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Niobrara River Basin Study Summary Report

U.S. Department of the Interior
Bureau of Reclamation
Technical Service Center | Nebraska-Kansas Office
Denver, Colorado | McCook, Nebraska

Nebraska
Department of Natural Resources
Lincoln, Nebraska

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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: Autumn colors along the Niobrara, as seen from the Cornell Bridge in the Fort Niobrara National Wildlife Refuge. Photo by National Park Service.

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Disclaimer

The Niobrara River Basin Study was funded jointly by the Bureau of Reclamation and the Nebraska Department of Natural Resources and is a collaborative product of the study participants as identified in section I-C of this report. The purpose of the study is to assess current and future water supply and demand in the Niobrara Basin and to identify a range of potential strategies to address any projected imbalances. The study is a technical assessment and does not provide recommendations or represent a statement of policy or position of the Bureau of Reclamation, the Department of the Interior, or the Department of Natural Resources. The study does not propose or address the feasibility of any specific project, program or plan. Nothing in the study is intended, nor shall the study be construed, to interpret, diminish, or modify the rights of any participant under applicable law. Nothing in the study represents a commitment for provision of Federal funds. All cost estimates included in this study are preliminary and intended only for comparative purposes.

Executive Summary

Introduction

Spanning portions of eastern Wyoming, southern South Dakota, and northern Nebraska, the Niobrara River Basin (Basin) links land and water to support a diverse natural environment rich with life. The vast east-west riparian corridor is 535 river miles in length and drains 12,600 square miles. As the longest river in Nebraska, the Niobrara River reaches across the 100th Meridian to connect a semiarid western landscape with a more humid midwestern prairie. This is a Basin where ecosystems converge resulting in a unique arrangement forest cover and mixed-grass prairie. A 76-mile stretch of the Niobrara River is lined with fossil-filled sandstone cliffs that host over 200 waterfalls and is protected under the National Wild and Scenic River system.

While beautiful and biologically diverse, the Niobrara River also gives life to farming communities and provides great economic value. Hydrologically linked with the underlying High Plains Aquifer system, the Niobrara River irrigates approximately 600,000 acres, supplies drinking water to nearly 20,000 people, and generates recreational revenues for local economies. Competition for limited water resources in the Basin is intense. As water management practices respond to a changing climate and competing demands, there is a need for better understanding what effect water imbalances may have on the vitality of the region and how they can be addressed.

Like many river basins with western origins, the Niobrara River Basin represents a variety of water management challenges. Competition for limited water resources gives rise to imbalances often revealed in the form of shortages for water right holders. Groundwater irrigation development is prevalent and a strong hydrologic connection between groundwater and surface water further complicates surface water supplies in the Basin. This interaction is recognized in the Upper Niobrara Basin where the Mirage Flats Irrigation District is currently receiving only a fraction of the surface water supply that was once delivered prior to widespread development of groundwater irrigation. Hydrologic records give no indication that greater surface water supplies for irrigation are to be expected in the future. Working together, a further understanding of water resources in the Basin will help stakeholders respond to future challenges and opportunities to better secure limited water supplies.

The information presented in this report was developed in conjunction with basin stakeholders and is intended to inform and assist stakeholders by identifying potential future scenarios for long term planning. The analyses provided in this report reflect the use of best available datasets and data development methodologies at the time of the study. It is important to acknowledge the uncertainties inherent within projecting future planning conditions for water supply and demand. For example, projections of future climate, population, water demand, and land use contain uncertainties that vary geographically and temporally depending on the model and methodology used. Trying to identify an exact impact at a particular place and time remains difficult, despite advances in modeling efforts over the past half-century. Accounting for these uncertainties, Reclamation and its stakeholders used a scenario planning approach that encompasses the estimated range of future planning conditions.

Basin Study Value

Fostering Collaboration

The Niobrara River Basin Study (Basin Study) engages a broad spectrum of stakeholders to explore complex water management issues in a collaborative setting with the Bureau of Reclamation (Reclamation) and the Nebraska Department of Natural Resources. While the Basin Study does not propose implementation of a specific project, program, or plan, it does provide a catalyst for collaboration among stakeholders including Reclamation, Nebraska Department of Natural Resources, National Park Service, United States Fish and Wildlife Service, Nebraska Game and Parks Commission, the Upper Niobrara White Natural Resources District (NRD), the Upper Loup NRD, the Upper Elkhorn NRD, the Middle Niobrara NRD, the Lower Niobrara NRD, Mirage Flats Irrigation District, Ainsworth Irrigation District, and Nebraska Public Power District.

Specifically, the Basin Study provided an opportunity for Reclamation and Nebraska Department of Natural Resources to attend a series of meetings with stakeholders to discuss resource challenges. These meetings offered a venue for gathering input, addressing concerns, and exploring shared responsibilities. Discussions ranged from important on-the-ground field experiences to high-level technical perspectives. A number of varied interests were represented at stakeholder meetings, including irrigation, drinking water supply, fish and wildlife, hydropower, and recreation.

Expanding Science

As stakeholder input is gathered, the Basin Study also explores ways to improve water management and system reliability by employing technical resources that can expand the reach of science within the Basin. This approach is an important initial step toward a more comprehensive long-range plan for the Basin. In the long-term, the Basin Study will help inform the Nebraska Department of Natural Resources and Basin stakeholders responsible for the ongoing development of a Niobrara Basin-Wide Management Plan that focuses on achieving sustainable balance between water users and water suppliers. As this Basin Study concludes, it is anticipated that the Niobrara Basin-Wide Management Plan will continue to be developed as part of a basin-wide planning process that continues to build upon on the science and analysis presented in this Basin Study.

The Basin Study also provides foundational information for development and implementation of Integrated Management Plans designed by the Nebraska Department of Natural Resources and local NRDs. Integrated Management Plans help achieve and sustain a balance between water uses and water supplies for the long term. The core components of Integrated Management Plans rely on utilization of sound science and an accurate understanding of water principles within the Basin. This Basin Study offers an additional resource that can help inform decision makers as they identify appropriate goals and continue monitoring overall effectiveness of Integrated Management Plans.

Enhancing Modeling Capacity

The Basin Study increases overall modeling capabilities by developing an integrated suite of models representing surface hydrology, groundwater hydrology, agricultural demands, and river management. The Basin Study provides additional tools for water resource managers evaluating future planning activities and potential management actions. Enhanced modeling capacity can have a meaningful impact on real world operational decisions. For example, in 2015, the Nebraska Public Power District entered into an agreement with the Nebraska Game and Parks Commission and Niobrara River Basin Alliance to sell the Spencer Hydropower facility (a senior water right holder). The Nebraska Game and Parks Commission and Niobrara River Basin Alliance can use modeling capabilities developed in this Basin Study to obtain insight into potential operational impacts resulting from a change in beneficial use (i.e. hydropower generation versus instream flow).

Authority

This Basin Study was conducted as part of the WaterSMART (Sustain and Manage America's Resources for Tomorrow) Basin Study Program. The SECURE Water Act of 2009 (P.L. 111-11) and Secretarial Order 3297 established the WaterSMART Program, which authorizes Federal water and science agencies to work with State and local water managers to pursue and protect sustainable water supplies and plan for future climate change by providing leadership and technical assistance on the efficient use of water. Through the Basin Studies, Reclamation works with States, Indian tribes, non-governmental organizations, other Federal agencies, and local partners to identify strategies to adapt to and mitigate current or future water supply and demand imbalances, including the impacts of climate change and other stressors on water and power facilities.

Using Section 9503 of P.L. 111-11 as a guide, Reclamation finalized Directives and Standards (D&S) that outline specific requirements for Basin Studies (www.usbr.gov/recman/temporary_releases/wtrtrmr-65.pdf). According to the D&S, the following elements must be included in Basin Studies: (1) Projections of future water supply and demand, considering specific impacts resulting from climate change; (2) Analyses of how existing water and power infrastructure and operations will perform given any current imbalances between water supply and demand and in the face of changing water realities due to climate change; (3) Development of appropriate alternative and mitigation strategies to meet current and future water demands; and (4) A trade-off analysis of the strategies identified in terms of their ability to meet study objectives.

Federal funding is allocated on a competitive, 50/50 cost-share basis with willing non-Federal entities that must submit an application through an open solicitation process. In Fiscal Year 2010, the State of Nebraska applied for and was allocated a total of $350,000 in Federal funding. Under the Basin Study Program, these funds are used to directly support Reclamation’s joint participation in the study. Funds were matched with non-Federal funds totaling about $500,000, representing a 41 to 59 percent Federal to non-Federal cost share. The total cost of the study is $850,000.

Location and Description of the Study Area

The Basin extends across diverse landscapes from the high plains of eastern Wyoming to its Missouri River termination along Nebraska’s northeastern border as shown in Figure ES-1. As the river flows east it cuts through the High Plains Aquifer system and principal aquifer units including the Arikaree group and Ogallala group. These two major aquifer formations supply groundwater to numerous irrigation wells and replenish the predominantly aquifer-supplied Niobrara River. A study by Jozsef Szilagyi et al. (2002) suggests 70-90 percent of river flow within the upper reaches of the Basin is attributed to seepage from groundwater. Hundreds of springs flow into the Niobrara River as it travels through the Nebraska Sand Hills. In addition, the Niobrara River collects water from four tributaries including the Snake River, Minnechaduza Creek, Keya Paha River, and Long Pine Creek.

Figure ES-1. Niobrara River Basin Map

Summary of Federal Features in the Area

There are two Reclamation irrigation projects in the Basin - the Mirage Flats Project and the Ainsworth Unit. Named for the region's deceptive landscape, the Mirage Flats Project is located in Dawes and Sheridan Counties and resides at an elevation around 3,500 feet. The Mirage Flats Project with a full water supply irrigates 11,662 acres and its main features include Box Butte Dam and Reservoir, Dunlap Diversion Dam, and the Mirage Flats main canal. Downstream from the Mirage Flats Project, the Ainsworth Unit is under the Pick-Sloan Missouri Basin Program and irrigates 35,000 acres. The Ainsworth Unit's main features consist of Merritt Dam and Reservoir and the Ainsworth Canal. Merritt Dam is located on the Snake River (a Niobrara River tributary). Water stored in Merritt Reservoir is conveyed in the Ainsworth Canal approximately 40 miles east to project lands near the town of Ainsworth at an elevation around 2,500 feet.

Existing Water Supply Challenges and Activities

Water management issues in the Basin are complex and represent a long history of involvement by customers and stakeholders in Wyoming, Nebraska, and South Dakota. Surface water supplies serve many uses including irrigation, municipalities, recreation, hydroelectric power generation, and fish and wildlife. Existing water supply challenges are most evident in the Upper Niobrara River Basin. When the Basin Study began in 2010, the entire Niobrara Basin held a fully appropriated designation. A fully appropriated designation requires an integrated water management plan within a basin under Nebraska State Law. The goals of the integrated management process are to ensure a balance between water supplies and uses, and to protect the rights of existing users of surface water and groundwater. In June 2011, a Nebraska Supreme Court decision reversed the fully appropriated designation for the Lower Niobrara River Basin, leaving only the Upper Niobrara River Basin declared fully appropriated.

The Upper Niobrara River is also subject to an interstate compact between Wyoming and Nebraska (States). Established in 1962, the major purposes of the Upper Niobrara River Compact (Compact) are to provide for an equitable division or apportionment of the available surface water supply of the Upper Niobrara River Basin between the States; to provide for obtaining information on groundwater and underground water flow necessary for apportioning the underground flow by supplement to this compact; to remove all causes, present and future which might lead to controversies; and to promote interstate comity. Within the Compact the States also recognize that the use of groundwater for irrigation in the Basin may be a factor in the depletion of the surface flows of the Niobrara River.

Surface water and groundwater interactions were evaluated in 2004 by the Nebraska Department of Natural Resources and it was determined that irrigation wells in the Upper Niobrara-White River region have almost doubled from 1,161 groundwater wells in 1980 to 2,057 groundwater wells in 2004. A moratorium on construction of new wells with a capacity of more than 50 gallons per minute (gpm) was put in place in the Upper Niobrara-White River region in 2003. The Nebraska Department of Natural Resources study concluded that groundwater use upstream of the Mirage Flats diversion is depleting the groundwater supply and where wells are depleting aquifers in hydrological connection to a river, the wells will cause depletions to streamflow in the river.

The Federal Nexus

The Federal nexus arises primarily from Reclamation's investment in Federal infrastructure within the Basin and Reclamation's related water management authorities. Potential solutions for increasing operational efficiencies within the Basin may involve use of Reclamation's dams and project infrastructure. Specifically, Reclamation has relationships with the Mirage Flats and Ainsworth Irrigation Districts and expertise operating Box Butte Reservoir and Merritt Reservoir. Reclamation also possesses technical water modeling capabilities and can assist with evaluating water supplies. Federal involvement can help bring together customers and stakeholders to evaluate solutions from a Basin-wide context. With appreciation for past customer and stakeholder efforts to protect water resources in the Basin, it is also important to recognize that any Federal participation in the Basin Study endeavors to be unbiased and is non- binding for any partner, particular outcome, or solution.

Study Purpose and Objectives

The Basin Study is a collaborative effort by the Nebraska Department of Natural Resources and Reclamation to evaluate current and future water supply and demand and to collaborate with stakeholders in the region to identify potential alternative strategies to address identified gaps.

The overarching objectives of the Niobrara Basin Study are to (1) evaluate future water supplies and demands and the effects of climate change on these and (2) identify potential strategies to rebalance water supplies and demands.

The more specific objectives of the study were to:

1. Characterize and quantify the water resources of the Basin;
2. Determine current and future water demands of the Basin;
3. Identify opportunities for meeting water demands through structural and nonstructural means such as: surface and aquifer storage and retiming;
4. Evaluate future operations of Box Butte Reservoir and Merritt Reservoir through variable supply conditions; and
5. Analyze the potential effects of climate variability on water supply.

The Basin Study relies on an integrated surface-groundwater model, which was developed to assess the hydrological effects of proposed alternatives aimed at improving Basin resiliency. In addition, an economic analysis was developed to evaluate potential alternative management strategies. Furthermore, the study included an outreach component to better inform stakeholders about river basin characteristics, surface water and groundwater interactions, and potential water management strategies.

Findings and Conclusions in the Summary

This study is a technical assessment and does not provide recommendations or represent a statement of policy or position of Reclamation, the Department of the Interior, or the funding partners. The study does not propose or address the feasibility of any specific project, program or plan. Nothing in the study is intended, nor shall the study be construed, to interpret, diminish, or modify the rights of any participant under applicable law. Nothing in the study represents a commitment for provision of Federal funds.

Through extensive collaboration with the State of Nebraska, modeling tools were developed to provide a consistent representation of hydrology and water operations in the Basin, which helps identify relationships between future management decisions and physical responses in the watershed. It is clear that surface water demands are expected to outpace supply and the path toward implementing potential management actions in the Basin requires further analysis.

Climate Change Analysis

Climate change scenarios and models were used to evaluate potential impacts on water supply and demand. Climate may be generally described as average weather (for example, temperature and precipitation), typically considered over time periods of decades, as opposed to days or weeks. In the climate change analysis, climate data and land characteristics were input to a surface hydrology model (the Variable Infiltration Capacity [VIC] model; Liang et al., 1994; Liang et al., 1996; Nijssen et al., 1997) to evaluate historical trends and future projections in natural (unmanaged) conditions. The VIC model has limited capability to simulate groundwater dynamics. Simulations using the VIC model are thus intended to provide broad context relevant to large spatial scale changes between historical and future surface water hydrology. An additional set of integrated models, including surface and groundwater hydrology, crop demands, and river operations, were developed for the study and were used in conjunction with the VIC hydrology model to further explore the impacts of climate change on managed Niobrara River conditions and how alternative strategies may reduce those impacts.

Historical Trends

Historical trends were computed using the Maurer et al. (2002) meteorological dataset and VIC model simulations. Historical trend analysis over the period 1950-2010 indicates an increasing trend in mean annual temperature and precipitation during this period, along with increases in simulated evapotranspiration and runoff. Specifically, mean annual precipitation increased approximately 2.2 inches; annual daily average temperature increased approximately 0.6 degrees F; simulated annual evapotranspiration increased 1.7 inches; and simulated annual runoff increased by approximately 0.6 inches basinwide.

Baseline Scenario

A Baseline scenario was developed using historical data to provide a benchmark for evaluating projected climate change effects on natural and managed water in the Basin. Historical climate over the period 1960-2010 was used to define Baseline scenario climate and natural hydrology. The Upper Niobrara River Basin has experienced groundwater drawdown due to groundwater pumping over the past 50 years. Groundwater declines are reflected in observations made by irrigators as well as maps produced by the University of Nebraska-Lincoln Conservation and Survey Division that document water level changes in Nebraska. Where groundwater wells are hydrologically connected to the river, surface water depletions have led to changes in managed river conditions. Because managed river conditions have changed over the historical record, management conditions in place in 2010 (including irrigated acreage) were held static and used to help define the Baseline scenario. The management conditions are also held constant for future climate change conditions as described below.

VIC model simulations for the Baseline scenario show that mean annual surface water availability is 1.5 inches, where surface water availability is defined as the mean annual difference between precipitation and evapotranspiration. Mean annual precipitation and temperature under this scenario is 19.6 inches and 47.3 degrees F, respectively, while mean annual evapotranspiration is 18.1 inches.

Climate Change Scenarios

Downscaled Global Climate Change projections used in the Basin Study are based on the CMIP3 (World Climate Research Programme's Coupled Model Intercomparison Project Phase 3; Meehl et al., 2007). CMIP3 projections reflect a range of uncertainty relative to future greenhouse gas emissions based on assumptions of future global population and economic growth as well as potential emissions reductions. The future period of 2030-2059 was selected to compare future possibilities to the Baseline scenario. Three climate change scenarios were developed for the Basin Study from a set of 112 Bias Corrected Spatially Downscaled (BCSD) climate change projections contained within a CMIP3 archive (Reclamation 2011). The three scenarios are described by their respective water availability characteristics, which reflect the statistical nature of the projection's summer precipitation and temperatures, and are hereafter designated as the Low scenario, Central Tendency (median), and High scenario.

- **Low scenario –** Low projected water availability combined with drier summers and greater summer warming.

- **Central Tendency** - Central projected water availability combined with central tendency of summer precipitation and temperature.

- **High scenario –** High projected water availability combined with wetter summers and less summer warming.

The Low, Central Tendency, and High scenarios span a range of projected water availability from a modest decrease in mean annual water availability to a substantial increase in mean annual water availability. The fact that the Central Tendency projection indicates an overall increase in water availability (10 percent above Baseline) suggests that a majority of the 112 projections indicate an increase in water availability as opposed to a decrease. However, each of the 112 projections used to derive the climate change scenarios is considered equally likely. All three climate change scenarios reflect a rise in temperature above the historic mean summer temperature.

Surface Water Supply

The VIC surface hydrology model was used as the basis for the assessment of surface water supply. The assessment of surface water supply provides a broad view of historical and projected climate (temperature and precipitation), as well as water balance variables including evapotransipiration and natural (i.e. unimpaired) streamflow. Analysis of water supply and demand gaps in the basin rely on an integrated suite of models that represent surface and groundwater hydrology, agricultural demand, and river management. The VIC model simulations helped inform this analysis.

An integrated suite of models, including the VIC model representing surface hydrology, used with models of groundwater hydrology, agricultural demands, and river management, were used as the basis for assessments of historical and projected water supply and demand in the Basin. As previously described, future temperatures are projected to increase under all three climate change scenarios. Precipitation is projected to decrease under the Low scenario and increase under the Central Tendency and High scenarios. Moderately drier conditions in the Low scenario resulted in minor changes in natural runoff while the Central Tendency and High scenarios indicate an increase in water availability. As described earlier, management conditions are assumed static at 2010 levels consistent with the baseline scenario development. Climate change scenarios coupled with 2010 management conditions result is an imbalance between water supplies and demands for all scenarios. Results from the integrated model simulations are provided below.

Temperature

Historical mean annual temperature from 1960-2010 is 47.3 degrees F, for the Basin. Comparing the historical temperature to projected temperatures for the 2050s time horizon, the mean annual temperature is projected to rise under all three scenarios — about 5.0, 3.0, and 2.5 degrees F, for the Low, Central Tendency, and High scenarios, respectively.

Precipitation

Historically, the Niobrara River Basin has a substantial moisture gradient from west to east; with the western semiarid portion receiving 16 inches mean annual precipitation and the eastern and more humid portion receiving 22 inches mean annual precipitation. Projected changes in mean annual precipitation for the 2050s time horizon will experience a Low scenario precipitation decrease of 3 percent in the eastern part of the Basin and an increase of 2 percent in the western part of the Basin. The Central Tendency scenario indicates that the Basin will experience a precipitation increase of approximately 7 to 8 percent. The High scenario indicates a precipitation increase ranging from 10 to 16 percent, with a greater increase in the eastern part of the Basin.

Evapotranspiration

Evapotranspiration by crops and natural vegetation are predominantly influenced by precipitation and temperature. As the Basin experiences greater warming in the future, evapotranspiration is expected to increase, but will be limited by available moisture. According to VIC model simulations, evapotranspiration comprises 95 percent of mean annual precipitation, leaving only about 5 percent to surface runoff. Historical mean annual evapotranspiration ranges from about 15 inches in the western part of the Basin to 20 inches in the eastern part of the Basin from 1960-2010. Projected changes in evapotranspiration for the 2050s time horizon range from a 1 percent decrease in the Low scenario to an 11 percent increase in the High scenario, both of which occur in the eastern part of the Basin. The Central Tendency scenario indicates about a 7.5 percent increase in evapotranspiration Basinwide, primarily as a result of projected increases in mean annual precipitation for the Central Tendency scenario. Projected decreases in evapotranspiration for the Low scenario are due to projected drier conditions, despite projected increases in temperature.

Streamflow

The VIC hydrology model is utilized to evaluate potential changes in future runoff and streamflows, relative to the Baseline scenario. Analysis of historical mean annual runoff for the period 1960-2010 indicates the eastern part of the Basin experiences a mean annual runoff of almost 2 inches compared to about 1 inch in the western portion of the Basin. Projected changes in mean annual runoff for the future time period range from about a 9 percent decrease for the Low scenario in the eastern portion of Basin to a 29 percent increase for the High scenario in the western portion of the Basin. The Central Tendency scenario indicates an increase in runoff ranging from approximately 11 percent in the eastern portion of the Basin to 15 percent in the western portion.

It should be noted that historical and projected unimpaired streamflow (natural) are not meant to reflect actual flow measured in the Niobrara River and its tributaries. Actual flow may deviate substantially from unimpaired values due to the effects of water deliveries, storage, and other management effects. However, it is presumed that the relative differences between Future scenario and Baseline scenario periods reflect reasonable and comparable differences. Beyond water management actions that are not accounted for within natural runoff projections there are model uncertainties that are also known and assumed to be consistent and thus make results comparable. For example, model bias results in a known shift between modeled seasonal timing and actual seasonal timing. This bias is assumed to exist within the Baseline and Future scenarios making the comparisons valid. Slightly drier projected conditions in the Low scenario produced a shift in seasonal peak flow by approximately one month resulting in unimpaired streamflow that is expected to be within 10 to 30 percent of historic averages (either higher or lower). Projected mean monthly unimpaired streamflow for the Central Tendency scenario indicates a substantial increase in seasonal peak flow for all areas analyzed within the Basin Study, on the order of 50 percent within the Upper Basin and on the order of 30 percent for the Lower Basin. In addition, High scenario streamflow volumes increased for most months of the year with projections increasing from approximately 5 percent to 50 percent or more.

Water Demand

Historical Water Demand

Surface water and groundwater resources in the Basin are used primarily for agriculture. The total irrigated area within the Basin is approximately 600,000 acres. Groundwater irrigation accounts for approximately 500,000 acres within the Basin. When surface water is available, the two Reclamation irrigation districts (Mirage Flats Project and Ainsworth Unit) irrigate more than 46,000 acres. In addition, approximately 500 other surface water appropriations are also active in the Basin. Additional water resource uses within the Basin include municipal and industrial use, hydropower, recreation, and ecosystem services. Recreation and hydropower are both non-consumptive uses that depend on maintaining a certain flow level in the river.

Future Water Demand

In the future, irrigation requirements for corn and alfalfa may increase significantly due to increased temperatures in the Basin. The growing season is projected to increase 30 to 40 days by 2100, which could allow for additional crop cycles each year and, hence, a larger water demand on Basin farms. While changes in agriculture development may have an effect on both historic and future imbalances, they were not evaluated in this Basin Study. As has been described above, agricultural and other demands were assumed static at 2010 levels. This approach allows for the evaluation of climate change impacts alone, without being confounded by land use activities such as groundwater development, which have increased since about 1970, or assumptions of future management conditions.

Gaps between Water Supply and Demand

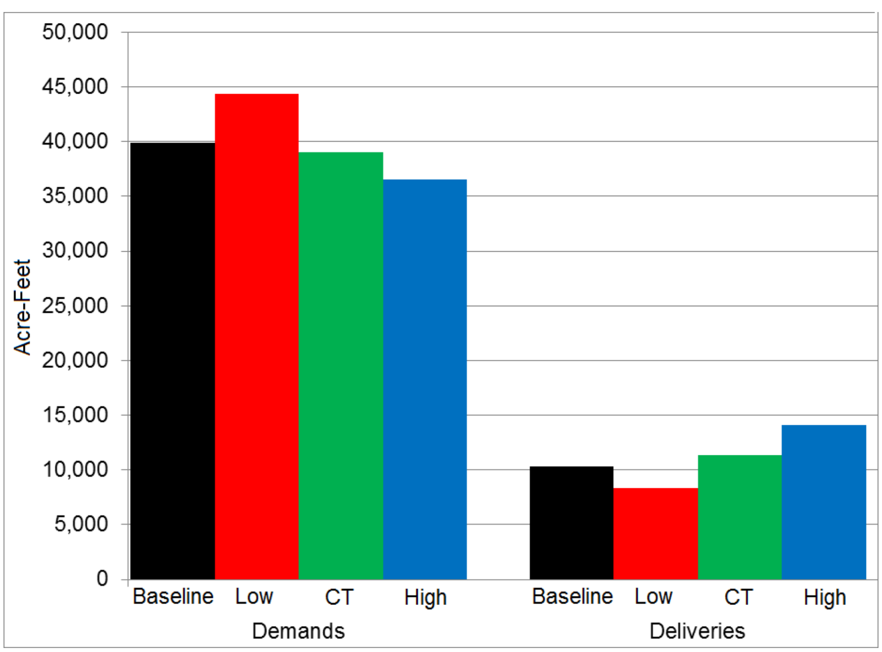
While surface water irrigated acreage in the Upper Niobrara River Basin has remained nearly level since the mid-1970’s, the number of groundwater irrigation wells and associated groundwater acres dramatically increased until 2003 when a moratorium was placed on construction of new wells with a capacity of more than 50 gpm. As analyzed in a Nebraska Department of Natural Resources study on hydrologically connected groundwater and surface water in the Upper Niobrara-White Natural Resources District (2004), when surface water flows and groundwater aquifers are hydrologically connected, a consumptive use of one depletes the supply of the other.

Water imbalances are demonstrated by surface water shortages in the Upper Niobrara River Basin. For example, during the first few years of operation in the 1950’s, the Mirage Flats Irrigation District delivered over 15,000 acre-feet of water to farms. Historical records also show that just prior to widespread groundwater irrigation development, Mirage Flats Irrigation District consistently delivered between 8,000 and 11,000 acre-feet of irrigation water to its service area. Periods of past robust surface water supply can be contrasted with the more recent period between 2006 and 2015, when surface water deliveries have declined to a level between 1,200 and 4,800 acre-feet. The Mirage Flats Irrigation District is not alone in experiencing water supply challenges. Shortages to the Spencer Hydropower facility have also occurred and resulted in halting deliveries to junior surface water appropriators on days when streamflow was insufficient. In addition, recreational users in the National Scenic River reach have observed decreased flows in recent years.

An integrated suite of models was developed and implemented to evaluated gaps in historical and projected water supply and demand. While the VIC model was used to provide a broad view of historical and projected water supply conditions, the water supply information used to estimate gaps included more detailed information about land use within the basin. Therefore, water supply computed for the gaps analysis differs somewhat from results summarized above as part of the water supply assessment.

Integrated model simulations also suggest average annual surface water demands are expected to outpace supply under all climate change scenarios. As shown in Figure ES-2 and studying climate change impacts alone, average annual surface water demands outpace surface water supply by almost 30,000 acre-feet under the Baseline scenario for the fourteen active irrigation areas in the Upper Niobrara Basin. As the system experiences increases in precipitation (Low to High scenarios) the irrigation demands decrease. Under the Low scenario, the gap is expected to be approximately 35,000 acre-feet. In addition, demands outpace surface water supply for the Central Tendency and High scenarios by roughly 27,000 acre-feet and 22,000 acre-feet, respectively (with agricultural demands assumed static at 2010 levels).

Figure ES-2. Average annual surface-water demands and deliveries in the Upper Niobrara Basin



Future Water Management Alternatives

As a result of the June 2011, Nebraska Supreme Court decision that reversed the fully appropriated designation for the Lower Niobrara River Basin, collaborators for this Basin Study focused on Upper Basin alternatives. The only large-scale irrigation operation in the Upper Basin is the Mirage Flats Irrigation District, which relies on releases from Box Butte Reservoir. Lower Basin alternatives were not considered.

An integrated water management model was developed to help assess climate change impacts and evaluate the hydrological effects of proposed alternatives aimed at improving Basin resiliency to water supply and demand imbalances. The integrated water management model consists of three different components: a watershed model for the land/soil water budget, a surface water operations model for Niobrara River operations, and a groundwater model for aquifer response.

The integrated water management model allows for current operational conditions to be simulated as a “No Action” alternative and for comparisons to potential alternative operations. Two proposed strategies deemed “Alternatives” are considered in an effort to explore ways to increase resiliency in the Basin.

- Alternative 1 proposes construction of the Mirage Flats Pumping Station and pipeline which would reduce canal seepage during surface water delivery leaving more surface water in the system.

- Alternative 2 proposes an operational change by using the Mirage Flats main canal and lateral system to recharge local groundwater.

Future No Action Scenario

The Future No Action scenario compares a Baseline and three climate change scenarios (Low, Central Tendency, and High) while maintaining current operational characteristics of Box Butte Reservoir and the Mirage Flats delivery system. Future land use conditions were represented by applying 2010 land use data. Assuming that current operations and land use conditions remain static in the Future No Action scenario isolates the impacts of climate change.

The Future No Action scenario compares results for key water budget elements including reservoir inflows/releases, irrigation diversions, co-mingled pumping, and aquifer recharge. As expected, results from the Future No Action scenario suggest Box Butte Reservoir inflows and releases are sensitive to changes in water availability. Therefore, the Low water availability scenario represents the lowest flow; the Central Tendency was in the middle; and the High water availability scenario results in the highest flows. Box Butte Reservoir inflows and releases for the Baseline scenario generally reside between the Low scenario and Central Tendency scenario. Mirage Flats Irrigation District diversions are consistent with Box Butte Reservoir releases.

Under the Future No Action scenario and even with increased levels of precipitation, the available surface water supply only meets a portion of the crop water demand. Groundwater pumping volumes on co-mingled acreage tend to be inversely proportional to surface water supplies (i.e. increasing surface water supply results in decreasing groundwater pumping). Overall, modeling results show that aquifer recharge levels are also sensitive to changes in water availability with the High scenario producing the greatest aquifer recharge levels and the Low scenario projecting increased aquifer drawdowns.

Alternative 1 – Mirage Flats Pumping Station

Under current operations, Mirage Flats Irrigation District diverts water for irrigation from the Niobrara River at a location downstream from Box Butte Reservoir. Diverted water flows in a main supply canal to a bifurcation for distribution to canal laterals. The canal is unlined and seepage losses are estimated to be at least 30 percent of diverted water. Engineering analysis concluded that canal lining is not viable due to the cost of implementation (IRZ Consulting 2013).

The objective of this proposed alternative is to reduce canal seepage during surface water delivery. Alternative 1 abandons the Mirage Flats diversion and main supply canal in favor of a new Mirage Flats Pumping Station and supply pipeline. The pumping station would extract water from a high aquifer; essentially making the effect similar to a surface water diversion. The irrigation water would then be would be pumped approximately 1.5 miles north to the bifurcation delivery area which is a more efficient portion of the canal where water can then be delivered to the fields. The ability of Alternative 1 to reduce the impacts of climate change is evaluated by comparing model results from the Baseline and three climate change scenarios (Low, Central Tendency, and High) for key water budget elements including reservoir inflows/releases, irrigation diversions, co-mingled pumping, and aquifer recharge.

As mentioned, transportation losses are a concern to the Mirage Flats Irrigation District. Low efficiency canals lose a significant portion of diverted water to seepage during transport. These losses translate to less water being applied to the crop. In Alternative 1, increasing delivery efficiencies for the Mirage Flats Irrigation District results in decreasing demands for Box Butte Reservoir releases because less water is lost to seepage in the main supply canal. Therefore, model results suggest that all climate scenarios for Alternative 1 have higher water surface elevations in Box Butte Reservoir than the Future No Action alternative.

In addition, the Mirage Flats Pumping Station included in Alternative 1 is expected to increase surface water deliveries resulting from increased transportation efficiencies. Increased surface water deliveries help offset supplemental co-mingled groundwater pumping requirements to meet crop water demands. Under all climate scenarios the average volume of co-mingled pumping for Alternative 1 decreased when compared to the Future No Action alternative.

As expected, a change in groundwater recharge for Alternative 1 is concentrated around the Mirage Flats Irrigation District. The lack of seepage along the canal greatly reduced the recharge in this general area, while the irrigated land realized a small increase resulting from increased deliveries.

Alternative 2 – Mirage Flats Recharge

Alternative 2 consists of the Mirage Flats canal system that would be operated solely as a recharge facility where no irrigation deliveries are made. Water will be released from Box Butte Reservoir, diverted in the Mirage Flats canal and the lateral system will be used to allow groundwater recharge within the project area. Canal check structures would be operated to hold the canal water at the designed elevation - as if making deliveries. Given no surface water irrigation deliveries are being made under this alternative, it is expected that groundwater pumping will increase.

Alternative 2 compares the Baseline and three climate scenarios (Low, Central Tendency, and High) for key water budget elements in the system including reservoir inflows/releases, irrigation diversions, co-mingled pumping, and aquifer recharge. Results from the model show Box Butte Reservoir levels that are substantially higher than the Future No Action alternative. This is the result of much lower releases for irrigation demands. Alternative 2 is able to meet full groundwater recharge demands for the Mirage Flats Irrigation District under all climate scenarios except for the Low climate scenario. In the Low climate scenario, there is not always enough water to divert the full recharge demand. Understanding surface water deliveries in Alternative 2 ceased, irrigators will need to pump additional groundwater. As expected, the average volume of co-mingled pumping for Alternative 2 increased from the Future No Action alternative for all climate scenarios. Furthermore, significant change in recharge for Alternative 2 is concentrated around the Mirage Flats Irrigation District and canal. All climate scenarios result in a significant increase in recharge within the Mirage Flats Irrigation District compared to the Future No Action alternative.

Economic Analysis

The economic analysis estimates tradeoffs in economic benefits for potential alternatives compared to a scenario with No Action. In addition, the economic analysis evaluates effects of the various climate change scenarios. The scope of this analysis focuses on agriculture and recreation benefits, as these categories are expected to include the majority of river and reservoir related economic benefits associated with the Basin Study's alternatives.

Agricultural benefits were based solely on the irrigated land within the Mirage Flats Irrigation District because it is the only area directly affected by either alternative. The analysis evaluates agricultural benefits which accrue to the agricultural district under hydrologic conditions specified by each alternative/scenario. Irrigation benefits are measured as a change in net farm

income received from the use of irrigation water to produce agricultural commodities (Reclamation, 2004a).

A collection of Federal, state, and private land ownership along the river affords relatively good access for recreation opportunities in the Basin. A separate study prepared by the University of Nebraska - Omaha analyzed the economic and social values of recreation on the Niobrara River and suggests visitations increase when surface flows are higher (2009). In contrast, periods of drought or low flows can jeopardize the quality of the recreational experience resulting in fewer people on the river and negative effects for the local economies.

Recreation benefits are based on reservoir recreation models developed for Box Butte and Merritt Reservoirs and a river recreation model developed for the most heavily used stretch of the designated Niobrara National Scenic River. To estimate recreation economic benefits under each alternative/scenario for the river and reservoir settings, the analysis estimated annual visitation and the value per visit.

Net benefits under the Future No Action alternative with climate change (i.e., Low, Central Tendency, and High) exceed the Baseline No Action alternative without climate change. It is assumed that recreation will increase when temperatures and reservoir levels are higher. Net benefits are dominated by the recreational benefits which increase under each Future No Action climate change scenario due to increased temperatures under all three scenarios and increased water elevation under the Central Tendency and High scenarios. Agricultural benefits are minimal compared to recreational benefits and range from 8% to 12% of the combined benefit for the alternatives/scenarios. Under each climate change scenario, the net benefits of Alternative 2 exceed those of Alternative 1. With the exception of the Alternative 1 Low scenario, proposed action alternatives/scenarios result in positive net benefits ranging from $1.0 to $14.2 million when compared to the Future No Action alternative/scenarios.

The only cost included in this analysis is a $4.46 million estimate for construction of the Mirage Flats Pumping Station proposed in Alternative 1. Annual operation, maintenance, replacement, and power (OMR&P) costs are beyond the scope of this analysis, but would be an important component of further analysis for both Alternative 1 and Alternative 2. For example, while Alternative 2 may present groundwater recharge benefits at no additional construction cost, this Alternative would require additional study to account for the full range of OMR&P costs related to increased pumping. In addition, a change in Mirage Flats canal system operations may require review of potential water right implications for the Mirage Flats Irrigation District and would be clarified upon further evaluation.

In summary, benefits of both Alternative 1 and Alterative 2 generally exceed a No Action scenario and suggest both strategies have potential to be considered in future studies. Alternatives 1 and 2 have not been undertaken because there are a number of implementation hurdles that would require additional study. First, there is uncertainty associated with projected climate scenarios as positive economic benefits rely heavily on an assumption that recreation will increase when temperatures and reservoir levels are higher. Second, a change in Mirage Flats canal system operations may present water rights implications for the Mirage Flats Irrigation District requiring further review. Third and finally, OMR&P costs were not factored in the economic analysis for Alternative 1 and Alternative 2 and these costs will likely decrease the potential for either alternative to be economically viable.

Study Limitations

The watershed model used in the integrated suite of models to simulate soil water balance has limited representation of some physical processes such as snowpack dynamics. The Basin Study's watershed model attempts to account for these items through an iterative calibration process with the groundwater model; however, further calibration may be necessary. The watershed model is also intended to assist in large scale planning projects. Using this Basin Study to employ crop management techniques for a specific location may not be effective because the study is intended to represent the system as a whole.

An in-depth analysis of endangered species responses to climate change was determined to be an undertaking outside the scope of this Basin Study. According to the U.S. Fish and Wildlife Service, fourteen species within the Niobrara River Basin are currently protected under the Endangered Species Act (ESA). This Basin Study does not explore vulnerabilities of endangered species as affected by climate change. However, this Basin Study may be a useful resource for researchers focusing on ESA and State designated species.

Finally, the tradeoff analysis focuses only on agricultural and recreational benefits. Agricultural benefits are based solely on irrigated land falling within the boundaries of Mirage Flats Irrigation District and results are not extrapolated to total Basin irrigated acreage. From a cost perspective, changing operations under proposed action alternatives could result in different annual OMR&P costs. However, OMR&P costs were not evaluated in the Basin Study's economic analysis. Thus, cost differentials are preliminary and based purely on construction costs.

Conclusion

The overarching objectives of the Basin Study were to identify the effects of climate change on future water supplies and identify potential management options in the Basin. The Basin Study relies on a series of models to assess hydrological effects of potential alternatives aimed at improving Basin resiliency. The Basin Study confirms that the Niobrara River faces a range of potential future imbalances between water supply and demand. Addressing such imbalances may require additional analysis and may not be resolved through any single approach or alternative.

Through collaboration with key stakeholders, the Basin Study elevates regional water planning efforts to new levels and offers sound science that can be used as a foundation for long-term planning efforts focusing on sustaining the balance between water uses and water supplies. Specifically, integrated models developed in this Basin Study are a useful resource that can assist Basin stakeholders as they continue coordinated efforts to improve system reliability and develop strategies that address the Basin's challenges. For example, information from this Basin Study may be used to help inform future planning efforts related to the Niobrara Basin- Wide Management Plan, Integrated Management Plan modifications, and future changes to river operations.

Projected water availability was evaluated using both historical data and climate change scenarios (Low, Central Tendency, and High), and could range from a modest decrease to a substantial increase. Future temperatures are projected to increase under all three climate change scenarios. In addition, precipitation is projected to increase for the central tendency and high water availability scenarios. Slightly dryer projected conditions in the Low scenario produced modest changes in unimpaired streamflow while the Central Tendency and High scenarios indicate a substantial increase in seasonal peak flow. Average annual surface water demands are expected to outpace supply under all climate change scenarios.

Potential management actions were evaluated in an effort to address the gap between water supply and demand. Alternative 1 would include a structural change with construction of the Mirage Flats Pumping Station which would reduce canal seepage during surface water delivery leaving more surface water in the system. Alternative 2 proposes an operational change by using the Mirage Flats main canal and lateral system to recharge local groundwater. Both alternatives result in Box Butte Reservoir levels that are higher than the Future No Action alternative due to increased canal delivery efficiencies in one scenario and lower irrigation diversions in the other scenario. Furthermore, both options show potential for future consideration as additional analysis in the Basin is conducted.

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Acronyms and Abbreviations

afd	acre-feet per day
AID	Ainsworth Irrigation District
BCA	benefit-cost analysis
BLNA	Baseline No Action Alternative
CENEB	Central Nebraska subregion
cfs	cubic feet per second
CT	Central tendency
DNR	Nebraska Department of Natural Resources
ESA	Endangered Species Act
ET	evapotranspiration
FA1	Future Action Alternative 1
FA2	Future Action Alternative 2
FNA	Future No Action Alternative
MFID	Mirage Flats Irrigation District
NPPD	Nebraska Public Power District
NRD	Natural Resources District
Reclamation	U.S. Bureau of Reclamation
RGL	reach gains or losses
RSWB	Regionalized Soil Water Balance Model
UNW	Upper Niobrara-White subregion
VIC	Variable Infiltration Capacity Model
WaterSMART	Water – Sustain and Manage America's Resources for Tomorrow
WWCRA	West-Wide Climate Risk Assessments

I. Introduction

A. Purpose, Scope, and Objectives of the Study

The Niobrara River Basin Study (Basin Study) is a collaborative effort by the Nebraska Department of Natural Resources (DNR) and the U.S. Bureau of Reclamation (Reclamation). Its purpose is to evaluate current and projected future water supply and demand and to collaborate with stakeholders in the region to identify potential alternative strategies to address identified gaps. This Basin Study has been conducted as part of the Department of the Interior's WaterSMART Program.[1] Projections of future water supply and demand are based on Reclamation's West-Wide Climate Risk Assessments (WWCRA) (Reclamation, 2011, 2015) but contain additional information, if available.

The Basin Study has produced an integrated surface-groundwater model to assess the effects of management options on hydrology, an economic analysis to evaluate the economic effects of those management options, and forums for public education and outreach. The study has also advanced the knowledge of Basin hydrology, aquifer characteristics, and surface-groundwater interactions. The hydrologic and economic analyses will help both State and local water management entities assess the costs and benefits of various proposed management options. The education and outreach component of the project has provided opportunities to educate those within the Basin about the Niobrara River, the underlying aquifer, water management strategies, and the implications of current and potential management options.

The overarching objectives of the Niobrara Basin Study are to (1) evaluate future water supplies and demands and the effects of climate change on these and (2) identify potential strategies to rebalance water supplies and demands.

The more specific objectives of the study were to:

1. Characterize and quantify the water resources of the Basin;

[1] The WaterSMART (Sustain and Manage America's Resources for Tomorrow) Program was established by the Secretary of Interior under Secretarial Order 3297 to address an increasing set of water supply challenges, including chronic water supply shortages due to increased population growth, climate variability and change, and heightened competition for finite water supplies. The Program is authorized under the SECURE Water Act of 2009 (Public Law 111-11). Through WaterSMART, Reclamation is making use of the best available science in the assessments it conducts and the policies it employs, with the goal of securing future water supplies.

2. Determine current and future water demands of the Basin;
3. Identify opportunities for meeting water demands through structural and nonstructural means such as: surface and aquifer storage and retiming;
4. Evaluate future operations of Box Butte Reservoir and Merritt Reservoir through variable supply conditions; and
5. Analyze the potential effects of climate variability on water supply.

The Basin Study has integrated results from groundwater, surface-water, and watershed models to evaluate future water supply scenarios resulting from: (1) climate change/variability; and (2) depletions from groundwater development. These results have been used in conjunction with an economic analysis to assess the relative benefits and economic viability of the two proposed management alternatives for the operation of irrigation canals in the Mirage Flats area.

B. Location and Description of the Study Area

The Niobrara River Basin extends across diverse landscapes from its origin on the High Plains of eastern Wyoming to its terminus at the Missouri River near Niobrara, Nebraska. The river is approximately 535 river miles in length and drains an area of 12,600 square miles of northern Nebraska and adjacent parts of Wyoming and South Dakota (Figure 1). Temperature and precipitation vary greatly along the Niobrara from one end to the other, from winter to summer, and sometimes from day to day.

Current uses within the Basin include approximately 600,000 irrigated acres, municipal use (approximately 20,000 people), hydropower, recreation, and wildlife. In 1991, a 76-mile stretch of the river was designated as the Niobrara National Scenic River, just downstream from the Fort Niobrara National Wildlife Refuge. Within Nebraska, the Basin has two Bureau of Reclamation projects for irrigation: the Mirage Flats Project (11,662 acres) and the Ainsworth Unit (35,000 acres). The Basin has one hydropower facility, Spencer Hydropower.

Near its origin in southeastern Wyoming, the river cuts through the water-bearing Arikaree Formation. As it bends through Sioux, Dawes, and Sheridan Counties, Nebraska, it gradually begins to run over the more prolific Ogallala Formation. Replenished by seepage from various formations, the Niobrara is a predominantly aquifer-supplied river. Data developed by Szilagyi et al. (2002) found that, in the river's upper reaches, 70–90 percent of its flow can be attributed to seepage from groundwater. Since the late 1800s, the Niobrara has been a significant source of water for water-rights holders along its banks. In 1948, the Box Butte Reservoir and canal distribution system, completed by the Bureau of Reclamation, began to provide irrigation for the Mirage Flats Irrigation District.

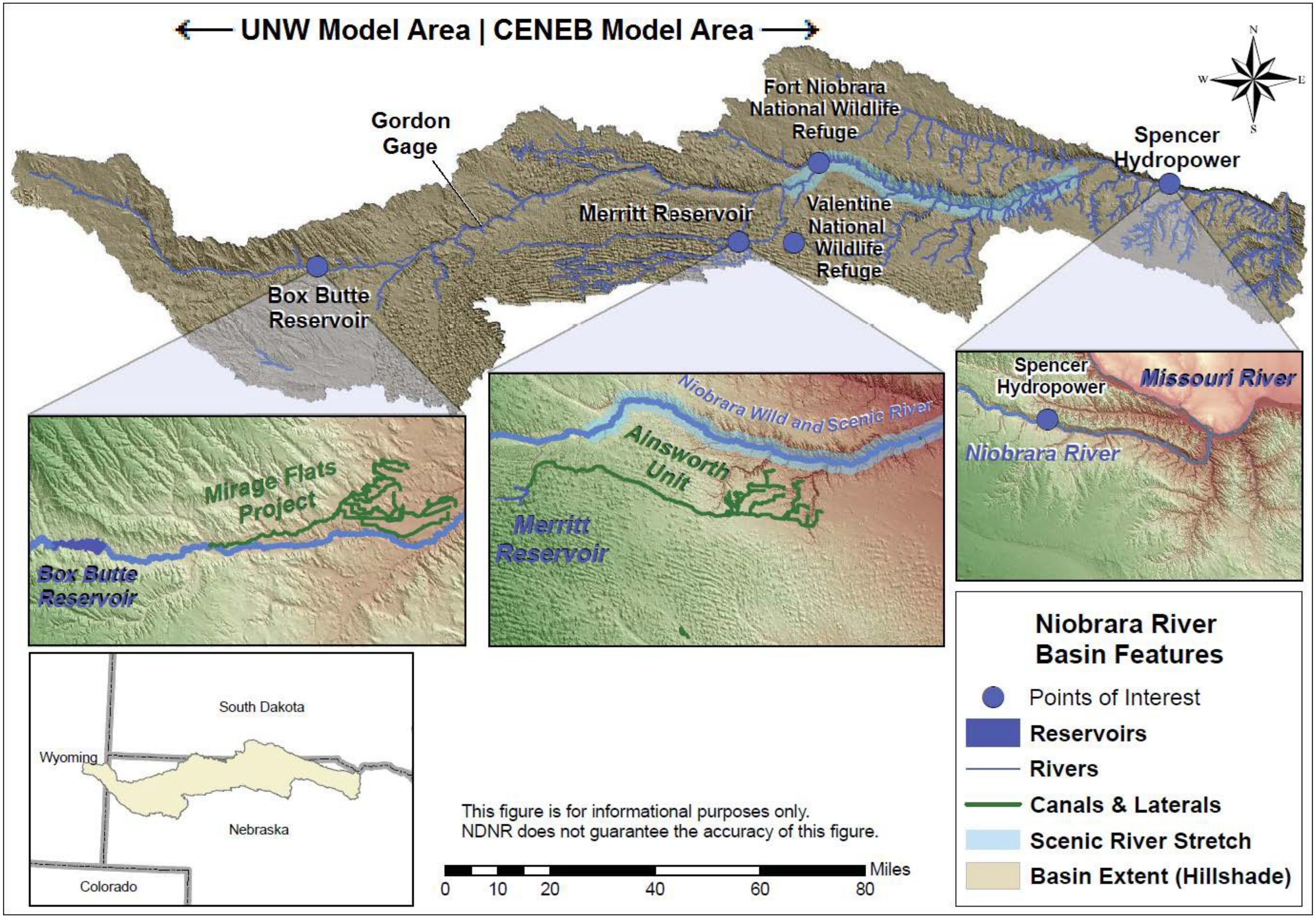

Figure 1. Location of Niobrara River Basin.

C. Collaboration and Outreach

The Upper Niobrara Basin Study was established under the U.S. Bureau of Reclamation's WaterSMART Program as a partnership between Reclamation, the Nebraska Department of Natural Resources, and the Upper Niobrara-White Natural Resources District. From the outset, it attracted interest and support from numerous stakeholders in and near the Niobrara Basin. Stakeholder agencies and organizations that have been involved include:

Federal:

- Bureau of Reclamation
- National Park Service
- Fish and Wildlife Service (Ft. Niobrara, Valentine National Wildlife Refuge Complex)

State:

- Nebraska Department of Natural Resources
- Nebraska Game and Parks Commission
- Wyoming State Engineer's Office

Local and Other:

- Ainsworth Irrigation District
- Lower Niobrara Natural Resources District (NRD)
- Middle Niobrara NRD
- Mirage Flats Irrigation District
- Nebraska Public Power District
- Niobrara Council
- Upper Elkhorn NRD
- Upper Loup NRD
- Upper Niobrara-White NRD

Representatives from most of these organizations attended the Niobrara Study "Kickoff Meeting" on July 19, 2011, and a "Mid-Point" informational meeting on August 8, 2012. Both of these meetings were held at the Niobrara Lodge in Valentine, Nebraska.

Public information about the project has been provided on-line by Reclamation (http://www.usbr.gov/WaterSMART/bsp/studies.html) and by DNR (http://www.dnr.ne.gov/iwm/niobrara-river-basin-study-update). In addition, Brandi Flyr of DNR provided a public presentation about the project on January 23, 2013, as part of the University of Nebraska's Nebraska Water Center "Spring Seminar" series (http://watercenter.unl.edu/SpringSeminars/SpringSeminarSeries.asp).

D. Interrelated Activities

The Niobrara River Compact is a compact between the States of Wyoming and Nebraska regarding the waters of the Upper Niobrara River. The major purposes of this compact are:

- To provide for an equitable division or apportionment of the available surface water supply of the Upper Niobrara River Basin between the States;
- To provide for obtaining information on groundwater and underground water flow necessary for apportioning the underground flow by supplement to this compact;
- To remove all causes, present and future which might lead to controversies; and
- To promote interstate comity.

The responsibilities for flood control, soil erosion, irrigation run-off, and groundwater quantity and quality issues within Nebraska are designated to 23 Natural Resources Districts (NRDs) which together cover the entire State. NRDs are local government entities with broad responsibilities for protecting natural resources. Generally, major Nebraska River Basins form the boundaries between NRDs. Three NRDs cover the area of the Niobrara River Basin — the Upper Niobrara-White NRD, Middle Niobrara NRD, and Lower Niobrara NRD. These three districts were important collaborators in conducting this Basin Study and developing the alternatives considered.

An effort was made, in the development of alternatives, to balance competing uses, so that the existing domestic, agricultural, environmental, recreational, commercial, and industrial activities are preserved to maintain the economic viability, social and environmental health, safety, and welfare of the Niobrara Basin for both the near term and long term while maintaining Nebraska’s compliance with the Niobrara River Compact.

This Niobrara Basin Study also provides valuable information to be utilized in the ongoing efforts to develop a Basinwide integrated water planning document.

II. Climate Change Analysis

A. Background

The climatic setting of the Niobrara River Basin is similar to that of State of Nebraska overall. Nebraska is well known for its climate extremes and for having a substantial moisture gradient from west to east, with the western portion being semiarid (16 inches average annual precipitation) and the eastern portion being more humid (22 inches average annual precipitation). As one example of its differences in seasonal climate, about 40 percent of mean annual precipitation falls from May through July, while only 5 to 7 percent falls from December through February. In addition, the State experienced widespread droughts in the 1930s and 1950s, while the last 50 years have generally been wetter than prior to the 1950's.

Nebraska has experienced an overall warming trend of about 1 °F since 1895, with greater warming in winter and spring (2.0 °F in the December–February time period and 1.8 °F in March–May). The length of the frost-free season in Nebraska has increased by more than one week since 1895 (University of Nebraska-Lincoln, 2014). Although it is difficult to attribute historical precipitation variability to human-induced change (Hoerling et al., 2010), there is growing evidence of a linkage between the warming of the globe, arctic sea ice decline, and extreme winters across the Great Plains region (Reclamation, 2013).

WWCRA projections of future climate (Reclamation, 2011) indicate that the Great Plains region will continue to experience recurring wet and dry cycles spanning periods of years to decades, as it has throughout its history. Climate change, however, is expected to exacerbate hazards such as tornadoes, droughts, floods and to increase economic losses in the future (University of Nebraska-Lincoln, 2014). According to Nebraska's climate change impacts assessment (University of Nebraska-Lincoln, 2014), projected changes in temperature for the State range from 4 to 9 °F by the late 21st century (2071–99). Projected changes in temperature and precipitation are expected to coincide with a decreasing trend in spring snow water equivalent, a decreasing trend in April–July runoff volume, increasing trends in December–March and annual runoff volumes, and reduced soil moisture levels (Reclamation, 2013).

The future climatic and hydrologic regime in the Niobrara River Basin will impact, to varying degrees, certain environmental resources pertinent to the Basin Study, including water resources, agriculture, aquatic ecosystems, invasive species, and other related resources. In some years, irrigators may face restrictions on the amount of water that can be applied to their fields. By the year 2100, according to the Third National Climate Assessment (Shafer et al., 2014), the frost-free season will increase by 30 to 40 days for Nebraska. The assessment also suggests that crop growth cycles have already been altered as a result of warming winters and changes in rainfall timing and magnitude. As these trends continue, they will require new agriculture and livestock management practices (Shafer et al., 2014).

B. Data and Models Used to Evaluate Climate Change Effects on Water Supply

Climate may be generally described as average weather (for example, temperature and precipitation), typically considered over time periods of decades, rather than days or weeks. Projections of future climate and hydrologic conditions developed under WWCRA (Reclamation, 2011) were used as the basis for the climate scenarios considered in this Basin Study.

The Basin Study uses various models to evaluate the watershed's response to projected future climate conditions and to water management alternatives. Three future climate change scenarios, using a time horizon of 2030–59, were developed to encompass a range of projected climate and water availability conditions.

These scenarios, further described in Appendix A, generally represent: (1) a hotter and drier future climate that results in low projected water availability (hereafter called the Low scenario), (2) a future climate representing the central tendency of all available global climate model projections, which features a middle range of projected water availability (hereafter called the Central Tendency or CT scenario), and (3) a wetter and less warm future climate having high projected water availability (hereafter called the High scenario). Together, the climate change scenarios are intended to represent a range of projected future conditions. The selected Low scenario corresponds with a decrease in water availability, Basinwide, of approximately 77,000 acre feet. The selected CT scenario corresponds with an increase in water availability of approximately 53,000 acre feet. The selected High scenario corresponds with an increase in water availability of approximately 290,000 acre feet.

The Basin Study explores the impacts of the three selected climate change scenarios on current level of development and water demands (set to 2010 levels) in comparison with historical climate. These three scenarios, along with the historical condition, have been named for consistency throughout the Basin Study summary report and appendices. The combination of the observed historical climate with current levels of development and current water management practices is termed the Baseline No Action scenario. The scenarios that combine the three projected future climates with current levels of development and current water management are termed the Future No Action scenarios (Low, CT, and High).

The Basin Study also explores two potential management alternatives under the same future change scenario data and assumed future demands. Generally, the first alternative consists of changing the location at which water is diverted from the Niobrara River to the Mirage Flats Irrigation District, in order to reduce conveyance losses in the current canal system. The second alternative involves using existing canal systems to recharge the groundwater system and to discontinue all surface water delivery. These alternative scenarios are termed Future with Alternative 1 (Low, CT, and High) and Future with Alternative 2 (Low, CT, and High).

Together, the three Future No Action scenarios are used here to evaluate how climate change might impact current water management. The Future with Alternative scenarios are used to evaluate how the operational alternatives may reduce projected water supply/demand gaps identified by the Future No Action scenarios.

III. Water Supply and Demand

A. Historical Water Supply

Typical flows in the river are around 5 cubic feet per second (cfs) near the Wyoming-Nebraska State line, around 15 cfs at the gage at Agate, and between 20 and 40 cfs at the gage above Box Butte Reservoir. The records from the stream gages upstream of Box Butte Reservoir, however, show indications that the streamflow has been decreasing over time. An analysis by the DNR (2004) showed that the amount of surface water available for diversion from the Niobrara River upstream of the Mirage Flats canal diversion has continued to decrease since the project was completed. At the State line, the 5-year annual average flow decreased by 567 acre-feet from the 1956–60 time period to the 1996–2000 time period. Between 1946 and 2001, the average annual flow above Box Butte Reservoir decreased by 4,332 acre-feet (Figure 2). Records also show that diversions to the Mirage Flats canal averaged 19 percent less per year during the 28 years from 1976 through 2003 than during the previous 28-year time period (1948–75).

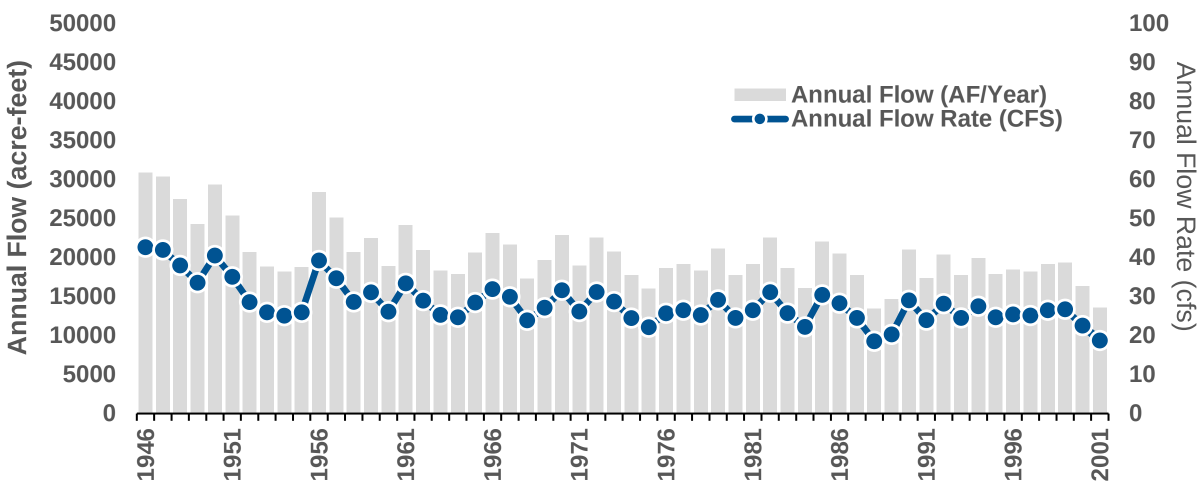

Figure 2. Annual flow and Annual Flow Rate of the Niobrara River above Box Butte.

The Variable Infiltration Capacity Model (VIC, described in detail in Appendix A) was applied to the historical period 1950–2010 to quantify historical trends in surface water availability. The VIC model is an advantageous tool for this type of evaluation since this model has been applied over the continental United States and beyond, and is the basis for the WWCRA assessments (Reclamation, 2011). Mean annual temperature and precipitation have increased over the period 1950–2010, as have evapotranspiration and runoff. Historical trends computed as part of the Basin Study are generally consistent with historical trends reported by the University of Nebraska-Lincoln (2014) study and with trends found by Reclamation's 2013 Literature Synthesis. Table 1 summarizes computed historical trends in mean annual precipitation, temperature and runoff.

Table 1. Historical Climatic Trends Computed from VIC Model Simulations for the Period 1950–2010

Parameter	Basinwide Change	Percent Change
Annual Precipitation	+ 2.2 in	+ 12%
Daily Average Temperature	+ 0.56 °F	--
Annual Runoff	+ 0.55 in	+ 45%

B. Future Water Supply

1. Surface Water

Climate changes are likely to result in an increased frequency of drought and heat waves. Combined with increased human demand for water, these conditions will result in lower streamflows and an increase in the frequency of de-watered stream segments and dried-up wetlands (University of Nebraska-Lincoln, 2014).

Historical and projected changes in climate and water balance variables are summarized for each of the three climate change scenarios developed for the Basin Study: Low, CT, and High. Together, the climate change scenarios are intended to represent a range of projected future conditions.

Projected changes Basinwide show that mean annual precipitation would decrease by about 2 percent under the Low scenario but increase under both the CT and High scenarios (about 8 and 14 percent, respectively). Mean annual temperature would rise under all three scenarios — about 5.0, 3.0, and 2.5 °F, respectively, for the Low, CT, and High scenarios. Mean annual runoff would decline about 8 percent under the Low scenario but increase as much as 13 and 27 percent in the CT and High scenarios, respectively. Refer to Appendix A, Table 7 for additional details.

Assessment of future water supply includes the analysis of changes in unimpaired streamflow, as computed by the VIC model, and of changes in the managed water supply at various locations in the Basin, including the two reservoirs, Merritt and Box Butte. Historically, unimpaired streamflow in the Basin has a seasonal peak in May and June, corresponding with the seasonality of precipitation. Projected mean monthly unimpaired streamflow for the CT scenario indicates a substantial increase in seasonal peak flow for all Basin Study model nodes, on the order of 50 percent in the Upper Basin and on the order of 30 percent for the Niobrara River near Spencer, Nebraska. For the low-flow season (generally defined as August through November), reductions in mean monthly unimpaired flow on the order of 10 to 20 percent are projected for the CT scenario.

Results for the Lower Basin show streamflows would be the lowest under the Low climate scenario and significantly higher under the High climate scenario. Compared to historical baseline flows, the Burge, Sparks, and Spencer gages would show average decreases of 46, 17, and 8 percent, respectively, under the Low scenario. Flows at these three points would increase under the other two climatic scenarios: 32, 11, and 15 percent for the Central Tendency scenario; and 87, 36, and 34 percent for the High scenario.

Simulations of current (2010 level) water management indicate only modest impacts to Merritt Reservoir operations under the CT and High future scenarios. Under the Low scenario, however, the reservoir levels at the end of the summer months would be on average 2 feet lower than projected for the Baseline, CT, or High modeled scenarios.

2. Groundwater

Overall, the groundwater modeling results show that baseflow and groundwater levels are sensitive to future projected climatic change. Across almost the entire Niobrara River Basin, climate scenarios of High and Low water availability can increase or reduce the baseflow and groundwater levels, respectively. Figure 3 shows a time series of baseflow between the Gordon and Sparks gages as it might have been if each of the modeled climate scenarios had been in effect during the period of 1960–2010. The actual historical baseflows during that period are shown for comparison. As shown there, the High and CT water availability scenarios both lead to higher baseflow, and the Low scenario corresponds to lower baseflow. In addition, modeling results show that baseflow on this part of the river would have increased throughout this period under the CT and High water availability scenarios but would have decreased under the Low water availability scenario.

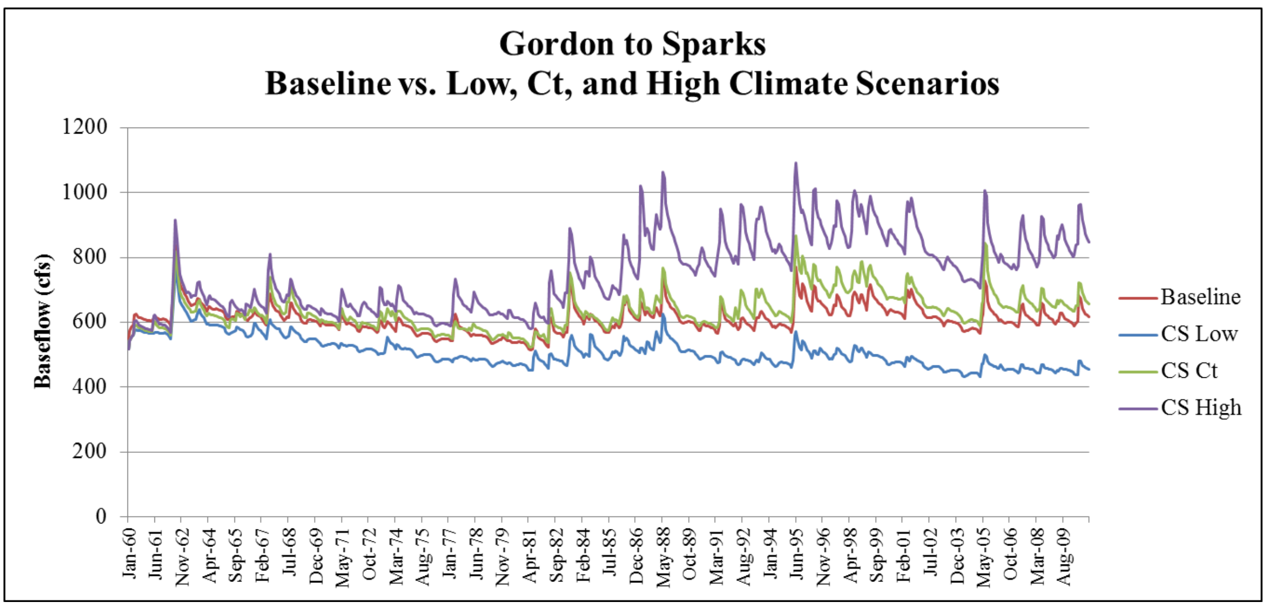

Figure 3. Gordon to Sparks reach baseflow comparison – climate scenarios of baseline, low, CT, and high without management operations (1960-2000).

The effects of the modeled climate scenarios on standing groundwater levels are well exemplified by the projections for Box County. Groundwater levels there, which have been declining for decades, are expected to decline further under Low water availability, but to rebound under CT or High water availability (Figure 4). The patterns of change in groundwater levels follow similar patterns in the Mirage Flats area.

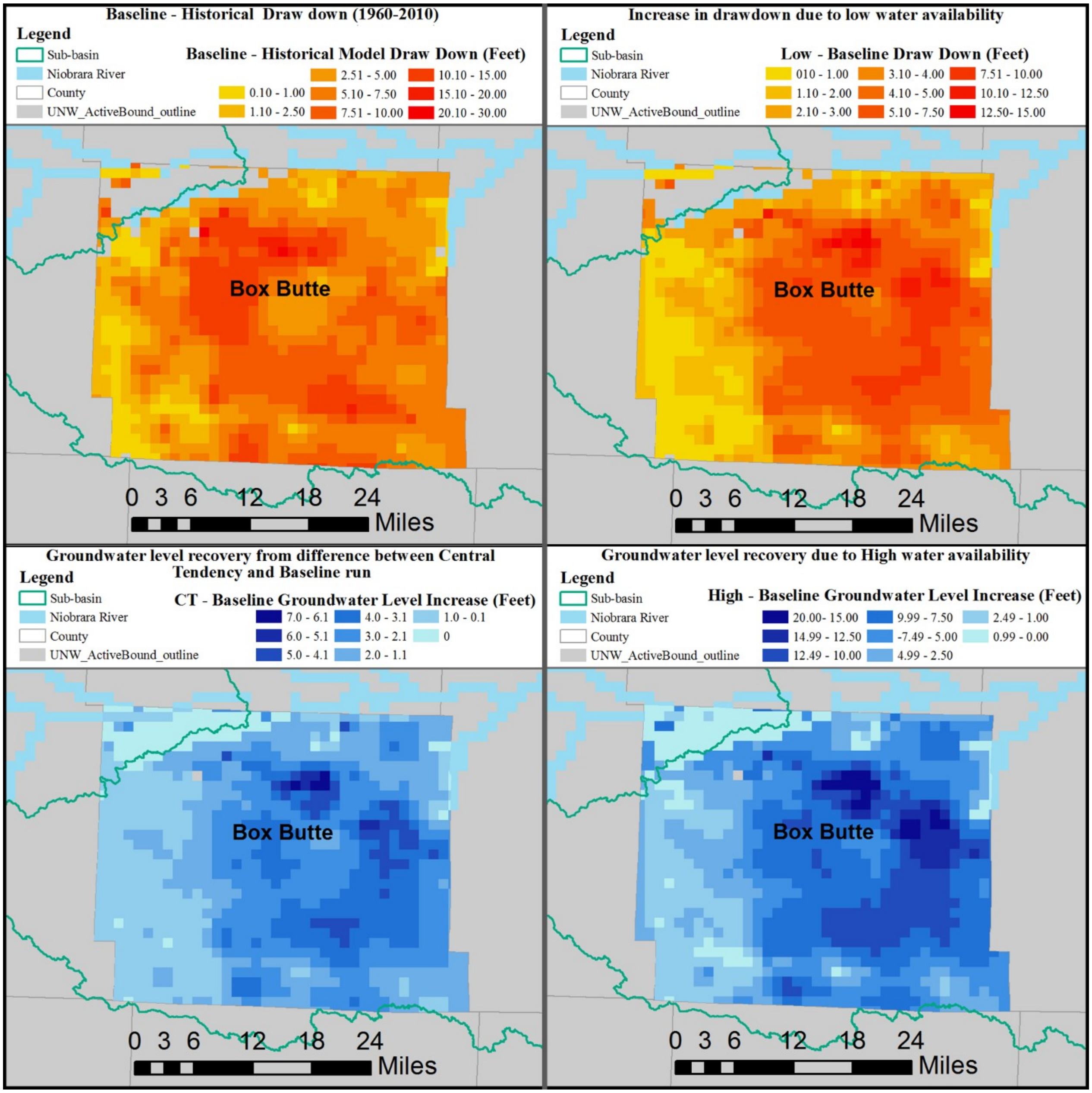

Figure 4. Groundwater drawdown comparison in Box Butte County for baseline, low, CT, and high scenario model runs with no change in management operations.

The patterns of change in groundwater levels in the CENEB area (Figure 5) follow patterns similar to those of the Box Butte and Mirage Flats area for different climate scenarios except in the low water availability scenario. In the lower portion of the Sparks to Spencer sub-basin, groundwater level did not change under this climate scenario. It is noted that the Baseline scenario consistently shows reduced baseflow (Figure 3) and groundwater levels (Figures 4 and 5). This is because all scenario analyses assume constant historic land use conditions maintained as of year 2000 for the purpose of isolating the impacts of land use change.

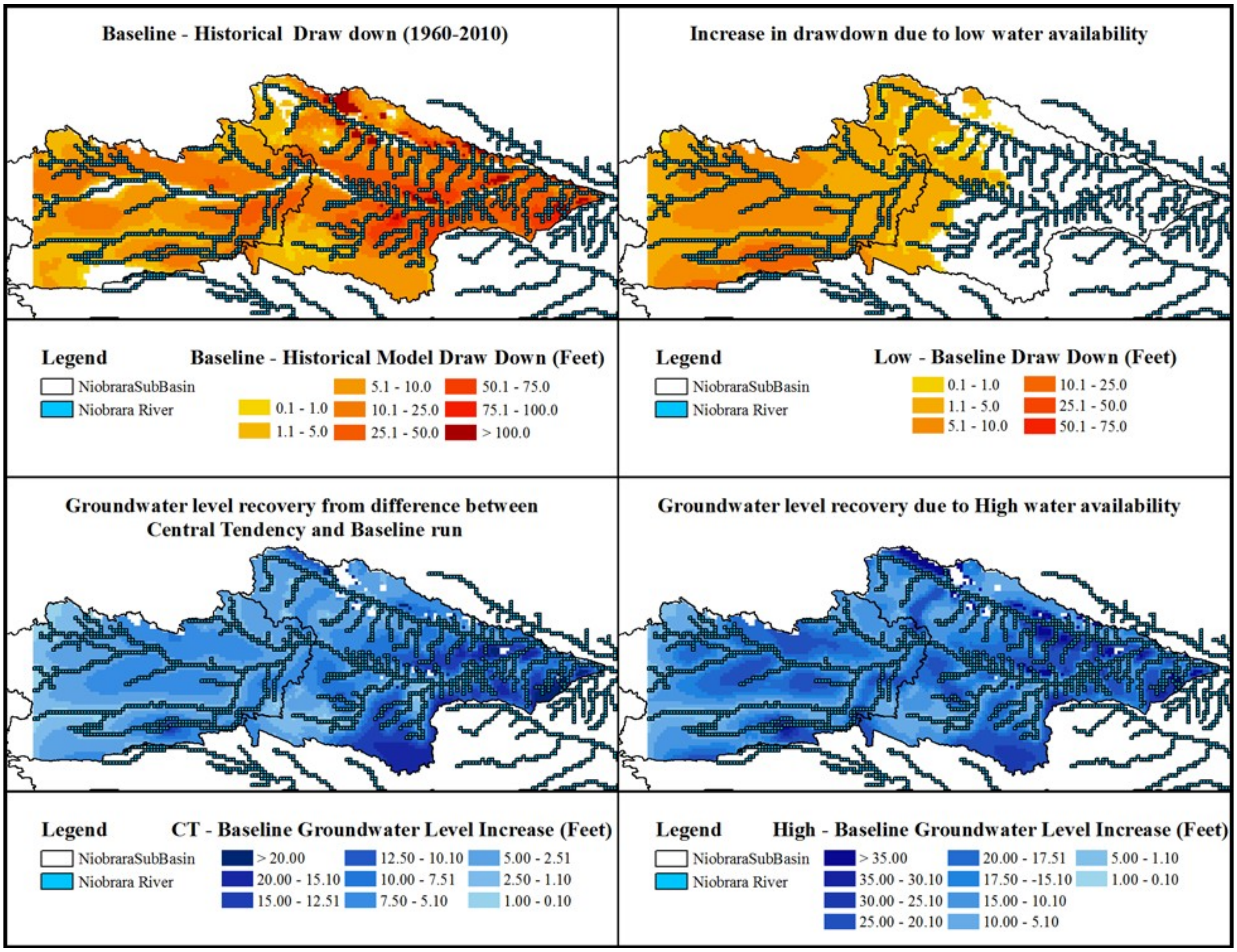

Figure 5. Groundwater level change comparison in CENEB model area under baseline, low, CT, and high scenario model runs with no change in management operations.

3. Watershed Model Simulation Results

Generally, the modeling results show changes in climate will influence the water balance within the watershed. Increases in precipitation decrease the need for irrigation and increase the evapotranspiration, recharge, and runoff contributions to streamflow. Table 2 describes the absolute change in the water balance of the two modeled areas under the various climate scenarios. In the UNW area, which has a relatively meagre supply of surface water, the increases in precipitation projected under the High and CT climate scenarios would yield more available surface water and, hence, would reduce the volume of groundwater that needs to be pumped.

The watershed model covers a large area and the results are available in several different resolutions. Appendix E provides an overview of the modeling results and investigates the changes due to climate and alternatives at various resolutions.

Table 2. Average Percent Change in Water Balance Parameters from the Baseline Climate in the Niobrara Basin

Climate Scenario	Precipi-tation	Groundwater Pumping	Surface Water Deliveries	Total Applied Water	ET	Recharge	Runoff Contributions to Streamflow
UNW Area (upstream of the Gordon Gage)							
Low	–16.12%	9.35%	–11.01%	–14.47%	–13.72%	–27.12%	–23.08%
CT	6.35%	–4.35%	17.46%	5.69%	4.96%	15.03%	10.95%
High	18.89%	–11.50%	42.75%	17.00%	13.66%	63.60%	46.23%
CENEB Area (from Gordon Gage to Spencer Gage)							
Low	–9.36%	–0.37%	–0.37%	–9.17%	–8.69%	–13.40%	–3.34%
CT	7.03%	–5.21%	–5.06%	6.77%	4.17%	24.22%	12.40%
High	13.49%	–6.41%	–6.27%	13.07%	7.31%	52.10%	26.07%

C. Historical Water Demand

In the Niobrara River Basin, surface water and groundwater resources are used to supply water for agricultural uses, primarily. However, additional uses of the Basin’s water resources include municipal use, hydropower, recreation, and ecosystem services.

Surface water and groundwater resources in the Niobrara Basin are used primarily for agriculture. The total irrigated area within the Basin is approximately 600,000 acres. Groundwater irrigation accounts for approximately 500,000 acres within the Basin. When surface water is available, the two Reclamation irrigation districts (Mirage Flats Project and Ainsworth Unit) irrigate more than 46,000 acres. In addition, approximately 500 other surface water appropriations are also active in the Basin.

Withdrawals for municipal and industrial use are relatively minor in the Niobrara Basin, totaling only about 3,500 acre-feet per year. Recreational activities (floating, canoeing, etc.), especially on the National Scenic River reach, are a key component of local economies. A recent survey of outfitters and other river users (Whittaker et al. 2008) found that most of them prefer maintaining a flow range of 600–900 cfs (at least through the summer recreation season) to achieve an optimal recreational experience. Hydropower, like recreation, is a nonconsumptive use that depends on maintaining a certain flow level in the river. Total water demand of the Spencer hydropower plant is 2,035 cfs or 4,037 acre-feet per day.

D. Future Water Demand

If temperatures increase during the growing season and precipitation decreases, as indicated by the Third National Climate Assessment (Shafer et al., 2014), rural water supplies will be more vulnerable to shortages because of competition from irrigation. Irrigators may face allocation restrictions that set limits on the amount of water that can be applied each year. The Third National Climate Assessment suggests that rising temperatures are leading to increased demand for water and energy. In parts of the region, this will constrain development, stress natural resources, and increase competition for water among communities, agriculture, energy production, and ecological needs (Shafer et al., 2014).

By the year 2100, the Third National Climate Assessment (Shafer et al., 2014) indicates that the frost-free season will increase by 30 to 40 days for Nebraska. Also, the Synthesis and Assessment Product 4.3 by the U.S. Climate Change Science Program (Lettenmaier et al., 2008) discusses the effects of climate change on agriculture and water resources (Hatfield et al., 2008). Findings suggest significant irrigation requirement increases for corn and alfalfa due to increased temperatures and carbon dioxide (CO_2) and reduced precipitation. Further, agricultural water demand could decrease due to crop failures caused by pests and disease exacerbated by climate change. On the other hand, agricultural water demand could increase if growing seasons lengthen and, assuming that farming practices could adapt to this opportunity, by planting more crop cycles per growing season. However, a shift toward earlier planting dates may not be viable because of the continued vulnerability to freeze damage in the spring (University of Nebraska-Lincoln, 2014). For example, the 2012, 2013, and 2014 growing seasons produced hard freeze conditions during the first half of May, even as favorable soil temperatures are occurring two weeks earlier when compared to the early 1980s. If precipitation amounts remain steady or decrease by the year 2100, evapotranspiration demand will result in less moisture available to grow crops during their critical reproductive periods that occur in May (wheat), July (corn), and August (sorghum, soybean). During 2012, native vegetation broke dormancy a month earlier than normal and soil moisture reserves were depleted across most of the U.S. Corn Belt well before the critical pollination period was reached.

There are no current plans to increase the water supply demands at the Spencer Hydro facility. However, if low flows become common in the future, junior surface water appropriators will likely to be administered more often to meet the flow requirements of the Spencer Hydro facility. The entire Basin upstream of the Spencer Hydropower Dam is now subject to stays on new surface water appropriations and on new high-capacity wells in areas hydrologically connected to the river.

No increase in municipal and industrial demand was modeled in this study because there are no indications that that this type of demand will change significantly in coming decades. Furthermore, it is currently such a minor component of total demand within the Basin (a fraction of a percent), that the overall water budget of the Basin would not be greatly affected even if municipal and industrial demand were to double. An additional source of demand could potentially come from the Nebraska Game and Parks Commission, which has undertaken studies to decide whether to pursue an instream flow right in the Basin.

E. Gaps between Water Supply and Demand

A primary objective of the Niobrara Basin Study is the quantification of gaps between surface water supply and demand. For the 14 active irrigation areas included in the UNW model, average annual surface-water demands outpace supply by almost 30,000 acre-feet under the Baseline climate (Figure 6). This gap is even larger under the projected Low climate scenario but progressively smaller under the CT and High scenarios. Even under the High scenario, though, there is still a deficit of more than 22,000 acre-feet. Supplemental groundwater pumping can make up some of that deficit, but not all

Other imbalances within the Basin are represented by the shortages that have been realized during recent drought conditions by Mirage Flats Irrigation District (MFID), the Spencer Hydropower facility (a nonconsumptive use), and junior surface water diverters. In addition, recreational users in the National Scenic River reach have noted decreased flows in recent years.

The MFID was completed in 1948 and initially delivered 16 inches per acre to its service area, but the water supply had diminished to 7 inches per acre by 2000. Recent drought conditions have resulted in deliveries of only 4 inches per acre. In contrast, the water supply of the Ainsworth Irrigation District (AID) has been very reliable and stable throughout the history of the project. AID draws its supplies from Merritt Reservoir, a Reclamation project along the Snake River, a tributary to the Niobrara. Snake River flows have been fairly constant under recent climatic conditions.

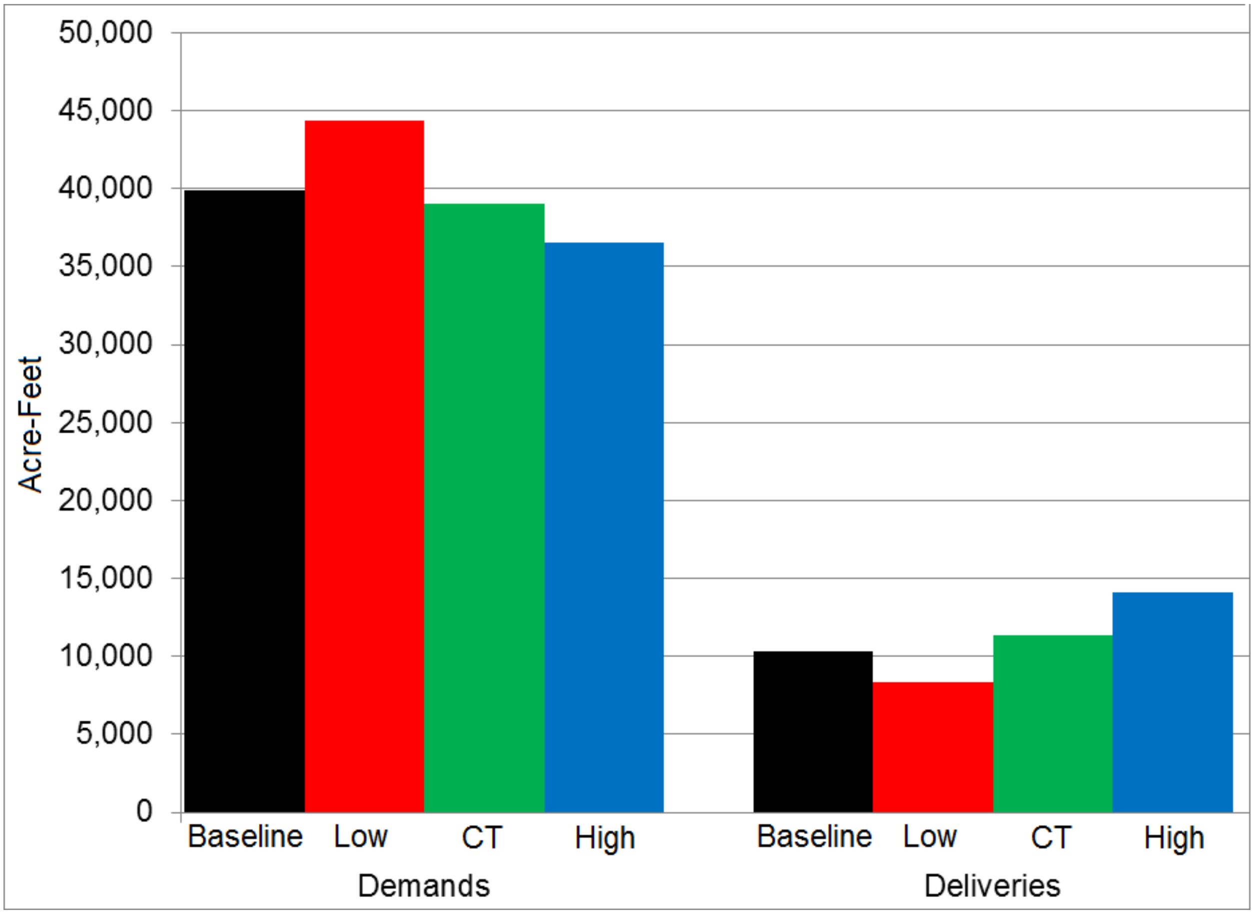

Figure 6. Average annual surface-water demands and deliveries in the UNW area under the Baseline and three projected future climates.

The Spencer Hydropower facility is owned by Nebraska Public Power District (NPPD) and holds a senior water right. When flows were not sufficient to meet the Spencer Hydropower facility water right, this resulted in halting deliveries to upstream junior surface water appropriators on days when streamflow was insufficient. Surface water diverters junior to Spencer Hydropower may elect to enter subordination agreements with NPPD, like the agreements made with MFID in 1943 and with AID in 1964.

Subordination agreements allow junior diverters to utilize their water rights, during periods shortage, in exchange for just compensation to NPPD. These agreements are necessary to provide junior diverters water to meet crop irrigation requirements, but gaps between demand and available supply remain.

IV. Development of Alternative Strategies

When the Niobrara River Basin study was undertaken in 2010, the entire Basin held a fully appropriated designation, which required the three responsible NRDs — Upper Niobrara-White, Middle Niobrara, and Lower Niobrara — to implement integrated management plans for their respective areas in the Niobrara River Basin. In June 2011, the Nebraska Supreme Court issued an opinion that impelled DNR to reverse the fully appropriated designation for the Lower Niobrara River Basin, leaving the Upper Basin still declared fully appropriated. This eliminated the mandatory requirement for the Middle Niobrara and Lower Niobrara NRDs to implement integrated management plans. As a result, the collaborators for this Basin Study did not see a need to develop operational alternatives in the Lower Basin and focused their attention on Upper Basin alternatives.

The only large-scale irrigation operation in the Upper Basin is the Mirage Flats Irrigation District (MFID). MFID diverts water from the Niobrara River at Dunlap diversion dam, approximately 14 miles downstream of Box Butte Dam (Figure 7). Diverted water flows in the Main canal and is delivered to a bifurcation for distribution to canal laterals. The canal is unlined and seepage losses are estimated to equal approximately 30 percent of the diverted water. Additionally, flow through the canal is restricted by voluminous sediment deposits. Furthermore, 12 bridges that cross the canal, primarily used for farmer access, are in poor condition. Seepage from the canal results in high groundwater levels at some locations; however, the groundwater also returns back into the canal system, providing flow at times when it would otherwise be empty. In order to address these problems, MFID commissioned a preliminary study, which was conducted in 2013. That study presented three management action plans (alternatives) for solutions to the problems with the Main canal.

The first alternative was to line the canal with geomembrane over a cushion of geotextile and to cover it with shotcrete for protection. Reclamation estimated that the cost of this alternative, for the lining alone, was approximately $5 million, and that cost does not include underdrain systems or easements for discharge to the river. This alternative also would only resolve the seepage losses and would not address concerns with sediment deposition in the canal and the farm bridges that are in poor condition and would benefit from reinforcement or reconstruction.

The second alternative was to relocate the diversion point of the Mirage Flats pumping station 12 miles downstream of the original location with a discharge pipeline running to the bifurcation. This alternative would substantially reduce the length of the canal to the bifurcation point and would reduce seepage and evaporative losses, sedimentation, siphoning issues, and the high groundwater table.

The third alternative was to use the canal primarily as a groundwater or aquifer recharge canal during high flows and to discontinue all surface water delivery. Irrigators would make up for the loss of surface water through additional pumping from the recharged aquifer. This alternative would address all of the concerns except for sedimentation.

Based on preliminary scoping, the canal lining alternative was not deemed viable due to the cost of implementation and its inability to address all of the aforementioned problems with the exception of seepage losses. Hence, this study evaluates only the pumping station relocation (here redesignated Alternative 1) and use of the existing canals for aquifer recharge (Alternative 2).

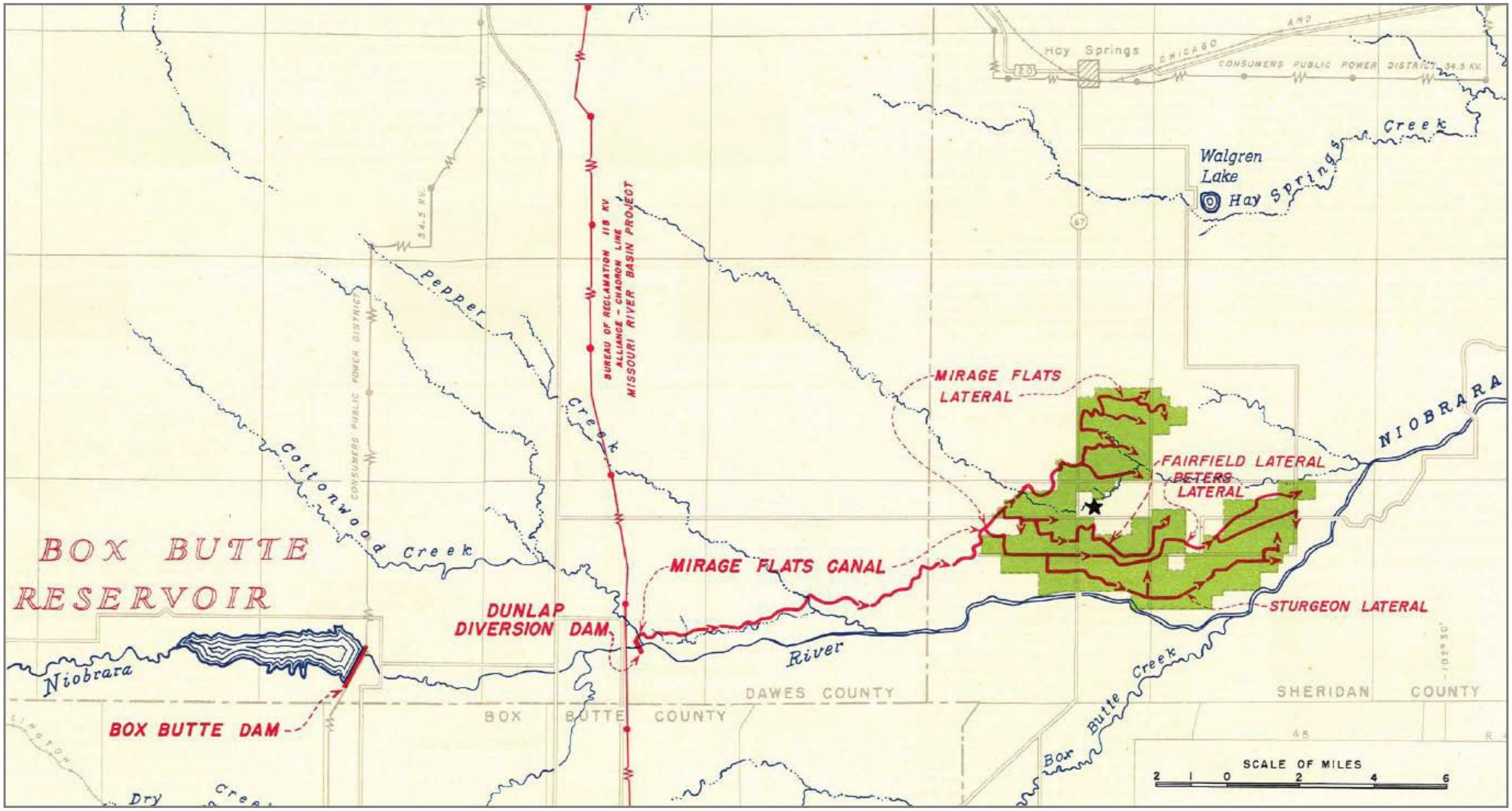

Figure 7. Map of the Mirage Flats Irrigation District (from the original Bureau of Reclamation project map, 1954).

V. Modeling of Alternatives

A. Overview of Models

Three different models were selected for this Basin Study. The watershed model, groundwater model, and surface water operations model for each model region (UNW and CENEB) were linked to form integrated models which are designed to present a dynamic representation of the total water budget for the Niobrara River. The three modeling tools were selected to simulate the three primary parts of the hydrologic cycle (Figure 8): land, river and aquifer. The integrated model provides decision makers with reliable quantitative information about the hydrologic consequences of alternative water management strategies.

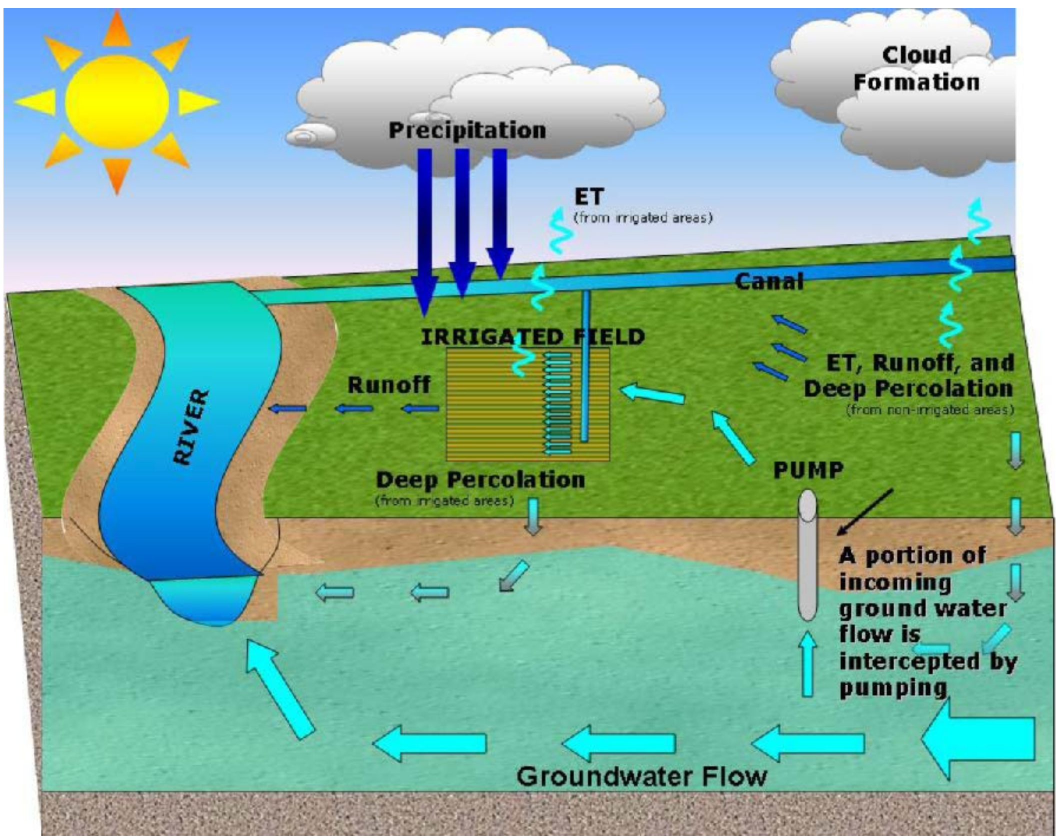

Figure 8. Illustration of hydrologic cycle in which irrigation is important.

- 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 that 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.

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 how this data exchange works in the two subregions is shown in Figure 9. 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.

Each individual model is operated independently from the other models and then the integration occurs through a series of data processing and transfer of results between models. This approach is considered to be a “passive” linkage. The primary purpose of integration is to use outputs from the watershed and groundwater models as inputs into the surface water operations model. Inputs into the water operations model form a dynamic representation of the total water budget of the Niobrara River. 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 Appendix F.

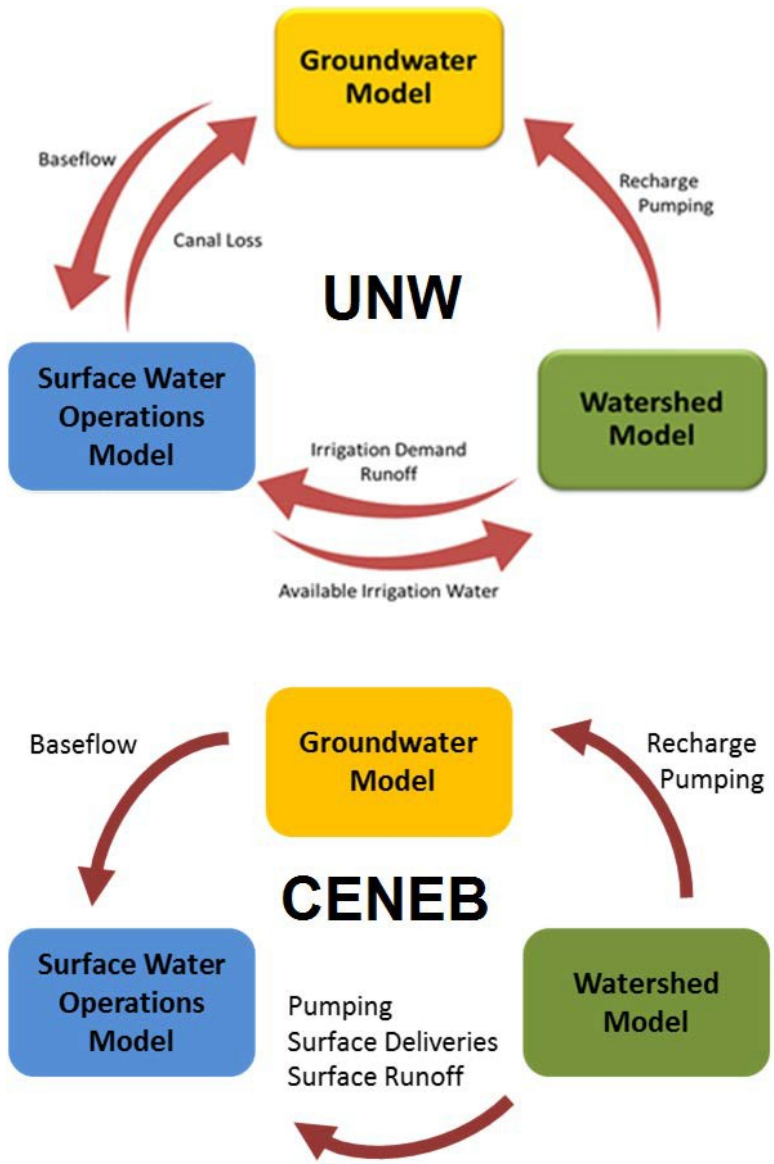

Figure 9. Linkage of individual models within the integrated models for the UNW and CENEB sub-regions.

B. Surface Water Operations

Surface water operations were modeled separately for the UNW and CENEB sub-regions. For the UNW sub-region there was already an existing surface water operation model. Therefore the UNW existing surface water operation model was used and for the CENEB sub-region a different model was created. Each of these models was developed to simulate the storage, release, diversion, and use of water along the Niobrara River and the canals that draw from the river.

1. Upper Niobrara White Region Surface Water Operations

The UNW surface water operations model was developed to simulate the present-day surface water components of the Niobrara River system from the Wyoming-Nebraska State Line to the Gordon gaging station (reservoirs, river, and canals) and to calculate the water budget terms of these components for the surface water operations system. Further details of how this model was set up, calibrated, and operated are available in Appendix C.

2. Central Nebraska Region Surface Water Operations

A surface water operations model, including the operations of Merritt Reservoir, was developed by Reclamation's Nebraska-Kansas Area Office for the CENEB region to simulate managed flows in the Niobrara River and to evaluate the effects of projected surface and groundwater hydrology on streamflows at three specific locations within the CENEB. Inputs to the CENEB surface water operations model primarily consist of baseflow (output from the groundwater model), deliveries from surface and groundwater sources (output from watershed model), and surface runoff (output from the watershed model). Additional inputs to the model include total streamflow at the Niobrara River gage at Gordon, the model's upstream boundary location, and simulated inflows and evaporation at Merritt Reservoir. Further details of how this model was set up, calibrated, and operated are available in Appendix D.

C. The Groundwater Model

There were two existing groundwater models covering different coverage area of the Niobrara Basin. UNW model covered only the Upper Niobrara White area whereas the CENEB model covered the middle and Lower Niobrara Basin Area. For time and efficiency purposes the determination was made to utilize these two groundwater models for this study instead of creating a different model covering all of the Niobrara Basin.

Groundwater flows were modeled separately for the Upper Basin (UNW region) and the Lower Basin (CENEB region). Both models extended beyond the geographical limits of the Niobrara surface-water Basin, to account for subsurface flow into and out of the Basin. Both models were constructed using variants of the U.S. Geological Survey's MODFLOW (MODular three-dimensional finite-difference groundwater FLOW model) program. MODFLOW-2000 (Harbaugh et al. 2000) was selected for the UNW model, and MODFLOW-2005 (Harbaugh, 2005) was applied to the CENEB area.

Both models divide up their respective areas into 1-mile by 1-mile grid cells, which is sufficient to understand the general hydraulics of the region and is supported by the amount of observational data recorded over several decades. Although the available data is sparse for some portions of the UNW region, such as parts of the Sand Hills and areas just east of the State line, many of the key areas for analysis (Box Butte County and the MFID) have sufficient data to support this spatial resolution.

The groundwater models each simulate a time period of several decades, extending from the approximate onset of groundwater irrigation in their areas up until recent years. The time spans modeled were 1960–2010 in the UNW and 1940–2011 in the CENEB area.

Each model begins with a postulated steady-state condition to represent ongoing “stresses” to the groundwater system (inflows, outflows, water-table levels, etc.) prior to the start of the model period. Then each models the subsequent time span as a series of “stress periods.” Either known or estimated values are provided for inflows, outflows, river stages, groundwater pumping, etc., at the start of each stress period. In the CENEB model, annual stress periods were simulated from 1940 through 1985, and then monthly intervals were used for the period from 1986 through 2011. The UNW model used monthly intervals throughout its modeled period of 1960–2010.

The time frame of model simulation described here is for the original model versions calibrated to the historic observed data. Future time periods were modeled using climate change data where 1) Baseline model was run from 1960 to 2010 with historic weather data (Baseline model) and constant 2010 land use data throughout, and 2) future climate projection (future time period) was run – CT, low, and high with 2010 land use data throughout. Then results from future climate change runs were compared with the results of Baseline runs.

Further details of how the groundwater models were set up, calibrated, and operated are available in Appendix B.

D. The Watershed Model

The primary role of the watershed model is to ensure that the water supplies and water uses have been accounted for within a balanced water budget. The water budget is represented by precipitation (P), applied irrigation water (I), evapotranspiration (ET), deep percolation, runoff, and change in soil water content.

Historically, watershed models have only interacted with the corresponding groundwater models. This Basin Study has introduced the interaction of the watershed model with the surface-water operations models. Surface-water irrigation groups were developed to pass surface water demands, supplies, and canal recharge between the watershed model and the surface water operations model (Appendix F). This allows projecting more accurate streamflow estimates.

1. UNW and CENEB Subregions

The watershed models used in this study include all the lands that drain to the Niobrara River, from its headwaters in eastern Wyoming to the stream gage near Spencer, NE: roughly 12,300 mi. in a primarily agricultural setting. The UNW model covers an area that includes the western portion of the Niobrara River, as well as some surrounding lands. It is situated largely in the northern half of the Nebraska panhandle, ranging from the eastern Wyoming headwaters area to the Sheridan-Cherry County border. This area consists of 8,700 mi., of which 4,800 mi. drains to the Niobrara River. The eastern portion of the Niobrara Basin Study falls within the domain of the CENEB model. The CENEB model covers nearly 34,500 mi. in north-central Nebraska, ranging from the panhandle in the west to the confluences of the Loup and Platte Rivers, the Elkhorn and North Fork of the Elkhorn Rivers, and the Niobrara and Missouri Rivers in the east. The model extends to the Platte River in the south and covers the extent of the Niobrara drainage area in the North. Of this area, approximately 7,500 mi. drains to the Niobrara River upstream of the gage at Spencer, NE.

2. Model Alternatives for the Niobrara Basin Study

For use in this study, the watershed model incorporated the climate data developed by Reclamation (Appendix A.). Four climate scenarios were created to represent both historical and possible future conditions under varying levels of water availability. Furthermore, two proposed management alternatives were investigated under each climate scenario:

1. The Mirage Flats Pumping Station Alternative proposed bypassing a relatively inefficient portion of the MFID’s canal by moving the district’s diversion point 9 miles downstream and installing a high-aquifer well field.
2. The Mirage Flats Canal Recharge Alternative would cease surface water irrigation deliveries and convert the district to groundwater. The district would continue to divert water during the growing season, allowing the water to seep from its canals as recharge to mitigate the effect of the increased pumping.

Either of these alternatives, if implemented, would be a long-term project. Therefore, information on the viability of either management plan under all of the projected climate change scenarios is critically important. To address this concern, the watershed models were updated to project future conditions. All aspects of the models which trended through time to represent historical conditions were updated to current (2010) values using the model representing that specific water component. These parameters include land use, irrigation development, municipal and industrial pumping, and application efficiencies, as well as crop characteristics and management practices. The current values were applied to the entire time span represented by the model. The integrated water management modeling procedure ensures that changes performed in separate models, including the surface-water operations models, are incorporated as input or output into the entire system represented in the groundwater, surface-water operations, and watershed models.

VI. Economic Analysis

A. Purpose, Scope, and Objectives

Please note, the economic analysis is preliminary in nature and its limitations do not allow it to be relied on for implementation a construction project. An economic analysis was performed as part of this Basin Study to provide a comparison of the net economic benefits of the proposed alternatives under a series of climate change scenarios. The alternatives propose operational and structural modifications designed to recharge aquifers and conserve surface water in the Niobrara River Basin. The Basin Study's leadership team decided to limit the scope of this economic analysis to agriculture and recreation, as these categories are expected to include the majority of river- and reservoir-related economic benefits associated with the study's alternatives. Therefore, the primary objective of the economic analysis was to estimate the net economic benefits for each proposed alternative as compared to the No Action Alternative based on benefits accruing only to agriculture and recreation. A secondary objective was to evaluate the economic effects associated with the various climate change scenarios. The results of the economic analysis are presented in section VII.C.

B. Alternatives Analyzed

This analysis evaluates the costs and benefits of two proposed operational alternatives under three projected climatic scenarios, as explained in Appendix G. In addition, four versions of the No Action Alternative are developed for comparison purposes: one based on historical climate/hydrologic conditions (without climate change) and the others based on the three future climate change scenarios. The Baseline No Action Alternative (BLNA) models historical climate with no climate change and no operational modifications. The Future No Action (FNA) Alternatives model the following:

- Future climate change scenario 1 (hot/dry) with no operational modification (FNA Low);
- Future climate change scenario 2 (central tendency) with no operational modification (FNA CT); and
- Future climate change scenario 3 (warm/wet) with no operational modification (FNA High).

Table 3 displays the three alternatives associated with each climate change scenario plus the BLNA for a total of 10 alternative/scenario combinations used for comparison purposes within this economics analysis

Table 3. Alternatives and Climate Change Scenarios Analyzed

Period	Alternative/Operational Modification	Climate Change Scenario	Designation
Baseline	No Action (current operations)	Historical (no climate change)	Baseline No Action
Future	No Action (current operations)	Low water availability	Low No Action
Future	(1) Mirage Flats pumping station	Low water availability	Alt 1 Low
Future	(2) Mirage Flats canal recharge	Low water availability	Alt 2 Low
Future	No Action (current operations)	Central Tendency	CT No Action
Future	(1) Mirage Flats pumping station	Central Tendency	Alt 1 CT
Future	(2) Mirage Flats canal recharge	Central Tendency	Alt 2 CT
Future	No Action (current operations)	High water availability	High No Action
Future	(1) Mirage Flats pumping station	High water availability	Alt 1 High
Future	(2) Mirage Flats canal recharge	High water availability	Alt 2 High

C. Economic Methodology

Agricultural and recreation benefits have been estimated independently under the conditions specified for each of the 10 alternatives/scenarios defined in Table 3. The sum of agricultural and recreation benefits under a given alternative/scenario yielded the *combined benefits*. The costs associated with each alternative/scenario were then subtracted from *combined benefits* to yield *net benefits* under each alternative/scenario. The results are presented in Appendix G and summarized below, in section VI-C.

The BCA was conducted as six net benefits comparisons—calculating the difference between each Action alternative/scenario and its No Action variant. Three additional net benefits comparisons are made solely for the purpose of evaluating the economic effects of the three future climate change scenarios. In this case, the BLNA *without* climate change is compared to the FNA *with* climate change under each of the three climatic scenarios. These comparisons are technically not part of the BCA because no costs can be assigned to the climate scenarios: they will happen — or not — without any expenditure of funds to bring them about.

1. Agricultural Benefits Analysis

Agricultural benefits are based solely on the irrigated land falling within the boundaries of the MFID, because that is the only area directly affected by either of the alternatives. The results have not been extrapolated to total Basin irrigated acreage. This assumption was directed by the Basin Study leadership team to facilitate the agricultural economic analysis. Further assumptions and modeling details concerning the agricultural benefits portion of this analysis are described in Appendix G, section 2.1.

For the purpose of this analysis, *agricultural benefits* under a defined alternative/ scenario are estimated as *irrigation benefits* accrued to the agricultural district under the hydrologic conditions specified by that alternative/scenario. *Irrigation benefits* are measured as the change in net farm income received from the use of irrigation water to produce agricultural commodities (Reclamation, 2004a).

2. Recreation Benefits Analysis

Recreation benefits are based on reservoir recreation models developed for Box Butte and Merritt Reservoirs and a river recreation model developed for the most heavily used stretch of the designated Niobrara National Scenic River. To estimate recreation economic benefits under each alternative/scenario for the river and two reservoir settings, analytical results were developed in terms of annual visitation and value per visit.

As discussed in Appendix G, section 2.2, average annual visitation estimates were developed based on hydrology and climate change projections specific to each alternative/scenario, but the value per visit is not alternative/scenario specific. Multiplying the average annual visitation estimates for each alternative/scenario times the values per visit for both the river and reservoirs results in estimates of average annual recreation economic value. Discounting and summing the range of annual values estimated across each year of the 50-year period of analysis results in a present value by alternative/scenario for use in the BCA.

3. Analysis of Costs

The only costs included in this analysis are those associated with construction activities. Annual operation, maintenance, replacement, and power costs likely vary by alternative, but are beyond the scope of this analysis. The only scenarios that have a construction-related cost are those based on Alternative 1, the proposed Mirage Flats pumping station (FA1-Low, FA1-CT, and FA1-High). These scenarios include the estimated $4.46 million cost of constructing a new pumping plant.

VII. Evaluation of Alternatives

A. Ability to Deliver Water

1. Groundwater Model Results

The modeling results show that management operations will affect the baseflow and groundwater levels at least in the Upper Niobrara Basin. Under the Baseline climate conditions, the baseflow under the two alternative management scenarios is generally lower between Dunlap and Gordon gages but higher between Box Butte Reservoir and the Dunlap gage than it is under the No-Action management scenario (Figure 10). Operational changes in the Mirage Flats area were found to have negligible effects on the baseflow downstream of the Gordon gage, so no comparative figures are presented here for Lower Basin baseflows under the two management alternatives.

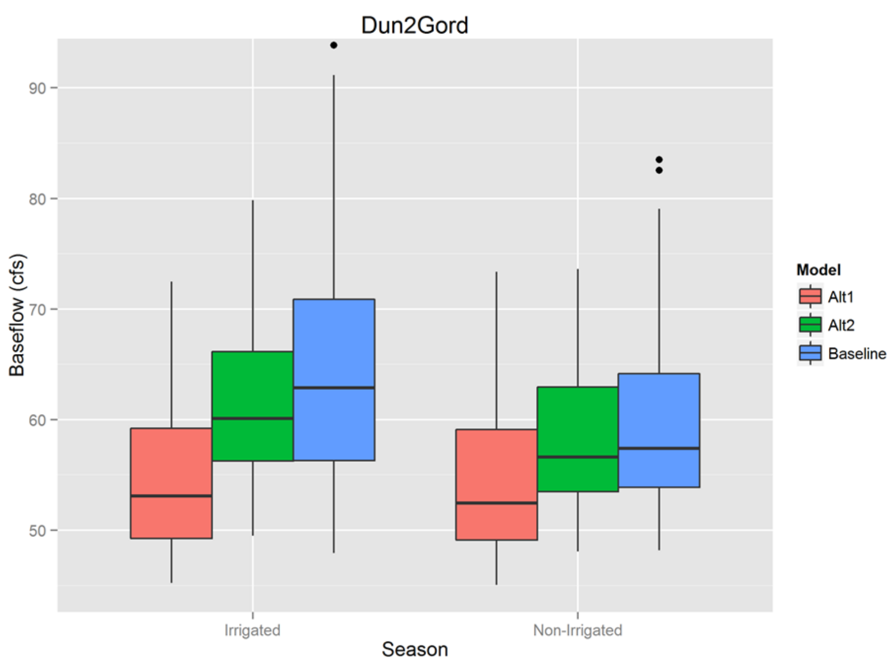

Figure 10. Box plot of baseflow between Dunlap and Gordon gages under Baseline, Alt1, and Alt2 management alternatives.

The purpose of operational Alternative 1 is to increase the efficiency of irrigation systems in the Mirage Flats area by installing a pumping station downstream and eliminating seepage from present canals to the groundwater system. However, the seepage losses in the canal are a significant source of localized recharge, which would be eliminated under Alternative 1. In the Alternative 1 model run, the reduction in seepage losses (which contribute to the baseflow of the aquifer system) exceeds the sum of the increase in recharge (direct and indirect recharge) and the reductions in groundwater pumping. Therefore the baseflow of the

Alternative 1 run is lower than that of the Baseline run. In Alternative 2, canals and laterals in the MFID are intentionally used for groundwater recharge rather than for crop irrigation. The cumulative effect of the increase in recharge (direct and indirect) and the increase in groundwater pumping for crop irrigation leads to a decrease in the baseflow of the Alternative 2 run as compared to that of the Baseline. These changes in stream reach baseflow due to the alternatives affect only the Mirage Flats area, not the overall Basin.

The two management alternatives would also lead to some change in groundwater levels in the Mirage Flats area. Levels beneath the currently irrigated cropland would generally rise under both alternatives — as much as 11 feet under alternative 1 and 50 feet under alternative 2. In alternative 1, however, groundwater levels would fall several feet in the area west of the new pumping plant, adjacent to the Main canal, which would be abandoned under this alternative. See Figure 8 in Appendix B for a graphical representation of these changes.

2. Watershed Model Results

The primary purpose of the watershed model was to ensure water supplies and water uses were accounted for within a balanced water budget while incorporating the climate data developed for this study. Alternative 1 (Mirage Flats Pumping) was shown to be able to achieve its objective of improving the transportation efficiency of the surface water supplies within the MFID: under all climatic scenarios, this alternative would increase the volume of surface water delivered to irrigators and reduce the need for supplemental groundwater pumping. (See Appendix E, Table 29 and Figures 152–155.) This increased efficiency is realized by moving MFID’s diversion point approximately 9 miles downstream and bypassing the relatively inefficient portion of the canal. However, the increase in efficiency of surface water deliveries would reduce the volume of canal seepage (Appendix E, Figure 172), which represents a significant source of localized recharge. The results summarized in Appendix E provide some helpful information should this alternative be considered in the future, but additional analyses of these results would be required to determine the tradeoffs between increased surface-water deliveries and reduced recharge from canal seepage.

Under Alternative 2 (Mirage Flats Canal Recharge), surface water deliveries in MFID would be eliminated and effectively change MFID into a groundwater-only district. Alternative 2 would create a relatively stable supply of groundwater recharge, generally at a rate greater than that of the No-Action alternative (Appendix E, Figure 199). The increase in recharge from the canal seepage would exceed any decrease in recharge resulting from changing the on-farm irrigation practice. This water management strategy improves the timing of irrigation water by eliminating the dependency on surface water supplies and canal management practices. Providing a timely and sufficient volume of water to the crop is paramount to maximizing the benefit of the water. This alternative would be worth considering in any future evaluation of water management alternatives for MFID.

3. Integrated Model Results

a) Box Butte Reservoir Elevations

Alternatives 1 and 2 maintain higher surface elevations in Box Butte Reservoir than the No Action alternative (Figure 11). Alternative 1 levels are higher because the increased canal efficiency allows a lower volume of releases. Alternative 2 reservoir levels are higher because releases for irrigation would be much lower. Significant droughts equivalent to those of the mid-1970's and late-2000's would create decreases in Alternative 1 elevations, even with the increased canal efficiencies. As shown in Table 4, both alternatives would have higher average daily elevations under the CT scenario over the course of the modeled 50-year period. The data is divided into annual and seasonal values (irrigation and non-irrigation season).

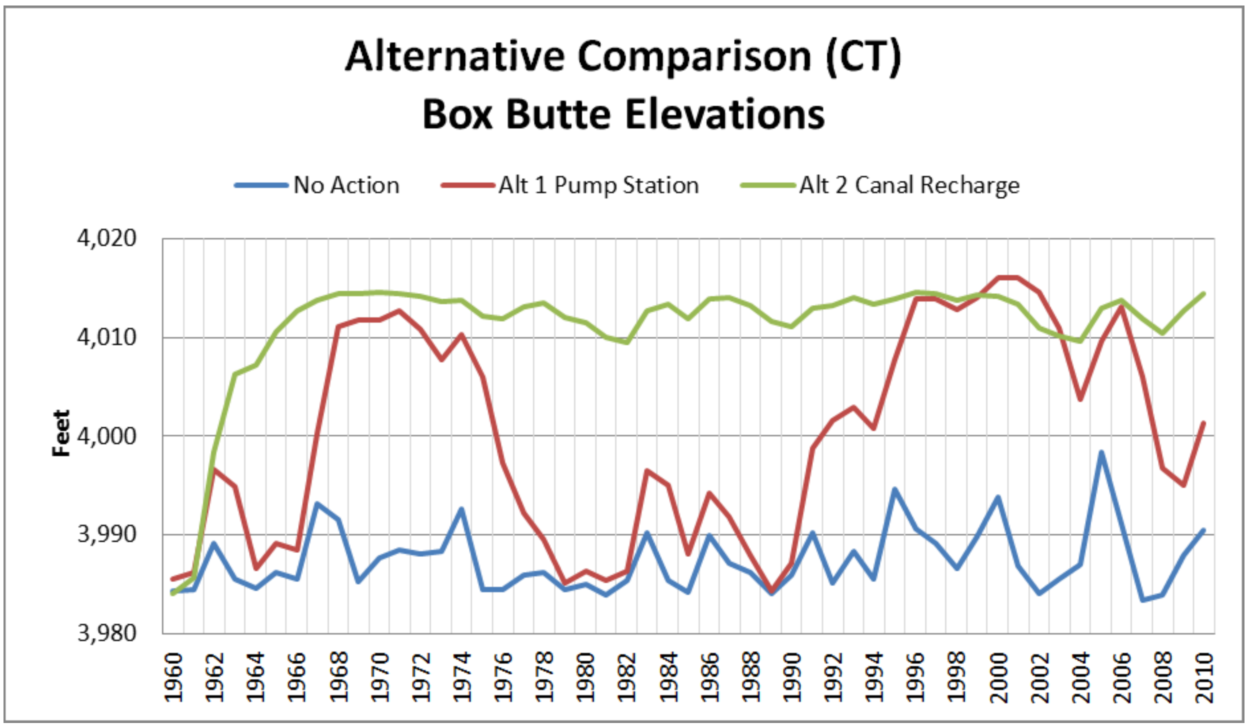

Figure 11. Average annual Box Butte Reservoir elevations under the CT scenario and the modeled operational alternatives.

Table 4. Annual and Seasonal Average Box Butte Reservoir Elevations, in feet, under the CT Scenario and the Modeled Operational Alternatives

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.

b) Mirage Flats Diversions

Under the CT climate scenario, Mirage Flats total annual diversions are lower under both action alternatives than under No Action. Alternative 1 diversions are lower because of the increased canal efficiencies resulting in a lower volume of diversions to meet irrigation demands. Alternative 2 diversions were established to meet recharge demand. Mirage Flats total annual diversions for all the alternatives, under the CT climate scenario, are plotted in Figure 12. Major differences are seen between the alternatives in the quantity of diversions. Overall, annual diversions to meet recharge demand under Alternative 2 are approximately 14 percent less than diversions required under Alternative 1 to meet MFID irrigation demands. Modeling of the diversions assumed that the canal has a 40-percent efficiency under the No Action alternative and a 98-percent efficiency under Alternative 1. Figure 12 shows the decreases in amount of diversions for that alternative.

Modeling of Alternative 2 assumed there would be no deliveries and used a constant diversion rate for June, July, August, and September during every year of the simulation. The flat line in Figure 12 shows an adequate supply to meet recharge demand. Table 5 summarizes the annual and seasonal daily average flows under the CT scenario over the course of the modeled 50-year period.

c) Surface Water Irrigation Deliveries

The operational alternatives would affect surface water deliveries only within the MFID. Under all scenarios the pumping station increased surface water deliveries. Figure 13 compares the irrigation demand in the MFID to the average annual surface water deliveries under the no action, pumping station, and canal recharge alternatives. Because the canal recharge alternative would use the existing network of canals only for recharging groundwater, surface-water deliveries under this alternative would be zero.

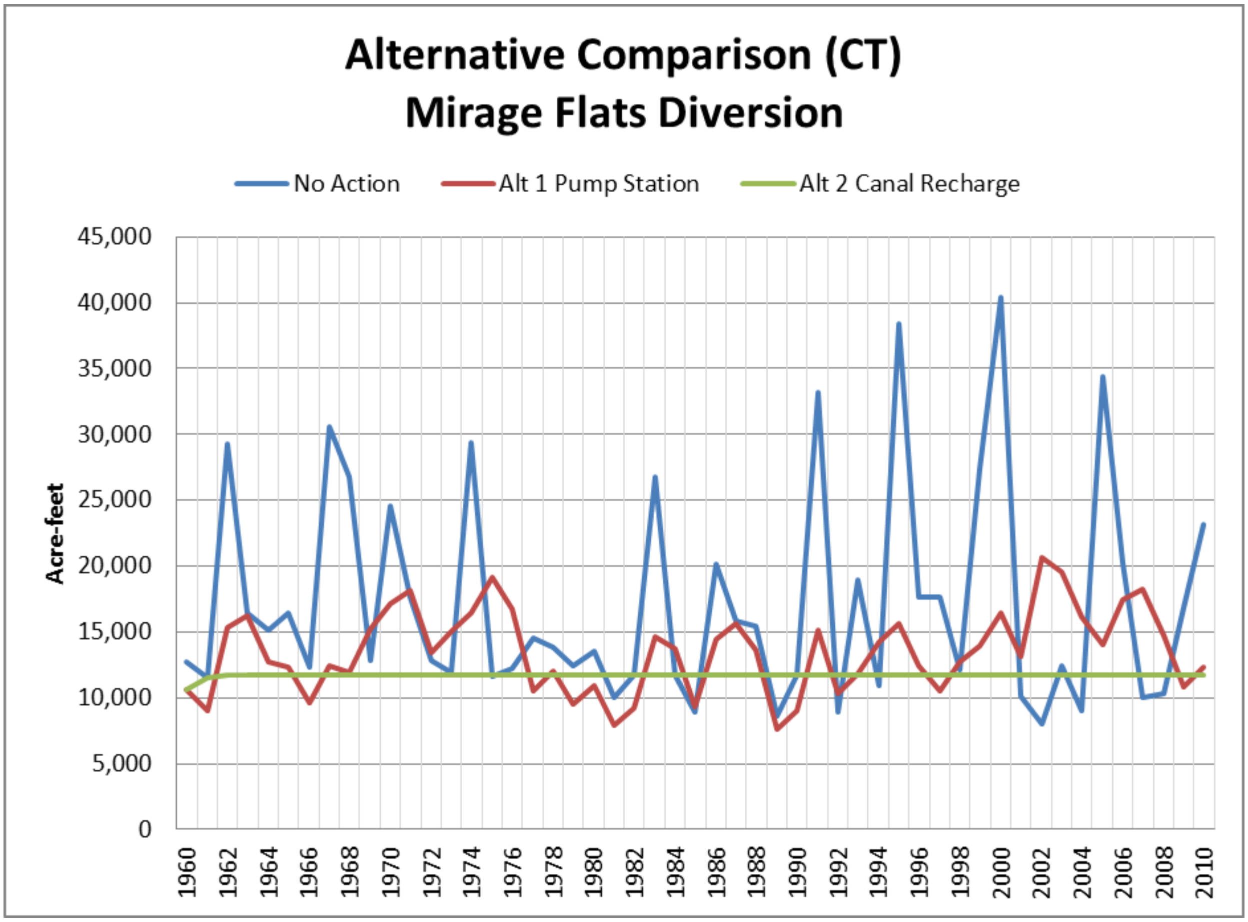

Figure 12. Total annual Mirage Flats diversion under the CT scenario and the modeled operational alternatives.

Table 5. Mirage Flats Annual and Seasonal Daily Average Diversion, in Thousands of Acre-Feet, under the CT Scenario and the Modeled Operational Alternatives

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.

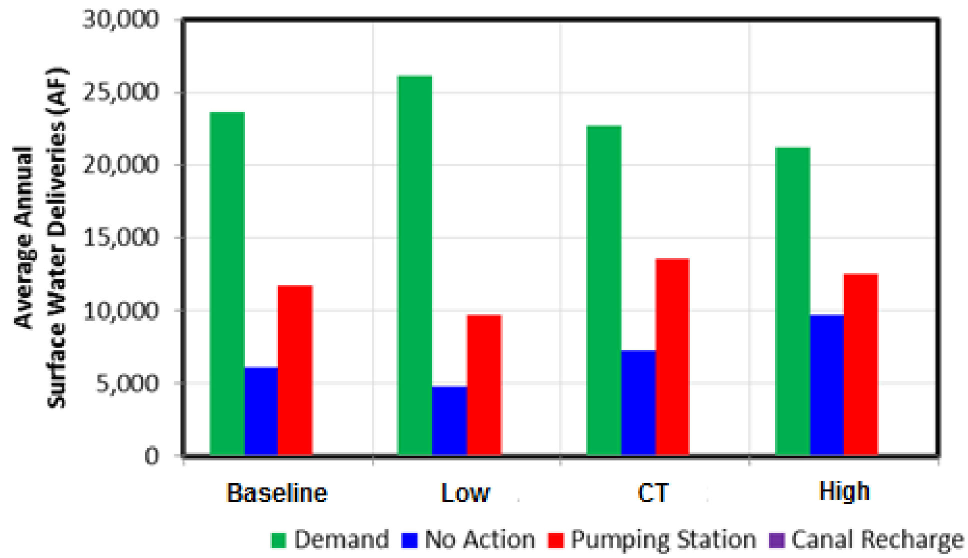

Figure 13. Mirage Flats average annual surface water demand versus deliveries under the modeled operational alternatives. Deliveries under Alternative 2 (Canal Recharge) are zero.

d) Volume of Supplemental Groundwater Pumping on Surface-Water Irrigated Acres

"Supplemental pumping" here refers to groundwater that irrigators have to pump when the supply of surface irrigation water is not sufficient for crop growth. The operational alternatives affected supplemental pumping only within the MFID. Under all scenarios the average volume of supplemental pumping decreased under the pumping station alternative and increased under the canal recharge alternative. Figure 14 compares the average annual supplemental pumping in the MFID under the no action, pumping station, and canal recharge alternatives.

e) Niobrara River at Gordon Gage

Total annual flows on the Niobrara River at Gordon gage are very similar for all the alternatives under both the Low and CT climate scenarios (Table 6). The similarity essentially shows that Box Butte Reservoir is an adequate buffer and can hold most of the surplus water generated by the lower demands under both operational alternatives. The reservoir is a less effective buffer under the High scenario, but even in that case the increase in flow is held to about 10 percent.

B. Hydroelectric Power Generation

Spencer Hydropower is the only hydropower facility in the Basin and a senior water-rights holder. A shortage of seasonal water supplies in recent years has led to the enforcement of the hydropower facility's water rights in the Basin. This has resulted in halting irrigation deliveries to upstream junior surface water appropriators on days that streamflow is insufficient to satisfy the senior rights. Current and future water availability at this facility is most directly represented by measured and projected flows at the Spencer gage, which is located a short distance upstream of the hydropower dam. The mean annual flows at Spencer would increase an average of 15 percent above Baseline under the CT scenario. For the Low scenario, the mean annual flows would decrease an average of 8 percent, whereas they would increase an average of 34 percent under the High scenario. Figure 15 shows Baseline flows at the dam from 1960 through 2010 compared to projected flows under the Low, CT, and High climate scenarios over a similar 50-year period.

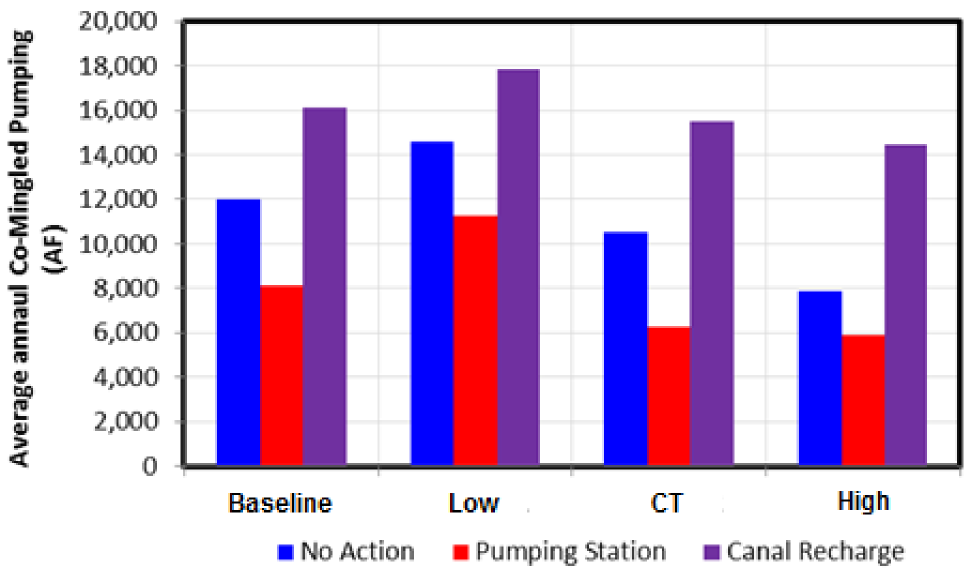

Figure 14. Mirage Flats average annual supplemental pumping under the modeled operational alternatives.

Table 6. Niobrara at Gordon Gage Average Flow, in Acre-Feet per Day (AFD), under the Three Climatic Scenarios and the Modeled Operational Alternatives

Alternative	Low Scenario		CT Scenario		High Scenario	
	AFD	% of Baseline	AFD	% of Baseline	AFD	% of Baseline
No Action	138		199		265	
Alt 1 Pumping Station	143	104%	208	105%	292	110%
Alt 2 Canal Recharge	136	99%	209	105%	293	111%

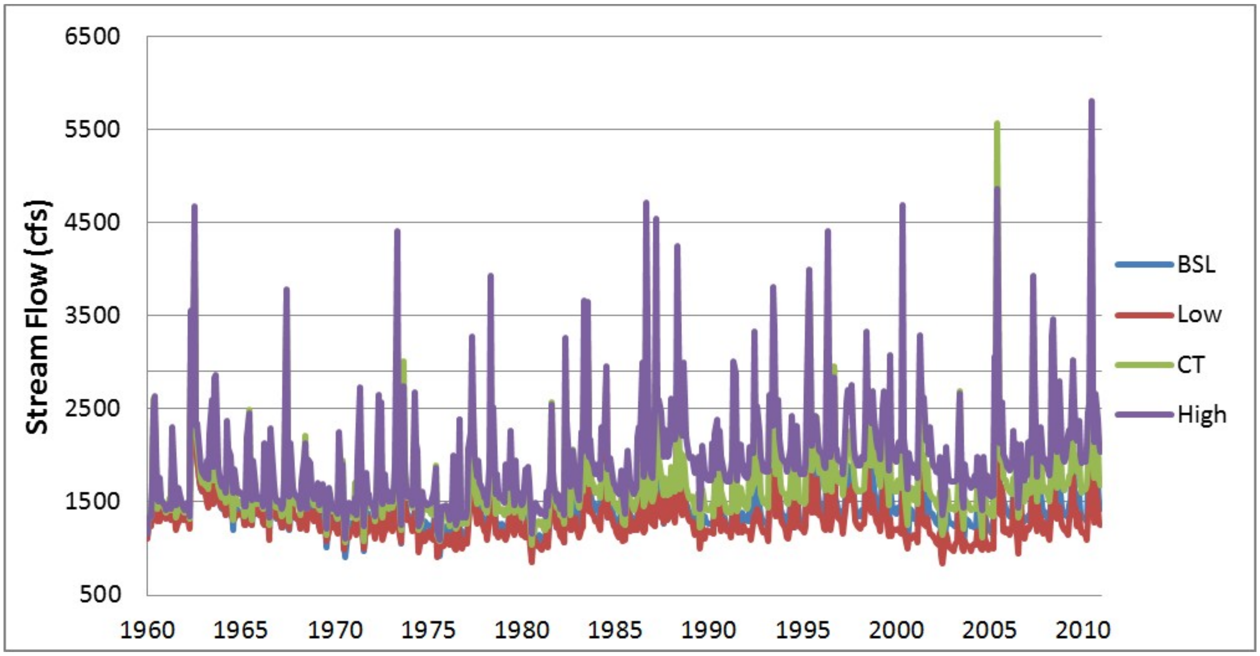

Figure 15. Monthly streamflows on Niobrara River near Spencer, Nebraska.

C. Agricultural and Recreation Benefits

Both agricultural and recreation benefits were initially estimated as annual values. The present value of the stream of annual benefits under each alternative/scenario was then calculated using a 50-year planning horizon and the FY2015 Federal discount rate of 3.375 percent (Reclamation, 2014). The results (reported in Table 7) show that either operational alternative would yield appreciably more benefits than No Action under either the CT or the High climate scenario. Under the Low scenario, net benefits do not differ greatly between the alternatives, although they are slightly higher for Alternative 2 and slightly lower for Alternative 1, compared to No Action. The net benefits are dominated by the recreational benefits, which increase under each Future No Action climate change scenario due to increased temperatures under all three scenarios and increased water elevations under the CT and High scenarios.

The results of the analysis indicate that both alternatives have economic benefits, but Alternative 2 (canal recharge) may provide greater benefits under all three future climate scenarios. It is important to reiterate here that these estimates are preliminary, and do not include the full range of relevant costs and benefits, e.g. these estimates do not include operation, maintenance, replacement, and power (OMR&P) costs, which would be significantly impacted by both Alternative 1 and Alternative 2.

Table 7. Present Value of Preliminary Net Benefits under Defined Alternatives and Scenarios

All costs and benefits reported in millions of dollars

Alternative/ Scenario	Agricultural Benefits[a]	Recreation Benefits[a]	Combined Benefits[a,b]	Costs[c]	Net Benefits[a,d]
Baseline No Action	$15.8	$112.5	$128.3	$0.0	$128.3
Low No Action	$15.1	$136.0	$151.1	$0.0	$151.1
Alt 1 Low	$17.3	$137.0	$154.3	$4.5	$149.8
Alt 2 Low	$13.1	$139.0	$152.1	$0.0	$152.1
CT No Action	$16.5	$137.2	$153.7	$0.0	$153.7
Alt 1 CT	$18.5	$146.3	$164.8	$4.5	$160.3
Alt 2 CT	$13.6	$154.3	$167.9	$0.0	$167.9
High No Action	$17.5	$133.7	$151.2	$0.0	$151.2
Alt 1 High	$18.3	$141.3	$159.6	$4.5	$155.1
Alt 2 High	$13.9	$147.7	$161.6	$0.0	$161.6

[a] 50-year stream of benefits discounted at the FY2015 Federal discount rate of 3.375% (Reclamation, 2014).
[b] The sum of agricultural benefits and recreation benefits.
[c] Costs are only associated with any Future Alternative/Scenario that includes the Mirage Flats Pumping Station operational modification—see section 3 of Appendix F.
[d] Combined benefits minus costs.

D. Fish and Wildlife

While all ecosystems in Nebraska will be affected by climate change, aquatic ecosystems (wetlands, lakes, streams, and rivers) may be the most highly impacted (University of Nebraska-Lincoln, 2014). Climate changes will alter both water quality and quantity. Increases in the frequency and intensity of high precipitation events, particularly in a landscape dominated by agriculture, will lead to increased runoff of sediments, fertilizers, and pesticides into water bodies. Increased frequency of drought and heat waves, combined with increased human demand for water, will result in lower stream flows and an increase in the frequency of stream segments being de-watered and wetlands drying up. Finally, increases in air temperature will result in increases in water temperature, causing a reduction in suitable habitat for cold-water dependent species such as trout.

Dunnell and Travers (2011) report that some spring flowering species have advanced their first flowering time, some fall species have delayed their first flowering, and some species have not changed. Given the importance of flowering timing for reproductive success, the changing climate in the Great Plains is expected to have long-term ecological and evolutionary consequences for native plant species.

Available information on patterns of spatial climate variability and subregions of importance to ecological processes within the Great Plains was summarized by

Covich et al. in 1997. Climate sensitive areas of the Great Plains range from cold water systems (springs and spring-fed streams) to warmer, temporary systems (intermittent streams, ponds, pothole wetlands, playas).

Warmer water temperatures also could exacerbate invasive species issues (e.g., quagga mussel reproduction cycles responding favorably to warmer water temperatures); moreover, climate changes could decrease the effectiveness of chemical or biological agents used to control invasive species (Hellman et al., 2008). Warmer water temperatures also could spur the growth of algae, which could result in eutrophic conditions in lakes, declines in water quality (Lettenmaier et al., 2008), and changes in species composition. In addition, continued development in the northern Great Plains for energy extraction and other purposes has fragmented much of the landscape. This means that species facing declining habitat quality in their present locations due to climate change (changing habitat composition, timing of plant cycles, etc.) may find themselves surrounded by physical barriers and/or areas of completely unsuitable habitat that prevent them from migrating to more compatible territories (Shafer et al., 2014). The magnitude of expected changes will exceed those experienced in the last century. Current adaptation and planning efforts may need to be revised and expanded to respond to these projected impacts (Shafer et al., 2014).

E. Threatened and Endangered Species

In-depth analysis of the effects of climate change on species protected under the Federal Endangered Species Act (ESA) was determined to be a large undertaking that was outside the scope of the Niobrara River Basin Study. According to the U.S. Fish and Wildlife Service, 14 species that may occur within the Niobrara River Basin Study Area are currently protected under ESA. Two ESA candidate species may also be present in the study area. The Flatwater Group conducted a literature review to summarize existing information for these 16 species. This included an online search for each species to determine its habitat position within the Basin, and then the species were grouped into aquatic habitat, terrestrial/ aquatic habitat, and terrestrial habitat groups. For each of these species, all identified threats and the species' vulnerability to climate change are listed in Table 8.

According to this literature analysis, these 16 species are expected to exhibit varying responses to the effects of climate change. Four species — the Colorado butterfly plant, Topeka shiner, Ute ladies'-tresses, and Western prairie fringed orchid — are regarded to be extremely vulnerable to the effects of climate change. According to Young et al. (2015), this means these species are "extremely likely" to experience a substantial decrease in their abundance and/or distribution within the study area by 2050. Two more species — the American burying beetle and the blowout penstemon — are classified as highly vulnerable to the effects of climate change, and are likely to experience significant decreases in distribution and/or abundance within the area by 2050 (Young et al., 2015).

Table 8. Literature Review of Habitat Position, Threats, and Climate Change Vulnerability for Federally Listed Species within the Niobrara River Basin

Habitat Group[1]	Species	Habitat[2]	ESA Status[3,4]	Species Range[4]			Threats[2]	Climate Change Vulnerability Index[5]
				NE	SD	WY		
AQUATIC	Pallid sturgeon (*Scaphirhynchus albus*)	Large turbid rivers, steep drop-offs at the edge of sandbars, sandy areas, downstream end of islands	E	X	X	X	Manipulation of water flow, sediment transport, channelization, lack of low flow, habitat fragmentation, loss of spawning habitat, illegal commercial harvest, current manipulation of hydrology	Not vulnerable, presumed stable
AQUATIC	Topeka shiner (*Notropis topeka*)	Cold/cool clear water streams with gravel, low gradient	E	X			Sedimentation, exotics, channelization, stocking of sport fish, row crop agriculture, flow modification, dewatering dams, loss of off-channel quiet-water habitats, degradation of riparian areas	Extremely vulnerable
AQUATIC / TERRESTRIAL	Least tern (*Sterna antillarum*)	Bare sand bars and sandy shorelines of large rivers, lakes and sand pits, housing developments	E	X	X	X	Loss of dynamic river flows to form and maintain bare macro-form sandbar and shoreline habitat, flooding of nests, loss of nests to vehicles and human disturbance, hydro-peaking, invasive plant species affecting nesting habitat	Not vulnerable, Presumed stable
AQUATIC / TERRESTRIAL	Piping plover (*Charadrius melodus*)	Bare sand bars and sandy shorelines of large rivers, lakes and sand pits	T	X	X	X	Loss of dynamic river flows to form and maintain bare macro-form sandbar and shoreline habitat, flooding of nests (hydro-peaking), loss of nests to vehicles and human disturbance, invasive plant species affecting nesting habitat, loss of over-wintering habitat along the Gulf	Not vulnerable, presumed stable
AQUATIC / TERRESTRIAL	Red knot (*Calidris canutus rufa*)	Sandy beaches.[6]	T		X		Loss of habitat across range due to sea-level rise, increased predation.[6]	Data Not Available
AQUATIC / TERRESTRIAL	Whooping crane (*Grus Americana*)	Wetlands, wet meadows, sandbars and shallow water in rivers; spring and fall migrant, does not nest in Nebraska	E	X	X	X	Loss of natural river flows to maintain wet meadows, bare sandbar and shallow water habitat, loss of wetland habitat, wind energy development, tree encroachment in wet meadows	Not vulnerable, Presumed stable
TERRESTRIAL	American burying beetle (*Nicrophorus americanus*)	Wet meadows in sandhills, open woodlands, loess canyons	E	X	X		Woody encroachment, drought, land development, light pollution	Highly vulnerable
TERRESTRIAL	Black-footed ferret (*Mustela nigripes*)	Prairie dog colonies found in short and mid-grass prairies of the Great Plains	E	X	X		Predators and disease	Data Not Available
TERRESTRIAL	Blowout penstemon (*Penstemon haydenii*)	Sandhills dune prairie (blowouts)	E	X		X	Loss of blowouts because of present range management practices, lack of fire, recent climatic conditions	Highly vulnerable

Habitat Group[1]	Species	Habitat[2]	ESA Status 3,4	Species Range[4] NE	SD	WY	Threats[2]	Climate Change Vulnerability Index[5]
TERRESTRIAL	Colorado butterfly plant (*Gaura neomexicana var. coloradensis*)	Western floodplain terrace grassland	T			X	Canada thistle invasion of habitat, herbicide spraying, groundwater level decline, haying and heavy grazing of habitat	Extremely vulnerable
	Greater sage-grouse (*Centrocercus urophasianus*)	Sagebrush country.[7]	C			X	Loss and fragmentation of sagebrush, agricultural conversion, infrastructure, invasive plants, fire cycle.[7]	Data Not Available
	Northern long-eared bat (*Myotis septentrionalis*)	Caves and mines (winter) and underneath tree bark, and cavities or crevices of dead trees (summer).[8]	PE		X		Cave entrance gates, development, wind farm operation.[8]	Data Not Available
	Preble's meadow jumping mouse (*Zapus hudsonius preblei*)	Well-developed plains riparian vegetation with adjacent undisturbed grassland communities and nearby water source.[9]	T			X	Habitat loss and predators.[9]	Data Not Available
	Sprague's pipit (*Anthus spragueii*)	Short to tall-grass prairies, grazed to 5–15 cm, pastures, harvested fields (alfalfa or wheat stubble); spring and fall migrant; does not nest in Nebraska	C		X		Undetermined, loss of breeding habitat, but unclear if there are threats during migration	Not vulnerable, Increase likely
	Ute ladies'-tresses (*Spiranthes diluvialis*)	Western alkaline meadow	T	X		X	Reduced groundwater levels, invasive species, conversion of meadows to cropland, annual haying of meadows	Extremely vulnerable
	Western prairie fringed orchid (*Platanthera praeclara*)	Eastern cordgrass wet prairie, northern cordgrass wet prairie, wet-mesic tallgrass prairie, tallgrass prairie	T	X	X	X	Invasive species, herbicide spraying, conversion of prairie to cropland and development, annual mid-summer haying, inappropriate grazing	Extremely vulnerable

[1] Generalized groupings for this table based on geomorphic location of habitat.

[2] Source of information *unless otherwise specified*: Appendix 8 of Nebraska Natural Legacy Project (NGPC) http://outdoornebraska.ne.gov/wildlife/programs/legacy/Natural_legacy_document.asp

[3] E=Endangered, T=Threatened, C=Candidate

[4] Source: USFWS IPAC (Information for Planning and Conservation) Tool, http://ecos.fws.gov/ipac/, accessed 6/1/2015

[5] Climate change vulnerability assessments were conducted using NatureServe's Climate Change Vulnerability Index tool (Young et al. 2011). The tool is designed to be used for a specific geographic area, which in this case was the State of Nebraska. Therefore the Index score may be incomplete for migratory bird species that spend part of the year outside of Nebraska.

[6] Source: http://www.fws.gov/northeast/redknot/pdf/DRAFT_QAs_red_knot_finallisting_120814_FINAL.pdf

[7] Source: http://www.fws.gov/greatersagegrouse/factsheets/GreaterSageGrouseCanon_FINAL.pdf

[8] Source: http://www.fws.gov/midwest/endangered/mammals/nlba/nlbaFactSheet.html

[9] Source: http://www.fws.gov/mountain-prairie/species/mammals/preble/

The results of this literature review illustrate the serious threat climate change poses for a number of ESA-listed species that may occur within the Niobrara River Basin Study Area. Climate information provided in this Study Report should be useful to researchers addressing the effects of climate change on ESA-listed species that occur within the Basin.

F. Species of Special Conservation Concern

In addition to the species protected under the Federal ESA, the States of Nebraska, South Dakota, and Wyoming have identified a number of species of special conservation concern that may occur within the Niobrara River Basin. Table 9 provides a list of these species and their status for each State. Species listed under the Nebraska Nongame and Endangered Species Conservation Act or the South Dakota State Endangered Species Law may be designated as threatened (ST) or endangered (SE). Wyoming species may be designated as Species of Greatest Conservation Need (SGCN) in accordance with the Wyoming State Wildlife Action Plan. Species listed as SGCN in Wyoming are assigned a ranking of NSS1 (extremely imperiled), NSS2 (severely imperiled or extremely vulnerable), NSS3 (severely vulnerable), NSS4 (moderately vulnerable or stable with severe limiting factors), or NSSU (status unknown, additional information needed) under the Wyoming Native Species Status (NSS) classification system (WGFD, 2010). The numerous State-designated species in Table 9 can be expected to exhibit varying responses to the effects of climate change. In-depth analysis of these responses was determined to be a large undertaking that was outside the scope of this Basin Study. However, the climate information provided here should be useful for researchers addressing the effects of climate change on these species.

G. Flood Control

The authorized purposes of Merritt and Box Butte Reservoirs are to provide storage for irrigation, recreation, and fish and wildlife. Box Butte also has the additional purpose of providing sediment control. Neither of these is operated as a flood control reservoir, and the operational changes considered here would probably have little effect on future flooding.

Table 9. State-Designated Species of Special Conservation Concern for the Niobrara River Basin Study Area

Common Name	Scientific Name	Nebraska Status	South Dakota Status	Wyoming Status
Bald eagle	*Haliaeetus leucocephalus*		ST	SGCN (NSS2)
Bighorn sheep	*Ovis canadensis*			SGCN (NSS4)
Blacknose shiner	*Notropis heterolepis*	SE	SE	
Brewer's sparrow	*Spizella breweri*			SGCN (NSS4)
Burrowing owl	*Athene cunicularia*			SGCN (NSSU)
Chestnut-collared longspur	*Calcarius ornatus*			SGCN (NSS4)
Dickcissel	*Spiza americana*			SGCN (NSS4)
False map turtle	*Graptemys pseudogeographica*		ST	
Ferruginous hawk	*Buteo regalis*			SGCN (NSSU)
Finescale dace	*Chrosomus neogaeus/ Phoxinus neogaeus*	ST	SE	
Grasshopper sparrow	*Ammodramus savannarum*			SGCN (NSS4)
Lake sturgeon	*Acipenser fulvescens*	ST		
Lewis's woodpecker	*Melanerpes lewis*			SGCN (NSSU)
Little brown myotis	*Myotis lucifugus*			SGCN (NSS4)
Long-billed curlew	*Numenius americanus*			SGCN (NSS3)
Mccown's longspur	*Rhynchophanes mccownii*			SGCN (NSS4)
Merlin	*Falco columbarius*			SGCN (NSSU)
Northern goshawk	*Accipiter gentilis*			SGCN (NSSU)
Northern leopard frog	*Lithobates pipiens*			SGCN (NSSU)
Northern many-lined skink	*Plestiodon multivirgatus multivirgatus*			SGCN (NSSU)
Northern pearl dace	*Margariscus nachtriebi*		ST	
Northern redbelly dace	*Chrosomus eos/Phoxinus eos*	ST	ST	
River otter	*Lontra canadensis*	ST	ST	
Sagebrush sparrow	*Artemisiospiza nevadensis*			SGCN (NSS4)
Sandhill crane	*Grus canadensis*			SGCN (NSS4)
Sicklefin chub	*Macrhybopsis meeki*		ST	
Short-eared owl	*Asio flammeus*			SGCN (NSS4)
Small white lady's slipper	*Cypripedium candidum*	ST		
Sturgeon chub	*Macrhybopsis gelida*	SE	ST	
Swift fox	*Vulpes velox*	SE	ST	SGCN (NSS4)
Virginia rail	*Rallus limicola*			SGCN (NSS3)

[1] Source: http://outdoornebraska.ne.gov/wildlife/programs/nongame/Heritage/ET_Ranges.asp and email correspondence with Rachel Simpson, Data Manager, Nebraska Natural Heritage Program, Nebraska Game and Parks Commission (April 8, 2015)

[2] Source: http://gfp.sd.gov/wildlife/docs/ThreatenedCountyList.pdf

[3] Source: Email correspondence with Melanie Arnett, Database Specialist, Wyoming Natural Diversity Database, University of Wyoming (March 27, 2015)

H. Water Quality

Climate changes are anticipated to alter not only the quantity but also the quality of water in the Niobrara River Basin. Increases in the frequency and intensity of high precipitation events, particularly in an agriculture-dominated landscape, will lead to increased runoff of sediments, fertilizers, and pesticides into water bodies.

Water quality in the Niobrara River Basin is monitored by Nebraska, South Dakota, and Wyoming. According to the State of Wyoming, water quality in the Niobrara River headwaters has been difficult to monitor because the surface water resources consist primarily of springs and ephemeral or intermittent streams. The limited amount of data available for one headwater stream, Silver Springs Creek, indicates that its water quality is good, with no reported impairments (WDEQ, 2014).

Water quality in the South Dakota portion of the Niobrara River Basin Study Area is monitored at one impoundment, Rahn Lake, and one Niobrara River tributary, the Keya Paha River. Rahn Lake is classified as impaired due to chlorophyll-a concentrations (SDDENR, 2014). Chlorophyll-a is an index of phytoplankton biomass; high chlorophyll-a levels may indicate nutrient enrichment (Carpenter et al., 1998; Hambrook Berkman and Canova 2007). No total maximum daily loads (TMDLs) have been developed for this impoundment. The water quality of the Keya Paha River is classified as threatened due to *Escherichia coli* (*E. coli*) and fecal coliform bacteria concentrations. The Keya Paha River has TMDLs in effect for both contaminants (SDDENR, 2014).

The State of Nebraska monitors water quality for 66 lakes and impoundments and 251 stream segments within the Niobrara River Basin Study Area. Ten of the 66 lakes/impoundments are classified as impaired due to various known and unknown contaminants including nutrients (nitrogen and phosphorous) and hazard index compounds (various PCBs, pesticides, heavy metals, and other compounds). The two largest impoundments, Box Butte and Merritt Reservoirs, are both classified as impaired due to pH (both reservoirs), fish consumption advisories (both reservoirs), and total nitrogen and phosphorous concentrations (Merritt only). No TMDLs have been developed for either reservoir (NDEQ, 2014).

Seventeen of the 251 Niobrara River Basin stream segments monitored by the State of Nebraska are classified as impaired due to known and unknown contaminants, including *E. coli* bacteria and hazard index compounds. The most common contaminant, *E. coli,* is reported for all 17 impaired segments (NDEQ, 2014). The State of Nebraska published *E. coli* TMDLs for all impaired stream segments of the Niobrara River Basin, including multiple segments of the Niobrara River, in 2005 (NDEQ, 2005).

Increases in runoff due to climate change would be expected to increase contaminant loads to surface waters. Increased contaminant loads could lead to additional impaired water designations within the Niobrara River Basin, as well as continued impairment of waters currently classified as impaired. See Figure 16 for a visual representation of the stream segments and lakes/impoundments currently classified as impaired within the Niobrara River Basin Study Area.

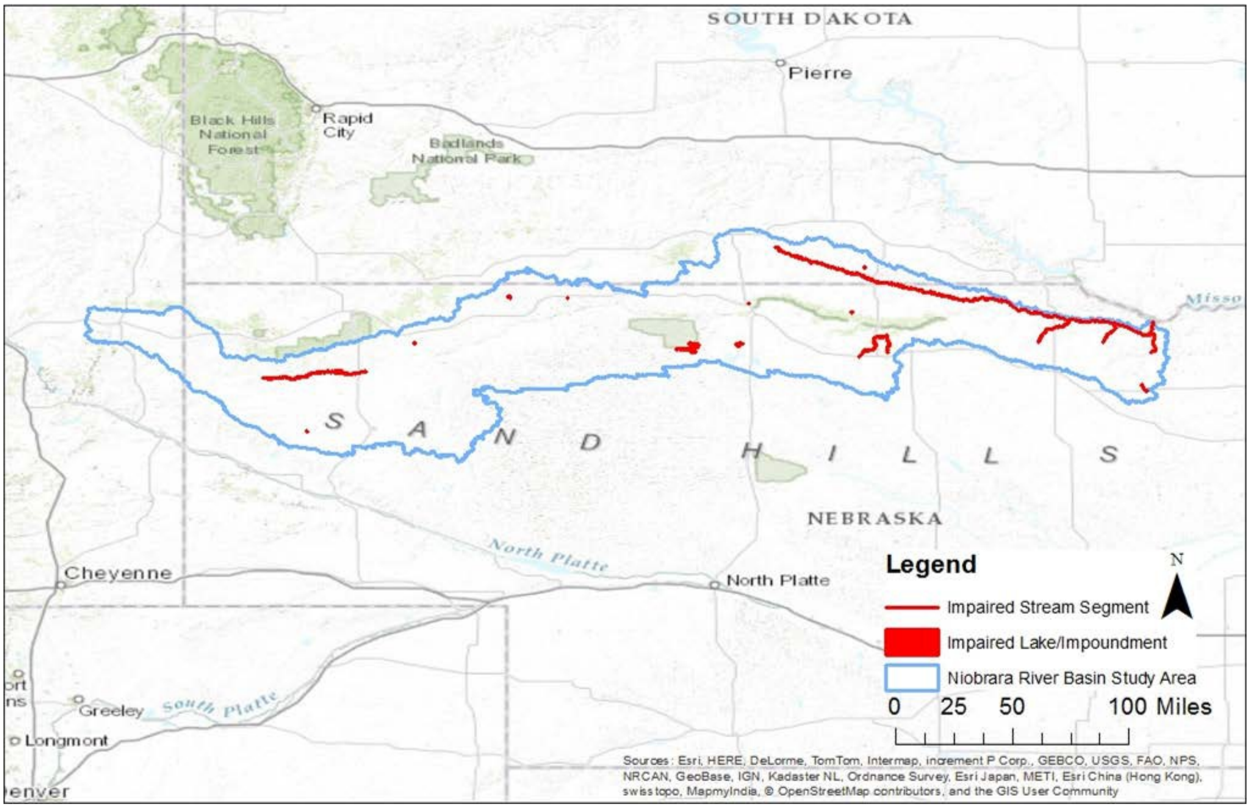

Figure 16. Impaired stream segments and lakes/impoundments within the Niobrara River Basin Study Area.

VIII. References

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