CUMULATIVE IMPACTS TO THE MISSOURI RIVER

FOR THE

BUREAU OF RECLAMATION'S

NORTHWEST AREA WATER SUPPLY PROJECT

Corps of Engineers

Northwestern Division

Missouri River Basin Water Management Division

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CUMULATIVE IMPACTS TO THE MISSOURI RIVER FOR THE BUREAU OF RECLAMATION'S NORTHWEST AREA WATER SUPPLY PROJECT

Executive Summary

In response to a request from the Bureau of Reclamation (Reclamation), the U.S. Army Corps of Engineers (Corps) conducted an analysis of the effects of the Northwest Area Water Supply (NAWS) Project on the Missouri River for incorporation into the NAWS Project Supplemental Environmental Impact Statement. This analysis was conducted using depletion files provided by Reclamation that were used to adjust the historic inflow data for each year in the 81-year period of analysis of 1930-2010 so that each year's inflows were based on the present level of development in the Missouri River Basin. These adjusted historic files were then used to simulate 2010 conditions, or Existing Conditions, using the Corps' Northwestern Division's Daily Routing Model (DRM) to provide the hydrologic, navigation service, and hydropower output files. The output files were then used to evaluate the economic benefits of the Missouri River Mainstem Reservoir System (System). Four other simulations were developed that were used to identify the effects of 1) continuing sedimentation in the System reservoirs up to the year 2060, the planning horizon for the NAWS Project; 2) the addition of non-Project Missouri River Basin depletions between 2010 and 2060 that were provided by Reclamation; and 3) the addition of the NAWS Project depletions resulting from the transbasin transfer of water from the Missouri River Basin to the Hudson Bay drainage under two conditions – forecasted average annual withdrawals from Lake Sakakawea and full Project capacity. The first part of this report summarizes the hydrologic, navigation service, hydropower, and economic effects for these five simulations – Existing Conditions, Sedimentation 2060, No Action, NAWS 13.6, and NAWS 29.1. The effects of the NAWS Project, whether for the NAWS 13.6 or NAWS 29.1 simulations, were relatively small. For example, the economic effects ranged from -0.81 percent to 0.07 percent, a range of less than 1 percent.

Reclamation also requested the Corps to complete an analysis of the effects of five climate change scenarios for the 2060 timeframe on the NAWS Project option based on the average annual withdrawals from Lake Sakakawea. Reclamation provided monthly percentage changes for five climate change scenarios to the historic inflow files for each reach included in the DRM, and the resulting inflow input files were used to simulate the effects of climate change on the NAWS 13.6 simulation for the Missouri River. This second analysis focused on the hydrologic effects of four (5th through 75th percentile projections) of the five climate change scenarios because the fifth scenario (95th percentile projection) increased the inflows so dramatically (approximately 60 percent in the higher runoff months) that the DRM simulation of this scenario was not possible with the current release limitations of the DRM. For example, the largest annual runoff event simulated for the 75th percentile projection was 59.75 million acre-feet (MAF) of runoff above Sioux City in 1997, and the 95th percentile had six events over 61 MAF (volume of runoff above Sioux City for the 2011 flood), with the highest being 79.23 MAF in 1997. The effects of the climate change scenarios were much larger than the effects of the NAWS 13.6 simulation that was based on no change in basin climate from that which occurred historically for the 50-year period of analysis of 1950-1999 for the climate change analysis, as discussed in the second part of this report. In fact, these effects could be characterized as dwarfing the effects of the NAWS Project under

the historic conditions used to analyze the Project effects in the year 2060, as discussed in the last section of this report. For example, the average annual change in System storage for the NAWS 13.6 simulation from the No Action simulation was 55,000 acre-feet, and the change for the four climate change scenarios from the NAWS 13.6 simulation ranged from -1,043,000 acre-feet to +7,002,000 acre-feet, a range of 8,045,000 acre-feet.

Background

Some background is presented upfront in this report to provide perspective as to why the Corps of Engineers evaluated the cumulative Missouri River impacts for the Northwest Area Water Supply (NAWS) Project Supplemental Environmental Impact Statement (SEIS). The following paragraphs provide background information on the activities by the Bureau of Reclamation (Reclamation) to prepare the SEIS for the NAWS Project.

The Garrison Diversion Unit's Municipal, Rural and Industrial Water Supply (MRI) program was authorized by the U.S. Congress on May 12, 1986, through the Garrison Diversion Unit Reformulation Act of 1986. This act authorized the appropriation of $200 million of Federal funds for the planning and construction of water supply facilities throughout North Dakota. The Dakota Water Resources Act of 2000 amended this authorization to include additional funding for the MRI program. The NAWS Project is authorized as a specific project within the MRI program

Project planning was initiated in 1987 and Reclamation has worked with the project sponsors and others to complete the planning and compliance documentation for the Project. An Environmental Assessment (EA) and Finding of No Significant Impact (FONSI) were completed in 2001. The selected alternative in the FONSI included using water from the Missouri River as the source for the project. Construction of Project features began in the spring of 2002 and in October 2002 the Province of Manitoba, Canada filed a legal challenge of the FONSI in U.S. District Court in Washington, D.C. In 2005 the case was remanded to Reclamation for completion of additional environmental analysis. The court allowed construction to continue on Project features that will not prejudice future decisions on water treatment. Reclamation initiated the preparation of an Environmental Impact Statement (EIS) in response to the court's remand. The Final EIS was released in 2008 and a Record of Decision was signed in 2009. At that time the Province of Manitoba filed a supplemental complaint and the State of Missouri filed a complaint against the Department of Interior and the U.S. Army Corps of Engineers (Corps) in the same District Court. Both complaints alleged Reclamation's EIS was insufficient and the State of Missouri challenged Reclamation's authority to withdraw water from a Corps reservoir (Lake Sakakawea). The court combined the two suits. In 2010 the court remanded the case to Reclamation to take a "hard look" at the cumulative impacts of water withdrawals on Lake Sakakawea and the Missouri River, and the consequences of transferring potentially invasive species into the Hudson Bay Basin.

In response to this court order, Reclamation is preparing an SEIS and requested assistance from the Corps in evaluating the cumulative impacts of water withdrawals on Lake Sakakawea and the Missouri River. The Corps is the federal agency responsible for the operation of the Missouri River Mainstem

Reservoir System (System). Reclamation has also asked to Corps to assist with evaluating how climate change may affect Lake Sakakawea as a potential water source for the Project. The Corps is participating as a cooperating agency in the preparation of the SEIS.

Introduction

Removal of water from the Missouri River Mainstem Reservoir System (System) results in varying levels of impacts, depending primarily on the volume of water being removed. In the SEIS being prepared for the NAWS Project, alternatives proposed include an annual volume of water totaling 10,000-30,000 acre-feet would be pumped from Lake Sakakawea to meet future water supply needs in the NAWS Project area, most of which is located within the Hudson Bay Basin. This transbasin diversion of water would result in no return flows to the Missouri River basin. Analysis of impacts of this transbasin diversion of water was accomplished using the best available information the Corps has regarding impacts of factors affecting the use of water stored in the System – models developed for the Missouri River Master Water Control Manual (Master Manual) Review and Update Study EIS. This report summarizes the methodology followed, the potential changes affecting System regulation (sedimentation in the reservoirs and various depletions of flows) evaluated, and the hydrologic and relative economic impacts among those changes. Finally, the hydrologic effects of four of the five climate change scenarios are presented in this report. Reclamation provided data relative to future climate change scenarios and these data were used as input for Corps models for the System to evaluate hydrologic changes and relative economic impacts of those changes.

Methodology

The Missouri River Basin Water Management (MRBWM) Division of the Corps' Northwestern Division was tasked with completing the identification of the relative impacts of the withdrawal of water from Lake Sakakawea for the NAWS Project. Since its completion of the Master Manual EIS, this office of the Corps has provided technical assistance to Reclamation for the Red River Valley Water Supply Project, which was also a Congressionally authorized transbasin diversion project resulting in the removal of water from System reservoirs (ultimately Lake Sakakawea was selected as the source) to another area of the Hudson Bay drainage area of North Dakota. The basic methodology used for that study was used for the NAWS Project analysis. The Corps process was basically a two-step process followed by the preparation of this report. Using historic and future depletions provided by Reclamation, MRBWM staff simulated the changes to be evaluated using its Daily Routing Model (DRM). The DRM provides hydrologic, navigation, and hydropower data that are then used in impacts models to provide the data for the delineation of the relative differences between and among the simulations of two changes affecting System regulation, continuing sedimentation in the System reservoirs and the depletion of Missouri River inflows and flows.

DRM Simulation Parameters

The DRM was developed during the Master Manual Study to provide daily time-step output data required for several of the Master Manual Study impacts models. The DRM also provides the necessary consolidated monthly files that are required for the other models relying on monthly-time step data.

Use of the DRM requires several input files, some of which can be adapted to allow each of the simulations to depict the change being evaluated. Four of these input files were adapted to complete the simulation of the changes the Corps was asked to evaluate for the NAWS Project. Three of these files – historic depletions to Missouri River inflows, System storage files to accommodate storage changes due to continuing sedimentation, and future depletions files to account for the loss of Missouri River flows due to the NAWS Project and other projects and factors within the Missouri River basin – were adapted to provide the hydrologic, navigation, and hydropower files needed to evaluate the changes. A fourth file, the historic Missouri River inflow file, had to be adapted to provide the hydrologic data needed to provide insight on the effects of climate change on one of the NAWS Project simulations.

Historic Depletions

The Master Manual Study and subsequent studies using the Master Manual models were based on a time-series analysis. Basically a historic period is modeled using the measured inflows coming into the Missouri River over that period. Daily inflow data for numerous Missouri River main stem locations are available going back to 1930; therefore, that is the first year of the period for which DRM simulations were conducted. An 81-year period of record was selected to use for this analysis of changes affecting System regulation, including the depletions associated with the NAWS Project. These historic flows, however, have to be modified to make every year in the modeling period to be set on the same basis as the last year in the modeling period, in this case 2010, which, with the exception of 2011, was the last year of complete data. In its current form, the DRM cannot simulate the extremely large inflows that occurred in 2011. Therefore, changes in depletions to those historic inflows for the simulation period of 1930 through 2010 were required.

Reclamation is the known expert in computing the required depletion files for adjusting historically measured inflows. Two depletion files were developed by Reclamation for this analysis. The first file, historic depletions, provides the data to adjust the measured inflows up such that the natural inflows with no water-using development are computed. Generally, the amount of irrigation and the resulting depletions increase from 1930 through 2010. The second file, present-level depletions, provides the data to adjust the natural inflows down so that every year in the period of analysis would be based on the current level of water-use development in the Missouri River basin. Even with the same irrigated acreage in all years, the effect of this irrigation on depletions varies as the amount of water used for irrigation varies with the historic climatic conditions during the period of record used for this analysis. Therefore, the present-level depletions are variable from year to year.

The differences between the historic depletions file and the present-level depletions file can be referred to as the net depletions file. It is this net depletions file that is used to adjust the historic inflows as the

DRM does its computations to determine the hydrology, navigation service, and hydropower generation of the System and downstream lower Missouri River. When the new net depletions file was incorporated as an input file for the DRM for this analysis of the NAWS Project, output data from the DRM can be viewed as representing the conditions that currently exist for the Missouri River main stem.

Depletions within the Missouri River basin were estimated for the depletion categories of agriculture, public supply, industrial supply, transbasin diversions, and storage losses in Reclamation reservoirs. Reclamation based the agriculture effect on the latest, or 2007, agricultural census data on irrigated acreage in the basin. Public supply depletions were based on population and average water use, and industrial supply depletions were based on varying factors of the public supply depletions for the various sub-basins in the Missouri River basin. Finally, Reclamation storage losses are related primarily to the evaporation losses at its reservoirs within the Missouri River basin.

Sedimentation

Sediment surveys are conducted periodically for each of the six reservoirs comprising the System. As these surveys are completed and the data are analyzed, the sedimentation rates are available for various studies, including the modeling of the System. As sediments accumulate in each reservoir, the amount of storage available at a given water surface elevation diminishes. Thus, the water surface elevation versus storage volume files (capacity files) must be updated following the sediment survey of each reservoir. For the purpose of the modeling studies, the rate of storage loss indicated for each storage zone in each reservoir by the last two sediment surveys is assumed to continue into the future.

Table 1 presents the cumulative storage values for each of the four storage zones, with the values for each storage zone being the total storage for the zones up to the top of that zone for each reservoir. Summation of the values for the top of the exclusive flood control zone for the six reservoirs results in the total System storage capacity. System storage in 2010 totals 72.3 million acre-feet (MAF), and the total System storage is reduced to 69.4 MAF by 2060. This is a net loss of 2.8 MAF (when rounded to nearest tenth) over the 50-year period from existing conditions in 2010 to No Action and the two simulated NAWS Project options in 2060. Simulating the change in System storage over the 50 years without any changes in depletions with the DRM identifies the associated changes in hydrology, navigation service, and hydropower production. This would allow the identification of relative impacts of sedimentation alone between 2010 and 2060, creating a new baseline for identifying the relative impacts of the second factor that would change between 2010 and 2060, additional non-Project depletions to System inflows without the additional depletions of the NAWS Project.

Table 1 also includes the total System storage in each of the four storage zones. The top two zones, the Exclusive Flood Control and the Flood Control and Multiple Use Zones provide for System flood control storage. The total flood control storage remains essentially the same as sedimentation continues primarily in the two lower storage zones from 2010 to 2060. The amount of storage spaces in the Carryover Multiple Use Zone and the Permanent Pool decreases from 2010 to 2060 by 3.81 percent and 7.83 percent, respectively, and total System storage decreases by 3.91 percent.

Table 1: Existing and future System reservoir storage

Storage Zone	Reservoir Elevation	Reservoir Storage to Top of Zone (kAF) 2010	2060
Fort Peck			
Exclusive Flood Control	2250	18,452.9	17,958.0
Flood Control and Multiple Use	2246	17,482.4	16,997.3
Carryover Multiple Use	2234	14,779.2	14,323.5
Permanent	2160	4,082.5	3,813.0
Garrison			
Exclusive Flood Control	1854	23,572.1	23,007.1
Flood Control and Multiple Use	1850	22,070.6	21,477.3
Carryover Multiple Use	1837.5	17,868.5	17,320.4
Permanent	1775	4,955.0	4,898.5
Oahe			
Exclusive Flood Control	1620	22,816.8	22,054.5
Flood Control and Multiple Use	1617	21,705.1	20,919.7
Carryover Multiple Use	1607.5	18,478.3	17,631.3
Permanent	1540	5,246.9	4,946.6
Big Bend			
Exclusive Flood Control	1423	1,666.0	1,156.0
Flood Control and Multiple Use	1422	1,605.6	1,095.6
Carryover Multiple Use	1420	1,488.9	978.9
Permanent	1415	1,220.7	710.7
Fort Randall			
Exclusive Flood Control	1375	5,301.7	4,890.9
Flood Control and Multiple Use	1365	4,317.9	3,902.9
Carryover Multiple Use	1350	3,008.8	2,602.1
Permanent	1320	1,472.6	1,314.9
Gavins Point			
Exclusive Flood Control	1210	445.0	360.0
Flood Control and Multiple Use	1208	388.7	312.2
Carryover Multiple Use	1204.5	303.9	244.4
Permanent	1204.5	303.9	244.4
System Storage in Each Zone			
Exclusive Flood Control		4,684.3	4,721.4
Flood Control and Multiple Use		11,642.7	11,604.5
Carryover Multiple Use		38,646.0	37,172.5
Permanent		17,281.6	15,928.1
Total		72,254.6	69,426.5

Note – Last two surveys: Fort Peck 1986 & 2007; Garrison 1979 & 1988; Oahe 1976 & 1989; Big Bend 1991 & 1997; Fort Randall 1986 & 1996; Gavins Point 1995 & 2007.

Future Depletions

Reclamation estimated future depletions accumulated from various sources by identifying potential projects throughout the Missouri River Basin in various stages of planning for potential implementation by 2060. Additional irrigated crop acreage is likely to occur and water use associated with population growth will result in the growth of depletions in the future. Public supply and industrial supply are forecasted to increase. Finally, the "other" category, which includes energy development in North Dakota, includes about 26 percent of the forecasted growth in depletions in the entire Missouri River Basin.

Table 2: Additional Missouri River Basin depletions, 2010 to 2060 (kaf)

Reach	Public Supply[1]	Industrial Supply[2]	Agriculture	Municipal[3]	Other[4]	Total
Above Fort Peck Dam	4.9	0.2	43.4	11.5	0.6	60.6
Fort Peck Dam to Garrison Dam	2.0	0.8	64.6	18.9	107.2	193.6
Garrison Dam to Oahe Dam	-1.5	-0.4	0.9	9.7	5.2	13.8
Oahe Dam to Big Bend Dam	0.0	0.0	0.0	3.3	5.7	8.9
Big Bend Dam to Fort Randall Dam	0.0	0.0	0.5	0.0	0.0	0.5
Fort Randall Dam to Gavins Point Dam	-0.1	0.0	0.0	0.3	0.0	0.2
Gavins Point Dam to Sioux City, IA	-0.3	0.0	0.0	12.7	13.4	25.8
Sioux City, IA to Omaha, NE	1.1	0.0	0.0	1.1	0.0	2.3
Omaha, NE to Nebraska City, NE	165.2	9.9	0.0	0.0	0.0	175.2
Nebraska City, NE to St. Joseph, MO	0.3	0.0	0.0	0.0	0.0	0.3
St. Joseph, MO to Kansas City, MO	11.8	0.0	0.0	0.4	0.0	12.2
Kansas City, MO to Boonville, MO	17.2	0.1	0.0	0.0	0.0	17.2
Boonville, MO to Hermann, MO	5.2	0.1	0.0	0.0	0.0	5.3
2010 to 2060 Total	205.8	10.6	109.4	57.8	132.2	515.8

[1] This column includes identified potential future water supply projects

[2] This column includes industrial supply, as represented as a percent of municipal.

[3] This column includes future municipal supply based on population projections from census data

[4] This column includes other depletions with zero return flow, e.g., the Red River Valley Water Supply Project

Simulation of the combination of the future depletions presented in Table 2 and the sedimentation that could occur between 2010 and 2060 using the DRM results in what could be the System's hydrologic values, navigation service, and hydropower generation under 2060 conditions without the NAWS Project. Adding in the anticipated depletions of the NAWS Project to a simulation run would identify the hydrologic, navigation service, and hydropower generation values for the total cumulative depletions anticipated by 2060.

Inflow File Modification for Climate Change Analyses

Reclamation's Technical Service Center, Water Resources Planning and Operations Support Group completed a climate change analysis for the Missouri River Basin to provide quantitative representation of how runoff in the basin might respond to a range of future climate projections. Even though best available datasets and modeling tools were used by the Technical Service Center staff and methodologies were followed that have been peer reviewed, uncertainties associated with climate projections and subsequent hydrologic impacts remain. To analyze uncertainty under climate change, future climate projections that responded to a range of future greenhouse emission pathways were analyzed, and a total of 112 bias-corrected and spatially downscaled (BCSD) climate change projections were used to develop 112 hydrologic projections for the Missouri River Basin. For each of the 112 climate projections, simulated runoff from the macro-scale hydrology model VIC (Variable Infiltration Capacity) was routed to each of the 15 DRM nodes to calculate the percentage change in mean monthly runoff from the reference hydrology period 1950-1999 for two look-ahead periods (2010-2039 and 2040-2069). Methods used to develop the climate change and hydrologic projections are described in Reclamation Technical Memorandum No. 86-68210-2012-03 entitled "Climate Change Analysis for the Missouri River Basin". Then the 5th, 25th, 50th, 75th, and 95th percentile runoff changes for each month were selected to represent five change scenarios to be simulated with the DRM to identify a range of potential changes in runoff for the System and lower Missouri River. These five change scenarios represent 90 percent of the range of future runoff changes computed from the 112 hydrologic projections. This range runs from the dry to wet scenarios as the percentile increases. DRM simulations were accomplished using the 2040-2069 tables for each of the five scenarios identifying the percentage change in the historic inflows emanating from the tributary areas at the nodes and incorporated as a primary input file to the DRM. In general, the 5th percentile table reduces inflows for each node, the 25th percentile nearly matches historic inflows, and the other three scenarios add increasing levels of inflows between the nodes. Table 3 presents the required DRM historic inflow changes for the five climate change scenarios informed by runoff changes developed from climate change projections.

Table 3: Climate Change Scenarios for the 2040-2069 Period (% change in mean monthly flows)

5th Percentile

Node Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Fort Peck Dam	-12.12%	-5.64%	-2.63%	6.97%	3.05%	-25.74%	-44.84%	-30.66%	-24.83%	-25.30%	-21.64%	-16.48%
Garrison Dam	-10.49%	-3.89%	-1.08%	3.80%	7.67%	-10.18%	-32.72%	-24.75%	-21.07%	-22.48%	-21.80%	-16.95%
Oahe Dam	-10.27%	-2.88%	-0.86%	3.31%	4.97%	-8.56%	-28.29%	-25.51%	-23.67%	-21.12%	-19.29%	-15.05%
Big Bend Dam	-10.54%	-3.05%	-0.81%	2.28%	4.76%	-7.34%	-27.52%	-25.89%	-23.67%	-21.01%	-19.18%	-14.77%
Fort Randall Dam	-10.42%	-2.60%	-2.04%	-0.19%	3.70%	-6.25%	-26.20%	-26.26%	-24.42%	-21.09%	-18.71%	-13.84%
Gavins Point Dam	-10.29%	-2.82%	-3.54%	-1.36%	3.17%	-6.17%	-25.26%	-26.52%	-25.07%	-20.95%	-18.04%	-13.64%
Sioux City, IA	-7.94%	-2.01%	-1.60%	-3.29%	3.80%	-6.59%	-23.24%	-27.29%	-26.19%	-21.45%	-15.49%	-11.35%
Omaha, NE	-7.92%	-0.87%	-4.60%	-6.45%	2.77%	-6.54%	-22.67%	-28.19%	-27.27%	-21.50%	-15.91%	-11.88%
Nebraska City, NE	-9.16%	-3.52%	-10.03%	-9.89%	-1.57%	-9.75%	-25.20%	-30.18%	-29.79%	-24.01%	-16.99%	-15.04%
Rulo, NE	-9.25%	-4.45%	-12.41%	-10.53%	-2.76%	-9.79%	-25.03%	-30.56%	-30.41%	-24.43%	-16.82%	-15.22%
St. Joseph, MO	-11.01%	-5.74%	-14.30%	-11.37%	-3.39%	-9.54%	-24.64%	-31.00%	-31.46%	-25.48%	-17.92%	-15.85%
Kansas City, MO	-15.96%	-12.08%	-19.15%	-15.94%	-8.63%	-12.49%	-27.23%	-33.74%	-34.65%	-29.80%	-24.19%	-22.89%
Waverly, MO	-16.89%	-12.49%	-19.73%	-15.98%	-8.59%	-12.52%	-26.88%	-33.97%	-34.92%	-30.19%	-24.93%	-23.44%
Boonville, MO	-20.50%	-15.10%	-21.10%	-16.10%	-8.76%	-13.27%	-27.14%	-35.05%	-37.95%	-30.63%	-26.53%	-24.80%
Hermann, MO	-24.35%	-17.17%	-20.77%	-18.31%	-10.74%	-13.88%	-27.72%	-35.87%	-40.91%	-33.04%	-30.31%	-30.05%

25th Percentile

Node Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Fort Peck Dam	0.06%	4.47%	12.23%	21.00%	15.13%	-17.23%	-35.56%	-23.94%	-17.40%	-17.54%	-12.92%	-7.51%
Garrison Dam	-0.91%	4.76%	11.27%	18.74%	18.44%	0.60%	-20.10%	-15.44%	-14.53%	-13.66%	-12.44%	-6.63%
Oahe Dam	-0.39%	6.60%	11.94%	17.38%	19.57%	2.40%	-18.66%	-14.78%	-11.81%	-13.28%	-10.54%	-4.06%
Big Bend Dam	-0.60%	6.56%	12.29%	17.36%	20.15%	3.00%	-18.11%	-15.04%	-11.46%	-12.89%	-9.97%	-4.31%
Fort Randall Dam	-0.94%	5.86%	11.95%	17.58%	19.77%	3.37%	-17.28%	-14.86%	-11.08%	-12.86%	-9.19%	-4.24%
Gavins Point Dam	-0.85%	5.62%	11.72%	15.19%	19.06%	4.00%	-16.24%	-14.67%	-10.57%	-12.95%	-9.39%	-4.31%
Sioux City, IA	1.21%	8.49%	13.89%	15.94%	16.77%	4.78%	-14.37%	-15.19%	-7.66%	-12.16%	-6.98%	-0.76%
Omaha, NE	1.81%	8.92%	11.58%	13.72%	16.79%	5.87%	-13.28%	-14.21%	-8.72%	-12.30%	-6.50%	-0.14%
Nebraska City, NE	1.98%	8.29%	8.91%	10.84%	13.57%	3.45%	-13.35%	-14.76%	-11.05%	-13.17%	-6.94%	-2.26%
Rulo, NEi	1.99%	8.12%	7.58%	9.69%	12.36%	4.33%	-12.55%	-14.45%	-11.64%	-12.90%	-6.89%	-2.19%
St. Joseph, MO	2.26%	7.26%	6.14%	8.79%	11.50%	4.44%	-11.41%	-14.15%	-12.35%	-12.07%	-7.76%	-2.76%
Kansas City, MO	1.09%	5.88%	-0.07%	4.28%	9.59%	1.78%	-11.13%	-15.66%	-13.41%	-11.89%	-10.35%	-5.80%
Waverly, MO	0.60%	5.50%	-0.32%	4.17%	9.31%	2.05%	-10.99%	-15.75%	-13.50%	-11.58%	-10.36%	-5.89%
Boonville, MO	2.04%	3.64%	-0.71%	2.07%	9.39%	2.20%	-10.76%	-14.38%	-13.12%	-10.53%	-10.68%	-5.96%
Hermann, MO	-1.85%	0.11%	-2.33%	-0.42%	5.90%	2.17%	-10.37%	-13.54%	-13.53%	-12.47%	-11.56%	-4.71%

50th Percentile

Node Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Fort Peck Dam	10.08%	14.45%	23.59%	34.19%	22.06%	-7.35%	-27.44%	-15.75%	-11.28%	-9.80%	-4.20%	2.85%
Garrison Dam	8.76%	14.30%	21.23%	29.26%	27.59%	7.71%	-13.03%	-8.61%	-6.02%	-7.25%	-4.19%	2.12%
Oahe Dam	9.98%	14.25%	21.78%	29.95%	27.44%	10.70%	-9.02%	-6.53%	-4.32%	-4.13%	-2.46%	2.72%
Big Bend Dam	10.06%	14.20%	21.43%	29.50%	27.52%	11.56%	-8.45%	-6.44%	-3.74%	-4.08%	-2.65%	2.34%
Fort Randall Dam	10.32%	14.17%	21.47%	29.48%	27.55%	12.66%	-7.31%	-5.73%	-3.15%	-3.75%	-2.47%	2.34%
Gavins Point Dam	10.40%	14.67%	20.67%	29.17%	28.35%	13.76%	-6.53%	-5.10%	-2.43%	-3.40%	-1.34%	2.47%
Sioux City, IA	13.11%	17.76%	23.83%	28.61%	30.01%	15.15%	-5.28%	-2.97%	-0.06%	1.70%	4.25%	6.52%
Omaha, NE	13.51%	19.20%	25.96%	26.72%	29.34%	15.96%	-3.65%	-2.41%	1.87%	1.35%	6.63%	8.20%
Nebraska City, NE	13.57%	19.27%	25.37%	23.62%	26.04%	14.36%	-4.65%	-1.81%	0.68%	0.51%	5.83%	8.44%
Rulo, NE	14.03%	18.76%	23.70%	22.38%	25.01%	14.45%	-4.34%	-1.53%	1.23%	0.75%	5.59%	9.58%
St. Joseph, MO	13.76%	18.87%	21.77%	20.66%	24.47%	14.77%	-3.20%	-1.28%	1.83%	0.37%	5.52%	11.02%
Kansas City, MO	11.62%	15.77%	19.09%	16.32%	22.87%	15.19%	-0.33%	1.31%	2.28%	0.04%	5.30%	10.46%
Waverly, MO	11.41%	15.55%	17.89%	16.30%	22.45%	15.55%	-0.13%	1.21%	2.65%	-0.45%	5.39%	10.54%
Boonville, MO	10.57%	14.27%	13.19%	15.65%	22.47%	16.48%	-0.28%	1.29%	3.14%	1.50%	4.74%	11.39%
Hermann, MO	11.35%	11.55%	10.92%	14.71%	20.64%	16.33%	0.14%	2.39%	3.61%	0.68%	4.87%	11.27%

75th Percentile

Node Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Fort Peck Dam	27.51%	35.52%	43.45%	56.62%	37.76%	6.68%	-14.59%	-1.62%	-0.80%	1.55%	5.70%	12.07%
Garrison Dam	21.89%	29.93%	38.11%	47.02%	39.19%	18.17%	-2.37%	0.53%	2.16%	4.12%	6.41%	11.90%
Oahe Dam	20.78%	30.44%	40.65%	42.34%	38.18%	21.47%	1.97%	3.25%	4.82%	5.61%	9.42%	11.86%
Big Bend Dam	20.42%	30.02%	40.69%	42.43%	37.50%	22.36%	2.84%	3.66%	4.90%	5.49%	9.79%	12.05%
Fort Randall Dam	20.29%	29.09%	40.41%	41.59%	38.27%	23.36%	3.63%	4.12%	5.11%	6.39%	10.07%	12.68%
Gavins Point Dam	20.29%	28.23%	39.82%	42.13%	38.56%	24.15%	4.34%	4.93%	5.83%	6.91%	10.38%	13.59%
Sioux City, IA	24.91%	31.61%	43.32%	44.43%	41.53%	24.85%	6.13%	7.36%	10.60%	11.47%	16.10%	19.26%
Omaha, NE	26.87%	32.32%	42.54%	42.44%	40.79%	24.37%	7.21%	6.95%	12.07%	12.27%	17.43%	20.91%
Nebraska City, NE	24.87%	33.87%	44.59%	42.57%	38.91%	25.44%	6.67%	7.50%	12.84%	11.80%	16.50%	19.73%
Rulo, NE	26.38%	33.14%	44.34%	41.38%	38.57%	25.60%	7.75%	8.05%	14.29%	11.53%	17.35%	20.21%
St. Joseph, MO	26.13%	31.31%	42.94%	39.38%	39.00%	26.07%	8.12%	8.30%	14.97%	12.25%	18.87%	20.54%
Kansas City, MO	29.36%	30.91%	40.49%	39.27%	38.91%	28.02%	12.58%	10.45%	14.72%	14.68%	22.22%	24.84%
Waverly, MO	29.40%	30.72%	40.22%	38.27%	39.08%	27.71%	13.20%	10.01%	15.47%	16.16%	21.79%	24.52%
Boonville, MO	27.54%	28.97%	35.27%	35.74%	38.83%	28.30%	15.16%	10.86%	16.94%	18.46%	20.11%	23.60%
Hermann, MO	26.23%	25.50%	29.64%	33.49%	37.89%	27.49%	16.35%	12.44%	18.43%	17.20%	19.64%	22.98%

95th Percentile

Node Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Fort Peck Dam	56.40%	67.79%	79.51%	90.11%	67.80%	28.52%	3.57%	18.49%	22.53%	30.14%	30.26%	42.38%
Garrison Dam	50.98%	54.07%	60.24%	67.01%	60.14%	38.53%	16.41%	19.00%	18.48%	24.64%	29.47%	36.06%
Oahe Dam	51.94%	50.28%	60.01%	69.85%	58.55%	41.66%	19.33%	18.68%	20.54%	26.64%	34.29%	40.90%
Big Bend Dam	51.79%	49.99%	60.69%	70.98%	59.42%	41.84%	19.92%	18.94%	21.19%	26.89%	34.34%	41.28%
Fort Randall Dam	51.45%	50.05%	60.46%	73.96%	59.85%	42.61%	21.19%	19.36%	22.08%	27.31%	33.95%	41.17%
Gavins Point Dam	51.55%	50.38%	59.39%	73.87%	59.86%	43.53%	22.48%	19.83%	22.95%	27.59%	33.72%	40.82%
Sioux City, IA	50.15%	52.46%	63.54%	78.06%	64.32%	43.32%	25.25%	20.47%	30.11%	32.48%	36.86%	43.19%
Omaha, NE	51.79%	55.31%	64.89%	75.57%	63.43%	45.47%	26.67%	20.78%	33.28%	31.78%	37.15%	43.72%
Nebraska City, NE	48.03%	53.22%	64.40%	75.36%	57.27%	41.88%	24.66%	21.86%	36.54%	29.72%	33.57%	39.79%
Rulo, NE	47.93%	54.58%	63.89%	73.24%	56.92%	41.26%	24.74%	22.88%	36.62%	30.03%	34.71%	40.72%
St. Joseph, MO	47.33%	55.35%	63.80%	72.61%	56.69%	41.46%	25.14%	22.84%	38.36%	30.56%	35.85%	39.32%
Kansas City, MO	45.83%	52.58%	69.09%	71.76%	56.31%	45.01%	29.70%	25.14%	41.72%	35.90%	39.88%	41.26%
Waverly, MO	45.30%	52.12%	67.45%	72.68%	56.35%	45.72%	30.55%	25.38%	42.18%	37.46%	39.43%	41.88%
Boonville, MO	45.01%	50.87%	59.46%	68.19%	55.57%	45.79%	32.40%	28.32%	47.45%	41.69%	40.34%	44.13%
Hermann, MO	43.27%	47.60%	51.14%	60.56%	55.77%	45.35%	33.67%	28.80%	54.94%	42.38%	42.77%	44.70%

Simulations

Five simulations of the changes that affect System regulation were analyzed for this study. They represent the range of conditions outlined in the previous section on DRM parameters.

Existing Conditions

The Existing Conditions simulation (Exist Cond in some tables and figures) represents the conditions existing in basically 2010. Net depletions are those updated through 2010. Sedimentation occurring in the six System reservoirs is that which has accumulated up to and since the last sediment survey for each reservoir, with the total System storage at 72.3 MAF and the storage space required for the Permanent Pool at 17.3 MAF. Therefore, System storage totaling 55.0 MAF is available for the control of floods and maintenance of System releases during droughts.

Sedimentation 2060

Reclamation requested that the Corps simulate the conditions that could occur in 2060. That would include the sediments that would accrue in the reservoirs and the additional depletions between 2010 and 2060. To separate out the effects of the sedimentation and the depletions, a simulation was modeled that included only the effects of continuing sedimentation in the System reservoirs. This simulation, referred to as Sedimentation 2060 (Sed 2060 in some tables and figures), included the sedimentation that would occur by 2060 if the rate of sedimentation for each reservoir were to continue at the same rate that occurred between the last two sediment surveys. The resulting storage changes were outlined in the DRM sedimentation discussion in the previous section.

No Action

Reclamation has determined that the simulations for the NAWS Project include future conditions out to 2060, which corresponds to a 50-year project life. The No Action simulation includes both the sedimentation and the additional non-Project depletions that could occur between 2010 and 2060. This simulation, as indicated by its name, would serve as the No Action alternative, as required for environmental documents prepared in response to the National Environmental Policy Act, for the NAWS Project options simulated for this analysis. It includes the forecasted sedimentation in the Sedimentation 2060 simulation and the additional non-Project depletions between 2010 and 2060, (does not include NAWS Project depletions), as forecasted by Reclamation. The additional depletions were outlined in the section above on the DRM input files.

NAWS 13.6

The first of two NAWS Project simulations selected by Reclamation for this analysis of the cumulative impacts of the NAWS Project is referred to as NAWS 13.6. This option represents the forecasted average monthly water use of the NAWS Project totaling 13,600 acre-feet (ac-ft) per year, or 13.6 thousand ac-ft (kAF) per year. It consists of the average monthly use of water in the service area (11.328 kAF) plus 20 percent for losses (e.g., back flushing treatment plant filters). Table 4 lists the monthly distribution of the annual depletion value for NAWS 13.6. NAWS 13.6 was selected as the baseline simulation for the hydrologic analysis of the climate change scenarios completed as part of this overall analysis of the cumulative effects of the NAWS Project to the Missouri River.

Table 4: Average monthly water use included in the NAWS 13.6 simulation

Month	% of Annual	Monthly Use (ac-ft)	Monthly Use w/ 20% (ac-ft)
January	3	339.8	407.8
February	3	339.8	407.8
March	6	679.7	815.6
April	7	793.0	951.6
May	10	1,132.8	1,359.4
June	13	1,472.6	1,767.2
July	18	2,039.0	2,446.8
August	15	1,699.2	2,039.0
September	11	1,246.1	1,495.3
October	8	906.2	1,087.5
November	3	339.8	407.8
December	3	339.8	407.8
Annual Total	100	11,328	13,594

NAWS 29.1

The second NAWS Project option selected by Reclamation for the cumulative effects analysis of the Project is NAWS 29.1, which includes the maximum capacity of the pipeline However, the NAWS Project could not physically operate at this maximum capacity 24 hours a day, 7 days a week for 365 days. This option, therefore, does not include the additional 20 percent that NAWS 13.6 option included. In this case, the exact amount in the simulation is not critical since this report will include a trends analysis following the results of the relative differences on which the analysis focuses. The average annual volume of 29.1 kAF breaks down to 2.427 AF per month, or 26 million gallons per day, which corresponds to the maximum capacity of the main transmission pipeline between Lake Sakakawea and Minot.

Impacts Analyses

Missouri River cumulative impacts analysis of the five simulations conducted for this analysis of the changes that affect System regulation can be broken down into two distinct categories. The first is the analysis of the hydrologic effects of the differences among the five simulations, which will look at the impacts incrementally as the sedimentation and depletion values are incorporated incrementally into the Existing Conditions simulation. The second is the economic analyses of the five simulations, which can also be examined for the changes incorporated incrementally into the Existing Conditions simulation.

Hydrologic Impacts

The DRM simulates an 81-year period of 1930 through 2010. Using the historic and present-level depletions, the historic inflows can be adjusted as if each occurred in 2010. The DRM routes these inflows through Missouri River main stem following the criteria of the current water control plan, as outlined in the 2006 Master Manual. Therefore, 81 years of hydrologic data are available for analysis in whatever method that makes sense. For example, one can look at daily data for each simulation; however, this was not the best presentation for all of the hydrologic parameters in a report because each simulation has 81 years of data for each node in the DRM for all 365 or 366 days of those 81 years, meaning that there are over 29,000 lines of data for each of the 20 locations with output data. Graphics programs allow the plotting of data on any basis one desires; however, many of the options do not provide a clear picture of the differences between two simulations or among three or more simulations. One such methodology was to compute the daily differences between two simulations and sorting those differences from most negative differences to most positive differences. The greater the differences and the more often there are differences between the two simulations are indicators of the relative hydrologic effects between the two simulations. Also, plotting the sorted differences between a single simulation and more than one of the other four simulations can be accomplished to identify the relative differences among that simulation and the others selected for comparison. The hydrologic variables that will be focused on in this report are the differences in the volume of water in System storage, reservoir levels, and reservoir releases. Differences in the releases from Gavins Point Dam will be identical to those differences in flows at the DRM output file locations on the lower Missouri River downstream from the System; therefore, no plots of differences were developed for the lower Missouri River locations. Since the climate change scenarios affect inflows not only to the reaches entering the System reservoirs but also downstream from the System, analysis of reservoir releases will be expanded to include the flows on the lower river reaches for that portion of the data presented in this report.

Economic Impacts

Many users rely on the water that is stored in the System reservoirs or that flows through the open Missouri River reaches. The effects of future depletions coupled with future sedimentation were computed using the economic impacts models developed for the Master Manual EIS. Table 5 lists the Missouri River economic uses for which effects were computed for this analysis. A brief description of each use follows.

Table 5: Missouri River economic uses evaluated for the NAWS Project cumulative impacts analysis

Use/Resource Category	Abbreviation	Unit
Flood Control	FC	$ million
Missouri River Navigation	NAV	$ million
Hydropower	HYD	$ million
Water Supply	WS	$ million
Recreation	REC	$ million
Total Economics	TOT	$ million

Flood control (FC) National Economic Development (NED) benefits are damages prevented by the construction and regulation of the six System dams on the Missouri River. The benefits computed represent the difference between the damages that would have occurred had the dams and reservoirs not been constructed and those with these projects in place. These benefits are computed using the hydrologic output files of the DRM.

Missouri River navigation NED (NAV) benefits represent the cost savings provided by navigation on the Missouri River from Sioux City, Iowa to the mouth versus movement of those commodities by the next least costly mode of transportation, which in the case of down-bound movements is generally rail or truck transport to St. Louis where Mississippi River navigation is used to transport the commodity to the ultimate destination and vice versa for up-bound movements. These economic benefits are computed using the DRM navigation output files.

Hydropower NED (HYD) benefits are computed for the capacity provided and the energy generated by the hydropower units at the six System dams. The benefits represent the cost savings provided by generating the electricity at the dams versus building additional generating facilities in the basin. These additional facilities would be a mix of base load and peaking power plants, and the cost for the power from them would be more costly than the hydropower. These economic benefits are computed using the DRM capacity and energy output files.

Water supply NED (WS) benefits are computed based on costs for water supply facilities that depend on the Missouri River or the System reservoirs as a direct source of water. Typically, the costs increase during extended droughts when the reservoir levels drop and the river flows are reduced. Increased costs occur when the users must increase efforts to ensure that the water intakes continue to operate as the water surface drops toward the top of intakes during the droughts. In some cases, the intakes must be modified to ensure that the user has continued access to the water throughout the drought. In the case of power plants that rely on once-through cooling, the cost for intake modifications are compared to the costs associated with meeting discharge requirements for the waste heat as it is returned to the Missouri River in the form of warmer water. Both the intake limitation and the discharge limitation generally result in reduced power generation. To meet the greater limitation of the two in any given month, replacement energy would need to be purchased from the power grid, which means that additional generating capability must be constructed to provide the capacity needed in the region during power shortfalls. The cost of providing this additional capacity was included in the water supply benefits for the power plants in the reach downstream from Garrison Dam in North Dakota and along the lower Missouri River from Gavins Point Dam, the lower most of the six dams, to the mouth of the river. The greater of the two costs (intake versus discharge limitations) is used to compute the benefits for the thermal power plants. The DRM hydrologic output files are used in the water supply economic impact computations.

Recreation NED (REC) benefits are based on the value of the various forms of recreation provided on the Missouri River and the Corps' six System reservoirs. This value is generally based on the amount of money the users are willing to spend to travel to the recreation facilities. Reductions in benefits are computed to reflect increased costs during abnormally high and low reservoir levels. Benefits, therefore, fluctuate as the visitation varies, and the costs increase during extreme events such as extended droughts and very wet years in the upper Missouri River basin. Because these benefits are based on reservoir levels and river flows, the DRM hydrologic output files are used in the computation of the recreation benefits.

Total NED (TOT) benefits are just a summation of the benefits for the five economic uses described above. All of these economic benefits are computed in millions of dollars.

Hydrologic Impacts for Simulations Conducted for the NAWS Project SEIS

The volume of water stored in the System varies with changes in annual inflows into the Missouri River mainstem and the amount of water released from the System to meet its authorized purposes. Daily decisions for the operation of the System depend on the amount of water stored in the System and the distribution of the water among the upper three, larger reservoirs. To maintain the desired levels in the individual reservoirs and to meet the flow requirements of the authorized purposes on the lower Missouri River downstream from the System, releases are set from each System project. This section of the report will summarize the impacts to the volume of water stored in the System, the water surface elevations of the four larger System reservoirs, and the releases from Gavins Point Dam and the upper three, larger reservoirs (Fort Peck, Garrison, and Oahe). This section will conclude with a discussion of minimum System storage and reservoir water levels to highlight the effects on the changes added to existing conditions on these two hydrologic factors. A subsequent section of the report addressing climate change scenarios will also include the basic hydrologic factors as well as flows on the lower Missouri River.

System Storage

Decisions on releases from the System are based on the amount of water in System storage. During extended droughts, the amount of water in System storage drops well below the base of flood control storage throughout the year. In the non-drought periods, the goal on March 1 of each year is to have the volume of water in System storage at the base of flood control storage, which is assumed to be 55.9 MAF under existing conditions (lower level compared to the currently reported 56.8 MAF that is based on estimating current System storage accounting for storage loss based on historic loss rates between the last two surveys for each reservoir to 2010). By 2060, the continuation of storage loss due to continuing sedimentation in the reservoirs at the most recently monitored rates will result in a reduction of the base of flood control to 53.1 MAF.

Plots of the volume of water in System storage (to be referred to as System storage from here on) over the 81-year period of analysis show the variability of System storage as it responds to drought and high inflow conditions. This type of plot, however, does not clearly show the differences in System storage between two simulations. These differences are more easily seen if only the differences from a single baseline, in this case the Existing Conditions simulation, are plotted over the period of analysis. Finally the sorting of these differences from most negative to most positive provides some additional perspective as to how much these differences vary from zero differences. All three plots will be shown, as needed, to provide some perspective as each variable is added – sedimentation between 2010 and 2060 (Exist Cond to Sed 2060), addition of non-Project depletions between 2010 and 2060 to the sedimentation in 2060 simulation (Sed 2060 to No Action), additional depletions resulting from the addition of the average monthly NAWS Project water use to No Action (No Action to NAWS 13.6), and additional depletions resulting from the addition of the main transmission pipeline capacity to No Action (No Action to NAWS 29.1).

Adding Sedimentation through 2060 to form the Sedimentation 2060 Simulation

Sedimentation will continue to reduce the availability to store water in the System reservoirs. In the 1973-1974 Annual Operating Plan, the reported total System storage was 74.7 MAF, with 58.3 MAF of that storage at the base of flood control. In 1989 when the Master Manual Study was initiated, the total System storage and that up to the base of flood control were 73.9 MAF and 57.6 MAF, respectively. The most recent values for these two System storage levels (August 2011 but first reported in August 2009) are 73.1 MAF and 56.8 MAF, respectively. The bulk of these storage changes have come from that volume stored under the base of flood control, with the losses under the base of flood control from 1973 to 1989 (16 years) totaling 0.7 MAF and from 1989 to 2011 (22 years) totaling 0.8 MAF. Therefore, loss of System storage below the base of flood control totaled 1.5 MAF over that 38-year period, assuming that the data used to generate those values was very recent. In the case of the 2009 value, the data are not very recent for all of the reservoirs, indicating that the loss over the 38-year period could have been greater than 1.5 MAF. As identified earlier in this report, the loss between 2010 and 2060 is estimated to be 2.8 MAF, which appears to be reasonable for that 50-year period.

The effect of the loss of 2.8 MAF of storage between 2010 and 2060 is reflected in Figures 1 through 3. Figure 1 shows the variability in System storage over the 1930-2010 period of analysis for the Existing

Conditions and Sedimentation 2060 simulations. The four extended droughts are readily apparent with the four larger dips in System storage. The effect of the loss of storage to 2060, however, is not a readily apparent. Figure 2 shows these losses on a scale that they are more readily apparent by presenting the differences on a daily basis between the two simulations. These differences between Existing Conditions (Exist Cond) and the addition of sedimentation in 2060 (Sed 2060) are lowest during the four droughts as the navigation guide curves "kick in" earlier in the four droughts to limit the differences. The large spike in System storage in 1942 occurred due to an additional non-navigation year for the Sedimentation 2060 simulation in 1940, saving an apparent almost 6 MAF of water in the System. The reduction in 1942 results from an additional non-navigation year for the Existing Conditions simulation, losing approximately 5.5 MAF in System storage. The sorted differences are presented in Figure 3, which also shows that there is a reduced amount of storage over the period of analysis that is also apparent in Figure 2. In general, future sedimentation will result in lower System storage in about 97 percent of the days during the 81-year period of analysis. The 3 percent that is the exception results when an additional non-navigation year occurs with the continuing sedimentation (the spike in System storage on Figure 2).

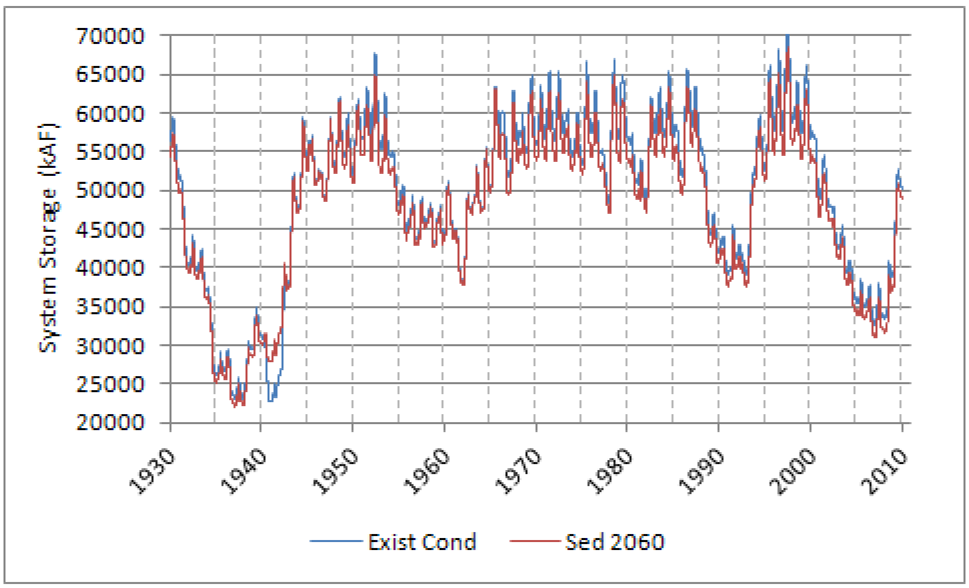

Figure 1. Daily System storage on an annual basis for Existing Conditions and Sedimentation 2060 for the period of analysis of 1930-2010.

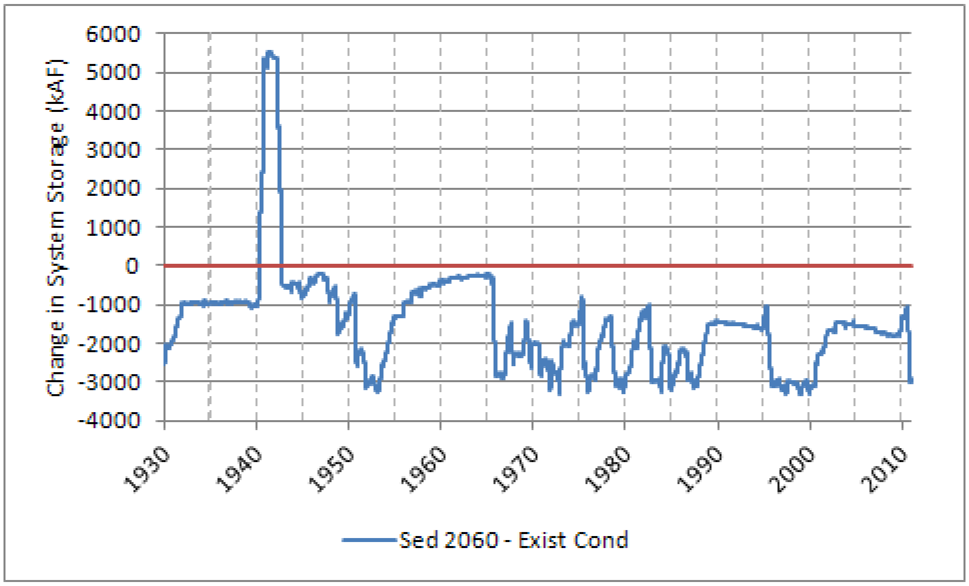

Figure 2. Daily System storage difference for Sedimentation 2060 minus those for Existing Conditions for the period of analysis of 1930-2010.

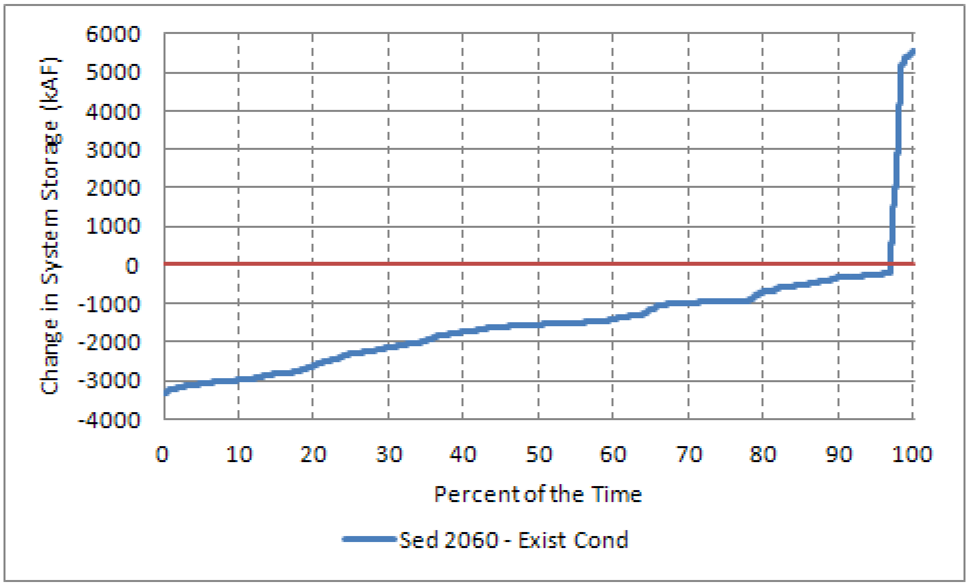

Figure 3. Sorted daily difference values for System storage level for Sedimentation 2060 minus those for Existing Conditions for the period of analysis of 1930-2010.

Adding Depletions and Sedimentation through 2060 to form the No Action Simulation

As the water entering the Missouri River is reduced due to factors that deplete that water, the System storage is likely to be further reduced, especially in drought periods. The addition of non-Project depletions that could occur between 2010 and 2060 to the Sedimentation 2060 simulation forms the No Action simulation to which the depletion options for the NAWS Project can subsequently be added to determine the effects of that project.

The forecasted additional non-Project depletions through 2060 were developed by Reclamation. These depletions total 516 kAF (approximately 3.8 percent of 13,579 kAF, the present level of depletions in 2010 at Hermann, MO, as developed by Reclamation) and resulted in reduced System storage when compared to the System storage for the Sedimentation 2060 simulations' storage levels. This response is shown in Figures 4 through 6. Figure 4 shows the annual storage values, and the differences between the two simulations are not very apparent due to the scale for System storage on the figure. These differences are readily apparent in the differences shown in Figure 5. The differences grow on an annual basis during the four extended droughts as these depletions accumulate. The differences diminish somewhat quickly after the 1950s and early 1990s droughts; however, they recover very quickly following the 1930s and 2000s droughts due to additional non-navigation years in 1942 and 2007 for the No Action simulation. The water saved in the System in those two years is about 5.5 MAF and 4.5 MAF, respectively. Figure 6 shows the System storage differences between the simulations for No Action and Existing Conditions. This figure also has the differences between the simulations for Sedimentation 2060 and Existing Conditions. It is readily apparent that the additional depletions in the No Action simulation would result in lower System storage when combined with the sedimentation than the sedimentation alone would cause. The differences between the two simulations occur primarily in the drought periods when the additional depletions exacerbate the drought effects.

To provide additional perspective on the effect of adding non-Project depletions with sedimentation to form the No Action simulation, the sorted differences between the Existing Conditions and Sedimentation 2060 simulations and the sorted differences between the Existing Conditions and No Action simulations are shown in Figure 7. This shows that the depletions had a lower incremental effect than the sedimentation, and the number of days lower was less for the No Action simulation (92 percent versus 97 percent for the Sedimentation 2060 simulation). In other words, the effect of 2.8 MAF of storage loss was greater than the additional effect of the 516 kAF, or 0.516 MAF, of depletions.

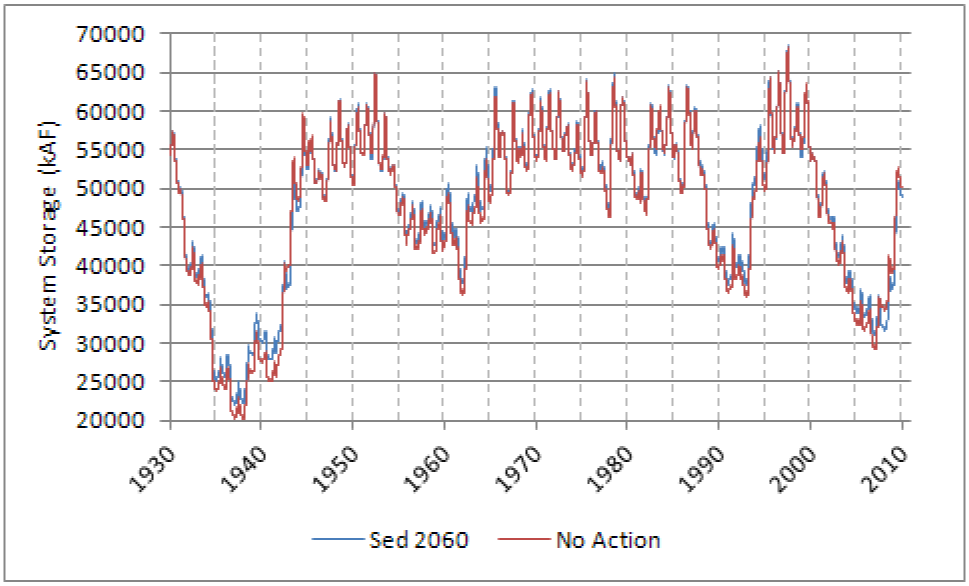

Figure 4. Daily System storage on an annual basis for Sedimentation 2060 and No Action for the period of analysis of 1930-2010.

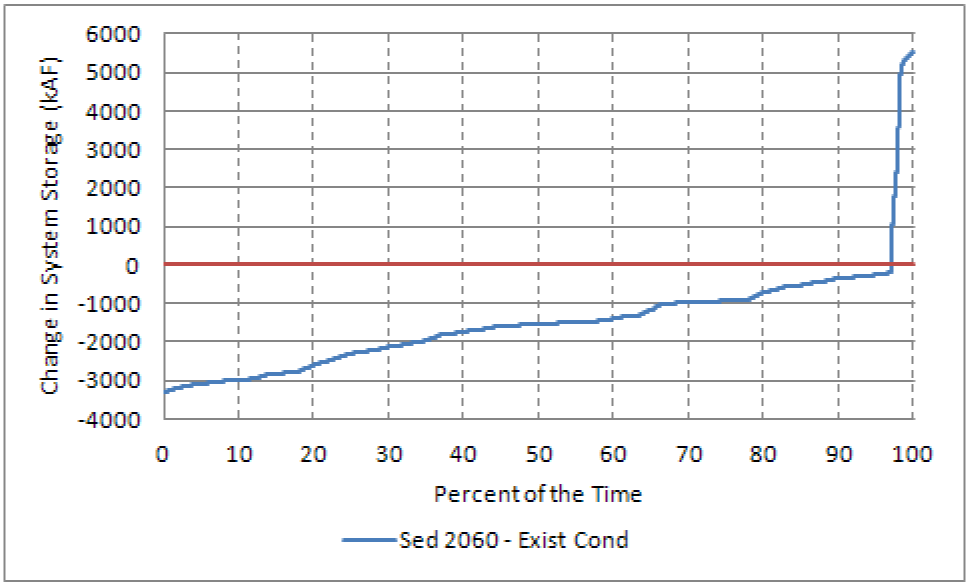

Figure 5. Daily System storage difference for No Action minus those for Sedimentation 2060 for the period of analysis of 1930-2010.

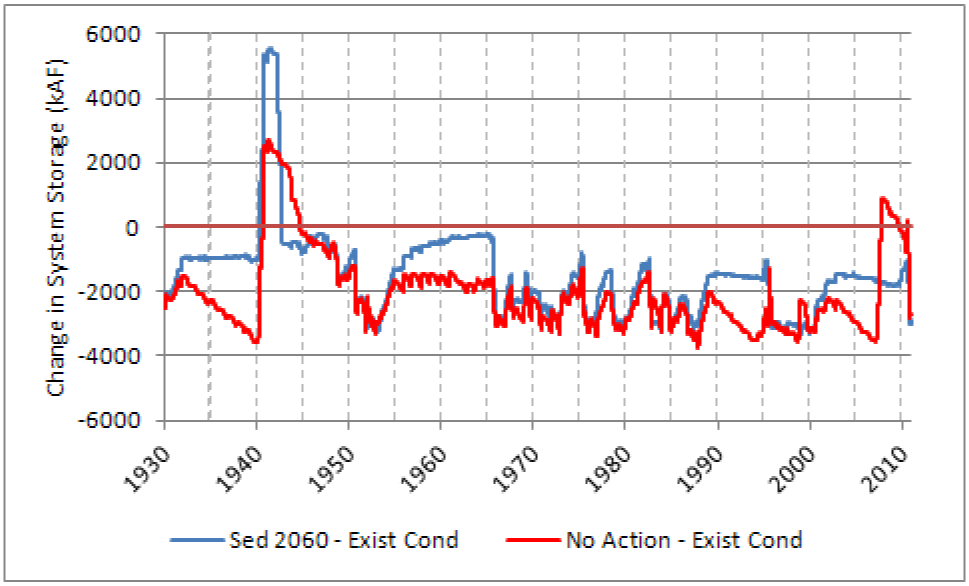

Figure 6. Daily System storage differences for No Action and Sedimentation 2060 relative to the storage values for Existing Conditions for the period of analysis of 1930-2010.

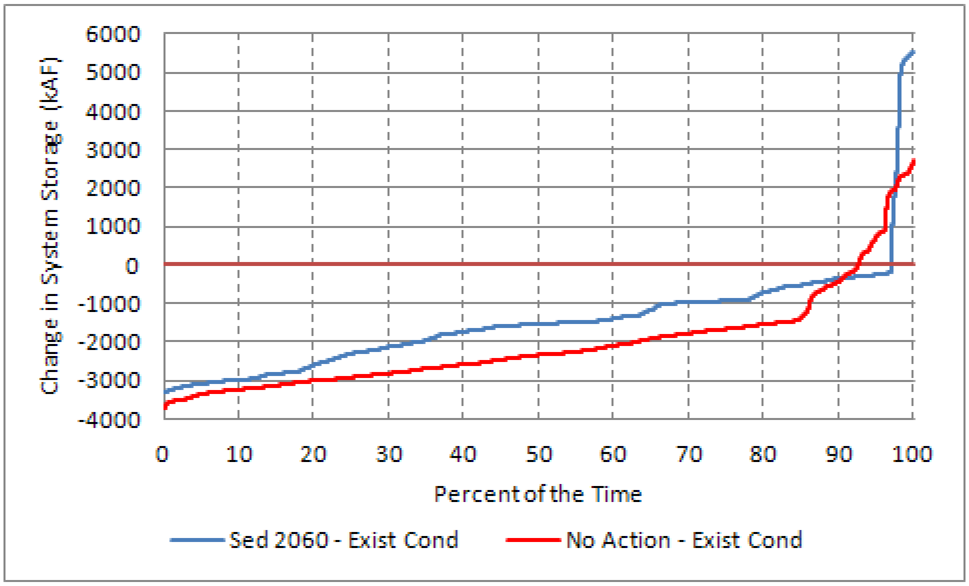

Figure 7. Comparison of the sorted daily storage difference values for Sedimentation 2060 and No Action when compared to Existing Conditions' storage levels for the 1930-2010 period of analysis.

Adding 13.6 kAF of depletions to No Action to form the NAWS 13.6 Simulation

The forecasted average monthly withdrawal of water from Lake Sakakawea for the NAWS Project is 13.6 kAF, which consists of the average daily use of water within the service area in a portion of the Hudson Bay drainage in northwestern North Dakota plus an additional 20 percent to cover various losses such as the water used for flushing back the filters in the water treatment plants. Due to the relatively small volume of water compared to the other depletions between existing conditions and 2060 conditions totaling 519 kAF, the daily differences between No Action and NAWS 13.6 would be expected to be relatively small. Figures 8 through 10 show the System storages for these two simulations and differences between them. Because of the relatively small differences in the figures, the differences from the Existing Conditions simulation will not be presented in this subsection nor the one for the 29.1 kAF of depletions for the NAWS Project in the sub-section below.

Figure 8 shows the daily System storage values in kAF for the full period of analysis of 1930 through 2010. It is essentially impossible to see any differences due to the scale of the figure. Consequently, Figure 9 was developed to show the daily differences between the two simulations, with the vertical axis scale being the same as similar plots between Existing Conditions and Sedimentation 2060; between Sedimentation 2060 and No Action; and among Existing Conditions, Sedimentation 2060, and No Action (Figures 2, 5, and 7). It is readily apparent that the differences between No Action and NAWS 13.6 are relatively small (less than 1,000 kAF during the 1930s drought and late 1980s and early 1990s drought). The two most notable declines in the storage differences between NAWS 13.6 and No Action occurred due to differing DRM decisions on season length in 1944 and 1998 (both high inflow years). In those two years, higher fall releases combined with extended navigation seasons resulted in greater drawdown of System storage that recovered as the result of lower NAWS 13.6 releases in the subsequent years. These two differences are the most noticeable differences, as shown on Figure 10, which shows both No Action and NAWS 13.6 minus Existing Conditions. Less significant differences for the NAWS 13.6 simulation occurred during each drought due to the removal of water from Garrison Reservoir. Finally, Figure 11 shows these relatively small differences sorted from most negative to most positive. This plot shows a relatively flat line about zero difference for about 95 percent of the time. Much of the difference near zero is negative due to the removal of 13.6 kAF during two of the four extended droughts. Also, Figure 12 shows the larger differences of NAWS 13.6 storages from those of Existing Conditions, with the No Action differences also included. The differences for 1944 and 1998 and the subsequent recovery periods are the most noticeable differences near the right side of the figure.

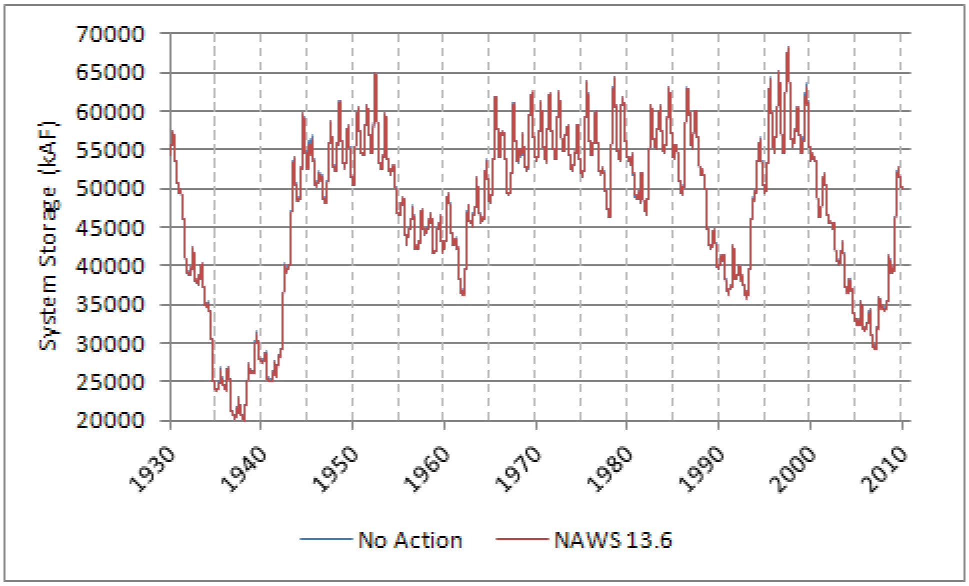

Figure 8. Daily System storage on an annual basis for No Action and NAWS 13.6 for the period of analysis of 1930-2010.

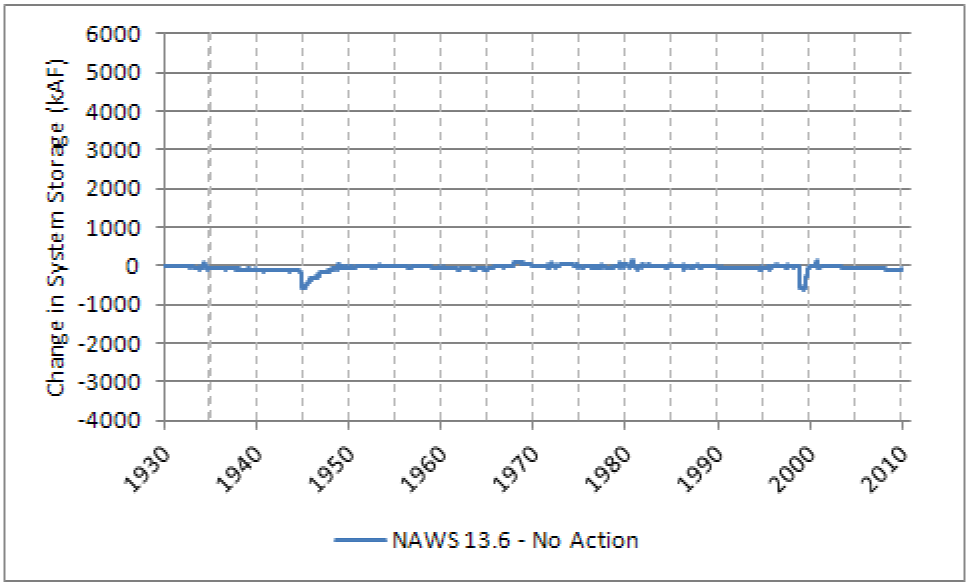

Figure 9. Daily System storage difference for NAWS 13.6 minus No Action for the period of analysis of 1930-2010.

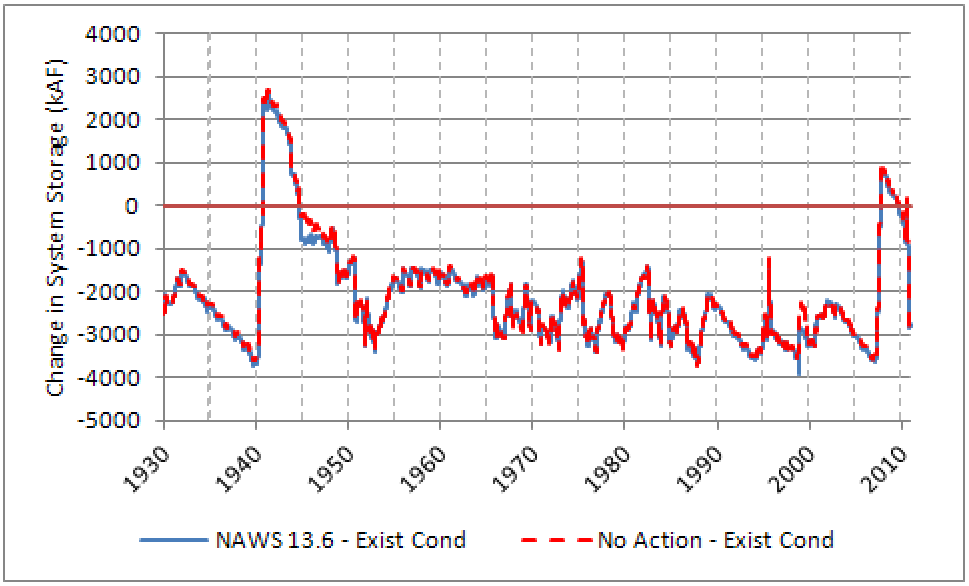

Figure 10. Daily System storage difference for both NAWS 13.6 and No Action from those for Existing Conditions for the period of analysis of 1930-2010.

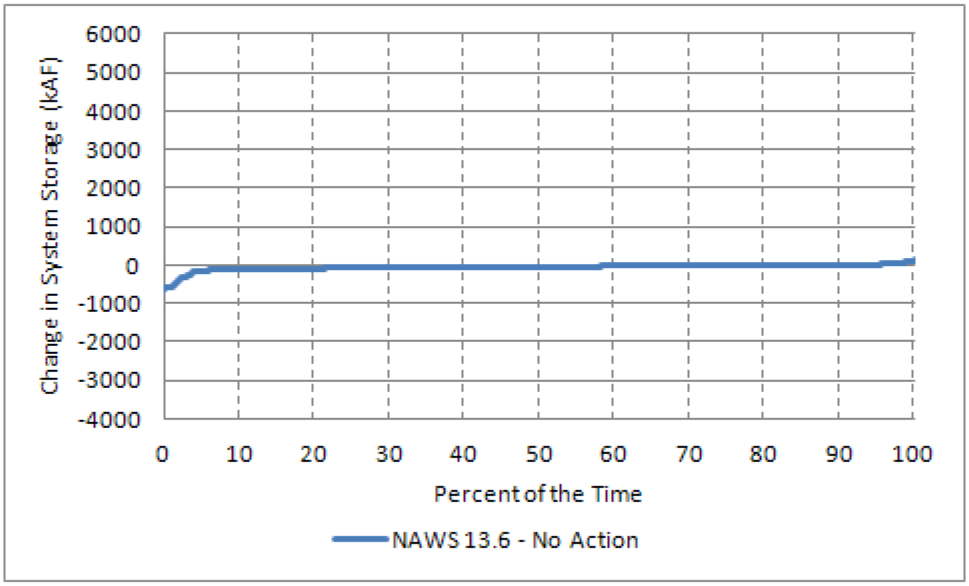

Figure 11. Sorted daily values for System storage difference for NAWS 13.6 minus No Action for the period of analysis of 1930-2010.

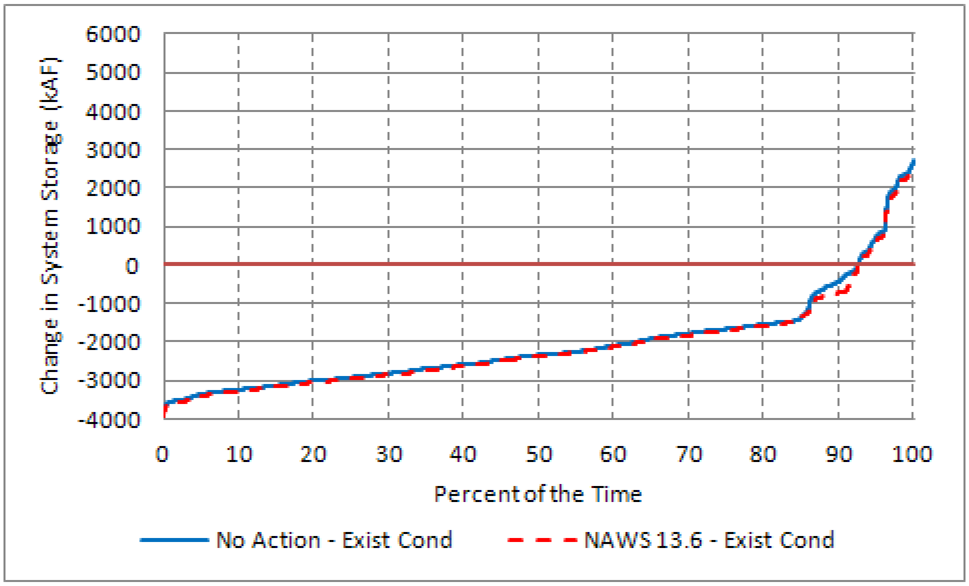

Figure 12. Sorted daily values for System storage difference for NAWS 13.6 and No Action from those for Existing Conditions for the period of analysis of 1930-2010.

Adding 29.1 kAF of depletions to No Action to form the NAWS 29.1 Simulation

Year-round withdrawal of the maximum main transmission pipeline capacity of the NAWS Project would result in the removal of 29.1 kAF per year of water from Lake Sakakawea. Due to the relatively small volume of water compared to the non-Project depletions between existing conditions and 2060 conditions totaling 516 kAF, the daily differences between No Action and NAWS 29.1 would be expected to be relatively small. Figures 13 through 15 show the System storages for these two simulations and differences between them.

Figure 13 shows the daily System storage values in kAF for the full period of analysis of 1930 through 2010. It is essentially impossible to see any differences due to the scale of the figure. Consequently, Figure 14 was developed to show the daily differences between the two simulations, with the vertical axis scale being the same as similar plots between Existing Conditions and Sedimentation 2060; between Sedimentation 2060 and No Action; and among Existing Conditions, Sedimentation 2060, and No Action (Figures 2, 5, and 7). It is readily apparent that the differences between No Action and NAWS 29.1 are relatively small at less than 300 kAF in two of the four extended droughts in the period of analysis. Greater differences occurred in 1944 and 1998 and the subsequent storage recovery periods, as discussed above for the NAWS 13.6 simulation. Finally Figure 15 shows these relatively small differences sorted from most negative to most positive. This plot shows a relatively flat line about zero difference for about 60 to 70 percent of the time. Much of the negative differences are due to the removal of 29.1 kAF each year, especially during the four extended droughts, and in 1944 and 1998.

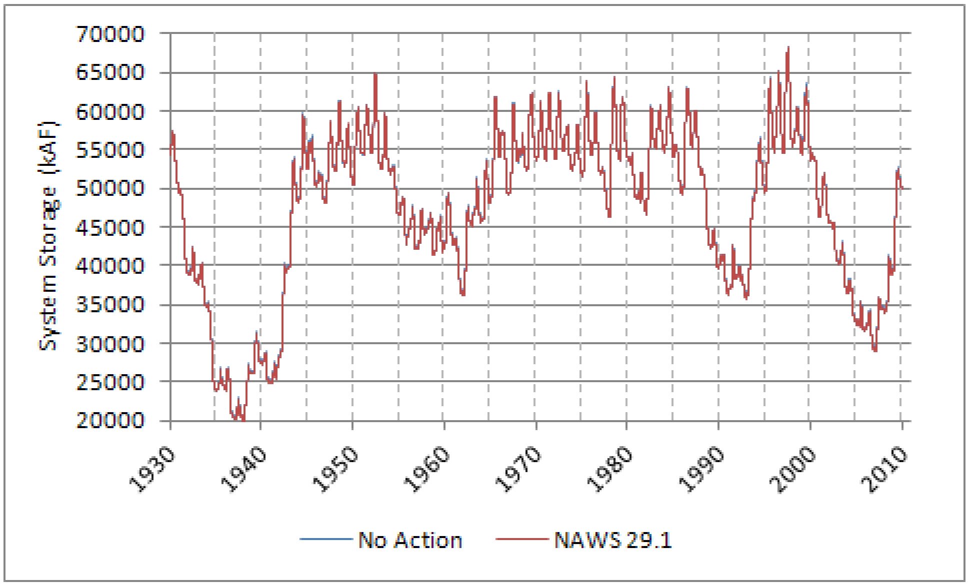

Figure 13. Daily System storage on an annual basis for No Action and NAWS 29.1 for the period of analysis of 1930-2010.

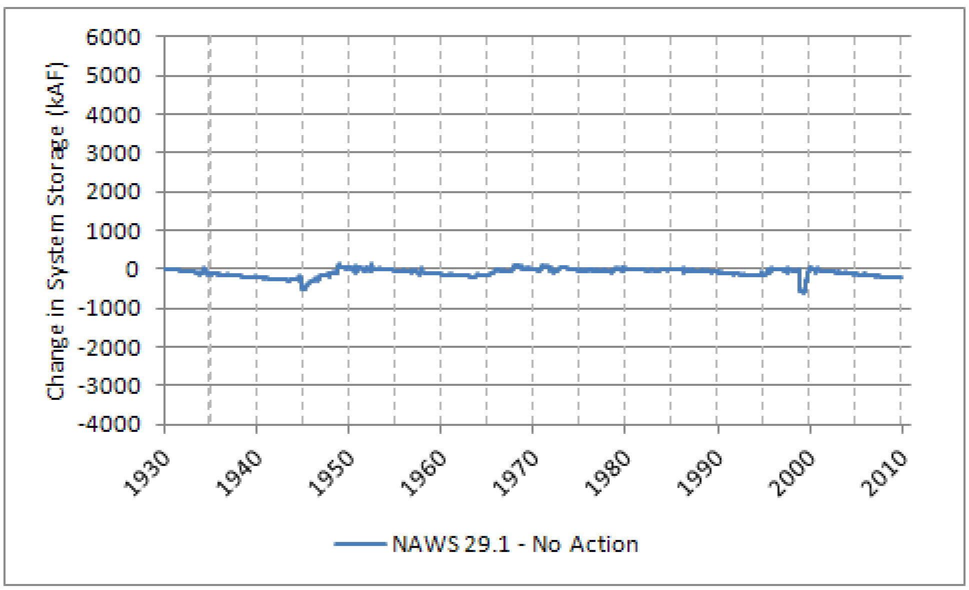

Figure 14. Daily System storage difference for NAWS 29.1 minus No Action for the period of analysis of 1930-2010.

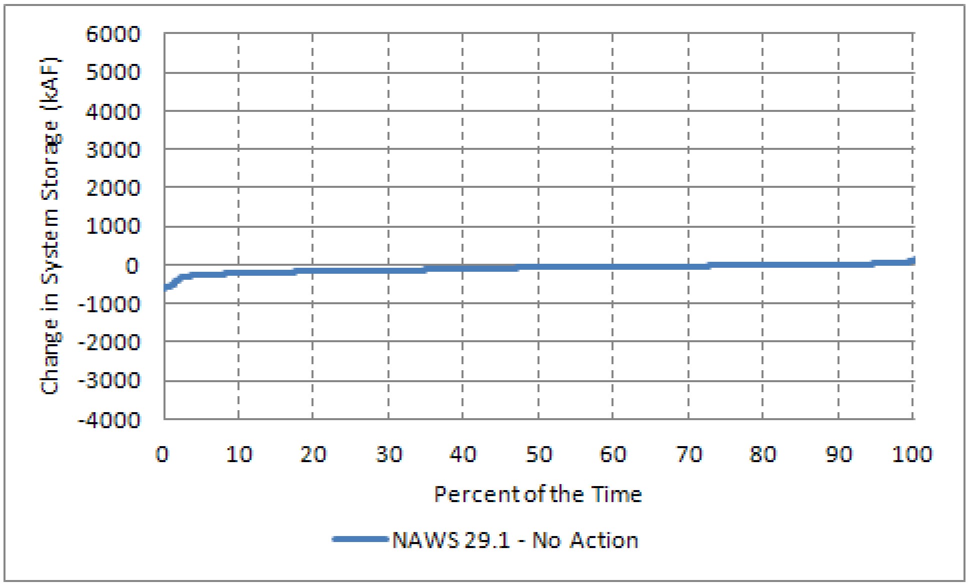

Figure 15. Sorted daily values for System storage difference for NAWS 29.1 minus No Action for the period of analysis of 1930-2010.

Water Surface Elevations of System Reservoirs

Changes in System storage primarily translate to changes in the elevations of the upper three, larger reservoirs in the System – Fort Peck Lake (Fort Peck Reservoir), Lake Sakakawea (Garrison Reservoir), and Lake Oahe (Oahe Reservoir). This section of the presentation of the result of the hydrologic effects analyses focuses on the effects of the five simulations on the water surface levels of these three reservoirs.

Adding Sedimentation through 2060 to form the Sedimentation 2060 Simulation

The changes in System storage resulted in lower storage values as sedimentation in the reservoirs continued to increase in the future. An analogy using a bowl may help provide some perspective why a factor resulting in less storage space may result in higher water levels. If the first of two bowls can hold 1.5 cups of water, a second, smaller bowl with a capacity of just 1.4 cups cannot hold the entire 1.5 cups of water. Thus a system of dams that loses 2.8 MAF of storage from its lower two zones (annual flood control and multiple use zone and the permanent pool) cannot hold as much water when it is targeted to be at its base of flood control zone on March 1 in those years adequate water is in the System (non-drought periods). It will be holding 2.8 MAF less in those years. Sedimentation resulted in less System storage in most years, as summarized in the previous section.

As sedimentation causes the storage volume in the bottom two storage zones in the six reservoirs to decrease, the water surface elevations will increase in many years. Another factor causing higher reservoir levels throughout many years will be the decreases in navigation service, as the lower amounts of System storage on March 15 (approximately 53.1 MAF in "normal" years) will be below the top of the service-level navigation guide curve of 54.5 MAF. This means that navigation service will be reduced from full service in more years than it would under existing conditions. This would result in slower drawdown in the April through June timeframe in many years, resulting in higher water surface elevations in System reservoirs in those months. These increases would be primarily in the upper three, larger System reservoirs – Fort Peck, Garrison, and Oahe, as noted earlier.

Since the withdrawal for the NAWS Project would occur from Lake Sakakawea, or Garrison Reservoir, the water surface changes on this reservoir will be discussed first and in more detail than the other two. Figures 16 through 18 show the effects of the continuing sedimentation in System reservoirs on the daily water surface elevation of Garrison Reservoir. Figure 16 presents the daily water surface elevations of the Existing Conditions and Sedimentation 2060 simulations. The four drought periods are shown by the larger reductions in the daily water surface elevations. The most notable differences between the two simulations occurs in the early 1940s, with Sedimentation 2060 having the higher water surface elevation (due to the water savings of the additional sedimentation and resulting earlier navigation service reductions and delaying a non-navigation year near the end of the 1930s drought from 1940 to 1942). All of the daily differences become more noticeable in Figure 17, which presents the daily differences between the two simulations (Existing Conditions values subtracted from Sedimentation 2060 values). The most noticeable daily elevation differences occur due to the different sequencing of the 7th non-navigation year for these two simulations near the end of the 1930s drought. In general, it appears that Garrison Reservoir is higher most of the time, with the greatest extended increases being in the four drought periods. Sorting of the daily differences from the most negative to the most positive results in the presentation of the data in Figure 18. It shows that additional sedimentation between 2010 and 2060 will result in higher Garrison Reservoir levels approximately 80 percent of the time.

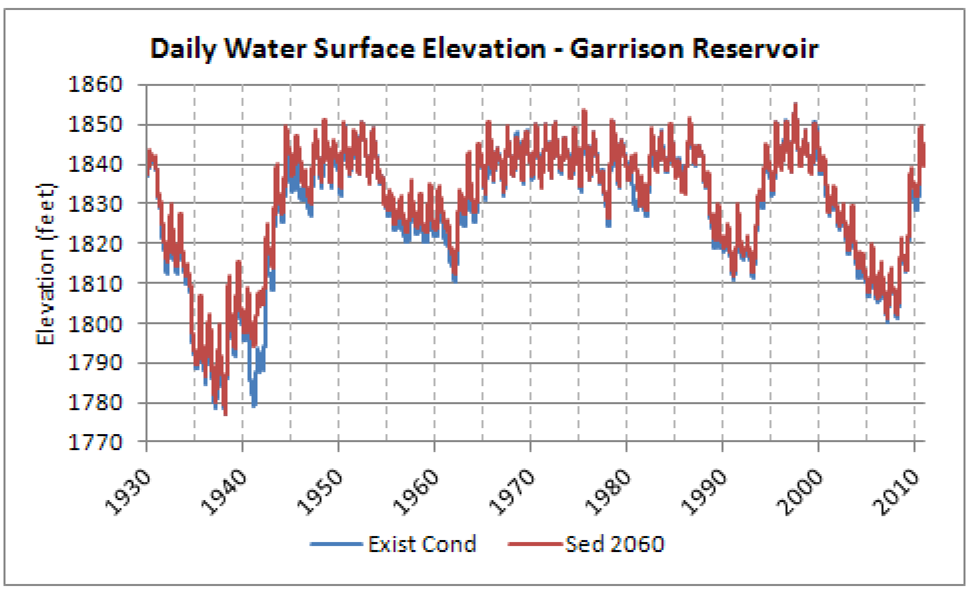

Figure 16. Garrison Reservoir daily water surface elevations for Existing Conditions and Sedimentation 2060 for the 1930-2010 period of analysis.

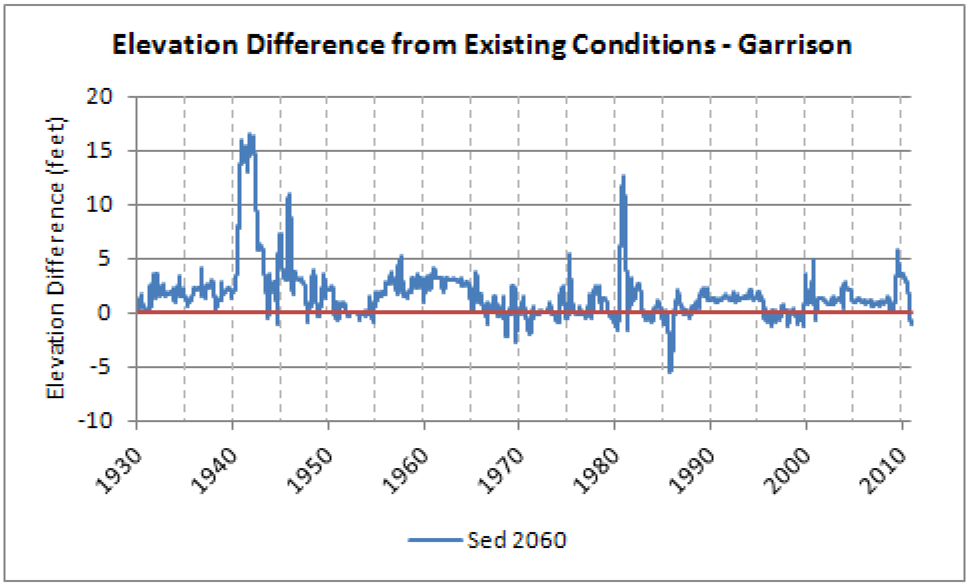

Figure 17. Garrison Reservoir daily water surface elevation differences for Sedimentation 2060 from those for Existing Conditions for the 1930-2010 period of analysis.

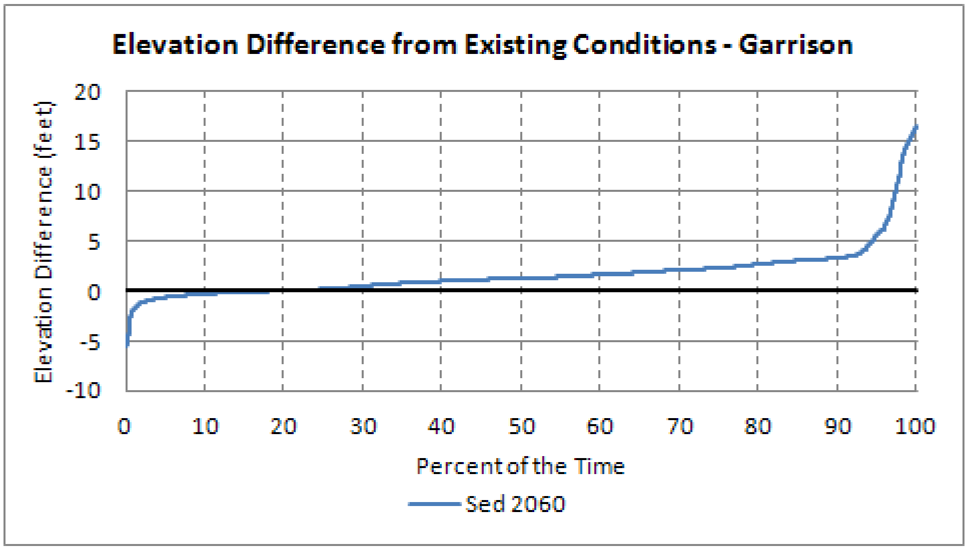

Figure 18. Garrison Reservoir sorted daily water surface elevation differences for Sedimentation 2060 from those for Existing Conditions for the 1930-2010 period of analysis.

Figures 19 and 20 present the sorted daily water surface elevation differences for Sedimentation 2060 compared to those of Existing Conditions for Fort Peck and Oahe reservoirs, respectively. The plots only show the sorted differences between Existing Conditions and Sedimentation 2060, and both reservoirs would have daily water surface elevations higher with future sedimentation about 80 percent of the time, which is the same as those for Garrison Reservoir. This is an indication that the balancing of the upper three projects will distribute the impacts of sedimentation equally among them.

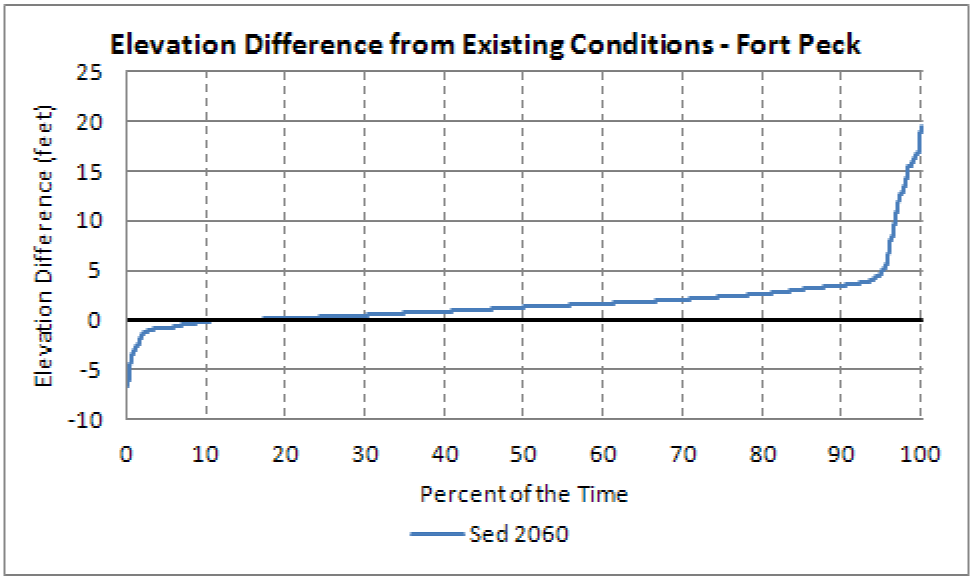

Figure 19. Fort Peck Reservoir sorted daily water surface elevation differences for Sedimentation 2060 from those for Existing Conditions for the 1930-2010 period of analysis.

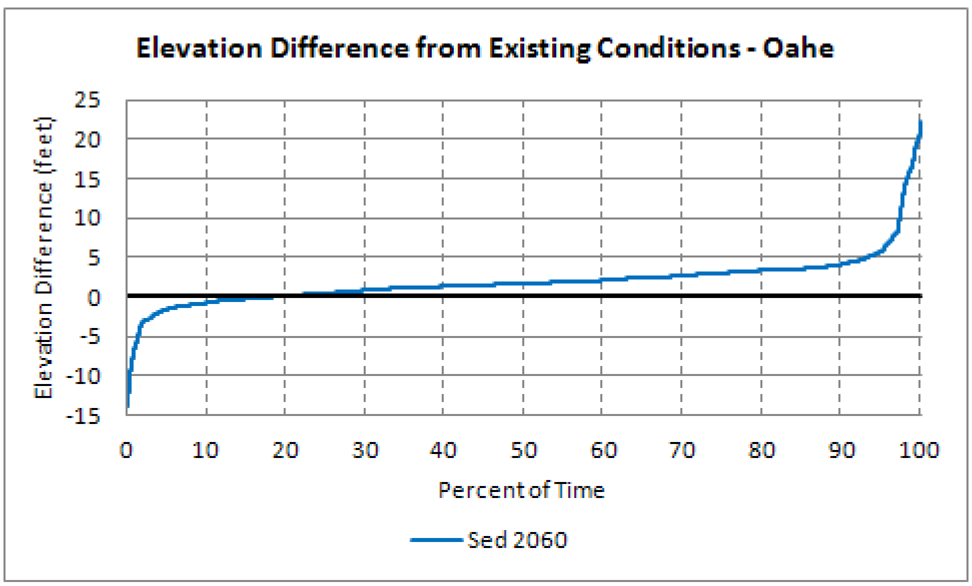

Figure 20. Oahe Reservoir sorted daily water surface elevation differences for Sedimentation 2060 from those for Existing Conditions for the 1930-2010 period of analysis.

Adding Depletions and Sedimentation through 2060 to form the No Action Simulation

Future population growth, irrigated agriculture growth, and additional projects withdrawing water from the Missouri River main stem and its tributaries will result in future depletions of water moving down the Missouri River main stem and through the System reservoirs. At this time, Reclamation estimates the growth in Missouri River Basin depletions by 2060 without the NAWS Project at 516 kAF. The effects of these increased depletions on the water surface elevations of the three, larger System reservoirs can be understood by looking at the data for the simulation of No Action, which includes the sedimentation and non-Project depletion growths between 2010 and 2060. Figures 21 through 23 present the sorted differences between No Action and Existing Conditions for the Garrison, Fort Peck, and Oahe reservoirs, respectively. These plots also include the differences between Sedimentation 2060 and Existing Conditions to see the separate effects of sedimentation and depletions on the same figure. To provide a clearer picture of the differences, the parts of the plots between difference of minus 5 feet and plus 5 feet are presented in the figures.

For all three reservoirs, the daily water surface elevations for No Action will generally be lower than those for Sedimentation 2060. Non-Project depletions reduce the gains in water surface elevation attributable to sedimentation, leaving a net increase in elevation in fewer days. For Garrison Reservoir, the water surface elevations will be about 2 feet lower for No Action versus Sedimentation 2060 for about 90 percent of the time, and greater than Existing Conditions about 55 percent of the time. Similarly, Fort Peck Reservoir will be about 2 feet or more lower than Sedimentation 2060 for No Action versus Sedimentation 2060 for about 90 percent of the time and higher than Existing Conditions about 60 percent of the time. Finally, Oahe Reservoir will be 1 to 2 feet lower for No Action versus Sedimentation 2060 85 percent of the time and higher than Existing Conditions about 65 percent of the time. All three reservoirs will be higher than under Existing Conditions 55 to 65 percent of the time, with the longer period of time increasing from Garrison to Fort Peck to Oahe.

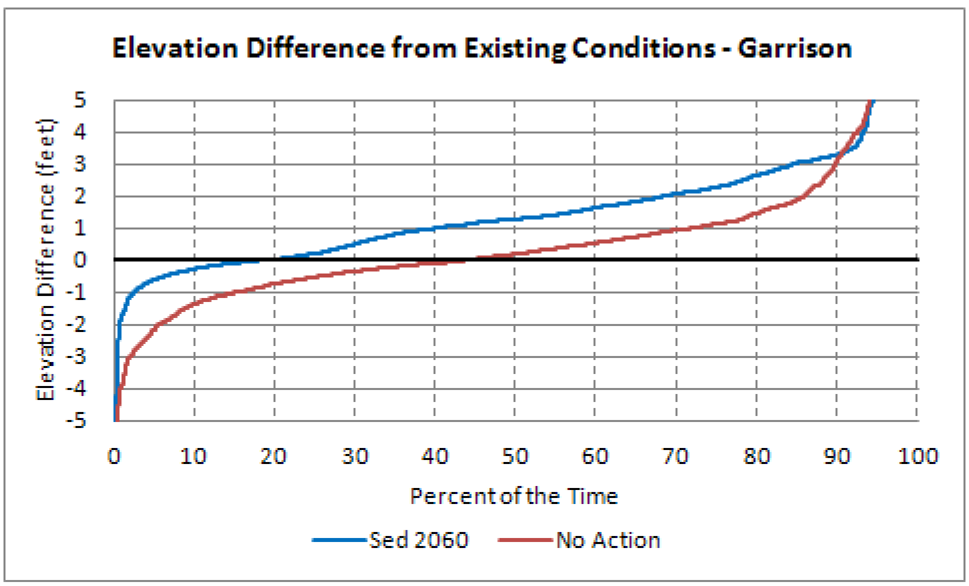

Figure 21. Garrison Reservoir sorted daily water surface elevation differences for No Action and Sedimentation 2060 from those for Existing Conditions for the 1930-2010 period of analysis.

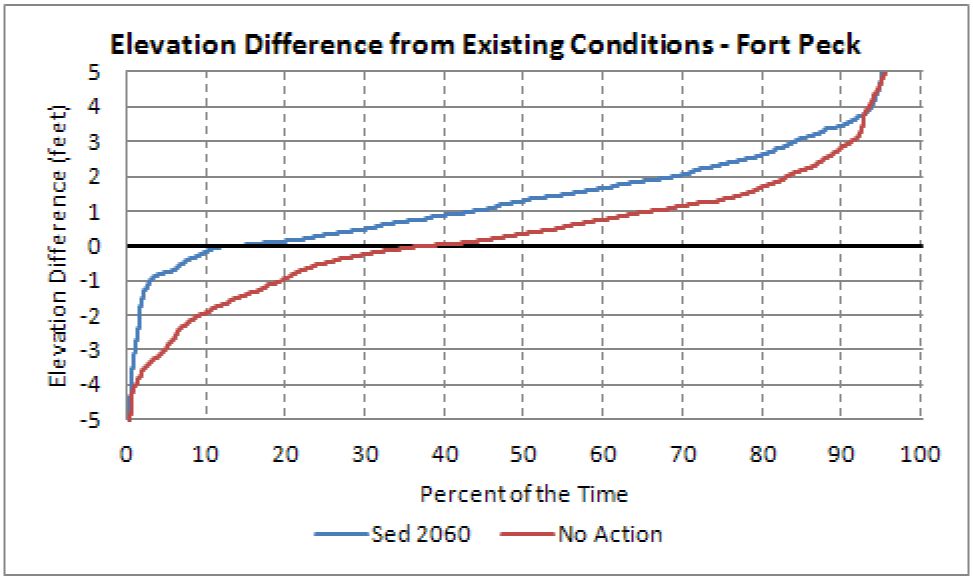

Figure 22. Fort Peck Reservoir sorted daily water surface elevation differences for No Action and Sedimentation 2060 from those for Existing Conditions for the 1930-2010 period of analysis.

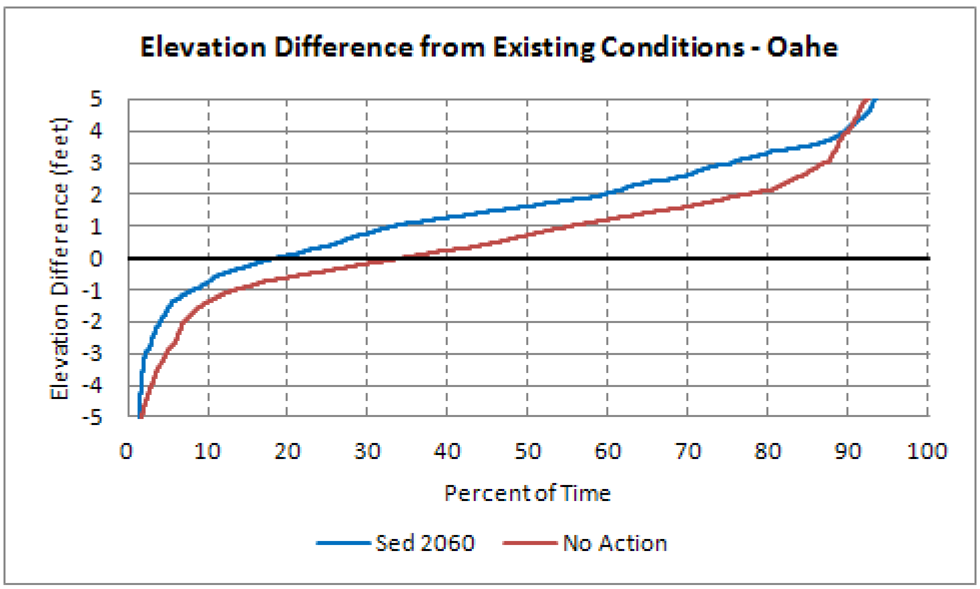

Figure 23. Oahe Reservoir sorted daily water surface elevation differences for No Action and Sedimentation 2060 from those for Existing Conditions for the 1930-2010 period of analysis.

Addition of the NAWS Project Depletions

Because the NAWS Project would remove water from Lake Sakakawea and transport it out of the Missouri River basin, each acre-foot of water removed from Lake Sakakawea would be an acre-foot of depletion. As shown above, depletions from the Missouri River lower the water surface elevations of the upper three reservoirs from the higher levels resulting from continuing sedimentation. This same response would be expected for the NAWS Project; however, the amount of depletions, whether 13.6

kAF, 29.1 kAF, or some other value below, within, or above that range would likely have a relatively small effect on the water surface elevations of the upper three, larger System reservoirs.

Figures 24 through 27 show the sorted differences in the water surface elevations of Garrison, Fort Peck, and Oahe reservoirs, respectively, between the simulations of the two NAWS Project options, depleting 13.6 kAF and 29.1 kAF, and the Existing Conditions simulation. Also included in the plots is the difference between No Action and Existing Conditions to demonstrate the effects of the two NAWS Project options versus those of No Action. These figures also include only the parts of the plots with differences between plus 5 feet and minus five feet. For a plus or minus 1-foot difference, Fort Peck and Garrison would be within this range 95 percent of the time, and Oahe would have water levels within this range 92 percent of the time when compared to the water levels of the No Action simulation. To provide additional perspective, Figure 25 shows the differences between the two NAWS Project simulations and the No Action simulation. All of the impacts on the four figures are all relatively small over almost all of the 81-year period of analysis at less than 2 feet, as shown on Figure 25.

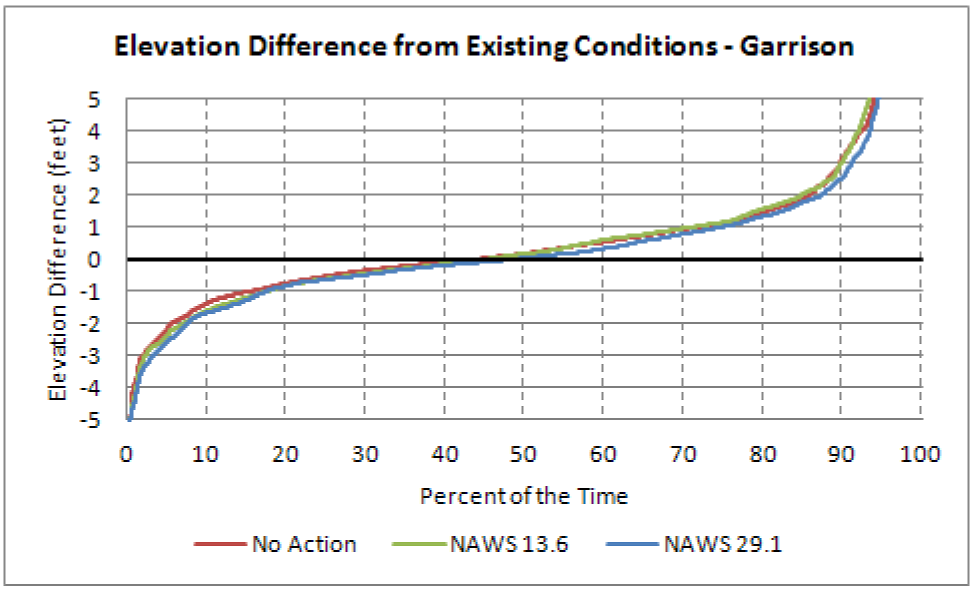

Figure 24. Garrison Reservoir sorted daily water surface elevation differences for the two NAWS Project and No Action simulations from those for Existing Conditions for the 1930-2010 period of analysis.

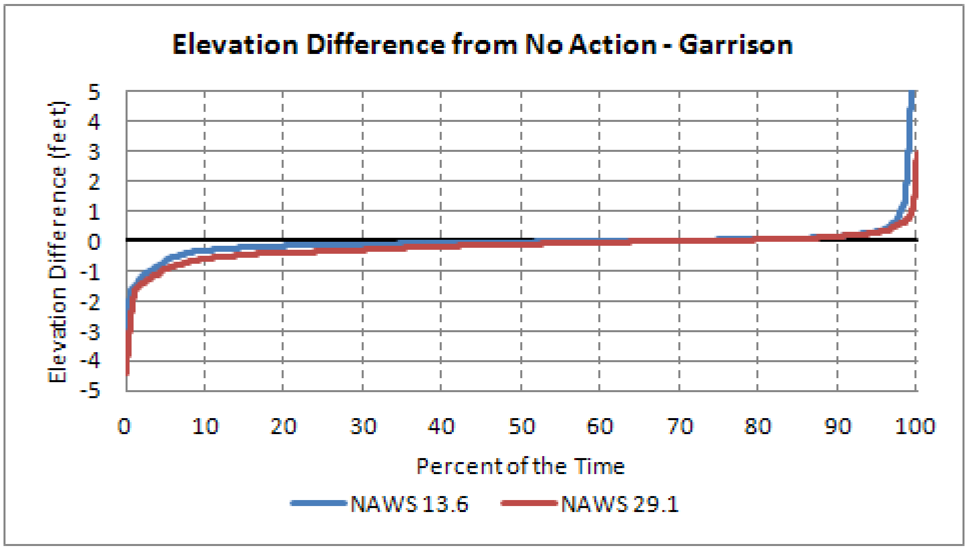

Figure 25. Garrison Reservoir sorted daily water surface elevation differences for the two NAWS Project simulations from those for No Action for the 1930-2010 period of analysis.

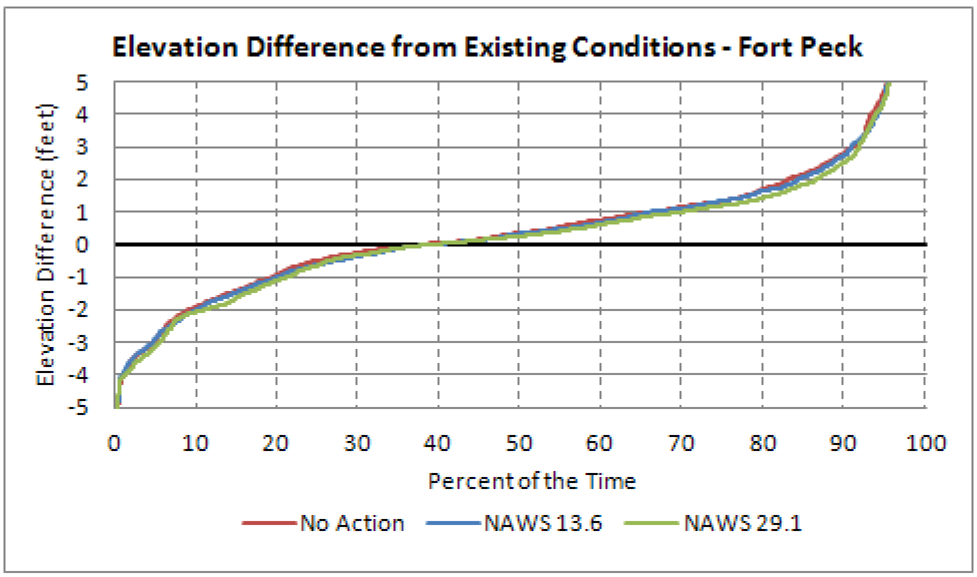

Figure 26. Fort Peck Reservoir sorted daily water surface elevation differences for the two NAWS Project and No Action simulations from those for Existing Conditions for the 1930-2010 period of analysis.

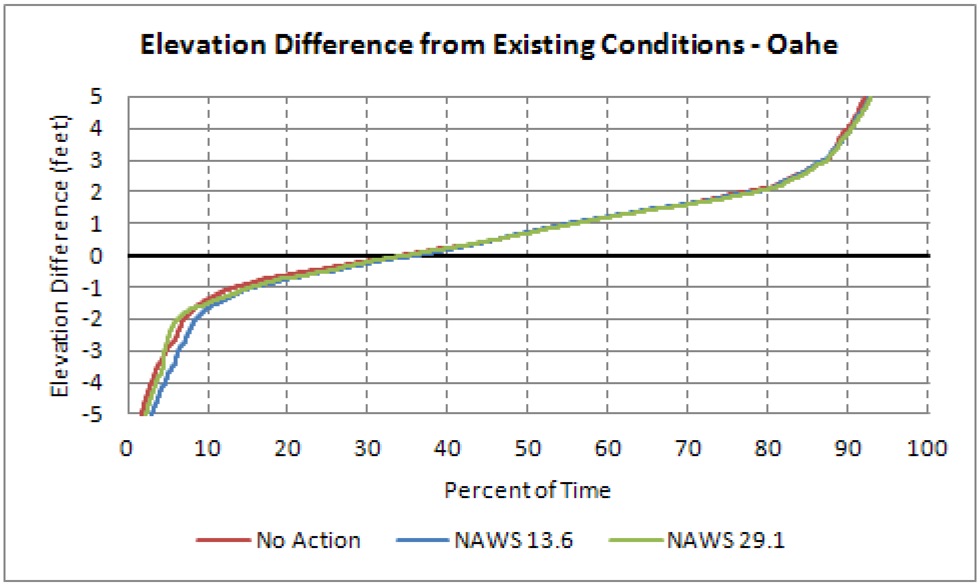

Figure 27. Oahe Reservoir sorted daily water surface elevation differences for the two NAWS Project and No Action simulations from those for Existing Conditions for the 1930-2010 period of analysis.

System Releases

Releases from the six System reservoirs are affected by the continuing growth of deposited sediments and depletion of System and lower Missouri River inflows. These effects will be discussed in the basic order of Gavins Point releases first followed by the releases from the upper three reservoirs. This order is generally the same as the daily decisions on System releases. The Gavins Point releases are made to meet lower Missouri River navigation and flood control requirements and to meet flood storage evacuation requirements from the System reservoirs as well as lower River flow requirements in non-navigation years. Releases from the upper three reservoirs are based on the need to balance the effects of depletions, sedimentation, and flood storage evacuation while ensuring that the water required for meeting the Gavins Point release is in Gavins Point Reservoir.

Gavins Point

Gavins Point releases vary from month to month as the System release requirements are met. For example, the navigation releases are affected by the inflows from the downstream tributaries, and these inflows are generally higher in the spring and lower during the summer. The summer releases are affected by the need to run as flat a release as possible to limit adverse impacts to downstream terns and plovers nesting on the islands and sandbars. During droughts, the service level can change on July 1 from that met in the months of April through June. Finally fall releases are sometimes higher than those in the summer (restricted in many years by terns and plovers) to evacuate as much of the water as needed to ensure that the volume of water in the System is at the base of flood control storage by the following March 1. This variability is shown in Table 6, which presents the average monthly Gavins Point release in thousands of cubic feet per second (kcfs) over the 81-year period of analysis of 1930-2010. Figure 28 presents the same data in graphic form. Table 7 and Figure 29 present the differences between the Existing Conditions simulation and the other four simulations. This table and figure shows that, even though almost all of the differences are less than 1 kcfs, the greater effects on the Gavins Point monthly average releases are future cumulative depletions except in the months of September and October. Incrementally, the depletions associated with the NAWS Project are barely detectable on the figure, indicating that the Project would have a relatively small effect on the Gavins Point releases.

Table 6: Monthly average Gavins Point release 1930-2010 (kcfs)

	Exist Cond	Sed 2060	No Action	NAWS 13.6	NAWS 29.1
Jan	15.00	14.53	14.48	14.47	14.48
Feb	15.17	14.71	14.73	14.73	14.74
Mar	18.12	17.81	17.74	17.73	17.73
Apr	22.73	22.50	22.26	22.23	22.22
May	27.60	27.48	27.21	27.18	27.16
Jun	29.07	29.16	28.71	28.67	28.68
Jul	31.45	31.45	30.75	30.70	30.70
Aug	33.42	33.56	33.01	32.97	32.95
Sep	32.39	33.80	33.45	33.40	33.36
Oct	30.33	31.16	30.55	30.53	30.48
Nov	24.28	24.17	23.56	23.64	23.55
Dec	16.04	15.06	14.69	14.69	14.69
Ann Ave (kcfs)	24.633	24.616	24.262	24.245	24.228
Ann Ave (ac-ft)	17834	17821	17565	17553	17541
DRM Depletions (ac-ft)	--	--	256.4	12.1	24.1
Actual Depletions (ac-ft)	--	--	277.6	13.6	29.1

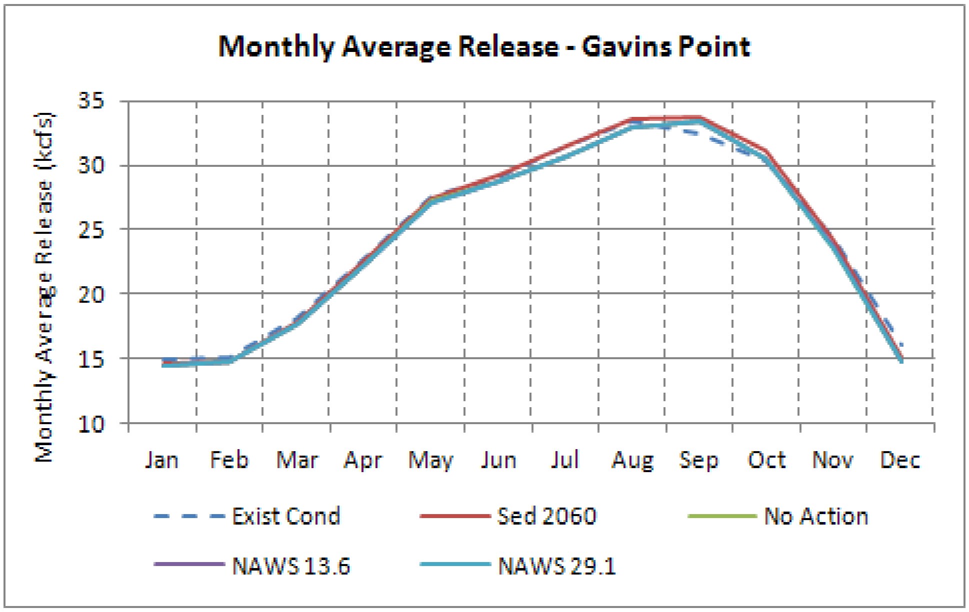

Figure 28. Monthly average releases from Gavins Point Dam for the five study simulations for the period of analysis, 1930-2010.

Table 7: Differences in average monthly Gavins Point releases between simulations 1930-2010 (kcfs)

	Sed 2060 - Exist Cond	No Action - Sed 2060	NAWS 13.6 - No Action	NAWS 29.1 - No Action
Jan	-0.47	-0.05	-0.01	0
Feb	-0.46	0.02	0	0.01
Mar	-0.31	-0.07	-0.01	-0.01
Apr	-0.23	-0.24	-0.03	-0.04
May	-0.12	-0.27	-0.03	-0.05
Jun	0.09	-0.45	-0.04	-0.03
Jul	0.00	-0.7	-0.05	-0.05
Aug	0.14	-0.55	-0.04	-0.06
Sep	1.41	-0.35	-0.05	-0.09
Oct	0.83	-0.61	-0.02	-0.07
Nov	-0.11	-0.61	0.08	-0.01
Dec	-0.98	-0.37	0	0

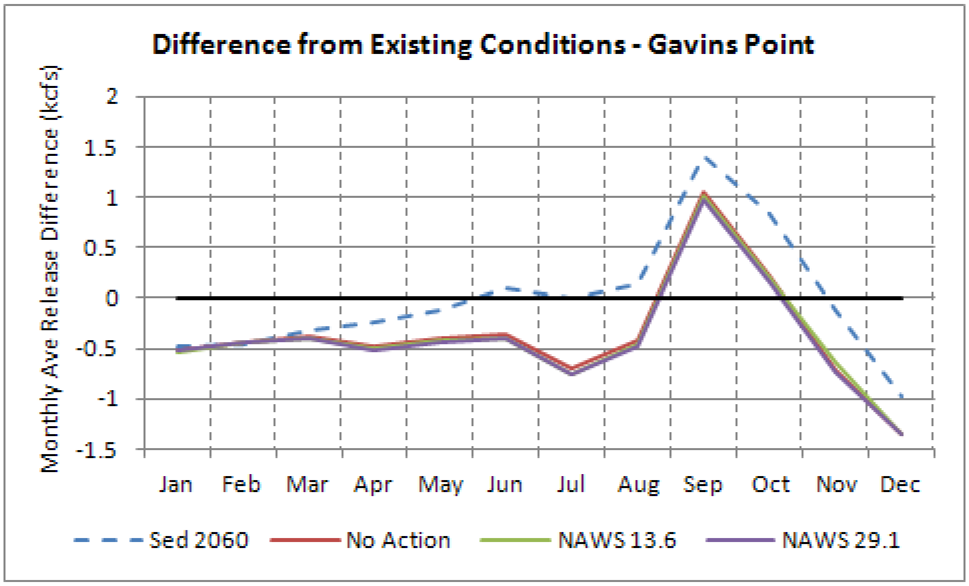

Figure 29. Differences in the monthly average releases from Gavins Point Dam between Existing Conditions and the other four simulations for the period of analysis, 1930-2010.

As shown in Table 6, using the annual monthly average releases, the annual average volume difference can be computed. This computation shows that the 277.6 kAF of depletions above Gavins Point for the No Action simulation resulted in a 256.4-kAF reduction in the Gavins Point release. Similarly, the 13.6 kAF and 29.1 kAF of the NAWS Project simulations resulted in 12.1 and 24.1 kAF reductions, respectively, in Gavins Point releases. These reductions are 92, 89, and 83 percent reductions of the total depletions for the No Action, NAWS 13.6, and NAWS 29.1 simulations. One reason these are not 100 percent of the added depletion values is the rounding of release values to the nearest hundredth of a kcfs by the DRM. Had the rounding been to the nearest thousandth of a kcfs (cfs), the values may have been closer to the amounts removed due to the depletions.

Another way to look at the effects of the sedimentation and depletions on Gavins Point releases are to look at the sorted daily release differences as each change is added incrementally. Figures 30 through 32 present the plots of the sorted data. The additional sedimentation to 2060 would have a slightly net reducing effect on the Gavins Point releases compared to those of Existing Conditions according to Figure 30. This can be noted by looking at the slightly negative values from 2 to about 25 percent of the time values on the figure. Similarly, the negative differences for the addition of future depletions up to the 516-kAF level (276 kAF above Gavins Point Dam) to form the No Action simulation are somewhat notable between the 5 to 20 percent of the time levels on Figure 31. Finally, the addition of either of the NAWS Project depletion levels to No Action shows relatively no differences for most of the percent of time changes, as shown on Figure 32. In all of the plots, the greater differences at each end are most generally related to flood storage evacuation differences between the simulations plotted. For the Sedimentation 2060 minus Existing Conditions plot, Figure 30, some of the greatest differences are due to the differences in the years that navigation is not supported in the 1930s drought. Also, the greatest differences for the change from Sedimentation 2060 to No Action are due to the addition of 2 non-navigation years during the period of analysis, 1942 and 2007, the latter being the first time that a non-navigation year has shown up outside of the 1930s drought in any simulation run through the DRM.

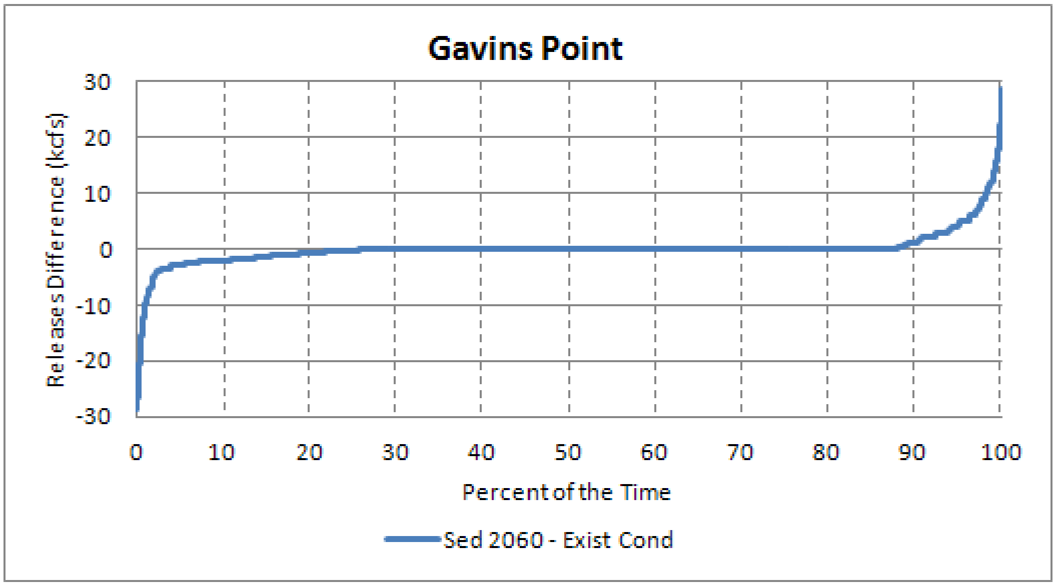

Figure 30. Gavins Point sorted daily release differences for Sedimentation 2060 from those for Existing Conditions for the 1930-2010 period of analysis.

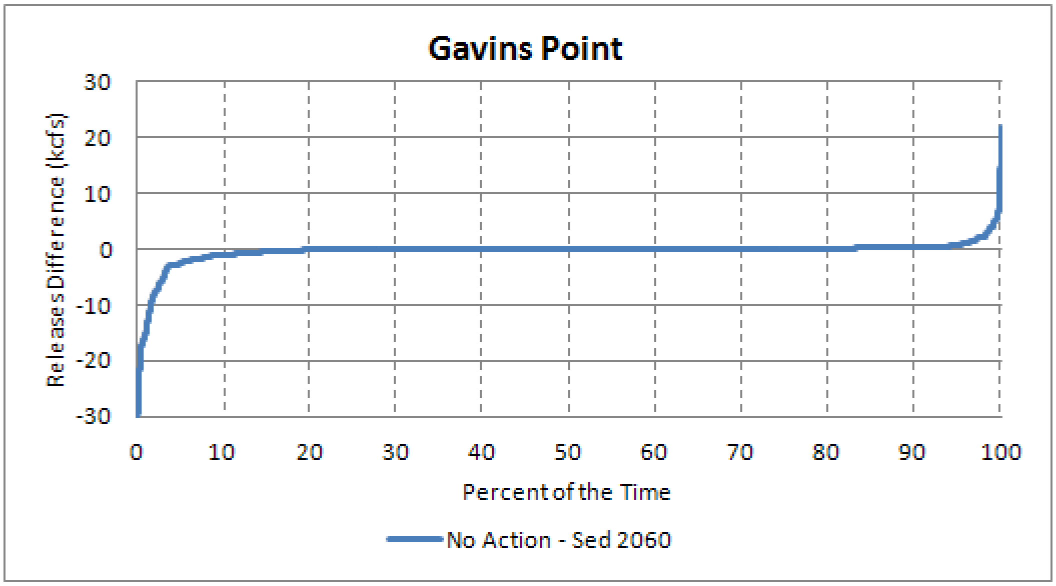

Figure 31. Gavins Point sorted daily release differences for No Action from those of Sedimentation 2060 for the 1930-2010 period of analysis.

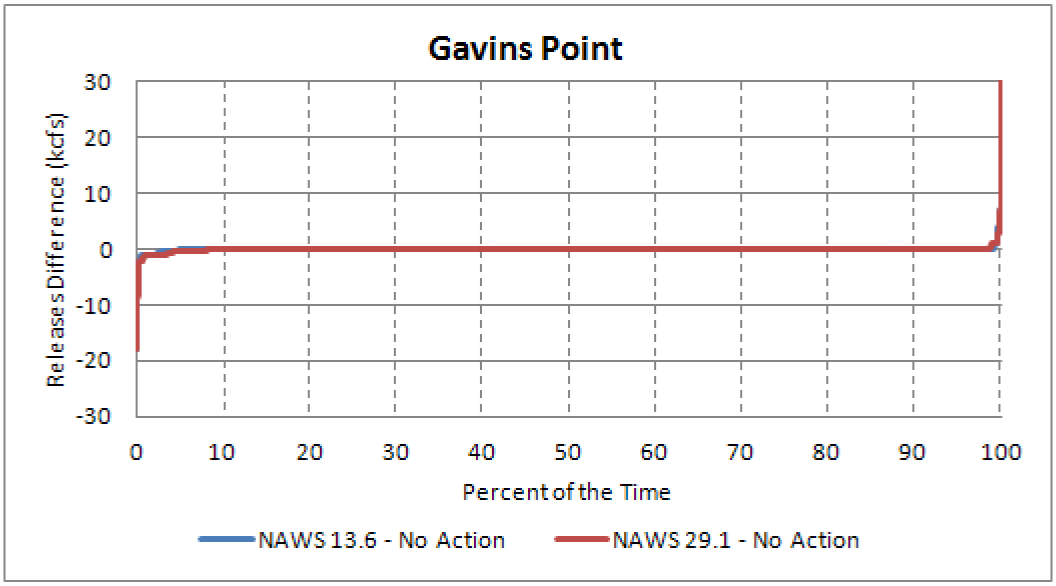

Figure 32. Gavins Point sorted daily release differences for the two NAWS Project simulations from those of No Action for the 1930-2010 period of analysis.

The daily differences were summed to see what the total effect on Gavins Point releases would be for the 81-year period. Converting the average daily (summed daily differences divided by 29,585 days in the 81-year period of analysis) release values in kcfs to acre-foot values in kAF/year (average daily kcfs times 365 days per year times 1.9835), these average daily releases over the 81-year period of analysis for No Action (277.6 kAF depletion above Gavins Point Dam) and the two NAWS Project simulations (additional 13.6 kAF and 29.1 kAF) are equivalent to the average annual values of 258.0 kAF, 11.1 kAF, and 24.9 kAF per year, respectively, with all values very similar to the annual depletions added to form the three simulations. The differences in the input and output depletion values could be due to the fact that the computations are based on average daily releases being rounded off to the nearest hundredth of a kcfs. The reason this could be a factor is that the average daily release difference is based on 29,585 values, and having values to the nearest thousandth of a kcfs could have made the values closer to the DRM input values. These differences support the capability of the DRM to account for the depletions over the period of analysis. (Note that the average annual difference in the Gavins Point releases in kAF were 256.4 kAF, 12.1 kAF, and 24.1 kAF, all nearly the same as those from the daily differences.)

Garrison

Since the NAWS Project would withdraw water from Lake Sakakawea, the effects of the five simulations on Garrison Reservoir releases will be presented next. Figures 33 and 34 are 81-year plots of the sorted differences in the average annual Garrison releases for each of the effects on the releases for adding the sedimentation and the three levels of depletions to form the four other simulations to the Existing Conditions simulation. Figure 33 presents the release differences of the Sedimentation 2060 simulation with just additional sedimentation and the No Action simulation with sedimentation plus the non-Project depletions through 2060 from those of the Existing Conditions simulation. This figure shows that the Sedimentation 2060 simulation will have negative values in 32 of the 81 years; whereas, the No Action simulation will add to those negative values such that it has negative values in 60 years of the 81 years in the period of analysis. Using the same vertical scale, the two NAWS simulations are compared to No Action. This plot also shows more negative than positive values; however, the negative values are just slightly negative. The net difference is relatively small for the additional of the NAWS Project as last-added to the No Action simulation, as shown on Figure 34.

The annual differences were summed and divided by 81 years to compute the average annual effect on Garrison release for the 81-year period. The average annual release values converted to kAF for No Action (depletion of 254.1 kAF above Garrison Dam) and the two NAWS Project simulations (additional depletions of 13.6 kAF and 29.1 kAF) are equivalent to 252.0 kAF, 14.3 kAF, and 27.7 kAF per year, respectively, with all values very similar to the annual depletions of the three simulations. These differences support the capability of the DRM to account for the depletions over the period of analysis.

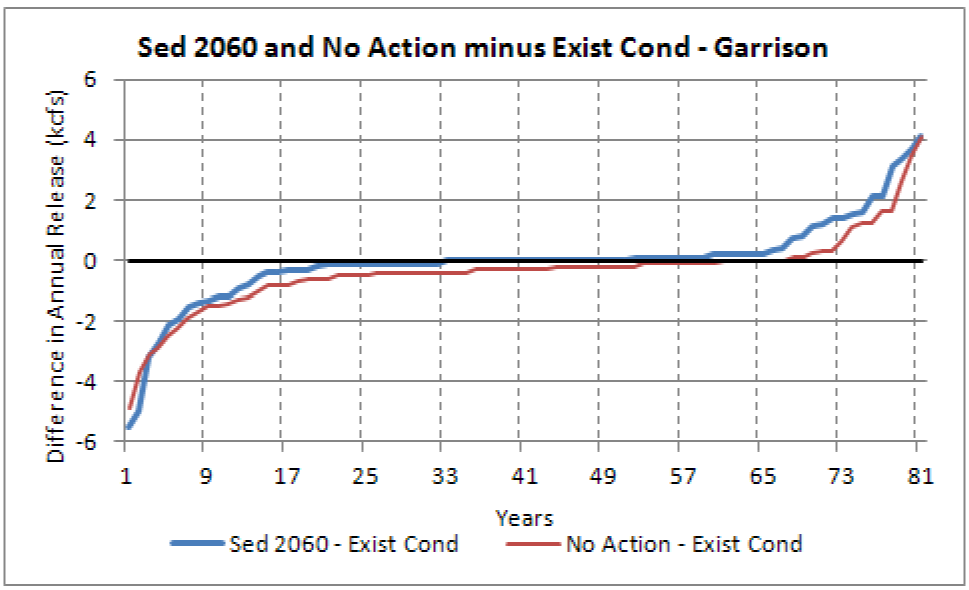

Figure 33. Sorted differences in the annual average Garrison releases between Sedimentation 2060 and No Action simulations and those of Existing Conditions for the 81-year period of analysis of 1930-2010.

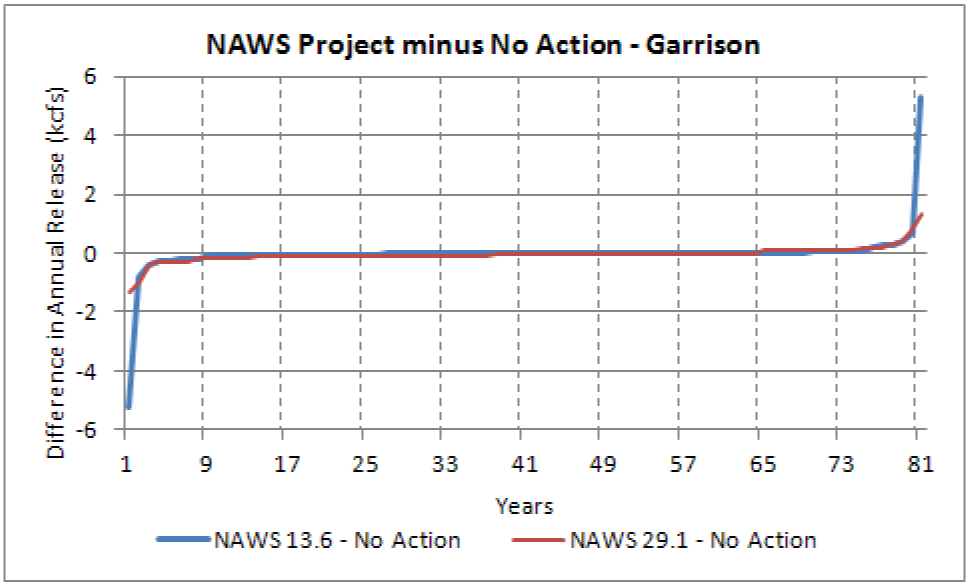

Figure 34. Sorted differences in the annual average Garrison releases between the two NAWS Project simulations and those of No Action for the 81-year period of analysis of 1930-2010.

Fort Peck

Figures 35 and 36 are 81-year plots of the sorted differences in the annual average Fort Peck releases for incrementally adding the sedimentation and the three levels of depletions to form the four simulations from the Existing Conditions simulation. Figure 35 compares the Sedimentation 2060 simulation with just the sedimentation and the No Action simulation with sedimentation plus the depletions through 2060 to the Existing Conditions simulation. This figure shows that the Sedimentation 2060 and No Action will have negative values in 38 of the 81 years. Using the same vertical scale, the two NAWS Project simulations are compared to No Action on Figure 36. This plot also shows negative values in 25 years or less for both NAWS Project simulations, with the negative values being just slightly negative (1.0 kcfs or less). The net difference is relatively small for the additional of the NAWS Project as last-added to the No Action simulation.

The annual differences were summed and divided by 81 to see the average annual effect on Fort Peck releases for the 81-year period. The average annual difference in releases for No Action (depletion of 60.6 kAF above Fort Peck Dam) and the two NAWS Project simulations (zero above Fort Peck) are equivalent to 64.4 kAF, 0.9 kAF, and 4.7 kAF per year, respectively. These differences also support the capability of the DRM to account for the depletions over the period of analysis.

Oahe

Figures 37 and 38 are 81-year plots of the sorted differences in the average annual Oahe releases for incrementally adding the sedimentation and the three levels of depletions to form the four simulations from the Existing Conditions simulation. Figure 37 compares the Oahe releases for the Sedimentation 2060 simulation with just sedimentation and the No Action simulation with sedimentation plus the depletions through 2060 to those of the Existing Conditions simulation. This figure shows that the

Sedimentation 2060 and No Action simulations will have negative release difference values in 42 and 43 of the 81 years, respectively. Using the same vertical scale in Figure 38, the two NAWS Project simulations are compared to the No Action simulation. This plot also shows negative values in 14 and 20 years for the two NAWS Project simulations, and the negative values are just slightly negative (less than 0.8 kcfs). The net difference is relatively small for the additional of the NAWS Project as last-added to No Action.

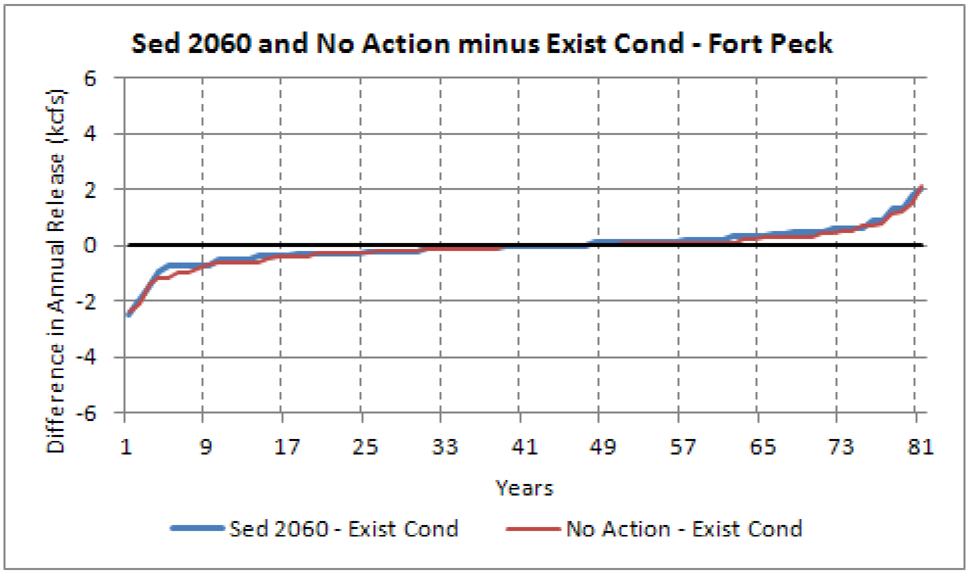

Figure 35. Sorted differences in the annual average Fort Peck releases between the Sedimentation 2060 and No Action simulations and those of the Existing Conditions simulation for the 81-year period of analysis of 1930-2010.

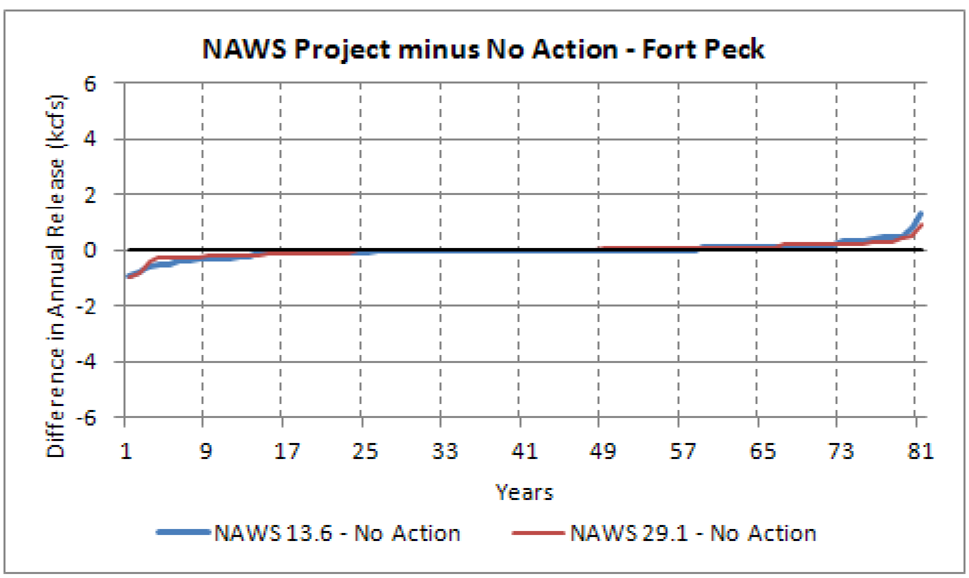

Figure 36. Sorted differences in the annual average Fort Peck releases between the two NAWS Project simulations and those of No Action for the 81-year period of analysis of 1930-2010.

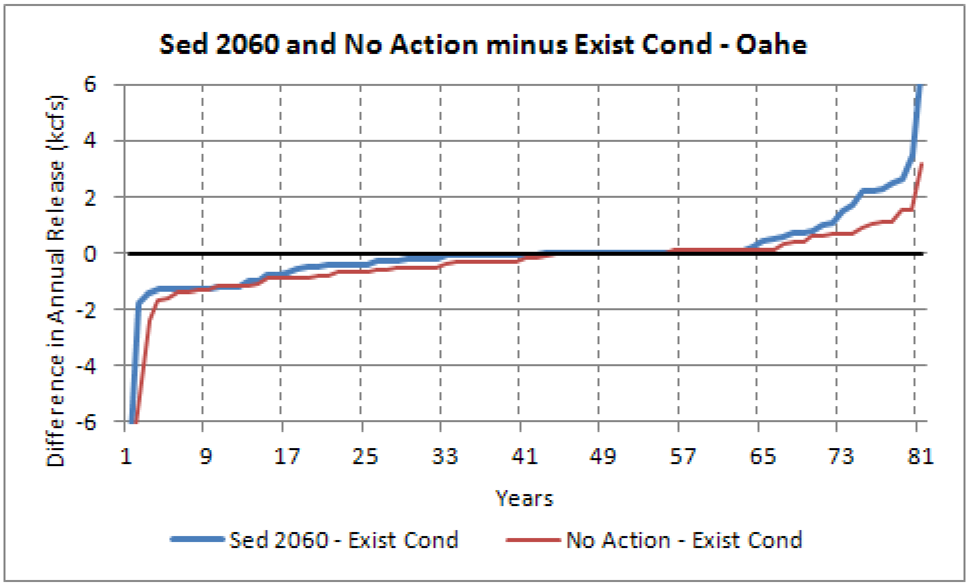

Figure 37. Sorted differences in the annual average Oahe releases between the Sedimentation 2060 and No Action simulations and those of the Existing Conditions simulation for the 81-year period of analysis of 1930-2010.

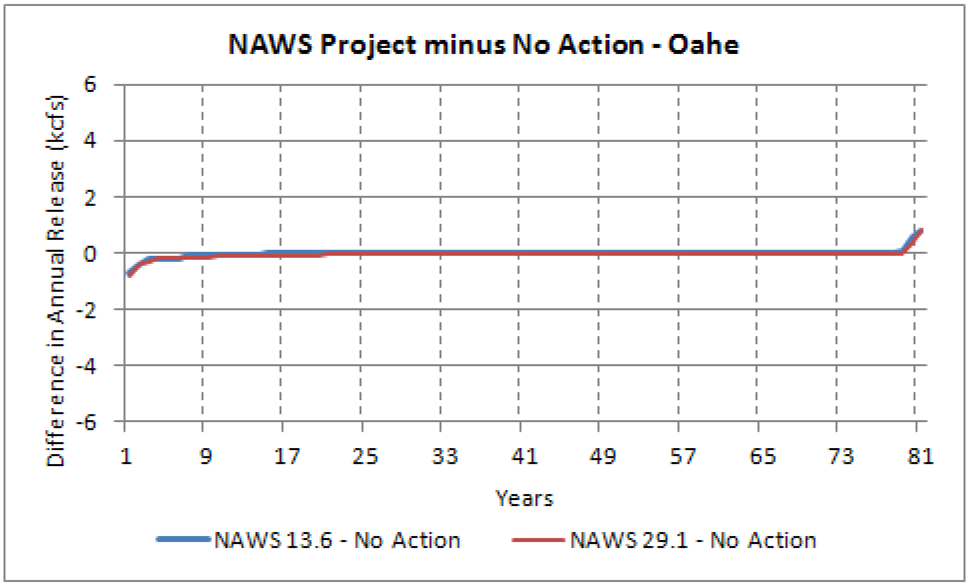

Figure 38. Sorted differences in the annual average Oahe releases between the two NAWS Project simulations and those of No Action for the 81-year period of analysis of 1930-2010.

The annual differences were summed and divided by 81 to see what the average annual effect on Oahe releases would be for the 81-year period. The average annual change in releases for No Action (depletion of 268 kAF above Oahe Dam) and the two NAWS Project simulations (additional 13.6 kAF and 29.1 kAF) are equivalent to 264.6 kAF, 10.7 kAF, and 24.1 kAF per year, respectively, all values very similar to the annual depletions of the three simulations. These differences also support the capability of the DRM to account for the depletions over the period of analysis.

Annual Minimum System Storage

System storage is important as it is the primary factor for determining the releases to the lower Missouri River. These releases also affect the releases from the upstream reservoirs, as they must maintain the storage level of Gavins Point Reservoir within a narrow range and balance the effects of System storage changes. Minimum System storage is also important to upstream and downstream interests, as these levels dictate key criteria such as navigation service level and season lengths, suspension of navigation in a given year, and effects to recreation and water supply uses on the three upstream reservoirs. This section focuses solely on the minimum System storage effects of the five simulations. Figure 39 through 42 are plots of the annual minimum System storage levels in the two greatest droughts in the 1930-2010 period of analysis – the 1930s and 2000s droughts.

Figure 39 presents the annual minimum System storages for the years of 1933-1943 for the Existing Conditions, Sedimentation 2060, and No Action simulations It shows that future sedimentation will result in lower minimum System storage levels through 1939; however, this factor results in higher levels in the post-1939 period on the figure because the additional sediments caused a non-navigation year in 1940 instead of delaying it until 1942 as had occurred for the Existing Conditions simulation. The additional depletions of the No Action simulation result in lower annual minimum storages in all years on Figure 39 except for 1943, as No Action had an additional non-navigation year (eight for the No Action simulation versus seven for the Sedimentation 2060 and Existing Conditions simulations).

Figure 40 presents the annual minimum storage levels for the 1933-1943 period for the simulations of the No Action and two NAWS Project simulations. The values for minimum System storage are very similar at the scale shown on the plot, which is the same as that of Figure 39.

Figure 41 presents the annual minimum System storages for the 2000-2010 period for the Existing Conditions, Sedimentation 2060, and No Action simulations. In all years, the Sedimentation 2060 resulted in lower System storages when compared to those of Existing Conditions. The No Action simulation values are lower than the Sedimentation 2060 values in the 2000-2007 period; however, they are higher in 2008-2010 due to a non-navigation year in 2007 for No Action.

Figure 42 presents the annual minimum storage levels for the 2000-2010 period for the simulations of No Action and two NAWS Project simulations. The values for minimum System storage are very similar at the scale shown on the plot, which is the same as that of Figure 41.

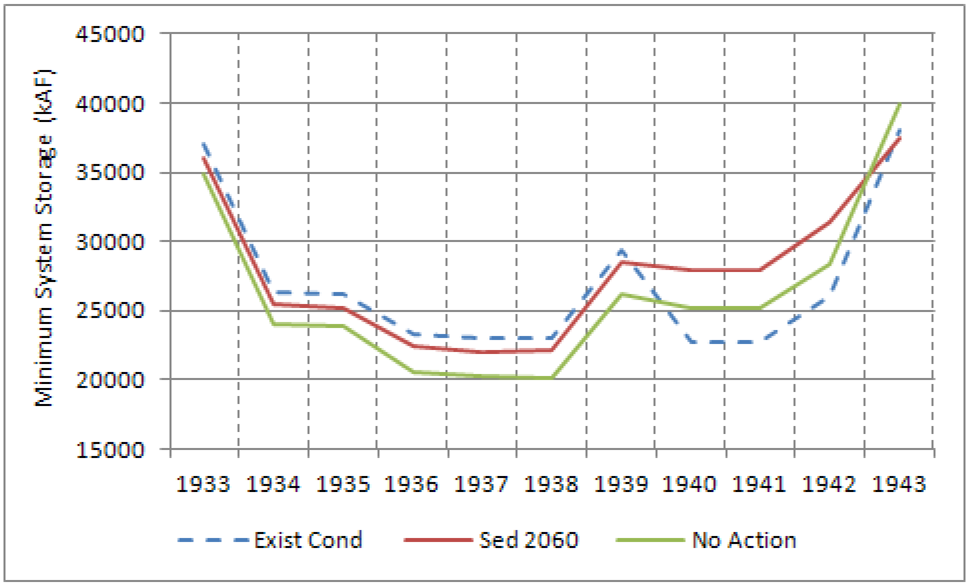

Figure 39. Annual minimum System storage levels in 1933-1943 for the Existing Conditions, Sedimentation 2060, and No Action simulations.

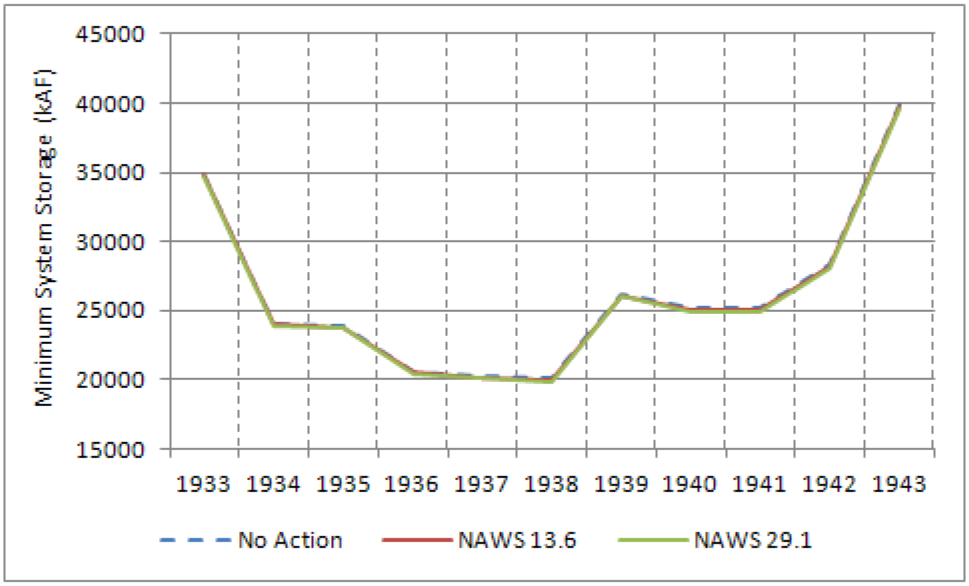

Figure 40. Annual minimum System storage levels in 1933-1943 for the No Action, NAWS 13.6, and NAWS 29.1 simulations.

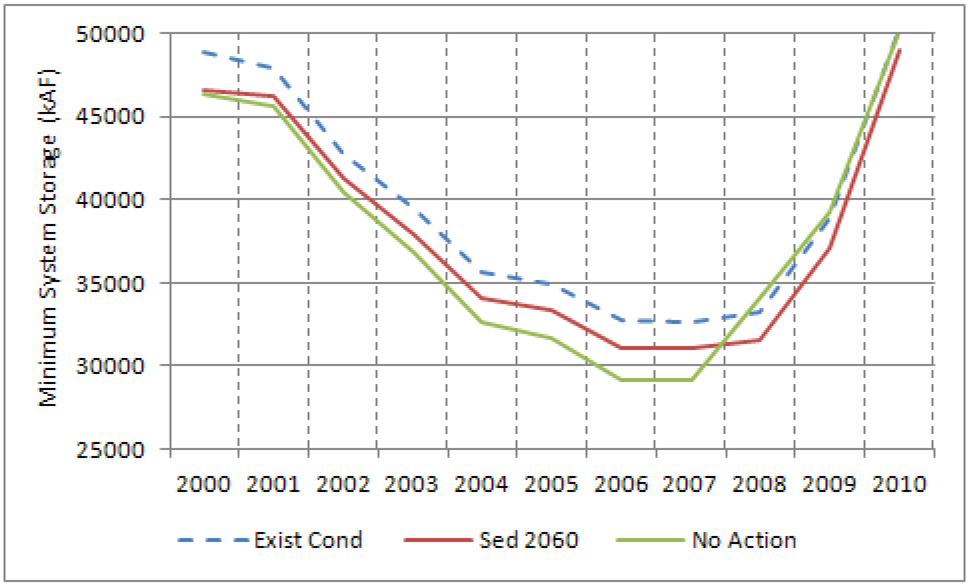

Figure 41. Annual minimum System storage levels in 2000-2010 for the Existing Conditions, Sedimentation 2060, and No Action simulations.

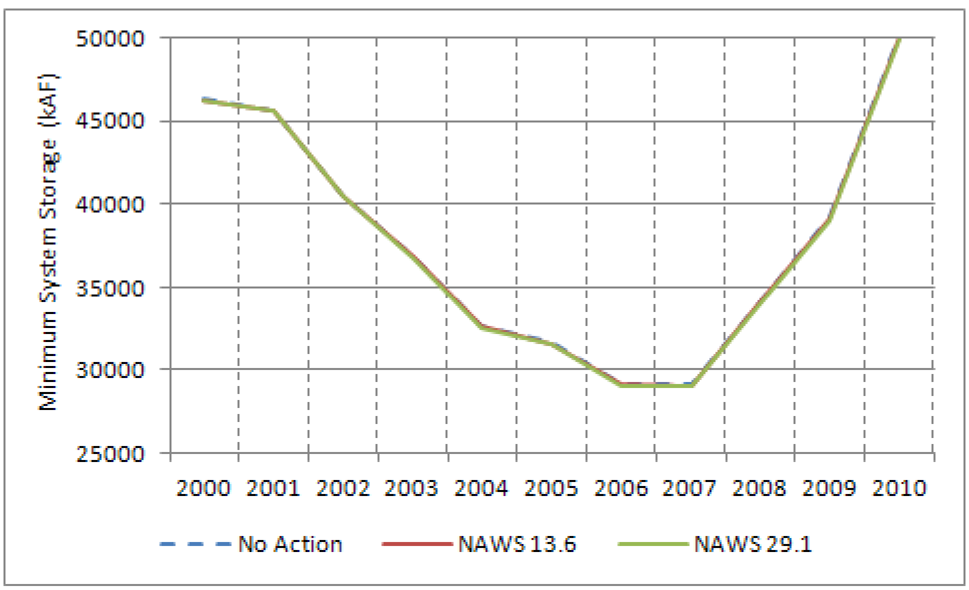

Figure 42. Annual minimum System storage levels in 2000-2010 for the No Action, NAWS 13.6, and NAWS 29.1 simulations.

Minimum System Storage Levels in the four Extended Droughts for all Five Simulations

The sedimentation and depletions resulted in System storage changes among the five simulations evaluated for this analysis and report. The minimum System storage values also varied among the simulations. Table 8 presents these values for the four major droughts. The minimum System storage levels changes among the simulations showed decreasing values as the sedimentation to 2060 was the first added change followed by the non-Project depletions to 2060 and, finally, the depletions simulations associated with the NAWS Project. The changes for the NAWS Project simulations were the lowest, and generally 0.1 MAF or less for NAWS 13.6 and between 0.1 and 0.2 MAF for NAWS 29.1; whereas, the changes for the sedimentation and the larger depletions between existing conditions and 2060 were somewhat larger, as high as about 2.0 MAF. Figure 43 shows the minimum storage levels in the four droughts for the five simulations. Again, it is readily apparent that there is relatively little change in the minimum storage levels of the NAWS Project simulations compared to the other three simulations.

Table 8: Minimum System Storage levels in the four Extended Droughts (1930-2010) (MAF)

	1930's	1950's	1990's	2000's
Existing Conditions	22.72	37.97	39.04	32.69
Sedimentation 2060	22.06	37.66	37.53	31.07
No Action	20.07	36.27	35.84	29.16
NAWS 13.6	19.99	36.18	35.77	29.09
NAWS 29.1	19.89	36.09	35.68	28.98

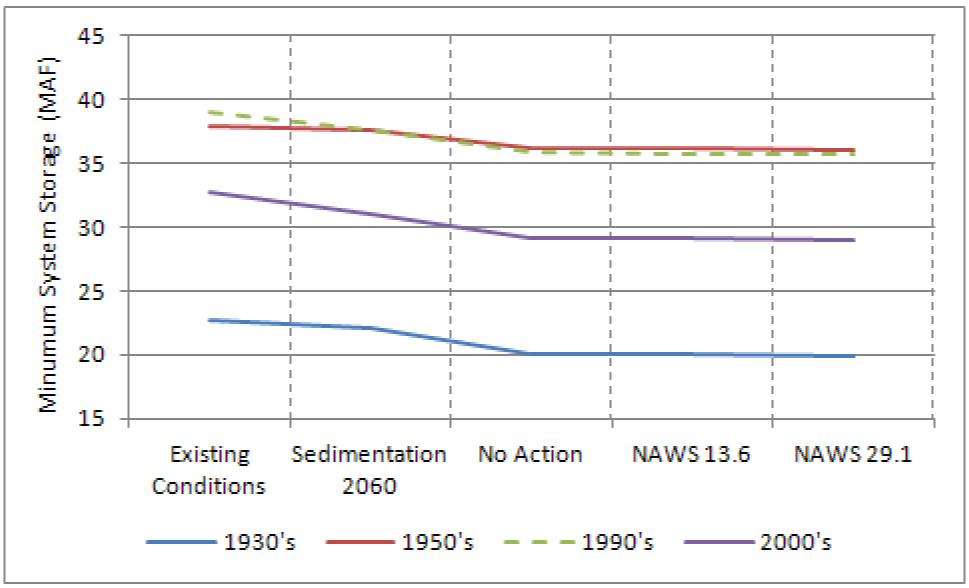

Figure 43. Minimum storage levels for the five simulations in the four extended droughts in the 81-year period of analysis of 1930-2010.

Annual Minimum Reservoir Elevations

Annual minimum reservoir elevations are important as they determine the level to which intakes for water supply and boat ramp extensions for recreation are required. This section focuses on the annual minimum reservoir elevations for the upper three, larger reservoirs – Fort Peck, Garrison, and Oahe. Because the plots of annual minimum reservoir elevations look very similar for all three reservoirs, the plots for only Garrison will be presented as Figures 44 through 47.

Figure 44 presents the minimum annual Garrison Reservoir levels during the 1930s drought. The minimum water levels will be higher under the Sedimentation 2060 simulation than they will be under the Existing Conditions simulation. Because of the difference in the non-navigation years (1940 for Sedimentation 2060 and 1942 for Existing Conditions), the minimum water levels will be higher for Sedimentation 2060 during the latter part of the 1930s drought. The No Action simulation with the forecasted non-Project depletions through 2060 will result in the lower annual minimum elevations of the three simulations through 1939 and will always be lower than Sedimentation 2060 until an extra (8 versus 7) non-navigation year occurs in 1942 for No Action.

Figure 45 presents the annual minimum Garrison Reservoir elevations for the 1933-1943 period for the No Action and the two NAWS simulations. The values for the annual minimum Garrison elevation are very similar among these three simulations.

The Sedimentation 2060 simulation always has higher minimum Garrison Reservoir levels throughout the 2000s drought than the Existing Conditions simulation has, as shown on Figure 46. The No Action simulation has a lower, growing minimum level difference from the two other non-Project simulations until 2007 when No Action has a non-navigation year that the other two simulations do not have. The growing difference between No Action and the other two simulations is a result of the accumulation of the non-Project depletions in the No Action simulation through the drought.

Figure 47 presents the annual minimum Garrison Reservoir elevation for the 2003-2010 period for the No Action and two NAWS Project simulations. The values for annual minimum elevation are very similar.

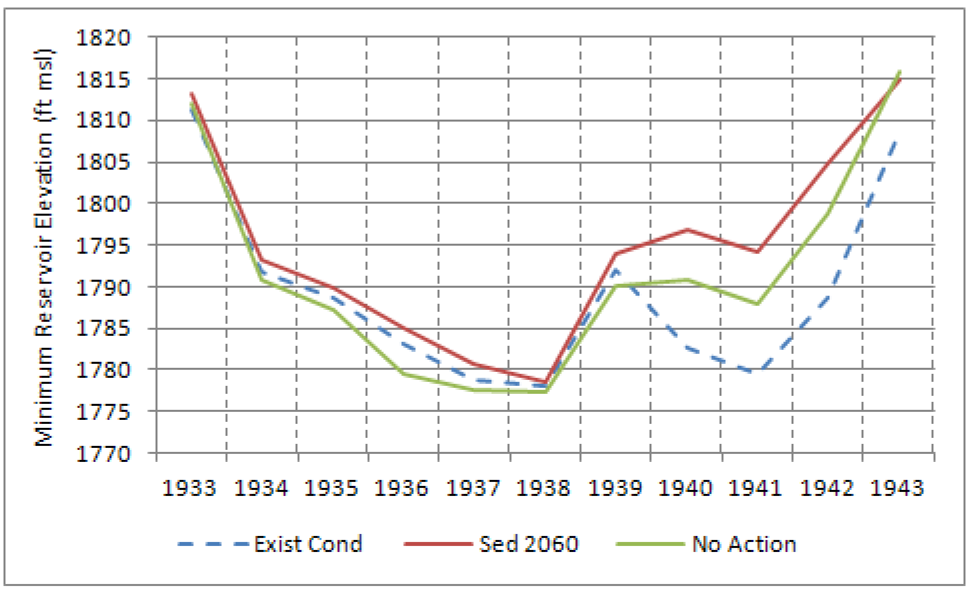

Figure 44. Annual minimum Garrison Reservoir levels in 1933-1943 for the Existing Conditions, Sedimentation 2060, and No Action simulations.

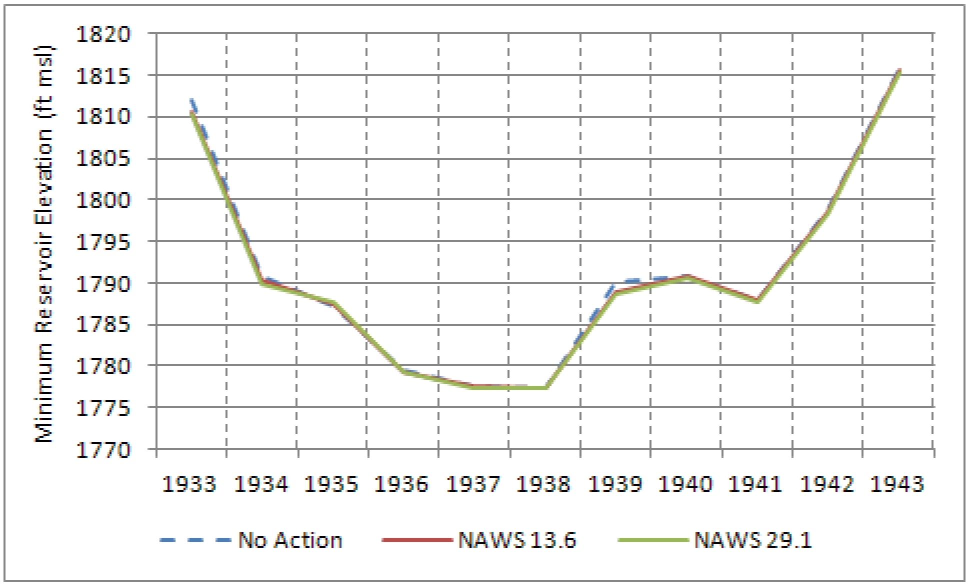

Figure 45. Annual minimum Garrison Reservoir levels in 1933-1943 for the No Action, NAWS 13.6, and NAWS 29.1 simulations.

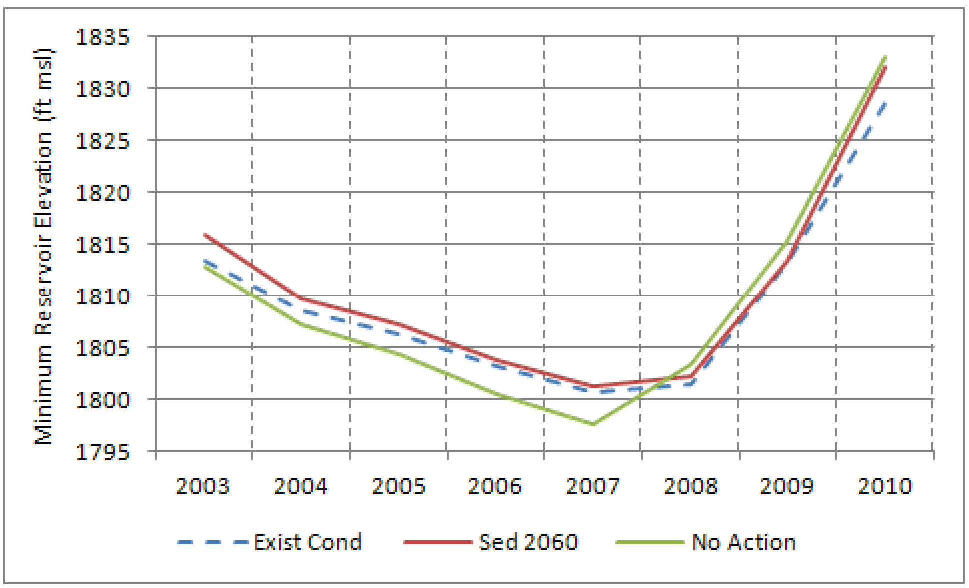

Figure 46. Annual minimum Garrison Reservoir levels in 2003-2010 for the Existing Conditions, Sedimentation 2060, and No Action simulations.

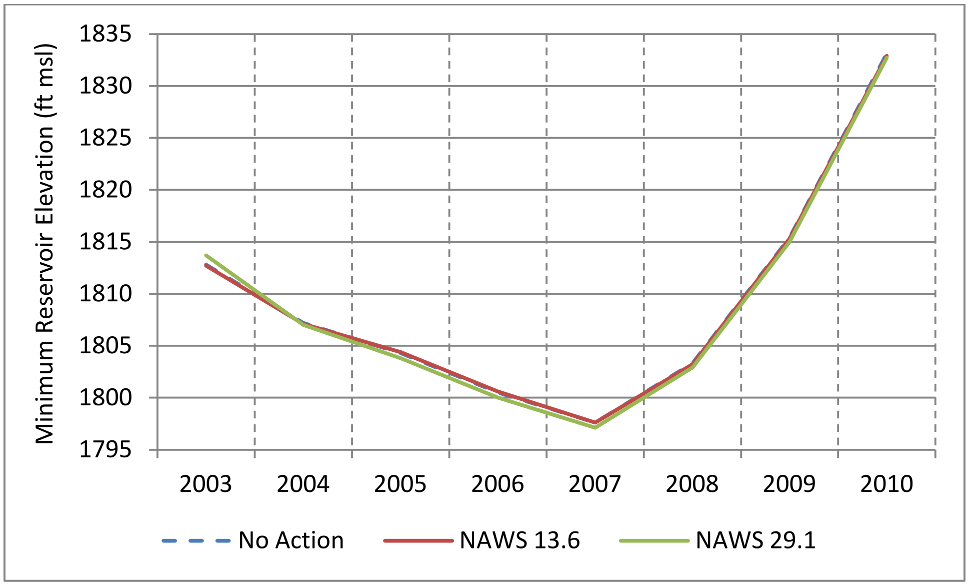

Figure 47. Annual minimum Garrison Reservoir levels in 2003-2010 for the No Action, NAWS 13.6, and NAWS 29.1 simulations.

Minimum Reservoir Levels in the four Extended Droughts for all Five Simulations

The sedimentation and depletions resulted in reservoir level changes among the five simulations evaluated for this analysis and report. The minimum reservoir level values also varied among the simulations. Table 9 presents the minimum reservoir water surface elevations for the three, larger reservoirs for the five simulations for the four extended droughts in the 81-year period of analysis of 1930-2010. Review of the table shows that the 1930s and 2000s droughts were the more severe droughts. The differences among the No Action and two NAWS Project simulations during the 1930s drought were 0.2 feet, 0.0 foot, and 0.8 feet for Fort Peck, Garrison, and Oahe, respectively. The differences among the No Action and two NAWS Project simulations during the 2000s drought were 0.3 feet, 0.5 feet, and 0.2 feet for Fort Peck, Garrison, and Oahe, respectively. The values presented in Table 9 are plotted in Figures 48, 49, and 50 to provide a visual perspective on the differences in minimum reservoir elevations for Fort Peck, Garrison, and Oahe, respectively.

Table 9: Minimum water surface elevations for the upper three, larger System reservoirs during the four extended droughts for the 1930-2010 period of analysis (ft msl)

	Exist Cond	Sed 2060	No Action	NAWS 13.6	NAWS 29.1
			Fort Peck Reservoir		
1930s	2163.6	2163.7	2163.1	2163.0	2162.9
1950s	2201.9	2206.3	2203.6	2203	2203.9
1990s	2203.1	2204.4	2201.6	2201.6	2201.7
2000s	2189.4	2189.4	2187.5	2187.2	2187.2
			Garrison Reservoir		
1930s	1778	1778.5	1777.4	1777.4	1777.4
1950s	1810.3	1812.3	1810	1811	1809.8
1990s	1810.8	1812	1809.9	1809.9	1809.5
2000s	1800.6	1801.3	1797.6	1797.6	1797.1
			Oahe Reservoir		
1930s	1546.2	1546.3	1543.1	1542.8	1542.3
1950s	1582.9	1586.5	1584.5	1584.4	1584.2
1990s	1584.9	1586.8	1585.5	1585.5	1585.3
2000s	1572.9	1574.5	1571.1	1570.9	1571.1

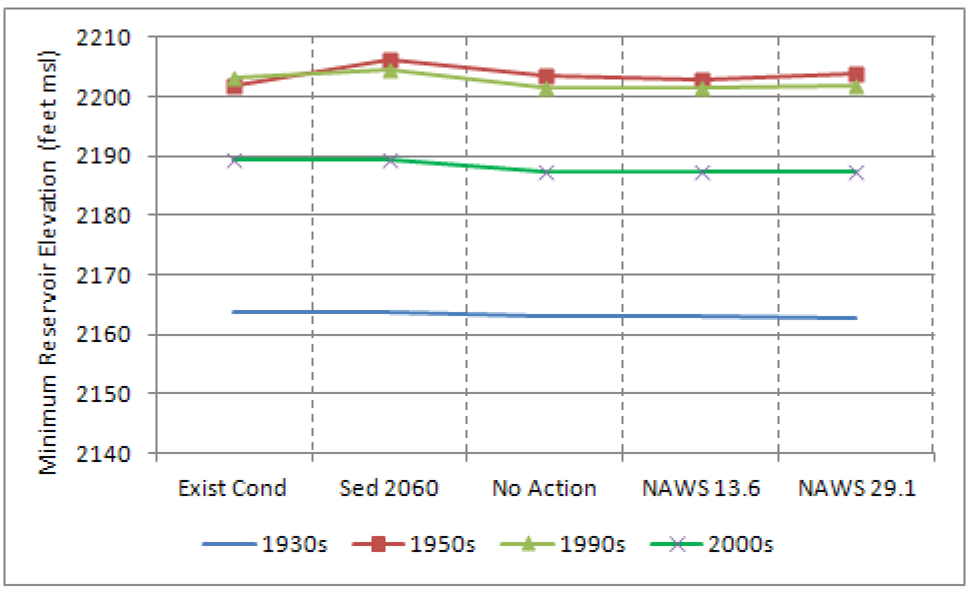

Figure 48. Fort Peck Reservoir minimum water surface elevations for the five simulations for the four extended droughts during the 1930-2010 period of analysis.

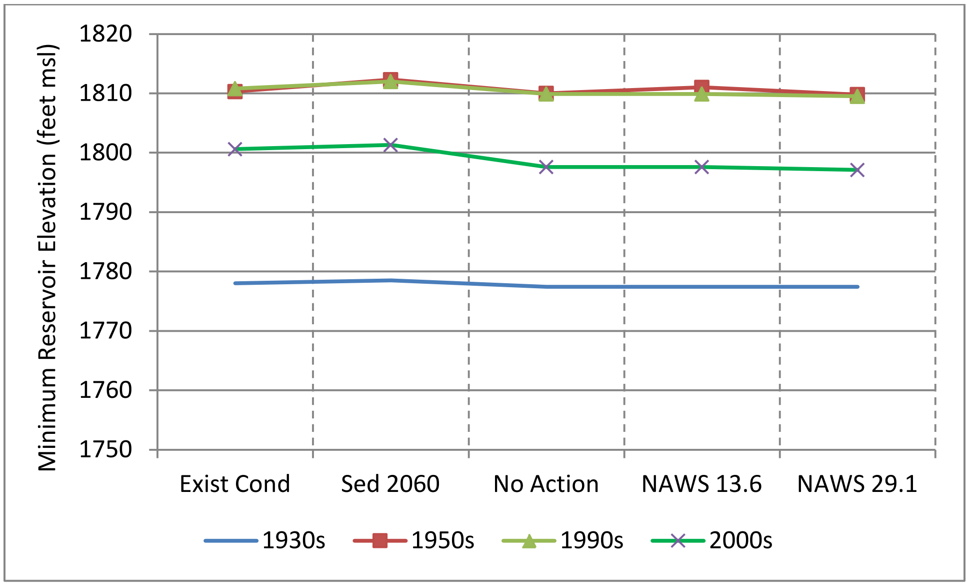

Figure 49. Garrison Reservoir minimum water surface elevations for the five simulations for the four extended droughts during the 1930-2010 period of analysis.

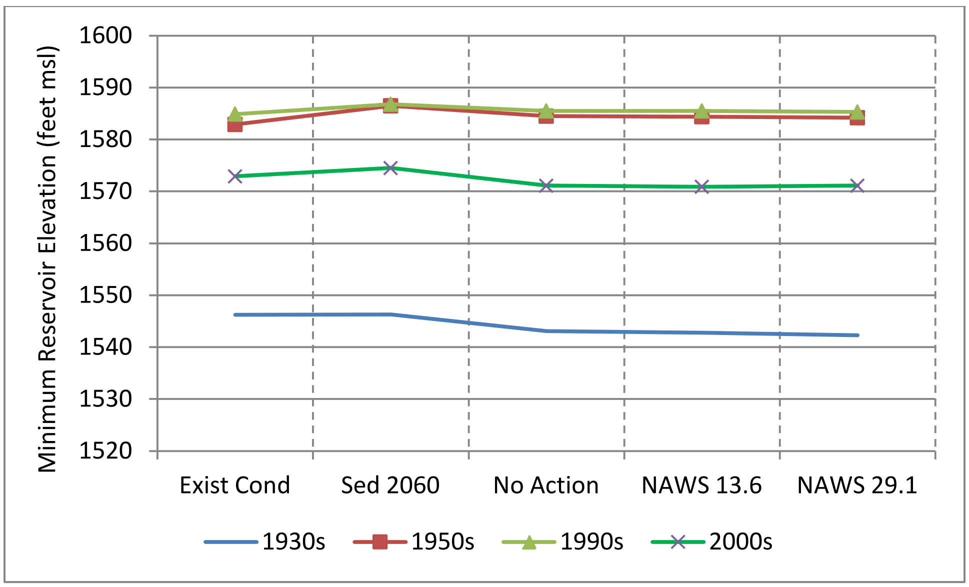

Figure 50. Oahe Reservoir minimum water surface elevations for the five simulations for the four extended droughts during the 1930-2010 period of analysis.

Summary of Hydrologic Effects

Hydrologic effects of sedimentation in the reservoirs and depletion of inflows to the System have been discussed above. This section summarizes those impacts.

Continuing deposition of sediments into the System reservoirs will reduce the storage capacity of primarily the Carryover and Multiple Use Zone and the Permanent Pool of the each reservoir. This will, in turn, reduce the storage capacity of the total System. Because the amount of water stored in the two flood control zones will remain relatively constant, the amount of water stored in the System reservoirs will be diminished annually by the sedimentation. Because the amount of storage in each reservoir will be lower, the net effect of sedimentation will be higher reservoir levels. Finally, the sedimentation will have essentially no impact on releases from the System reservoirs in most years because the same volume of water will enter the System reservoirs and will need to be evacuated to the base of flood control in normal to wet years. The minor differences will result from slightly different releases during droughts as the navigation service level will be reduced in the first 3 months in most years of the droughts due to the lower System storages.

Non-Project depletions that would reduce inflows to the System reservoirs and the lower Missouri River are forecasted to reach 516 kAF by 2060. These depletions to inflows will reduce the amount of water in System storage, especially during extended droughts. This reduction in System storage will carry over to the water surface elevations, or levels of water, in each of the three, larger System reservoirs (Fort Peck, Garrison, and Oahe), as levels will drop in increasing amounts in the droughts as the depletions continue to accumulate each year. Finally, releases from the System reservoirs will drop with the increasing non-Project depletions, with the amount of release reductions being nearly equivalent to the amount of the cumulative depletions above each reservoir.

NAWS Project depletions will have similar effects as the non-Project depletions; however, the amount of Project depletions is relatively small (13.6 and 29.1 kAF are 2.6 and 5.6 percent, respectively) compared to 516 kAF of non-Project depletions. Consequently, the effect of NAWS Project depletions will be relatively small, as shown on the various plots of the hydrologic effects of the two NAWS Project simulations.

Economic Impacts for Simulations Conducted for the NAWS Project SEIS

The economic impacts models developed for the Master Manual Study compute the absolute economic values described previously in this report. Development of these impacts models were completed from about 1993 through 2002, and revision should be made to them to have more accurate <u>absolute</u> numbers (i.e. economic values) for the effects. No new information was readily available nor collected to update the economic value data for the impact models. The process of revision would be very costly and time consuming; therefore, the existing models outputs on economic effects are the best available information at this time. One way to minimize concerns about the absolute numbers is to present only the relative differences among the simulations being modeled with the economic impacts model. However, there are merits for presenting the absolute numbers. For example, the absolute numbers provide insight on the distribution of the benefits among the reaches, the reaches that are primarily affected by the changes included in each simulation, and the magnitude of those effects. The tables and discussion on each economic use will have the absolute values but will also include the relative differences for the other four simulations from the Existing Conditions simulation and for the two NAWS Project simulations relative to the No Action simulation. To provide the desired perspective, a discussion focusing on the relative differences, or percentage changes, among the simulations will be presented in a summary of economic effects at the end of this section of the results of the economic analyses.

Flood Control

The System provides flood control to the river reaches between Fort Peck Dam and Garrison Reservoir, between Garrison Dam and Oahe Reservoir, between Oahe Dam and Big Bend Reservoir, between Fort Randall Dam and Gavins Point Reservoir, and on the lower Missouri River downstream from Gavins Point Dam. These reaches can be separated into the Upper River and Lower River reaches. The flood control model computes the damages resulting from high water levels in these reaches and compares them to the damages that would have resulted had the System not been constructed (run-of-river damages). The net differences are the damages prevented, or the flood control benefits of the System. When the upper three, larger reservoirs rise into the upper parts of their Annual Flood Control and Multiple Use pools and their Exclusive Flood Control Pool, damages can occur to some of the recreation facilities around their shorelines. The flood control model also computes these damages, which would be negative benefits.

Table 10 presents the average annual flood control benefits for the five simulations analyzed for this report. The left half of the table presents the total benefits and the relative differences between the Existing Conditions simulation and the other four simulations (to provide some perspective as to how flood control will be affected between basically now and 2060) and between No Action and the two NAWS Project simulations (to provide some perspective of the flood control effects of just the addition of the NAWS Project under 2060 conditions). The right side of the table presents the reach data for each of the five simulations.

The continuing deposition of sediments into the System reservoirs will cause flood control benefits to drop slightly (by 0.13 percent) between now and 2060. Future depletion of flows into the Missouri River main stem will eliminate this loss of benefits and make the net change positive by 0.02 percent (net change of 0.15 percent). Addition of the NAWS Project will have no effect on the flood control benefits (changes are in the thousandth of percent level). Overall, the change in flood control benefits due to the combined forecasted sedimentation and depletions to 2060 are extremely small (0.02 percent). The reach with essentially all of the differences (losses then gains) is the lower river reach.

Table 10: Average annual flood control benefits ($ millions)

	Total	% Chg from	% Chg from	Reach Benefits		
	Benefits	Exist Cond	No Action	Reservoirs	Upper River	Lower River
Exist Cond	393.78	--	--	-0.52	81.24	313.06
Sed 2060	393.29	-0.13	--	-0.55	81.25	312.59
No Action	393.86	0.02	--	-0.55	81.31	313.11
NAWS 13.6	393.84	0.02	-0.01	-0.54	81.29	313.09
NAWS 29.1	393.85	0.02	0.00	-0.54	81.28	313.11

To provide further perspective on the flood control benefits, Figure 51 was prepared. This figure shows the slight gain in total flood control benefits as the depletions increase (as added to the sedimentation that is forecasted for this analysis). The figure also includes the regression equation for the line through the data points and the coefficient of determination, R^2. The number in front of the "x" in the equation is the slope of the line, and the R^2 value indicates how well the line fits the data, with the closer the value to 1.0 being an indication of the better fit to the data. In this case, the slope indicates a gain of almost $1.06 million for each MAF of depletions. At a depletion of 1.0 MAF, the relative change in benefits is 0.27 percent, a relatively small amount.

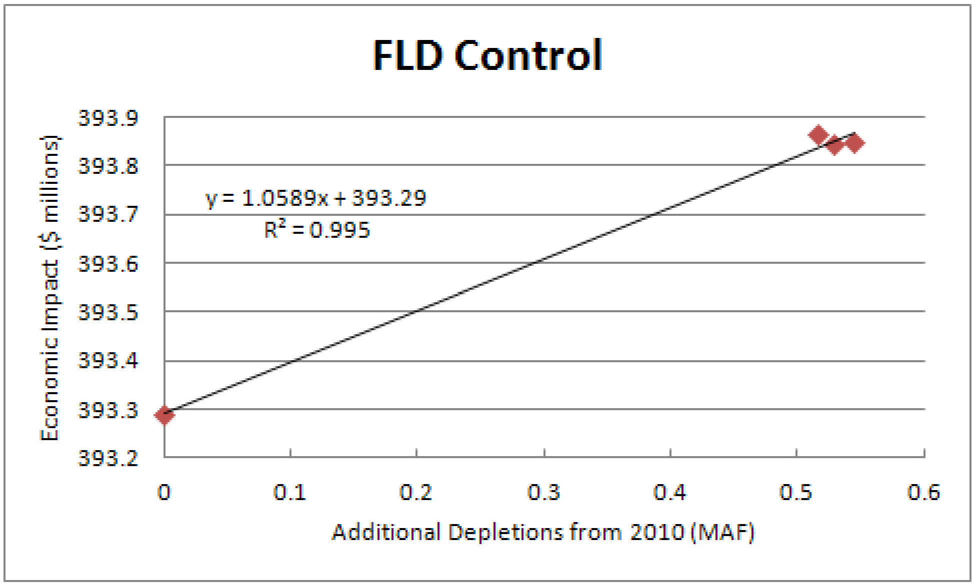

Figure 51. Plot of flood control benefits of Sedimentation 2060, No Action, and two NAWS Project simulations versus additional depletions from 2010, including the linear line fitting the data, its equation, and coefficient of determination.

While Figure 51 and the data within the figure provide some perspective on the changes with increasing depletions, a second plot using only the No Action and two NAWS Project simulations provides even another look at the potential flood control effects of the NAWS Project and an indication that the exact ultimate size of the project does not have to be evaluated directly to understand the associated flood control effects. Figure 52 shows the resulting plot, equation, and coefficient of determination. The fit of the data is much poorer than on Figure 51, and the slope of the line is very slightly negative. This results because the benefits of the three simulations are essentially the same, with the NAWS 13.6 simulation having the lower of the three values. The best way to interpret this plot is that the benefits will essentially not change for any potential different NAWS Project option.

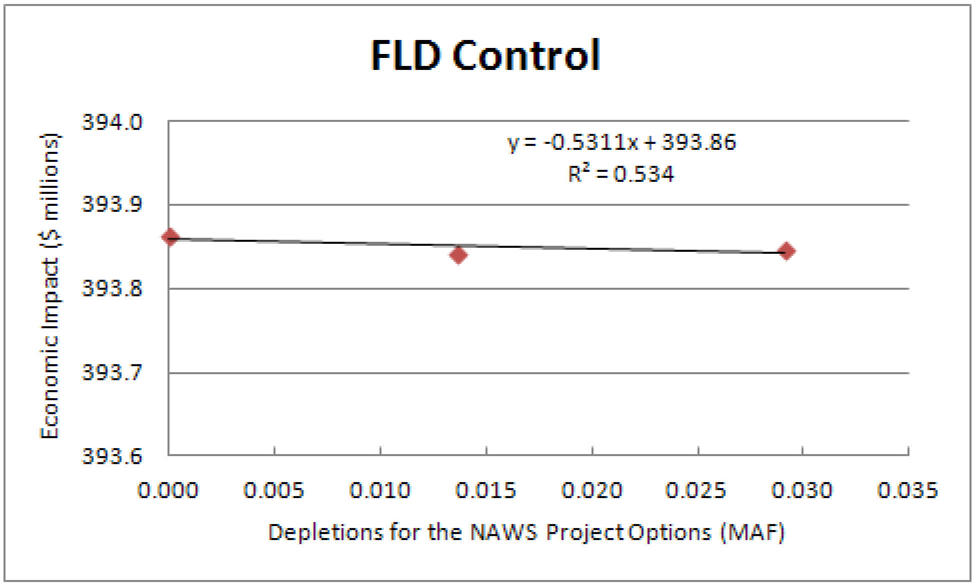

Figure 52. Plot of flood control benefits of No Action and two NAWS Project simulations versus additional depletions, including the linear line fitting the data, its equation, and coefficient of determination.

Missouri River Navigation

Operation of the System is directly affected by the navigation requirements for the lower Missouri River flood storage evacuation requirements in high System inflow years, and other authorized requirements when navigation is suspended in extended droughts. Future sediment deposition and depletions will have an effect on the navigation service (service level and season length) on the Missouri River, and these changes will have an effect on the navigation economic benefits provided by the System.

Table 11 presents the average annual navigation benefits on the Missouri River for the five simulations analyzed in this report. The left side of the table focuses on the total average annual benefits and the right side breaks those benefits down by reach. The relative changes in total benefits are presented in two ways; the first is by percent change from the Existing Conditions simulation for the other four simulations and the second is by change from the No Action simulation for the two NAWS Project simulations. The changes from Existing Conditions are relatively large at about -13 percent to about -16 percent, with the greatest change occurring for the additional sedimentation alone that is included in the Sedimentation 2060 simulation. However, the changes from No Action for the two NAWS Project simulations are relatively small at -0.07 percent and -0.14 percent for NAWS 13.6 and NAWS 29.1, respectively. The loss in navigation benefits is distributed among all of the four reaches.

Table 11: Average annual Missouri River navigation benefits ($ millions)

	Total Benefits	% Chg from Exist Cond	% Chg from No Action	Reach Benefits			
				Sioux City	Omaha	Nebr. City	Kan. City
Exist Cond	6.753	--	--	0.870	0.657	0.414	4.812
Sed 2060	5.872	-13.05	--	0.710	0.535	0.261	4.366
No Action	5.708	-15.48	--	0.694	0.520	0.275	4.220
NAWS 13.6	5.712	-15.42	0.07	0.693	0.520	0.273	4.227
NAWS 29.1	5.700	-15.60	-0.14	0.691	0.518	0.271	4.221

Figure 53 was prepared to provide some additional perspective on the effects of depletions alone. It includes the changes associated with the addition of 516 kAF of additional depletions between 2010 and 2060 within and downstream from the System and the two NAWS Project simulations' additional depletions of 13.6 kAF and 29.1 kAF on top of the 516 kAF. The best-fit linear line and associated equation and coefficient of determination are also included on the figure. The line fit is very good with a coefficient of determination of 0.9979, and the slope of the line is -$0.3122 million per MAF of depletions. The loss of Missouri River navigation benefits is about 5.3 percent per every MAF of depletions from Existing Conditions, according to the data in Figure 53.

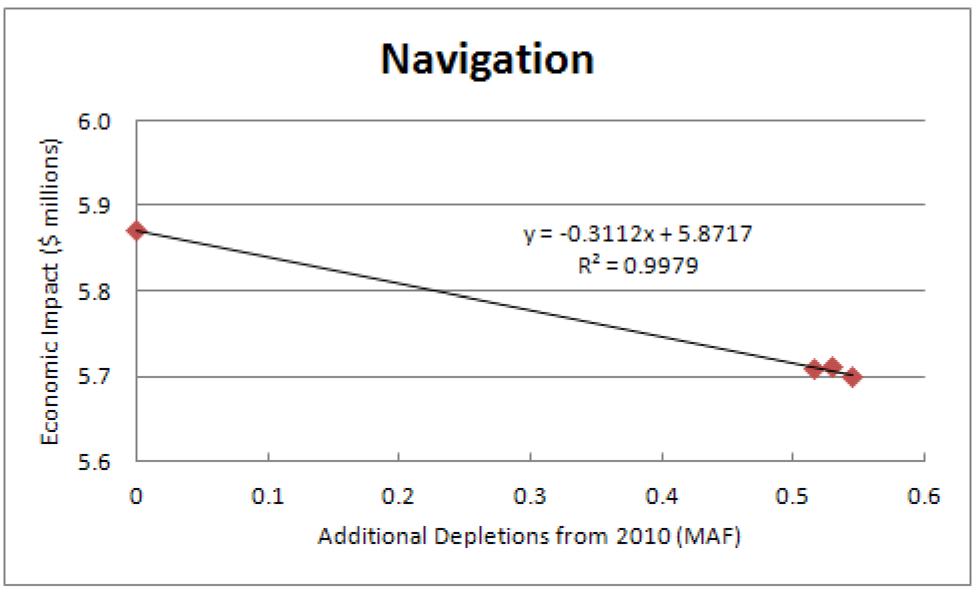

Figure 53. Plot of navigation benefits of Sedimentation 2060, No Action, and two NAWS Project simulations versus additional depletions from 2010, including the linear line fitting the data, its equation, and coefficient of determination.

Another way to plot the depletion data is to focus on the changes from No Action to the two NAWS Project potions, as shown in Figure 54. The slope of the best fit line is essentially flat at $0.2868 million per MAF with a relatively low coefficient of determination of 0.4547. The loss per MAF is a loss of navigation benefits of about 5.02 percent per MAF of depletions. The depletions of the NAWS Project are in the range of about 0.02 MAF, making the percentage changes of the NAWS Project essentially the same no matter what the ultimate value of depletions may be for the NAWS Project.

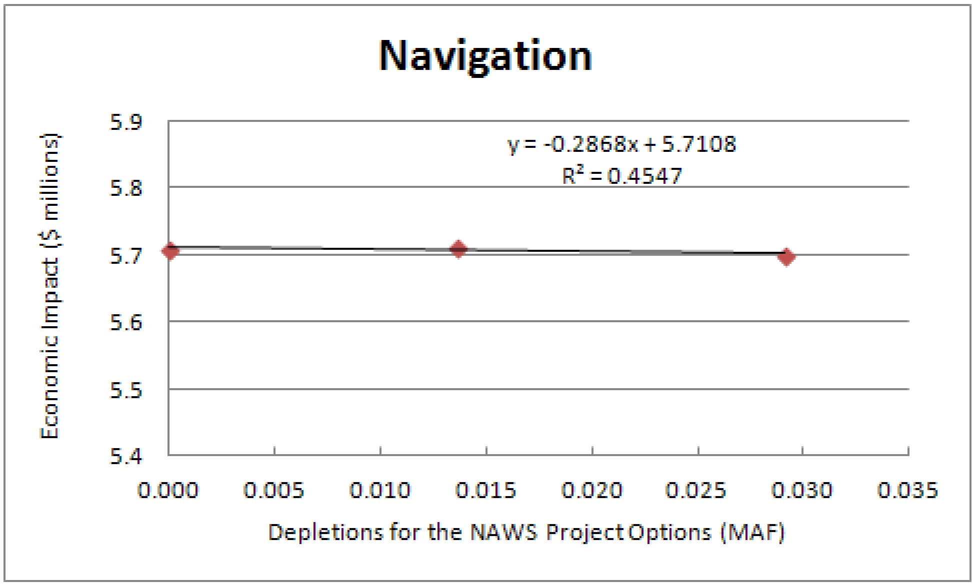

Figure 54. Plot of navigation benefits of No Action and two NAWS Project simulations versus additional depletions, including the linear line fitting the data, its equation, and coefficient of determination.

To help understand the navigation economic effects, DRM navigation output data on service level and season length are presented in Figures 55 through 57. Figure 55 shows that, for the March 15 System storage service level checks, the greatest difference is for the change in the number of years at full service for the addition of sediment deposition into the reservoirs between 2010 and 2060. This loss of years is 8 out of 81 years in the period of analysis, about a 10 percent reduction. The additional 516 acre-feet of depletions to form the No Action simulation results in a loss of 2 more full service years. Adding the NAWS Project simulations to No Action adds just one more year in which full service would not be provided in a repeat of the 1930-2010 period of record. Adjustments are made to the number of years of intermediate service and minimum service, with the greater changes occurring to intermediate service. Another important change was the addition of two more non-navigation years for the additional depletions of the No Action and NAWS Project simulations. Most of these changes are due to the fact that the base of flood control would be dropped to near the top of the navigation guide curve that dictates when full service would begin to be reduced to intermediate service; the base of flood control being reduced to 53.1 MAF and the top of the guide curve being 54.5 MAF. Full navigation service would, therefore, be provided in years with early high runoff such that either the base of flood control would not be reached by March 1 or at least 1.4 MAF of runoff in excess of the System releases were to occur in those years.

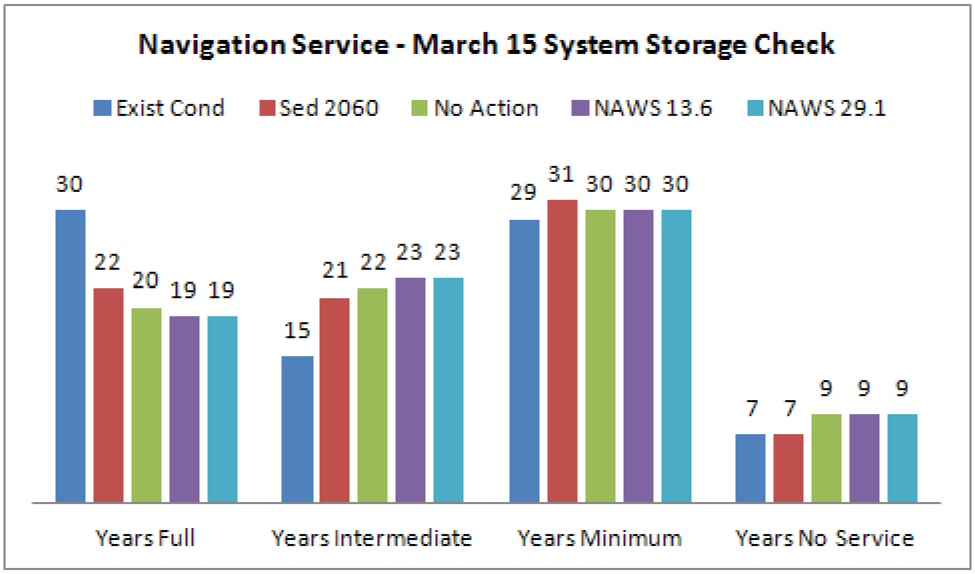

Figure 55. Navigation service level based on the March 15 System storage check for the five simulations.

The service level reductions in the April through June period would adjust System storage so that the effects based on the July 1 System storage check would be reduced from those made on the March 15 check. Figure 56 shows the results on navigation service based on the July 1 service level check. It shows that the number of years in which full service years would be provided went up from 30 during the first 3 months of the year to 37 in the last 5 months of the 81-year period of analysis. Any reductions in the number of years of full service would be due to the sedimentation, and that effect would only be a reduction of 4 years. The net effect would be 2 more years of intermediate service and either two years of minimum service (Sedimentation 2060) or 2 more years of no service (No Action and NAWS Project simulations). The more dramatic effect would be the 2 more years of no service, which was determined based on the March 15 check.

Figure 57 presents the navigation season length data for the 81-year period of analysis. It shows that the number of extended seasons of 8.33 months will be cut by almost a half by the sedimentation in the reservoirs by 2060. They will be further cut to only 10 extended service seasons in the 81-year period by the non-Project depletions. These cuts will move to full 8-month season with some spill over to some seasons shorter than 8 months. There would be no change in the season lengths for the additional depletions resulting directly from the NAWS Project.

In summary, the NAWS Project would have very limited effects on service level and very little, if any, effect on season lengths. The service-level effect would be to move 1 year of full service to intermediate service based on the March 15 System storage check. This change would affect navigation in only the 3 months of April through June. The other changes would be within the intermediate service level years and less-than-8-month years that fall within the breakdown included in Figures 55 through 57.

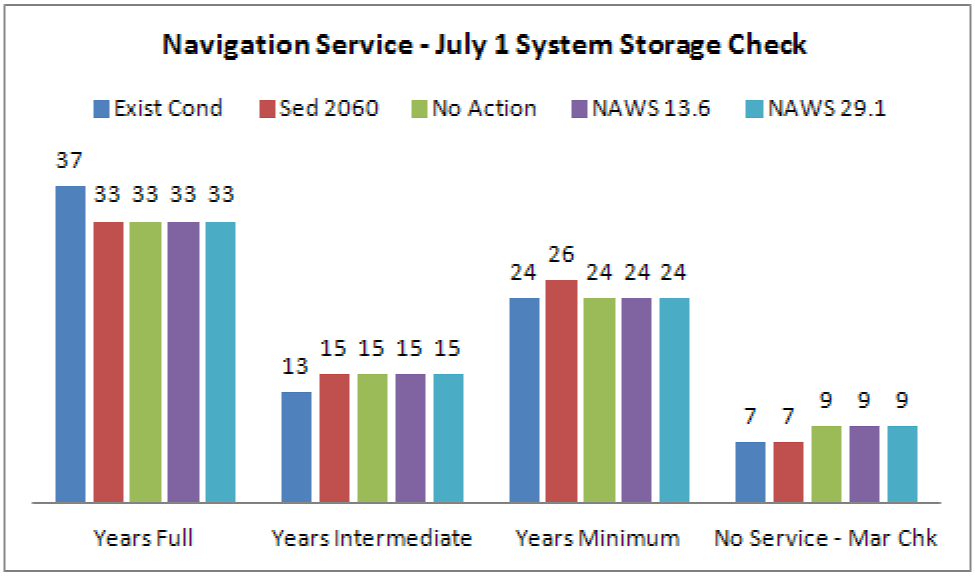

Figure 56. Navigation service level based on the July 1 System storage check for the five simulations.

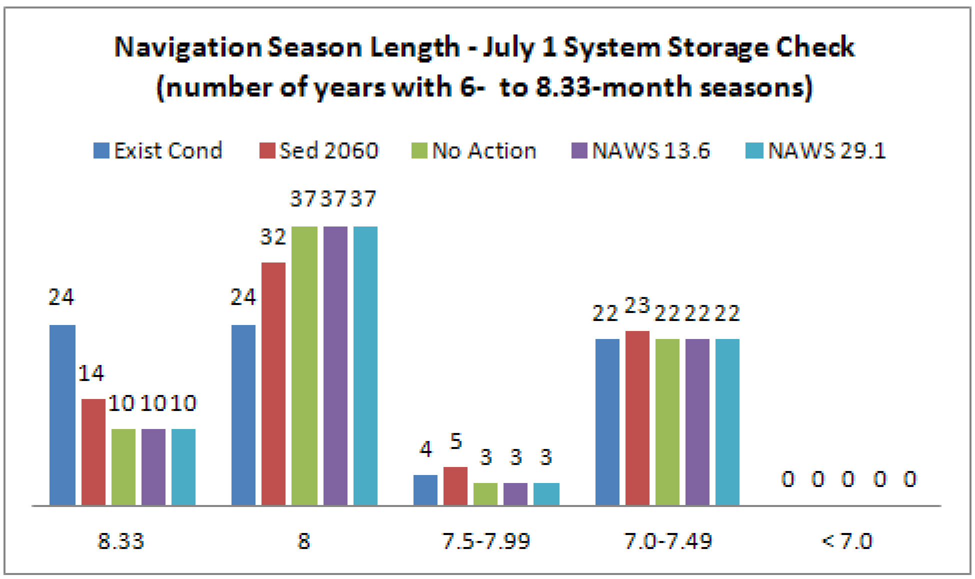

Figure 57. Navigation season length based on the July 1 System storage check for the five simulations.

Mississippi River Navigation

Analysis of Mississippi River navigation effects due to changes on the Missouri River is a complex, time-consuming, and expensive process, which could not be accomplished within the timeframe of the analysis of the NAWS Project. In the past, the most significant year for increases in lost Mississippi River navigation benefits was 1939; therefore, differences in the amount of water released from the Missouri River System of reservoirs focused on only differences in this year. All five simulations completed for this report had no Missouri River navigation service in 1939, meaning that there would be no differences among the simulations in terms of Mississippi River navigation in that most critical year.

Hydropower

All six System dams have hydropower units that have a total capacity of 2,501 megawatts (MW). The movement of the water through the System dams has averaged about 10 million MW-hours (MW-h) of electricity annually. The capacity of the System hydropower units varies with the amount of "head" (height of water above the units); therefore the full capacity is not always available, with the amount of generation that is capable referred to as capability. The amount of energy generated also varies with capability and with the amount of water moving through the units. In droughts, the generation decreases and in wet periods the generation increases as long as the capacity of the units is not exceeded. If the amount of water exceeds the capacity of the units, the excess water is moved either through flood control tunnels or over spillways, depending on the System project.

Table 12 presents the average annual capability and generation over the 81-year period of analysis of 1930-2010. Under the Existing Conditions, the average annual capability is 2,094 MW. As sedimentation continues in the System reservoirs through 2060, the average annual capability will increase by 1.07 percent because the average annual head on the hydropower units will be at a higher level (reservoir levels will be higher on average, as discussed under the hydrologic impacts). Depletions will decrease the head; therefore, capability will drop to a 0.45 percent increase for the No Action simulation and drop slightly more for the two NAWS Project simulations. The average annual higher capability and lower releases of the Sedimentation 2060 simulation in the earlier part of the navigation season in some years (as compared to Existing Conditions) will result in a generation increase of only 0.18 percent. The lower capability and even lower releases of the No Action and NAWS Project simulations will result in a reduction of from 1.44 percent to 1.62 percent compared to Existing Conditions as the depletions increase from a total of 516 kAF for No Action to 545 kAF for NAWS 29.1.

Table 12: Average annual System hydropower capability and generation

	Capability (MW)	% Change	Generation (1000 MW-h)	% Change
Exist Cond	2094	--	8951	--
Sed 2060	2116	1.07	8967	0.18
No Action	2103	0.45	8822	-1.44
NAWS 13.6	2102	0.40	8813	-1.54
NAWS 29.1	2101	0.35	8806	-1.62

Benefits are computed for both capability and generation by the hydropower economic impacts model using the monthly hydropower output data from the DRM. Table 13 summarizes these benefits on a reach and total basis as average annual benefits over the 1930-2010 period of analysis. Because the average annual capability and generation both go up for the continuing sedimentation included in the Sedimentation 2060 simulation, it has the highest average annual total hydropower benefits. However, on a reach basis, only the upper three, larger projects have the highest hydropower benefits for the Sedimentation 2060 simulation. The sedimentation does not result in any appreciable change in the levels of Fort Randall, Big Bend, and Gavins Point and the releases through all of these smaller reservoirs is lower than under Existing Conditions; therefore, the average annual hydropower benefits for these three smaller System projects drop with the continuing sedimentation. Additional depletions result in both lower heads and releases; therefore, the average annual benefits of the No Action and NAWS Project simulations drop on a total and individual project basis as the future depletions included in these simulations increase from 516 kAF for No Action to 545 kAF for NAWS 29.1. The net effect (relative difference) of the depletions of the NAWS Project on the average annual hydropower benefits is in the range of -0.06 percent to -0.12 percent, relatively small effects.

Table 13: Average annual hydropower benefits ($ millions)

	Total	% Chg from	% Chg from	Reach Benefits					
	Benefits	Exist Cond	No Action	Fort Peck	Garrison	Oahe	Big Bend	Ft. Randall	Gavins Pt.
Exist Cond	628.84	--	--	60.39	126.30	184.36	111.40	108.01	38.37
Sed 2060	632.74	0.62	--	60.87	128.75	186.34	111.33	107.36	38.09
No Action	626.17	-0.43	--	60.25	126.33	184.18	110.68	106.86	37.88
NAWS 13.6	625.79	-0.49	-0.06	60.24	126.24	183.92	110.70	106.83	37.87
NAWS 29.1	625.40	-0.55	-0.12	60.21	125.89	183.96	110.65	106.82	37.86

The effect of depletions on the total average annual hydropower benefits were also analyzed using the plotting and regression tools in Excel. Figure 58 presents the plot of benefits versus depletions with the Sedimentation 2060 simulation having zero depletions and the No Action and NAWS Project simulations having from 516 to 545 kAF, or 0.516 and 0.545 MAF, of depletions. This figure shows that as the depletions increase, the total average annual hydropower benefits decrease. The slope of the line is -$13.151, meaning that the hydropower benefits drop by $13.151 million per each MAF of depletions, and the coefficient of determination is very good at 0.998. One MAF of depletions would have about a 2.1 percent impact on the hydropower benefits. A closer look was conducted using only the No Action and NAWS Project simulations, meaning that the No Action depletion was zero and the NAWS Project simulations depletions were 0.0136 and 0.0291 MAF, as shown in Figure 59. The slope of the line means that the loss of benefits would be $26.368 million per MAF of depletions, a loss of benefits of 4.21 percent for every MAF.

Another measure of the hydropower impacts is the value of the energy (generation in Table 12) that is marketed from the System by the Western Area Power Administration (Western). A spreadsheet model was developed by Western for the Master Manual Study, and Western updated the data required for the analysis in August 2010. Table 14 lists the average annual System hydropower revenues that Western would collect for the five simulations included in this analysis. The percent changes are similar to those shown in Table 12 for changes in generation by the System when compared to the Existing Conditions. Sedimentation 2060 resulted in a slight increase in revenue while the other three simulations that had increasing levels of depletions resulted in a reduction of revenues. The reason the percent changes are not identical to those in Table 12 for generation is that the monthly values for purchases and sales are variable for the 12 months of the year. When compared to the revenues of the

No Action simulation, the NAWS 13.6 and NAWS 29.1 simulations would produce 0.09 percent and 0.19 percent less energy revenues, respectively, relatively small differences.

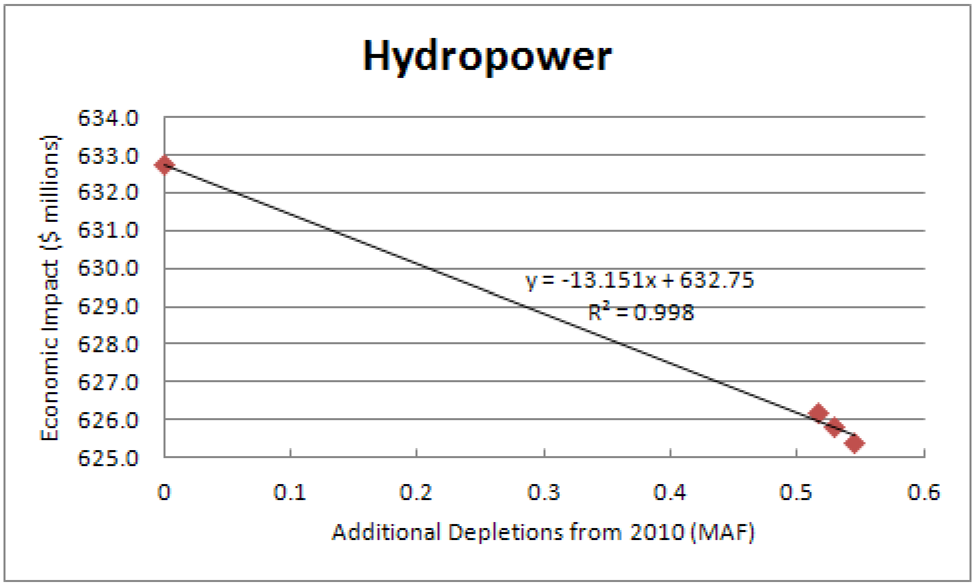

Figure 58. Plot of hydropower benefits of the Sedimentation 2060, No Action, and two NAWS Project simulations versus additional depletions from 2010, including the linear line fitting the data, its equation, and coefficient of determination.

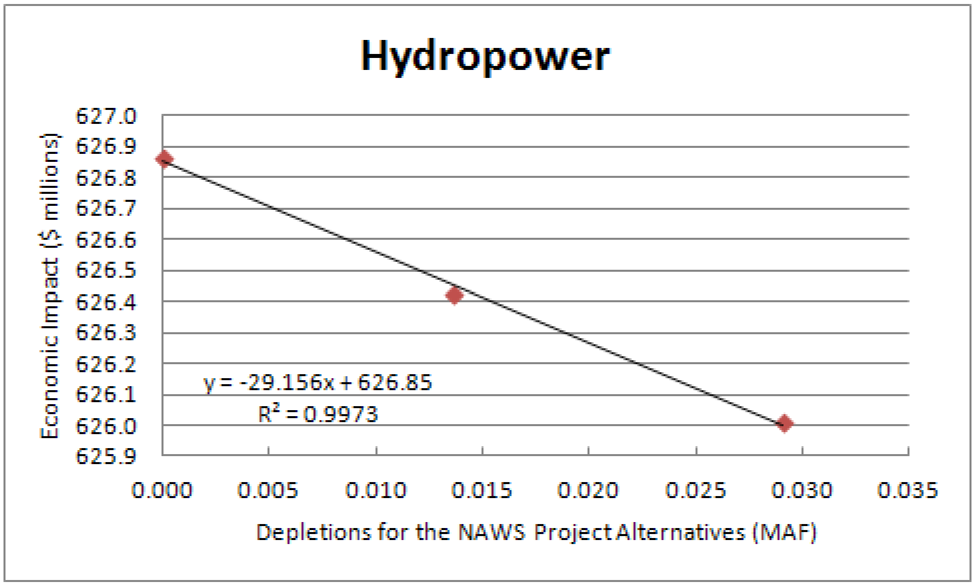

Figure 59. Plot of hydropower benefits of No Action and two NAWS Project simulations versus additional depletions from 2010, including the linear line fitting the data, its equation, and coefficient of determination.

Table 14: Average annual energy revenues ($ millions)

	Total Energy Revenue	% Change from Exist Cond	% Change from No Action
Exist Cond	262.516	--	--
Sed 2060	262.767	0.10	--
No Action	258.481	-1.54	--
NAWS	258.244	-1.63	-0.09
NAWS 29.1	257.990	-1.72	-0.19

Water Supply

The water supply economic impacts model computes benefits for not only those relying on the river as a source of water but also for water quality issues for the power plants along the river that discharge their heated water after running through the cooling units of the generators to the river. These benefits are summarized in Table 15 that includes the total and reach benefits broken down into three categories – upper and lower Missouri River reaches and reservoir reaches. Because the water level in the upper three, larger reservoirs are generally higher due to the sediments being continuously deposited in them, the water supply benefits (all water use benefits) would be expected to go up for the Sedimentation 2060 simulation. Because the releases generally go down, the riverine benefits would be expected to go down with the sediment deposition in the reservoirs. This is the case as the reservoirs category is the only one that the benefits went up, and these increases resulted in a net total benefit increase of 0.01 percent. Depletions result in lower reservoir levels and releases to both go down, causing water supply benefits, whether intake or discharge (for water quality) to go down on all reaches. This is the case as shown for the No Action and two NAWS Project simulations. Addition of the depletions associated with the two NAWS Project simulations resulted in an unexpected annual loss of about $5 million of water supply benefits (-0.8% change from No Action). This loss basically occurs in the reach downstream from Garrison Dam, which includes three power plants. Detailed investigation of the data associated with the flows and water supply economics could not identify the reason for the lost benefits. Earlier simulations with a different set of non-Project depletions did not have a similar loss of water supply benefits. At a loss of about 0.8 percent, this loss of water supply benefits does not appear to be reasonable when a loss of 516 acre-feet of water per year resulted in a loss of benefits of only 0.29 percent.

Table 15: Average annual water supply benefits ($ millions)

	Total Benefits	% Change from Exist Cond	% Change from No Action	Reach Benefits		
				Reservoirs	Upper River	Lower River
Exist Cond	607.77	--	--	19.69	95.81	492.27
Sed 2060	607.81	0.01	--	20.06	95.80	491.95
No Action	606.07	-0.28	--	19.83	95.32	490.93
NAWS 13.6	601.20	-1.08	-0.804	19.84	90.44	490.93
NAWS 29.1	601.19	-1.08	-0.806	19.82	90.43	490.93

Figure 60 presents the plots of water supply benefits versus depletions, with the Sedimentation 2060 simulation representing zero depletion. The equation for the fitted line (R^2 = 0.5785, indicating a not-so-good fit) through the data points defines the rate of loss of water supply benefits as depletions increase at $9.7327 million per MAF, a loss of 1.60 percent of the water supply benefits per MAF of depletions. This loss per MAF further supports the questioning of the loss of water supply benefits equivalent to 0.8 percent for just an increase in depletions of 0.014 to 0.029 MAF associated with the NAWS Project simulations simulated for this analysis. The plot of water supply values of just the No Action and two NAWS Project simulations is not included (as was done for the other economic use categories) due to the questionable losses computed for the two NAWS Project simulations.

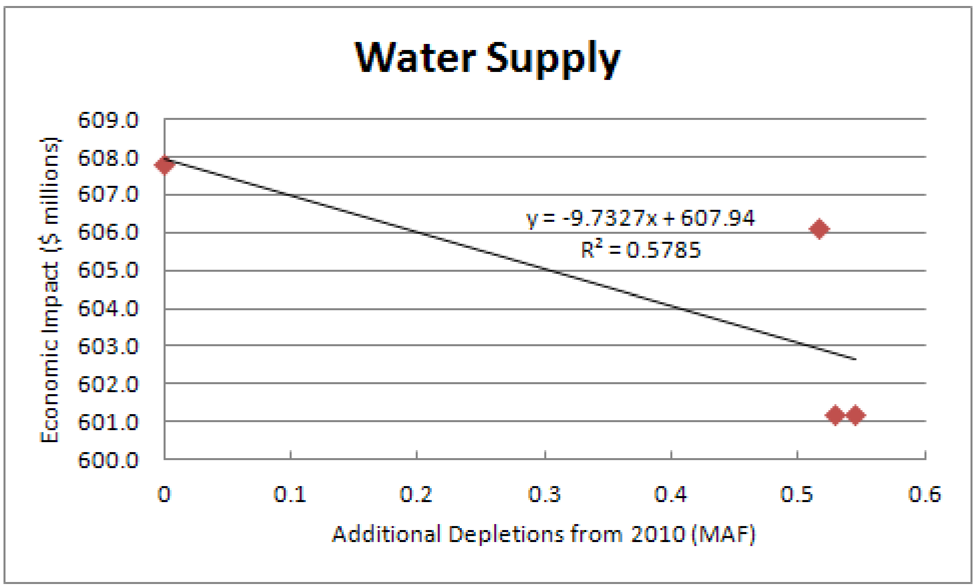

Figure 60. Plot of water supply benefits of the Sedimentation 2060, No Action, and two NAWS Project simulations versus additional depletions from 2010, including the linear line fitting the data, its equation, and coefficient of determination.

Recreation

Recreation use occurs on all reaches of the Missouri River. The economic benefits of recreation are distributed among all of the reaches; however, the loss of recreation benefits on the upper three, larger reservoirs has always been an issue during drought periods. Table 16 summarizes the average annual benefits over the 81-year period of analysis on a reach and total basis. The reaches are aggregated into four categories. Recreation benefits for the lower three reservoirs are separated from those of the upper three reservoirs because the water levels of the lower three are relatively unaffected in all DRM simulations. This is reflected in the essentially no change in the recreation benefits for these three lower reservoirs, as shown in Table 16. Similarly, the change in benefits among the five simulations analyzed for this report for the upper river reaches is also near zero. The upper three, larger reservoirs have the most significant changes among the simulations, and these changes are reflected in the changes of the total recreation benefits. Continuing sedimentation results in higher water levels in the upper three reservoirs. The recreation benefits increase in the reservoirs and on a total basis in response to the higher levels. Depletions normally result in lower reservoir levels and, therefore, lower recreation benefits. The benefits decrease for the No Action simulation before decreasing further for the two NAWS Project simulations. The relative differences for the two NAWS Project simulations are -0.28 percent for NAWS 13.6 and -0.77 percent for NAWS 29.1, both relatively small differences. When looking at the locations that the differences are greatest, they are 1.8 percent for Oahe Reservoir for the NAWS 13.6 option and 2.8 and 2.3 percent for Fort Peck and Garrison reservoirs, respectively, for the NAWS 29.1 option.

Table 16: Average annual recreation benefits ($ millions)

	Total	% Chg from	% Chg from	Reach Benefits			
	Benefits	Exist Cond	No Action	Up 3 Res.	Lwr. 3 Res.	Upper River	Lower River
Exist Cond	82.37	--	--	29.40	29.01	4.50	19.47
Sed 2060	83.97	1.94	--	31.07	29.03	4.48	19.38
No Action	83.61	1.50	--	30.78	29.04	4.47	19.32
NAWS 13.6	83.38	1.22	-0.28	30.54	29.04	4.47	19.32
NAWS 29.1	82.97	0.72	-0.77	30.13	29.04	4.47	19.32

As with the other economic use categories, a plot of the depletion data was completed with the Excel software, which provides a best-fit equation and coefficient of determination. Figure 61 shows that the relationship between depletions and recreation economics is relatively poor at 0.6388. The slope of the line is a loss of $1.269 million per MAF of depletions. A second plot, Figure 62, has an excellent correlation coefficient of 0.9853. The slope of the line is a negative $22.365 million per MAF of

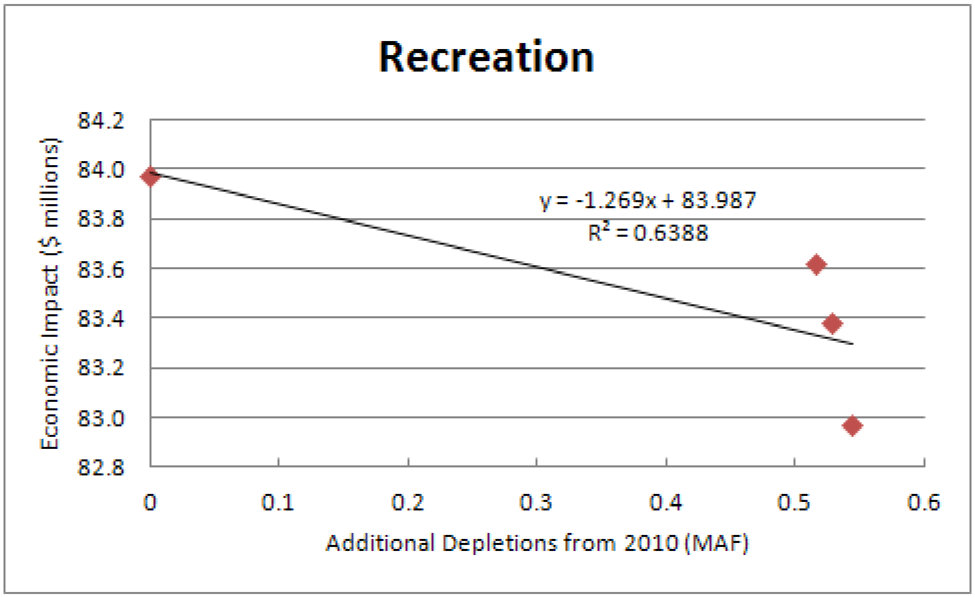

Figure 61. Plot of recreation benefits of the Sedimentation 2060, No Action, and two NAWS Project simulations versus additional depletions from 2010, including the linear line fitting the data, its equation, and coefficient of determination.

depletions (26.8 percent loss of benefits per MAF of depletions). Because the depletions likely to result from the NAWS Project are relatively small at 0.01 to 0.03 MAF, the actual loss is expected to be relatively small, as indicated in Table 16 (0.28 to 0.77 percent).

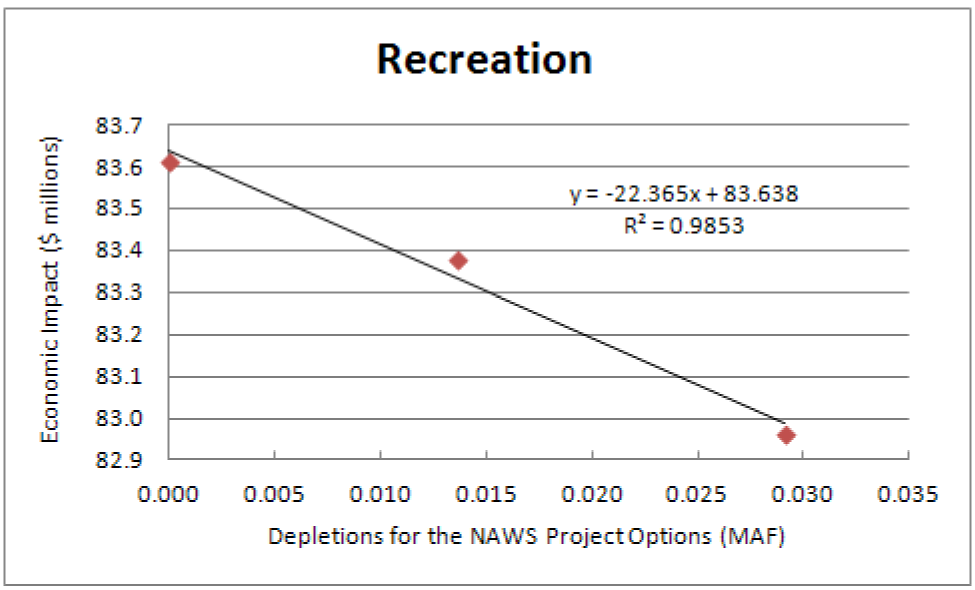

Figure 62. Plot of recreation benefits of No Action and two NAWS Project simulations versus additional depletions from 2010, including the linear line fitting the data, its equation, and coefficient of determination.

Total National Economic Development (NED) Benefits

Summation of the flood control, navigation, hydropower, water supply, and recreation benefits for the System provides some perspective on the total benefits to the Nation on an average annual basis. These benefits can also be split between those provided within the System and those to the lower Missouri River.

Table 17 presents the Total NED benefits and the breakdown in these benefits into those that are within the System and those that are along the lower Missouri River for all five simulations. The Table 17 values for the split between those within and those downstream from the System were derived by summing the appropriate values in the reach columns to the corresponding region for each of the economic uses discussed above. In the case of hydropower, 60 percent of the benefits were assigned to the area within the System and 40 percent were assigned to the lower river based on a historical distribution of the hydropower to the States of Nebraska and Iowa. A larger portion of the aggregated benefits are assigned to the lower river because of the large values accruing for flood control, hydropower, and water supply (and water quality for the power plants). Only hydropower has a larger value for the reach within the System with the next higher value being for water supply (and water quality for the power plants in the reach downstream from Garrison). Flood control and recreation benefits are each less than $100 million in value for the within System region.

Table 17: Total National Economic Development Benefits ($ millions)

	Total	w/in System	Lower River
Existing Conditions	1719.52	636.44	1083.09
Sedimentation 2060	1723.68	640.79	1082.89
No Action	1715.42	635.89	1079.54
NAWS 13.6	1709.92	630.55	1079.37
NAWS 29.1	1709.10	629.87	1079.23

Figure 63 presents the plot of the Total NED benefits for the depletion changes from Sedimentation 2060 for the No Action and two NAWS Project simulations. Based on the equation in the figure, the loss of benefits to the Nation due to depletion of water from the System from the Sedimentation 2060 baseline (zero additional depletion from Existing Conditions) is $23.4 million per MAF of depletions, a loss of 1.36 percent of the System's benefits per every MAF of depletions.

Figure 64 presents the plot of the net change in NED benefits from Existing Conditions split between the two reaches (slopes of the linear regression line and the coefficients of determination would be the same if total benefits were plotted, with the scale differences for the total values between the two reaches being an issue). The reach within the System loses almost $17 million of benefits for each MAF of depletions; whereas, the lower river reach loses benefits at the rate of about $7 million per MAF. The rate of loss is higher within the System (upper basin States) versus those along the lower Missouri River (lower basin States). Similar plots with the percent changes shown on the plots are presented in Figure 65. The percent losses per MAF should be the more appropriate numbers as they represent relative differences instead of absolute differences, which may be off somewhat due to the age of the economic models. These percent changes are -2.64 percent within the System and only -0.61 percent along the lower Missouri River. Even though the lower basin States have expressed concerns regarding depletions, the losses accrue within the System (upper basin States) at more than twice the percentage rate of the losses along the lower Missouri River.

The wider spread of the benefits for the upper basin for the three simulations with depletions above those in 2010 (No Action, NAWS 13.6, and NAWS 29.1 simulations) resulted primarily for the unexpected drop in benefits for the two NAWS Project simulations. If the points on the plots had been closer together, the coefficient of determination would have been much closer to 1.0. If the three points shifted up to the higher one for No Action, the loss per MAF would have been about $9.5 million. If the No Action point would have shifted down (less likely of the two situations), the loss could have been as high as $19.5 million per MAF. In either case, the losses in the within the System would have been greater per MAF than for the lower river.

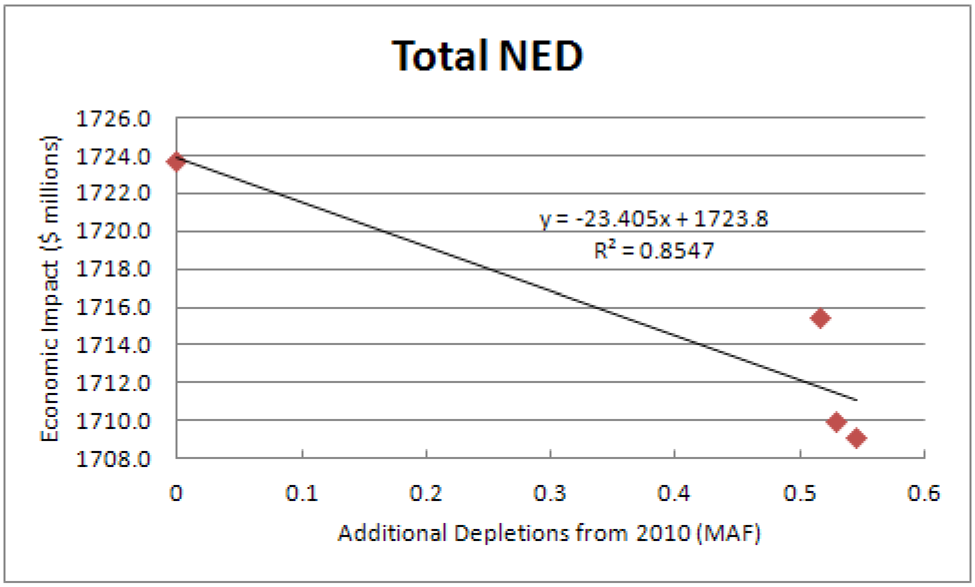

Figure 63. Plot of the change in Total NED benefits of the Sedimentation 2060, No Action, and two NAWS Project simulations versus additional depletions from 2010, including the linear line fitting the data, its equation, and coefficient of determination.

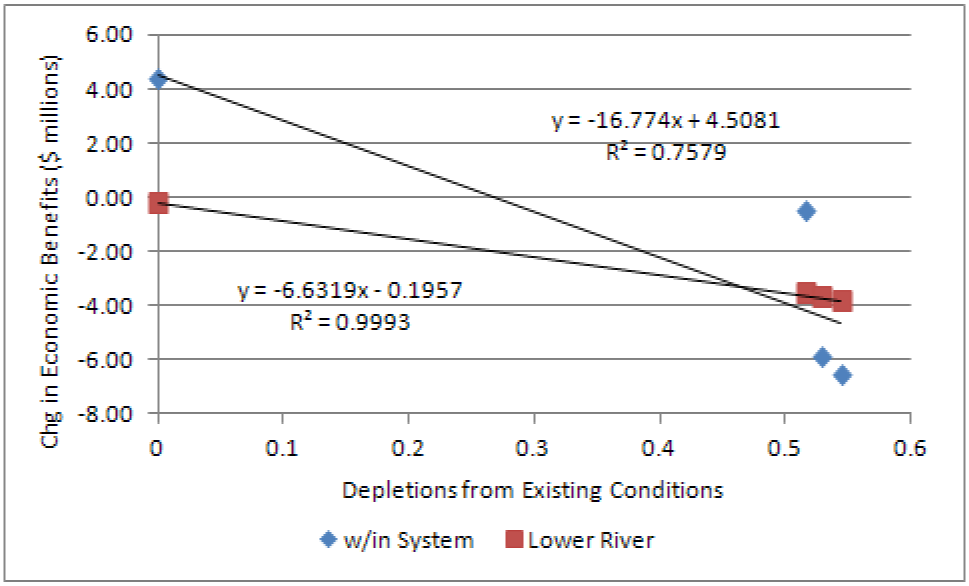

Figure 64. Plot of the change in the within-basin and lower-river split of Total NED benefits of the Sedimentation 2060, No Action, and two NAWS Project simulations versus additional depletions from 2010, including the linear line fitting the data, its equation, and coefficient of determination.

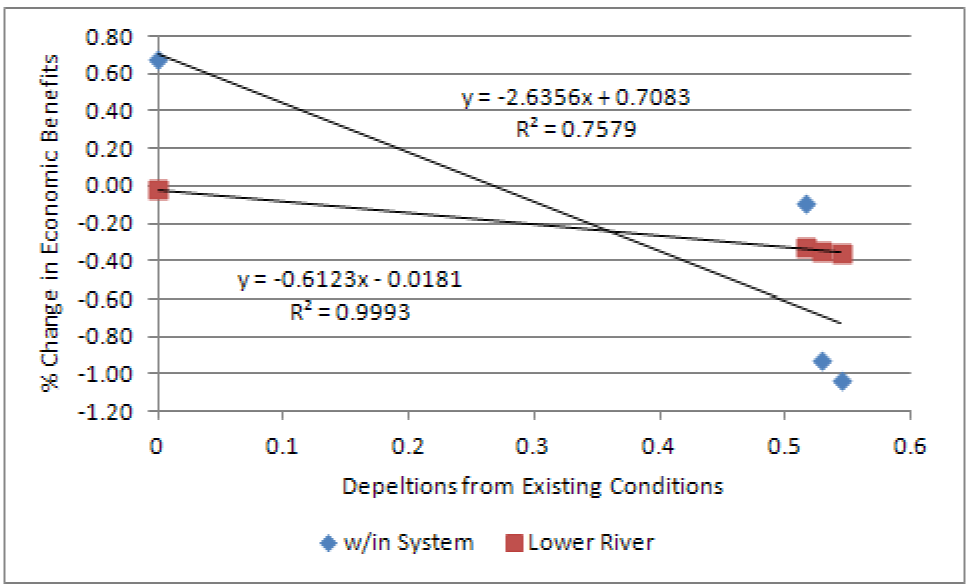

Figure 65. Plot of the percent change in Total NED benefits of the Sedimentation 2060, No Action, and two NAWS Project simulations versus additional depletions from 2010, including the linear line fitting the data, its equation, and coefficient of determination.

Summary of Economic Effects in Terms of Relative Differences

Even though absolute numbers have been presented, the focus of the economic analysis of effects has been on the relative differences among the simulations analyzed for this report. Existing Conditions was simulated using the DRM and the Economics Impacts Models to provide some perspective of how the hydrology and the associated economic effects will change due to the two primary factors that will cause change, the continuing deposition of sediments in the System reservoirs and the continuing growth of the depletion of water that enters the Missouri River main stem, with the NAWS Project being one of the projects that deplete this water. The relative effects of the NAWS Project in 2060 due to the Project's removal of water from Lake Sakakawea (Garrison Reservoir) added to the effects of the continuing accumulation of the depletion of Missouri River inflows. This section of the report focuses on consolidating the relative economic effects in terms of percent changes from two perspectives – from the Existing Conditions simulation and from the No Action simulation.

Table 18 presents the relative differences from the Existing Conditions simulation, which can be viewed as the cumulative impacts of the continuing sedimentation and depletions to inflows to the Missouri River. The greatest impact from Existing Conditions (essentially 2010 conditions) in the future will be to navigation, primarily because of the continuing sedimentation in the reservoirs and that factor's effect on System releases (as long as navigation guide curves remain as they are current set in the Master Manual). The loss of benefits will be in the range of 13 to almost 16 percent. The next greatest impact will be to recreation, and the impact will be positive due to the effect of continuing sedimentation on higher water surface elevations in the upper three, larger reservoirs. Energy revenues will be the third greatest impact due to the lower releases resulting primarily from future depletion of inflows into the Missouri River upstream of the System. All of the other economic use categories have cumulative impacts that are less than 1 percent when compared to the economic benefits under Existing Conditions.

Table 18: Relative differences of the economic benefits of the other alternatives from those of the Existing Conditions simulation (percent)

	Flood Control	Navigation	Hydropower	Water Supply	Recreation	Total	Energy Revenues
Sed 2060	-0.13	-13.05	0.62	0.01	1.94	0.24	0.10
No Action	0.02	-15.48	-0.43	-0.28	1.50	-0.24	-1.54
NAWS 13.6	0.02	-15.42	-0.49	-1.08	1.22	-0.56	-1.63
NAWS 29.1	0.02	-15.60	-0.55	-1.08	0.72	-0.61	-1.72

Table 19 lists the impacts of the NAWS Project as a last-added depletion to the System. The relative impacts in terms of percent changes from the No Action simulation are all less than 1 percent. With the exception of water supply and recreation, the impacts are less than 0.2 percent. The impacts resulting from additional depletions were as expected, with the impacts being negative for all of the economic uses except for flood control, the use that requires additional storage space that would be provided by the additional depletion effect of the NAWS Project. Flood control effects of the NAWS 13.6 simulation were -0.01 percent; however, the flood control impacts of depletions should be considered to be zero.

Table 19: Relative differences of the economic benefits of the NAWS Project alternatives from those of the No Action simulation (percent)

	Flood Control	Navigation	Hydropower	Water Supply	Recreation	Total	Energy Revenues
NAWS 13.6	-0.01	0.07	-0.06	-0.80	-0.28	-0.32	-0.09
NAWS 29.1	0.00	-0.14	-0.12	-0.81	-0.77	-0.37	-0.19

Climate Change Analysis for the NAWS Project

Introduction

Climatic and hydrologic variability occur on a basis as frequently as annually, as demonstrated by the record runoff in the upper Missouri River Basin in 2011 followed by drought over much of the basin in 2012. Since the System became fully operational in 1967, hydrologic variability in the basin has led to an extended period of near-normal runoff (1967-1987), with some individual years above and below normal occurring during this period; two extended droughts (1988-1993 and 2000-2007); and a relatively wet period (1994-1999). Therefore, multiple-hydrologic-year types have occurred since 1967. The Corps has been tasked to look at alternative future climate changes in terms of the effects of five climate change scenarios developed by Reclamation on the hydrology of a portion (1950-1999) of the period of analysis (1930-2010) used in the first half of this report on the effect of the NAWS Project on the Missouri River. The period 1950-1999 is the baseline used by Reclamation for simulating future climatic and hydrologic changes.

The climate change effects on future System hydrology (storage levels, reservoir levels, and reservoir releases) and on lower Missouri River flows were analyzed using the NAWS 13.6 simulation as the baseline simulation, as this simulation was based on the historic daily values for inflows (runoff when converted to acre-feet) that were adjusted for changes in depletions during the period of analysis and controlled by the System that will be affected by continuing sedimentation in the reservoirs. Four of five climate change scenarios developed by Reclamation were simulated using the DRM. The highest runoff-change scenario (95th percentile) had more runoff in some years than the DRM in its present format could simulate. For example, the 75th percentile scenario's highest runoff year above Sioux City was 59.75 MAF, which was almost equal to the 2011 flood runoff of 61.00 MAF, while the 95th percentile scenario had runoff in six years ranging from 61.19 MAF to 79.23 MAF. The five climate change scenarios represent the middle 90 percent (5th percentile through 95th percentile) of a set of 112 projections of potential climate change effects on the volume of water that would move through the System. The methodology and resulting adjustment factors to be used to simulate the climate change scenarios are presented in Reclamation Technical Memorandum No. 86-68210-2012-03 entitled "Climate Change Analysis for the Missouri River Basin".

The adjustment factors used to modify the historic runoff volumes in the DRM are listed previously in this report as Table 3. Typically, the factors make the larger changes in the volumes of water in the spring and summer months of March through June (normally the highest inflow months) and make smaller changes to the volumes of water in the remainder of the year. In general, the climate change is forecast to have a greater chance of being wetter, with the 25th percentile scenario having an annual runoff for each year in the period very near to the historic inflow record included in the DRM for the modeling of the NAWS Project simulations. Only one scenario, the 5th percentile scenario, averages considerably less runoff in the period of analysis, which is limited to 1950-1999, a 50-year sub-period of the 81-year modeling capability of the DRM at this time. The 50th percentile and above scenarios have greater runoff than the historic values. These changes in runoff occur not only for the tributaries feeding into the System reservoirs but also for the tributaries to the lower Missouri River. Therefore, while the System reservoirs are filling to higher levels in the scenarios with higher spring inflows, the downstream tributaries are increasing flows in the lower Missouri River, exacerbating the potential for flood flows and likely limiting releases from the System at times.

The average annual runoff values for the Missouri River Basin upstream from Sioux City for the five climate change scenarios and their changes from the historic average (those included in the runoff input files for the NAWS 13.6 simulation that are adjusted for present level, or 2010, uses in the Missouri River Basin) are listed in Table 20. Figure 66 presents the annual changes from the historic runoff values to the projected runoff volumes under the five climate change scenarios developed by Reclamation. Finally, the actual upper decile historic runoff is 34.3 MAF, based on a 114-year period of record dating back to 1898. The 75th percentile climate change scenario (highest runoff scenario that could be run using the DRM) would increase the number of years with a greater than the current upper decile runoff from 7 to 19 years in the 50-year period for the climate change analysis of 1950-1999. To provide some perspective on the 95th percentile scenario, its 50-year average annual runoff of 40.76 MAF is essentially equal to the third highest actual runoff of record of 40.634 MAF that occurred in 1978. The volume of water to be simulated for the 95th percentile climate change scenario was also extremely high in several years. For example, the largest annual runoff event simulated for the 75th percentile projection was 59.75 million acre-feet (MAF) of runoff above Sioux City in 1997, and the 95th percentile had six events over 60 MAF (volume of runoff above Sioux City for the 2011 flood), with the highest being 79.23 MAF in 1997.

Table 20: Climate change scenarios - effect on Missouri River Basin annual runoff volumes above Sioux City, Iowa (1950-1999)

	50-year Average (MAF)	Change from Historic Average (MAF)	% Change from Historic Average
Historic	25.65	--	--
5th percentile	22.68	-2.96	-11.6
25th percentile	25.59	-0.06	-0.2
50th percentile	27.93	2.28	8.9
75th percentile	31.35	5.70	22.2
95th percentile	40.76	15.11	58.9

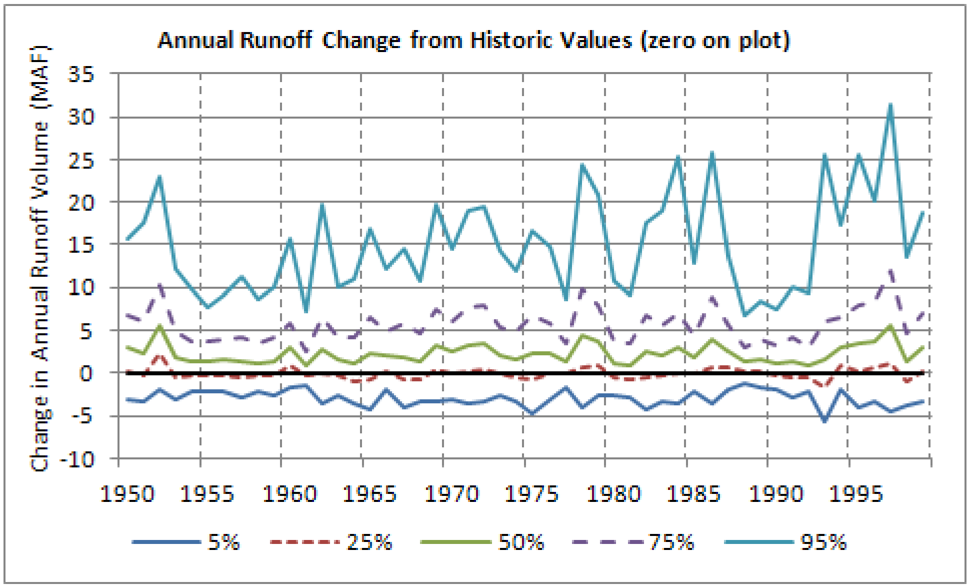

Figure 66. Annual changes to the historic runoff values (used in NAWS 13.6 simulation) for the Missouri River Basin upstream from Sioux City, Iowa for the five climate change scenarios for the 50-year period of analysis, 1950-1999.

Table 20 and Figure 66 demonstrate that there is a greater likelihood for increased runoff in the future. The runoff values presented would be reduced by the future Project and non-Project depletions included in the NAWS 13.6 simulation. The "zero-change" percentile for climate change appears to be somewhat close to the 25th percentile, indicating that there is somewhere near a 75 percent likelihood that the future runoff conditions will be "wetter".

Modeling of the Climate Change Scenarios

The DRM was used to simulate the climate change scenarios for the 1950-1999 portion of the 1930-2010 period modeled for the NAWS Project analysis discussed in the first half of this report. This period (1950-1999) is the historic baseline used to develop the bias-corrected, spatially downscaled, future climate and runoff projections. Modeling of the climate change scenarios required that the historic inflows included in the DRM be modified, using the monthly change factors developed by Reclamation and listed in Table 3 of this report. March through July was the period affected the most by the monthly change factors because these five months had the greatest runoff values within most years (percent of annual runoff ranges from 11.6 percent for March to 13.2 percent for May). Because the monthly change factors were the same whether the historic year was a wet or a dry year, the use of the factors had a greater effect on the wet years. These historically high runoff values for each of these months or combination of historically high runoff months resulted in much larger increases in runoff, making the runoff in the wettest years on record considerably higher as the scenarios progressed from the 5th percentile scenario to the 95th percentile scenario, as shown in Figure 66. Higher runoff years were difficult to simulate in the DRM, which has rules that were modified to allow downstream flood constraints to be raised to much higher flow values than previously included in the DRM. The 5th, 25th, 50th, and 75th percentile scenarios were the four of the five provided by Reclamation that could be modeled for this analysis of climate change. Large runoff volume changes for the 95th percentile scenario within the System and also the lower Missouri River resulted in the DRM not being able to simulate the higher inflow years. Because the May factors average about +60 percent for the 95th percentile scenario, considerable water would need to accumulate in the System reservoirs while downstream inflows are very high. Use of the same monthly runoff-change factors in all years of the modeling period resulted in problems with the modeling of the 95th percentile scenario, limiting successful simulation to the 5th, 25th, 50th, and 75th percentile scenarios.

Simulation Results for the Climate Change Scenarios

This climate change analysis is based on DRM outputs, with an emphasis on the hydrologic differences among the climate change scenarios. Because the DRM also provides data on navigation service levels and season lengths (dictate water movement within and from the System in normal runoff and drought periods) and on hydropower production, these data will also be provided. Finally, to demonstrate the relative differences among the climate change scenarios and their impact on the System's project purposes, the percent change in the economic impacts will be presented.

System Storage

The volume of water in System storage (referred hereafter as System storage) will vary, with the amount of System storage generally increasing during the 1950-1999 period of the climate change analysis with the 5th through 75th percentile scenarios. Figure 67 presents the end-of-month (EOM) System storage values for the historic inflows of the NAWS 13.6 simulation and the 5th through 75th percentile climate change scenarios (CC 5%, CC 25%, CC 50%, and CC 75%) for the 50-year period of the climate change analysis of 1950-1999. Due to the scale of the plot, it is difficult to see the storage values for each of the scenarios; however, the CC 5% scenario is the lowest of the four data sets, the CC 25% and NAWS 13.6 (historic runoff) scenarios have very similar System storage plots, and the CC 50% and CC 75% scenarios have the highest System storages on the plot. Because the System storage for the CC 25% scenario over the 50-year period is essentially the same as the System storage for the NAWS 13.6 simulation, climate changes in the future have approximately a 75 percent chance of resulting in higher System storage levels than would occur with no climate change. In fact, scenarios higher than the 75th percentile scenario have runoff factors so high that many, if not all, of these scenarios cannot be simulated due to the extremely high increase in runoff at this time and would have even higher System storage levels than shown in Figure 67.

Also notable on Figure 67, the CC 5% scenario starts out in 1950 at a much lower level than the other scenarios and NAWS 13.6. This is consistent with the pattern that occurs throughout the 81-year period of analysis in which CC 5% scenario started at the same storage in 1930 but diverged lower quickly except when it's significantly more non-navigation years reduced the negative difference. During extremely wet years, i.e., when inflows were about 30 MAF or more, the CC 5% scenario's storage level became about the same as the NAWS 13.6 alternative's storage level.

The range in the System storage among the four climate change scenarios that were simulated for this analysis is readily apparent on Figure 67; therefore, Figure 68 presents the System storage values for just the 25th percentile and 75th percentile scenarios. This figure presents the System storages for the middle 50 percent of the range of 112 projections of climate change effects. Another way of looking at the plot is that, assuming that future climate change is represented by one of the 112 scenarios developed by Reclamation, 25 percent of the potential System storage levels in the future (2060 conditions) falls below the range presented in Figure 62 and another 25 percent fall above the range. Also, remember that the 25th percentile scenario would have System storage values very similar to those for the adjusted historic inflows included in the NAWS 13.6 simulation, indicating that only 25 percent of the climate change forecasts would result in lower values in many years (and also potentially more non-navigation years).

Figure 69 also makes it easier to see the differences among the four climate change scenarios, as the System storage differences from the NAWS 13.6 simulation are plotted. Almost all of the storage values are lower than the base simulation (NAWS 13.6) for CC 5% except when two non-navigation years in the 1988 through 1993 major drought reduce System releases (CC 5% non-navigation years - 1957, 1959, 1962, 1990, and 1991). The other three climate change scenarios do not have any non-navigation years in the period of analysis. The differences for CC 25% vary around zero, and the differences for CC 50% and CC 75% are all generally greater than or narrowly fluctuating around zero difference from the NAWS 13.6 alternative's values, with the CC 75% scenario having the greater values. The most notable differences for the three higher runoff scenarios from NAWS 13.6 occur during the two major droughts and some of the lower runoff years or sequences of more than a single year.

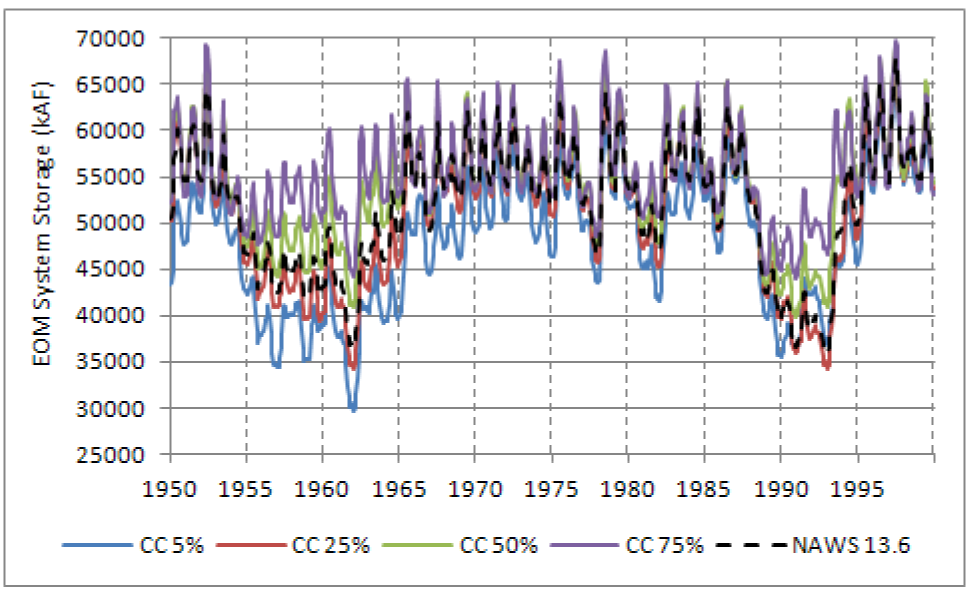

Figure 67. EOM System storage values for the NAWS 13.6 simulation and the four climate change scenarios for the 1950-1999 period of analysis.

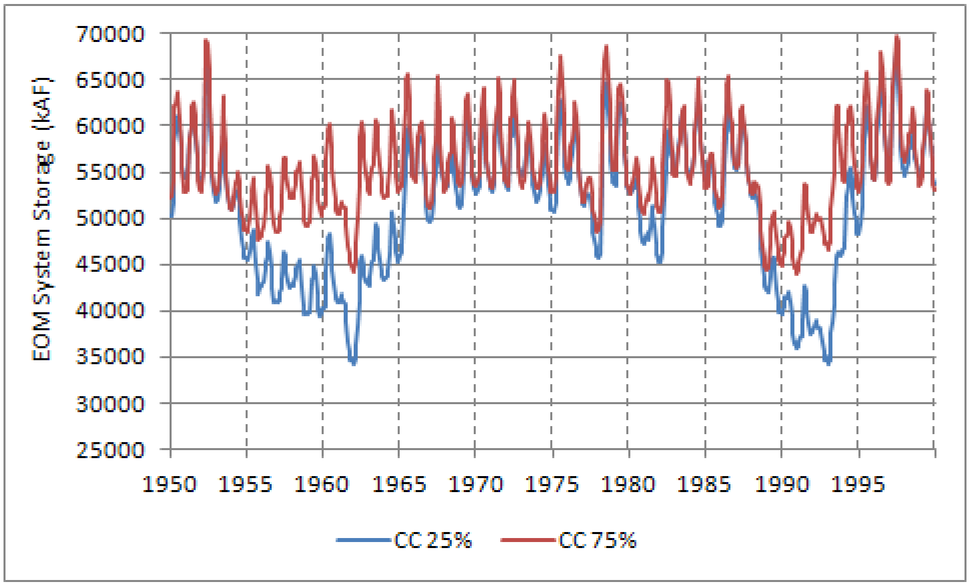

Figure 68. Range of EOM System storage values for the middle 50 percent of the 112 climate change scenarios for the 1950-1999 period of analysis.

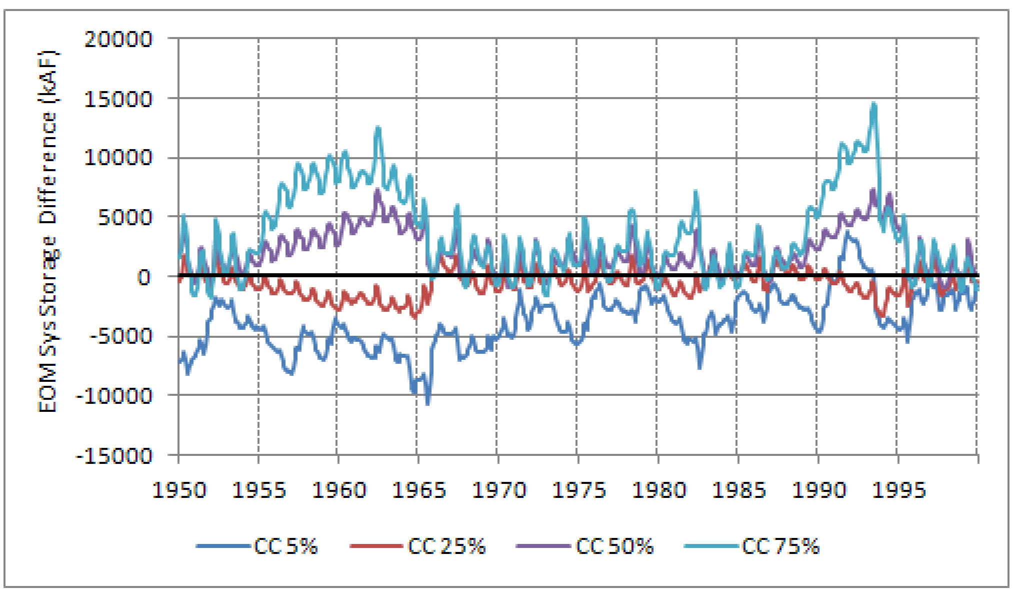

Figure 69. Differences in the EOM System storage values for the four climate change scenarios from the historic runoff values included in the simulation of the NAWS 13.6 alternative for the 1950-1999 period of analysis.

Figure 70 is a plot of the sorted EOM differences from the NAWS 13.6 values included in Figure 69 for the four climate change scenarios. It clearly shows the same differences discussed above. The CC 5% sorted values are less than zero in about 95 percent of the 50 years, or about 47 out of 50 years. As shown previously in Table 20, the CC 25% scenario has slightly less runoff, and the sorted difference in System storage plot for this scenario indicates that the difference in System storage for the CC 25%

scenario would be less than zero in about 70 percent of years, or fewer years than the CC 5% scenario. Also the negative values are much less negative than those for CC 5%. The EOM System storage values for the CC 50% scenario are greater than zero in about 90 percent of the years, or about 45 years out of the 50 years included in the analysis. Finally, the EOM System storage values for the CC 75% scenario is greater than zero in 85 percent of the years of the period of analysis, with many of the positive values being greater than those for the CC 50% scenario. The average EOM System storage values range from 3.8 MAF average difference from those of NAWS 13.6 for the CC 5% scenario to +3.5 MAF average difference for the CC 75% scenario. The net average difference in the EOM System storage between the CC 5% and CC 75% climate change scenarios is, therefore, 7.3 MAF of water in the System under 2060 depletion and sedimentation conditions.

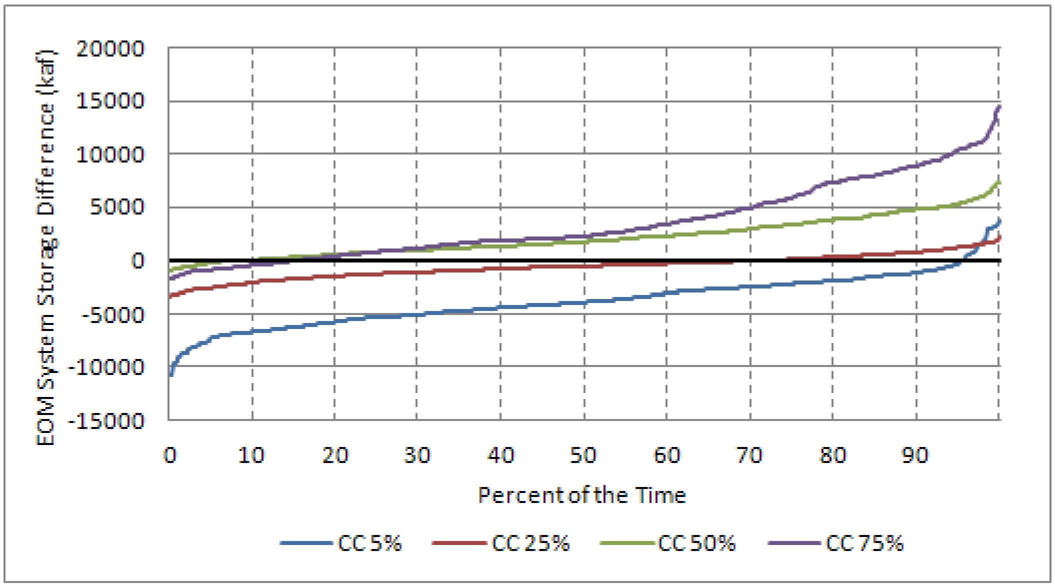

Figure 70. Sorted differences in the EOM System storage values for the four climate change scenarios from the historic runoff values included in the simulation of the NAWS 13.6 alternative for the 1950-1999 period of analysis.

System Reservoir Elevations

Changes in the System storage levels for the climate change scenarios through the period of analysis of 1950-1999 should be reflected in the water surface elevations of the upper three, larger System reservoirs. This section of the report presents the elevation data for these three reservoirs plus the water elevation data for Fort Randall Reservoir, the fourth largest of the six System reservoirs. The set of figures will be the same for each of these four reservoirs. These figures include the variation of reservoir elevation with time for the CC 5% and 75% climate change scenarios (basically bracket the elevations of the other two climate change scenarios and the NAWS 13.6 simulation), the difference between the four climate change scenarios and the NAWS 13.6 simulation, and the sorted differences between the elevations for the NAWS 13.6 simulation and each of the four climate change scenario simulations. EOM data are presented in each of the three plots, which would look essentially the same if daily DRM data were to be presented.

The three plots for Fort Peck Reservoir are presented as Figures 71 through 73. Figure 71 shows that the Fort Peck water surface elevations at the end of each month follow the System storage pattern of declining during the two extended droughts during the 50-year period of analysis (1954-1961 and 1988-1993) and being higher in the wetter years (e.g., 1952, 1975, 1978, and 1997). With the additional water during each year of the two major droughts, the CC 75% scenario results in a drop of Fort Peck elevation considerably less than under the CC 25% scenario. The base of the Exclusive Flood Control Zone for Fort Peck Reservoir is included in this figure to demonstrate that the additional runoff of the CC 75% scenario would result in the storage of water in the Fort Peck Exclusive Flood Control Zone in about 20 years of the 50 years in the period of analysis.

The differences between the Fort Peck levels for all four climate change scenarios from those of the NAWS 13.6 simulation are shown as Figure 72. This figure shows that the elevations for the NAWS 13.6 simulation and the CC 25% and CC 50% scenarios lie between the CC 5% and CC 75% scenarios in almost all of the years. The differences between the NAWS 13.6 simulation and the four climate change scenarios would be greatest during the two major droughts in the period of analysis. The two non-navigation years of 1990 and 1991 of the CC 5% scenario limits the negative elevation differences for that scenario from those of the NAWS 13.6 simulation during the 1988-1993 drought. The 25th percentile scenario, CC 25%, Fort Peck levels would generally be no more than 5 feet below those of the NAWS 13.6 simulation with some periods when it is almost the same as the NAWS 13.6 alternative. The CC 50% scenario levels would generally be higher than those of the NAWS 13.6 simulation, especially during the two extended droughts when the CC 50% scenario would have Fort Peck Reservoir levels up to about 10 feet higher. Finally, the CC 75% scenario would result in the highest water levels during the two droughts, with the levels being from about 10 to over 20 feet higher. During the generally "normal" runoff period of 1967 through 1987, the Fort Peck water surface elevations for the CC 25%, CC 50%, and CC 75% climate change scenarios would be very similar to those of the NAWS 13.6 simulation much of the time.

A final Fort Peck Reservoir plot, Figure 73, shows the sorted water surface elevation differences of the four climate change scenarios from those of the NAWS 13.6 simulation. This figure shows that the CC 5% scenario would be lower than NAWS 13.6 about 95 percent of the time, with this difference declining to about minus 15 feet before the more dramatic changes occur for the last 5 percent of the time. CC 25% would have water surface elevations lower than NAWS 13.6 about 70 percent of the time; however, these negative differences generally range up to a minus 5 feet for much of that 70 percent of the 50-year period of analysis. The CC 50% and CC 75% climate change scenarios are higher than the NAWS 13.6 simulation about 85 percent of the time, with much of that 85 percent ranging from 0 to 10 (CC 50%) or 25 (CC 75%) feet higher. In general, the patterns in the Fort Peck Reservoir water surface elevations are very similar to the System storage changes. Finally, the average EOM elevation of the CC 5% and CC 75% scenarios are -7.15 feet and +6.17 feet, respectively, for a net difference of 13.32 feet.

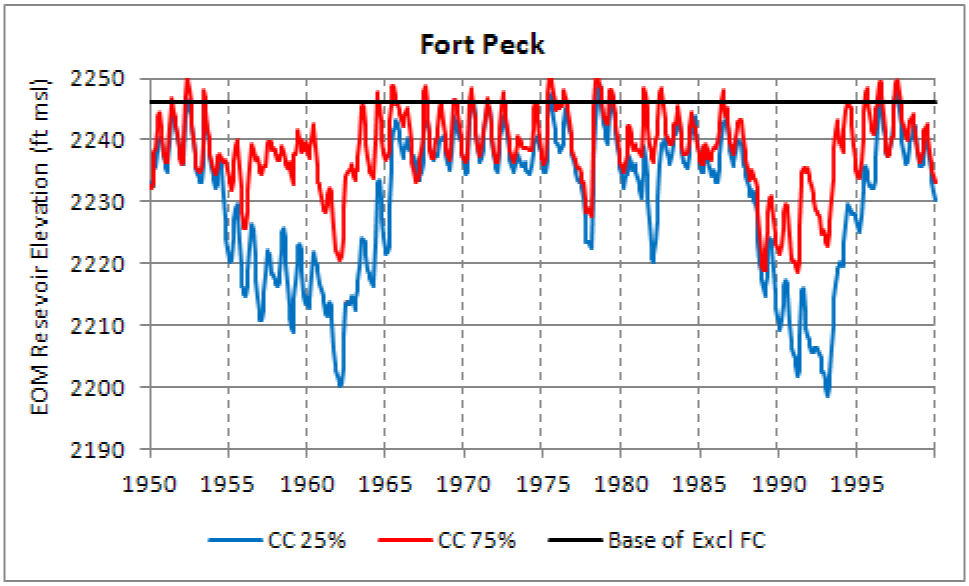

Figure 71. EOM Fort Peck Reservoir water surface elevation values for the CC 25% and CC 75% climate change scenarios for the 1950-1999 period of analysis.

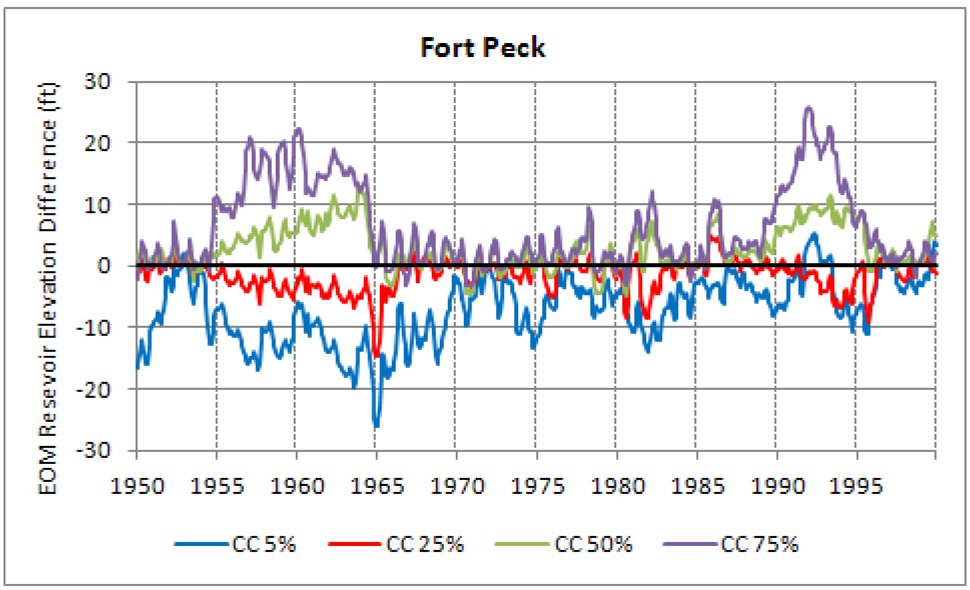

Figure 72. Differences in the EOM Fort Peck Reservoir water surface elevation values for the four climate change scenarios from those of the NAWS 13.6 alternative for the 1950-1999 period of analysis.

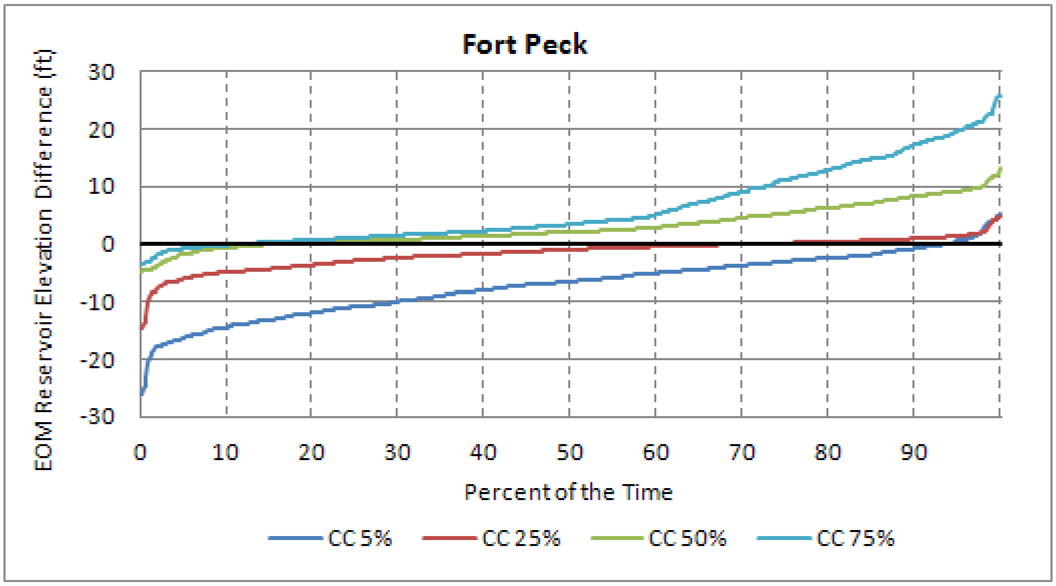

Figure 73. Sorted differences in the EOM Fort Peck water surface elevation values for the four climate change scenarios from those of the NAWS 13.6 alternative for the 1950-1999 period of analysis.

The DRM simulations appear to be heavily influenced by the requirement to balance the amount of water in System storage evenly among the upper three, larger reservoirs. Therefore, as with Fort Peck Reservoir, Garrison Reservoir would have water level changes that tend to mirror the System storage plots. Figures 74 through 76 present data on Garrison water levels with time, differences in these water levels from the NAWS 13.6 simulation, and the sorted plot of these difference values. Figure 74 shows that the Garrison water surface levels of the CC 25% and CC 75% scenarios vary with the amount of inflow, and the reservoir declines during the droughts and is highest, with the CC 75% scenario entering the Garrison Exclusive Flood Control Zone (base elevation shown on the figure) in the wetter, or higher inflow, years a total of 21 years of the 50-year period of analysis. The differences among all five simulations would be difficult to see if put on Figure 74, however, they are clearly shown in Figures 75, which shows the water level differences between each climate change scenario and the NAWS 13.6 simulation. The water surface level differences increase from being the most negative to the most positive as the percentile of the climate change scenario increases. The CC 75% scenario has the highest positive Garrison Reservoir water surface elevation differences with the greatest differences occurring in the two extended droughts. They are also larger in the two dry years of 1980 and 1981. Finally, the sorted plots are shown in Figure 76. The Garrison water surface elevation for the CC 5% scenario is lower than for the NAWS 13.6 simulation about 90 percent of the time. CC 25% has lower water surface elevations about 65 percent of the time; however, the negative values are generally less than 5 feet versus the up to 10 feet for the CC 5% scenario most of the time. The CC 50% climate change scenario has higher EOM water surface elevations (compared to the NAWS 13.6 simulation) in 88 percent of the months. Finally, the CC 75% scenario has higher Garrison water surface elevation in 89 percent of the months of the 50-year period of analysis, with the higher levels being up to 22 feet higher versus only 12 feet higher for the CC 50% scenario. The average EOM elevation differences across the 50-year period of analysis from the NAWS 13.6 simulation are - 4.91 feet, -0.67 feet, + 3.01 feet, and +5.45 feet, for a net difference across the for scenarios of 10.36 feet.

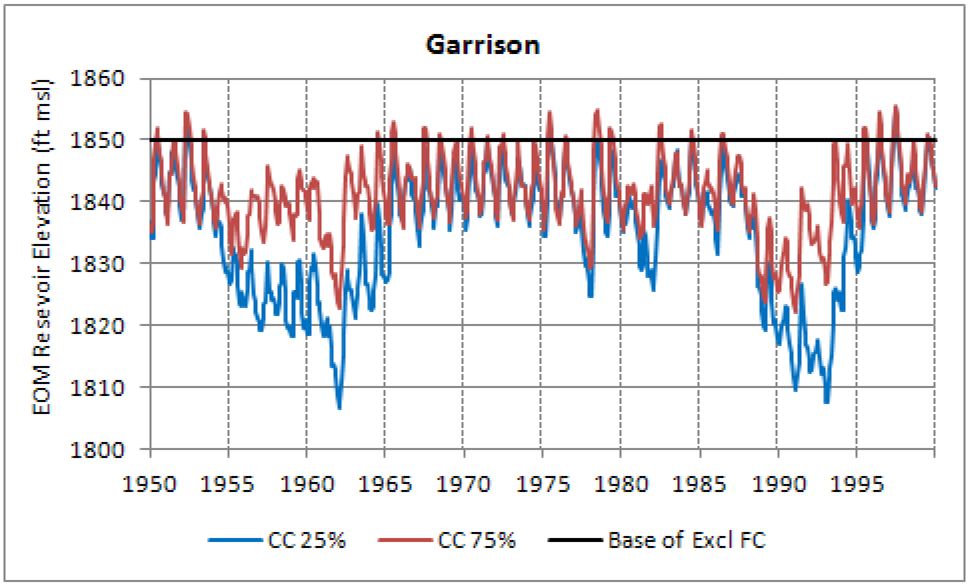

Figure 74. EOM Garrison Reservoir water surface elevation values for the CC 25% and CC 75% climate change scenarios for the 1950-1999 period of analysis.

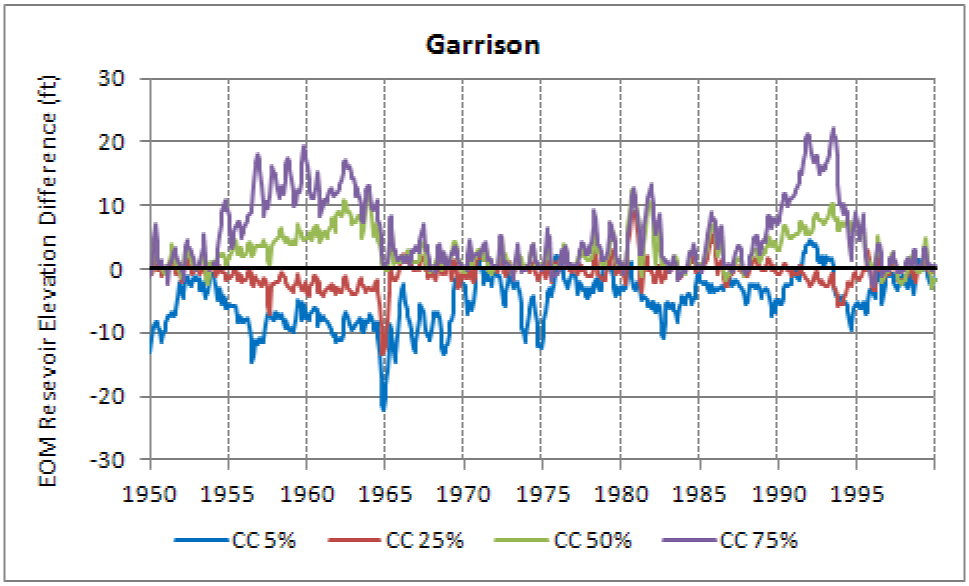

Figure 75. Differences in the EOM Garrison Reservoir water surface elevation values for the four climate change scenarios from those of the NAWS 13.6 alternative for the 1950-1999 period of analysis.

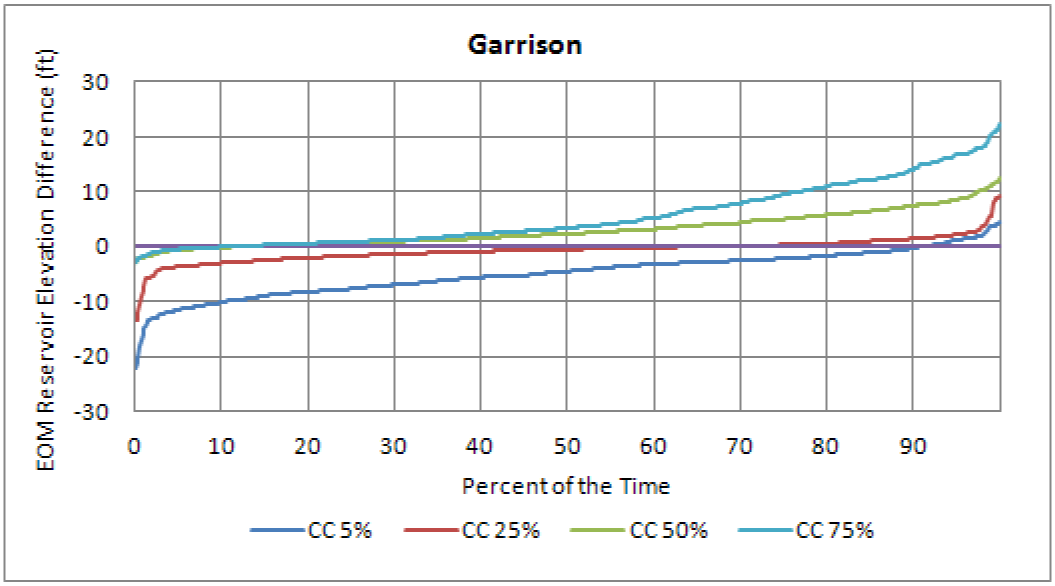

Figure 76. Sorted differences in the EOM Garrison water surface elevation values for the four climate change scenarios from those of the NAWS 13.6 alternative for the 1950-1999 period of analysis.

Because 50 percent of the time the EOM level of Garrison Reservoir for the CC 5% scenario is within 5 feet or even higher than the NAWS 13.6 alternative water levels, some explanation is required to better understand why these smaller negative or even positive changes would occur. Figures 77 and 78 are 25-year plots of the EOM data for Garrison Reservoir with only the NAWS 13.6 and CC 5% EOM water-level data presented. These plots show that the water level of the CC 5% scenario approaches some of the higher water levels of the NAWS 13.6 simulation. This occurs in high inflow years such as 1952, 1969, 1971, 1975, 1978, 1984, 1986, 1995-1997, and 1999. The inflows in these years were all above 30 MAF, which means they were all at or above the current upper quartile annual runoff value of 30.3 MAF. In these years, the NAWS 13.6 alternative likely has higher releases to keep the water levels in Garrison Reservoir from getting too high and the CC 5% scenario reaches the same water level elevations with lower releases required from the reservoir. In the two droughts, the water levels of the two simulations approach the same level. This occurs because the CC 5% scenario has non-navigation years in 1957, 1959, 1962, 1990, and 1991 that the NAWS 13.6 simulation does not have. The water savings resulting from the lower System releases in those additional non-navigation years results in higher water levels in those 5 years in the 5th percentile climate change scenario. Finally, the water levels are closer together in the second half of the 50-year period of analysis due to the higher frequency of high runoff years and the shorter drought with 2 of the 6 years being non-navigation years.

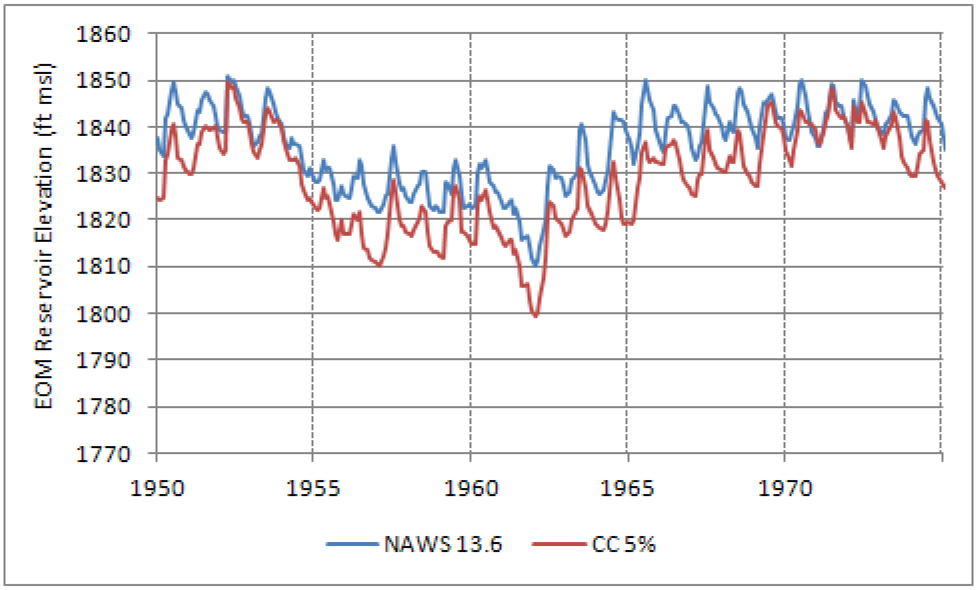

Figure 77. EOM Garrison Reservoir water surface elevation values for the NAWS 13.6 simulation and CC 5% climate change scenario for the 1950-1974 period.

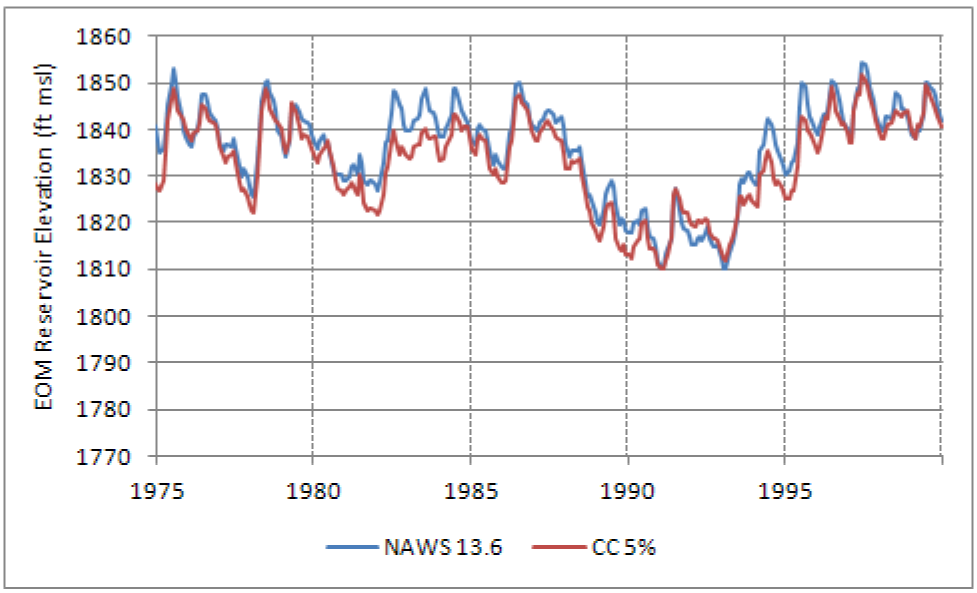

Figure 78. EOM Garrison Reservoir water surface elevation values for the NAWS 13.6 simulation and CC 5% climate change scenario for the 1975-1999 period.

Figures 79 through 81 present the water level data for Oahe Reservoir. Similar statements to those above for Fort Peck and Garrison reservoirs can be said regarding these three figures. Notable in Figure 79 are the 18 years (out of 50) that the CC 75% scenario has water levels in the Oahe Exclusive Flood Control Zone. The differences between the climate change scenarios and the NAWS 13.6 simulation Oahe levels in Figure 80 are somewhat different than the similar figures for the other two reservoirs, with the differences being likely due to the combination of inflows and upstream releases from Garrison

Reservoir in this downstream reservoir. The most notable negative differences in this figure are the three larger negative values in 1969-1971 (non-drought period) for the CC 5% scenario. This likely occurred as the inflows into Garrison Reservoir were not released to the downstream Oahe Reservoir to balance the reservoir level changes in those years. Similar spikes occurred for the CC 75% scenario in the 1950s drought. The extra space in Oahe for both scenarios would allow for higher winter releases for hydropower production from the two upstream reservoirs. Figure 81 presents the sorted data, which provides the opportunity to identify the number of years the water levels were either lower for the 5th and 25th percentile climate change scenarios (87 and 60 percent of the time, respectively) or higher for the 50th and 75th percentile scenarios (81 and 65 percent of the time, respectively). The negative differences are greater for the CC 5% scenario than for the CC 25% scenario, and the positive differences are greater for the CC 75% scenario than for the CC 50% scenario. The average EOM elevation differences from the NAWS 13.6 simulation values for the four climate change scenarios are -3.88 feet, -0.57 feet, +2.25 feet, and + 2.34 feet for the CC 5% through CC 75% scenarios, respectively. The net average EOM difference between the CC 5% and CC 75 % scenarios is 6.22 feet, a relatively narrow difference compared to the other two reservoirs (13.32 feet for Fort Peck and 10.36 feet for Garrison). Also the difference values for the CC 50% and CC 75% scenarios are very close to being the same.

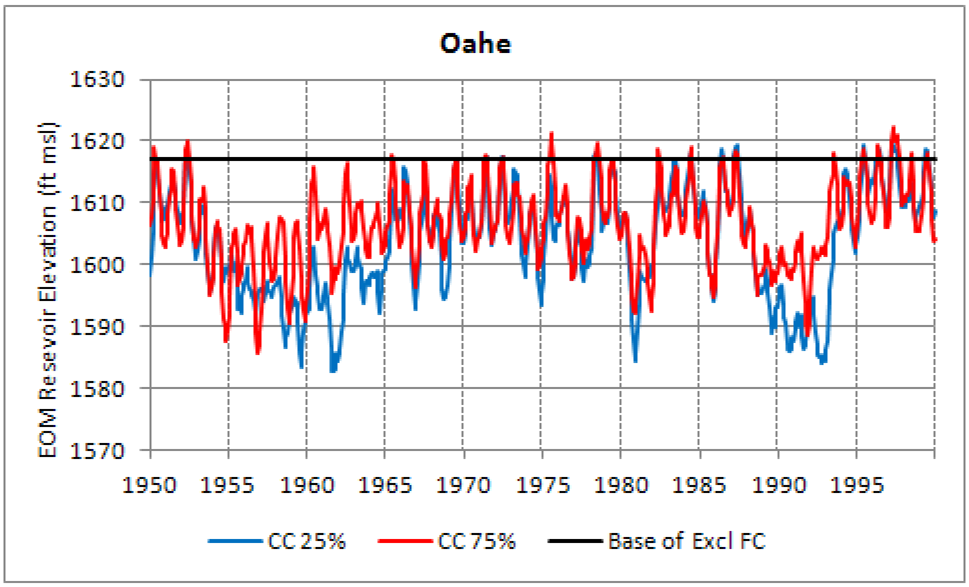

Figure 79. EOM Oahe Reservoir water surface elevation values for the CC 25% and CC 75% climate change scenarios for the 1950-1999 period of analysis.

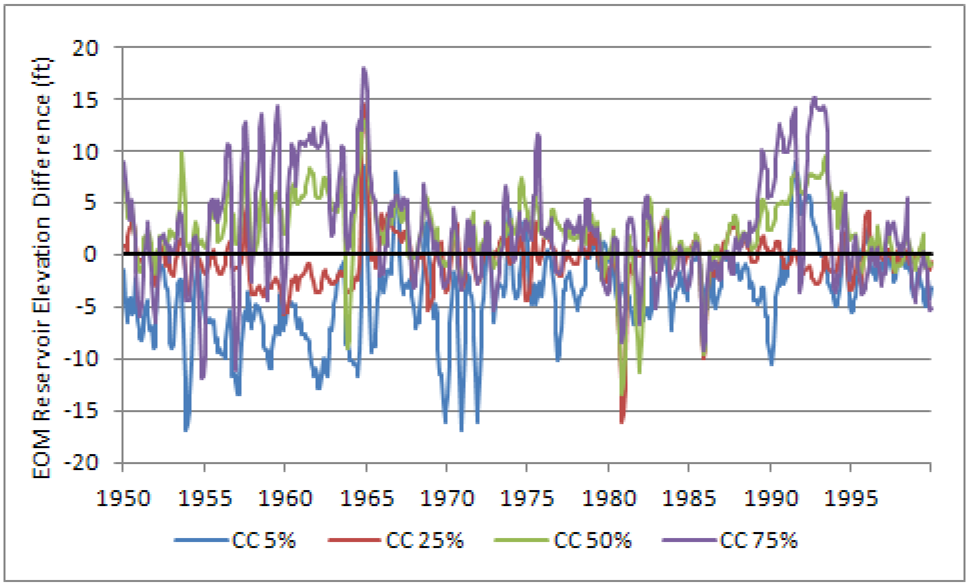

Figure 80. Differences in the EOM Oahe Reservoir water surface elevation values for the four climate change scenarios from those of the NAWS 13.6 simulation for the 1950-1999 period of analysis.

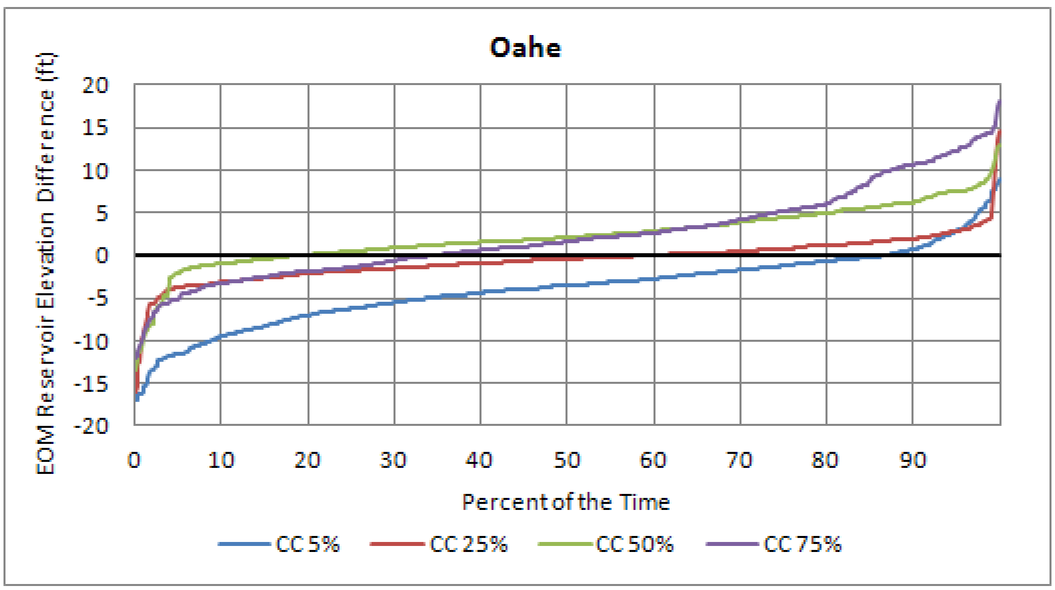

Figure 81. Sorted differences in the EOM Oahe water surface elevation values for the four climate change scenarios from those of the NAWS 13.6 alternative for the 1950-1999 period of analysis.

Fort Randall Reservoir, the fourth largest reservoir in the six-reservoir System, is relatively unaffected by the climate change scenarios; however, two notable differences occur. Figure 82 presents the EOM water surface elevation data for only the CC 5% climate change scenario. In five of the years, the annual fall drawdown did not occur, and these five years were the non-navigation years in the 50-year period of analysis, which are unique to the CC 5% scenario. Figure 83 presents the EOM data for the CC 75% scenario, and the notable difference is the increase in the number of years that relatively high water levels occur. Because of the higher inflows from tributary runoff and upstream Oahe releases, the flood control storage in Fort Randall is used more often. This more likely occurs in the same years that the Exclusive Flood Control Zone is used in one or more of the upper three, larger reservoirs. Figure 84 shows the sorted difference plot for the three climate change scenarios when their EOM water surface elevations are compared to those for the NAWS 13.6 alternative. It is readily apparent that the water surface elevations are identical a majority of the time (about 65 percent).

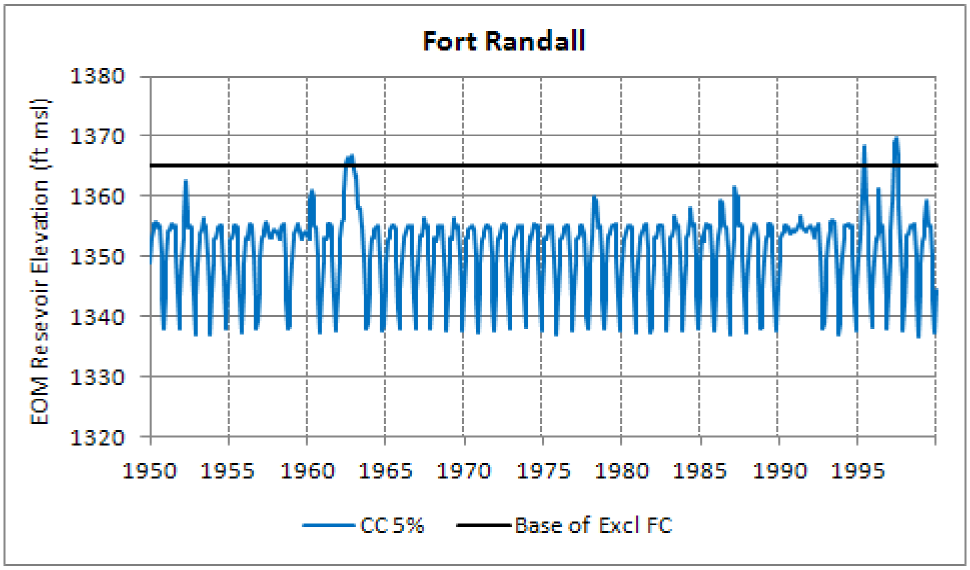

Figure 82. EOM Fort Randal Reservoir water surface elevation values for the CC 5% climate change scenario for the 1950-1999 period of analysis.

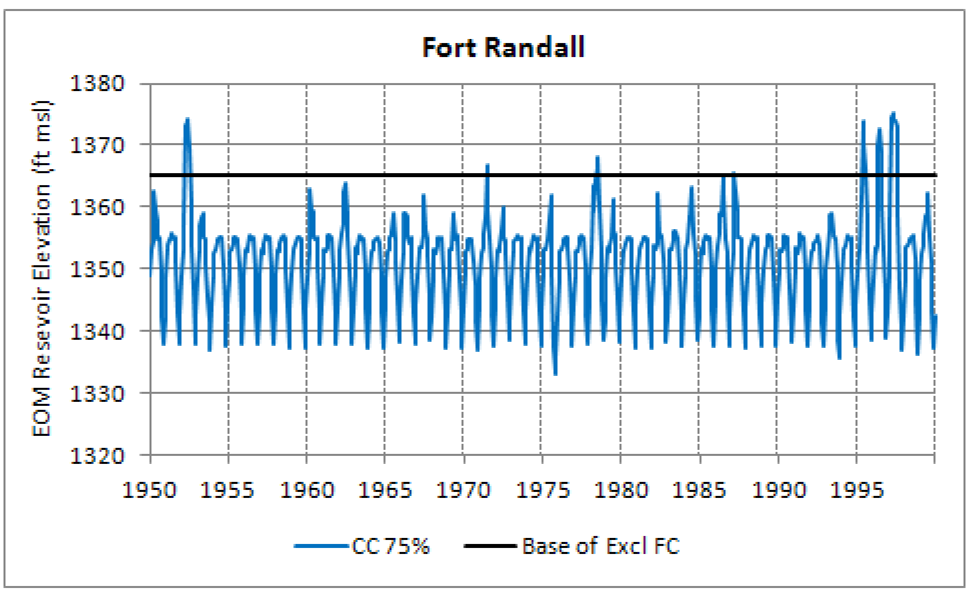

Figure 83. EOM Fort Randall Reservoir water surface elevation values for the CC 75% climate change scenario for the 1950-1965 period.

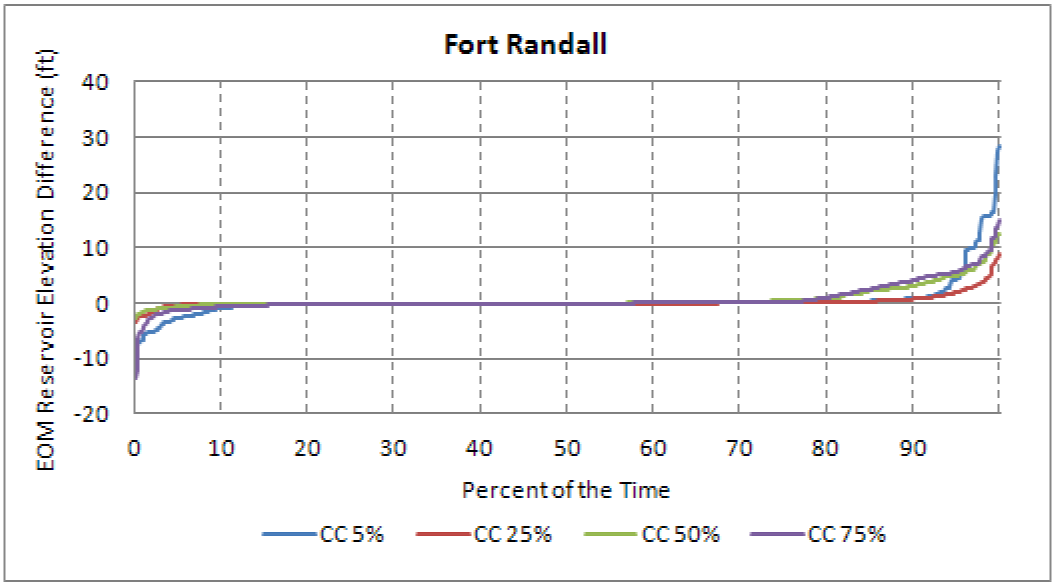

Figure 84. Sorted differences in the EOM Fort Randall water surface elevation values for the three climate change scenarios from those of the NAWS 13.6 alternative for the 1950-1999 period of analysis.

System Releases and Lower Missouri River Flows

Just as System storage and reservoir levels are higher in high System inflow years, reservoir releases and river flows will also be higher. Therefore, reservoir releases and river flows would be expected to be higher as the climate change scenarios increase in their percentage values. This section on the hydrologic effects of climate change presents the reservoir release and river flow data.

The DRM was originally developed to allow the modeling of "flood" impacts on a daily time-step basis. All of the "non-flood" impacts were already computed using monthly data when the DRM was developed. Flooding along the Missouri River, especially the lower Missouri River can be categorized into three categories – direct flooding, cropland flooding due to interior drainage restrictions resulting from higher river stages, and "flooding" of crops due to high groundwater levels. The DRM computes releases from Gavins Point and downstream flows extremely well on a daily basis; however, its flow values also get somewhat erratic when very high releases are required that conflict with downstream flow limits. Due to this periodic erratic variability of daily releases, focusing analyses on average monthly release and flow data eliminates most of the erratic variability. Within the System, however, the month-to-month variability in releases focuses on a combination of providing flat summer releases for terns and plovers and balancing the volume of water within the System among the upper three, larger reservoirs. The balancing of water among the reservoirs, especially in higher inflow years tends to take priority, which results in some variability in monthly releases that may not be consistent with the normal real-time, month-to-month operations for interior least terns and piping plovers within the System. However, these differences may be too high in some years and too low in others such that average monthly releases likely adjust for the year to year variability. For this reason, use of annual average and average monthly reservoir releases for analyses will eliminate the somewhat unrealistic, within-year variability of reservoir releases, especially those from Fort Peck and Garrison reservoirs. The methodologies that will be used to demonstrate the climate change effects on river flows is the change in the annual average, average annual, and/or average monthly flows between each of the climate change scenarios and those of the NAWS 13.6 simulation. The NAWS 13.6 simulation includes the inflows that occurred historically (adjusted to represent 2010 conditions for all years in the period of analysis).

Description of the Methodology for Presenting System Releases and Lower Missouri River Flows

Another methodology had to be developed for presenting the results of the analysis of System releases and lower Missouri River flows than was used for presentation of the System storage and reservoir level effects discussed above. System reservoir releases and lower Missouri River flows are more variable on a month-to-month basis than the storage and reservoir levels. The reservoir levels and System storage “gradually” increase and decrease throughout the year. The amount of data available for analysis on these two factors is also considerably less – one column in a single file for System storage and five columns in a single file for reservoir elevations versus a total of 17 columns (for the 17 locations that could have been included in the analysis) in two files for releases and flows. To simplify the analyses of release/flow data yet retain enough detail, monthly average data was the most detailed data used and only eight of the 17 locations were included in the analysis and presentation of releases/flow data.

To demonstrate the complexity of presenting the release/flow data, three years were selected that represented three different conditions during the 50-year period of analysis of 1950-1999. An average year (1974), a very wet year (1997), and a very dry year (1991) were selected to show the variability of releases and flows in just those years among the reaches and the climate change scenarios.

Figures 85 through 87 show the monthly average and the average of the monthly averages, or the annual average, data for the CC 50% climate change scenario at four locations for releases or flows – Garrison, Gavins Point, Omaha, and Hermann. Figure 85 shows the data for 1974, an average inflow year (25.01 MAF). This figure shows the variability of the two releases at Garrison and Gavins Point through the year and the variability of the flows at the two downstream locations on the lower Missouri River. Next, Figure 86 presents the data for the highest inflow year (above Sioux City) in the period of analysis (49.04 MAF). Again note the variability within and among the months for the CC 50% scenario. Finally, Figure 87 presents the data for the low-flow year of 1990 (16.69 MAF). Even though the releases were relatively low throughout the year, very high inflows somewhere downstream from Omaha resulted in very high monthly average flows at Hermann in May and June. Again, very high variability in flows occurred among the months of the year. High variability in the data among the months leads to the decision to present monthly average release/flow data in this report.

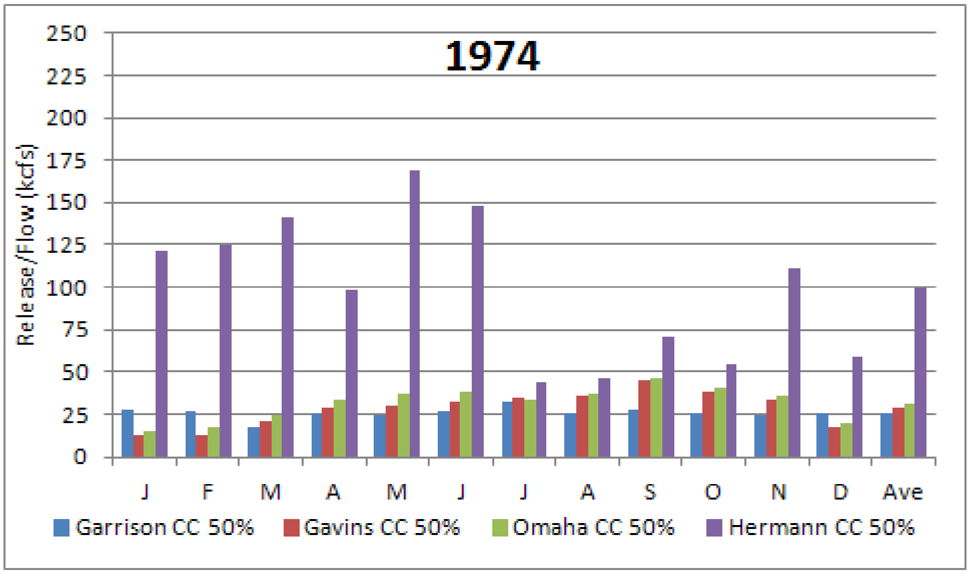

Figure 85. Monthly average releases for 1974, a year with average System inflows, from two of the System reservoirs and flows at two locations on the lower Missouri River for the CC 50% climate change scenario.

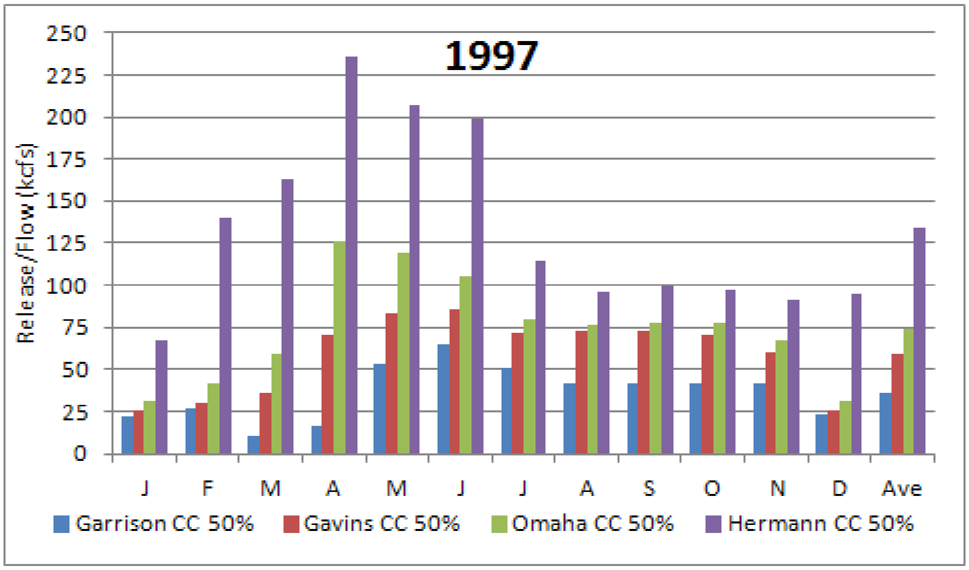

Figure 86. Monthly average releases for 1997, a year with high System inflows, from two of the System reservoirs and flows at two locations on the lower Missouri River for the CC 50% climate change scenario.

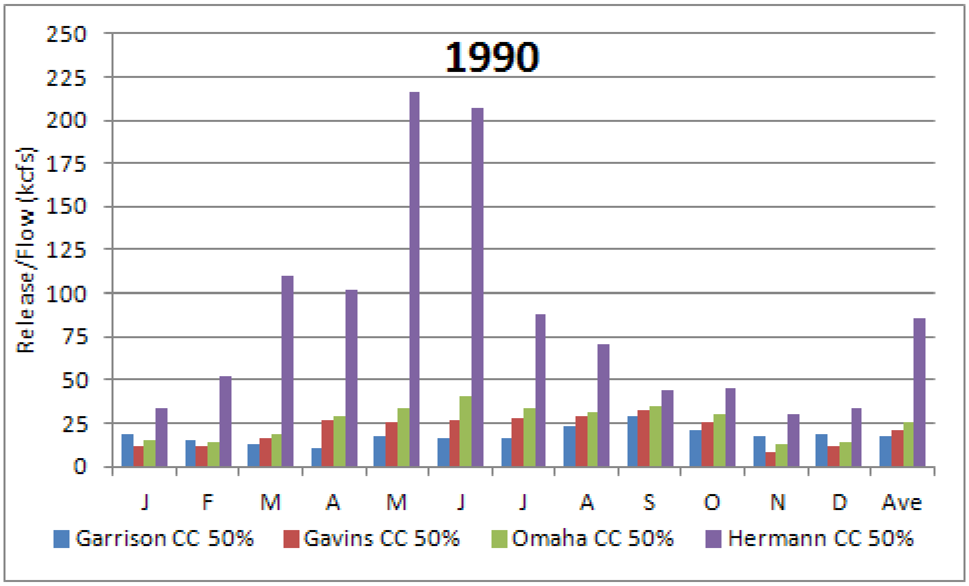

Figure 87. Monthly average releases for 1990, a year with low System inflows, from two of the System reservoirs and flows at two locations on the lower Missouri River for the CC 50% climate change scenario.

Figures 88 through 90 show the monthly average data for the Gavins Point release for the four climate change scenarios to show the range of releases for the climate change scenarios. The NAWS 13.6 simulation values are not presented in the figures; however, they would be very similar to the values for the CC 25% climate change scenario. Basically these figures show that there is not a lot of variability in the releases in the average and below runoff years, except when the CC 5% scenario has a non-navigation year (1990, or Figure 90). Conversely, considerable variability occurs among the months in the higher runoff years (1997, or Figure 88). All three figures present the annual average values for the four scenarios, and the variability among the scenarios is captured by the annual average value. These two factors lead to the conclusion that the presentation of monthly and annual average values should capture both forms of variability.

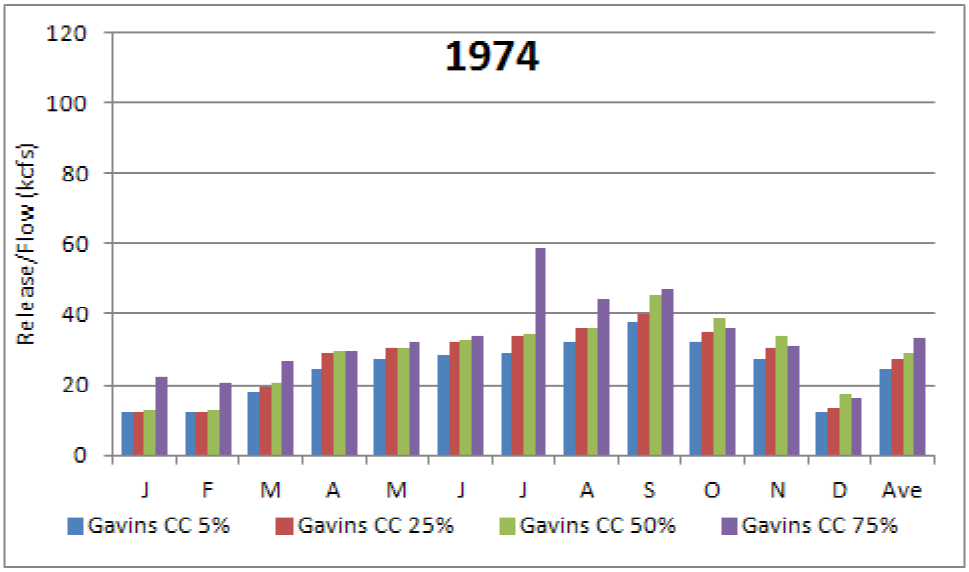

Figure 88. Average monthly Gavins Point releases for 1974, a year with average inflows, for the four climate change scenarios.

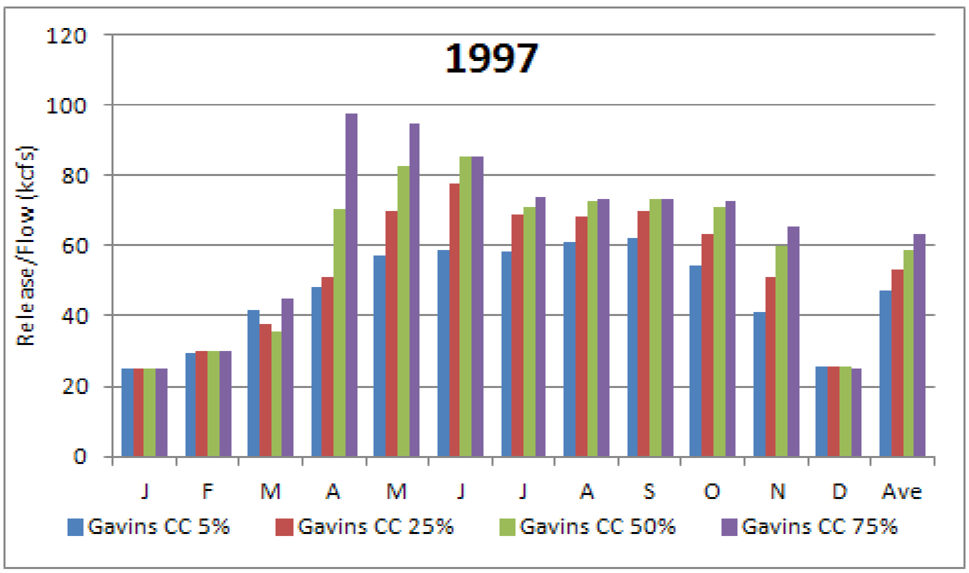

Figure 89. Average monthly Gavins Point releases for 1997, a year with high inflows, for the four climate change scenarios.

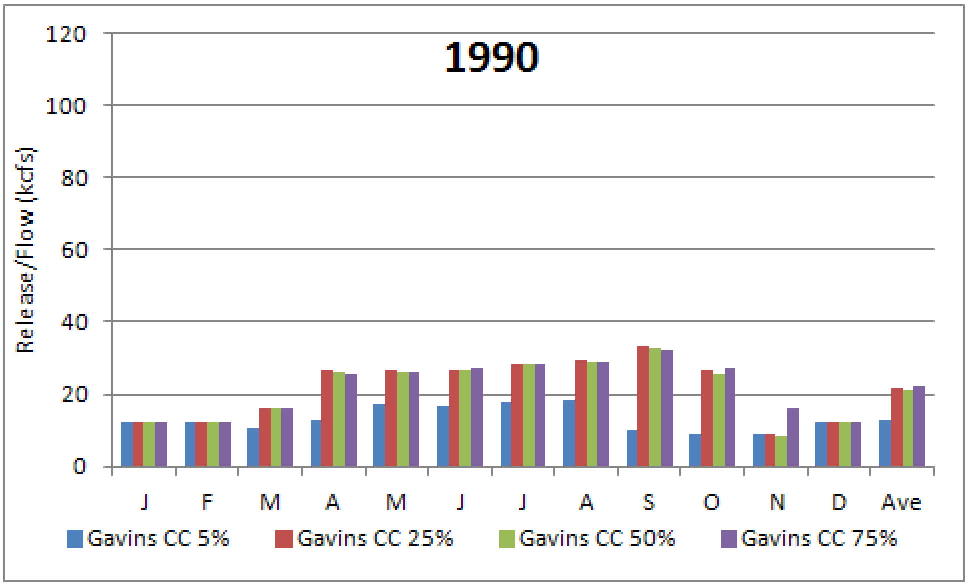

Figure 90. Average monthly Gavins Point releases for 1990, a year with low inflows, for the four climate change scenarios.

Similar to the System storage and reservoir elevation analyses, the average monthly release/flow data for eight gage locations included in the DRM were plotted for the 50-year period of analysis (Figure 91 for Garrison releases for the NAWS simulation and the CC 5% scenario). The differences between the NAWS 13.6 and CC 5% data in the figure were then plotted (Figure 92). Finally, the difference data were sorted and plotted (Figure 93). This process was followed for each climate change scenario for all eight analysis locations (Fort Peck, Garrison, Oahe, and Gavins Point reservoirs within the System and Omaha, St. Joseph, Kansas City, and Hermann on the lower Missouri River). The average annual values for each set of difference data (from the NAWS 13.6 release/flow values), the minimum value for the CC 5% scenario, and the maximum value for the CC 75% scenario were plotted for each of the eight locations selected for inclusion in the analysis as a single figure (these values are -12.8 and -3.3, respectively, for the CC 5% minimum and average for the Garrison release from the data in Figures 92 or 93). The resulting figure for the annual average release/flow analysis is shown as Figure 94. The two aforementioned CC 5% data points are highlighted on the figure. This figure shows that the average annual releases generally increase (the positive values become more positive and the negative values become more negative) at the four reservoir locations shown on the figure as the inflows are stored in the System reservoirs and are released to meet the authorized purposes for the System. As the Gavins Point release joins the inflows on the lower Missouri River, the annual average, maximum, and minimum flows at the lower river locations further increase from Gavins Point to Hermann.

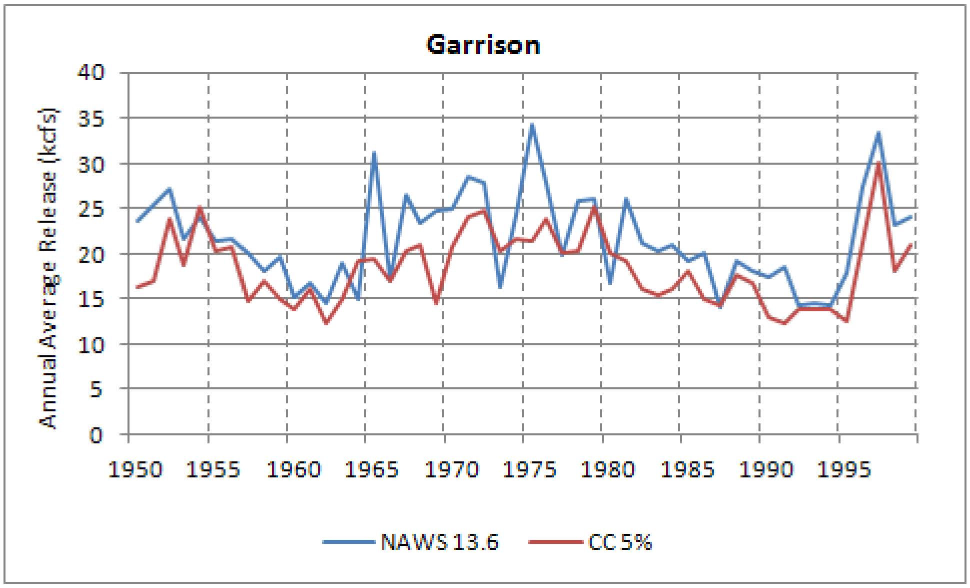

Figure 91. Garrison annual average release data for the NAWS 13.6 simulation and the CC 5% climate change scenario for the 50 years of the period of analysis, 1950-1999.

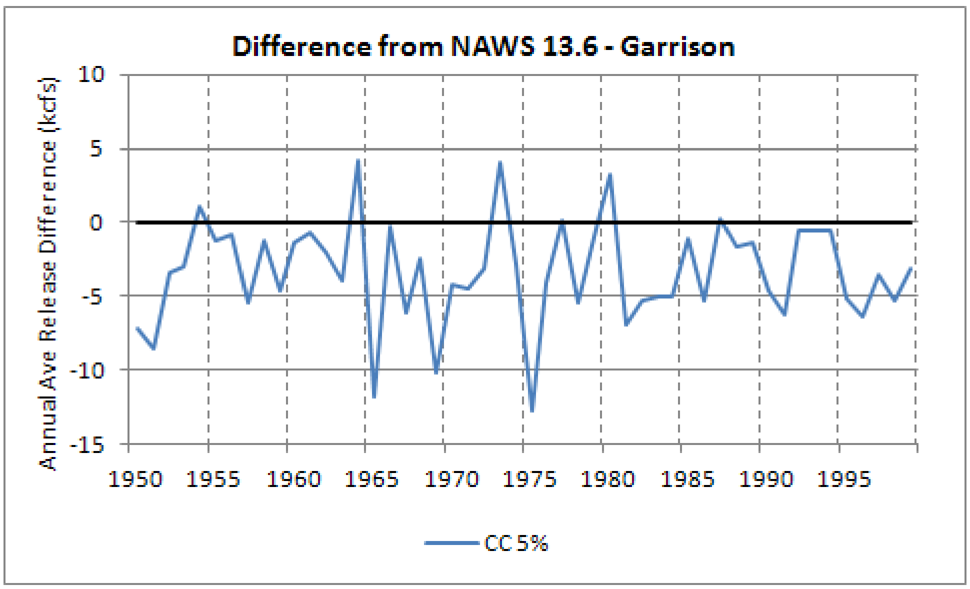

Figure 92. Garrison annual average release difference data created by subtracting the NAWS 13.6 simulation data from the CC 5% climate change scenario data for the 50 years of the period of analysis, 1950-1999.

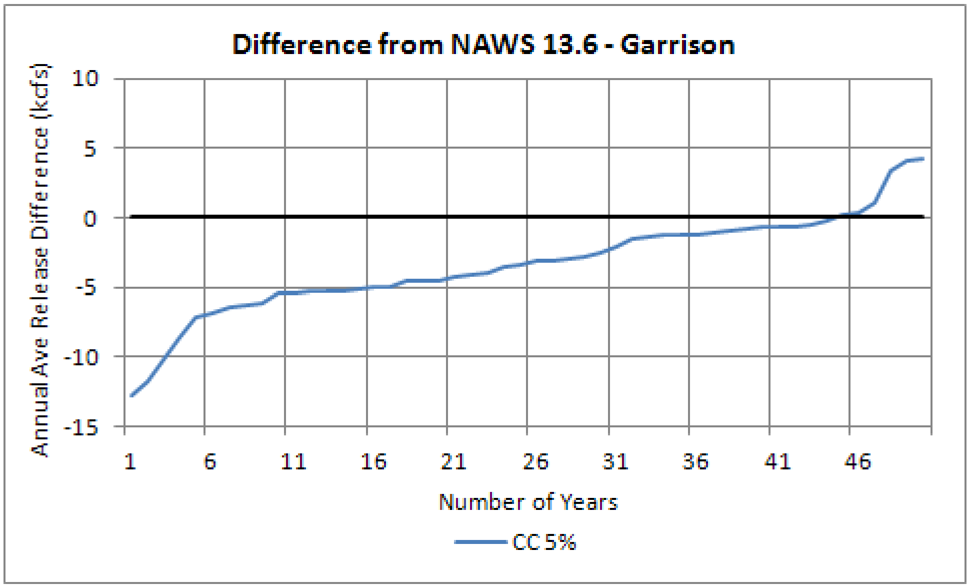

Figure 93. Sorted Garrison annual average release difference data created by subtracting the NAWS 13.6 simulation data from the CC 5% climate change scenario for the 50 years of the period of analysis, 1950-1999.

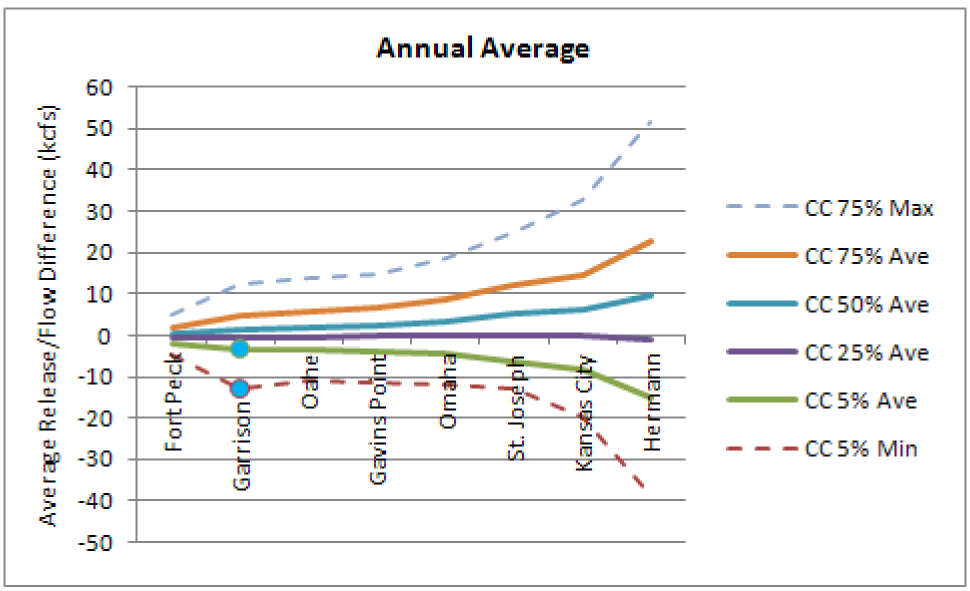

Figure 94. Average annual release/flow difference values for the four climate change scenarios from the release/flow values for the NAWS 13.6 simulation for the 50-year period of analysis, 1950-1999. (Note the two highlighted data points for the CC 5% scenario for the Garrison release.)

The methodology implemented for the annual average release/flow values discussed above was also followed for the monthly average data for all 12 months of the year. The variability that occurs on a month-to-month basis could not be demonstrated using the annual average data, requiring the additional steps of setting up the series of spreadsheets with data for each month, with the end result being a plot of average monthly release/flow difference for each month of the year, including the CC 5% minimum monthly average difference and CC 75% maximum monthly average difference values.

Annual Average Release/Flow Analysis Results

Figure 94 showed the bottom-line results of the analysis of the annual average release/flow data for the full 50-year period of analysis for eight of the 17 locations for the reservoirs or upper and lower river gages included in the DRM's Q1M and Q2M output files. Basically, this figure shows the upper and lower bounds of annual release/flow changes from the NAWS 13.6 simulation and the averages of the annual average release/flow differences from the NAWS 13.6 simulation that could occur under the four climate change scenarios analyzed for this report. The figure shows that the CC 25% climate change scenario apparently has an annual average set of inflows somewhat similar that of the NAWS 13.6 simulation because the net average annual differences for the eight locations are very near zero on the plot. Since the CC 5% scenario average difference values plot negative, the releases/flows, and accordingly inflows, must be lower than those for the NAWS 13.6 simulation. Therefore, the most basic statement that can be made is that, on an average annual basis, approximately 25 percent of the climate change scenarios would result in lower average annual (and monthly and daily) System reservoir releases or lower Missouri River flows. Conversely, approximately 75 percent of the climate change scenarios would result in higher System reservoir releases or higher Missouri River flows. The actual splits on an average annual basis are apparently slightly greater than 25 percent for lower values and slightly less than 75 percent for higher values using annual average release/flow data.

The data included in this climate change analysis includes 70 percent (75th percentile minus 5th percentile) of the range of potential changes to climate by the 2060 timeframe. From the results of the analysis of this 70 percent, much lower inflow, or dry basin, conditions could occur under from 1 percent to some value somewhat greater than 5 percent of the 112 climate change scenarios developed for the NAWS Project analysis. This is based on the average annual values being over 10 kcfs lower at Hermann and one year's flow being almost 40 kcfs lower on an annual average basis. Similarly, from about the 75th percentile to 100th percentile of the scenarios would potentially result in extremely higher inflow, or very wet basin, conditions by 2060 (average annual increase of over 20 kcfs with one year being up to 50 kcfs higher on an annual average basis for the lower end of the range of high inflow scenarios, in this case the 75th percentile scenario).

The differences in the average annual releases/flows generally increase in a downstream direction. For example, the decreases in the releases for the CC 5% decrease from -1.75 kcfs at Fort Peck to -3.78 kcfs at Gavins Point. Average annual flows for this climate change scenario then further decrease on the lower Missouri River to -8.2 kcfs at Kansas City and -14.9 kcfs at Hermann. If only the minimum values are considered, the annual average release in a single year in the period of analysis decreased by -4.7 kcfs at Fort Peck (1975, a high inflow year, which would be most dramatically affected) and -11.3 kcfs at Gavins Point (1975), which decreased to - 19.6 kcfs at Kansas City (1951, an extremely high fall runoff year in the lower Missouri River basin) and -38.5 kcfs at Hermann (1951). The switch in the years the minimum occurred is an indication that the monthly inflow factors for the lower Missouri River basin became the overriding factor for the more dramatic change in river flows from the changes to reservoir releases. The data listed in this paragraph are only for the CC 5% scenario for four of the 17 locations with data from the DRM simulations of NAWS 13.6 and the four climate change scenarios. Situations such as this demonstrate the difficulty in presenting data on climate change in a narrative format. Table 21 presents the average annual difference data for the four climate change scenarios and the data for the CC 5% minimums and CC 75% maximums in Figure 94.

Table 21: Annual average release/flow difference data points on Figure 94 (kcfs)

	CC 5% Min	CC 5% Ave	CC 25% Ave	CC 50% Ave	CC 75% Ave	CC 75% Max
Fort Peck	-4.7	-1.8	-0.6	0.3	1.9	5.1
Garrison	-12.8	-3.3	-0.6	1.4	4.7	12.1
Oahe	-11.0	-3.4	-0.3	2.0	5.8	13.8
Gavins Point	-11.3	-3.8	-0.2	2.6	6.8	14.9
Omaha	-11.8	-4.5	0.0	3.6	8.7	18.7
St. Joseph	-12.9	-6.2	0.1	5.2	12.0	24.9
Kansas City	-19.6	-8.2	-0.2	6.2	14.5	32.9
Hermann	-38.5	-14.9	-1.1	9.5	22.6	51.5

Monthly Average Release/Flow Analysis Results

The annual average data presented above does not give a complete picture of the effect of the climate change scenarios on releases from the System reservoirs and the flows on the lower Missouri River. To provide a better picture, the monthly average data for four months - January, April, July, and October - one for each season, are presented below. The monthly average data provide a much clearer picture of the effects of having the variability in the inflows for the different parts of the year for the climate change scenarios.

Table 22 presents the January percentage changes for the inflows for the tributary area above each of the 14 nodes in the DRM for all five of the climate change scenarios (includes CC 95%, which could not be simulated with the DRM in its current form). These percentage changes are the January values in Table 3 of this report. The changes in the inflows range from negative for the CC 5% scenario to near zero for the CC 25% scenario to positive for the other three scenarios. To provide some perspective on how much these percentage changes could affect the annual release/flow values, 3.0 percent of the annual average inflow above Sioux City occurs during January, based on the historic inflows for 1989 to 2009.

Figure 95 and Table 23 present the January average release/flow data for the eight locations included in the climate change data presentation. As expected, the CC 5% climate change scenario would reduce the releases/flows at the eight locations shown in the table, and the CC 50% and CC 75% scenarios would increase the releases/flows. Also, the CC 25% scenario would have releases and flows very similar to those that would have occurred in 2060 should there be no change in the long-term climate in the Missouri River Basin. The average January release/flow changes during this low inflow month are generally less than 3 kcfs at all eight locations, with the exceptions occurring for the Garrison releases for the CC 5% and CC 75% scenarios (-3.6 kcfs and +3.2 kcfs, respectively). The minimum and maximum values in the release/flow "envelope" of values range from -3.3 kcfs at Fort Peck (1995, historic inflow = 4.9 kcfs) to -22.7 kcfs at Hermann (1973) for the CC 5% scenario and from +4.2 kcfs at Fort Peck (1994, 7.5 kcfs) to +34.9 kcfs at Hermann (1974) for the CC 75% scenario. These difference values are the monthly average difference values, and daily minimum and maximum difference values could be even greater.

Table 22: Climate change effects on historic January Inflows at the 14 node locations in 2060

	CC 5%	CC 25%	CC 50%	CC 75%	CC 95%
Fort Peck Dam	-12.12%	0.06%	10.08%	27.51%	56.40%
Garrison Dam	-10.49%	-0.91%	8.76%	21.89%	50.98%
Oahe Dam	-10.27%	-0.39%	9.98%	20.78%	51.94%
Big Bend Dam	-10.54%	-0.60%	10.06%	20.42%	51.79%
Fort Randall Dam	-10.42%	-0.94%	10.32%	20.29%	51.45%
Gavins Point Dam	-10.29%	-0.85%	10.40%	20.29%	51.55%
Sioux City, IA	-7.94%	1.21%	13.11%	24.91%	50.15%
Omaha, NE	-7.92%	1.81%	13.51%	26.87%	51.79%
Nebraska City, NE	-9.16%	1.98%	13.57%	24.87%	48.03%
Rulo, NE	-9.25%	1.99%	14.03%	26.38%	47.93%
St. Joseph, MO	-11.01%	2.26%	13.76%	26.13%	47.33%
Kansas City, MO	-15.96%	1.09%	11.62%	29.36%	45.83%
Waverly, MO	-16.89%	0.60%	11.41%	29.40%	45.30%
Boonville, MO	-20.50%	2.04%	10.57%	27.54%	45.01%
Hermann, MO	-24.35%	-1.85%	11.35%	26.23%	43.27%
w/in System Ave.	-10.69%	-0.61%	9.93%	21.86%	52.35%
Lower River Ave.	-13.66%	1.24%	12.55%	26.85%	47.18%

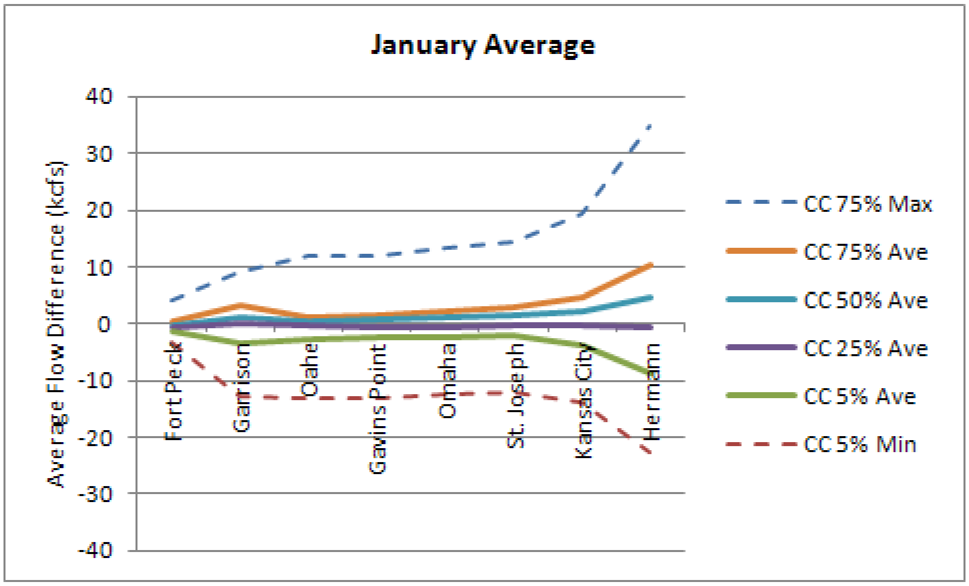

Figure 95. January average release/flow difference values for the four climate change scenarios from the release/flow values for the NAWS 13.6 simulation for the 50-year period of analysis, 1950-1999.

Table 23: January average release/flow difference data points on Figure 95 (kcfs)

	CC 5% Min	CC 5% Ave	CC 25% Ave	CC 50% Ave	CC 75% Ave	CC 75% Max
Fort Peck	-3.3	-1.2	-0.6	-0.1	0.4	4.2
Garrison	-12.9	-3.6	0.1	1.1	3.2	9.0
Oahe	-13.3	-2.6	-0.4	0.6	1.2	11.9
Gavins Point	-13.1	-2.2	-0.5	0.7	1.6	12.0
Omaha	-12.3	-2.4	-0.5	1.0	2.1	13.5
St. Joseph	-12.2	-2.1	-0.1	1.4	2.7	14.4
Kansas City	-13.9	-3.6	-0.3	2.3	4.8	19.3
Hermann	-22.7	-8.6	-0.6	4.7	10.5	34.9

Table 24 presents the April percentage changes for the inflows for the tributary area above each of the 14 nodes in the DRM for all five of the climate change scenarios (includes CC 95%, which could not be simulated with the DRM in its current form). These percentage changes are the April values in Table 3 of this report. The inflow changes within the System are all positive for the four scenarios, except for Fort Randall under the CC 5% scenario. On the lower Missouri River reaches, the inflow changes are all negative for the CC 5% scenario and all positive for the other three scenarios, except at Hermann for the CC 25% scenario. The "no change" scenario for April is somewhere around CC 5%. To provide some perspective on how much these percentage changes could affect the annual release/flow values, 11.7

percent of the annual average inflow above Sioux City occurs during April, based on the historic inflows for 1989 to 2009.

Figure 96 and Table 25 present the April average release/flow data for the eight locations included in the climate change data presentation. As expected, the CC 5% climate change scenario would reduce the releases/flows at the eight locations shown in the table, and the CC 50% and CC 75% scenarios would increase the releases/flows. Also, the release/flow differences for these two scenarios are averaging higher than before. The CC 25% scenario would have releases from the four System reservoirs below those of the historic inflow values, as there would be adequate System storage space available in the upper three reservoirs at that time of the year. Conversely, the lower Missouri River flow differences for CC 25% are slightly higher than with the historic inflows. The average April release/flow changes during this higher inflow month are generally getting wider apart at all eight locations. The minimum and maximum values in the release/flow "envelope" of values range from -13.7 kcfs at Fort Peck (1965) to -47.9 kcfs at Hermann (1973) for the CC 5% scenario and from +18.7 kcfs at Fort Peck (1996, 17.9 kcfs) to +111.7 kcfs at Hermann (1973) for the CC 75% scenario. The primary reason that 1973 is the year when Hermann is most affected is that the inflows to the lower Missouri River resulted in extremely high March and April flows at Hermann in 1973, and the higher factors for changing inflows in March and April cause larger swings in the flows at Hermann among the CC 5% scenario (more negative) and the CC 50% and CC 75% scenarios (more positive). These difference values are the monthly average difference values, and daily minimum and maximum difference values could be even greater.

Table 24: Climate change effects on historic April Inflows at the 14 node locations in 2060

	CC 5%	CC 25%	CC 50%	CC 75%	CC 95%
Fort Peck Dam	6.97%	21.00%	34.19%	56.62%	90.11%
Garrison Dam	3.80%	18.74%	29.26%	47.02%	67.01%
Oahe Dam	3.31%	17.38%	29.95%	42.34%	69.85%
Big Bend Dam	2.28%	17.36%	29.50%	42.43%	70.98%
Fort Randall Dam	-0.19%	17.58%	29.48%	41.59%	73.96%
Gavins Point Dam	-1.36%	15.19%	29.17%	42.13%	73.87%
Sioux City, IA	-3.29%	15.94%	28.61%	44.43%	78.06%
Omaha, NE	-6.45%	13.72%	26.72%	42.44%	75.57%
Nebraska City, NE	-9.89%	10.84%	23.62%	42.57%	75.36%
Rulo, NE	-10.53%	9.69%	22.38%	41.38%	73.24%
St. Joseph, MO	-11.37%	8.79%	20.66%	39.38%	72.61%
Kansas City, MO	-15.94%	4.28%	16.32%	39.27%	71.76%
Waverly, MO	-15.98%	4.17%	16.30%	38.27%	72.68%
Boonville, MO	-16.10%	2.07%	15.65%	35.74%	68.19%
Hermann, MO	-18.31%	-0.42%	14.71%	33.49%	60.56%
w/in System Ave.	2.47%	17.88%	30.26%	45.36%	74.30%
Lower River Ave.	-11.98%	7.68%	20.55%	39.66%	72.00%

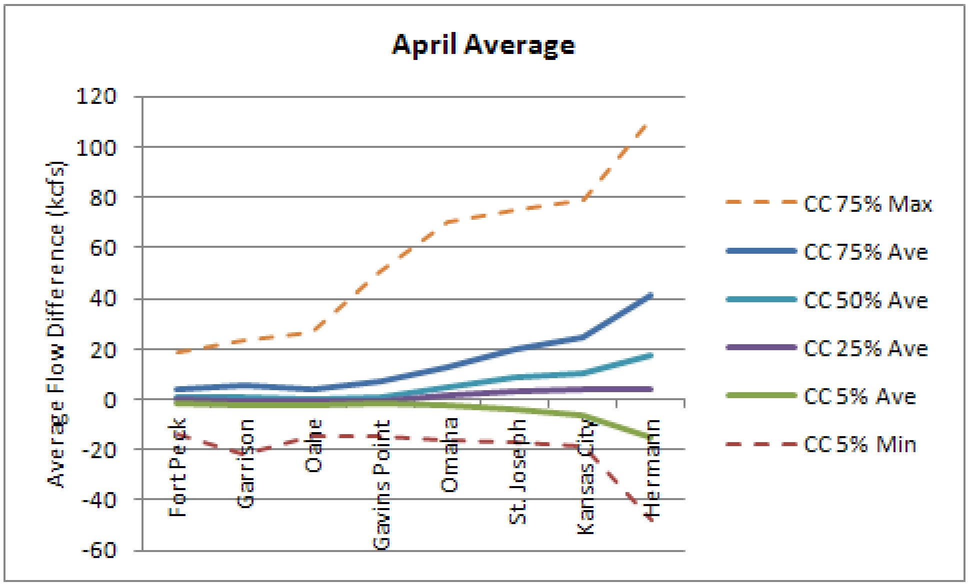

Figure 96. April average release/flow difference values for the four climate change scenarios from the release/flow values for the NAWS 13.6 simulation for the 50-year period of analysis, 1950-1999.

Table 25: April average release/flow difference data points on Figure 96 (kcfs)

	CC 5% Min	CC 5% Ave	CC 25% Ave	CC 50% Ave	CC 75% Ave	CC 75% Max
Fort Peck	-13.7	-1.2	-0.3	0.5	4.3	18.7
Garrison	-21.8	-2.0	-0.9	0.7	5.6	23.3
Oahe	-14.6	-2.3	-1.1	-0.2	4.1	26.7
Gavins Point	-14.9	-1.8	-0.5	1.2	7.3	50.8
Omaha	-16.0	-2.4	1.6	4.9	13.1	70.3
St. Joseph	-17.4	-4.1	3.2	8.6	19.8	75.0
Kansas City	-18.3	-6.2	3.8	10.6	24.8	79.3
Hermann	-47.9	-14.8	4.0	17.9	41.3	111.7

Table 26 presents the July percentage changes for the inflows for the tributary area above each of the 14 nodes in the DRM for all five of the climate change scenarios (includes CC 95%, which could not be simulated with the DRM in its current form). These percentage changes are the July values in Table 3 of this report. The changes in inflows within the System are all negative for the four scenarios except for the lower four reservoirs under the CC 75% scenario. Most of the changes for the lower Missouri River for the three lower percentage scenarios are negative, and the changes for the CC 75% scenario are all positive. The "no change" scenario for July is somewhere between CC 50% and CC 75%. To provide some perspective on how much these percentage changes could affect the annual release/flow values, 12.9 percent of the annual average inflow above Sioux City occurs during July, based on the historic inflows for 1989 to 2009.

Figure 97 and Table 27 present the July average release/flow data for the eight locations included in the climate change data presentation. As expected, the CC 5% climate change scenario would reduce the releases/flows at the eight locations shown in the table. For the CC 50% and CC 75% scenarios, all reaches would have higher releases/flows, and those for the CC 50% scenario are relatively constant from Oahe to Hermann (historic July inflows remained relatively unchanged from Kansas City to Hermann at less than 1 percent change). The CC 25% scenario would have lower releases from the upper two System reservoirs compared to those of the historic inflow values, with the lower Missouri River flow differences for CC 25% shifting from being higher at Omaha to lower at the other three locations than with the historic inflows. The minimum and maximum values in the release/flow "envelope" of values range from -27.9 kcfs at Fort Peck (1975, monthly average inflow = 36.6 kcfs) to -110.2 kcfs at Hermann (1951) for the CC 5% scenario and from +15.5 kcfs at Fort Peck (1978, 20.4 kcfs) to +52.7 kcfs at Hermann (1995) for the CC 75% scenario. The primary reason that 1951 is the year when Hermann is most affected is that the inflows to the lower Missouri River resulted in extremely high July flows at Hermann in 1951, and the higher factors for changing inflows in July cause larger swings in the flows at Hermann among the CC 5% scenario (more negative) and the CC 50% and CC 75% scenarios (more positive). These difference values are the monthly average difference values, and daily minimum and maximum difference values could be even greater.

Table 26: Climate change effects on historic July Inflows at the 14 node locations in 2060

	CC 5%	CC 25%	CC 50%	CC 75%	CC 95%
Fort Peck Dam	-44.84%	-35.56%	-27.44%	-14.59%	3.57%
Garrison Dam	-32.72%	-20.10%	-13.03%	-2.37%	16.41%
Oahe Dam	-28.29%	-18.66%	-9.02%	1.97%	19.33%
Big Bend Dam	-27.52%	-18.11%	-8.45%	2.84%	19.92%
Fort Randall Dam	-26.20%	-17.28%	-7.31%	3.63%	21.19%
Gavins Point Dam	-25.26%	-16.24%	-6.53%	4.34%	22.48%
Sioux City, IA	-23.24%	-14.37%	-5.28%	6.13%	25.25%
Omaha, NE	-22.67%	-13.28%	-3.65%	7.21%	26.67%
Nebraska City, NE	-25.20%	-13.35%	-4.65%	6.67%	24.66%
Rulo, NE	-25.03%	-12.55%	-4.34%	7.75%	24.74%
St. Joseph, MO	-24.64%	-11.41%	-3.20%	8.12%	25.14%
Kansas City, MO	-27.23%	-11.13%	-0.33%	12.58%	29.70%
Waverly, MO	-26.88%	-10.99%	-0.13%	13.20%	30.55%
Boonville, MO	-27.14%	-10.76%	-0.28%	15.16%	32.40%
Hermann, MO	-27.72%	-10.37%	0.14%	16.35%	33.67%
w/in System Ave.	-30.81%	-20.99%	-11.96%	-0.70%	17.15%
Lower River Ave.	-25.53%	-12.02%	-2.41%	10.35%	28.09%

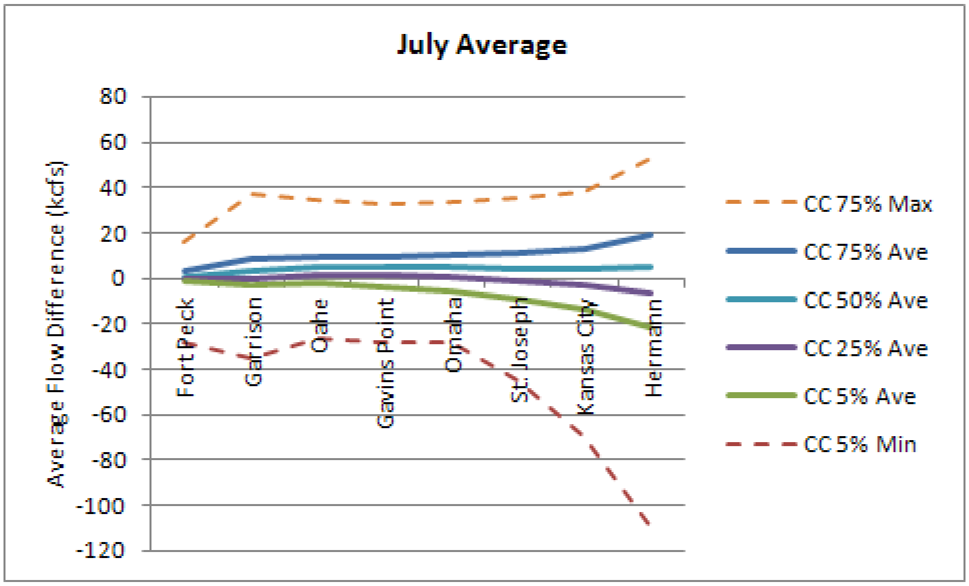

Figure 97. July average release/flow difference values for the four climate change scenarios from the release/flow values for the NAWS 13.6 simulation for the 50-year period of analysis, 1950-1999.

Table 27: July average release/flow difference data points on Figure 97 (kcfs)

	CC 5% Min	CC 5% Ave	CC 25% Ave	CC 50% Ave	CC 75% Ave	CC 75% Max
Fort Peck	-27.9	-1.6	-0.6	0.8	3.2	15.5
Garrison	-35.1	-3.4	-0.5	3.5	8.3	37.1
Oahe	-26.8	-2.3	1.7	5.0	9.1	34.3
Gavins Point	-27.8	-3.5	1.5	5.1	9.6	32.5
Omaha	-27.8	-5.4	0.3	4.7	10.0	33.6
St. Joseph	-44.7	-9.1	-1.5	4.1	11.1	35.2
Kansas City	-69.7	-13.4	-3.2	4.1	13.2	37.6
Hermann	-110.2	-21.8	-6.2	4.6	18.7	52.7

Table 28 presents the October percentage changes for the inflows for the tributary area above each of the 14 nodes in the DRM for all five of the climate change scenarios (includes CC 95%, which could not be simulated with the DRM in its current form). These percentage changes are the October values in Table 3 of this report. The changes in inflows within the System are somewhat similar to those for August and September for the four scenarios, with the values being negative for the CC 5% through CC 50% scenarios and positive for the CC 75% scenario. All of the changes for the lower Missouri River for the two lower percentage scenarios are negative, and the changes for the CC 50% and CC 75% scenarios are generally positive. The "no change" scenario for October is somewhere around CC 50%. To provide some perspective on how much these percentage changes could affect the annual release/flow values, 4.7 percent of the annual average inflow above Sioux City occurs during October, based on the historic inflows for 1989 to 2009.

Figure 98 and Table 29 present the October average release/flow data for the eight locations included in the climate change data presentation. As expected, the CC 5% and CC 25% climate change scenarios would reduce the releases/flows at the eight locations shown in the table. For the CC 50% and CC 75% scenarios, all reaches would have higher releases/flows except at Fort Peck for CC 50%, and those for the CC 50% scenario are relatively constant from Oahe to Hermann. The average October release/flow changes during this lower inflow month are generally similar to those that occurred in August and September at all eight locations. The minimum and maximum values in the release/flow "envelope" of values range from -12.7 kcfs at Fort Peck (1972, monthly average inflow = 8.2 kcfs) to -91.5 kcfs at Hermann (1986) for the CC 5% scenario and from +8.7 kcfs at Fort Peck (1964) to +65.2 kcfs at Hermann (1993) for the CC 75% scenario. These difference values are the monthly average difference values, and daily minimum and maximum difference values could be even greater.

Table 28: Climate change effects on historic October Inflows at the 14 node locations in 2060

	CC 5%	CC 25%	CC 50%	CC 75%	CC 95%
Fort Peck Dam	-25.30%	-17.54%	-9.80%	1.55%	30.14%
Garrison Dam	-22.48%	-13.66%	-7.25%	4.12%	24.64%
Oahe Dam	-21.12%	-13.28%	-4.13%	5.61%	26.64%
Big Bend Dam	-21.01%	-12.89%	-4.08%	5.49%	26.89%
Fort Randall Dam	-21.09%	-12.86%	-3.75%	6.39%	27.31%
Gavins Point Dam	-20.95%	-12.95%	-3.40%	6.91%	27.59%
Sioux City, IA	-21.45%	-12.16%	1.70%	11.47%	32.48%
Omaha, NE	-21.50%	-12.30%	1.35%	12.27%	31.78%
Nebraska City, NE	-24.01%	-13.17%	0.51%	11.80%	29.72%
Rulo, NE	-24.43%	-12.90%	0.75%	11.53%	30.03%
St. Joseph, MO	-25.48%	-12.07%	0.37%	12.25%	30.56%
Kansas City, MO	-29.80%	-11.89%	0.04%	14.68%	35.90%
Waverly, MO	-30.19%	-11.58%	-0.45%	16.16%	37.46%
Boonville, MO	-30.63%	-10.53%	1.50%	18.46%	41.69%
Hermann, MO	-33.04%	-12.47%	0.68%	17.20%	42.38%
w/in System Ave.	-21.99%	-13.86%	-5.40%	5.01%	27.20%
Lower River Ave.	-26.73%	-12.12%	0.72%	13.98%	34.67%

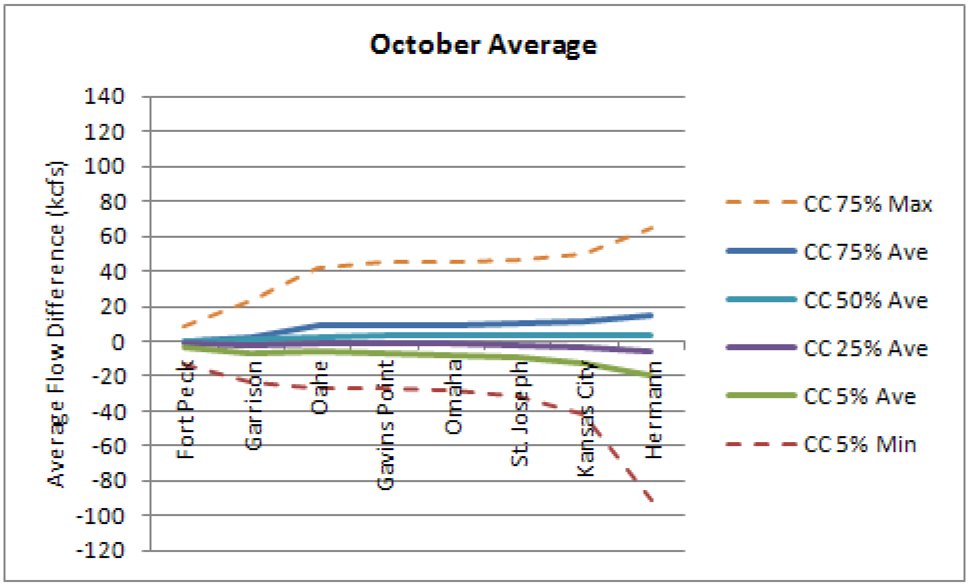

Figure 98. October average release/flow difference values for the four climate change scenarios from the release/flow values for the NAWS 13.6 simulation for the 50-year period of analysis, 1950-1999.

Table 29: October average release/flow difference data points on Figure 98 (kcfs)

	CC 5% Min	CC 5% Ave	CC 25% Ave	CC 50% Ave	CC 75% Ave	CC 75% Max
Fort Peck	-12.7	-3.5	-1.5	-0.1	-0.4	8.7
Garrison	-23.5	-6.6	-1.9	1.3	2.6	23.7
Oahe	-27.3	-5.3	-0.7	2.7	8.6	41.4
Gavins Point	-27.4	-6.6	-1.0	2.9	9.1	45.2
Omaha	-27.9	-7.5	-1.5	3.0	9.4	45.4
St. Joseph	-31.5	-9.6	-2.6	3.0	10.4	46.9
Kansas City	-41.4	-12.1	-3.6	3.0	11.6	49.4
Hermann	-91.5	-19.2	-6.1	3.2	15.3	65.2

The discussion above has outlined the changes in the annual average and monthly average releases from the System reservoirs and flows on the lower Missouri River. Several generalizations can be made regarding the data presented. First, the range in average annual changes in the releases and flows among the climate change scenarios may not seem to be very large on an average annual or monthly basis; however, the data represent the average change over the entire year or month. Therefore, a difference of 5 kcfs in the plot or on the table represents a much larger array of values, meaning that the monthly average change value in a given year can be much larger. Second, the System reservoirs respond to changes in the inflows by storing these increased volumes of water and releasing them at controlled rates to limit adverse impacts of the changes in the volume of water being stored in the reservoirs, especially the upper three, larger reservoirs. Third, the inflows entering the lower Missouri River from lower river tributaries are relatively uncontrolled; therefore, changes to these inflows under the various climate change scenarios are magnified as the Gavins Point releases move downstream. Fourth, the "zero change" climate change scenario is essentially very near the CC 25% scenario on an average annual basis; however, the "zero change" scenario on an average monthly (e.g., January, February, etc.) basis varies from above the CC 5% scenario to over the CC 50 % scenario. Fifth, the range between the maximum monthly average release of the CC 75% scenario and the minimum monthly average release of the CC 5% scenario is relatively large, especially for the lower reaches of the Missouri River. Finally, the maximum increase in flows on the lower Missouri River resulting from the CC 75% scenario typically happens in a year that historically had extremely high flows, making a serious condition even more serious.

Results of other Approaches using Average Monthly and Average Annual Data

Addressing climate change has been difficult from not only the amount of data available for analysis but also from the determination of a simple and easy-to-follow format for presentation of the data. The format followed in the above discussion may not be that easy to follow; therefore, other formats were evaluated while the above discussion was developed and prepared. Three other formats follow that look at the data from the perspective of the use of monthly average and annual average data. First, the average monthly and average annual data will be presented with the 50-year average for all 12 months and the annual values plotted on the same plot for each of the eight reaches included in the analysis discussed above. Second, the percent change in the average monthly values for each reach will then be shown and compared to plots of the percent change in the inflows for that reach for the four climate change scenarios simulated. This process allows the viewing of the raw average monthly and average annual data and the result of the System regulation of the inflows into the System on the associated releases the lower Missouri River flows. Finally, a graphic presentation of the average annual data for each reach versus the climate change scenarios on the x-axis provides a final look at the data.

Figures 99 through 102 present the average monthly and average annual releases from Fort Peck, Garrison, Oahe, and Gavins Point reservoirs, respectively, for the historic inflow conditions used in the NAWS 13.6 simulation and adjusted inflows for the four climate change scenarios. The y-axis scale is the same on each of these figures to provide some perspective for how the releases increase as additional inflows enter the tributary area of each reservoir. The Fort Peck releases are generally in the 5- to 13-kcfs range, with the April through August releases being lower. Garrison releases are somewhat higher at from 13 to 33 kcfs, with some more variability among the months (February and March releases are noticeably lower). Oahe releases (range from 11 to 44 kcfs) have a much greater month-to-month variability, with the releases increasing each month from February through August and then decreasing to December. Finally the Gavins Point release figure looks very similar to the Oahe figure (releases for Gavins Point slightly higher due to intervening inflows) because there is very little regulation capability at the three lower System reservoirs.

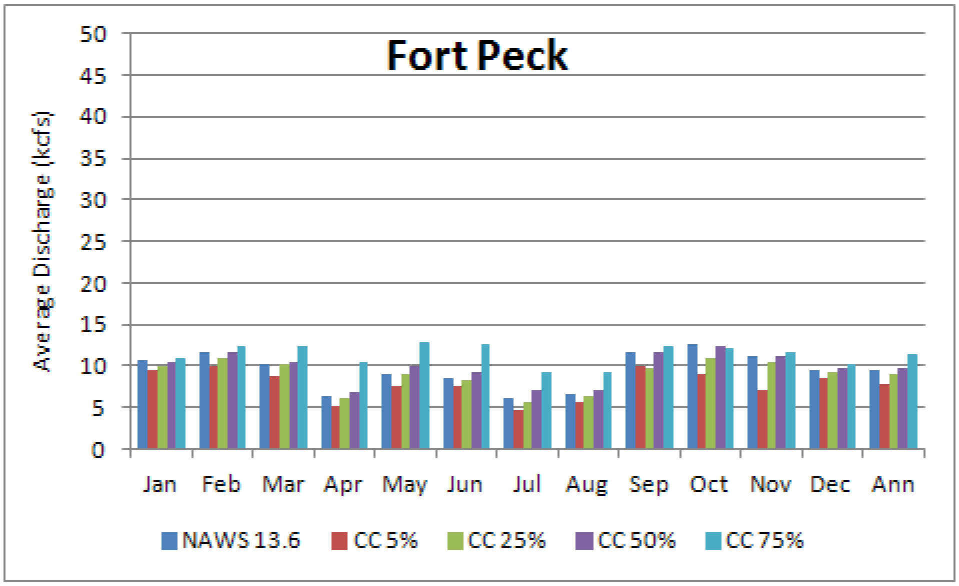

Figure 99. Average monthly and average annual releases from Fort Peck for the 50-year period of analysis, 1950-1999.

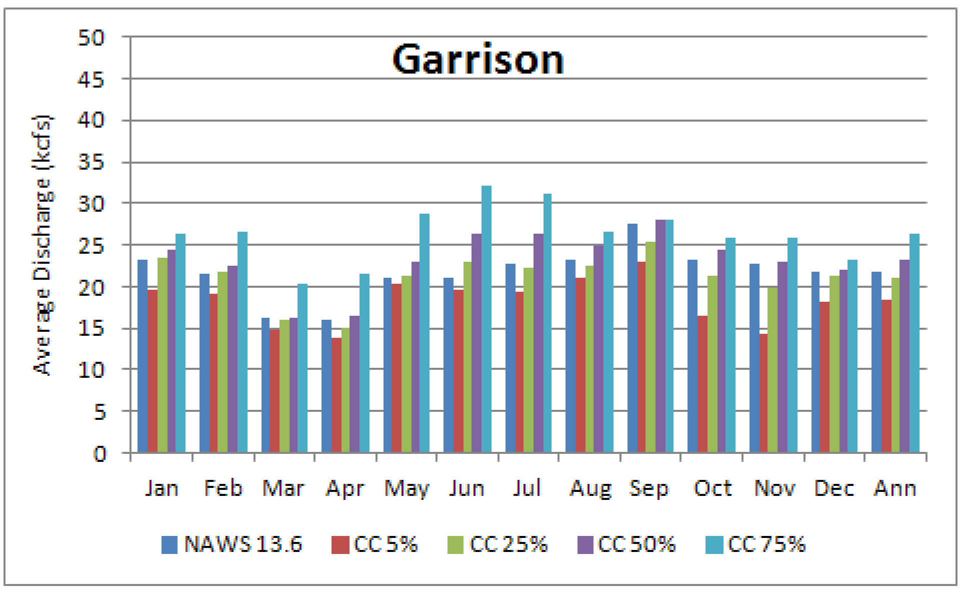

Figure 100. Average monthly and average annual releases from Garrison for the 50-year period of analysis, 1950-1999.

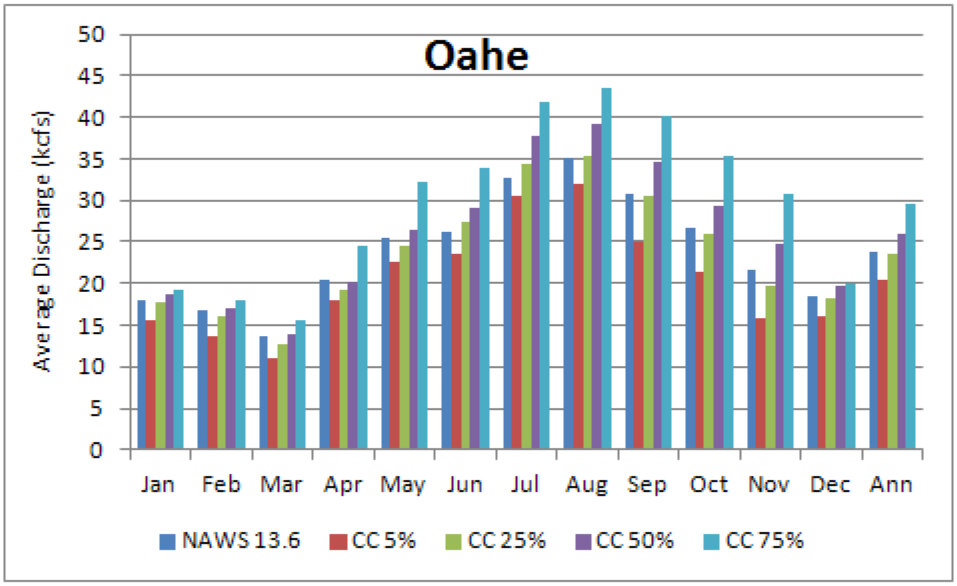

Figure 101. Average monthly and average annual releases from Oahe for the 50-year period of analysis, 1950-1999.

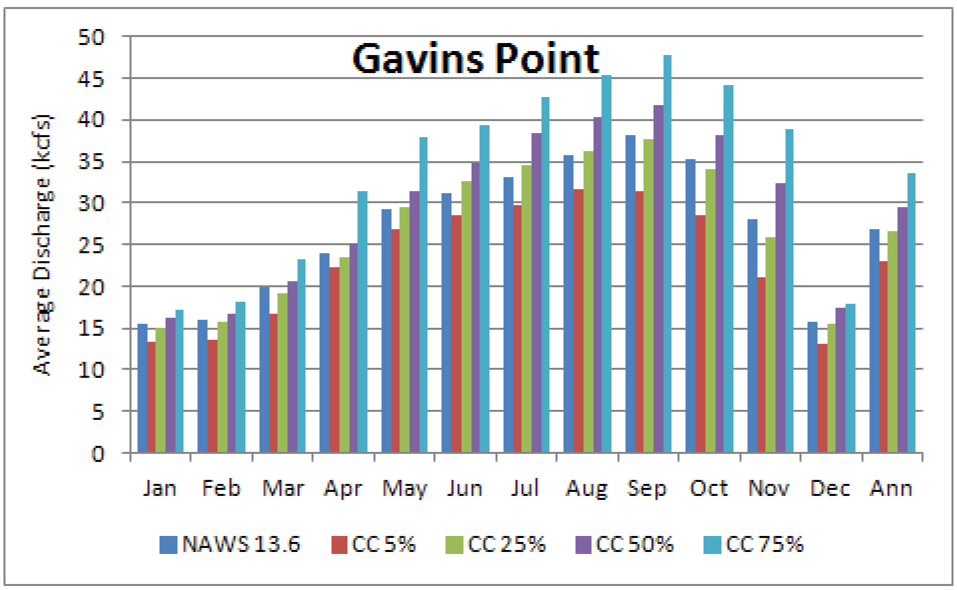

Figure 102. Average monthly and average annual releases from Gavins Point for the 50-year period of analysis, 1950-1999 (small scale).

Variation among the climate change scenarios at Fort Peck (see Figure 99) is relatively small in magnitude because the releases in general are the lowest in the System. For each month and on an annual basis, the release increases as the scenarios percentile value increase from the 5th percentile to the 75th percentile. The changes are generally about 1 kcfs per increase in percentile among the four climate change scenarios simulated. The NAWS 13.6 simulation average release values can be compared to the average values for the four scenarios to see where the release associated with the historic inflows match with the scenarios' averages. The scenario corresponding to "zero change" from the NAWS 13.6 release varies from the CC 25% scenario to as high as above the CC 50% and CC 75% scenarios in October. The "zero-change" scenario tends to be the CC 25% scenario in the higher-inflow months of April, May, and June.

The releases from Garrison are noticeably higher than those for Fort Peck in all months. Typically, the tributary inflows into Garrison are similar to those into and released from Fort Peck; therefore, Garrison has to move about twice as much water annually as Fort Peck must move. The month-to-month pattern starts out similarly to that of Fort Peck, with January and February being higher than the next 2 or 3 months (meeting winter energy needs in January and February). Garrison releases increase more in the summer months when Fort Peck's tended to decrease. Variation among the climate change scenarios continue to follow the expected pattern of increasing releases with increasing climate change percentage. The difference from one scenario to the next, however, is somewhat larger at 2 to 5 kcfs at many times. The annual average difference is about 3 kcfs from one scenario to the next. The "zero-change" from the Existing Conditions release follows a similar pattern to those from Fort Peck.

The pattern of releases from Oahe varies considerably from the upper two reservoirs. Since this is the last reservoir with a large amount of storage capacity, its releases must be oriented towards meeting the requirements for the lower Missouri River. Typically, these requirements increase when navigation service releases from Gavins Point start near the end of March. Since the inflows to the lower Missouri River are also typically higher in the spring, the April through June releases are lower than the July and August releases. Inflows to the lower river then pick up beginning in September, making the releases for September through November lower. The average monthly releases for October and November are also the lowest, especially for the CC 5% scenario, which has more non-navigation years and likely more shorter navigation seasons, therefore, requiring lower releases in those two months. December then is lower as the navigation season has ended in most years on the first, especially at Oahe as the releases are typically lowered in mid- to late November (timing depends of if the season is extended to December 10^{th}, which is more likely as the percentage of the scenario increases). The December release (as well as the January and February releases) is typically between 10 and 17 kcfs to the lower Missouri River, with the tendency towards the higher level the higher the percentage associated with the scenario. In some cases the winter release is above that range when additional evacuation of flood control storage space is required, which also increases with the higher percentage scenario s. The "zero change" scenario tends to be between CC 25% and CC 50% in all but one of the months.

Gavins Point releases mirror Oahe releases except they are slightly higher in response to the inflows to Big Bend, Fort Randall, and Gavins Point reservoirs. Conversely, the Oahe release is lower in response to these lower System inflows. The "zero-change scenario is between CC 25% and CC 50% in all months.

Figure 103 is a larger-scale, y-axis plot of the Gavins Point releases than the scale for the y axis used in Figure 102. This has been done to provide some perspective for the four plots of flows for the lower Missouri River that follow and are discussed next.

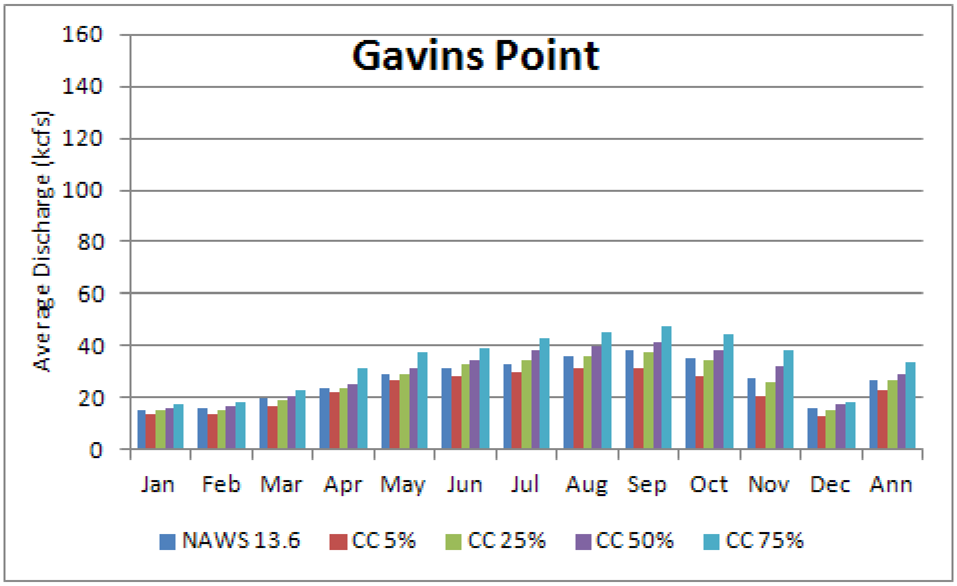

Figure 103. Gavins Point average monthly and average annual releases for the 50-year period of analysis, 1950-1999 (larger-scale, y-axis plot).

Figure 104 to 107 are plots of the average monthly and average annual flows on the lower Missouri River at Omaha, St. Joseph, Kansas City, and Hermann. These four sites were selected for the analysis because they represent locations that have either multiple or major tributaries providing inflows to these gage locations. Omaha has numerous large tributaries between it and Gavins Point Dam. St. Joseph has numerous smaller tributaries and the Platte River between its gage and Omaha. Kansas City has several smaller tributaries and the Kansas River providing inflows between its gage and St. Joseph. Finally, Hermann has many large tributaries in the lower basin area downstream from Kansas City. The flows at these four lower Missouri River locations increase in a downstream direction. The Omaha flows are greater than the Gavins Point releases in, primarily, the spring months of April through June, with smaller increases the other nine months of the year. The inflows increase by 15 kcfs to just over 30 kcfs between Omaha and St. Joseph in the April through November timeframe. The flows at Kansas City further increase primarily in the March through July timeframe. Finally, the flows at Hermann are dramatically higher in the spring months of April through June and somewhat higher in the other eight months of the year. The average annual releases of from 23 to 33 kcfs at Gavins Point grew to average annual flows of 70 to 110 kcfs at Hermann, approximately 3 times the Gavins Point release rate. Finally, the "zero-change" scenario is close to CC 25% for the lower Missouri River sites.

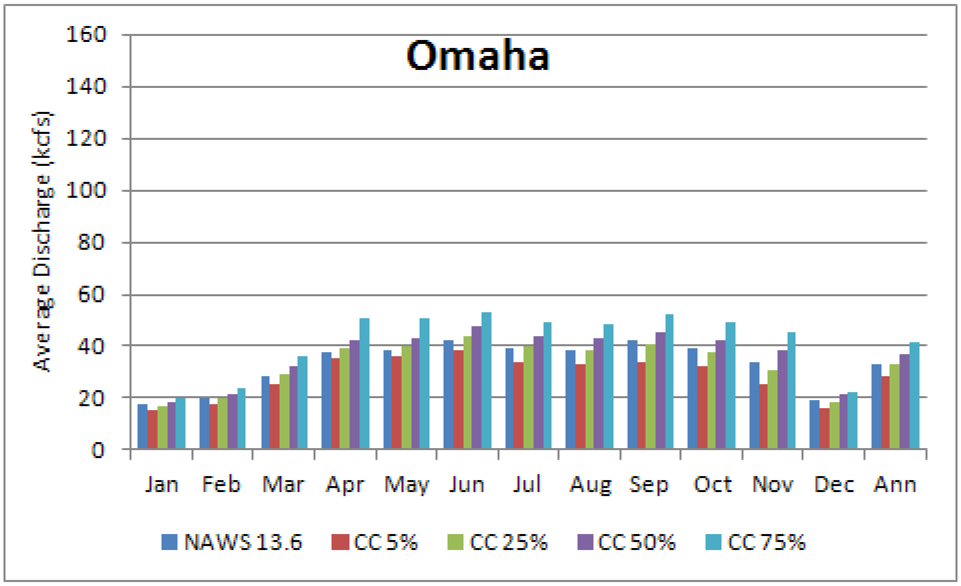

Figure 104. Omaha average monthly and average annual flows for the 50-year period of analysis, 1950-1999.

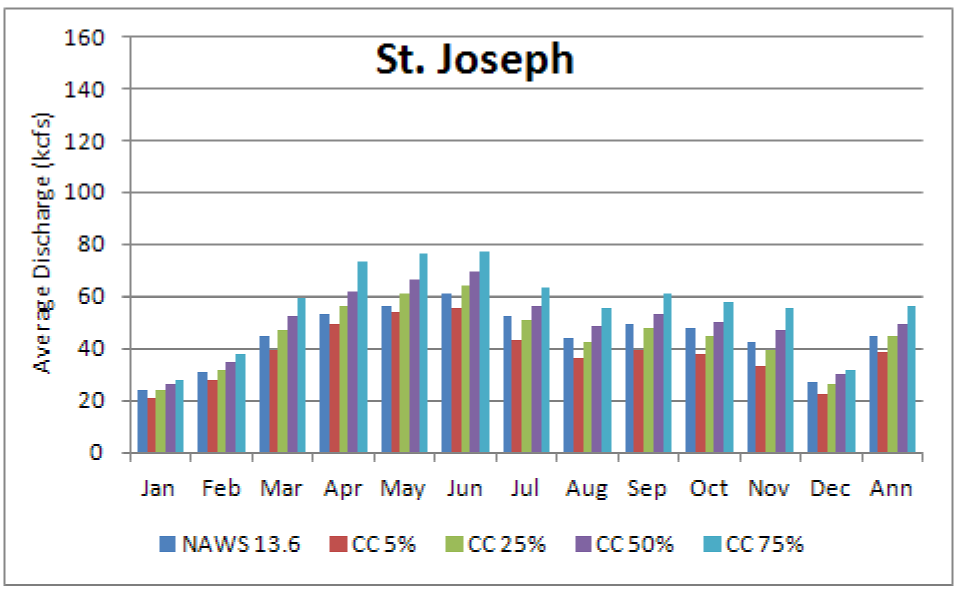

Figure 105. St. Joseph average monthly and average annual flows for the 50-year period of analysis, 1950-1999.

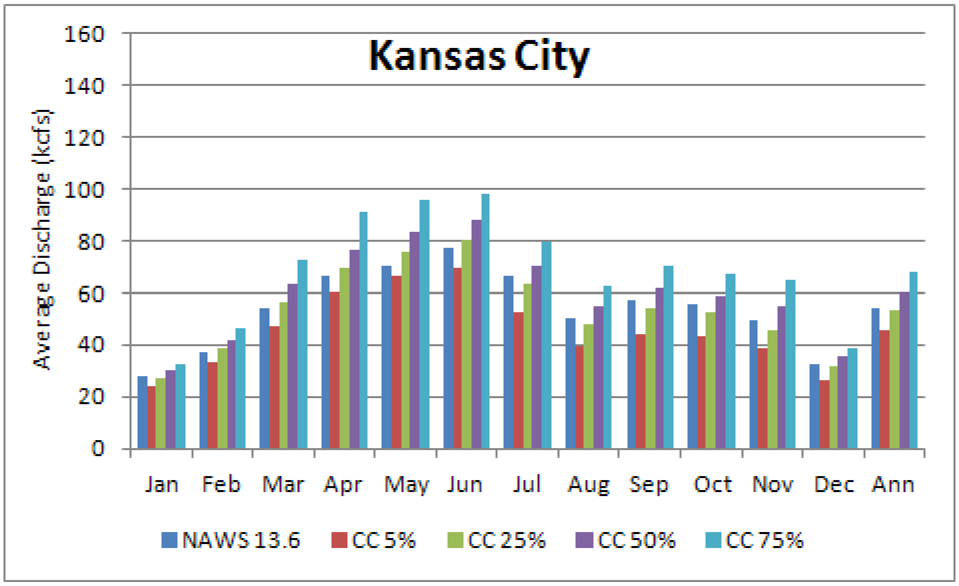

Figure 106. Kansas City average monthly and average annual flows for the 50-year period of analysis, 1950-1999.

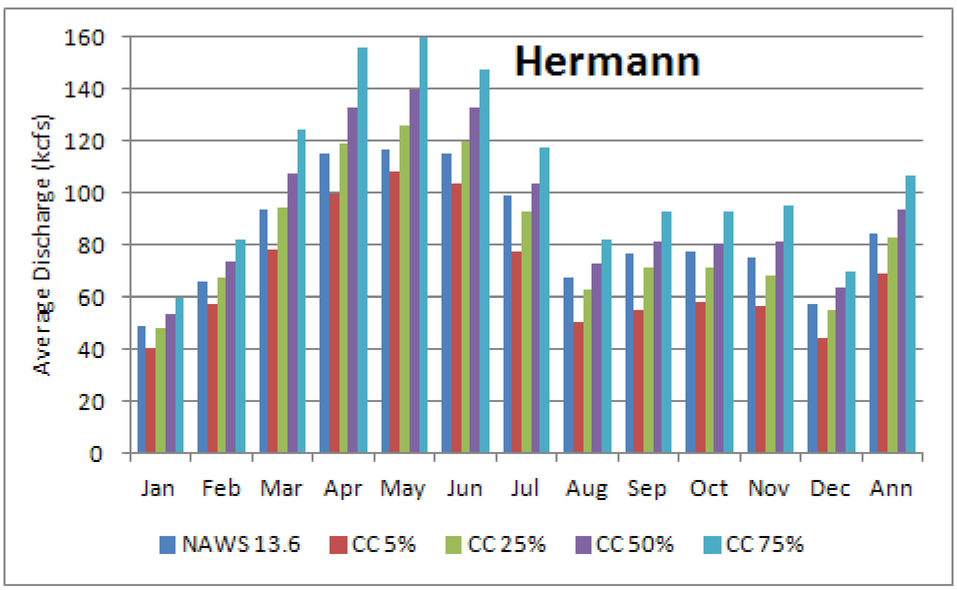

Figure 107. Hermann average monthly and average annual flows for the 50-year period of analysis, 1950-1999.

The average monthly release/flow values presented in Figures 99 through 107 for the four climate change scenarios were used to compute the percent changes from the releases/flows of the NAWS 13.6 simulation. Comparing the plot of the inflow percentage changes by month with the plot of the release or flow percentage changes provides insight on the effects the dams have on the inflows and the lack of any dampening of the inflows on the lower Missouri River reaches. In general terms, the CC 5% values for both the changes in the inflows (except for March and April) and in the releases/flows are negative. Scenario CC 25% generally has values around zero, and CC 50% has values near zero to above zero. All of the percent changes for the CC 75% scenario are much greater than zero, with the values for the winter months being the closest to zero.

Figures 108 and 109 are the monthly inflow and average monthly release change percentages, respectively, for Fort Peck. Figure 108 shows that the inflow changes increase month by month from January through April after which the inflow changes drop through July. The inflows percentage changes then increase over the August through December timeframe. The inflow changes for each scenario follow the same basic pattern of the changes for the other three scenarios. The release patterns look entirely different, especially among the four climate change scenarios at Fort Peck. Figure 109 shows that the variation in the inflows month by month are dampened by Fort Peck Reservoir for the CC 5%, CC 25%, and CC 50% scenarios; however, the releases changes are dramatically higher from about March through August for the CC 75% scenario. Apparently the increased inflows for this scenario were high enough that Fort Peck had to pass on these inflows to Garrison Reservoir in many years. Somewhat the opposite, the releases from Fort Peck were much lower especially in the months of October and November for the CC 5% scenario. Apparently water was being stored in those months so that the generating capacity of Fort Peck could be higher through the winter months. The percentage changes among all four scenarios are closest in the winter months, as the generating capacity is needed but limited.

Even though the percent changes in the Fort Peck and the Garrison (to be discussed next) releases do not quite present a parallel pattern among the four climate change scenarios that is readily apparent in the inflows, there still remains somewhat of a parallel pattern that is not nearly as noticeable. From Oahe to Hermann, the parallel patterns among the percent changes in the inflows and releases/ flows are readily apparent.

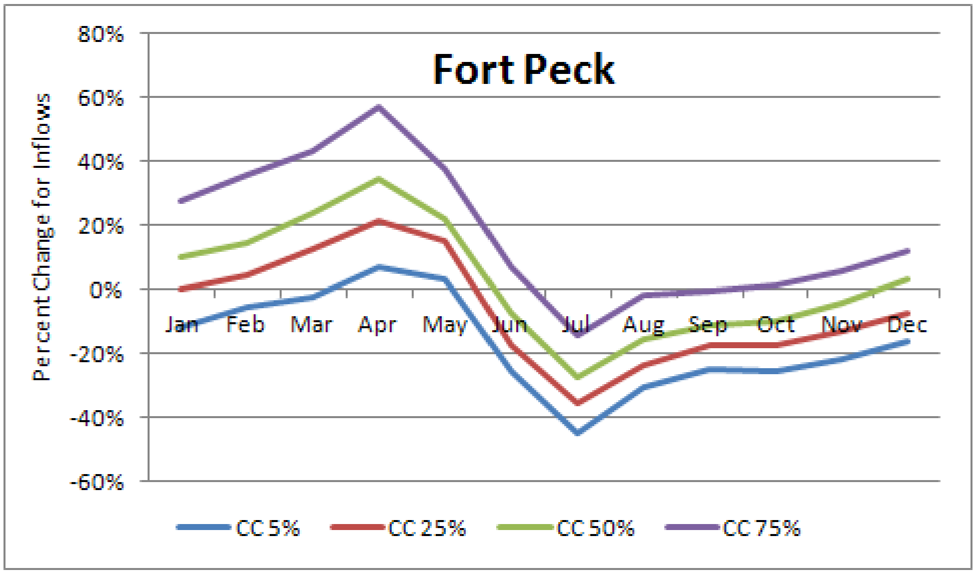

Figure 108. Monthly percentage changes in inflows to historic inflows to Fort Peck Reservoir for the four climate change scenarios.

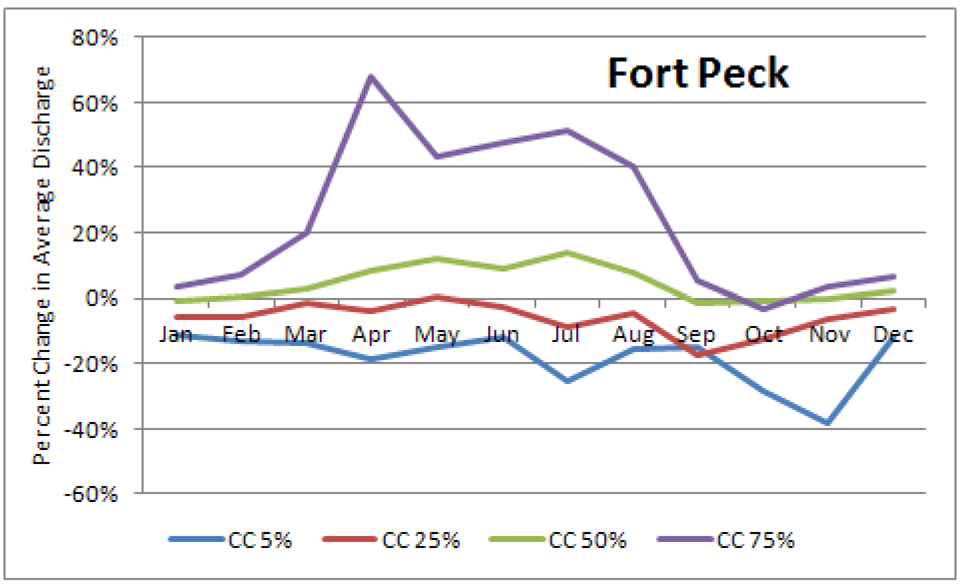

Figure 109. Monthly percentage changes in average monthly releases for the 50-year period of record, 1950-1999, from Fort Peck Reservoir from those of the NAWS 13.6 scenario, which was simulated with historic inflows.

Figures 110 and 111 are plots of the monthly average data for the inflow changes and releases from Garrison, respectively. Again, the patterns of both plots do not match each other very well. The inflows, which have a similar annual pattern to those for Fort Peck, are dampened by their storage in the reservoir. The same comments can be made for Garrison as were made for Fort Peck for the CC 5% and CC 75% climate change scenarios as they have the lowest and highest inflows into the reservoir. The noticeably higher releases of the CC 75% scenario are in response to the higher releases from Fort Peck and the higher inflows from the intervening tributary area.

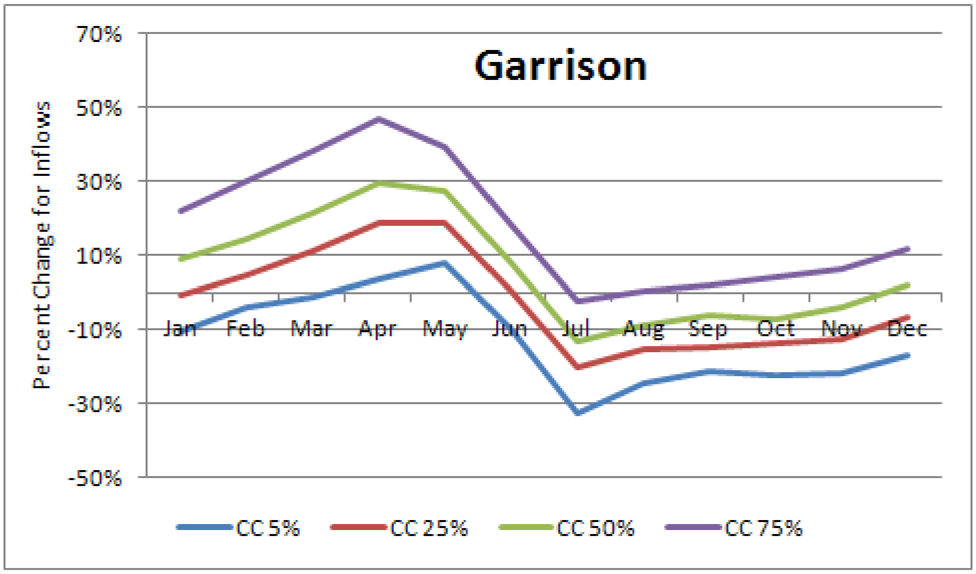

Figure 110. Monthly percentage changes in inflows to historic inflows to Garrison Reservoir for the four climate change scenarios.

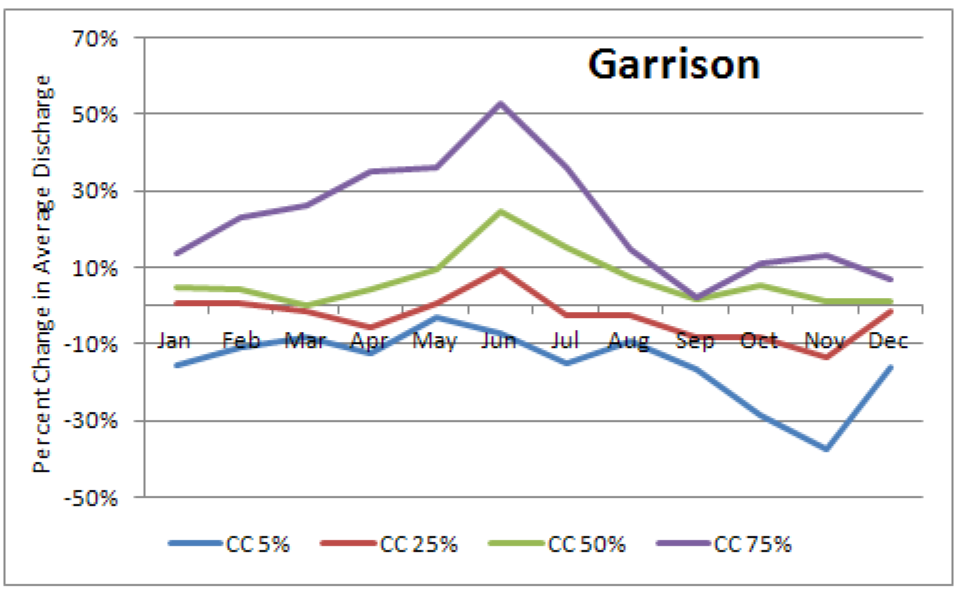

Figure 111. Monthly percentage changes in average monthly releases for the 50-year period of record, 1950-1999, from Garrison Reservoir from those of the NAWS 13.6 scenario, which was simulated with historic inflows.

Figures 112 and 113 present the percentage changes for the inflows and releases for Oahe, respectively. The inflow pattern continues to be very similar to the other two, upstream reservoirs. The release pattern, however, continues to change from those of the other two reservoirs. In general, the changes in releases are increasing later in the year, with the increases being diminished for the CC 5% and CC 25% scenarios. This latter observation makes sense as the CC 25% scenario has annual inflows most similar to the NAWS 13.6 scenario and the CC 5% scenario has considerably lower inflows. The release changes converge in December as the releases to the lower Missouri River are lower and similar among the scenarios and NAWS 13.6 simulation.

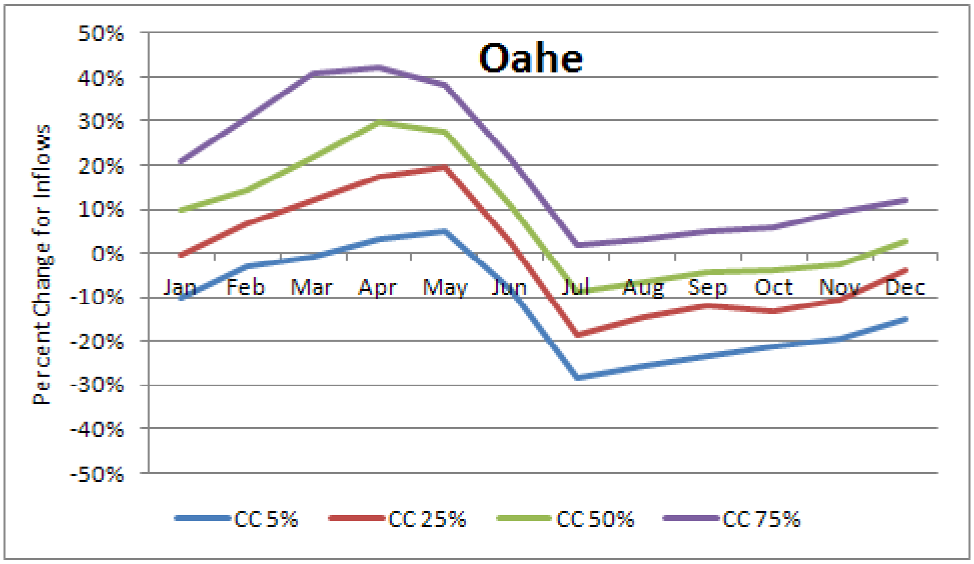

Figure 112. Monthly percentage changes in inflows to historic inflows to Oahe Reservoir for the four climate change scenarios.

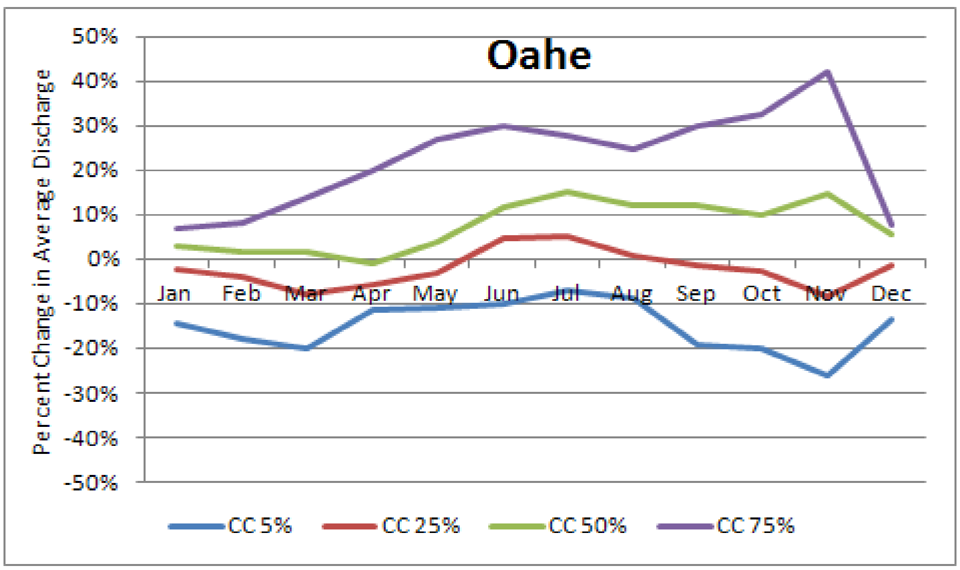

Figure 113. Monthly percentage changes in average monthly releases for the 50-year period of record, 1950-1999, from Oahe Reservoir from those of the NAWS 13.6 scenario, which was simulated with historic inflows.

Figures 114 and 115 present the percentage changes for the inflows and releases for Gavins Point, respectively. The inflow pattern continues to be very similar to the three other, upstream reservoirs. The percent change in the release pattern is similar to Oahe's for the CC 5%, CC 25%, and CC 50% scenarios; however, for the CC 75% scenario, the percent change from the NAWS 13.6 releases peaks in April instead of June (as it did at Oahe) and remains relatively constant until the upswing in November. In summary, the percent change in the releases during the navigation season has become relatively constant with the maximum change over the season being about 15 percent.

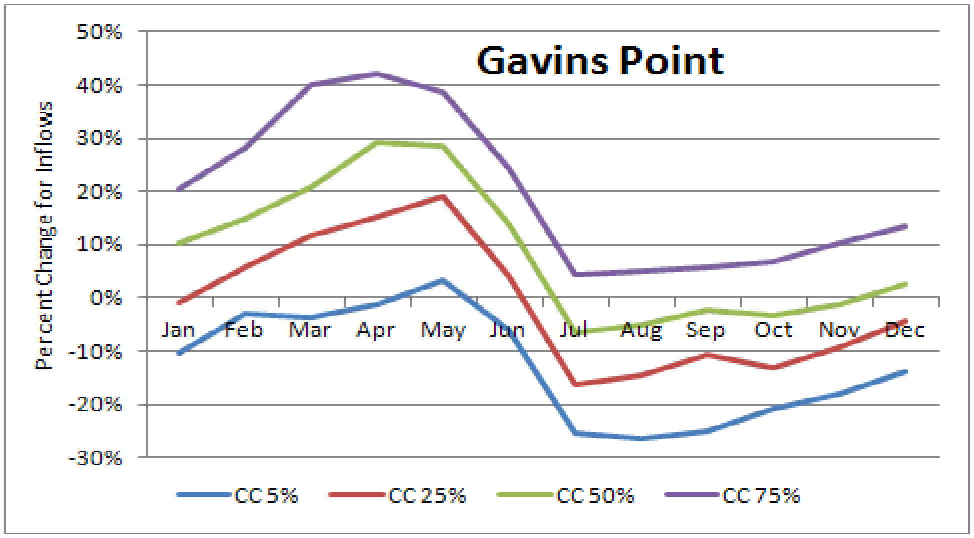

Figure 114. Monthly percentage changes in inflows to historic inflows to Gavins Point Reservoir for the four climate change scenarios.

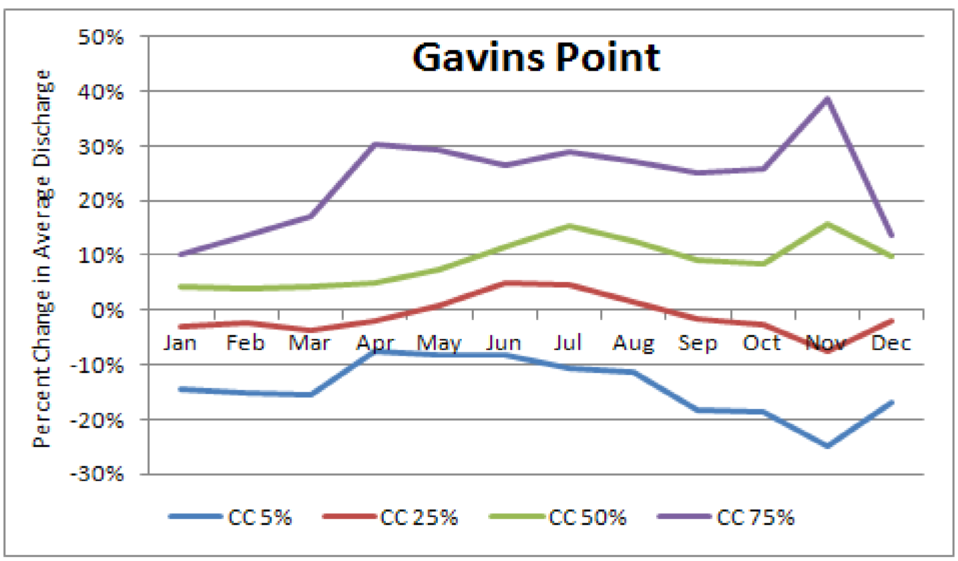

Figure 115. Monthly percentage changes in average monthly releases for the 50-year period of record, 1950-1999, from Gavins Point Reservoir from those of the NAWS 13.6 scenario, which was simulated with historic inflows.

As the Gavins Point releases move downstream to the lower Missouri River, the relatively flat percent changes in flows from those of the NAWS 13.6 simulation begin to show the more dramatic and common higher inflows in the first half of the year and lower inflows in the latter half of the year. Figures 116 and 117 present the percent change for the inflows between Gavins Point and Omaha and flows past Omaha, respectively. The highest percent change in the Omaha flow is now in April in response to the higher percent increase in the inflows that month.

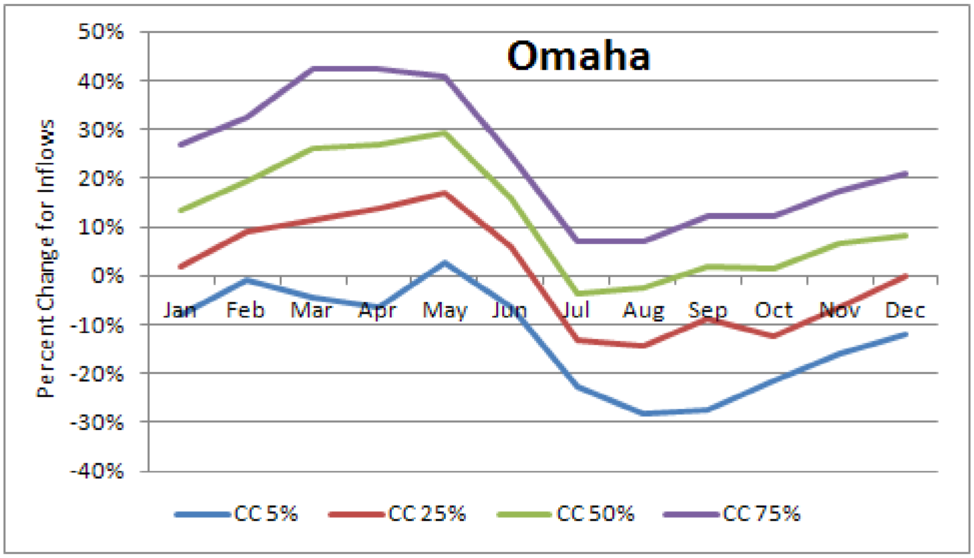

Figure 116. Monthly percentage changes in inflows to historic inflows between Gavins Point and Omaha for the four climate change scenarios.

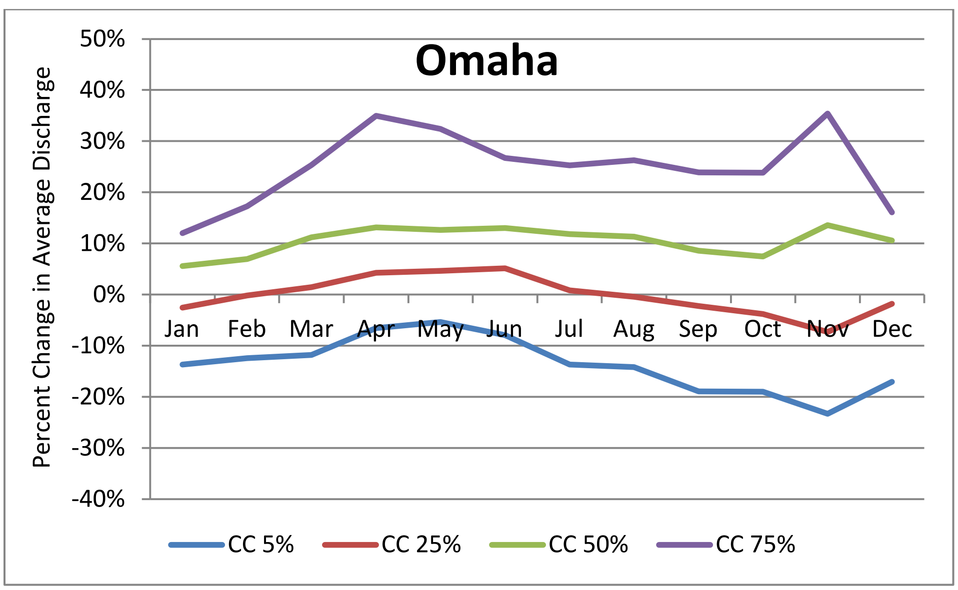

Figure 117. Monthly percentage changes in average monthly flows for the 50-year period of record, 1950-1999, past Omaha from those of the NAWS 13.6 scenario, which was simulated with historic inflows.

Figures 118 and 119 present the percentage changes for the inflows between Omaha and St. Joseph and the flows past St. Joseph, respectively. The inflows continue to have the same annual pattern as all of the other sites. The percent change in the flows continues to see an increase in the spring-month release percent changes in response to the higher spring inflows, with the flows most of the rest of the year (July through January) having the strong influence of the Gavins Point release changes (relatively flat with the rise in November).

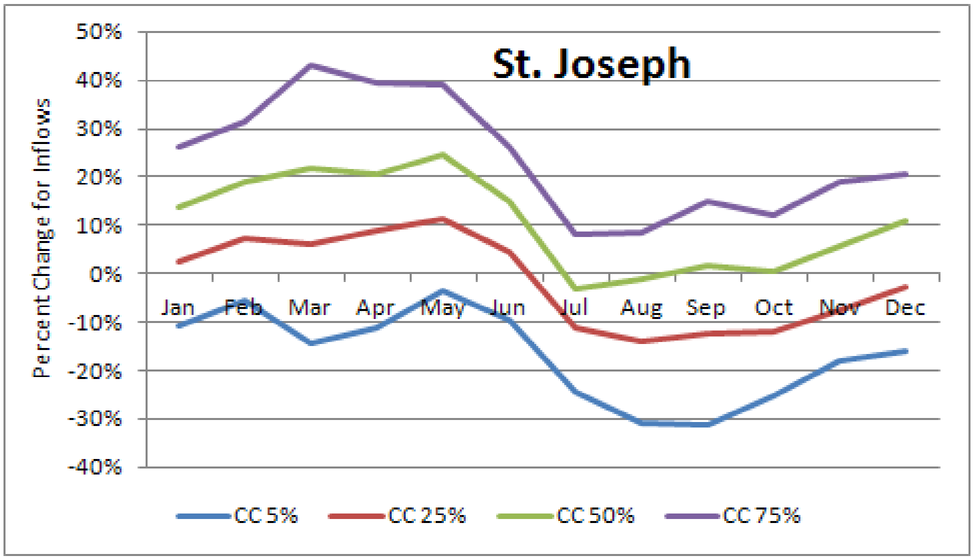

Figure 118. Monthly percentage changes in inflows to historic inflows between Omaha and St. Joseph for the four climate change scenarios.

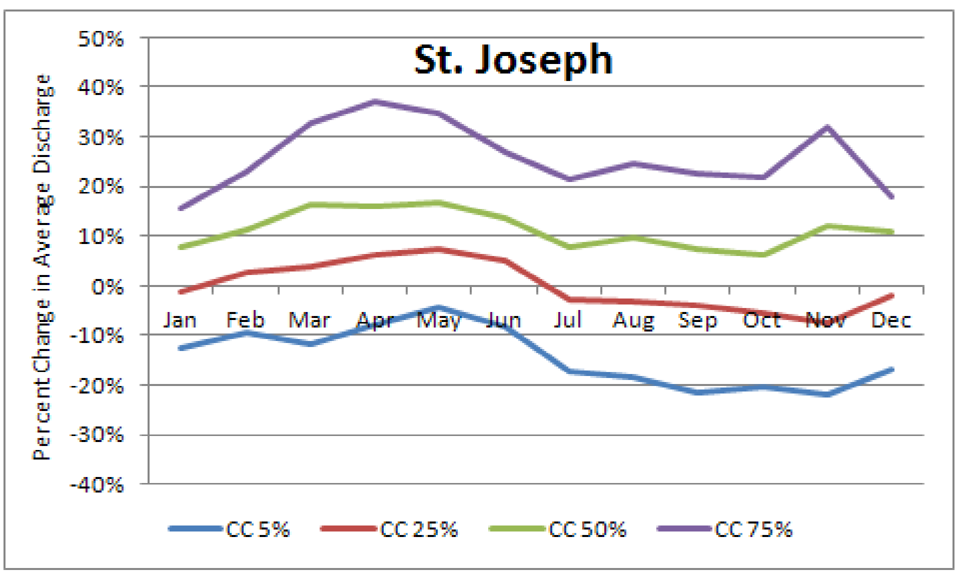

Figure 119. Monthly percentage changes in average monthly flows for the 50-year period of record, 1950-1999, past St, Joseph from those of the NAWS 13.6 scenario, which was simulated with historic inflows.

Figures 120 through 121 present the plots of the percent changes for the inflow between St. Joseph and Kansas City and the average monthly flow past Kansas City, respectively. These two figures look very similar to those for St. Joseph.

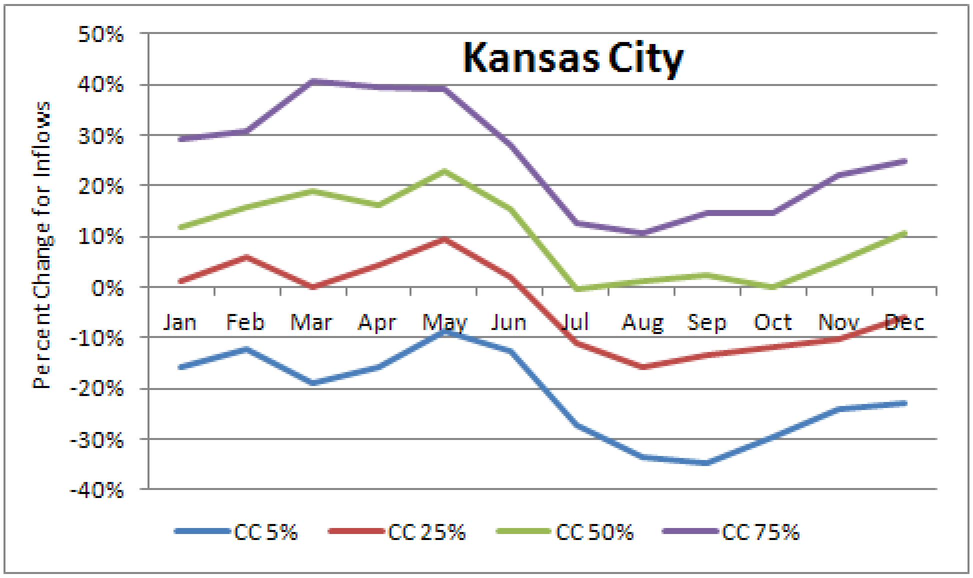

Figure 120. Monthly percentage changes in inflows to historic inflows between St. Joseph and Kansas City for the four climate change scenarios.

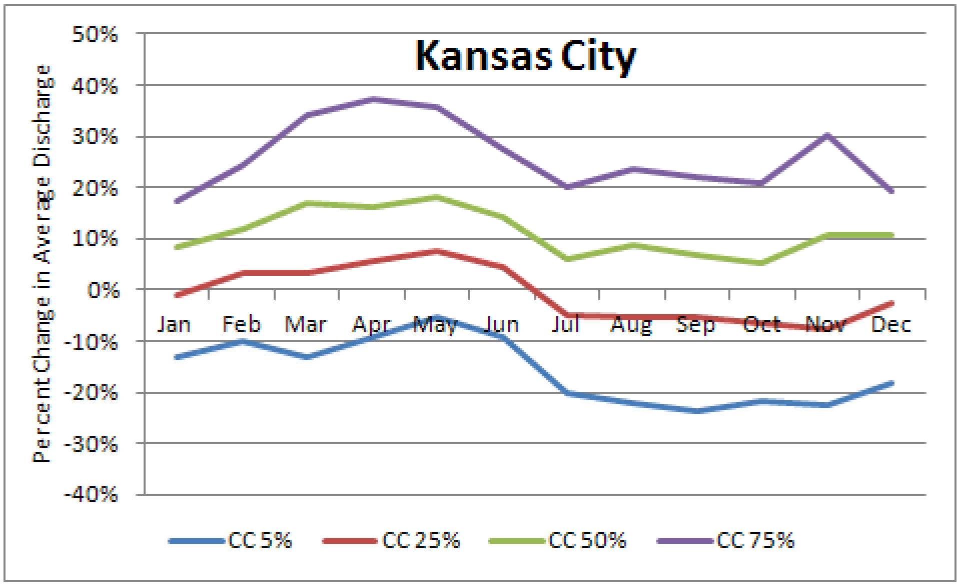

Figure 121. Monthly percentage changes in average monthly flows for the 50-year period of record, 1950-1999, past Kansas City from those of the NAWS 13.6 scenario, which was simulated with historic inflows.

Figures 122 and 123 present the plots of the percent changes for the inflow between Kansas City and Hermann and the average monthly flow past Hermann. The percent change for the inflows from the lower part of the Missouri River basin between Kansas City and Hermann change the most in May, which results in the percent change in the flows past Hermann from those of the NAWS 13.6 simulation being the highest in May. The percent changes in the latter half of the year remains relatively flat except for November, which drops somewhat from that seen in the upper reaches of the lower Missouri River.

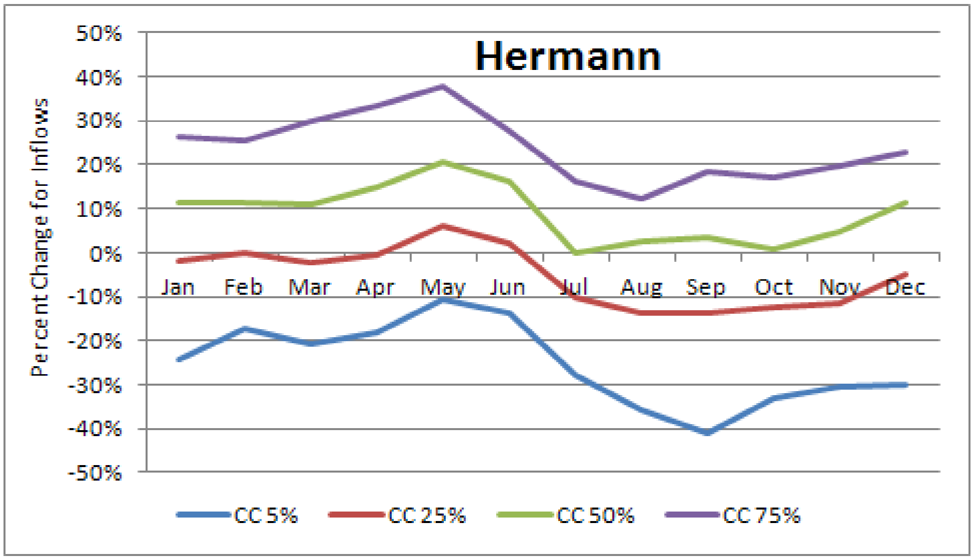

Figure 122. Monthly percentage changes in inflows to historic inflows between Kansas City and Hermann for the four climate change scenarios.

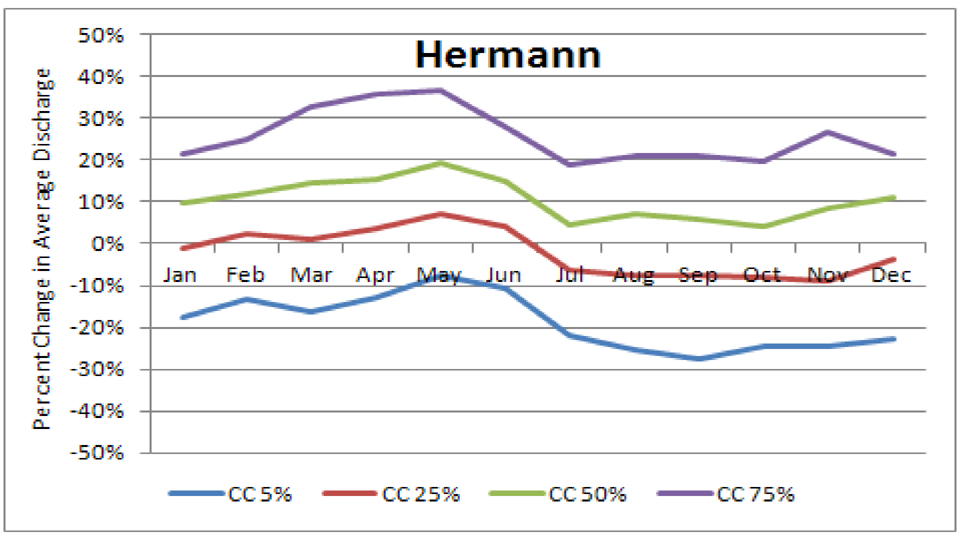

Figure 123. Monthly percentage changes in average monthly flows for the 50-year period of record, 1950-1999, past Hermann from those of the NAWS 13.6 scenario, which was simulated with historic inflows.

The month-to-month presentation of the average monthly effects of the climate change scenarios demonstrated that the System reservoirs dampened the larger inflow increases into the reservoirs and eventually led to a relatively flat annual release pattern from Oahe and Gavins Point reservoirs. However, with essentially no control of inflows to the lower Missouri River reaches, the higher spring and lower fall flow pattern returned to some extent, still dampened by the control of the inflows to the System reservoirs.

One final look at the climate change scenario effects was completed. The average annual flows for the NAWS 13.6 simulation and the four climate change scenarios were plotted (Figure 124) to show the effects on the most condensed data set. This figure provides some additional perspective on the inflows for the eight locations.

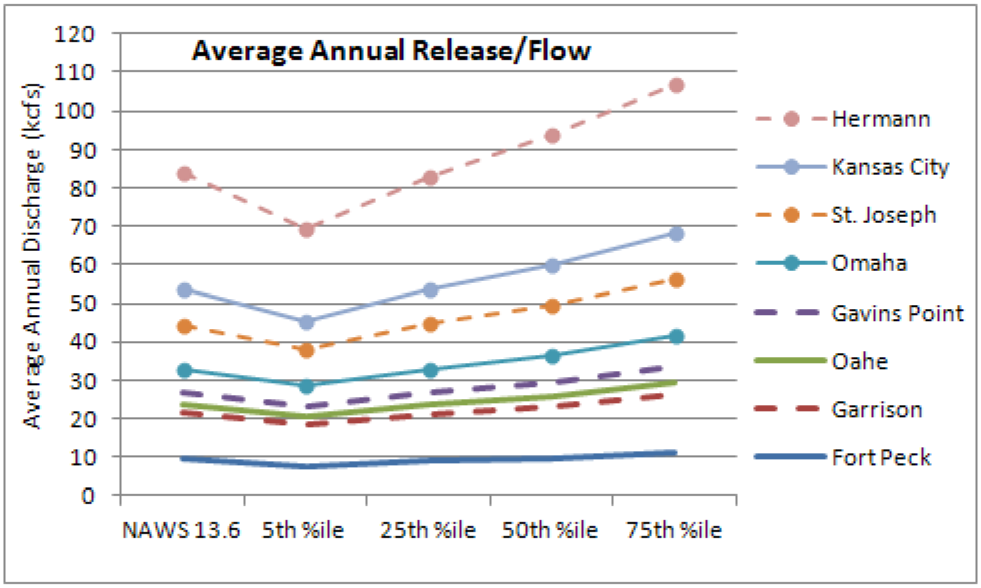

Figure 124. Average annual releases and flows for the 50-year period of analysis, 1950-1999, at eight locations on the Missouri River.

The pattern at all eight locations for the changes from the NAWS 13.6 average annual flows to the average annual flows of the four climate change scenarios is the same. The CC 5% scenario reduces releases and flows, and the other three scenarios sequentially have higher average annual releases or flows. The average annual values for the NAWS 13.6 simulation and the CC 25% scenario are very similar at all eight locations.

Fort Peck has the lowest releases; therefore, it controls a relatively small portion of the Missouri River basin inflows. Garrison releases are a little over double the Fort Peck releases, indicating that the tributary inflows to Fort Peck and Garrison are somewhat similar. Changes in the average annual release from Oahe and Gavins Point indicate that relatively little additional inflow enters the four lower System reservoirs on an average annual basis. The tributaries between Gavins Point and Omaha provide less water to the Missouri River than provided above Fort Peck and Garrison. The Platte River and smaller tributaries add about 10 kcfs to the average annual flows at Omaha to arrive at the St. Joseph average annual flows. The Kansas River and some minor tributaries add another less than 10 kcfs to the Missouri River flows at Kansas City. Finally, the lower basin tributaries between Kansas City and Hermann (highest rainfall portion of the basin) add over 20 kcfs to the flows in the Missouri River.

Average annual releases at Gavins Point range from 23 kcfs to about 34 kcfs; whereas, the average annual flows at Hermann range from about 70 to almost 110 kcfs, about a threefold increase in Missouri River flows as the Gavins Point releases move downstream.

Finally, there is some divergence of the average annual flows on the Lower Missouri River as the percentage of the scenario increases. For example, the difference between the average annual values at Kansas City and Hermann (greatest divergence) are 23.6 kcfs, 29.4 kcfs, 33.6 kcfs, and 38.4 kcfs for the CC 5%, CC 25%, CC 50%, and CC 75% scenarios, respectively. This factor makes sense as the inflows are increased by sequentially higher amounts, as shown on Figures 108, 110, 112, 114, 116, 118, 120, and 122.

In summary, four different presentations of average annual and/or average monthly release and flow data were presented in this section of the report on the hydrologic effects of four potential climate change scenarios. Each presentation of the data provides different perspectives on the effects of the climate change scenarios on the releases from four of the System reservoirs and the flows at four locations on the lower Missouri River. Unanswered, however, is one of the scenarios more likely to occur in 2060? Historically, climate can vary considerably over short periods of time, as illustrated by the drought periods from 1988 to 1993 or from 2000 to 2007 and the "wet" period from 1994 to 1999. An even more dramatic example was the record runoff in 2011 followed by a "dry" year in 2012. At this time, the available climate projections indicate that there is a greater likelihood that the future will be "wetter" because the historic conditions fall very close to the 25th percentile runoff change projection for the 2060 timeframe. Consequently, there is about a 75 percent likelihood that the runoff into the Missouri River main stem will be higher in the future, as demonstrated with the analysis of a range of potential climate change scenarios completed for this report.

Navigation Service Level and Season Length

A primary factor affecting System releases in extended droughts is the requirement to meet the navigation authorized purpose. The DRM creates an output file of the navigation service and season length data for each year of the period being simulated. This output file provides data on the service level based on the March 15 and July 1 service-level checks (Figures 125 and 126, respectively). This same file provides the season length for each year based on either the March 15 check for service level (service level of zero means no season that year) or the July 1 season-length check (Figure 127).

Figure 125 shows the service level for the first 3 months of the navigation season, April through June. Overall, the service provided to navigation diminished for the CC 5% scenario from the service provided for the NAWS 13.6 simulation. Service level improved incrementally for each increase in the percentile associated with the climate change scenarios. The most notable difference among the NAWS 13.6 simulation and the four climate change scenarios is the addition of five non-navigation years for the CC

5% scenario, the only one with non-navigation years in the climate change period of analysis (1950-1999).

Figure 126 shows that the navigation service for the second part of the navigation season also improved as the percentage associated with the climate change scenario increases. Notable about this figure is that the CC 50% and CC 75% scenarios had only 5 and 2 years of minimum service, respectively.

Figure 127 shows that navigation continues to benefit from the additional water provided as the percentage increases for the climate change scenarios. The CC 50% and CC 75% scenarios have the most extended seasons (8.33 -month season) at 18 apiece. The CC 50% scenario has only five seasons that are shorter than 7.5 months, and the CC 75% scenario has no seasons shorter than 7.5 months.

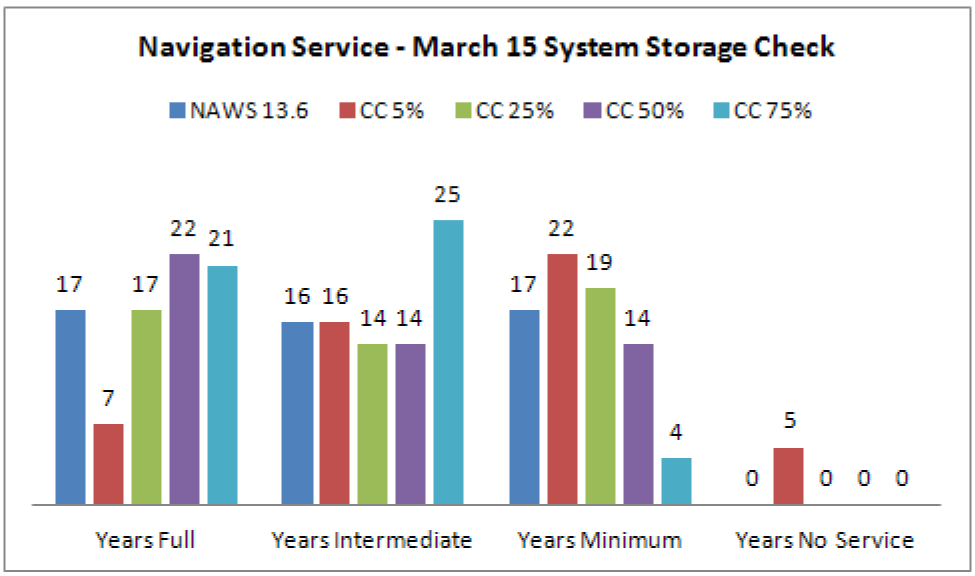

Figure 125. Navigation service level based on the March 15 storage check for the 50-year period of analysis, 1950-1999.

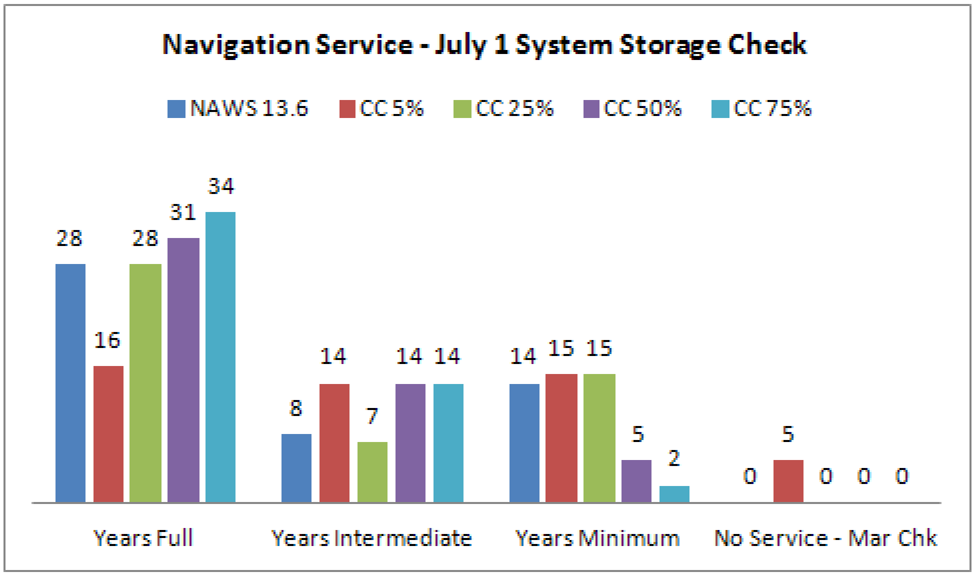

Figure 126. Navigation service level based on the July 1 storage check for the 50-year period of analysis, 1950-1999.

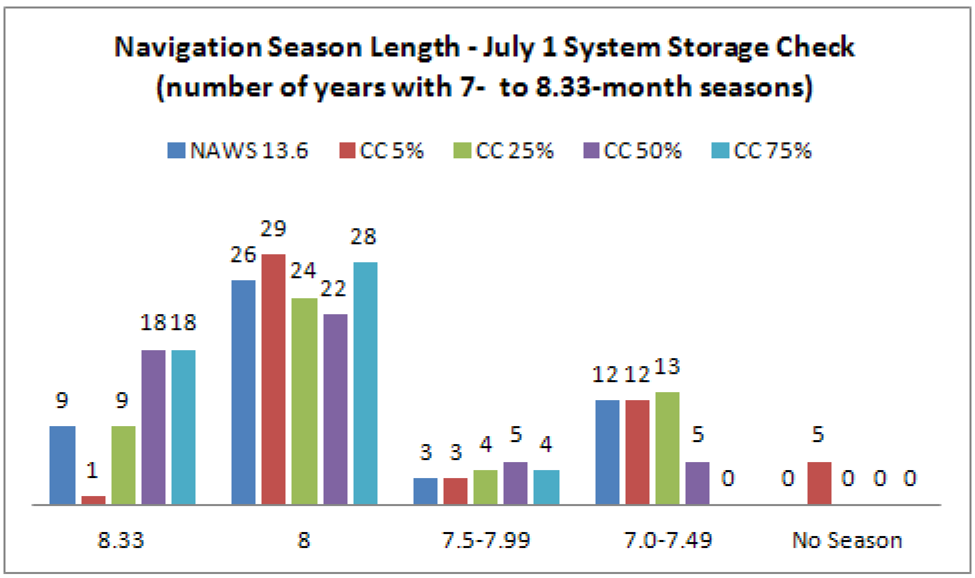

Figure 127. Navigation season length based on the July 1 storage check (March 15 check for years of no season) for the 50-year period of analysis, 1950-1999.

The longer seasons and higher service levels of the higher percentage climate change scenarios lead to higher releases in the months of October and November and higher releases throughout the 8- or 8.33-month navigation season, respectively, in those years when the releases are based primarily on the navigation project purpose. Understanding this concept is important to understanding the difference in releases in some of the 50-year period of analysis.

Hydropower Production

Even though hydropower production does not lead to changes in System releases, System releases and reservoir levels affect hydropower produced by the System. Figures 128 and 129 present the annual values for the System capability (average capacity available each year based on the "head" on the generators) and System energy (based on "head" on, and releases through, the generators) produced annually, respectively. System capability primarily drops during the droughts, and the amount of annual average capability increases during these drought periods as the percentage associated with the climate change scenario increases. Short-term dips also occur during "dry" years. Similarly, System generation also drops during extended droughts with the amount of generation during those periods increasing as the percentage associated with the climate change scenario increases. Gaps among the capability and generation occur in all years because the "heads" and releases continue to be higher in all years as the percentage associated with each scenario increases. Finally, the capability and generation for the CC 25% scenario are nearly the same as those values for the NAWS 13.6 simulation.

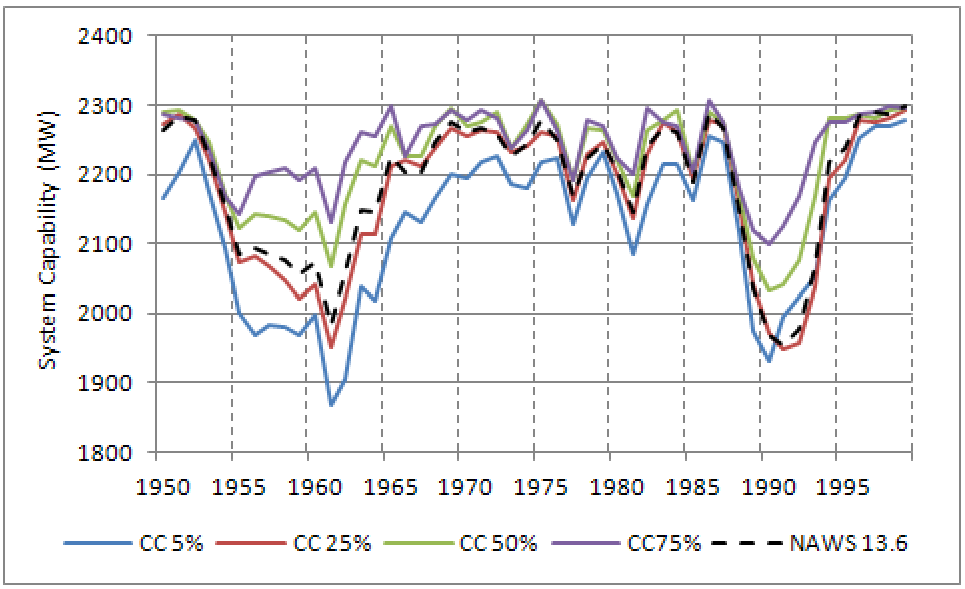

Figure 128. Annual System capability for the four climate change scenarios over the 50-year period of analysis, 1950-1999.

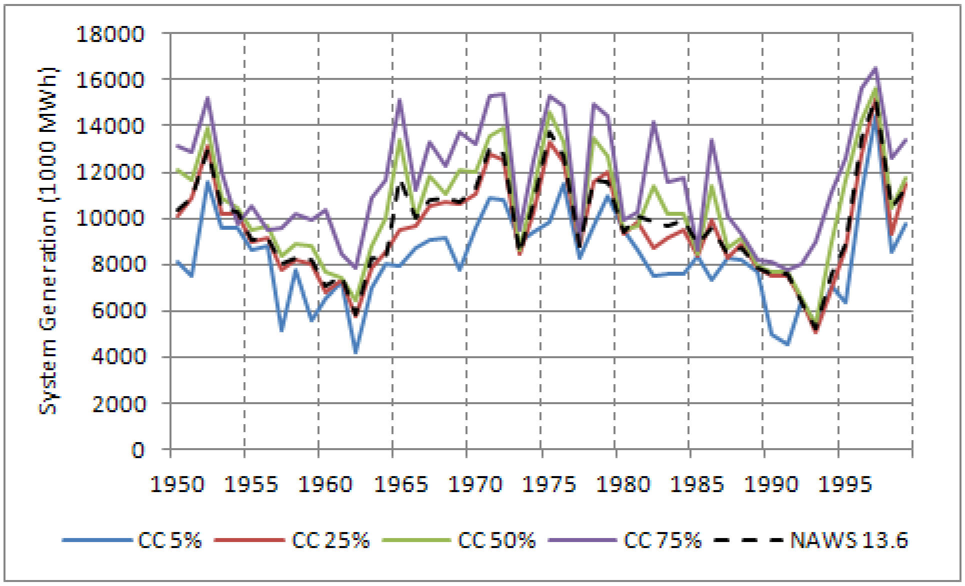

Figure 129. Annual System generation for the four climate change scenarios over the 50-year period of analysis, 1950-1999.

Economics

Based on the effects to navigation and hydropower described above, the expectation for economic benefits in these two categories is that the benefits will go up as the percentage of the climate change scenario increases. Compared to the NAWS 13.6 simulation, these benefits would initially decrease for the CC 5% scenario and increase as just described. The percentage changes from the economic benefits for the NAWS 13.6 simulation for the full NAWS Project 81-year period of analysis for all of the economic use categories are presented in Table 30. The changes are as expected in terms of positive and negative changes. The magnitudes are considerably higher for all of the use categories than for the changes presented for the NAWS Project simulations (Tables 18 and 19) because the amount of change in the annual System runoff (inflows) is much larger than the losses due to depletions included in the NAWS Project simulations. The lost or gained benefits for the NAWS Project and other anticipated depletion increases and continuing sedimentation could be dwarfed by the changes in climate if these changes are relatively far from the CC 25% scenario, which has impacts closest to zero percent.

Table 30: Relative differences of the economic benefits of the climate change scenarios from those of the NAWS 13.6 simulation – 1950-1999 (percent)

	Flood Control	Navigation	Hydropower	Water Supply	Recreation	Total	Energy Revenues
CC 5%	9.82	-18.53	-7.57	-1.32	-0.80	-0.92	-15.28
CC 25%	-0.97	1.63	-0.22	-0.05	-0.79	-0.37	-2.57
CC 50%	-15.82	2.59	-41.44	0.21	-0.12	-18.94	6.36
CC 75%	-43.31	5.72	9.01	0.37	-0.51	-7.18	18.70

Comparing the Effects of the NAWS Project with those of Climate Change

Two distinct analyses were conducted by the Corps for the NAWS Project SEIS. The first was to determine the effects of the NAWS Project by 2060. To complete this analysis, the changes from existing conditions to 2060 conditions without the NAWS Project were identified due to continuing sedimentation in the System reservoirs and non-Project depletions resulting from additional use of water from the Missouri River to form a No Action condition that was also simulated with the DRM. Two NAWS Project options were then simulated and the effects of the resulting four simulations were compared to existing conditions effects to arrive at the relative effects of continuing sedimentation (Sed 2060), this sedimentation plus non-Project depletions (No Action), and the NAWS Project (NAWS 13.6 and NAWS 29.1). The NAWS 13.6 simulation was then used as a base condition for the simulation and analysis of four climate change scenarios (CC 5%, CC 25%, CC 50%, and CC 75%). A fifth climate change scenario could not be simulated due to the extremely large increase in the inflows to the Missouri River main stem. This section of the report was completed to provide the results of the comparison of the results of the first analysis with the results of the second analysis. Three hydrologic factors and the relative economic effects will be presented to provide perspective the relative effects of the NAWS Project and future climate change in the Missouri River Basin.

System storage, Garrison elevation, and Gavins Point releases are the three hydrologic factors selected for this section of the report. Table 31 lists the values that are plotted in Figures 130 through 132. Differences for the NAWS 13.6 values are all for the 81-year period of analysis, and the differences for the climate change scenarios are for the 50–year period of analysis. These different periods of analysis are not a factor in understanding the relative effects of the NAWS Project and climate change. The table and the figures basically demonstrate that the NAWS Project effects in 2060 are dwarfed by the potential effects of the four climate change scenarios.

Table 31: Average differences in the effects to three hydrologic factors in the Missouri River Basin*

	NAWS 13.6	CC 5%	CC 25%	CC 50%	CC 75%
System Storage (kAF)	55	-1043	1473	5002	7002
Garrison Reservoir Elevation (ft)	-0.007	-4.91	-0.67	3.01	5.45
Gavins Point Releases (cfs)	17	-3782	-190	2592	6844

* Effects for NAWS 13.6 are measured as a last-added project in 2060 and effects of the climate change scenarios are measured from NAWS 13.6.

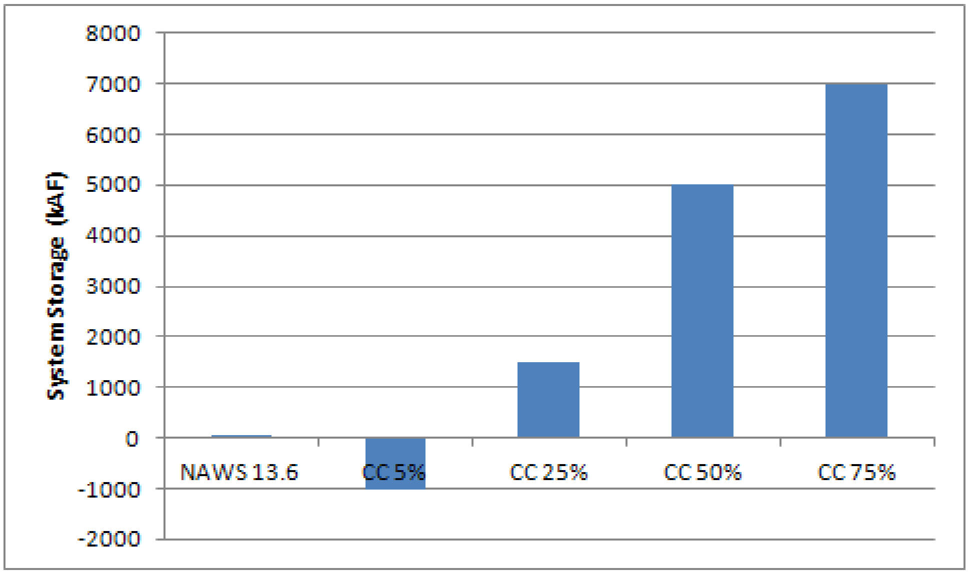

Figure 130. Comparison of the relative average differences in the effects of the NAWS Project and four climate change scenarios on System storage.

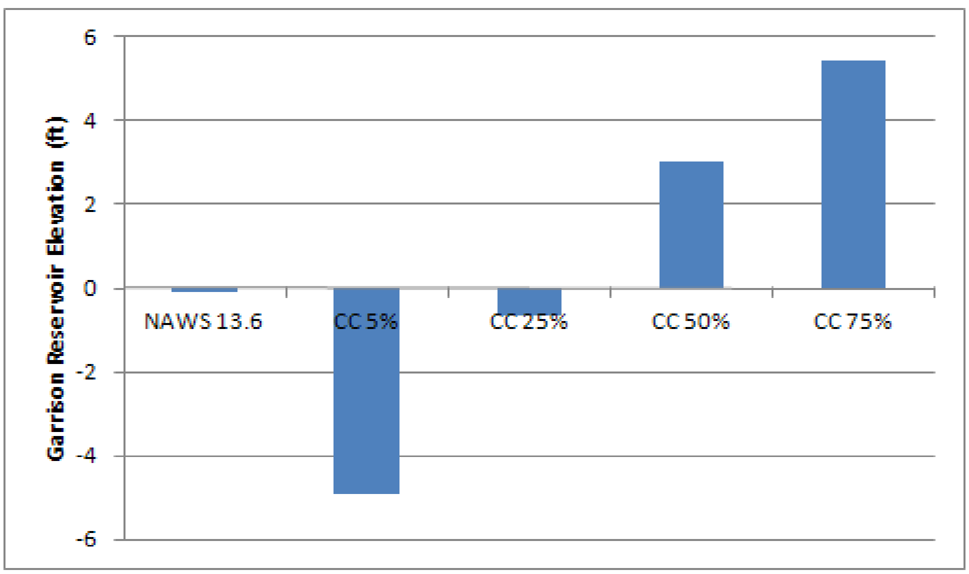

Figure 131. Comparison of the relative average differences in the effects of the NAWS Project and four climate change scenarios on the Garrison Reservoir elevation.

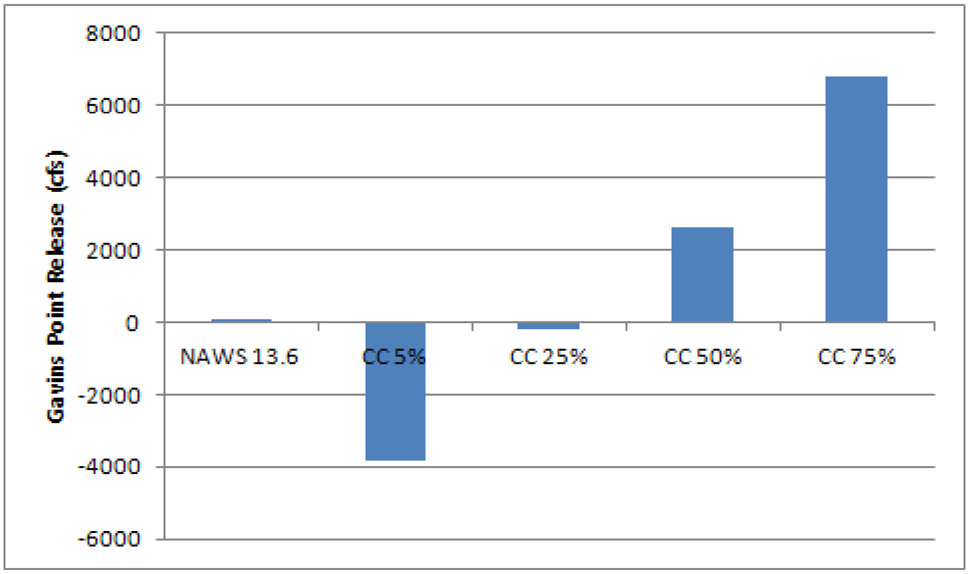

Figure 132. Comparison of the relative average differences in the effects of the NAWS Project and four climate change scenarios on the Gavins Point release.

Finally, Table 32 presents the relative economic differences of the NAWS 13.6 and four climate change simulations from those of the No Action simulation. This comparison was made because all five simulations represent a change from No Action in 2060, one with no climate change from existing conditions and four with different climate change scenarios. This table readily shows that many of the relatively small changes for the NAWS 13.6 simulation are also dwarfed by the relative differences of three of the simulations – CC 5%, CC 50%, and CC 75% - and are still somewhat smaller than those for the CC 25% simulation, which was identified as being the climate change scenario with hydrologic effects closest to the NAWS 13.6 simulation.

Table 32: Relative differences of the economic benefits of the NAWS 13.6 and climate change simulations from those of the No Action simulation – 1950-1999 (percent)

	Flood Control	Navigation	Hydropower	Water Supply	Recreation	Total	Energy Revenues
NAWS 13.6	0.0	0.5	0.0	-0.6	0.1	-0.2	-0.1
CC 5%	9.8	-18.5	-7.6	-1.3	-0.8	-0.9	-15.3
CC 25%	-1.0	1.6	-0.2	-0.1	-0.8	-0.4	-2.6
CC 50%	-15.8	2.6	-41.4	0.2	-0.1	-18.9	6.4
CC 75%	-43.3	5.7	9.0	0.4	-0.5	-7.2	18.7