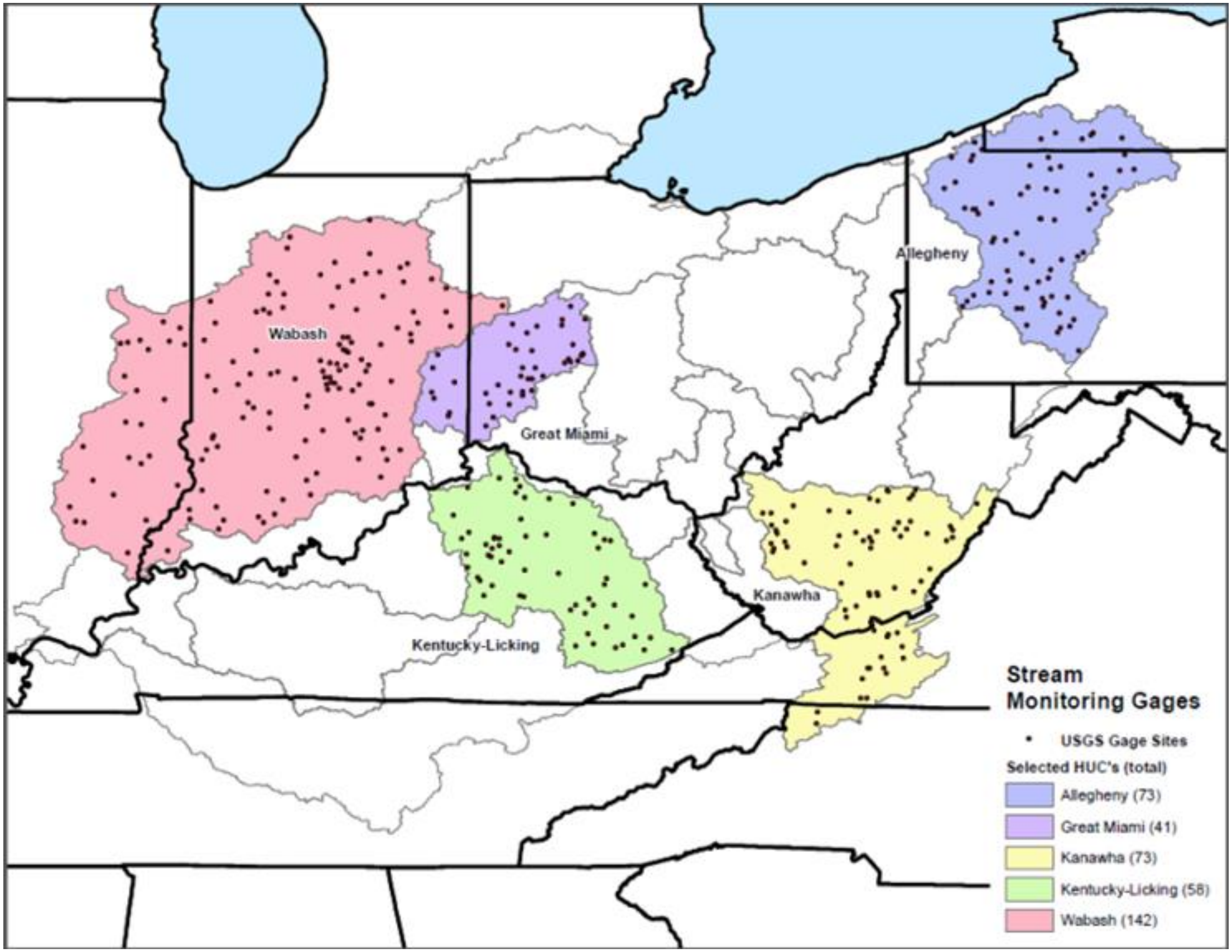


Figure E-2: USGS Monitoring Gages (Flow and WQ) for Selected HUC-4s

Table E-3: USGS Gage Monitoring Stations (Flow and WQ) for Selected HUC-4s

USGS Monitoring Gage Sites for Five Selected HUC-4s in Ohio River Basin						
HUC Code	HUC-4 NAME	Gage Site ID	Gage Site Name	Peak Discharge Samples	Water Quality Samples	Total Samples Taken
0501	Allegheny	03007800	Allegheny River at Port Allegany, PA	39	113	152
0501	Allegheny	03009680	Potato Creek at Smethport, PA	24	13	37
0501	Allegheny	03010500	Allegheny River at Eldred, PA	98	74	172
0501	Allegheny	03010800	OLEAN CREEK NEAR OLEAN NY	39	6	45
0501	Allegheny	03011000	GREAT VALLEY CREEK NEAR SALAMANCA NY	35	3	38
0501	Allegheny	03011020	ALLEGHENY RIVER AT SALAMANCA NY	110	44	154
0501	Allegheny	03011500	ALLEGHENY RIVER AT RED HOUSE NY	61	17	78
0501	Allegheny	03011800	Kinzua Creek near Guffey, PA	48	27	75
0501	Allegheny	03012550	Allegheny River at Kinzua Dam, PA	23	148	171
0501	Allegheny	03012600	Allegheny River at Warren, PA	12	155	167
0501	Allegheny	03013000	CONEWANGO CREEK AT WATERBORO NY	56	136	192
0501	Allegheny	03014500	CHADAKOIN RIVER AT FALCONER NY	79	37	116
0501	Allegheny	03015000	Conewango Creek at Russell, PA	75	98	173
0501	Allegheny	03015500	Brokenstraw Creek at Youngsville, PA	104	125	229
0501	Allegheny	03015795	East Hickory Creek near Queen, PA	2	88	90
0501	Allegheny	03016000	Allegheny River at West Hickory, PA	70	76	146
0501	Allegheny	03017500	Tionesta Creek at Lynch, PA	44	89	133
0501	Allegheny	03017800	Minister Creek at Trumans, PA	21	30	51
0501	Allegheny	03020500	Oil Creek at Rouseville, PA	103	103	206
0501	Allegheny	03021350	French Creek near Wattsburg, PA	39	1	40
0501	Allegheny	03021410	West Branch French Creek near Lowville, PA	20	1	21
0501	Allegheny	03021500	French Creek at Carters Corners, PA	61	4	65
0501	Allegheny	03021520	French Creek near Union City, PA	23	1	24
0501	Allegheny	03021700	Little Conneauttee Creek near McKean, PA	18	1	19

USGS Monitoring Gage Sites for Five Selected HUC-4s in Ohio River Basin						
HUC Code	HUC-4 NAME	Gage Site ID	Gage Site Name	Peak Discharge Samples	Water Quality Samples	Total Samples Taken
0501	Allegheny	03022540	Woodcock Creek at Blooming Valley, PA	39	8	47
0501	Allegheny	03023100	French Creek at Meadville, PA	25	5	30
0501	Allegheny	03024000	French Creek at Utica, PA	82	290	372
0501	Allegheny	03025000	Sugar Creek at Sugarcreek, PA	47	273	320
0501	Allegheny	03025200	Patchel Run near Franklin, PA	18	7	25
0501	Allegheny	03025500	Allegheny River at Franklin, PA	101	56	157
0501	Allegheny	03026500	Sevenmile Run near Rasselas, PA	62	12	74
0501	Allegheny	03027500	EB Clarion River at EB Clarion River Dam, PA	49	41	90
0501	Allegheny	03028000	West Branch Clarion River at Wilcox, PA	60	97	157
0501	Allegheny	03028500	Clarion River at Johnsonburg, PA	69	23	92
0501	Allegheny	03029000	Clarion River at Ridgway, PA	33	24	57
0501	Allegheny	03029200	Clear Creek near Sigel, PA	22	5	27
0501	Allegheny	03029400	Toms Run at Cooksburg, PA	19	71	90
0501	Allegheny	03029500	Clarion River at Cooksburg, PA	76	147	223
0501	Allegheny	03030500	Clarion River near Piney, PA	67	71	138
0501	Allegheny	03030852	Clarion River at Callensburg, PA	9	71	80
0501	Allegheny	03031000	Clarion River at St. Petersburg, PA	12	35	47
0501	Allegheny	03031500	Allegheny River at Parker, PA	82	46	128
0501	Allegheny	03032500	Redbank Creek at St. Charles, PA	104	146	250
0501	Allegheny	03033222	Beaver Run near Troutville, PA	2	1	3
0501	Allegheny	03033225	East Branch Mahoning Creek near Big Run, PA	2	5	7
0501	Allegheny	03034000	Mahoning Creek at Punxsutawney, PA	76	112	188
0501	Allegheny	03034500	Little Mahoning Creek at McCormick, PA	74	15	89
0501	Allegheny	03036000	Mahoning Creek at Mahoning Creek Dam, PA	58	148	206
0501	Allegheny	03036500	Allegheny River at Kittanning, PA	129	682	811

USGS Monitoring Gage Sites for Five Selected HUC-4s in Ohio River Basin						
HUC Code	HUC-4 NAME	Gage Site ID	Gage Site Name	Peak Discharge Samples	Water Quality Samples	Total Samples Taken
0501	Allegheny	03037400	South Branch Plum Creek near Home, PA	1	5	6
0501	Allegheny	03037525	South Branch Plum Creek at Five Points, PA	2	44	46
0501	Allegheny	03038000	Crooked Creek at Idaho, PA	78	18	96
0501	Allegheny	03039000	Crooked Creek at Crooked Creek Dam near Ford City	86	2	88
0501	Allegheny	03039200	Clear Run near Buckstown, PA	18	3	21
0501	Allegheny	03039925	North Fork Bens Creek at North Fork Reservoir, PA	11	144	155
0501	Allegheny	03039930	South Fork Bens Creek near Thomasdale, PA	2	31	33
0501	Allegheny	03040000	Stonycreek River at Ferndale, PA	98	65	163
0501	Allegheny	03041000	Little Conemaugh River at East Conemaugh, PA	75	1	76
0501	Allegheny	03041500	Conemaugh River at Seward, PA	76	43	119
0501	Allegheny	03042000	Blacklick Creek at Josephine, PA	62	17	79
0501	Allegheny	03042200	Little Yellow Creek near Strongstown, PA	20	5	25
0501	Allegheny	03042280	Yellow Creek near Homer City, PA	46	6	52
0501	Allegheny	03042500	Two Lick Creek at Graceton, PA	62	24	86
0501	Allegheny	03042700	Cherry Run near Homer City, PA	1	6	7
0501	Allegheny	03044000	Conemaugh River at Tunnelton, PA	56	155	211
0501	Allegheny	03045000	Loyalhanna Creek at Kingston, PA	74	488	562
0501	Allegheny	03047000	Loyalhanna Creek at Loyalhanna Dam, PA	56	7	63
0501	Allegheny	03048500	Kiskiminetas River at Vandergrift, PA	77	78	155
0501	Allegheny	03049000	Buffalo Creek near Freeport, PA	73	2	75
0501	Allegheny	03049500	Allegheny River at Natrona, PA	76	33	109
0501	Allegheny	03049646	Deer Creek near Dorseyville, PA	5	76	81
0501	Allegheny	03049800	Little Pine Creek near Etna, PA	51	3	54
0501	Allegheny	03049819	Girtys Run above Grant Avenue at Millvale, PA	6	19	25
0505	Kanawha	03189600	GAULEY RIVER BELOW SUMMERSVILLE DAM, WV	47	161	208

USGS Monitoring Gage Sites for Five Selected HUC-4s in Ohio River Basin						
HUC Code	HUC-4 NAME	Gage Site ID	Gage Site Name	Peak Discharge Samples	Water Quality Samples	Total Samples Taken
0505	Kanawha	03189650	COLLISON CREEK NEAR NALLEN, WV	12	88	100
0505	Kanawha	03190000	MEADOW RIVER AT NALLEN, WV	52	150	202
0505	Kanawha	03190400	MEADOW RIVER NEAR MT. LOOKOUT, WV	45	104	149
0505	Kanawha	03191500	PETERS CREEK NEAR LOCKWOOD, WV	43	254	297
0505	Kanawha	03192000	GAULEY RIVER ABOVE BELVA, WV	86	207	293
0505	Kanawha	03193000	KANAWHA RIVER AT KANAWHA FALLS, WV	136	146	282
0505	Kanawha	03193830	GILMER RUN NEAR MARLINTON, WV	21	57	78
0505	Kanawha	03194700	ELK RIVER BELOW WEBSTER SPRINGS, WV	84	195	279
0505	Kanawha	03195100	RIGHT FORK HOLLY RIVER AT GUARDIAN, WV	10	87	97
0505	Kanawha	03195250	LEFT FORK HOLLY RIVER NEAR REPLETE, WV	30	91	121
0505	Kanawha	03195500	ELK RIVER AT SUTTON, WV	76	236	312
0505	Kanawha	03195600	GRANNY CREEK AT SUTTON, WV	25	65	90
0505	Kanawha	03196500	BIRCH RIVER AT HEROLD, WV	8	59	67
0505	Kanawha	03196600	ELK RIVER NEAR FRAMETOWN, WV	55	150	205
0505	Kanawha	03196800	ELK RIVER AT CLAY, WV	51	117	168
0505	Kanawha	03197000	ELK RIVER AT QUEEN SHOALS, WV	86	243	329
0505	Kanawha	03198000	KANAWHA RIVER AT CHARLESTON, WV	74	73	147
0505	Kanawha	03198350	CLEAR FORK AT WHITESVILLE, WV	17	75	92
0505	Kanawha	03198450	DRAWDY CREEK NEAR PEYTONA, WV	18	90	108
0505	Kanawha	03198500	BIG COAL RIVER AT ASHFORD, WV	91	288	379
0505	Kanawha	03198550	BIG COAL RIVER NEAR ALUM CREEK,	8	81	89
0505	Kanawha	03199000	LITTLE COAL RIVER AT DANVILLE, WV	54	312	366
0505	Kanawha	03199300	ROCK CREEK NEAR DANVILLE, WV	15	93	108
0505	Kanawha	03199400	LITTLE COAL RIVER AT JULIAN, WV	10	90	100
0505	Kanawha	03199700	COAL RIVER AT ALUM CREEK, WV	5	43	48

USGS Monitoring Gage Sites for Five Selected HUC-4s in Ohio River Basin						
HUC Code	HUC-4 NAME	Gage Site ID	Gage Site Name	Peak Discharge Samples	Water Quality Samples	Total Samples Taken
0505	Kanawha	03200500	COAL RIVER AT TORNADO, WV	58	141	199
0505	Kanawha	03200600	LITTLE SCARY CREEK NR NITRO, WV	12	1	13
0505	Kanawha	03201000	POCATALICO RIVER AT SISSONVILLE, WV	54	237	291
0505	Kanawha	03201410	POPLAR FORK AT TEAYS, WV	32	58	90
0505	Kanawha	03201500	OHIO RIVER AT POINT PLEASANT, WV	74	4	78
0505	Kanawha	03161000	SOUTH FORK NEW RIVER NEAR JEFFERSON, NC	87	72	159
0505	Kanawha	03162500	NORTH FORK NEW RIVER AT CRUMPLER, NC	40	48	88
0505	Kanawha	03164000	NEW RIVER NEAR GALAX, VA	84	319	403
0505	Kanawha	03165000	CHESTNUT CREEK AT GALAX, VA	70	20	90
0505	Kanawha	03165500	NEW RIVER AT IVANHOE, VA	73	12	85
0505	Kanawha	03166800	GLADE CREEK AT GRAHAMS FORGE, VA	20	3	23
0505	Kanawha	03167000	REED CREEK AT GRAHAMS FORGE, VA	95	102	197
0505	Kanawha	03167500	BIG REED ISLAND CREEK NEAR ALLISONIA, VA	68	14	82
0505	Kanawha	03168000	NEW RIVER AT ALLISONIA, VA	84	22	106
0505	Kanawha	03168500	PEAK CREEK AT PULASKI, VA	17	9	26
0505	Kanawha	03170000	LITTLE RIVER AT GRAYSONTOWN, VA	85	62	147
0505	Kanawha	03171000	NEW RIVER AT RADFORD, VA	119	11	130
0505	Kanawha	03171500	NEW RIVER AT EGGLESTON, VA	69	222	291
0505	Kanawha	03172500	WALKER CREEK AT STAFFORDSVILLE, VA	8	1	9
0505	Kanawha	03173000	WALKER CREEK AT BANE, VA	77	26	103
0505	Kanawha	03175500	WOLF CREEK NEAR NARROWS, VA	84	28	112
0505	Kanawha	03176400	RICH CREEK NEAR PETERSTOWN, WV	10	1	11
0505	Kanawha	03176500	NEW RIVER AT GLEN LYN, VA	100	521	621
0505	Kanawha	03178000	BLUESTONE R NR SPANISHBURG, WV	11	34	45
0505	Kanawha	03178500	CAMP CREEK NEAR CAMP CREEK, WV	32	242	274

USGS Monitoring Gage Sites for Five Selected HUC-4s in Ohio River Basin						
HUC Code	HUC-4 NAME	Gage Site ID	Gage Site Name	Peak Discharge Samples	Water Quality Samples	Total Samples Taken
0505	Kanawha	03179000	BLUESTONE RIVER NEAR PIPESTEM, WV	63	226	289
0505	Kanawha	03180000	NEW RIVER AT BLUESTONE DAM, WV	55	212	267
0505	Kanawha	03180500	GREENBRIER RIVER AT DURBIN, WV	70	298	368
0505	Kanawha	03181200	INDIAN DRAFT NEAR MARLINTON, WV	9	55	64
0505	Kanawha	03182000	KNAPP CREEK AT MARLINTON, WV	20	7	27
0505	Kanawha	03182500	GREENBRIER RIVER AT BUCKEYE, WV	84	294	378
0505	Kanawha	03182700	ANTHONY CREEK NEAR ANTHONY, WV	12	120	132
0505	Kanawha	03182950	HOWARD CREEK AT CALDWELL, WV	7	160	167
0505	Kanawha	03183000	SECOND CREEK NEAR SECOND CREEK, WV	30	309	339
0505	Kanawha	03183500	GREENBRIER RIVER AT ALDERSON, WV	118	304	422
0505	Kanawha	03184000	GREENBRIER RIVER AT HILLDALE, WV	78	226	304
0505	Kanawha	03184200	BIG CREEK NEAR BELLEPOINT, WV	21	67	88
0505	Kanawha	03184500	NEW RIVER AT HINTON, WV	77	162	239
0505	Kanawha	03185000	PINEY CREEK AT RALEIGH, WV	42	703	745
0505	Kanawha	03185400	NEW RIVER AT THURMOND, WV	33	69	102
0505	Kanawha	03186500	WILLIAMS RIVER AT DYER, WV	84	288	372
0505	Kanawha	03187000	GAULEY RIVER AT CAMDEN ON GAULEY, WV	91	153	244
0505	Kanawha	03187300	NORTH FORK CRANBERRY RIVER NEAR HILLSBORO, WV	19	53	72
0505	Kanawha	03187500	CRANBERRY RIVER NEAR RICHWOOD, WV	56	148	204
0505	Kanawha	03189000	CHERRY RIVER AT FENWICK, WV	43	155	198
0505	Kanawha	03189100	GAULEY RIVER NEAR CRAIGSVILLE, WV	49	165	214
0505	Kanawha	03189500	GAULEY RIVER NEAR SUMMERSVILLE, WV	45	2	47
0510	Kentucky-Licking	03248500	LICKING RIVER NEAR SALYERSVILLE, KY	57	221	278
0510	Kentucky-Licking	03249500	LICKING RIVER AT FARMERS, KY	57	149	206
0510	Kentucky-Licking	03250000	TRIPLETT CREEK AT MOREHEAD, KY	44	52	96

USGS Monitoring Gage Sites for Five Selected HUC-4s in Ohio River Basin						
HUC Code	HUC-4 NAME	Gage Site ID	Gage Site Name	Peak Discharge Samples	Water Quality Samples	Total Samples Taken
0510	Kentucky-Licking	03250100	NORTH FORK TRIPLETT CREEK NEAR MOREHEAD, KY	28	156	184
0510	Kentucky-Licking	03250320	ROCK LICK CREEK NEAR SHARKEY, KY	9	42	51
0510	Kentucky-Licking	03251000	NORTH FORK LICKING RIVER NEAR LEWISBURG, KY	46	132	178
0510	Kentucky-Licking	03251200	NORTH FORK LICKING RIVER NEAR MT OLIVET, KY	22	37	59
0510	Kentucky-Licking	03251500	LICKING RIVER AT MCKINNEYSBURG, KY	74	771	845
0510	Kentucky-Licking	03252000	STONER CREEK AT PARIS, KY	38	130	168
0510	Kentucky-Licking	03252300	HINKSTON CREEK NEAR CARLISLE, KY	21	39	60
0510	Kentucky-Licking	03252500	SOUTH FORK LICKING RIVER AT CYNTHIANA, KY	78	142	220
0510	Kentucky-Licking	03253000	SOUTH FORK LICKING RIVER AT HAYES, KY	4	5	9
0510	Kentucky-Licking	03253500	LICKING RIVER AT CATAWBA, KY	127	161	288
0510	Kentucky-Licking	03254000	LICKING RIVER AT BUTLER, KY	5	207	212
0510	Kentucky-Licking	03254400	NORTH FORK GRASSY CREEK NEAR PINER, KY	16	51	67
0508	Great Miami	03260450	South Fork Great Miami River near Huntsville OH	1	2	3
0508	Great Miami	03260700	Bokengehalas Creek near De Graff OH	35	8	43
0508	Great Miami	03260800	Stony Creek near De Graff OH	18	8	26
0508	Great Miami	03261500	Great Miami River at Sidney OH	100	194	294
0508	Great Miami	03261950	Loramie Creek near Newport OH	48	45	93
0508	Great Miami	03262000	Loramie Creek at Lockington OH	98	10	108
0508	Great Miami	03262700	Great Miami River at Troy OH	51	84	135
0508	Great Miami	03263000	Great Miami River at Taylorsville OH	96	25	121
0508	Great Miami	03264000	Greenville Creek near Bradford OH	82	76	158
0508	Great Miami	03265000	Stillwater River at Pleasant Hill OH	97	63	160
0508	Great Miami	03266000	Stillwater River at Englewood OH	88	259	347
0508	Great Miami	03266500	Mad River at Zanesfield OH	33	49	82
0508	Great Miami	03267000	Mad River near Urbana OH	79	64	143

USGS Monitoring Gage Sites for Five Selected HUC-4s in Ohio River Basin						
HUC Code	HUC-4 NAME	Gage Site ID	Gage Site Name	Peak Discharge Samples	Water Quality Samples	Total Samples Taken
0508	Great Miami	03267900	Mad River at St Paris Pike at Eagle City OH	45	203	248
0508	Great Miami	03267950	Buck Creek near New Moorefield OH	9	29	38
0508	Great Miami	03267960	East Fork Buck Creek near New Moorefield OH	9	29	38
0508	Great Miami	03268000	Buck Creek at New Moorefield OH	17	45	62
0508	Great Miami	03268500	Beaver Creek near Springfield OH	21	15	36
0508	Great Miami	03269000	Buck Creek at Springfield OH	57	6	63
0508	Great Miami	03269500	Mad River near Springfield OH	102	8	110
0508	Great Miami	03270000	Mad River near Dayton OH	99	281	380
0508	Great Miami	03270500	Great Miami River at Dayton OH	120	9	129
0508	Great Miami	03270800	Wolf Creek at Trotwood OH	25	8	33
0508	Great Miami	03271000	Wolf Creek at Dayton OH	39	36	75
0508	Great Miami	03271300	Holes Creek near Kettering OH	8	7	15
0508	Great Miami	03271500	Great Miami River at Miamisburg OH	77	9	86
0508	Great Miami	03271601	Great Miami River below Miamisburg OH	21	1	22
0508	Great Miami	03271800	Twin Creek near Ingomar OH	38	46	84
0508	Great Miami	03272000	Twin Creek near Germantown OH	96	16	112
0508	Great Miami	03272100	Great Miami River at Middletown OH	17	269	286
0508	Great Miami	03272700	Sevenmile Creek at Camden OH	42	3	45
0508	Great Miami	03272800	Sevenmile Creek at Collinsville OH	17	55	72
0508	Great Miami	03274000	Great Miami River at Hamilton OH	106	51	157
0508	Great Miami	03274500	Great Miami River at Venice OH	13	20	33
0508	Great Miami	03274650	WHITEWATER RIVER NEAR ECONOMY, IN	43	2	45
0508	Great Miami	03274750	WHITEWATER RIVER NEAR HAGERSTOWN, IN	33	76	109
0508	Great Miami	03274950	LITTLE WILLIAMS CREEK AT CONNERSVILLE, IND	23	2	25
0508	Great Miami	03275000	WHITEWATER RIVER NEAR ALPINE, IN	85	110	195

USGS Monitoring Gage Sites for Five Selected HUC-4s in Ohio River Basin						
HUC Code	HUC-4 NAME	Gage Site ID	Gage Site Name	Peak Discharge Samples	Water Quality Samples	Total Samples Taken
0508	Great Miami	03275600	EAST FORK WHITEWATER RIVER AT ABINGTON, IN	48	151	199
0508	Great Miami	03276000	EAST FORK WHITEWATER RIVER AT BROOKVILLE, IN	48	75	123
0508	Great Miami	03276500	WHITEWATER RIVER AT BROOKVILLE, IN	96	168	264
0510	Kentucky-Licking	03277300	NORTH FORK KENTUCKY RIVER AT WHITESBURG, KY	42	5	47
0510	Kentucky-Licking	03277400	LEATHERWOOD CREEK AT DAISY, KY	26	41	67
0510	Kentucky-Licking	03277450	CARR FORK NEAR SASSAFRAS, KY	32	182	214
0510	Kentucky-Licking	03277500	NORTH FORK KENTUCKY RIVER AT HAZARD, KY	70	459	529
0510	Kentucky-Licking	03278500	TROUBLESOME CREEK AT NOBLE, KY	33	39	72
0510	Kentucky-Licking	03280000	NORTH FORK KENTUCKY RIVER AT JACKSON, KY	92	167	259
0510	Kentucky-Licking	03280500	NORTH FORK KENTUCKY RIVER NEAR AIRDALE, KY	5	4	9
0510	Kentucky-Licking	03280600	MIDDLE FORK KENTUCKY RIVER NEAR HYDEN, KY	36	139	175
0510	Kentucky-Licking	03280700	CUTSHIN CREEK AT WOOTON, KY	55	139	194
0510	Kentucky-Licking	03280900	MIDDLE FORK KENTUCKY RIVER AT BUCKHORN, KY	20	4	24
0510	Kentucky-Licking	03281000	MIDDLE FORK KENTUCKY RIVER AT TALLEGA, KY	80	177	257
0510	Kentucky-Licking	03281040	RED BIRD RIVER NEAR BIG CREEK, KY	30	151	181
0510	Kentucky-Licking	03281100	GOOSE CREEK AT MANCHESTER, KY	52	159	211
0510	Kentucky-Licking	03281200	SOUTH FORK KENTUCKY RIVER AT ONEIDA, KY	26	7	33
0510	Kentucky-Licking	03281500	SOUTH FORK KENTUCKY RIVER AT BOONEVILLE, KY	82	174	256
0510	Kentucky-Licking	03282000	KENTUCKY RIVER AT LOCK 14 AT HEIDELBERG, KY	93	75	168
0510	Kentucky-Licking	03282040	STURGEON CREEK AT CRESSMONT, KY	21	24	45
0510	Kentucky-Licking	03282500	RED RIVER NEAR HAZEL GREEN, KY	59	157	216
0510	Kentucky-Licking	03283000	STILLWATER CREEK AT STILLWATER, KY	29	7	36
0510	Kentucky-Licking	03283500	RED RIVER AT CLAY CITY, KY	79	150	229
0510	Kentucky-Licking	03284000	KENTUCKY RIVER AT LOCK 10 NEAR WINCHESTER, KY	105	156	261
0510	Kentucky-Licking	03284300	SILVER CREEK NEAR KINGSTON, KY	16	43	59

USGS Monitoring Gage Sites for Five Selected HUC-4s in Ohio River Basin						
HUC Code	HUC-4 NAME	Gage Site ID	Gage Site Name	Peak Discharge Samples	Water Quality Samples	Total Samples Taken
0510	Kentucky-Licking	03284310	SILVER CREEK NEAR BEREA, KY	18	8	26
0510	Kentucky-Licking	03284500	KENTUCKY RIVER AT LOCK 8 NEAR CAMP NELSON, KY	72	1	73
0510	Kentucky-Licking	03284550	WEST HICKMAN CREEK AT JONESTOWN, KY	11	47	58
0510	Kentucky-Licking	03285000	DIX RIVER NEAR DANVILLE, KY	70	142	212
0510	Kentucky-Licking	03286200	DIX RIVER AT DIX DAM NEAR BURGIN, KY	3	3	6
0510	Kentucky-Licking	03286500	KENTUCKY RIVER AT LOCK 7 AT HIGHBRIDGE, KY	21	26	47
0510	Kentucky-Licking	03287000	KENTUCKY RIVER AT LOCK 6 NEAR SALVISA, KY	119	124	243
0510	Kentucky-Licking	03287250	KENTUCKY RIVER AT LOCK 5 NEAR TYRONE, KY	10	1	11
0510	Kentucky-Licking	03287500	KENTUCKY RIVER AT LOCK 4 AT FRANKFORT, KY	123	820	943
0510	Kentucky-Licking	03287600	N ELKHORN CR AT BRYAN STATION RD AT MONTROSE, KY	15	7	22
0510	Kentucky-Licking	03288000	NORTH ELKHORN CREEK NEAR GEORGETOWN, KY	44	121	165
0510	Kentucky-Licking	03288100	NORTH ELKHORN CREEK AT GEORGETOWN, KY	21	22	43
0510	Kentucky-Licking	03288110	ROYAL SPRINGS AT GEORGETOWN, KY	21	17	38
0510	Kentucky-Licking	03288200	CANE RUN AT BEREA ROAD NEAR DONERAIL, KY	12	3	15
0510	Kentucky-Licking	03288500	CAVE CREEK NEAR FORT SPRING, KY	27	1	28
0510	Kentucky-Licking	03289000	SOUTH ELKHORN CREEK AT FORT SPRING, KY	58	129	187
0510	Kentucky-Licking	03289200	TOWN BRANCH AT YARNALLTON ROAD AT YARNALLTON, KY	16	7	23
0510	Kentucky-Licking	03289300	SOUTH ELKHORN CREEK NEAR MIDWAY, KY	31	133	164
0510	Kentucky-Licking	03289500	ELKHORN CREEK NEAR FRANKFORT, KY	76	165	241
0510	Kentucky-Licking	03290500	KENTUCKY RIVER AT LOCK 2 AT LOCKPORT, KY	129	285	414
0510	Kentucky-Licking	03291500	EAGLE CREEK AT GLENCOE, KY	86	138	224
0512	Wabash	03322500	WABASH RIVER NEAR NEW CORYDON, IND	37	56	93
0512	Wabash	03322900	WABASH RIVER AT LINN GROVE, IN	50	86	136
0512	Wabash	03323000	WABASH RIVER AT BLUFFTON, IND	62	29	91
0512	Wabash	03323500	WABASH RIVER AT HUNTINGTON, IN	53	8	61

USGS Monitoring Gage Sites for Five Selected HUC-4s in Ohio River Basin						
HUC Code	HUC-4 NAME	Gage Site ID	Gage Site Name	Peak Discharge Samples	Water Quality Samples	Total Samples Taken
0512	Wabash	03324000	LITTLE RIVER NEAR HUNTINGTON, IN	70	68	138
0512	Wabash	03324200	SALAMONIE RIVER AT PORTLAND, IND.	34	6	40
0512	Wabash	03324300	SALAMONIE RIVER NEAR WARREN, IN	56	119	175
0512	Wabash	03324500	SALAMONIE RIVER AT DORA, IN	78	8	86
0512	Wabash	03325000	WABASH RIVER AT WABASH, IN	91	5	96
0512	Wabash	03325500	MISSISSINEWA RIVER NEAR RIDGEVILLE, IN	67	57	124
0512	Wabash	03326000	MISSISSINEWA RIVER NEAR EATON, IND	20	1	21
0512	Wabash	03326070	BIG LICK CREEK NEAR HARTFORD CITY, IN	32	4	36
0512	Wabash	03326500	MISSISSINEWA RIVER AT MARION, IN	91	14	105
0512	Wabash	03327000	MISSISSINEWA RIVER AT PEORIA, IN	50	10	60
0512	Wabash	03327520	PIPE CREEK NEAR BUNKER HILL, IND.	35	25	60
0512	Wabash	03328000	EEL RIVER AT NORTH MANCHESTER, IN	92	5	97
0512	Wabash	03328430	WEESAU CREEK NEAR DEEDSVILLE, IN	31	1	32
0512	Wabash	03328500	EEL RIVER NEAR LOGANSPORT, IN	71	97	168
0512	Wabash	03329400	RATTLESNAKE CREEK NEAR PATTON, IND.	25	15	40
0512	Wabash	03329700	DEER CREEK NEAR DELPHI, IN	71	79	150
0512	Wabash	03330500	TIPPECANOE RIVER AT OSWEGO, IN	65	5	70
0512	Wabash	03331500	TIPPECANOE RIVER NEAR ORA, IN	70	57	127
0512	Wabash	03331753	TIPPECANOE RIVER AT WINAMAC, IN	12	20	32
0512	Wabash	03332500	TIPPECANOE RIVER NEAR MONTICELLO, IND.	50	8	58
0512	Wabash	03333050	TIPPECANOE RIVER NEAR DELPHI, IN	26	5	31
0512	Wabash	03333450	WILDCAT CREEK NEAR JEROME, IN	53	118	171
0512	Wabash	03333700	WILDCAT CREEK AT KOKOMO, IN	58	1	59
0512	Wabash	03334000	WILDCAT CREEK AT OWASCO, IN	65	5	70
0512	Wabash	03334500	SOUTH FORK WILDCAT CREEK NEAR LAFAYETTE, IN	71	7	78

USGS Monitoring Gage Sites for Five Selected HUC-4s in Ohio River Basin						
HUC Code	HUC-4 NAME	Gage Site ID	Gage Site Name	Peak Discharge Samples	Water Quality Samples	Total Samples Taken
0512	Wabash	03335000	WILDCAT CREEK NEAR LAFAYETTE, IN	59	121	180
0512	Wabash	03335500	WABASH RIVER AT LAFAYETTE, IN	110	59	169
0512	Wabash	03335690	MUD PINE CREEK NEAR OXFORD, IND	33	15	48
0512	Wabash	03335700	BIG PINE CR NR WILLIAMSPORT IND	32	89	121
0512	Wabash	03336000	WABASH RIVER AT COVINGTON, IN	88	8	96
0512	Wabash	03336500	BLUEGRASS CREEK AT POTOMAC, IL	33	49	82
0512	Wabash	03336645	MIDDLE FORK VERMILION RIVER ABOVE OAKWOOD, IL	37	264	301
0512	Wabash	03336900	SALT FORK NEAR ST. JOSEPH, IL	43	396	439
0512	Wabash	03337000	BONEYARD CREEK AT URBANA, IL	66	185	251
0512	Wabash	03337570	SALINE BRANCH ABOVE 1700E NEAR URBANA, IL	5	1	6
0512	Wabash	03338000	SALT FORK NEAR HOMER, IL	38	4	42
0512	Wabash	03338780	NORTH FORK VERMILION RIVER NEAR BISMARCK, IL	25	215	240
0512	Wabash	03339000	VERMILION RIVER NEAR DANVILLE, IL	91	444	535
0512	Wabash	03339500	SUGAR CREEK AT CRAWFORDSVILLE, IN	78	56	134
0512	Wabash	03340000	SUGAR CREEK NEAR BYRON, IND.	31	22	53
0512	Wabash	03340500	WABASH RIVER AT MONTEZUMA, IN	90	5	95
0512	Wabash	03340800	BIG RACCOON CREEK NEAR FINCASTLE, IN	57	59	116
0512	Wabash	03340900	BIG RACCOON CREEK AT FERNDALE, IN	46	36	82
0512	Wabash	03341300	BIG RACCOON CREEK AT COXVILLE, IN	54	5	59
0512	Wabash	03341700	BIG CREEK TRIBUTARY NEAR DUDLEY, IL	15	2	17
0512	Wabash	03342100	BUSSERON CREEK NEAR HYMERA, IN	37	13	50
0512	Wabash	03342150	WEST FORK BUSSERON CREEK NEAR HYMERA, IN	20	30	50
0512	Wabash	03342250	MUD CR NR DUGGER IN	15	9	24
0512	Wabash	03342300	BUSSERON CR NR SULLIVAN IN	20	84	104
0512	Wabash	03342500	BUSSERON CREEK NEAR CARLISLE, IN	67	20	87

USGS Monitoring Gage Sites for Five Selected HUC-4s in Ohio River Basin						
HUC Code	HUC-4 NAME	Gage Site ID	Gage Site Name	Peak Discharge Samples	Water Quality Samples	Total Samples Taken
0512	Wabash	03343400	EMBARRAS RIVER NEAR CAMARGO, IL	53	192	245
0512	Wabash	03343550	EMBARRAS RIVER AT STATE HWY 133 NR OAKLAND, IL	4	67	71
0512	Wabash	03344000	EMBARRAS RIVER NEAR DIONA, IL	28	354	382
0512	Wabash	03344500	RANGE CREEK NEAR CASEY, IL	41	147	188
0512	Wabash	03345000	EMBARRAS RIVER AT NEWTON, IL	6	1	7
0512	Wabash	03345500	EMBARRAS RIVER AT STE. MARIE, IL	103	386	489
0512	Wabash	03346000	NORTH FORK EMBARRAS RIVER NEAR OBLONG, IL	73	249	322
0512	Wabash	03346500	EMBARRAS RIVER AT LAWRENCEVILLE, IL	12	1	13
0512	Wabash	03346650	RIVER DESHEE TRIB NR FRICHTON, IND.	10	2	12
0512	Wabash	03347000	WHITE RIVER AT MUNCIE, IN	91	30	121
0512	Wabash	03347500	BUCK CREEK NEAR MUNCIE, IN	49	64	113
0512	Wabash	03348000	WHITE RIVER AT ANDERSON, IN	91	2	93
0512	Wabash	03348020	KILLBUCK CREEK NEAR GASTON, IND.	24	29	53
0512	Wabash	03348500	WHITE RIVER NEAR NOBLESVILLE IND	61	44	105
0512	Wabash	03349000	WHITE RIVER AT NOBLESVILLE, IN	68	1	69
0512	Wabash	03349500	CICERO CREEK NR ARCADIA, IN	27	1	28
0512	Wabash	03349700	LITTLE CICERO CREEK NEAR ARCADIA, IND.	26	1	27
0512	Wabash	03350100	HINKLE CREEK NEAR CICERO, IND.	26	1	27
0512	Wabash	03350500	CICERO CREEK AT NOBLESVILLE, IND.	38	9	47
0512	Wabash	03350700	STONY CREEK NEAR NOBLESVILLE, IN	46	104	150
0512	Wabash	03351000	WHITE RIVER NEAR NORA, IN	86	74	160
0512	Wabash	03351072	WILLIAMS CREEK AT 96TH STREET, INDIANAPOLIS, IN	6	65	71
0512	Wabash	03351500	FALL CREEK NEAR FORTVILLE, IN	73	59	132
0512	Wabash	03352200	MUD CREEK AT INDIANAPOLIS, IND.	24	1	25
0512	Wabash	03352500	FALL CREEK AT MILLERSVILLE, IN	86	5	91

USGS Monitoring Gage Sites for Five Selected HUC-4s in Ohio River Basin						
HUC Code	HUC-4 NAME	Gage Site ID	Gage Site Name	Peak Discharge Samples	Water Quality Samples	Total Samples Taken
0512	Wabash	03352875	FALL CREEK AT 16TH STREET AT INDIANAPOLIS, IN	6	63	69
0512	Wabash	03353000	WHITE RIVER AT INDIANAPOLIS, IN	105	75	180
0512	Wabash	03353180	BEAN CREEK AT INDIANAPOLIS, IND	23	114	137
0512	Wabash	03353200	EAGLE CREEK AT ZIONSVILLE, IN	57	204	261
0512	Wabash	03353551	LITTLE EAGLE CREEK AT 52ND ST. AT INDIANAPOLIS, IN	11	28	39
0512	Wabash	03353600	LITTLE EAGLE CREEK AT SPEEDWAY, IN	54	30	84
0512	Wabash	03353611	WHITE R. AT STOUT GEN. STN. AT INDIANAPOLIS, IN	21	2	23
0512	Wabash	03353630	LITTLE BUCK CREEK NEAR SOUTHPORT, IN	11	27	38
0512	Wabash	03353637	LITTLE BUCK CREEK NEAR INDIANAPOLIS, IN	24	367	391
0512	Wabash	03353700	WEST FORK WHITE LICK CREEK AT DANVILLE, IN	47	2	49
0512	Wabash	03353800	WHITE LICK CREEK AT MOORESVILLE, IN	58	25	83
0512	Wabash	03354000	WHITE RIVER NEAR CENTERTON, IN	70	232	302
0512	Wabash	03354500	BEANBLOSSOM CREEK AT BEANBLOSSOM, IN	42	155	197
0512	Wabash	03357000	WHITE RIVER AT SPENCER, IN	48	1	49
0512	Wabash	03357300	BIG WALNUT CREEK NR BARNARD, IN	1	1	2
0512	Wabash	03357330	BIG WALNUT CREEK NEAR ROACHDALE, IN	12	199	211
0512	Wabash	03357500	BIG WALNUT CREEK NEAR REELSVILLE, IN	53	92	145
0512	Wabash	03358000	MILL CREEK NEAR CATARACT, IN	64	54	118
0512	Wabash	03359000	MILL CREEK NEAR MANHATTAN, IN	63	9	72
0512	Wabash	03360000	EEL RIVER AT BOWLING GREEN, IN	85	1	86
0512	Wabash	03361000	BIG BLUE RIVER AT CARTHAGE, IN	55	66	121
0512	Wabash	03361440	LITTLE BLUE RIVER AT SHELBYVILLE, IN	4	5	9
0512	Wabash	03361500	BIG BLUE RIVER AT SHELBYVILLE, IN	72	81	153
0512	Wabash	03361632	SUGAR CREEK NEAR EDEN, IN	3	2	5
0512	Wabash	03361638	LEARY-WEBER DITCH AT MOHAWK, IN	9	190	199

USGS Monitoring Gage Sites for Five Selected HUC-4s in Ohio River Basin						
HUC Code	HUC-4 NAME	Gage Site ID	Gage Site Name	Peak Discharge Samples	Water Quality Samples	Total Samples Taken
0512	Wabash	03361650	SUGAR CREEK AT NEW PALESTINE, IN	46	18	64
0512	Wabash	03361850	BUCK CREEK AT ACTON, IN	46	70	116
0512	Wabash	03362500	SUGAR CREEK NEAR EDINBURGH, IN	71	80	151
0512	Wabash	03363500	FLATROCK RIVER AT ST. PAUL, IN	84	86	170
0512	Wabash	03363900	FLATROCK RIVER AT COLUMBUS, IN	46	3	49
0512	Wabash	03364200	HAW CREEK NEAR CLIFFORD, IN	28	17	45
0512	Wabash	03364500	CLIFTY CREEK AT HARTSVILLE, IN	67	7	74
0512	Wabash	03364650	CLIFTY CREEK NEAR COLUMBUS, IN	7	38	45
0512	Wabash	03365000	SAND CREEK NEAR BREWERSVILLE, IND.	39	46	85
0512	Wabash	03365500	EAST FORK WHITE RIVER AT SEYMOUR, IN	91	102	193
0512	Wabash	03366500	MUSCATATUCK RIVER NEAR DEPUTY, IN	66	105	171
0512	Wabash	03368000	BRUSH CREEK NEAR NEBRASKA, IN	58	47	105
0512	Wabash	03369500	VERNON FORK MUSCATATUCK RIVER AT VERNON, IN	74	33	107
0512	Wabash	03371500	EAST FORK WHITE RIVER NEAR BEDFORD, IN	75	12	87
0512	Wabash	03371520	BACK CREEK AT LEESVILLE, IN	34	2	36
0512	Wabash	03372300	STEPHENS CREEK NEAR BLOOMINGTON, IND.	21	151	172
0512	Wabash	03372500	SALT CREEK NEAR HARRODSBURG, IN	46	9	55
0512	Wabash	03373500	EAST FORK WHITE RIVER AT SHOALS, IN	111	46	157
0512	Wabash	03373530	LOST RIVER NEAR LEIPSIC, IN	12	35	47
0512	Wabash	03373700	LOST RIVER NR. WEST BADEN SPRINGS, IND.	30	21	51
0512	Wabash	03374000	WHITE RIVER AT PETERSBURG, IN	91	20	111
0512	Wabash	03374100	WHITE RIVER AT HAZLETON, IN	3	877	880
0512	Wabash	03374500	PATOKA RIVER NEAR CUZCO, IN	41	8	49
0512	Wabash	03375500	PATOKA RIVER AT JASPER, IN	68	3	71
0512	Wabash	03375800	HALL CREEK NEAR ST. ANTHONY, IND.	31	1	32

USGS Monitoring Gage Sites for Five Selected HUC-4s in Ohio River Basin						
HUC Code	HUC-4 NAME	Gage Site ID	Gage Site Name	Peak Discharge Samples	Water Quality Samples	Total Samples Taken
0512	Wabash	03376300	PATOKA RIVER AT WINSLOW, IN	40	20	60
0512	Wabash	03376350	SOUTH FORK PATOKA RIVER NEAR SPURGEON, IND.	30	1267	1297
0512	Wabash	03376500	PATOKA RIVER NEAR PRINCETON, IN	79	72	151
0512	Wabash	03378000	BONPAS CREEK AT BROWNS, IL	73	272	345
0512	Wabash	03378550	BIG CREEK NEAR WADESVILLE, IN	48	25	73
0512	Wabash	03378635	LITTLE WABASH RIVER NEAR EFFINGHAM, IL	46	252	298
0512	Wabash	03378900	LITTLE WABASH RIVER AT LOUISVILLE, IL	30	333	363
0512	Wabash	03379500	LITTLE WABASH RIVER BELOW CLAY CITY, IL	99	252	351
0512	Wabash	03380350	SKILLET FORK NEAR IUKA, IL	18	268	286
0512	Wabash	03380475	HORSE CREEK NEAR KEENES, IL	31	66	97
0512	Wabash	03380500	SKILLET FORK AT WAYNE CITY, IL	96	277	373
0512	Wabash	03381500	LITTLE WABASH RIVER AT CARMI, IL	74	98	172
0512	Wabash	402913084285400	Chickasaw Creek at St. Marys, OH	2	33	35
Total		**387**		**19,111**	**36,664**	**55,775**

20. Appendix F: Report References

Adams, R. M., C.-C. Chang, R. A. Fleming, B. A. McCarl, and C. Rozenzweig. 1995. A reassessment of the economic effects of global climate change on U.S. agriculture. *Climatic Change*, vol. 30, pp. 147-167.

Adler, R. F., P. Arkin, D. Bolvin, A. Chang, S. Curtis, R. Ferraro, A. Gruber, G. J. Huffman, J. Janowiak, E. Nelkin, B. Rudolf, U. Schneider, J. Susskind, and P. Xie. 2003. The Version-2 Global Precipitation Climatology Project (GPCP) monthly precipitation analysis (1979-present). *J. Hydrometeorology*, vol. 4, issue 6, pp. 1147-1167.

AHPA (American Herbal Plants Association). 2007. Tonnage survey of select North American wild-harvested plants, 2004-2005.

ALCOSAN (Allegheny County Sanitary Authority). n.d. Accessed January 8, 2014, from http://www.alcosan.org/AboutUs/tabid/54/Default.aspx.

Allan, J. D. 2004. Landscape and riverscapes: The influence of land use on stream ecosystems. *Ann. Rev. Ecol., Evol. Syst.*, vol. 35, pp. 257-284.

Armstrong, D. S, S. B. Levin, and T. A. Richards. 2011. Factors influencing riverine fish assemblages in Massachusetts. U.S. Geological Survey Scientific-Investigations Report 2011-5193, 58 pp.

Baker, D. B., J. K. Kramer, T. T. Loftus, and R. P. Richards. 2004. A new flashiness index: Characteristics and applications to midwestern rivers and streams. *JAWRA*, vol. 40, issue 2, pp. 503-522.

Bates, B. C., Z. W. Kundzewicz, J. P. Palutikof, and S. Wu, eds. 2008. Climate change and water. Technical paper of the Intergovernmental Panel on Climate Change, IPCC Secretariat, Geneva, Switzerland, 210 pp.

Bin, O., J. B. Kruse, and C. E. Landry. 2008. Flood hazards, insurance rates, and amenities: Evidence from the coastal housing market. *J. Risk and Insurance*, vol. 75, pp. 63-82.

Binzer, A., U. Brose, C. Guill, and B. C. Rall. 2012. The dynamics of food chains under climate change and nutrient enrichment. *Phil. Trans. Royal Soc. London*, vol. B 367, pp. 2935-2944.

Blann, K. L., J. L. Anderson, G. R. Sands, and B. Vondracek. 2009. Effects of agricultural drainage on aquatic ecosystems: A review. *Critical Reviews Environ. Sci. Technol.*, vol. 39, pp. 11,909-1001.

Bolund, P., and S. Hunhammar. 1999. Analysis: Ecosystem services in urban areas. *Ecolog. Econ.*, vol. 29, pp. 293-301.

Bonan, G. B., D. Pollard, and S. L. Thompson. 1992. Effects of boreal forest vegetation on global climate. *Nature*, vol. 359, pp. 716-718.

Bonan, G. B., F. S. Chapin III, and S. L. Thompson. 1995. Boreal forest and tundra ecosystems as components of the climate system. *Clim. Change*, vol. 29, pp. 145-167.

BOR (Bureau of Reclamation). 2003. Guidelines for achieving public protection in dam safety decision making. Denver, CO, 19 pp.

Bormann, F. H., and G. E. Likens. 1979. Pattern and process in a forested ecosystem. New York, NY: Springer-Verlag.

Bowen, Z., K. Bovee, and M. Freeman. 1998. Evaluation of generalized habitat criteria for assessing impacts of altered flow regimes on warmwater fishes. *Trans. Amer. Fisheries Soc*., vol. 127, pp. 455-468.

Brose, U., J. A. Dunne, U. Jacob, J. M. Montoya, O. L. Petchey, and F. D. Schneider. 2012. Climate change in size-structured ecosystems. *Phil. Trans. Royal Soc. London*, vol. B 367, pp. 2903-2912.

Brown, C., D. Fay, W. Leger, and W. Werick. 2011. A decision-analytic approach to managing climate risks: Application to the upper Great Lakes. *JAWRA*, vol. 47, issue 3, pp. 524-534.

Brown, J. H., A. P. Allen, J. F. Gillooly, V. M. Savage, and G. B. West. 2004. Toward a metabolic theory of ecology. *Ecology*, vol. 85, pp. 1771-1821.

Burnash, R., and L. Ferral. 2002. Conceptualization of the Sacramento soil moisture accounting model. NWSRFS user manual documentation. Silver Spring, MD: National Weather Service, NOAA.

Burnash, R. J. C., R. L. Ferral, and R. A. McGuire. 1973. A generalized streamflow simulation system: Conceptual modeling for digital computers. National Weather Service and California Dept. of Water Resources.

Carpenter, S. R., W. A. Brock, and D. Ludwig. 1999. Management of eutrophication for lakes subject to potentially irreversible change. *Ecol. Appl*., vol. 9, pp. 751-771.

Carpenter, S. R., J. Agard, D. Capistrano, R. S. DeFries, S. Diaz, T. Dietz, A. K. Duraiappah, H. A. Mooney, A. Oteng-Yeboah, H. M. Pereira, C. Perrings, W. V. Reid, J. Sarukhan, R. J. Scholes, and A. Whyte. 2009. The science for managing ecosystem services: Beyond the Millennium Ecosystem Assessment. *Proc. Natl. Acad. Sci*., vol. 106, pp. 1305-1312.

Cassie, D. 2006. The thermal regime of rivers: A review. *Freshw. Biol*., vol. 51, pp. 1389-1406.

CCSP (Climate Change Science Program). 2008a. Preliminary review of adaptation options for climate-sensitive ecosystems and resources. A report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research. J. S. Baron, B. Griffith, L. A. Joyce, P. Kareiva, B. D. Keller, M. A. Palmer, C. H. Peterson, and J. M. Scott; ed. S. H. Julius and J. M. West. Washington, DC: USEPA, 873 pp.

CCSP. 2008b. The effects of climate change on agriculture, land resources, water resources, and biodiversity in the United States. A report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research. P. Backlund, A. Janetos, D. Schimel,

J. Hatfield, K. Boote, P. Fay, L. Hahn, C. Izaurralde, B. A. Kimball, T. Mader, J. Morgan, D. Ort, W. Polley, A. Thomson, D. Wolfe, M. G. Ryan, S. R. Archer, R. Birdsey, C. Dahm, L. Heath, J. Hicke, D. Hollinger, T. Huxman, G. Okin, R. Oren, J. Randerson, W. Schlesinger, D. Lettenmaier, D. Major, L. Poff, S. Running, L. Hansen, D. Inouye, B. P. Kelly, L. Meyerson, B. Peterson, and R. Shaw. Washington, DC: USDA, 362 pp. http://www.usda.gov/oce/climate_change/effects.htm.

Chapin III, F. S.1993. Functional role of growth forms in ecosystem and global processes. In: *Scaling physiological processes: Leaf to globe*, ed. J. R. Ehleringer and C. B. Field. San Diego, CA: Academic Press, pp. 287-312.

Chapin III, F. S., S. E. Hobbie, and J. P. McFadden. 1997. The role of arctic vegetation in ecosystem and global processes. In: *Ecology of arctic environments*, ed. S. J. Woodin and M. Marquiss. Oxford, UK: Blackwell Scientific, pp. 121-135.

Charney, J. G., S.-H. Chow, J. Kornfield, and W. J. Quirk. 1977. A comparative study of effects of albedo change on drought in semiarid regions. *J. Atmos. Sci*., vol. 34, pp. 1366-1385.

Cheek, T. E., C. C. Coutant, and M. J. Van den Avyle. 1985. Influences of water quality on distribution of striped bass in a Tennessee River impoundment. *Trans. Amer. Fisheries Soc*., vol. 114, pp. 67-76.

Cho, J., D. D. Bosch, Y. Her, R. R. Lowrance, T. C. Strickland, and G. Vellidis. 2010a. Effect of watershed subdivision and filter width on SWAT simulation of a coastal plain watershed. *J. Am. Water Resour. As*., vol. 46, pp. 586-602.

Cho, J., D. D. Bosch, R. Lowrance, T. Strickland, and G. Vellidis. 2010b. Water quality effects of simulated conservation practice scenarios in the Little River experimental watershed. *J. Soil Water Conserv*., vol. 65, pp. 463-473.

Cincinnati MSD o.G. (Metropolitan Sewer District of Greater Cincinnati). 2005. 2010 Sustainability Report. http://www.cincinnati-oh.gov/water/linkservid/D146DA6A-B1D7-4099-AD3A66E6D2FCF553/showMeta/0/.

City of Cincinnati. n.d. About Greater Cincinnati Water Works. Accessed January 9, 2014, from http://www.cincinnati-oh.gov/water/about-greater-cincinnati-water-works/.

Compton, J. E., H. V. Campbell, R. L. Dennis, T. L. Greaver, J. A. Harrison, B. H. Hill, S. J. Jordan, and H. Walker. 2011. Ecosystem services altered by human changes in the nitrogen cycle: A new perspective for US decision making. *Ecol. Lett*., vol. 14, pp. 804-815.

Costanza, R., R. d'Arge, R. de Groot, S. Farber, M. Grasso, B. Hannon, K. Limburg, S. Naeem, R. V. O'Neill, J. Paruelo, and R. G. Raskin. 1997. The value of the world's ecosystem services and natural capital. *Nature*, vol. 387, pp. 253-260.

Covich, A. P., S. C. Fritz, P. J. Lamb, R. D. Marzolf, W. J. Matthews, K. A. Poiani, E. E. Prepas, M. B. Richman, and T. C. Winter. 1997. Potential effects of climate change on aquatic ecosystems of the Great Plains of North America. *Hydrol. Proc.*, vol. 11, pp. 993-1021.

Daily, G. C., and P. A. Matson. 2008. Ecosystem services: From theory to implementation. *Proc. Natl. Acad. Sci. USA*, vol. 105, pp. 9455-9456.

Daufresne, M., K. Lengfellner, and U. Sommer. 2009. Global warming benefits the small in aquatic ecosystems. *Proc. Natl. Acad. Sci. USA*, vol. 106, pp. 12788-12793.

Dephilip, M., and T. Moberg. 2013. Ecosystem flow recommendations for the Upper Ohio River basin in western Pennsylvania. Harrisburg, PA: The Nature Conservancy.

Dessai, S., M. Hulme, R. Lempert, and R. Pielke Jr. 2009. Climate prediction: A limit to adaptation. In: *Adapting to climate change: Thresholds, values, governance*. Cambridge, UK: Cambridge University Press, pp. 64-78.

Dewald, T. G. 2006. Applications of the NHD at the U.S. Environmental Protection Agency. *Water Resources Impact*, vol. 8, pp. 5-7.

Doering III, O., R. A. Pfeifer, J. C. Randolph, and J. Southworth. 2002. Effects of climate change and variability on agricultural production systems. Boston, MA: Kluwer Academic Publishers.

Dolan, D. M., and R. P. Richards. 2008. Analysis of late 90s phosphorus loading pulse to Lake Erie. In: *Checking the pulse of Lake Erie*, ed. M. Munawar and R. Heath. Aquatic Ecosystem Health and Management Society Envirovision Series.

Eaton, J. G., and R. M. Scheller. 1996. Effects of climate warming on fish thermal habitat in streams of the United States. *Limnol. Oceanogr*., vol. 41, pp. 1109-1115.

Eklöf, A., L. Kaneryd, and P. Münger. 2012. Climate change in metacommunities: Dispersal gives double-sided effects on persistence. *Phil. Trans. Royal Soc. London*, vol. B 367, pp. 2945-2954.

Ficke, A. D., and C. A. Myrick. 2007. Potential impacts of global climate change on freshwater fisheries. *Rev. Fish Biol. and Fisheries*, vol. 7, pp. 581-613.

Firehammer, J., and D. L. Scarnecchia. 2007. The influence of discharge on duration, ascent distance, and fidelity of the spawning migration for paddlefish of the Yellowstone-Sakakawea stock, Montana and North Dakota, USA. *Environ. Biol. Fishes*, vol. 78, pp. 23-36.

Frechione, B. 2011. Ohio River navigation system as a source of M&I water supply. Accessed January 9, 2014, from http://www.corpsresults.us/docs/watersupply/June11WaterSupplyPresentations/Water-intakes-05-23-11.pdf.

Frederick, K. D., and P. H. Gleick. 1989. Water resources and climate change. In: *Greenhouse warming: Abatement and adaptation*, ed. N. J. Rosenberg, W. E. Easterling III, P. R. Crosson, and J. Darmstadter. Washington, DC: Resources for the Future, pp. 133-143.

Furniss, M. J., D. Cenderelli, J. Chatel, C. F. Clifton, A. Clingenpeel, P. E. Hays, D. Higgins, K. Hodges, C. Howe, L. Jungst, J. Louie, C. Mai, R. Martinez, K. Overton, K. B. Roby, B. P. Staab, R. Steinke, and M. Weinhold. 2013. Assessing the vulnerability of watersheds to climate change: Results of national forest watershed vulnerability pilot assessments. Gen. Tech. Rep. PNW-GTR-884. Portland, OR: U.S. Forest Service, Pacific Northwest Research Station. 32 pp.

GCWW (Greater Cincinnati Water Works). 2011. We are the Water Works. Accessed January 9, 2014, from http://www.cincinnati-oh.gov/water/linkservid/D146DA6A-B1D7-4099-AD3A66E6D2FCF553/showMeta/0/.

Gillooly, J. F., J. H. Brown, E. L. Charnov, V. M. Savage, and G. B. West. 2001. Effects of size and temperature on metabolic rate. *Science*, vol. 293, pp. 2248-2251.

GLMRIS (Great Lakes and Mississippi River Interbasin Study) Team. 2012. Commercial fisheries baseline economic assessment: U.S. waters of the Great Lakes, Upper Mississippi River, and Ohio River Basins. Accessed January 27, 2014, from http://glmris.anl.gov/documents/docs/Commercial_Fisheries_Report.pdf.

Gómez-Baggethun, E., E. Andersson, D. N. Barton, Å. Gren, Z. Hamstead, P. Kremer, J. Langemeyer, T. McPhearson, and P. O'Farrell. 2013. Urban ecosystem services. In: *Urbanization, biodiversity and ecosystem services: Challenges and opportunities: A global assessment*. The Netherlands: Springer Netherlands, pp. 175-251.

Groffman, P. M., N. D. Bettez, M. T. Bremigan, J. Cavender-Bares, J. A. Downing, C. E. Fergus, C. T. Filstrup, E. N. Henry, N. R. Lottig, E. H. Stanley, C. A. Stow, P.-N. Tan, T. Wagner, and K. E. Webster. 2014. Ecological homogenization of urban USA. *Front. Ecol. Environ*., vol. 12, pp. 74-81.

Haag, W., and M. Warren. 2008. Effects of severe drought on freshwater mussel assemblages. *Trans. Amer. Fisheries Soc*., vol. 137, pp. 1165-1178.

Haldar, A., and S. Mahadevan. 1999. *Probability, reliability and statistical methods in engineering design*. Wiley.

Handler, S. D., L. A. Brandt, P. R. Butler, M. K. Janowiak, M. D. Powers, P. D. Shannon, and C. W. Swanston. 2012. Climate change vulnerabilities within the forestry sector for the midwestern United States. *U.S. National Climate Assessment Midwest Technical Input Reporter*, coord. J. A. J. Winkler, J. Hatfield, D. Bidwell, and D. Brown.

Harrison, J. A., R. B. Alexander, A. E. Giblin, P. A. Jacinthe, R. J. Maranger, E. Mayorga, S. P. Seitzinger, D. J. Sobota, and W. M. Wollheim. 2009. The regional and global significance of nitrogen removal in lakes and reservoirs. *Biogeochemistry*, vol. 93, pp. 143-157.

Hartfield P., and E. Hartfield. 1996. Observations on the conglutinates of *Ptychobranchus greeni* (Conrad, 1834) Mollusca: Bivalvia: Unionidae. *Amer. Midland Natur.*, vol. 135, p. 370.

Havsy, J. 2013. Timber returns stay positive in first quarter. Media release from the National Council of Real Estate Investment Fiduciaries.

Hester, E. T., and M. W. Doyle. 2011. Human impacts to river temperature and their effects on biological processes: A quantitative synthesis. *JAWRA*, vol. 47, issue 3, pp. 571-587.

HVRI (Hazards and Vulnerability Research Institute). n.d. Property damage adjusted for inflation to 2011 dollars: The Spatial Hazard Events and Losses Database for the United States (version 8), from www.Sheldus.org. Referenced in ODNR, n.d., Reducing flood damage and promoting natural function of floodplains. Floodplain Management Program.

IPCC (Intergovernmental Panel on Climate Change). 2000. *Emissions scenarios: A special report of IPCC Working Group III*, ed. N. Nakicenovic and R. Swart. Cambridge, UK: Cambridge University Press, 570 pp. https://www.ipcc.ch/pdf/special-reports/spm/sres-en.pdf.

IPCC. 2007. Summary for policymakers. In: *Climate change 2007: Impacts, adaptation and vulnerability*., ed M. L. Parry, O. F. Canziani, J. P. Palutikof, P. J. van der Linden, and C. E. Hanson. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, UK: Cambridge University Press.

IPCC, 2014. Climate change 2014: Synthesis report: Contribution of Working Groups I, II, and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Core writing team and ed. R. K. Pachauri and L. A. Meyer. Geneva, Switzerland: IPCC, 151 pp.

James, P. E. 1922. Köppen's classification of climates: A review. *Monthly Weather Rev.*, vol. 50, issue 2, pp. 69-72.

Janse, J. H. 2005. Model studies on the eutrophication of shallow lakes and ditches. Wageningen, The Netherlands: Wageningen University.

Jetz, W., J. H. Brown, C. Carbone, and J. Fulford. 2004. The scaling of animal space use. *Science*, vol. 306, pp. 266-268.

Johnson, S. L., M. J. Kirisits, and D. R. Maidment. 2013. TMDL balance: A model for coastal water pollutant loadings. *J. Am. Water Resour. As*., vol. 49, pp. 838-850.

Johnson, T., and C. Weaver. 2009. A framework for assessing climate change impacts on water and watershed systems. *Environ. Manage*., vol. 43, pp. 118−134.

Jones, M. C., S. R. Dye, J. A. Fernandes, T. L. Frölicher, J. K. Pinnegar, R. Warren, and W. W. Cheung. 2013. Predicting the impact of climate change on threatened species in UK waters. *PLoS One*, vol. 8, issue 1, p. e54216.

Julius, S. H., P. Backlund, R. Hauser, A. C. Janetos, D. Nover, D. S. Schimel, M. K. Walsh, and J. M. West. 2013. Climate change and U.S. natural resources: Advancing the Nation's capability to adapt. *Issues in Ecol.*, vol. 18, pp. 1-17.

Kenny, J. F., N. L. Barber, S. S. Hutson, K. S. Linsey, J. K. Lovelace, and M. A. Maupin. 2009. Estimated use of water in the United States in 2005. U.S. Geological Survey Circular 1344 52.

Kishi, D., K. Maekawa, M. Murakami, and S. Nakano. 2005. Water temperature determines strength of top-down control in a stream food web. *Freshw. Biol*., vol. 50, pp. 1315-1322.

Kundzewicz, Z. W., N. W. Arnell, P. Doll, B. Jimenez, L. J. Mata, K. Miller, T. Oki, Z. Sen, and I. Siklomanov. 2008. The implications of projected climate change for freshwater resources and their management. *Hydrol. Sci.*, vol. 53, issue 91, pp. 3-10.

Lambers, H., F. S. Chapin III, and T. L. Pons. 1998. *Plant physiological ecology*. New York, NY: Springer-Verlag New York.

Leavesley, G. H., F. A. D'agnese, D. McKnight, and K. Turner. 1997. Regional delineation of North America for the assessment of freshwater ecosystems and climate change. *Hydrol. Proc.*, vol. 11, issue 8, pp. 819-824.

Lempert, R. J., D. G. Groves, S. W. Popper, and S. C. Bankes. 2006. A general, analytic method for generating robust strategies and narrative scenarios. *Manage. Sci.*, vol. 52, pp. 514-528.

Lettenmaier, D., D. Major, L. Poff, and S. Running. 2008. Water resources. In: *The effects of climate change on agriculture, land resources, water resources, and biodiversity*. Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research. Washington, DC.

Ligon, F. K., W. E. Dietrich, and W. J. Trush. 1995. Downstream ecological effects of dams. *Bioscience*, vol. 45, pp. 183-192.

Limpert, E., M. Abbt, and W. A. Stahel. 2001. Log-normal distributions across the sciences: Keys and clues. *Bioscience*, vol. 51, pp. 341-352.

Lin, J. 2004. Review of published export coefficient and event mean concentration (EMC) data. Wetlands Regulatory Assistance Program. ERDC-TN-WRAP-04-3. Vicksburg, MS: Engineer Research and Development Center, p. 16.

Loehr, R. C., S. O. Ryding, and W. C. Sonzogni. 1989. Estimating the nutrient load to a waterbody. In: *The control of eutrophication of lakes and reservoirs*, vol. I, Man and the biosphere series. Parthenon Publishing Group.

Lurgi, M., B. C. Lopez, and J. M. Montoya. 2012. Novel communities from climate change. *Phil. Trans. Royal Soc. London*, vol. B 367, pp. 2913-2922.

MA (Millennium Ecosystem Assessment). 2005. *Ecosystems and human well-being: Synthesis*. Washington, DC: Island Press.

MacBroom, J. G. 2008. *Applied fluvial geomorphology*, 2nd ed. 232 pp.

Martin R., F. Boetter, J. Clingerman, E. Hansen, A. Hereford, S. Letsinger, T. Petty, and J. Strager. 2012. Ohio River Basin and Southeast Aquatic Resources Partnership Model summaries. In: *Midwest Fish Habitat Partnership fish habitat modeling results*. 251 pp.

McCluney, K. E., J. S. Baron, M. A. Palmer, N. L. Poff, G. C. Poole, J. H. Thorp, B. S. Williams, and M. R. Williams. 2014. Riverine macro-systems ecology: Sensitivity, resistance, and resilience of whole river basins with human alterations. *Front. Ecol. Environ.*, vol. 12, pp. 48-58.

McIntyre, N. E., K. Hayhoe, G. M. Henebry, G. Liu, F. W. Schwartz, S. Swain, and C. K. Wright. 2014. Climate forcing of wetland landscape connectivity in the Great Plains. *Front. Ecol. Environ*., vol. 12, pp. 59-64.

McKnight, D., and A Covich. 1997. Regional assessment of climate change and freshwater ecosystems. *Hydrol. Proc.*, vol. 11, pp. 819-1067.

Melillo, J. M., T. Richmond, and G. W. Yohe (eds.). 2014. Climate change impacts in the United States: The third National climate assessment. U.S. Global Change Research Program.

Meyer, J. L., P. J. Mulholland, N. L. Poff, and M. J. Sale. 1999. Impacts of climate change on aquatic ecosystem functioning and health. *JAWRA*, vol. 35, pp. 1373-1386.

Miller, B. A., V. Alavian, M. D. Bender, D. J. Benton, L. L. Cole, L. K. Ewing, N. A. Nielsen, P. Ostrowski Jr., J. A. Parsly, W. B. Proctor, and H. M. Samples. 1993. Sensitivity of the TVA reservoir and power supply systems to extreme meteorology. Report No-WR28-1-680-111. Knoxville, TN: Tennessee Valley Authority, 166 pp.

Mion, J., E. Marschall, and R. Stein. 1998. River discharge drives survival of larval walleye. *Ecol. Appl*., vol. 8, pp. 88-103.

Mitsch, W. J., and J. G. Gosselink. 2007. *Wetlands*, 4th ed. New York, NY: John Wiley & Sons, 582 pp.

Mooij, W. M., L. N. De Senerpont Domis, and J. H. Janse. 2009. Linking species- and ecosystem-level impacts of climate change in lakes with a complex and a minimal model. *Ecol. Modell*., vol. 220, pp. 3011-3020.

Moore, M. V., C. Y. Chen, C. T. Driscoll, P. A. Flebbe, C. L. Folt, H. F. Hemond, R. W. Howarth, J. R. Mather, P. S. Murdoch, and M. L. Pace. 1997. Potential effects of climate change on freshwater ecosystems of the New England/mid-Atlantic region. *Hydrol. Proc.*, vol. 11, pp. 925-947.

Morales, Y., A. Mynett, I. Newton, and L. Weber. 2006. Effects of substrate and hydrodynamic conditions on the formation of mussel beds in a large river. *J. North Amer. Benthol. Soc*., vol. 25, pp. 664-676.

Morgan II, R. P., and K. M. Kline. 2011. Nutrient concentrations in Maryland non-tidal streams. *Environ. Monit. Assess.*, vol. 178, pp. 221-235.

Moriasi, D. N., J. G. Arnold, R. L. Bingner, R. D. Harmel, M. W. V. Liew, and T. L. Veith. 2007. Model evaluation guidelines for systematic quantification of accuracy in watershed simulations. *T. Asabe*, vol. 50, pp. 885-900.

Mulholland, P. J., and M. J. Sale. 1998. Impacts of climate change on water resources: Findings of the IPCC regional assessment of vulnerability for North America. Water resources update, Universities Council on Water Resources, issue 112.

Murray, B., S. Faulkner, A. Jenkins, and R. Kramer. 2009. Valuing ecosystem services from wetlands restoration in the Mississippi alluvial valley. Report prepared under a cooperative agreement between Duke University and the U.S. Forest Service.

Naiman, R. J., J. J. Magnuson, D. M. McKnight, and J. A. Stanford. 1995. *The freshwater imperative*. Washington, DC: Island Press, 165 pp.

Olsen, A. R., and D. V. Peck. 2008. Survey design and extent estimates for the Wadeable Stream Assessment. *J. North Amer. Benthol*. *Soc*., vol. 27, pp. 822-836.

Olsen, A. R., J. Pitt, B. Snyder, and L. Stahl. 2009. Survey design for lakes and reservoirs in the United States to assess contaminants in fish tissue. *Environ. Monit. & Assess.*, vol. 150, pp. 91-100.

ODNR (Ohio Department of Natural Resources). n.d. Floodplain management program: Reducing flood damage and promoting natural function of floodplains. ODNR Division of Soil and Water Resources. Accessed December 9, 2013, from http://www.dnr.state.oh.us/portals/12/Pubs/SuccessFS/FloodplainManagement.pdf.

ORSANCO (Ohio River Valley Water Sanitation Commission). n.d. Source water protection. Accessed December 21, 2013, from http://www.orsanco.org/source-water-protection.

ORSANCO, USNPS (U.S. National Park Service), and ORBC (Ohio River Basin Commission). 1994. What's a river worth? A valuation study of the Ohio River corridor.

ORSANCO. 2012. The ORSANCO 2011 Annual Report. http://www.orsanco.org/images/stories/files/annualReport/2011annualreport.pdf.

ORSANCO. 2013a. Characterizing the water-use in the Ohio River basin. Water Resources Initiative. Draft report prep. J. P. Spaeth.

ORSANCO. 2013b. Hydropower impacts. Accessed December 21, 2013, from http://www.orsanco.org/hydropower-impacts.

Pijanowski, B. C., and J. Doucette. 2014. Multi-temporal land use generation for the Ohio River basin. Draft report EPA/600/R-14/X.

Plantinga, A. J., R. N. Lubowski, and R. N. Stavins. 2002. The effects of potential land development on agricultural land prices. *J. Urban Econ.*, vol. 52, pp. 561-581.

Poff, N. L., M. M. Brinson, and J. W. Day. 2002. Aquatic ecosystems and global climate change: Potential impacts on inland freshwater and coastal wetland ecosystems in the United States. Arlington, VA: Pew Center on Global Climate Change.

PWSA (Pittsburgh Water and Sewer Authority). 2011. PGH2O: Pittsburgh's Finest Water 2010 annual report. Accessed January 9, 2014, from http://apps.pittsburghpa.gov/pwsa/annual_2010.pdf.

PWSA. 2013. 2012 Annual drinking water quality report. Accessed January 9, 2014, from http://apps.pittsburghpa.gov/pwsa/2012_Water_Quality_Report.pdf.

Ranganathan, J., N. Ash, K. Bennett, F. Irwin, N. Lucas, C. Raudsepp-Hearne, P. West, and M. Zurek. 2008. *Ecosystem services: A guide for decision makers.* World Resources Institute.

Rankin, E. T., and C. O. Yoder. 2009. Temporal change in regional reference conditions as a potential indicator of global climate change: Analysis of the Ohio Regional Reference Condition Database (1980-2006). Midwest Biodiversity Institute. 30 pp.

Rankin, E. T., R. Mueller, and C. O. Yoder. 2012. Ecological low flow protection process for Ohio streams and rivers of the Lake Erie basin. Midwest Biodiversity Institute. 88 pp.

Ray, D. K., and B. C. Pijanowski. 2010. A backcast land use change model to generate past land use maps: Application and validation at the Muskegon River watershed of Michigan, USA. *J. Land Use Sci.*, vol. 5, pp. 1-29.

Reckhow, K. H., M. N. Beaulac, and J. T. Simpson. 1980. Modeling phosphorus loading and lake response under uncertainty: A manual and compilation of export coefficients. USEPA, Office of Water Regulation.

Richter, B. D., J. Baumgartner, D. Braun, and J. Powell. 1996. A method for assessing hydrologic alteration within ecosystems. *Conserv. Biol.*, vol. 10, pp. 1163-1174.

Robbins, C. 1999. Medicine from U.S. wildlands: An assessment of native plant species harvested in the United States for medicinal use and trade, and evaluation of the conservation and management implications. The Nature Conservancy, Information Systems Division, National Agricultural Library (computer file).

Sarewitz, D., R. Byerly Jr., and R. S. Pielke Jr. 2000. Introduction: Death, taxes, and environmental policy. In: *Prediction: Science, decision making, and the future of nature*. Washington, DC: Island Press.

Schwalb, A., J. Ackerman, K. Cottenie, and M. Poos. 2011. Dispersal limitations of unionid mussels and implications for their conservation. *Freshw. Biol*., vol. 56, pp. 1509-1518.

Schwarz, G. E., R. B. Alexander, A. B. Hoos, and R. A. Smith. 2009. *The SPARROW surface water-quality model: Theory, application and user documentation*. Reston, VA: U.S. Geological Survey, p. 248.

Shankman, D., and S. A. Sampson. 1991. Channelization effects on Obion River flooding, western Tennessee. *Water Resour. Bull*., vol. 27, pp. 247-254.

Shuter, B. J., and J. R. Post. 1990. Climate, population viability and the zoography of temperate fishes. *Trans. Amer. Fish. Soc*., vol. 119, pp. 316-336.

Sipkay, C., L. Hufnagel, K. T. Kiss, and C. Vadadi-Fulop. 2009. Trends in research on the possible of effects of climate change concerning aquatic ecosystems with special emphasis on the modeling approach. *Appl. Ecol. Environ. Res.*, vol. 7, pp. 171-198.

Soranno, P. A., and D. S. Schimel. 2014. Macrosystems ecology: Big data, big ecology. *Front. Ecol. Environ.*, vol. 12, p. 3.

Stein, B. A., N. Edelson, P. Glick, and A. Staudt. 2014. *Climate-smart conservation: Putting adaption principles into practice*. Reston, VA: National Wildlife Federation.

Strayer, D. L. 2008. *Freshwater mussel ecology: A multifactor approach to distribution and abundance*. Berkeley, CA: University of California Press.

Tayyebi, A., D. Braun, J. S. Doucette, B. K. Pekin, B. C. Pijanowski, and J. D. Plourde. 2012. Hierarchical modeling of urban growth across the conterminous USA: Developing mesoscale quantity drivers for the Land Transformation Model. *J. Land Use Sci.*, vol. 8, issue 4, pp. 422-442.

Torcellini, P., N. Long, and R. Judkoff. 2003. Consumptive water use for U.S. power production. Technical Report National Renewable Energy Laboratory, NREL/TP-550-33905. 12 pp.

Trust for Public Land. 2013. The economic benefits of clean Ohio fund conservation.

USACE (U.S. Army Corps of Engineers). 2006. Ohio River mainstem system study integrated main report and programmatic environmental impact statement, Louisville District.

USACE. 2009. Ohio River basin comprehensive reconnaissance report. http://www.lrh.usace.army.mil/Portals/38/docs/orba/Ohio%20River%20Basin%20Comp%20Recon%20Study%20-%20Dec%202009.pdf.

U.S. Census. 2010. 2010 United States census. U.S. Census Bureau.

USDA (U.S. Department of Agriculture). 2013. USDA land values 2013 summary.

USEIA (U.S. Energy Information Administration). 2013. Electric power monthly. Accessed January 9, 2014, from http://www.eia.gov/electricity/monthly/epm_table_grapher.cfm?t=epmt_5_6_a.

USEPA (U.S. Environmental Protection Agency). 2001. Environmental monitoring and assessment program (EMAP): National coastal assessment quality assurance project plan 2001-2004. EPA/620/R-01/002. Washington, DC: USEPA ORD; Gulf Breeze, FL: National Health and Environmental Effects Research Laboratory, Gulf Ecology Division. www.epa.gov/emap/nca/html/docs/c2k.qapp.pdf.

USEPA. 2003. Guidance for 2004 assessment, listing and reporting requirements pursuant to Sections 303(d) and 305(b) of the Clean Water Act. Washington, DC: USEPA OW and Office of Wetlands, Oceans, and Watersheds (OWOW).

USEPA. 2006. Wadeable streams assessment: A collaborative survey of the Nation’s streams. EPA/841/B/06/002. Washington, DC: USEPA ORD and OW.

USEPA. 2008a. Climate change effects on stream and river biological indicators: A preliminary analysis. EPA/600/R-07/085. Global Change Research Program. Washington DC: National Center for Environmental Assessment. http://www.epa.gov/ncea.

USEPA. 2008b. U.S. EPA’s report on the environment: Final report, chapter 3: Water. EPA/600/R-07/045F. Washington, DC: USEPA.

USEPA. 2008c. National wetland condition fact sheet. EPA-843-F-08-001. Washington, DC: USEPA.

USEPA. 2009. National lakes assessment: A collaborative survey of the Nation's lakes. EPA/841/R/09/001. Washington, DC: USEPA ORD.

USEPA. 2011. Aquatic ecosystems, water quality, and global change: Challenges of conducting multi-stressor global change vulnerability assessments. EPA/600/R-11/01F. http://cfpub.epa.gov/ncea/global/recordisplay.cfm?deid=231508.

USEPA. 2013a. The national rivers and streams assessment 2008-2009: A collaborative survey. EPA/ 841/D-13/001. Washington, DC: USEPA OW, OWOW, and ORD.

USEPA. 2013b. Watershed modeling to assess the sensitivity of streamflow, nutrient and sediment loads to potential climate change and urban development in 20 U.S. watersheds. EPA/600/R-12/058F. Washington, DC: USEPA ORD and National Center for Environmental Assessment. http://cfpub.epa.gov/ncea/global/recordisplay.cfm?deid=256912.

USEPA 2014. National Aquatic Resources Survey. http://water.epa.gov/type/watersheds/monitoring/aquaticsurvey_index.cfm.

USEPA 2016. National wetland condition assessment: A collaborative survey of the Nation's wetlands. EPA-843-R-15-005. Washington, DC: USEPA.

U.S. Forest Service. 2013. Forest sustainability reporting in the United States. Accessed December 8, 2103, from http://www.fs.fed.us/research/sustain/criteria-indicators/indicators/indicator-214.php.

USFWS (U.S. Fish and Wildlife Service). 2009. Status and trends of wetlands in the conterminous United States 2004 to 2009. T. E. Dahl. Washington, DC: USFWS Fisheries and Habitat Conservation.

Waterways Council, Inc. n.d. Ohio River basin profile. Accessed January 9, 2014, from http://waterwayscouncil.org/wp-content/uploads/2013/03/Ohio-River-Basin-Profile-2011.pdf.

West, G. B., J. H. Brown, and B. J. Enquist. 2001. A general model for ontogenetic growth. *Nature*, vol. 413, pp. 628-631.

Wetzel, R. G. 2001. Limnology. In: *Lake and river ecosystems*. San Diego, CA: Academic Press.

Whiteaker, T. 2006. Integrating arc hydro features with a schematic network. *Transaction in GIS*, vol. 10, pp. 219-237.

Whitehead, P. G., R. W. Battarbee, M. Kernan, A. J. Wade, R. L. Wilby. 2009. A review of the potential impacts of climate change on surface water quality. *Hydrol. Sci.*, vol. 54, pp. 101-123.

Williams, J. E., W. T. Colyer, N. G. Gillespie, A. L. Haak, and H. M. Neville. 2007. Climate change and western trout: Strategies for restoring resistance and resilience in native populations. In: *Sustaining wild trout in a changing world*, ed. R. F. Carline and C. LoSapio. Proceedings of the wild trout IX symposium. Bozeman, MT: Joseph Urbani & Associates, Inc., pp. 236-246.

Woodward, G., D. M. Perkins, and L. E. Brown. 2010. Climate change and freshwater ecosystems: Impacts across multiple levels of organization. *Phil. Trans. Royal Society of London*, vol. B 365, pp. 2093-2106.