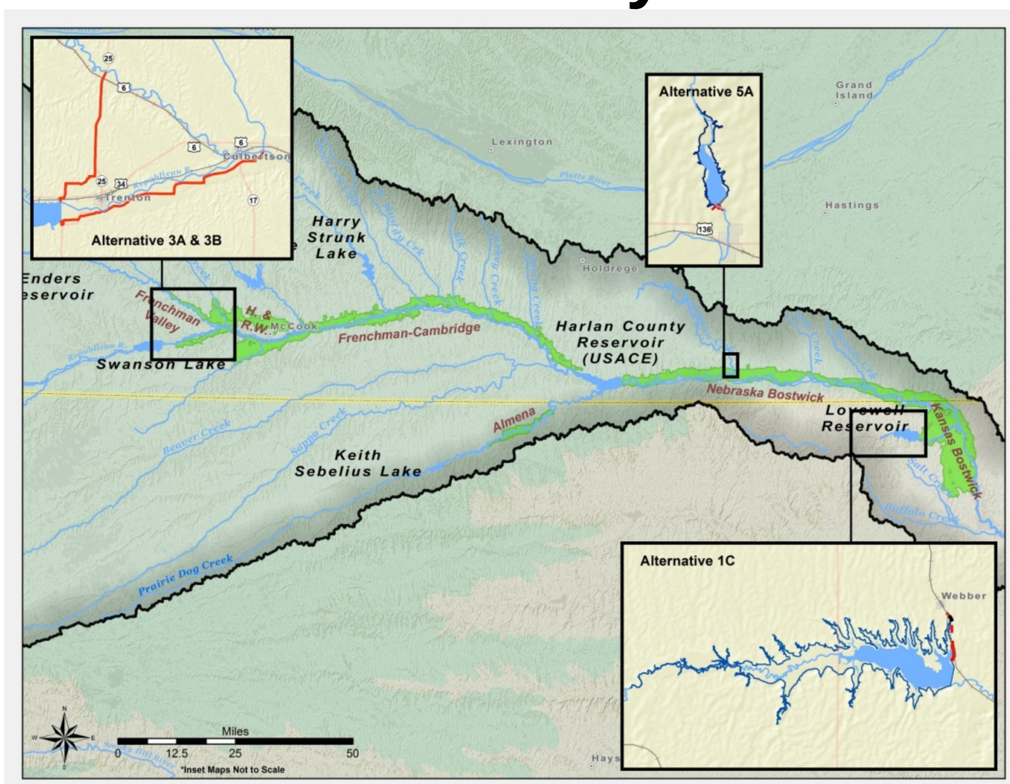
RECLAMATION

Managing Water in the West

FINAL EXECUTIVE SUMMARY REPORT

Republican River Basin Study



U.S. Department of the Interior
Bureau of Reclamation
Technical Service Center
Denver, Colorado

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Mission Statements

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.

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.

Cover image: Conceptual map illustrating adaptation strategies evaluated in the Republican River Basin Study.

FINAL EXECUTIVE SUMMARY REPORT

Republican River Basin Study

STUDY PARTNERS

Bureau of Reclamation
Nebraska-Kansas Area Office, Great Plains Region

State of Colorado
Colorado Division of Water Resources

State of Nebraska
Nebraska Department of Natural Resources

State of Kansas
Kansas Water Office
Kansas Department of Agriculture, Division of Water Resources

Acronyms and Abbreviations

AF	acre-foot or acre-feet
BAC	Basin Advisory Committee (Kansas)
Basin	Republican River Basin
BCA	benefit-cost analysis
BCSD	bias corrected and spatially disaggregated
BOD	biochemical oxygen demand
CDF	cumulative distribution functions
CFR	Comprehensive Facility Review
cfs	cubic-feet per second
CMIP	Coupled Model Intercomparison Project
COD	chemical oxygen demand
Commission	Colorado Ground Water Commission
Compact	Republican River Compact of 1942
CWA	Clean Water Act
D&S	Reclamation Directives and Standards
EIS	Environmental Impact Statement
EOM	end-of-month
EPA	Environmental Protection Agency
ESA	Endangered Species Act of 1973, as amended
ET	evapotranspiration
FCID	Frenchman-Cambridge Irrigation District (Nebraska)
FSS	2003 U.S. Supreme Court Final Settlement Stipulation
FVID	Frenchman Valley Irrigation District (Nebraska)
GCM	General Circulation Model
GHG	greenhouse gases
GMD 4	Northwest Kansas Groundwater Management District No. 4
gpm	gallons per minute
HGS	HydroGeoSphere (software)
ID	irrigation district
IDC	interest during construction
IMP	Integrated Management Plan
IQR	inter quartile range
IWS	imported water supply (RRCA accounting)

KAF	thousands of acre-feet
KBID	Kansas Bostwick Irrigation District No. 2
KBID-DOWN	KBID below Lovewell Reservoir
KBID-UP	KBID above Lovewell Reservoir
KDWPT	Kansas Department of Wildlife, Parks and Tourism
KNESCA	Kansas Nongame and Endangered Species Conservation Act
km^2	square-kilometer
MDS	minimum desirable streamflow
MOA	Memorandum of Agreement
NBID	Bostwick Irrigation District (Nebraska)
NCSD	Nebraska Conservation and Survey Division
NDNR	Nebraska Department of Natural Resources
NED	National Economic Development
NeRRMDA	Nebraska Republican River Management Districts Association
NIR	net irrigation requirement
NFI	net farm income
NNESCA	Nebraska Nongame and Endangered Species Conservation Act
NRD	Natural Resource Districts (Nebraska)
NGPC	Nebraska Game and Parks Commission
NWS	National Weather Service
OASIS	Operational Analysis and Simulation of Integrated Systems (modeling software)
OMR&P	operations, maintenance, replacement and power
PDSI	Palmer Drought Severity Index
POS	Plan of Study
PR&G	Principles, Requirements, and Guidelines for Water, Land and Related resources Implementation Studies
P-SMBP	Pick-Sloan Missouri Basin Program
Reclamation	Bureau of Reclamation
RRCA	Republican River Compact Administration
RRWCD	Republican River Water Conservation District (Colorado)
RTU	remote terminal unit
STORRM	STELLA Operations Republican River Model
SYMAP	synergraphic mapping system

TDS	total dissolved solids
The (Basin) States	Colorado, Kansas and Nebraska
TMDL	total maximum daily load
STELLA	Systems Thinking Environment and Learning Laboratory Approach (model)
UNL	University of Nebraska - Lincoln
USACE	U.S. Army Corps of Engineers
USDA-NASS	U.S. Department of Agriculture – National Agricultural Statistics Service
USGS	U.S. Geological Survey
VE	value engineering
VIC	variable infiltration capacity
WEEG	Water and Energy Efficiency Grants
WWCRA	West-Wide Climate Risk Assessments

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I. Introduction

The Republican River Basin is an important region for the states of Nebraska, Colorado and Kansas (the States) that includes highly productive agricultural lands, large reservoirs with recreational and wildlife habitat features, and established communities that rely on the agriculturally-driven economy and the water supplies that sustain it. The water management issues in the Republican River Basin are extremely complex and involve a long history of stakeholder involvement and activities. Declines in groundwater levels and streamflows have and continue to be widespread throughout the Basin, creating competition for limited water supplies and litigation. This Basin Study provided an opportunity for the three States to work toward overcoming some of these challenges by coordinating with the Bureau of Reclamation (Reclamation) to identify and evaluate alternative management and infrastructure changes that might benefit water users within the Basin, while strengthening the local economy and protecting environmental resources. The inclusion of future climate change scenarios provided an indication of the robustness of the system under climate variability, such as how the reservoirs and canals might operate and adapt under severe drought conditions, and how physical and operational changes may impact local economic benefits relative to costs. Because of the legal, physical, and institutional complexity of water operations in the Basin, the models developed under this Basin Study may be especially important in helping the States investigate relationships between management decisions and physical responses to the Basin water supply. The achievements made through this Basin Study are owed to the high levels of professionalism and collaboration displayed among Basin Study partners. Coupled with recent and ongoing negotiations and agreements, sustainable, win-win solutions to solving the Basin's complex water supply issues appear promising.

A. Authority

This Basin Study was conducted under the authority of the 2009 SECURE Water Act (P.L. 111-11) which directed the U.S. Department of the Interior to develop a sustainable water management policy that considers the risks and associated impacts of climate change on water supplies, as well as adaptation strategies to mitigate and minimize those impacts. The Secretary of the Interior established the WaterSMART (Sustain and Manage America's Resources for Tomorrow) program, an umbrella program with many components designed to implement various directives set forth in P.L. 111-11. The Basin Study Program is one of those components, which allows Reclamation to partner with Tribal, State, regional, and local water managers in collaborative efforts to address basin-wide issues associated with water scarcity.

Using Section 9503(b)(3) 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 adaptation 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 provided 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 2012, the States of Colorado, Kansas, and Nebraska applied for and were allocated a total of $413,000 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 $435,000, representing a 49 to 51 percent federal to non-federal cost share[1].

B. Location and Description of the Study Area

The Republican River Basin covers approximately 16 million acres and lies primarily within the Ogallala Aquifer, the largest groundwater system in North America that spans eight western states. Thirty-one percent of the Basin (Figure 1) lies within Colorado, thirty percent within Kansas, and thirty-nine percent in Nebraska.

The Republican River originates in the high plains of northeastern Colorado, western Kansas, and southern Nebraska. Tributaries originating in northeastern Colorado and western Nebraska flow to the southeast to join the northern side of the mainstem. Tributaries originating primarily in northwestern Kansas flow in a northeastern direction to join the south side of the mainstem. The study area of this Basin Study covers most of the Republican River Basin from the headwaters in Colorado but terminates at Clay Center, Kansas just above the upper reaches of Milford Lake in north-central Kansas (Figure 1). Milford Lake was excluded from the study area because it is owned by the U.S. Army Corps of Engineers (USACE) and, with the exception of flood management, operations do not affect Reclamation projects, which are the focus of the study. The study area drains approximately 24,540 square miles of eastern Colorado, southern Nebraska, and northern Kansas, and contains over 2.7 million acres of irrigated agriculture served by surface and groundwater supplies. Of this total farmland, 1.6 million acres are in Nebraska (approximately 90,000 acres in Reclamation projects), 435,000 acres are in Kansas (approximately 50,000 acres in Reclamation projects), and 550,000 acres are in Colorado. In addition to irrigated agriculture,

[1] The non-Federal contribution has substantially exceeded this amount. A final accounting of Federal and non-Federal costs will be done at the conclusion of this study.

the water resources provide flood control and serve municipalities, industry, recreation, and wildlife.

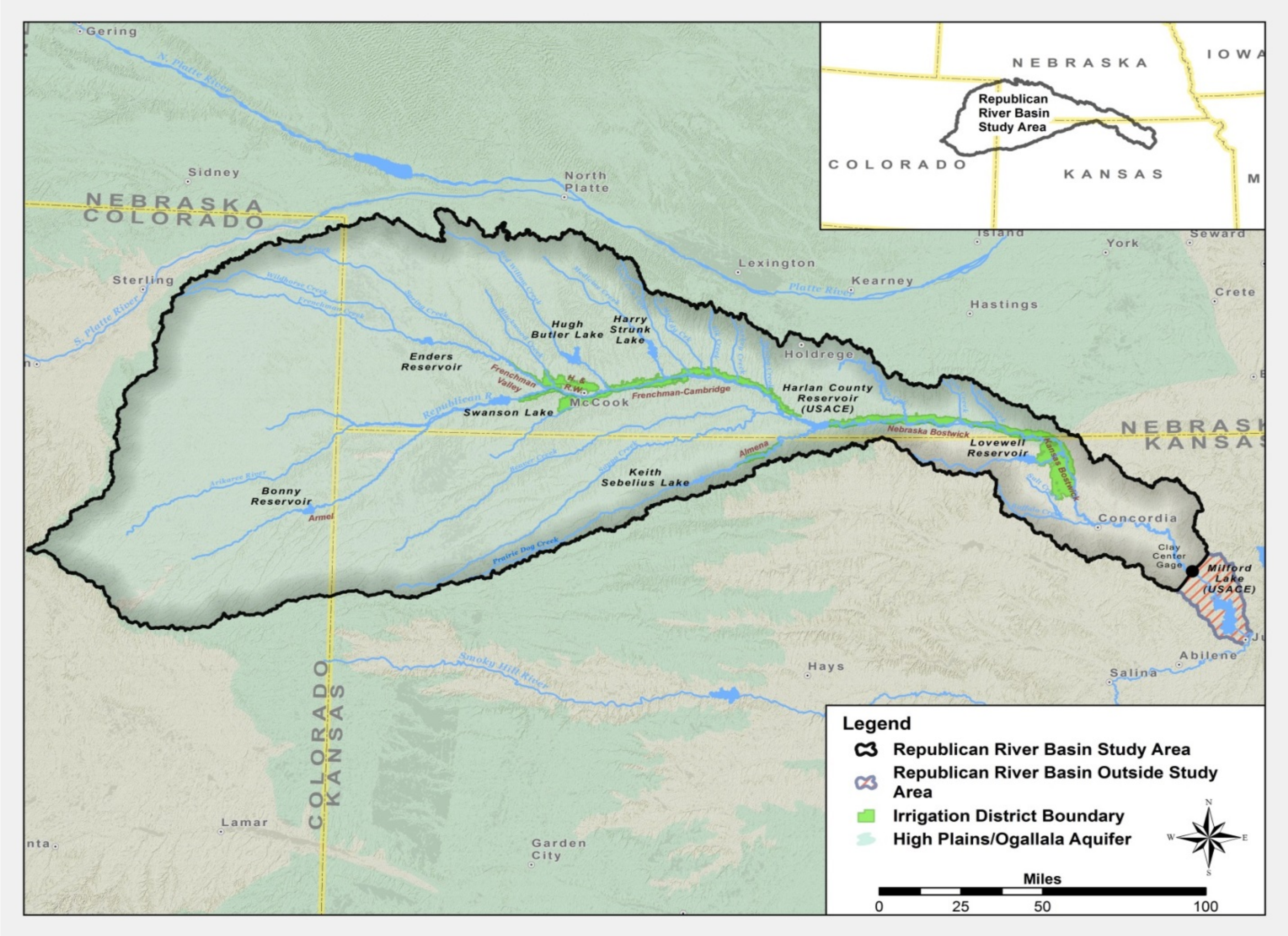


Figure 1. — Map of Republican River Basin and Study Area

C. Summary of Federal Features in the Study Area

The federal features in the Republican River Basin were constructed in the 1940s and 1950s as part of Reclamation's Pick-Sloan Missouri River Program. The features in the study area include a system of seven Bureau of Reclamation reservoirs, one U.S. Army Corps of Engineers (USACE) reservoir, and six irrigation districts that serve approximately 140,000 acres. The Reclamation reservoirs include Bonny Reservoir, Swanson Lake, Enders Reservoir, Hugh Butler Lake, Harry Strunk Lake, Keith Sebelius Lake, and Lovewell Reservoir; the USACE reservoir is Harlan County Lake.

D. Existing Water Supply Challenges and Activities

The Republican River is subject to an interstate compact between Colorado, Nebraska and Kansas. The Compact, established in 1943, divides the Basin's water supply across eastern Colorado, northwest Kansas, and southwest Nebraska. The water management issues in the Republican River Basin are extremely complex and involve a long history of stakeholder involvement and activities by Colorado, Nebraska, and Kansas. The Republican River Basin has many demands on its limited water supplies, including demands for irrigation, recreation, fish and wildlife, and municipalities. By far, the largest demands come from groundwater wells that pump water from the Ogallala Aquifer for agricultural irrigation. The pumping, combined with depletions associated with reduced recharge from conservation measures and other factors, has resulted in declines in adjacent streamflows. Competing demands for limited water supplies have resulted in litigation over Republican River Compact compliance. In February 2015, the U.S. Supreme Court issued a ruling to settle matters related to the Compact, including monetary compensation for previous noncompliance and how water would be accounted for in the future. Both Nebraska and Kansas viewed the ruling as a victory, while also recognizing that continued collaboration was necessary to avoid future conflict and to manage the Basin in a sustainable manner.

E. The Need for Federal Involvement

The need for federal involvement, in particular Reclamation, stems from the nexus of federal infrastructure and authorities, as well as the complexity and nature of interstate issues. While key federal and state stakeholders have been working diligently to improve water management in the Basin, the Basin Study undertaken here was pursued in response to a need for a comprehensive assessment of current and future hydrologic and demand conditions, including risks associated with climate change/variability. Such an assessment is only made possible by coordination and development of modeling tools to quantify conditions and evaluate impacts, and by evaluating solutions within a basin-wide context, in an unbiased manner, and without binding any partner to a particular outcome or solution.

F. Study Purpose

The overall purpose of this Basin Study is to identify and help address current and future water supply and management challenges in the Republican River Basin, while also providing a mechanism that allows Colorado, Nebraska, and Kansas to coordinate with Reclamation using basin-wide modeling tools that quantify supplies and demands and consider impacts of climate change on overall system reliability. In doing so, the study must address the elements required under the WaterSMART Basin Study Program which are described in Reclamation's Directives and Standards (D&S) as described in the Authority section. While this Study did include a robust process for evaluating conditions and identifying evaluating alternatives for each state, it stopped short of comparing/contrasting alternatives from one state against those from another or from making any recommendations with regards to basin-wide management and optimization. This enabled study partners to follow a more stream-lined process and complete the study in a timely manner.

G. Study Objectives

In accomplishing the purposes outlined above, the following objectives were established by study partners:

- <u>Quantify Water Supply and Demand</u>: Estimate current and future water supplies and demands at the basin and sub-basin levels, and assess the effects of projected future climates on water resources, management, and availability for current and future water rights, and natural and ecological needs.

- <u>Develop Basin Modeling Tools</u>: Develop transparent and scientifically defendable hydrologic and economic models and compile the best available environmental information to aid in conjunctive surface and ground water management planning. These tools would be used to assess system performance in the trade-off analysis of adaptation strategies.

- Evaluate the Impacts of No Action: Evaluate performance of existing infrastructure and operations under current and future climate conditions based on performance metrics developed by each state.

- Identify and Evaluate Adaptation Strategies: Identify structural and non-structural alternatives that address state-specific objectives described below; evaluate the alternatives based on performance metrics and benefit/cost ratios.

H. Objectives of Study Partners

Each partner also put forth a more specific list of objectives that each wanted to be addressed in accomplishing the overall study objectives described above. Details are provided in the Basin Study Report.

1. Reclamation

The overall objective of Reclamation is to operate Reclamation project facilities within the Republican River Basin, as well as the USACE Project, Harlan County Lake, to (1) Maximize water storage in Reclamation and USACE storage facilities, as allowed under applicable state and federal laws; (2) Consistently meet contractual delivery obligations to Reclamation contractors; and (3) Provide for secondary project benefits, including fish, wildlife, and recreation.

2. Colorado

The overall objective for Colorado is to better understand projected climate change in an effort to maintain compliance with the Republican River Compact and Final Settlement Stipulation (FSS).

3. Nebraska

The overall objective for Nebraska is to maintain compliance with the Republican River Compact and FSS while maximizing the beneficial use of water for all Nebraska users in the Basin.

4. Kansas

The overall objective for Kansas is to secure Kansas' share of the water it is entitled to under the Republican River Compact with the ability to manage that water for the maximum benefit of Kansas water users. This includes maximizing the ability to meet the water demands for irrigation, recreation, wildlife areas, municipalities, industries, while also maintaining minimum desirable streamflows.

I. Collaboration and Stakeholder Involvement

Reclamation and the States of Colorado, Nebraska, and Kansas agreed to share responsibility for management of the Study. The Nebraska-Kansas Area Office represented Reclamation, and the Colorado Division of Water Resources, Nebraska Department of Natural Resources, Kansas Department of Agriculture, and Kansas Water Office represented the States.

A Basin Study Work Group managed both technical and policy aspects of the Study, while a Study Technical Team conducted technical evaluations and prepared technical memoranda and reports for review by the Basin Study Work Group. Study managers maintained an administrative record of all electronic and paper documents that substantively recorded study progress and decision points. Copies of the administrative record are available upon request from Reclamation's Great Plains Regional Office in Billings, Montana.

Communication with stakeholders and the public varied across each agency. Details are provided Section 2.4 of the Basin Study Report.

II. Findings and Conclusions Summary

A more in depth discussion of study findings is provided at the end of this summary report and in Section 9.0 in the Basin Study Report. A summary follows:

- This study was 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 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 collaborative efforts between the States, modeling tools were developed for the Nebraska and Lower Kansas sub-basins that provide a consistent representation of hydrology and water operations in the Basin; this was important in helping the States assess the impacts of taking no action and may be especially important in investigating relationships between future management decisions and physical responses to the Basin water supply.

A. Impacts of Climate Variability and Change under No Action

1. Surface and Groundwater Supplies

- Average annual streamflow in the Colorado sub-basin is projected to decrease by 7% under the warmer/drier scenario ("Scenario 1") but increase by 22% under the less warm/wetter scenario ("Scenario 3", with little change under the central tendency scenario ("Scenario 2").

- Average annual streamflow in the Upper Kansas sub-basin is projected to decrease by 10% under Scenario 1 and increase substantially under Scenarios 2 and 3 by 28% and 166%, respectively.

- Average annual streamflow in the Nebraska sub-basin is projected to decrease by 8% under Scenario 1 and increase under Scenarios 2 and 3 by 10% and 59%, respectively.

- Average annual streamflow in the Lower Kansas sub-basin is projected to increase slightly under Scenarios 1 and 2 by about 1% and increase moderately under Scenario 3 by 12%. Increases under Scenario 1 result from a large projected increase in precipitation over the Lower Kansas sub-basin, despite a projected decrease in basin-average precipitation under this scenario.

- Projected changes in precipitation suggest that groundwater recharge is likely to decrease in the Colorado and Upper Kansas sub-basins under Scenarios 1 and 2, with little change under Scenario 3. Precipitation recharge is likely to increase in the Nebraska sub-basin under Scenarios 2 and 3, with little change under Scenario 1. Precipitation recharge is likely to increase in varying degrees over the Lower Kansas sub-basin under all scenarios, as all three scenarios project increased precipitation over the sub-basin. The effects of changes in surface water diversions, and corresponding seepage and deep percolation, on the total amount of recharge in each sub-basin is likely to be much smaller than the effects of changes in precipitation.

2. Water Demands

- For Nebraska, average net irrigation requirements (NIR) for canal service areas increases by 6.9% under Scenario 1 due to a combination of temperature-driven increase in evaporative demand and decreased precipitation. Average NIR decreases by 8.8% under Scenario 2 and decreases by 20.9% under Scenario 3. Results suggest that projected increases in precipitation over the majority of the Nebraska sub-basin under Scenarios 2 and 3 more than offset temperature-driven increases in evaporative demand (reference evapotranspiration) under these scenarios.

- For Nebraska, when applying district acreages and applying an area weighted average, the NIR decreases by 21% for Scenario 1 and increases by 15% and 44% for Scenarios 2 and 3, respectively. This result is based on Nebraska's modeling approach which estimates irrigated acreage based on available supply (i.e., more water is available under the cool/wet scenario, so acreage is increased and total demand (acres x NIR) increases). Under Scenario 1, acreage is reduced due to low supply, resulting in a decrease in overall demand.

- For Kansas, average NIR increases by 41.4% under Scenario 1 due to a combination of temperature-driven increase in evaporative demand and decreased precipitation. Average NIR increases by 9.3% under Scenario 2 and decreases by 22.1% under Scenario 3.

3. Water Supply Imbalances

- This study assessed the effects of imbalances as part of the System Reliability Analysis. System reliability for the Nebraska sub-basin evaluated the effects of water supply imbalances based on irrigated acreage, irrigation diversions and deliveries, and the frequency of Compact Call Years[2]. System reliability for the Lower Kansas sub-basin evaluated the effects of water supply imbalances based on irrigation diversions and deliveries to the Kansas-Bostwick Irrigation District (KBID) above and below Lovewell Reservoir.

B. Nebraska Alternatives

- Nebraska formulated action alternatives to ensure compliance with the Republican River Compact and to increase supplies for all users in the basin. The alternatives evaluated included augmenting the supply of Swanson Lake and building a new dam on Thompson Creek, a tributary of the Republican River.

- Augmentation of Swanson Lake could be done either by pumping water from Frenchman Creek (Alternative "3A") or from the Republican River (Alternative "3B"). Results showed that both options would

[2] Deficits and shortages for Nebraska were calculated by Reclamation staff based on Nebraska's modeling results. The analysis was for hypothetical purposes only and is not representative of Nebraska's modeling approach.

increase diversions to the Frenchman-Cambridge Irrigation District (FCID), but this may reduce storage in Harlan County Lake (HCL), which is important to the system in determining when a "Compact Call Year" would be triggered[3]. A reduction in HCL storage would increase the number of Compact Call Years and reduce diversions to the Nebraska-Bostwick Irrigation District (NBID) by a proportionate amount.

- The capital costs estimated by Reclamation for Alternative 3B are over two times more than Alternative 3A ($82 million versus $36 million, respectively).

- Results indicate that that the pumping volumes of 3,000 and 5,000 gallons per minute (gpm) proposed under Alternatives 3A and 3B, respectively, could be increased because pump augmentation operations were almost always able to operate at full capacity for those years in which pumping was allowed. Higher pumping levels would also make the impacts from pump augmentation operations more pronounced, perhaps providing more definitive results to help determine which alternative has more merits.

- Results from this study also indicate that options exist to modify operations of Alternative 3A/3B – for instance to allow for releases at Swanson Lake in exchange for additional storage at HCL. This would require a more complex modeling effort than that which was undertaken for this study.

- Construction of a new dam on Thompson Creek (Alternative "5A") increases Franklin Canal diversions, which allows HCL to store more water, thereby increasing NBID diversions. The capital costs estimated by Reclamation for Alternative 5A total $92 million.

- The net economic benefits of 3A were the highest of Nebraska's three alternatives, followed by 3B and Alternative 5A. All three alternatives yielded negative net benefits.

C. Kansas Alternatives

- Kansas formulated action alternatives to address water supply shortages to KBID and to maximize beneficial uses. The primary alternative

[3] During Compact Call Years, special provisions are triggered regarding supply augmentation pumping, reservoir releases, and canal diversions throughout the Nebraska portion of the Basin to ensure that compact compliance is achieved.

evaluated included raising the dam at Lovewell Reservoir, which would yield a corresponding increase in volume by 16,000 acre-feet (AF), 25,000 AF, or 35,000 AF.

- Results showed that raising Lovewell Reservoir's dam reduces the magnitude and frequency of KBID shortages by only a small amount under the Baseline Climate Scenario. This is largely due to operational assumptions under the No Action Alternative made by Nebraska during Compact Call Years which require measures to be taken to ensure Compact compliance.

- A reduction in the magnitude and frequency of KBID shortages is slightly more pronounced under the warmer/drier climate scenario, with the 25,000 AF option providing a greater shortage reduction than the 16,000 AF option and a similar shortage reduction than the 35,000 AF option - but at a lower capital cost ($59 million for 25,000 AF versus $84 million for 35,000 AF[4], respectively).

- Considering the high cost of reservoir expansion options and the relatively small reductions to KBID shortages, the only expansion alternative that was selected for an economics analysis (i.e., benefit relative to costs) was the 25,000 AF expansion option. The economics analysis suggests that this alternative may yield positive net benefits due to the increase in reservoir elevation and surface acreage associated with raising the dam and the resulting projected increase in recreational visitation to Lovewell Reservoir; water supply benefits were relatively low.

III. Study Technical Memoranda

Several technical memoranda (TM) were completed throughout key milestones in support of tasks outlined in the Plan of Study (POS). For the sake of report brevity, these TMs are not included as appendices of either this summary report or the Basin Study Report; rather, only the most substantive and applicable TM content was inserted in the body of this report. A list of TMs is provided below, copies of which are available at Reclamation's regional office in Billings, Montana upon request:

[4] The cost estimates for other expansion options is provided in *Republican River Basin Appraisal-Level Engineering and Cost Estimates on Structural Alternatives, Technical Memorandum No. RRB-8130-BSA-2014-1*. Prepared by the Bureau of Reclamation, Technical Service Center, August 2014.

1. *Memorandum of Agreement No. R12MA60094* and *Plan of Study* on the Republican River Basin Study. Prepared by Reclamation and the States of Colorado, Nebraska, and Kansas, November 2012.

2. *Republican River Basin Appraisal-Level Engineering and Cost Estimates on Structural Alternatives, Technical Memorandum No. RRB-8130-BSA-2014-1*. Prepared by the Bureau of Reclamation, Technical Service Center, August 2014.

3. *Nebraska Modeling Methods for the Republican River Basin Study Project*. Prepared by the State of Nebraska, May 2015.

4. *Nebraska Modeling Results for the Republican River Basin Study Project*. Prepared by the State of Nebraska, May 2015.

5. *Integrated Groundwater/Surface Water Model for the Lower Republican River Basin, Kansas: A Progress Report*. Prepared by the Kansas Geological Survey and Kansas Water Office, February 2015.

6. *Republican River Basin Study: Kansas Modeling Results Technical Memorandum*. Prepared by the Kansas Geological Survey and Kansas Water Office, May 2015.

7. *Republican River Basin Study: Summary of Sub-Basin Model Coordination, Technical Memorandum No. 86-68210-2015-04*. Prepared by the Bureau of Reclamation, Technical Service Center, May 2015.

8. *Climate Change Analysis for the Republican River Basin Study, Technical Memorandum No. 86-68210-2015-07*. Prepared by the Bureau of Reclamation, Technical Service Center, June 2015.

9. *Economics Technical Report for the Republican River Basin Study, Technical Memorandum No. EC-2015-02*. Prepared by the Bureau of Reclamation, Technical Service Center, June 2015.

Each technical memorandum underwent a technical sufficiency review pursuant to Reclamation's Directives and Standards WTR TRMR-65 on Basin Studies to ensure that the technical information, data, models, analyses, and conclusions were technically supported and defensible. Reviews were conducted by reviewers who had relevant expertise and were not directly involved with conducting the portion of the Basin Study they were reviewing. Details are provided in Section 2.6 of the Basin Study Report.

IV. Current Climate Conditions

The section below describes the spatial and temporal variability of climate conditions in terms of precipitation and temperature. Details are provided in Section 3.0 of the Basin Study Report.

A. Current Precipitation

Climate conditions in the Basin exhibit an east-west moisture gradient, with wetter conditions in the eastern portion of the Basin and semiarid conditions in the western portion. Historical annual mean precipitation ranged from more than 35 inches per year near the eastern extent of the Basin in Kansas to less than 12 inches per year near the western extent of the Basin in Colorado. While the east-west precipitation gradient is evident in all seasons, it is strongest during summer, with average summer precipitation greater than 15 inches in the eastern portion of the Basin in Kansas and less than 5 inches in the western portion of the Basin in Colorado. Climate conditions also exhibit strong seasonal variability with hot, wet summers and cold, dry winters. The Basin typically receives most of its precipitation during spring and summer, with approximately 70% of the annual total precipitation occurring between April and September. Figures are provided in Section 3.1 of the Basin Study Report.

B. Current Temperature

Similar to precipitation, temperatures in the Basin exhibit a strong east-west gradient. Annual mean temperature ranges from less than 48 degrees Fahrenheit (°F) in the west to approximately 55 °F in the east. Seasonal temperature variability is also similar to precipitation, with large temperature variations consistent with cold winters and hot summers over the region. Seasonal variability of mean annual temperatures is also large, similar to seasonal variability of precipitation. Figures are provided in Section 3.1 of the Basin Study Report.

V. Future Climate Conditions

Analysis of future climate variability and change, and their corresponding implications for basin hydrology and water resources, requires reliable projections of future climate conditions. Projections of future climate are developed primarily through the use of global climate models (GCMs; also referred to as general circulation models). GCMs simulate large-scale weather and climate conditions over the globe and are used to simulate natural climate variability as well as the climate response to specified changes, including changes in atmospheric greenhouse gas concentrations. Using models, these conditions can then be scaled down to a smaller geographic area to evaluate future climate conditions on a basin-level scale. Details on the methods used to develop climate projections for the Republican River Basin are provided in Section 3.2 of the Basin Study Report.

A. Future Precipitation

Median (central tendency) projections predict that precipitation over the Basin will slightly increase (by about 5%) over the 21st century, with increases occurring during the fall and winter and with little change in spring and summer. Results, including figures, of each climate simulation are provided in Section 3.2.2.2 of the Basin Study Report.

B. Future Temperature

Median (central tendency) projections predict that temperatures in the Basin will increase significantly over the 21th century. Projected trends are largest during summer (> 3.5 °F) and smallest during winter (> 2 °F). Annual mean temperature is projected to increase by approximately 3.5 °F over the entire Basin. Results, including figures, of each climate simulation are provided in Section 3.2.2.3 of the Basin Study Report.

C. Selection of Climate Scenarios for Detailed Analysis

Depending on the preferences of a given study, the development of future climate scenarios may involve pooling of individual climate projections based on specified criteria or selection of individual climate projections for use as representative climate scenarios. Previous studies by Reclamation have explored the advantages and disadvantages of each approach. For this study, climate scenarios were developed based on three individual climate projections selected directly from projection archives as inputs to the hydrologic, water operations, and economic modeling tools used in the study (Table 1).

Table 1. — Water availability, temperature, and precipitation projections associated with three climate scenarios evaluated in the Republican River Basin

Name	Climate Condition	Mean Annual Water Availability	Mean Annual Temperature	Mean Annual Precipitation
Scenario 1	Warmer/Drier	-0.20 in (-33%)	+5.2 °F	-3.5 in (-17%)
Scenario 2	Central Tendency	+0.01 in (+10%)	+3.5 °F	+0.9 in (+5%)
Scenario 3	Less Warm/Wetter	+0.60 in (+89%)	+2.9 °F	+4.1 in (+21%)

VI. Current and Future Water Supplies and Demands

A. Water Supplies

1. Description of Basin Water Supplies

Water supplies in the Republican River Basin include a combination of surface water and groundwater. Surface waters throughout the basin are managed primarily for agricultural uses and flood control. Groundwater throughout the basin is managed for agricultural, municipal, and industrial uses. The primary surface water supplies within the Republican River Basin were illustrated previously in Figure 1. Surface water is primarily managed for flood control and irrigation supply, and used largely for irrigated agriculture in the alluvial valleys bordering much of the Republican River and its tributaries in Nebraska and Kansas. The Ogallala Aquifer is the primary groundwater supply throughout most of the basin. Groundwater is the primary water supply for most of the irrigated agriculture in the basin, and the sole supply for municipal, industrial, and domestic uses throughout most the basin.

Surface water and groundwater resources within the basin are managed by each of the basin States: water management, use, and administration are subject to the laws and regulations of each respective state. In addition, the Republican River is subject to the Republican River Compact, an interstate compact that allocates the water supply of the basin among the States. Following litigation in the U.S. Supreme Court, the States entered into a Final Settlement Stipulation, approved by the U.S. Supreme Court in 2003. Under the Final Settlement Stipulation, most stream flow depletions caused by surface water and groundwater diversions for beneficial consumptive use are included in the determination and allocation of the virgin water supply of the Basin. As a result, interaction between groundwater and surface water is a key component of water management within the basin.

2. Approach to Water Supply Analysis

As described in the *System Reliability and Impact Analysis* section below, modeling and analysis of current and future water supplies were carried out at the sub-basin scale, with each State leading the development of modeling tools and related datasets for its respective portion of the basin. Basin-scale analysis was then carried out by integrating results across sub-basins. This sub-basin modeling approach was selected by the Basin Study partners to facilitate the use of best-available data, tools, and expertise in modeling and evaluating current and future water supplies and demands and system reliability, as well as in developing and evaluating management alternatives to improve water operations throughout the basin. For the purpose of this study, the Republican River Basin was divided into four sub-basins (Figure 2). Details of the sub-basin modeling approach are provided in Section 4.1.2 of the Basin Study Report. Current groundwater supplies in the Colorado, Upper Kansas, and Nebraska sub-basins were characterized based on computed groundwater recharge in each of these sub-basins.

New modeling tools and detailed evaluations on system reliability and associated adaptation strategies were conducted on the Nebraska and lower Kansas sub-basins. These tools simulate the hydrology and water operations of these sub-basins and provide the basis for detailed analysis of current and future water supplies and demands, as well as for an analysis of system reliability under various alternatives and under a range of projected future climate scenarios.

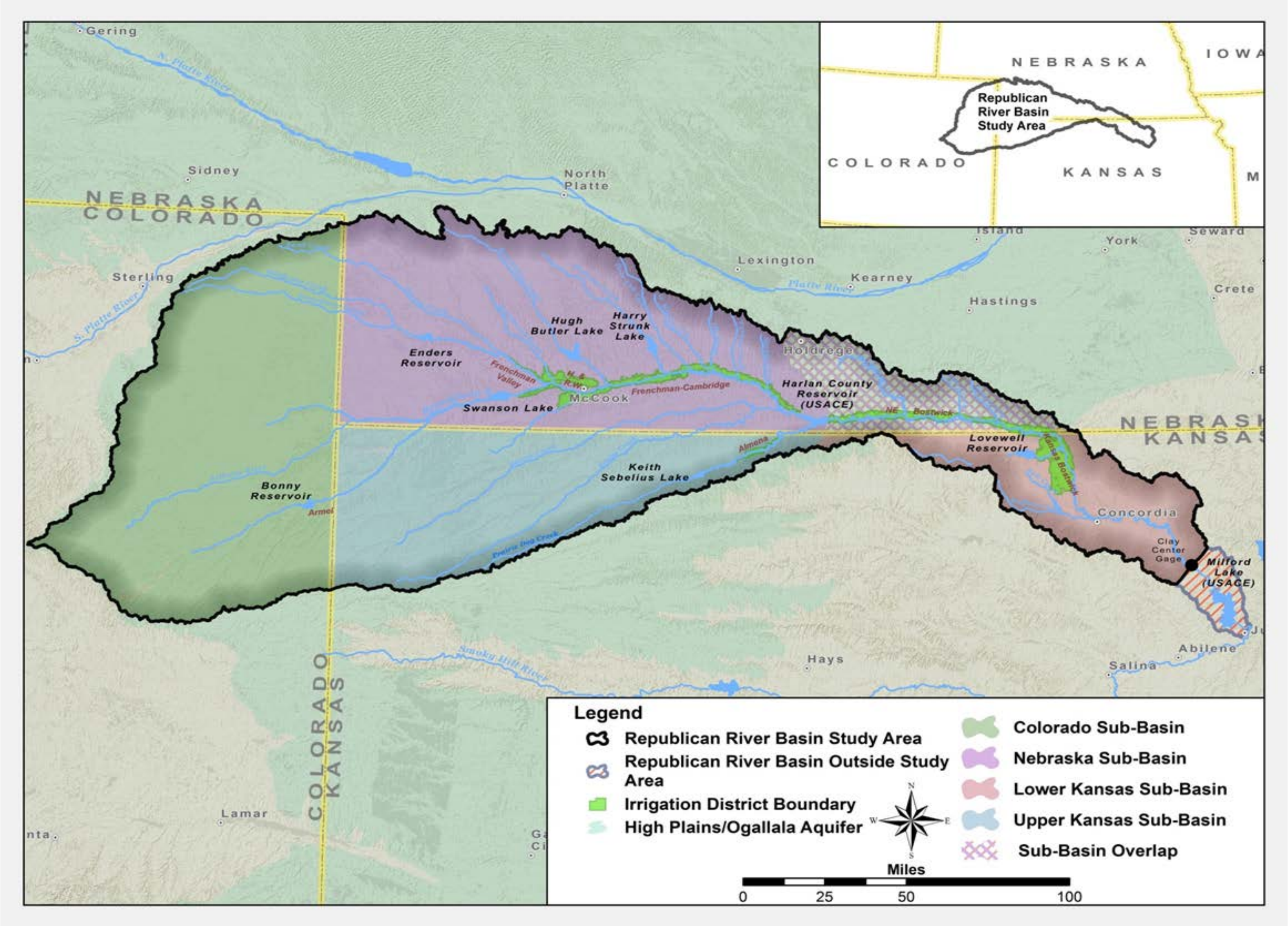


Figure 2. — Republican River Sub-Basins

3. Current Surface Water Availability

a. *Colorado Sub-Basin*

For the purposes of this study, current surface water availability in the Colorado sub-basin is characterized based on the sum of annual streamflows out of the sub-basin, annual gross diversions within the sub-basin, and the annual net change in reservoir storage in the sub-basin for the period 1995-2010. In Figure 3, outflows are summed over the sub-basin's three primary tributaries: North Fork Republican River, Arikaree River, and South Fork Republican River. The Colorado sub-basin includes one storage facility, Bonny Reservoir on the South Fork Republican River. The annual surface water supply in the sub-basin ranges from 30,050 AF to 55,100 AF, with an average of 38,500 AF for the period shown. Surface diversions make up a very small portion of the total water use in the Colorado sub-basin and were therefore not included in this analysis. Details are provided in Section 4.1.3 of the Basin Study Report.

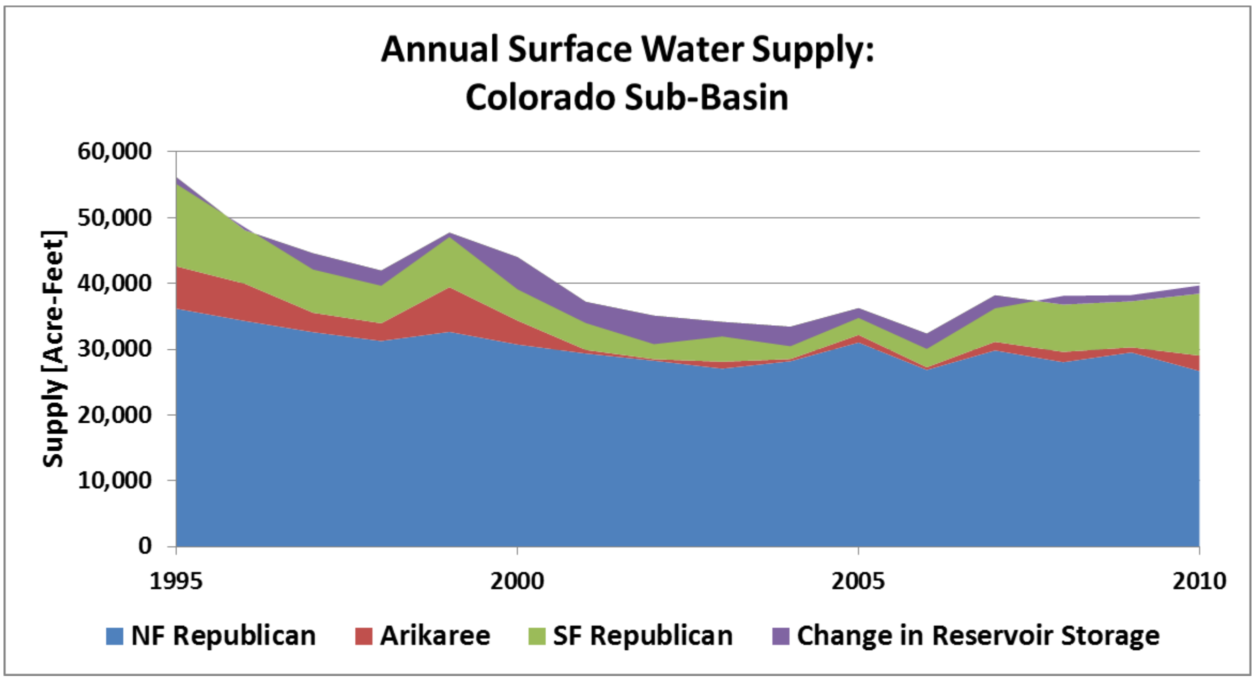


Figure 3. — Annual surface water supply in the Colorado sub-basin for years 1995-2010

b. *Upper Kansas Sub-Basin*

For the purposes of this study, current surface water availability in the Upper Kansas sub-basin is characterized based on the sum of annual streamflows out of the sub-basin and the annual net change in reservoir storage in the sub-basin for the period 1995-2010. In Figure 4, outflows are summed over the sub-basin's four primary tributaries: South Fork Republican River, Beaver Creek, Sappa Creek, and Prairie Dog Creek. The Upper Kansas sub-basin includes one storage facility, Keith Sebelius Reservoir on Prairie Dog Creek, which serves irrigation demands in the Almena Unit and municipal demands for the city of Norton, Kansas. Similar to current conditions in the Colorado sub-basin, the majority of surface water rights in the Upper Kansas sub-basin have been abandoned, retired, or leased; as a result, annual surface water diversions in the sub-basin are very small and not included in this analysis. The annual surface water supply in the sub-basin ranges from a minimum of just 1,032 AF to a maximum of 126,462 AF, with an average of 31,710 AF per year for the period shown. Details are provided in Section 4.1.3 of the Basin Study Report.

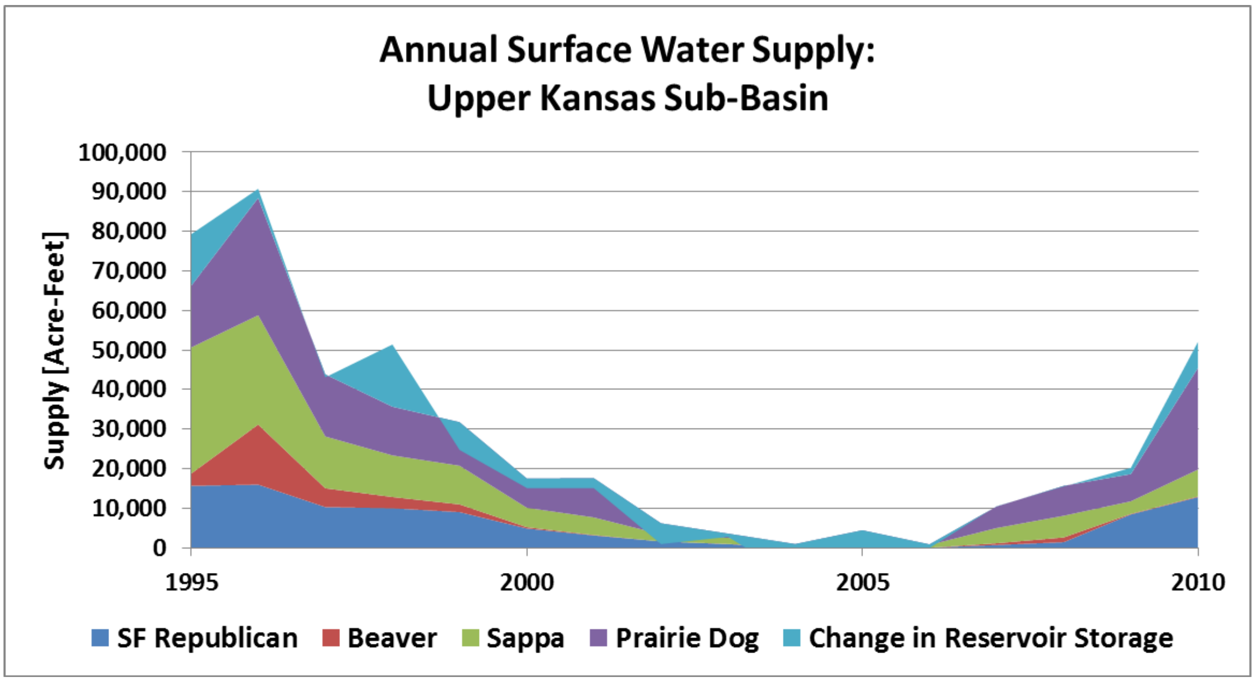


Figure 4. — Annual surface water supply in the Upper Kansas sub-basin for years 1995-2010

c. *Nebraska Sub-Basin*

Unlike the Colorado and Upper-Kansas basins, current surface water availability in the Nebraska sub-basin was characterized based on simulations of hydrology and water operations carried out by the state of Nebraska. Simulations represent all major surface water features within the sub-basin, including sixteen federal and non-federal canals and five federal storage facilities. Minor tributaries, diversions, and impoundments within the sub-basin are implicitly represented through the model’s stream gain and loss terms and are thus accounted for in the simulated surface water budget. A list of the components comprising diversions, storage, and outflow is provided in Table 5 within Section 4.1.3 of the Basin

Study Report. Surface water supplies in the Nebraska sub-basin range from approximately 132,000 to 650,750 AF, with an average of 337,232 AF per year. Republican River outflow from the Nebraska sub-basin to the Lower Kansas sub-basin is the largest component of surface water supply in most years. Outflow ranges from 72,000 to 483,400 AF, with an average of approximately 217,700 AF per year. Gross diversions within the basin range from a total of 21,600 to 280,750 AF per year and the annual change in reservoir storage ranges from a loss of 212,500 AF to a gain of 260,250 AF. Results are summarized in Figure 5.

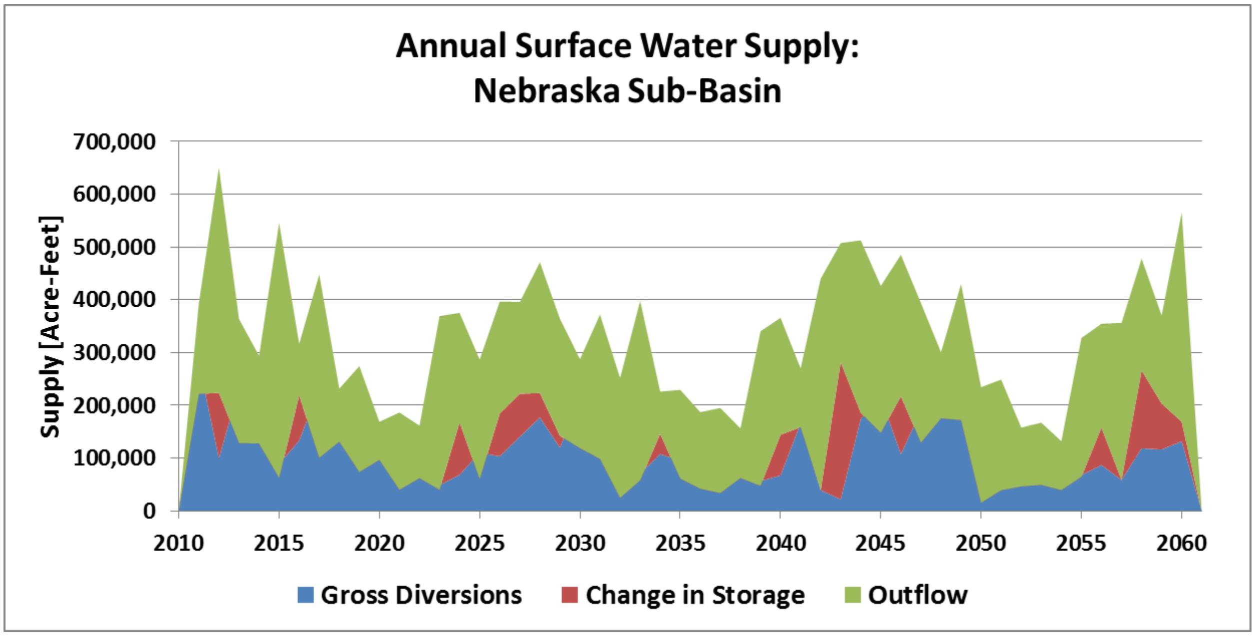


Figure 5. — Annual surface water supply in the Nebraska sub-basin based on model results from a 50-year simulation under the Baseline Scenario – No Action Alternative

d. *Lower Kansas Sub-Basin*

Similar to the Nebraska sub-basin, current surface water availability is characterized based on simulations of hydrology and water operations carried out by the State. In this case, a new modeling platform was developed based on the physical hydrology of the basin, including groundwater and surface water flows, with operations of all major surface water features within the sub-basin. Specific surface water supply components are listed in Table 6 within Section 4.1.3 of the Basin Study Report. Surface water supplies in this sub-basin range from approximately 135,000 to 2,850,000 AF, with an average of 651,150 AF per year. Republican River outflow from the sub-basin at Clay Center, Kansas, is by far the largest component of surface water supply. Outflow ranges from 87,350 to 2,815,000 AF, with an average of approximately 600,000 AF per year. Gross diversions range from a total of 10,300 to 95,850 AF per year and the annual change in reservoir storage ranges from a loss of 18,250 AF to a gain of 17,300

AF. Details are provided in Section 4.1.3 of the Basin Study Report. Results are shown in Figure 6.

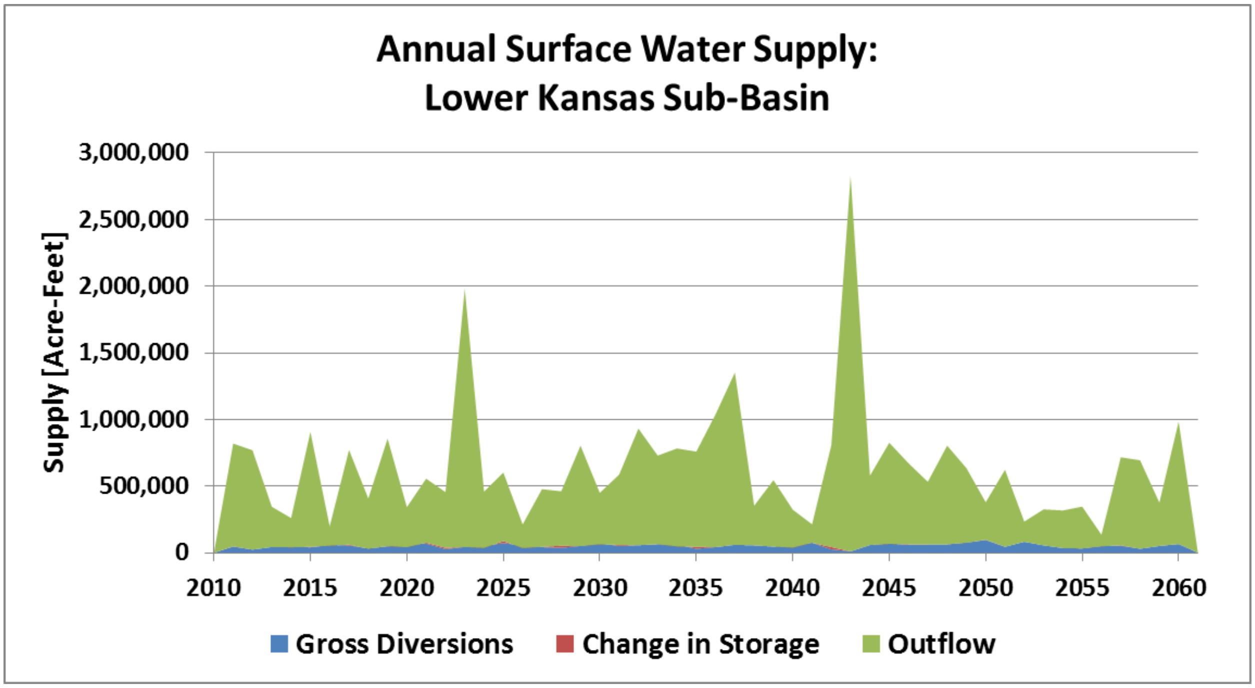


Figure 6. — Annual surface water supply in the Lower Kansas sub-basin based on model results from a 50-year simulation under the Baseline Scenario – No Action Alternative

4. Current Groundwater Availability

a. *Colorado Sub-Basin*

Current groundwater supply in the Colorado sub-basin was characterized based on the estimated annual recharge within the sub-basin. Recharge estimates were developed by the Republican River Compact Administration (RRCA) Groundwater Modeling Committee for use with the RRCA groundwater model and include the years 2001-2014. The average recharge rate over the sub-basin ranges from 0.48 to 3.28 inches, with an average of 1.19 inches per year. Annual gross recharge ranges from 200,000 to 1,350,000 AF, with an average of approximately 500,000 AF per year (Figure 7).

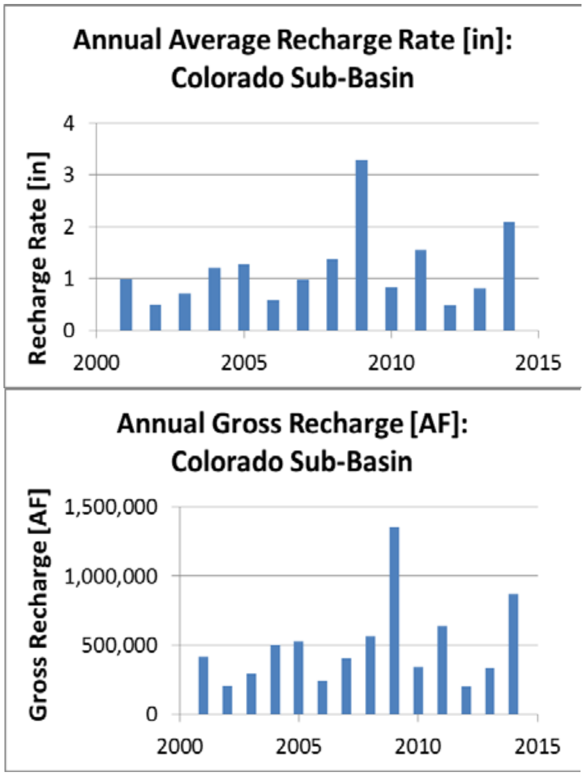


Figure 7. — Estimated annual average recharge rate (left) and annual gross recharge (right) over the Colorado sub-basin for the period 2001-2014

b. *Upper Kansas Sub-Basin*

Current groundwater supply in the Upper Kansas sub-basin was characterized based on estimated annual recharge within the sub-basin using the same approach as for the Colorado sub-basin. The average recharge rate over the sub-basin ranges from 0.22 to 1.47 inches, with an average of 0.60 inches per year. Annual gross recharge ranges from 58,000 to 385,000 AF, with an average of approximately 150,000 AF per year (Figure 8).

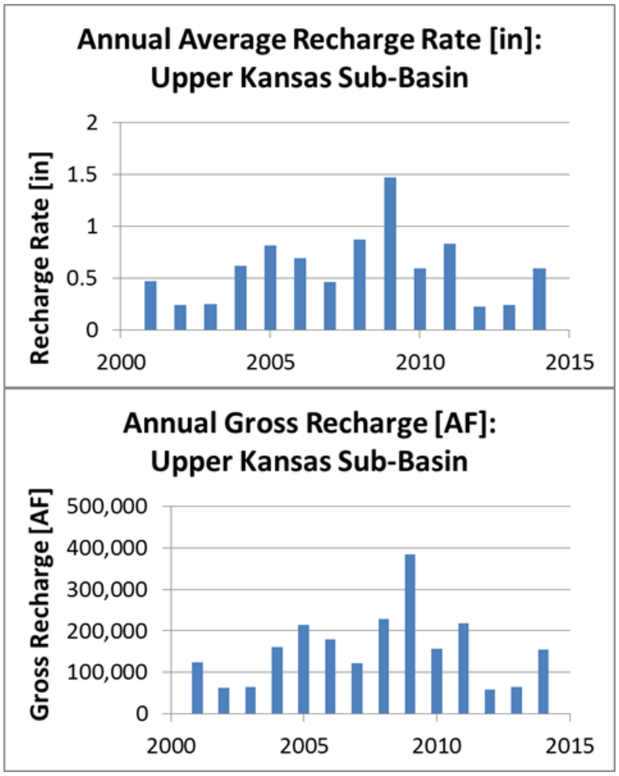
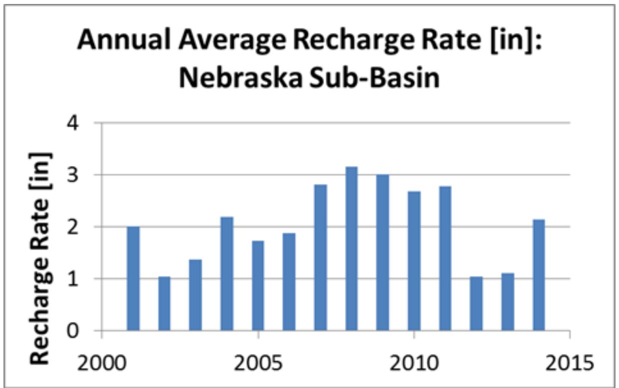


Figure 8. — Estimated annual average recharge rate (left) and annual gross recharge (right) over the Upper Kansas sub-basin for the period 2001-2014

c. *Nebraska Sub-Basin*

Current groundwater supply in the Nebraska sub-basin was characterized based on estimated annual recharge within the sub-basin using the same approach as for the Upper Kansas sub-basin. The average recharge rate over the sub-basin ranges from 1.03 to 3.16 inches, with an average of 2.07 inches per year. Annual gross recharge ranges from 520,000 to 1,600,000 AF, with an average of approximately 1,000,000 AF per year (Figure 9).



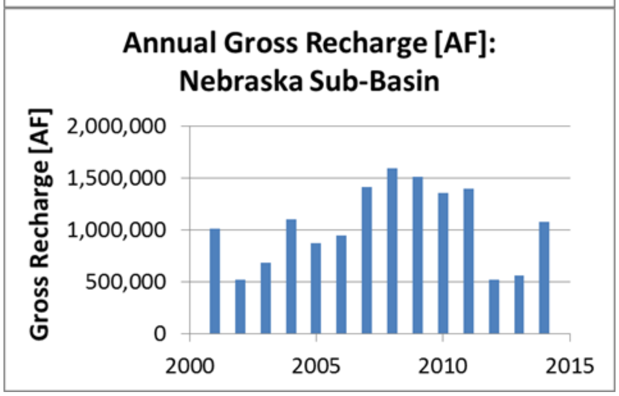


Figure 9. — Estimated annual average recharge rate (left) and annual gross recharge (right) over the Nebraska sub-basin for the period 2001-2014

d. *Lower Kansas Sub-Basin*

Unlike the sub-basins described above, this sub-basin lies outside of the RRCA modeling domain; therefore, current groundwater supply in the Lower Kansas sub-basin was characterized based on the estimated annual net recharge within the sub-basin that was developed based on model simulations of hydrology and water operations in the Lower Kansas sub-basin under the Baseline Scenario and No Action Alternative as described in Section 5.2 of the Basin Study Report. Estimated annual net recharge rate (inches) and annual net recharge (acre-feet) over the Lower Kansas sub-basin are shown in Figure 10. Annual net recharge rate averaged over the sub-basin ranges from a minimum of -4.5 inches to a maximum of 12.9 inches, with an average of 4.2 inches per year; annual net recharge aggregated over the sub-basin ranges from -580,000 AF to 1,650,000 AF, with an average of approximately 550,000 AF per year.

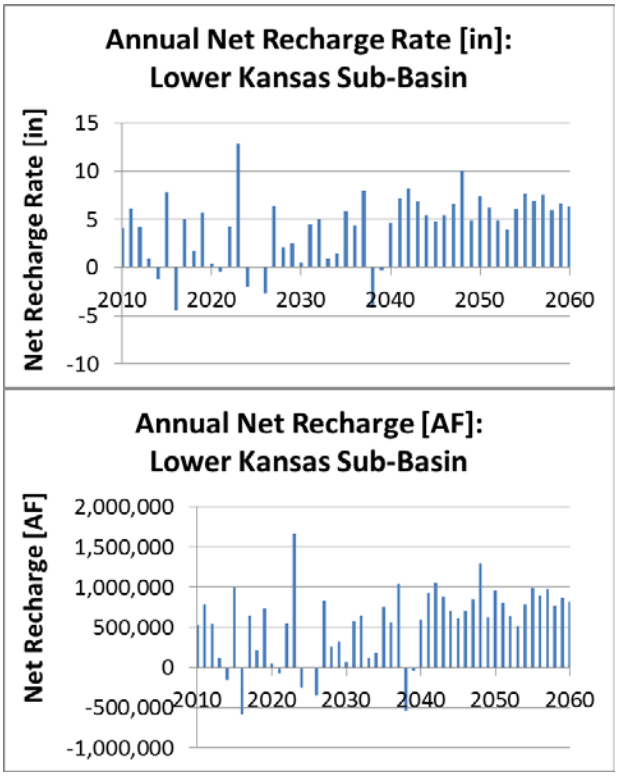


Figure 10. — Estimated annual net recharge rate (left) and annual net recharge (right) over the Lower Kansas sub-basin for a 50-year simulation under the Baseline Scenario and No Action Alternative

5. Effects of Climate Variability and Change on Supply

Future ground and surface water supplies in each sub-basin were evaluated for each of the three future climate scenarios considered in the Basin Study. The three future climate scenarios encompass the range of projected changes in climate and water availability over the basin between a historical reference period (1970-1999) and selected future period (2030-2059). Overall, with the exception of the Lower Kansas sub-basin, surface water supplies across the basin are projected to decrease under Scenario 1 (warmer and drier) and increase under Scenario 3 (less warm and wetter). The effects on groundwater supplies, driven by precipitation and recharge, vary across the basin. Additional details on data, models, and methods used are provided in Section 4.1.5 in the Basin Study Report.

6. Future Surface Water Availability

a. *Colorado Sub-Basin*

Surface water supplies in the Colorado sub-basin are projected to decrease under Scenario 1 (warmer and drier) and increase substantially under Scenario 3 (less warm and wetter), with little change under Scenario 2 (central tendency). Details are provided in Table 2 below.

Table 2. — Projected Percent Change in Minimum, Average, and Maximum Annual Surface Water Supply in Primary Tributaries of the Colorado Sub-Basin Under Future Climate Scenarios

	Scenario 1 (Warmer + Drier)	Scenario 2 (Central Tendency)	Scenario 3 (Less Warm + Wetter)
	Projected Change in Minimum Annual Streamflow		
NF Republican	-7.1%	-4.1%	+9.4%
Arikaree	-14.5%	-1.5%	+11.2%
SF Republican	-29.0%	-0.5%	+36.4%
Sub-Basin Total	-6.0	-3.5%	+7.0%
	Projected Change in Average Annual Streamflow		
NF Republican	-7.6%	-2.0%	+24.9%
Arikaree	-17.6%	+6.8%	+56.4%
SF Republican	-18.0%	+2.7%	+43.3%
Sub-Basin Total	-7.3%	-1.24%	+22.3%
	Projected Change in Maximum Annual Streamflow		
NF Republican	-8.4%	+6.6%	+65.4%
Arikaree	-21.4%	+23.6%	+84.8%
SF Republican	-26.2%	+30.6%	+95.2%
Sub-Basin Total	-10.0%	+8.6%	+56.3%

b. *Upper Kansas Sub-Basin*

Similar to the Colorado sub-basin, surface water supplies in the Upper Kansas sub-basin are projected to decrease substantially under Scenario 1 (warmer and drier) and increase substantially under Scenario 3 (less warm and wetter). In contrast to the Colorado sub-basin, however, surface water supplies are projected to increase substantially under Scenario 2 (central tendency). Details are provided in Table 3 below.

Table 3. — Projected Percent Change in Minimum, Average, and Maximum Annual Surface Water Supply in Primary Tributaries of the Upper Kansas Sub-Basin Under Future Climate Scenarios

	Scenario 1 (Warmer + Drier)	Scenario 2 (Central Tendency)	Scenario 3 (Less Warm + Wetter)
	Projected Change in Minimum Annual Streamflow		
SF Republican	0.0%	0.0%	0.0%
Beaver Creek	-11.2%	-2.0%	+37.7%
Sappa Creek	-21.1%	+1.45%	+30.9%
Prairie Dog Creek	-6.0%	-6.9%	+21.8%
Sub-Basin Total	-12.6%	+1.3%	+34.7%
	Projected Change in Average Annual Streamflow		
SF Republican	-4.8%	-5.6%	+70.7%
Beaver Creek	-9.4%	+15.5%	+171.3%
Sappa Creek	-8.0%	+34.1%	+158.8%
Prairie Dog Creek	-13.6%	+47.5%	+226.8%
Sub-Basin Total	-9.5%	+28.2%	+165.5%
	Projected Change in Maximum Annual Streamflow		
SF Republican	+34.6%	+6.5%	+116.3%
Beaver Creek	-12.2%	+19.4%	+200.4%
Sappa Creek	-5.5%	+56.2%	+199.3%
Prairie Dog Creek	-28.1%	+79.0%	+318.4%
Sub-Basin Total	-20.5%	+45.0%	+216.3%

c. *Nebraska Sub-Basin*

The total surface water supply in the Nebraska sub-basin is projected to decrease moderately under Scenario 1 (warmer and drier) and increase under Scenarios 2 and 3 (central tendency and less warm and wetter, respectively). Details are provided in Table 4 below.

Table 4. — Projected Percent Change in Minimum, Average, and Maximum Annual Surface Water Supply Components in the Nebraska Sub-Basin Under Future Climate Scenarios

	Scenario 1 (Warmer + Drier)	Scenario 2 (Central Tendency)	Scenario 3 (Less Warm + Wetter)
	Projected Change in Minimum Annual Streamflow		
Gross Diversions	-10.4%	-2.8%	-71.8%
Change in Storage	-27.6%	-3.9%	-43.1%
Sub-Basin Outflow	-1.8%	+1.7%	+29.2%
Sub-Basin Total	-15.5%	-2.0%	+57.9%
	Projected Change in Average Annual Streamflow		
Gross Diversions	-14.4%	+14.2%	+30.9%
Change in Storage	-51.1%	-9.5%	-11.8%
Sub-Basin Outflow	-4.7%	+7.3%	+74.7%
Sub-Basin Total	-8.2%	+9.7%	+59.1%
	Projected Change in Maximum Annual Streamflow		
Gross Diversions	+7.1%	+14.3%	-1.8%
Change in Storage	+9.2%	-20.9%	-43.1%
Sub-Basin Outflow	-14.9%	+19.0%	+104.1%
Sub-Basin Total	-17.0%	+16.6%	+72.9%

d. *Lower Kansas Sub-Basin*

The total surface water supply in the Lower Kansas sub-basin is projected to increase slightly under Scenarios 1 and 2 (warmer and drier and central tendency, respectively) and increase moderately under Scenario 3 (less warm and wetter). Increases under Scenario 1 result from a large projected increase in precipitation over the Lower Kansas sub-basin, despite a projected decrease in basin-average precipitation under this scenario. Details are provided in Table 5.

Table 5. — Projected Percent Change in Minimum, Average, and Maximum Annual Surface Water Supply Components in the Lower Kansas Sub-Basin Under Future Climate Scenarios

	Scenario 1 (Warmer + Drier)	Scenario 2 (Central Tendency)	Scenario 3 (Less Warm + Wetter)
	Projected Change in Minimum Annual Streamflow		
Gross Diversions	+60.0%	-14.9%	-100.0%
Change in Storage	+0.2%	+0.6%	-1.1%
Sub-Basin Outflow	+55.4%	+59.8%	+81.1%
Sub-Basin Total	+24.9%	+21.6%	+36.8%
	Projected Change in Average Annual Streamflow		
Gross Diversions	+36.9%	+6.8%	-20.1%
Change in Storage	-19.7%	-11.7%	-69.9
Sub-Basin Outflow	-2.3%	+0.3%	+15.2%
Sub-Basin Total	+.08%	+.08%	+12.4%
	Projected Change in Maximum Annual Streamflow		
Gross Diversions	-1.2%	+8.8%	-5.0%
Change in Storage	+6.1%	+2.3%	-1.1%
Sub-Basin Outflow	-0.2%	+7.6%	+19.8%
Sub-Basin Total	+0.3%	+7.5%	+19.4%

7. Future Groundwater Availability

As described previously in this chapter, groundwater supplies in the Colorado, Upper Kansas, and Nebraska sub-basin are characterized based on estimated annual recharge in each sub-basin, while groundwater supplies in the Lower Kansas sub-basin are characterized based on estimated annual net recharge. Previous studies suggest that recharge from precipitation is the dominant component of recharge throughout the basin in most years (RRCA 2003[5]), with recharge from surface water conveyance and from deep percolation of surface water irrigation also contributing to recharge in the Nebraska sub-basin. Deep percolation of groundwater irrigation also contributes to recharge in all three sub-basins.

Projected changes in precipitation suggest that precipitation recharge is likely to decrease in the Colorado and Upper Kansas sub-basins under Scenarios 1 and 2, with little change under Scenario 3. Precipitation recharge is likely to increase in the Nebraska sub-basin under Scenarios 2 and 3, with little change under Scenario

[5] http://www.republicanrivercompact.org/v12p/RRCAModelDocumentation.pdf

1. Precipitation recharge is likely to increase to varying degrees over the Lower Kansas sub-basin under all scenarios, as all three scenarios project increased precipitation over the sub-basin. The effects of changes in surface water diversions, and corresponding seepage and deep percolation, on the total amount of recharge in each sub-basin is likely to be much smaller than the effects of changes in precipitation.

B. Water Demands

1. Description of Basin Water Demands

Irrigation is by far the dominant water demand throughout the basin. The basin contains over
2.7 million acres of irrigated agriculture. Corn is the dominant crop throughout the basin, along with soybeans, alfalfa, sorghum, and a variety of other crops. As described in the previous section, irrigation demand is met by a combination of surface water and groundwater, with groundwater being the dominant supply in all sub-basins. Non-irrigation Municipal and Industrial (M&I) demands currently make up a small fraction of the total water demands in each sub-basin and are projected to remain at current levels in the future. For these reasons, non-irrigation demands are not discussed in detail.

2. Approach to Water Demand Analysis

Current water demands within each sub-basin were characterized based on county-level estimates of irrigated acreage and net irrigation requirement (NIR) during the period 2003-2008. NIR is the amount of water that must be applied by irrigation (in addition to precipitation and soil moisture) to provide enough water for the crop to grow effectively. These data were selected for this analysis because they were previously compiled by the RRCA groundwater modeling team for use in developing and verifying inputs to the RRCA groundwater model.

3. Current Water Demands

Irrigated acreage, area-weighted NIR (the amount of water used to irrigate each acre in inches), and annual total NIR (acre-feet) are provided in Table 6 for each sub-basin.

Table 6. — Irrigated acreage, annual area-weighted NIR, and total annual NIR for each sub-basin

Sub-Basin	2003	2004	2005	2006	2007	2008	Average
Annual Irrigated Acreage (acres)							
Colorado	572,649	572,378	577,953	572,409	549,199	N/A	568,918
Upper Kansas	532,180	466,467	456,490	459,387	472,745	431,160	469,738
Nebraska	N/A[1]	1,360,645	1,102,484	1,167,813	1,068,118	1,030,543	1,145,921
Lower Kansas	74,475	74,445	97,323	94,015	106,723	106,642	92,271
Annual Area-Weighted NIR (inches)							
Colorado	19.9	16.3	16.0	17.0	15.1	N/A	16.9
Upper Kansas	16.4	14.7	14.3	14.5	14.8	13.6	14.7
Nebraska	N/A	14.0	15.0	14.2	12.6	10.6	14.0
Lower Kansas	9.0[2]	9.0[2]	9.2[2]	9.2[2]	9.2[2]	9.2[2]	9.1
Annual Total NIR (acre-feet)							
Colorado	947,706	777,269	771,365	811,389	691,785	N/A	799,903
Upper Kansas	532,180	466,467	456,490	459,387	472,745	431,160	469,738
Nebraska	N/A	1,588,635	1,378,769	1,385,438	1,121,264	911,202	1,588,635
Lower Kansas	55,804	55,733	74,502	72,112	82,171	82,149	70,412

1 Data not available.
2 Annual NIR estimated from median NIR values obtained from NRCS (2014) and annual cropping data provided by the State of Kansas.

4. Effects of Climate Variability and Change on Demands

Future demands in each sub-basin were evaluated for each of the three future climate scenarios considered in the Basin Study. Future NIR was calculated for surface-water irrigation districts in the Nebraska sub-basin by the state of Nebraska using a CropSIM crop water use model. NIR in the lower Kansas sub-basin was calculated using NIR data obtained from NRCS (2014). The different approaches by each state to calculate NIR yielded differing demand results described below. Details are provided in Section 5.2.1 of the Basin Study Report.

a. *Future Water Demands*

For Nebraska, the average NIR for canal service areas across FCID and NBID increases by 6.9% under Scenario 1 due to a combination of temperature-driven increase in evaporative demand and decreased precipitation. Average NIR decreases by 8.8% under Scenario 2 and decreases by 20.9% under Scenario 3. When applying district acreages and applying an area weighted average, the NIR decreases by 21% for Scenario 1 and increases by 15% and 44% for Scenarios 2 and 3, respectively. This result is based on Nebraska's modeling approach which estimates irrigated acreage based on available supply (i.e., more water is available under the cool/wet scenario, so acreage is increased and total demand [acres x NIR] increases). Under Scenario 1, acreage is reduced due to low supply, resulting in a decrease in overall demand. For Kansas, irrigated acreage was held constant, leaving temperature-driven evapotranspiration and precipitation as direct drivers of NIR. Under Scenario 1, average KBID NIR increases by 41.4%. Average NIR increases by 9.3% under Scenario 2 and decreases by 22.1% under Scenario 3. These results explain the changes in water deliveries provided in Table 4 below in the *System Reliability and Impact Analysis* Section.

C. Water Supply Imbalances

Water supply imbalances occur when available supplies are not sufficient to meet demands. Water supply imbalances may occur due to physical or institutional constraints. Physical water supply imbalances occur when water demands in a given area exceed the quantity of water that is physically available in that area; the imbalances may result from insufficient water availability in a specific area, or from the lack of infrastructure to convey sufficient water to that area (e.g., insufficient capacity of a canal, pipeline, or groundwater well). Institutional water supply imbalances occur when water demands in a given area exceed the quantity of water that is legally available for use in that area under applicable federal, state, and local laws and regulations, including individual water rights as well as interstate compacts. Water supply imbalances ultimately occur at the local level due to imbalances between demands of individual water users and the supplies that are physically and legally available to meet those demands. As a result, imbalances may occur in one area of a basin or sub-basin while surpluses occur in other areas and at different points in time. This study assessed the effects of these imbalances as part of the system reliability analysis (next section). The system reliability analysis for the Nebraska sub-basin evaluates the effects of water supply imbalances based on irrigated acreage, irrigation diversions and deliveries, and the frequency of Compact Call Years[6]. The system reliability analysis for the Lower Kansas sub-basin evaluates the effects of water supply imbalances based on irrigation diversions and deliveries to KBID above and below Lovewell Reservoir. These results, combined with each partners' specific objectives, helped inform the adaptive strategies ultimately selected for further analyses.

[6] During Compact Call Years, special provisions are imposed on reservoir releases and canal diversions throughout the Nebraska portion of the basin to ensure that compact compliance is achieved.

VII. System Reliability and Impact Analysis

Section 9503(b)(3) of P.L. 111-11 requires an analysis 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 (including extreme events such as floods and droughts) and population growth, including an analysis of the extent to which changes in the water supply will impact Reclamation operations and facilities.

This analysis is typically performed on what is commonly called the "No Action Alternative", which represents the future condition if no strategies were undertaken to address water supply needs. It entails an analysis of how the No Action Alternative is affected by various future climate conditions. A summary is provided below. Details are provided in Section 5.0 of the Basin Study Report.

A. No Action – Future without Adaptation Strategies

In general, the No Action Alternative is used to assess system performance of existing and anticipated water infrastructure and operations under current and future conditions, including projected climate change impacts on water supply and demand. Anticipated actions include those that are currently in place, which represent current water resource development in the Basin, and those actions that have been approved or are in the process of being implemented.

The No Action Alternative serves as the baseline for evaluating changes in system performance and associated benefits for evaluating proposed structural and non-structural alternatives. It defines a specific level of development (fixed infrastructure) and associated operating practices (fixed operating conditions), but may differ from current or existing conditions in that it includes infrastructure or operation practices that are approved or being implemented but not yet in place. Simulation of the No Action Alternative under historical conditions may differ from actual historical operations in that the No Action Alternative assumes a fixed infrastructure and operating conditions, whereas, in reality, infrastructure and operations have changed over time.

For the purposes of this study, a No Action Alternative was constructed to represent future conditions over the 2011 to 2060 time period in which current management practices were maintained. Details regarding No Action assumptions for each state are provided in Section 5.1 of the Basin Study Report.

B. Approach to System Reliability Analysis

The analysis of system reliability focuses on surface water operations and deliveries throughout the Basin to meet the Republican River Compact requirements. No significant surface water operations occur within the Colorado or Upper Kansas sub-basins; water demands in these sub-basins are met almost exclusively by groundwater. Detailed analysis of system reliability is therefore limited to the Nebraska and Lower Kansas sub-basins.

System reliability was analyzed by simulating surface water operations within each sub-basin under the No Action Alternative, described above. Simulations were carried out for four scenarios: a Baseline Scenario representing current climate and hydrologic conditions in the Basin, and three future climate scenarios representing the range of projected future climate conditions in the Basin.

In order to simulate surface water operations in the Basin, new modeling tools and related datasets were developed for the Nebraska and Lower Kansas sub-basins. Modeling and analysis were carried out at the sub-basin scale, with each State leading the development of modeling tools and related datasets for its respective portion of the Basin. This sub-basin modeling approach was selected by the Basin Study partners to facilitate the use of best-available data, tools, and expertise in modeling and evaluating current and future water supplies and demands and system reliability, as well as in developing and evaluating management alternatives to improve water operations throughout the Basin. As detailed in the Basin Study Report, despite differences in the modeling approaches and implementation, modeling tools developed for the Nebraska and Lower Kansas sub-basins provide a consistent representation of hydrology and water operations in the Basin. This was accomplished through extensive collaboration between states to consistently represent water supplies, demands, and operations in their individual sub-basin modeling tools for the portion of the Basin from Harlan County Lake to the Nebraska-Kansas state line, an area referred to as the "sub-basin overlap region" (Reclamation 2015c).

A brief synopsis of sub-basin models follows.

C. Modeling Approach for Nebraska Sub-Basin

Models for the Nebraska sub-basin are documented in Section 5.2.1 of the Basin Study Report and in more detail in a technical memorandum prepared by The Flatwater Group, Inc., a technical consultant to the State of Nebraska (TFG 2015a). First, the CropSIM crop water use model was applied to evaluate net irrigation requirements for surface-water irrigation districts within the Nebraska sub-basin. Second, a new water operations model was developed using the Systems Thinking Environment and Learning Laboratory Approach (STELLA) modeling platform to simulate surface water supplies, demands, and operations in the sub-basin under current and projected future conditions. STELLA is a generalized software tool for modeling a broad range of dynamic systems and has been widely used in fields ranging from biology to economics to water resources management. The STELLA model developed and used in this Basin Study is referred to as the STELLA Operations Republican River Model (STORRM). STORRM represents the physical and operational components of the Republican River Basin in Nebraska and simulates operation of six federal reservoirs and diversions to 16 federal and private canals, as well as tributary inflows and reach gains and losses throughout the sub-basin.

D. Modeling Approach for Lower Kansas Sub-Basin

Models for the Kansas sub-basin are documented in Section 5.2.2 of the Basin Study Report and in more detail in a technical memorandum prepared the Kansas Geological Survey and Kansas Water Office (KGS and KWO 2015b). In order to simulate hydrologic conditions in the sub-basin, an integrated groundwater/surface-water model was developed using the HydroGeoSphere (HGS) modeling software. HGS was selected for use in this study by KGS based on the model's demonstrated ability to simulate complex interactions and feedbacks between surface water and groundwater under varying climate conditions. In addition to the HGS model, a water operations model was developed to simulate surface water operations within the Lower Kansas sub-basin using the Operational Analysis and Simulation of Integrated Systems (OASIS) modeling software (Hydrologics 2009). For the purposes of this Basin Study, OASIS is linked with HGS to allow for interactions between groundwater and surface water management and use within the sub-basin.

E. Impacts of Climate Variability and Change under No Action

Each state selected metrics it believed important in evaluating impacts of the No Action Alternative on system reliability evaluating impacts of action alternatives. Table 4 below displays various metrics evaluated for the system reliability analysis. System reliability analysis for the Nebraska sub-basin evaluates the effects of water supply imbalances based on irrigation diversions and deliveries, net farm income, and the frequency of Compact Call Years. The system reliability analysis for the Lower Kansas sub-basin evaluates the effects of water supply imbalances based on irrigation diversions and deliveries, net farm income, and the magnitude and frequency of delivery shortages to KBID above and below Lovewell Reservoir. These results, combined with each partners' specific objectives, helped inform the adaptive strategies ultimately selected for further analyses.

1. Water Operations and Deliveries

It is important to note that the differences in water deliveries between Nebraska and Kansas are due to the different methodologies used to compute irrigation demands as described in *Section 5.2.1* of the Basin Study Report. Under Scenario 1, for example, irrigation deliveries decrease in Nebraska and increase in Kansas. For Nebraska, the modeling approach used to calculate irrigation demands assumes that irrigated acreage varies year to year depending on the available surface water supply: irrigated acreage in Nebraska decreases under Scenario 1 in response to decreases in surface water supply; this results in a decrease in overall demand and a corresponding decrease in deliveries. For Kansas, irrigated acreage is held constant in all years; irrigation demands in Kansas increase due to decreases in precipitation and increases temperature, both of which result in increased crop irrigation requirements. This increase in demand drives an increase in water deliveries, despite an overall decrease in surface water supply. The ability for Kansas to deliver additional water despite an overall decrease in surface water supply results from two factors: first, less water is released for flood control purposes during the non-irrigation season; second, the Kansas modeling approach assumes that KBID will exercise its option to purchase up to 60,000 AF of additional water from Harlan County Lake during Compact Call years if available. It should be noted that despite increases in irrigation deliveries to Kansas, the proportionate increase in demands exceeds the increase in deliveries, resulting in an increase in shortages.

Regarding water delivery shortages, Reclamation requires an assessment of water supply imbalances as part of the system reliability analysis for all basin studies. The modeling approach used for the Nebraska sub-basin calculates irrigated acreage within each canal service area prior to the irrigation season. Irrigated acreage is calculated based on the projected surface water supply available for the season and the historical relationship between surface water supply and irrigated acreage; in general, acreage is increased in years with high surface water supplies and decreased in years with low surface water supplies. The Nebraska model then simulates reservoir operations and surface water diversions and deliveries based on irrigation demands for the calculated acreage. To evaluate surface water imbalances, Reclamation staff used Nebraska's modeling results to calculate the amount of land irrigated relative to fully irrigated conditions, as well as the associated delivery shortage relative to what irrigation demands could potentially be for the fully irrigated condition. It is important to point out that this calculation is for hypothetical use only and is not representative of Nebraska's modeling approach.

The other metrics included in the table were selected by the study partners as a means of measuring how well an alternative meets each state's objectives. As previously discussed, Nebraska's objective is to maintain compliance with the Republican River Compact and Final Settlement Stipulation while maximizing water availability for all users, as measured in this study through their ability to deliver water to FCID and NBID. Kansas' objective is to secure Kansas' share of the water under the Republican River Compact while maximizing their ability to meet the demands for KBID. Table 7 below summarizes the results Further explanation on the selection and use of the other metrics in the table below is provided in *Section 7.1* and *Section 7.3* of the Basin Study Report for Nebraska and Kansas, respectively.

Table 7. — Results of the system reliability analysis evaluating impacts of future climate conditions on water deliveries in Nebraska and Kansas over a 50-year simulation period of 2011-2060

Metric (2011-2060)		**Climate Condition**			
		Baseline	**Scenario 1: Warmer/Drier**	**Scenario 2: Central Tendency**	**Scenario 3: Less Warm/Wetter**
Nebraska					
Water Delivered (Acre-In/Acre)		7.4	6.3	8.9	8.2
Acres Affected		45,521	30,847	53,953	75,504
No. of Compact Call Determinations		23	33	16	0
Harlan County Lake Levels (AF)		223,760	210,829	233,515	285,588
Courtland Canal Flows (AF)		41,268	43,027	43,818	38,272
FCID	FCID Irrigation Diversions (AF)	36,960	28,293	43,600	58,359
	Irrigated Acreage Reduction (No. of Years)	38	42	31	6
	Cumulative Irrigated Acres Reduced	1,000,500	1,287,500	695,000	54,500
	Delivery Shortage (No. of Years)	40	36	37	25
	Cumulative Delivery Shortage (AF)	122,000	200,500	888,500	2,000
NBID	NBID Irrigation Diversions (AF)	25,204	17,098	30,709	38,685

	Irrigated Acreage Reduction (No. of Years)	27	37	22	1
	Cumulative Irrigated Acres Reduced	428,000	706,000	260,000	2,500
	Delivery Shortage (No. of Years)	37	25	35	28
	Cumulative Delivery Shortage (AF)	104,000	34,500	83,500	29,000
Kansas					
Water Delivered (Acre-Inches/Acre)		12.4	15.5	13.8	10.4
KBID Up	Cumulative Water Shortage (AF)	84,573	120,015	92,230	9,823
	Percent of Demand Unmet	11.3	11.4	11.3	1.6
	No. of Water-Short Years	8	14	9	1
KBID Down	Cumulative Water Shortage (AF)	56,812	149,734	57,364	1,366
	Percent of Demand Unmet	3.4	6.4	3.2	0.1
	No. of Water-Short Years	5	9	3	1

2. Recreation Benefits

Per the methodology described in Section 7.6.4 in the Basin Study Report, recreation benefits were estimated based on the correlation of reservoir levels and annual visitation/assigned recreation values per visit. Six reservoirs within the Republican River Basin were evaluated: five in Nebraska (Enders, Swanson, Hugh Butler, Harry Strunk, and Harlan County) and one in Kansas (Lovewell). Overall, recreation benefits increase by 14%, 18%, and 29%, respectively under Scenarios 1, 2, and 3 (Table 8). These increases are driven by higher temperatures and/or reservoir levels which attract visitors to swim, boat, etc. Whether the driver is temperature or reservoir level is dependent on the size and bathymetry of the reservoir, along with the magnitude and timing of changes in either variable. At Harlan County Lake for instance, the large increases in recreation benefits under Scenario 1 and Scenario 2 are due primarily to the increases in average monthly air temperatures (increased temperature ranges from 3.8 °F to 8.2 °F for Scenario 1 and 3.8 °F to 4.9 °F for Scenario 2). The increase under Climate Scenario 3 (less warm/ wetter) is driven by both changes in water levels (4.2 ft to 5.3 ft equating to a change in surface area of 1,257 to 1,612 acres) and temperatures (1.6 °F to 3.9 °F). Similarly at Lovewell Reservoir, the increase in recreation benefits under all three climate scenarios is primarily due to air temperature increases in the 1.6 °F to 8.3 °F range. This is due to the fact that the public enjoy swimming (for example) when the temperature is hotter.

Table 8. — Recreation benefits comparison of the Baseline Climate Scenario versus the three future climate scenarios, all under the Future No Action Alternative

Present Value of the Change in the 50-Year Stream of Recreation Benefits (Million $)					
			Climate Scenario Comparisons		
Reservoir	State Providing Hydrologic Modeling Results	Baseline No Action	Scenario 1	Central Tendency	Scenario 3
Enders	Nebraska	19.31	-1.12	7.97	11.80
Harry Strunk	Nebraska	22.52	2.35	7.22	13.27
Hugh Butler	Nebraska	37.36	-1.77	3.94	8.06
Swanson	Nebraska	16.36	-7.47	8.82	49.22
Harlan County (*)	***Nebraska***	301.82	49.28	37.04	37.84
Lovewell	Kansas	109.75	27.91	25.04	25.53
Total:		507.12	+69.18	+90.04	+145.72
Enders	Nebraska	19.31	-1.12	7.97	11.80
Harry Strunk	Nebraska	22.52	2.35	7.22	13.27
Hugh Butler	Nebraska	37.36	-1.77	3.94	8.06
Swanson	Nebraska	16.36	-7.47	8.82	49.22
Harlan County (*)	***Kansas***	303.55	47.77	37.66	39.45
Lovewell	Kansas	109.75	27.91	25.04	25.53
Total:		508.85	+67.67	+90.66	+147.33

(*) Two versions of hydrologic output for Harlan County Lake were provided, one from the Nebraska model and one from the Kansas model. The total reservoir recreation effect of climate change as compared to the without climate change baseline is presented using Harlan County Lake results based on both the Nebraska and Kansas input data.

3. Net Economic Benefits

Net economic benefits of action alternatives under all future climate change scenarios exceeded net benefits under the Baseline Climate Scenario. The net benefits are dominated by the recreational benefits which reflect 72 to 98 percent of the net benefits depending on the climate change scenario. The increase in recreation benefits is driven by increased temperatures under all three scenarios and increased water elevations under Climate Scenarios 2 and 3.

4. Environmental Resources

A detailed inventory of environmental resources is provided in Section 8.0 of the Basin Study Report. Impacts under No Action are described in Section 5.5 of the Basin Study Report. High water temperatures and low flows in Frenchman Creek during the summer months would continue to be a limiting factor to the fish community. Thompson Creek supports a fish population of central stonerollers, red shiners, orangethroat darters, creek chubs, suckermouth minnows, flathead minnows and northern plains killifish. Under the No Action Alternative, all of these species would have the ability to persist in Thompson Creek. The Kansas Minimum Desirable Streamflow (MDS) would remain unchanged under the No Action Alternative. Federal and state-listed species would not be impacted further than under historic conditions.

Overall, decreased flows and altered flow regimes would continue throughout the Basin. This would continue to affect the types of fish populations, favoring certain types of spawning habitat over others. The Basin could also continue to see an increased shift towards non-native species. Invasive species such as Canadian thistle, musk thistle, European buckthorn and garlic mustard would continue to persist throughout the area. No ground disturbing actions would take place under the no action that would increase the spread these species. Reservoirs are currently stocked with non-native game species for recreation. These species would continue to persist in the reservoir environments and could spread into the Republican River and Frenchman Creek.

Several water quality impairments are described in Section 8.1.9 of the Basin Study Report, all of which may be expected to continue depending on the outcome of management practices identified by Total Maximum Daily Load (TMDL) studies. Headwater tributaries into Lovewell Reservoir may continue to be impaired for water supply and aquatic life by arsenic, selenium and total phosphorus. White Rock Creek upstream and downstream from Lovewell Reservoir may continue to have impaired water supply by arsenic and an impaired aquatic life due to total phosphorus and total suspended solids.

VIII. Development of Adaptation Strategies

Section 9503(b)(3) of P.L. 111-11 requires development of appropriate adaptation and mitigation strategies to meet current and future water demands, including development of both structural and nonstructural alternatives. Adaptation strategies (i.e., alternatives) were formulated to improve future conditions, address impacts identified in the system reliability analysis described above under the No Action Alternative, and to meet identified objectives. The purposes and objectives of Nebraska and Kansas are briefly summarized again here in terms of their approach in identifying adaptation strategies for consideration. As discussed below, the ability of an alternative to meet these objectives was only one of the criteria used to determine whether an alternative would be eliminated from consideration. The elimination of alternatives itself was an iterative process that has occurred over the course of decades of investigations. In the context of this Basin Study, time and funding constraints, along with the availability of data, were key limiting factors in assessing which, how many, and when to consider and/or advance alternatives.

It is important to point out that each state's model accounted for conveyance and on-farm irrigation efficiencies, as well as return flows, all of which were assumed to be a constant percentage over the 50-year simulation period. This assumption was driven by review of historical records which indicated no significant trends within the recent past. Moreover, with respect to conservation practices, while measures have been implemented throughout the various districts, with benefits to water, soils, and erosion control, development of new conservation measures within the districts likely would provide little benefit to baseflows as such measures would likely reduce groundwater recharge and ultimately reduce adjacent groundwater supplies or baseflows in the Republican River. If such benefits did accrue, those benefits are not likely to be of a scale to provide significant improvements in baseflows throughout the basin.

A. Nebraska Approach

Alternatives were formulated to meet Nebraska's objective of maintaining compliance with the Republican River Compact and FSS while maximizing the beneficial use of water for all Nebraska users in the basin; the latter objective was measured by improving supply reliability to FCID and NBID, while also improving recreation benefits. Maximizing the beneficial use of water in Nebraska's portion of the basin must not conflict with the intent and provisions of the state's Integrated Management Plans (IMPs).

B. Kansas Approach

Alternatives were formulated to meet Kansas' overall objective to secure the share of water the state is entitled to under the Republican River Compact with the ability to manage that water for the maximum benefit of Kansas water users. This includes maximizing the ability to meet water demands for irrigation, recreation, wildlife areas, municipalities, and industries, while also maintaining minimum desirable streamflows, along with appropriate management of the timing, magnitude, and frequency of reservoir storage to minimize shortages to KBID.

C. Nebraska Adaptation Strategies Considered But Eliminated

Using the No Action Alternative as a baseline, four alternatives were considered for evaluation: Non-Irrigation Canal Recharge, Swanson Reservoir Augmentation via New Frenchman Creek Pipeline, Swanson Reservoir Augmentation via New Republican River Pipeline, and Exchange Downstream Supplies for Harlan County Releases (New Thompson Creek Dam or new Beaver Creek Dam). The selection of alternatives was a collaborative process that took place over the course of years, and which involved early input from stakeholders in Nebraska's portion of the basin. Decisions to reduce the number of alternatives were made based on budget and time constraints, modeling and data considerations, and input from Reclamation staff. Non-irrigation canal recharge and the development of a new dam on Beaver Creek in Nebraska (known in previous reports as Alternative 3B) were not carried forward for further consideration in this study, although each still has merits and are being considered outside the Basin Study Program. In the case of canal recharge, this alternative required the use of the RRCA Groundwater Model which presented extra challenges in terms of transferring results between the groundwater model and the STELLA surface water model. Preliminary results for the canal recharge options do, however, show great promise in terms of the ability to conduct future recharge projects across the Basin, and the potential for consistent available flows for diversion during years when Compact Call Year operations are not required. Regarding Beaver Creek Dam, gaps in the historical flow record made it difficult to estimate available supplies and potential reservoir sizes. Details are provided in Section 6.3 in the Basin Study Report.

D. Kansas Adaptation Strategies Considered But Eliminated

Kansas focused its analysis on management alternatives within the Lower Republican Basin downstream of Harlan County Lake. Time and funding constraints required a reduction in alternatives before model development began. The focus was then set on raising Lovewell Dam and expanding Lovewell Reservoir's storage by various capacities (known as "Alternative 1" in previous reports). Several options were studied extensively by Reclamation in a 2005 Appraisal Investigation. This alternative also included an option of storing surplus water from Lovewell Reservoir in Jamestown Wildlife Area, a large wetland complex, where the water could be stored for alluvial aquifer recharge, thereby augmenting groundwater supplies and adjacent stream flows, reducing MDS administration requirements. However, this option was eliminated from further review in this study because Kansas questioned whether this option could effectively augment flows upstream of Concordia; additionally, the spatial and temporal resolution of the modeling tools for this study was not sufficient to meaningfully evaluate the low flow conditions that trigger MDS administration. The process of refining this alternative and narrowing down expansion options is discussed in the next section below and was based on modeling runs and assessing the potential benefits in terms of meeting Kansas' objectives. Details are provided in Section 6.4 of the Basin Study Report.

IX. Description of Adaptation Strategies Evaluated

Four alternatives were selected for further evaluation in this study – one in Kansas; three in Nebraska. A brief description of the alternatives, including prominent features, is below[7]. More detailed information can be found in Reclamation's Engineering TM (Reclamation 2014).

- Alternative 1 – Expansion of Lovewell Reservoir, KS
- Alternative 3A – Swanson Reservoir Augmentation via New Frenchman Creek Pipeline, NE
- Alternative 3B – Swanson Reservoir Augmentation via New Republican River Pipeline, NE
- Alternative 5A – New Thompson Creek Dam, NE

A. Alternative 1 – Expansion of Lovewell Reservoir, Kansas

This alternative proposes to increase storage in Lovewell Reservoir located eight miles south of Superior, Nebraska on White Rock Creek. This alternative is subdivided into three options of increasing storage by 16,000, 25,000, or 35,000 AF. This option includes raising the crest elevation of the existing dam, dike, and spillway by varying elevations depending on the alternative, as well as extension of the adjacent dike. Overall, these improvements would result in Lovewell

[7] The naming/numbering convention was derived from previously completed reports and was left unchanged in this study for the purposes of staying consistent with previous reports and avoiding confusion.

Reservoir filling earlier in the spring and would provide additional water to Lovewell Reservoir, when available, through additional storage space that would be provided by raising the top of active conservation pool level. Details, including engineering assumptions, are provided in Section 6.5.1 of the Basin Study Report and in Reclamation 2014. An illustration is provided in Figure 11.

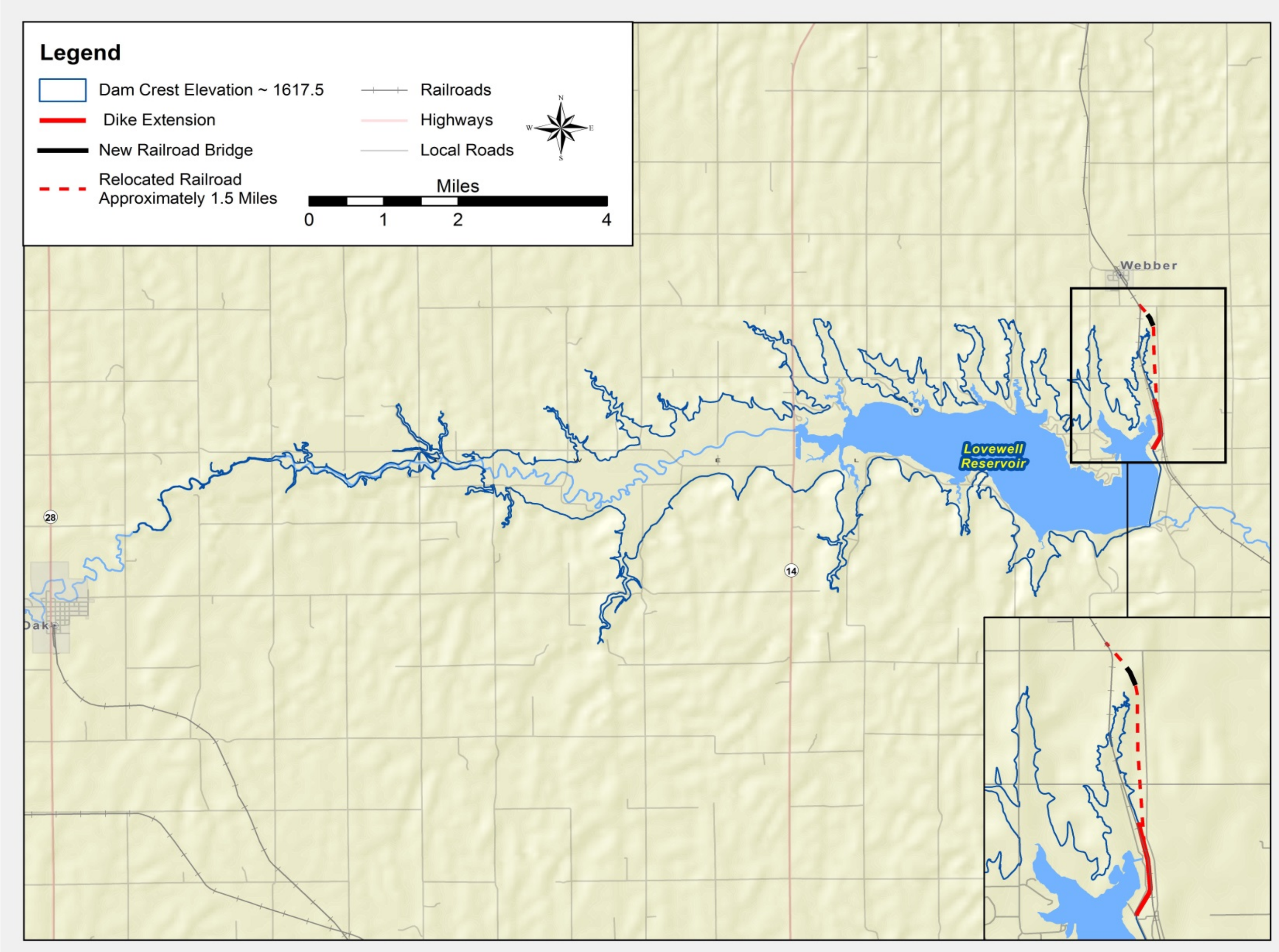


Figure 11. — Conceptual illustration of Alternative 1, Expansion of Lovewell Reservoir. For simplicity, only one of the three expansion options (25,000 AF expansion) is included

B. Alternative 3A and 3B – Swanson Reservoir Augmentation, Nebraska

These alternatives involve augmentation of Swanson Reservoir by taking advantage of existing available storage and diverting water from either Frenchman Creek or the Republican River. In recent years, Swanson Reservoir has consistently had available storage capacity. This alternative would divert water directly from Frenchman Creek (3A) or just downstream of the confluence of Frenchman Creek and the Republican River (3B) into Swanson Reservoir when storage space is available. Alternative 3A would entail construction/installation of a 50,000 gallon regulating tank, a series of three pumps with a total capacity of 3,000 gpm (6.7 cfs), and 11.3 miles of 16- to 18-inch PVC pipe. Alternative 3B would entail construction/installation of three pumps with a total capacity of 5,000 gpm (11.1 cfs) pumps and 17.4 miles of 30-inch PVC pipe. Both alternatives would also require construction of intake and outlet structures. Details, including engineering assumptions, are provided in Section 6.5.2 of the Basin Study Report and Reclamation 2014. An illustration is provided in Figure 12.

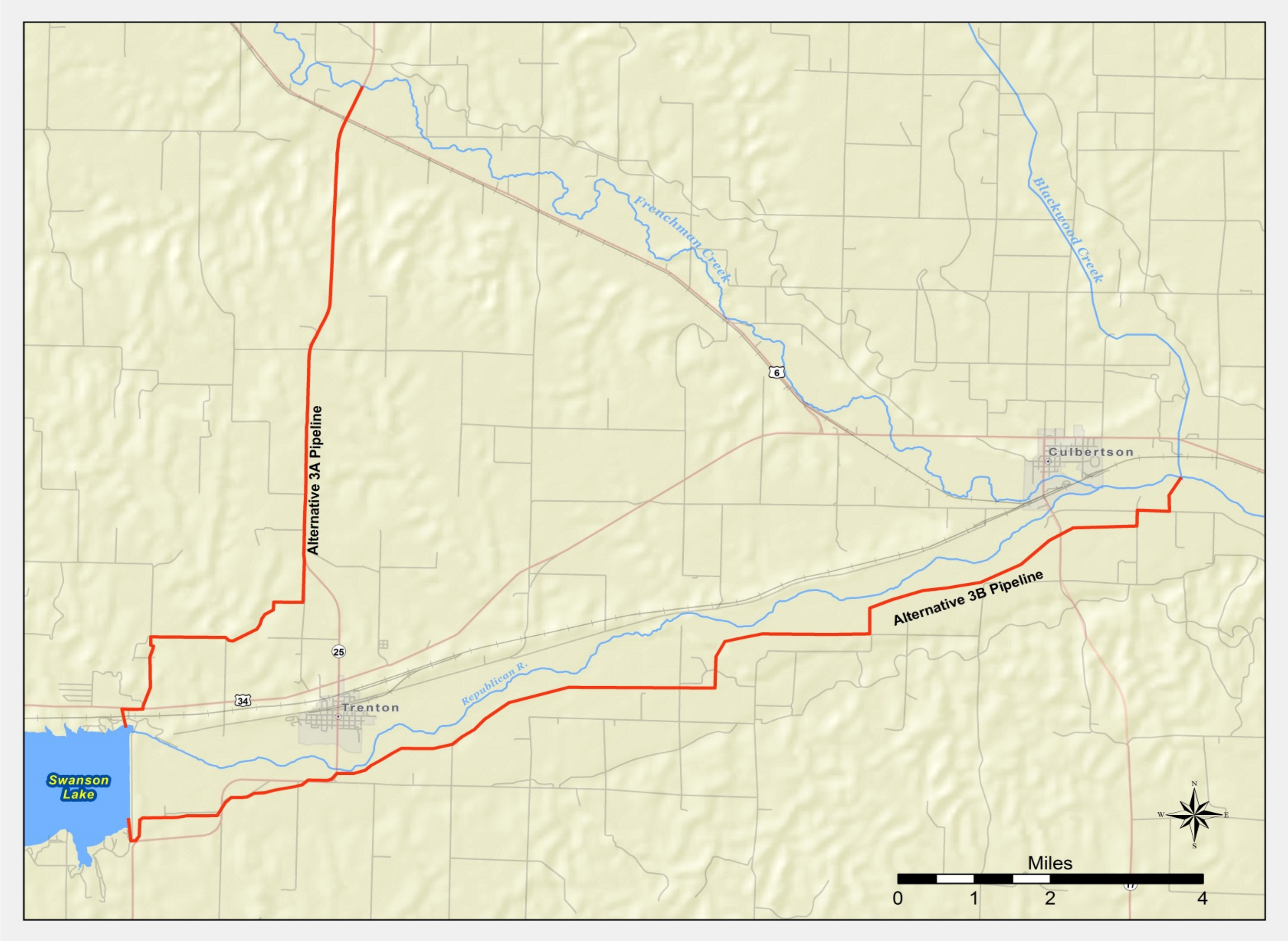


Figure 12. — Conceptual illustration of Alternatives 3A and 3B, Swanson Reservoir Augmentation

C. Alternative 5A – New Thompson Creek Dam, Nebraska

This alternative involves construction of a 5,000 AF reservoir on Thompson Creek, a tributary to the Republican River, and conveyance of the water to the Franklin Canal for delivery to the NBID in exchange for allowing water to be stored in Harlan County Lake. To impound 5,000 AF, a new embankment would need to be constructed about 50 feet high with a crest length of about 2,200 feet. A new pumping plant also would be required to deliver water to the existing Franklin Canal. Details, including engineering assumptions, are provided in Section 6.5.3 of the Basin Study Report and Reclamation (2014). An illustration is provided in Figure 13.

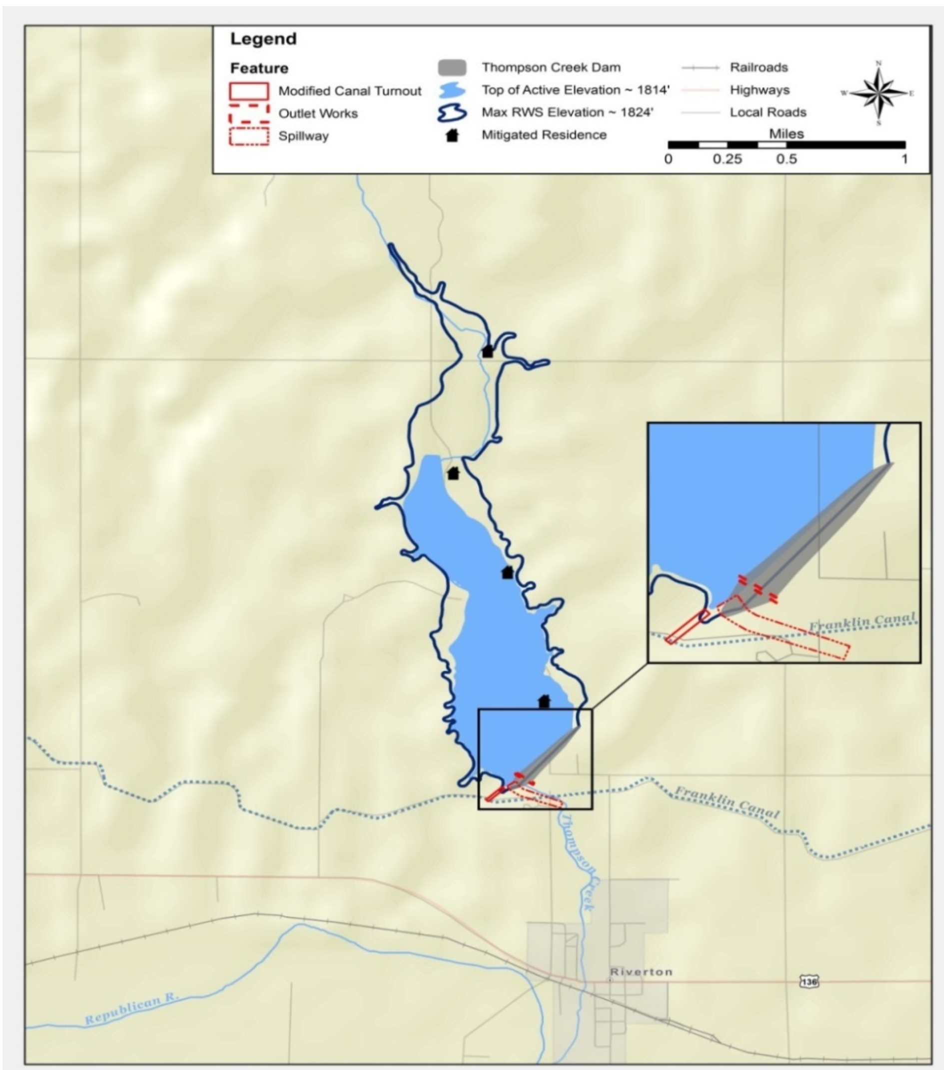


Figure 13. — Conceptual illustration of Alternative 5A, New Thompson Creek Dam

X. Evaluation of Adaptation Strategies

Section 9503(b)(3) of P.L. 111-11 requires a quantitative or qualitative trade-off analysis of the adaptation and mitigation strategies identified. Such analyses are to examine all proposed strategies in terms of (1) their ability to meet study objectives; (2) the extent to which they minimize imbalances between water supply and demand and address potential impacts of climate change; (3) level of stakeholder support; (4) relative costs; and (5) environmental impacts. The first two criteria were addressed quantitatively through model simulations that compared the performance of several metrics identified by each state, as described below. Stakeholder support and environmental impacts were assessed qualitatively.

A. Nebraska Approach

The evaluation of the alternatives was based on several metrics developed to measure the ability of the alternative to help maximize water use and ensure Compact compliance. These metrics included the number of Compact Call Years predicted by the model, reservoir storage levels, irrigation diversions, and diversions made for project-specific purposes. In each case, the metrics as measured under the No Action Alternative were compared with the metrics for the action alternative, for Baseline Climate conditions, and for climate scenarios developed by Reclamation. In this way it was possible to consider how well the given alternative improved the metrics, or if they in fact led to less desirable results than the No Action alternative in some cases.

This section includes descriptions of these alternatives, including information on their purpose and objective and information on what metrics would be used to evaluate their effectiveness in meeting management objectives. Details are provided in Section 7.1 of the Basin Study Report.

1. Alternative 3A - Swanson Reservoir Augmentation Via Frenchman Creek Pipeline

a. *Purpose and Objective*

One of the main objectives for this alternative would involve increasing the water supply reliability for Frenchman-Cambridge Irrigation District (FCID). Increased storage within Swanson Reservoir would potentially be available to FCID irrigators, based on their storage contracts with Reclamation. The additional storage could also be used to assist with Compact compliance efforts, by providing additional supplies that could be made available downstream to the

State of Kansas. Recreation interests could also benefit from increased storage levels.

b. *Evaluation Metrics*

The metrics used for this alternative included Compact Call Year determinations, annual pumping rates, Swanson Lake levels, Harlan County Lake levels, irrigation diversions by the FCID canals, and total NBID irrigation diversions (without Courtland Canal).

2. Alternative 3B - Swanson Reservoir Augmentation Via Republican River Pipeline

a. *Purpose and Objective*

The purpose and objective would be identical to that for Alternative 3A.

b. *Evaluation Metrics*

As with Alternative 3A, the metrics used for this alternative included Compact Call Year determinations, annual pumping rates, Swanson Lake levels, Harlan County Lake levels, irrigation diversions by the FCID canals, and total NBID irrigation diversions (without Courtland Canal).

3. Alternative 5A – New Thompson Creek Dam, NE

a. *Purpose and Objective*

This alternative, with its corresponding new reservoir and new tie-in with Franklin Canal, could be used to serve multiple objectives. By drawing from sources downstream of Harlan County Lake, demands for Harlan County releases could be decreased, improving water supply reliability for NBID users. Retaining storage in Harlan County Lake could also assist with Compact compliance activities, by reducing instances of Water-short Year Administration and Compact Call Years, and enhancing supply reliability for KBID as well. Regulating north-side tributary flows would provide flexibility and operational benefits by making it possible to capture high tributary flows during periods of excess, and using those stored supplies when water supplies are scarce and of greater beneficial value. The resulting higher reservoir levels in Harlan County Lake could also benefit recreation uses in the reservoir, while benefiting the community that relies on the economic opportunities provided by Harlan County Lake use. Recreational benefits could also be realized for the new smaller dam.

b. *Evaluation Metrics*

The primary metrics considered for the Thompson Creek Reservoir alternative included Compact Call Years, Franklin Canal diversions/releases from Thompson Creek Reservoir, Thompson Creek Reservoir levels, Harlan County Lake levels, total diversions by all NBID canals except Courtland Canal (including Franklin

Canal), total combined diversions by upstream FCID canals, diversions by the Courtland Canal from the Republican River, Guide Rock flows, and flows in the Courtland Canal at the state line. This wide range of metrics provided several ways of considering maximization of water uses and Compact compliance.

B. Nebraska Results

A summary of Nebraska's results is provided below. A detailed description of the modeling results, including figures, associated with each alternative's performance in terms of metrics and objectives is provided in Section 7.2 of the Basin Study Report.

1. Alternative 3A – Swanson Reservoir Augmentation via Frenchman Creek Pipeline

- In terms of whether Alternative 3A meets or exceeds the purpose and objectives, findings were mixed. From the perspective of increasing the water supply reliability for FCID, results indicate that there would likely be additional diversions made by the FCID canals as a result of the supply augmentation operations. Swanson Lake levels also would benefit from the new supply of water from Frenchman Creek. However, in terms of Compact compliance efforts, there may be a slight negative impact, largely due to a slight decrease in inflows to, and storage levels in, Harlan County Lake. A small increase in the number of Compact Call Years may be expected. In addition, there appears to be a tradeoff in terms of FCID and NBID water supplies, as NBID diversions may decrease slightly under the alternative.

- It is clear from the results that the pumping level of 3,000 gpm could be increased, since pumping operations were almost always able to operate at full capacity for those years in which pumping was allowed.

- Regarding climate change impacts on FCID deliveries, Alternative 3A produces slightly higher FCID diversions compared to No Action conditions over the 50-year time horizon for Baseline Climate conditions, as well as under the alternative climate scenarios. Climate Scenario 3 shows the smallest impacts due to the overall abundance of available stored water supplies and maximization of irrigated acres.

- Regarding climate change impacts on NBID deliveries, under Baseline Climate and Climate Scenarios 1 and 2, there appears to be a negative impact – on the order of a few thousand acre-feet – to NBID diversions under Alternative 3A when compared to the No Action Alternative. Under Climate Scenario 3, the impact is particularly difficult to discern.

In general, there appears to be a small negative impact to NBID resulting from increased consumptive use on the FCID irrigated acres upstream.

2. Alternative 3B – Swanson Reservoir Augmentation via Republican River Pipeline

- In terms of whether Alternative 3B meets or exceeds its purpose and objectives, the results point, as they did for Alternative 3A, to mixed findings. Results indicate that there would likely be additional diversions made by the FCID canals. Swanson Lake levels also would benefit from the new supply of water from Frenchman Creek. However, in terms of Compact compliance efforts, there may be a slight negative impact, largely due to a slight decrease in inflows to, and storage levels in, Harlan County Lake. A small increase in the number of Compact Call Years may be expected under Alternative 3B, although less than under Alternative 3A. In addition, there appears to be a tradeoff in terms of FCID and NBID water supplies, as NBID diversions may decrease slightly under the alternative.

- As was the case with Alternative 3A, it is clear from the results that the pumping level of 5,000 gpm could be increased, since pumping was almost always able to operate at full capacity for those years in which pumping was allowed.

- Regarding climate change impacts on FCID deliveries, Alternative 3B produces generally higher FCID diversions compared to No Action conditions over the 50-year time horizon for Baseline Climate conditions, as well as under the alternative climate scenarios. Climate Scenario 3 shows the smallest impacts due to the overall abundance of available stored water supplies and maximization of irrigated acres.

- Regarding climate change impacts on NBID deliveries, under Baseline Climate and Climate Scenarios 1 and 2, there appears to be a negative impact – on the order of a few thousand acre-feet – to NBID diversions under Alternative 3B when compared to the No Action Alternative. The impact also appears to be of a slightly higher magnitude than that observed for Alternative 3A, which is understandable given the higher pumping capacity under Alternative 3B. Under Climate Scenario 3, the impact is particularly difficult to discern. In general, there appears to be a small negative impact to NBID resulting from increased consumptive use on the FCID irrigated acres upstream.

3. Alternative 5A – New Thompson Creek Dam

- In terms of whether Alternative 5 meets or exceeds its purpose and objectives, there are again mixed results, as was the case with Alternatives 3A and 3B. From the perspective of increasing the water supply reliability for NBID, the results indicate that there would likely be additional diversions made by the Franklin Canal as a result of Thompson Creek Reservoir operations. The remaining NBID demands likely would be unaffected, as would FCID canals upstream of Harlan County Lake. Harlan County Lake levels would likely improve for those years when Thompson Creek Reservoir pumping to Franklin Canal occurred, with perhaps a few thousand acre-feet of additional storage supply within Harlan County Lake for some years over the 50-year period. This does indicate a potential benefit to Harlan County Lake resulting from the substitute supply originating from Thompson Creek.

- In terms of Compact-related impacts, there appears to be little if any impacts to the number of Compact Call Years as a result of Thompson Creek operations compared to No Action conditions. The small benefit to storage levels in Harlan County does not directly result in reductions in Compact Call Years. This may be in part due to the increased consumptive use on Franklin Canal lands, which negatively affects Nebraska's Compact balance, but that same consumption would provide benefits to NBID irrigators on Franklin Canal. The small size of the Thompson Creek Reservoir alternative may also be a factor, and it may be beneficial to consider larger reservoir sizes in future analyses. The consistent ability of Thompson Creek Reservoir to fill its conservation pool each year, and the regular incursion of water into the flood pool when climate conditions are wetter, both indicate that the reservoir could benefit from greater conservation and flood storage. Finally, both Guide Rock flows and flows on the Courtland Canal at the state line, which have direct impacts on Compact balances for Nebraska, would appear to be unchanged as a result of Thompson Creek Reservoir operations. As with Alternatives 3A and 3B, different management options, such as modifying the water supply calculations in NBID contracts and possibly the language in the Consensus Plan and RRCA Accounting Procedures to reflect the new storage supply from the Thompson Creek Reservoir, may also be worth considering if water planners wish to conduct future analyses of the potential reservoir site.

- Impacts of climate change have negligible impacts on FCID and NBID deliveries under Alternative 5A.

- Regarding Republican River flows at the Guide Rock gage, which are critically important in determining Compact allocations and balances, differences between No Action and action flow rates are small under all climate scenarios. As evident in the 50-year averages, and through inspection of the graphs, there appears to be little to any difference in Guide Rock flows between No Action and alternative conditions. For all climate conditions except for the dry Climate Scenario 1, there was a slight decrease in Guide Rock flows under Alternative 5, but the magnitude and variability over the course of the study period indicate little if any impacts.

C. Kansas Approach

The evaluation of the Lovewell Reservoir expansion alternative was based on several metrics developed to help ensure Compact compliance and minimize water shortages to KBID. Operationally, KBID is broken into two areas: that portion located above Lovewell Reservoir referred to in this document as upper KBID (or KBID-UP) and that portion below Lovewell Reservoir referred to as lower KBID (or KBID-DOWN). Of particular interest is the ability to meet demands of both the upper and lower KBID. Historically, KBID has experienced severe water shortages during droughts or periods of compact non-compliance.

To assess the effectiveness of each expansion option, upper and lower KBID shortages were compared between the No Action Alternative and Action Alternative for each of the three expansion options. This was done first only under the Baseline Climate Scenario. After observing only minimal benefits of reservoir expansion, a comparison was then made under what could be perceived as a “worst case” climate scenario (i.e., Scenario 1 – hotter and drier). Details are provided in Section 7.4.7 of the Basin Study Report.

1. Alternative 1 – Expansion of Lovewell Reservoir, Kansas

a. *Purpose and Objective*

Increase the storage in Lovewell Reservoir by 16,000 AF, 25,000 AF, or 35,000 AF to accommodate additional flows during winter months, thereby making more water available to KBID.

b. *Evaluation Metrics*

The primary metric used to evaluate the benefits of the three expansion options was the magnitude and frequency of shortages to KBID both upstream and downstream of Lovewell Reservoir.

D. Kansas Results

A summary of Kansas' results are below. A detailed description of the modeling results, including figures, associated with each alternative's performance in terms of metrics and objectives is provided in Section 7.4 of the Basin Study Report.

1. Alternative 1 - Expansion of Lovewell Reservoir, Kansas

- Kansas' modeling results indicate that under the Baseline Climate Scenario, increasing the storage at Lovewell Reservoir reduces the frequency and magnitude of shortages to KBID downstream of the reservoir, but not by much, relative to the No Action Alternative. For instance, under the No Action Alternative, shortages are observed in only five of the 50 years simulated, with relatively small annual shortages (i.e., less than two inches and less than 11 percent of the total demand) in three of the five shortage years. This is largely due to operational assumptions under the No Action Alternative made by Nebraska during Compact Call Years which require measures to be taken to ensure Compact compliance.

- As well, under the Baseline Climate Scenario, increasing storage at Lovewell Reservoir does very little to reduce the frequency or magnitude of shortages to KBID upstream of Lovewell Reservoir. Therefore, the utility of any alternative increasing storage at Lovewell Reservoir appears low under the Baseline Climate Scenario. This does not consider the associated agricultural and recreation benefits described below, both of which add utility to this alternative.

- Under Climate Scenario 1, the frequency and magnitude of shortages to KBID downstream of Lovewell Reservoir increased over the Baseline Scenario for the No Action run with shortages occurring in nine of the 50 simulation years. The expansion alternatives reduce the frequency and magnitude of the shortages over the No Action alternative, with the 16,000 AF storage increase reducing the shortage frequency to seven years, the 25,000 AF storage increase reducing the shortage frequency to three years during the 50-year simulation, and the 35,000 AF increase also reducing the shortage to KBID to three years.

- Considering the high cost of expansion alternatives and the small relative reductions to shortage frequencies under the hotter, drier climate scenario, the only expansion alternative that was selected for further benefit/cost evaluation was the 25,000 AF storage increase to Lovewell Reservoir under the Scenario 1 and Baseline Climate conditions (Alternative 1C in Reclamation's 2005 Appraisal Report).

E. Economics Evaluation

The primary purpose of the economics analysis was to estimate the net economic benefits (i.e., benefits minus costs) for each action alternative as compared to the No Action Alternative based on construction costs, including interest during construction, and agricultural and recreation benefits. A secondary objective of the analysis was to evaluate the economic effect of climate change associated with the various climate change scenarios.

1. Cost Methods

Based on Kansas' modeling results described above, only the costs of Alternative 1C are presented here (Reclamation 2014 includes costs for all storage options). Costs for all three Nebraska alternatives were developed. Cost estimates were prepared by Reclamation's Technical Service Center Estimating Group (Denver, Colorado). The estimates are in accordance with Reclamation Manual Directives and Standards and are considered "appraisal-level", as prepared from cost graphs, simple sketches, or rough general designs which use the available site-specific design data. Appraisal-level costs estimates are developed at an early stage of project development and are therefore not suitable for requesting project authorization or construction fund appropriations from Congress. All costs are in April 2014 dollars. Details on cost methodologies are provided in Section 7.5.2 of the Basin Study Report.

2. Cost Results

Table 9 summarizes the construction cost estimates. Costs for operations and maintenance were not evaluated. Cost estimate worksheets with detailed breakdowns of quantities, unit prices, and amounts, for the proposed structural alternatives, are presented in Reclamation's Engineering TM.

Table 9. — 2014 Appraisal Level Cost Estimates[1]

Alternative Description	Field Cost	Noncontract[2] Cost	Construction Cost Estimate
1C: 25,000 AF Expansion of Lovewell Reservoir	$44,000,000	$15,000,000	$59,000,000
3A: Swanson Reservoir Augmentation – New Frenchman Creek Pipeline	$27,000,000	$9,000,000	$36,000,000
3B: Swanson Reservoir Augmentation – New Republican River Pipeline	$61,000,000	$21,000,000	$82,000,000
5A: New Thompson Creek Dam	$68,000,000	$24,000,000	$92,000,000

1 All costs are in April 2014 dollars.
2 Non-Contract Costs were estimated to be approximately 35% of the Total Field Costs based on percentage ranges from past large Reclamation projects.

To complete the cost estimation process, interest during construction (IDC) was estimated for each alternative based on an allocation of total construction costs across presumed construction periods for each alternative. These are included in the costs listed below in Table 10.

3. Benefits Methods

Benefits were calculated for both agriculture and recreation. Agricultural benefits are measured as the change in net farm income (NFI) received from the use of irrigation water to produce agricultural commodities such as corn and soybeans (Reclamation 2004). NFI was based solely on irrigation water deliveries and assumes constant precipitation; therefore, NFI is used for comparative purposes between alternatives within a particular climate scenario, but not *across* climate scenarios. Details are provided in Section 7.6.3 of the Basin Study Report. Recreation benefits were evaluated for all six reservoirs within the Republican River Basin based on annual visitation estimates that were modeled for each alternative. Details are provided in Section 7.6.4 of the Basin Study Report.

4. Benefits Results

Tables 10, 11, and 12 below summarize the incremental agricultural, recreation, and total net benefits, respectively, of each Action Alternative relative to No Action. Section 7.7 in the Basin Study Report provides details on methods and results. Alternative 1C yielded the largest agricultural and recreation benefits of all four alternatives; this is due to the increased water deliveries and higher lake levels associated with reservoir expansion. Furthermore, relative to total costs, Alternative 1C was the only alternative to yield positive net benefits. These benefits were driven primarily by recreation as opposed to agricultural production from water deliveries. The agricultural and recreation benefits of Alternatives 3A, 3B, and 5A were mixed depending on the climate scenario, but overall, the net benefits were all negative relative to costs. Results are considered preliminary; a more complete economics analysis would include operations, maintenance, replacement, and power (OMR&P) costs and address the data gaps and assumptions provided in Section 7.7.4 of the Basin Study Report. For instance, adding OMR&P costs would reduce net benefits across all alternatives; in the case of Alternative 1C, this reduction could be substantial enough to result in net benefits becoming negative.

Table 10. — Present value of incremental agricultural benefits of Action Alternatives versus the No Action Alternative under different climate scenarios, Republican River Basin Study. Scenario 1 = warmer/drier; Scenario 2 = central tendency; Scenario 3 = less warm/wetter

Climate Scenario	Comparison Alternative	Agricultural Benefits[a]
Baseline	1C[b]	19.12
Baseline	3A	-3.08
Baseline	3B	-0.84
Baseline	5A	0.80
1	1C	7.72
1	3A	0.64
1	3B	0.30
1	5A	0.00
2	3A	-11.85
2	3B	-3.02
2	5A	-1.00
3	3A	-5.33
3	3B	0.00
3	5A	0.00

a 50-year stream of benefits discounted at the FY 2015 Federal Discount rate of 3.375% (Reclamation 2014)
b Due to budget and time restraints, benefits for Alternative 1C were only estimated under the Baseline Scenario and Scenario 1

Table 11. — Present value of incremental recreation benefits of Action Alternatives versus the No Action Alternative under different climate scenarios, Republican River Basin Study. Scenario 1 = warmer/drier; Scenario 2 = central tendency; Scenario 3 = less warm/wetter

Climate Scenario	Comparison Alternative	Recreation Benefits[a]
Baseline	1C[b]	49.48
Baseline	3A	1.14
Baseline	3B	1.62
Baseline	5A	0.57
1	1C	64.98
1	3A	0.27
1	3B	0.39
1	5A	0.15
2	3A	-6.63
2	3B	-1.74
2	5A	0.37
3	3A	1.95
3	3B	7.59
3	5A	0.54

a 50-year stream of benefits discounted at the FY 2015 Federal Discount rate of 3.375% (Reclamation 2014)
b Due to budget and time restraints, benefits for Alternative 1 were only estimated under the Baseline Scenario and Scenario 1

Table 12. — Present value net benefits of Action Alternatives versus the No Action Alternative under different climate scenarios, Republican River Basin Study. Scenario 1 = warmer/drier; Scenario 2 = central tendency; Scenario 3 = less warm/wetter

		All benefits, costs, and net benefits reported in millions of dollars				
Climate Scenario	**Comparison Alternative**	**Agricultural Benefits[a]**	**Recreation Benefits[a]**	**Combined Benefits[a,b]**	**Costs[c]**	**Net Benefits[a,d]**
Baseline	1C[e]	19.12	49.48	68.60	66.30	2.30
Baseline	3A	-3.08	1.14	-1.94	41.12	-43.06
Baseline	3B	-0.84	1.62	0.78	90.64	-89.86
Baseline	5A	0.80	0.57	1.37	100.05	-98.68
1	1C	7.72	64.98	72.70	66.30	6.40
1	3A	0.64	0.27	0.91	41.12	-40.21
1	3B	0.30	0.39	0.69	90.64	-89.95
1	5A	0.00	0.15	0.15	100.05	-99.90
2	3A	-11.85	-6.63	-18.48	41.12	-59.60
2	3B	-3.02	-1.74	-4.76	90.64	-95.40
2	5A	-1.00	0.37	-0.63	100.05	-100.68
3	3A	-5.33	1.95	-3.38	41.12	-44.50
3	3B	0.00	7.59	7.59	90.64	-83.05
3	5A	0.00	0.54	0.54	100.05	-99.51

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 include interest during construction, and are associated with action alternatives/scenarios but not the No Action Alternative/scenarios. Costs exclude operations, maintenance, replacement, and power costs.
d Combined Benefits minus Costs.
e Due to budget and time restraints, benefits for Alternative 1 were only estimated under the Baseline Scenario and Scenario 1

F. Evaluation of Environmental Resources

A summary of impacts on environmental resources is below. Details on the existing environment and specific impacts of each alternative relative to the No Action Alternative on fish and wildlife, threatened and endangered species, invasive species, water quality, and ecological resiliency is provided in Section 8.0 in the Basin Study Report.

1. Alternative 1C – 25,000 AF Expansion of Lovewell Reservoir

a. *Fish and Wildlife*

Lovewell Reservoir would still provide habitat to waterfowl and shorebirds for migration and nesting. Species such as song birds, cormorants, white-pelicans, gulls, and herons would continue to utilize the area. The large areas of short-grass habitat to the north of the reservoir could be impacted by the increase in water surface elevations, which would have a negative impact on the current population of black-tailed prairie dogs. Higher reservoir elevations could reduce the amount of wetlands that currently exist. The reservoir would continue to provide ample habitat for the current population of walleye, white bass, wipers, channel catfish, and crappie. The current habitat and carrying capacity of the reservoir would increase due to the increased storage. Inundation of new riparian and wetland habitat would have a positive impact on productivity and habitat within the reservoir in the short term. White bass, wipers, and catfish would continue to be found in the Republican River just downstream of the dam. The minimum desired stream flow in the lower Republican River would still need to be met to ensure that aquatic species are not impacted downstream from Lovewell Reservoir.

b. *Federal and State Threatened, Endangered, and Species of Concern*

No impacts would be expected.

c. *Invasive Species*

Ground disturbances could increase the spread of invasive species such as Canadian thistle, musk thistle, Johnson grass, bindweed and lespedeza. Although not identified as invasive, cheatgrass and smooth broom may become established in these areas. The increase in reservoir habitat could increase the population of non-native species that currently exists. This could have a negative impact on the native fish population in the Republican River upstream and downstream of the reservoir.

d. *Water Quality*

Headwater tributaries into Kansas would continue to be impaired for water supply and aquatic life by arsenic, selenium and total phosphorus. White Rock Creek upstream from Lovewell Reservoir would continue to have impaired water supply by arsenic and an impaired aquatic life due to total phosphorus and total suspended solids.

e. *Ecological Resiliency*

Decreased flows and altered hydrographs are the primary limiting factors throughout the Basin. The state of Kansas has implemented a MDS for the protection of instream flows for water quality, fish, wildlife, aquatic life, recreation, general aesthetics and domestic uses which would continue under the action alternative. Fish populations in the Republican River would continue to shift towards species that spawn in the substrate over those that spawn in open water. The basin could also continue to see an increased shift towards non-native species.

2. Alternative 3A – Swanson Reservoir Augmentation via Frenchman Creek Pipeline

a. *Fish and Wildlife*

Swanson Reservoir would continue to provide ideal habitat for migrating waterfowl, shorebirds, and wading birds that are moving through the area during spring and fall migrations. Approximately 4,000 acres of adjacent public lands would still be accessible for public access and wildlife. Swanson Reservoir would continue to support the introduced populations of walleye, white bass, wipers, largemouth bass, channel catfish, bullheads and crappie. Additional reservoir habitat would be created if additional water is stored throughout the year due to diversions out of Frenchman Creek. Water level fluctuations would have an impact on the reservoir fishery. With additional diversions out of Frenchman Creek into Swanson Reservoir, it is likely that these would continue into the future or possibly increase. Also, dewatering may become an increased issue in Frenchman Creek which would be detrimental to the current fish populations.

b. *Federal and State Threatened, Endangered, and Species of Concern*

If Swanson Reservoir elevations were increased due to the additional diversion, piping plover habitat on the reservoir margins could be impacted. The American burying beetles range includes some of the upland habitat around Enders Reservoir and Frenchman Creek. Impacts to this species could be possible with the installation of the new water pipe from Frenchman Creek to Swanson Reservoir. As proposed, the new pipeline would be routed along existing roadways which could reduce the likelihood of impacts. Reclamation conducted surveys in 2014 and did not find any beetles in area, but if this alternative were to move forward, additional surveys would be needed.

c. *Invasive Species*

Ground disturbances could increase the spread of invasive species such as Canadian and musk thistles. Although not identified as invasive, cheatgrass and smooth broom may become established along the disturbed route. Increased storage levels in Swanson Reservoir could increase the population of non-native species that currently exists. This could have a negative impact on the native fish population in the Republican River upstream and downstream of the reservoir.

d. *Water Quality*

Some minor water quality impacts would be expected with this alternative. High water temperatures and low flow conditions in Frenchman Creek that currently exist would not likely improve but could become more frequent with additional diversions. Existing water quality impairments in Swanson Reservoir due to elevated levels of phosphorus, nitrogen, chlorophyll a, and mercury would not be expected to worsen. With additional water being stored in Swanson Reservoir, some of these elements could become diluted and have less of an impact on the current fishery. It is likely that the fish consumption advisories would not be lifted.

e. *Ecological Resiliency*

Decreased flows and timing of peak flows are the primary limiting factors within the basin. Diverting more water out of Frenchman Creek could increase these effects. It is expected that the species composition in Frenchman Creek would continue to shift towards species that spawn in the substrate over those that spawn in open water.

3. Alternative 3B – New Republican River Pipeline

a. *Fish and Wildlife*

Swanson Reservoir would continue to provide ideal habitat for migrating waterfowl, shorebirds, and wading birds that are moving through the area during spring and fall migrations. Approximately 4,000 acres of adjacent public lands would still be accessible for public access and wildlife. Swanson Reservoir would continue to support the introduced populations of walleye, white bass, wipers, largemouth bass, channel catfish, bullheads and crappie. Additional reservoir habitat would be created if additional water is stored throughout the year due to diversions out of the Republican River. Water level fluctuations would still have an impact on the reservoir fishery.

b. *Federal and State Threatened, Endangered, and Species of Concern*

Like the previous alternative, if Swanson Reservoir elevations are increased, it could negatively impact the amount of piping plover habitat along the reservoir margins. The American burying beetles range does not extend down to Swanson Reservoir or the proposed pipeline route, so impacts to the species would not be expected.

c. *Invasive Species*

Ground disturbance could increase the spread of invasive species such as Canadian and musk thistles. Although not identified as invasive, cheatgrass and smooth broom may become established along the disturbed route. Increased storage levels in Swanson Reservoir could increase the population of non-native species that currently exists. This could have a negative impact on the native fish population in the Republican River upstream and downstream of the reservoir.

d. *Water Quality*

Water quality impacts such as high water temperatures and low flow conditions in Frenchman Creek that currently exist would not likely improve. Water quality impairments in Swanson Reservoir due to elevated phosphorus, nitrogen, chlorophyll a, and mercury would not be expected to worsen. With additional water being stored in Swanson Reservoir, some of these elements could become diluted and have less of an impact on the current fishery. It is likely that the fish consumption advisories would not be lifted.

e. *Ecological Resiliency*

As mentioned above, decreased flows and timing of peak flows are the primary limiting factors within the basin. Diverting more water out of the Republican River could increase these effects. It is expected that the species composition in the Republican River would continue to shift towards species that spawn in the substrate over those that spawn in open water.

4. Alternative 5A – New Thompson Creek Dam

a. *Fish and Wildlife*

The creation of a new reservoir to capture Thompson Creek flows would eliminate approximately 97 acres of forested riparian habitat and approximately seven acres of wetlands. Although there would be a loss of forested riparian and wetland habitat, the new reservoir would provide for approximately 5,000 AF of new reservoir habitat. This new habitat would have a positive impact on migrating waterfowl, shore birds and wading bird species. It is likely that the existing Thompson Creek fish population of central stonerollers, red shiners, orangethroat darters, creek chubs, suckermouth minnows, flathead minnows and northern plains killifish would be negatively impacted. Most of these species are specialized and best suited to survive in riverine environments and are unable to survive in a reservoir habitat. It is likely that the reservoir would turn into a recreation fishery with introduced non-native species being the primary focus.

b. *Federal and State Threatened, Endangered, and Species of Concern*

With the creation of a new reservoir, piping plover habitat along the reservoir margins could increase. The amount of increased habitat would depend highly on reservoir elevations. No other impacts on listed species would be expected.

c. *Invasive Species*

Ground disturbances could increase the spread of invasive species such as Canadian and musk thistles. Although not identified as invasive, cheatgrass and smooth broom may become established in these areas. The creation of a reservoir habitat could increase the population of non-native species that currently exists. This could have a negative impact on the native fish population in the Thompson Creek upstream and downstream of the reservoir.

d. *Water Quality*

Currently, Thompson Creek is impaired by E. coli and naturally high water temperatures due to reduced summer and fall flows. Depending on the changes to TMDLs, these impairments would worsen due to decreased flow in Thompson Creek downstream of the dam.

e. *Ecological Resiliency*

Decreased flows and altered hydrographs throughout the basin are the primary limiting factors that would occur under this alternative. Flows in Thompson Creek are expected to change dramatically with the construction of a new storage reservoir. The new reservoir would likely decrease spring flows and increase late summer flows due to irrigation demands downstream. Native fish populations would likely decline with the introduction of non-native game fishes for the reservoir fishery. Fish populations would continue to shift towards species that spawn in the substrate over those that spawn in open water.

5. Considerations for Future Investigations on Environmental Resources

All alternatives discussed above would be subject to National Environmental Policy Act, National Historic Preservation Act, and Endangered Species Act requirements. This document does not alleviate these requirements. Surveys for endangered and threatened species would need to be completed before an alternative were to move forward. For example if alternative 3A was to move forward, American burying beetle surveys would need to be completed before the final pipeline route could be identified. To fully understand all environmental effects, a more in-depth hydrologic analysis would need to be completed.

XI. Findings and Conclusions

A. Disclaimers

This 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 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. All cost estimates included in this study are preliminary and intended only for comparative purposes only.

The States participating in this Basin Study understand that this study provides multi-state collaborative opportunities to explore management alternatives in the context of sustaining a long-term balance between water uses and supplies in the Republican River Basin. The findings of the study do not and will not compromise any state's position in litigation or any other dispute between or among the States, nor will they be binding upon any state as a result of that state's participation. No statements made or positions taken by any state's representatives may be used in any way as part of any present or future dispute between or among the States. However, data, study results, and potential projects generated or exchanged as part of this study may be used by any state for any purpose.

These findings and analyses do not constitute a position of the federal government to support or recommend implementation of any adaptation strategies/alternatives identified and evaluated in this report. Although Reclamation will continue to work within its authorities to collaborate with the States as it relates to federal projects/interests within the Basin, unless otherwise directed by Congress, it is the responsibility and at the discretion of the States to undertake additional investigations and/or implement the adaptation strategies/alternatives identified in this report.

As described previously, evaluations on system reliability and associated adaption strategies were not conducted for the Colorado or upper Kansas sub-basins. Study partners chose to focus on meeting the water supply needs of FCID, NBID, and KBID. To evaluate water supplies and operations for these districts, new modeling tools and related datasets were developed for the Nebraska and Lower-Kansas sub-basins. These tools simulate the hydrology and water operations of these sub-basins and provide the basis for detailed analysis of current and future water supplies and demands, as well as for an analysis of system reliability under various alternatives and under a range of projected future climate scenarios. No new modeling tools were developed for the Colorado or Upper Kansas sub-basins. The findings described below reflect these considerations.

B. Impacts of Climate Variability and Change under No Action

1. Surface and Groundwater Supplies

- Average annual streamflow in the Colorado sub-basin is projected to decrease by 7% under Scenario 1 but increase by 22% under Scenario 3, with little change under Scenario 2.

- Average annual streamflow in the Upper Kansas sub-basin is projected to decrease by 10% under Scenario 1 and increase substantially under Scenarios 2 and 3 by 28% and 166%, respectively.

- Average annual streamflow in the Nebraska sub-basin is projected to decrease by 8% under Scenario 1 and increase under Scenarios 2 and 3 by 10% and 59%, respectively.

- Average annual streamflow in the Lower Kansas sub-basin is projected to increase slightly under Scenarios 1 and 2 by about 1% and increase moderately under Scenario 3 by 12%. Increases under Scenario 1 result from a large projected increase in precipitation over the Lower Kansas sub-basin, despite a projected decrease in basin-average precipitation under this scenario.

- Impacts on groundwater supplies were not directly quantified under this study; however, projected changes in precipitation suggest that precipitation recharge is likely to decrease in the Colorado and Upper Kansas sub-basins under Scenarios 1 and 2, with little change under Scenario 3. Precipitation recharge is likely to increase in the Nebraska sub-basin under Scenarios 2 and 3, with little change under Scenario 1. Precipitation recharge is likely to increase to varying degrees over the Lower Kansas sub-basin under all scenarios, as all three scenarios project increased precipitation over the sub-basin. The effects of changes in surface water diversions, and corresponding seepage and deep percolation, on the total amount of recharge in each sub-basin is likely to be much smaller than the effects of changes in precipitation.

2. Water Demands

- For Nebraska, average NIR for canal service areas increases by 6.9% under Scenario 1 due to a combination of temperature-driven increase in evaporative demand and decreased precipitation. Average NIR decreases by 8.8% under Scenario 2 and decreases by 20.9% under Scenario 3. Results suggest that projected increases in precipitation over the majority of the Nebraska sub-basin under Scenarios 2 and 3 more than offset temperature-driven increases in evaporative demand (reference evapotranspiration) under these scenarios.

- For Nebraska, when applying district acreages and applying an area weighted average, the NIR decreases by 21% for Scenario 1 and increases by 15% and 44% for Scenarios 2 and 3, respectively. This result is based on Nebraska's modeling approach which estimates irrigated acreage based on available supply (i.e., more water is available under the cool/wet scenario, so acreage is increased and total demand [acres x NIR] increases). Under Scenario 1, acreage is reduced due to low supply, resulting in a decrease in overall demand.

- For Kansas, average NIR for KBID increases by 41.4% under Scenario 1 due to a combination of temperature-driven increase in evaporative demand and decreased precipitation. Average NIR increases by 9.3% under Scenario 2 and decreases by 22.1% under Scenario 3.

- It should be noted that projected changes in NIR for KBID are greater than corresponding projected changes in NIR for nearby lands in the Nebraska sub-basin served by the Courtland and Superior canals. In particular, the methodology used to compute NIR for KBID in the Lower Kansas sub-basin is more sensitive to projected changes in precipitation than the method used compute NIR for canal service areas in the Nebraska sub-basin. Differences highlight known uncertainties regarding calculation of NIR.

3. Water Supply Imbalances

- This study assessed the effects of imbalances as part of the System Reliability Analysis, the results of which are summarized in the next section below. System reliability for the Nebraska sub-basin evaluated the effects of water supply imbalances based on irrigated acreage, irrigation diversions and deliveries, and the frequency of Compact Call Years. System reliability for the Lower Kansas sub-basin evaluated the effects of water supply imbalances based on irrigation diversions and deliveries to KBID above and below Lovewell Reservoir.

4. Water Operations and Deliveries

- Based on the historical relationship between surface water availability and irrigated acreage, NBID experiences reduced acreage during more than half of the analysis period under Baseline (27 of 50 years) and Climate Scenario 1 (37 of 50 years), during slightly less than half of the analysis period under Climate Scenario 2 (22 of 50 years), and during just one year under Climate Scenario 3. Cumulative acreage reduction in NBID is 428,000 acres under the Baseline Climate Scenario; cumulative acreage reduction is greatest under Climate Scenario 1 at 706,000 acres, and is less under Climate Scenarios 2 and 3 at 260,000 and 2,500 acres, respectively. For FCID, reduced acreage occurs in 38 of 50 years under the Baseline Scenario with a cumulative reduction of 345,000 acres over the 50-year simulation period. The frequency and magnitude of acreage reduction are greater under Climate Scenario 1 and are less under Climate Scenarios 2 and 3 compared to the Baseline scenario.

- Despite acreage reductions, delivery shortages in NBID occur in more than half of all years under all scenarios. Shortages are greatest under the Baseline Climate Scenario, with shortages occurring in 37 of 50 years with a cumulative delivery shortage of 104,000 AF. The frequency and magnitude of shortages is smaller under all other climate scenarios compared to the Baseline Scenario. Surface water delivery shortages to FCID occur during 40 years under the Baseline Scenario with a cumulative shortage of 122,000 AF. Delivery shortages are less frequent under all climate scenarios compared to the baseline; however, the magnitude of shortages is greater under Climate Scenarios 1 and 2 and much less under Climate Scenario 3. It should be emphasized, however, that the frequency and magnitude of shortages do not depend on the available water supply but rather on the relationship between available water supply and water demands for the irrigated acreage calculated by the model.

5. Recreation Benefits

- Overall, compared to the Baseline No Action Alternative, Climate Scenarios 1, 2, and 3 result in an approximate increase of recreation benefits by 14%, 18%, and 29%, respectively for both Nebraska and Kansas.

- While certain reservoirs result in negative recreation benefits under Scenario 1, the overall recreation economic effect of climate change on the No Action Alternative is positive for all three climate change scenarios as compared to the Baseline No Action. Under Scenarios 1 and 2, Harlan County Lake and Lovewell Reservoir generate the majority of the increase in recreation benefits. Under Scenario 3, Swanson Reservoir also contributes heavily along with Harlan County and Lovewell.

- The reason for increased benefits under the climate change scenarios is the positive correlation of air temperatures and water levels with recreation visitation. In other words, people tend to recreate on reservoirs more when it is hotter and water levels are higher; either variable may have a stronger influence depending on the size and composition of the reservoir. For example, a one-foot change in water level at Harlan County Lake would lead to a substantially larger change in surface area as compared to a similar change in water levels at the other much smaller reservoirs included in this study.

6. Net Economic Benefits

- Net economic benefits of action alternatives under all future climate change scenarios exceeded net benefits under the Baseline Climate Scenario. The net benefits are dominated by the recreational benefits, discussed above, which reflect 72 to 98 percent of the net benefits depending on the climate change scenario.

- The increase in recreation benefits is primarily driven by increased temperatures under all three scenarios, with increased water elevations playing a more significant role under Scenarios 2 and 3. Again, this is attributable to the public visiting reservoirs more when it is hotter and/or more water is in the reservoir.

7. Environmental Resources

- High water temperatures and low flows in Frenchman Creek during the summer months would continue to be a limiting factor to the fish community. Thompson Creek supports a fish population of central stonerollers, red shiners, orangethroat darters, creek chubs, suckermouth minnows, flathead minnows and northern plains killifish. Under the no action, all of these species would have the ability to persist in Thompson Creek. The Kansas MDS would remain unchanged under the no action.

- Federal and state-listed species would not be impacted further than under historic conditions.

- Invasive species such as Canadian thistle, musk thistle, European buckthorn and garlic mustard would continue to persist throughout the area. No ground disturbing actions would take place under the No Action Alternative that would increase the spread these species. Non-native fish species stocked in reservoir environments would continue to persist and could spread into the Republican River and Frenchman Creek.

- All water quality impairments may be expected to continue depending on the status and outcome of TMDL-related management actions. Headwater tributaries into Lovewell Reservoir may continue to be impaired for water supply and aquatic life by arsenic, selenium and total phosphorus. White Rock Creek upstream and downstream from Lovewell Reservoir may continue to be impaired by arsenic and aquatic life impaired due to total phosphorus and total suspended solids.

- Decreased flows and altered hydrographs are the primary limiting factors throughout the basin which would continue. Fish populations would continue to shift towards species that spawn in the substrate rather than those that spawn in open water. The basin could also continue to see an increased shift towards non-native species.

C. Nebraska Findings

- Alternatives 3A and 3B increase Swanson Lake levels which increase FCID diversions, but this may come at a cost to HCL storage, thereby increasing the number of Compact Call Years and reducing NBID diversions by a proportionate amount. The capital costs estimated by Reclamation for Alternative 3B are over two times more than those for Alternative 3A ($82 million versus $36 million, respectively).

- Results indicate that that the pumping volumes of 3,000 and 5,000 gpm proposed under Alternatives 3A and 3B, respectively, could be increased because pump augmentation operations were almost always able to operate at full capacity for those years in which pumping was allowed. Higher pumping levels would also make the impacts from pump augmentation operations more pronounced, perhaps providing more definitive results.

- Options exist to modify operations of Alternative 3A/3B – for instance to allow for releases at Swanson Lake in exchange for additional storage at HCL[8]. This would require a more complex modeling effort than that which was undertaken for this study.

- Alternative 5A clearly increases Franklin Canal diversions, which allows HCL to store more water, thereby increasing NBID diversions.

[8] Frenchman-Cambridge Irrigation District, Swanson Reservoir Pumpback Project, April 20, 2012 PowerPoint by Brad Edgerton, accessed on May 30, 2015 at www.fcidwater.com/Swanson Project/Swanson Project.pdf

The capital costs estimated by Reclamation for Alternative 5A total $92 million.

D. Kansas Findings

- The expansion of Lovewell Reservoir by 16,000 AF, 25,000 AF, or 35,000 AF reduces the magnitude and frequency of KBID shortages by a relatively small amount under the Baseline Climate Scenario. This is largely due to operational assumptions under the No Action Alternative made by Nebraska during Compact Call Years which require measures to be taken to ensure Compact compliance.

- A reduction in the magnitude and frequency of KBID shortages is slightly more pronounced under Scenario 1, with the 25,000 AF option providing a greater shortage reduction than the 16,000 AF option and a shortage reduction similar to the 35,000 AF option, but at a lower capital cost ($59 million for 25,000 AF versus $84 million for 35,000 AF[9], respectively).

- Considering the high cost of reservoir expansion options and the relatively small reductions to KBID shortages, the only expansion alternative that was selected for further benefit/cost evaluation was the 25,000 AF option.

E. Economics Benefits Findings for Action Alternatives

- The action alternatives were developed to appraisal-level design in accordance with Reclamation's D&S FAC 09-01 and project costs were developed without any engineering data other than topographic mapping, satellite imagery, and design drawings of existing Reclamation features. Estimated capital costs ranged from $36 to $92 million[10].

- Benefit estimates were primarily driven by recreation; agricultural benefits were relatively low for all alternatives.

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[9] The cost estimates for other expansion options is provided in *Republican River Basin Appraisal-Level Engineering and Cost Estimates on Structural Alternatives, Technical Memorandum No. RRB-8130-BSA-2014-1*. Prepared by the Bureau of Reclamation, Technical Service Center, August 2014.
[10] Excluded operations, maintenance, replacement, and power costs.

- Alternative 1C may be the only alternative to yield positive net benefits, due in large part to the recreational benefits. The net benefits of 3A were the highest of Nebraska's three alternatives. Alternative 5A yielded the lowest net benefits of the three Nebraska alternatives. However, these results are preliminary. A more complete economics analysis would include OMR&P costs and address data gaps and uncertainties summarized below and discussed in Section 7.7.4 of the Basin Study Report.

- Future investigations seeking to develop more detailed benefit/cost analyses would need to consider the following from a cost standpoint: formal site inspections, geotechnical studies, hydrologic and hydraulic investigations, risk analyses, etc. Regarding agricultural benefits, a consistent method for developing cropping patterns across states could be implemented, such as using irrigation district information for both states or use only U.S. Department of Agriculture National Agricultural Statistics Service data for both states. As well, a more detailed analysis on groundwater pumping evaluation across climate scenarios could be conducted. A more detailed analysis might examine additional factors of production and include them in the agricultural benefits analysis. Regarding recreation benefits, collection of additional data could be conducted on travel costs and/or contingent valuation modeling where both visitation and value could be derived from the same model. And finally, inclusion of annual OMR&P costs would provide a more complete economics analysis.

F. Ongoing Negotiations and Agreements

The findings of this Basin Study should be considered in the context of the ongoing negotiations and agreements among Colorado, Nebraska, and Kansas pertaining to the management of the Republican River Basin. An agreement was signed in October 2014 between Colorado and Kansas helping improve the reliability of water supplies in the South Fork Republican River in Kansas by authorizing Colorado to receive credit in Compact accounting for water from its augmentation project on the North Fork Republican River. Yet other agreements recently signed during the production of this Basin Study include provisions between Nebraska and Kansas to integrate more flexibility into achieving Compact compliance while maximizing surface water use by irrigators. For instance, in March 2015, the RRCA, Reclamation, and the Bostwick Irrigation District reached a short-term agreement that allowed surface water rights to remain open during Compact Call Years, thereby providing surface water users with more certainty in their water supplies. At the same time, Nebraska was allowed to offset any current-year shortfalls through augmentation pumping (as described in Nebraska's IMPs) the following year outside the irrigation season. The states are currently working on a long-term agreement similar to the framework agreed to in 2015. If the states can reach agreement, it would minimize Nebraska's need to issue Compact Calls, administer surface water rights for Compact compliance, and limit the need to make releases from Reclamation's reservoirs outside the irrigation season.

In addition to the RRCA, organizations and programs, such as the Republican River Riparian and Restoration Partners, are helping foster sustainable water resources management throughout the Republican River Basin. The Riparian and Restoration Partners, led by seven Resource Conservation and Development Programs, has been created to help provide leadership in the planning and coordination of sound conservation practices, and to bring federal, state, and local entities together to implement a viable living Republican River Basin by 2037. These local and federal projects are managed cooperatively to help ensure a healthy Basin in the years to come.

G. Other Programs and Opportunities

Although the Basin Study Program provides an avenue to conduct planning on a basin-wide scale to identify and evaluate adaptation and mitigation strategies, it does not provide the means to construct or otherwise implement those strategies. Funding for construction/implementation may be provided under other WaterSMART programs, namely through Water and Energy Efficiency Grants (WEEG) or Water Conservation Field Services Grants. The irrigation districts in Nebraska and Kansas have demonstrated their familiarity with these programs by their recent successes in being awarded grants under these programs for the conversion of open laterals into pipelines. As these districts are aware, the administration of Reclamation’s construction grant funding follows strict program requirements and is subject to Congressional appropriations, both of which may change in any given year. Prospective non-federal project sponsors are encouraged to visit: *www.usbr.gov/WaterSMART/weeg/* to learn about program developments and funding opportunities relating to WEEGs. To learn more about Water Conservation Field Services, contact should be made with Reclamation’s Nebraska-Kansas Area Office.

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