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Water Utility Planning Strategies to Mitigate Impacts of Climate Change in Central Ohio - Sustaining Scioto Adaptive Management Plan

May 2015

THE CITY OF
COLUMBUS
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DEPARTMENT OF
PUBLIC UTILITIES

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Contents

List of Tables v

List of Figures vii

Executive Summary ES-1
  - Identify Climate Change Vulnerabilities ES-1
  - Establish Adaptive Management Strategies ES-2
    - Public Outreach ES-3
    - Future Water Demands ES-3
    - Upper Scioto River Watershed Water Inventory ES-4
    - Vulnerability Assessment ES-5
    - Climate Change Adaptation Strategies ES-9

1. Project Purpose 1-1
  - 1.1 Project Location 1-1
  - 1.2 Adaptive Management Planning Introduction 1-2

2. Public Outreach and Stakeholder Involvement 2-1
  - 2.1 Public Outreach Meetings 2-1
  - 2.2 Stakeholder Advisory Committee 2-1

3. Water Use Projections 3-1
  - 3.1 Population Projections 3-1
    - 3.1.1 Population Data 3-1
    - 3.1.2 Utility Service Areas 3-2
  - 3.2 Water Use Projections 3-2

4. Scioto River Watershed Water Inventory 4-1
  - 4.1 Climate Data 4-1
  - 4.2 Water Inventory 4-3
    - 4.2.1 Historical Water Inventory 4-4
    - 4.2.2 Projected Water Inventories: 2035 and 2090 4-4
    - 4.2.3 Water Inventory Conclusions 4-6

5. Water Quality Assessment 5-1
  - 5.1 Data Collection 5-1
  - 5.2 Rainfall 5-5
  - 5.3 Turbidity 5-6
  - 5.4 Total Organic Carbon 5-7
  - 5.5 Herbicides and Pesticides 5-8
  - 5.6 Nutrients (Nitrogen and Phosphorus) 5-10
  - 5.7 Algae and Cyanobacteria 5-11
  - 5.8 Microcystin 5-12

- 5.9 Taste and Odor Complaints 5-13
- 5.10 Existing Surface Water Quality Impairments 5-13
- 5.11 Reservoir Trophic State 5-14
- 5.12 Predicted Future Water Quality 5-15

6. Vulnerability Assessment 6-1
   - 6.1 Watershed Model 6-1
     - 6.1.1 Watershed Model Data 6-2
     - 6.1.2 Climate Data 6-2
     - 6.1.3 Water-Use Data 6-2
     - 6.1.4 Land-Cover Data 6-2
     - 6.1.5 Climate Model Results 6-3
     - 6.1.6 Watershed Model Results 6-5
   - 6.2 Vulnerability Assessment 6-9
     - 6.2.1 Vulnerability Prioritization 6-9
     - 6.2.2 High-Priority Vulnerabilities 6-11
7. Adaptive Management Strategies 7-1
   - 7.1 Introduction to Adaptation Strategies 7-1
   - 7.2 Prioritization Methodology 7-2
   - 7.3 Climate Change Adaptation Strategies by Sector 7-4
     - 7.3.1 Water Supply/Water Quality 7-4
     - 7.3.2 Water Treatment 7-11
     - 7.3.3 Wastewater Utility 7-18
   - 7.4 Adaptation Strategy Implementation 7-20
8. Conclusions 8-1
9. Limitations 9-1
10. References 10-1

List of Abbreviations 10-3

Appendix A: Stakeholder Handouts and Public Outreach Materials .... A

Appendix B: Graphs of Predicted Stream Flow and Reservoir Levels at Selected Sites .... B

Appendix C: Summary of Prioritized Risks by Service Sector C

Appendix D: Adaptive Strategies, Non-Water Service Sectors C

List of Tables

Table ES-1. Upper Scioto River Watershed Current and Predicted Future Water Average Daily Demands ES-4

Table ES-2. Upper Scioto River Watershed Summary of Prioritized Predicted Changes ES-6

Table ES-3. Upper Scioto River Watershed Summary of Highest-Priority Risks by Service Sector and Vulnerability Scenario ES-7

Table ES-4. Categories of Adaptive Strategies ES-9

Table ES-5. Relative Costs Associated with Adaptive Strategies ES-10

Table ES-6. Recommended Adaptation Strategies for the Upper Scioto River Watershed ES-11

Table 2-1. Public Outreach Meeting Locations 2-1

Table 2-2. Sustaining Scioto Stakeholder Advisory Committee Members 2-2

Table 3-1. Upper Scioto River Watershed Water and Wastewater Utilities 3-2

Table 3-2. Upper Scioto River Watershed Projected Population and Water Withdrawals 3-3

Table 3-3. Upper Scioto River Watershed Projected Population and Wastewater Discharges 3-4

Table 4-1. Upper Scioto River Watershed Historical Water Inventory 4-4

Table 4-2. Upper Scioto River Watershed Water Inventory: 2035 4-5

Table 4-3. Upper Scioto River Watershed Water Inventory: 2090 4-6

Table 5-1. Evaluation of Lake Habitat Aquatic Life Criteria and O’Shaughnessy and Griggs Reservoir Median Levels 5-14

Table 5-2. Summary of Lake Trophic Conditions and Water Quality Characteristics 5-15

Table 6-1. Nine Service Sectors 6-1

Table 6-2. Summary of Predicted Changes Reflected in Climate and Watershed Model Results 6-9

Table 6-3. Summary of Prioritized Vulnerabilities 6-10

Table 6-4. Risk Prioritization 6-11

Table 6-5. Upper Scioto River Watershed Summary of Highest-Priority Risks by Service Sector and Vulnerability Scenario 6-13

Table 7-1. Categories of Adaptive Strategies 7-1

Table 7-2. Relative Costs Associated with Adaptive Strategies 7-2

Table 7-3. Water Supply/Water Quality High-Priority Risks 7-4

Table 7-4. Recommended Adaptation Strategies for Mitigating Increased Water Demand and Reduced Water Supply Reliability 7-7

Table 7-5. Recommended Adaptation Strategies for Protecting/Improving Water Quality 7-11

Table 7-6. Water Treatment High-Priority Risks 7-13

Table 7-7. Recommended Strategies for Mitigating Impacts related to Taste, Odors and Potential for Algal Toxins 7-14

Table 7-8. Increased Source Water Pollutant Concentrations, Such as Turbidity and Disinfection By-products Due to Higher Maximum Sustained Stream Flow 7-15

Table 7-9. Damage to Infrastructure and Infrastructure Failure Related to Increased Intensity of Rain and Wind Events 7-17

Table 7-10. Wastewater Utility High-Priority Risks 7-18

Table 7-11. Wastewater Utility Strategies to address Lower DO and Increased Temperature in Receiving Water 7-19

Table 7-12. Damage to Wastewater Infrastructure and Infrastructure Failure Due to Increased Intensity of Rain and Wind Events 7-20

Table 7-13. Adaptation Strategy Prioritization 7-22

List of Figures

Figure ES-1. Adaptation strategy prioritization classification and time frames 2

Figure ES-2. Upper Scioto River watershed water inventory 5

Figure ES-3 Upper Scioto River watershed risk assessment service sectors 5

Figure 1-1. Sustaining Scioto study area 1-2

Figure 1-2. Overview of the adaptive management process 1-3

Figure 4-1. Upper Scioto River watershed comparison of average annual historical and projected precipitation 4-2

Figure 4-2. Upper Scioto River watershed comparison of average annual historical and projected temperature 4-3

Figure 4-3. Upper Scioto River watershed comparison of water inventory scenarios for current condition, 2035 and 2090 4-7

Figure 5-1. Upper Scioto River basin major water and wastewater utilities and water quality monitoring locations 5-3

Figure 5-2. Historical precipitation data at the Port Columbus Station 5-5

Figure 5-3. Daily precipitation from January 2009 through December 2011 at Westerville, Ohio Station 5-6

Figure 5-4. Atrazine concentrations and daily precipitation in O'Shaughnessy and Griggs reservoirs in 2009, 2010, and 2011 5-9

Figure 6-2. Climate model annual average temperature for the Upper Scioto River basin 6-5

Figure 6-3. Upper Scioto River basin selected sites for discussion 6-6

Figure 7-1. Strategy prioritization classification and time frames 7-3

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- Franklin County Commissioners
- Franklin County Metro Parks
- Water Research Foundation
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Stakeholder Advisory Committee members:

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- U.S. Geological Survey
- Aqua Ohio
- City of Westerville
- City of Gahanna
- Ohio Township Association
- City of Marion
- Franklin County Emergency Management and Homeland Security
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- City of Circleville
- Union County Engineer
- Franklin County Engineer
- Ohio State University
- Delaware County RPC
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- Nationwide Insurance
- Franklin County SWCD
- City of Columbus Public Utilities
- Ohio Farm Bureau Federation
- Ohio Environmental Council
- Franklin County Public Health
- Water Management Association Board
- Ohio Environmental Protection Agency
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Executive Summary

There is no question that climate change is occurring. What is less clear are the impacts these changes will have on our region, its people, its environment, and its resources. There is substantial concern regarding the potential impacts of climate change to resources, utilities, and economies in the Midwest (Melillo 2014). National studies indicate that the projected increase in temperature, rainfall variability, and extreme weather may increasingly compromise the ability of municipalities and water suppliers to effectively manage water supplies, critical water supply and treatment infrastructure, and water quality (EPA 2012b, Wilbanks and Fernandez 2012, NACWA 2009, Brekke et al. 2011). Ancillary impacts to water utilities may include increased cost of service, reduced customer confidence, and increased difficulty meeting regulatory compliance requirements.

The Mid-Ohio Regional Planning Commission (MORPC), in partnership with the City of Columbus Department of Public Utilities, Del-Co Water Company, Inc., U.S. Geological Survey (USGS), Ohio Water Development Authority (OWDA), and Water Research Foundation (WRF), has performed a study to evaluate the anticipated effects of climate change on water supply in the Upper Scioto River watershed. **The primary objective of this project, named Sustaining Scioto, is the development of an Adaptive Management Plan (Plan) to guide future actions within the region to achieve a resilient water supply system.**

The Sustaining Scioto Project

Ensuring that Central Ohio has clean and secure water resources for current and future residents, today and tomorrow.

Identify Climate Change Vulnerabilities

The evaluation considered modeling and scientific analysis in conjunction with input from a diverse regional stakeholder group to identify potential vulnerabilities to the region's water resources. These vulnerabilities were prioritized based on the potential impacts to the livability in the region. The study results indicate that the region will need to plan for increased temperatures and heat waves and the increased incidence of extreme storm and weather events.

Temperature-related vulnerabilities include:

- Reduced surface water supply availability coupled with increased water demand
- Lower water quality
- Increased waterborne and heat related illnesses
- Increased energy cost

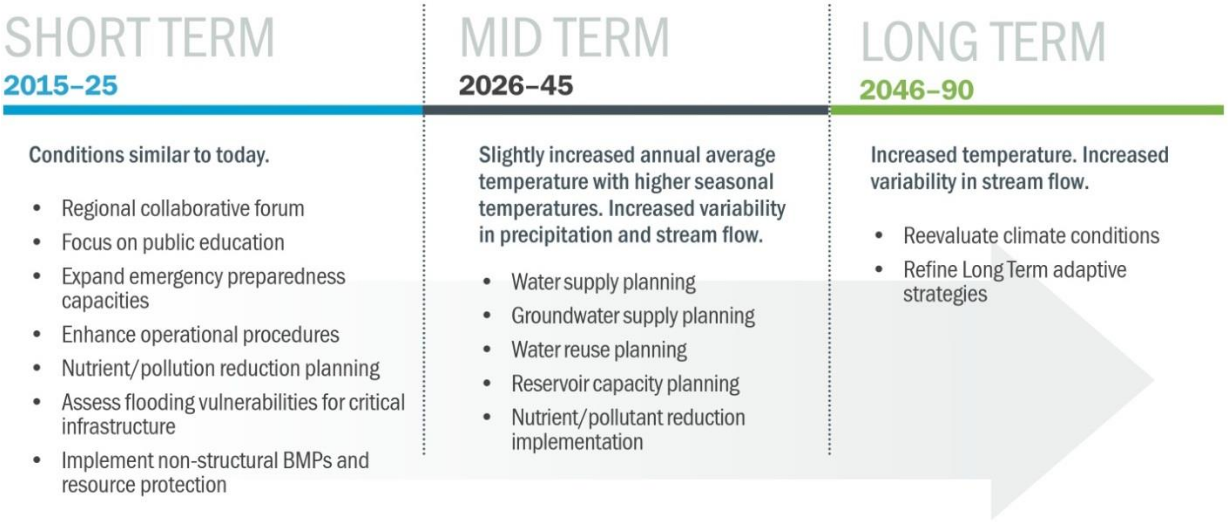
Extreme weather event-related vulnerabilities include:

- Damage to infrastructure
- Loss of power
- Increased burden on economy to repair damages
- Highly variable and overall lower water quality

If the past can no longer be relied upon to predict the future, municipalities need to consider the function of their public utilities under more extreme droughts and storms.

Establish Adaptive Management Strategies

Adaptive management strategies were developed to prepare the region for predicted changes. The basic approach to adaptive management includes understanding and prioritizing risks, developing strategies to reduce risks, implementing strategies, and reevaluating strategies as more information becomes available. The key findings for the water service sectors from the project and the time frame for implementing strategies over the course of the next 75 years are illustrated in Figure ES-1.



Conditions similar to today.

- Regional collaborative forum
- Focus on public education
- Expand emergency preparedness capacities
- Enhance operational procedures
- Nutrient/pollution reduction planning
- Assess flooding vulnerabilities for critical infrastructure
- Implement non-structural BMPs and resource protection

Slightly increased annual average temperature with higher seasonal temperatures. Increased variability in precipitation and stream flow.

- Water supply planning
- Groundwater supply planning
- Water reuse planning
- Reservoir capacity planning
- Nutrient/pollutant reduction implementation

Increased temperature. Increased variability in stream flow.

- Reevaluate climate conditions
- Refine Long Term adaptive strategies

Figure ES-1. Adaptation strategy prioritization classification and time frames

Project elements include:

- Public outreach
- Future water demand projections
- Future watershed inventory evaluation
- Climate and watershed modeling
- Vulnerability assessment
- Adaptive strategy development

Regional Collaboration Is Required. The projected impacts to the Scioto River basin associated with climate change are regional and will require regional collaboration and planning. This is a new approach for central Ohio, where the need to collaborate on resource planning has not been required in the past. In the short term, it is recommended that the region's municipal leaders begin by establishing a forum for planning and collaboration, to address and consider the larger-scale issues related to maintaining safe and reliable water resources and water supply systems both now and in the future.

Water Quality Improvements Are a Key Focus Area. It is important to note that surface waters in the Scioto River basin already contain elevated concentrations of nitrogen, phosphorus, and other pollutants. Higher temperatures in the future, combined with additional nutrient loads, will increase algal bloom frequency and intensity. Algal blooms can lead to a variety of aesthetic, health, and drinking water issues. There is some urgency in identifying and reducing the primary sources of nutrients in the watershed. Minimizing the nutrient and other pollutant loads is essential to protecting/improving surface water quality in the region.

Robust Emergency Plan Is Critical for the Region. Over the past decade, the region has experienced record-breaking heat, unprecedented flooding, and prolonged periods of drought.

Across the United States, we have also seen the impact of extreme weather events on utilities. Robust emergency planning and preparedness is an important element of this Plan for central Ohio.

Public Outreach

A key component of the Sustaining Scioto project was public outreach and involvement. Multiple presentations at milestone points in the project were made to planning agencies, city council members, civic groups, and environmental organizations to inform the public about the project and seek input. A Stakeholder Advisory Committee (SAC) was also developed to provide input to the project from a broad range of regional stakeholders. The committee was composed of approximately 25 representatives from public utilities, agriculture, transportation, environmental advocacy groups, private industry, and municipal offices. The committee met bimonthly to review milestone project results and provide feedback to the project team. The committee was integral in the vulnerability assessment and development of adaptive management strategies. The input from the SAC helped to inform the project team on the issues facing the entire Upper Scioto River watershed and its users. A list of SAC members is provided in the Acknowledgements section of this Plan.

Future Water Demands

Analysis of multiple criteria was performed to assess the effects on the watershed from climate change and land development. Future water demands were calculated based on projected growth within the region. Water use was predicted for conditions in 2035 and 2090 to develop an understanding of the demands on the watershed’s water supply based on regional growth. The predicted water demands are shown in Table ES-1. It is important to note that these demands were developed using existing water use rates and land use zoning, both of which have the potential to change over the remainder of the century. The water demand for 2090 is based on total buildout of the region with the existing land use zoning for each municipal area.

The Stakeholder Advisory Committee was composed of representatives from public utilities, agriculture, transportation, environmental advocacy groups, private industry, and municipal offices.

Table ES-1. Upper Scioto River Watershed Current and Predicted Future Water Average Daily Demands

Utility	2010[a] Surface Water (mgd)	2035 Surface Water (mgd)	2090 Surface Water (mgd)
City of Columbus	142.4	148.5	292.3
City of Westerville	3.8	4.5	5.0
City of Delaware	3.6	5.4	6.3
Del-Co	10.8	24	36.2
City of Marysville	1.9	3.7	9.0
Ohio Aqua: Marion	6.2	4.6	8.1
City of Galion	1.1	1.1	1.7
Total	169.8	191.8	358.6

a. Reference: "Upper Scioto River Watershed, Water Use Projections Technical Memorandum" (Brown and Caldwell, 2014a)

Upper Scioto River Watershed Water Inventory

A water inventory was developed for the watershed using the predicted future water demands and availability. Global Climate Model (GCM) data were used to analyze the predicted temperature and precipitation changes and evaluate the future evapotranspiration and rainfall amounts within the watershed. Four climate projection models were selected for this analysis. Each model contained data for both medium- and high-emission scenarios, which resulted in a total of eight data sets being used in the analysis. Model data for a low-emission scenario were also available, but were not used because the projected climate conditions were too similar to existing climate conditions. It is important to note that each of the climate models has an equal likelihood of occurrence. No single climate model results can be used as an exact prediction of future events, but rather the results should be viewed as a range of potential outcomes. The USGS watershed model was used to evaluate each of the eight climate model data sets along with a historical data set.

USGS modeled future water supply availability using predicted climatic conditions (temperature and precipitation), and compared it to the predicted future water demands to assess the balance of water demand versus availability within the watershed. The results of the water inventory are depicted in Figure ES-2. This analysis considered future changes in climate as well as population growth. The water inventory results indicate that for most of the climate models, a surplus of water will be available in the watershed as we move further into the 21st century. However, results from several models indicate a negative amount of water, meaning that there will be more demand than supply.

It is recommended that a more detailed water balance model be developed in the future as the population grows and water demands approach the levels that have been projected in this Plan. The more detailed analysis of the watershed water balance should also include the evaluation of existing and future groundwater storage, use, and discharge. This more detailed modeling will allow the region to more carefully balance growth with the available water supply.

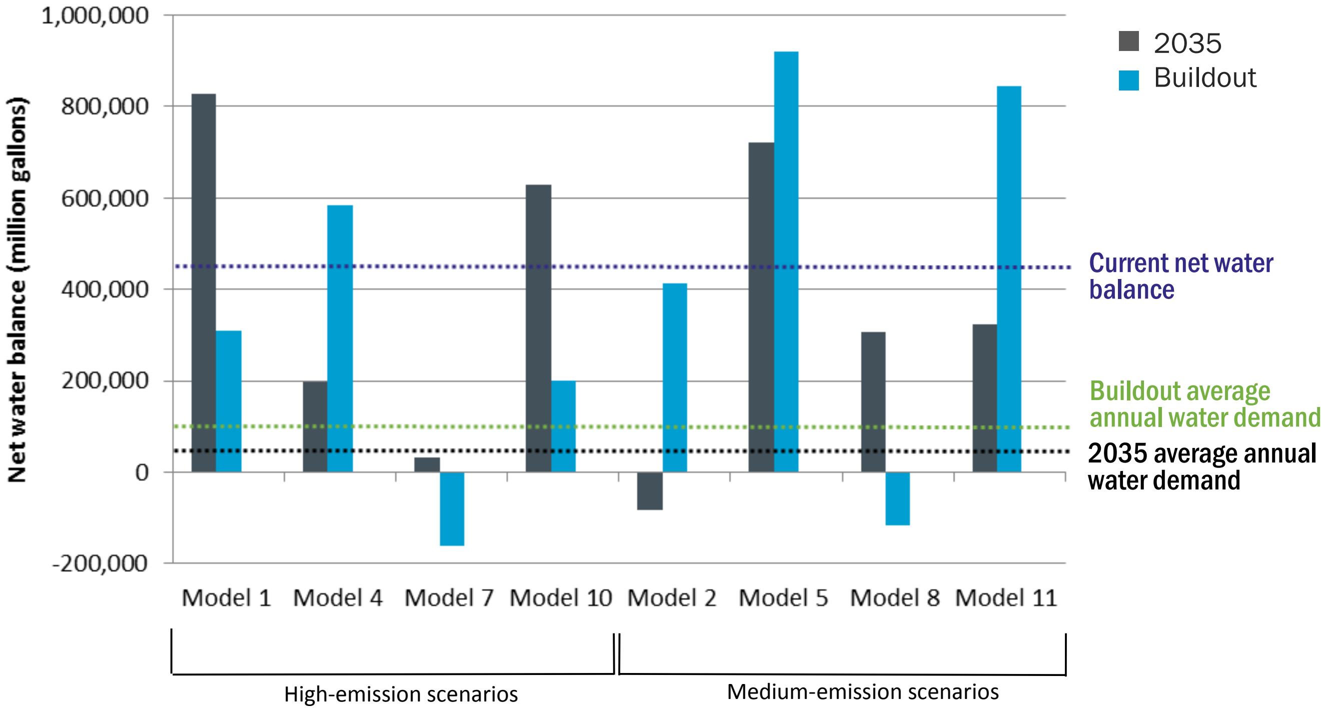


Figure ES-2. Upper Scioto River watershed water inventory

Vulnerability Assessment

Using the results of the USGS watershed model, future water use projections, and water inventory, the project team, along with the SAC, identified key vulnerabilities in the region. The potential risks from changes in temperature, precipitation, and stream flow were assessed and prioritized for nine service sectors based on likelihood of occurrence and severity of impact. The nine service sectors considered for the risk assessment are shown in Figure ES-3.

Figure ES-3

Upper Scioto River watershed risk assessment service sectors

Predicted changes to climate and stream flows were developed based on the climate data and watershed model output. These changes were then prioritized based on their likelihood to occur. Those ranked as highly likely to occur were linked to refined trends from the model results and climate data, such as increases in temperature. These changes were assigned a score of "High" and shaded red in Table ES-2. Predicted changes were categorized as "Medium" and shaded yellow if linked to results that were shown in the models, but with less distinct trends, such as those associated with buildout or precipitation. A "Low" score was assigned for changes that were not directly predicted by the model results and were considered less likely to occur based on the analysis.

Table ES-2. Upper Scioto River Watershed Summary of Prioritized Predicted Changes

Predicted Changes	Priority Based on Likelihood of Occurrence
Increased summer air temperatures/increased incidence of heat waves	High
Increased water temperature	High
Warmer soil temperatures/decreased soil moisture	High
Increased winter temperature and reduced ice cover	High
30- and 7-day higher peak river flows	Medium
Decreased minimum 30-day river flows/extended dry periods/summer drought	Medium
Increased intensity of rain and wind events	Medium
Change in vegetation/animal species composition	Low

Vulnerabilities were then identified within each of the nine service sectors for the predicted changes. These vulnerabilities were prioritized based on their impact to the region. High-impact vulnerabilities are those that would affect livability within the region. Medium-impact vulnerabilities would change the way services are offered and how people within the region live. Low-impact vulnerabilities would have a minimal impact on daily life.

The overall highest-priority risks are summarized in Table ES-3. The highest-priority risks are identified for each vulnerability scenario and service sector. The largest number of highest-priority risks is in the water supply/water quality and water treatment sectors. This outcome could be expected given that a safe and reliable water supply is a basic service critical to the livability and economy of the region.

Table ES-3. Upper Scioto River Watershed Summary of Highest-Priority Risks by Service Sector and Vulnerability Scenario

No.	Highest-Priority Vulnerability Scenarios	Highest-Priority Risks by Affected Sector								
		Water Supply/ Water Quality	Water Treatment	Wastewater Treatment	Public Health	Agriculture	Environment	Economy	Energy	Transportation
1	Increased air temperatures/increased incidence of heat waves	Increased water demand due to irrigation Increased nutrient/pesticide/herbicide load due to extended growing season, increased algal blooms	Taste and odor (T&O) concerns, potential for algal toxins		Increased issues for asthma and allergies Impacts to human mortality; increase in heat illnesses and stresses on health care	Livestock health/mortality Increased need for irrigation and controlled drainage	Increased smog/decreased air quality	Increased service cost for food Increased cost for utility services (water, wastewater, and energy) Decreased human productivity	Increased power disruptions (brownouts)	
2	Increased water temperature	Increased algal blooms including blue-greens (potential for increased toxin release)	T&O concerns, potential for algal toxins	Lower DO/changes in temperature affect wastewater discharge allocation	Increase in waterborne diseases	Increased cost to control water quality from fields			Lack of cooling water could reduce power production	
3	Warmer soil temperatures/decreased soil moisture					Increased need for irrigation and controlled drainage				
5	Higher maximum sustained flow (30- and 7-day higher maximum stream flows)	Increased algal blooms, including blue-greens (potential for increased toxin release) Increased total organic carbon (TOC), nutrients, turbidity, sediment, and other pollutant loads to surface waters Increased supply management challenges related to greater variability in stream flow Increased watershed and stream bank erosion	T&O concerns, potential for algal toxins Increased treatment cost due to increased pollutant concentrations and increased disinfection by-products (DBPs)					Increased flood damage		
6	Extended dry periods/summer drought (decreased minimum 30-day stream flow)	Decreased reservoir flow/volume and reduced mixing Increased water demand Increased algal blooms, including blue-greens (potential for increased toxin release) Reduced reliability of yield from supply sources	Reduced groundwater supply/recharge T&O concerns, potential for algal toxins; Increased treatment costs due to algae and potentially algal toxins		Increased allergens and dust	Increased demand for irrigation but decreased water availability		Increased food costs due to decreased agricultural production (crop loss)		
7	Increased intensity of rain and wind events	Increased watershed and stream bank erosion Increased TOC, nutrients, turbidity, sediment, and other pollutant loads	Damage to infrastructure/infrastructure failure including power outages, flooding, and intake damages	Damage to infrastructure/infrastructure failure including power outages and flooding Increased combined sewer overflow (CSO)/sanitary sewer overflow (SSO) discharges	Loss of electrical/water/sanitation services during and after event Increased demand on public health services Restricted access to critical care Disaster-related injuries/mortalities			Increased insurance costs; Increased damages due to floods/storms	Increased vulnerability of power supply system	Infrastructure access Infrastructure damage/failure Interruption to emergency services including the transportation of food and water in critical situations

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Climate Change Adaptation Strategies

Climate change presents challenges to water and wastewater utilities and to the other regional service sectors. Challenges include impacts associated with increases in air and water temperature, degraded water quality, increased potential for droughts with longer duration, and increased occurrence of floods associated with more intense rain events. One of the overarching challenges to managing utilities and services in the region is the need to increase flexibility in planning and operations to adapt to the increased variability and extremes of precipitation, stream flow, and water quality.

The projected climate changes could have a significant effect on facilities and operations, yet the probability and magnitude of these changes are not known with a high degree of certainty. To manage these critical infrastructure systems prudently, utility operators must determine strategies to address the issues that pose the greatest threat and make appropriate investments. They must also determine trigger points using climate and water quality parameters that would initiate further action and monitor these parameters on a regular schedule. This approach will allow utility managers and regional leaders to adapt future planning strategies and investments as climatic conditions change over time.

One of the overarching challenges to managing utilities and services in the region is the need to increase flexibility in planning and operations to adapt to the increased variability and extremes of precipitation, stream flow, and water quality.

This Plan provides a description of potential adaptation strategies that the utilities and the region may implement to mitigate the risks expected from climate change. Adaptive strategies were developed for the water sector and each of the non-water service sectors: environment, public health, agriculture, economy, energy, and transportation. Table ES-4 shows how the adaptive strategies for each service sector are divided into three categories.

Table ES-4. Categories of Adaptive Strategies

Category	Definition
Planning	Strategies that include studies, demand or development planning, and regulatory policy or ordinance changes
Operational	Strategies that include operational changes to reservoir or treatment plant operations, conservation efforts, and other management strategies
Capital improvement	Strategies that include construction of new infrastructure, significant rehabilitation or retrofit of existing infrastructure, and new technologies

Each adaptive strategy has also been categorized based on the relative level of investment for the region. The three levels of cost are defined in Table ES-5.

Table ES-5. Relative Costs Associated with Adaptive Strategies

Assigned Cost	Definition
$	Options that can be funded by the utility or service sector within the typical annual budget
$$	Investments that require planning to implement as part of the capital improvement plan for the utility or service sector
$$$	Projects or improvements that may require significant bonding, federal or grant funding, or changes to utility rates to implement the improvement

In many cases, strategies are identified that provide a significant benefit to the utility or service sector under both the current climate and climate change scenarios. These strategies are labeled throughout the Plan as "no regrets" strategies. Implementing such strategies will increase the region's resilience to climate change while also providing immediate benefits. The "no regrets" actions are not cost-free but do provide benefits to the service sector regardless of future climate conditions.

"No regrets" strategies are strategies that provide benefit under current and potential climate change conditions.

Three planning terms:

Short Term: strategies that should be implemented between 2015 and 2025

Mid Term: strategies that should be implemented between 2026 and 2045

Long Term: strategies that should be implemented between 2046 and 2090

Finally, the strategies were organized by the sequence in which they should occur to provide a clear plan for implementation. Three planning terms were defined: Short Term, which are strategies that should be implemented between 2015 and 2025; Mid Term, strategies that should be implemented between 2026 and 2045; and Long Term, strategies that should be implemented between 2046 and 2090.

It is neither feasible nor necessary to implement all of the adaptive strategies identified in this study immediately. Most of the recommended strategies are "no regrets" and relatively low cost while providing substantial benefits. Implementation of these strategies will require action by local governments in combination with regional coordination.

Table ES-6 includes a summary of the recommended Short Term and Mid Term adaptation strategies for the water service sectors and the time frame in which they should be implemented. Long Term strategies are more likely to change as the climate and the region change over the next 30 years. It is anticipated that the Long Term strategies identified in this study will be refined based on the outcomes from the Mid Term planning studies. Adaptive strategies for the non-water service sectors are detailed in Appendix D.

Developing a more thorough understanding of the watersheds and surface water system through monitoring and analyses would allow the preparation of operational strategies to further improve the reliability and resilience of the water supply and utility systems and improve future decision making. Additional regional coordination and planning would also enhance system reliability and resilience. Other strategies, such as the more expensive capital improvements, may not be appropriate under current conditions, but may become necessary as conditions change and more is understood. Once the water supply and watershed planning is completed, capital projects will likely be identified that should be completed in the Mid and Long Terms to improve the resilience of the water supply system, reduce pollutant loads, improve surface water quality, and reduce drinking water treatment requirements.

Table ES-6. Recommended Adaptation Strategies for the Upper Scioto River Watershed

Short Term (10 Years) 2015–25	Mid Term (11–30 Years) 2026–45
Regional Collaborative Forum Establish forum for regional collaboration and planning with regard to issues related to water supply, water quality, treatment, and climate change impacts. **Public Education** Implement public education and outreach on sources of pollutants, water quality, supply, and climate change. **Improve Emergency Preparedness Capacities** Develop or update Regional Emergency Preparedness and Response Plans for extreme weather and water quality events. Evaluate and provide flood protection for critical assets. Develop Emergency Power Supply Plans. **Enhance Operational Procedures** Conduct (expand) water quality monitoring throughout supply system and treatment process and identify primary sources of external and internal pollutants. Establish SOPs for modified reservoir and treatment plant operation during high turbidity, algae, and organics events. **Resource Protection** Develop a guide for and promote high-efficiency irrigation systems and low water use landscaping. Modify local stormwater management and land development ordinances to incorporate low-impact development (LID) practices. Develop a cooperative program with agriculture to reduce runoff pollutant loads. Implement public LID demonstration projects and promote/incentivize private LID retrofit. Implement additional non-structural BMPs to reduce nutrient/pollutant loads to surface waters.	**Water Supply Planning** Develop Regional Water Supply Management Plan including sustainable groundwater supply, and irrigation needs. **Groundwater Supply Planning** Conduct a regional groundwater study to assess availability of groundwater for regional growth and irrigation uses. **Water Reuse Planning** Identify areas for water reuse (e.g., irrigation, industrial applications, etc.) to reduce water demands. **Reservoir Capacity Planning** Develop Reservoir Operational Plan for optimizing reservoir capture and reservoir management during drought and high flow conditions. **Nutrient/Pollutant Reduction Planning and Implementation** Continue Regional Watershed Management Planning based on expanded monitoring to identify primary watershed external and internal pollutant loads and protect/improve reservoir water quality. Install structural BMPs to reduce nutrient/pollutant loads to surface waters. Complete necessary in-reservoir treatment to protect/improve reservoir water quality. **Reevaluate Climate Conditions** Continue to monitor and evaluate changes to climate, water demand, and watershed. Update plan as needed.

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Section 1

Project Purpose

The Mid-Ohio Regional Planning Commission (MORPC), together with partners, the City of Columbus Department of Public Utilities, Del-Co Water Company, Inc., U.S. Geological Survey (USGS), and Ohio Water Development Authority (OWDA), initiated a study to model the effects of climate change on water supply in the Upper Scioto River basin. The primary objective for this project was the development of an Adaptive Management Plan (Plan) for the region, a Plan that will ensure a resilient water supply system well in to the future. This project, named Sustaining Scioto, was a two-phased project:

- Phase I involved the development of a computer model for the prediction of the impacts of projected climatic conditions on the water resources of the basin through 2090, also referred to as buildout. USGS developed the watershed model and calibrated/validated the results using historical gauging station data. Model outputs reflect the expected flow volumes in the Scioto River, with a range of scenarios reflecting projected changes to climatic conditions. Model input for historical conditions included existing withdrawals and discharges to the Scioto River from public utilities, agriculture, and industry. For future conditions, USGS modeled projected future water demands, buildout land use, and a range of climate (rainfall and temperature) projections.
- Phase II involved development of future water use projections, evaluation of a water inventory, and evaluation of the vulnerability of water supply sources and infrastructure based on the USGS model results. One of the first tasks involved evaluation of the future development within the region and the associated water demand projections based on population growth, and commercial and industrial development. A water inventory for the region was prepared based on these demands that assessed the water system intakes and wastewater discharge rates at present and into the future to determine potential system risks and provide the framework for future planning. Using the results of the model and the water inventory, the project team, along with the Stakeholder Advisory Committee (SAC), identified vulnerabilities for nine service sectors within the watershed based on the potential effects of climate change and development. These vulnerabilities were prioritized and adaptive strategies were developed for the highest-priority vulnerabilities to establishing an Adaptive Management Plan. This Plan will provide utilities, developers, agriculture, and industry in the region with an understanding of the potential risks imposed by climate change and will also serve as a guide for future investment and planning for water resource management within the region.

During completion of the second phase of the project, additional funding was provided by the City of Columbus and the Water Research Foundation (WRF) to evaluate the potential impacts of climate change on water quality and water treatment needs in the region. An assessment of current water quality and potential changes in water quality and treatment needs due to climate change was completed and incorporated into the project results.

1.1 Project Location

Sustaining Scioto encompasses the Upper Scioto River watershed from its headwaters in northern Ohio to just north of Circleville, in the south. The project includes Franklin, Delaware, Pickaway, Union, Marion, Morrow, Madison, Champaign, Logan, Crawford, and Hardin counties. A map of the project area is shown on Figure 1-1. The project area includes portions of the Scioto River; Big

Walnut Creek; Olentangy River; the Griggs, O'Shaughnessy, Alum Creek, and Hoover reservoirs; and Delaware Lake.

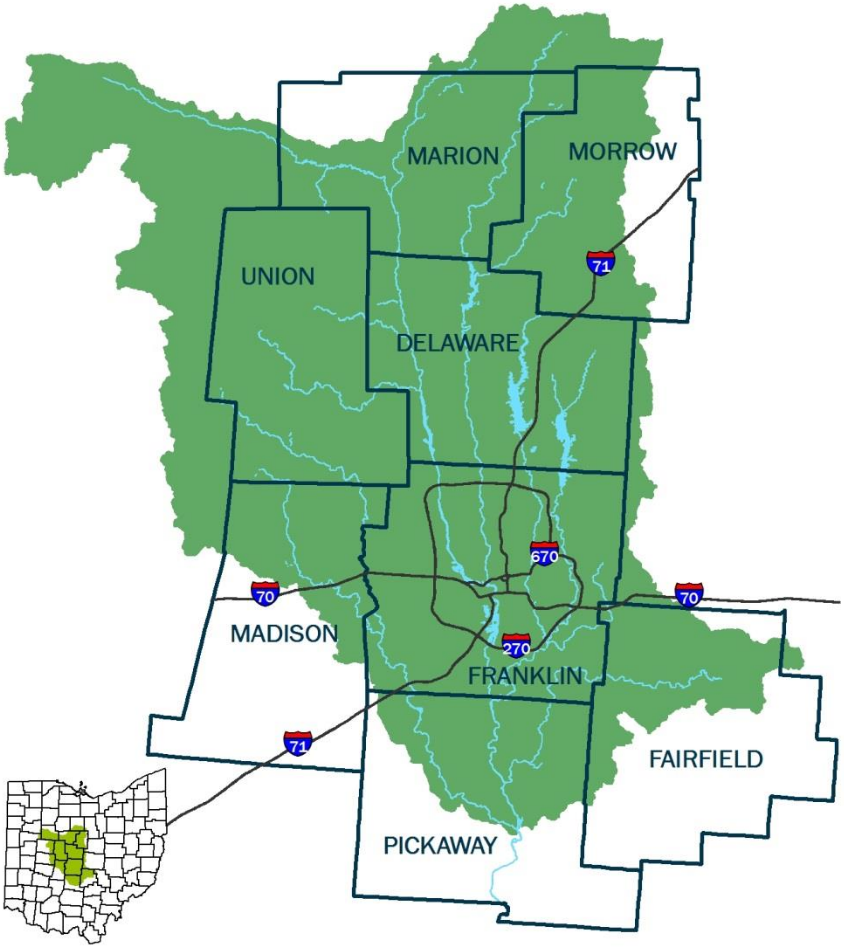

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Figure 1-1. Sustaining Scioto study area

1.2 Adaptive Management Planning Introduction

The purpose of this Plan is to identify adaptation strategies that can be used to address high-priority vulnerabilities related to climate change for the region. The vulnerabilities presented in this Plan were identified based on an evaluation of climate projection data and watershed modeling results provided by USGS. The potential impacts from changes in temperature, precipitation, and stream flow were assessed and prioritized based on likelihood of occurrence and severity of impact. Adaptation strategies were then developed and prioritized to address the highest-priority risks.

Adaptive management is a flexible strategy for developing, evaluating, and making decisions (EPA 2012a, Conrad et al. 2013). Adaptive management can be applied when evaluating options for a region (such as in this study) or utilized for a specific entity, such as a water utility. The basic approach to adaptive management, shown in Figure 1-2, includes understanding and prioritizing risks, developing strategies to reduce risks, implementing strategies, and reevaluating strategies as more information becomes available. Adaptive management's flexible approach makes it valuable in making decisions in an uncertain environment. It proves especially useful in the context of climate change planning because it is an iterative process. The strategies will be periodically modified based on monitoring results and updated climate change projections. New strategies will be developed and implemented based on new information and the iterative process will continue.

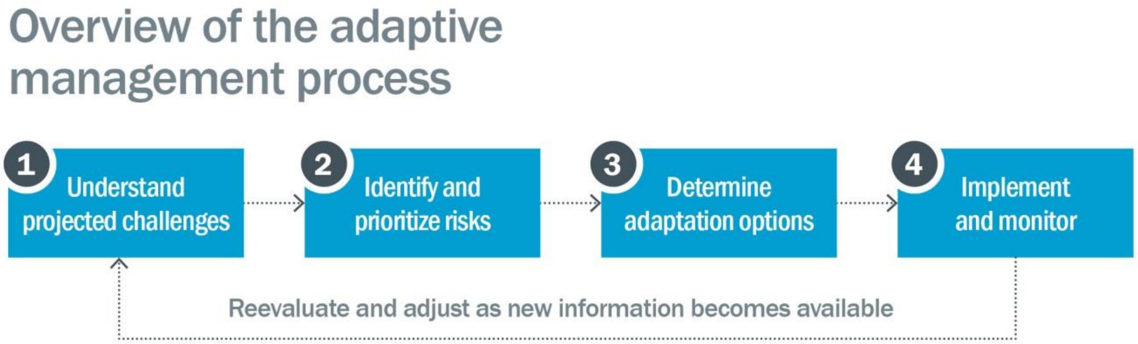

Figure 1-2. Overview of the adaptive management process

The first step in developing an Adaptive Management Plan for climate change is the evaluation of the predicted regional changes and the corresponding challenges. The USGS watershed modeling, conducted as part of Phase I of this project (USGS 2015), provided the input needed to understand the potential impacts associated with climate change. The results from the USGS modeling, discussed in Section 6 of this Plan, define potential water quantity impacts due to climate change. Additional evaluations of potential impacts are presented in the Watershed Water Inventory (Section 4) and the Water Quality Assessment (Section 5). The associated vulnerabilities that arise from all of these changing conditions were identified and prioritized (Section 6) based on the climate and watershed modeling results, literature review, and input from regional stakeholders. Finally, the associated adaptive management strategies were developed as presented in Section 7. It should be noted that input from a diverse stakeholder group was an important element of both the evaluation of regional vulnerabilities and the development of the adaptive strategies. Section 2 provides an overview of the stakeholder and public engagement efforts.

Adaptive management's flexible approach makes it valuable in making decisions in an uncertain environment.

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Section 2

Public Outreach and Stakeholder Involvement

The Upper Scioto River watershed encompasses 3,200 square miles. Land use within the watershed varies from rural agricultural to urban high-density. The interests and uses of the water resources within the watershed vary widely. An important part of the project was ensuring that many of these interests were represented. To accomplish this effort, public outreach meetings were held to inform the general public and the SAC was formed to provide in-depth information about the needs of selected service sectors within the region.

2.1 Public Outreach Meetings

A primary goal of the public outreach efforts was to provide public education and outreach to citizens and agencies within the watershed. This task was accomplished by holding a series of public outreach meetings at project milestone points to disseminate project information and seek public input. Presentations were provided at a variety of settings including planning commission meetings, city council meetings, county commissioner meetings, and organizational meetings of private groups. Additional meetings were set up with representatives from the water utilities and water treatment plant (WTP) operators within the watershed. Table 2-1 includes a listing of some of the organizations that were part of the public outreach effort. The presentation locations were intentionally selected to cover a wide geographical area within the watershed.

Table 2-1. Public Outreach Meeting Locations

Delaware County Regional Planning Commission	Logan-Union-Champaign Regional Planning Commission
Marion Regional Planning Commission	City of Marysville
Franklin County Commissioners	Fairfield County Regional Planning Commission
Rural Water Association of Ohio	Olentangy Forum
Ohio Environmental Professionals Network	Ohio Watershed Leaders
Ohio Environmental Leaders Institute	Ohio Farm and Food Leadership Forum

An initial presentation was made at the outset of the project to introduce the project and answer questions from the public about project intent and scope. Upon completion of the risk assessment and development of the preliminary adaptive strategies, MORPC presented the project findings to the groups to gather public input and feedback. Upon completion of the final Adaptive Management Plan, MORPC will meet with these groups again and present the final Plan findings and recommendations.

2.2 Stakeholder Advisory Committee

Climate change has the potential to have a significant effect on the entire region, but these changes will affect each service sector and citizen within the region differently. MORPC thought it was critical to closely involve stakeholders in the project to ensure that the diverse interests of water users within the watershed were heard and understood. Potential SAC members were identified by the Sustaining Scioto Steering Committee and issued invitations to participate. The organizations represented on the SAC are listed in Table 2-2.

Table 2-2. Sustaining Scioto Stakeholder Advisory Committee Members

Del-Co Water Company	City of Columbus Public Utilities	Franklin County Engineer
Ohio Farm Bureau Federation	U.S. Geological Survey	Ohio State University
Aqua Ohio	Ohio Environmental Council	Delaware County RPC
City of Westerville	Franklin County Public Health	The Nature Conservancy
City of Gahanna	City of Marysville	AEP
Ohio Township Association	City of Circleville	Water Management Association Board
City of Marion	Friends of the Scioto River	Logan-Union-Champaign RPC
City of Delaware	Union County Engineer	ODOT District 6
Fairfield County Utilities	Franklin County SWCD	Nationwide Insurance
Ohio Environmental Protection Agency	Franklin County Emergency Management and Homeland Security	Natural Resources Conservation Service
City of Columbus Development Department	MORPC Transportation	MORPC Greenways and Water Quality

The SAC members met with the project team on a bimonthly basis during the course of the project. During each meeting, the SAC members were presented with the results of the project tasks and invited to provide comments and input on the results. Presentations and small-group working sessions were also included to explain upcoming tasks and to seek committee input. This was done to ensure that the project team was considering all pertinent available information. The SAC was an integral part of the team identifying vulnerabilities within the watershed and developing potential adaptive management strategies. Handouts and outreach materials used in both the stakeholder and public outreach meetings are provided in Appendix A.

Section 3

Water Use Projections

To understand the effects of climatic conditions on Scioto River flow, it is necessary to quantify the amount of water withdrawn from and discharged back to the Scioto River. Water is withdrawn from the Scioto River for a variety of purposes including human consumption, agricultural uses, industrial processes, and lawn irrigation. The amount of water necessary for municipal and industrial use that requires potable treatment can be estimated based on current treatment rates and population. As the population in an area increases, the amount of water consumed in that area generally also increases. Both water and wastewater flow rates can be estimated based on population projections and local per capita water usage.

For this project, the buildout water demand and wastewater discharge rate was projected using the existing per capita rate and the projected population at buildout. USGS used these water and wastewater utility future demand projections, along with known withdrawals and discharges from industrial and agricultural users in the watershed, in the watershed model to analyze future stream flow volumes in the Scioto River.

3.1 Population Projections

The water withdrawal rates from the Scioto River watershed are projected to increase with population growth. As the population in the region increases and industrial and commercial development continues, the public water supply utilities will need to supply more water to meet the needs of the region. Prolonged drought could also increase the demand for water from agricultural and landscaping-based industries. The future population and development within the region was estimated to enable the associated projections of water demand and wastewater discharge throughout the project planning horizon (to 2090). The increased water demands were estimated based on current treatment rates and population projections for each utility. The USGS model was then used to evaluate the availability of water in the river based on the increased demands and the climatic projections.

3.1.1 Population Data

The USGS watershed model evaluated runoff and stream flow volumes for two future development scenarios: 2035 and 2090, which is also referred to as “buildout.” To develop water demands for these scenarios it was necessary to estimate the population within the region at those time periods. The population data used for the growth projections in this study was provided by MORPC. MORPC uses census data and input from local government planning agencies to develop population projections and land use designations for the central Ohio region. The most current population projections available from MORPC are based on the 2010 census and are available in geographic information system (GIS) format in the form of 40-acre grids covering the central Ohio area. The data for each of these grids include population values for 2000, 2010, 2035, and buildout; current and projected future land use; current and future projected number of households; and location data such as county, township, and city. It is important to note that the buildout population was developed based on the assumption that each area was fully developed with the existing land use zoning. This analysis did not include the potential future re-zoning of areas, such as the re-zoning of agricultural land to mid-density residential or urban land use.

3.1.2 Utility Service Areas

Each utility with a water withdrawal or wastewater discharge into the Scioto River has an associated service area. To determine the amount of water that must be supplied from or discharged to the river, the population within the service area must be defined. In many municipalities, the service area can be assumed to follow approximately the boundary of the city or village. However, in larger cities, private utility systems and regional utilities service areas may not be as clearly defined.

GIS layers including the city, county, and township boundaries were used to identify the service area boundaries for the utilities shown in Table 3-1.

Table 3-1. Upper Scioto River Watershed Water and Wastewater Utilities

- City of Columbus
- Canal Winchester
- City of Delaware
- Galion
- Kenton
- Delaware County
- Fairfield County
- Del-Co Water, Inc.
- City of Marion
- Marysville
- Pickerington
- Westerville
- Marion County

The population for each of the above service areas was determined by summing the populations of each of the MORPC grid areas located within the service area boundaries. Future growth beyond the existing boundaries was accounted for based on MORPC land development mapping of anticipated growth areas in the region.

3.2 Water Use Projections

Once the population of an area was determined, the water demand and wastewater treatment facility discharge was evaluated for each service area. It is common in utility planning to establish a planning-level unit demand based on gallons of water treated per person per day (gpcd). This value is based on the amount of water consumed or treated per day per customer in the facility service area. The consumption values are unique for each utility and vary based on the regional and economic characteristics of the facility service area. These values can vary greatly between utilities. For example, a utility with a large number of industrial clients with high water usage would generally have a higher unit demand (gpcd) than a suburban community with primarily residential occupancy. Demand can be calculated based solely on residential consumption, industrial and commercial demands, or a combination of both. The values calculated for this study are based on total water system demands including all industrial, commercial, and residential demands.

Water and wastewater facilities also use peak demand factors to ensure that the treatment facility can treat flows outside of the average daily range. WTPs use maximum day flows to size tanks and equipment to meet the demands of peak water usage. Wastewater treatment facilities use peak flows to ensure that tanks and equipment can handle the excess flows experienced during wet weather events. The watershed modeling performed for the Sustaining Scioto Study analyzed average river flows based on a range of scenarios representing long-term climate conditions, so peak demand or flow values are not appropriate for the scale of this project. Therefore, the demands developed for this task and used in the model are calculated for an average day.

Five of the eight water utilities identified as having surface water withdrawals also withdraw groundwater as an additional water source. Total system water demand was calculated for these utilities based on the total recorded withdrawal of both surface water and groundwater sources to establish the demand for the utility service area. The projected demands calculated for 2035 and 2090 were then adjusted to account for the same percentage of groundwater currently used at each utility. The projected water withdrawals and discharges are shown in Tables 3-2 and 3-3.

Table 3-2. Upper Scioto River Watershed Projected Population and Water Withdrawals

Utility	Percent Total Water Supply from Groundwater	Water Usage per Person (gpcd)	Population 2035	Avg. Day Demand 2035 Surface Water (mgd)	Population at Buildout	Avg. Day Demand at Buildout Surface Water (mgd)
City of Columbus	17	138.1	1,296,700	148.5	2,553,354	292.3
City of Westerville	5.0	105.0	45,045	4.5	50,123	5.0
City of Delaware	15	103.7	60,754	5.4	71,482	6.3
Del-Co	0	121.5	188,848	24.1	292,032	36.2
City of Marysville	46	87.3	77,376	3.7	190,277	9.0
Ohio Aqua: Marion	35	167.8	42,554	4.6	74,650	8.1
City of Galion	0	100.6	11,038	1.1	16,414	1.7

Table 3-3. Upper Scioto River Watershed Projected Population and Wastewater Discharges

Utility	Average Design Flow per NPDES Permit (mgd)	Wastewater per Person (gpcd)	Population 2035	Average Daily Flow Rate 2035 (mgd)	Population at 2090 (Buildout)	Average Daily Flow Rate 2090 (Buildout) (mgd)
City of Columbus	182	110.0	2,050,000	225.5	3,420,000	376.2
City of Delaware: Upper Olentangy WRC	10	129.5	60,754	7.9	71,482	9.3
City of Marysville	8	181.0	77,376	14.0	190,277	34.5
City of Marion	10.5	228.8	42,554	9.7	74,650	17.1
City of Galion	2.7	256.9	11,038	2.8	16,414	4.2
City of Kenton	2.4	145.2	8,675	1.3	24,320	3.5
City of Canal Winchester	2.48	333.7	12,220	4.1	28,005	9.4
City of Pickerington	3.2	168.9	29,377	5.0	53,295	9.0
Delaware County Regional Sewer Dist.	16	109.6	133,125	14.5	155,720	17.0
Marion County Regional Sewer District SD No. 7	1.75	254.2	6,003	1.5	13,169	3.4
Fairfield County: Tussing Road WWTP	3	176.5	16,100	2.8	19,973	3.5

Section 4

Scioto River Watershed Water Inventory

A water inventory provides an estimation of the overall availability of water within a watershed, documenting the amount of water coming into and leaving the hydrologic system. Water inventories can have varying levels of detail, from large-scale accounting of water inflows and outflows in a region to highly detailed hydrologic simulations within a watershed. The purpose of this inventory was to develop an understanding of the total current water availability and demands and expected changes to that balance with the projected climatic changes and development in the watershed. For this project, potential changes to water availability within the watershed were evaluated based on predicted land development, population growth, and climate change.

Because of the large planning horizon for this project (through 2090), the water inventory was performed at a large scale, thereby providing a large-scale analysis of water inflows (precipitation and wastewater treatment plant [WWTP] discharges) and outflows (WTP withdrawals and evaporation). By performing this analysis for current conditions and future conditions in 2035 and 2090 (buildout), the potential changes in water availability within the watershed were assessed based on predicted weather in conjunction with projected land development.

This task provides an overview of the potential comprehensive impacts to water availability within the Upper Scioto River watershed. It should be noted that at this large scale, it is most important to look at the overall trends and general changes to the water balance in the watershed. This analysis does not include an evaluation of all the minor inflows and losses from the watershed, including groundwater infiltration and discharges. For this reason the study results should not be used as a quantitative estimate of actual water availability. Detailed results of the watershed water inventory is provided in the Water Inventory Technical Memorandum (Brown and Caldwell 2014b).

4.1 Climate Data

Two types of climate data were used in the development of the water inventory. Historical data were used to establish the baseline conditions within the watershed over the 20-year calibration period from 1980 to 1999. The climate data for the future scenarios were provided by the four Global Climate Model (GCM) data sets that were used by USGS as part of the development of the watershed model. Each of these climate model data sets has a high-emission scenario and a medium-emission scenario, producing a total of eight potential future conditions data sets.

USGS modeling of each of the eight climate data sets produced variable results. A comparison of the baseline (1980–99) average annual precipitation and temperature to the predicted average annual precipitation and temperature (2015–90) is shown on Figures 4-1 and 4-2, respectively. Note that average annual precipitation from lowest to highest result varies by 10 inches, with six data sets producing slightly more rainfall and two data sets producing slightly less rainfall. Average annual temperature varies by approximately 3 degrees Fahrenheit (°F) with all of the data sets predicting higher temperatures.

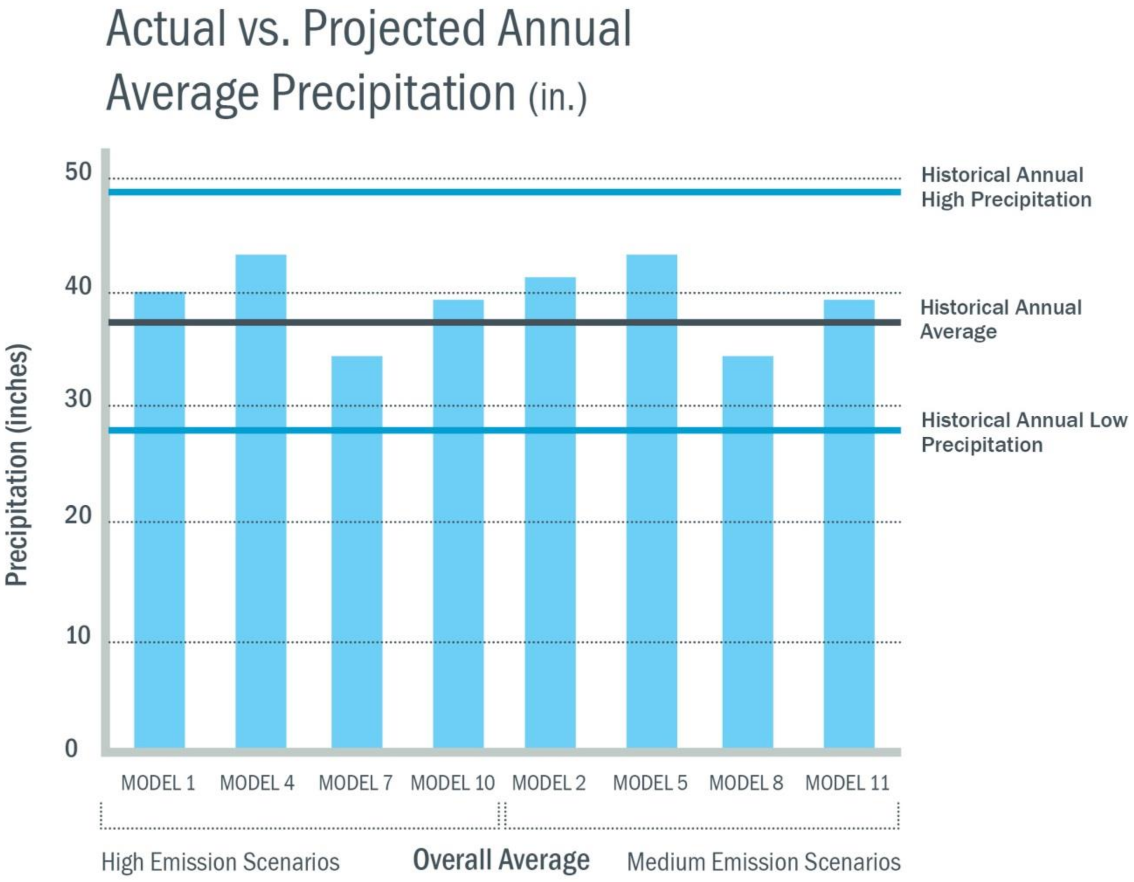

Figure 4-1. Upper Scioto River watershed comparison of average annual historical and projected precipitation

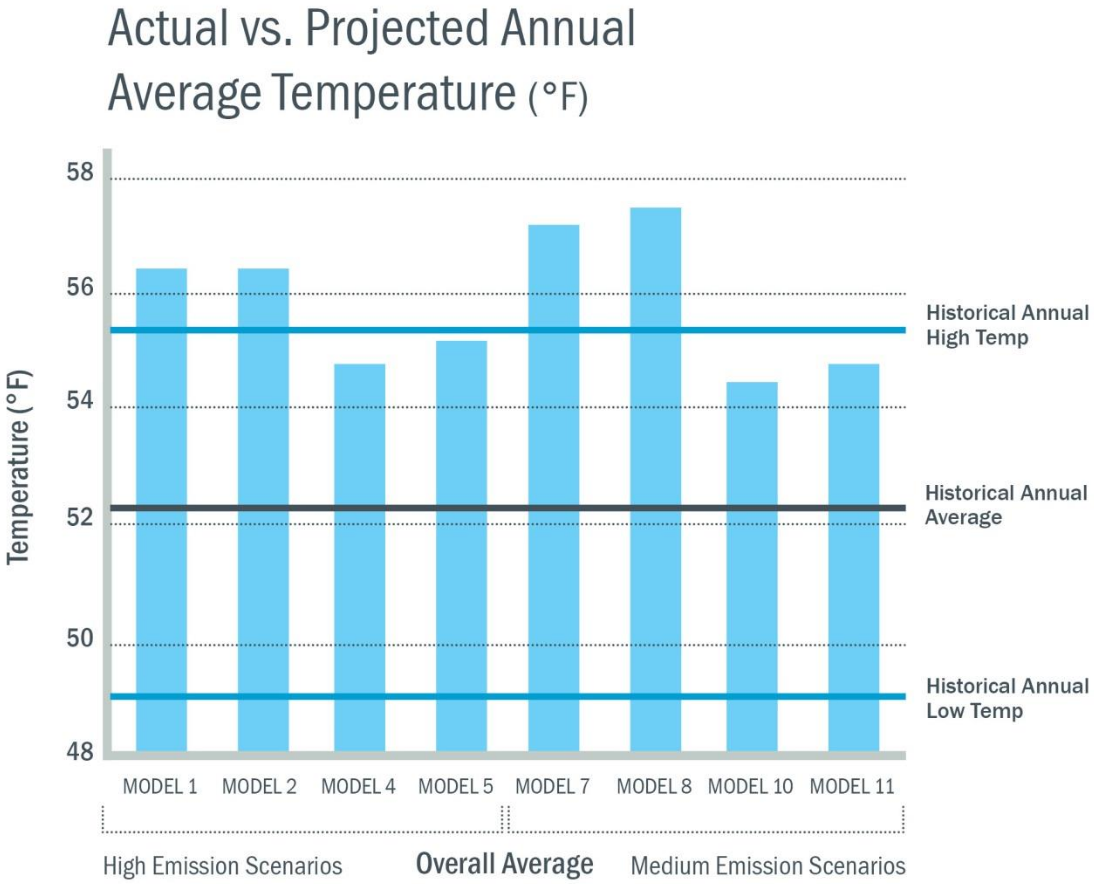

Figure 4-2. Upper Scioto River watershed comparison of average annual historical and projected temperature

4.2 Water Inventory

The surface water inventory includes the estimated amount of water that flows into and out of a watershed or basin. If the area being evaluated includes the headwaters of the receiving surface water, then precipitation is the primary water input for the inventory. This is the case for the water inventories developed for the Upper Scioto River watershed. The other significant water inputs for the inventory are the discharges from wastewater treatment facilities. Because many of the water utilities within the watershed use groundwater as a supply source, the amount of water discharged to the watershed from the wastewater treatment facilities can be greater than the amount of surface water withdrawn by the water treatment facilities.

There are two primary water withdrawals within the watershed. The first is withdrawals for public water supplies. This information was determined in the water use projections included in Section 3 for current water demands, demands in 2035, and demands in 2090. The other source of water withdrawal or loss is evapotranspiration. Evapotranspiration is the loss of water returned to the atmosphere through evaporation from the water surface of streams and reservoirs and uptake by plants based on climatic conditions. This loss is heavily dependent on temperature and will increase with rising temperatures.

Nine separate water inventories were developed as part of this task. A historical water inventory was developed to provide an understanding of the current balance of water availability within the region.

Future water inventories were developed for each of the eight future climate data sets for 2035 and 2090. Each future year inventory accounted for the effects of climate change, population growth, and development within the region.

4.2.1 Historical Water Inventory

The historical surface water inventory was developed using historical (1980–2010) precipitation, temperature, and water demand data. The calculated water balance based on the historical data is summarized in Table 4-1. The results of the historical inventory indicate that the available water volume exceeds the water demand by approximately 0.5 trillion gallons in an average year.

<table>
<tr><th colspan="3">Table 4-1. Upper Scioto River Watershed Historical Water Inventory</th></tr>
<tr><th colspan="3">Average Annual Inflow
(MG)</th></tr>
<tr><th>Average Annual Precipitation</th><th>WWTP Discharges</th><th>Total Inflow</th></tr>
<tr><td>2,143,874</td><td>69,459</td><td>2,213,333</td></tr>
<tr><th colspan="3">Average Annual Losses
(MG)</th></tr>
<tr><th>Evaporation</th><th>Withdrawals</th><th>Total Losses</th></tr>
<tr><td>1,658,413</td><td>61,981</td><td>1,720,393</td></tr>
<tr><th colspan="3">Water Inventory/Balance = Total Inflow - Total Losses</th></tr>
<tr><td colspan="3">Net balance: 2,213,333 - 1,720,393 = 492,940 million gallons</td></tr>
</table>

4.2.2 Projected Water Inventories: 2035 and 2090

The same calculation process was repeated for each of the future climate data sets for 2035 and 2090. As indicated in the tables and figure below, while there is substantial variability in the projected balance with the different climate models, five out of eight indicate reduced water availability in both 2035 and 2090. In 2035, one of the climate scenarios results in a water demand greater than the available volume. In 2090, demand exceeds the available volume for two of the eight climate scenarios.

It should be noted that several of the models indicate there will be increased surface water quantity. The water inventory is significantly impacted by the projected increased water demand and water discharges from the water and wastewater treatment facilities as indicated in Tables 4-2 and 4-3.

Table 4-2. Upper Scioto River Watershed Water Inventory: 2035

Average Annual Inflow (MG)								
	Model 1	Model 2	Model 4	Model 5	Model 7	Model 8	Model 10	Model 11
Precipitation	2,571,917	1,647,871	1,927,933	2,451,828	1,853,344	2,092,732	2,347,636	2,052,175
Discharges	105,530	105,530	105,530	105,530	105,530	105,530	105,530	105,530
Total inflow	**2,677,447**	**1,753,401**	**2,033,464**	**2,557,358**	**1,958,874**	**2,198,262**	**2,453,167**	**2,157,705**

Average Annual Losses (MG)								
	Model 1	Model 2	Model 4	Model 5	Model 7	Model 8	Model 10	Model 11
Evaporation	1,780,136	1,764,380	1,766,066	1,766,583	1,857,259	1,822,294	1,754,026	1,765,043
Withdrawals	69,994	69,994	69,994	69,994	69,994	69,994	69,994	69,994
Total losses	**1,850,129**	**1,834,374**	**1,836,060**	**1,836,577**	**1,927,253**	**1,892,287**	**1,824,020**	**1,835,037**
Net balance	**827,318**	**-80,973**	**197,404**	**720,781**	**31,621**	**305,974**	**629,147**	**322,668**

Table 4-3. Upper Scioto River Watershed Water Inventory: 2090

Average Annual Inflow (MG)

	Model 1	Model 2	Model 4	Model 5	Model 7	Model 8	Model 10	Model 11
Precipitation	2,229,251	2,341,584	2,392,503	2,806,999	1,871,926	1,959,369	2,041,457	2,677,267
Discharges	177,737	177,737	177,737	177,737	177,737	177,737	177,737	177,737
Total inflow	**2,406,988**	**2,519,322**	**2,570,241**	**2,984,737**	**2,049,663**	**2,137,107**	**2,219,194**	**2,855,004**

Average Annual Losses (MG)

	Model 1	Model 2	Model 4	Model 5	Model 7	Model 8	Model 10	Model 11
Evaporation	1,965,303	1,974,149	1,855,301	1,933,255	2,078,802	2,121,913	1,888,020	1,879,627
Withdrawals	130,888	130,888	130,888	130,888	130,888	130,888	130,888	130,888
Total losses	**2,096,191**	**2,105,037**	**1,986,189**	**2,064,143**	**2,209,690**	**2,252,801**	**2,018,908**	**2,010,515**
Net balance	**310,797**	**414,285**	**584,052**	**920,594**	**-160,027**	**-115,694**	**200,286**	**844,489**

4.2.3 Water Inventory Conclusions

As indicated on Figure 4-3, there is substantial variability in the projected water inventory with the different climate scenarios. This is a reflection of the inherent uncertainty related to climate change predictions. Several of the models indicate that the projected water demand in the watershed may be close to or exceed the overall capacity of the basin in the future with the projected growth in population and climate changes. It is important to note that this inventory calculation was developed to provide only an overview of potential water availability trends within the watershed. This analysis does not include evaluation of all the minor inflows and losses from the basin and should not be used to as a quantitative estimate of actual water availability.

While five out of the eight models indicate reduced water availability in both 2035 and 2090, several of the models indicate there will be increased water availability. The inventory is significantly impacted by the projected increased water demand and water discharges from the water and wastewater treatment facilities. In some portions of the Upper Scioto River watershed, increased demands associated with population growth are projected to be met using groundwater supplies. If this shift in water use to groundwater is not realized as the region develops, there would be further increases in water demand that are not reflected in this analysis. Also, as noted above, this large-scale inventory accounts only for municipal water use. The inventory does not reflect the impact that increased irrigation may have on the overall demand due to temperature increases or longer periods with little or no rainfall.

It is recommended that a more detailed water balance model be developed in the future as the population grows and water demands approach the levels that have been projected in this study. The more detailed analysis of the watershed balance should also include the evaluation of existing and future groundwater storage, use, and discharge. This more detailed modeling will allow for the region to more carefully balance growth with available water supply.

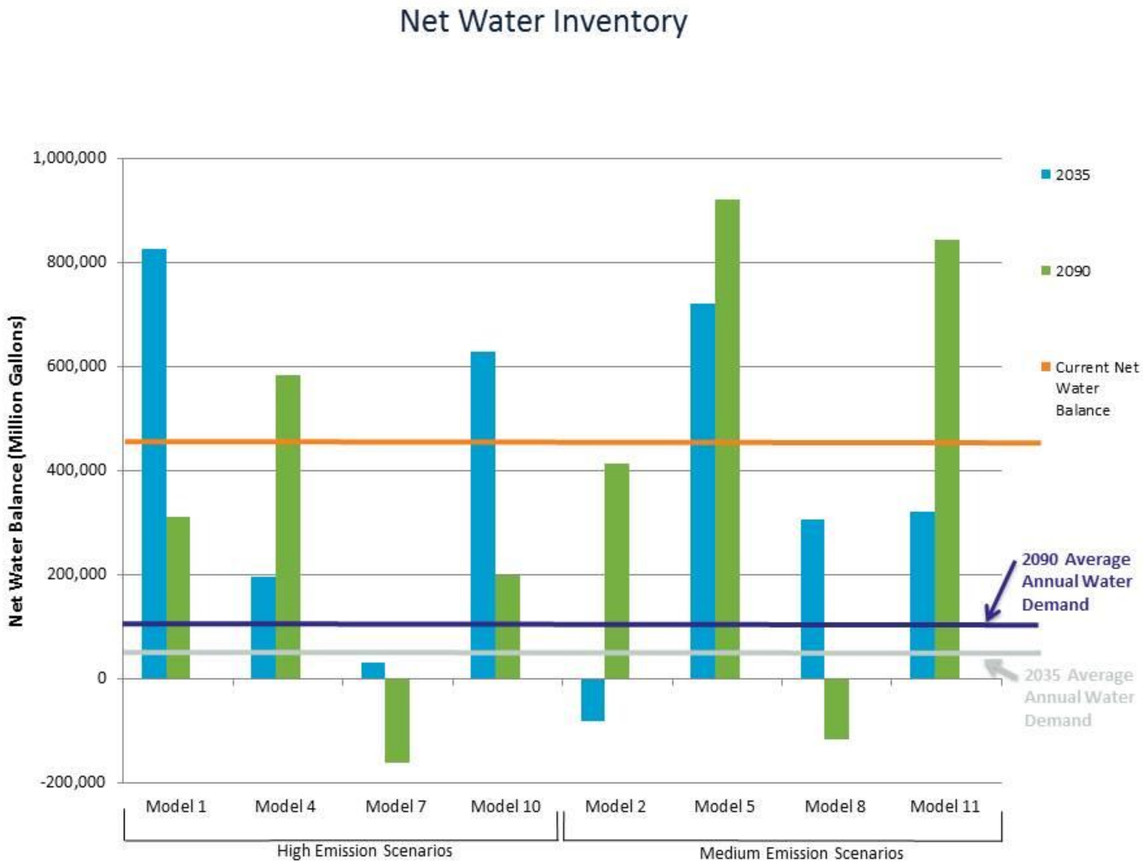

Figure 4-3. Upper Scioto River watershed comparison of water inventory scenarios for current condition, 2035 and 2090

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Section 5

Water Quality Assessment

This section provides an overview of the water quality in the Upper Scioto River watershed. Water quality data was analyzed to better understand existing water quality within the watershed and the impacts that climate change and development may have on the region's water resources in the future.

5.1 Data Collection

An extensive amount of data is available in the region to characterize water quality including stream, reservoir, drinking water intake, finished water, and water distribution system water quality; rainfall; and customer complaints. Available water quality parameters include herbicides and pesticides, organics and disinfection by-products (DBPs), turbidity, color, nutrients, algae, zooplankton, and cyanobacteria. Available data from 1977 through 2013 were collected, analyzed, and summarized in a separate Water Quality Assessment Technical Memorandum (Brown and Caldwell 2015). The assessment includes the identification of water quality trends over approximately 30 years and predicted future water quality in the region based on observed trends and expected changes in climate conditions. A brief summary of the water quality assessment results is provided in the following section.

To understand the water quality discussion, it is important to understand the monitoring locations and relationships between the various water supply components.

On the Scioto River, the most upstream reservoir is the O'Shaughnessy Reservoir. This reservoir is a widened section of the Scioto River. The Griggs Reservoir is also a widened section of the Scioto River located downstream of the O'Shaughnessy Reservoir. The Dublin Road Water Plant (DRWP) draws raw water from the Scioto River downstream of Griggs Reservoir and is therefore affected by the raw water quality in both the O'Shaughnessy and Griggs reservoirs. Because these two reservoirs are relatively small and in-line with the Scioto River, water quality is highly variable and can change rapidly during storm events. The water quality in these reservoirs and the DRWP intake is generally a reflection of the water quality in the Scioto River and the mean residence time in O'Shaughnessy and Griggs reservoirs is approximately 12 days.

The City of Columbus and Del-Co Water Company also recently completed the construction of a new upground reservoir, the John R. Doutt Upground Reservoir, with an intake on the Scioto River, upstream of both the Griggs and O'Shaughnessy reservoirs. The City of Columbus, which operates the reservoir, selectively pumps from the Scioto River to this reservoir to augment available water storage from this supply source. It is anticipated that the City of Columbus will selectively pump to the reservoir during periods of high water quality, thereby minimizing water quality problems within the upground storage reservoir.

The Hoover Reservoir is located to the east in a separate subwatershed on Big Walnut Creek. The Alum Creek Reservoir is located on Alum Creek, a tributary to Big Walnut Creek. Alum Creek discharges into Big Walnut Creek well south of the Hoover Reservoir. Water is pumped from the Alum Creek Reservoir to the Hoover Reservoir to supplement Hoover Reservoir capacity. The Alum Creek and Hoover reservoirs are much larger than the O'Shaughnessy and Griggs reservoirs and are capable of diluting and assimilating watershed pollutant loads within the reservoirs. Water quality changes occur more slowly over time in the Alum Creek and Hoover reservoirs and the mean residence time is estimated at approximately 180 days in Hoover Reservoir and even longer in Alum Creek Reservoir. The Hoover Reservoir is the raw water supply for the Hap Cremean Water Plant (HCWP).

The Parsons Avenue Water Plant (PAWP) is located south of Columbus with raw water provided by groundwater wells. The existing collector wells are located in an area adjacent to the Scioto River and Big Walnut Creek near sand and gravel mining operations.

The City of Westerville withdraws raw water for treatment from Alum Creek downstream of the Alum Creek Reservoir. The City of Westerville also uses groundwater wells to supplement its surface water source.

The Del-Co Water Company’s primary sources of water are the Olentangy River and the Alum Creek Reservoir. These surface water sources supply water to three of the system’s four water treatment plants: the Olentangy Plant, the Ralph E. Scott (Alum Creek) Plant, and the Timothy F. McNamara (Old State). When stream flows are adequate, Del-Co pumps water from the Olentangy River below Delaware Reservoir and from Alum Creek below the Alum Creek Reservoir to offline upground reservoirs for storage prior to treatment. Del-Co Water Company’s fourth water plant is a groundwater plant in Knox County, which is treated by the Thomas E. Steward Plant. The fourth plant is only used as a peaking plant and has not been used in a number of years.

Similar to the City of Columbus, it will be important to monitor pollutant concentrations and pump water to the upground reservoirs when concentrations are lower. Del-Co Water Company also relies on groundwater for its raw water supply.

The City of Delaware also withdraws raw water from the Olentangy River below Delaware Reservoir and treats the water at the Delaware Water Treatment Facility. The City of Delaware has the capability to blend this surface water with groundwater from several wells located at the treatment facility. The City of Marysville relies on surface water from Mill Creek, a tributary to the Scioto River, and groundwater wells for its water supply.

Numerous other surface water monitoring sites are located within the study area. The various monitoring locations referenced in this section are shown on Figure 5-1.

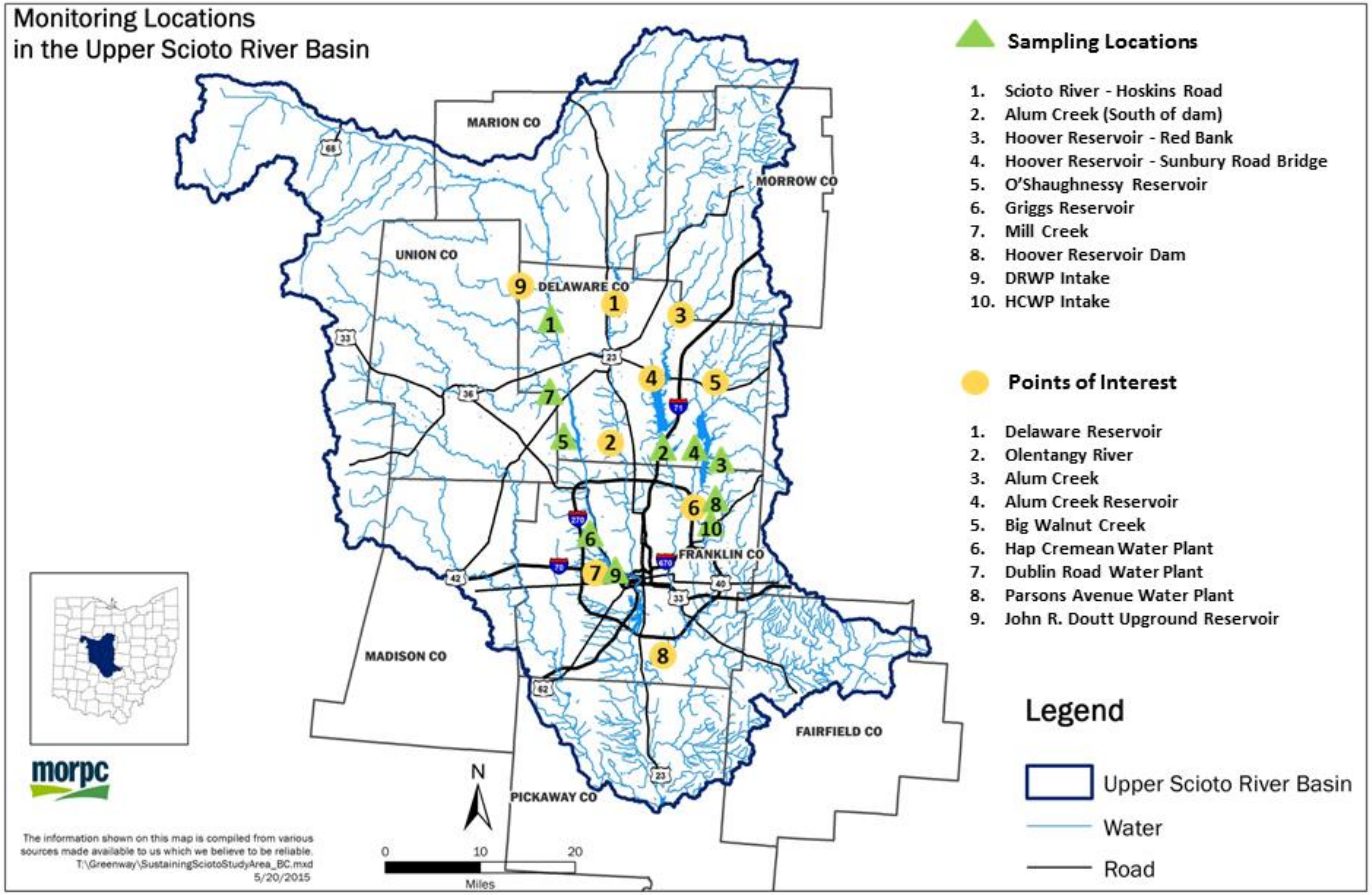

Figure 5-1. Upper Scioto River basin major water and wastewater utilities and water quality monitoring locations

Source: Adapted from MORPC

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5.2 Rainfall

A review of historical annual precipitation data was completed by BC to evaluate annual rainfall depths and identify periods of drought and heavier rainfall. Figure 5-2 includes historical annual precipitation data from the National Weather Service, Port Columbus Station. The average annual precipitation from 1981 through 2013 was 38 inches. The highest average monthly rainfall occurs in May through July, at more than 4 inches. The minimum average monthly rainfall occurs in February, at just over 2 inches. Average monthly precipitation is relatively consistent throughout the year but actual precipitation rarely follows the average patterns. Periods of drought and heavier rainfall can occur in years with annual precipitation above or below the long term average.

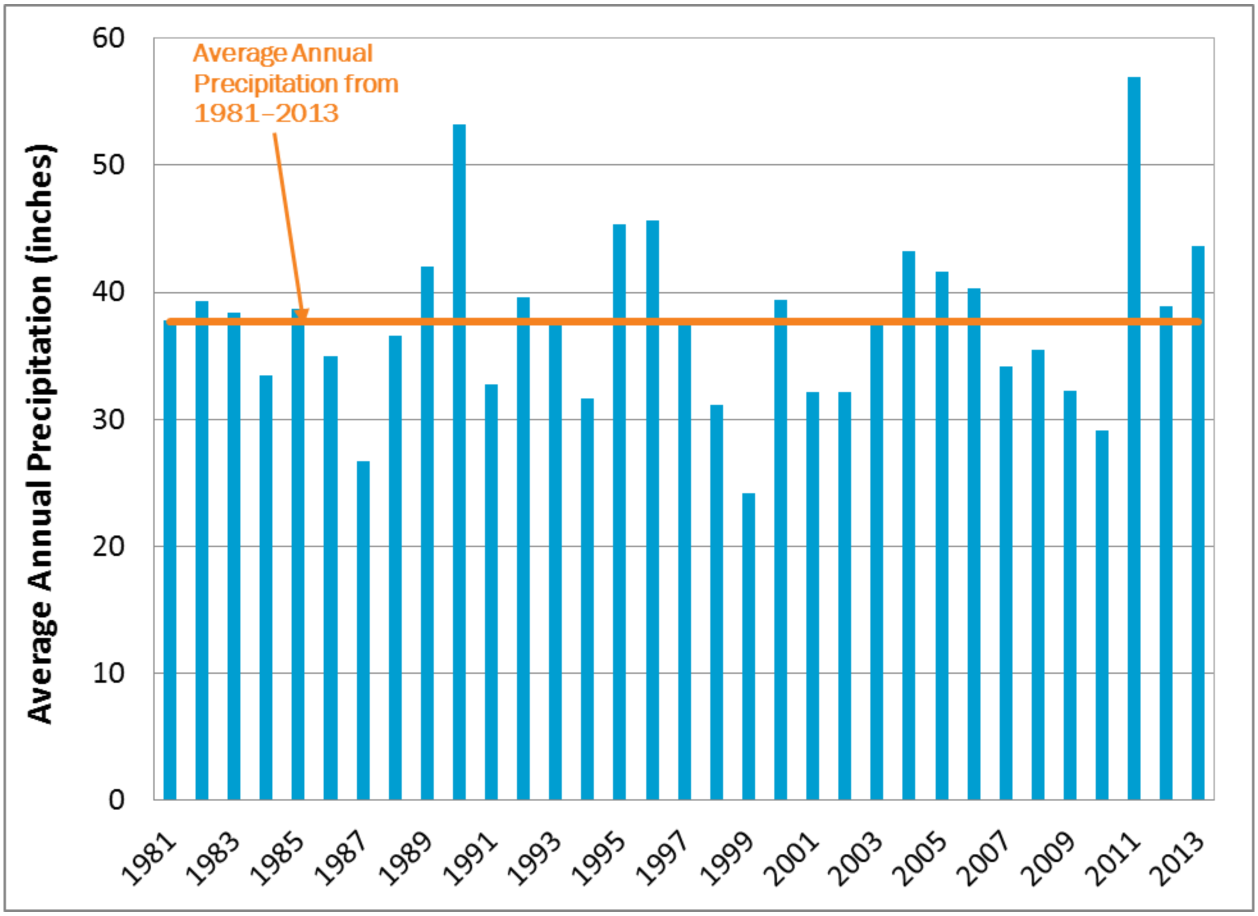

Figure 5-2. Historical precipitation data at the Port Columbus Station

Source: National Weather Service

Daily precipitation collected by the National Oceanic and Atmospheric Administration (NOAA) at the Westerville, Ohio, weather station from January 2009 to December 2011 is shown on Figure 5-3. This station is located close to Hoover and Alum Creek reservoirs. In this section, comparisons of water quality data for wet and dry periods are discussed from January 2009 to December 2011. This time period included total annual precipitation substantially above and below the long-term, annual average of approximately 38 inches. Over 7 inches of rainfall occurred between May 11 and June 9, 2010, during the third driest year (between 1981 and 2013). From July 14 to September 22, 2010, only 2.8 inches of rain was measured. In 2011, over 5 inches of rain fell in two days, July 23 and 24, and almost 17 inches of rain was measured between June 10 and August 25.

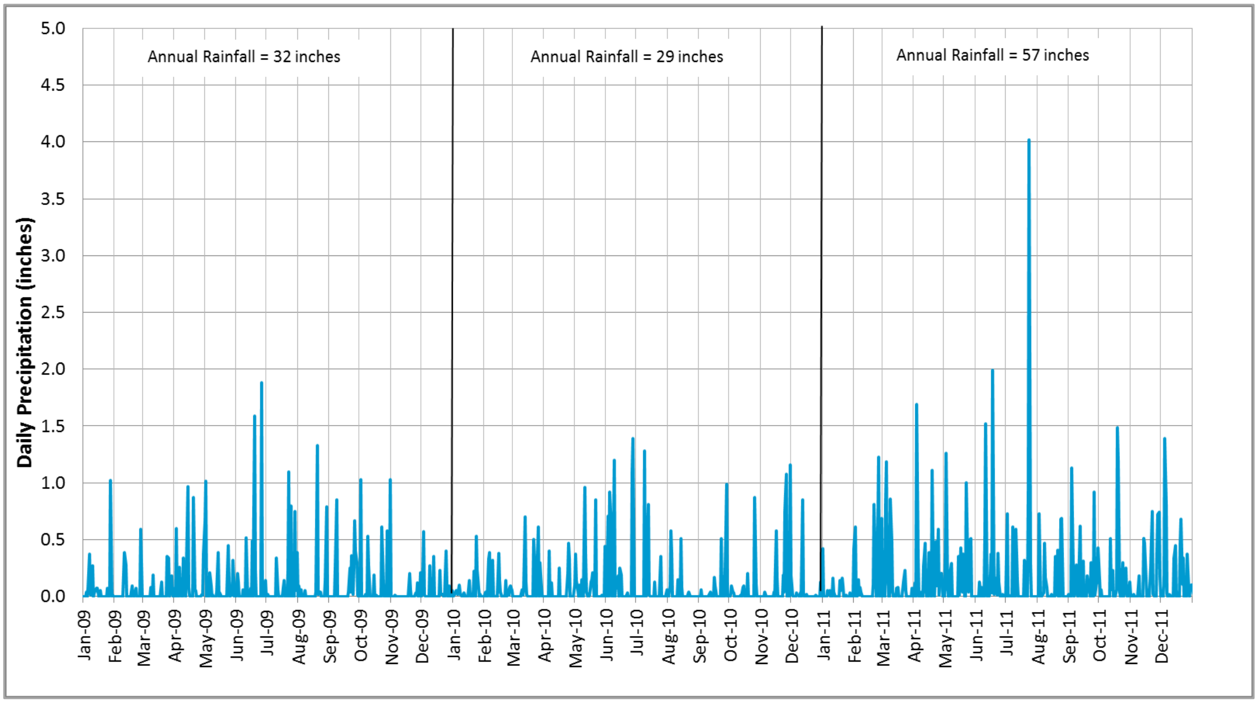

Figure 5-3. Daily precipitation from January 2009 through December 2011 at Westerville, Ohio Station

Source: National Oceanic and Atmospheric Administration, Westerville weather station

5.3 Turbidity

Turbidity is the cloudiness or haziness in water caused by small particles that are generally invisible to the naked eye. After rain events, an increase in water turbidity is common and results in decreased surface water clarity. Turbidity increase results from stream channel and watershed soil erosion and wash-off of pollutants from surfaces in the watershed. Light penetration is lower in turbid water, and therefore turbidity can reduce the growth of algae in lakes and reservoirs. Turbidity provides an indication of solids loading, which can fill area drainage systems and reservoirs causing flooding and reducing water storage and pollutant assimilative capacity.

Turbidity measurements at the DRWP intake and the HCWP intake between 1999 and 2013 were analyzed to identify apparent trends. The mean monthly turbidity spikes seasonally, most typically between December and March. Monthly turbidity values were much higher at the DRWP intake when compared to the HCWP intake. Lower turbidity values at the HCWP are expected because the Hoover Reservoir has a long residence time, and turbidity has time to dissipate in the reservoir during runoff events. Raw water mean monthly turbidity values at the DRWP intake appear to be similar throughout this 14-year period with no apparent increasing or declining trend.

More extreme and intense weather is expected in the future because of climate change. Drought followed by more intense storms will likely increase the concentration of turbidity in runoff, which will translate into higher turbidity concentrations in the raw water supplies. Elevated turbidity values in the future would increase the solids loading to water supply reservoirs and reduce reservoir water storage in a shorter time period. Loss of storage would also reduce the reservoir residence time and assimilative capacity for pollutant attenuation. Reservoir solids accumulation should be monitored and at some point in the future, solids removal may be necessary to restore adequate water storage.

Elevated turbidity at the water treatment plant intake can normally be removed using existing treatment processes with additional chemical use although there is a practical limit of approximately 800 NTU. As raw water turbidity increases, the volume of residual solids produced by the water plant also increases. This reduces the life of the solids storage area and additional solids handling equipment and space may be needed.

5.4 Total Organic Carbon

Total organic carbon (TOC) in source waters comes from decaying natural organic matter (NOM) as well as synthetic sources. Humic acid and fulvic acid are examples of NOM. Some detergents, pesticides, fertilizers, herbicides, industrial chemicals, and chlorinated organics are examples of synthetic sources of TOC. A portion of the NOM reacts with chlorine to create disinfection by-products (DBPs), regulated drinking water contaminants.

The City of Columbus provided TOC data for its three water plants. TOC values typically range from 3.5 to 13.5 milligrams per liter (mg/L) in study area surface waters. For groundwater sources in the region, TOC concentrations are typically less than 2 mg/L. Raw water TOC concentrations were relatively constant over the past 27 years, with no apparent increasing or decreasing trend.

Rainfall has some impact on TOC concentrations at the DRWP intake but there are many other factors at play including: time of year; status of vegetation in the watershed; reservoir biology; antecedent rainfall; and activities in the watershed such as chemical application. For example, more organic material would be present in the spring and fall that can be carried into area surface waters with stormwater runoff. Substantial rainfall following an extended dry period would convey more organic material to the reservoirs during these times. In comparison, rainfall during the summer months would not convey as much organic material. Substantial rainfall following a recent rain event would be expected to produce much lower TOC concentrations.

More extreme and intense weather is expected in the future because of climate change. Drought and more intense storms are likely to increase the concentration of NOM in runoff, which will translate into higher NOM concentrations in the reservoirs and raw water intakes. More intense storm events following drought will produce higher NOM concentrations from watershed wash-off and in-stream erosion, which will be conveyed through area streams to reservoirs.

Water temperatures are also expected to increase in the future because of climate change. DBP formation increases with increasing temperature (Singer et al. 1992, AWWA 1999). The speciation of TTHMs and haloacetic acids (HAAs) also can shift with increasing temperature. For instance, at 24 degrees Celsius, higher total trihalomethane (TTHM) concentrations are expected, while higher HAA values are expected at temperatures near 3 degrees Celsius (EPA 2003). Chlorine demand may also be greater because of warmer temperatures, and this would require higher doses to maintain chlorine residual in the water distribution system. All of these factors could increase the formation of DBPs in the future, requiring additional organics removal prior to disinfection. Additional treatment would translate into higher operation and maintenance costs.

In addition to the traditional coagulation/settling/filtration processes used for the removal of NOM from surface drinking water sources, Columbus will provide enhanced treatment for the removal of DBP precursors (PAC, ozone, and biofiltration). Other utilities in the region have also made upgrades to their facilities for water quality reasons.

5.5 Herbicides and Pesticides

A majority of the land use in the study area is agricultural, with extensive row crop production. Growers use herbicides and pesticides to control the growth of weeds and to limit insect damage. Herbicide and pesticide data from 1987 through 2013 were obtained for the three reservoirs that serve the City of Columbus (O'Shaughnessy, Griggs, and Hoover) and downstream of Alum Creek Reservoir, which provides drinking water to the cities of Westerville and Columbus and Del-Co Water Company.

Of the herbicides, atrazine was measured most frequently and at the highest concentrations in the reservoirs. Atrazine is normally applied as an herbicide in the spring. Of the four locations, the highest atrazine concentrations were measured in the O'Shaughnessy and Griggs reservoirs, which have very short residence times and receive discharges from a largely agricultural watershed. Based on an analysis of the atrazine concentrations over time, there appears to be a slight decreasing trend. This trend is more pronounced in Hoover Reservoir and downstream of Alum Creek Reservoir than in O'Shaughnessy and Griggs reservoirs.

Elevated atrazine concentrations in the Hoover Reservoir in the 1990s led to a watershed-based approach to reduce concentrations (King et al. 2012). Atrazine concentrations in the Hoover Reservoir commonly exceeded 3 micrograms per liter (µg/L), the drinking water maximum contaminant level (MCL). Due to concerns over increasing atrazine concentrations, a special Environmental Quality Incentives Program (EQIP) was implemented by the Natural Resources Conservation Service (NRCS) in 1999 in the Hoover Reservoir watershed (from passage of the 1996 Farm Bill). EQIP was a voluntary program that provides financial incentives and technical assistance to agricultural producers, through contracts up to a maximum of 10 years in duration, to reduce reservoir atrazine concentrations and maintain concentrations below the drinking water standard. The effect of EQIP in this region is summarized in King et al., 2012.

From 2001 through 2011, the atrazine concentration in the Hoover Reservoir remained below 3 µg/L. This was lower than the atrazine concentrations in the O'Shaughnessy and Griggs reservoirs, which were greater than 3 µg/L during the summer season. EQIP ended in 2009 although Hoover Reservoir atrazine values have remained below 3 µg/L through the end of 2013, demonstrating the effectiveness of the EQIP program.

Atrazine values in 2009, 2010, and 2011 in O'Shaughnessy and Griggs reservoirs are plotted with daily precipitation in Figure 5-4. This time period was selected due to the below average annual precipitation in 2009 and 2010 followed by the near record setting annual precipitation in 2011. The maximum annual atrazine values were observed during a single monitoring event in the late spring or early summer each year following herbicide application and ample rainfall. This peak value is substantially larger than the background concentration during other times of the year. Once the excess atrazine has been flushed from the field and drainage system, no further atrazine spikes were observed even with excessive rainfall in July and August 2011. The rapid concentration increase followed by an equally rapid decline is due to the characteristics of atrazine and the short residence time in these connected reservoirs on the Scioto River. The peak atrazine concentrations in Hoover Reservoir were substantially lower than the peak concentrations in O'Shaughnessy and Griggs reservoirs. The primary reason for the gradual increase and then decline in atrazine concentration is the much longer residence time in Hoover Reservoir.

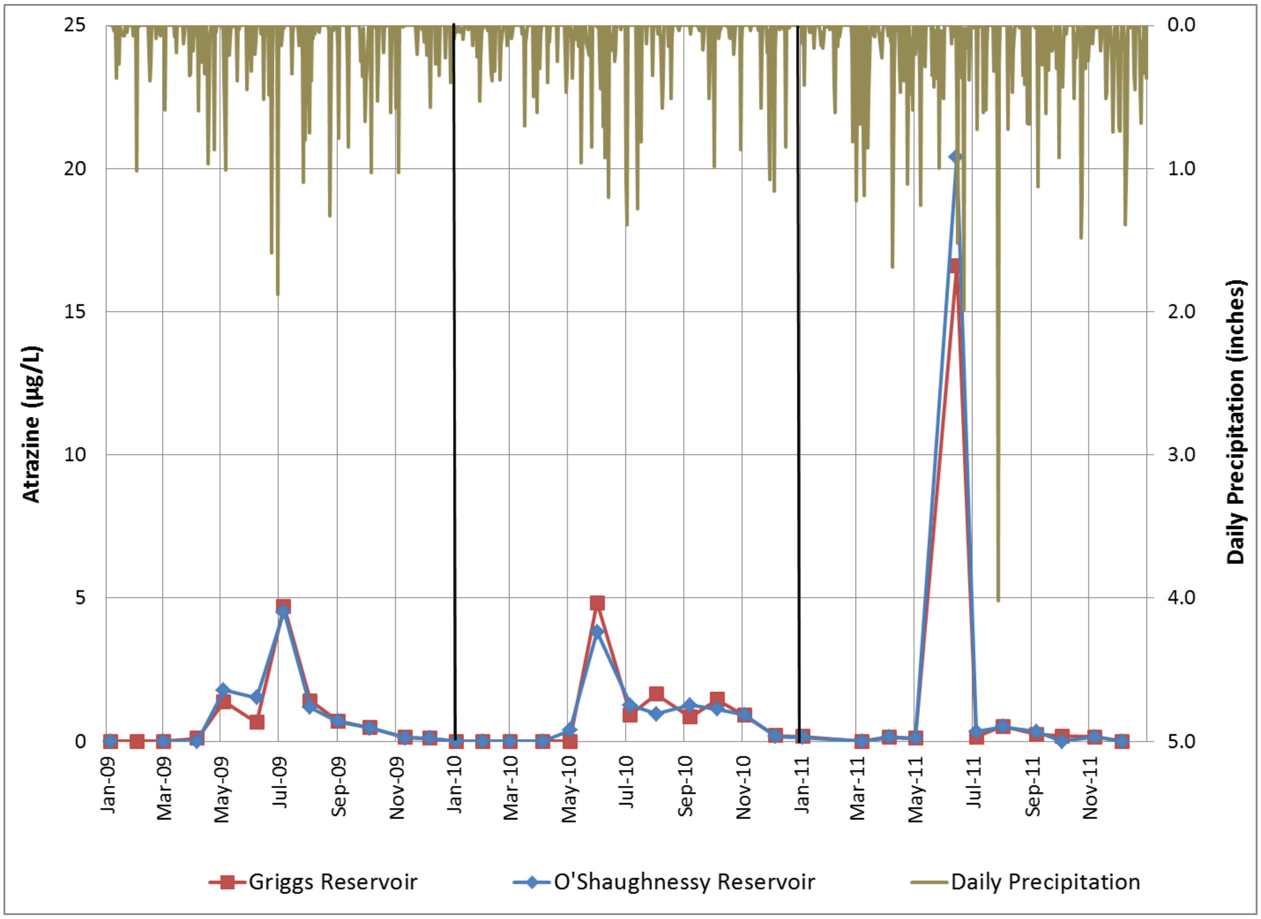

Figure 5-4. Atrazine concentrations and daily precipitation in O'Shaughnessy and Griggs reservoirs in 2009, 2010, and 2011

The concentration of herbicides and pesticides in the study area surface water system is primarily a function of chemical selection, application process, and weather. As temperatures increase in the future, the length of the growing season is expected to increase. Two growing seasons may even be possible for some crops. In addition, weeds and insects can become resistant to chemicals, requiring the use of more or different compounds. These factors are expected to lead to additional herbicide and pesticide application in the watershed in the future.

More intense storm events in the future may also contribute to higher herbicide and pesticide concentrations in stormwater runoff. Higher runoff concentrations would increase reservoir concentrations and require additional treatment at drinking water plants, resulting in higher operation and maintenance costs.

The measured reduction in reservoir atrazine values as a result of EQIP demonstrates the benefit of implementing watershed-based programs. The program not only resulted in much lower atrazine concentrations in the Hoover Reservoir, but it also reduced City drinking water treatment costs by more than $1 million each year. With the potential increase in herbicide and pesticide use in the future, implementation of non-structural practices can help to reduce water treatment costs by reducing surface water pollutant concentrations

5.6 Nutrients (Nitrogen and Phosphorus)

Nutrients are almost always present in natural surface waters and are essential for life. Nutrient enriched surface waters can produce a wide variety of issues including: algae and cyanobacteria blooms; public health and safety concerns; taste and odor issues; and loss of aesthetic and economic value.

The primary sources of nutrients (nitrogen and phosphorus) in the study area include stormwater runoff from urban and agricultural land, groundwater, discharges from home sewage treatment systems (HSTSs), decomposition of organic matter, soil erosion, and atmospheric deposition. The study area is primarily agricultural, which typically produces elevated nitrogen concentrations and loads. The more careful application of fertilizer in recent years may have produced somewhat lower nitrogen loads leaving agricultural lands.

It is important to recognize that surface water nutrient concentrations are a function of: watershed water volume inputs and nutrient loads (external); internal loads (seasonal turnover events, groundwater seepage, sediment nutrient flux); and the assimilative capacity of the surface water. The assimilative capacity is primarily a function of surface area, dimensions, depth, permanent pool volume, biology, and residence time.

Surface water samples were collected and analyzed once or twice per month from each of the four reservoirs in the study area from 1987 through 2013. Reservoir water samples were analyzed for total phosphorus (TP), ortho-phosphate (OP), nitrate-nitrite (NOx), and ammonia (NH3). Plots of the nutrient data from 1987 to 2013 were created and reviewed to identify any apparent increasing or declining concentration trends during this 27-year period. Identifying existing trends may assist in predicting future trends as a result of climate change. Further review of nutrient data for 2010 and 2011 was completed to identify any apparent annual trends and relationships between rainfall and nutrient concentrations, and assist in developing climate change mitigation strategies. 2011 was a very wet year, with 56.9 inches of precipitation; the 29.1 inches of precipitation in 2010 was well below the annual average. All data collected for this project and analyses are included in the Water Quality Assessment TM.

The measured nutrient concentrations in the O'Shaughnessy and Griggs reservoirs are comparable and generally substantially higher (up to an order of magnitude or more for peak values) than Alum Creek and Hoover Reservoir. This difference is primarily a function of the size, volume, and depth of the reservoirs. The Alum Creek and Hoover reservoirs are much larger and capable of diluting and assimilating watershed nutrient loads within the reservoirs. Water quality changes occur more slowly over time in the Alum Creek and Hoover reservoirs. This was observed in the atrazine and TOC data presented earlier in this section. The water quality in these deeper, more stratified reservoirs can be more influenced by longer-term watershed nutrient loads (external loads) and internal nutrient loads including: seasonal turnover events; sediment flux; and groundwater seepage.

Over the period from 1987 through 2013, there are several apparent nutrient trends. TP and OP concentrations are increasing in O'Shaughnessy and Griggs reservoirs. The concentration of TIN appears to be decreasing in all four reservoirs. Both of these trends (increasing TP and OP, and decreasing TIN) are expected to continue in the future because of development in the watershed combined with climate change.

Both nitrogen and phosphorus are necessary for algal growth. It is common to calculate the ratio of total nitrogen to total phosphorus (TN:TP) to determine if algal growth is limited by nitrogen, phosphorus, or both nutrients (balanced or co-limited). This is not true for cyanobacteria which are also called "blue green algae". Cyanobacteria, as discussed in Section 5.5, can fix nitrogen from the atmosphere and therefore have a competitive advantage in lower nitrogen waters. Although algal productivity is normally limited by nitrogen and/or phosphorus, the quantity of algae present can still be substantial including algae and cyanobacteria blooms, and taste and odor issues.

The City of Columbus only measured the inorganic portion (TIN) of TN; therefore TIN was used to calculate the nutrient ratio. Generally, if the TN:TP ratio is less than 10, the surface water is considered nitrogen-limited. A TN:TP ratio between 10 and 30 indicates balanced or co-limitation, and a ratio greater than 30 indicates phosphorus limitation. Other factors, such as color, turbidity, light penetration, and water movement, also affect algae and cyanobacteria growth. One approach to protect or improve surface water quality is to limit the concentration of one or both of the nutrients, thereby controlling algae growth.

For all four locations, but especially Hoover Reservoir and Alum Creek downstream of Alum Creek Reservoir dam, more recent TIN:TP values are generally lower and much less variable. This favors the growth of cyanobacteria. During wet years, reservoir water quality will continue to be more sensitive to phosphorus inputs because of an excess of available nitrogen. During dry years, nitrogen inputs will continue to have a stronger influence on reservoir water quality. The general trend of balanced or nitrogen-limited conditions in the O’Shaughnessy and Griggs reservoirs is expected to continue in the future because of declining TIN concentrations and increasing TP concentrations. The Alum Creek and Hoover reservoirs are expected to continue their trend to balanced or phosphorus limitation. This is a concern because of increasing TP concentrations throughout the watershed.

Because the agricultural land in the study area is not irrigated, substantial water discharges occur only during storm events. As land is converted from agriculture to urban land use in the future, nitrogen concentrations and loads are expected to continue to decrease. This is partially a function of a reduction in groundwater infiltration and stormwater runoff nitrogen concentrations. Phosphorus concentrations and loads are expected to continue to increase because of an increase in stormwater runoff volume from additional impervious areas. Intense storm events can produce runoff with elevated nitrogen and phosphorus concentrations on a short-term basis. This effect would be more evident in the O’Shaughnessy and Griggs reservoirs because of their small water volume compared to the Alum Creek and Hoover reservoirs. Lower TIN:TP ratios in the reservoirs in the future will favor the growth of cyanobacteria. This is a primary concern especially in Alum Creek and Hoover reservoirs.

5.7 Algae and Cyanobacteria

Algae are a very large and diverse group of simple organisms, ranging from single cells to large plants. They are present in almost all freshwater systems and consume available forms of nitrogen and phosphorus. Typically the quantity of algae increases with increasing nitrogen and phosphorus loads. Algae need more nitrogen than phosphorus (ratio of 10:1 to 30:1). Other factors play key roles in the production and quantity of algae present, including predators such as zooplankton, herbicides, water color and turbidity, water movement, and sunlight (energy).

Of primary concern in lakes and reservoirs is the presence of cyanobacteria, aka, “blue-green” algae. These bacteria (not a true alga) can out-compete algae because of their ability to move up in the water column to capture more sunlight. Cyanobacteria can also fix nitrogen from the atmosphere and therefore have a competitive advantage over algae in lower nitrogen waters. Cyanobacteria thrive in warm, slow-moving water with an abundance of nutrients and sunlight. Some species are common in colder surface waters. Blue-green algae are a concern because of their ability to release toxins, which are harmful to aquatic life and humans. Cyanobacteria produce neurotoxins and peptide hepatotoxins, such as microcystin and cyanopeptolin (Tooming-Klunderud 2007). Currently the conditions and timing associated with toxin release is not fully understood. Cyanobacteria are commonly present in surface waters but not actively releasing toxins.

Water samples were collected and analyzed by Columbus from 2002 to 2006 and from 2008 to 2012 for different forms of algae, cyanobacteria, and dinoflagellates at up to seven study area locations. The seven locations include the HCWP intake, Hoover Reservoir Dam, Hoover Reservoir - Red Bank, Hoover Reservoir - Sunbury Road Bridge, DRWP intake, O'Shaughnessy Reservoir and Griggs Reservoir. An analysis of the available data is summarized in the Water Quality Assessment TM.

The reservoir and water intake monitoring results for green algae and cyanobacteria from 2002 to 2006 were compared to the results from 2008 to 2012 to identify apparent trends. Both 5-year periods had very similar precipitation. The total precipitation from 2002 to 2006 was 195 inches, or 39 inches per year. The total precipitation from 2008 to 2012 was 193 inches, or 38.6 inches per year. Both means are very close to the long-term average annual precipitation of approximately 38 inches. No comparison is provided for the Hoover Dam because data were available only from 2010 to 2012.

Between 2008 and 2012, green algae counts at the various monitoring locations ranged from 100 to 10 million organisms per liter (org/L). Green algae counts appear to be increasing over time at all locations. This change is likely in response to the measured increase in TP concentrations and water temperature in all reservoirs. The largest increases are at the O'Shaughnessy and Griggs reservoirs. These reservoirs typically have the highest peak concentrations. The peak green algae concentrations at the Hoover Dam and HCWP intake were generally higher during 2011, a very wet year, compared to 2010, a dry year. Conversely, the peak green algae counts in Griggs Reservoir were higher during 2010. This is likely a function of the size of the reservoir. The large flow of water is flushing Griggs Reservoir while simply adding additional load to Hoover Reservoir. The data generally showed the highest green algae counts in May and the lowest values in January.

Between 2008 and 2012, cyanobacteria counts ranged from 100 to 800,000 org/L at the two water plant intake monitoring locations. The concentration of cyanobacteria is increasing substantially at the HCWP intake on Big Walnut Creek while decreasing at the DRWP intake.. In recent years, the highest peak concentrations are typically measured at the Hoover Dam and can be up to two orders of magnitude higher than values in Griggs Reservoir. One possible explanation is the phosphorus limitation in the Hoover and Alum Creek reservoirs and the possible increasing TP concentration in combination with the longer residence time in Hoover Reservoir.

5.8 Microcystin

Columbus sampled and analyzed several water samples in 2009, 2011, 2012, 2013, and 2014 for microcystin, a toxin released by cyanobacteria. Sampling locations included the HCWP intake, HCWP finished water, and the Hoover Reservoir. In 1998, the World Health Organization (WHO) released a provisional drinking water guideline of 1 µg/L for microcystin, but for no other toxins (WHO 1998). In June of 2014 Ohio Environmental Protection Agency (Ohio EPA) issued the draft Public Water System Harmful Algal Bloom Response Strategy to protect people from toxins produced by cyanobacteria that may be in drinking water sources at concentrations that can affect human health. The strategy identifies toxin levels of concern that will be used to make advisory decisions. Sampling targets four toxins that may be present at levels of concern and compare them to threshold criteria established by the State of Ohio (state reporting limit of 0.3 µg/L).

A summary of the microcystin monitoring results include:

- In 2009, all 12 water samples were below the Ohio EPA reporting limit of 0.3 µg/L with one exception.
- In 2011, one Hoover Reservoir value from July 13 was 0.37 µg/L. The other eight values in 2011 were below the reporting limit.

- All three values in 2012 were below the reporting limit.
- In 2013, 22 water samples were analyzed. Five Hoover Reservoir water samples collected in July and August, ranging from 0.35 µg/L to 0.96 µg/L, exceeded the reporting limit.
- In 2014, 13 water samples were collected from the Hoover Reservoir. Between July 28 and September 29, all nine samples exceeded the reporting limit with values from 0.34 µg/L to 1.97 µg/L. Two of the HCWP intake samples slightly exceeded the reporting limit, with values of 0.35 µg/L and 0.46 µg/L in September.
- In the past two years (2013 and 2014), the region has experienced higher measurements of microcystin than observed in 2009, 2011, and 2012.

5.9 Taste and Odor Complaints

Taste and odor (T&O) complaints can stem from biological or chemical causes. Conditions in source water, during treatment, or in distribution systems can result in T&O complaints. The presence of salts and metals can produce undesirable flavors. Green algae can create a grassy or fishy odor. Blue-green algae in surface supplies produce compounds that cause earthy/musty odors. DBPs can cause off-flavors. Ammonia can produce a “chemical” taste. Some consumers are much more sensitive to T&O issues than others.

Historical customer T&O complaints from 1977 to 2013 for the city of Columbus are provided in the Water Quality Assessment TM. T&O complaints at the two surface water plants (DRWP and HCWP) typically ranged from 50 to 150 per year. From reviewing the historical T&O complaint data, two noteworthy spikes were observed by City of Columbus staff. More than 1,100 customers complained about T&O in 1998. In 2013, there was a spike of over 1,600 T&O complaints. The HCWP service area had the highest number of complaints.

There are a wide variety of potential T&O sources in drinking water. Based on historical complaint information and climate change scenarios, it is difficult to predict future changes in T&O issues. In 2013, the sampling showed elevated ammonia concentrations in the Hoover Reservoir. No other available water quality parameters were outside the range of typical values in the Hoover Reservoir in 1998 or 2013; however, algal concentrations are unavailable for either of these years.

As discussed in Section 5.5, green and blue-green algae concentrations in the Hoover Reservoir are expected to increase in the future because of elevated temperatures and increased nutrient runoff. There are also potential increases in turbidity and TOC. All of these parameters could create additional T&O complaints.

In the future, surface water plants in the region may need to utilize additional treatment processes at the water plants to reduce complaint numbers. The enhanced treatment processes (PAC and ozone) added by Columbus are effective for removing many of the taste and odor sources from drinking water surface sources. Operation and maintenance costs may increase in the future due to additional use of these enhanced processes.

5.10 Existing Surface Water Quality Impairments

Griggs Reservoir and O’Shaughnessy Reservoir

In 2012 Ohio EPA published Technical Report EAS/2012-12-12, *Biological and Water Quality Study of the Middle Scioto River and Select Tributaries, 2010.* This report describes water quality impairments in the middle Scioto River basin related to nutrients, organics, and bacteria. Enrichment sources include combined sewer overflows, home sewage treatment systems, yard maintenance, livestock, and agriculture. The report includes monitoring data and proposed Lake Habitat Aquatic Life Criteria for the O'Shaughnessy and Griggs reservoirs.

Table 5-1 summarizes the Lake Habitat Aquatic Life Criteria and the median values reported for O'Shaughnessy and Griggs Reservoirs from the Ohio EPA report (Ohio EPA 2012). The median values from May through October in 2010 in the epilimnion of stratified lakes and throughout the water column in unstratified lakes, as measured by Ohio EPA, are provided in Table 4-1 (Ohio EPA 2012).

Table 5-1. Evaluation of Lake Habitat Aquatic Life Criteria and O'Shaughnessy and Griggs Reservoir Median Levels

Parameter	Lake Aquatic Life Criteria	O'Shaughnessy Reservoir Median Values	Griggs Reservoir Median Values
Total nitrogen	930 µg/L	3,760 µg/L	3,052 µg/L
Total phosphorus	34 µg/L	57 µg/L	92 µg/L
Chlorophyll-a	14 µg/L	52 µg/L	50.6 µg/L
Dissolved oxygen	6.0 mg/L	< 6.0 mg/L for 2 of 11 events	< 6.0 mg/L for 4 of 11 events

Median values were measured from May through October in 2010 by Ohio EPA in the epilimnion of stratified lakes and throughout the water column of unstratified lakes.

The measured O'Shaughnessy and Griggs reservoir TN, TP, chlorophyll-a, and dissolved oxygen (DO) concentrations are in excess of Ohio EPA's Lake Habitat Aquatic Life Criteria. The nutrient monitoring results discussed in Section 5.4 include similar or even higher concentrations also exceeding the reservoir criteria. Elevated water turbidity and color may have contributed to lower-than-expected algal growth. In fact, based on the measured nutrient concentrations, algae and chlorophyll-a concentrations are expected to be higher than reported. The water color and turbidity in surface waters throughout the region appear to be suppressing algal growth to some extent.

Hoover Reservoir and Alum Creek Reservoir

In 2005, Ohio EPA published the Final Total Maximum Daily Load (TMDL) for the Big Walnut Creek watershed, which includes the Alum Creek watershed and both the Hoover and Alum Creek reservoirs. The TMDL describes widespread impairments due to flow alteration, habitat alteration, siltation, nutrients, pathogens, and organic enrichment. The primary causes include crop production, channelization, range land, and home sewage treatment systems. More than half of the watershed land use is in agriculture, primarily row crop.

Although the TMDL includes no specific nutrient load reduction requirements for the Hoover and Alum Creek reservoirs, TP and fecal coliform load reductions are specified throughout the watershed. TP load reductions up to 65 percent are specified for the main stem of Big Walnut Creek. Fecal coliform load reductions of 91 percent are specified in the TMDL. The recorded TP concentrations for the Hoover and Alum Creek reservoirs are substantially less than those for the Griggs and O'Shaughnessy reservoirs, but are still indicative of biologically productive systems as described in the following section.

5.11 Reservoir Trophic State

Lakes and reservoirs can be classified into one of the four following primary productivity categories: oligotrophic (very low algal concentrations, very clear water); mesotrophic (moderate algal concentrations, moderate water clarity); eutrophic (high algal concentrations, poor water clarity); and hypereutrophic (excess algal concentrations, very poor water clarity). A summary of TSI categories and typical corresponding Secchi disk depths, and chlorophyll-a and TP concentrations, are provided in Table 5-2.

Table 5-2. Summary of Lake Trophic Conditions and Water Quality Characteristics

Lake Trophic Condition	Carlson TSI	Secchi Disk Depth (ft)	Chlorophyll-a (μg/L)	TP (μg/L)
Oligotrophic	< 38	> 15	< 2.2	< 10
Mesotrophic	38–48	7.5–15	2.2–6	10–20
Eutrophic	49–61	3–7.4	6.1–22	20.1–50
Hypereutrophic	> 61	< 3	> 22	> 50

From 2010 through 2012, TP concentrations in the Griggs and O'Shaughnessy reservoirs consistently exceeded 50 μg/L. Based on the TP values listed in Table 5-2, both reservoirs are presently hypereutrophic year-round. This finding indicates that the O'Shaughnessy and Griggs reservoirs are highly productive and susceptible to algae and cyanobacteria blooms and toxin release.

The TP concentrations in the Hoover and Alum Creek reservoirs throughout the year are not known because of the TP laboratory detection limit. Since 2002, the detection limit for TP has been 0.05 mg/L. The TP concentrations in both reservoirs were above 0.05 mg/L during at least several months in 2011 and 2012. The TP concentration for the other months is not known.

Based on the TP values listed in Table 5-2, the Hoover Reservoir is eutrophic for at least half the year and likely mesotrophic during the remaining months. The Alum Creek Reservoir is likely mesotrophic for much of the year with periodic eutrophic conditions. It is advisable to reduce the TP laboratory method detection limit to 0.01 mg/L. This would allow for the proper tracking of TP concentrations in the Hoover and Alum Creek reservoirs.

There are documented nutrient-related water quality impairments below the Hoover Dam in Big Walnut Creek as summarized in the final TMDL for Big Walnut Creek. In addition, the Columbus data shows elevated algae and cyanobacteria counts in the Hoover Reservoir, as summarized in Section 5.5.

With higher temperatures and more extreme weather likely in the future due to climate change in combination with additional development, TP and chlorophyll-a concentrations are expected to increase. Without improvements in current practices these changes will produce a corresponding increase in trophic state in area reservoirs and declining water quality. The reservoirs will be more prone to algae and cyanobacteria blooms and the release of toxins.

5.12 Predicted Future Water Quality

Two primary factors will influence future surface water quality within the study area: changes in climate and watershed land use. The main climate change issues are increasing temperatures and more extreme and intense weather. Warmer air temperatures will produce warmer water temperatures. Algae and cyanobacteria thrive in warmer water with abundant nutrients. More extreme weather likely translates into longer periods of drought when vegetation will be diminished or lost. More intense storm events following drought will produce large turbidity, organic, and nutrient loads from watershed wash-off and in-stream erosion, which will be conveyed through area streams to reservoirs. These changes will likely increase organic and nutrient loads to area streams and reservoirs, decrease DO concentrations, increase algae and cyanobacteria blooms and generally degrade surface water quality.

The study area is largely undeveloped or currently used for agriculture. Some land uses will change into residential, commercial, and industrial properties. Development is expected to increase phosphorus loads to area streams and reservoirs in the future because of increases in stormwater runoff volume, wastewater effluent discharges, and home sewage treatment system discharges.

Pathogens are another pollutant of concern in the study area. Although not a concern related to drinking water because of disinfection, elevated pathogen concentrations in reservoirs are a concern because of their potential impact on aquatic life and human health. Pathogens were not evaluated as part of this study, but they are included in the Big Walnut Creek TMDL. Ohio EPA discussed them in the Middle Scioto River basin study. If current practices continue, pathogen concentrations are expected to increase because of rising temperatures and additional stormwater runoff and home sewage treatment system discharges from development.

Based on the analysis of existing water quality data and the anticipated effects from climate change and development, the following long-term trends are probable in the study area:

- Increase in turbidity
- Elevated peak herbicide concentrations
- Increase in organics concentrations and DPB formation potential
- Increase in TP concentrations
- Decrease in TIN concentrations
- Increase in pathogens
- Decrease in DO concentrations
- More frequent and intense algae and cyanobacteria blooms
- More taste and odor and toxin issues

As described in Section 5.5, there is an apparent trend to lower cyanobacteria densities in the Griggs and O'Shaughnessy reservoirs. Because of the uncertainties associated with both cyanobacteria growth and climate change, it is difficult to predict future trends. These reservoirs are considered hypereutrophic; highly productive surface waters are prone to cyanobacteria growth. Whether or not cyanobacteria densities increase in the future, it is likely that the O'Shaughnessy and Griggs reservoirs will experience periodic cyanobacteria blooms and toxin release. It is possible that such blooms will be more frequent and intense.

Because of the documented existing water quality impairments and anticipated future trends, strategies should be implemented in the watershed to reduce organic, nutrient, and pathogen loads to streams and reservoirs. The primary sources of pollutants in the watershed include: stormwater runoff from urban and agricultural land; discharges from wastewater treatment facilities and home sewage treatment systems; groundwater; decomposition of organic matter; and soil erosion. Both structural and non-structural practices should be included in the watershed to protect and improve water quality and maintain reservoir volume.

Further assessment of reservoir sediment accumulation and internal nutrient loads should be completed to fully understand changes in reservoir storage volume and magnitude of all nutrient sources. Internal sources include: seasonal turnover events; groundwater seepage; and sediment nutrient flux. The significance of reservoir internal nutrient sources is unknown at this time. Once understood, strategies should be implemented to reduce internal nutrient sources and maintain reservoir storage volume.

Reservoir operational changes should be considered to help reduce reservoir pollutant, algae, and cyanobacteria concentrations. In recent years, the Hoover and Alum Creek reservoirs have experienced the highest cyanobacteria densities and are the immediate concern.

In recent years, the Hoover and Alum Creek reservoirs are experiencing the highest cyanobacteria densities and are the immediate concern.

Based solely on the current regional surface water quality conditions, watershed pollutant load reductions and reservoir operational strategies are warranted now.

It is important to reinforce that, based solely on the current regional surface water quality conditions summarized in this section, watershed pollutant load reductions and reservoir operational strategies are warranted now. Adopting such changes is independent of the future water quality impacts as a result of climate change. The implementation of pollutant load reduction and operational strategies should reduce the potential for drinking water T&O issues and harmful algal blooms, and protect aquatic life and human health.

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Section 6

Vulnerability Assessment

This section discusses the vulnerabilities identified within the region related to climate change. The information in this section is an overview of the results from the analysis; more detailed results can be found in the Vulnerability Assessment Technical Memorandum (Brown and Caldwell 2014c). The vulnerabilities were identified based on an evaluation of the GCM data and the watershed modeling results provided by the USGS. The potential impacts from changes in temperature, precipitation, and stream flow were assessed and prioritized within nine service sectors (listed in Table 6-1) based on the likelihood of occurrence and the severity of the impact.

Table 6-1. Nine Service Sectors

Water supply/water quality	Wastewater treatment
Water treatment	Economy
Environment	Energy
Public health	Transportation
Agriculture	

The identification and prioritization of vulnerabilities, or risks, is essential for the development of an Adaptive Management Plan for the region. The first step is the evaluation of the predicted regional changes and corresponding challenges. The USGS modeling results provide the basis for projection of potential changes both to climate and stream flow conditions. The results incorporate climate change projections with other expected regional changes, including population growth and land development. The next step is the prioritization of vulnerabilities through evaluation of how the predicted changes may impact the livability of the region.

The potential vulnerabilities were identified and prioritized based on the USGS climate and watershed modeling results for the Upper Scioto River basin, literature review from national and regional sources, and input from the SAC.

6.1 Watershed Model

The information in this section summarizes the methods and results of the USGS climate projection modeling and the associated hydrologic impacts due to projected changes in climate, water use, and land cover through 2090 in the Upper Scioto River basin. A complete description of the USGS model results is presented in the *Hydrological Effects of Potential Changes in Climate, Water Use, and Land Cover in the Upper Scioto River Basin, Ohio* (USGS 2015).

The USGS used the Hydrological Simulation Program-FORTRAN (HSPF) precipitation-runoff model to simulate the effects of climate change on stream flow and reservoir water levels at selected locations throughout the Upper Scioto River watershed (USGS 2015). The HSPF watershed model simulates the complex river-basin management and reservoir operations of the Scioto River watershed, including operation of the numerous regulated reservoirs.

Two future-conditions scenarios were simulated in the HSPF model of the basin. The first scenario, referred to as "climate-only," includes expected changes in climate and the future operations of three City of Columbus upground reservoirs. The second, more complicated scenario, referred to as "buildout," incorporates future population growth and development-driven changes in land cover and water use in addition to the changes in climate and future reservoir operations.

6.1.1 Watershed Model Data

Multiple types of data were used as input to the HSPF model. Historical and projected climate data were necessary to model the projected changes in climate to the year 2090. Water use and land development data were used to model the potential changes in water use in the region based on development in accordance with current zoning and plans. The types of data used in the development of the USGS model are summarized below.

6.1.2 Climate Data

Two types of climate data, historical and future with predicted climate changes, were used to develop the HSPF watershed model. Historical data were used to calibrate the model and establish baselines within the watershed over the 20-year period from 1989 to 2010.

Future predicted climate data were developed from four data sets from the GCM (source: World Climate Research Programme's Coupled Model Intercomparison Project phase 3 multi-model data set). Each of the data sets has a high carbon emission scenario and a medium carbon emission scenario; eight total data sets were used to develop predicted future-conditions model results due to climate change.

6.1.3 Water-Use Data

Water use data for the model were obtained in the form of monthly surface water withdrawals, return flows (wastewater discharges), and future changes in selected water uses as detailed in Section 3. Monthly surface water withdrawal information for the period 1990–2010 was obtained from the Ohio Department of Natural Resources (ODNR) Water Withdrawal Facilities Registration Program (WWFRP) for public water supplies, agricultural/commercial/industrial users, and golf courses. Data on return flows were obtained from two sources, the ODNR WWFRP and the National Pollutant Discharge Elimination System (NPDES) permits from Ohio EPA. Only data for wastewater treatment facilities designated as major facilities (design flow of 1 million gallons per day [mgd] or greater or facilities with EPA/State-approved industrial pretreatment programs) were considered.

Future changes in selected water uses were considered for withdrawals and return flows associated with development (buildout) for major water suppliers and wastewater treatment facilities. While there may also be changes in withdrawals for irrigation and certain industrial activities because of climate change, these water uses were held constant because of uncertainty related to these changes.

6.1.4 Land-Cover Data

Land-cover data were used along with other data (such as soil types and ground surface elevation data) in the HSPF watershed model to help divide the watershed into subwatersheds. Land-cover data were also used to model hydrologic processes within the watershed such as infiltration, evapotranspiration, and stormwater runoff. The 2006 National Land Cover Database (Fry et al. 2011) was used as the basis for determining land cover for the calibration period from 1989 to 2010.

Predicted future changes in land use for 2035–90 were provided by MORPC. MORPC created these data by translating future land use plans from local communities into GIS data sets. These changes were applied to different time periods based on linear interpolation of the rate of development to the year 2090. Land use data were computed to reflect the future development conditions for the target dates of 2035 and 2090. With the exception of the Little Scioto River basin, most of the development is anticipated to occur in the southern two-thirds of the Upper Scioto River basin, primarily development of agricultural land to urban cover.

6.1.5 Climate Model Results

The annual average precipitation and temperature model results are shown in Figures 6-1 and 6-2. The calibration period is shown at the beginning of the figures. The shaded areas denote the historical range for precipitation and temperature for the Upper Scioto River basin. The historical average precipitation and temperature is also shown on the graphs for reference. It is important to note that each of the model results has an equal likelihood of occurrence. No model result is more correct or more likely than another. The purpose of the climate and watershed modeling is to determine the range of possibilities in order to facilitate the identification of potential vulnerabilities within the watershed.

The predicted annual average precipitation data are shown on Figure 6-1. Although it is not possible to identify a clear trend in the projected future precipitation, there does appear to be an overall increase in total precipitation as compared to the calibration period (USGS 2015). Six of the climate models predict higher annual average precipitation in the future, while two of the models predict lower future precipitation (Section 4). The predicted average annual temperatures are shown on Figure 6-2. All of the climate models predict a substantial increase in the future average annual temperature.

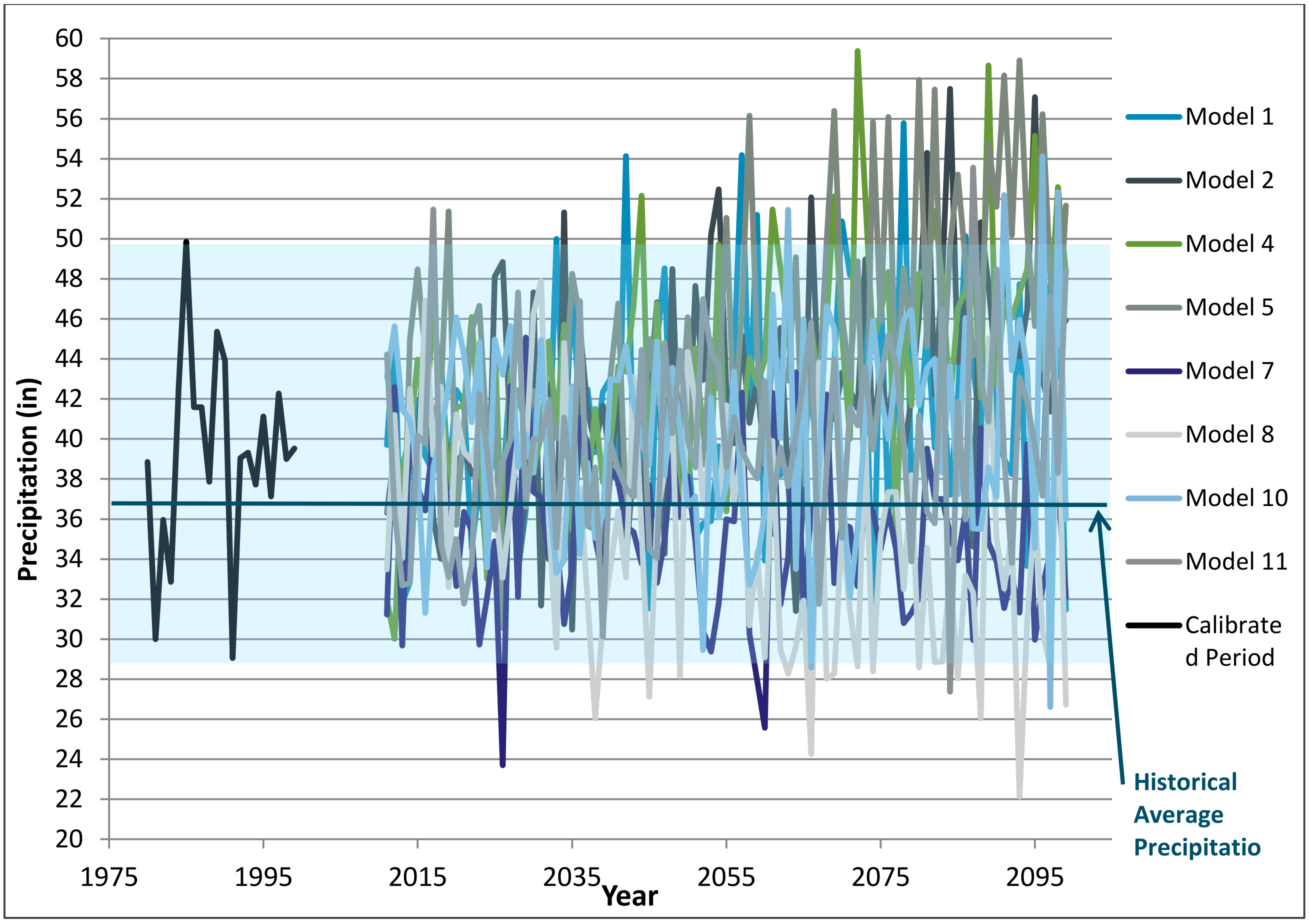

Figure 6-1. Climate model annual average precipitation for the Upper Scioto River basin

Source: Modified from USGS 2015

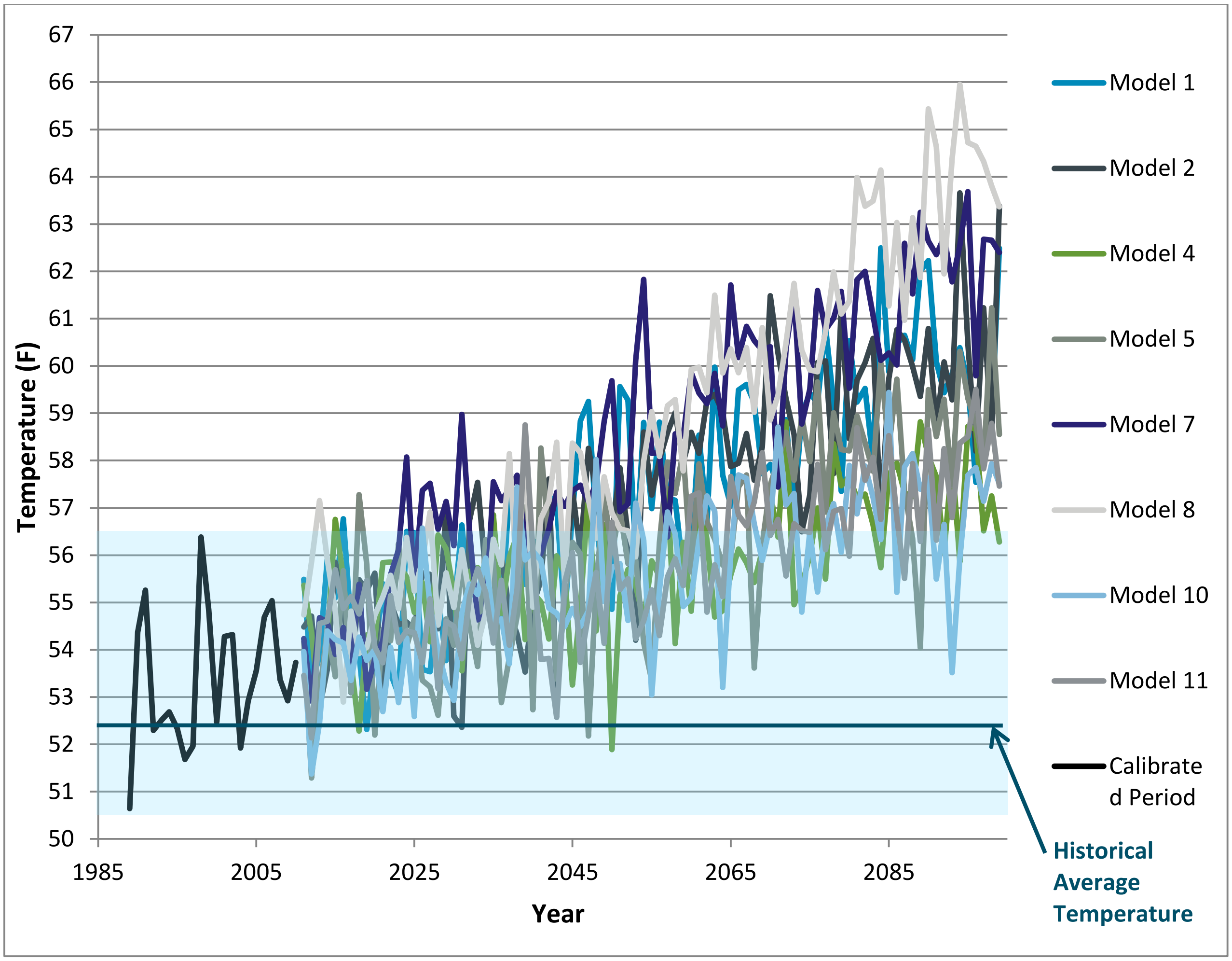

Figure 6-2. Climate model annual average temperature for the Upper Scioto River basin

Source: Modified from USGS 2015

6.1.6 Watershed Model Results

The watershed model results reflect the potential impacts of climate change on the stream flow and reservoir levels throughout the watershed. The results should be considered as potential future conditions based on current climate projections, not as statements of definite future conditions. USGS prepared data plots for the seasonal analysis of the average 7- and 30-day minimum and maximum stream flows and reservoir water levels for both the climate-only and buildout scenarios.

The USGS Final Report and Brown and Caldwell's TM3 on the Vulnerability Assessments include detailed descriptions as well as plots of the stream flow and reservoir level projections throughout the Scioto River basin. The following stream sites were selected for discussion in this Plan to provide an overview of projected changes throughout the Upper Scioto River watershed:

- Little Scioto Reach with Marion Public Water Supply (headwaters)
- Olentangy River at Del-Co intake (center of watershed on Olentangy River)
- Scioto River at Columbus (center of the watershed, downstream of confluence with Olentangy)
- Scioto River at Circleville (downstream end of project)

The three reservoirs also discussed in this section include:

- Hoover Reservoir

- O’Shaughnessy Reservoir
- Griggs Reservoir

These site locations are shown on a map of the Upper Scioto River basin on Figure 6-3. Graphical plots of results for these sites are provided in Appendix B.

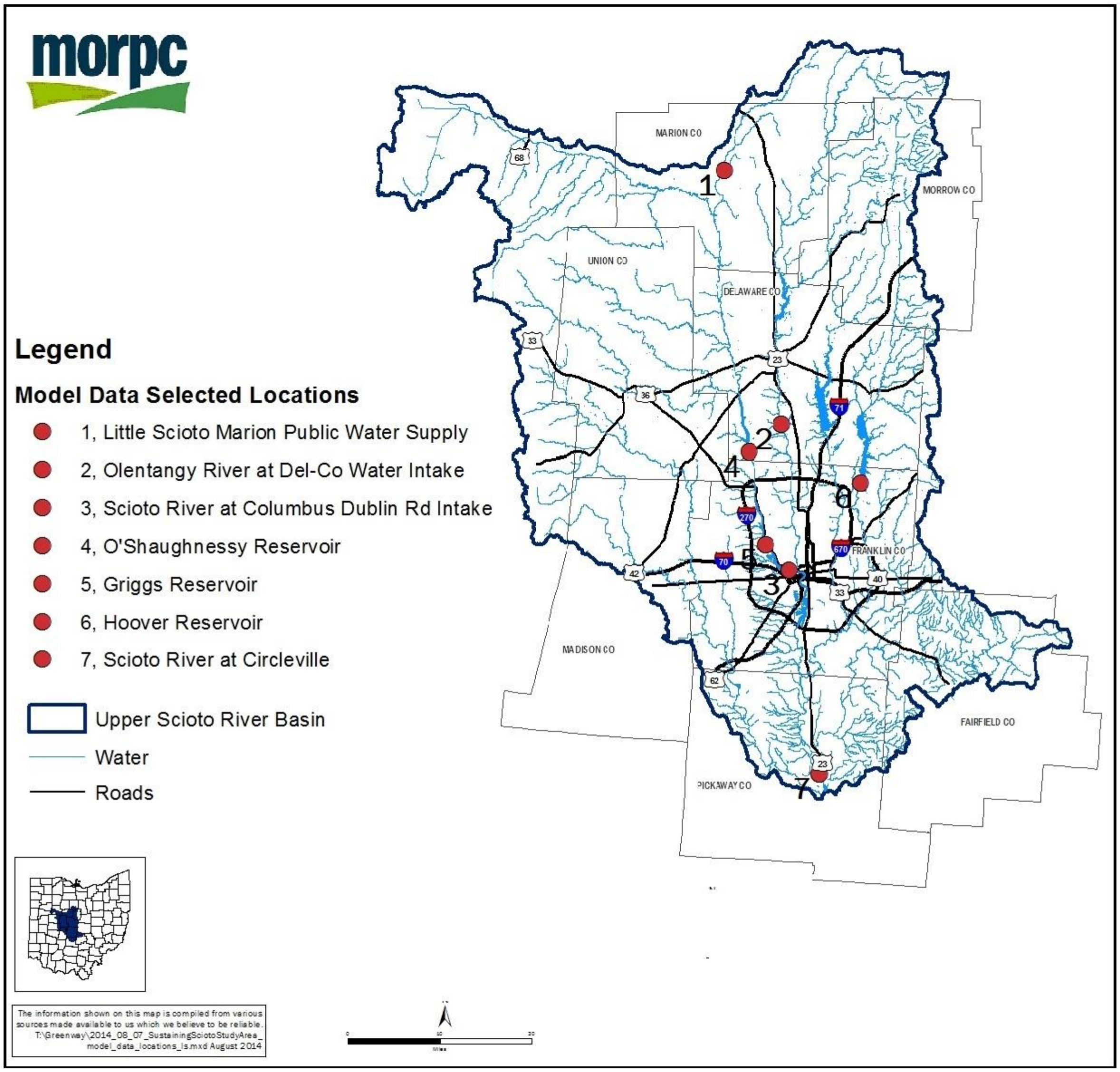

Figure 6-3. Upper Scioto River basin selected sites for discussion

Source: Modified from MORPC

The model results were compared to the average stream flow or reservoir level during the calibration period of 1989–2010. This comparison to the calibration period can be considered a comparison to “what we know now” as far as typical flow or water surface elevation conditions. In general, the model results indicate both higher maximum flows and water surface elevations, especially on the 7-day or weekly average basis and also lower minimum flows, especially on the 30-day or monthly. These results suggest a trend to longer periods with low flow and also more extreme high flow events. An increase in high flow events in the spring with increased drought in the summer are consistent with the predicted climate changes for the Midwest presented in the *Adaptation Strategies Guide for Water Utilities* (EPA, 2012a), *Climate Change Impacts in the United States* (Melillo et al., 2014), and U.S. Army Corps of Engineers *Study of Climate Change Impacts of the Ohio River Basin* (Nolan, 2014 – personal communication).

The model results indicate both higher maximum flows and water surface elevations, especially on the 7-day or weekly average basis and also lower minimum flows, especially on the 30-day or monthly basis. These results suggest a trend to longer periods with low flow and also more extreme high flow events.

In the spring and summer, greater than average stream flows were reflected in the results with higher peak maximum flows over both weekly and monthly time periods. During this same seasonal period, the model indicated decreased minimum stream flows over both weekly and monthly time periods, suggesting longer periods of dry weather. The more extreme and variable stream flows are consistent with the predicted increased variability of precipitation and increased air temperature from climate projections during the development of the watershed model. The impact of land development varied depending on the location of the site and type of development. Buildout could increase flows because of both increased runoff and increased wastewater generation. Development could also result in lower flows and reservoir levels because of increased water usage.

The Little Scioto River reach associated with the Marion Public Water Supply is located at the top of the Upper Scioto River watershed. Stream flow at this location often drops to very low levels because of the relatively small drainage area. In the climate-only simulations, the models predict lower minimum flows than the calibration period during spring, especially over a weekly time scale (7-day mean). During this same season, somewhat higher maximum flows are also predicted on a weekly basis. This again reflects the trend toward greater variability in stream flow than is currently typical for this location. During the climate-only simulations, higher maximum flows and slightly lower minimum flows were again projected in the summer season. During the fall/winter, higher maximum flows are projected, while the minimum flow remains close to low flows during the calibration period. The buildout simulations for this headwater location clearly reflect the impact of increased runoff and increased discharge of wastewater associated with development. The buildout models reflect somewhat higher maximum and minimum flows throughout each season.

The Olentangy River at the Del-Co upground water reservoirs intake and WTP is located slightly north of center in the Upper Scioto River watershed. There is a minimum flow requirement at this site of 35 cubic feet per second (cfs), limiting pumping to the Del-Co reservoirs only when flow is above this level. The climate-only model simulations again project higher maximum flows and lower minimum flows than the calibration period at this site for both spring and summer. It is important to note that the models indicate increased time periods in the spring (30-day mean and 7-day mean flow) where the flow will be below the 35 cfs cutoff for use by Del-Co. This may be significant to Del-Co as this is a time period when the reservoirs are typically being recharged. During summer, low flows in the river are already below this cutoff level. Del-Co is unable to recharge its reservoirs and must use reservoir storage to meet summer water demand. In the buildout scenarios, the models indicate that minimum flows during spring and summer may drop to zero cfs with the added demand for water supply at this location. These simulations indicate that with the projected changes in stream flow reliability associated with climate change and the increased water usage, additional reservoir storage may be needed to maintain adequate water supply.

The Scioto River at Columbus is located in the lower-central portion of the watershed, downstream of the confluence with the Olentangy River. Slightly lower minimum monthly average stream flows were reflected in the climate-only simulations in the spring, while slightly higher maximum flows were reflected in both weekly and monthly means for the summer season. During fall/winter, both higher 7-day maximum flows and lower 30- and 7-day minimum flows are predicted. This indicates a trend toward longer periods of dry weather with additional short-duration high flow events (storms). Buildout does not have as significant an impact at this location. The buildout model results indicate somewhat higher minimum stream flows for the 30-day period and slightly higher maximum flows for the 7-day period for all seasons. The increase in stream flows with buildout is likely attributable to the increased runoff because of development in the watershed and increased generation of wastewater exceeding the additional drinking water demand.

The Scioto River at Circleville is located at the bottom of the watershed. Similar trends are noted for both the summer and spring seasons in the climate-only simulations with higher maximum stream flows, especially during the shorter-duration periods (7-day mean) and lower minimum flows (both 30- and 7-day). The simulations with buildout development reflect increased monthly and weekly mean low stream flows in all seasons, most likely because of increased runoff and generation of wastewater greater than the increase in drinking water demand.

The Hoover Reservoir is located in the central-eastern part of the watershed. Water is released from this reservoir to meet the water demand at the HCWP for the City of Columbus. When the reservoir level drops below 80 percent capacity (elevation [El] 889), the City pumps additional supply from the Alum Creek Reservoir to the Hoover Reservoir. This existing water transfer was simulated in the watershed model. In the climate-only simulations, the Hoover Reservoir water surface elevations are not significantly different from the calibration period. However, with full buildout development, minimum water levels in the reservoir drop to or close to zero capacity (El 840) during all seasons. These extremely low water levels are projected for both the 30- and 7-day means, indicating that additional storage, supply, or operational modifications (i.e. shifting demand to another City of Columbus water plant) may be needed to meet the projected future demand at the HCWP.

The O’Shaughnessy and Griggs reservoirs are both located in the central portion of the watershed on the Scioto River. Scioto River water flows south through the O’Shaughnessy Reservoir into the Griggs Reservoir. The intake for the City of Columbus DRWP is downstream of the Griggs Reservoir. Both of these reservoirs have fairly small water storage volumes relative to the drainage area, making them flow-through reservoirs rather than long-term storage reservoirs. The City’s new upground reservoir and two planned upground reservoirs will provide off-stream storage of water from the Scioto River to augment the supply in the O’Shaughnessy and Griggs reservoirs. The watershed model includes water storage and release from the upground reservoirs to maintain reservoir water levels and meet the demand at this location.

At the O’Shaughnessy Reservoir, the climate-only simulations indicate slightly lower minimum water levels during both spring and summer. With buildout development, water levels are projected to be higher than the calibration period for all seasons. This is likely related to the net increase in water availability due to the projected shift to groundwater supply with increased wastewater discharge to the river at the city of Marysville, just upstream of this reservoir. The predicted trends at the downstream Griggs Reservoir are very similar to those at the O’Shaughnessy Reservoir.

6.2 Vulnerability Assessment

The predicted changes due to temperature, precipitation, water use, water quality, and buildout data reflected in the model simulations would all impact the region. These predicted changes pose challenges and risks to the region as summarized in Table 6-2. The associated vulnerabilities were developed by analyzing the data and model simulation results in conjunction with performing a review of Midwestern-specific climate change literature (EPA, 2012a; Melillo et al., 2014). The vulnerabilities associated with each predicted climate and watershed change were then refined in stakeholder meetings as presented in Section 2.

Table 6-2. Summary of Predicted Changes Reflected in Climate and Watershed Model Results

Predicted Change in Climate	Challenges due to Predicted Changes in:		
	Temperature	Precipitation	Flow / Levels
Increased summer air temperatures/increased incidence of heat waves	●		
Increased water temperature	●		
Warmer soil temperatures/decreased soil moisture	●	●	
Increased winter temperature and reduced ice cover	●		
Change in vegetation/animal species composition	●	●	
Higher maximum sustained stream flows (30- and 7-day higher maximum stream flows)		●	●
Extended dry periods/summer drought (decreased minimum 30-day stream flow)	●	●	●
Increased intensity of extreme rain and wind events	●	●	●

6.2.1 Vulnerability Prioritization

The results of the climate change and watershed modeling indicate the potential for the following changes in the Upper Scioto River watershed through the end of the century:

- Increase in the mean annual air temperature (model predictions ranged from 53.5 to 66°F by 2090)
- Increase in the variability of precipitation with a slight overall increase in mean annual precipitation
- Increase in the variability of stream flow, including higher maximum flows and lower minimum flows
- Longer durations of extended minimum stream flows and reservoir water levels

While the modeling results indicate significant Long Term changes in climate, temperature conditions are predicted to rise above the current range of variability after 2025 while precipitation conditions appear to stay within the current range of variability through 2045. Beyond 2045, the model results indicate that the region will experience higher temperatures as well as greater variability in maximum and minimum stream flows and overall precipitation.

Key vulnerabilities for each of the predicted climate and stream flow changes were defined for each service sector. The risks were prioritized based on likelihood and impact, with the most significant risks associated with a change that is likely to occur and having a significant impact. For likelihood of occurrence, the predicted changes were given a ranking of High, Medium, or Low based on the potential to occur. The specific risks were then assigned a ranking of High, Medium, or Low based on the expected impact on the region.

The likelihood rankings assigned to the vulnerability scenarios are summarized in Table 6-3. Those that were highly likely to occur were linked to clear trends from the model results and climate data. Examples include those caused by increases in temperature, more extreme variability in precipitation, and decreases in minimum stream flow or reservoir water levels as observed in the model results. These risks were assigned a ranking of "High" and shaded red in Table 6-3. Vulnerabilities were categorized as "Medium" and shaded yellow if linked to results that were shown in the models, but with more uncertainty, such as those associated with buildout or increased intensity of rain and wind events. A "Low" score was assigned to changes that were not directly predicted by the model results and were considered less likely to occur based on the analysis. Low-risk vulnerabilities are shaded green in Table 6-3.

Table 6-3. Summary of Prioritized Vulnerabilities

No.	Predicted Change	Priority Based on Likelihood of Occurrence
1	Increased summer air temperatures/increased incidence of heat waves	High
2	Increased water temperature	High
3	Warmer soil temperatures/decreased soil moisture	High
4	Increased winter temperature and reduced ice cover	High
5	Higher sustained maximum flow (30- and 7-day higher peak river flows)	Medium
6	Extended dry periods/summer drought (decreased minimum 30-day stream flow)	Medium
7	Increased intensity of rain and wind events	Medium
8	Change in vegetation/animal species composition	Low

Once the vulnerability scenarios were scored based on likelihood of occurrence, the individual risks were ranked based on their potential impact on the region. The risks were categorized based on the severity of their impact, rated "High," "Medium," and "Low," and represented by the colors red, yellow, and green, respectively. The designations and their definitions are shown in Table 6-4. Detailed results of the climate change impact and risk prioritization are provided in Appendix C, Summary of Prioritized Risks by Service Sector.

Table 6-4. Risk Prioritization

Risk Prioritization Designation	Risk Prioritization Definition
High	Risks that affect the livability of the region by impeding access to basic services; e.g., food production, water treatment, wastewater treatment, energy production, access to health care
Medium	Risks that affect the quality of life in the region; e.g., basic services available but at a reduced level of service (LOS)
Low	Risks that have a minor effect on the livability of the region or require little or no investment to address

6.2.2 High-Priority Vulnerabilities

As described above, the highest-priority risks were defined through an evaluation of their likelihood and impact for each vulnerability scenario and service sector. The resultant high-priority risks are summarized in Table 6-5. As indicated in this table, numerous high-priority risks were identified for each vulnerability scenario and service sector. The largest number of high-priority risks is in the water supply/water quality and water treatment sectors. This outcome could be expected given that a safe and reliable water supply is a basic service critical to the livability of the region.

As discussed in Section 7, adaptive strategies were then developed and a sequential Adaptive Management Plan was established for the region to mitigate the impacts and prioritize strategies to maintain reliable resources within the watershed.

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Table 6-5. Upper Scioto River Watershed Summary of Highest-Priority Risks by Service Sector and Vulnerability Scenario

No.	Highest-Priority Vulnerability Scenarios	Highest-Priority Risks by Affected Sector								
		Water Supply/ Water Quality	Water Treatment	Wastewater Treatment	Public Health	Agriculture	Environment	Economy	Energy	Transportation
1	Increased air temperatures/increased incidence of heat waves	Increased water demand due to irrigation Increased nutrient/pesticide/ herbicide load due to extended growing season, increased algal blooms	T&O concerns, potential for algal toxins		Increased issues for asthma and allergies Impacts to human mortality; increase in heat illnesses and stresses on health care	Livestock health/mortality Increased need for irrigation and controlled drainage	Increased smog/decreased air quality	Increased service cost for food Increased cost for utility services (water, wastewater, and energy) Decreased human productivity	Increased power disruptions (brownouts)	
2	Increased water temperature	Increased algal blooms including blue-greens (potential for increased toxin release)	T&O concerns, potential for algal toxins	Lower DO/changes in temperature affect wastewater discharge allocation	Increase in waterborne diseases	Increased cost to control water quality from fields			Lack of cooling water could reduce power production	
3	Warmer soil temperatures/decreased soil moisture					Increased need for irrigation and controlled drainage				
5	Higher maximum sustained flow (30- and 7-day higher maximum stream flows)	Increased algal blooms, including blue-greens (potential for increased toxin release) Increased TOC, nutrients, turbidity, sediment, and other pollutant loads to surface waters Increased supply management challenges related to greater variability in stream flow Increased watershed and stream bank erosion	T&O concerns, potential for algal toxins Increased treatment cost due to increased pollutant concentrations and increased DBPs					Increased flood damage		
6	Extended dry periods/summer drought (decreased minimum 30-day stream flow)	Decreased reservoir flow/volume and reduced mixing Increased water demand Increased algal blooms, including blue-greens (potential for increased toxin release) Reduced reliability of yield from supply sources	Reduced groundwater supply/recharge T&O concerns, potential for algal toxins; Increased treatment costs due to algae and potentially algal toxins		Increased allergens and dust	Increased demand for irrigation but decreased water availability		Increased food costs due to decreased agricultural production (crop loss)		
7	**Increased intensity of rain and wind events**	Increased watershed and stream bank erosion Increased TOC, nutrients, turbidity, sediment, and other pollutant loads	Damage to infrastructure/ infrastructure failure including power outages, flooding, and intake damages	Damage to infrastructure/infrastructure failure including power outages and flooding Increased CSO/sanitary sewer overflow (SSO) discharges	Loss of electrical/water/ sanitation services during and after event Increased demand on public health services Restricted access to critical care Disaster related injuries/ mortalities			Increased insurance costs; Increased damages due to floods/storms	Increased vulnerability of power supply system	Infrastructure access Infrastructure damage/ failure Interruption to emergency services including the transportation of food and water in critical situations

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Section 7

Adaptive Management Strategies

This section includes a description of potential adaptation strategies to address the high-priority risks identified for the water quality/water supply, water treatment, and wastewater utility sectors. A discussion of strategies for the region's additional sectors, including public health, environment, economy, energy, transportation, and agricultural, is included in Appendix D, Adaptive Strategies, Non-Water Service Sectors and also published in Brown and Caldwell, 2014d.

The adaptive management framework presented in this study assumes that utilities and/or planners will use an iterative approach to plan and implement strategies for regional climate resilience. **It is recommended that this analysis be revisited regularly as new information becomes available or when there is capacity to implement additional strategies.**

One of the overarching challenges to managing utilities and services in the region is the need to increase flexibility in planning and operations to adapt to the increased variability and extremes of precipitation, stream flow, and water quality.

One of the overarching challenges to managing utilities and services in the region is the need to increase flexibility in planning and operations to adapt to the increased variability and extremes of precipitation, stream flow, and water quality. The projected changes could have a significant effect on facilities and operations, yet the probability and magnitude of these changes are not known with a high degree of certainty. **To manage these critical infrastructure systems prudently, utility operators must determine strategies to address the issues that pose the greatest threat and make appropriate investments.**

7.1 Introduction to Adaptation Strategies

The adaptation strategies for each service sector are divided into three categories: planning, operational, and capital improvement, as described in Table 7-1. In some cases, new planning studies are recommended to evaluate alternative operational or infrastructure investments to mitigate the identified risk. In other cases, infrastructure improvements are recommended including accelerating timing of planned projects.

Table 7-1. Categories of Adaptive Strategies

Category	Definition
Planning	Strategies that include studies, demand or development planning, and regulatory policy or ordinance changes
Operational	Strategies that include operational changes to reservoir or treatment plant operations, conservation efforts, and other management strategies
Capital improvement	Strategies that include construction of new infrastructure, significant rehabilitation or retrofit of existing infrastructure, and new technologies

Each adaptive strategy has also been categorized based on the relative level of investment for the region. Table 7-2 includes a description of the three levels of cost as referenced within this Plan.

Table 7-2. Relative Costs Associated with Adaptive Strategies

Assigned Cost	Definition
$	Options that can be funded by the utility or service sector within the typical annual budget
$$	Investments that require planning to implement as part of the capital improvement plan for the utility or service sector
$$$	Projects or improvements that may require significant bonding, federal or grant funding, or changes to utility rates to implement the improvement

The benefits of each adaptive management strategy for mitigating climate change risks were considered for each service sector. In many cases, strategies are identified that provide a significant benefit to the utility or service sector under both the current climate and climate change scenarios. These strategies are labeled throughout this section as "no regrets" strategies. Implementing such strategies will increase the region's resilience to future climate change while also providing immediate benefits. While these "no regrets" actions are not cost-free, they do provide benefits to the service sectors regardless of future climate conditions.

"No regrets" strategies are strategies that provide benefit under current and potential climate change conditions.

7.2 Prioritization Methodology

The strategies described in this section have been categorized with regard to timing for implementation based on the predicted changes from the USGS modeling. Three planning terms were defined: Short Term, which are strategies that should be implemented in the next 10 years (2015–25); Mid Term, strategies that should be implemented in the next 30 years (2026–45); and Long Term, strategies that should be implemented by the turn of the century. The strategies and their associated implementation periods are summarized in Figure 7-1.

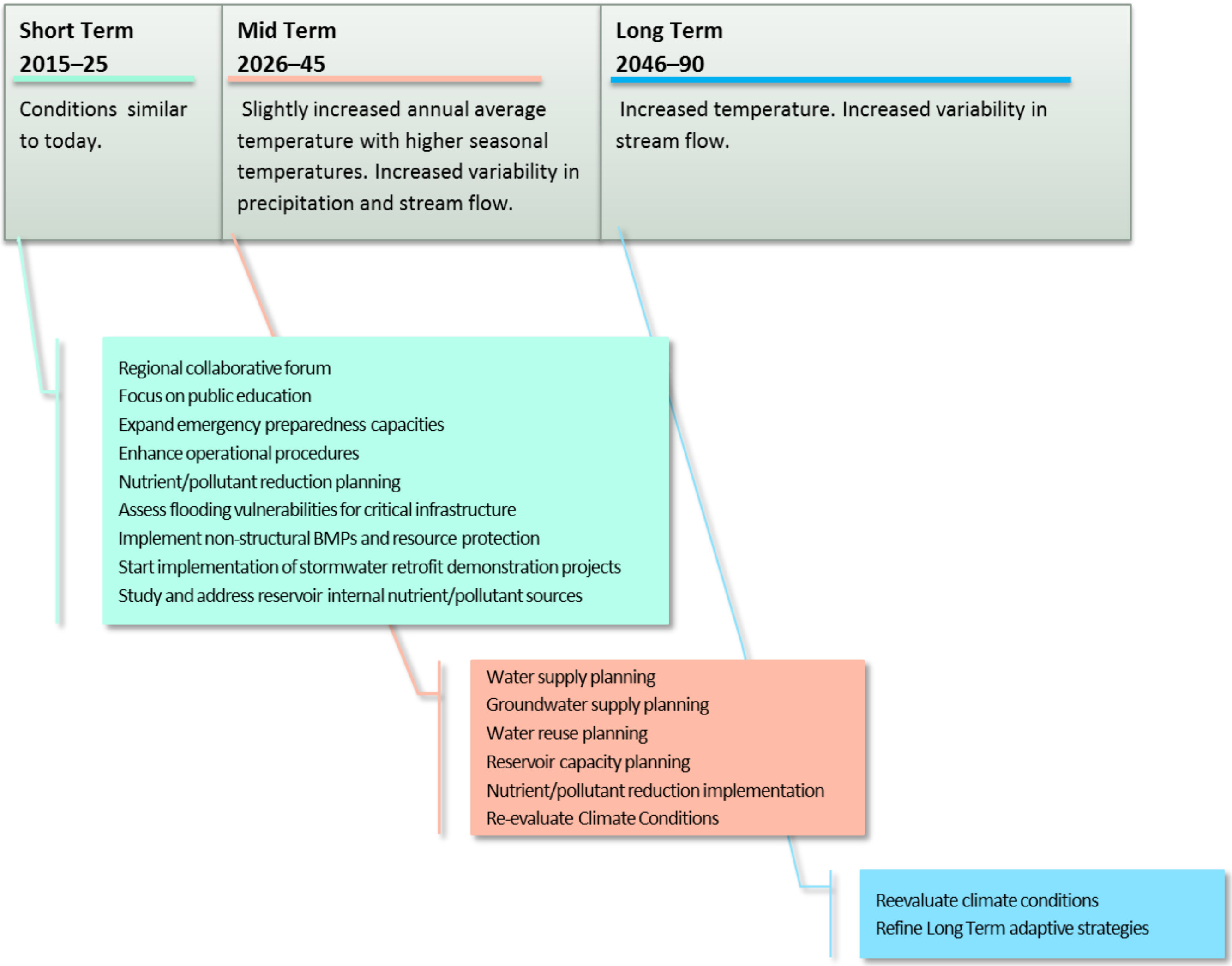

Figure 7-1. Strategy prioritization classification and time frames

In the Short Term, which consists of the next 10 years, the models predict minor changes, within the level of standard climate variability. During this time frame the region needs to: monitor existing conditions; protect existing resources; enhance operational procedures; initiate regional watershed planning; assess the flooding vulnerabilities of critical infrastructure; implement non-structural best management practices (BMPs) and begin the implementation of stormwater LID retrofit demonstration projects in the watershed to reduce nutrient/pollutant loads; evaluate and address reservoir internal nutrient/pollutant sources; and lay the groundwork for potential regional coordination and collaboration, which may be needed to address regional climate change issues in the future. These efforts need to address both water quantity and water quality. It is recommended that the region's municipal leaders begin to meet to share thoughts on potential implications and begin to consider collaboration with regard to resource planning.

In the Mid Term, which consists of the next 30 years, the models reflect more variability in precipitation and stream flow along with the projected increase in mean annual temperature. During this time frame, the region needs to conduct planning studies to inform and refine Long Term adaptation strategies, continue the implementation of non-structural BMPs, implement stormwater retrofit projects to reduce watershed nutrient/pollutant loads, and improve surface water quality.

Looking out toward the end of the century, the models reflect significant variability with respect to precipitation, but all models indicate a significant increase in temperature. It is anticipated that the Long

Term strategies identified in this study will be refined based on outcomes of the Mid Term planning studies. Although the types of projects and activities may change, the need to continue to implement non-structural and structural BMPs is expected to improve water quality. It is likely that there will be additional pollutant of concern that will need to be addressed in the future such as pharmaceuticals and hormones.

In the sections below, the recommended adaptive strategies are discussed in detail. Those that should be addressed in the Short Term (next 10 years) are highlighted in green; those that should be addressed in the Mid Term (11–30 years) are highlighted in pink. Additional strategies that may be considered in the Long Term—through the turn of the century—are included for consideration as this Plan is updated over time, but have not been highlighted in the tables. **It is anticipated that the Long Term strategies identified in this study will be refined based on updated climate projections, outcomes of the Mid Term planning studies, and the effectiveness of structural and non-structural BMPs implemented through 2045.**

A key factor in implementation of all of the strategies is the routine monitoring of climate and risk conditions. Strategies will need to be modified over time as the climate projections are refined. By reviewing updated data on a routine cycle (i.e., every 10 years), the region can monitor what changes are occurring and alter the implementation of strategies accordingly.

7.3 Climate Change Adaptation Strategies by Sector

This section describes adaptation strategies for the highest-priority risks by sector: water supply/water quality, water treatment, and wastewater utility. Adaptation strategies for the ancillary service sectors are provided in Appendix D. A detailed discussion of the impacts these risks can have on the region is included in TM3, Vulnerability Assessment.

7.3.1 Water Supply/Water Quality

The high-priority risks identified for water supply/water quality are listed in Table 7-3. It should be noted that several of these risks also impact the water treatment sector, requiring treatment system adaptations to changing water quality conditions in the source water, as discussed in Section 7.2.2.

Table 7-3. Water Supply/Water Quality High-Priority Risks

No.	Vulnerability Scenario	High-Priority Risks
1	Increased air temperature	Increased water demand due to irrigation
		Increased nutrient/pesticide/herbicide load due to extended growing season
2	Increased water temperature	Increased algal blooms, including blue-greens (potential for increased toxin release)
5	Higher maximum peak stream flows	Increased organics, nutrients, turbidity, sediment, and other pollutant loads to surface waters
		Increased algal blooms, including blue-greens (potential for increased toxin release)
		Increased supply management challenges related to greater variability in stream flow
		Increased soil and stream bank erosion
6	Extended dry periods/summer drought	Increased water demand
		Reduced reliability of yield from existing water supply sources
		Decreased reservoir inflow/volume and reduced mixing
		Increased algal blooms, including blue-greens (potential for increased toxin release)
7	Increased intensity of wind and rain events	Increased soil and stream bank erosion
		Increased organics, nutrients, turbidity, sediment, and other pollutant loads to surface waters

Several of these high-priority risks are associated with multiple vulnerability scenarios and can be summarized into the following six categories:

- Increased water demand due to increased air temperatures and extended droughts
- Increased algal blooms due to increased air and water temperature, higher maximum stream flows, and extended droughts
- Increased organics, nutrients, turbidity, sediment, and other pollutant loads to surface waters due to increased air temperature, higher maximum stream flows, and more extreme rain and wind events
- Reduced reliability of yield from supply sources due to greater variability in stream flow, higher maximum stream flows, and extended droughts
- Increased soil and stream bank erosion due to higher maximum stream flows and more extreme rain and wind events
- Decreased reservoir inflow/volume and reduced mixing due to extended droughts

Two of the highest-priority risks, associated with water demand and water supply reliability, share common strategies. The other four highest-priority risks are linked to protecting water quality and also have common mitigation strategies. The following sections summarize the potential adaptation strategies related to planning and policy and operational and capital improvements, along with the relative costs to mitigate the highest-priority risks for water supply/water quality; i.e., water demand and water supply reliability, and water quality protection.

7.3.1.1 Increased Water Demand and Water Supply Reliability Strategies

Recommended adaptation strategies for mitigating increased water demand and reduced water supply reliability are provided in Table 7-4.

In the Short Term, it is recommended that the region focus on strategies to increase the resilience of the existing water supply system through demand management and the use of low-impact development (LID) practices. Increased conservation by residential, commercial, industrial, agricultural, and other users will continue to gain importance to reduce overall potable water demands. Water use audits and leak detection studies should be completed to identify areas for conservation. Guidance should be developed to promote the use of high-efficiency irrigation systems, landscaping materials that minimize irrigation needs, and rainwater and stormwater harvesting and reuse for irrigation.

Under current stormwater treatment regulations, new development will degrade surface water quality due to the generation of new pollutant loads from additional impervious surfaces. Local ordinances should be modified to require Low Impact Development (LID, green infrastructure) construction to more closely mimic natural hydrology, improve groundwater recharge throughout the watershed, and reduce pollutant loads. LID practices may include infiltration features, such as bioretention and bioswales. Ponds and tanks can be used to capture and store rainwater from roofs and stormwater runoff from developed areas for irrigation. As conservation is an important element of current utility planning, increased focus on conservation and water use efficiency are considered as “no regrets” strategies for the region.

As a part of the City of Columbus’s Blueprint Columbus project, the City is working to separate downspouts from the sanitary sewer system and routing the rainwater to green infrastructure.

In the Mid Term, it is recommended that the region collaborate on the development of a Regional Water Supply Management Plan, including the evaluation of water demand, availability, potential new sources, and the identification of emergency supply sources that can be used during extreme drought conditions. Preparation or updates to the Reservoir Operational Plans for each reservoir to optimize operations during both drought and high stream flow conditions is also recommended in the mid-range time frame. As noted in Section 4, a strategy is needed to evaluate regional water availability and changes to water demand that would result from climate change and future development. The demand should include future irrigation needs and groundwater usage. Many of the utilities in the region have developed individual water master plans that evaluate potable water needs within their service area. Compilation of these individual plans and expansion to include evaluation of all water needs would provide the region with a more comprehensive understanding of the availability and reliability of this important resource. The demand projections through buildout conditions (2090), presented in Section 3, indicate that several utilities in the region plan for increased use of groundwater as a supply source. Evaluation of sustainable groundwater withdrawal rates should be incorporated into the Regional Water Supply Management Plan. Strategies should also be developed in this plan to allow adjacent water suppliers to share water during extended droughts. This will require regional coordination, collaboration, and planning studies to determine feasibility, as well as the construction of water system interties. It is believed that this type of plan would be of value to the region under our current climatic conditions, thereby making this one of the “no regrets” strategies for this sector.

Water reuse should also be considered for future water supply. Up to 50 percent of water demand does not require potable water, as it is used for irrigation and toilet flushing (Sharvelle 2014). Alternative sources for non-potable needs may include groundwater, wastewater reuse, and rainwater and stormwater harvesting and reuse. It will be necessary to determine the potential yield and economical uses of each of these sources prior to implementation.

Potential Long Term capital improvement strategies include the construction of wastewater reuse systems, emergency water system interties, additional water storage/reservoirs, and systems to store and reuse stormwater. Implementation of wastewater reuse may also require improvements at the wastewater treatment facilities to meet reuse water quality requirements. It is important to note that the Long Term impact of wastewater reuse on surface and groundwater quality should be considered during the early planning. Additional water storage tanks and reservoirs may be needed in the watershed to capture stormwater and provide adequate irrigation water during extended droughts. The region may be able to use existing quarries in the area located adjacent to the river for additional water storage. Undeveloped tracts of land adjacent to rivers could be modified to provide water storage and possibly passive treatment. River water could be diverted offline, stored, and released more slowly over time or during periods of drought. These water storage areas could provide additional water supply and could also provide treatment to reduce nutrient and other pollutant concentrations upstream of the reservoirs.

Table 7-4. Recommended Adaptation Strategies for Mitigating Increased Water Demand and Reduced Water Supply Reliability

Strategy	No Regrets	Cost
Planning and Policy		
Increase conservation through residential and commercial rebate programs, device distribution, and public education on efficient irrigation techniques	✓	$
Develop a guide for and promote rainwater and stormwater harvesting/reuse	✓	$
Develop Regional Water Supply Management Plan to identify strategies for extended drought conditions. As part of Regional Supply Management Plan, evaluate alternative sources of water supply, including potential irrigation-only sources	✓	$$
Develop or update Reservoir Operational Plans for optimizing reservoir management during drought and high flow conditions	✓	$
Identify areas for water reuse (e.g., irrigation, industrial applications, etc.) to reduce potable water demands	✓	$
Conduct study to evaluate sustainable groundwater withdrawal rates	✓	$$
Develop an agricultural water conservation/BMP/reuse program through collaboration with state/local agricultural agencies*	✓	$
Operational		
Conduct water use audits and leak detection surveys to identify areas for conservation	✓	$$
Modify local stormwater management and land development ordinances to require LID, reduce impervious areas, and encourage rainwater and stormwater harvesting/reuse	✓	$
Establish framework for municipal collaboration on climate change and water supply issues	✓	$
Educate/outreach to community on conservation, water supply management and climate change	✓	$
Establish mutual aid agreements that detail water sharing with other municipalities through system interties during emergency or extreme supply situations*		$
Capital Improvement		
Construct emergency water system connections between municipalities in the Scioto River watershed, where feasible*		$$
Implement recycled water treatment at the wastewater treatment facility and construct piping for water reuse users*		$$$
Construct larger pump stations to allow capture of peak stream flow*		$$$
Construct additional water storage/reservoirs in the watershed*		$$$
Construct storage ponds/tanks to collect and store stormwater for reuse*		$$
Develop an aquifer storage and recovery (ASR) program		$$

$: Can be funded by the service sector within the typical annual budget.

$$: Requires planning to implement as part of the capital improvement plan for the service sector.

$$$: Requires significant bonding, federal or grant funding, or changes to utility rates to implement the improvement.

** Long Term strategies need to be refined based on updated climate projections and outcomes of the Mid Term planning.*

7.3.1.2 Water Quality Protection Strategies

Recommended adaptation strategies for protecting water quality are provided in Table 7-5. The strategies have been divided into the same relative time frames for recommended implementation. The pollutants of primary concern at this time include: nutrients; organics; sediment; pathogens; and pesticides/herbicides.

Algal blooms have become an increasing problem for surface waters in Ohio. Grand Lake St. Mary in Celina began reporting unsafe levels of microcystin, a toxin released from certain types of cyanobacteria in 2010. The lake is the primary drinking water source for the city of Celina. More recently, the City of Toledo warned 400,000 residents in August 2014 not to drink, cook, or bathe with the water because of potentially harmful levels of microcystin found in the City's drinking water supply. Lakes, reservoirs, and streams in the state have been experiencing an increase in algal blooms for the last decade. Increasing temperatures and higher-intensity rainfall events, which are predicted by the climate model data, will exacerbate the issue by providing ideal temperatures for algal growth and additional food (nitrogen and phosphorus) carried to surface waters by stormwater runoff.

Watershed Action Plans have been developed for the Upper Scioto River, Upper and Lower Olentangy River, Upper and Lower Big Walnut Creek, Lower Alum Creek, Rocky Fork Creek, Blacklick Creek, and the Darby Accord.

Because of the documented existing water quality impairments and anticipated future trends in the Scioto River watershed, strategies should be implemented to reduce nutrient, organic, sediment, pathogen, and pesticides/herbicides loads to streams and reservoirs (external loads). Reservoir internal nutrient/pollutant loads (i.e., internal recycling of nutrients from the reservoir hypolimnion and sediments) should also be evaluated to determine the affect on surface water quality and addressed based on the study results. Both external and internal nutrient/pollutant loads can be primary sources which degrade surface water quality. Reservoir operational changes may also be warranted to help reduce reservoir pollutant, algae, and cyanobacteria concentrations. In recent years, the Hoover and Alum Creek reservoirs have experienced increasing cyanobacteria densities, which are of immediate concern. Under current conditions surface waters in the Scioto River basin are impaired and could experience the same cyanobacteria bloom and microcystin levels experienced by Celina and Toledo.

Other water quality issues of concern include: drinking water taste and odor; DBPs from the chlorination of reactive organic carbon; and contaminants of emerging concern such as hormones and pharmaceuticals. These are also very important water quality issues that are expected to be of increasing regulatory concern in the future.

Recommended Short Term strategies for protecting/improving water quality include developing and implementing a comprehensive regional water quality-monitoring program, identifying primary sources of nutrients/pollutants throughout the watershed and reservoirs, and implementing policies and practices to reduce nutrients and other pollutants of concern in the region. Reducing pollutant loads will improve stream and reservoir water quality.

While substantial monitoring is being conducted in the central portion of the watershed (Section 5), limited data are available on water quality in the headwaters or in the more remote sections of the watershed. The primary specific sources of pollutants and the significance of reservoir internal nutrient/pollutant sources are also not known at this time. A comprehensive Water Quality Monitoring Program is needed to identify the primary sources and magnitudes of nutrients and other key pollutants throughout the watersheds and reservoirs, and evaluate the water quality response in regional streams and reservoirs.

The monitoring program should address in-stream and reservoir water quality during different weather conditions, both wet and dry weather, throughout the year. Analyses to quantify contributions from specific areas and land uses within the study area are needed. Quantifying loads from reservoir bottom sediments and the hypolimnion should also be completed. The monitoring program should also assess the condition of the stream banks and riparian buffers and identify areas with stream bank erosion and loss of natural riparian buffers. The results of the monitoring program should be used to identify primary sources of nutrients, sediment, reactive organic carbon, and other key pollutants that affect drinking water quality and to select the most appropriate strategies to reduce pollutant loads and improve water quality.

Multiple strategies have been identified to reduce nutrient and other pollutant loads in the region. One strategy involves the development of an agricultural nutrient/herbicide/pesticide/pollutant management program through collaboration with state/local agricultural agencies and soil and water conservation districts. This type of program is one of the many ongoing programs of the local soil and water conservation districts throughout the watershed. It is recommended that additional focus be placed on this important work with the agricultural community in conjunction with increased public education. Stormwater discharges from agricultural land are a primary source of nutrients, organics, pathogens, and herbicides in the study area. The Environmental Quality Incentives Program, EQIP, was successfully implemented in the Hoover Reservoir watershed to reduce atrazine levels for over a decade. Similar approaches could be expanded throughout the watershed to address known water quality issues.

MORPC has facilitated the development of Balanced Growth Plans in five central Ohio watersheds to provide communities with development and conservation tools including LID practices that best serve the watershed and the region.

Residents and business owners throughout the watershed need to be educated related to their activities in the watershed and reservoir eutrophication, algal blooms, and other water quality issues. Local regulations can be modified to reduce the application of unneeded fertilizers. In many cases, phosphorus and/or nitrogen fertilizers are applied that are not needed based on existing levels of nutrients in the soil. Fertilizer use in both rural and urban settings is one of the primary sources of nutrients in a watershed, resulting in reservoir eutrophication and algal blooms.

The City of Columbus initiated a Watershed Management Plan in 2014 to evaluate sources upstream of its reservoirs on the Scioto River and Big Walnut Creek.

Loss of natural riparian buffers adjacent to streams and stream bank erosion are commonly primary sources of sediment and other pollutants in a watershed. Protection and re-vegetation of riparian buffers and re-vegetation of stream banks is recommended to reduce sediment loads to area streams and reservoirs. Many of the municipal separate storm sewer systems (MS4s) throughout the watershed have adopted riparian buffer protection ordinances. Local governments should be encouraged to protect and maintain natural riparian buffers, wetlands, and floodplains adjacent to streams and reservoirs as development progresses in the watersheds.

The implementation of LID regulations by local governments for new development and redevelopment will reduce the discharge of stormwater runoff to receiving waters, thereby reducing nutrient and other pollutant loads. LID practices retain runoff on site and thereby reduce the volume of runoff and pollutant load leaving a developed site. Stored water can be used for irrigation, reducing the potable water demand in the area. New development and re-development in the watershed can be required to retain a set volume of stormwater runoff on site, typically between 0.5 and 2 inches. A minimum of 1 inch of onsite retention is recommended for this region.

LID retrofit demonstration projects which treat stormwater runoff are **recommended to educate developers, citizens and businesses about the benefits of LID.** Incentives can be provided to local businesses and citizens to implement LID retrofit projects on private property (i.e. rain gardens and cisterns) to further reduce nutrient/pollutant loads in the developed areas of the watershed.

It is important for utilities to prepare for algae blooms and other water quality upsets that could disrupt the supply of drinking water. Operational procedures should be evaluated to determine if operational changes can improve reservoir water quality and reduce the frequency and intensity of algae blooms. Emergency Operational Plans should be prepared with detailed procedures to be put in action in the event of an algae bloom, T&O problem, or other major water quality issue. The plans may include changing operations, treatment, or installing temporary equipment.

In the Mid Term planning horizon, the preparation of a Regional Watershed Management Plan (WMP) is recommended. Watershed planning is currently occurring through multiple organizations and municipalities within the watershed. The next step is to take the information from these individual studies and begin to develop a framework for a regional WMP, including an analysis of information gaps that need to be filled with additional monitoring or studies. Other sources of information that could be used to streamline the development of this Regional WMP include the Olentangy River, Walnut Creek, and other TMDL studies from Ohio EPA.

Once the primary sources of nutrients/pollutants are identified, strategies can be developed to reduce the primary sources and maintain acceptable water quality. Strategies are needed to address both watershed (external) and internal surface water pollutant loads. Strategies are needed to manage reservoirs to minimize the occurrence of algal blooms and to provide stream and/or reservoir treatment when necessary to control nuisance blooms (water treatment is discussed in Section 7.2.2).

The WMP should also address other pollutants of concern such as reactive organic carbon and contaminants of emerging concern. Structural and non-structural strategies should be developed and prioritized for controlling the sources of these pollutants in the watershed along with in-reservoir maintenance and operational strategies to protect water quality. Strategies may include purchasing sensitive lands, restoring stream banks and riparian buffers, constructing regional and/or local stormwater retrofit projects to treat stormwater runoff, removing reservoir bottom sediments, and installing in-reservoir treatment systems. Implementation of selected strategies should continue during the Mid Term.

Long Term capital improvements will likely be needed to continue to reduce nutrient and other pollutant loads depending on the Regional Watershed Management Planning results. These improvements may include in-reservoir treatment (e.g., sediment treatment or removal, hypolimnetic oxygenation) and the construction of structural stormwater BMPs in the watershed. Example structural BMPs that can be constructed as retrofits to reduce pollutant loads from existing developed land uses include LID practices (bioretention, storage and reuse), wet detention, gross pollutant removal structures (i.e. baffle box, hydrodynamic separator) and coagulant treatment. Stream and riparian buffer restoration may also be beneficial if stream bank and/or riparian buffer degradation has occurred. Installation of permanent remote sensing in situ water quality sondes is recommended to continuously monitor surface water quality. Using established thresholds and triggers, algal blooms and other severe water quality events can be detected early so that actions can be implemented immediately to resolve the water quality issue.

Table 7-5. Recommended Adaptation Strategies for Protecting/Improving Water Quality

Strategy	No Regrets	Cost
Planning and Policy		
Develop Water Quality Monitoring Plan to identify primary watershed (external) and reservoir (internal) nutrient and other pollutant sources; include identification of degraded streams and riparian buffers	✓	$
Develop an Agricultural Nutrient Management/BMP/Herbicide/Pesticide Program through collaboration with federal/state/local agricultural agencies	✓	$
Modify local regulations to limit fertilizer use	✓	$
Implement public education and outreach on sources of pollutants and surface water quality/water supply impacts	✓	$
Modify local stormwater management and land development ordinances to promote LID, reduce impervious areas, and encourage rainwater and stormwater harvesting/reuse, thereby reducing runoff volume and pollutant loads	✓	$
Evaluate reservoir operations to improve raw water quality; develop Emergency Operational Plans for reservoir water quality events (i.e. algae bloom; T&O)	✓	$
Assess Regional Watershed Management Plan to reduce nutrient runoff and algal growth	✓	$
Operational		
Conduct Water Quality Monitoring to determine sources and magnitudes of external and internal pollutant sources (nutrients, sediment, T&O compounds, DBP precursors, and algal toxins; identify contributing factors for algae blooms and algal toxin release)	✓	$$
Reduce nutrients/sediment/herbicides/pesticides in runoff from agricultural land through partnerships and agricultural program	✓	$$
Implement increased fertilizer reduction programs, protection of riparian buffers/wetlands/floodplains, re-vegetation of streams and riparian buffer zones, and other non-structural practices to reduce runoff and surface water pollutant concentrations	✓	$$
Begin LID/BMP retrofit demonstration projects on public lands and promote/provide incentives for local businesses and citizens to install LID retrofits	✓	$$
Capital Improvement		
Install permanent in situ water quality monitors for early algal bloom detection*		$$
Implement reservoir capital improvement projects (i.e., sediment removal, hypolimnetic oxygenation)* for internal loads		$$$
Implement pollutant reduction projects (BMPs) to reduce pollutants of concern within the watershed* for external loads		$$$

$: Can be funded by the service sector within the typical annual budget.

$$: Requires planning to implement as part of the capital improvement plan for the service sector.

$$$: Requires significant bonding, federal or grant funding, or changes to utility rates to implement the improvement.

** Long Term strategies need to be refined based on updated climate projections and outcomes of the Mid Term planning.*

7.3.2 Water Treatment

The high-priority risks identified for the water treatment sector are listed in Table 7-6. A number of these risks overlap with those in the Water Supply section outlined in Section 7.2.1. The discussion below focuses on the treatment strategies related to these same vulnerabilities. The potential adaptation planning and policy, operational and capital improvement strategies, and relative costs to mitigate each of the high-priority risks for water treatment are discussed in the following sections and summarized in Tables 7-7 through 7-9.

Table 7-6. Water Treatment High-Priority Risks

Vulnerability Scenario	Risks
Increased air temperature	T&O concerns, potential for algal toxins
Increased water temperature	
Higher maximum sustained stream flows	Increased pollutant loads (from increased turbidity, organics, nutrients, microorganisms, and other contaminants) in surface waters
Increased intensity of rain and wind events	Damage to infrastructure/infrastructure failure including power outages, flooding, and intake damages

7.3.2.1 Increase of Taste and Odor Concerns, Algal Blooms, and Associated Toxins

Warm air and water temperatures are known to cause algal blooms, leading to T&O concerns as well as potential algal toxins. As discussed in Section 5, two compounds, geosmin (1,2,7,7-tetramethyl-2-norborneol) and MIB (2-methylisoborneol), are produced by algae (cyanobacteria and actinomycetes). Both geosmin and MIB have extremely low odor thresholds to humans; the average person can often detect the presence of these compounds in the 10 parts per trillion (ppt) concentration range (Crittenden et al. 2005). These compounds are aesthetically unpleasing, but do not represent a serious health concern.

Although not as common as T&O compounds, cyanobacteria (also referred to as blue-green algae) toxins are a cause for much greater concern when present in drinking water supplies. These toxins can cause serious health issues including poisoning, impacting the liver and the nervous system, and skin and mucous irritation. Microcystins, a class of natural toxins produced by certain genera of cyanobacteria, are of increasing interest and concern around the world as the number of poisoning incidents associated with cyanobacteria exposure increases, both in inland water bodies and coastal areas (de Figueiredo et al. 2004).

Most of the microcystin toxins are not released until the cell wall is lysed, which occurs when the cyanobacteria die (Heinze 1999, WHO 2003, Svircev et al. 2009). A large “die-off” of an algal bloom therefore may result in substantial release of microcystins to the water column. Treatment approaches should be focused on removing microcystin prior to cell lysing or inactivation of the extracellular toxin. The effectiveness of removal/inactivation processes depends on the type, concentration, and location of the toxins. Intracellular toxins are more easily removed because conventional treatment processes can be used for flocculation and coagulation followed by sedimentation and filtration (AWWA 2010). Extracellular toxins can be oxidized by disinfectants, such as chlorine, but may require advanced treatment, such as reverse osmosis filtration, granular activated carbon (GAC) adsorption, or ozonation (AWWA 2010).

The Columbus DRWP and HCWP are currently constructing ozonation and biologically active GAC treatment processes.

Recommended Short Term treatment strategies for addressing T&O concerns and associated algal blooms include developing water treatment goals and water quality monitoring plans to identify T&O outbreaks or algal toxin events throughout the treatment process (from reservoir concentrations through finished water production). Finished water quality trigger points for public notification and an emergency management plan in case of an algal toxin event should be developed. Several utilities monitor for microcystin, but there are no U.S. regulatory limits. The World Health Organization (WHO) guideline for an MCL for microcystin-LR is 1 µg/L (WHO 1998). WHO terms this guideline as a “provisional value” because data are limited on the toxicity of cyanobacteria toxins. At this time, the region would need to develop trigger points without U.S. water quality regulations in place.

Mid Term strategies include evaluation of reservoir management options including source susceptibility analyses and the identification of alternative sources and treatment processes for use during algal blooms or T&O events. The timing for these planning-level studies will be determined by the level of problem being experienced within each source of supply.

Potential Long Term strategies include implementation of surface reservoir treatment options. Algaecides, destratification/aeration, oxygenation, and watershed management are potential reservoir treatment methods. There are also several options within the WTP to modify operation to ensure removal of T&O compounds when outbreaks occur by increasing chemical and oxidant dosages.

Treatment plants not designed for enhanced organics removal will have more difficulty removing T&O compounds during outbreak events. Water treatment facilities with ozonation and biologically active filtration should be able to remove geosmin and MIB if an adequate ozone dosage is applied and the biofilm on the filter media is well established. If the GAC media has adsorptive capacity, this can be an additional mechanism for removal of these compounds. Geosmin and MIB removal should be monitored.

Table 7-7. Recommended Strategies for Mitigating Impacts related to Taste, Odors and Potential for Algal Toxins

Strategy	No Regrets	Cost
Planning and Policy		
Develop and conduct Water Quality Monitoring Plan to identify T&O outbreaks and presence of algal toxins throughout the treatment process (intake to finished water)	✓	$
Establish water quality treatment goals and levels that would trigger treatment modification and levels of contamination in the finished water that would trigger public notification	✓	$$
Develop Emergency Treatment Response Plan for T&O/toxic algal events	✓	$
Conduct study to evaluate source susceptibility and identify redundant source options	✓	$
Operational		
Activate additional treatment for facilities with T&O/algal toxin treatment options, increase chemical and oxidant dosages during summer and fall seasons when algal outbreaks can occur*	✓	$$–$$$
Implement reservoir treatment strategies or operational changes such as water withdrawal depths*		$$
Capital Improvement		
Install reservoir treatment strategies*		$$–$$$
For water treatment facilitates without a means to remove algal toxins, such as microcystin or T&O compounds, construct additional treatment processes*		$$$
Construct emergency water system connections between communities, where feasible*		$$$

$: Can be funded by the service sector within the typical annual budget.

$$: Requires planning to implement as part of the capital improvement plan for the service sector.

$$$: Requires significant bonding, federal or grant funding, or changes to utility rates to implement the improvement.

** Long Term strategies need to be refined based on updated climate projections and outcomes of the Mid Term planning.*

7.3.2.2 Increased Source Water Pollutant Concentrations, Such as Turbidity and Disinfection By-products

Increased peak stream flow is predicted to increase source water turbidity and DBP levels, as well as other pollutant concentrations. Table 7-8 outlines strategies to address this concern.

Short Term strategies include establishing protocols and standard operating procedures (SOPs) for modified treatment plant operation during high turbidity and organic events to guide operators on chemical dosages, unit process loading rates, and water quality testing requirements. Additional SOPs may include using a secondary coagulant to reduce turbidity/organic levels and reduce or eliminate prechlorination to reduce DBP levels. As noted previously, another Short Term strategy is implementation of a water quality monitoring program.

Mid Term strategies may include evaluation of alternative sources of supply as part of the larger-scale resource planning efforts. This could include developing new groundwater sources or implementing an aquifer storage and recovery (ASR) system. ASR is the enhancement of natural groundwater supplies using man-made conveyances, such as infiltration basins or injection wells, that it is stored in the ground for use at a later time (EPA 2012). ASR can supplement water availability in the summer months when water use is high and naturally most limited. ASR can serve the same purpose as traditional storage in surface reservoirs and has the benefits of being less costly because large impoundments are not required, being more environmentally friendly because it may reverse declining water levels in aquifers, and being less vulnerable from a water quality standpoint due to limited exposure (Ecology 2014).

In the Long Term (or as needed based on monitoring results), additional treatment processes may need to be brought online or constructed if not available. Ozonation, dosing of powdered activated carbon, and GAC polishing units are treatment processes that are effective at removing already-formed DBPs. If chloroform is the main DBP of concern, in-tank aeration can be used in the distribution system to strip chloroform from the water.

Table 7-8. Increased Source Water Pollutant Concentrations, Such as Turbidity and Disinfection By-products Due to Higher Maximum Sustained Stream Flow

Strategy	No Regrets	Cost
Planning and Policy		
Establish water quality monitoring program	✓	$$
Develop alternative source of supply	✓	$$$
Operational		
Establish protocols or SOPs for modified treatment plant operation during high turbidity and organic events	✓	$
Increase water quality monitoring and testing (special testing of additional water contaminants)		$
Reduce prechlorination practices if DBP levels are high and prechlorination is practiced*		$
Use secondary coagulants to reduce high turbidity and organics levels*		$
Bring additional treatment processes online to remove already formed DBPs*		$
Use of alternative sources of supply during high stream flow events*		$
Capital Improvement		
Install reservoir treatment strategies for high turbidity events*		$$–$$$
Install equalization storage upstream of treatment plant*		$$$
Construct additional treatment facilities as needed, such as ozonation and/or GAC filtration*		$$$
Develop alternative source of supply (such as groundwater)*		$$$

$: Can be funded by the service sector within the typical annual budget.

$$: Requires planning to implement as part of the capital improvement plan for the service sector.

$$$: Requires significant bonding, federal or grant funding, or changes to utility rates to implement the improvement.

** Long Term strategies need to be refined based on updated climate projections and outcomes of the Mid Term planning.*

7.3.2.3 Damage to Infrastructure and Infrastructure Failure

Planning, operation, and capital adaptive strategies to mitigate infrastructure damage and failures are summarized in Table 7-9. Based on treatment facilities' close proximity to rivers, plants are at a high risk for flooding. They are also vulnerable to loss of power during extreme events. Additional challenges to water production include increased turbidity and pollutant concentrations following storm events.

Short Term strategies include the development of regional emergency plans that identify key contacts with regulators, health departments, local officials, and special-use customers, such as hospitals and schools. As part of this Plan, water utilities should evaluate water system infrastructure vulnerability and define the appropriate level of service (LOS) for extreme weather events. It is also recommended that utilities evaluate their infrastructure relative to both the 500-year and 100-year flood zones and establish treatment protocols for operation during high flow events with increased turbidity and organic levels. Emergency strategies should include plans to provide water in cases of extensive infrastructure failure, including use of tanker trucks with water and use of Federal Emergency Management Agency (FEMA) or Army portable treatment units. These plans should also address backup and alternative sources of power, additional flood protection, and operational planning to restore function of the plant following extreme storm events.

Table 7-9. Damage to Infrastructure and Infrastructure Failure Related to Increased Intensity of Rain and Wind Events

Strategy	No Regrets	Cost
Planning and Policy		
Develop or update Regional Emergency Preparedness and Response Plans for extreme weather events	✓	$
As part of emergency plan, evaluate water system infrastructure vulnerabilities and lack of redundancy, and needs for system redundancy/new facilities	✓	$$
Determine appropriate LOS during extreme weather events	✓	$
Operational		
Establish protocols or SOPs for modified treatment plant operation during extreme events with high turbidity and organic levels	✓	$
Use of alternative sources of supply (likely more use of groundwater sources)*		$
Capital Improvement		
Install alternative power sources to provide power during outages (generators, solar or wind generators)	✓	$$–$$$
Install reservoir treatment strategies for high turbidity events caused from increased runoff*		$$
Construct pipelines (and emergency interties) to increase water system redundancy*		$$$
Rehabilitate or replace most vulnerable infrastructure*		$$$
Implement flood control strategies at the WTP*		$
Construct additional treatment facilities as needed (may be onsite treatment system or trailer-mounted treatment system)*		$$–$$$

$: Can be funded by the service sector within the typical annual budget.

$$: Requires planning to implement as part of the capital improvement plan for the service sector.

$$$: Requires significant bonding, federal or grant funding, or changes to utility rates to implement the improvement.

** Long Term strategies need to be refined based on updated climate projections and outcomes of the Mid Term planning.*

7.3.3 Wastewater Utility

The high-priority risks identified for the wastewater treatment sector are listed in Table 7-10, below. Adaptive strategies to mitigate each of these vulnerabilities are provided in the following tables and discussed in the subsequent paragraphs.

Table 7-10. Wastewater Utility High-Priority Risks

Vulnerability Scenario	Risks
Increased water temperature	Lower DO/changes in temperature result in more stringent discharge requirements and affect wastewater discharge allocation
Increased intensity of rain and wind events	Damage to infrastructure/infrastructure failure including power outage and flooding
	Increased CSO/SSO discharges

Climate change will impact wastewater utilities in a number of ways. Extreme storm events and increased precipitation may result in increased need for wet weather program enhancements. Both infiltration and inflow (I/I) are expected to increase. Water quality considerations driven by increased temperature may lead to the need for significant investments at treatment plants to incorporate advanced treatment systems. Flood protection measures may also be required to address the increased flood potential associated with extreme precipitation and runoff.

7.3.3.1 Strategies to Mitigate Temperature Impacts

Adaptive management strategies for wastewater utilities to mitigate impacts related to potential changes to wastewater discharge allocations are presented in Table 7-11. It is anticipated that, with the changing rainfall/runoff patterns, increased temperature, and the associated degradation of water quality in receiving waters, more stringent requirements may be placed on wastewater discharges. In several parts of the watershed, wastewater discharges represent the majority of the flow to the rivers and streams, especially during drought conditions.

As in the other sectors, Short Term strategies focus on monitoring water quality within the watershed in order to understand where and when current discharges are not maintaining water quality. This monitoring will allow utilities to develop advanced treatment plans and wastewater reuse strategies to mitigate the adverse impact of their discharges on the watershed.

Mid Term strategies include evaluation of reuse feasibility as part of the larger-scale resource management planning efforts.

Table 7-11. Wastewater Utility Strategies to address Lower DO and Increased Temperature in Receiving Water

Strategy	No Regrets	Cost
Planning and Policy		
Develop Water Quality Monitoring Plan to identify water quality problems associated with changing DO and temperature	✓	$
Conduct water reuse feasibility study to determine potential customers for reuse water and investments required to implement a reuse program	✓	$
Operational		
Conduct Water Quality Monitoring Program		$$
Establish receiving water quality conditions that could trigger treatment modifications		$$
Capital Improvement		
Implement capital projects to increase treatment and provide needed infrastructure for wastewater reuse*		$$$
Increase treatment capacity to address more stringent treatment requirements*		$$$

$: Can be funded by the service sector within the typical annual budget.

$$: Requires planning to implement as part of the capital improvement plan for the service sector.

$$$: Requires significant bonding, federal or grant funding, or changes to utility rates to implement the improvement.

** Long Term strategies need to be refined based on updated climate projections and outcomes of the Mid Term planning.*

7.3.3.2 Strategies to Mitigate Potential Increases in CSOs/SSOs and Damages to Wastewater Infrastructure

Adaptive management strategies to mitigate potential impacts related to the increased intensity of rain and wind events are presented in Table 7-12. Wastewater infrastructure is particularly at risk of flooding when extreme events occur because of the low elevation of these facilities in the watershed. Wastewater infrastructure close to or crossing streams and rivers is also vulnerable to storm damage. With more intense weather events, stream banks may erode, exposing wastewater infrastructure. Extreme storm events can also cause overflows by overwhelming the capacity of sewer systems, causing physical failures, and interrupting power at key facilities. When an overflow is next to a stream or river, the discharges can erode the stream bank and expose the utility line. Infrastructure along streams and rivers should be routinely inspected and any damage should be repaired immediately before a system failure occurs.

Short Term strategies include emergency planning and vulnerability assessments. Investments to flood-proof the most vulnerable facilities should be included in this planning effort. In some areas, pump stations may need to be flood-proofed or levees built. Additional Short Term strategies include modifying local ordinances to encourage green infrastructure (GI). Wet weather management may be addressed by traditional “gray” infrastructure such as storage tunnels or rapid disinfection processes. Many utilities are incorporating GI as part of their wet weather management portfolio. GI technologies include permeable pavement, bioretention or rain gardens, wetlands, bioswales, and green roofs. These systems can reduce the load on drainage systems, recharge aquifers, and ultimately reduce loading on wastewater collection systems.

Table 7-12. Damage to Wastewater Infrastructure and Infrastructure Failure Due to Increased Intensity of Rain and Wind Events		
Strategy	**No Regrets**	**Cost**
Planning and Policy		
Develop or update Regional Emergency Preparedness and Response Plans for extreme weather events	✓	$
As part of Emergency Preparedness Plan, evaluate wastewater system infrastructure vulnerabilities and lack of redundancy, and needs for system redundancy/new facilities	✓	$$
Establish Emergency Treatment Plan for recovery following extreme storm events as part of Emergency Preparedness Plan	✓	$$
Determine appropriate LOS during extreme weather events as part of Emergency Preparedness Plan	✓	$
Develop Emergency Power Plan including alternative power supplies to support operations in case of power loss	✓	$
Evaluate options for increased wastewater/stormwater storage for more extreme storm events as part of resource planning efforts	✓	$
Operational		
Establish protocols or SOPs for modified treatment plant operation during extreme events		$
Modify local stormwater management and land development ordinances to require LID, reduce impervious areas, and use rainwater and stormwater harvesting/reuse, thereby reducing runoff volume and potential I/I	✓	$
Implement backup power supplies at pump stations and treatment facilities including alternative power supply sources such as wind or solar*		$$$
Capital Improvement		
Reduce I/I to the sewer collection system*	✓	$$
Eliminate CSOs and implement a separate stormwater and wastewater collection system*		$$$
Implement asset management plan to rehabilitate or replace most vulnerable infrastructure		$$–$$$
Set aside land to support future flood-proofing needs (berms, dikes etc.)		$$$
Implement flood control strategies at the WWTP, protect vulnerable facilities and infrastructure		$$$
Increase capacity for wastewater and stormwater collection, treatment, and discharge including redundancies for system function with potential infrastructure losses and disruption		$$$

$: Can be funded by the service sector within the typical annual budget.

$$: Requires planning to implement as part of the capital improvement plan for the service sector.

$$$: Requires significant bonding, federal or grant funding, or changes to utility rates to implement the improvement.

** Long Term strategies need to be refined based on updated climate projections and outcomes of the Mid Term planning.*

7.4 Adaptation Strategy Implementation

It is neither feasible nor necessary that all of the adaptive strategies identified in this Plan be addressed immediately. Adaptation strategies identified as “no regrets” should be strongly considered and implemented where appropriate to strengthen the reliability and resilience of services and infrastructure within the region.

The strategies identified for the Short Term are those that should be considered in the next 10 years. The models are predicting only minor changes over this period, within the level of standard climate variability. Based solely on the current regional surface water quality conditions summarized in Section 5, watershed pollutant load reductions and reservoir operational strategies are warranted at this time. This is true independent of the future water quality impacts as a result of climate change.

The implementation of pollutant load reduction and operational strategies should reduce the potential for drinking water T&O issues and harmful algal blooms, and protect aquatic life and human health.

In the Short Term the region needs to: monitor existing conditions; identify primary external and internal pollutant sources; protect existing resources; enhance operational procedures; initiate regional watershed planning; assess the flooding vulnerabilities of critical infrastructure; implement non-structural best management practices (BMPs) and begin the implementation of stormwater LID retrofit demonstration projects in the watershed to reduce nutrient/pollutant loads; and lay the groundwork for potential regional coordination and collaboration, which may be needed to address regional climate change issues in the future. These efforts need to address both water quantity and water quality. It is recommended that the region's municipal leaders begin to meet to share thoughts on potential implications and begin to consider collaboration with regard to resource planning.

In the Mid Term, which consists of the next 30 years, the models reflect more variability in precipitation and stream flow along with the projected increase in mean annual temperature. During this time frame, the region needs to conduct planning studies to inform and refine Long Term adaptation strategies, continue the implementation of non-structural BMPs, implement stormwater retrofit projects to reduce watershed nutrient/pollutant loads, and improve surface water quality.

The Long Term strategies are strategies that should be implemented from 2045 out to the end of the century. The climate predictions for this period suggest significant variability between the different climate models with respect to precipitation. A significant increase in temperature is predicted during this period by all of the climate models. Because of the variability and uncertainty during this time frame, strategy implementation will have to be reassessed based on the realization of climate changes and updated based on outcomes from the Mid Term planning studies. Although the types of projects and activities may change, the need to continue to implement non-structural and structural BMPs is expected to improve water quality. It is likely that there will be additional pollutant of concern that will need to be addressed in the future such as pharmaceuticals and hormones.

A key factor in implementation of all of the strategies is the routine monitoring of climate and risk conditions. Strategies will need to be modified over time as climate projections are refined. By reviewing updated data on a routine cycle (i.e., every 10 years), the region can monitor what changes are occurring and alter the implementation of strategies accordingly. The strategies and their implementation time frames are summarized in Table 7-13 below.

Table 7-13. Adaptation Strategy Prioritization

Short Term (10 Years) 2015–25	Mid Term (11–30 Years) 2026–45	Long Term (31–75 Years) 2046–90
Regional Collaborative Forum Establish forum for regional collaboration and planning with regard to issues related to water supply, water quality, treatment, and climate change impacts. Public Education Implement public education and outreach on sources of pollutants, water quality, supply, and climate change. Improve Emergency Preparedness Capacities Develop or update Regional Emergency Preparedness and Response Plans for extreme weather and water quality events. Evaluate and provide flood protection for critical assets. Develop Emergency Power Supply Plans. Enhance Operational Procedures Conduct (expand) water quality monitoring throughout the watershed and treatment process and identify primary sources of external and internal pollutants. Establish SOPs for modified reservoir and treatment plant operations during high turbidity, algae, and organics events. Resource Protection Develop a guide for and promote high efficiency irrigation systems and low water use landscaping. Reduce fertilizer use. Modify local stormwater management and land development ordinances to incorporate LID practices. Develop a cooperative program with agriculture to reduce runoff pollutant loads. Implement public LID demonstration projects and promote/incentivize private LID retrofit. Implement additional non-structural BMPs to reduce nutrient/pollutant loads to surface waters.	Water Supply Planning Develop Regional Water Supply Management Plan including sustainable groundwater supply, and irrigation needs. Groundwater Supply Planning Conduct a regional groundwater study to assess availability of groundwater for regional growth and irrigation uses. Water Reuse Planning Identify areas for water reuse (e.g. irrigation, industrial applications, etc.) to reduce water demands. Reservoir Capacity Planning Develop Reservoir Operational Plan for optimizing reservoir capture and reservoir management during drought and high flow conditions. Nutrient/Pollutant Reduction Planning and Implementation Continue Regional Watershed Management Planning based on expanded monitoring to identify primary watershed external and internal pollutant loads and protect/improve reservoir water quality. Install structural BMPs to reduce nutrient/pollutant loads to surface waters. Complete necessary in-reservoir treatment to protect/improve reservoir water quality. Re-evaluate Climate Conditions Continue to monitor and evaluate changes to climate, water demand, and watershed. Update plan as needed.	Reevaluate Climate Conditions Continue to monitor and evaluate changes to climate and watershed. Update plan as needed. Refine Long Term adaptive strategies Refine and implement Long Term strategies based on outcomes of Mid Term planning studies.

Section 8

Conclusions

There is no question that climate change is occurring. What is less clear are the impacts these changes will have on our region, its people, its environment, and its resources. This project has sought to identify the potential changes in both climate and development that may occur within the region over the next 75 years. These potential changes were evaluated to identify vulnerabilities to water resources, infrastructure, public health, the economy, agriculture, and the environment and to prioritize those vulnerabilities based on their likelihood of occurrence and their impact on livability to the region. Each of the high-priority vulnerabilities was analyzed to develop potential adaptive strategies to address and mitigate the risks. This project provides a solid foundation for future planning within the region with regard to development, infrastructure investment, natural resources, and public health and safety. However, this is an iterative process and analysis of the factors affecting the identified vulnerabilities should continue to be monitored and adaptive strategies refined based on updated data.

It is important to note that based on current monitoring results, surface waters in the Scioto River basin already contain elevated concentrations of nitrogen, phosphorus, and other pollutants of concern. With higher temperatures in the future combined with additional nutrient loads, algal bloom frequency and intensity is expected to increase. Even under current conditions, algal blooms could be more prevalent and intense. For these reasons there is some urgency in identifying and reducing the primary sources of pollutants in the watershed. With new development in the watershed, stormwater runoff nutrient loads are expected to further increase in the future.

Developing a more thorough understanding of the watersheds and surface water system through monitoring and analyses will allow the preparation of operational strategies to further improve the reliability and resilience of the water supply and utility systems and improve future decision making. Additional regional coordination and planning would also enhance system reliability and resilience. Other strategies, such as the more expensive capital improvements, may not be appropriate under current conditions, but may become necessary as conditions change and more is understood. Once the water supply and watershed planning is completed, capital projects will likely be identified that should be completed in the Long Term.

Adaptation strategies identified as “no regrets” should be strongly considered and implemented where appropriate to strengthen the reliability and resilience of services and infrastructure within the region. Most of the “no regrets” strategies are relatively low cost while providing substantial benefits. Implementation of these strategies will require action by local governments in combination with regional coordination.

In the short term, it is recommended that the region focus on establishing a framework for regional collaboration, identify and address immediate water quality concerns, and update or enhance its emergency planning to address more extreme and more frequent storm events.

Regional Collaboration Is Required. The projected impacts to the Scioto River basin associated with climate change are regional and will require regional collaboration and planning. This is a new approach for central Ohio, where the need to collaborate on resource planning has not been required in the past. In the Short Term, it is recommended that the region’s municipal leaders begin by establishing a forum for planning and collaboration, to address and consider the larger-scale issues related to maintaining safe and reliable water resources and water supply systems, both now and in the future.

Water Quality Improvements Are a Key Focus Area. Surface waters in the Scioto River basin already contain elevated concentrations of nitrogen and phosphorus. Higher temperatures in the future, combined with additional nutrient loads, will increase algal bloom frequency and intensity. Algal blooms can lead to a variety of aesthetic, health, and drinking water issues. There is some urgency in identifying and reducing the primary sources of nutrients in the watershed. Minimizing the nutrient and other pollutant loads is essential to protecting surface water quality in the region. A combination of structural and non-structural BMPs is recommended to address the primary external pollutant loads in the watershed. Optimization of reservoir operations and reservoir management is recommended to address primary internal reservoir pollutant loads. Enhanced monitoring is proposed to identify the primary external and internal pollutant loads.

A Robust Emergency Plan Is Critical for the Region. Over the past decade, the region has experienced record-breaking heat, unprecedented flooding, and prolonged periods of drought. Across the United States, we have also seen the impact of extreme weather events on utilities. Fortifying critical water infrastructure and robust emergency planning and preparedness is an important element of this Adaptive Management Plan for central Ohio.

Section 9

Limitations

This Adaptive Management Plan was prepared using information provided by the City of Columbus and information contained in the watershed modeling study completed by USGS (USGS 2015). The USGS modeling included the following assumptions and limitations in its regional analyses:

- The water use and wastewater discharges projected over the planning period for the modeling study (2015–90) were limited to the evaluation of surface water use. Groundwater infiltration was calculated in the model, but groundwater withdrawals for use were not accounted for in the model or in the water inventory developed for the watershed.
- Water use and wastewater discharge projections are based on constant per capita usage/discharge rates and the projected population change over the planning horizon. This assumes a similar mix of industrial/commercial/residential water use and water conservation efforts as currently exist in the region.
- The population data used for the growth projections were based on population projections provided by MORPC. MORPC uses census data and input from local government planning agencies to develop population projections and land use designations for the central Ohio region.
- Buildout population was developed based on the assumption that each area would be fully developed based on the existing land use zoning. This does not include the potential for future re-zoning of areas, such as the re-zoning of agricultural land to urban/commercial or industrial land use.
- The USGS watershed model output indicated changes in trends of stream flow or reservoir elevation with the projected changes to the climate in the region. This output cannot be used to develop a frequency for the projected changes to flow or reservoir elevation. The goal of the modeling was to provide an understanding of the range of expectations for regional planning efforts.

The adaptive management strategies in this Plan are provided for three general planning horizons: Short Term (next 10 years), Mid Term (10–30 years), and Long Term (by turn of century). This plan assumes that the Long Term and Mid Term strategies will both be updated over time based on collected monitoring data and updated information related to projected changes to the climate. The Plan also assumes that the Long Term strategies would be updated and refined based on outcomes of the Mid Term planning studies.

This document was prepared solely for MORPC in accordance with professional standards at the time the services were performed and in accordance with the contract between MORPC and Brown and Caldwell dated May 1, 2013. This document is governed by the specific scope of work authorized by MORPC; it is not intended to be relied upon by any other party. We have relied on information or instructions provided by MORPC and other parties and, unless otherwise expressly indicated, have made no independent investigation as to the validity, completeness, or accuracy of such information.

Further, Brown and Caldwell makes no warranties, express or implied, with respect to this document, except for those, if any, contained in the agreement pursuant to which the document was prepared.

Section 10

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List of Abbreviations

°F	degree(s) Fahrenheit
µg/L	microgram(s) per liter
AEP	American Electric Power
ASR	aquifer storage and recovery
BMP	best management practice
cfs	cubic foot/feet per second
CSO	combined sewer overflow
DBP	disinfection by-product
DO	dissolved oxygen
DRWP	Dublin Road Water Plant
El	elevation
EPA	(Ohio) Environmental Protection Agency
EQIP	Environmental Quality Incentives Program
FEMA	Federal Emergency Management Agency
GAC	granular activated carbon
GCM	Global Climate Model
GI	green infrastructure
GIS	geographic information system
gpcd	gallon(s) per capita per day
HCWP	Hap Cremean Water Plant
HAA	haloacetic acid
HSPF	hydrologic simulation program-FORTRAN
HSTS	home sewage treatment system
I/I	infiltration and inflow
LID	low-impact development
LOS	level of service
MCL	maximum contaminant level
MG	million gallon(s)
mgd	million gallon(s) per day
mg/L	milligram(s) per liter
MORPC	Mid-Ohio Regional Planning Commission
MS4	municipal separate storm sewer system
NACWA	National Association of Clean Water Agencies
NH_3	ammonia
NOM	natural organic matter
NO_x	nitrate-nitrite
NPDES	National Pollutant Discharge Elimination System

NTU	nephelometric turbidity unit(s)
ODNR	Ohio Department of Natural Resources
ODOT	Ohio Department of Transportation
OP	organic phosphorus
org/L	organism(s) per liter
OWDA	Ohio Water Development Authority
PAWP	Parsons Avenue Water Plant
PCU	platinum cobalt unit(s)
Plan	Adaptive Management Plan
ppt	part(s) per trillion
RPC	Regional Planning Commission
SAC	Stakeholder Advisory Committee
SOP	standard operating procedure
SWCD	Soil and Water Conservation District
T&O	taste and odor
TIN	total inorganic nitrogen
TM	technical memorandum
TMDL	total maximum daily load
TOC	total organic carbon
TP	total phosphorus
TSI	Trophic State Index
TTHMs	total trihalomethanes
USDA	U.S. Department of Agriculture
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey
WHO	World Health Organization
WMP	watershed management plan
WRF	Water Research Foundation
WTP	water treatment plant
WWTP	wastewater treatment plant
WWFRP	Water Withdrawal Facilities Registration Program

Appendix A: Stakeholder Handouts and Public Outreach Materials

Extreme Weather, Changing Climate, and the Future of our Water

MID-OHIO REGIONAL PLANNING COMMISSION

SUSTAINING SCIOTO

INVESTING TODAY. PRESERVING TOMORROW.

MORPC, together with the U.S. Geological Survey (USGS), the City of Columbus, Del-Co Water Company, Inc., the Ohio Water Development Authority, and Brown and Caldwell has initiated a planning study called "Sustaining Scioto".

This proactive, science-based study is to ensure that Central Ohio has clean and secure water resources for current residents and businesses, and to sustain needs from future growth. It includes developing adaptive strategies to manage water quality and quantity during extreme drought or flood. The study has two-phases and will be completed in 2015.

Phase I: Develop a computer model for projecting the impacts of changing weather patterns on the region's water resources. This model is now complete. It was developed by the USGS specifically for the Upper Scioto watershed.

Phase II: Develop an adaptive management plan using the results of the model and input from a broadly based Stakeholder Advisory Committee.

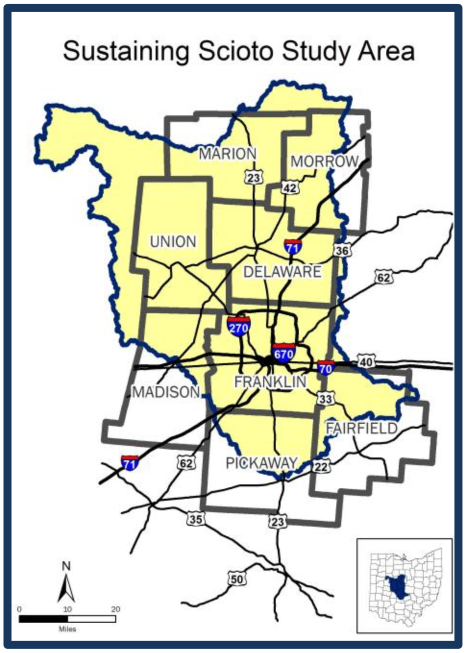
The need to prepare for future extreme weather

Rare and extreme weather events are becoming more common. Over the past few years, the region has experienced record-breaking heat, unprecedented flooding, and prolonged periods of drought.

Did you know?

- 2011 was the wettest year on record for many locations in Ohio.
- 2012 had 75 record-breaking heat, rainfall and snow events in Ohio.
- 2013 had Ohio's third wettest July on record.

Flooding along Indianola Avenue, July 2013



Preventing impact on the region's water resources

Clean water is a critical resource for public health and the long-term growth of our region. The weather patterns in Central Ohio are changing, elevating the need to prepare and protect the region's valuable water resources and infrastructure.

- Existing drinking water supply systems, stormwater and wastewater sewer systems are designed to handle historic rainfall volumes that may not reflect future conditions.
- Planning for extreme weather is required to effectively manage the quality and quantity of our water supply sources.
- Weather extremes jeopardize the reliability of critical water treatment facilities.

September, 2013

Project Stakeholders

- **Stakeholder Advisory Committee**
  A Stakeholder Advisory Committee comprised of representatives from municipalities, agricultural, industrial and regulatory communities and environmental advocacy groups will be formed to provide input on current and future water needs and water resource vulnerabilities to aid in consideration of adaptive management strategies.

Project Results

- **Water Use Projections**
  Future water use within the Scioto River watershed will be defined based on projected population growth and changes in commercial, industrial and agricultural water use.

This project will include:

- **Evaluation of the total water resources within the region**
- **Evaluation of current and future water uses**
- **Development of an integrated adaptive management plan for responding to impacts to our water resources from changing weather patterns**

- **Scioto River Watershed Inventory**
  A water inventory will be developed for the watershed that includes the major water consumers and the available surface water within the watershed. This inventory will help MORPC and the Stakeholder Advisory Committee evaluate various management scenarios and understand how the changing weather patterns may impact water resources through time.

- **Public Outreach**
  MORPC is taking a proactive role by conducting this study to ensure that the region has sustainable and secure water resources for growth and economic development into the future. Support and input from the public and local businesses will be a critical part of plan development.

- **Risk Assessment**
  During the risk assessment phase of the project, water sources and infrastructure will be evaluated to determine the vulnerability to the changing weather patterns based on the USGS modeling results.

- **Adaptive Management Planning**
  Adaptive management planning provides a flexible planning approach that will consider multiple alternatives for water resource management and allow for adaptation to changing weather conditions. The project team and Stakeholders will consider options to reduce the risk and vulnerability of critical resources. Water resource management strategies will be developed to limit the future vulnerability of our supply sources. Strategies may include modifying utility operations, managing water demand and modifying existing water/wastewater infrastructure as needed to continue to serve Central Ohio's water and wastewater needs.

Questions?

Visit the website for more information at www.morpc.org/energy/center/sustainingscioto.asp or contact David Rutter at the Mid-Ohio Regional Planning Commission with any questions about Sustaining Scioto at drutter@morpc.org or (614) 233-4186.

September, 2013

SUSTAINING SCIOTO

INVESTING TODAY. PRESERVING TOMORROW.

SUSTAINING SCIOTO

Ensuring that Central Ohio has clean and secure water resources for current and future residents, today and tomorrow.

morpc
Mid-Ohio Regional
Planning Commission

Climate models predict Ohio will experience temperature increases and greater weather variability. Overall temperature in Ohio has steadily increased across all seasons, and more extreme storms and droughts in Ohio are predicted in the long-term.

WEATHER is a specific event or condition that happens over a short period of time, such as a thunderstorm or daily temperature.

CLIMATE is the average weather conditions in a place over a long period of time.

So even though weather may not seem consistently more severe, Ohio's temperatures are rising and weather patterns are becoming increasingly more variable...

Increasing air temperatures. → Warmer air holds more water. → Increasing variability in amounts and intensity of precipitation. → Extreme weather events.

This will change the amount and quality of water we have available for our communities.

ABOUT THIS STUDY

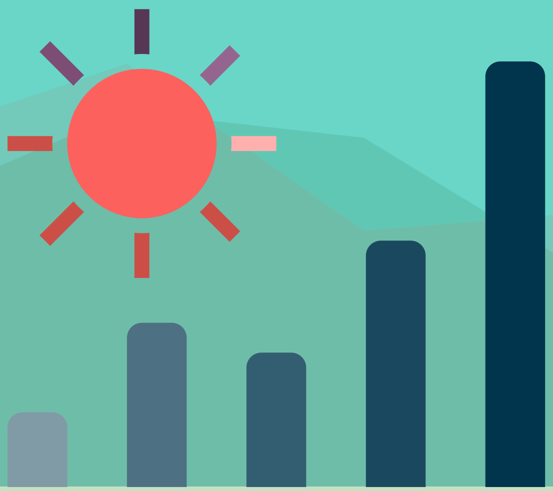
The Upper Scioto Basin provides drinking water for close to 2 million people.

Surface water from the Scioto River and its tributaries provide almost 85% of the region's water supplies.

This study was conducted to proactively identify risks to the region's water resources due to climate change. The project brings together technical data, climate modeling and stakeholder input. The end result will be an adaptive management plan to respond to impacts resulting from climate change.

The study uses United States Geological Survey watershed modeling to assess the impacts of changing weather patterns and regional development on water resources within the Upper Scioto watershed. Vulnerabilities to water resources, public health, the economy and other sectors within the region were identified and prioritized. Adaptive strategies were to developed to address these vulnerabilities both now and in the future.

WWW.MORPC.ORG/SUSTAININGSCIOTO



INCREASE IN TEMPERATURES AND HEAT WAVES

- Reduced water volumes coupled with increased water demand
- Lower water quality
- Increased waterborne and heat- related illnesses and deaths
- Increased energy costs

INCREASE IN EXTREME STORMS/WEATHER

- Damage to infrastructure or infrastructure failure
- Loss of power
- Increased burden on economy to repair the damage
- Lower water quality

ADAPTIVE MANAGEMENT STRATEGIES

If the past can no longer be relied upon to predict the future, municipalities need to also consider system function with more extreme droughts and storms. Developing infrastructure is expensive and takes time, so planning now is important!

The basic approach to adaptive management includes understanding and prioritizing risks, developing strategies to reduce risks, implementing strategies, and reevaluating strategies as more information becomes available.

SHORT TERM
2015 - 2025

Conditions similar to today

- **Regional Collaborative Forum**
- **Focus on Public Education**
- **Expand Emergency Preparedness Capacities**
- **Enhance Operational Procedures**
- **Implement Resource Protection**

MID TERM
2026 - 2045

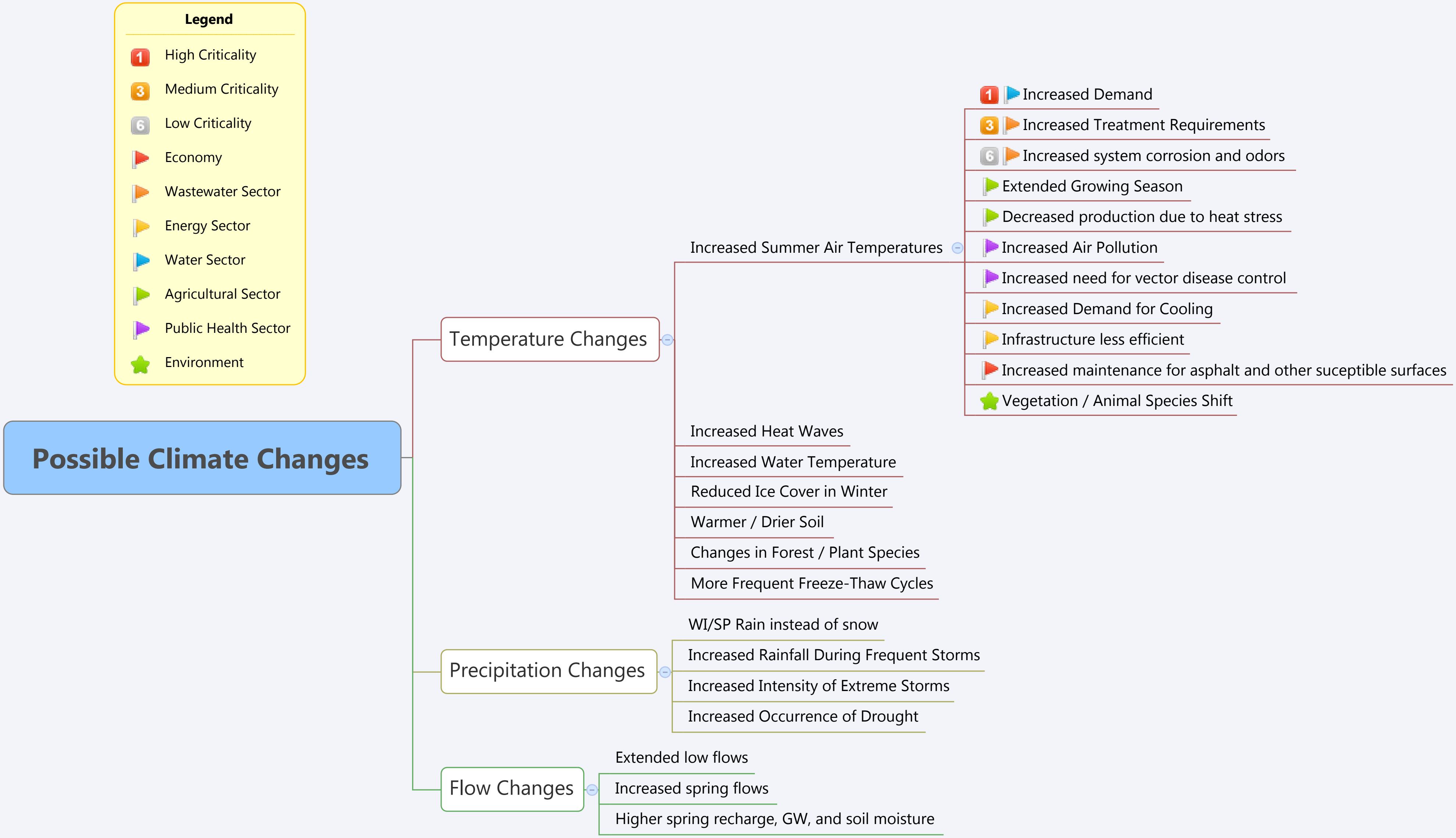
Slightly increased annual average temperature but higher seasonal temperatures; more variability in stream flow and precipitation

- **Water Supply Planning**
- **Groundwater Supply Planning**
- **Water Reuse Planning**
- **Reservoir Capacity Planning**
- **Nutrient/Pollutant Reduction Planning**
- **Re-evaluate Climate Conditions**

LONG TERM
2046 - 2090

Increased temperature; more variability in stream flow; Update plans on actual climate conditions

- **Re-evaluate Climate Conditions**
- **Refine Long Term Adaptive Strategies**



Legend

1	High Criticality
3	Medium Criticality
6	Low Criticality
🟥	Economy
🟧	Wastewater Sector
🟨	Energy Sector
🟦	Water Sector
🟩	Agricultural Sector
🟪	Public Health Sector
★	Environment

Possible Climate Changes

- Temperature Changes
  - Increased Summer Air Temperatures
    - 1 🟦 Increased Demand
    - 3 🟧 Increased Treatment Requirements
    - 6 🟧 Increased system corrosion and odors
    - 🟩 Extended Growing Season
    - 🟩 Decreased production due to heat stress
    - 🟪 Increased Air Pollution
    - 🟪 Increased need for vector disease control
    - 🟨 Increased Demand for Cooling
    - 🟨 Infrastructure less efficient
    - 🟥 Increased maintenance for asphalt and other suceptible surfaces
    - ★ Vegetation / Animal Species Shift
  - Increased Heat Waves
  - Increased Water Temperature
  - Reduced Ice Cover in Winter
  - Warmer / Drier Soil
  - Changes in Forest / Plant Species
  - More Frequent Freeze-Thaw Cycles
- Precipitation Changes
  - WI/SP Rain instead of snow
  - Increased Rainfall During Frequent Storms
  - Increased Intensity of Extreme Storms
  - Increased Occurrence of Drought
- Flow Changes
  - Extended low flows
  - Increased spring flows
  - Higher spring recharge, GW, and soil moisture

Adaptation Options Planning Worksheet - EXAMPLE

MID-OHIO REGIONAL PLANNING COMMISSION
SUSTAINING
SCIOTO
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Critical Impact Title and Description
Increased flooding from severe storm events

List the Critical Threshold conditions that may result in damage or failure of your assets, change in your operational strategy or may negatively impact the region. Some examples might be a minimum flow or a flood level and associated peak flows that impact your current operating capacity.
Flooding in excess of 100 year storm; Increased frequency of flooding events

Adaptation Options:

Planning Strategies	Cost*
Identify and protect vulnerable facilities	$- $$
Integrate flood management and modeling into land use planning by elevating flood impacts associated with more extreme floods (ie 500 years)	$
Consider potential water quality changes and costs of resultant changes in treatment	$
Integrate climate-related risks into capital improvement plans	$

Operational Strategies	Cost*
Monitor and inspect existing infrastructure	$$
Monitor flood events	$
Monitor surface water quality and modify treatment process	$

Capital Improvement Strategies	Cost*
Monitor weather conditions and establish flood warning system based on rain / flow gauge network	**$$-$$$**
Acquire and manage ecosystems, such as forested watersheds, vegetation strips, and wetlands, to buffer against floods and sediment and nutrient inflows.	$$$
Implement green infrastructure on site and in municipalities to reduce runoff and associated pollutants	$$$
Implement or retrofit source control measures that address altered flow and quality at treatment plants	$$-$$$
Increase water storage capacity, including silt removal to expand capacity at existing reservoirs and construction of new reservoirs.	$$$
Relocate or protect critical infrastructure and facilities	$$-$$$

**General relative estimates expressed in terms of: $, $$, $$$*

Climate Change Adaptation Questionnaire

Source Water Quality

Question	Water Quality Issue				
	Taste & Odor	Algal Blooms	High Turbidity Events	High Organic Events	Drought
Do you monitor for these water quality issues?	☐ Yes ☐ No	☐ Yes ☐ No	☐ Yes ☐ No	☐ Yes ☐ No	☐ Yes ☐ No
Do you have an action plan to address any of these issues when they occur?	☐ Yes ☐ No	☐ Yes ☐ No	☐ Yes ☐ No	☐ Yes ☐ No	☐ Yes ☐ No
What actions do you take to mitigate for these issues?	☐ Adjust chemical treatment ☐ Change supply source ☐ Treat at source	☐ Adjust chemical treatment ☐ Change supply source ☐ Treat at source	☐ Adjust chemical treatment ☐ Change supply source ☐ Treat at source	☐ Adjust chemical treatment ☐ Change supply source ☐ Treat at source	☐ Change supply source ☐ Implement conservation measures

- What are your current conservation practices?
  - ☐ Watering restrictions
  - ☐ Plumbing codes
  - ☐ Tiered rates
  - ☐ Other
- What level of confidence do you have that your community will be able to provide reliable high quality water supply to meet water demands for the next 30 years?
  - ☐ High
  - ☐ Medium
  - ☐ Low

Water Supply Management

Question	Water Management			
	Long Range Water Supply Plan	Watershed Management Plan	Drought Management Plan	Emergency Supply Source/Agreement
Does your utility currently have a:	☐ Yes ☐ No	☐ Yes ☐ No	☐ Yes ☐ No	☐ Yes ☐ No
If no, is this part of your CIP?	☐ Yes ☐ No	☐ Yes ☐ No	☐ Yes ☐ No	☐ Yes ☐ No

Infrastructure Reliability

Question	Infrastructure			
	Treatment Infrastructure	Pump Stations	Raw Water Intake	Electrical Equipment
Are critical facilities outside the 100-yr flood plain?	☐ Yes ☐ No	☐ Yes ☐ No	☐ Yes ☐ No	☐ Yes ☐ No
Are these facilities flood proof?	☐ Yes ☐ No	☐ Yes ☐ No	☐ Yes ☐ No	☐ Yes ☐ No
Do these facilities have back-up power?	☐ Yes ☐ No	☐ Yes ☐ No	☐ Yes ☐ No	☐ Yes ☐ No

- What information would be helpful in determining whether your community will be able to provide reliable high quality water supply to meet water demands for the next 30 years?

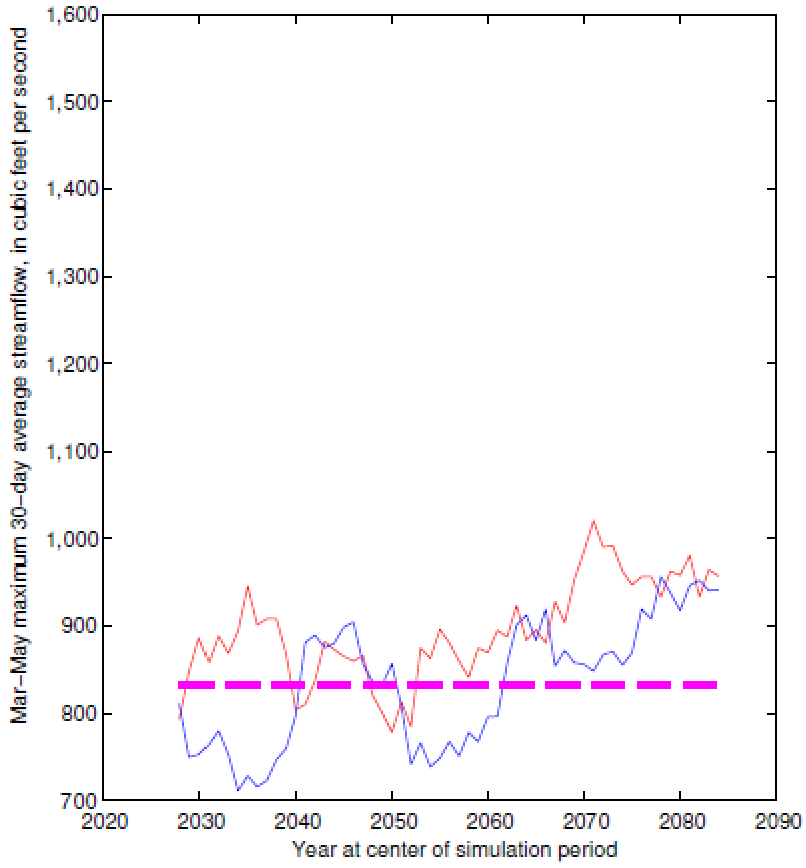
Appendix B: Graphs of Predicted Stream Flow and Reservoir Levels at Selected Sites

Little Scioto Reach with Marion Public Water Supply

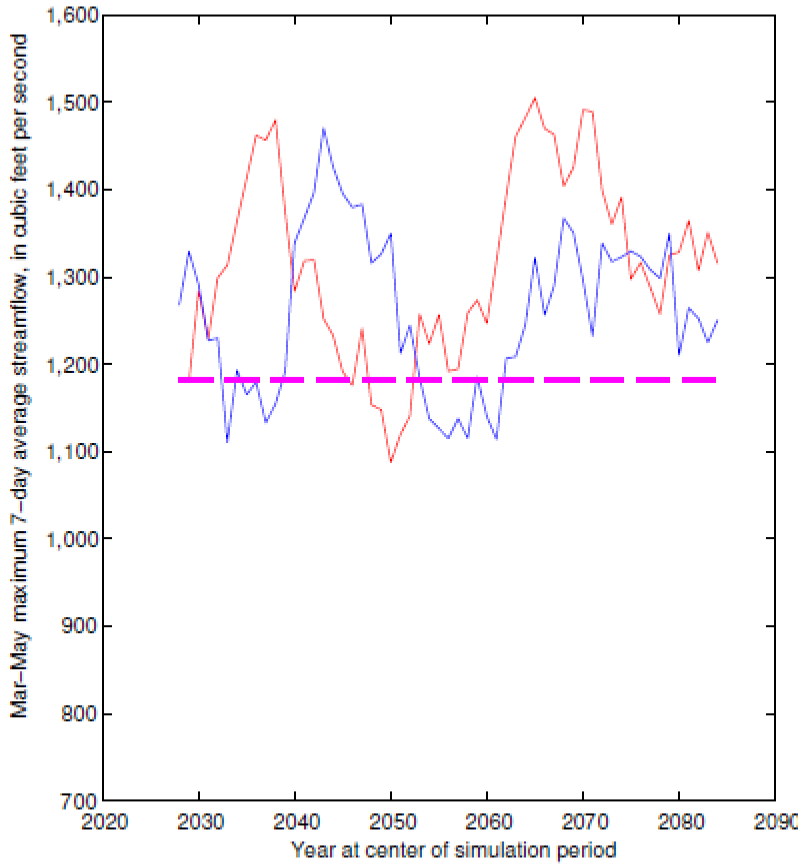
Median A1b
Median A2
Calibration period

Spring Average Maximum Stream Flow: Climate Only

30-Day

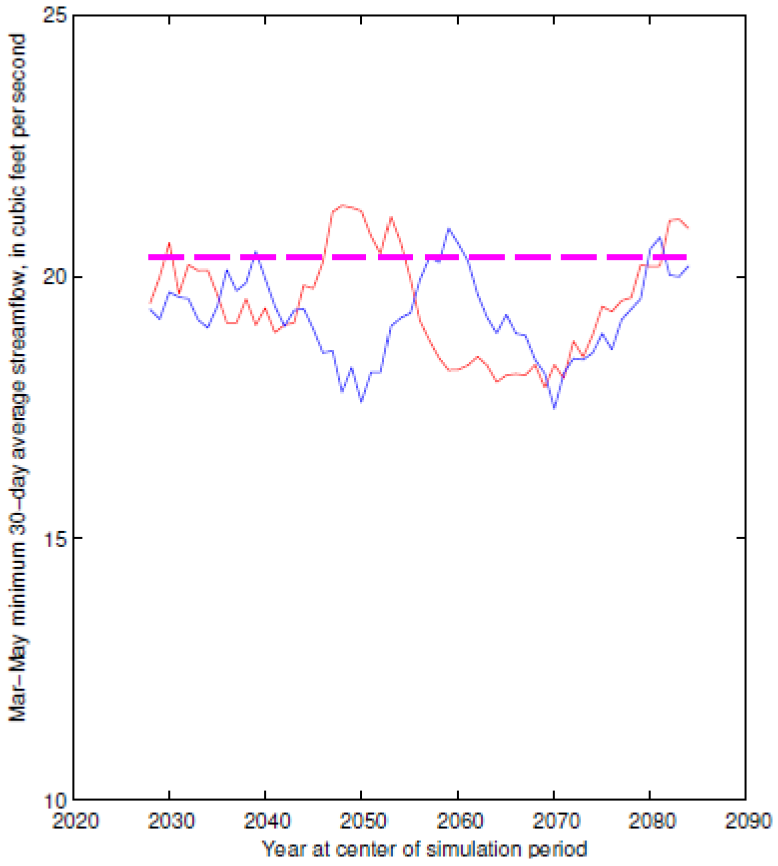


7-Day



Spring Average Minimum Stream Flow: Climate Only

30-Day



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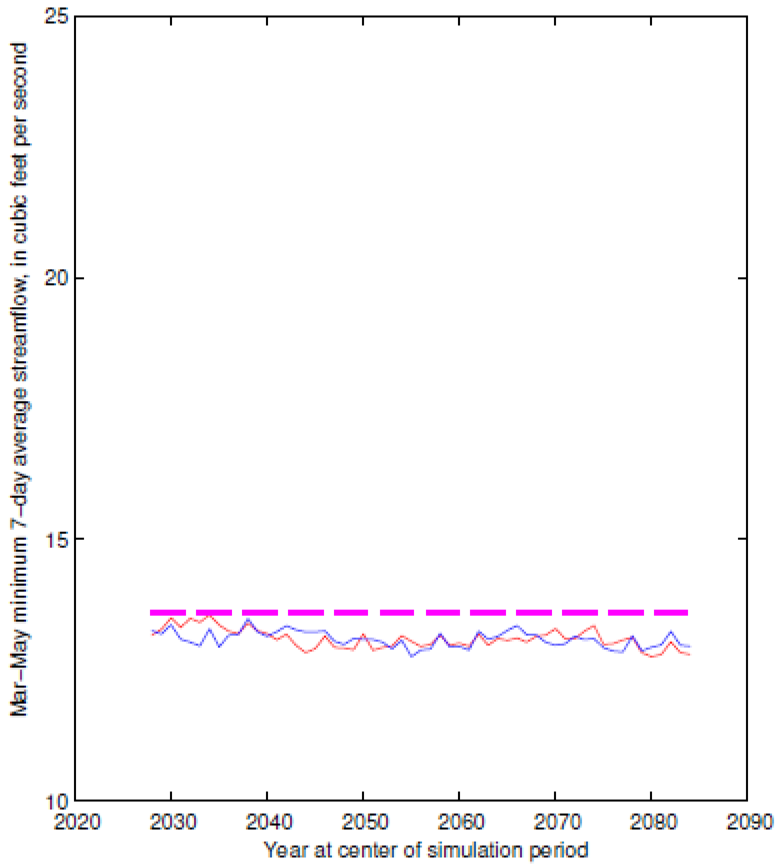
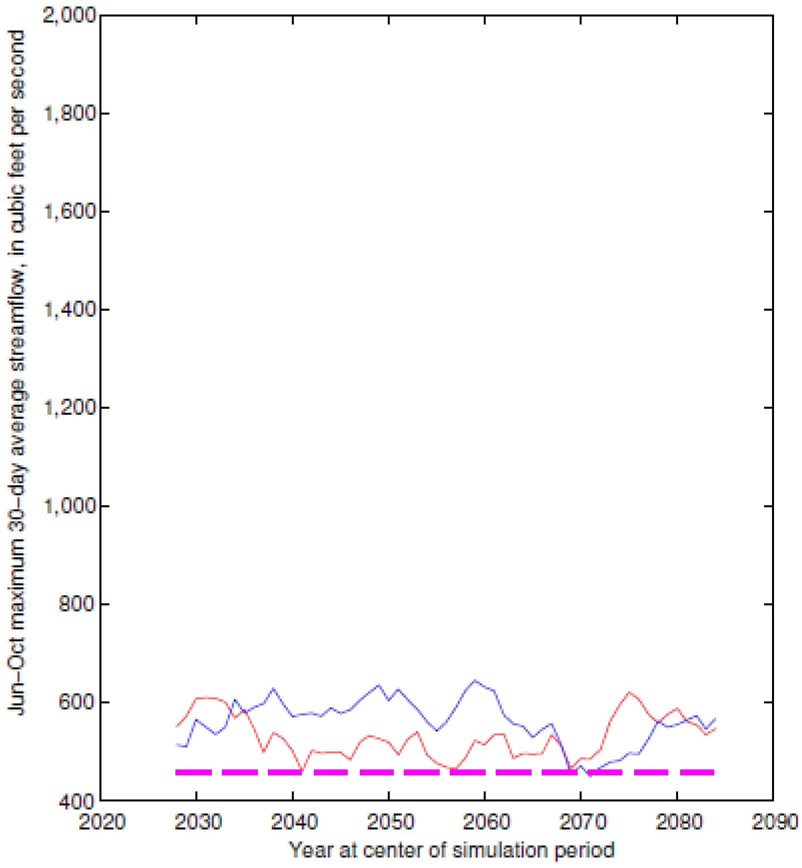


Little Scioto Reach with Marion Public Water Supply

Summer Average Maximum Stream Flow: Climate Only

30-Day



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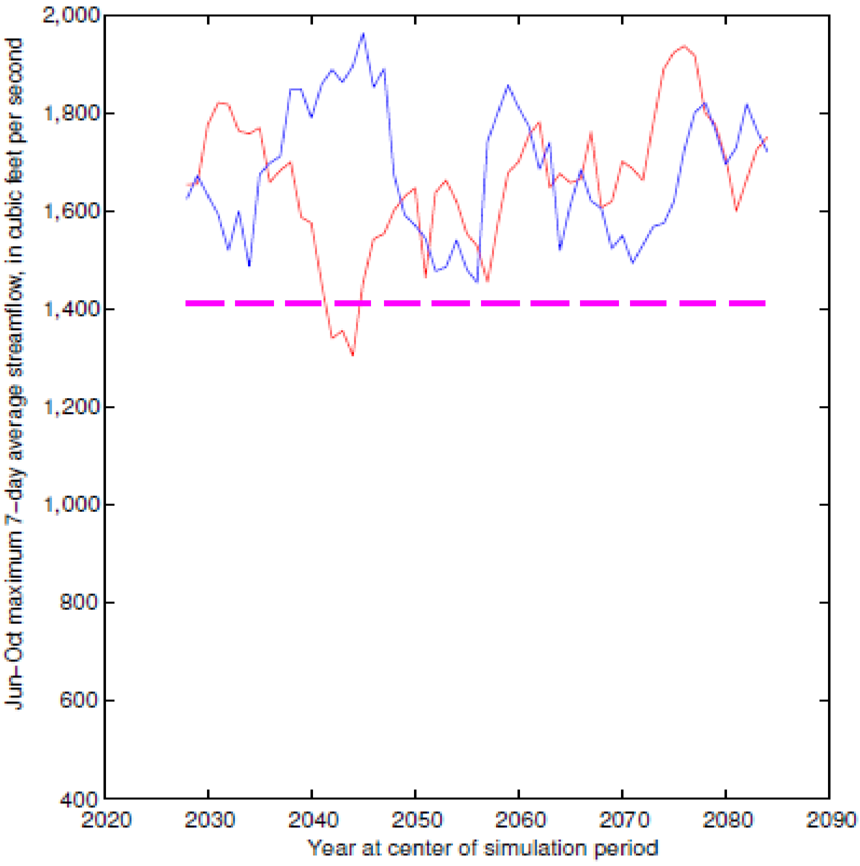
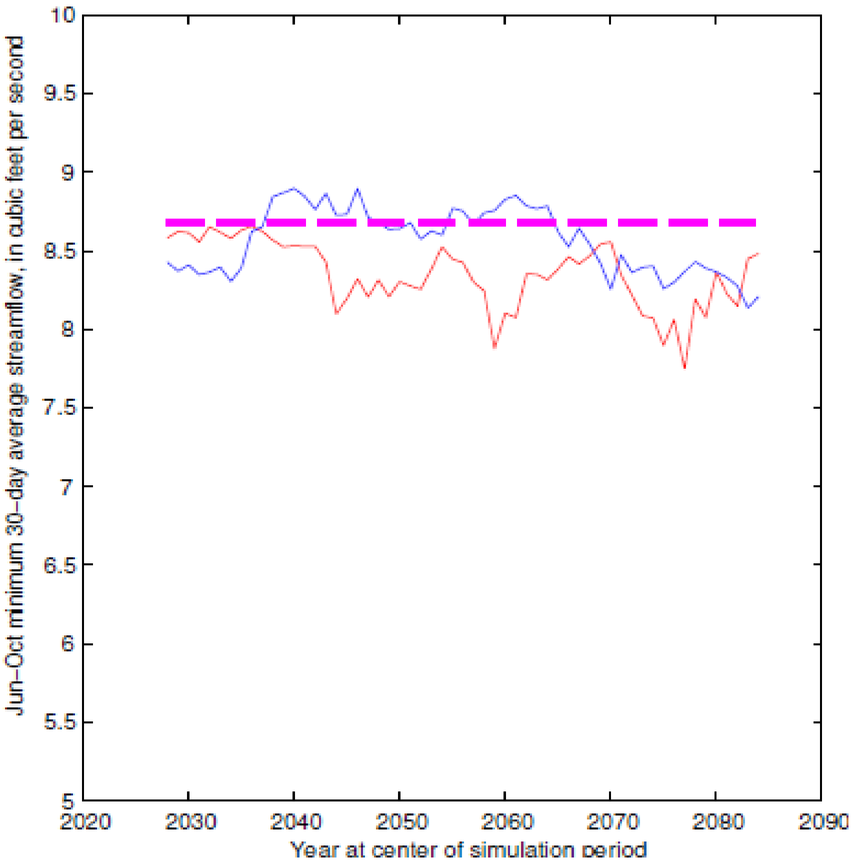


Summer Average Minimum Stream Flow: Climate Only

30-Day



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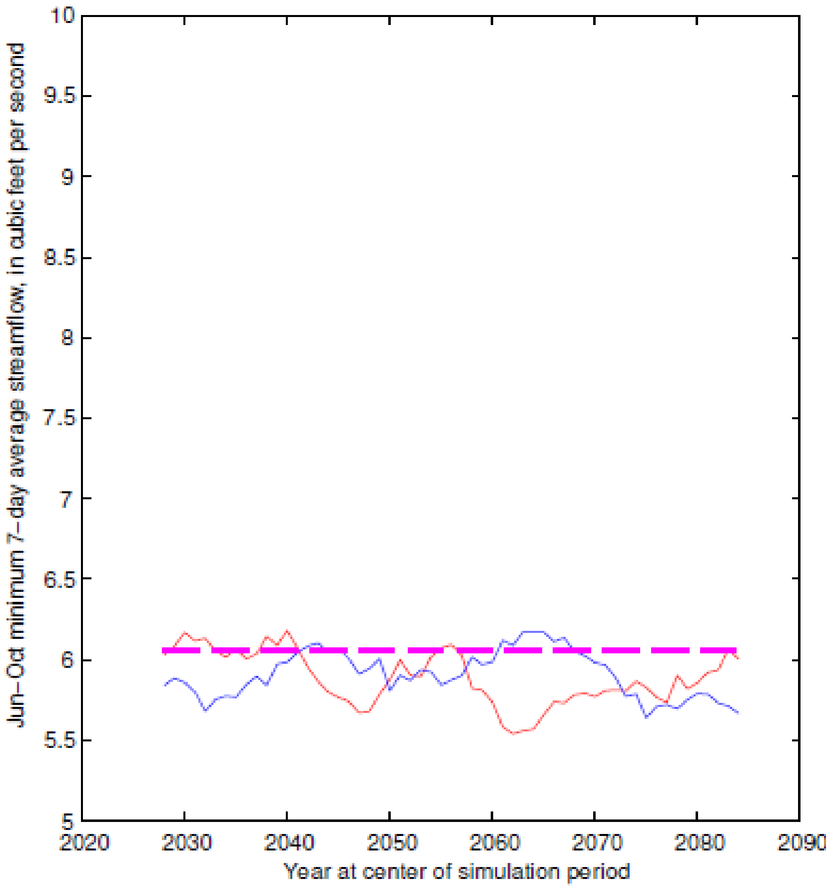
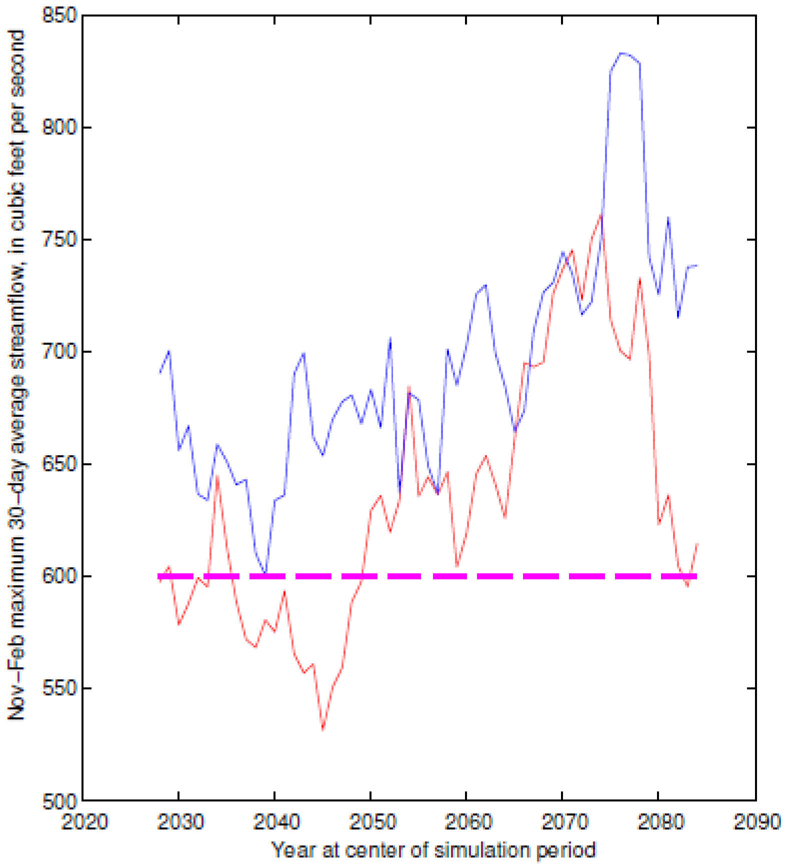


Little Scioto Reach with Marion Public Water Supply

Median A1b
Median A2
Calibration period

Fall/Winter Average Maximum Stream Flow: Climate Only

30-Day



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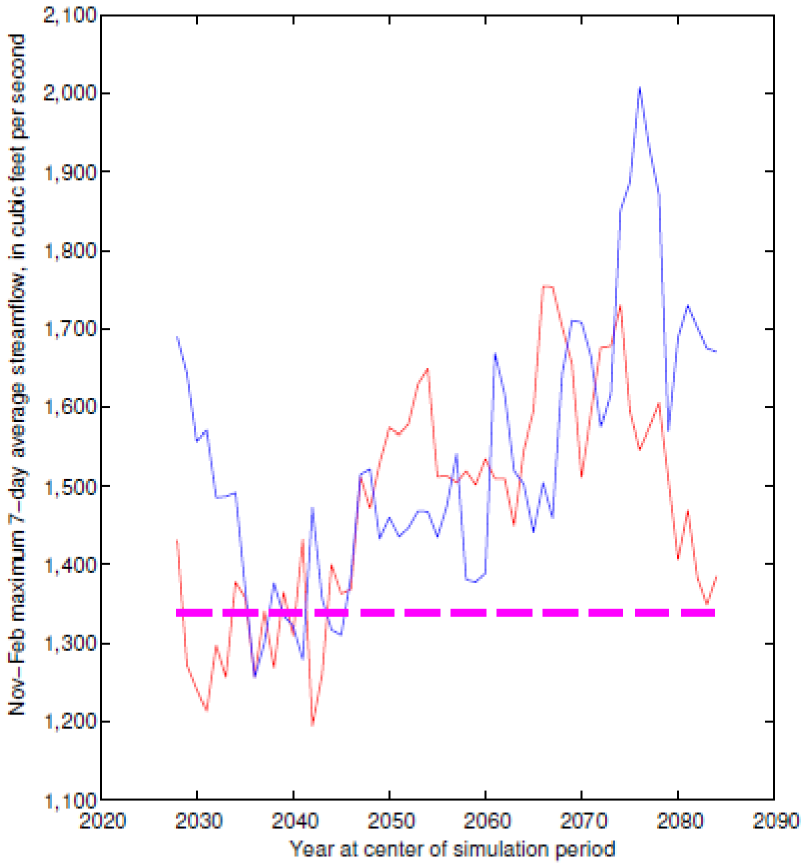
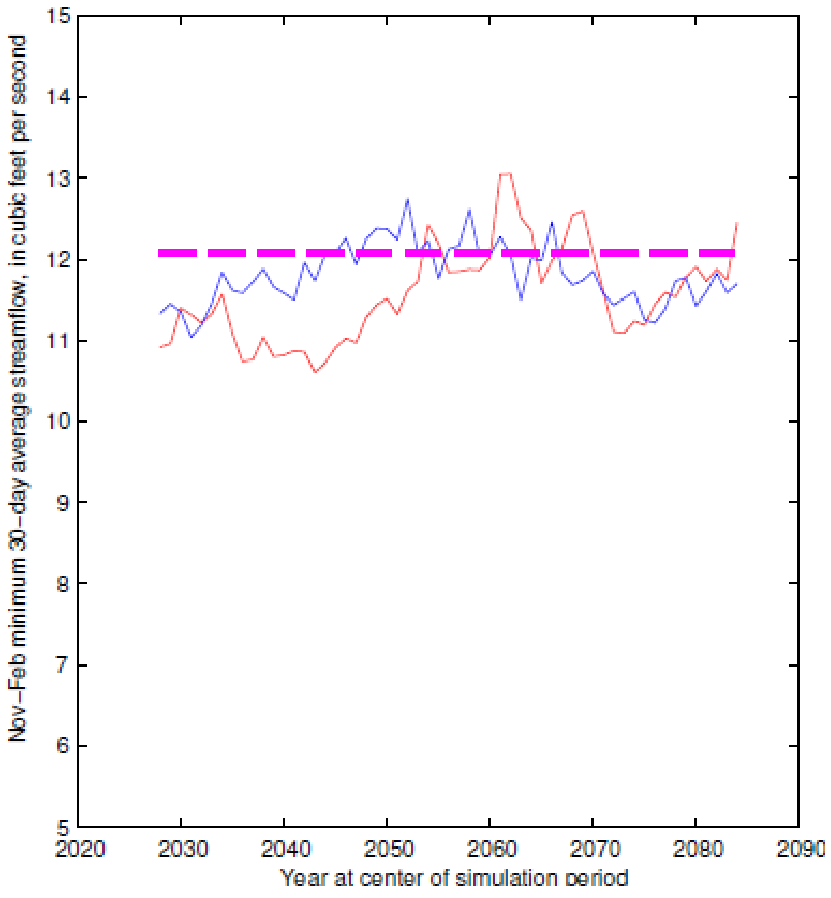


Fall/Winter Average Minimum Stream Flow: Climate Only

30-Day



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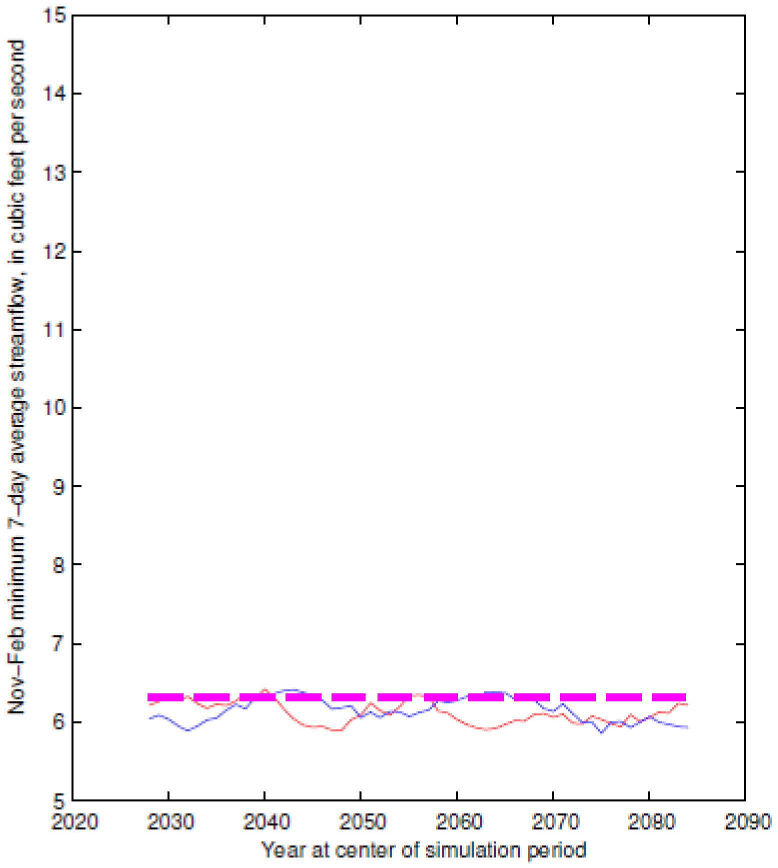

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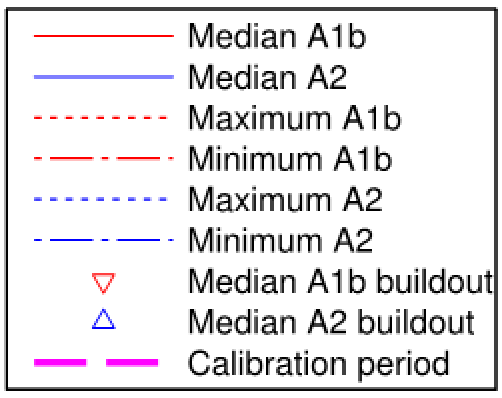
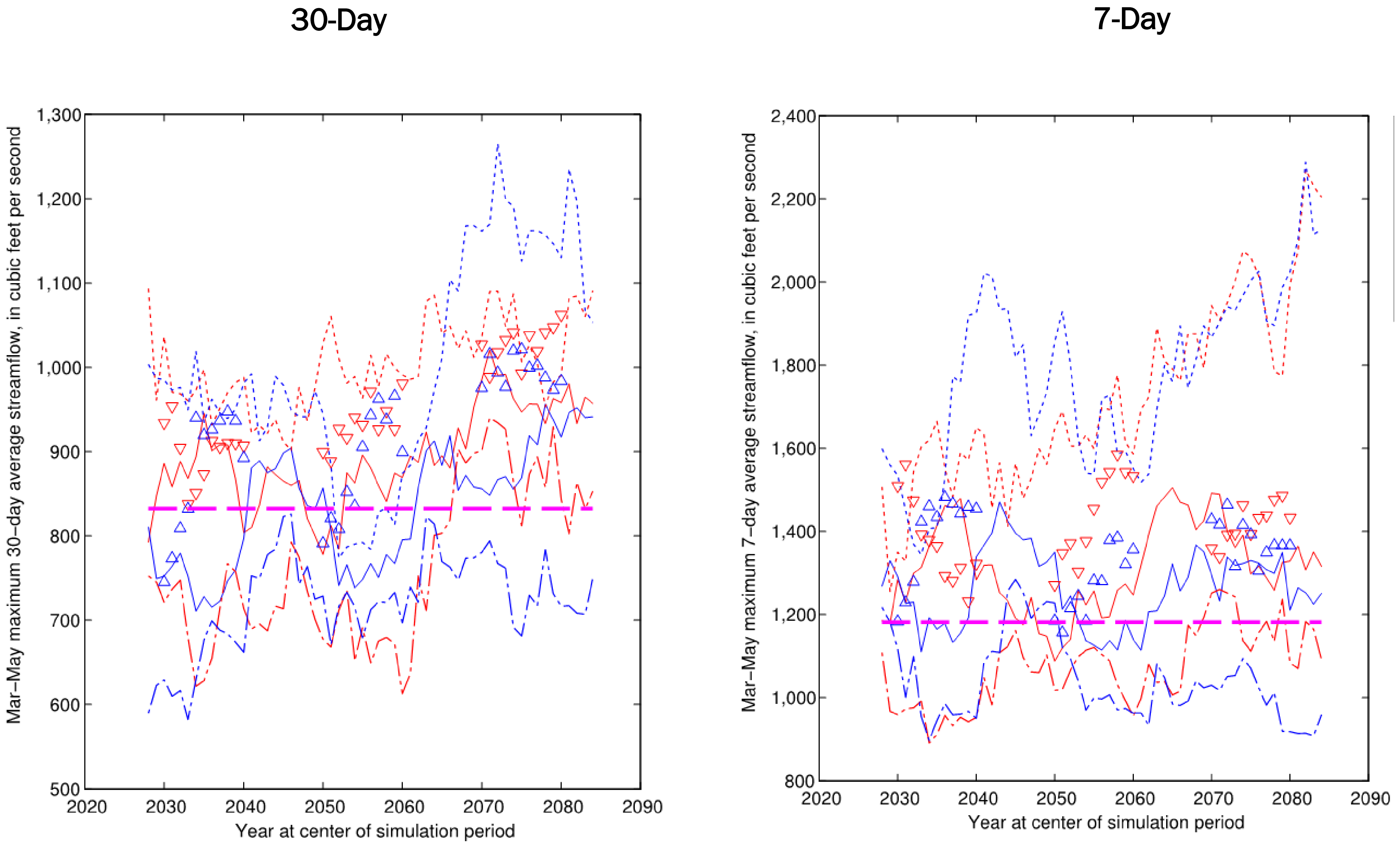
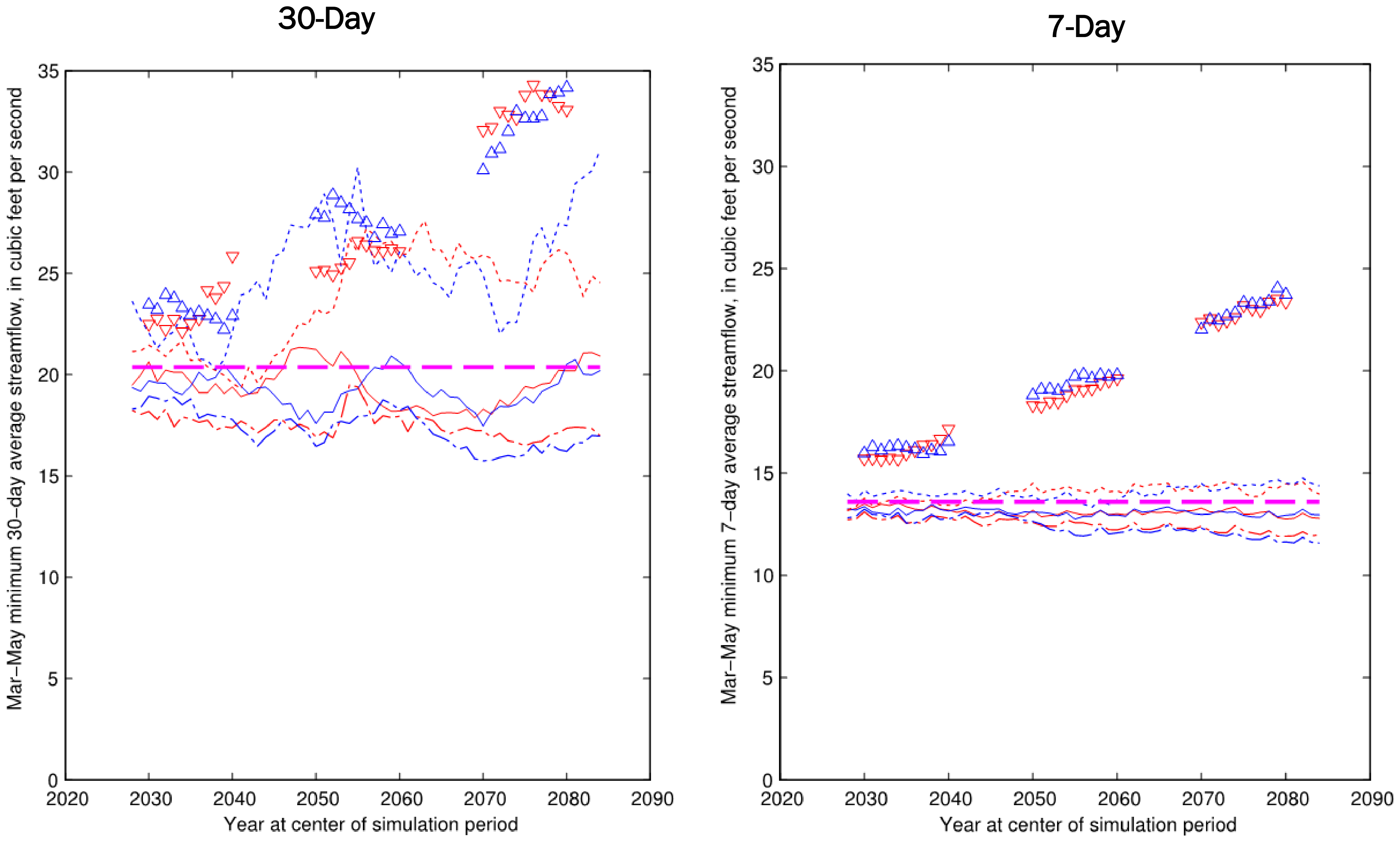


Spring Average Maximum Stream Flows with Development



Spring Average Minimum Stream Flows with Development



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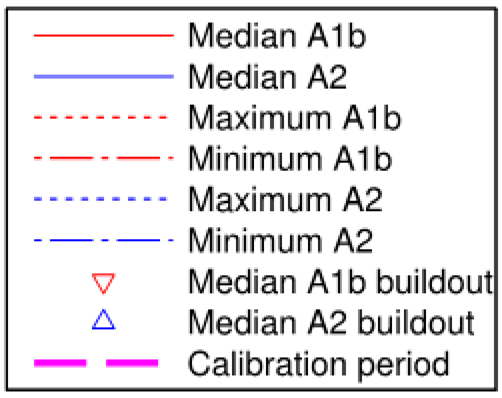
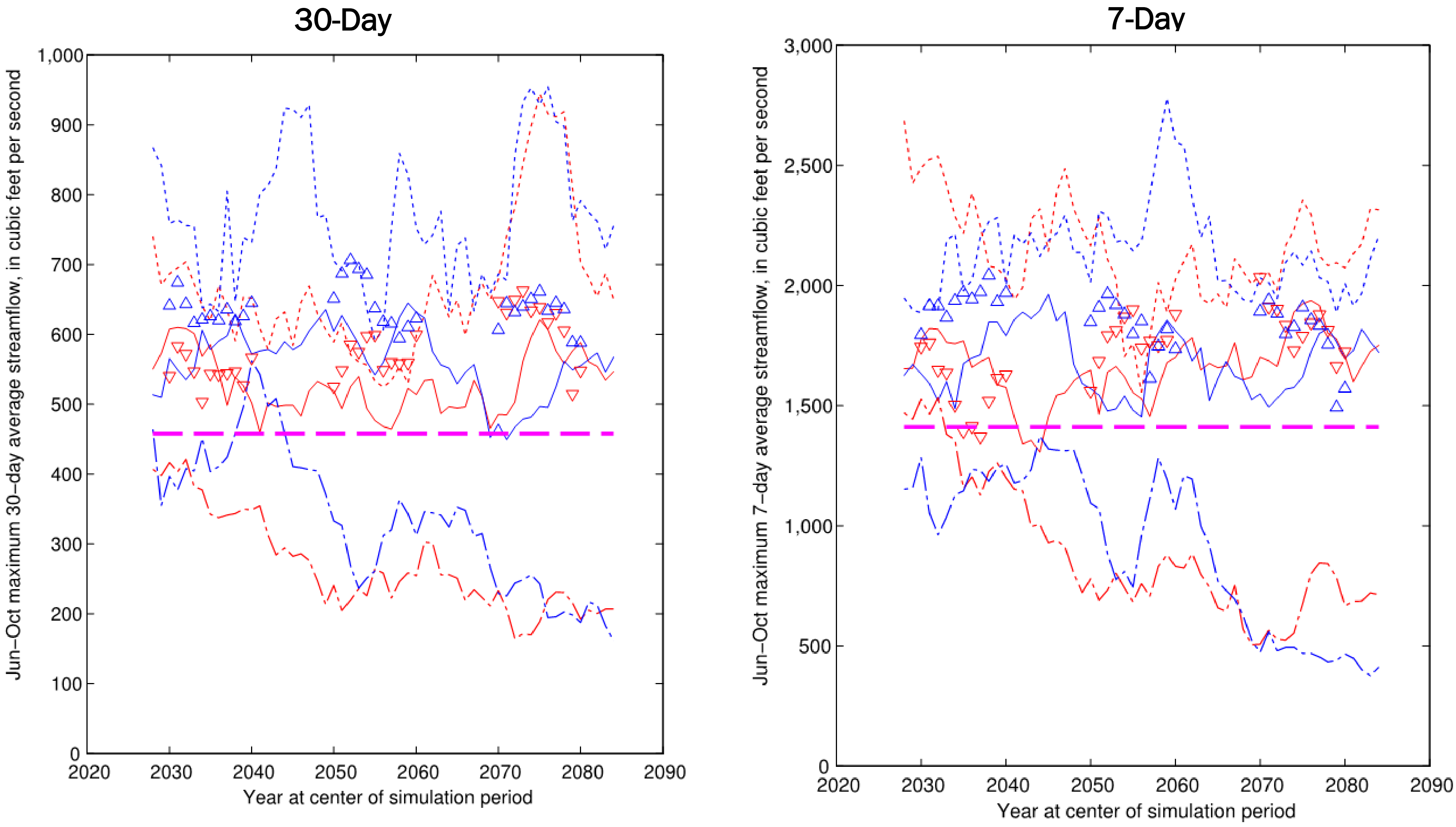
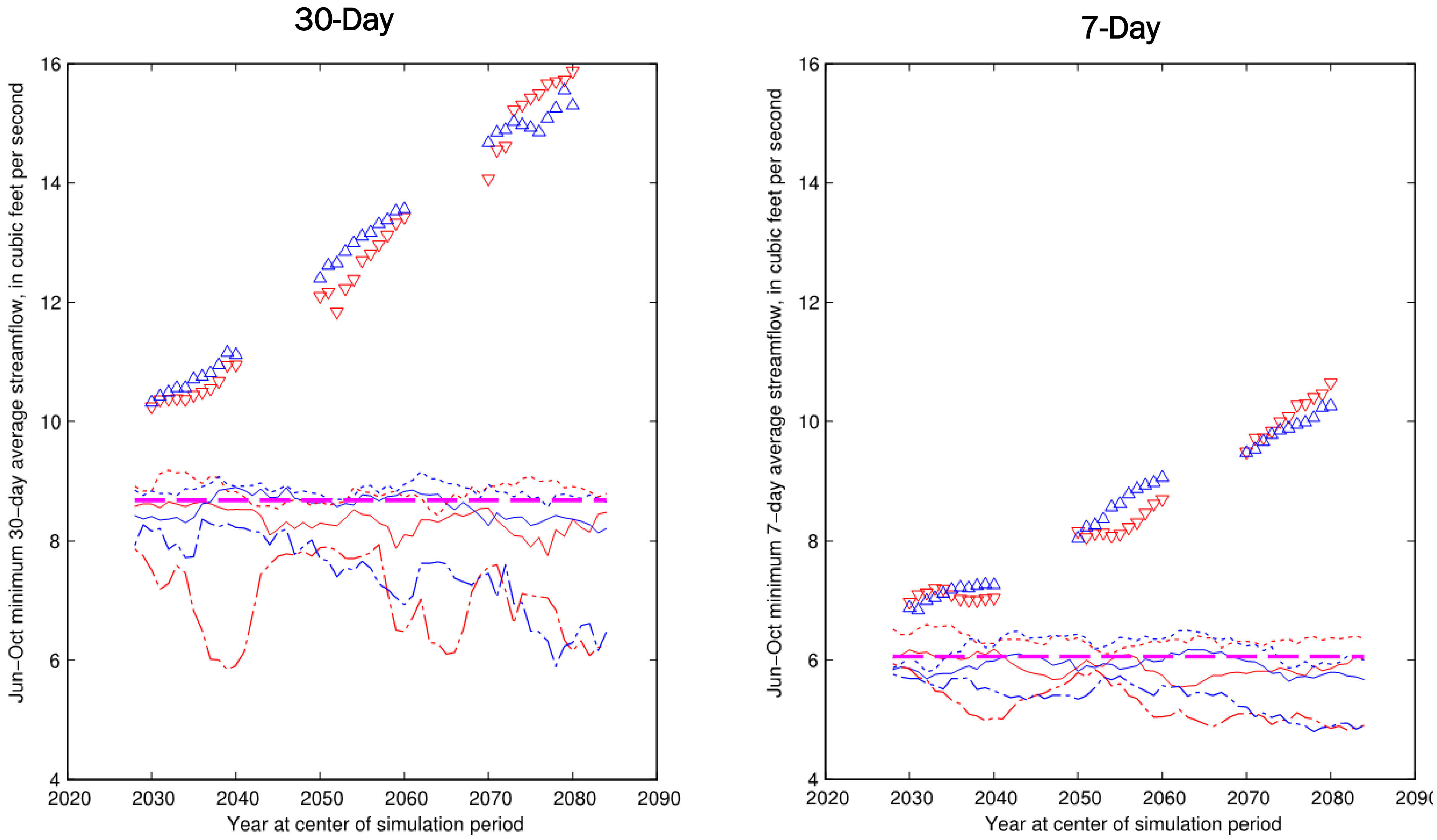


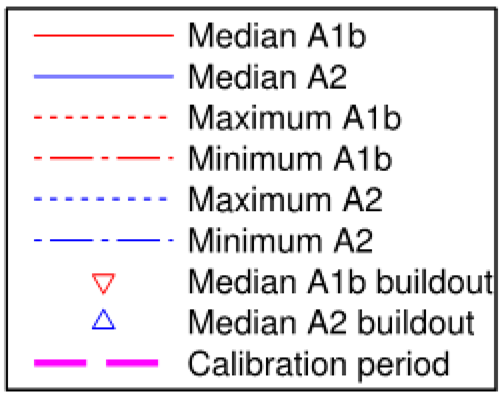
Summer Average Maximum Stream Flows with Development



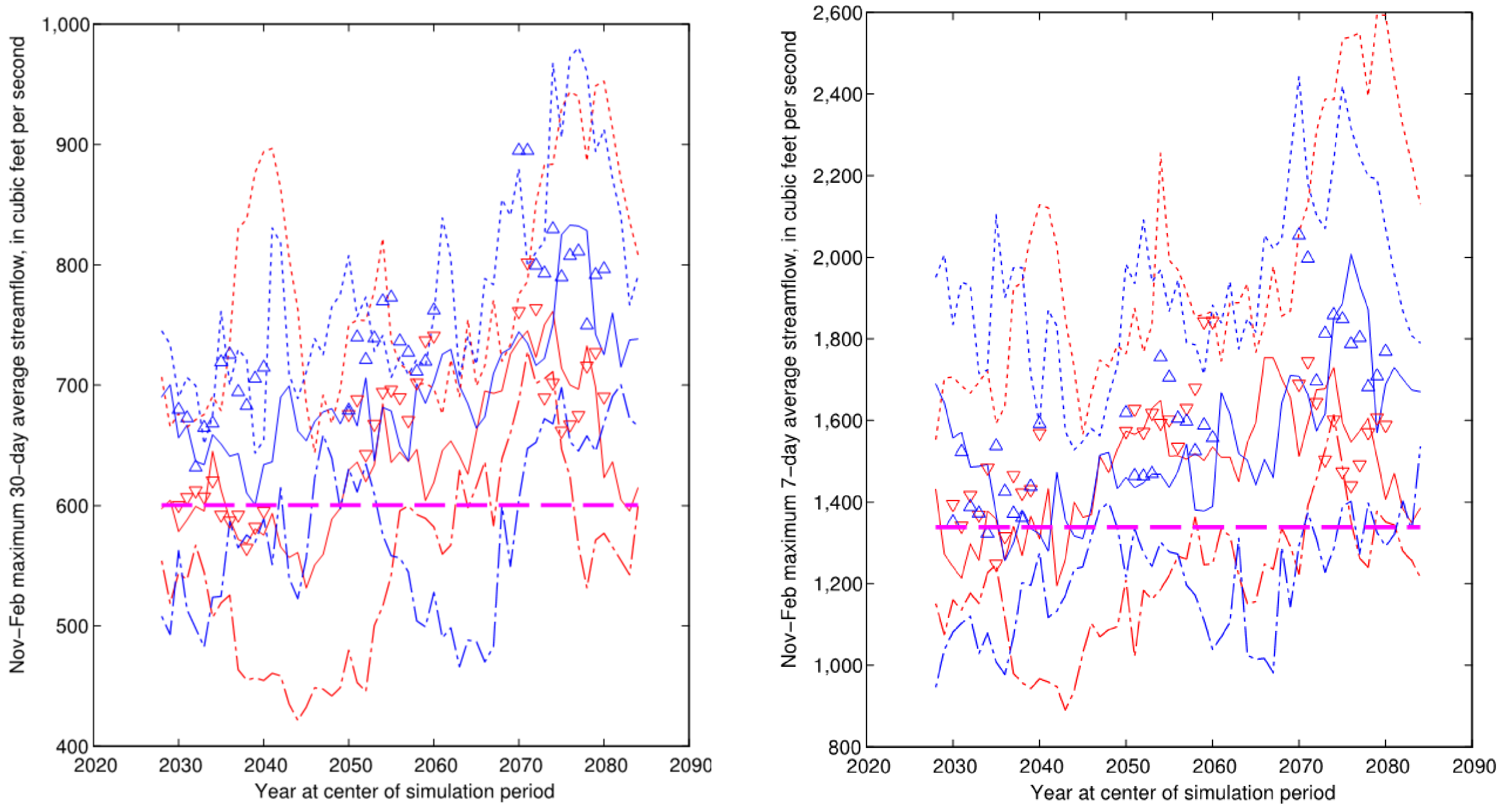
Summer Average Minimum Stream Flows with Development



Little Scioto Reach with Marion Public Water Supply

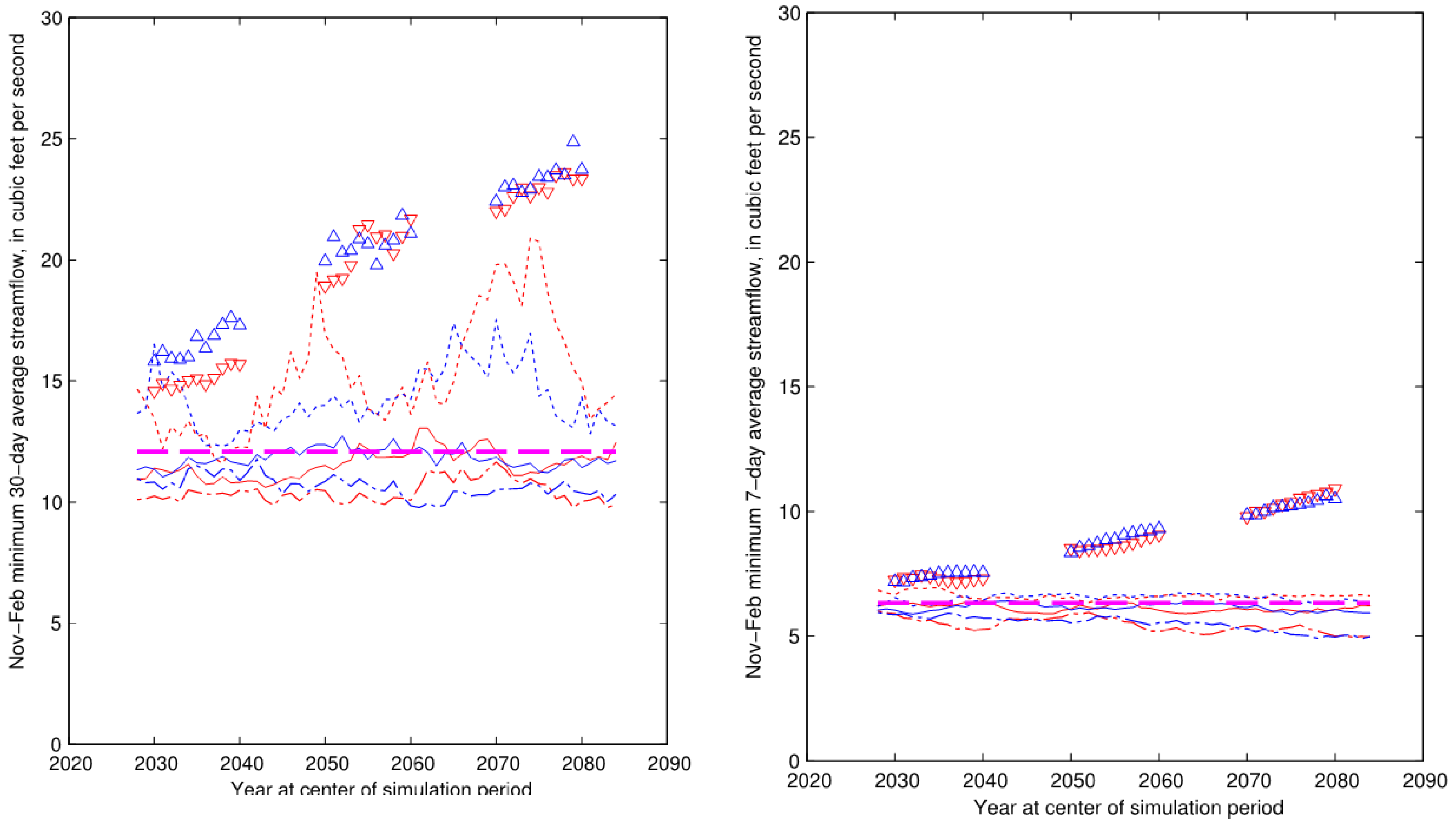


Fall/Winter Average Maximum Stream Flows with Development


30-Day

7-Day

Fall/Winter Average Minimum Stream Flows with Development


30-Day

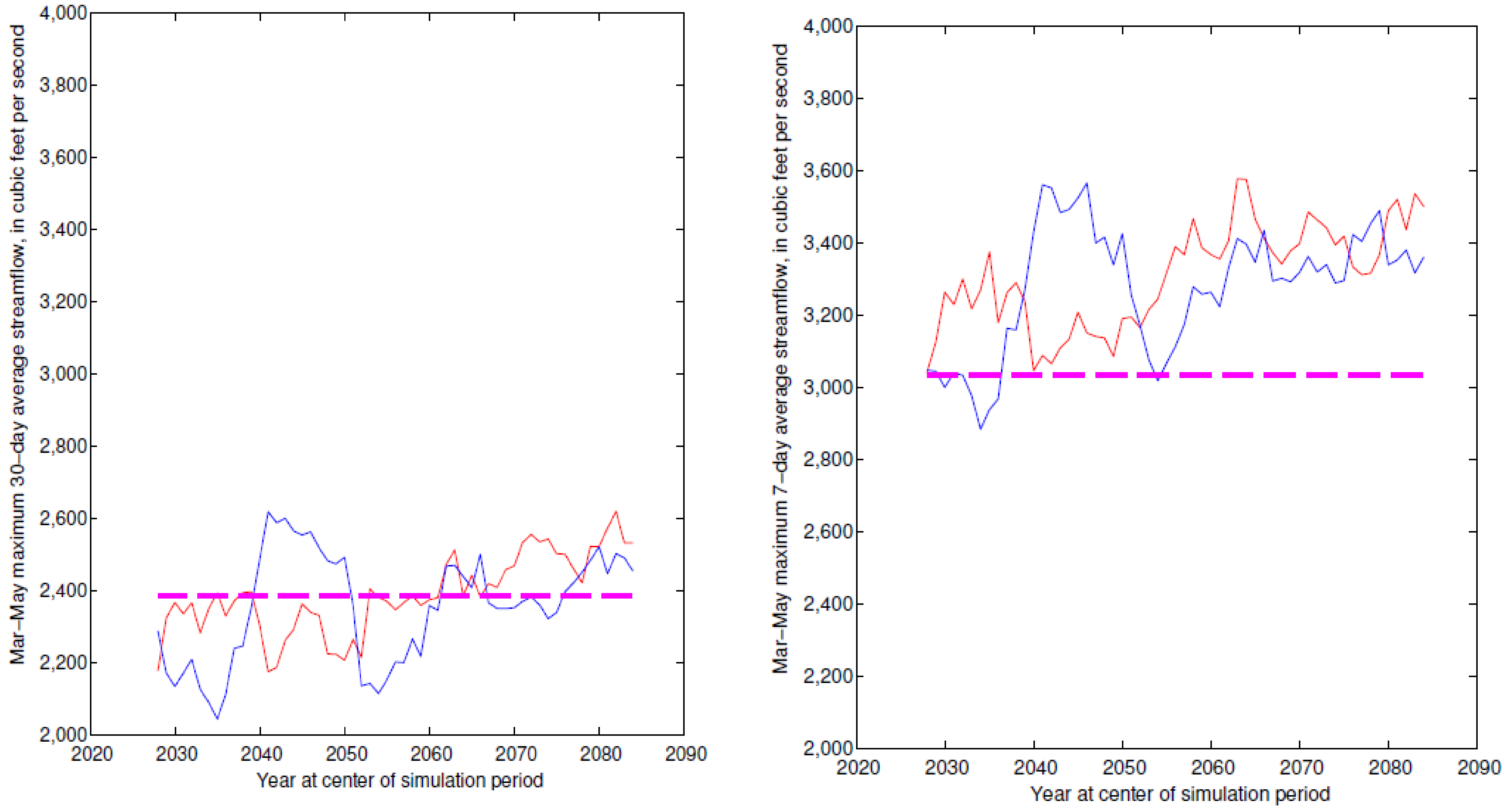
7-Day

Olentangy River at DEL-CO Intake Seasonal Stream Flows

Spring Average Maximum Stream Flow: Climate Only

30-Day

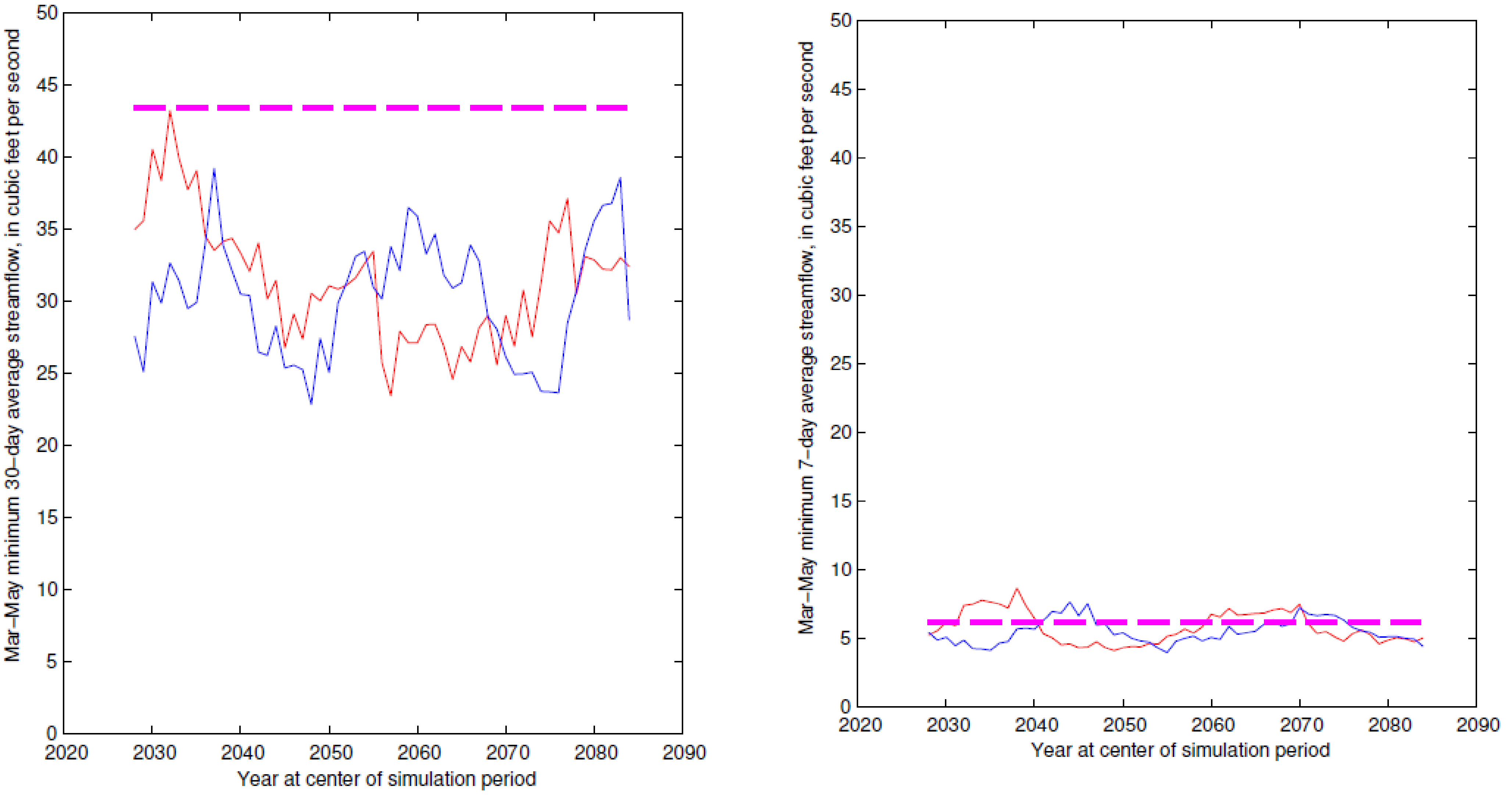
7-Day



Spring Average Minimum Stream Flow: Climate Only

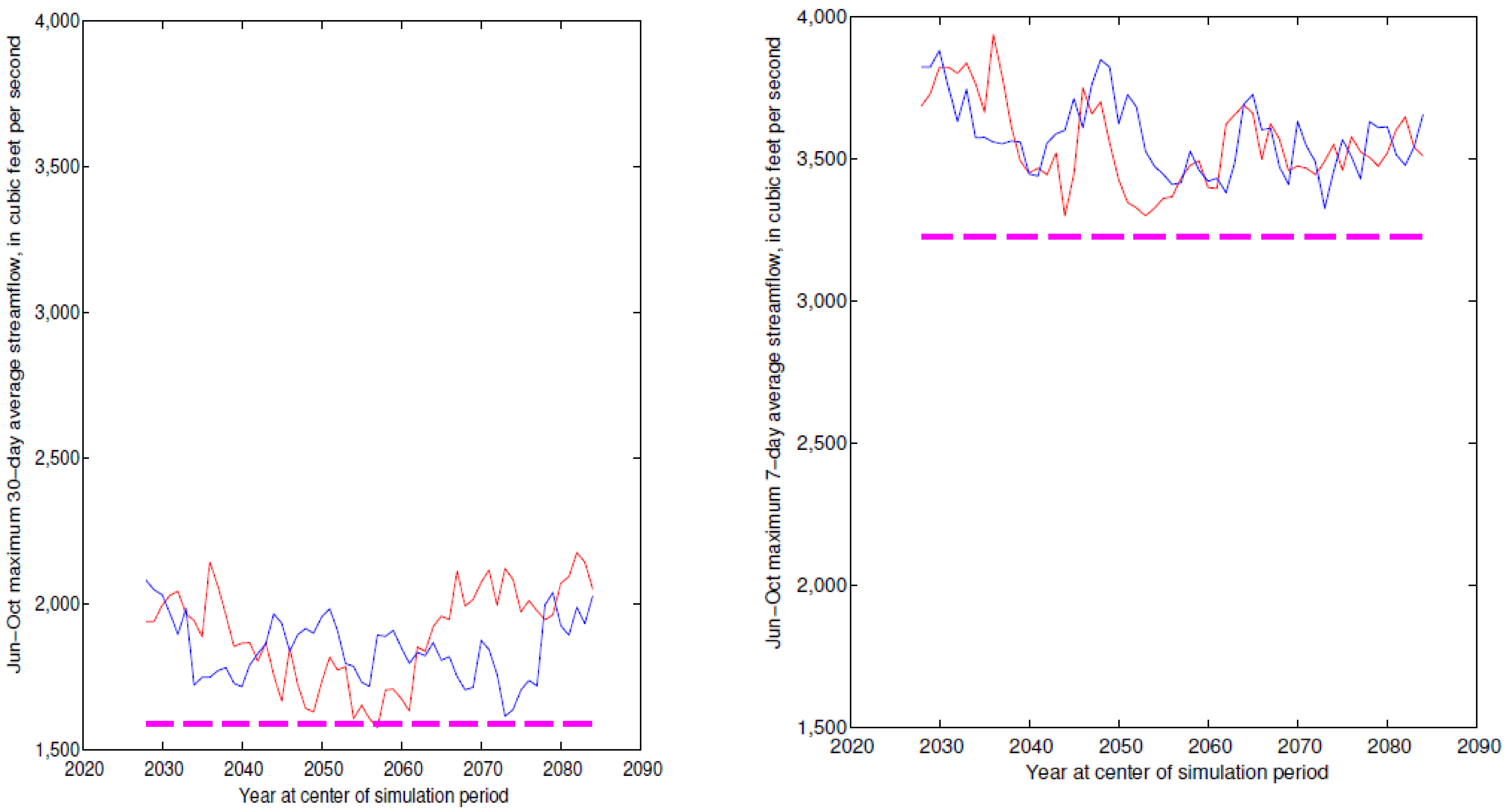
30-Day

7-Day



Olentangy River at DEL-CO Intake

Summer Average Maximum Stream Flow: Climate Only



30-Day

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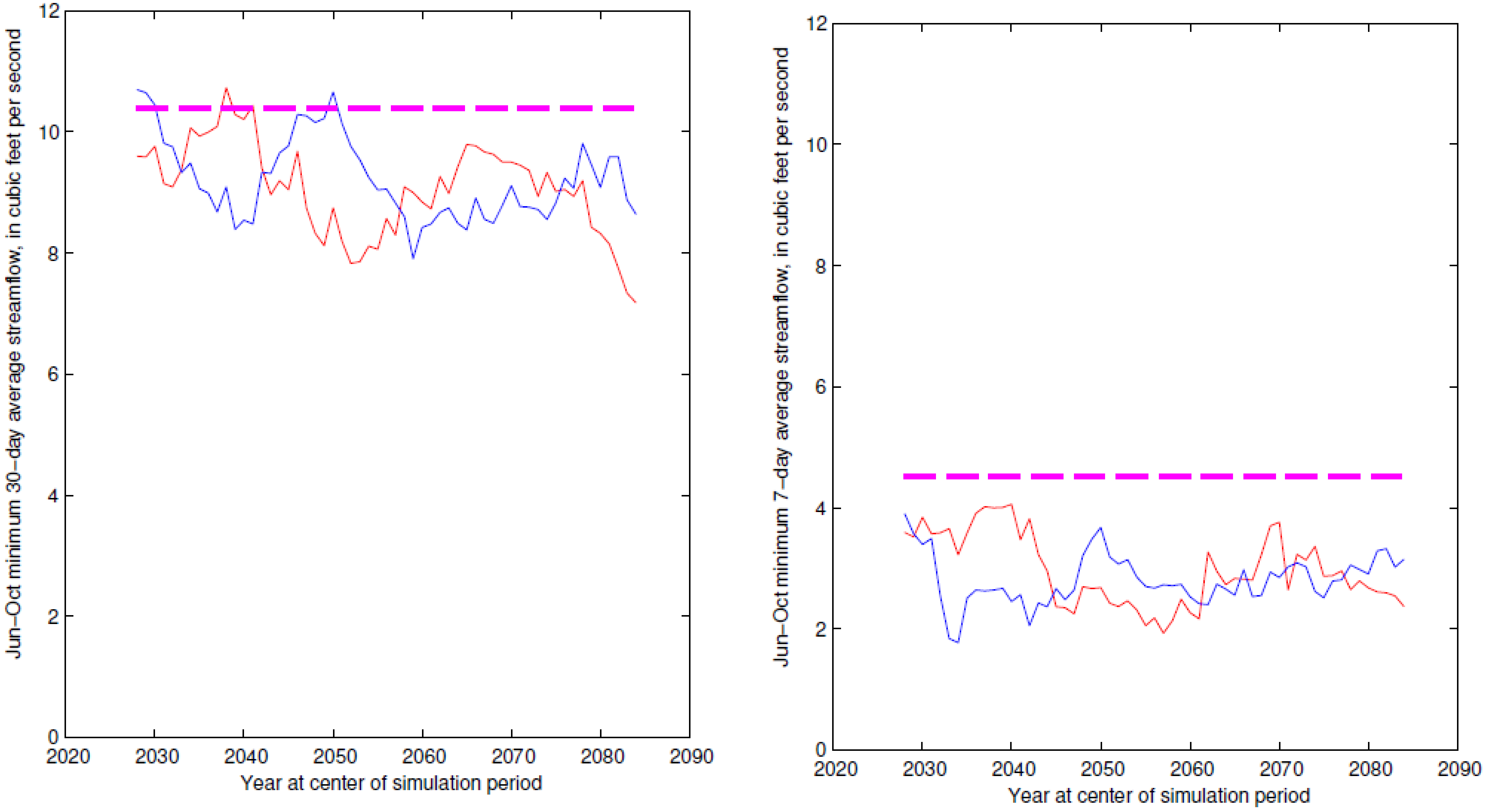
Summer Average Minimum Stream Flow: Climate Only

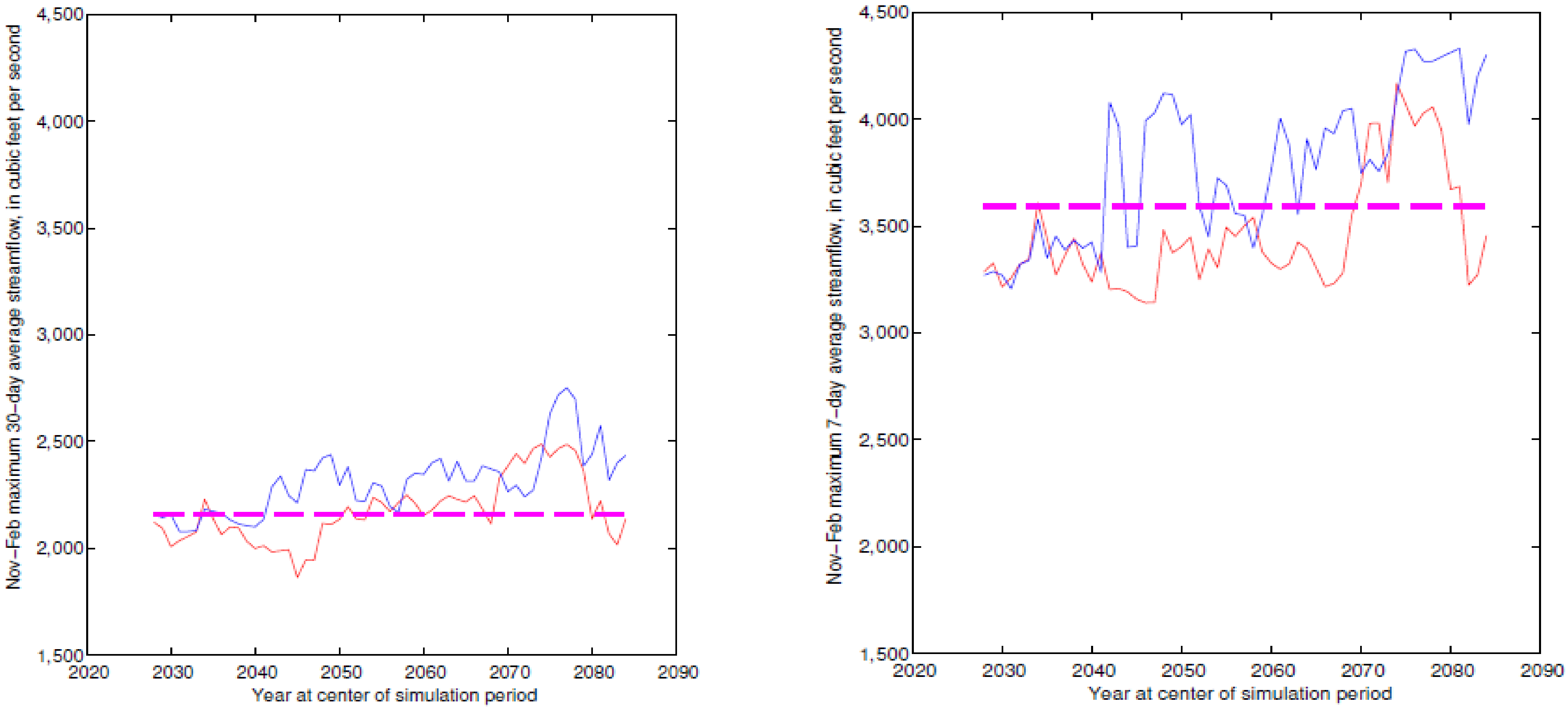


30-Day

7-Day

Olentangy River at DEL-CO Intake

Fall/Winter Average Maximum Stream Flow: Climate Only



30-Day

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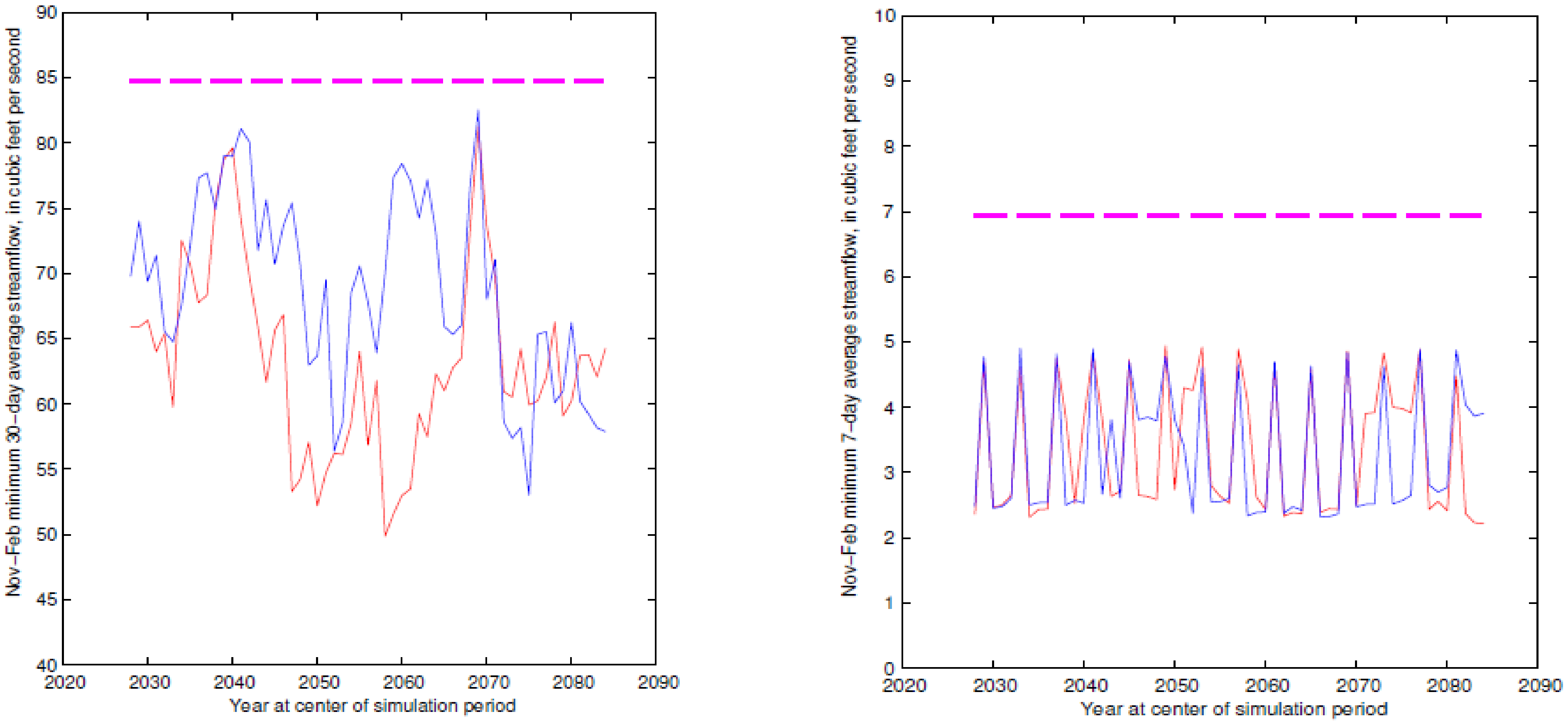
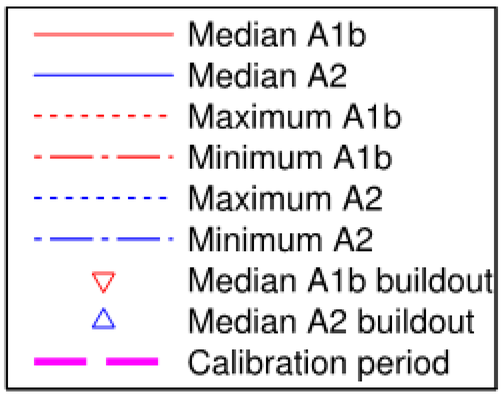
Fall/Winter Average Minimum Stream Flow: Climate Only



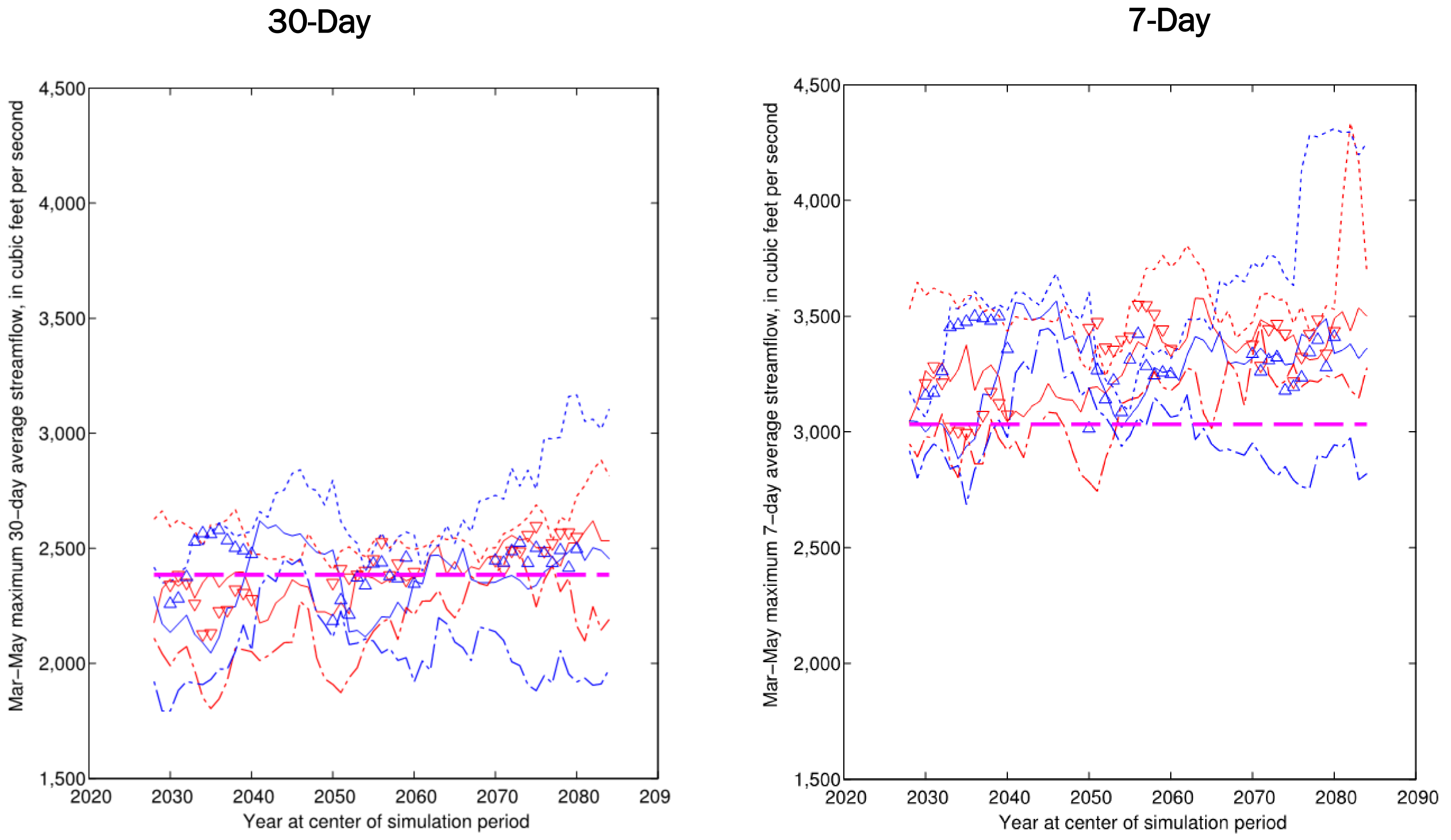
30-Day

7-Day

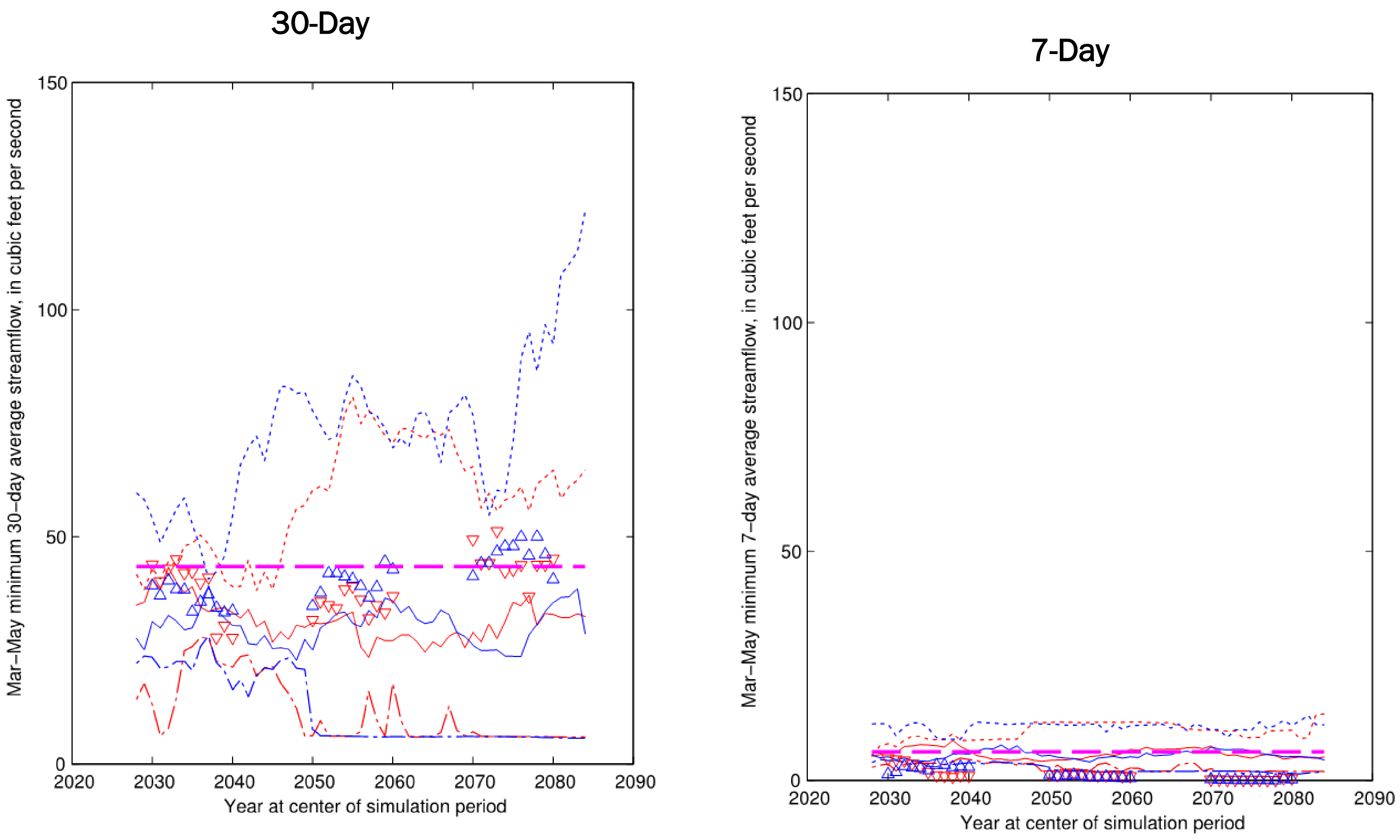
Olentangy River at DEL-CO Intake



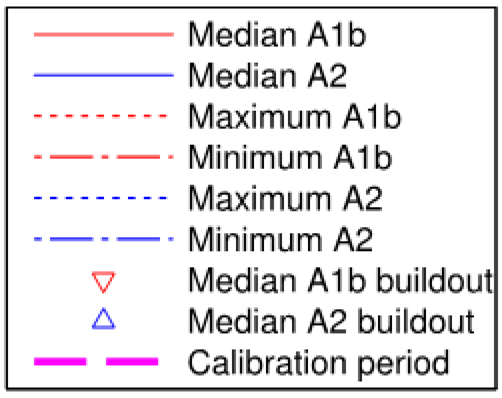
Spring Average Maximum Stream Flows with Development



Spring Average Minimum Stream Flows with Development

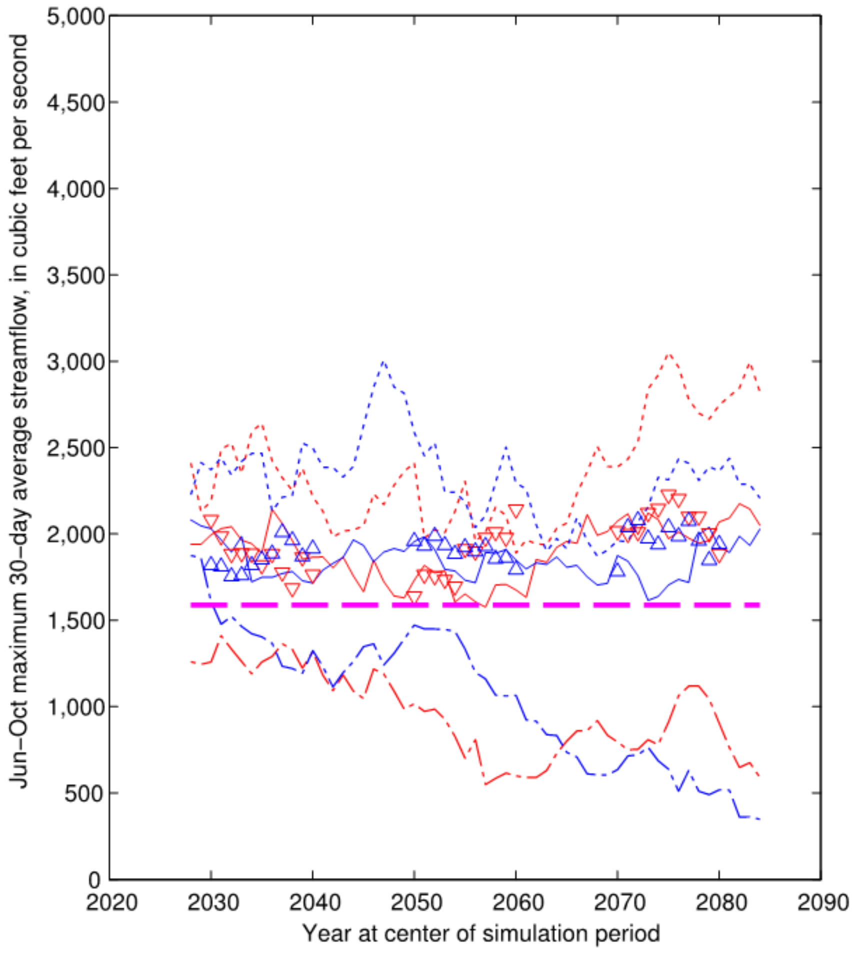


Olentangy River at DEL-CO Intake

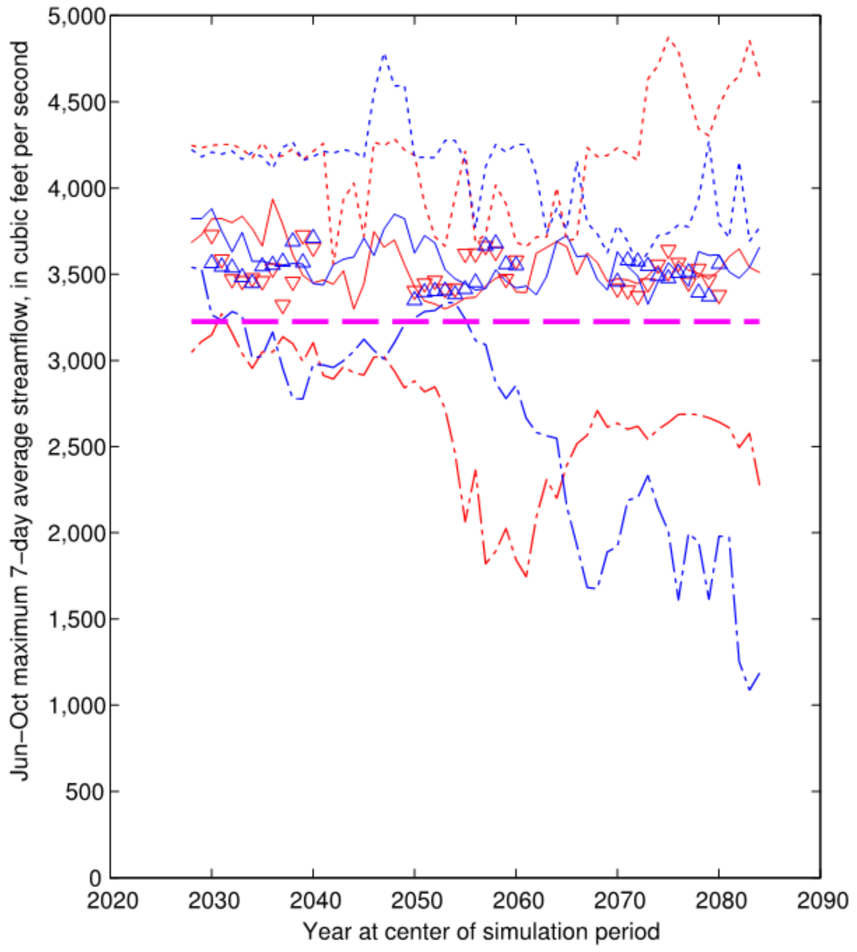


Summer Average Maximum Stream Flows with Development

30-Day

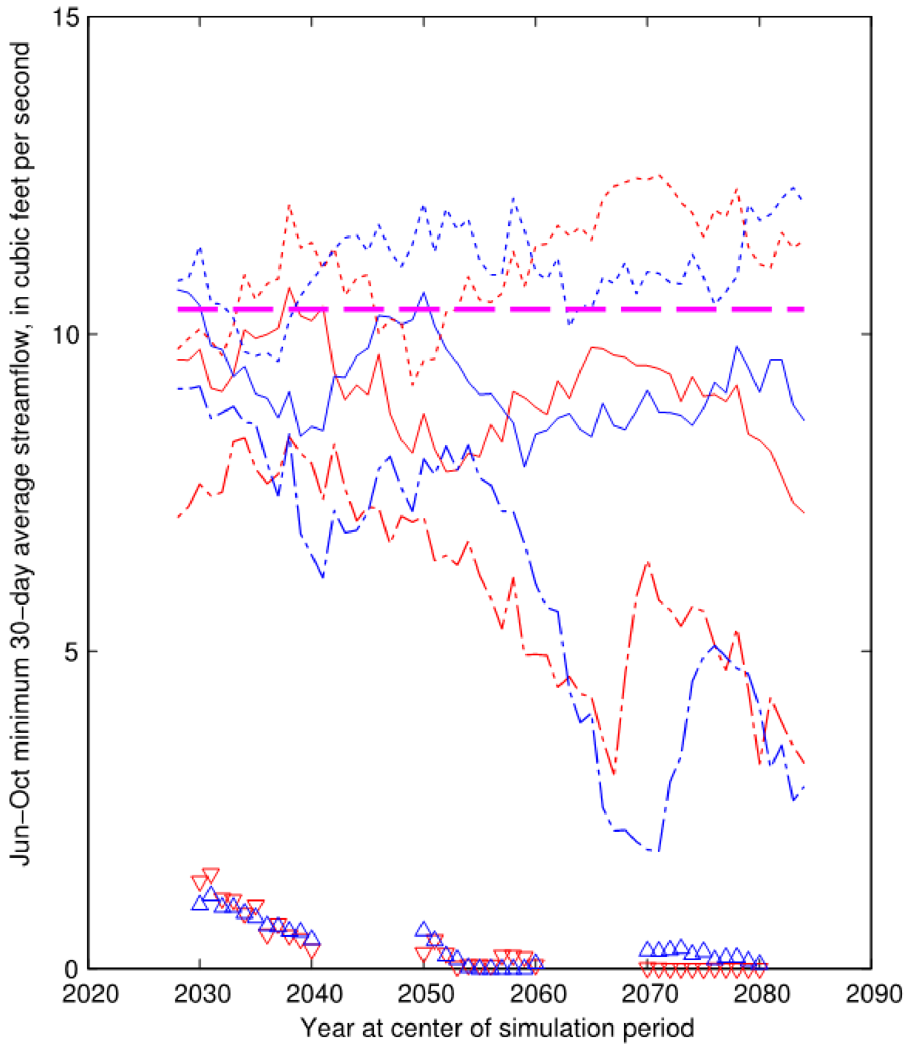


7-Day

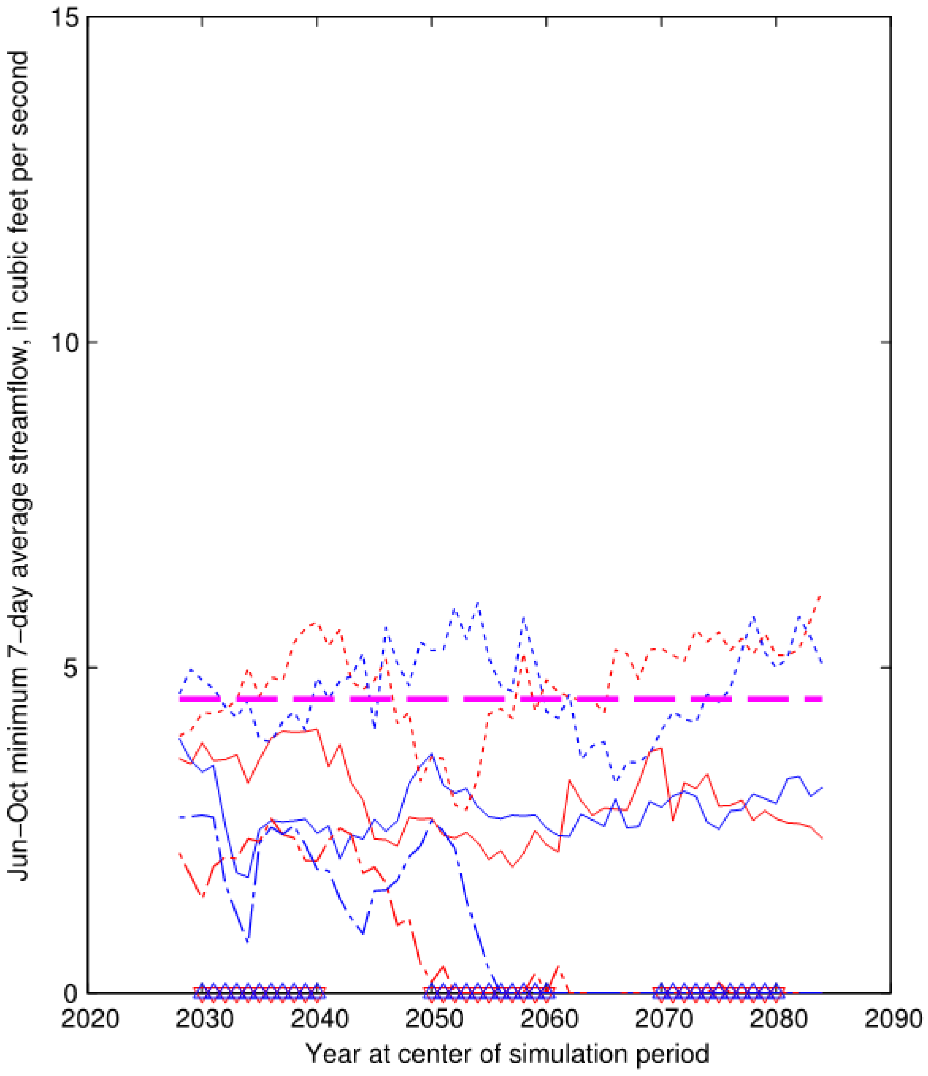


Summer Average Minimum Stream Flows with Development

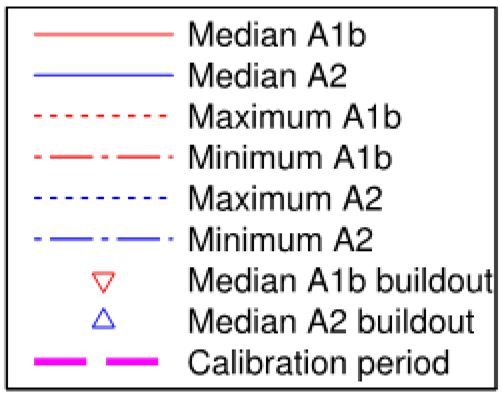
30-Day



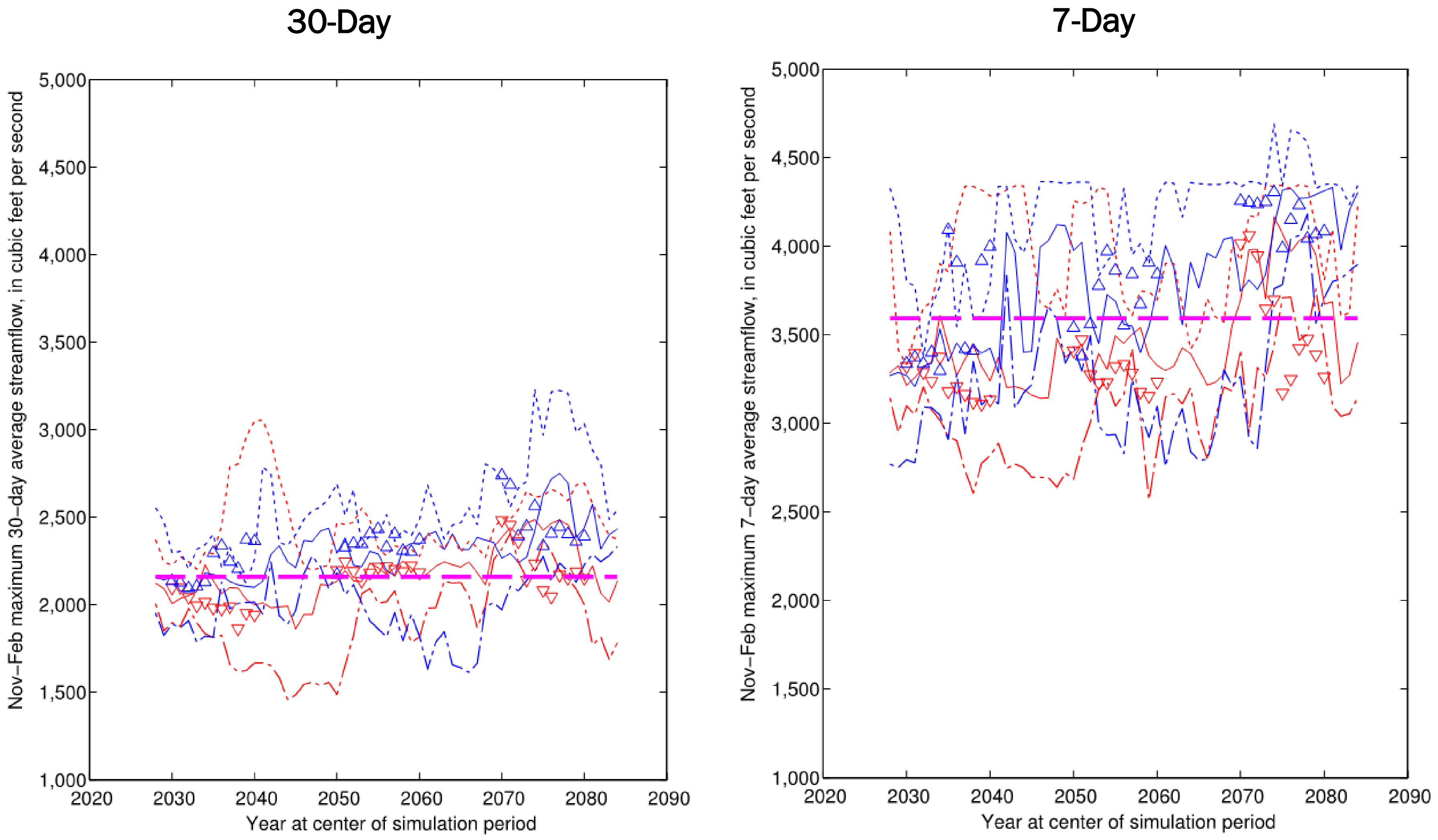
7-Day



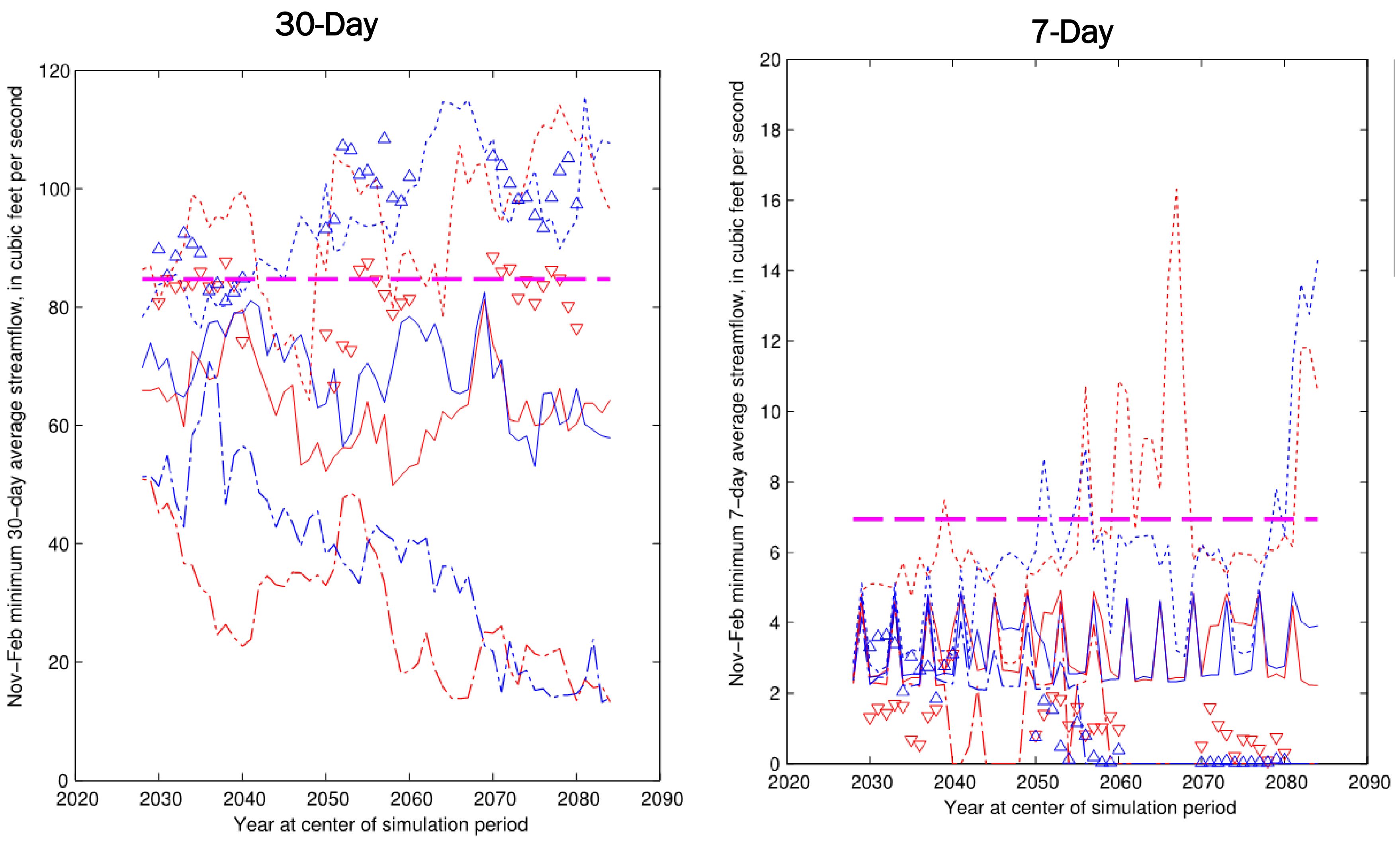
Olentangy River at DEL-CO Intake



Fall/Winter Average Maximum Stream Flows with Development

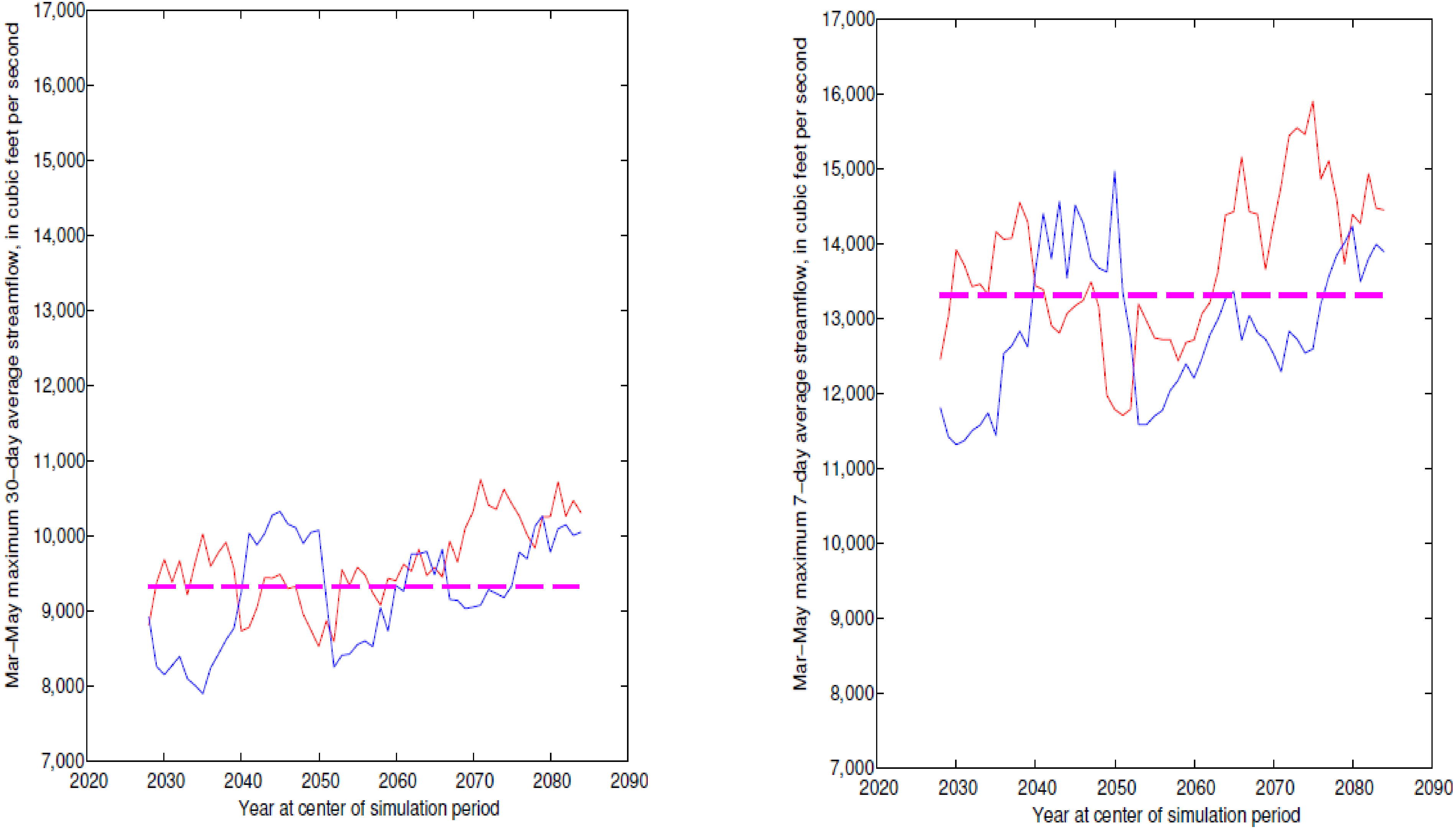


Fall/Winter Average Minimum Stream Flows with Development



Scioto River at Columbus Seasonal Stream Flows

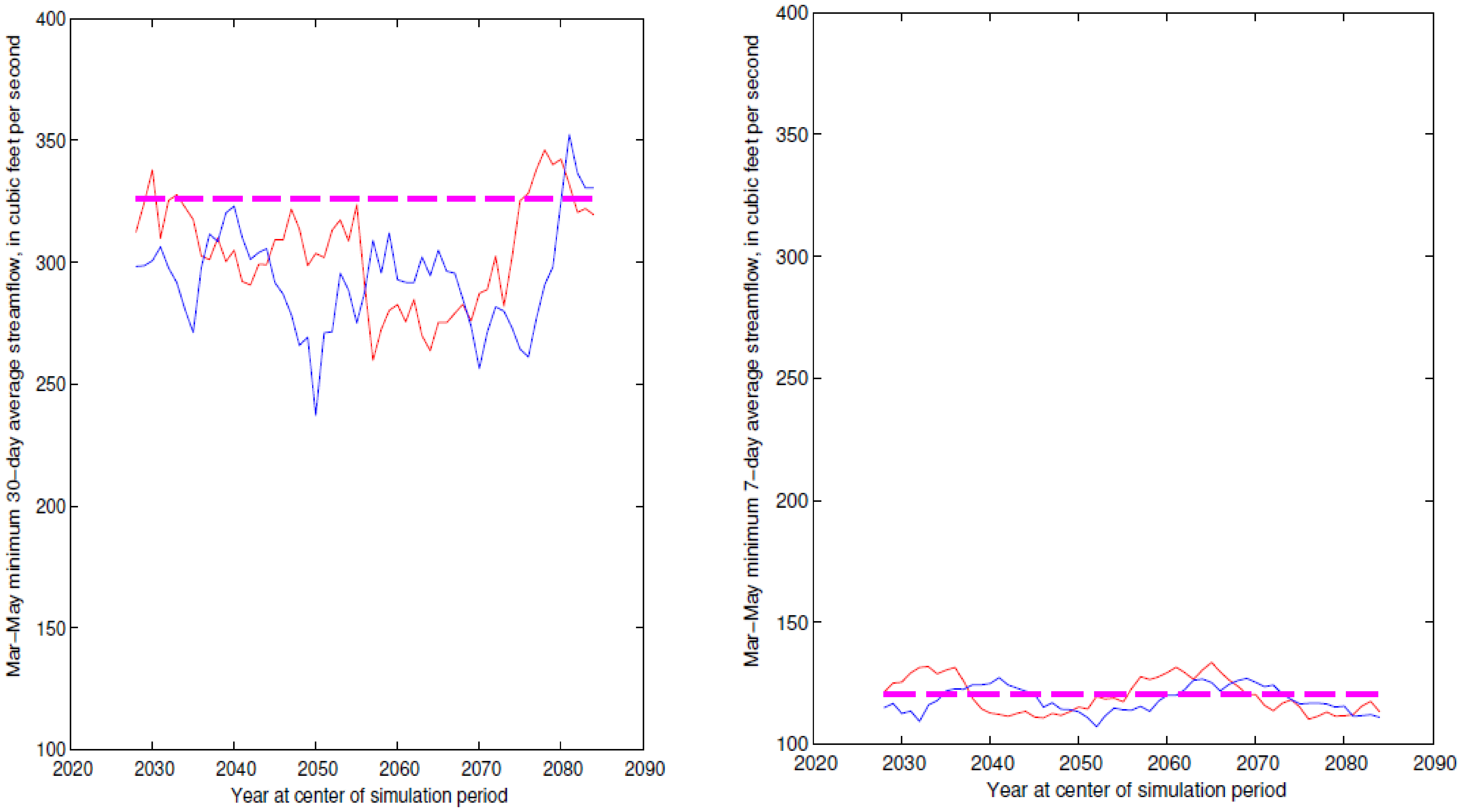
Spring Average Maximum Stream Flow: Climate Only



30-Day

7-Day

Spring Average Minimum Stream Flow: Climate Only

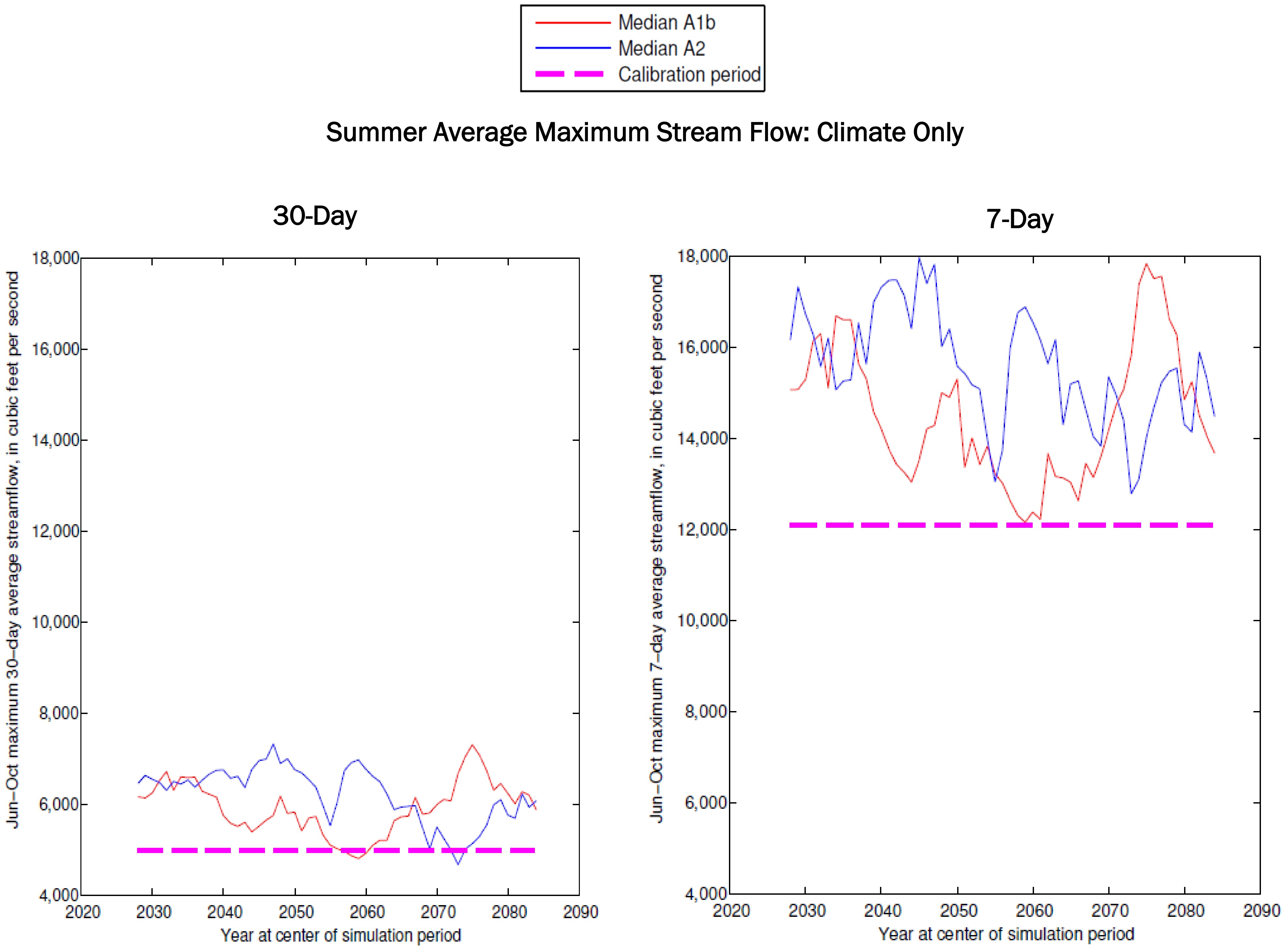


30-Day

7-Day

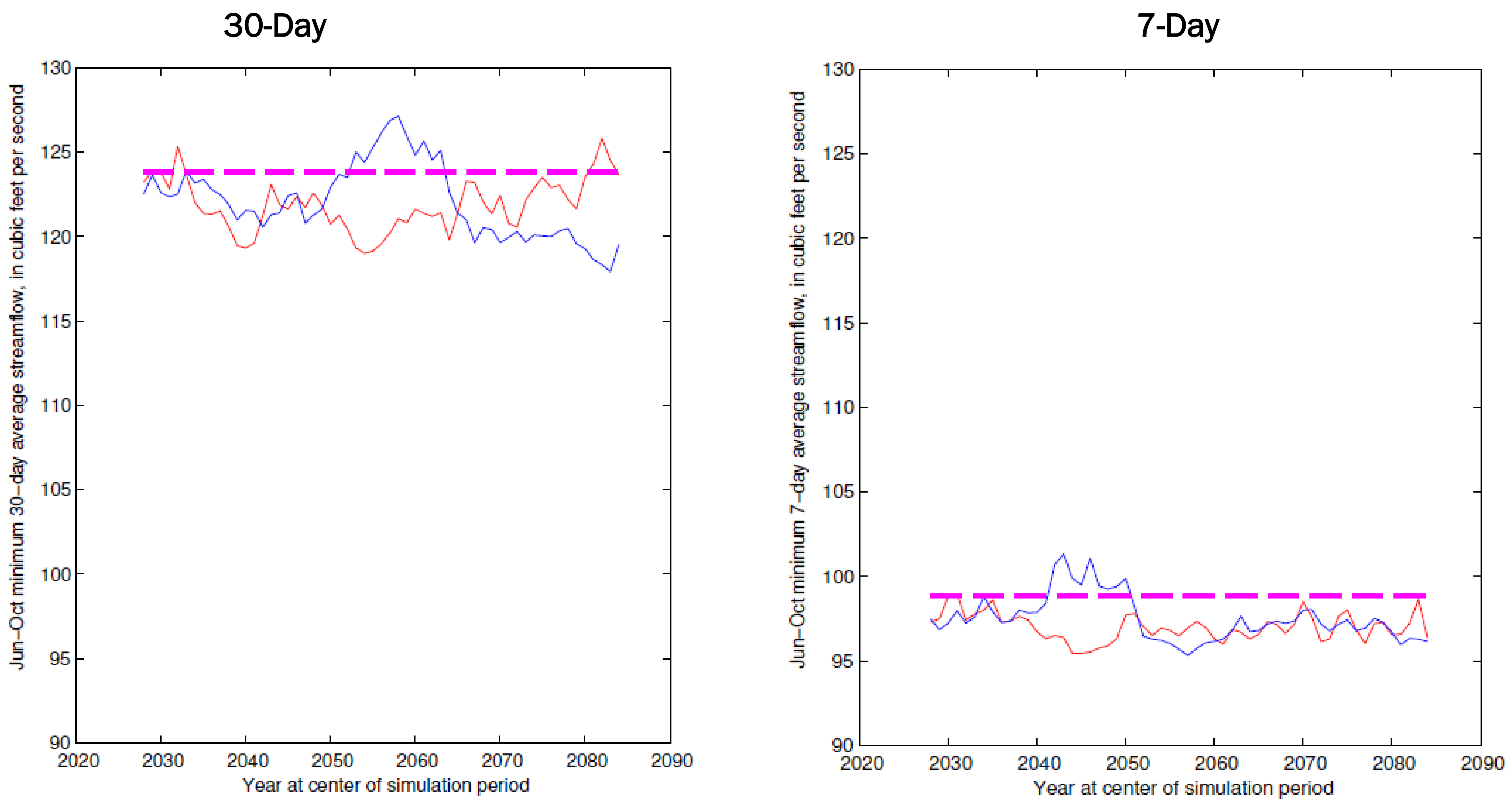
Scioto River at Columbus

Summer Average Maximum Stream Flow: Climate Only


30-Day

7-Day

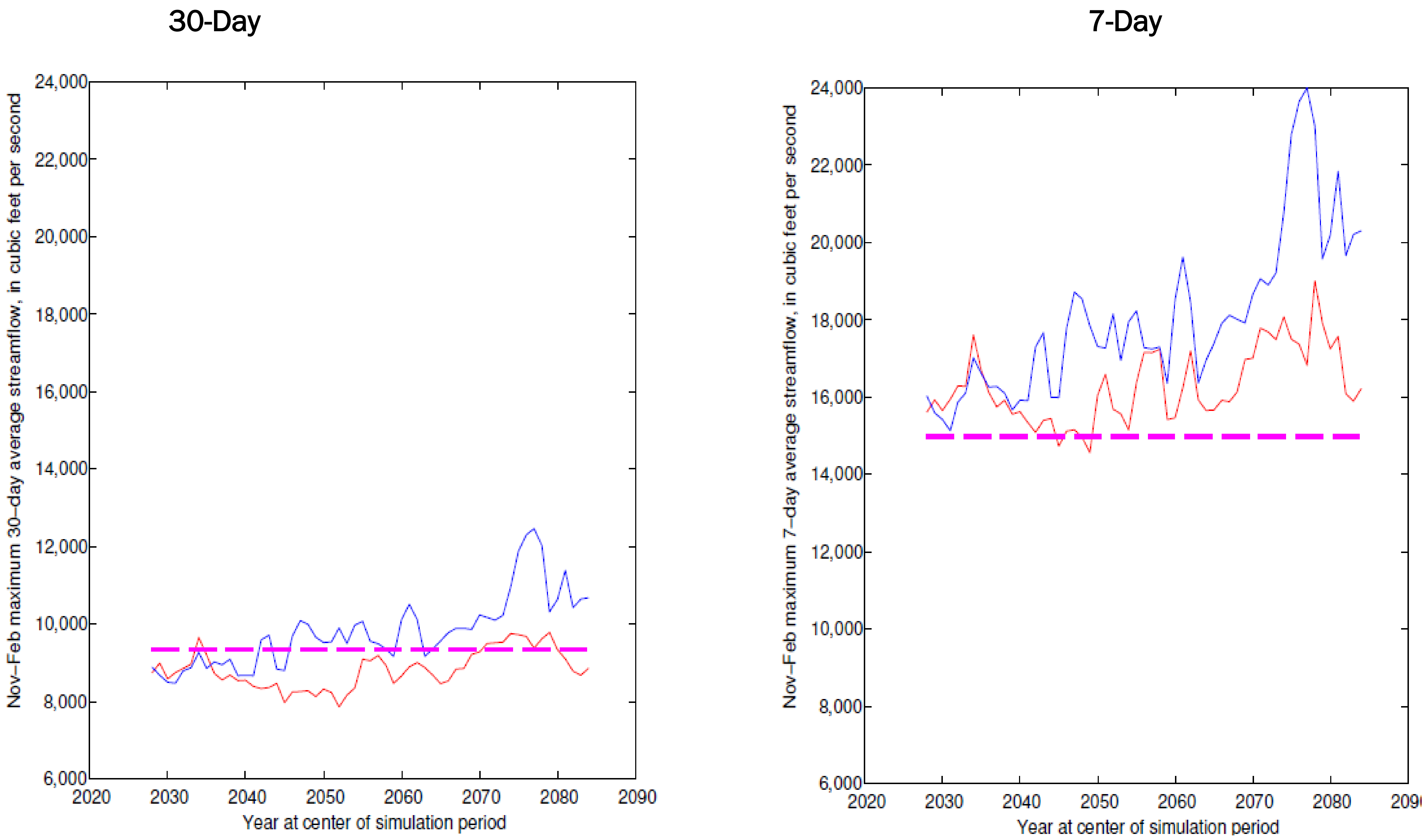
Summer Average Minimum Stream Flow: Climate Only


30-Day

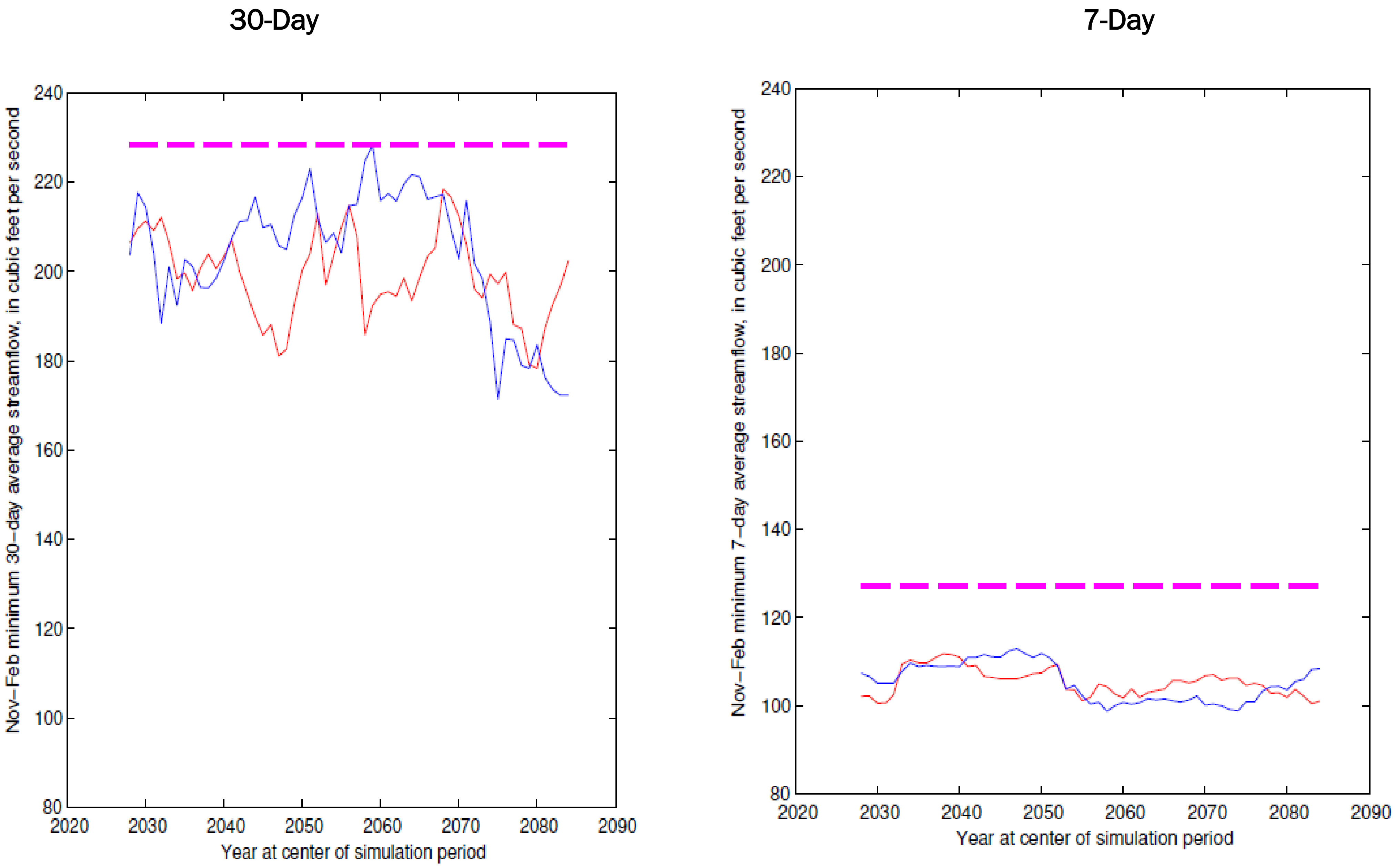
7-Day

Scioto River at Columbus Seasonal Stream Flows

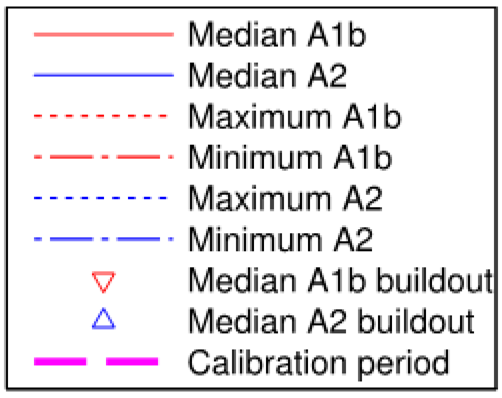
Fall/ Winter Average Maximum Stream Flow: Climate Only



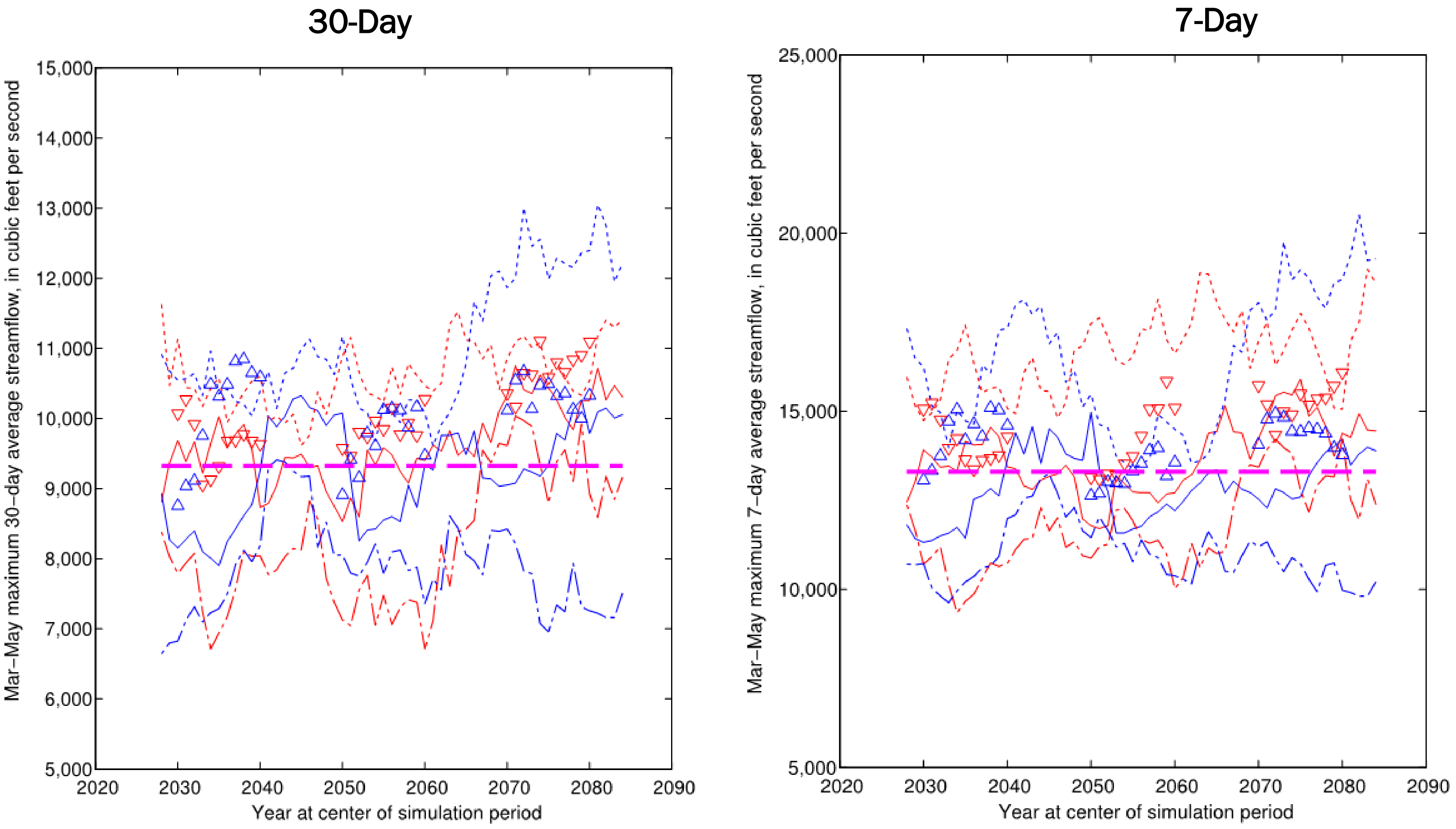
Fall/ Winter Average Minimum Stream Flow: Climate Only



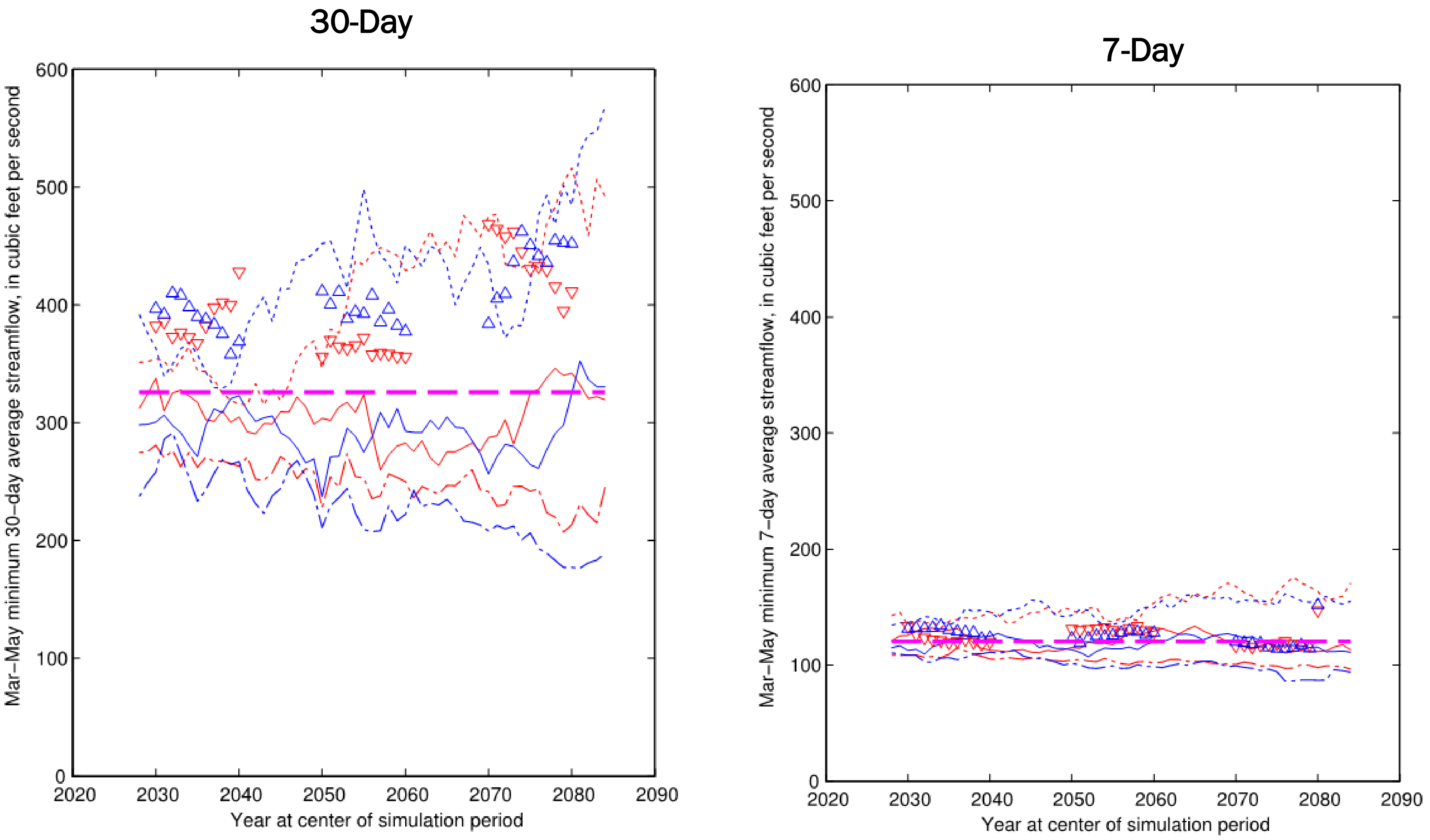
Scioto River at Columbus



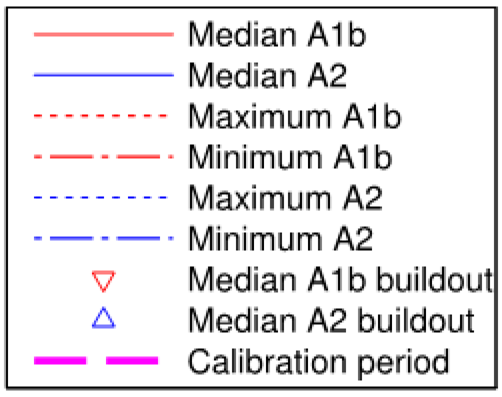
Spring Average Maximum Stream Flows with Development



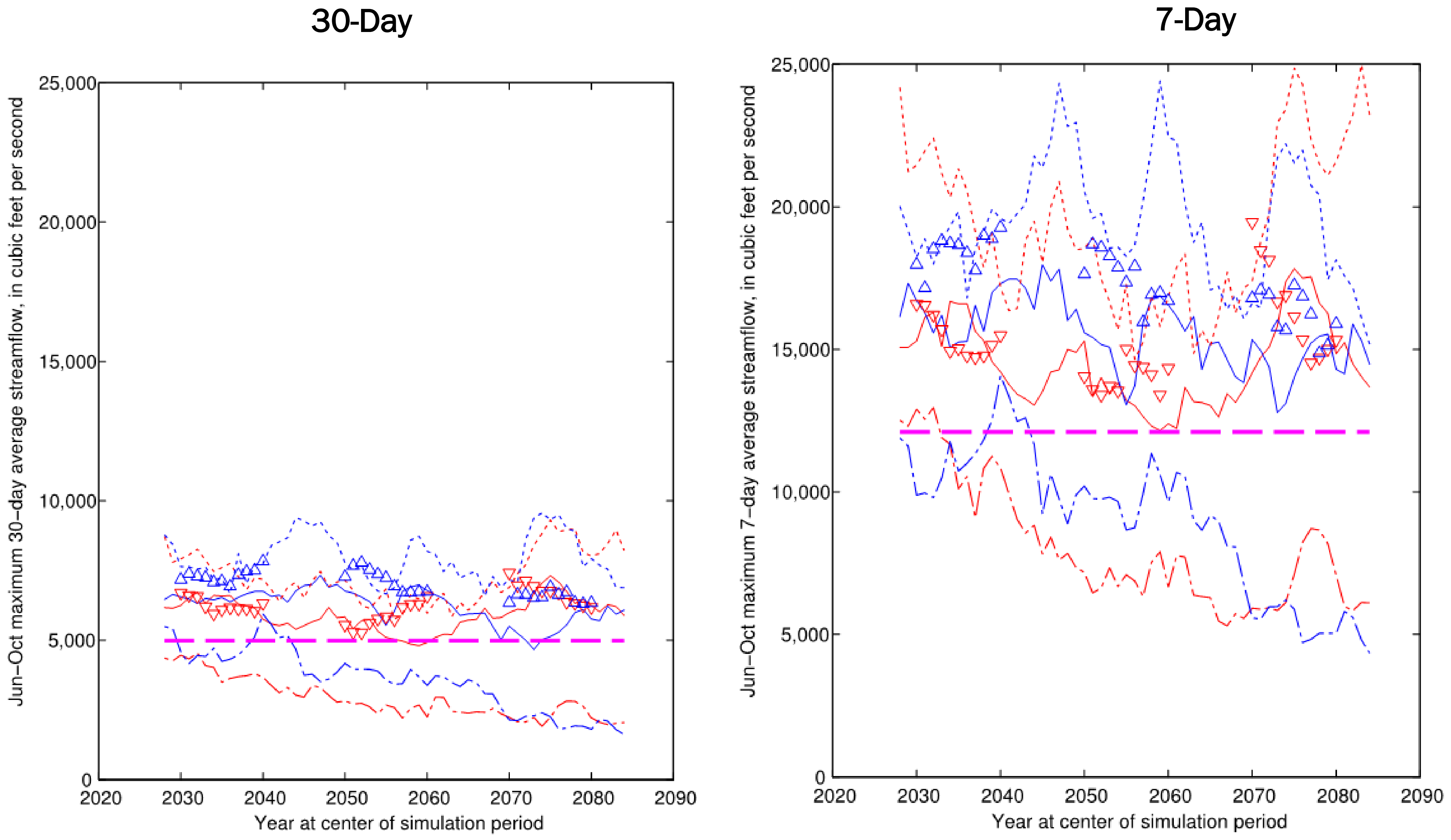
Spring Average Minimum Stream Flows with Development



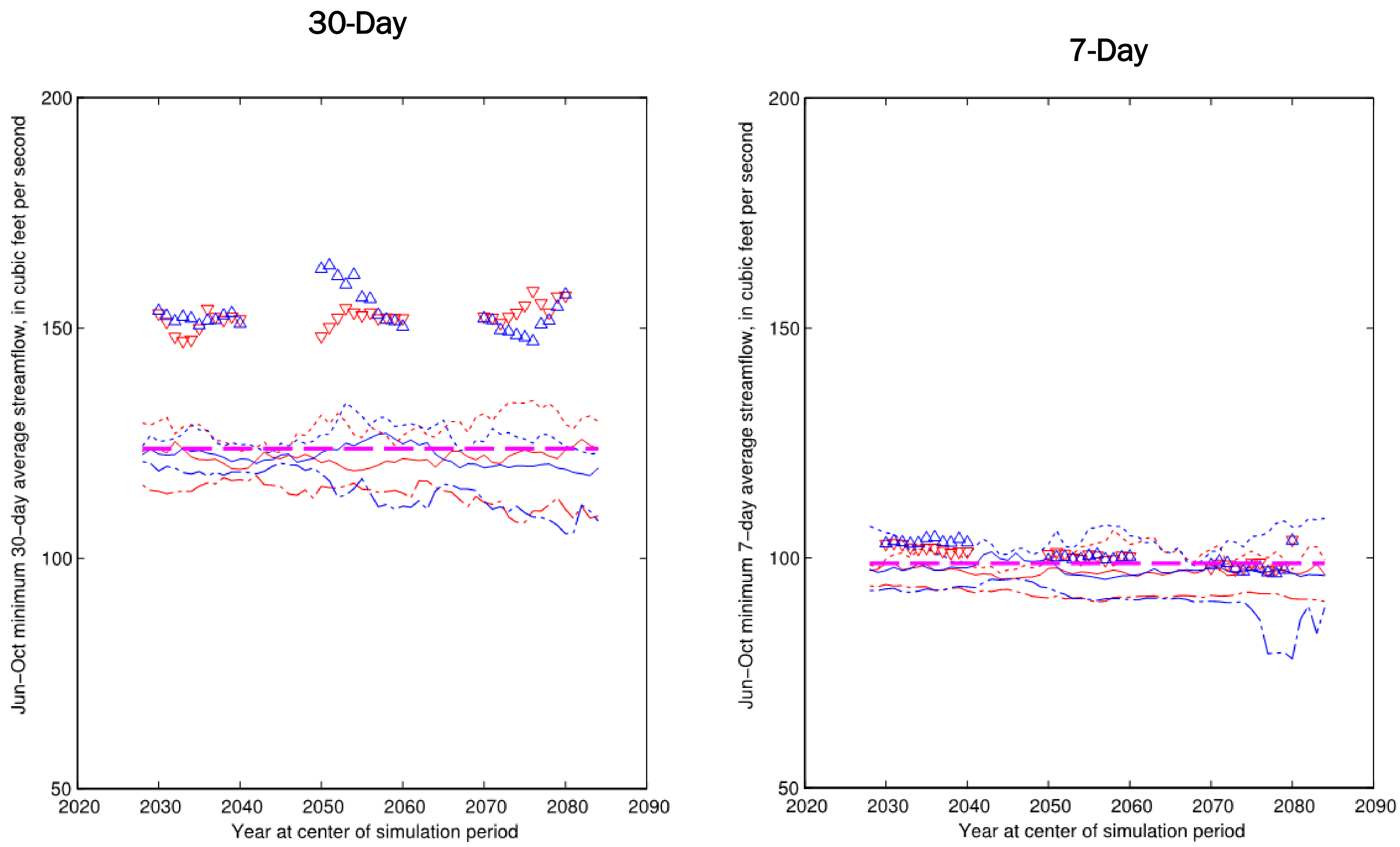
Scioto River at Columbus



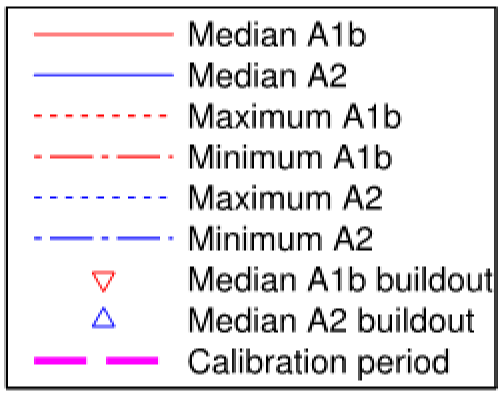
Summer Average Maximum Stream Flows with Development



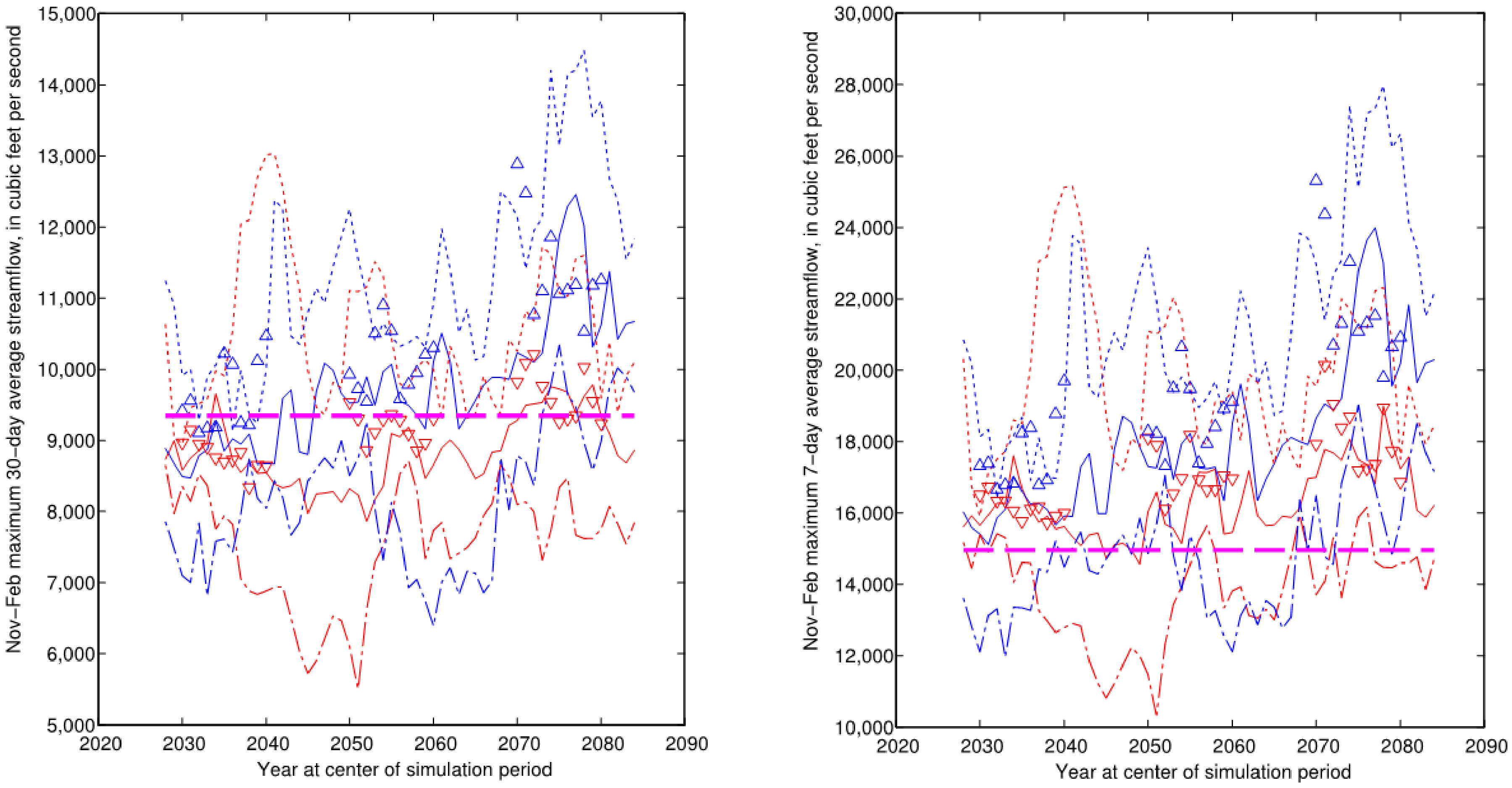
Summer Average Minimum Stream Flows with Development



Scioto River at Columbus



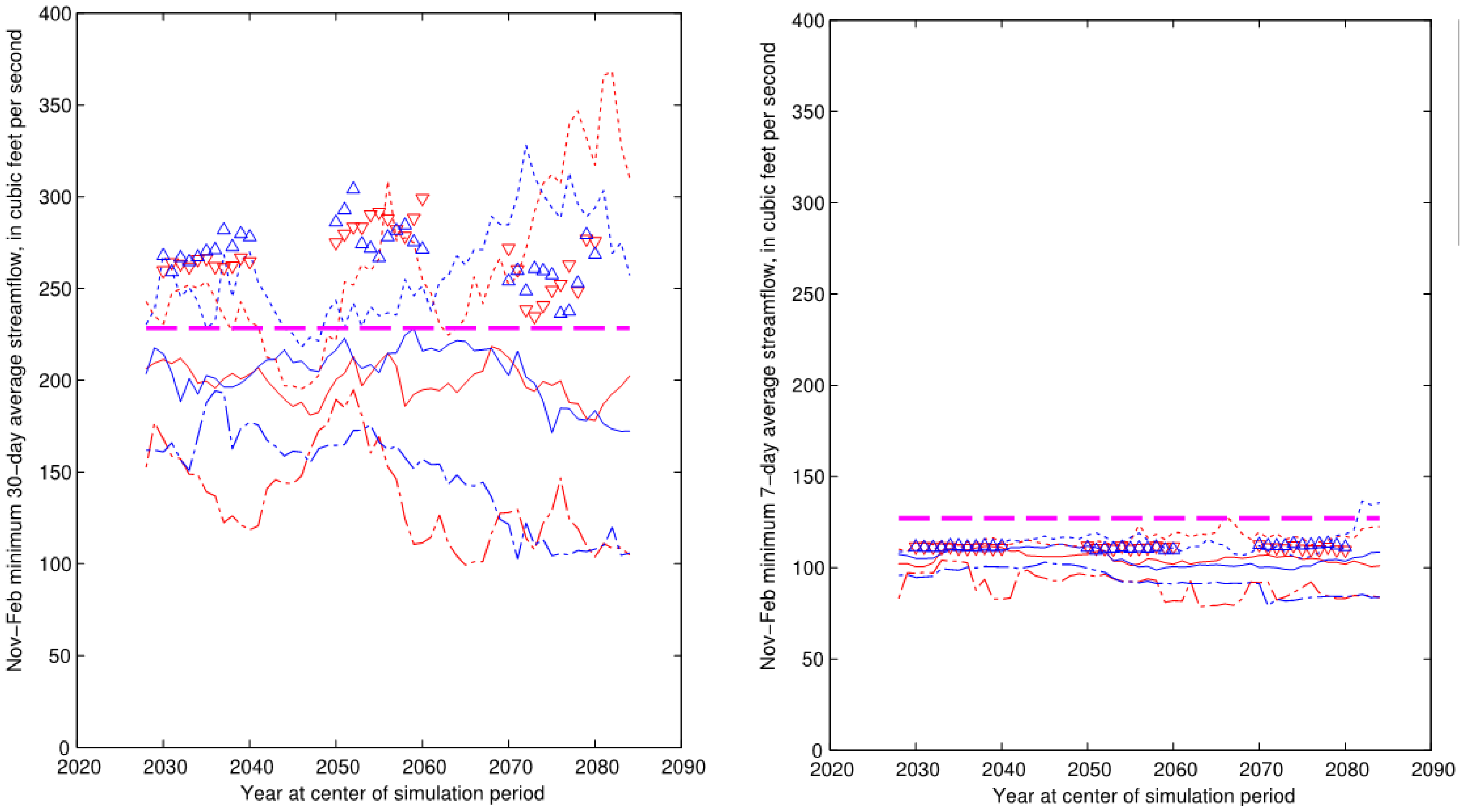
Fall/Winter Average Maximum Stream Flows with Development



30-Day

7-Day

Fall/Winter Average Minimum Stream Flows with Development



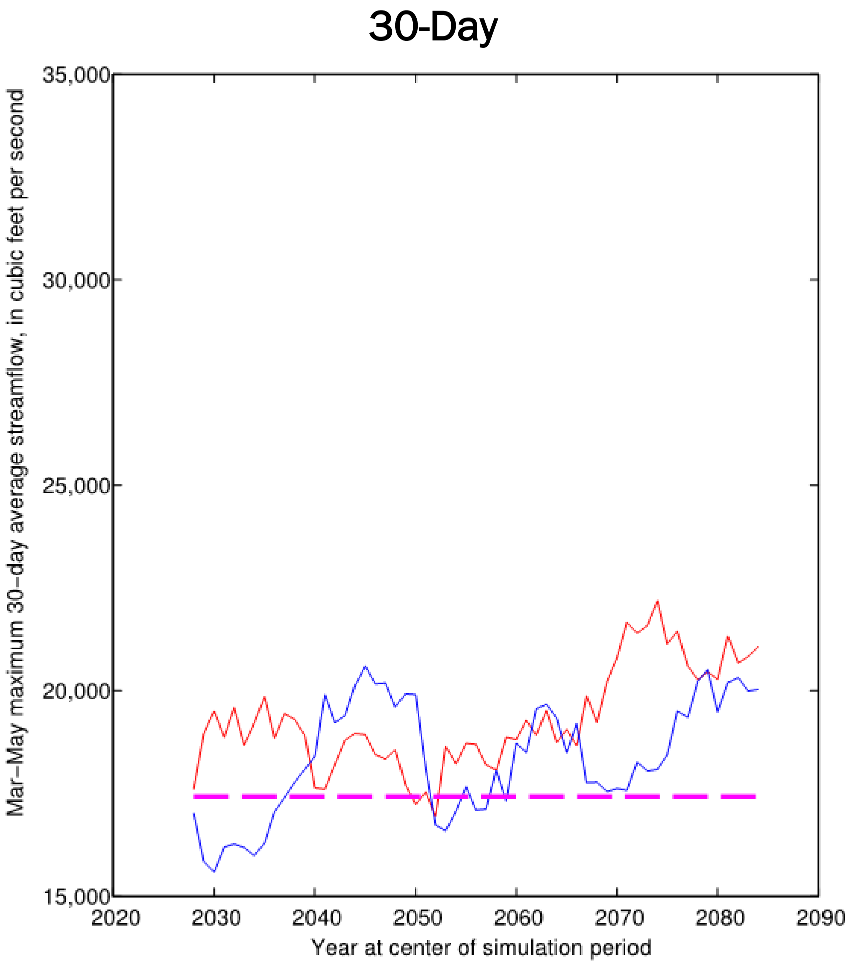
30-Day

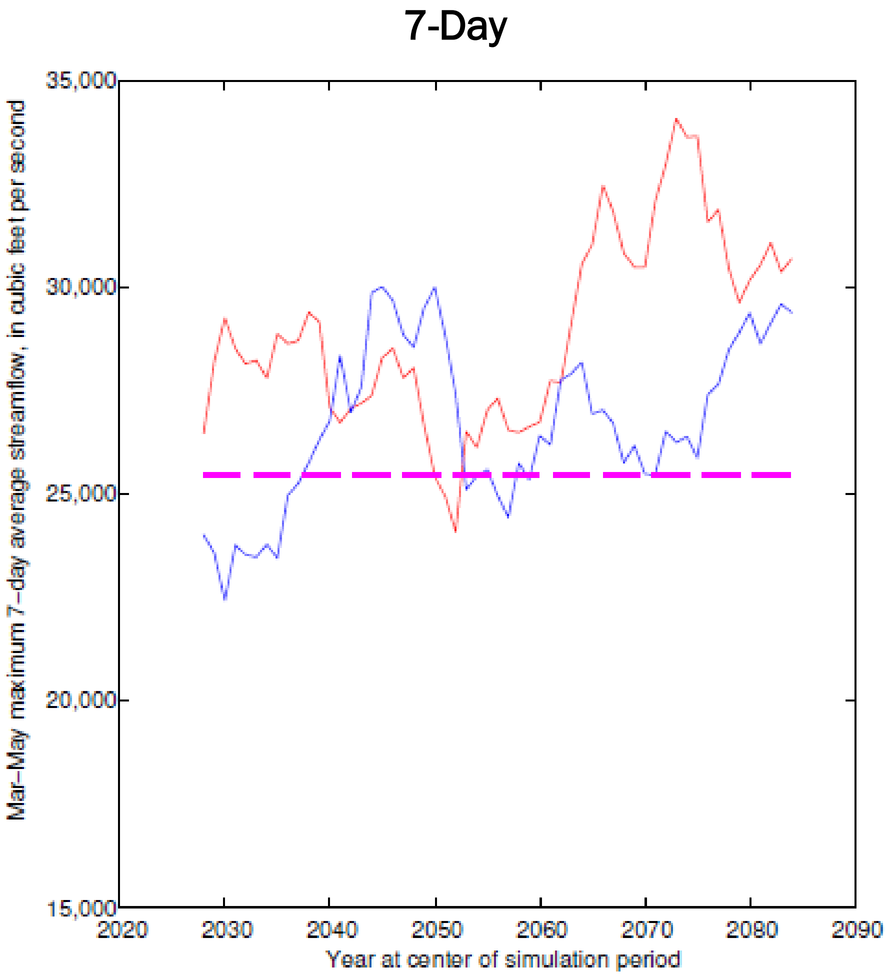
7-Day

Scioto River at Circleville: Seasonal Stream Flows

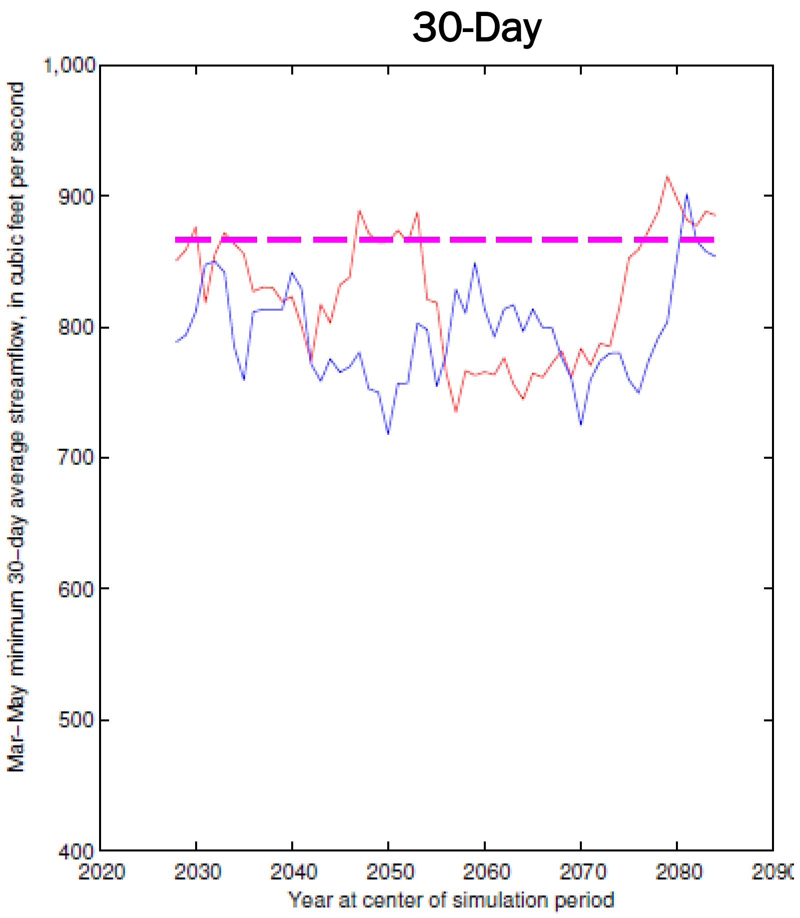
— Median A1b
— Median A2
– – Calibration period

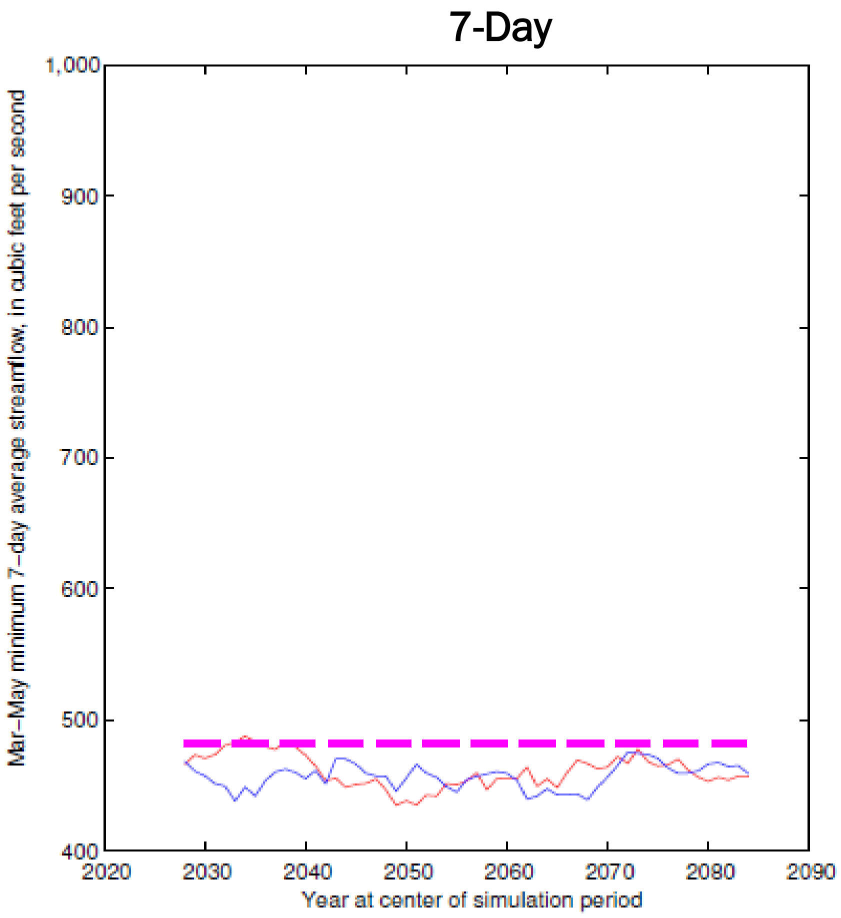
Spring Average Maximum Stream Flow: Climate Only


30-Day

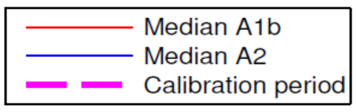

7-Day

Spring Average Minimum Stream Flow: Climate Only


30-Day

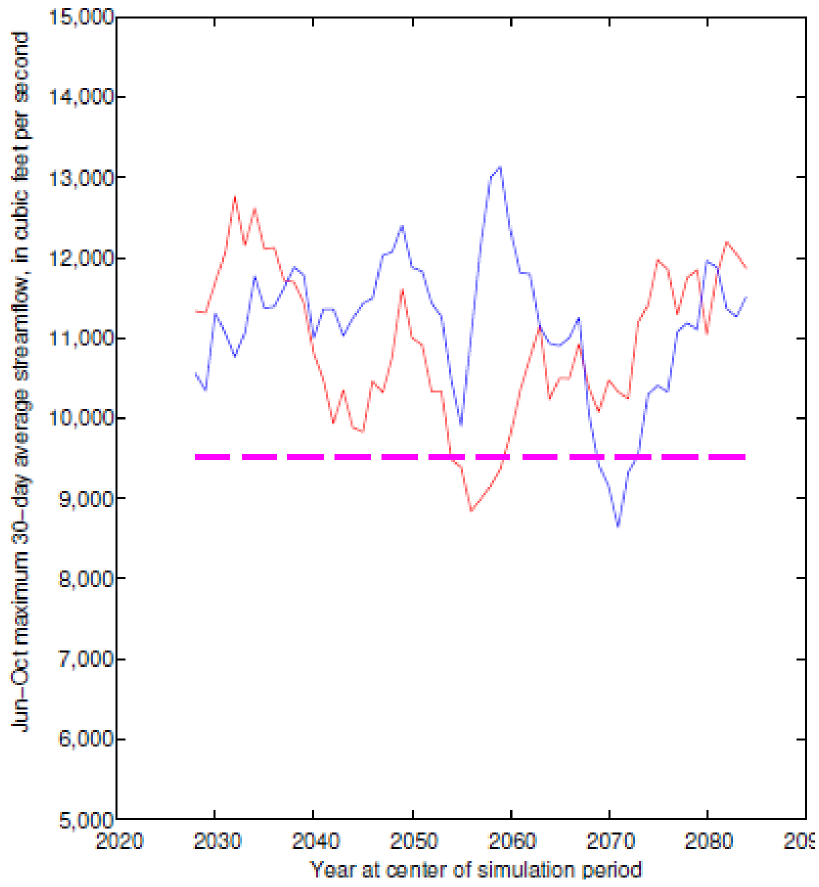

7-Day

Scioto River at Circleville

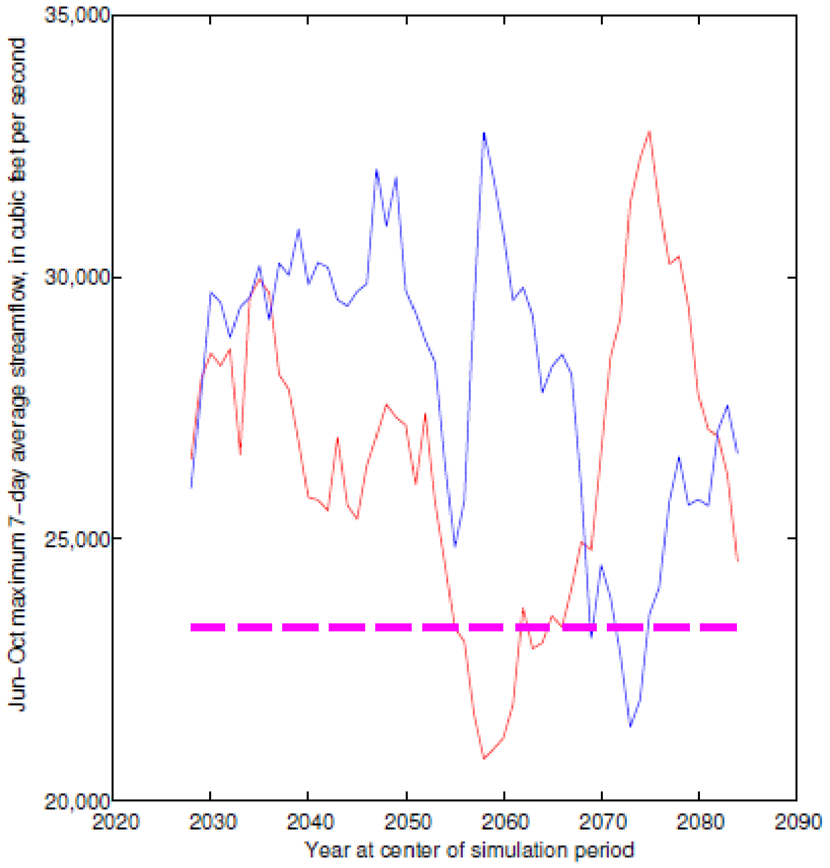


Summer Average Maximum Stream Flow: Climate Only

30-Dav

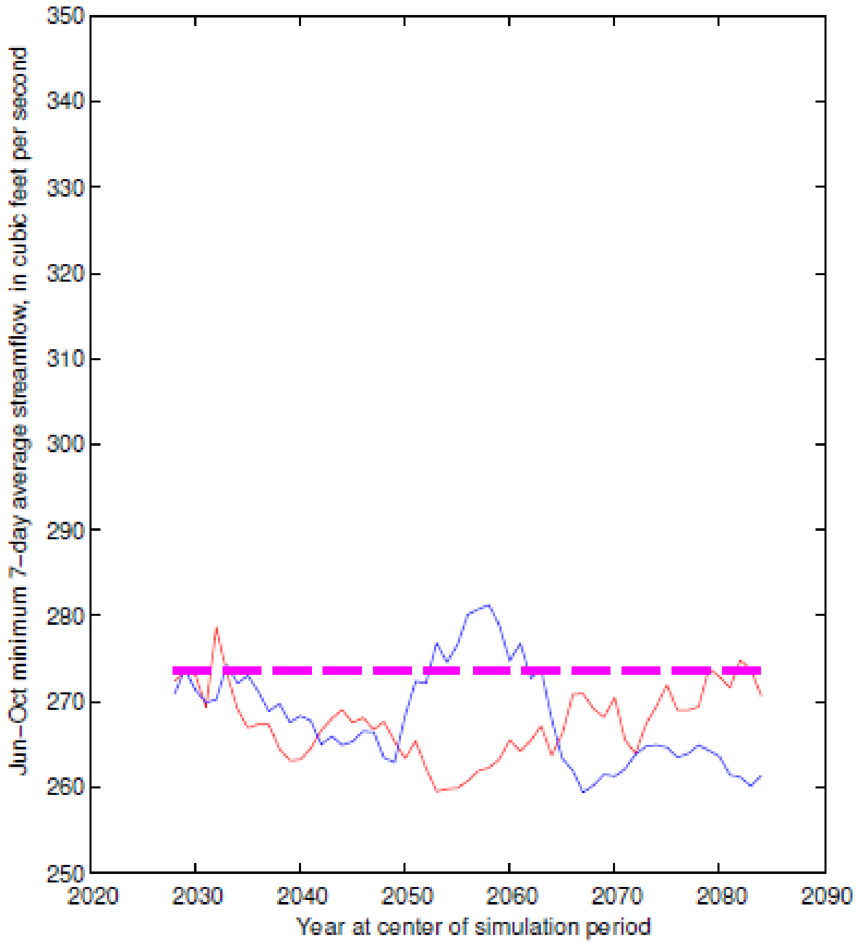


7-Day

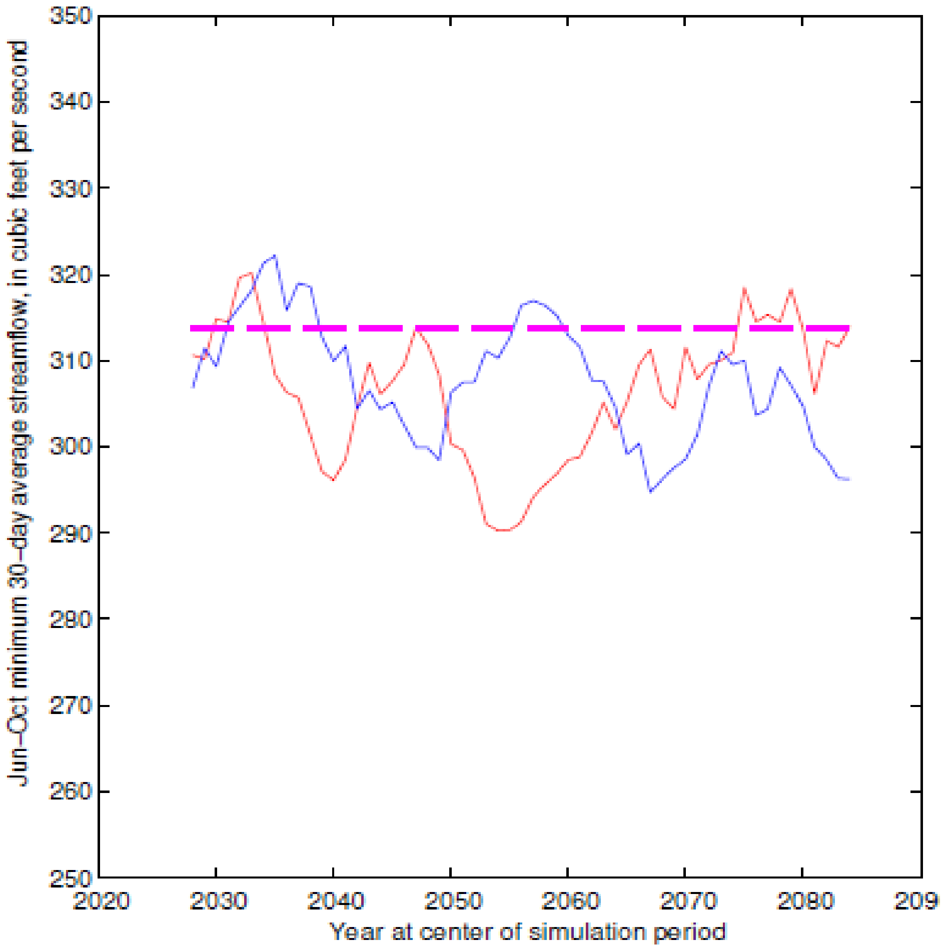


Summer Average Minimum Stream Flow: Climate Only

30-Day



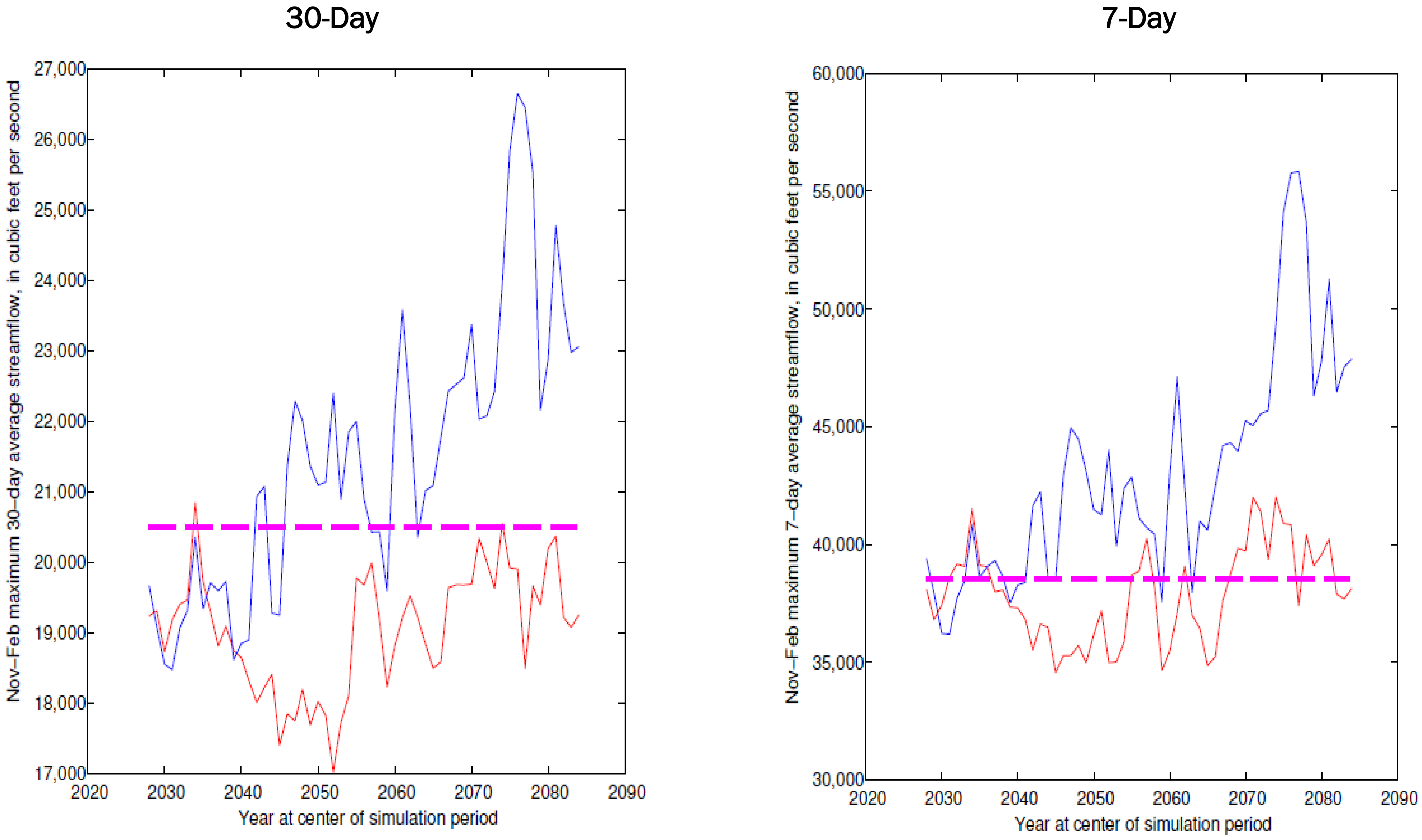
7-Day



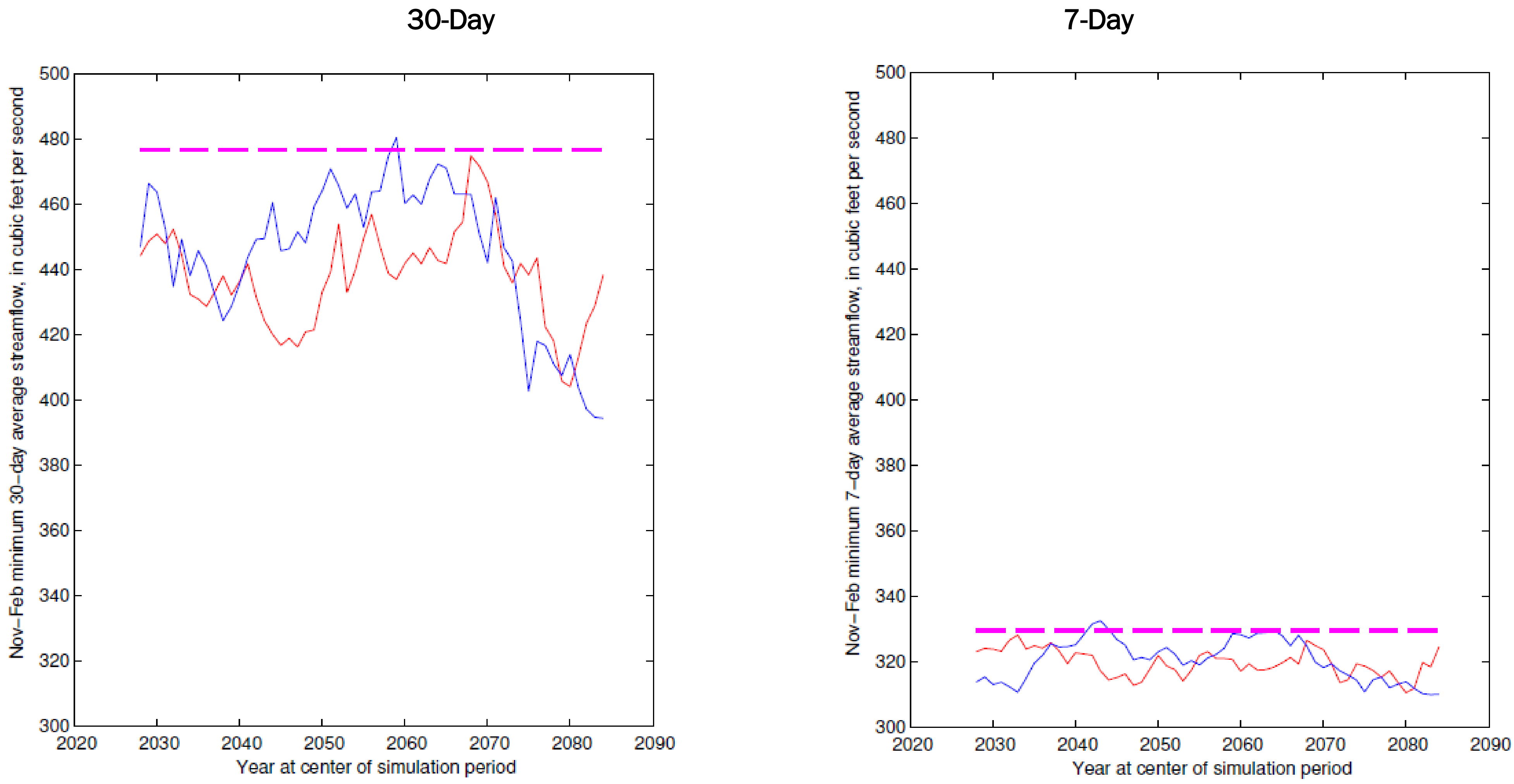
Scioto River at Circleville

Median A1b
Median A2
Calibration period

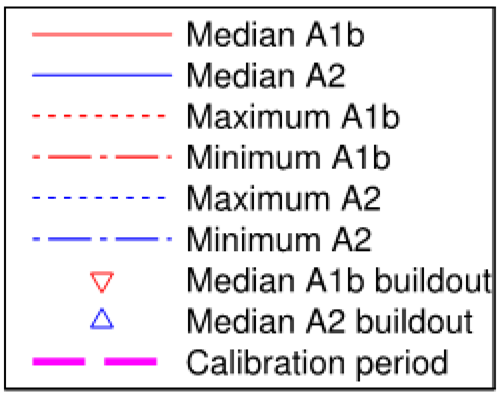
Fall/Winter Average Maximum Stream Flow: Climate Only



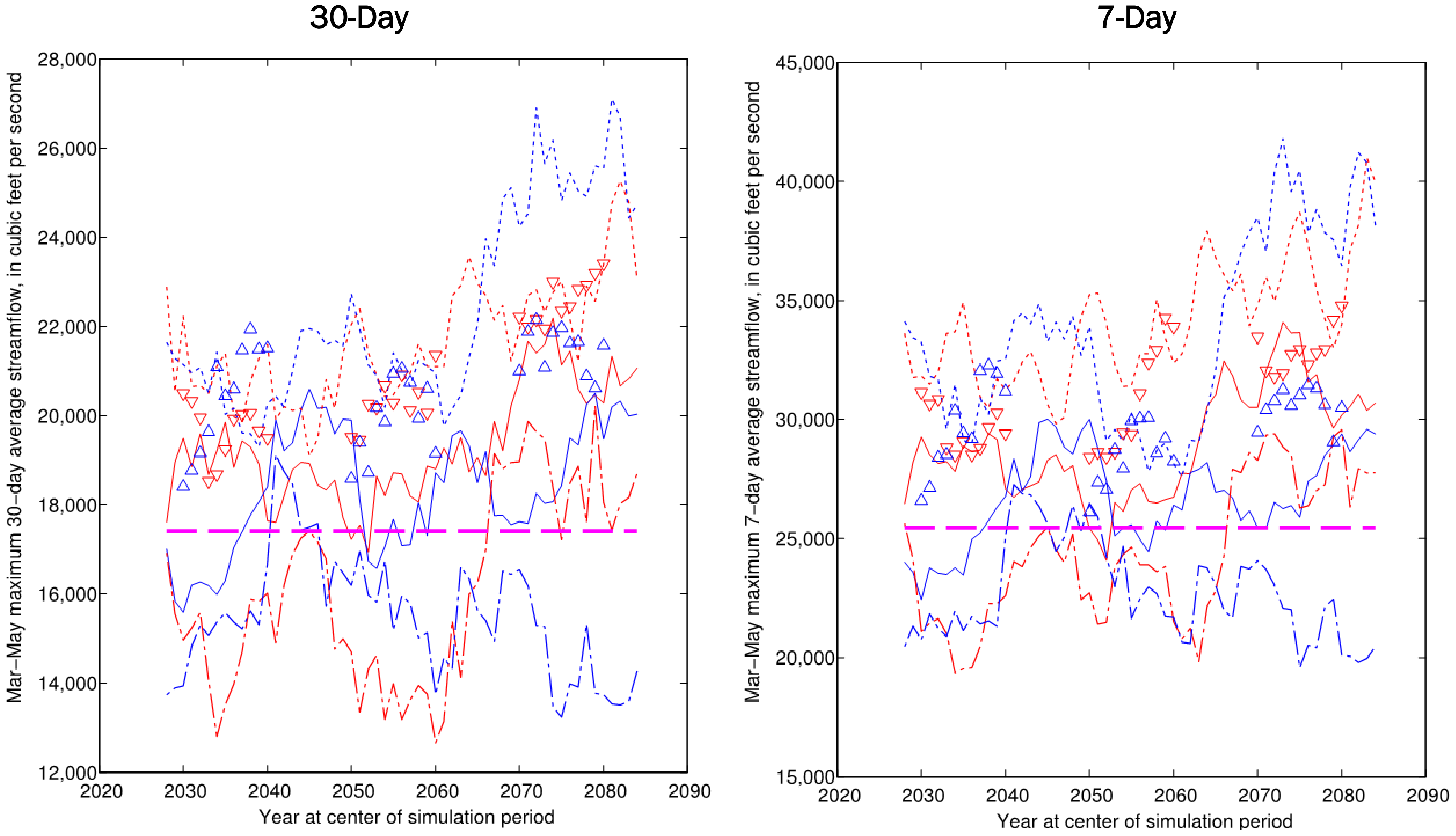
Fall/Winter Average Minimum Stream Flow: Climate Only



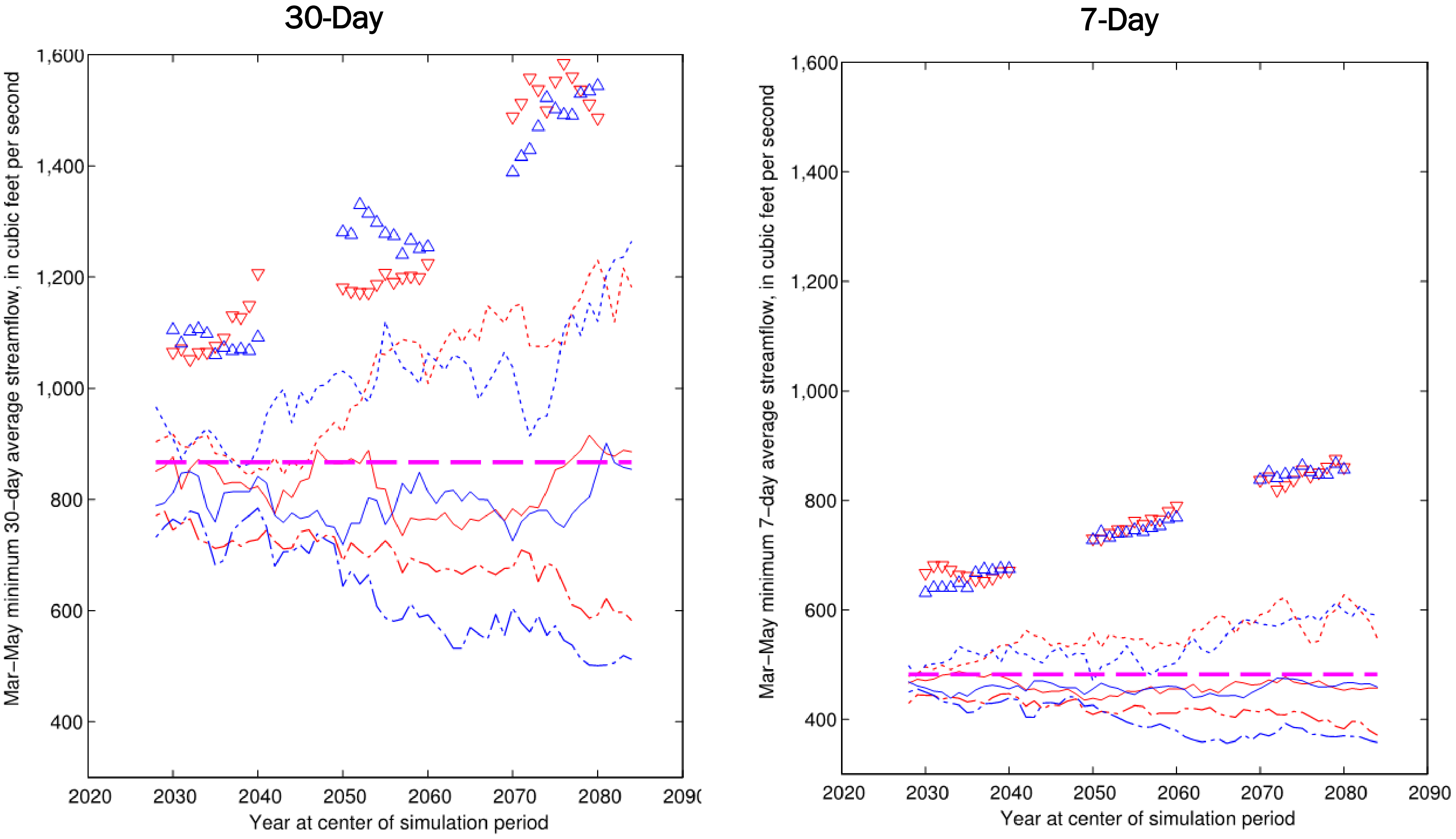
Scioto River at Circleville



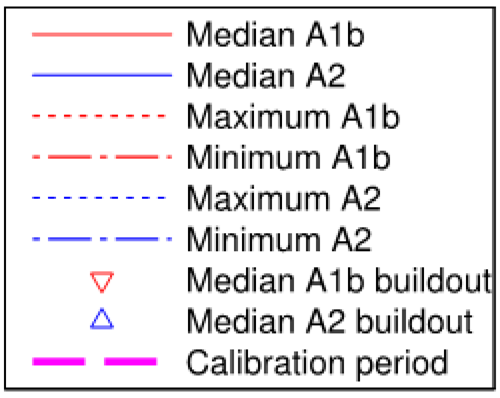
Spring Average Maximum Stream Flows with Development



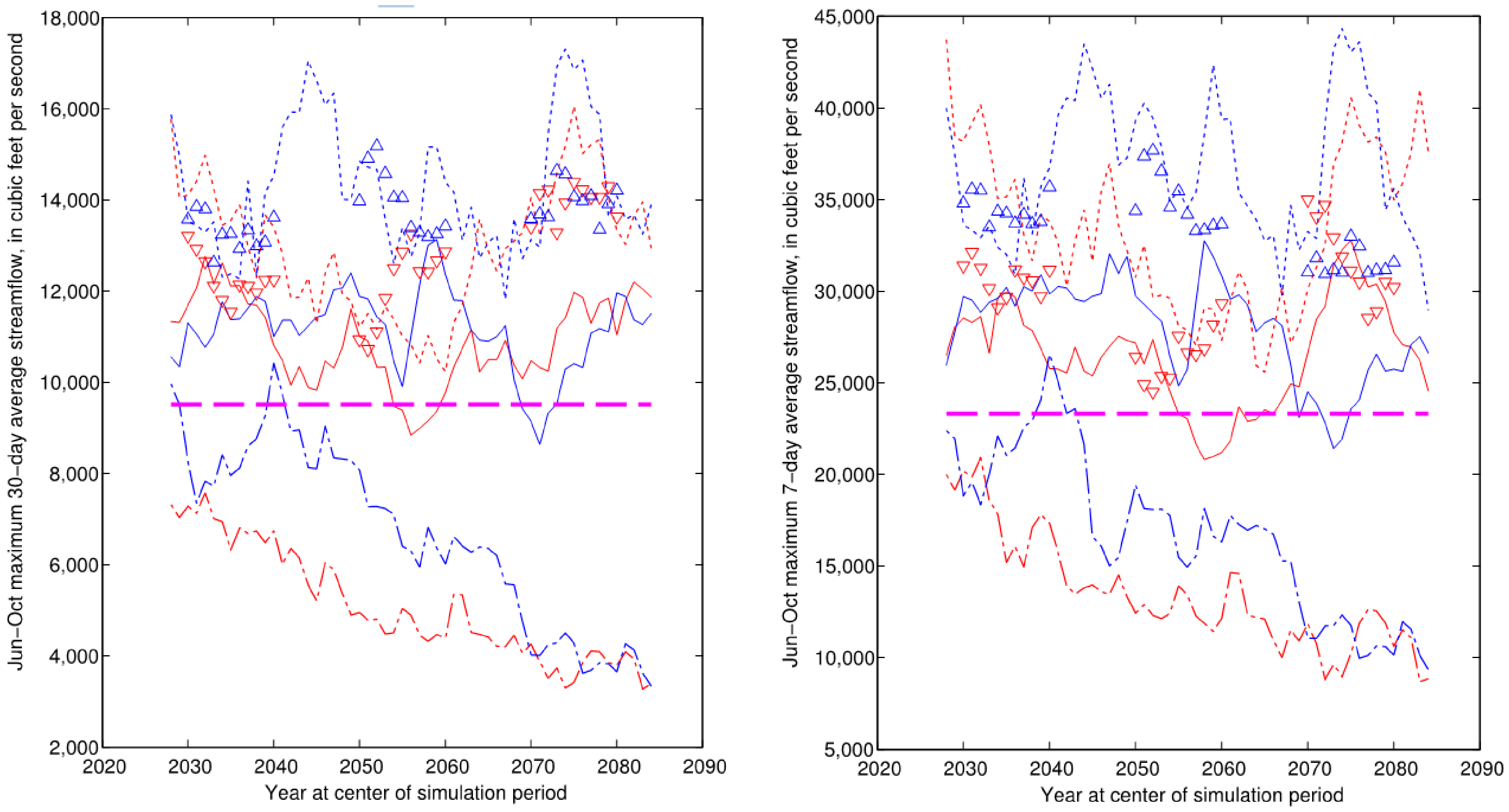
Spring Average Minimum Stream Flows with Development



Scioto River at Circleville

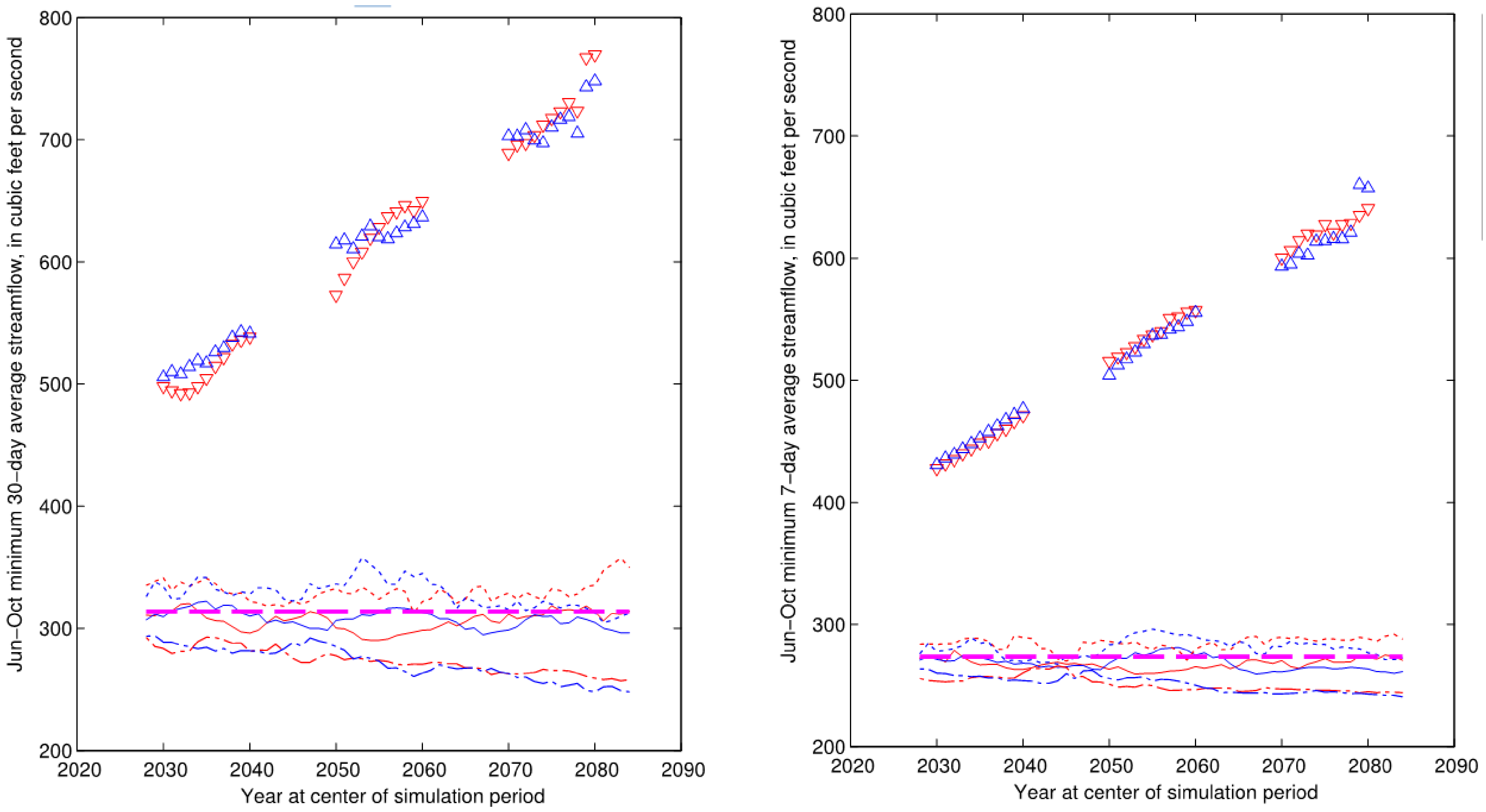


Summer Average Maximum Stream Flows with Development


30-Day

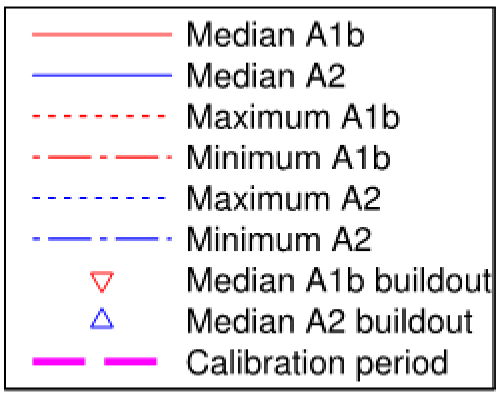
7-Day

Summer Average Minimum Stream Flows with Development

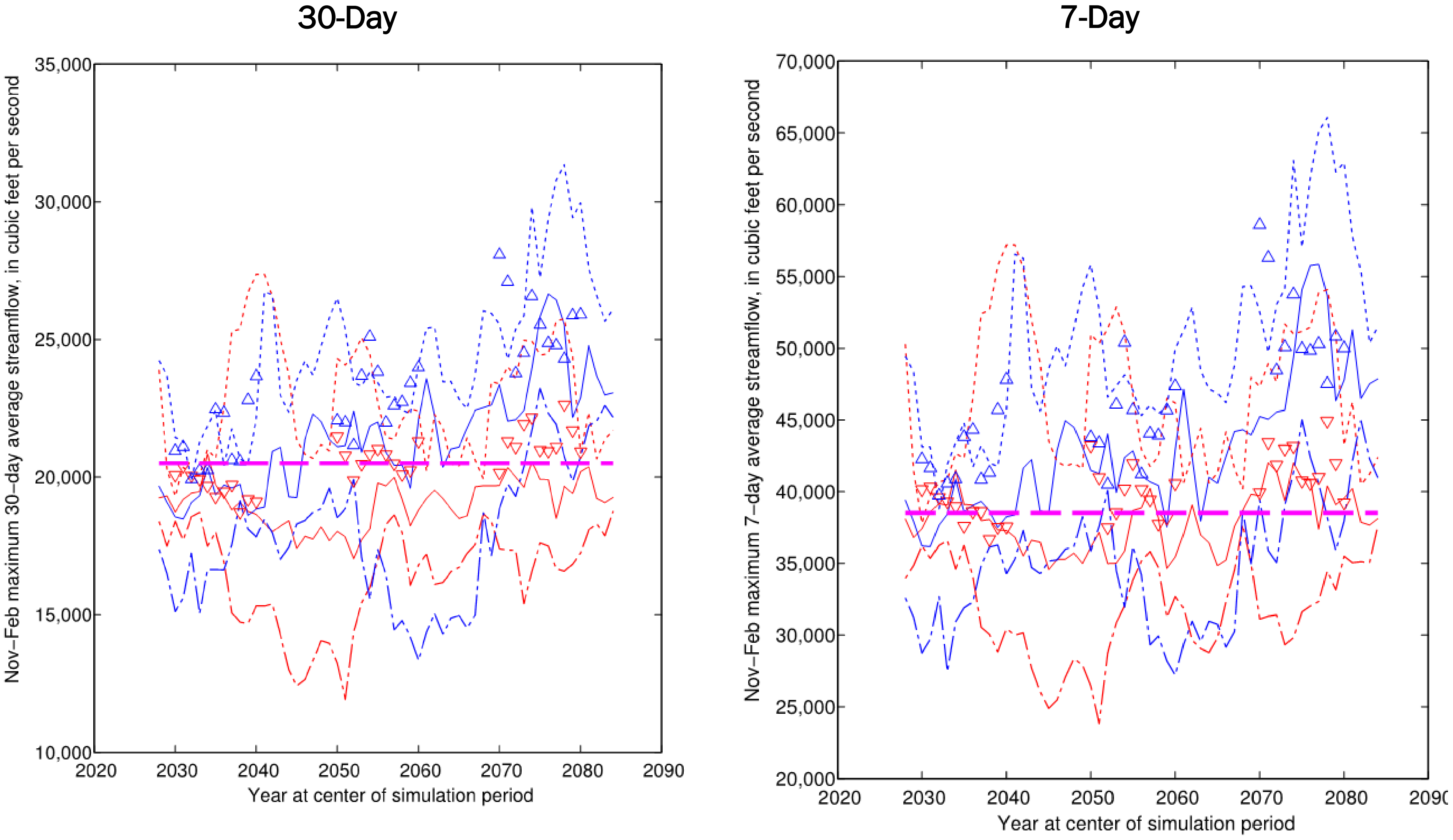

30-Day

7-Day

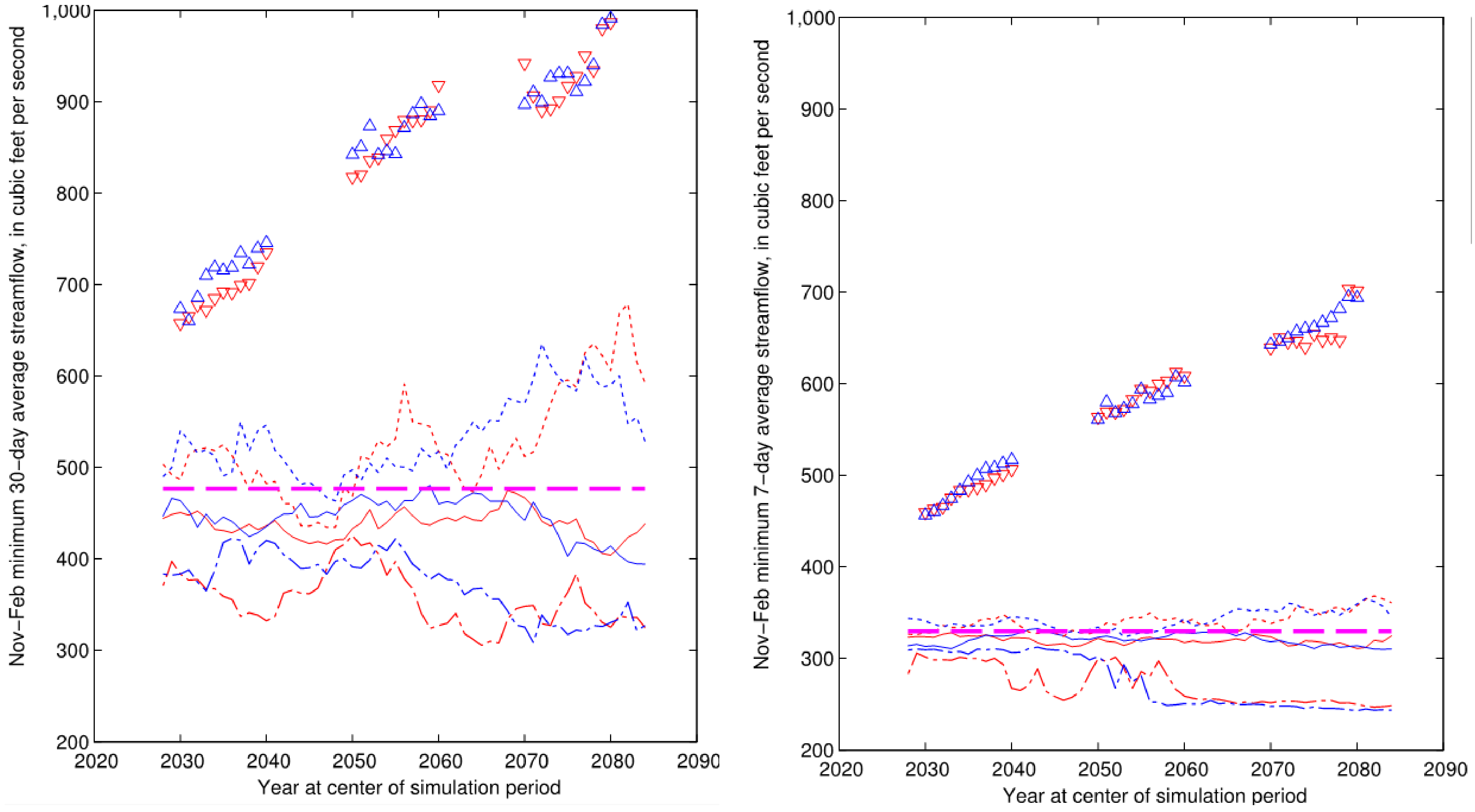
Scioto River at Circleville



Fall/Winter Average Maximum Stream Flows with Development



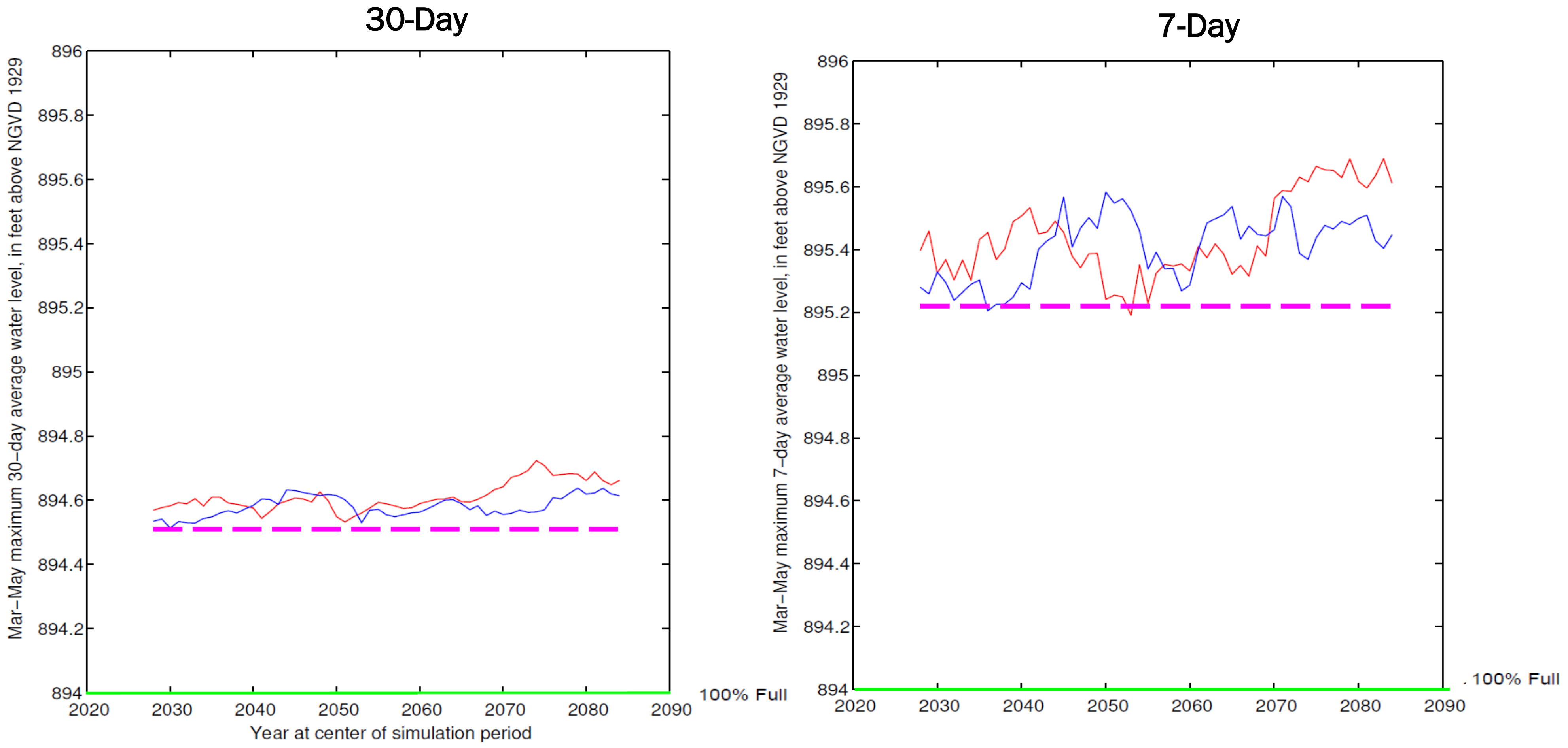
Fall/Winter Average Minimum Stream Flows with Development



Hoover Reservoir: Seasonal Water Levels

— Median A1b
— Median A2
- - Calibration period

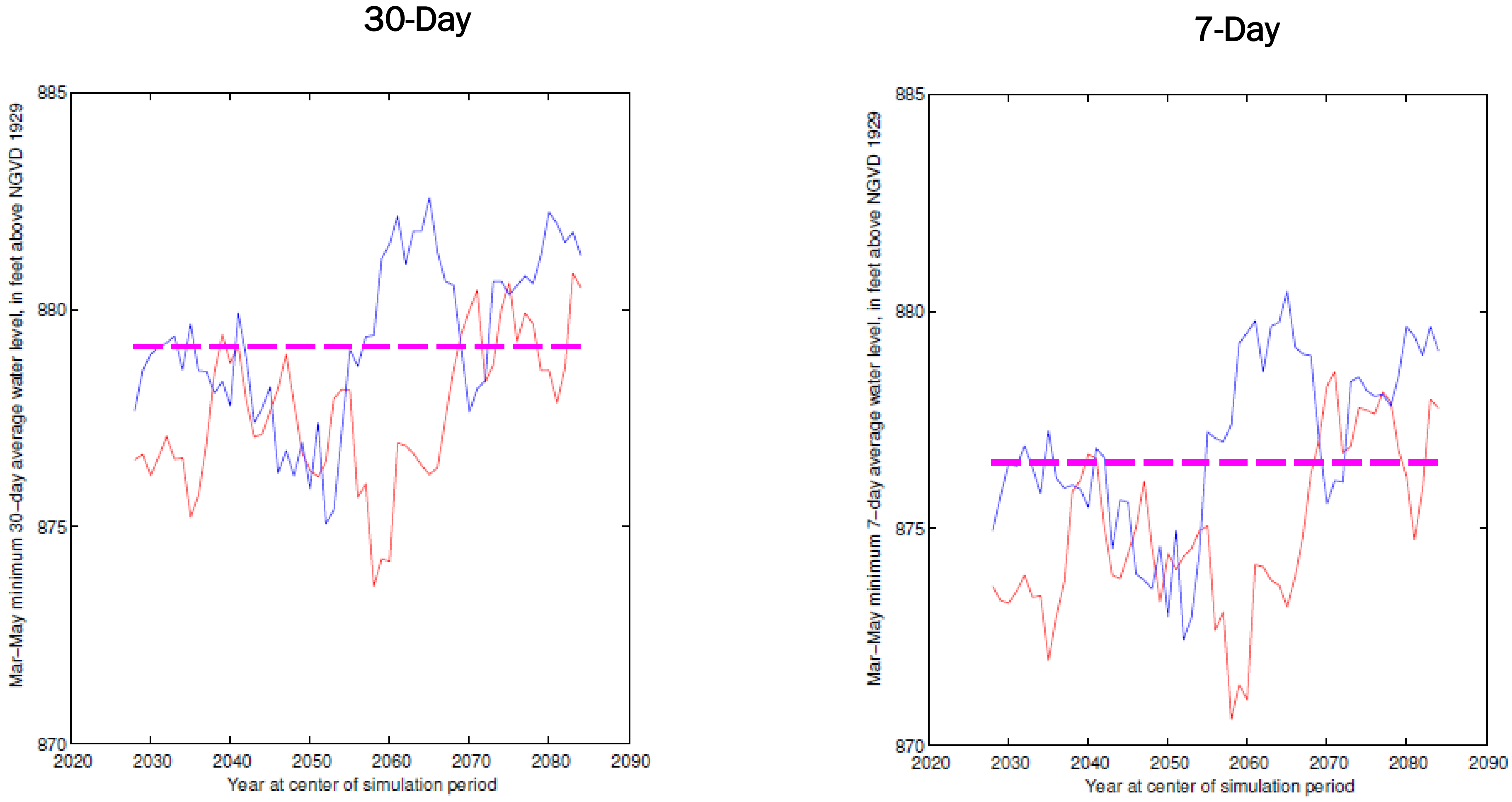
Spring Average Maximum Water Levels: Climate Only



30-Day

7-Day

Spring Average Minimum Water Levels: Climate Only



30-Day

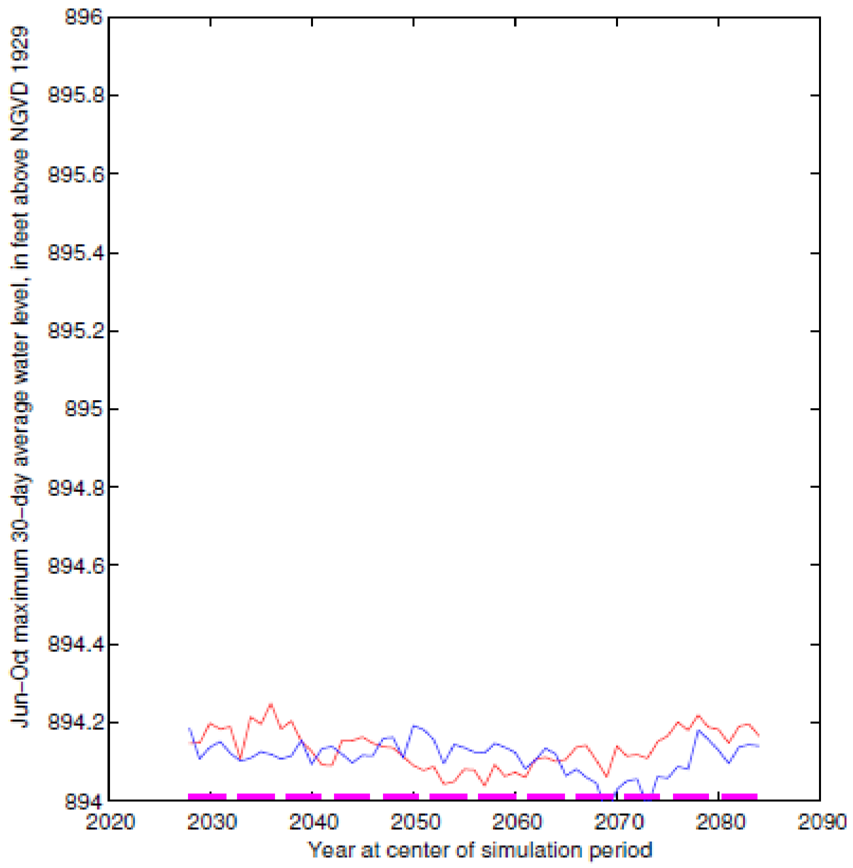
7-Day

Hoover Reservoir: Seasonal Water Levels

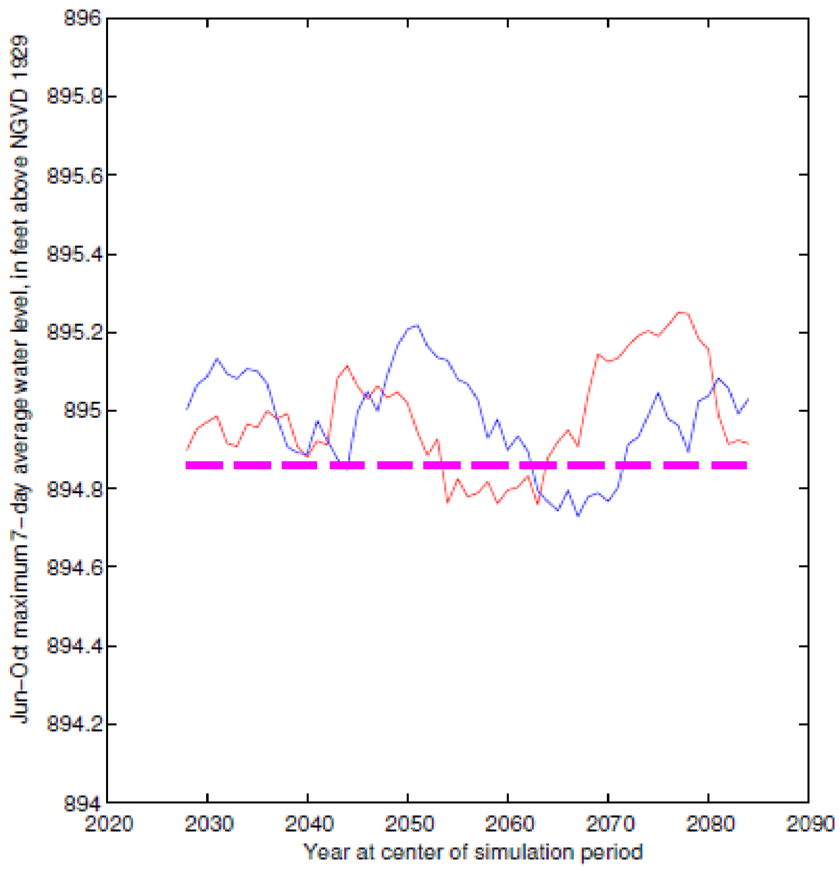
Median A1b
Median A2
Calibration period

Summer Average Maximum Water Levels: Climate Only

30-Day

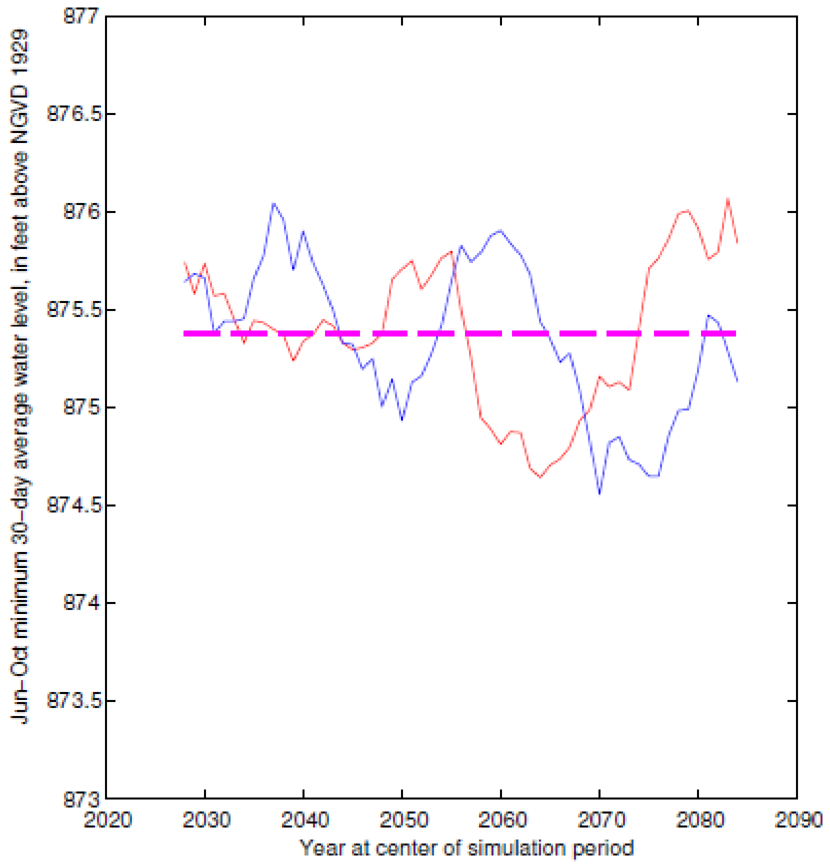


7-Day

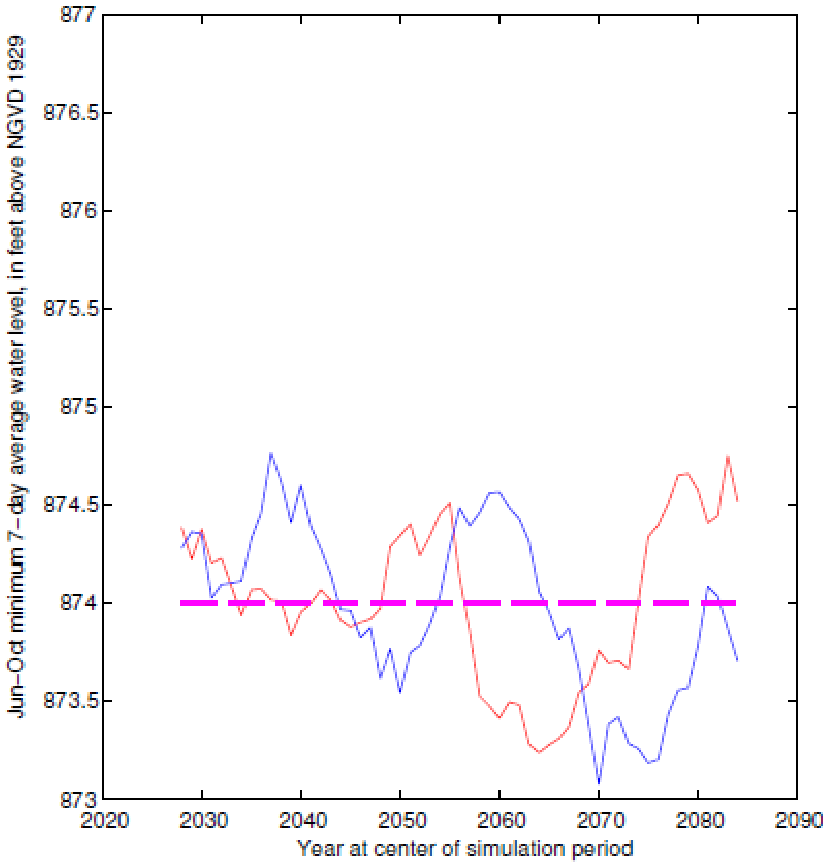


Summer Average Minimum Water Levels: Climate Only

30-Day

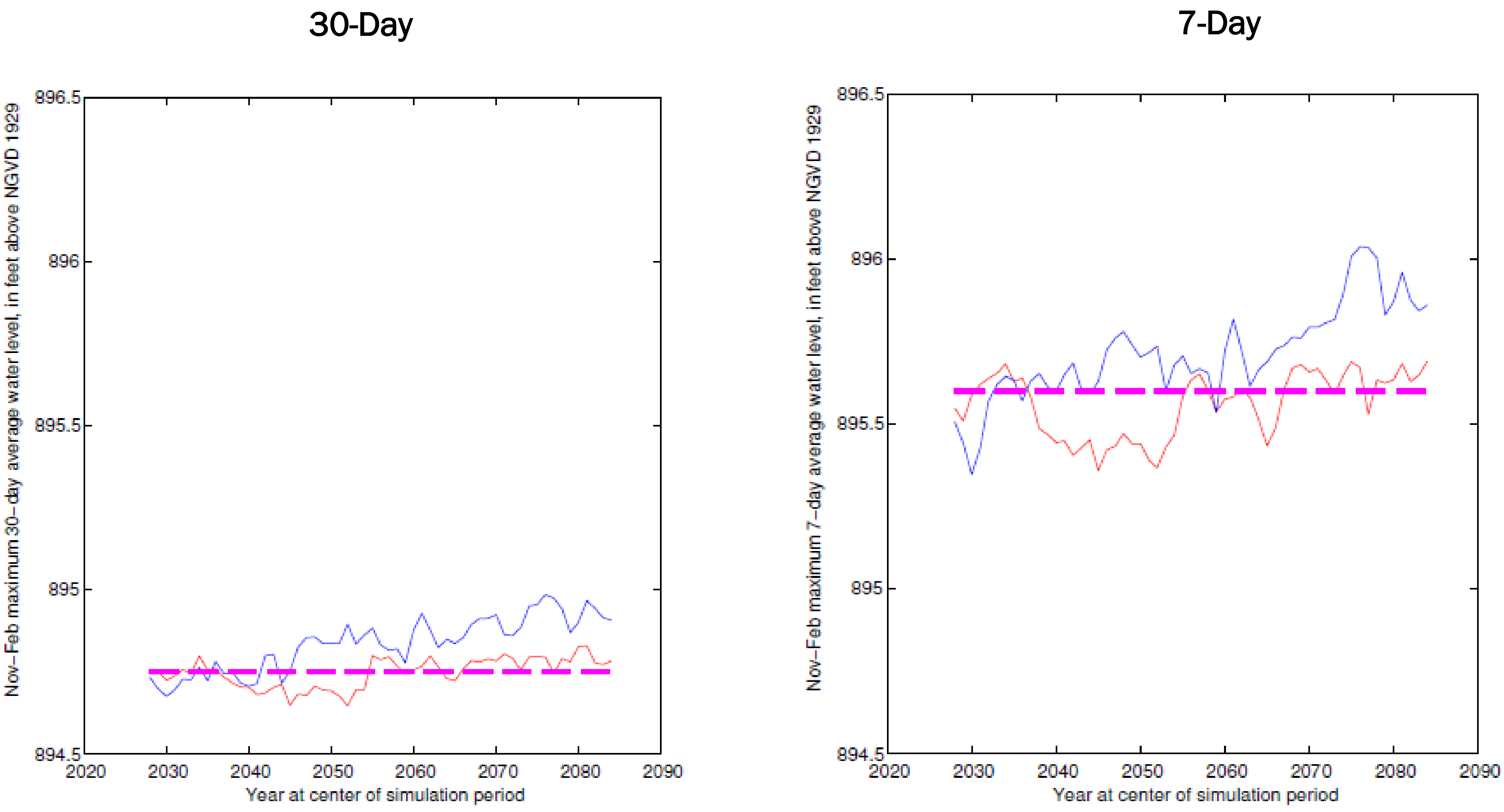


7-Day

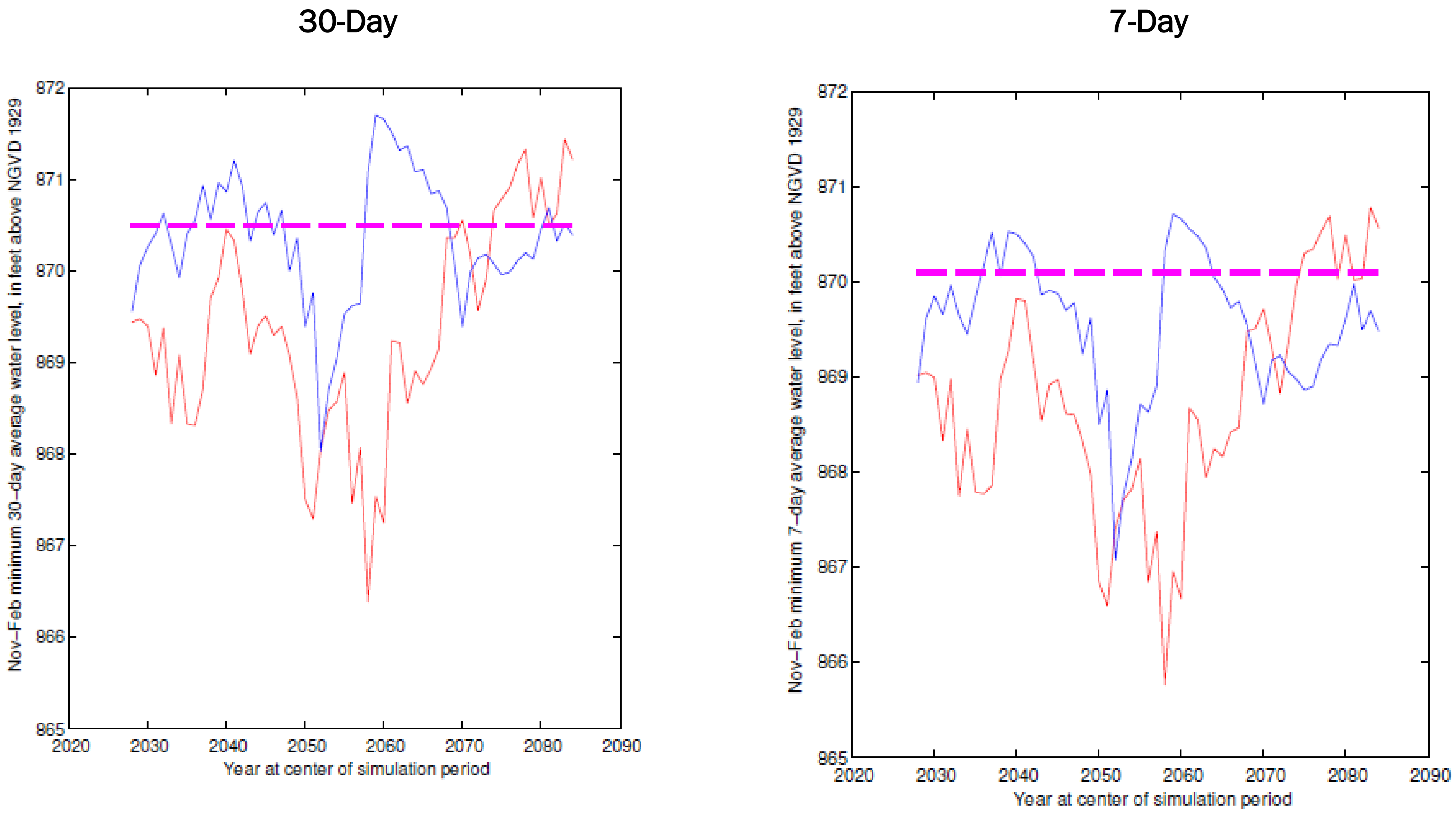


Hoover Reservoir: Seasonal Water Levels

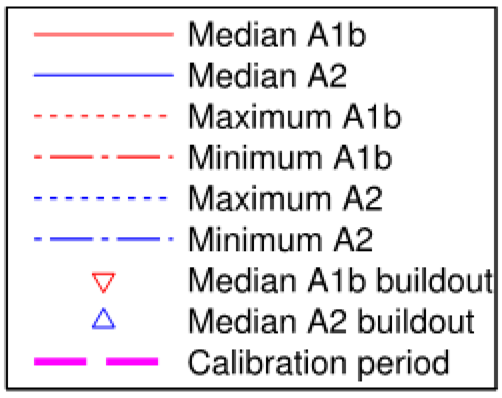
Fall/Winter Average Maximum Water Levels: Climate Only



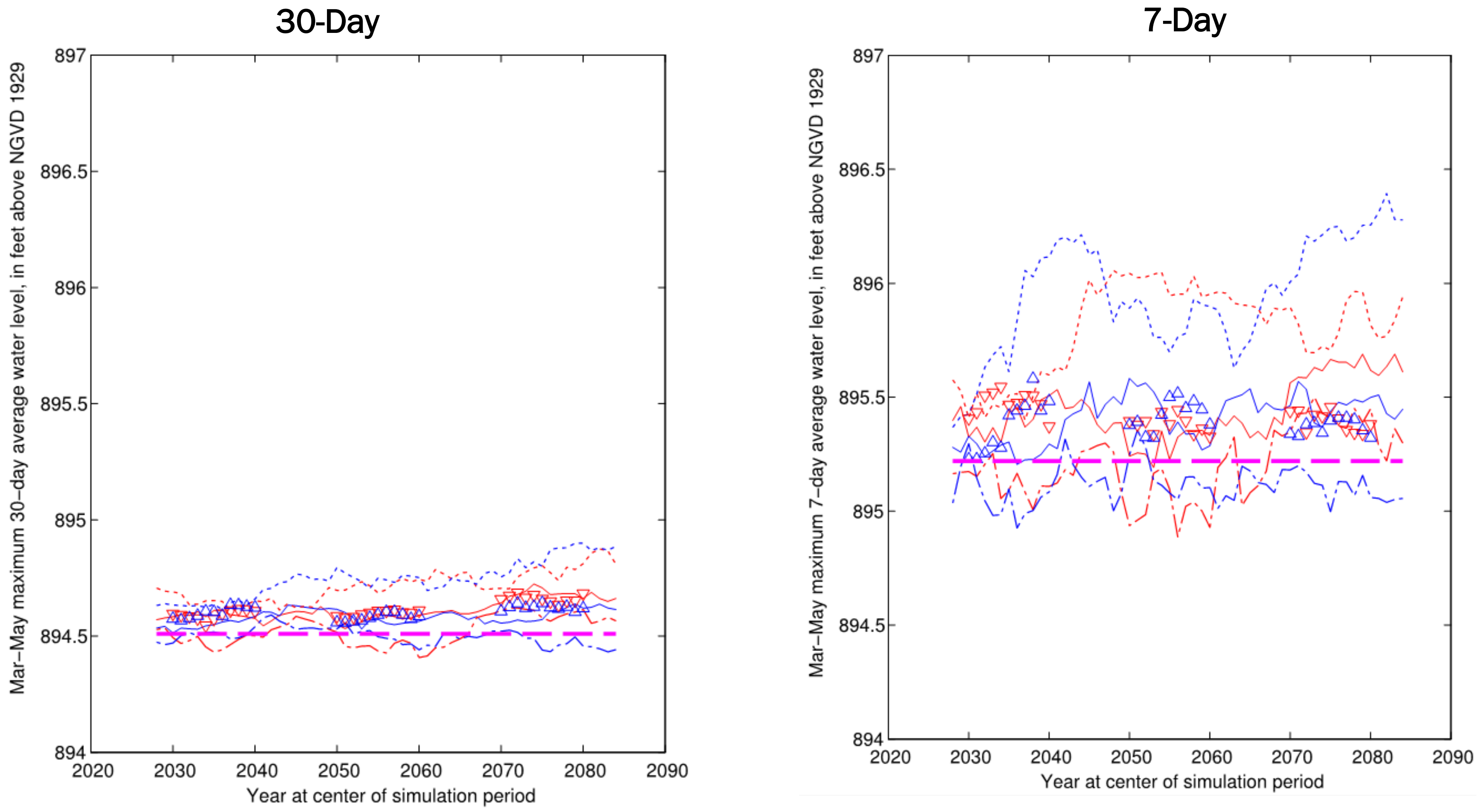
Fall/Winter Average Minimum Water Levels: Climate Only



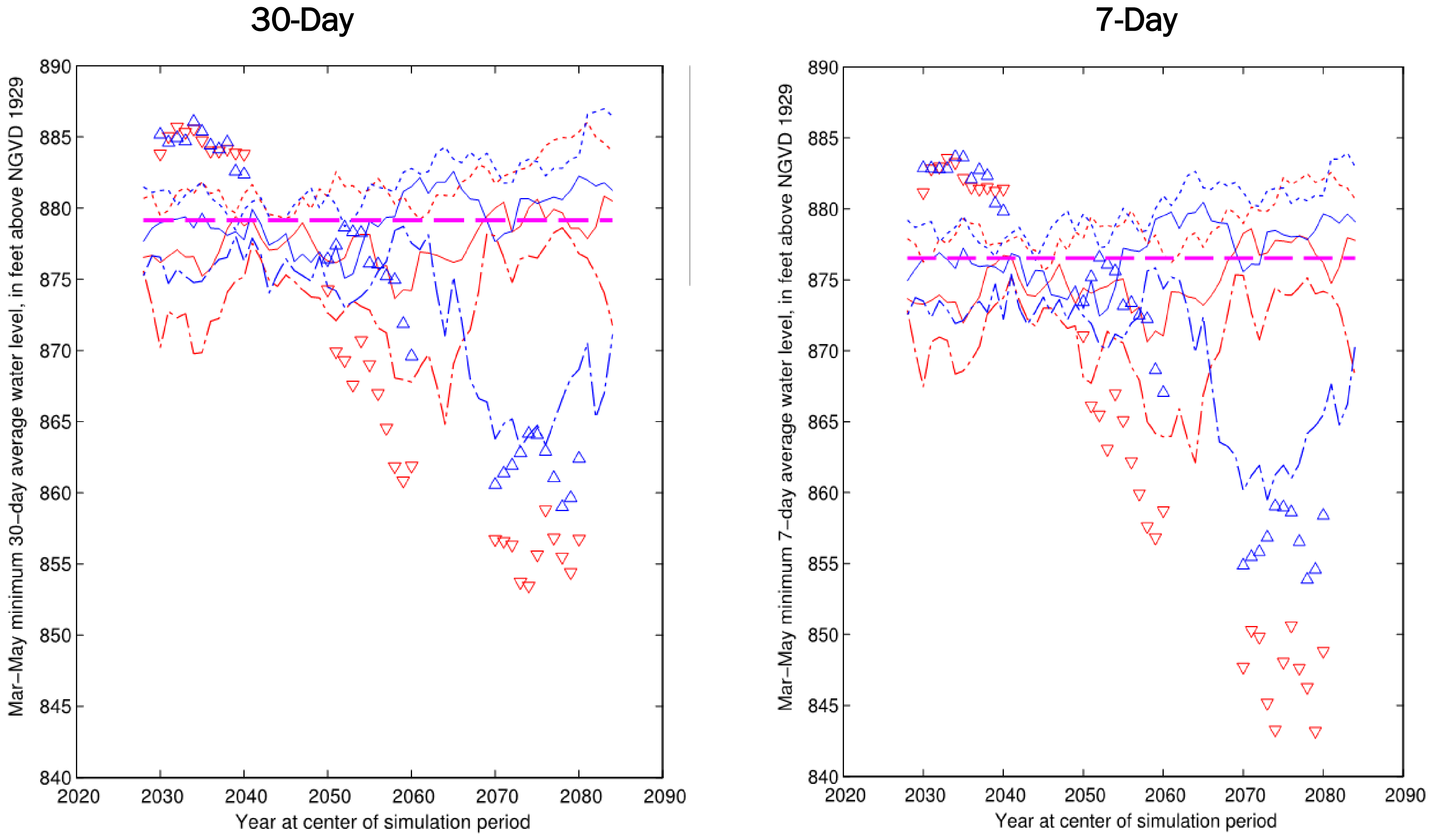
Hoover Reservoir: Seasonal Water Levels



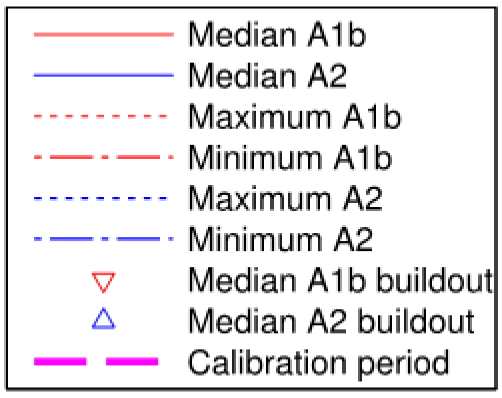
Spring Average Maximum Water Levels with Development



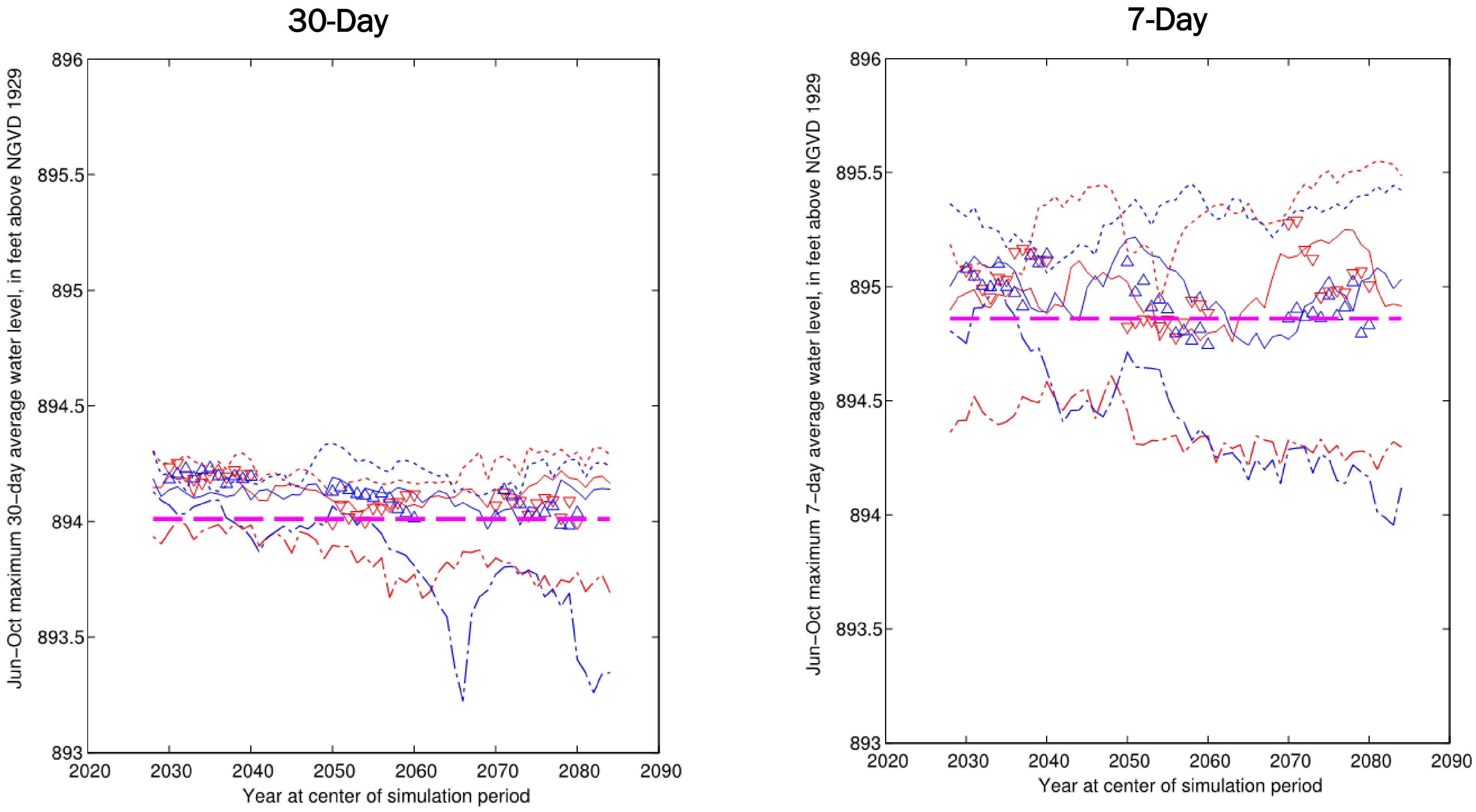
Spring Average Minimum Water Levels with Development



Hoover Reservoir: Seasonal Water Levels

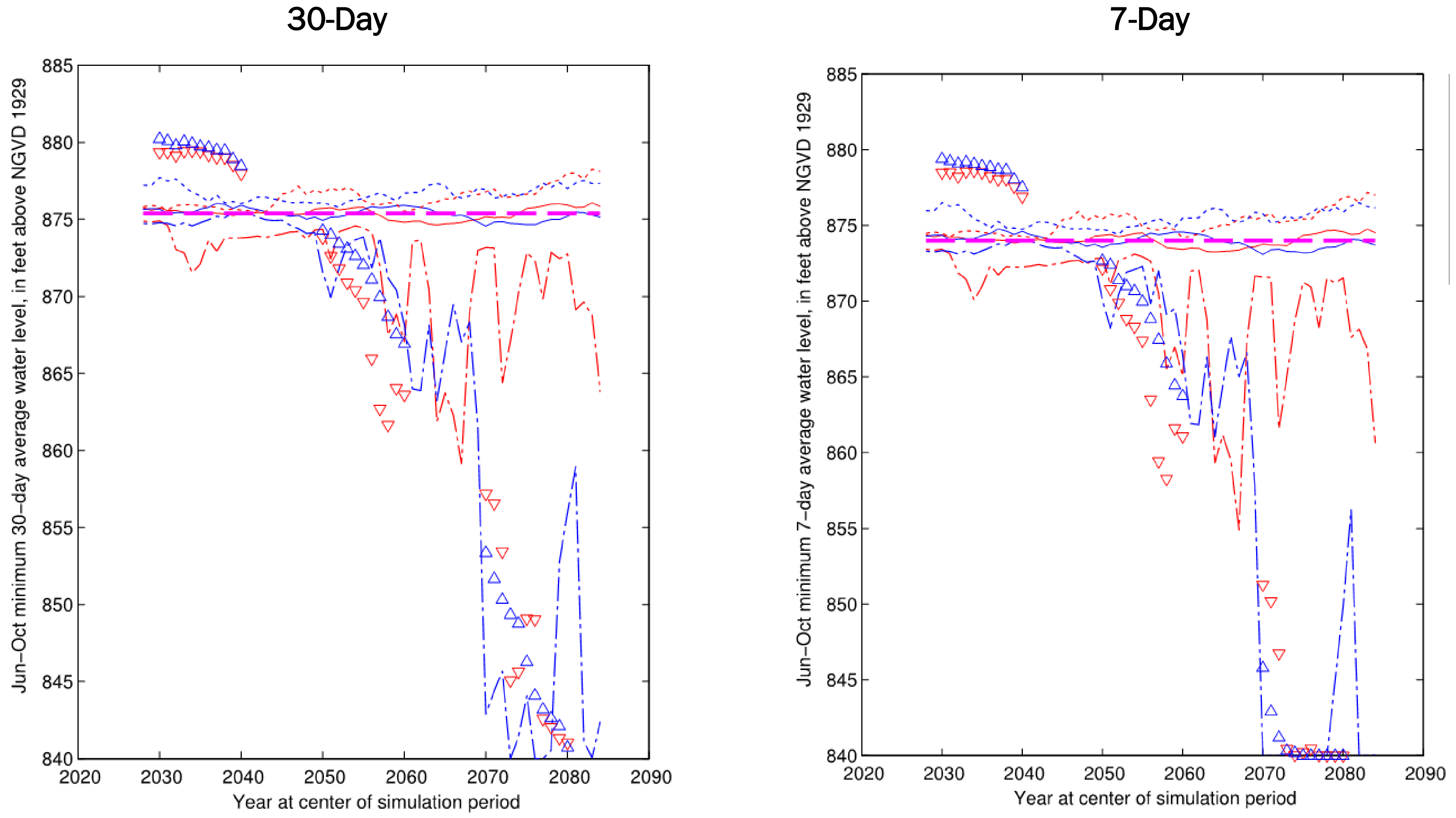


Summer Average Maximum Water Levels with Development


30-Day

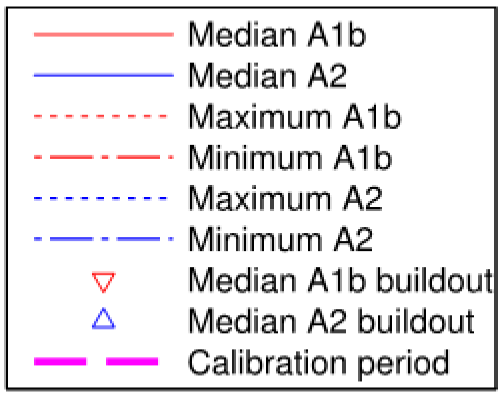
7-Day

Summer Average Minimum Water Levels with Development

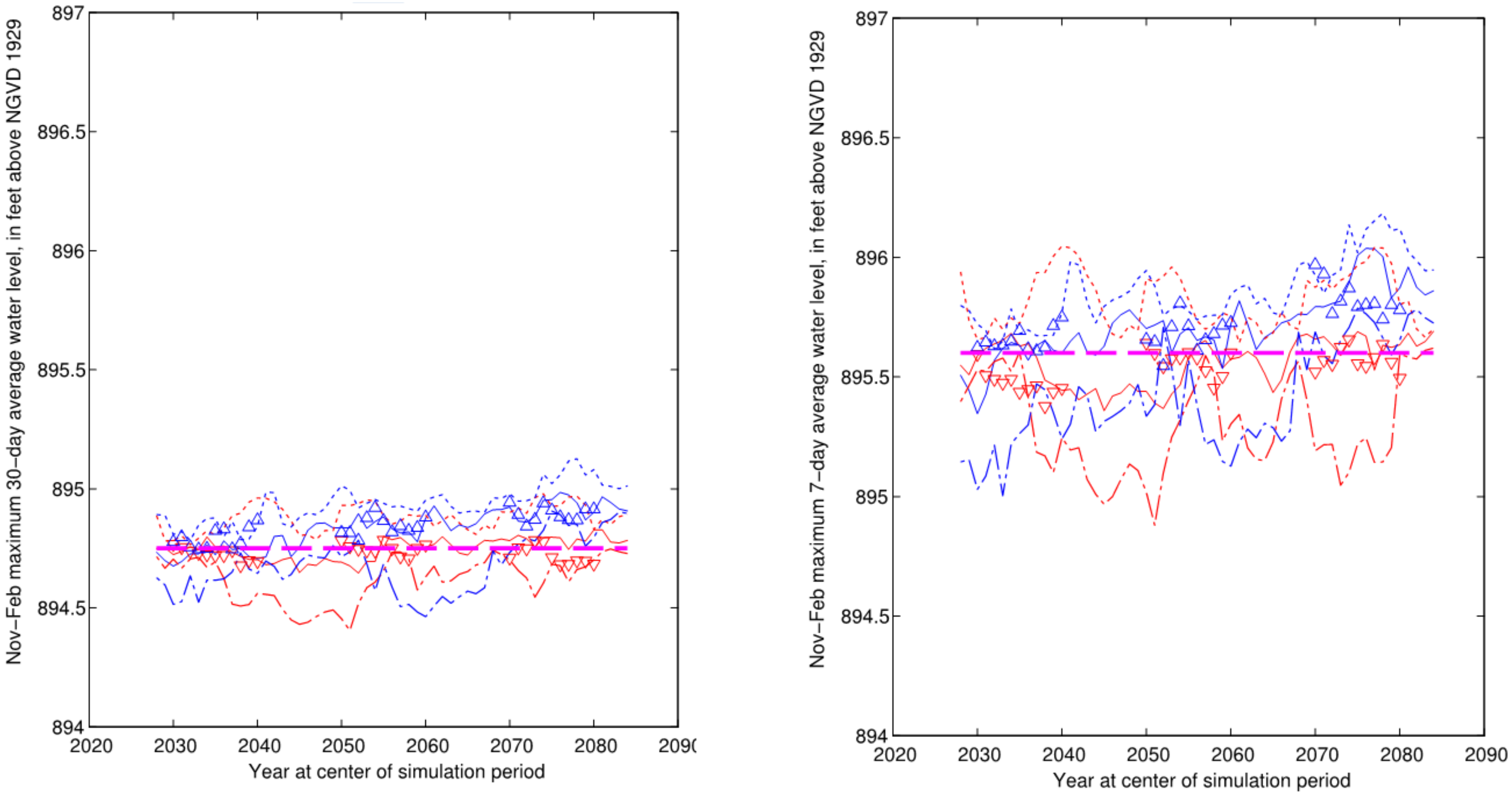

30-Day

7-Day

Hoover Reservoir: Seasonal Water Levels

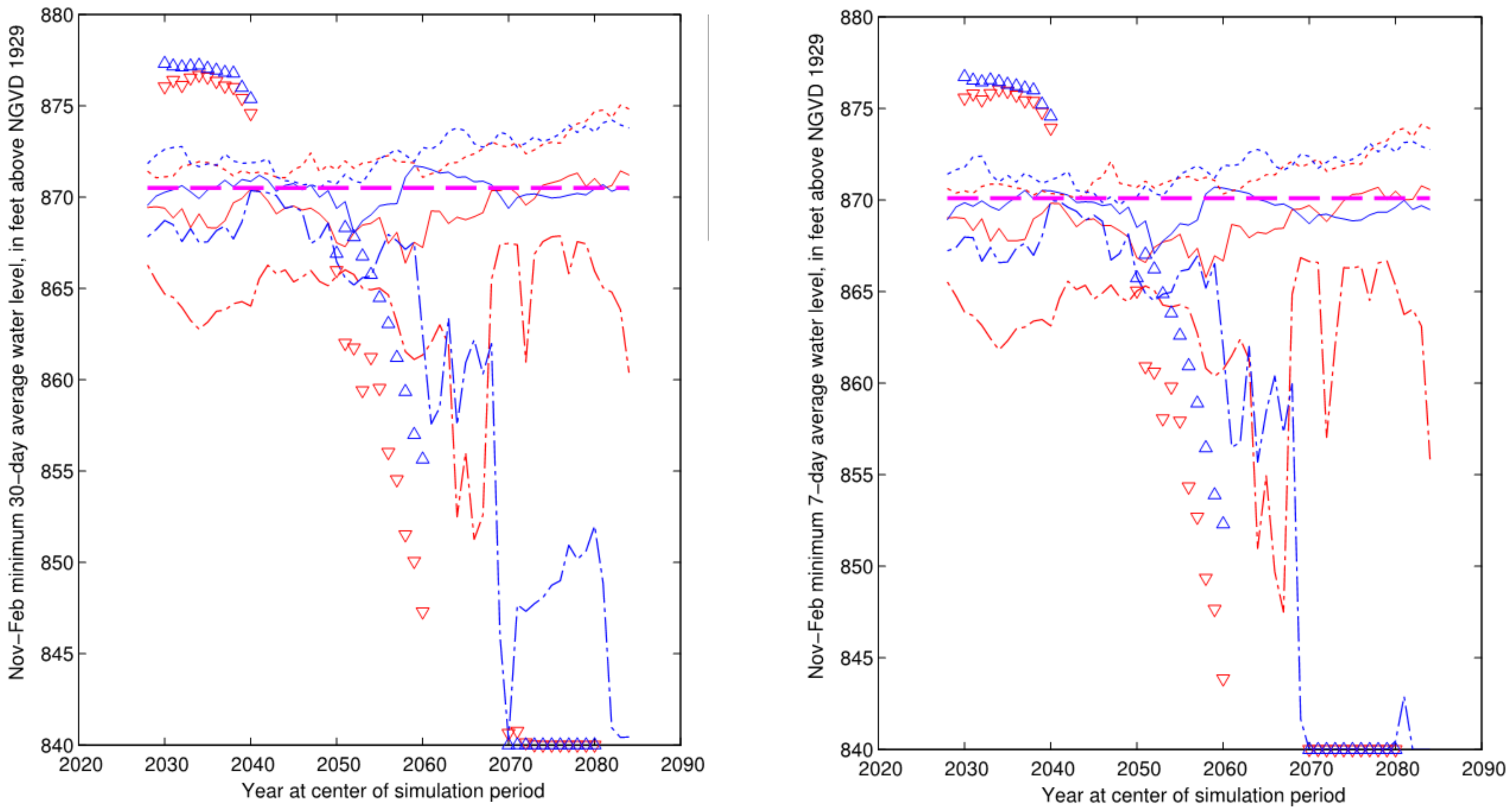


Fall/Winter Average Maximum Water Levels with Development


30-Day

7-Day

Fall/Winter Average Minimum Water Levels with Development

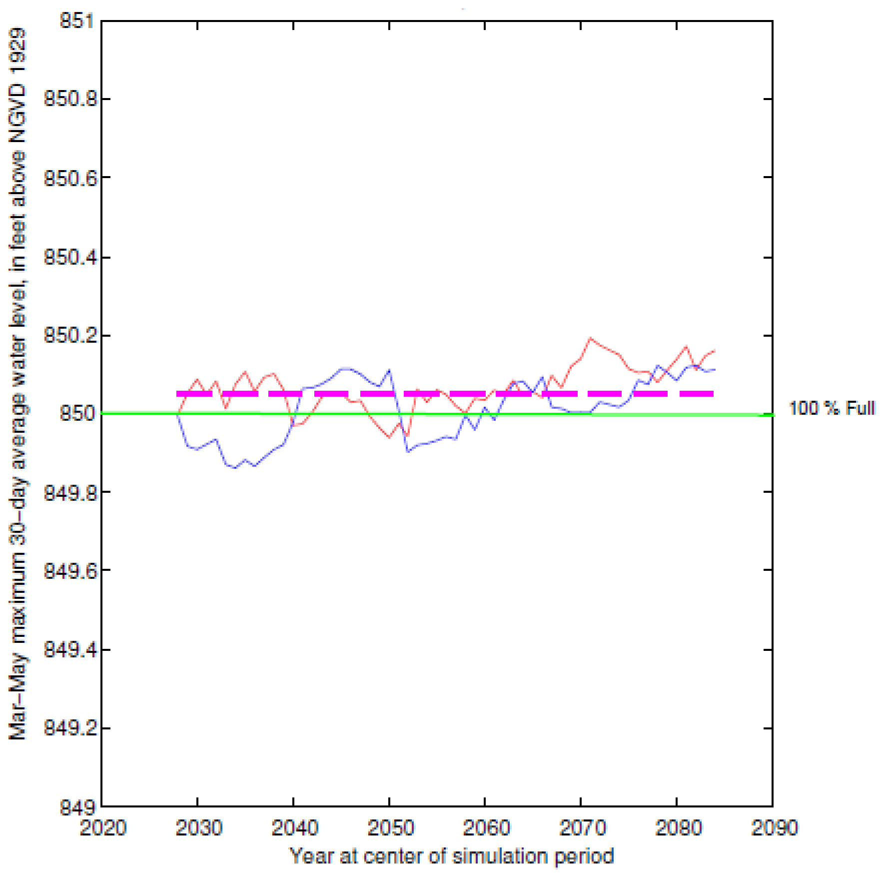

30-Day

7-Day

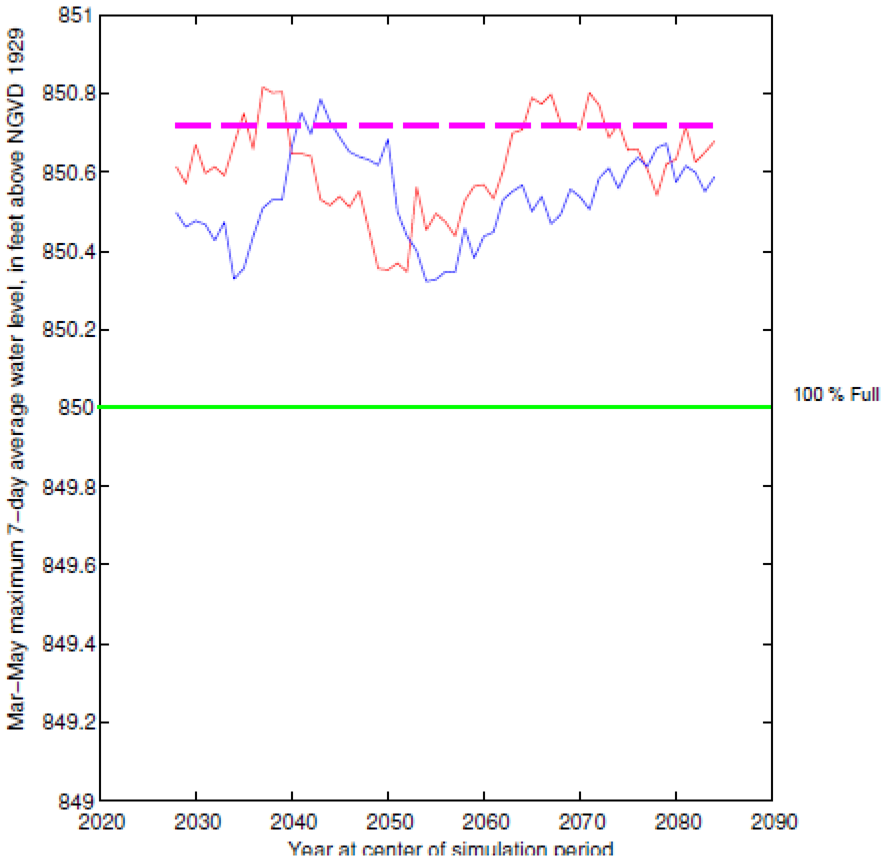
O'Shaughnessy Reservoir: Seasonal Water Levels

Spring Average Maximum Water Levels: Climate Only

30-Day

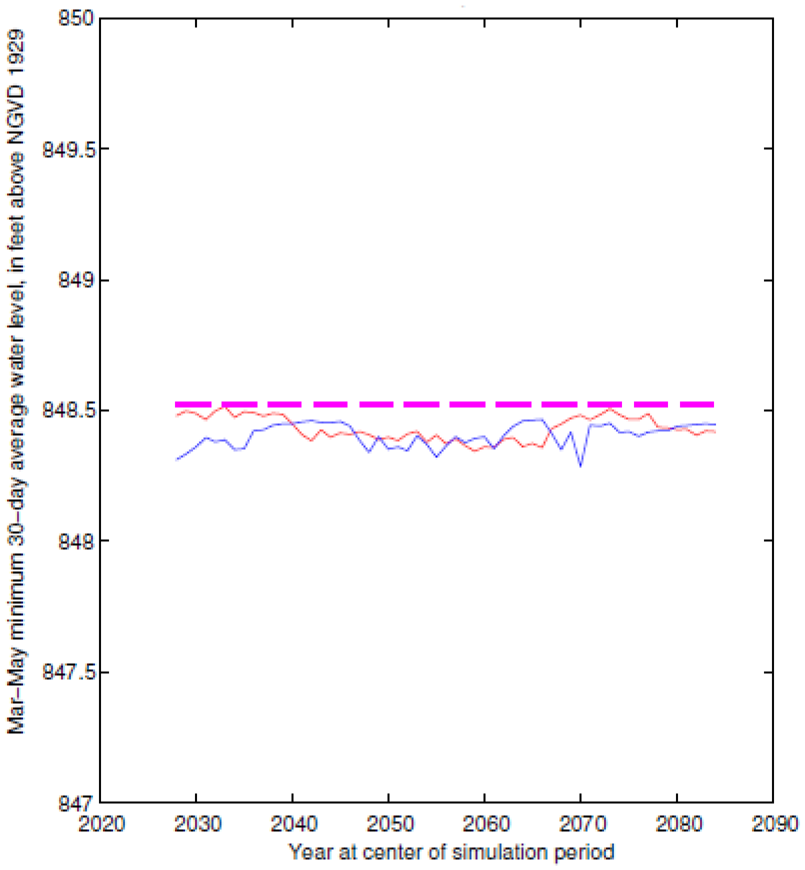


7-Day

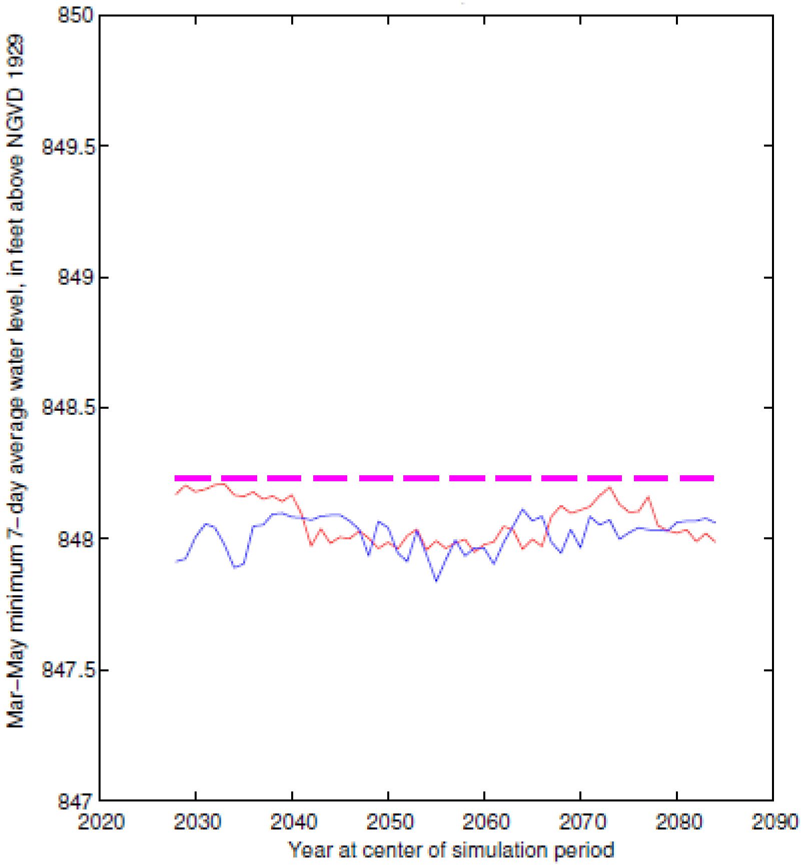


Spring Average Minimum Water Levels: Climate Only

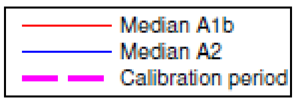
30-Day



7-Day

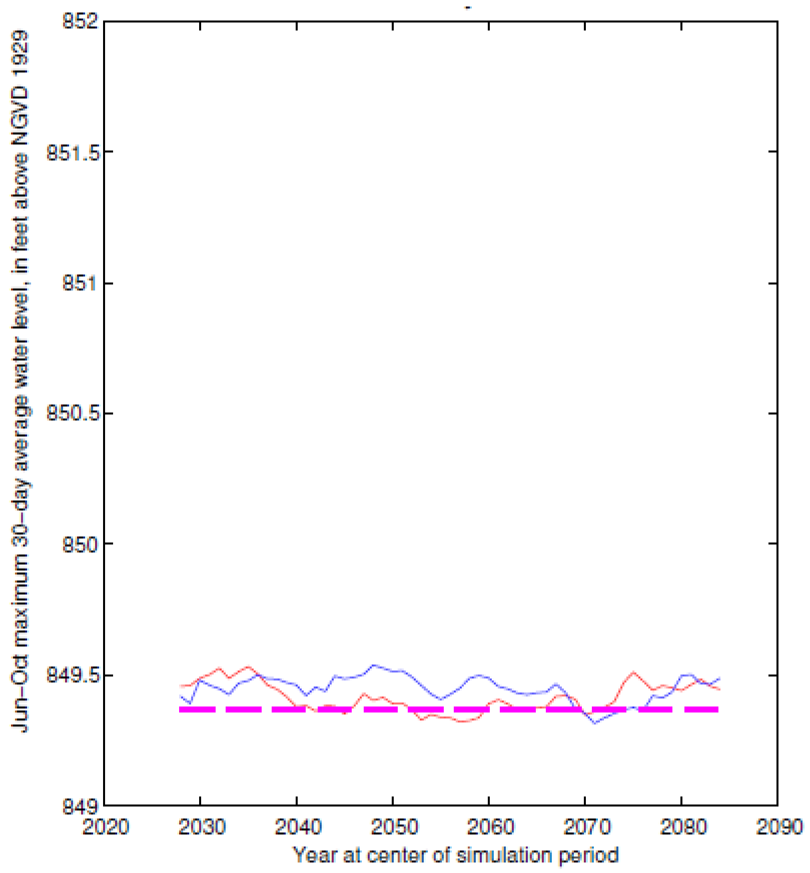


O’Shaughnessy Reservoir

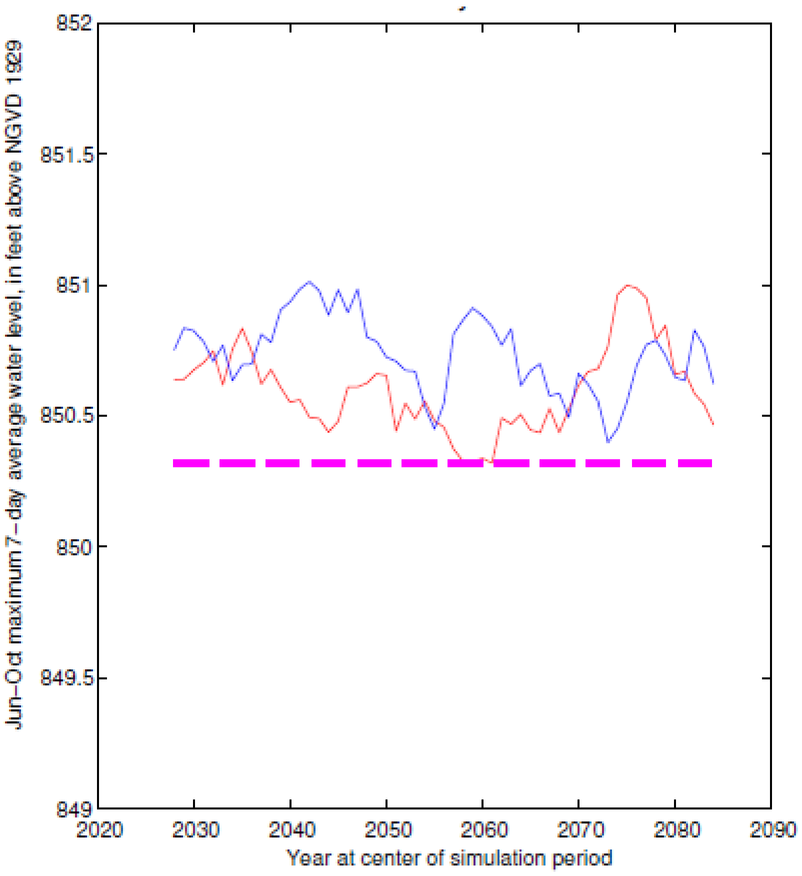


Summer Average Maximum Water Levels: Climate Only

30-Day

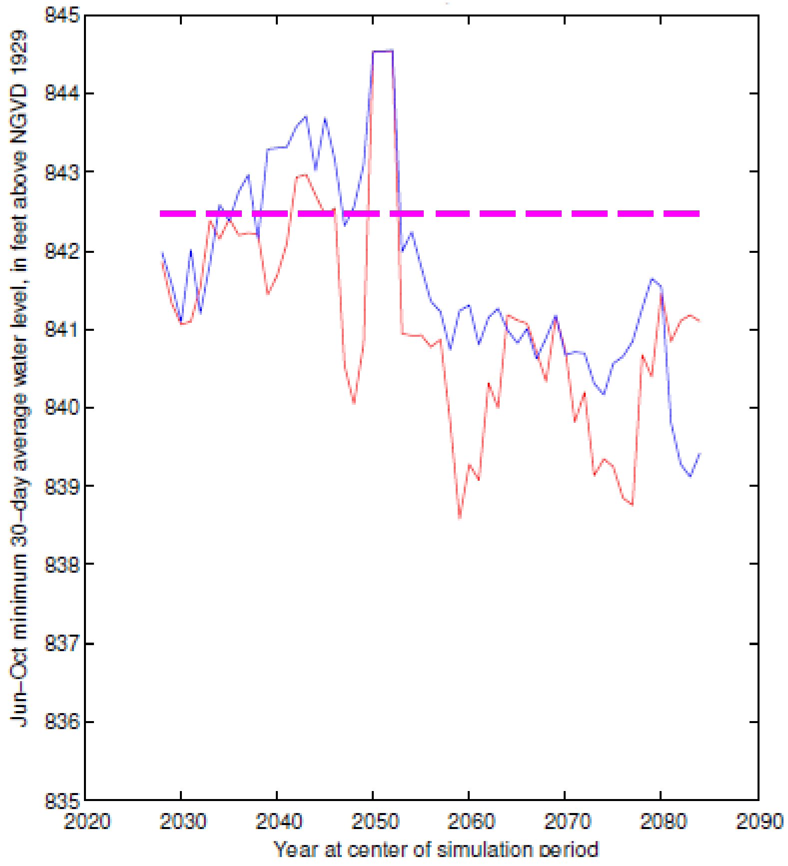


7-Day

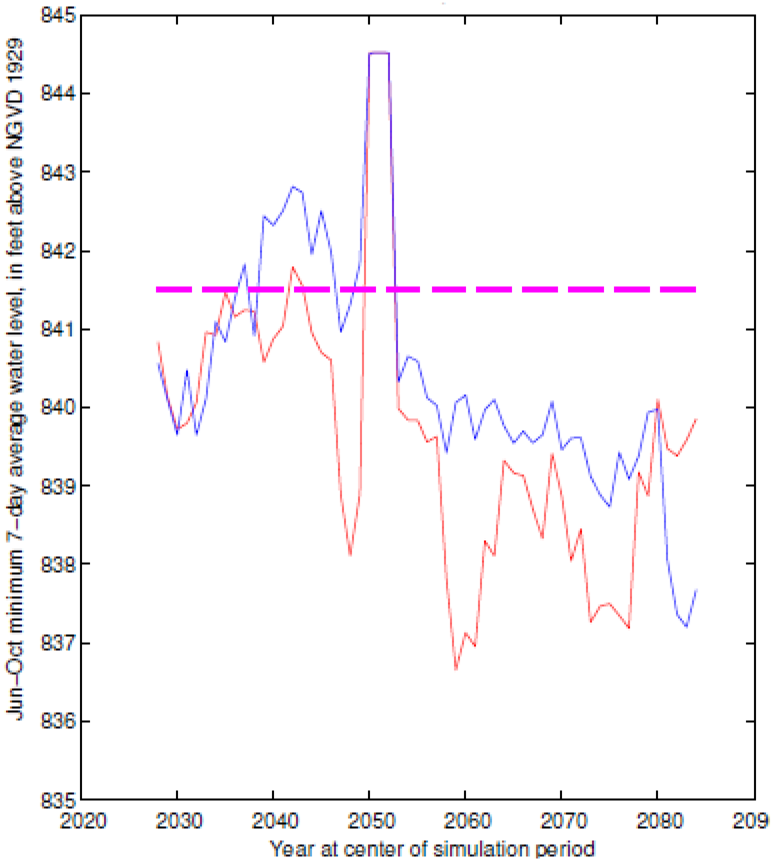


Summer Average Minimum Water Levels: Climate Only

30-Day

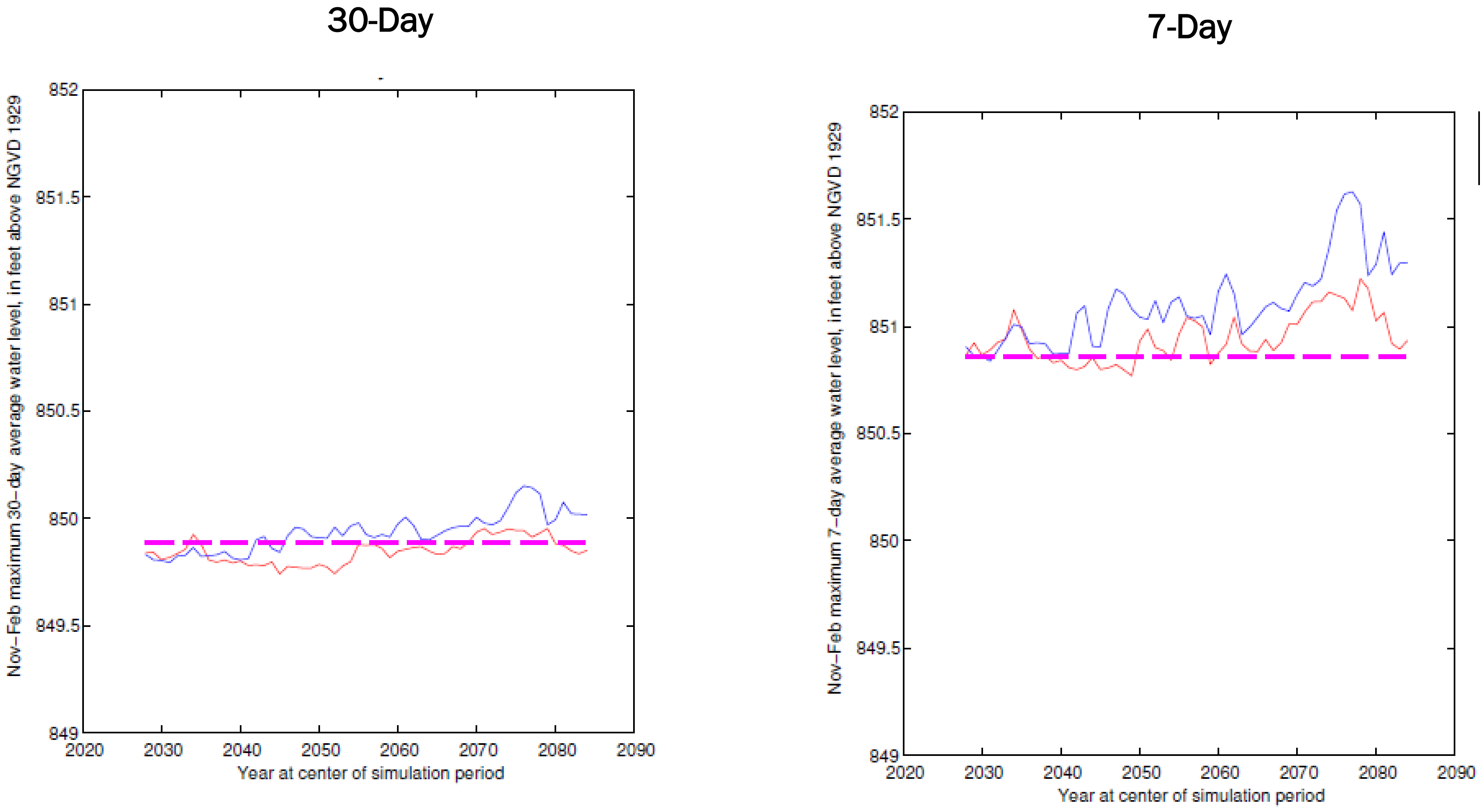


7-Day

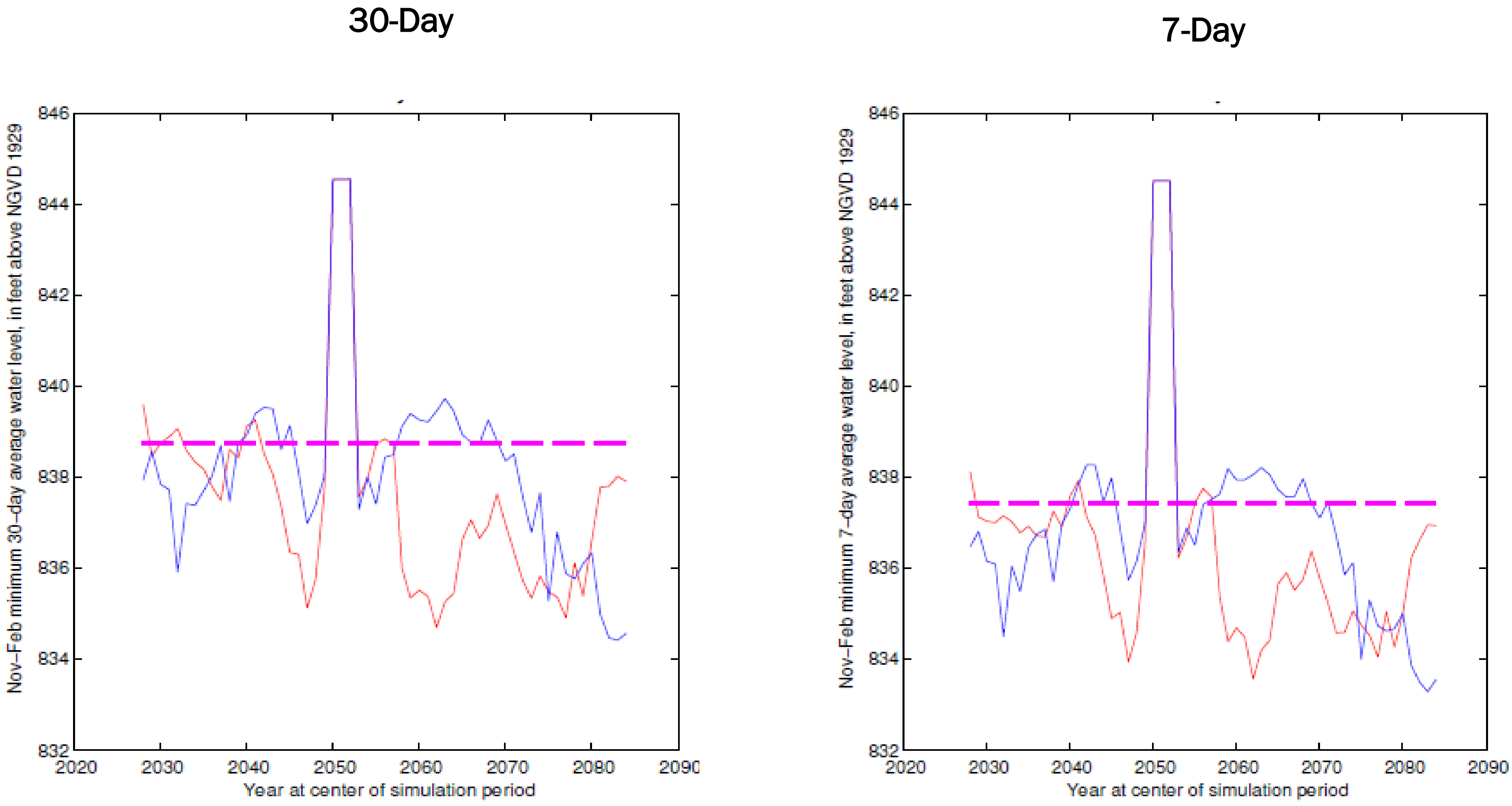


O’Shaughnessy Reservoir: Seasonal Water Levels

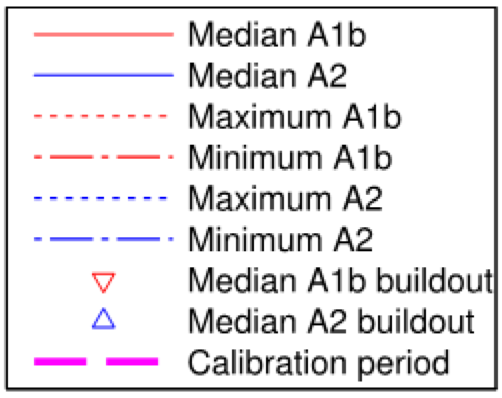
Fall/Winter Average Maximum Water Levels: Climate Only



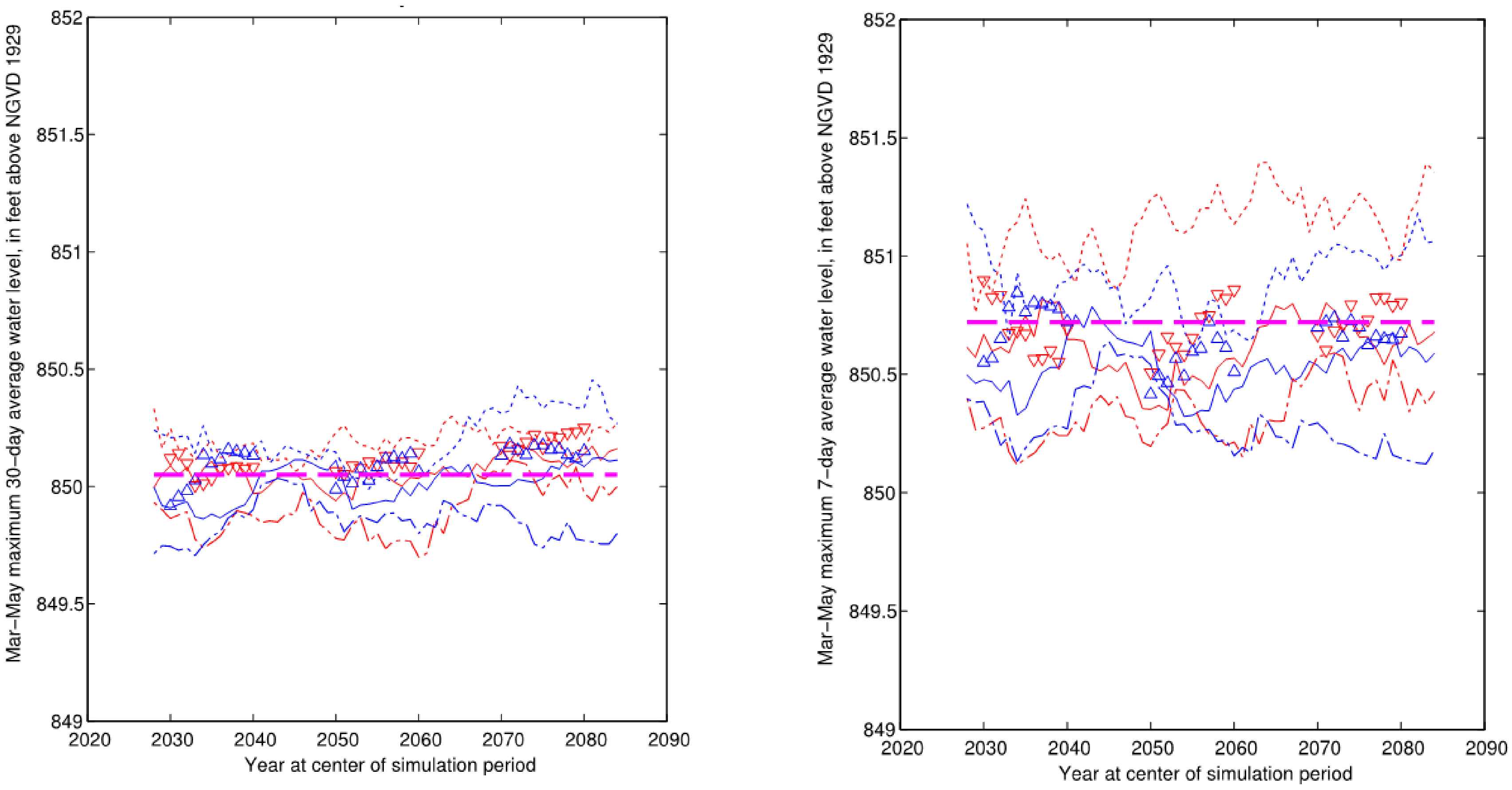
Fall/Winter Average Minimum Water Levels: Climate Only



O’Shaughnessy Reservoir



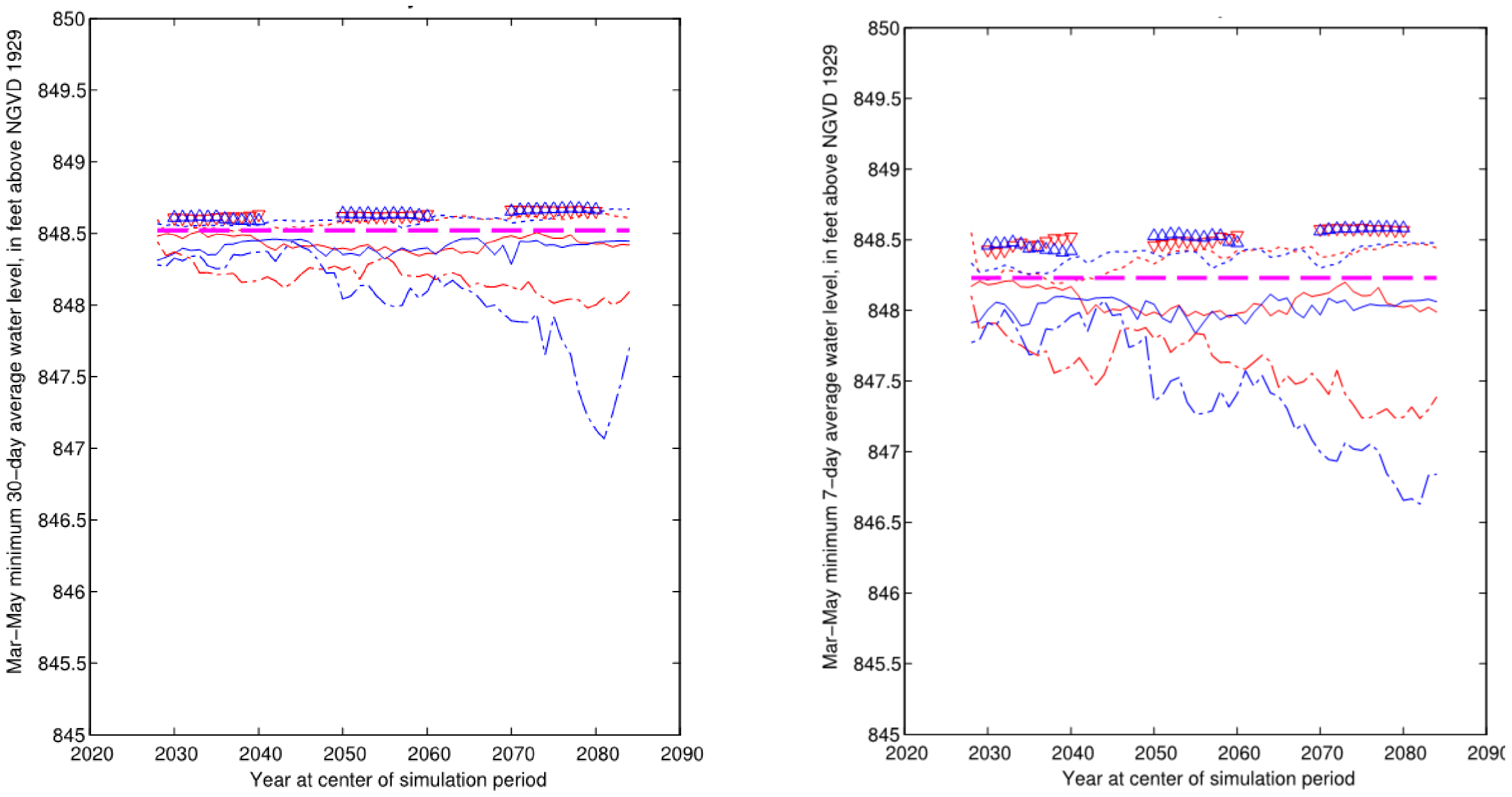
Spring Average Maximum Water Levels with Development



30-Day

7-Day

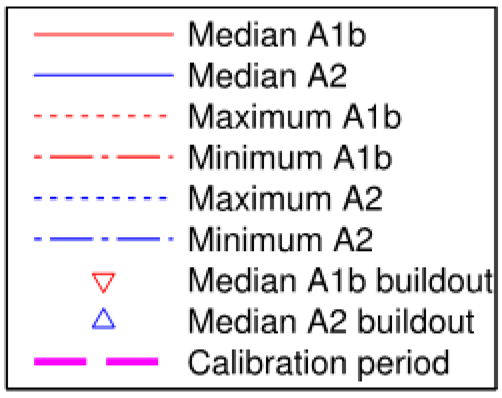
Spring Average Minimum Water Levels with Development



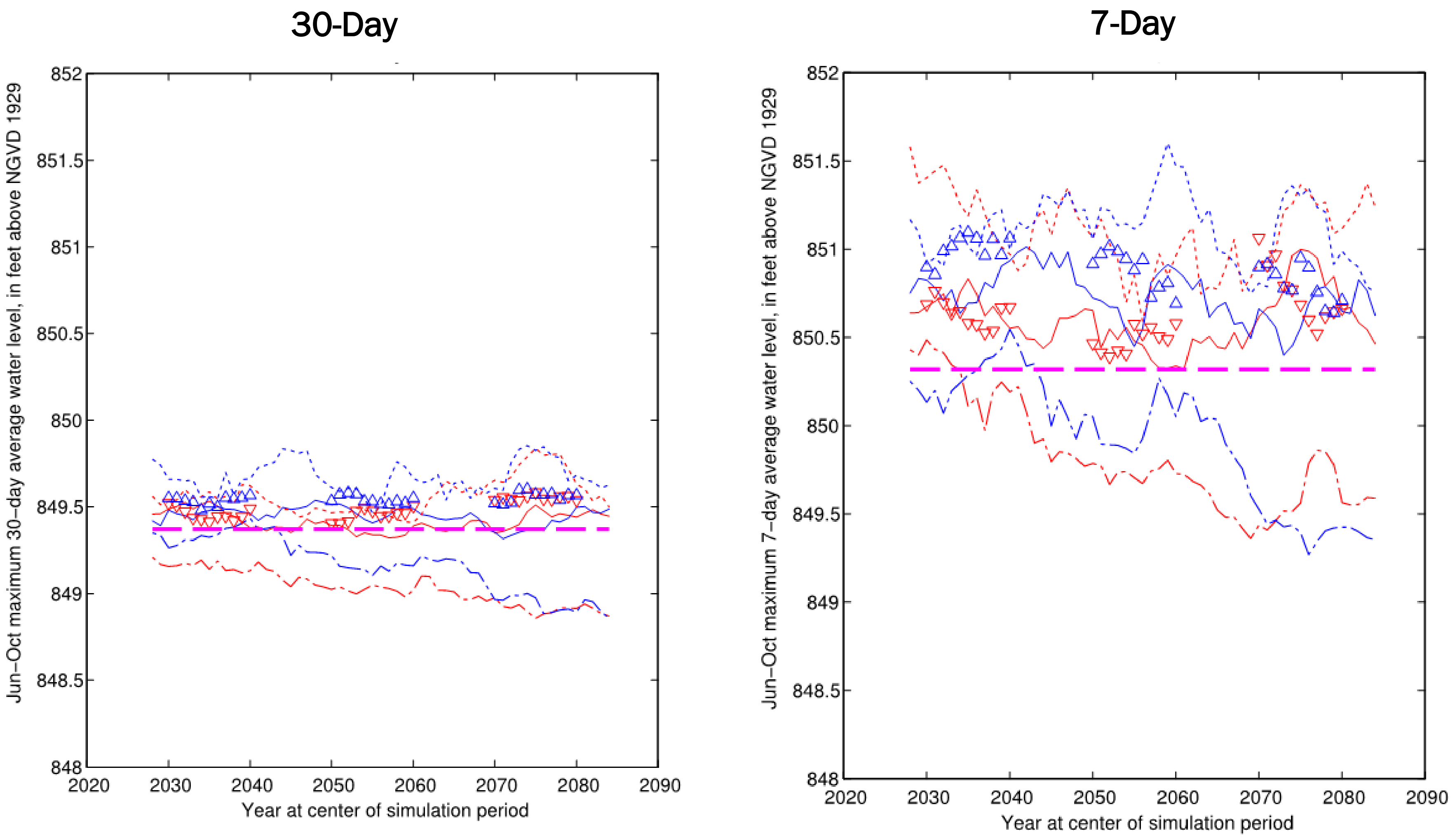
30-Day

7-Day

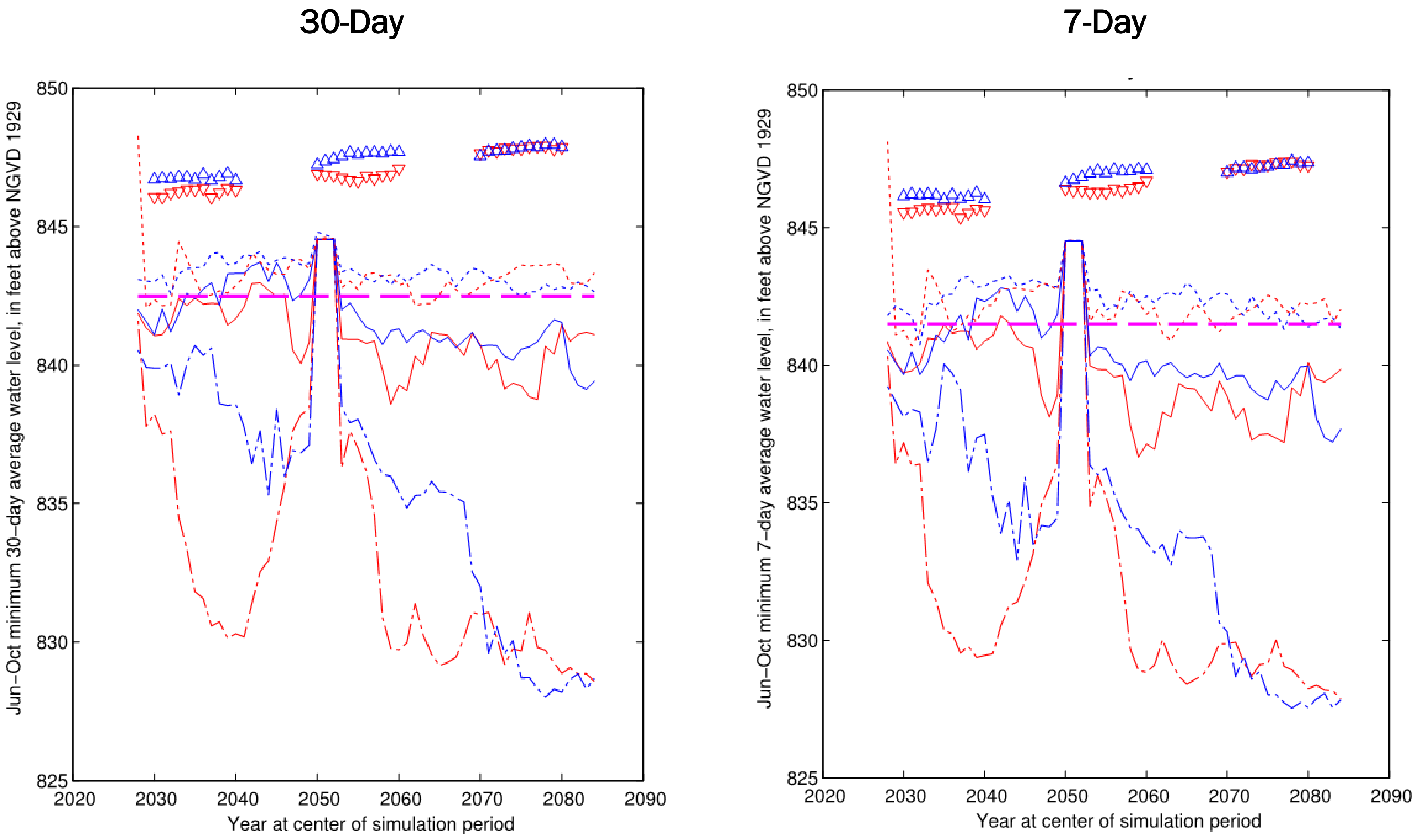
O’Shaughnessy Reservoir



Summer Average Maximum Water Levels with Development



Summer Average Minimum Water Levels with Development



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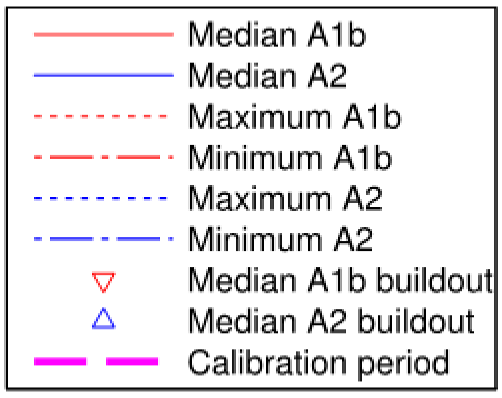
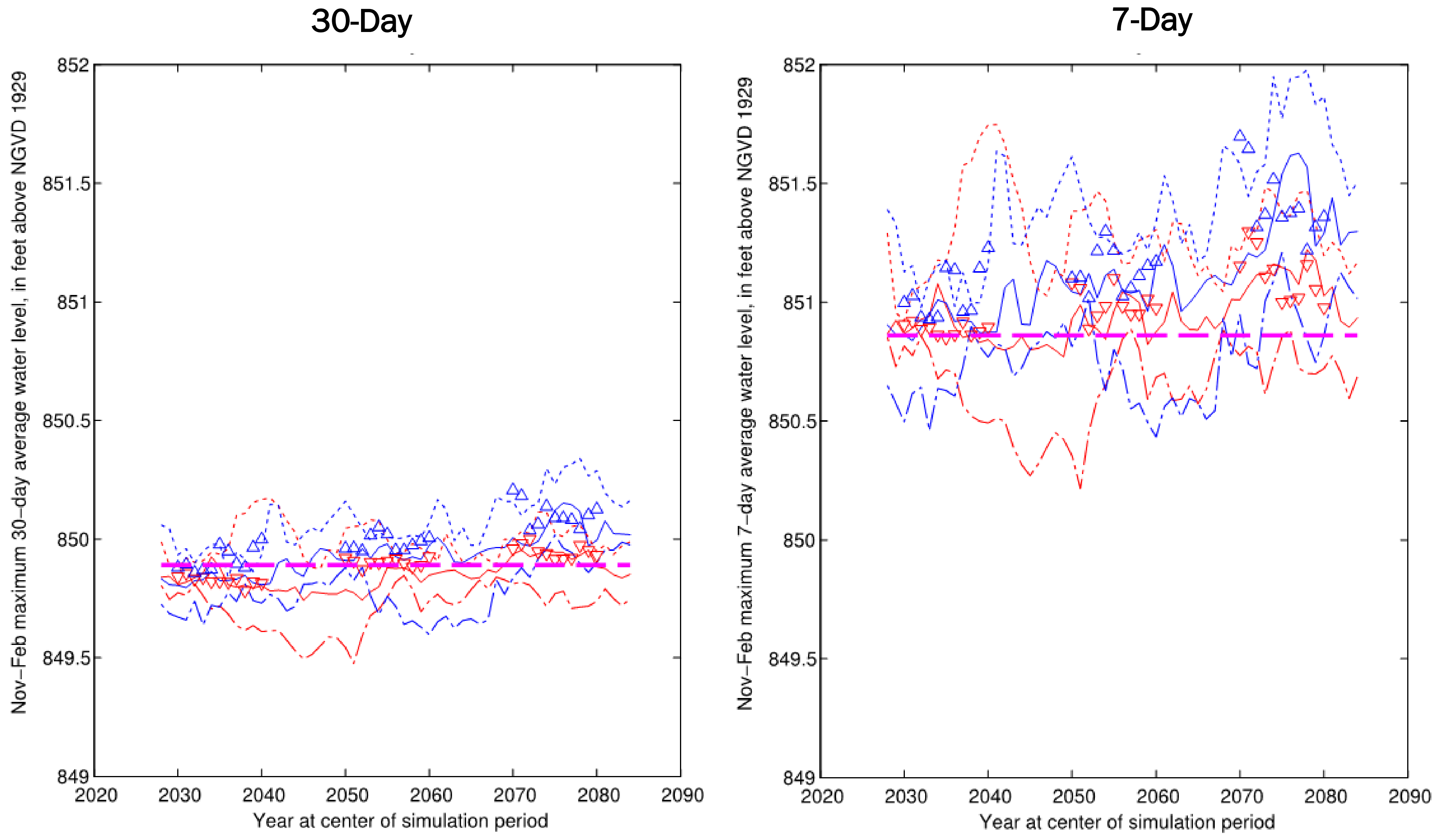
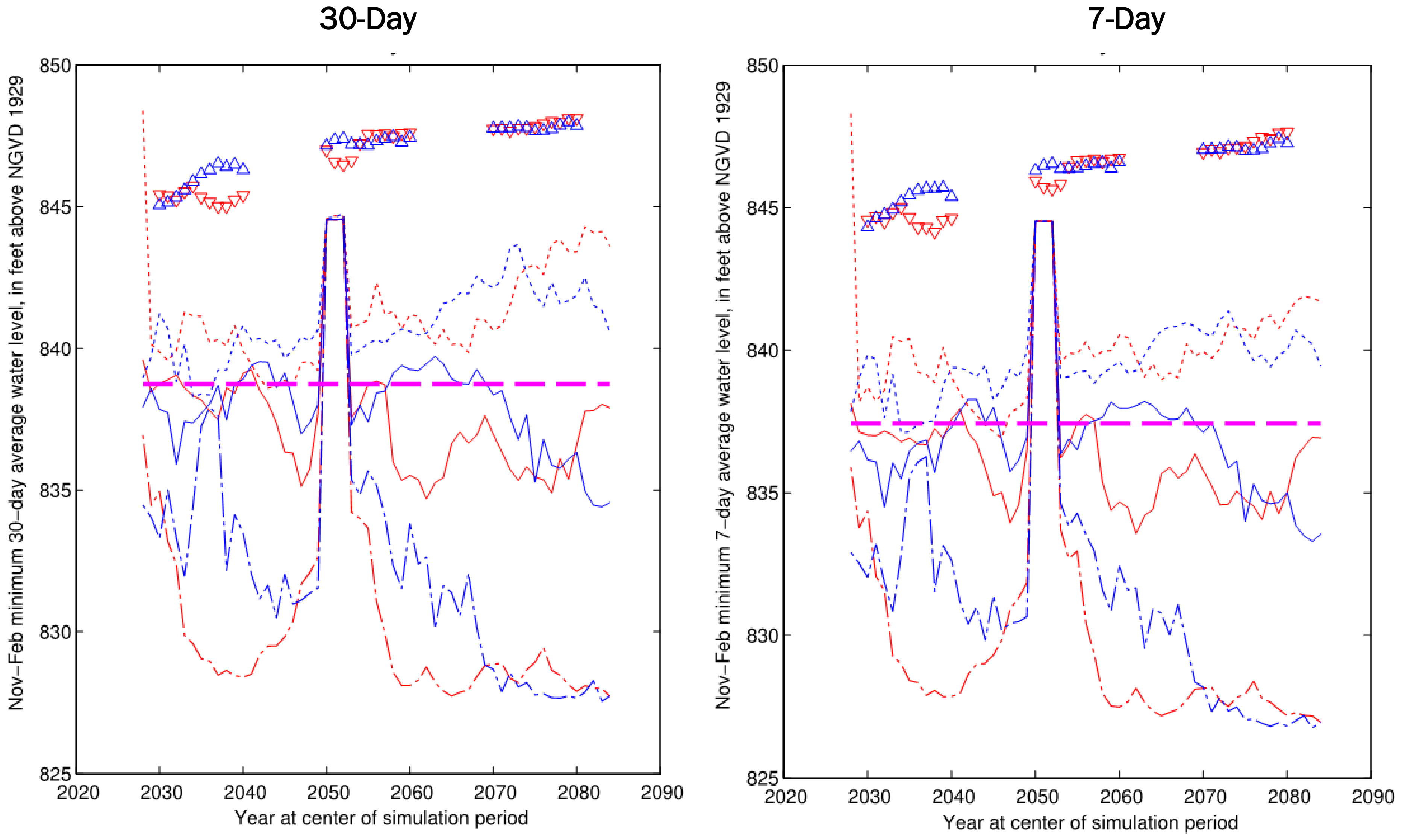


Fall/Winter Average Maximum Water Levels with Development

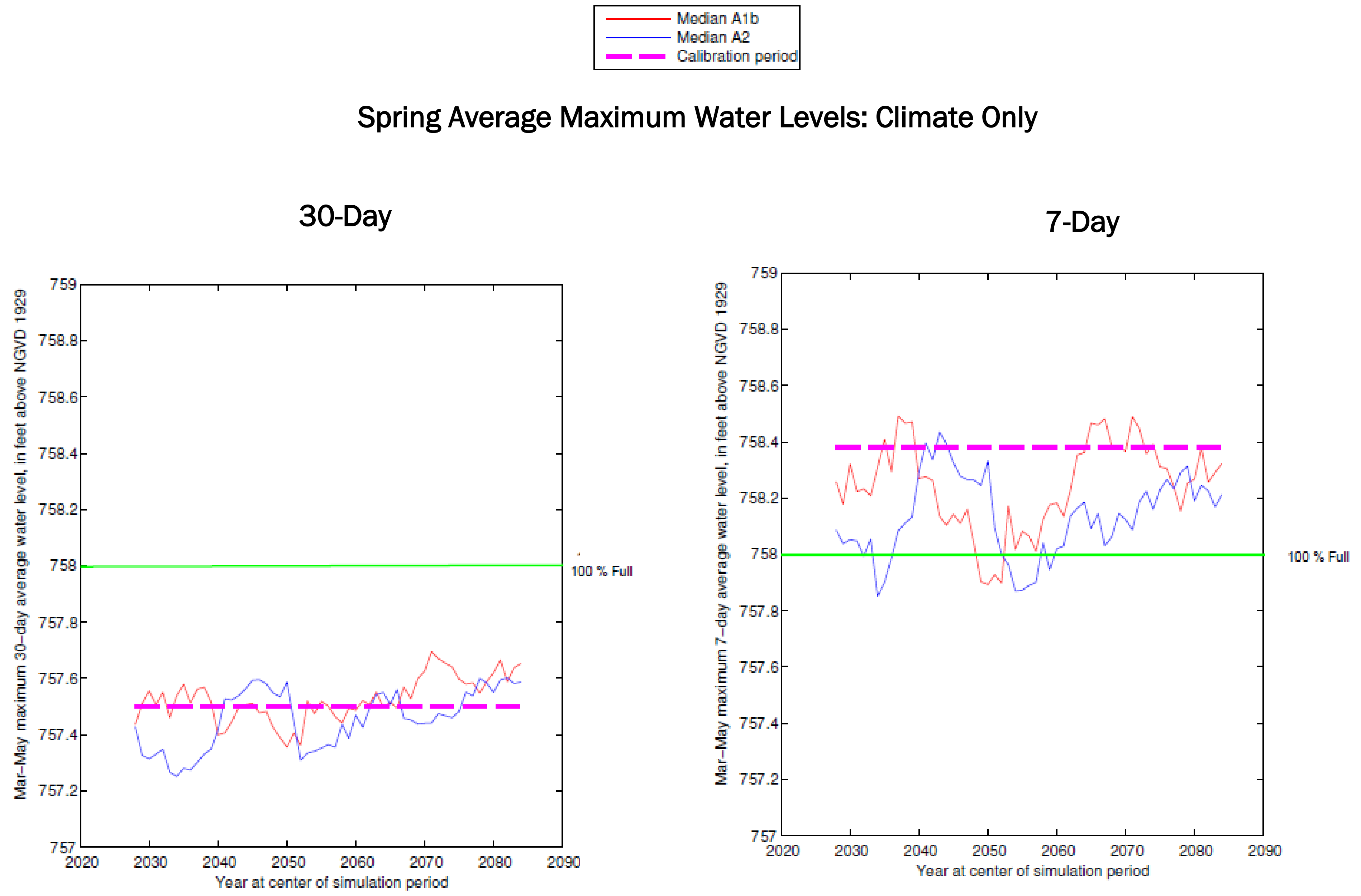


Fall/Winter Average Minimum Water Levels with Development

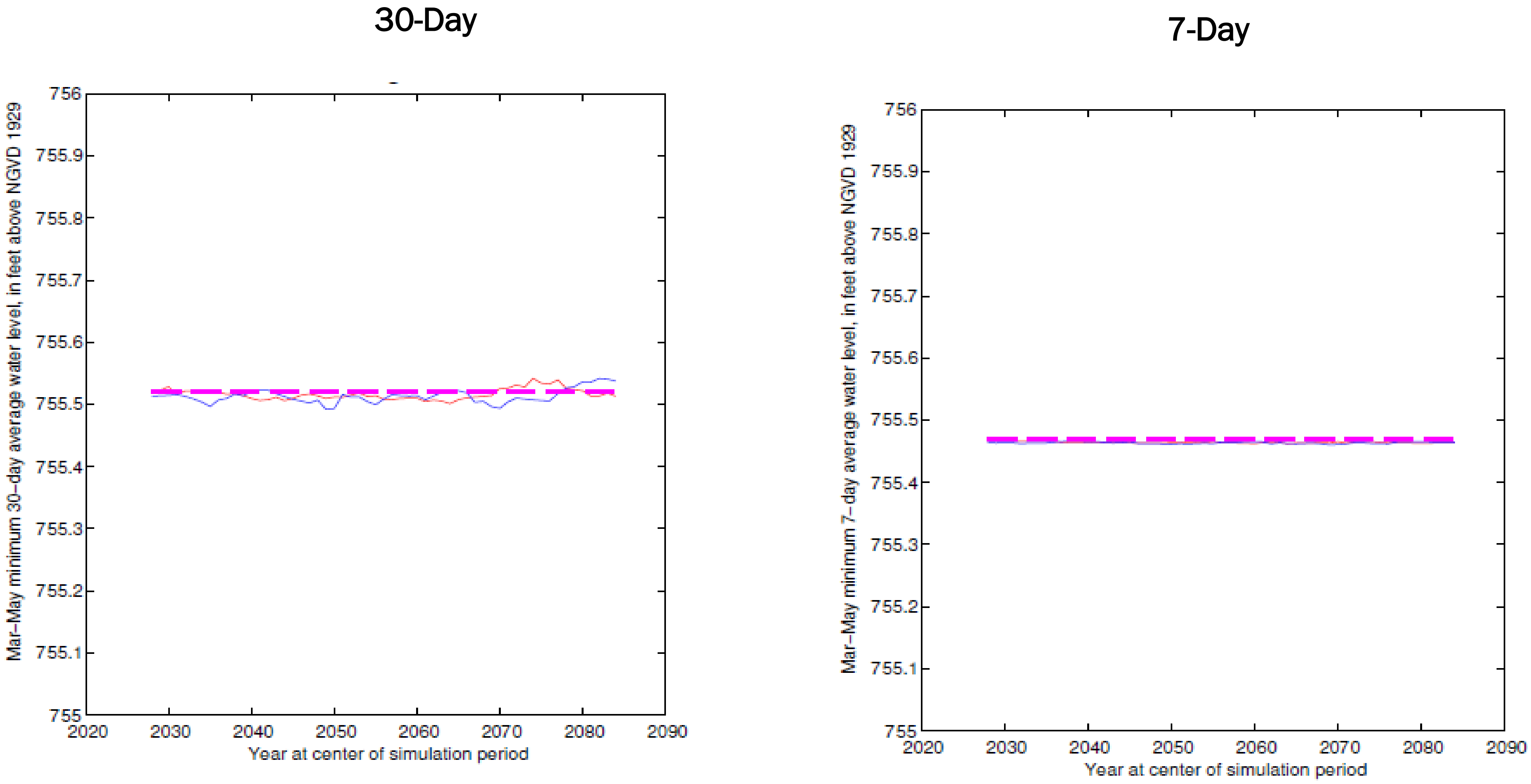


Griggs Reservoir: Seasonal Water Levels

Spring Average Maximum Water Levels: Climate Only



Spring Average Minimum Water Levels: Climate Only

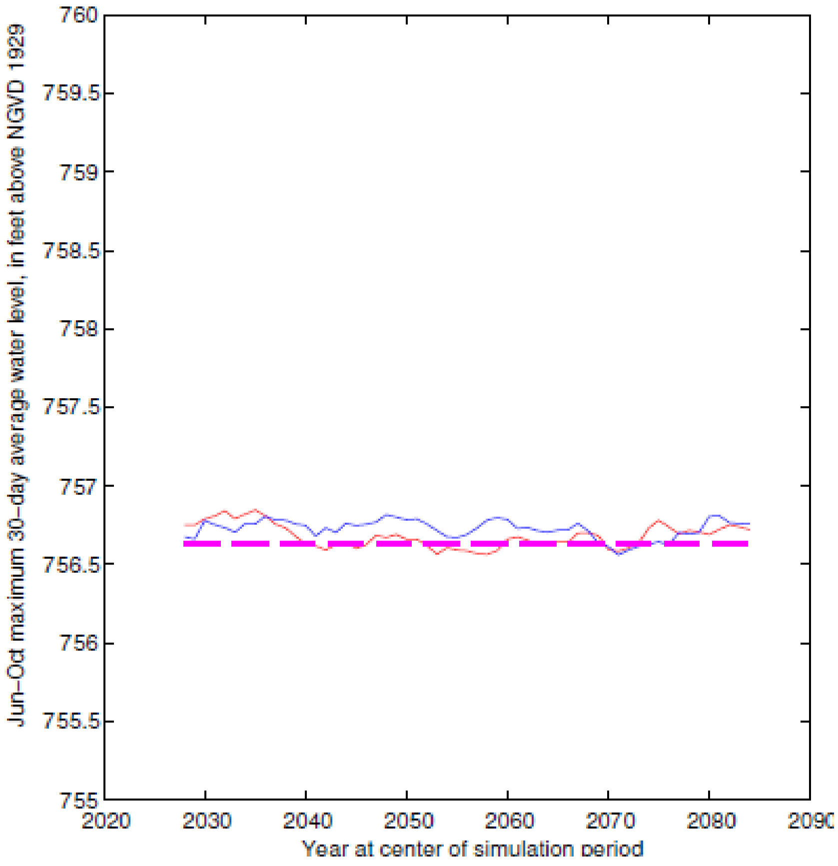


Griggs Reservoir

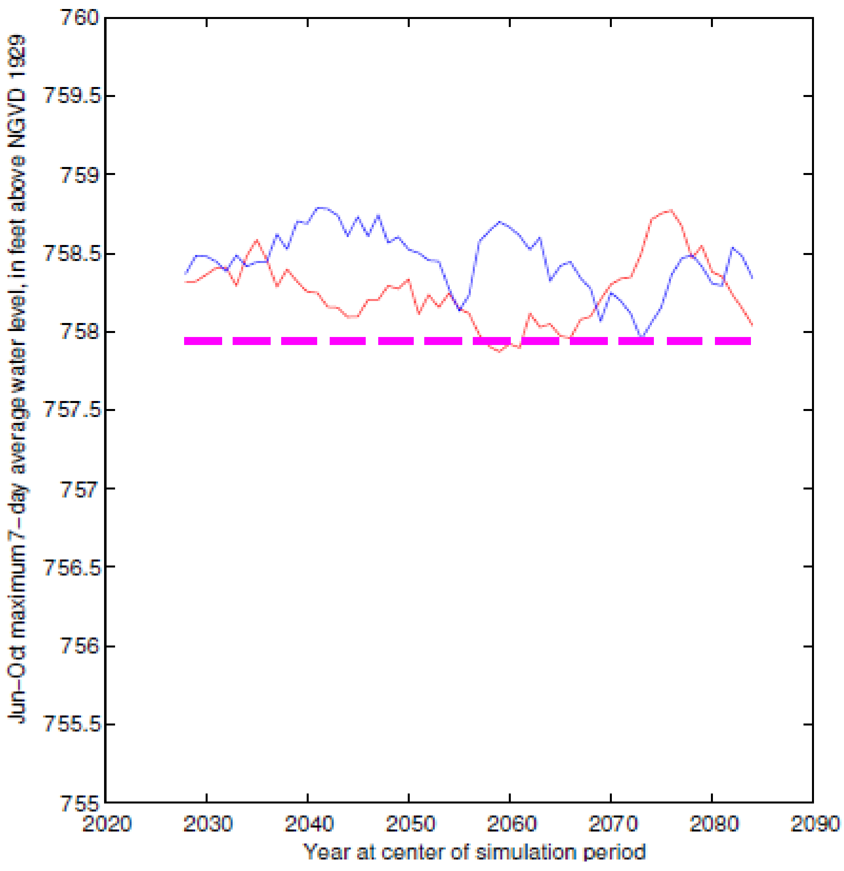
Median A1b
Median A2
Calibration period

Summer Average Maximum Water Levels: Climate Only

30-Day

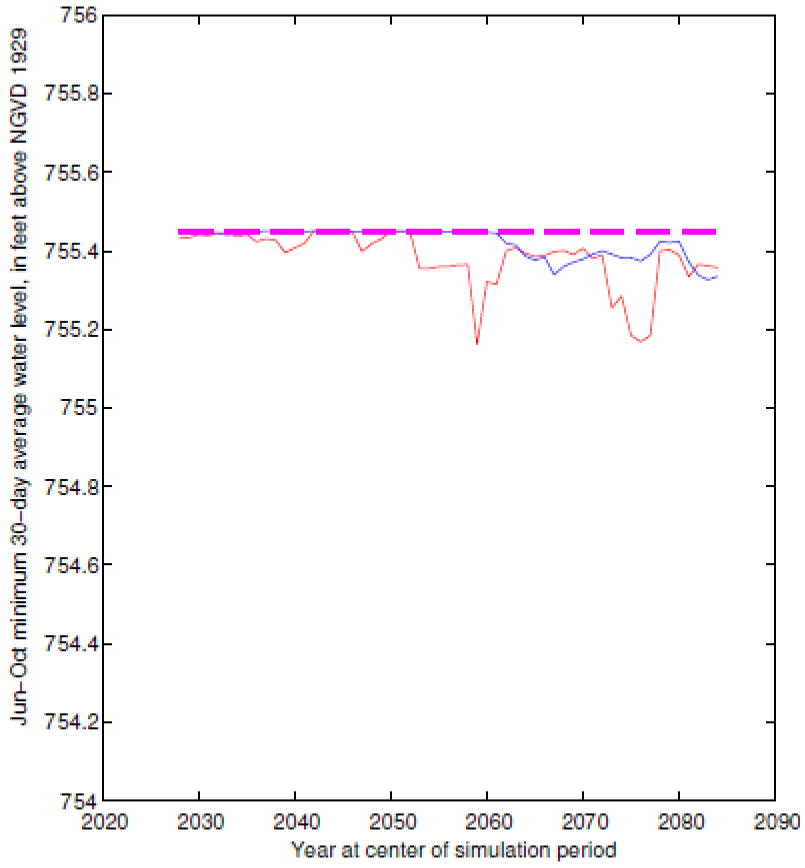


7-Day

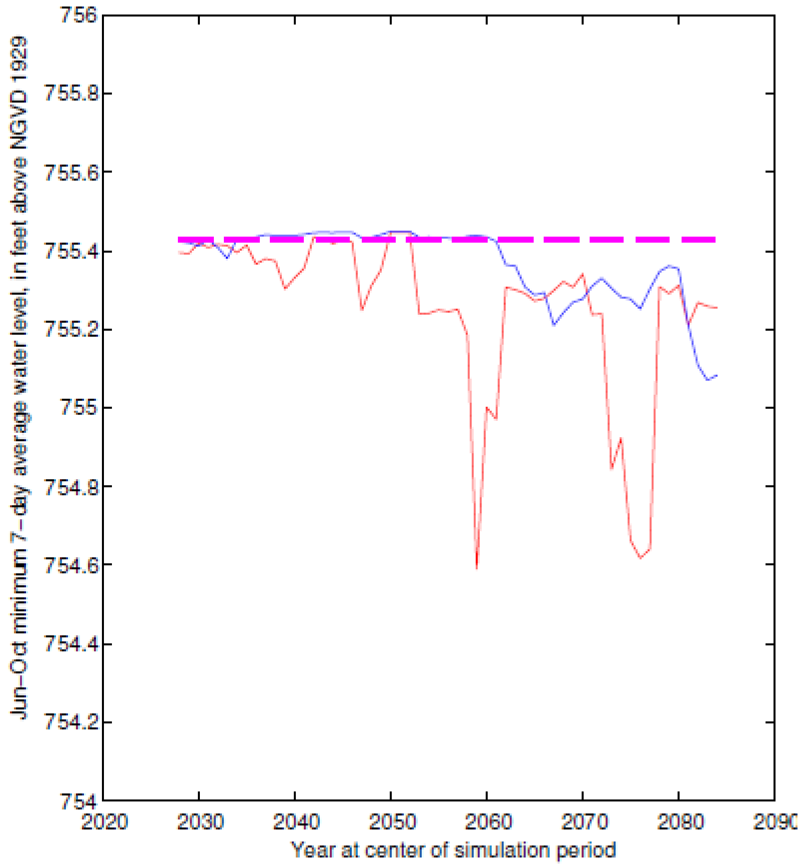


Summer Average Minimum Water Levels: Climate Only

30-Day



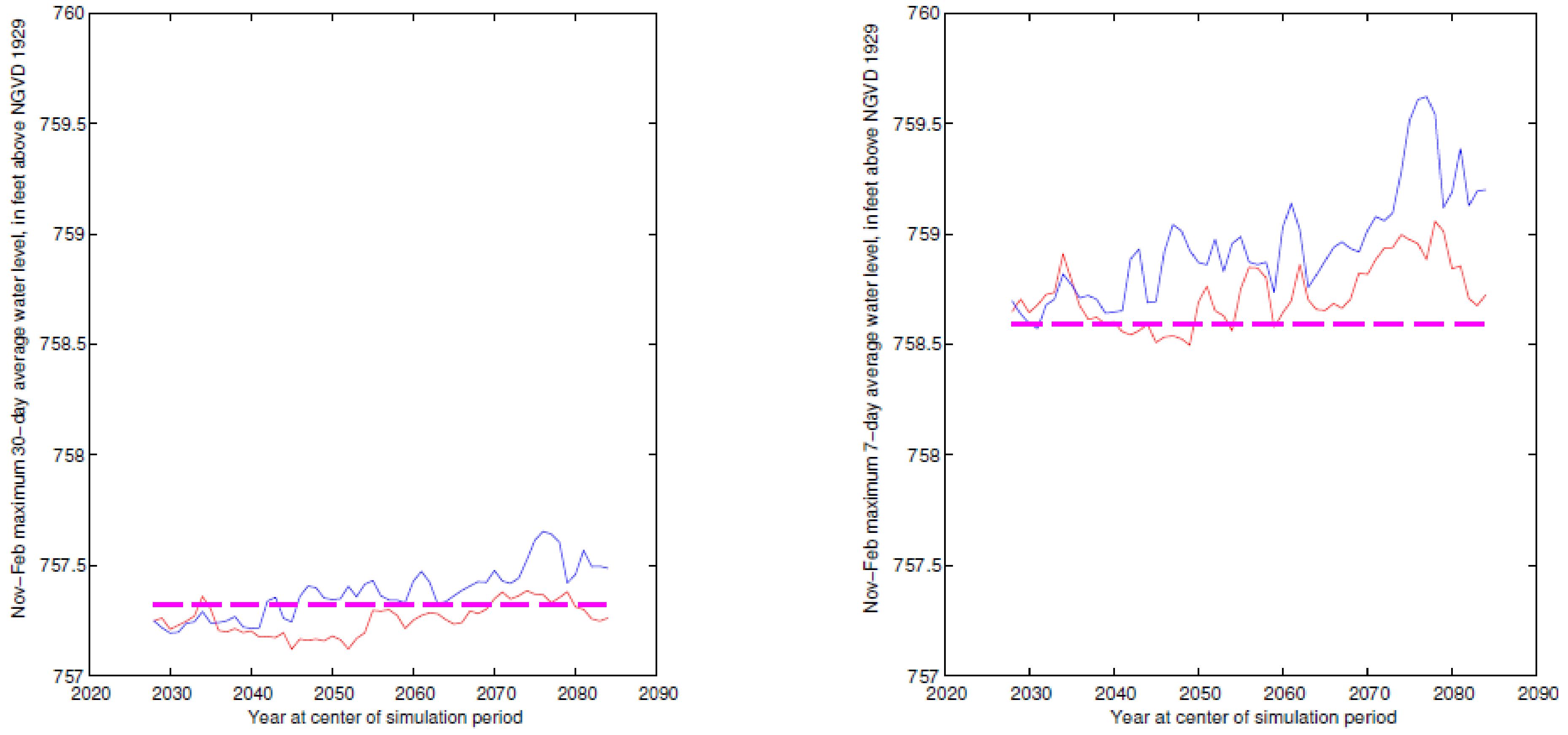
7-Day



Griggs Reservoir

Median A1b
Median A2
Calibration period

Fall/Winter Average Maximum Water Levels: Climate Only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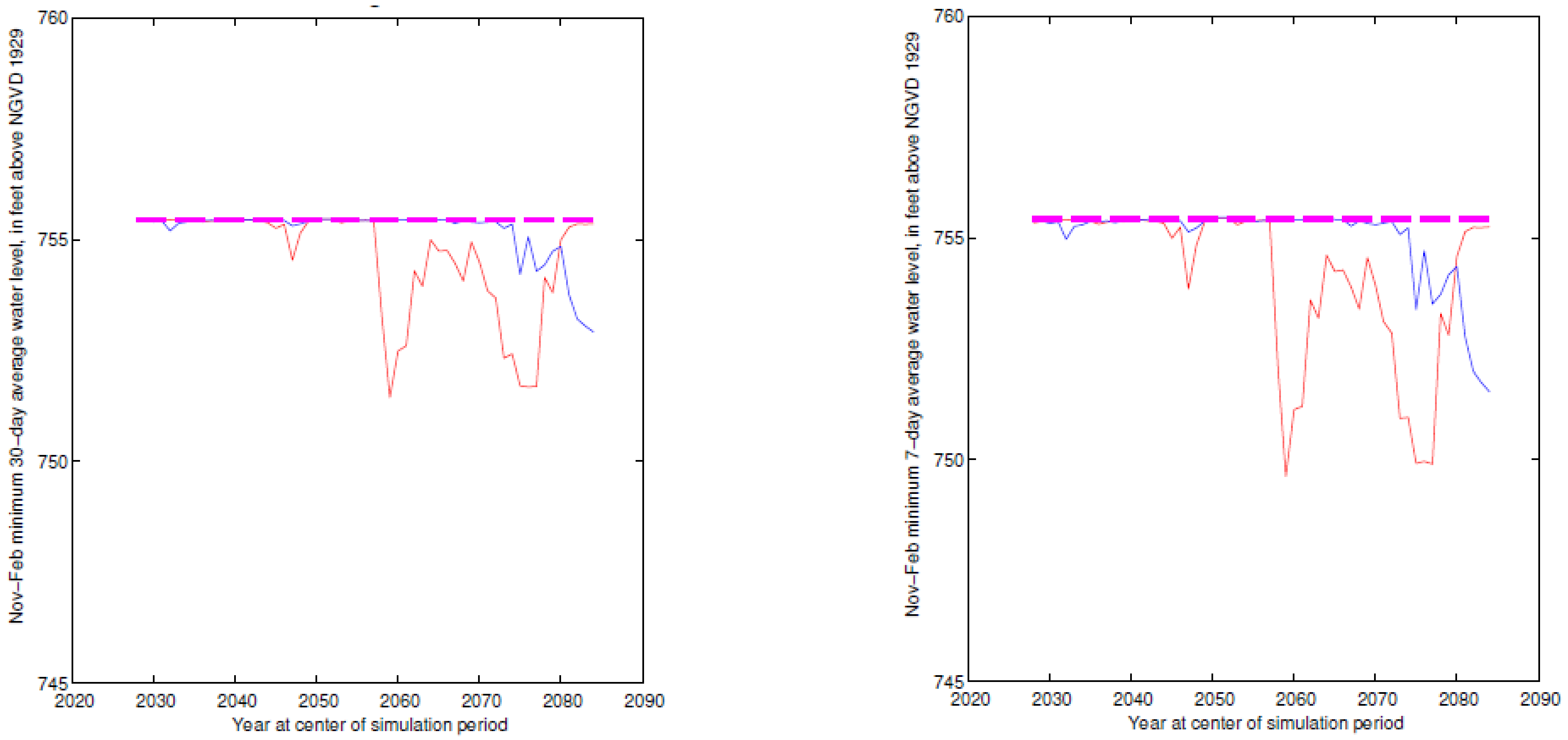
Fall/Winter Average Minimum Water Levels: Climate Only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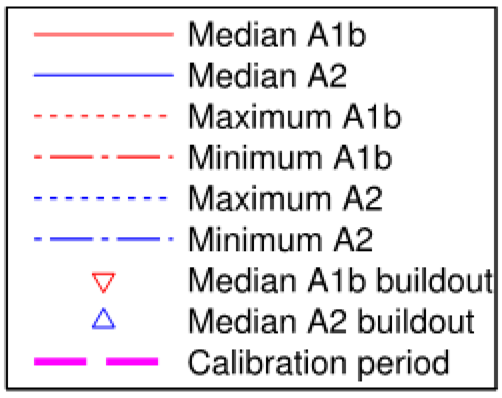
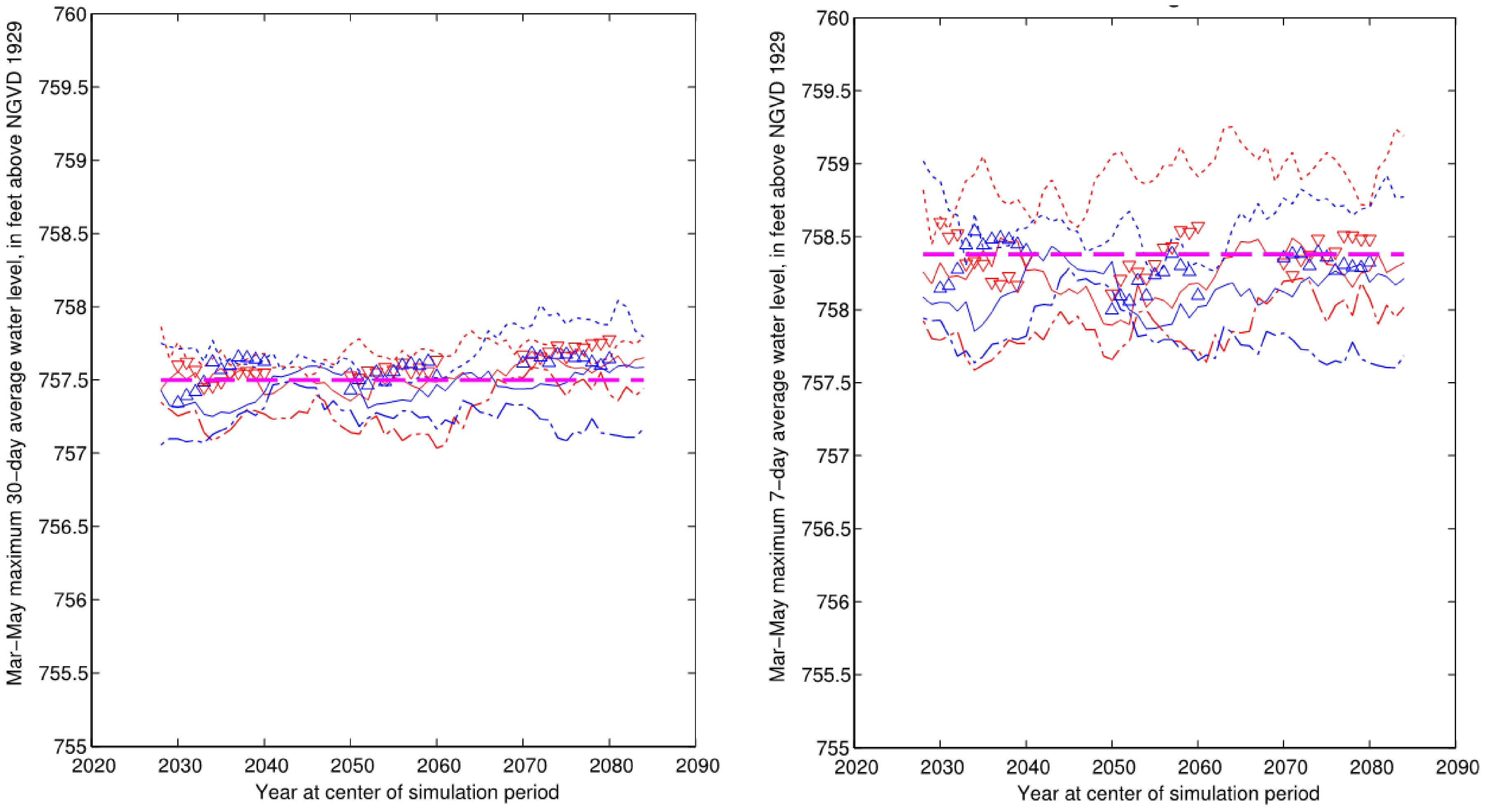
Griggs Reservoir



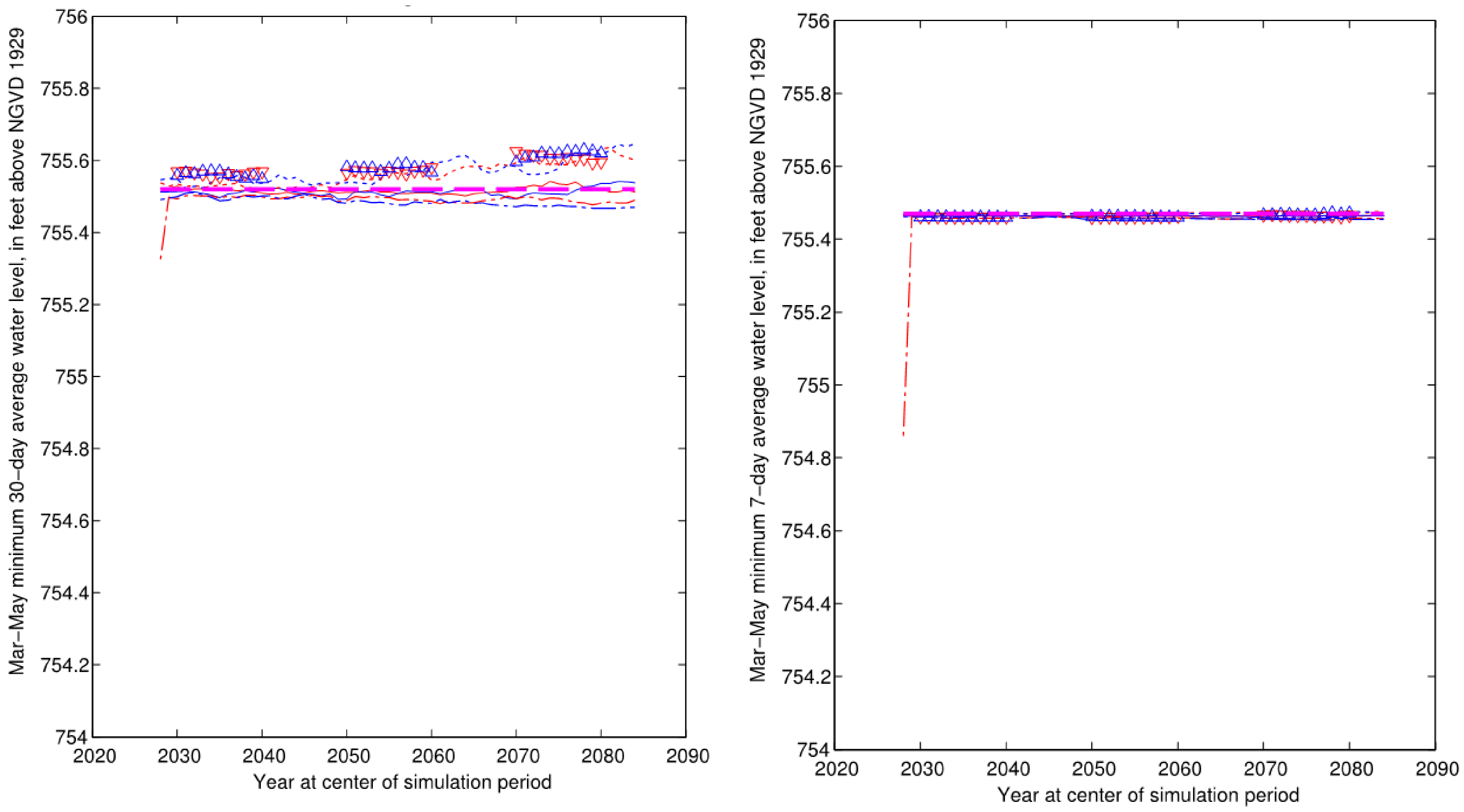
Spring Average Maximum Water Levels with Development



30-Day

7-Day

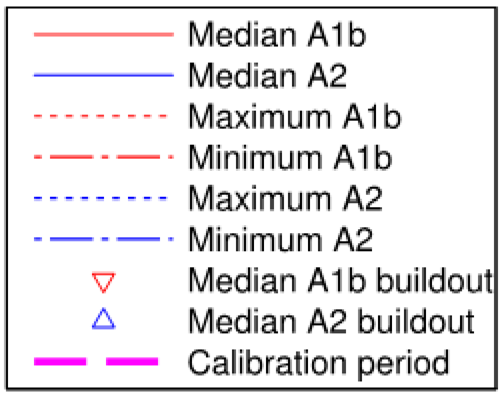
Spring Average Minimum Water Levels with Development



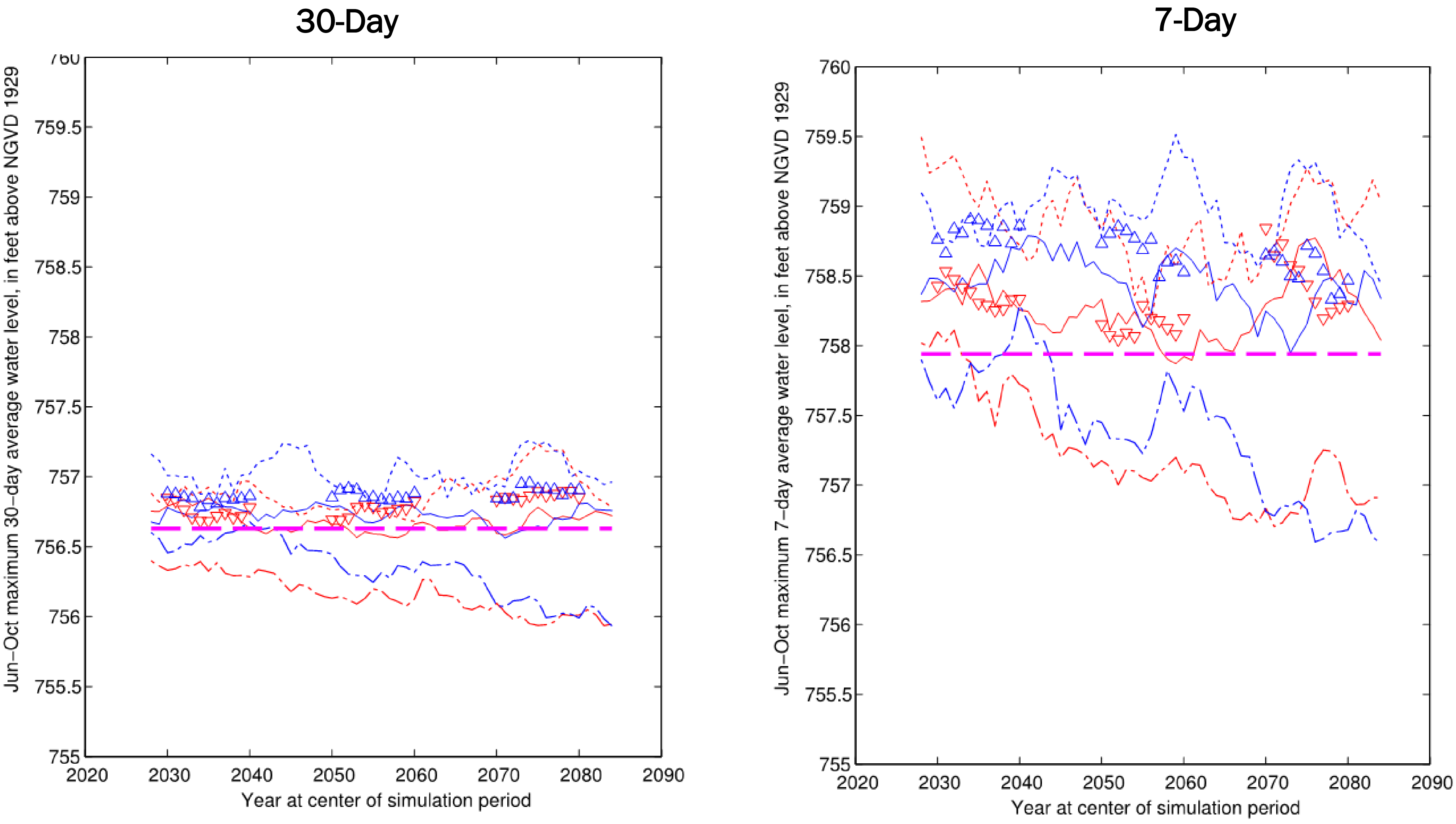
30-Day

7-Day

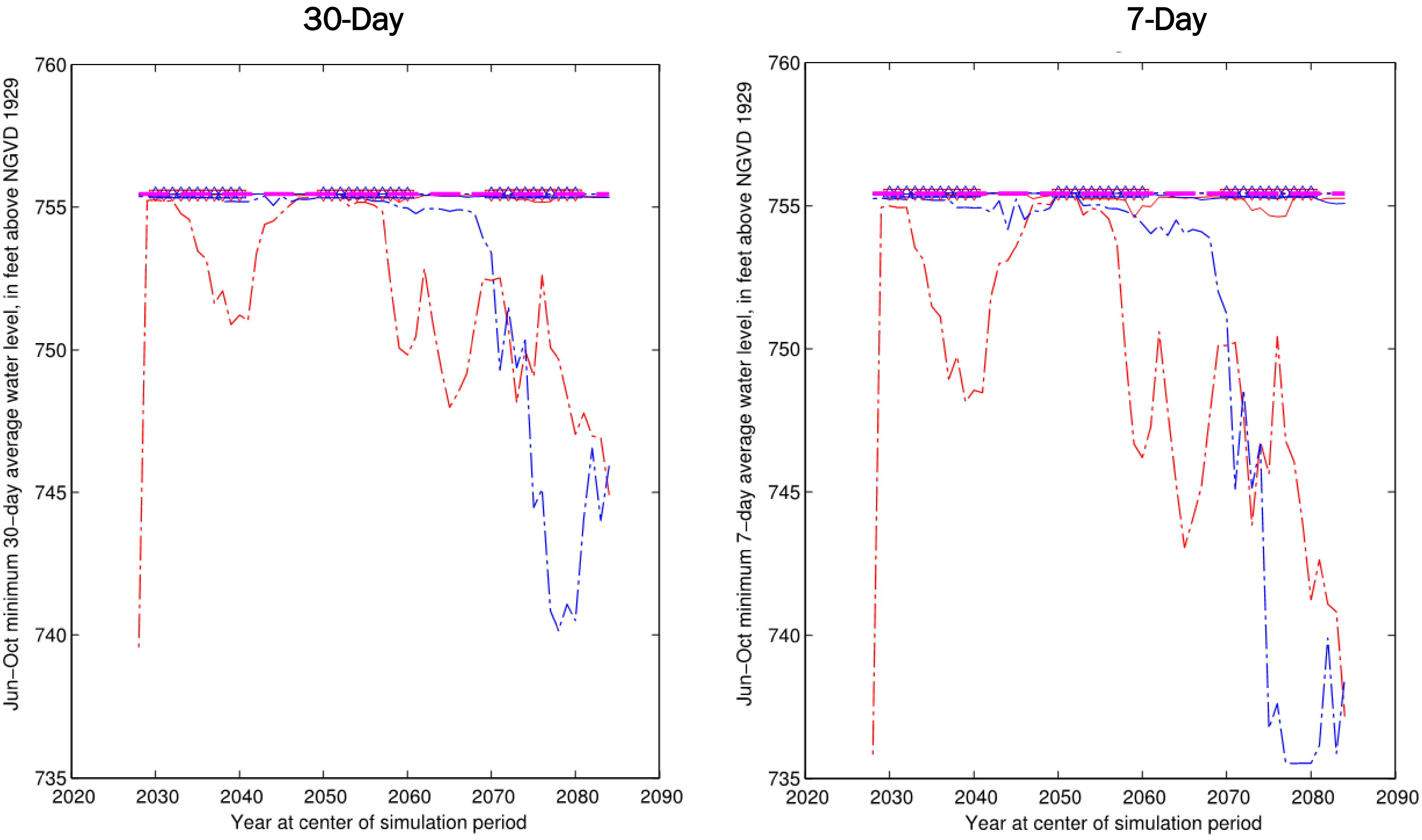
Griggs Reservoir



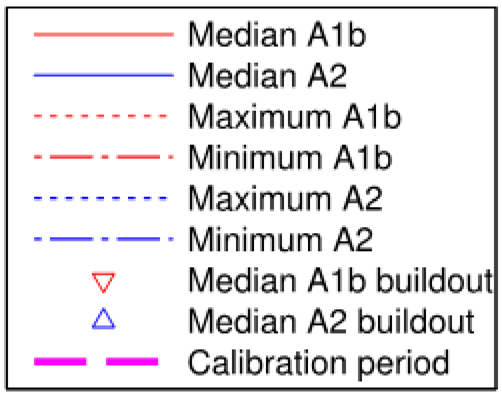
Summer Average Maximum Water Levels with Development



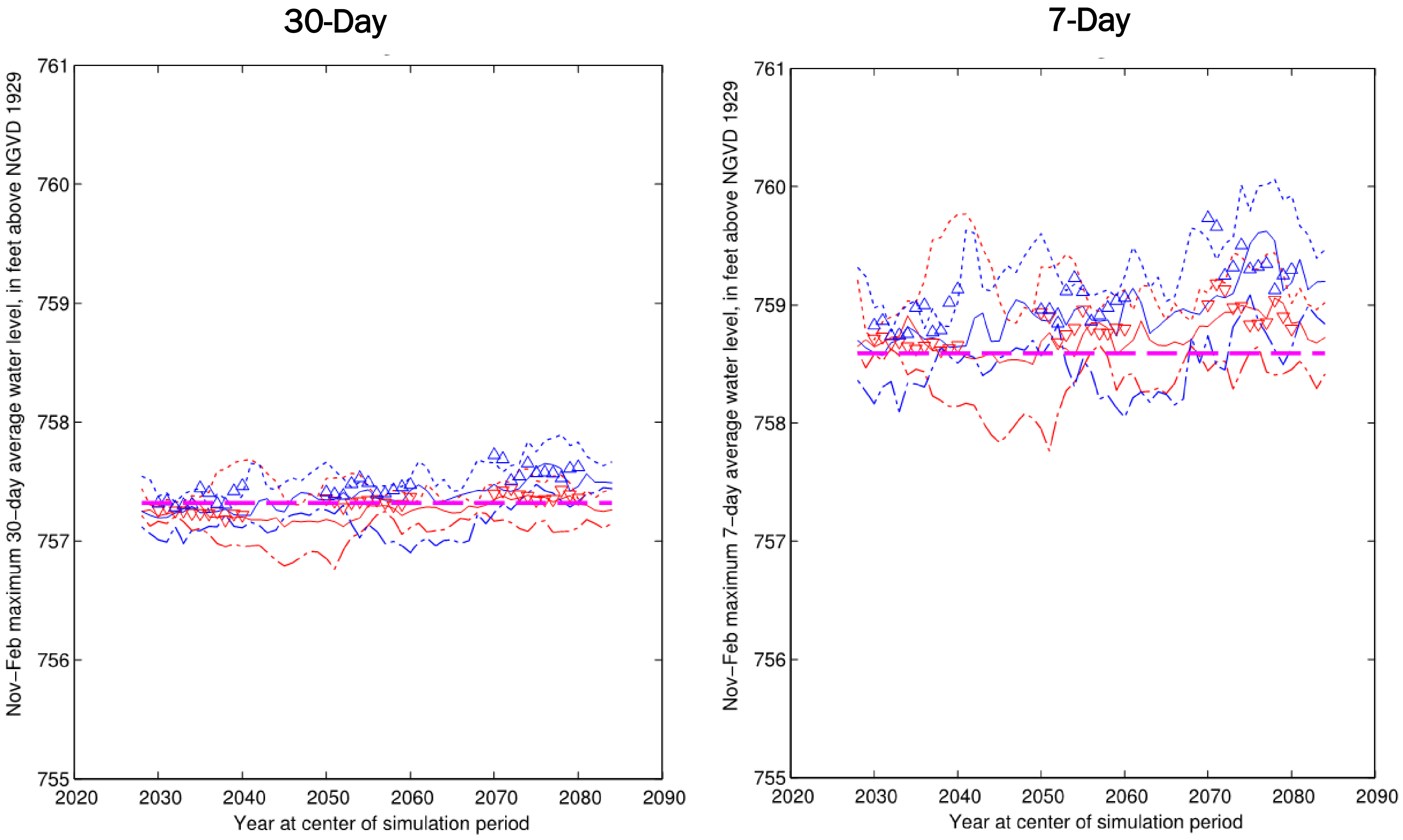
Summer Average Minimum Water Levels with Development



Griggs Reservoir

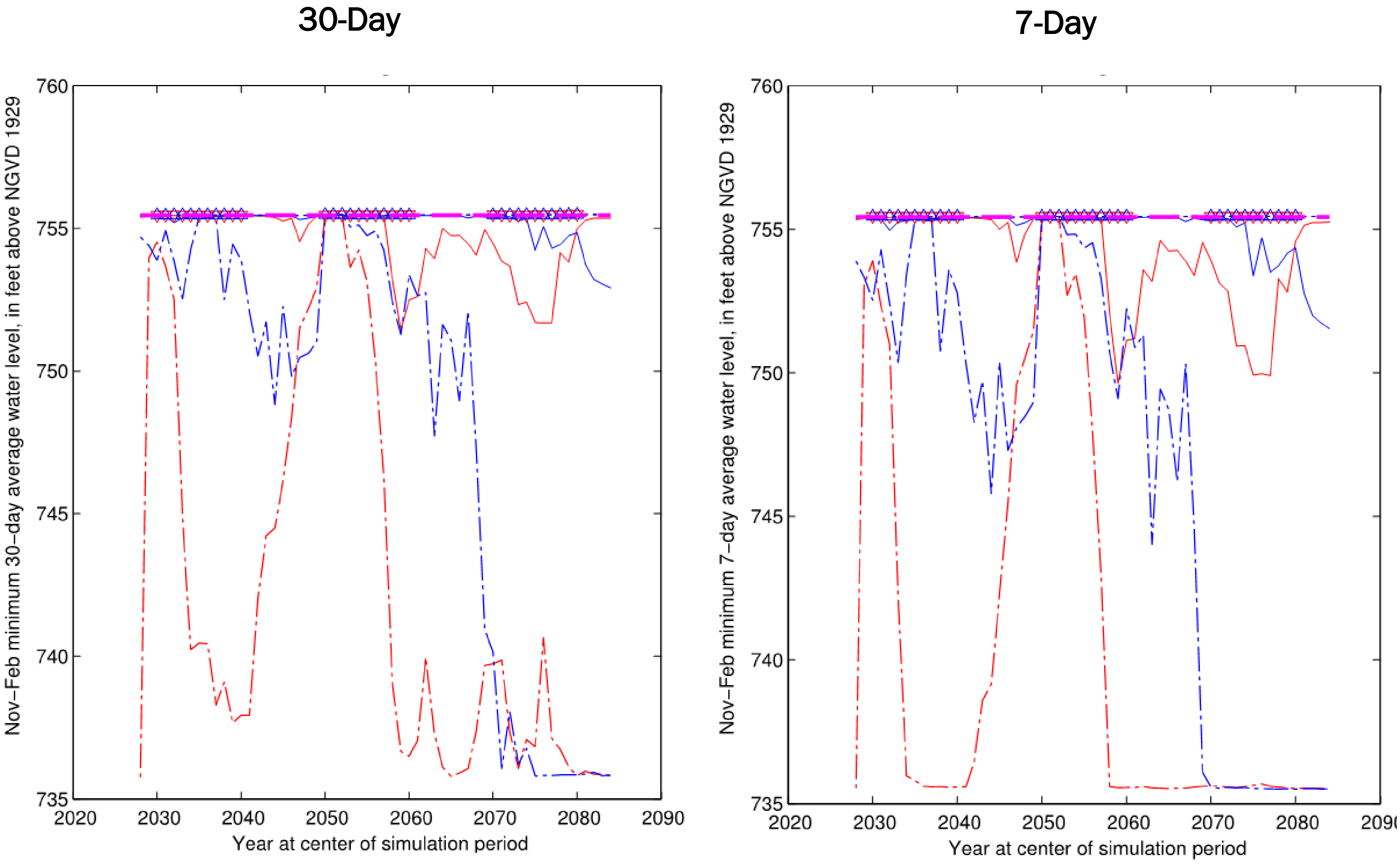


Fall/Winter Average Maximum Water Levels with Development


30-Day

7-Day

Fall/Winter Average Minimum Water Levels with Development


30-Day

7-Day

Appendix C: Summary of Prioritized Risks by Service Sector

Table A-1. Summary of Prioritized Risks by Service Sector

Predicted Changes	Affected Sector								
	Water Supply/ Water Quality	Water Treatment	Wastewater Treatment	Public Health	Agriculture	Environment	Economy	Energy	Transportation
Increased Air Temperatures / Increased incidence of heat waves	Increased evaporation, Reduced water volume	Negatively affects water quality	Impacts to infrastructure (increased corrosion)	Vector Diseases	Vegetation / Animal species shift	Vegetation / Animal species shift	Extended recreational season	Increased energy demand due to air conditioning, increased use of pumps for water / wastewater	Increase in road and bridge repairs and disruptions due to heat stress
	Increased water demand and demand due to irrigation				Negative impact on livestock health / mortality				Increased use of private vehicles
	Increased in-stream organics			Increased issues for asthma and allergies	Extended/disruptions to growing season		Increased costs for utility services (water, wastewater, and energy)		
	Increased nutrient/ pesticide / herbicide runoff due to extended growing season, increased algal blooms	Increased capital investment due to designing for peaking factors	Lower flow affects discharge permits and treatment		Increased use of herbicides/pesticides/ nutrients with longer growing season	Increased smog / Decreased air quality		Decreased efficiency throughout production as temperature rises	Change in construction materials for higher temperatures
	Increased soil erosion	Taste and odor concerns, potential for algal toxins	Increase need for odor control	Impacts to human mortality, Increase in heat illnesses and stresses on healthcare	Increased need for irrigation and controlled drainage		Increased service cost for food	Increased power disruptions (brownouts)	Extended but less efficient construction season
		Increased chlorine demand, Increase DBPs					Decreased human productivity		
Increased water temperature	Decreased dissolved oxygen	Taste and odor concerns, potential for algal toxins	Lower DO / changes in temp require affect wastewater discharge allocation	Increase in waterborne diseases	Increased costs to control water quality from fields	Changes in pH and pollutant toxicity	Algae growth could impact recreational use	Lack of cooling water could reduce energy production	Limited applicability
		Increased treatment costs due to algae and potentially algal toxins							
	Increased release of phosphorus and other pollutants from anoxic zones/sediment								
	Decreased mixing	Increased treatment efficiency	Decreased organics at plant due to DBPs	Increased use of disinfectants; increased DBPs	Treatment and disinfection use increases		Increased energy cost due to power plant discharge cooling		
	Longer duration of poorer water quality				Energy use for cooling	Negative impact on aquatic life diversity and numbers			
	Increased algal blooms including blue greens (potential for increased toxin release)				Livestock management and aquaculture	Decreased dissolved oxygen			
						Increase in algal blooms			
Warmer soil temperatures / Decreased soil moisture	Decreased groundwater base flow to streams	Increased treatment demands due to lower water WQ	Increased use of effluent sludge on farm fields	Impacts to private water systems	Increased need for irrigation and controlled drainage	Vegetation / Animal species shift	Negative impact on winter recreational activities if less snow/ice	Increased albedo; greater urban heat island effect leads to increased cooling demands	Reduced salt usage in winter
	Reduction/change in vegetative cover				Vegetation / Animal species shift	Increased erosion			
	Increased soil erosion	Change of frequency in water main breaks in winter			Increased soil conservation practices				Embankment erosion and damage due dry soils
	Increased in-stream organics				Increased need for crop insurance	Increase in invasive species	Higher food prices and potential job losses if results in loss of agricultural crops		
	Increased sediment deposition/loss of volume								
Increased winter temperature and reduced ice cover	Increased water temperature	Reduced chance of frozen water lines and breaks in winter	Extended season for I/I	Fewer snow/ice related injuries	Increased pests and invasive species	Vegetation / Animal species shift	Increased transportation / navigation season	Lower heating costs	Extended transportation season
	Declining water levels due to				Damage to crops that use snow	Shift in growing seasons			Reduced use of road salts / snow clearing

Table A-1. Summary of Prioritized Risks by Service Sector

Predicted Changes	Affected Sector								
	Water Supply/ Water Quality	Water Treatment	Wastewater Treatment	Public Health	Agriculture	Environment	Economy	Energy	Transportation
	increased evaporation in winter Earlier spring turnover Longer duration of poorer water quality		Warmer water easier to treat Extended season for odor control	Increase in vector diseases	as cover Increased growing season which increases use of nutrients and potential for erosion	Increased evaporation	Reduce road salt usage Reduction in winter recreational activities		
Change in vegetation / animal species composition	Reduction/change in vegetative cover which causes loss of stream bank shading and increased water temperature Increased soil erosion Increased sediment deposition/loss of volume Increased in-stream organics Increased nutrient, turbidity, and sediment loads and increased potential for algal blooms	Invasive plant / animals can negatively impact water quality, such as zebra mussels or phragmites	Limited applicability	Change in disease vectors	Increase and change in use of herbicides / pesticides Negative impacts to crop growth	Reduced resiliency of ecosystems Reduced carbon sequestration as forest compositions change	Impacts to agriculture and forestry industries	Limited applicability	Limited applicability
Higher maximum sustained stream flow (30 and 7-day higher maximum stream flows)	Increased organics, nutrient, turbidity, and sediment loads and other pollutant loads to surface water Increased watershed and stream bank erosion Increased algal blooms, including blue greens and potential for increased toxin release Increased sediment deposition/ loss of volume Negatively affects groundwater recharge Increased supply management challenges related to greater variability in stream flow	Increased treatment costs due to increased pollutant concentrations and increased disinfection by-products (DBPs) Increased turbidity Increased potential for viruses and bacteria Taste and odor concerns, potential for algal toxins	Increased treatment demands Reduced effectiveness of stormwater management measures Increased CSO volume and frequency	Increased use of cisterns for drinking water Increased mosquito populations Increase disease spread	Increased soil erosion, Loss of nutrients	Negative impact on aquatic life diversity and numbers	CSO/SSOs increase will increase the cost of treatment to ratepayers Increased flood damage Increase need for social services	Increased energy costs for water treatment	Update design sizes for bridges and culverts to new drainage standards Increase of hazardous drainage issues along highway during storm events

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Table A-1. Summary of Prioritized Risks by Service Sector

Predicted Changes	Affected Sector								
	Water Supply/ Water Quality	Water Treatment	Wastewater Treatment	Public Health	Agriculture	Environment	Economy	Energy	Transportation
Extended dry periods / summer drought (Decreased minimum 30 day stream flow)	Decreased reservoir flow/volume and reduced mixing	Taste and odor concerns, potential for algal toxins, Increased treatment cost for algae and potential algal toxins	Lower flow affects discharge permits and treatment	Reduction in some vector diseases	Lowered crop production	Vegetation / Animal species shift toward those better adapted to drought conditions	Decreased recreation	Increased energy for WWTP requirements	Shipping Impacts
	Decreased groundwater flow to streams								
	Increased water demand	Reduced groundwater supply/ recharge	Reduced infiltration into sewers resulting in increased H2S production		Increased demand for irrigation but decreased water availability		Increased industrial treatment costs		
								Increased pumping costs for water supply	
				Increased allergens and dust		Negative impact on aquatic life diversity and numbers			
	Increased algal blooms, including blue greens (potential for increased toxin release)	Reduced WQ and dilution of non-point source discharges	Stresses on plants in LID such as rain gardens		Vegetation/ animal shifts toward species better adapted to drought conditions		Low flow could affect transportation navigation through water		
	Reduction/change in vegetative cover			Impacts to PWS			Increased food cost due to decreased agricultural production (crop loss)		
	Reduced reliability of yield from supply sources								
Increased intensity of rain and wind events	Increased in-stream organics, nutrients, turbidity, and sediment and other pollutant loads	Reduced treatment capacity due to higher turbidity	Increased CSO/SSO discharges	Loss of electrical/ water / sanitation services during and after event	Crop losses	Soil / Channel Erosion	Increased insurance costs; increased damages due to floods/storms	Increased vulnerability of power supply system	Infrastructure access Infrastructure damage / failure
	Increased watershed and stream bank erosion			Increased demand on public health services					Inability to transport food and water in critical situations
			Flooding can create solid disposal issues/treatment	Restricted access to critical care		Impacts from flood mitigation structures such as flood walls and increased flood zones			
					Soil erosion		Could affect recreational use	Increased investment in resilient infrastructure	Increased snow: changing fleet needs
	Increased algal blooms, including blue greens (Potential for increased toxin release)	Damage to Infrastructure / Infrastructure failure including power outages, flooding and intake damages	Increased cost to treat Increased I/I to WWTPs	Septic System Failures					
					Need additional land set aside for increased flood zones		Increased snow: Expensive to remove		
						Negative impact on aquatic life diversity and numbers			
			Damage to Infrastructure/ Infrastructure failure including power outages and flooding	Disaster related injuries / mortalities					Increased snow: Increased road deterioration
	Increased sediment deposition/ loss of volume								

Appendix D: Adaptive Strategies, Non-Water Service Sectors

B.1 Public Health

The high-priority risks identified for the public health sector are listed in Table B-1. The changing climatic conditions projected by the USGS modeling will impact the public health and well-being of the region in a variety of ways. Climate change may worsen existing diseases and conditions and introduce new pests and pathogens into communities (U.S. Department of Health and Human Services, 2012). In addition, increased temperatures and more extreme storms will have a direct negative impact on human mortality. The most vulnerable populations are children, the elderly, the poor, and those with underlying health conditions. The potential adaptation planning and policy, operational and capital improvement strategies, and relative costs to mitigate each of the high-priority risks for public health are summarized in the discussion below and Tables B-2 through B-5.

Table B-1. High-Priority Risks to Public Health

Vulnerability Scenario	Risks
Increased air temperature	Increased issues for respiratory issues among sensitive groups
	Impacts to human mortality, increase in heat illnesses, and stresses on health care
Increased water temperature	Increase in waterborne diseases
Extended dry periods/summer drought	Increased allergens and dust
Increased intensity of rain and wind events	Loss of electrical/water/sanitation services
	Increased demand on public health services
	Restricted access to critical care
	Disaster related injuries/mortalities

B.1.1 Mitigating Impacts from Poor Air Quality

> Columbus, Ohio ranked 34 on the list of 100 most challenging places to live with asthma. –
>
> *Allergy Capitals 2010,* Asthma and Allergy Foundation of America

Adaptive management strategies for alleviating the impacts due to poor air quality as related to projected increased temperatures are provided in Table B-2. Strategies focus on decreasing air pollutant levels and mitigating urban dust during extended dry weather. Warmer temperatures could increase the concentration of unhealthy air pollutants, exacerbating health issues for people with asthma and respiratory issues. More than 20 million people in the Midwest already experience air quality that fails to meet national ambient air quality standards, and this number is projected to increase (Melillo, 2014). In addition, warmer temperatures are lengthening the pollen season. Spring is already occurring earlier in the United States, creating longer periods of respiratory issues for people with allergies (USEPA, 2014).

In the Short Term, public outreach and education is recommended to help keep at-risk groups safer. MORPC has an ongoing public education and monitoring program for ground-level ozone and particle pollution levels (MORPC Air Quality). MORPC issues daily air quality forecasts using the Air Quality Index (AQI) which tells residents how clean or polluted the air is, and the associated health effects. On Air Quality Alert days, sensitive groups including active children, older adults, and those with breathing or heart conditions can reduce their exposure by planning outdoor activities in the morning when ozone levels are generally lower. Besides providing public education, this ongoing program provides good data for evaluating the changes to air quality over time Increasing street sweeping during dry periods is another “no regrets” strategy. Street sweeping significantly reduces the accumulation of dust, debris, and pollutants on streets in urban areas, thereby reducing both air pollution and water pollution from stormwater runoff.

In the midterm, a Regional Transportation plan should be developed. Increased mass transit would reduce overall air pollution. Adoption of low or zero-emitting fuels, such as compressed natural gas or electricity, would reduce air pollution loading. Fleet management policies, such as anti-idling, would also provide air quality benefits.

In the Long Term planning horizon, if air monitoring indicates significant negative changes to regional air quality, other identified strategies such as changing air pollution regulations should be considered. Modifications to zoning and development planning to increase opportunities for pedestrian and bicycle transportation would reduce automobile emissions. Capital improvements that came out of the regional transportation plan would also be implemented during this time period.

Table B-2. Increased Issues for Respiratory Issues Due to Increased Temperature and Increased Summer Drought

Strategy	No Regrets	Cost
Planning and Policy		
Monitor and release information on air quality		$
Develop Regional Transportation Plan to limit pollution related to cars/mass transit		$$
Institute anti-idling policies on fleet vehicles	✓	$
Increase statewide regulations on air pollution *		$$
Implement sustainable development patterns to promote walkable communities*		$$
Operational		
Expand the public outreach and education program using social media throughout the region	✓	$
Increase street sweeping in urban areas	✓	$$
Adopt use of low or zero-emitting fuels at point of use	✓	$$
Capital Improvement		
Implement light rail in municipal areas, rail or other options for regional transit *		$$$

$ - Can be funded by the service sector within the typical annual budget

$$ - Require planning to implement as part of the capital improvement plan for the service sector

$$$ - Require significant bonding, federal or grant funding, or changes to utility rates to implement the improvement

**Long Term strategies need to be refined based on updated climate projections and outcomes of the Mid Term planning*

B.1.2 Mitigating Impacts of Heat on Human Mortality

Public health and human mortality will also be impacted by increasing temperatures and incidences of heat waves. Heat waves and greater temperatures will increase the number of heat illnesses such as heat stroke and dehydration in the region. Heat waves, such as the one that occurred in Chicago in 1995, are projected to significantly increase in the latter half of this century. The 5-day-long heat wave in Chicago peaked at 106°F and resulted in more than 700 deaths (USEPA, 2012). In the United States, mortality increases 4 percent during heat waves compared with non-heat wave days (Melillo, 2014).

In the Short Term, it is recommended to leverage MORPC's existing air quality monitoring public education forum to also communicate the risks of higher temperatures on human health. Conservation measures are also recommended, including incentives for developers to install green roofs and tree planting in an effort to reduce the urban heat island effect.

In the midterm planning horizon, it is recommended to conduct a Community Heat Stress Mitigation Plan to identify at-risk areas where residents may be especially susceptible to heat-related illnesses, and to identify potential access to cooling centers. As heat-related illnesses are already a problem facing the region, it is recommended that at a minimum, the region needs to develop a plan for neighborhood support and for providing access to air-conditioned centers or pools to alleviate heat stress.

In the Long Term, as climate changes and the associated local impacts on health are better understood, capital improvement strategies related to the construction of additional pools and cooling centers and air conditioning of schools should be considered and incorporated into municipal plans. Building standards should be improved to conserve energy. Health services should also be expanded, especially in at-risk areas, to accommodate underserved and critical populations.

Table B-3. Impacts to Human Mortality Due to Increased Temperature

Strategy	No Regrets	Cost
Planning and Policy		
Conduct Community Heat Stress Mitigation Plans to identify potential community cooling centers, splash pads or pools, and to include neighborhood support plan (neighbors check on neighbors) during heat	✓	$
Update building standards to promote better energy usage		$$
Operational		
Implement public education and outreach plans regarding heat stress and hydration (in conjunction with air quality outreach program)	✓	$
Implement incentive program for developers related to use of green roofs in development and re-development projects		
Provide access to cooling centers during summer months, potentially in schools/churches with air conditioning*		$$
Capital Improvement		
Implement tree planting program to increase shade in urban areas		$$
Implement green roofs in urban centers to reduce heat island effect		$$
Construct and maintain neighborhood pools/splash pads*		$$
Expand health services as needed to facilitate response to increased heat related illnesses*		$$
Install air conditioning in neighborhood schools to serve as cooling centers during summer months*		$$
Provide fans and distribute to low income areas*		$

$ - Can be funded by the service sector within the typical annual budget

$$ - Require planning to implement as part of the capital improvement plan for the service sector

$$$ - Require significant bonding, federal or grant funding, or changes to utility rates to implement the improvement

**Long Term strategies need to be refined based on updated climate projections and outcomes of the Mid Term planning*

B.1.3 Increase in Waterborne Disease

The associated increase in water temperatures will likely encourage the spread of waterborne diseases. Warmer water temperatures promote the development of many vector organisms and could also shift additional organisms northward that currently do not exist in the Upper Scioto River watershed. Diarrheal diseases as well as viruses and parasites such as giardiasis and cryptosporidiosis are commonly spread through contact with water (SDWF, 2010; CDC, 2010). As temperatures increase human contact with water generally increases, which creates a rise in the number of waterborne illnesses.

The incidence of cryptosporidiosis peaks in late summer and coincides with the summer swimming season. The number of non-outbreak cryptosporidiosis cases reported nationally increased from 3,411 cases in 2004 to nearly 8,300 in 2007 (CDC, 2008). This substantial increase (143 percent) mirrors the increase in the number of nationally reported cryptosporidiosis outbreaks associated with treated recreational water venues (e.g., pools, water parks, and interactive fountains). This health issue may be exacerbated in the future with increased need for access to public pools for cooling during extended heat waves.

Under current climate conditions, the region is also experiencing increased blooms of blue-green algae associated with nutrient runoff and higher temperatures. These algal blooms pose a health risk to the region. Cyanobacteria (blue-green algae) toxins are a concern when present in drinking water supplies as discussed in Section 3.2. These toxins can also cause serious health issues including poisoning, impacting the liver and the nervous system, and skin and mucous irritation from human or animal contact. The recent toxic algae problem in Toledo, Ohio, reflected the impact this problem is having on municipalities in central Ohio under current climatic conditions. Projected increases in temperature will likely exacerbate this problem associated with algal blooms.

Adaptive strategies that have been recommended to mitigate the health risks associated with waterborne disease and toxic algae are also presented in Section 3.2. Strategies range from planning studies to capital improvements all focused on reducing bacteria and nutrient runoff into streams, rivers, and reservoirs. Many of these strategies are recommended under current conditions to alleviate the nutrient loads from stormwater and septic systems in order to address the growing problems associated with bacteria and algae blooms. **In addition to these strategies, in the Short Term, public outreach could be focused on pet waste awareness, reducing biological pollutant loads.**

In the Mid Term planning horizon, it is recommended that a sewer connection plan be developed to identify aging home sewage treatment systems (HSTS) and where they may potentially be contributing bacteria to water sources. Developing a Regional Watershed Management Plan will identify strategies to improve water quality issues and reduce the potential for spread of many waterborne illnesses.

In the Long Term, it is recommended that HSTSs are inspected frequently and regularly, and eventually eliminated as connections to the sewerage system are made. It is also recommended that the U.S. Department of Agriculture's (USDA's) program that offers grants to farmers to assist with farm fencing is expanded possibly through the Ohio Farm Bureau or the soil and water conservation district offices. This program significantly reduces biological pollutant sources in the watershed.

Table B-4. Increase in Waterborne Disease Due to Increased Temperature

Strategy	No Regrets	Cost
Planning and Policy		
Conduct Sewer Connection Plan to reduce bacteria in water sources from areas served by aging home sewage treatment systems (HSTS)	✓	$
Develop Regional Watershed Management Plan to identify strategies to improve water quality including focus on land use planning options to reduce bacteria and other potential disease organisms in water	✓	$
Operational		
Implement increased pet waste awareness campaigns	✓	$
Increase frequency of inspections of HSTS*	✓	$
Capital Improvement		
Implement sewer connections to serve areas currently served by HSTS*		$$$
Implement livestock fencing and other measures to reduce non-point source pollution due to animal waste	✓	$$

$ - Can be funded by the service sector within the typical annual budget

$$ - Require planning to implement as part of the capital improvement plan for the service sector

$$$ - Require significant bonding, federal or grant funding, or changes to utility rates to implement the improvement

**Long Term strategies need to be refined based on updated climate projections and outcomes of the Mid Term planning*

B.1.4 Impacts to Electrical/Water/Wastewater Services and Critical-Care Facilities

Flooding and storm damage from major storm events can have severe impacts on public health. Flooding can inundate urban areas and disrupt transportation along the region's roads. For example, flooding in the Midwest in 2008 caused 24 deaths and closure of key transportation routes (Melillo, 2014). Flooding and high winds can damage roadways, drainage structures, and power supply equipment, thereby reducing access to health care facilities. It is especially critical for health care facilities and other emergency response infrastructure to incorporate future climate change into their planning for continuous operation during such events. Table B-5 provides the detailed strategies to alleviate impacts to public health associated with increased intensity of rain and wind events.

In addition to the immediate fatalities and injuries associated with extreme storm and flood events, are numerous illnesses and deaths associated with consumption of contaminated water. Floods can lead to transmission of waterborne diseases by contaminating fresh water with untreated and partially treated sewage and indirectly by causing the breakdown of water supply and treatment facilities (NRDC, 2012). An extreme example was the outbreak of cryptosporidiosis in Milwaukee in 1993 when 54 people were killed and over 400,000 illnesses were reported due to water contamination following heavy storms.

In the Short Term, an emergency plan which accounts for vulnerabilities in the transportation, power, and basic utilities and how they impact critical care facilities is recommended. The more prepared the region is to restore these services, the more lives will be saved in the event of an emergency. This emergency plan includes understanding system vulnerabilities including flooding and identifying opportunities for redundancy in critical or isolated parts of the health care network. It also includes developing mutual aid agreements and sharing resources between critical care facilities within the region.

Long term strategies include the implementation of capital improvements as identified in the emergency plan to address vulnerabilities. These improvements could include redundant infrastructure, back-up power, flood-proofing, and elevated roadways.

Table B-5. Impacts to Electrical/Water/Wastewater Services and Critical-Care Facilities Due to Increased Intensity of Rain and Wind Events		
Strategy	**No Regrets**	**Cost**
Planning and Policy		
Develop or update Regional Emergency Preparedness and Response Plans including focus on utilities and critical-care facilities including a health care access plan	✓	$
As part of emergency plan, develop regional flooding potential maps for more intense and longer-duration storm events (in excess of the 100-year flood based on past climatic conditions)	✓	$$
Evaluate options for increased wastewater/stormwater storage during storm events	✓	$
Evaluate potential to increase redundancy in systems to allow for sharing resources	✓	$$
Develop mutual aid agreements between critical-care facilities within the region	✓	$
Develop backup power plans to maintain utility service and service to critical-care facilities	✓	$
Capital Improvement		
Invest in alternative power supply options at facilities including generators, solar panels, and wind generators*	✓	$$$
Increase flood-proofing of utilities, roadways, and critical-care facilities*	✓	$$$
Increase spillway capacity and armoring of dams to reduce potential for dam breaks*		$$$
Invest in additional storage capacity in wastewater and stormwater utilities to mitigate flooding*		$$$
Invest in elevated roadways to maintain access to critical-care facilities (as needed per emergency response plan)*		$$$

$ - Can be funded by the service sector within the typical annual budget

$$ - Require planning to implement as part of the capital improvement plan for the service sector

$$$ - Require significant bonding, federal or grant funding, or changes to utility rates to implement the improvement

**Long Term strategies need to be refined based on updated climate projections and outcomes of the Mid Term planning*

B.2 Agriculture

The high-priority risks identified for the agricultural sector are listed in Table B-6. Adaptive strategies to mitigate each of these vulnerabilities are provided in the following tables and following paragraphs. It should be noted that many of the risks identified for the agricultural sector have been evaluated in relation to water quality as presented in Section 3.2.1. The potential adaptation planning and policy, operational and capital improvement strategies, and relative costs to mitigate each of the high-priority risks for agriculture are summarized in Table B-7 and in the discussion below.

Table B-6. High-Priority Risks to Agricultural Sector	
Vulnerability Scenario	**Risks**
Increased air temperature	Negative impact on livestock health and mortality
	Crop die off
	Increased need for irrigation and controlled drainage
Increased water temperature	Increased cost to control water quality from fields
Warmer soil temperatures/decreased soil moisture	Increased need for irrigation and controlled drainage
Decreased minimum 30-day river flows/extended dry periods/summer drought	Increased demand for irrigation with decreased water availability

B.2.1 Strategies to mitigate impacts from increased heat and changes in flow

Increasing temperatures and greater variability in precipitation will impact water availability and quality, crop production, and livestock health and productivity. As stated in the USDA Climate Change Adaptation Plan, "the agricultural sector has a strong record of innovation and adaptability, but the magnitude of climatic changes projected for this century including increased frequency of extreme events, exceed the variations that have been managed in the past and will challenge all elements of agricultural production systems" (USDA, 2012).

As discussed in Section 3.2.1, predicted changes in temperature and precipitation will have a negative impact on water quality and availability within the region. Longer growing seasons and higher-intensity rain events could lead to increased nonpoint pollution from runoff. Longer dry periods could also lead to a need for crop irrigation and increased demand on water sources.

Longer dry periods and greater heat could stress existing crops. Extreme wind and precipitation events can also cause significant damage to crops.

Increased temperatures can have a detrimental effect on the health and productivity of livestock. When experiencing heat stress dairy cattle experience a reduction in the amount of milk produced and beef cattle experience a reduction in growth. Other livestock animals such as pigs and chickens can suffer health effects from heat stress as well. Changes in climate will also have an impact on the production of food for livestock. This reduction in production and animal health has a direct effect on food supply and the economy due to reduced supplies of meat, milk, and eggs and increased food prices.

These vulnerabilities can be mitigated through nutrition and heat management strategies. Agricultural producers can shift the timing of animal feeding to cooler parts of the day, which reduces the animal's core temperature increase as the food digests. Farms can install shade structures for grazing areas with little or no natural shade. The addition of sprinklers and additional water sources also helps to reduce the heat stress experienced by livestock. The costs of these strategies would be borne by the agricultural producers and could be significant depending on the size of the herds being managed.

In the Short Term, mitigation of these vulnerabilities will require a regional approach including public education, partnerships with key stakeholders to develop nutrient management and water sharing plans, as well as agricultural investment in conservation practices. As discussed in Section 3.2.1, the modification of local ordinances to require LID will improve groundwater recharge throughout the region as these practices more closely mimic natural hydrology.

In the Mid Term planning horizon, it is recommended that the region collaborate on the development of a Regional Water Supply Management Plan as discussed in Section 3.2.1,, including the evaluation of water demand, availability, potential new sources, and the identification of emergency supply sources that can be used during drought extreme conditions. Changes in agricultural practices may significantly impact the ability of drinking water utilities to provide sufficient supply for residents. Rather than competing for this potentially limited resource, these two sectors can work together to establish mutually beneficial solutions to meet their water needs. Solutions may include increased use of stormwater harvesting or wastewater reuse to address regional water needs.

In the Long Term, the changing conditions will need to be evaluated and agricultural practices adjusted to fit these needs, including installing high efficiency irrigation systems, water reclamation, controlled drainage, and rotating crops or even developing new crops that will be more successful in this changing climate. Long term investments may also include heat abatement equipment such as fans and sprinklers to maintain livestock health. Based on the results of the Regional Water Supply Management plan, new water supply sources to irrigate may need to be developed.

Table B-7. Strategies to mitigate impacts from increased heat and changes in flow		
Strategy	No Regrets	Cost
Planning and Policy		
Implement public outreach and education on water quality issues: causes and prevention	✓	$
Establish partnerships among key stakeholders: education and information sharing	✓	$
Modify local stormwater management and land development ordinances to require LID, reduce impervious areas, and use rainwater and stormwater harvesting/reuse, thereby reducing pollutant runoff volume		$
Develop Regional Water Supply Management Plan to identify strategies for extended drought conditions including irrigation water needs and water sharing alternative evaluation	✓	$
As part of Supply Plan, determine potential future water needs for agriculture as well as potential for use of recycled water for irrigation		$
As part of Supply Plan, develop guide for and promote rainwater and stormwater harvesting/reuse		$
Operational		
Implement conservation practices; e.g., cover crops, conservation tillage, nutrient management planning, etc.	✓	$-$$
Adjust crop mix and/or planting schedules, as needed*		$
Development of crop insurance programs that would aid in the reduction of chemicals used*		$$
Alter livestock feeding schedules and nutritional balance*		$
Capital Improvement Strategies		
Reduce agricultural water use by working with irrigators to install advanced equipment such as drip or other micro-irrigation systems with weather linked controls*		$$
Installation of controlled drainage in agricultural fields*		$$$
Development of water sources; irrigation, ponds, cisterns*		$–$$
Build systems to reclaim wastewater for energy, industrial, agricultural, or irrigation water use*		$$$
Installation of heat abatement equipment: fans, shade tarps, sprinklers, additional water sources*		$–$$

$ - Can be funded by the service sector within the typical annual budget

$$ - Require planning to implement as part of the capital improvement plan for the service sector

$$$ - Require significant bonding, federal or grant funding, or changes to utility rates to implement the improvement

Long Term strategies need to be refined based on updated climate projections and outcomes of the Mid Term planning

B.3 Environment

Only one high-priority risk was identified for the environment as listed in Table B-8 below. Adaptive strategies have been evaluated in relation to environmental water quality and water supply and are presented in Section 3.2.1. The strategies related to increased smog and decreased air quality is presented in relation to public health in Sections B.1.

Table B-8. High-Priority Risks to the Environment	
Vulnerability Scenario	Risks
Increased air temperature	Increased smog/decreased air quality (see Section B.1.1)

B.4 Economy

The high-priority risks identified for the economy are listed in Table B-9, below. Adaptive strategies to mitigate each of these vulnerabilities are provided in the following tables and discussed in the subsequent paragraphs. It should be noted that many of the high-priority threats to the economy have also been evaluated in relation to the other service sectors.

Table B-9. High-Priority Risks to the Economy

Vulnerability Scenario	Risks
Increased air temperature	Increased service cost for food
	Increased cost for utility services (water, wastewater, and energy)
	Decreased human productivity
Increased 30-day and 7-day maximum high stream flow	Increased flood damage
Extended dry periods/summer drought	Increased food cost due to decreased agricultural production (crop loss)
Increased intensity of rain and wind events	Increased insurance costs; Increased damages due to floods/storms

B.4.1 Minimizing Economic Impacts

Many of the risks to the other sectors will ultimately have an effect on the economic health of the region. The strategies to minimize the economic impacts are summarized in Table B-10. Decreased water quality and reduced water supplies increase the cost to supply and treat water for human use. Higher temperatures result in the increased use of air conditioning and fans, which increase electrical usage and air pollutant emissions, and drive up energy costs. Finally, increased agricultural costs to bring water to fields and install advanced drainage systems, and loss of production will all increase the cost of food within the region and beyond. The recent drought in northern Georgia provides an example of the impact of increased drought and climate change on the economy of a region. In late spring 2008, Lake Lanier, the region's major water supply, was at 50 percent of its storage capacity. This drought, combined with record high temperatures, resulted in an estimated $1.3 billion in economic losses related to impacts to industries, decreased agricultural production, and reductions to water utility revenues related to increased conservation (WERF, WRF, 2013).

Storm damage and the disruption of service associated with increased incidence and intensity of weather events not only represents a cost to the region associated with cleanup, repair, or replacement of infrastructure but also economic and social impacts as the supply chains are disrupted, economic activities are suspended, and social well-being is threatened. The impacts to the economy associated with increased flooding are well documented by FEMA in relation to response to recent floods across the country. In Ohio, $240 million in damages were caused in just over one week by severe storms and flooding in several counties including Allen, Crawford, and Hardin (FEMA, 2011). Flooding presents urgent challenges to all sectors during a flood event as well as Long Term recovery efforts that result in large capital costs related to damages to communities, infrastructure, and industries.

In the Short Term, strategies such as energy and water conservation that will also impact this sector have largely been addressed under the other sectors in TM4. Increased focus on planning for increased heat-related problems such as health effects and power supply, which has also been discussed throughout TM4, will also mitigate the impacts of climate change on the economy. Critical to mitigating economic damages is developing or updating a regional emergency preparedness and response plan. The more prepared the region is to deal with an extreme weather event, the faster key processes can be restored, and the faster economic losses can be recovered. Similar emergency planning is recommended for most other sectors in TM4.

Mid Term planning includes conducting a regional health care access plan and regional energy study. These plans will help mitigate disruptions to key service while identify out the most affordable regional improvements.

Long Term efforts include adjusting working strategies and capital investments to reduce impacts on the economy.

Table B-10. Minimizing Economic Impacts

Strategy	No Regrets	Cost
Planning and Policy		
Develop or Update Regional Emergency Preparedness and Response Plans for extreme weather events	✓	$
Conduct Regional Energy Study to evaluate alternatives to increase peak energy capacity to minimize brownouts and	✓	$
Develop Regional Health Care Access Plan to evaluate stress on health care systems related to increased heat related disease and illnesses	✓	$
Conduct Utility Rate Studies to evaluate impact of utility rate changes on regional industries and the economy*		$
Operational		
Implement energy conservation practices	✓	$–$$
Adjust working hours due to lower productivity during high heat*		$

$ - Can be funded by the service sector within the typical annual budget

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B.5 Energy

The high-priority risks identified for the energy sector are listed in Table B-11. The potential adaptation planning and policy, operational and capital improvement strategies, and relative costs to mitigate each of the high-priority risks for the energy sector are summarized in the discussion below and in Table B-12.

Table B-11. High-Priority Risks to Energy Sector

Vulnerability Scenario	Risks
Increased air temperature	Increased power disruptions (brownouts)
Increased water temperature	Lack of power plant cooling water could reduce power production
Increased intensity of rain and wind	Increased vulnerability of power supply

The effects of climate change on the energy sector will be felt on both supply and demand. Increased variability in water quantity and timing due to projected changes in the frequency and timing of precipitation will have impacts on hydropower. The likely increase in heat waves will result in more peak load demands, stresses on energy distribution systems, and more frequent brownouts or blackouts. These will also have negative impacts on public health and the economy. The energy required by the water sector is a significant percentage of the overall energy use in a region. Municipal water processing and transport consumes about 4 percent of the nation’s electricity. Increased treatment requirements for both wastewater and water would further increase energy use for treatment. These impacts will be most significant during summer months when water quality is typically degraded, treatment requirements increased, and water and energy demands both peak.

B.5.1 Minimizing Power Disruptions

Energy supply systems are also at risk from severe weather events. Increased temperatures result in powerline sagging, degradation of conductor insulation, increased voltage drop and increased transmission losses. In some areas the existing transmission and/or distribution systems are already operating at or above capacity. At times of peak demand this is exacerbated, and may result in outages due to overloaded transformers. Severe weather such as lightning and wind can have devastating effects on energy supply infrastructure, resulting in power loss to customers.

In the Short Term, public education on energy conservation combined with incentive plans to encourage conservation practices will help to reduce system demands. Performance of a regional energy study would help energy distributers understand critical needs as well as identify the best areas for capital investment in energy production. Developing a regional emergency preparedness and response plan is critical to quickly restoring service during an extreme weather event. As part of this emergency plan, infrastructure assessments should be conducted to provide energy producers with an understanding of existing assets and potential vulnerabilities.

In the midterm, investments should be made to energy infrastructure based on the results of the regional energy study including increased deployment of distributed renewable energy systems.

Potential Long Term strategies would include implementing micro-grids with all energy needs produced locally with renewable energy; increased redundancy in transmission and distribution infrastructure, particularly to critical facilities; deploy distributed battery storage systems to supply power during peak demand periods and to reduce the capacity of standby generation that is needed; decommissioning high-pollutant power generating facilities (i.e. coal-fired power plants) and replacing them with lower-polluting (combined-cycle natural gas) or renewable (solar, wind) central plants.

Table B-12. Minimizing Power Disruptions

Strategy	No Regrets	Cost
Planning and Policy		
Implement public education on power consumption and conservation	✓	$
Maintain/Expand incentive plans for high-efficiency HVAC, appliances, insulation, etc.	✓	$$
Develop/or update of Regional Emergency Preparedness and Response Plans		$
As part of emergency plan, evaluate vulnerability of existing infrastructure	✓	$
Conduct Regional Energy Study to evaluate alternatives to increase peak energy capacity to minimize brownouts and to evaluate potential sources for additional power sources including wind and solar alternatives		$
Adopt Architecture 2030 for the design of new publicly-funded buildings with the goal of achieving net-zero energy and carbon emissions*		$$$
Operational		
Implement energy conservation		$
Develop revised infrastructure design standards*		$
Capital Improvement		
Upgrade critical infrastructure to withstand increased demands and storm events*		$$$
Construct alternative and back-up power supply sources including solar and wind generation with battery storage at critical facilities including health care, water/wastewater treatment, and pumping stations*		$$$

$ - Can be funded by the service sector within the typical annual budget

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**Long Term strategies need to be refined based on updated climate projections and outcomes of the Mid Term planning*

B.6 Transportation

The high-priority risks identified for the transportation sector are listed in Table B-13. The potential adaptation planning and policy, operational and capital improvement strategies, and relative costs to mitigate the high priority risk of damage from increased intensity of rain and wind events is summarized in Table B-14 and in the discussion below.

Table B-13. High-Priority Risks to the Transportation Sector

Vulnerability Scenario	Risks
Increased intensity of rain and wind events	Infrastructure access/infrastructure damage/failure
	Interruption to emergency services including the transportation of food and water in critical situations

B.6.1 Increasing the Resilience of the Transportation System

Existing transportation infrastructure is designed to handle historical precipitation and temperature ranges. These design parameters could allow roadway drainage to be overwhelmed by higher-intensity rain events and roadways to become impassible and potentially damaged by fast-moving floodwaters.

In the Short Term, it is recommended that a regional emergency preparedness and response plan be developed or updated. Transportation is a critical piece to the preparedness of the rest of the region – without the ability to transport goods, services, and repair crews, the region will not be able to recover from a severe event. Failure of the transportation system limits the ability to respond to emergencies and provide essential supplies and services, which can cost lives in a critical situation. As part of this emergency plan, transportation infrastructure assessments should be conducted to provide energy producers with an understanding of existing assets and potential vulnerabilities. Critical transportation routes and infrastructure and alternative routing should be identified in case of a failure.

Interstates 70 and 75 near Dayton, Ohio were closed due to flooding after a rain event in May, 2014 that dropped almost four inches of rain in four hours. This event stranded motorists on the interstates and prevented traffic access for six hours on several major roadways.

In the Long Term, it is recommended that upgrades and improvements be made to the infrastructure as well as design standards that are based on changing conditions. The existing transportation system should be assessed for performance based on potential future storm events.

Table B-14. Increasing the Resilience of the Transportation System

Strategy	No Regrets	Cost
Planning and Policy		
Development/update of Regional Emergency Preparedness and Response Plans	✓	$
As part of emergency preparedness plan, evaluate transportation system vulnerability to assess existing transportation infrastructure based on potential storm events	✓	$
Operational		
Develop revised transportation drainage infrastructure design standards*		$
Capital Improvement		
Upgrade critical transportation infrastructure to withstand greater storm events*		$$$

$ - Can be funded by the service sector within the typical annual budget

$$ - Require planning to implement as part of the capital improvement plan for the service sector

$$$ - Require significant bonding, federal or grant funding, or changes to utility rates to implement the improvement

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