

**Low Flow Variations in Source Water Supply for the Occoquan Reservoir System
Based on a 100-Year Climate Forecast**

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ABSTRACT

The reliability of future water supplies comes into question with the onset of global climate change and the variations in local weather patterns that it brings. Changes in temperature, precipitation, soil moisture, and sea level can all have an impact on drinking water storage and supply. As these impacts are realized, it is increasingly important to use forward projecting estimates of future supply through the use of general circulation models (GCMs). GCMs can be used to predict changes in local weather over the next century. Using GCM data as input to a hydrologic model of local water supplies, water supply managers can assess and be better prepared for the impact of these possible changes.

Land use/demand in particular has an impact on runoff characteristics within a watershed. By incorporating changes in land use/demand into hydrologic model simulations, a more complete picture can be generated of the possible runoff characteristics, and thereby source water supply. The four land use scenarios used in this study are: 1) present day land use/demand; 2) projected land use/demand to 2040; 3) projected land use/demand to 2070; and 4) projected land use/demand to 2100.

This study uses established techniques to incorporate both climate and land use/demand change into a hydrologic model of the Occoquan watershed, which encompasses an area of approximately 1,550 square kilometers in Northern Virginia, U.S.A., and is part of the drinking water supply to approximately 1.7 million residents.

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1 Introduction and Overview

“One recurrent lesson of history is that societies that passively live too long off old water engineering accomplishments are routinely overtaken by states and civilizations that find innovative ways to exploit water’s ever-evolving balance of challenges and opportunities.”

– Steven Solomon, *Water: the Epic Struggle for Wealth, Power, and Civilization*, 2010, pp.150

The Occoquan watershed lies in Northern Virginia, U.S.A. and encompasses an area of approximately 1,550 km² (Hagen and Steiner 1998). The primary drinking water source within the watershed is the Occoquan reservoir, with a storage capacity of approximately 32.2 Mm³ (Hagen and Steiner 2000). Direct management of the reservoir is the primary responsibility of Fairfax Water (FW), with supporting efforts performed by the Occoquan Watershed Monitoring Laboratory (OWML), and the Upper Occoquan Sewage Authority (UOSA) (NMOTF 2003). FW is the sole water purveyor using the Occoquan reservoir as a water supply, in conjunction with supplies from the Potomac River. As a user of Potomac River water, FW must coordinate with other Washington, D.C. Metropolitan Area (WMA) municipalities during times of serious drought, to conform with the 1940 law (amended in 1970) enacted by the U.S. Congress allowing for a compact to be created between the states of Maryland, West Virginia, and the Commonwealths of Virginia, and Pennsylvania, and the District of Columbia (U.S. Congress 1970).

The Compact, as it has come to be known, created the Interstate Commission on the Potomac River Basin (ICPRB) to coordinate management of the water supply in the WMA (ICPRB 2008). As part of this responsibility the ICPRB also coordinates research within the WMA with the intent of improving management of the Potomac River and its watershed. A

recent ICPRB report (Kame'enui and Hagen 2005) directs researchers in the WMA to use a method outlined by Wiley (2004) to downscale global circulation model (GCM) climate output for local watershed assessments. The ICPRB report builds on a sequencing for climate change impact assessment described in a paper produced by Frederick and Gleick (1999) which uses the following generalized project organization: (1) Use multiple regional outputs of climate model projections, (2) downscale the outputs to the scale of a river basin, (3) use hydrologic models to simulate stream flow with the climate model output, (4) use multiple simulation and analysis metrics to incorporate the full range of predicted variation, and (5) include impacts of other variables important to water system management like water policy and operations and changing land use and demand. The methodology used by Wiley (2004) expanded upon Wood et al. (2004) to study different downscaling techniques in an analysis of the water supply for the City of Seattle. However, Wiley (2004) focused on optimizing the downscaling process and therefore did not address step (5) from Frederick and Gleick (1999) to include other variables important to water system management.

1.1 Research Objectives

This study combines both climate and land use/demand change into a local watershed model to assess the impacts on the water supply. The focus of this study is on low flows, or drought conditions, which are of great importance to water supply managers. Accomplishing this study requires the following objectives to be combined into a single assessment of the watershed:

1. Calibrate a hydrologic model to represent the local watershed system under current conditions;

2. Downscale GCM output to incorporate impacts from climate change into the calibrated hydrologic model;
3. Develop a land use model to project changes in land use that can be incorporated into the calibrated hydrologic model;
4. Use the calibrated hydrologic model to forecast future streamflow under climate and/or land use conditions; and
5. Use relevant low flow analysis techniques to assess variations induced from climate and/or land use change (see Appendix A).

Table 1.1-1 lists the relevant input collected and used in this study. The table is divided into three sections representing the scale at which the data are presented (local is less than 10^4 km², regional is between 10^4 and 10^7 km², and global is greater than 10^7 km²) (IPCC 2007).

Table 1.1-1 Relevant input for assessment

LOCAL (<10⁴ km²)		
Washington D.C. Dulles Airport, COOP ID 448903 (DULL)	Observed station record, 1963-2006, prec. & temp.	(USEPA 2007a)
Ocoquan Watershed Monitoring Laboratory (OWML), with extended record from Manassas 3 NW, COOP ID 445213	Observed station record, 1951-2007, prec. & temp.	(USEPA 2007a; OWML 2009)
The Plains 2 NNE, COOP ID 448396 (PLNS)	Observed station record, 1955-2006, prec. & 1970-2006, temp.	(USEPA 2007a)
Warrenton 3 SE, COOP ID 448888 (WARR)	Observed station record, 1952-2005, prec. & temp.	(USEPA 2007a)
Northern Virginia Regional Commission (NVRC) land use data, 1977-2006	Observed land use for the Ocoquan watershed at 5-year intervals	(NVRC 2010)
Ocoquan Watershed Monitoring Laboratory (OWML)	Observed streamflow, 1993-2004	(OWML 2009)
REGIONAL (10⁴–10⁷ km²)		
University of East Anglia, Climate Research Unit, in conjunction with the Tyndall Centre for Climate Change Research (CRU)	Observed globally gridded climate record, 1901-2002	(Hulme 1994; Jones and Moberg 2003; Mitchell et al. 2004)
GLOBAL (>10⁷ km²)		
Australia, CSIRO Mark 3.0 (CSMK)	GCM model output, 1891-2001, prec. & temp.	(Gordon et al. 2002)
Canada, CGCM 3.1 (T47) (CGMR)	GCM model output, 1891-2001, prec. & temp.	(McFarlane et al. 2005)
Germany, ECHAM5/MPI-OM (MPEH)	GCM model output, 1891-2001, prec. & temp.	(Jungclaus et al. 2005)
Japan, MIROC version 3.2 (MIMR)	GCM model output, 1891-2001, prec. & temp.	(CCSR/NIES/FRCGC 2004)
United Kingdom, HadCM3 (HADCM)	GCM model output, 1891-2000, prec. & temp.	(Gordon et al. 2000)
United States, GFDL-CM2.0 (GFCM)	GCM model output, 1891-2001, prec. & temp.	(Delworth et al. 2006)
United States, Parallel Climate Model (NCPCM)	GCM model output, 1891-2000, prec. & temp.	(Washington et al. 2000)

The Hydrologic Simulation Program, FORTRAN (HSPF) (Bicknell et al. 2001) was used to model the hydrology of the Occoquan watershed. HSPF was chosen because of its open-source availability and its broad use in the water community, including its use by the OWML as the hydrologic component for a water quality model of the Occoquan reservoir. The Better Assessment Science Integrating point and Nonpoint Sources (BASINS) (USEPA 2008) software was used to define and segment the watershed, and download the majority of local input required for model analysis. Additional local input was gathered from the OWML including weather station data, flow rate measurements at the outlet of the Occoquan reservoir, and bathymetric measurements used to model the reservoir in HSPF (OWML 2009). The HSPF input file was generated directly from the BASINS software, and once created, BASINS Technical Note 6 (USEPA 2000) was used to guide calibration in combination with the Expert System for calibration of HSPF (HSPEXP) (Lumb et al. 1994).

The Nash-Sutcliffe coefficient (R^2_{NS}) (Nash and Sutcliffe 1970) and deviation of runoff volume (Dv) (ASCE 1993) were both used for quantitative comparison and goodness-of-fit of modeled versus observed flows. These coefficients were used in an iterative process until a good calibration was achieved for the monthly flow rates (R^2_{NS} of 0.79 and Dv of -0.1) (see Appendix C). The R^2_{NS} is shown in Equation (1), and Dv is shown in Equation (2).

$$R^2_{NS} = 1 - \frac{\sum (Q - Q')^2}{\sum (Q - \bar{Q})^2} \quad (1)$$

$$Dv = \frac{(\sum Q' - \sum Q)}{\sum Q} \quad (2)$$

where Q is the observed flow rate; Q' is the simulated flow rate; and \bar{Q} is the mean observed flow rate.

The HSPF model was difficult to calibrate at lower flows due to the large area modeled and the limited number of weather stations that were suitable for downscaling. Weather stations with an extended recorded history are necessary for use in the downscaling process to capture the variability in the local weather patterns. This requirement limited the study to using the four stations listed in Table 1.1, making it difficult to capture in the modeling the small-scale weather events that normally occur in the summer months. Also, the OWML modelers have had difficulty calibrating to both the peak and low flows within the watershed while using more weather stations and smaller segmentation, indicating that HSPF may have inherent difficulties modeling at these extremes. Despite these difficulties it was possible to attain a strong goodness-of-fit overall. The graph of percent exceedance for outflow values in Figure 1.1-1 highlights how there was difficulty finding agreement with the low flow values generated using this model. This graph is important because it demonstrates how the model produces a flow distribution closely matching the observed data with a low flow error that exceeds the observed, therefore producing a conservative approximation of the observed hydrologic runoff.

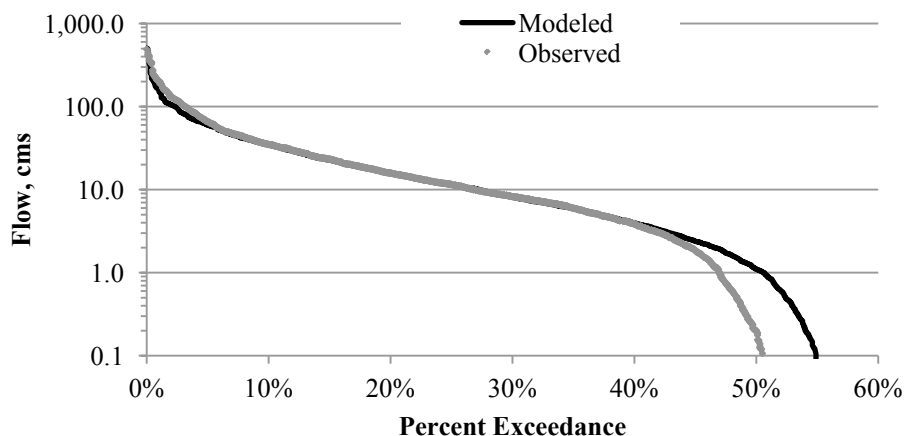


Figure 1.1-1 Daily Occoquan reservoir dam outflow - percent exceedance

Using direct GCM data as input to run a hydrologic model will produce a large amount of local weather variation making it difficult to analyze output with any certainty (Wiley 2004).

These variations arise from the difference in scale between the global and local data. GCM models use relations from large scale climate phenomena to determine model interactions, and therefore are not well suited for direct comparison to local weather patterns. Downscaling methodology incorporates statistical relations to use the climate signal generated by GCMs while maintaining local weather phenomena. Wiley (2004) uses a deterministic method of downscaling called quantile mapping, that creates a downscaled time series suitable for use in a water supply assessment, and was used for this study (see Appendix B). Figures 1.1-2 through 1.1-5 demonstrate why downscaling was necessary (the abbreviated GCM titles used in these figures are found in Table 1.1-1). Figures 1.1-2 and 1.1-3 display the 21-year moving average of the annual total precipitation and annual average temperature for the raw GCM output, respectively. While indicative of the general trend of each GCM, the figures show how broad the variation can be from model to model.

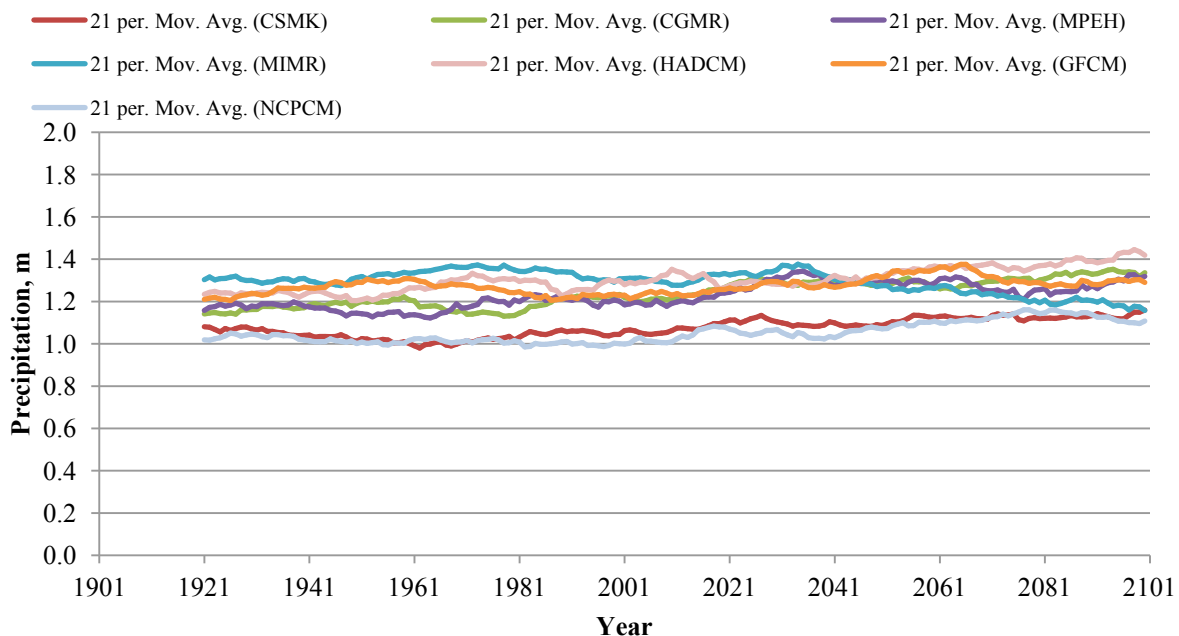


Figure 1.1-2 Annual total precipitation 21-year moving average from GCM model regional average

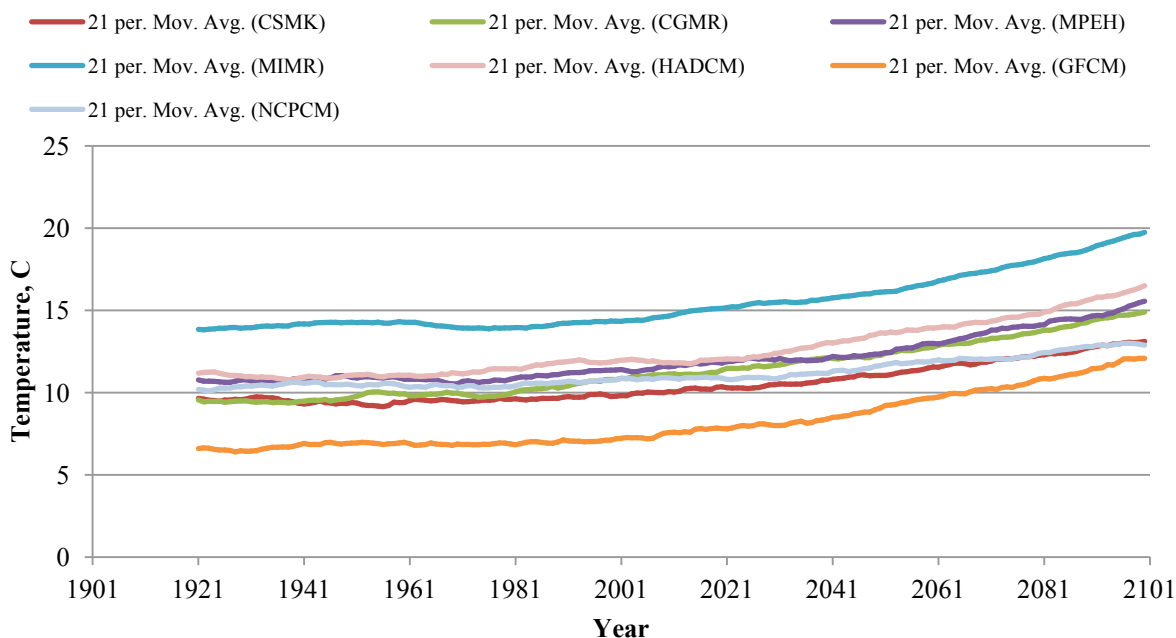


Figure 1.1-3 Annual average temperature 21-year moving average from GCM model regional average

Figures 1.1-4 and 1.1-5, respectively, display the 21-year moving average of the annual total precipitation and annual average temperature for the downscaled GCM station output.

These figures show time series that are in line with the historic regional trend for the Occoquan watershed while taking on more of the characteristics of each GCM when projected into this century.

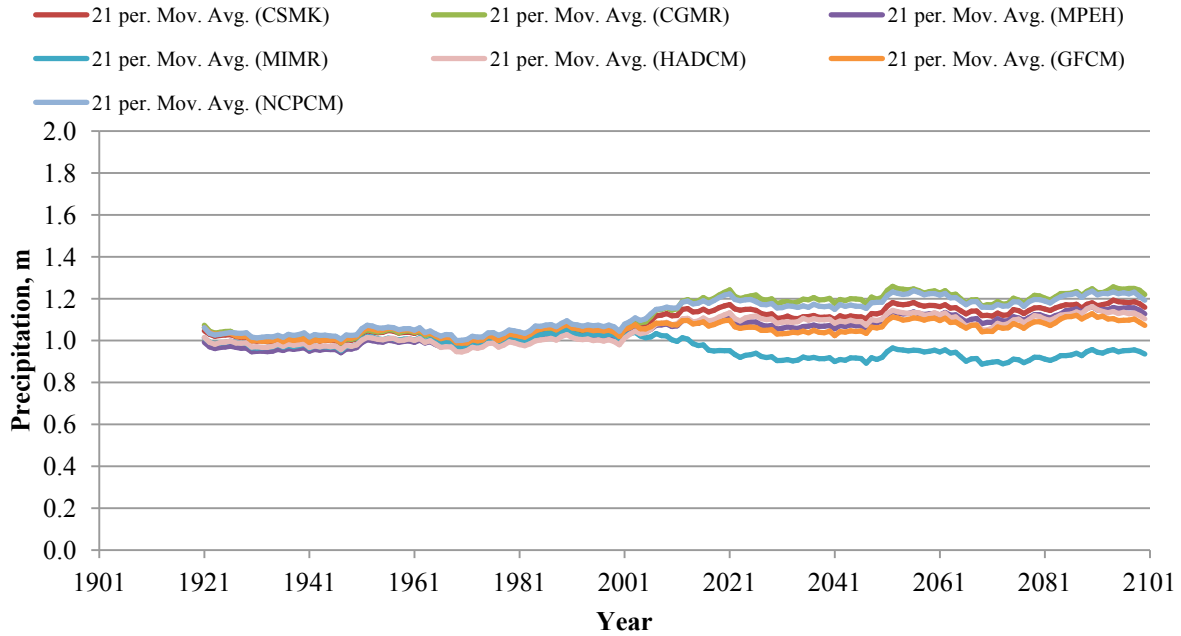


Figure 1.1-4 Annual total precipitation 21-year moving average from downscaled GCM local station average

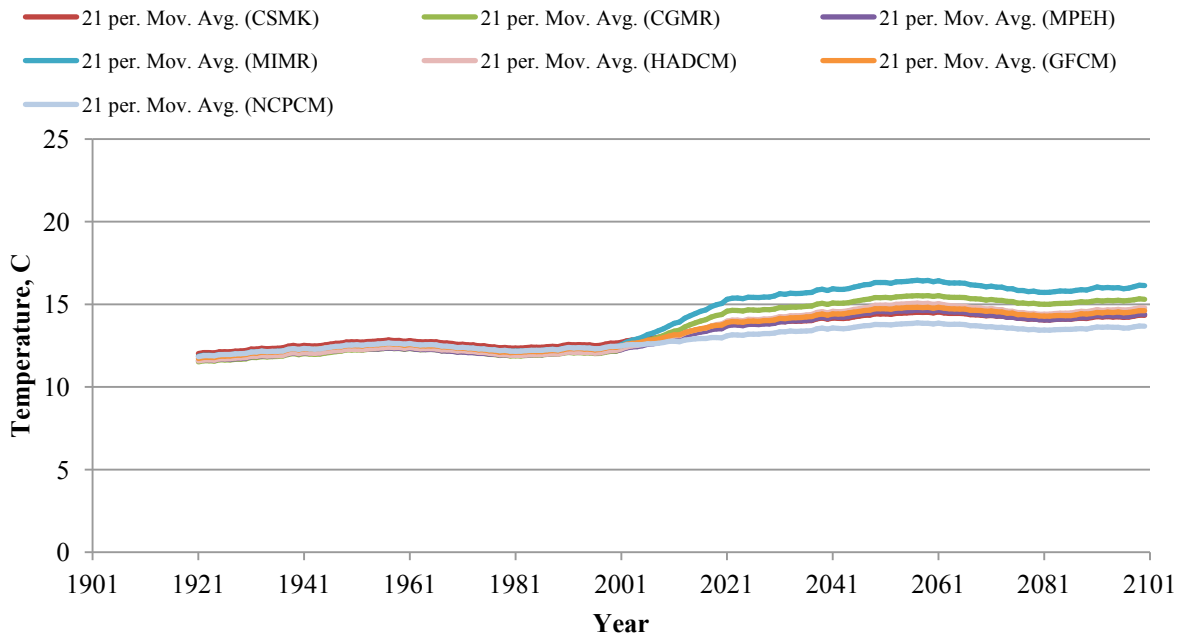


Figure 1.1-5 Annual average temperature 21-year moving average from downscaled GCM local station average

The downscaling was achieved through processing of the data sets in a variety of ways.

First, the data sets were classified into three separate time series: 1) Historical, ranging from

1901-2000, 2) Future, ranging from 2001-2100, and 3) Station historical, ranging from the initial station observation-2000. Second, a climatically representative data set was generated for both the historical and future GCM data. The 21-year moving average of the GCM time series (GCM21) was used to represent the general climatic changes of the data set. The 21-year moving average was developed at any single year by taking the average of the 10 years preceding and the 10 years following the year of interest. For example, the average of the years 2010-2030 represents the year 2020. Finally, each of the three time series were formatted as a ranked distribution of data. Taking each distribution (Historic, Future, and Station historic) and arranging the data on a monthly basis into cumulative probability distribution functions (CDF) allowed for a comparative analysis of the different data sets. For example, by plotting January precipitation of the historic CRU CDF to the historic GCM21 CDF for Japan's MIMR model, a relational map was generated that can be mathematically quantified (quantile map) and used to transfer the regional weather properties of the CRU data onto the climatic trend of the GCM, as shown fully in Appendix B.

Development of these relationships was the primary driver of the quantile mapping process. Eight transfer functions must be generated for each GCM for each month: Two for the historical distributions, CRU-GCM21 and GCM21-GCM, two for the future distributions, CRU-GCM21 and GCM21-GCM, and four for the Station historical distributions, GCM-DULL, GCM-OWML, GCM-PLNS, and GCM-WARR. The requirement of eight transfer functions for twelve months for seven GCMs for two parameters will generate 1,344 transfer functions, or quantile relationships. The quantile mapping process was repeated on a month-by-month basis for each of the seven GCMs for both precipitation and temperature and for both historical and

future time series. The end product was a monthly time series for each station downscaled from each of the GCMs and ranging from 1901-2100.

Wiley (2004) determined precipitation matching to be the optimal method of temporal downscaling. The precipitation matching process can be described in three steps. The first step was to match the downscaled monthly precipitation for each station to the monthly precipitation of the corresponding month from the station's historical record. The second step was to develop the delta, or scalar, value using the monthly precipitation and temperature. The delta value defines the shift in magnitude between the GCM and observed monthly values. The precipitation values are the monthly sum, therefore the delta value was derived from the quotient of the downscaled monthly precipitation to the observed monthly precipitation. The temperature values are the monthly average, therefore the delta value was derived from the difference between the downscaled monthly temperature and the observed monthly temperature. In the third step, the precipitation delta value was used as a multiplier to each hourly value of the observed monthly time series in order to transform the data set to equal the monthly sum of the downscaled precipitation. The temperature delta value was added to each hourly value of the observed monthly time series in order to transform the data set to equal the monthly average of the downscaled temperature. The new hourly time series will retain the seasonal variation of the observed station record and match the magnitude of the downscaled GCM monthly time series. This process was repeated on a month-by-month basis until the entire desired monthly time series was disaggregated to an hourly format as shown fully in Appendix B.

An ensemble average (average of GCM models chosen for analysis) of GCM generated streamflows was used for analysis in conforming to Wiley (2004). The three models chosen to make up the ensemble were the model showing the greatest increase in precipitation (NCPCM),

the model showing the greatest decrease in precipitation (MIMR), and the model, from the remaining, that generated the streamflow with the closest relation to observed years 1980-2000 streamflow (MPEH).

Land use/demand change has long been studied for its impacts on watershed hydrology and source water supply. A U.S. Geological Survey (USGS) report by Moglen and Shivers (2005) used a non-linear numeric model for impervious area to adjust USGS rural regression equations. This numeric model was used in this study to project the change in urban area, by assuming urban area changes in relation to impervious area, and thereby set the basis for modeling changes in overall land use. The urban area used is defined by the National Land Cover Database 2001 (USGS 2001), and is modeled in HSPF at 50 percent imperviousness. The land use model defined by these changes was used in the hydrologic model of the Occoquan watershed. Figure 1.1-6 shows the projected percent urban area model for all 21 sub-areas within the watershed.

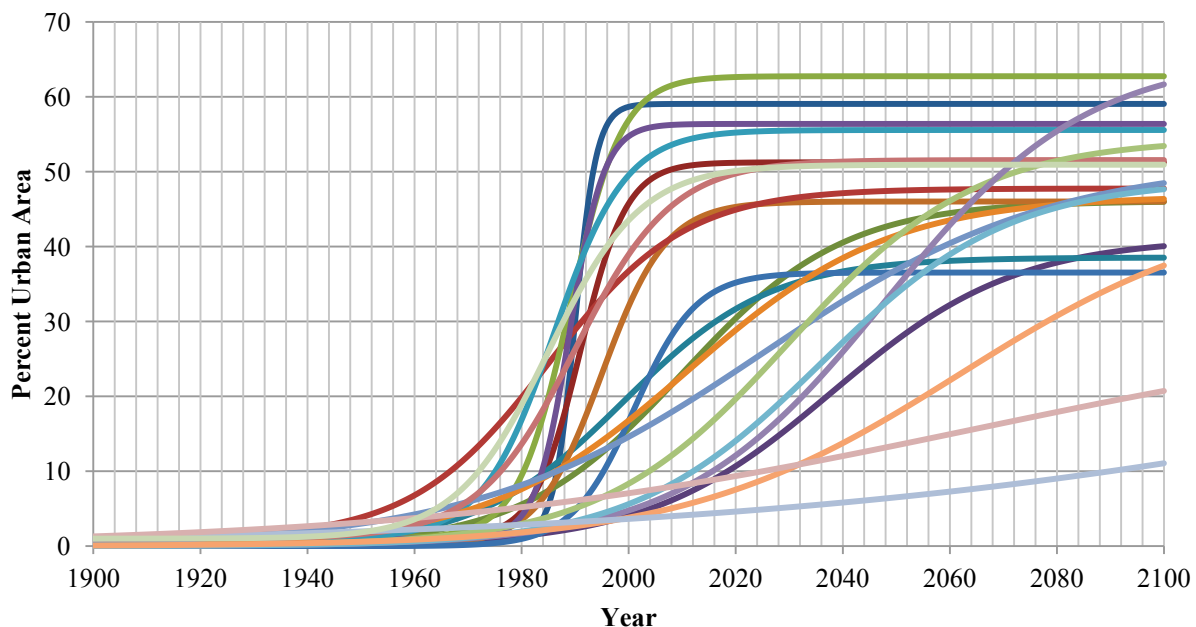


Figure 1.1-6 Occoquan watershed land use model of percent urban area shown for all 21 sub-areas within the watershed

The Occoquan reservoir's current management practices are based on the determination of the drought of record, which occurred from June 1930 to January 1932 (Hagen et al. 1998). Every five years the ICPRB produces a demand forecast for the Potomac River that includes the Occoquan reservoir. This forecast numerically projects future demand and compares this demand to the amount of storage that would be available given a repeat of the drought of record. This methodology complies with the quantile mapping downscaling technique, such that the downscaled data repeats the historically observed time series (which includes the drought of record) while combining the influence of climate change. Therefore, the scenarios for analysis were designed to correspond to these current operational practices. This was done by projecting land use/demand to a specified year, and using that land use/demand as a constant while modeling the downscaled GCM input, thereby capturing the effects not only during a repeat of the drought of record, but during a repeat of all of the droughts of the last century as influenced by climate change. For this study, the years chosen for the projections of land use/demand are 2040, 2070, and 2100.

Three scenarios and four analysis metrics were chosen to focus this study on low flows and to separate the impacts from climate change alone (S1), from land use/demand change alone (S2), and from the joint effects of climate and land use/demand change (S3).

- S1 was performed for the future century (years 2001-2100) using the present day land use/demand in combination with the downscaled GCM input.
- S2 was performed for the future century using the historic time series as input while accounting for development in the watershed at the land use/demand years of 2040, 2070, and 2100.

- S3 was performed by modeling the future century using the downscaled GCM input and accounting for development in the watershed at the land use/demand years of 2040, 2070, and 2100 (see Appendix A).

The following metrics were used for analysis:

- A. Metric A compared the 5th percentile average monthly flow on a seasonal basis between the ensemble historic streamflow and the ensemble future streamflows for each scenario.
- B. Metric B compared the 30-day, 20-year low flow (30Q₂₀) between the ensemble historic and future streamflows. The analysis for both metric A and B is performed using the Hydrologic Engineering Center Statistical Software Package (HEC-SSP) (Brunner and Fleming 2010), and the streamflow analyzed is the inflow to the Occoquan reservoir.
- C. Metric C used the storage response curves generated from the drought of record, and used by operations staff managing the Occoquan reservoir (Hagen and Steiner 2000). The storage response curves allow operations staff to maintain a safe demand from the reservoir (firm yield) based on the time of year and storage level in the reservoir. Metric C compared the storage response curves of the ensemble historic and future scenarios for the drought of record.
- D. Metric D used the performance measures of reliability (ρ), resilience (σ), and vulnerability (τ), to calculate an overall drought risk index (*DRI*) for the reservoir (McMahon et al. 2006). The *DRI* is a measure of probability for drought affecting the operational capacity of the reservoir. Metric D compared the ensemble historic and future *DRI*s.

The reliability (ρ) is shown in Equation (3), the resilience (σ) is shown in Equation (4), the vulnerability (τ) is shown in Equation (5), and the *DRI* is shown in Equation (6).

$$\rho = \frac{N_s}{N} \quad (3)$$

$$\sigma = \frac{f_s}{f_d} \quad (4)$$

$$\tau = \frac{\sum_{i=1}^{f_s} S_i^{\max}}{D} \quad (5)$$

$$DRI = \omega_1(1 - \rho) + \omega_2(1 - \sigma) + \omega_3\tau; \rightarrow 0 < DRI \leq 1 \quad (6)$$

where N_s is the number of periods in which target demand was met; N is the total number of periods; f_s is the number of continuous sequences of failure; f_d is the total duration of failure; S_i^{\max} is the maximum volume shortfall during each failure period, D is the target demand; and $\omega_1 = \omega_2 = \omega_3 = 0.33$.

Combining the aforementioned data into the hydrologic model of the watershed, while incorporating the scenario procedures and analysis metrics, created the following experimental procedure for water supply assessment:

- Weather inputs were transferred from the three GCM outputs to the Watershed Data Management (WDM) format suitable for HSPF input.
- Reservoir demand and reclaimed water input time series were created for future (years 2001-2100) model runs at year 2001 (representing present conditions), 2040, 2070, and 2100, and then transferred to the WDM format.
- HSPF input files were created with the land use distribution for the year 2001, 2040, 2070, and 2100.
- Three model runs were performed for historic re-creation (one for each GCM), using year 2001 land use/demand and historic input to create one ensemble output.

- Three model runs were performed for scenario S1, using year 2001 land use/demand and future input to create one ensemble output.
- Nine model runs were performed for scenario S2, using year 2040, 2070, and 2100 land use/demand and historic input to create three ensemble outputs.
- Nine model runs were performed for scenario S3, using year 2040, 2070, and 2100 land use/demand and future input to create three ensemble outputs.
- Each scenario ensemble was analyzed using the defined metrics for low-flow comparison to the re-creation of the ensemble historic conditions.

2 Low Flow Variations in Source Water Supply for the Occoquan Reservoir System Based on a 100-Year Climate Forecast

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Abstract

The onset of climate and land use change is forcing water managers to develop new techniques in response to the changing environment. This study uses established techniques to incorporate both projected climate change and projected land use change into a hydrologic model of the Occoquan watershed, which encompasses an area of approximately 1,550 square kilometers in Northern Virginia, U.S.A. The techniques used develop a future projection of weather that re-creates the historic time series, including the drought of record, as influenced by climate change, thereby facilitating integration into existing water management practices. Incorporating land use and using multiple low-flow (drought) analysis metrics allow for the determination of variations between the historic and future model flows. This study revealed a likelihood of increased low flow volumes for the Occoquan watershed from both climate and land use change, of which the majority were produced from land use change in combination with expanded reclaimed water supply. Also, the increases from climate change, while influencing measurable changes in flow patterns were much less than those from land use change.

2.1 Introduction

The Occoquan watershed, at approximately 1,550 square kilometers, is part of the drinking water supply to approximately 1.7 million residents in the Washington, District of Columbia (D.C.), suburbs of Northern Virginia. The watershed supplies water for two drinking water reservoirs, Lake Manassas near the center of the watershed, and the Occoquan located at the watershed outlet. In 1940 the U.S. Congress created the Interstate Commission on the Potomac River Basin (ICPRB) to coordinate management of the water supply in the Washington, D.C. Metropolitan Area (WMA) (ICPRB 2008). Since its creation, the ICPRB has directed research in the region to help improve the management of the Potomac River and its watershed. An ICPRB publication authored by Kame'enui and Hagen (2005) directed researchers to an approach of managing watersheds in the WMA that incorporates downscaled general circulation model (GCM) global climate projections into a local hydrologic model. Kame'enui and Hagen (2005) referenced Wiley (2004) as a model for implementing water supply assessments. Wiley (2004) expanded upon Wood et al. (2004) to study the effects of climate change to the water supply for the City of Seattle. While Kame'enui and Hagen (2005) referred to Wiley (2004) for its use of GCMs to evaluate climate change impacts, it did not address other variables important to water system management. There are many studies showing the impacts of land use/demand change on watershed behavior and reservoir management (Kame'enui et al. 2005; Moglen and Shivers 2005; Ahmed et al. 2010). Moglen and Shivers (2005) used a non-linear numeric model for impervious area to adjust U.S. Geological Survey (USGS) rural regression equations. Using this model to project the development of the urban area land use class provided the basis for a

localized land use model. This study combines these techniques to present a more comprehensive projection of variables for low-flow assessment.

The Occoquan Watershed Monitoring Laboratory (OWML), of the Virginia Tech Department of Civil and Environmental Engineering, has studied the Occoquan watershed from its inception in 1971 (NMOTF 2003). These studies by the OWML provided a long history of using the Hydrologic Simulation Program, FORTRAN (HSPF) for water quality modeling of the watershed (Bicknell et al. 2001; Xu 2005; Xu et al. 2007). Given this history, the availability of HSPF as open source software, and its capacity to meet all required modeling needs, HSPF was selected to model the hydrology for this study.

The Better Assessment Science Integrating point and Nonpoint Sources (BASINS) Version 4.0, Technical Note 6 (USEPA 2000; USEPA 2008) was used as the basis for calibration of the HSPF model used in this study in combination with the expert system for calibration of the Hydrologic Simulation Program, Fortran (HSPEXP) (Lumb et al. 1994). Weather, land use, and geographic data were acquired through the BASINS software, with local stream flow and demand obtained from the OWML. The calibrated HSPF model was used with climate and land use change projections to produce output for analysis.

There are many procedures and techniques for analyzing risk in water supply systems (Hirsch 1978; Steiner et al. 1997; McMahon et al. 2006; Lorie and Hagen 2007; Brekke et al. 2009). Some use stochastic methods of prediction, while others rely on the historic record to provide probabilistic insight. Each has its strengths and weaknesses dependent upon the desired outcome and observed data available. The Occoquan watershed and water supply reservoir have management procedures in place with a proven record of effectiveness, which were used for this study (COG Task Force 2000; Hagen and Steiner 2000; Hagen et al. 2007). These procedures

were used for analysis along with established methods for determining low-flows such as the 30-day, 20-year ($30Q_{20}$) measurement (Brunner and Fleming 2010), as well as the drought risk index, a more recently developed performance measure used to assess risk (McMahon et al. 2006).

2.2 HSPF Model Calibration for the Occoquan Watershed

This study focuses primarily on differences in hydrologic behavior under climate change. A simple (single input file) HSPF modeling approach was taken in which the four weather stations selected to be used for the climate model downscaling process were also used for calibration. The four weather stations were selected because of the extended historical record for each, which was necessary to transfer local weather patterns in the downscaling process. Calibration was conducted using the modeled versus observed rates for the Occoquan dam outflow.

Model Input

BASINS 4.0 uses Map Window GIS (Ames 2007), a non-proprietary, open-source geographic information system (GIS) software that provides the integrating framework necessary to import, display, and manipulate the multiple databases accessible through the BASINS software. The region of interest for this study is Hydrologic Unit Code (HUC) 02070010: Mid Potomac – Anacostia – Occoquan which encompasses areas of northern Virginia, Washington D.C., and central Maryland, U.S.A. For this study it was necessary to import many data sets into HUC 02070010, including the 2001 National Land Cover Database (NLCD), a USGS Digital Elevation Model (DEM) Grid, the National Hydrographic Database (NHD) of streams and rivers, the National Weather Service meteorological station data, and U.S. Census data (USGS 1999; USGS 2001; USEPA 2007a; USEPA 2007b).

Model Calibration

BASINS Technical Note 6 (USEPA 2000) is a directed outline for estimating initial HSPF parameter values, and provides ranges of typical, maximum, and minimum calibrated

values. This resource was useful in developing new calibration values for the BASINS generated HSPF model created for this study.

The USGS's HSPEXP software provides direct feedback on the modeled output that does not correlate to the observed conditions, and identifies the associated parameters that should be adjusted to correct these discrepancies. The USGS has developed HSPEXP for assisting modelers with calibration of watershed models that facilitates interaction between the modeler and the modeling process. Once initial estimates were made, this software was used in an iterative process to highlight the important parameters that influence the hydrologic modeling outcomes, thereby adjusting the model to a more calibrated state.

The Nash-Sutcliffe coefficient (Nash and Sutcliffe 1970) and deviation of runoff volume (ASCE 1993) were both used for quantitative comparison of goodness-of-fit of modeled versus observed Occoquan dam outflow. The ten year period from 1995 through 2004 was selected for calibration of the HSPF model because this time span contains two recorded drought years (1998, 2002) along with two above normal wet years (1996, 2003) thus providing a broad representation of watershed behavior. The observed lower flow values were isolated for goodness-of-fit comparison by ranking the flows for this time span and determining the 50 percent non-exceedance value.

Results

Table 2.2-1 lists the attained goodness-of-fit for 100 percent and 50 percent of ranked flows. The Nash-Sutcliffe (R^2_{NS}) is a normalized statistic that determines the relative magnitude of the modeled residual variance compared to the observed data variance (Nash and Sutcliffe, 1970). Values of R^2_{NS} calculated greater than 0.0 are generally viewed as acceptable levels of performance (Moriassi et al. 2007). The ideal deviation of runoff volume (Dv) is 0.0, with the objective of calibration to achieve as close to ideal as possible. The R^2_{NS} value of 0.79 for the

monthly 100 percent flows indicates very good agreement for this model, and -0.10 for the Dv was the best value achieved. The R^2_{NS} value of 0.30 for the daily 100 percent flows indicates a fair agreement for this model, again producing a Dv of -0.10. Low-flow values are difficult to use for calibration, which is exemplified by the R^2_{NS} value of -0.16 that was attained for the daily 50 percent flows, and is indicative of poor model correlation using this indicator, although the Dv that was attained (0.02) indicates close agreement between modeled and observed flow volumes. The daily 50 percent of ranked flow R^2_{NS} value once again improves for the monthly flows, attaining a value of 0.38 with a Dv value of 0.02 indicating fair agreement.

Table 2.2-1 Nash-Sutcliffe (R^2_{NS}) and Deviation Volume (Dv) goodness-of-fit measures for calibration period (1995-2004)

	R^2_{NS}	Dv
Monthly – 100% of ranked flows	0.79	-0.10
Monthly – 50% of ranked flows	0.38	0.02
Daily – 100% of ranked flows	0.30	-0.10
Daily – 50% of ranked flows	-0.16	0.02

The graphical representation of agreement between modeled and observed values is displayed in Figure 2.2-1 for the monthly 100 percent outflows. This graph shows the strong agreement between the modeled and observed streamflows.

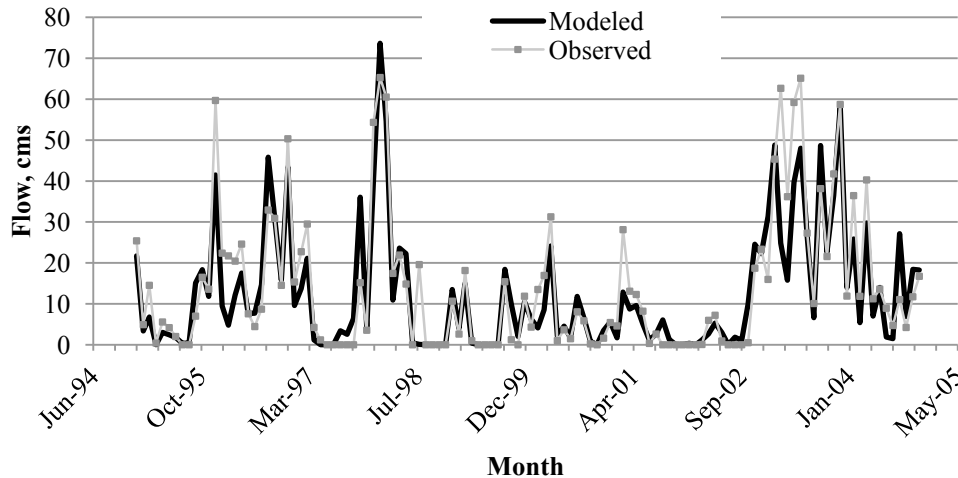


Figure 2.2-1 Monthly 100 percent modeled and observed Occoquan reservoir dam outflow

The Occoquan Reservoir water surface elevation was also used to determine model agreement. HSPF uses a routing technique classified as the “storage routing” or “kinematic wave” method (Bicknell et. al. 2001). The program requires a fixed relationship between the depth, surface area, and volume. This one-dimensional flow model with simplified geometry made attaining strong agreement between the modeled and observed water surface elevations difficult. Comparing the modeled to observed elevations showed a pattern of similar reservoir behavior that never exceeded the observed low-flow elevations during the calibration period. This indicated the model was representative of the same behavior as the physical watershed, while achieving poor to fair statistical agreement ($R^2_{NS} = 0.15$).

There are four flow meters located within the watershed, including the outlet, where areas may be evaluated for evaporation rates. These evaporation rates were used as an additional means of determining agreement between modeled and observed data for the Occoquan. These locations are named for the sub-areas they represent: Cedar Run, Broad Run, Bull Run, and Occoquan (representing the entire watershed). The percent difference (modeled to observed) for evaporation during the calibration period was calculated to be 9.4% at Cedar Run, 21% at Broad

Run, and 1.1% at Bull Run. A percent difference of -4.4% was calculated for the entire Occoquan watershed, showing a range of levels of agreement at these four locations.

Because models are an informed representation of the observed environment, not an exact replication, this study used a modeled re-creation of the historic streamflow (years 1901-2000) for comparative analysis with future iterations of streamflow (years 2001-2100), to limit uncertainties introduced from direct comparison to the observed record.

2.3 Climate Model Output Downscaling

The objective of downscaling is to adjust GCM output in a way that preserves the trends present in the GCM data while also capturing the weather phenomenon that occur at the local scale. There are a variety of ways to downscale climate model output dependent upon the type and amount of observed local data available and the goal that is desired. This study used the deterministic method called quantile mapping that is described in Wiley (2004). This method is based on a scheme for downscaling climate model output originally developed by Wood et al. (2004). It is a process developed to extend the delta method (Smith and Tirpak 1989) in a manner that better captures the potential variability of future climate change. The A2 scenario from the Special Report on Emissions Scenarios (SRES) was used for all GCM outputs (IPCC 2007).

To use this methodology, many observed and projected data sets must be assembled. The GCM outputs are necessary, for both the historic recreation of the last century and the future projection of the current century. The Intergovernmental Panel on Climate Change (IPCC) has collected these data for many years as a basis to the periodically released assessment report on climate change. The data used for this study are from the IPCC Fourth Assessment Report: Climate Change 2007 (AR4) (IPCC 2007). The IPCC collected and used twenty two (22) GCM models from countries around the world for the AR4. To be consistent with the quantile mapping methodology outlined in Wiley (2004), only seven of the model outputs were selected to be used. The models used were Australia's CSIRO Mark 3.0 model (Gordon et al. 2002), Canada's CGCM 3.1 (T47) model (McFarlane et al. 2005), Germany's ECHAM5/MPI-OM model (Jungclaus et al. 2005), Japan's MIROC version 3.2 model (CCSR/NIES/FRCGC 2004), the

United Kingdom's HadCM3 model (Gordon et al. 2000), and the United States' GFDL-CM2.0 model (Delworth et al. 2006) and Parallel Climate Model (PCM) (Washington et al. 2000).

The Climate Research Unit (CRU), in conjunction with the Tyndall Centre for Climate Change Research at the University of East Anglia, have constructed and maintain a comprehensive set of high-resolution grids of monthly climate at a spatial resolution of 0.5 degrees for the global land surface. The set comprises the observed global climate record for the past century covering the years from 1901 through 2002 (Mitchell et al. 2004; Mitchell and Jones 2005; CRU 2011). The data are constructed from information gathered from the global network of meteorological observing stations. The CRU TS 2.1 data was used in this study for a regional representation of climate for both precipitation and temperature. The primary sources for the CRU data are Jones and Moberg (2003) for temperature, and Hulme's CRU global gridded dataset for precipitation, updated via a personal communication to Mitchell (Hulme 1994; Mitchell and Jones 2005).

To use the quantile mapping method, it is desirable to have an extended historic record of continuous observations to capture all of the local weather variability. For consistency, the majority of the observed station data, stream data, and GIS input were collected through BASINS. The weather station data collected through BASINS were from the National Oceanic and Atmospheric Administration's National Climatic Data Center. For this study four (4) stations were selected: Washington D.C. Dulles Airport, COOP ID 448903, (DULL), The Plains 2 NNE, COOP ID 448396, (PLNS), Warrenton 3 SE, COOP ID 448888, (WARR), and Manassas 3 NW, COOP ID 445213 (USEPA 2007).

The Manassas 3 NW station was discontinued in July 1985. The observations from this area of the watershed were taken over by the OWML. The locations are physically close to one

another, and therefore have a well correlated record of observation. Verification of correlation was done using the double-mass-curve analysis method of comparison for both temperature and precipitation records using methods described in McCuen (2005). A direct combination of both records created a continuous extended record for this station from 1951 through 2007 for precipitation and a discontinuous extended record from 1951-1984 and 1993-2007 for temperature. This combined record is referred to henceforth as the observed record for the OWML station, making the four local weather stations used DULL, PLNS, WARR, and OWML.

Spatial and Temporal Downscaling

The goal of the quantile mapping downscaling method was to capture the local climatic variability through each station while incorporating long term climate change trends of the GCMs. This transformation was accomplished through the use of transfer functions, which are the mathematical relationship generated from the plotted position of two ranked data sets. The quantile mapping method occurs in a three step process that used the regional CRU time series as an intermediary observed data set that captures the extended regional variability. The first step began with the CRU historic time series and converted the data set into a representation of the 21-year moving average of the GCM historic time series (GCM21) by multiplying the time series by the CRU to GCM21 transfer function (the GCM21 was used to represent the general climatic changes of the data set). This quantile map allowed for the CRU regional variability to be imprinted on to the GCM climatic trend. The second step took this newly formed time series and multiplied it by the GCM21 to GCM transfer function. This quantile map expanded the GCM21 time series (as modified by the regional CRU time series) to the magnitude of the original GCM time series. The third step used the regional GCM time series and transformed it into a monthly local station time series by multiplying by each of the four GCM to historic station transfer functions.

Downscaled station precipitation and temperature were used at an hourly time step for the HSPF modeling. To accomplish this, the monthly time series must be temporally downscaled, or disaggregated, into an hourly representation of local weather. Wiley (2004) determined precipitation matching to be the optimal method of performing this temporal downscaling. This method matches the downscaled monthly precipitation to an aggregated precipitation of the same month from the historical record of the station of interest. The temperature record from the same month is used from the matched precipitation.

2.4 Land Use Model

The Occoquan Watershed is located in Northern Virginia, U.S.A. encompassing an area of 1,550 km². The city of Manassas is located near the center of the watershed with Dulles International Airport on its northern border, the city of Warrenton on its western border, and the city of Washington, D.C. located approximately 30 miles to the east. The western half of the watershed is less urbanized with large areas of agricultural lands, and the eastern half is predominantly urbanized with small areas of agricultural lands. Land use patterns for the Occoquan for 1977 through 2006 show a steady increase in urban area with equivalent decreases in agricultural and forested land (NVRC 2010).

The Northern Virginia Regional Commission (NVRC) is a regional council of fourteen member local governments in the Northern Virginia suburbs of Washington, D.C. (NVRC 2011). Every five years NVRC performs an assessment of changes in land uses in the watershed to help localities in their land management efforts. The OWML works with the NVRC to maintain a record of land use for the Occoquan watershed that extends from 1977 to 2006 (NVRC 2010). The Occoquan assessments for the years 1995, 2000, and 2006 were developed in a GIS format making it easy to segment into the sub-areas used in the hydrologic watershed model for this study.

The National Land Cover Database (NLCD) 2001 was used for HSPF calibration (USGS 2001). Using the comparative ratio of NVRC 2000 to NLCD 2001 data, the NLCD 1992 (USGS 1992) data were used to derive an equivalent NVRC data for 1992, which provided four distinct snapshots of land use data with the appropriate segmentation (years 1992, 1995, 2000, and

2006). These four years were used to calibrate the numerical land use model for the Occoquan watershed.

The land use model was taken from a peak discharge adjustment method for streamflow developed by Moglen and Shivers (2005). This method uses an equation to define a scaled (non-linear) imperviousness value with respect to time in order to impart an adjustment to the USGS rural regression equations (Jennings et al. 1994; Bisese 1995) for predicting peak discharge. The impervious area scaling equation was used in this study to predict the change in the urban area land use class as defined by the NLCD 2001. The assumption was made that the urban area land use class has a direct relational equivalence to the impervious area as defined by Moglen and Shivers (2005). Equation (7) was used to model the percent urban area ($\%UA$) in this study.

$$\%UA = \frac{\gamma}{e^{\alpha[\beta-t]}} \quad (7)$$

where γ is the maximum percent urban area; α is the rate of urbanization; β is the year corresponding to the point of inflection in the relationship; and t is the year.

Calibration was performed using a non-linear, least-squares optimization program. The optimizer takes the observed percent urban area ($\%UA$) and the year the observation was recorded (t) along with the maximum percent urban area (γ) and returns a value for rate of urbanization (α) and the point of inflection year (β) that provides the optimal least-squares value from the observed data points. The maximum percent urban area was determined using the sum of the lowest recorded value of forested area and the water/wetlands area from each watershed sub-area for the years 1995-2006, and subtracting that value from one hundred percent. This γ value assumes the worst case scenario of all the available agricultural land being converted to urban area.

To validate this relationship, the GIRAS (Geographic Information Retrieval and Analysis System) (USGS 1980) land use data were used in combination with the NVRC 1977 to derive an equivalent GIRAS data set for comparison. Graphically comparing the GIRAS data to the model of urban growth showed consistent agreement. Figure 2.4-1 provides an example of the land use model for urban area for the hydrologic sub-area within the Occoquan watershed containing the Occoquan reservoir (RCH1).

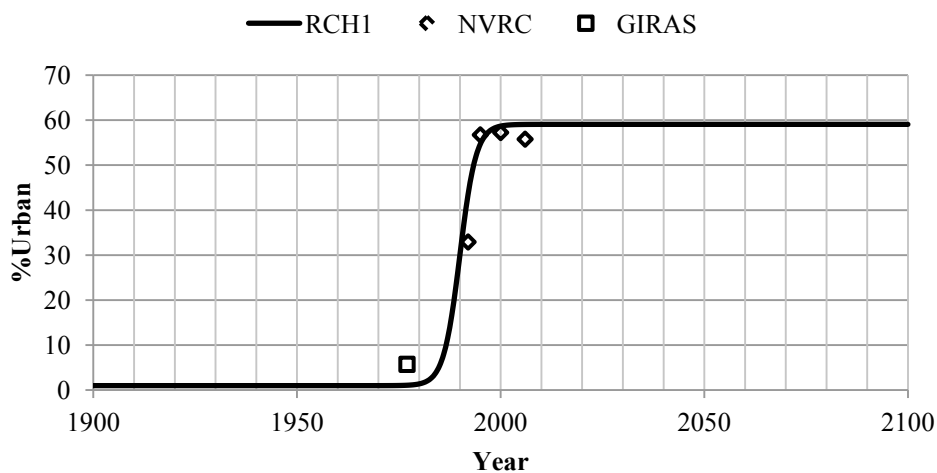


Figure 2.4-1 Model of percent urban area for RCH1 containing the Occoquan reservoir

The NLCD 2001 land use data divide into six classifications when imported into the HSPF model. As described above, the percent urban area was the driver for this land use model, and of greatest importance for assessing impacts to watershed runoff, but to describe the change in the other five land use classes some basic assumptions were made:

- Assumption 1, the water/wetland and barren land use classes will remain constant over the study time period (years 1901-2100);
- Assumption 2, the urban land use class will change in the non-linear manner described based on the observed NVRC data, with an adjustment to agree with the NLCD 2001 urban values making the land use model consistent with the calibrated HSPF model;

- Assumption 3, the forest land use class will change according to a declining linear function (derived from the 1977-2006 NLCD data for the entire watershed) until the maximum urban area is reached; and,
- Assumption 4, the crop and pasture (agricultural) land use classes will comprise the remaining area, maintaining the same percentage of total watershed sub-area as determined by the NLCD 2001 data.

Combining the calibrated urban area model with these assumptions created a complete land use model that describes the required land use input for the HSPF hydrologic model at any year within the study scope.

2.5 Water Supply Model Experimentation

The approach to water supply management articulated by Wiley (2004) was used in this study to account for the changing dynamics that water managers must deal with as the onset of climate and land use change are realized. The downscaling method described re-creates the observed historical time series (years 1901-2000) for the future projection (years 2001-2100) while incorporating the effects of the GCM data over the entire period. Multiple model run scenarios and analysis metrics were used to focus the analysis on low-flows (drought periods). To ensure impacts were assessed at all low-flow segments during the modeling time series, the land use model projections were fixed to a single year and modeled over the entire period.

GCMs provide output that can vary widely from one model's output to another. To compensate, multiple GCMs were combined in an ensemble to create the outcome of highest likelihood given the uncertainty of the models used. For this study, three of the downscaled GCMs were used for analysis. The GCM output projecting the greatest increase and projecting the greatest decrease in precipitation were selected first, followed by the HSPF-modeled GCM output that compared best with the observed Occoquan reservoir inflow from among the remaining models for the 20-year period from 1980 through 2000. The average of these three HSPF-modeled GCM outputs was used to make up the ensemble flow for this analysis.

Three scenarios were used in the HSPF model to generate model runs. Each scenario was intended to isolate for the desired forcing factor: climate change, land use change, and the combined effects of both climate and land use change. Climate change was isolated in scenario 1 (S1) by modeling the downscaled future climate model input (2001-2100) while maintaining the present land use and demand. In scenario 2 (S2), land use change was isolated by modeling the

downscaled historic climate model input as the future projection, in other words, repeating the previous century's climate. In scenario 3 (S3) the combined effects were projected by modeling the future climate model input at the three incremental levels of land use change.

There were four analysis metrics used to observe variations in low-flow. The first metric was the direct comparison of monthly inflows to the Occoquan reservoir between the modeled historic flows and the modeled future flows. The inflows were separated into quarters to observe the seasonal variations that occur. The second metric was the difference between the modeled historic and future 30-day, 20-year low-flow ($30Q_{20}$) into the Occoquan reservoir. The first two metrics were generated using the Hydrologic Engineering Center Statistical Software Package (HEC-SSP) (Brunner and Fleming 2010). The third metric was the difference between the modeled historic and future firm yield of the Occoquan reservoir. The firm yield was defined by the storage response curves developed by Hagen and Steiner (2000). The final metric used methods from McMahon et al. (2006) to determine the difference between the modeled historic and future drought risk index (*DRI*) of the Occoquan reservoir. The *DRI* is a measure of probability for drought affecting the operational capacity of the reservoir, and was derived by combining the reservoir performance measures of reliability, resilience, and vulnerability.

Land use changes with population growth, and as population grows there is greater demand on drinking water supplies and wastewater collection systems. Each of these forces will have different impacts on the management actions necessary to adequately sustain the Occoquan reservoir for future use. Observed daily demands for the Occoquan reservoir and Lake Manassas, along with daily input flows of reclaimed water from the Upper Occoquan Sewage Authority (UOSA), were used for the calibration of the HSPF model. The ICPRB produced a study recreating the historic natural daily inflows to the Occoquan reservoir (Hagen et al. 1998), in

which projections for both Lake Manassas demand and UOSA input flows were used. The ICPRB also produces a water supply reliability forecast every five years (Kame'enui et al. 2005; Ahmed et al. 2010) that outlines projections for Fairfax Water, from which the demands for the Occoquan reservoir were estimated.

The ensemble historic model of the Occoquan watershed was used as the comparative baseline against simulations of the future ensemble model. A current management practice for the Occoquan reservoir assesses system stability by comparing operational parameters to those that would have been encountered during the 1930-31 drought of record (Hagen and Steiner 2000; Hagen et al. 2007). Using HSPF, both the historic and future models were created using the same management practice. The historic and S1 models used an annual series of daily averages from current (1995-2004) land use/demand parameters throughout the entire time series of the model run in order to capture the effects during the drought of record, along with any other major drought periods in the recorded meteorological history of the past century. Scenarios S2 and S3 used land use/demand projections to the years 2040, 2070, and 2100.

2.6 Results and Analysis

The average annual inflow volumes for the Occoquan reservoir showed increases between the ensemble historic and future model runs. Table 2.6-1 shows increases in total (year 2100) cumulative annual volume, in billions of cubic meters (Bm^3), between the ensemble historic scenario and future scenarios S1, S2, and S3. The increase in volume from climate change is shown in S1, the increase from land use/demand change is shown in S2, and the increase from the joint effects of climate and land use/demand change are shown in S3.

The values in Table 2.6-1 demonstrate a large step increase from the historic to 2040 (2040S2 is 11.7 Bm^3 , and 2040S3 is 15.2 Bm^3), with a smaller increase between 2040 and 2070 ($16.9 - 11.7 = 5.2 \text{ Bm}^3$ for S2, and $20.7 - 15.2 = 5.5 \text{ Bm}^3$ for S3), and a comparatively minor increase between 2070 and 2100 ($17.5 - 16.9 = 0.6 \text{ Bm}^3$ for S2, and $21.5 - 20.7 = 0.8 \text{ Bm}^3$ for S3). The lack of increase in the latter part of the century is a consequence of the saturation of urban area within the watershed. For S1, the cumulative volume in year 2100 is 2.8 Bm^3 . The difference between S1 and 2040S2 of 8.9 Bm^3 indicates that the influence to runoff from land use change through the year 2040 will be much greater than the influence from climate change alone. The difference between 2040S2 and 2070S2 of 5.2 Bm^3 indicates that the development capacity of the watershed, while slower than during the period Hist-2040S2, is still larger than the increased runoff from climate change. It is not until the end of the century, years 2070-2100, that the incremental difference from land use change becomes less than the influence from climate change (0.8 Bm^3), although the total difference remains much greater (17.5 Bm^3).

To determine the impact of the reclaimed water inflow on the system, a separate model run was completed for scenarios S2 and S3 in which the reclaimed water inflows were held

constant at the levels used for the historic and S1 models (average of 1995 through 2004) and the land use/demand were modeled at the future projections. These scenarios are also shown in Table 2.6-1. These volumes show less of an increase when compared to the volumes modeled with reclaimed water, indicating that while land use/demand has a discernable impact, the importance of the reclaimed water inflow should not be ignored.

Table 2.6-1 Total cumulative volume difference (at year 2100) from historic (Bm³) for annual inflow volume

	<i>Hist</i>	<i>S1</i>	<i>2040S2</i>	<i>2070S2</i>	<i>2100S2</i>	<i>2040S3</i>	<i>2070S3</i>	<i>2100S3</i>
	Cumulative Volume Difference (Bm³)							
Volume from Hist	-	2.8	11.7	16.9	17.5	15.2	20.7	21.5
	No Reclaimed Expansion							
Volume from Hist	-	2.8	7.0	9.2	9.9	10.5	13.1	13.8

Low Flow Statistics (Metrics A and B)

Metric A was defined as the 5 percent non-exceedance value from the seasonal flow duration curves generated from the average monthly flow rate. This metric provided a bulk comparison of average monthly flows, as separated by season, between the historic and future model scenarios. Metric B was defined as the volume frequency of the 30-day, consecutive low flow with a 20-year return period (30Q₂₀). This metric was an indicator of changes in low flows complementing the seasonal results in metric A. Together these metrics indicated changes in drought conditions between scenarios. Table 2.6-2 shows the model results for metrics A and B. All of the metric values increased from the historic model except for the 30Q₂₀, and summer and fall flow durations of S1, which showed small decreases in flow. These values show that generally low flow volumes into the reservoir are likely to increase, primarily due to expanded imperviousness from the growth of urban area, the impacts of which are much greater than the slight decreases in the summer and fall seasons from climate change.

Table 2.6-2 Modeled low flow for metrics A and B (cms), flow duration is derived from average monthly values and volume frequency is derived from average daily values

	<i>Hist</i>	<i>S1</i>	<i>2040S2</i>	<i>2070S2</i>	<i>2100S2</i>	<i>2040S3</i>	<i>2070S3</i>	<i>2100S3</i>
Season	Metric A, Flow Duration							
Jan-Mar	7.0	7.8	8.5	9.7	9.8	10.0	11.2	11.3
Apr-Jun	3.3	3.7	5.9	7.0	7.1	5.9	7.2	7.3
Jul-Sep	1.9	1.8	3.7	4.8	4.9	3.6	4.6	4.7
Oct-Dec	2.4	2.3	4.7	5.8	5.9	4.4	5.6	5.7
	Metric B, Volume Frequency							
30Q ₂₀	2.0	1.8	4.0	5.0	5.2	3.7	4.8	4.9

Firm Yield (Metric C)

The Occoquan reservoir is managed using a set of storage response curves developed for the system by the ICPRB. Using these curves, operators can determine the safe volume, or firm yield, that can be withdrawn from the reservoir based upon the time of year and current storage volume. The figures in this metric are presented in English units to conform to the operational practices from which they were derived. The withdrawal rates of 40, 50, and 60 MGD (1.75, 2.19, and 2.63 cms, respectively) and associated safe reservoir volumes are shown in Figure 2.6-1, along with the storage volume curves associated with the modeled droughts of record for the historic, S1, and S3 scenarios. The figure shows that all of the future scenarios increase in the amount of reservoir storage volume for all model scenarios during the most severe drought period. The daily minimum volume for each scenario is 2.6 BG (9.8 Mm³) for the historic (1930-31), 2.7 BG (10.2 Mm³) for S1, 6.6 BG (25.0 Mm³) for 2040S3, 6.4 BG (24.2 Mm³) for 2070S3, and 4.3 (16.3 Mm³) BG for 2100S3. The curves for S2 showed only a slight decrease from the scenarios shown.

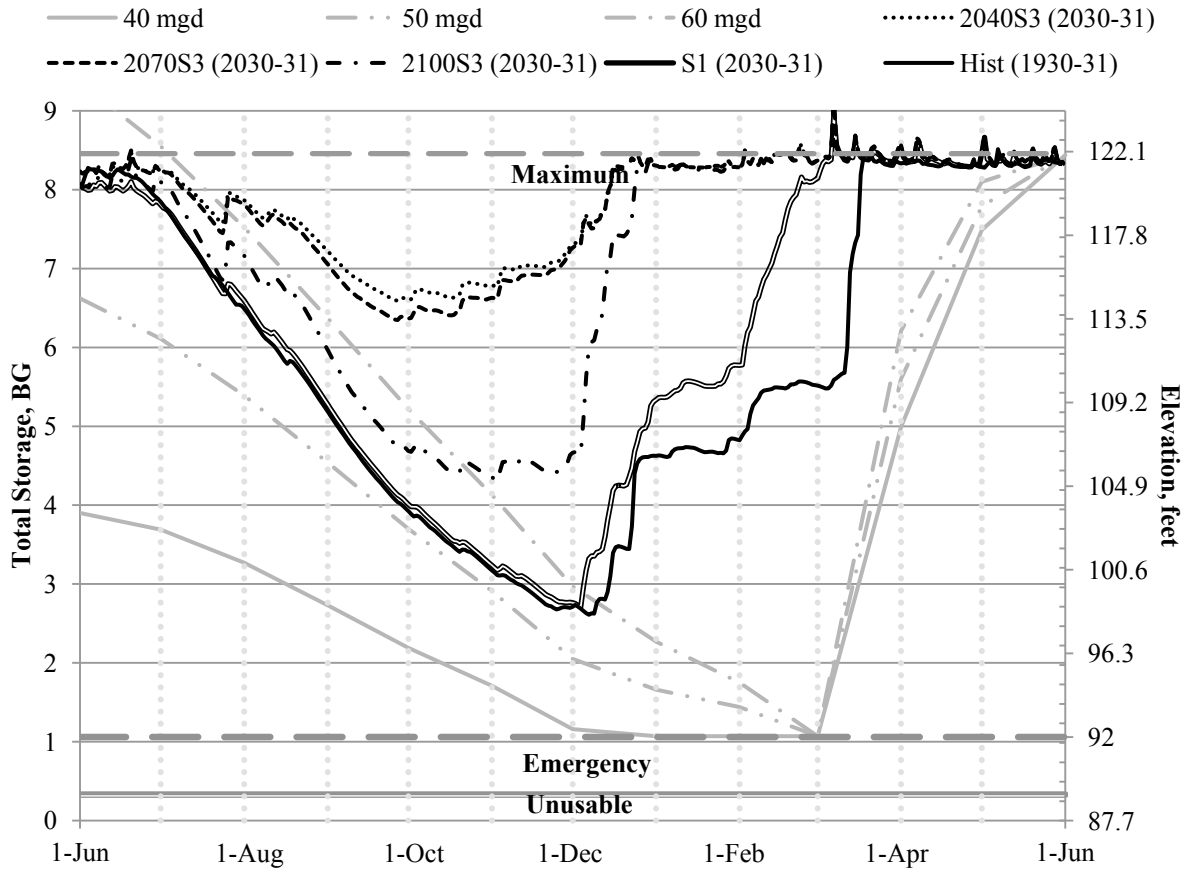


Figure 2.6-1 Occoquan reservoir storage response curves (firm yield) comparing the historic to future scenarios S1 and S3 for the drought of record

A dramatic change was indicated when examining the impacts of not accounting for expansion of reclaimed water inflow, as shown in Figure 2.6-2. The 2040S3 curve shows little to no improvement from the historic model (minimum of 2.4 BG, or 9.1 Mm³), and both the 2070S3 and 2100S3 curves go to failure by reaching 0.4 BG (1.5 Mm³) (below emergency storage level) and 0.0 BG, respectively. These results show that the reclaimed water inflow may not only be important, but may be integral to the future sustainable operation of this reservoir. The storage curves for S2 showed similar results with slightly lower minimum volumes.

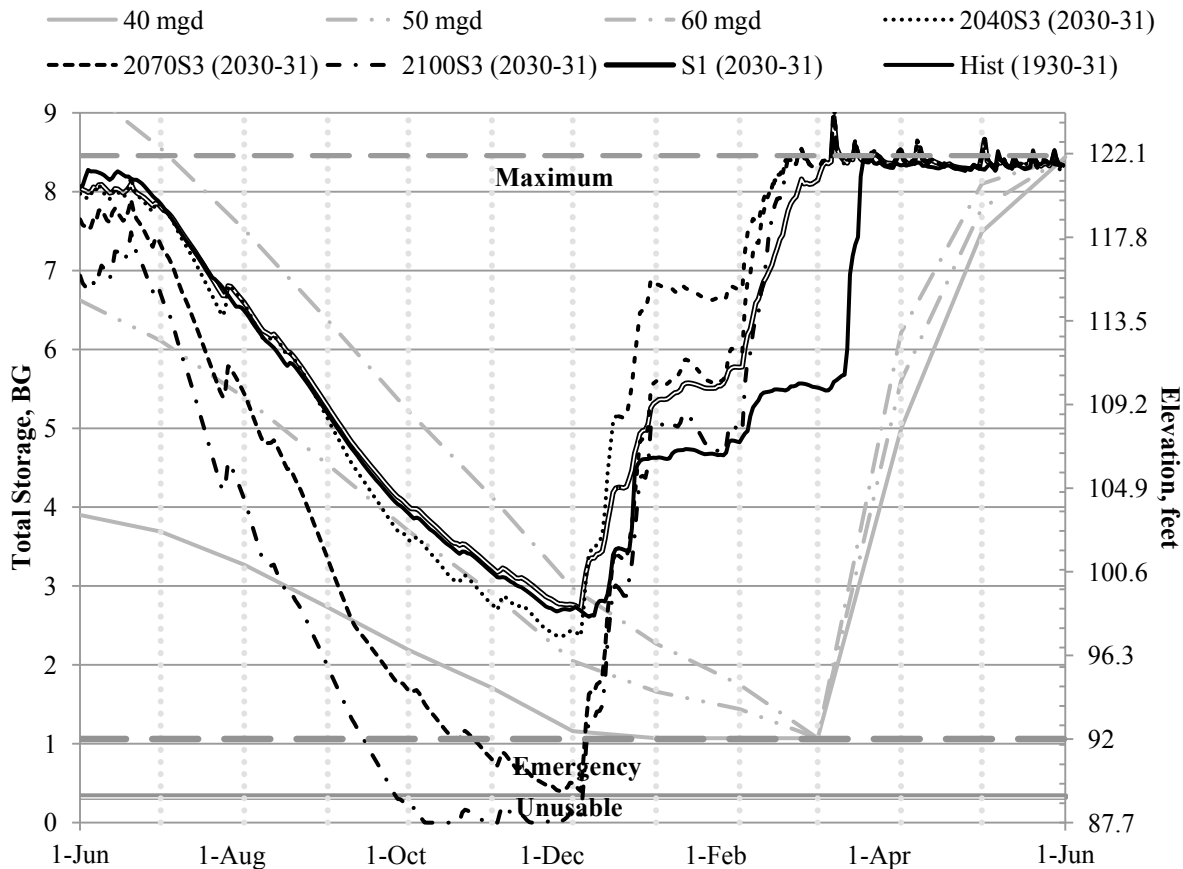


Figure 2.6-2 Occoquan reservoir storage response curves (firm yield) comparing the historic to future scenarios S1 and S3 for the drought of record, not accounting for expansion in reclaimed water inflow

Reservoir Performance Measures (Metric D)

Metric D combines three reservoir performance measures: reliability, resilience, and vulnerability to produce the drought risk index (*DRI*), a dimensionless quantity relating to the probability of operational risk for drought impacts for a specified reservoir. The demand, or withdrawal rates, for this metric were the same as those for metric C to maintain consistency (40, 50, and 60 MGD, or 1.75, 2.19, and 2.63 cms, respectively). Table 2.6-3 shows a *DRI* of zero at the lower demands and a *DRI* maximum of 0.28 for S1 at the highest demand. This is only a difference of 0.03 higher than the historic *DRI*, indicating a marginal increase in the risk of being operationally affected by drought when looking at climate change alone and operating the reservoir at the highest withdrawal rate. This result is negligible for the highest demand (60

MGD, or 2.63 cms) because the storage curve is greater than the maximum storage of the reservoir for the first month of calculations, making it impossible to achieve a value of zero. Other than S1, all of the future *DRI* are less than or equal to the historic model indicating a lowered probability to being affected by drought.

Table 2.6-3 also provides the *DRI* values calculated when not accounting for the expansion in reclaimed water inflow. Consistent with previous metrics, the *DRI* values substantially increase, indicating risk probabilities of operational effects at the lowest withdrawal rate (40 MGD, or 1.75 cms) for scenarios 2100S2, 2070S3, and 2100S3. These values show the increased risk developed when reclaimed water is not expanded along with land use/demand.

Table 2.6-3 Metric D, Drought Risk Index (*DRI*) values for all scenarios

Demand Rate	<i>Hist</i>	<i>S1</i>	<i>2040S2</i>	<i>2070S2</i>	<i>2100S2</i>	<i>2040S3</i>	<i>2070S3</i>	<i>2100S3</i>
40 MGD (1.75 cms)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
50 MGD (2.19 cms)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
60 MGD (2.63 cms)	0.25	0.28	0.15	0.15	0.21	0.15	0.16	0.23
	No Reclaimed Expansion							
40 MGD (1.75 cms)	0.00	0.00	0.00	0.00	0.25	0.00	0.22	0.23
50 MGD (2.19 cms)	0.00	0.00	0.00	0.26	0.26	0.00	0.18	0.25
60 MGD (2.63 cms)	0.25	0.28	0.26	0.33	0.42	0.29	0.38	0.48

Summary

Through the use of an ensemble model average and the combination of multiple analysis metrics, a strong likelihood is indicated for increased flow and drought resistance for the Occoquan reservoir system in the future. Climate change is expected to affect the timing and intensity of precipitation within the watershed, but these changes appear to be dampened by the planned expansion of reclaimed water inflows. By modeling the system without accounting for expansion in the reclaimed water inflow, a clear picture of the growing reliance on this source

becomes apparent within this century. This is demonstrated by the failure of the reservoir during a repeat of the drought of record, as influenced by climate change, and given the land use/demand projected for the latter part of this century (years 2070 and 2100).

This modeling also indicates that land use/demand change, especially when coupled with reclaimed water inflow, has a larger impact than climate change for this water supply system for the majority of this century (years 2040 and 2070). This impact is diminished towards the end of the century (year 2100) as the watershed becomes urbanized and the growth of impervious area is slowed by the limited amount of developable land remaining. It is at this time when the incremental influence from climate change will exceed that from land use/demand change, but the cumulative impacts from land use/demand change will still be nearly eight times greater than climate change in the year 2100.

This study used a deterministic method based on the observed history of the region and watershed in combination with an ensemble average of multiple climate model outputs to define the hydrologic model output of highest agreement with local weather phenomena as influenced by climate and land use/demand change. As stated in the IPCC Annual Report 4, “Warming of the climate is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice and rising global average sea level” (IPCC 2007), indicating agreement within the scientific community that impacts from climate change are certain to occur. While impacts from climate change are certain, the precise form of those impacts at the watershed scale can vary immensely. Results from this study should be interpreted only as an indication of the sensitivity of current systems to predicted future climate, not as a certainty of what the effects of climate change will be.

This study has defined the impacts of greatest likelihood to be increased precipitation with higher annual peak and annual low flows. Many watershed managers are facing the difficulty of dealing with low flows in part because of combined increases in temperature and demand along with increased flash runoff brought about by expanded impervious surface area. The current management practices in the Occoquan watershed, which incorporate the use of reclaimed water supplies, multiple storage reservoirs and source supplies, and coordinated drought management plans, are well-situated to absorb the impacts from both climate and land use/demand change. Continued adherence to this philosophy of expanding storage and supply along with conservation and inter-agency coordination should promote the existence of reliable supplies of water for the foreseeable future.

3 Conclusions

One of the seven climate models downscaled for this study predicted a decrease in precipitation for the Occoquan watershed through the year 2100. The other six climate models projected increased precipitation, suggesting flow volume increases are likely for the modeled runoff. The low precipitation climate model output was combined with two others to create the ensemble used for analysis. Three scenarios of future change were modeled to represent the effects of climate change (S1), land use/demand change (S2), and joint climate and land use/demand change (S3).

In meeting the research objectives described in Chapter 1, care was taken to ensure both data and methods used were drawn from established entities and techniques. Local input was gathered from local entities where possible and global data were gathered from entities with inter-governmental support and recorded histories of work, which helped increase certainty when using statistical methods to relate data at different scales. Using these data the objectives were successfully attained in the following ways:

- Objective 1: As shown in Chapter 2.2, very good agreement was attained for the calibrated hydrologic model using established correlation techniques. This agreement ensures that the calibrated model is a good representation of the physical watershed, and provided meaningful output for analysis.
- Objective 2: Chapters 1 and 2.3, along with Appendix B, describe how the downscaling of GCM output relied heavily on observed local and regional data, allowing this study to produce useful data for water supply managers. The downscaling process produced a weather forecast similar to the historic time

series but influenced by the GCM used, allowing for a direct comparison for changes between the historic and future hydrologic outputs.

- Objective 3: The land use model, as shown in Chapter 2.4, showed a strong agreement when validated using an independently collected land use data set. This validated model was then adjusted to correspond to the land use profile used for calibrating the hydrologic model creating a continuous time series of land use change suitable for direct input into the hydrologic model.
- Objective 4: The information provided in this chapter and Chapter 2.6 demonstrate the effectiveness of the forecast streamflows generated using the methods in this study, by showing the clear distinctions between the future impacts of climate change, of land use/demand change, and the joint effects of both climate and land use/demand change. The ensemble created by averaging the highest precipitation GCM, the lowest precipitation GCM, and the GCM that best matched the historic streamflow, from the remaining, for the years 1980-2000, can be defined as the forecasted output of greatest likelihood, and provides the analysis of highest certainty.
- Objective 5: The low flow analysis techniques, as shown in Chapters 2.5 and 2.6, provided a broad assessment of low flow variations for both runoff and reservoir storage, thereby transferring the modeling results into readily available and useful data. Using multiple techniques for both runoff and reservoir storage provided increased certainty in the analysis results.

3.1 Conclusions and Discussion

Figures 3.1-1 and 3.1-2 show increases in annual flow rate into the Occoquan reservoir between the ensemble historic hydrograph and scenarios S1 and S2 respectively. The increase in the hydrograph from climate change is shown in S1, and supports the projections made by the Intergovernmental Panel on Climate Change (IPCC) that stipulate change will occur with more variation and intensity (higher peaks and lower minimum flows) rather than a direct increase or decrease in overall precipitation (IPCC 2007). The increase from land use/demand change is shown in the S2 hydrographs that demonstrate a large step increase from the historic to 2040, with a smaller increase between 2040 and 2070, and practically no increase between 2070 and 2100. These differences can be seen quantitatively by the average annual flow rate, averaged over the century, listed in Table 3.1-1. The lack of increase in the latter part of the century is a consequence of the saturation of urban area within the watershed.

Table 3.1-1 Average annual flow rate into the Occoquan reservoir as a century average (cms)

	<i>Hist</i>	<i>S1</i>	<i>2040S2</i>	<i>2070S2</i>	<i>2100S2</i>	<i>2040S3</i>	<i>2070S3</i>	<i>2100S3</i>
	Average annual flow rate as a century average (cms)							
Annual Ave. Rate	17.3	18.2	21.0	22.6	22.8	22.1	23.8	24.1
	No Reclaimed Expansion							
Annual Ave. Rate	17.3	18.2	19.5	20.2	20.4	20.6	21.4	21.7

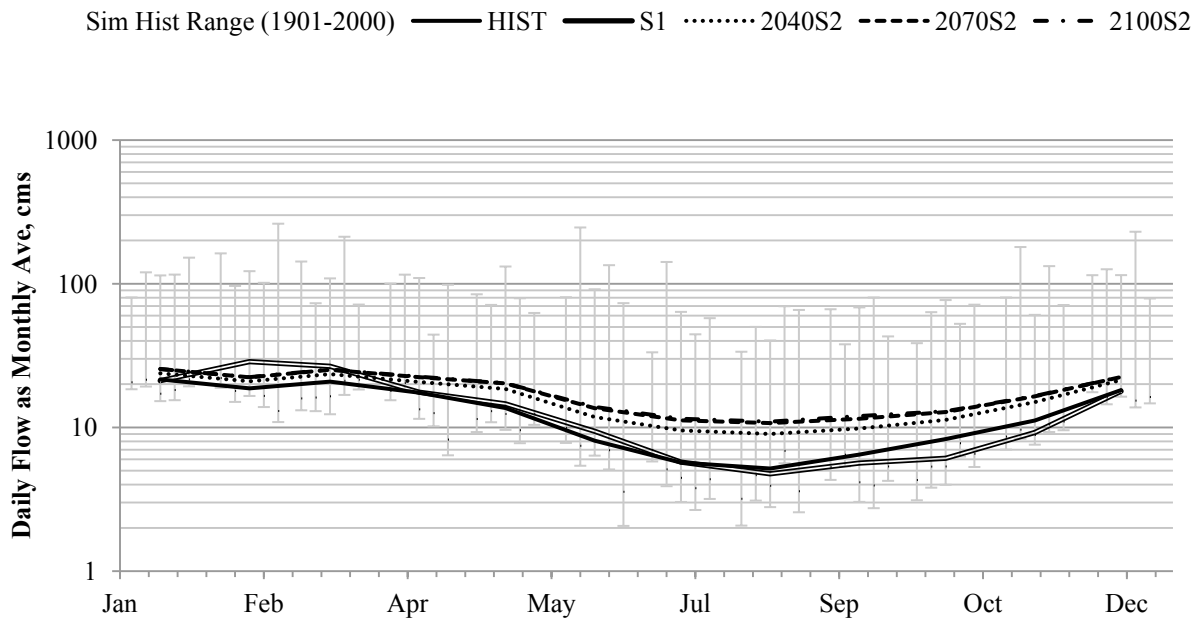


Figure 3.1-1 Average annual hydrograph comparing the ensemble historic to future scenarios S1 and S2 of average daily flows as monthly averages. Average shown at the 15th of each month, and range is shown for every 5th day through the 25th of each month.

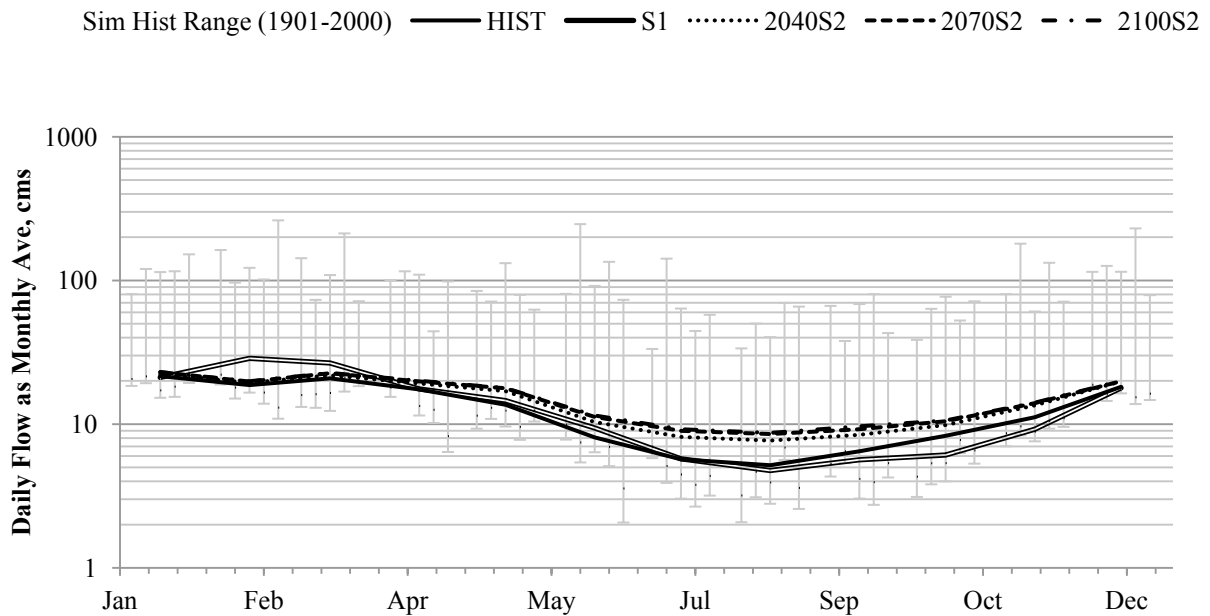


Figure 3.1-2 Average annual hydrograph comparing the ensemble historic to future scenarios S1 and S2 of average daily flows as monthly averages, not accounting for expansion in reclaimed water inflow. Average shown at the 15th of each month, and range is shown for every 5th day through the 25th of each month.

The hydrographs in Figures 3.1-3 and 3.1-4 compare the historic model with scenarios S1 and S3 respectively. These figures show a similar relationship to those in Figures 3.1-1 and 3.1-2

respectively, but the hydrographs take a shape similar to S1 with increased differences between peak and low annual flows.

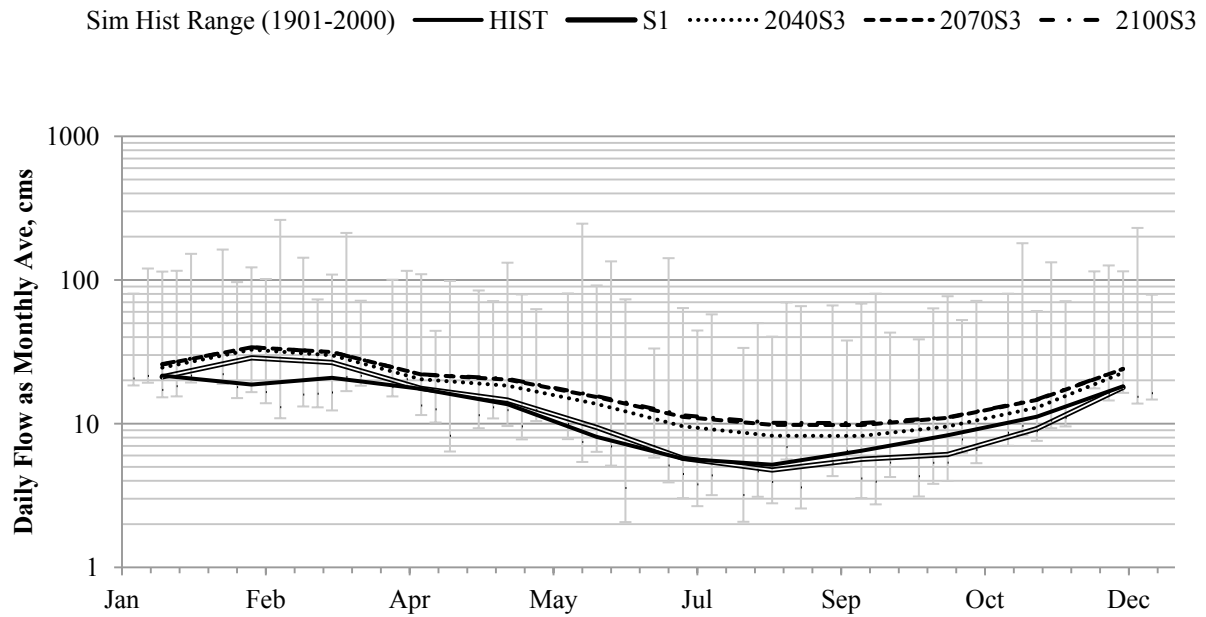


Figure 3.1-3 Average annual hydrograph comparing the ensemble historic to future scenarios S1 and S3 of daily flow as monthly averages. Average shown at the 15th of each month, and range is shown for every 5th day through the 25th of each month.

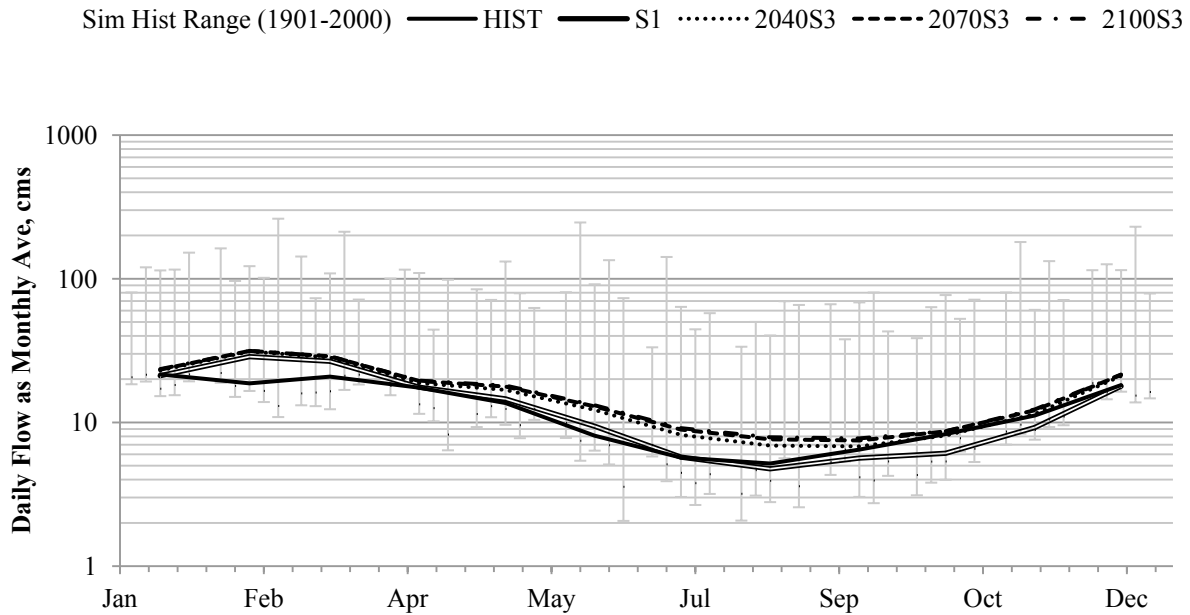


Figure 3.1-4 Average annual hydrograph comparing the ensemble historic to future scenarios S1 and S3 of daily flows as monthly averages, not accounting for expansion in reclaimed water inflow. Average shown at the 15th of each month, and range is shown for every 5th day through the 25th of each month.

Figures 3.1-5 through 3.1-8 are the graphical representations of the cumulative difference data described in the previous chapter in Table 2.6-1. These graphs show a similar relationship to the hydrographs in Figures 3.1-1 through 3.1-4 respectively, except a clearer differential can be seen between scenarios. The cumulative difference from the historic annual inflow volume is shown in Figures 3.1-5 and 3.1-6 for the ensemble future scenarios S1 and S2 respectively.

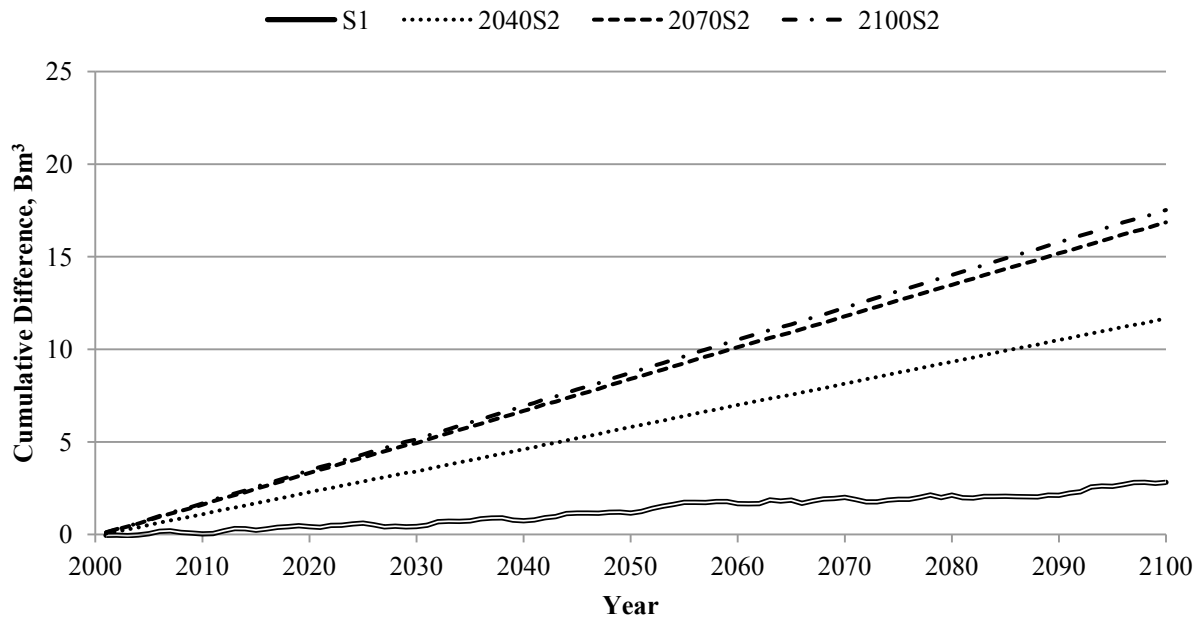


Figure 3.1-5 Cumulative differences in annual inflow volume comparing the ensemble historic to future scenarios S1 and S2

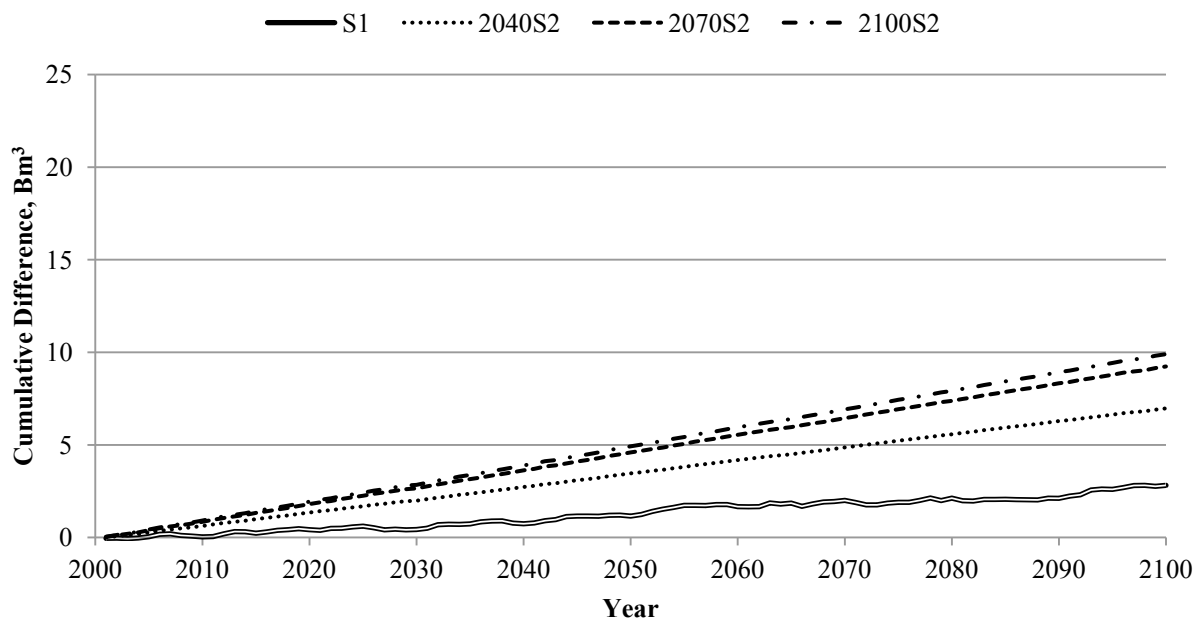


Figure 3.1-6 Cumulative differences in annual inflow volume comparing the ensemble historic to future scenarios S1 and S2, not accounting for expansion in reclaimed water inflow

The cumulative differences in Figures 3.1-7 and 3.1-8 compare the historic model with scenarios S1 and S3 respectively. These figures show a similar relationship to those in Figures 3.1-5 and 3.1-6 respectively, but with increased volume differences.

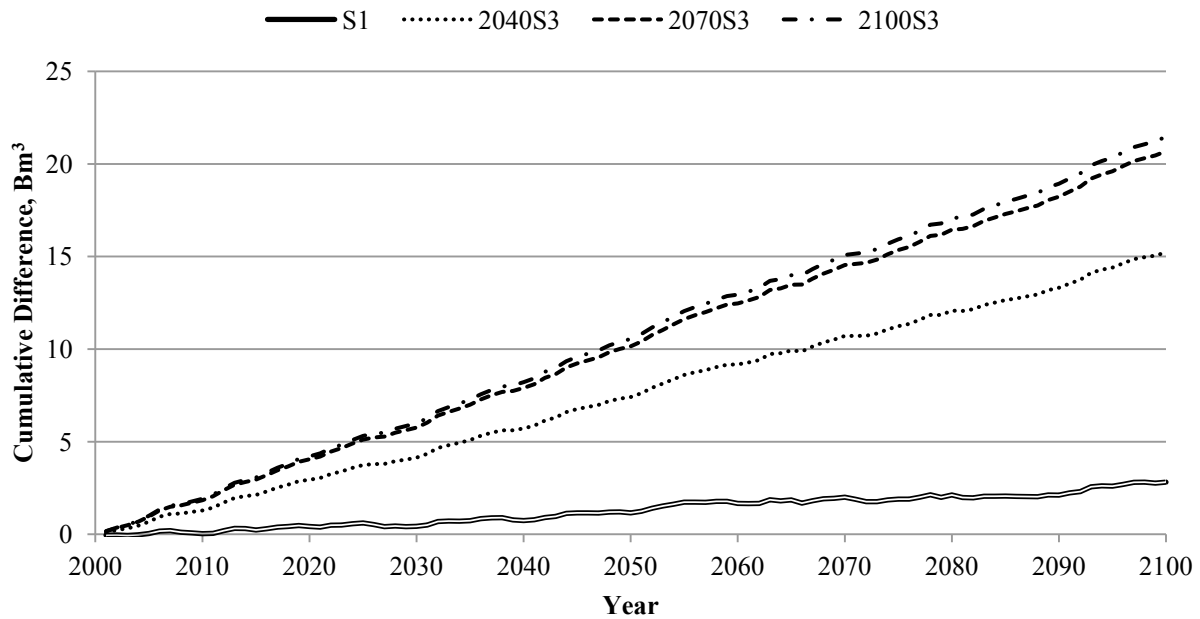


Figure 3.1-7 Cumulative differences in annual inflow volume comparing the ensemble historic to future scenarios S1 and S3

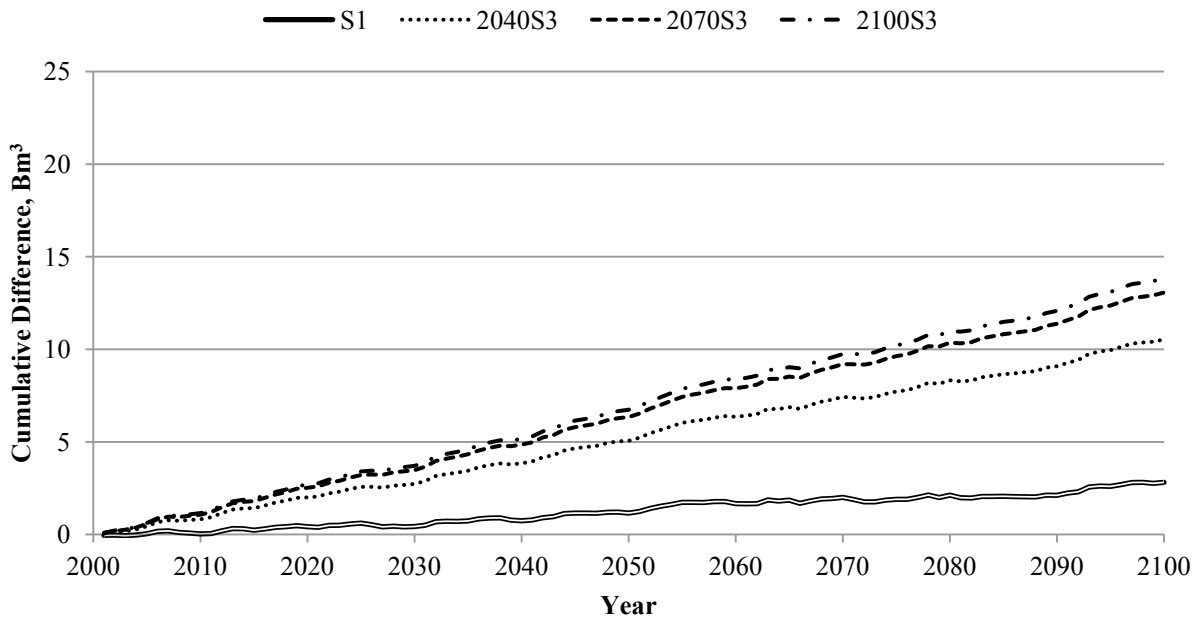


Figure 3.1-8 Cumulative differences in annual inflow volume comparing the ensemble historic to future scenarios S1 and S3, not accounting for expansion in reclaimed water inflow

The preceding figures highlight the likelihood of increased runoff in the Occoquan watershed from both climate and land use change. While climate change is expected to alter the intensity and timing of runoff, these impacts will be relatively minor compared to the increased runoff from land use change for the greater part of this century (through year 2070). Towards the end of this century, as urbanized area reaches its maximum, the incremental impacts of climate change become larger than the incremental impacts from land use change. As stated in the IPCC AR4 (IPCC 2007) the most intense effects of climate change will be realized in the latter part of this century. This timing sets up the possibility for the Occoquan watershed to reach maximum development capacity at the same time as changes to infrastructure may be required to deal with increasingly severe impacts brought about by climate change.

The current management practices for the Occoquan watershed include the use of reclaimed water supply, multiple source water supplies, and regional inter-agency drought coordination. The modeling in this study shows that with these practices in place the Occoquan

reservoir will support the most extreme demands projected to be placed on it by both climate and land use/demand change.

Future Research

This study focused on low flows (drought), the water supply of primary concern to water managers, and used techniques to incorporate future projections of climate variability and land use change, for a full assessment of impacts to the watershed. While ensuring supply during times of drought is the first part of a thorough watershed management plan, additional topics should be considered for future research in order to maintain a clean and reliable source of drinking water. These watershed management topics include but are not limited to:

- The water quality impacts of changes in rainfall intensity from climate change along with increased urban area runoff. The increase in urban area will change the composition of nutrient loading in the runoff from the watershed. Also, increases in total runoff are likely to increase the total nutrient load from both natural and urbanized land use areas.
- Reduction in groundwater supply from changes in rainfall patterns and expanded urbanization and demand. As impervious area increases with expanded urbanization more water is swept from the surface as opposed to percolating into groundwater aquifers. This process can be compounded by changes in the timing and intensity of rainfall patterns.
- The impacts from peak flow and flood variations like changes in sediment transport, along with stream bed erosion and damage to bridge and dam foundations. Increased peak flow is likely correlated to increases stream bed erosion. This erosion will increase the amount of sediment and debris transported through the watershed. Increased sediment and debris is likely to intensify erosion to civil structures, along with possibly increasing the siltation of reservoirs, within the waterway.

- The use of different statistical techniques for downscaling and data treatment to better define the uncertainty of analysis. The use of more climate model outputs may increase the statistical certainty of the final simulations. Also, changes to the statistical downscaling techniques can increase the GCM imparted variations in the projected local weather signal. Increase in the use of downscaling methods, and using multiple downscaling techniques, can develop consensus results amongst independent studies that convey greater certainty of projected outcomes.

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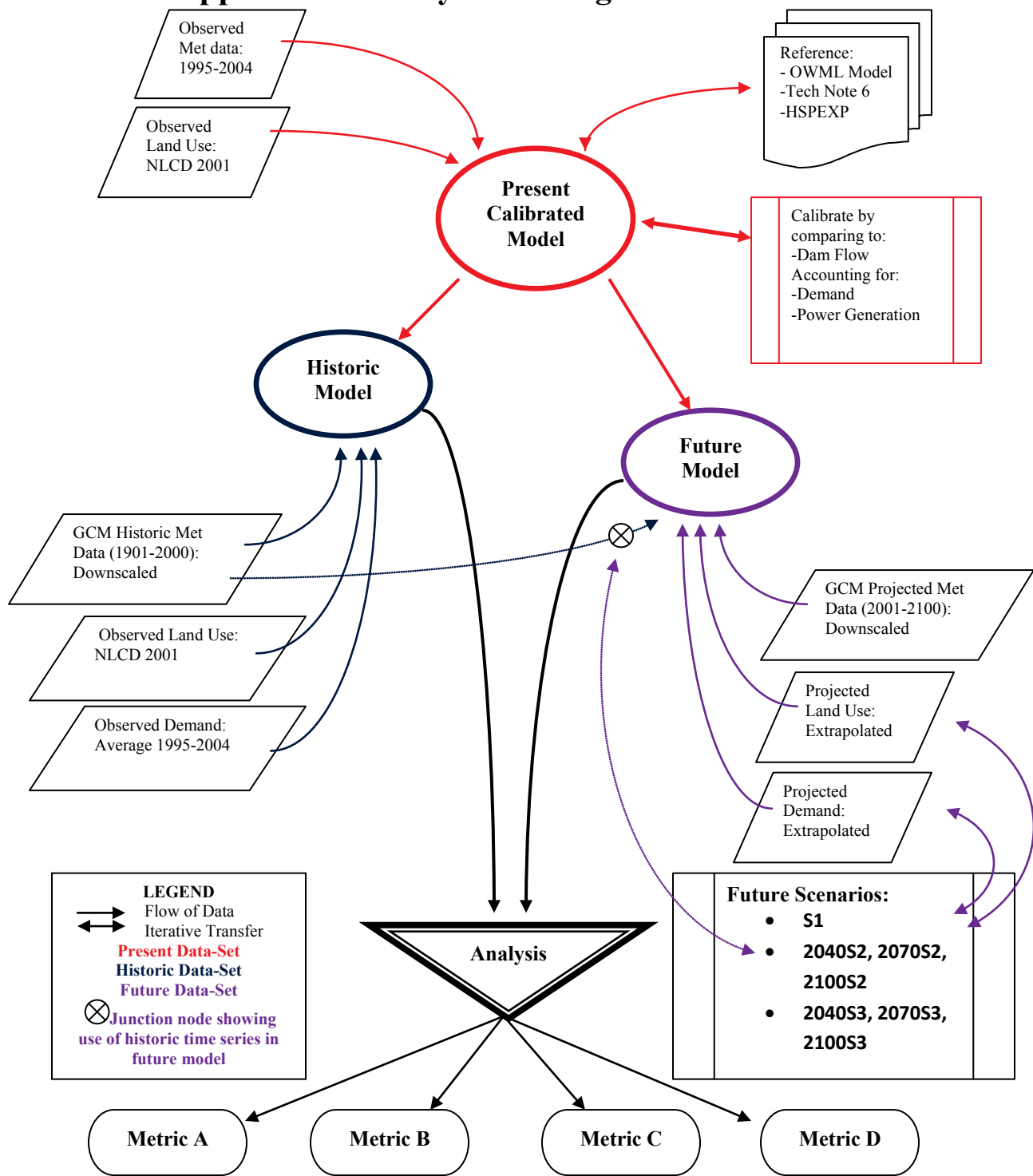
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5 Appendices

5.1 Appendix A: Study Flow Diagram



5.2 Appendix B: Downscaling Process Flow Diagram

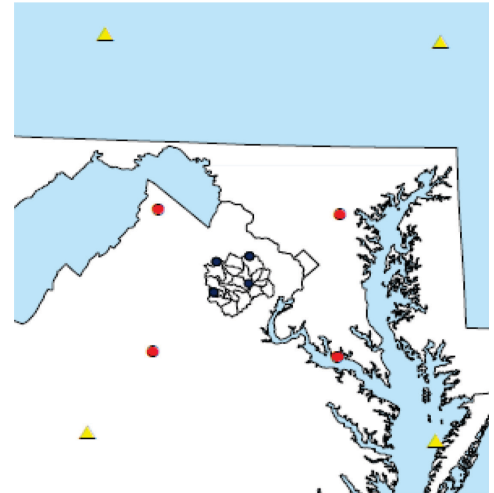
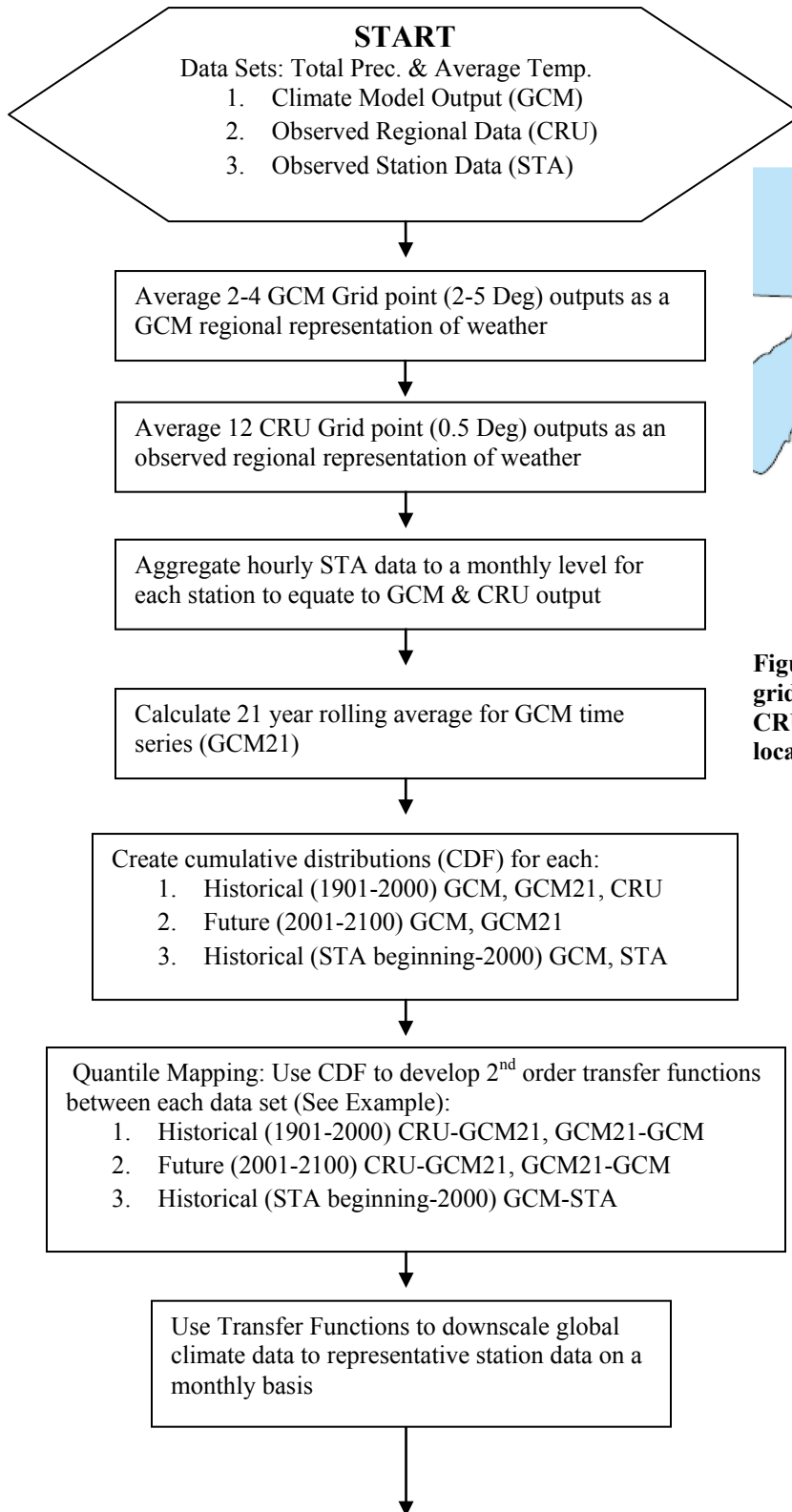


Figure 5.2-1 GIS representation of gridded data: Yellow is GCM grid, red is CRU grid boundary, and blue are station locations

Appendix B: (continued)

Spatial Downscaling:

6. Begin with CRU time series
7. Multiply (6) by CRU-GCM21 transfer function
8. Multiply (7) by GCM21-GCM transfer function
9. Multiply (8) by GCM-STA transfer function for each station
10. Output for each station will be a local representation of the globally produced data set

Disaggregate the monthly downscaled station data to an hourly representation by matching the monthly downscaled precipitation to an aggregated monthly precipitation from the observed station record, and use the quotient of the monthly values as a multiplier to the hourly time series (for temperature use the difference of the two values and add it to the hourly time series)

Temporal Downscaling:

1. Begin with downscaled STA time series
2. Match the monthly precipitation to one from the observed record of the same month
3. Use the quotient of the two values as a multiplier or delta value (for temperature use the difference of the two values and add)
4. Apply the delta value to the hourly time series
5. The new time series should have the monthly total precipitation (or average temperature) of the downscaled time series, but maintain the hourly representation of observed local weather

Repeat temporal downscaling on a month by month basis until desired time period is achieved

END

Transfer Function Examples:

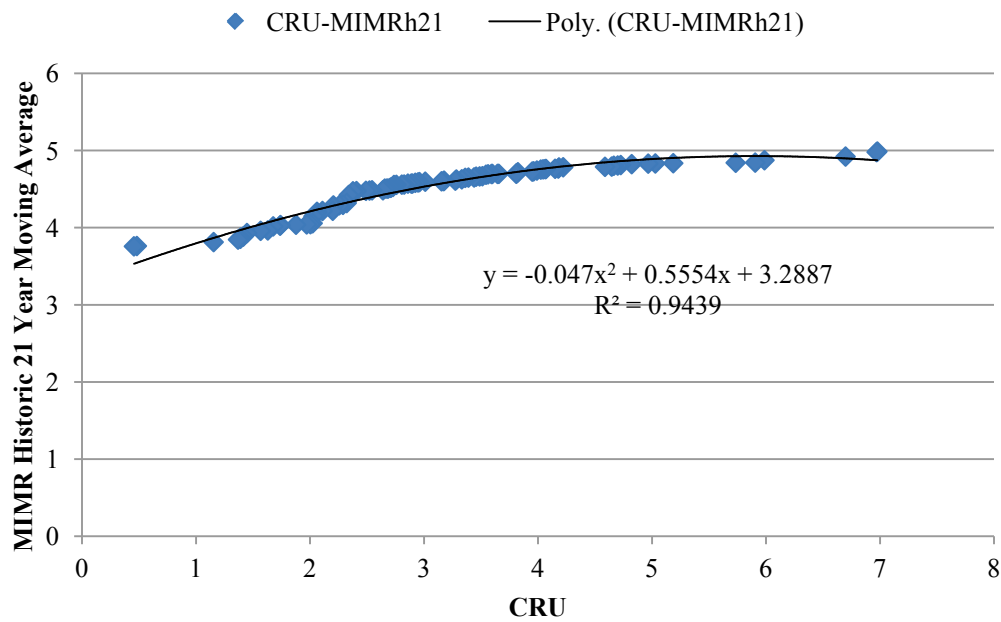


Figure 5.2-2 CRU-GCM21 transfer function for MIMR historic model January precipitation

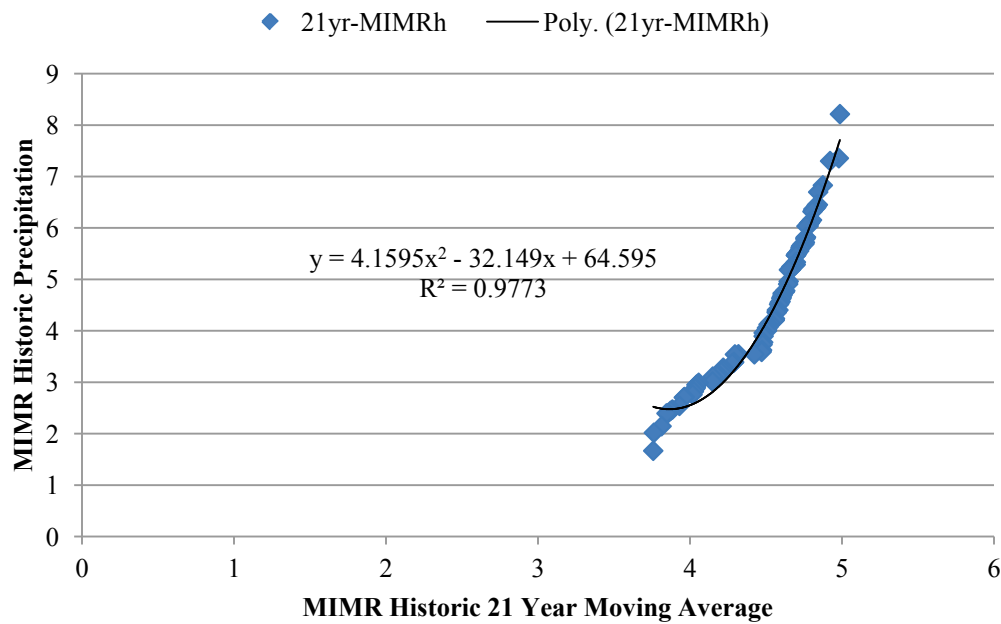


Figure 5.2-3 GCM21-GCM transfer function for MIMR historic model January precipitation

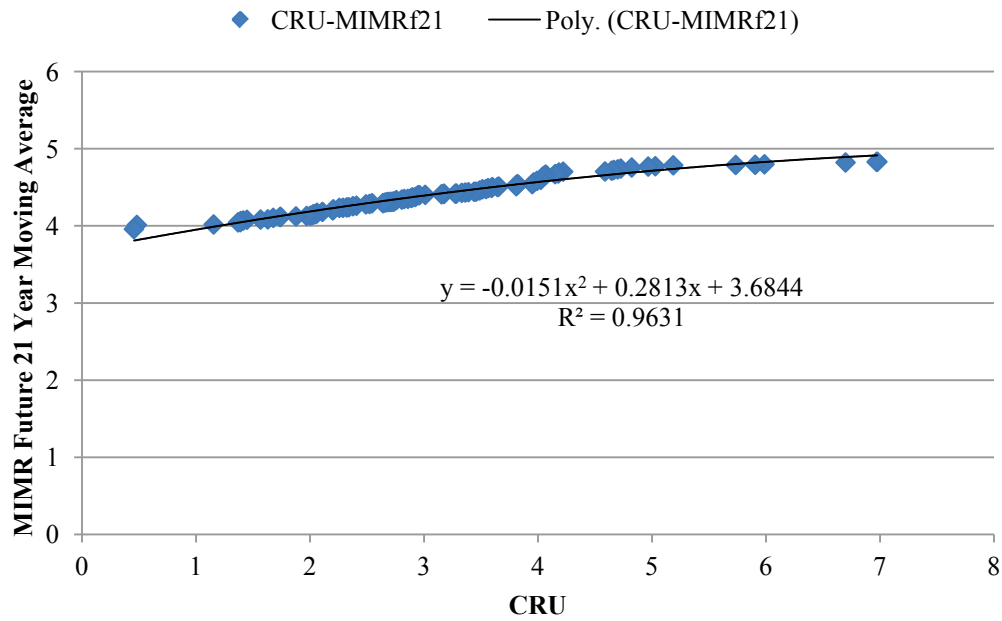


Figure 5.2-4 CRU-GCM21 transfer function for MIMR future model January precipitation

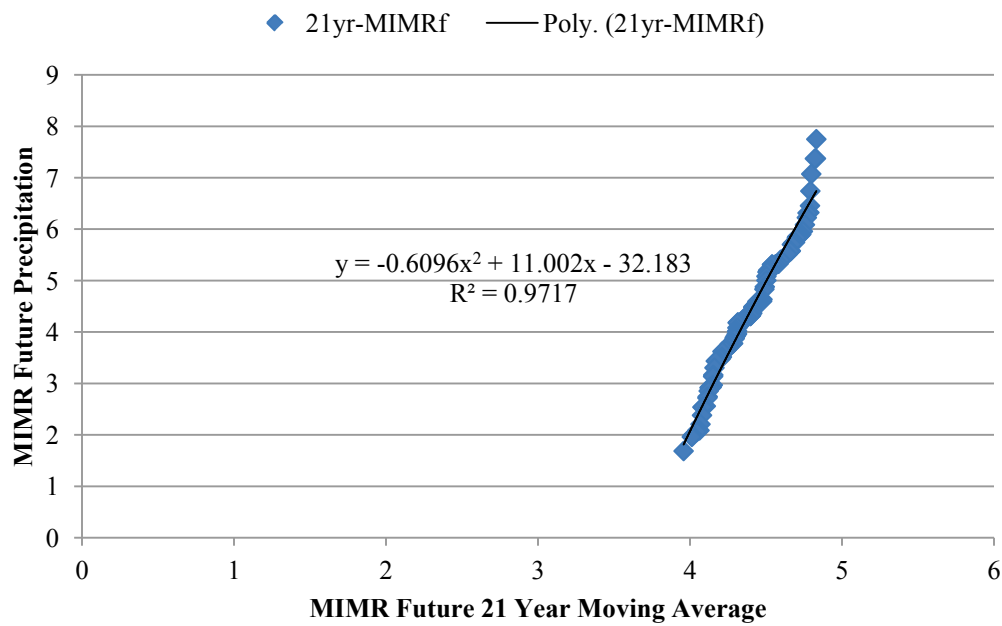


Figure 5.2-5 GCM21-GCM transfer function for MIMR future model January precipitation

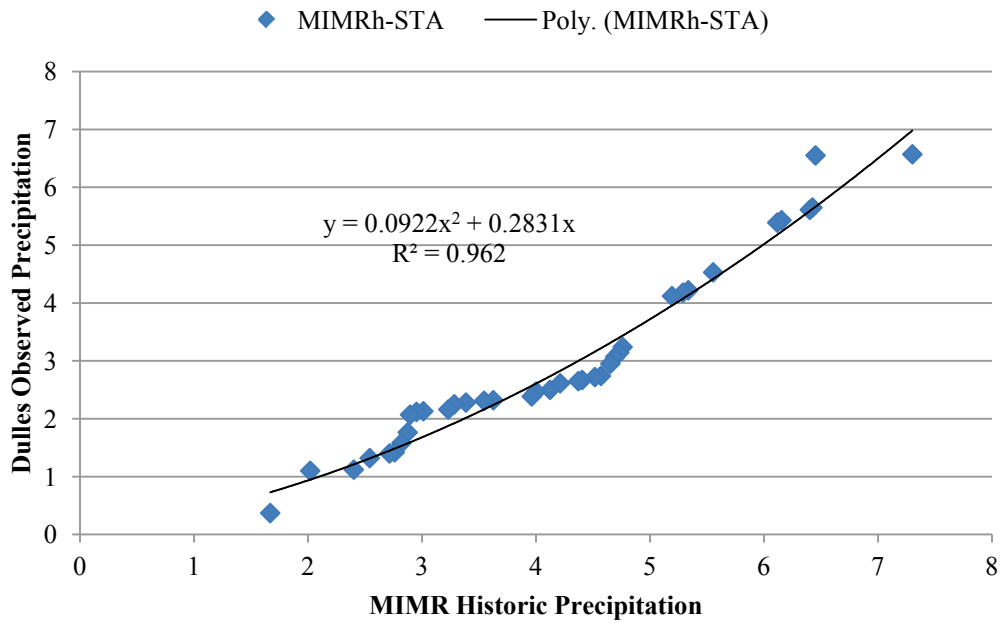


Figure 5.2-6 GCM-Station (DULL) transfer function for MIMR historic model January precipitation

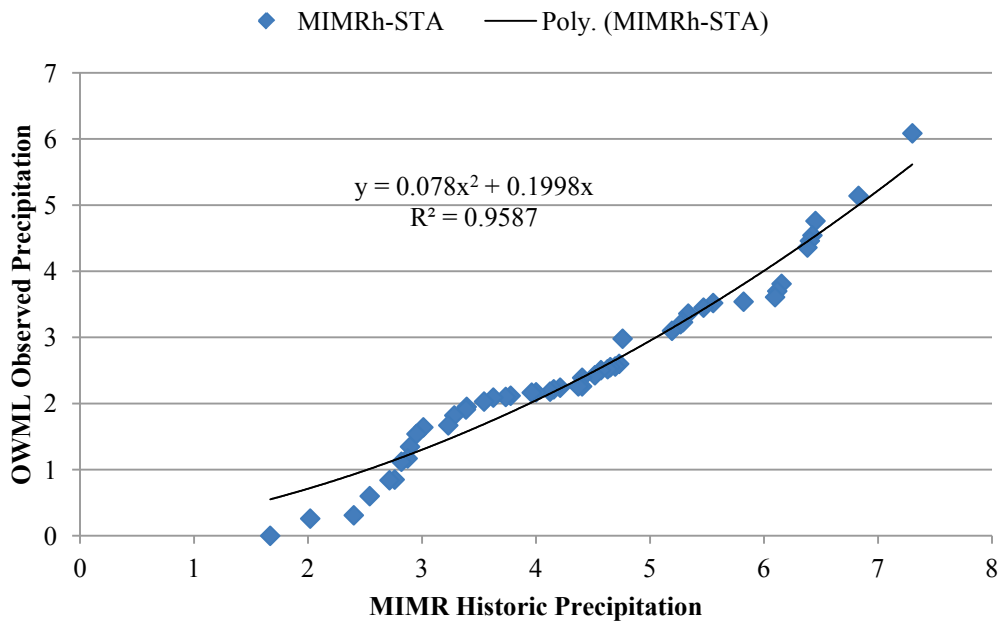


Figure 5.2-7 GCM-Station (OWML) transfer function for MIMR historic model January precipitation

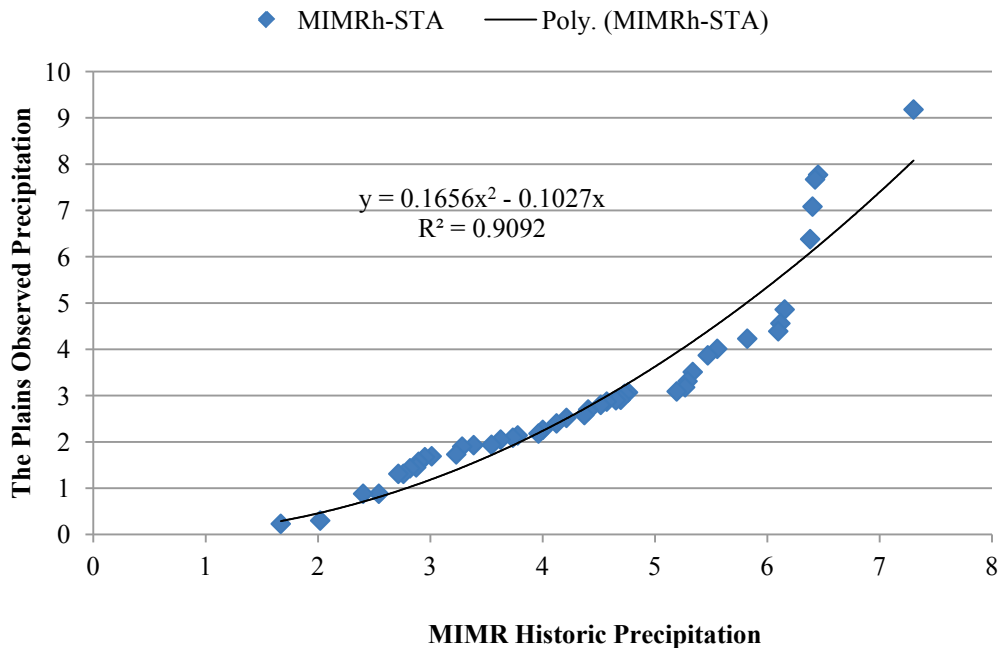


Figure 5.2-8 GCM-Station (PLNS) transfer function for MIMR historic model January precipitation

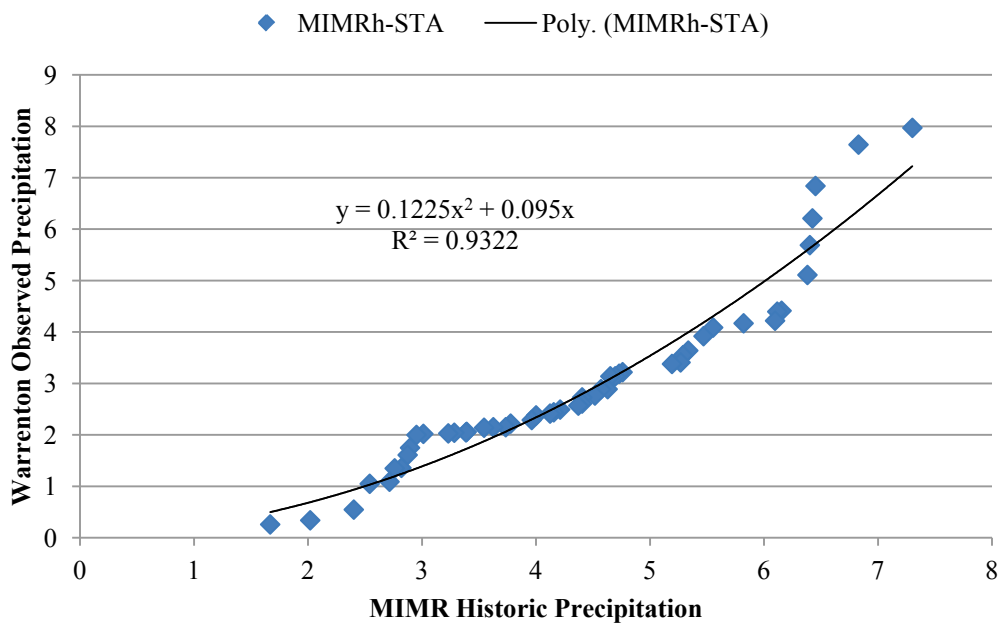


Figure 5.2-9 GCM-Station (WARR) transfer function for MIMR historic model January precipitation

5.3 Appendix C: HSPF Calibration Input File

RUN

GLOBAL

UCI Created by WinHSPF for the Occoquan Watershed

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RUN INTERP OUTPT LEVELS 5 0

RESUME 0 RUN 1 UNITS 1

END GLOBAL

FILES

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91 OccCalibInput.out

WDM1 25 OccCalibInput.wdm

WDM2 26 ..\..\data\02070010-4\met\inputOccWtrsd.wdm

BINO 92 OccCalibInput.hbn

END FILES

OPN SEQUENCE

INGRP INDELT 01:00

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PERLND 42

PERLND 43

PERLND 44

PERLND 45

PERLND 46

IMPLND 42

PERLND 71

PERLND 72

PERLND 73

PERLND 74

PERLND 75

PERLND 76

IMPLND 72

PERLND 151

PERLND 152

PERLND 153

PERLND 154

PERLND 155

PERLND 156

IMPLND 152

PERLND 121

PERLND 122

PERLND 123

PERLND 124

PERLND 125

PERLND 126

IMPLND 122

PERLND 131

PERLND 132

PERLND 133

PERLND 134

PERLND 135

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IMPLND	12

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END INGRP
 END OPN SEQUENCE

PERLND

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 END PRINT-INFO

BINARY-INFO

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GEN-INFO

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51 56	-123.	59.
61 66	-30.	60.
71 76	104.	59.
81 86	-10.	60.
91 96	-20.	60.
101 106	15.	60.
111 116	-10.	60.
121 126	59.	46.1
131 136	20.	60.
141 146	-47.	60.
151 156	-5.	46.1
161 166	-111.	46.1
171 176	-55.	46.1
181 186	-126.	46.1
191 196	-47.	46.1
201 206	35.	60.
211 216	-51.	60.

END ATEMP-DAT

PWAT-PARM1

*** <PLS >	Flags												
*** x - x	CSNO	RTOP	UZFG	VCS	VUZ	VNN	VIFW	VIRC	VLE	IFFC	HWT	IRRG	IFRD
11 216	0	1	1	1	1	0	0	0	1	1	0	0	0

END PWAT-PARM1

PWAT-PARM2

*** < PLS>	FOREST	LZSN	INFILT	LSUR	SLSUR	KVARY	AGWRC
*** x - x		(in)	(in/hr)	(ft)		(1/in)	(1/day)
11	0.	5.	0.08	298.1	0.06245	0.	0.92
12	0.	4.3	0.03	298.1	0.06245	0.	0.88
13	0.	4.3	0.03	298.1	0.06245	0.	0.88
14	0.	4.8	0.08	298.1	0.06245	0.	0.92
15	0.	4.5	0.06	298.1	0.06245	0.	0.91
16	0.	4.8	0.06	298.1	0.06245	0.	0.91
21	0.	5.6	0.03	457.8	0.04401	0.	0.92
22	0.	4.9	0.005	457.8	0.04401	0.	0.88
23	0.	4.9	0.005	457.8	0.04401	0.	0.88
24	0.	5.4	0.03	457.8	0.04401	0.	0.92
25	0.	5.2	0.01	457.8	0.04401	0.	0.91
26	0.	5.4	0.01	457.8	0.04401	0.	0.91
31	0.	5.6	0.06	311.8	0.05915	0.	0.92
32	0.	4.9	0.01	311.8	0.05915	0.	0.88
33	0.	4.9	0.01	311.8	0.05915	0.	0.88
34	0.	5.4	0.06	311.8	0.05915	0.	0.92
35	0.	5.2	0.04	311.8	0.05915	0.	0.91
36	0.	5.4	0.04	311.8	0.05915	0.	0.91

41	0.	6.1	0.08	433.4	0.05991	0.	0.92
42	0.	5.4	0.03	433.4	0.05991	0.	0.88
43	0.	5.4	0.03	433.4	0.05991	0.	0.88
44	0.	5.9	0.08	433.4	0.05991	0.	0.92
45	0.	5.7	0.06	433.4	0.05991	0.	0.91
46	0.	5.9	0.06	433.4	0.05991	0.	0.91
51	0.	5.	0.07	379.9	0.0523	0.	0.92
52	0.	4.3	0.02	379.9	0.0523	0.	0.88
53	0.	4.3	0.02	379.9	0.0523	0.	0.88
54	0.	4.8	0.07	379.9	0.0523	0.	0.92
55	0.	4.5	0.05	379.9	0.0523	0.	0.91
56	0.	4.8	0.05	379.9	0.0523	0.	0.91
61	0.	3.	0.03	395.9	0.04695	0.	0.98
62	0.	2.3	0.005	395.9	0.04695	0.	0.92
63	0.	2.3	0.005	395.9	0.04695	0.	0.92
64	0.	2.8	0.03	395.9	0.04695	0.	0.98
65	0.	2.5	0.01	395.9	0.04695	0.	0.97
66	0.	2.8	0.01	395.9	0.04695	0.	0.97
71	0.	5.	0.06	353.4	0.05453	0.	0.92
72	0.	4.3	0.01	353.4	0.05453	0.	0.88
73	0.	4.3	0.01	353.4	0.05453	0.	0.88
74	0.	4.8	0.06	353.4	0.05453	0.	0.92
75	0.	4.5	0.04	353.4	0.05453	0.	0.91
76	0.	4.8	0.04	353.4	0.05453	0.	0.91
81	0.	5.	0.04	398.	0.04071	0.	0.92
82	0.	4.3	0.005	398.	0.04071	0.	0.88
83	0.	4.3	0.005	398.	0.04071	0.	0.88
84	0.	4.8	0.04	398.	0.04071	0.	0.92
85	0.	4.5	0.02	398.	0.04071	0.	0.91
86	0.	4.8	0.02	398.	0.04071	0.	0.91
91	0.	5.	0.03	476.9	0.04344	0.	0.92
92	0.	4.3	0.005	476.9	0.04344	0.	0.88
93	0.	4.3	0.005	476.9	0.04344	0.	0.88
94	0.	4.8	0.03	476.9	0.04344	0.	0.92
95	0.	4.5	0.01	476.9	0.04344	0.	0.91
96	0.	4.8	0.01	476.9	0.04344	0.	0.91
101	0.	5.	0.06	345.4	0.05573	0.	0.92
102	0.	4.3	0.01	345.4	0.05573	0.	0.88
103	0.	4.3	0.01	345.4	0.05573	0.	0.88
104	0.	4.8	0.06	345.4	0.05573	0.	0.92
105	0.	4.5	0.04	345.4	0.05573	0.	0.91
106	0.	4.8	0.04	345.4	0.05573	0.	0.91
111	0.	5.	0.07	226.7	0.05838	0.	0.92
112	0.	4.3	0.02	226.7	0.05838	0.	0.88
113	0.	4.3	0.02	226.7	0.05838	0.	0.88
114	0.	4.8	0.07	226.7	0.05838	0.	0.92
115	0.	4.5	0.05	226.7	0.05838	0.	0.91
116	0.	4.8	0.05	226.7	0.05838	0.	0.91
121	0.	5.7	0.05	350.6	0.05831	0.	0.92
122	0.	5.	0.01	350.6	0.05831	0.	0.88
123	0.	5.	0.01	350.6	0.05831	0.	0.88
124	0.	5.5	0.05	350.6	0.05831	0.	0.92
125	0.	5.3	0.03	350.6	0.05831	0.	0.91
126	0.	5.5	0.03	350.6	0.05831	0.	0.91
131	0.	3.	0.03	320.8	0.05172	0.	0.98
132	0.	2.3	0.01	320.8	0.05172	0.	0.92
133	0.	2.3	0.01	320.8	0.05172	0.	0.92

134	0.	2.8	0.03	320.8	0.05172	0.	0.98
135	0.	2.5	0.01	320.8	0.05172	0.	0.97
136	0.	2.8	0.01	320.8	0.05172	0.	0.97
141	0.	3.	0.05	309.9	0.04038	0.	0.98
142	0.	2.3	0.01	309.9	0.04038	0.	0.92
143	0.	2.3	0.01	309.9	0.04038	0.	0.92
144	0.	2.8	0.05	309.9	0.04038	0.	0.98
145	0.	2.5	0.03	309.9	0.04038	0.	0.97
146	0.	2.8	0.03	309.9	0.04038	0.	0.97
151	0.	5.7	0.07	311.7	0.05694	0.	0.92
152	0.	5.	0.02	311.7	0.05694	0.	0.88
153	0.	5.	0.02	311.7	0.05694	0.	0.88
154	0.	5.5	0.07	311.7	0.05694	0.	0.92
155	0.	5.3	0.05	311.7	0.05694	0.	0.91
156	0.	5.5	0.05	311.7	0.05694	0.	0.91
161	0.	5.7	0.05	255.6	0.05691	0.	0.98
162	0.	5.	0.01	255.6	0.05691	0.	0.92
163	0.	5.	0.01	255.6	0.05691	0.	0.92
164	0.	5.5	0.05	255.6	0.05691	0.	0.99
165	0.	5.3	0.03	255.6	0.05691	0.	0.97
166	0.	5.5	0.03	255.6	0.05691	0.	0.97
171	0.	5.7	0.07	377.3	0.04931	0.	0.92
172	0.	5.	0.02	377.3	0.04931	0.	0.88
173	0.	5.	0.02	377.3	0.04931	0.	0.88
174	0.	5.5	0.07	377.3	0.04931	0.	0.92
175	0.	5.3	0.05	377.3	0.04931	0.	0.91
176	0.	5.5	0.05	377.3	0.04931	0.	0.91
181	0.	5.	0.05	342.6	0.04992	0.	0.98
182	0.	4.3	0.01	342.6	0.04992	0.	0.92
183	0.	4.3	0.01	342.6	0.04992	0.	0.92
184	0.	4.8	0.05	342.6	0.04992	0.	0.99
185	0.	4.5	0.03	342.6	0.04992	0.	0.97
186	0.	4.8	0.03	342.6	0.04992	0.	0.97
191	0.	5.7	0.05	354.6	0.05151	0.	0.92
192	0.	5.	0.01	354.6	0.05151	0.	0.88
193	0.	5.	0.01	354.6	0.05151	0.	0.88
194	0.	5.5	0.05	354.6	0.05151	0.	0.92
195	0.	5.3	0.03	354.6	0.05151	0.	0.91
196	0.	5.5	0.03	354.6	0.05151	0.	0.91
201	0.	5.	0.07	314.1	0.05148	0.	0.98
202	0.	4.3	0.02	314.1	0.05148	0.	0.92
203	0.	4.3	0.02	314.1	0.05148	0.	0.92
204	0.	4.8	0.07	314.1	0.05148	0.	0.99
205	0.	4.5	0.05	314.1	0.05148	0.	0.97
206	0.	4.8	0.05	314.1	0.05148	0.	0.97
211	0.	5.	0.05	268.3	0.0536	0.	0.97
212	0.	4.3	0.01	268.3	0.0536	0.	0.90
213	0.	4.3	0.01	268.3	0.0536	0.	0.90
214	0.	4.8	0.05	268.3	0.0536	0.	0.97
215	0.	4.5	0.03	268.3	0.0536	0.	0.96
216	0.	4.8	0.03	268.3	0.0536	0.	0.96

END PWAT-PARM2

PWAT-PARM3

*** < PLS>	PETMAX	PETMIN	INFEXP	INFILD	DEEPFR	BASETP	AGWETP
*** x - x	(deg F)	(deg F)					
11 216	40.	35.	2.	2.	0.1	0.08	0.

END PWAT-PARM3

PWAT-PARM4

```
*** <PLS >      CEPSC      UZSN      NSUR      INTFW      IRC      LZETP
*** x - x      (in)      (in)      (1/day)
  11  16         0        0.5        0.3        2.0        0.7        0.5
  21  26         0        0.5        0.3        3.0        0.5        0.5
  31  36         0        0.5        0.3        3.0        0.5        0.5
  41  46         0        0.5        0.3        3.0        0.5        0.5
  51  56         0        0.5        0.3        3.0        0.5        0.5
  61  66         0        0.5        0.3        2.0        0.5        0.5
  71  76         0        0.5        0.3        3.0        0.5        0.5
  81  86         0        0.5        0.3        2.0        0.5        0.5
  91  96         0        0.5        0.3        2.0        0.5        0.5
 101 106         0        0.5        0.3        2.0        0.5        0.5
 111 116         0        0.5        0.3        2.0        0.7        0.5
 121 126         0        0.5        0.3        3.0        0.5        0.5
 131 136         0        0.5        0.3        2.0        0.5        0.5
 141 146         0        0.5        0.3        2.0        0.5        0.5
 151 156         0        0.5        0.3        3.0        0.5        0.5
 161 166         0        0.5        0.3        3.0        0.5        0.5
 171 176         0        0.5        0.3        3.0        0.5        0.5
 181 186         0        0.5        0.3        3.0        0.5        0.5
 191 196         0        0.5        0.3        3.0        0.5        0.5
 201 206         0        0.5        0.3        2.0        0.5        0.5
 211 216         0        0.5        0.3        2.0        0.7        0.5
```

END PWAT-PARM4

PWAT-STATE1

```
*** < PLS> PWATER state variables (in)
*** x - x      CEPS      SURS      UZS      IFWS      LZS      AGWS      GWVS
  11  216         0        0.5        0.77        0        5.13        1        0
END PWAT-STATE1
```

MON-INTERCEP

```
*** <PLS > Interception storage capacity at start of each month (in)
*** x - x  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC
  11         0.20 0.20 0.20 0.20 0.20 0.20 0.20 0.20 0.20 0.20 0.20 0.20
  12  13  0.05 0.05 0.07 0.07 0.10 0.10 0.10 0.10 0.10 0.07 0.05 0.05
  14  16  0.17 0.17 0.19 0.19 0.22 0.22 0.22 0.22 0.22 0.19 0.17 0.17
  21         0.20 0.20 0.20 0.20 0.20 0.20 0.20 0.20 0.20 0.20 0.20 0.20
  22  23  0.05 0.05 0.07 0.07 0.07 0.10 0.10 0.10 0.10 0.10 0.10 0.05
  24  26  0.11 0.11 0.13 0.13 0.13 0.16 0.16 0.16 0.16 0.16 0.16 0.11
  31         0.20 0.20 0.20 0.20 0.20 0.20 0.20 0.20 0.20 0.20 0.20 0.20
  32  33  0.05 0.05 0.07 0.07 0.07 0.10 0.10 0.10 0.10 0.10 0.10 0.05
  34  36  0.20 0.20 0.22 0.22 0.22 0.25 0.25 0.25 0.25 0.25 0.25 0.20
  41         0.20 0.20 0.20 0.20 0.20 0.20 0.20 0.20 0.20 0.20 0.20 0.20
  42  43  0.05 0.05 0.07 0.07 0.10 0.10 0.10 0.10 0.10 0.07 0.05 0.05
  44  46  0.26 0.26 0.28 0.28 0.31 0.31 0.31 0.31 0.31 0.28 0.26 0.26
  51         0.20 0.20 0.20 0.20 0.20 0.20 0.20 0.20 0.20 0.20 0.20 0.20
  52  53  0.05 0.05 0.07 0.07 0.10 0.10 0.10 0.10 0.10 0.07 0.05 0.05
  54  56  0.17 0.17 0.19 0.19 0.22 0.22 0.22 0.22 0.22 0.19 0.17 0.17
  61         0.20 0.20 0.20 0.20 0.20 0.20 0.20 0.20 0.20 0.20 0.20 0.20
  62  63  0.05 0.05 0.07 0.07 0.10 0.10 0.10 0.10 0.10 0.07 0.05 0.05
  64  66  0.10 0.10 0.12 0.12 0.15 0.15 0.15 0.15 0.15 0.12 0.10 0.10
  71         0.20 0.20 0.20 0.20 0.20 0.20 0.20 0.20 0.20 0.20 0.20 0.20
  72  73  0.05 0.05 0.07 0.07 0.07 0.10 0.10 0.10 0.10 0.10 0.10 0.05
```

74	76	0.17	0.17	0.19	0.19	0.19	0.22	0.22	0.22	0.22	0.22	0.22	0.17
81		0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
82	83	0.05	0.05	0.07	0.07	0.07	0.10	0.10	0.10	0.10	0.10	0.10	0.05
84	86	0.10	0.10	0.12	0.12	0.12	0.15	0.15	0.15	0.15	0.15	0.15	0.10
91		0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
92	93	0.05	0.05	0.07	0.07	0.07	0.10	0.10	0.10	0.10	0.10	0.10	0.05
94	96	0.10	0.10	0.12	0.12	0.12	0.15	0.15	0.15	0.15	0.15	0.15	0.10
101		0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
102	103	0.05	0.05	0.07	0.07	0.07	0.10	0.10	0.10	0.10	0.10	0.10	0.05
104	106	0.17	0.17	0.19	0.19	0.19	0.22	0.22	0.22	0.22	0.22	0.22	0.17
111		0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
112	113	0.05	0.05	0.07	0.07	0.10	0.10	0.10	0.10	0.10	0.07	0.05	0.05
114	116	0.17	0.17	0.19	0.19	0.22	0.22	0.22	0.22	0.22	0.19	0.17	0.17
121		0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
122	123	0.05	0.05	0.07	0.07	0.07	0.10	0.10	0.10	0.10	0.07	0.07	0.07
124	126	0.20	0.20	0.22	0.22	0.22	0.25	0.25	0.25	0.25	0.22	0.22	0.22
131		0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
132	133	0.05	0.05	0.07	0.07	0.10	0.10	0.10	0.10	0.10	0.07	0.05	0.05
134	136	0.17	0.17	0.19	0.19	0.22	0.22	0.22	0.22	0.22	0.19	0.17	0.17
141		0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
142	143	0.05	0.05	0.07	0.07	0.10	0.10	0.10	0.10	0.10	0.07	0.05	0.05
144	146	0.17	0.17	0.19	0.19	0.22	0.22	0.22	0.22	0.22	0.19	0.17	0.17
151		0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
152	153	0.05	0.05	0.07	0.07	0.07	0.10	0.10	0.10	0.10	0.07	0.07	0.07
154	156	0.20	0.20	0.22	0.22	0.22	0.25	0.25	0.25	0.25	0.22	0.22	0.22
161		0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
162	163	0.05	0.05	0.07	0.07	0.07	0.10	0.10	0.10	0.10	0.07	0.07	0.07
164	166	0.20	0.20	0.22	0.22	0.22	0.25	0.25	0.25	0.25	0.22	0.22	0.22
171		0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
172	173	0.05	0.05	0.07	0.07	0.07	0.10	0.10	0.10	0.10	0.07	0.07	0.07
174	176	0.20	0.20	0.22	0.22	0.22	0.25	0.25	0.25	0.25	0.22	0.22	0.22
181		0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
182	183	0.05	0.05	0.07	0.07	0.07	0.10	0.10	0.10	0.10	0.07	0.07	0.07
184	186	0.17	0.17	0.19	0.19	0.19	0.22	0.22	0.22	0.22	0.19	0.19	0.19
191		0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
192	193	0.05	0.05	0.07	0.07	0.07	0.10	0.10	0.10	0.10	0.07	0.07	0.07
194	196	0.24	0.24	0.26	0.26	0.26	0.29	0.29	0.29	0.29	0.26	0.26	0.26
201		0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
202	203	0.05	0.05	0.07	0.07	0.07	0.10	0.10	0.10	0.10	0.07	0.07	0.07
204	206	0.20	0.20	0.22	0.22	0.22	0.25	0.25	0.25	0.25	0.22	0.22	0.22
211		0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
212	213	0.05	0.05	0.07	0.07	0.10	0.10	0.10	0.10	0.10	0.07	0.05	0.05
214	216	0.20	0.20	0.22	0.22	0.25	0.25	0.25	0.25	0.25	0.22	0.20	0.20

END MON-INTERCEP

MON-UZSN

*** <PLS > Upper zone storage at start of each month (inches)

*** x -	x	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
11		1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
12	13	.464	.464	.464	.464	.464	.464	.464	.464	.464	.464	.464	.464
14	16	.812	.811	.808	.805	.802	.799	.799	.8	.802	.806	.809	.811
21		1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
22	23	.512	.512	.512	.512	.512	.512	.512	.512	.512	.512	.512	.512
24	26	.896	.895	.892	.889	.886	.883	.883	.884	.886	.89	.893	.895
31		1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
32	33	.512	.512	.512	.512	.512	.512	.512	.512	.512	.512	.512	.512
34	36	.896	.895	.892	.889	.886	.883	.883	.884	.886	.89	.893	.895

41		1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
42	43	.552	.552	.552	.552	.552	.552	.552	.552	.552	.552	.552
44	46	.966	.965	.962	.959	.956	.953	.953	.954	.956	.96	.963
51		1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
52	53	.552	.552	.552	.552	.552	.552	.552	.552	.552	.552	.552
54	56	.966	.965	.962	.959	.956	.953	.953	.954	.956	.96	.963
61		1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
62	63	.464	.464	.464	.464	.464	.464	.464	.464	.464	.464	.464
64	66	.812	.811	.808	.805	.802	.799	.799	.8	.802	.806	.809
71		1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
72	73	.552	.552	.552	.552	.552	.552	.552	.552	.552	.552	.552
74	76	.966	.965	.962	.959	.956	.953	.953	.954	.956	.96	.963
81		1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
82	83	.464	.464	.464	.464	.464	.464	.464	.464	.464	.464	.464
84	86	.812	.811	.808	.805	.802	.799	.799	.8	.802	.806	.809
91		1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
92	93	.464	.464	.464	.464	.464	.464	.464	.464	.464	.464	.464
94	96	.812	.811	.808	.805	.802	.799	.799	.8	.802	.806	.809
101		1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
102	103	.464	.464	.464	.464	.464	.464	.464	.464	.464	.464	.464
104	106	.812	.811	.808	.805	.802	.799	.799	.8	.802	.806	.809
111		1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
112	113	.464	.464	.464	.464	.464	.464	.464	.464	.464	.464	.464
114	116	.812	.811	.808	.805	.802	.799	.799	.8	.802	.806	.809
121		1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
122	123	.52	.52	.52	.52	.52	.52	.52	.52	.52	.52	.52
124	126	.91	.909	.906	.903	.9	.897	.897	.898	.9	.904	.907
131		1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
132	133	.464	.464	.464	.464	.464	.464	.464	.464	.464	.464	.464
134	136	.812	.811	.808	.805	.802	.799	.799	.8	.802	.806	.809
141		1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
142	143	.464	.464	.464	.464	.464	.464	.464	.464	.464	.464	.464
144	146	.812	.811	.808	.805	.802	.799	.799	.8	.802	.806	.809
151		1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
152	153	.52	.52	.52	.52	.52	.52	.52	.52	.52	.52	.52
154	156	.91	.909	.906	.903	.9	.897	.897	.898	.9	.904	.907
161		1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
162	163	.52	.52	.52	.52	.52	.52	.52	.52	.52	.52	.52
164	166	.91	.909	.906	.903	.9	.897	.897	.898	.9	.904	.907
171		1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
172	173	.52	.52	.52	.52	.52	.52	.52	.52	.52	.52	.52
174	176	.91	.909	.906	.903	.9	.897	.897	.898	.9	.904	.907
181		1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
182	183	.52	.52	.52	.52	.52	.52	.52	.52	.52	.52	.52
184	186	.91	.909	.906	.903	.9	.897	.897	.898	.9	.904	.907
191		1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
192	193	.52	.52	.52	.52	.52	.52	.52	.52	.52	.52	.52
194	196	.91	.909	.906	.903	.9	.897	.897	.898	.9	.904	.907
201		1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
202	203	.464	.464	.464	.464	.464	.464	.464	.464	.464	.464	.464
204	206	.812	.811	.808	.805	.802	.799	.799	.8	.802	.806	.809
211		1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
212	213	.464	.464	.464	.464	.464	.464	.464	.464	.464	.464	.464
214	216	.812	.811	.808	.805	.802	.799	.799	.8	.802	.806	.809

END MON-UZSN

MON-LZETPARM

```

*** <PLS > Lower zone evapotransp      parm at start of each month
*** x - x JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
11      0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8
12 13    0.4 0.4 0.4 0.4 0.4 0.4 0.4 0.4 0.4 0.4 0.4 0.4
14      0.8 0.79 0.76 0.73 0.7 0.68 0.67 0.68 0.7 0.74 0.77 0.79
15 16    0.7 0.69 0.66 0.63 0.6 0.58 0.57 0.58 0.6 0.64 0.67 0.69
21      0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8
22 23    0.3 0.3 0.3 0.3 0.3 0.3 0.3 0.3 0.3 0.3 0.3 0.3
24      0.7 0.69 0.66 0.63 0.6 0.58 0.57 0.58 0.6 0.64 0.67 0.69
25 26    0.6 0.59 0.56 0.53 0.5 0.48 0.47 0.48 0.5 0.54 0.57 0.59
31      0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8
32 33    0.4 0.4 0.4 0.4 0.4 0.4 0.4 0.4 0.4 0.4 0.4 0.4
34      0.7 0.69 0.66 0.63 0.6 0.58 0.57 0.58 0.6 0.64 0.67 0.69
35 36    0.6 0.59 0.56 0.53 0.5 0.48 0.47 0.48 0.5 0.54 0.57 0.59
41      0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8
42 43    0.4 0.4 0.4 0.4 0.4 0.4 0.4 0.4 0.4 0.4 0.4 0.4
44      0.7 0.69 0.66 0.63 0.6 0.58 0.57 0.58 0.6 0.64 0.67 0.69
45 46    0.6 0.59 0.56 0.53 0.5 0.48 0.47 0.48 0.5 0.54 0.57 0.59
51      0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8
52 53    0.4 0.4 0.4 0.4 0.4 0.4 0.4 0.4 0.4 0.4 0.4 0.4
54      0.8 0.79 0.76 0.73 0.7 0.68 0.67 0.68 0.7 0.74 0.77 0.79
55 56    0.7 0.69 0.66 0.63 0.6 0.58 0.57 0.58 0.6 0.64 0.67 0.69
61      0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8
62 63    0.3 0.3 0.3 0.3 0.3 0.3 0.3 0.3 0.3 0.3 0.3 0.3
64 66    0.52 0.5 0.5 0.5 0.5 0.5 0.5 0.49 0.5 0.53 0.56 0.56 0.56
71      0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8
72 73    0.4 0.4 0.4 0.4 0.4 0.4 0.4 0.4 0.4 0.4 0.4 0.4
74      0.7 0.69 0.66 0.63 0.6 0.58 0.57 0.58 0.6 0.64 0.67 0.69
75 76    0.6 0.59 0.56 0.53 0.5 0.48 0.47 0.48 0.5 0.54 0.57 0.59
81      0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8
82 83    0.3 0.3 0.3 0.3 0.3 0.3 0.3 0.3 0.3 0.3 0.3 0.3
84      0.7 0.69 0.66 0.63 0.6 0.58 0.57 0.58 0.6 0.64 0.67 0.69
85 86    0.6 0.59 0.56 0.53 0.5 0.48 0.47 0.48 0.5 0.54 0.57 0.59
91      0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8
92 93    0.3 0.3 0.3 0.3 0.3 0.3 0.3 0.3 0.3 0.3 0.3 0.3
94      0.7 0.69 0.66 0.63 0.6 0.58 0.57 0.58 0.6 0.64 0.67 0.69
95 96    0.6 0.59 0.56 0.53 0.5 0.48 0.47 0.48 0.5 0.54 0.57 0.59
101     0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8
102 103   0.4 0.4 0.4 0.4 0.4 0.4 0.4 0.4 0.4 0.4 0.4 0.4
104     0.7 0.69 0.66 0.63 0.6 0.58 0.57 0.58 0.6 0.64 0.67 0.69
105 106   0.6 0.59 0.56 0.53 0.5 0.48 0.47 0.48 0.5 0.54 0.57 0.59
111     0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8
112 113   0.4 0.4 0.4 0.4 0.4 0.4 0.4 0.4 0.4 0.4 0.4 0.4
114     0.7 0.69 0.66 0.63 0.6 0.58 0.57 0.58 0.6 0.64 0.67 0.69
115 116   0.6 0.59 0.56 0.53 0.5 0.48 0.47 0.48 0.5 0.54 0.57 0.59
121     0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8
122 123   0.4 0.4 0.4 0.4 0.4 0.4 0.4 0.4 0.4 0.4 0.4 0.4
124 126   .7 .699 .696 .693 .689 .687 .686 .687 .69 .694 .697 .7
131     0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8
132 133   0.3 0.3 0.3 0.3 0.3 0.3 0.3 0.3 0.3 0.3 0.3 0.3
134 136   0.52 0.5 0.5 0.5 0.5 0.5 0.5 0.49 0.5 0.53 0.56 0.56 0.56
141     0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8
142 143   0.3 0.3 0.3 0.3 0.3 0.3 0.3 0.3 0.3 0.3 0.3 0.3
144 146   0.52 0.5 0.5 0.5 0.5 0.5 0.5 0.49 0.5 0.53 0.56 0.56 0.56
151     0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8
152 153   0.4 0.4 0.4 0.4 0.4 0.4 0.4 0.4 0.4 0.4 0.4 0.4
154 156   .7 .699 .696 .693 .689 .687 .686 .687 .69 .694 .697 .7

```


161		0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
162	163	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
164	166	.7	.699	.696	.693	.689	.687	.686	.687	.69	.694	.697
171		0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
172	173	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
174	176	.7	.699	.696	.693	.689	.687	.686	.687	.69	.694	.697
181		0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
182	183	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
184	186	.7	.699	.696	.693	.689	.687	.686	.687	.69	.694	.697
191		0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
192	193	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
194	196	.7	.699	.696	.693	.689	.687	.686	.687	.69	.694	.697
201		0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
202	203	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
204	206	.7	.699	.696	.693	.689	.687	.686	.687	.69	.694	.697
211		0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
212	213	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
214		0.7	0.69	0.66	0.63	0.6	0.58	0.57	0.58	0.6	0.64	0.67
215	216	0.6	0.59	0.56	0.53	0.5	0.48	0.47	0.48	0.5	0.54	0.57

END MON-LZETPARM

END PERLND

IMPLND

ACTIVITY

*** <ILS > Active Sections

*** x - x	ATMP	SNOW	IWAT	SLD	IWG	IQAL
12 212	1	0	1	0	0	0

END ACTIVITY

PRINT-INFO

*** <ILS > ***** Print-flags ***** PIVL PYR

*** x - x	ATMP	SNOW	IWAT	SLD	IWG	IQAL	*****	PIVL	PYR
12 212	4	4	4	4	4	4	1	12	

END PRINT-INFO

BINARY-INFO

*** <ILS > ***** Binary-Output-flags ***** PIVL PYR

*** x - x	ATMP	SNOW	IWAT	SLD	IWG	IQAL	*****	PIVL	PYR
12 212	4	4	4	4	4	4	1	12	

END BINARY-INFO

GEN-INFO

***	Name	Unit-systems	Printer	BinaryOut
*** <ILS >		t-series	Engl Metr	Engl Metr
*** x - x		in out		
12 212Urban		1 1	0 0	92 0

END GEN-INFO

ATEMP-DAT

*** <PLS >	ELDAT	AIRTEMP
*** x - x	(ft)	(deg F)
12	-26.	60.
22	-5.	36.5
32	-11.	36.5
42	236.	59.
52	-123.	59.

62	-30.	60.
72	104.	59.
82	-10.	60.
92	-20.	60.
102	15.	60.
112	-10.	60.
122	59.	46.1
132	20.	60.
142	-47.	60.
152	-5.	46.1
162	-111.	46.1
172	-55.	46.1
182	-126.	46.1
192	-47.	46.1
202	35.	60.
212	-51.	60.

END ATEMP-DAT

IWAT-PARM1

```
*** <ILS >      Flags
*** x - x CSNO RTOP VRS VNN RTLI
    12  212    0    1    0    0    0
END IWAT-PARM1
```

IWAT-PARM2

```
*** <ILS >      LSUR      SLSUR      NSUR      RETSC
*** x - x      (ft)
    12      298.1    0.06245    0.014    0.1
    22      457.8    0.04401    0.014    0.2
    32      311.8    0.05915    0.014    0.1
    42      433.4    0.05991    0.014    0.1
    52      379.9    0.05230    0.014    0.1
    62      395.9    0.04695    0.014    0.2
    72      353.4    0.05453    0.014    0.1
    82       398     0.04071    0.014    0.2
    92      476.9    0.04344    0.014    0.2
   102      345.4    0.05573    0.014    0.1
   112      226.7    0.05838    0.014    0.1
   122      350.6    0.05831    0.014    0.1
   132      320.8    0.05172    0.014    0.1
   142      309.9    0.04038    0.014    0.1
   152      311.7    0.05694    0.014    0.1
   162      255.6    0.05691    0.014    0.1
   172      377.3    0.04931    0.014    0.1
   182      342.6    0.04992    0.014    0.1
   192      354.6    0.05151    0.014    0.1
   202      314.1    0.05148    0.014    0.1
   212      268.3    0.05360    0.014    0.1
END IWAT-PARM2
```

IWAT-PARM3

```
*** <ILS >      PETMAX      PETMIN
*** x - x      (deg F)      (deg F)
    12  212      40.      35.
END IWAT-PARM3
```

IWAT-STATE1

*** <ILS > IWATER state variables (inches)

*** x - x RETS SURS
 12 212 0.01 0.01
 END IWAT-STATE1

END IMPLND

RCHRES

ACTIVITY

*** RCHRES Active sections

*** x - x HYFG ADFG CNFG HTFG SDFG GQFG OXFG NUFG PKFG PHFG
 1 21 1 0 0 0 0 0 0 0 0
 END ACTIVITY

PRINT-INFO

*** RCHRES Printout level flags

*** x - x HYDR ADCA CONS HEAT SED GQL OXRX NUTR PLNK PHCB PIVL PYR
 1 21 4 4 4 4 4 4 4 4 1 12
 END PRINT-INFO

BINARY-INFO

*** RCHRES Binary Output level flags

*** x - x HYDR ADCA CONS HEAT SED GQL OXRX NUTR PLNK PHCB PIVL PYR
 1 21 4 4 4 4 4 4 4 4 1 12
 END BINARY-INFO

GEN-INFO

***		Name	Nexits	Unit Systems		Printer				
*** RCHRES				t-series		Engl	Metr	LKFG		
*** x - x				in	out					
1	1		3	1	1	91	0	1	92	0
2	2		1	1	1	91	0	0	92	0
3	3		1	1	1	91	0	0	92	0
4	4		1	1	1	91	0	0	92	0
5	5		2	1	1	91	0	1	92	0
6	6		1	1	1	91	0	0	92	0
7	7		1	1	1	91	0	0	92	0
8	8		1	1	1	91	0	0	92	0
9	9		1	1	1	91	0	0	92	0
10	10		1	1	1	91	0	0	92	0
11	11		1	1	1	91	0	0	92	0
12	12		1	1	1	91	0	0	92	0
13	13		1	1	1	91	0	0	92	0
14	14		1	1	1	91	0	0	92	0
15	15		1	1	1	91	0	0	92	0
16	16		1	1	1	91	0	0	92	0
17	17		1	1	1	91	0	0	92	0
18	18		1	1	1	91	0	0	92	0
19	19		1	1	1	91	0	0	92	0
20	20		1	1	1	91	0	0	92	0
21	21		1	1	1	91	0	0	92	0

END GEN-INFO

HYDR-PARM1

*** Flags for HYDR section

***RC HRES	VC A1 A2 A3	ODFVFG for each	*** ODGTFG for each	FUNCT for each
*** x - x	FG FG FG FG	possible exit	*** possible exit	possible exit

1		0	1	1	1	4	0	0	0	0		0	1	2	0	0		3	3	3	3	3
2	4	0	1	1	1	4	0	0	0	0		0	0	0	0	0		3	3	3	3	3
5		0	1	1	1	4	0	0	0	0		0	1	0	0	0		3	3	3	3	3
6	21	0	1	1	1	4	0	0	0	0		0	0	0	0	0		3	3	3	3	3

END HYDR-PARM1

HYDR-PARM2

***	RCHRES	FTBW	FTBU	LEN	DELTH	STCOR	KS	DB50
***	x	-	x	(miles)	(ft)	(ft)		(in)
1		0	1	7.44	30	0	0.5	0.01
2		0	2	9.33	31	0	0.3	0.01
3		0	3	6.37	30	0	0.3	0.01
4		0	4	9.91	77	0	0.5	0.01
5		0	5	3.51	15	0	0.5	0.01
6		0	6	12.83	30	0	0.5	0.01
7		0	7	4.14	30	0	0.3	0.01
8		0	8	8.02	31	0	0.3	0.01
9		0	9	4.86	25	0	0.3	0.01
10		0	10	2.21	29	0	0.3	0.01
11		0	11	6.68	28	0	0.5	0.01
12		0	12	10.38	62	0	0.5	0.01
13		0	13	6.09	16	0	0.5	0.01
14		0	14	2.32	12	0	0.5	0.01
15		0	15	1.94	14	0	0.5	0.01
16		0	16	4.01	6	0	0.5	0.01
17		0	17	7.5	17	0	0.5	0.01
18		0	18	6.02	17	0	0.5	0.01
19		0	19	5.71	15	0	0.5	0.01
20		0	20	10.22	15	0	0.5	0.01
21		0	21	10.61	30	0	0.5	0.01

END HYDR-PARM2

HYDR-INIT

*** Initial conditions for HYDR section

***RC	HRES	VOL	CAT	Initial value	of COLIND	initial value	of OUTDGT	
***	x	-	x	ac-ft	for each possible	exit	for each possible exit,ft3	
1		26150		4.0	4.5	4.5	4.2	2.1 57.2 0 1.2 1.8
2		216		4.0	4.5	4.5	4.2	2.1 1.2 0.5 1.2 1.8
3		109		4.0	4.5	4.5	4.2	2.1 1.2 0.5 1.2 1.8
4		212		4.0	4.5	4.5	4.2	2.1 1.2 0.5 1.2 1.8
5		15651		4.0	4.5	4.5	4.2	2.1 12.4 0.5 1.2 1.8
6		201		4.0	4.5	4.5	4.2	2.1 1.2 0.5 1.2 1.8
7		48		4.0	4.5	4.5	4.2	2.1 1.2 0.5 1.2 1.8
8		93		4.0	4.5	4.5	4.2	2.1 1.2 0.5 1.2 1.8
9		41		4.0	4.5	4.5	4.2	2.1 1.2 0.5 1.2 1.8
10		18		4.0	4.5	4.5	4.2	2.1 1.2 0.5 1.2 1.8
11		43		4.0	4.5	4.5	4.2	2.1 1.2 0.5 1.2 1.8
12		171		4.0	4.5	4.5	4.2	2.1 1.2 0.5 1.2 1.8
13		68		4.0	4.5	4.5	4.2	2.1 1.2 0.5 1.2 1.8
14		2		4.0	4.5	4.5	4.2	2.1 1.2 0.5 1.2 1.8
15		14		4.0	4.5	4.5	4.2	2.1 1.2 0.5 1.2 1.8
16		12		4.0	4.5	4.5	4.2	2.1 1.2 0.5 1.2 1.8
17		105		4.0	4.5	4.5	4.2	2.1 1.2 0.5 1.2 1.8
18		39		4.0	4.5	4.5	4.2	2.1 1.2 0.5 1.2 1.8
19		98		4.0	4.5	4.5	4.2	2.1 1.2 0.5 1.2 1.8
20		212		4.0	4.5	4.5	4.2	2.1 1.2 0.5 1.2 1.8
21		128		4.0	4.5	4.5	4.2	2.1 1.2 0.5 1.2 1.8

END HYDR-INIT

END RCHRES

FTABLES

```
FTABLE      4
rows cols
19      4
depth      area      volume      outflow1 ***
0.0         0.         0.0         0.0
0.02        58.8        1.18        0.11
0.06        58.94       3.53        0.68
0.1         59.08       5.89        1.59
0.2         59.44      11.82        5.05
0.6         60.86      35.88       31.58
1.          62.29      60.51       74.08
1.2         63.        73.04      100.47
1.6         64.42      98.52     162.56
2.          65.84     124.57     236.26
3.          69.4      192.19     467.11
4.          72.95     263.37     759.75
5.          76.51     338.1      1110.71
5.23        77.33     355.75     1199.27
7.84       211.52     733.39     2902.88
10.46      220.82    1298.62     6340.29
13.07      230.12    1888.18    10802.17
15.69      239.42    2502.04    16210.07
52.3       369.61   13649.2    182068.6
END FTABLE  4
```

```
FTABLE      7
rows cols
18      4
depth      area      volume      outflow1 ***
0.0         0.         0.0         0.0
0.02        19.11       0.38        0.07
0.06        19.17       1.15        0.45
0.1         19.23       1.92        1.05
0.2         19.39       3.85        3.35
0.6         20.01      11.73       20.93
1.          20.63      19.85       49.15
1.2         20.94      24.01       66.68
1.6         21.56      32.51      107.99
2.          22.18      41.26      157.12
3.          23.73      64.21      311.66
4.          25.28      88.71      508.84
4.55        26.13     102.91      635.4
6.83        70.64     213.05     1555.42
9.11        74.17     377.86     3397.44
11.38       77.69     550.69     5792.59
13.66       81.22     731.55     8701.67
45.53      130.58    4106.32    99796.04
END FTABLE  7
```

```
FTABLE     15
rows cols
***
```

```

18      4
depth    area    volume    outflow1 ***
0.0      0.      0.0      0.0
0.02     7.15    0.14    0.05
0.06     7.18    0.43    0.33
0.1      7.21    0.72    0.77
0.2      7.28    1.44    2.45
0.6      7.57    4.41    15.34
1.       7.86    7.5     36.03
1.2      8.      9.08    48.91
1.6      8.29    12.34   79.3
2.       8.58    15.72   115.52
3.       9.31    24.66   229.97
4.      10.03    34.33   376.99
4.1      10.1    35.34   393.44
6.15     27.04    73.41   972.
8.2      28.53   130.38  2123.34
10.25    30.01   190.38  3622.73
12.3     31.49   253.42  5447.23
41.      52.26  1455.35 63581.97

```

END FTABLE 15

```

FTABLE      12
rows cols
18      4
depth    area    volume    outflow1 ***
0.0      0.      0.0      0.0
0.02     54.47    1.09    0.09
0.06     54.62    3.27    0.57
0.1      54.77    5.46    1.34
0.2      55.14   10.95    4.24
0.6      56.63   33.31   26.51
1.       58.13   56.26   62.22
1.2      58.87   67.96   84.39
1.6      60.36   91.81  136.6
2.       61.86  116.25  198.62
3.       65.59  179.98  393.16
4.       69.32  247.43  640.37
4.93     72.79  313.51  915.24
7.4      198.13  647.42  2225.73
9.86     207.33 1147.16  4861.38
12.33    216.53 1669.56  8284.91
14.79    225.72 2214.63 12437.82
49.3     354.48 12226.   140897.1

```

END FTABLE 12

```

FTABLE      13
rows cols
18      4
depth    area    volume    outflow1 ***
0.0      0.      0.0      0.0
0.02     25.66    0.51    0.07
0.06     25.74    1.54    0.44
0.1      25.83    2.57    1.03
0.2      26.04    5.17    3.26
0.6      26.89   15.75   20.38
1.       27.73   26.67   47.84

```

1.2	28.16	32.26	64.91
1.6	29.01	43.7	105.13
2.	29.85	55.47	152.98
3.	31.97	86.38	303.53
4.	34.09	119.41	495.7
4.51	35.18	137.11	609.42
6.77	95.01	283.93	1492.96
9.02	99.79	503.62	3261.05
11.28	104.57	734.09	5560.35
13.53	109.36	975.35	8353.43
45.11	176.3	5485.41	95941.61

END FTABLE 13

FTABLE 10				***
rows	cols			
18	4			
depth	area	volume	outflow1	***
0.0	0.	0.0	0.0	
0.02	8.67	0.17	0.06	
0.06	8.71	0.52	0.35	
0.1	8.74	0.87	0.83	
0.2	8.82	1.75	2.64	
0.6	9.16	5.34	16.51	
1.	9.49	9.07	38.79	
1.2	9.66	10.99	52.64	
1.6	9.99	14.92	85.33	
2.	10.32	18.98	124.26	
3.	11.16	29.72	247.13	
4.	11.99	41.29	404.68	
4.2	12.16	43.74	440.79	
6.3	32.62	90.79	1086.56	
8.41	34.37	161.18	2373.51	
10.51	36.12	235.25	4048.86	
12.61	37.87	313.	6086.52	
42.03	62.37	1787.61	70737.18	

END FTABLE 10

FTABLE 2				***
rows	cols			
18	4			
depth	area	volume	outflow1	***
0.0	0.	0.0	0.0	
0.02	34.39	0.69	0.09	
0.06	34.49	2.06	0.58	
0.1	34.58	3.45	1.35	
0.2	34.81	6.92	4.28	
0.6	35.75	21.03	26.74	
1.	36.69	35.52	62.74	
1.2	37.16	42.9	85.1	
1.6	38.09	57.95	137.74	
2.	39.03	73.38	200.26	
3.	41.37	113.58	396.39	
4.	43.71	156.12	645.6	
4.94	45.92	198.4	926.98	
7.42	125.03	409.68	2253.75	
9.89	130.82	725.89	4922.58	
12.36	136.61	1056.4	8389.08	

14.83	142.4	1401.22	12593.94
49.44	223.44	7730.98	142604.9

END FTABLE 2

FTABLE 19

rows	cols			***
18	4			
depth	area	volume	outflow1	***
0.0	0.	0.0	0.0	
0.02	30.4	0.61	0.09	
0.06	30.48	1.83	0.56	
0.1	30.57	3.05	1.32	
0.2	30.78	6.11	4.19	
0.6	31.62	18.59	26.17	
1.	32.46	31.41	61.41	
1.2	32.88	37.94	83.29	
1.6	33.72	51.26	134.83	
2.	34.56	64.92	196.04	
3.	36.66	100.53	388.1	
4.	38.76	138.24	632.21	
4.91	40.67	174.31	896.78	
7.36	110.67	360.01	2181.6	
9.82	115.83	637.93	4764.99	
12.27	120.99	928.5	8120.83	
14.72	126.15	1231.74	12191.9	
49.08	198.36	6806.02	138202.3	

END FTABLE 19

FTABLE 17

rows	cols			***
18	4			
depth	area	volume	outflow1	***
0.0	0.	0.0	0.0	
0.02	37.23	0.74	0.08	
0.06	37.34	2.24	0.51	
0.1	37.45	3.73	1.2	
0.2	37.73	7.49	3.8	
0.6	38.83	22.8	23.73	
1.	39.94	38.56	55.7	
1.2	40.49	46.6	75.56	
1.6	41.59	63.02	122.33	
2.	42.7	79.88	177.92	
3.	45.46	123.96	352.51	
4.	48.22	170.79	574.76	
4.75	50.29	207.68	771.11	
7.12	136.44	429.37	1880.95	
9.5	142.99	761.13	4108.39	
11.87	149.55	1108.45	7003.06	
14.25	156.1	1471.33	10516.43	
47.49	247.85	8185.62	119808.9	

END FTABLE 17

FTABLE 5

rows	cols			***
19	4			
depth	area	volume	outflow1	***
0.0	0.	0.0	0.0	

0.1	25.77	2.57	0.0
1.	26.93	26.28	0.0
1.6	27.7	42.67	0.0
2.	28.21	53.85	0.0
3.	29.5	82.71	0.0
4.	30.79	112.85	0.0
5.	32.07	144.28	0.0
5.72	33.	167.58	0.0
8.57	90.9	344.62	0.0
11.43	94.57	609.66	0.0
14.29	98.25	885.21	0.0
17.15	101.93	1171.27	0.0
57.16	153.44	6280.23	0.17
290.	401.69	15651.	0.17
290.3	402.08	15663.07	234.4
294.9	408.0	15848.2	9511.1
295.2	408.39	15860.28	19992.9
299.8	414.31	16045.41	80704.5

END FTABLE 5

FTABLE 3

rows cols ***

19 4

depth	area	volume	outflow1	***
0.0	0.	0.0	0.0	
0.02	59.07	1.18	0.11	
0.06	59.21	3.55	0.72	
0.1	59.35	5.92	1.68	
0.2	59.69	11.87	5.34	
0.6	61.06	36.02	33.35	
1.	62.44	60.72	78.24	
1.2	63.13	73.28	106.11	
1.6	64.5	98.8	171.67	
2.	65.87	124.88	249.47	
3.	69.31	192.47	493.06	
4.	72.75	263.5	801.63	
5.	76.18	337.97	1171.43	
5.33	77.31	363.06	1305.25	
7.99	211.79	748.06	3154.93	
10.65	220.94	1324.35	6890.79	
13.32	230.09	1925.01	11739.08	
15.98	239.25	2550.05	17613.86	
53.27	367.38	13860.34	197327.3	

END FTABLE 3

FTABLE 6

rows cols ***

20 4

depth	area	volume	outflow1	***
0.0	0.	0.0	0.0	
0.02	111.31	2.23	0.19	
0.06	111.49	6.68	1.16	
0.1	111.68	11.14	2.71	
0.2	112.14	22.34	8.61	
0.6	113.98	67.56	53.77	
1.	115.83	113.52	126.08	
1.2	116.75	136.78	170.93	

1.6	118.59	183.85	276.37
2.	120.44	231.65	401.33
3.	125.05	354.39	791.45
4.	129.66	481.75	1283.39
5.	134.27	613.71	1869.89
6.	138.88	750.29	2546.41
6.26	140.09	786.76	2737.78
9.39	388.5	1614.2	6540.82
12.52	402.94	2853.1	14286.52
15.65	417.37	4137.19	24322.98
18.78	431.81	5466.47	36460.81
62.62	633.91	28821.87	400178.5

END FTABLE 6

FTABLE 16

rows cols ***

19 4

depth	area	volume	outflow1	***
0.0	0.	0.0	0.0	
0.02	26.75	0.53	0.13	
0.06	26.81	1.61	0.79	
0.1	26.87	2.68	1.85	
0.2	27.01	5.37	5.87	
0.6	27.6	16.3	36.68	
1.	28.18	27.45	86.03	
1.2	28.47	33.11	116.65	
1.6	29.05	44.62	188.7	
2.	29.63	56.35	274.17	
3.	31.09	86.71	541.59	
4.	32.54	118.53	879.99	
5.	34.	151.79	1285.01	
5.5	34.72	168.99	1511.93	
8.25	95.37	347.88	3645.63	
11.	99.37	615.67	7962.56	
13.75	103.37	894.46	13563.03	
16.5	107.37	1184.25	20346.36	
55.01	163.37	6396.54	226947.5	

END FTABLE 16

FTABLE 18

rows cols ***

20 4

depth	area	volume	outflow1	***
0.0	0.	0.0	0.0	
0.02	53.82	1.08	0.19	
0.06	53.91	3.23	1.16	
0.1	54.	5.39	2.71	
0.2	54.23	10.8	8.61	
0.6	55.12	32.67	53.79	
1.	56.01	54.89	126.13	
1.2	56.45	66.14	170.99	
1.6	57.35	88.9	276.47	
2.	58.24	112.02	401.47	
3.	60.47	171.37	791.73	
4.	62.7	232.95	1283.84	
5.	64.93	296.76	1870.53	
6.	67.15	362.8	2547.28	

6.26	67.74	380.47	2739.09
9.39	187.86	780.61	6543.86
12.52	194.84	1379.73	14293.16
15.66	201.82	2000.7	24334.28
18.79	208.8	2643.52	36477.73
62.62	306.51	13937.48	400356.6

END FTABLE 18

FTABLE 20

rows	cols				***
21	4				
	depth	area	volume	outflow1	***
	0.0	0.	0.0	0.0	
	0.02	118.37	2.37	0.27	
	0.06	118.52	7.1	1.71	
	0.1	118.66	11.85	4.	
	0.2	119.04	23.73	12.69	
	0.6	120.53	71.65	79.23	
	1.	122.02	120.15	185.74	
	1.2	122.76	144.63	251.78	
	1.6	124.25	194.03	406.95	
	2.	125.74	244.03	590.73	
	3.	129.46	371.63	1163.66	
	4.	133.19	502.96	1884.44	
	5.	136.91	638.01	2741.43	
	6.	140.63	776.78	3727.03	
	7.	144.36	919.28	4835.97	
	7.14	144.88	939.74	5002.61	
	10.71	405.4	1922.21	11850.44	
	14.28	418.7	3393.54	25885.81	
	17.85	432.	4912.35	44053.79	
	21.42	445.29	6478.64	65997.7	
	71.42	631.44	33391.78	714156.1	

END FTABLE 20

FTABLE 14

rows	cols				***
20	4				
	depth	area	volume	outflow1	***
	0.0	0.	0.0	0.0	
	0.02	23.92	0.48	0.22	
	0.06	23.96	1.44	1.35	
	0.1	23.99	2.4	3.17	
	0.2	24.08	4.8	10.06	
	0.6	24.44	14.5	62.83	
	1.	24.79	24.35	147.31	
	1.2	24.97	29.33	199.7	
	1.6	25.33	39.39	322.84	
	2.	25.68	49.59	468.73	
	3.	26.57	75.71	923.9	
	4.	27.46	102.72	1497.26	
	5.	28.34	130.62	2179.99	
	6.	29.23	159.41	2966.47	
	6.6	29.76	177.14	3487.43	
	9.9	82.85	362.97	8302.54	
	13.2	85.78	641.24	18134.95	
	16.5	88.7	929.17	30869.8	

```

19.8      91.63    1226.77  46262.65
66.01     132.63    6408.01  504744.4
END FTABLE 14

```

```

FTABLE      8
rows cols
20      4
depth      area      volume  outflow1 ***
0.0        0.        0.0      0.0
0.02       64.8      1.3      0.17
0.06       64.91     3.89     1.04
0.1        65.03     6.49     2.43
0.2        65.32    13.01     7.7
0.6        66.48    39.37    48.1
1.         67.64    66.19   112.79
1.2        68.22    79.78   152.92
1.6        69.39   107.3   247.28
2.         70.55   135.29   359.13
3.         73.45   207.29   708.52
4.         76.36   282.19  1149.49
5.         79.26   360.01  1675.74
6.         82.17   440.72  2283.44
6.03       82.26   443.15  2302.57
9.04       227.5    910.07  5515.41
12.06      236.26  1609.12 12046.63
15.07      245.02  2334.58 20512.24
18.09      253.78  3086.45 30754.56
60.3       376.4   16385.3 339065.4
END FTABLE 8

```

```

FTABLE      9
rows cols
20      4
depth      area      volume  outflow1 ***
0.0        0.        0.0      0.0
0.02       51.97     1.04     0.25
0.06       52.04     3.12     1.53
0.1        52.11     5.2      3.59
0.2        52.28    10.42    11.4
0.6        52.99    31.48    71.2
1.         53.69    52.81   166.92
1.2        54.05    63.59   226.26
1.6        54.75    85.35   365.74
2.         55.46   107.39   530.96
3.         57.22   163.73   1046.2
4.         58.99   221.83  1694.75
5.         60.75   281.7   2466.35
6.         62.51   343.33  3354.39
6.89       64.08   399.48  4235.83
10.33      178.87   817.77  10056.8
13.77      184.94  1444.18 21967.28
17.22      191.02  2091.49 37388.68
20.66      197.09  2759.72 56021.27
68.87      282.11 14310.71 608451.8
END FTABLE 9

```

```

FTABLE      21

```

```

rows cols          ***
 22      4
  depth      area   volume  outflow1 ***
  0.0        0.     0.0     0.0
  0.02      170.85   3.42    0.41
  0.06      171.01  10.25    2.58
  0.1       171.17   17.1    6.04
  0.2       171.57   34.23   19.18
  0.6       173.18  103.18  119.7
  1.        174.78  172.78  280.56
  1.2       175.58  207.81  380.27
  1.6       177.19  278.37  614.5
  2.        178.79  349.56  891.77
  3.        182.8   530.36 1755.35
  4.        186.81  715.17 2840.02
  5.        190.83  903.99 4127.24
  6.        194.84 1096.82 5604.51
  7.        198.85 1293.66 7262.85
  8.        202.86 1494.51 9095.52
  8.22      203.73 1538.73 9516.68
 12.33      574.93  3138.4 22360.24
 16.44      591.41 5534.52 48848.64
 20.54      607.89 7998.35 83106.85
 24.65      624.37 10529.89 124439.3
 82.18      855.09 53081.18 1329304.
END FTABLE 21

```

```

FTABLE      11
rows cols          ***
 21      4
  depth      area   volume  outflow1 ***
  0.0        0.     0.0     0.0
  0.02      80.76   1.61    0.28
  0.06      80.86   4.85    1.74
  0.1       80.96   8.08    4.07
  0.2       81.21  16.19   12.92
  0.6       82.21  48.88   80.64
  1.        83.22  81.96  189.03
  1.2       83.72  98.66  256.23
  1.6       84.72 132.35  414.14
  2.        85.73 166.44  601.16
  3.        88.24 253.42 1184.16
  4.        90.74 342.91 1917.55
  5.        93.25 434.91 2789.44
  6.        95.76 529.41 3792.08
  7.        98.27 626.43 4920.05
  7.18      98.74 644.61 5141.53
 10.78     276.38 1318.35 12175.09
 14.37     285.39 2327.35 26595.06
 17.96     294.4  3368.73 45260.14
 21.55     303.42 4442.49 67803.29
 71.85     429.6 22874.77 733261.8
END FTABLE 11

```

```

FTABLE      1
rows cols          ***
 18      4

```

depth	area	volume	outflow1	***
0.0	0.	0.0	0.0	
60.	.44	0.197	0.0	
64.	6.81	11.99	0.0	
70.	31.06	126.0	0.0	
74.	63.21	313.9	0.0	
80.	109.4	821.8	0.0	
84.	149.5	1342.2	0.0	
90.	223.7	2445.1	0.0	
94.	288.3	3466.0	0.0	
100.	427.1	5589.7	0.0	
104.	555.1	7542.4	0.0	
110.	795.5	11550.3	0.0	
114.	1002.4	15133.0	0.0	
120.	1424.2	22428.0	0.0	
122.	1538.2	25400.7	0.0	
123.	1594.8	27007.4	2500.3	
127.	1806.9	33958.5	19998.7	
131.	1939.	41767.1	53749.	

END FTABLE 1
END FTABLES

EXT SOURCES

<-Volume->	<Member>	SsysSgap<--Mult-->	Tran	<-Target vols>	<-Grp>	<-Member->	***
<Name>	x	<Name>	x	tem strg<-factor->	strg	<Name>	x x ***
*** Met Seg PLNS							
WDM2	641	PREC	ENGL	SAME	PERLND	41 46 EXTNL	PREC
WDM2	643	ATEM	ENGL	SAME	PERLND	41 46 EXTNL	GATMP
WDM2	646	PEVT	ENGL	SAME	PERLND	41 46 EXTNL	PETINP
*** Met Seg WARR							
WDM2	631	PREC	ENGL	SAME	PERLND	121 126 EXTNL	PREC
WDM2	633	ATEM	ENGL	SAME	PERLND	121 126 EXTNL	GATMP
WDM2	636	PEVT	ENGL	SAME	PERLND	121 126 EXTNL	PETINP
*** Met Seg WARR							
WDM2	631	PREC	ENGL	SAME	PERLND	151 176 EXTNL	PREC
WDM2	633	ATEM	ENGL	SAME	PERLND	151 176 EXTNL	GATMP
WDM2	636	PEVT	ENGL	SAME	PERLND	151 176 EXTNL	PETINP
*** Met Seg WARR							
WDM2	631	PREC	ENGL	SAME	PERLND	191 196 EXTNL	PREC
WDM2	633	ATEM	ENGL	SAME	PERLND	191 196 EXTNL	GATMP
WDM2	636	PEVT	ENGL	SAME	PERLND	191 196 EXTNL	PETINP
*** Met Seg OWML							
WDM2	71	PREC	ENGL	SAME	PERLND	11 16 EXTNL	PREC
WDM2	53	ATEM	ENGL	SAME	PERLND	11 16 EXTNL	GATMP
WDM2	56	PEVT	ENGL	SAME	PERLND	11 16 EXTNL	PETINP
*** Met Seg OWML							
WDM2	71	PREC	ENGL	SAME	PERLND	51 76 EXTNL	PREC
WDM2	53	ATEM	ENGL	SAME	PERLND	51 76 EXTNL	GATMP
WDM2	56	PEVT	ENGL	SAME	PERLND	51 76 EXTNL	PETINP
*** Met Seg OWML							
WDM2	71	PREC	ENGL	SAME	PERLND	81 116 EXTNL	PREC
WDM2	53	ATEM	ENGL	SAME	PERLND	81 116 EXTNL	GATMP
WDM2	56	PEVT	ENGL	SAME	PERLND	81 116 EXTNL	PETINP
*** Met Seg OWML							
WDM2	71	PREC	ENGL	SAME	PERLND	131 146 EXTNL	PREC
WDM2	53	ATEM	ENGL	SAME	PERLND	131 146 EXTNL	GATMP
WDM2	56	PEVT	ENGL	SAME	PERLND	131 146 EXTNL	PETINP

*** Met Seg OWML								
WDM2	71	PREC	ENGL	SAME	PERLND	181	186	EXTNL PREC
WDM2	53	ATEM	ENGL	SAME	PERLND	181	186	EXTNL GATMP
WDM2	56	PEVT	ENGL	SAME	PERLND	181	186	EXTNL PETINP
*** Met Seg OWML								
WDM2	71	PREC	ENGL	SAME	PERLND	201	216	EXTNL PREC
WDM2	53	ATEM	ENGL	SAME	PERLND	201	216	EXTNL GATMP
WDM2	56	PEVT	ENGL	SAME	PERLND	201	216	EXTNL PETINP
*** Met Seg DULL								
WDM2	651	PREC	ENGL	SAME	PERLND	21	36	EXTNL PREC
WDM2	653	ATEM	ENGL	SAME	PERLND	21	36	EXTNL GATMP
WDM2	656	PEVT	ENGL	SAME	PERLND	21	36	EXTNL PETINP
*** Met Seg PLNS								
WDM2	641	PREC	ENGL	SAME	IMPLND	42		EXTNL PREC
WDM2	643	ATEM	ENGL	SAME	IMPLND	42		EXTNL GATMP
WDM2	646	PEVT	ENGL	SAME	IMPLND	42		EXTNL PETINP
*** Met Seg WARR								
WDM2	631	PREC	ENGL	SAME	IMPLND	122		EXTNL PREC
WDM2	633	ATEM	ENGL	SAME	IMPLND	122		EXTNL GATMP
WDM2	636	PEVT	ENGL	SAME	IMPLND	122		EXTNL PETINP
*** Met Seg WARR								
WDM2	631	PREC	ENGL	SAME	IMPLND	152	172	EXTNL PREC
WDM2	633	ATEM	ENGL	SAME	IMPLND	152	172	EXTNL GATMP
WDM2	636	PEVT	ENGL	SAME	IMPLND	152	172	EXTNL PETINP
*** Met Seg WARR								
WDM2	631	PREC	ENGL	SAME	IMPLND	192		EXTNL PREC
WDM2	633	ATEM	ENGL	SAME	IMPLND	192		EXTNL GATMP
WDM2	636	PEVT	ENGL	SAME	IMPLND	192		EXTNL PETINP
*** Met Seg OWML								
WDM2	71	PREC	ENGL	SAME	IMPLND	12		EXTNL PREC
WDM2	53	ATEM	ENGL	SAME	IMPLND	12		EXTNL GATMP
WDM2	56	PEVT	ENGL	SAME	IMPLND	12		EXTNL PETINP
*** Met Seg OWML								
WDM2	71	PREC	ENGL	SAME	IMPLND	52	72	EXTNL PREC
WDM2	53	ATEM	ENGL	SAME	IMPLND	52	72	EXTNL GATMP
WDM2	56	PEVT	ENGL	SAME	IMPLND	52	72	EXTNL PETINP
*** Met Seg OWML								
WDM2	71	PREC	ENGL	SAME	IMPLND	82	112	EXTNL PREC
WDM2	53	ATEM	ENGL	SAME	IMPLND	82	112	EXTNL GATMP
WDM2	56	PEVT	ENGL	SAME	IMPLND	82	112	EXTNL PETINP
*** Met Seg OWML								
WDM2	71	PREC	ENGL	SAME	IMPLND	132	142	EXTNL PREC
WDM2	53	ATEM	ENGL	SAME	IMPLND	132	142	EXTNL GATMP
WDM2	56	PEVT	ENGL	SAME	IMPLND	132	142	EXTNL PETINP
*** Met Seg OWML								
WDM2	71	PREC	ENGL	SAME	IMPLND	182		EXTNL PREC
WDM2	53	ATEM	ENGL	SAME	IMPLND	182		EXTNL GATMP
WDM2	56	PEVT	ENGL	SAME	IMPLND	182		EXTNL PETINP
*** Met Seg OWML								
WDM2	71	PREC	ENGL	SAME	IMPLND	202	212	EXTNL PREC
WDM2	53	ATEM	ENGL	SAME	IMPLND	202	212	EXTNL GATMP
WDM2	56	PEVT	ENGL	SAME	IMPLND	202	212	EXTNL PETINP
*** Met Seg DULL								
WDM2	651	PREC	ENGL	SAME	IMPLND	22	32	EXTNL PREC
WDM2	653	ATEM	ENGL	SAME	IMPLND	22	32	EXTNL GATMP
WDM2	656	PEVT	ENGL	SAME	IMPLND	22	32	EXTNL PETINP
*** Met Seg PLNS								

WDM2	641	PREC	ENGL	SAME	RCHRES	4	EXTNL	PREC		
WDM2	643	ATEM	ENGL	SAME	RCHRES	4	EXTNL	GATMP		
WDM2	646	PEVT	ENGL	SAME	RCHRES	4	EXTNL	POTEV		
*** Met Seg WARR										
WDM2	631	PREC	ENGL	SAME	RCHRES	12	EXTNL	PREC		
WDM2	633	ATEM	ENGL	SAME	RCHRES	12	EXTNL	GATMP		
WDM2	636	PEVT	ENGL	SAME	RCHRES	12	EXTNL	POTEV		
*** Met Seg WARR										
WDM2	631	PREC	ENGL	SAME	RCHRES	15	17	EXTNL	PREC	
WDM2	633	ATEM	ENGL	SAME	RCHRES	15	17	EXTNL	GATMP	
WDM2	636	PEVT	ENGL	SAME	RCHRES	15	17	EXTNL	POTEV	
*** Met Seg WARR										
WDM2	631	PREC	ENGL	SAME	RCHRES	19		EXTNL	PREC	
WDM2	633	ATEM	ENGL	SAME	RCHRES	19		EXTNL	GATMP	
WDM2	636	PEVT	ENGL	SAME	RCHRES	19		EXTNL	POTEV	
*** Met Seg OWML										
WDM2	71	PREC	ENGL	SAME	RCHRES	1		EXTNL	PREC	
WDM2	53	ATEM	ENGL	SAME	RCHRES	1		EXTNL	GATMP	
WDM2	56	PEVT	ENGL	SAME	RCHRES	1		EXTNL	POTEV	
*** Met Seg OWML										
WDM2	71	PREC	ENGL	SAME	RCHRES	5	7	EXTNL	PREC	
WDM2	53	ATEM	ENGL	SAME	RCHRES	5	7	EXTNL	GATMP	
WDM2	56	PEVT	ENGL	SAME	RCHRES	5	7	EXTNL	POTEV	
*** Met Seg OWML										
WDM2	71	PREC	ENGL	SAME	RCHRES	8	11	EXTNL	PREC	
WDM2	53	ATEM	ENGL	SAME	RCHRES	8	11	EXTNL	GATMP	
WDM2	56	PEVT	ENGL	SAME	RCHRES	8	11	EXTNL	POTEV	
*** Met Seg OWML										
WDM2	71	PREC	ENGL	SAME	RCHRES	13	14	EXTNL	PREC	
WDM2	53	ATEM	ENGL	SAME	RCHRES	13	14	EXTNL	GATMP	
WDM2	56	PEVT	ENGL	SAME	RCHRES	13	14	EXTNL	POTEV	
*** Met Seg OWML										
WDM2	71	PREC	ENGL	SAME	RCHRES	18		EXTNL	PREC	
WDM2	53	ATEM	ENGL	SAME	RCHRES	18		EXTNL	GATMP	
WDM2	56	PEVT	ENGL	SAME	RCHRES	18		EXTNL	POTEV	
*** Met Seg OWML										
WDM2	71	PREC	ENGL	SAME	RCHRES	20	21	EXTNL	PREC	
WDM2	53	ATEM	ENGL	SAME	RCHRES	20	21	EXTNL	GATMP	
WDM2	56	PEVT	ENGL	SAME	RCHRES	20	21	EXTNL	POTEV	
*** Met Seg DULL										
WDM2	651	PREC	ENGL	SAME	RCHRES	2	3	EXTNL	PREC	
WDM2	653	ATEM	ENGL	SAME	RCHRES	2	3	EXTNL	GATMP	
WDM2	656	PEVT	ENGL	SAME	RCHRES	2	3	EXTNL	POTEV	
WDM2	200	UFLO	ENGL	DIV	RCHRES	9		INFLOW	IVOL	1 1
WDM2	192	FLOW	ENGL	SAME	RCHRES	5		EXTNL	OUTDGT	1 1
WDM2	172	FLOW	ENGL	SAME	RCHRES	1		EXTNL	OUTDGT	1 1
WDM2	174	FLOW	ENGL	SAME	RCHRES	1		EXTNL	OUTDGT	2 1
END EXT SOURCES										

SCHEMATIC

<-Volume->		<--Area-->	<-Volume->	<ML#>	***	<sb>
<Name>	x	<-factor->	<Name>	x	***	x x
PERLND	41	201.4	RCHRES	4	2	
PERLND	42	831.8	RCHRES	4	2	
IMPLND	42	831.8	RCHRES	4	1	
PERLND	43	72.4	RCHRES	4	2	

PERLND	44	16309	RCHRES	4	2
PERLND	45	1527.3	RCHRES	4	2
PERLND	46	12470.4	RCHRES	4	2
PERLND	71	160.3	RCHRES	7	2
PERLND	72	886.3	RCHRES	7	2
IMPLND	72	886.3	RCHRES	7	1
PERLND	73	325.6	RCHRES	7	2
PERLND	74	8461.3	RCHRES	7	2
PERLND	75	1746.7	RCHRES	7	2
PERLND	76	5043.6	RCHRES	7	2
PERLND	151	70.7	RCHRES	15	2
PERLND	152	501.7	RCHRES	15	2
IMPLND	152	501.7	RCHRES	15	1
PERLND	153	167.4	RCHRES	15	2
PERLND	154	3620.4	RCHRES	15	2
PERLND	155	1081	RCHRES	15	2
PERLND	156	5125.9	RCHRES	15	2
PERLND	121	246.4	RCHRES	12	2
PERLND	122	1200.9	RCHRES	12	2
IMPLND	122	1200.9	RCHRES	12	1
PERLND	123	222.5	RCHRES	12	2
PERLND	124	10230.2	RCHRES	12	2
PERLND	125	2493.4	RCHRES	12	2
PERLND	126	9227.3	RCHRES	12	2
PERLND	131	110.1	RCHRES	13	2
PERLND	132	690.4	RCHRES	13	2
IMPLND	132	690.4	RCHRES	13	1
PERLND	133	238.7	RCHRES	13	2
PERLND	134	6085.8	RCHRES	13	2
PERLND	135	2209.4	RCHRES	13	2
PERLND	136	6905.4	RCHRES	13	2
PERLND	101	102	RCHRES	10	2
PERLND	102	1283.9	RCHRES	10	2
IMPLND	102	1283.9	RCHRES	10	1
PERLND	103	98.9	RCHRES	10	2
PERLND	104	6851.9	RCHRES	10	2
PERLND	105	977.3	RCHRES	10	2
PERLND	106	1753.4	RCHRES	10	2
PERLND	21	355.1	RCHRES	2	2
PERLND	22	8977.9	RCHRES	2	2
IMPLND	22	8977.9	RCHRES	2	1
PERLND	23	341.6	RCHRES	2	2
PERLND	24	10229.6	RCHRES	2	2
PERLND	25	2639.8	RCHRES	2	2
PERLND	26	3437	RCHRES	2	2
PERLND	191	219.8	RCHRES	19	2
PERLND	192	205.4	RCHRES	19	2
IMPLND	192	205.4	RCHRES	19	1
PERLND	193	312.1	RCHRES	19	2
PERLND	194	11811.9	RCHRES	19	2
PERLND	195	3418.8	RCHRES	19	2
PERLND	196	9604.7	RCHRES	19	2
PERLND	171	266.3	RCHRES	17	2
PERLND	172	489.8	RCHRES	17	2
IMPLND	172	489.8	RCHRES	17	1
PERLND	173	322.1	RCHRES	17	2
PERLND	174	6924.9	RCHRES	17	2

PERLND	175	3002.7	RCHRES	17	2
PERLND	176	9591	RCHRES	17	2
PERLND	51	997.6	RCHRES	5	2
PERLND	52	978.2	RCHRES	5	2
IMPLND	52	978.2	RCHRES	5	1
PERLND	53	166.3	RCHRES	5	2
PERLND	54	6806.7	RCHRES	5	2
PERLND	55	1714.4	RCHRES	5	2
PERLND	56	3791.1	RCHRES	5	2
RCHRES	4		RCHRES	5	3
PERLND	31	199.3	RCHRES	3	2
PERLND	32	532.3	RCHRES	3	2
IMPLND	32	532.3	RCHRES	3	1
PERLND	33	289.3	RCHRES	3	2
PERLND	34	10398.9	RCHRES	3	2
PERLND	35	4304.6	RCHRES	3	2
PERLND	36	9481.9	RCHRES	3	2
PERLND	61	281	RCHRES	6	2
PERLND	62	4339.4	RCHRES	6	2
IMPLND	62	4339.4	RCHRES	6	1
PERLND	63	171.9	RCHRES	6	2
PERLND	64	7642.1	RCHRES	6	2
PERLND	65	2658	RCHRES	6	2
PERLND	66	4116.1	RCHRES	6	2
RCHRES	5		RCHRES	6	4
PERLND	161	32.1	RCHRES	16	2
PERLND	162	180.2	RCHRES	16	2
IMPLND	162	180.2	RCHRES	16	1
PERLND	163	47.1	RCHRES	16	2
PERLND	164	984.3	RCHRES	16	2
PERLND	165	515.4	RCHRES	16	2
PERLND	166	2412.3	RCHRES	16	2
RCHRES	15		RCHRES	16	3
RCHRES	12		RCHRES	16	3
PERLND	181	115.1	RCHRES	18	2
PERLND	182	233.1	RCHRES	18	2
IMPLND	182	233.1	RCHRES	18	1
PERLND	183	165.9	RCHRES	18	2
PERLND	184	4279.3	RCHRES	18	2
PERLND	185	1552.2	RCHRES	18	2
PERLND	186	3167	RCHRES	18	2
RCHRES	16		RCHRES	18	3
RCHRES	17		RCHRES	18	3
PERLND	201	342.2	RCHRES	20	2
PERLND	202	536.4	RCHRES	20	2
IMPLND	202	536.4	RCHRES	20	1
PERLND	203	545.5	RCHRES	20	2
PERLND	204	18605.7	RCHRES	20	2
PERLND	205	2620.3	RCHRES	20	2
PERLND	206	8129.9	RCHRES	20	2
RCHRES	18		RCHRES	20	3
RCHRES	19		RCHRES	20	3
PERLND	141	17.6	RCHRES	14	2
PERLND	142	143.4	RCHRES	14	2
IMPLND	142	143.4	RCHRES	14	1
PERLND	143	2.3	RCHRES	14	2
PERLND	144	846	RCHRES	14	2

PERLND	145	90.2	RCHRES	14	2
PERLND	146	209.5	RCHRES	14	2
RCHRES	6		RCHRES	14	3
RCHRES	13		RCHRES	14	3
PERLND	81	115.3	RCHRES	8	2
PERLND	82	3461.2	RCHRES	8	2
IMPLND	82	3461.2	RCHRES	8	1
PERLND	83	178.8	RCHRES	8	2
PERLND	84	5839.8	RCHRES	8	2
PERLND	85	2371.4	RCHRES	8	2
PERLND	86	2033.1	RCHRES	8	2
RCHRES	7		RCHRES	8	3
RCHRES	3		RCHRES	8	3
PERLND	91	178.4	RCHRES	9	2
PERLND	92	2938.5	RCHRES	9	2
IMPLND	92	2938.5	RCHRES	9	1
PERLND	93	94.6	RCHRES	9	2
PERLND	94	4159.8	RCHRES	9	2
PERLND	95	1050.9	RCHRES	9	2
PERLND	96	1440.2	RCHRES	9	2
RCHRES	8		RCHRES	9	3
RCHRES	2		RCHRES	9	3
PERLND	211	567.9	RCHRES	21	2
PERLND	212	1021.9	RCHRES	21	2
IMPLND	212	1021.9	RCHRES	21	1
PERLND	213	128.6	RCHRES	21	2
PERLND	214	12875.4	RCHRES	21	2
PERLND	215	1337.1	RCHRES	21	2
PERLND	216	1247.7	RCHRES	21	2
RCHRES	14		RCHRES	21	3
RCHRES	20		RCHRES	21	3
PERLND	111	329.1	RCHRES	11	2
PERLND	112	334.3	RCHRES	11	2
IMPLND	112	334.3	RCHRES	11	1
PERLND	113	51.6	RCHRES	11	2
PERLND	114	6376.3	RCHRES	11	2
PERLND	115	938.5	RCHRES	11	2
PERLND	116	1312	RCHRES	11	2
RCHRES	9		RCHRES	11	3
RCHRES	10		RCHRES	11	3
PERLND	11	1181.6	RCHRES	1	2
PERLND	12	1606.7	RCHRES	1	2
IMPLND	12	1606.7	RCHRES	1	1
PERLND	13	112.6	RCHRES	1	2
PERLND	14	11999.8	RCHRES	1	2
PERLND	15	1182.2	RCHRES	1	2
PERLND	16	1035.6	RCHRES	1	2
RCHRES	21		RCHRES	1	3
RCHRES	11		RCHRES	1	3

END SCHEMATIC

EXT TARGETS

<-Volume->	<-Grp>	<-Member->	<--Mult-->	Tran	<-Volume->	<Member>	Tsys	Aggr	Amd	***		
<Name>	x	<Name>	x	x<-factor->	strg	<Name>	x	<Name>	qf	tem	strg	strg***
RCHRES	5	HYDR	O	1 1	AVER	WDM1	1007	O1	1	ENGL	AGGR	REPL
RCHRES	5	HYDR	DEP	1 1	AVER	WDM1	1008	DEP	1	ENGL	AGGR	REPL
RCHRES	6	HYDR	IVOL	1 1	AVER	WDM1	1003	IVOL	1	ENGL	AGGR	REPL

```

RCHRES 1 HYDR IVOL 1 1 12.1 AVER WDM1 1012 IVOL 1 ENGL AGGR REPL
RCHRES 1 HYDR RO 1 1 AVER WDM1 1001 RO 1 ENGL AGGR REPL
RCHRES 1 HYDR O 1 1 AVER WDM1 1002 O1 1 ENGL AGGR REPL
RCHRES 1 HYDR DEP 1 1 AVER WDM1 1005 DEP 1 ENGL AGGR REPL
END EXT TARGETS

```

MASS-LINK

```

MASS-LINK 2
<-Volume-> <-Grp> <-Member-><--Mult--> <-Target vols> <-Grp> <-Member-> ***
<Name> <Name> x x<-factor-> <Name> <Name> x x ***
PERLND PWATER PERO 0.0833333 RCHRES INFLOW IVOL
END MASS-LINK 2

```

```

MASS-LINK 1
<-Volume-> <-Grp> <-Member-><--Mult--> <-Target vols> <-Grp> <-Member-> ***
<Name> <Name> x x<-factor-> <Name> <Name> x x ***
IMPLND IWATER SURO 0.0833333 RCHRES INFLOW IVOL
END MASS-LINK 1

```

```

MASS-LINK 3
<-Volume-> <-Grp> <-Member-><--Mult--> <-Target vols> <-Grp> <-Member-> ***
<Name> <Name> x x<-factor-> <Name> <Name> x x ***
RCHRES ROFLOW RCHRES INFLOW
END MASS-LINK 3

```

```

MASS-LINK 4
<-Volume-> <-Grp> <-Member-><--Mult--> <-Target vols> <-Grp> <-Member-> ***
<Name> <Name> x x<-factor-> <Name> <Name> x x ***
RCHRES ROFLOW RCHRES INFLOW
RCHRES OFLOW 1 RCHRES INFLOW
END MASS-LINK 4
END MASS-LINK

```

END RUN

5.4 Appendix D: Additional Graphs and Tables

Annual Hydrographs

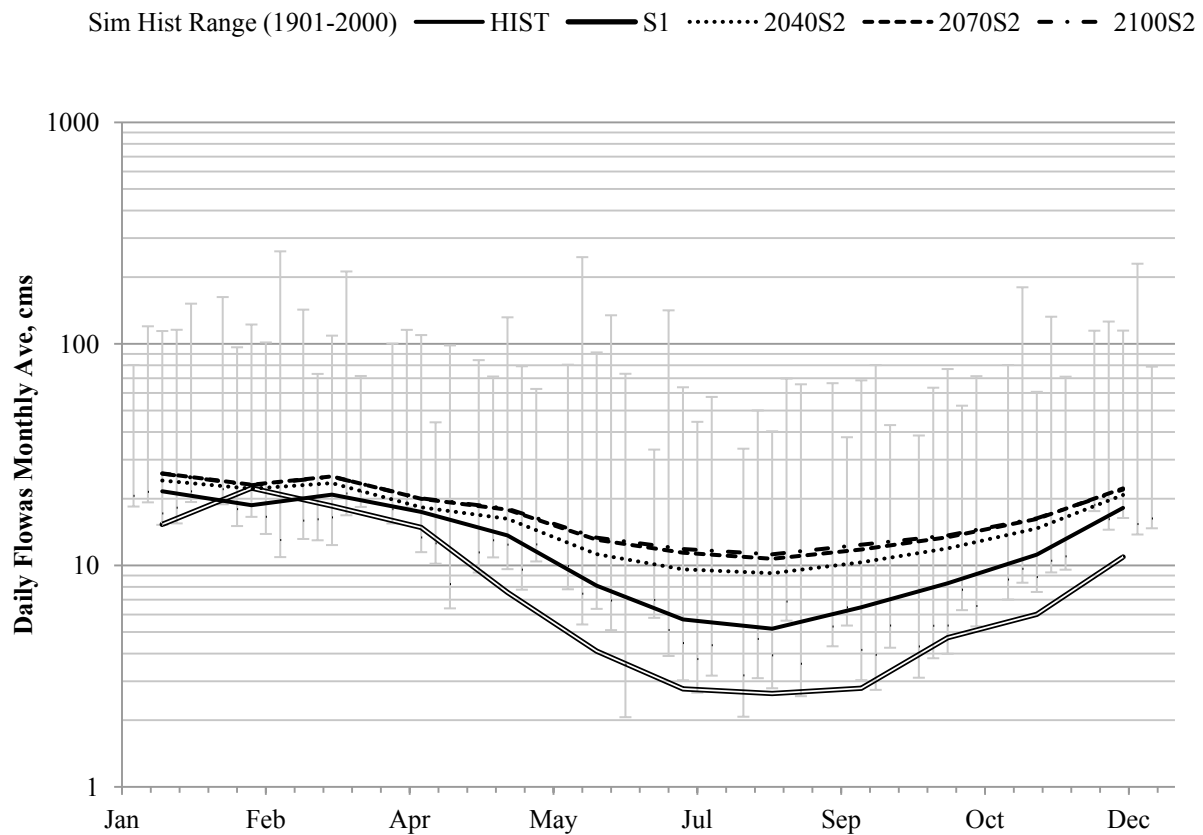


Figure 5.4-1 Average annual hydrograph comparing the ensemble historic to MIMR future scenarios S1 and S2 of average daily flows as a monthly average. Average shown at the 15th of each month, and range is shown for every 5th day through the 25th of each month.

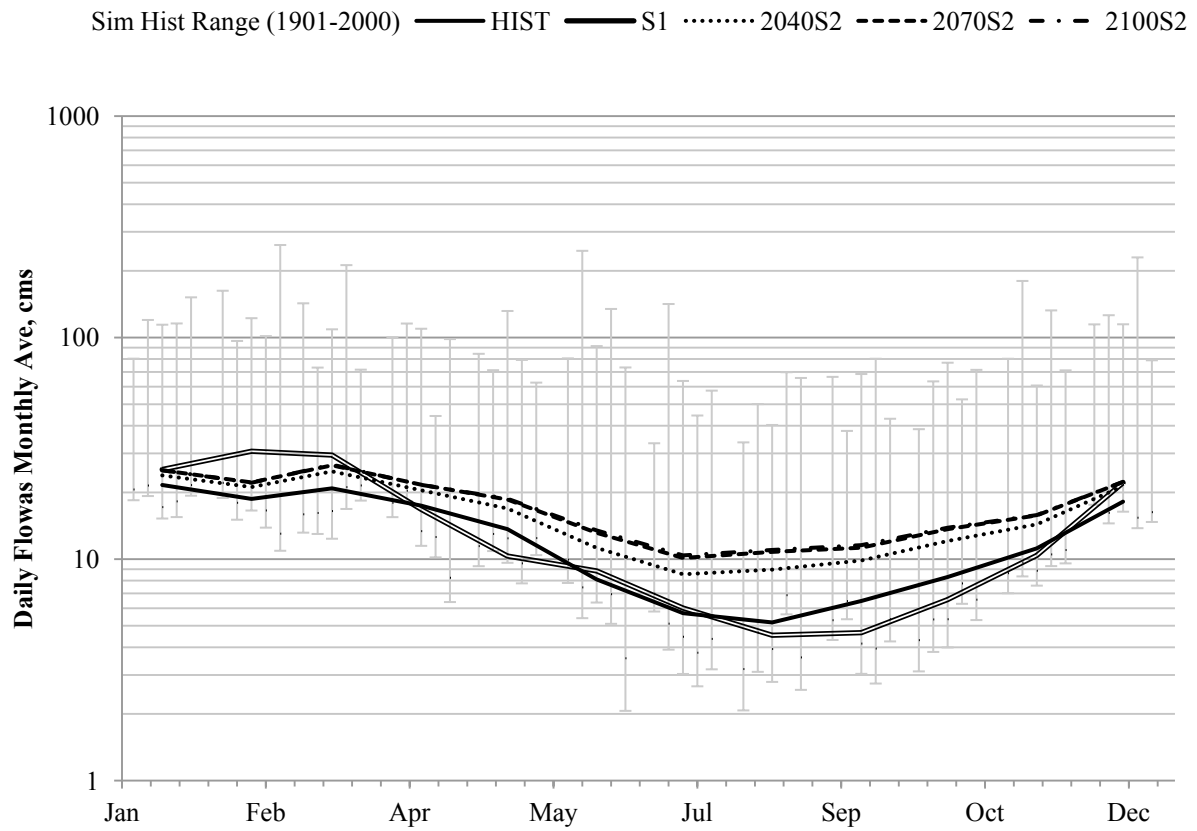


Figure 5.4-2 Average annual hydrograph comparing the ensemble historic to MPEH future scenarios S1 and S3 of average daily flows as monthly averages. Average shown at the 15th of each month, and range is shown for every 5th day through the 25th of each month.

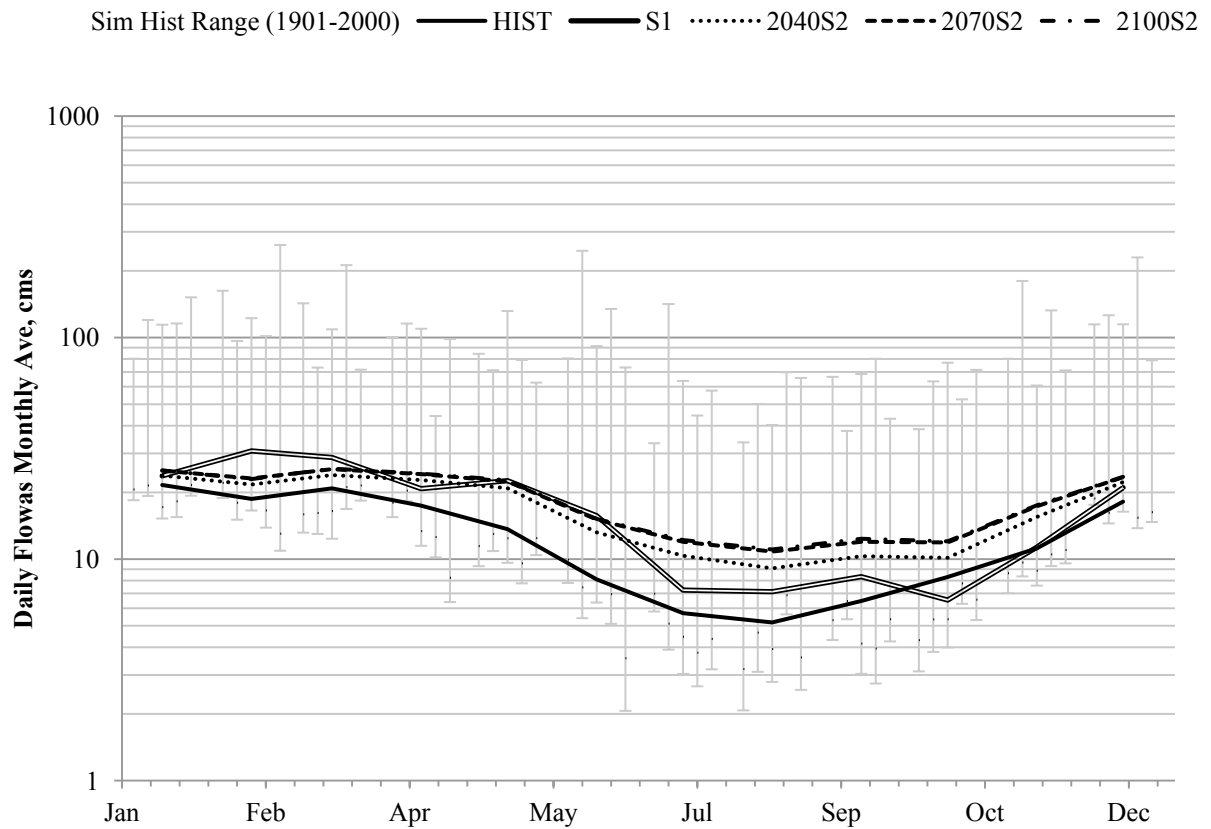


Figure 5.4-3 Average annual hydrograph comparing the ensemble historic to NCPCM future scenarios S1 and S2 of average daily flows as monthly averages. Average shown at the 15th of each month, and range is shown for every 5th day through the 25th of each month.

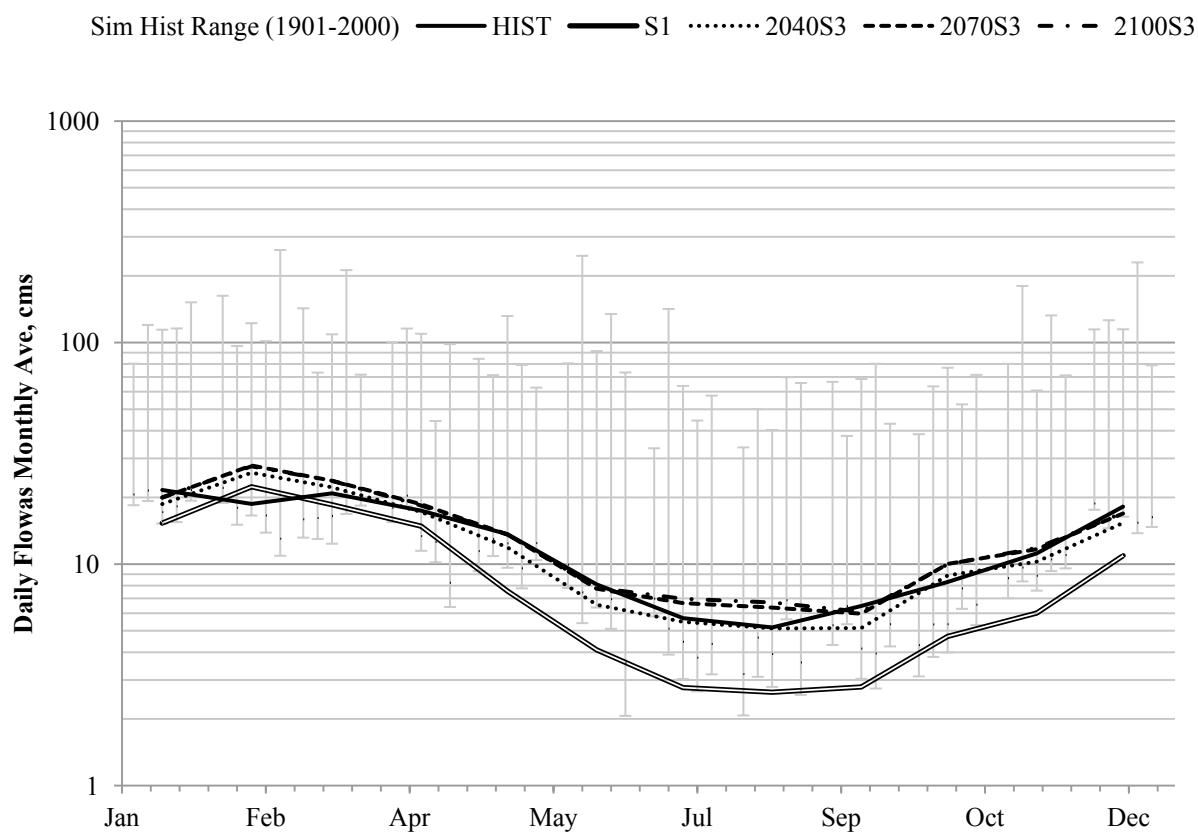


Figure 5.4-4 Average annual hydrograph comparing the ensemble historic to MIMR future scenarios S1 and S3 of average daily flows as monthly averages. Average shown at the 15th of each month, and range is shown for every 5th day through the 25th of each month.

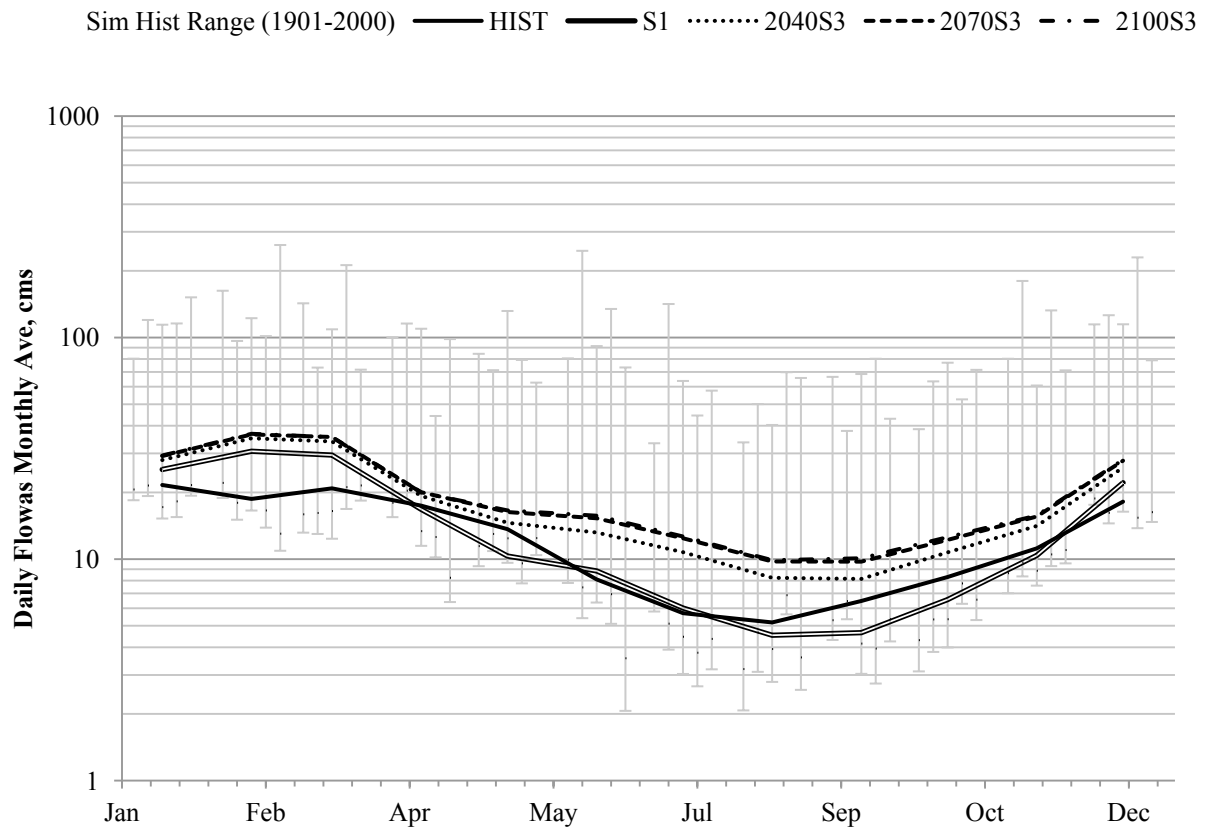


Figure 5.4-5 Average annual hydrograph comparing the ensemble historic to MPEH future scenarios S1 and S3 of average daily flows as monthly averages. Average shown at the 15th of each month, and range is shown for every 5th day through the 25th of each month.

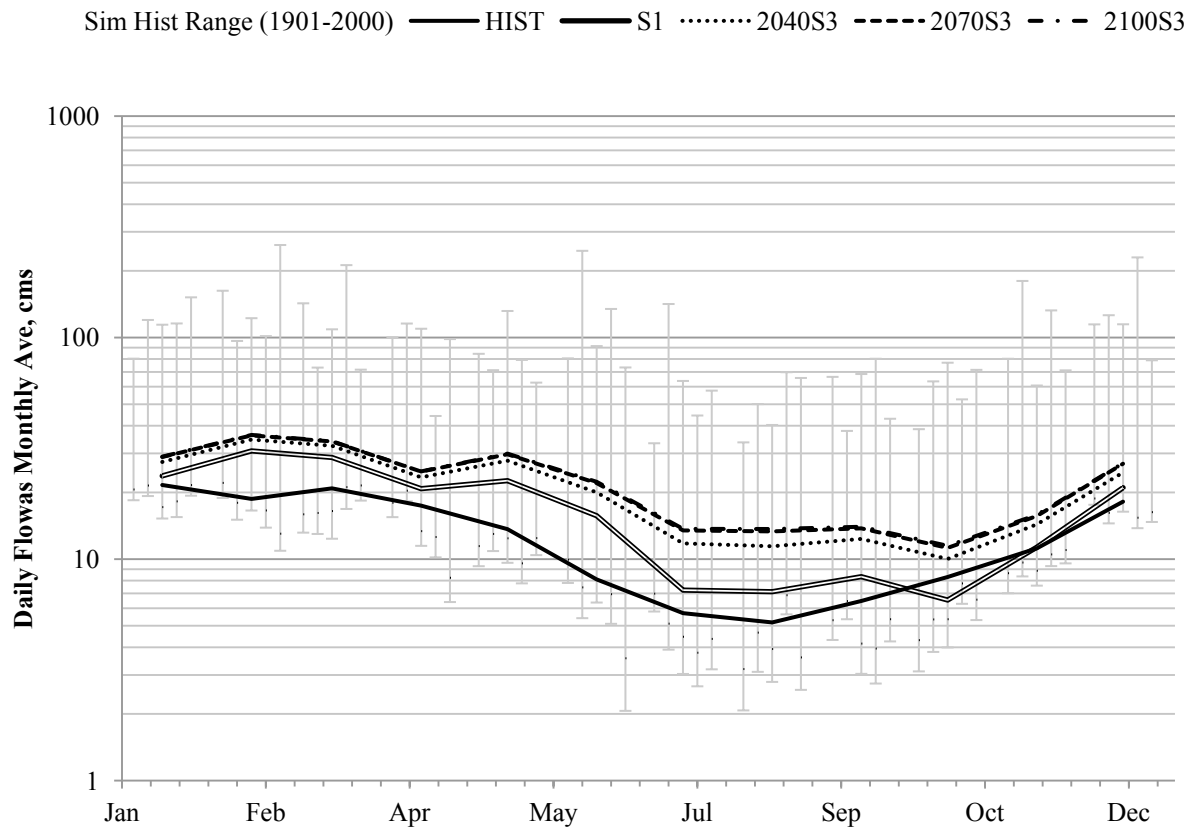


Figure 5.4-6 Average annual hydrograph comparing the ensemble historic to NCPM future scenarios S1 and S3 of average daily flows as monthly averages. Average shown at the 15th of each month, and range is shown for every 5th day through the 25th of each month.

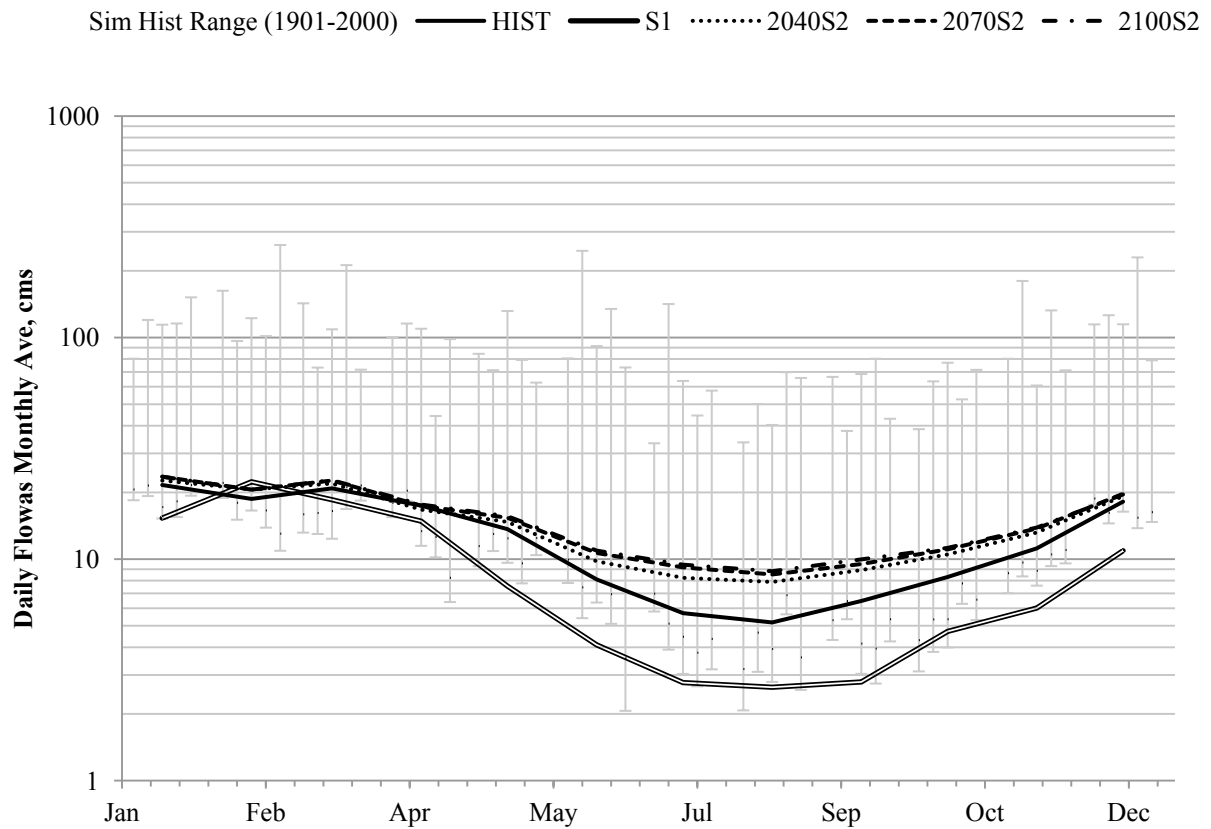


Figure 5.4-7 Average annual hydrograph comparing the ensemble historic to MIMR future scenarios S1 and S2 of average daily flows as monthly averages, not accounting for expansion in reclaimed water inflow. Average shown at the 15th of each month, and range is shown for every 5th day through the 25th of each month.

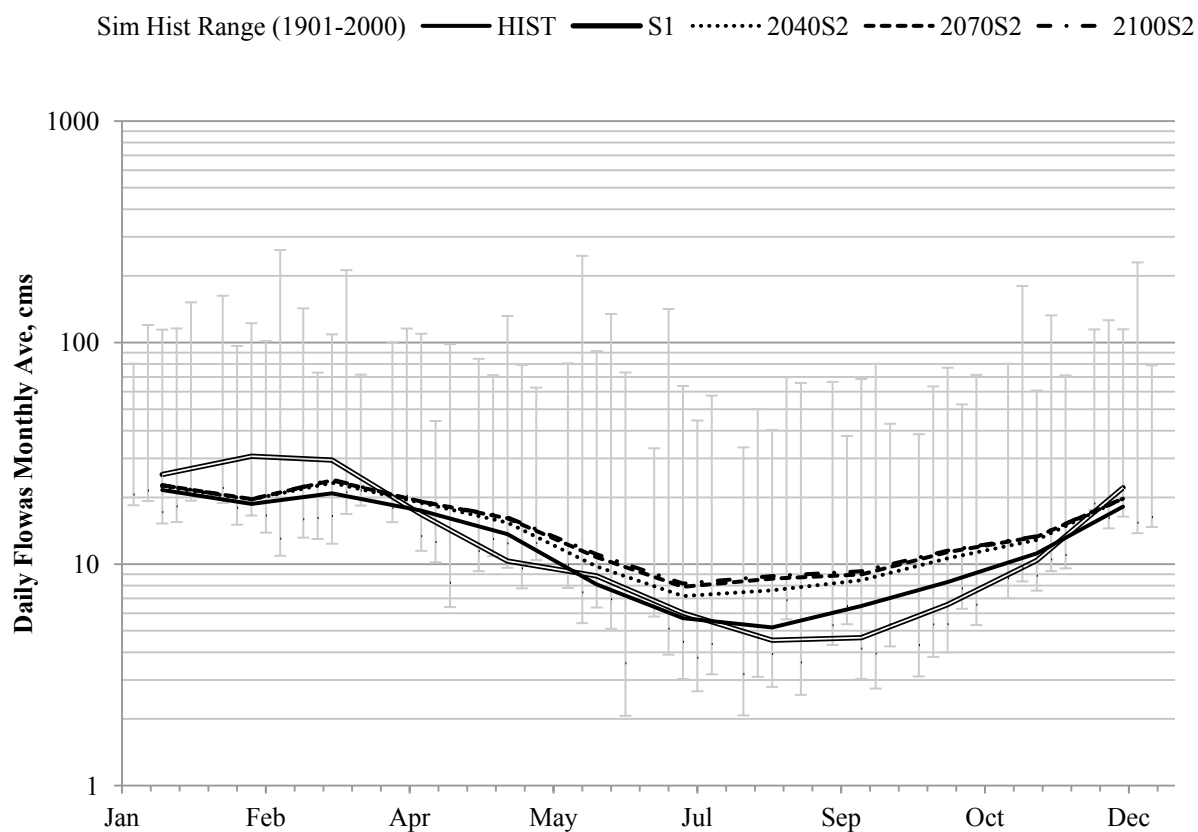


Figure 5.4-8 Average annual hydrograph comparing the ensemble historic to MPEH future scenarios S1 and S2 of average daily flows as monthly averages, not accounting for expansion in reclaimed water inflow. Average shown at the 15th of each month, and range is shown for every 5th day through the 25th of each month.

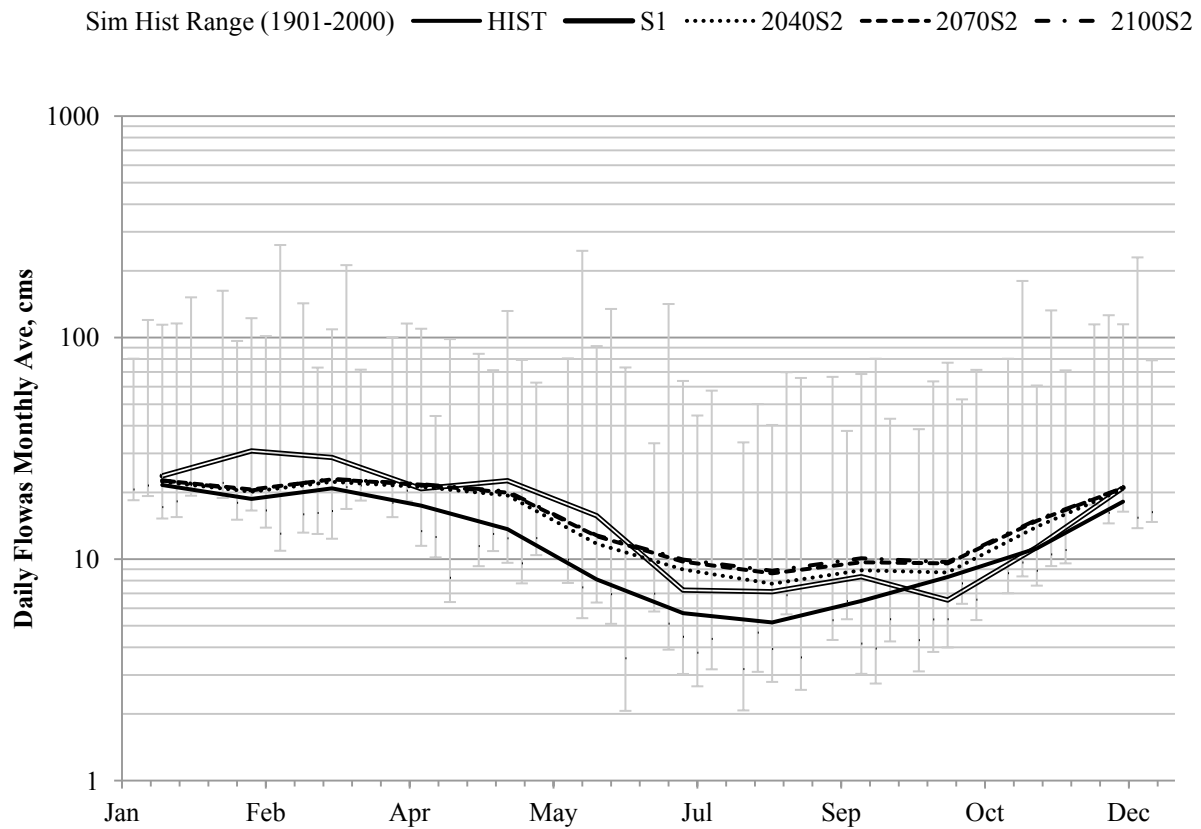


Figure 5.4-9 Average annual hydrograph comparing the ensemble historic to NCPCM future scenarios S1 and S3 of average daily flows as monthly averages, not accounting for expansion in reclaimed water inflow. Average shown at the 15th of each month, and range is shown for every 5th day through the 25th of each month.

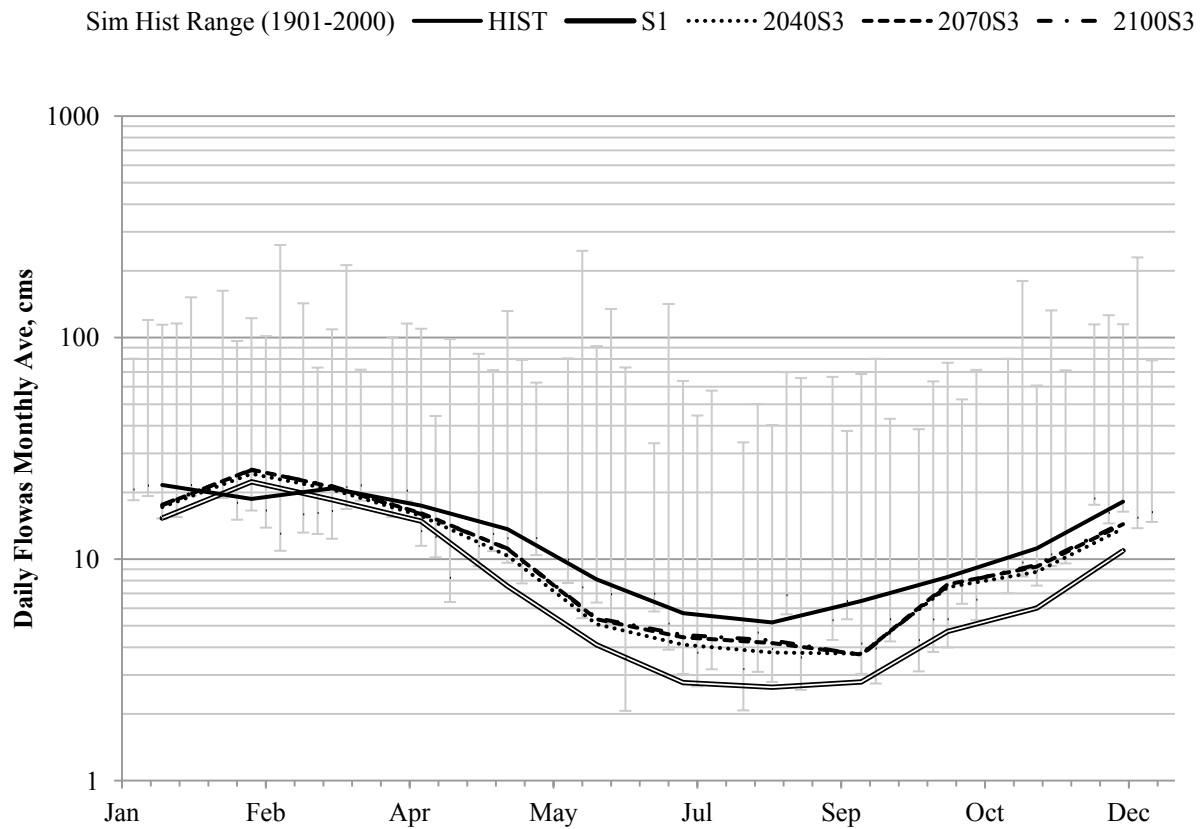


Figure 5.4-10 Average annual hydrograph comparing the ensemble historic to MIMR future scenarios S1 and S3 of average daily flows as monthly averages, not accounting for expansion in reclaimed water inflow. Average shown at the 15th of each month, and range is shown for every 5th day through the 25th of each month.

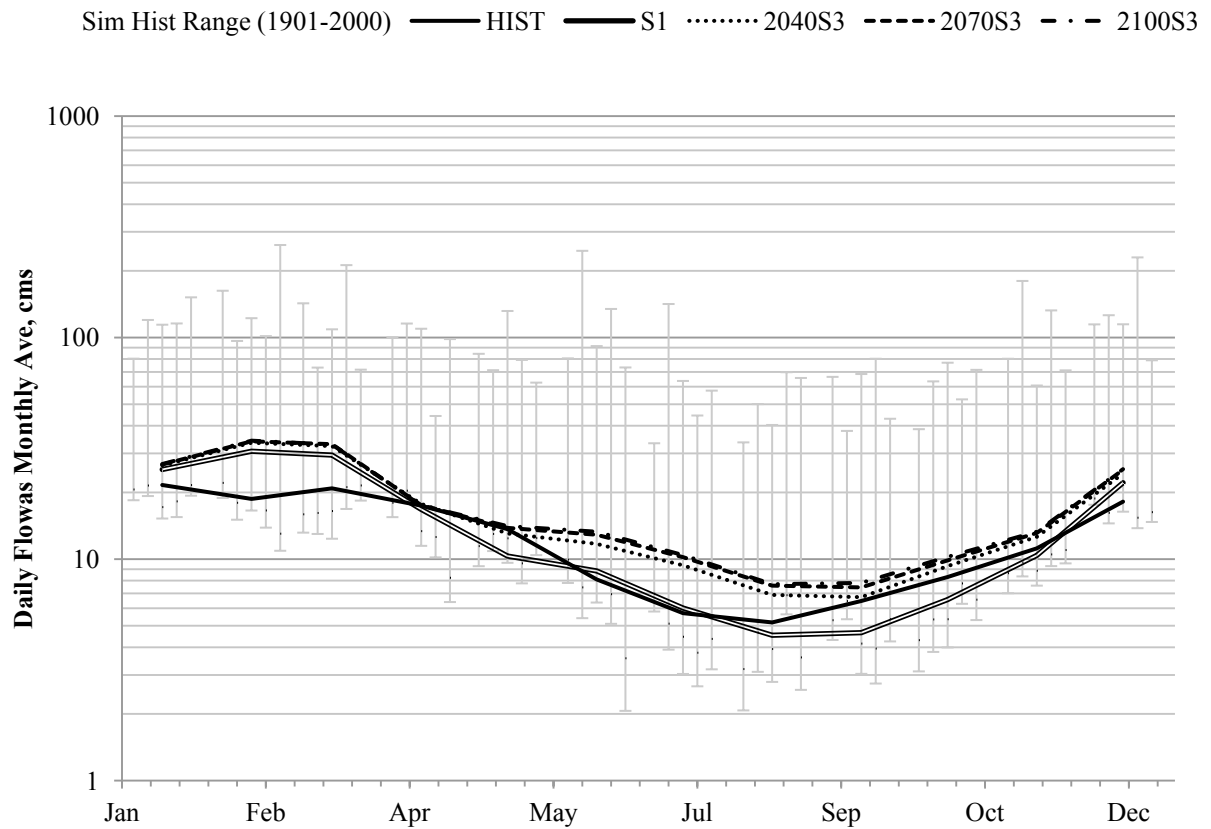


Figure 5.4-11 Average annual hydrograph comparing the ensemble historic to MPEH future scenarios S1 and S3 of average daily flows as monthly averages, not accounting for expansion in reclaimed water inflow. Average shown at the 15th of each month, and range is shown for every 5th day through the 25th of each month.

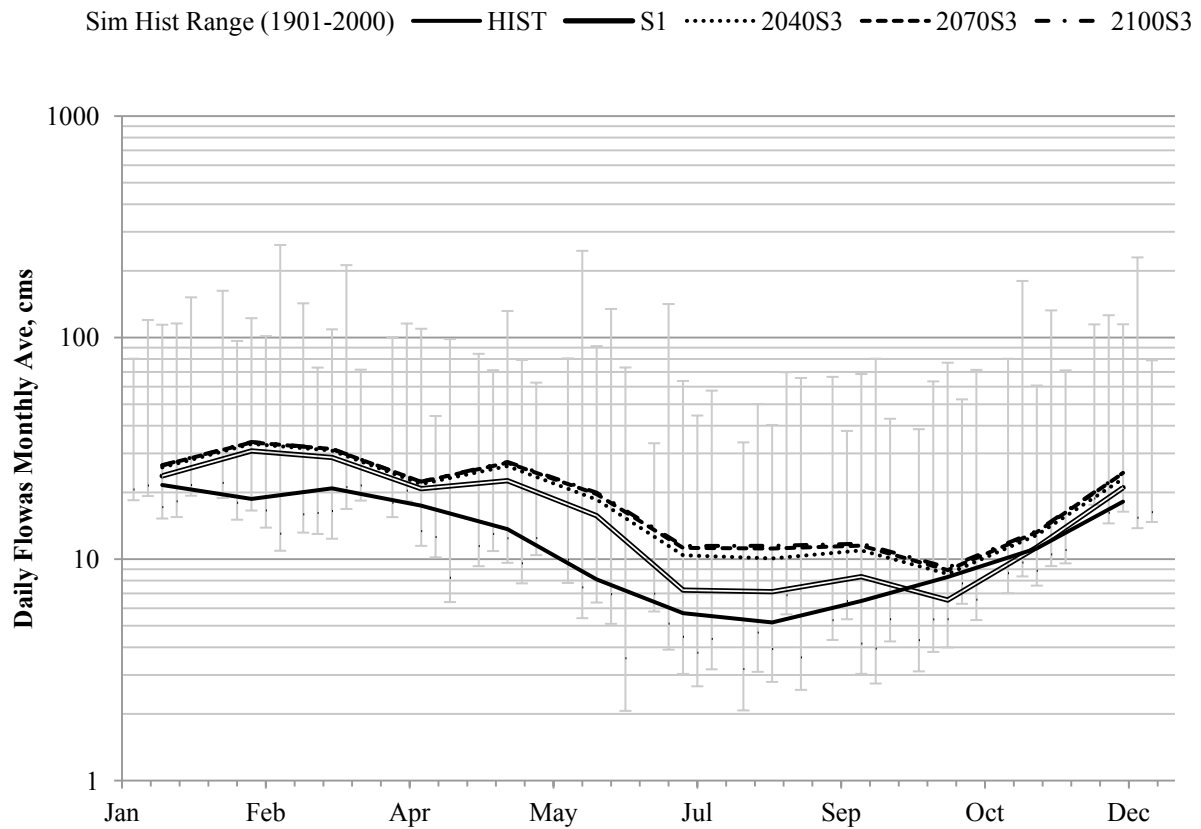


Figure 5.4-12 Average annual hydrograph comparing the ensemble historic to NCCPM future scenarios S1 and S3 of average daily flows as monthly averages, not accounting for expansion in reclaimed water inflow. Average shown at the 15th of each month, and range is shown for every 5th day through the 25th of each month.

Metric C, Storage Response Curves

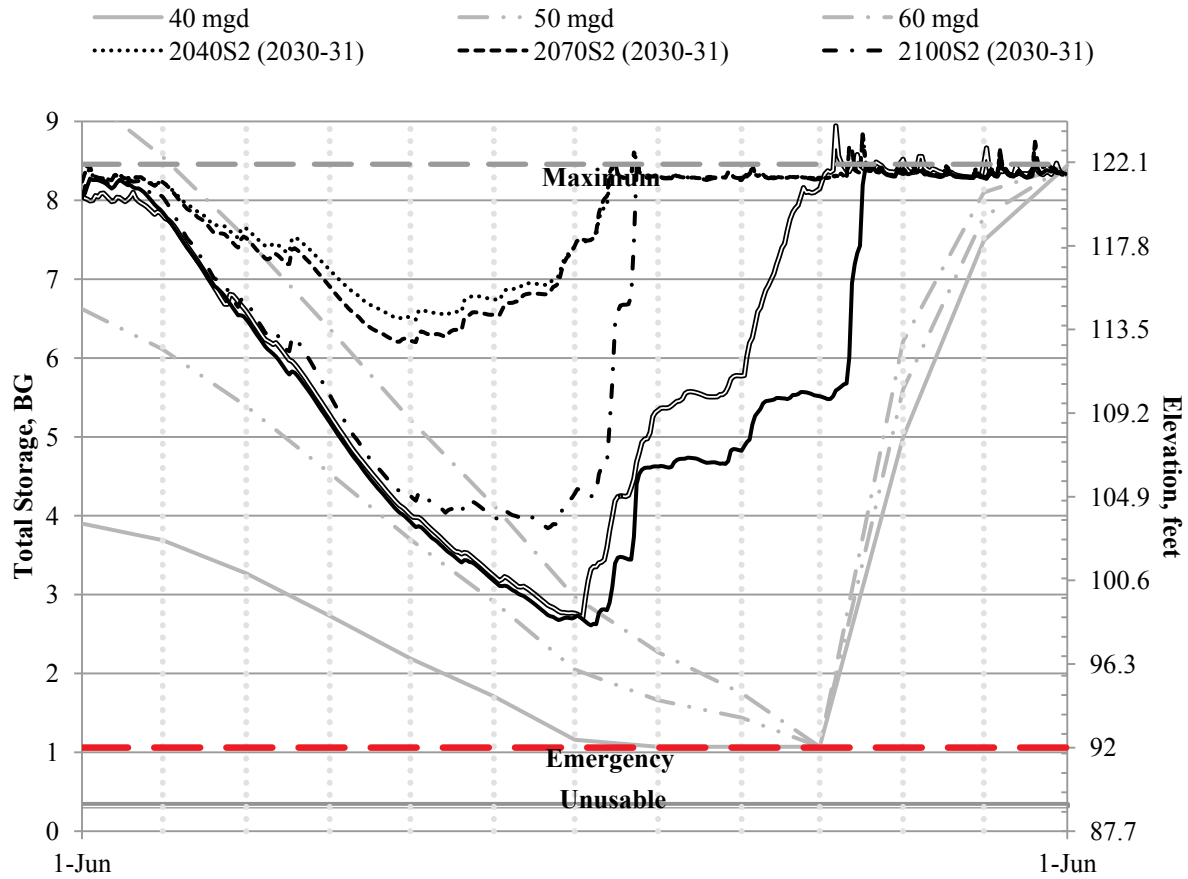


Figure 5.4-13 Occoquan reservoir storage response curves (firm yield) comparing the ensemble historic to future scenarios S1 and S2 for the drought of record

Minimum volume (BG): Hist = 2.6, S1 = 2.7, 40S2 = 6.5, 70S2 = 6.2, 00S2 = 3.8

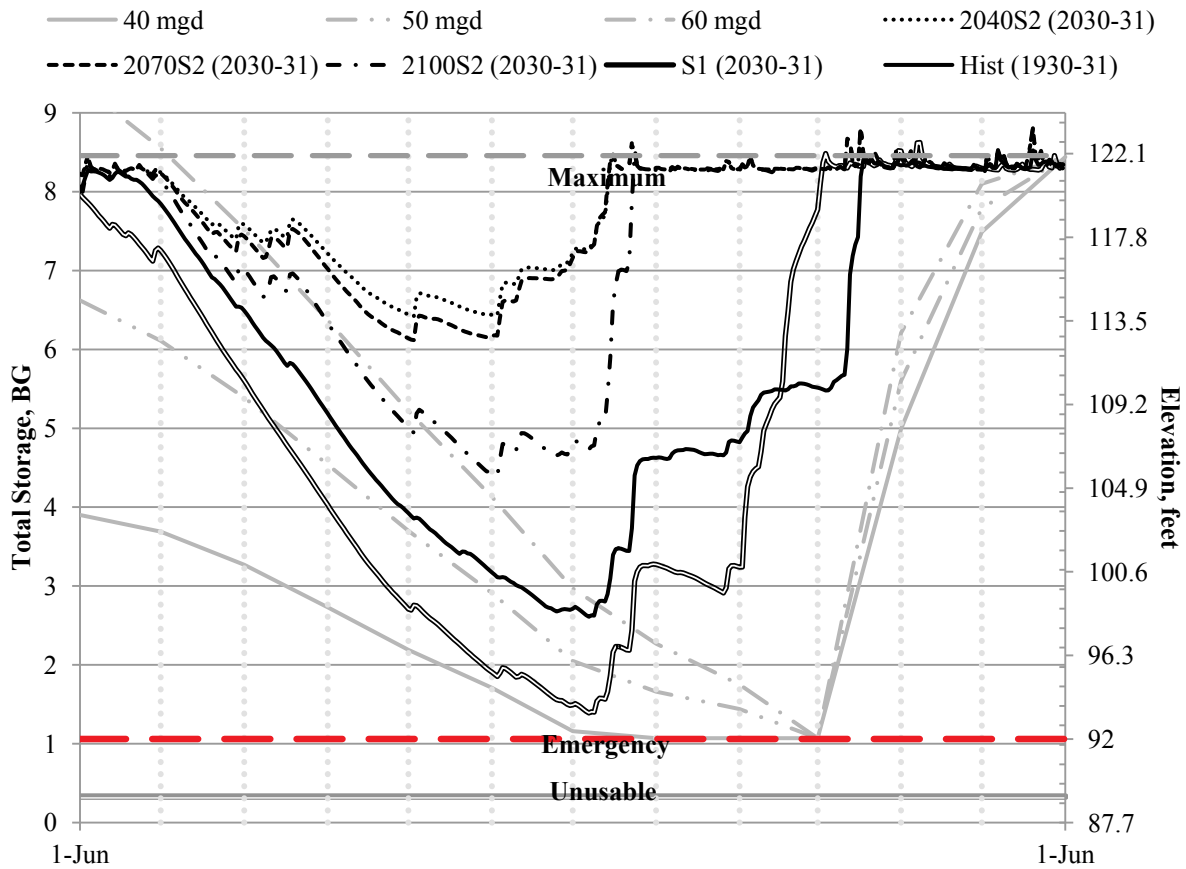


Figure 5.4-14 Occoquan reservoir storage response curves (firm yield) comparing the ensemble historic to MIMR future scenarios S1 and S2 for the drought of record

Minimum volume (BG): Hist = 2.6, S1 = 1.4, 40S2 = 6.4, 70S2 = 6.1, 00S2 = 4.4

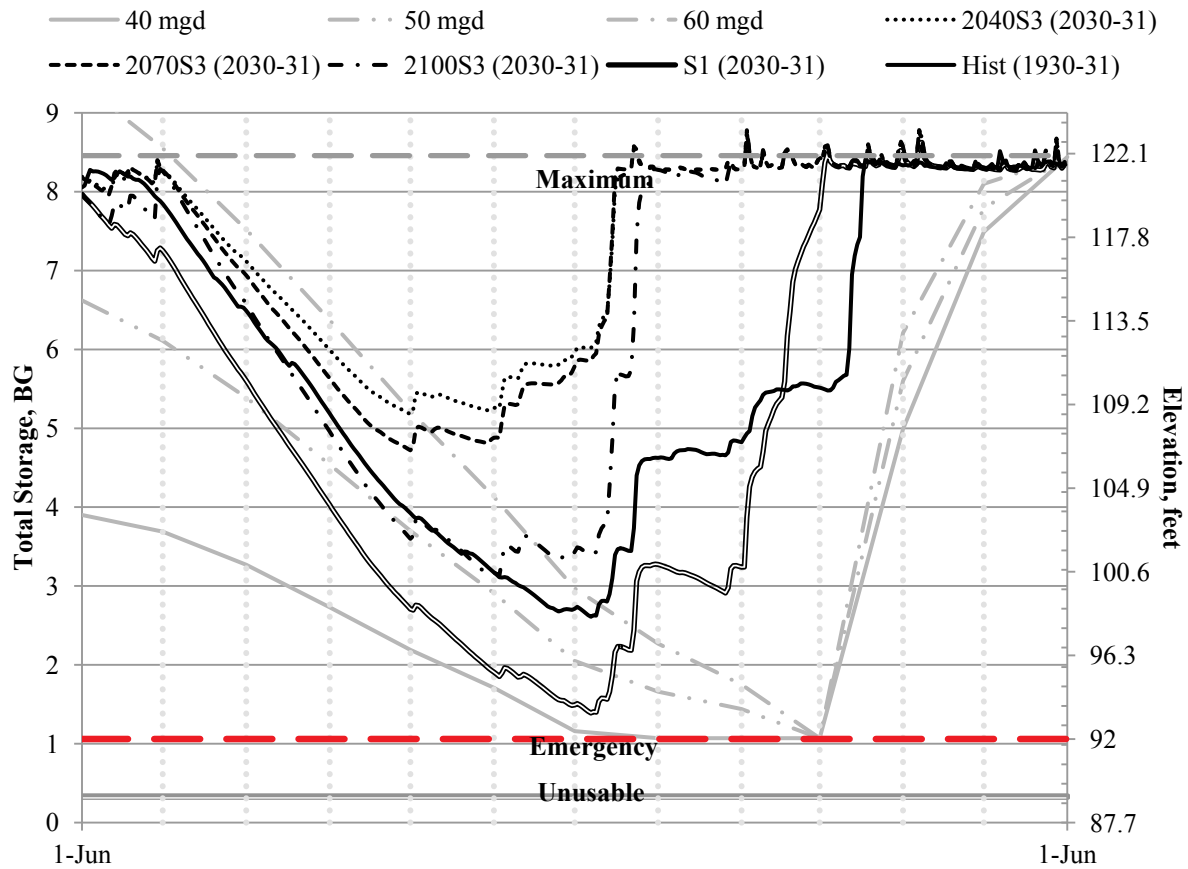


Figure 5.4-15 Occoquan reservoir storage response curve (firm yield) comparing the ensemble historic to MIMR future scenarios S1 and S3 for the drought of record

Minimum volume (BG): Hist = 2.6, S1 = 1.4, 40S3 = 5.2, 70S3 = 4.7, 00S3 = 3.1

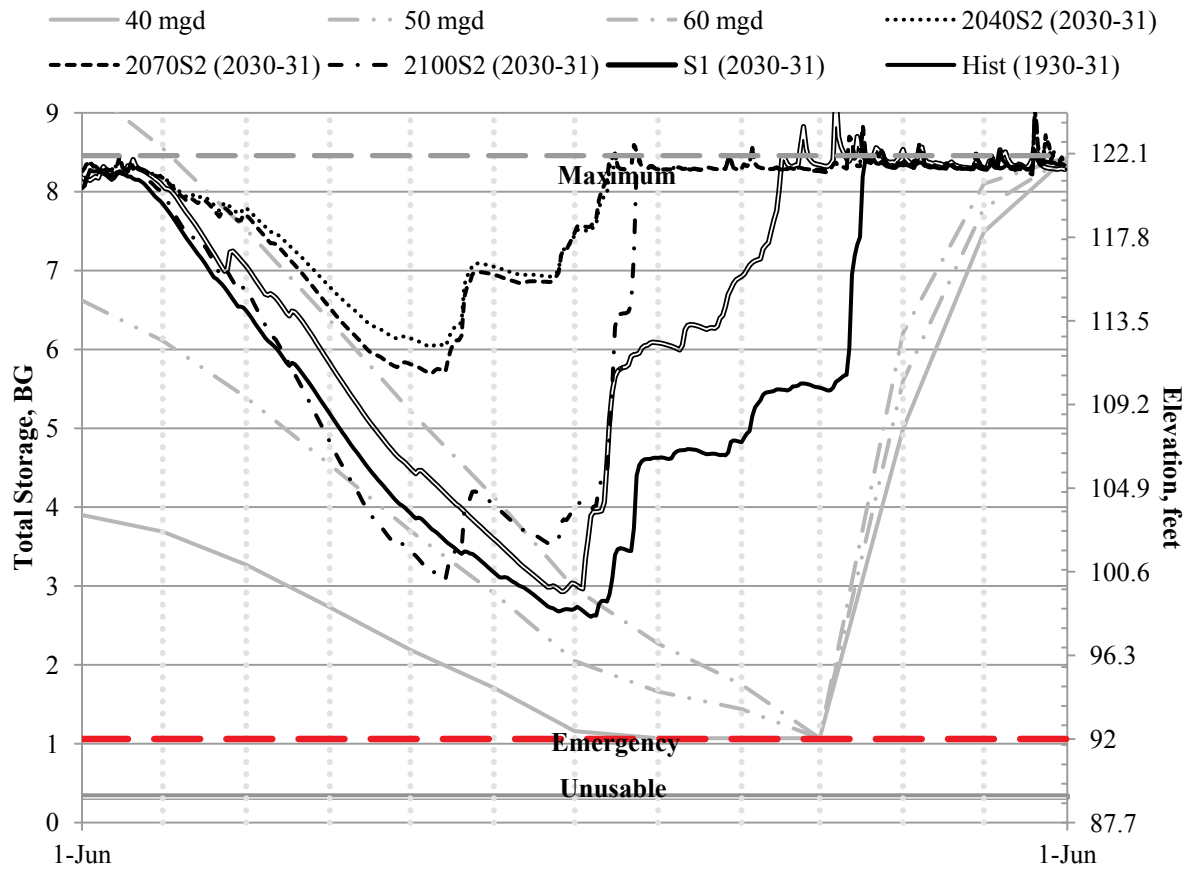


Figure 5.4-16 Occoquan reservoir storage response curves (firm yield) comparing the ensemble historic to MPEH future scenarios S1 and S2 for the drought of record

Minimum volume (BG): Hist = 2.6, S1 = 2.9, 40S2 = 6.0, 70S2 = 5.7, 00S2 = 3.1

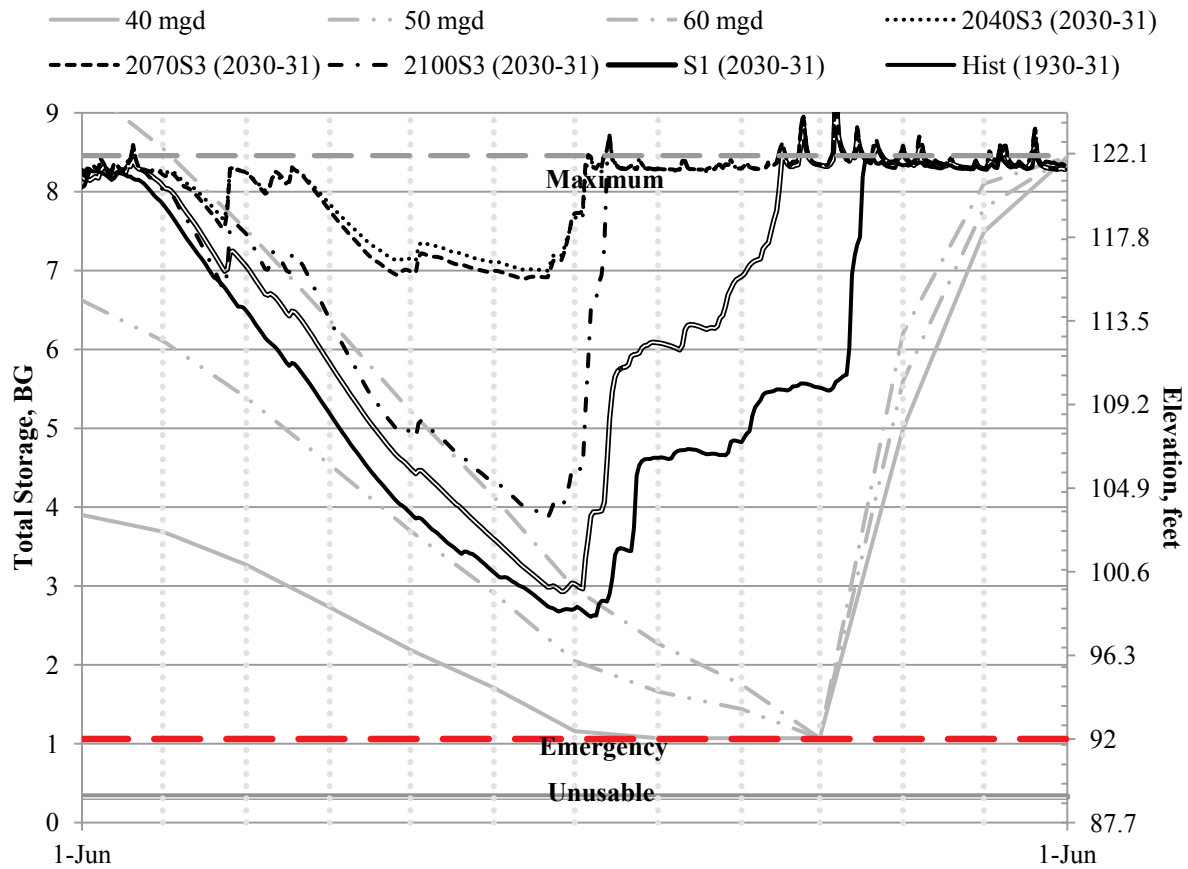


Figure 5.4-17 Occoquan reservoir storage response curves (firm yield) comparing the ensemble historic to MPEH future scenarios S1 and S3 for the drought of record

Minimum volume (BG): Hist = 2.6, S1 = 2.9, 40S3 = 7.0, 70S3 = 6.9, 00S3 = 3.9

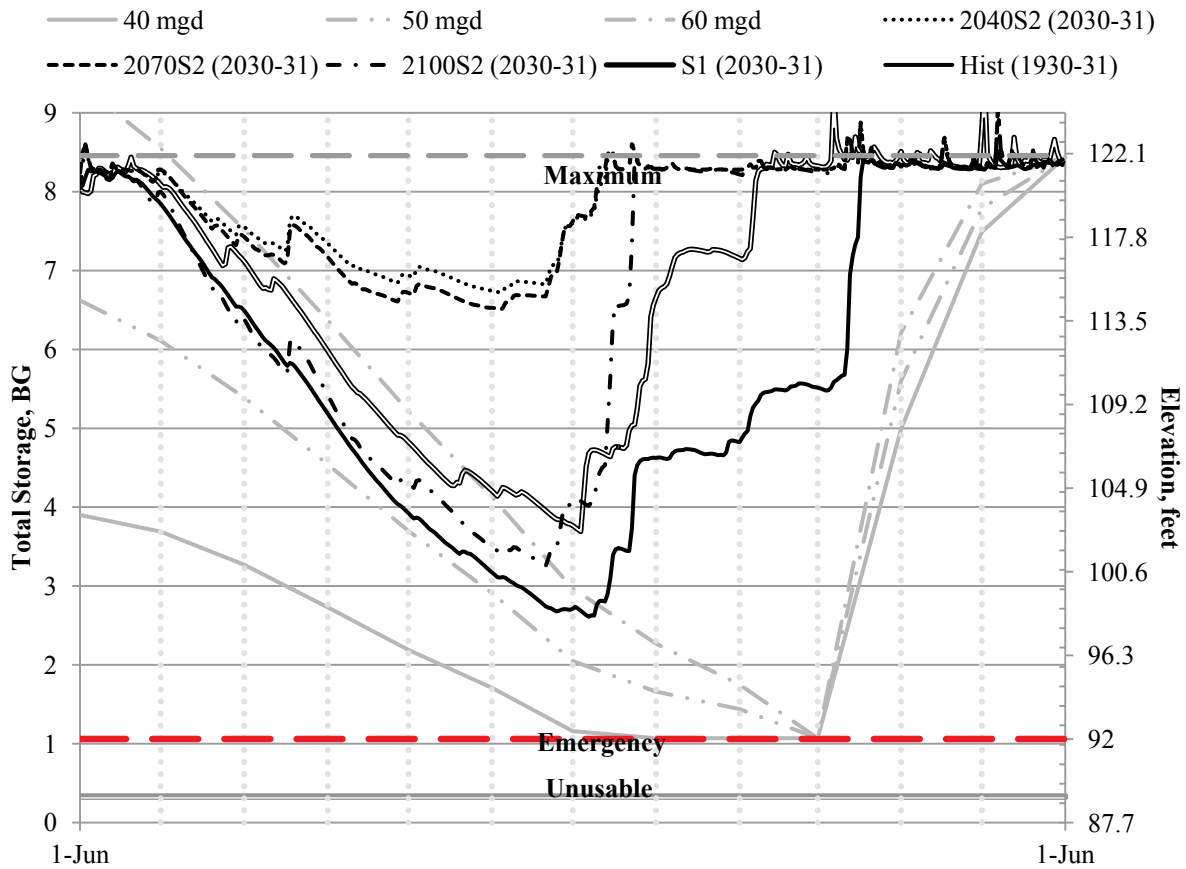


Figure 5.4-18 Occoquan reservoir storage response curves (firm yield) comparing the ensemble historic to NCPCM future scenarios S1 and S2 for the drought of record

Minimum volume (BG): Hist = 2.6, S1 = 3.7, 40S2 = 6.7, 70S2 = 6.5, 00S2 = 3.3

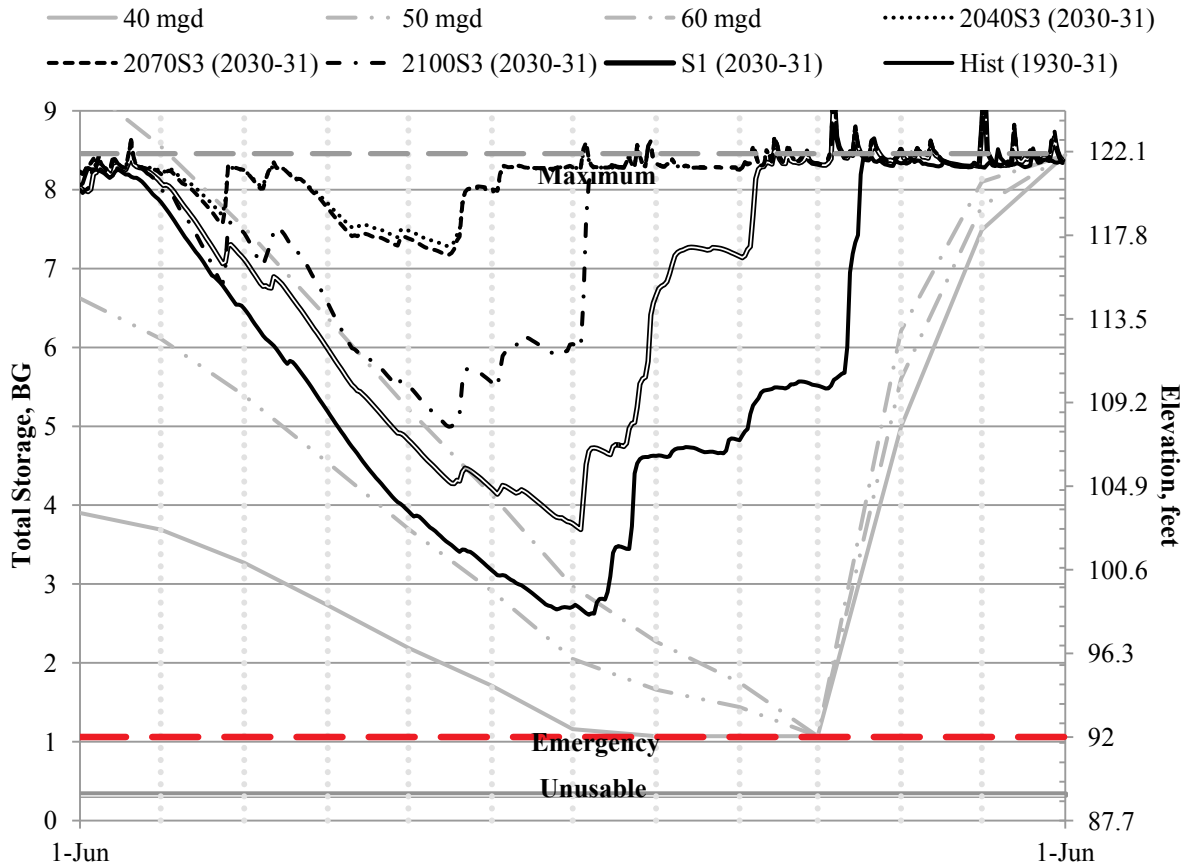


Figure 5.4-19 Occoquan reservoir storage response curves (firm yield) comparing the ensemble historic to NCPCM future scenarios S1 and S3 for the drought of record

Minimum volume (BG): Hist = 2.6, S1 = 3.7, 40S3 = 7.3, 70S3 = 7.2, 00S3 = 5.0

Table 5.4-1 Minimum volumes (BG) from modeled Occoquan reservoir storage response curves

	<i>Hist</i>	<i>S1</i>	<i>2040S2</i>	<i>2070S2</i>	<i>2100S2</i>	<i>2040S3</i>	<i>2070S3</i>	<i>2100S3</i>
ENSEMBLE	2.6	2.7	6.5	6.2	3.8	6.6	6.3	4.3
MIMR	2.7	1.4	6.4	6.1	4.4	5.2	4.7	3.1
MPEH	2.6	2.9	6.0	5.7	3.1	7.0	6.9	3.9
NCPCM	2.5	3.7	6.7	6.5	3.3	7.3	7.2	5.0

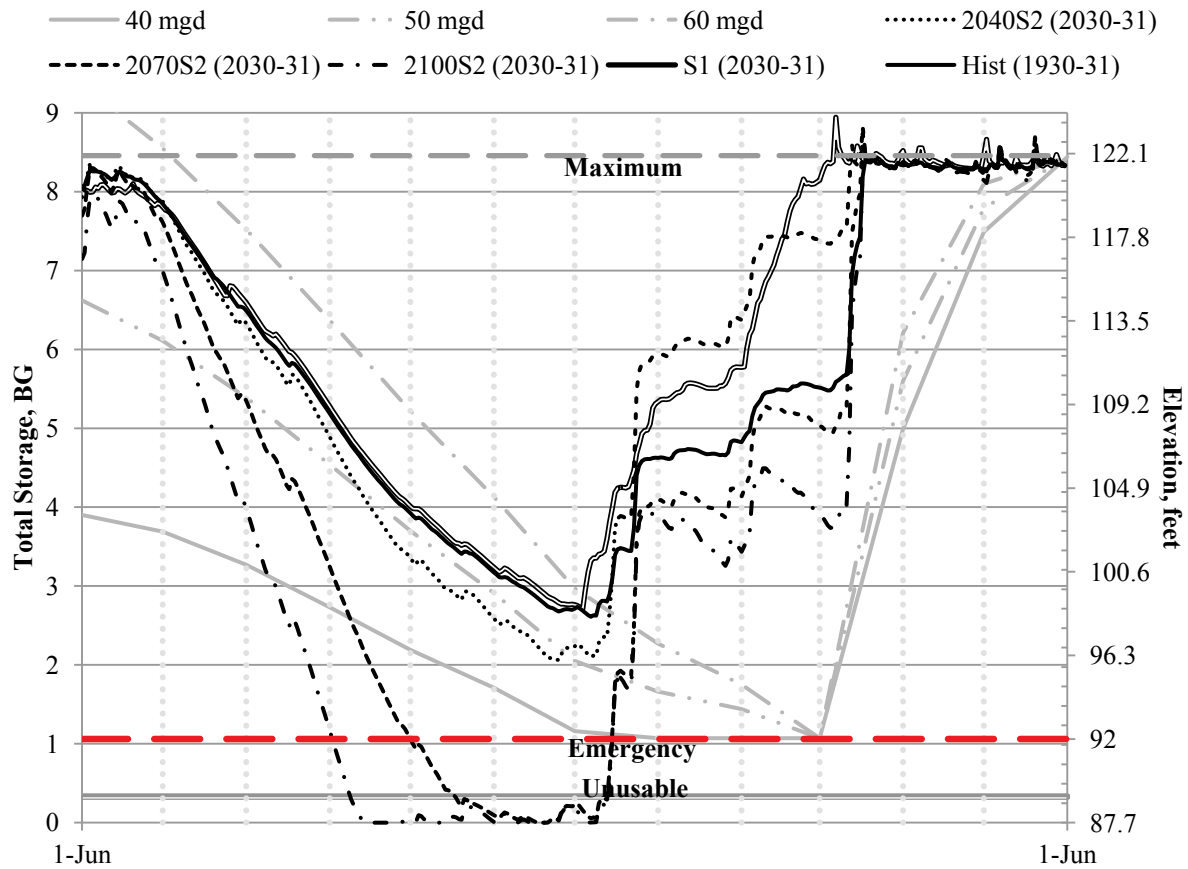


Figure 5.4-20 Occoquan reservoir storage response curves (firm yield) comparing the ensemble historic to future scenarios S1 and S2 for the drought of record, not accounting for expansion in reclaimed water inflow

Minimum volume (BG): Hist = 2.6, S1 = 2.7, 40S2 = 2.1, 70S2 = 0.0, 00S2 = 0.0

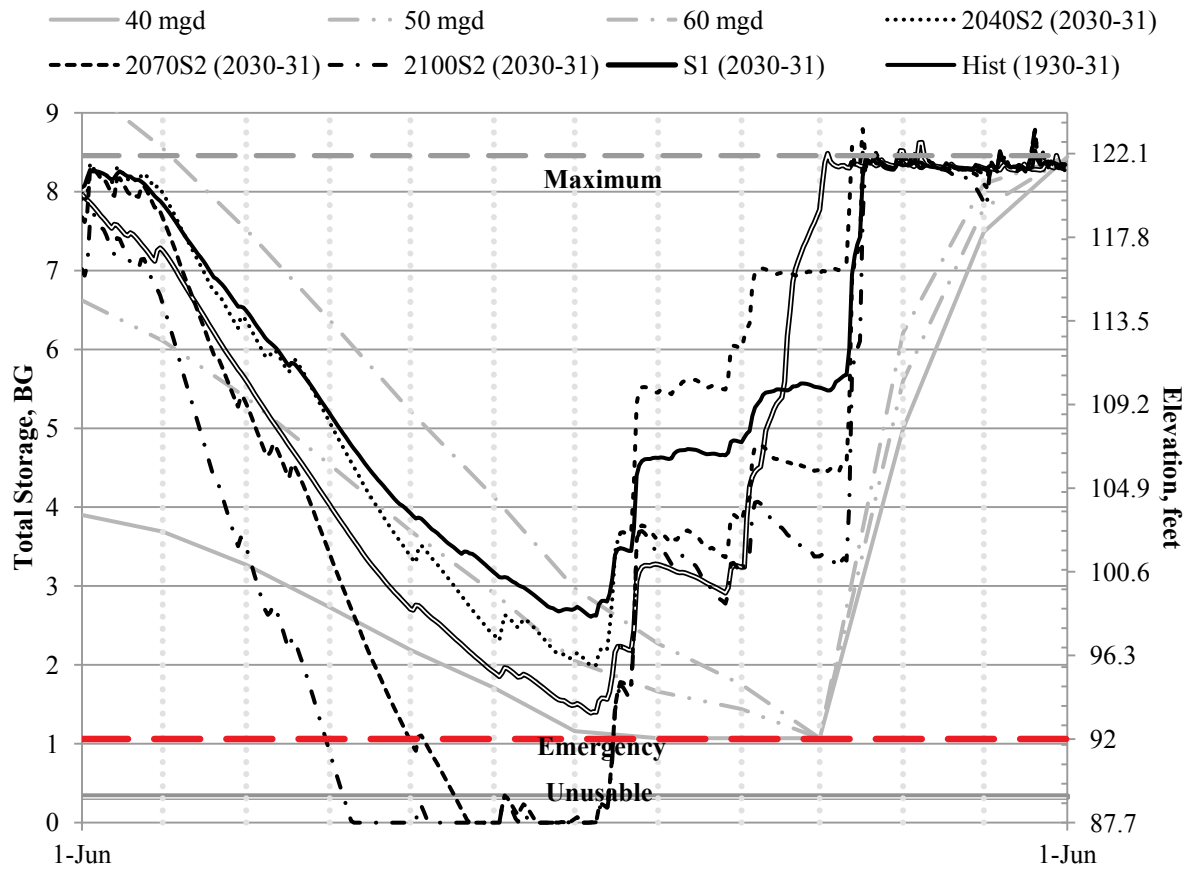


Figure 5.4-21 Occoquan reservoir storage response curves (firm yield) comparing the ensemble historic to MIMR future scenarios S1 and S2 for the drought of record, not accounting for expansion in reclaimed water inflow

Minimum volume (BG): Hist = 2.6, S1 = 1.4, 40S2 = 2.0, 70S2 = 0.0, 00S2 = 0.0

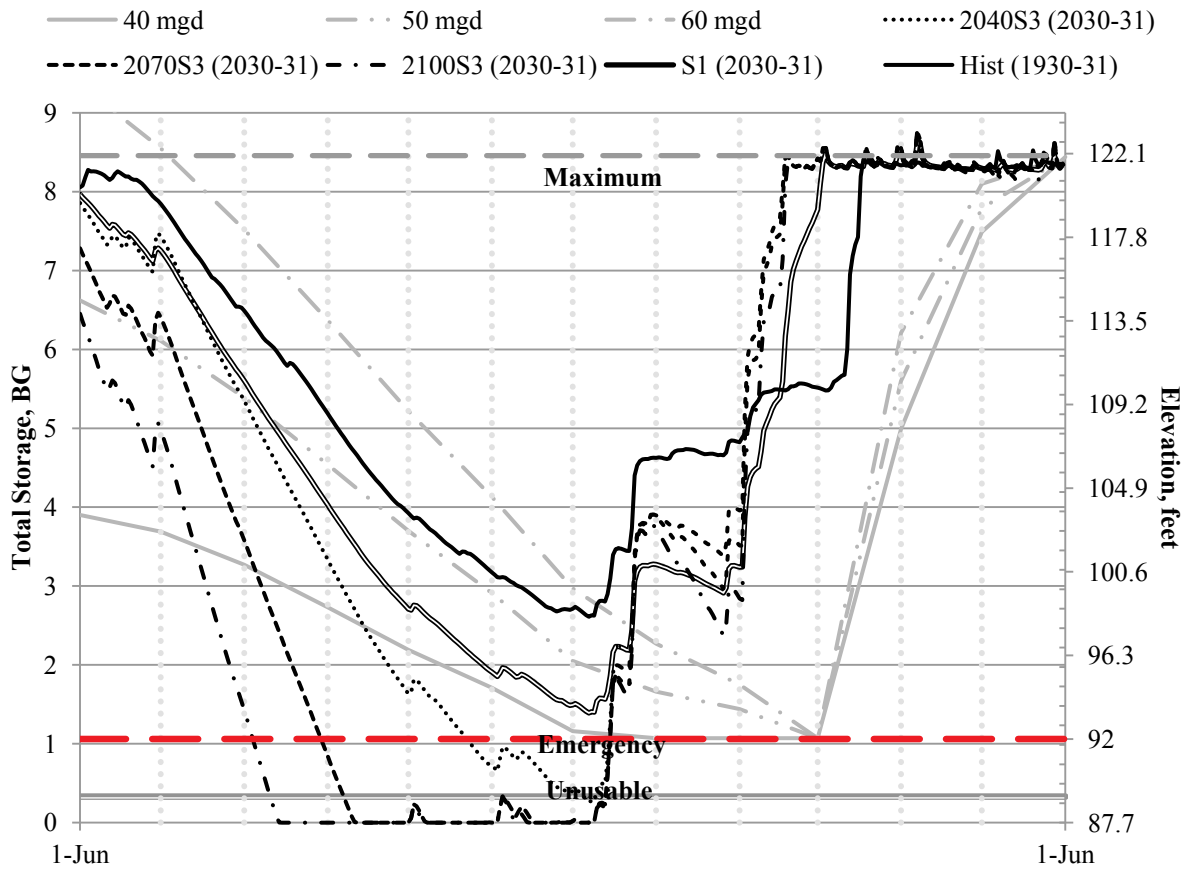


Figure 5.4-22 Occoquan reservoir storage response curves (firm yield) comparing the ensemble historic to MIMR future scenarios S1 and S3 for the drought of record, not accounting for expansion in reclaimed water inflow

Minimum volume (BG): Hist = 2.6, S1 = 1.4, 40S2 = 0.26, 70S2 = 0.0, 00S2 = 0.0

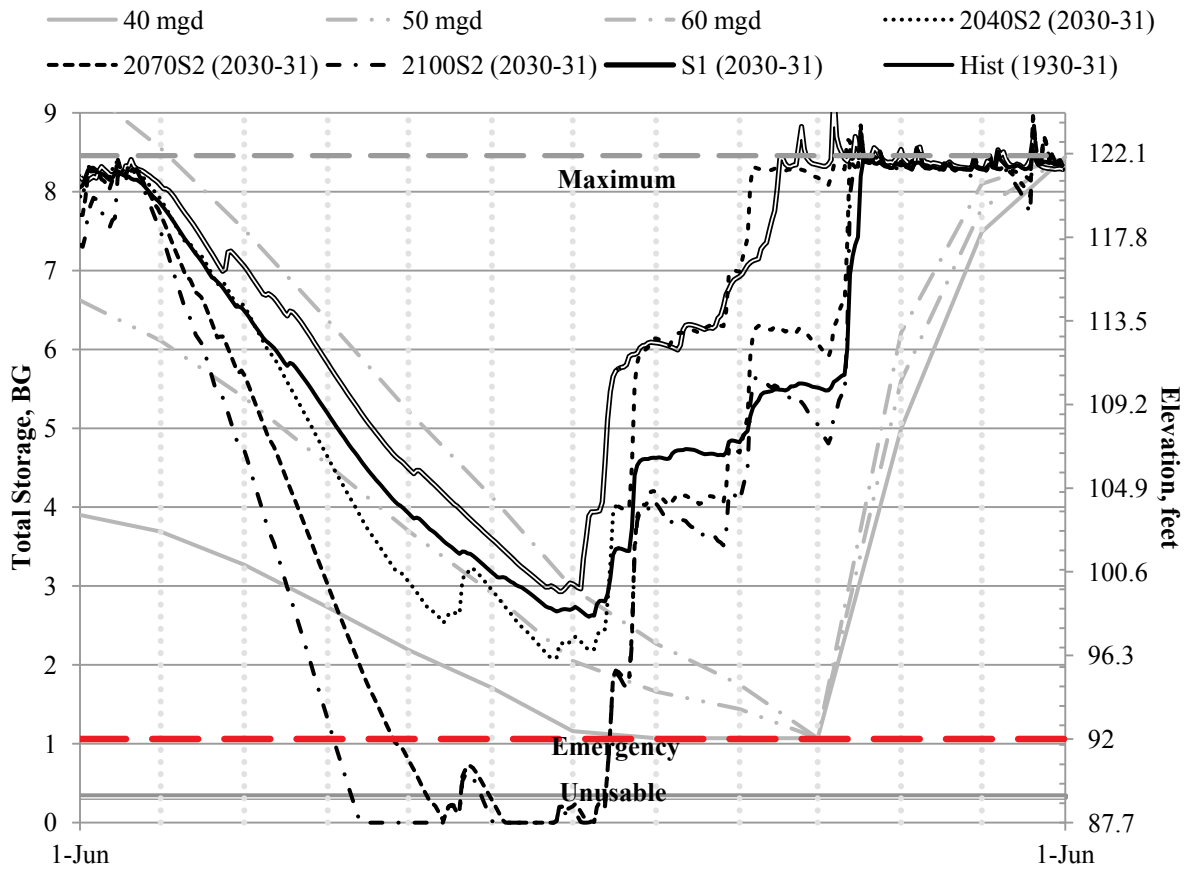


Figure 5.4-23 Occoquan reservoir storage response curves (firm yield) comparing the ensemble historic to MPEH future scenarios S1 and S2 for the drought of record, not accounting for expansion in reclaimed water inflow

Minimum volume (BG): Hist = 2.6, S1 = 2.9, 40S2 = 2.1, 70S2 = 0.0, 00S2 = 0.0

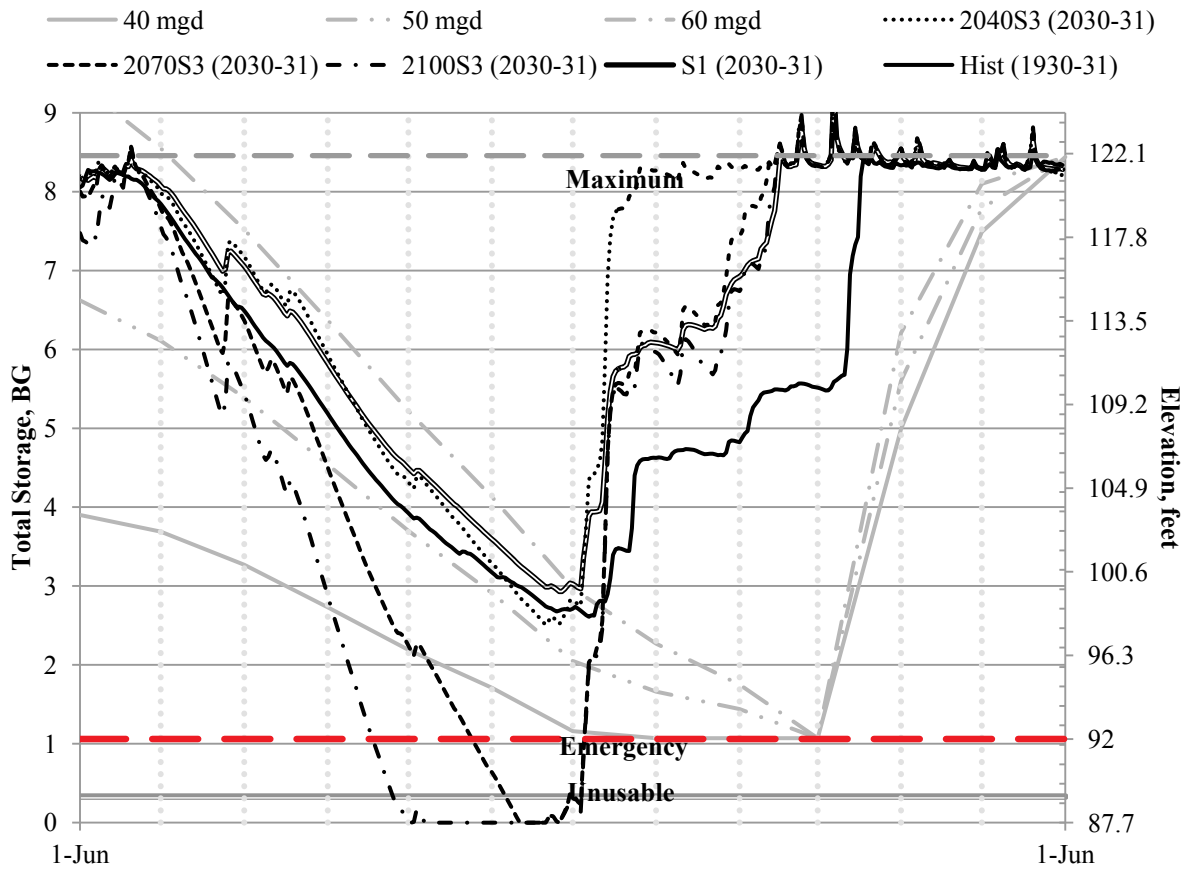


Figure 5.4-24 Occoquan reservoir storage response curves (firm yield) comparing the ensemble historic to MPEH future scenarios S1 and S3 for the drought of record, not accounting for expansion in reclaimed water inflow

Minimum volume (BG): Hist = 2.6, S1 = 2.9, 40S2 = 2.5, 70S2 = 0.0, 00S2 = 0.0

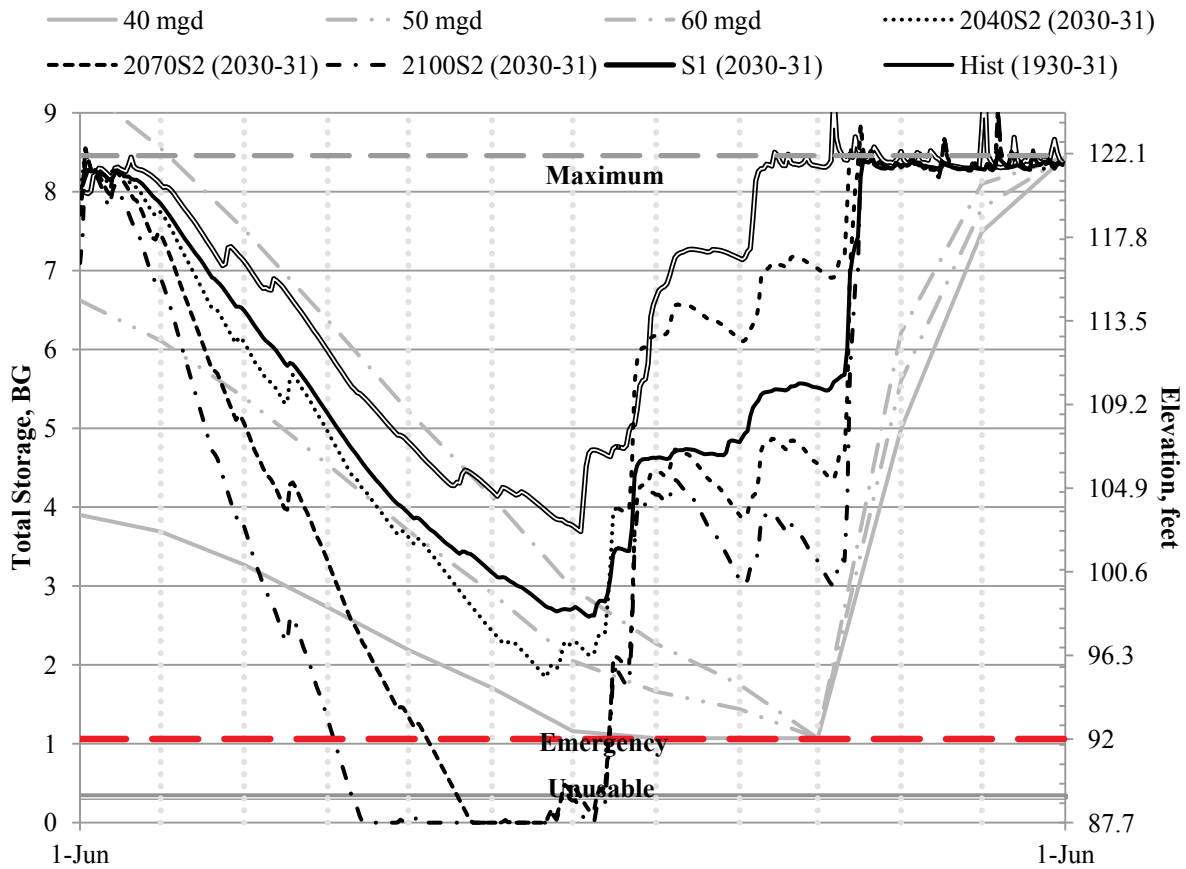


Figure 5.4-25 Occoquan reservoir storage response curves (firm yield) comparing the ensemble historic to NCPDM future scenarios S1 and S2 for the drought of record, not accounting for expansion in reclaimed water inflow

Minimum volume (BG): Hist = 2.6, S1 = 3.7, 40S2 = 1.8, 70S2 = 0.0, 00S2 = 0.0

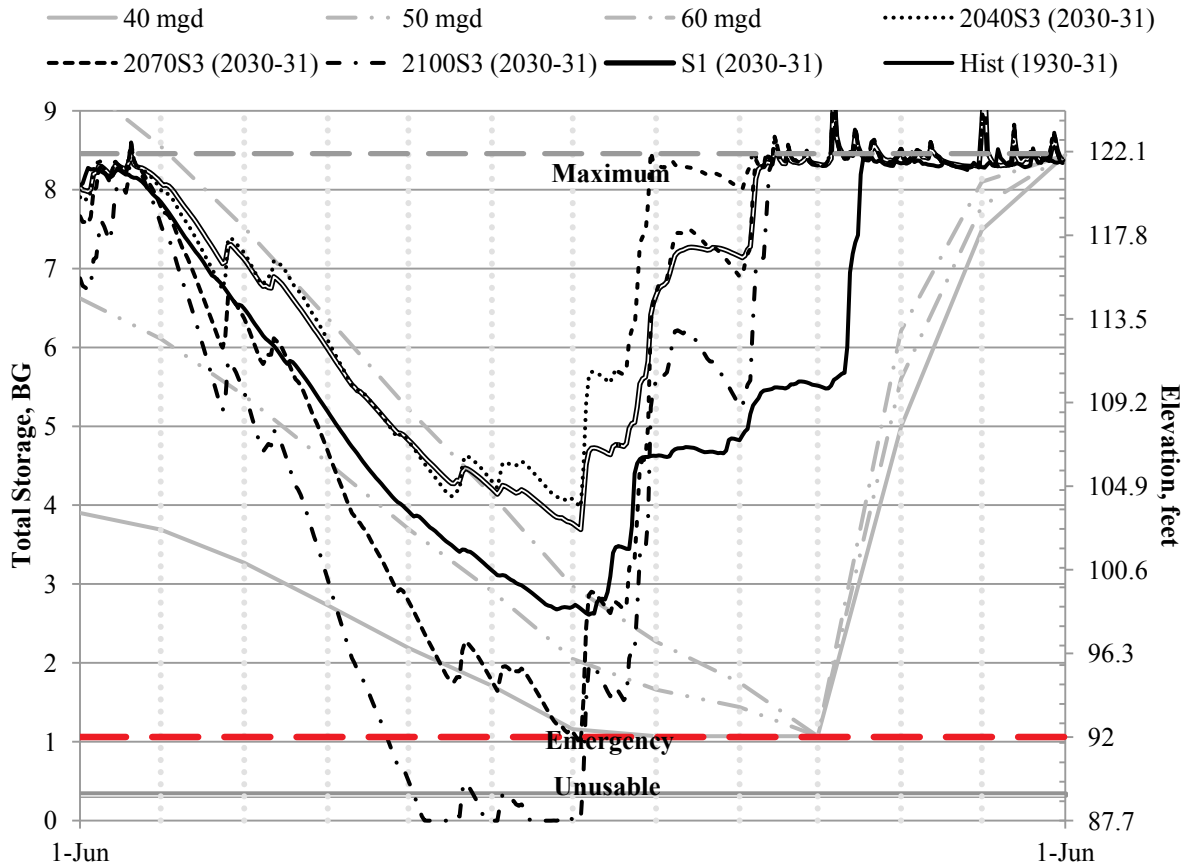


Figure 5.4-26 Occoquan reservoir storage response curves (firm yield) comparing the ensemble historic to NCCPM future scenarios S1 and S3 for the drought of record, not accounting for expansion in reclaimed water inflow

Minimum volume (BG): Hist = 2.5, S1 = 3.7, 40S2 = 4.0, 70S2 = 1.0, 00S2 = 0.0

Table 5.4-2 Minimum volumes (BG) for modeled Occoquan reservoir storage response curves, not accounting for expansion in reclaimed water inflow

	<i>Hist</i>	<i>S1</i>	<i>2040S2</i>	<i>2070S2</i>	<i>2100S2</i>	<i>2040S3</i>	<i>2070S3</i>	<i>2100S3</i>
ENSEMBLE	2.6	2.7	2.1	0.0	0.0	2.4	0.4	0.0
MIMR	2.7	1.4	2.0	0.0	0.0	0.3	0.0	0.0
MPEH	2.6	2.9	2.1	0.0	0.0	2.5	0.0	0.0
NCCPM	2.5	3.7	1.8	0.0	0.0	4.0	1.0	0.0