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Niobrara River Basin Study

Appendix B — Groundwater System Response to Variable Climate and Water Management Scenarios

U.S. Department of the Interior
Bureau of Reclamation

Nebraska
Department of Natural Resources
Lincoln, Nebraska

April 2015

Mission Statements

Department of the Interior

The U.S. Department of the Interior protects America's natural resources and heritage, honors our cultures and tribal communities, and supplies the energy to power our future.

Bureau of Reclamation

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

Nebraska Department of Natural Resources

The Nebraska Department of Natural Resources is dedicated to the sustainable use and proper management of the State's natural resources.

On cover: A center-pivot sprinkler system in operation. Many such systems in the Niobrara Basin operate using pumped groundwater. Photo by USGS.

Niobrara River Basin Study Appendix B — Groundwater System Response to Variable Climate and Water Management Scenarios

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U.S. Department of the Interior
Bureau of Reclamation

Department of Natural Resources
Lincoln, Nebraska

April 2015

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Abbreviations

Organizations

NDNR – Nebraska Department of Natural Resources
BOR – Bureau of Reclamation
IPCC – Intergovernmental Panel on Climate Change
CSD – University of Nebraska-Lincoln Conservation and Survey Division
USGS – U.S. Geological Survey
NRD – Natural Resources District

Models & Data

CENEB – Central Nebraska Model
UNW – Upper Niobrara-White Model
STR – Streamflow Routing Package
DEM – Digital Elevation Model
NHD – National Hydrography Dataset
GHB – General Head Boundary
CALMIT - University of Nebraska-Lincoln Center for Advanced Land Management Information Technologies

Units

AMSL – Above Mean Sea Level
RMSE – Root Mean Squared Error
MAE – Mean Absolute Error
ME – Mean Error
cfs – Cubic Feet per Second

Executive Summary

Purpose, Scope and Objectives

The Niobrara River Basin Study (Basin Study) is a collaborative effort by the Nebraska Department of Natural Resources (Department) and the United States Bureau of Reclamation (Reclamation), which is authorized under the SECURE Water Act (Title IX, Subtitle F of Public Law 111-11). The purpose of the Basin Study is to evaluate current and projected future water supply and demand, and evaluate potential adaptation strategies which may reduce any identified gaps as part of the Water Sustain and Manage America's Resources for Tomorrow (WaterSMART) Program.

Understanding the responses of basin-wide hydrologic systems to possible climate and alternative management scenarios have been a difficult problem, and require a suite of modeling techniques and tools. This study used a groundwater model as one of the major tools to analyze the condition of water resources in terms of water supply and demand in both present and future time frames. Different water resources models (such as a soil-water balance model and a surface water operation model) were used in an integrated manner based on both historical and future climate data as part of the Basin Study.

The purpose of this report is to summarize the effects of climate change and alternative management activities on the magnitude and timing of baseflow in the Niobrara River Basin, as well as changes in groundwater levels. The report provides a general basin-wide account of the geography, geology, land use, and hydrology of the Niobrara River Basin, followed by a description of the groundwater model that will be used to simulate the changes in groundwater availability between the scenarios and baseline conditions. A comparison of groundwater conditions between the baseline and different climate and management scenarios is supplied in detailed charts.

Geography, Geology, and Hydrology of Niobrara River Basin

The Niobrara River Basin extends across diverse landscapes from its origin on the high plains of eastern Wyoming to its termination at the Missouri River along Nebraska’s northeastern border, showing large variation in temperature and precipitation both spatially and temporally. The entire basin spans across two groundwater models, the Upper Niobrara-White (UNW) Model and the Central Nebraska (CENEB) model. Both models were developed at one mile model grids.

The UNW model domain covers the upper portion of the Niobrara River Basin with its eastern boundary roughly aligning with the boundary of Sheridan and Cherry Counties. It encompasses topographic regions including plains, sand hills, valleys, bluffs, rolling hills, and dissected plains. The UNW area climate is considered to be semi-arid, characterized by large annual variations in temperature and an annual mean precipitation of approximately 15 inches (HPRCC, 2012). The landscape generally slopes downward to the east through the UNW model area, with land surface elevations ranging from nearly 5,500 feet in the western portions near Wyoming, to 3,000 feet in the east and south along the North Platte River. For the most part, the Niobrara River channel and valley floor sit well below the surrounding landscape with the deeper valley floor in the eastern part of the UNW area. The near-surface geology (i.e. in the zone reaching roughly 1000 feet below land surface in most areas) of the UNW area is dominated by units of unconsolidated sand, silt, and clay deposited between and including the Cretaceous and Quaternary periods. The water bearing units in the UNW area include the White River Group formations, the Arikaree formations, and the Ogallala Group formations. In the UNW area, Box Butte County has experienced significant drawdown due to groundwater pumping for over the past 50 years. This considerable decline coincided with the fast development of irrigated acres, and has affected agricultural sustainability in the area.

The CENEB model domain covers approximately 34,449 square miles in central Nebraska with a small extension into South Dakota. Its western boundary is in the Nebraska sand hills and the eastern boundary is in the loess hills, coinciding with the westernmost extent of glacial till (Peterson et al., 2008). Across the CENEB model area, the long-term average precipitation ranges from a high of slightly over 28 inches in the eastern portion of the model to a low of 17 inches on the western edge of the model (NCDC, 2012). Topographic relief in the model region is approximately 3,143 feet, ranging from a high of 4,286 feet on the western boundary to a low of 1,143 feet near its eastern boundary. The High Plains Aquifer, covering the entire model domain, is composed of near-surface, generally unconsolidated sedimentary deposits of mid-Tertiary to Holocene age, underlain by relatively impermeable fine-grained sedimentary rocks of Upper Cretaceous to mid-Tertiary age (Peterson et al., 2008). Most of the CENEB area is underlain by a variable thickness of Quaternary eolian and alluvial deposits burying Ogallala Formation, Arikaree Group, and White River Group sediments, with the exception of the north end of the model domain, where Quaternary erosion along the Niobrara River and Ponca Creek has exposed the Upper Cretaceous Pierre Shale.

The Niobrara River originates in south eastern Wyoming, cutting through the water bearing Arikaree formation. As the river bends though Sioux, Dawes, and Sheridan Counties, it gradually begins to run over the more prolific Ogallala formation. Replenished by seepage from various formations, the river is a predominantly aquifer-supplied river. A study by Jozsef Szilagyi et al. (2002) suggests that, in the region of the UNW study area, 70-90 percent of river flow can be attributed to seepage from groundwater. Thus, one of the foci of this study is the response of baseflow to different climate and management alternative scenarios. Since the late 1800's, the Niobrara has been a significant source of water for water rights holders along the river. In 1948, the Box Butte Reservoir and canal distribution system, completed by the Bureau of Reclamation, began to provide irrigation for the Mirage Flats Irrigation District.

Typical flows in the river are around 5 cubic feet per second near the stateline, around 15 cubic feet per second at the gage at Agate, and between 20 to 40 cubic feet per second at the gage above Box Butte Reservoir. The records from the streamgages upstream of Box Butte Reservoir, however, show indications that the streamflow has been decreasing over time. According to an analysis conducted in a 2004 report, the amount of surface water available for diversion from the Niobrara River upstream of the Mirage Flats canal diversion has continued to decrease since the project was completed (DNR, 2004). At the stateline, the 5 year annual average flow decreased by 567 acre-feet from the 1956-1960 time period to the 1996-2000 time period. Between 1946 and 2001, the average annual flow above Box Butte Reservoir decreased by 4,332 acre-feet (Figure 1). Records also show that diversions to the Mirage Flats canal averaged 19 percent less per year during the 1976-2003 time period than during the 1948-1975 time period.

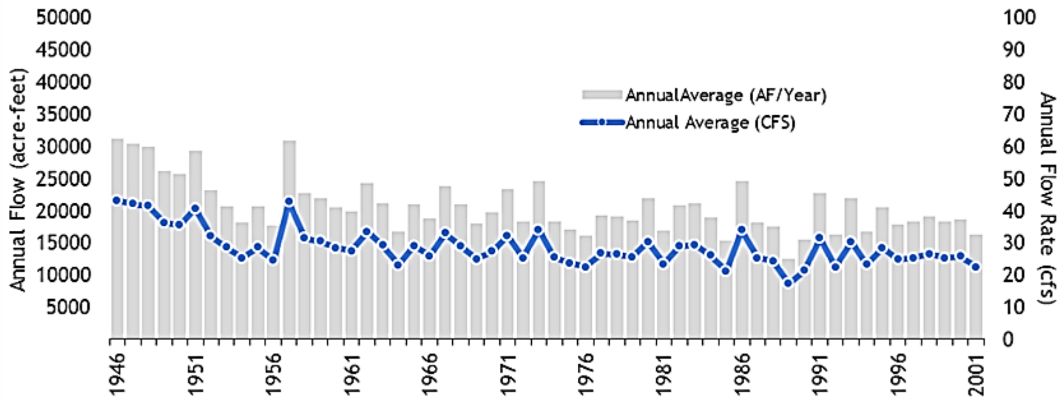

Figure 1. Average annual flow of the Niobrara River above Box Butte.

Modeling Scenarios

A combination of four climate scenarios and two management alternative scenarios were developed in this project. The climate scenarios include the Baseline, Low, Central-Tendency (CT) and High water availability, which were developed by plotting the Intergovernmental Panel on Climate Change (IPCC) climate project datasets (see Appendix A: Climate Change Analysis Report). Baseline indicates continuity with current climate conditions. Three management scenarios include No-action, Mirage Flats Pumping (i.e., relocating the diversion points 12 miles downstream the original location to reduce the potential canal seepage and evaporation loss), and Mirage Flats Recharge (i.e., Mirage Flats canal system operated solely as a recharge facility without surface water delivery). No-action means no management operation is applied in the scenario analyses. Table 1 shows a summary of the scenarios used for the modeling.

Table 1. A Matrix of Climate Scenario and Alternative Management Operations

Climate Scenarios	Management Alternatives		
	Baseline No-Action	**Baseline Alt1**	**Baseline Alt2**
Baseline	Baseline No-Action	Baseline Alt1	Baseline Alt2
Water Availability-Low	Low No-Action	Low Alt1	Low Alt2
Water Availability-CT	CT No-Action	CT Alt1	CT Alt2
Water Availability-High	High No-Action	High Alt1	High Alt2

Summary of Groundwater Modeling Results and Analysis

Overall, the modeling results show that baseflow and groundwater levels are sensitive to future projected change in climate conditions. Across almost the entire Niobrara River Basin, climate scenarios of high water availability and low availability can increase or reduce the baseflow and groundwater levels, respectively. Figure 2 shows a time-series of baseflow between the Gordon and Sparks gages under the different climate scenarios, in which the scenario of high water availability leads to higher baseflow but the scenario of low water availability corresponds to lower baseflow. In addition, modeling results show the CT and high water availability scenarios increase in baseflow (in sub-basin scale) but the scenario of low water availability contributes to decrease in baseflow (Figure 3). Box County, a local area long plagued with declining groundwater levels, is expected to have further decline in groundwater levels under low water availability, but to have groundwater levels rebound with CT and high water availability (Figure 4). The patterns of change in groundwater levels follow similar patterns in the Mirage Flats area. Figure 5 illustrates the increase in groundwater level in Mirage Flats area of CT water availability climate scenario.

The patterns of change in groundwater levels in the CENEB area (Figure 6) follows similar patterns of Box Butte and Mirage Flats area for different climate scenarios except in the low water availability scenario. In lower portion of Sparks to Spencer sun-basin, groundwater level did not change to this climate scenario. It is noted that the scenario of baseline no-action consistently shows reduced baseflow (Figure 2) and groundwater levels (Figures 4, 5, and 6). This is because all scenario analyses assume constant historic land use conditions maintained as of year 2000 for the purpose of isolating the impacts of land use change.

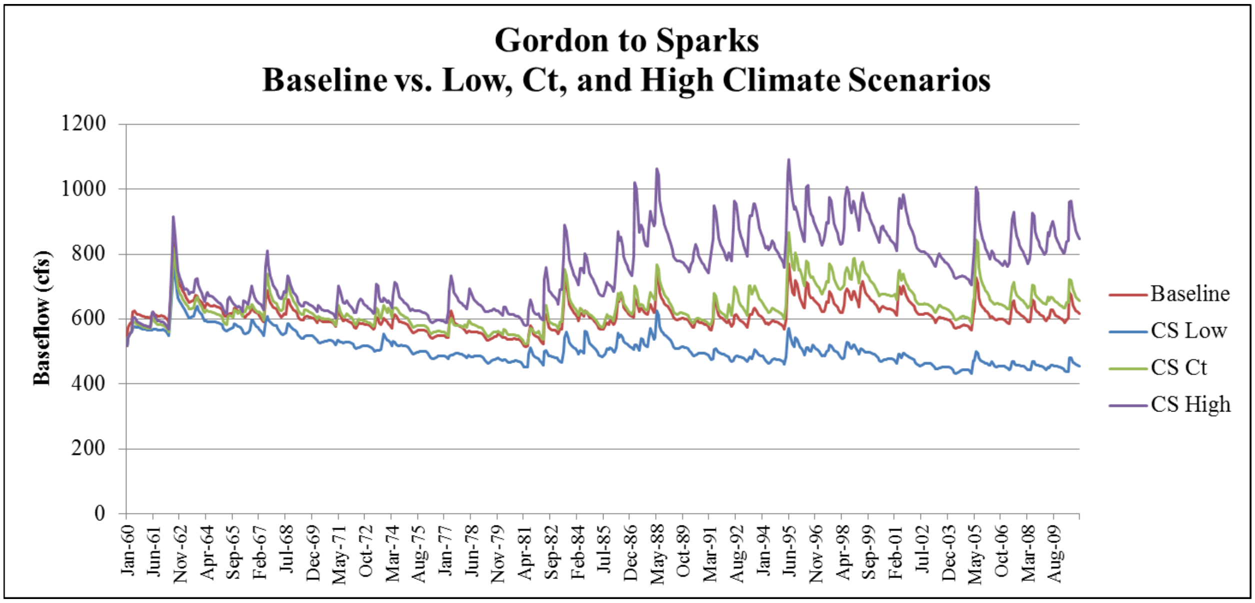

Figure 2. Gordon to Sparks reach baseflow comparison – climate scenarios of baseline, low, CT, and high without management operations (1960-2000).

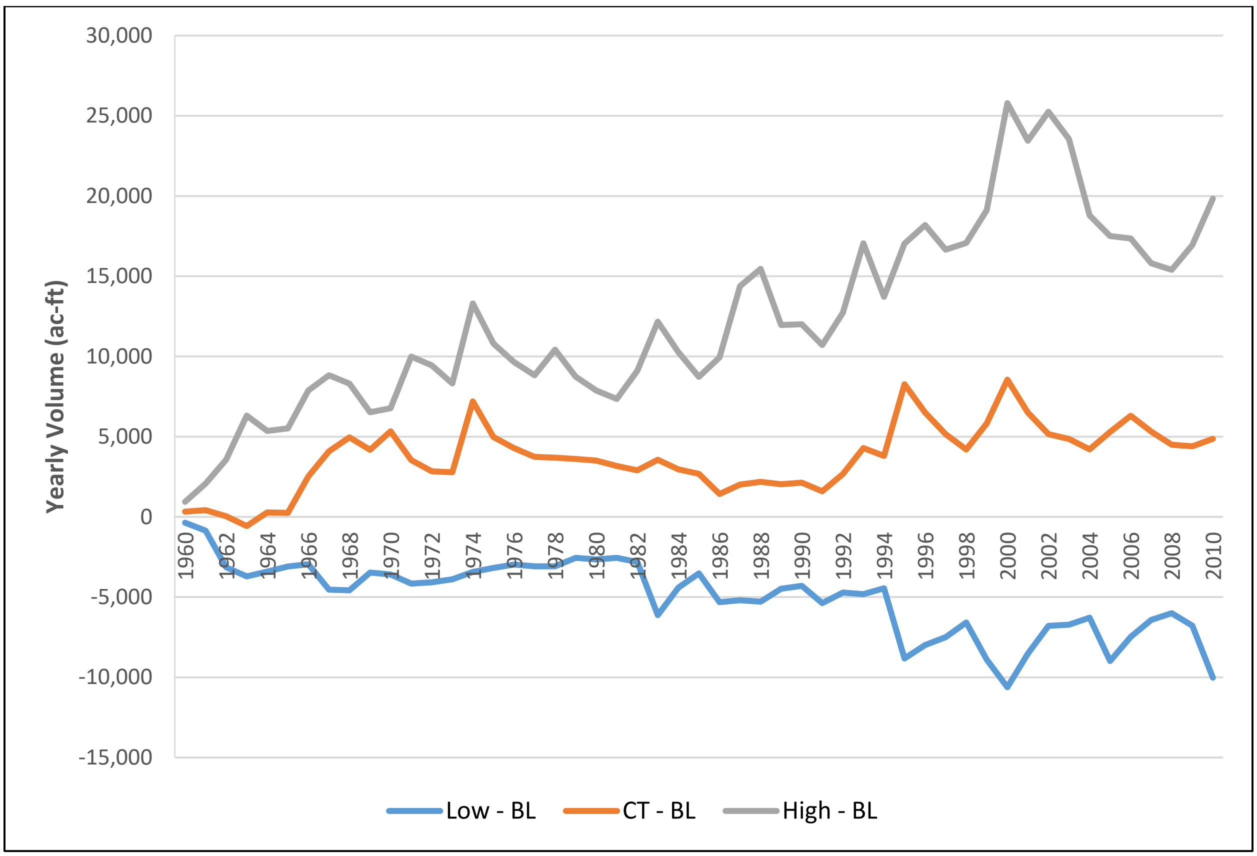

Figure 3. Yearly baseflow amount change in Box Butte to Gordon subbasin.

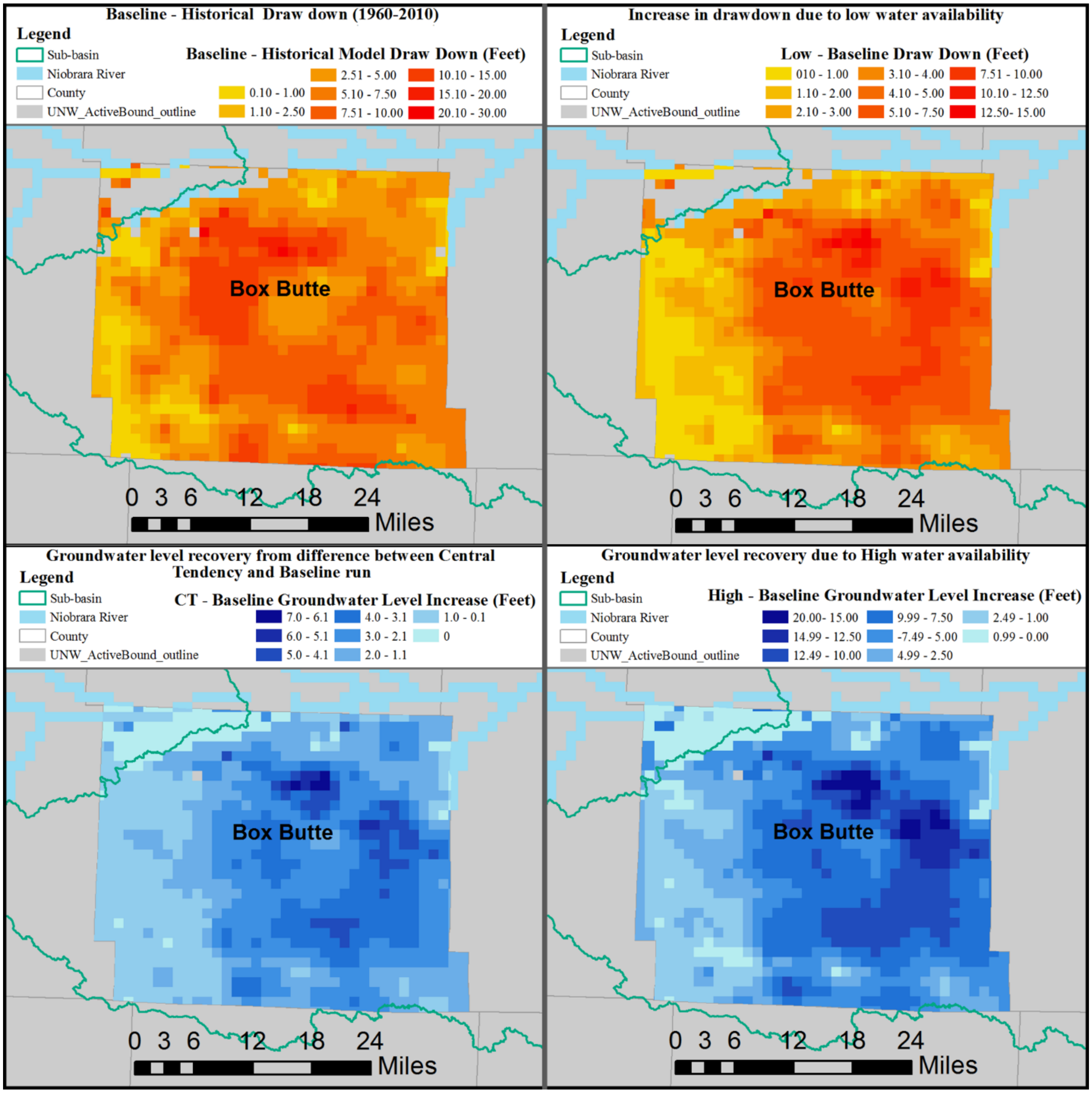

Figure 4. Groundwater drawdown comparison in Box Butte County for baseline, low, CT, and high scenario model runs without management operations.

The modeling results show that management operations will also affect the baseflow and groundwater levels of the area. Under the baseline climate conditions, the baseflow under two alternative management scenarios are generally lower between Dunlap and Gordon gages but higher between Box Butte Reservoir and the Dunlap gage than the no-action management scenario (Figure 6). However no alternative management scenarios were applied to estimate the baseflow downstream of the Gordon gage, because the baseflow in the CENEB area is found not to be sensitive to upstream management scenarios.

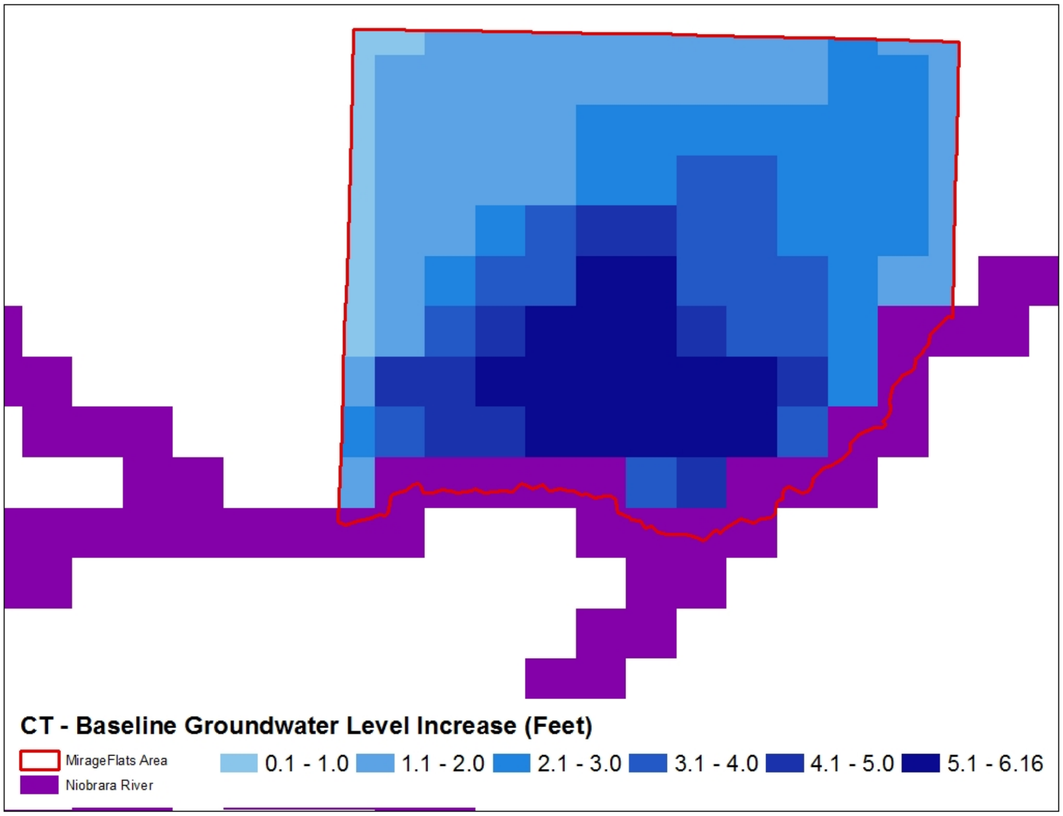

Figure 5. Groundwater level increase in Mirage Flats area for CT scenario model run without management operations.

The purpose of Alt1 scenario is to increase the efficiency of irrigation system in Mirage Flats area by installing pumping station downstream and eliminating seepage from present canal to the groundwater system; however the seepage losses in the canal are a significant source of localized recharge which does not exist in Alt1 scenario. In Alt1 run the reduction in seepage losses which contributes to the baseflow of the aquifer system sufficiently exceeds the increase in recharge (direct and indirect recharge) and reductions in groundwater pumping, therefore the baseflow of Alt1 run is lower than that of baseline run. In Alt2 scenario canal and laterals in Mirage Flats Irrigation District are used for groundwater recharge rather than crop irrigation delivery. The cumulative effect of changes in groundwater recharge (direct and indirect recharge) and source of crop irrigation (increase in groundwater pumping) led to decrease in baseflow of Alt2 run as compared to that of baseline. These changes is stream reach baseflow due to alternative scenarios are in localized scale rather than regional.

Management scenarios are expected to cause local change in groundwater levels. For example, two management scenarios (Alt1 and Alt2) lead to some change in groundwater levels in the Mirage Flat areas relative to the baseline no-action scenario (Figure 8).

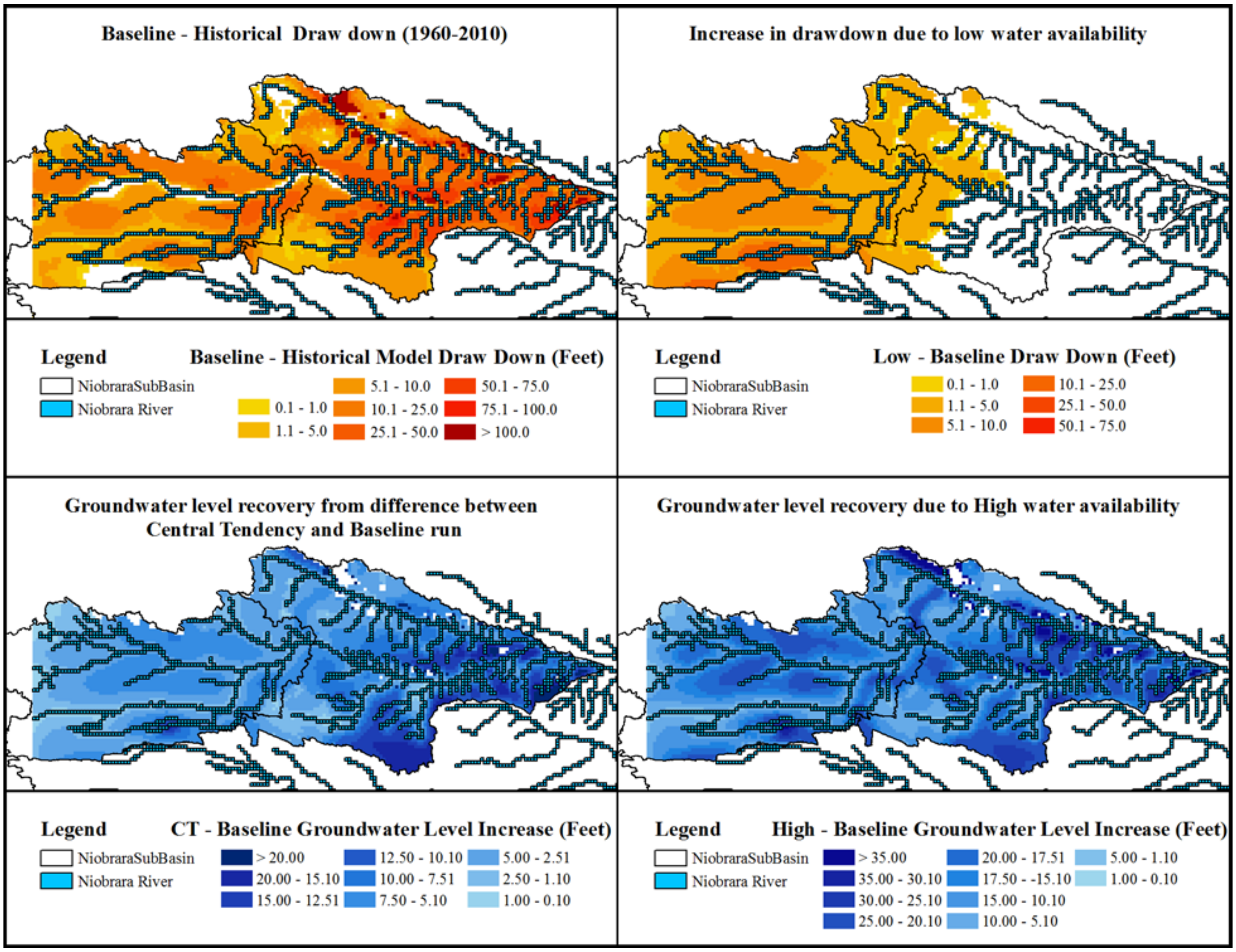

Figure 6. Groundwater level change comparison in CENEB model area under baseline, low, CT, and high scenario model runs without management operations.

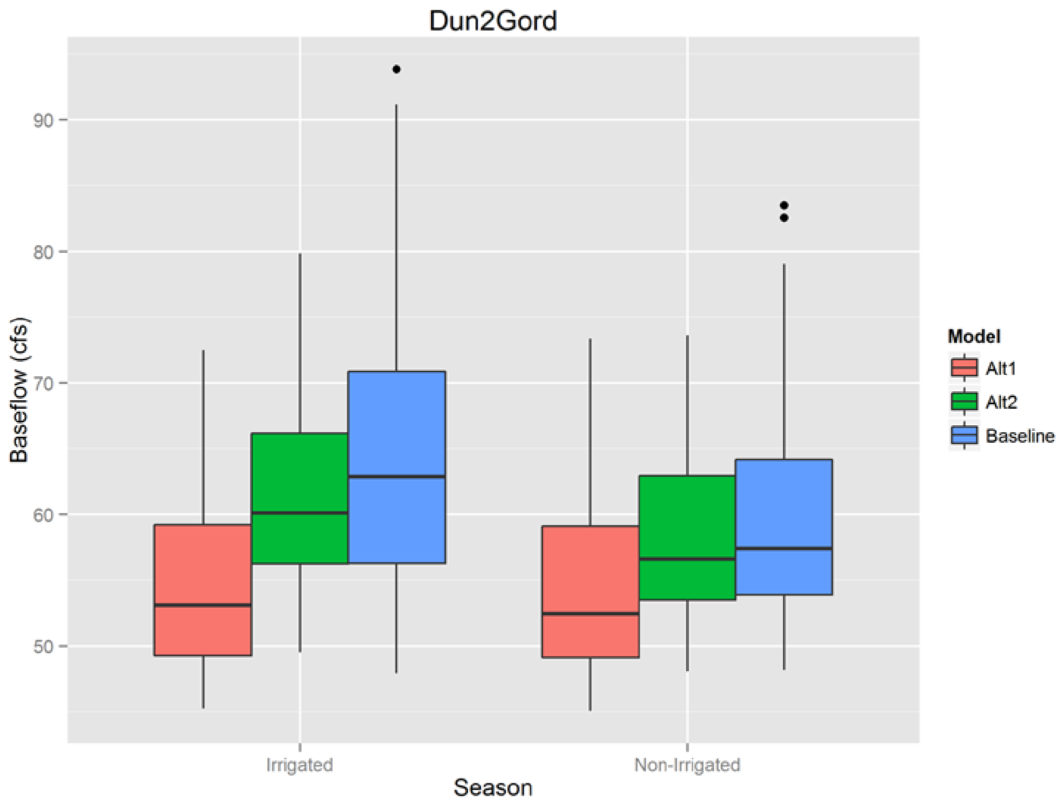

Figure 7. Box Plot of baseflow between Dunlap and Gordon gages under baseline, Alt1, and Alt2 management alternatives.

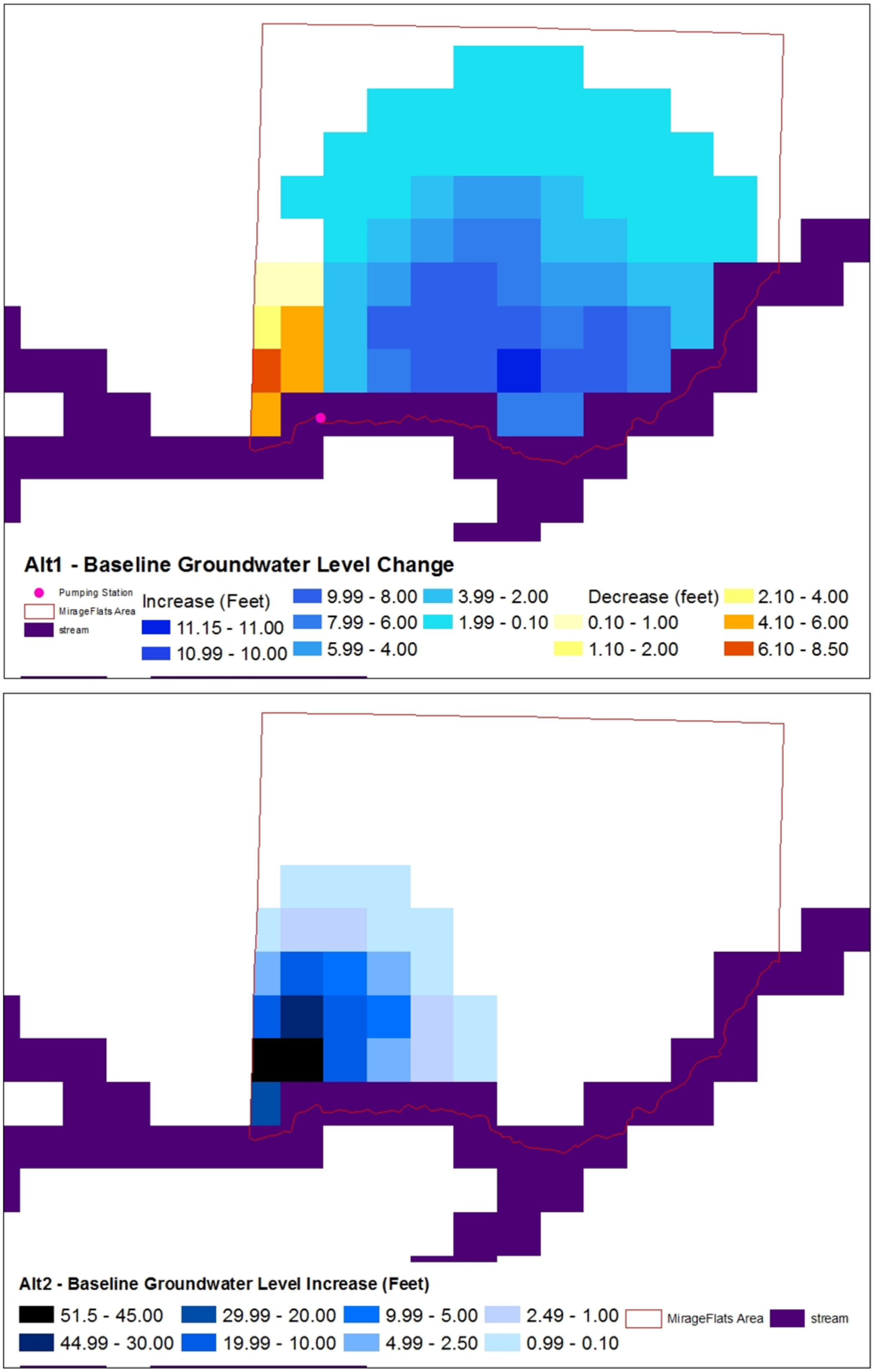

Figure 8. Groundwater level change relative to baseline in the Mirage Flat area under Alt1 and Alt2 management alternatives.

1 Introduction

1.1 Purpose, Scope, and Objective of Study

The purpose of Niobrara River Basin Study (Basin Study) is to evaluate current and projected future water supply and demand and evaluate potential adaptation strategies which may reduce any identified gaps as part of the Water Sustain and Manage America's Resources for Tomorrow (WaterSMART) Program. It is a collaborative effort by the Nebraska Department of Natural Resources (Department) and the United States Bureau of Reclamation (BOR).

Different water resources models were used in an integrated manner with both historical climate data and future projected climate data to evaluate the condition of water resources in terms of water supply and demand in both present and future time frames. The purpose of this report is to summarize the use of existing groundwater models as applied to this study and analysis of the groundwater system response to variable climate and water management alternative scenarios as part of the Basin Study.

1.2 Description of Study Area

The Niobrara River Basin extends across diverse landscapes from its origin on the high plains of eastern Wyoming to its termination at the Missouri River along Nebraska's northeastern border. The upper western portion of the Basin is considered to be semi-arid, characterized by large annual variations in temperature and an annual mean precipitation of approximately 15 inches (HPRCC, 2012), whereas in the lower eastern portion of the Basin the long-term average precipitation ranges from a high of slightly over 28 inches. Annual mean precipitation in the middle portion of the Basin is 17 inches. In the Basin, surface water and groundwater resources are used primarily to supply water for agricultural uses. Additional water uses in the Basin are for hydropower, municipal, recreation, and ecosystem services. The Niobrara River is a highly aquifer-supplied river. In addition aquifer discharging flows to the river, additional precipitation runoff contributes to the stream flow.

The Niobrara River Basin is divided into four subbasins: Above Box Butte, Box Butte to Gordon, Gordon to Sparks, and Sparks to Spencer, from west to east, respectively. The areal coverage of Niobrara River subbasins and the other major river systems of Nebraska are illustrated in Figure 1.1.

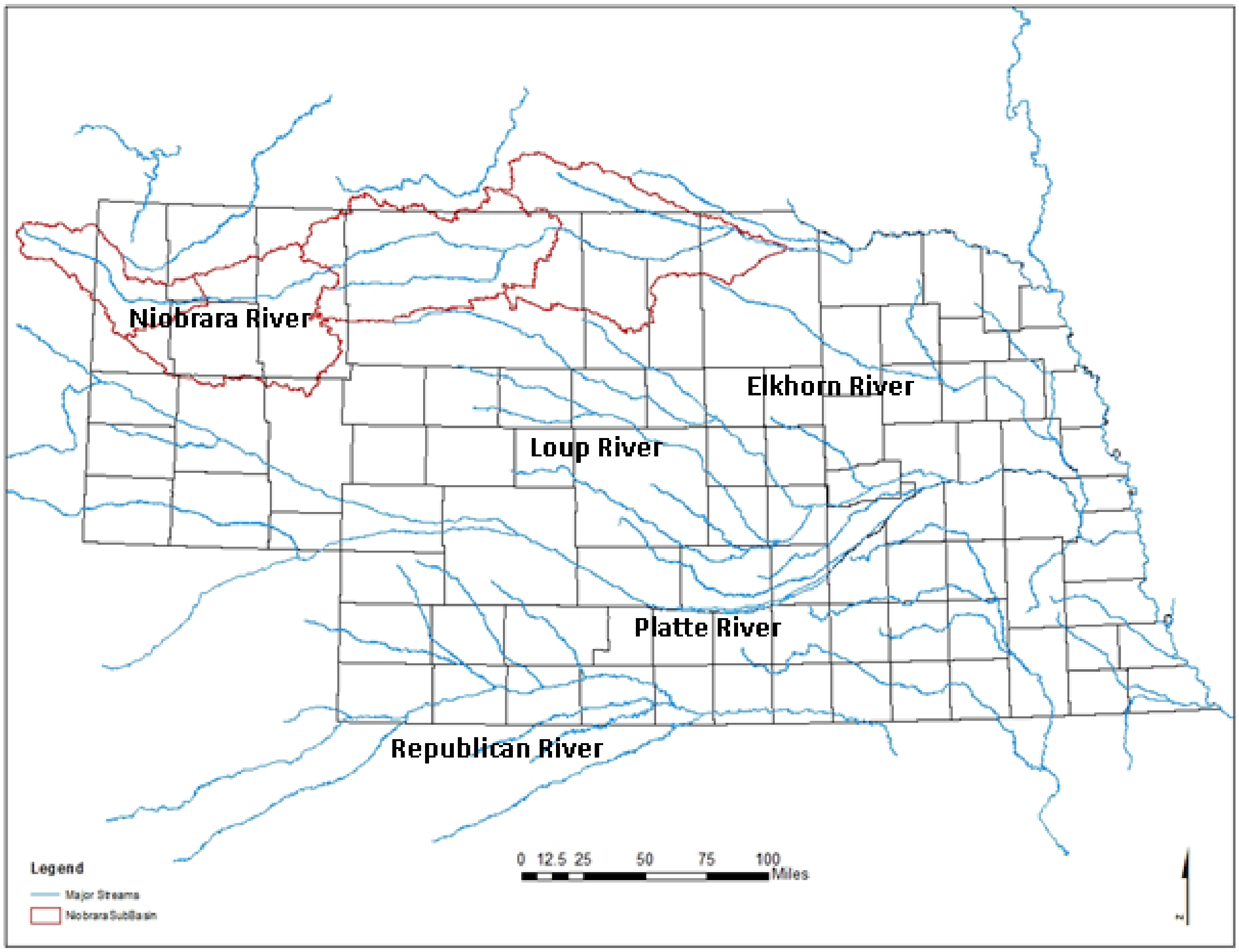

Figure 1.1. Niobrara Basin Study Area and major rivers in the State of Nebraska.

1.3 Models and Data Used for Study

Various scientific data were incorporated, and existing water resources models were brought into use, for analyzing the impacts of climate variability in the Niobrara River Basin. Future climate projection data from IPCC were used to generate the low, central-tendency (CT), and high projected water availability scenarios. These data were then incorporated in the Integrated Water Management Model which consists of three different models: a watershed model for the land/soil water budget, a surface water operations model for Niobrara River operations, and a groundwater model for aquifer response. These water resources models use different scientific data including: weather station rainfall data, aquifer test hole data, stream-gage flow data, soil data, surface water operations rules of reservoirs, and water rights information.

Based on a conceptual model of the hydrologic cycle that emphasizes agricultural irrigation, the three separate models in the Integrated Water Management Model were used to analyze the impacts of climate variability and alternative water management scenarios of the Niobrara River Basin. The downscaled results of IPCC climate projections were first incorporated into watershed model, and then were simulated with the surface water operation model and the groundwater model in an integrated manner, exchanging model results exclusively with each other as part of the Integrated Water Management Model. Figure 1.2 illustrates the mechanics of the Integrated Water Management Model.

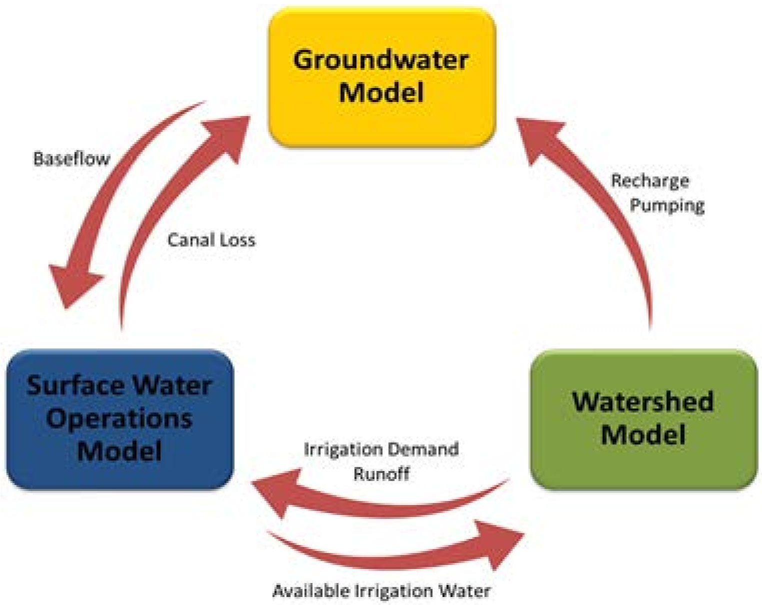

Figure 1.2. Integrated water management model.

In addition to the climate variability scenarios, two alternative water management scenarios were developed and tested:

1. Changing the location of surface water diversion from the Niobrara River (hereafter called Alt1) to the Mirage Flats Irrigation District to reduce conveyance losses in the current canal system.
2. Using existing canal systems to recharge the groundwater system during periods of excess available water (hereafter called Alt2).

Theses alternative management scenarios were developed to increase the efficiency of surface water diversion for agriculture use and reduce the impacts of groundwater pumping on the baseflow of the Niobrara River. The management scenarios were then compared against the baseline no-action scenario to evaluate the applicability of these alternatives for efficiently managing water resources of the Basin.

1.4 Report Organization

This report consists of three major sections which are divided into sub-sections. Section 2 consists of a description of the study area in terms of physical setting, topography, geology, and climatic condition. It also includes the description of river system within the Niobrara River Basin, its nature of connection with the groundwater aquifer system, and historical flow analysis. Section 3 discusses how the groundwater models were used for the study. It includes a discussion on how the different climate and alternative management scenarios were set-up and how the groundwater models were incorporated for the technical analysis. The types of data used and the mechanics of the Integrated Water Management Model are discussed in this section. Section 4 contains the results of the groundwater model portion of integrated model run for different climate and alternative management scenarios in terms of stream reach baseflow. It also includes discussions on the response of the groundwater system of the basin to variable climate and alternative management scenarios on regional and local area basis.

2 Historical Surface Water and Groundwater Availability

2.1 Physical Settings

2.1.1 Location

The Niobrara River Basin extends across diverse landscapes from its origin on the high plains of eastern Wyoming to its termination at the Missouri River along Nebraska's northeastern border. The Upper Niobrara-White (UNW) Basin considered in this report falls primarily in the Great Plains physiographic province and encompasses numerous topographic regions, including: plains, sand hills, valleys, bluffs, rolling hills, and dissected plains. The UNW groundwater model area covers the portion of the Niobrara River Basin beginning at the headwaters of the Niobrara River near the town of Manville, Wyoming, east to a line roughly coincident with the boundary of Sheridan and Cherry Counties in Nebraska. The point at which the Niobrara River exits this model area on the eastern boundary is about 10 miles downstream of the USGS streamgaging station near Gordon, Nebraska.

The Central Nebraska (CENEB) active model domain encompasses approximately 34,449 square miles in central Nebraska with a small extension into South Dakota. The western boundary is in the Nebraska Sand Hills, the eastern boundary is in the Loess Hills, coinciding with the westernmost extent of glacial till (Peterson et al., 2008). The Platte River flows along the southern boundary, and to the north the model extends into South Dakota with the boundary defined at the northernmost extent of the Ogallala Formation within the Ponca Creek and Keya Paha drainage basins. Approximately 95 percent of the model domain is in Nebraska; the remaining 5 percent is in central South Dakota.

2.1.2 Climate

The UNW area climate is considered to be semi-arid, characterized by large annual variations in temperature and an annual mean precipitation of approximately 15 inches (HPRCC, 2012). Across the CENEB model area, the long-term average precipitation ranges from a high of slightly over 28 inches in the eastern portion of the model (NE-Zone 6), to a low of 17 inches on the western edge of the model (NE-Zone 1) (NCDC, 2012). Table 2.1 provides a breakdown of the climate divisions within the model area, the long-term average precipitation for that division, and the percent of the climate division within the model area

Due to the wide range in precipitation, two major climatic zones are represented in Nebraska: the eastern half of the state has a humid continental climate characterized by large seasonal temperature differences, with warm to hot summers and cold winters, and the western half has a semi-arid climate where precipitation is less than the potential ET. The western portion is also characterized by average monthly temperatures that range from a high of 89.5 degrees Fahrenheit to a low of 8.9 degrees Fahrenheit.

South Dakota has an interior continental climate, with cold, dry winters and hot, semi-humid summers. The average high summer temperature is 90 degrees Fahrenheit; the average low winter temperature is below 10 degrees Fahrenheit.

Table 2.1. CENEB Precipitation by NCDC Climate Division

NCDC Climate Division	Long-Term Average Annual Precipitation	Percent of CENEB Model Domain
Nebraska		
1	17.3	1%
2	21.5	55%
3	26.1	10%
5	23.9	20%
6	28.5	4%
7	20.1	5%
South Dakota		
8	20.1	5%
Total Weighted Average	22.5	100%

[1] Weighted average based on the amount of climate division in the model area.

2.1.3 Topography

The UNW model area, in general, is characterized by areas of rolling plains and table lands dissected by narrow valleys or canyons that accommodate intermittent and perennial streams. The Pine Ridge Escarpment forms a distinct topographic break between the Niobrara River drainage and those of the White River and Hat Creek drainages to the north (Bradley and Rainwater, 1956; Gwillim et al., 1940). To the south, the Box Butte Table serves as the boundary, albeit less distinct, between the Niobrara and North Platte drainages (Cady and Scherer, 1946; Souders et al., 1980). The Box Butte Table is dissected by small ephemeral streams oriented in a predominantly southeasterly direction (Souders et al., 1980). The southeast portion of the model area is marked by the dune formations of the western sand hills region, roughly coincident with the Box Butte-Sheridan County line.

The landscape generally slopes downward to the east through the UNW model area, with land surface elevations ranging from nearly 5,500 feet in the western portions near Wyoming, to 3,000 feet in the east and south along the North Platte River. Elevations in the Box Butte County area, dominated by the Box Butte Table, range from 4,620 feet on the uplands to approximately 3,800 feet near the

Niobrara valley in the north. The Niobrara drainage area begins west of the Rawhide fault near Manville, Wyoming, with the channel at the headwaters sitting at an altitude of roughly 5,300 feet (Bradley and Rainwater, 1956). The channel slope varies in steepness as it crosses more roughly rolling topography in Wyoming and western Sioux County, Nebraska, into more gently rolling lands in the central and eastern part of the model area. Overall, the channel drops at an average rate of 10 feet per mile from west to east, with the elevation at the Sheridan-Cherry County line at 3,400 feet (Bradley and Rainwater, 1956).

For the most part, the Niobrara River channel and valley floor sit well below the surrounding landscape. In the western portion of the model area where terrain is more variable, Sioux County, for example, the valley floor is 200-500 feet below the surrounding land surface (Bradley and Rainwater, 1956; Souders et al., 1980). The difference in elevation is less extreme farther east, with valley floor elevations estimated at 90 feet below the surrounding land surface, although this can be higher where sand hills are present (Bradley and Rainwater, 1956; Souders et al., 1980).

The following topographic regions are found within the CENEB model domain (in order of prominence); sand hills (dune sands), dissected plains (hilly land eroded by water and wind), plains (sandstone and stream-deposited silt, clay, sand, and gravel overlain by wind-deposited silt), valleys (flat-lying land along the major streams composed of unconsolidated silt, clay, sand, gravel), and bluffs and escarpments. The small, south-central portion of South Dakota included in the CENEB model domain is in the central lowlands and includes an extension of the sand hills region (Malo, 1997).

Topographic relief in the model region is approximately 3,143 feet, ranging from a high of 4,286 feet above mean sea level (amsl) on the western boundary to a low of 1,143 feet amsl near the eastern model boundary.

2.1.4 Geology

The UNW model area near-surface geology (i.e. in the zone reaching roughly 1,000 feet below land surface in most areas) is dominated by units of unconsolidated sand, silt, and clay deposited between and including Cretaceous and Quaternary periods. In Wyoming, Precambrian metasedimentary/ metavolcanic rock outcrop or subcrop in areas near the Rawhide fault (Hinckley et al., 2009). At the top of Cretaceous-age units, the Pierre shale underlies the majority of the model area at general depths around or exceeding 1,000 feet, except north of the Pine Ridge Escarpment where it forms the base of the White River-Hat Creek valley floor (Burchett, 1986; Cady and Scherer, 1946; Souders et al., 1980).

Oligocene age White River Group sediments rest on the Pierre shale and vary in composition from clay, silt, sand, ash, and some clastic and precipitated material (Souders et al., 1980; Bradley and Rainwater, 1956; Cady and Scherer, 1946). The White River Group is defined by Souders et al. (1980) as including two main formations across portions of the model area: the Chadron and the Brule, each containing one or more distinct hydrogeologic units. The hydrogeologic units are distinguished by sediment types and composition. The uppermost Brown Siltsone unit of the Brule Formation is the most relevant to the model area due to its proximity to the surface near the Niobrara River in northern Box Butte County, and its potential for locally significant groundwater yield (Souders et al., 1980; Burchett et al., 1986).

The Miocene age Arikaree unit (variably referred to as a group or unit, depending on location, geologist, and convention) in turn, overlies the White River Group formations. The Arikaree that exists throughout most of the UNW model area is composed of sand, sandstone, and silty sand deposited by a mix of fluvial and eolian processes (Souders et al., 1980; Ayers, 2007). The Arikaree exists at the land surface in the area extending from the Rawhide Fault in Wyoming to areas north and south of the Niobrara River valley in Box Butte, Dawes, and Sheridan Counties (Burchett et al., 1986). The Arikaree thickness varies from minimal in areas where it pinches out, to more than 500 feet in southwestern Box Butte County (Ayers, 2007). The base of the Arikaree in the model area slopes generally eastward and southward while, in those same directions, the total thickness of Arikaree sediment increases (Cady and Scherer, 1946).

The Ogallala Group is another primary aquifer unit that consists of gravelly sand, sand, siltstones, and clay. This formation outcrops in the western portion of the study area and then thickens to the east. In Sheridan County, the unit can exceed 800 feet in thickness. Overlaying this formation in eastern portions of the study area are Quaternary sands which constitute the “sand hills” of the region. These sands are very permeable and allow precipitation to contribute to the aquifer as recharge. On average, the Ogallala formation is more transmissive than the Arikaree. Its water levels vary greatly, from near surface in many wetland areas, to more than 300 feet below the surface in others (DNR, 2004).

The CENEB model domain lies within the extent of the High Plains Aquifer region as described by McMahon et al. (2007). Within the model domain, the High Plains Aquifer is composed of near-surface, generally unconsolidated sedimentary deposits of mid-Tertiary to Holocene age, underlain by relatively impermeable fine-grained sedimentary rocks of Upper Cretaceous to mid-Tertiary age (Peterson et al., 2008). Individual geologic units are variably incorporated into the High Plains Aquifer system depending on lateral and vertical hydraulic connectivity, degree of saturation, and, in older deposits, the presence of secondary permeability resulting from joints and fractures (McMahon et al., 2007; Peterson et al., 2008). Most of the study area is underlain by a variable thickness of Quaternary eolian and alluvial deposits burying Ogallala Formation, Arikaree Group, and White River Group sediments, with the exception of the north end of the model domain, where Quaternary erosion along the Niobrara River and Ponca Creek has exposed the Upper Cretaceous Pierre Shale.

Quaternary deposits consist of alluvial gravel, sand, silt, and clay as well as eolian sands of the sand hills area and silty to very fine sandy loess. Quaternary deposits are commonly 0 to 200 feet thick, though locally up to 700 feet thick, and, with sufficient saturated thickness, can be a substantial source of groundwater (Peterson et al., 2008). Deposits are typically unconsolidated, with the exception of local caliche accumulations, and are considered a part of the High Plains Aquifer system where saturated and hydraulically connected to adjacent units (McMahon et al., 2007).

The Tertiary Ogallala Formation has the largest areal extent of all the geologic units of the High Plains Aquifer (McMahon et al., 2007) and is nearly ubiquitous across the CENEB model domain. It is a heterogeneous deposit of clay, silt, sand, and gravel associated with aggrading streams derived from Miocene-age highlands to the west that filled and buried paleovalleys carved into pre-Ogallala strata (McMahon et al., 2007). It is typically unconsolidated, with the exception of the upper portion of the formation which is locally cemented by calcium carbonate (caliche) and very locally by silica. Based on exploration drill holes, the maximum thicknesses for Ogallala deposits in the model domain area are approximately 700 feet, with an average thickness of 170 feet (Conservation and Survey Division, 2010). Many of these test holes did not penetrate the entire thickness of the deposit, however, and Peterson et al. (2008) suggest this calculated average thickness underestimates the true average thickness for the area. The Ogallala Formation, as well as overlying Quaternary deposits, are locally absent along the Niobrara River and Ponca Creek at the north end of the model domain (McMahon et al., 2007).

The Tertiary Arikaree Group is composed of poorly consolidated, tuffaceous sandstone, siltstone, shale, and silty clay (Long et al., 2003). It is generally a low permeability/low conductivity unit but can be a part of the High Plains Aquifer system when exhibiting secondary permeability from fracturing (Long et al., 2003; McMahon et al., 2007). Maximum thickness for this unit is approximately 1,000 feet, and it is absent from the eastern portion of the model domain (McMahon et al., 2007).

Tertiary White River Group sediments typically consist of poorly consolidated siltstones and claystones, with local fine sandstones (Long et al., 2003). Deposits are typically low permeability/low conductivity, but the Brule Formation, the uppermost unit of the White River Group, locally contributes to the aquifer system where substantial thicknesses of saturated sandstones are present or where joints and fractures have induced secondary permeability (Long et al., 2003; McMahon et al., 2007). Maximum thickness for the Brule Formation is approximately 600 feet, and deposits are absent from the eastern portion of the study area ((McMahon et al., 2007).

Underlying the High Plains Aquifer in the model domain is the Upper Cretaceous, marine Pierre Shale. The shale is of low permeability and generally not considered a productive unit within the local or regional aquifer system. The unit is up to 1,400 feet thick (Long et al., 2003), and it is locally exposed in the study area along the Niobrara River and Ponca Creek, where Quaternary erosion has removed the overlying strata.

2.2 Niobrara River

The Niobrara River is a highly aquifer-supplied river whose headwaters originate in eastern Wyoming. It is a perennial stream from approximately the Nebraska-Wyoming stateline, downstream through the remaining portion of the study area, with flow generally present year-round. Since the late 1800's, the Niobrara has been a significant source of water for water rights holders along the river. In 1948, the Box Butte Reservoir and canal distribution system, completed by the BOR, began to provide irrigation for the Mirage Flats irrigation district.

The flows in the Niobrara River are due in part to precipitation runoff, but the predominant source is groundwater. The River begins in south eastern Wyoming, cutting through the water bearing Arikaree formation. As the River bends though Sioux, Dawes, and Sheridan Counties, it gradually begins to run over the more prolific Ogallala formation. These formations play a key role in both the quantity of water in the River, and the quantity of water that can be relied upon for irrigation.

Typical flows in the River are around 5 cubic feet per second near the stateline, around 15 cubic feet per second at the gage at Agate, and between 20 to 40 cubic feet per second at the gage above Box Butte Reservoir. The records from the stream gages upstream of Box Butte Reservoir, however, show indications that the streamflow has been decreasing over time. According to Department analysis in a 2004 report, the amount of surface water available for diversion from the Niobrara River upstream of the Mirage Flats canal diversion has continued to decrease since the project was completed (DNR, 2004). At the stateline, the 5-year annual average flow decreased by 567 acre-feet from the 1956-1960 time period to the 1996-2000 time period. For the same time periods, the average flow above Box Butte Reservoir decreased by 4,332 acre-feet. Records also show that diversions to the Mirage Flats canal averaged 19 percent less per year during the 1976-2003 time period than during the 1948-1975 time period.

The gaps in the flow graphs in Figure 2.2, Figure 2.4, and Figure 2.5 are due to missing streamgage data.

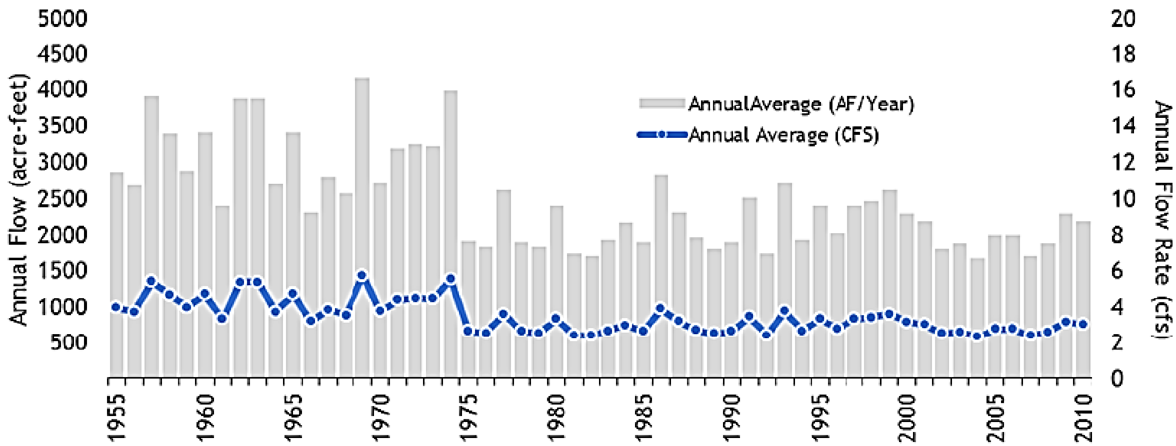

Figure 2.1. Average annual flow of the Niobrara River at the state line gage.

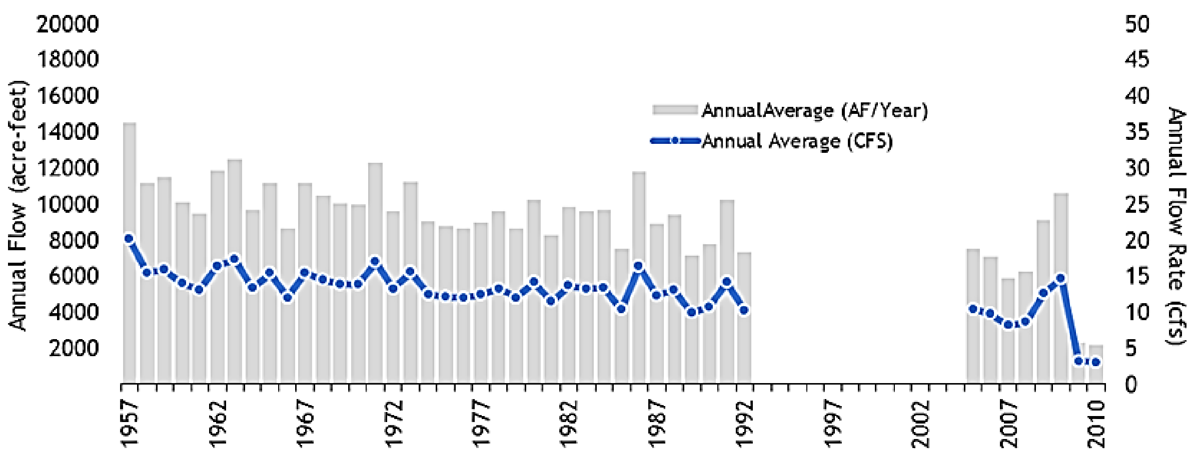

Figure 2.2. Average annual flow of the Niobrara River at Agate.

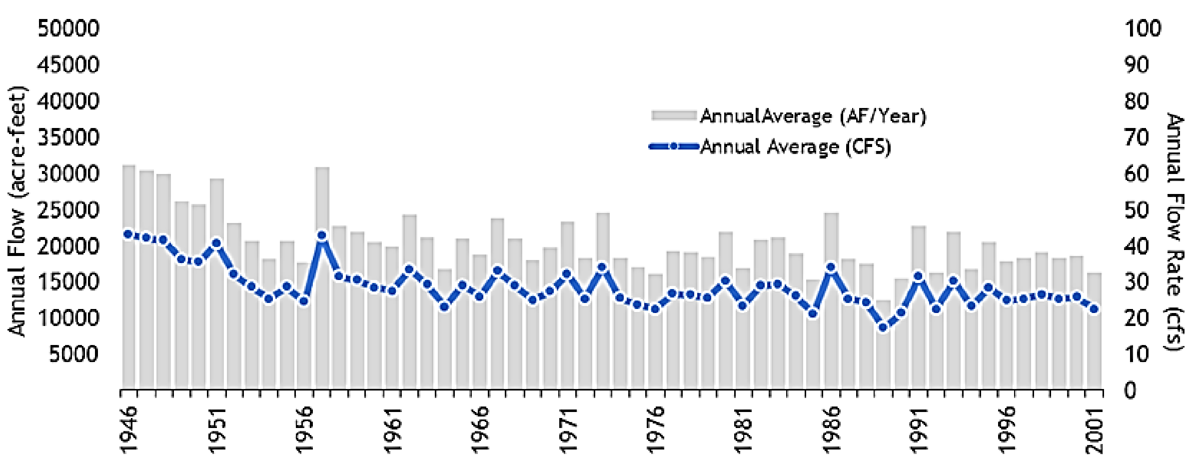

Figure 2.3. Average annual flow of the Niobrara River above Box Butte.

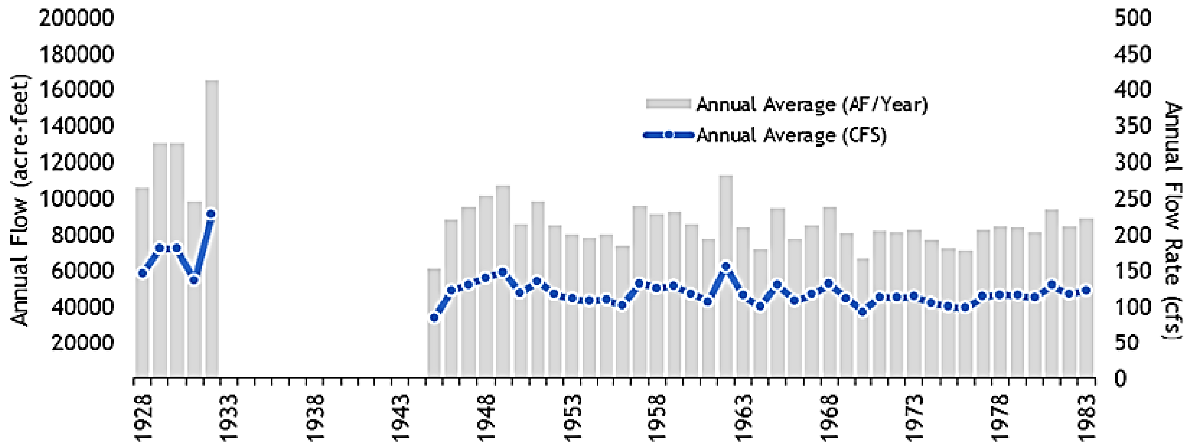

Figure 2.4. Average annual flow of the Niobrara River below Box Butte.

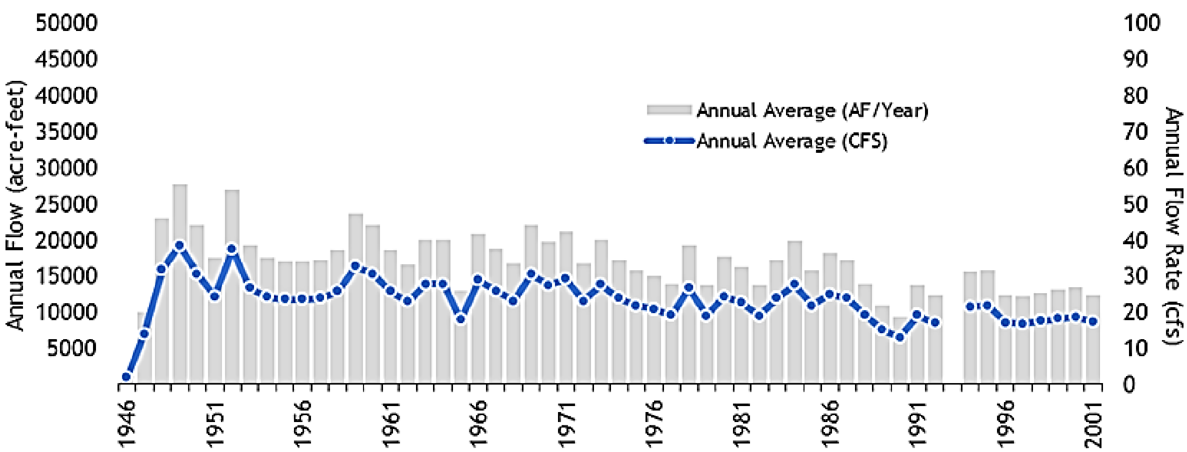

Figure 2.5. Average annual flow of the Niobrara River at Gordon.

2.3 River-Aquifer Connection

The primary indication of a significant connection between the Niobrara River and the underlying formations beneath it is the relatively high volume of flow during times of low precipitation. The amount of water flowing in the River which is contributed by the aquifer is known as baseflow, or groundwater discharge. Baseflow is relatively insensitive to weather conditions. Therefore, rivers with a high degree of connection typically have sustained flows, even during drought periods. Baseflow is, however, sensitive to changes to head in the aquifer. When the head in an aquifer decreases, the flow of water to the river decreases.

Studies performed in Nebraska to quantify the degree of connection between river systems and aquifers have produced estimates of the proportion of flow in a river that is due to groundwater contribution. A study by Jozsef Szilagyi et al. (2002) suggests that, in the region of the UNW study area, 70-90 percent of river flow can be attributed to seepage from groundwater. This approximation is derived from the baseflow index: an estimate of the ratio of baseflow to total flow volume.

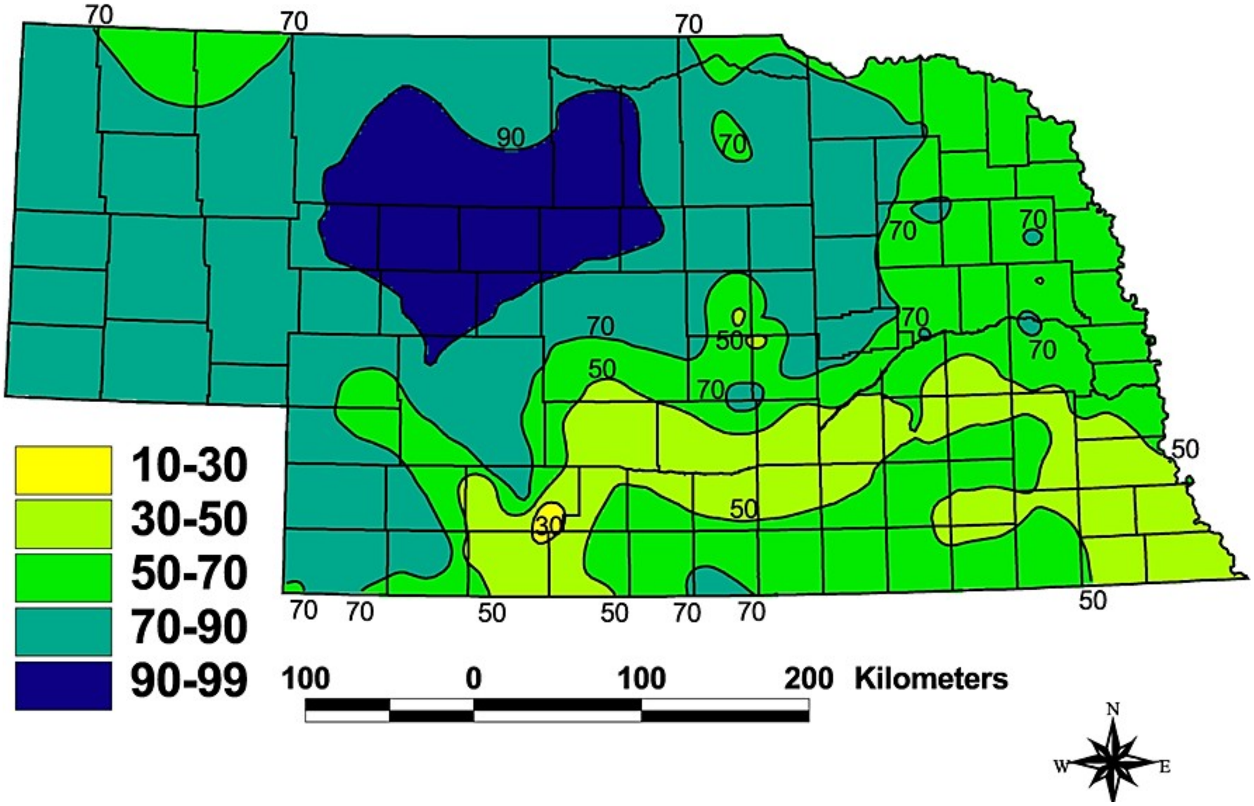

Figure 2.6. Map showing the baseflow index for Nebraska (Szilagyi et al. 2002). In the UNW area, 70-90 percent of river flow originates from groundwater (far northwest portion of Nebraska).

The Tertiary-age Ogallala and Arikaree formations are the primary water bearing sediments in the CENEB study area, and together form what is known as the High Plains Aquifer. Both of these formations are readily found in the study area, though the water well development gradually shifts from the Arikaree group sediments in the west to the Ogallala in the east. For this study the two formations are modeled as one primary aquifer. This is consistent with UNL's Conservation and Survey Division (CSD) interpretations of heads in the area because both groups are in connection with each other and do not exhibit separate hydraulic characteristics in the study area (as in different head regimes), and no distinct confining layer exists between the two groups in the study area. The primary aquifer (the High Plains Aquifer) acts as one continuous and hydraulically connected unit. At a regional scale it exhibits properties similar to an unconfined water table aquifer and is connected to many of the surface water features in the study area. The connection between the aquifer and surface water features in this area is a key feature of the region.

Groundwater in the unconfined High Plains Aquifer within the CENEB model domain generally flows from west-northwest to east-southeast (Conservation and Survey Division, 1996; 2003). The average hydraulic gradient is approximately 0.0019 feet/feet. The maximum water level elevations of approximately 3,850 feet amsl are located along the western model boundary; the lowest water level elevations are less than 1,500 feet amsl and located along the eastern model boundary.

Most of the rivers and tributaries within the CENEB model domain are gaining from groundwater discharge (Nebraska Natural Resources Commission, 1982). The streams gain water from the groundwater system when groundwater levels are higher than the stream bottom and recharge the aquifer when water levels are below the stream bottom, maintaining an equilibrium that is characterized by long-term stability in aquifer water levels. Within the model domain, there are both gaining and losing stream reaches; however, there is a net loss from the aquifer to the streams.

A study by the USGS on the High Plains Aquifer states that water level changes from predevelopment (i.e., before about 1950) to 2007 across most of the CENEB model area ranged between -10 and +10 feet (McGuire, 2009). Thus, the groundwater flow system has been relatively stable since predevelopment. The USGS analysis shows isolated areas of greater rises and declines scattered throughout the model area; however, most of these areas exhibit less than a 25 feet rise or decline (McGuire, 2009). A comparison of water table contours from 1979 and 1995 demonstrates that there is little to no change in groundwater elevations from 1979 to 1995 in the western portion of the model area and only slight changes exhibited in the east.

The Niobrara River and the Upper, Middle, and Lower Loup Rivers and their tributaries serve as a groundwater drain for the sand hills region. Soils in the sand hills are coarser grained than the surrounding areas, and, therefore, have a much greater rate of recharge. Minor amounts of precipitation reach the streams as overland runoff; thus, streamflow is maintained almost wholly by groundwater discharge (Nebraska Natural Resources Commission, 1982).

2.4 Analysis of Niobrara River Flows

In the past half century, the UNW basin has changed rapidly. The increase in irrigated agriculture after the building of Box Butte Reservoir and the development of many groundwater wells has caused long-term shifts in the water balance.

When regular regression lines are charted for the annual flow and monthly average flow at gages in the Niobrara River Basin, they show decreasing trends. The R-squared values, however, are low, indicating that the lines do not fit the data well and that the lines are not good predictors of the data. This is likely due to the high amount of variability and dissymmetry in the data.

According to Wen and Chen (2006), a Mann-Kendall analysis of streamflow records indicated significant decreasing trends at three gaging stations in the Niobrara River Basin: (1) above Box Butte Reservoir (USGS 06454500); (2) below Box Butte Reservoir (USGS 06455500); and (3) at Gordon, Nebraska (USGS 06457500). Wen and Chen (2006) hypothesize that the decline in streamflow is associated with the use of groundwater in Box Butte County. The same Mann-Kendal trend test was performed on data from gages at the Nebraska-Wyoming stateline (USGS 06454000) and near Agate, Nebraska (USGS 06454100). The analysis indicated a significant decreasing trend at both gages, with the null hypothesis of no trend rejected at greater than a 95 percent confidence level.

Therefore it is apparent that the Niobrara River is experiencing a reduction of flows. There are three ways that flows can be reduced in the river: (1) a reduction of direct runoff as a result of precipitation; (2) an increase in upstream surface water diversions; or (3) a reduction in baseflow. At this point it is unclear which scenario is to blame for the reduction of flow.

3 Groundwater Flow Models

3.1 Historical Calibrated Models

3.1.1 Upper Niobrara White Groundwater Model

The USGS MODFLOW-2000 (MF2K) (Harbaugh et al., 2000) code was selected for use in simulating the groundwater flow system.

The grid cell size of 1 mile by 1 mile, square is sufficient to understand the general hydraulics of the region, and is supported by the amount of observational data recorded through the past century. While some portions of the study area have little data, such as areas of the sand hill region and areas just east of the stateline, many of the key regions for analysis (Box Butte County and the Mirage Flats area) have sufficient data to support this choice.

The UNW groundwater model simulates the time period spanning the approximate onset of groundwater irrigation development in the region, through the year 2010. This time period was separated into two sequential parts – one period to simulate pre-groundwater development conditions, and one period to simulate the more recent 50 years (1960-2010) of groundwater development in the region.

Groundwater development in the UNW basin was simulated using transient stress periods over the period starting in January 1960 and ending in December 2010. Stress periods were defined for each of the intervening 612 months in the simulation period. Stress period lengths were assigned, consistent with the calendar year, such that stress periods varied from 28 to 31 days in length with the inclusion of a leap day every fourth year in February.

The Niobrara River and its key perennial tributaries were modeled as head dependent streams using the STR package in MODFLOW. The major reaches were modeled as stream reaches (Figure 3.1) and the streams' parameters were zones on these reaches. The elevations of the stream and drain boundaries were determined by the 10 meter DEM.

The western boundary of the UNW model, located predominantly in Wyoming, is a general head boundary that traces the extent of the Arikaree portion of the High Plains Aquifer. There is a small no-flow portion on the southern edge of the Wyoming area where the aquifer was deemed not to exist. Most of this boundary was described in the UNW model as a general head boundary (GHB). The GHB was implemented in the UNW model to control simulated ambient groundwater levels on the edges of the active model in areas where flow in and out of the model is assumed to occur.

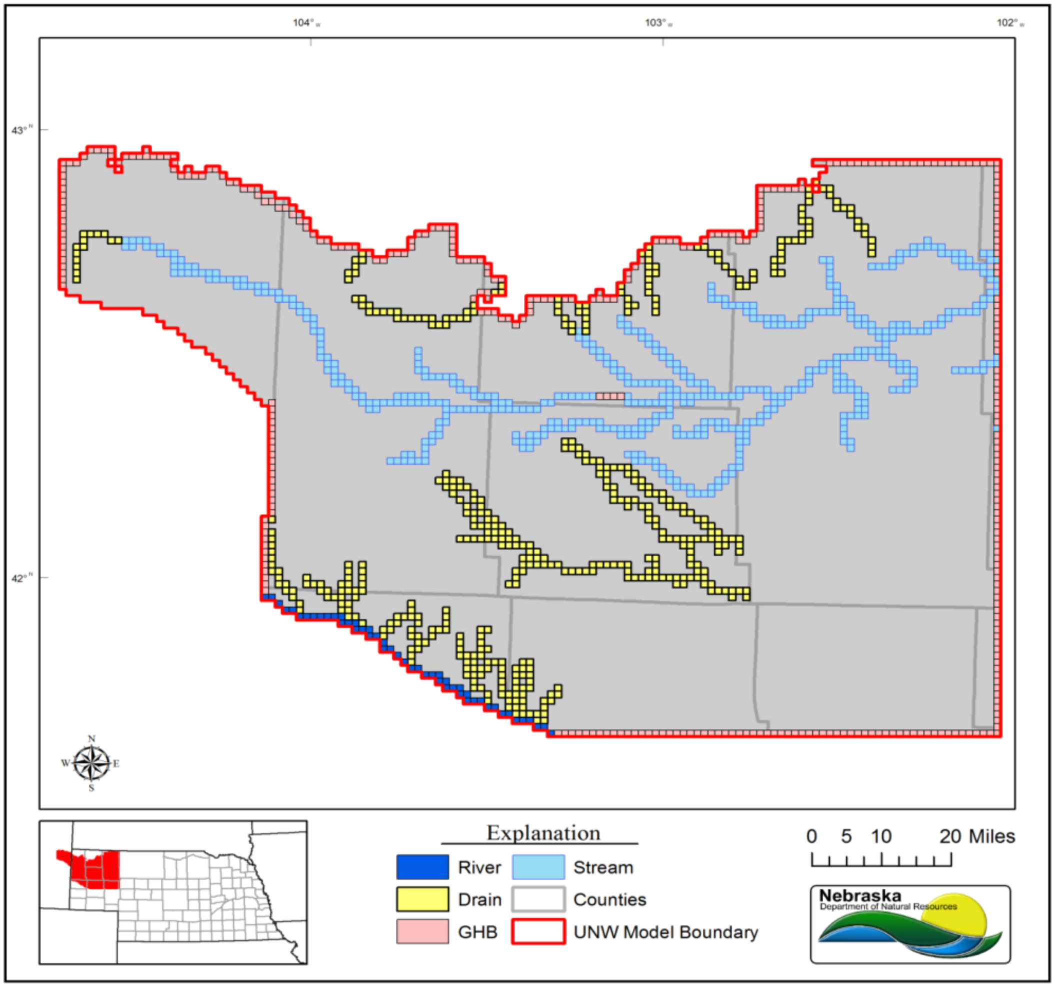

Figure 3.1. Map of UNW model area showing major reaches.

The northern boundary is dominated by the White River Group. This was assumed to be the northernmost extent of groundwater connected with High Plains Aquifer sediments. A GHB was assigned to the north side of the model.

The boundary to the east was arbitrarily located outside of the Upper Niobrara White Natural Resources District (UNWNRD) border so that the model simulation captured the extent of changes within the District's borders. The area was also far enough away from the main groundwater region and exhibited no significant head change in observation wells. It was modeled as a GHB, which presumes that the groundwater levels there do not change with time. While that is unlikely, the changes over time in that area have been small and have not been significantly affected by groundwater development in the Box Butte or Mirage Flats areas.

The southern boundary is a combination of the North Platte River, modeled as a constant head river boundary, and to the east, a GHB due to the lack of overall change in head in that area.

The Niobrara River and its tributaries were modeled as head-dependent stream boundaries. The description of streams in the model was derived from the National Hydrologic Dataset (NHD). Only the reaches that flowed perennially were chosen for the model.

3.1.1.1 Box Butte Area

The Box Butte area has experienced drawdown due to groundwater pumping for over 50 years. This is reflected in the observations that irrigators have taken through time, as well as the maps that the CSD has produced to document water level changes in Nebraska through time. A selection of hydrographs from the Box Butte region is included to show how the models simulate the head in Box Butte County (Figures 3.2 and 3.3). The wells were chosen for the overall length and quality of their record.

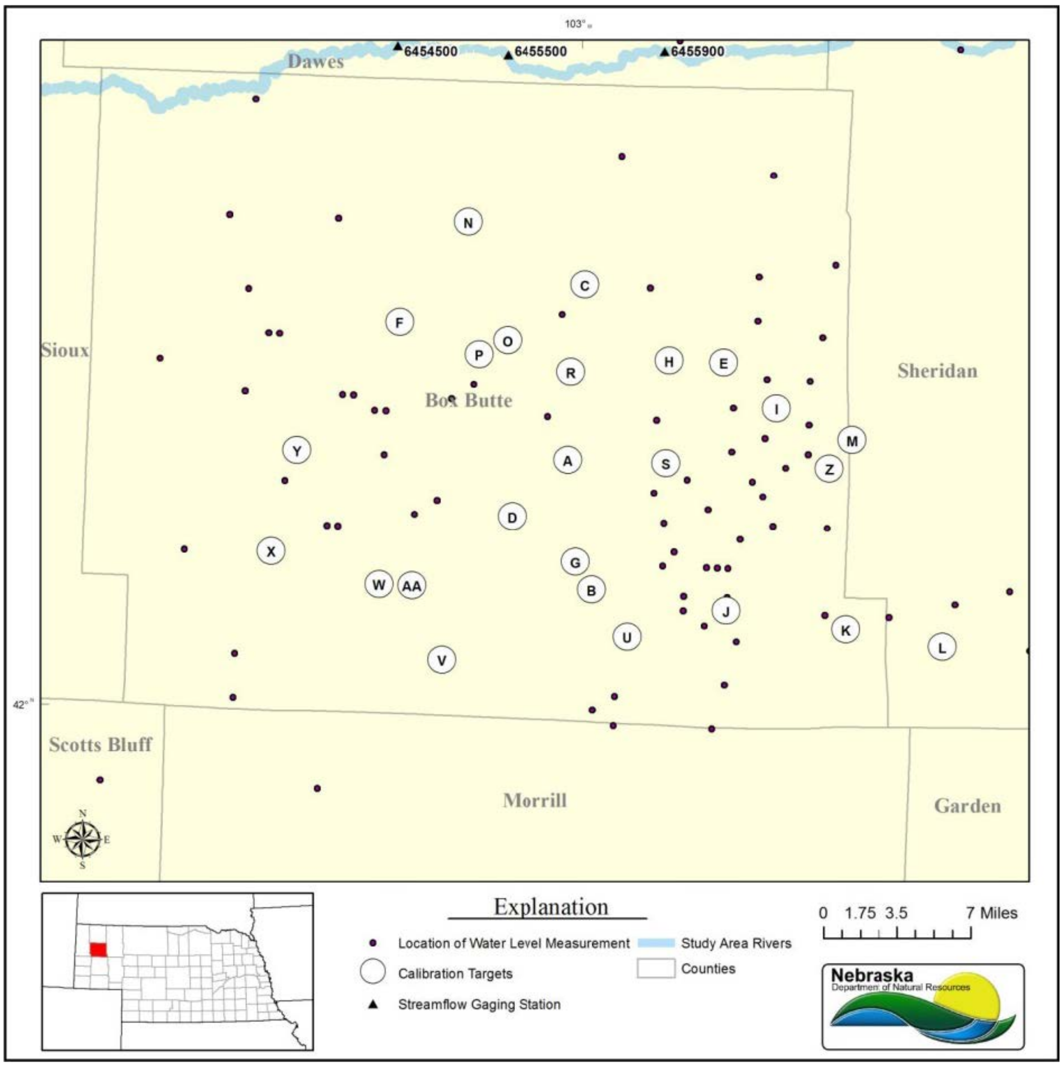

Figure 3.2. Map showing calibration targets in Box Butte County. The targets are labeled with letters, some of which are referred to in the observed vs. simulated streamflow charts shown in Figure 3.3.

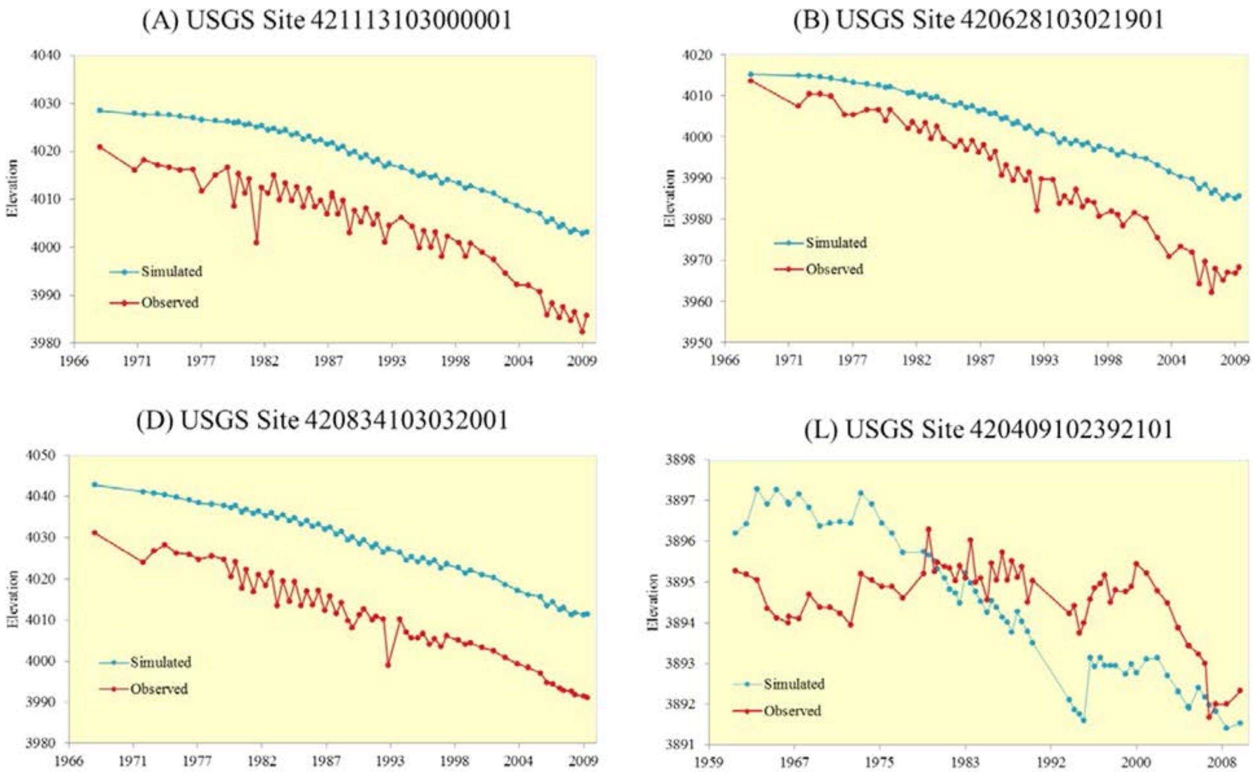

Figure 3.3. Panel of charts showing observed vs. simulated groundwater elevation some of the Box Butte calibration targets shown in Figure 3.2.

3.1.1.2 Mirage Flats Area

The Mirage Flats area has also experienced drawdown due to groundwater pumping in recent years. This is reflected in the observations that irrigators have taken through time, as well as the maps that the CSD has produced to document water levels in Nebraska through time. While the amount of drawdown is less than in the Box Butte area, it is still substantial.

Figures 3.4 and 3.5 include a selection of hydrographs from the Mirage Flats region to show how the model simulates the head in the area. The wells were chosen for the overall length and quality of their record.

3.1.1.3 Comparison of Measured and Simulated Baseflows

The simulation of baseflow, which resulted from the model runs, is compared with the target baseflow, which is the calculated estimate for baseflow separation derived from the Baseflow Index (BFI program. This comparison was made for baseflow at the stateline gage (Figure 3.6). At all other gages, comparisons were made using the gain between the two gages (e.g., Agate to Above Box Butte, Figures 3.7–3.12).

Generally, the main reaches of interest were the reach upstream of Box Butte Reservoir (from the stateline gage to the gage above Box Butte, Figure 3.11), and the reach downstream of Box Butte Reservoir (from the above Box Butte gage to the Gordon gage, Figure 3.12).

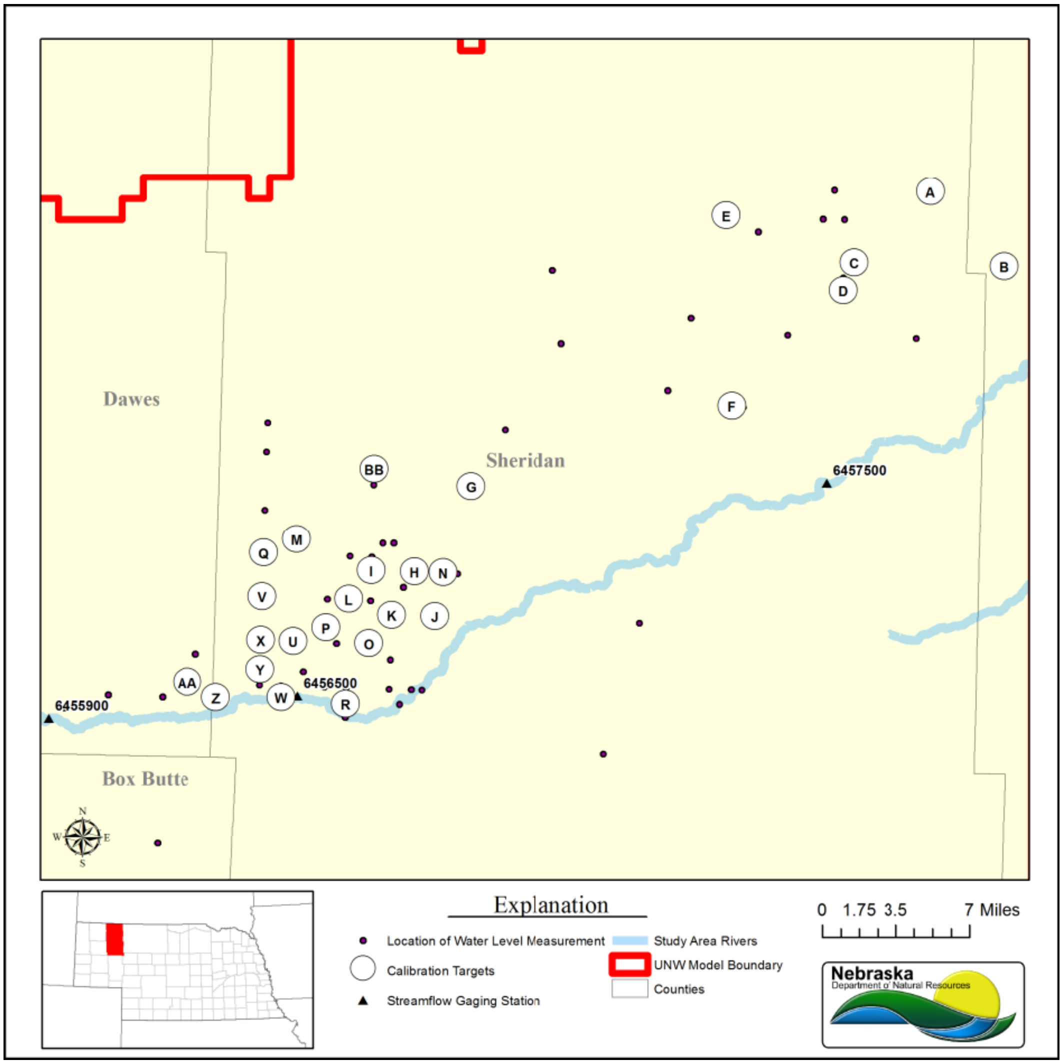

Figure 3.4. Map showing calibration targets in the Mirage Flats area of Sheridan County. The targets are labeled with letters, some of which are referred to in the observed vs. simulated streamflow charts shown in Figure 3.5.

While the fit at the stateline is a little high, the actual amount of water is small, so it does not affect much of the calibration downstream. The simulated gain from the stateline to Agate tends to be slightly higher than the target values. Possible reasons for this include: too much recharge in that area of the model, not enough groundwater ET, or heads that are too high. Since recharge is an output of the CROPSIM process, the land use characteristics in this reach may need to be revisited. The area may exhibit more ET than was modeled due to the fact that the river valley in that reach is an area where visible seeps and wetlands occur frequently. Heads in the area are difficult to estimate due to the very limited amount of data.

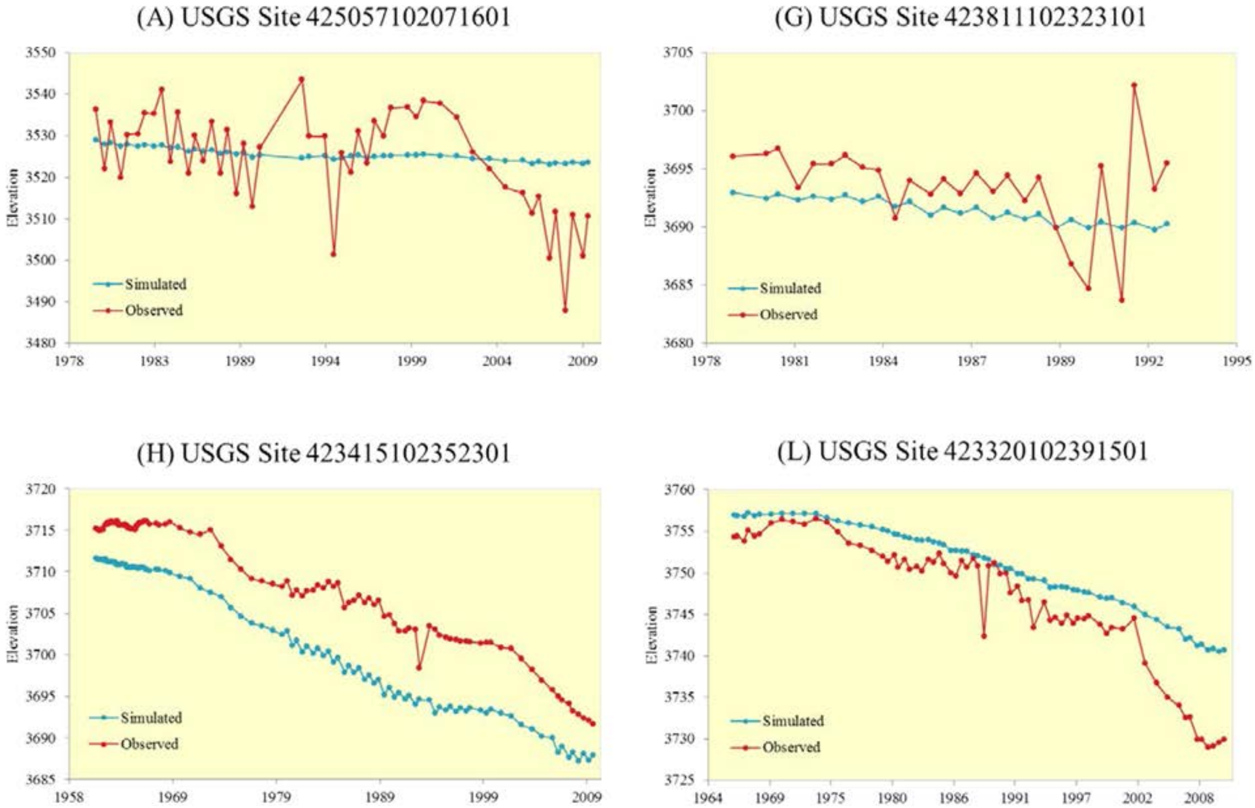

Figure 3.5. Panel of charts showing observed vs. simulated groundwater elevation for some of the Mirage Flats calibration targets shown in Figure 3.4.

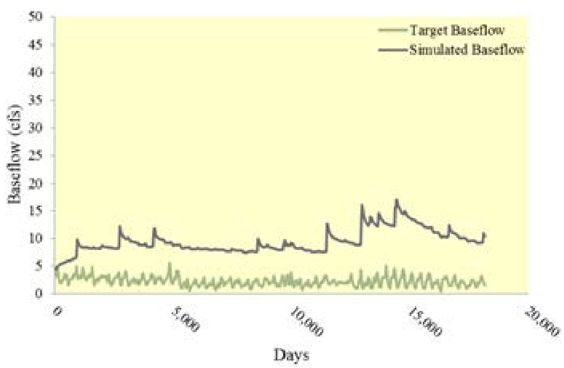

Figure 3.6. Simulated baseflow versus target baseflow at the stateline gage.

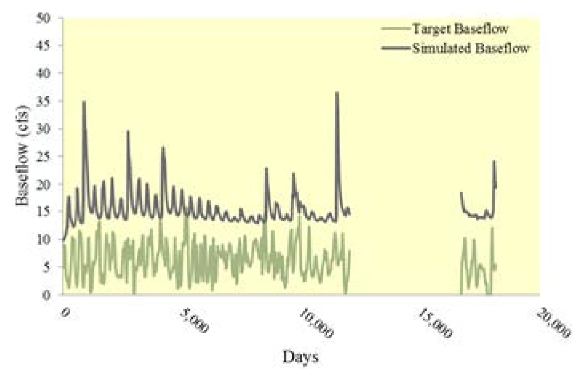

Figure 3.7. Simulated baseflow versus target baseflow between stateline and Agate gages.

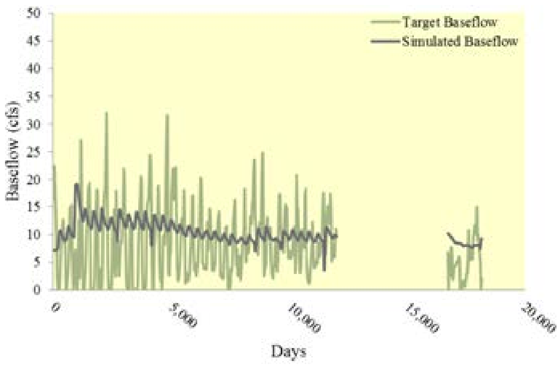

Figure 3.8. Simulated baseflow versus target baseflow between Agate and above Box Butte gages.

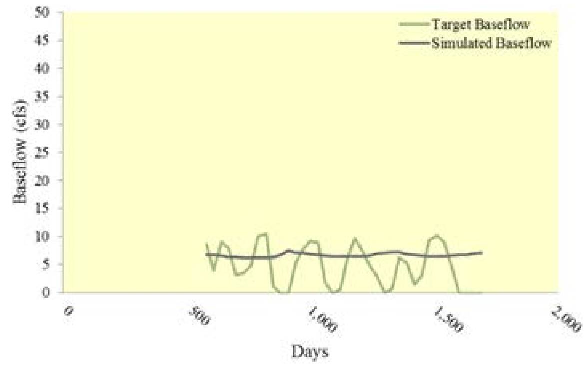

Figure 3.9. Simulated baseflow versus target baseflow between Duncan and Hay Springs gages.

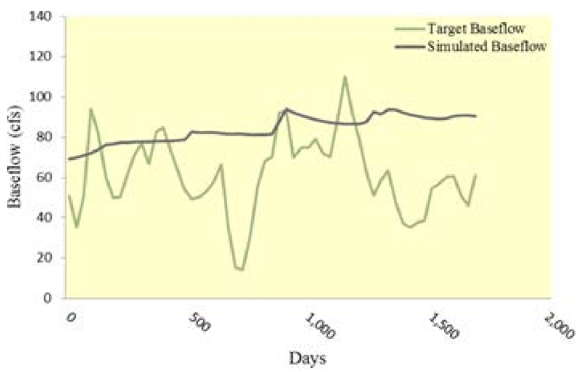

Figure 3.10. Simulated baseflow versus target baseflow between Hay Springs and Gordon gages.

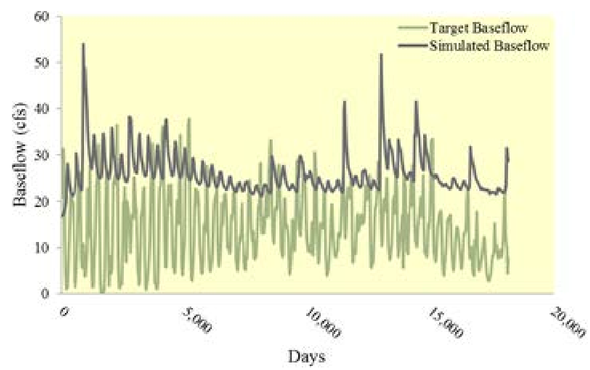

Figure 3.11. Simulated baseflow versus target baseflow between stateline and above Box Butte gages.

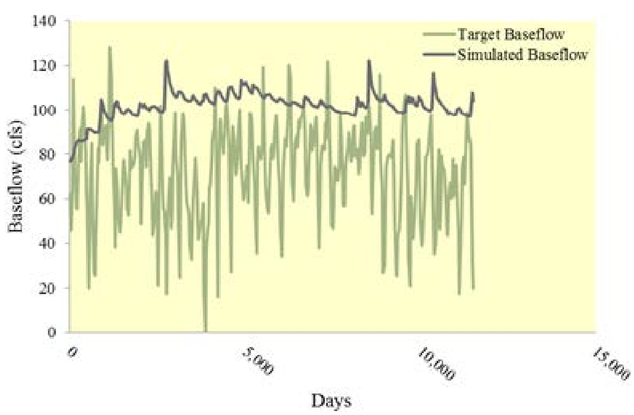

Figure 3.12. Simulated baseflow versus target baseflow between Box Butte and Gordon gages.

Inversely, the Agate to above Box Butte reach is slightly low. There could be several reasons for this (same as those outlined above), but also including the fact that the aquifer may be slightly more connected to the stream than modeled.

The upstream reach as a whole looks to be a representative match (stateline to Above Box Butte). Simulated baseflow downstream of the Box Butte Reservoir also shows a reasonable match to observations. While the overlapping records at the Duncan to Hay Springs reach, and the Hay Springs to Gordon reach were shorter than those observed in other reaches, the simulated baseflows appeared to match well. The simulated baseflows matched the observations well in the whole downstream reach (Box Butte to Above Gordon). The simulation does show a gradual decline in gain through time, suggesting that the modeled groundwater development is causing a shift.

3.1.2 Central Nebraska Groundwater Model

The CENEB model was built using MODFLOW-2005, a modular, 3-dimensional, finite-difference groundwater modeling package developed by USGS (Harbaugh, 2005).

The active model domain is 34,449 square miles, or 22,047,270 acres. The model grid consists of 195 rows x 255 columns with an active domain of 34,449 cells. The model has a uniform cell size of 1 mile by 1 mile. The expansion area allows for a more complete evaluation of streamflow depletion scenarios in northern Nebraska. The model grid is coincident with the State of Nebraska 1-mile grid system.

Stress periods in the CENEB model were defined such that the steady-state and transient model solutions were calculated sequentially in a single model run. This allowed the refinement of model stresses, inflows, and hydraulic parameters simultaneously for both the steady-state (pre-1940) and transient (1940 through 2011) timelines. The simulation period was discretized into a total of 359 stress periods. The first stress period is defined as a steady-state simulation, with the remaining 358 stress periods assigned to the transient simulation. Annual stress periods are simulated from 1940 through 1985. Beginning in 1986 and continuing through 2011, stress periods decrease to monthly intervals.

Model boundaries include no-flow boundaries, general head boundaries (GHBs), and constant head boundaries. No-flow boundaries were assigned to cells in areas where flow directions parallel model boundaries and groundwater neither enters nor leaves the model domain, or where the aquifer is not present. Selected cells along the western and eastern edge of the CENEB model were assigned GHB conditions with the reference head estimated for a location 2 miles away from the active model boundary. These GHBs initially used head elevations based on the 1995 water table contour map developed by the CSD (2003). Constant head boundaries were assigned to the southern and far northeastern areas of the model representing the Platte River and the Missouri River, respectively. Water level elevations for these constant head boundaries were defined using the minimum elevation within the model grid cell from a 10-meter DEM to represent groundwater discharge to the rivers.

Rivers and streams located within the active CENEB model domain (not located on boundaries such as the Platte and Missouri Rivers) were represented using the Streamflow-Routing Package (SFR2) (Niswonger and Prudic, 2010). The SFR2 package is capable of simulating unsaturated flow where the water table is disconnected from the stream network.

Calibration is the process of modifying model parameters within a fixed range of reasonable estimates to improve the match between the predicted and observed hydraulic heads, baseflow, and other relevant hydrogeologic data. These observed data are referred to as calibration “targets.” Initial estimates for hydrogeologic parameters are varied within an observed or estimated range of values to improve the model’s ability to simulate these targets.

Calibration statistics based on the residual are used as a quantitative measure of the ability of the model to match calibration targets. Calibration statistics that were used to evaluate the calibration included Root Mean Squared Error (RMSE) – the square root of the average of the squares of the residuals (also conceptualized as generalized standard deviation), which provides a useful measure of the variability of the error by adding statistical weight to larger errors.

One of the goals of the quantitative calibration was that the mean absolute error (MAE) and RMSE of the head residuals should be less than 2 percent of the total head change across the model for any given calibration period (scaled MAE or RMSE). As total head change across the model is 2,696 feet, the MAE and RMSE should be less than 54 feet.

Estimates of the groundwater contribution to streamflow (baseflow) over time were assembled for the 74 gage points within the CENEB model. Calibration statistics for all head residuals for both steady-state and transient stress periods are well within the goals established for the CENEB model calibration: MAE as a percent of total range in observations is 0.74 percent (goal: less than 2 percent), and the RMSE as a percent of total range in observations is 1.03 percent (goal: less than 2 percent). The MAE for the model calibration is 20 feet, less than half the calibration goal of 54 feet. The mean error (ME) of 3 feet indicates that the observed heads are slightly higher than the calculated heads (averaged over the model domain); the very low magnitude of the mean indicates that there is not a significant bias overall. A plot of the observed versus model-simulated head targets is presented below to graphically illustrate the calibration. Points that plot on or near the perfect fit line (in red on Figures 3.13–3.20 below) indicate a close match between observed and simulated water levels. Overall, the graph below illustrates that the residuals are clustered along the perfect fit line, with model values slightly low in the range from 3,000 to 3,300 feet amsl.

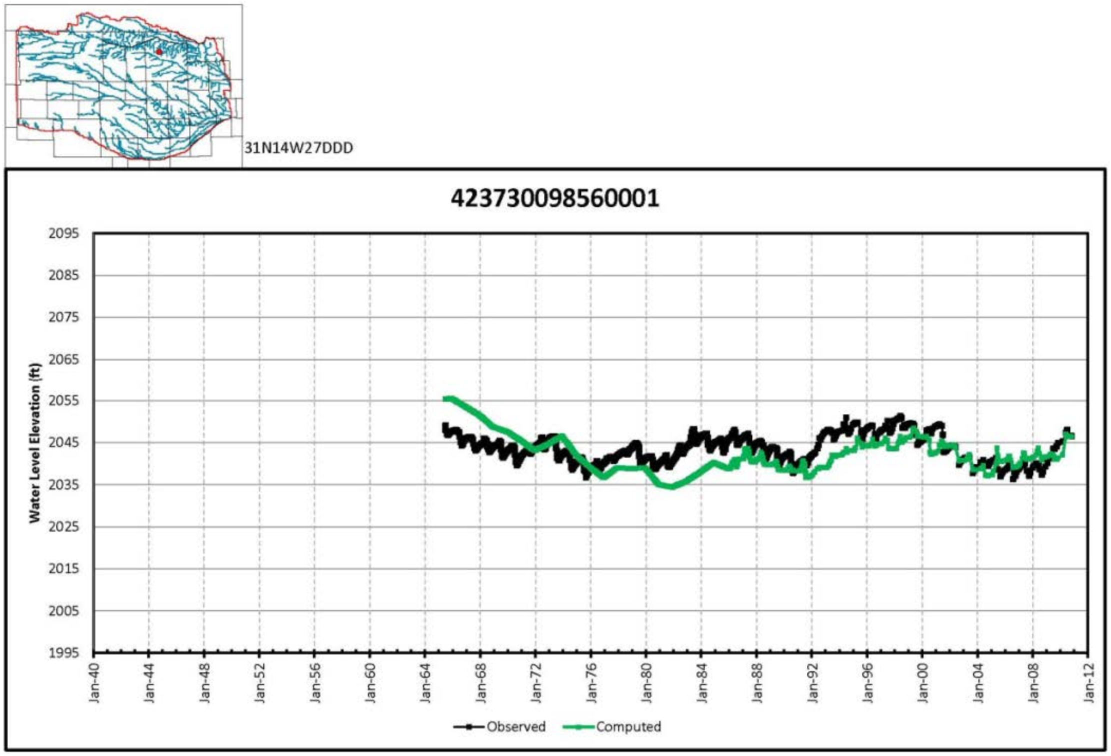

Figure 3.13. Observed vs. Simulated Hydrograph for Well 4237300985600001.

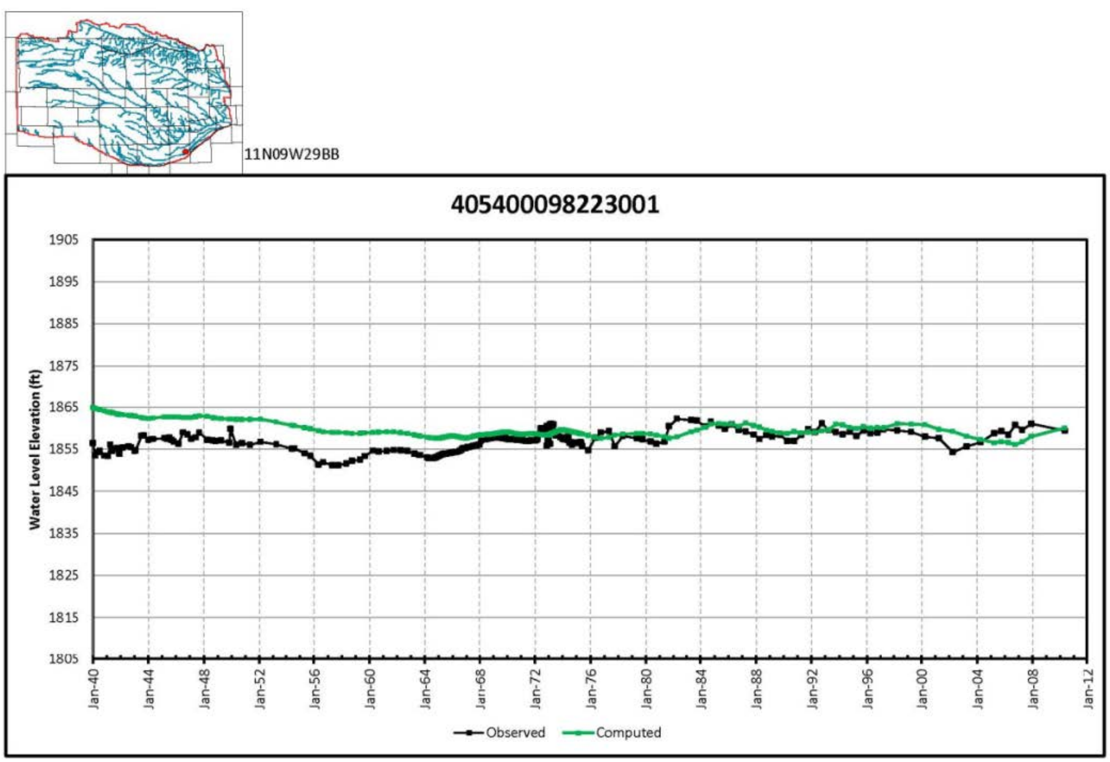

Figure 3.14. Observed vs. Simulated Hydrograph for Well 405400098223001.

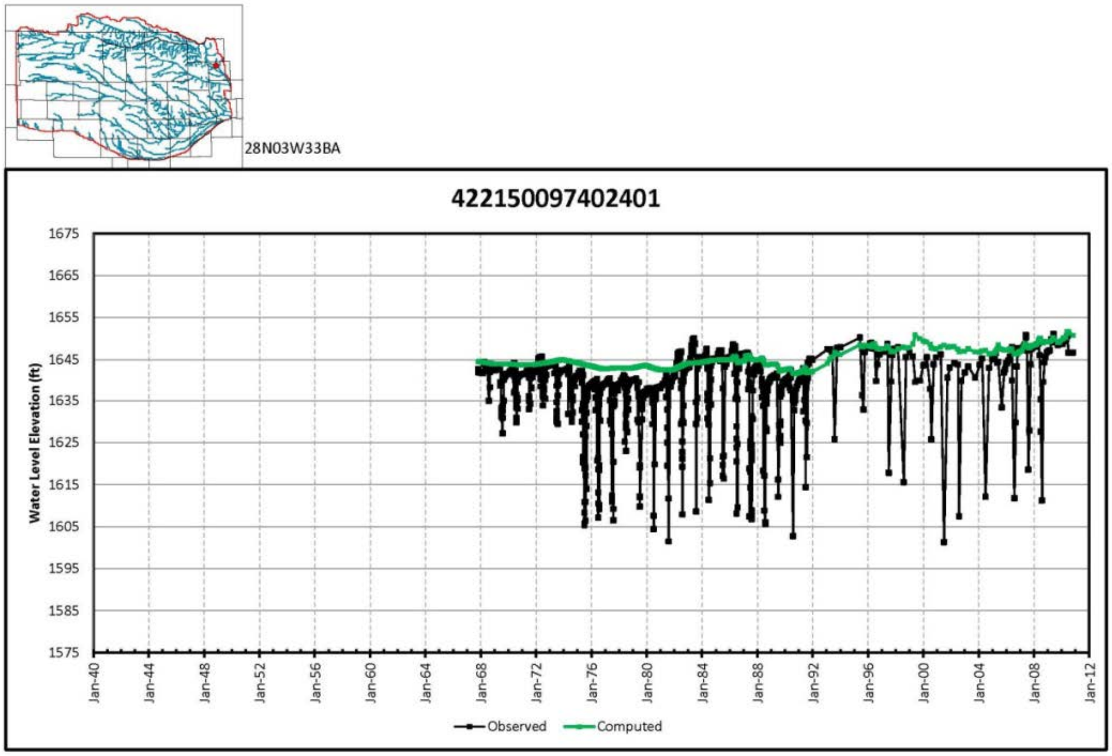

Figure 3.15. Observed vs. Simulated Hydrograph for Well 422150097402401.

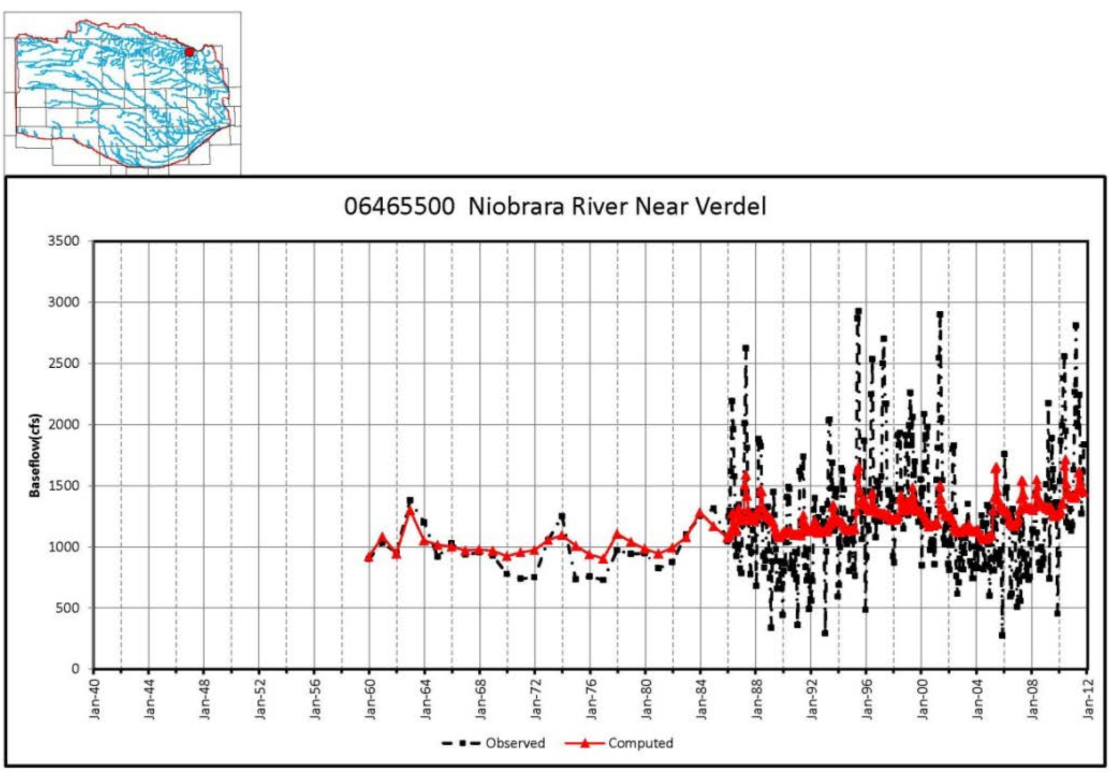

Figure 3.16. Observed vs. Simulated Baseflow -- Niobrara River near Verdel.

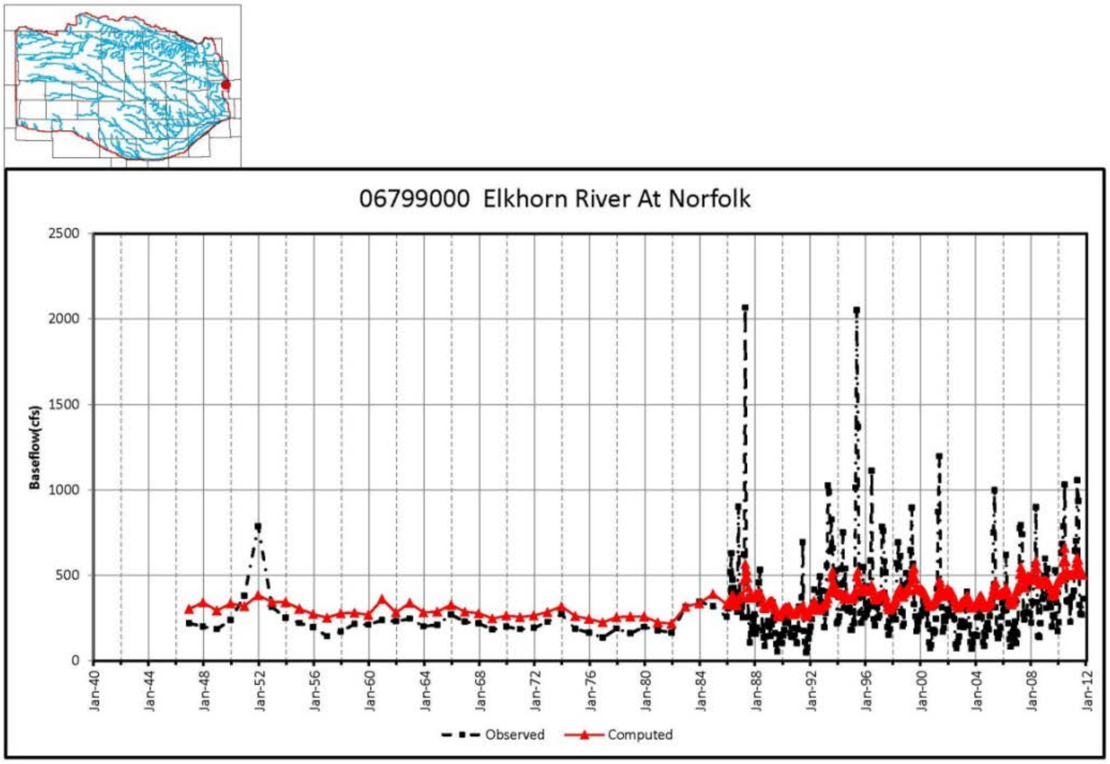

Figure 3.17. Observed vs. Simulated Baseflow — Elkhorn River at Norfolk.

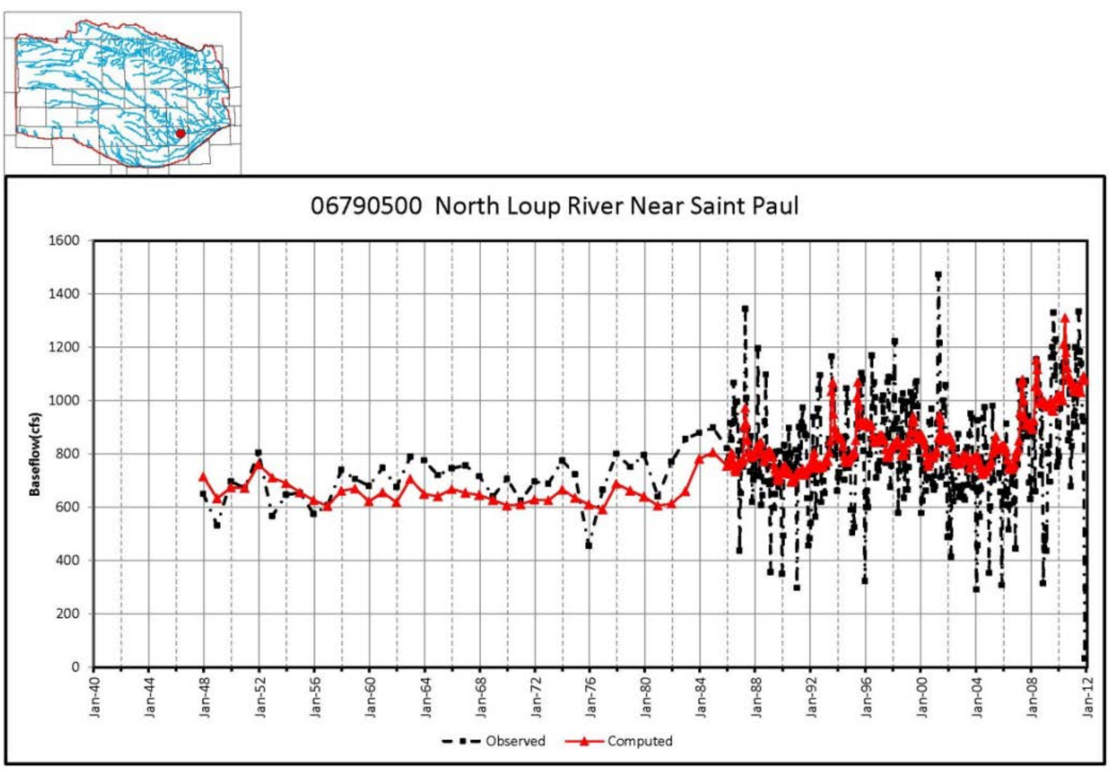

Figure 3.18. Observed vs. Simulated Baseflow — North Loup River near St. Paul.

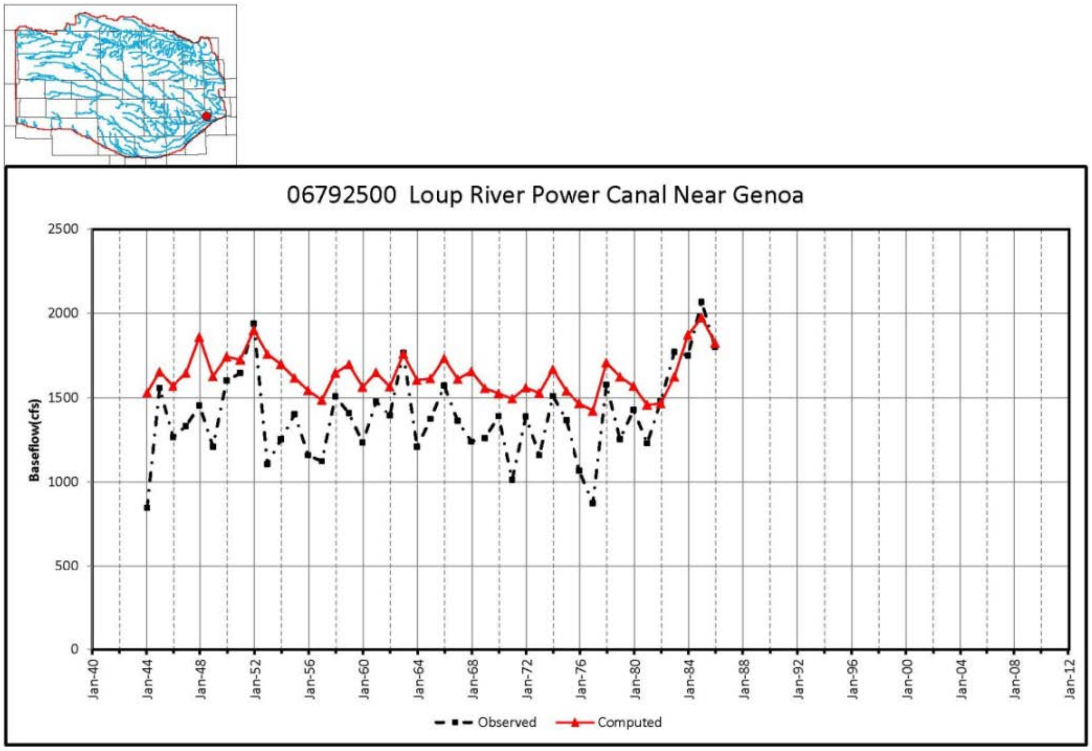

Figure 3.19. Observed vs. Simulated Baseflow — Loup River near Genoa gage (0679300).

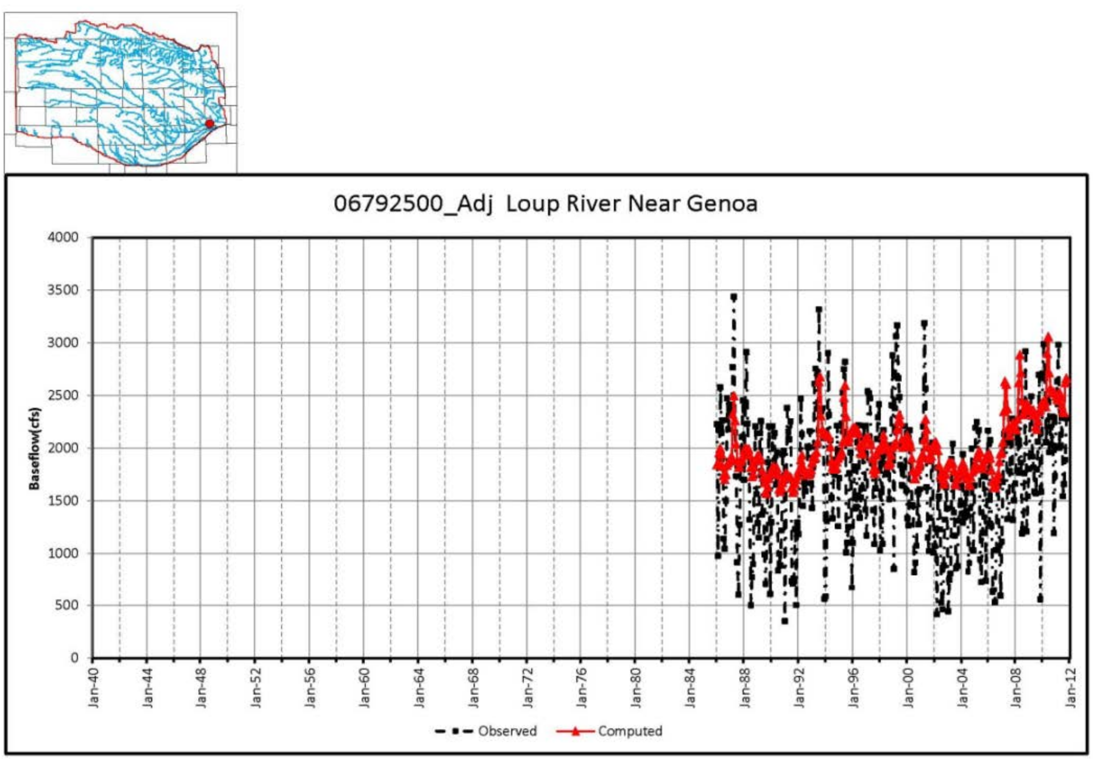

Figure 3.20. Observed vs. Simulated Baseflow — Loup River near Genoa, adjusted by the Loup Power Canal diversions (gage 06792500).

3.2 Data and Inputs for Climate Change Analysis

3.2.1 Climate Variability and Water Management Alternatives Scenario Setup

3.2.1.1 No Action Scenario

Four different model runs were generated for the no action scenario. A baseline condition model run was simulated from year 1960 to 2010 in monthly time step with only year 2010 level development of land use data. The groundwater model received aquifer pumping and recharge inputs from the watershed model as the major stress to the groundwater system of Niobrara River Basin area. Overland runoff from agricultural fields to streams estimated by the watershed model was also included in groundwater model run. Canal seepage, diversion, and return data that the surface water operations model generated after model simulation were incorporated in the groundwater model run. After model simulation, stream baseflow generated from the groundwater model at different gages were passed on to the surface water operations model.

With similar working mechanics to the groundwater model setup of the baseline run, results of three different scenarios from the IPCC climate projection were incorporated into groundwater model runs. A low water availability scenario representing a drier climate condition, a high water availability scenario representing a wetter climate condition, and a central tendency (CT) scenario with a slightly wet climate condition were generated and these scenario results were incorporated into the modeling. The watershed model incorporated the climate projection results and runs were made with similar working mechanics to the baseline run groundwater model.

3.2.1.2 Mirage Flats Pumping Station Scenario (Alt1)

The objective of the Mirage Flats pumping station alternative water management scenario (Alt1 here after) is to reduce canal seepage during surface water deliveries to agricultural fields. The Mirage Flats Irrigation District is exploring options to reduce the operational water losses associated with their main canal. Water losses are considered to be between 50% to 60% of the water diverted at Dunlap Diversion to the main canal bifurcation (IRZ Consulting, 2013). One option is to divert water from the Niobrara River downstream of the current point of diversion via a pumping station which is near the agricultural field. Figure 3.21 shows the location of the current point of water diversion and the proposed pumping station. In this alternative scenario a pumping plant is installed and the first twelve miles of the Mirage Flats Irrigation District’s canal is retired, which would increase the efficiency of the irrigation system by increasing the portion of the diverted water that is delivered to crops.

One of the objectives of this alternative water management scenario is to increase the efficiency of surface water deliveries so that less groundwater pumping will be used to satisfy the crop irrigation demand. The baseflow response of the Niobrara River to this alternative scenario is of an interest. To test this water management idea, the groundwater model is run in an integrated manner with the surface water operations model and the watershed model, while exchanging model simulation results within models. The baseflow at different stream reaches and groundwater level changes will be analyzed through the groundwater model.

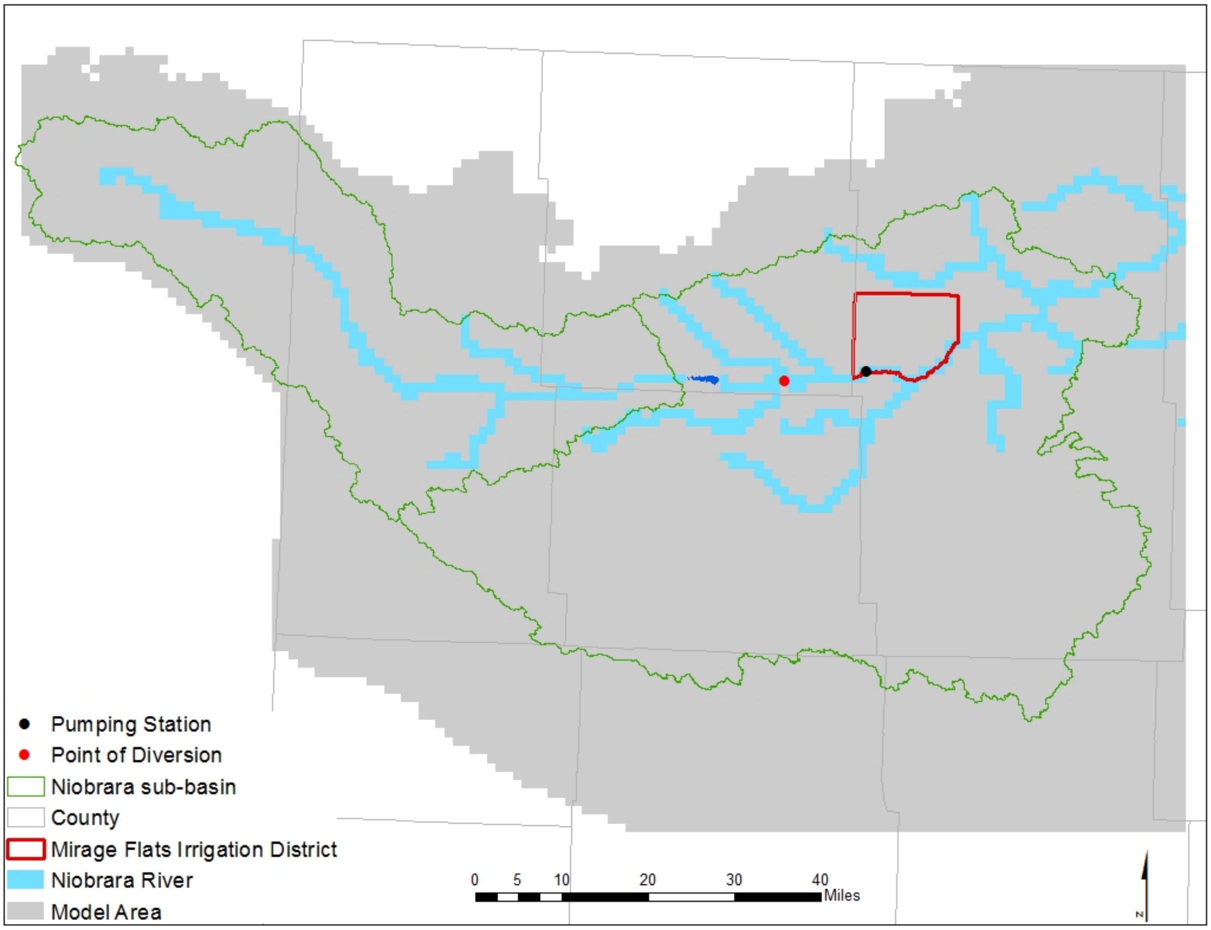

Figure 3.21. Location of point of diversion and new proposed pumping station.

3.2.1.3 Mirage Flats Canal Recharge Scenario (Alt2)

The idea behind the Mirage Flats recharge alternative water management scenario (Alt2 here after) is to use the canal system in the Mirage Flats project area as a recharge system to the aquifer. In this scenario, no surface water deliveries will be made to the agricultural fields. Water will be released from Box Butte Dam, diverted into the Mirage Flats Canal at Dunlap Diversion Dam, and will be allowed to seep into the groundwater in the project area. Figure 3.22 shows the locations of the canal system that will be used as a recharge system to Mirage Flats project area.

The objective of this management scenario is to increase the groundwater level in Mirage Flats area. To test this water management idea, the groundwater model is run in an integrated manner with the surface water operations model and the watershed model, while exchanging model simulation results within models. The baseflow response of the Niobrara River to this alternative scenario is of an interest The baseflow at different stream reaches and groundwater level changes will be analyzed through the groundwater model.

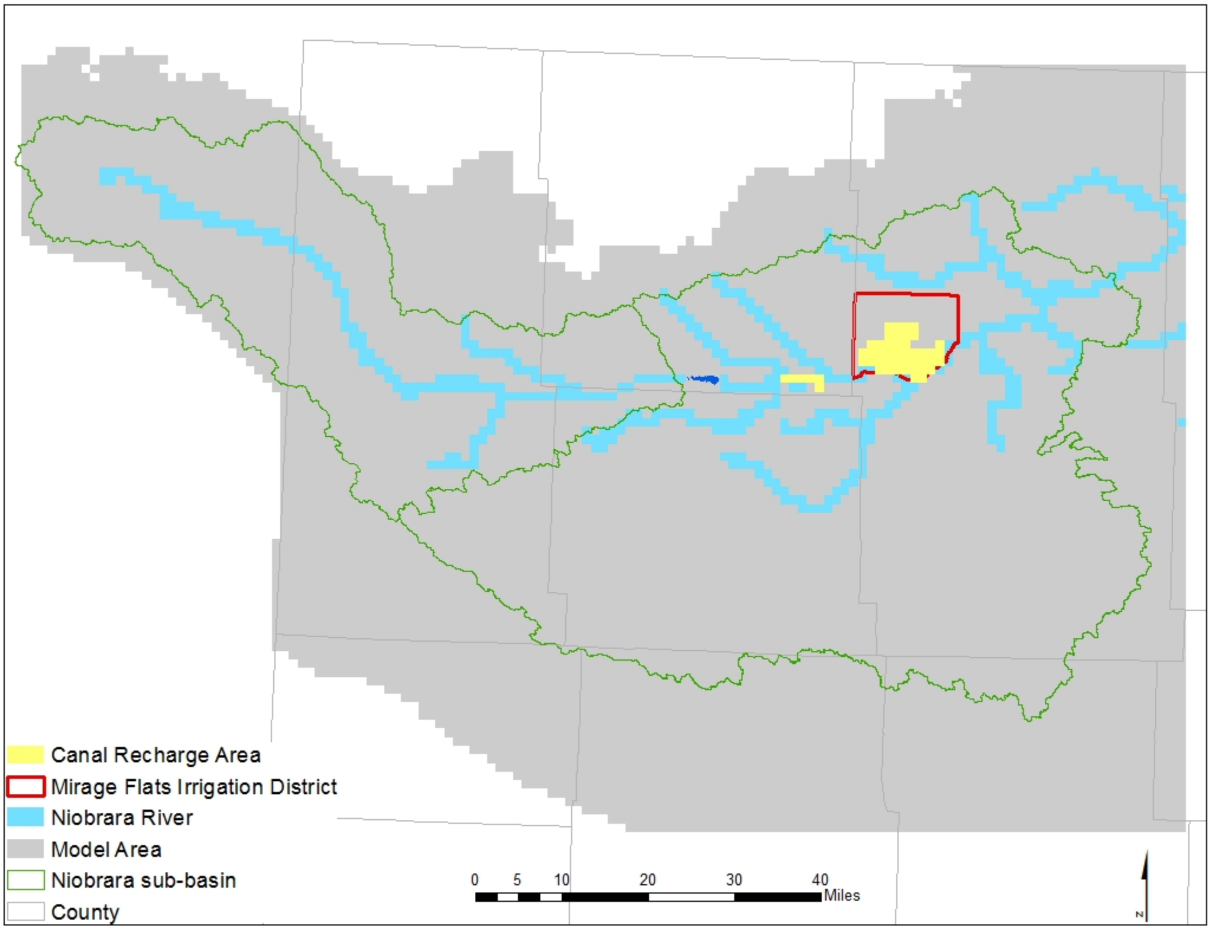

Figure 3.22. Location of proposed canal recharge area.

3.2.1.4 Sensitivity Analysis of UNW–CENEB Region Groundwater Connectivity

For the Niobrara River Basin area, a sensitivity analysis of the changes made in the UNW model area was done for baseflow of the CENEB model area. Through a sensitivity test with two inflow inputs (i.e., inflow1 as the very high constant inflow and inflow2 as the simulated outflow from the UNW area) to the headwater of the CENEB model, we found the simulated baseflow is not expected to change significantly in response to streamflow changes caused by alternative management scenarios in UNW model area. Figures 3.23, 3.24, and 3.25 illustrate the simulated baseflow comparison of inflow1 and inflow2 with the historically calibrated model at the upstream segment, midstream segment, and downstream segment of the CENEB model area, respectively.

Through this sensitivity analysis it was noted that the baseflow of the CENEB model is not sensitive to the changes in the baseflow of the UNW model. Therefore, the analyses of alternative water management scenarios (changes made in the UNW model) to baseflow in the CENEB model area were not done.

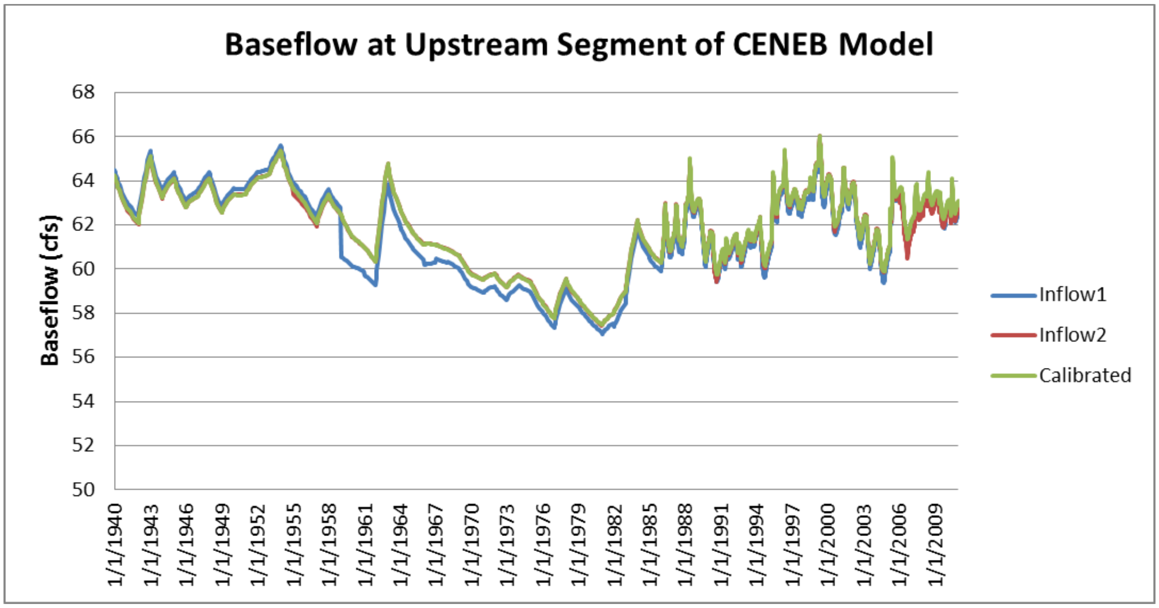

Figure 3.23. Baseflow comparison of two inflow scenarios with the historically calibrated model at the upstream segment of CENEB model.

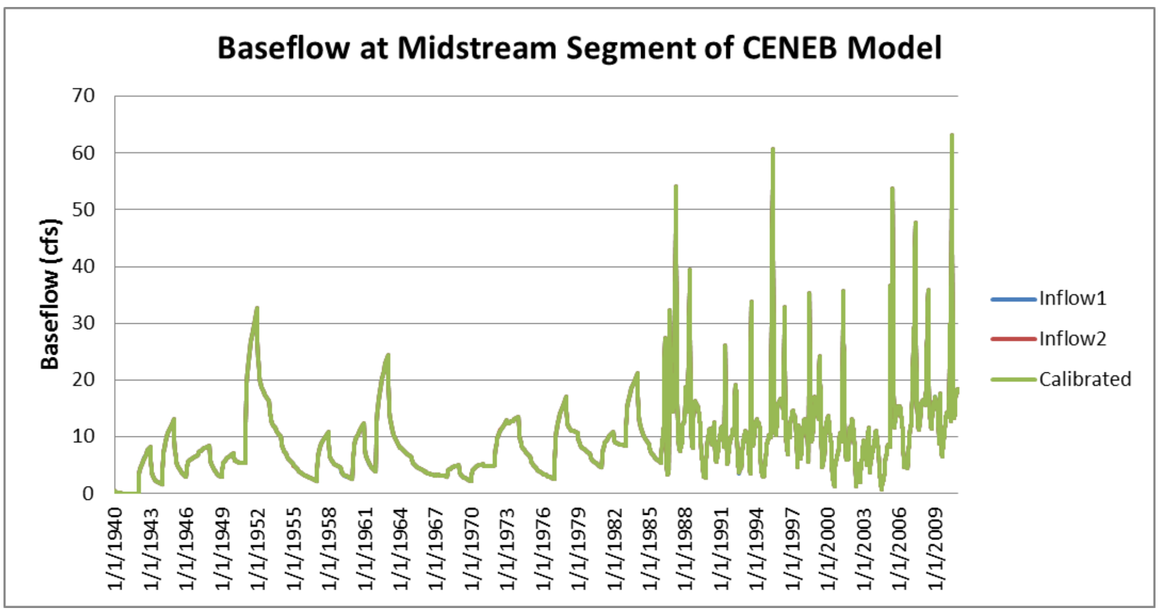

Figure 3.24. Baseflow comparison of inflow1 and inflow2 with the historically calibrated model at the midstream segment of CENEB model.

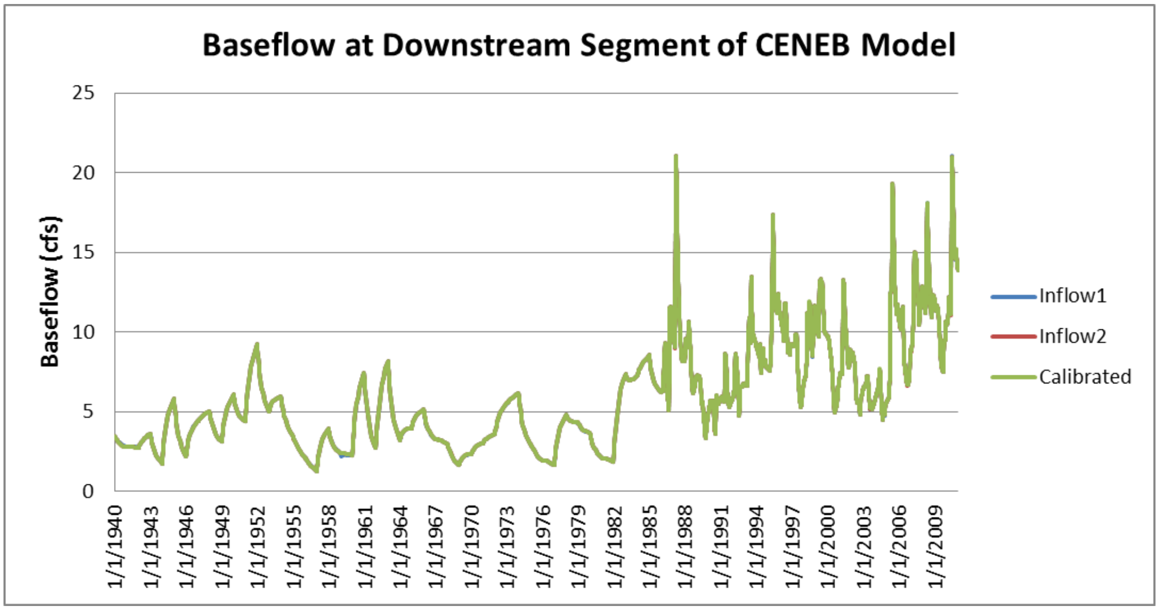

Figure 3.25. Baseflow comparison of inflow1 and inflow2 with the historically calibrated model at the downstream segment of CENEB model.

3.2.2 Land Use and Climate Data

During the water resources modeling process, seamless datasets of historic land use were created for the UNW and CENEB areas by using:

- NRD reported irrigation data
- Department coverage of surface water irrigated lands
- Field level digitized center pivots from University of Nebraska-Lincoln Center for Advanced Land Management Information Technologies (CALMIT) and
- County level crop types and irrigated land estimates from National Agricultural Statistics Service (NASS)

Historical land use datasets were passed on to the watershed model for estimating crop water demand and creating groundwater model input datasets such as aquifer pumping and groundwater recharge. Annually changing land use datasets throughout the historical years were used to create historically calibrated groundwater models, but a constant level of land use data for year 2010 was applied from year 1960 to 2010 to create a baseline model run for isolating the impacts of climate variability in this basin study. Figures 3.26 and 3.27 illustrate the difference in the amount of irrigation water applied between the historically calibrated and baseline runs for the UNW and CENEB models, respectively.

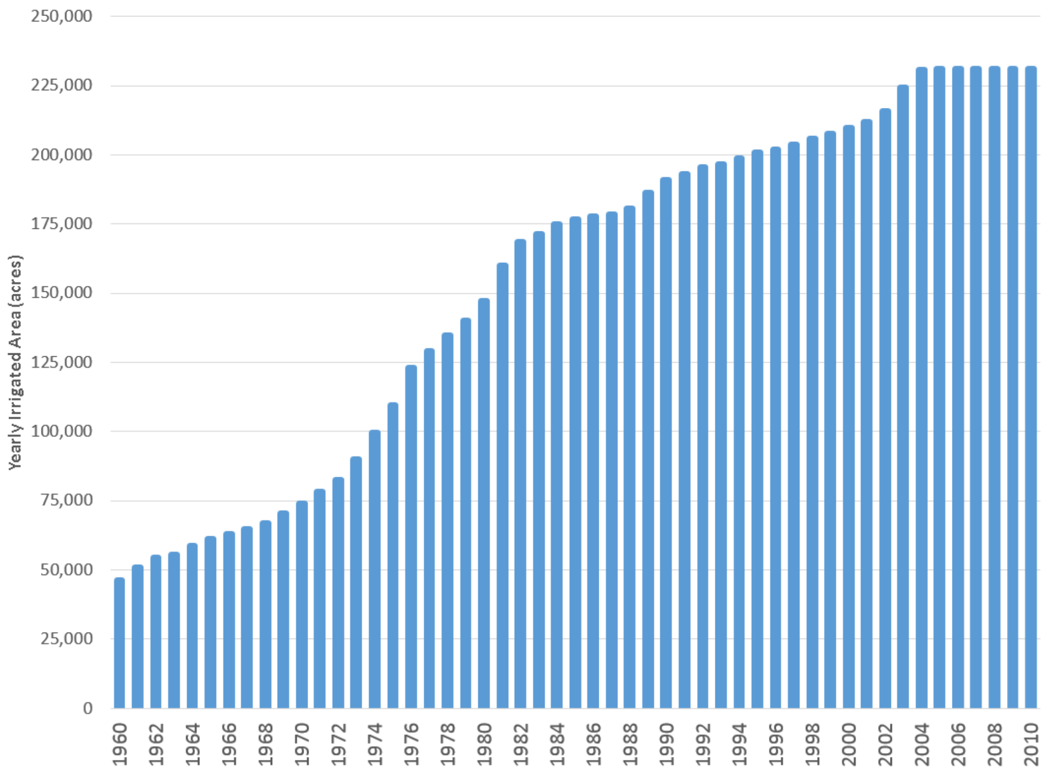

Figure 3.26. Difference in irrigation amount applied in the UNW model.

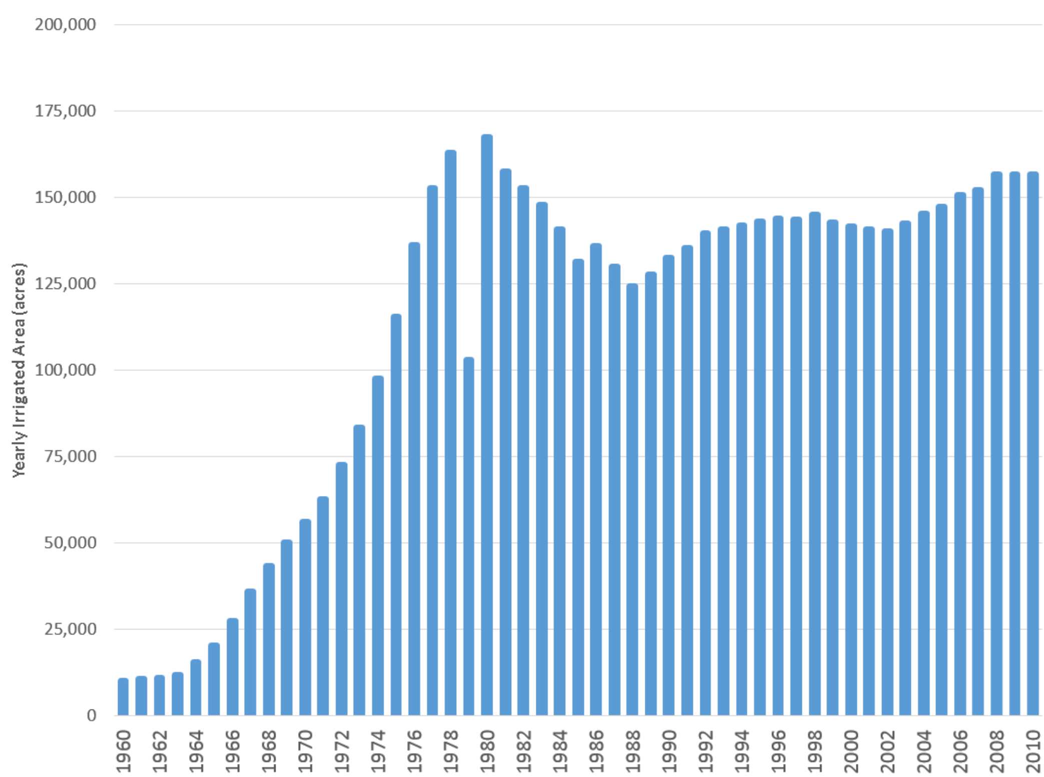

Figure 3.27. Difference in irrigation amount applied in CENEB model.

For the Niobrara River Basin study, the course resolution IPCC climate projection results were downscaled to a finer resolution in both space and time (detail description in Section 3.1 of Climate Change Analysis for the Niobrara River Basin Study report, Appendix A). The downscaled results were then incorporated into the Integrated Water Management Model to evaluate the Basin's response to projected future climate conditions and to various water management alternatives.

The projected climate variability results from IPCC were developed to represent projected water availability for the 2030-2059 future time horizon (detail description in Climate Change Analysis report, Appendix A).Three scenarios were developed to represent:

1) Low projected water availability (hereafter called the low scenario) with a decrease in water availability by approximately 17 percent.
2) Median projected water availability (hereafter called the central tendency or CT scenario) with an increase in water availability by approximately 10 percent.
3) High projected water availability (hereafter called the high scenario) with an increase in water availability by approximately 33 percent.

To isolate and analyze the impacts of climate variability to the water resources condition of the Basin, a baseline no action scenario with constant level (2010 level) of land use development and historical climate data was developed. This scenario was used as a benchmark against which different water availability scenarios were compared. It will help us to evaluate how projected climate variability might impact the current water management.

3.2.3 Model Discretization

Two groundwater models: 1) the UNW model, representing upper subbasin of the Niobrara area; and 2) the CENEB model, representing middle and lower subbasins of the Niobrara area, were used for the study of Climate Variability and Alternative Water Management scenarios. Figure 3.28 illustrates the areal coverage of these two groundwater models in the State of Nebraska.

MODFLOW, a finite-difference numerical model used for solving groundwater flow equations and to model the flow of groundwater in aquifer in saturated condition, was used. The original historically calibrated UNW groundwater model runs from years 1960 to 2010 in monthly stress periods, and the CENEB groundwater model runs from years 1940 to 2011, in a combination of both annual (1940 to 1985) and monthly (1985 to 2011) stress periods, were also used. The aquifer properties of the model, such as hydraulic conductivity and specific yield; and boundary condition properties of the model, such as stream bed conductance, were adjusted in the original model during the calibration process.

For the Climate Variability and Alternative Water Management scenarios study, the adjusted model parameters and temporal discretization of the original historically calibrated model were kept as is for the UNW model. For the CENEB model, adjusted model parameters of the original historically calibrated model were kept as is, but the temporal discretization were changed to only monthly stress periods and the time frame of model simulation was assigned from 1960 to 2010 to match the time frame of the Basin Study.

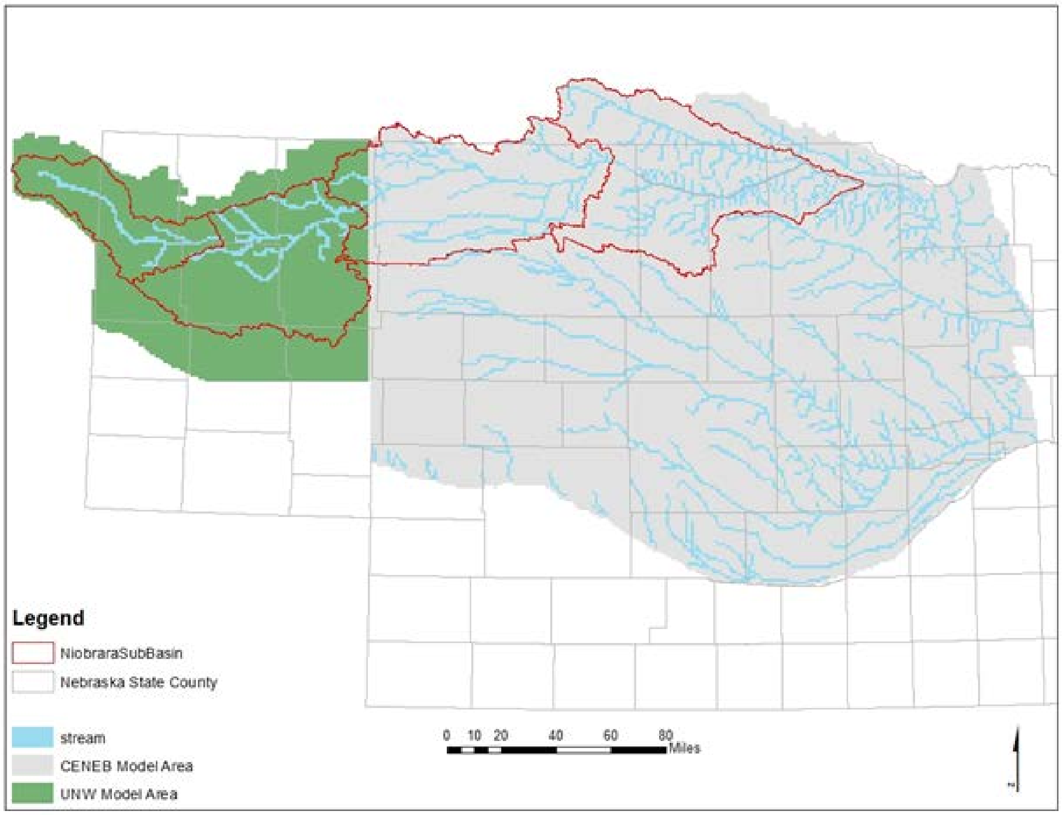

Figure 3.28. Areal coverage of the UNW and CENEB groundwater models.

As part of the Integrated Water Management Model, the groundwater model receives groundwater recharge and aquifer pumping estimates from the watershed model during the model simulations. Canal seepage into the aquifer and surface water canal diversion and return estimates are received from the surface water operations model. After the model run, simulated stream baseflow from the groundwater model is passed to the surface water operations model to calculate the total streamflow. The stepwise sequence of the different model runs in the Integrated Water Management Model is given below:

1) After incorporating the historical and climate projected weather data, the watershed model estimates the crop water demand and passes that information to the surface water operations model.
2) The surface water operations model estimates the total streamflow at different gages and points of diversion and provides an initial estimate of the amount of surface water that could be diverted for surface water irrigation.

This water delivery estimate is passed to the watershed model; and canal seepage, diversion and return estimates are passed to the groundwater model.

3) With the surface water delivery estimates, the watershed model estimates the groundwater pumping, recharge, and overland runoff amounts and passes this information to the groundwater model.
4) The groundwater model incorporates overland runoff, groundwater recharge and pumping, and canal seepage, diversion, and return data from the watershed and surface water operations models for model simulation. Then the simulated stream baseflow amounts at different gages are passed to the surface water operations model.
5) The surface water operations model incorporates the baseflow from the groundwater model in order to estimate the total streamflow amount.

Steps 2 to 5 above are repeated again as part of the model iteration, which is also called Closure Loop Runs of Integrated Water Management Model.

4 Effects of Variable Climate on Groundwater System

4.1 Baseflow Response

The following sections contain the results of the UNW and CENEB groundwater models' response in terms of stream baseflow to different climate variability and alternative water management scenarios (UNW only). Different water accounting locations were established in the model area and baseflow by different reaches were calculated from the model run results. First, the stream baseflow comparison of the historically calibrated model and baseline model were made. Second, the stream baseflow of different climate scenarios were compared with that of the baseline model. Lastly, the stream baseflow of different alternative water management scenarios were compared with that of the baseline run. Since baseflow of the CENEB model is insensitive to the changes made in UNW model, only the results from the UNW model for alternative water management scenarios are discussed.

4.1.1 Upper Niobrara White Region Base Flow Response

The locations of established water accounting points for the UNW groundwater model are illustrated in Figure 4.1.

The comparison of stream baseflow between the historically calibrated model and baseline model at different Niobrara River reaches is discussed in section below

4.1.1.1 Historically Calibrated Baseline Model Run vs Baseline No Action Model Run

Figure 4.2 depicts the differences in baseflow between the historically calibrated baseline (calibrated baseline hereafter) and baseline no action run (no alternative management scenario applied) in the Wyoming to stateline reach of the Niobrara River for the 1960 to 2010 modeling period. The baseline no action baseflow condition remained fairly stable with minimal variability with values ranging between approximately 3 cubic feet per second to less than 5 cubic feet per second during the entire period. The baseflow peaks, while similar in number and occurrence, were more pronounced in the calibrated baseline condition. The calibrated baseline modeled baseflow values show higher variability and ranged between 4 cubic feet per second and 9 cubic feet per second during the same period.

Figure 4.3 illustrates the differences in baseflow between the calibrated baseline and baseline no action run in the stateline to Agate reach. The baseline no action baseflow condition was generally stable between 5 cubic feet per second and 10 cubic feet per second, with a few peaks in the 10 cubic feet per second to 25 cubic feet per second range. Similarly, the calibrated baseline values were stable between approximately 7 cubic feet per second to 25 cubic feet per second, with a number of peaks exceeding 20 cubic feet per second up to a maximum baseflow of approximately35 cubic feet per second in 1995.

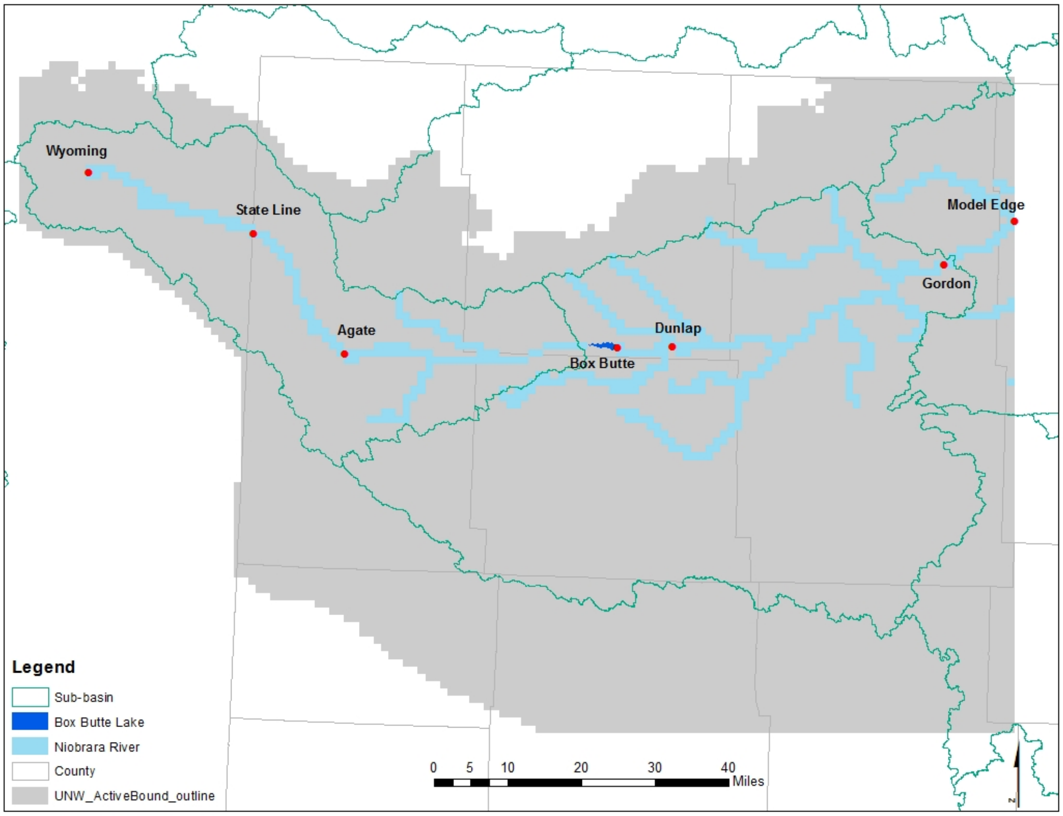

Figure 4.1. Water accounting locations of the UNW model.

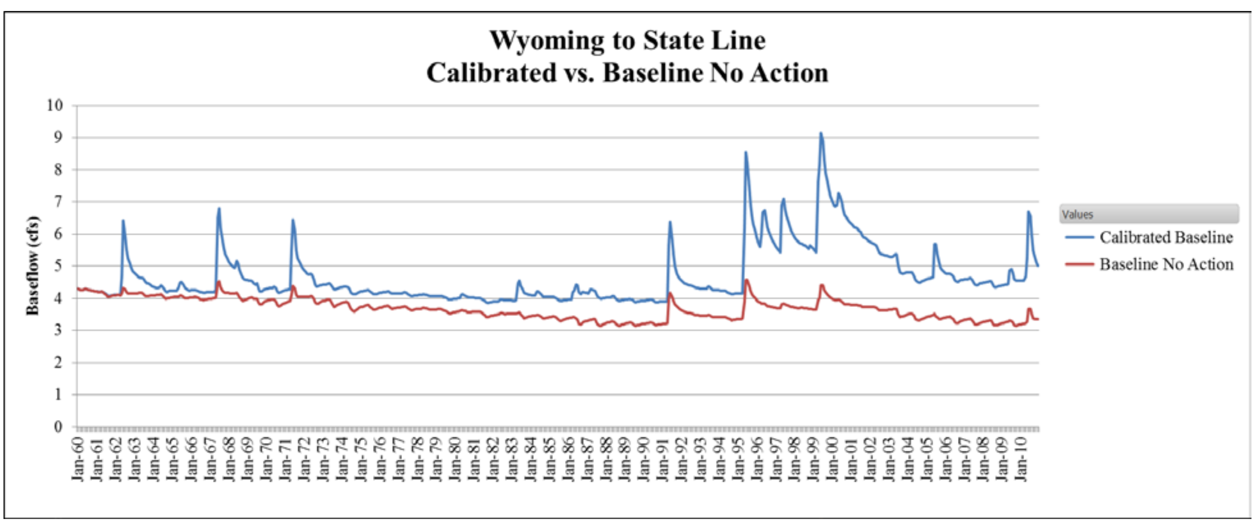

Figure 4.2. Wyoming to stateline reach baseflow comparison – Calibrated baseline vs baseline no action run.

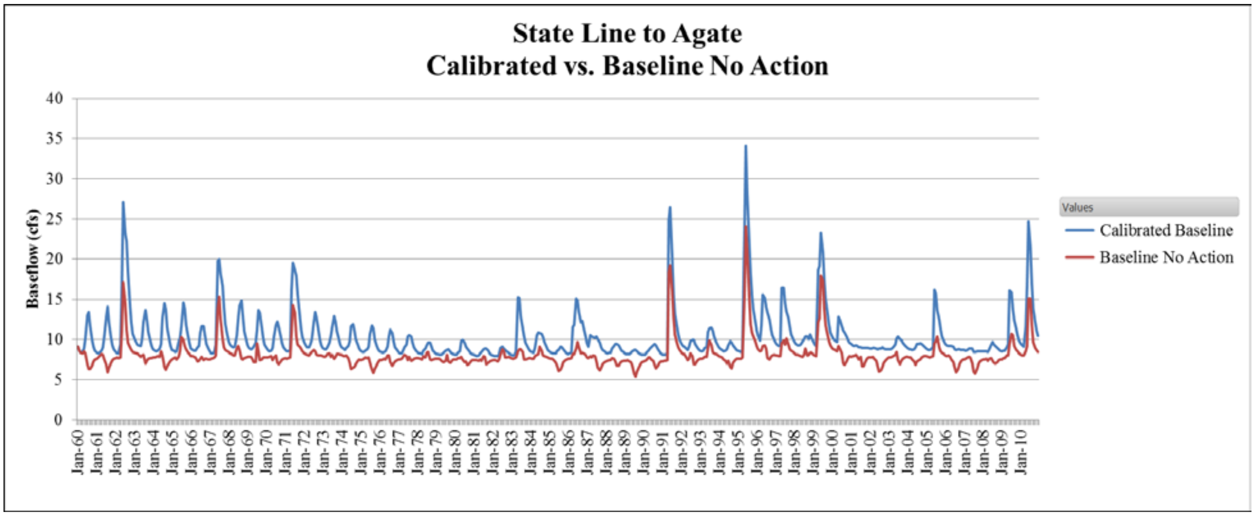

Figure 4.3. Stateline to Agate reach baseflow comparison – Calibrated baseline vs baseline no action run.

Figure 4.4 represents the differences between the calibrated baseline and baseline no action run in the Agate to Box Butte reach. The baseline no action baseflow condition was variable between years, but generally remained between 2 and 8 cubic feet per second. The 1991 and 1995 data values represent the lowest baseflow contribution (approximately 0 cubic feet per second) during the modeled period. The calibrated baseline observations show higher baseflow discharge between 1960 and 1970, followed by a decreased yet stable baseflow between 1970 and 1990. Unlike the previous reach, there are instances where the baseline no action condition was either equivalent or even higher in baseflow (e.g, 1978, 1982, 1983, 2006, and 2009).

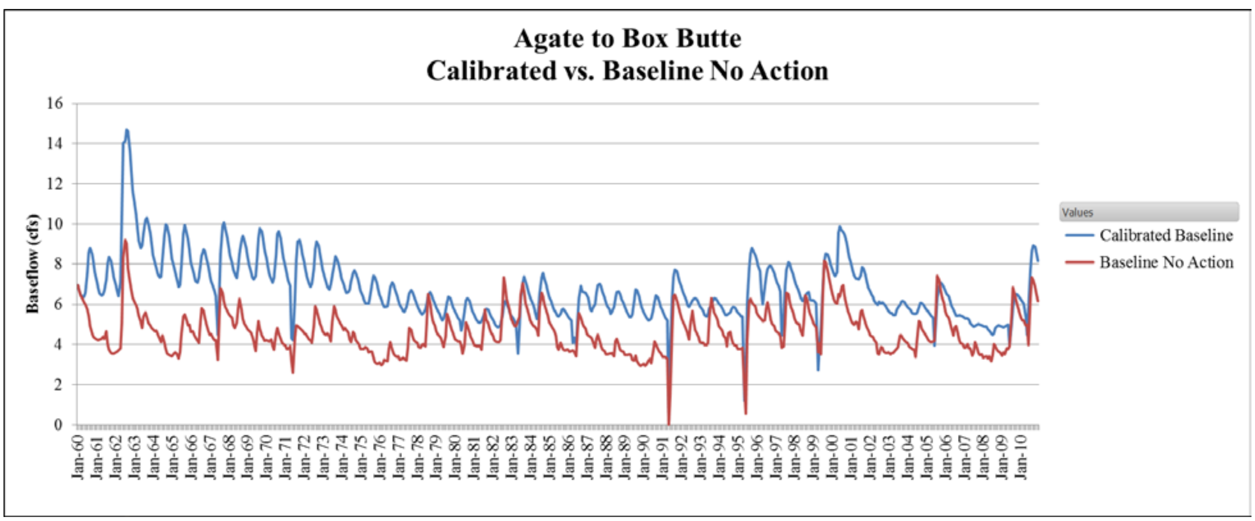

Figure 4.4. Agate to Box Butte reach baseflow comparison – Calibrated baseline vs baseline no action run.

Figure 4.5 illustrates the differences between the calibrated baseline and baseline no action run in the Box Butte to Dunlap reach. While the calibrated baseline condition is generally higher, both conditions were relatively stable during the entire modeling period. The calibrated baseline condition is typically between 1.5 cubic feet per second and 2.5 cubic feet per second, while the baseline no action ranges between 1.5 cubic feet per second and 3 cubic feet per second, but contains sporadic peak baseflows as high as 3.75 cubic feet per second.

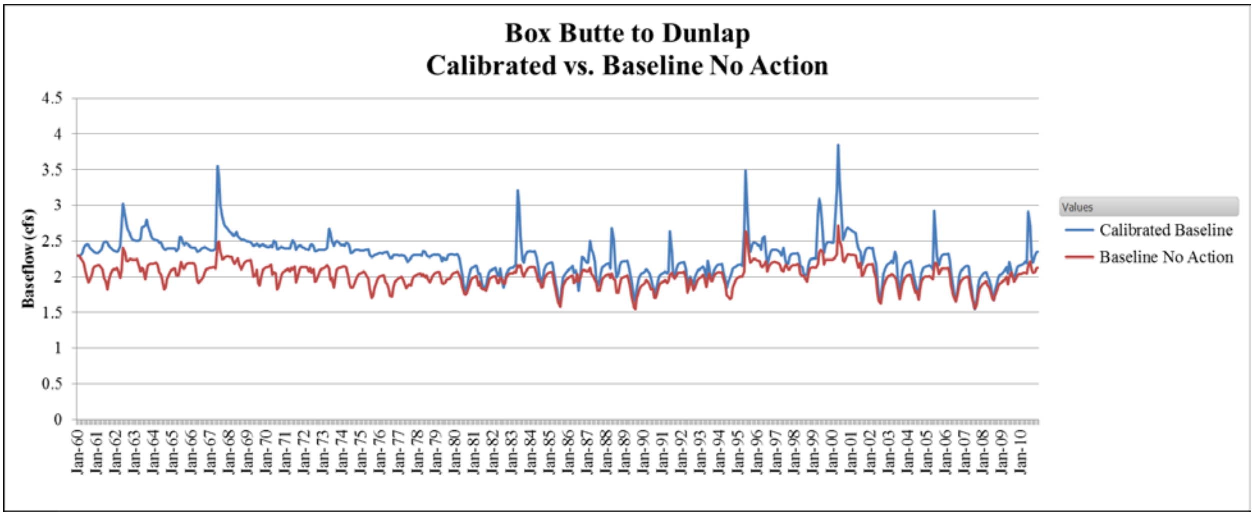

Figure 4.5. Box Butte to Dunlap reach baseflow comparison – Calibrated baseline vs baseline no action run.

Figure 4.6 illustrates the differences between the calibrated baseline and baseline no action run in the Dunlap to Gordon reach. This reach consists of substantially more baseflow compared to the previous reaches represented in the above graphs. The calibrated baseline was relatively constant between 70 cubic feet per second and 80 cubic feet per second, and generally contained more baseflow except for the 1960 to 1969 period.

Figure 4.7 depicts the differences between the calibrated baseline and baseline no action run in the Gordon to the eastern edge of the model reach. The baseline no action condition results were stable around 35 cubic feet per second for most of the modeling period with a few baseflow peaks as high as 40 cubic feet per second. Similarly, the calibrated baseline condition was stable around 40 cubic feet per second with sporadic peaks reaching 45 cubic feet per second.

4.1.1.2 Climate Variability Scenario – No Action

Figure 4.8 depicts the differences between the baseline no action and the climate action scenario outputs in the Wyoming to Stateline reach of the Niobrara River for the 1960 to 2010 modeling period. The no action low scenario produced the lowest baseflow output, declining from 4 cubic feet per second in 1960 to 3 cubic feet per second in 2000. The baseline no action and no action CT outputs were slightly higher. The no action high scenario was markedly different, especially with a number of significantly higher peaks reaching up to 9 cubic feet per second.

Figure 4.9 depicts the differences between the baseline no action and the climate action scenario outputs in the Stateline to Agate reach. The no action low scenario produced the lowest baseflow while the no action high produced the highest. However, there was a significant overlap of between no action low and CT scenarios, which ranged between 5 and 15 cubic feet per second. The no action high scenario was also stable between 5 and 15 cubic feet per second with several peaks exceeding 20 cubic feet per second and a maximum of 35 cubic feet per second.

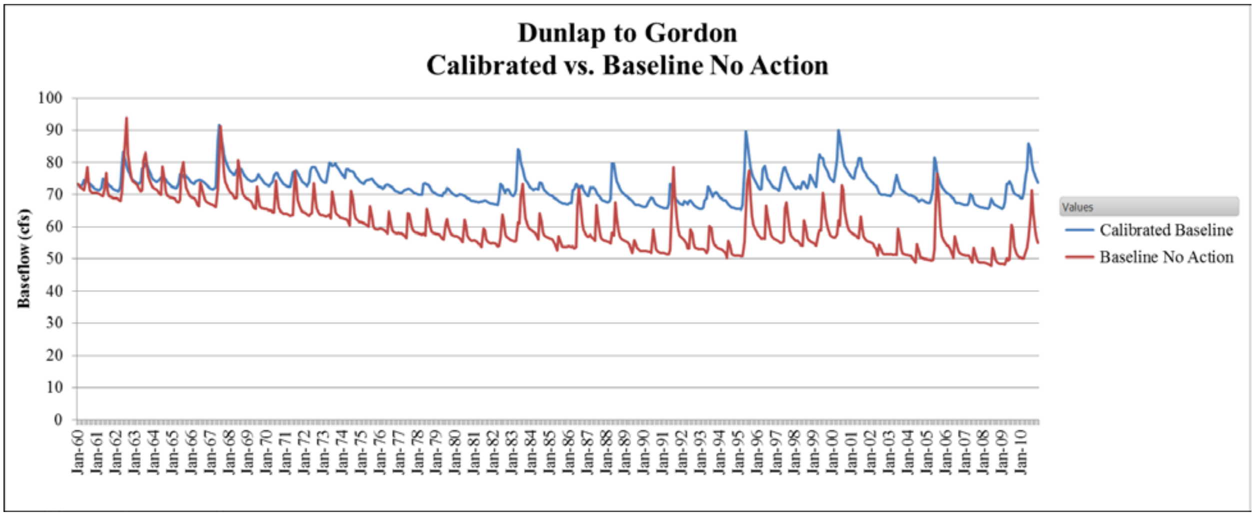

Figure 4.6. Dunlap to Gordon reach baseflow comparison – Calibrated baseline vs baseline no action run.

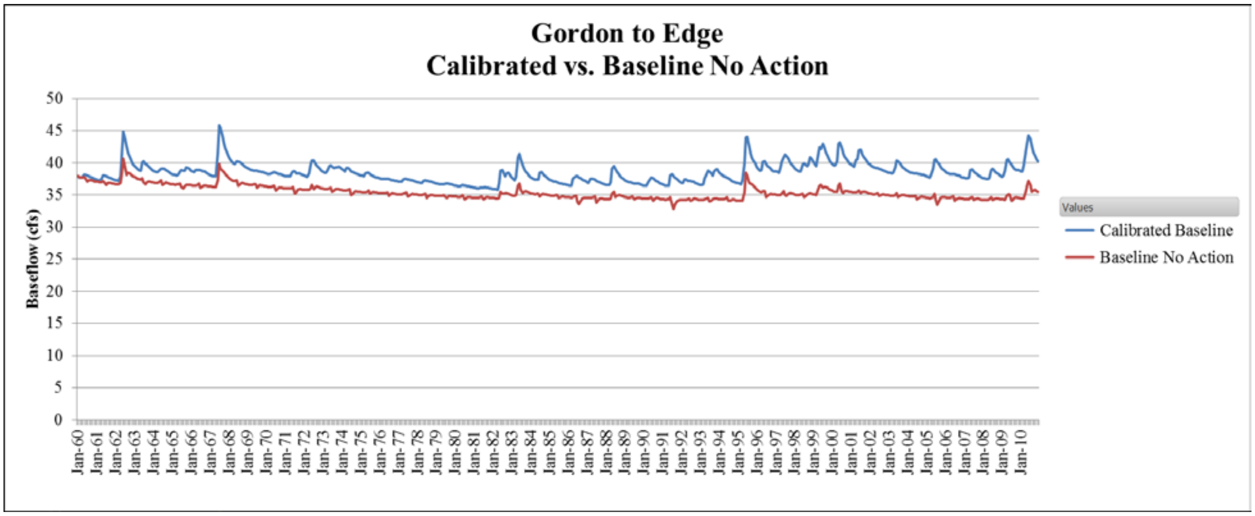

Figure 4.7. Gordon to eastern model edge reach baseflow comparison – Calibrated baseline vs baseline no action run.

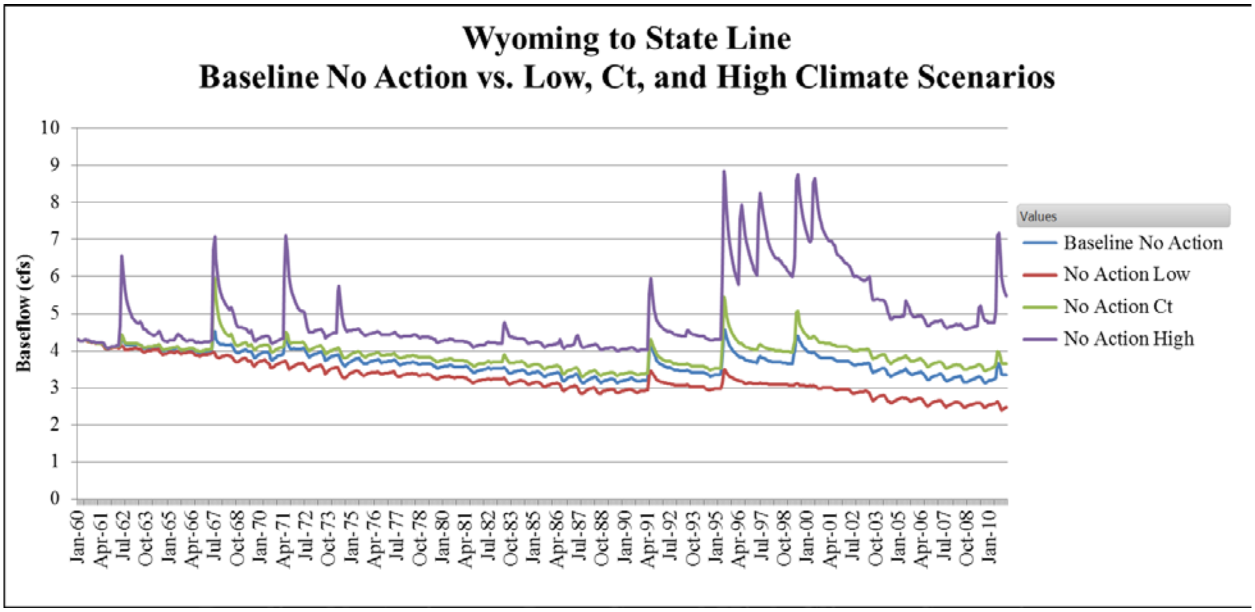

Figure 4.8. Wyoming to Stateline reach baseflow comparison –Baseline vs low, CT, and high no action runs.

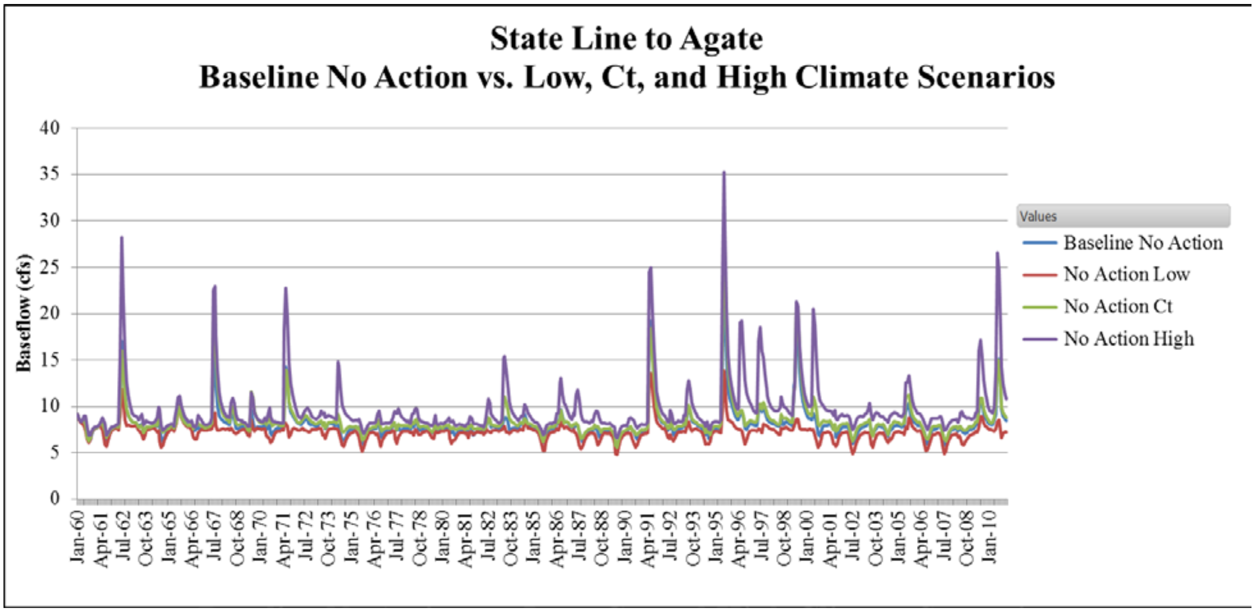

Figure 4.9. Stateline to Agate reach baseflow comparison –Baseline vs low, CT, and high no action runs.

Figure 4.10 represents the differences between the baseline no action and the climate action scenario outputs in the Agate to Box Butte reach. The no action low scenario produced the least amount of baseflow followed by the baseline no action and no action CT. The no action high scenario once again produced the highest baseflow. The baseflow generally ranged between 2 cubic feet per second and 8 cubic feet per second with the no action high scenario producing baseflow as high as 15 cubic feet per second.

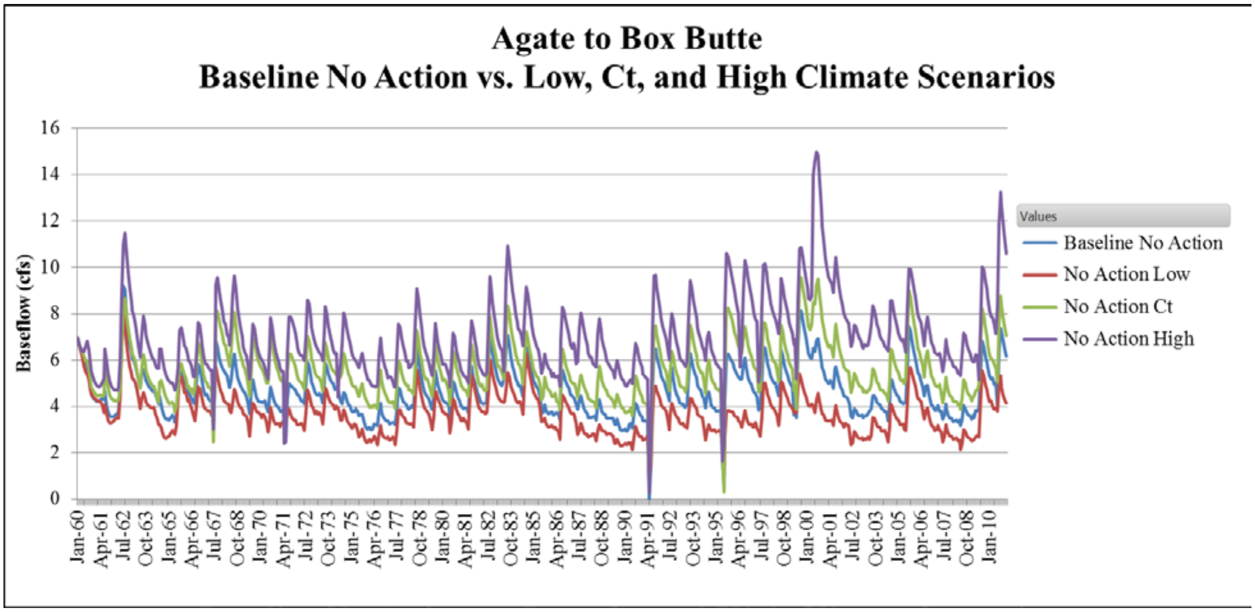

Figure 4.10. Agate to Box Butte reach baseflow comparison –Baseline vs low, CT, and high no action runs.

Figure 4.11 represents the differences between the baseline no action and the climate action scenario outputs in the Box Butte to Dunlap reach. The no action low scenario resulted in the least amount of baseflow and was typically between 1 cubic feet per second and 2 cubic feet per second. The no action and action under CT scenarios were generally within 1 cubic feet per second and 3 cubic feet per second, while the no action high scenario had baseflow ranging between 2 cubic feet per second and 4 cubic feet per second, with a maximum just under 6 cubic feet per second.

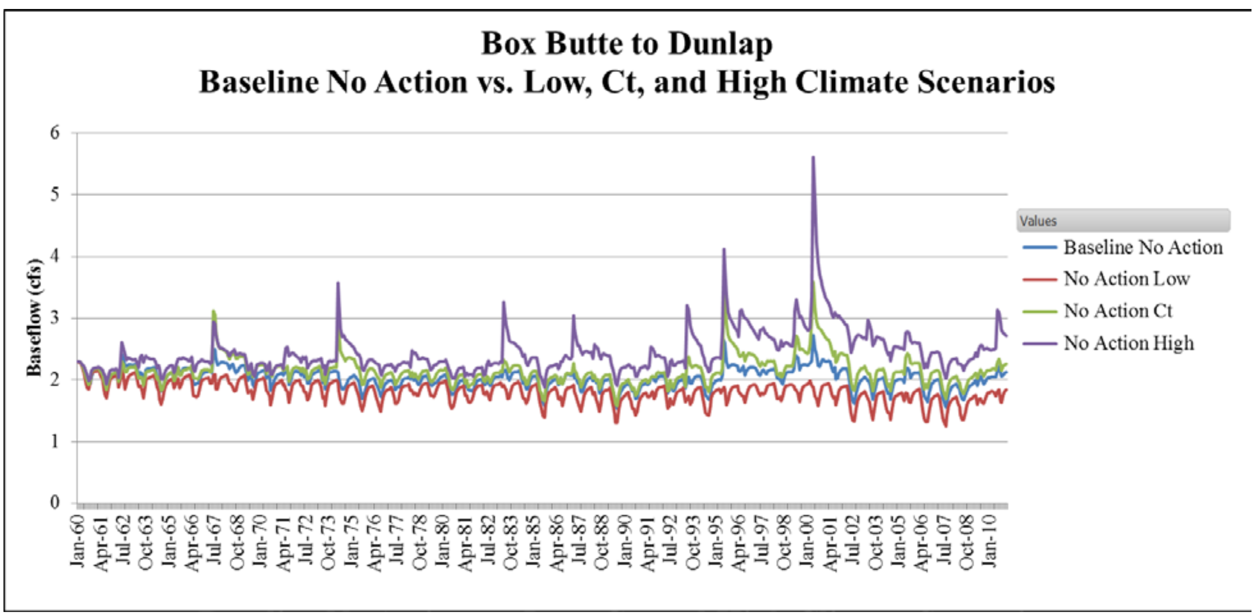

Figure 4.11. Box Butte to Dunlap reach baseflow comparison –Baseline vs low, CT, and high no action runs.

Figure 4.12 illustrates the differences between the baseline no action and the climate action scenario outputs in the Dunlap to Gordon reach. The no action low scenario resulted in the least amount of baseflow and was typically between 1 cubic feet per second and 2 cubic feet per second. The no action and action under central tendency scenarios were generally within 1 cubic feet per second and 3 cubic feet per second, while the no action high scenario had baseflow ranging between 2 cubic feet per second and 4 cubic feet per second, with a maximum just under 6 cubic feet per second.

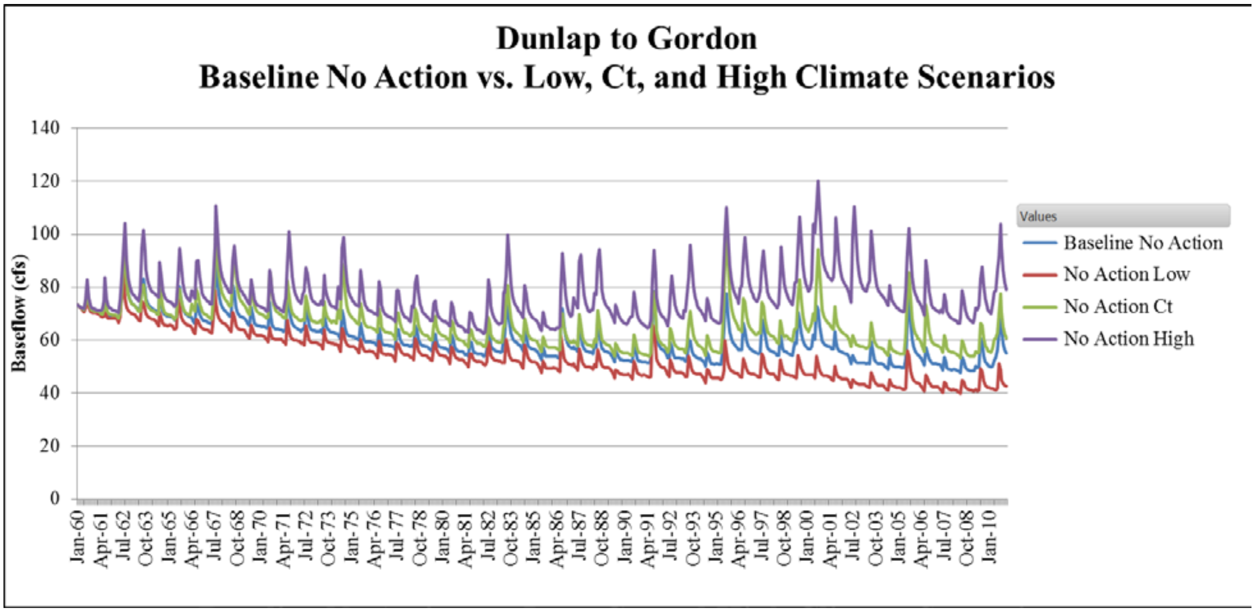

Figure 4.12. Dunlap to Gordon reach baseflow comparison –Baseline vs low, CT, and high no action runs.

Figure 4.13 represents the differences between the baseline no action and the climate action scenario outputs in the Gordon to the eastern edge of the model reach. The no action low, baseline no action, and no action CT ranged between approximately 33 cubic feet per second to 40 Central Tendency and closely overlapped until 1995. The no action high generated the most baseflow ranging from 35 cubic feet per second to 47 cubic feet per second.

4.1.1.3 Alternative Water Management Scenarios Without Climate Variability vs Baseline No Action Model Run

In this section the impacts of alternative water management scenarios were analyzed without accounting the influence of climate variability. The baseflow at different reaches of the Niobrara River for the two alternatives, Mirage Flats Pumping Station (Alt1) and Mirage Flats Canal Recharge (Alt2), were compared to that of the baseline run.

Since the changes made in alternative water management scenarios are near Mirage Flats area, they had no impact on baseflow of the upper reaches of the Niobrara River. Therefore, in the following reaches: Wyoming to stateline,

stateline to Agate, and Agate to Box Butte, the baseflow of Alt1 and Al2 no action were identical to that of the baseline no action run.

Figure 4.14 represents the differences between the baseline no action and the alternative water management scenarios in the Box Butte to Dunlap reach. The Alt1 consists of a surface water diversion location change scenario and Alt2 is the Mirage Flats canal recharge scenario. When compared to Alt1, the baseline baseflow output did not show any significant difference and ranged between approximately 1.5 cubic feet per second to 2.5 cubic feet per second. The Alt2 run generated slightly higher baseflow compared to the baseline.

Figure 4.15 represents the differences between the baseline no action and the alternative water management scenarios in the Dunlap to Gordon reach. The baseline run has higher baseflow as compared to that of Alt1 and Alt2 run. The outputs between the baseline and Alt2 represent some amount of overlap throughout the modeling period, but baseflow of Alt1 is clearly below baseline baseflow curve by around five cubic feet per second.

The purpose of Alt1 scenario is to increase the efficiency of irrigation system in Mirage Flats area by installing pumping station downstream and eliminating seepage from present canal to the groundwater system; however the seepage losses in the canal are a significant source of localized recharge which does not exist in Alt1 scenario. In Alt1 run the reduction in seepage losses which contributes to the baseflow of the aquifer system sufficiently exceeds the increase in recharge (direct and indirect recharge) and reductions in groundwater pumping, therefore the baseflow of Alt1 run is lower than that of baseline run.

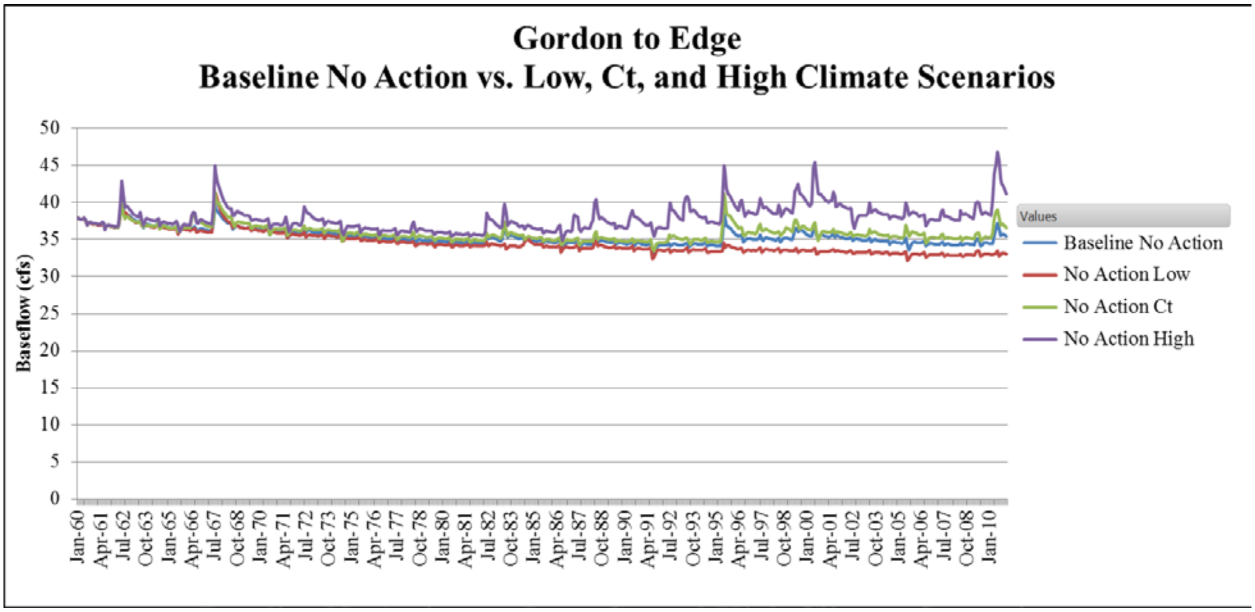

Figure 4.13. Gordon to model eastern edge reach baseflow comparison –Baseline vs low, CT, and high no action runs.

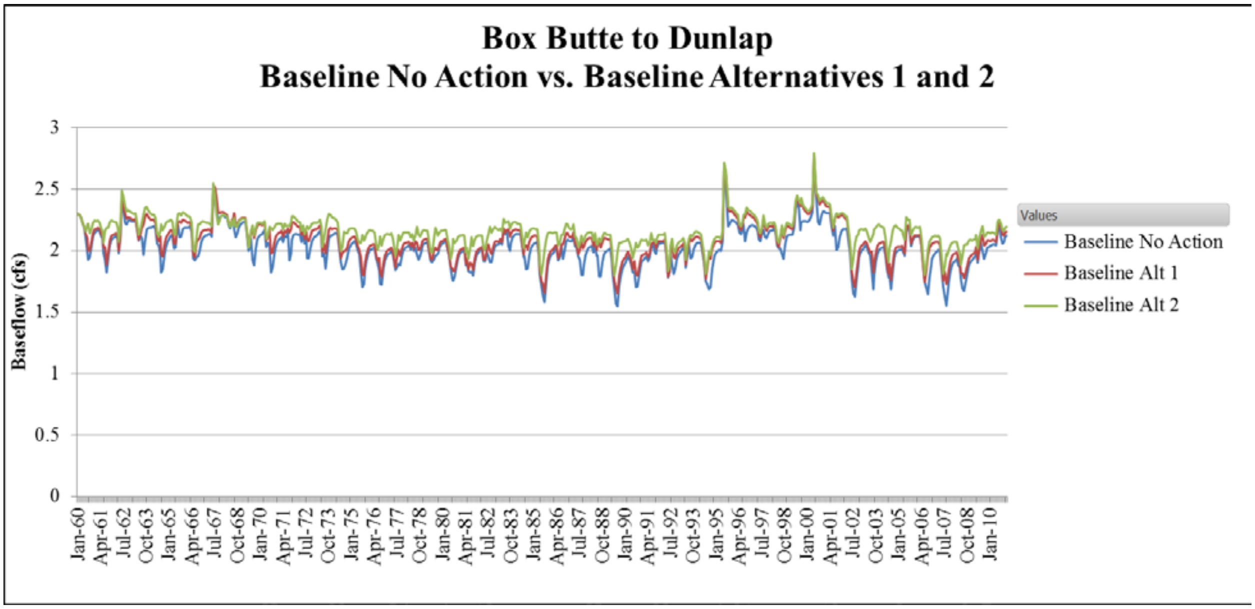

Figure 4.14. Box Butte to Dunlap reach baseflow comparison – Baseline no action vs Alt1 and Alt2 no action runs.

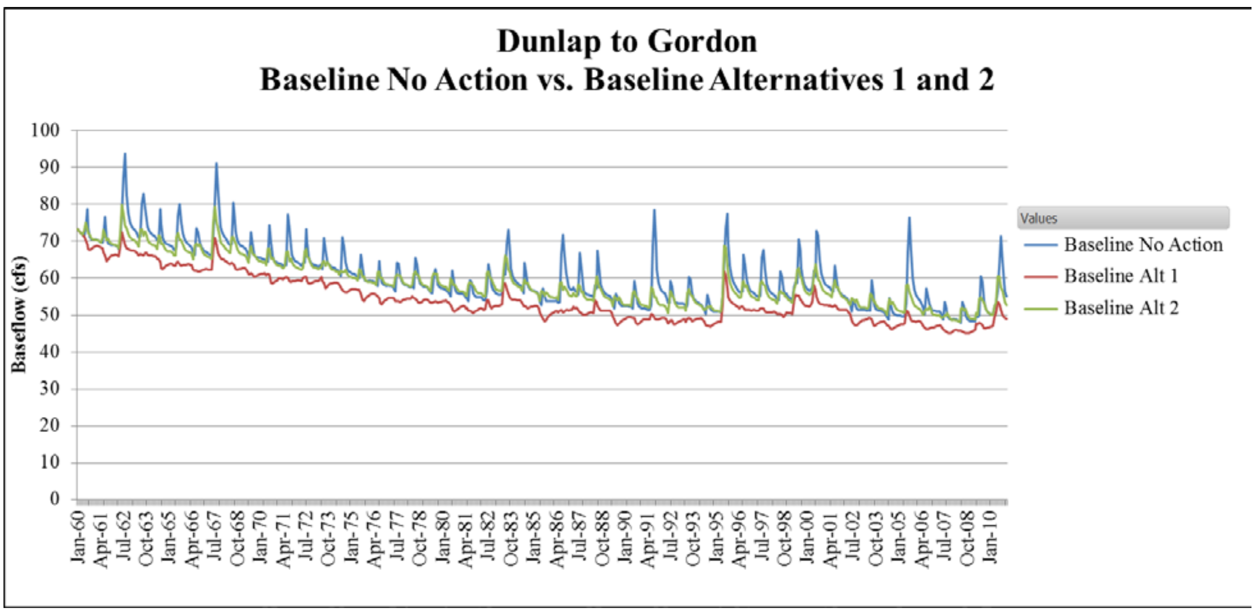

Figure 4.15. Dunlap to Gordon Reach baseflow comparison – Baseline no action vs Alt1 and Alt2 no action runs.

In Alt2 scenario canal and laterals in Mirage Flats Irrigation District are used for groundwater recharge rather than crop irrigation delivery. The cumulative effect of changes in groundwater recharge (direct and indirect recharge) and source of crop irrigation (increase in groundwater pumping) led to decrease in baseflow of Alt2 run as compared to that of baseline. These changes is stream reach baseflow due to alternative scenarios are in localized scale rather than regional.

Figure 4.16 represents the differences between the baseline no action and the alternative water management scenarios in the Gordon to the eastern edge of the model reach. The Alt1 and Alt2 scenarios were not substantially different from the baseline run. The baseflow range for all three runs ranged from approximately 33 cubic feet per second to 41 cubic feet per second.

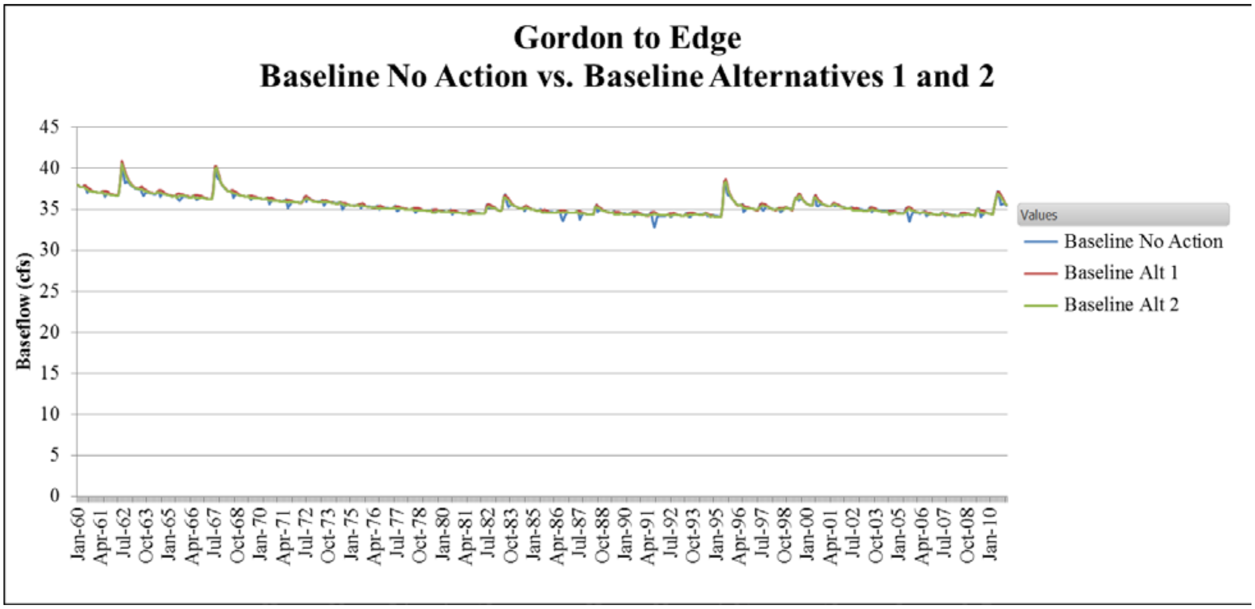

Figure 4.16. Gordon to edge of model reach baseflow comparison – Baseline no action vs Alt1 and Alt2 no action runs.

4.1.1.4 Climate Variability with Alternative Water Management Scenarios

In this section, both the impacts of alternative water management scenarios and the influence of climate variability were analyzed. Through an analysis of baseflow at different reaches of the Niobrara River, the effect of the two alternative management scenarios, Mirage Flats Pumping Station (Alt1) and Mirage Flats Canal Recharge (Alt2), were compared to that of the baseline run at different levels of water availability.

4.1.1.4.1 Climate variability scenario – Mirage Flats Pumping Station (Alt1) (i.e., baseline of Alt1 vs low, CT, and high scenarios of Alt1)

Since the changes made in alternative water management scenarios are near Mirage Flats area, they had no impact on baseflow of the upper reaches of the Niobrara River. Therefore, in the following reaches: Wyoming to stateline, stateline to Agate, and Agate to Box Butte, the baseflow of Alt1 and Al2 no action were identical to that of the baseline no action run.

Figure 4.17 represents the differences between the baseline Alt1 (surface water diversion location change) and the Alt1 in low, CT, and high climate scenarios in the Box Butte to Dunlap reach. Change in water diversion location combined with the low climate scenario resulted in the lowest baseflow output; however, the values were not significantly different than the baseline Alt1 run. The Alt1 CT and Alt1 high runs produced equivalent baseflow values ranging between approximately 1.8 cubic feet per second to 3.5 cubic feet per second. The high scenario run, however, consisted of a peak higher than the CT, exceeding 5 cubic feet per second.

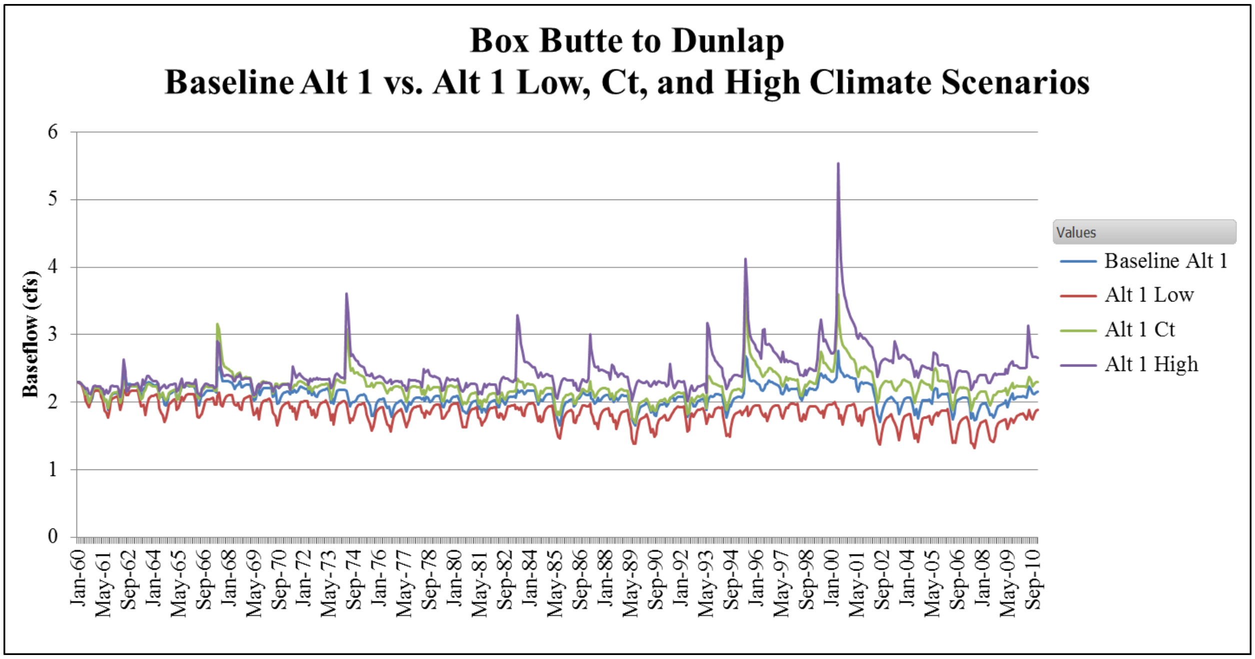

Figure 4.17. Box Butte to Dunlap reach baseflow comparison – Baseline Alt1 vs low, CT, and high Alt1 runs.

Figure 4.18 represents the differences between the baseline Alt1 (surface water diversion location change) and the Alt1 in low, CT, and high climate scenarios in the Dunlap to Gordon Reach. Change in water diversion location combined with the low climate scenario resulted in the lowest baseflow output, followed by the baseline and CT runs. The high climate scenario generated the highest baseflow output and ranged between 60 cubic feet per second and 92 cubic feet per second.

Figure 4.19 represents the differences between the baseline Alt1 (surface water diversion location change) and the Alt1 in low, CT, and high climate scenarios in the Gordon to the eastern edge of the model reach. The low, baseline, and CT scenarios resulted in baseflow with minor differences and ranged from approximately 33 cubic feet per second to 40 cubic feet per second. The high climate scenario generated slightly higher baseflow and ranged between approximately 37 cubic feet per second and 47 cubic feet per second.

4.1.1.4.2 Climate variability scenario – Mirage Flats Recharge (Alt2) (i.e., baseline of Alt2 vs low, CT, and high scenarios of Alt2

Since the changes made in alternative water management scenarios are near Mirage Flats area, they had no impact on baseflow of the upper reaches of the Niobrara River. Therefore, in the following reaches: Wyoming to stateline,

stateline to Agate, and Agate to Box Butte, the baseflow of Alt2 was identical to that of the baseline run.

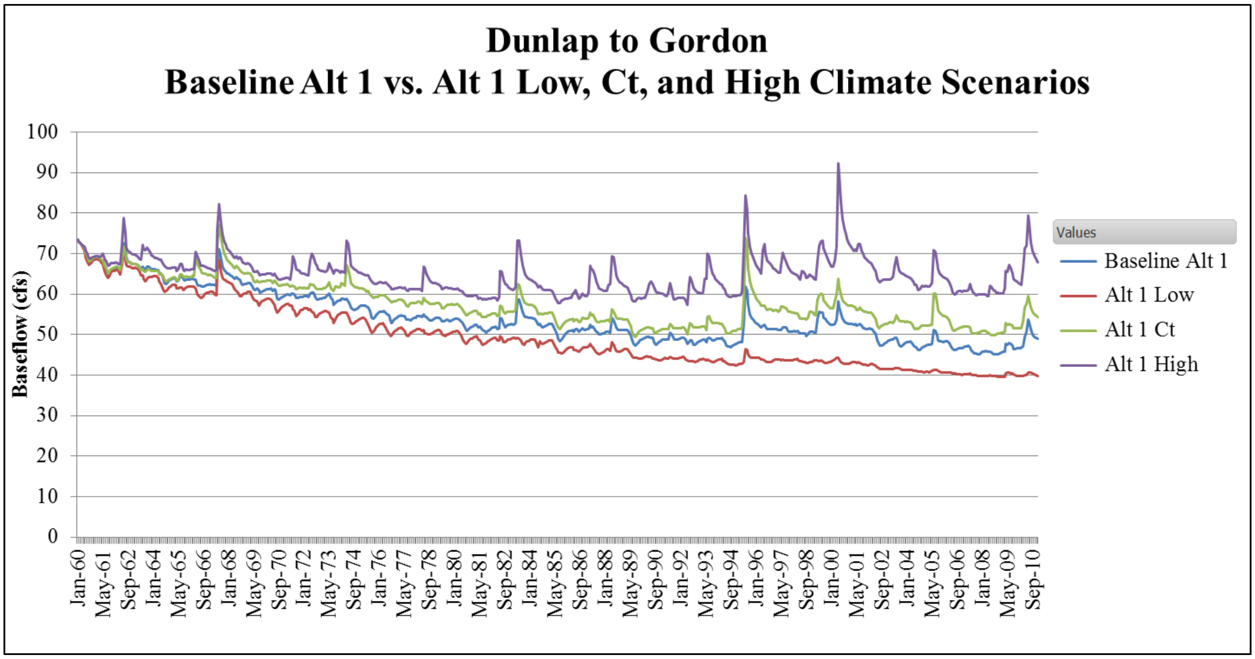

Figure 4.18. Dunlap to Gordon reach baseflow comparison – Baseline Alt1 vs low, CT, and high Alt1 runs.

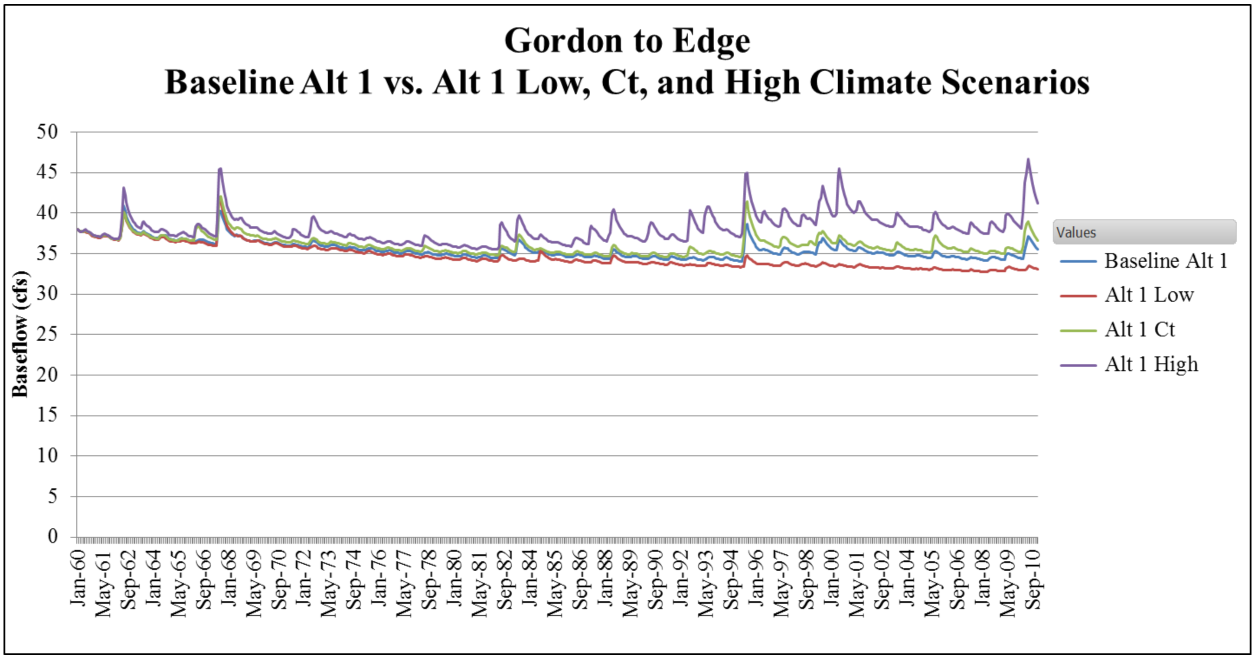

Figure 4.19. Gordon to model edge reach baseflow comparison – Baseline Alt1 vs low, CT, and high Alt1 runs.

Figure 4.20 represents the differences between the baseline Alt2 (Mirage Flats canal system operated as recharge facility) and the Alt2 in low, CT, and high climate scenarios in the Dunlap to Box Butte reach. The low climate scenario showed minor difference in baseflow compared to the baseline. The CT and high climate runs generated slightly higher baseflow and ranged between approximately 2 cubic feet per second to 5.5 cubic feet per second.

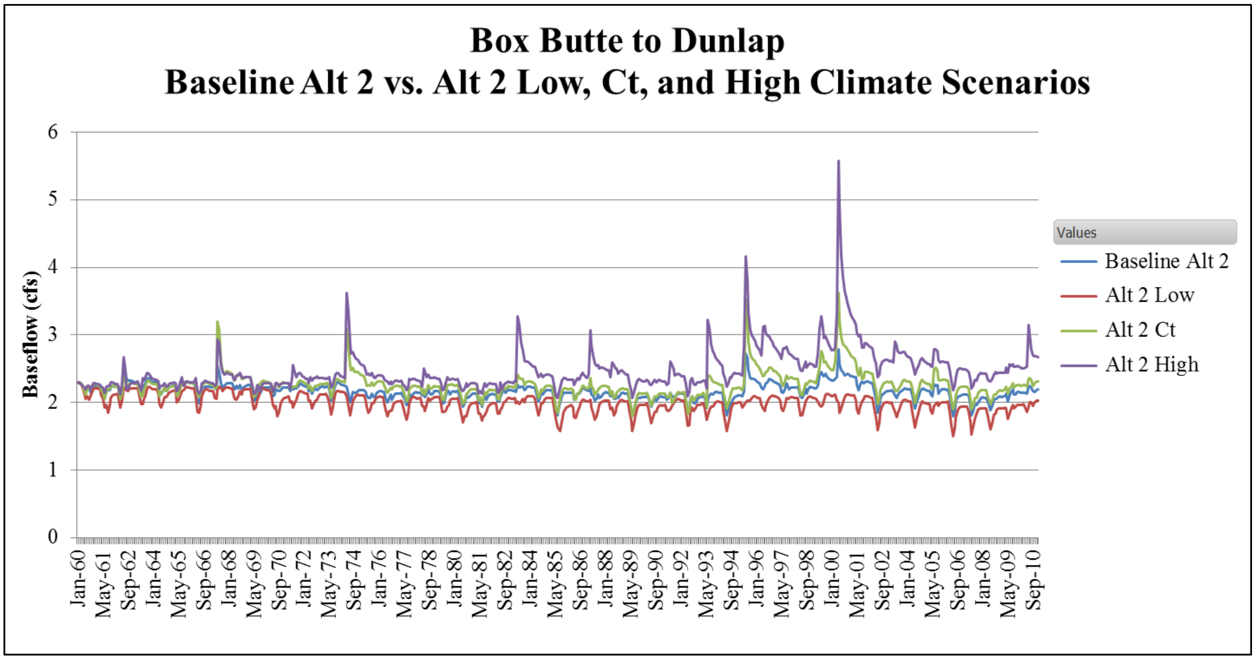

Figure 4.20. Box Butte to Dunlap reach baseflow comparison – Baseline Alt1 vs low, CT, and high Alt2 runs.

Figure 4.21 represents the differences between the baseline Alt2 (Mirage Flats canal system operated as recharge facility) and the Alt2 in low, CT, and high climate scenarios in the Dunlap to Gordon reach. The four scenarios generated an equivalent amount of baseflow in the early years of the model run. The differences became greater starting in 1970 and were more substantial by 2000. The low climate scenario baseflow ranged between approximately 40 cubic feet per second and 80 cubic feet per second, while the high climate run ranged between approximately 78 cubic feet per second and 100 cubic feet per second.

Figure 4.22 represents the differences between the baseline Alt2 (Mirage Flats canal system operated as recharge facility) and the Alt2 in low, CT, and high climate scenarios in the Gordon to the eastern edge of the model reach. All of the model run scenarios produced equivalent baseflow output until 1980. The low climate scenario generated marginally lower baseflow. The baseline run and the CT scenarios were mostly identical with minor differences starting in the late 1990s. The high climate scenario generated slightly higher baseflow and ranged between 35 cubic feet per second and 45 cubic feet per second.

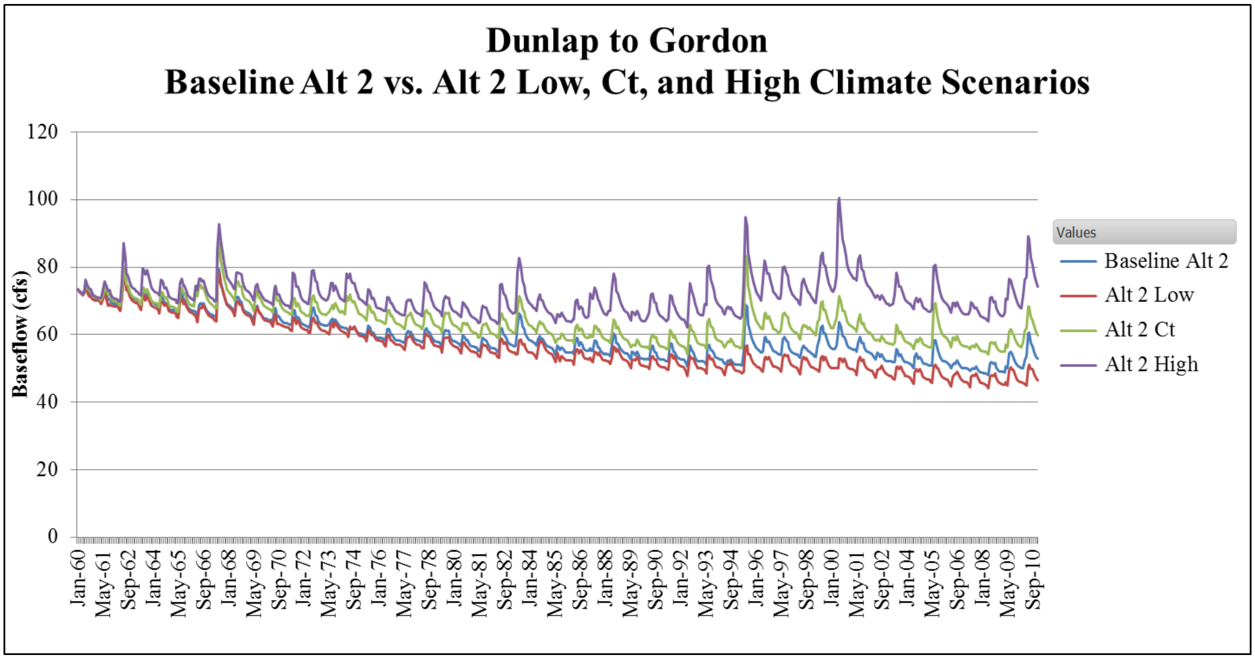

Figure 4.21. Dunlap to Gordon reach baseflow comparison – Baseline Alt1 vs low, CT, and high Alt2 runs.

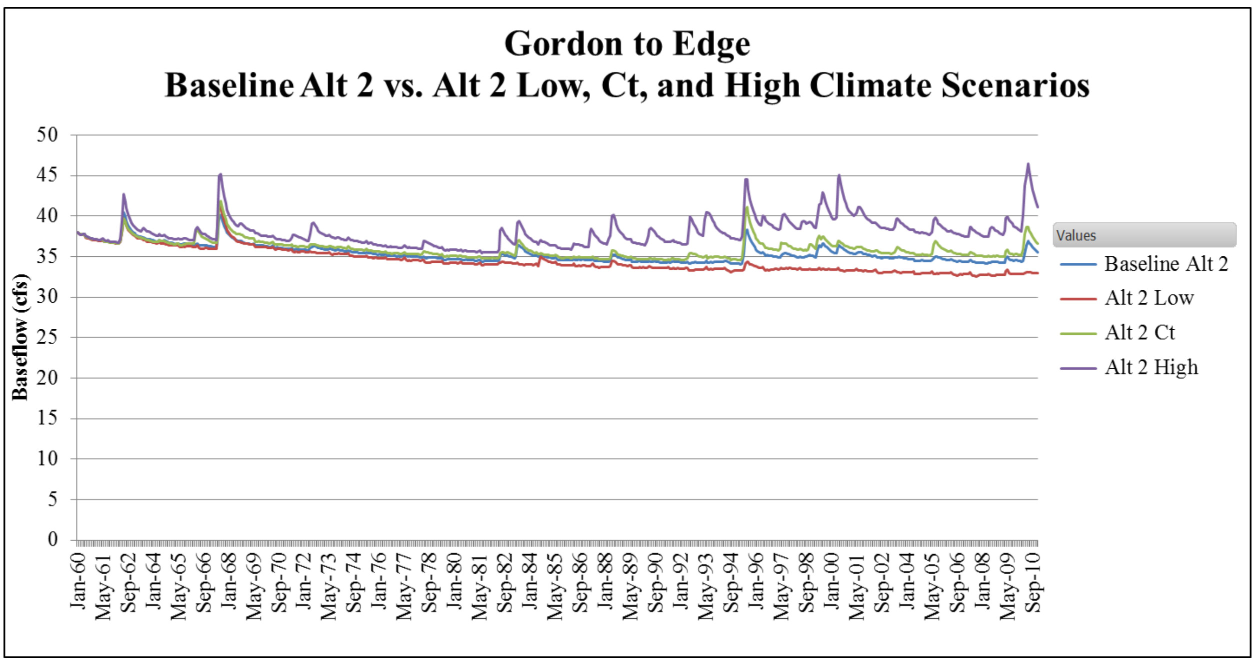

Figure 4.22. Gordon to model edge reach baseflow comparison – Baseline Alt1 vs low, CT, and high Alt2 runs.

4.1.2 Central Nebraska Region Baseflow Response

4.1.2.1 Historically Calibrated Baseline Model Run vs. Baseline No Action Model Run

In CENEB model region only the impact of climate scenarios were analyzed. Since baseflow of the CENEB model is not sensitive to changes in baseflow in the UNW model (as explained in section 4.1), only the impacts of different levels of water availability scenarios in middle Niobrara River area were analyzed. Figure 4.23 illustrates the baseflow accounting point of the middle Niobrara River area in CENEB model.

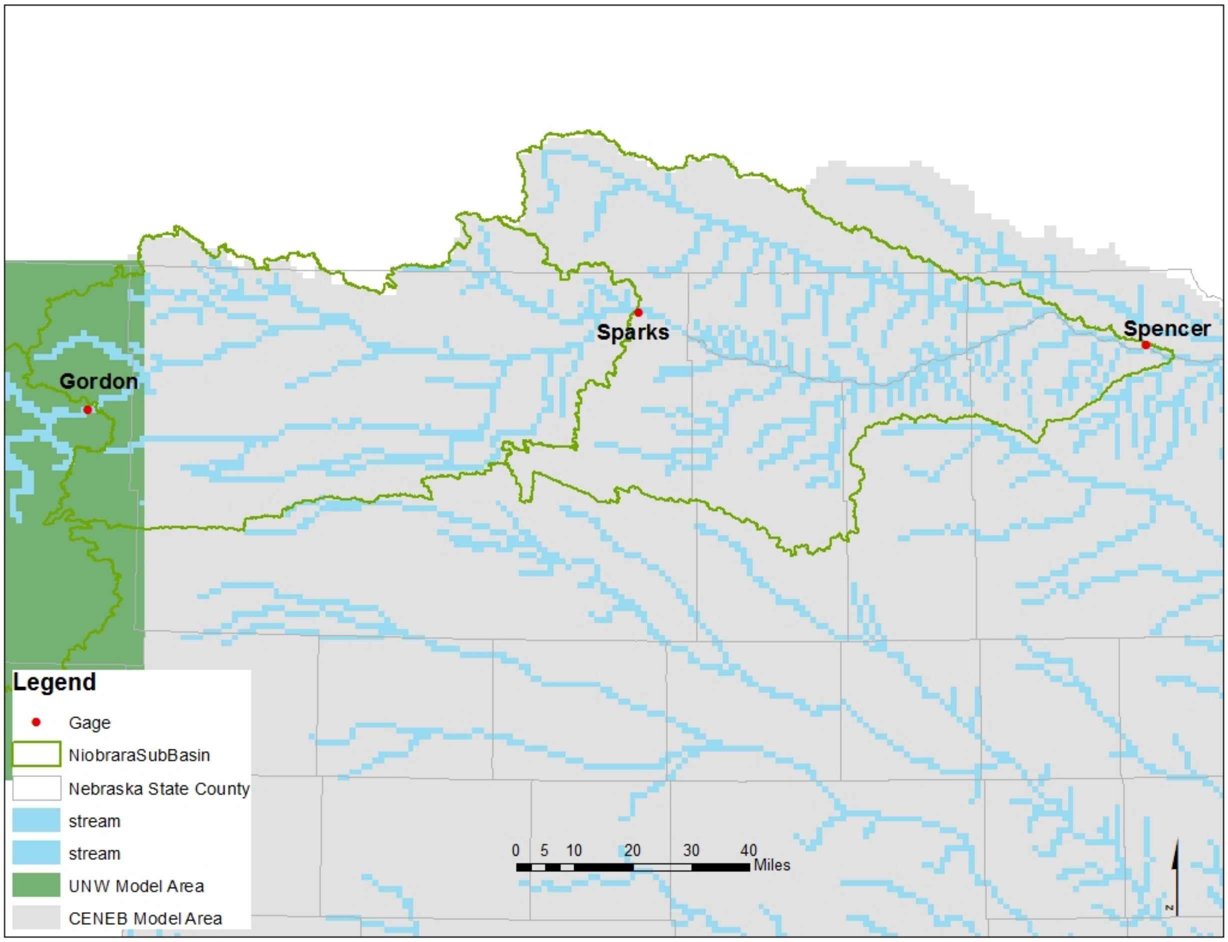

Figure 4.23. Gage and baseflow accounting locations.

Figure 4.24 represents a comparison between the historically calibrated baseline run with the baseline no action run in the Gordon to Sparks reach. The calibrated baseline run produced substantially higher baseflow than the baseline no action model run. The calibrated run ranged between 550 cubic feet per second to 850 cubic feet per second, while the baseline no action range was from approximately 490 cubic feet per second to 640 cubic feet per second. The differences between these two runs were greatest in the first half (1960 to 1985) and least in the second half (1986 to 2010) of the model run time periods.

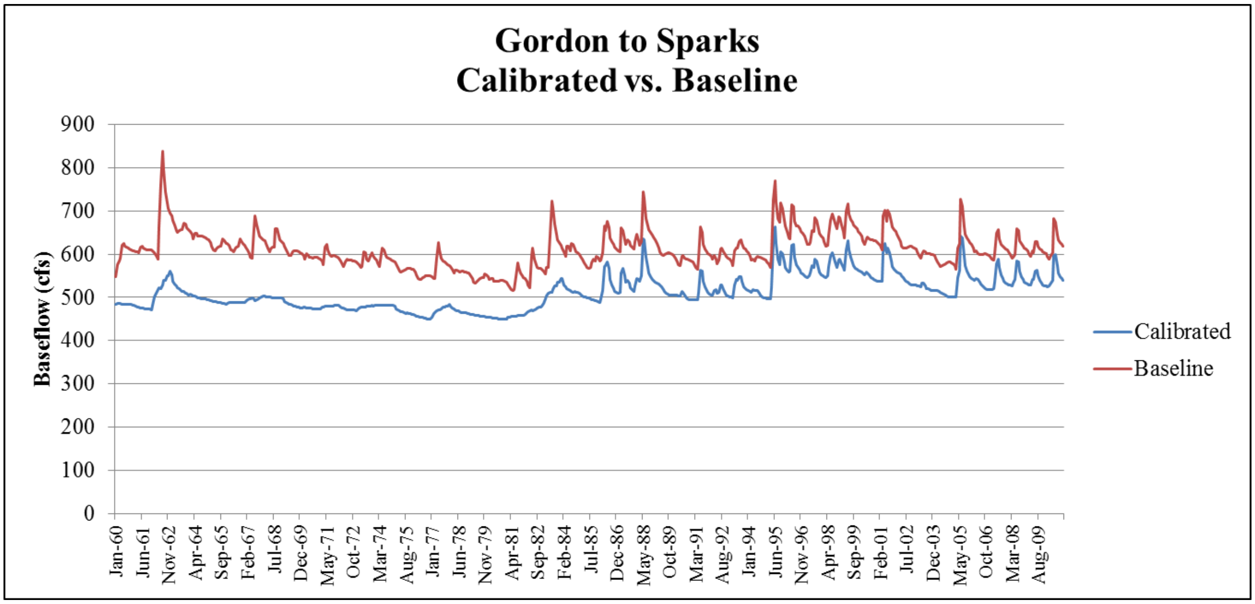

Figure 4.24. Gordon to Sparks reach baseflow comparison – Calibrated vs baseline no action runs.

Figure 4.25 represents a comparison between the historically calibrated baseline run with the baseline no action run in the Sparks to Spencer reach. The calibrated baseline run generated higher baseflow than the baseline no action model run, until 1985. The calibrated run ranged between 400 cubic feet per second to 1,025 cubic feet per second, while the baseline no action range was from approximately 300 cubic feet per second to 850 cubic feet per second. The baseflow outputs overlap significantly between these runs from 1985 until the end of the model run time period.

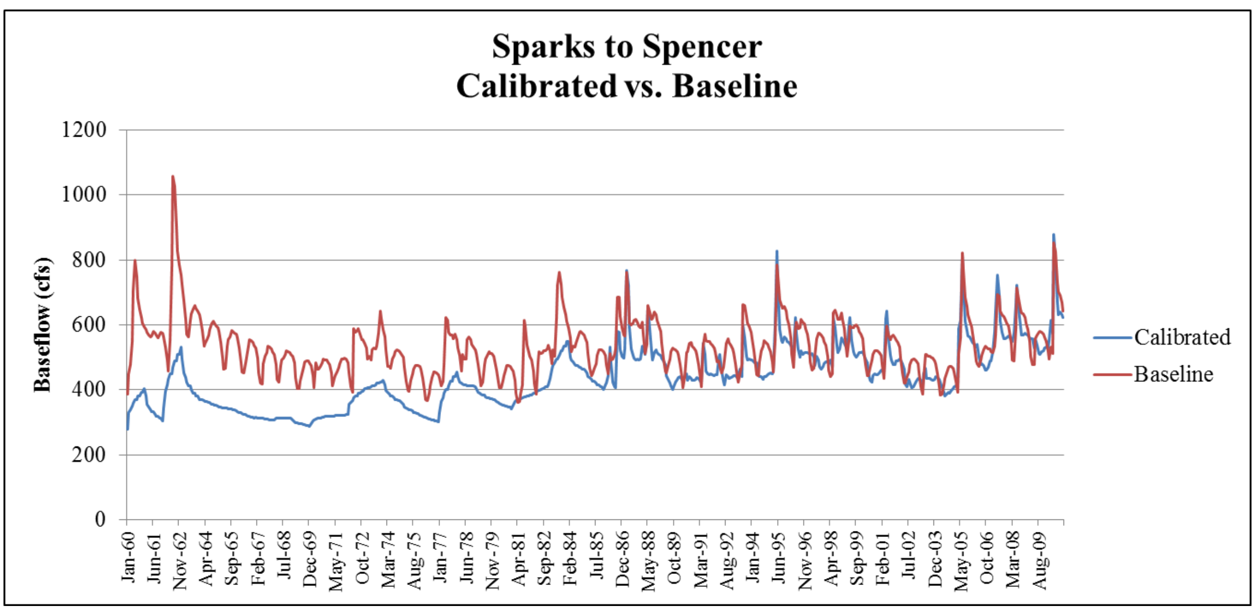

Figure 4.25. Sparks to Spencer reach baseflow comparison – Calibrated vs baseline no action runs.

4.1.2.2 Climate Variability Scenarios

Figure 4.26 represents a comparison between the baseline run with the low, CT, and high climate scenario runs in the Gordon to Sparks reach. The high climate scenario run generated higher baseflow than the baseline, low, or high climate scenarios. The differences between these scenarios were lower in the early time period and substantially greater starting in the 1980s. The baseline and low climate scenarios produced almost similar baseflow outputs ranging from 550 cubic feet per second to 850 cubic feet per second. The high climate scenario generated baseflow as high as 1,050 cubic feet per second.

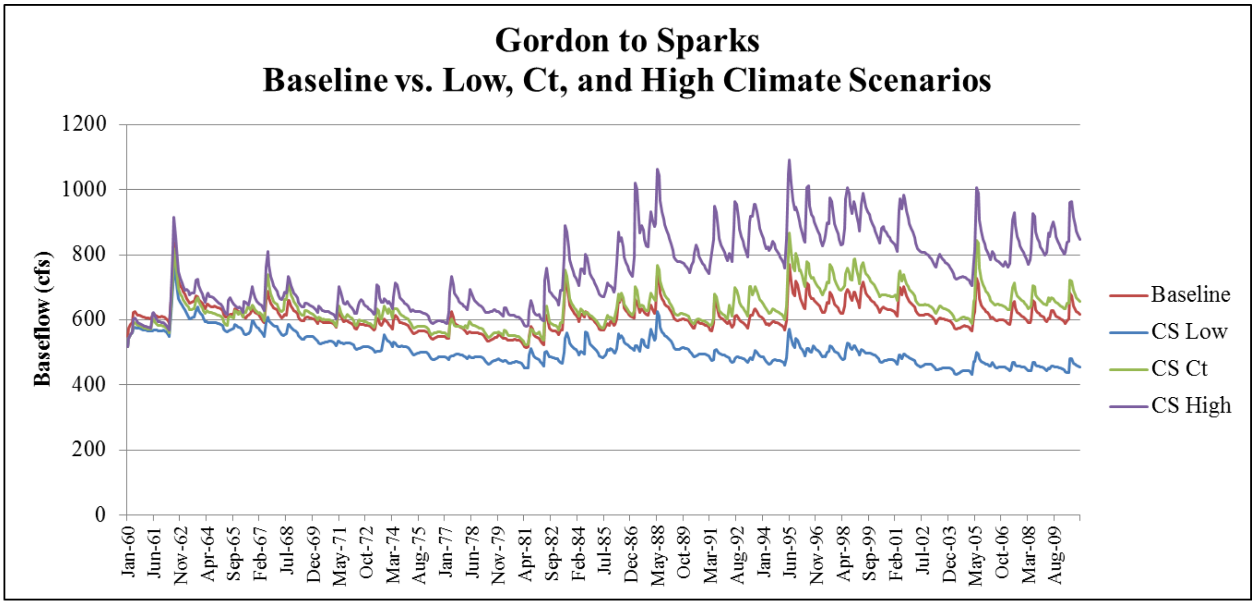

Figure 4.26. Gordon to Sparks reach baseflow comparison – Baseline vs low, CT, and high scenarios runs.

Figure 4.27 represents a comparison between the baseline run with low, CT, and high climate scenario runs in the Sparks to Spencer reach. Unlike the previous runs where low climate scenarios produced the least baseflow and the high climate scenario produced the most, the typical hierarchy of baseflow outputs were not apparent in this run. Although the high climate scenario generated the biggest peaks (up to 1,200 cubic feet per second), there is consistent overlap between the scenarios, particularly between the baseline and low climate scenarios and the CT and high climate scenarios.

4.2 Groundwater Level Change

4.2.1 UNW Region Response

The groundwater level in Box Butte County in the Upper Niobrara White area is of concern since this area exhibited very high levels of drawdown in the past due to groundwater pumping for irrigated agriculture. In this section, the change in groundwater levels in Box Butte County under different water availability scenarios is analyzed.

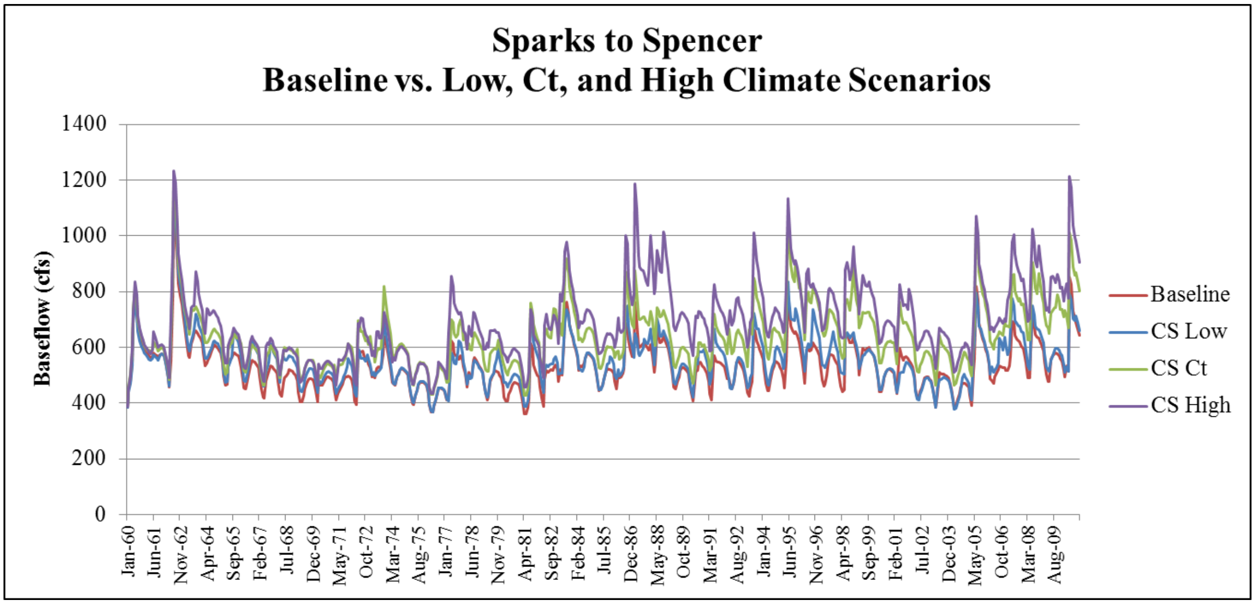

Figure 4.27. Sparks to Spencer reach baseflow comparison – Baseline vs low, CT, and high scenarios runs.

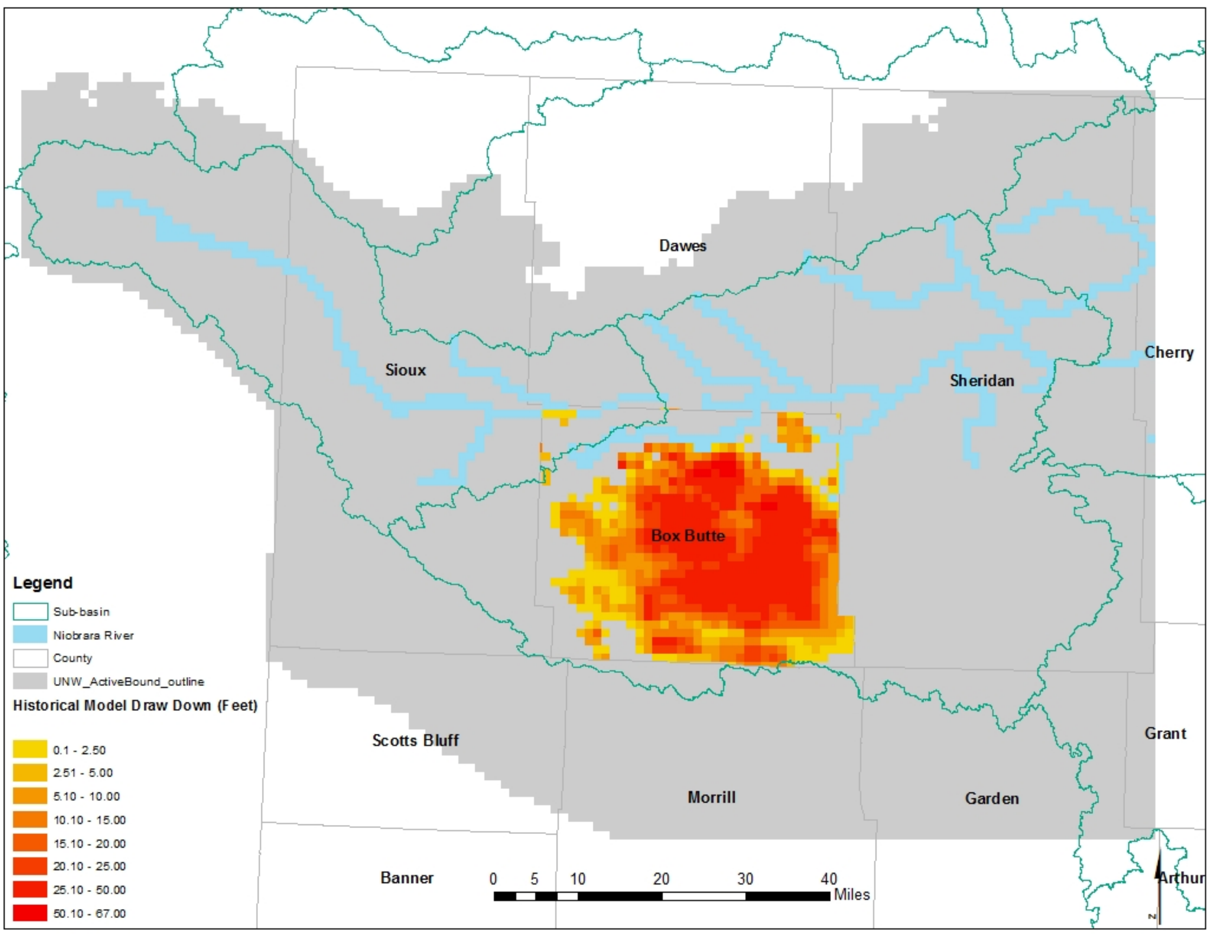

Figure 4.28. Historical model draw down (1960–2010).

Figure 4.28 represents the historical model drawdown (1960-2010) in Box Butte County. The model drawdown indicates that the majority of the Box Butte area has experienced a drop in the groundwater table of up to 67 feet. The outskirts of the Box Butte area has exhibited relatively less groundwater drawdown, ranging from 0.1 to 20 feet.

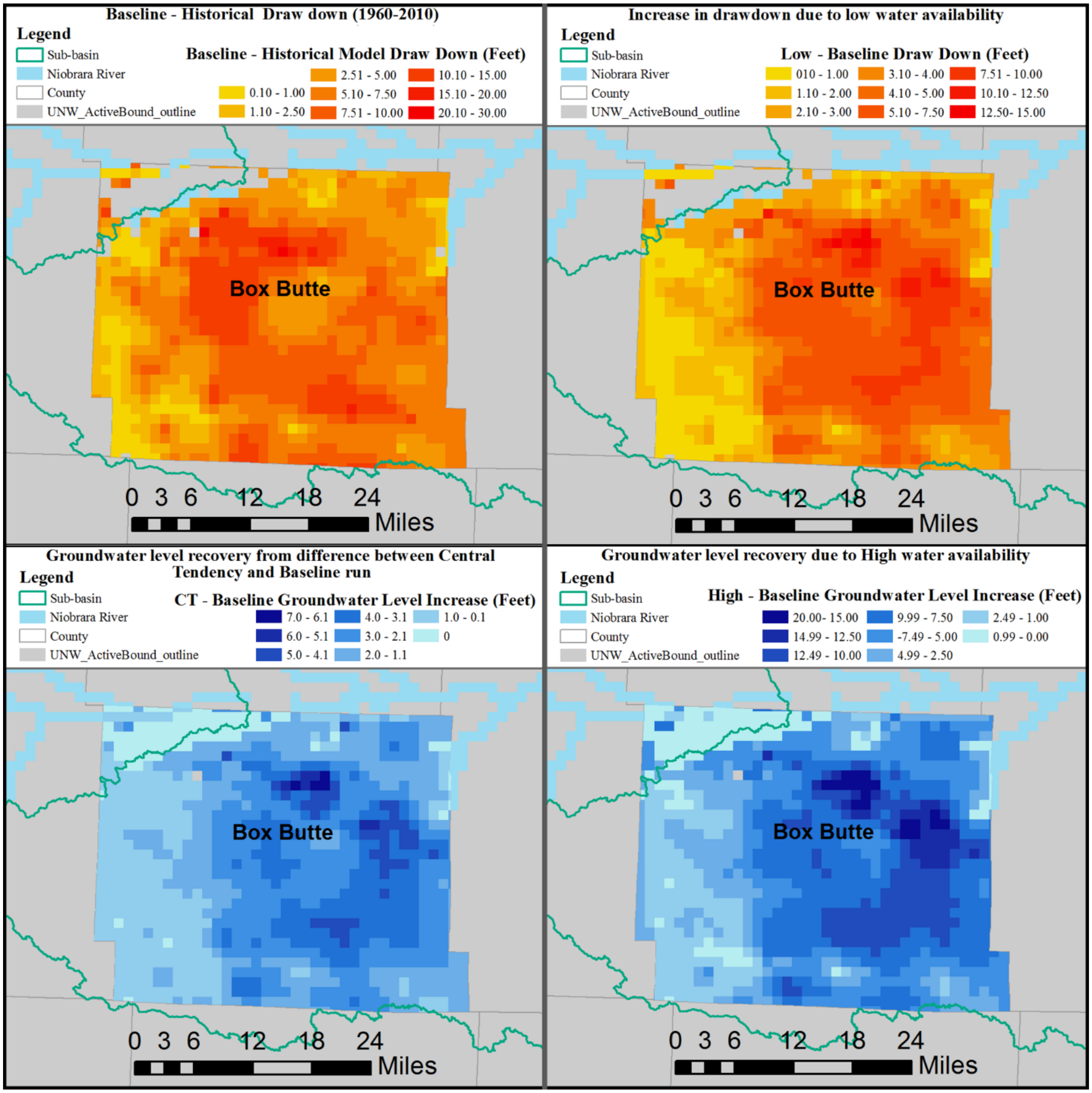

Figure 4.29. Groundwater drawdown comparison in Box Butte County for scenario model runs.

Figure 4.29 illustrates changes in groundwater levels in Box Butte County in the Upper Niobrara White area under different water availability scenarios. The upper left figure illustrates the difference in groundwater drawdown in the baseline run as compared to the historically calibrated model runs (1960-2010). The central region of the county shows the highest increase in drawdown: up to a 30 foot drop in the groundwater table. The peripheries of the County generally have a smaller increase in drawdown, ranging from 0.10 feet in the southwest to 7.5 feet in the southeast. The upper right figure depicts the increase in drawdown due to low water availability in Box Butte County, as compared to the baseline run. The Box Butte region shows a smaller increase in drawdown (0.10 feet) in the western portion of the model boundary. The central and eastern portions of the model boundary exhibited a substantial increase in drawdown of up to 15 feet.

The lower left figure of Figure 4.29 illustrates the groundwater level recovery in the CT scenario run as compared with the baseline run. The groundwater level increased from 0.10 feet in the northwest boundary of Box Butte County, up to 7 feet in the north central and northeast boundaries. The lower right figure shows the increase in groundwater level recovery in the high water availability scenario, as compared to the baseline run. The northern, central, and eastern portions of the County exhibit an increase in groundwater level recovery of up to 20 feet in the modeling period. The western portion of the county generally received the smallest increase in groundwater recovery.

4.2.2 CENEB Region Response

The response of the middle Niobrara River area in terms of groundwater level change to different levels of water availability scenarios are analyzed in this section.

Figure 4.30 represents the change in groundwater levels in the historical model (1960- 2010). The majority of the central and western regions exhibited an increase in water levels, typically 0.10 to 10 feet. The eastern and southeastern regions of the area show groundwater level changes of as much as 50 feet. A few dense pockets in the west, central, and eastern portions of the area exhibit a groundwater level reduction of as much as 20 feet.

Figure 4.31 illustrates the changes in groundwater levels of middle Niobrara River area under different water availability scenarios. The upper left figure depicts the difference in drawdown in the baseline run as compared to the historically calibrated model run. The region typically has drawdown of 0.10 to 10 feet. However, a substantial portion of the northern and western regions show a drawdown increase of up to 100 feet. The upper right figure illustrates the increase in groundwater drawdown due to low availability of water as compared to the baseline run. The western side of Keya Paha County, as well as the eastern and western sides of Cherry County, exhibit a relatively low drawdown increase. The central and southern regions of Cherry County show a much higher increase in drawdown, ranging up to 75 feet.

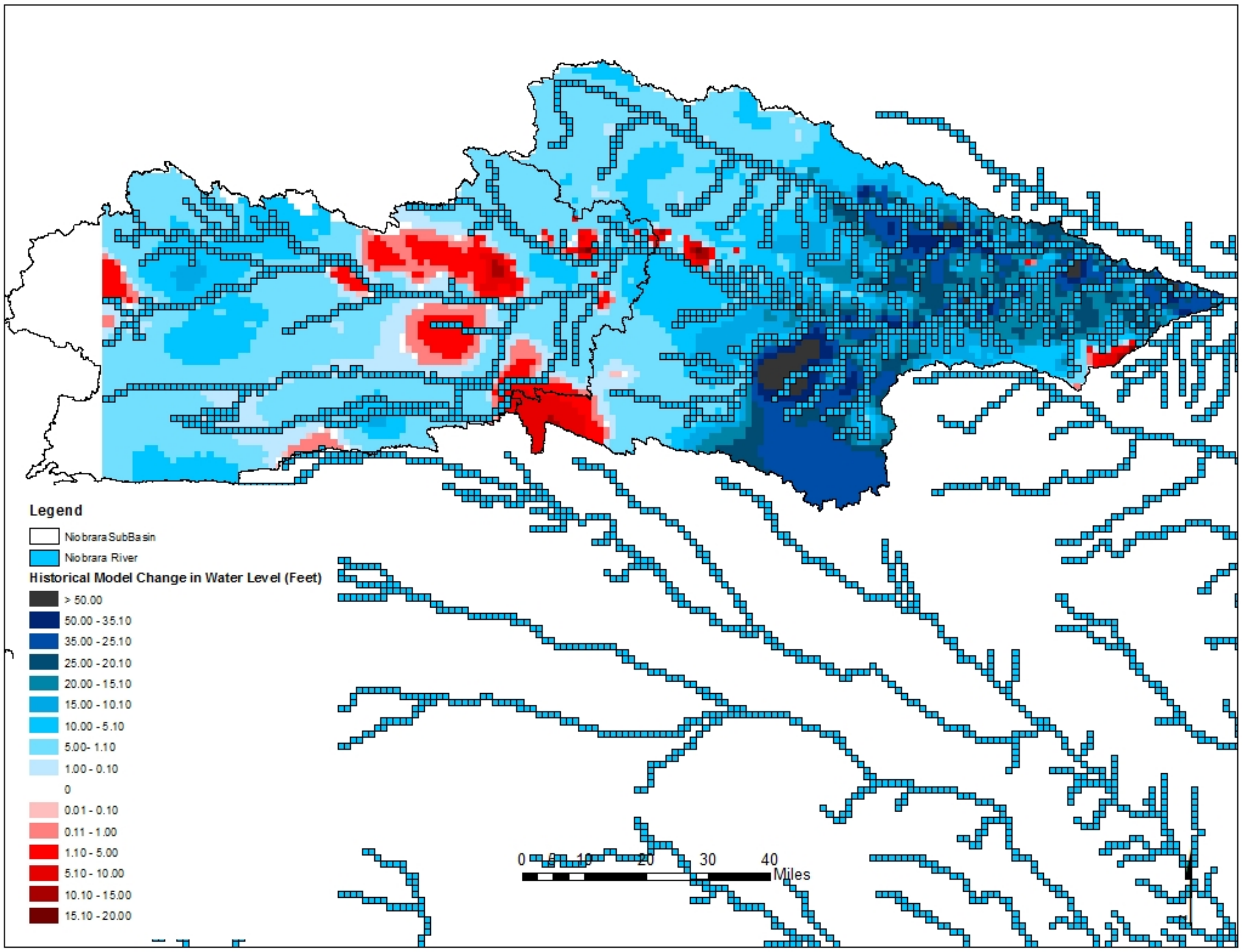

Figure 4.30. Change in groundwater level in Historical model (1960–2010).

The lower left figure represents the change in groundwater recovery obtained from the difference between the CT and baseline runs. The majority of the central and western regions exhibited an increase in water level, typically 0.10 to 10 feet. The eastern and southeastern regions of the county represent groundwater level increases of as much as 20 feet. The lower right figure represents the groundwater level recovery due to the high water availability change in groundwater, as compared to the baseline model run. The majority of the central and western regions exhibited an increase in groundwater levels, typically 0.10 to 20 feet. The northern, eastern and southeastern regions of the model area show groundwater level changes of as much as 35 feet.

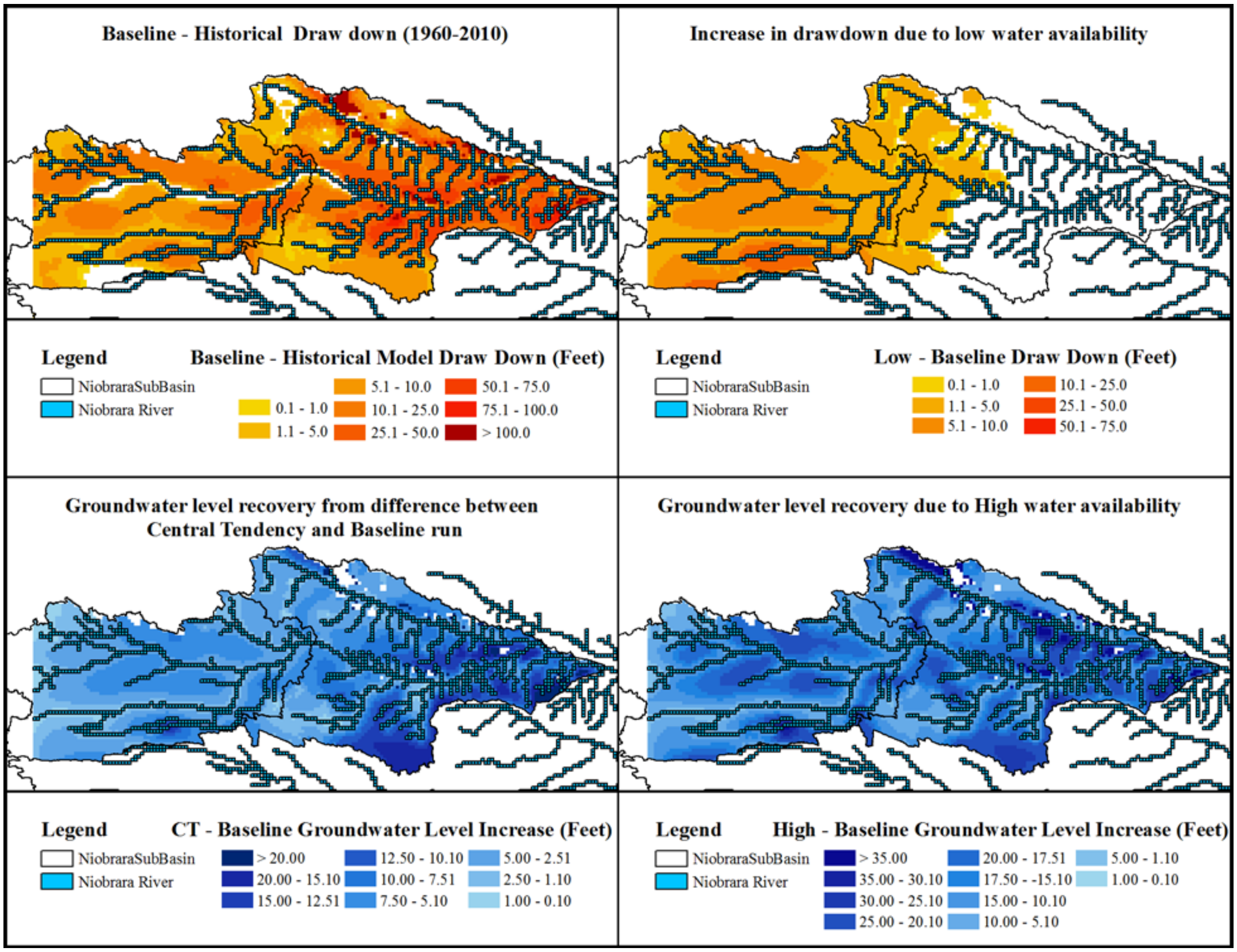

Figure 4.31. Groundwater level change comparison in middle Niobrara River area for different water availability scenario model runs.

4.3 Annual Baseflow Change Comparison in Subbasin Scale

The Niobrara River Basin has four subbasins: Above Box Butte, Box Butte to Gordon, Gordon to Sparks, and Sparks to Spencer, extending from west to east, respectively, as shown in Figure 4.32. The change in baseflow amount compared to baseline model run based on subbasins of Niobrara River Basin in an annual basis was estimated with the results of UNW and CENEB model runs.

The annual baseflow amount of subbasins from baseline model run was subtracted from no action - low, CT, and high water availability scenarios to analyze the change in baseflow volume in annual time frame.

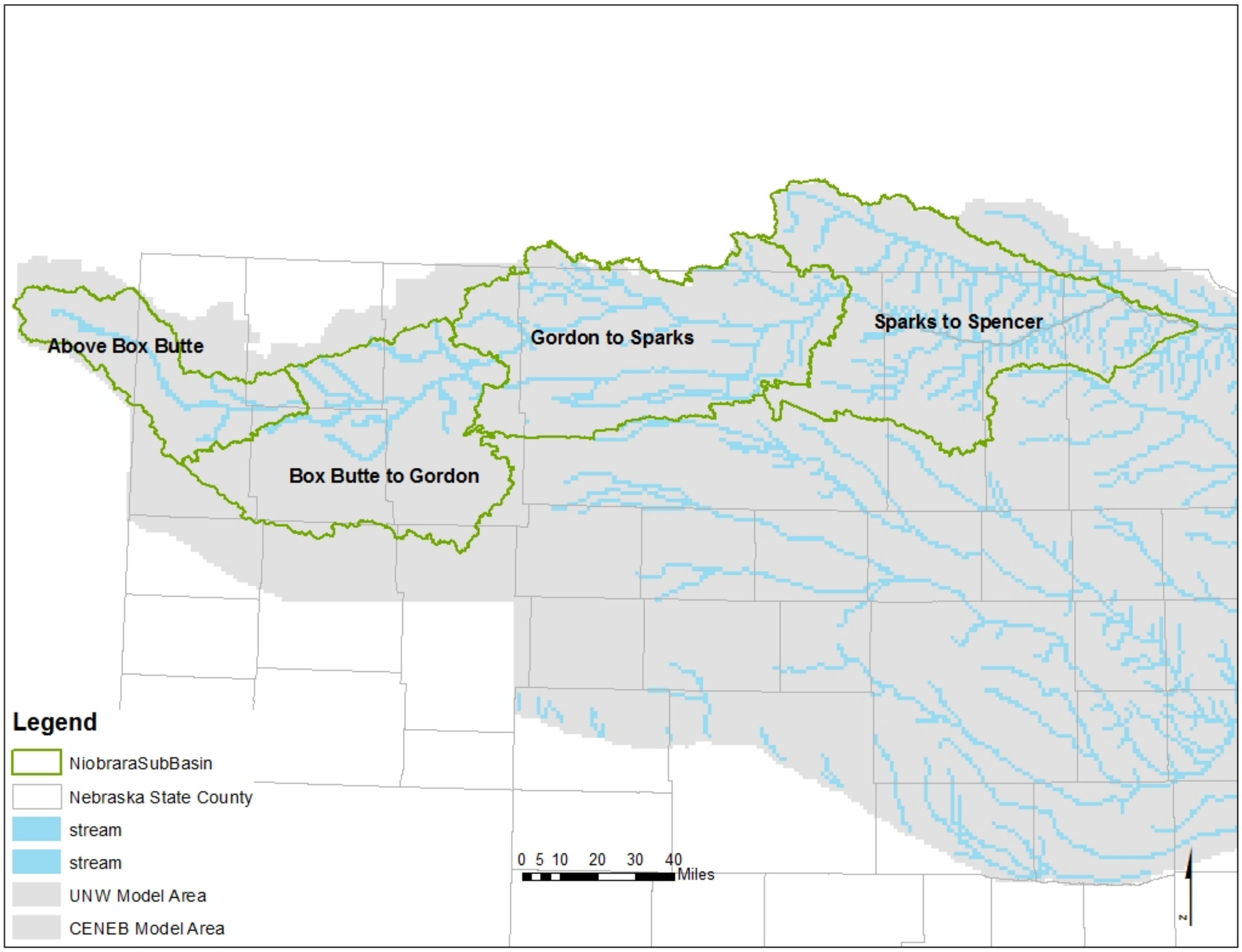

Figure 4.32. Subbasins of the Niobrara River Basin.

Figure 4.33 illustrates the estimates of yearly change in baseflow amounts in the Above Box Butte subbasin of Niobrara River Basin. In the low water availability scenario there is baseflow change in every year, with a mean of around 1,000 acre-feet baseflow decrease per year. The impact of the CT scenario is inclined toward increase in baseflow amount, with mean estimates of around 1,000 acre-feet per year. In the high water availability scenario there is increase in baseflow in every year, with a mean of around 3,000 acre-feet increase per year.

Figure 4.34 illustrates the estimates of yearly change in baseflow amounts in the Box Butte to Gordon subbasin of Niobrara River Basin. In the low water availability scenario there is decrease in baseflow every year, with a mean of around 5,000 acre-feet per year. The impact of the CT scenario is inclined toward increase in baseflow, with mean estimates of around 3,000 acre-feet per year. In the high water availability scenario there is increase in baseflow every year, with a mean of around 15,000 acre-feet increase per year.

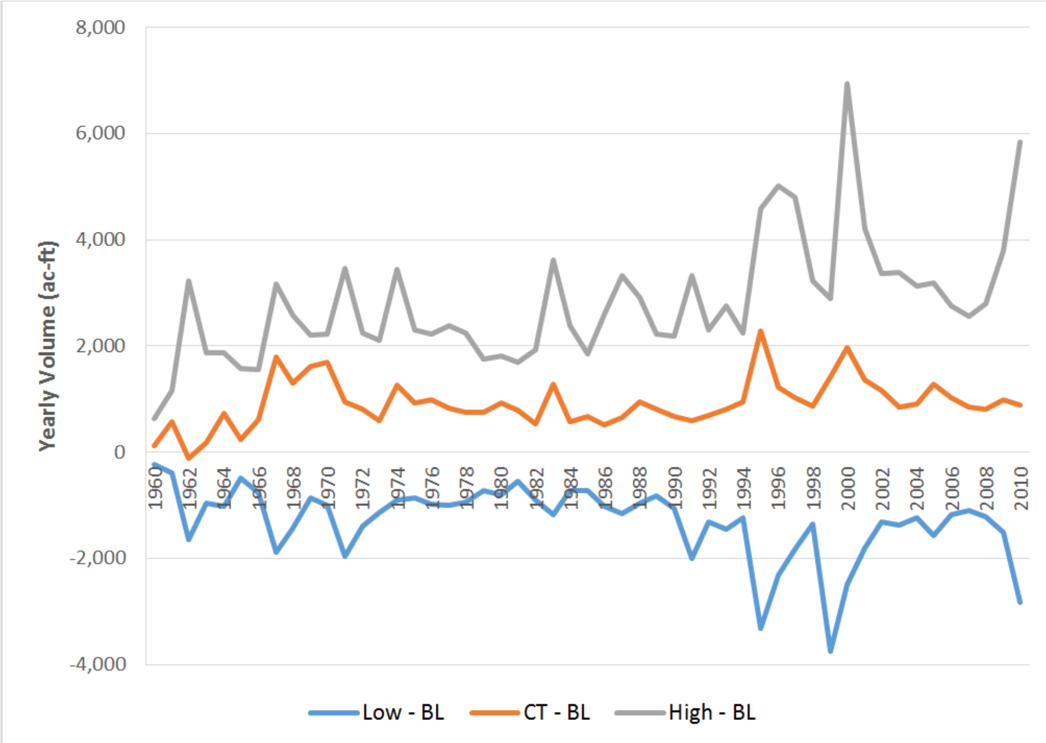

Figure 4.33. Yearly baseflow amount change in the Above Box Butte subbasin.

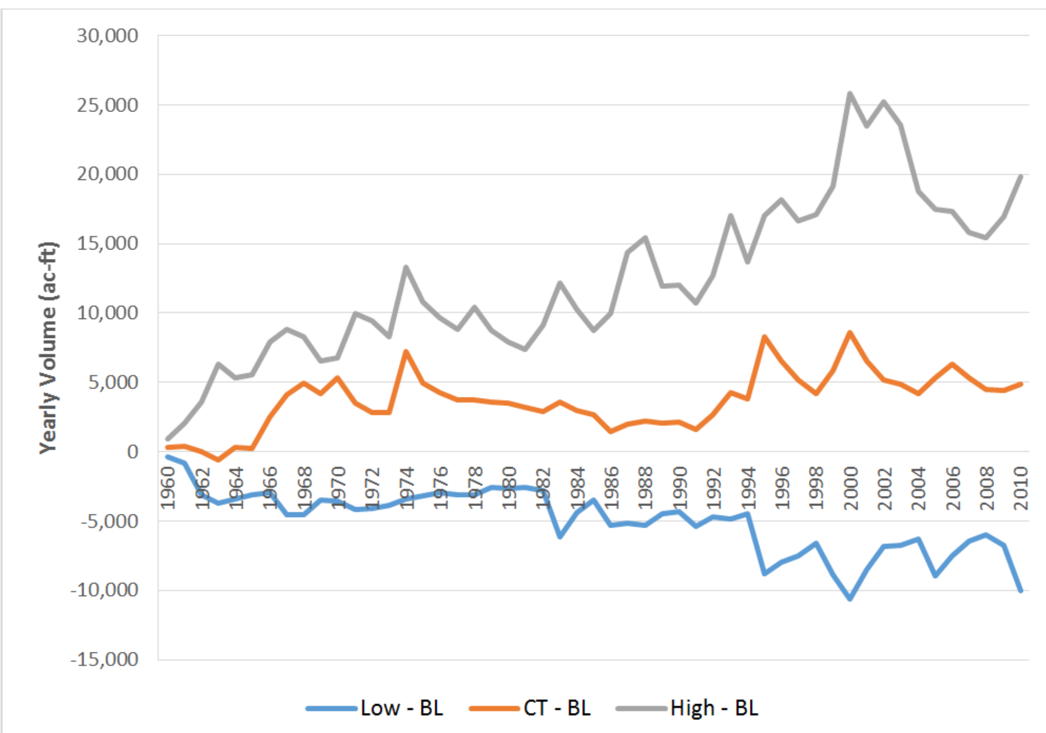

Figure 4.34. Yearly baseflow amount change in the Box Butte to Gordon subbasin.

Figure 4.35 illustrates the estimates of yearly change in baseflow amounts in the Gordon to Sparks subbasin of Niobrara River Basin. Compared to the subbasins in the west, the amount of increase and decrease in baseflow amount is much higher in magnitude in the eastern subbasins. In the low water availability scenario there is decrease in baseflow every year, with a mean of around 800,000 acre-feet decrease per year. The impact of the CT scenario is inclined toward baseflow increase, with mean estimates of around 7,000 acre-feet per year. In the high water availability scenario there is increase in baseflow every year, with a mean of around 2.4 million acre-feet increase per year.

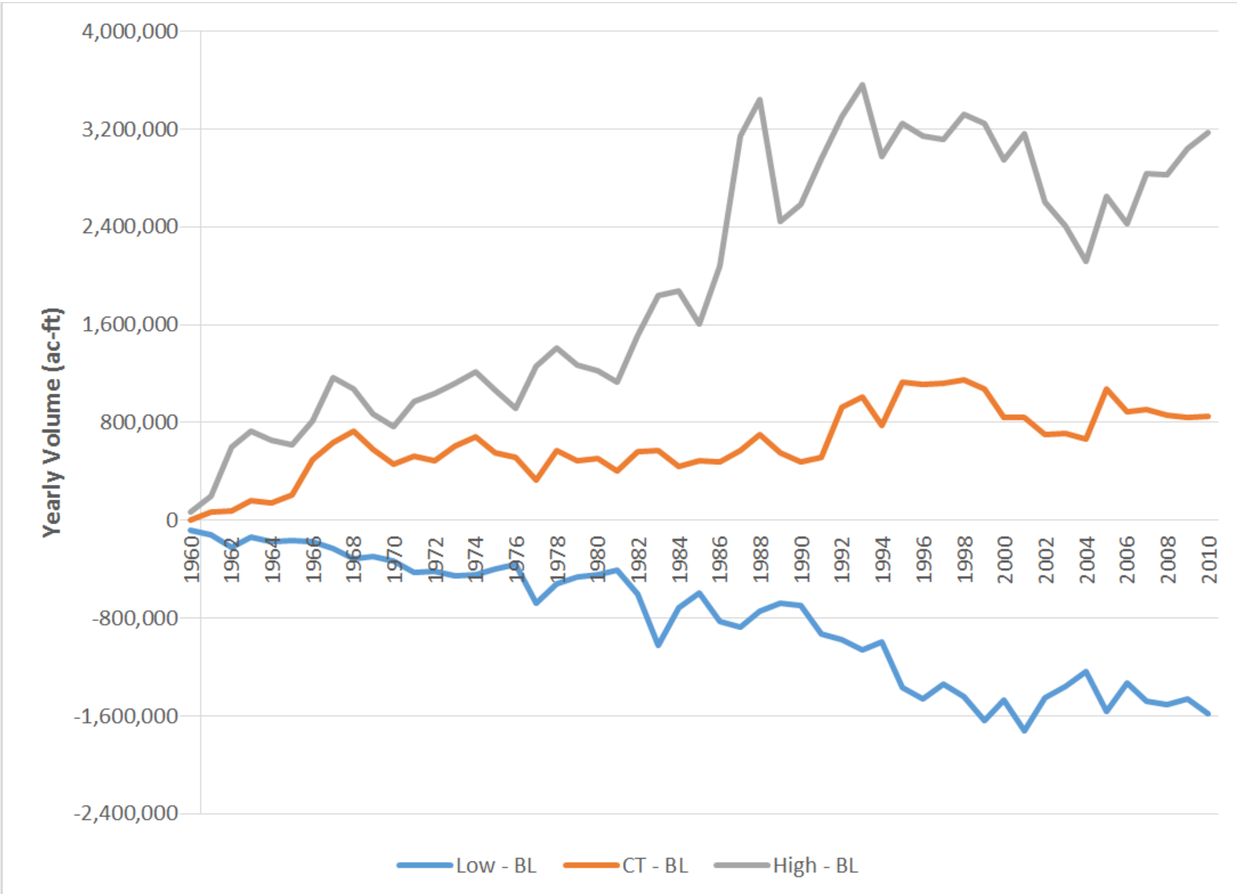

Figure 4.35. Yearly baseflow amount change in the Gordon to Sparks subbasin.

Figure 4.36 illustrates the estimates of yearly change in baseflow amounts in the Sparks to Spencer subbasin of Niobrara River Basin. In this subbasin all scenario runs resulted in increase in baseflow. In the low water availability scenario there is increase in baseflow amount in most years, with a mean of around 250,000 acre-feet increase per year. In the CT scenario the mean estimate for increase in baseflow is around 1 million acre-feet per year. In the high water availability scenario there is increase in baseflow amount in every year, with a mean of around 1.5 million acre-feet increase per year.

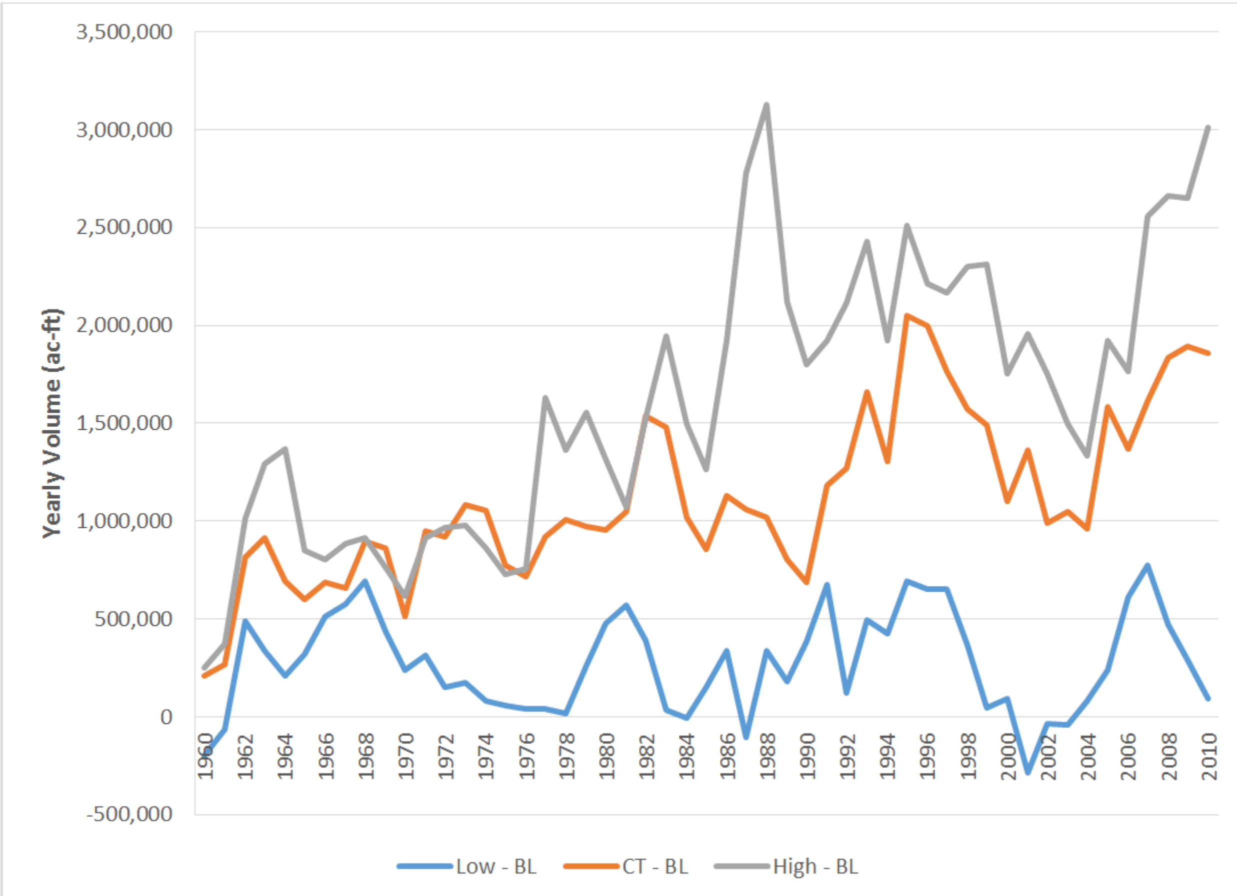

Figure 4.36. Yearly baseflow amount change in the Sparks to Spencer subbasin.

5 Conclusions

The purpose of the Niobrara River Basin Study is to evaluate current and projected future water supply and demand, and evaluate potential adaptation strategies which may reduce any identified gaps as part of the Water Sustain and Manage America's Resources for Tomorrow (WaterSMART) Program.

As part of the effort, this study evaluated two management action plans (alternatives) in Sheridan County located within the Niobrara River Basin and three different future climate scenarios (i.e. low, central tendency, and high water availability) based on the Intergovernmental Panel on Climate Change (IPCC) climate projections. The first alternative considered is Mirage Flats pumping station relocation to reduce canal distance and diminish associated issues such as seepage and evaporative losses. The second alternative is utilizing the canal for recharge only, without surface delivery, to increase aquifer recharge. These two alternatives are also evaluated under each projected climate scenario.

This study used a groundwater model as one of the major tools to analyze the condition of water resources in terms of water supply and demand in both present and future time frames. Based on a conceptual model that emphasizes agricultural water uses, three distinct models (i.e. surface water operations, groundwater, and watershed) were used in an integrated manner relying on both historical and future (projected) climate data as part of the Basin Study.

A time-series of baseflow between the Gordon and Sparks gages under the different climate scenarios shows that the high water availability leads to higher baseflow while the scenario of low water availability corresponds to lower baseflow. In addition, modeling results show the central tendency and high water availability scenarios increase baseflow; however, the low water availability scenario indicates a decrease in baseflow. Box County, a local area long plagued with declining groundwater levels, is expected to have further decline in groundwater levels under low water availability, but to have groundwater levels rebound with central tendency and high water availability scenarios.

The patterns of change in groundwater levels follow similar patterns in the Mirage Flats area. The results indicate an increase in groundwater level in Mirage Flats area of central tendency and high water availability climate scenario. The patterns of change in groundwater levels in the CENEB area also follow similar patterns of Box Butte and Mirage Flats area for different climate scenarios except in the low water availability scenario. In lower portion of Sparks to Spencer sun-basin, groundwater level did not change to this climate scenario. It should be noted that the baseline no-action scenario consistently shows reduced baseflow and groundwater levels. This is in part because all scenario analyses assume constant historic land use conditions maintained as of year 2000 for the purpose of isolating the impacts of land use change.

Overall, the modeling results show that baseflow and groundwater levels are sensitive to future projected change in climate conditions. Across almost the entire Niobrara River Basin, climate scenarios of high water availability and low availability can increase or reduce the baseflow and groundwater levels, respectively.

6 References

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