4700 Lakehurst Court
Suite 100
Columbus, Ohio 43016

Prepared for: Mid-Ohio Regional Planning Commission

Project Title: Sustaining Scioto

Project No.: 144491

Technical Memorandum No. 3

Subject: Upper Scioto River Watershed, Vulnerability Assessment

Date: August 15, 2014

To: David Rutter, Project Manager, Mid-Ohio Regional Planning Commission

From: Kristin Knight, PE, Deputy Project Manager, Brown and Caldwell

Table of Contents

List of Figures

List of Tables

Section 1: Introduction

1.1 Project Background

The Mid-Ohio Regional Planning Commission in partnership with the City of Columbus Department of Public Utilities, Del-Co Water Company, Inc., the U.S. Geological Survey (USGS) and the Ohio Water Development Authority (OWDA) has initiated a study to model the effects of climate change on water supply in the Upper Scioto River Basin. The primary objective of this project is the development of an adaptive management plan for the region, a plan that will ensure a resilient water supply system well into the future.

There is substantial concern regarding the potential impacts of climate change to utilities, economies, and resources in the Midwest (Melillo 2014). This project, while taking into account climate impacts to all key sectors within the Scioto River Basin, focuses on impacts to water resources and utilities. National studies indicate that the projected extreme weather variations and altered patterns of precipitation, stormwater runoff, and dry weather base flow may increasingly compromise the ability to effectively manage water supplies and critical water supply and treatment infrastructure, and maintain water quality (USEPA 2012; Wilbanks and Fernandez 2012; NACWA 2009; Brekke et al. 2011). Ancillary impacts to water utilities may include increased cost for service, reduced supply reliability, impacts to customer confidence, and increased difficulty meeting regulatory compliance requirements.

The concerns of the water and wastewater utilities related to the potential impacts of climate change are exacerbated in Central Ohio where 85% of daily water usage is supplied by surface water. With such strong dependence on surface water, there is concern related to the impact of oscillating weather patterns associated with climate change on the reliability of supply sources. In order to maintain a resilient water supply system, utilities must develop a comprehensive understanding of the increased risks to their systems and develop management strategies to address these risks.

This project, named “Sustaining Scioto”, includes two phases: evaluating the potential impacts associated with climate change; and developing adaptive management strategies to reduce these impacts. The first phase includes the development of a watershed model to predict the impacts of projected climatologic conditions on the water resources of the Scioto River basin through the year 2090. The USGS developed the watershed model and has calibrated and validated the results using historical gaging station data. This climate change modeling effort is more robust and inclusive than most similar modeling efforts undertaken in the United States. In addition to including anticipated changes in climate, changes to the water demand due to population growth and build-out development are also simulated.

The second phase of the project includes the development of future water use projections, evaluation of the water budget, identification of water supply source and infrastructure vulnerabilities, and development of strategies to address these vulnerabilities through an adaptive management plan. Future development within the region and the associated water demand projections were evaluated based on predicted population growth and commercial and industrial development. A water budget was prepared for the region based on these demands. Current and future water uses and discharges from the watershed were evaluated 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 a Stakeholder Advisory Committee, identified key vulnerabilities in the region. The team will develop an adaptive management plan for the region that will provide utilities, developers, agriculture and industry with an understanding of the risks imposed by climate change. This plan will also serve as a guide for future investment and planning for water resource management.

1.2 Project Location

The Sustaining Scioto project area encompasses the Upper Scioto River basin from its headwaters in northern Ohio to just north of Circleville, in the south. A map of the area is shown in Figure 1-1. This 3,200 square mile watershed provides water to over two million people, encompasses 12 counties, and includes the Scioto River, Big Walnut Creek and the Olentangy River. The Upper Scioto River watershed also includes Griggs, O'Shaughnessy, Alum Creek, and Hoover Reservoirs and Delaware Lake. There are nine water treatment facilities drawing a total average flow of 170 million gallons per day (MGD) of surface water from the watershed. There are also 13 wastewater treatment facilities with a combined discharge flow of 190 MGD. The basin is primarily rural, with more development near the City of Delaware, the greater Columbus metro area, and small pockets of urbanization in cities such as Galion, Kenton, Marion, and Marysville.

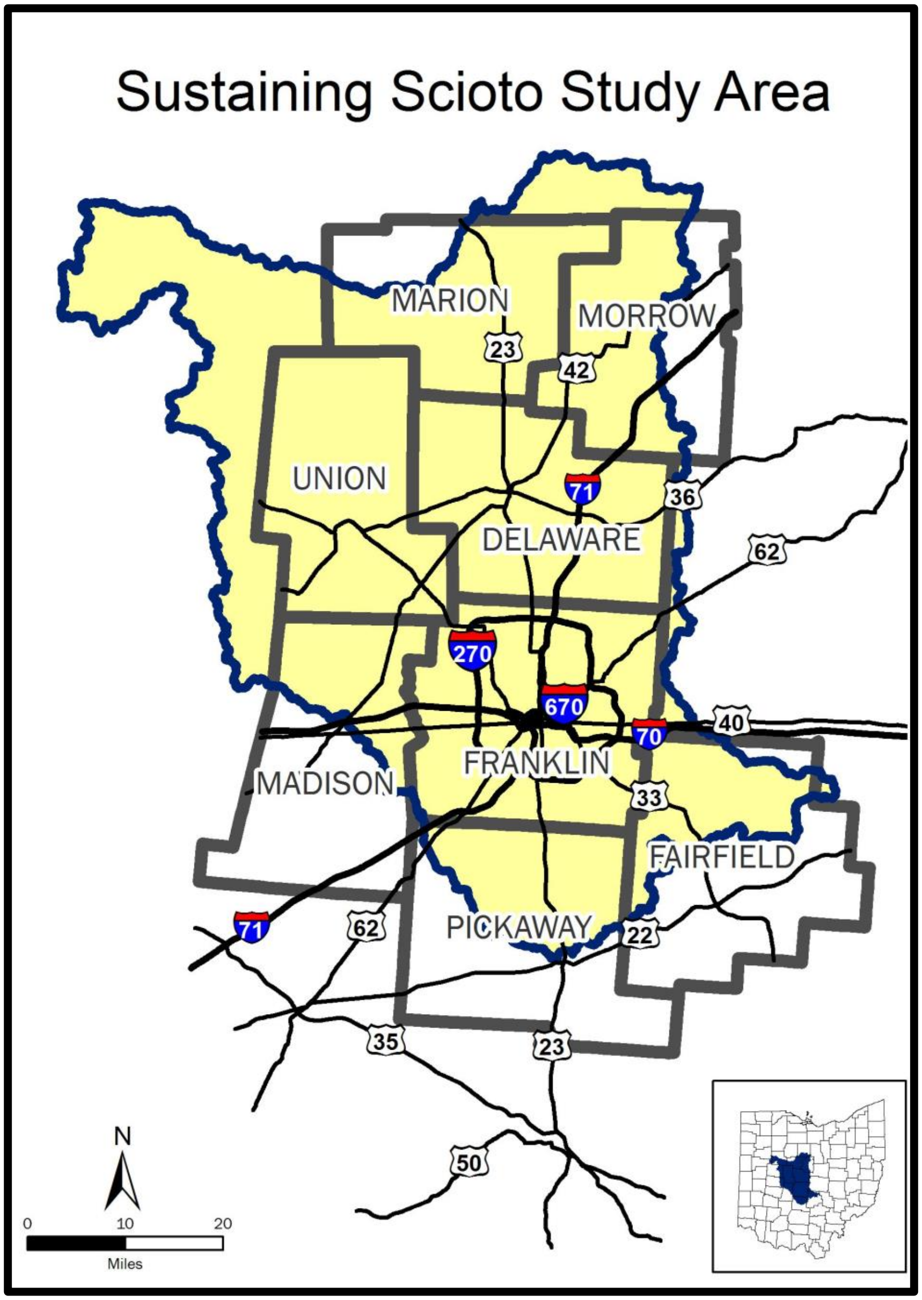


Figure 1 1. Map of the Sustaining Scioto Project Area

1.3 Purpose

The purpose of this technical memorandum is to explain the vulnerabilities identified within the region due to climate change. These vulnerabilities were identified based on an evaluation of the global climate model (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 based on the likelihood of occurrence and the severity of the impact.

The identification and prioritization of vulnerabilities, or risks, is essential for the development of an adaptive management plan for the region. This plan will be included in a subsequent technical memorandum. Adaptive management is a structured, flexible strategy for developing, evaluating, and making decisions. The basic approach to adaptive management is shown in Figure 1-2, and includes: understanding and prioritizing risks; developing strategies to reduce risks; implementing strategies; and re-evaluating strategies as more information becomes available. Adaptive management's flexibility and holistic approach makes it valuable in making decisions in an environment with a lot of uncertainty. It proves especially useful in the context of climate change planning because it is an iterative process. The strategy is periodically modified based on monitoring results and updated climate change projections. New strategies are developed and implemented based on new information and the iterative process continues.

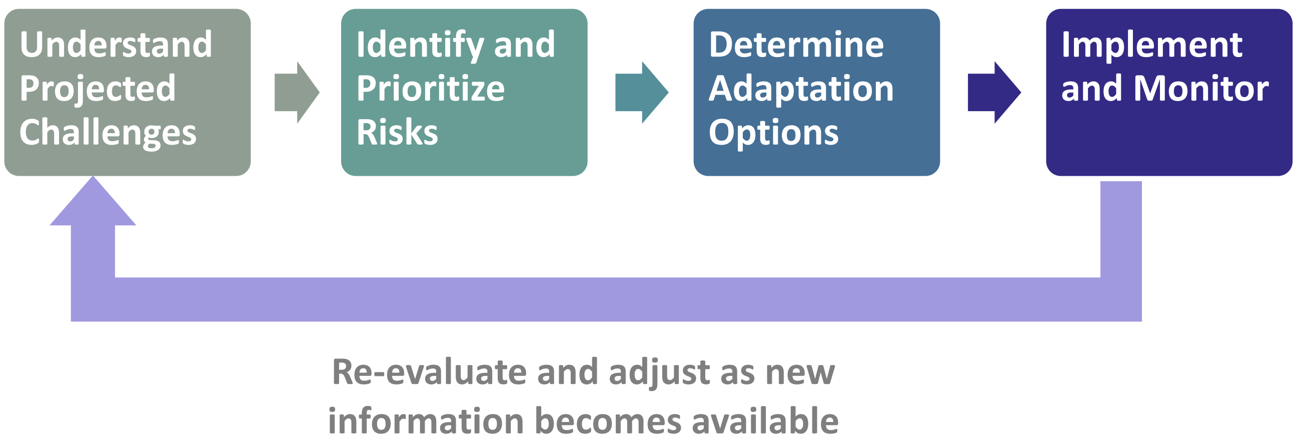


Figure 1-2. Overview of the Adaptive Management process

The first step in developing an adaptive management plan is the evaluation of the predicted regional changes and corresponding challenges. The USGS regional modeling results provide these changes as discussed in Section 2. These models incorporate climate in combination with other expected changes including population growth and land development.

The next step in developing an adaptive management plan is the identification and prioritization of vulnerabilities that arise from these challenges which may impact the livability of the region. The potential vulnerabilities were identified and prioritized based on the climate and watershed modeling results, literature review from sources such as USEPA and US National Climate Change Assessment, and input from regional Stakeholders representing the key service sectors. Section 3 includes a description of the prioritization methodology and the resulting prioritized vulnerabilities.

Section 2: Projected Regional Challenges

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 methods and results are presented in the Hydrological Effects of Potential Changes in Climate, Water Use, and Land Cover in the Upper Scioto River Basin, Ohio (USGS, 2014).

2.1 USGS Model Development

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 in the Upper Scioto watershed (USGS, 2014). The HSPF watershed model simulates the complex river-basin management and reservoir operations within this watershed including operation of the numerous regulated reservoirs. The HSPF watershed model was developed by: creating a conceptual model to represent the surface water flow within the basin; dividing the basin into smaller watersheds (sub-watersheds); compiling and processing input data and selecting initial model boundaries; calibrating (adjusting) the model based on historical observed climate data, water uses, and hydrologic responses; and comparing the performance of the calibrated model against historical observations of stream flow not used for calibration purposes.

The HSPF watershed model was used to simulate two future conditions scenarios of water supply and flow conditions in the Upper Scioto River 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 “build-out”, incorporates future population growth and development driven changes in land cover and water use in addition to the changes in climate and reservoir operations.

2.2 Model Data

Multiple data types were necessary to provide input to the HSPF model. Historical and projected climate data was necessary to model the possible changes in climate out to the year 2090. Water use and land development data were developed to model the potential changes in water use in the region based on development in accordance with current zoning and plans. This section details the types of data used in the development of the USGS model.

2.2.1 Climate Data

Two types of climate data, historical and future with predicted changes, were used to develop the 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 was provided by four data sets from the GCM (Source: World Climate Research Programme’s Coupled Model Intercomparision Project phase 3 multi-model dataset). Each of the data sets has a high emission scenario and a medium emission scenario based on projected carbon emissions, so there are eight total data sets used to develop predicted future conditions model outputs due to climate change.

2.2.2 Water-Use Data

Water-use data for the model were obtained in the form of monthly surface-water withdrawals, return flows, and future changes in selected water uses. 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. In all, water-withdrawal data for 60 unique withdrawals were used in the HSPF watershed model. Data on return flows were obtained from two sources, the ODNR WWFRP and the National Pollutant Discharge Elimination System (NPDES) permit. Only data for wastewater treatment facilities designated as major facilities (design flow of 1 MGD or greater or facilities with Environmental Protection Agency (EPA) /State approved industrial pretreatment programs) were considered. In total, return-flow information was obtained for 38 unique entities.

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

Brown and Caldwell, with input from MORPC and several municipalities, provided current (1990 to 2010), as well as estimated 2035 and 2090 withdrawals and return flows for major facilities, including those serving the cities of Canal Winchester, Columbus, Delaware, Galion, Kenton, Marion, Marysville, and Delaware, Fairfield, and Marion counties. A complete description of the development of the future water demand projections is provided in the technical memorandum titled “Upper Scioto River Watershed, Water Use Projections” (Brown and Caldwell 2014).

2.2.3 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 sub-watersheds. 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 (NLCD) (Fry et al, 2011) was used as the basis for determining land cover for the calibration period of 1989 to 2010.

Predicted future changes in land-use for the years 2035 to 2090 was provided by MORPC. MORPC created this 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 was computed to reflect the future development conditions for the target dates of 2035, 2055, and 2075. 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 showing the development of agricultural land to urban cover.

2.3 Methods of Analysis

The USGS modeled two different scenarios; climate-only and build-out. The results for these scenarios were analyzed over different time periods to determine anticipated maximum and minimum stream flow and reservoir water levels.

The climate-only simulation results reflect the anticipated changes in stream flows and water levels due to predicted changes in temperature and precipitation and the anticipated operations of the three City of Columbus upground reservoirs.

The build-out simulation results reflect the anticipated changes in stream flows and water levels associated with predicted changes in land-use, population and water/wastewater use, as well as with climatic changes and operation of the upground reservoirs. The effects of build-out on stream flow within the watershed at any given point in the study area can be cumulative. For example, even though a particular sub-watershed may be expected to remain relatively unchanged with respect to its land-cover and/or water-use characteristics in the future, changes in the upstream contributing drainage area could result in appreciable changes to stream flows in the downstream sub-watershed.

Results from both scenarios were analyzed to evaluate climate-driven changes in annual and seasonal stream flow and reservoir water level characteristics as well as maximum and minimum 7-, 30-, and 180-day average stream flow and reservoir water levels. Results from the build-out simulations were compared with the climate-only simulations to analyze the effects of development on the average stream flows and reservoir water levels.

For both the climate-only and build-out scenarios, seasonal analyses were completed to provide information on potential season specific changes in stream flow and water level conditions. These results were computed based only on daily-mean values. Three seasons were defined based on temperature changes as listed in Table 2-1. No seasonal analyses were conducted for 180-day average stream flows because the duration of the seasons are less than 180 days.

Table 2-1. Upper Scioto River Basin Basis for Seasonal Analysis

Season	Months
Spring	March through May
Summer	June through October
Fall / Winter	November through February

For both climate-only and build-out scenarios, stream flow and water level was evaluated at specific locations in the Upper Scioto River system, including the five reservoirs in the project area and 13 stream sites. A list of these sites and their location is included in Table 2-2. These locations were selected to provide information at key locations within the watershed including: headwaters; confluence of streams; reservoirs; major water withdrawals and discharges; and major waterways.

Table 2-2. Upper Scioto River Basin Site Analysis Locations

Site Name	Location Description	Site Type
AFRI	Alum Creek at Africa	Stream
ALUM	Alum Creek Lake	Reservoir
CBUS	Scioto River at Columbus	Stream
CCOL	Big Walnut Creek at Central College	Stream
CIRC	Scioto River at Circleville	Stream
DELA	Olentangy River near Delaware	Stream
DELL	Delaware Lake	Reservoir
DLCO	Olentangy River at Del-Co intake	Stream
DUBL	Columbus City Public Water Supply (PWS) – Dublin Road Plant intake	Stream
GALI	Olentangy River Galion PWS Reach	Stream
GRIG	Griggs Reservoir	Reservoir
HOOV	Hoover Reservoir	Reservoir
MARI	Little Scioto Reach with Marion PWS	Stream
MARY	Mill Creek Marysville Reach	Stream
OLEN	Olentangy River at mouth	Stream
OSHY	O'Shaughnessy Reservoir	Reservoir
PROS	Scioto River at Prospect	Stream

The simulations for both climate-only and build-out scenarios were divided into two groups: one group based on GCM-emission scenario outputs for the medium emission models and the second group based on outputs for the higher emission model. The median results for both medium and high emission scenarios were computed separately from the results of each individual GCM model for each year.

2.4 Model Results

Results were analyzed from two different model outputs to assess the potential impacts of climate change on the watershed. The climate model results from the GCM were compared to historical climate data for the region to assess the potential changes in temperature and precipitation. The USGS model results provided stream flow and reservoir levels based on the modeled future conditions and were compared to historical values for each location.

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 modeling exercise is to determine the range of possibilities to allow the identification of potential vulnerabilities within the watershed. The model results included in this report should be considered as potential future conditions based on current climate projections if no action were taken, not as statements of definite future conditions.

This section contains a summary of the results from both the climate and the USGS model.

2.4.1 Climate Model Results

The annual average precipitation model results are shown in Figure 2-1 for high emission scenarios and in Figure 2-2 for medium emission scenarios. 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 2014). Six of the climate models predict higher annual average precipitation in the future, while two of the models predict less future precipitation (Brown and Caldwell 2014).

The predicted annual average temperature for the high emission models and the medium emission models are shown on Figures 2-3 and 2-4, respectively. The calibration period is shown at the beginning of the figures for reference. All of the climate models predict a substantial increase in the future annual average temperature.

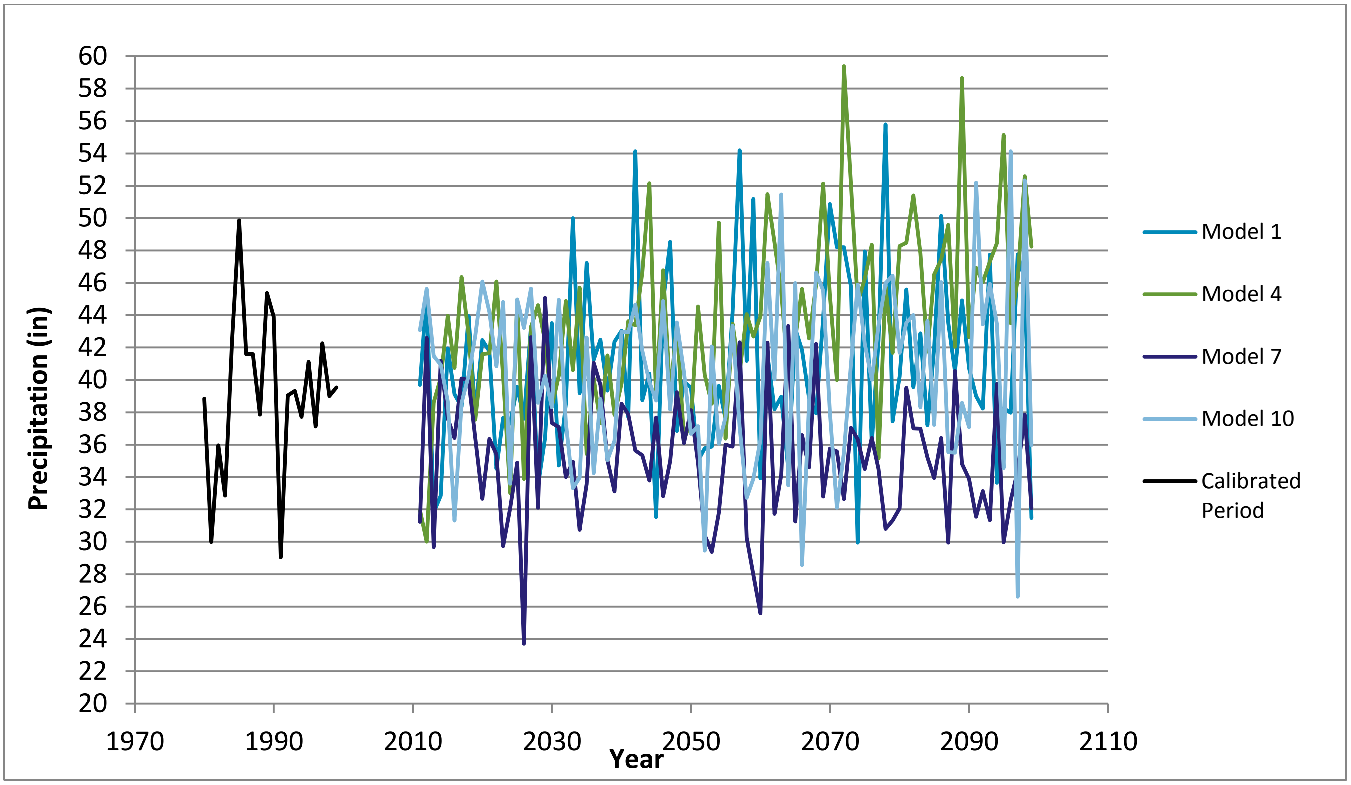


Figure 2-1 Climate model annual average precipitation for high emission scenarios

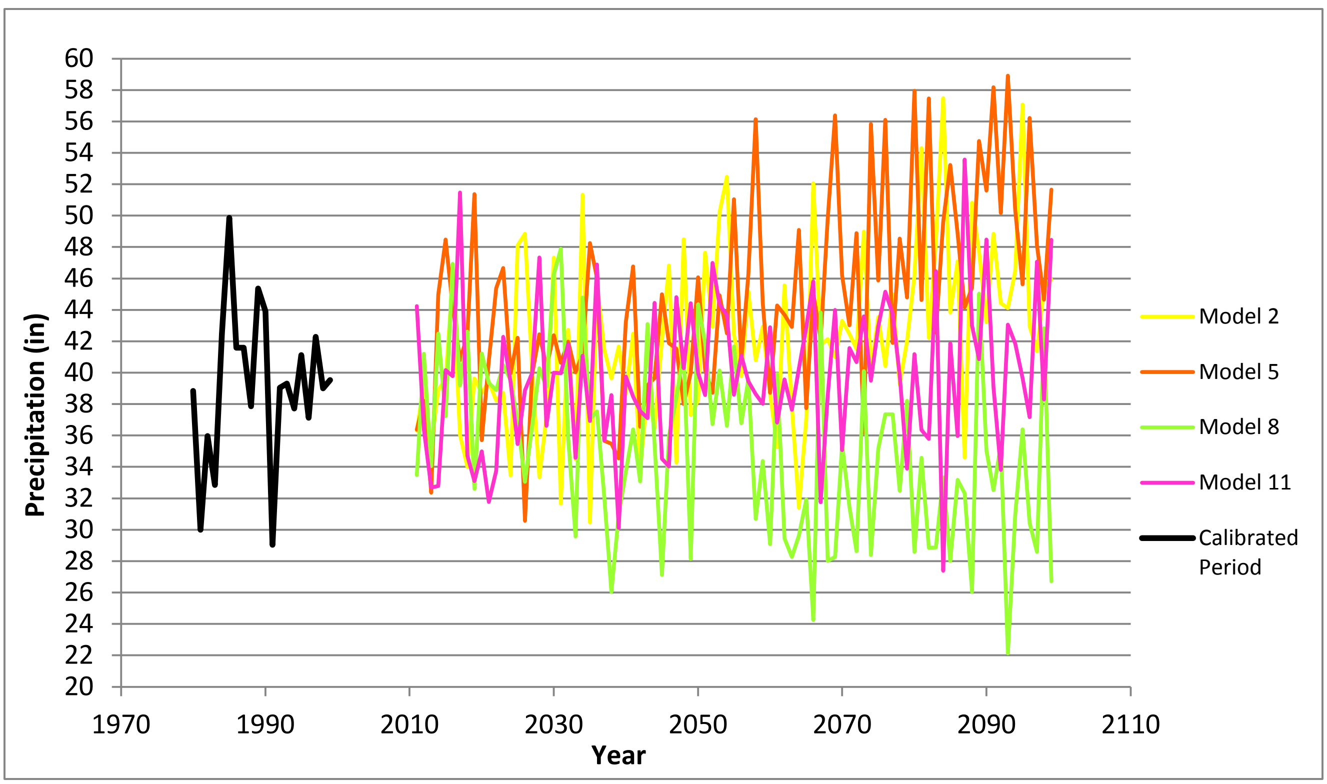


Figure 2-2 Climate model annual average precipitation for medium emission scenarios

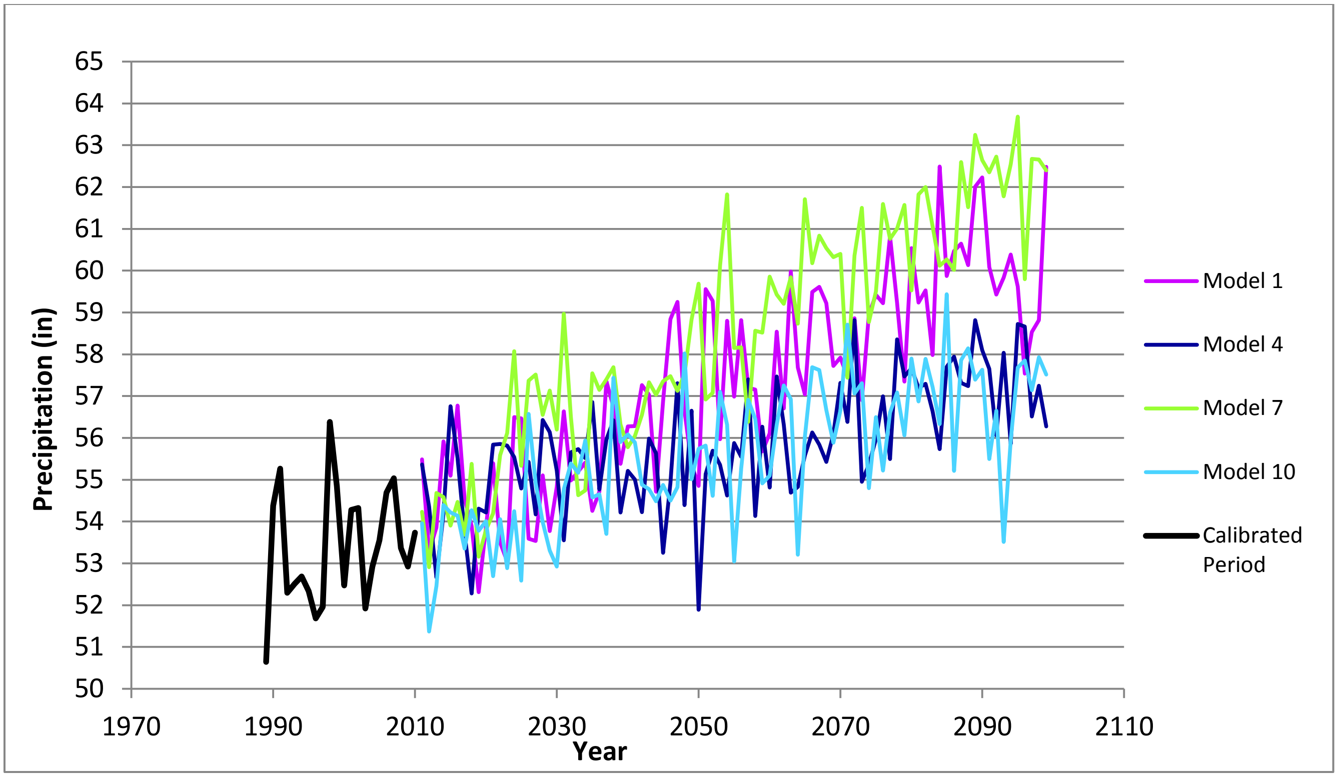


Figure 2-3. Climate model annual average temperature for high emission scenarios

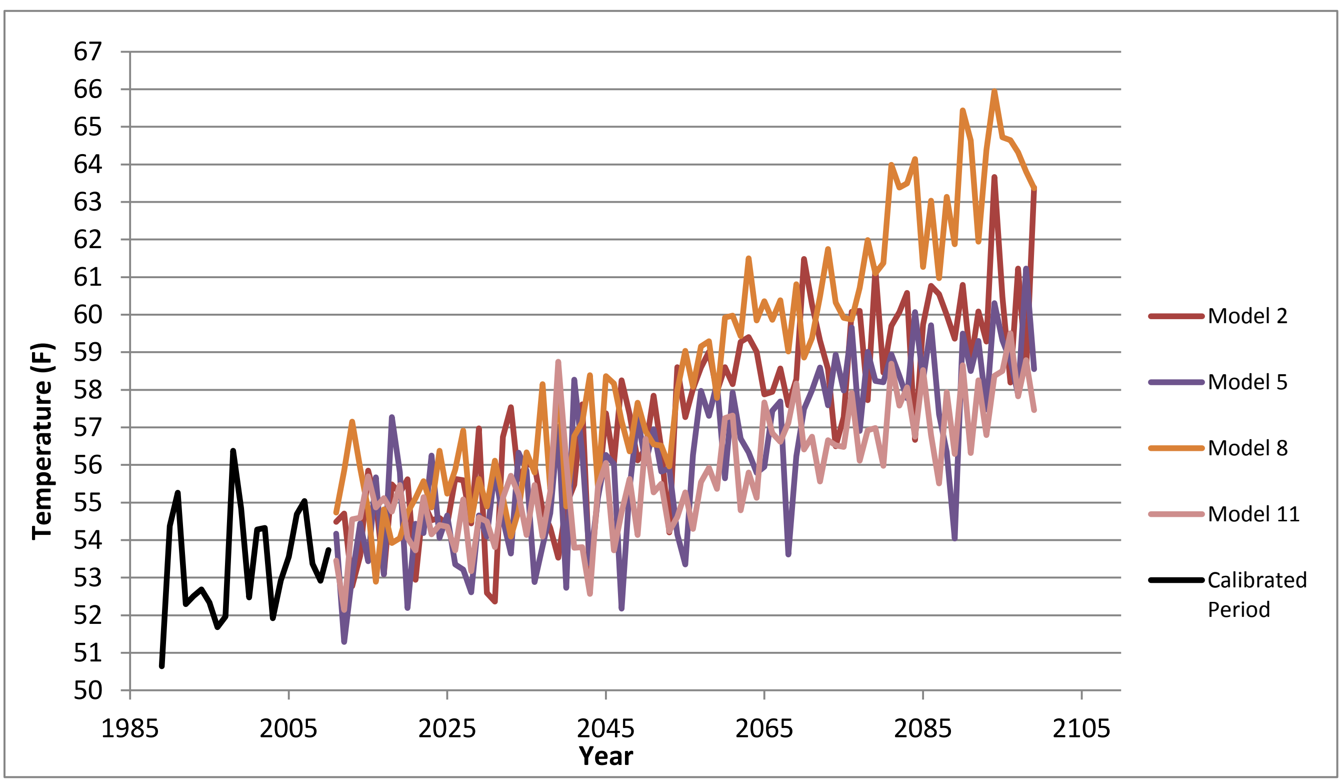


Figure 2-4. Climate model annual average temperature for medium emission scenarios

2.4.2 USGS Model Results

This section contains discussion of general trends as well as site-specific differences reflected in the model results. Graphical plots were prepared by USGS for the seasonal analysis of the average 7- and 30-day minimum and maximum stream flows and reservoir water levels for both climate-only and build-out scenari-os. A subset of the total stream and reservoir sites are discussed in this section. The following stream sites were selected to provide an overview of projected changes throughout the Upper Scioto River Watershed:

- Little Scioto Reach with Marion PWS (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 2-5.

The model output for each of these scenarios was a set of daily means based on predicted future climate change from the GCM – four high and four medium emission data sets. Examples of these scenarios are shown in Figures 2-6, 2-7, and 2-8. In the figures high emission scenarios are labeled as A2 and medium emission are labeled as A1b. The daily means for each of these data sets are shown as the thin multi-colored lines on Figure 2-6 to show the range of variability. To simplify the data presented and make it easier to observe trends, the median value was calculated and illustrated as one line for high and medium emis-sion for all remaining figures. The bold lines on Figure 2-6 correspond to these median values.

Figure 2-7 and 2-8 show the median results for both the climate-only and build-out scenario, respectively, for both emission scenarios (A1b and A2) were computed separately from the ensemble of simulation results. In both figures, the dashed pink line corresponds to the scenario results for the calibration period. In both figures, the dashed pink line corresponds to the simulation results for the calibration period (1989 to 2010). The red lines and symbols in both figures correspond to results based on GCM outputs for the medium emission scenarios, while the blue lines and symbols correspond to the results of higher emission outputs. In both figures, the solid red and blue lines represent the medians of the four model simulation values. For the reservoir plots, additional reference elevation lines have been added to reflect the storage capacity of the reservoir which is associated with that specific elevation.

In Figure 2-8, the build-out results, the dashed red and blue lines represent the maximum and minimum values of the climate-only simulation models, providing a sense of the breadth of the model results and the highs and lows that are being summarized into the two median value lines. The red and blue triangles represent the medians of the build-out simulation results for years associated with the target dates of 2035, 2055, and 2075. When reviewing the build-out results, it is important to note that for several municipalities (most significantly Marysville) future water use plans include increased use of groundwater rather than surface water for supply purposes. This groundwater supplied drinking water is then discharged into the river as wastewater, leading to a significant net increase in stream flow in these areas.

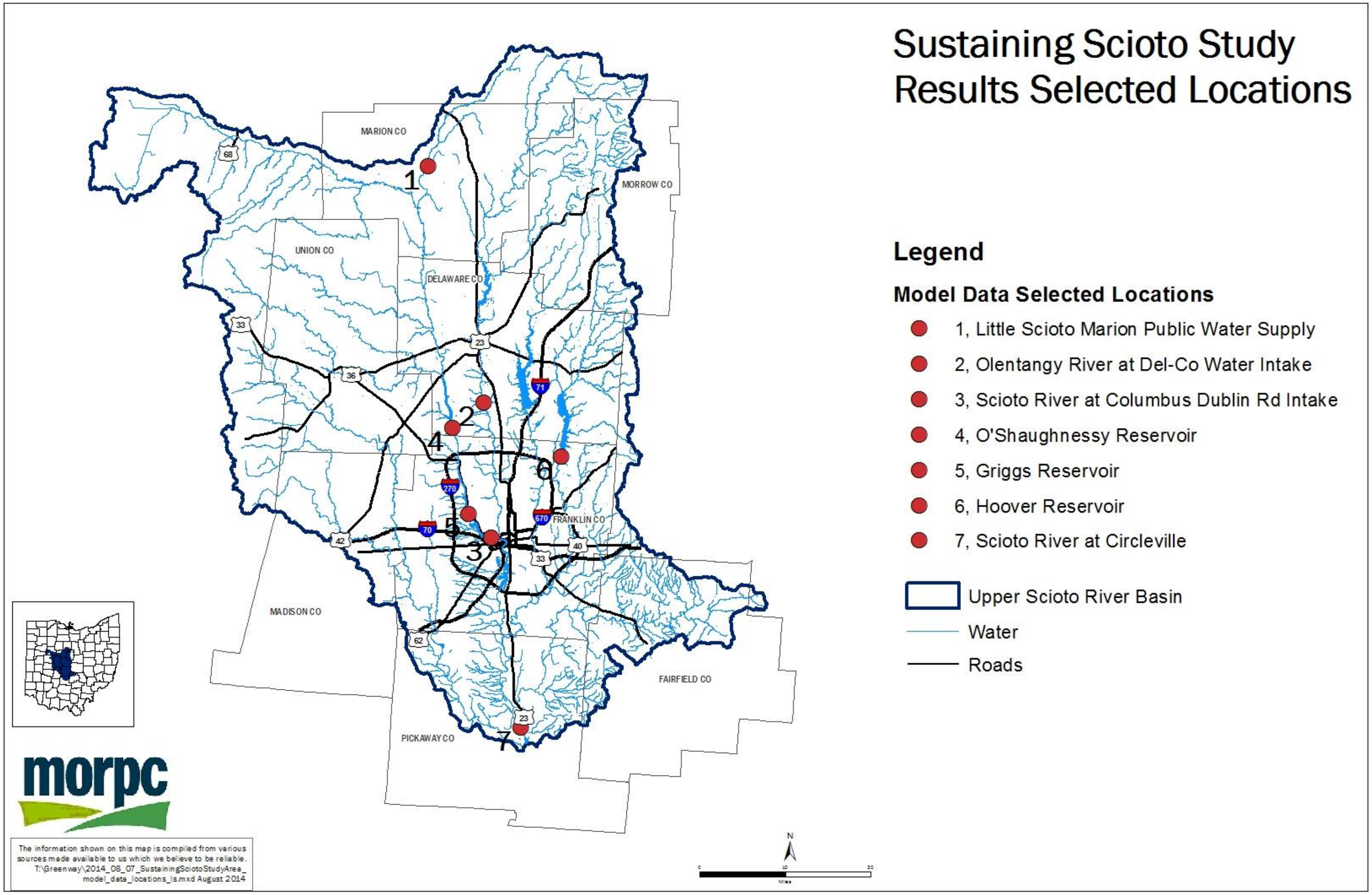


Figure 2 5. Sustaining Scioto Study model results for selected locations

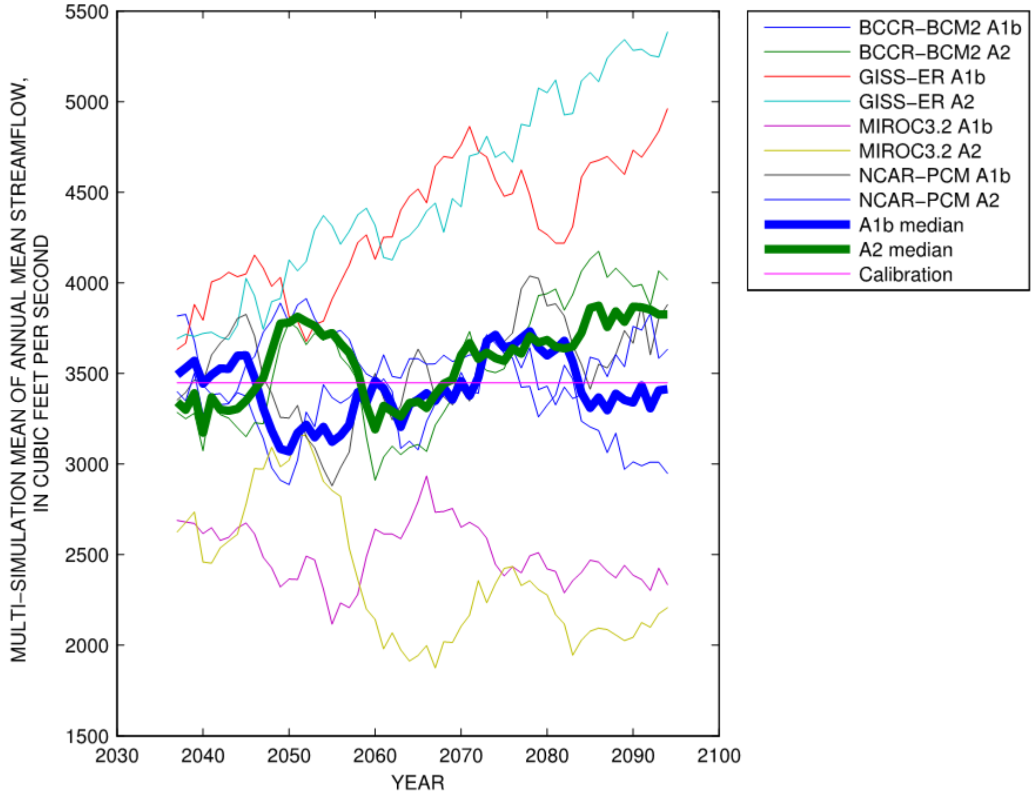


Figure 2 6. Example graph for daily means for all emissions scenarios

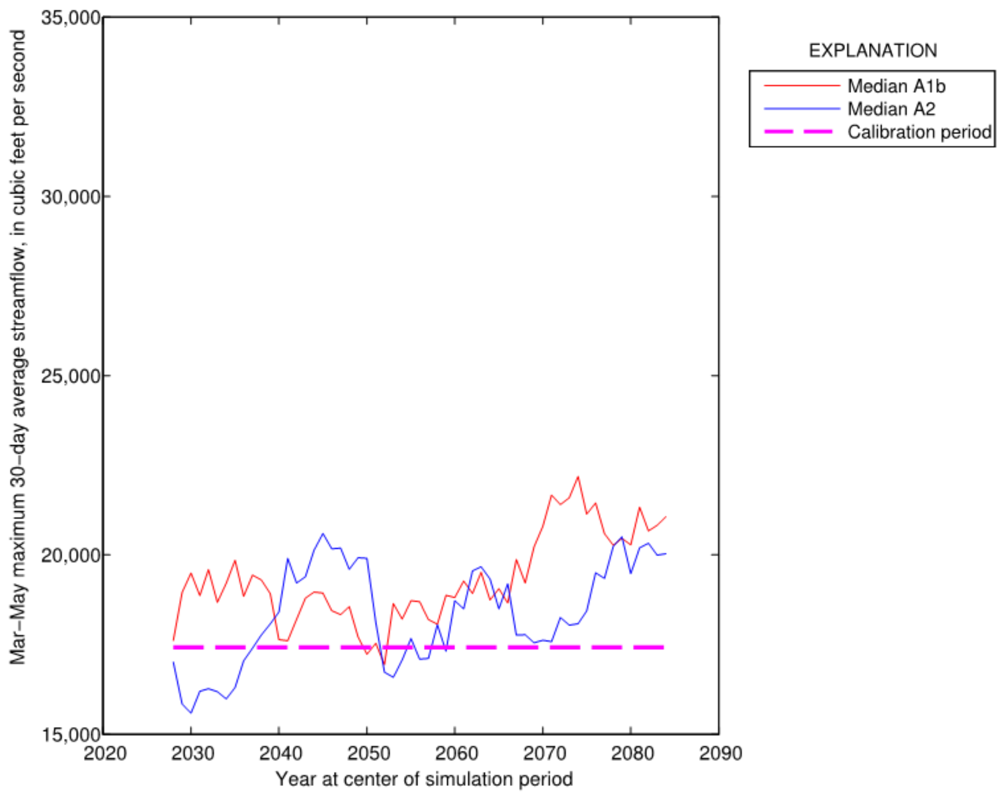


Figure 2-7. Example graph for climate-only median results

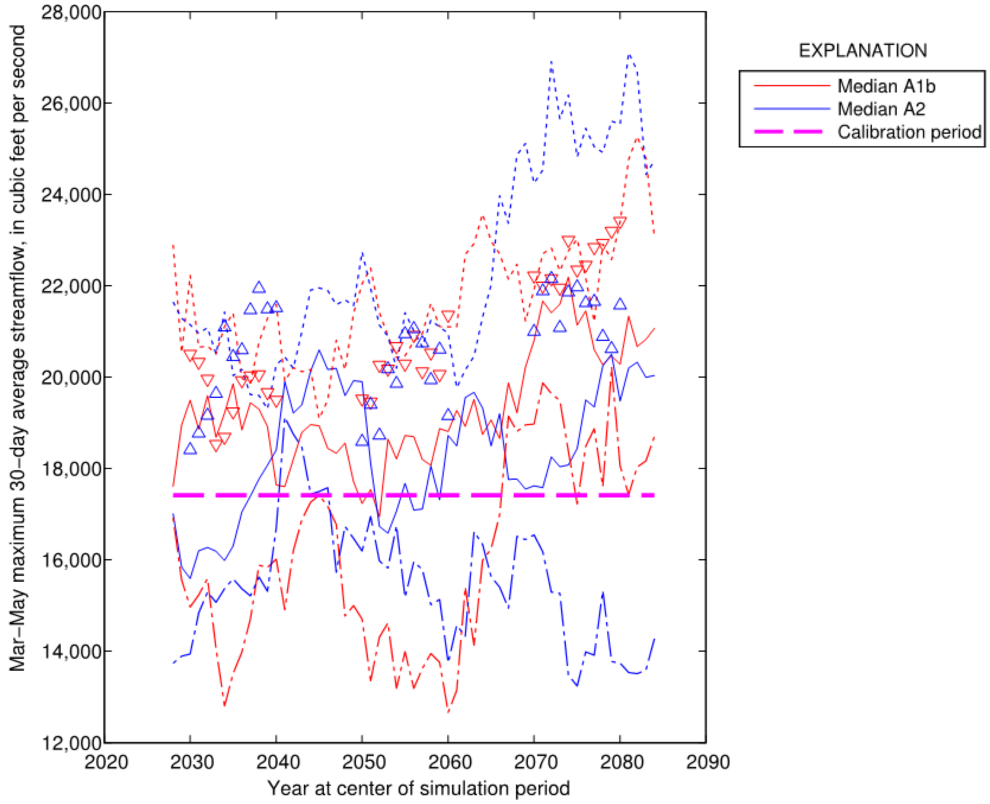


Figure 2-8 Example graph for build-out median results

While the simulation trends are summarized in this section, the graphical plots for each of the four stream and three reservoir sites are included in Attachment A, *Predicted Average Stream Flows and Water Levels.* These graphical plots include average 7- and 30-day minimum and maximum stream flows or water levels for spring, summer and fall/winter. Both climate-only and build-out scenarios are represented.

Throughout this section, the model results are compared to the average of the calibration period of 1989 to 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 levels, especially on the 7-day or weekly basis and also lower minimum flows, especially on the 30-day or monthly basis. This type of result suggests a trend to longer periods with low flow and also more extreme high flow events. The increase of high flow events in the spring with increased droughts in the summer are consistent with the predicted climate changes for the Midwest presented in both the Adaptation Strategies Guide for Water Utilities (USEPA 2012) and Climate Change Impacts in the United States (Melillo 2014).

In the spring and summer, greater than average flows were reflected in the results with higher peak maximum flows over both weekly and monthly periods. During this same seasonal period, the model indicated that there would be decreased minimum flows over both weekly and monthly periods, suggesting more extended drier periods of time. The more extreme and more variable flow rates are consistent with the predicted increased variability of precipitation and increased air temperature data used during the development of the model. The impact of development varied depending on the location of the site as build-out could increase flows related to increased runoff and also to increased wastewater generation, but could also result in lower flows and reservoir levels due to increased water usage.

Trends specific to the observed subset of sites are described below.

The Little Scioto Reach with 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 due to the relatively small drainage area. In the spring climate-only simulations, the models predict lower minimum flows than the calibration period, 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 more variability in the flow than is currently typical for this location. During the summer climate-only simulations, higher maximum flows and slightly lower minimum flows were again projected. During the fall/winter, higher maximum flows are projected, while the minimum flow remains close to that of the calibration period. The build-out simulations for this site clearly reflect the impact of increased runoff and increased discharge of wastewater associated with development at this headwater location. The build-out models reflect somewhat higher maximum and minimum flows throughout each season.

The Olentangy River at the Del-Co intake is located slightly north of center in the Upper Scioto River watershed, near the intake for the Del-Co upground water reservoirs and plant. There is a minimum flow requirement at this site of 35 cubic feet per second (cfs), limiting pumping to the Del-Co reservoirs when flow is below 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 seasons. 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 the water company as this is a time period when the reservoirs are typically being recharged. During the summer time period, low flows in the river are already below this cut-off level and the company is unable to recharge its reservoirs and must use reservoir storage during the summer season to meet water demand. In the build-out scenarios, the models indicate minimum flows during spring and summer may drop to zero cfs with the added demand for water at this location. These simulations indicate that with projected changes in stream flow reliability associated with climate change and also with the increased water usage, additional reservoir storage may be needed to maintain adequate 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 flows were reflected in the spring climate-only simulations while slightly higher maximum flows were reflected in both weekly and monthly means for the summer season. During the fall/winter season both higher 7-day maximum flows and lower 30-day and 7-day minimum flow are predicted. This indicates a trend toward increased periods of dry weather with more short period high flow events (storms). Build-out does not have as significant an impact at this location. The build-out model results indicate somewhat higher minimum flows for 30-day means and slightly higher maximum flows for the 7-day periods for all seasons. This is likely attributable to the increased runoff due to development in the watershed.

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 flows, especially during the shorter duration periods (7-day mean) while also lower minimum flows (both 30-day and 7-day). The simulations with build-out development reflect increased monthly and weekly mean low flows in all seasons, most likely due to increased runoff and increased generation of wastewater as compared to use of drinking water.

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 Hap Cremean Water Plant for the City of Columbus. When the reservoir level drops below 80% 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, Hoover Reservoir elevations are not significantly different from the calibration period. However with full build-out development in year 2075, minimum water levels in the reservoir drop to or close to zero percent capacity (El 840) during all seasons. These extremely low water levels are projected for both 30-day and 7-day means, indicating that additional storage or supply may be needed to meet the projected future demand at the Hap Cremean plant.

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

At O'Shaughnessy Reservoir, the climate-only simulations indicate slightly lower minimum water levels during both spring and summer. With build-out 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 trends at the downstream Griggs Reservoir are very similar to those at O'Shaughnessy Reservoir.

Section 3: Vulnerabilities Assessment

The trends and conditions shown in the model simulations, as well as the predicted changes in temperature, precipitation, water use, and build-out data that were used to develop the model, can all impact the region. In this section the potential impacts of these predicted changes are summarized.

3.1 Predicted Changes

These predicted changes pose challenges and risks to the region, as summarized in Table 3-1. These changes were developed by analyzing the predicted data and model simulations as well as performing a review of mid-western specific climate change literature (USEPA 2012; (Melillo 2014). The changes were then refined in stakeholder meetings with representatives from the planning commissions and key service sectors including the Ohio EPA, ODNR, water and wastewater utilities, public health, agriculture, and environmental advocacy groups.

Table 3-1. Summary of Predicted Changes Reflected in Climate and Watershed Model Results

Vulnerability Scenarios	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 forest / plant species composition	●	●	
Both 30 and 7 day higher peak maximum flows		●	●
Decreased minimum flow over month (30 day) and more extended drier periods of time / Increased occurrence of summer drought	●	●	●
Increased intensity of extreme rain and wind events	●	●	●

3.2 Prioritization of Vulnerabilities

Once these predicted changes were identified, the technical panel and stakeholder group worked together to identify key vulnerabilities by service sector. The sectors considered include:

- Water Supply/Water Quality
- Water Treatment
- Wastewater Treatment
- Public Health
- Agriculture
- Environment
- Economy
- Energy
- Transportation

This section contains a discussion of the most significant risks posed by these predicted changes with an emphasis on surface water quality and water and wastewater treatment. The risks were prioritized based on likelihood and impact, with the most significant risks being both likely to occur and having a significant impact if they were to occur.

Scores were assigned to both likelihood and impact of occurrence to develop overall prioritization scores. For likelihood of occurrence the predicted changes were given a score of high, medium, or low based on the potential to occur. The specific risks were then assigned a score of high, medium, or low based on the expected impact on the region.

The scores assigned to the predicted changes are summarized in Table 3-2. Those ranked as highly likely to occur were linked to refined 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 changes were assigned a score of “High” and shaded red in Table 3-2. 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 build-out or trends in precipitation. A “Low” score was assigned changes which were not directly predicted by the model results and were considered less likely to occur based on the analysis. Low risk changes are shaded green in Table 3-2.

Table 3-2. Summary of Prioritized Predicated 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

Once the predicted changes were scored based on likelihood of occurrence, the individual risks were scored based on their potential impact on the region. The risks were categorized similar to the vulnerability scenarios with “High”, “Medium”, and “Low” designations. The impact classifications are detailed in Table 3-3.

Table 3-3. 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

The results of the predicted changes and risk prioritization are shown in Table 3-4. “High”, “Medium”, and “Low” designations are indicated by the colors red, yellow, and green respectively.

Table 3-4. 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 Increased water demand and demand due to irrigation Increased in-stream TOC Increased nutrient/ pesticide / herbicide runoff due to extended growing season, increased algal blooms Increased watershed erosion	Negatively affects water quality Increased capital investment due to designing for peaking factors Taste and odor concerns, potential for algal toxins Increased chlorine demand, Increase DBPs	Impacts to infrastructure (increased corrosion) Lower flow affects discharge permits and treatment Increase need for odor control	Vector Diseases Increased issues for asthma and allergies Impacts to human mortality, Increase in heat illnesses and stresses on healthcare	Vegetation / Animal species shift Negative impact on livestock health / mortality Extended/disruptions to growing season Increased use of herbi-cides/pesticides/ nutrients with longer growing season Increased need for irrigation and controlled drainage	Vegetation / Animal species shift Increased smog / Decreased air quality	Extended recreational season Increased costs for utility services (water, wastewater, and energy) Increased service cost for food Decreased human productivity	Increased energy demand due to air conditioning, increased use of pumps for water / wastewater Decreased efficiency throughout production as temperature rises Increased power disruptions (brownouts)	Increase in road and bridge repairs and disruptions due to heat stress Increased use of private vehicles Change in construction materials for higher temperatures Extended but less efficient construction season
Increased water temperature	Decreased dissolved oxygen Increased release of phosphorus and other pollutants from anoxic zones/sediment Decreased mixing Longer duration of poorer water quality Increased algal blooms including blue greens (potential for increased toxin release)	Taste and odor concerns, potential for algal toxins Increased treatment costs due to algae and poten-tially algal toxins Increased treatment efficiency	Lower DO / changes in temp require affect wastewater discharge allocation Decreased organics at plant due to DBPs	Increase in waterborne diseases Increased use of disinfectants; increased DBPs	Increased costs to control water quality from fields Treatment and disinfection use increases Energy use for cooling Livestock management and aquaculture	Changes in pH and pollutant toxicity Negative impact on aquatic life diversity and numbers Decreased dissolved oxygen Increase in algal blooms	Algae growth could impact recreational use Increased energy cost due to power plant discharge cooling	Lack of cooling water could reduce energy production	Limited applicability
Warmer soil temperatures / Decreased soil moisture	Decreased groundwater base flow to streams Reduction/change in vegetative cover Increased watershed erosion Increased in-stream TOC Increased sediment deposition/loss of volume	Increased treatment demands due to lower water WQ Change of frequency in water main breaks in winter	Increased use of effluent sludge on farm fields	Impacts to private water systems	Increased need for irrigation and controlled drainage Vegetation / Animal species shift Increased soil conservation practices Increased need for crop insurance	Vegetation / Animal species shift Increased erosion Increase in invasive species	Negative impact on winter recreational activities if less snow/ice Higher food prices and potential job losses if results in loss of agricultural crops	Increased albedo; greater urban heat island effect leads to increased cooling demands	Reduced salt usage in winter Embankment erosion and damage due dry soils

Table 3-4. 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 winter temperature and reduced ice cover	Increased water temperature Declining water levels due to increased evaporation in winter Earlier spring turnover Longer duration of poorer water quality	Reduced chance of frozen water lines and breaks in winter	Extended season for I/I Warmer water easier to treat Extended season for odor control	Fewer snow/ice related injuries Increase in vector diseases	Increased pests and invasive species Damage to crops that use snow as cover Increased growing season which increases use of nutrients and potential for erosion	Vegetation / Animal species shift Shift in growing seasons Increased evaporation	Increased transportation / navigation season Reduce road salt usage Reduction in winter recreational activities	Lower heating costs	Extended transportation season Reduced use of road salts / snow clearing
Change in vegetation / animal species composition	Reduction/change in vegetative cover which causes loss of stream bank shading and increased water temperature Increased watershed erosion Increased sediment deposition/loss of volume Increased in-stream TOC 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 TOC, 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 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

Table 3-4. 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 supply management challenges related to greater variability in stream flow								
Extended dry periods / summer drought (Decreased minimum 30 day stream flow)	Decreased reservoir flow/volume and reduced mixing Decreased groundwater flow to streams Increased water demand Increased algal blooms, including blue greens (potential for increased toxin release) Reduction/change in vegetative cover Reduced reliability of yield from supply sources	Taste and odor concerns, potential for algal toxins, Increased treatment cost for algae and potential algal toxins Reduced groundwater supply/ recharge Reduced WQ and dilution of non-point source discharges	Lower flow affects discharge permits and treatment Reduced infiltration into sewers resulting in increased H_2S production Stresses on plants in LID such as rain gardens	Reduction in some vector diseases Increased allergens and dust Impacts to PWS	Lowered crop production Increased demand for irrigation but decreased water availability Vegetation/ animal shifts toward species better adapted to drought conditions	Vegetation / Animal species shift toward those better adapted to drought conditions Negative impact on aquatic life diversity and numbers	Decreased recreation Increased industrial treatment costs Low flow could affect transportation navigation through water Increased food cost due to decreased agricultural production (crop loss)	Increased energy for WWTP requirements Increased pumping costs for water supply	Shipping Impacts
Increased intensity of rain and wind events	Increased in-stream TOC, nutrients, turbidity, and sediment and other pollutant loads Increased watershed and stream bank erosion Increased algal blooms, including blue greens (Potential for increased toxin release) Increased sediment deposition/ loss of volume	Reduced treatment capacity due to higher turbidity Damage to Infrastructure / Infrastructure failure including power outages, flooding and intake damages	Increased CSO/SSO discharges Flooding can create solid disposal issues/treatment Increased cost to treat Increased I/I to WWTPs Damage to Infrastructure/ Infrastructure failure including power outages and flooding	Loss of electrical/ water / sanitation services during and after event Increased demand on public health services Restricted access to critical care Septic System Failures Disaster related injuries / mortalities	Crop losses Soil erosion Need additional land set aside for increased flood zones	Soil / Channel Erosion Impacts from flood mitigation structures such as flood walls and increased flood zones Negative impact on aquatic life diversity and numbers	Increased insurance costs; increased damages due to floods/storms Could affect recreational use Increased snow: Expensive to remove	Increased vulnerability of power supply system Increased investment in resilient infrastructure	Infrastructure access Infrastructure damage / failure Inability to transport food and water in critical situations Increased snow: changing fleet needs Increased snow: Increased road deterioration

3.3 Vulnerabilities Discussion

This section contains a discussion of each of the high priority vulnerabilities identified in Table 3-3 as having a major impact on the livability within the region.

3.3.1 Increased Summer Air Temperature / Increased Incidence of Heat Waves

The predicted climate data indicates the region will experience increased air temperatures throughout the year especially during the summer months. The following high priority regional vulnerabilities due to increased air temperature are listed below.

Affected Service Sector	High Priority Risks
Water Supply / Water Quality	Increased evaporation and reduced water volumes
	Increased water demand – Public water supply and Irrigation
	Increased nutrient runoff, potential toxicity from algal blooms
Water Treatment	Increased incidence of taste and odor issues
Public Health	Increase in waterborne diseases
	Impacts to human mortality; increases in heat illnesses and increased stress on healthcare
	Impacts to health due to poor air quality from increased emissions
Agriculture	Increased need for irrigation / controlled drainage
	Impacts to livestock health/mortality
Economy	Increased energy costs

Increased evaporation and evapotranspiration from increased air temperatures can create several serious risks related to water supply / quality and treatment. These risks can lead to water supply shortages from declines in dry weather base flow in area creeks due to lower groundwater discharges. Increased evaporation and evapotranspiration will also decrease the total volume of water flowing in area creeks and discharging into reservoirs. These reduced stream flows have the potential to create water supply issues due to **increased demands for water** both for public use and for irrigation.

Lower groundwater discharges from creeks and evaporation from the reservoir surface will reduce the total water volume inputs and may concentrate water quality constituents including nitrogen, phosphorus, and organic carbon. If nutrient concentrations increase, concentrations of algae, commonly measured as chlorophyll, will also increase resulting in **lower overall water quality** and loss of aesthetic and recreational value. Raw water with higher pollutant concentrations is more difficult and costly to treat.

Reduced vegetative cover in watersheds, streams, and riparian corridors will be caused by a combination of higher temperatures, increased evaporation and evapotranspiration, higher soil temperatures, lower dry weather base flows, and periods of lower rainfall. Loss of vegetation in stream corridors and the watershed would increase overland and stream bank erosion during rain events increasing the production and **release of a variety of pollutants into the surface water** system including nitrogen, phosphorus, organic carbon, turbidity, and sediment. This will increase in-stream pollutant concentrations as well as reservoir concentrations and total loads. Sediment will accumulate in certain segments of the creeks (larger cross sectional areas and lower velocities) and at the reservoir inflows. Sediment accumulation in the reservoirs reduces the available water storage capacity and is expensive to remove.

Increased pollutant loads and water temperatures will generally degrade water quality and depending on the nutrient contribution may also increase the frequency and severity of algal blooms. **With increasing algal blooms come impacts from potential toxins as well as taste and odor issues in drinking water.**

Although not as common as taste and odor compounds, because of their potential high toxicity, cyanobacteria (blue green algae) toxins are a much greater concern when present in drinking water supplies. These toxins can cause serious health issues including poisoning, impacting the liver, the nervous system, and skin and mucous irritation. There are several treatment and detection options—conventional and advanced—available for the removal of cyanobacteria toxins. All of these options will likely increase capital and operating costs.

Additional costs could be incurred by responding to taste and odor complaints in drinking water due to algal blooms – much more common than toxins. Two compounds, geosmin (1,2,7,7-tetramethyl-2-norborneol) and MIB (2-methylisoborneol) originate primarily from algae and bacteria and attribute to taste and odor issues in drinking water. 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 to 30 part per trillion (ng/L) concentration range. Often during the summer months, water systems that depend upon surface water sources will experience complaints from consumers regarding taste and odor that can directly be attributed to geosmin and MIB.

Treatment plants not designed for enhanced organics removal will have more difficulty producing water that is aesthetically pleasing during algal bloom periods. 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. The Dublin Road and Hap Cremean WTPs for the City of Columbus are currently constructing ozonation and biologically active granular activated carbon treatment processes. These two facilities should be able to handle future taste and odor outbreaks with the addition of these new treatment processes. However, higher operational and maintenance costs should be expected during taste and odor outbreaks. Additional water quality sampling will be necessary to detect these taste and odor events and confirm adequate water treatment process control.

There will also be the risk of **water supply shortages due to additional water demand for both residential and irrigation.** An extended growing season coupled with lower river and reservoir levels from increased evaporation and evapotranspiration could strain water supplies. These demand increases may lead to the need for increased treatment or storage capacity since water supply systems are typically designed to meet maximum demands. Several utilities in the region have limits on the amount of water they can withdraw from surface water supplies in order to maintain minimum stream flows. As noted in Section 2.4.2, the Del-Co Water Company, Inc.'s Olentangy Water Treatment Plant (WTP) has an in-stream intake on the Olentangy River. Some of the model simulation results indicate stream flow will be below the minimum flow rate requirement of 35 cfs; Del-Co would not be able to withdraw water during those times. With increased evaporation, there will be less available water in this surface supply which conflicts with increased water demand. Cities with groundwater as a water supply source, such as Marysville and Delaware, could still be impacted from increased agricultural demand and reduced groundwater supplies through increased evapotranspiration and extended droughts reducing well yields.

Warmer temperatures could also create a longer agricultural growing season. Longer growing seasons could impact water quality through the **increased use of pesticides, herbicides, and fertilizers. During storm events these pollutants enter the surface water system in stormwater runoff and groundwater.** Warmer temperatures in combination with periods of lower rainfall could also increase watershed and in-stream soil erosion. This is due to a loss of vegetation. When severe storms then occur there is less vegetation to hold the soils in place resulting in erosion and sediment transport. The sediment carries a variety of pollutants besides solids including nutrients. Temperature increase would also increase the demand for **agricultural irrigation and controlled drainage,** the controlled capture of water runoff from a field to maintain the water on-site. High temperatures are also very stressful for livestock and impact milk production and **overall animal health.**

Beyond the impacts to water supply and quality, **public health will 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 later half of this century. The five 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). 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 respiratory issues for people with allergies (USEPA 2014).

Each of the above risks ultimately has an effect on the economic health of the region. Decreased water quality and reduced water supplies increase the cost to move and treat water for human use. Higher temperatures drive the increased use of air conditioning and fans which increase electrical usage and drive up **energy costs**. Increased energy consumption will be reliant on the use of coal or natural gas, which will also increase pollutant emissions. These increased emissions will contribute to decreased air quality and associated health costs to public health. Additionally, several studies have linked warmer temperatures to reduced productivity in people, which could impact the economy. Finally, increased agricultural costs to bring water to fields, install advanced drainage systems, and loss of production from livestock increase the costs of food within the region and beyond.

3.3.2 Increased water temperature

Higher air temperatures will also cause a corresponding increase in water temperature. The identified high priority regional vulnerabilities due to increased water temperature are listed below.

Affected Service Sector	High Priority Risks
Water Supply / Water Quality	Longer duration of poorer water quality
Water Treatment	Taste and odor issues from increased algal growth
	Increased treatment costs due to algae and potential algal toxins
Wastewater Treatment	Lower dissolved oxygen and temperature increases affect discharge requirements
Public Health	Increase in waterborne diseases
Energy	Lack of cooling water could reduce energy production

Higher water temperatures increase the likelihood of algal blooms in reservoirs. Increased algal blooms can result in **increased taste and odors events and potential toxicity.** Water treatment costs are expected to increase to detect and remove toxins, as well as to address taste and odor issues. For a full discussion of the impacts of algal blooms, see Section 3.3.1.

Lower dissolved oxygen (DO) levels will occur as the water temperature increases, impacting the diversity and number of aquatic life. In reservoirs, the lower DO may create a larger hypoxic zone that extends over a greater range of depths. Additional phosphorus and other pollutants may be released from bottom sediments due to longer and stronger periods of hypoxia. Loosely bound phosphorus is commonly released from sediment under hypoxic conditions. If additional phosphorus is released into the water column algal growth is expected to increase resulting in lower overall water quality and loss of aesthetic and recreational value. Spring turnover of water in the reservoirs may occur earlier resulting in **poorer water quality for a longer period of time each year**. Increased water temperatures are also expected to increase the frequency and severity of algal blooms including blue greens. Higher pollutant loads and resulting algae blooms will likely increase water treatment costs.

One benefit of higher water temperature is that **most water treatment processes will improve** as water temperatures increases. At higher temperatures the coagulation chemical reaction rate is more rapid and the resulting floc are larger. Floc tend to settle faster in the sedimentation tanks, and thus clarification is enhanced. This works the same way for the lime softening process, which is used at many of the water treatment plants within the region. Higher temperatures increase hydrolysis and precipitation kinetics in the lime softening process. For ozonation, a higher water temperature favors disinfection efficacy. As an example for 3-log Giardia inactivation, the required ozone contact time (CT) at 25° Celsius (C) is 0.48 min-mg/L and at 5°C is 1.9 min-mg/L. For granular activated carbon (GAC) adsorption of disinfection byproducts, such as trihalomethanes (THMs) and haloacetic acids (HAA5), a higher water temperature would lower the empty bed contact time (EBCT) requirement for equivalent removal efficiency. Higher water temperatures also favor biological activity in biofiltration, and thus should improve removal of organic compounds. The higher water temperature would improve particle filtration because of improved flocculation.

There are some potential negative impacts of increased water temperature on treatment processes. Due to the low density of backwash water at a higher temperature, a higher backwash flow rate is required to expand the filter bed. This may negatively impact granular media filtration. There is also a potential for nitrification if chloramines are used for secondary disinfection.

Lower DO and higher water temperatures may reduce treatment facility effluent limits included in discharge permits. **Wastewater treatment costs are expected to increase as a result of these stricter discharge limits.** Wastewater treatment facilities and industrial users will have to enhance treatment to meet their permit discharge limits.

Increasing water temperatures also encourage the spread of **waterborne diseases**. Warmer water temperature promotes the development of many vector organisms and could shift northward organisms that currently do not exist in the Upper Scioto watershed. Diarrheal diseases as well as viruses such as giardiasis and cryptosporidiosis are commonly spread through contact with water. As temperatures increase human contact with water generally increase which creates a rise in the number of waterborne illnesses.

Summer drought results in decreased flow and increased temperatures of waterways. **Many of the power plants supplying electricity in Ohio use river water for cooling.** When the plant exhaust water temperature gets too high it can harm fish and wildlife in the river and may result in an order to shut down the power plant. If the intake water temperature is not sufficiently cool and there is not enough capacity to remove waste heat power plant production would need to be reduced or shut down. If this problem is widespread (i.e. impacting multiple power plants) it may result in electricity shortages, brown-outs and black-outs. This, in turn, will impact public health (i.e. excessive heat that is detrimental to the elderly, individuals with existing health problems, etc.)

3.3.3 Warmer soil temperatures / Decreased soil moisture

The soil temperature and soil moisture will both be directly impacted by the temperature increases projected for the region. As the overall soil and air temperature increases, soil moisture will decrease and evaporation and evapotranspiration will increase. The high priority regional vulnerability due to increased temperature and decreased moistures in soils are increased needs for irrigation in the agricultural sector.

As soil temperatures increase and soil moisture decreases, the **agricultural community's need for irrigation will continue to increase** during a time when water availability is at a minimum. This increased irrigation demand could further compound drought conditions. For a full discussion on summer drought and low flow conditions, see Section 3.3.5.

3.3.4 30 and 7-day higher peak river flows

The USGS simulation results indicate that on both a monthly and weekly average basis, peak maximum river flows are expected to increase. The identified high priority regional vulnerabilities due to higher peak maximum flows are listed below.

Affected Service Sector	High Priority Risks
Water Supply / Water Quality	Increased taste and odors from algal blooms
	Negatively impacts groundwater recharge
	Increased variability in stream flow volume increases difficulty of supply management
	Increased temperature of urban runoff

Higher peak maximum flows can impact the reliability and availability of the water supply. Groundwater aquifers do not recharge as well from high intensity, short duration rain events. Much of the precipitation from these types of events becomes stormwater runoff and drains into rivers, lakes and reservoirs. Capturing this runoff for future water supply in a reservoir is also difficult because a large volume of water is created in a short period of time. Reservoirs must be drawn down to create the available volume and capture the inflow. If the event does not occur or is not as large as expected, the reservoir will not refill as anticipated, creating a potential water supply shortage.

Water quality can also be negatively impacted by higher peak maximum flows. Stormwater runoff from intense storm events is more likely to cause soil erosion and produce larger pollutant loads to streams and reservoirs. This large pollutant load degrades water quality and creates conditions ideal for increased algae growth and the potential for taste, odor, and toxicity issues. As discussed in Section 3.3.1, water with higher pollutant concentrations and algae blooms is more difficult and expensive to treat. Additionally, urban runoff during warmer months will see an increase in temperature due to increases in the heat island effect. Urban runoff can already be much higher in temperature under current conditions which can negatively impact quality.

3.3.5 Decreased minimum 30-day flow / Extended dry periods / Summer droughts

The USGS simulation results indicate decreased minimum monthly stream flows over longer periods of time. Additionally, due to the changes in water use, land development, precipitation patterns and increased temperatures, it appears likely that there will be increased occurrences of summer drought. This is reflected in some of the low stream flows and Hoover reservoir water levels. The identified high priority regional vulnerabilities due to decreased minimum flows and drought conditions are listed below.

Affected Service Sector	High Priority Risks
Water Supply / Water Quality	Decreased groundwater flow to streams
	Decreased reservoir flow / volume; reduced mixing
	Increased taste and odors from algal blooms
Water Treatment	Reduced reliability and availability of supply
	Reduced groundwater recharge
	Lower lake and reservoir levels
Agriculture	Increased irrigation demands but decreased availability

As precipitation levels decrease for longer periods of time, **water demand will increase for both agricultural and residential irrigation.** This combination will further compound water supply shortage issues. These climate and development factors will lead to a **reduced water supply, as well as historically low groundwater recharge, stream flow and lake and reservoir levels.** These factors may require increased treatment or storage capacity since water supply systems are typically designed to meet maximum demands. Several utilities in the region have limits on the amount of water they can withdraw from surface water supplies in order to maintain minimum stream flows. As noted in Section 2.4.2, the Del-Co Water Company's Olentangy

Water Treatment Plant (WTP) has an in-stream intake on the Olentangy River. There are model simulations which produce stream flow below the minimum flow requirement of 35 cfs. Del-Co would not be able to withdraw water during those times. With increased evaporation, there will be less supply in this surface water source even though the forecasted water demand is increasing. Cities with groundwater as a source of supply, such as Marysville and Delaware, could still be impacted from increased agricultural demand. Climate change may also reduce groundwater supplies through increased evapotranspiration and extended droughts reducing well yields.

Water quality will be negatively impacted during drought conditions as stream flows will be less than the historic minimum, with shallower water depths that will produce higher water temperatures. Drought will also result in the loss of vegetative cover. Loss of woody stream bank vegetation will reduce water shading and further increase in-stream water temperatures. Aquatic life may be negatively impacted by low flows, higher water temperatures, and loss of shading.

During rain events overland and stream bank erosion will increase due to a loss of vegetation in stream corridors and the watershed. Increases in the production and release of nitrogen, phosphorus, organic carbon, turbidity, and sediment into the surface water system are expected. Wet weather in-stream pollutant concentrations, reservoir concentrations, and total loads will increase. Sediment will accumulate in the creeks and reservoirs.

Stormwater runoff following an extended period of drought can contain elevated concentrations of a wide variety of pollutants. If an extended dry period is followed by one or more intense rain events, in-stream water quality may be severely degraded with a large pollutant load reaching the reservoirs in a short period of time. Reservoir concentrations of phosphorus, nitrogen, turbidity, organic carbon, and chlorophyll may be much higher (up to an order of magnitude) than typical values.

Due to the increased pollutant load and warmer water temperatures, the frequency and severity of algal blooms may increase. Increased blooms could lead to toxicity, taste, and odor issues, and resulting increased water treatment costs. Algal blooms issues are discussed in detail in Section 3.3.1.

Moving forward it will be extremely important to maximize operator flexibility related to raw water supplies, reservoir operations, and drinking water treatment to produce high quality potable water at a reasonable cost.

3.3.6 Increased Intensity of Extreme Rain and Wind Events

The USGS simulation results showed increased peak max flows, and increased intensity of extreme events is expected to continue because of predicted increases in air temperature and increased evaporation. The following top priority regional vulnerabilities due to decreased minimum flows and drought conditions are listed below.

Affected Service Sector	High Priority Risks
Water Supply / Water Quality	Increased taste, odors and potential toxicity from algal blooms
Water Treatment	Damage to infrastructure / infrastructure failure
Wastewater Treatment	Increased CSOs/ SSOs
	Damage to infrastructure / infrastructure failure
Public Health	Loss of electrical / water / sanitation services during and after event
	Disaster related injuries / mortalities
Agriculture	Crop loss
	Soil erosion

Affected Service Sector	High Priority Risks
Energy	Infrastructure damage / Loss of power
Economy	Increase in insurance costs to repair damage

Water quality is reduced during more extreme rainfall events which produce larger watershed stormwater runoff volumes, larger pollutant loads, and higher maximum stream discharges. The impact of more intense rainfall events is magnified by the physical changes due to higher air and water temperatures as described in previous sections. With less vegetative cover in the watersheds, more intense rainfall events will produce even more stormwater runoff volume, more pollutant load, greater stream bank erosion and higher peak stormwater discharges. The result is higher maximum stream discharges and higher in-stream pollutant concentrations. The stormwater runoff contains phosphorus, nitrogen, turbidity, sediment, organic carbon, pathogens, and other pollutants. Elevated nutrient concentrations may increase in-stream algal productivity and the potential for algae blooms. Higher peak discharges and pollutant loads can also negatively impact in-stream aquatic life, including fish and benthic macroinvertebrates.

In addition to larger pollutant loads from the watershed, there will be additional pollutant load generated from in-stream erosion. This is a result of higher maximum stream discharges and less vegetative cover on stream banks and floodplain corridor. The reservoirs will therefore be receiving additional watershed runoff volume and pollutant load as well as additional pollutant load from in-stream erosion. The end result will be higher pollutant loads to reservoirs and higher reservoir pollutant concentrations. The frequency and severity of algae blooms, including blue green blooms, is expected to increase. Blue green algae can release toxins which are harmful to aquatic life and humans.

The pollutants of primary concern in the reservoirs include: phosphorus, nitrogen, turbidity, sediment, organic carbon, and pathogens. Phosphorus and nitrogen are a concern due to eutrophication and algae blooms. Algae, turbidity, nitrate and organic carbon are a concern during drinking water treatment. Pathogens are a concern related to recreational use and human health. There is also a concern related to sediment accumulation in reservoirs and the loss of water storage capacity. Maintenance to remove accumulated sediment will need to be completed periodically. Sediment on the bottom of the reservoirs can release phosphorus and other pollutants into the overlying water column under hypoxic conditions further degrading reservoir water quality.

During high storm events, nitrogen concentrations in the surface water supplies are likely to increase. Facilities not designed for nitrogen treatment may have difficulty meeting nitrate and nitrite maximum contaminant levels (MCLs). Facilities with ozonation and biological filtration should have the most success reducing herbicide levels, such as atrazine.

Treatment capacity is reduced during extreme weather events. As infrastructure is designed based on historical patterns of precipitation and stream flow, they can be overwhelmed by the increased volume of water creating sewer overflows and forcing wastewater treatment plants to bypass directly to rivers. Because treatment plants are often in low laying areas, they can be flooded out, becoming unable to treat waste during a time when treatment is at its greatest demand. These storm events can also damage key sewer infrastructure as weak pipes are pushed to the breaking point, or pump stations lose power. These failures incur large costs, both in disruption of service and in repair and emergency response.

In addition, the heavy downpours increase the amount of runoff into rivers and lakes, washing sediment, nutrients, pollutants, trash and other materials into the water supply, **severely degrading water quality and increasing turbidity** in surface water supplies. Facilities with direct river intakes and no downstream rivers would be most impacted by the turbidity spikes. Other facilities would have the option of optimizing reservoir operation to have the reservoir act as a settling basin. Increased raw water turbidity requires higher concentrations of coagulant chemicals. Additional pretreatment may be required in the reservoir or within the treatment facility itself. Filtration processes could be limited in the filter loading rate that can be applied to the filters during such events, and water production would be limited. Additional backwash water would be required during these times and more solids would be produced from the settling and filtration processes. Events such as these could stress unit process capacities.

Flooding and storm damage from **major storm events can have severe impacts on many aspects of the region including the economy, public health, agricultural, and transportation beyond water and wastewater disruption.** Flooding can inundate agricultural and urban land and disrupt transportation and trade along the region's roads and rivers. For example, flooding in the Midwest in 2008 caused 24 deaths, $15 billion in losses via reduced agricultural yields due to crop damage, and closure of key transportation routes (Melillo 2014). Flooding and high winds can cause damage to roadways, drainage structures, power supply equipment, homes, and businesses. Economic factors are impacted when basic services such as power become unavailable and transportation is limited due to road and railway closures.

Section 4: Conclusions

The results of the climate change and watershed modeling indicate the potential for the following trends in the Upper Scioto River watershed:

- Increase in the mean annual air temperature (up to 10°F increase by 2090);
- Increase in the variability of precipitation with 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 levels; and

As a result of these changes, the regional impacts and vulnerabilities were identified, evaluated, and prioritized based on likelihood of occurrence and severity of the impact. The top priority vulnerabilities were defined through an evaluation of the risks associated with predicted climate changes and future hydrologic conditions within the watershed. The high priority vulnerabilities include impacts to: water supply source reliability; water quality from an environmental and treatment perspective; and potential impacts to public health. Many additional medium priority vulnerabilities were identified related to many of the service sectors evaluated in this study. The medium priority vulnerabilities include impacts to agriculture, energy, and the economy. Adaptive management strategies for all of the top priority impacts will be evaluated and presented in a subsequent technical memorandum and in the adaptive management plan for the region.

Section 5: References

1. Brekke, Levi. *Addressing Climate Change in Long-Term Water Resources Planning and Management*. United States Army Corps of Engineers (US ACOE). 2011.
2. Brown and Caldwell. *Upper Scioto River Watershed Water Inventory.* Prepared for the Mid-Ohio Regional Planning Commission. 2014.
3. Fry, J., Xian, G., Jin, S., Dewitz, J., Homer, C., Yang, L., Barnes, C., Herold, N., and Wickham, J., 2011, Completion of the 2006 National Land Cover Database for the Conterminous United States, PE&RS, Vol. 77 (9): 858-864.
4. Melillo, Jerry M., Terese (T.C.) Richmond, and Gary W. Yohe, Eds. *Climate Impacts in the United States: The Third National Climate Assessment.* U.S. Global Change Research Program. 2014.
5. National Association of Clean Water Agencies (NACWA). *Confronting Climate Change in Long-Term Water Resources Planning and Management.* NACWA. 2009.
6. Wilbanks and Fernandez. *Climate Change and Infrastructure, Urban Systems and Vulnerabilities.* United States Department of Energy (US DOE). 2012.
7. United States Environment Protection Agency (US EPA). *Adaptation Strategies Guide for Water Utilities.* Climate Ready Water Utilities EPA. 2012.
8. USEPA. *Climate Impacts and Adaptation Website.* http://www.epa.gov/climatechange/impacts-adaptation/water.html USEPA. 2014.
9. USEPA. *National Water Program 2012 Strategy: Response to Climate Change.* 2012.
10. United States Geological Survey (USGS). *Hydrological Effects of Potential Changes in Climate, Water Use, and Land Cover in the Upper Scioto River Basin, Ohio.* 2015.

Attachment A: Predicted Average Stream Flows and Water Levels

Little Scioto Reach with Marion PWS

Olentangy River at DEL-CO intake

Scioto River at Columbus

Scioto River at Circleville

Hoover Reservoir

O'Shaughnessy Reservoir

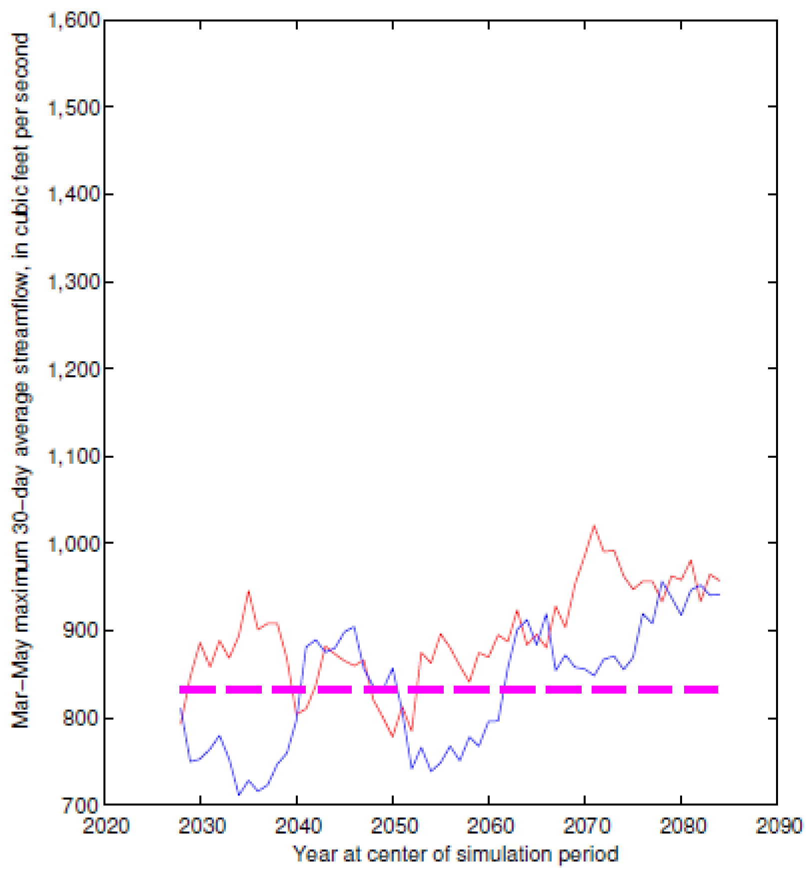
Griggs Reservoir

Little Scioto Reach with Marion Public Water Supply

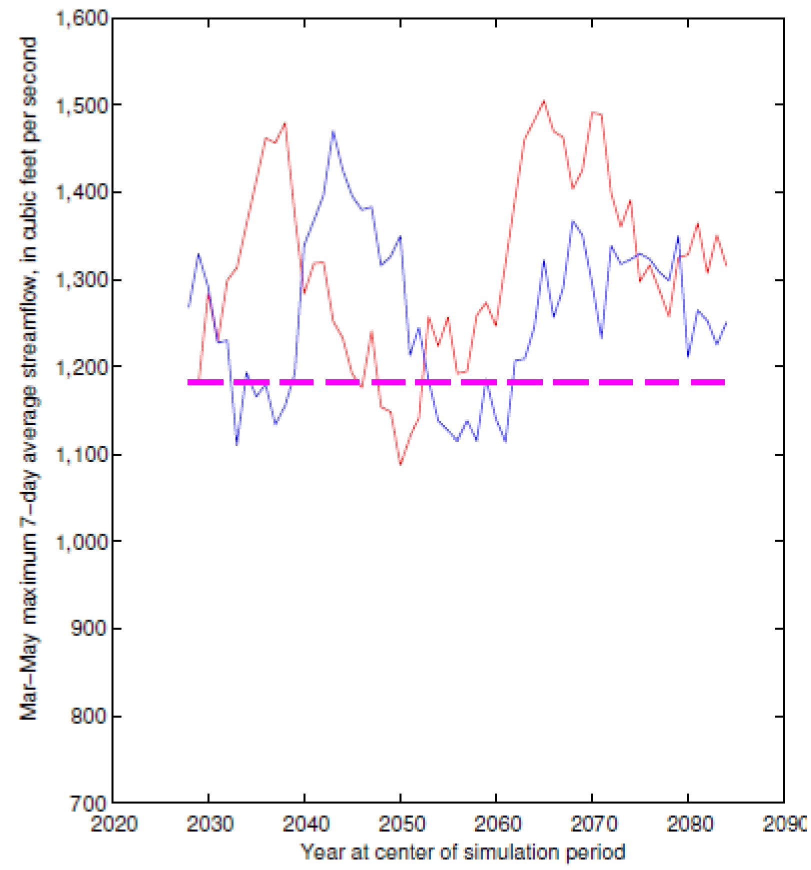
Median A1b
Median A2
Calibration period

Spring Average Maximum Stream Flow: Climate Only

30-Day

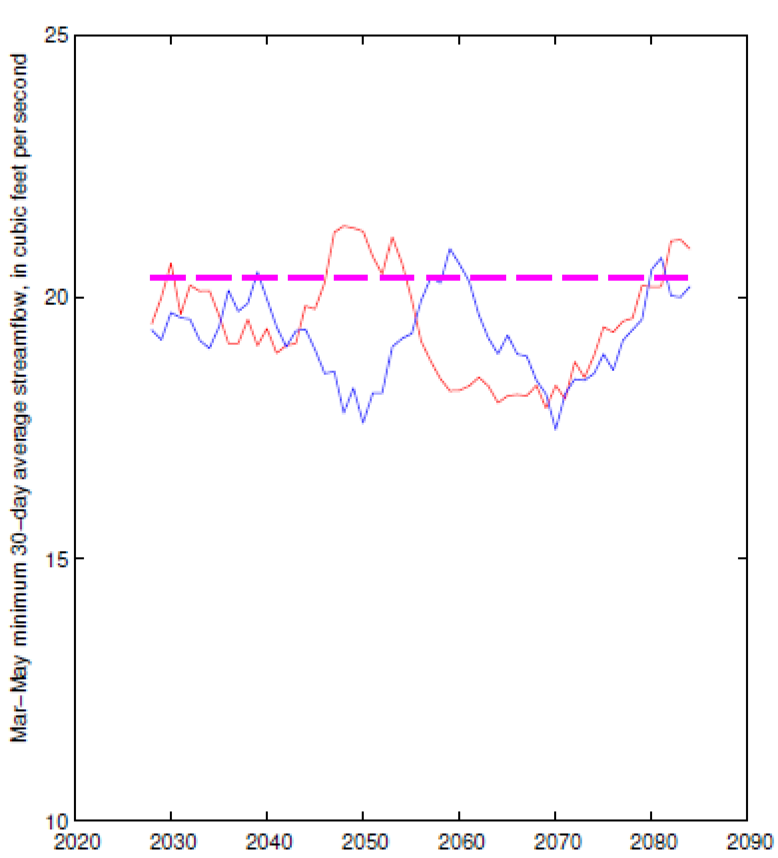


7-Day

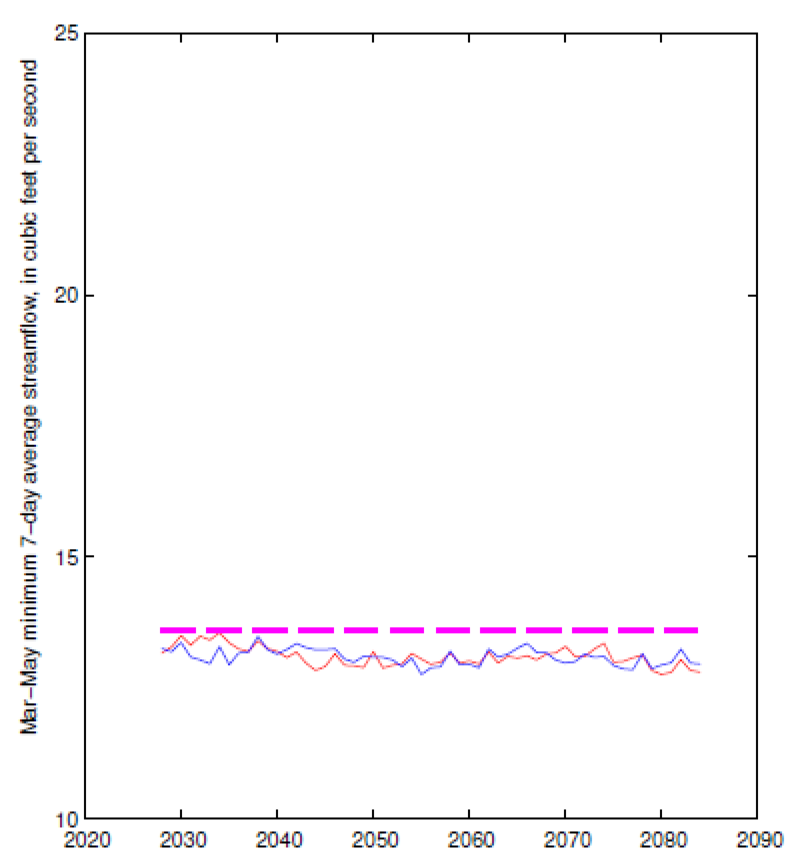


Spring Average Minimum Stream Flow: Climate Only

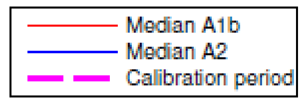
30-Day



7-Day

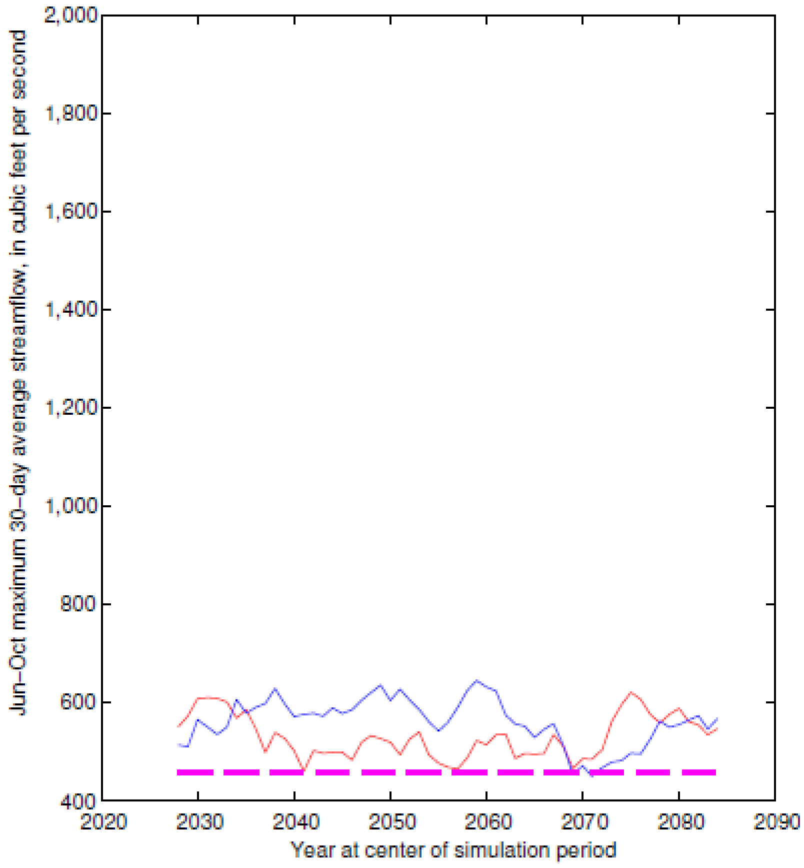


Little Scioto Reach with Marion Public Water Supply

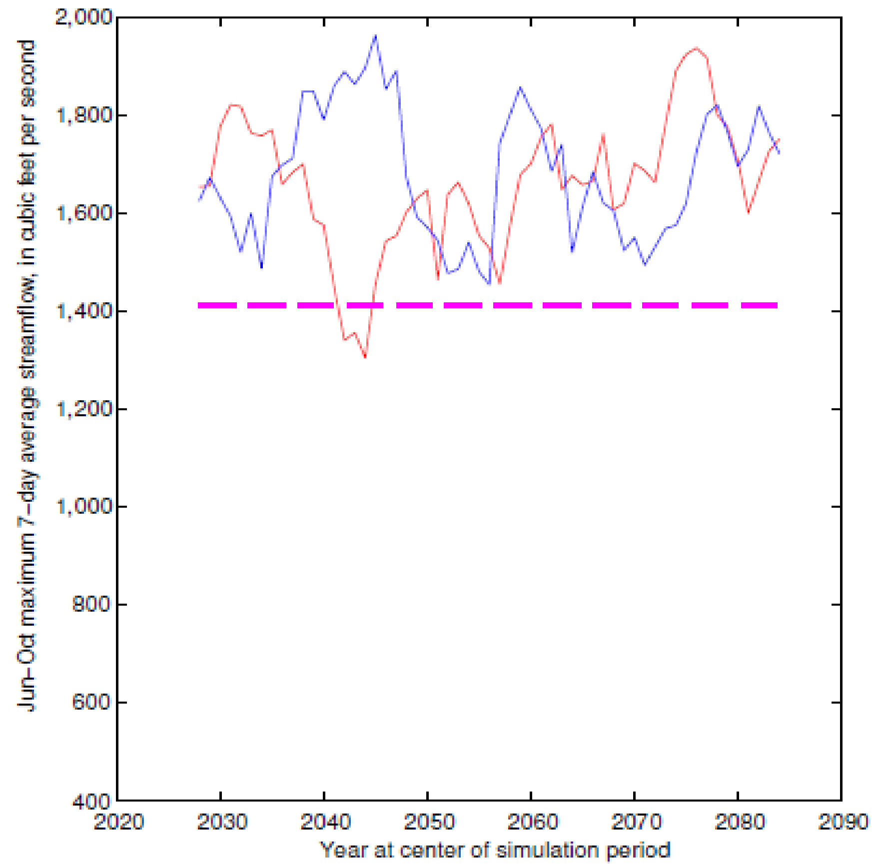


Summer Average Maximum Stream Flow: Climate Only

30-Day

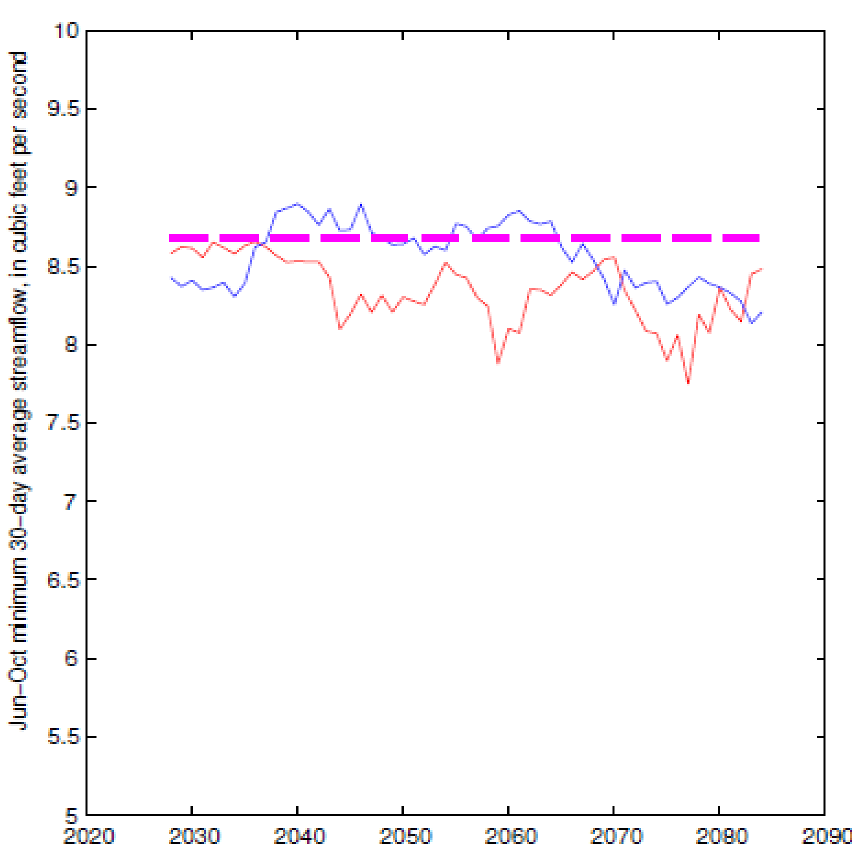


7-Day

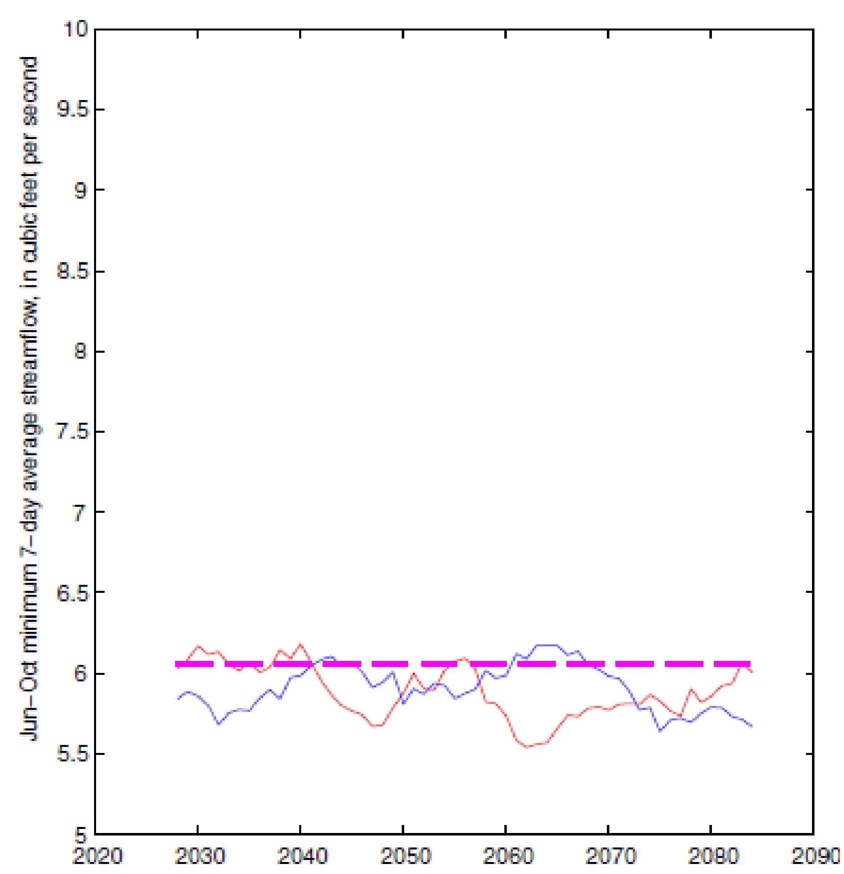


Summer Average Minimum Stream Flow: Climate Only

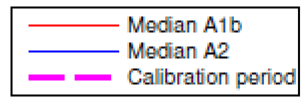
30-Day



7-Day

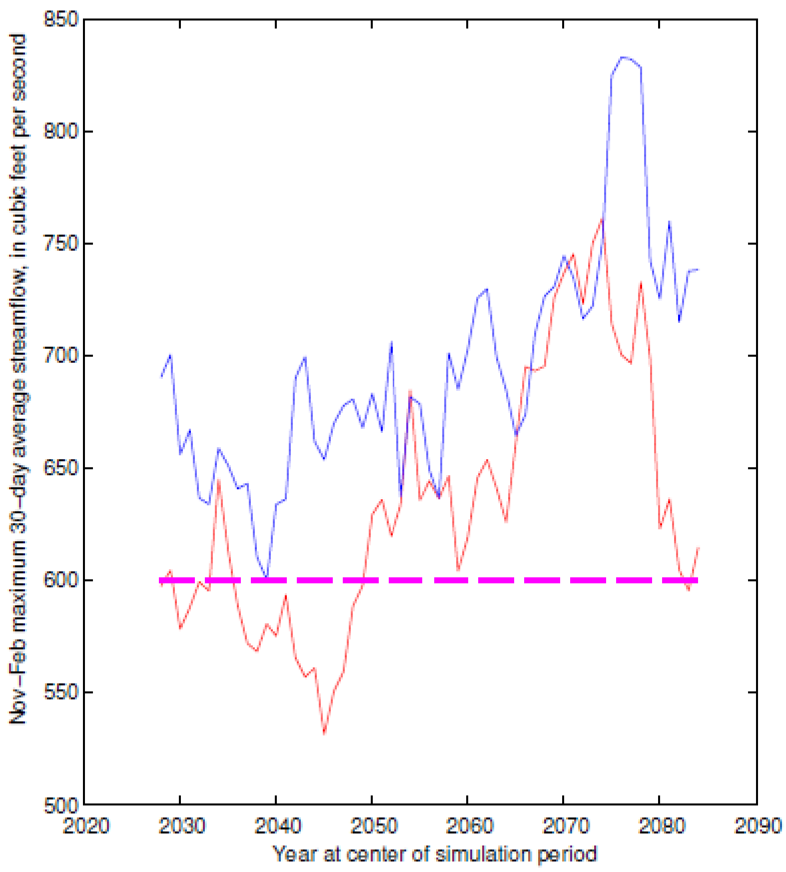


Little Scioto Reach with Marion Public Water Supply

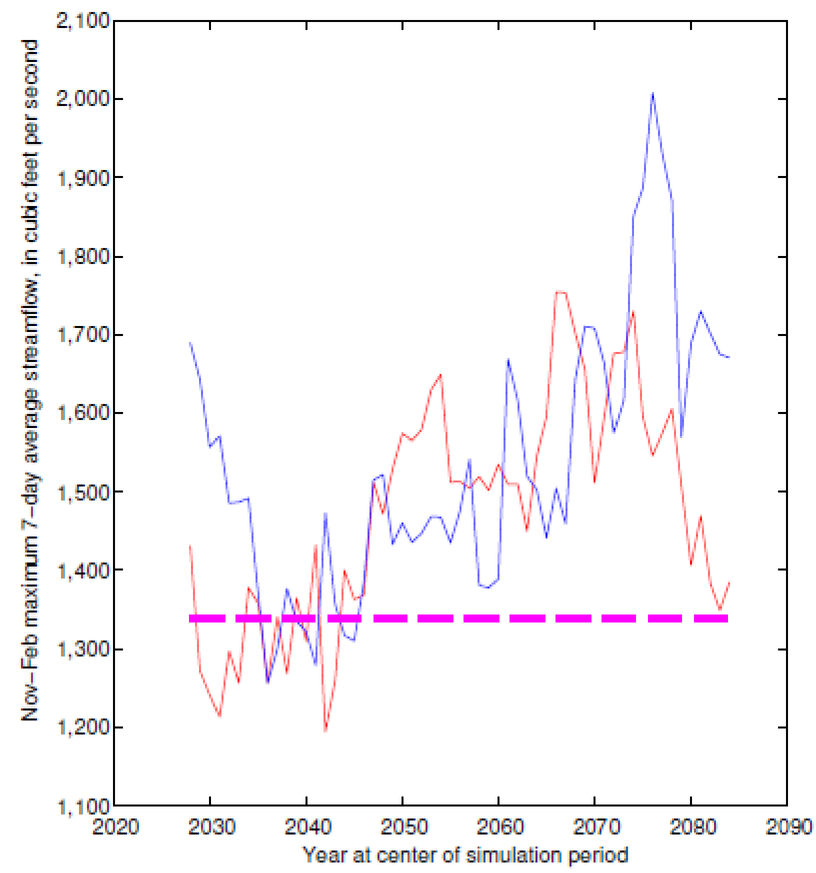


Fall/Winter Average Maximum Stream Flow: Climate Only

30-Day

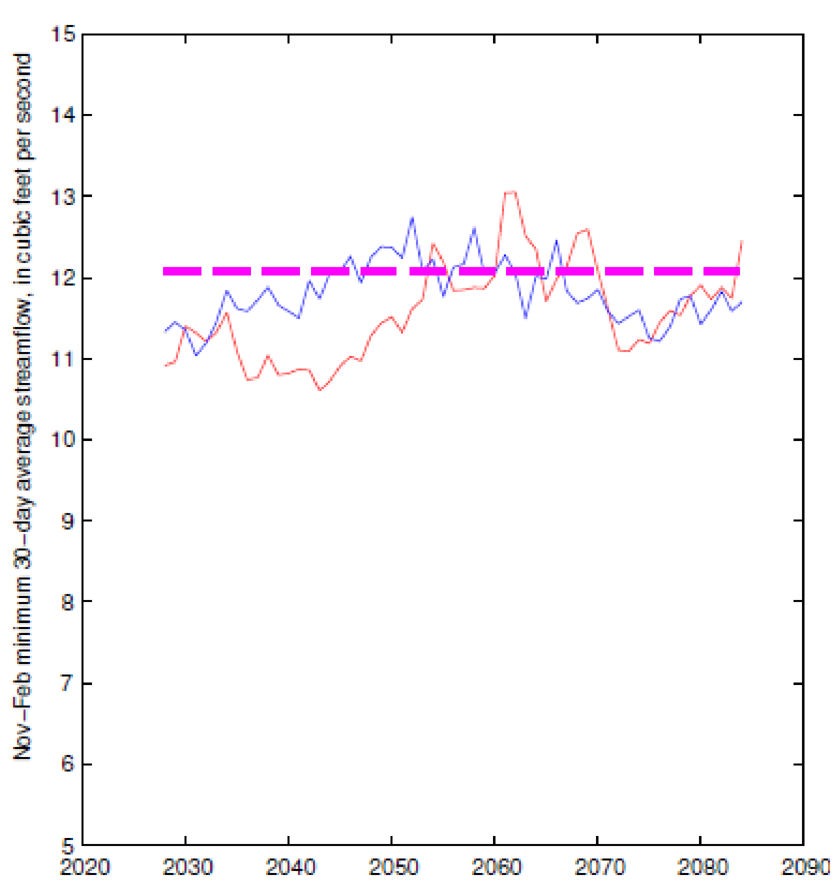


7-Day

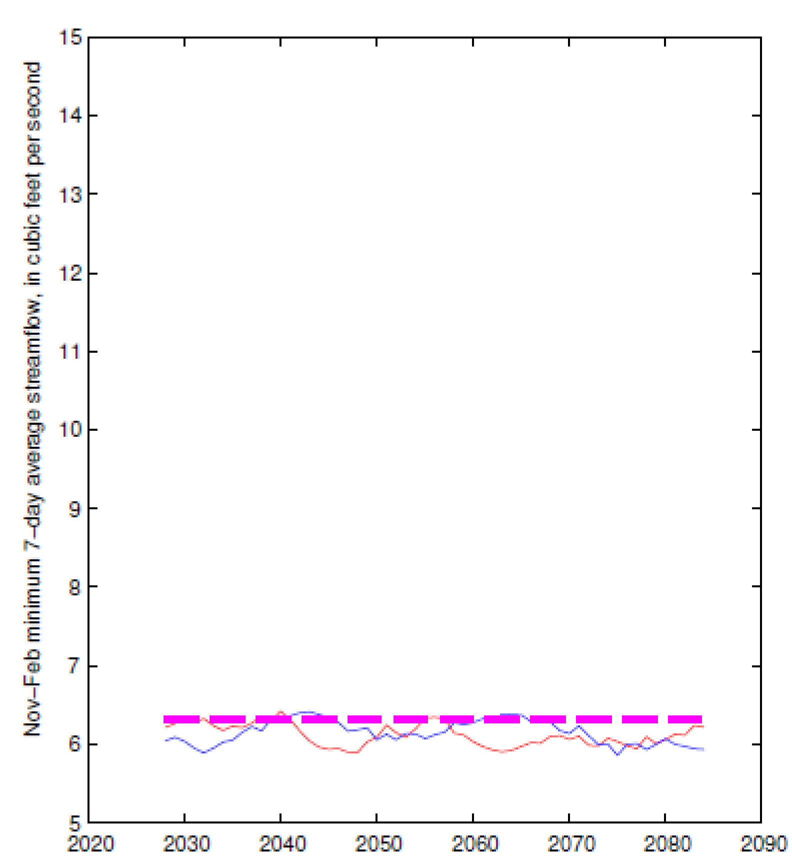


Fall/Winter Average Minimum Stream Flow: Climate Only

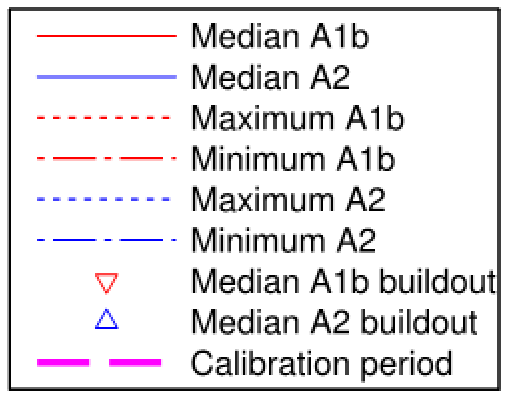
30-Day



7-Day

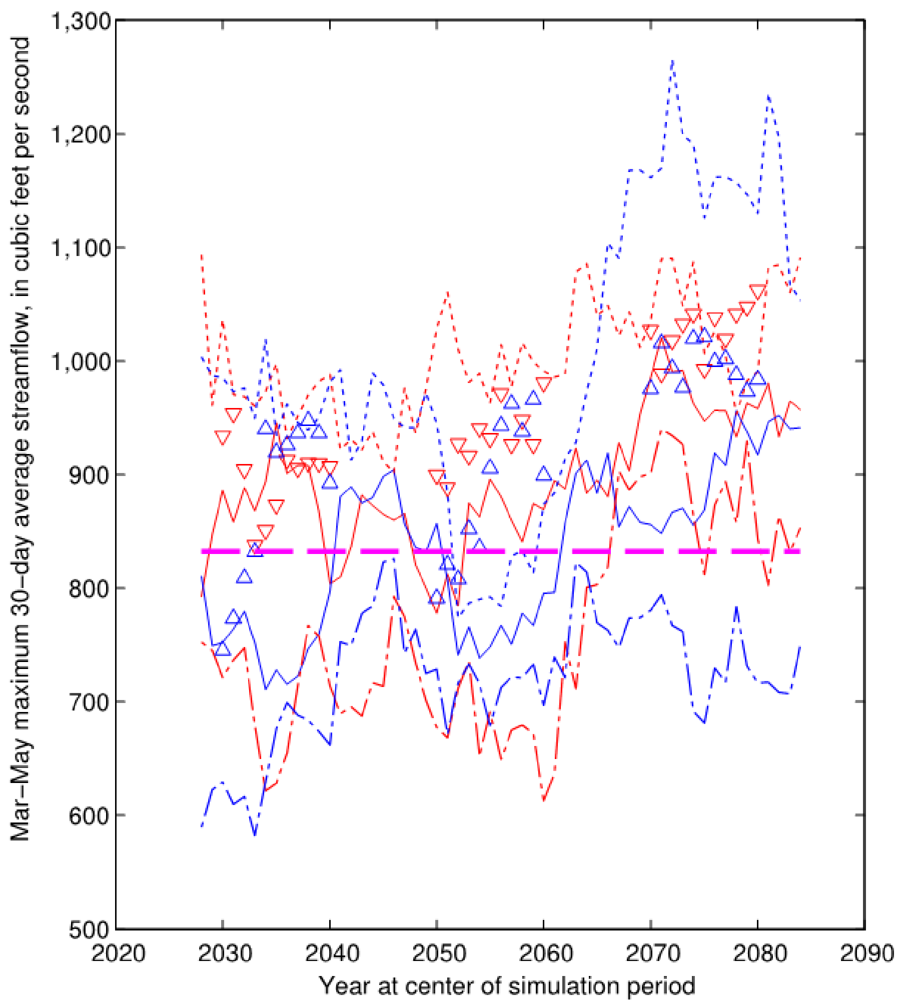


Little Scioto Reach with Marion Public Water Supply

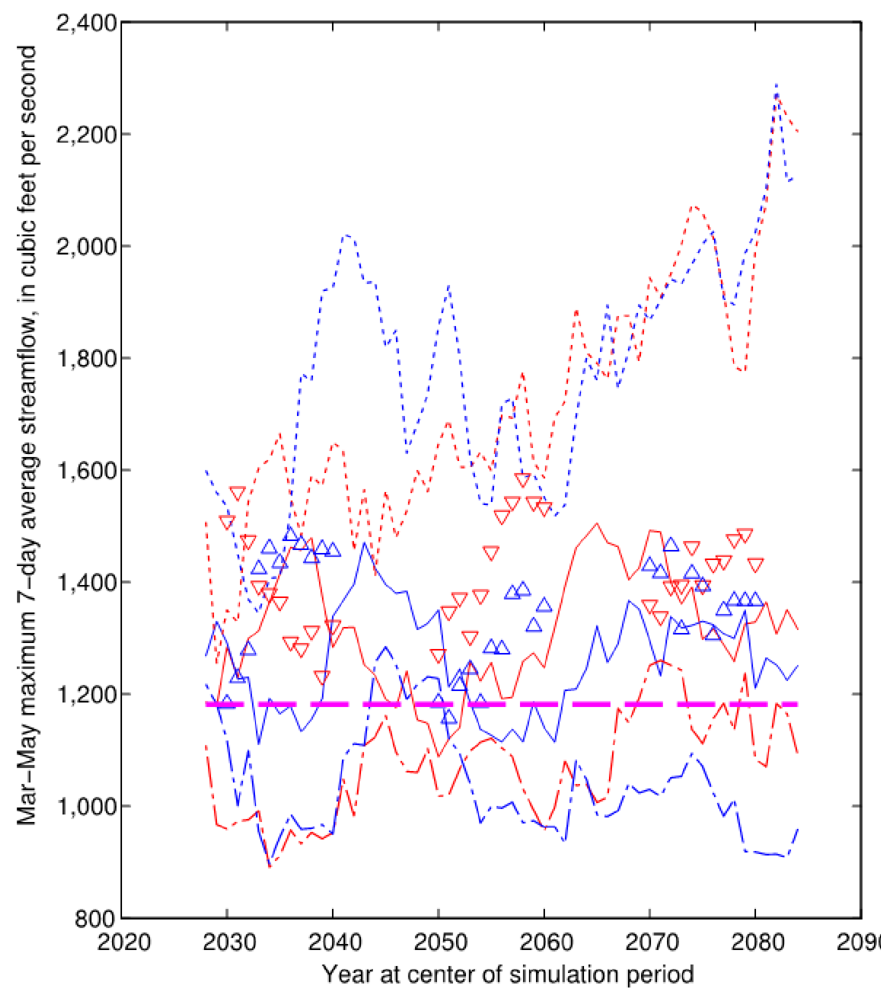


Spring Average Maximum Stream Flows with Development

30-Day

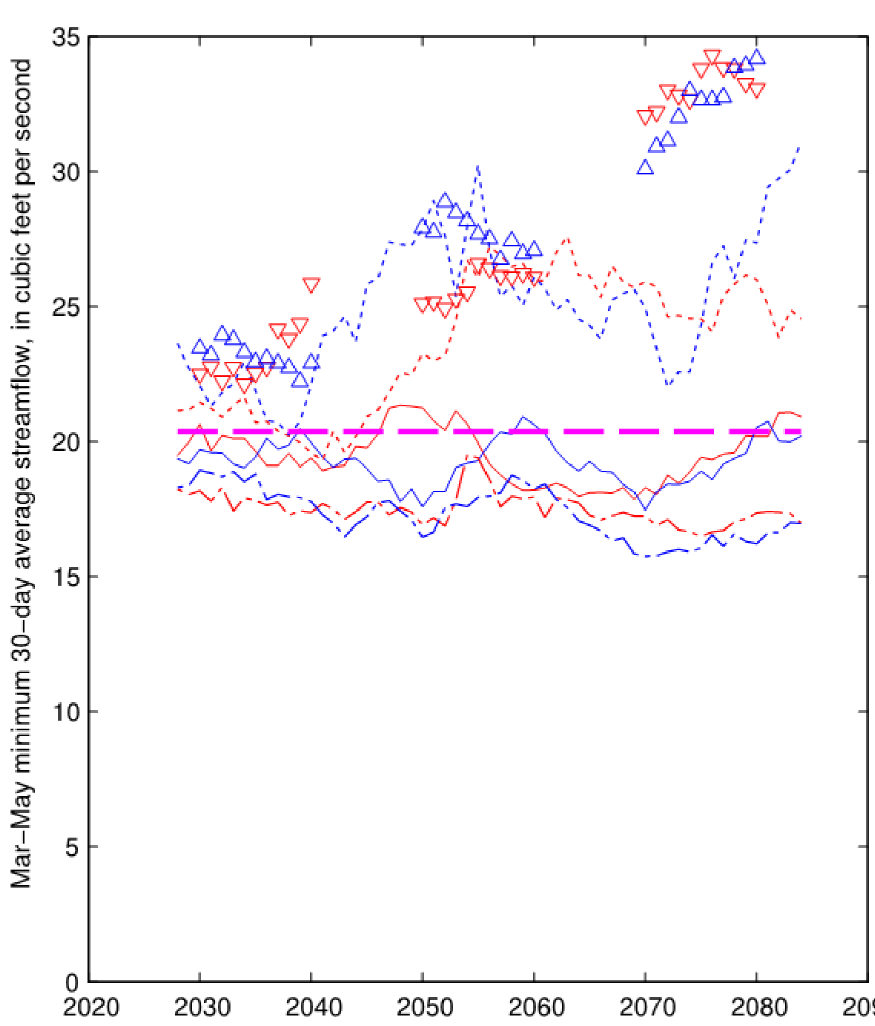


7-Day

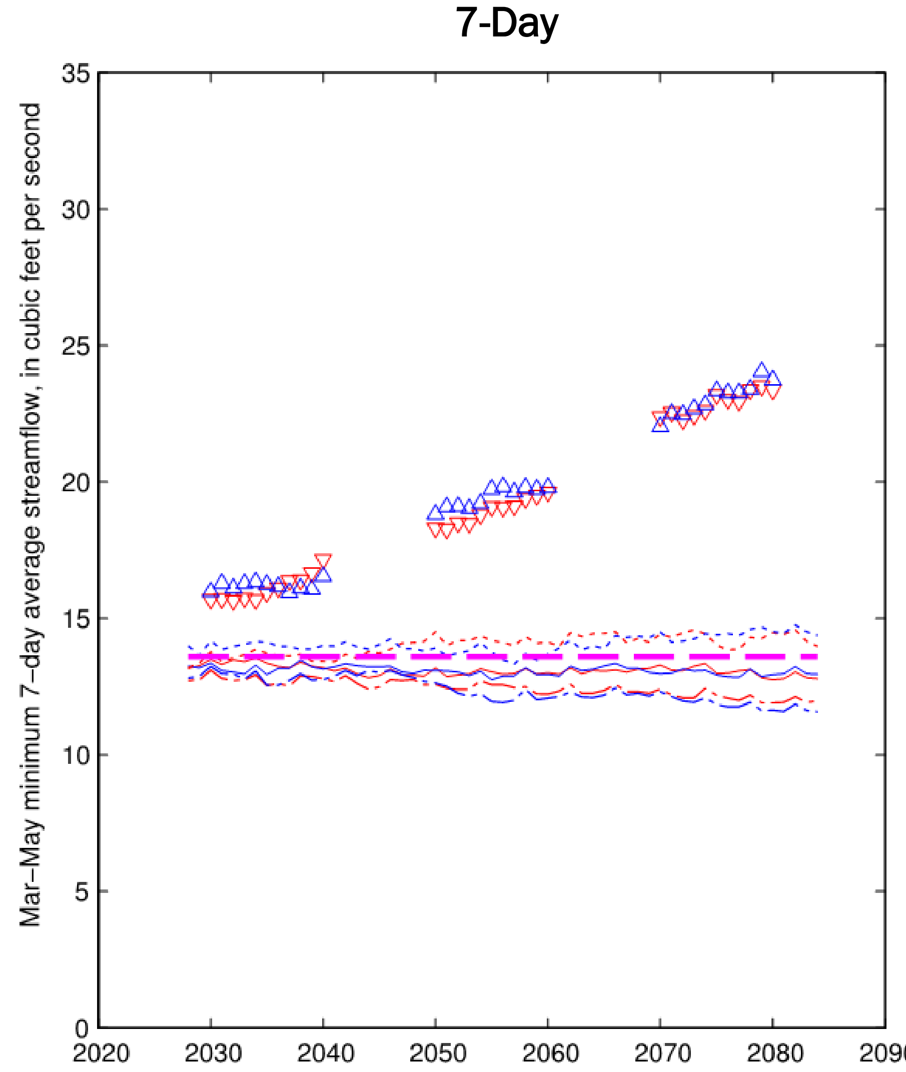


Spring Average Minimum Stream Flows with Development

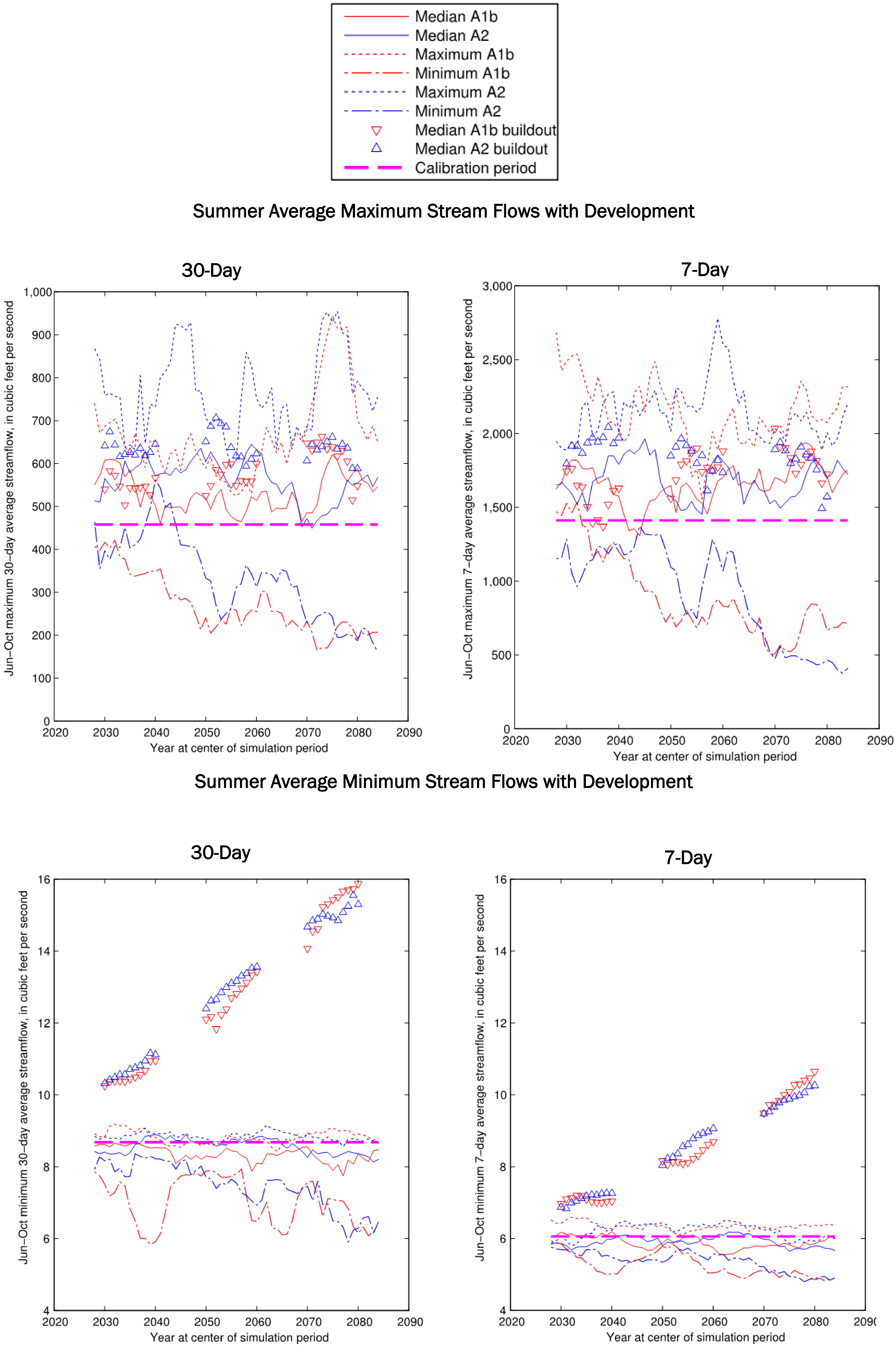
30-Day

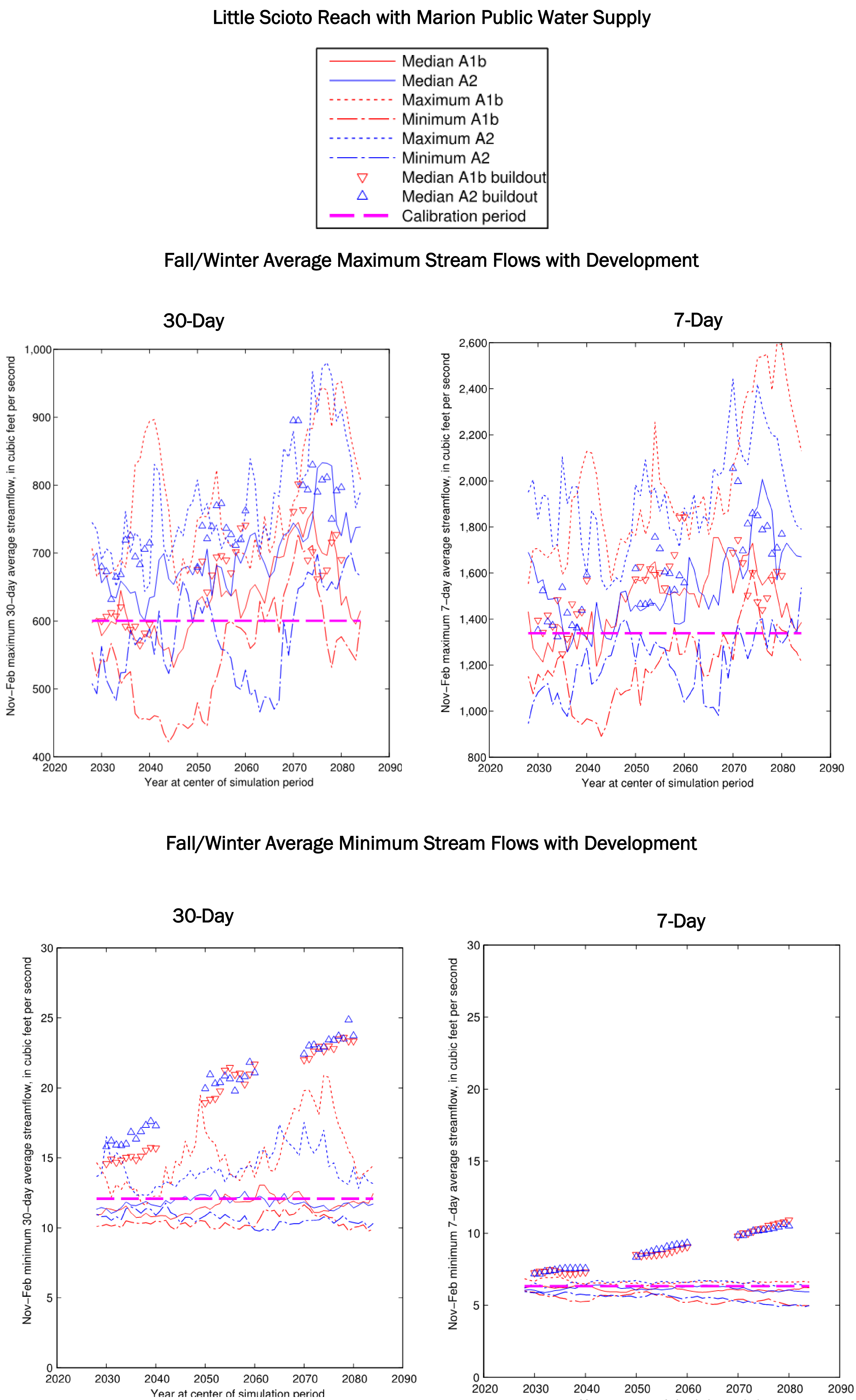


7-Day



Little Scioto Reach with Marion Public Water Supply





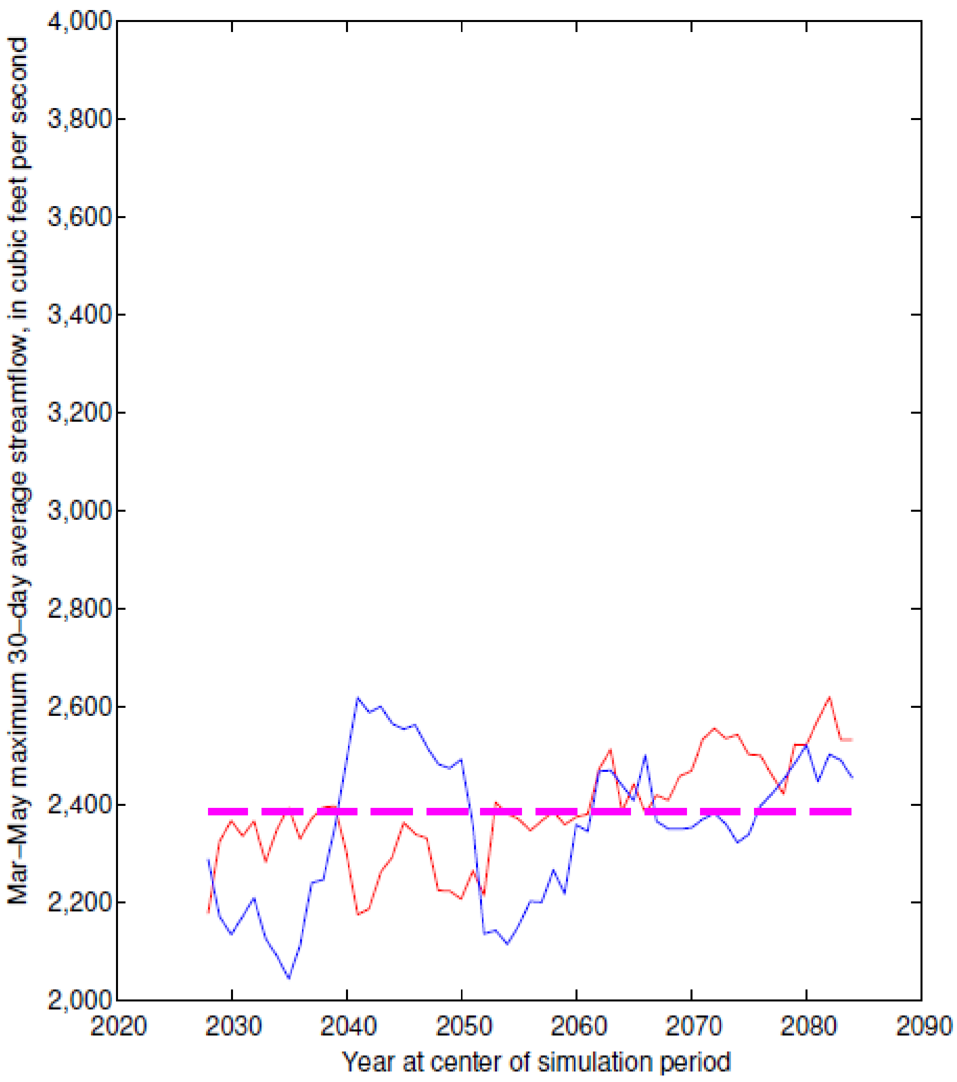
Little Scioto Reach with Marion Public Water Supply
Median A1b
Median A2
Maximum A1b
Minimum A1b
Maximum A2
Minimum A2
Median A1b buildout
Median A2 buildout
Calibration period
Fall/Winter Average Maximum Stream Flows with Development
30-Day
7-Day
Nov–Feb maximum 30–day average streamflow, in cubic feet per second
1,000
900
800
700
600
500
400
Nov–Feb maximum 7–day average streamflow, in cubic feet per second
2,600
2,400
2,200
2,000
1,800
1,600
1,400
1,200
1,000
800
2020
2030
2040
2050
2060
2070
2080
2090
Year at center of simulation period
Fall/Winter Average Minimum Stream Flows with Development
30-Day
7-Day
Nov–Feb minimum 30–day average streamflow, in cubic feet per second
Nov–Feb minimum 7–day average streamflow, in cubic feet per second
30
25
20
15
10
5
0
Year at center of simulation period

Olentangy River at DEL-CO Intake Seasonal Stream Flows

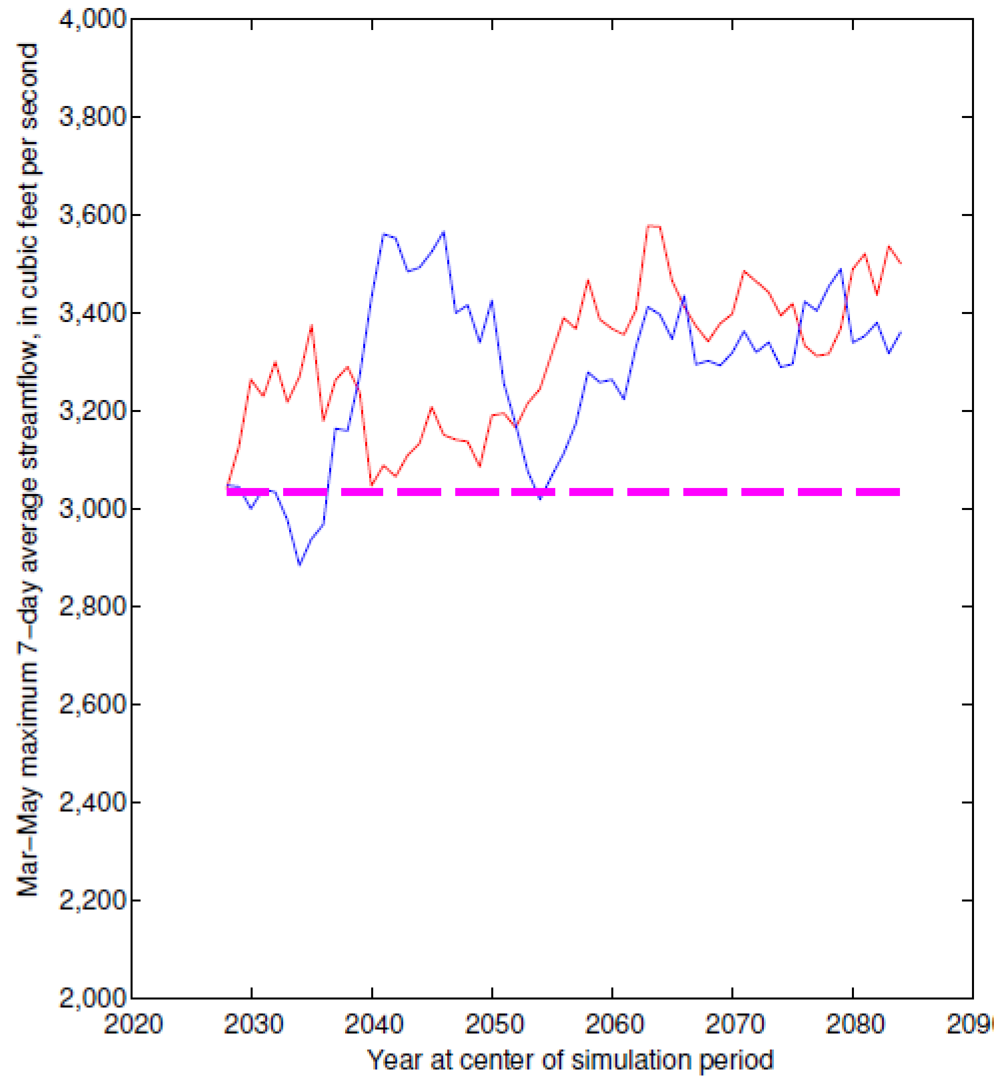
Median A1b
Median A2
Calibration period

Spring Average Maximum Stream Flow: Climate Only

30-Day

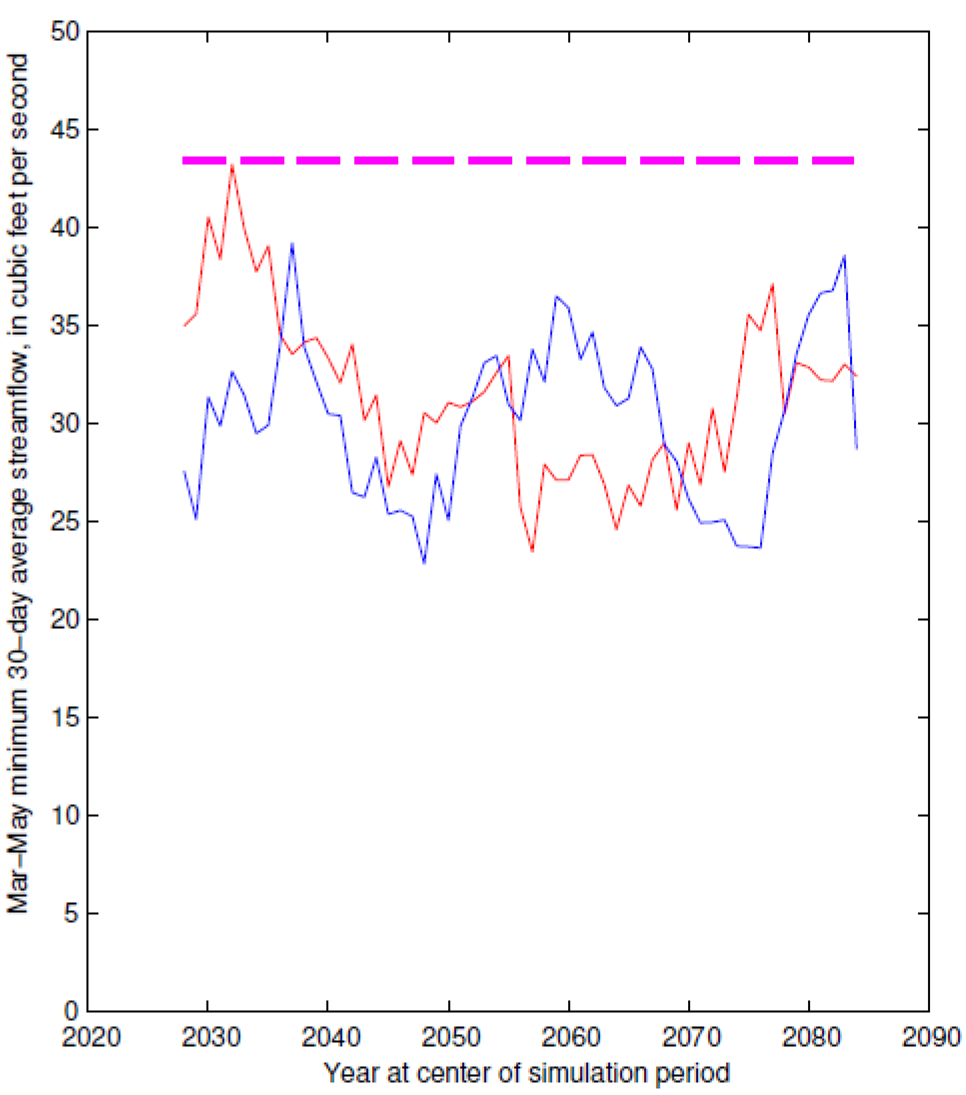


7-Day

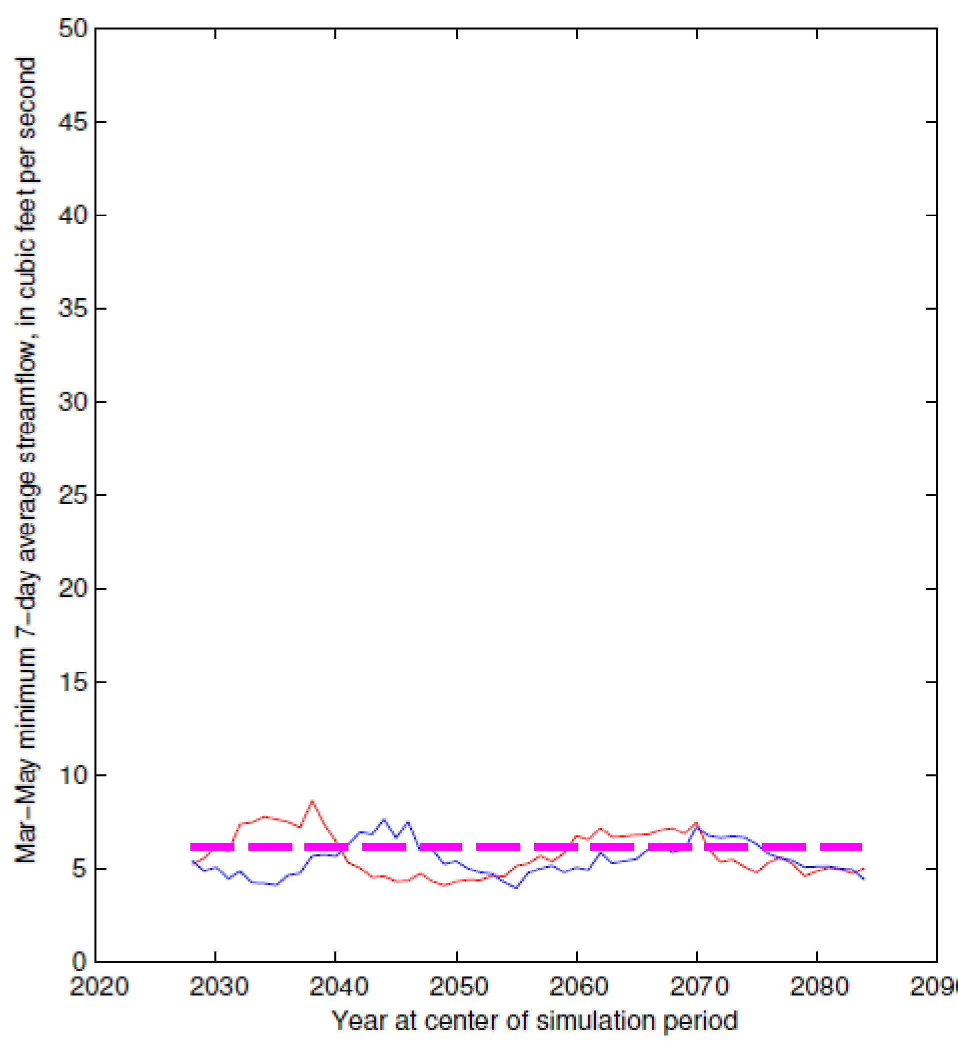


Spring Average Minimum Stream Flow: Climate Only

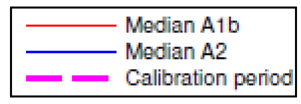
30-Day



7-Day

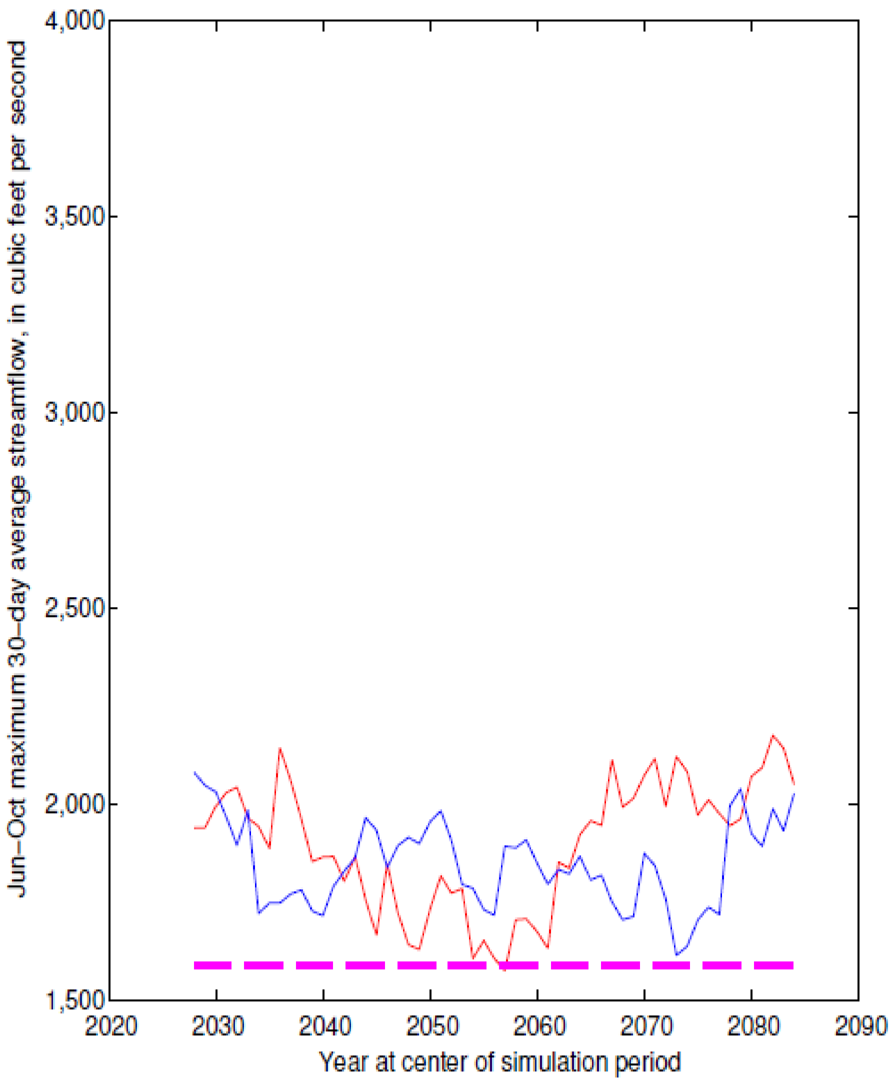


Olentangy River at DEL-CO Intake

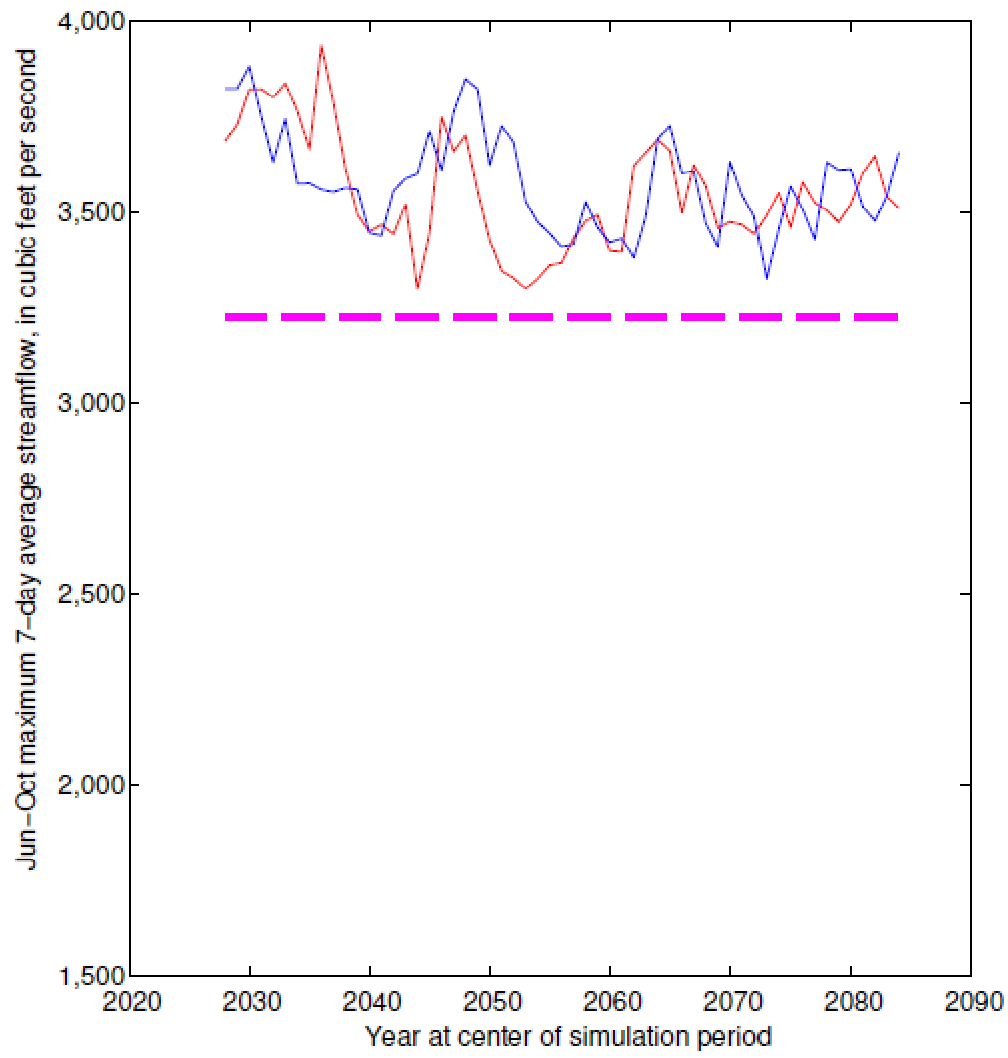


Summer Average Maximum Stream Flow: Climate Only

30-Day

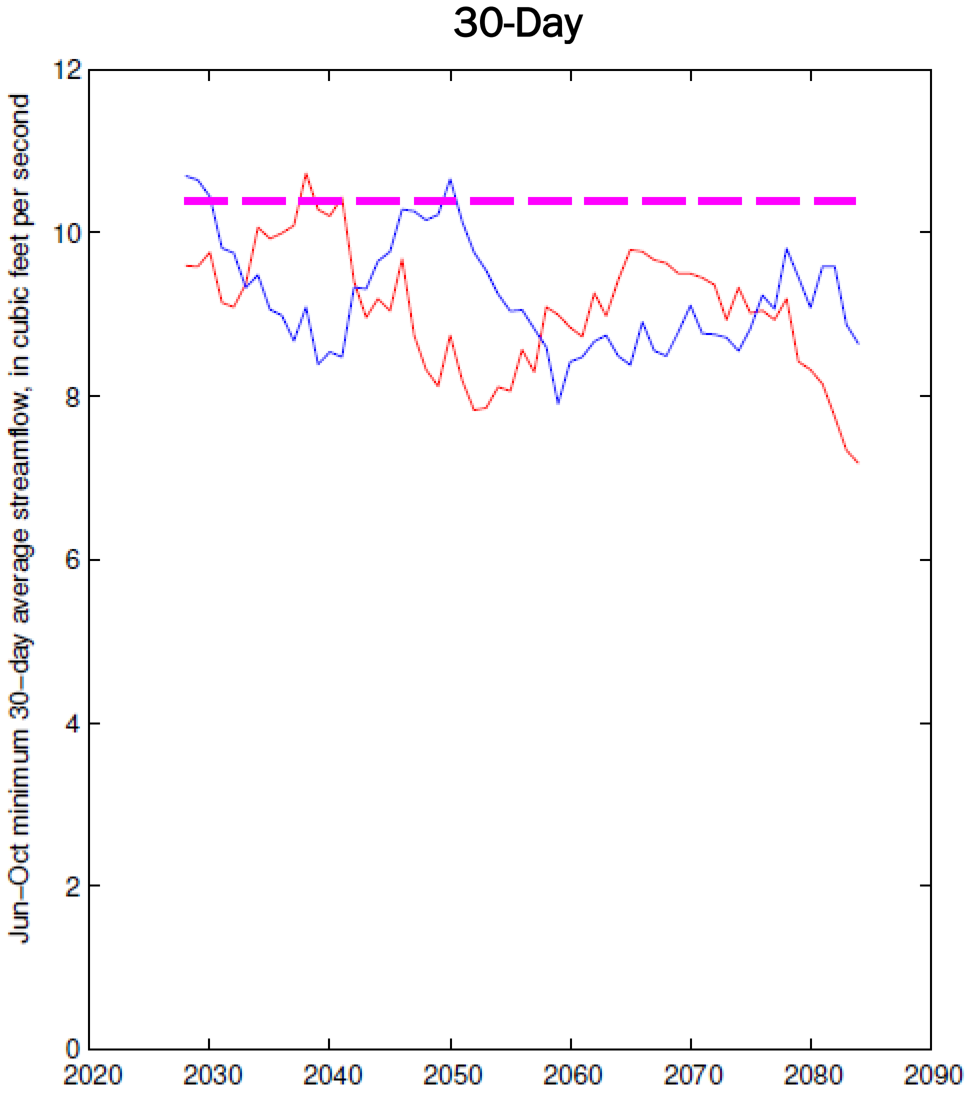


7-Day

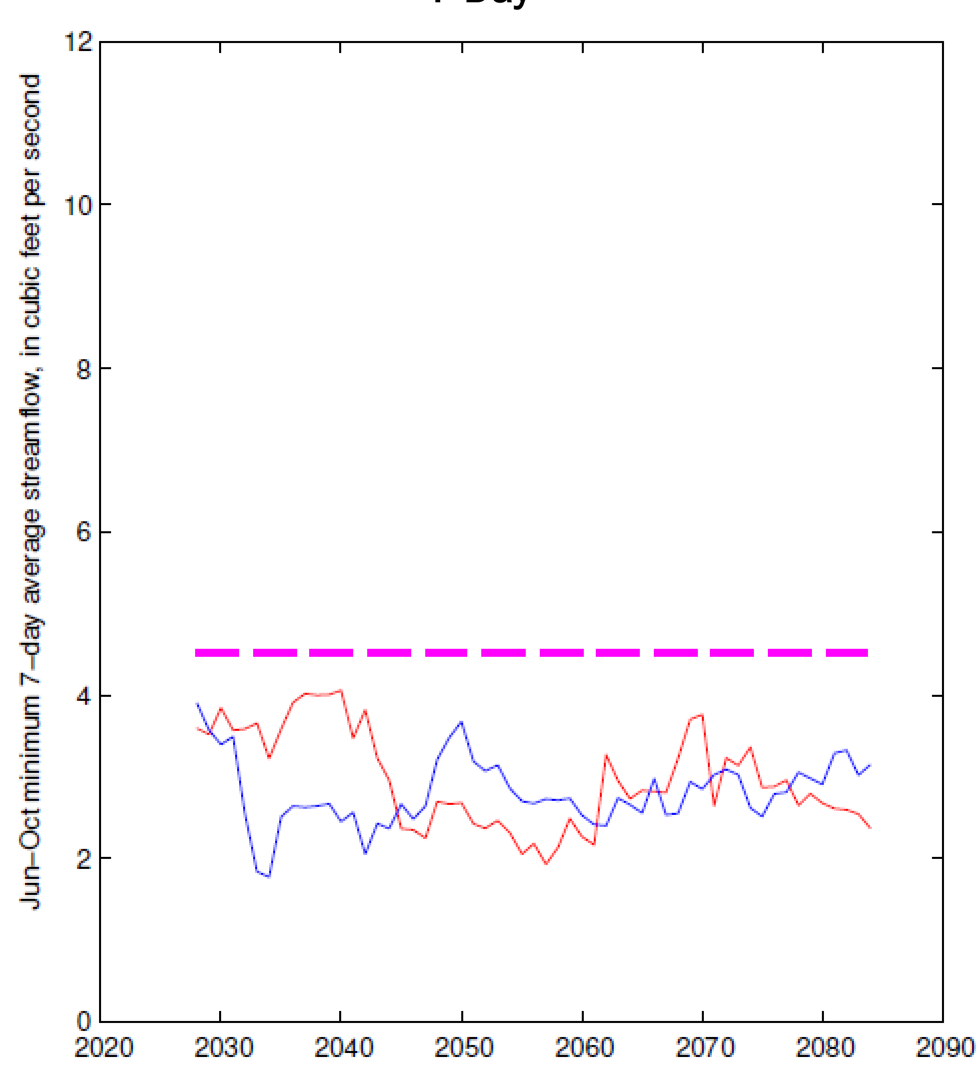


Summer Average Minimum Stream Flow: Climate Only

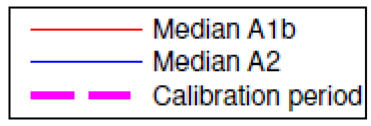
30-Day



7-Day

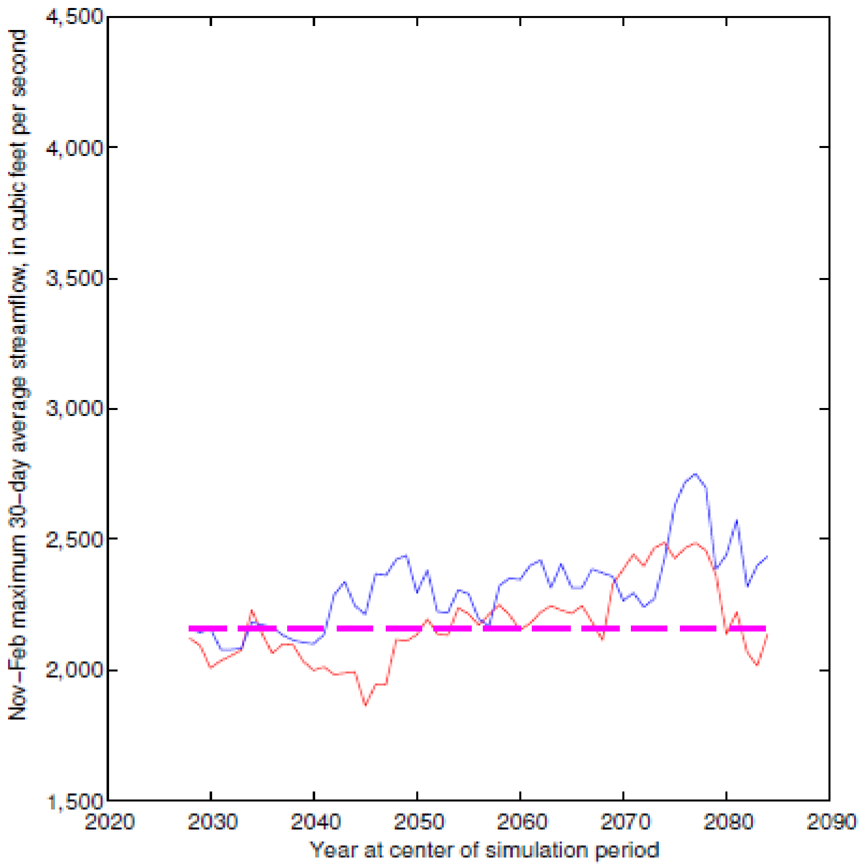


Olentangy River at DEL-CO Intake

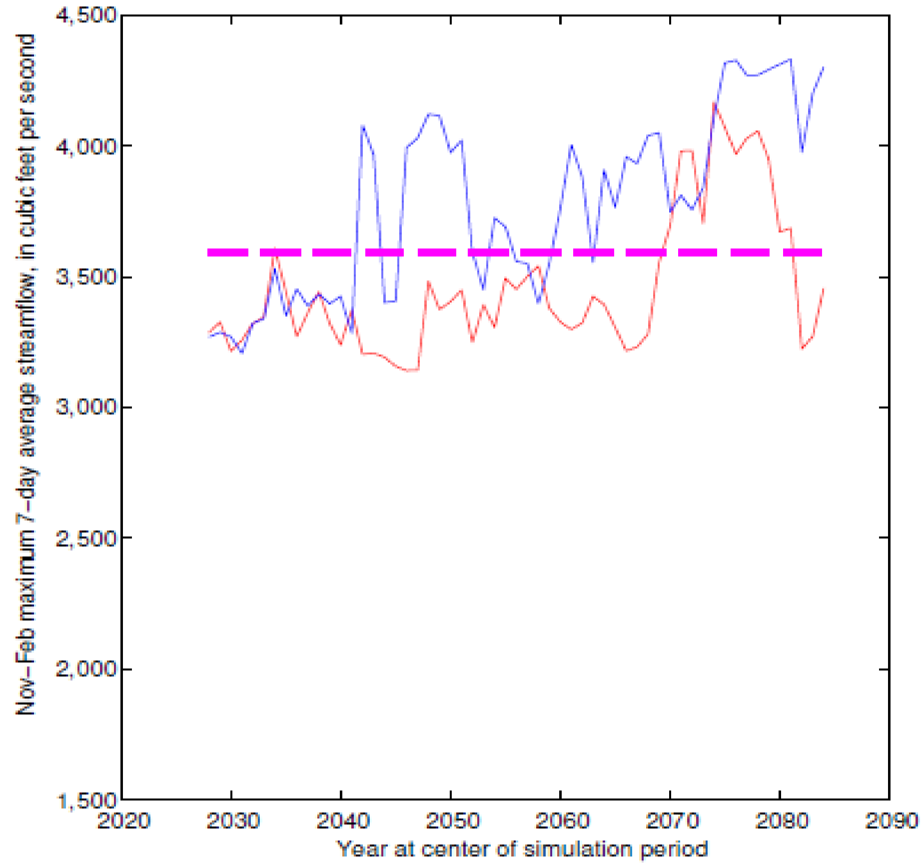


Fall/Winter Average Maximum Stream Flow: Climate Only

30-Day

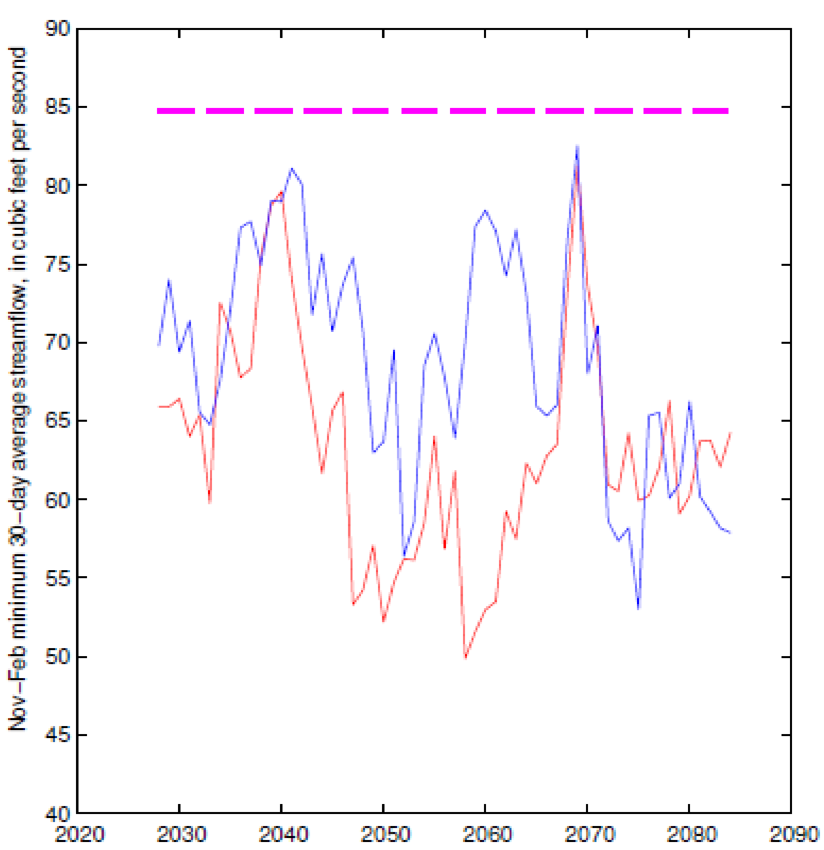


7-Day

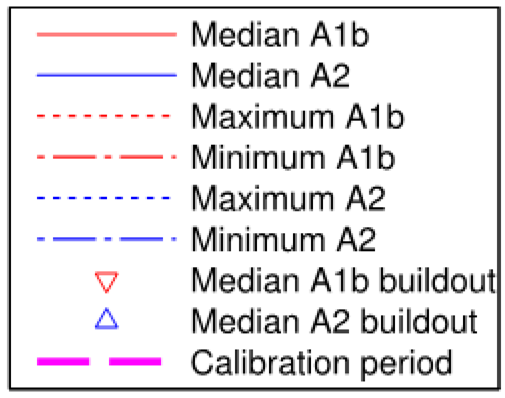


Fall/Winter Average Minimum Stream Flow: Climate Only

30-Day

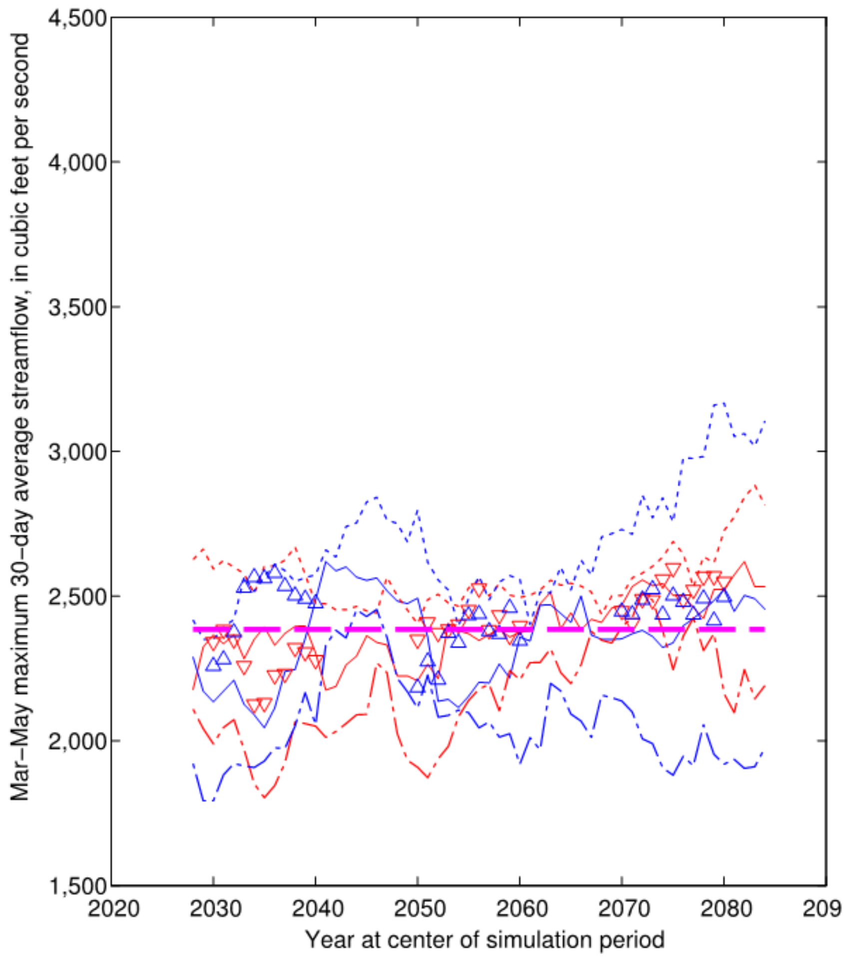


Olentangy River at DEL-CO Intake

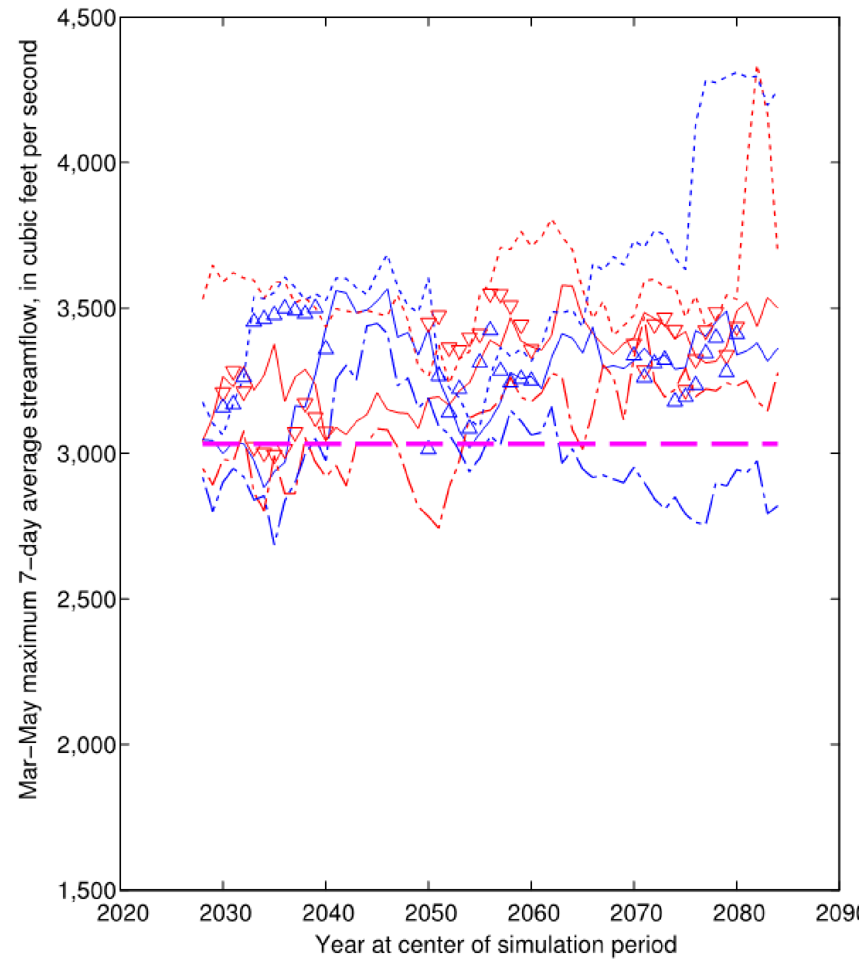


Spring Average Maximum Stream Flows with Development

30-Day

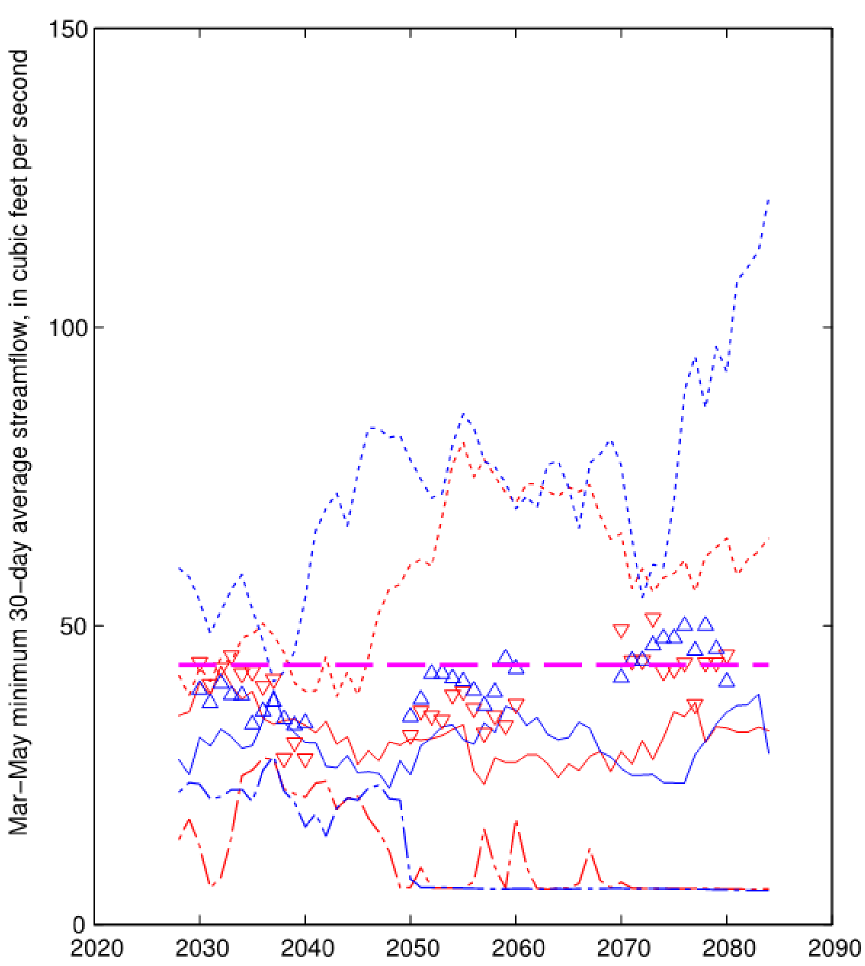


7-Day

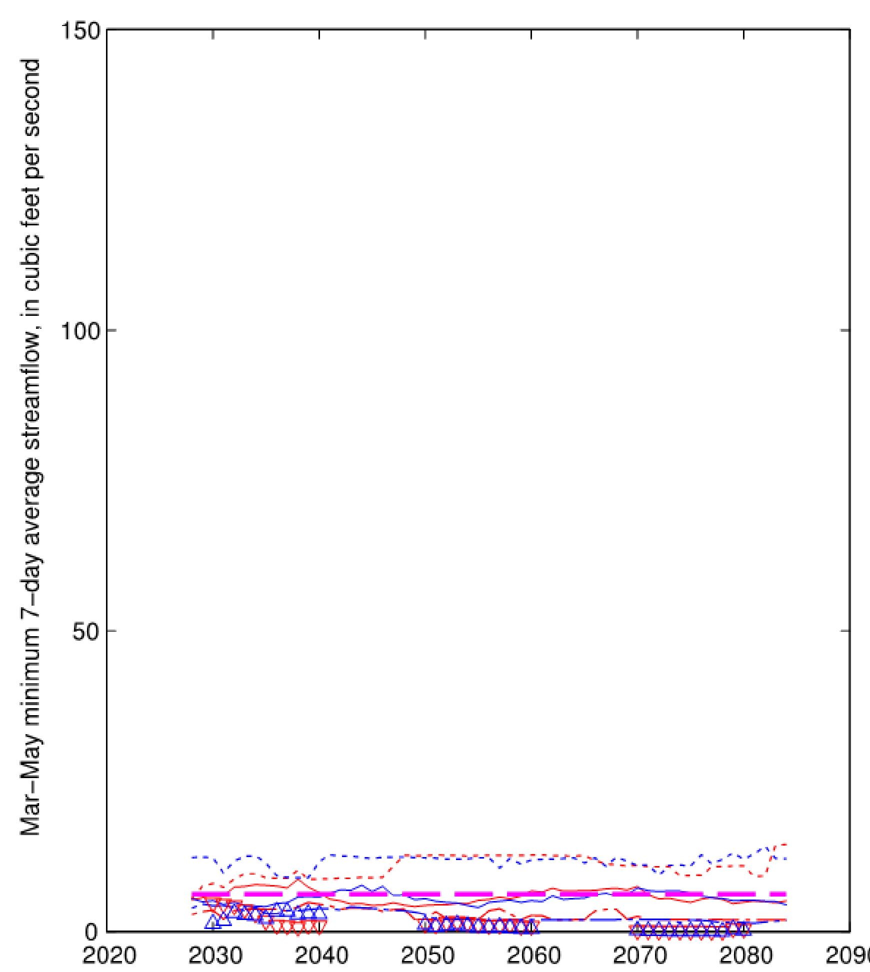


Spring Average Minimum Stream Flows with Development

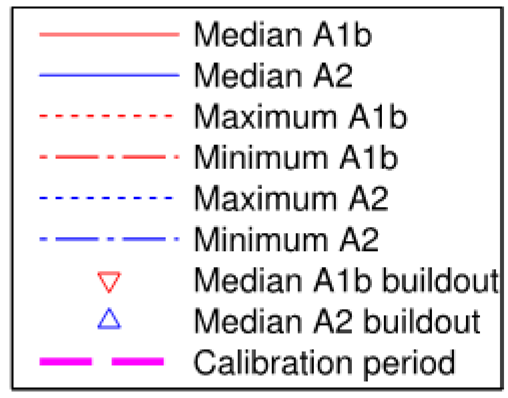
30-Day



7-Day

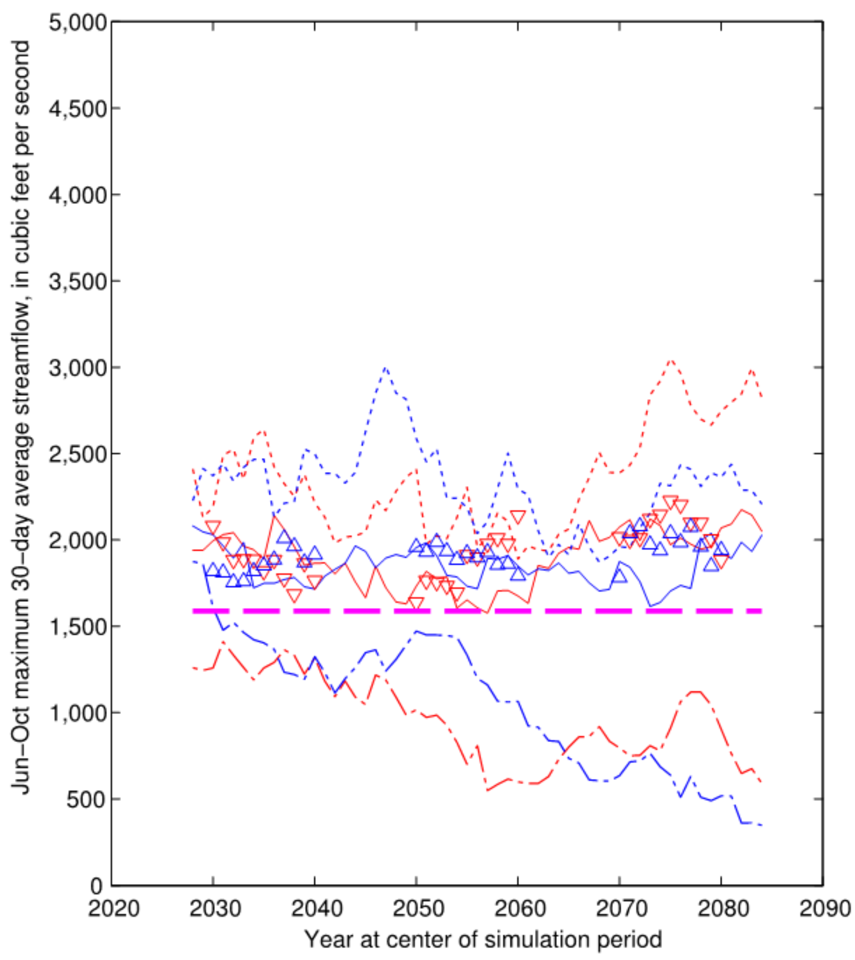


Olentangy River at DEL-CO Intake

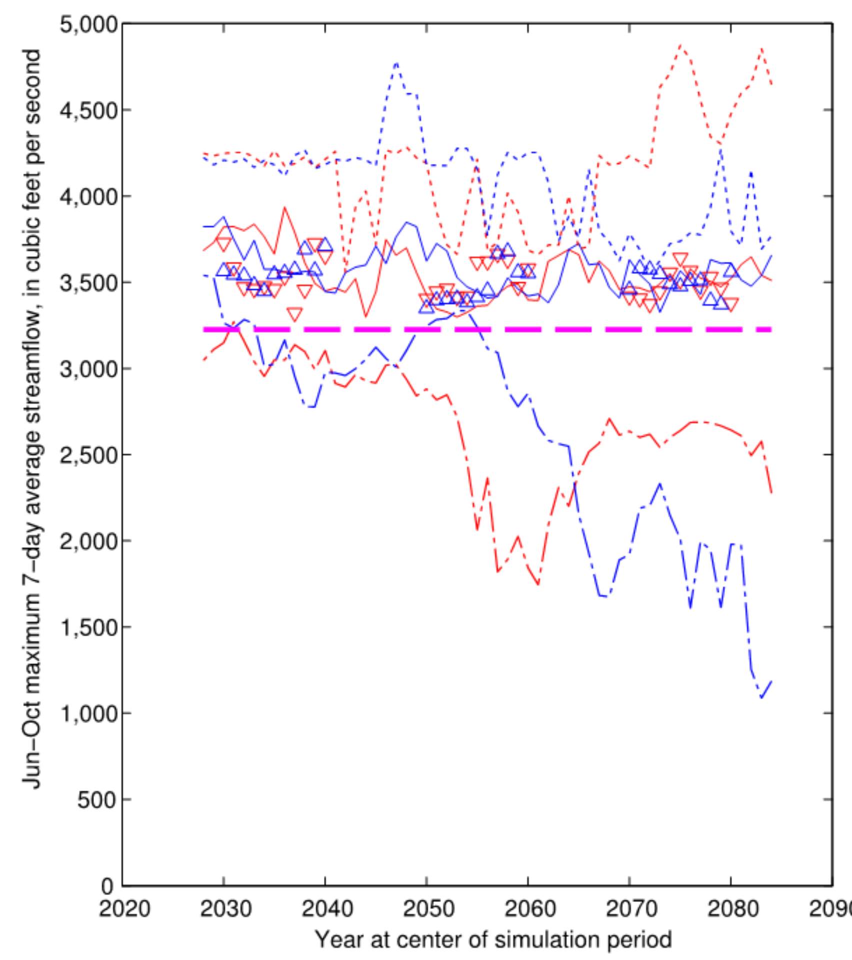


Summer Average Maximum Stream Flows with Development

30-Day

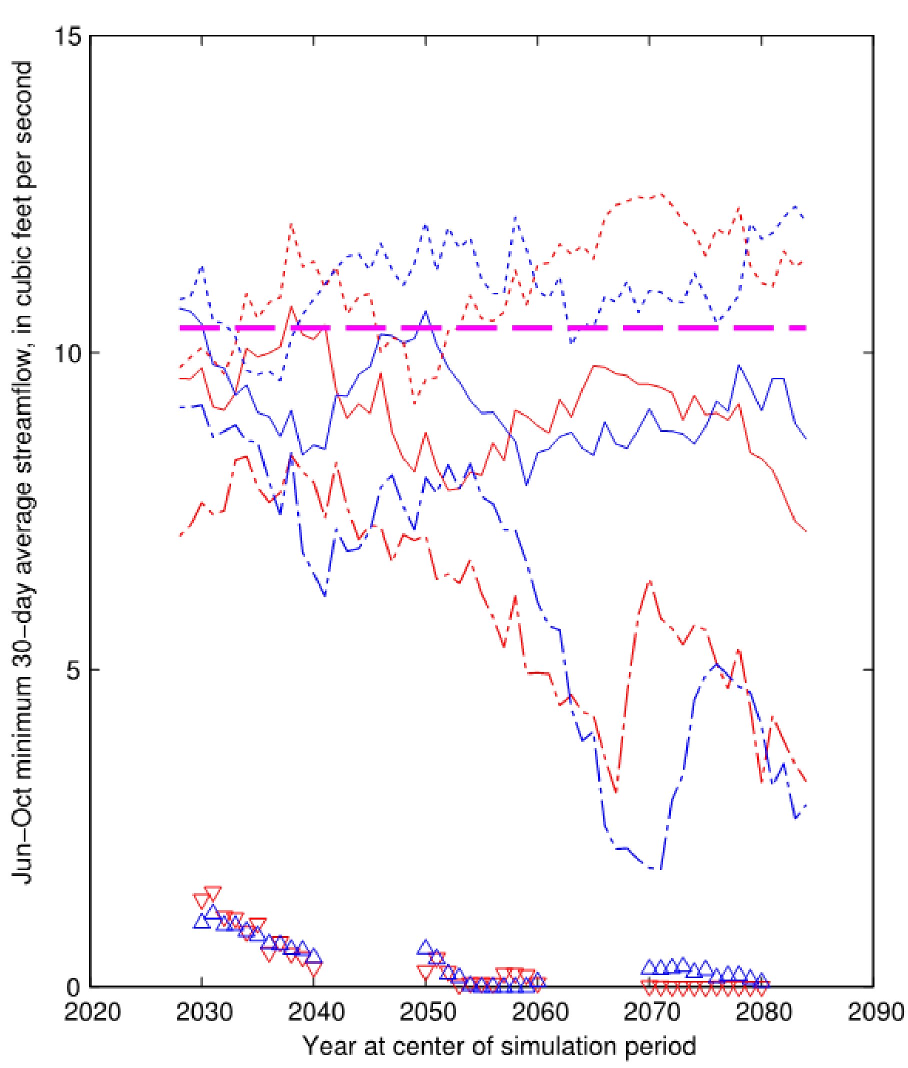


7-Day

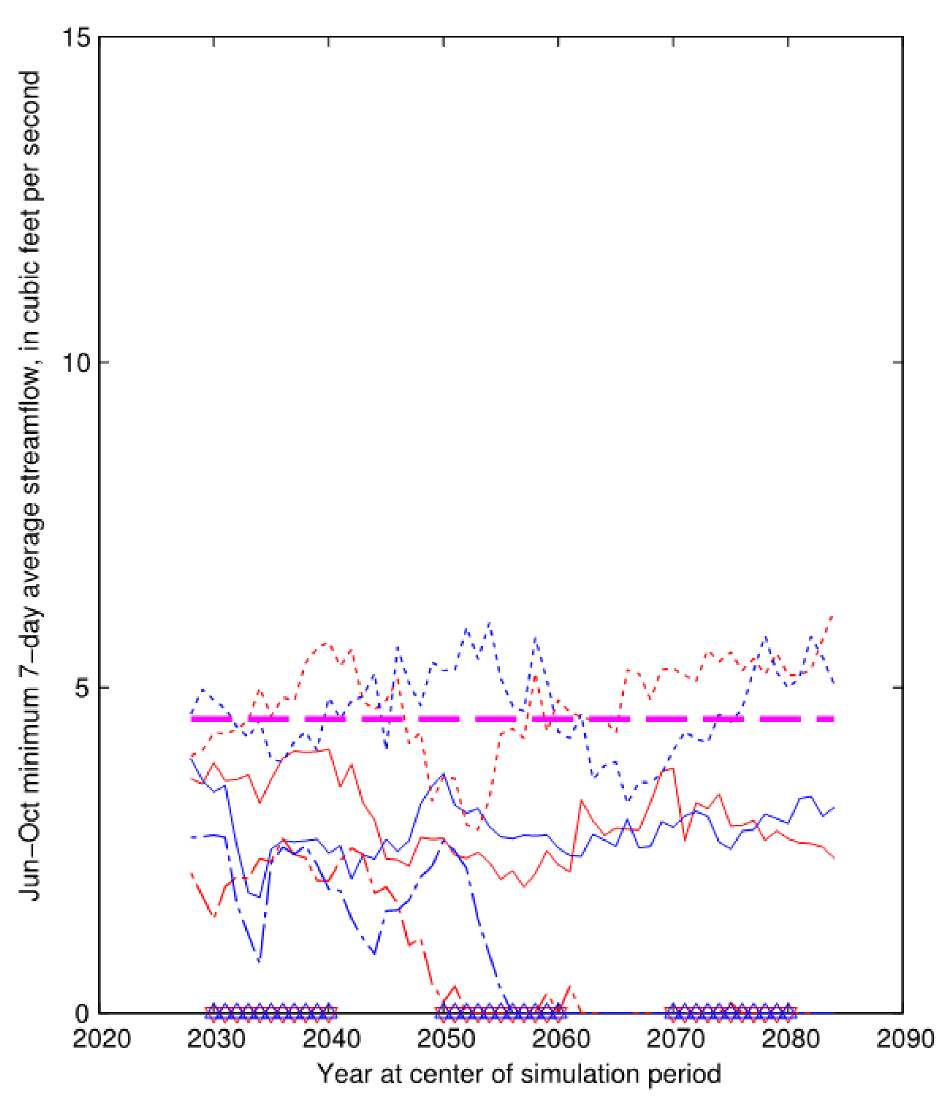


Summer Average Minimum Stream Flows with Development

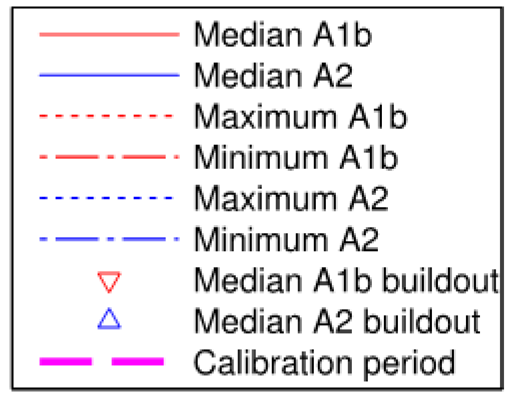
30-Day



7-Day

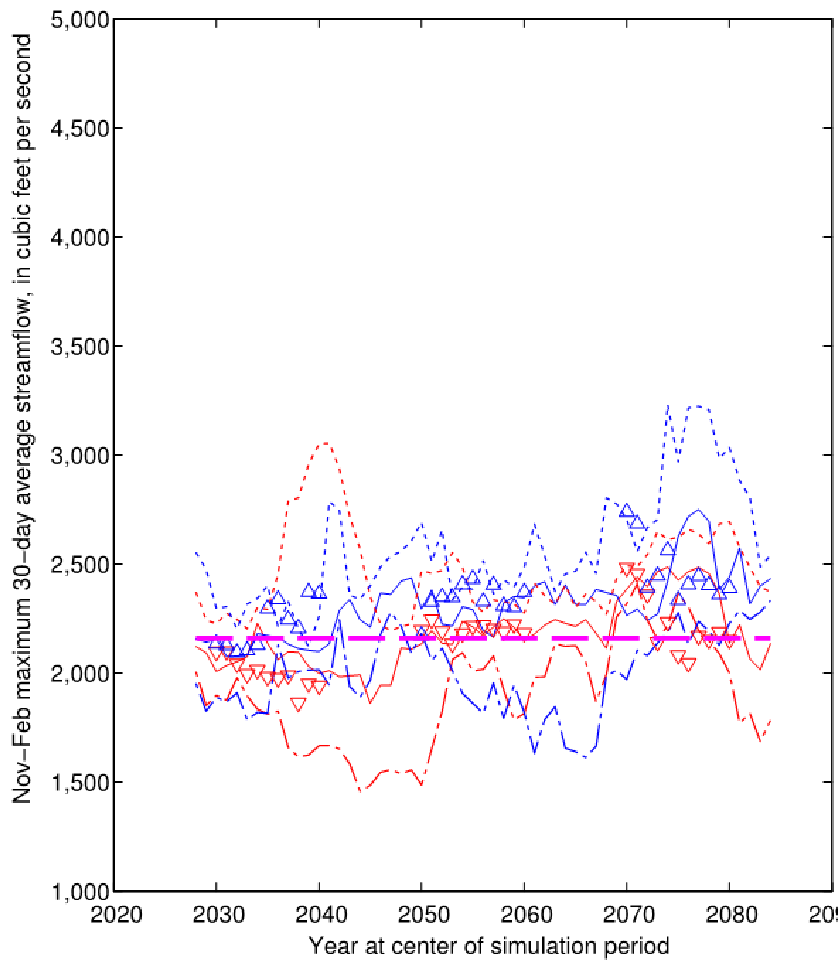


Olentangy River at DEL-CO Intake

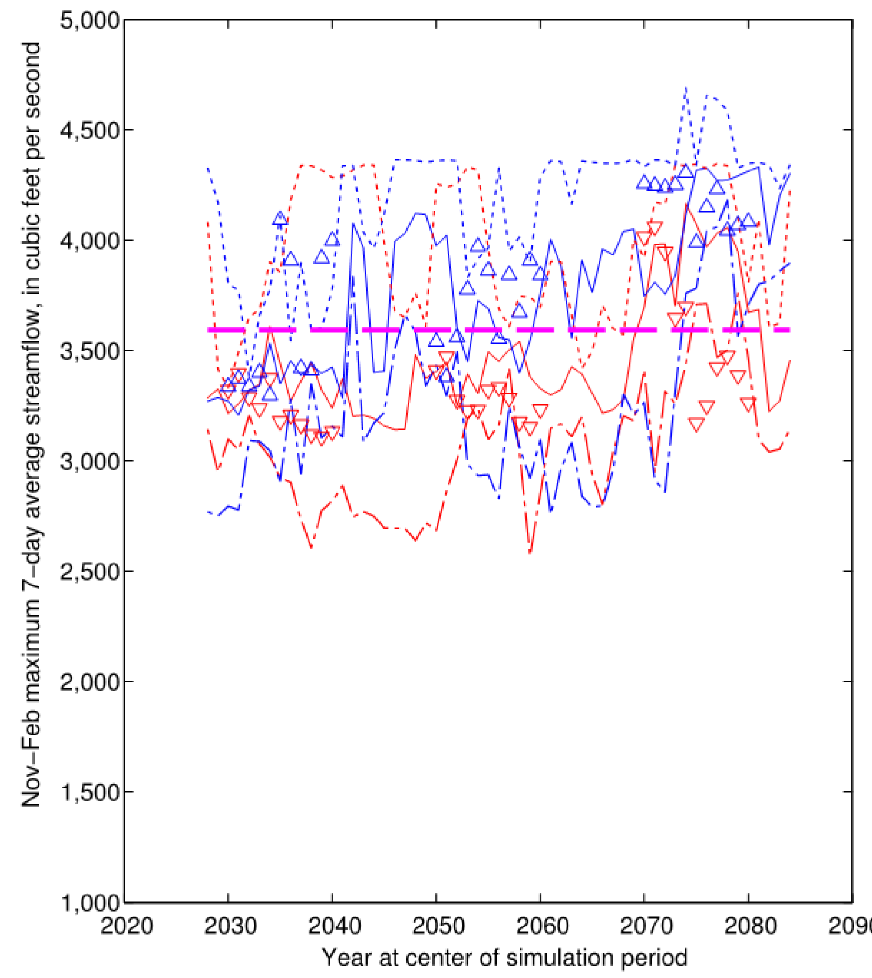


Fall/Winter Average Maximum Stream Flows with Development

30-Day

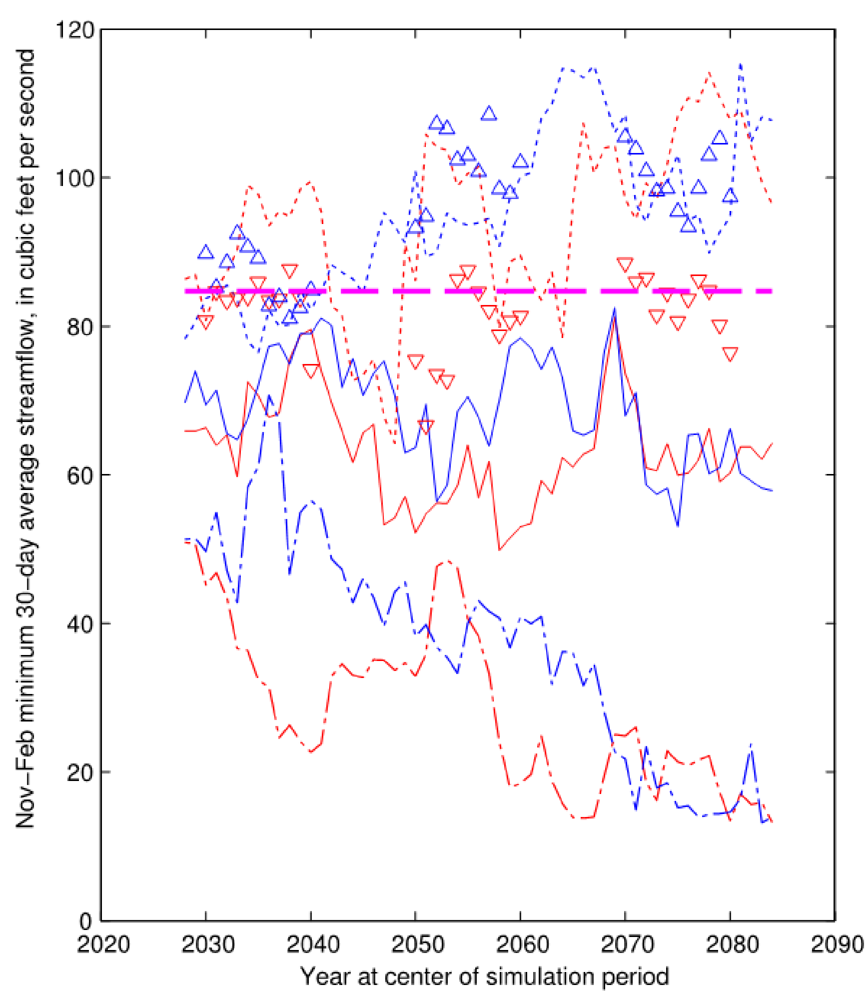


7-Day

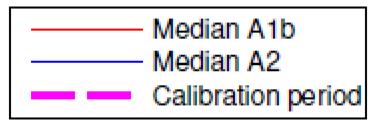


Fall/Winter Average Minimum Stream Flows with Development

30-Day

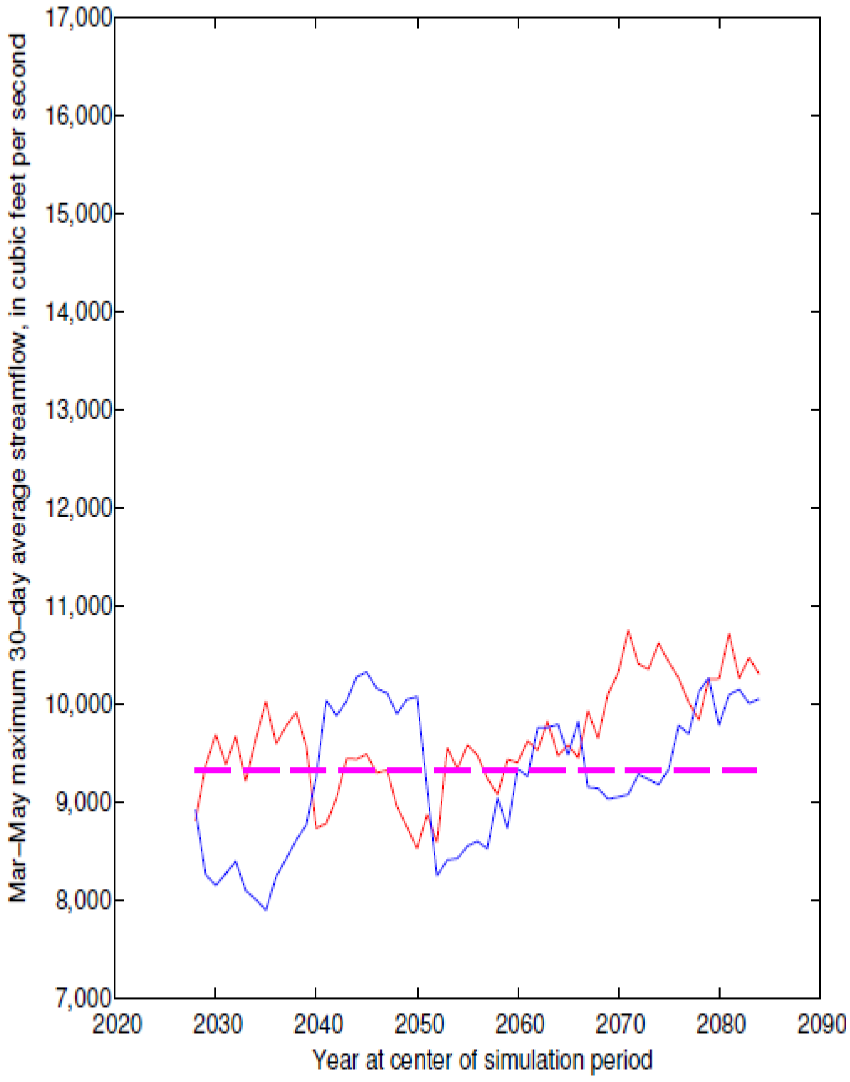


Scioto River at Columbus Seasonal Stream Flows

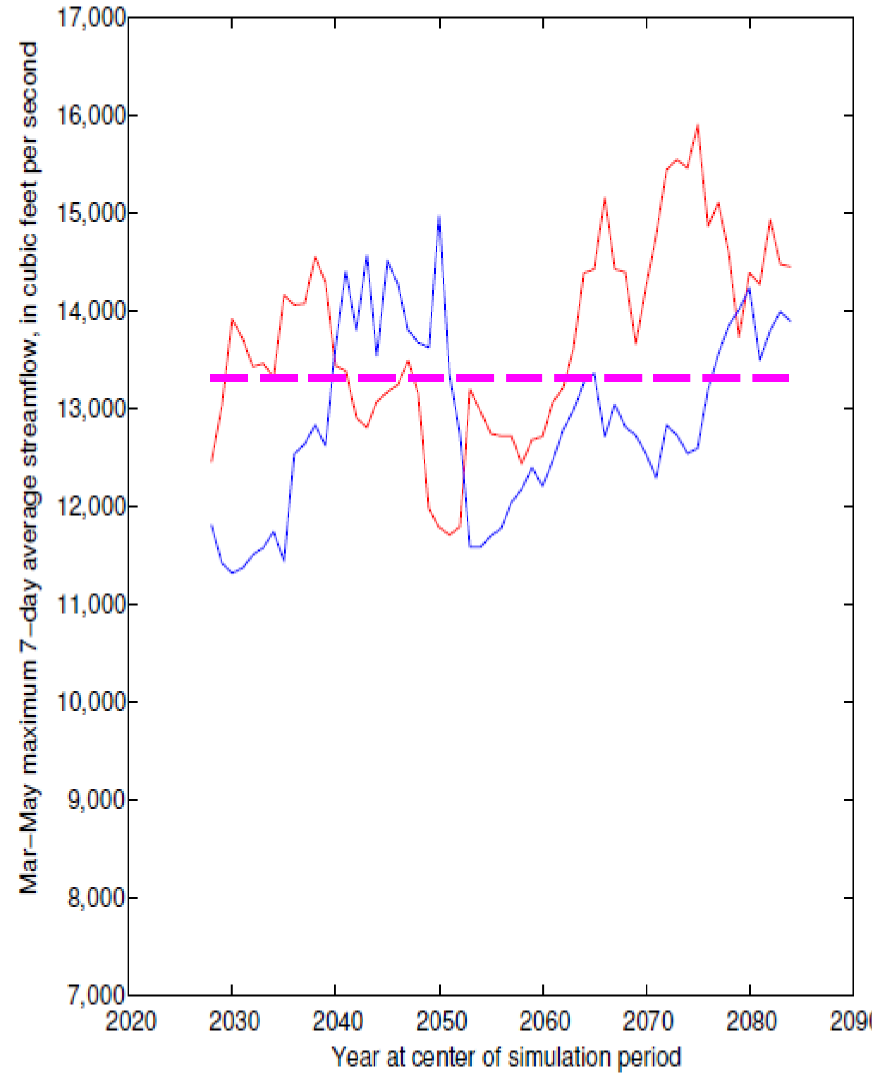


Spring Average Maximum Stream Flow: Climate Only

30-Day

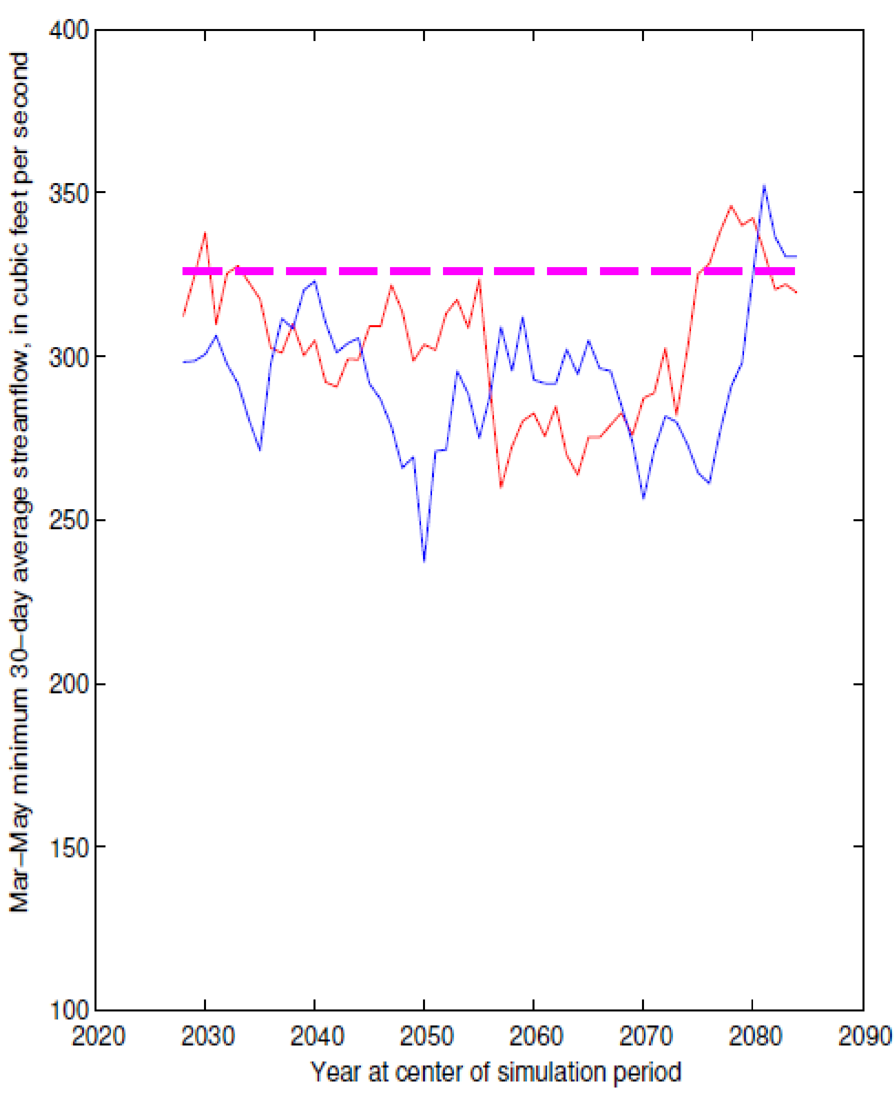


7-Day

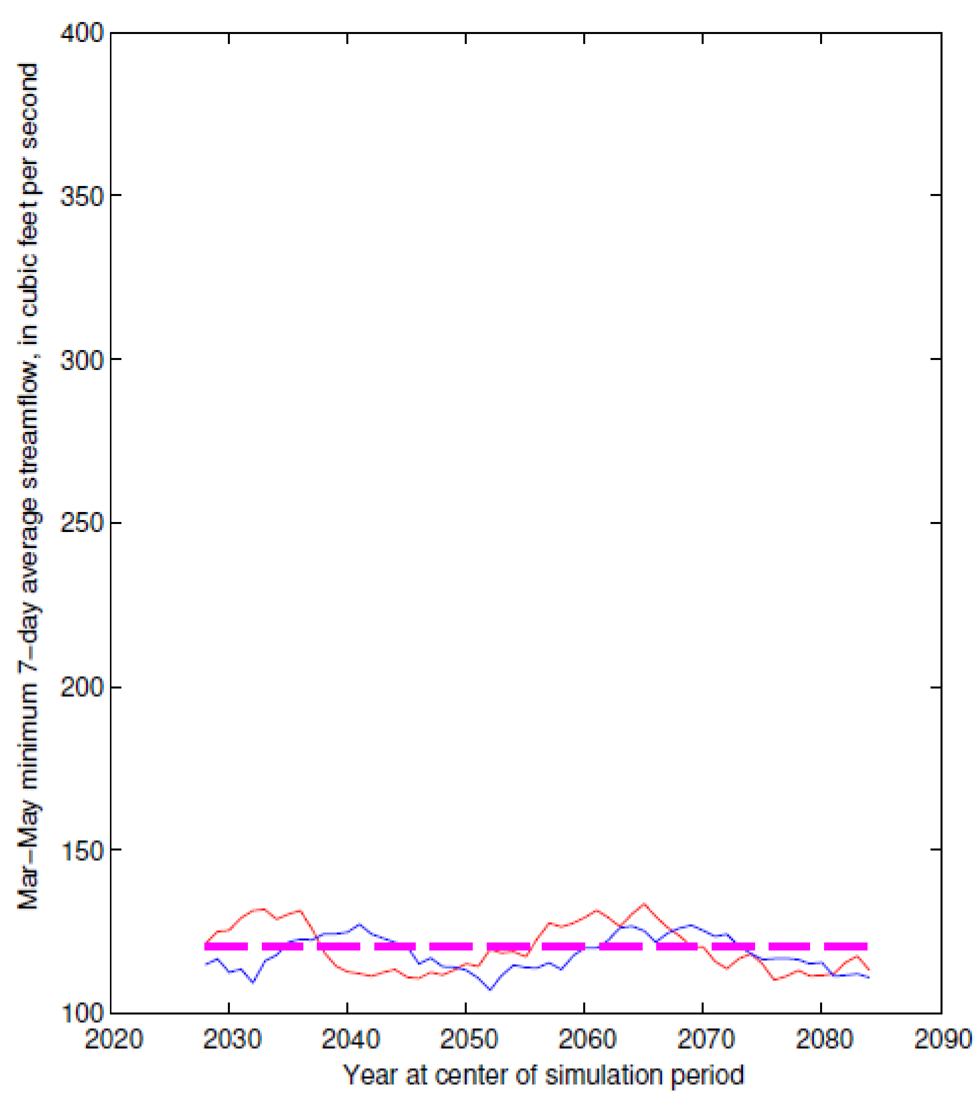


Spring Average Minimum Stream Flow: Climate Only

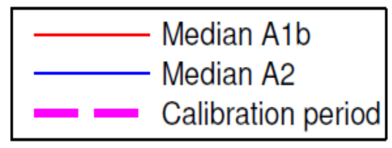
30-Day



7-Day

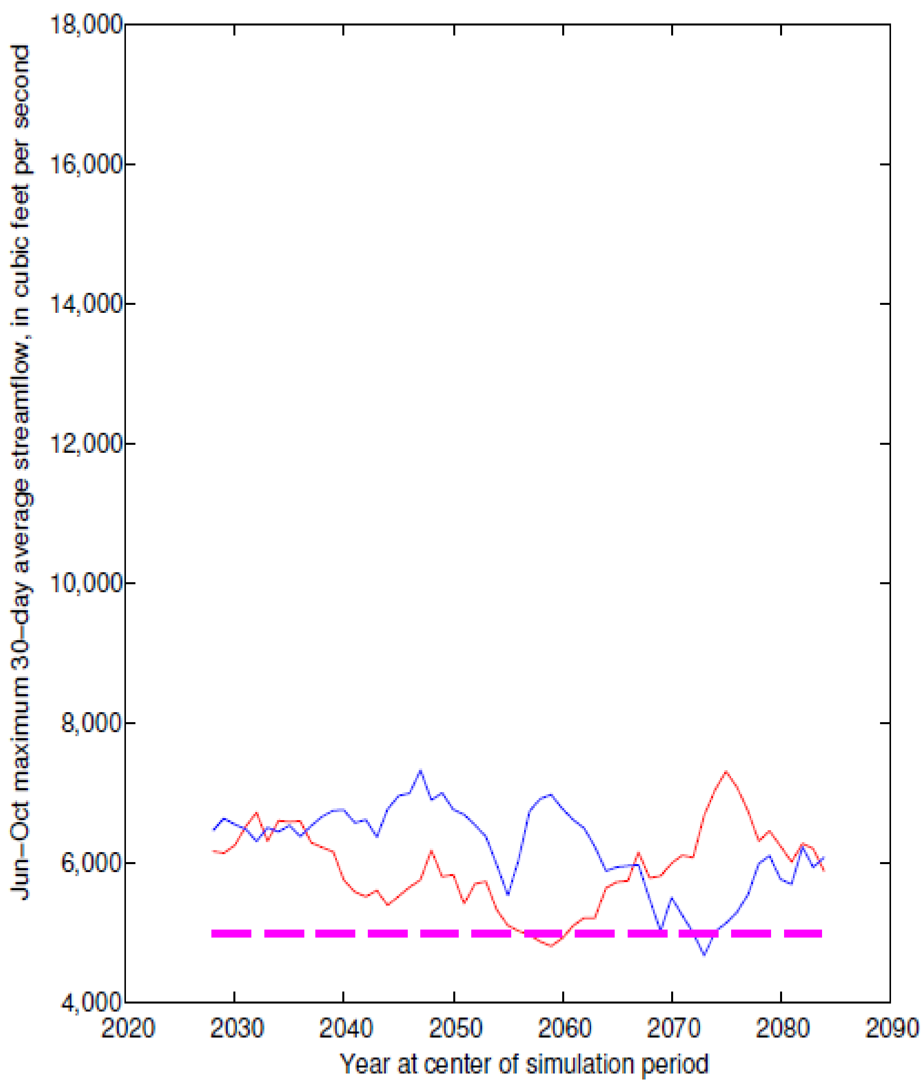


Scioto River at Columbus

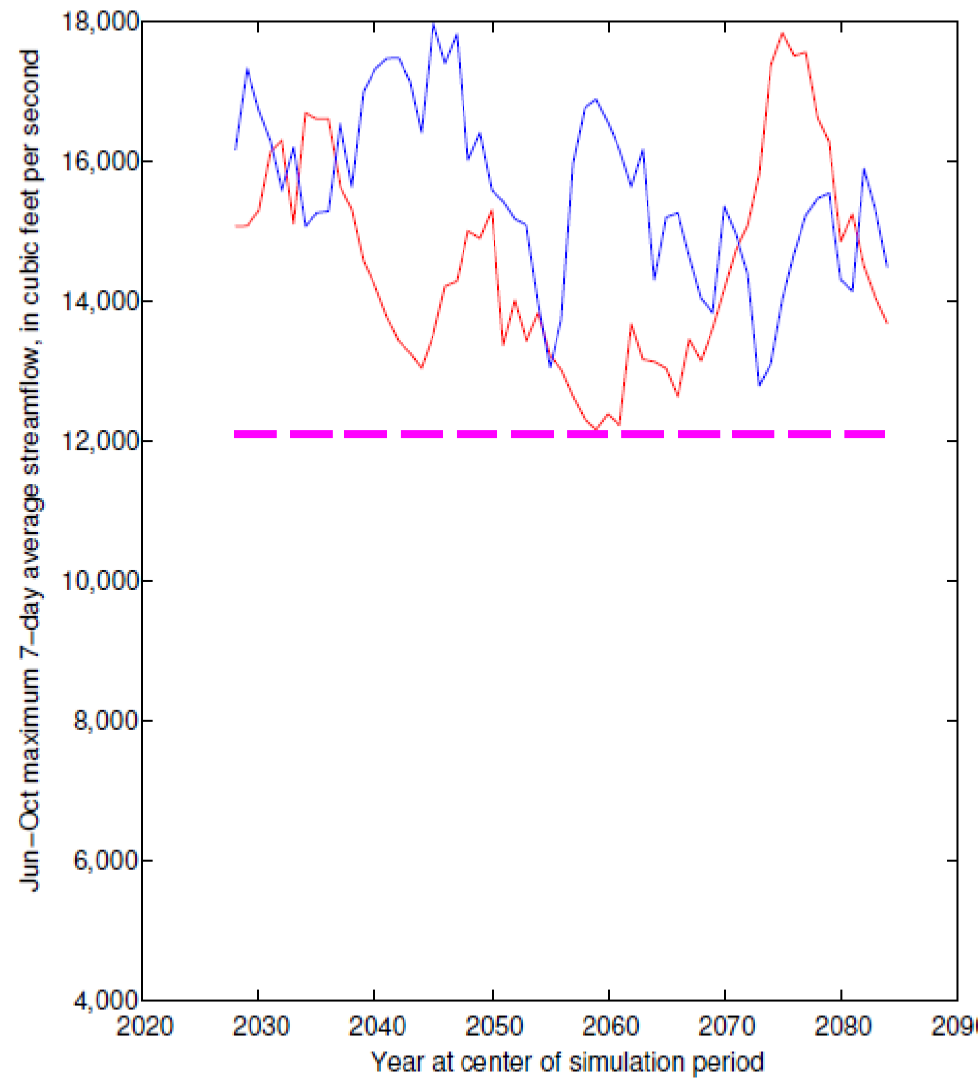


Summer Average Maximum Stream Flow: Climate Only

30-Day

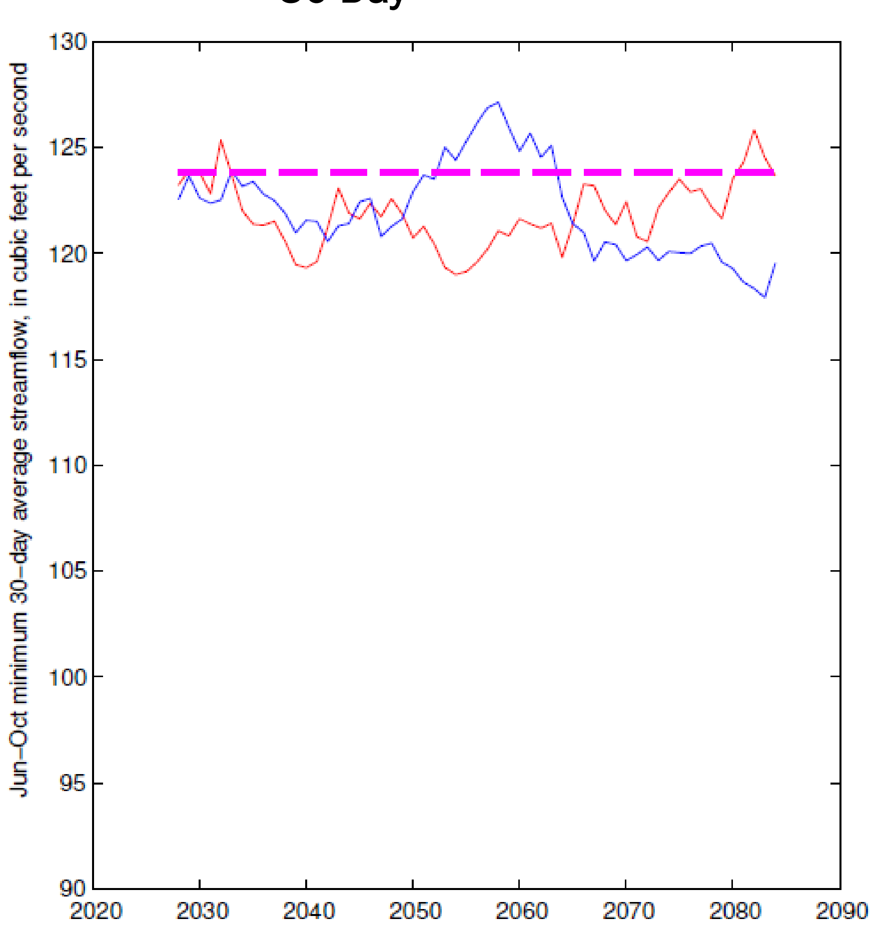


7-Day

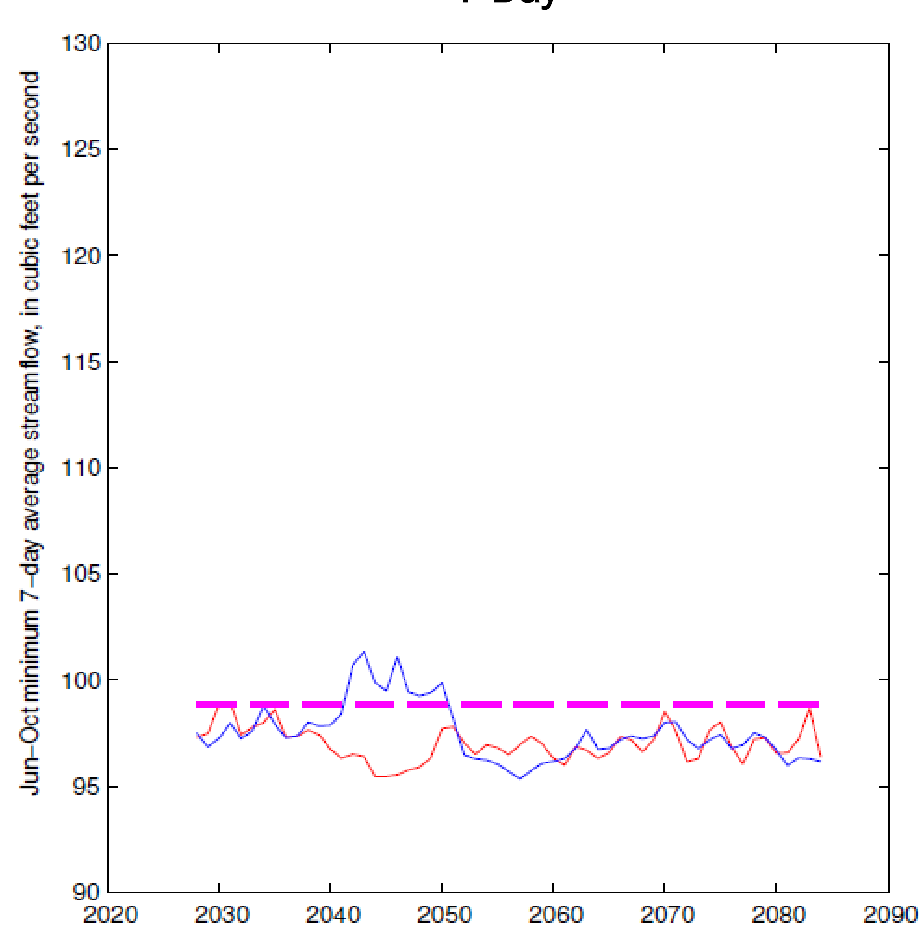


Summer Average Minimum Stream Flow: Climate Only

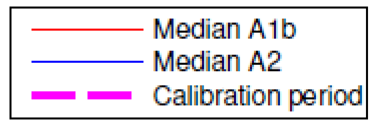
30-Day



7-Day

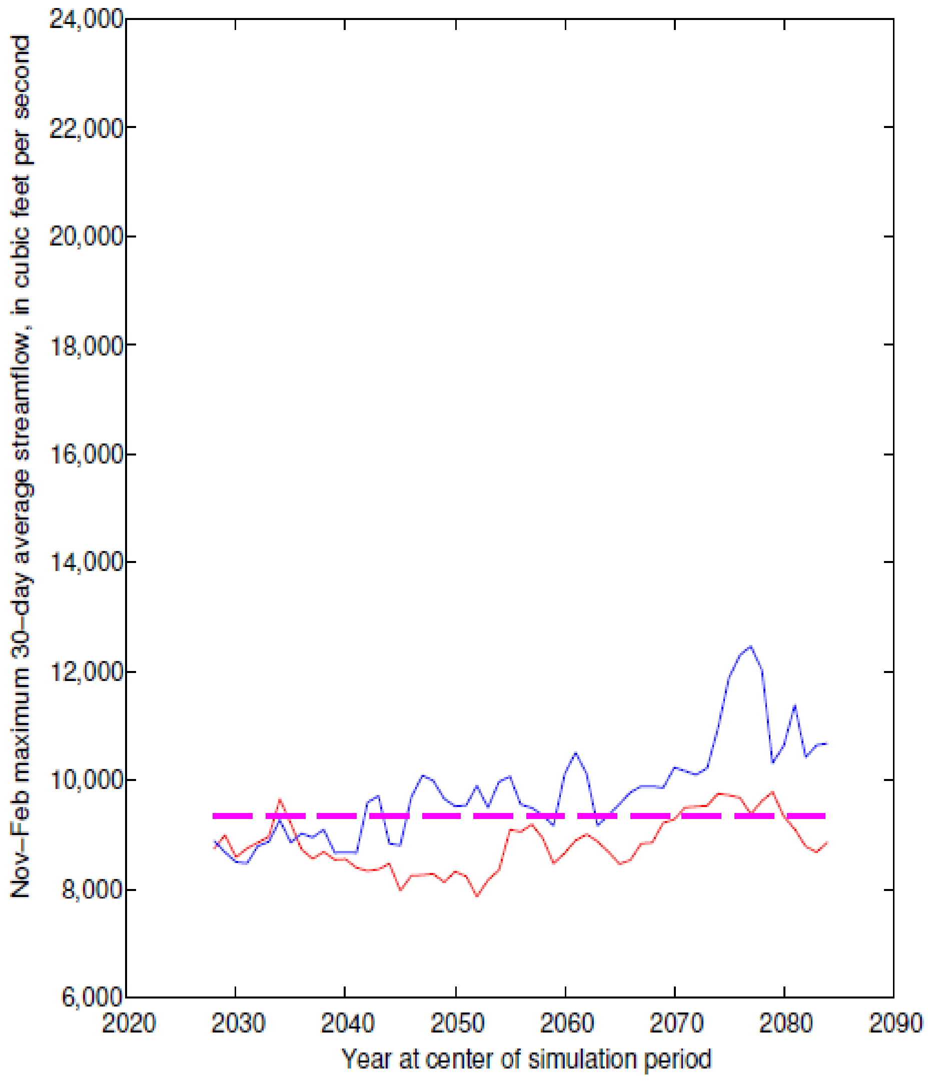


Scioto River at Columbus Seasonal Stream Flows

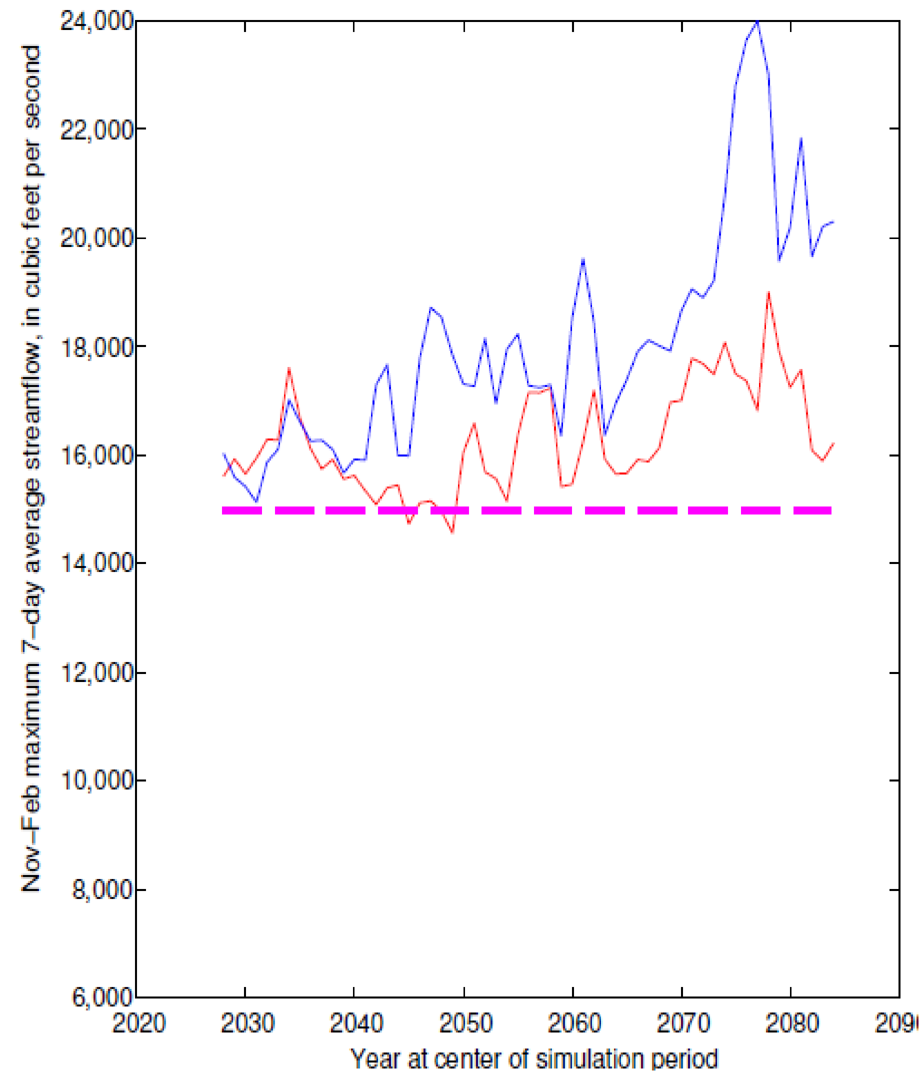


Fall/ Winter Average Maximum Stream Flow: Climate Only

30-Day

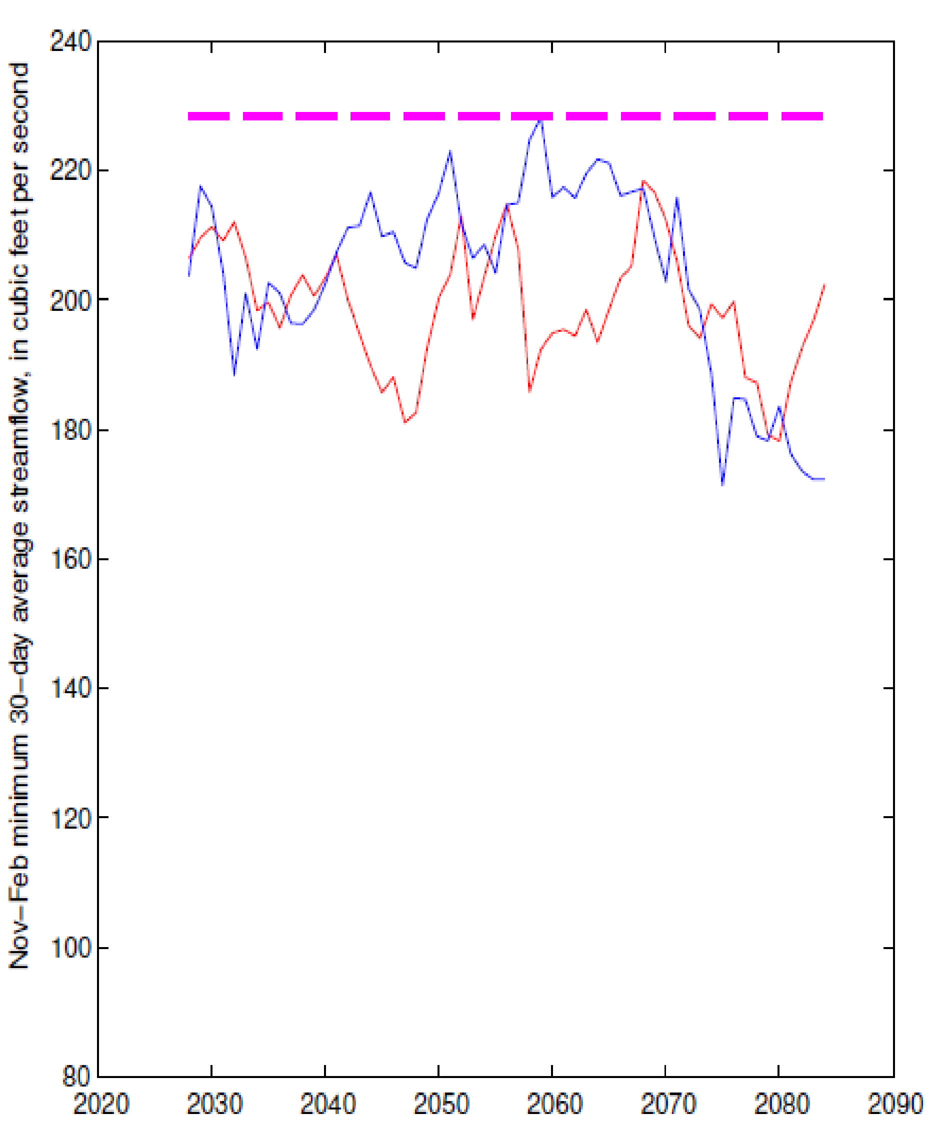


7-Day

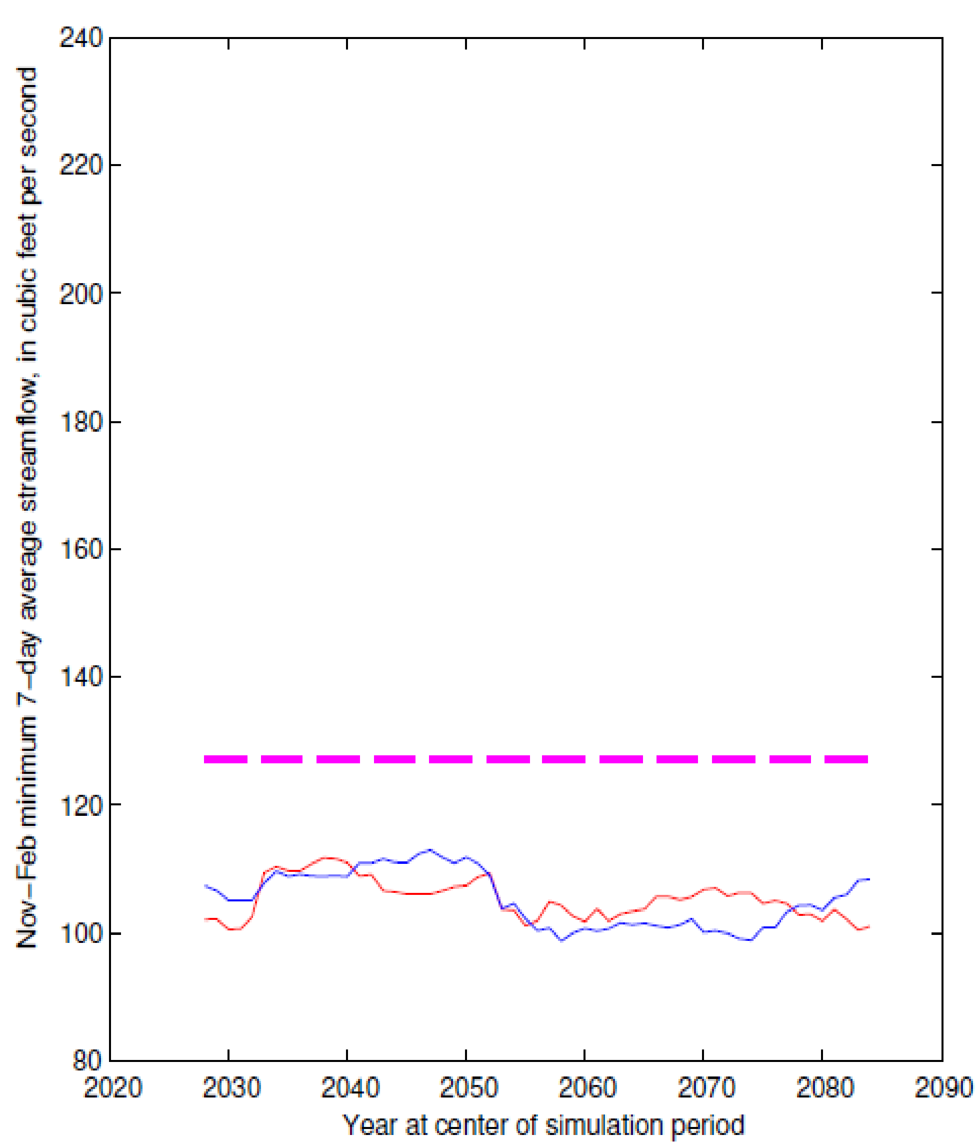


Fall/ Winter Average Minimum Stream Flow: Climate Only

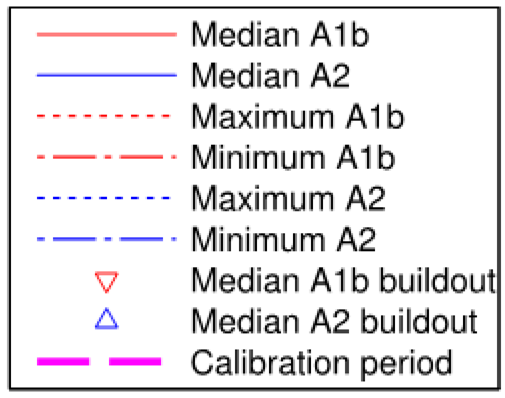
30-Day



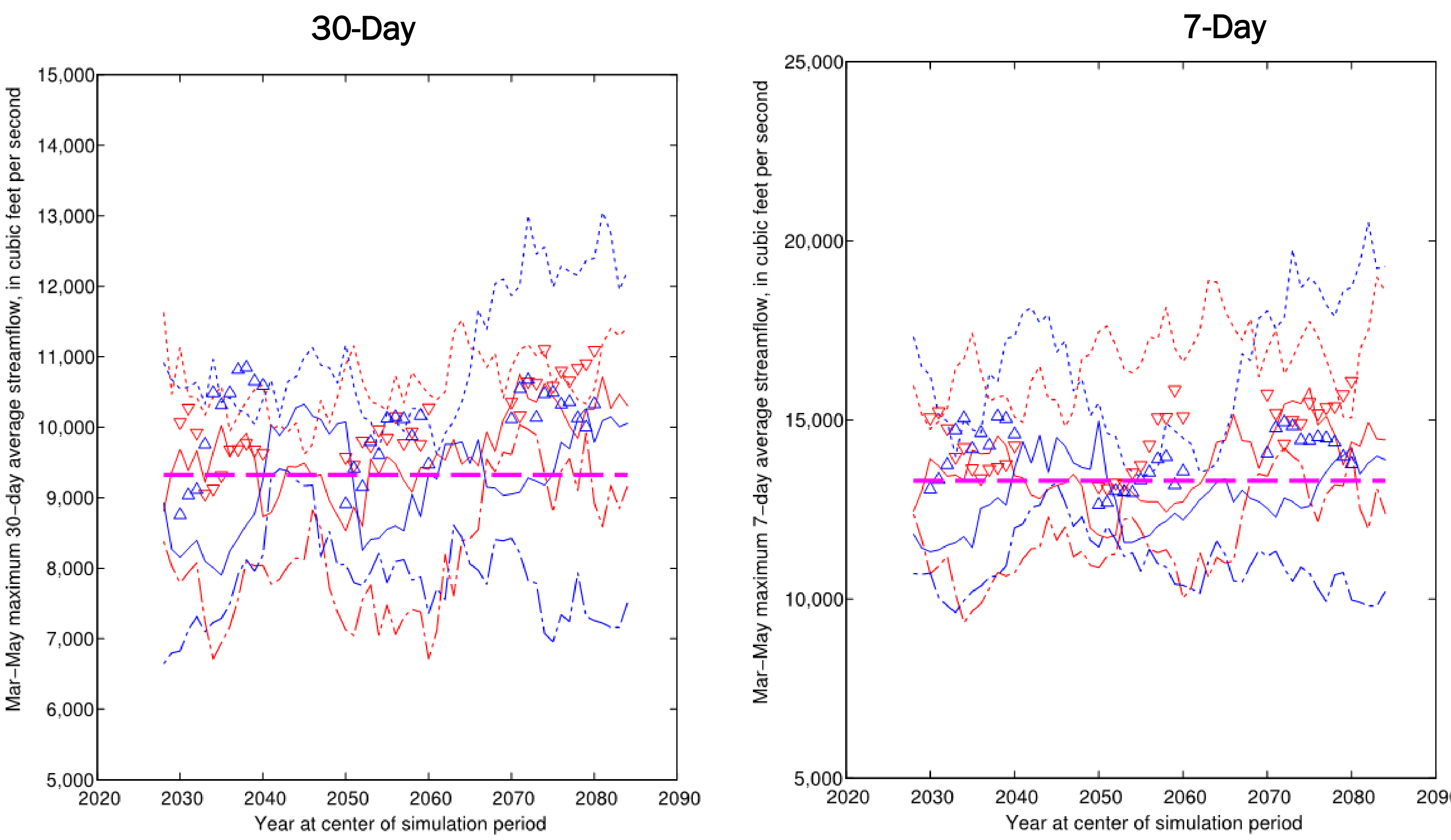
7-Day



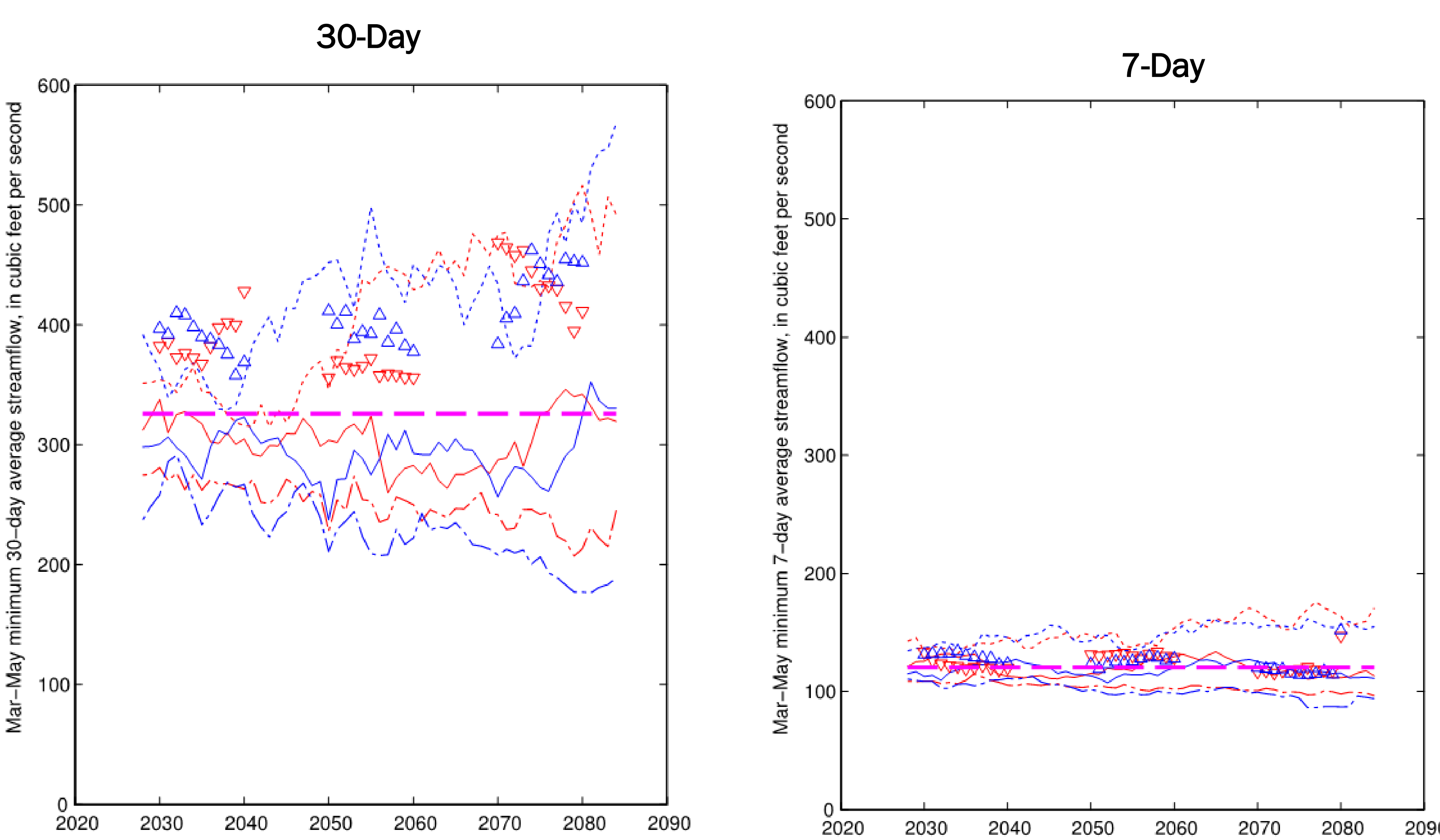
Scioto River at Columbus

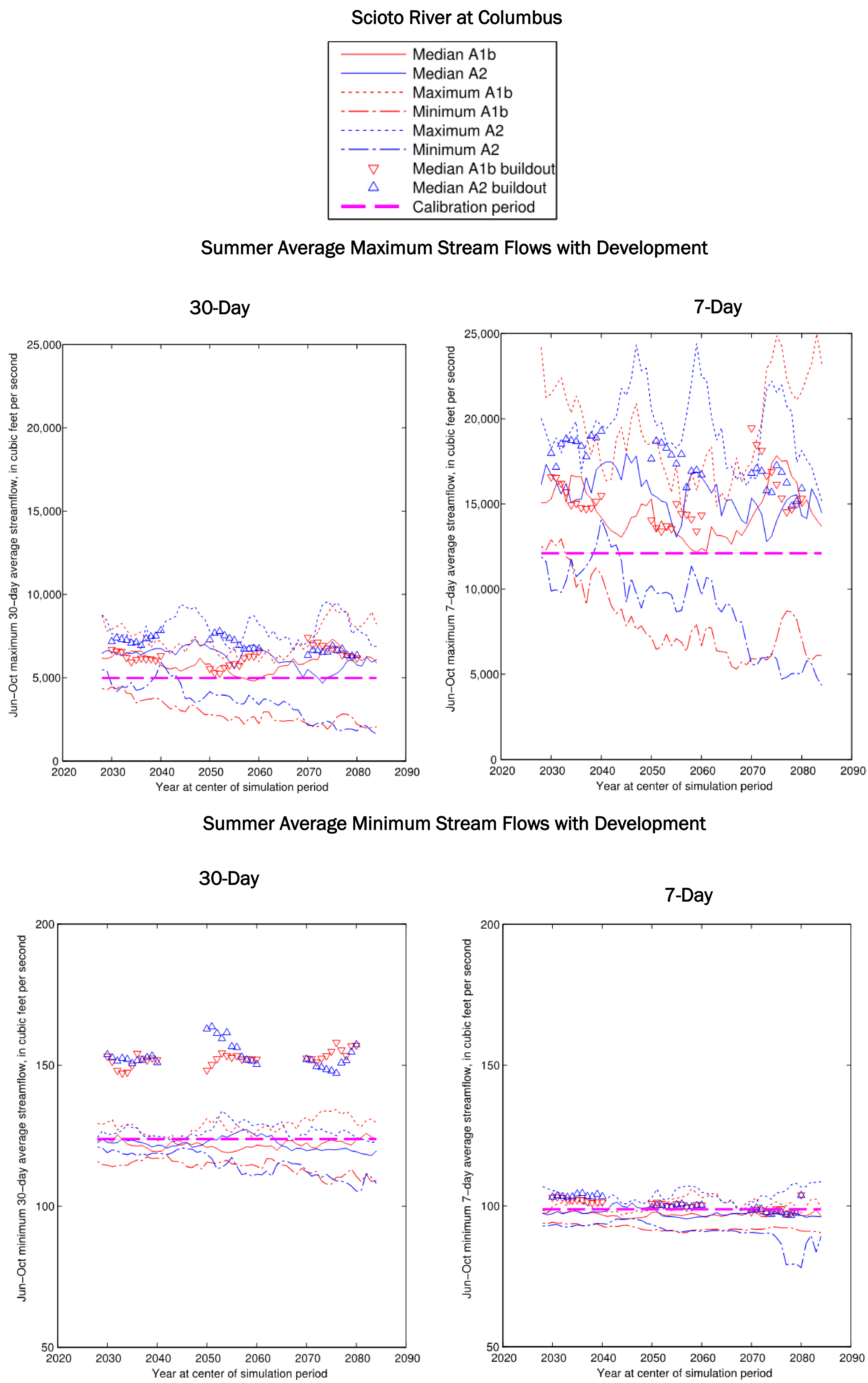


Spring Average Maximum Stream Flows with Development



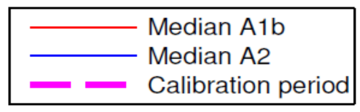
Spring Average Minimum Stream Flows with Development




Scioto River at Columbus
Median A1b
Median A2
Maximum A1b
Minimum A1b
Maximum A2
Minimum A2
Median A1b buildout
Median A2 buildout
Calibration period
Summer Average Maximum Stream Flows with Development
30-Day
7-Day
Jun–Oct maximum 30–day average streamflow, in cubic feet per second
Jun–Oct maximum 7–day average streamflow, in cubic feet per second
0
5,000
10,000
15,000
20,000
25,000
2020
2030
2040
2050
2060
2070
2080
2090
Year at center of simulation period
Summer Average Minimum Stream Flows with Development
30-Day
7-Day
Jun–Oct minimum 30–day average streamflow, in cubic feet per second
Jun–Oct minimum 7–day average streamflow, in cubic feet per second
50
100
150
200
Year at center of simulation period

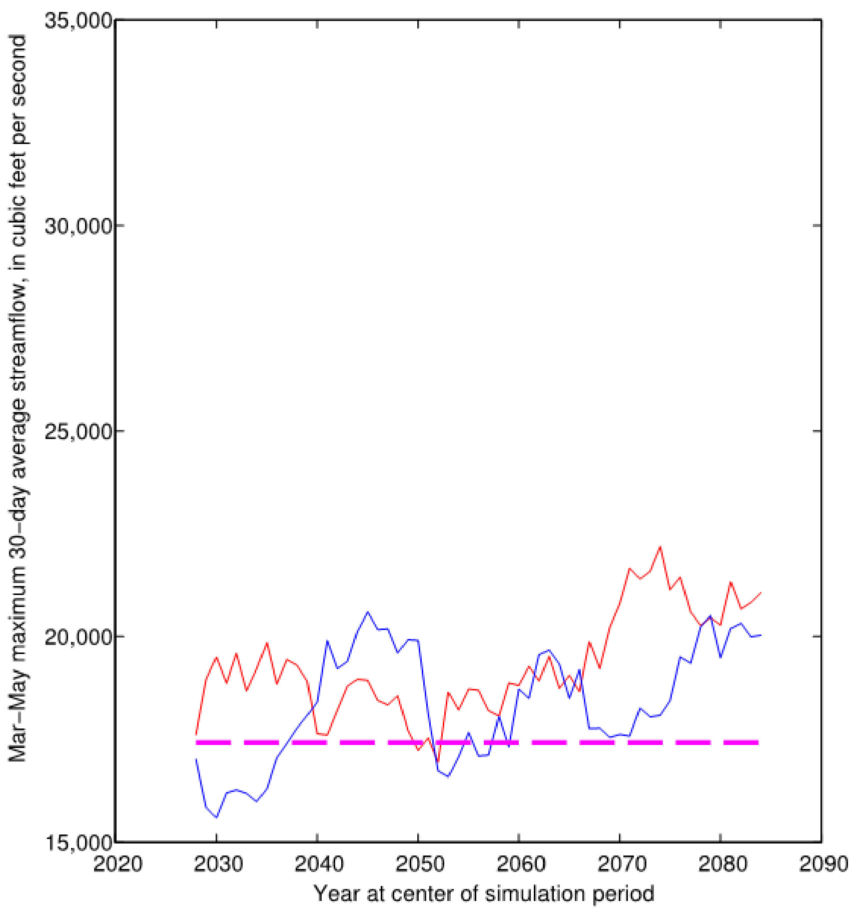

Scioto River at Columbus
Median A1b
Median A2
Maximum A1b
Minimum A1b
Maximum A2
Minimum A2
Median A1b buildout
Median A2 buildout
Calibration period
Fall/Winter Average Maximum Stream Flows with Development
30-Day
7-Day
Nov–Feb maximum 30–day average streamflow, in cubic feet per second
Nov–Feb maximum 7–day average streamflow, in cubic feet per second
Year at center of simulation period
Fall/Winter Average Minimum Stream Flows with Development
30-Day
7-Day
Nov–Feb minimum 30–day average streamflow, in cubic feet per second
Nov–Feb minimum 7–day average streamflow, in cubic feet per second
Year at center of simulation period

Scioto River at Circleville: Seasonal Stream Flows

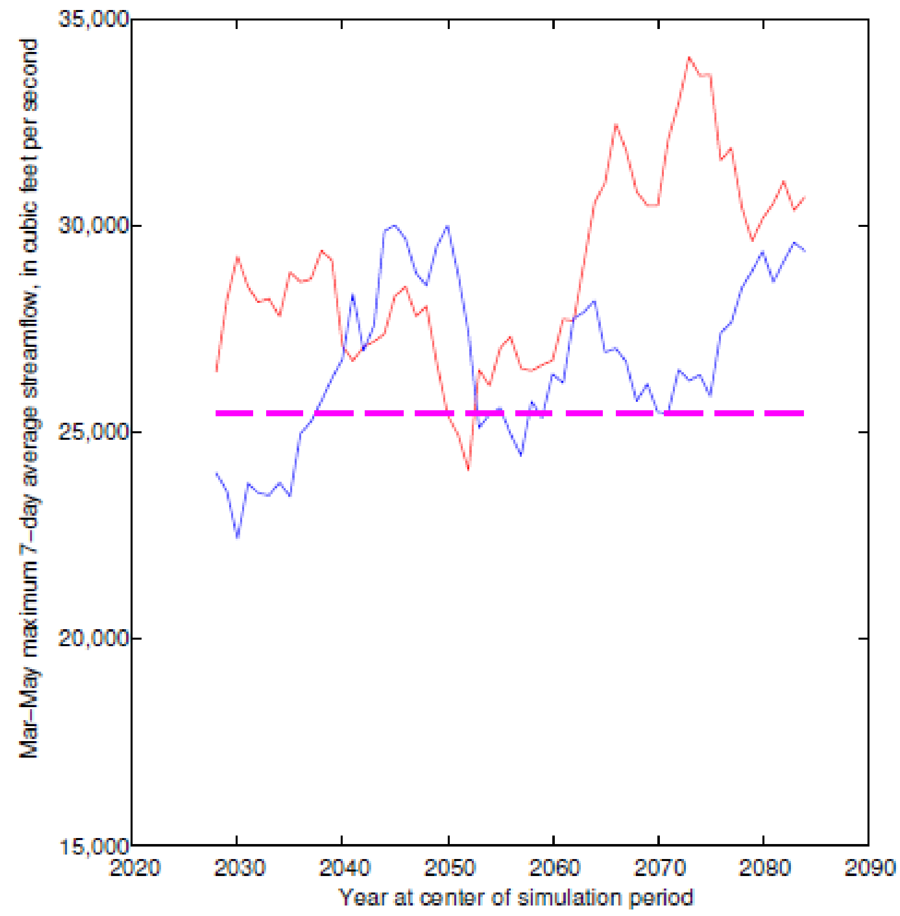


Spring Average Maximum Stream Flow: Climate Only

30-Day

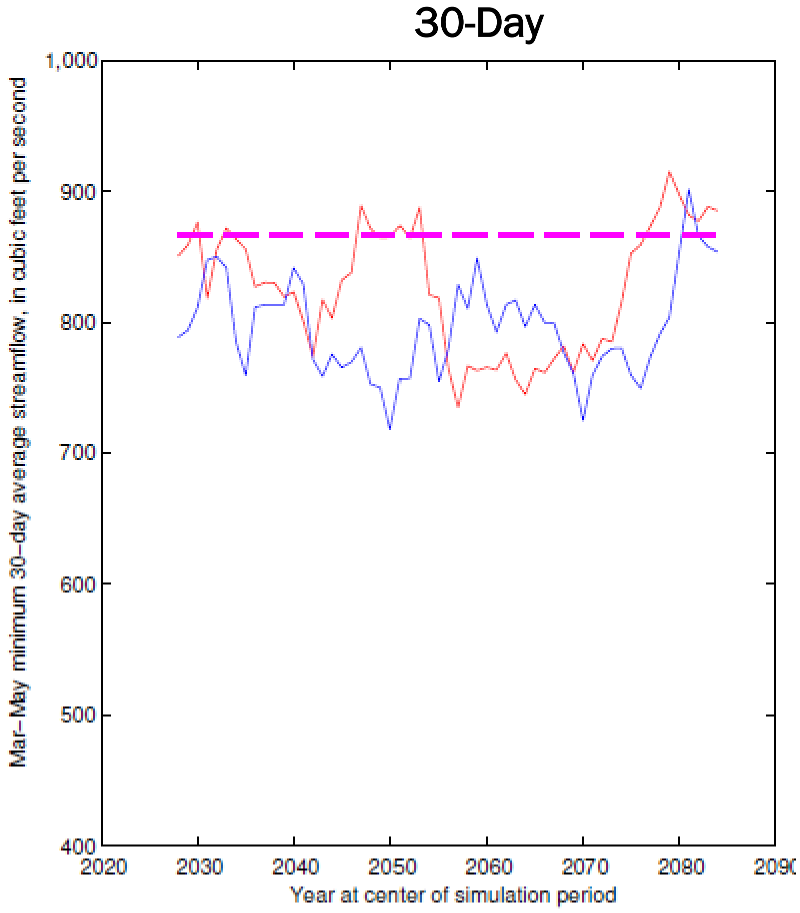


7-Day

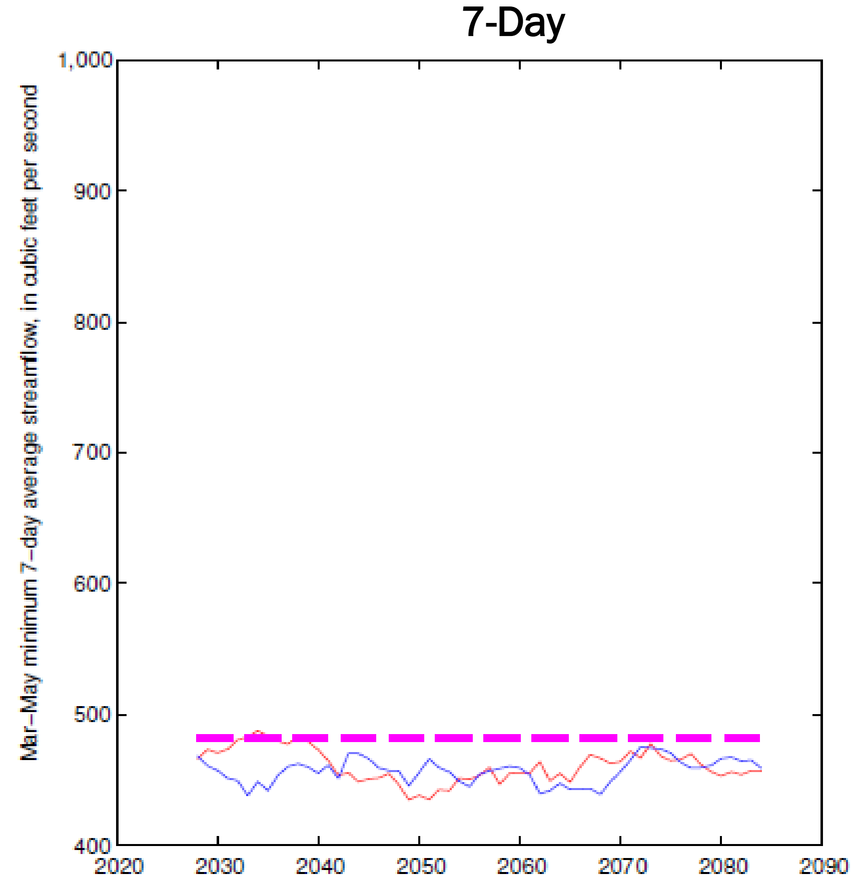


Spring Average Minimum Stream Flow: Climate Only

30-Day



7-Day

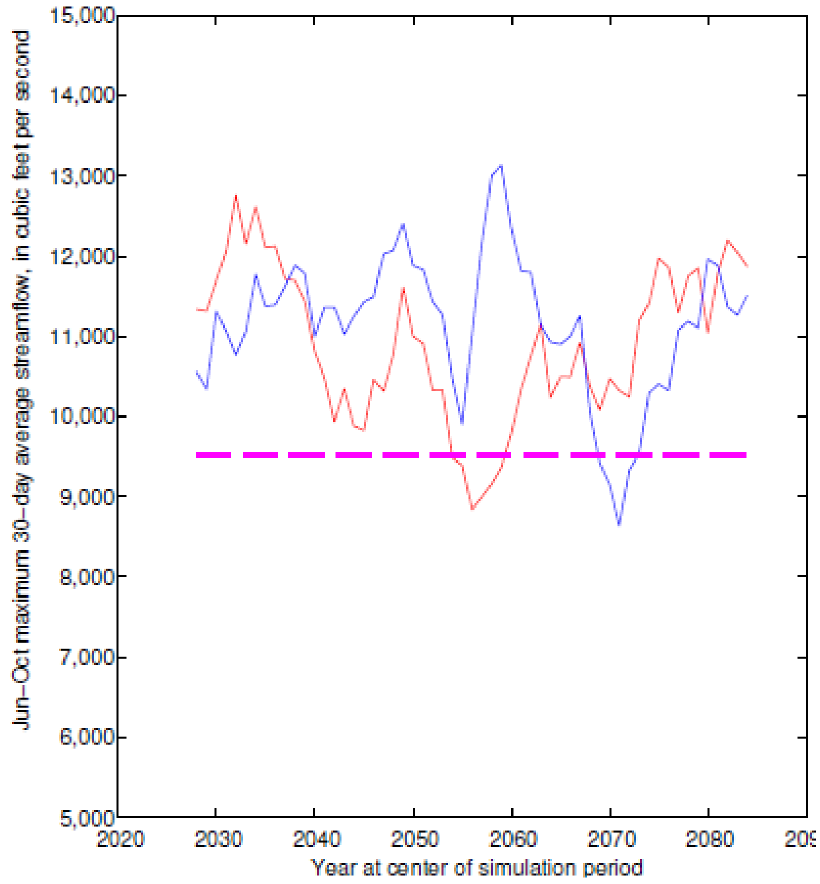


Scioto River at Circleville

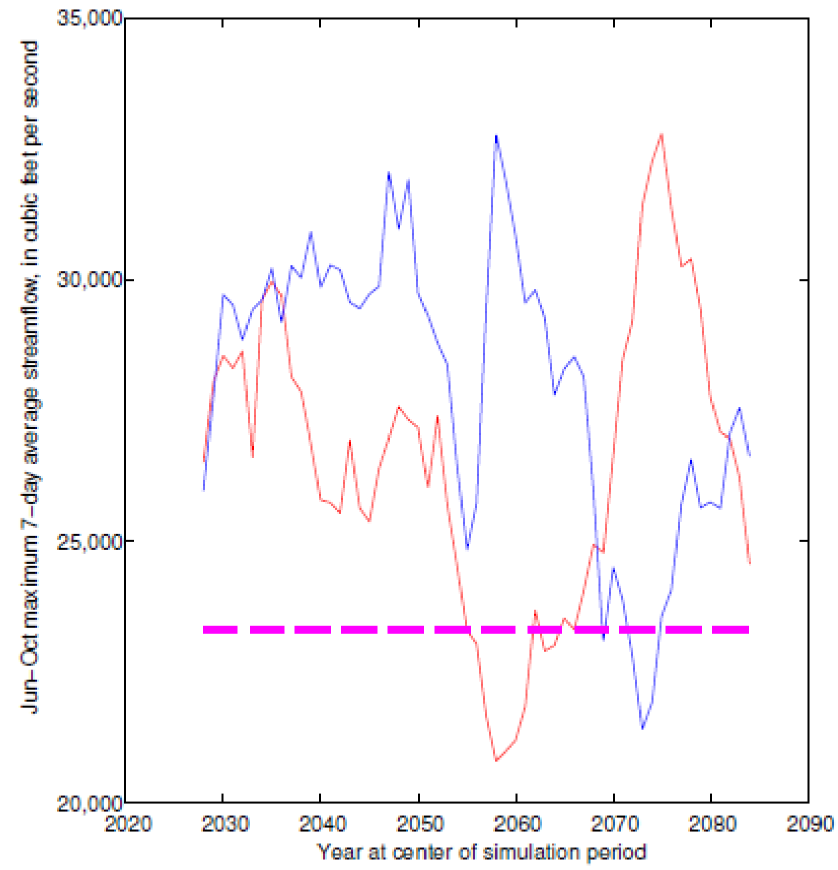
Median A1b
Median A2
Calibration period

Summer Average Maximum Stream Flow: Climate Only

30-Day

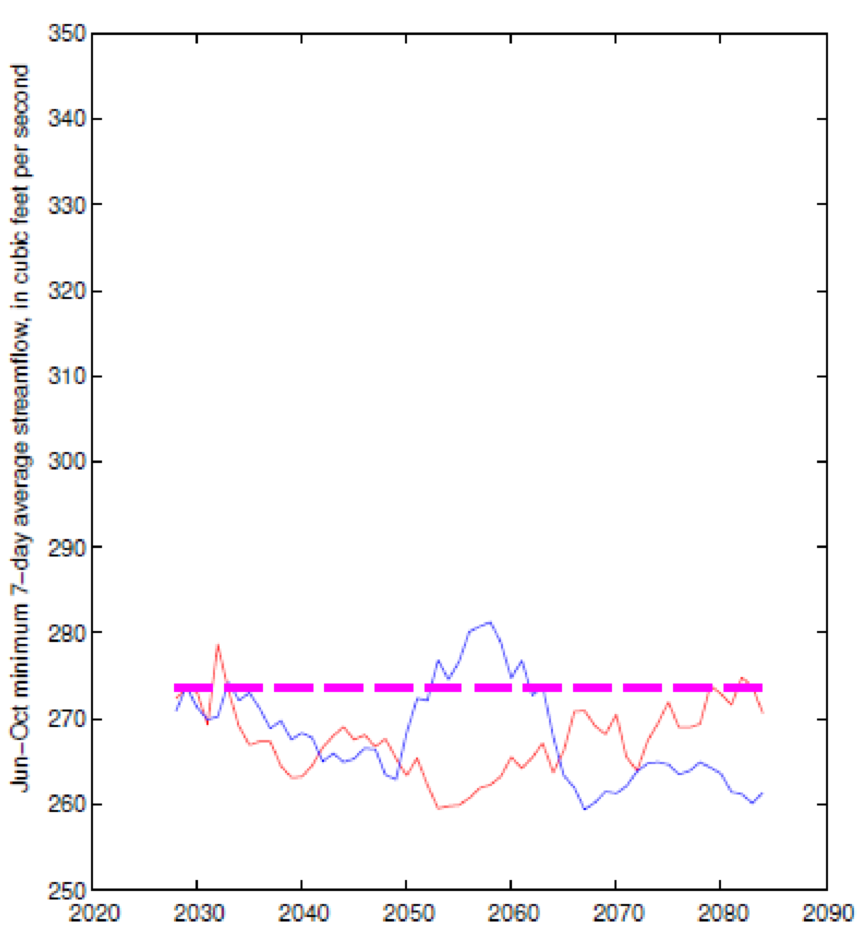


7-Day

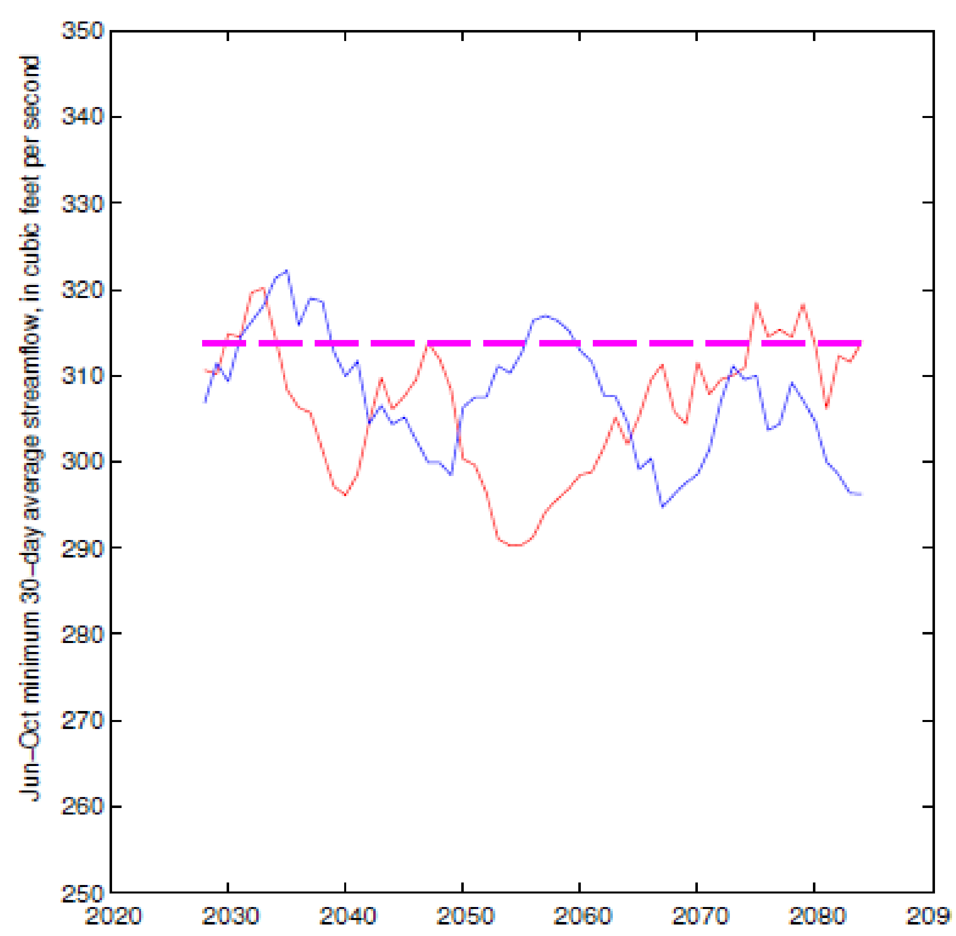


Summer Average Minimum Stream Flow: Climate Only

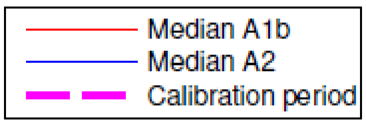
30-Day



7-Day

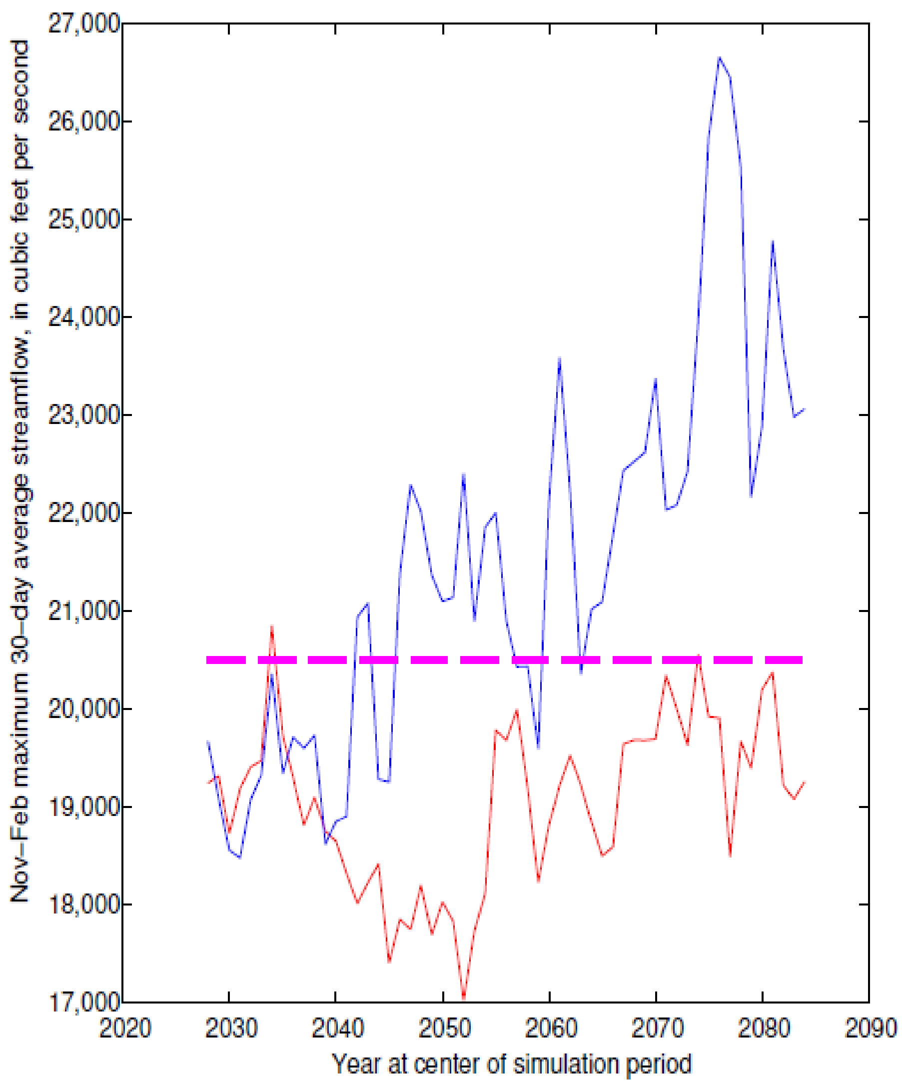


Scioto River at Circleville

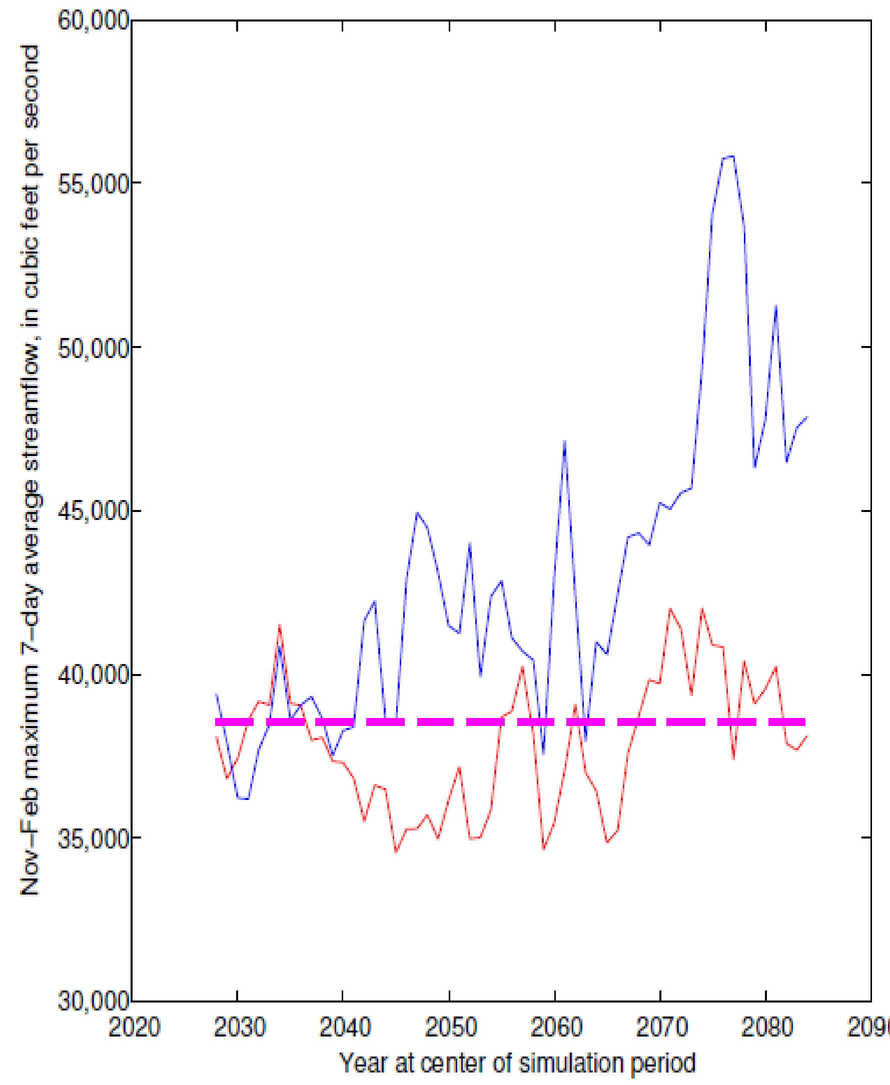


Fall/Winter Average Maximum Stream Flow: Climate Only

30-Day

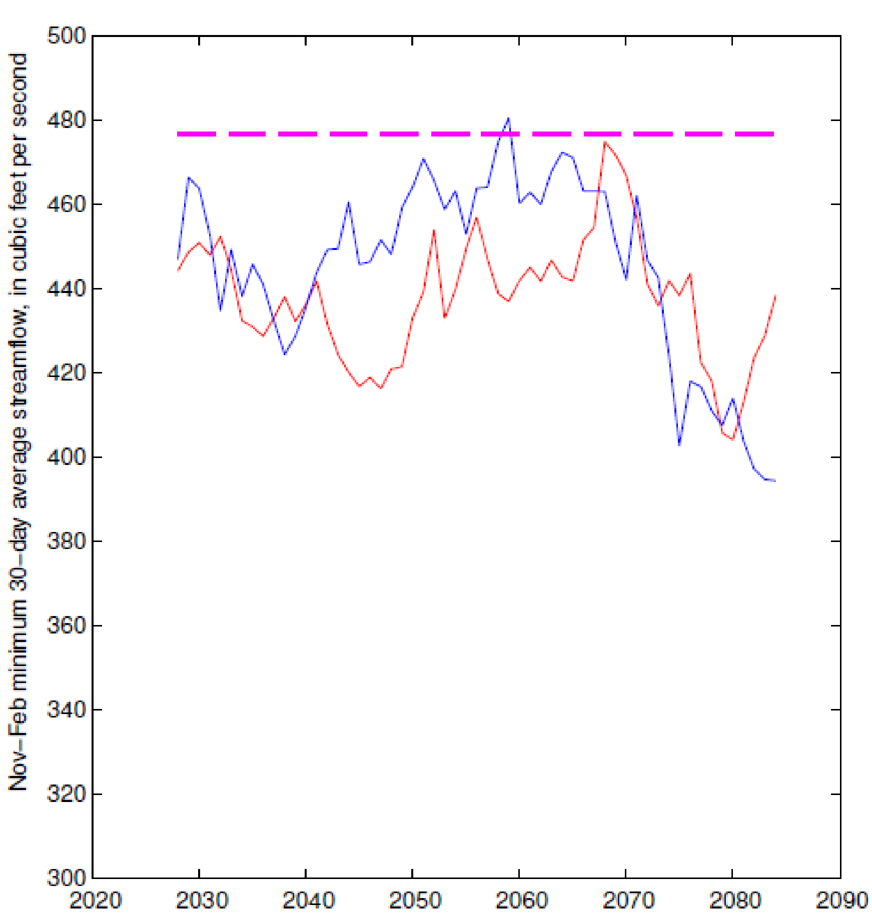


7-Day

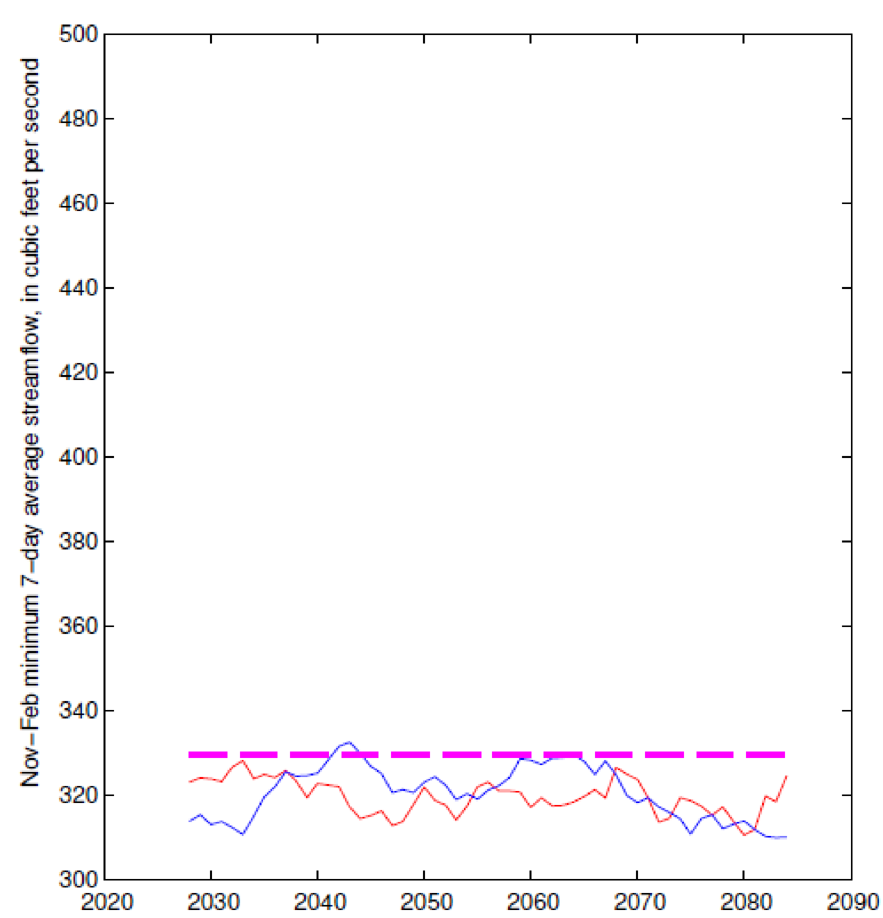


Fall/Winter Average Minimum Stream Flow: Climate Only

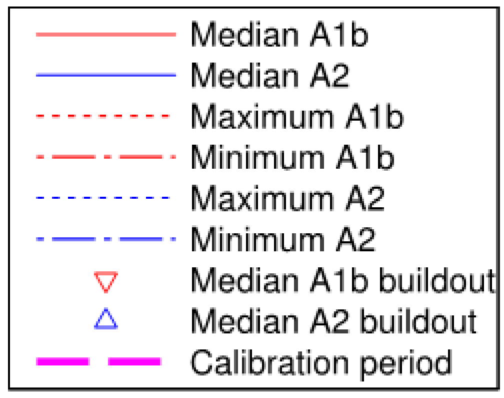
30-Day



7-Day

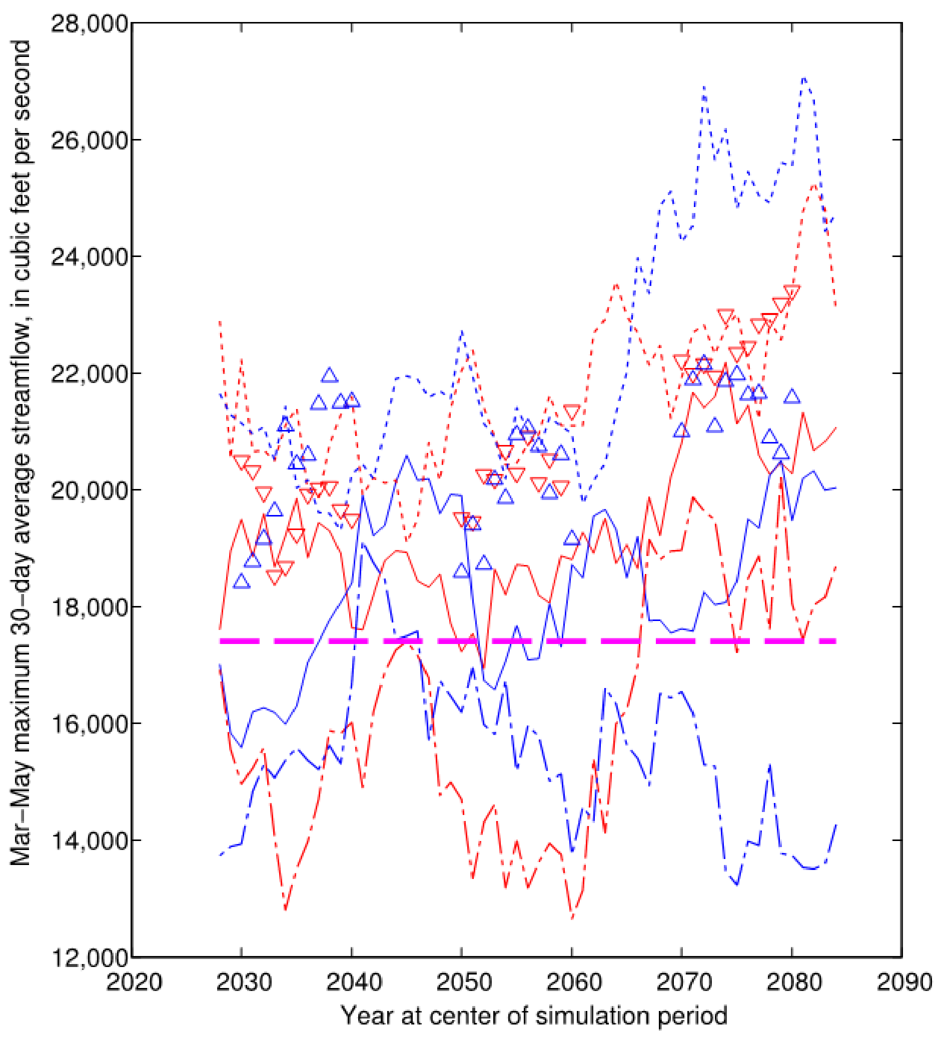


Scioto River at Circleville

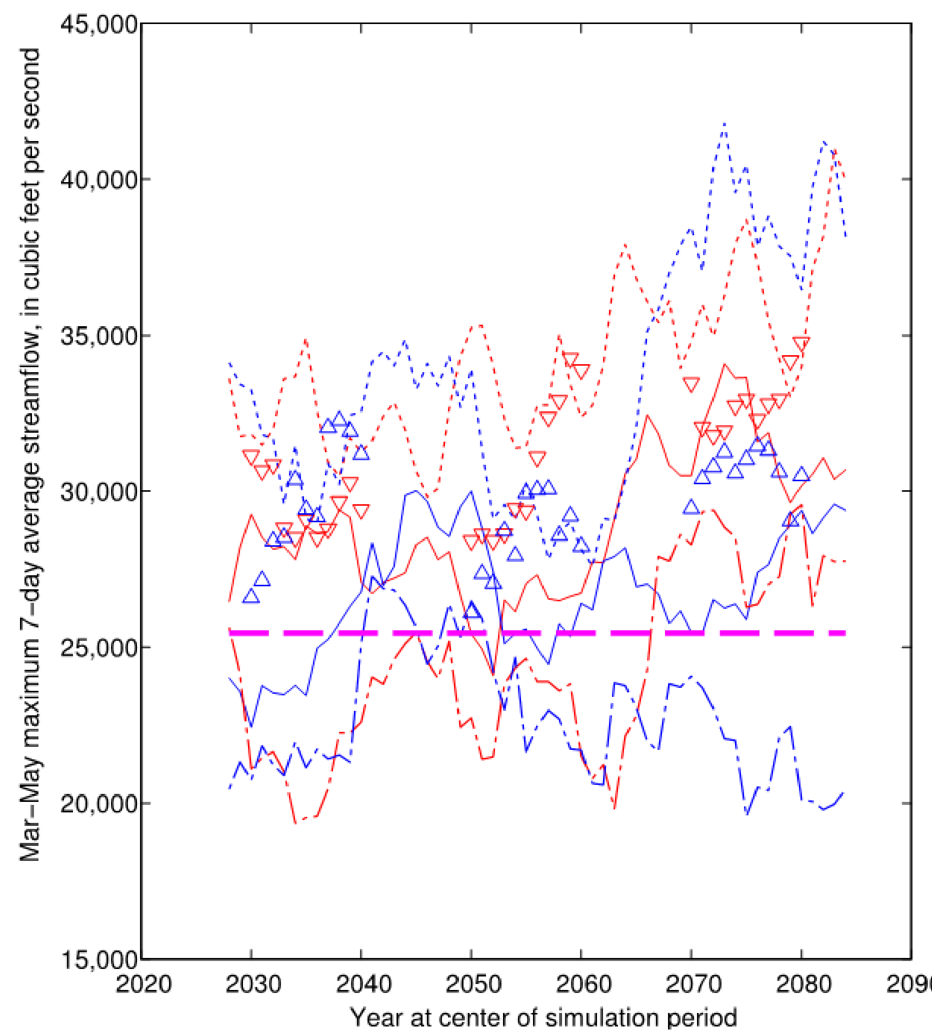


Spring Average Maximum Stream Flows with Development

30-Day

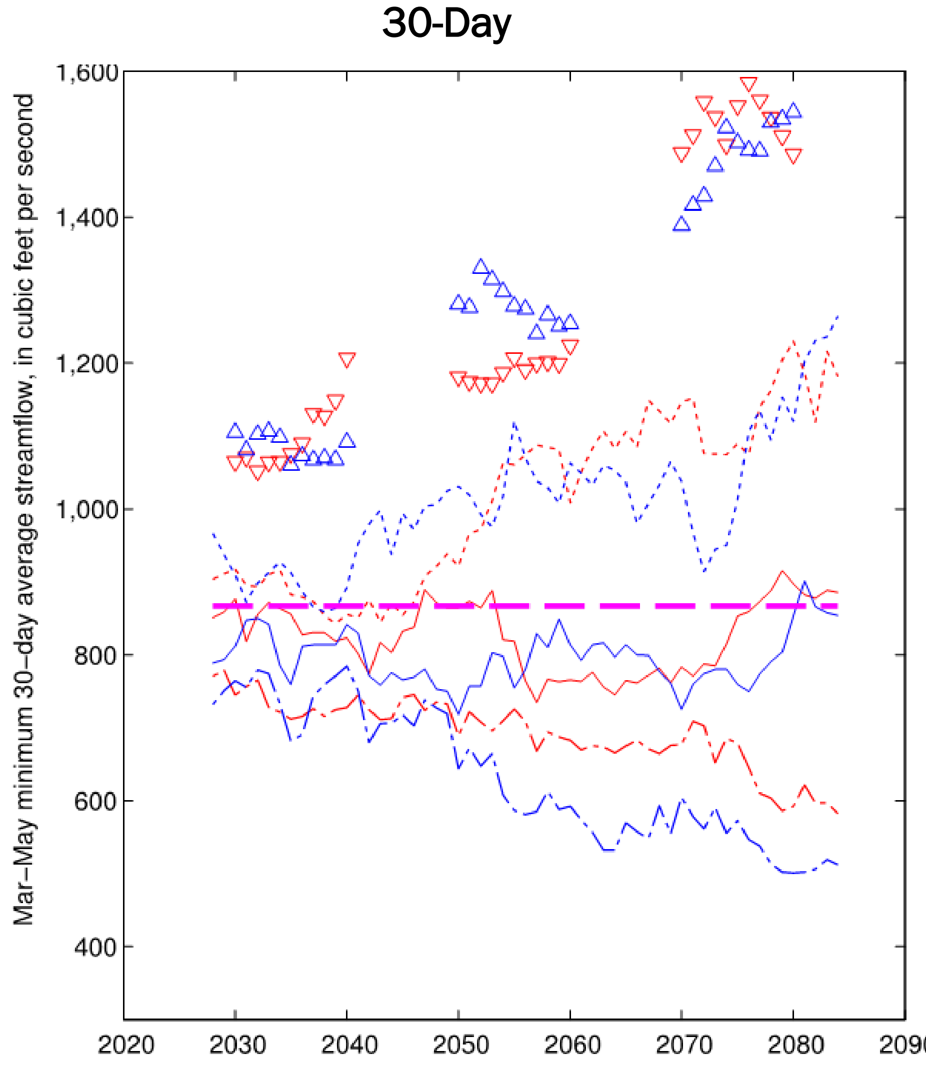


7-Day

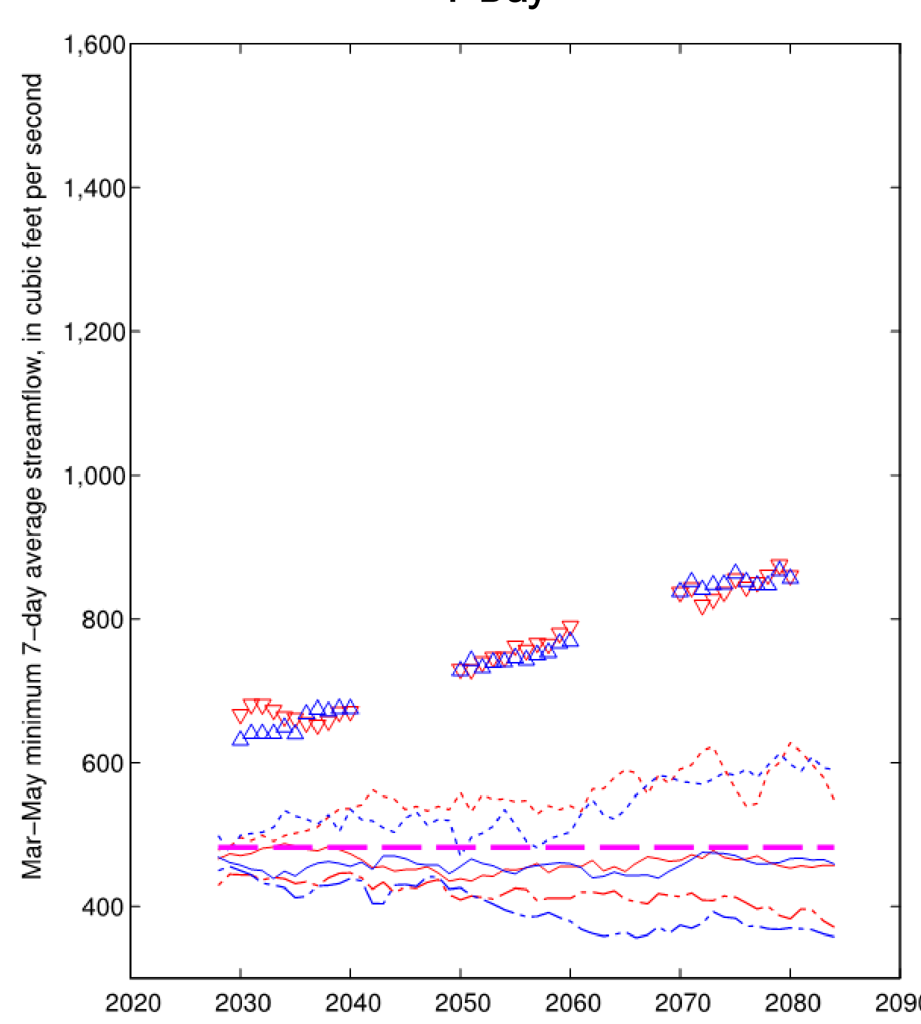


Spring Average Minimum Stream Flows with Development

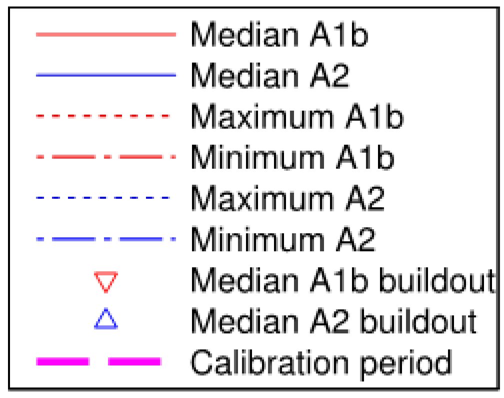
30-Day



7-Day

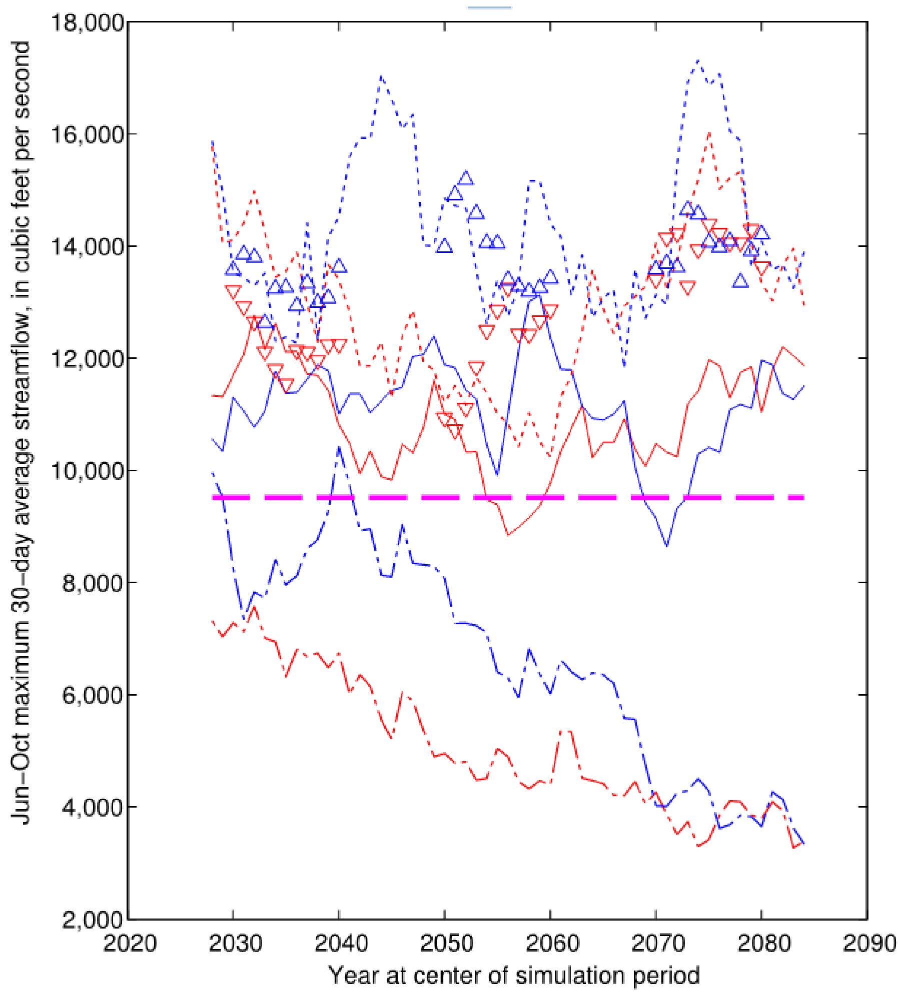


Scioto River at Circleville

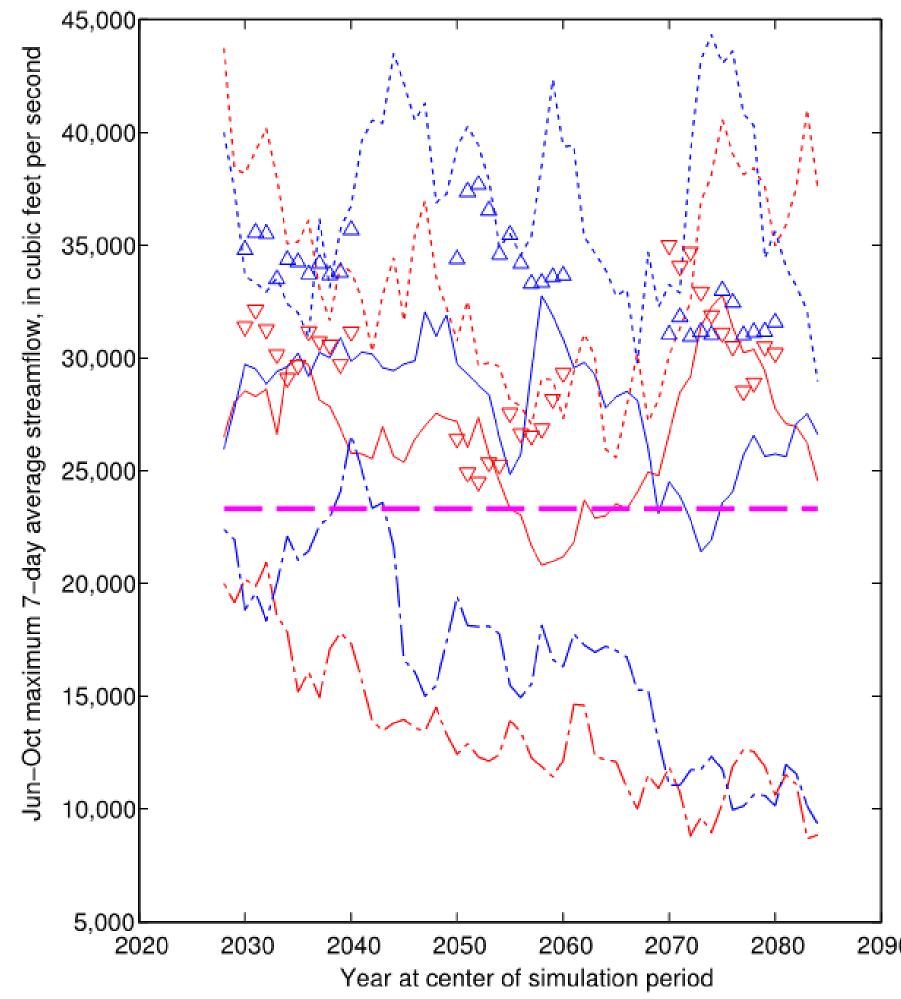


Summer Average Maximum Stream Flows with Development

30-Day

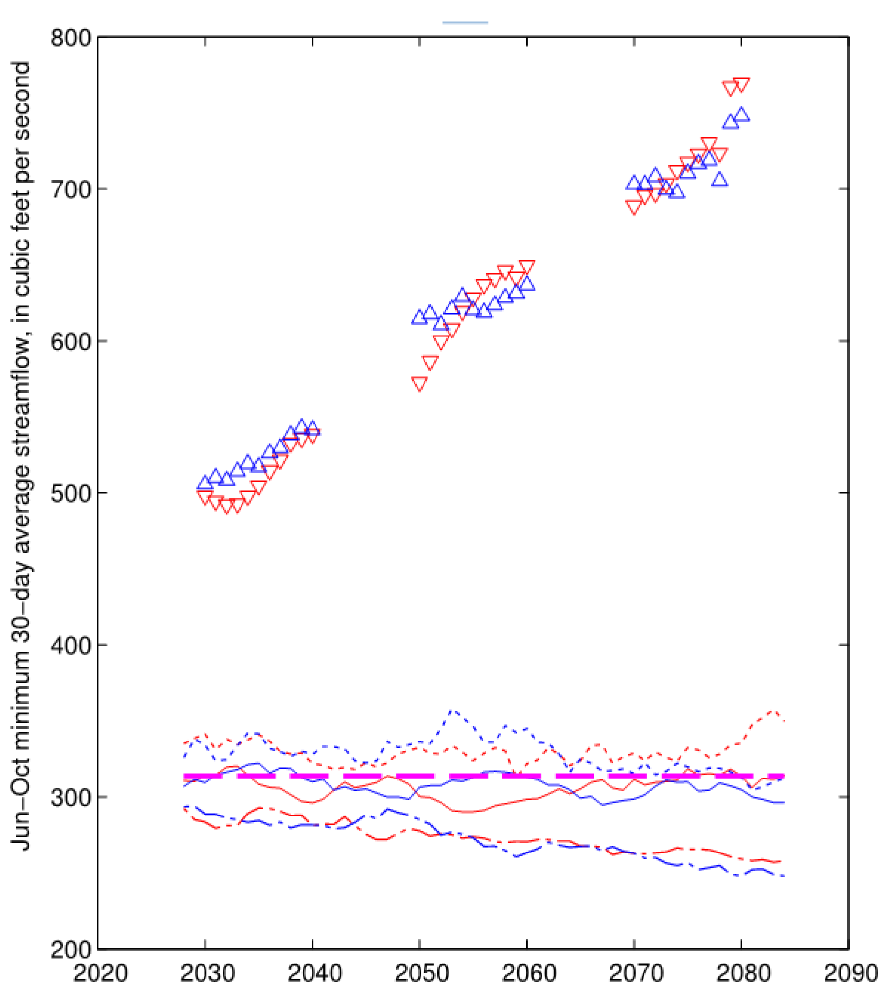


7-Day

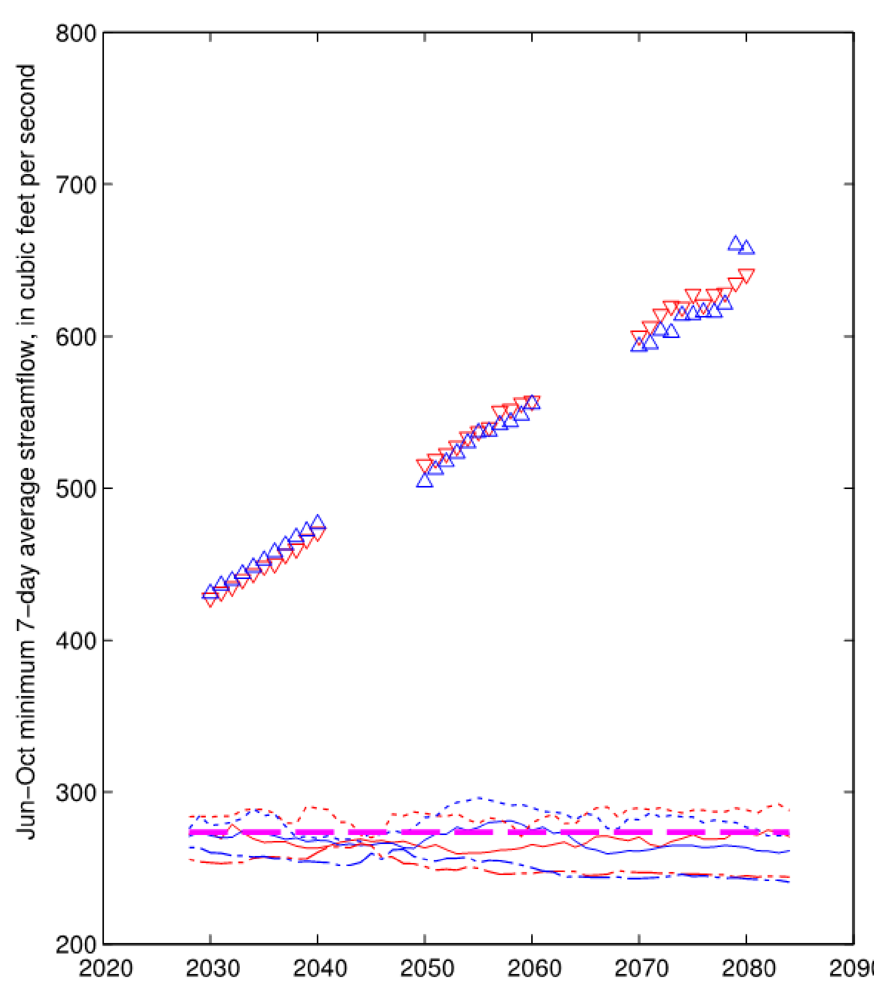


Summer Average Minimum Stream Flows with Development

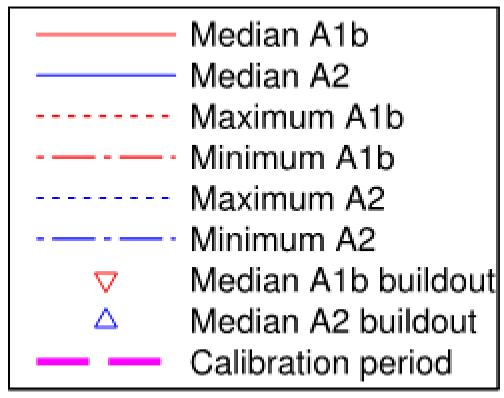
30-Day



7-Day

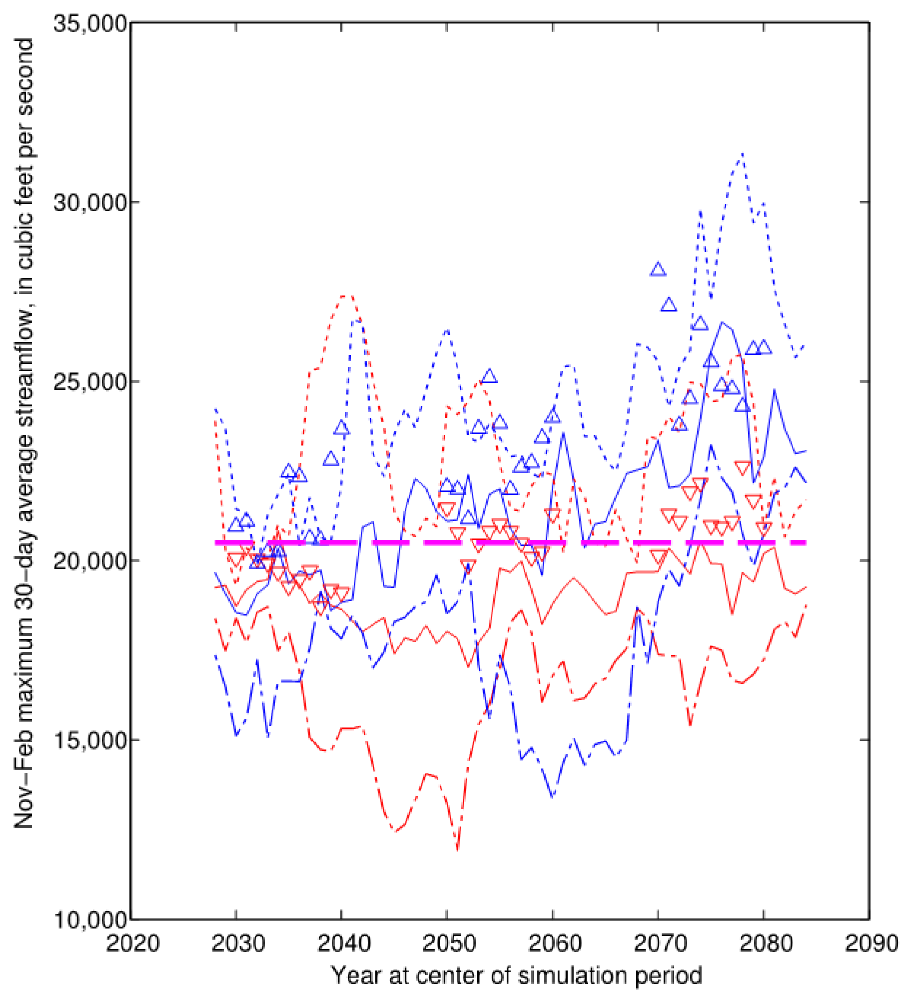


Scioto River at Circleville

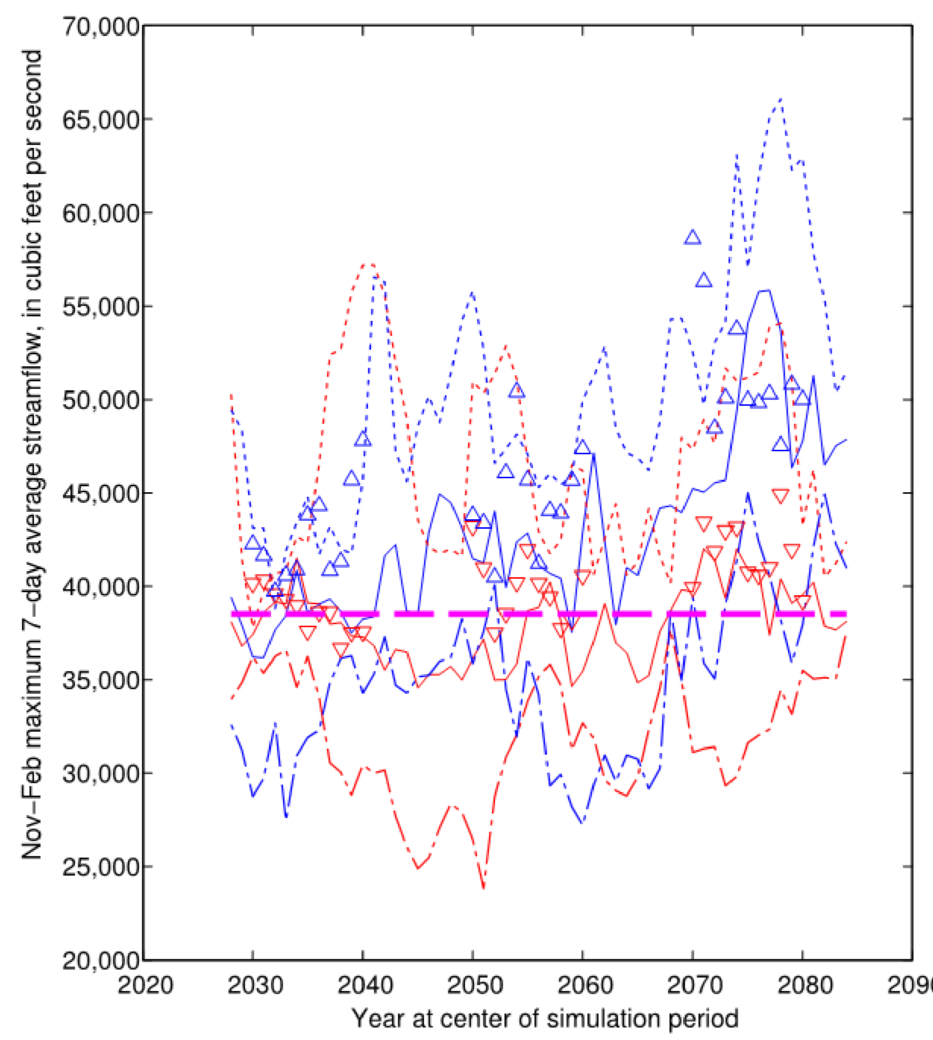


Fall/Winter Average Maximum Stream Flows with Development

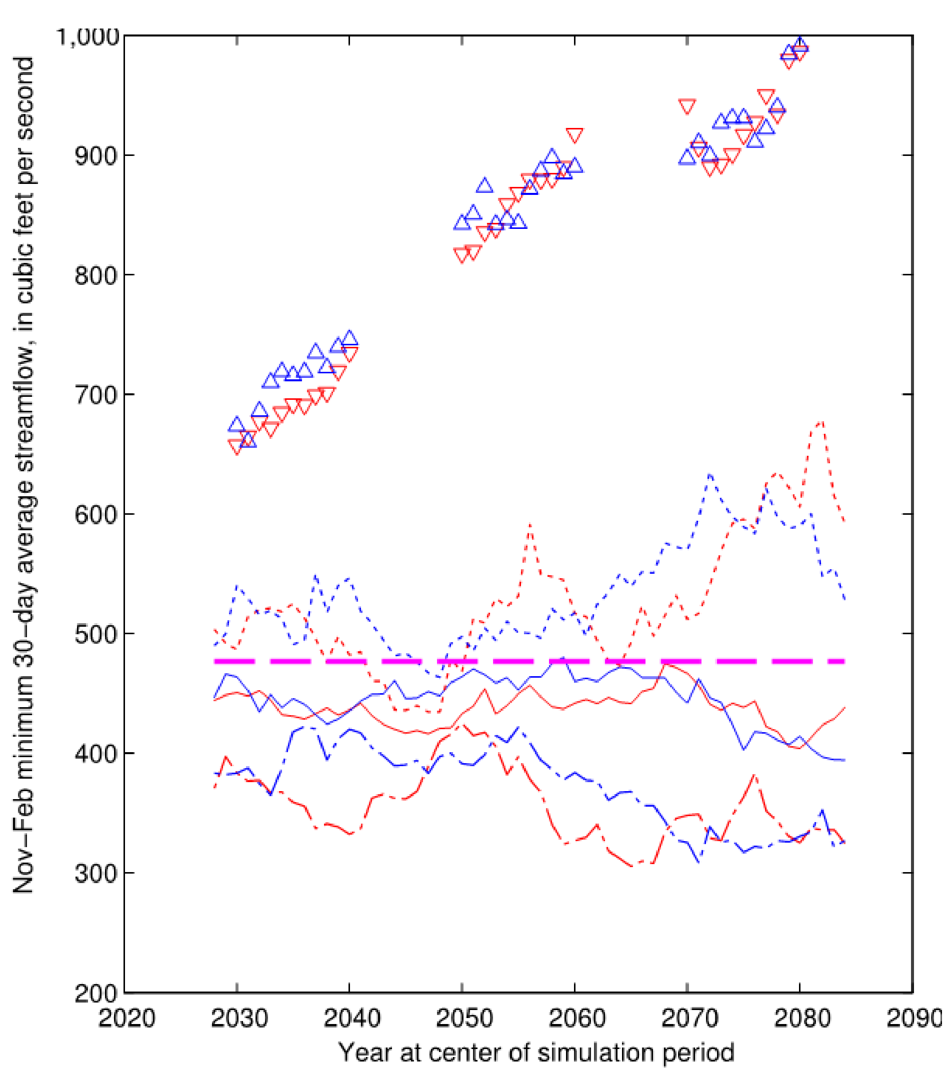
30-Day

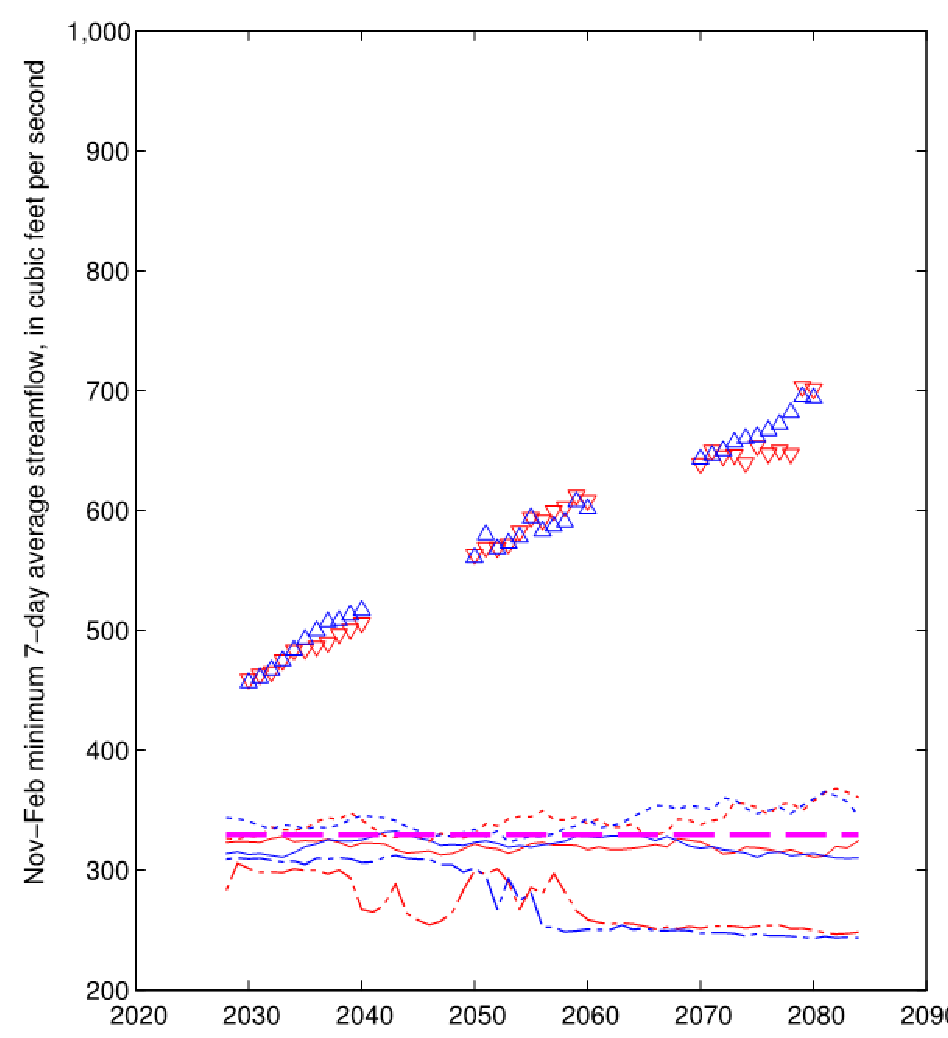


7-Day

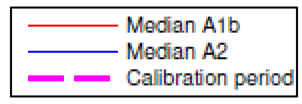


Fall/Winter Average Minimum Stream Flows with Development



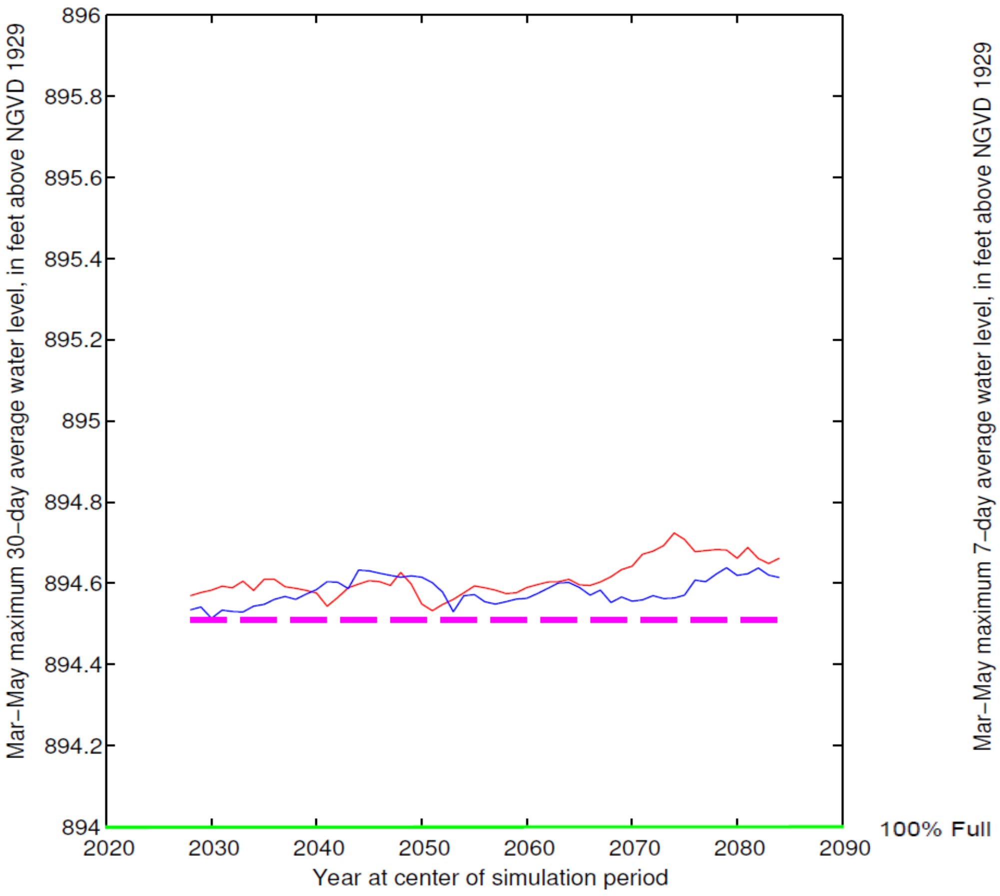


Hoover Reservoir: Seasonal Water Levels

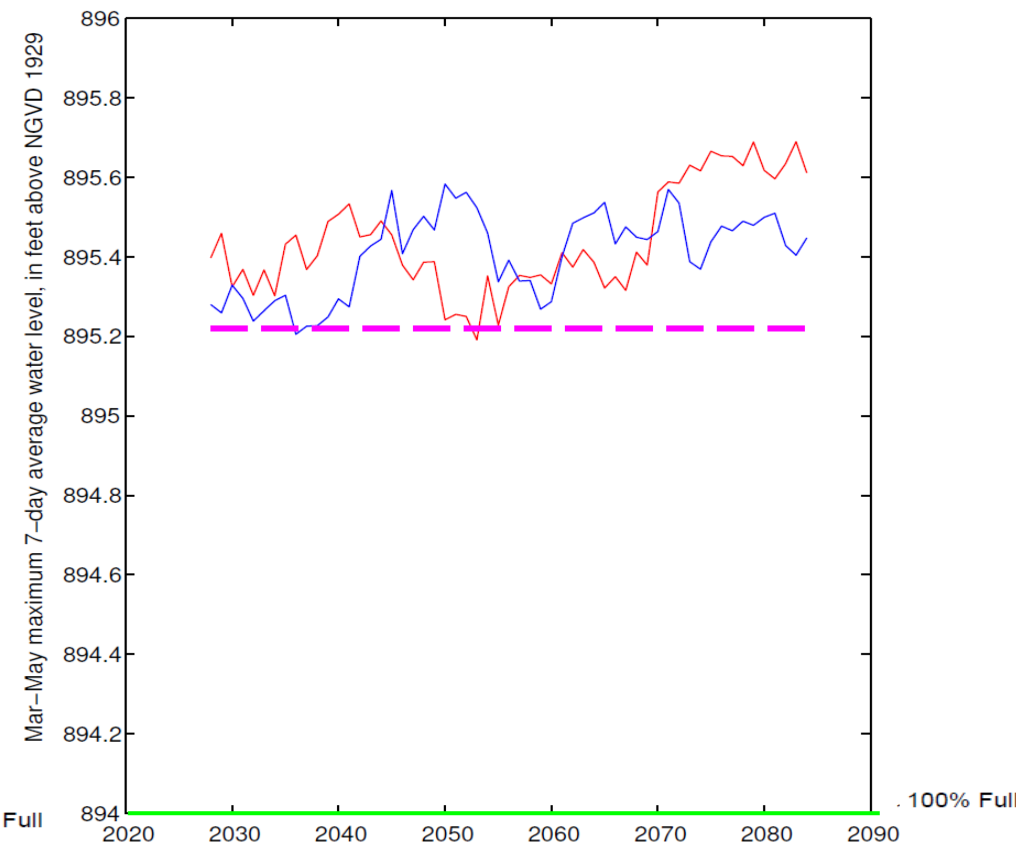


Spring Average Maximum Water Levels: Climate Only

30-Day

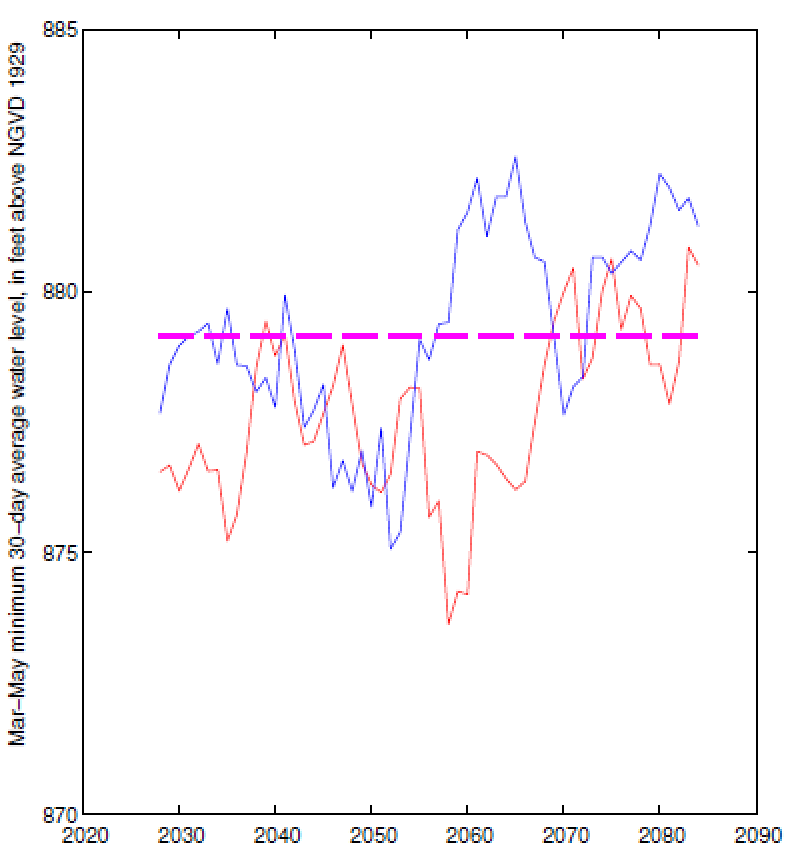


7-Day

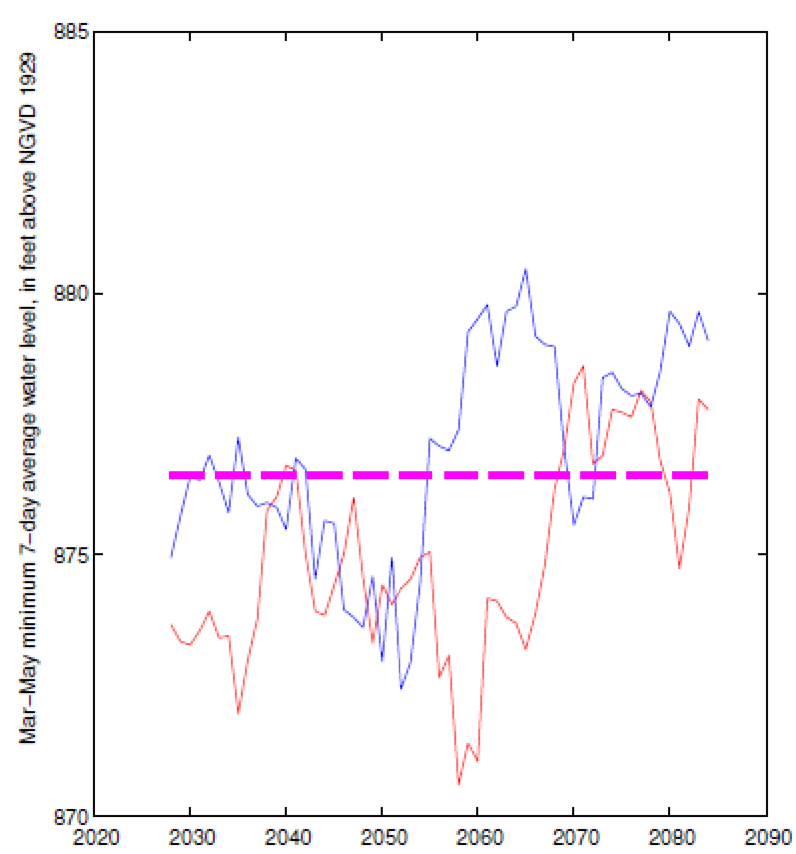


Spring Average Minimum Water Levels: Climate Only

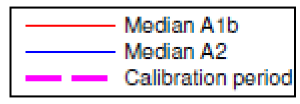
30-Day



7-Day

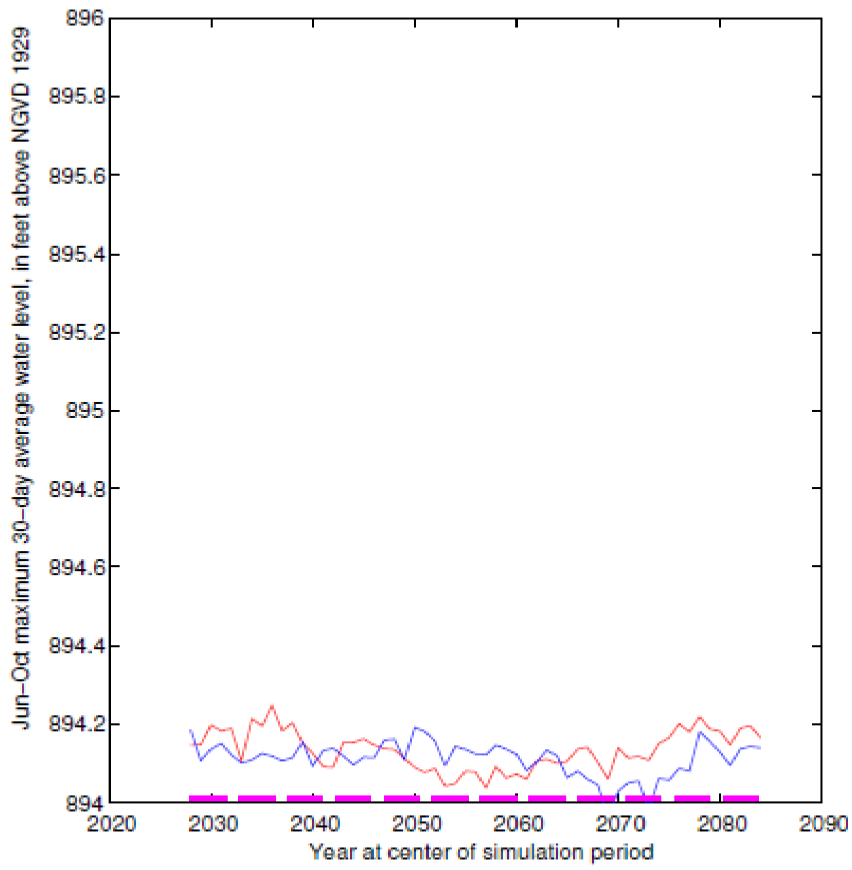


Hoover Reservoir: Seasonal Water Levels

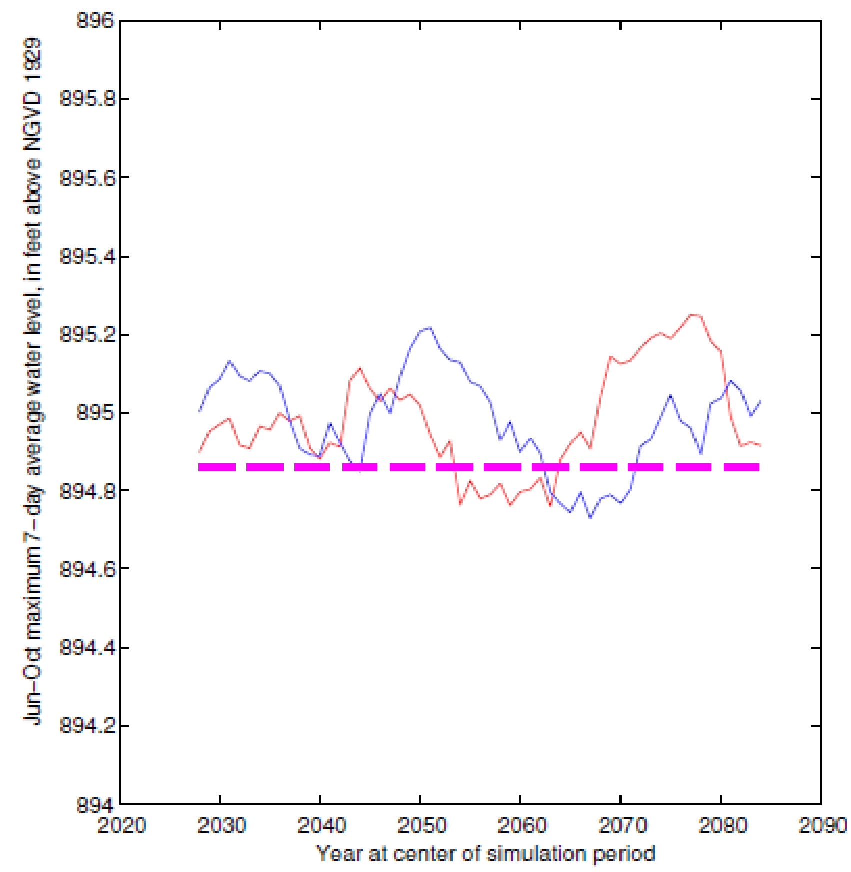


Summer Average Maximum Water Levels: Climate Only

30-Day

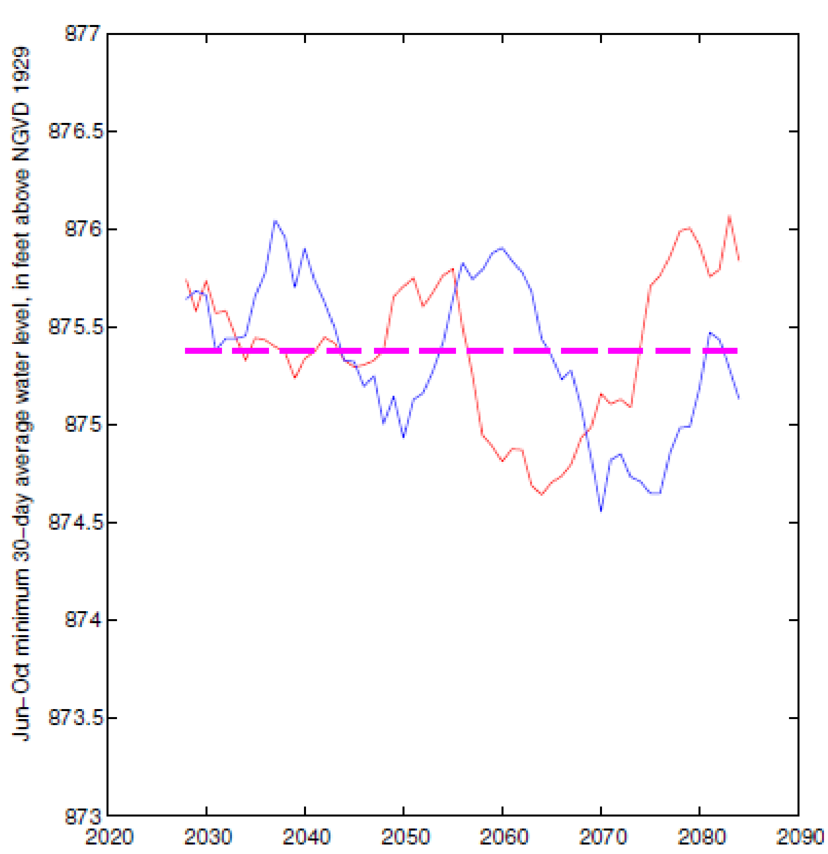


7-Day

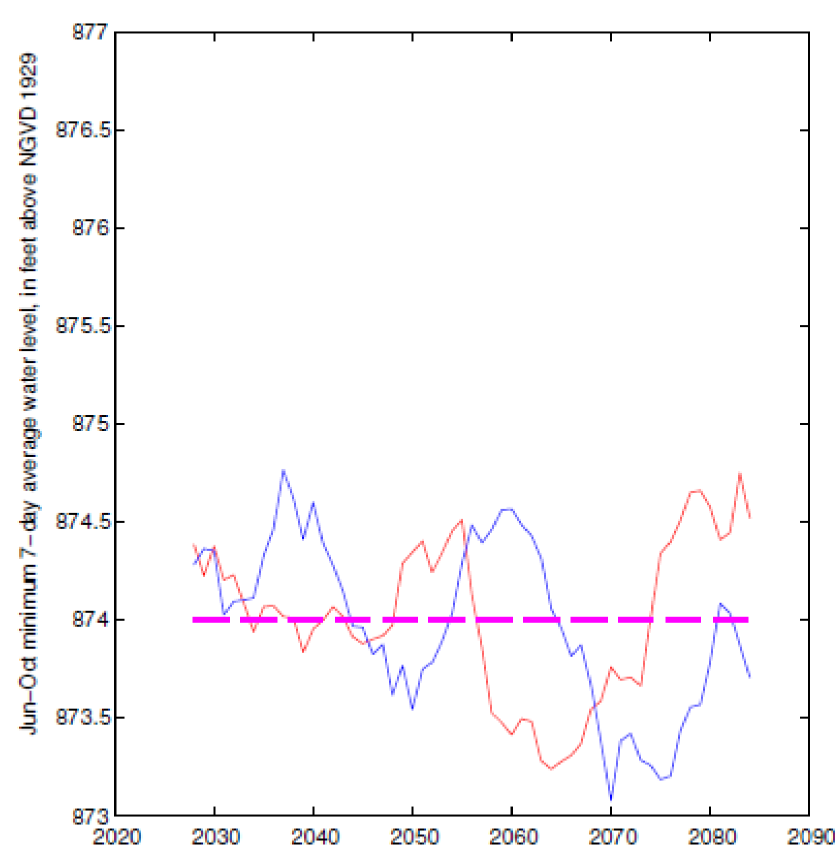


Summer Average Minimum Water Levels: Climate Only

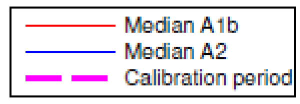
30-Day



7-Day

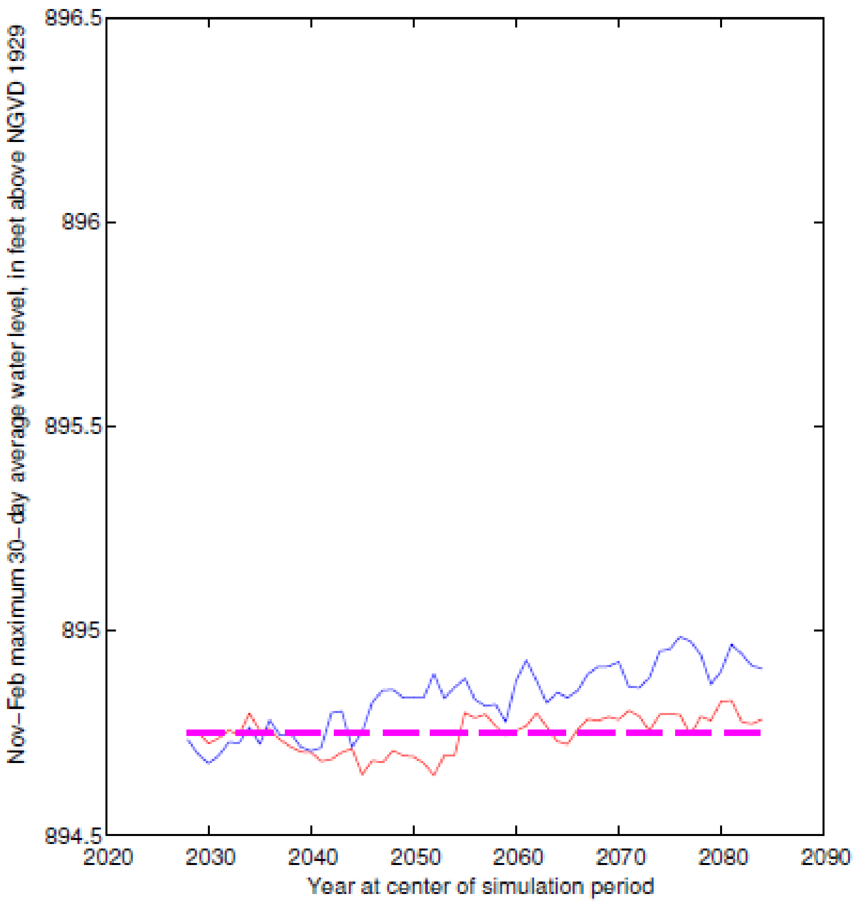


Hoover Reservoir: Seasonal Water Levels

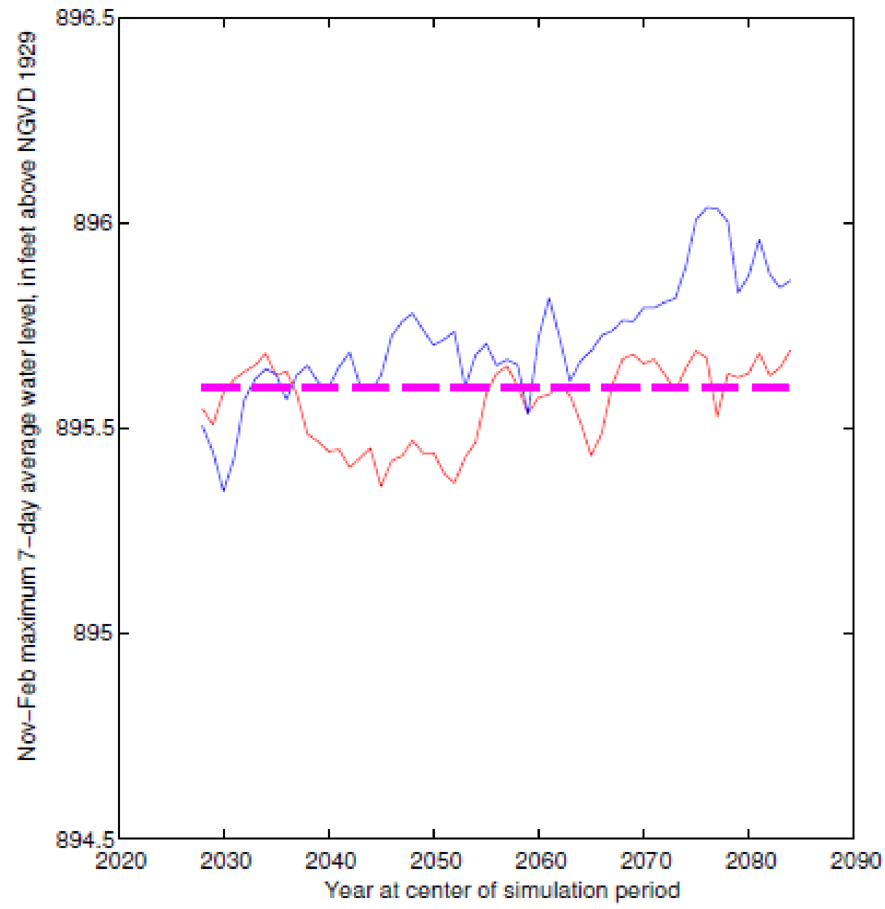


Fall/Winter Average Maximum Water Levels: Climate Only

30-Day

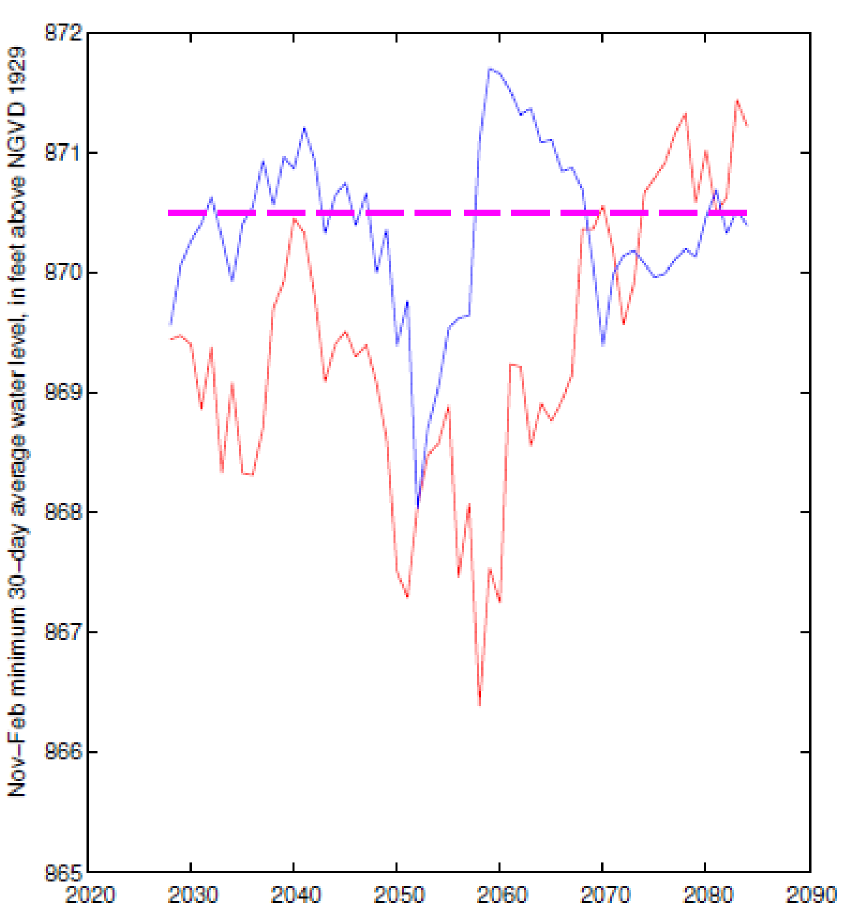


7-Day

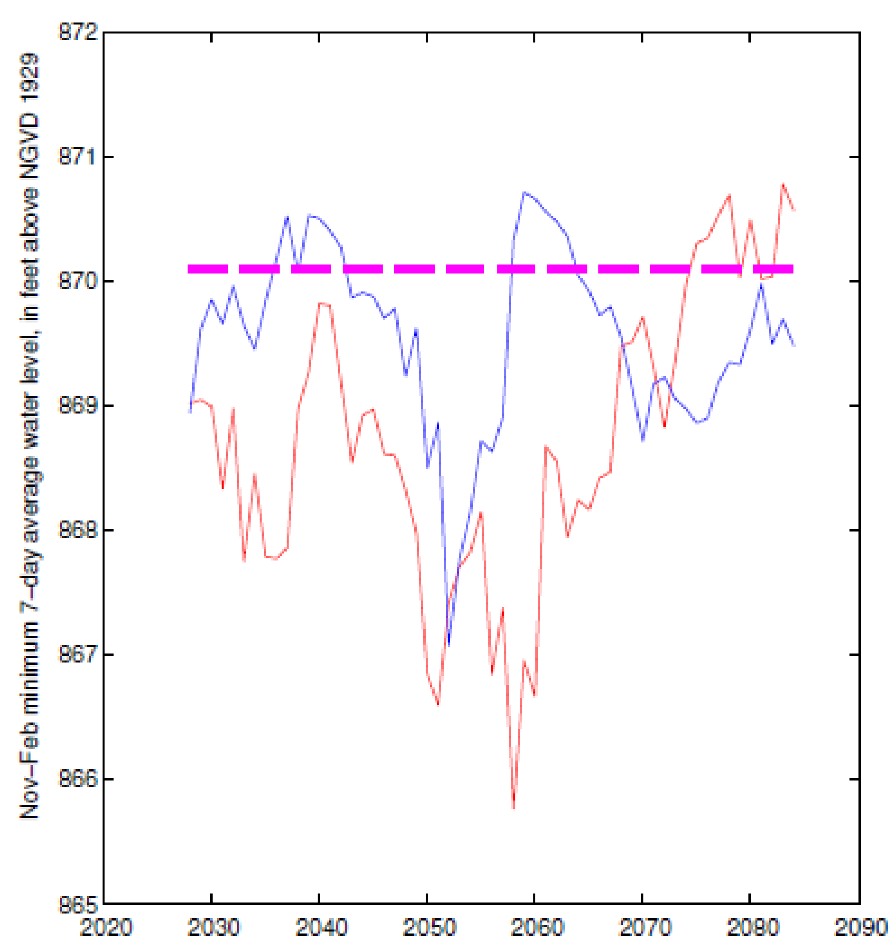


Fall/Winter Average Minimum Water Levels: Climate Only

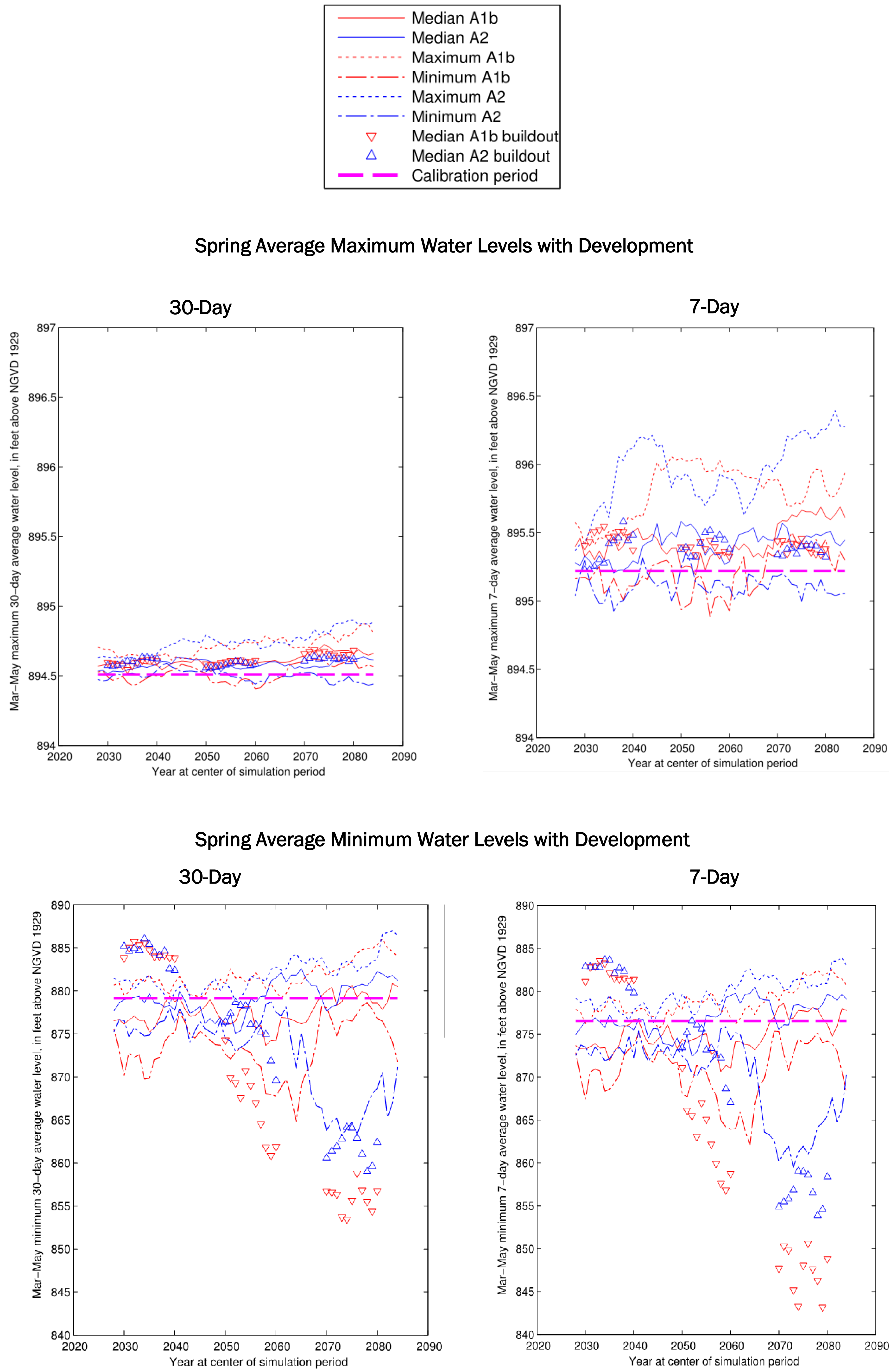
30-Day



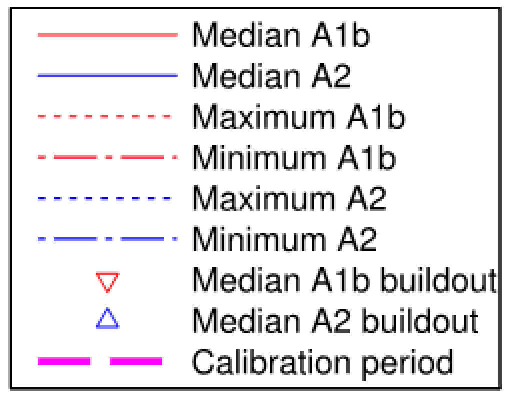
7-Day



Hoover Reservoir: Seasonal Water Levels

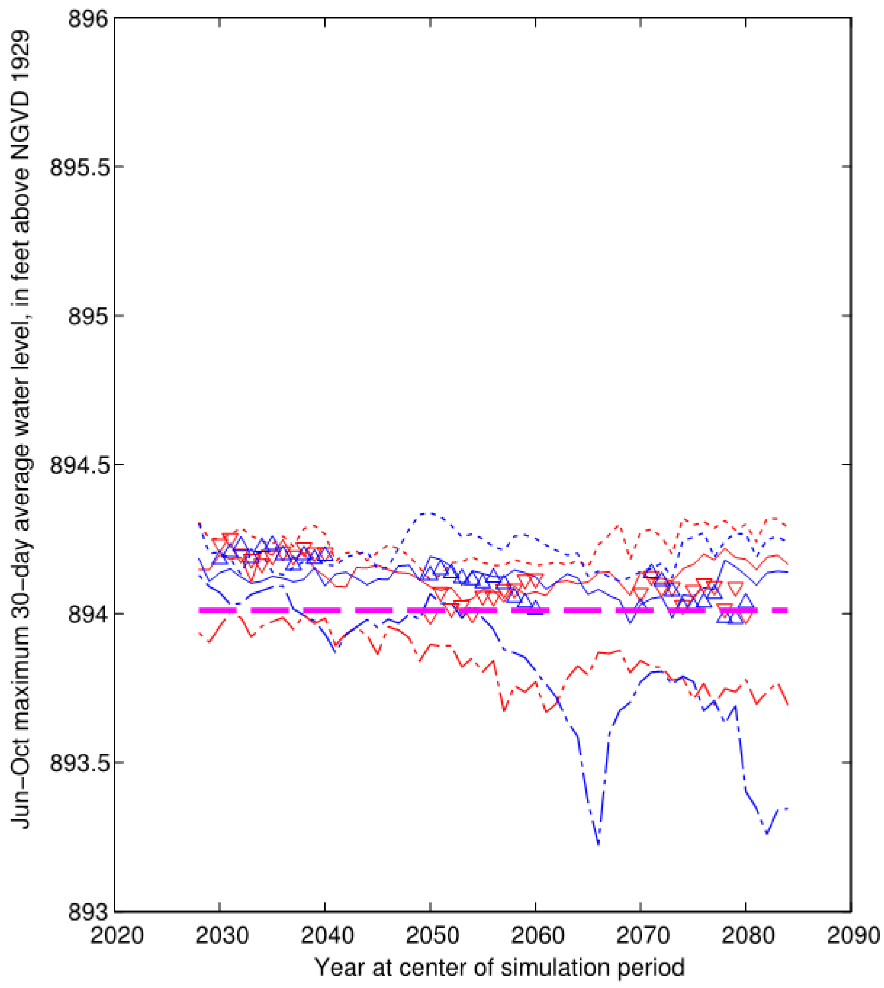


Hoover Reservoir: Seasonal Water Levels

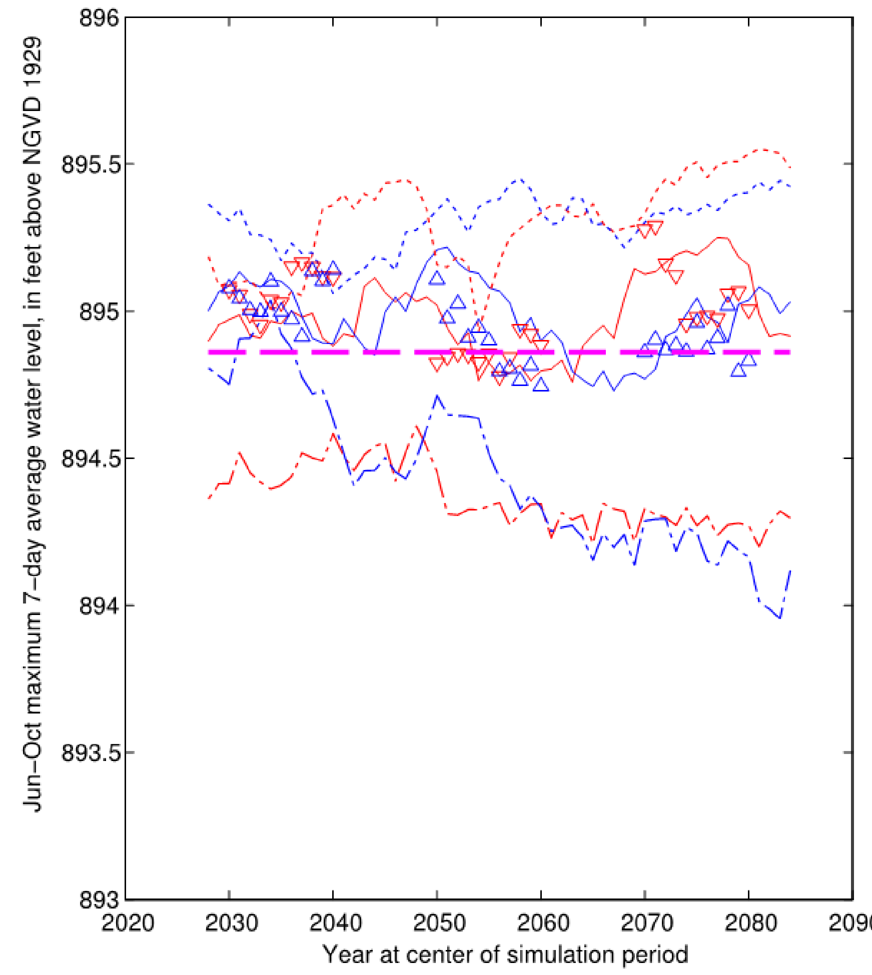


Summer Average Maximum Water Levels with Development

30-Day

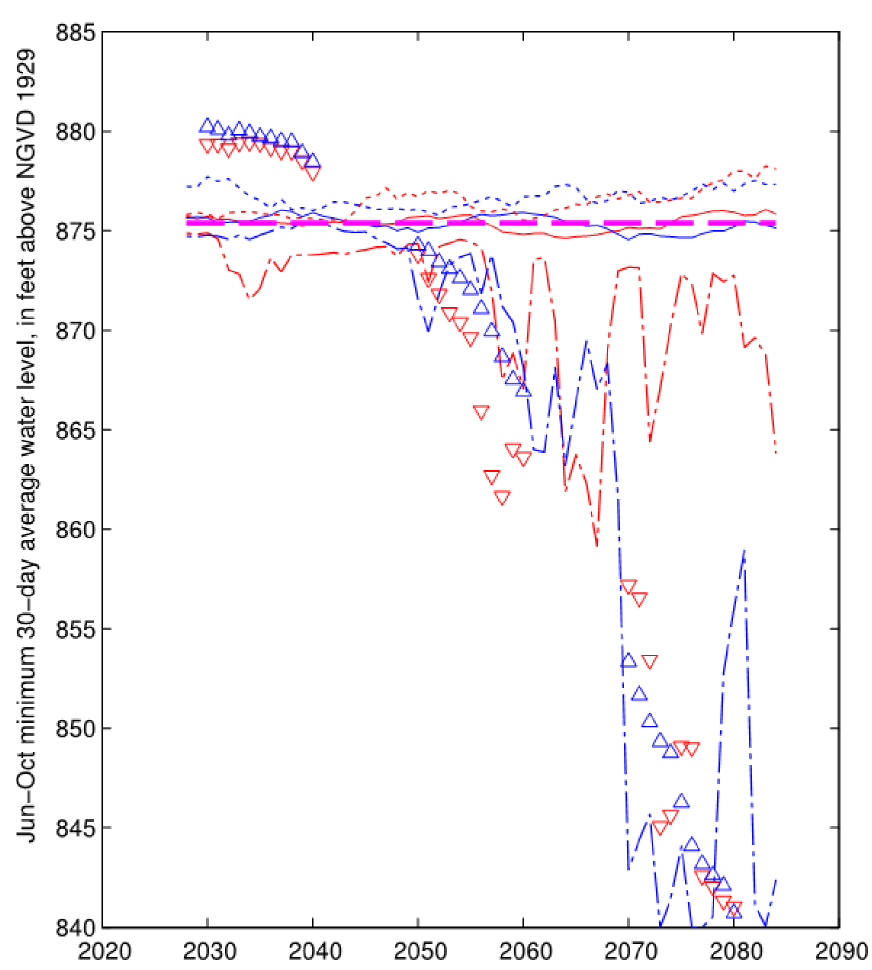


7-Day

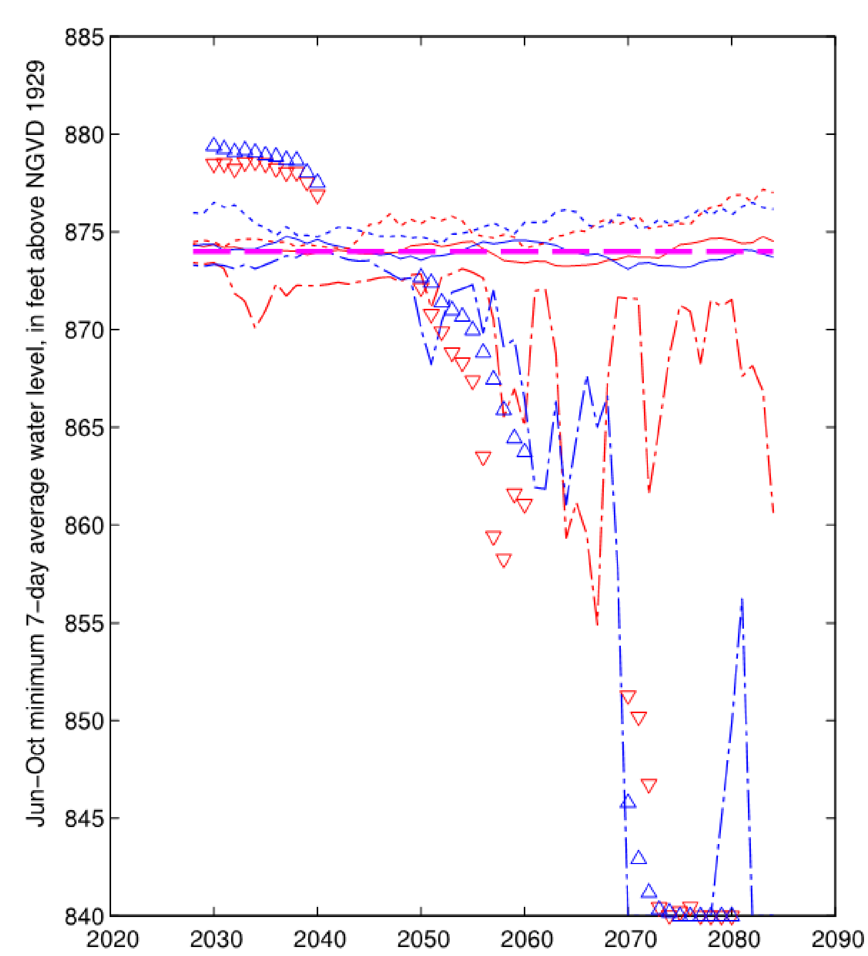


Summer Average Minimum Water Levels with Development

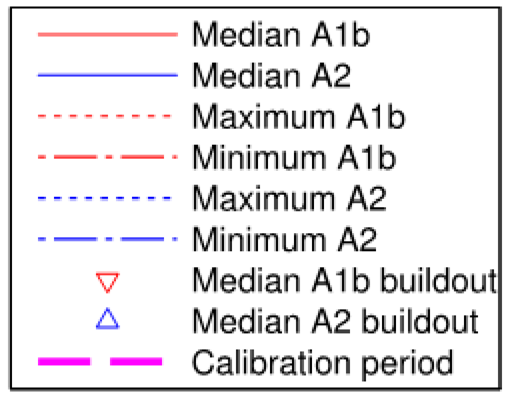
30-Day



7-Day

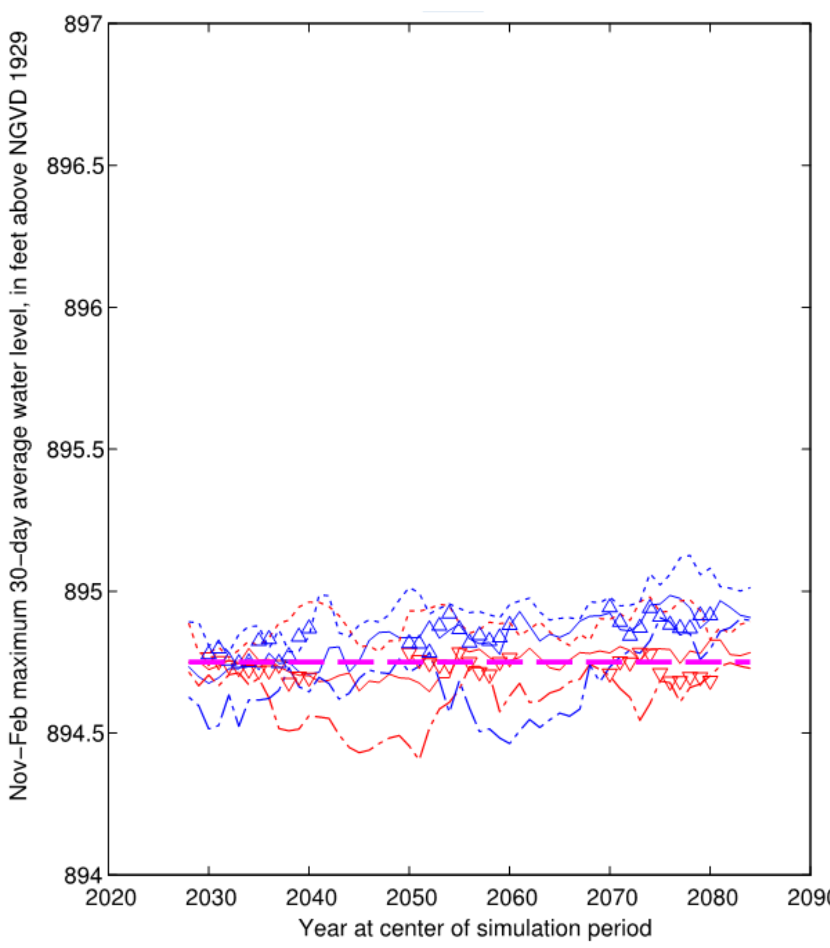


Hoover Reservoir: Seasonal Water Levels

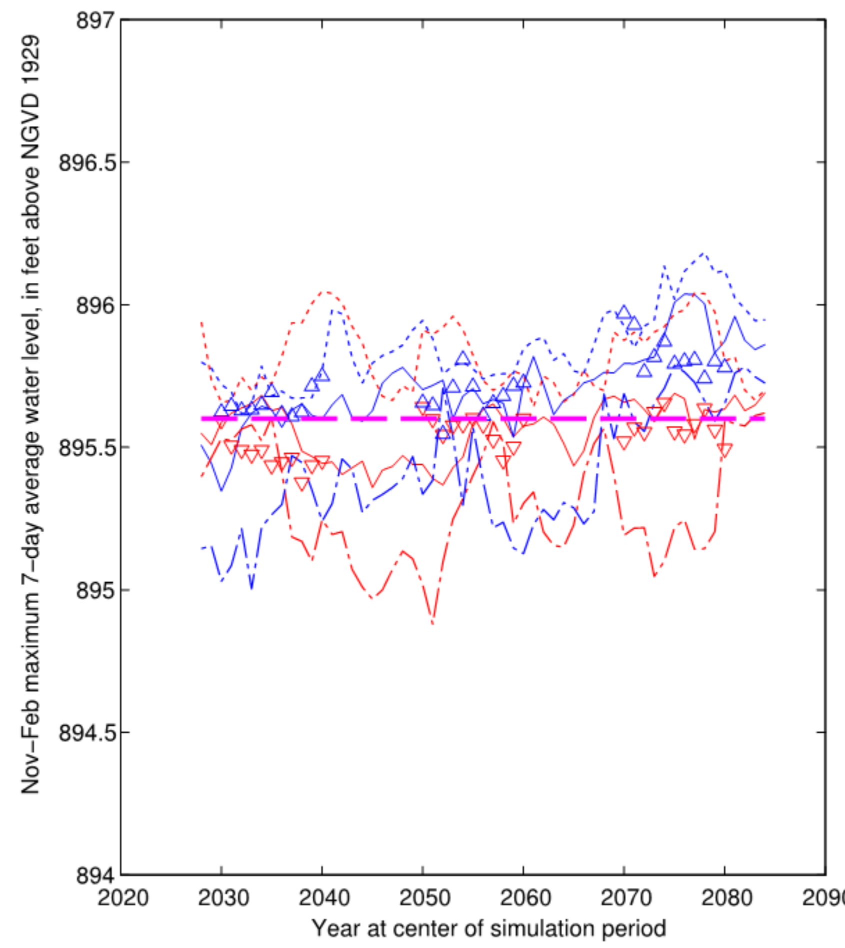


Fall/Winter Average Maximum Water Levels with Development

30-Day

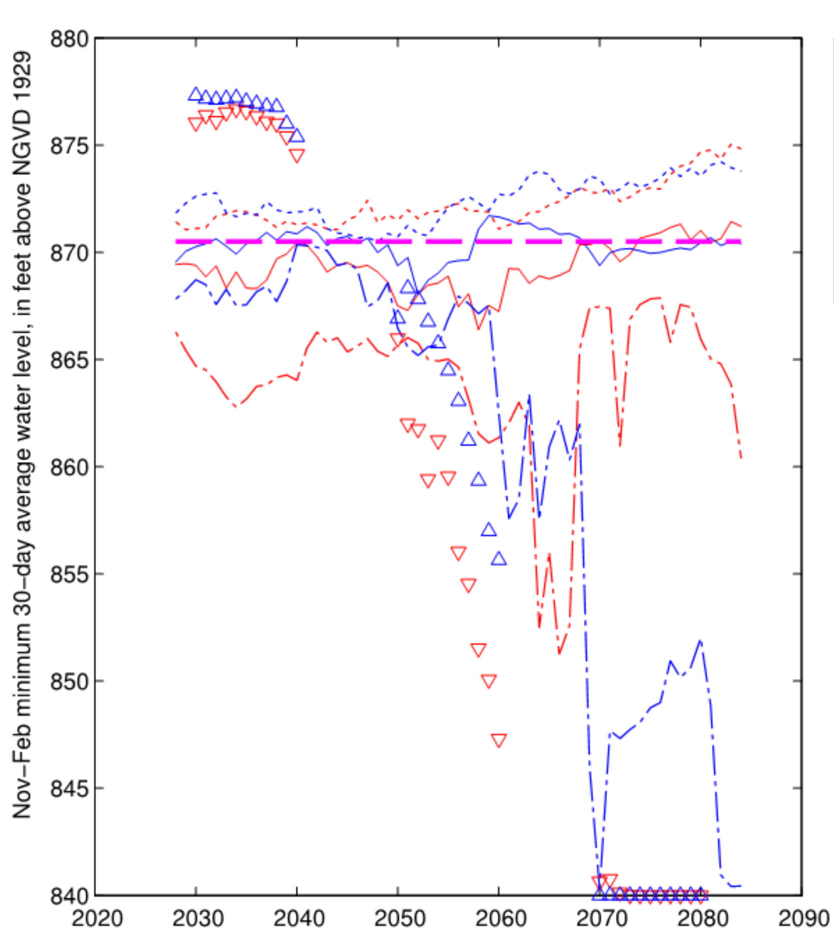


7-Day

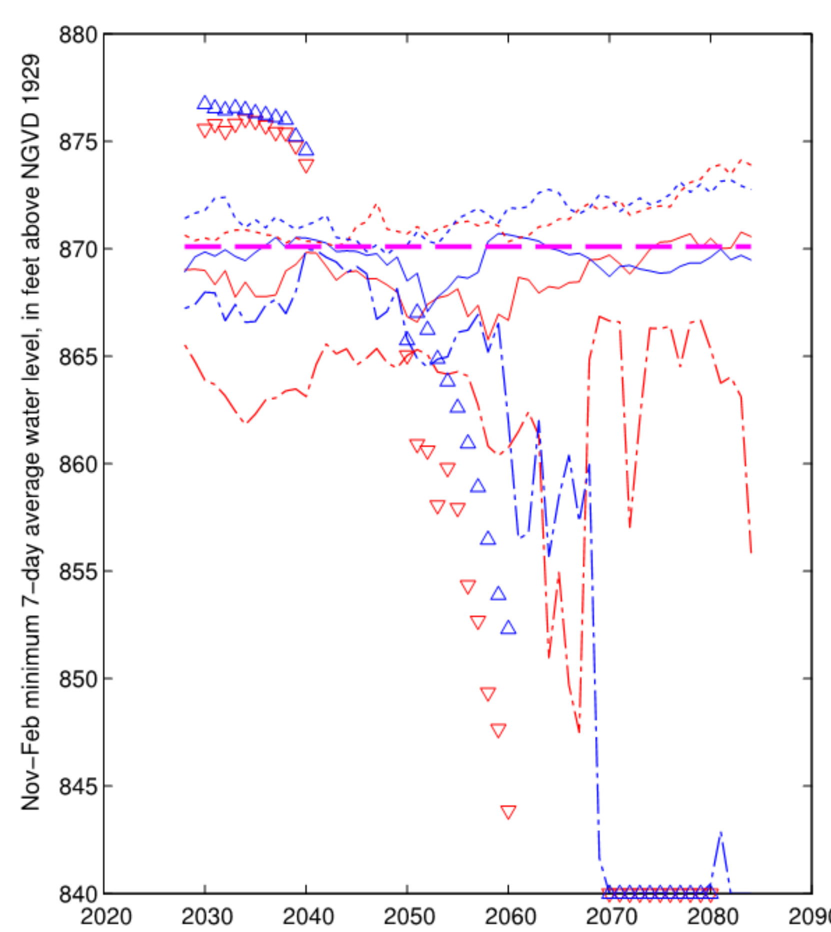


Fall/Winter Average Minimum Water Levels with Development

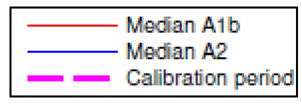
30-Day



7-Day

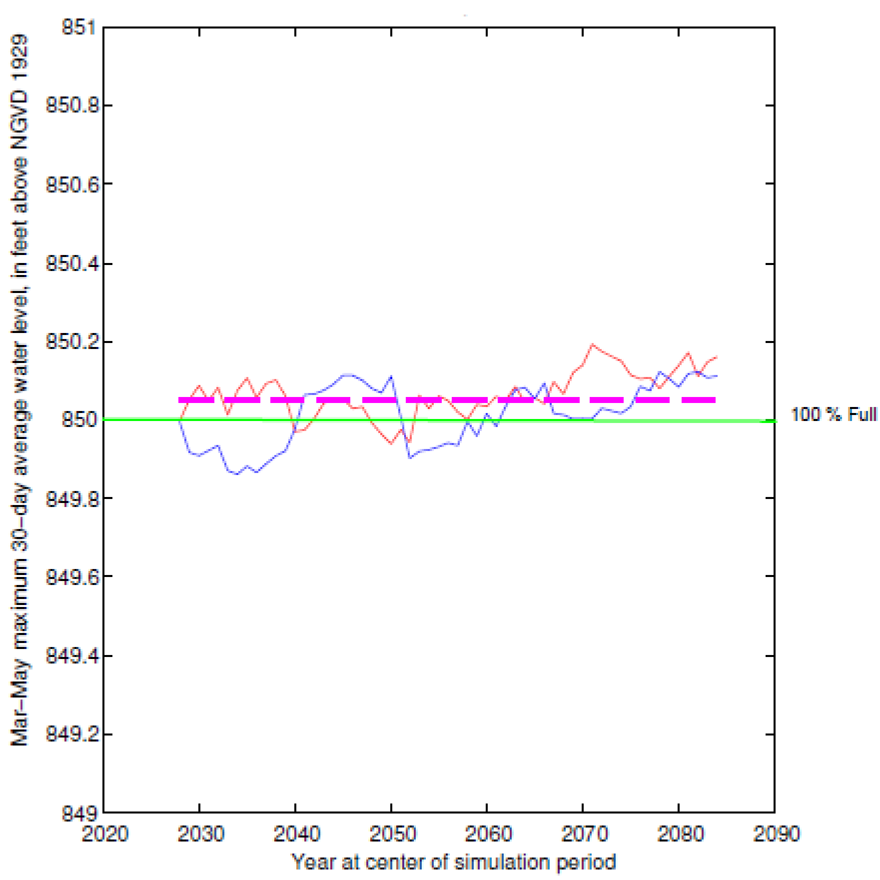


O'Shaughnessy Reservoir: Seasonal Water Levels

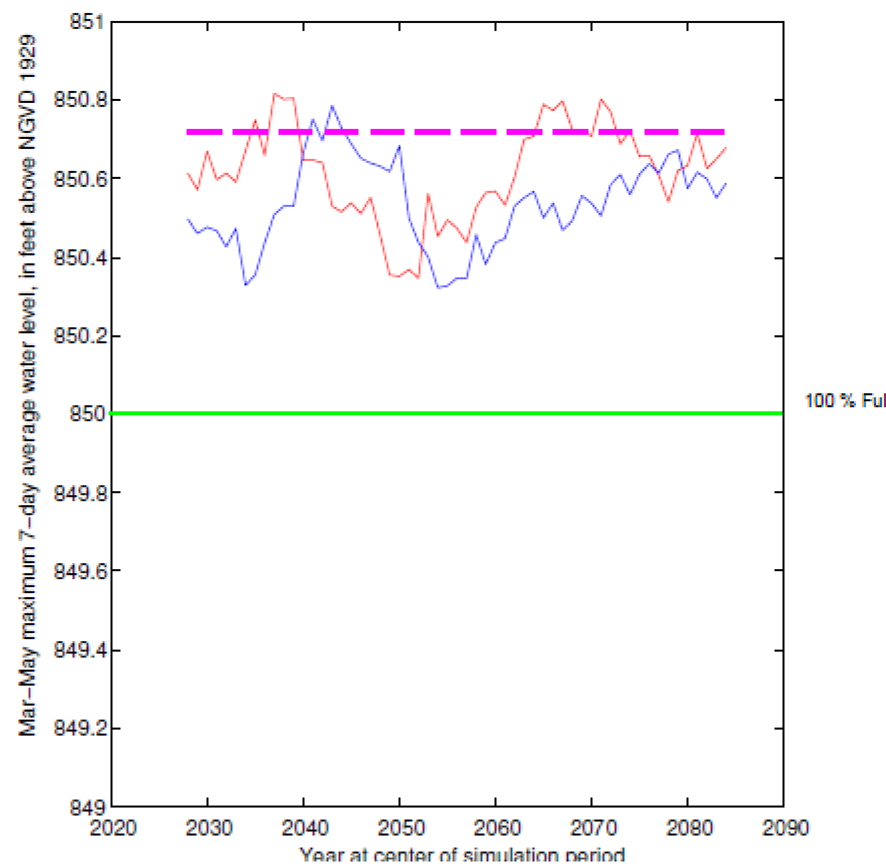


Spring Average Maximum Water Levels: Climate Only

30-Day

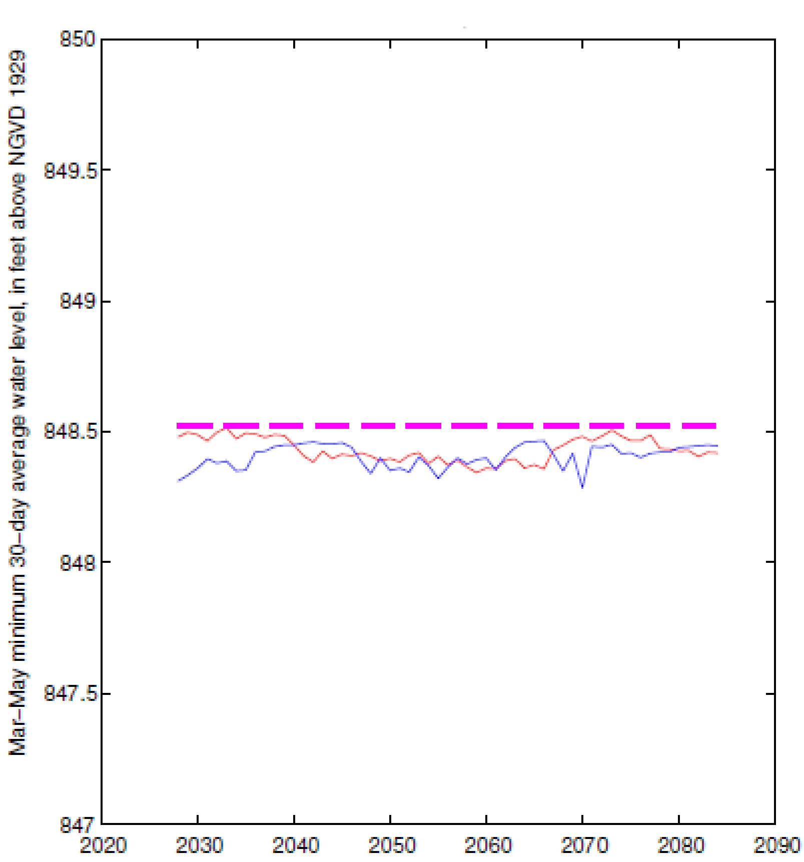


7-Day

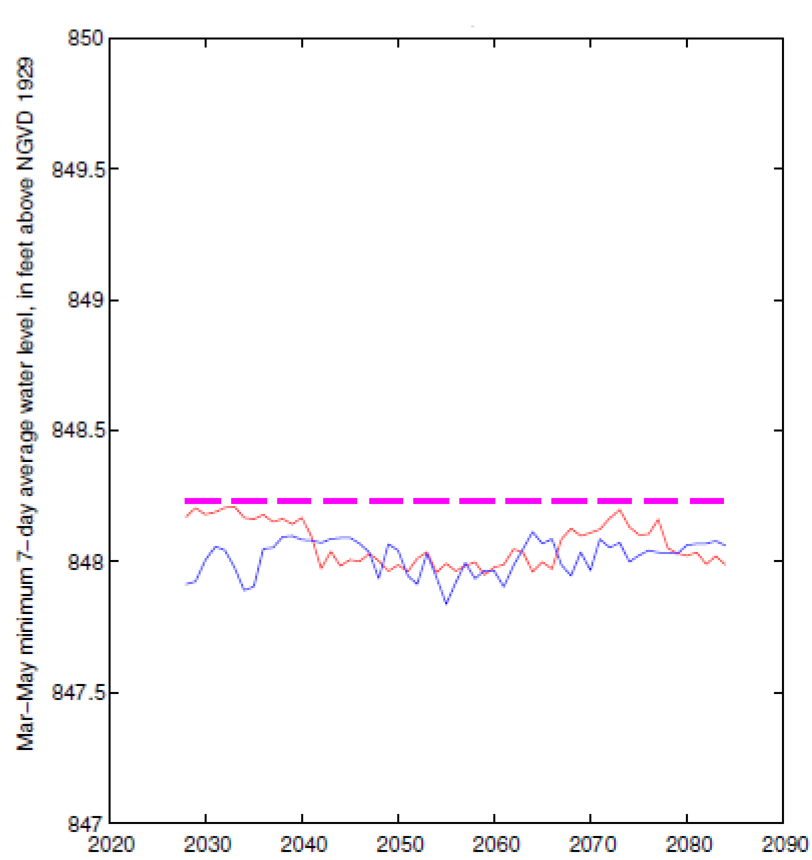


Spring Average Minimum Water Levels: Climate Only

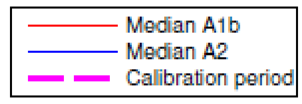
30-Day



7-Day

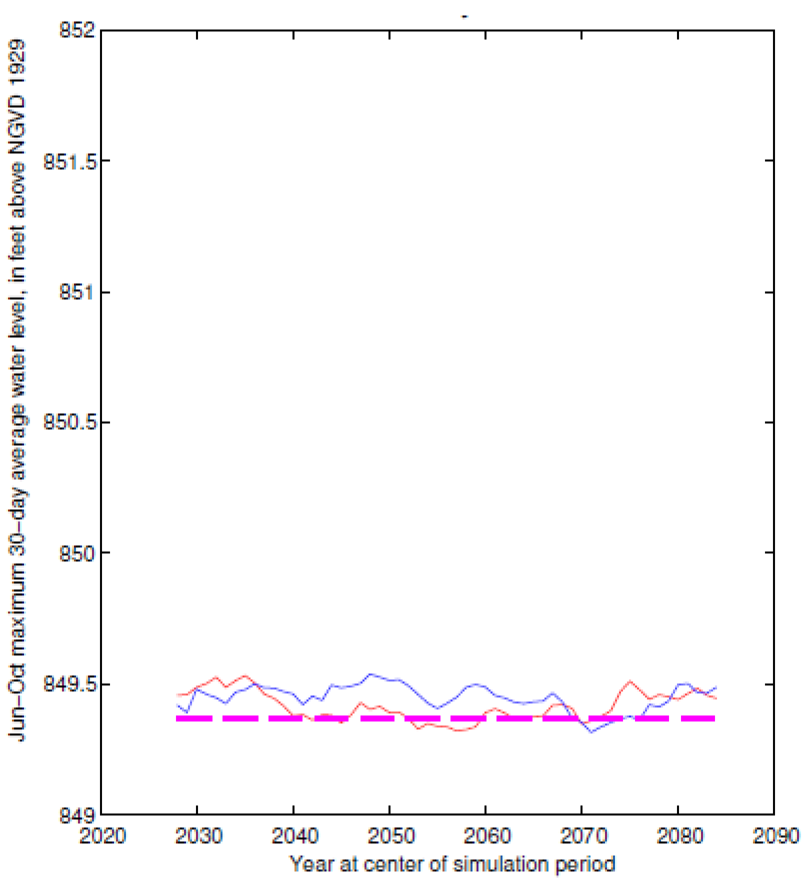


O'Shaughnessy Reservoir

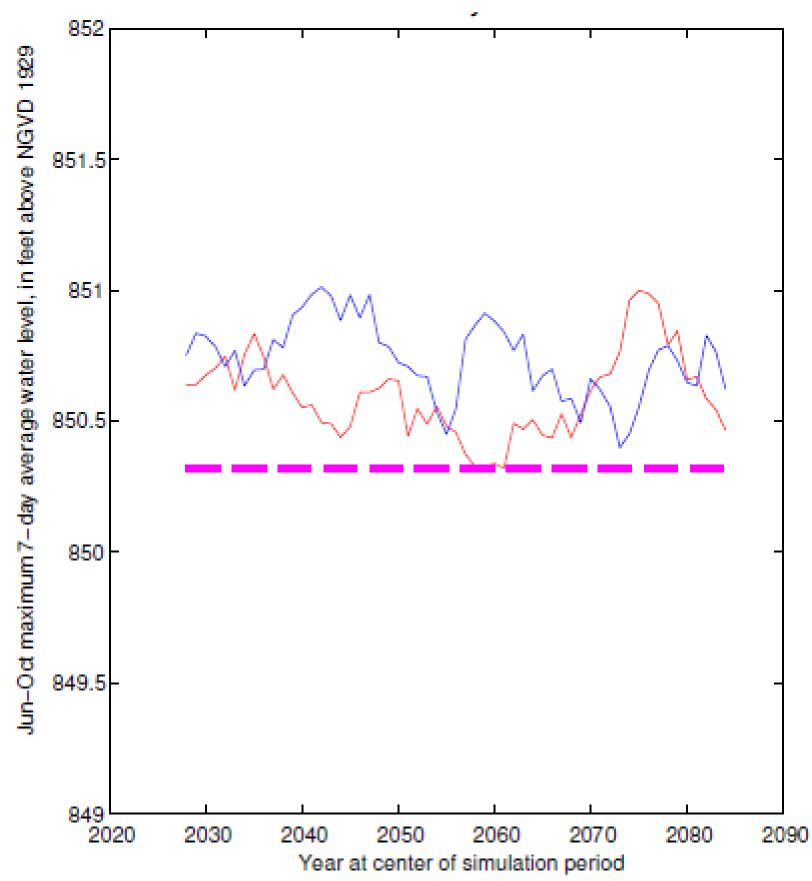


Summer Average Maximum Water Levels: Climate Only

30-Day

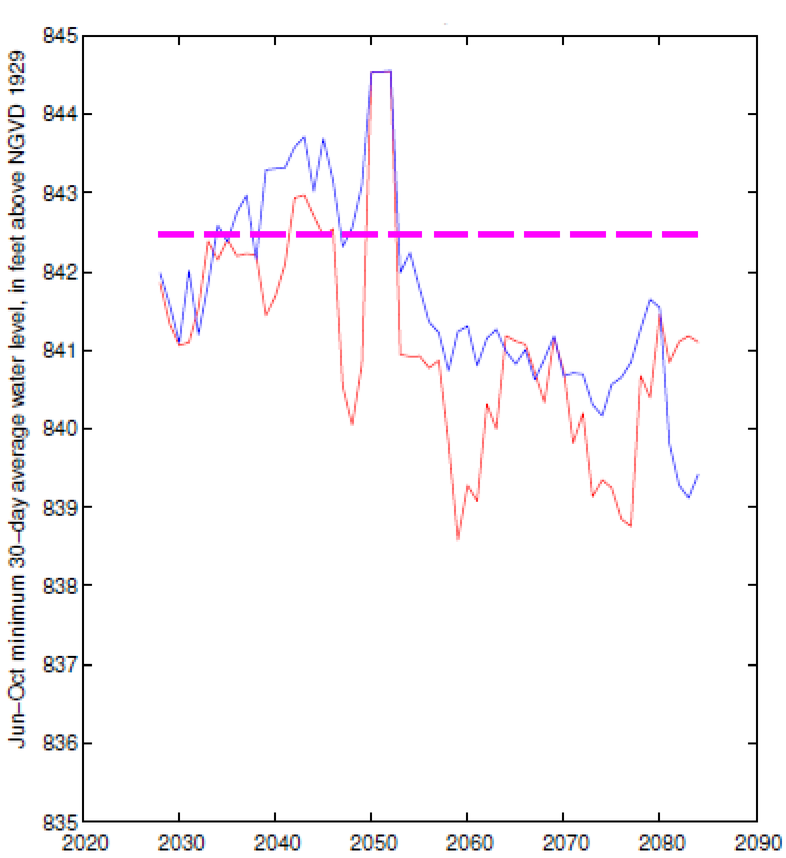


7-Day

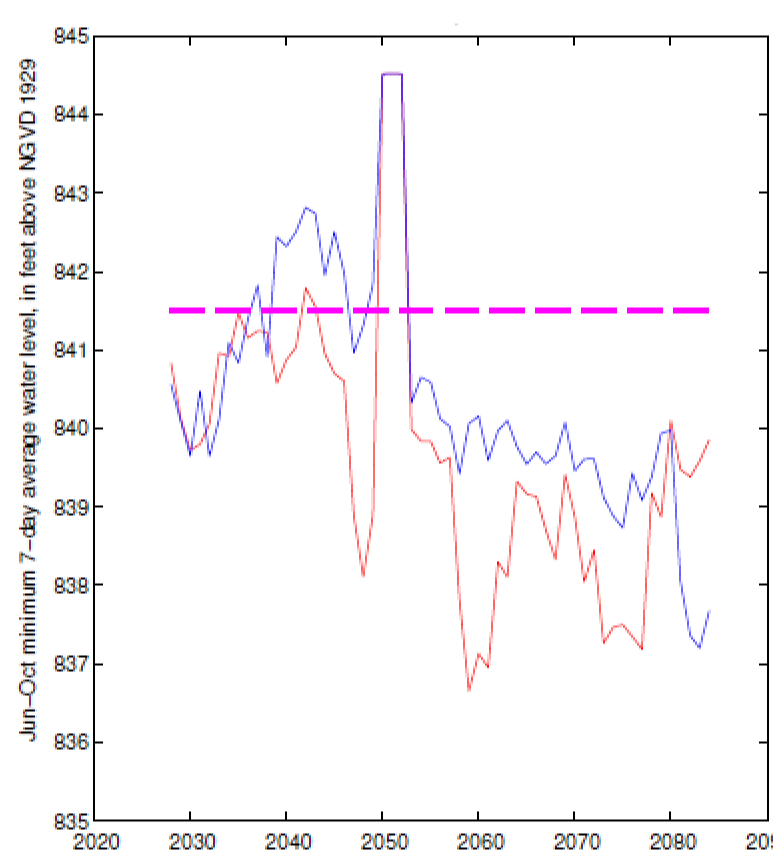


Summer Average Minimum Water Levels: Climate Only

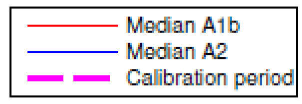
30-Day



7-Day

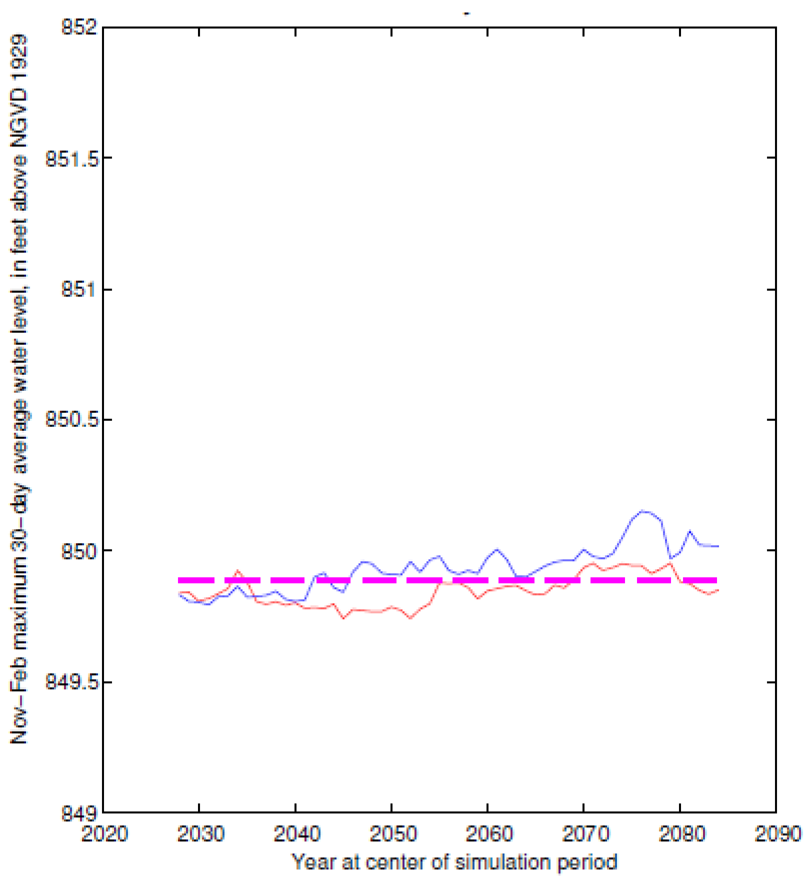


O'Shaughnessy Reservoir: Seasonal Water Levels

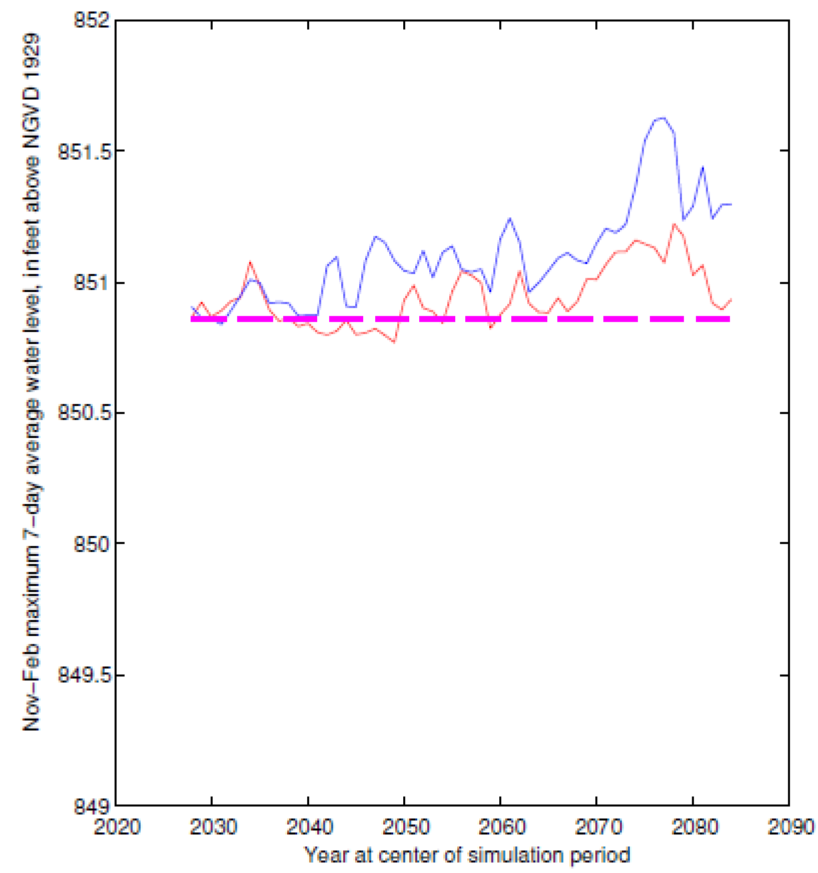


Fall/Winter Average Maximum Water Levels: Climate Only

30-Day

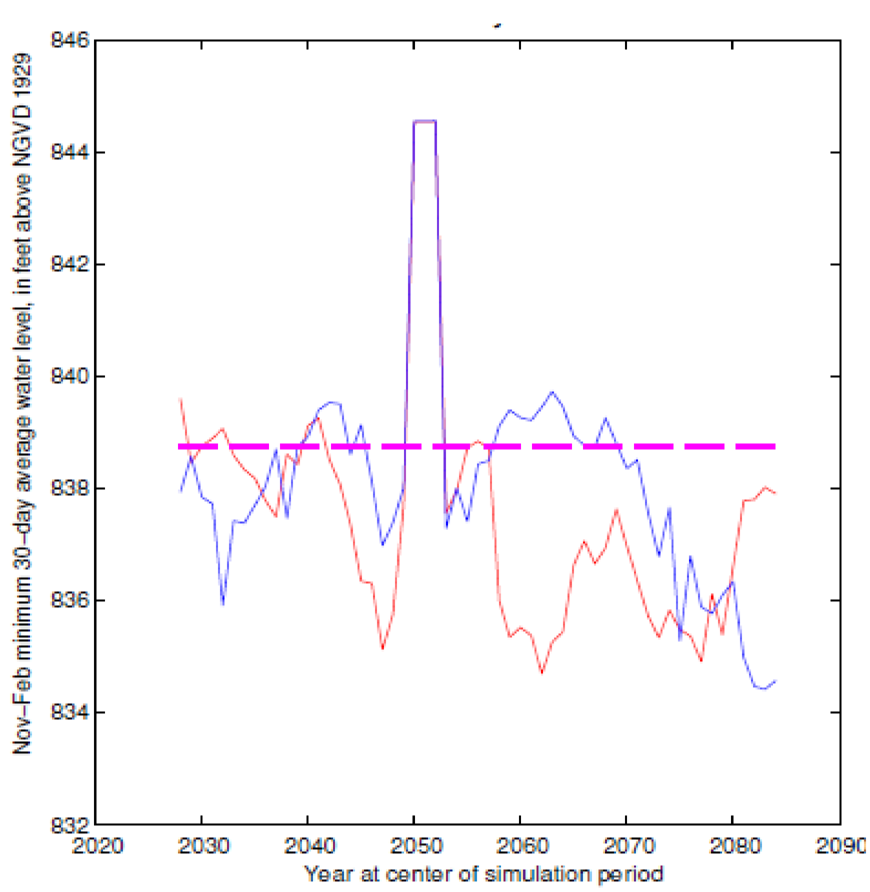


7-Day

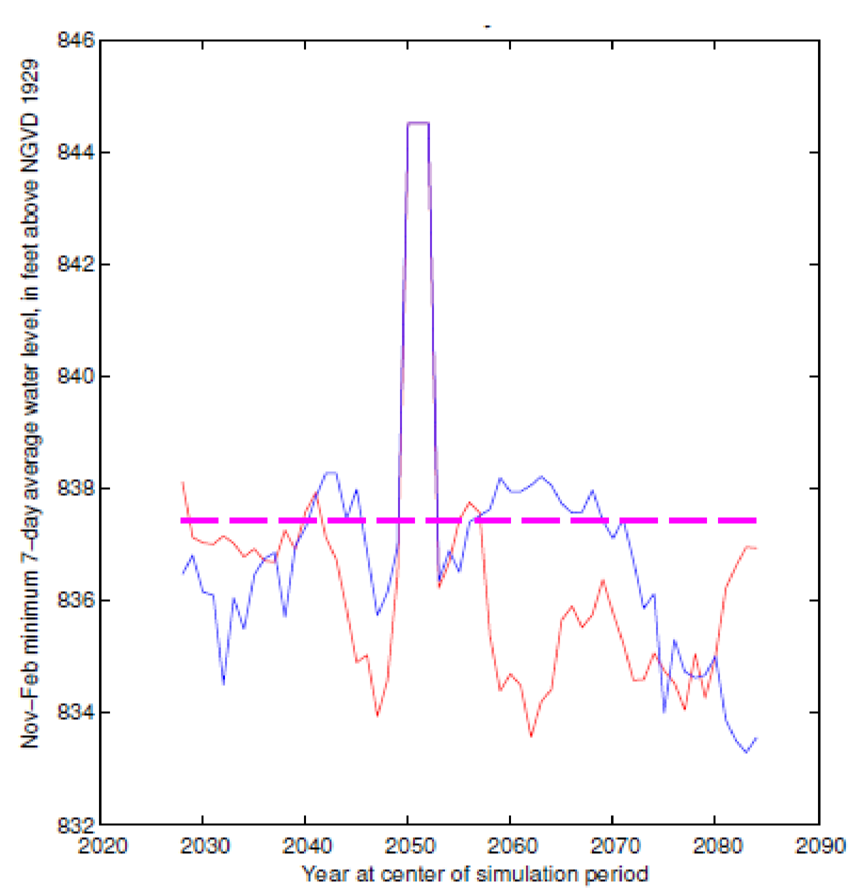


Fall/Winter Average Minimum Water Levels: Climate Only

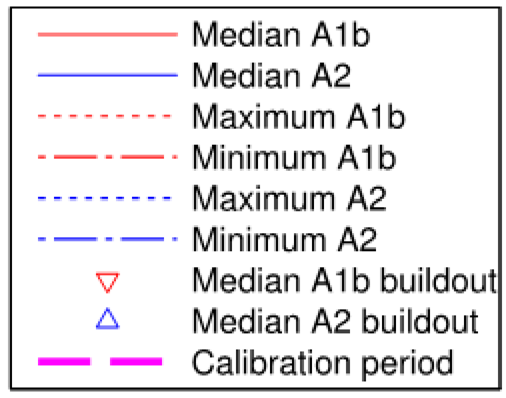
30-Day



7-Day

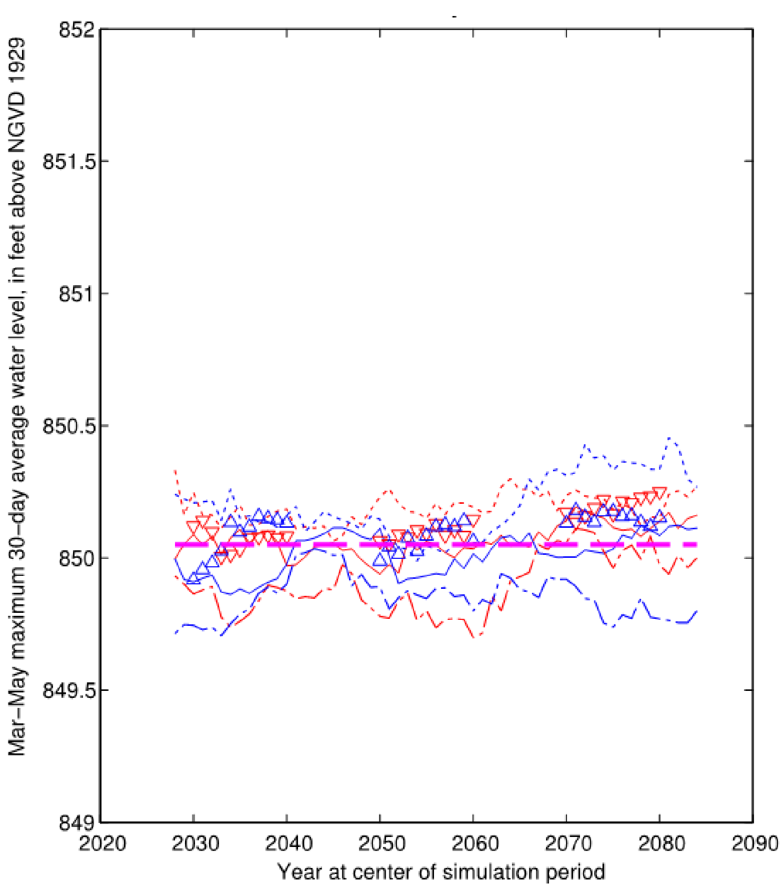


O’Shaughnessy Reservoir

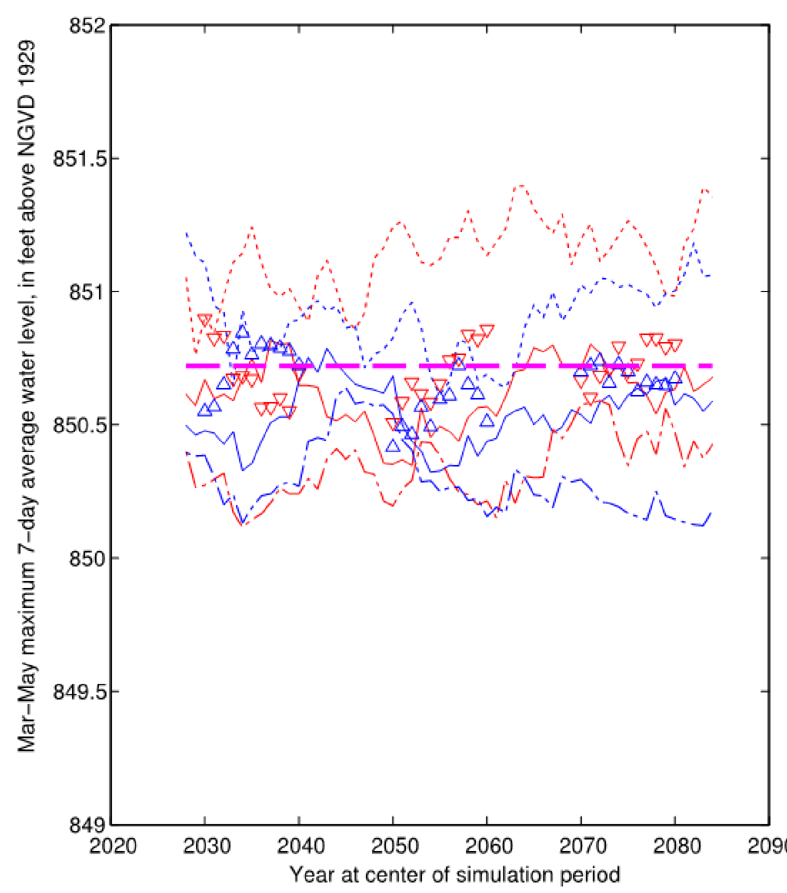


Spring Average Maximum Water Levels with Development

30-Day

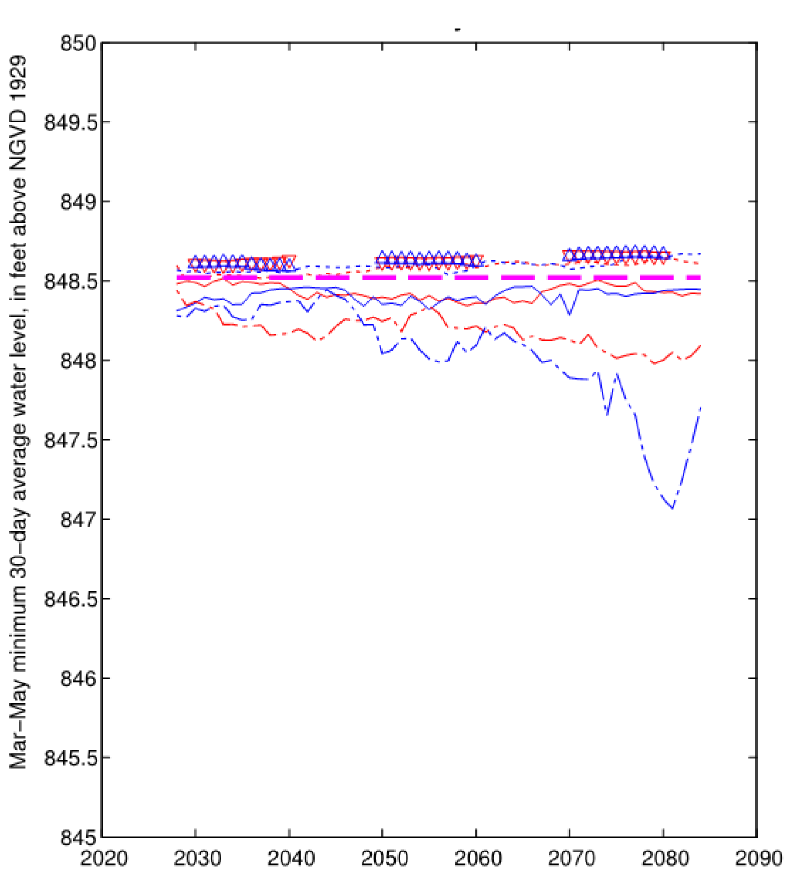


7-Day

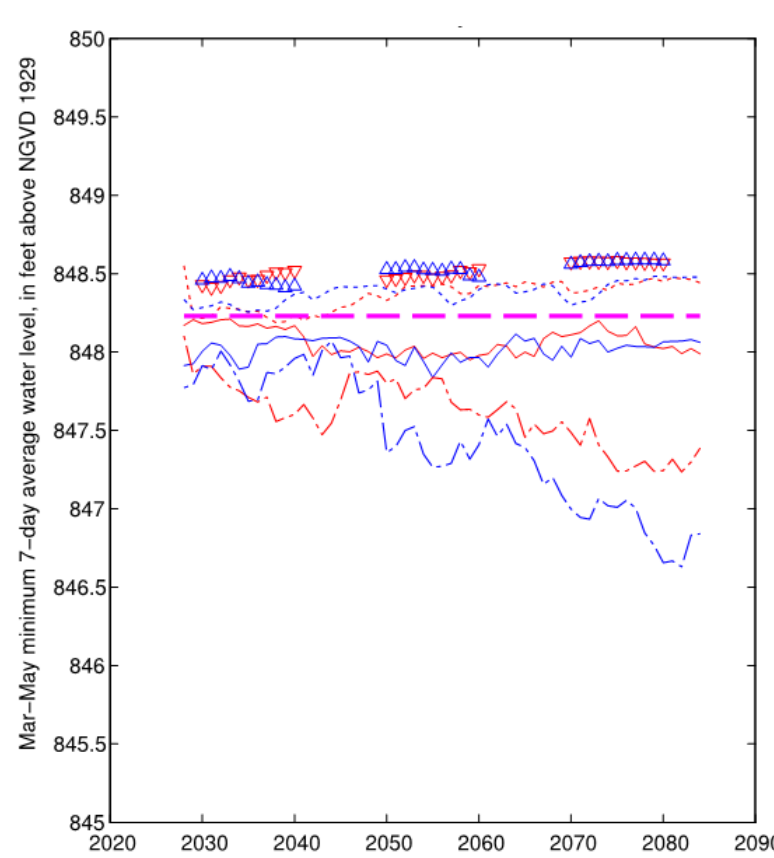


Spring Average Minimum Water Levels with Development

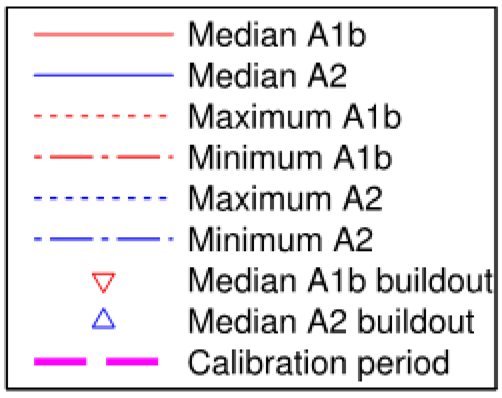
30-Day



7-Day

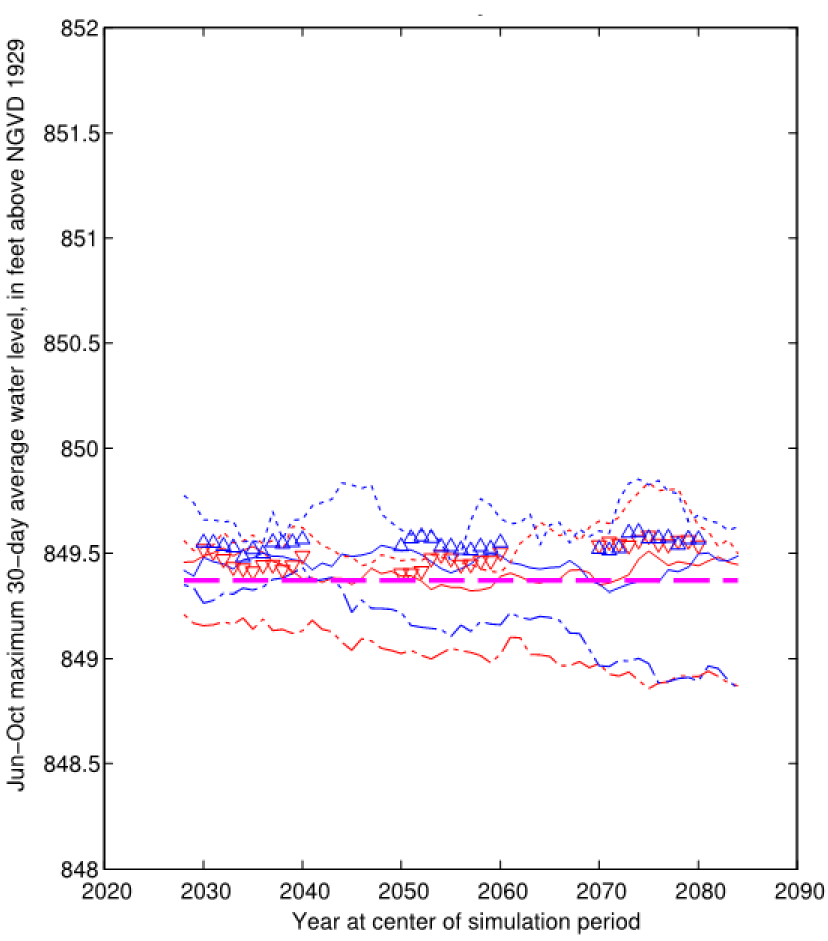


O’Shaughnessy Reservoir

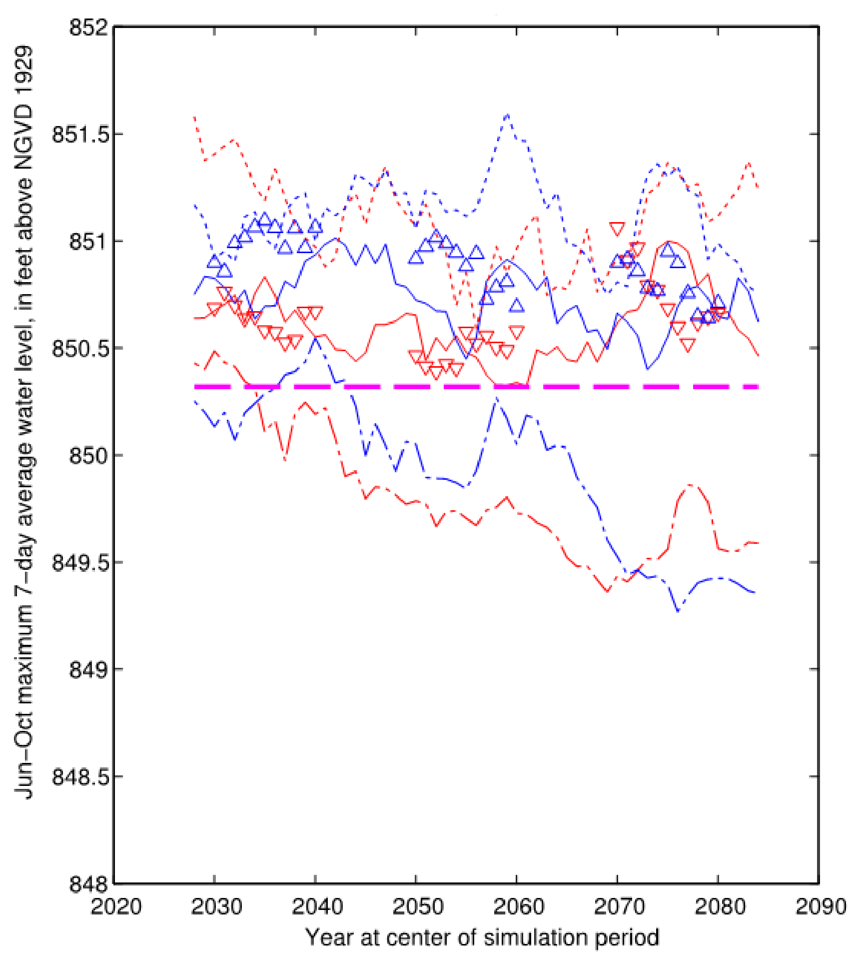


Summer Average Maximum Water Levels with Development

30-Day

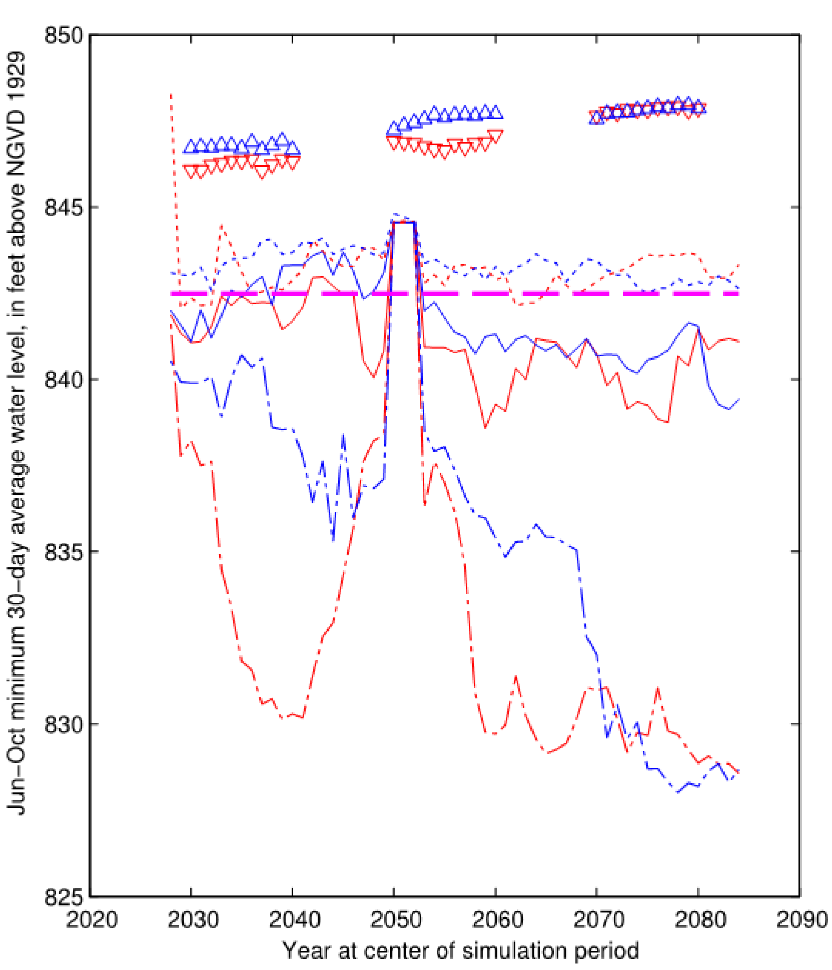


7-Day

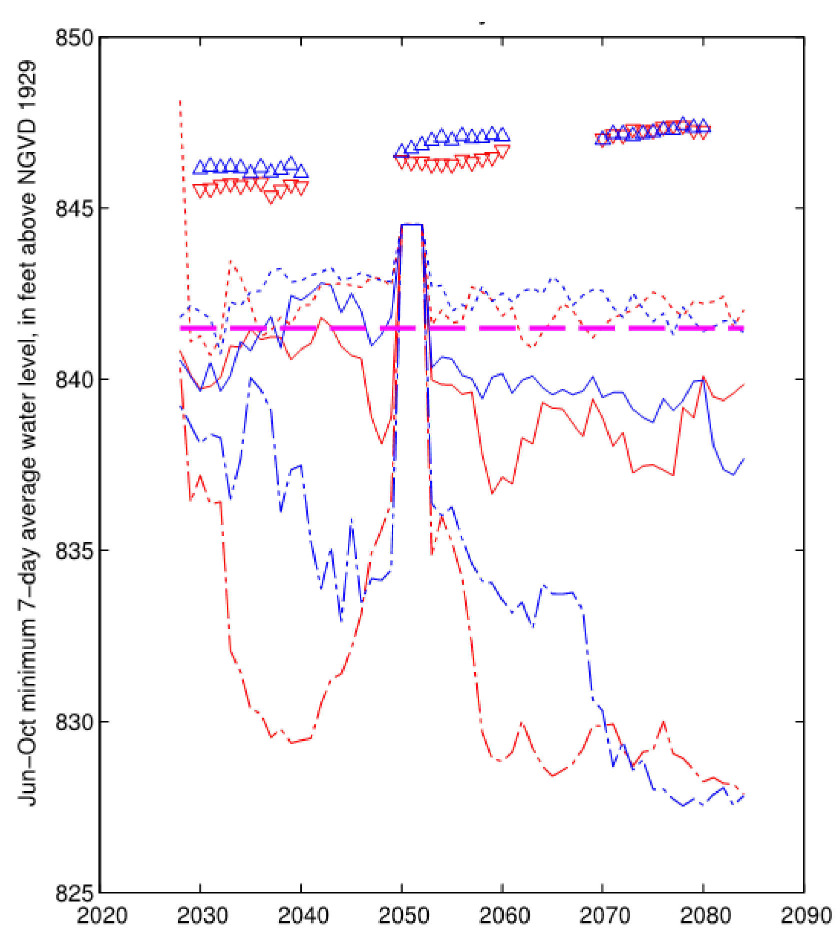


Summer Average Minimum Water Levels with Development

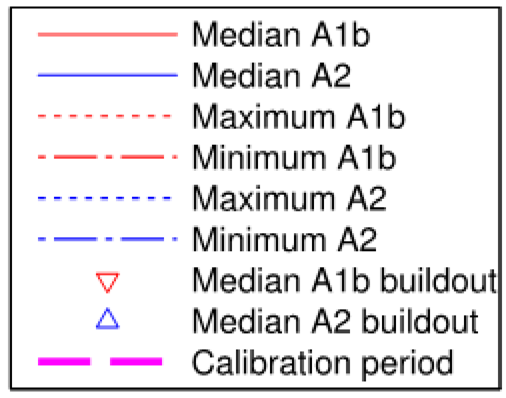
30-Day



7-Day

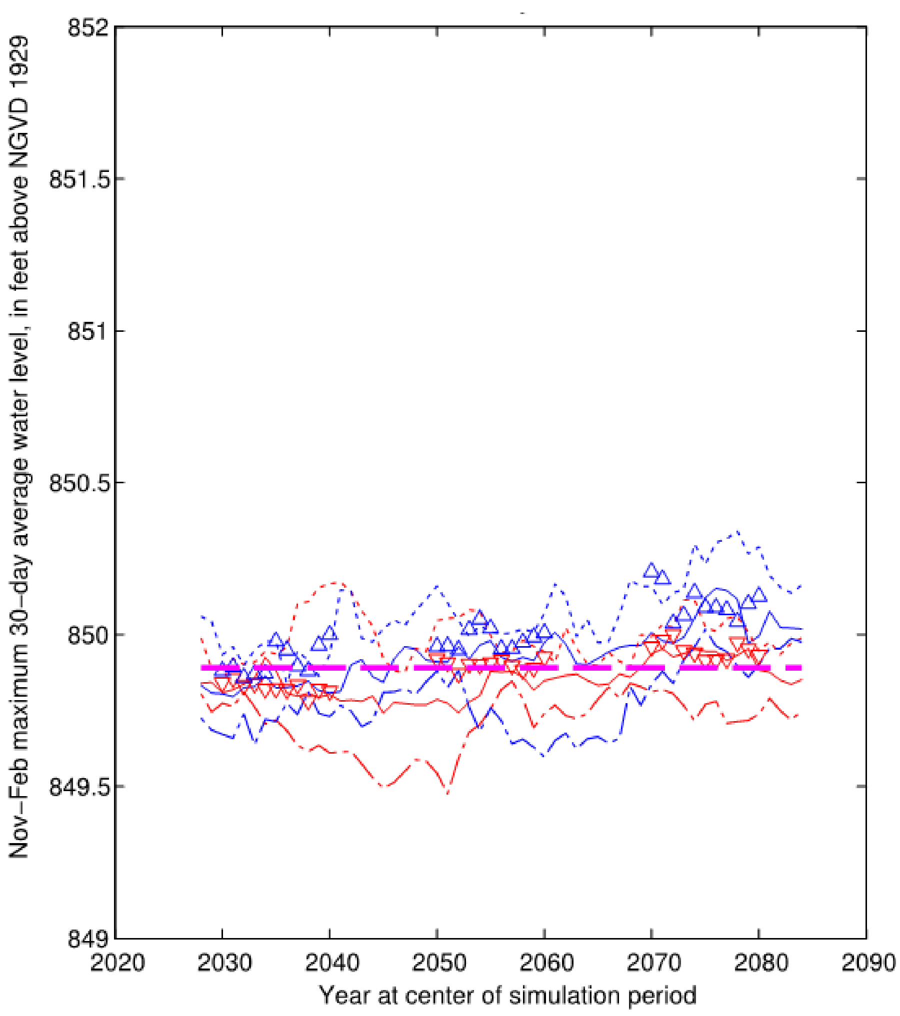


O’Shaughnessy Reservoir

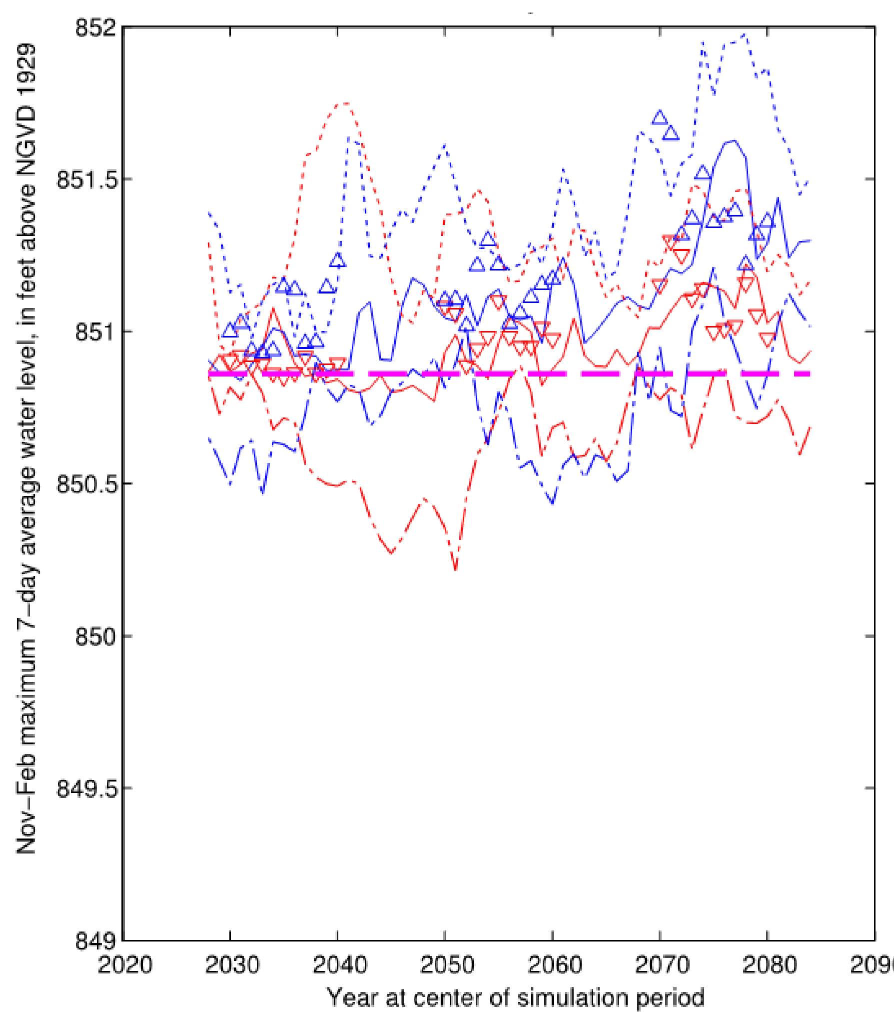


Fall/Winter Average Maximum Water Levels with Development

30-Day

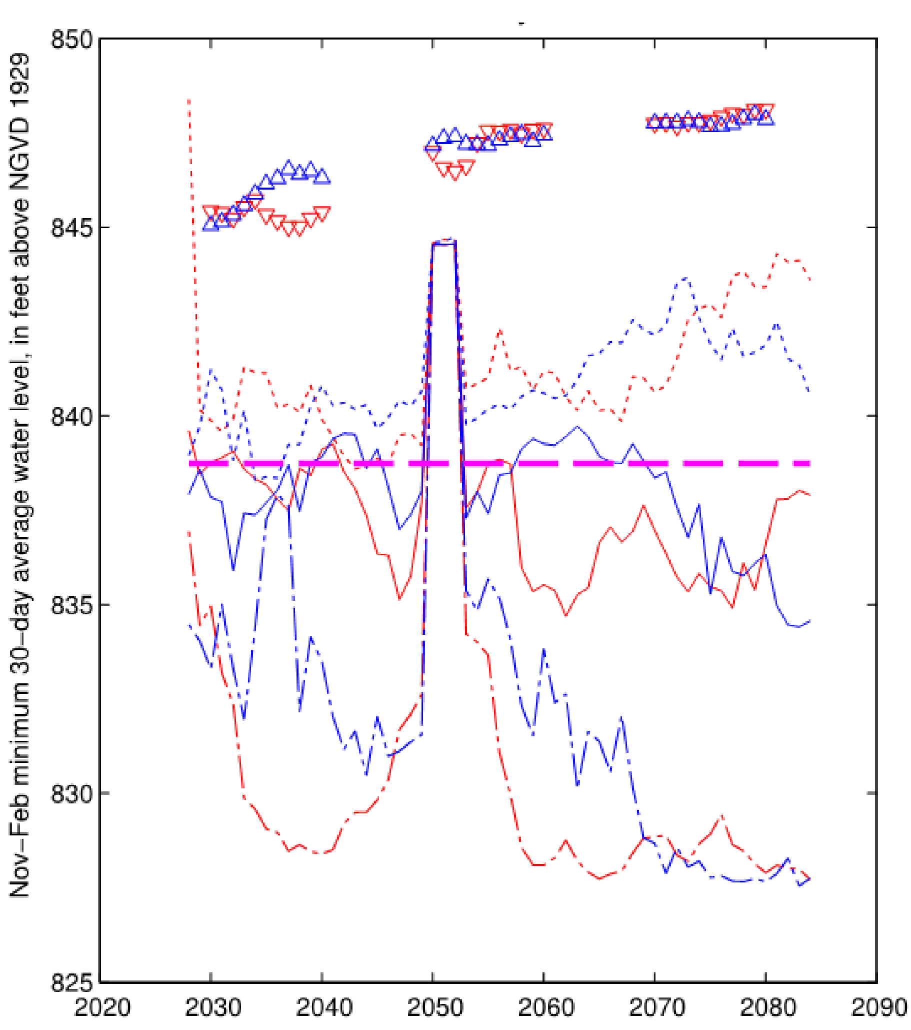


7-Day

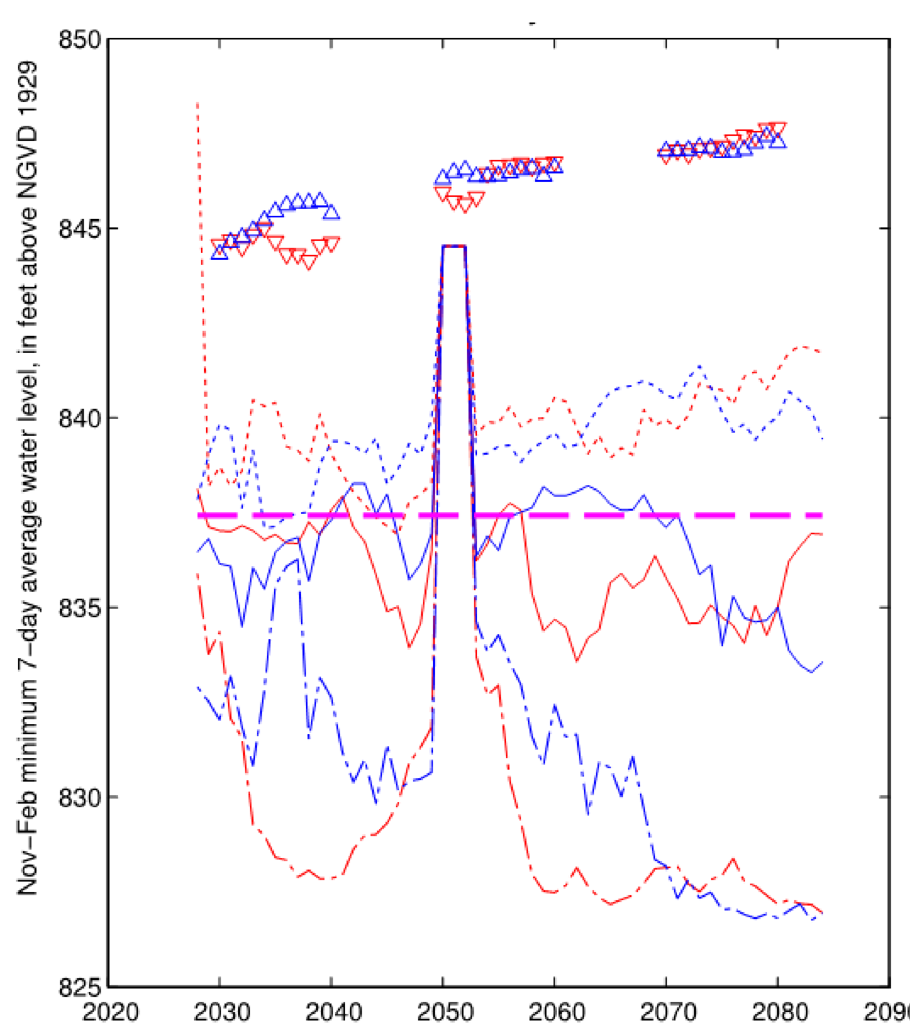


Fall/Winter Average Minimum Water Levels with Development

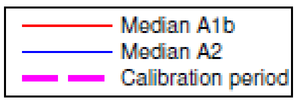
30-Day



7-Day

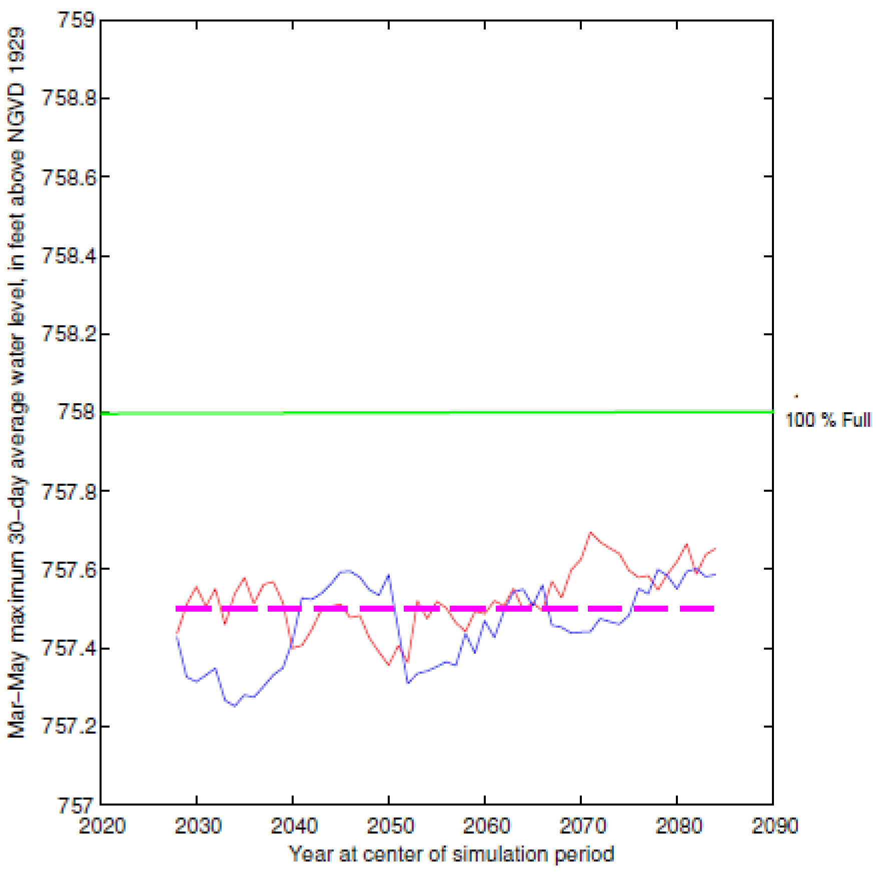


Griggs Reservoir: Seasonal Water Levels

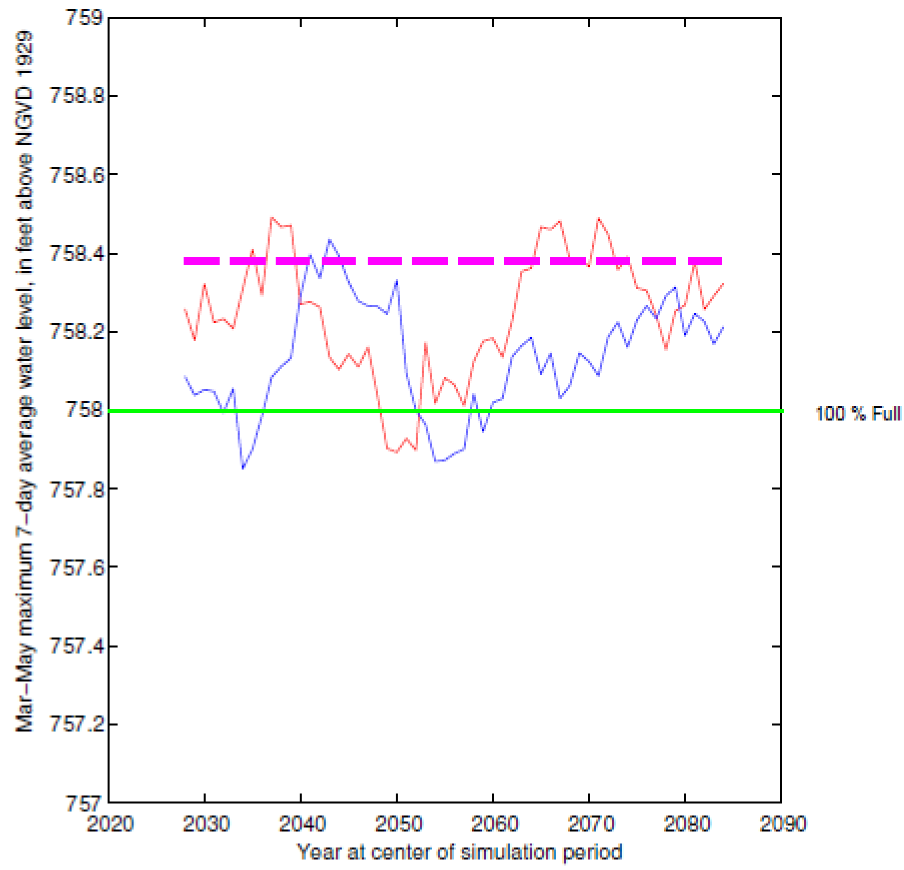


Spring Average Maximum Water Levels: Climate Only

30-Day

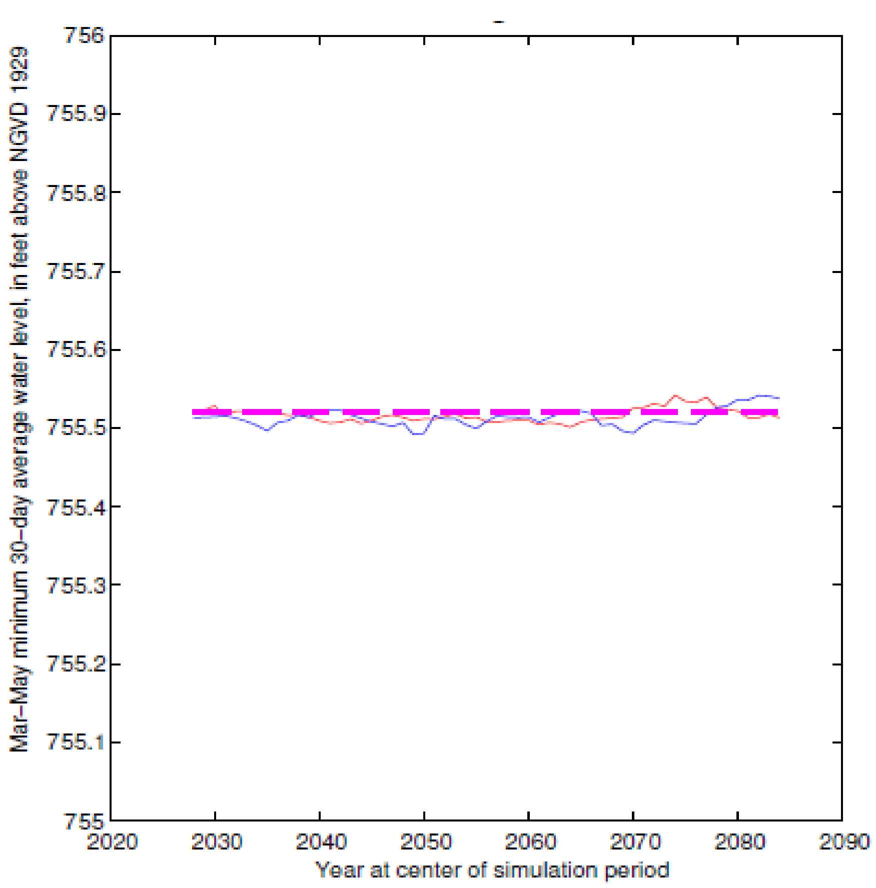


7-Day

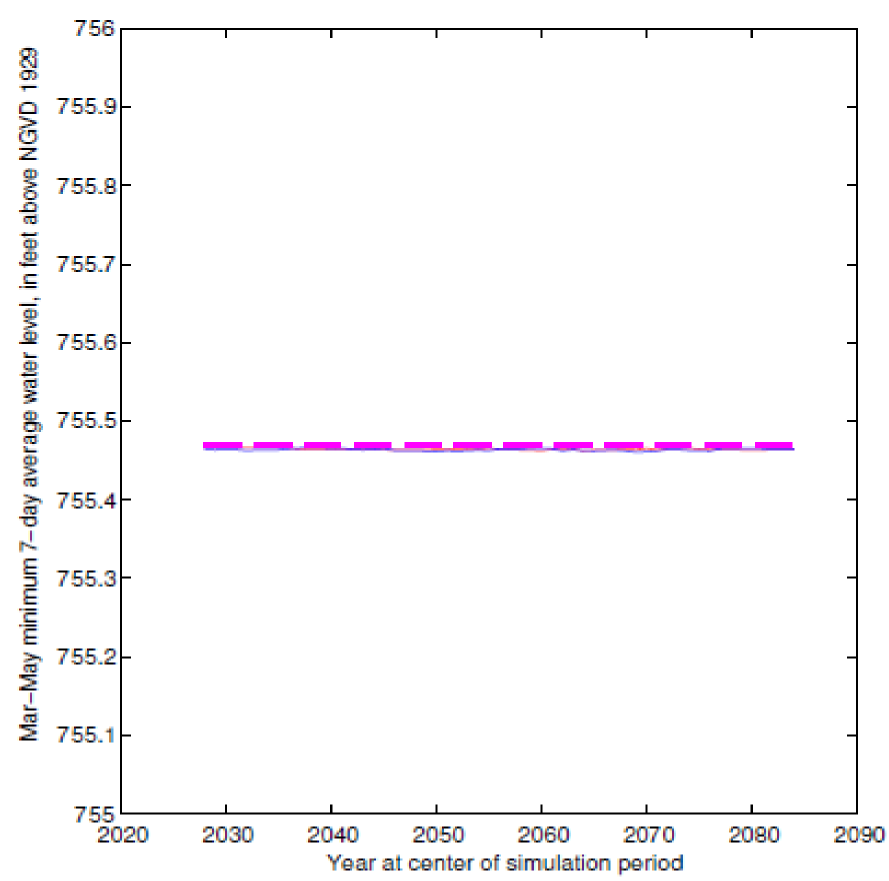


Spring Average Minimum Water Levels: Climate Only

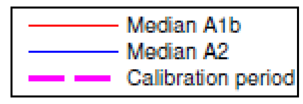
30-Day



7-Day

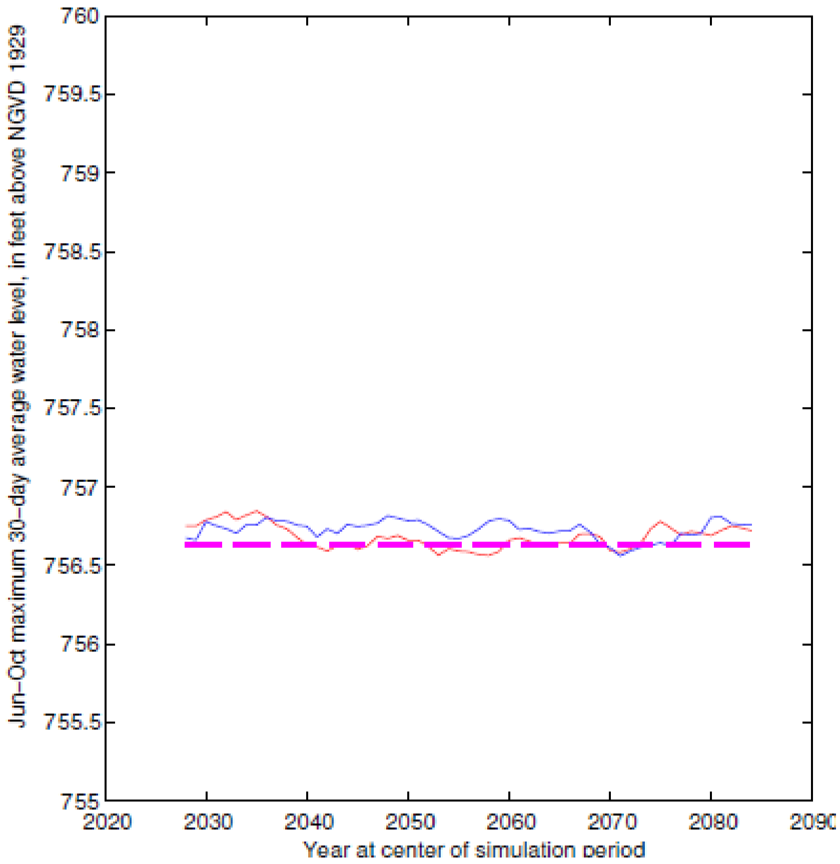


Griggs Reservoir

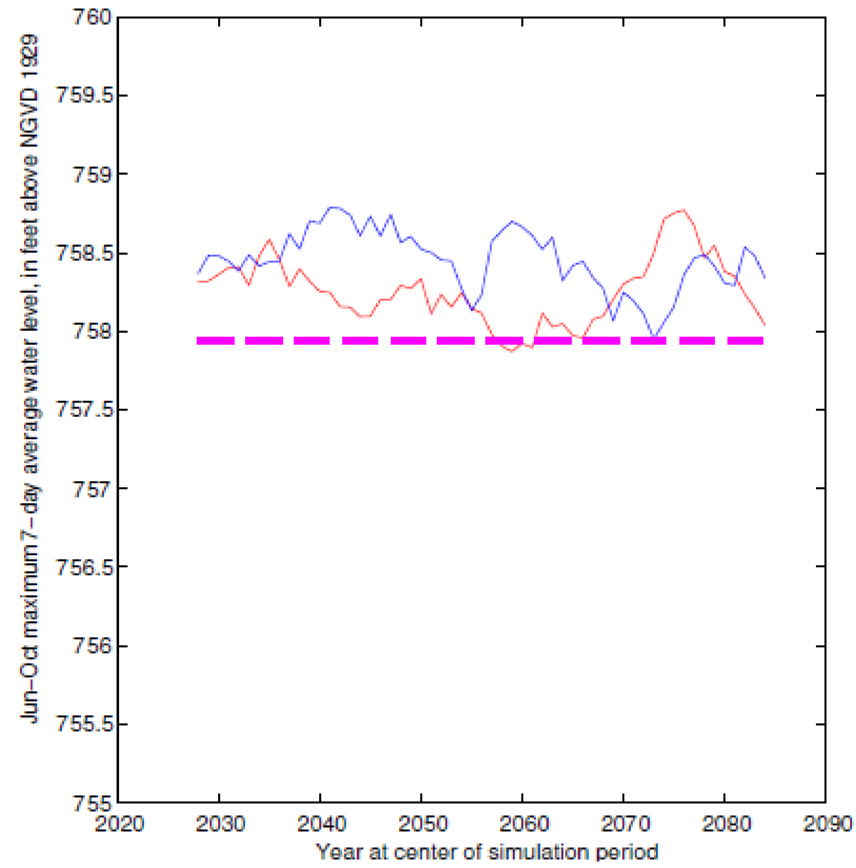


Summer Average Maximum Water Levels: Climate Only

30-Day

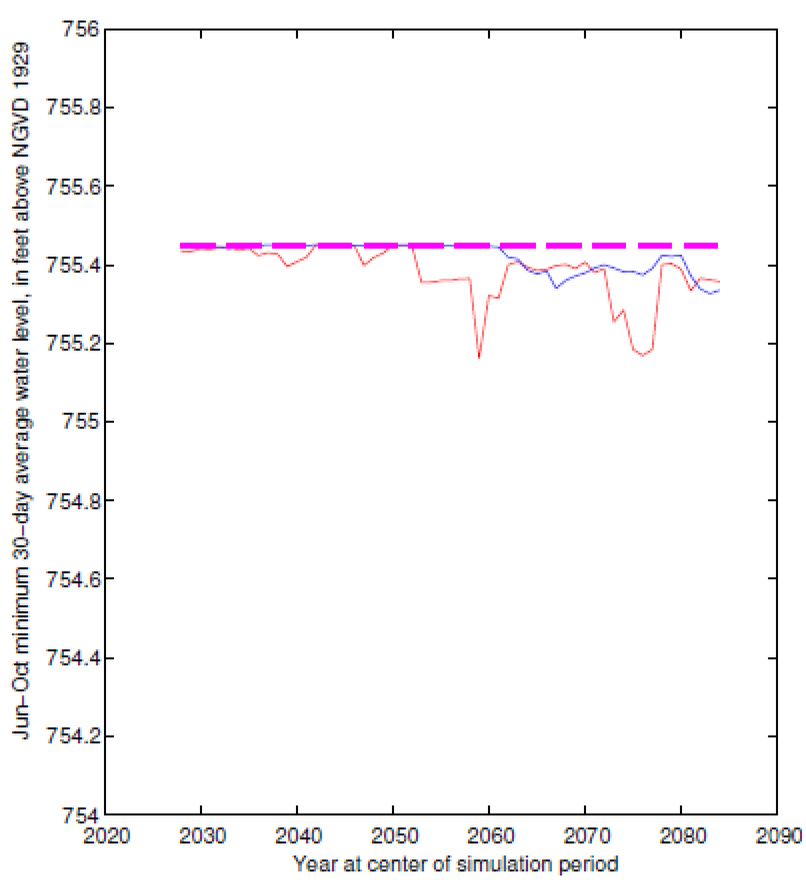


7-Day

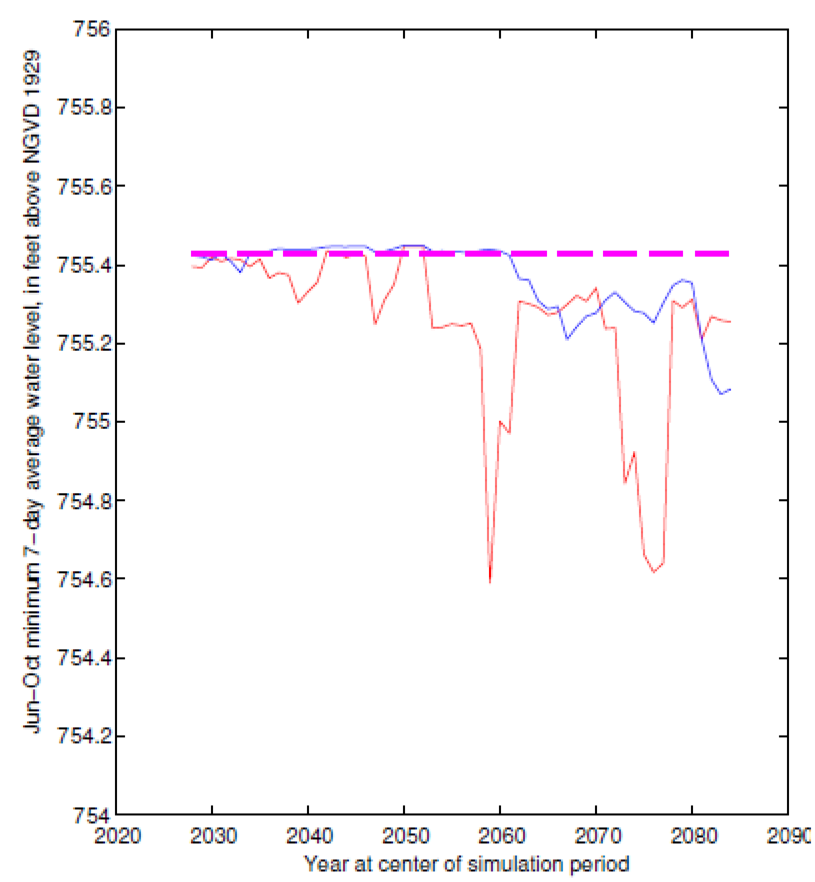


Summer Average Minimum Water Levels: Climate Only

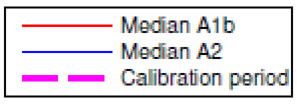
30-Day



7-Day

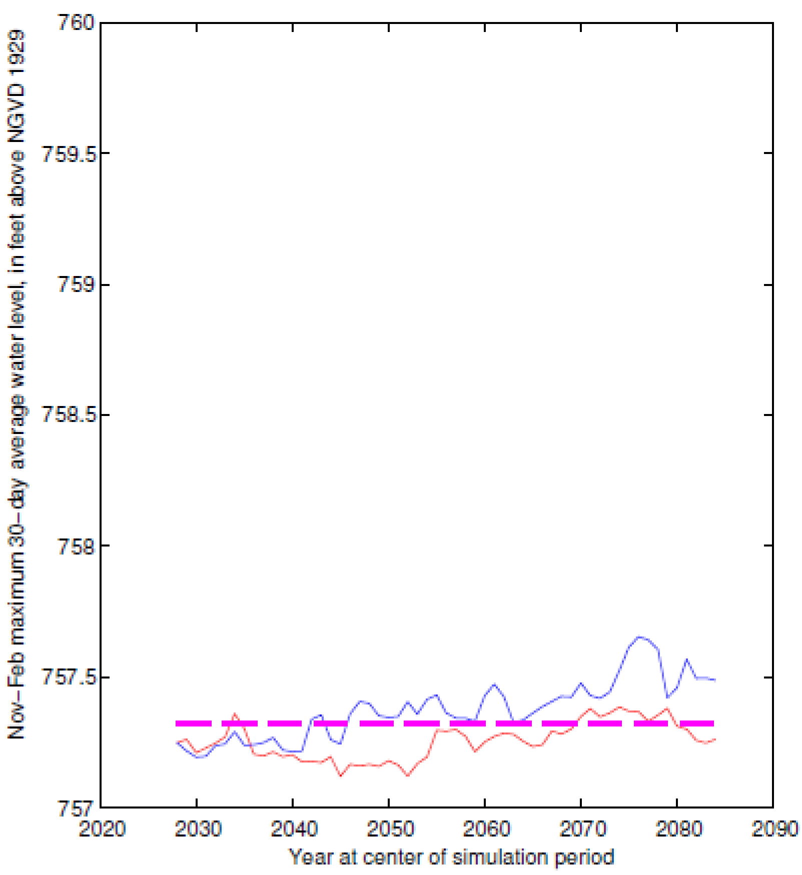


Griggs Reservoir

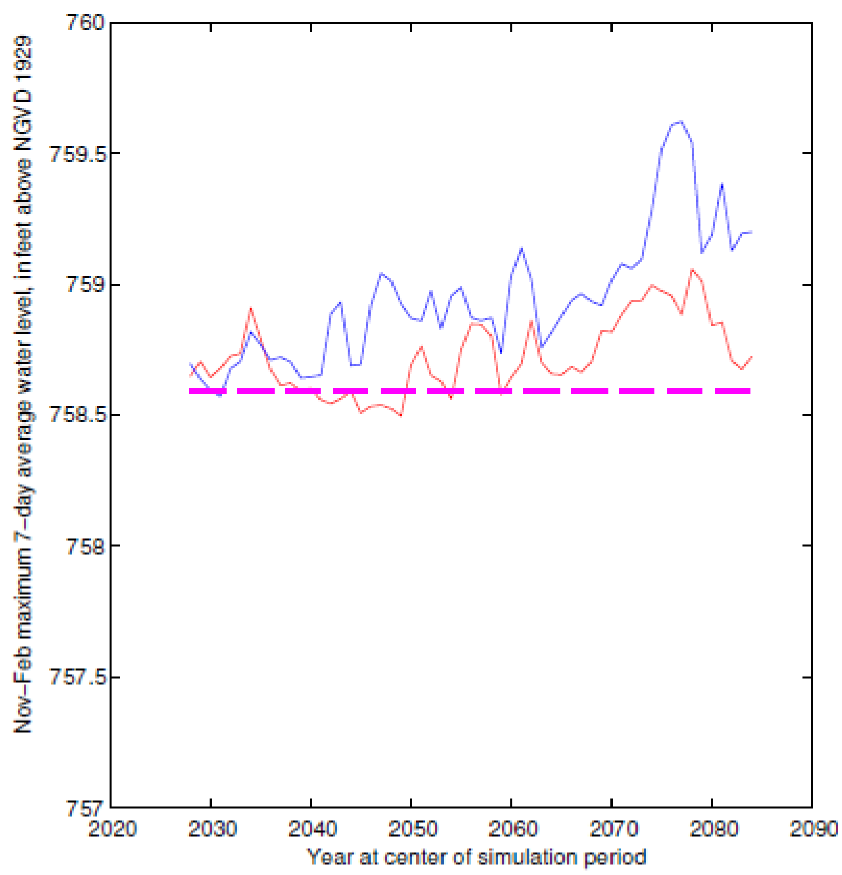


Fall/Winter Average Maximum Water Levels: Climate Only

30-Day

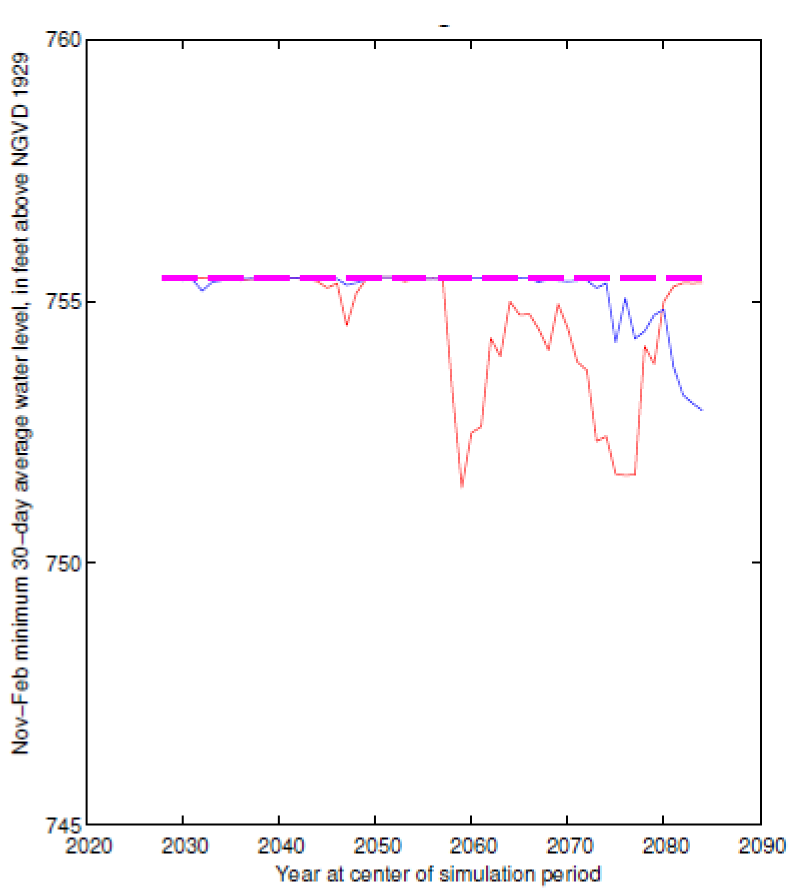


7-Day

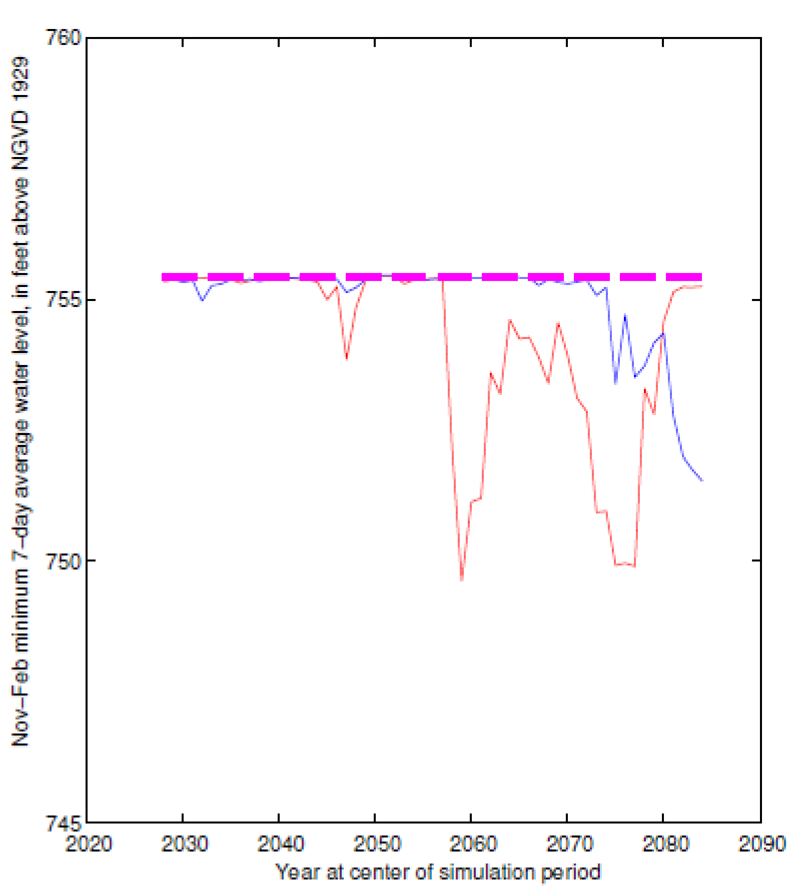


Fall/Winter Average Minimum Water Levels: Climate Only

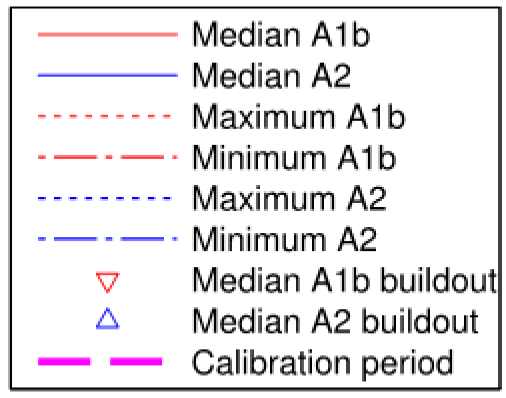
30-Day



7-Day

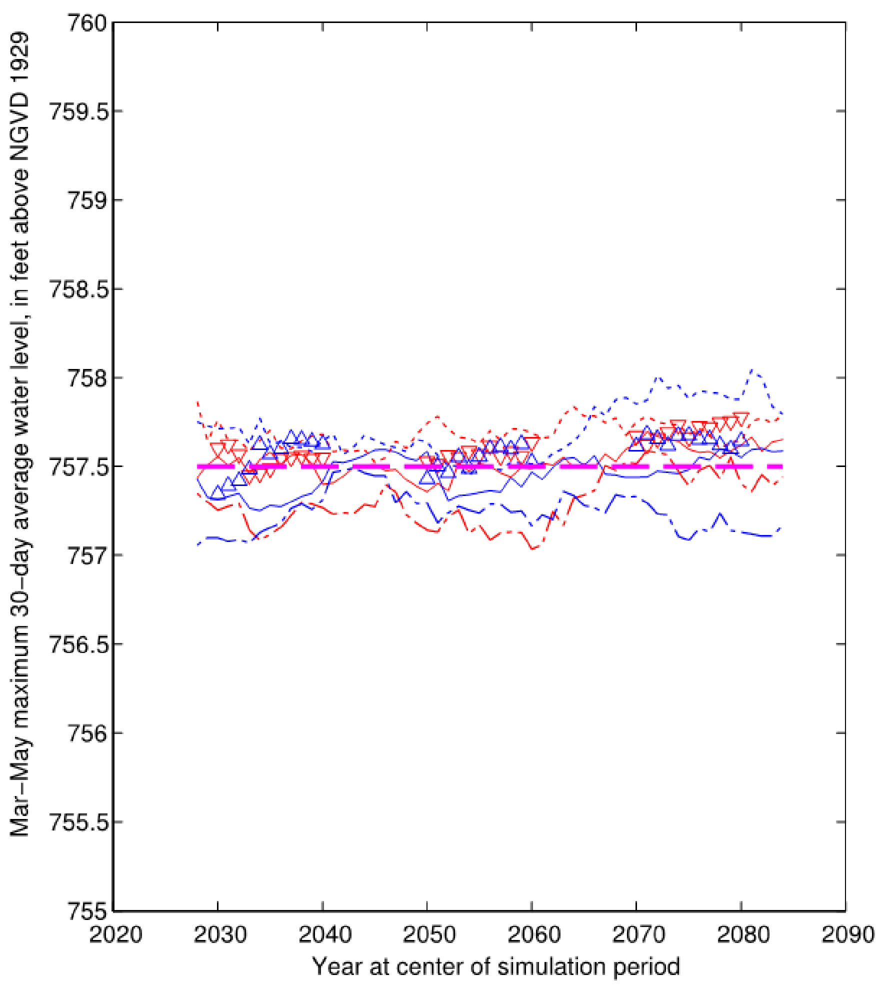


Griggs Reservoir

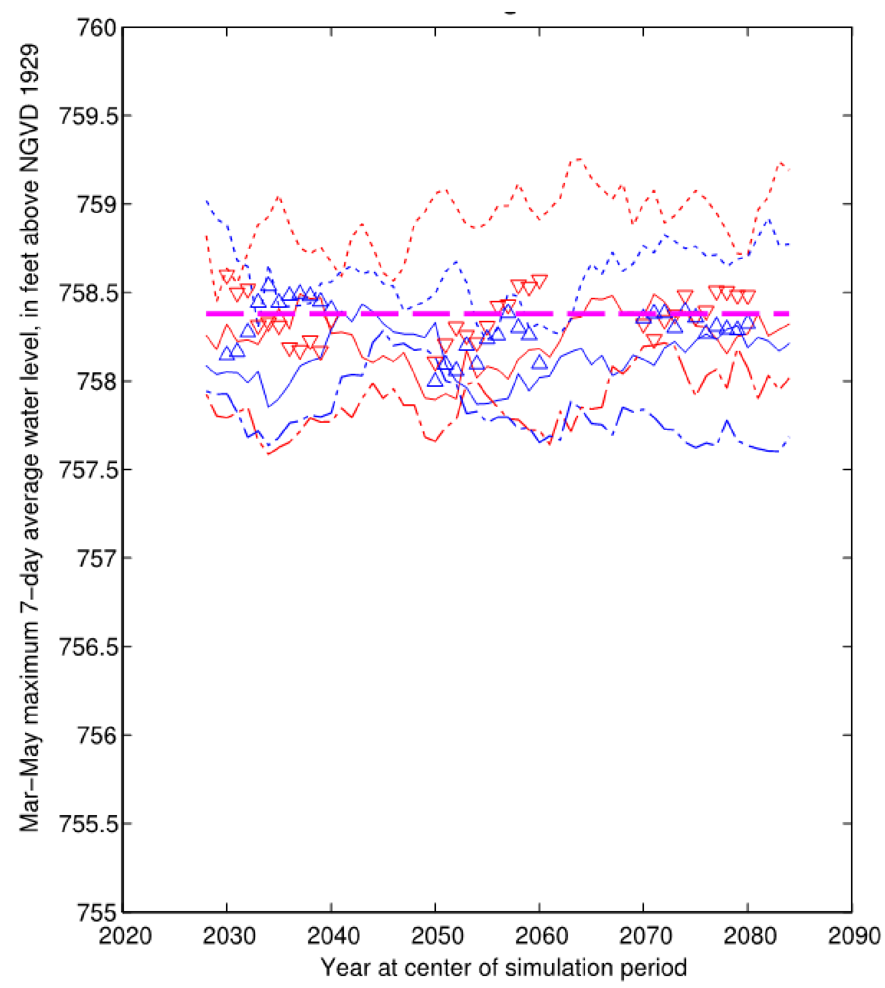


Spring Average Maximum Water Levels with Development

30-Day

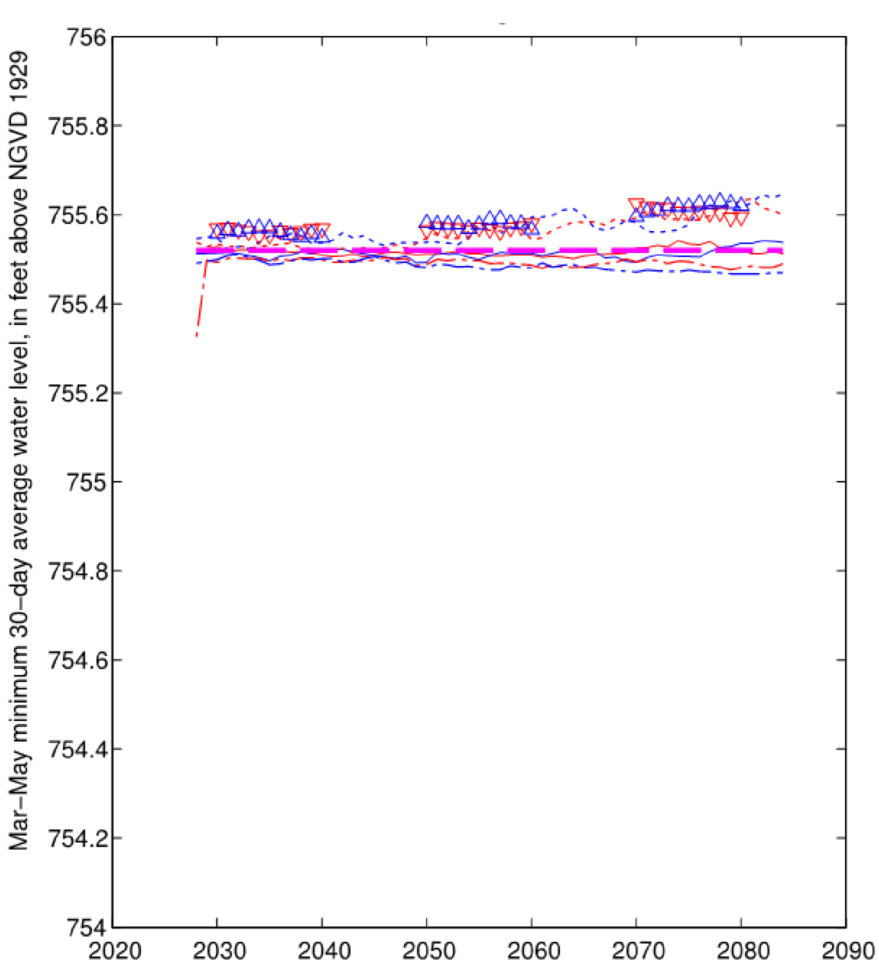


7-Day

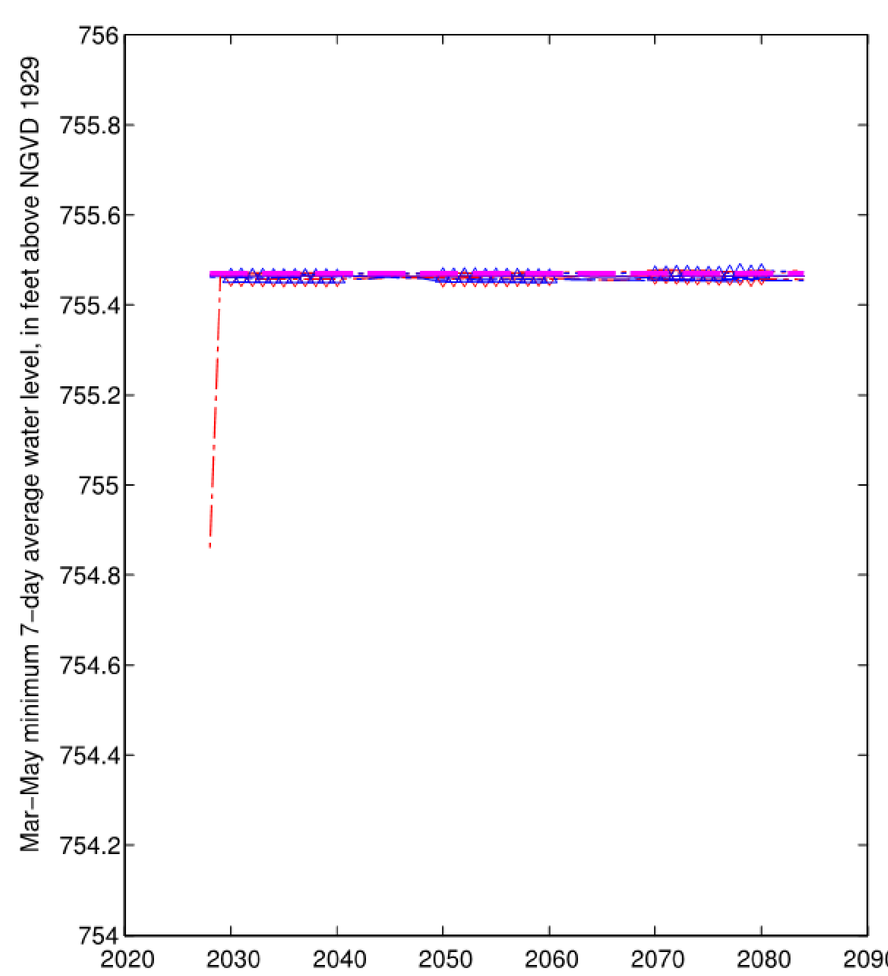


Spring Average Minimum Water Levels with Development

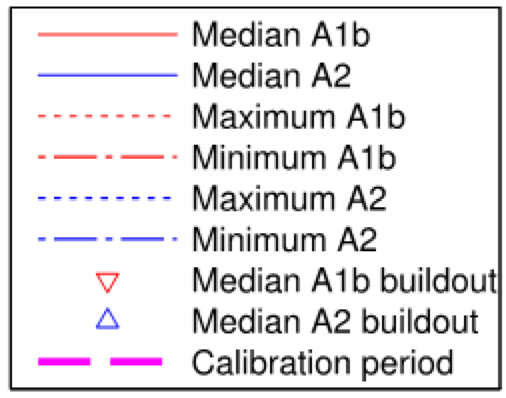
30-Day



7-Day

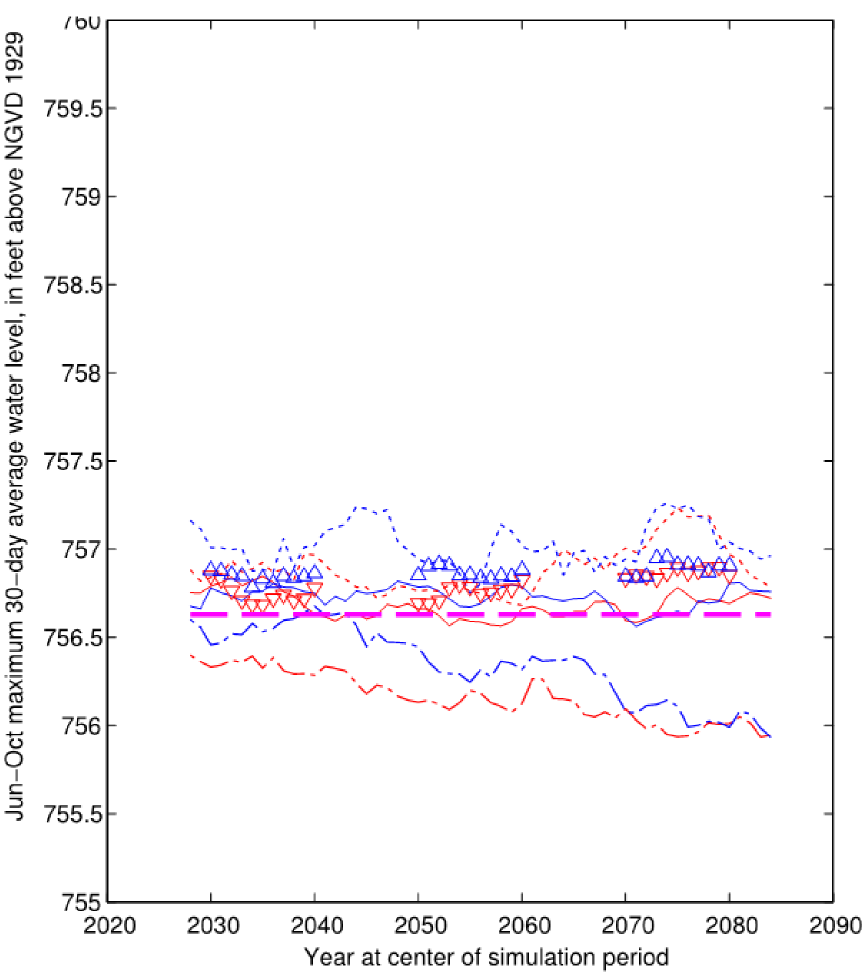


Griggs Reservoir

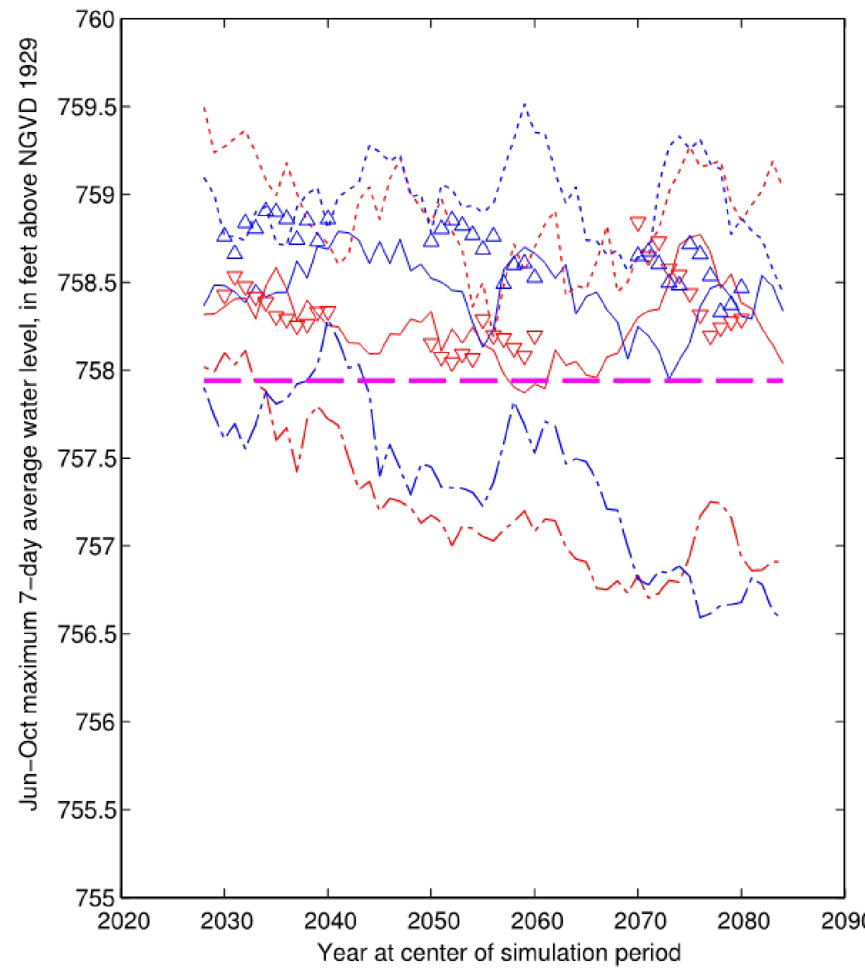


Summer Average Maximum Water Levels with Development

30-Day

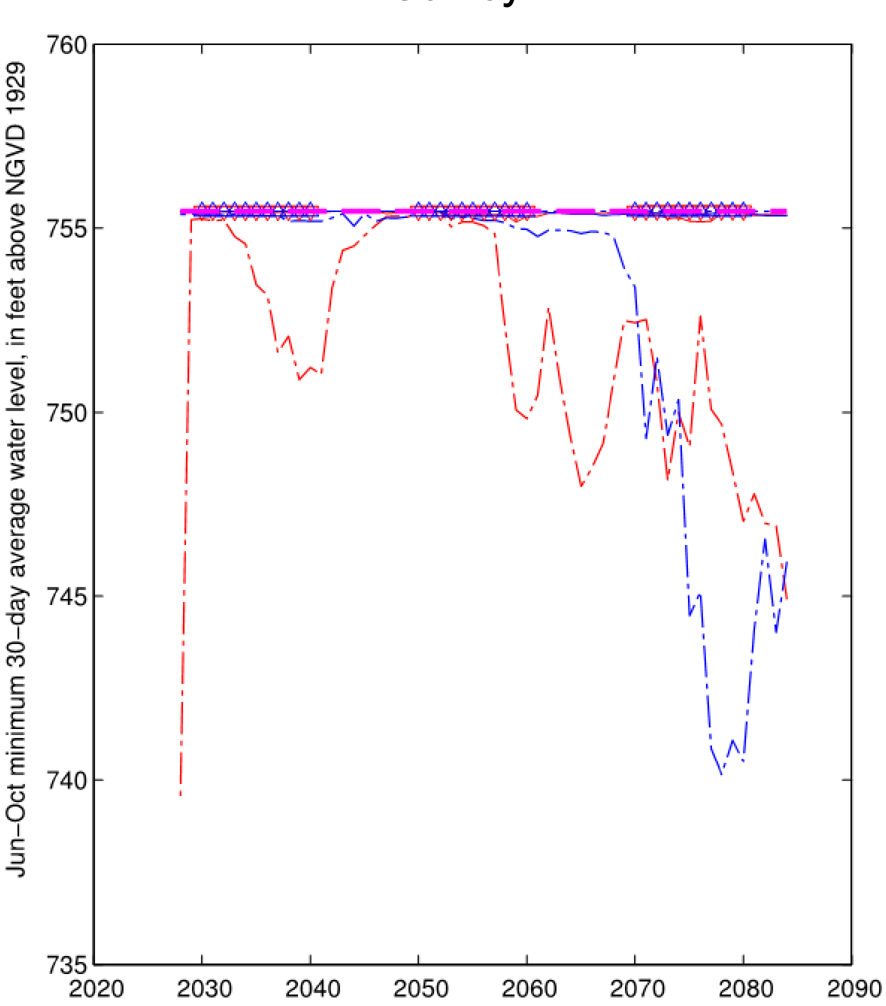


7-Day

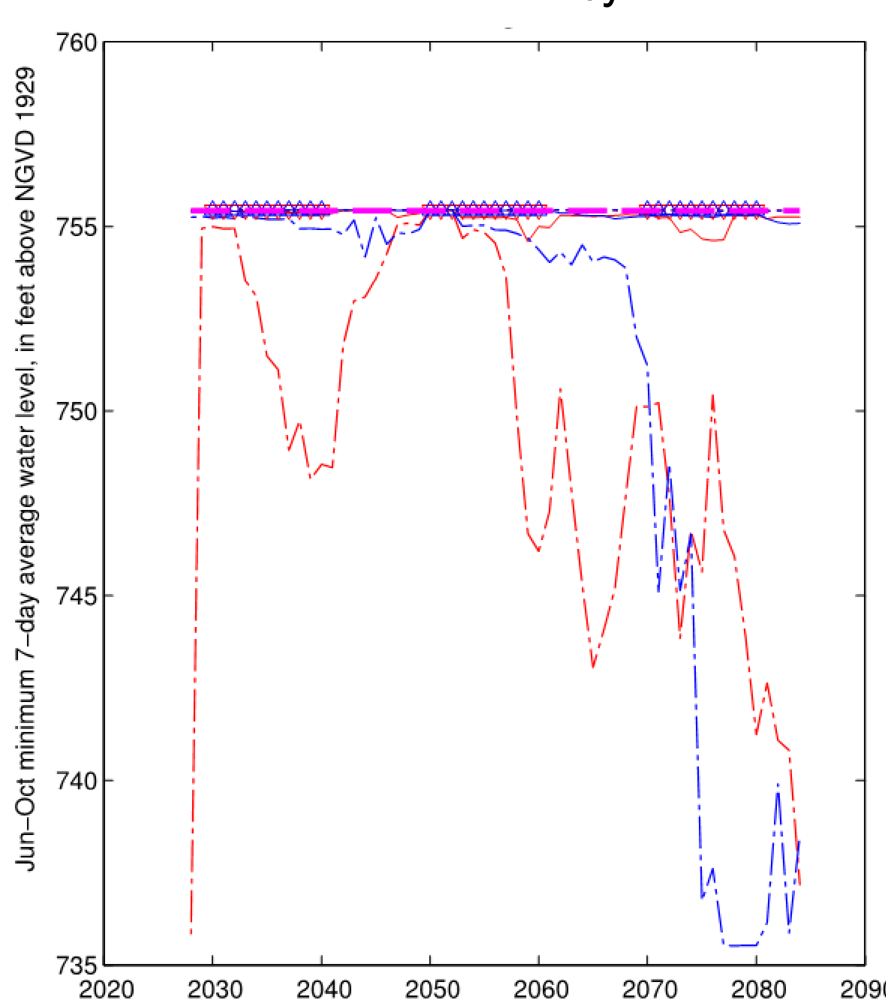


Summer Average Minimum Water Levels with Development

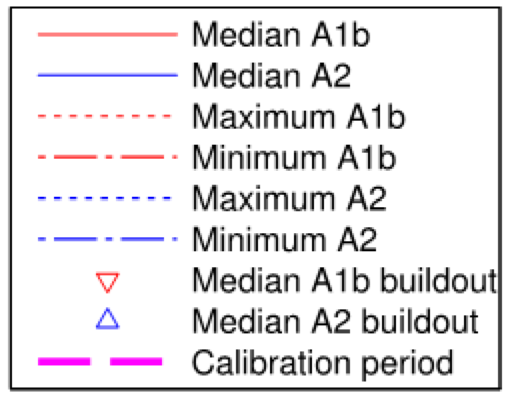
30-Day



7-Day

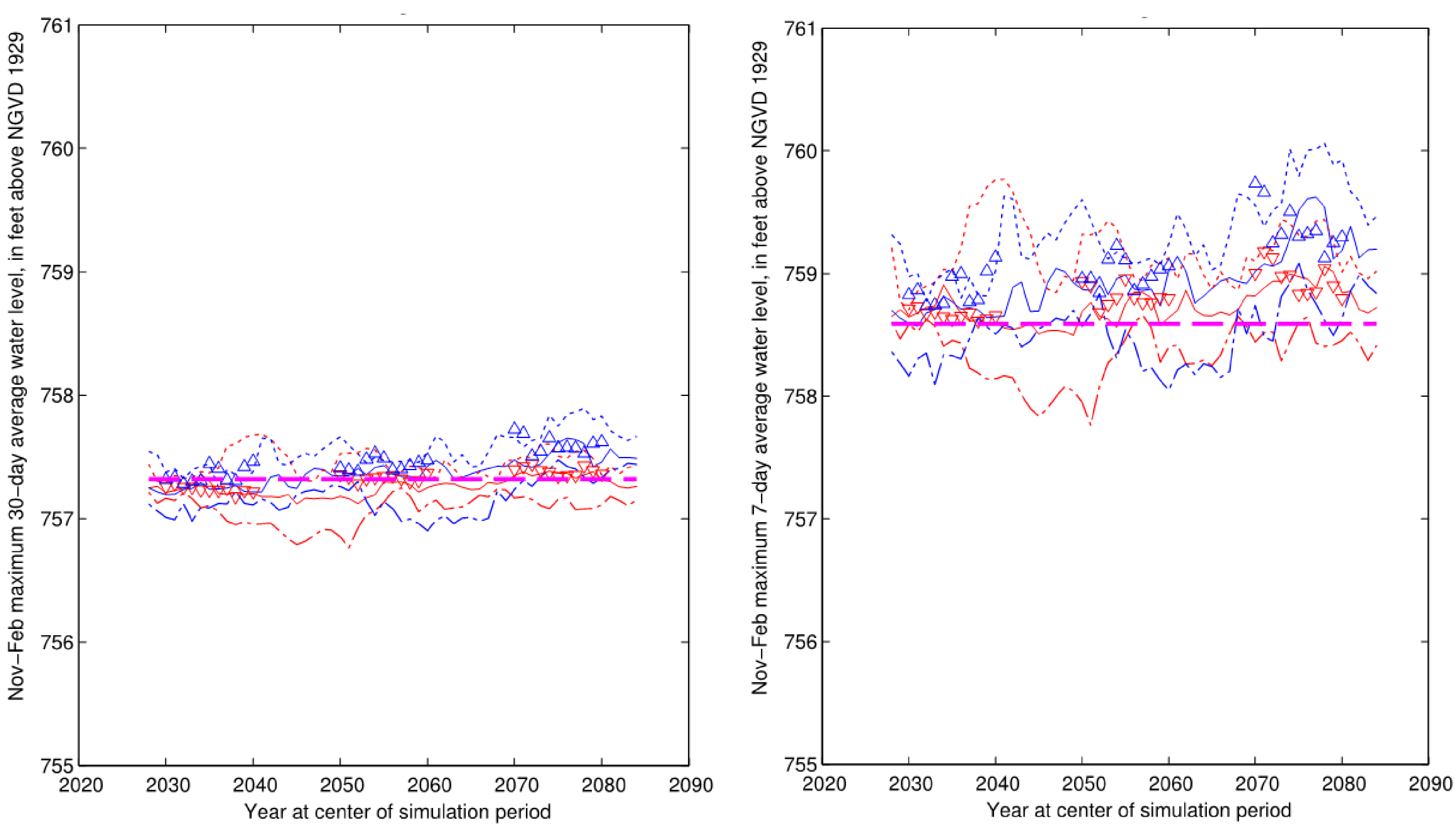


Griggs Reservoir



Fall/Winter Average Maximum Water Levels with Development

30-Day | 7-Day



Fall/Winter Average Minimum Water Levels with Development

30-Day | 7-Day