Niobrara River Basin Study

Appendix F — Integrated Water Management Model

U.S. Department of the Interior

Nebraska
Department of Natural Resources
Lincoln, Nebraska

March 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: Aerial view of the lower Niobrara River. Photo by U.S. Army Corps of Engineers.

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Appendix F — Integrated Water Management Model

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Executive Summary

Purpose, Scope and Objectives

The Niobrara River Basin Study (Basin Study) is a collaborative effort by the Nebraska Department of Natural Resources (NDNR) and the US Bureau of Reclamation (Reclamation), which is authorized under the SECURE Water Act (Title IX, Subtitle F of Public Law 111-11). The purpose of 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.

The Niobrara River Basin Study extends along the Niobrara River from the Nebraska/Wyoming Stateline to the Spencer gage. The study area was divided into two regions based on the groundwater models available. The Upper Niobrara White (UNW) portion of the model extends from the Nebraska State line to the Gordon gage. The UNW integrated model is made up of UNW groundwater model, UNW watershed model and the UNW surface water operations model using Stella. The Central Nebraska Model (CENEB) extends from the Gordon gage to the Spencer gage. The CENEB integrated model is made up of CENEB groundwater model, CENEB watershed model and the CENEB spreadsheet model for the surface water operations model.

This report has two purposes. The first purpose of this report is to describe how the watershed model, groundwater model and surface water operations model were linked to form the integrated model which is designed to be a dynamic representation of the total water budget. The other purpose of this report is to discuss results of the modeling efforts to have an overall understanding of the effects of the climate scenarios and operation alternatives. Results from all models were compiled into this report.

Integration of Models

The watershed model, groundwater model and surface water operations model for each Niobrara White model region (UNW and CENEB) were linked to form integrated models which are designed to be a dynamic representation of the total water budget for the Niobrara River.

Information generated in one model can be used as input to or as a calibration target for another model. As currently structured, users pass results from one model to another. A simplified illustration of this data exchange for the UNW model is shown in Figure ES-1. The primary elements of information exchanges are listed below.

- Water diversions in the surface water operations model and well pumping in the groundwater model are taken from outputs of the watershed model.
- Recharge to the groundwater model is taken from the watershed model for deep percolation from the land, and from the surface water operations model for canal seepage. The stream routing in the groundwater model requires inputs from the surface water operations model.
- The surface water operations model gains runoff as calculated by the watershed model, and baseflow as calculated by the groundwater model. Streamflows can be lost to the groundwater model (calculated by the groundwater model) if the river stage is higher than the underlying water table.

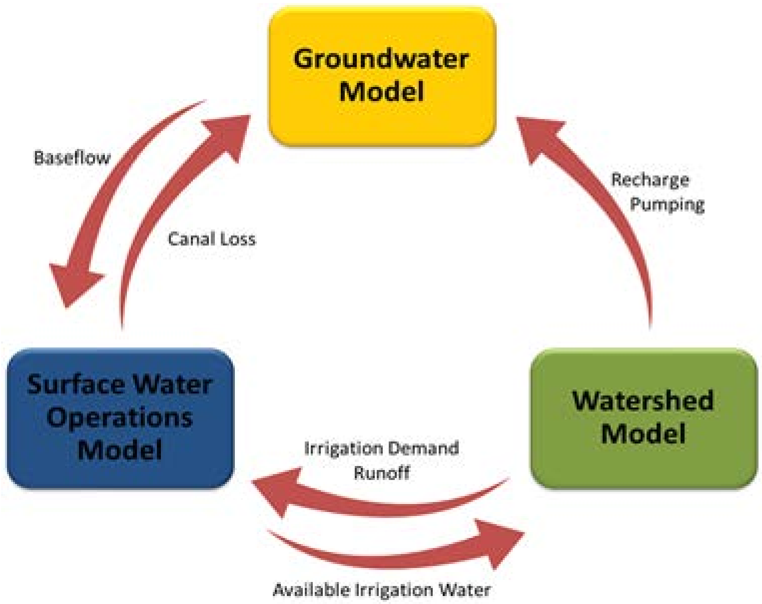

Figure ES-1. Linkage of individual models within the UNW Integrated Model

Each individual model is operated independently from the other models and then the integration occurs through a series of data processing and transfer. This approach is considered to be a "passive" linkage. The primary purpose of integration is to replace the observed reach gain-loss values used in the historical surface water operations model with the runoff and baseflow values that are the output from the watershed and groundwater models respectively. Thus streamflow estimates are the integrated results of all three models.

More information on the detailed sequence of the integrated models for the UNW and CENEB models is found in Section 2.

Upper Niobrara-White Alternative Scenarios

Alternative management scenarios were developed to increase the efficiency of the surface water diversion for agriculture use and reduce the impacts of groundwater pumping in the Niobrara River baseflow. A combination of four climate scenarios and two management alternative scenarios were developed for this project. The climate scenarios include the Baseline, Low, Central-tendency (CT) and High water availability, which are described in more detail in Appendix A, Climate Change Analysis Technical Report.

The two management scenarios include replacement of the existing diversion and main supply canal with a pumping station near the Mirage Flats Irrigation District and operating the Mirage Flats canal as a recharge facility without making irrigation deliveries. Each of these scenarios is described in more detail below.

Climate Scenarios

As discussed in Appendix A, four climate scenarios were evaluated as a part of this study. Net evaporation rates for future scenarios were developed as inputs to the UNW integrated models. The climate scenarios included Future No Action, Low, Central Tendency (CT) and High. The Low scenario generally corresponds with more warming and drier conditions. The CT scenario generally corresponds with central tendency warming and precipitation. The High scenario generally corresponds with less warming and wetter conditions.

Future No Action

Current operational conditions were simulated as “No Action” alternative to establish a baseline condition for evaluation alternatives. The no action scenario maintains current operational characteristics of Box Butte Reservoir and Mirage Flats delivery system. Future conditions were represented by applying a constant level year 2010 land use data to the future no action climate and three climate changes that occurred from 1960-2010. This isolated the impacts of climate variability in this basin study. The 1960-2010 temporal scale was used for all four climate scenarios as it allows readers to identify wet and dry climate periods in the data in the evaluation of the modeling results.

Key water budget elements were identified to get an overall picture of the results from the UNW integrated model. The key water budget elements included:

- Box Butte Reservoir inflows
- Box Butte Reservoir elevations
- Box Butte Reservoir releases
- Mirage Flats diversions
- Surface water irrigation deliveries
- Volume of groundwater pumping on co-mingled acres

- Total aquifer recharge
- Groundwater elevations
- Baseflow Contributions
- Niobrara River at Gordon gage

All UNW water budget elements for the Future No Action scenario are discussed further in Section 3.2.2. Overall, the gage plots show the Low water availability scenario to typically have the lowest flow, the CT to typically be in the middle, and the High water availability scenario to typically have the highest flows. The baseline no action typically has lower flow than the High water availability and the amount of flow is typically between the Low water availability and CT scenarios.

Identified patterns to the Box Butte Reservoir releases and the operating rules of Box Butte are directly linked to the Mirage Flats diversions. Consistent with the Box Butte releases, the High water availability scenario diversions are generally higher than the other scenarios, and all climate scenarios typically follow a similar pattern.

As the system experiences increases (Low to High climates) in precipitation the irrigation demands decrease. Even with the increased levels of precipitation, however, the available supply of surface water only meets a portion of the crop water demand. The Mirage Flats Irrigation District (Group 9) has the largest demand and also receives the largest volume of deliveries. Demands are generally higher in the Low climate and less in the High climate. Conversely with water being the limiting factor, greater amount of water in the system allows larger annual deliveries in the wetter High climate.

Key water budget elements were identified to get an overall picture of the results from the CENEB integrated model. The key water budget elements included:

- Merritt Reservoir Elevations
- Merritt Reservoir Releases
- Flow at Sparks (the Niobrara Wild and Scenic River)
- Flow at Spencer (private hydropower facility)
- Deliveries to Ainsworth Irrigation District
- Baseflow contributions
- Volume of Groundwater pumping

All CENEB water budget elements for the Future No Action scenario are discussed further in Section 3.2.4. Overall, the modeling results show the streamflows at the model nodes are the lowest under the Low climate scenario and significantly higher under the High climate scenario. The impacts to the Merritt Reservoir operations are modest for the Central Tendency and High future scenarios as compared to the Baseline No Acton scenario. Impacts to the reservoir under the Low scenario, corresponding to the hot and dry climate, are slightly greater than the other scenarios analyzed in this report. Further discussion and additional analysis of the CENEB model results may be found in Appendix D, Central Nebraska Surface Water Operations Modeling Report.

Alternative 1 – Mirage Flats Pumping Station

Alternative 1 represents the replacement of the existing Mirage Flats Diversion and main supply canal with the Mirage Flats Pumping Station. The objective of this alternative water management scenario is to reduce canal seepage during surface water deliveries to the agricultural fields. Diversions from Niobrara River will be pumped to the delivery area (approximate distance of 12 miles). It is assumed the diversion point from the Niobrara River will remain approximately the same.

Key water budget elements were identified to get an overall picture of the results from the UNW integrated model. All UNW water budget elements for the Future No Action scenario are discussed further in Section 3.3.2.

Box Butte Reservoir levels reflect reduction in required releases due to increased canal delivery efficiencies. All climate scenarios for Alternative 1 have higher water surface elevations in Box Butte Reservoir than the Future No Action alternative. Alternative 1 Box Butte Releases are typically reduced from the Future No Action alternative due to increased canal delivery efficiencies. Compared to the Future No Action alternative, the Mirage Flats diversions for Alternative 1 are largely minor diversions. Under all climate scenarios, Alternative 1 increased surface water deliveries from Future No Action alternative. Under all climate scenarios the average volume of co-mingled pumping for Alternative 1 decreased from the Future No Action alternative. As expected, the change in recharge for Alternative 1 is concentrated around the Mirage Flats Irrigation district. The lack of seepage along the canal greatly reduced the recharge in those cells, while the irrigated land saw a small increase resulting from the increased deliveries. 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.

The Niobrara River at the Gordon gage location serves as the downstream most node in the UNW surface water operations model as well as the upstream most node in the CENEB surface water operations model. As such, this location also serves as the linkage between UNW and CENEB integrated models. The total streamflow simulated by the UNW model is used as input to the CENEB model at Gordon for the corresponding scenarios (Baseline No Action and Future No Action Low, Central Tendency, and High). Future with Alternative scenarios, including the Mirage Flats pumping plant alternative, was not simulated by the CENEB surface water operations model. The reasoning for not simulating these scenarios in the CENEB model is the lack of sensitivity of managed flows in the CENEB region to changes in flow in the UNW region. Sensitivity analyses were performed both with respect to groundwater and managed surface water and the lack of sensitivity is summarized in Appendix B and Appendix C, respectively.

Alternative 2 – Mirage Flats Recharge

Alternative 2 consists of the Mirage Flats canal system operated solely as a recharge facility and no irrigation deliveries will be made. Water will be released from Box Butte Reservoir, diverted in Mirage Flats Canal at Dunlap Diversion Dam, and the lateral system will be checked up to allow the water to recharge the groundwater within the project area.

The canal will be checked to normal water surface elevation within the project area, meaning the canal check structures will be operated to hold the canal water surface at the designed elevation (if making deliveries).

Alternative 2 Box Butte Reservoir levels are substantially higher than Future No Action alternative reflecting much lower releases for irrigation. All climate scenarios are able to meet the Mirage Flats Diversion full recharge demands except for the low climate scenario. In the low climate scenario, there is not always enough water to divert the full recharge demand. The principal change in surface water deliveries for Alternative 2 occurred within the Mirage Flats Irrigation District. Within the district, surface water deliveries ceased. The average volume of co-mingled pumping for Alternative 2 increased from the Future No Action alternative for all climate scenarios. As expected, the change in recharge for Alternative 2 is concentrated around the Mirage Flats Irrigation district and canal. All four climate scenarios saw a significant increase in the recharge within the Mirage Flats Irrigation District compared to the Future No Action alternative. 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. The flows at Gordon for Alternative 2 have similar trends as the Box Butte Reservoir releases, reflecting the forced releases during the baseline, CT and high conditions where attenuation and storage in Box Butte Reservoir is limited.

Similar to Alternative 1, the Mirage Flats canal recharge alternative was not simulated by the CENEB surface water operations model. The reasoning for not simulating these scenarios in the CENEB model is the lack of sensitivity of managed flows in the CENEB region to changes in flow in the UNW region. Sensitivity analyses were performed both with respect to groundwater and managed surface water and the lack of sensitivity is summarized in Appendix B and Appendix C, respectively.

Comparison of Alternatives

The previous sections compared the climate scenarios to the individual alternatives. This section will focus on comparing the alternatives to the baseline in one climate scenario. The central tendency water availability scenario was chosen. Key water budget elements were analyzed to get an overall picture of the results of each alternative.

All elements are further discussed in Section 3.5. Some results are highlighted below.

Box Butte Reservoir Elevations

The average annual Box Butte elevations for the CT scenario for No Action, Alternative 1 and Alternative 2 are shown in Figure ES-2. Alternatives 1 and 2 have higher elevations than the No Action alternative. Alternative 1 levels are higher due to an increased canal efficiency requiring less releases and Alternative 2 reservoir levels are higher reflecting much lower releases for irrigation. Significant droughts in the mid-1970's and late-2000's create decreases in Alternative 1 elevations even with the increases canal efficiencies. Table ES-1 summarizes the CT annual daily average elevations (ft) from 1960-2010. The data is divided into annual and seasonal values (irrigation and non-irrigation).

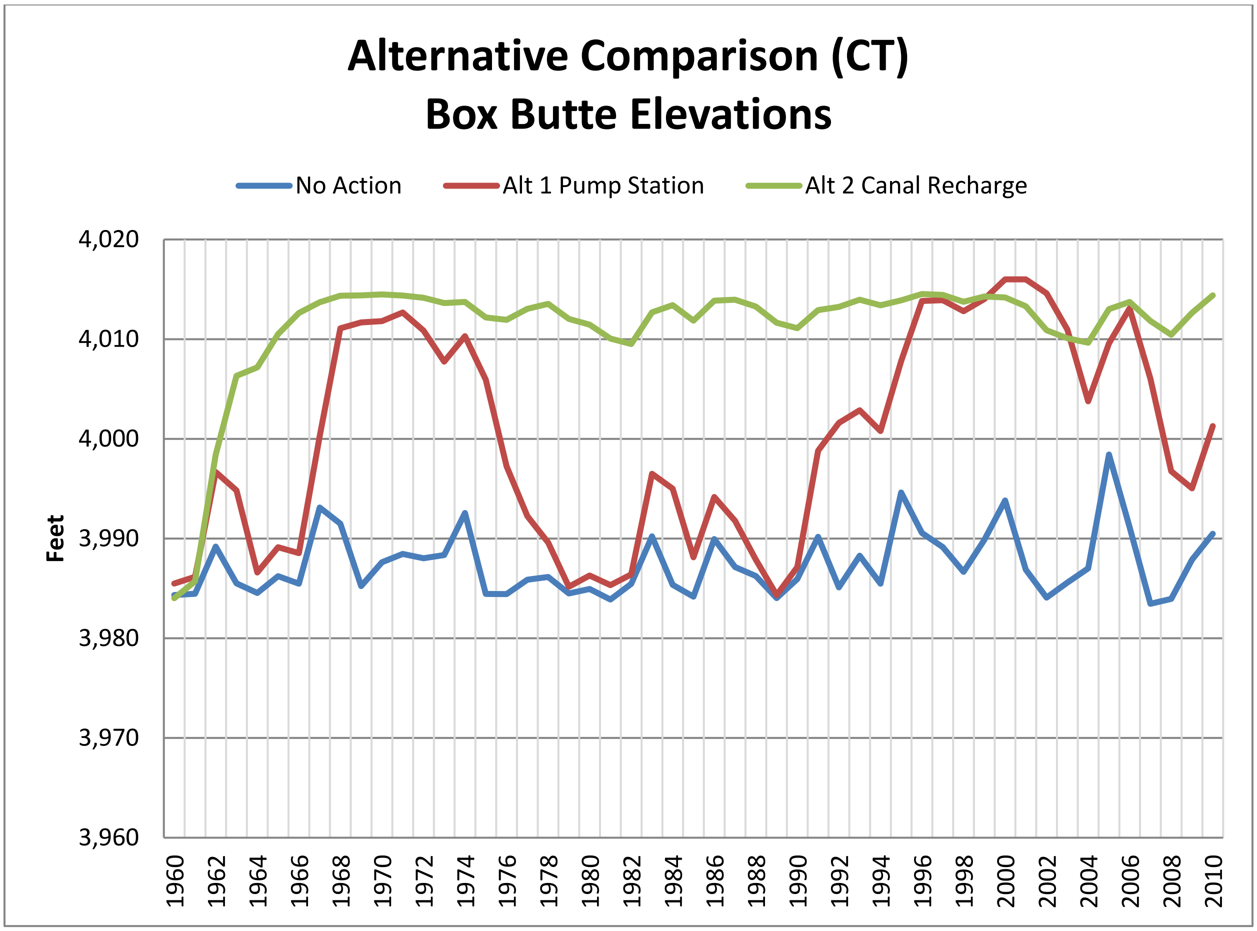

Figure ES-2. Average annual Box Butte Reservoir Elevations (CT) – No Action, Alt 1, Alt 2.

Table ES-1. Annual Daily Average Box Butte Reservoir Elevations (CT) – No Action, Alt 1, Alt 2

	Annual	Irrigation Season [1]	Non-Irrigation Season [1]
No Action	3987.5	3983.5	3988.8
Alt 1 Pumping Station	4000.1	3999.3	4000.4
Alt 2 Canal Recharge	4011.2	4010.7	4011.4

[1] The irrigation season for No Action and Alternative 1 was July, August, and September. The diversion pattern provided by J. Wergin for Alternative 2 extended outside of the typical diversion season of Mirage Flats that was used to designate irrigation and non-irrigation seasons. The irrigation season for Alternative 2 was June, July, August, and September.

Mirage Flats Diversions

Mirage Flats total annual diversions for all the alternatives for the CT climate scenario are plotted in Figure ES-3. Major differences are seen in the Mirage Flats Diversion between the alternatives. The No Action diversion assumes the canal has a 40% efficiency. Alternative 1 assumes 98% efficiency and Figure ES-3 shows the decreases in amount of diversions for that alternative. Alternative 2 assumes no deliveries and has a constant diversion rate for June, July, August and September that is used for every year of the simulation. The flat line shows adequate supply to meet recharge demand. Table ES-2 summarizes the CT annual daily average flows (AFD) from 1960-2010. The data is divided into annual and seasonal values (irrigation and non-irrigation).

Surface Water Irrigation Deliveries

The principal change in surface water deliveries occurred within the Mirage Flats Irrigation District. Figure ES-4 compares the average annual surface water deliveries at the Mirage Flats Irrigation District under the no action, pumping station alternative, and canal recharge alternative to the irrigation demand. Under all scenarios the pumping station increased surface water deliveries. No deliveries were made as a part of the canal recharge alternative.

Volume of Groundwater Pumping on Co-mingled Acres

The principal change in co-mingled pumping occurred within the Mirage Flats Irrigation District. Figure ES-5 compares the average annual co-mingled pumping in the Mirage Flats Irrigation District under the no action, pumping station alternative, and canal recharge alternative. Under all scenarios the average volume of co-mingled pumping decreased during the pumping station alternative and increased during the canal recharge alternative.

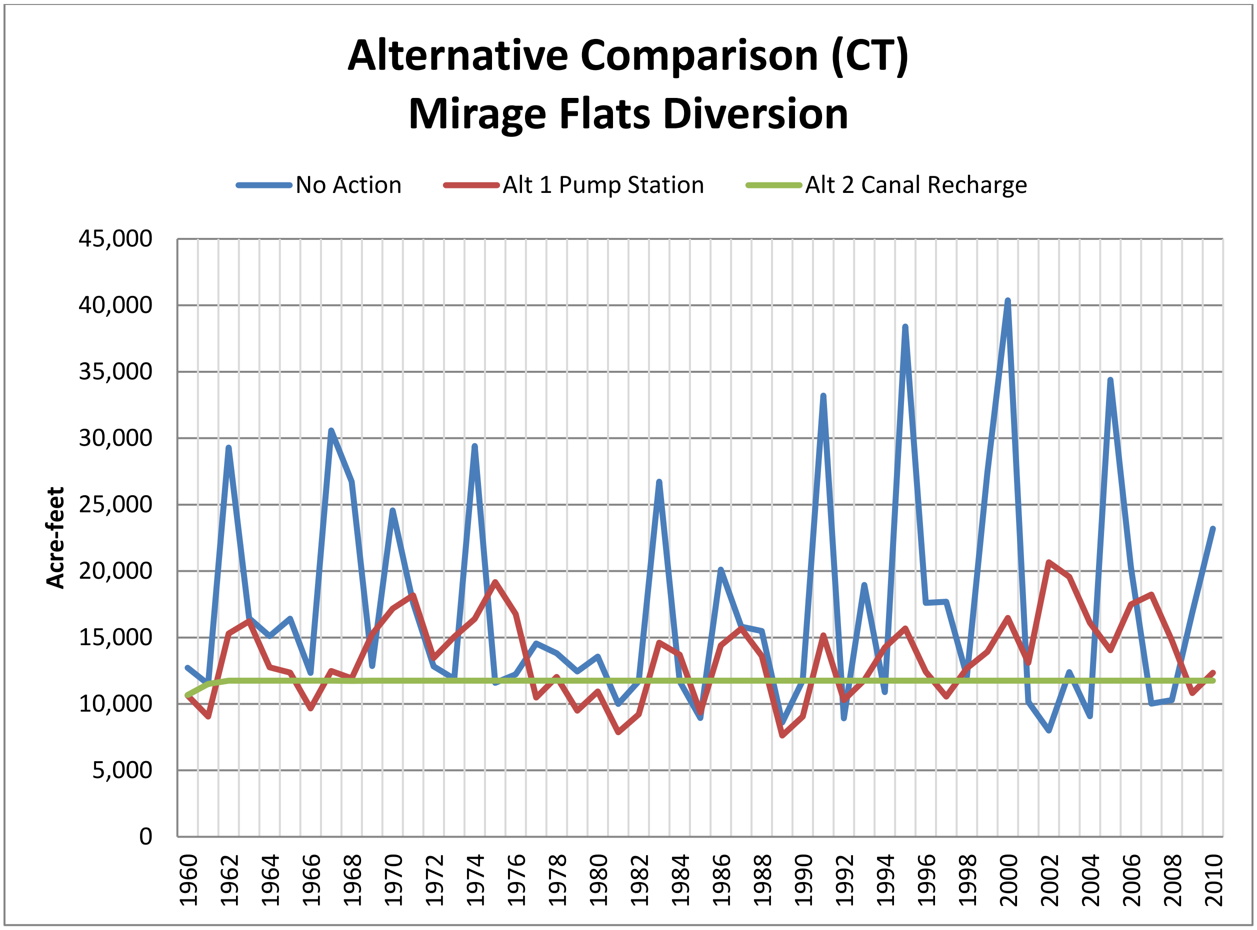

Figure ES-3. Total annual Mirage Flats diversion (CT) – No Action, Alt 1, Alt 2.

Table ES-2. Mirage Flats Annual Daily Average Diversion (CT) – No Action, Alt 1, Alt 2

	Annual	Annual % of Baseline	Irrigation Season [1]	Non-Irrigation Season [1]
No Action	47.2		187.5	0.0
Alt 1 Pumping Station	37.1	79%	147.1	0.0
Alt 2 Canal Recharge	32.1	68%	79.0	16.3

[1] The irrigation season for No Action and Alternative 1 was July, August, and September. The diversion pattern provided by J. Wergin for Alternative 2 extended outside of the typical diversion season of Mirage Flats that was used to designate irrigation and non-irrigation seasons. The irrigation season for Alternative 2 was June, July, August, and September.

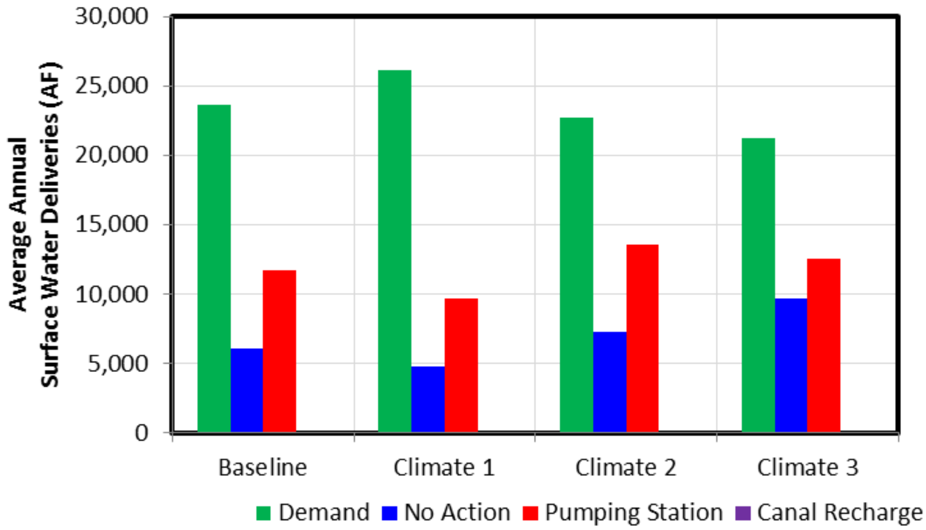

Figure ES-4. Mirage Flats average annual surface water deliveries – Demand vs No action, Alternative 1, Alternative 2; Baseline vs Low, CT, High.

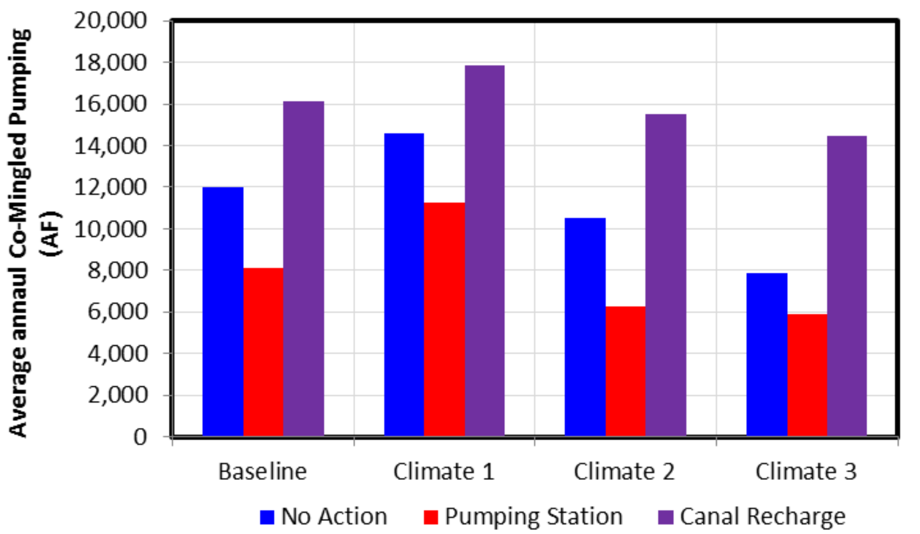

Figure ES-5. Mirage Flats average annual co-mingled pumping – No Action vs Alternative 1, Alternative 2; Baseline vs Low, CT, High.

Niobrara River at Gordon Gage

Niobrara River at Gordon gage total annual flows for all the alternatives for the CT climate scenario are plotted in Figure ES-6. The flows at Gordon are very similar between the different alternatives. This essentially shows that Box Butte Reservoir is an adequate buffer and can hold most of the surplus water generated by Alternatives 1 and 2 lower demands. Table ES-3 summarizes the CT annual daily average flows (AFD) from 1960-2010. The data is divided into annual and seasonal values (irrigation and non-irrigation).

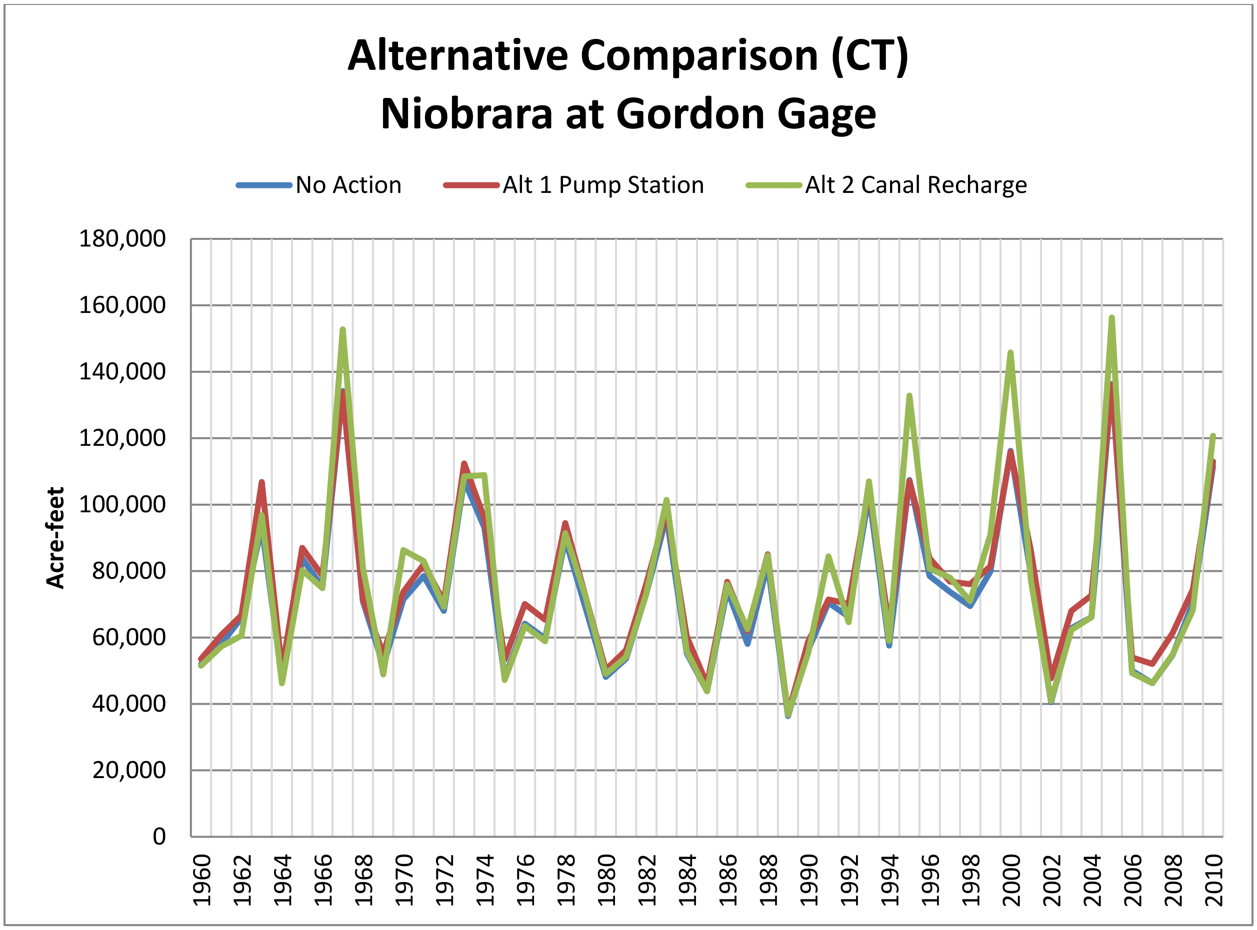

Figure ES-6. Total annual flows at Niobrara at Gordon Gage (CT) – No Action, Alt 1, Alt 2.

Table ES-3. Niobrara at Gordon Gage Annual Daily Average (CT) – No Action, Alt 1, Alt 2

	Annual	Annual % of Baseline	Irrigation Season [1]	Non-Irrigation Season [1]
No Action	198.6		276.8	172.2
Alt 1 Pumping Station	208.2	105%	316.0	171.9
Alt 2 Canal Recharge	208.8	105%	255.9	192.9

[1] The irrigation season for No Action and Alternative 1 was July, August, and September. The diversion pattern provided by J. Wergin for Alternative 2 extended outside of the typical diversion season of Mirage Flats that was used to designate irrigation and non-irrigation seasons. The irrigation season for Alternative 2 was June, July, August, and September.

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Acronyms

BOR	Bureau of Reclamation
CENEB	Central Nebraska model region (includes Middle Niobrara, Lower Niobrara, Upper Elkhorn, Lower Elkhorn, Upper Loup, and Lower Loup Natural Resources Districts)
CIR	Crop Irrigation Requirement
CT	Central Tendency Climate Scenario
NDNR	Nebraska Department of Natural Resources
UNW	Upper Niobrara – White model region (includes Upper Niobrara White Natural Resources Districts)
USGS	United States Geological Survey
WaterSMART	Water Sustain and Manage America's Resources for Tomorrow

1 Introduction

The Niobrara River Basin Study extends along the Niobrara River from the Nebraska/Wyoming Stateline to the Spencer gage. The study area was divided into two regions based on the groundwater models available. The Upper Niobrara White (UNW) portion of the model extends from the Nebraska State line to the Gordon gage. The UNW integrated model is made up of UNW groundwater model, UNW watershed model and the UNW surface water operations model using Stella. The Central Nebraska Model (CENEB) extends from the Gordon gage to the Spencer gage. The CENEB integrated model is made up of CENEB groundwater model, CENEB watershed model and the CENEB spreadsheet model for the surface water operations model.

The watershed model, groundwater model and surface water operations model for each Niobrara White model region (UNW and CENEB) were linked to form integrated models which are designed to be a dynamic representation of the total water budget for the Niobrara River.

Each individual model is operated independently from the other models and then the integration occurs through a series of data processing and transfer. This approach is considered to be a “passive” linkage. The primary purpose of integration is to replace the observed reach gain-loss values used in the historical surface water operations model with the runoff and baseflow values that are the output from the watershed and groundwater models respectively. Thus streamflow estimates are the integrated results of all three models.

1.1 Overview of Models

This section describes the integrated model concept and the physical processes it represents. The complete hydrologic cycle as modified by irrigation and other human activity is the conceptual model of the Niobrara River. Figure 1 is a schematic illustration of the hydrologic cycle for a system where use of water for irrigation is important. This figure provides visual context for subsequent discussion of how the system is modeled.

An initial step in building the actual models was to specify the elements of the hydrologic cycle that are to be considered in the models, as listed in Table 1. The overall water balance of the system is that outflows must equal inflows, plus or minus changes in storage.

The hydrologic cycle can be broken up into three primary parts: land, river and aquifer. Modeling tools were chosen to simulate each part of the system. The watershed model was used to represent the land/soil part of the cycle. The objective of a land/soil water model is to calculate water demands for irrigation, and the fate of rainfall and applied water on the land. This requires use of a method to simulate the soil water balance as a function of climate, soil, and land use. The surface water operations model was used to represent the river part of the cycle. The objective of a surface water operations model is to route flows down the river and to simulate the storage, release, diversion, and use of water along the Niobrara River and the canals that draw from the river. This requires a method which can replicate operation of the system (reservoirs and canals) and routing of water to meet surface water demands. The groundwater model was used to represent the aquifer part of the cycle. The objective of a groundwater model is to quantify changes in aquifer water levels (thus water in storage) resulting from recharge to and pumping of the aquifer; and representation to simulate the effects of pumping on baseflow contributions to streamflow, and predict subsurface flows in and out of the study area. The primary requirement is knowledge of aquifer properties and stream connections.

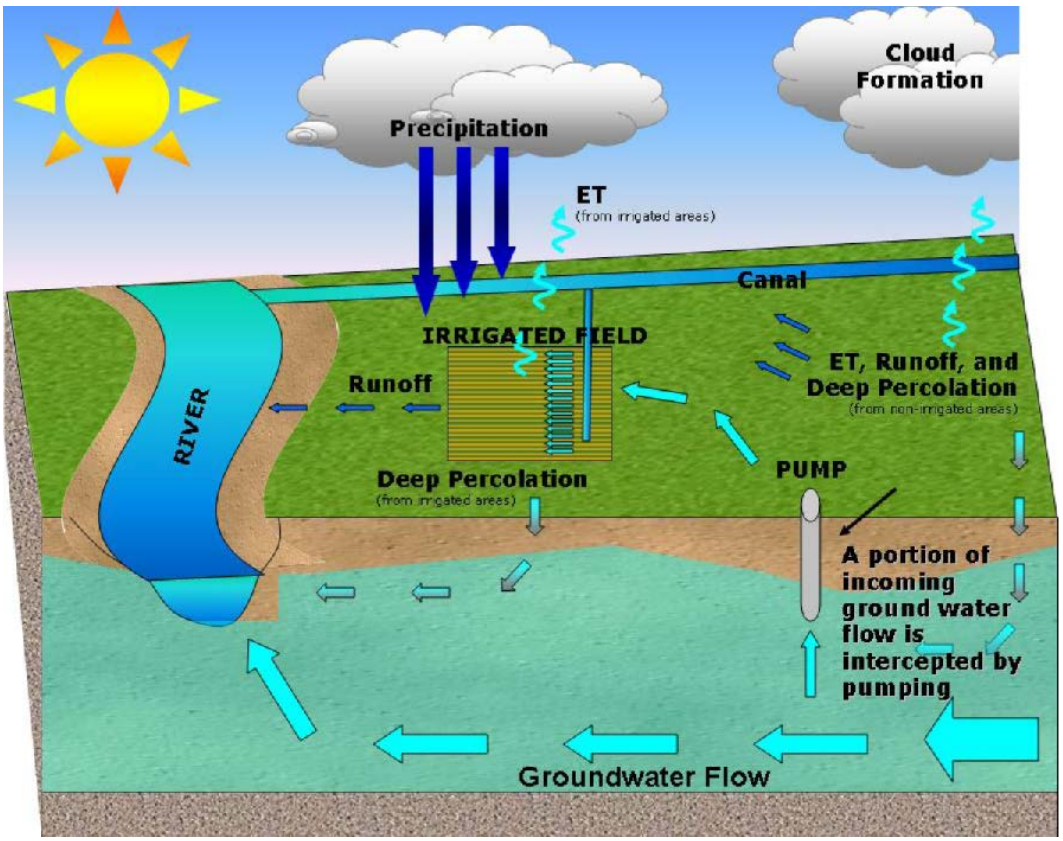

Figure 1. Illustration of Hydrologic Cycle in which Irrigation is important.

This figure does not encompass all important relationships; for example, canal seepage is not shown. From USGS.

Table 1. Components of the Niobrara River Hydrologic Cycle that are Included in the Models

Inflows (sources of water)
• Surface inflows at the Niobrara River USGS gage Nebraska State Line. • Groundwater inflows to the study area from the west. No other major subsurface inflows occur in the study area. • Precipitation on the landscape within the study area.
Outflows (sinks of water)
• Surface outflows on the mainstem Niobrara River at Gordon • Groundwater outflows to the east. • Evapotranspiration from the landscape.
Storage of water
• Surface water reservoirs with a large capacity and variable storage: Box Butte Reser • The regional aquifer within the study area.
Internal Exchanges (relate to the natural and managed hydrology within the system)
• Applied water diverted from streams or pumped from the aquifer and put on the land as needed to meet crop needs not satisfied from rainfall. • Precipitation and applied water are consumed (evapotranspiration), or become runoff or aquifer recharge. • Water is added to or released from reservoirs into rivers or canals in accordance with factors such as irrigation or power demands. • Surface waters may gain water from or lose water to the aquifer; groundwater may gain or lose water to streams.

2 Integration of Models

The integration of the watershed, groundwater and surface water operations models occurs through the processing and transfer of data between the models. A simplified illustration of this data exchange for the UNW model is shown in Figure 2. A similar simplified illustration of this data exchange for the CENEB model is shown in Figure 3.

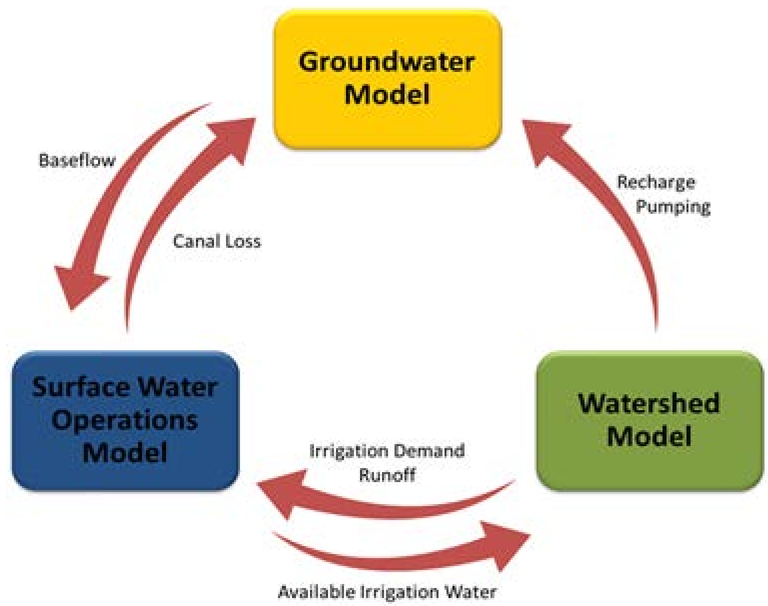

Figure 2. Linkage of individual models within the UNW Integrated Model.

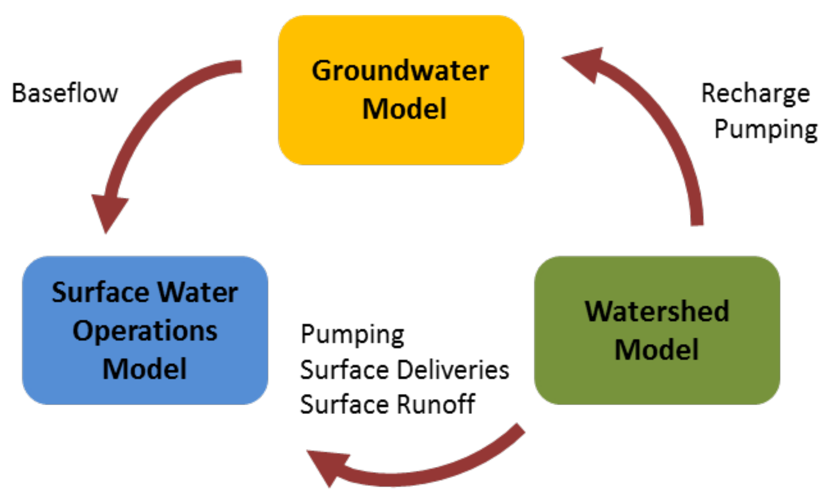

Figure 3. Model interactions for the CENEB sub-region of the study area.

The sequence of Individual model simulations and the data transfers to achieve an integrated simulation for the UNW model is described in Table 2. The sequence of individual model simulations and data transfers to achieve an integrated simulation for the CENEB model is described in Table 3.

Information generated in one model can be used as input to or as a calibration target for another model. As currently structured, users pass results from one model to another. The primary elements of information exchanges are listed below.

- Water diversions in the surface water operations model and well pumping in the groundwater model are taken from outputs of the watershed model.
- Recharge to the groundwater model is taken from the watershed model for deep percolation from the land, and from the surface water operations model for canal seepage. The stream routing in the groundwater model requires inputs from the surface water operations model.
- The surface water operations model gains runoff as calculated by the watershed model, and baseflow as calculated by the groundwater model. Streamflows can be lost to the groundwater model (calculated by the groundwater model) if the river stage is higher than the underlying water table.

Currently the exchange of data transfer between models is achieved by transmitting results of the individual models in text or Microsoft Excel formats via email or ftp site. Macros or short scripts have been developed for processing data into appropriate formats for use as inputs to the respective models.

2.1 Baseflow and Runoff Exchange

Baseflow output from the groundwater model and runoff output from the watershed model is imported into the surface water operations model, in lieu of the historical reach gain/loss for the integrated model run.

The baseflow output is provided as a monthly volume (acre-feet) aggregated at each main stem Niobrara River gage node in the surface water operations model. The data are discretized into daily values using Microsoft Excel and imported into the surface water operations model. For reaches where intermediate main stem nodes are present in the surface water operations model (for example at locations of diversions), the reach baseflow gain is partitioned using the lengths of sub-reaches between the intermediate nodes.

Table 2. Integrated Modeling Sequence for UNW Region

Step	Model	Operation	Output
1.	Watershed	Develop irrigation water demands based on irrigated acreage estimates Partition precipitation and applied water between ET, deep percolation, and field runoff (in turn partitioned to runoff to stream, recharge via transmission losses, and non-beneficial ET)	Irrigation demands for SW (to Surface Water Operations Model) Watershed runoff (to Surface Water Operations Model)
2.	Surface Water Operations	Import SW demands and runoff from Watershed Use irrigation demands from Watershed, system operating rules and targets, and initial reach gains for initial simulation Compute reach gains from: 1) historical RGL; 2) initial baseflow estimates from GW model plus SW runoff returns; or 3) initial baseflow estimates from separation work plus SW returns and runoff from Step (1)	Streamflow, diversions, returns Initial total flow estimates at mainstem nodes (to Groundwater Model) Canal/reservoir Seepage Losses by grid cell (to Watershed Model) Irrigation delivery to SW irrigated acreages (to Watershed Model)
3	Watershed	Repeat of Step (1) using irrigation deliveries from Surface Water Operations Model to determine amount of supplemental pumping required for comingled acres	GW pumping and recharge (to Groundwater Model)
4.	Groundwater	Import pumping and recharge file from Watershed model	Groundwater levels Baseflow by reach (to Surface Water Operations Model)
5.	Surface Water Operations	Import baseflow from Groundwater Model Repeat of Step (2) using Groundwater Model baseflow to replace estimated baseflow in computing reach gains	Streamflow, diversions, returns Total flow at mainstem nodes (to Groundwater Model) Canal/reservoir Seepage Losses by grid cell (to Watershed Model) Irrigation delivery to SW irrigated acreages (to Watershed Model)
6a.	Watershed	Determine if updated estimates of diversions would cause a significant shift in SW or GW uses (i.e. more or less supplemental GW pumping).	If so, go to Step (2) and provide output to Surface Water Operations Model for another iteration If not, modeling sequence is complete.
6b.	Groundwater	Determine if updated total flow values would cause a significant shift in computed baseflows	If so, go to Step (2) and provide output to Surface Water Operations Model for another iteration If not, modeling sequence is complete.

Table 3. Integrated Modeling Sequence for CENEB Region

Step	Model	Operation	Output
1.	Watershed	Develop irrigation water demands based on irrigated acreage estimates Partition precipitation and applied water between ET, deep percolation, and field runoff (in turn partitioned to runoff to stream, recharge via transmission losses, and non-beneficial ET)	Irrigation demands for SW (to Surface Water Operations Model) Watershed runoff (to Surface Water Operations Model)
2.	Groundwater	Import pumping and recharge data from Watershed model	Groundwater levels Baseflow by reach (to Surface Water Operations Model)
3	Surface Water	Import SW demands and runoff from Watershed Import Baseflow from Groundwater Model Import total streamflow at Niobrara River at Gordon gage from UNW surface water operations model Use irrigation demands from Watershed, simulated inflows and evaporation (determined by the CRLE model) for Merritt Reservoir, operating rules for the Merritt Reservoir	Streamflow and diversions Total flow at Snake River node and mainstem Niobrara River nodes

The watershed runoff is provided in monthly volume (acre-feet) for each subbasin shown in the Figure 4. Using Microsoft Excel, the subbasin runoff is aggregated at each main stem Niobrara River gage node in the surface water operations model. The reach runoff is discretized into daily values and imported into the surface water operations model. For reaches where intermediate main stem nodes are present in the surface water operations model (for example at locations of diversions), the reach runoff is partitioned using the lengths of sub-reaches between the intermediate nodes. Table 4 lists the Site Number and location description for the stream gauges delineating the runoff zones in the UNWNRD model domain.

2.2 Recharge from Canal and Reservoirs

Canal and reservoir recharge is exchanged from the surface water operations model to the watershed model using a Microsoft Excel based macro. The macro program uses the calculated seepage values from the surface water operations model, which are provided in daily volumes (acre-feet), for each canal reach and reservoir. Using the grid coverage used by the groundwater and watershed models, computed daily seepage from each canal reach and reservoir is partitioned on an equal basis amongst the grid cells associated with each canal reach/reservoir. The canal/reservoir seepage is ultimately included in the recharge file used as input to the groundwater model.

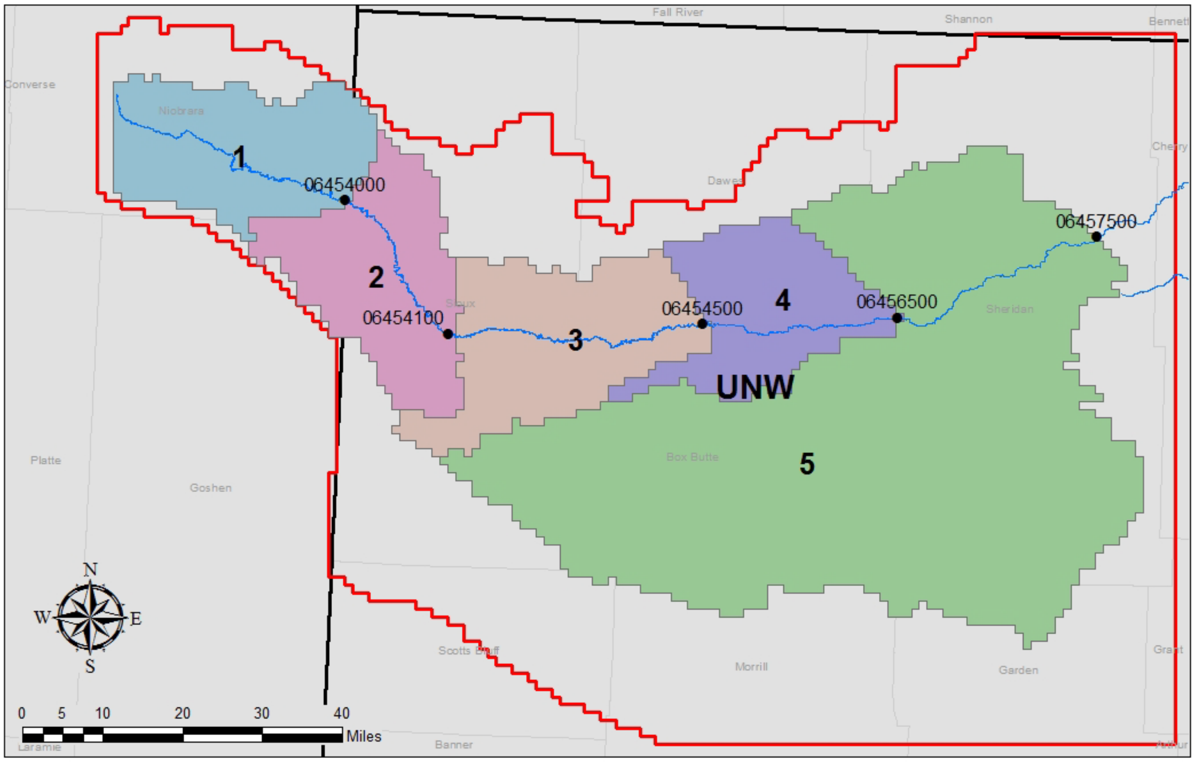

Figure 4. Drainage basins used in watershed model.

Table 4. Stream Gages Delineating the Runoff Zones in the UNWNRD Model Domain

Zone	Site Number	Location
1	06454000	Niobrara River at WY-NE state line
2	06454100	Niobrara River at Agate, NE
3	06454500	Niobrara River Above Box Butte Reservoir, NE
4	06456500	Niobrara River near Hay Springs, NE
5	06457500	Niobrara River near Gordon, NE

2.3 Calculated Irrigation Delivery

Irrigation demands calculated by the watershed model are used to develop surface water diversion demands as discussed in Appendix C, UNW Surface Water Operations Model Report. In the integrated modeling sequence, irrigation deliveries to meet those demands are calculated to identify deficits in crop deliveries due to limitations in available water for delivery. If there is a deficit between the crop irrigation demand and the available water for delivery, then the deficit is passed back to the watershed model (Step 3 in the modeling sequence) and ground water pumping is increased on comingled acres to compensate for the deficit.

3 Upper Niobrara White Alternative Scenarios

Alternative management scenarios were developed to increase the efficiency of the surface water diversion for agriculture use and reduce the impacts of groundwater pumping in the Niobrara River baseflow. A combination of four climate scenarios and two management alternative scenarios were developed for this project. The climate scenarios include the Baseline, Low, Central-tendency (CT) and High water availability, which are described in more detail in Appendix A, Climate Change Analysis Technical Report.

The two management scenarios include replacement of the existing diversion and main supply canal with a pumping station near the Mirage Flats Irrigation District and operating the Mirage Flats canal as a recharge facility without making irrigation deliveries. Each of these scenarios is described in more detail in this section.

3.1 Climate Scenarios

As discussed in Appendix A, four climate scenarios were evaluated as a part of this study. Net evaporation rates for future scenarios were developed as inputs to the UNW integrated models. The climate scenarios included Future No Action, Low, Central Tendency (CT) and High. The Future No Action climate scenario is represented by repeating the historic climatic conditions. The Low scenario generally corresponds with more warming and drier conditions. The CT scenario generally corresponds with central tendency warming and precipitation. The High scenario generally corresponds with less warming and wetter conditions.

3.2 Future No Action Model

Current operational conditions were simulated as “No Action” alternative to establish a baseline condition for evaluation alternatives. The no action scenario maintains current operational characteristics of Box Butte Reservoir and Mirage Flats delivery system. Future conditions were represented by applying a constant level year 2010 land use data to the future no action climate and three climate changes that occurred from 1960-2010. This isolated the impacts of climate variability in this basin study. The 1960-2010 temporal scale was used for all four climate scenarios as it allows readers to identify wet and dry climate periods in the data in the evaluation of the modeling results.

3.2.1 UNW Model Representation

No change to the groundwater model, watershed model, or operational rules in the surface water operations model. The different climate scenarios were incorporated, the changes to available water and demands due to climatic conditions for that water were reflected and impacts to the study area water budget projected.

3.2.2 UNW Future No Action Results

The Future No Action scenario allows for comparison of the climate scenarios excluding any affect of the alternative operation scenarios. The climate scenarios are generally described in Section 3.1 and further discussed in Appendix A. Key water budget elements were identified to get an overall picture of the results from the UNW integrated model. The key water budget elements included:

- Box Butte Reservoir inflows
- Box Butte Reservoir elevations
- Box Butte Reservoir releases
- Mirage Flats diversions
- Surface water irrigation deliveries
- Volume of groundwater pumping on co-mingled acres
- Total aquifer recharge
- Groundwater elevations
- Baseflow Contributions
- Niobrara River at Gordon gage

These elements are discussed further below.

3.2.2.1 Box Butte Reservoir Inflows

Annual plots of total inflow into Box Butte Reservoir for the simulation period (1960-2010) in Figure 5 show all four climate scenarios. While these plots can be difficult to read, they show qualitative results and general responses during cyclical wet/dry cycles. As expected, the gage plots show the Low water availability scenario to typically have the lowest flow, the CT to typically be in the middle, and the High water availability scenario to typically have the highest flows. The baseline no action always has lower flow than the High water availability and the amount of flow is typically between the Low water availability and CT scenarios.

For a more quantitative analysis, tables of average daily values per year for each climate scenario characterize the data illustrated in the plots. Table 5 summarizes the annual daily average flows (AFD) from 1960-2010. The data is divided into annual and seasonal values (irrigation and non-irrigation). The irrigation season for the Basin Study was based on Mirage Flats typical operations and was considered to be July, August and September. The Mirage Flats deliveries begin the Monday after the fourth of July and typically continue until no storage water is available[1] in Box Butte Reservoir.

[1] Personal Communication with M. Brozek, Mirage Flats Irrigation District Manager, March 2014.

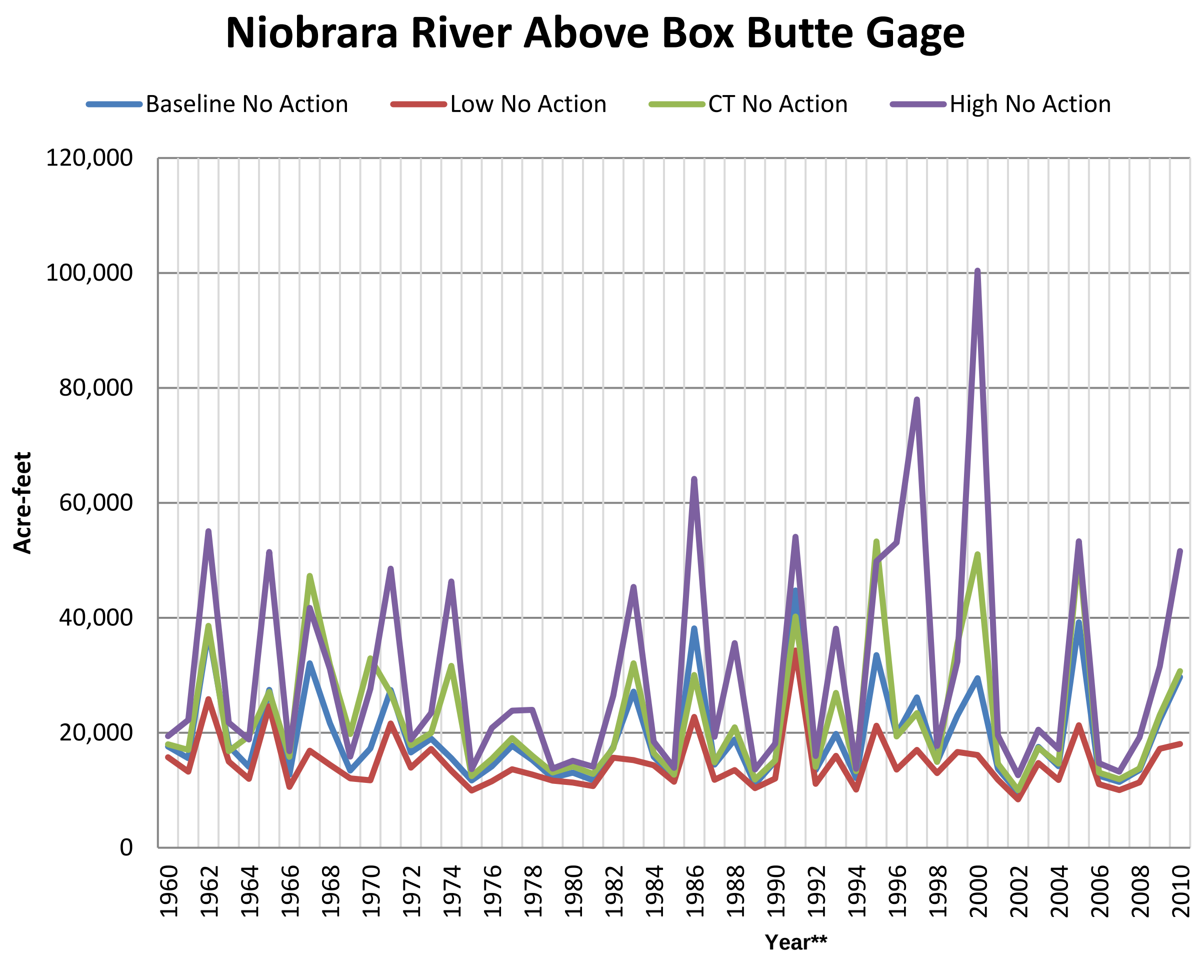

Figure 5. Total Annual Flows at Niobrara Above Box Butte Gage – No Action Baseline vs. Low, CT, High

****Future conditions were represented by applying a constant level year 2010 land use data to the climate changes that occurred from 1960-2010. This isolated the impacts of climate variability in this basin study and by keeping the historic yearly designation allows readers to identify wet and dry climate periods in the data.**

Table 5. No Action Annual Daily Average Flows for Niobrara Above Box Butte Gage (AFD)

	Annual	Annual % of Baseline	Irrigation Season	Non-Irrigation Season
Baseline	53		26	63
Low	40	75%	20	47
CT	62	117%	28	73
High	83	157%	35	99

3.2.2.2 Box Butte Reservoir Elevations

Box Butte Reservoir average annual elevations for the Future No Action alternative for all four climate scenarios are plotted in Figure 6. Box Butte elevations for the High water availability scenario are generally higher than the other scenarios and all scenarios typically follow a similar pattern. However during very wet years (as shown in 1996-2003), the High water availability results in Box Butte reservoir levels much higher than other years, and other climate scenarios. Table 6 summarizes the annual daily average elevations from 1960-2010. The data is divided into annual and seasonal values (irrigation and non-irrigation).

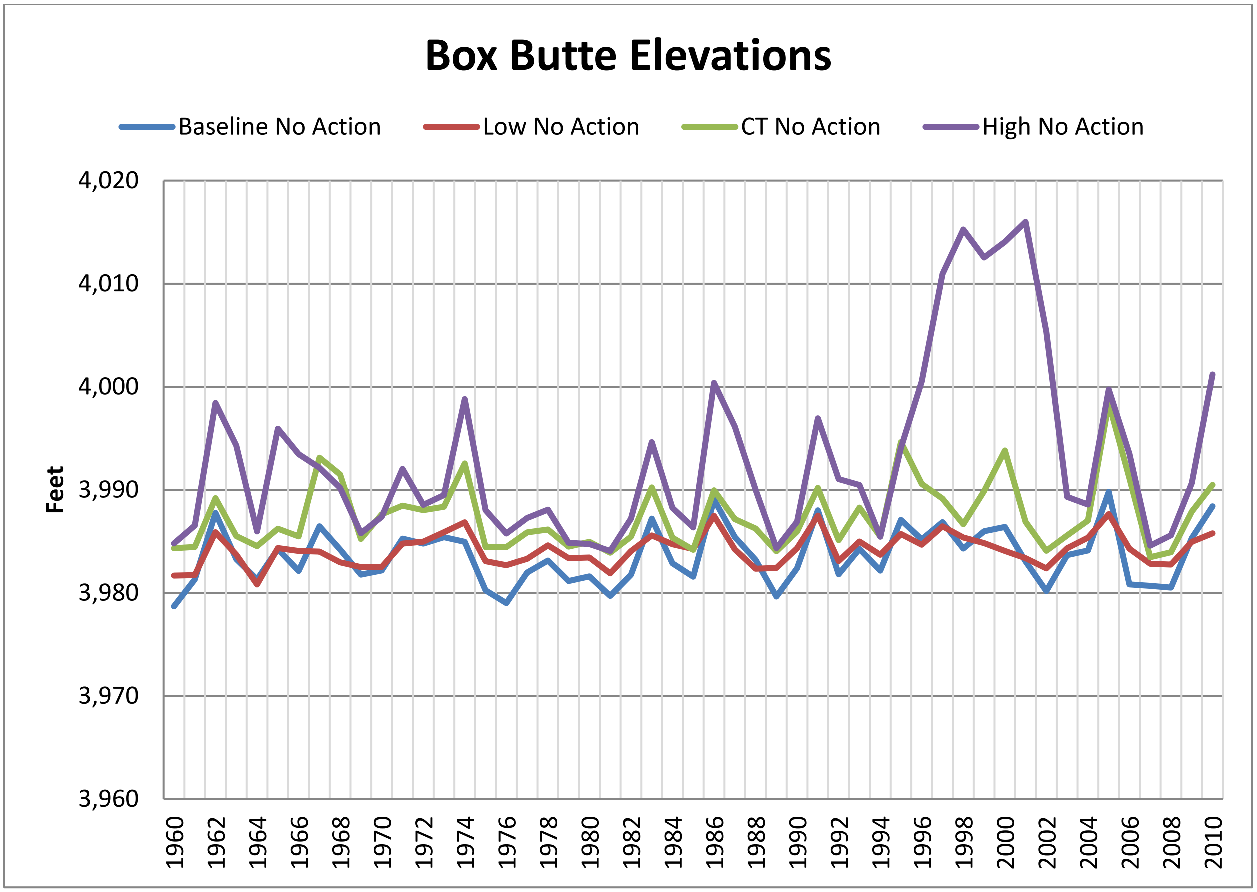

Figure 6. Annual average Box Butte Elevations – No Action Baseline vs Low, CT, High.

Table 6. No Action Annual Daily Average Elevations at Box Butte Reservoir (ft)

	Annual	Annual % of Baseline	Irrigation Season	Non-Irrigation Season
Baseline	3,984		3,977	3,986
Low	3,984	100%	3,979	3,986
CT	3,987	100%	3,983	3,989
High	3,993	100%	3,991	3,994

3.2.2.3 Box Butte Reservoir Releases

Total annual Box Butte Reservoir releases for the Future No Action alternative for all four climate scenarios are plotted in Figure 7. Box Butte Reservoir releases for the High water availability scenario are generally higher than the other scenarios, which is consistent with the high reservoir elevations, more storage water availability for delivery, and in the wettest years, forced releases due to high reservoir elevations near the operational thresholds defined in the operating rules. All climate scenarios typically follow a similar pattern. Table 7 summarizes the annual daily average releases (AFD) from 1960-2010. The data is divided into annual and seasonal values (irrigation and non-irrigation).

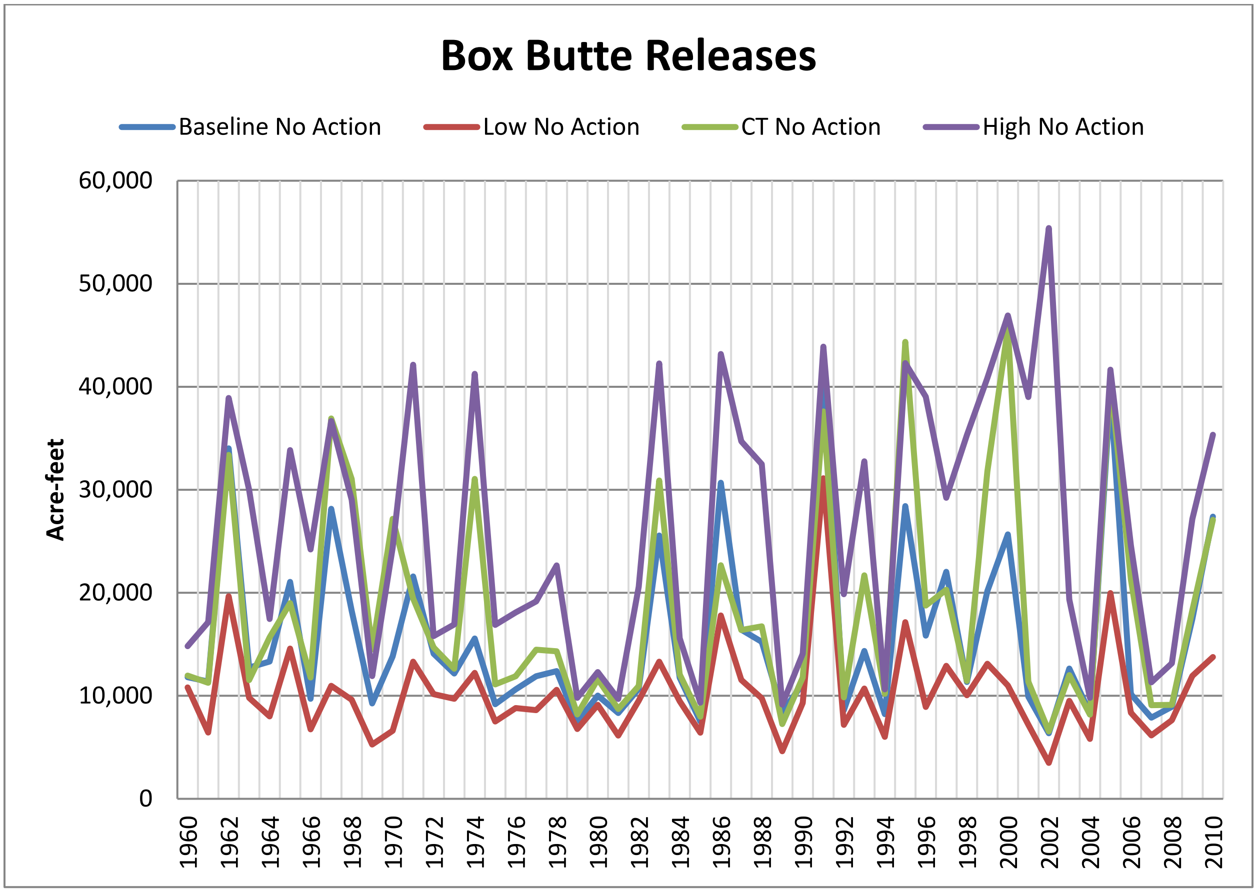

Figure 7. Total annual Box Butte releases – No Action Baseline vs. Low, CT, High.

Table 7. No Action Annual Average Daily Box Butte Reservoir Releases (AFD)

	Annual	Annual % of Baseline	Irrigation Season	Non-Irrigation Season
Baseline	43		170	0
Low	28	65%	112	0
CT	50	116%	199	0
High	72	167%	286	0

3.2.2.4 Mirage Flats Diversions

The total annual diversions for Mirage Flats for the Future No Action alternative for the four climate scenarios are plotted in Figure 8. Identified patterns to the Box Butte Reservoir releases and the operating rules of Box Butte are directly linked to the Mirage Flats diversions. Consistent with the Box Butte releases, the High water availability scenario diversions are generally higher than the other scenarios, and all climate scenarios typically follow a similar pattern. Table 8 summarizes the annual daily average diversions (AFD) from 1960-2010 for the irrigation season. During the Future No Action scenario, Mirage Flats Diversions only occur during the irrigation season.

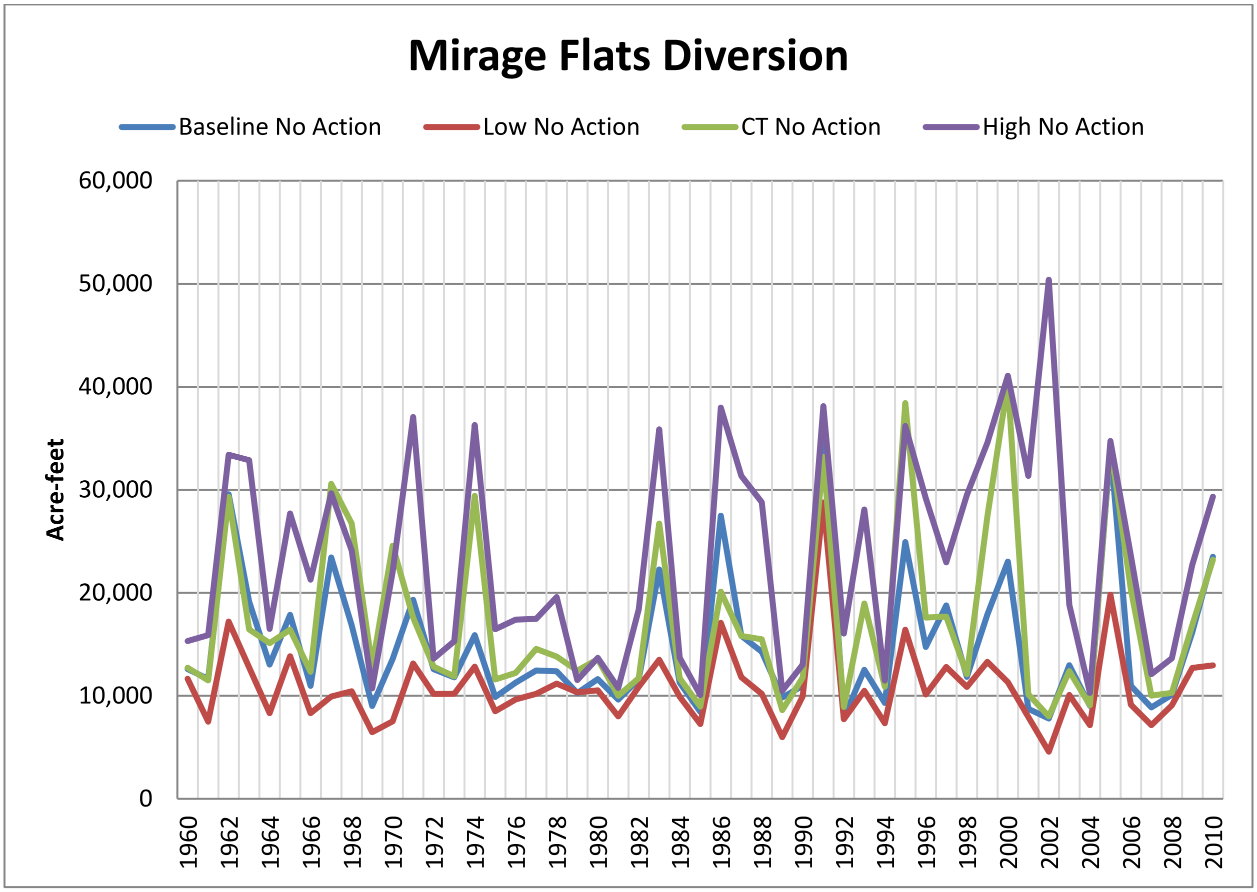

Figure 8. Total annual Mirage Flats diversion – No Action Baseline vs. Low, CT, High

Table 8. No Action Annual Daily Average Mirage Flats Diversions (AFD)

	Irrigation Season	% of Baseline
Baseline	164	
Low	118	72%
CT	187	114%
High	254	155%

3.2.2.5 Surface water irrigation deliveries

Average crop water demands and available surface water supplies for each of the 14 surface water irrigation groups for the Future No Action alternative and the four climate scenarios are shown in Figures 9-10. As the system experiences increases (Low to High climates) in precipitation the irrigation demands decrease. Even with the increased levels of precipitation, however, the available supply of surface water only meets a portion of the crop water demand.

The Mirage Flats Irrigation District (Group 9) has the largest demand and also receives the largest volume of deliveries. Figure 9 depicts the total annual crop demand; while Figure 10 shows the volume of water the surface water system can deliver to the crops. Demands are generally higher in the Low climate and less in the High climate. Conversely with water being the limiting factor, greater amount of water in the system allows larger annual deliveries in the wetter High climate. Figures 11 and 12 illustrate the annual irrigation demands and deliveries for the Mirage Flats Canal for the 1960-2010 period.

3.2.2.6 Volume of groundwater pumping on co-mingled acres

In the event there is insufficient surface water irrigation to meet the full ET requirements of the crops, ground water pumping was use to supplement the deficit on co-mingled acres when available. The average volume of co-mingled pumping for each surface water irrigation group is shown in Figure 13.

The Mirage Flats Irrigation District (Group 9) experiences the highest average demand for co-mingled pumping. Figure 14 shows the annual volume of co-mingled pumping needed to reach full evaporative demand by crops served by the Mirage Flat Irrigation District.

3.2.2.7 Total aquifer recharge

The average annual recharge within the Niobrara Drainage Basin for the Future No-Action alternative for the four climate scenarios are plotted in Figures 15-18. The pattern in recharge rates are related to precipitation rates, soils, land use, and canal recharge.

3.2.2.8 Groundwater elevations

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 19 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.

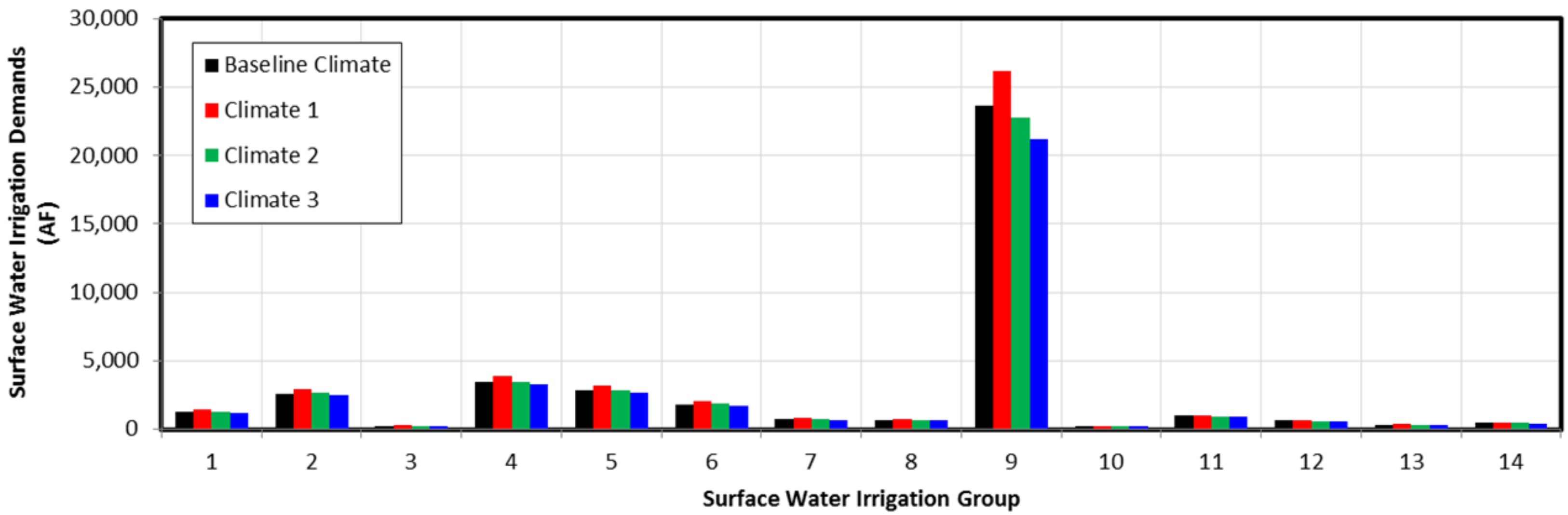

Figure 9. Average annual crop water demands by surface water irrigation group – No Action; Baseline vs Low, CT, High.

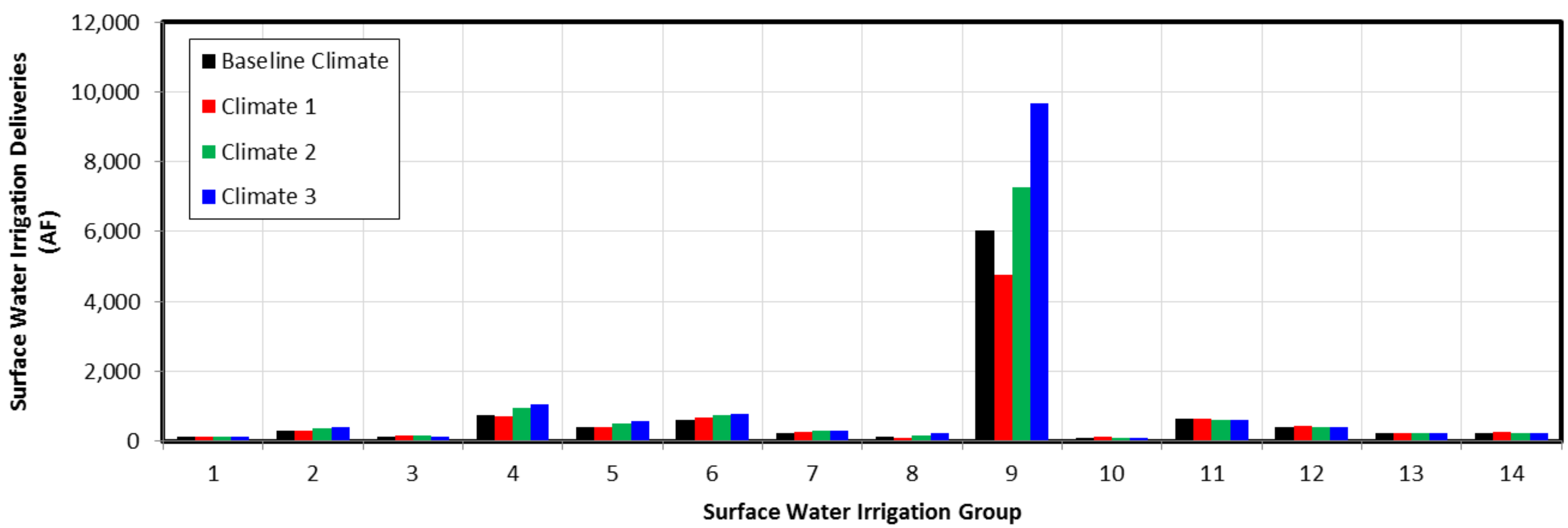

Figure 10. Average annual surface water supplies by irrigation group– No Action; Baseline vs Low, CT, High.

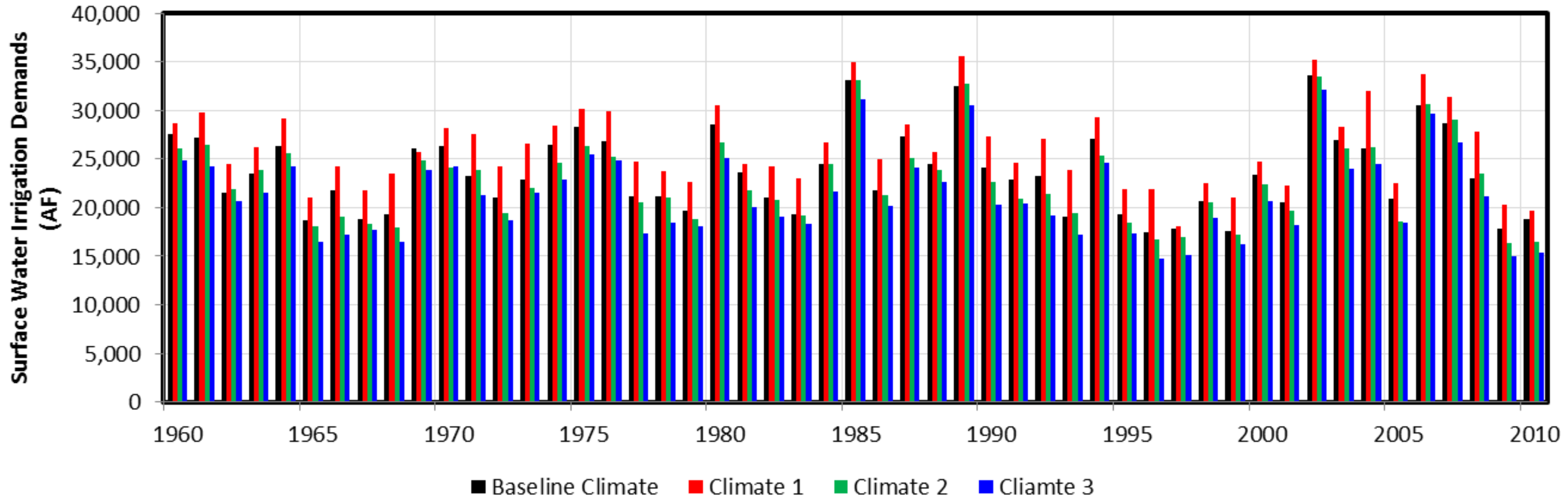

Figure 11. Total annual Mirage Flats surface water irrigation demands – No Action; Baseline vs Low, CT, High.

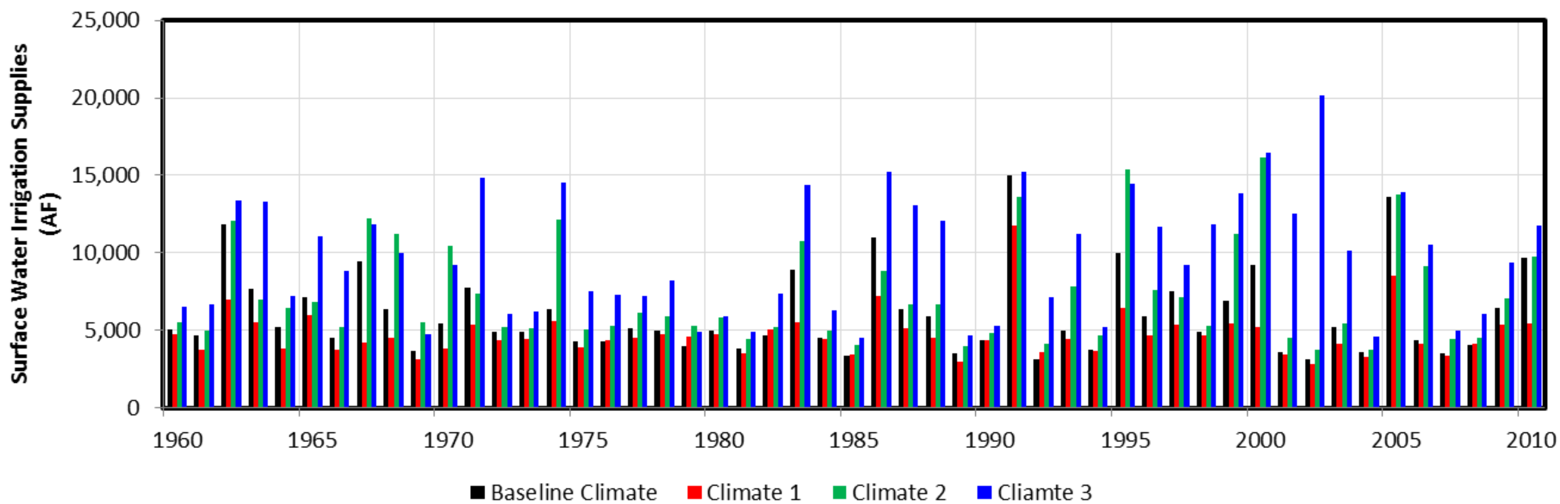

Figure 12. Total Annual Mirage Flats surface water irrigation deliveries – No Action; Baseline vs Low, CT, High.

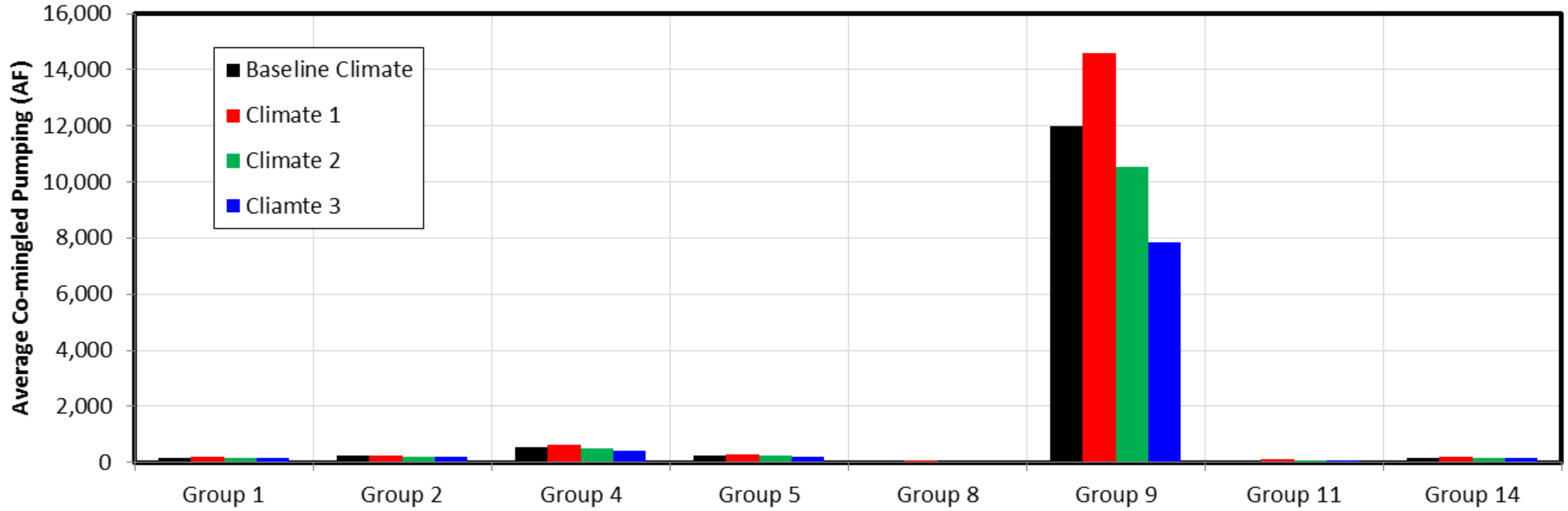

Figure 13. Average surface water irrigation group's supplemental co-mingled pumping – No Action; Baseline vs Low, CT, High.

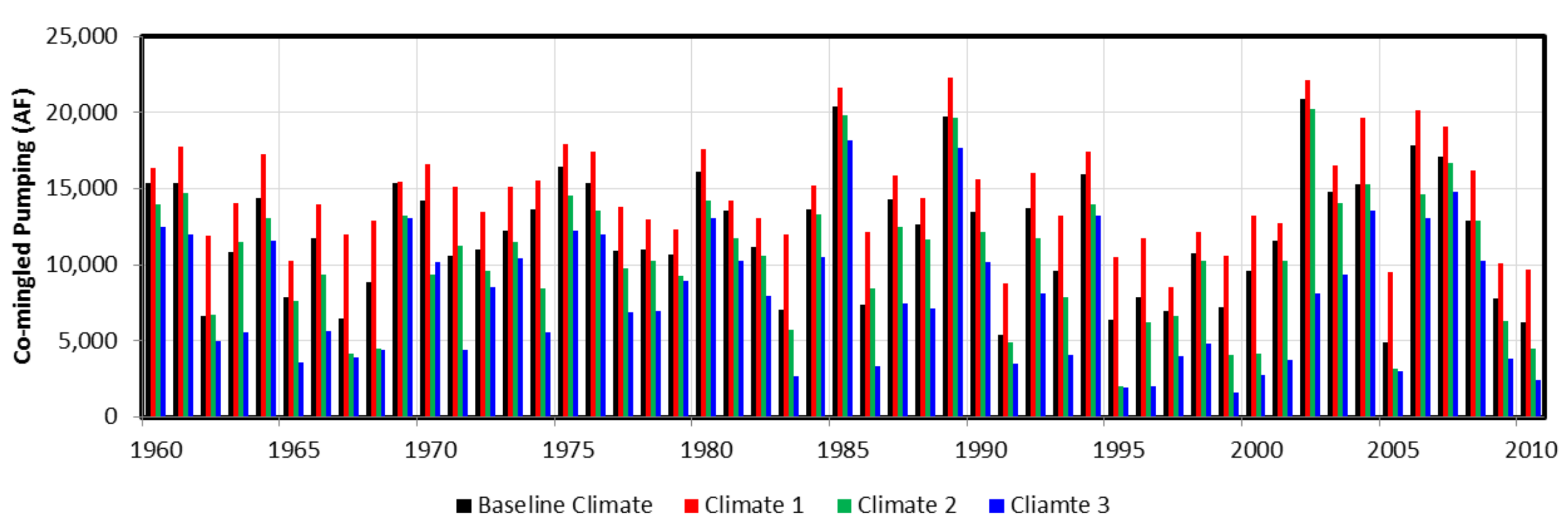

Figure 14. Annual co-mingled pumping in the Mirage Flats Irrigation District – No Action; Baseline vs Low, CT, High.

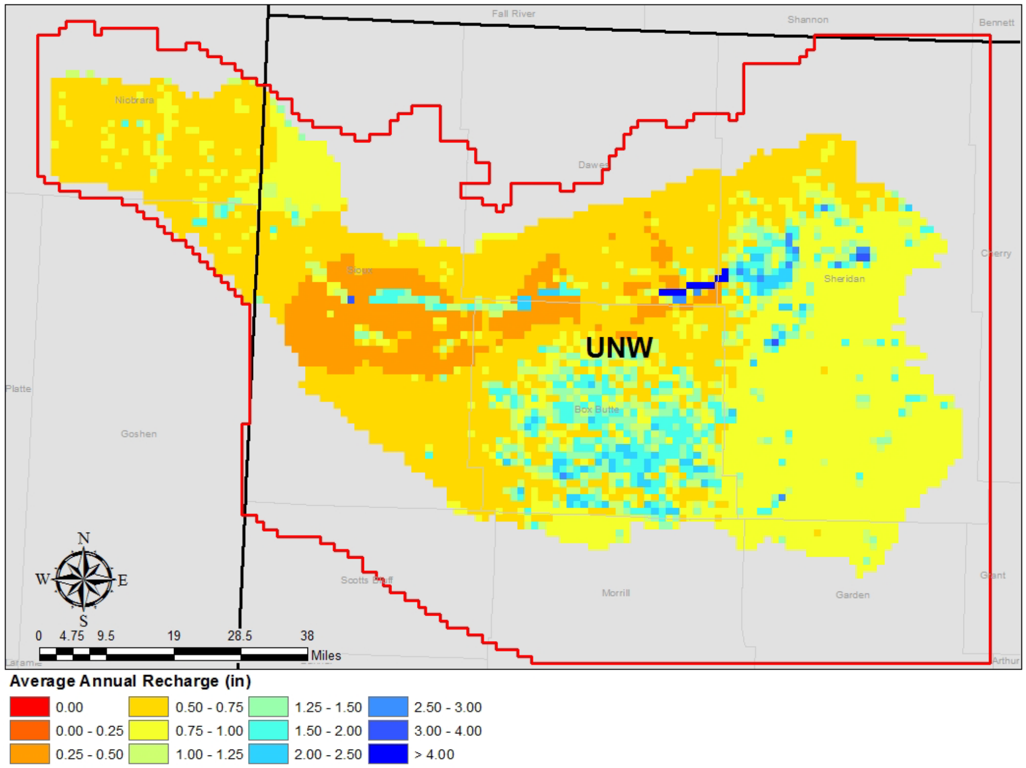

Figure 15. Average annual recharge – No Action; Baseline.

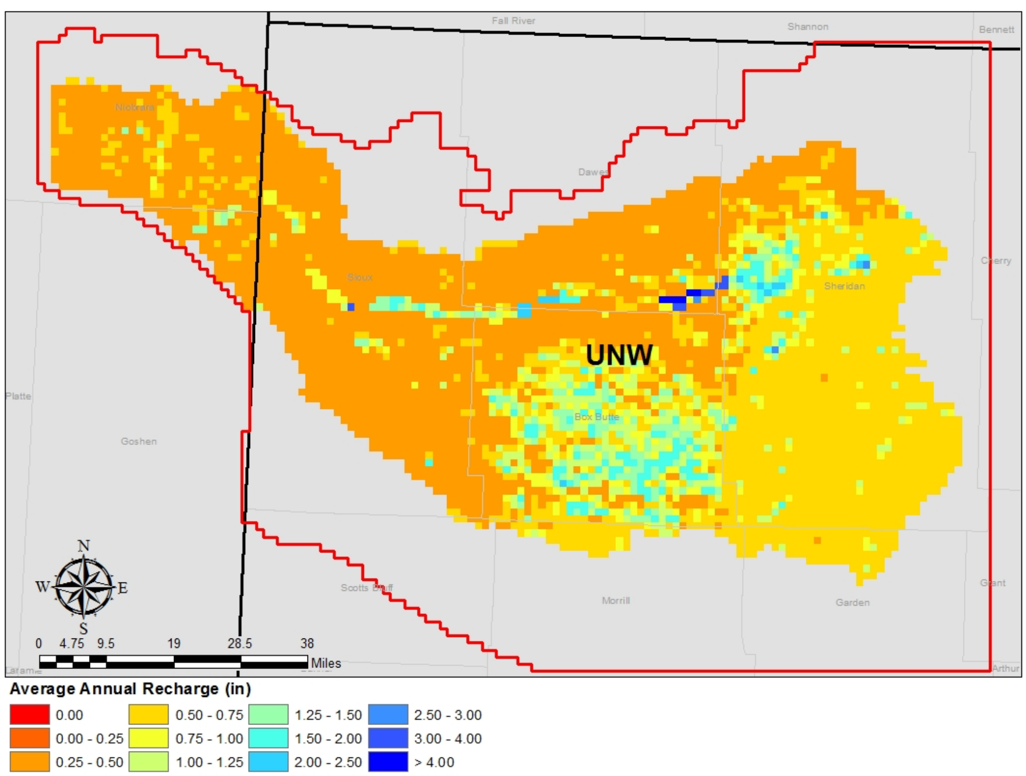

Figure 16. Average annual recharge – No Action; Low.

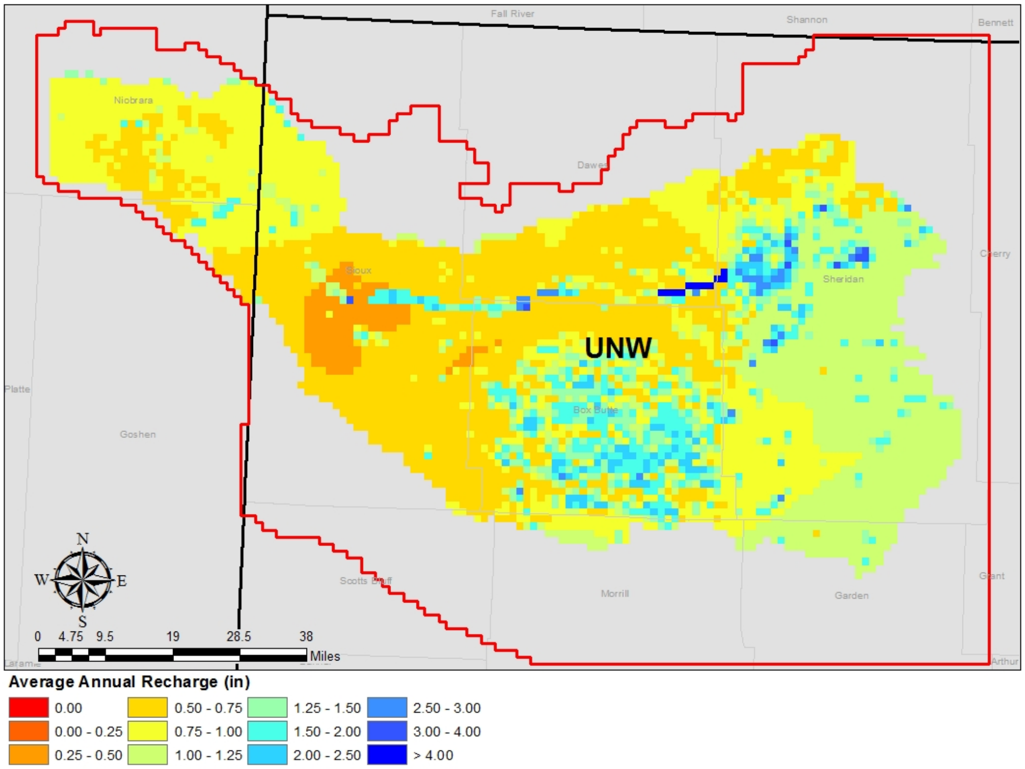

Figure 17. Average annual recharge – No Action; CT.

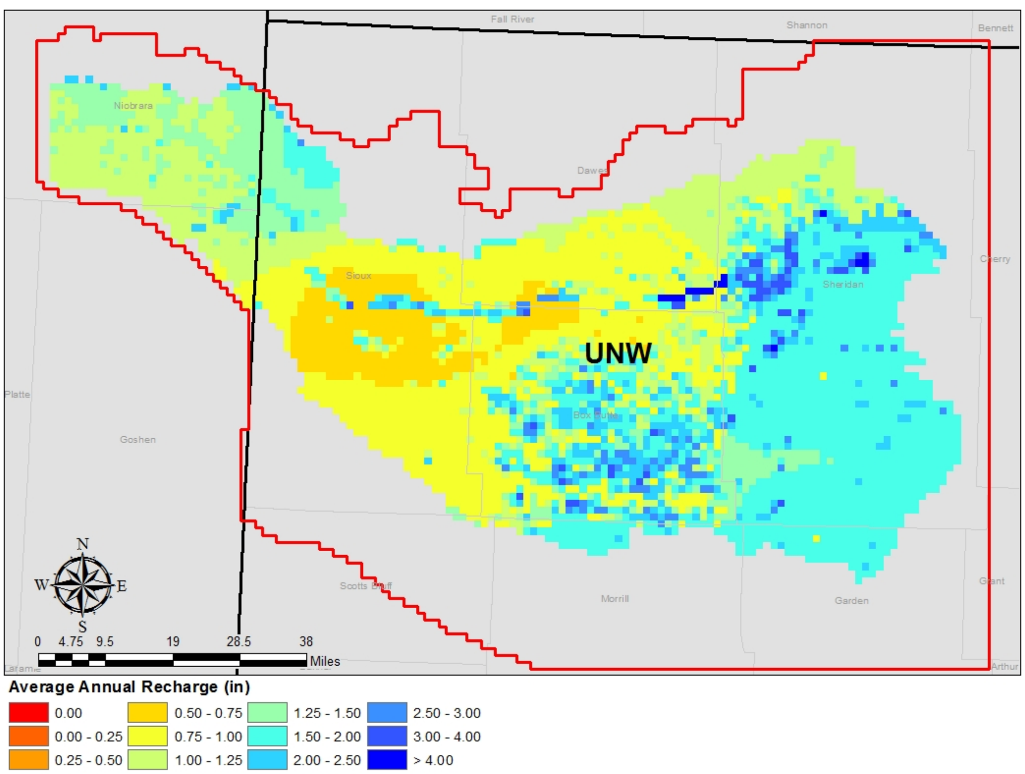

Figure 18. Average annual recharge – No Action; High.

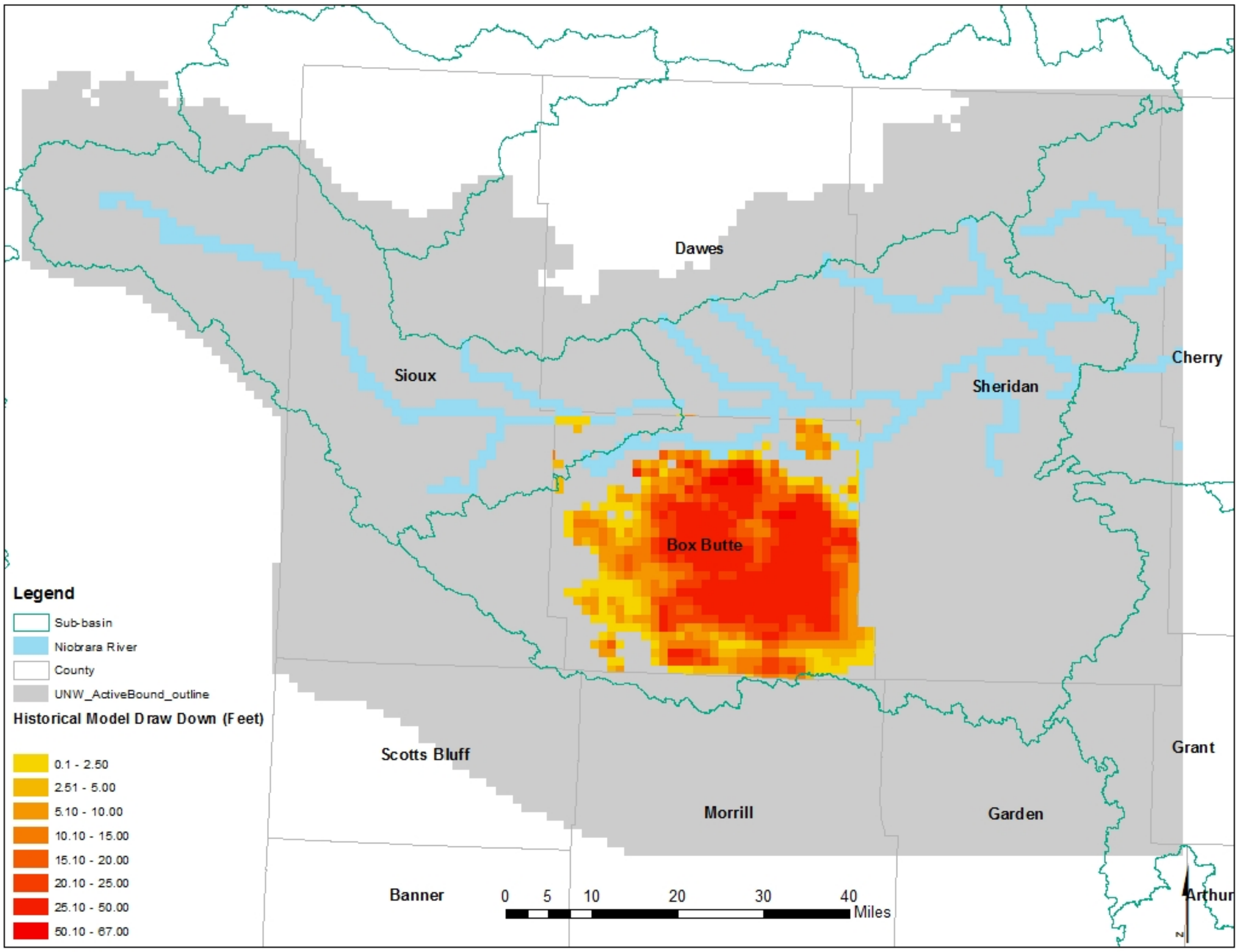

Figure 19. Historical model draw down (1960- 2010).

Figure 20 illustrates changes in groundwater levels in Box Butte County in the Upper Niobrara White area under different water availability (based on climate) scenarios.

The upper left figure illustrates the difference in groundwater drawdown in the Future No Action 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.

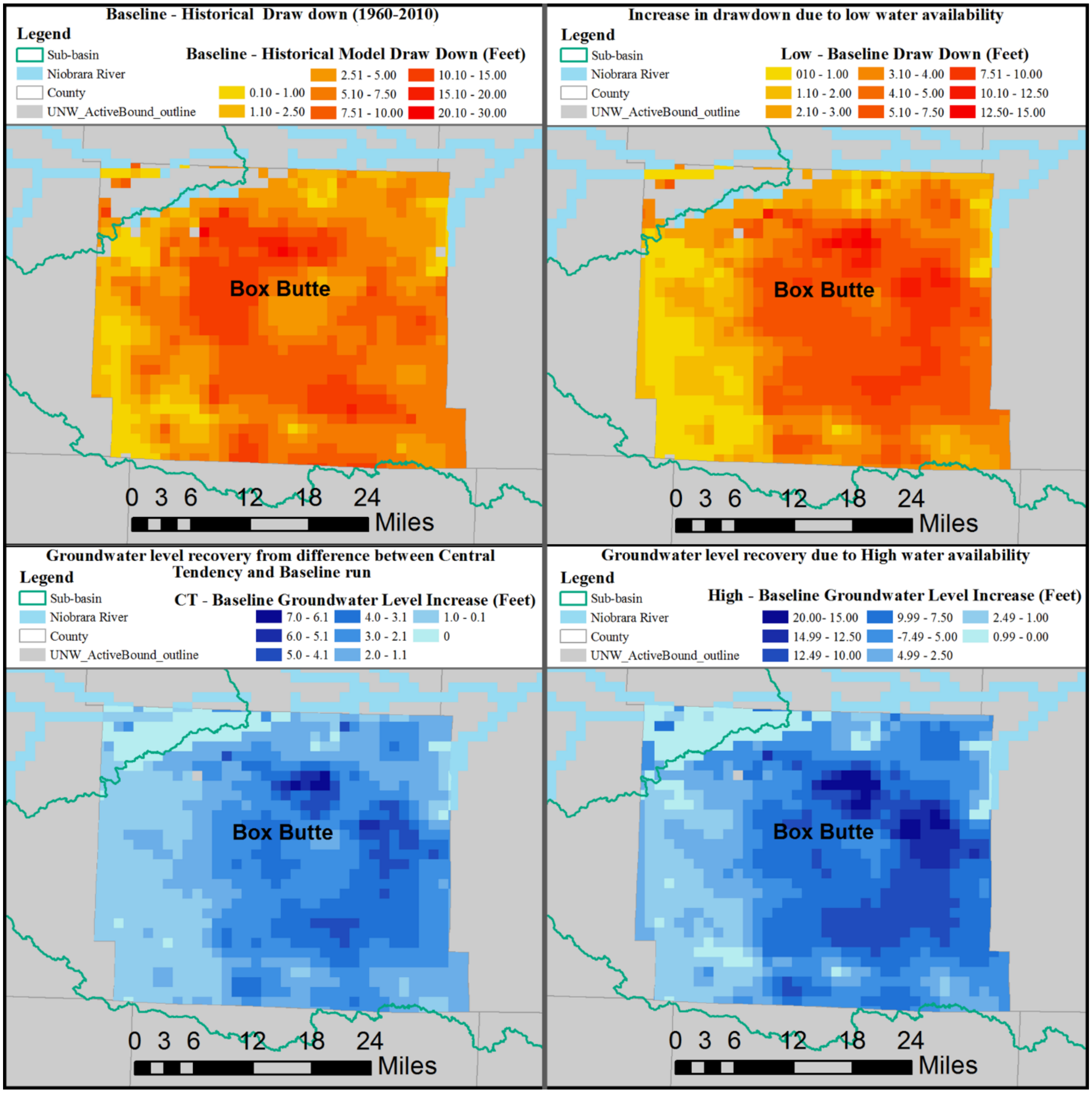

Figure 20. Groundwater drawdown comparison in Box Butte County for scenario model runs.

The lower left figure of Figure 20 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.

3.2.2.9 Baseflow Contributions

Figure 21 depicts the differences between the Future 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.

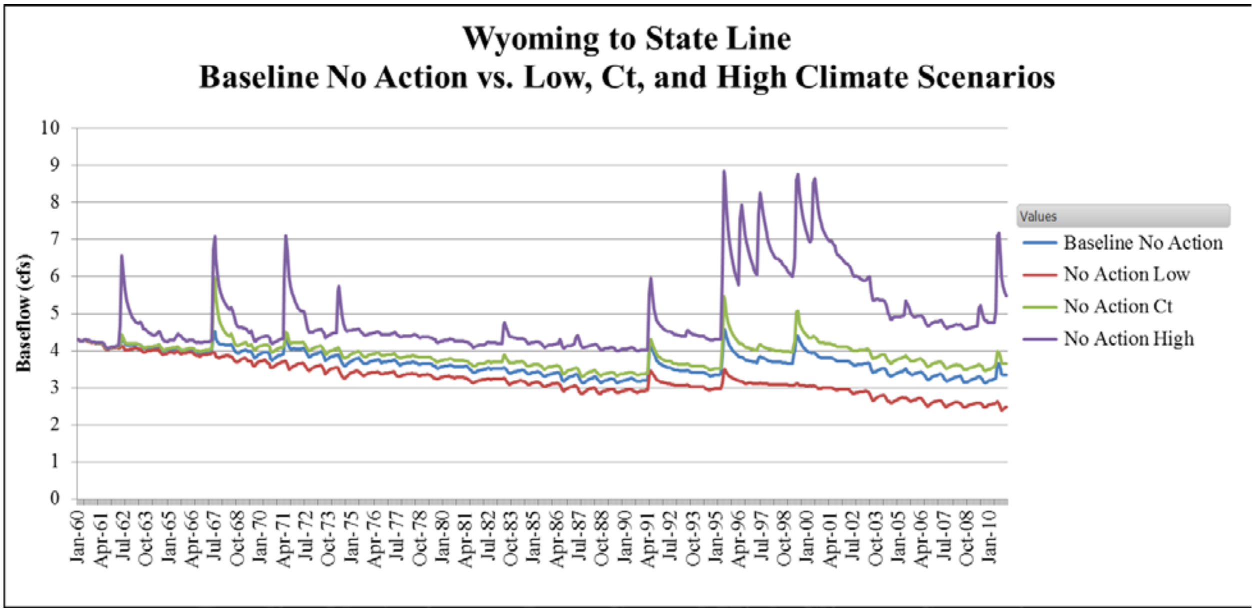

Figure 21. Wyoming to Stateline reach baseflow comparison –Baseline vs low, CT, and high no action runs.

Figure 22 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 23 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.

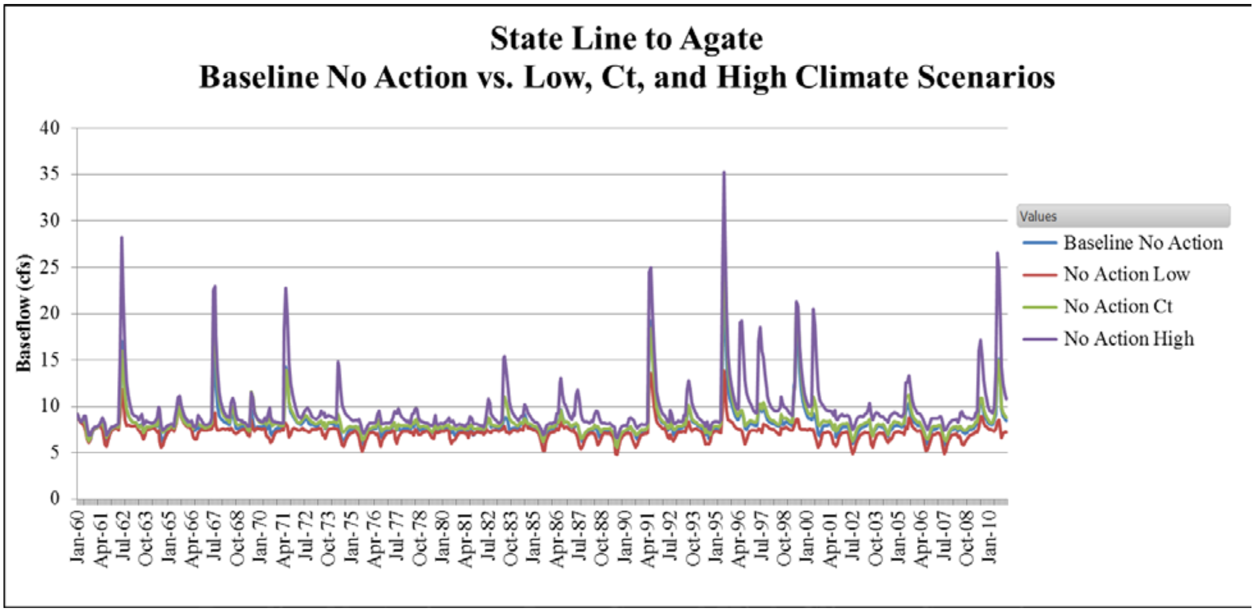

Figure 22. Stateline to Agate reach baseflow comparison –Baseline vs low, CT, and high no action runs.

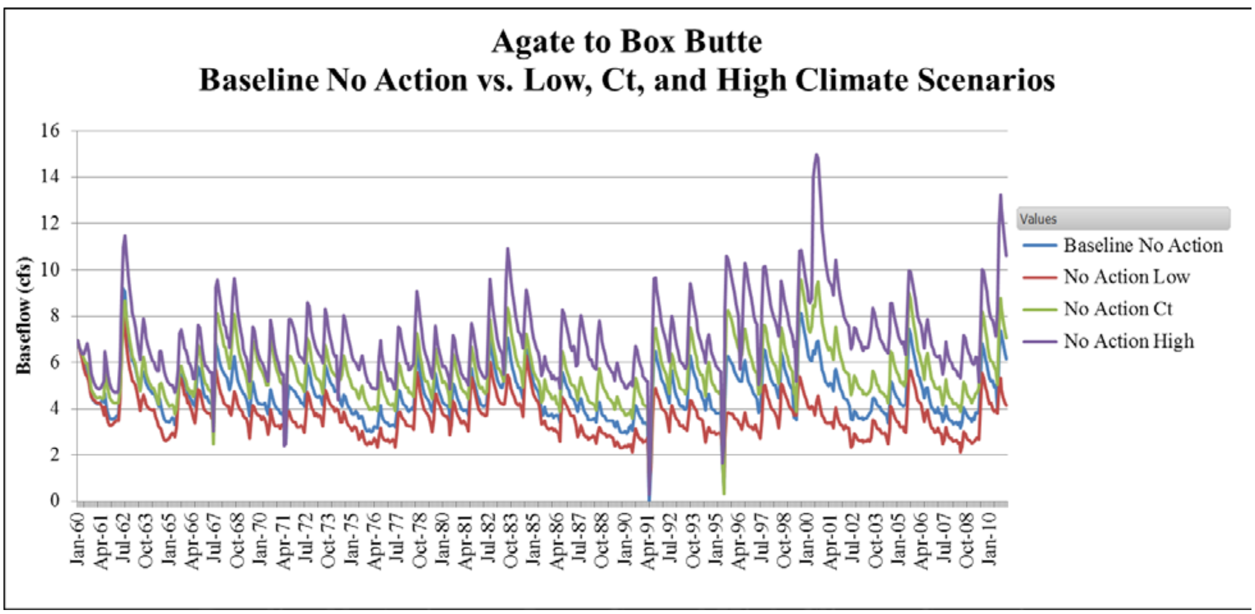

Figure 23. Agate to Box Butte reach baseflow comparison –Baseline vs low, CT, and high no action runs.

Figure 24 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.

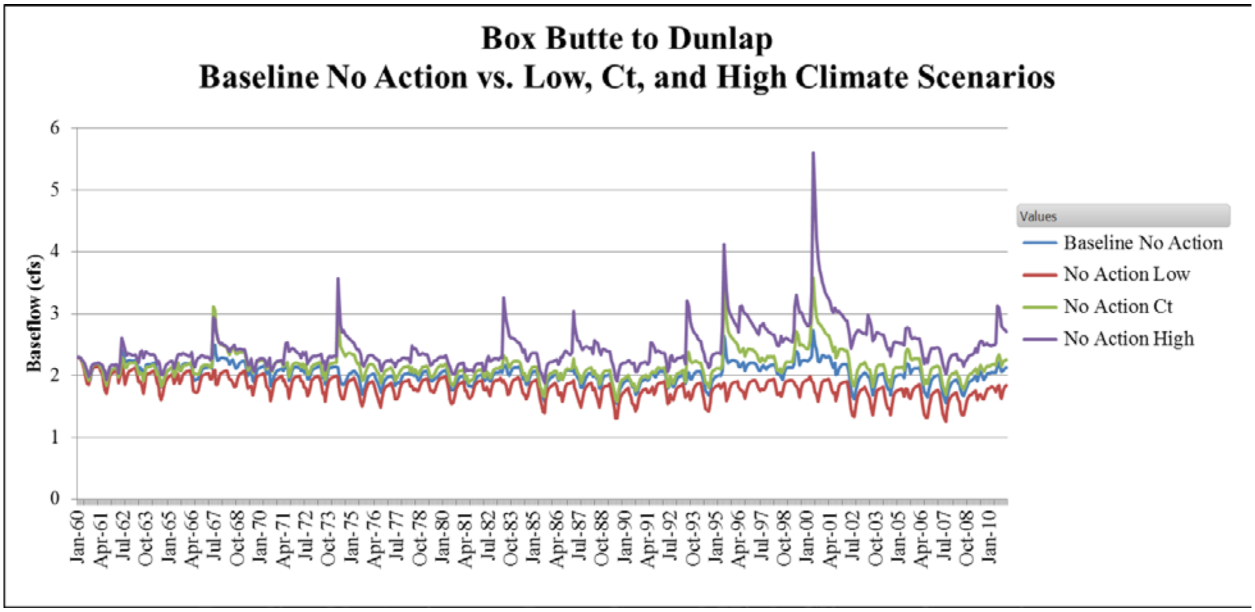

Figure 24. Box Butte to Dunlap reach baseflow comparison –Baseline vs low, CT, and high no action runs.

Figure 25 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 26 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.

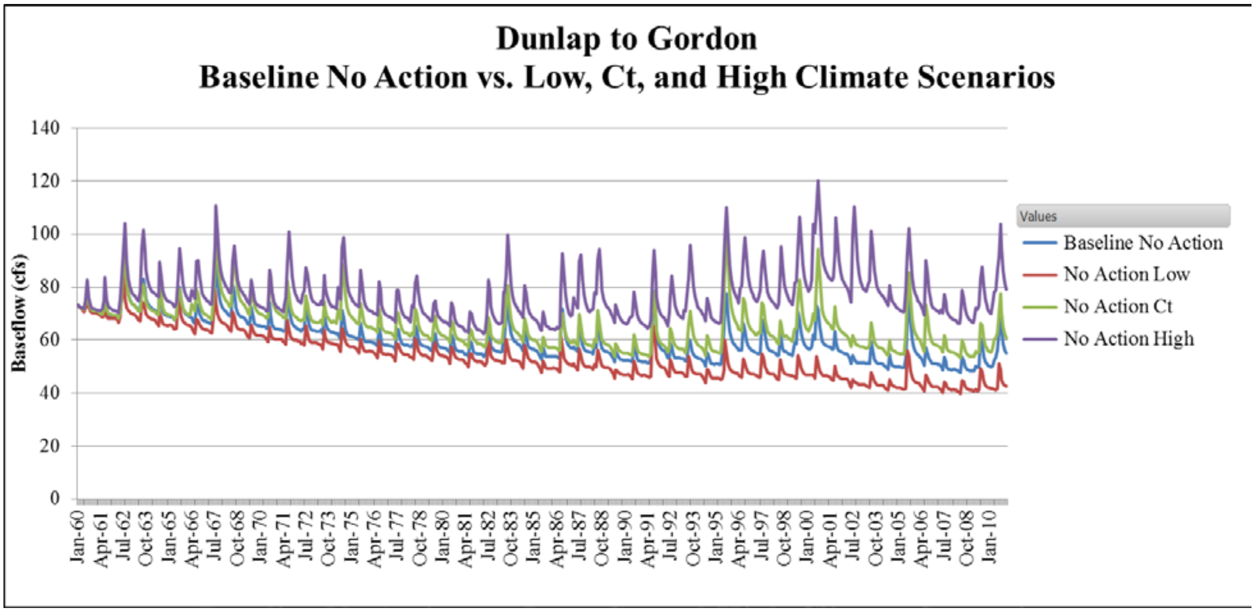

Figure 25. Dunlap to Gordon reach baseflow comparison –Baseline vs low, CT, and high no action runs.

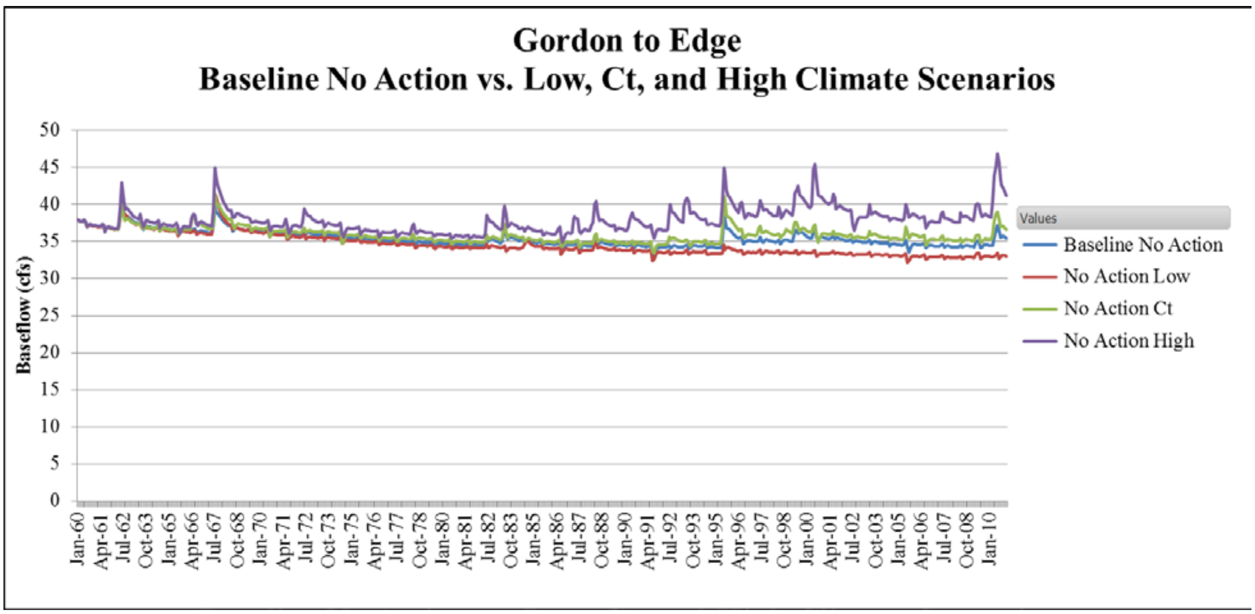

Figure 26. Gordon to model eastern edge reach baseflow comparison –Baseline vs low, CT, and high no action runs.

3.2.2.10 Niobrara River at Gordon Gage

The total annual flows at the Niobrara River at Gordon gage for the Future No Action alternative for the four climate scenarios are plotted in Figure 27 for the simulation period. Similar to other results, the high water availability scenario flows are generally higher than the other scenarios, but the differences are somewhat dampened over the Mirage Flats to Gordon reach of the Niobrara River. All climate scenarios typically follow a similar pattern. Table 9 summarizes the annual daily average flows from 1960-2010. The data is divided into annual and seasonal values (irrigation and non-irrigation).

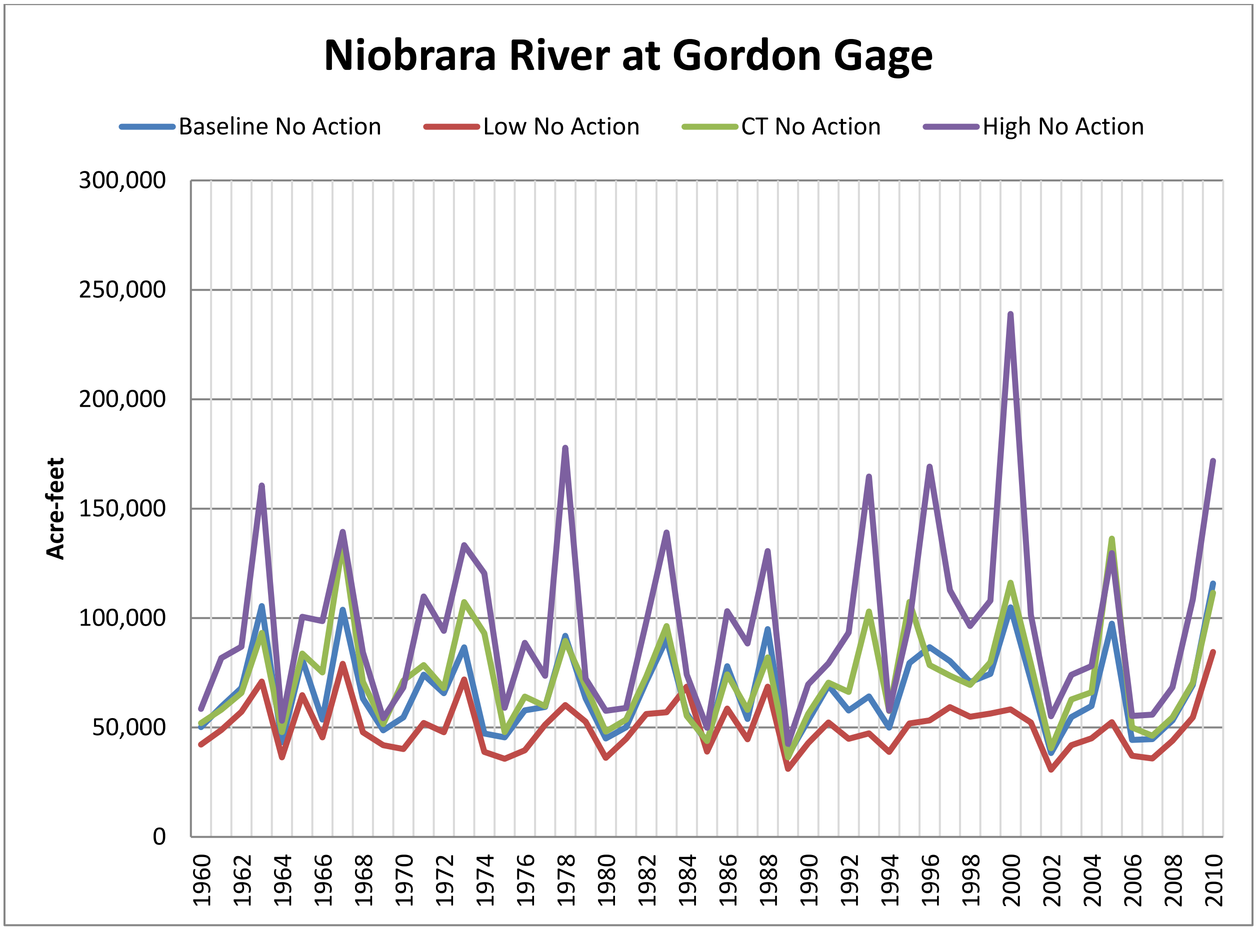

Figure 27. Total Annual Flows at Niobrara River at Gordon – No Action Baseline vs Low, CT, High.

Table 9. No Action Niobrara River at Gordon Annual Daily Average Flow (AFD)

	Annual	Irrigation Season	Non-Irrigation Season
Baseline	182	267	153
Low	138	205	115
CT	199	277	172
High	265	343	239

Trends based on wet, dry or median years were also analyzed. The years in the simulation (1960-2010) were ranked by total annual precipitation to determine the 10 wettest years, the 10 driest years and the 10 median years. The annual precipitation data was obtained from the No Action scenario water budget provided by the watershed model. Table 10 is a summary of the years used for the wet, dry, median analyses.

Table 10. Dry, Median and Wet Years

Ten Driest Years	Ten Median Years	Ten Wettest Years
2002	1963	2009
1989	1972	1965
1974	1968	1995
1964	1991	1982
2007	2004	1993
1975	1979	1973
1980	1990	1998
1985	2001	2010
1960	2008	1986
1976	1992	2005

Trends based on wet, dry or median years were analyzed for the average daily flow at the Niobrara River at Gordon gage. Figures 28, 29, and 30 show the average daily flow at Niobrara at Gordon gage for the four climate scenarios and are broken up by the dry, median and wet years. As expected, during the simulation the lowest flows occurred during the low water availability climate scenario and the highest flows occurred during the high water availability climate scenario. During the dry periods, the climate scenarios have a smaller impact on the amount of flow at Niobrara River at Gordon gage. The climate scenarios have more influence on the flows during the median and wet years. The flow ranges for the low to high climate scenarios are listed in Table 11 for the dry, median and wet years. The low and high climate scenario flows vary the most during the wet years.

Table 11. Niobrara River at Gordon Gage Flow Ranges (AFD) for Wet, Dry, Median Years

	Dry	Median	Wet
Low to High Climate Range	100-175	140-250	160-330
Difference	75	110	170

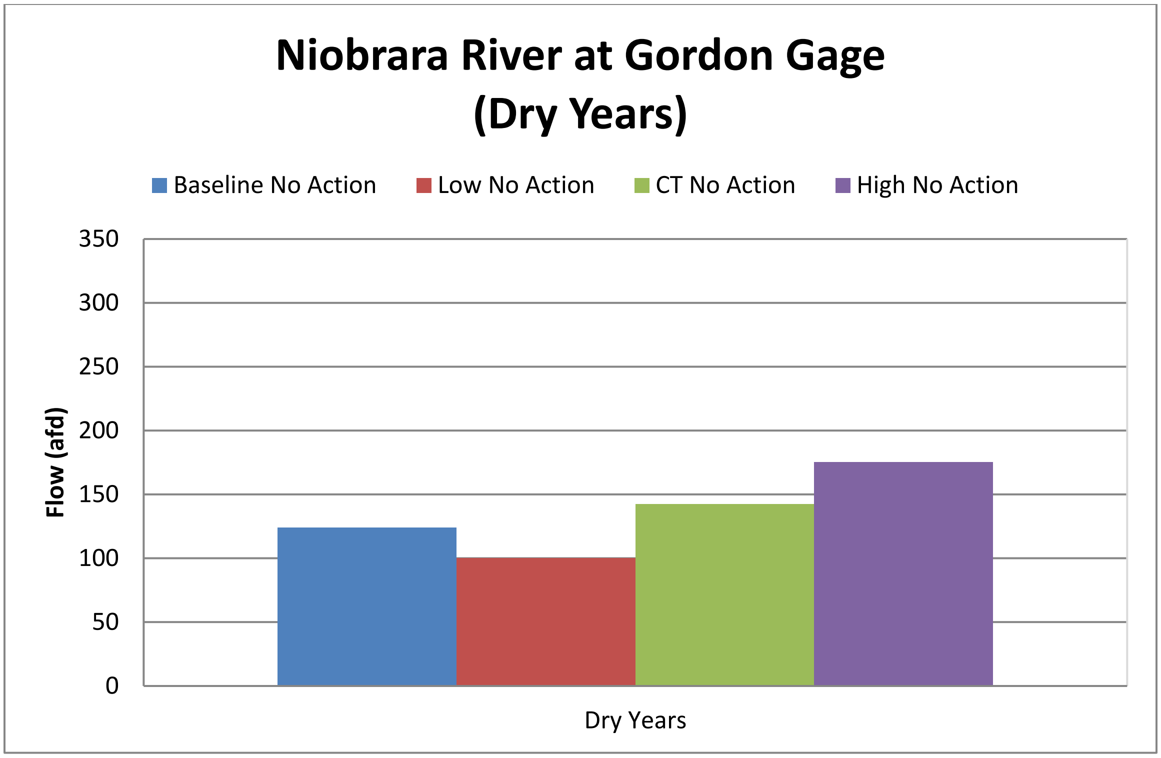

Figure 28. Average daily flow at Niobrara River at Gordon Gage (Dry Years) – No Action Baseline vs Low, CT, High.

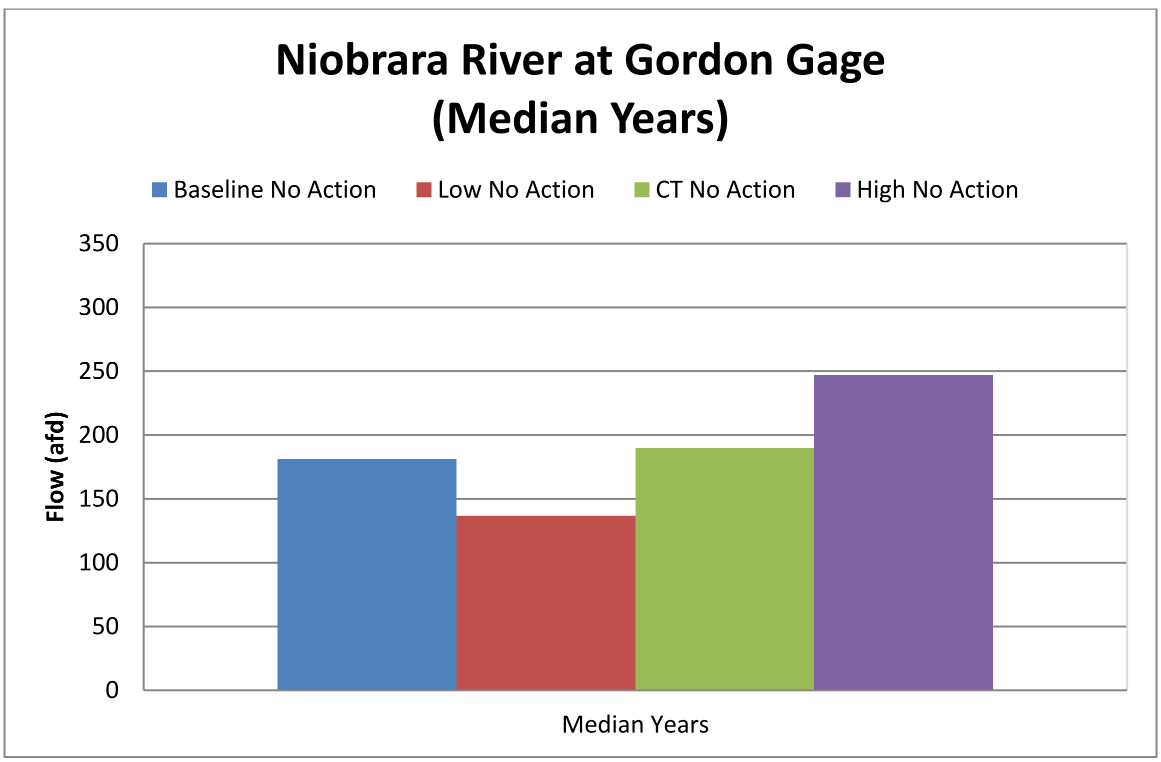

Figure 29. Average daily flow at Niobrara River at Gordon Gage (Median Years) – No Action Baseline vs Low, CT, High.

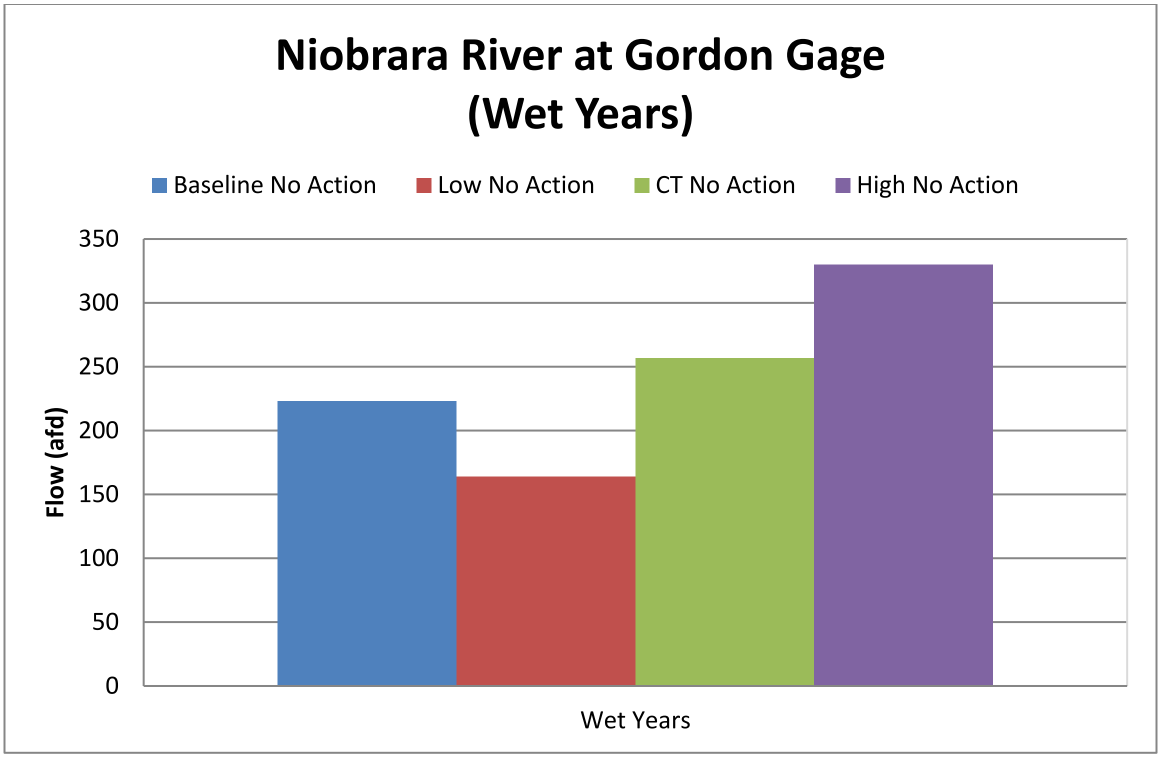

Figure 30. Average daily flow at Niobrara River at Gordon Gage (Wet Years) – No Action Baseline vs Low, CT, High.

Trends based on dry, median and wet years were also analyzed for the average daily Box Butte Reservoir levels. Figures 31, 32, and 33 show the average daily Box Butte elevations for the four climate scenarios by dry, median and wet years. Again, the figures show the climate scenarios have more influence on the flows (and subsequent reservoir levels) during the median and wet years than the dry years.

3.2.3 CENEB Model Representation

Similar to the UNW model region, inputs to the surface model region were taken from the groundwater model and watershed model for the CENEB sub-region. The total streamflow simulated by the UNW model was used as input to the CENEB model at Gordon for each of the corresponding scenarios. Additional inputs to the model include simulated inflows and evaporation for the operations of Merritt Reservoir. It should be noted that CENEB groundwater and watershed model simulations were not available for Baseline No Action and Future No Action Scenarios. Due to time constraints, a historical simulation for the model was not performed. Based on analysis of historical cropping patterns, it was determined that year to year variability in crop mix was not substantial, supporting the assumption that baseline No Action conditions sufficiently represent historical conditions.

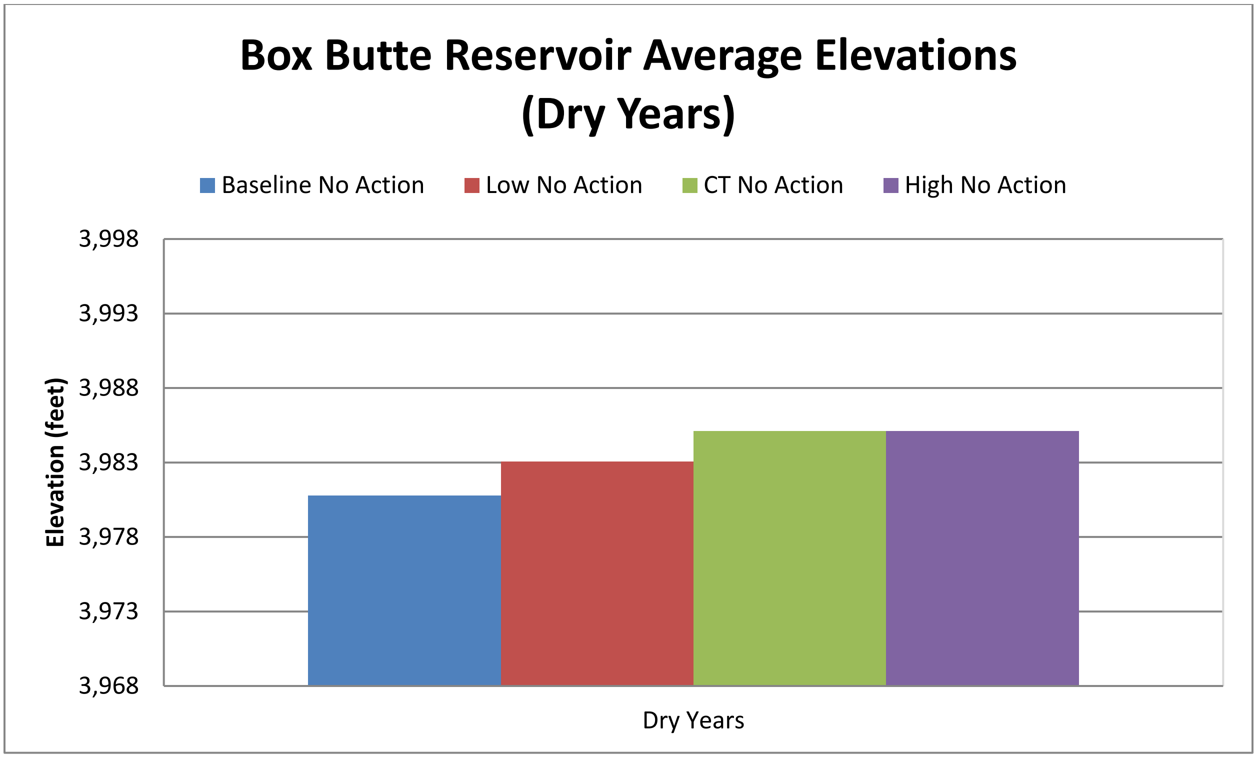

Figure 31 Average daily Box Butte Reservoir elevations (Dry Years) – No Action Baseline vs Low, CT, High.

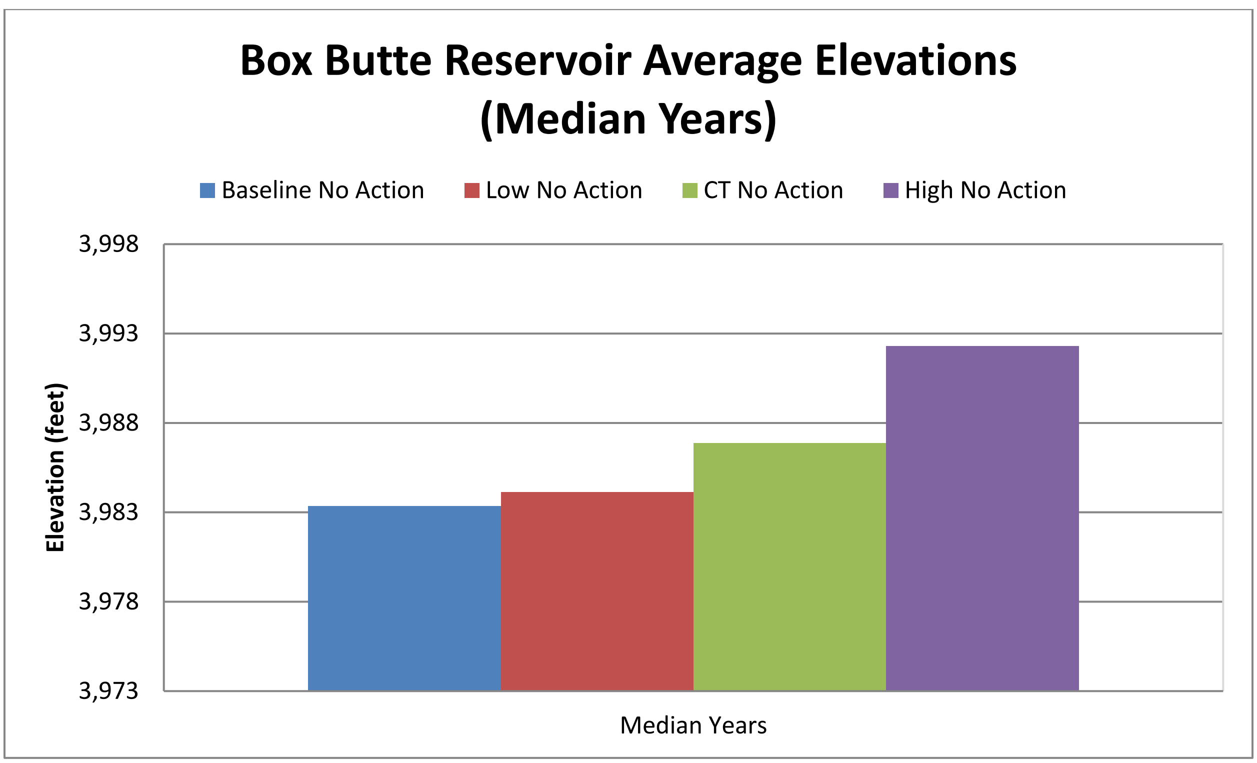

Figure 32. Average daily Box Butte Reservoir elevations (Median Years) – No Action Baseline vs Low, CT, High.

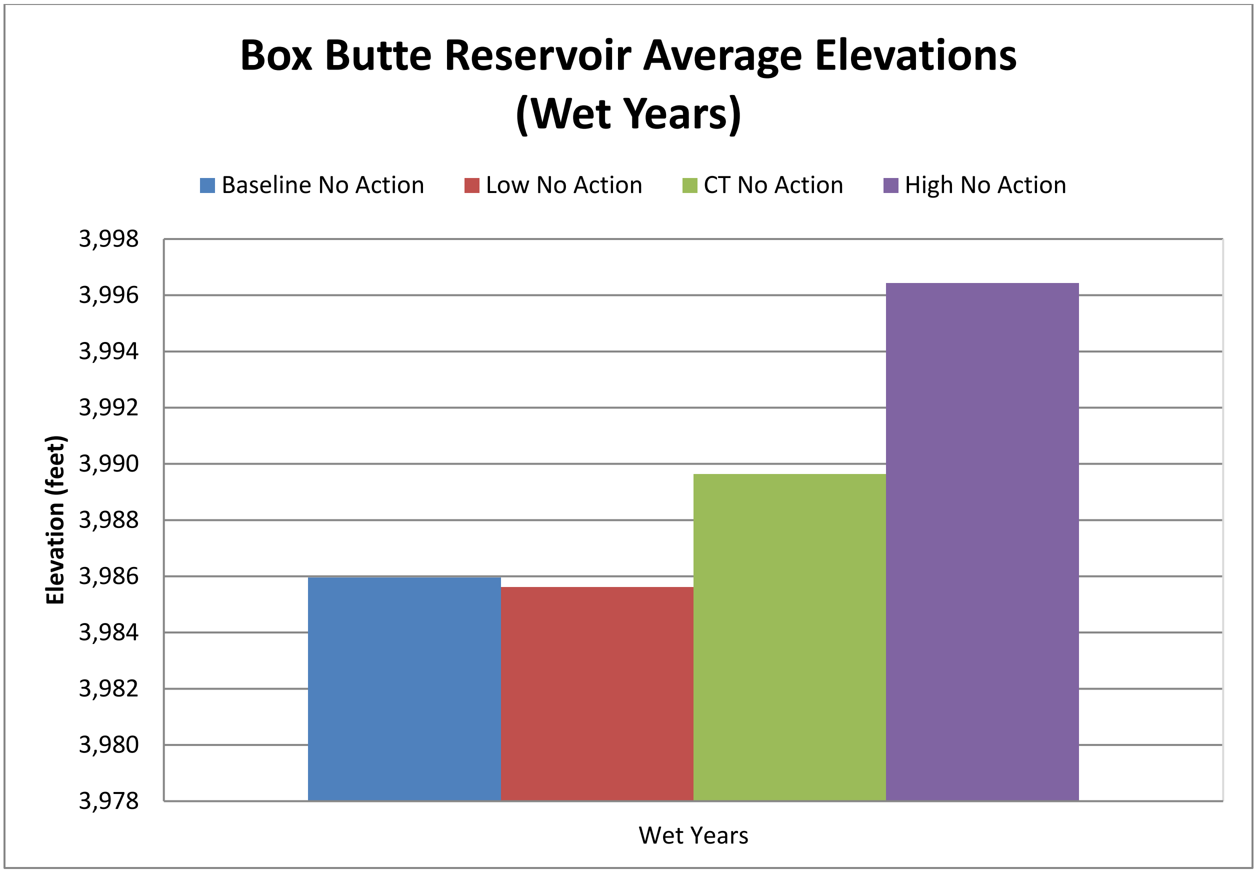

Figure 33. Average daily Box Butte Reservoir elevations (Wet Years) – No Action Baseline vs Low, CT, High.

3.2.4 CENEB Future No Action Results

Key water budget elements were identified to get an overall picture of the results from the CENEB integrated model. The key water budget elements included:

- Merritt Reservoir Elevations
- Merritt Reservoir Releases
- Flow at Sparks (the Niobrara Wild and Scenic River)
- Flow at Spencer (private hydropower facility)
- Deliveries to Ainsworth Irrigation District
- Baseflow contributions
- Volume of Groundwater pumping

These elements are discussed further below.

3.2.4.1 Merritt Reservoir Elevations

Figure 34 illustrates the comparison of the annual end of month reservoir elevations for Merritt Reservoir for each of the No Action scenarios. In each scenario, the projected inflows are sufficient to refill the reservoir each year to the desired level in the fall following the irrigation season. For the Central Tendency and the High climate scenarios, the change in the end of month reservoir elevations is modest as compared to the Baseline No Action scenario. For the Low scenario (corresponding to the hot and dry climate), the average reservoir elevations at the end of the irrigation season are approximately 2 feet lower as compared to the Baseline No Action scenario.

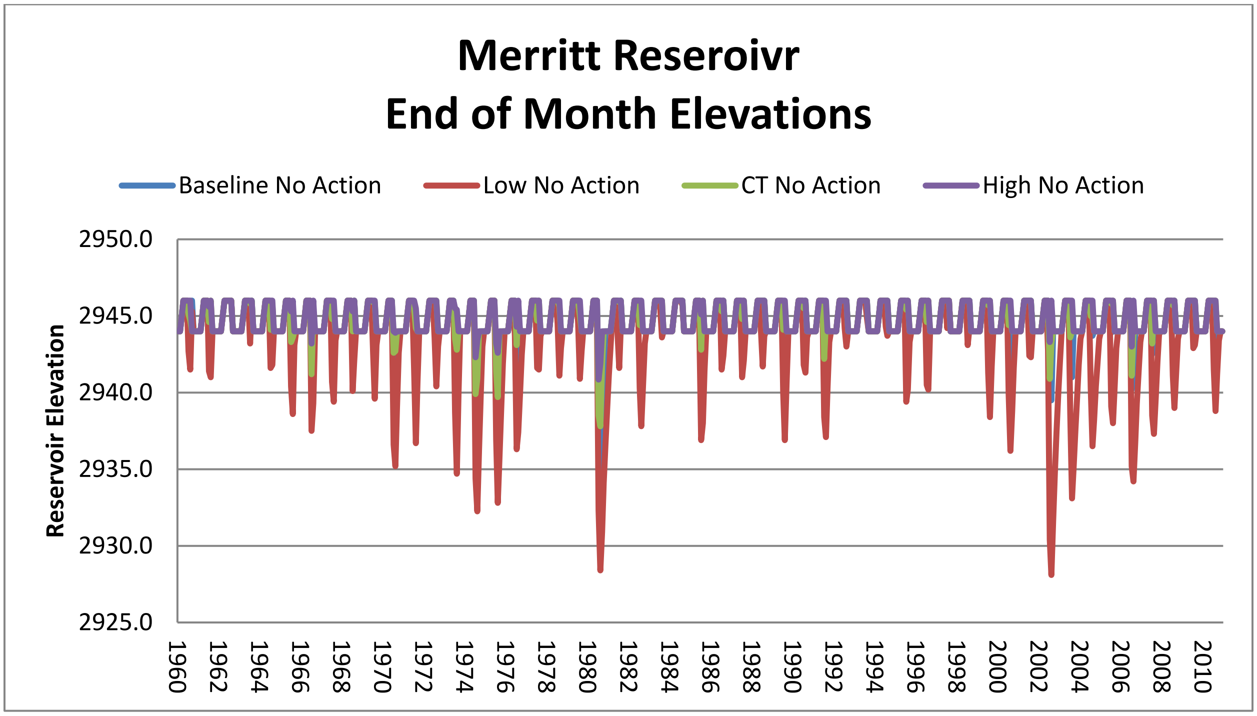

Figure 34. Merritt Reservoir end-of-month elevations.

3.2.4.2 Merritt Reservoir Releases

Reservoir releases from Merritt Reservoir consist of operational releases to the Snake River and irrigation releases directly to Ainsworth Canal. Operational spills to the river, or forced releases, generally occur to the river once the reservoir is refilled to the desired level each fall following the irrigation season. Releases to the river generally peak in May and June. Once the irrigation season begins the majority of the releases from the dam are made directly to the canal. Overall, reservoir releases are the highest for the High climate scenario, which is consistent with a cooler, wetter climate condition. Table 12 summarizes future climate mean daily flows at the Snake River gage near Burge, Nebraska as compared to the Baseline No Action. The river gage near Burge reflects the releases to the river from Merritt Reservoir.

Table 12. No Action Annual Mean Daily Computed Flows at Burge, NE

Climate	(AFD)	% of Baseline
Baseline	361	
Low	195	54%
CT	476	132%
High	677	188%

3.2.4.3 Flow at Sparks (the Niobrara Wild and Scenic River)

The Niobrara River gage near Sparks is located near the upstream edge of the Niobrara National Scenic River area. Historical flows in the National Scenic River area typically peak during May and June which correspond closely with seasonal surface runoff patterns related to precipitation in the basin. For the Central Tendency scenario, mean annual flows showed an increase of 11 percent, compared to the Baseline No Action scenario. Increases in monthly flows during the wetter years for the Central Tendency, such as the mid-90's or late 2000's, ranged from approximately 10 percent to 30 percent. While increases in monthly flows during the dry periods of the mid-70's or early 90's ranged from zero percent to about 12 percent.

The projected mean daily flows for the Low scenario decreased by an average of 17 percent over the study period. The mean monthly flows also showed corresponding decreases in nearly every month of the year. Projected decreases in mean monthly flows varied from about 10 to 30 percent. Further details of the projected changes in streamflows at the Sparks gage is illustrated in Table 13.

Table 13. No Action Annual Mean Daily Computed Flows at Sparks, NE

Climate	(AFD)	% of Baseline
Baseline	1,707	
Low	1,416	83%
CT	1,898	111%
High	2,318	136%

3.2.4.4 Flow at Spencer (Private Hydropower Facility)

The Spencer Hydropower, the single hydropower facility in the basin, is located near the Spencer, Nebraska. As a result, the projected flows at the Spencer river gage provide a better understanding of the potential effects of future climate impacts on the water supplies available for the hydropower facility. Similar to the other results, the High water availability scenario flows are generally higher than the other scenarios. The mean annual flows for the Central Tendency scenario increased by an average of 15 percent as compared to the Baseline No Action. Increases in mean monthly varied from zero to 70 percent. For the Low scenario, the mean annual flows decreased by an average of 8 percent while the mean annual flows for the High scenario increased by an average of 34 percent. Table 14 summarizes the streamflow simulations at the river gage near Spencer.

Table 14. No Action Annual Mean Daily Computed Flows at Spencer, NE

Climate	(AFD)	% of Baseline
Baseline	2,929	
Low	2,689	92%
CT	3,365	115%
High	3,918	134%

3.2.4.5 Deliveries to Ainsworth Irrigation District

The mean annual diversions for the Ainsworth Irrigation District are summarized in Table 15. The change in the average annual deliveries is modest as compared to the Baseline No Action scenario. Deliveries to Ainsworth Irrigation District typically follow a similar pattern, starting in the Spring and peaking during July and August for all four scenarios. Inflows in the Snake River combined with storage water in Merritt Reservoir are sufficient in all four scenarios to meet the demands Ainsworth Irrigation District.

Table 15. No Action Ainsworth Mean Annual Diversions

Climate	(kAF)	% of Baseline
Baseline	37.04	
Low	36.95	100%
CT	35.39	96%
High	34.83	94%

3.2.4.6 Total Aquifer Recharge

The average annual recharge within the Niobrara Drainage Basin for the Future No-Action alternative for the four climate scenarios are plotted in Figures 35-38. The pattern in recharge rates are related to precipitation rates, soils, and land use.

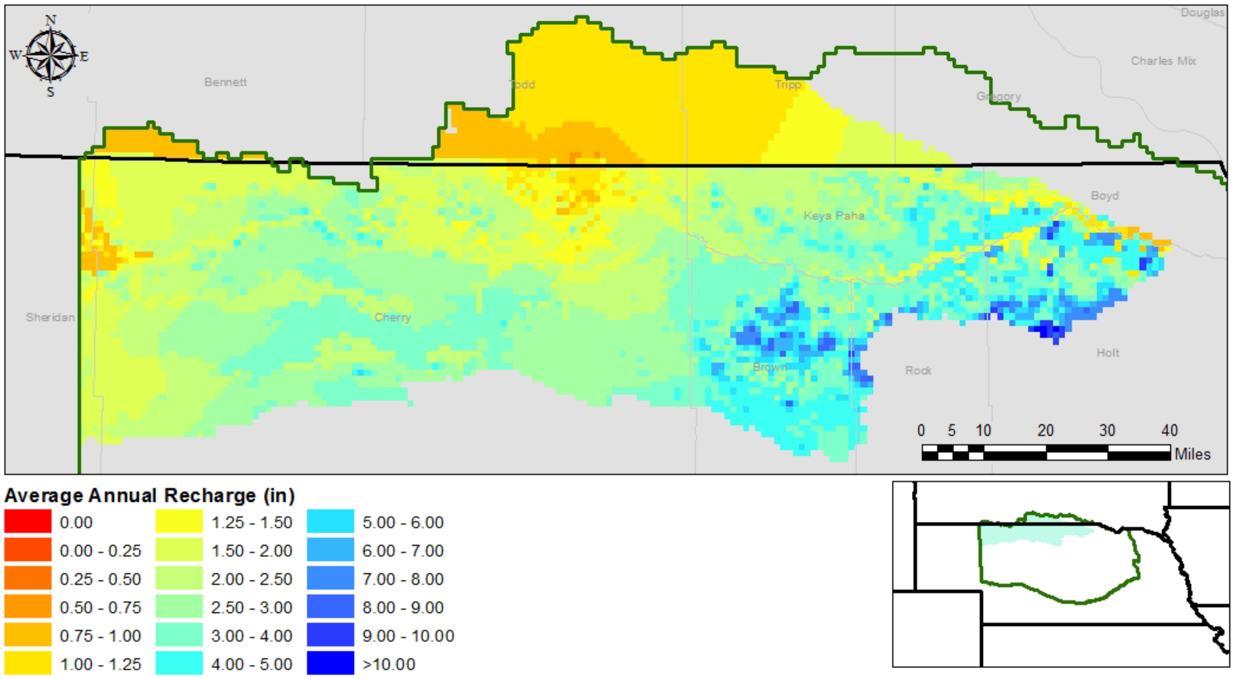

Figure 35. Average annual recharge – No Action; Baseline.

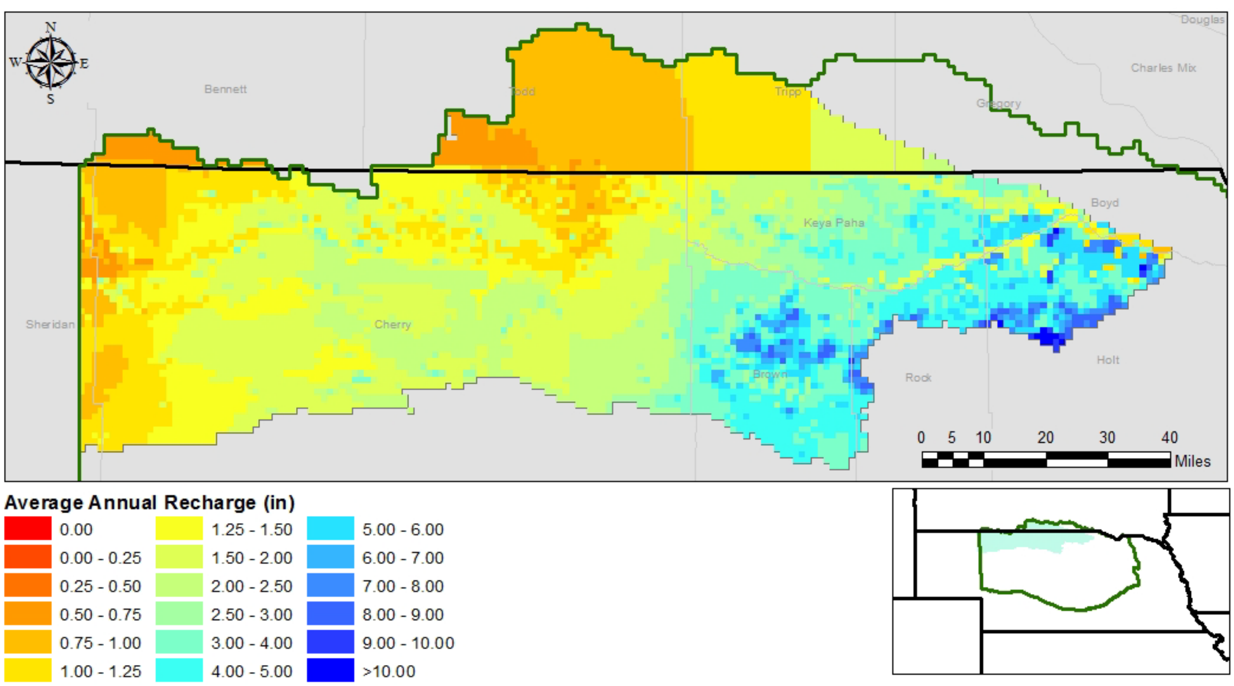

Figure 36. Average annual recharge – No Action; Low.

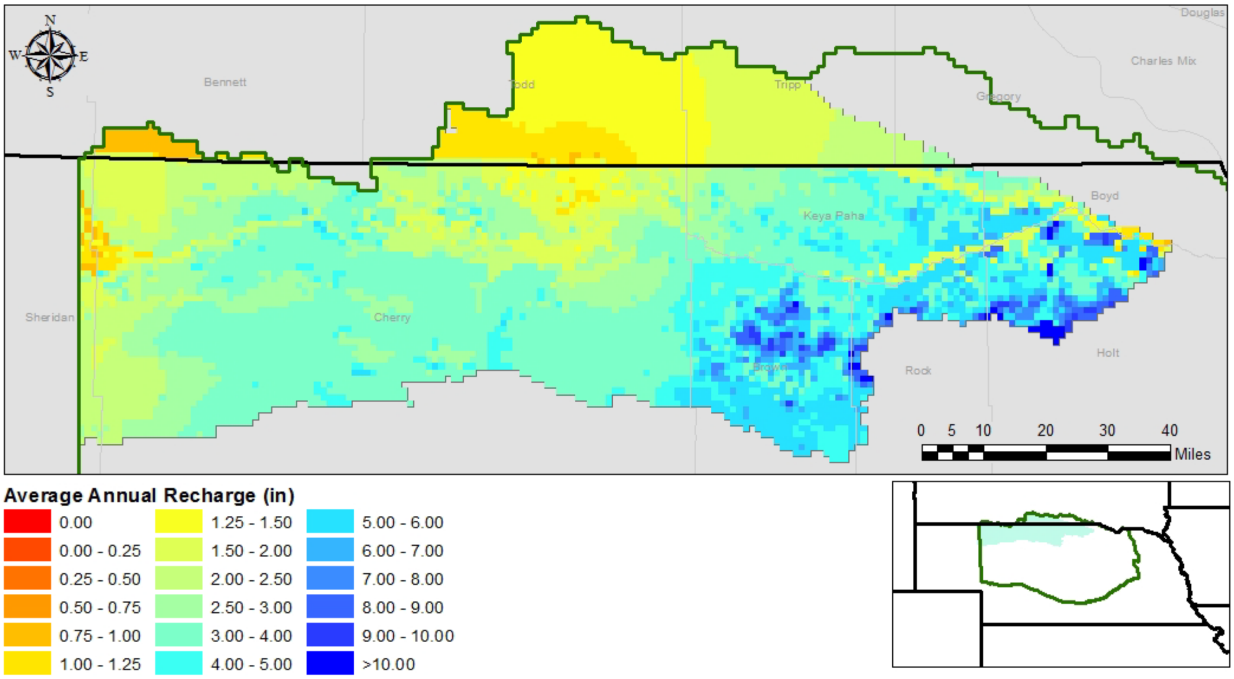

Figure 37. Average annual recharge – No Action; CT.

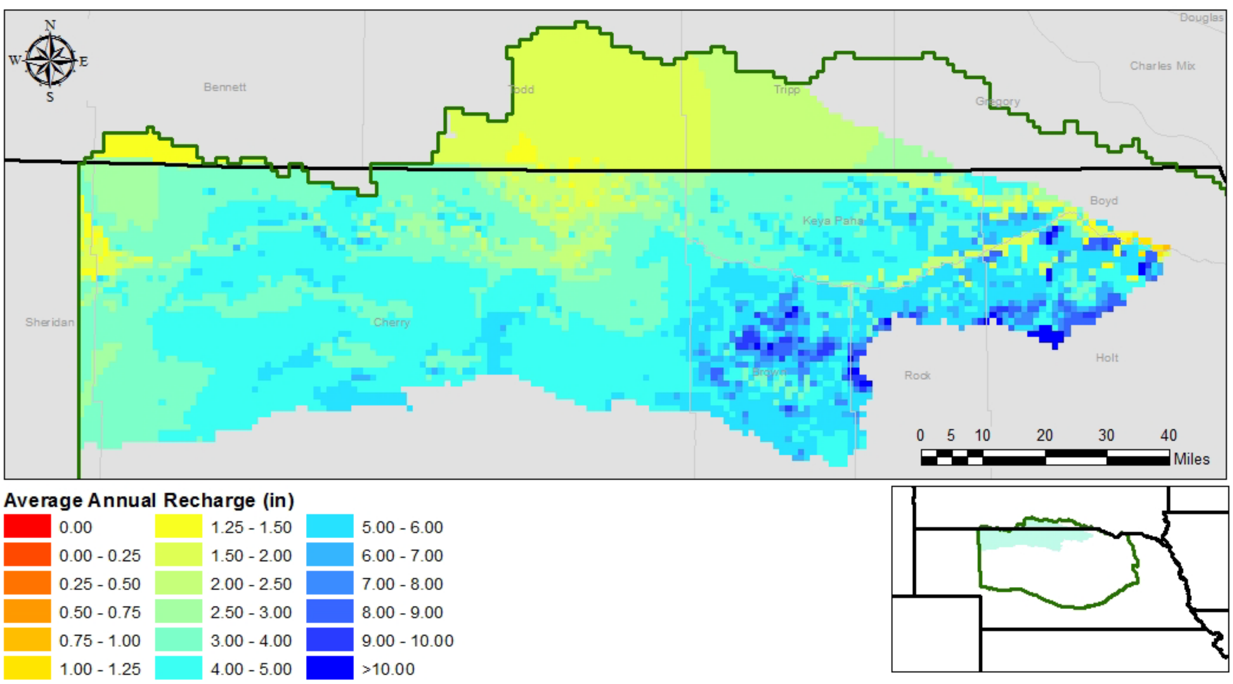

Figure 38. Average annual recharge – No Action; High.

3.2.4.1 Baseflow Contributions

Groundwater generated baseflow is the dominant component of total flow in the Niobrara River Basin. Baseflow inputs to the CENEB surface water operations model come directly from the CENEB groundwater model. Baseflow values represent the contributing flow upstream of the CENEB surface water operations model nodes. Further details on the simulated baseflow coming from the CENEB groundwater model can be found in Appendix B, Groundwater Modeling Report.

3.2.4.2 Volume of Groundwater Pumping

Total annual groundwater pumping for runoff zones 1-3 in the CENEB model area under all four climate scenarios is plotted in Figure 39. Groundwater pumping volumes tend to be inversely proportional to precipitation volumes; i.e. increases in precipitation generally result in decreases in pumping totals. However, the timing, magnitude, and effectiveness of the precipitation also influence the volume of pumping. Depending on the soil characteristics and soil water content, larger precipitation events or a series of precipitation events in a short time frame may yield less effective rainfall and greater volumes of runoff and deep percolation. This concept helps to explain incidences such as 2009 where the high water availability climate applied a larger volume of pumping despite a greater amount of precipitation when compared to the low water availability climate.

3.2.4.3 Summary

Overall, the modeling results show the streamflows at the model nodes are the lowest under the Low climate scenario and significantly higher under the High climate scenario. The impacts to the Merritt Reservoir operations are modest for the Central Tendency and High future scenarios as compared to the Baseline No Acton scenario. Impacts to the reservoir under the Low scenario, corresponding to the hot and dry climate, are slightly greater than the other scenarios analyzed in this report. Further discussion and additional analysis of the CENEB model results may be found in Appendix D, Central Nebraska Surface Water Operations Modeling Report.

3.3 Alternative 1 – Mirage Flats Pumping Station

Alternative 1 represents the replacement of the existing Mirage Flats Diversion and main supply canal with the Mirage Flats Pumping Station. The objective of this alternative water management scenario is to reduce canal seepage during surface water deliveries to the agricultural fields. Diversions from Niobrara River will be pumped to the delivery area (approximate distance of 12 miles). It is assumed the diversion point from the Niobrara River will remain approximately the same.

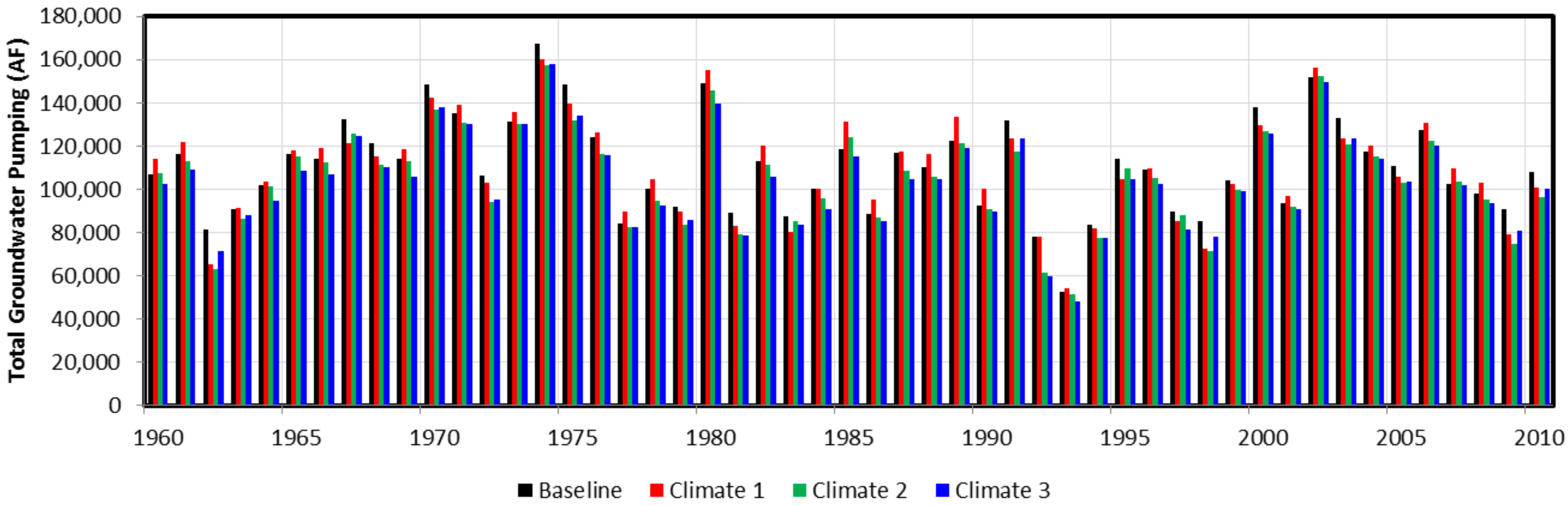

Figure 39. Annual total groundwater pumping for runoff zones 1-3 in the CENEB model domain – No Action; Baseline vs Low, CT, High.

3.3.1 Alternative 1 Model Representation

3.3.1.1 UNW Watershed Model

To represent the Mirage Flats Pumping Station Alternative, no changes occurred to the UNW watershed model, but the UNW watershed model does reflect the effect of greater water availability due to increased delivery efficiencies.

3.3.1.2 UNW Surface Water Operations Model

The modifications to the UNW Surface Water operations model to represent the Mirage Flats Pumping Station alternative include:

- Elimination of seepage in first 12 miles of main supply canal. The Mirage Flats delivery efficiency for this canal reach was changed from 40% to 98%.
- Change in diversion temporal pattern to remove initial seasoning of 12 miles of main supply canal (this will also be reflected in Box Butte releases).

3.3.1.3 UNW Groundwater Model

The modifications to the UNW groundwater model to represent the Mirage Flats Pumping Station alternative include:

- Change in pumping to reflect increased deliveries based on efficiency gains.
- Change in groundwater recharge along the Mirage Flats 12-mile reach (canal seepage and deep percolation of applied water).

3.3.2 Alternative 1 Model Results

Key water budget elements were identified to get an overall picture of the results from the integrated model for the Mirage Flats Pumping Station alternative. The key water budget elements were the same elements identified in the Future No Action alternative and included:

- Box Butte Reservoir inflows
- Box Butte Reservoir elevations
- Box Butte Reservoir releases
- Mirage Flats diversions
- Surface water irrigation deliveries
- Volume of groundwater pumping on co-mingled acres
- Total aquifer recharge
- Groundwater elevations
- Baseflow Contributions
- Niobrara River at Gordon gage

These key elements are discussed further below.

3.3.2.1 Box Butte Reservoir Inflows

The Box Butte Reservoir total annual inflows for Alternative 1 for the four climate scenarios are shown in Figure 40. As expected, there is no change to the

Niobrara River above Box Butte gage compared to the Future No Action Alternative. No change was expected because Alternative 1 does not affect anything upstream of Box Butte Reservoir. Table 16 summarizes the annual daily average flows from 1960-2010. The data is divided into annual and seasonal values (irrigation and non-irrigation).

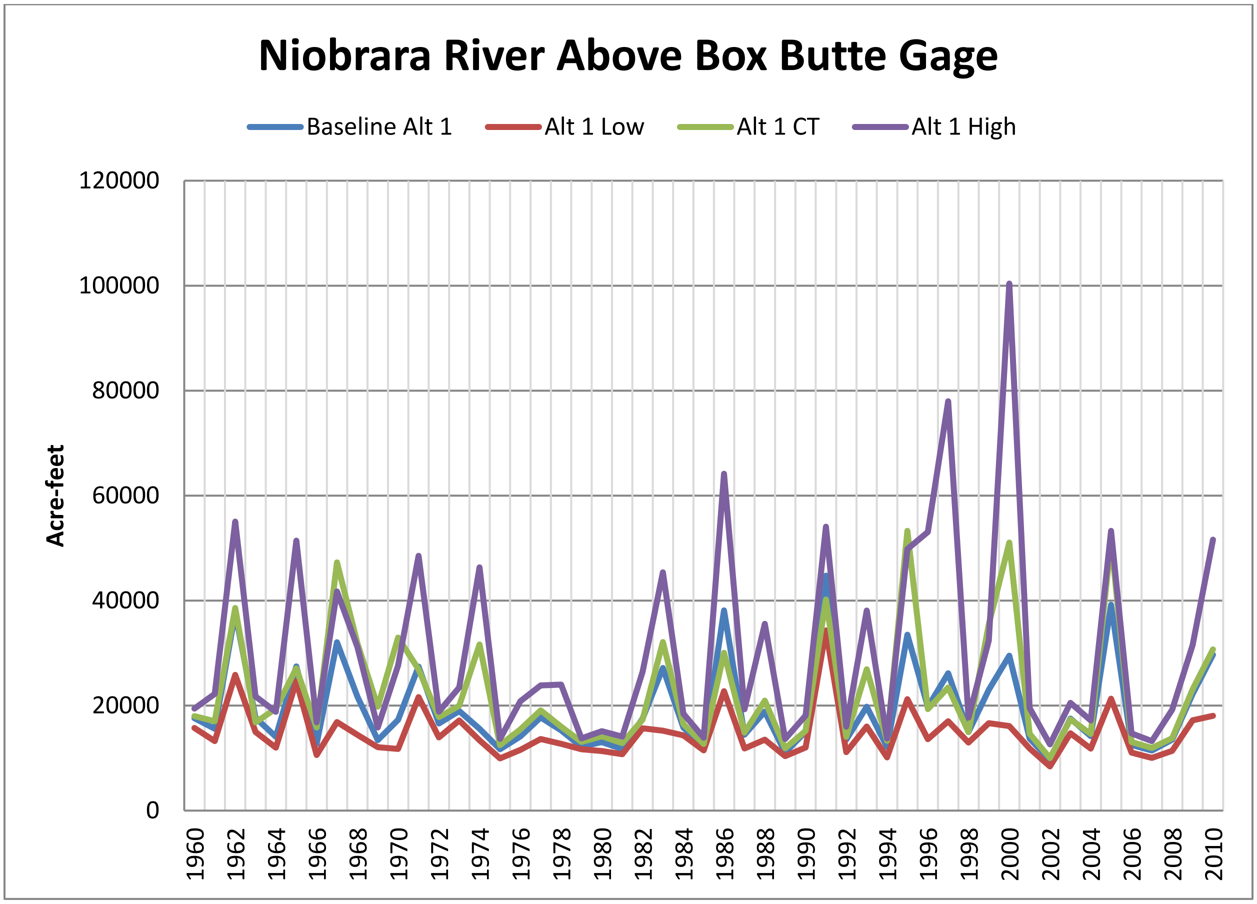

Figure 40. Niobrara River Above Box Butte Gage – Alternative 1 Pumping Station Baseline vs Low, CT, High.

Table 16. Alternative 1 Annual Daily Average Niobrara River Above Box Butte (AFD)

Climate	Annual	Annual % of Baseline	Irrigation Season	Non-Irrigation Season
Baseline	53		26	63
Low	40	75%	20	47
CT	62	117%	28	73
High	83	157%	35	99

3.3.2.2 Box Butte Reservoir Elevations

Average daily Box Butte Reservoir elevations for Alternative 1 are shown for all four climate scenarios in Figure 41. Reservoir levels reflect reduction in required releases due to increased canal delivery efficiencies. All climate scenarios for Alternative 1 have higher water surface elevations than the Future No Action alternative. Note that the CT scenario actually exceeds the high scenario in during two time periods. This is likely due to a seasonal spike in the CT scenario. Table 17 summarizes the annual daily average elevations from 1960-2010. The data is divided into annual and seasonal values (irrigation and non-irrigation).

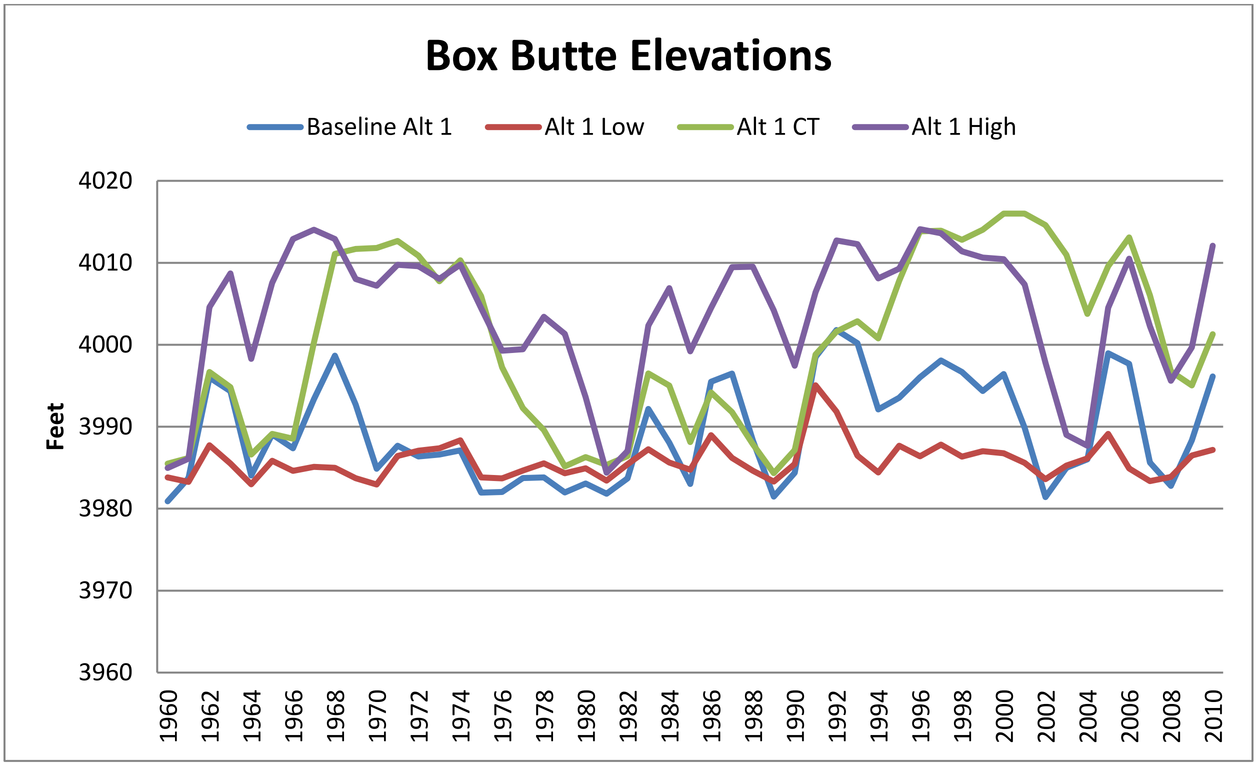

Figure 41. Box Butte Average Annual Elevations – Alternative 1 Baseline vs Low, CT, High.

Table 17. Alternative 1 Annual Daily Average Box Butte Elevations (ft)

Climate	Annual	Annual % of Baseline	Irrigation Season	Non-Irrigation Season
Baseline	3,989		3,987	3,990
Low	3,986	100%	3,982	3,987
CT	4,000	100%	3,999	4,000
High	4,004	100%	4,004	4,004

3.3.2.3 Box Butte Reservoir Releases

Alternative 1 Box Butte Reservoir total annual releases for the simulation period for all climate scenarios are plotted in Figure 42. Releases are typically reduced from the Future No Action alternative due to increased canal delivery efficiencies. The high releases shown in the high climate scenarios are likely due to forced releases during the late 90’s due to high reservoir levels. Table 18 summarizes the annual average daily releases (AFD) from 1960-2010. The data is divided into annual and seasonal values (irrigation and non-irrigation).

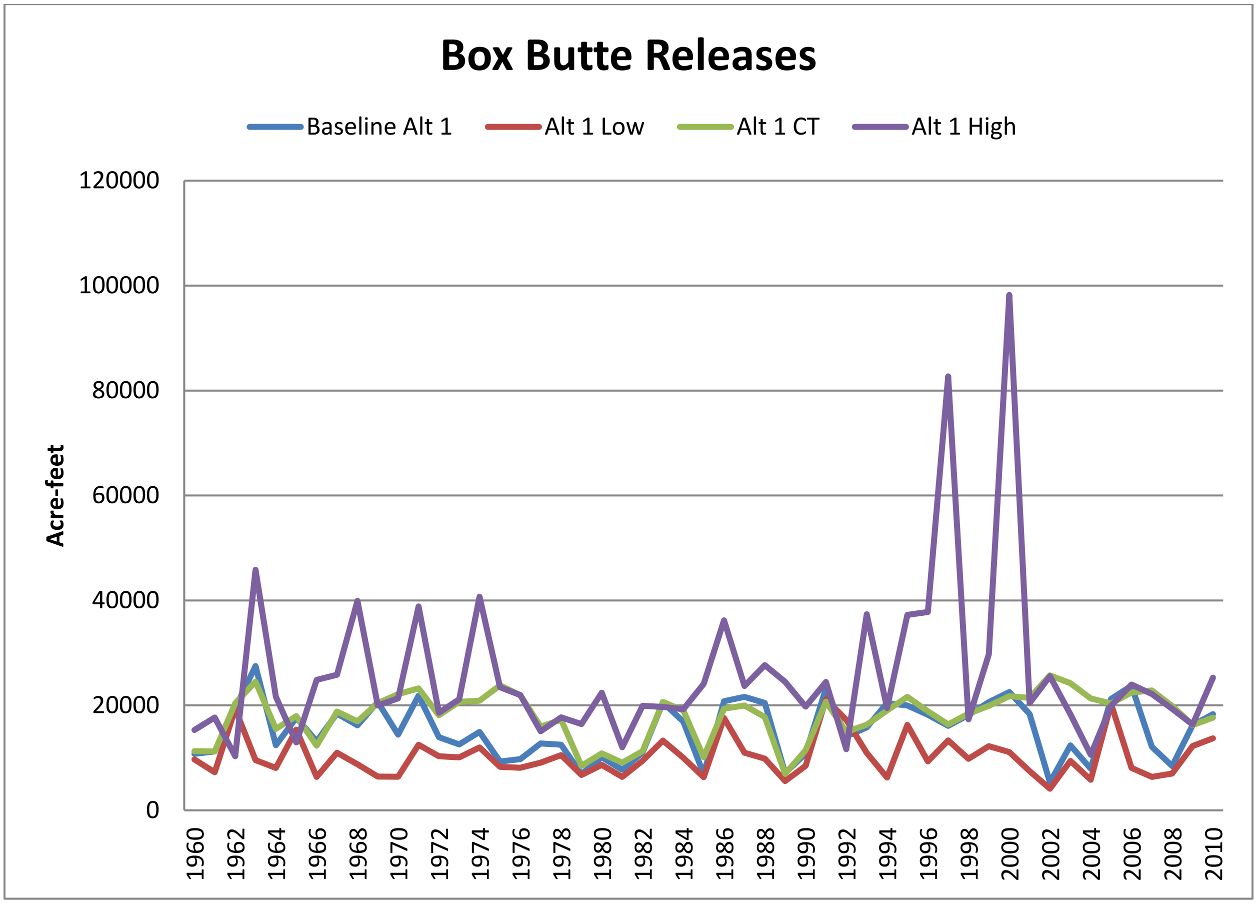

Figure 42. Total Annual Box Butte Releases – Alternative 1 Baseline vs Low, CT, High.

Table 18. Alternative 1 Annual Daily Average Box Butte Releases (AFD)

Climate	Annual	Annual % of Baseline	Irrigation Season	Non-Irrigation Season
Baseline	42		167	0
Low	28	67%	112	0
CT	49	117%	196	0
High	71	169%	189	31

3.3.2.4 Mirage Flats Diversions

Total annual Mirage Flats diversions for Alternative 1 for all four climate scenarios for the entire simulation are shown in Figure 43. Compared to the Future No Action alternative, the Mirage Flats diversions for Alternative 1 are largely minor diversions. Note that high climate scenario results below CT and low scenarios are due to reduced irrigation demand, not water shortage. Table 19 summarizes the annual daily average diversions (AFD) from 1960-2010 for the irrigation season. Mirage Flats diversions only occur during the irrigation season for Alternative 1.

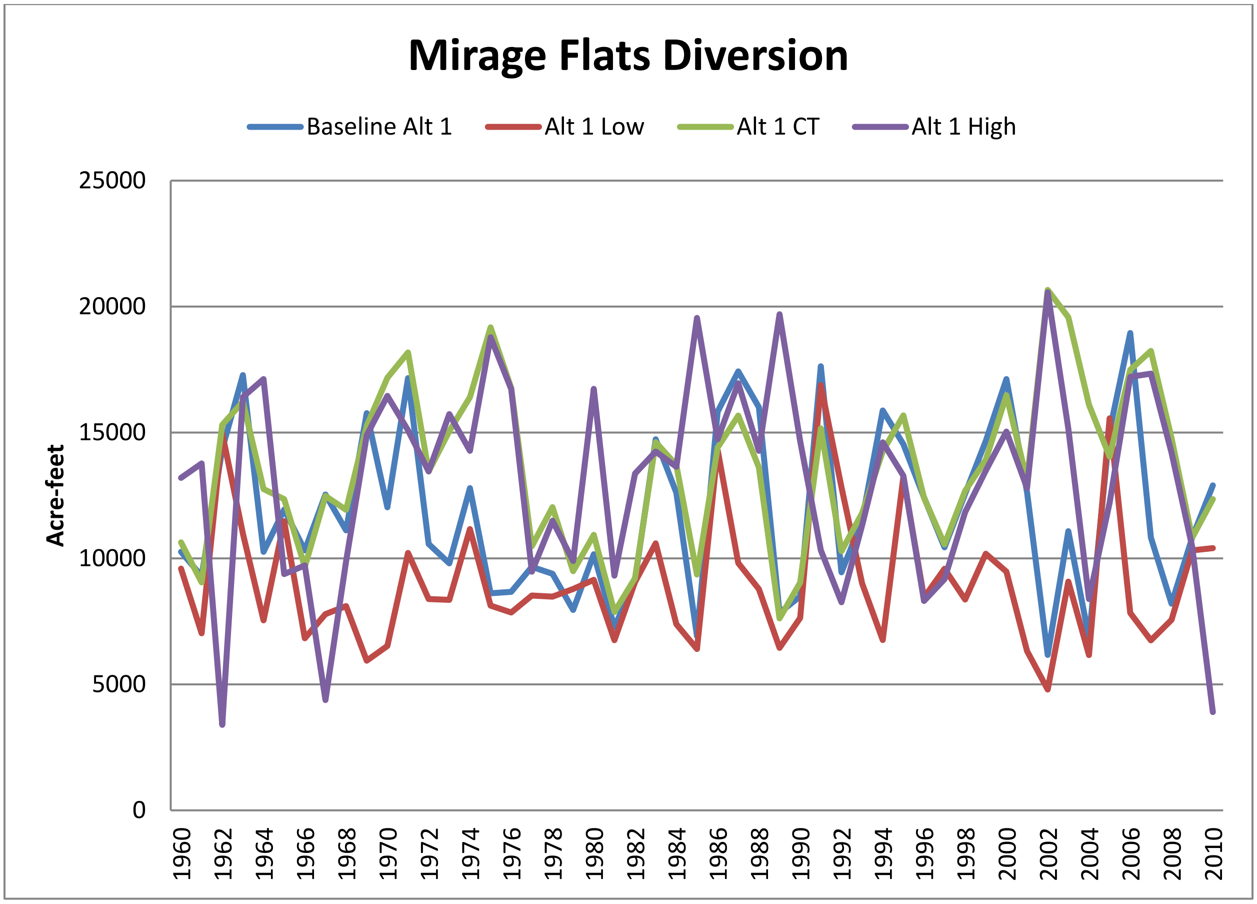

Figure 43. Mirage Flats Total Annual Diversions – Alternative 1 Pumping Station Baseline vs Low, CT, High.

Table 19. Alternative 1 Annual Daily Average Mirage Flats Diversion (AFD)

Climate	Irrigation Season	% of Baseline
Baseline	129	
Low	99	77%
CT	147	114%
High	142	110%

3.3.2.5 Surface Water Irrigation Deliveries

The principal change in surface water deliveries occurred within the Mirage Flats Irrigation District. Figure 44 compares the average annual surface water deliveries at the Mirage Flat Irrigation District under the no action and pumping station alternatives to the irrigation demand. Under all scenarios the pumping station increased surface water deliveries.

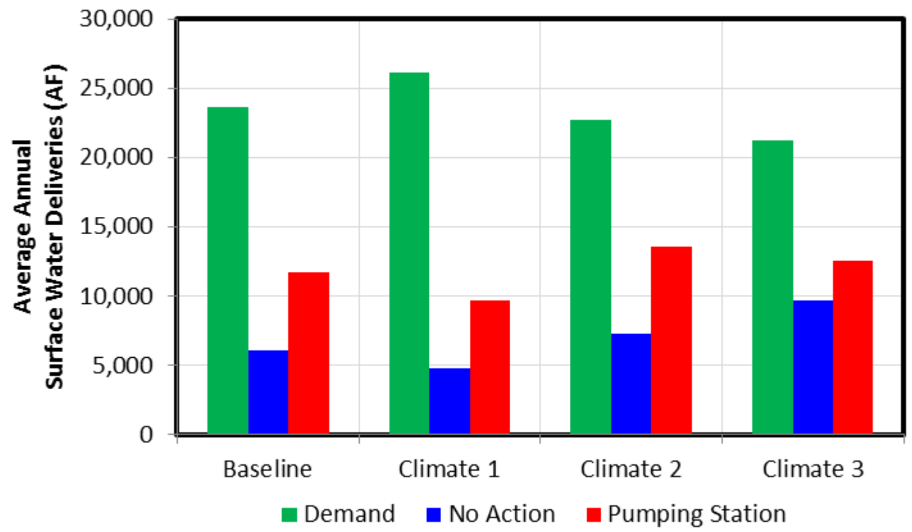

Figure 44. Mirage Flats average annual surface water deliveries – Demand vs No Action, Alternative 1 Pumping Station; Baseline vs Low, CT, High.

3.3.2.6 Volume of Groundwater Pumping on Co-mingled Acres

The principal change in co-mingled pumping occurred within the Mirage Flats Irrigation District. Figure 45 compares the average annual co-mingled pumping in the Mirage Flats Irrigation District under the no action and pumping station alternatives. Under all scenarios the average volume of co-mingled pumping decreased.

3.3.2.7 Total Aquifer Recharge

The percent change in average aquifer recharge between the No Action and Alternative 1 for all four climate scenarios are shown in Figures 46-49. As expected, the change in recharge is concentrated around the Mirage Flats Irrigation district. The lack of seepage along the canal greatly reduced the recharge in those cells, while the irrigated land saw a small increase resulting from the increased deliveries.

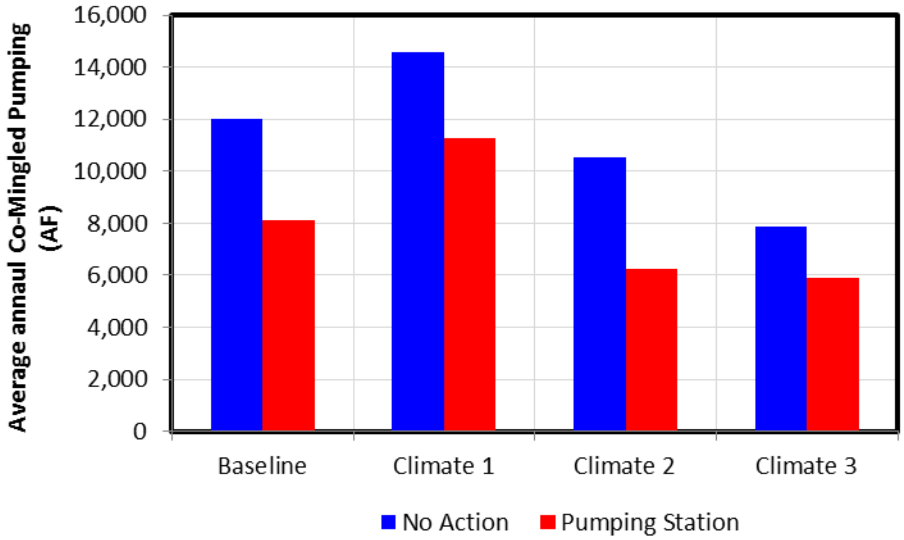

Figure 45. Mirage Flats average annual supplemental co-mingled pumping – No Action vs Alternative 1 Pumping Station; Baseline vs Low, CT, High.

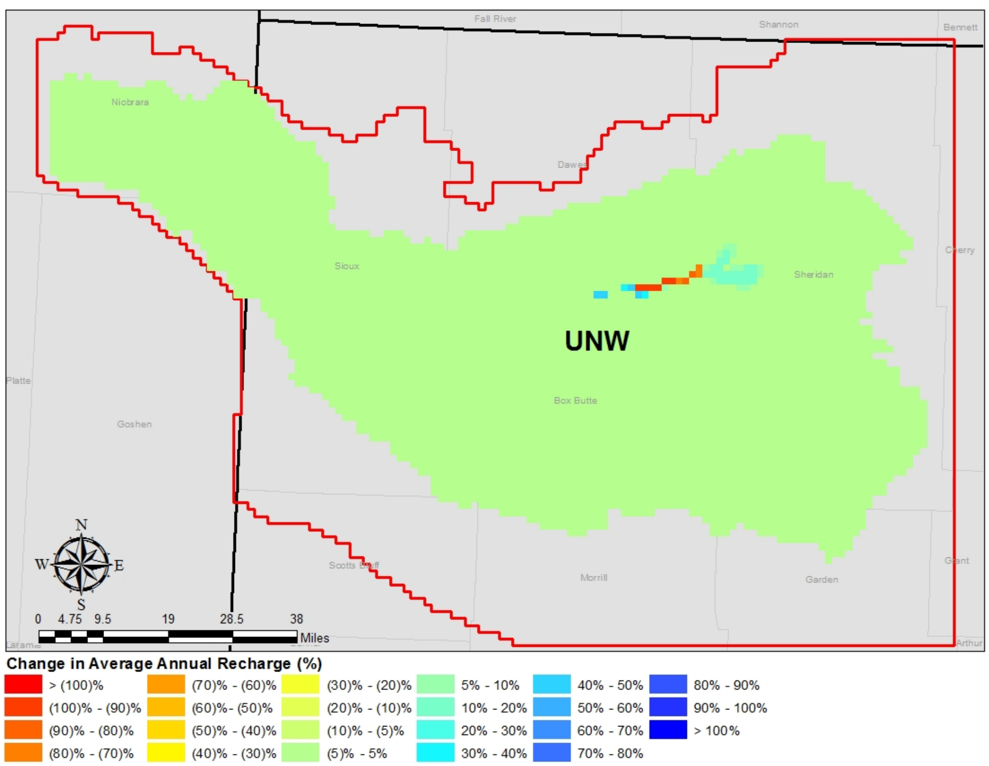

Figure 46. Percent change in average annual recharge – No Action vs Alternative 1; Baseline.

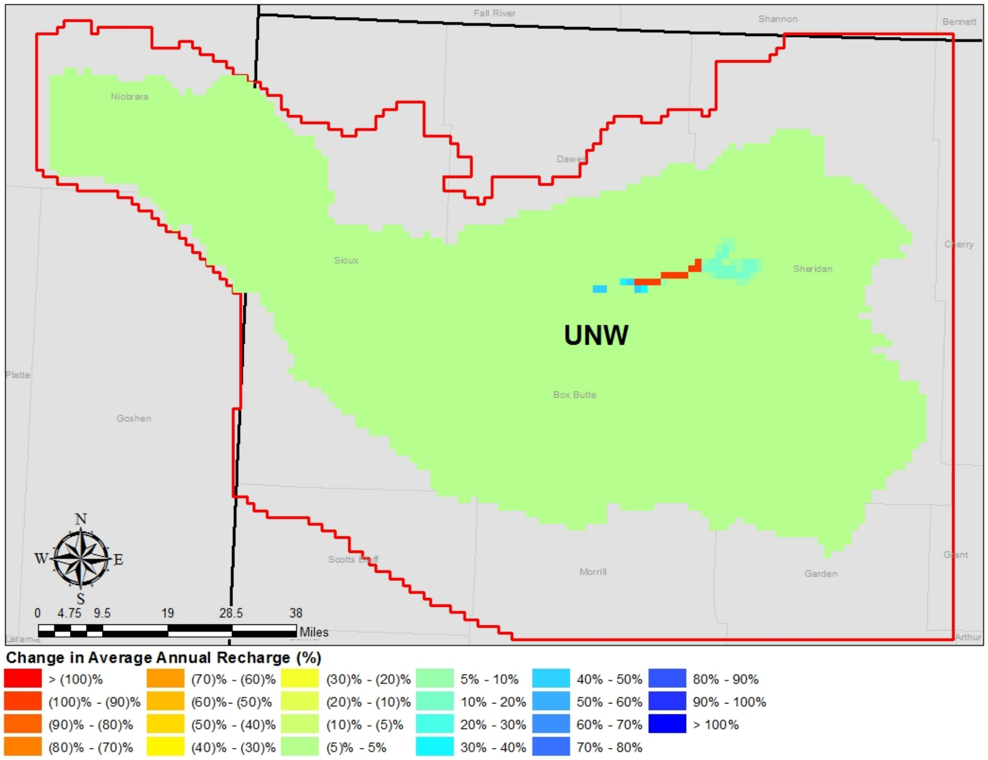

Figure 47. Percent change in average annual recharge – No Action vs Alternative 1; Low.

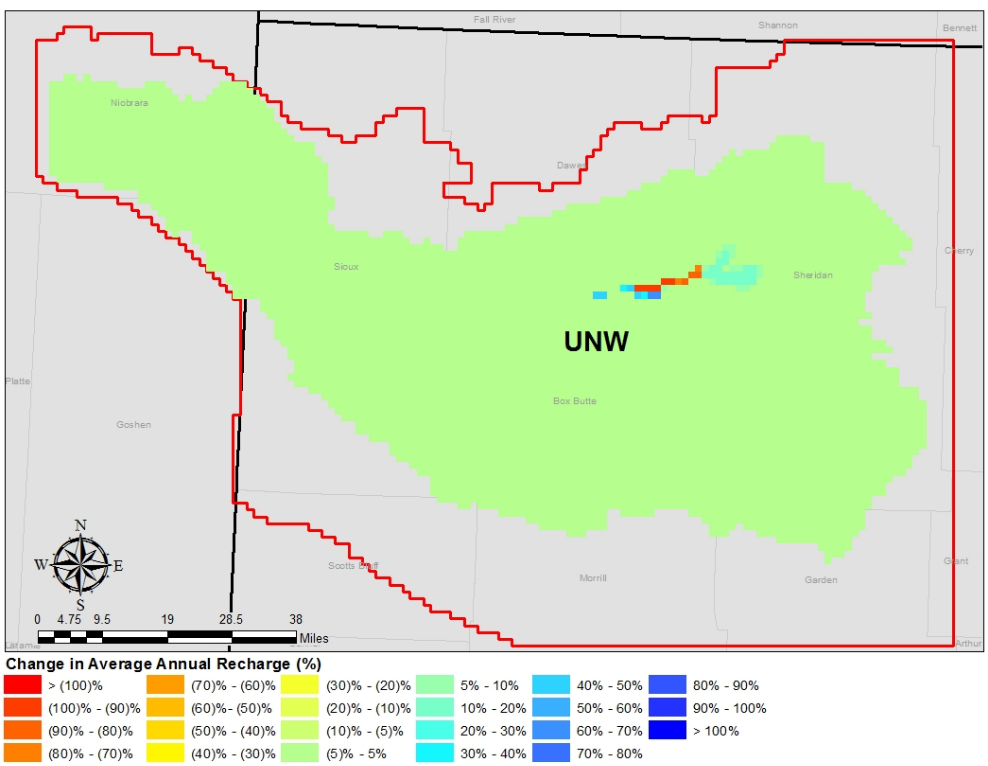

Figure 48. Percent change in average annual recharge – No Action vs Alternative 1; CT.

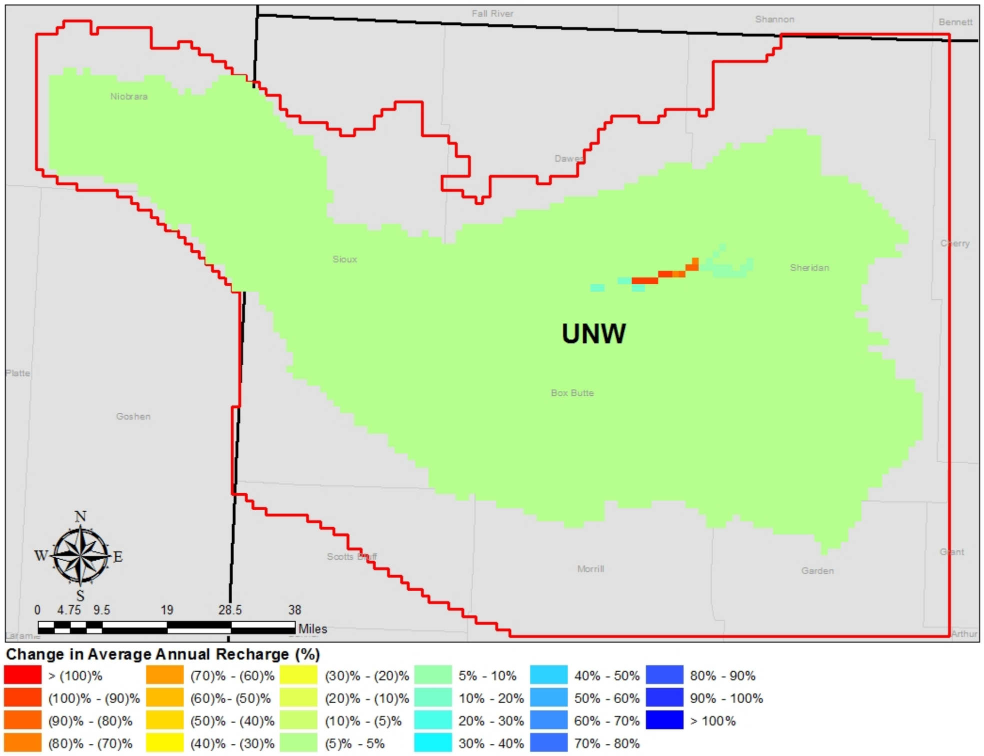

Figure 49. Percent change in average annual recharge – No Action vs Alternative 1; High.

3.3.2.8 Groundwater Elevations

The aquifer response to Alternative 1 management with climate scenarios were as expected with decrease in groundwater level in Low water availability scenario and increase in water level in High water availability and Central Tendency scenarios. Figure 50 shows the slight increase in groundwater levels in Box Butte county and Mirage Flats Irrigation District area of Central Tendency with Alternative 1 scenario as compared with Baseline with Alternative 1 scenario.

3.3.2.9 Baseflow Contributions

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 51 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 52 represents the differences between the baseline Alternative 1 (surface water diversion location change) and the Alternative 1 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.

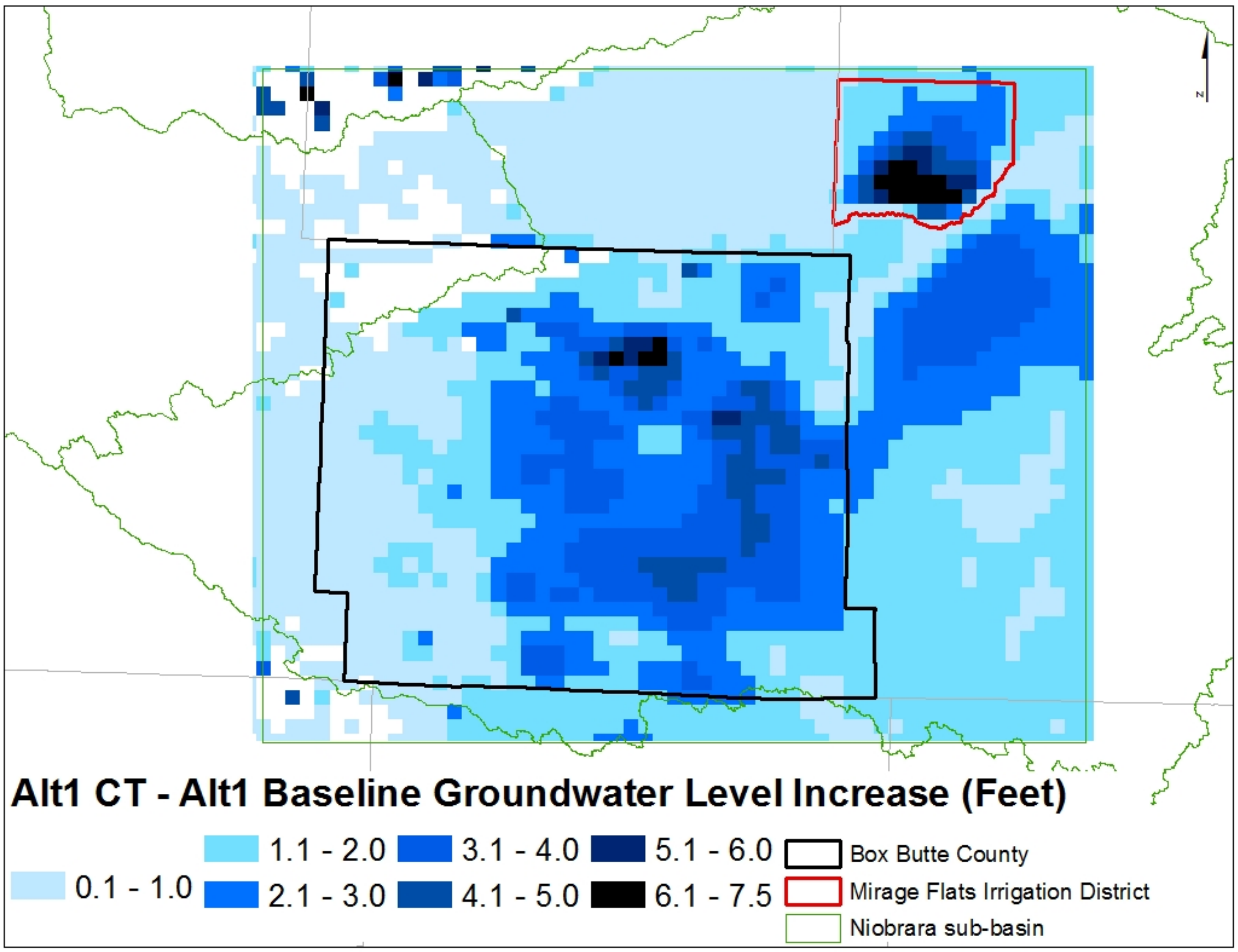

Figure 50. Increase in groundwater level in Box Butte County and Mirage Flats Area in Central Tendency with Alt 1 scenario as compared to Baseline with Alt 1 Scenario.

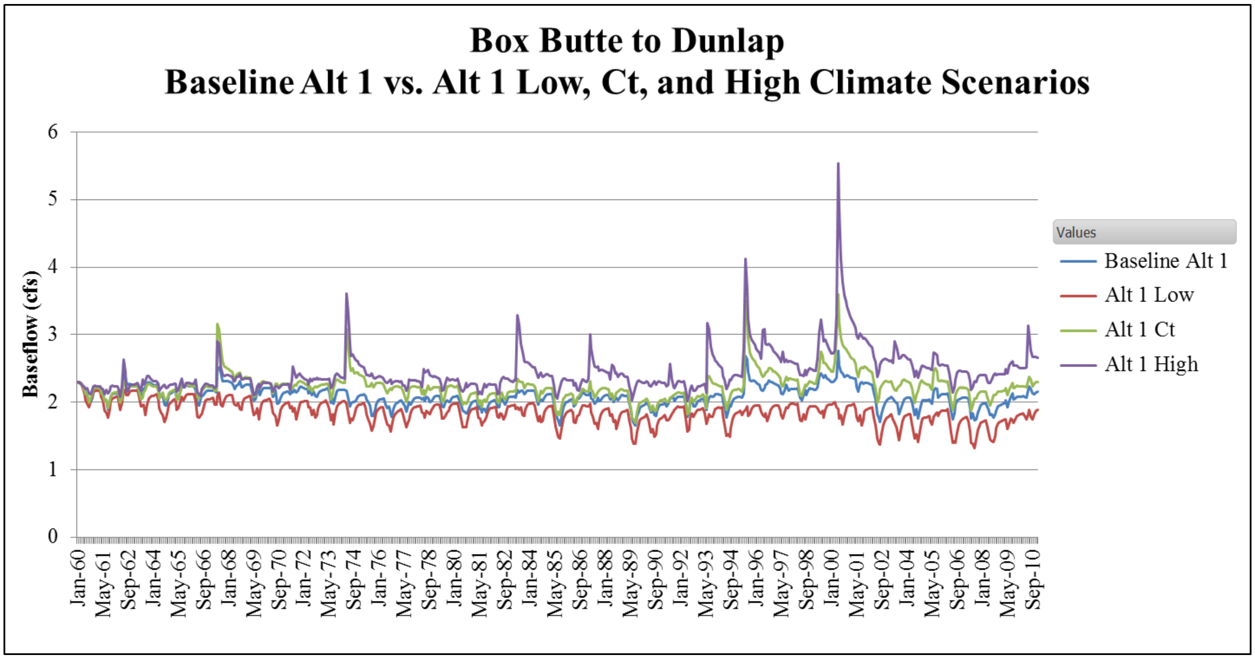

Figure 51. Box Butte to Dunlap reach baseflow comparison – Baseline Alt1 vs low, CT, and high Alt1 runs.

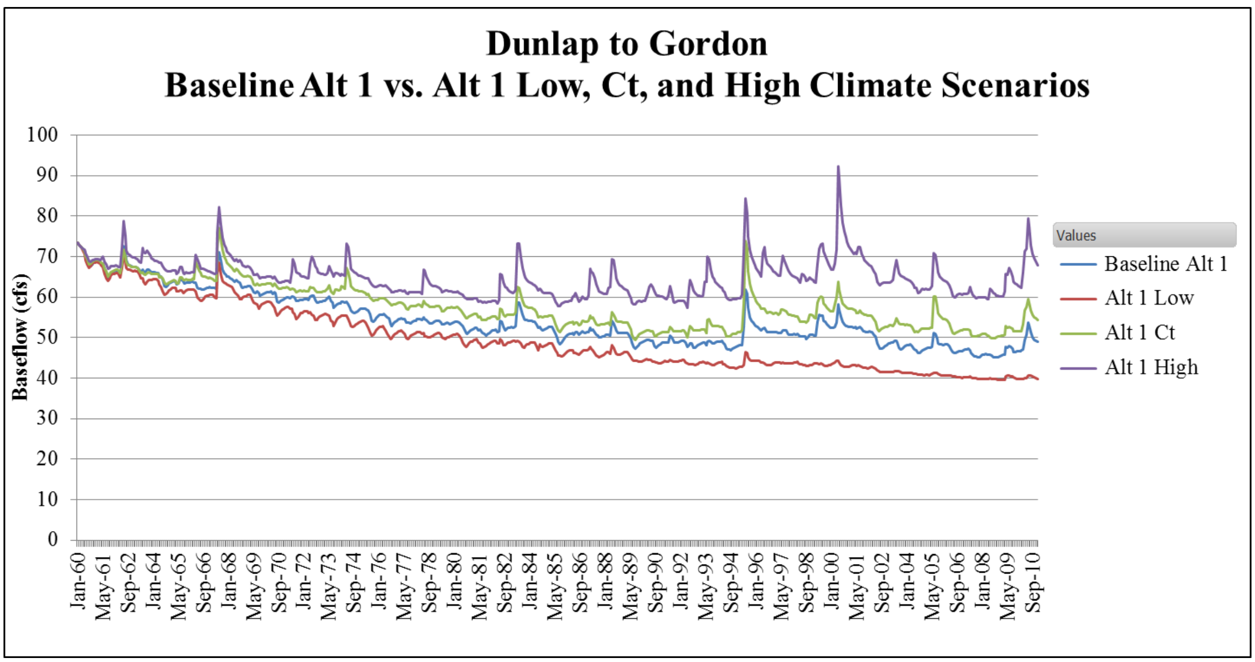

Figure 52. Dunlap to Gordon reach baseflow comparison – Baseline Alt1 vs low, CT, and high Alt1 runs.

Figure 53 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.

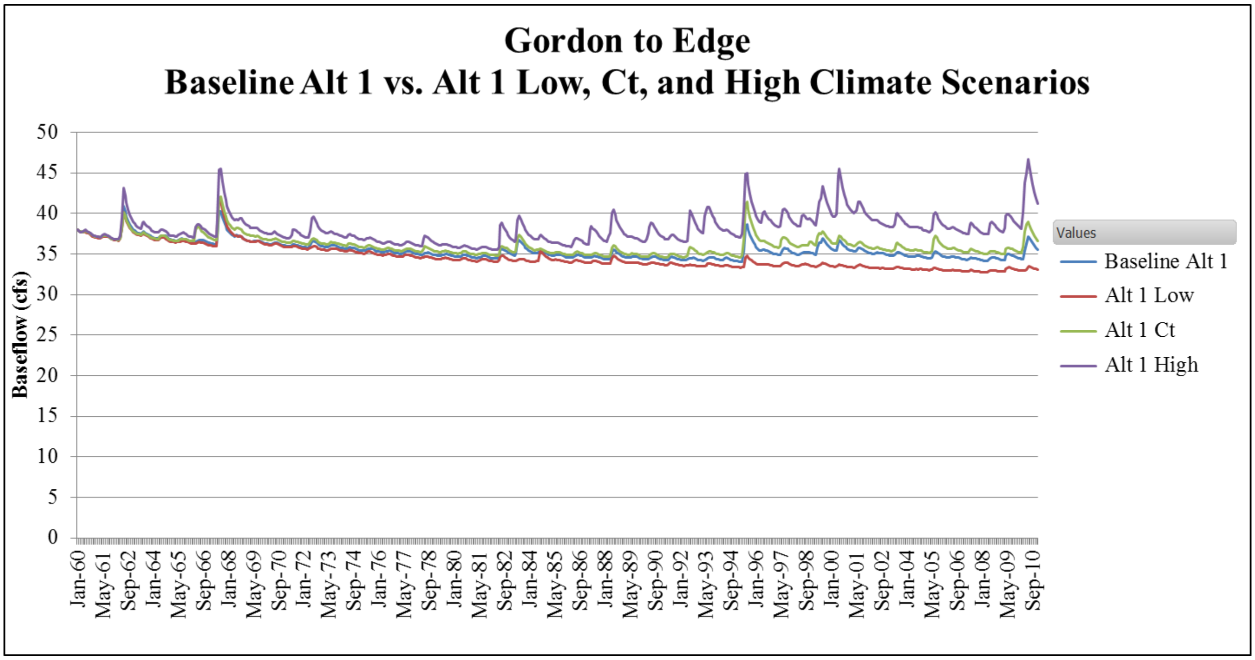

Figure 53. Gordon to model edge reach baseflow comparison – Baseline Alt1 vs low, CT, and high Alt1 runs.

3.3.2.10 Niobrara River at Gordon Gage

The total annual flows at the Niobrara River at Gordon gage for Alternative 1 for all climate scenarios are shown in Figure 54. The flows at Gordon have similar trends as the Box Butte Reservoir releases, but are somewhat dampened. Table 20 summarizes the annual daily average flows (AFD) from 1960-2010 for Alternative 1. The data is divided into annual and seasonal values (irrigation and non-irrigation).

3.3.2.11 Summary

Box Butte Reservoir levels reflect reduction in required releases due to increased canal delivery efficiencies. All climate scenarios for Alternative 1 have higher water surface elevations in Box Butte Reservoir than the Future No Action alternative. Alternative 1 Box Butte Releases are typically reduced from the Future No Action alternative due to increased canal delivery efficiencies. Compared to the Future No Action alternative, the Mirage Flats diversions for Alternative 1 are largely minor diversions. Under all climate scenarios, Alternative 1 increased surface water deliveries from Future No Action alternative. Under all climate scenarios the average volume of co-mingled pumping for Alternative 1 decreased from the Future No Action alternative. As expected, the change in recharge for Alternative 1 is concentrated around the Mirage Flats Irrigation district. The lack of seepage along the canal greatly reduced the recharge in those cells, while the irrigated land saw a small increase resulting from the increased deliveries. 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.

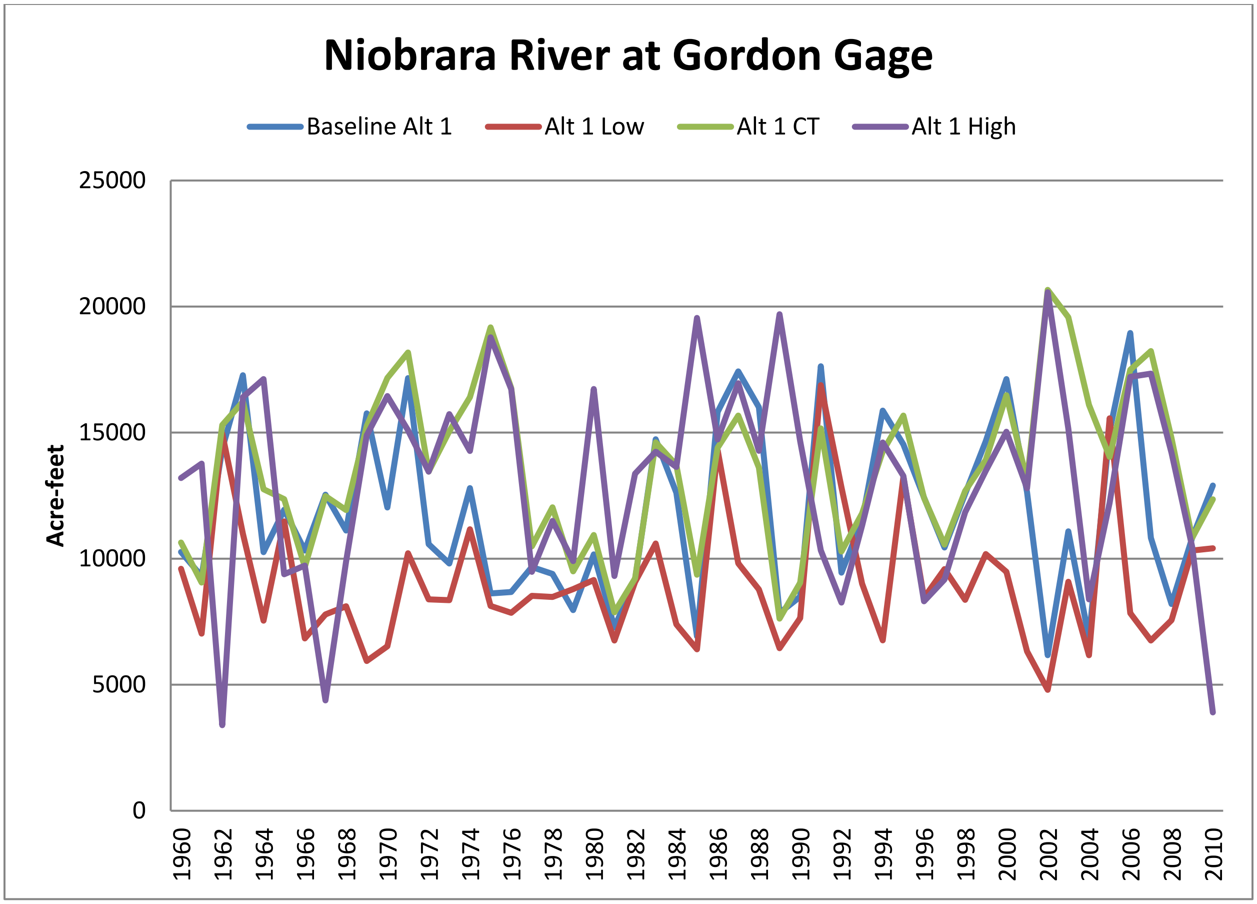

Figure 54. Niobrara River at Gordon Gage Total Annual Flows – Alternative 1 Baseline vs Low, CT, High.

Table 20. Alternative 1 Annual Daily Average Niobrara River at Gordon (AFD)

Climate	Annual	% of Baseline	Irrigation Season	Non-Irrigation Season
Baseline	190		300	153
Low	143	75%	226	115
CT	208	109%	316	172
High	292	154%	360	269

3.3.3 Alternative 1 Impacts to CENEB Region

The Niobrara River at the Gordon gage location serves as the downstream most node in the UNW surface water operations model as well as the upstream most node in the CENEB surface water operations model. As such, this location also serves as the linkage between UNW and CENEB integrated models. The total streamflow simulated by the UNW model is used as input to the CENEB model at Gordon for the corresponding scenarios (Baseline No Action and Future No Action Low, Central Tendency, and High). Future with Alternative scenarios, including the Mirage Flats pumping plant alternative, was not simulated by the CENEB surface water operations model. The reasoning for not simulating these scenarios in the CENEB model is the lack of sensitivity of managed flows in the CENEB region to changes in flow in the UNW region. Sensitivity analyses were performed both with respect to groundwater and managed surface water and the lack of sensitivity is summarized in Appendix B and Appendix C, respectively.

3.4 Alternative 2 – Mirage Flats Recharge

Alternative 2 consists of the Mirage Flats canal system operated solely as a recharge facility and no irrigation deliveries will be made. Water will be released from Box Butte Reservoir, diverted in Mirage Flats Canal at Dunlap Diversion Dam, and the lateral system will be checked up to allow the water to recharge the groundwater within the project area.

The canal will be checked to normal water surface elevation within the project area, meaning the canal check structures will be operated to hold the canal water surface at the designed elevation (if making deliveries).

3.4.1 Alternative 2 Model Representation

3.4.1.1 UNW Watershed Model

The UNW watershed model reflects no surface water deliveries and simulates increase groundwater pumping on co-mingled lands to meet CIR (crop irrigation requirement) due to lost surface water supplies. Laterals receiving water for recharge were defined (may be more limited than current operations) for computed seepage data transfer to groundwater model.

3.4.1.2 UNW Surface Water Operations Model

The modifications to the UNW surface water operations model to represent the Mirage Flats Recharge alternative include:

- Change in diversion pattern
- Change in Box Butte release rules to reflect diversion patterns

The Mirage Flats diversion pattern was altered to divert a constant amount of water every day during the months of June, July, August and September.[2] The daily diversion amounts for each month are listed in Table 21.

Table 21. Alternative 2 Mirage Flats Diversions

Month	Daily Diversion (cfs)
June	75
July	50
August	35
September	35

3.4.1.3 UNW Groundwater Model

The modifications to the UNW groundwater model to represent the Mirage Flats Recharge alternative include:

- Change in pumping to reflect increased pumping on co-mingled lands due to lost surface water deliveries.
- Change in groundwater recharge (canal seepage and deep percolation of applied water).

3.4.2 Alternative 2 Model Results

Key water budget elements were identified to get an overall picture of the results from the integrated model for the Mirage Flats Recharge alternative. The key water budget elements were the same elements identified in the Future No Action and Alternative 2 and included:

- Box Butte Reservoir inflows
- Box Butte Reservoir elevations
- Box Butte Reservoir releases
- Mirage Flats diversions
- Surface water irrigation deliveries
- Volume of groundwater pumping on co-mingled acres
- Total aquifer recharge
- Groundwater elevations
- Baseflow Contributions
- Niobrara River at Gordon gage

These key elements are discussed further below.

[2] Written Communication with J. Wergin, Bureau Of Reclamation (BOR), May 2014.

3.4.2.1 Box Butte Reservoir Inflows

The Box Butte Reservoir total annual inflows for Alternative 2 for the four climate scenarios are shown in Figure 55. As expected, there is no change to the Niobrara River above Box Butte gage compared to the Future No Action Alternative. No change was expected because Alternative 2 does not affect anything upstream of Box Butte Reservoir. Table 22 summarizes the annual daily average flows from 1960-2010. The data is divided into annual and seasonal values (irrigation and non-irrigation).

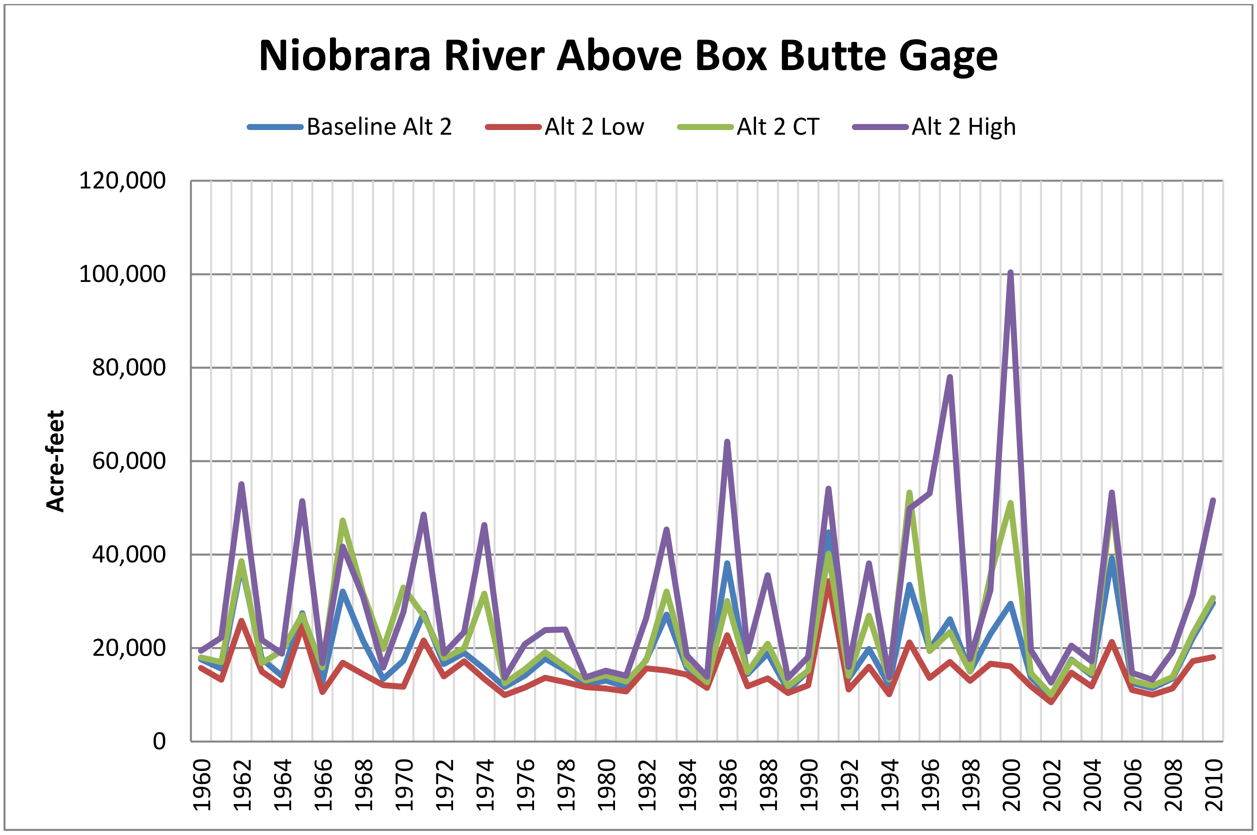

Figure 55. Niobrara River Above Box Butte Gage– Alternative 2 Baseline vs Low, CT, High.

Table 22. Alternative 2 Annual Daily Average Niobrara River above Box Butte (AFD)

Climate	Annual	Annual % of Baseline	Irrigation Season [1]	Non-Irrigation Season [1]
Baseline	53		26	63
Low	40	75%	20	47
CT	62	117%	28	73
High	83	157%	35	99

[1] The diversion pattern provided by J. Wergin for Alternative 2 extended outside of the typical diversion season of Mirage Flats that was used to designate irrigation and non-irrigation seasons. The irrigation season for Alternative 2 was June, July, August, and September.

3.4.2.2 Box Butte Reservoir Elevations

Average annual Box Butte Reservoir elevations for Alternative 2 are shown for all four climate scenarios in Figure 56. Alternative 2 reservoir levels are substantially higher reflecting much lower releases for irrigation. Table 23 summarizes the annual daily average elevations from 1960-2010 for Alternative 2. The data is divided into annual and seasonal values (irrigation and non-irrigation).

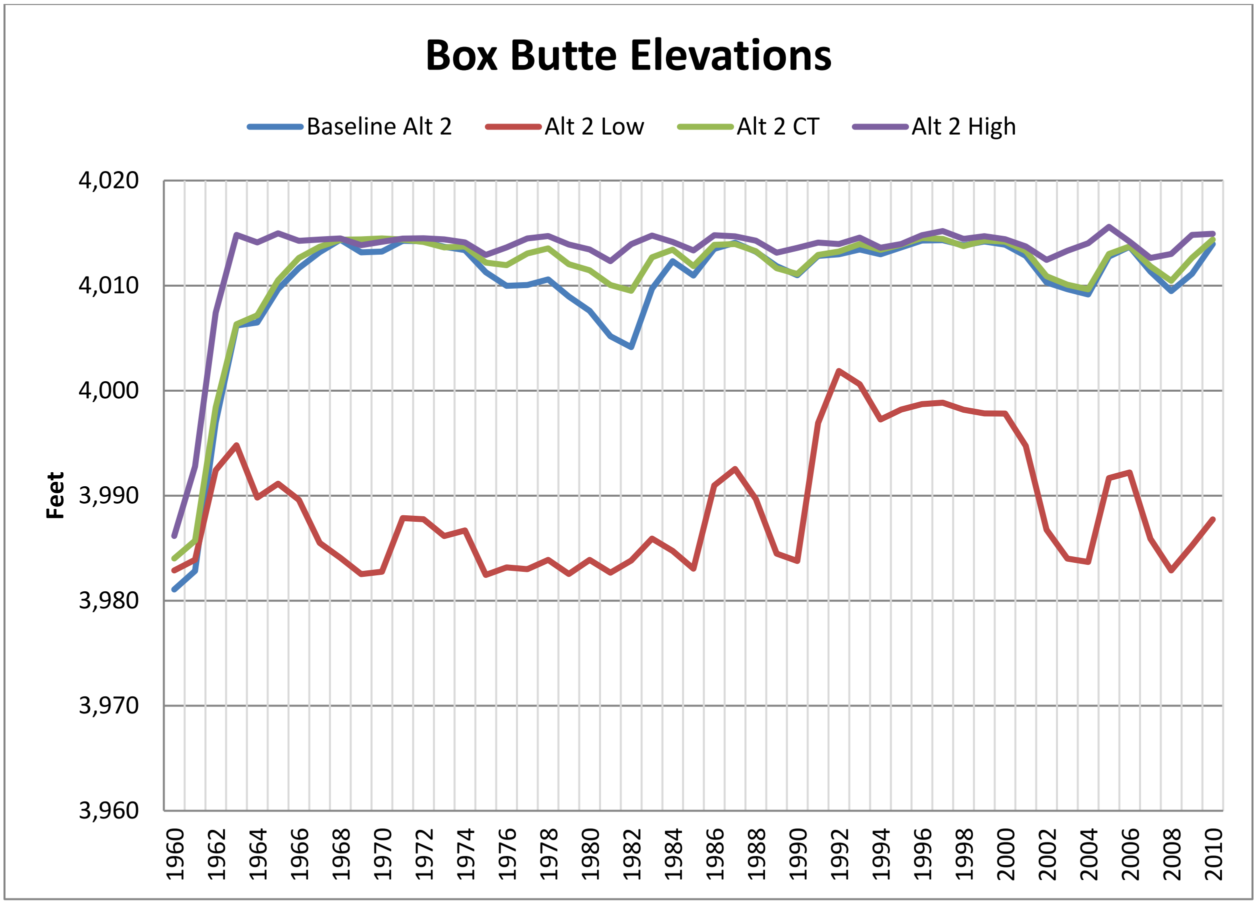

Figure 56. Annual Average Box Butte Elevations – Alternative 2 Baseline vs Low, CT, High.

Table 23. Annual Daily Average Box Butte Elevations (feet)

Climate	Annual	Annual % of Baseline	Irrigation Season [1]	Non-Irrigation Season [1]
Baseline	4,010		4,010	4,010
Low	3,989	99.5%	3,987	3,990
CT	4,011	100%	4,011	4,011
High	4,013	100%	4,013	4,013

[1] The diversion pattern provided by J. Wergin for Alternative 2 extended outside of the typical diversion season of Mirage Flats that was used to designate irrigation and non-irrigation seasons. The irrigation season for Alternative 2 was June, July, August, and September.

3.4.2.3 Box Butte Reservoir Releases

Alternative 2 Box Butte Reservoir total annual releases for the simulation period for all climate scenarios are plotted in Figure 57. The figure shows three release patterns. The straight line pattern represents a release due to diversion only with adequate storage. The concave up pattern represents water levels up against the limit in the reservoir and therefore releases are due to demand and forced releases. The concave down pattern represents shortages of releases to meet the full recharge demand. Table 24 summarizes the annual average daily releases (AFD) for Alternative 2 from 1960–2010. The data is divided into annual and seasonal values (irrigation and non-irrigation).

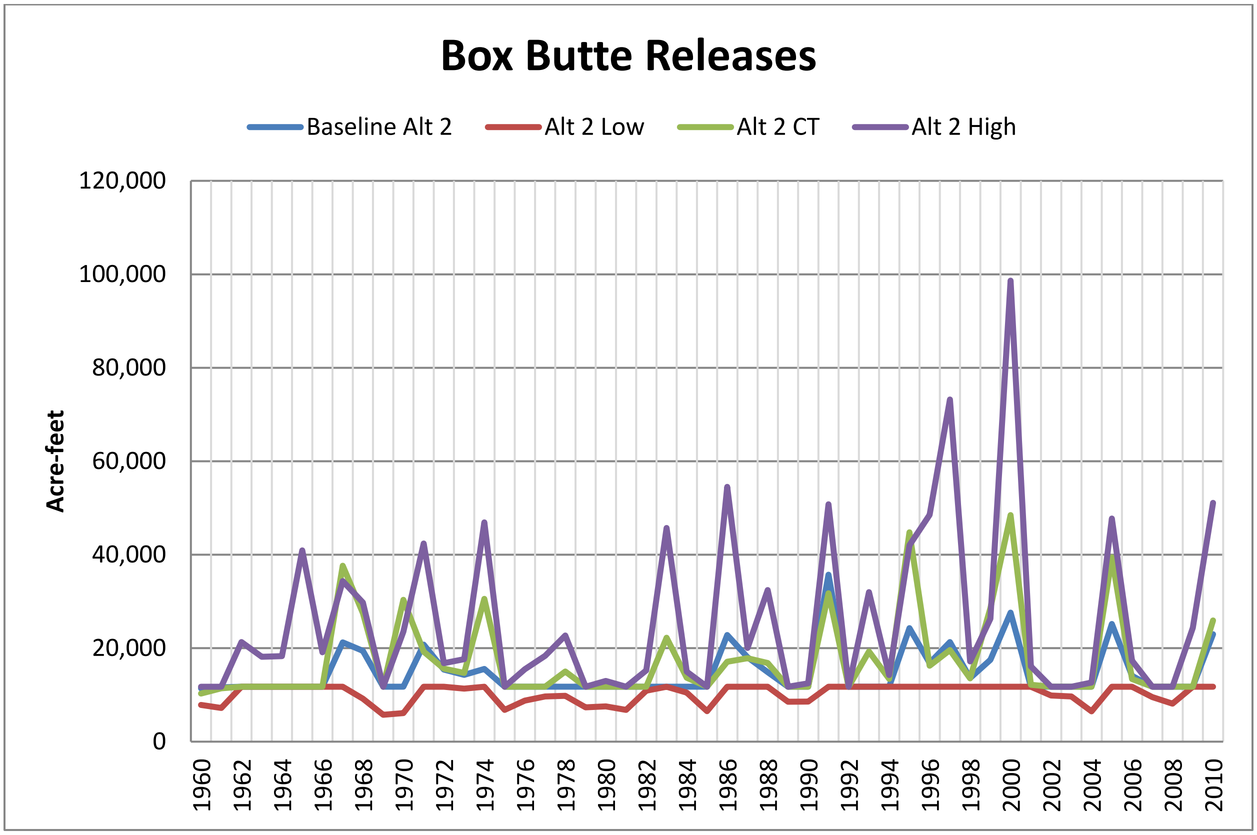

Figure 57. Total Annual Box Butte Releases – Alternative 2 Baseline vs Low, CT, High.

Table 24. Alternative 2 Annual Daily Average Box Butte Releases (AFD)

Climate	Annual	Annual % of Baseline	Irrigation Season [1]	Non-Irrigation Season [1]
Baseline	41		80	28
Low	28	68%	63	16
CT	48	117%	80	37
High	71	173%	82	67

[1] The diversion pattern provided by J. Wergin for Alternative 2 extended outside of the typical diversion season of Mirage Flats that was used to designate irrigation and non-irrigation seasons. The irrigation season for Alternative 2 was June, July, August, and September.

3.4.2.4 Mirage Flats Diversions

Total annual Mirage Flats diversions for Alternative 2 for all four climate scenarios are shown in Figure 58. The straight line pattern shown in the figure represents full recharge demands are met. All climate scenarios are able to meet the full recharge demands except for the low climate scenario. In the low climate scenario, the dips below the straight line represent not enough water to divert the full recharge demand. Table 25 summarizes the annual daily average diversions (AFD) from 1960-2010 for the irrigation season. Mirage Flats diversions only occur during the June through September period for Alternative 2.

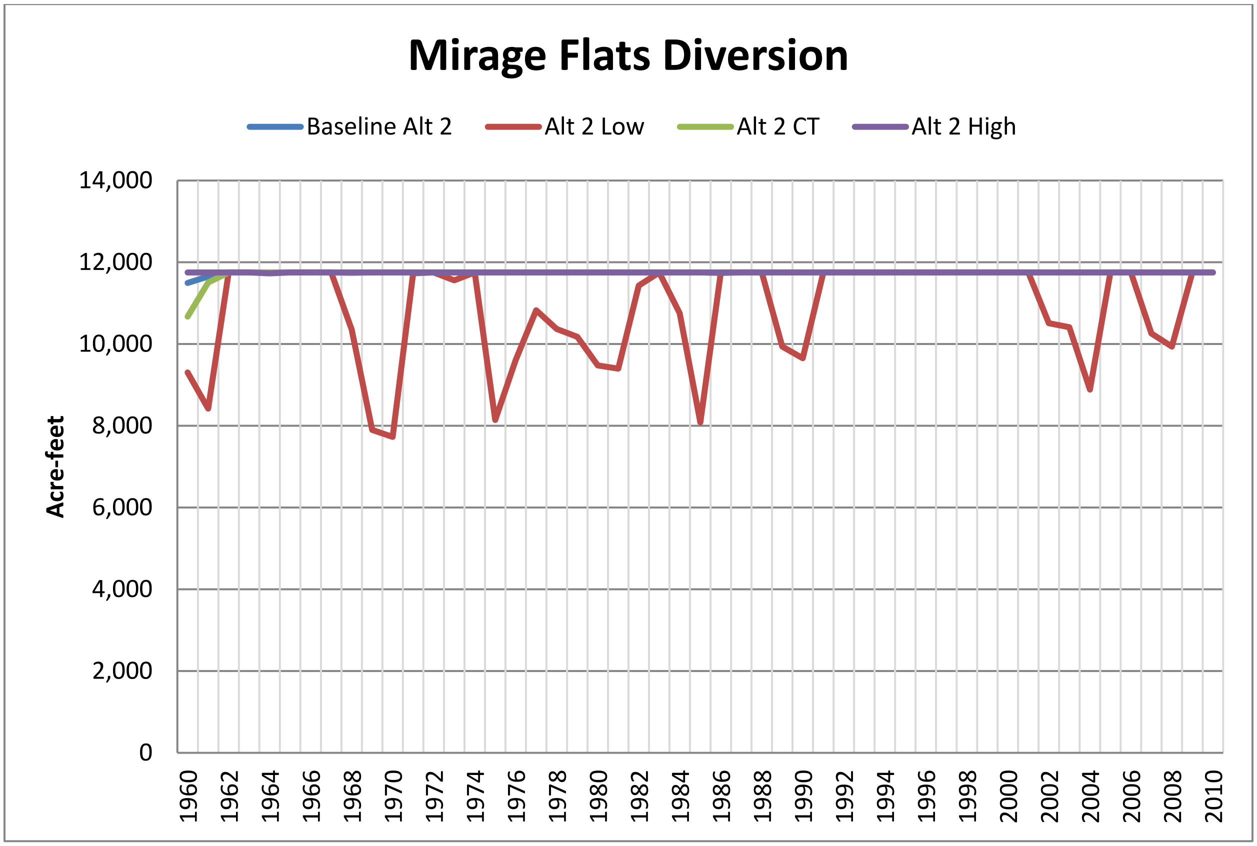

Figure 58. Total Annual Mirage Flats Diversion s– Alternative 2 Baseline vs Low, CT, High.

Table 25. Alternative 2 Annual Daily Average Mirage Flats Diversions (AFD)

Climate	Annual	Annual % of Baseline	Irrigation Season [1]	Non-Irrigation Season [1]
Baseline	32		79	16
Low	30	94%	69	16
CT	32	100%	79	16
High	32	100%	79	16

[1] The diversion pattern provided by J. Wergin for Alternative 2 extended outside of the typical diversion season of Mirage Flats that was used to designate irrigation and non-irrigation seasons. The irrigation season for Alternative 2 was June, July, August, and September.

3.4.2.5 Surface Water Irrigation Deliveries

The principal change in surface water deliveries occurred within the Mirage Flats Irrigation District. Within the district, surface water deliveries ceased.

3.4.2.6 Volume of Groundwater Pumping on Co-mingled Acres

The principal change in co-mingled pumping occurred within the Mirage Flats Irrigation District. The average volume of co-mingled pumping increased for all climate scenarios (Figure 59).

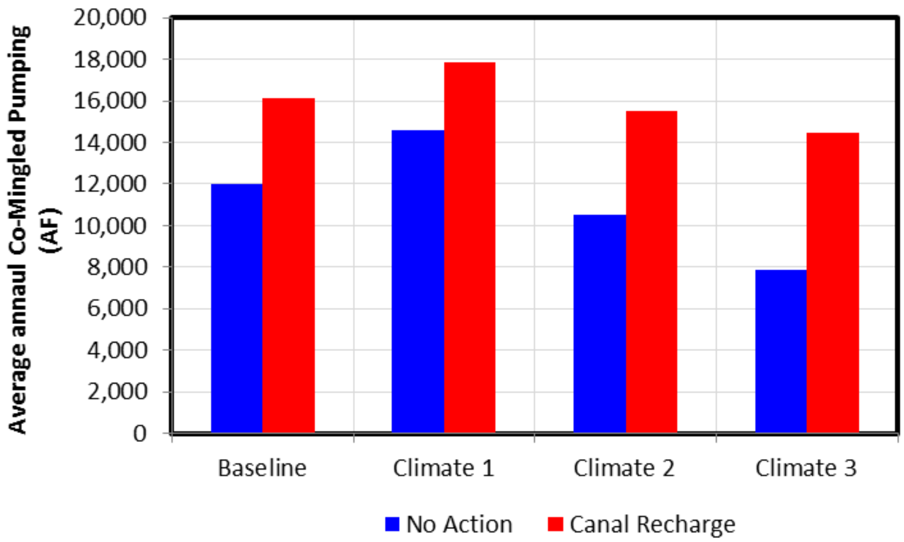

Figure 59. Mirage Flats average annual co-mingled pumping – No Action vs Alternative 2; Baseline vs low, CT, High.

3.4.2.7 Total Aquifer Recharge

The percent change in average aquifer recharge between the No Action and Alternative 2 for all four climate scenarios are shown in Figures 60-63. As expected the change in recharge is concentrated around the Mirage Flats Irrigation district and canal. All four climate scenarios saw a significant increase in the recharge within the Mirage Flats Irrigation District; while three of the climate scenarios saw a small decrease in recharge along the canal.

3.4.2.8 Groundwater Elevations

The aquifer response to Alternative 2 management with climate scenarios were as expected with decrease in groundwater level in Low water availability scenario and increase in water level in High water availability and Central Tendency scenarios. Figure 64 shows the slight increase in groundwater levels in Box Butte county and Mirage Flats Irrigation District area of Central Tendency with Alternative 2 scenario as compared with Baseline with Alternative 2 scenario.

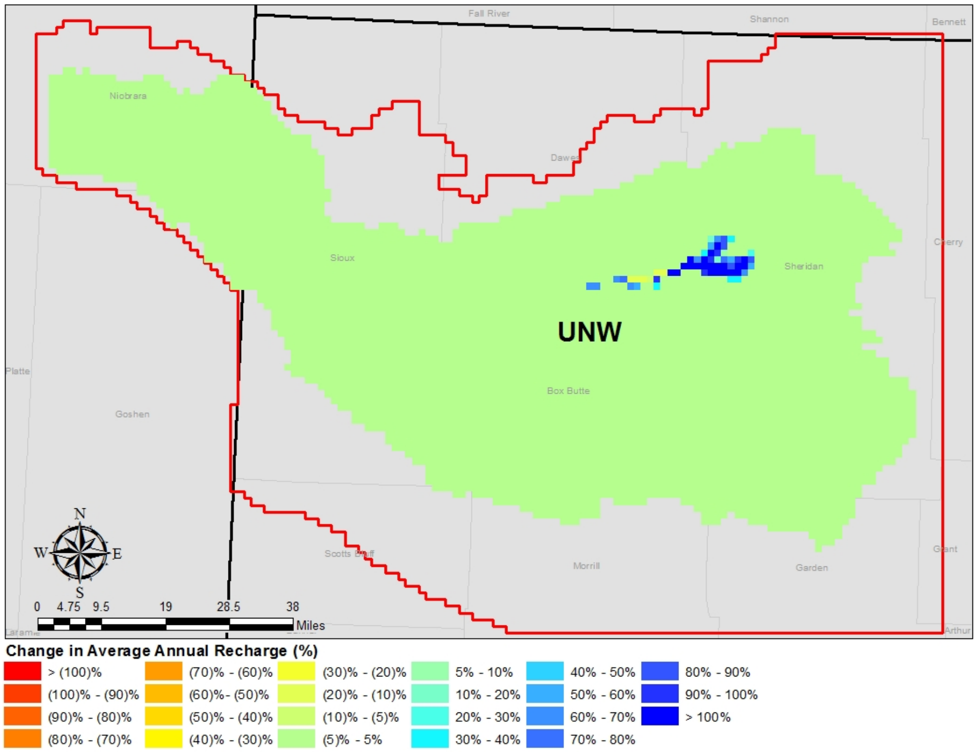

Figure 60. Percent change in average annual recharge – No Action vs Alternative 2; Baseline.

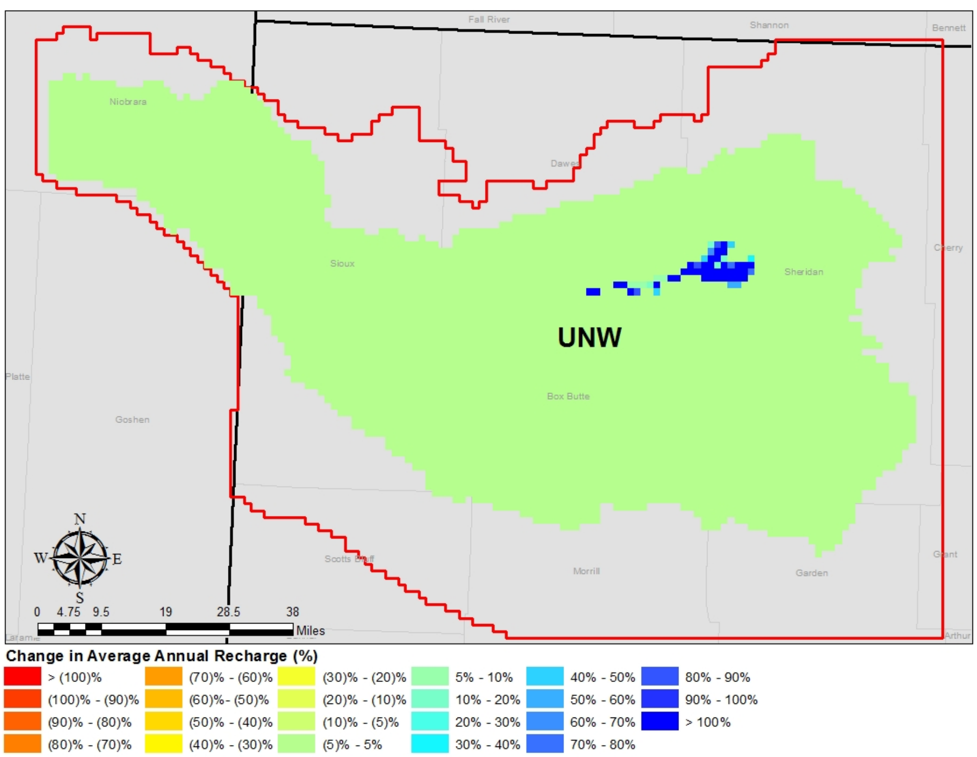

Figure 61. Percent change in average annual recharge – No Action vs Alternative 2; Low.

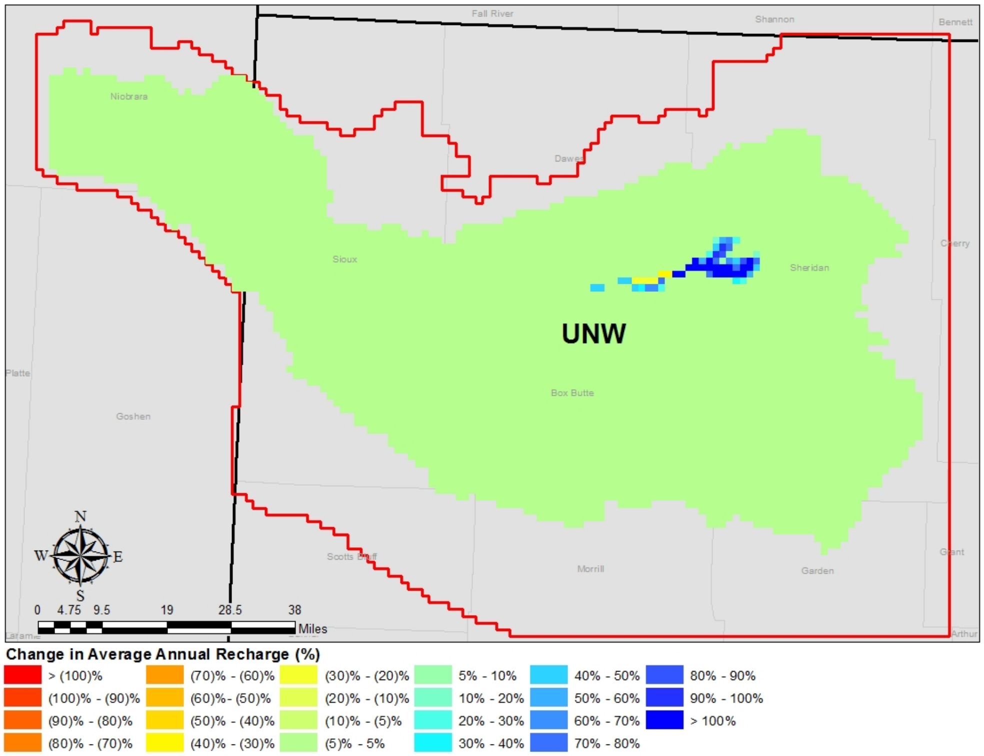

Figure 62. Percent change in average annual recharge – No Action vs Alternative 2; CT.

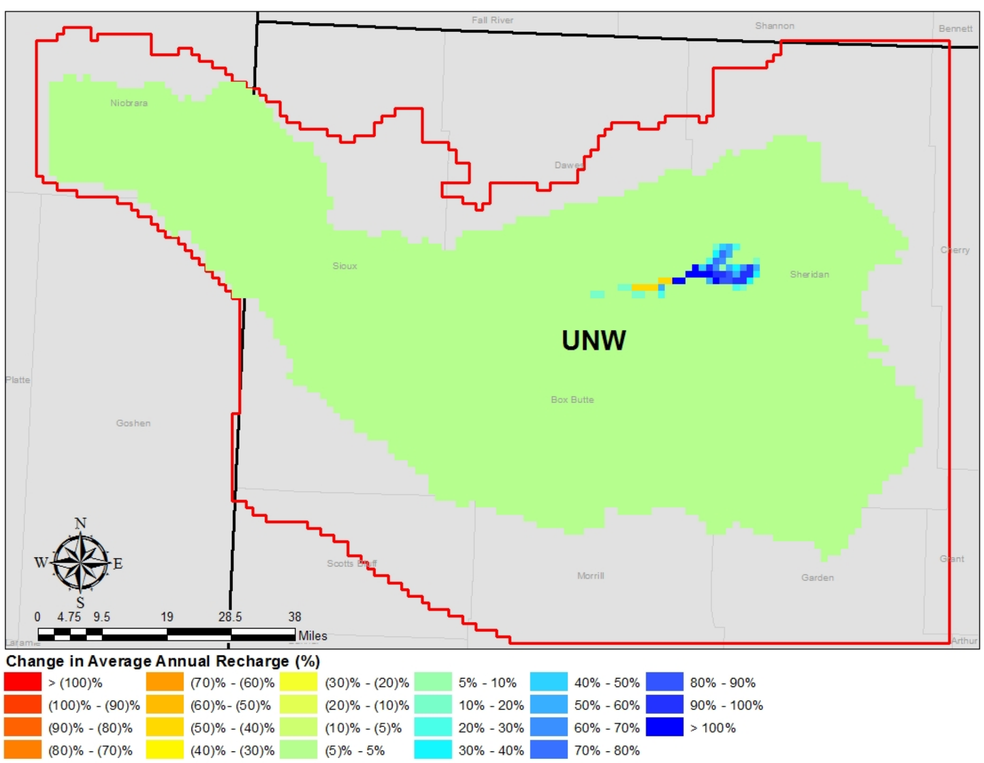

Figure 63. Percent change in average annual recharge – No Action vs Alternative 2; High.

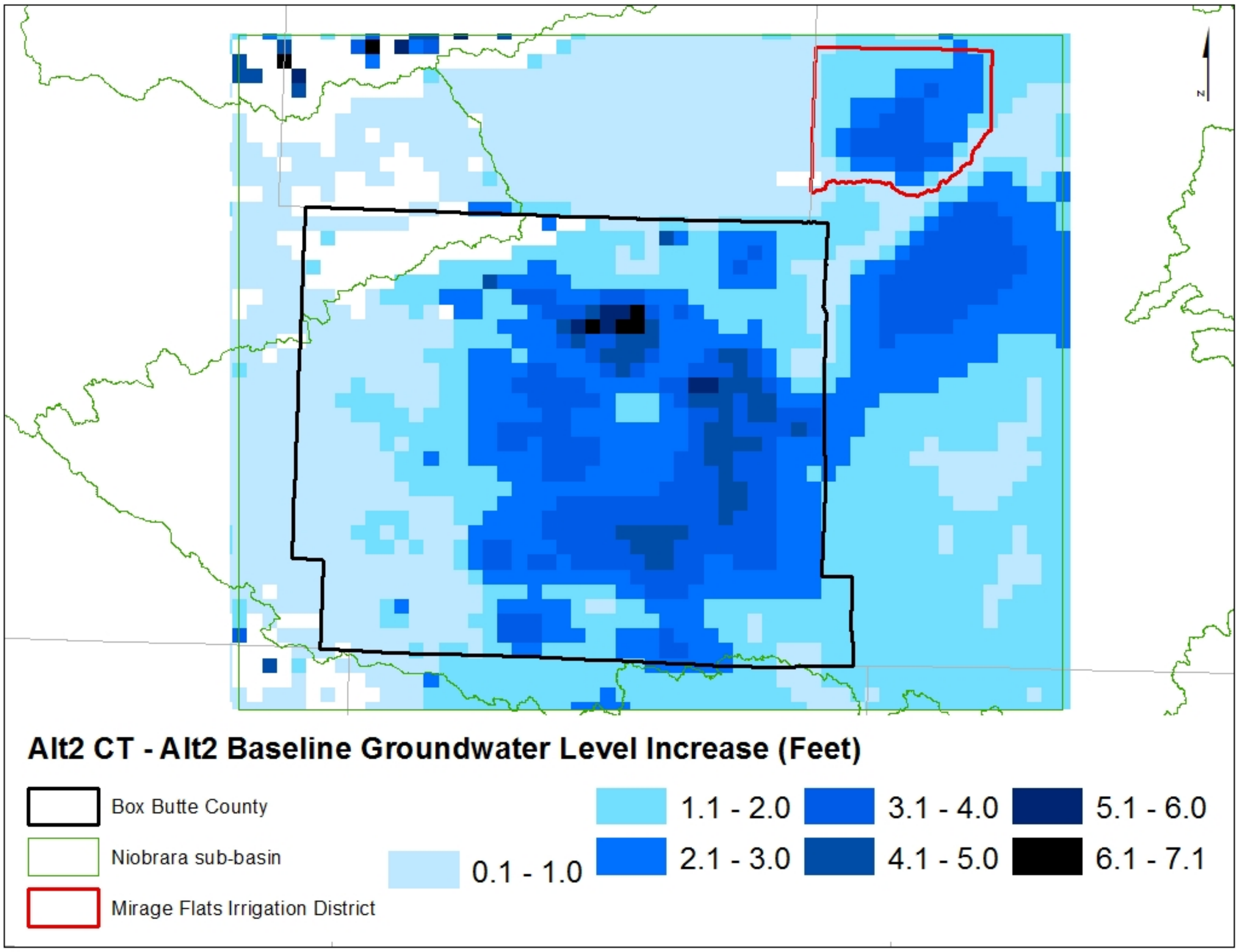

Figure 64. Increase in groundwater level in Box Butte County and Mirage Flats Area in Central Tendency with Alt 2 scenario as compared to Baseline with Alt 2 scenario.

3.4.2.9 Baseflow Contributions

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 Alternative 2 was identical to that of the baseline run.

Figure 65 represents the differences between the baseline Alternative 2 (Mirage Flats canal system operated as recharge facility) and the Alternative 2 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.

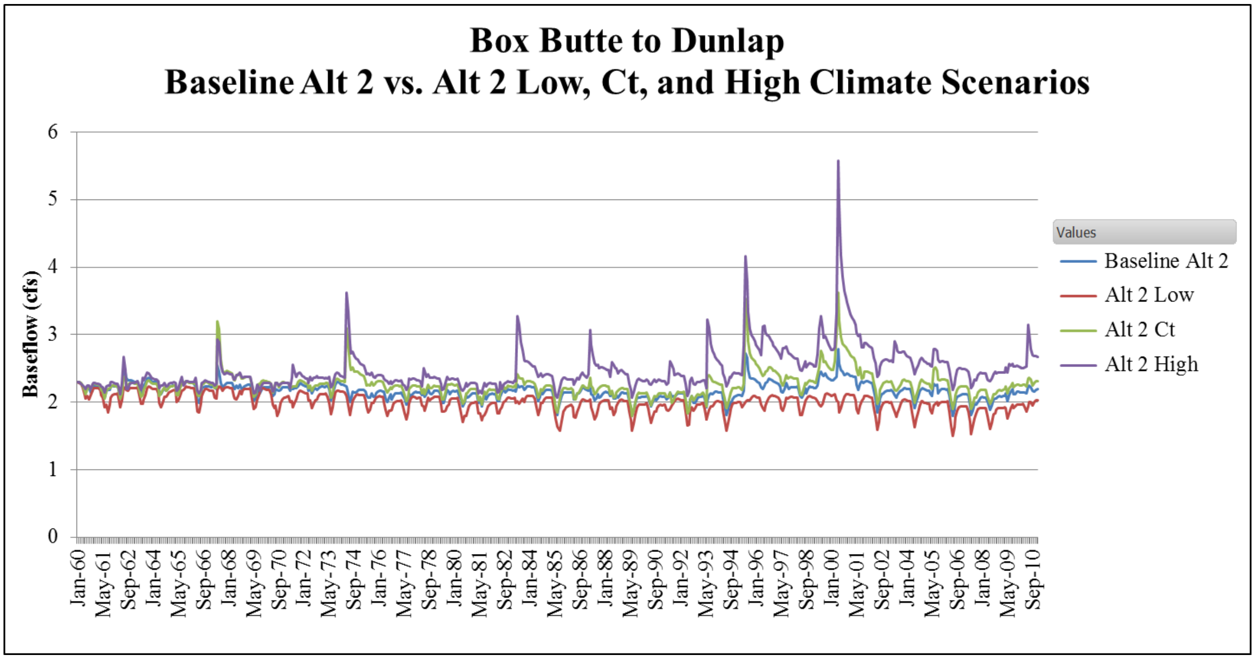

Figure 65. Box Butte to Dunlap reach baseflow comparison – Baseline Alt1 vs low, CT, and high Alternative 2 runs.

Figure 66 represents the differences between the baseline Alternative 2 (Mirage Flats canal system operated as recharge facility) and the Alternative 2 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 67 represents the differences between the baseline Alternative 2 (Mirage Flats canal system operated as recharge facility) and the Alternative 2 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.

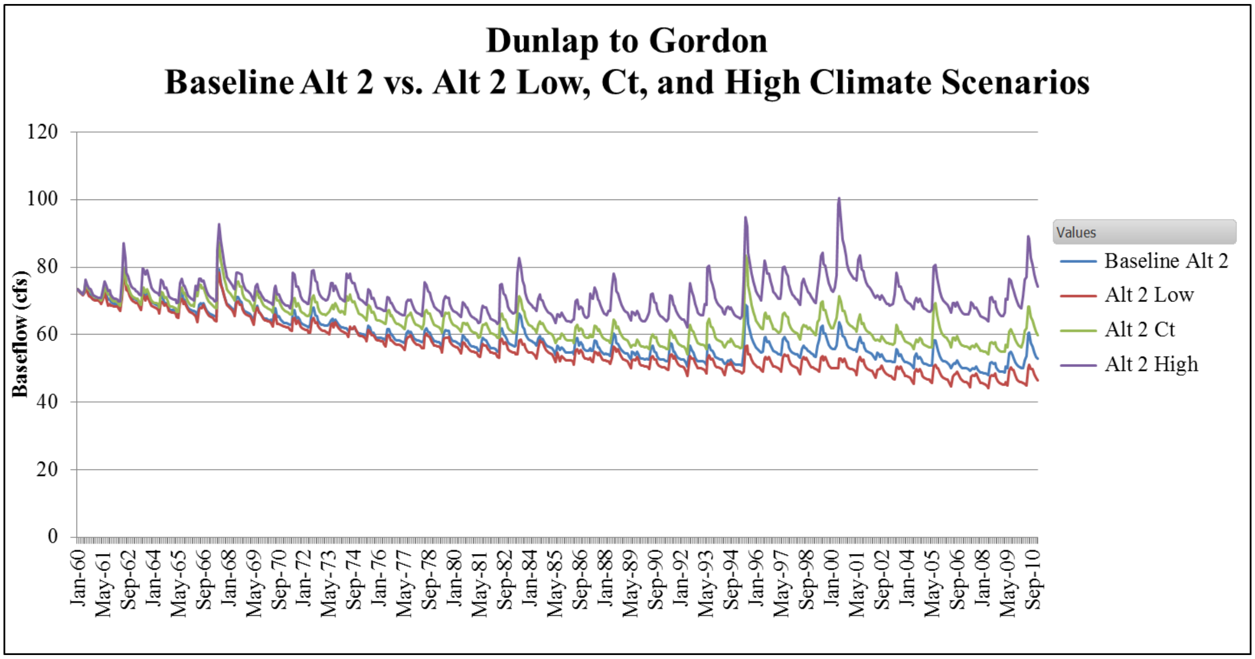

Figure 66. Dunlap to Gordon reach baseflow comparison – Baseline Alt1 vs low, CT, and high Alternative 2 runs.

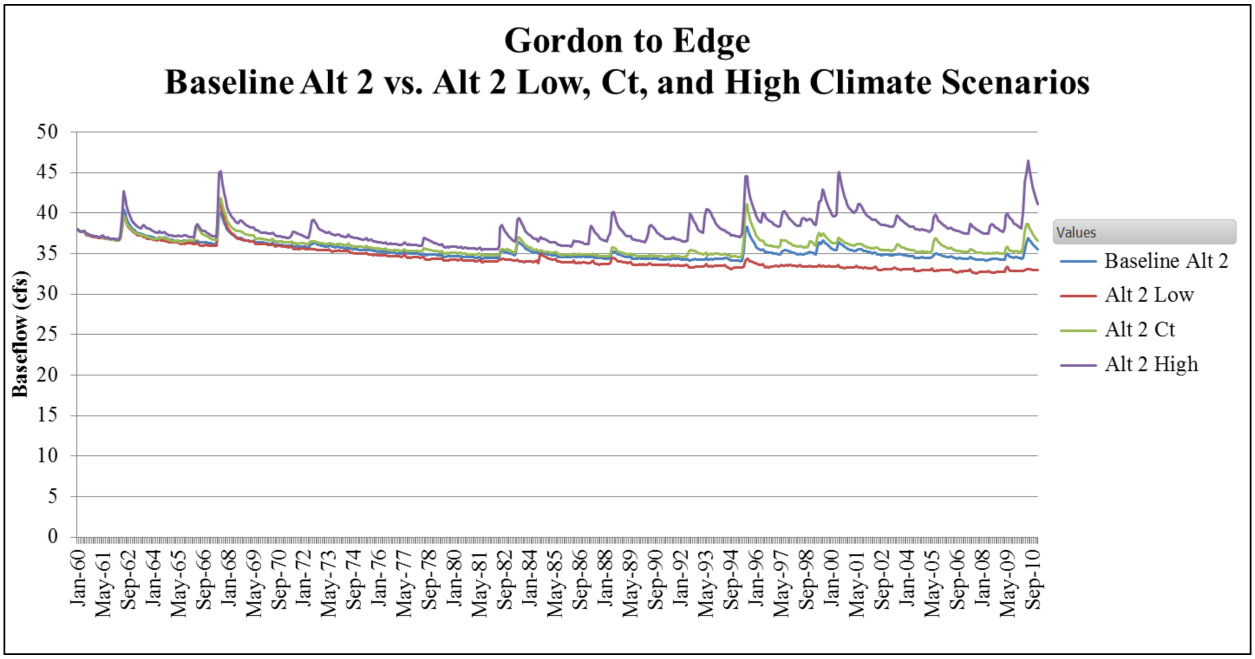

Figure 67. Gordon to model edge reach baseflow comparison – Baseline Alt1 vs low, CT, and high Alternative 2 runs.

3.4.2.10 Niobrara River at Gordon Gage

The total annual flows at the Niobrara River at Gordon gage for Alternative 2 for all climate scenarios are shown in Figure 68. The flows at Gordon have similar trends as the Box Butte Reservoir releases, reflecting the forced releases during the baseline, CT and high conditions where attenuation and storage in Box Butte Reservoir is limited. Table 26 summarizes the annual daily average flows (AFD) from 1960-2010 for Alternative 2. The data is divided into annual and seasonal values (irrigation and non-irrigation).

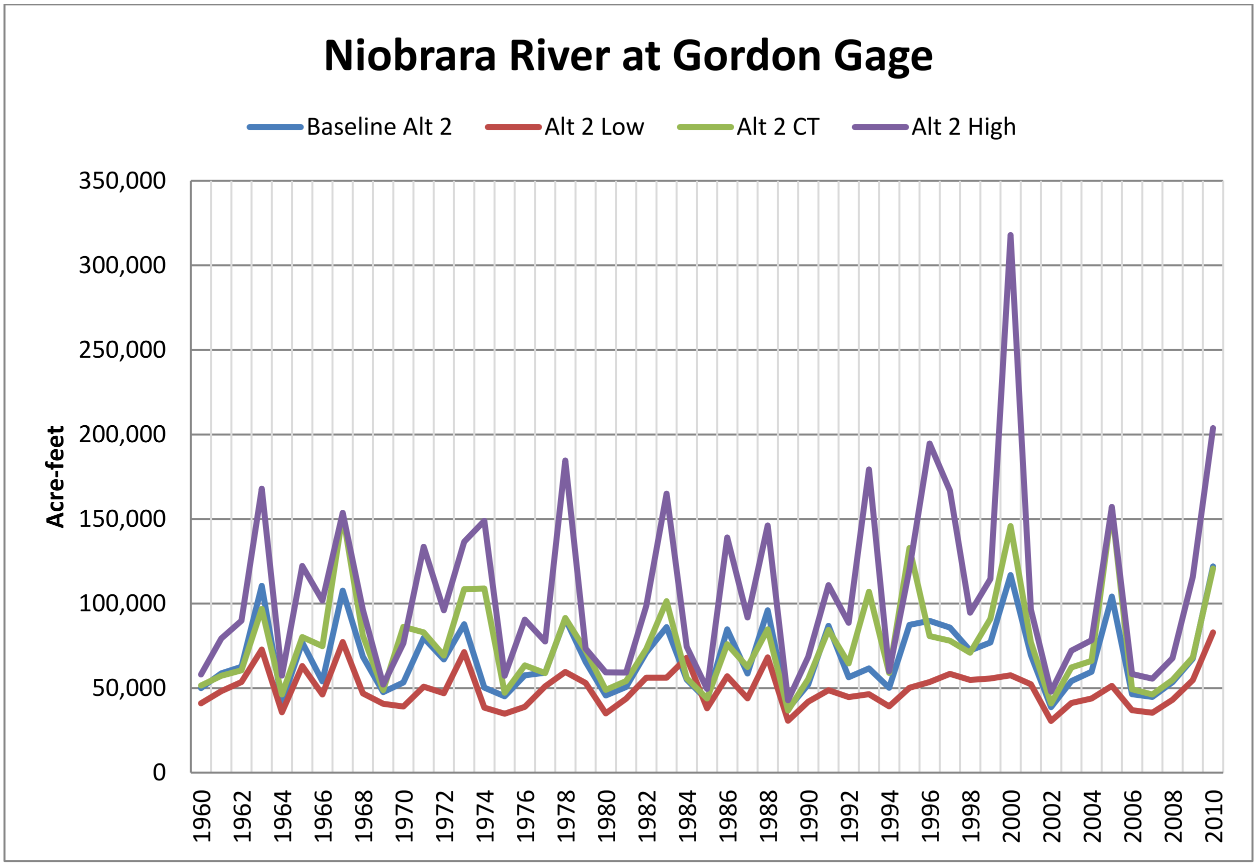

Figure 68. Total Annual Flows at Niobrara River at Gordon Gage – Alternative 2 Baseline vs Low, CT, High.

Table 26. Alternative 2 Annual Daily Average Flows at Niobrara River at Gordon Gage (AFD)

Climate	Annual	Annual % of Baseline	Irrigation Season [1]	Non-Irrigation Season [1]
Baseline	186		251	164
Low	136	73%	196	116
CT	209	112%	256	193
High	293	158%	302	289

[1] The diversion pattern provided by J. Wergin for Alternative 2 extended outside of the typical diversion season of Mirage Flats that was used to designate irrigation and non-irrigation seasons. The irrigation season for Alternative 2 was June, July, August, and September.

3.4.2.11 Summary

Alternative 2 Box Butte Reservoir levels are substantially higher than Future No Action alternative reflecting much lower releases for irrigation. All climate scenarios are able to meet the Mirage Flats Diversion full recharge demands except for the low climate scenario. In the low climate scenario, there is not always enough water to divert the full recharge demand. The principal change in surface water deliveries for Alternative 2 occurred within the Mirage Flats Irrigation District. Within the district, surface water deliveries ceased. The average volume of co-mingled pumping for Alternative 2 increased from the Future No Action alternative for all climate scenarios. As expected, the change in recharge for Alternative 2 is concentrated around the Mirage Flats Irrigation district and canal. All four climate scenarios saw a significant increase in the recharge within the Mirage Flats Irrigation District compared to the Future No Action alternative. 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. The flows at Gordon for Alternative 2 have similar trends as the Box Butte Reservoir releases, reflecting the forced releases during the baseline, CT and high conditions where attenuation and storage in Box Butte Reservoir is limited.

3.4.3 Alternative 2 Impacts to CENEB Region

Similar to Alternative 1, the Mirage Flats canal recharge alternative was not simulated by the CENEB surface water operations model. The reasoning for not simulating these scenarios in the CENEB model is the lack of sensitivity of managed flows in the CENEB region to changes in flow in the UNW region. Sensitivity analyses were performed both with respect to groundwater and managed surface water and the lack of sensitivity is summarized in Appendix B and Appendix C, respectively.

3.5 Comparison of Alternatives

The previous sections compared the climate scenarios to the individual alternatives. This section will focus on comparing the alternatives to the baseline in one climate scenario. The central tendency water availability scenario was chosen. Key water budget elements were analyzed to get an overall picture of the results of each alternative.

3.5.1 Box Butte Reservoir Elevations

The average annual Box Butte elevations for the CT scenario for No Action, Alternative 1 and Alternative 2 are shown in Figure 69. Alternatives 1 and 2 have higher elevations than the No Action alternative. Alternative 1 levels are higher due to an increased canal efficiency requiring less releases and Alternative 2 reservoir levels are higher reflecting much lower releases for irrigation. Significant droughts in the mid-1970’s and late-2000’s create decreases in Alternative 1 elevations even with the increases canal efficiencies. Table 27 summarizes the CT annual daily average elevations (ft) from 1960-2010. The data is divided into annual and seasonal values (irrigation and non-irrigation).

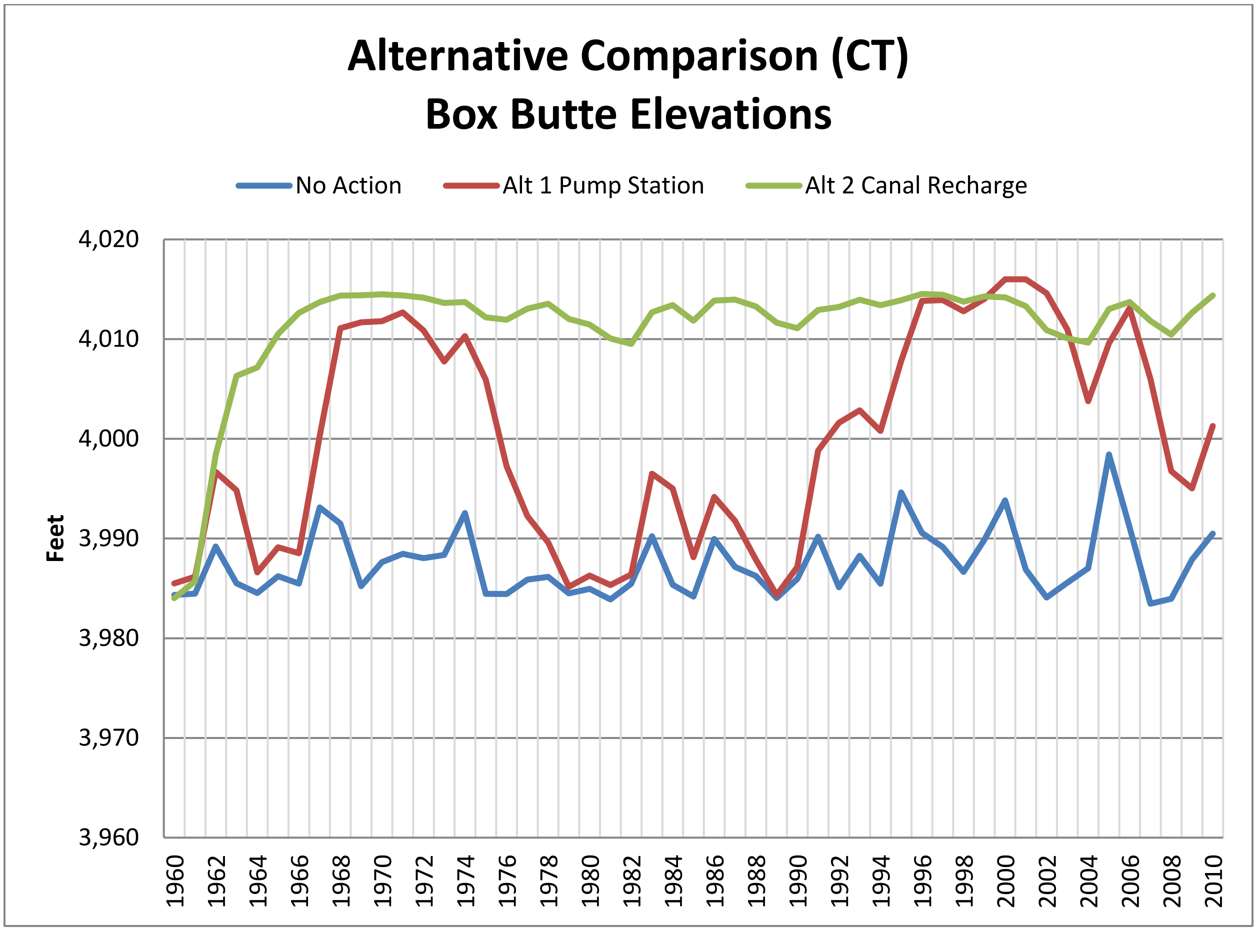

Figure 69. Average Annual Box Butte Reservoir Elevations (CT) – No Action, Alt 1, Alt 2.

Table 27. Annual Daily Average Box Butte Reservoir Elevations (CT) – No Action, Alt 1, Alt 2

Alternative	Annual	Irrigation Season [1]	Non-Irrigation Season [1]
No Action	3987.5	3983.5	3988.8
Alt 1 Pumping Station	4000.1	3999.3	4000.4
Alt 2 Canal Recharge	4011.2	4010.7	4011.4

[1] The irrigation season for No Action and Alternative 1 was July, August, and September. The diversion pattern provided by J. Wergin for Alternative 2 extended outside of the typical diversion season of Mirage Flats that was used to designate irrigation and non-irrigation seasons. The irrigation season for Alternative 2 was June, July, August, and September.

3.5.2 Box Butte Reservoir Releases

Box Butte Reservoir total annual releases for all the alternatives for the CT climate scenario are plotted in Figure 70. The plots shows No Action alternative releases sometimes exceed the releases for Alternatives 1 and 2. These are higher releases because of crop irrigation requirements and system inefficiencies. The Alternative 2 releases show a flat line pattern at approximately 12,000 acre-feet. The Alternative 2 releases above this flat line reflect forced releases based on reservoir water levels. Table 28 summarizes the CT annual average daily releases (AFD) for from 1960-2010. The data is divided into annual and seasonal values (irrigation and non-irrigation).

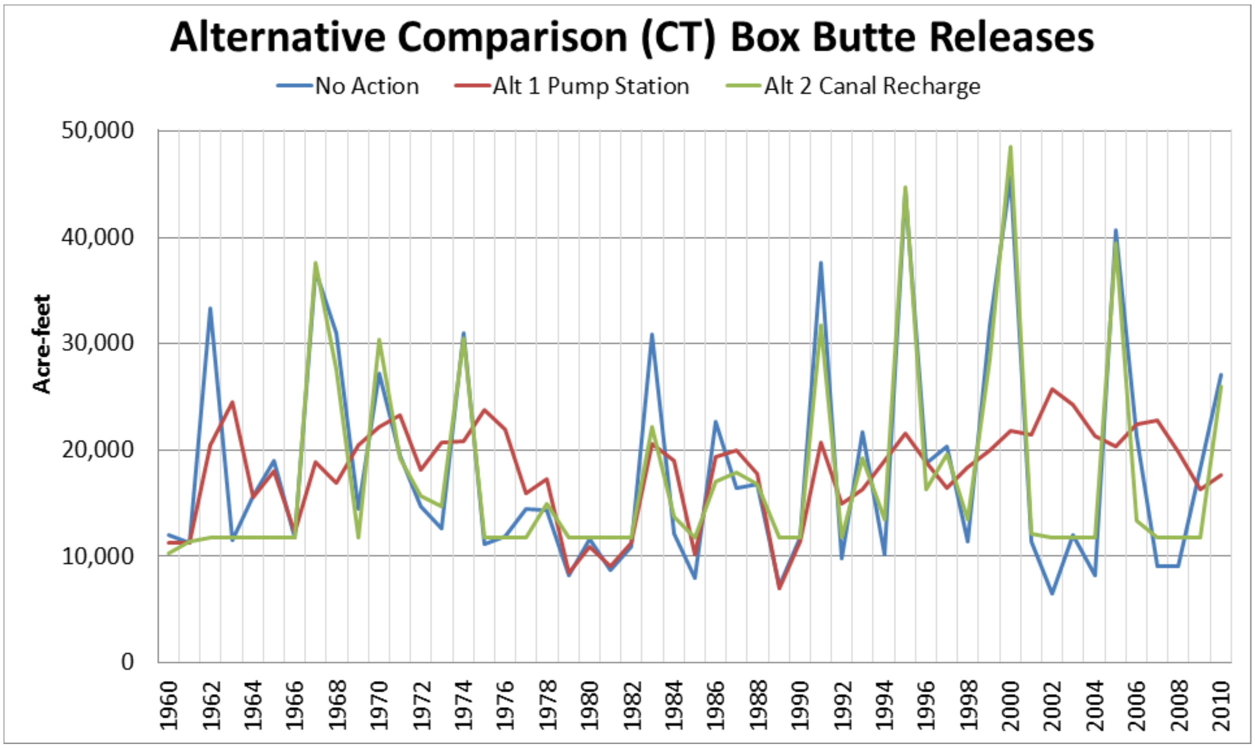

Figure 70. Total Annual Box Butte Reservoir Releases (CT) – No Action, Alt 1, Alt 2.

Table 28. Box Butte Reservoir Annual Daily Average Releases (CT) – No Action, Alt 1, Alt 2

Alternative	Annual	Annual % of Baseline	Irrigation Season [1]	Non-Irrigation Season [1]
No Action	50.2		199.2	0.0
Alt 1 Pumping Station	49.3	98%	195.8	0.0
Alt 2 Canal Recharge	48.2	96%	80.5	37.3

[1] The irrigation season for No Action and Alternative 1 was July, August, and September. The diversion pattern provided by J. Wergin for Alternative 2 extended outside of the typical diversion season of Mirage Flats that was used to designate irrigation and non-irrigation seasons. The irrigation season for Alternative 2 was June, July, August, and September.

3.5.3 Mirage Flats Diversions

Mirage Flats total annual diversions for all the alternatives for the CT climate scenario are plotted in Figure 71. Major differences are seen in the Mirage Flats Diversion between the alternatives. The No Action diversion assumes the canal has a 40% efficiency. Alternative 1 assumes 98% efficiency and Figure 70 shows the decreases in amount of diversions for that alternative. Alternative 2 assumes no deliveries and has a constant diversion rate for June, July, August and September that is used for every year of the simulation. The flat line shows adequate supply to meet recharge demand. Table 29 summarizes the CT annual daily average flows (AFD) from 1960-2010. The data is divided into annual and seasonal values (irrigation and non-irrigation).

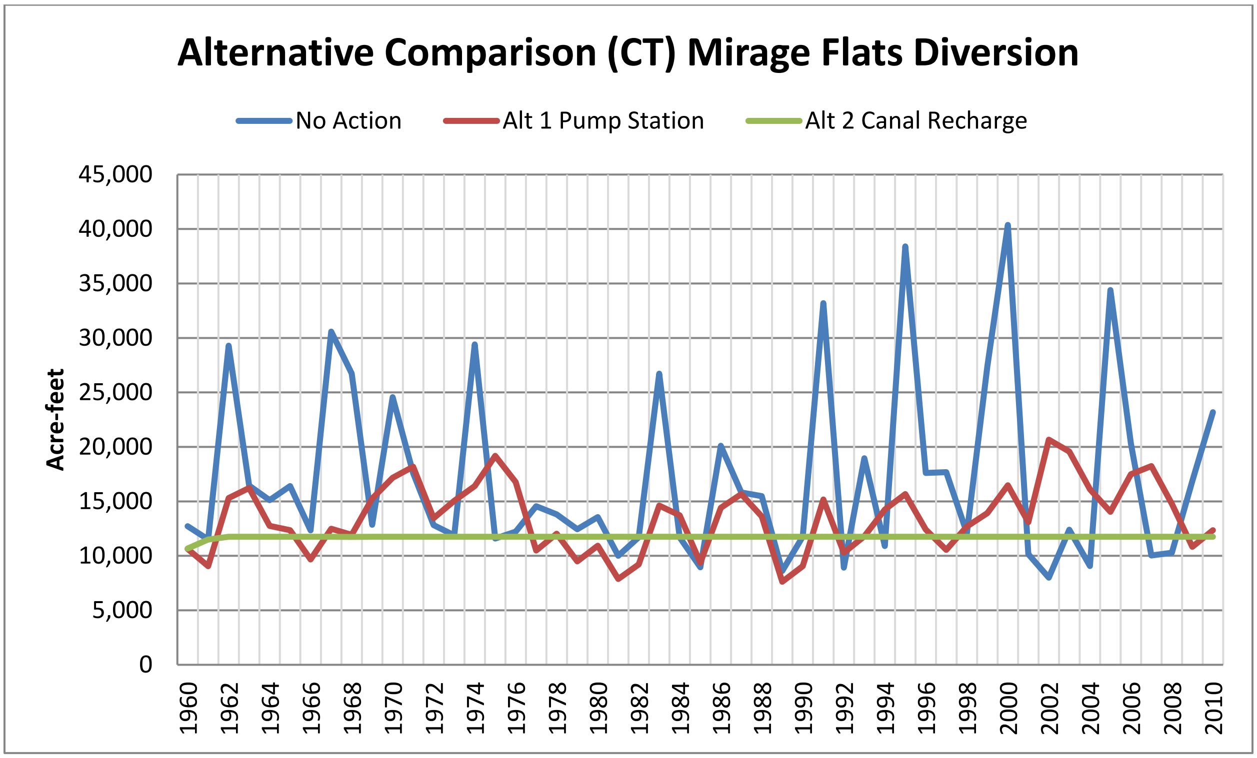

Figure 71. Total Annual Mirage Flats Diversion (CT) – No Action, Alt 1, Alt 2.

Table 29. Mirage Flats Annual Daily Average Diversion (CT) – No Action, Alt 1, Alt 2

Alternative	Annual	Annual % of Baseline	Irrigation Season [1]	Non-Irrigation Season [1]
No Action	47.2		187.5	0.0
Alt 1 Pumping Station	37.1	79%	147.1	0.0
Alt 2 Canal Recharge	32.1	68%	79.0	16.3

[1] The irrigation season for No Action and Alternative 1 was July, August, and September. The diversion pattern provided by J. Wergin for Alternative 2 extended outside of the typical diversion season of Mirage Flats that was used to designate irrigation and non-irrigation seasons. The irrigation season for Alternative 2 was June, July, August, and September.

3.5.4 Surface Water Irrigation Deliveries

The principal change in surface water deliveries occurred within the Mirage Flats Irrigation District. Figure 72 compares the average annual surface water deliveries at the Mirage Flats Irrigation District under the no action, pumping station alternative, and canal recharge alternative to the irrigation demand. Under all scenarios, Alternative 1 increased surface water deliveries. No deliveries were made as a part of Alternative 2.

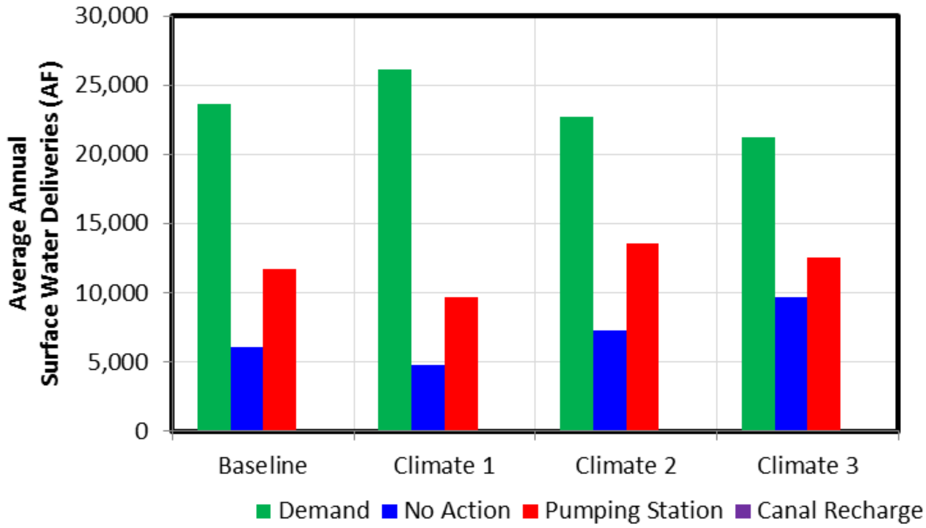

Figure 72. Mirage Flats average annual surface water deliveries – Demand vs No action, Alternative 1, Alternative 2; Baseline vs Low, CT, High.

3.5.5 Volume of Groundwater Pumping on Co-mingled Acres

The principal change in co-mingled pumping occurred within the Mirage Flats Irrigation District. Figure 73 compares the average annual co-mingled pumping in the Mirage Flats Irrigation District under the no action, pumping station alternative, and canal recharge alternative. Under all scenarios the average volume of co-mingled pumping decreased during the pumping station alternative and increased during the canal recharge alternative.

3.5.6 Total Aquifer Recharge

The change in aquifer recharge as a result of the alternatives is available in Figures 45-48 for Alternative 1 the pumping station and Figures 59-62 for Alternative 2 the canal recharge project. The change in recharge was concentrated around the Mirage Flats Irrigation District and its canal. Alternative 1 created reductions in recharge around the Mirage Flats Delivery Canal. Alternative 2 experiences both increases and decreases in recharge based upon the climate scenario. Both Alternatives increased the rate of recharge within the irrigated area of Mirage Flats District. Under Alternative 1, the increase was due to an increase in field recharge from an increase in surface water deliveries. The increase experience by Alternative 2 was due to additional recharge in the irrigation district's laterals.

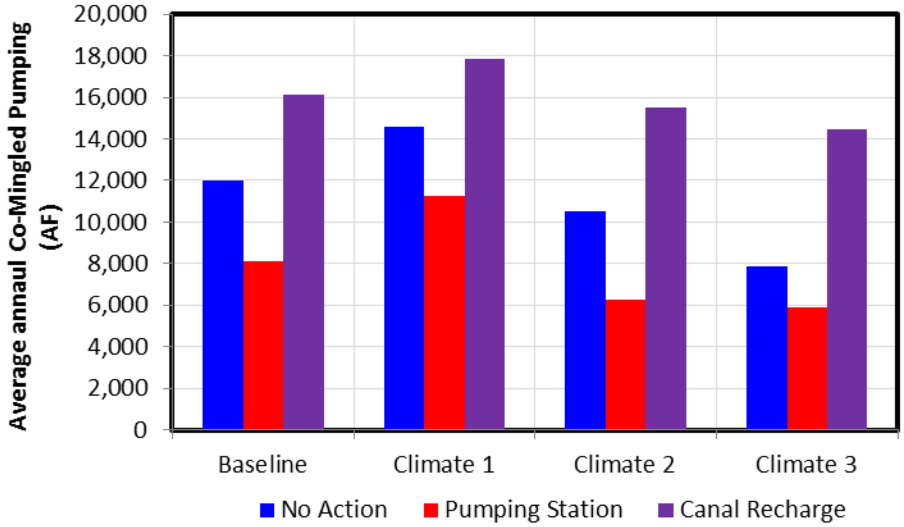

Figure 73. Mirage Flats average annual co-mingled pumping – No Action vs Alternative 1, Alternative 2; Baseline vs Low, CT, High.

3.5.7 Groundwater Elevations

Management scenarios are expected to cause local change in groundwater levels. For example, two management scenarios (Alt1 and Alternative 2) lead to some change in groundwater levels in the Mirage Flat areas relative to the baseline no-action scenario (Figures 74 and 75).

3.5.8 Baseflow Contributions

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 (Alternative 1) and Mirage Flats Canal Recharge (Alternative 2), 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 Alternative 1 and Alternative 2 no action were identical to that of the baseline no action run.

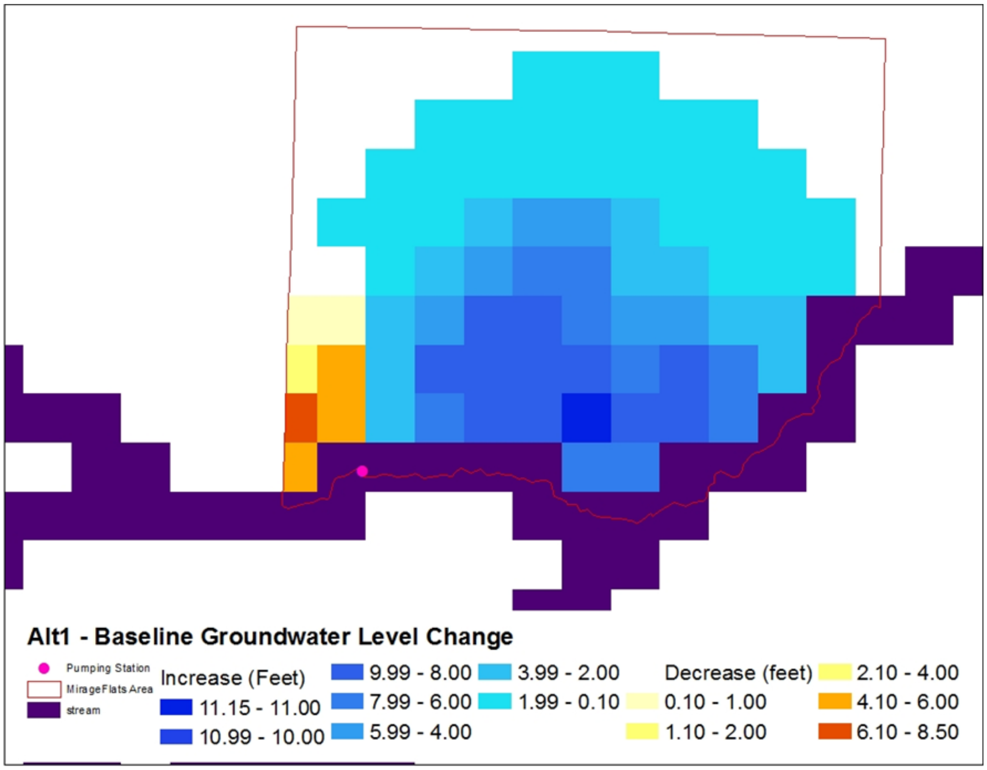

Figure 74. Groundwater level change relative to baseline in the Mirage Flat area under Alternative 1 management alternatives.

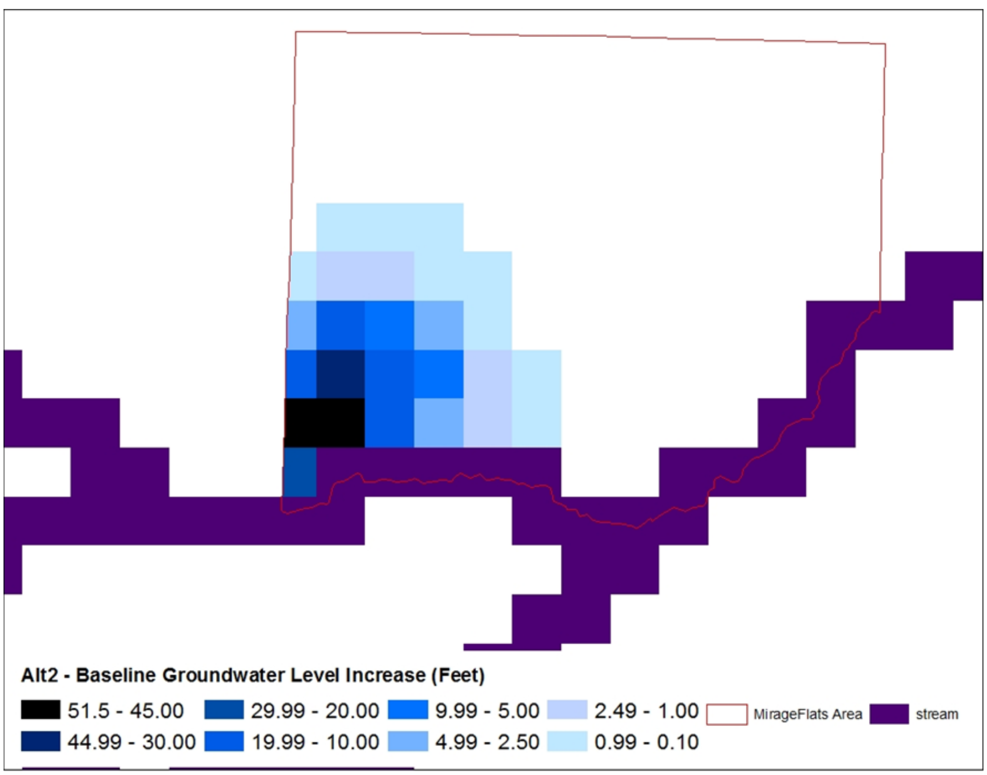

Figure 75. Groundwater level change relative to baseline in the Mirage Flat area under Alternative 2 management alternatives.

Figure 76 represents the differences between the baseline no action and the alternative water management scenarios in the Box Butte to Dunlap reach. The Alternative 1 consists of a surface water diversion location change scenario and Alternative 2 is the Mirage Flats canal recharge scenario. When compared to Alternative 1, 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 Alternative 2 run generated slightly higher baseflow compared to the baseline.

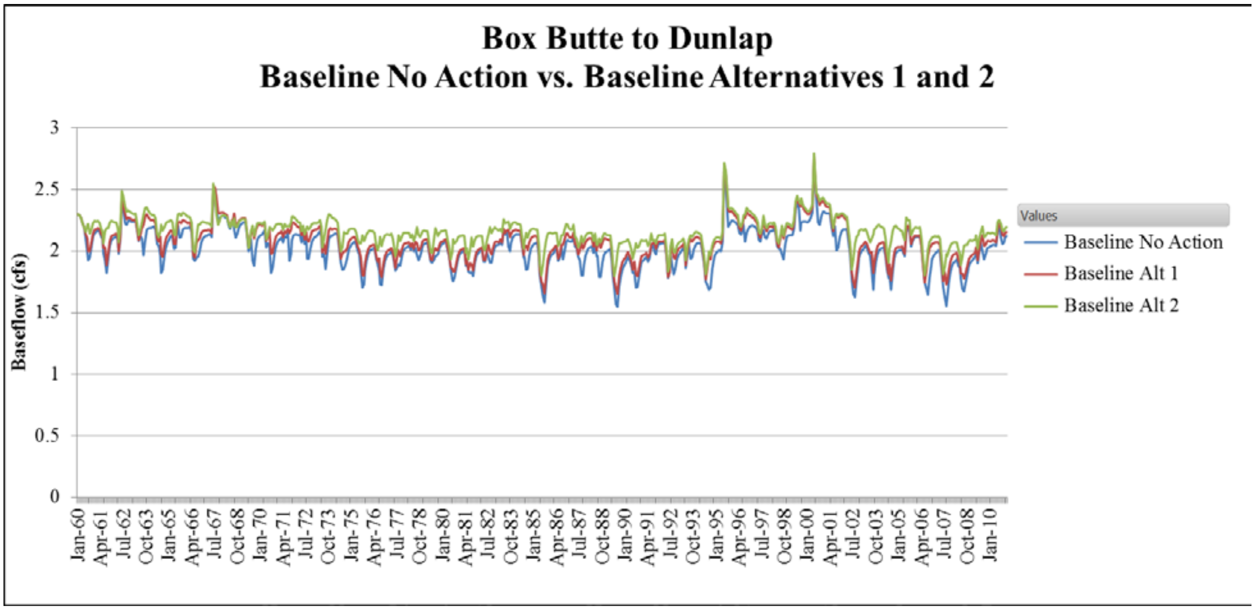

Figure 76. Box Butte to Dunlap reach baseflow comparison – Baseline no action vs Alternative 1 and Alternative 2 no action runs.

Figure 77 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 Alternative 1 and Alternative 2 run. The outputs between the baseline and Alternative 2 represent some amount of overlap throughout the modeling period, but baseflow of Alternative 1 is clearly below baseline baseflow curve by around five cubic feet per second.

The purpose of the Alternative 1 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 Alternative 1 scenario. In Alternative 1 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 Alternative 1 run is lower than that of the baseline run.

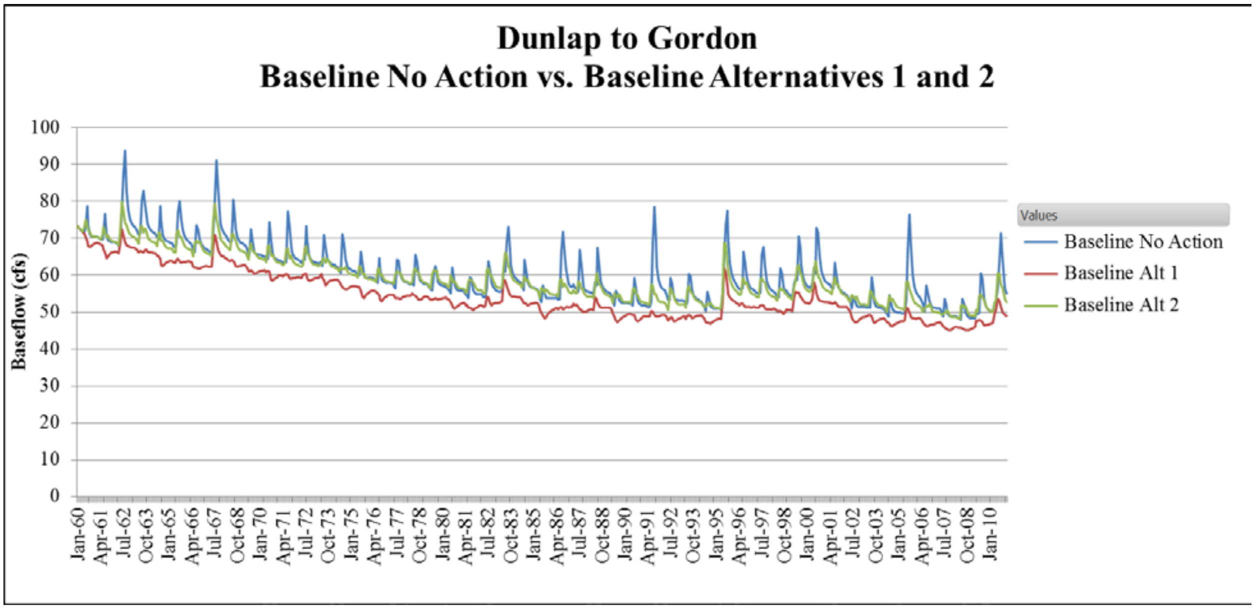

Figure 77. Dunlap to Gordon Reach baseflow comparison – Baseline no action vs Alternative 1 and Alternative 2 no action runs.

In the Alternative 2 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 Alternative 2 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 78 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 Alternative 1 and Alternative 2 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.

3.5.9 Niobrara River at Gordon Gage

Niobrara River at Gordon gage total annual flows for all the alternatives for the CT climate scenario are plotted in Figure 79. The flows at Gordon are very similar between the different alternatives. This essentially shows that Box Butte Reservoir is an adequate buffer and can hold most of the surplus water generated by Alternatives 1 and 2 lower demands. Table 30 summarizes the CT annual daily average flows (AFD) from 1960-2010. The data is divided into annual and seasonal values (irrigation and non-irrigation).

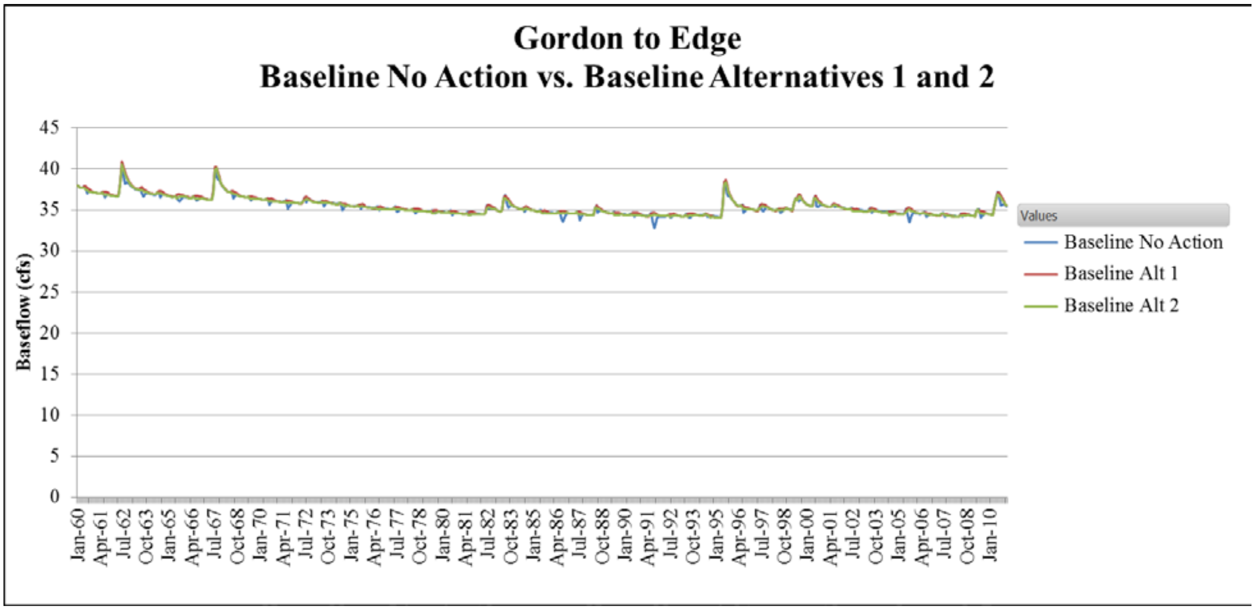

Figure 78. Gordon to edge of model reach baseflow comparison – Baseline no action vs Alternative 1 and Alternative 2 no action runs.

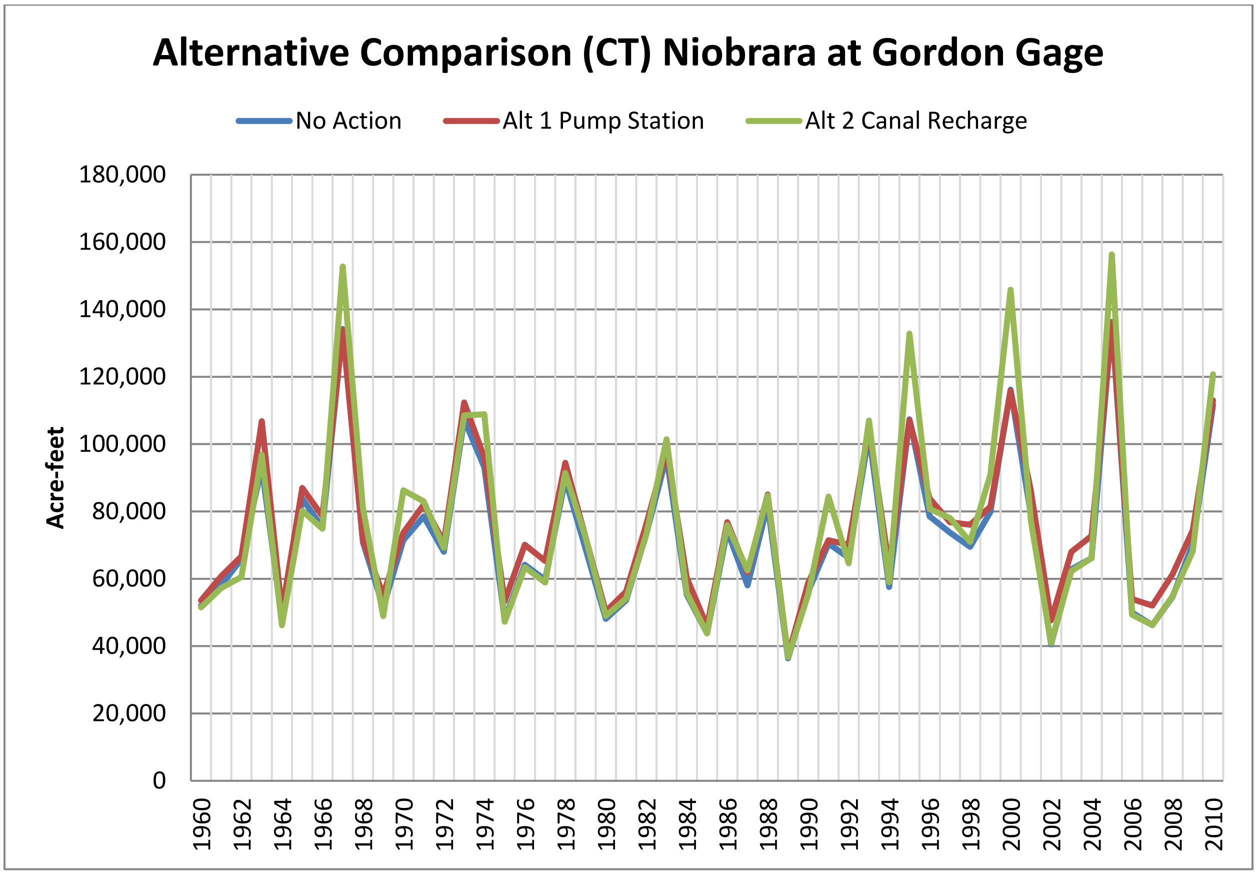

Figure 79. Total Annual Flows at Niobrara at Gordon Gage (CT) – No Action, Alt 1, Alt 2.

Table 30. Niobrara at Gordon Gage Annual Daily Average (CT) – No Action, Alt 1, Alt 2

Alternative	Annual	Annual % of Baseline	Irrigation Season [1]	Non-Irrigation Season [1]
No Action	198.6		276.8	172.2
Alt 1 Pumping Station	208.2	105%	316.0	171.9
Alt 2 Canal Recharge	208.8	105%	255.9	192.9

[1] The irrigation season for No Action and Alternative 1 was July, August, and September. The diversion pattern provided by J. Wergin for Alternative 2 extended outside of the typical diversion season of Mirage Flats that was used to designate irrigation and non-irrigation seasons. The irrigation season for Alternative 2 was June, July, August, and September.

3.5.10 Summary

Alternatives 1 and 2 have higher Box Butte Reservoir elevations than the No Action alternative. Alternative 1 Box Butte Reservoir levels are higher due to an increased canal efficiency requiring less releases and Alternative 2 reservoir levels are higher reflecting much lower releases for irrigation. Major differences are seen in the Mirage Flats Diversion between the alternatives. The No Action diversion assumes the canal has a 40% efficiency, while Alternative 1 assumes 98% efficiency. Alternative 2 assumes no deliveries and has a constant diversion rate for June, July, August and September that is used for every year of the simulation. Under all scenarios, Alternative 1 increased surface water deliveries. No deliveries were made as a part of Alternative 2. Under all climate scenarios the average volume of co-mingled pumping decreased during Alternative 1 and increased during Alternative 2. The change in recharge was concentrated around the Mirage Flats Irrigation District and its canal. Alternative 1 created reductions in recharge around the Mirage Flats Delivery Canal. Alternative 2 experiences both increases and decreases in recharge based upon the climate scenario. Both Alternatives increased the rate of recharge within the irrigated area of Mirage Flats District. Under Alternative 1, the increase was due to an increase in field recharge from an increase in surface water deliveries. The increase experience by Alternative 2 was due to additional recharge in the irrigation district’s laterals. 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. The flows at Gordon are very similar between the different alternatives. This essentially shows that Box Butte Reservoir is an adequate buffer and can hold most of the surplus water generated by Alternatives 1 and 2 lower demands.