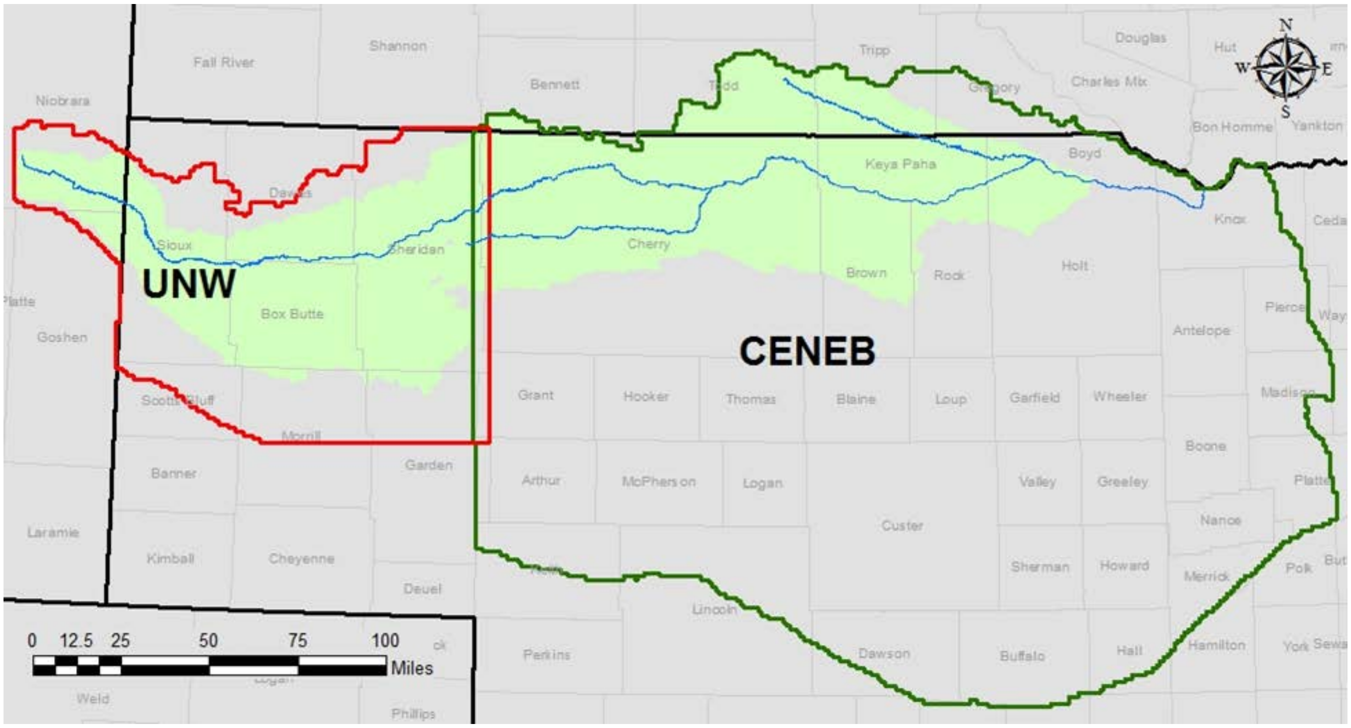
BUREAU OF RECLAMATION

Niobrara River Basin Study

Appendix E — The Watershed Model



U.S. Department of the Interior

Nebraska
Department of Natural Resources
Lincoln, Nebraska

February 2015

Mission Statements

Department of the Interior

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

Bureau of Reclamation

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

Nebraska Department of Natural Resources

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

On cover: Map showing the two adjacent watershed modeling areas used in this study: the Upper Niobrara-White (UNW) area and the Central Nebraska (CENEB) area.

Niobrara River Basin Study

Appendix E —
The Watershed Model

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U.S. Department of the Interior

Nebraska

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February 2015

Executive Summary

Purpose and Scope

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

The purpose of this report is to introduce the Upper Niobrara White Natural Resources Districts Conjunctive Management Model (UNWNRD) and the Central Nebraska Model (CENEB); the watershed models used within the Niobrara Basin Study. The report will provide an overview of the historical model, the adaptation made for the Niobrara Basin Study, and a summary of the watershed model results.

The Watershed Model

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

The watershed model can be divided in to four parts; climate, soil water balance, spatial distribution of water balance parameters, and the adaptation of local conditions. Weather is the primary input into the watershed model; the remaining parts represent how the system reacts to the climate. The soil water balance model (CROPSIM) combines the weather data with representative system characteristics (phenology, soil, management, and system) to simulate the flux of water into and out of a single point soil profile. This process is repeated at multiple weather stations across the modeled domain. The spatial distribution of the water balance parameters relates the results from the soil water balance model at nearby weather station to the localized soil types. The adaptation of local conditions represents the final component of the watershed model, the Regionalized Soil Water Balance Model (RSWB). The RSWB adjusts the spatially distributed water balance parameters to further refine the model representation of local conditions such as land use, irrigation systems, and management conditions. The RSWB is then used to create .RCH and .WEL input files for the groundwater model.

Within the watershed models the Niobrara Basin Study considers the lands which drain to the Niobrara River from head waters in eastern Wyoming to the stream gauge near Spencer, NE; roughly 12,300 mi^2 in a primarily agricultural setting. The UNWNRD model covers the western portion of the Niobrara River. It is situated in the northern half of the Nebraska panhandle, ranging from the eastern Wyoming to the Sheridan-Cherry County boarder. This area consists of 8,700 mi^2 of which 4,800 mi^2 drain to the Niobrara River. The eastern portion of the Niobrara Basin Study falls within the domain of the CENEB model. The CENEB model covers nearly 34,500 mi^2 in North Central Nebraska ranging from the panhandle in the west to the confluences of the Loup and Platte Rivers, Elkhorn and North fork of the Elkhorn Rivers, and Niobrara and Missouri Rivers in the East. The model extends to the Platte River in the south and covers the extent of the Niobrara Drainage area in the North. Of this area approximately 7,500 mi^2 drain to the Niobrara River upstream of the gauge at Spencer, NE.

Model Adaptations for the Niobrara Water Smart Project

The watershed model incorporated the climate data develop by the USBR (Appendix A.). Four climates were created to represent both historical conditions as wells as possible future conditions under varying levels of water availability. Furthermore, two proposed management alternatives were investigated under each climate scenario. The Mirage Flats Pumping Station Alternative proposed bypassing a relatively inefficient portion of the Mirage Flats Irrigation District's canal by moving the districts diversion point 9 miles downstream and installing a high aquifer well field. The second alterative, Mirage Flats Canal Recharge Alternative would cease surface water irrigation deliveries and convert the district to groundwater. The district would continue to divert during the growing season, allowing the water to seep from the canal as recharge to mitigate the effect of increases in pumping.

Historically, the two watershed models only interacted with the groundwater model. The Niobrara Basin Study introduced the interaction of the watershed model with the surface water operations models. A system of surface water irrigation groups were developed to pass surface water irrigation demands, supplies, and canal recharge between the watershed model and the surface water operations model (Appendix F).

The watershed models were updated to project current conditions into the future. All aspects of the model which trended through time to represent historical conditions were updated to current values. These parameters include land use, irrigation development, municipal and industrial pumping, and application efficiencies; as well as crop characteristics and management practices. The current values were used over the entire temporal domain of the model.

Simulation Results

Generally, the modeling results show changes in climate will influence the water balance within the watershed. Increases in precipitation, decrease the need for irrigation and increase evapotranspiration, recharge, and runoff contributions to stream flow. In the UNWNRD model where the supply of surface water is limited, increases in precipitation yield more available surface water and reduce the volume of supplemental co-mingled pumping. Figure ES-1 shows the average distribution of sources and destination of water for the Niobrara Drainage Basin within the UNWNRD model under the baseline climate. Table ES-1 describes the absolute change in the water balance under the various climate scenarios. The watershed model covers a large area and the results are available on several different resolutions. This report provides an overview of the modeling results and investigates the changes due to climate and alternatives for a representative number of resolutions.

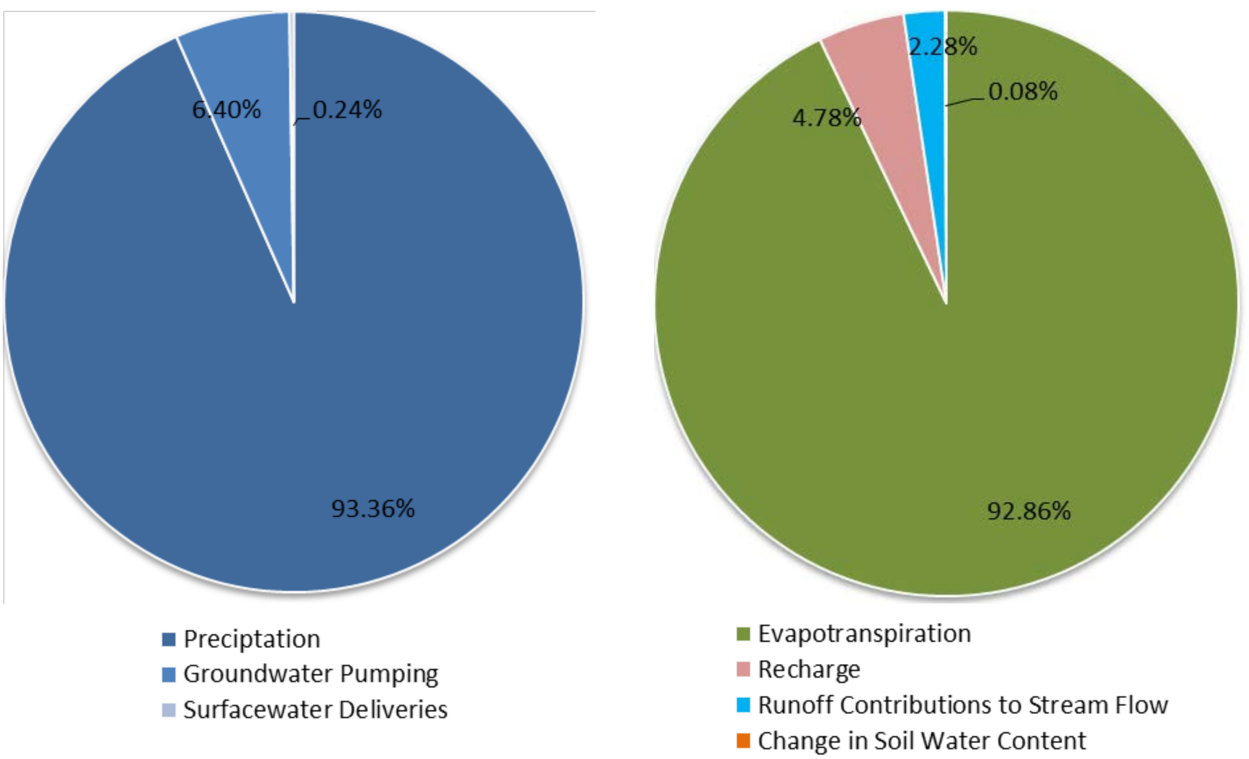


Figure ES-1. Sources of 17.21 in/ac of total available water and partitioned total available water for the Niobrara Basin within the UNWNRD model; Baseline No Action.

Table ES-1. Average percent change in water balance parameters in the Niobrara Drainage Basin within the UNWNRD model upstream of the gauge near Gordon, NE; Baseline No Action

Climate Scenario	Precipi-tation	Ground-water Pumping	Surface Water Deliveries	Total Applied Water	ET	Recharge	Runoff Contributions to Streamflow
Climate 1	–16.12%	9.35%	–11.01%	–14.47%	–13.72%	–27.12%	–23.08%
Climate 2	6.35%	–4.35%	17.46%	5.69%	4.96%	15.03%	10.95%
Climate 3	18.89%	–11.50%	42.75%	17.00%	13.66%	63.60%	46.23%

A primary objective of the Niobrara Basin Study is the quantification of shortages in available surface water. Figures ES-2 through ES-4 show the change in surface water demands, supplies, and supplemental co-mingled pumping for each of the surface water irrigation groups in the UNWNRD model.

The Mirage Flats Pumping Station Alternative was able to achieve its objective, by increasing the transportation efficiency of the surface water diversion (Figure ES-5) and reducing the volume of co-mingled pumping (Figure ES-6). However, the increase in efficiency reduced the volume of canal seepage (Figure ES-7) which represents a significant source of localized recharge.

The Mirage Flats Canal Recharge Alternative was able to create a relatively stable supply of canal recharge, generally at a rate greater than the annual No-Action rate (Figure ES-8). The increase in canal recharge exceeded any decreases in field recharge from the new supply of irrigation water (Figure ES-9, Table ES-2).

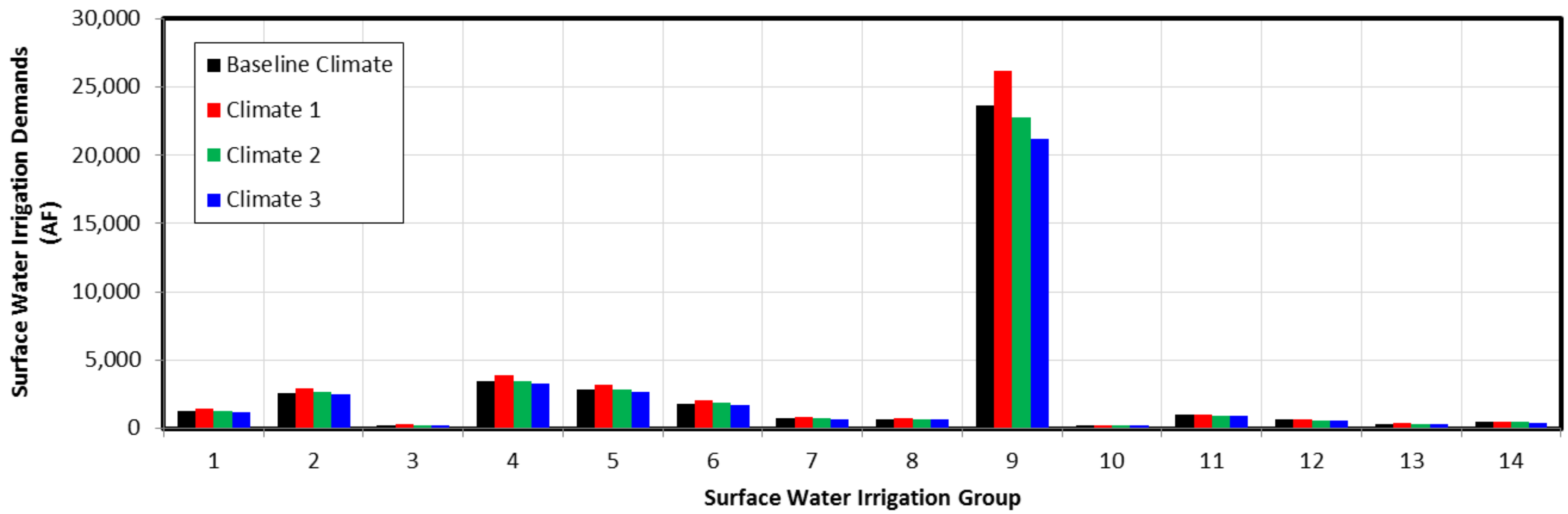


Figure ES-2. Average annual surface water demands under each climate scenario in the UNWNRD model.

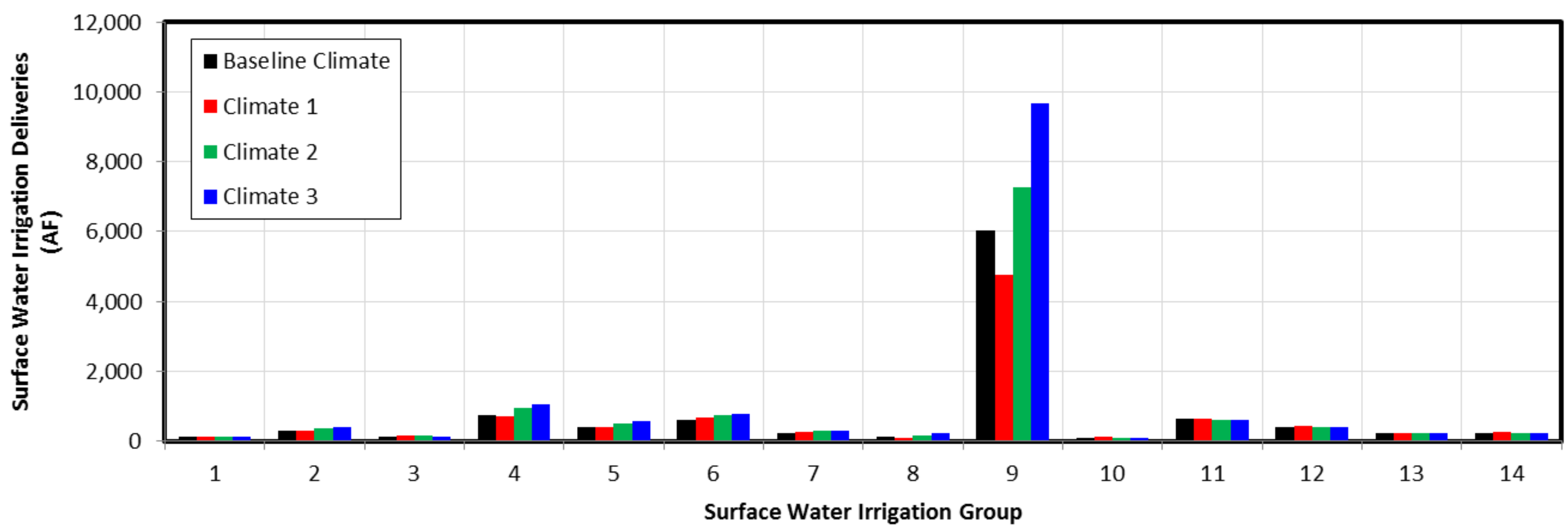


Figure ES-3. Average annual surface water deliveries under each climate scenario in the UNWNRD model.

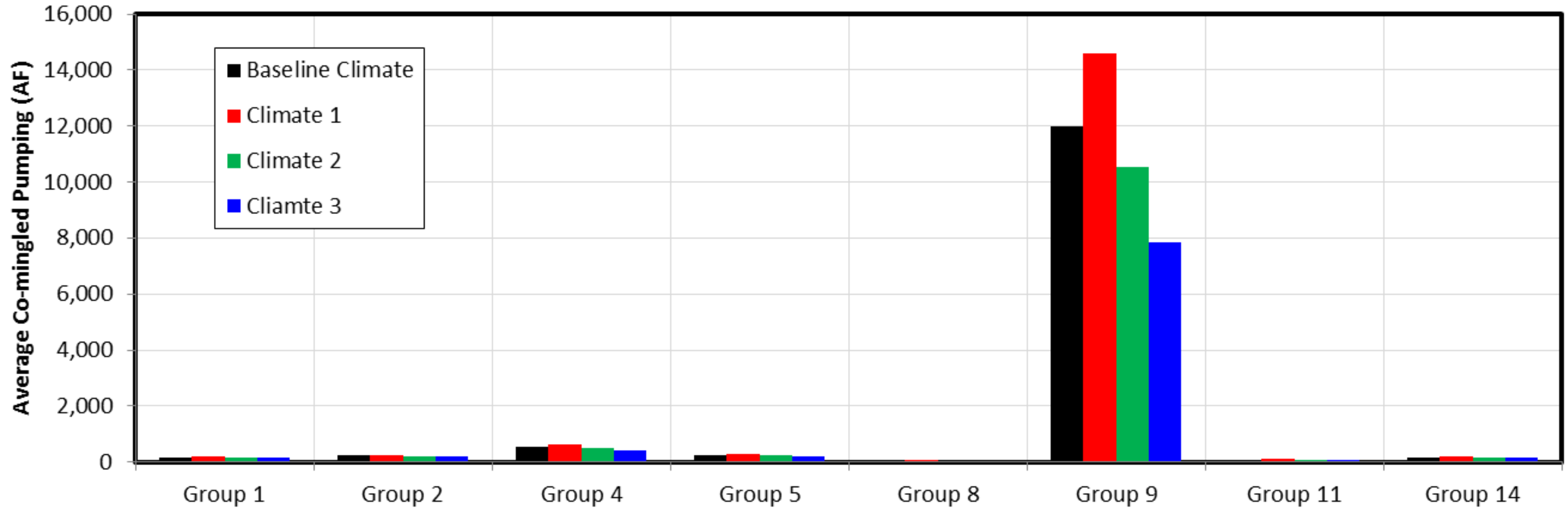


Figure ES-4. Average supplemental co-mingled pumping under each climate scenario in the UNWNRD model.

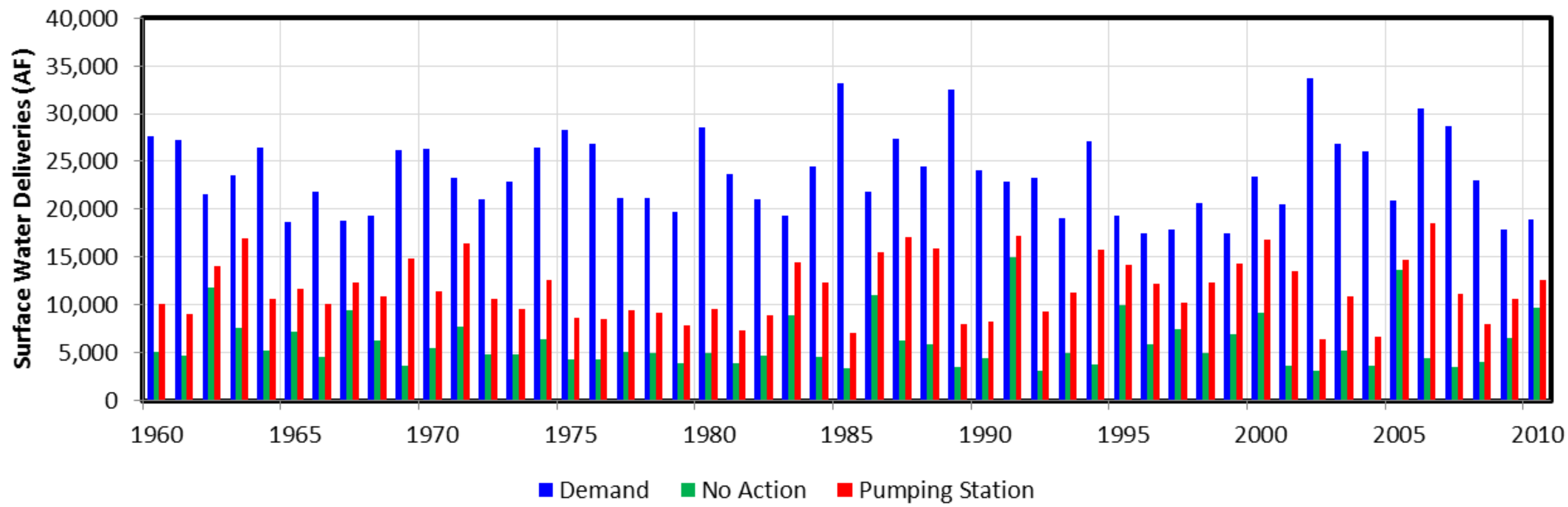


Figure ES-5. Comparison of the annual surface water demands and deliveries for the pumping station alternative for Group 9; Baseline No Action.

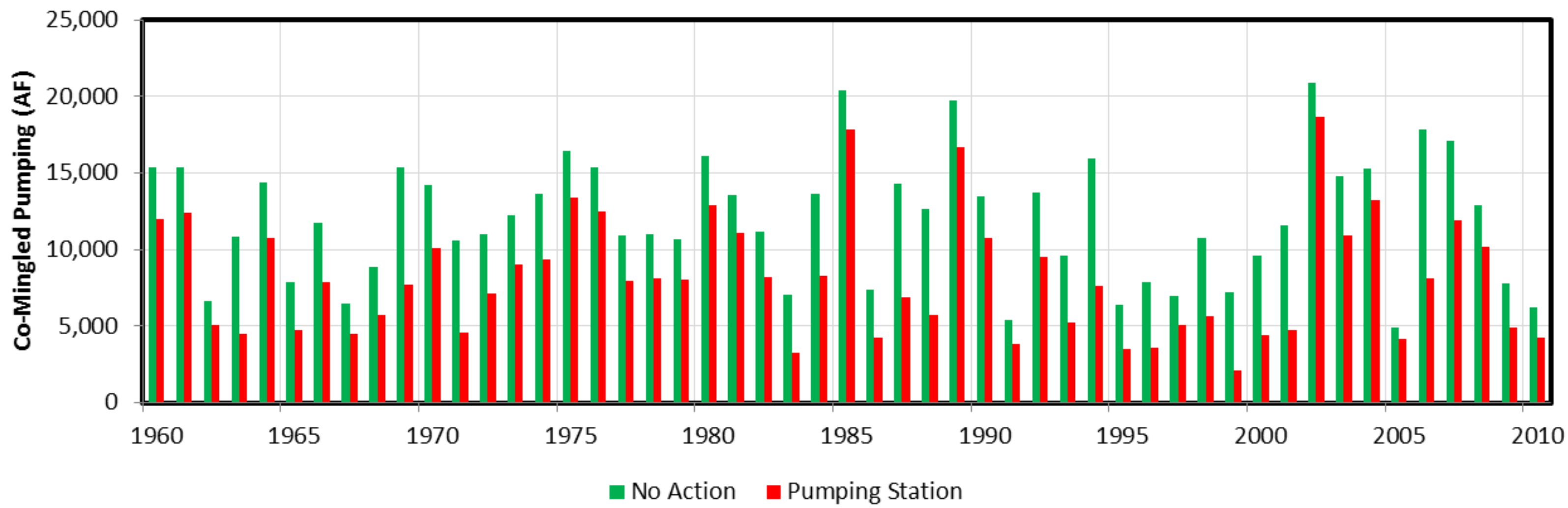


Figure ES-6. Comparison of the annual co-mingle pumping volumes for the pumping station alternative for Group 9; Baseline No Action.

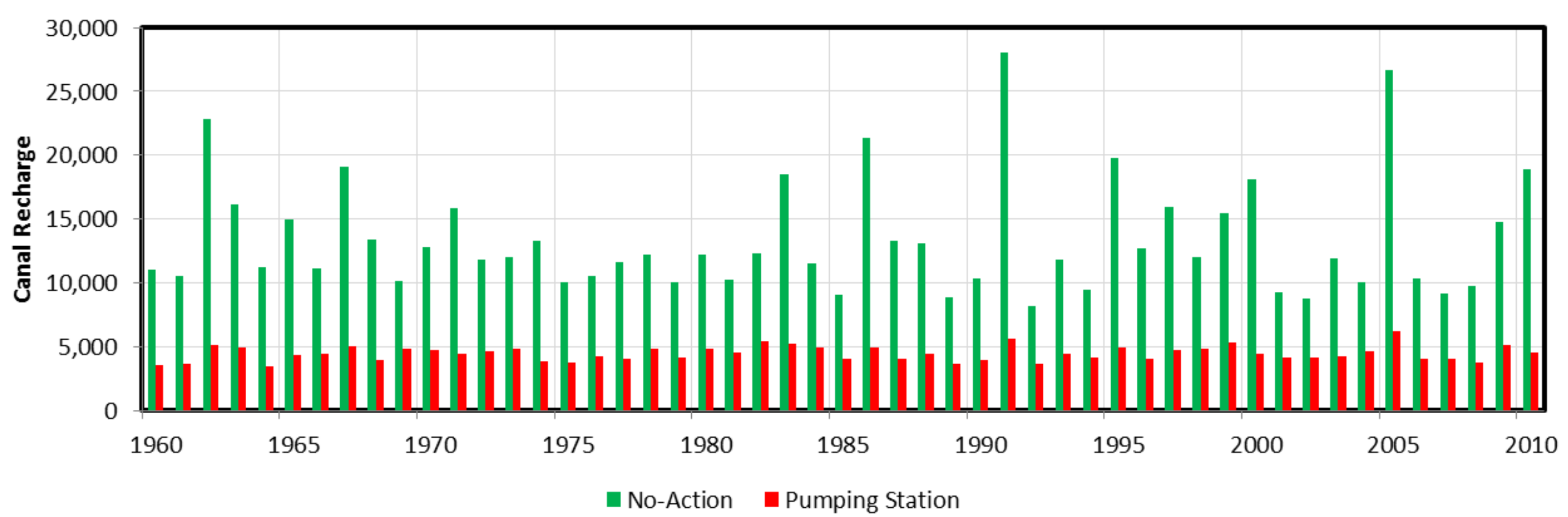


Figure ES-7. Comparison of annual basin wide canal recharge for the pumping station alternative; Baseline No Action.

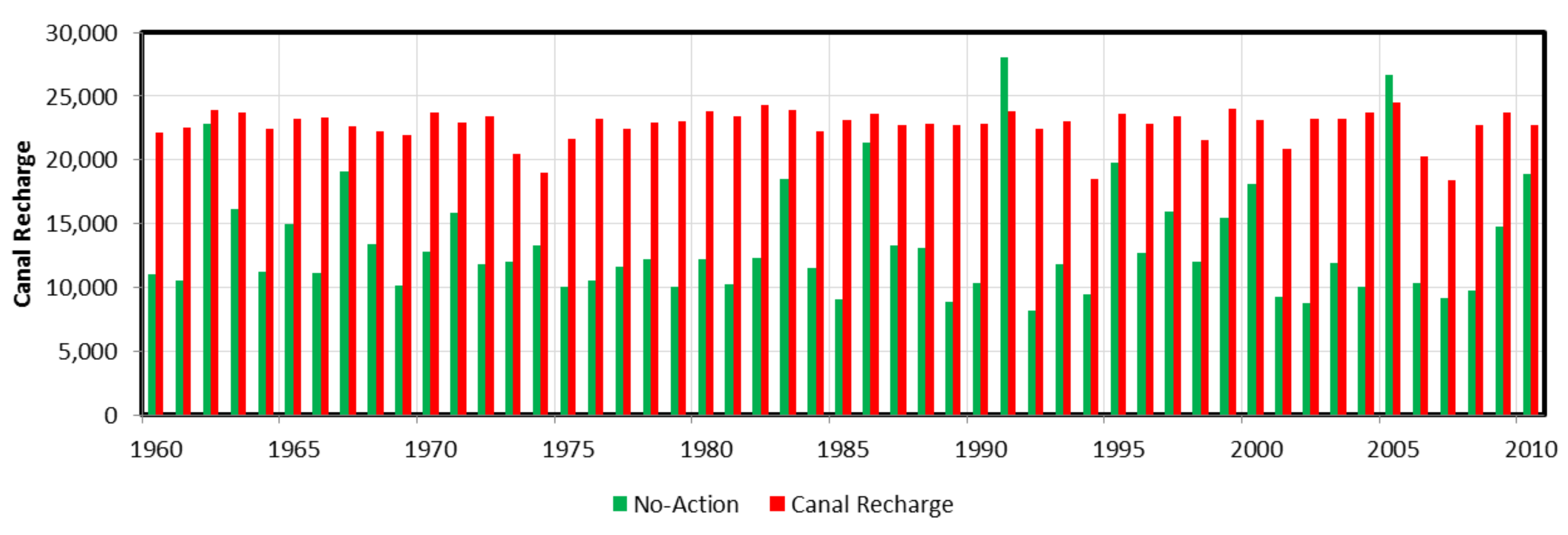
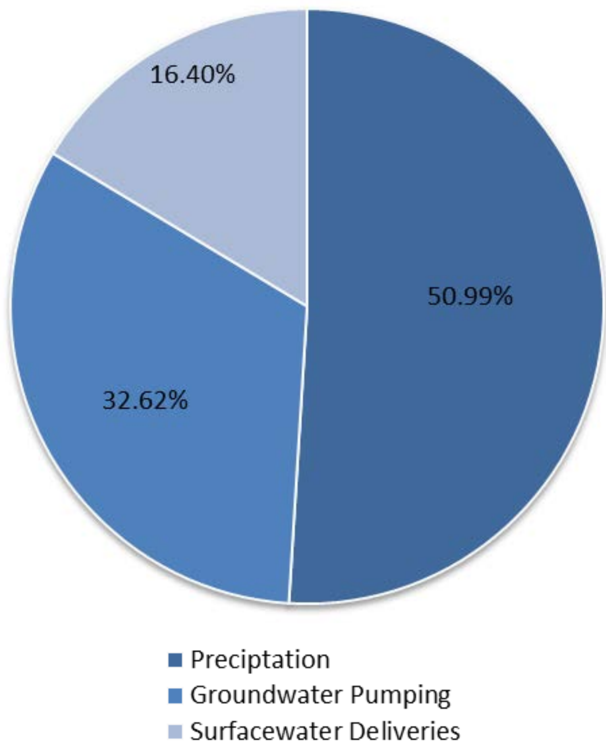


Figure ES-8. Comparison of annual basin wide canal recharge for the canal recharge alternative; Baseline No Action.



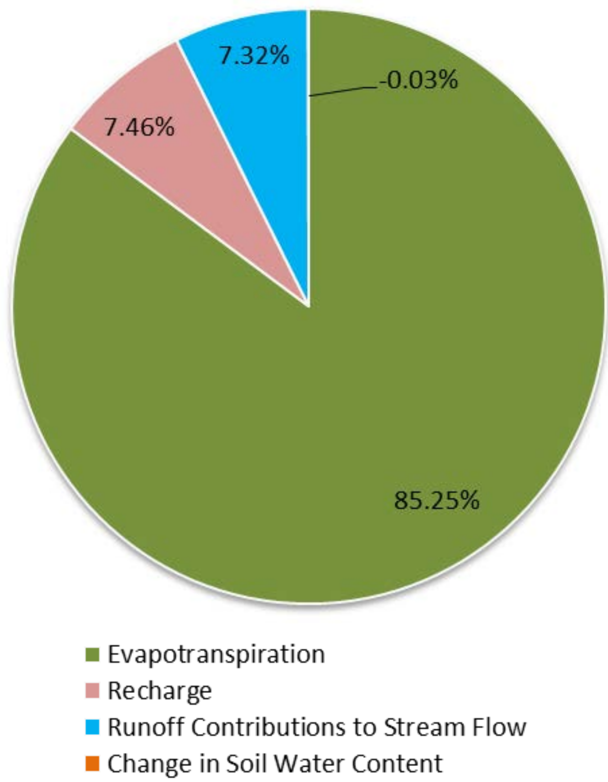


Figure ES-9. Sources of 32.81 in/ac of total available water and partitioned total available water for the Mirage Flats Irrigation District within the UNWNRD model; Baseline No Action.

Table ES-2. Percent Change in the Average Water Balance between the No Action and Canal Recharge Alternatives under the Various Climate Scenarios

Climate Scenario	Precipi-tation	Ground-water Pumping	Surface Water Deliveries	Total Applied Water	ET	Recharge	Runoff Contributions to Streamflow
Baseline	–	34.40%	–100.00%	–5.18%	0.32%	–15.82%	–20.18%
Climate 1	–	22.39%	–100.00%	–4.27%	0.96%	–16.06%	–17.91%
Climate 2	–	47.21%	–100.00%	–6.05%	–0.45%	–16.68%	–23.18%
Climate 3	–	84.37%	–100.00%	–7.68%	–1.46%	–17.82%	–26.51%

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Glossary of Terms

Abbreviations and Acronyms

AF	acre feet
Alternative 1	Mirage Flats Irrigation District's pumping station project
Alternative 2	Mirage Flats Irrigation District's canal recharge project
AWDN	Automated Weather Data Network
Baseline Climate	estimated historical climate
Climate 1	climate classified as low water availability
Climate 2	climate classified as central tendency
Climate 3	climate classified as high water availability
CENEB	Central Nebraska Model
CROPSIM	point source soil water balance model
DNR	Nebraska Department of Natural Resources
DP	deep percolation
ET	evapotranspiration
ETr	tall crop reference ET
I	applied irrigation
in., in/ac	inch, inch per acre; depth of water per unit area
NBS	Niobrara Basin Study
NWS/Coop	National Weather Service and Cooperative Observers Network
No Action	Alternative which assumes status quo
P	precipitation
.RCH	recharge input file for the groundwater model
RO	runoff
RSWB	Regionalized Soil Water Balance Model
SWC	change in soil water content
TFG	The Flatwater Group, Inc.
UNWNRD	Upper Niobrara White Natural Resource District's Conjunctive Management Model
USBR	United States Bureau of Reclamation
.WEL	well pumping input file for the groundwater model

Definitions

Application Efficiency	ratio defining to the portion of applied irrigation which infiltrates into the soil for use by the crops
Canal Seepage	diverted surface water which drains from the canal during transportation
Co-mingled	refers to irrigated lands capable of using groundwater and surface water irrigation sources

Confluence	point where a tributary flows into
Consumptive Use	evapotranspiration; beneficial consumptive use represents ET used for crop growth and development, non-beneficial consumptive use represents ET from other sources not related to crop growth and development
Deep Percolation	water which drains below the root zone
Evapotranspiration	combination of evaporation and transpiration
Full Evaporative	amount of water the crop would evaporated during the normal growing process
Demand	when water is not a limiting factor
Groundwater	relating to water in aquifers
Head Water	furthest upstream point of the river
Hydrologic Cycle	model describing the flux of water in the system
Hydrologic Soil Group	property of the soil describing the propensity of the soil to allow infiltration
Irrigation Group	collection of local surface water diverters
Net Irrigation	depth of water need to be delivered to the soil profile for crop to reach full
Requirement	transpiration potential
Phenology	characteristics of the plant life cycle events
Recharge	water which travels from the surface to the aquifer
Reference ET	rate of evapotranspiration for a reference crop under standardized conditions
Runoff Contributions	portion of field runoff estimated to reach stream gauges without joining the
to Stream Flow	groundwater supply
Soil Class	representative description of soils with similar properties
Soil Profile	description of soils from which the crop can extract water
Soil Water Balance	method used to ensure all water is accounted for within, entering, and leaving the system
Spatial	related to the geographic location
Stream Gauge	device for measuring stream flows
Surface Losses	irrigation inefficiencies lost to evapotranspiration
Surface Water	water within the river system
Temporal	related to the period of time
Tributaries	creeks, streams, and rivers which feeds into the main river

1 Introduction

1.1 Authorization

The purpose of this report is to describe the role, development, and calibration of the surface water operations model using the STELLA software package. The surface water operations model was developed for the Niobrara River (from Nebraska State Line to the Gordon gage) to be used as a part of the integrated modeling approach described in Appendix F, Integrated Water Management Model Report.

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

The Flatwater Group, Inc. (TFG) has prepared this report as authorized in Contract 802 Task Order #201501 between the Nebraska Department of Natural Resources (DNR) and TFG originally dated 17 November 2014.

1.2 Purpose and Scope

The purpose of Niobrara River Basin Study is to evaluate current and projected future water supply and demand and evaluate potential adaptation strategies which may reduce any identified gaps as part of the Water Sustain and Manage America's Resources for Tomorrow (WaterSMART) Program. The United States Bureau of Reclamation (USBR), in conjunction with the Nebraska DNR, developed a basin study to estimate and evaluate available water supplies in the Niobrara Basin from the headwaters in Wyoming to Spencer, NE. The project consists of a climate model, two groundwater models, two surface water operations model, an economic model, and two watershed models. Through this project, the results from the various models are integrated to quantify changes and their effects on water availability in the basin.

Two watershed models were incorporated into the Basin Study. The first is from the Upper Niobrara White Natural Resources District's Conjunctive Management Model (UWNNRD). The second is from the Central Nebraska Model (CENEB). This report highlights the processes and describes the adaptation of the watershed models for the Basin Study. Furthermore, the report will discuss the interaction of the RSWB with other models within the project. Finally summaries of select watershed model results are presented to provide context to the reader.

The primary role of the watershed is to ensure that the water supplies and water uses were accounted for within a balanced water budget. The water budget was represented by precipitation (P), applied irrigation water (I), evapotranspiration (ET), deep percolation[1] (DP), runoff (RO), and change in soil water content (SWC).

[1] Deep percolation is defined as water which infiltrates below the bottom of the root zone.

2 The Watershed Model

2.1 Study Area

The area of interest for the Niobrara Basin study consists of the lands which drain to the Niobrara Basin from the headwaters in eastern Wyoming to the stream gauge at Spencer, NE; roughly 12,300 mi^2. The model domain is covered by two watershed models developed to investigate water usage in the predominantly agricultural settings.

The western edge portion of the study area falls within the domain of the Upper Niobrara White Conjunctive Management Model (UNWNRD). The UNWNRD model covers approximately 8,700 mi^2 in the northern portion of the Nebraska panhandle and eastern Wyoming (Figure 1). Of this area, nearly 4,800 mi^2 drain to the Niobrara River.

The eastern portion of the study is contained within the Central Nebraska Model (CENEB). The CENEB model covers approximately 34,500 mi^2 of north central Nebraska and southern South Dakota (Figure 2). The model extends from the panhandle of Nebraska in the west to roughly the confluences of the Niobrara and Missouri, Elkhorn and North fork of the Elkhorn, and the Loup and Platte rivers in the east. The southern border is comprised of the North Platte River and the Platte Rivers; while the northern border extends the edge of the Niobrara drainage basin. Within the CENEB domain roughly 7,500 mi^2 drain to the Niobrara River upstream of the gauge at Spencer, NE.

This report will provide a broad overview of the watershed models. Further detail is available in the draft documentation for each model.

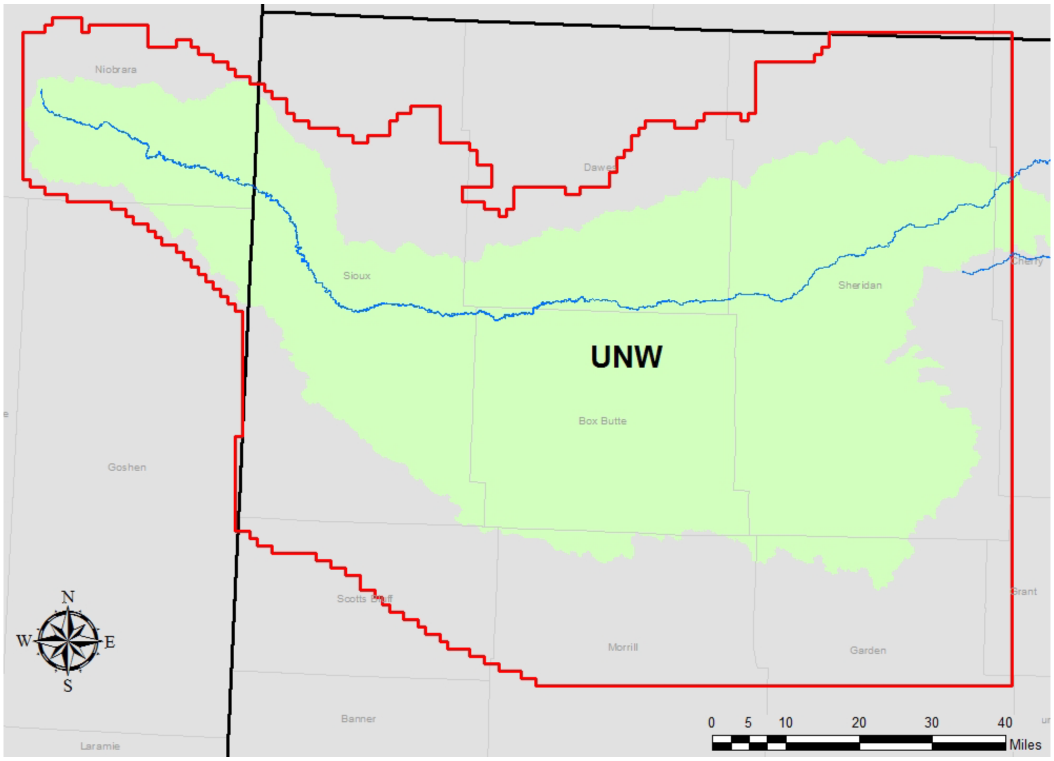

Figure 1. Domain of the Niobrara Basin Study within the UNWNRD Model.

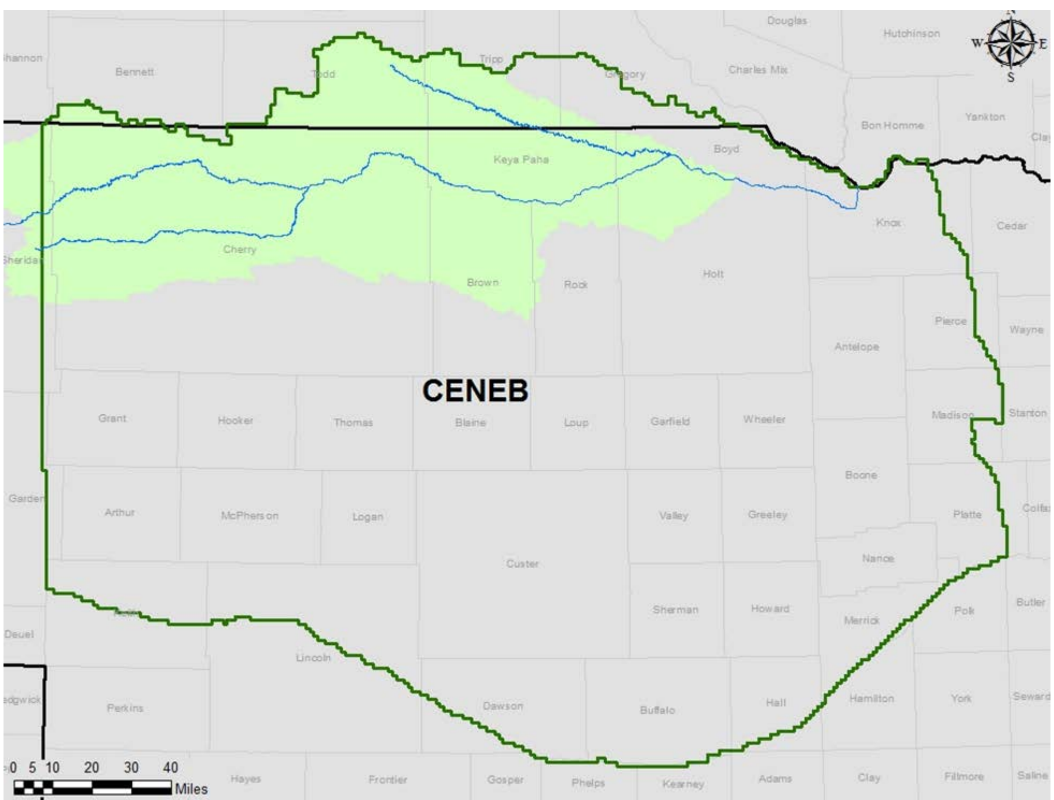

Figure 2. Domain of the Niobrara Basin Study within the CENEB Model.

2.2 Conceptual Model

The complete hydrologic cycle as modified by irrigation and other human activity serves as the conceptual model for this project. Figure 3 is a schematic illustration of the hydrologic cycle for a system where use of water for irrigation is important. This figure provides visual context for discussion of the system as modeled.

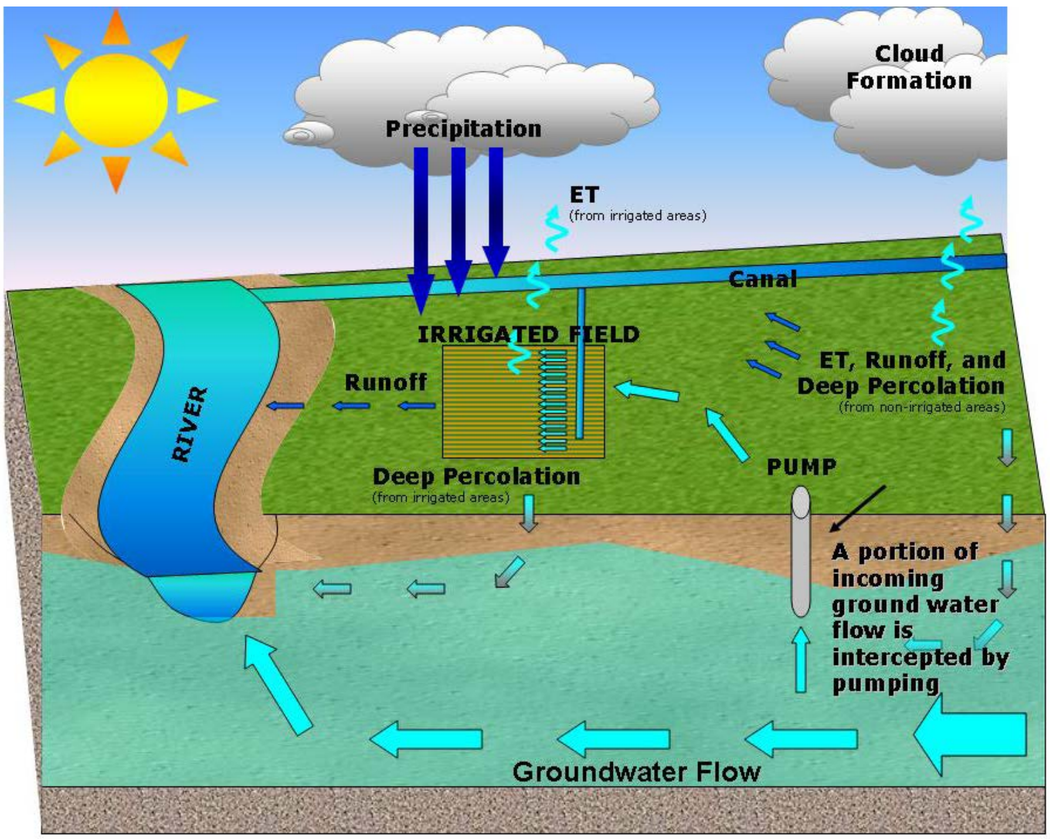

Figure 3. Illustration of hydrologic cycle in which irrigation is important.

The intended use of the model drives what physical characteristics of the study area are important to properly represent. In the case of the RSWB model, information about the area's climate, soils, land use, and farming practices are important characteristics to address when attempting to estimate the amount of water needed to irrigate crops, develop estimates of recharge to groundwater, and runoff contributions to stream flow.

2.3 Model Construction

The watershed model can be divided into four parts; climate, soil water balance, spatial distribution of water balance parameters, and the adaptation of local conditions. Weather data is the primary input to the watershed model; the remaining parts represent how the system reacts to the climate. The soil water balance model CROPSIM[2] applies the climate to several sets of representative system characteristics (phenology, soils, management, and system) to simulate the flux of water into and out of a single point soil profile. This process is repeated for multiple weather stations scattered throughout the model domain. The spatial distribution of the water balance parameters relates the water balance results from CROPSIM at the nearby weather stations to the localized soil types. The final part of the watershed model is the Regionalized Soil Water Balance (RSWB) Model. The RSWB applies and adjusts the spatially distributed water balance parameters to further refine the model and better represent local conditions.

2.4 Climate

Historic weather data was acquired from the High Plains Regional Climate Center at the University of Nebraska in Lincoln. There are two databases from which historical weather data can be retrieved; the Automated Weather Data Network (AWDN) and the National Weather Service and the Cooperative Observers Network (NWS/Coop). NWS/Coop weather stations tend to have a longer period of recorded data. Frequently these weather stations began collecting data in the late 1940s, with some records extending into the 1800s. However, the type of data collected by these stations is limited to minimum and maximum temperature and precipitation. Conversely, AWDN stations collect a wide variety of data including temperature, precipitation, wind speed, relative humidity, and soil temperature. However, these stations were generally brought on-line in the last couple of decades, limiting the temporal scope of the available data. With a time frame of 1960-2010, the modeling process used the NWS/Coop weather stations.

Twelve weather stations were incorporated into the UNWNRD model (Figure 4,[3] Table 1). The historical climate ranged from roughly 14.5 in. of annual precipitation in around the Agate weather station in central Sioux County to 17.7 in. near the Gordon weather station in north east Sheridan County.

The CENEB model utilized 43 stations (Figure 5,[3] Table 2) within and around the model domain. Annual historical precipitation displays a general pattern with decreasing depths as one progresses from the southeast (28.5 in. NE Saline County) to west (17.5 in. SE Sheridan County). The same pattern describes the Niobrara Basin as well with annual precipitation values ranging from 25.0 in. near the confluence with the Missouri river to 17.7 in. at the Gordon weather station.

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[2] CROPSIM and the watershed model are not the same entity.

[3] Not all weather stations are shown in the figure.

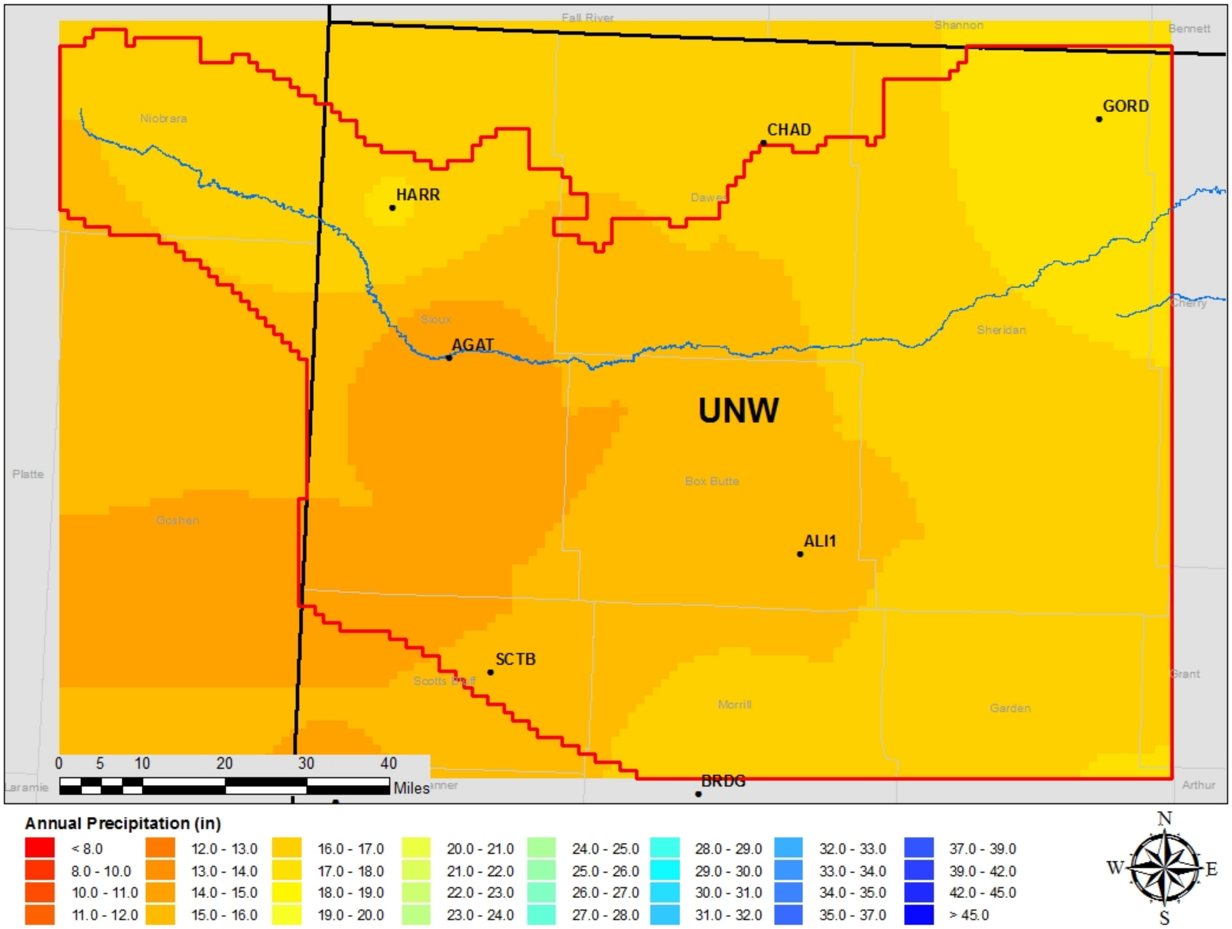

Figure 4. Average historical precipitation in the UNWNRD model area 1960 - 2010.

Table 1. UNW NWS/Coop Weather Stations

Station	Code	Latitude	Longitude
Agate 3 E	AGAT	42.42	–103.73
Alliance 1 WNW	ALI1	42.10	–102.88
Big Springs	BIGS	41.05	–102.13
Bridgeport	BRDG	41.67	–103.10
Harrisburg 12 WNW	HRSB	41.63	–103.95
Kimball	KMBL	41.27	–103.65
Oshkosh	OSHK	41.42	–102.33
Scottsbluff AP	SCTB	41.87	–103.60
Sidney 6 NNW	SDN2	41.20	–103.02
Gordon 6 N	GORD	42.88	–102.20
Harrison	HARR	42.68	–103.88
Chadron 1 NW	CHAD	42.82	–103.00

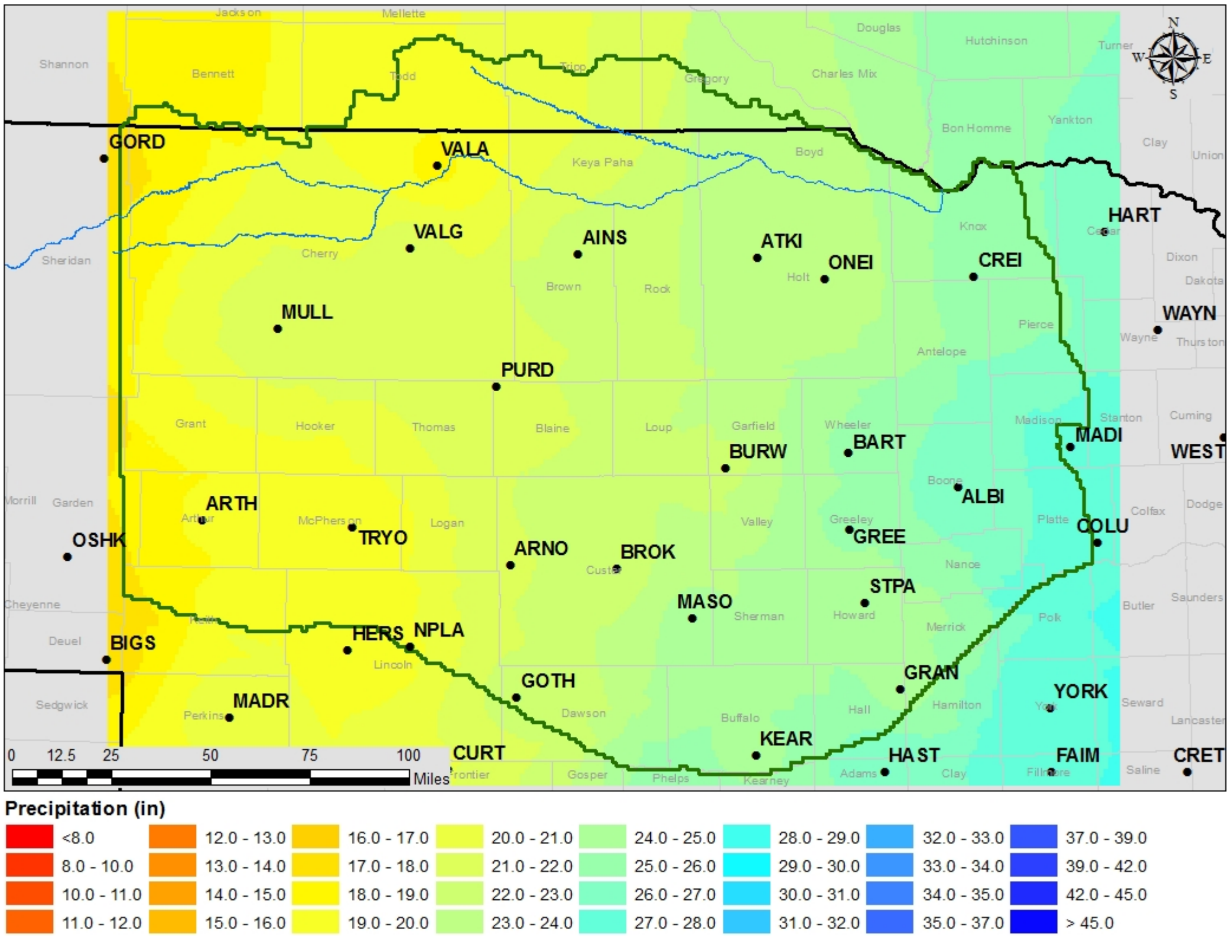

Figure 5. Average historical precipitation in the CENEB model area 1940 - 2011.

The CROPSIM model is dependent upon four climatic variables; minimum and maximum temperature, precipitation, and tall crop reference ET[4] (ETr).[5] Nebraska's climate exhibits large seasonal and annual temperature variations. The semi-arid conditions of the study area provide high evaporative demands due to ample sunshine and hot, dry winds. The reference crop methodology is employed to account for this variability and normalize crop water use to climatic conditions.

Historical reference ET was developed using a modified Hargreaves-Samani (Hargreaves & Samani, 1985) approach. A state-wide regression was developed to create a geographically dependent coefficient to the Hargreaves equation. Using the AWDN weather station data, the ASCE standardized Penman-Monteith reference ET (Allen, et al., 2005) was calculated along with the standard Hargreaves-Samani reference ET. Using 60 AWDN stations across Nebraska,

[4] Alfalfa.

[5] These inputs at all stations were provided to USBR to develop the perturbed climate for the climate change analysis.

Kansas, and the front range of Colorado a regression equation was developed to relate Hargreave reference ET to the Standardized Penman-Monteith reference ET. The regression was then applied to NWS/Coop stations over the entire period of record.

Table 2. CENEB NWS/Coop Weather Stations

Station	Code	Lati-tude	Longi-tude
Ainsworth	AINS	42.55	–99.85
Albion	ALBI	41.68	–98.00
Arnold	ARNO	41.42	–100.18
Arthur	ARTH	41.57	–101.68
Atkinson	ATKI	42.53	–98.97
Bartlett 4 S	BART	41.82	–98.53
Big Springs	BIGS	41.05	–102.13
Broken Bow 2 W	BROK	41.40	–99.67
Burwell	BURW	41.77	–99.13
Clay Center 6 ESE	CLY6	40.50	–97.93
Columbus 3 NE	COLU	41.47	–97.33
Creighton	CREI	42.45	–97.90
Crete	CRET	40.62	–96.93
Curtis 3 NNE	CURT	40.67	–100.48
Fairmont	FAIM	40.63	–97.58
Geneva	GENE	40.52	–97.58
Gordon 6 N	GORD	42.88	–102.20
Gothenburg	GOTH	40.93	–100.15
Grand Island WSO AP	GRAN	40.95	–98.30
Greeley	GREE	41.53	–98.53
Hartington	HART	42.60	–97.25
Hastings 4 N	HAST	40.65	–98.38

Station	Code	Lati-tude	Longi-tude
Hershey 5 SSE	HERS	41.10	–100.97
Holdrege	HOLD	40.43	–99.35
Imperial	IMPE	40.52	–101.63
Kearney	KEAR	40.72	–99.00
Madison 2 W	MADI	41.82	–97.45
Madrid	MADR	40.85	–101.53
Mason City	MASO	41.22	–99.30
Minden	MIND	40.50	–98.95
Mullen 21 NW	MULL	42.27	–101.33
North Platte WSO AP	NPLA	41.12	–100.67
O'Neill	ONEI	42.45	–98.63
Oshkosh	OSHK	41.42	–102.33
Purdum	PURD	42.07	–100.25
St. Paul 4 N	STPA	41.27	–98.47
Tryon	TRYO	41.55	–100.95
Valentine WSO AP	VALA	42.87	–100.55
Valentine LKS Game Res	VALG	42.57	–100.68
Wahoo	WAHO	41.22	–96.62
Wayne	WAYN	42.23	–97.00
West Point	WEST	41.83	–96.70
York 3 N	YORK	40.87	–97.58

2.5 CROPSIM

The watershed model is predicated around the results of a daily point source soil water balance model called CROPSIM. Dr. Derrel Martin with the University of Nebraska-Lincoln's Department of Biological Systems Engineering developed the CROPSIM model to aid in the estimation of the water balance parameters over a range of cropped and naturally vegetated systems occurring in primarily agricultural regions. CROPSIM utilizes climate data along with representative soil, crop phenology, management and system characteristics and their changes over time to simulate vegetative production and the water balance parameters. Greater detail about the methodology and algorithms employed by CROPSIM is available from the model documentation (Martin, Watts, & Gilley, 1984).

Eight primary crops (corn, soybeans, alfalfa, sugar beets, dry edible beans, winter wheat, small spring grains, and pasture) within the region were simulated using historical climate at each weather station under irrigation and non-irrigation conditions. CROPSIM maintains a daily soil water balance, and compiles the results into monthly output for precipitation, ET, deep percolation, runoff, and net irrigation requirement. This process was repeated for each of the model's soils at each weather station. The modeled results were then spatially distributed to the cells using the inverse weighted distance from the three nearest weather stations and the cell's assigned soil class.

2.6 Soils

Soil characteristics influence how crops respond to climatic conditions and management decisions. Soil can be thought of as acting as miniature reservoirs that store and release water for vegetative growth (ET), allow the water to drain as recharge, or restrict the water from infiltrating resulting in runoff. Soil in the study include eolian sand forming the sandhills in the eastern portion of the study area, shallow loamy soils located along topographically steep upland areas, and deep well drained loamy soils located along valley floors and more level upland areas.

Within each model, each cell is assigned a soil classification. The Statsgo2 soils database was used to identify the soils in the study area. The soils were grouped according to the water holding capacity, hydrologic soil group, and distance to groundwater to be consistent with the CROPSIM model. Each cell was then classified by the dominant soil within its boundary (Figures 6-7).

2.7 RSWB

This report contains highlights of the RSWB for each of the watershed models. Greater detail is available in the historical model documentation (The Flatwater Group, Inc., 2013).

2.7.1 Land Use

Within the watershed model land use describes the vegetation and irrigation characteristics of the system. Throughout the temporal domain of the model, developed land parcels were identified on an annual basis. The cropping pattern and irrigation sources[6] were determined. This information was overlaid by the model grid. Within each cell the number of acres of each combination of crop and irrigation source was determined.

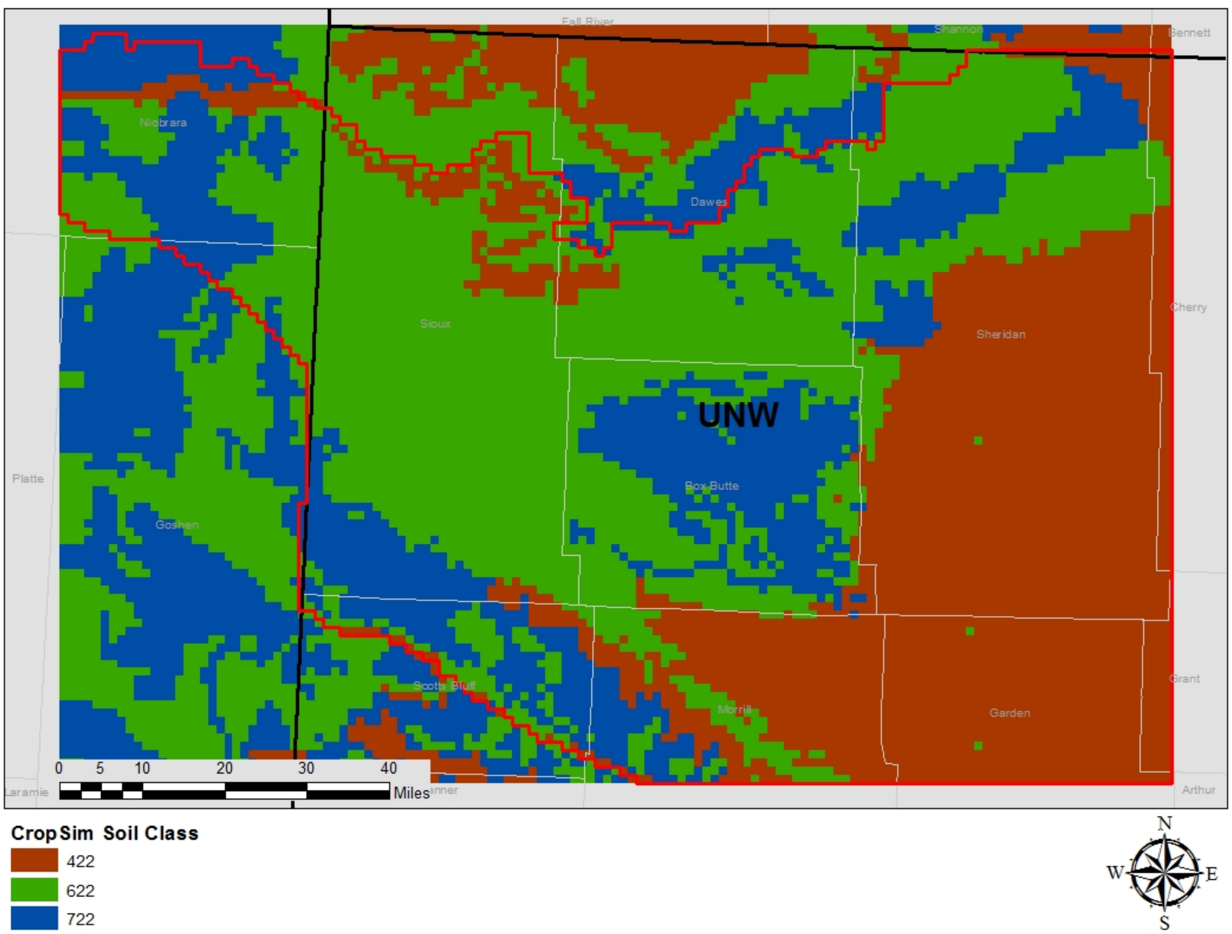

Figure 6. UNWNRD soils map.

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[6] There are four irrigation sources; dryland (non-irrigated), groundwater only pumping, surface water deliveries, and co-mingled lands. Co-mingled lands can receive water from both groundwater and surface water.

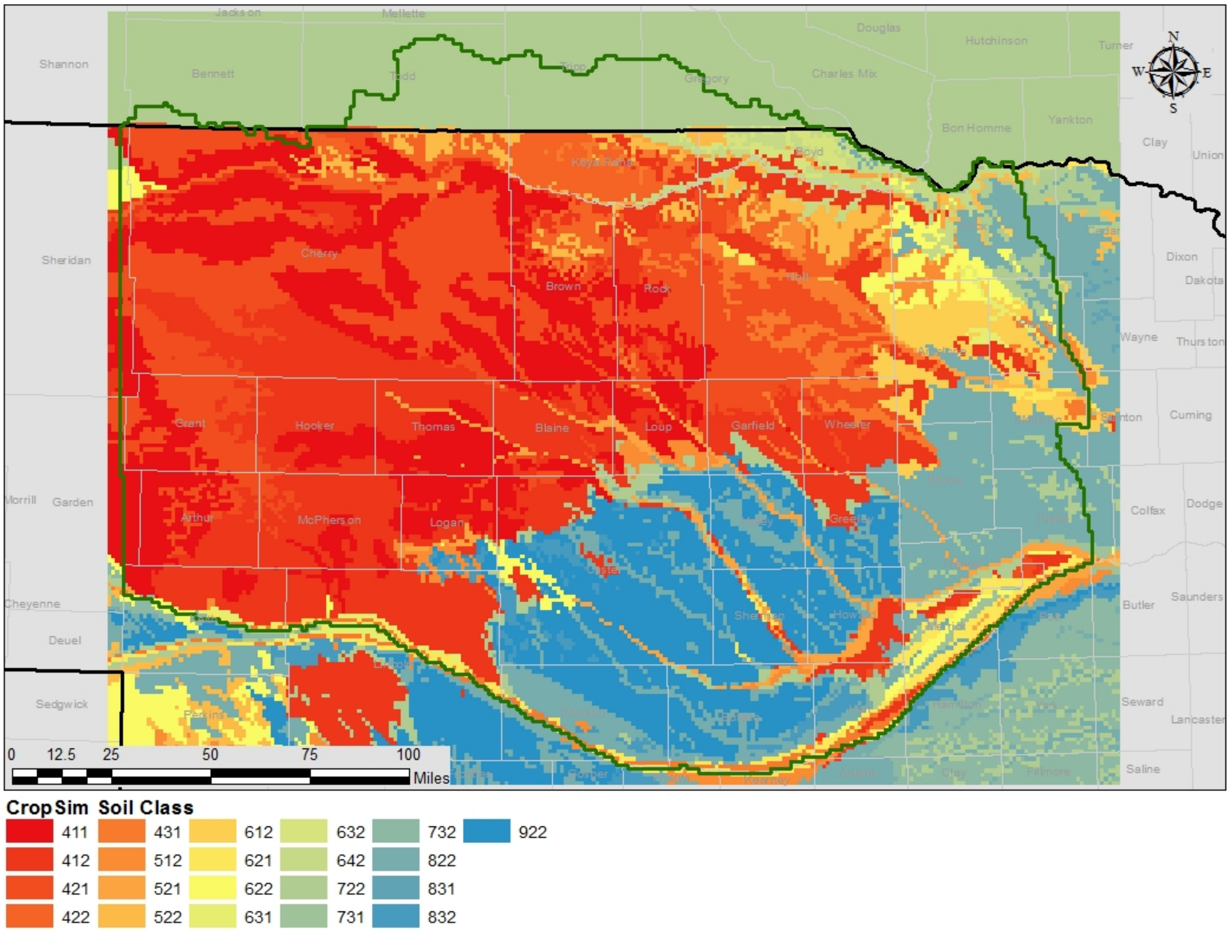


Figure 7. CENEB soils map.

2.7.2 Operational Regions

The watershed models contain multiple types of the operational regions to manage and analyze the model; the runoff zones are of specific interest for the Niobrara Basin Study. Detailed information about the additional operational zones is available in the historical models' documentation. Runoff zones are defined by the area of a basin which contributes runoff to a gauged location. Within the UNWNRD model domain there are five runoff zones delineating the drainage area upstream of the gauge at Gordon (Figure 8, Table 3).

Within historical CENEB model, there is a single runoff zone for the entire Niobrara Drainage Basin. Further information on the runoff zones in the CENEB model area is located in Model Adaptations for the Niobrara Water SMART Project.

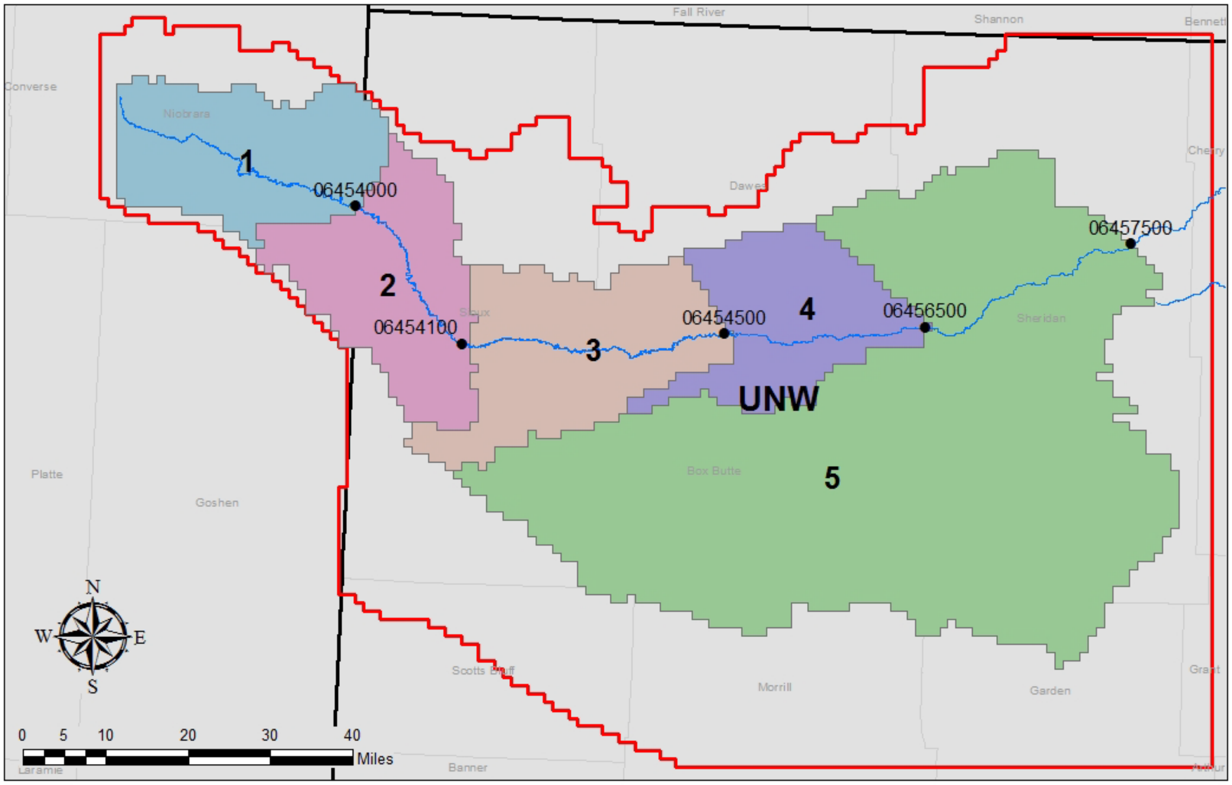


Figure 8. Runoff zones in the UNWNRD model domain.

Table 3. Stream Gauges Delineating the Runoff Zones in the UNWNRD Model Domain

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

2.7.3 Irrigation Demand

Irrigation demand[7] represents the gross volume of irrigation that a crop requires to achieve maximum ET (and thereby yield) potential. Within the CROPSIM model, it is assumed that water is the limiting factor to production. However, many external factors influence water use and yields; insects, disease, nutrition, weather, management decisions, hybrids, etc. An adjustment factor is applied to

[7] There is no surface water operations model in either the historical UNWNRD or CENEB model.

the CROPSIM NIR value within the watershed model to account for these exogenous forces. Furthermore, the irrigation value must be scaled due to application inefficiencies; application losses such as drift evaporation, interception, runoff, and deep percolation. The application efficiency is system dependent and varies from low (non-surge flood irrigation) to high (sprinkler). The per-acre demand is multiplied by the acres in production of the crop to arrive at the irrigation demand for the cell.

2.7.4 Partitioning of the Water Supply

The next step within the watershed model is to partition the precipitation and applied irrigation between evapotranspiration, runoff, deep percolation, and change in soil water content. Beginning with the estimates developed with the CROPSIM model; two potential adjustments are made. The first adjustment accounts for how much water is being applied to the crop. A Cobb-Douglas diminishing returns function is used to partition applied irrigation water between ET-gain, surface losses, change in soil water content, field runoff, and recharge. The second adjustment is to account for the external factors described in the Irrigation Demands section effect on consumptive use. The crop is no longer consuming water at the estimated rate. This water remains in the system and is partitioned between field runoff and recharge. Finally, the field runoff is partitioned between contributions to stream flow and transportation losses (non-beneficial consumptive use and recharge).

Upon completion, the watershed model creates properly formatted .WEL and .RCH file for inclusion into the groundwater model.

3 Model Adaptations for the Niobrara Water Smart Project

3.1 Updates to Simulate Current Management and System Practices

The Niobrara Basin study required several changes to the historical watershed models. The Niobrara Basin study was using the watershed model to project current conditions into the future.

3.1.1 Land use

All land use was converted to the 2010 land use.[8] An overview of the land use information is available in Tables 4-7.

Table 4. UNW 2010 Land Use by Irrigation Source (ac)

Zone	Non-Irrigated	Groundwater Only	Surface Water Only	Co-Mingled	Total
1	319,360	–	–	–	319,360
2	316,507	1,628	1,598	266	320,000
3	349,557	6,186	3,385	551	359,680
4	256,359	14,000	759	2,162	273,280
5	1,599,026	188,484	1,783	10,387	1,799,680

Table 5. UNW 2010 Land Use by Crop (ac)

Zone	Corn	Sugar Beets	Dry Edible Beans	Alfalfa	Winter Wheat	Pasture	Total
1	–	–	–	2	–	319,357	319,360
2	1,655	–	353	2,001	181	315,810	320,000
3	4,376	293	1,099	9,292	8,919	335,701	359,680
4	5,891	935	1,931	15,460	38,815	210,247	273,280
5	79,810	24,744	46,151	45,552	161,659	1,441,764	1,799,680

Table 6. CENEB 2010 Land Use by Irrigation Source (ac)

Zone	Non-Irrigated	Groundwater Only	Surface Water Only	Co-Mingled	Total
1	346,531	323	1,306	-	348,160
2	1,836,159	16,231	4,688	202	1,857,280

[8] Land use data was not compiled for areas outside of Nebraska. Dry pasture and miscellaneous pumping estimates were supplemented for these areas.

3	2,355,093	89,740	34,640	9,487	2,488,960

Table 7. CENEB 2010 Land Use by Crop (ac)

Zone	Corn	Soybeans	Alfalfa	Small Spring Grains	Pasture	Total
1	1,632	–	76	–	346,452	348,160
2	21,620	–	11,973	–	1,823,687	1,857,280
3	97,777	42,392	20,373	2,837	2,325,582	2,488,960

3.1.2 Application Efficiency

For the complete temporal domain the annual application efficiency was converted to 2010 levels; 85% for sprinkler and 65% for flood.

3.2 Implementation of the Climate Change Scenarios

A primary goal of the Niobrara Basin Study was to investigate the effects of climate change on irrigated agricultural production. The USBR developed a baseline climate (Baseline No Action) and three climate scenarios to investigate conditions moving forward in time (See Appendix A). Daily precipitation, reference ET (ETr), minimum and maximum temperature values were created and provided at each weather station in the historical models for the CROPSIM model to develop estimates of the water balance parameters in each climate scenario. Each crop was simulated under each soil at each of the weather stations using the current set of farming practices and system characteristics. The results for each climate scenario were spatially distributed across the model domains of the UNWNRD and CENEB models to create the distributed water balance parameter inputs for the watershed models.

3.2.1 Baseline Climate

The baseline climate scenario (Baseline No Action) represents historical data with only a slight deviation involving weather stations with incomplete historical records from 1960–2010.[9] Where the historical models omitted weather stations with incomplete records, data estimates were created to complete the data within the period of record for the baseline climate. Figures 9-10 show the average annual precipitation for the baseline climate scenario in the Niobrara Basin Study area. Annual precipitation ranges from 14.2 in. in central Sioux County near Agate, to approximately 17.7 in. in northeast Sheridan County near Gordon, and has a maximum value of 24.1 in. around Spencer, NE in south central Boyd County.

[9] The years 1960-2010 are used as placeholders to represent the projected conditions.

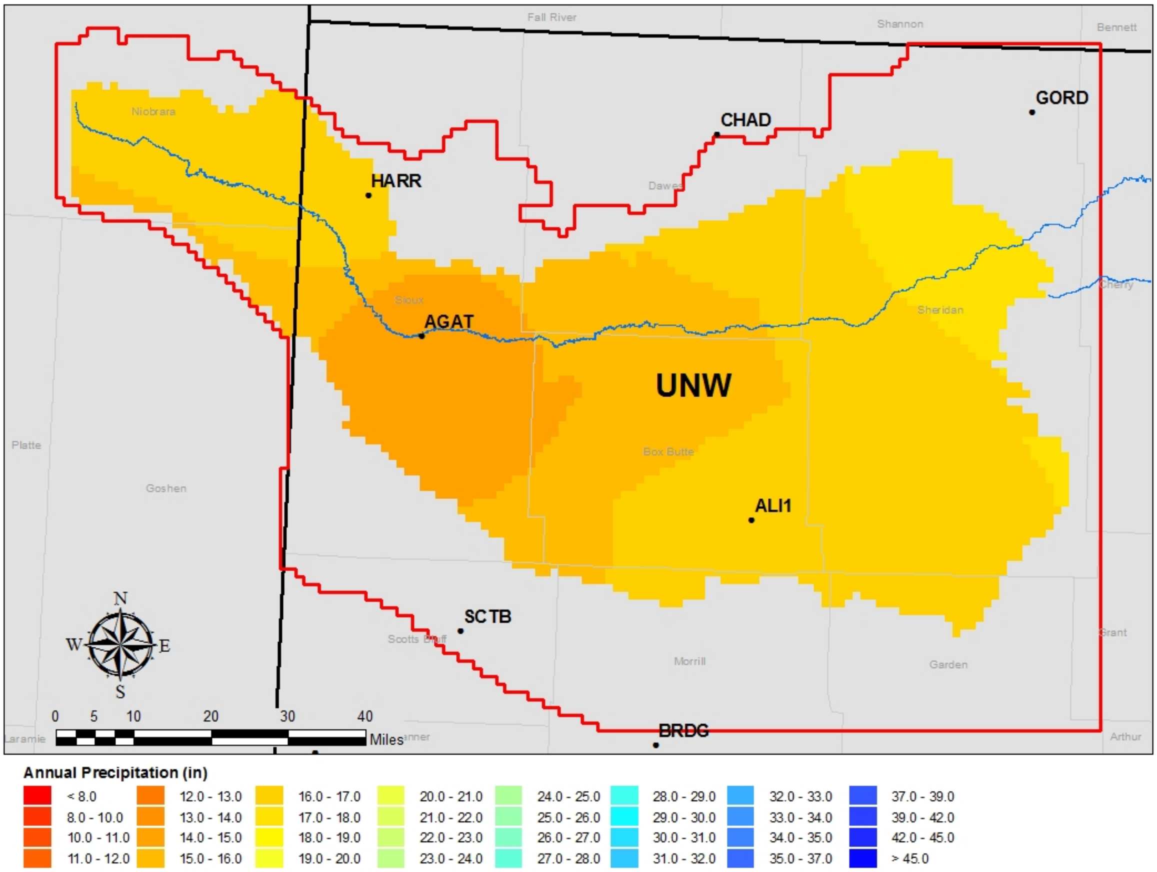


Figure 9. Average annual precipitation in the UNWNRD model domain 1960-2010[9]; Baseline No Action.

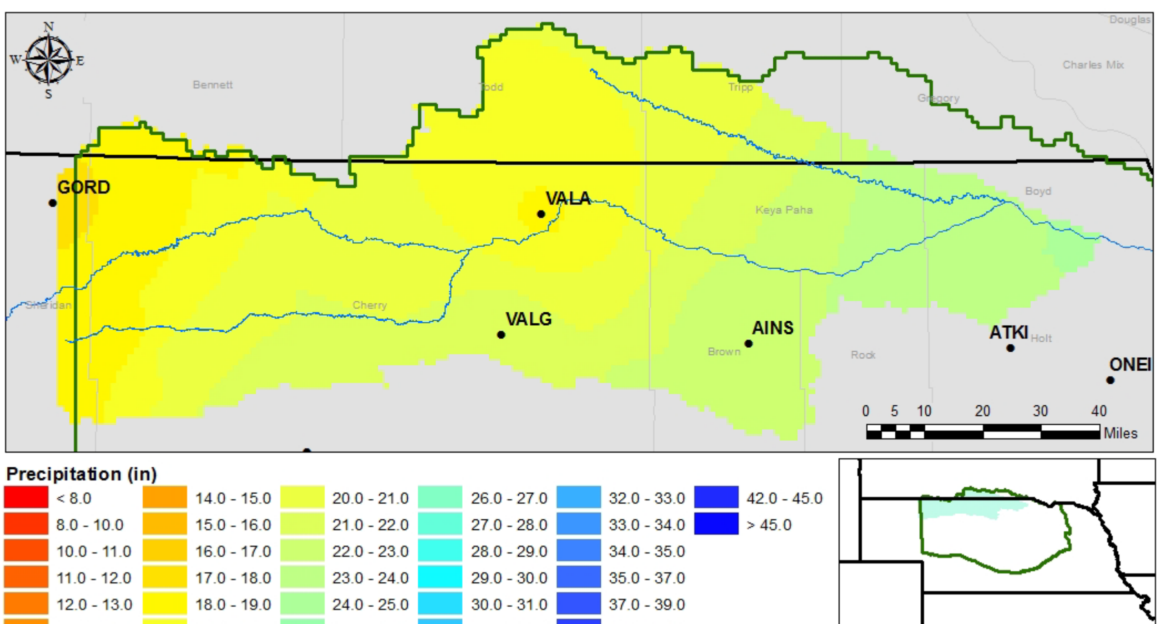


Figure 10. Average annual precipitation in the CENEB model domain 1960-2010 Error! Bookmark not defined.**; Baseline No Action.**

3.2.2 Climate Scenario 1

Climate Change Scenario 1 represents conditions with low water availability (Low No Action); or “hot and dry”. Figures 11-12 show the average annual precipitation for the Climate Change Scenario 1 in the Niobrara Basin Study area. Annual precipitation ranges from 12.0 in. in central Sioux County near Agate, to approximately 14.8 in. in northeast Sheridan County near Gordon, and has a maximum value of 24.8 in. around Spencer, NE in south central Boyd County.

3.2.3 Climate Scenario 2

Climate Change Scenario 2 represents conditions which exhibit a central tendency (CT No Action). Figures 13-14 show the average annual precipitation for the Climate Change Scenario 2 in the Niobrara Basin Study area. Annual precipitation ranges from 15.1 in. in central Sioux County near Agate, to approximately 19.0 in. in northeast Sheridan County near Gordon, and has a maximum value of 25.8 in. around Spencer, NE in south central Boyd County.

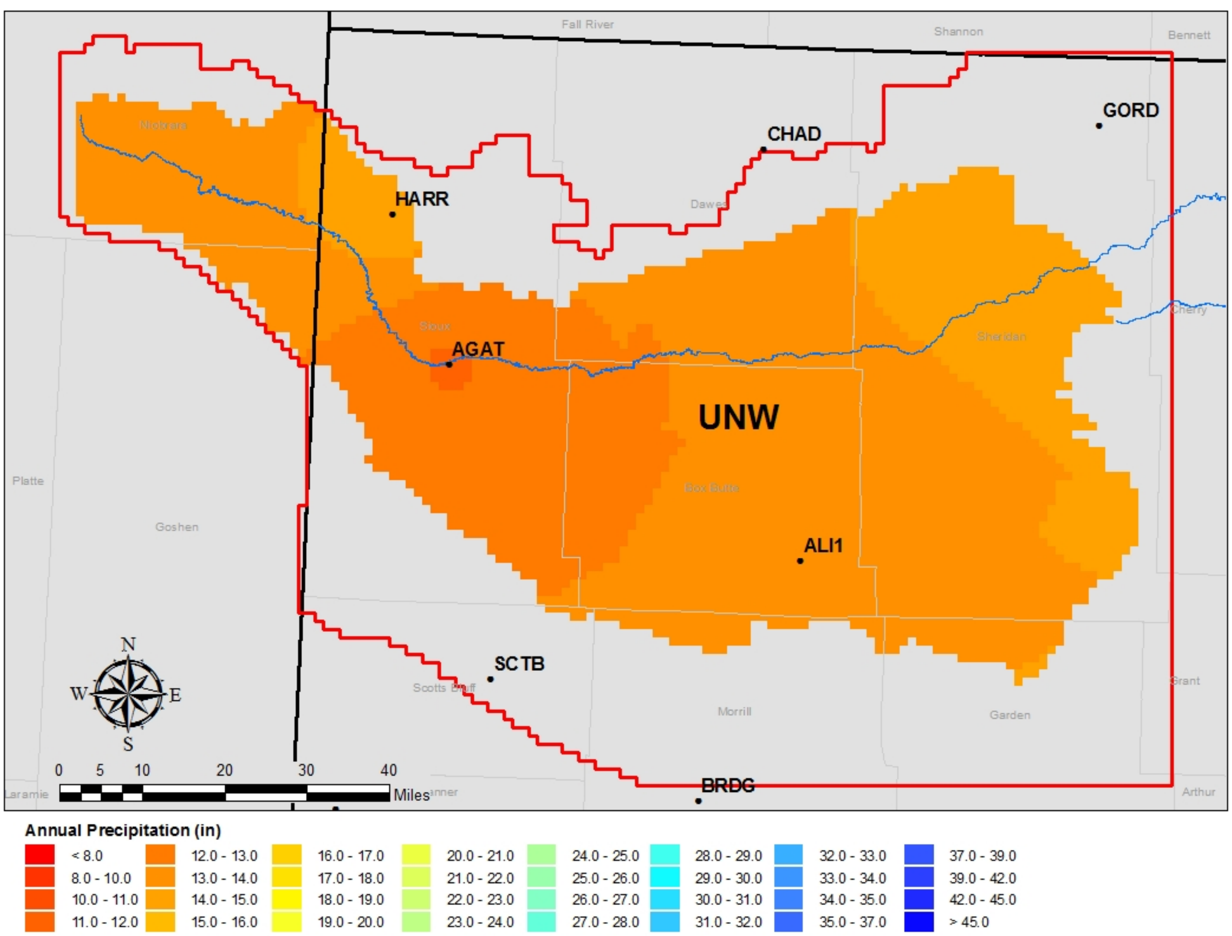


Figure 11. Average annual precipitation in the UNWNRD model domain 1960-2010 Error! Bookmark not defined.**; Low No Action.**

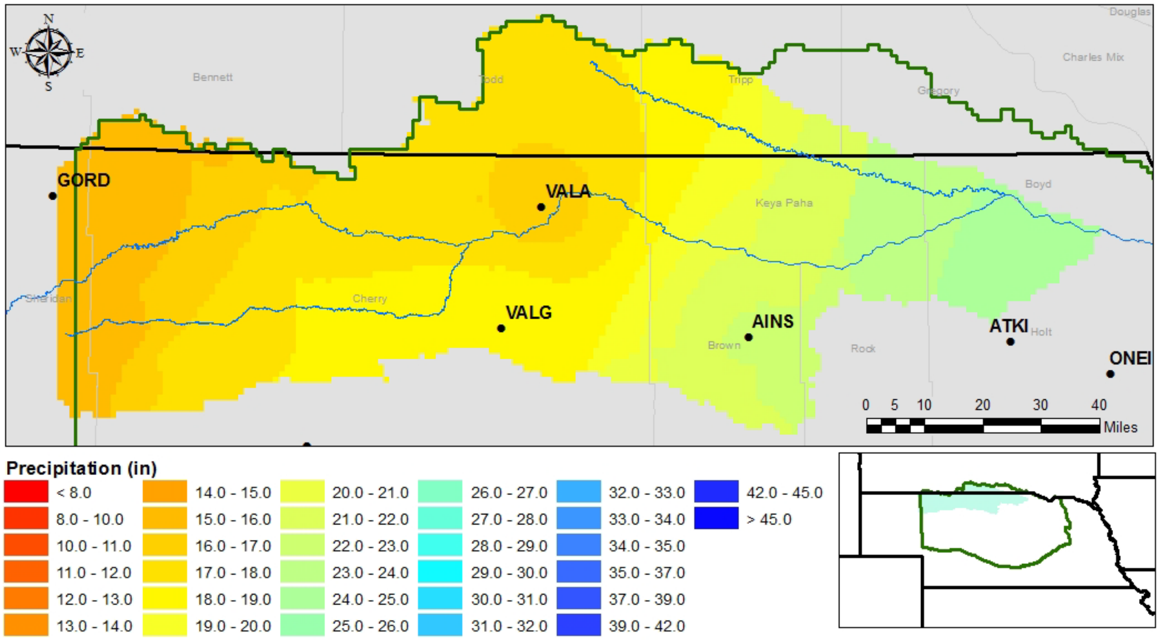


Figure 12. Average annual precipitation in the CENEB model domain 1960-2010Error! Bookmark not defined.; Low No Action.

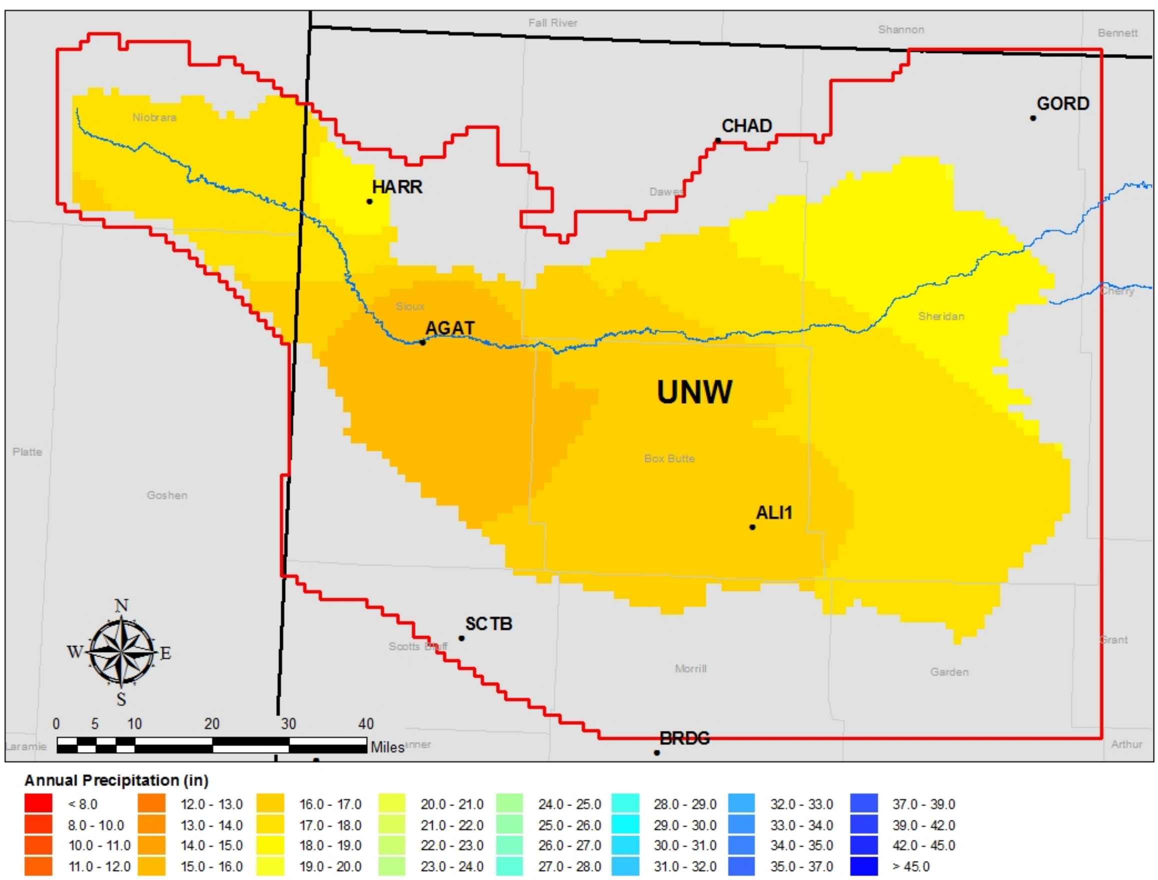


Figure 13. Average annual precipitation in the UNWNRD model domain 1960-2010Error! Bookmark not defined.; CT No Action.

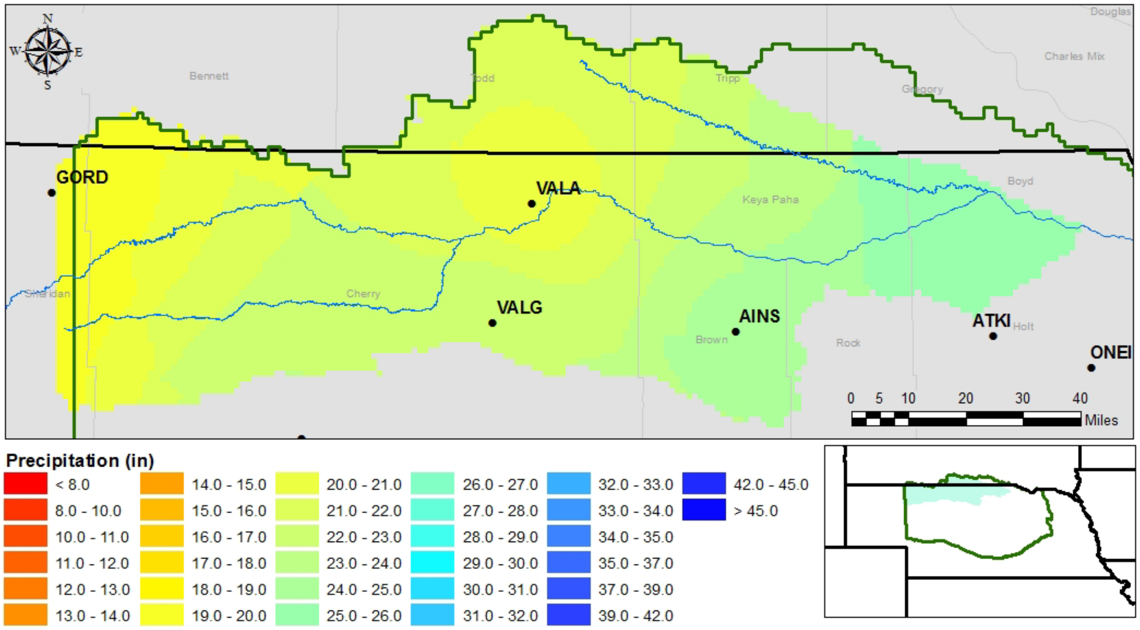


Figure 14. Average annual precipitation in the CENEB model domain 1960-2010[Error! Bookmark not defined.]**; CT No Action.**

3.2.4 Climate Change Scenario 3

Climate Change Scenario 3 represents conditions with high water availability (High No Action); or "cool and wet". Figures 15-16 show the average annual precipitation for the baseline climate scenario (Baseline No Action) in the Niobrara Basin Study area. Annual precipitation ranges from 16.9 in. in central Sioux County near Agate, to approximately 20.8 in. in northeast Sheridan County near Gordon, and has a maximum value of 26.3 in. around Spencer, NE in south central Boyd County.

3.3 Model Integration of the UNWNRD model

3.3.1 Surface Water Irrigation Groups

The Niobrara Basin Study expanded the UNWNRD model from the watershed and groundwater models to integrate the surface water operations model. The inclusion and interaction with the surface water operations model required the adaptation of the UNWNRD watershed model. Fourteen irrigation groups were developed to manage surface water deliveries (Figure 17, Table 8).

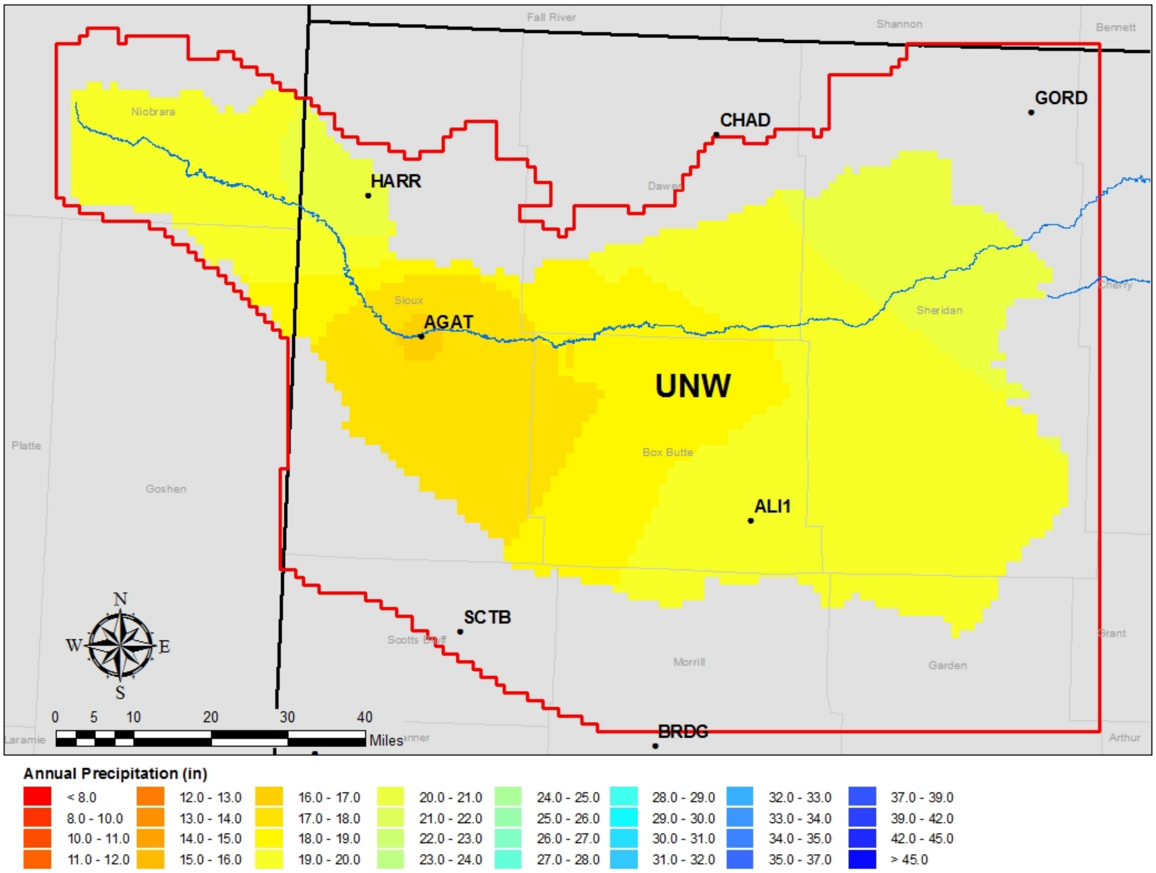


Figure 15. Average annual precipitation in the UNWNRD model domain 1960-2010 Error! Bookmark not defined.**; High No Action.**

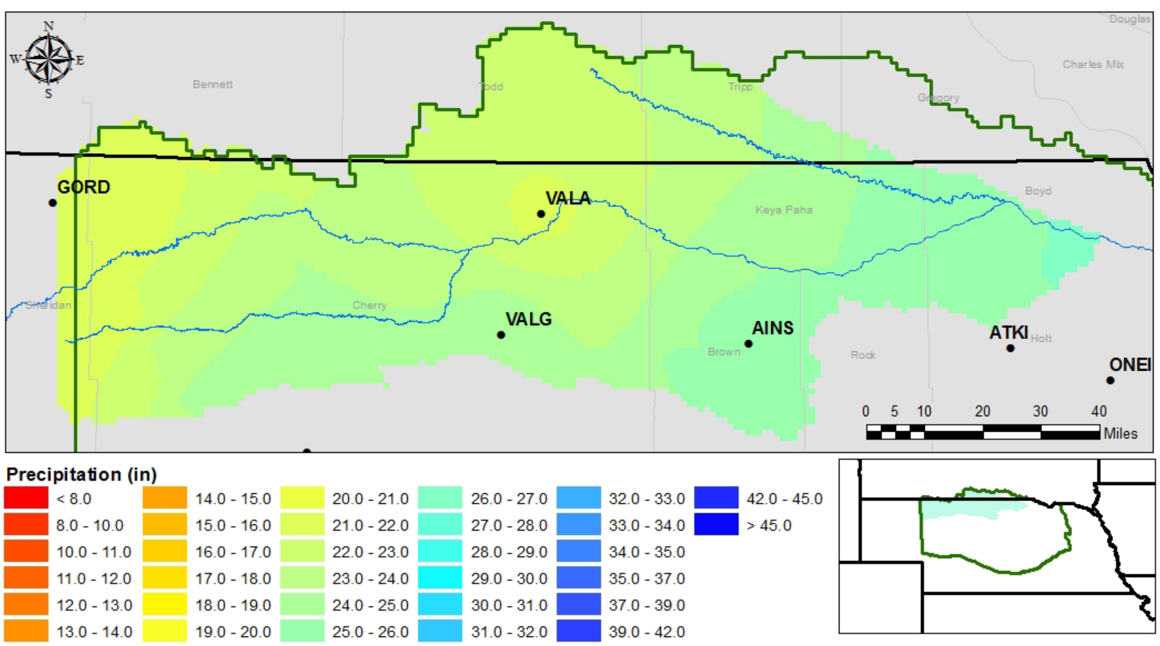


Figure 16. Average annual precipitation in the CENEB model domain 1960-2010 Error! Bookmark not defined.**; High No Action.**

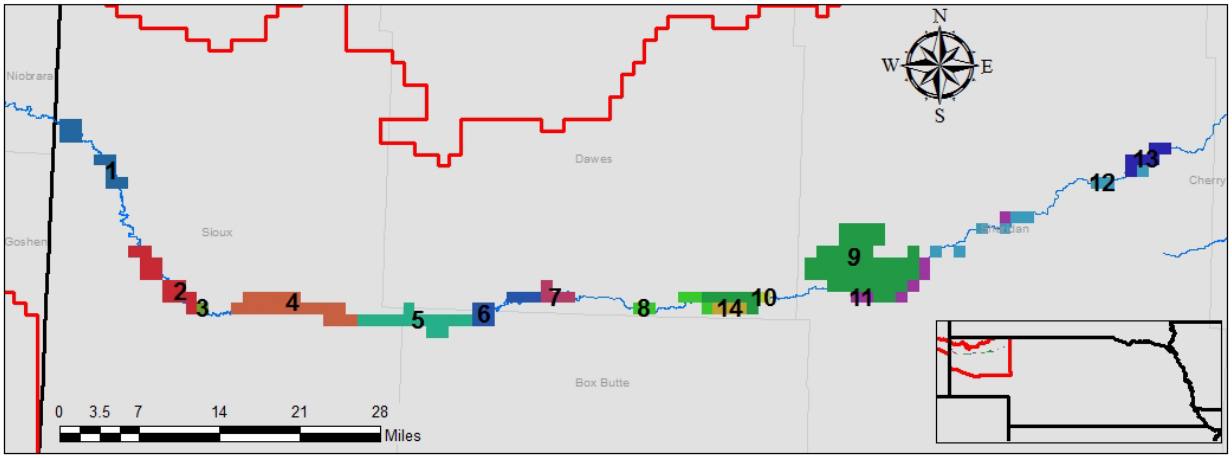


Figure 17. UNWNRD model's surface water irrigation groups.

Table 8. UNW Surface Water Irrigation Groups

Group	Surface Water Irrigators
1	Dout Hoover; Johnson; Lakotah
2	Earnest 1; Earnest 2; McGinley N; McGinley S; McGinley Cook
3	Cook; McGinley Pump; Cook Pump;
4	Manning Pump; Bennett-Kay; Harris-Neece; Labelle; Mettlen
5	Moore; Geohitshew; Hitshew; McLaughlin; Excelsor; Hughes
6	Hollibaugh; Lees; Crow Butte; Pioneer
7	Klaes; Campbell
8	Desling; Montague; Lichte; Iodence
9	Mirage Flats
10	A18389; A18168; A12893
11	A5531; A17398; Carlson; Terrell; A5854; A10432; A10490; A8216; A10761; A4717
12	A9018; A2654; A9017; A9572; A7871; A7477; A5467; A9838
13	A2555; A4603; A2623
14	Potmesil

3.3.2 Run Iteration Pattern

Cells receiving surface water deliveries from the Niobrara River were classified as being part of one of these groups. Surface water only and co-mingled surface water demands were compiled monthly for each of these groups and provided to the surface water operations model. The assumption was made that the irrigation demands could be met by irrigation supply. This volume of irrigation water was applied to the field and partitioned like the historical model. The resulting .WEL file and .RCH files were provided to the groundwater model. The estimates of runoff contributions to stream flow were provided to the surface water and groundwater models for inclusion in the stream flow package. This constitutes the completion of the watershed model's 'A' run.

The surface water operation model would then determine the volume of surface water that the system could provide each group each month as well as the canal losses necessary to facilitate this delivery. The volume delivered to the group was distributed among the surface water only and co-mingled lands weighted by the crop demand and number of acres. For co-mingled lands, groundwater pumping was used to make up for the surface water irrigation deficits. These new irrigation volumes were applied and partitioned to develop the results of the 'B' run (the runoff contribution to stream flow, the recharge file, and the well file) which in turn were provided to the surface water and groundwater models. Further detail describing the integrated model is available in Appendix F.

3.4 Model Integration in the CENEB Area

The iterative integrated approach was not implemented in the CENEB model area. The assumption that irrigation supplies were sufficient to meet irrigation demands was retained. However, the single runoff zone within the Niobrara Basin was split into five runoff zones (1-5) with three (1-3) being investigated within the study (Figure 18, Table 9).

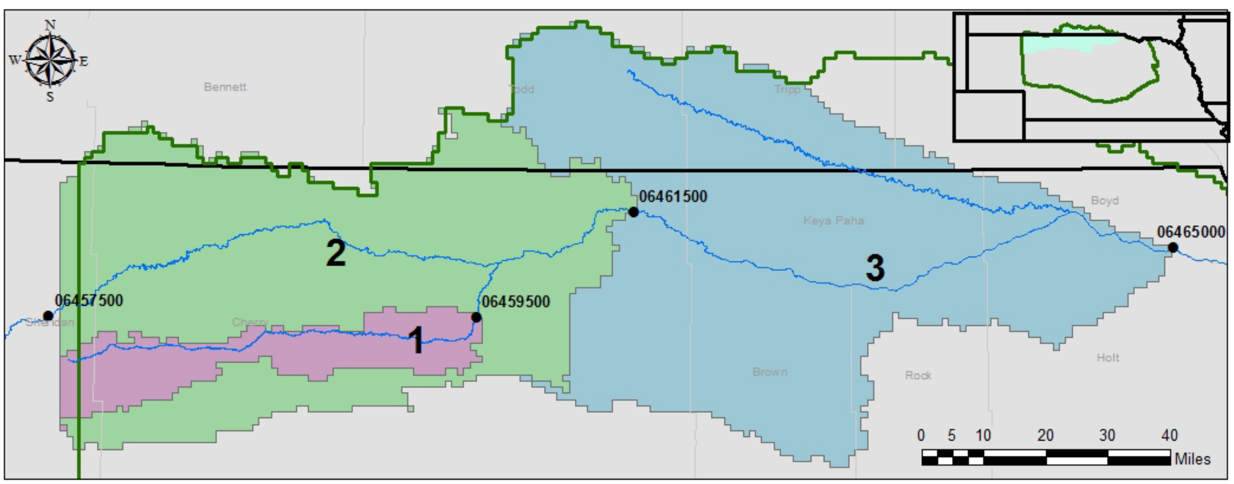


Figure 18. CENEB model Runoff Zones Developed for the Niobrara Basin Study.

Table 9. Stream flow gauges used to delineate the runoff zones in the CENEB model area.

Zone	Site Number	Location
1	06459500	Snake River near Burge, NE
2	06461500	Niobrara River Near Sparks, NE
3	06465000	Niobrara River Near Spencer, NE

3.5 Application of Municipal and Industrial Pumping

Municipal and Industrial pumping developed as part of the statewide M&I data set was incorporated into both the UNW and CENEB models. Municipal pumping estimates were based upon a developed monthly per capita consumption rate. The industrial pumping data set was developed by applying a similar industry consumption rate base upon total consumption and well capacity. Further information is available in the statewide M&I documentation. M&I pumping was kept constant at 2010 levels for both model areas. Tables 10-11 describe the volume of M&I pumping in the Niobrara drainage basin.

Table 10. 2010 Municipal and Industrial pumping in the UNW model (AF).

Zone*	Municipal and Industrial Pumping
1	–
2	30
3	–
4	856
5	1,714
Total	2,610

Table 11. 2010 Municipal and Industrial pumping in the CENEB model (AF).

Zone*	Municipal and Industrial Pumping
1	–
2	512
3	388
Total	900

* M&I pumping was not modeled outside of the state of Nebraska.

3.6 Miscellaneous Wyoming Pumping and Recharge

The UNW model incorporates miscellaneous pumping and recharge to account for the lack of land use data available for the portion of the model located in Wyoming. An annual estimate of pumping was developed by the Nebraska Department of Natural Resources (Figure 19). It was then distributed throughout the year proportional to the irrigated pasture NIR. The DNR annual estimates were retained, but the distribution was altered to reflect the irrigated pasture NIR within each climate. A net recharge of 10% of the pumping was applied to the cell in which the pumping occurred.

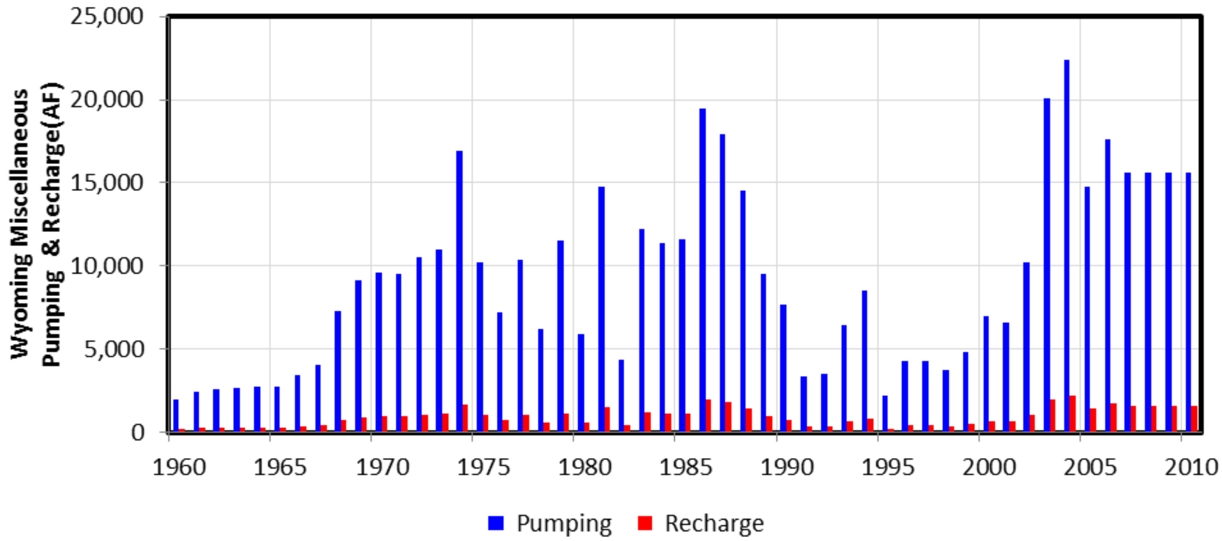


Figure 19. Annual miscellaneous pumping and recharge in the state of Wyoming.

4 Alternatives

In addition to the current conditions under each climate change scenarios, two alternatives were investigated under each of the climate; the pumping station alternative and canal recharge alternative.

Irrigation is the application of water to vegetation to supplement insufficient natural sources. The Mirage Flats irrigation district relies on surface water from the Niobrara River and storage in the Box Butte reservoir. Typically, surface water deliveries are insufficient to meet the full crop demand. On co-mingled lands irrigation wells are used to extract groundwater to complement the deficit amounts of surface water.

4.1 Alternative 1 – Pumping Station

4.1.1 Description and Purpose

Transportation losses are a concern for surface water irrigators. Low efficiency canals lose a significant portion of diverted water to seepage during transport. These losses translate to less water being applied to the crop. In a semi-arid region, such as where Mirage Flats Irrigation District is located, there is already an insufficient amount of water available to the crops. The irrigation losses reduce crop production and impact the livelihood of the irrigators that depend upon it.

For the Mirage Flats Irrigation district the first 12 miles of their canal is particularly inefficient (~40%). A proposed alternative has been made to abandon the current point of diversion in favor of installing a pumping station 9 miles downstream. The pumping station would extract water from a high aquifer; essentially making the effect similar to a surface water diversion. The irrigation water would then be piped to the more efficient portion of the canal where it would be delivered to the fields.

The purpose of the pumping station is to increase the portion of diverted water that reaches the irrigators crops by improving the efficiency of the transportation mechanism.

4.1.2 Model Adaptations

No additional adaptations of the model were necessary to implement the pumping station alternative. As the pumping station is being treated as a surface water diversion; changes in the available water are recognized in the surface water operations model and provided to the watershed model in the deliveries file. The deliveries are not included in the .WEL file. Change in seepage rates are also developed in the surface water operations model. The watershed model then partitions the precipitation and newly developed irrigation values to ET, stream flow, recharge, and change in soil moisture content as normal. This process was applied to the baseline climate and all three climate scenarios.

4.2 Alternative 2 – Canal Recharge

4.2.1 Description and Purpose

The purpose of the canal recharge alternative is to effectively turn the Mirage Flats Irrigation District's canals and laterals into a seepage basin. During the normal irrigation season, the irrigation district will divert water at the head gate, fill the canals and laterals, and allow the water to seep into the ground as recharge, while replenishing the recharged volume with additional diversion. Irrigators will no longer receive surface water deliveries. Instead, the lands will effectively become groundwater pumping only lands.

The purpose of this approach is to improve the timing of irrigation using groundwater, and allows the seepage from the canals and laterals to mitigate the effect of additional pumping on the system; specifically stream flow and aquifer levels. The ability to provide a timely and sufficient volume of water to the crop is paramount to efficiently and effectively maximizing the benefit of the water. Surface water projects often deliver water on a fixed rotation and irrigators choose either to take the water or not when it is available to them. These rotation times depend upon the canal management practices, but have been known to be on the magnitude of weeks (ex. 14 days) between deliveries. Depending upon the conditions in the field and the phenologic stage of the crops this period may or may not be sufficient. Water stress at an inopportune time can cause significant irreparable damage to the production capabilities of the crop. Corn, for example, is highly sensitive to stress during the flowering and pollination stage. Water stress during this time can cause the pollen not to take and\or the plant to abort kernels resulting in unfilled ears and decimating the harvest potential. The same amount of water stress later in the grain fill stage or earlier during the vegetative stage does not have the same damaging effect.

4.2.2 Model Adaptations

Within the watershed model irrigation demand remained constant for the diversion. However, deliveries for the Mirage Flats Irrigation District from the surface water operations model were restricted. Delivery volumes were provided to account for seepage in the districts laterals. The seepage was distributed to the cells in the district weighted by the number of surface water irrigable lands. These lateral seepage values are combined with the canal seepage and all other sources of recharge in the development of the .RCH file.

Co-mingled lands strictly pump groundwater to meet their irrigation demands. No irrigation water is applied on surface water only lands. The precipitation and applied irrigation is then partitioned between ET, stream flow, recharge, and change in soil moisture content through the normal process. This alternative was simulated using the baseline (Baseline No Action) and all three climate scenarios.

5 Results

5.1 UNWNRD Model – Baseline Climate

5.1.1 Overview of the Niobrara Drainage Basin Water Balance

Under the baseline climate the average total available water was 17.21 in/ac. The primary source of water was precipitation (93.3%), while the primary use was evapotranspiration (92.9%) (Figure 20). The annual model wide field water balance and runoff balance are available in Tables 12-13.

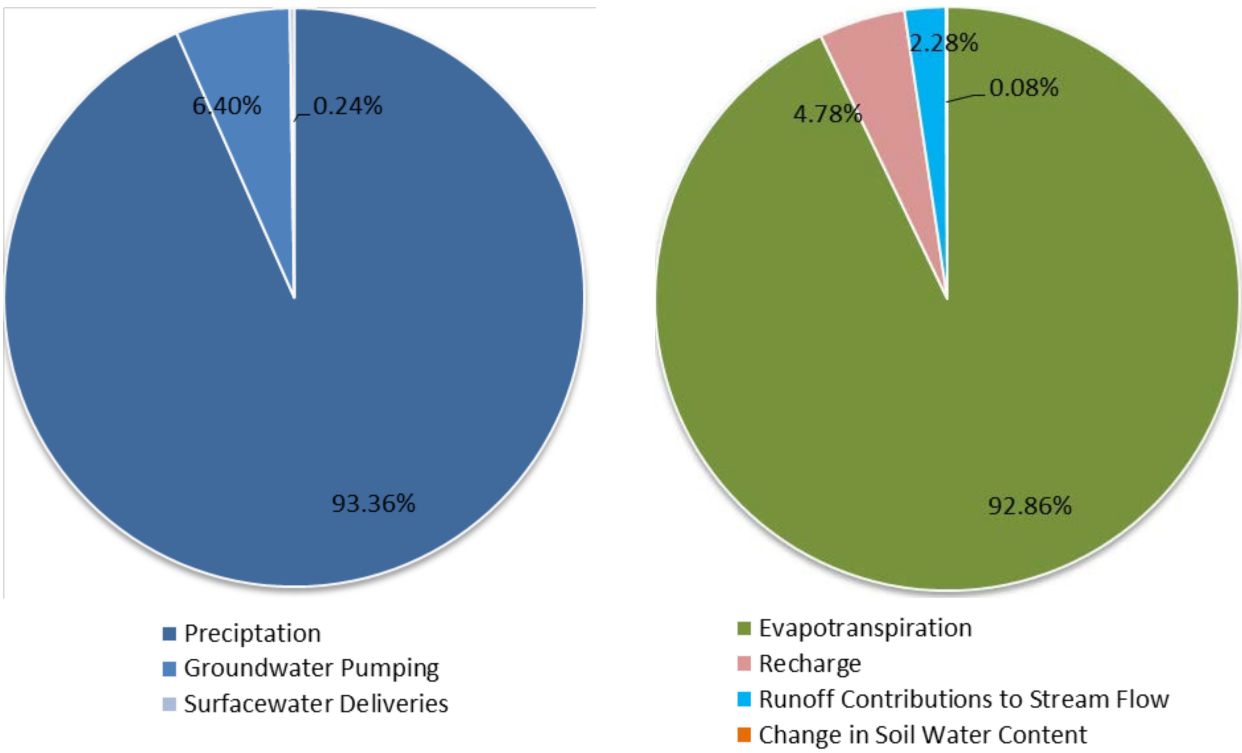


Figure 20. Sources of 17.21 in/ac of total available water and partitioned total available water for the Niobrara Basin within the UNWNRD model; Baseline No Action.

Table 12. UNWNRD Field Water Balance for the Niobrara Basin (AF); Baseline No Action

Year	Precipi-tation	Groundwater Pumping	Surface Water Deliveries	Total Applied Water	Direct Evapo-transpiration	Direct Runoff	Direct Recharge	Surface Losses	Field Water Balance
1960	3,316,970	319,347	8,602	3,644,919	3,787,493	140,688	121,543	6,817	(411,622)
1961	3,829,933	305,083	8,355	4,143,371	3,744,107	158,963	119,734	6,518	114,049
1962	4,497,496	248,043	16,999	4,762,538	4,283,048	216,131	295,876	5,811	(38,328)
1963	4,547,700	264,585	12,424	4,824,709	4,183,795	270,494	162,578	5,913	201,929
1964	2,843,985	333,676	8,721	3,186,382	3,243,581	118,530	113,157	7,109	(295,995)
1965	5,424,686	208,025	11,524	5,644,235	4,835,226	224,964	169,011	4,737	410,297
1966	3,780,251	244,072	8,936	4,033,259	4,014,346	143,724	129,524	5,327	(259,662)
1967	4,925,674	221,496	14,506	5,161,676	4,560,384	263,677	298,661	5,155	33,799
1968	4,323,383	236,020	10,312	4,569,715	4,294,917	176,106	132,441	5,236	(38,985)
1969	3,724,065	291,768	8,414	4,024,247	3,681,530	132,960	112,699	6,256	90,802
1970	3,594,152	288,381	10,138	3,892,671	3,718,868	157,793	130,615	6,275	(120,880)
1971	4,686,533	261,687	12,014	4,960,234	4,436,195	214,303	205,077	5,835	98,824
1972	4,295,919	241,205	9,477	4,546,601	4,185,953	170,937	139,946	5,298	44,467
1973	5,123,655	268,969	9,699	5,402,323	4,603,922	223,909	193,160	5,865	375,467
1974	3,048,369	291,025	10,260	3,349,654	3,588,954	131,012	133,240	6,334	(509,886)
1975	3,102,753	337,629	7,990	3,448,372	3,179,870	123,966	104,967	7,151	32,418
1976	3,485,146	302,244	8,482	3,795,872	3,601,752	160,541	116,942	6,468	(89,831)
1977	4,592,326	253,810	9,217	4,855,353	4,487,636	163,558	129,445	5,536	69,178
1978	4,709,632	238,474	9,829	4,957,935	4,361,462	233,284	138,258	5,260	219,671
1979	4,220,124	215,834	8,198	4,444,156	4,113,645	169,150	124,473	4,727	32,161
1980	3,213,532	329,053	9,871	3,552,456	3,502,905	131,864	123,686	7,075	(213,074)
1981	3,791,835	274,428	8,455	4,074,718	3,810,657	138,738	112,773	5,911	6,639
1982	5,052,940	242,450	9,996	5,305,386	4,662,345	194,767	161,553	5,350	281,371
1983	4,463,623	238,778	14,075	4,716,476	4,348,834	242,199	235,872	5,480	(115,909)
1984	3,793,238	276,035	9,459	4,078,732	4,009,654	155,371	123,656	5,994	(215,943)
1985	3,266,977	365,668	7,514	3,640,159	3,093,665	125,467	96,909	7,688	316,430

Year	Precipi-tation	Groundwater Pumping	Surface Water Deliveries	Total Applied Water	Direct Evapo-transpiration	Direct Runoff	Direct Recharge	Surface Losses	Field Water Balance
1986	4,951,328	269,204	15,958	5,236,490	4,699,399	244,736	173,067	6,182	113,106
1987	3,665,844	314,271	10,263	3,990,378	3,851,377	149,556	154,199	6,798	(171,552)
1988	3,789,239	311,103	10,243	4,110,585	3,929,042	233,395	177,449	6,734	(236,035)
1989	2,722,966	401,824	7,279	3,132,069	2,768,184	107,322	95,350	8,400	152,813
1990	3,963,193	286,508	8,323	4,258,024	4,041,422	145,160	131,744	6,146	(66,448)
1991	4,260,154	289,545	20,667	4,570,366	4,092,277	243,288	260,054	6,824	(32,077)
1992	3,773,000	302,137	6,799	4,081,936	3,772,743	146,431	117,171	6,383	39,208
1993	4,950,056	253,338	9,457	5,212,851	4,537,869	172,257	152,367	5,539	344,819
1994	3,296,547	323,411	7,757	3,627,715	3,323,708	137,971	119,144	6,856	40,036
1995	5,181,320	253,994	14,848	5,450,162	4,622,189	242,285	681,593	5,822	(101,727)
1996	4,753,768	224,017	9,832	4,987,617	4,527,601	216,283	141,975	4,972	96,786
1997	4,477,276	250,502	12,298	4,740,076	4,417,093	220,945	174,507	5,625	(78,094)
1998	4,996,113	261,755	9,676	5,267,544	4,473,909	182,126	149,438	5,719	456,352
1999	4,630,136	228,452	12,121	4,870,709	4,852,650	203,145	358,654	5,174	(548,914)
2000	4,800,923	291,976	13,605	5,106,504	4,455,293	267,864	251,206	6,519	125,622
2001	3,941,681	251,869	7,525	4,201,075	4,073,619	173,023	149,455	5,413	(200,435)
2002	2,290,378	430,384	7,332	2,728,094	2,511,815	109,938	84,199	8,975	13,167
2003	3,920,735	349,590	9,364	4,279,689	4,008,642	151,797	141,210	7,460	(29,420)
2004	4,268,697	315,874	8,366	4,592,937	4,127,126	161,452	121,103	6,736	176,520
2005	4,936,331	242,569	19,892	5,198,792	4,614,040	296,851	215,171	5,846	66,884
2006	3,168,265	360,957	8,339	3,537,561	3,326,292	124,084	104,187	7,636	(24,638)
2007	3,001,288	346,306	7,558	3,355,152	3,166,570	122,709	117,147	7,303	(58,577)
2008	3,842,688	308,278	7,885	4,158,851	3,888,002	143,363	120,244	6,559	683
2009	5,589,534	206,097	11,636	5,807,267	5,134,592	196,514	200,605	4,704	270,852
2010	4,943,858	219,476	14,197	5,177,531	4,716,295	300,870	350,956	5,100	(195,690)
Average	4,113,141	282,181	10,484	4,405,806	4,044,441	181,891	169,961	6,168	3,346

Table 13. UNWNRD Runoff Balance for the Niobrara Basin (AF); Baseline No Action

Year	Direct Runoff	Runoff Contributions to Streamflow	Runoff Losses to Recharge	Runoff Losses to Evapotranspiration
1960	140,688	76,780	31,953	31,953
1961	158,963	84,581	37,191	37,191
1962	216,131	126,715	44,707	44,707
1963	270,494	140,737	64,878	64,878
1964	118,530	65,941	26,296	26,296
1965	224,964	125,216	49,874	49,874
1966	143,724	78,593	32,565	32,565
1967	263,677	149,933	56,870	56,870
1968	176,106	97,299	39,404	39,404
1969	132,960	72,283	30,338	30,338
1970	157,793	84,911	36,440	36,440
1971	214,303	118,022	48,140	48,140
1972	170,937	93,153	38,892	38,892
1973	223,909	118,252	52,830	52,830
1974	131,012	71,358	29,827	29,827
1975	123,966	67,465	28,251	28,251
1976	160,541	85,050	37,745	37,745
1977	163,558	90,794	36,383	36,383
1978	233,284	120,718	56,283	56,283
1979	169,150	90,106	39,522	39,522
1980	131,864	72,424	29,720	29,720
1981	138,738	75,243	31,748	31,748
1982	194,767	105,254	44,756	44,756
1983	242,199	131,969	55,114	55,114
1984	155,371	87,455	33,958	33,958
1985	125,467	67,234	29,116	29,116
1986	244,736	145,007	49,863	49,863
1987	149,556	78,445	35,555	35,555
1988	233,395	127,549	52,922	52,922
1989	107,322	58,655	24,334	24,334
1990	145,160	79,531	32,815	32,815
1991	243,288	148,924	47,183	47,183
1992	146,431	81,445	32,493	32,493
1993	172,257	95,981	38,137	38,137
1994	137,971	73,317	32,327	32,327
1995	242,285	138,306	51,988	51,988
1996	216,283	120,214	48,034	48,034
1997	220,945	125,293	47,827	47,827

Year	Direct Runoff	Runoff Contributions to Streamflow	Runoff Losses to Recharge	Runoff Losses to Evapotranspiration
1998	182,126	99,672	41,227	41,227
1999	203,145	114,544	44,300	44,300
2000	267,864	147,559	60,152	60,152
2001	173,023	93,956	39,533	39,533
2002	109,938	59,166	25,387	25,387
2003	151,797	85,414	33,191	33,191
2004	161,452	87,887	36,781	36,781
2005	296,851	170,541	63,154	63,154
2006	124,084	67,451	28,318	28,318
2007	122,709	67,423	27,641	27,641
2008	143,363	79,372	31,994	31,994
2009	196,514	109,041	43,738	43,738
2010	300,870	164,205	68,331	68,331
Average	181,891	100,321	40,785	40,785

5.1.2 Average Gaps in Surface Water Irrigation Availability

Within the UNWNRD model the demand for surface water irrigation notably exceeds the ability of the irrigators to retrieve surface water from the system. On average, surface water irrigation groups were able to apply approximately a quarter of the crop demand (Figure 21). To account for the lack of available surface water, irrigators with co-mingled lands pumped groundwater to overcome the surface water irrigation deficit. Figure 22 shows the average annual co-mingled pumping for each of the surface water irrigation groups (Table 8).

5.1.3 Average Annual Recharge Rates

Figure 23 shows the average annual recharge in the UNWNRD model region. The recharge pattern reflects several model components; soils (Figure 6), precipitation patterns (Figure 9), land use (irrigated vs. non-irrigated), and canal recharge (Figure 24).

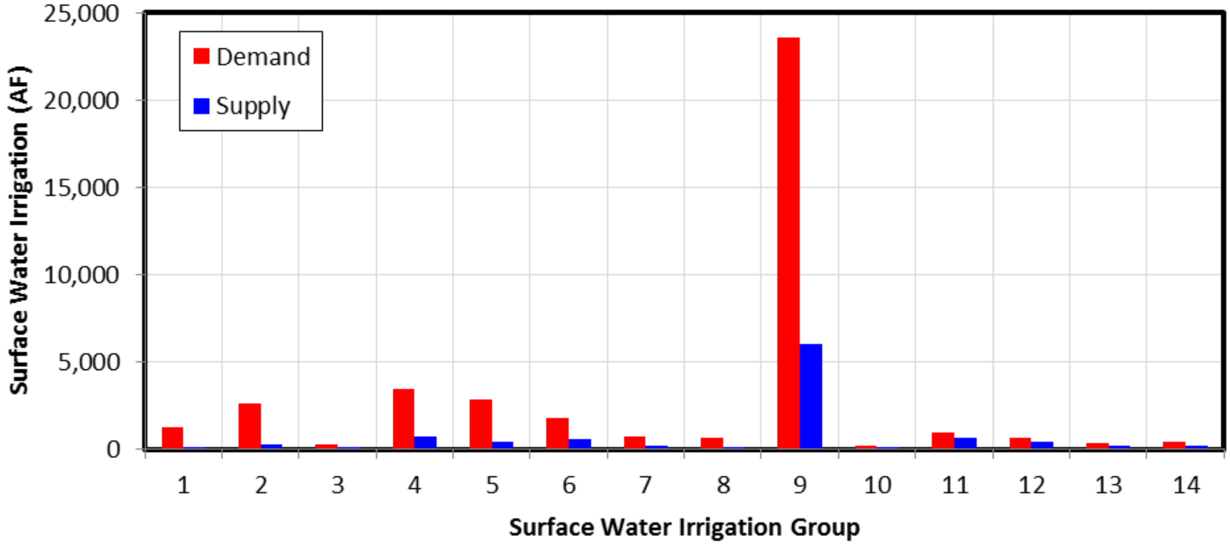


Figure 21. Surface water irrigation demand and supply for each surface water irrigation groups in the UWNNRD model; Baseline No Action.

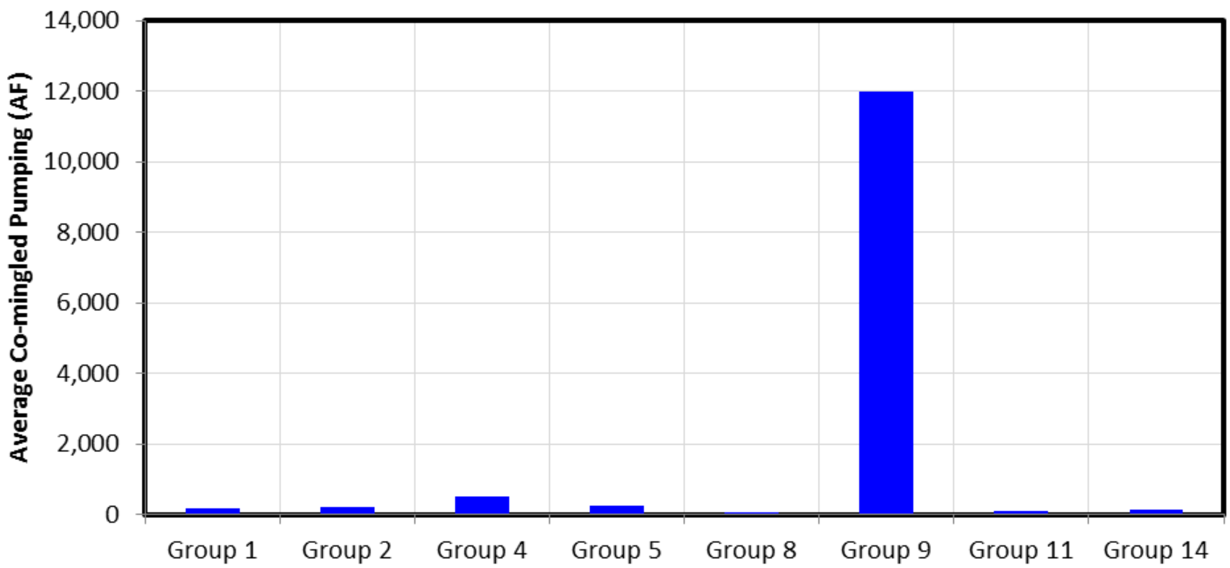


Figure 22. UNWNRD model's average co-mingled pumping for each surface water irrigation group; Baseline No Action. Surface water irrigation groups 3, 6, 7, 10, 12, and 13 not shown because they did not include any co-mingled lands.

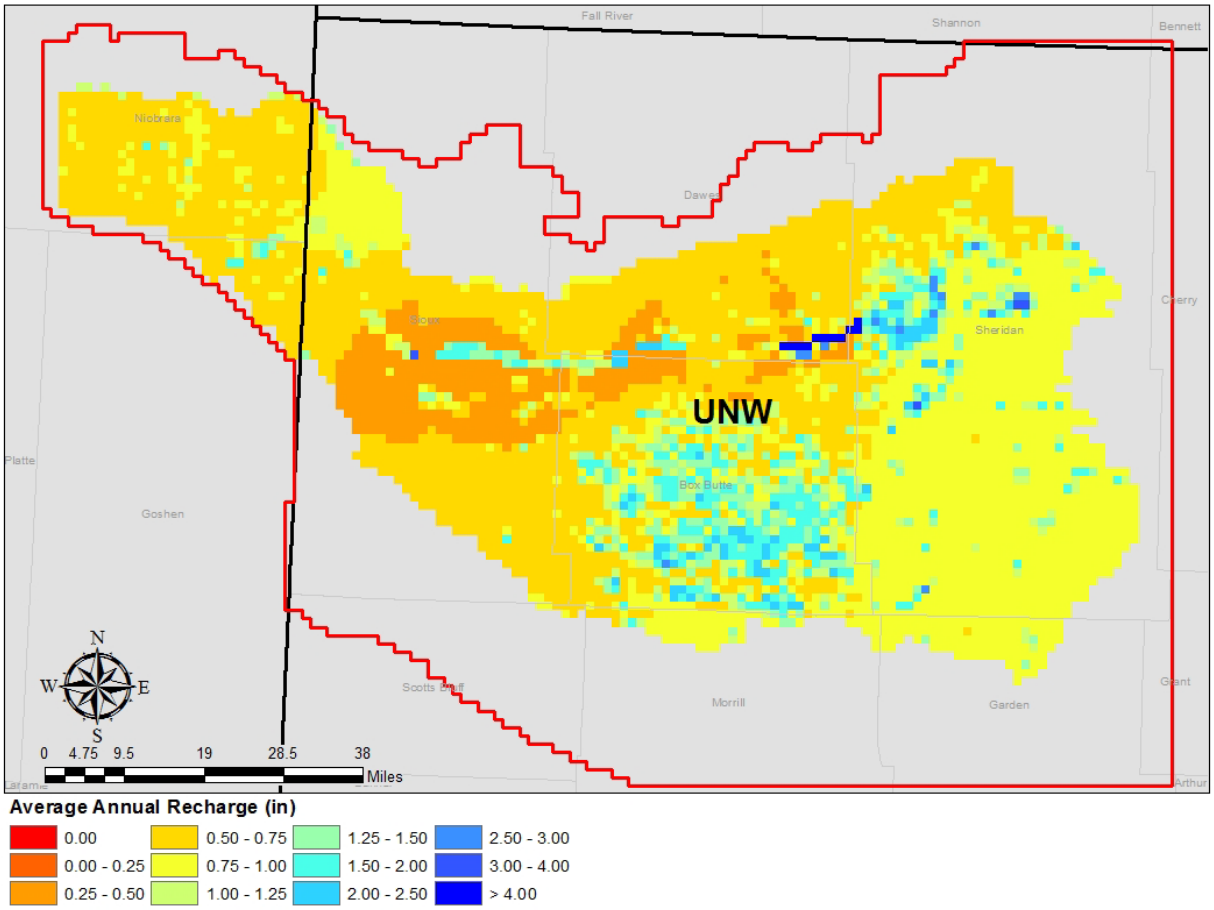


Figure 23. Average annual recharge for the Niobrara Drainage Basin in the UNWNRD model area; Baseline No Action.

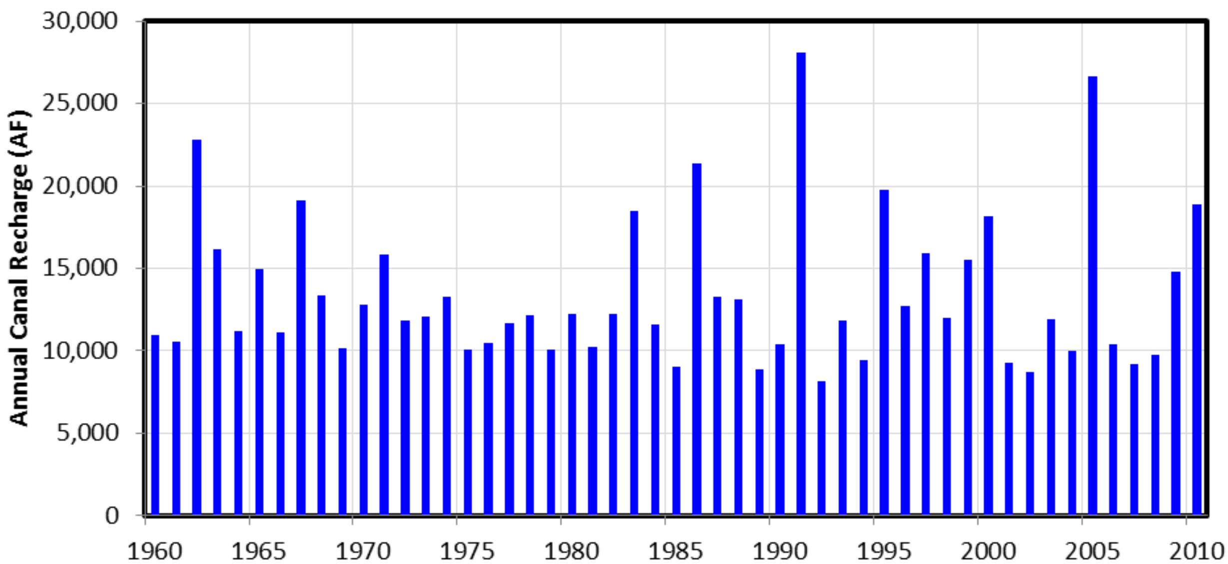


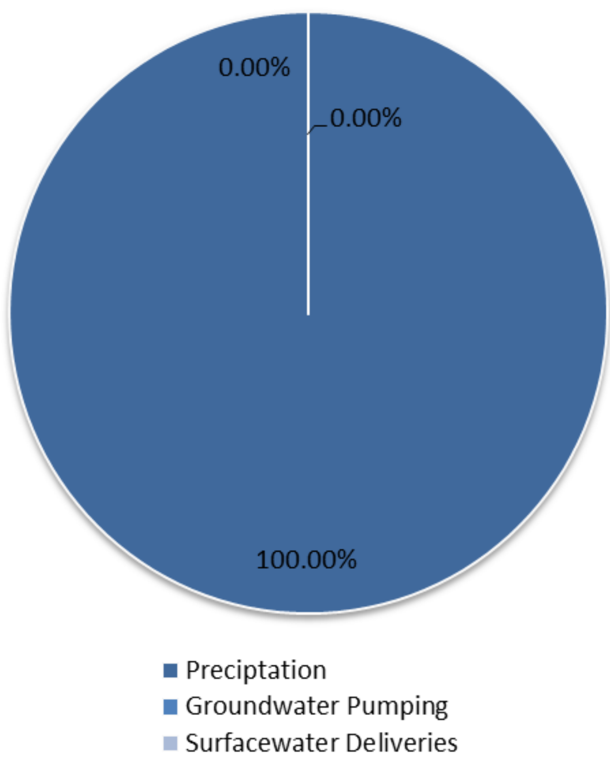
Figure 24. UNWNRD model's annual Canal Recharge in the Niobrara Basin; Baseline No Action.

5.1.4 Canal Recharge

Canal recharge (Figure 24) represents a transportation loss in the delivery of surface water irrigation. The volume of canal seepage is a function of the surface water diversion and the efficiency of the canal. Frequently, canal seepage represents a significant portion of the local. This characteristic is specifically prevalent in the Mirage Flats Irrigation District's canal; the deep blue in Figure 23.

5.1.5 Overview of Runoff Zones Water Balances

The UNWNRD model was further analyzed on the runoff zone operational regions shown in Figure 8. The average annual field water balance and runoff water balance are summarized for each of the runoff zones in Figures 25-29. The left diagram shows the sources of applied water,[10] while the right diagram depicts where the water ultimately went.



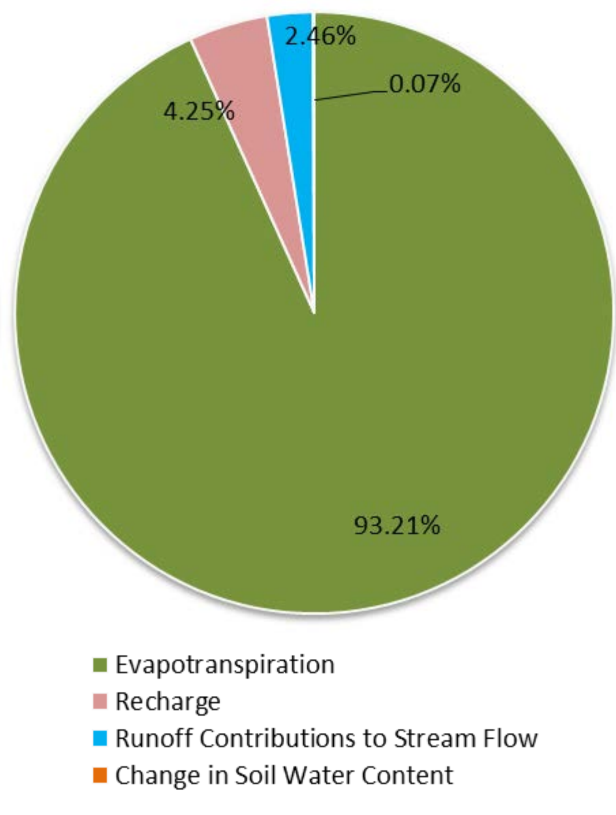


Figure 25. Sources of 16.28 in/ac of total available water and partitioned total available water for the runoff zone 1 within the UNWNRD model; Baseline No Action.

[10] Not all sources of water were applied to all lands.

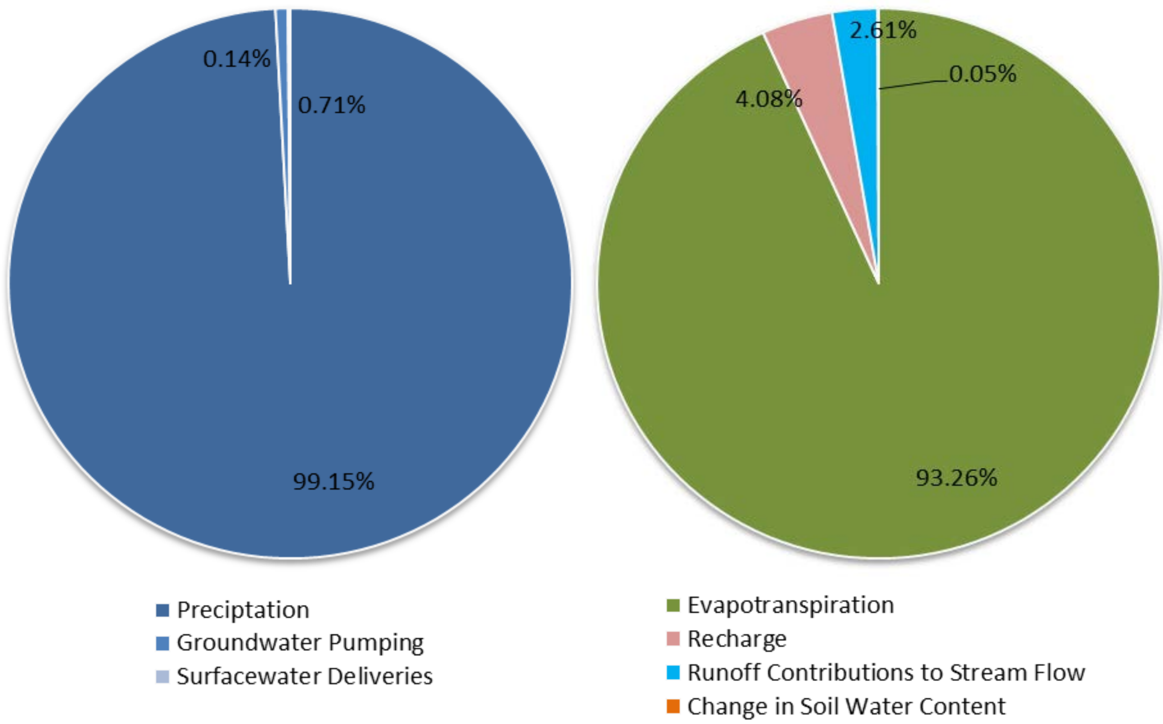


Figure 26. Sources of 15.83 in/ac of total available water and partitioned total available water for the runoff zone 2 within the UNWNRD model; Baseline No Action.

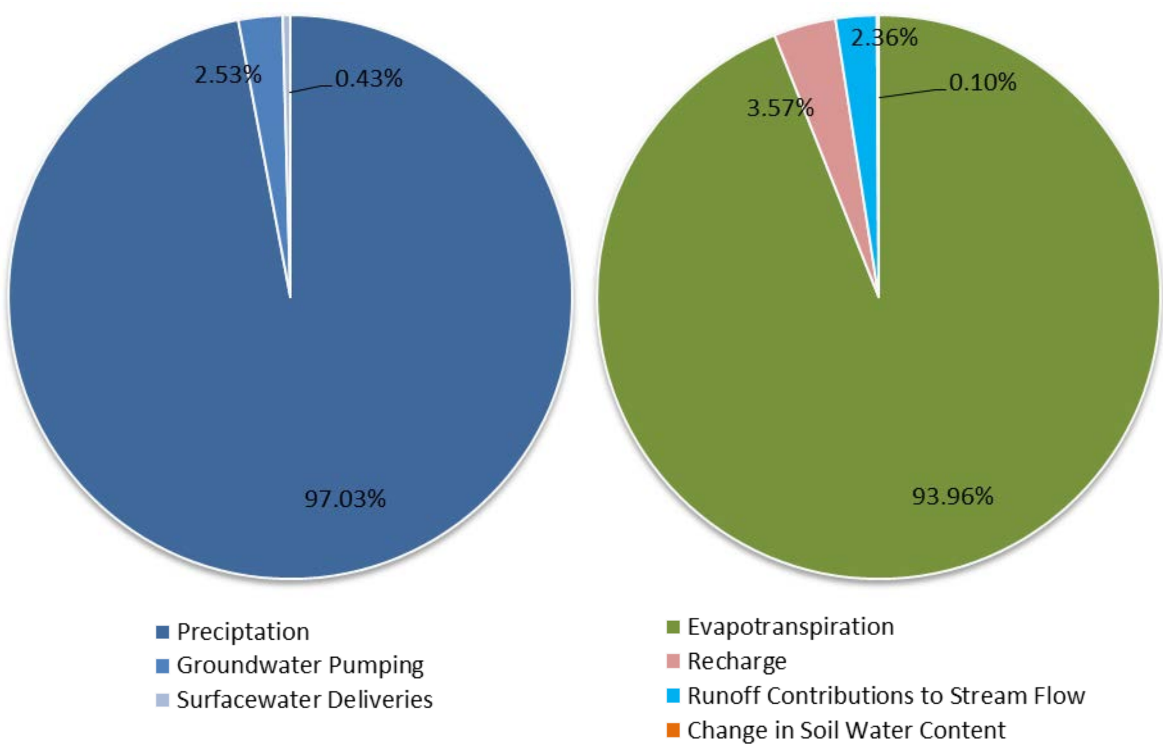


Figure 27. Sources of 15.36 in/ac of total available water and partitioned total available water for the runoff zone 3 within the UNWNRD model; Baseline No Action.

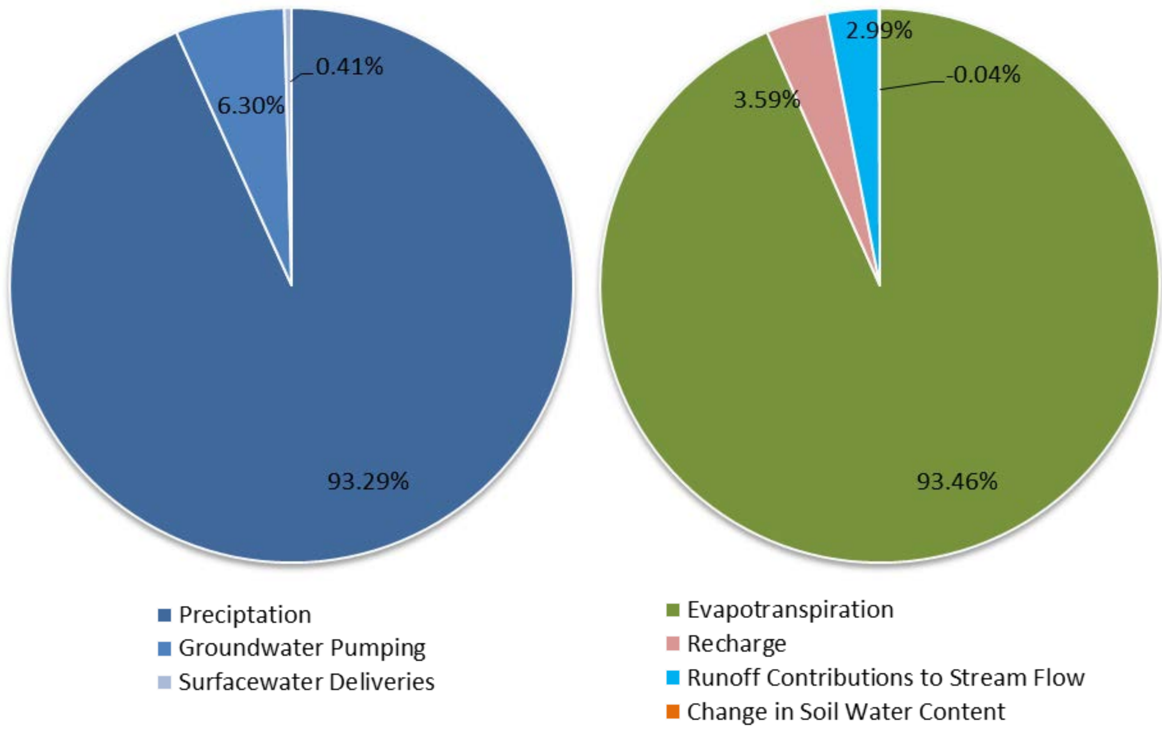


Figure 28. Sources of 17.18 in/ac of total available water and partitioned total available water for the runoff zone 4 within the UNWNRD model; Baseline No Action

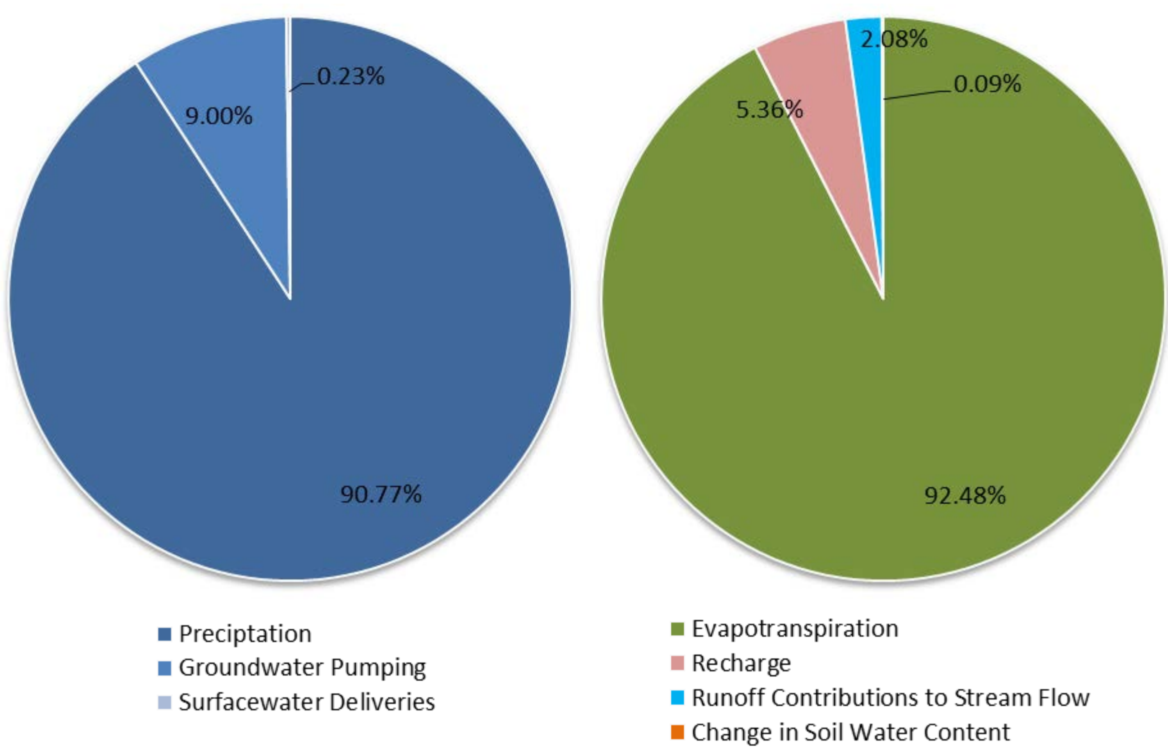


Figure 29. Sources of 18.00 in/ac of total available water and partitioned total available water for the runoff zone 5 within the UNWNRD model; Baseline No Action.

5.1.6 Gaps in Surface Water Irrigation Group's Water Availability

Irrigation water is a vital tool for agricultural producers in the Niobrara Basin to improve crop production and their economic viability. There are two sources of irrigation water available; surface water and groundwater. Surface water is diverted from the Niobrara River. Unfortunately, there is insufficient available water in the Niobrara River to meet crop demands. This has led many irrigators to supplement their irrigation with groundwater pumping on co-mingled lands. Figures 30-51 depict the deficit of surface water irrigation and how irrigators respond to the deficit with co-mingled pumping.

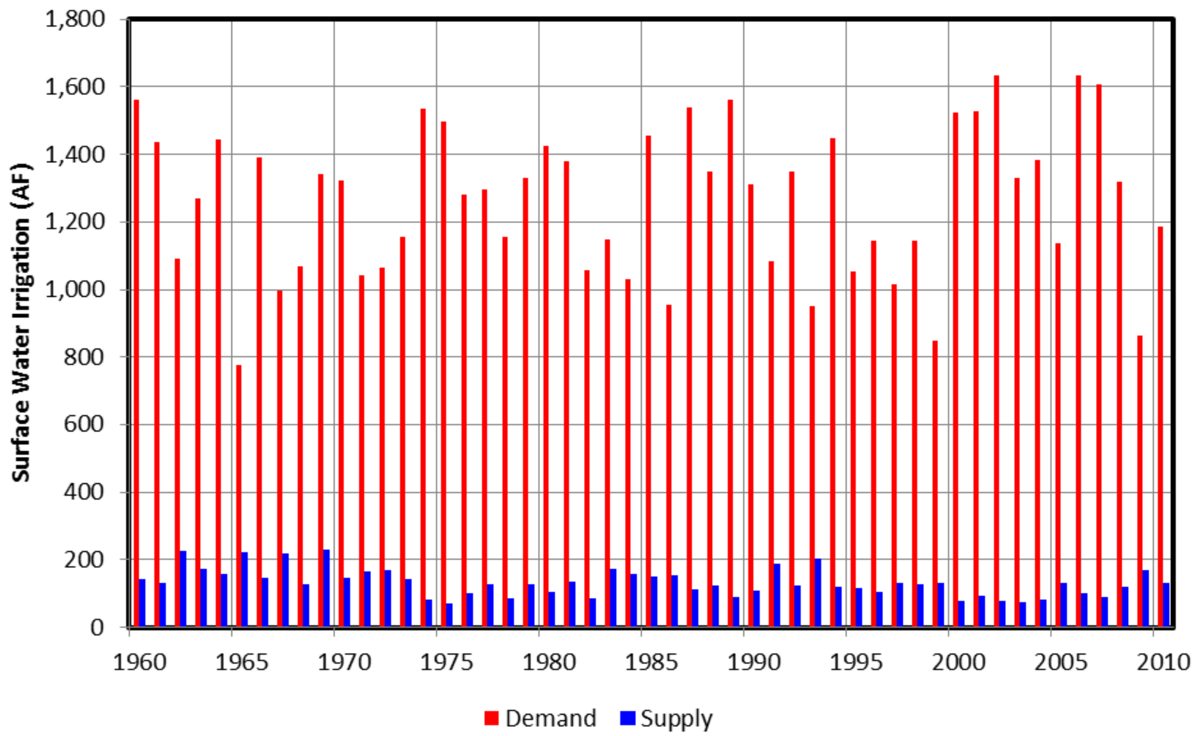


Figure 30. Irrigation Supply and Demand for Surface Water Irrigation Group 1; Baseline No Action.

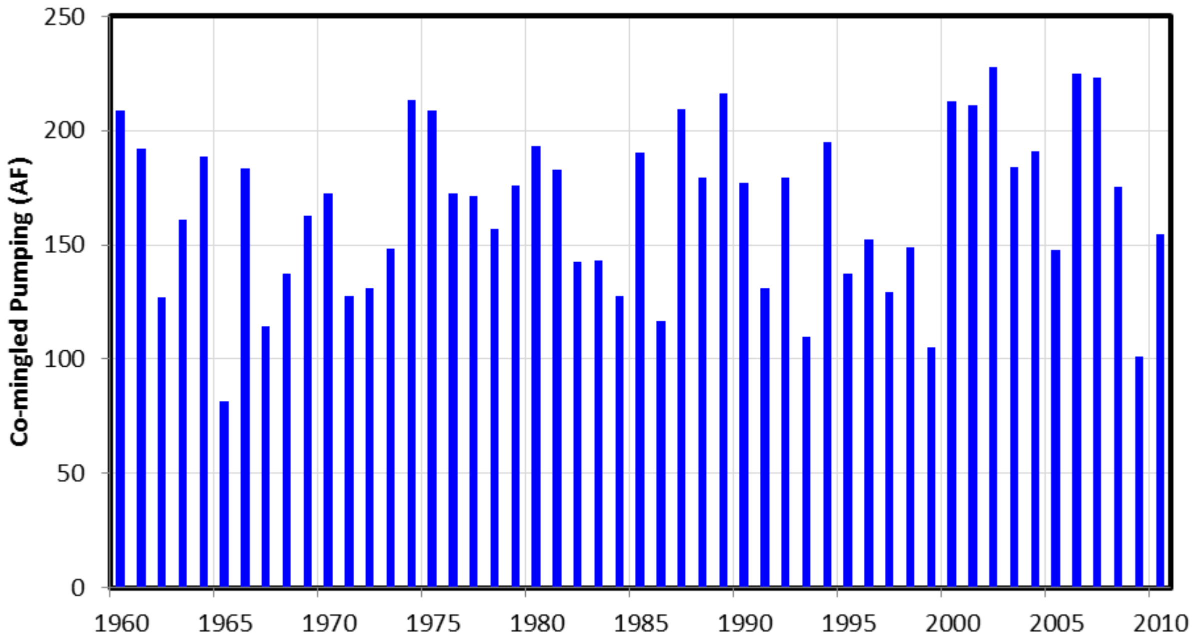


Figure 31. Co-mingled pumping for Surface Water Irrigation Group 1; Baseline No Action.

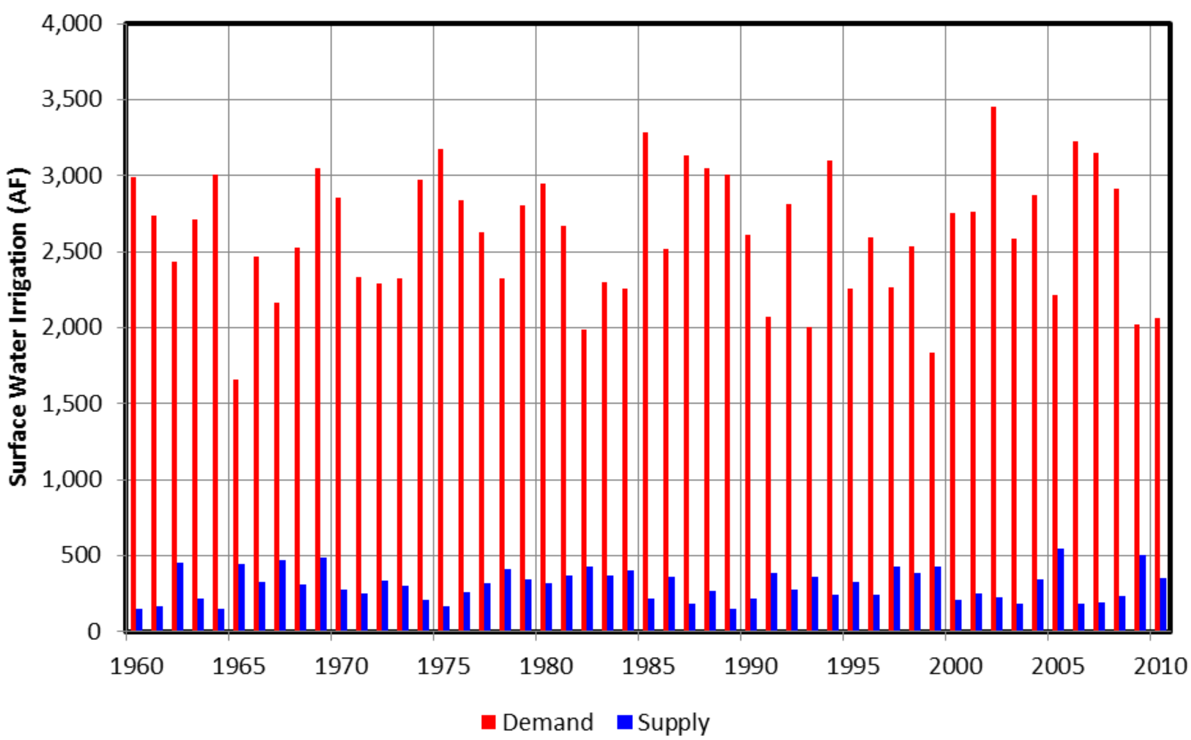


Figure 32. Irrigation Supply and Demand for Surface Water Irrigation Group 2; Baseline No Action.

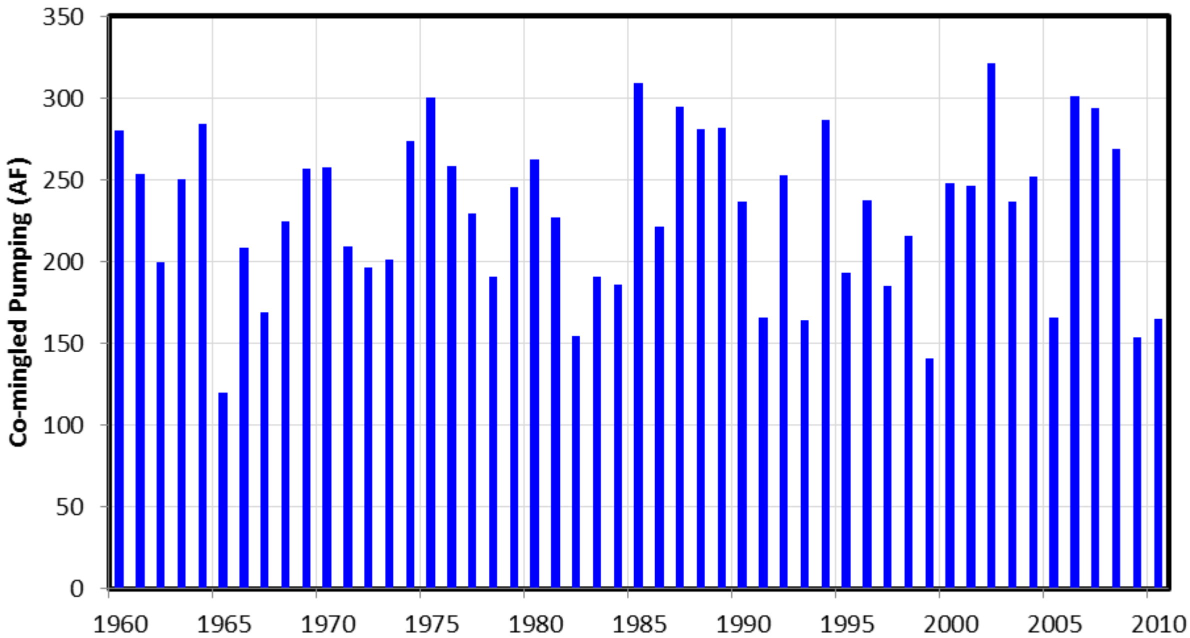


Figure 33. Co-mingled pumping for Surface Water Irrigation Group 2; Baseline No Action.

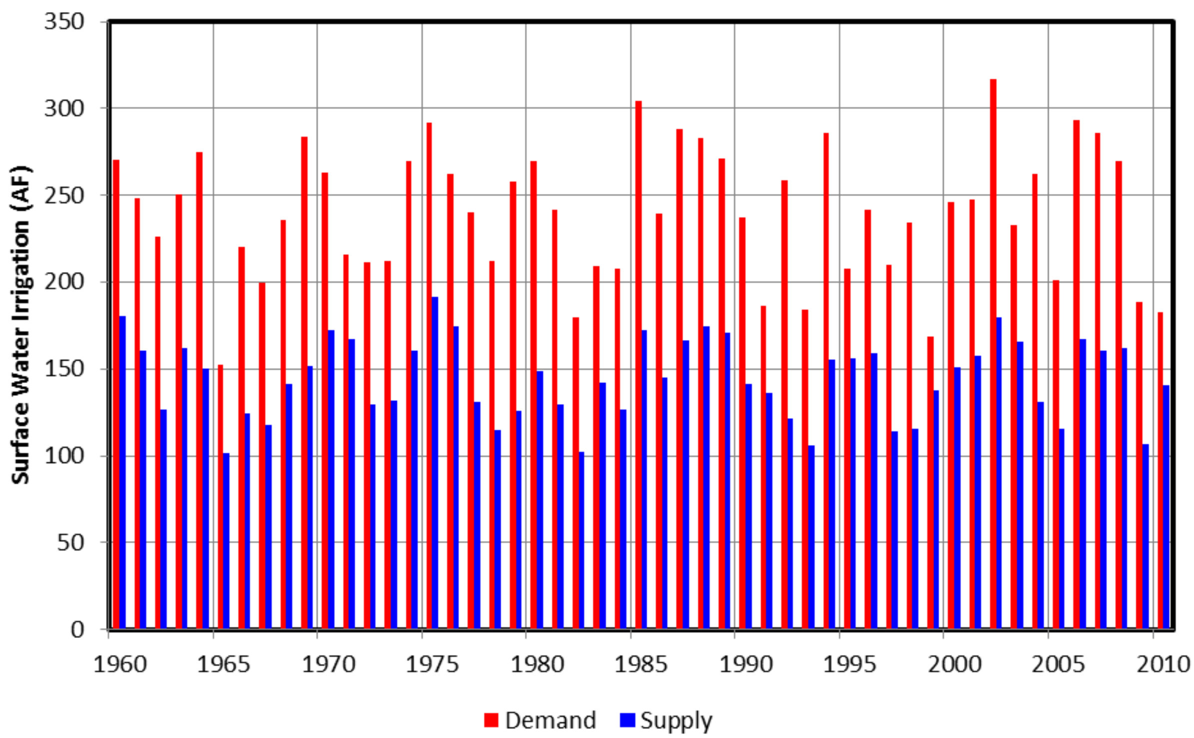


Figure 34. Irrigation Supply and Demand for Surface Water Irrigation Group 3; Baseline No Action.

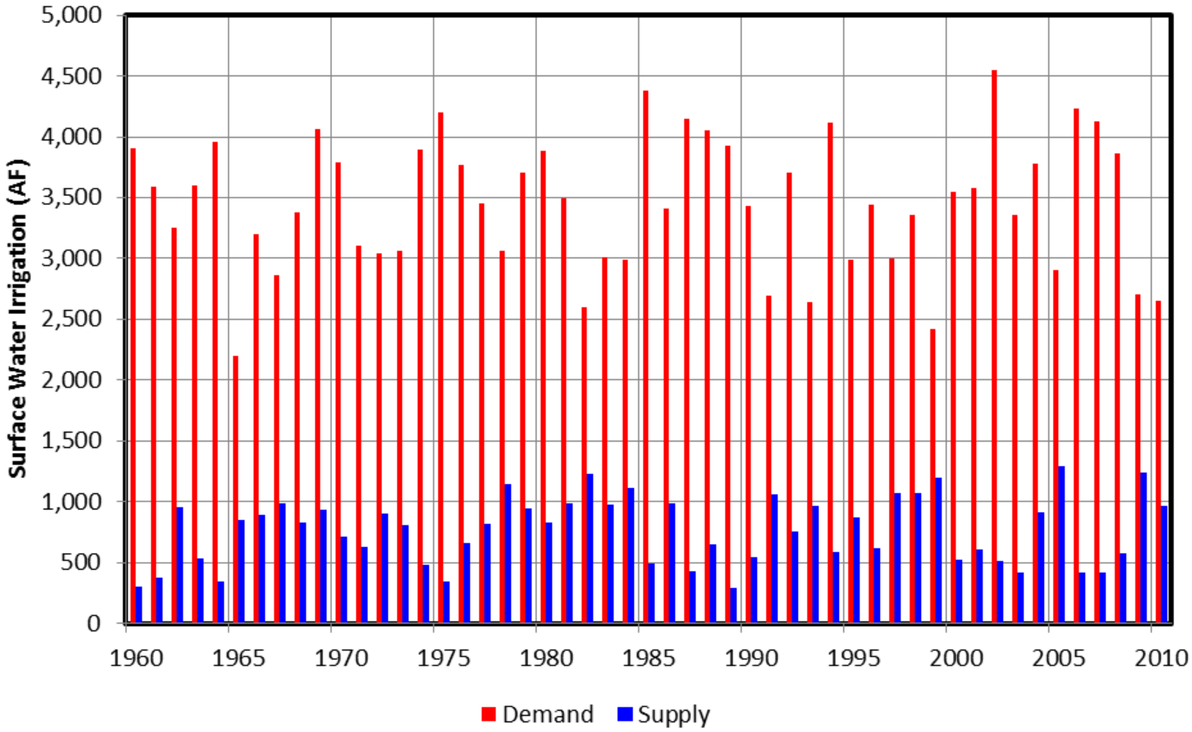


Figure 35. Irrigation Supply and Demand for Surface Water Irrigation Group 4; Baseline No Action.

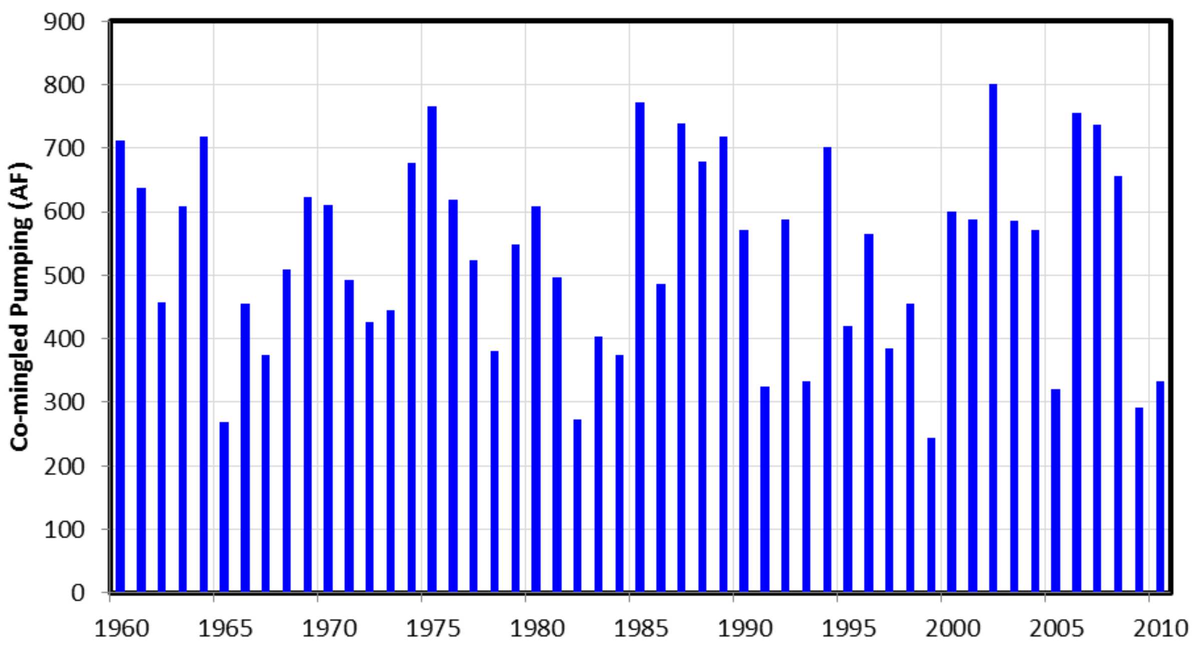


Figure 36. Co-mingled pumping for Surface Water Irrigation Group 4; Baseline No Action.

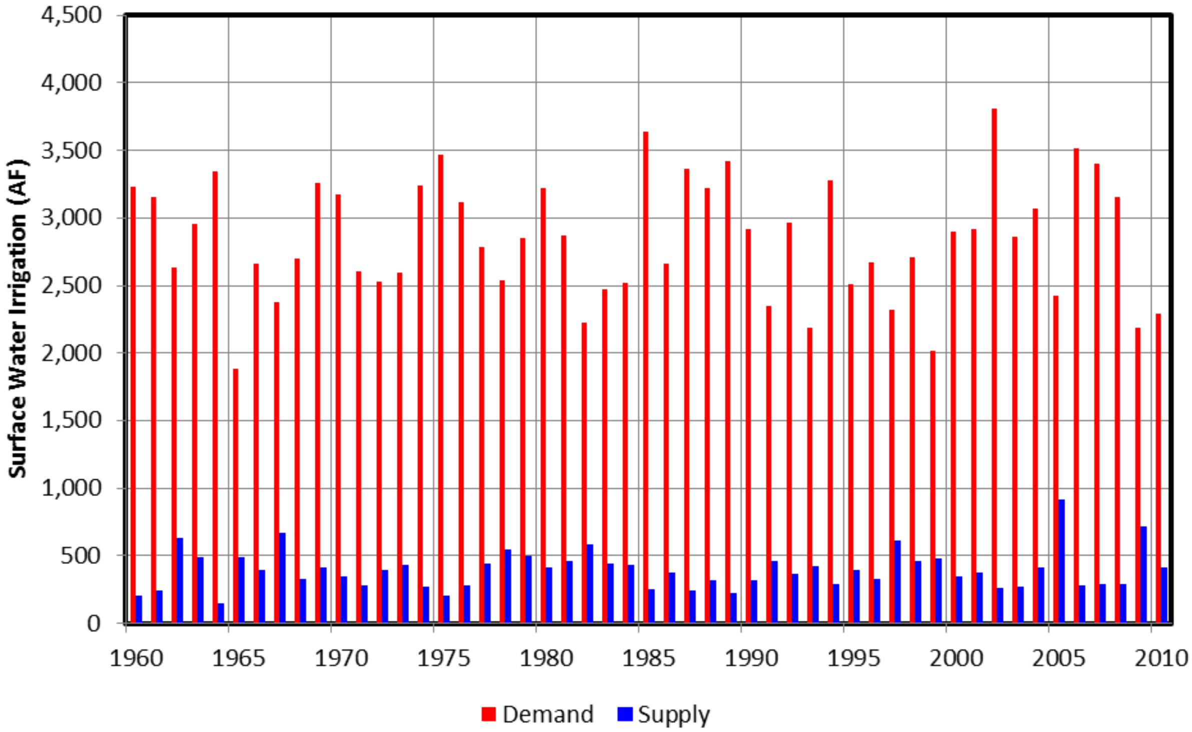


Figure 37. Irrigation Supply and Demand for Surface Water Irrigation Group 5; Baseline No Action.

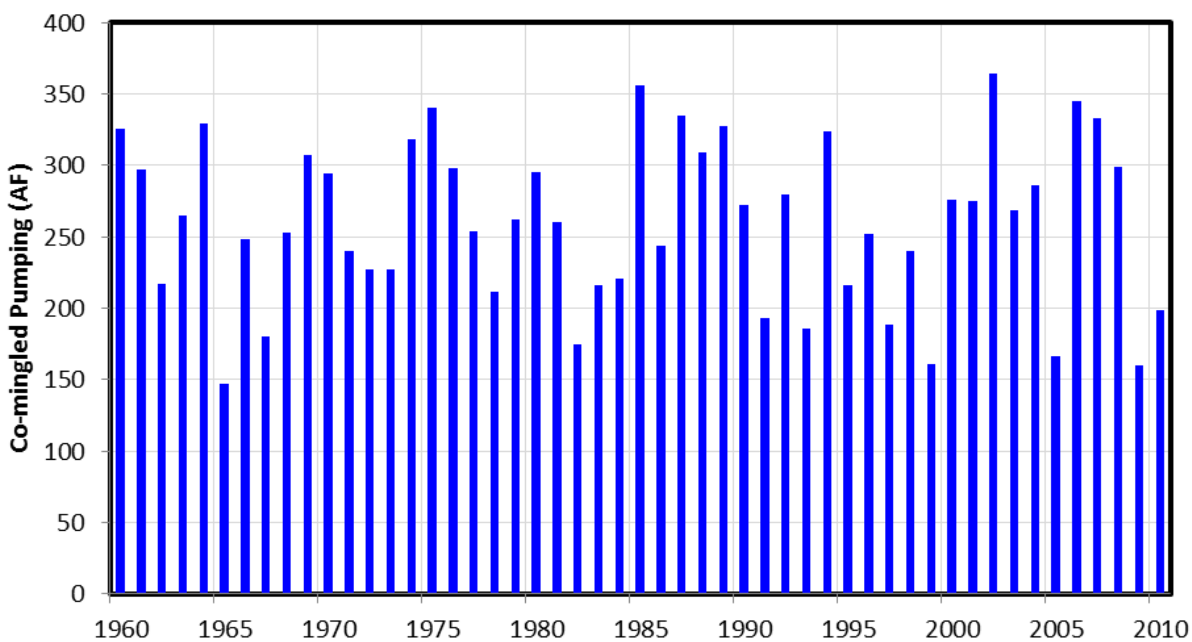


Figure 38. Co-mingled pumping for Surface Water Irrigation Group 5; Baseline No Action.

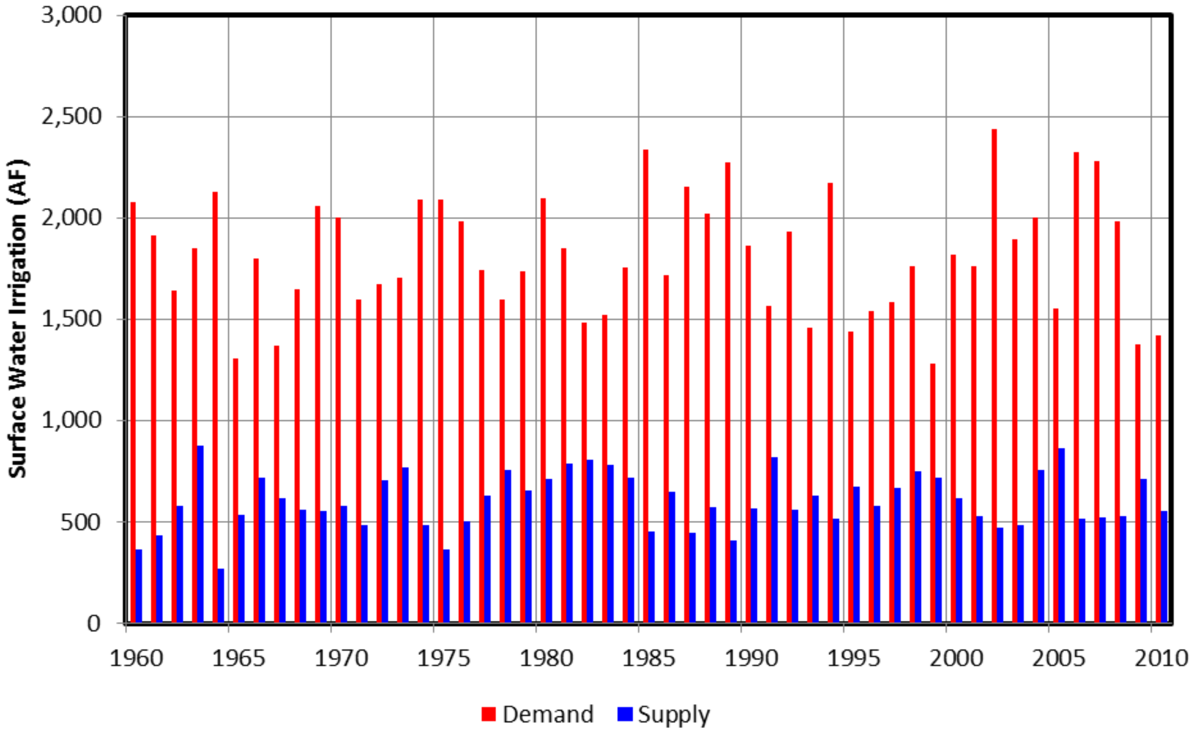


Figure 39. Irrigation Supply and Demand for Surface Water Irrigation Group 6; Baseline No Action.

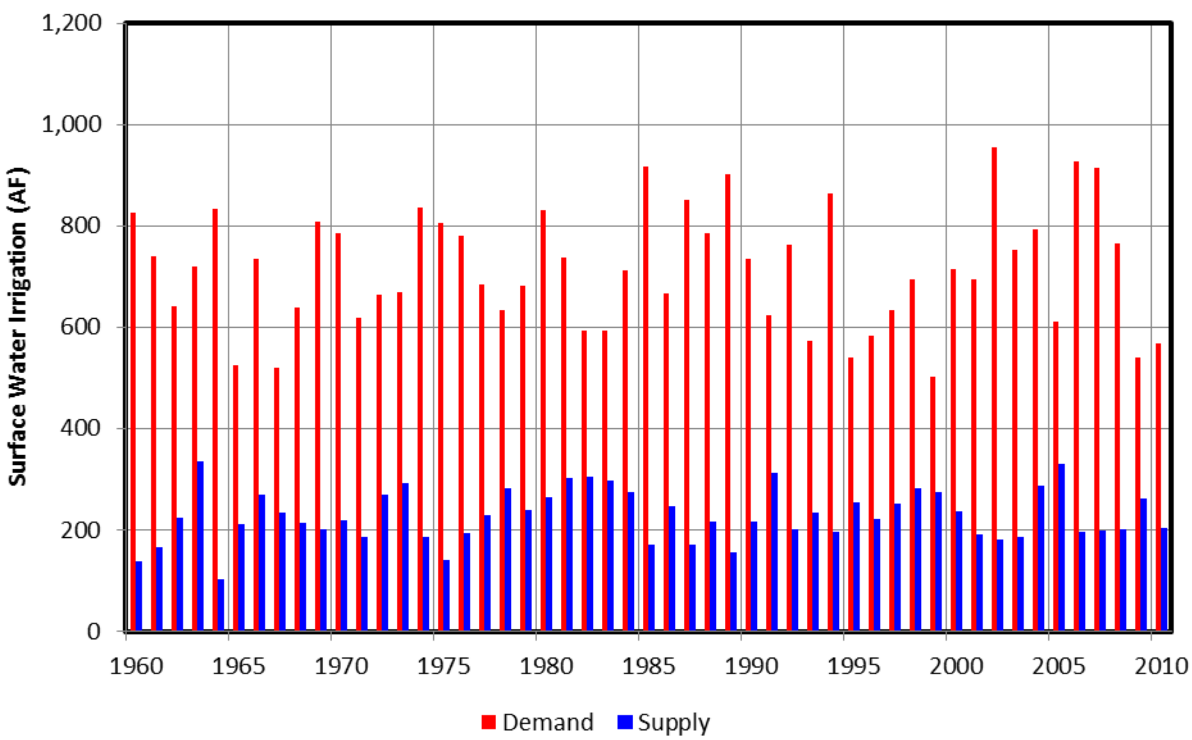


Figure 40. Irrigation Supply and Demand for Surface Water Irrigation Group 7; Baseline No Action.

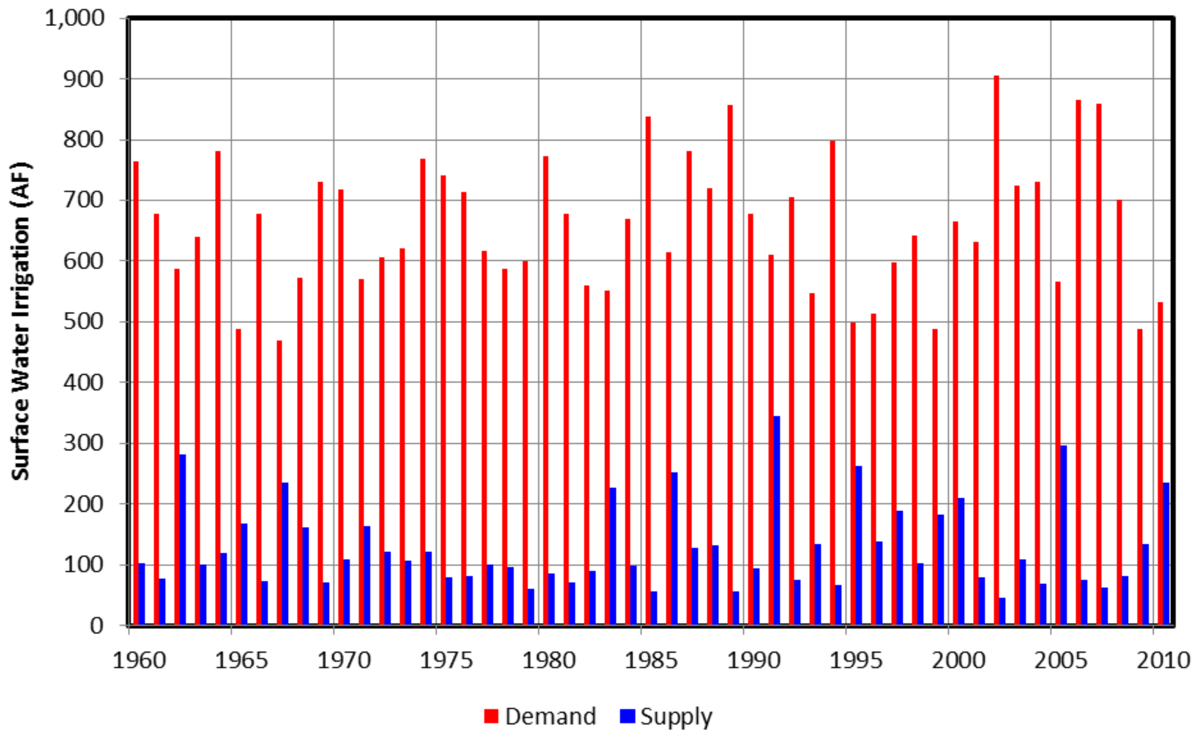


Figure 41. Irrigation Supply and Demand for Surface Water Irrigation Group 8; Baseline No Action.

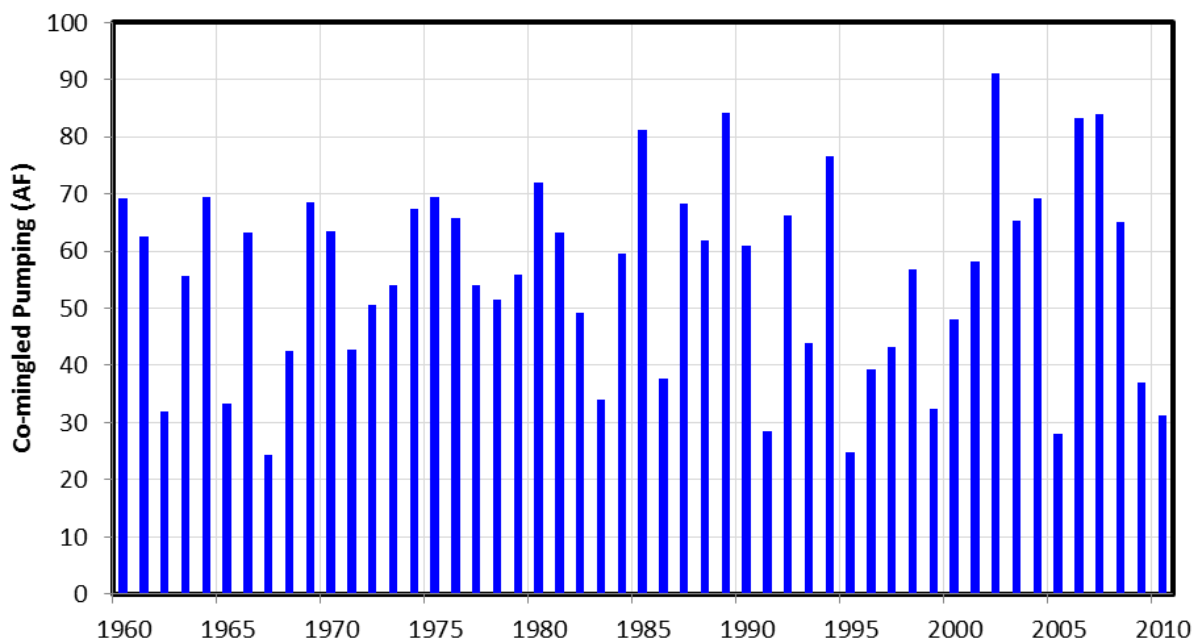


Figure 42. Co-mingled pumping for Surface Water Irrigation Group 8; Baseline No Action.

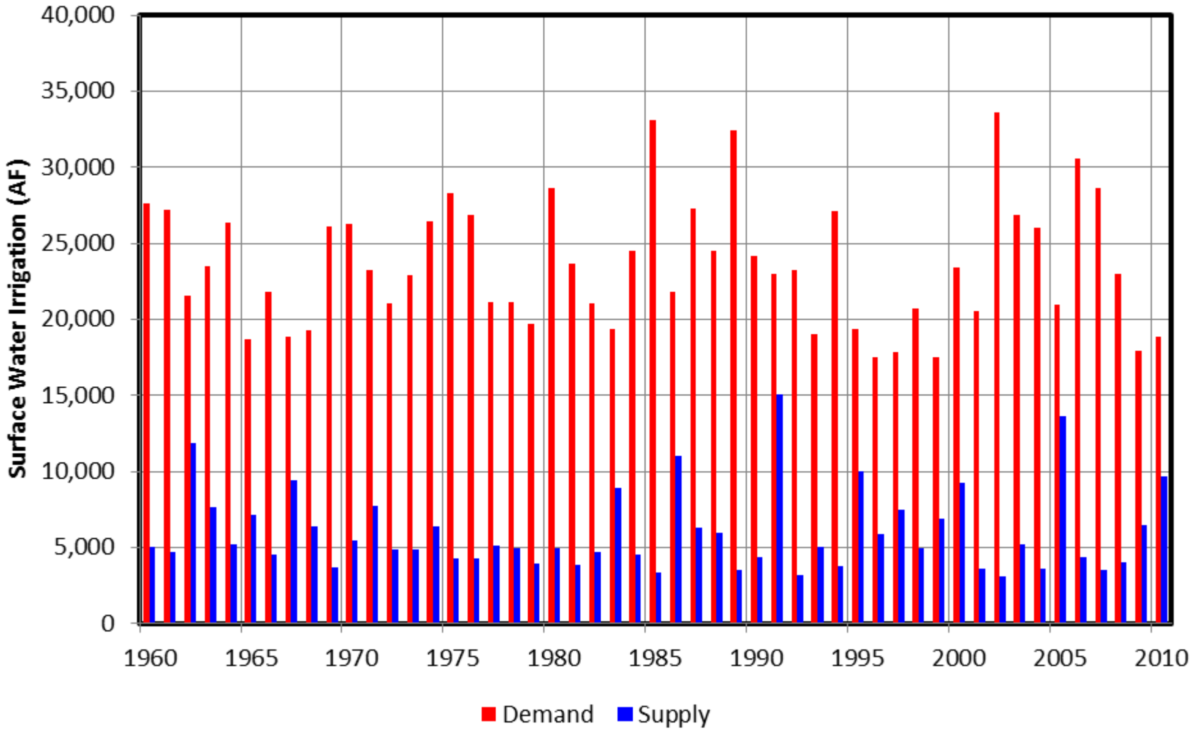


Figure 43. Irrigation Supply and Demand for Surface Water Irrigation Group 9; Baseline No Action.

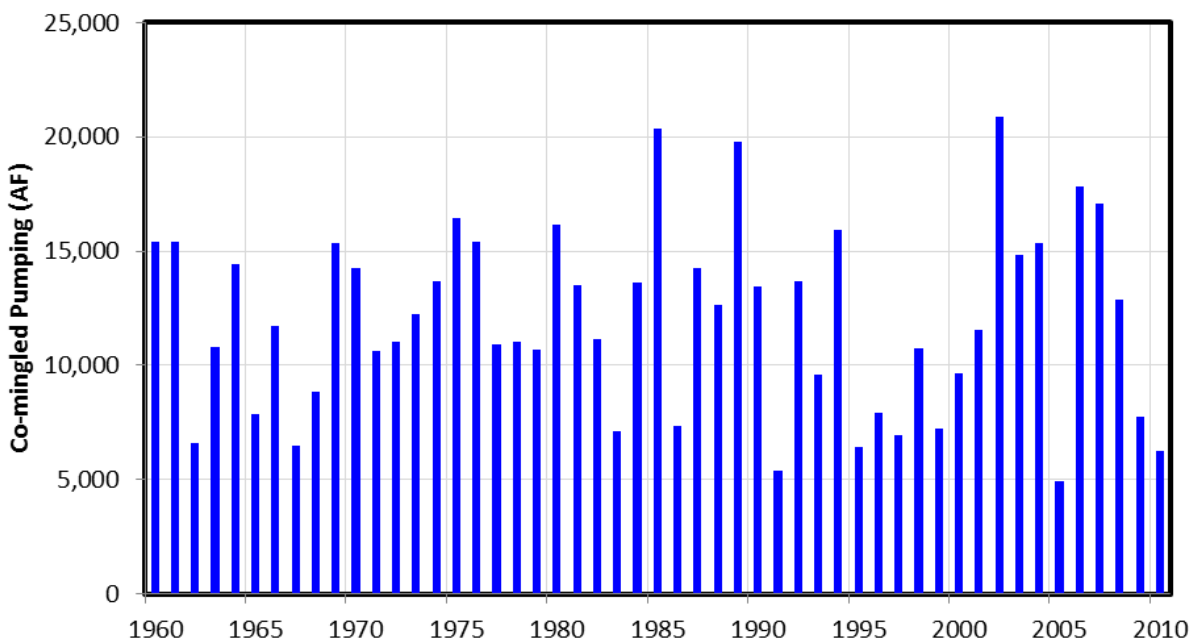


Figure 44. Co-mingled pumping for Surface Water Irrigation Group 9; Baseline No Action.

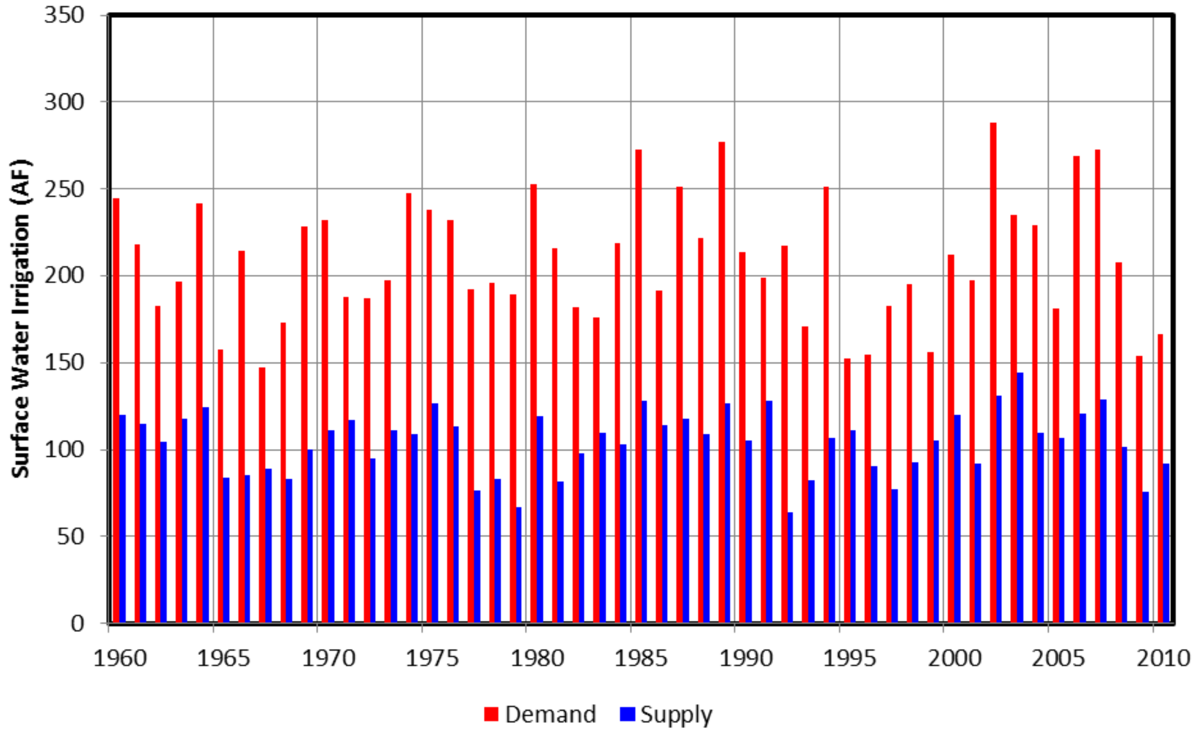


Figure 45. Irrigation Supply and Demand for Surface Water Irrigation Group 10; Baseline No Action.

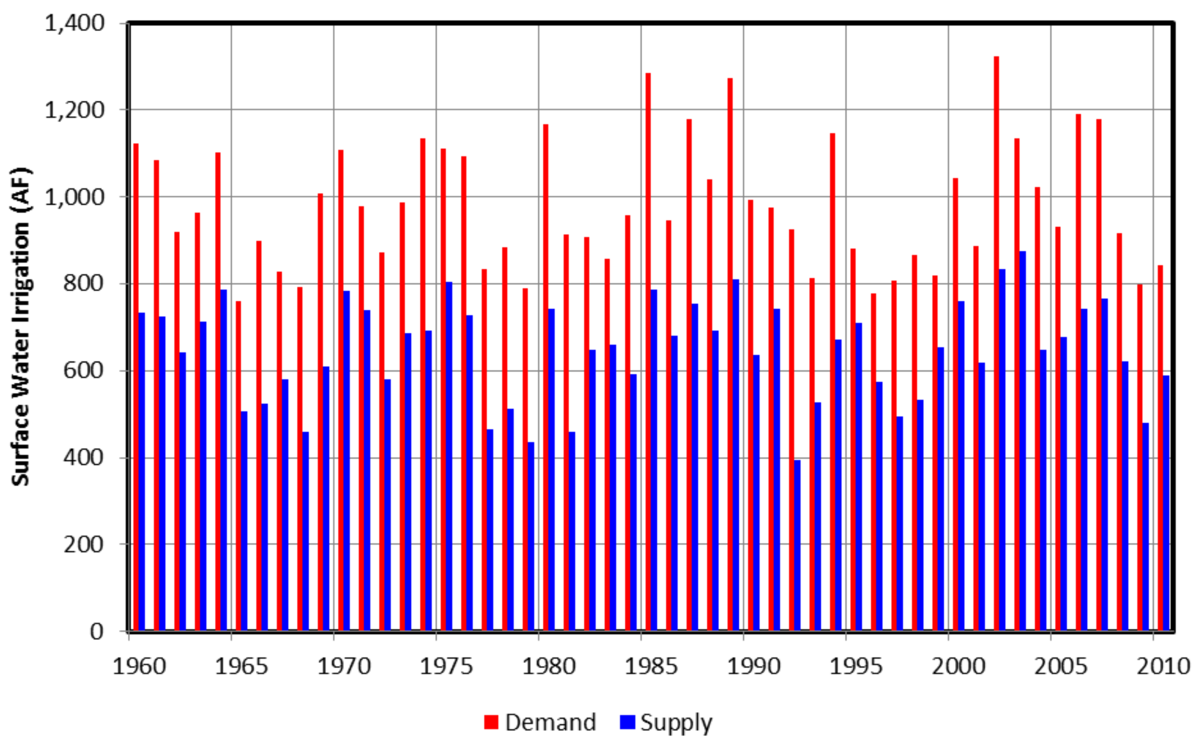


Figure 46. Irrigation Supply and Demand for Surface Water Irrigation Group 11; Baseline No Action.

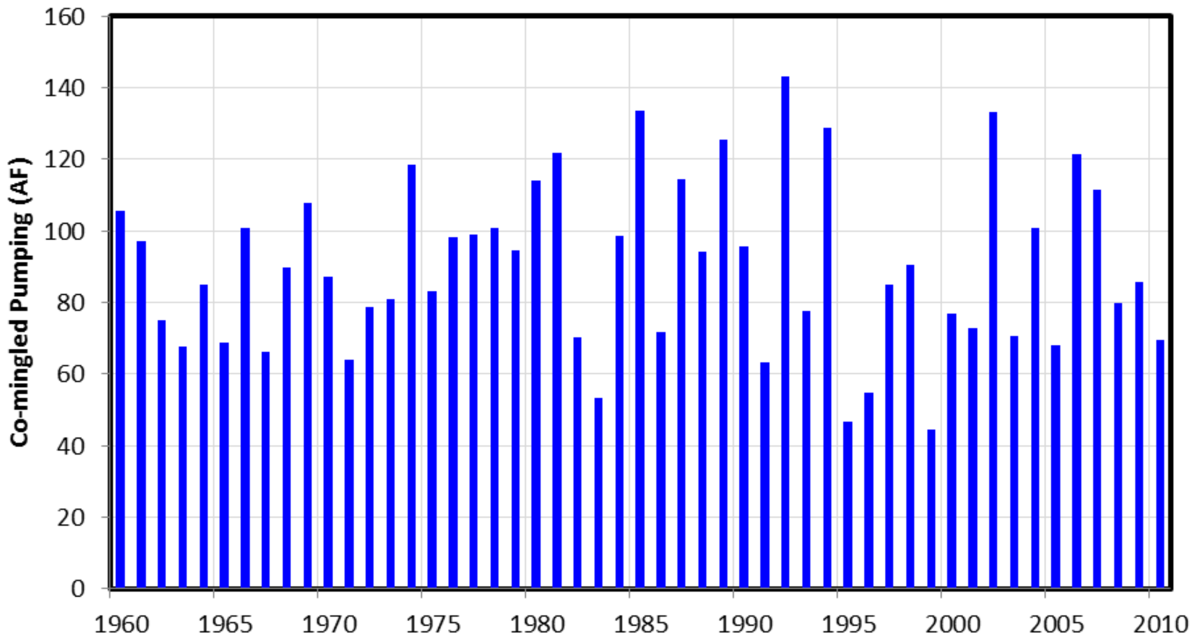


Figure 47. Co-mingled pumping for Surface Water Irrigation Group 11; Baseline No Action.

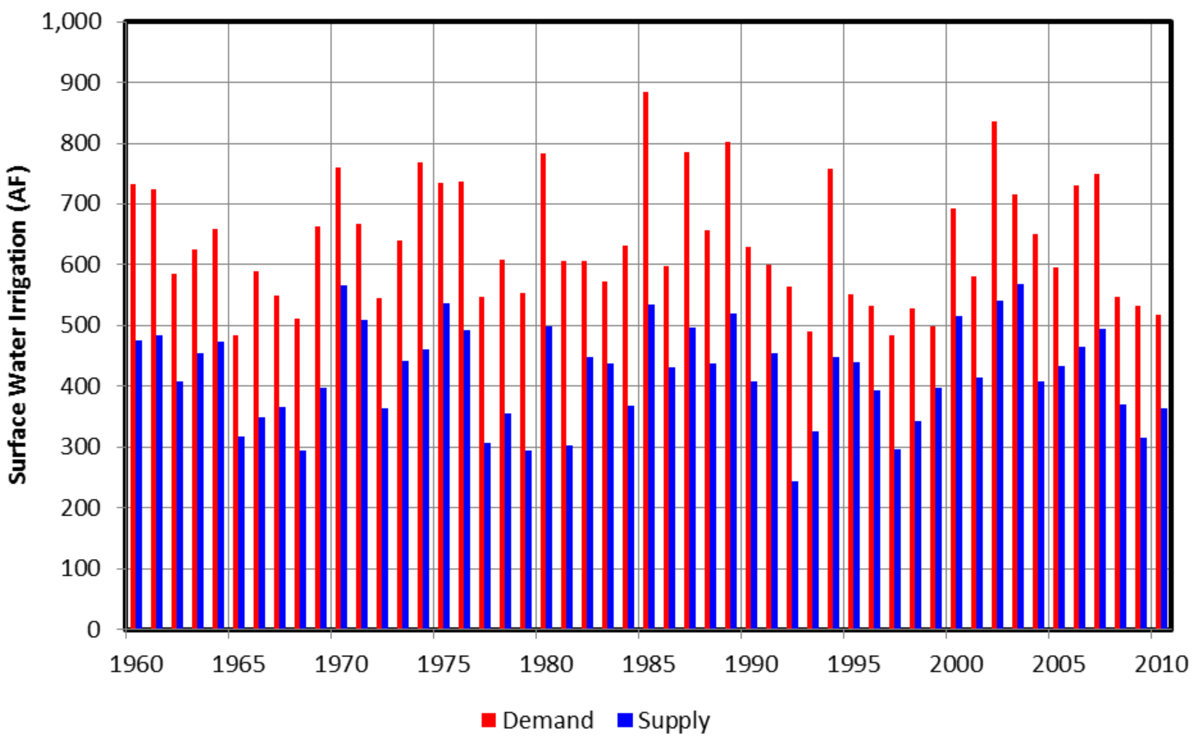


Figure 48. Irrigation Supply and Demand for Surface Water Irrigation Group 12; Baseline No Action.

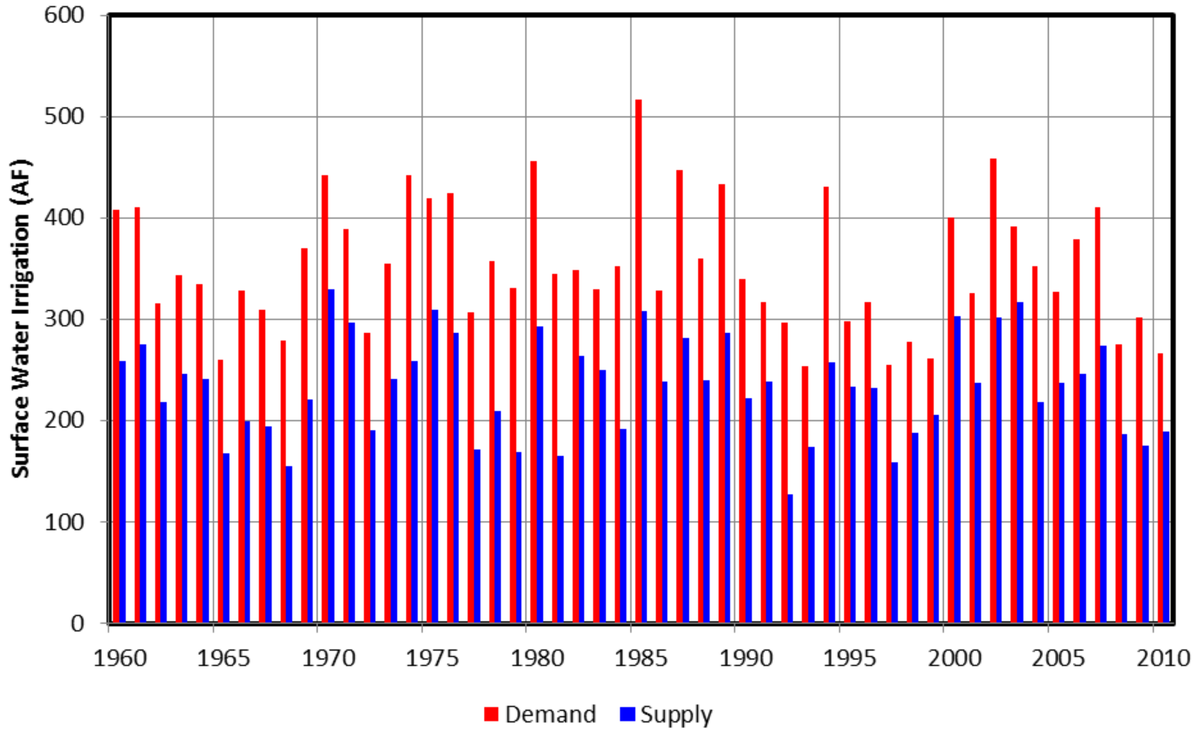


Figure 49. Irrigation Supply and Demand for Surface Water Irrigation Group 13; Baseline No Action.

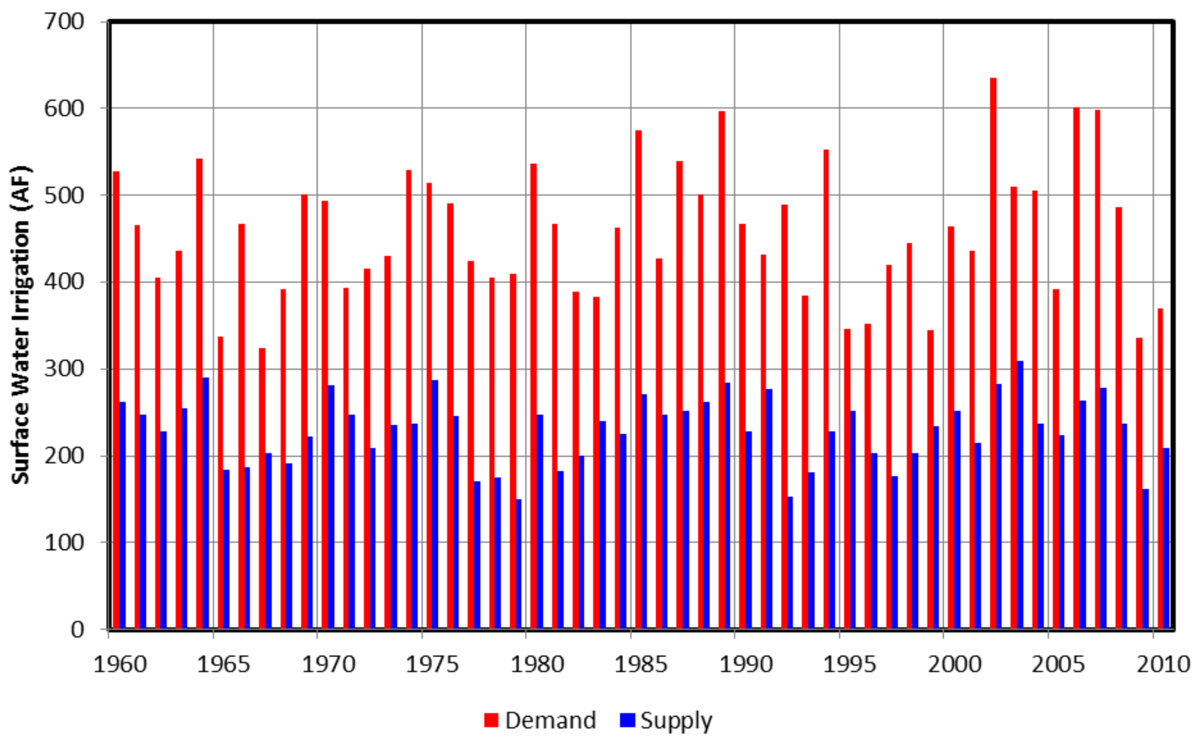


Figure 50. Irrigation Supply and Demand for Surface Water Irrigation Group 14; Baseline No Action.

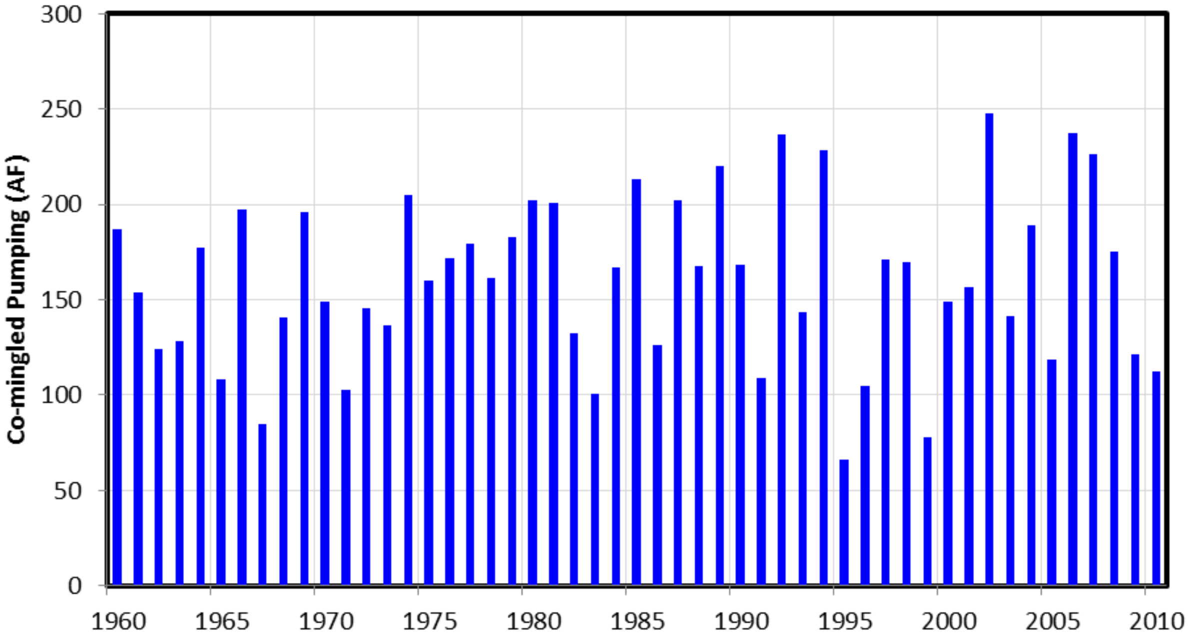


Figure 51. Co-mingled pumping for Surface Water Irrigation Group 14; Baseline No Action.

5.1.7 Overview of Mirage Flats Irrigation District (Group 9)

The Mirage Flats Irrigation District is the largest of the Surface Water Irrigation Group in terms of acres and applied surface water irrigation. Within the watershed model, there are 13,450 acres[11] serviced by the irrigation district. Of these acres, 12,100 acres are co-mingled while 1,350 acres are surface water only lands. The largest portion of the model area was used to raise corn (38.8%), followed by alfalfa (27.4%), dry edible beans (19.4%), winter wheat (10.2%), and sugar beets (4.2%).

With a majority of the irrigation district being co-mingled, Mirage Flats uses both surface water and groundwater to supplement the natural precipitation. On average surface water supplies (5.4 in) are only able to meet a fraction of the irrigation requirement. The co-mingled pumping necessary to meet full evaporative demand averaged 10.7 in. Figure 52 show the average annual total applied water and its ultimate destination. The annual surface water irrigation supply and demand for the Mirage Flats Irrigation District are shown in Figures 43-44.

[11] Actual acreage may differ. Surface water irrigation groups were delineated by grid cell. Therefore all surface water only and co-mingled acres within the cells designated as Mirage Flats were included in the Mirage Flats Analysis.

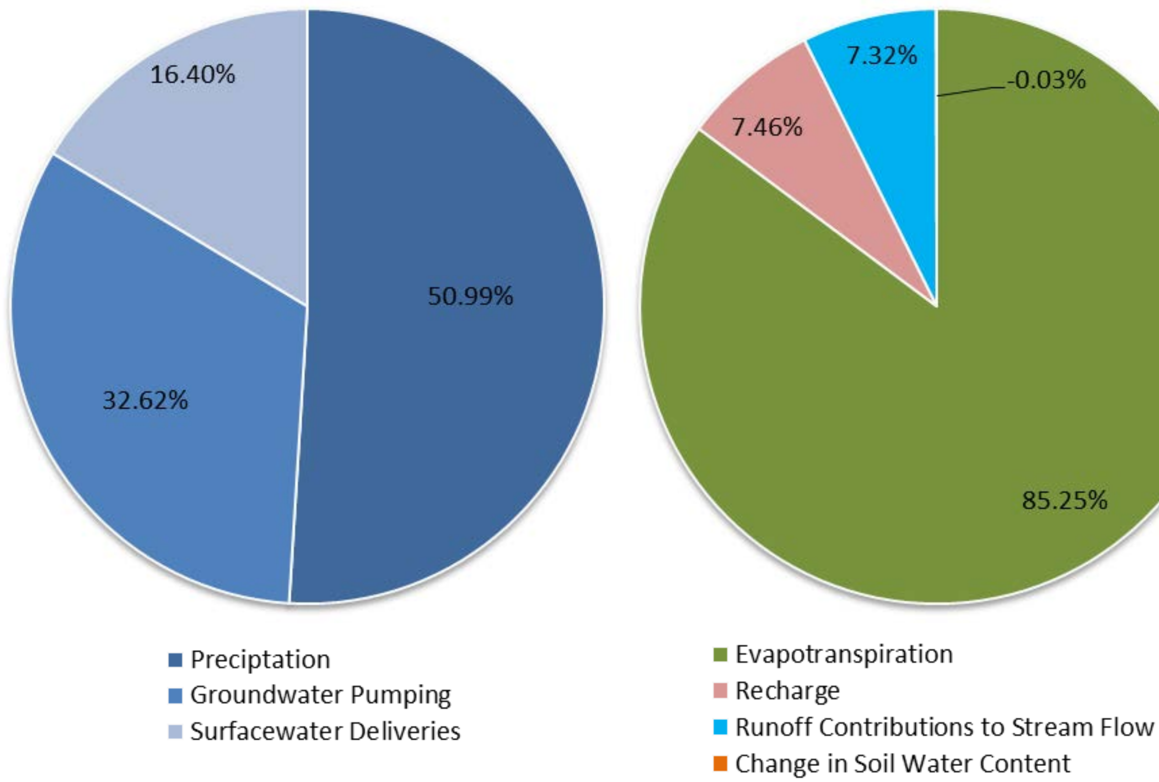


Figure 52. Sources of 32.81 in/ac of total available water and partitioned total available water for the Mirage Flats Irrigation District within the UNWNRD model; Baseline No Action.

5.1.8 Overview of Box Butte County Water Balances

Box Butte County is located in the center of the Nebraska Panhandle on the south side of the Niobrara River. The county contains nearly 690,000 acres[12] ; of which, 78% are dry, 21.8% are irrigated exclusively by groundwater pumping, and 0.2% is irrigated by surface water deliveries. There are no identified co-mingled acres within Box Butte County in the water shed model. Pasture represents the largest portion (56.9%) of vegetative cover in the county, followed by winter wheat (23.5%), corn (8.5%), dry edible beans (5.2%), sugar beets (3.4%), and alfalfa (2.53%).

Box Butte County is of particular interest due to the magnitude of declines in measured groundwater levels within the county (Conservation and Survey Divsion of the School of Natural Resources; University of Nebraska Lincoln, 2014); including but not limited to the scale and effect of groundwater pumping in the area and how it interacts with the system as a whole under varying climate

[12] Actual acreage may differ. Cells were assigned to a county based upon the location of the centroid of the cell. All acres with these were then identified as being part of the county.

conditions. The source of total applied water and its ultimate destination are shown in Figure 53.

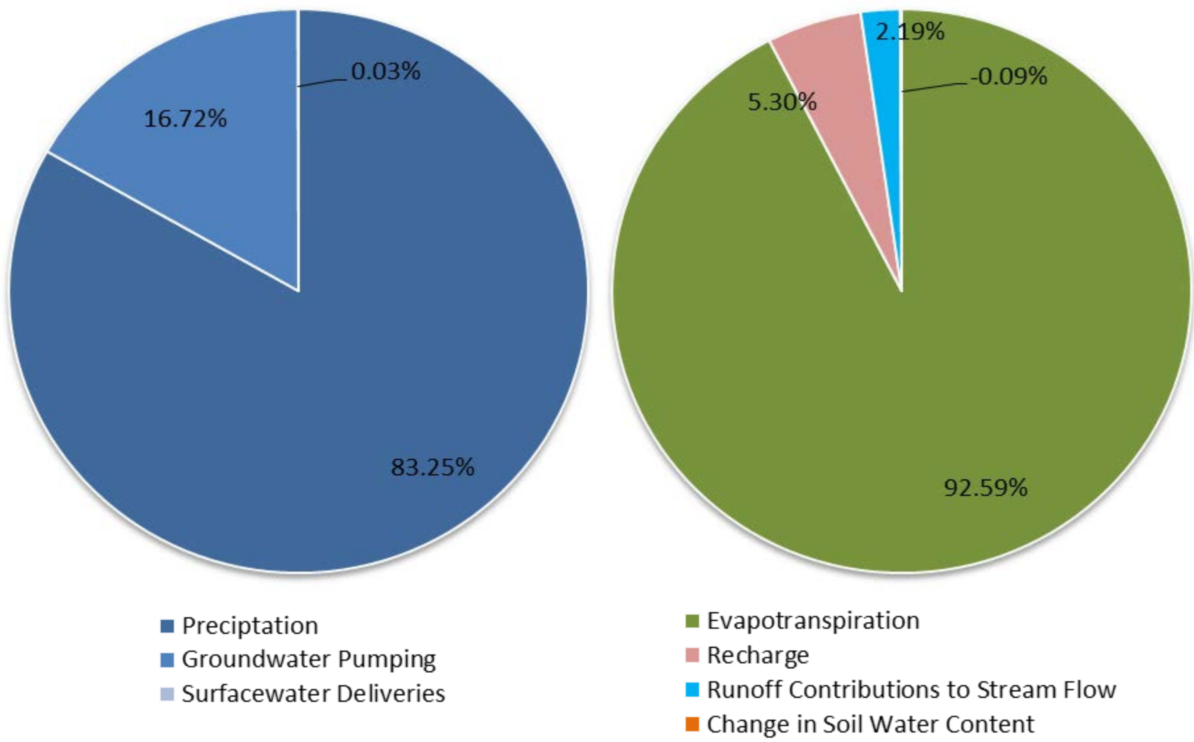


Figure 53. Sources of 18.95 in/ac of total available water and partitioned total available water for the Box Butte county area within the UNWNRD model; Baseline No Action.

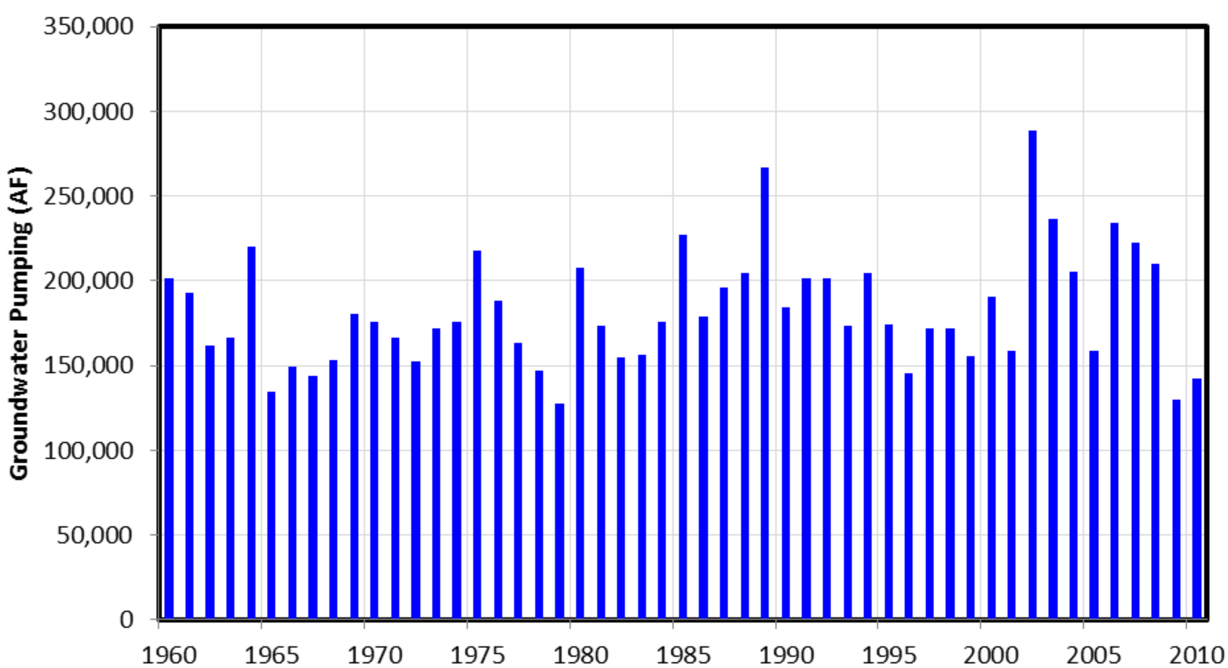


Figure 54. Annual groundwater pumping in Box Butte County in the UNWNRD model; Baseline No Action.

5.2 CENEB Model – Baseline Climate

5.2.1 Overview of Niobrara Drainage Basin Water Balance

Under the baseline climate (Baseline No Action) the total available water was 21.34 in/ac. The primary source of water was precipitation (97.9%), while the primary use was evapotranspiration (86.27%) (Figure 55). The annual model wide field water balance and runoff balance are available in Tables 14-15.

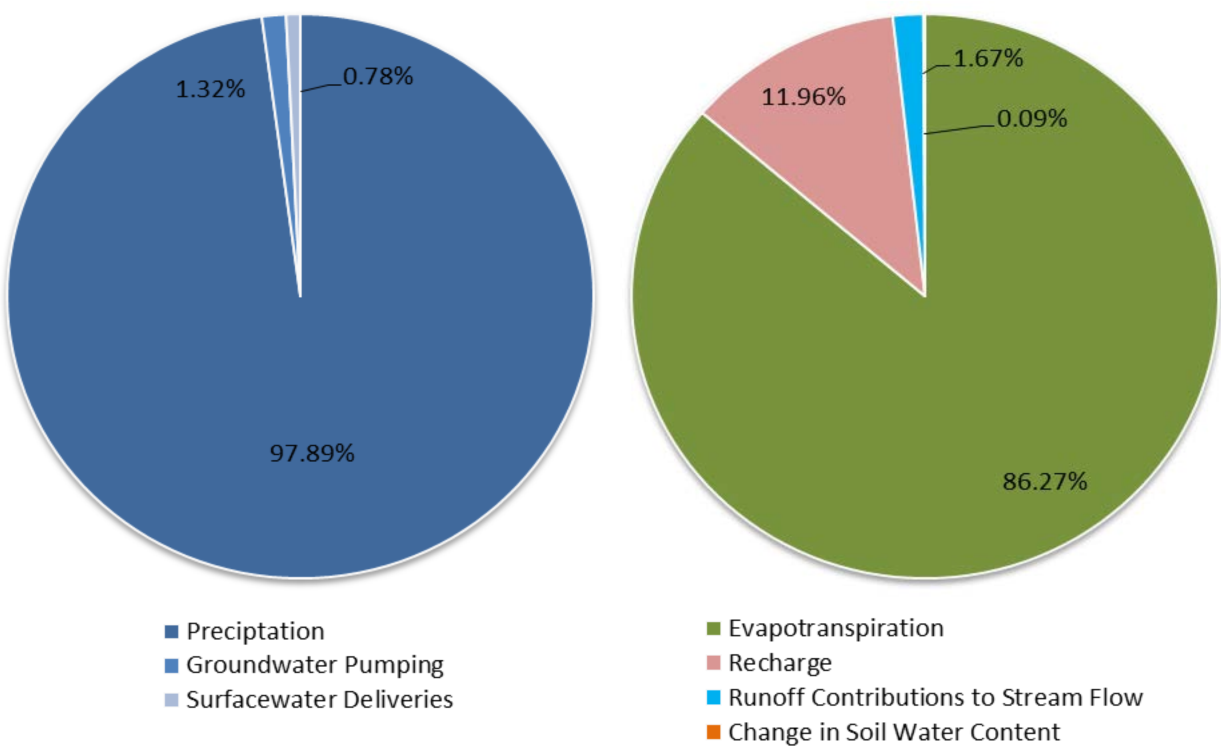


Figure 55. Sources of 21.34 in/ac of total available water and partitioned total available water for the Niobrara River Basin upstream of Spencer, NE within the CENEB model; Baseline No Action.

Table 14. CENEB Field Water Balance for the Niobrara Basin (AF); Baseline No Action

Year	Precipitation	Groundwater Pumping	Surface Water Deliveries	Total Applied Water	Direct Evapo-transpiration	Direct Runoff	Direct Recharge	Surface Losses	Field Water Balance
1960	8,318,163	107,113	62,056	8,487,332	7,428,995	398,462	957,462	5,245	(302,832)
1961	6,676,729	116,100	65,463	6,858,292	6,330,128	239,891	279,663	5,595	3,015
1962	10,730,027	81,599	42,733	10,854,359	7,428,519	694,211	2,679,278	3,768	48,583
1963	8,512,913	90,501	52,553	8,655,967	7,487,211	298,355	373,038	4,438	492,925
1964	6,646,040	101,941	66,759	6,814,740	6,717,270	259,288	460,967	5,377	(628,162)
1965	8,327,922	116,016	74,070	8,518,008	6,747,468	306,726	439,169	6,025	1,018,620
1966	7,513,806	113,931	70,521	7,698,258	7,448,590	292,261	489,550	5,805	(537,948)
1967	7,141,177	132,323	84,992	7,358,492	6,526,662	357,346	729,976	6,896	(262,388)
1968	8,316,108	121,185	72,368	8,509,661	7,432,867	303,385	602,080	6,042	165,287
1969	5,983,103	113,891	69,140	6,166,134	5,762,535	212,398	258,318	5,735	(72,852)
1970	6,200,680	148,544	88,456	6,437,680	5,804,157	272,722	509,414	7,393	(156,006)
1971	8,389,939	135,056	78,279	8,603,274	7,081,212	318,392	703,348	6,616	493,706
1972	8,130,901	106,354	63,370	8,300,625	7,091,663	383,378	869,289	5,296	(49,001)
1973	9,663,323	131,456	83,095	9,877,874	7,697,429	467,968	1,059,018	6,784	646,675
1974	5,134,837	167,393	98,995	5,401,225	5,829,897	248,573	566,166	8,298	(1,251,709)
1975	5,754,713	148,345	88,274	5,991,332	5,401,240	202,973	213,463	7,381	166,275
1976	5,342,517	123,789	70,112	5,536,418	5,202,776	196,289	186,934	5,981	(55,562)
1977	11,564,734	84,079	52,941	11,701,754	8,798,261	523,985	1,523,842	4,330	851,336
1978	7,563,201	100,420	58,796	7,722,417	7,479,251	311,977	638,098	4,948	(711,857)
1979	8,693,372	91,776	54,784	8,839,932	7,649,034	288,498	441,821	4,574	456,005
1980	5,595,558	149,236	90,611	5,835,405	5,795,603	210,525	345,652	7,515	(523,890)
1981	8,834,001	89,125	47,738	8,970,864	7,221,574	366,832	762,263	4,169	616,026
1982	9,845,713	113,179	63,228	10,022,120	8,146,741	404,405	1,154,191	5,425	311,358
1983	10,436,254	87,373	49,540	10,573,167	8,063,354	585,128	2,377,088	4,225	(456,628)
1984	9,081,729	100,355	58,055	9,240,139	8,225,353	390,959	727,222	4,909	(108,304)
1985	7,179,637	118,645	66,368	7,364,650	6,025,025	240,123	428,673	5,691	665,138
1986	9,997,781	88,497	49,429	10,135,707	8,284,915	531,809	1,545,714	4,242	(230,973)

Year	Precipitation	Groundwater Pumping	Surface Water Deliveries	Total Applied Water	Direct Evapo-transpiration	Direct Runoff	Direct Recharge	Surface Losses	Field Water Balance
1987	9,314,667	117,045	67,195	9,498,907	7,492,845	345,328	1,389,562	5,701	265,471
1988	9,200,400	110,082	61,455	9,371,937	7,988,569	401,351	1,550,352	5,274	(573,609)
1989	4,662,592	122,412	78,633	4,863,637	4,876,691	177,808	168,503	6,380	(365,745)
1990	8,405,157	92,578	52,900	8,550,635	7,438,881	340,953	512,930	4,497	253,374
1991	8,880,645	131,706	77,799	9,090,150	7,370,822	374,143	1,061,866	6,525	276,794
1992	8,405,882	78,140	50,754	8,534,776	7,782,340	301,242	748,579	4,101	(301,486)
1993	10,485,919	52,457	29,973	10,568,349	8,222,100	393,778	1,270,159	2,548	679,764
1994	7,866,759	83,314	49,973	8,000,046	7,688,232	318,639	472,666	4,165	(483,656)
1995	10,916,107	114,127	67,856	11,098,090	7,326,815	574,675	2,449,545	5,675	741,380
1996	7,866,963	109,198	63,825	8,039,986	7,086,158	382,868	986,766	5,375	(421,181)
1997	9,193,917	89,386	47,105	9,330,408	8,075,849	356,857	795,046	4,143	98,513
1998	10,455,192	85,432	50,656	10,591,280	8,107,982	447,153	1,485,536	4,241	546,368
1999	7,304,231	103,873	65,675	7,473,779	7,305,649	302,133	1,084,364	5,361	(1,223,728)
2000	7,499,092	137,717	78,483	7,715,292	6,589,580	248,448	333,378	6,679	537,207
2001	9,028,565	93,411	59,945	9,181,921	7,530,288	439,504	1,311,660	4,865	(104,396)
2002	4,545,282	151,768	92,640	4,789,690	4,656,751	171,236	172,732	7,666	(218,695)
2003	6,702,462	132,869	75,426	6,910,757	6,297,141	281,936	508,789	6,428	(183,537)
2004	7,217,940	117,538	72,502	7,407,980	6,498,991	230,823	260,129	5,976	412,061
2005	9,647,128	110,486	66,707	9,824,321	7,209,142	593,976	2,187,000	5,545	(171,342)
2006	7,126,086	127,629	77,484	7,331,199	6,118,595	262,074	367,501	6,427	576,602
2007	9,332,764	102,205	59,587	9,494,556	7,484,798	490,812	1,481,228	5,023	32,695
2008	9,028,953	97,949	55,394	9,182,296	7,775,472	423,629	1,178,814	4,728	(200,347)
2009	9,049,123	90,748	51,366	9,191,237	8,096,923	343,722	741,178	4,384	5,030
2010	9,123,859	107,921	66,296	9,298,076	7,516,196	484,140	1,662,876	5,473	(370,609)
Average	8,173,227	110,553	65,536	8,349,316	7,091,069	352,825	892,213	5,488	7,721

Table 15. CENEB runoff balance for the Niobrara Basin (AF); Baseline No Action

Year	Direct Runoff	Runoff Contributions to Streamflow	Runoff Losses to Recharge	Runoff Losses to Evapotranspiration
1960	398,462	160,065	119,198	119,198
1961	239,891	91,594	74,149	74,149
1962	694,211	264,197	215,008	215,008
1963	298,355	111,445	93,454	93,454
1964	259,288	108,998	75,145	75,145
1965	306,726	124,787	90,969	90,969
1966	292,261	115,288	88,486	88,486
1967	357,346	133,814	111,767	111,767
1968	303,385	114,161	94,612	94,612
1969	212,398	84,862	63,767	63,767
1970	272,722	107,817	82,453	82,453
1971	318,392	127,927	95,232	95,232
1972	383,378	152,521	115,429	115,429
1973	467,968	184,478	141,744	141,744
1974	248,573	97,086	75,744	75,744
1975	202,973	81,896	60,540	60,540
1976	196,289	80,021	58,135	58,135
1977	523,985	209,155	157,415	157,415
1978	311,977	121,557	95,210	95,210
1979	288,498	114,668	86,914	86,914
1980	210,525	82,753	63,886	63,886
1981	366,832	140,352	113,240	113,240
1982	404,405	160,018	122,193	122,193
1983	585,128	226,433	179,347	179,347
1984	390,959	153,275	118,841	118,841
1985	240,123	98,380	70,872	70,872
1986	531,809	215,987	157,911	157,911
1987	345,328	144,489	100,421	100,421
1988	401,351	153,163	124,095	124,095
1989	177,808	72,431	52,689	52,689
1990	340,953	140,890	100,031	100,031
1991	374,143	149,160	112,492	112,492
1992	301,242	122,261	89,490	89,490
1993	393,778	157,030	118,374	118,374
1994	318,639	127,985	95,327	95,327
1995	574,675	221,844	176,416	176,416
1996	382,868	146,953	117,957	117,957
1997	356,857	133,013	111,922	111,922

Year	Direct Runoff	Runoff Contributions to Streamflow	Runoff Losses to Recharge	Runoff Losses to Evapotranspiration
1998	447,153	175,203	135,975	135,975
1999	302,133	125,181	88,476	88,476
2000	248,448	95,675	76,387	76,387
2001	439,504	173,656	132,924	132,924
2002	171,236	67,592	51,822	51,822
2003	281,936	105,812	88,062	88,062
2004	230,823	92,842	68,992	68,992
2005	593,976	239,168	177,404	177,404
2006	262,074	103,834	79,120	79,120
2007	490,812	191,405	149,704	149,704
2008	423,629	173,143	125,243	125,243
2009	343,722	131,426	106,149	106,149
2010	484,140	202,915	140,612	140,612
Average	352,825	139,424	106,701	106,701

Figure 56 shows the average annual recharge for the Niobrara Basin upstream of Spencer, NE within the CENEB model region. The recharge patterns reflect several model components; soils (Figure 7), precipitation patterns (Figure 10), and land use (irrigated vs. non-irrigated).

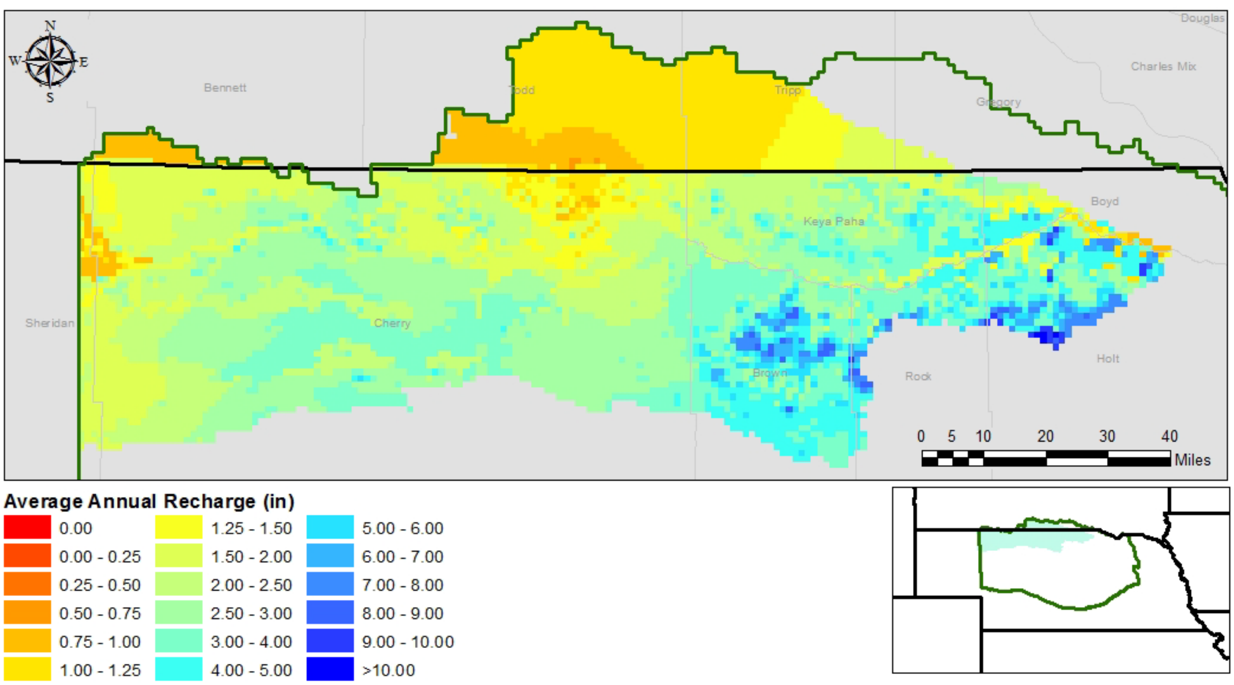


Figure 56. Average annual recharge for the Niobrara Drainage Basin in the CENEB model area; Baseline No Action.

5.2.2 Overview of Runoff Zones Water Balances

The CENEB model was further analyzed on the runoff zone operational regions shown in Figure 18. The average annual field water balance and runoff water balance are summarized for each of the runoff zones in Figures 57-59. The left diagram shows the sources of applied water, while the right diagram depicts where the water ultimately went.

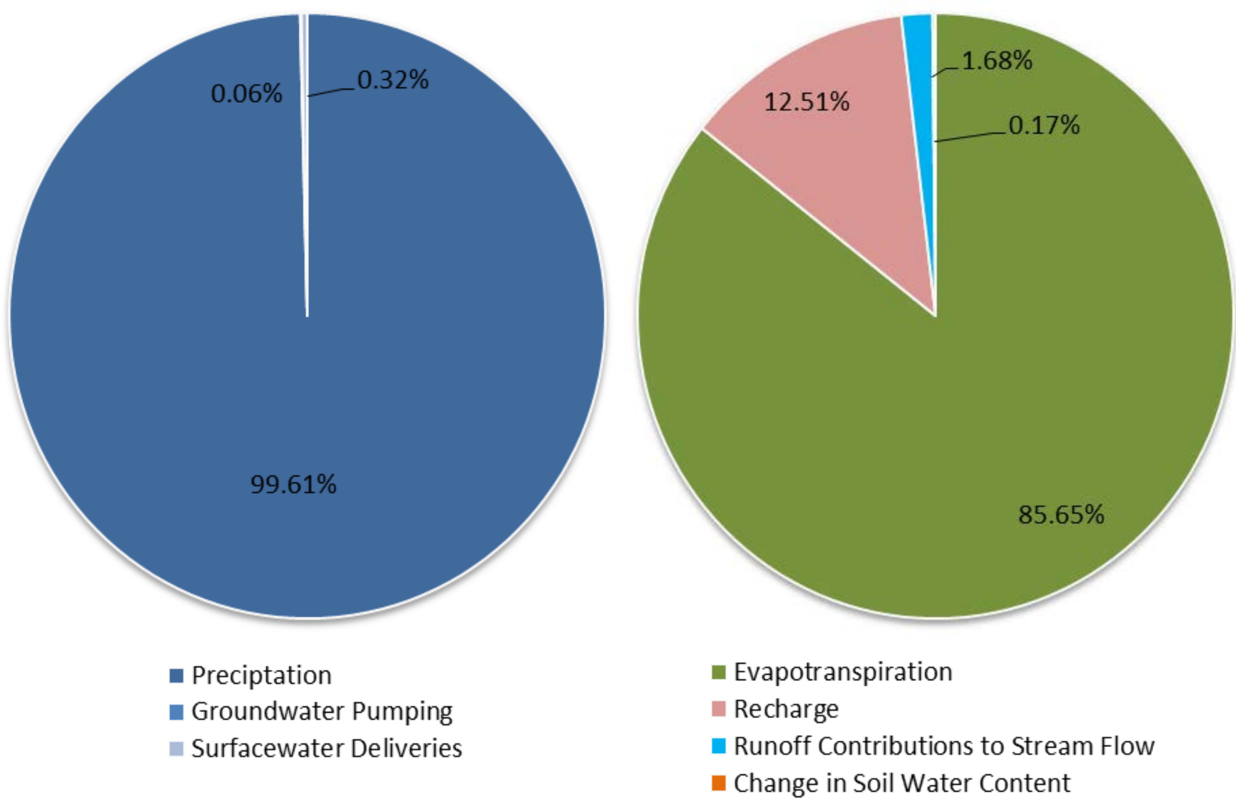


Figure 57. Sources of 20.37 in/ac of total available water and partitioned total available water for runoff zone 1 in the CENEB model; Baseline No Action.

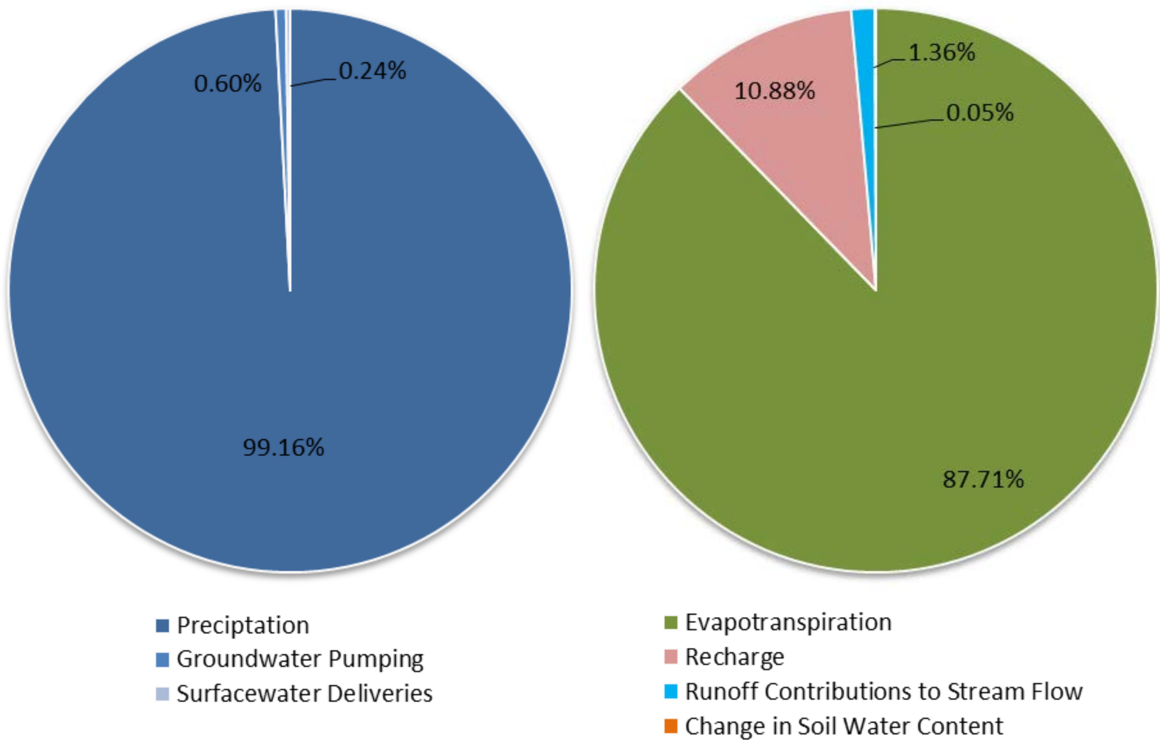


Figure 58. Sources of 20.00 in/ac of total available water and partitioned total available water for runoff zone 2 in the CENEB model; Baseline No Action.

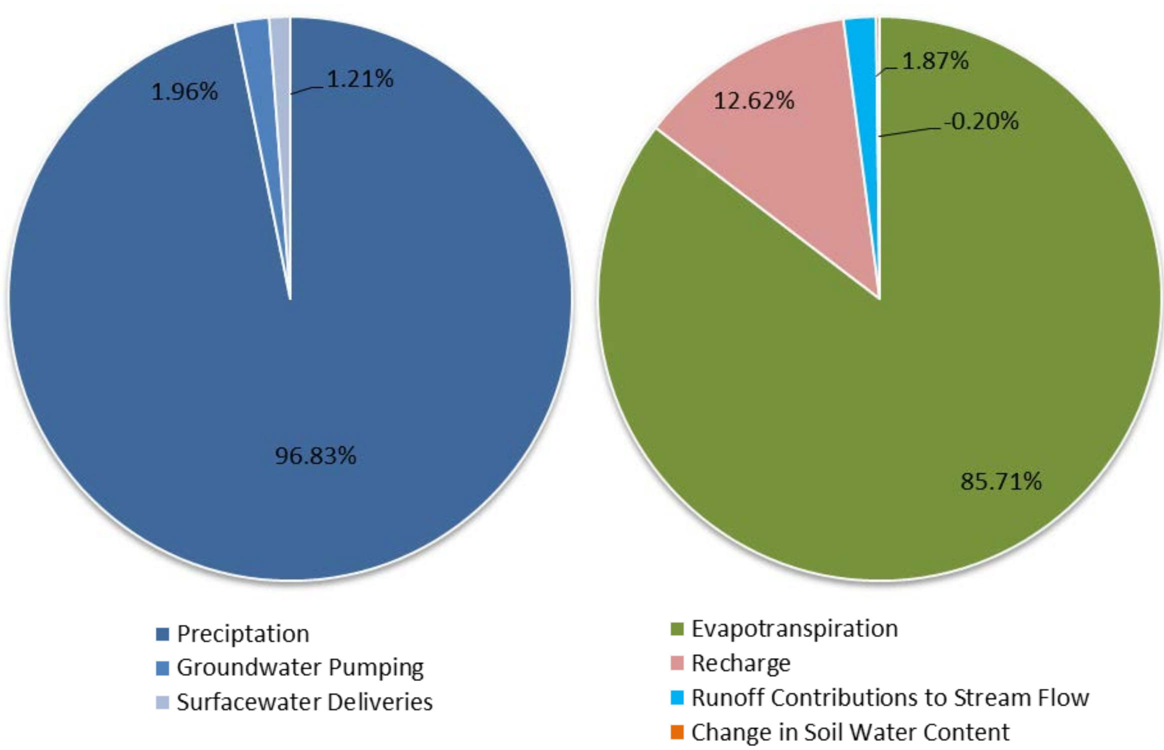


Figure 59. Sources of 22.48 in/ac of total available water and partitioned total available water for runoff zone 3 in the CENB model; Baseline No Action.

5.3 UNWNRD Model – Climate Scenarios

5.3.1 Overview of the Niobrara Drainage Basin Water Balance

Upon completion of the baseline run (Baseline No Action), each of the three climate scenarios was applied to the watershed model. Figures 60-62 provide the sources of and ultimate destination of the total applied water for each of the three climates from the entire Niobrara Drainage Basin upstream of the gauge near Gordon, NE within the UNWNRD model domain.

A general pattern emerged that as precipitation increased, the water available for surface water deliveries increased, and less groundwater pumping was necessary. Furthermore; the basin saw increases in evapotranspiration, recharge, runoff contributions to stream flow from the increased precipitation (Table 16).

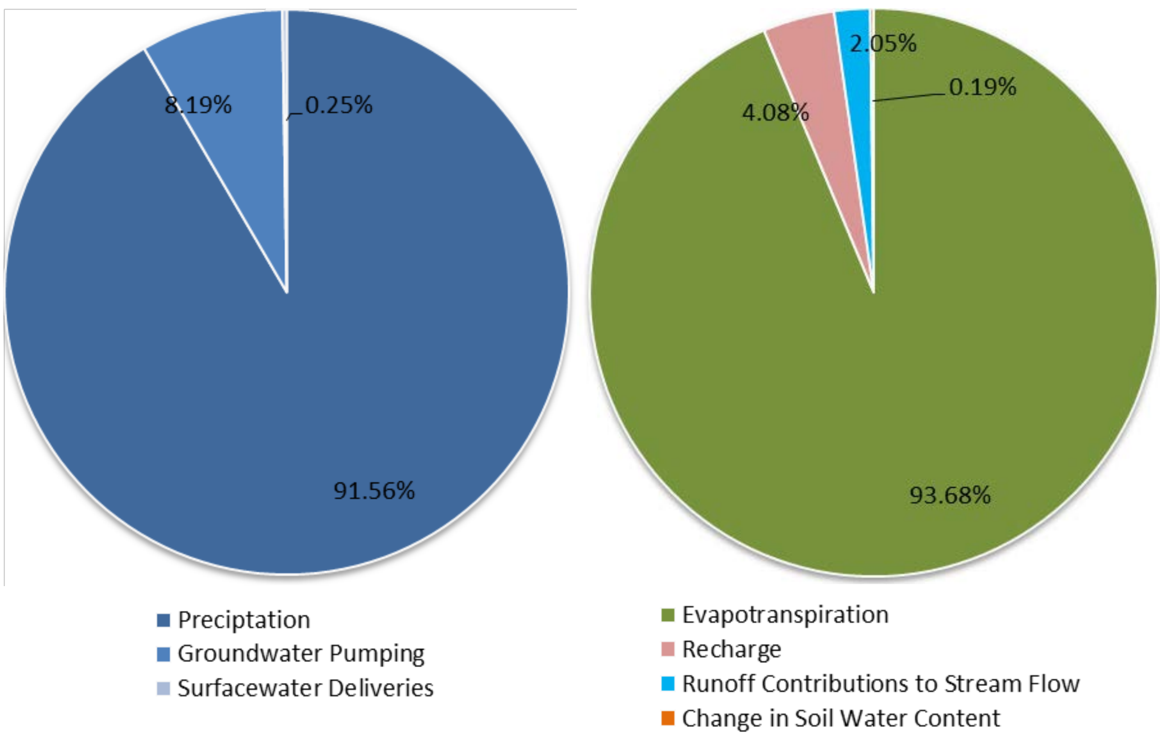


Figure 60. Sources of 14.72 in/ac of total available water and partitioned total available water for the Niobrara Basin within the UNWNRD model; Low No Action.

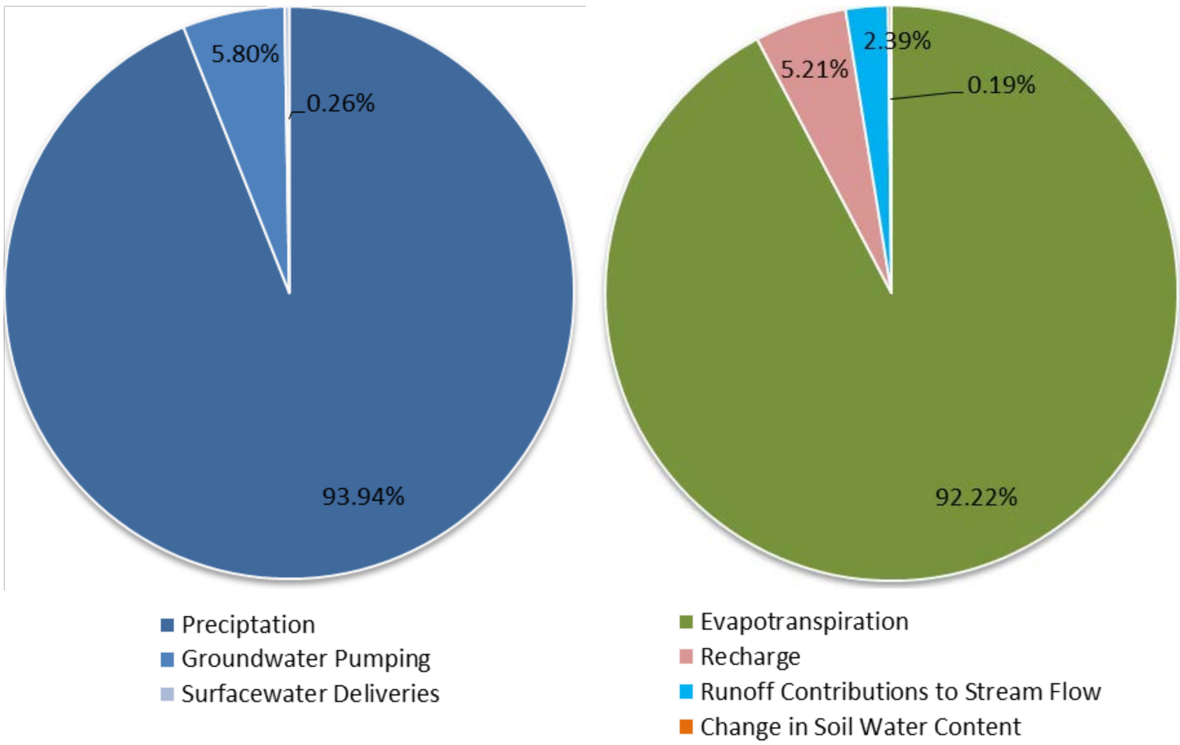


Figure 61. Sources of 18.19 in/ac of total available water and partitioned total available water within the UNWNRD model; CT No Action.

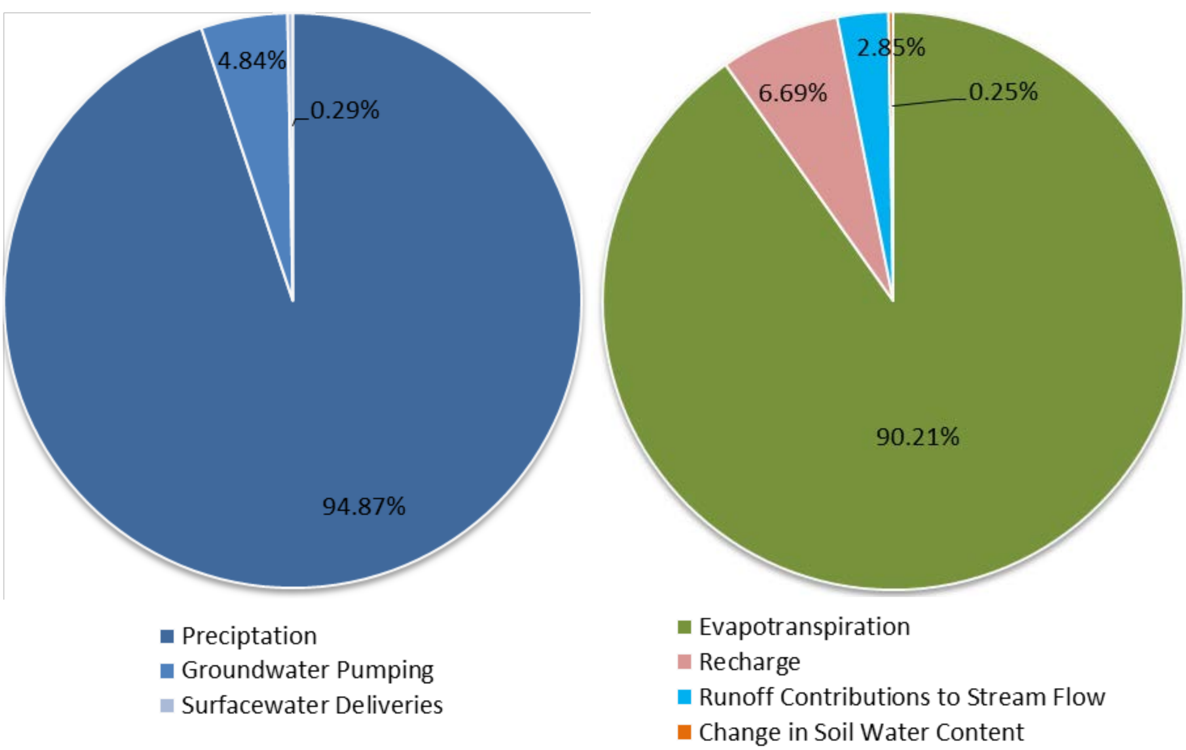


Figure 62. Sources of 20.14 in/ac of total available water and partitioned total available water within the UNWNRD model; High No Action.

Table 16. Average Percent Change in Water Balance Parameters in the Niobrara Drainage Basin within the UNWNRD Model Upstream of the gauge near Gordon, NE; Baseline No Action

Climate Scenario	Precipi-tation	Groundwater Pumping	Surface Water Deliveries	Total Applied Water	ET	Recharge	Runoff Contributions to Streamflow
Climate 1	–16.12%	9.35%	–11.01%	–14.47%	–13.72%	–27.12%	–23.08%
Climate 2	6.35%	–4.35%	17.46%	5.69%	4.96%	15.03%	10.95%
Climate 3	18.89%	–11.50%	42.75%	17.00%	13.66%	63.60%	46.23%

5.3.2 Average Gaps in Surface Water Irrigation Availability

As expected, increases in precipitation improved the ability of the system to meet surface water demands (Table 17). These increases are influenced both by reductions in demand and increases in stream flow (Figures 63-64). An increased in the portion of demand meet by surface water deliveries leads to a reduction in co-mingled pumping (Figure 65).

Table 17. Comparison of the Ability Of The System to Meet the Surface Water Irrigation Demands

Group	Climate Scenario					
	Climate 1		Climate 2		Climate 3	
	Portion of Demands Met by Surface Water	Percent Change from Baseline	Portion of Demands Met by Surface Water	Percent Change from Baseline	Portion of Demands Met by Surface Water	Percent Change from Baseline
Group 1	9.7%	–0.8%	10.6%	0.1%	11.3%	0.8%
Group 2	10.0%	–1.7%	14.3%	2.6%	17.0%	5.3%
Group 3	60.2%	0.0%	62.1%	1.8%	63.5%	3.2%
Group 4	18.7%	–3.4%	27.7%	5.6%	32.7%	10.5%
Group 5	12.9%	–1.0%	18.2%	4.3%	21.5%	7.6%
Group 6	32.4%	–0.9%	41.2%	7.9%	45.0%	11.8%
Group 7	31.0%	–1.0%	39.1%	7.2%	42.8%	10.9%
Group 8	11.6%	–8.0%	23.3%	3.7%	35.0%	15.4%
Group 9	18.2%	–7.3%	31.9%	6.4%	45.6%	20.0%
Group 10	48.3%	–1.6%	50.6%	0.7%	53.0%	3.1%
Group 11	63.3%	–2.8%	66.3%	0.2%	68.6%	2.6%
Group 12	63.5%	–2.7%	66.5%	0.3%	68.9%	2.6%
Group 13	63.7%	–2.4%	66.7%	0.5%	69.0%	2.9%
Group 14	48.8%	–1.5%	50.3%	0.1%	52.6%	2.4%
Total Basin	20.8%	–5.3%	31.3%	5.3%	40.8%	14.7%

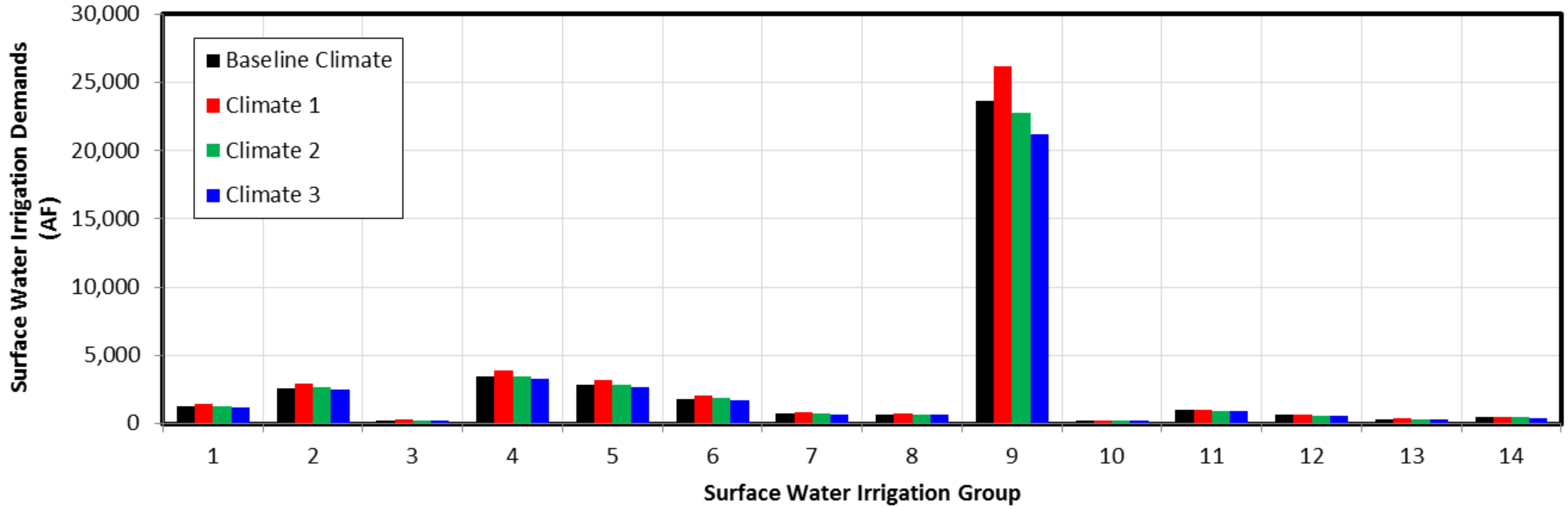


Figure 63. Average annual surface water demands under each climate scenario in the UNWNRD model.

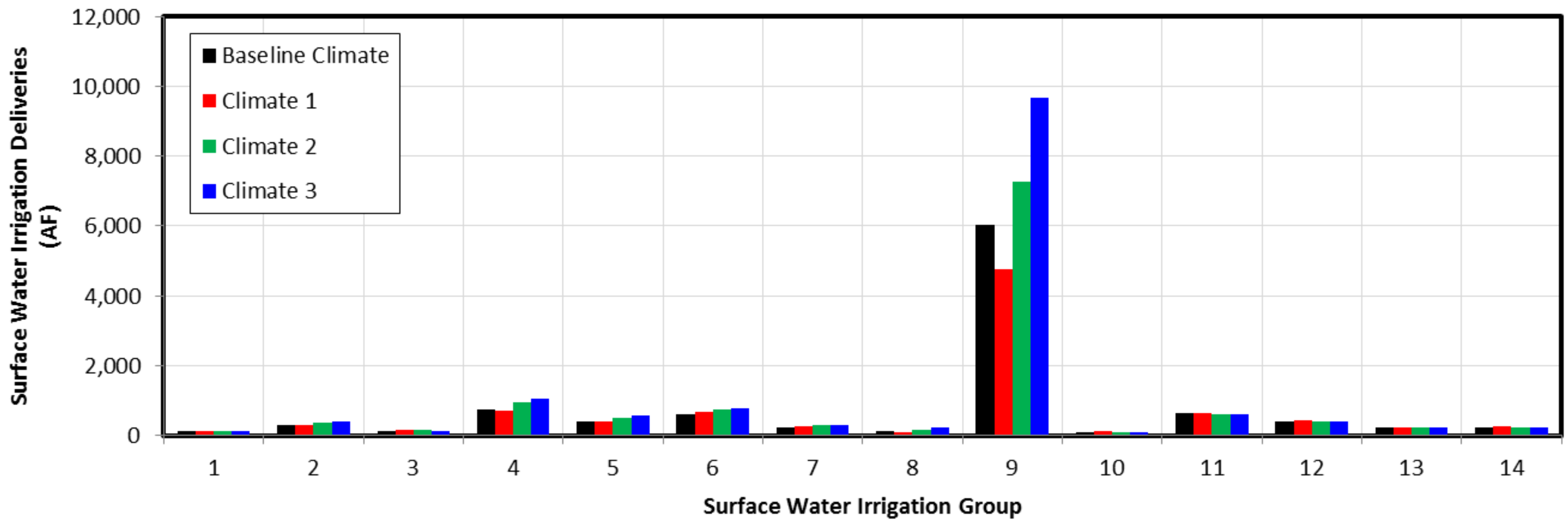


Figure 64. Average annual surface water deliveries under each climate scenario in the UNWNRD model.

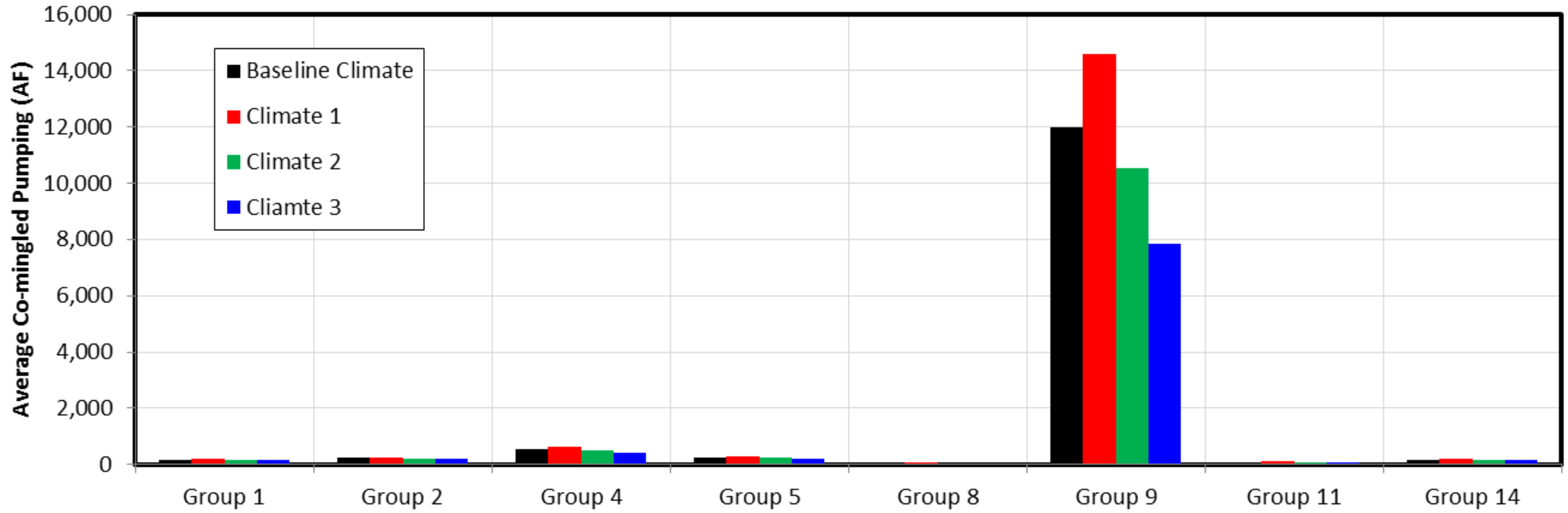


Figure 65. Average supplemental co-mingled pumping under each climate scenario in the UNWNRD model.

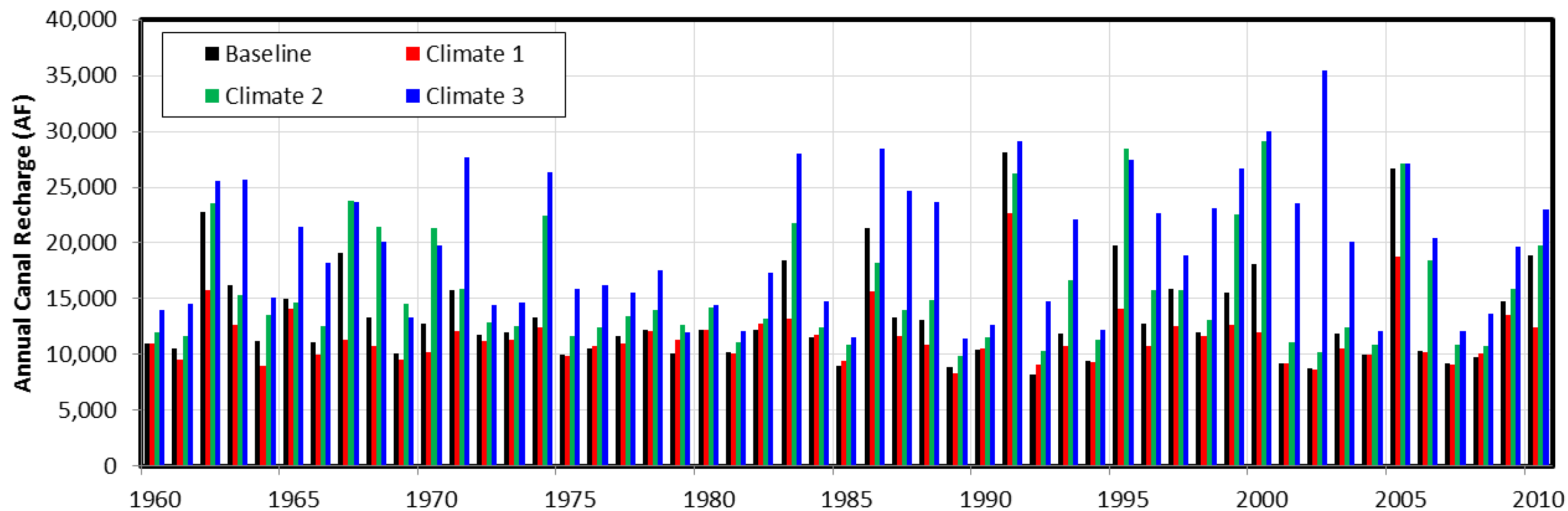


Figure 66. Annual canal recharge under the various climate scenarios.

5.3.3 Average Annual Recharge

Canal recharge in the UNW NRD model varied with the volume of surface water that the system was able to deliver to the surface water irrigated lands. Figure 66 depicts the annual canal recharge totals for the entire basin under the different climate scenarios.

The average annual recharge rates shown in Figure 67 for climate scenario 1 (Alt 2 Low) generally fall below the recharge rates in the baseline climate (Baseline No Action) (Figure 23) as illustrate in Figure 68. The same general pattern exists within both climates; where irrigated land, sandy soils, and canal recharge are present, the recharge rates tend to be relatively higher.

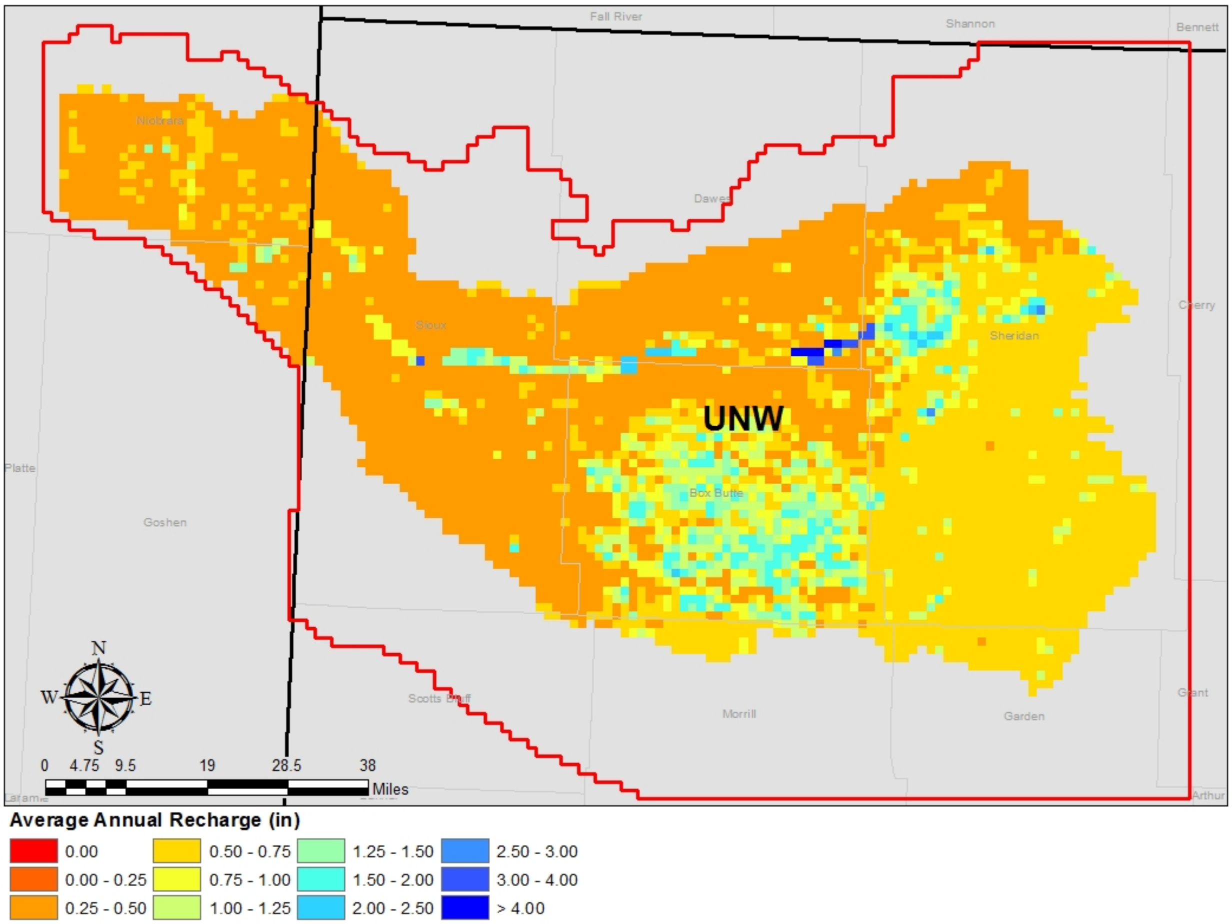


Figure 67. Average annual recharge in the UNWNRD model; Alt 2 Low.

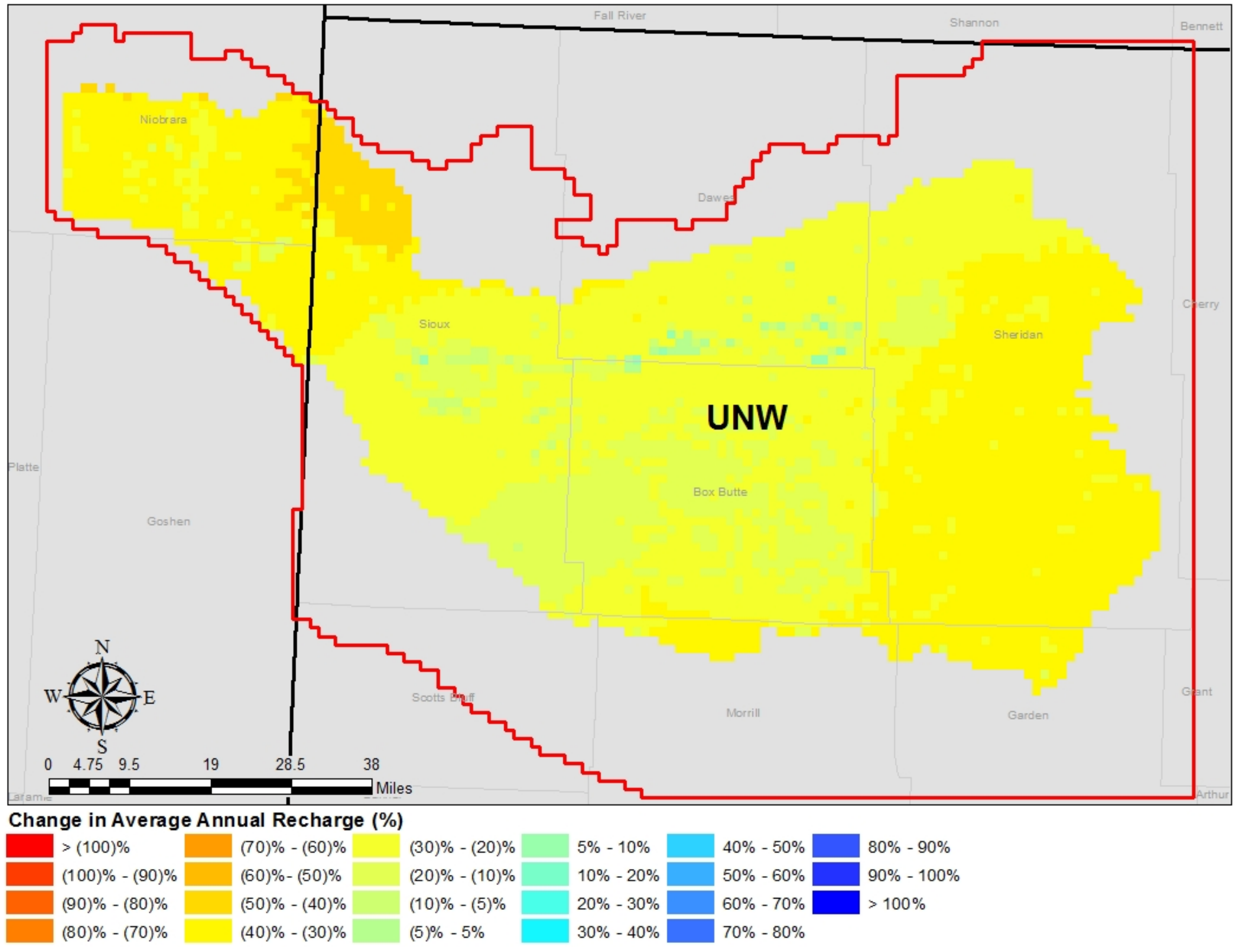


Figure 68. Percent change in average annual recharge within the UNWNRD model; Alt 2 Low and Baseline No Action.

Figure 69 shows the average annual recharge rates for the UNWNRD model under climate scenario 2 (Alt 2 CT). Across the model domain, recharge rates generally experienced a moderate increase (Figure 70) when compared to the baseline climate (Baseline No Action) (Figure 23). The same general pattern exists within both climates; where irrigated land, sandy soils, and canal recharge are present, the recharge rates tend to be relatively higher.

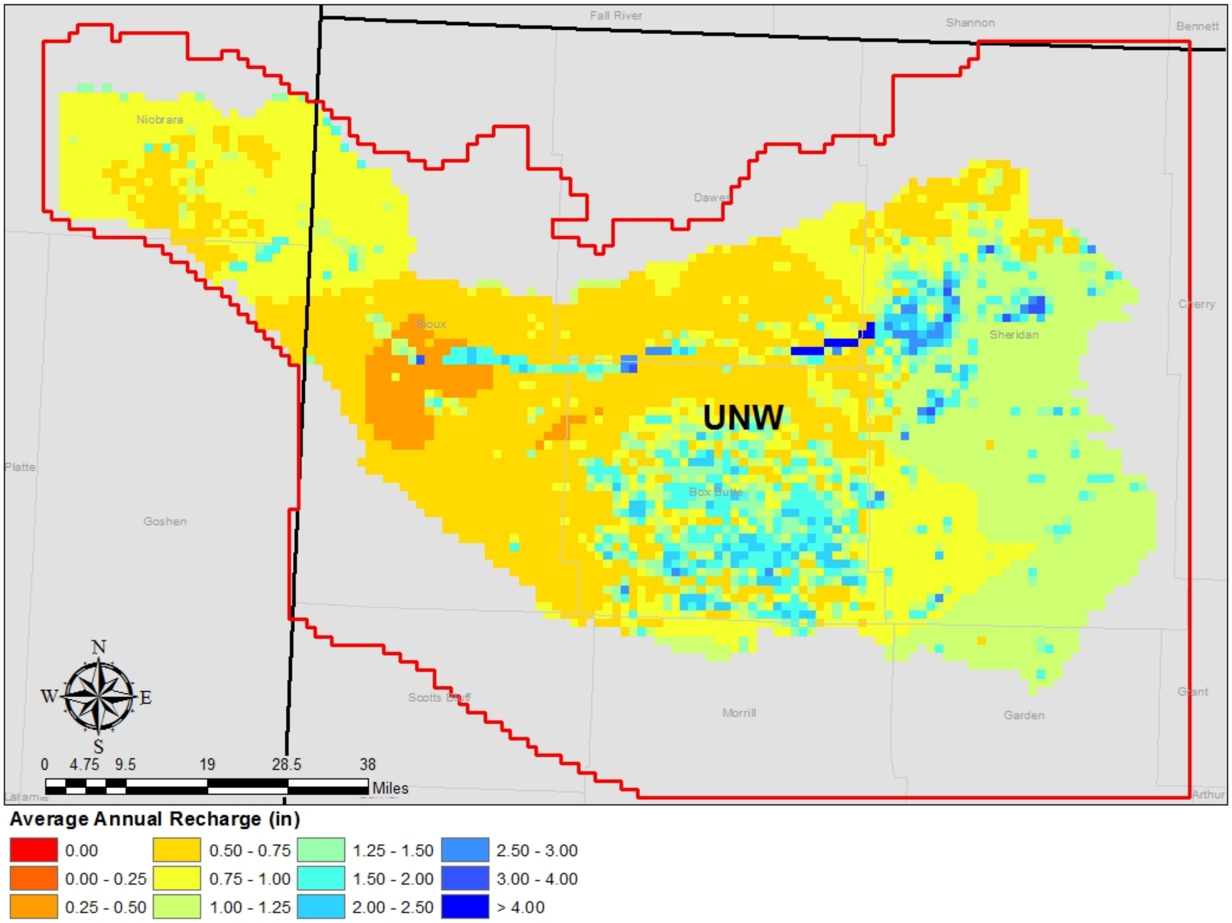


Figure 69. Average annual recharge in the UNWNRD model; Alt 2 CT.

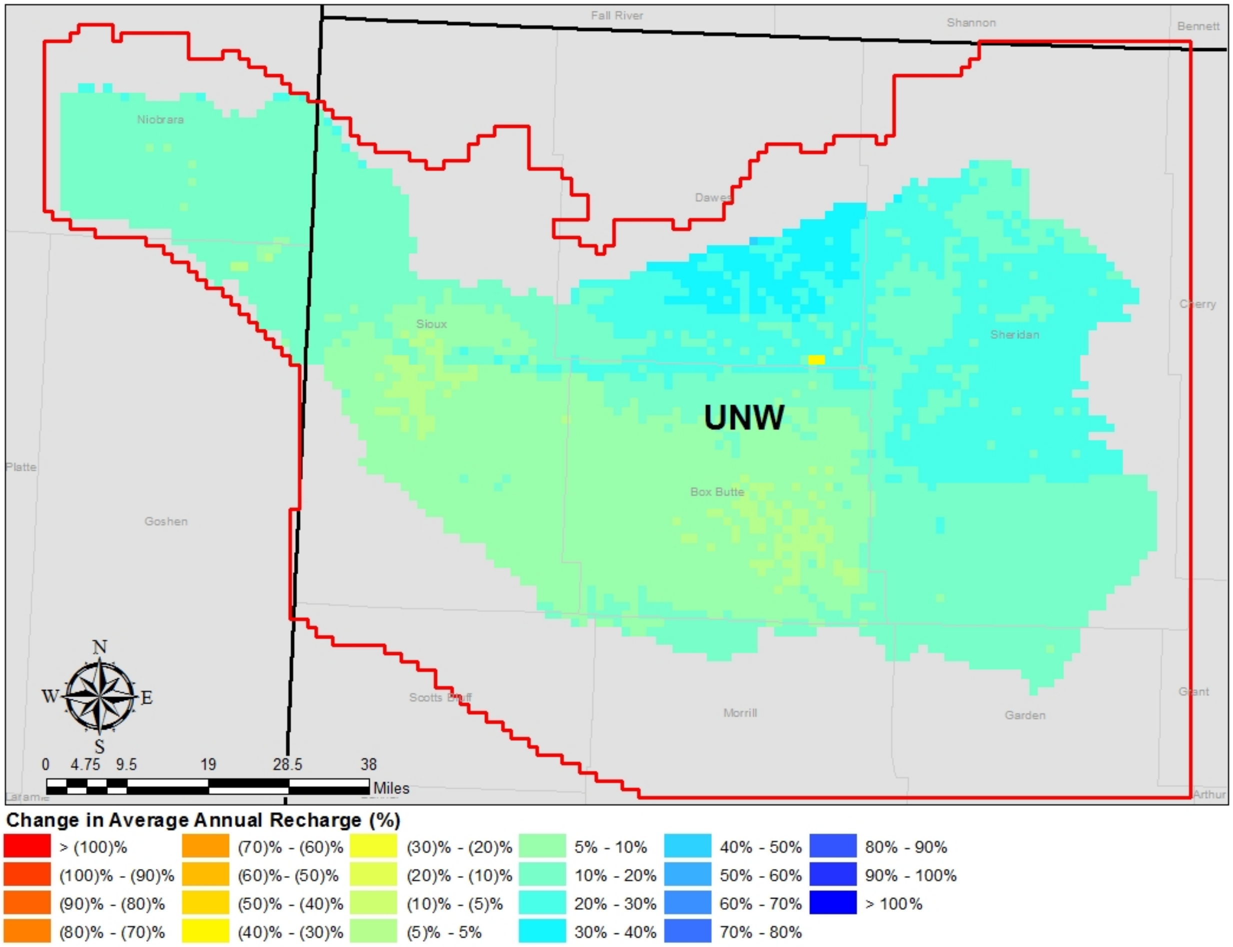


Figure 70. Percent change in average annual recharge within the UNWNRD model; Alt 2 CT and Baseline No Action.

The influence of the wetter climate on average recharge rates is readily visible in Figures 71-72, both in absolute terms and as a change from the baseline climate (Baseline No Action). However, the same general pattern exists with respect the spatial distribution of the recharge; with relatively larger recharge rate occurring around irrigated lands, sandy soils, and surface water irrigation canals.

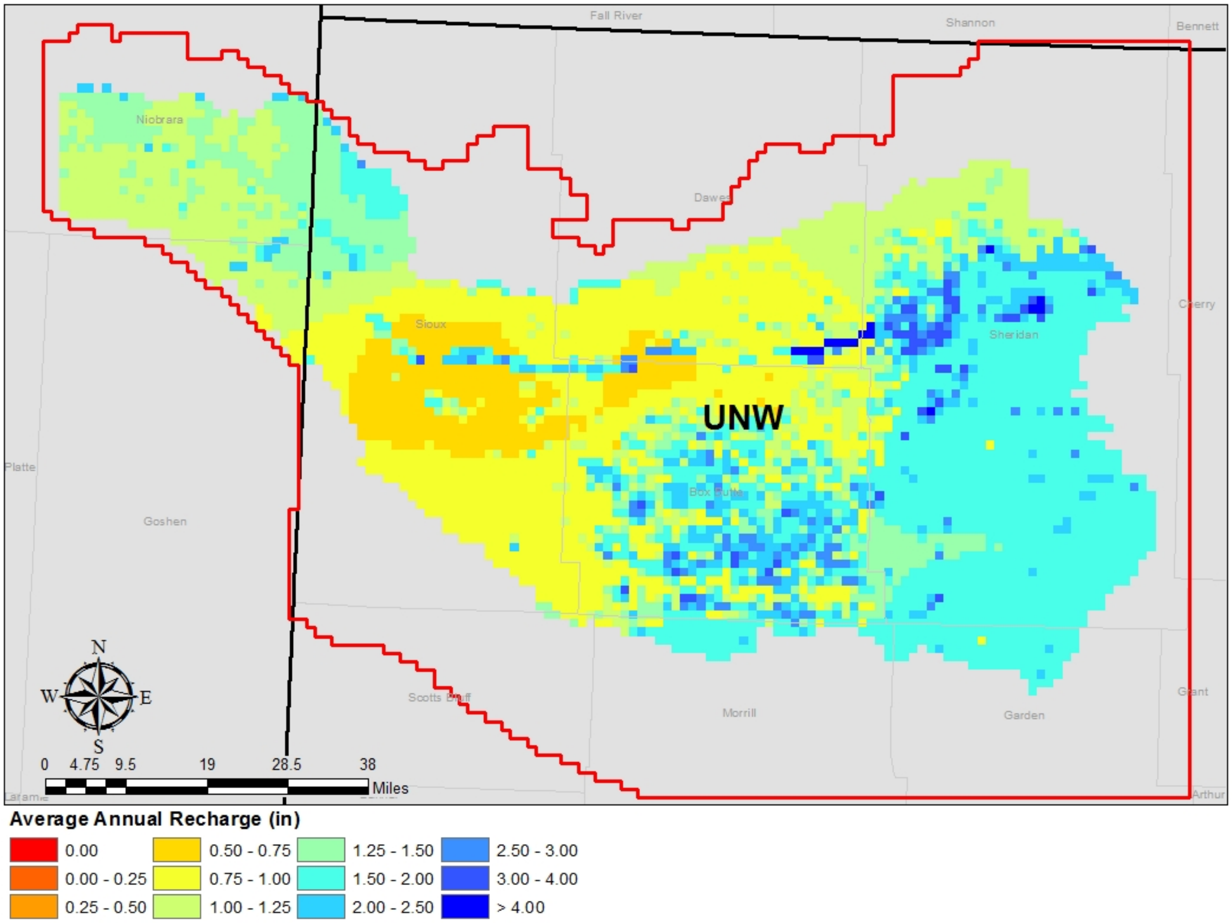


Figure 71. Average annual recharge in the UNWNRD model; Alt 2 High.

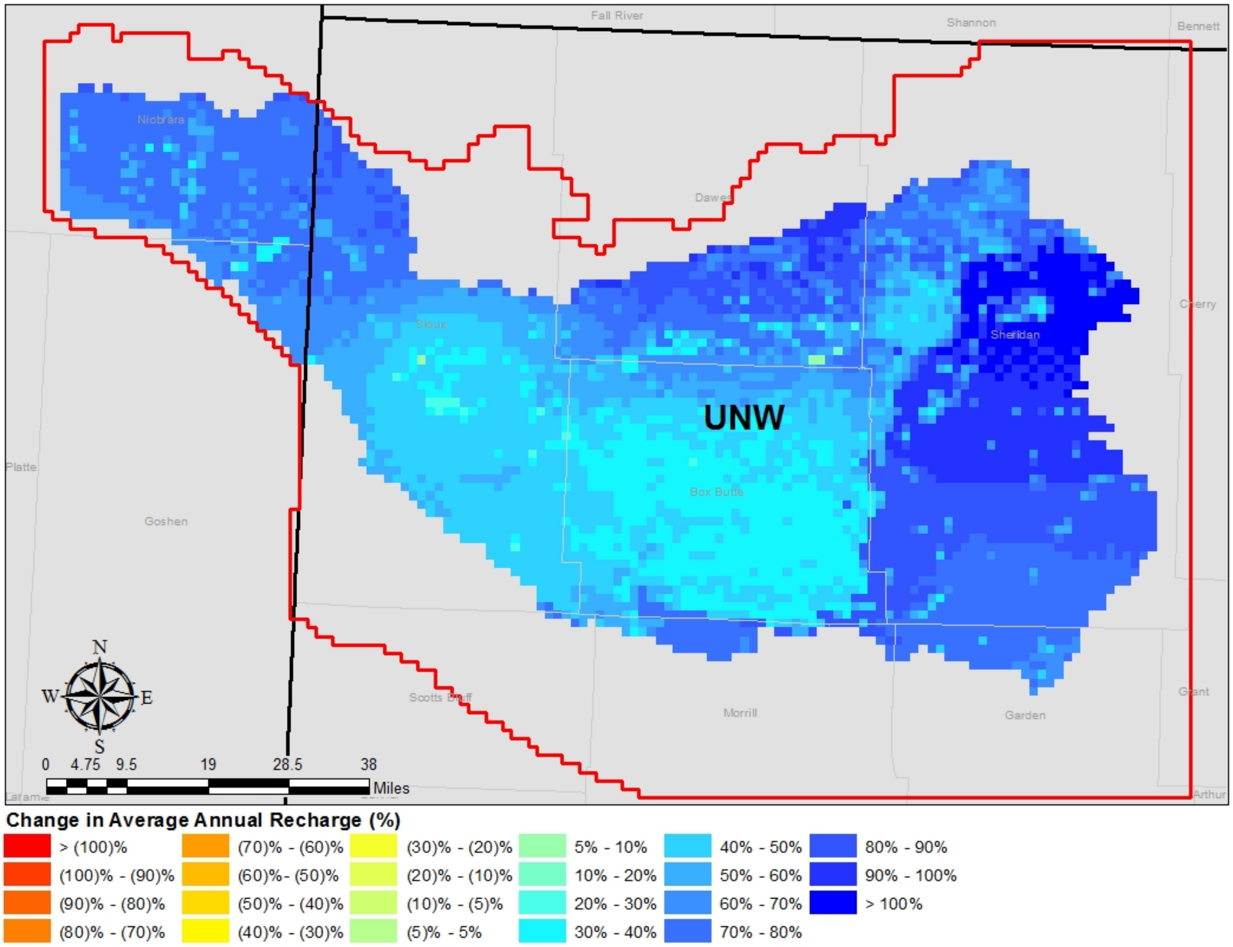


Figure 72. Percent change in average annual recharge within the UNWNRD model; Alt 2 High and Baseline No Action.

5.3.4 Runoff Zone 1

Runoff zone 1 showed the same general pattern experienced by the basin as a whole (Figures 73-75). Increases in precipitation led to increases in evapotranspiration, recharge, and runoff contributions to stream flow (Table 18). Due to the technique used to model land use in runoff zone 1, there was no change in groundwater pumping or surface water deliveries.

Table 18. Average Percent Change in Water Balance Parameters in Runoff Zone 1 of the UNWNRD model; Baseline No Action

Climate Scenario	Precipi-tation	Ground-water Pumping	Surface Water Deliveries	Total Applied Water	ET	Recharge	Runoff Contributions to Streamflow
Climate 1	–15.54%	–	–	–15.54%	–14.05%	–35.77%	–29.12%
Climate 2	7.44%	–	–	7.44%	6.66%	16.26%	18.88%
Climate 3	20.42%	–	–	20.42%	16.50%	75.21%	63.29%

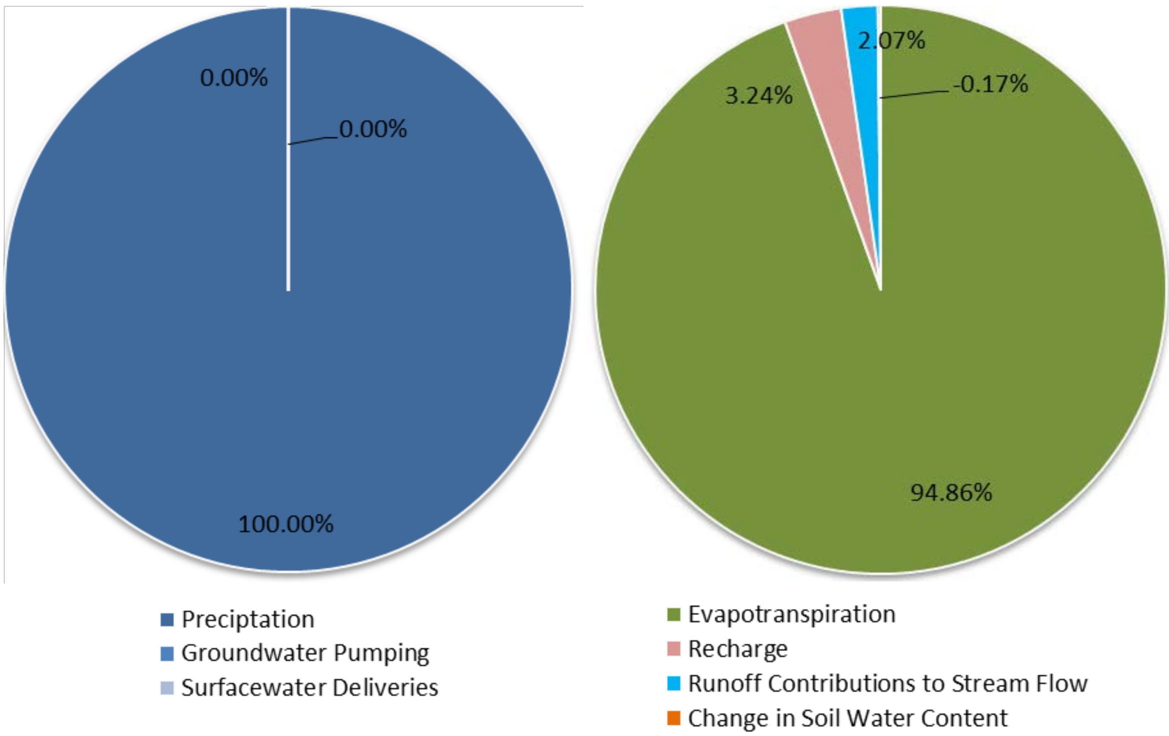


Figure 73. Sources of 13.75 in/ac of total available water and partitioned total available water within runoff zone 1 of the UNWNRD; Low No Action.

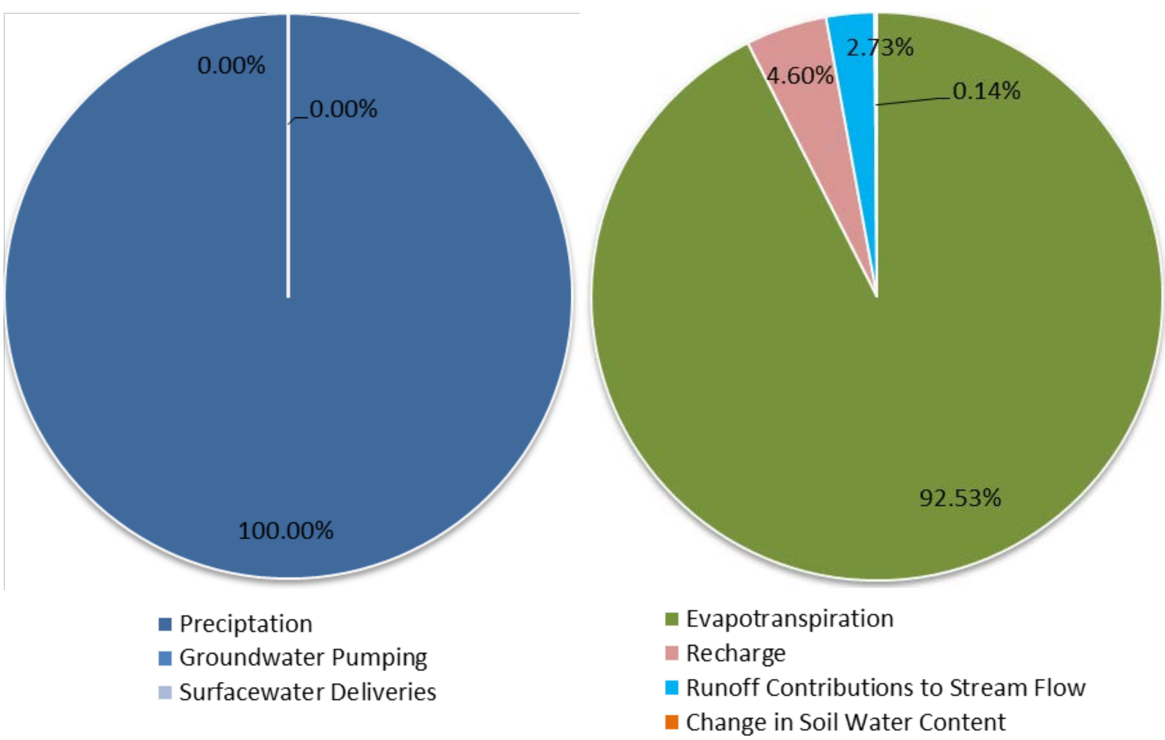


Figure 74. Sources of 17.49 in/ac of total available water and partitioned total available water within runoff zone 1 of the UNWNRD model; CT No Action.

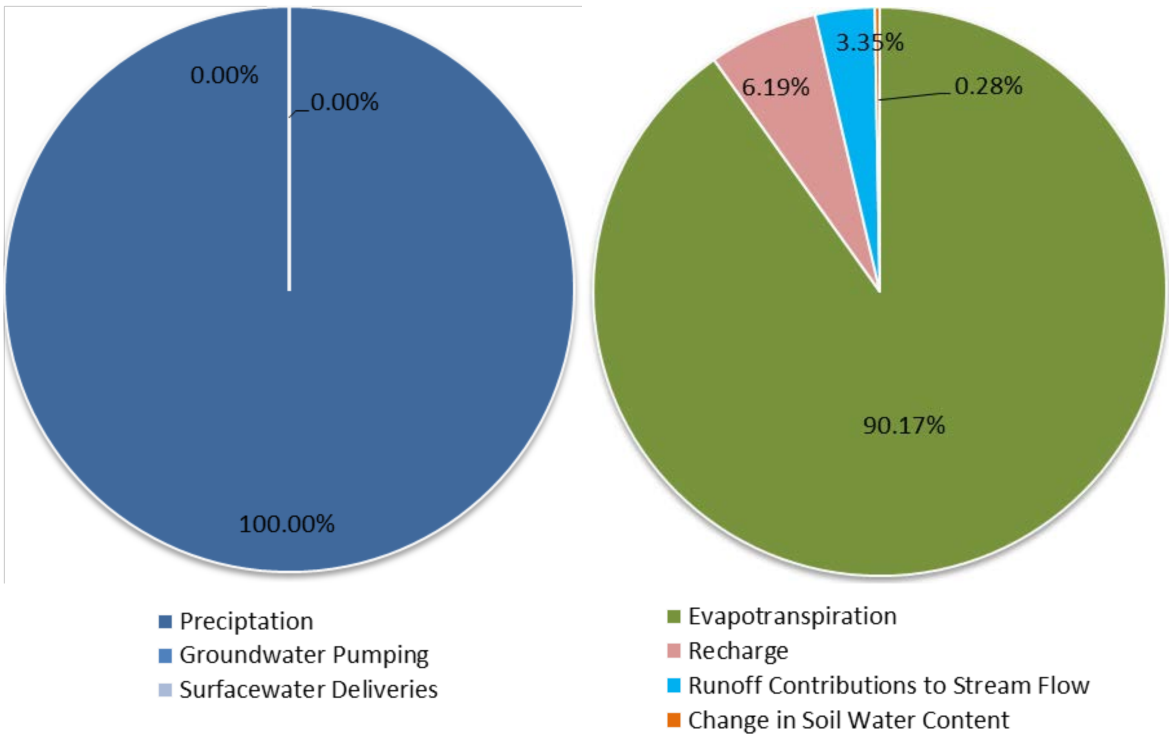


Figure 75. Sources of 19.61 in/ac of total available water and partitioned total available water within runoff zone 1 of the UNWNRD model; High No Action.

5.3.5 Runoff Zone 2

Runoff zone 2 exhibited the same general pattern across the climate scenarios as the basin as whole (Figures 76-78). Increases in precipitation led to reductions in groundwater pumping, as well as increases in evapotranspiration, recharge, and runoff contributions to stream flow (Table 19). One noticeable deviation from the established pattern is the increase in surface water deliveries. This increase was the result of surface water lands not included in the surface water operations model; those which divert from tributaries. These lands were modeled using a virtual delivery system and the assumption that supplies were sufficient to meet demands.

Table 19. Average percent change in water balance parameters in runoff zone 2 of the UNWNRD Model; Baseline No Action

Climate Scenario	Precipi-tation	Ground-water Pumping	Surface Water Deliveries	Total Applied Water	ET	Recharge	Runoff Contributions to Streamflow
Climate 1	–15.50%	12.22%	1.37%	–15.28%	–13.89%	–33.51%	–27.21%
Climate 2	7.07%	0.17%	13.70%	7.03%	6.45%	12.64%	16.24%
Climate 3	20.10%	–6.68%	19.69%	19.91%	16.53%	67.01%	57.24%

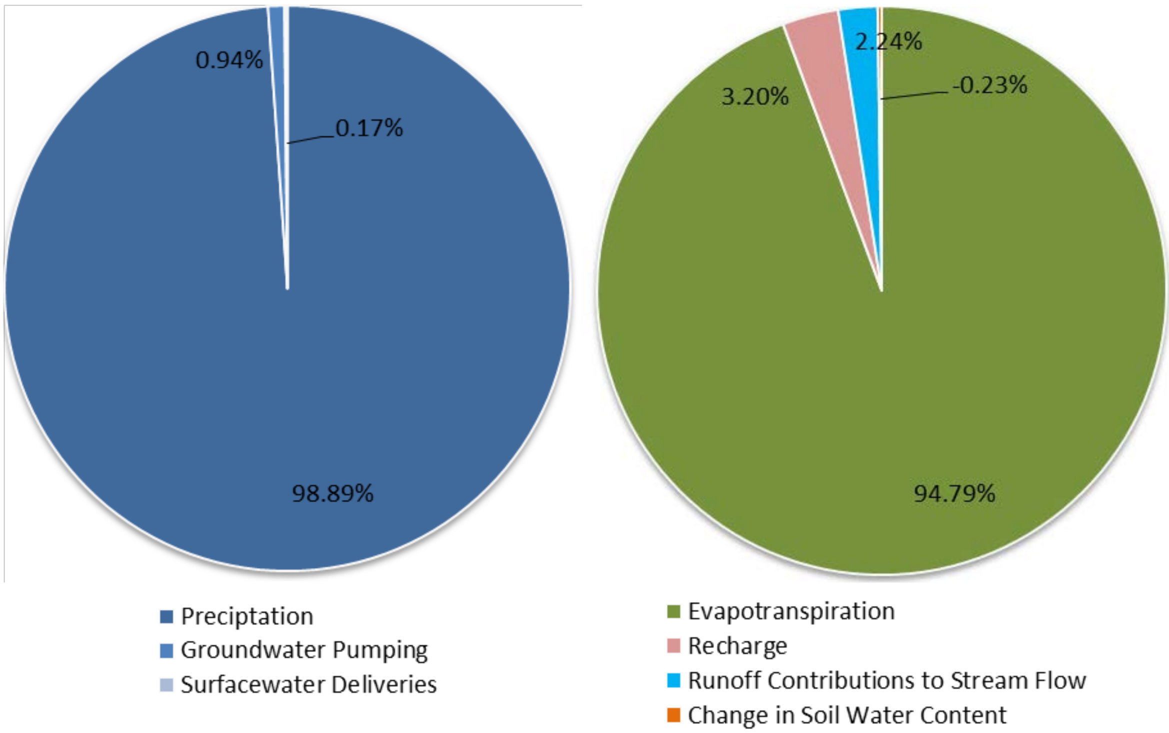


Figure 76. Sources of 13.41 in/ac of total available water and partitioned total available water within runoff zone 2 of the UNWNRD; Low No Action.

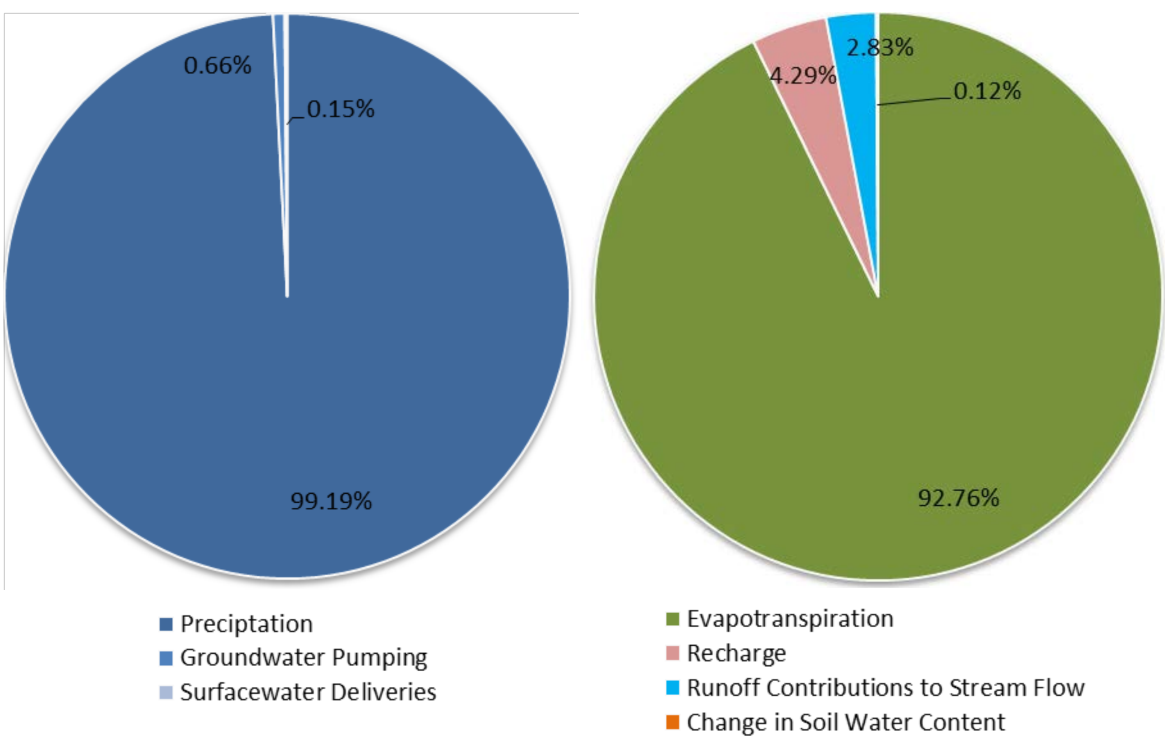


Figure 77. Sources of 16.94 in/ac of total available water and partitioned total available water within runoff zone 2 of the UNWNRD model; CT No Action.

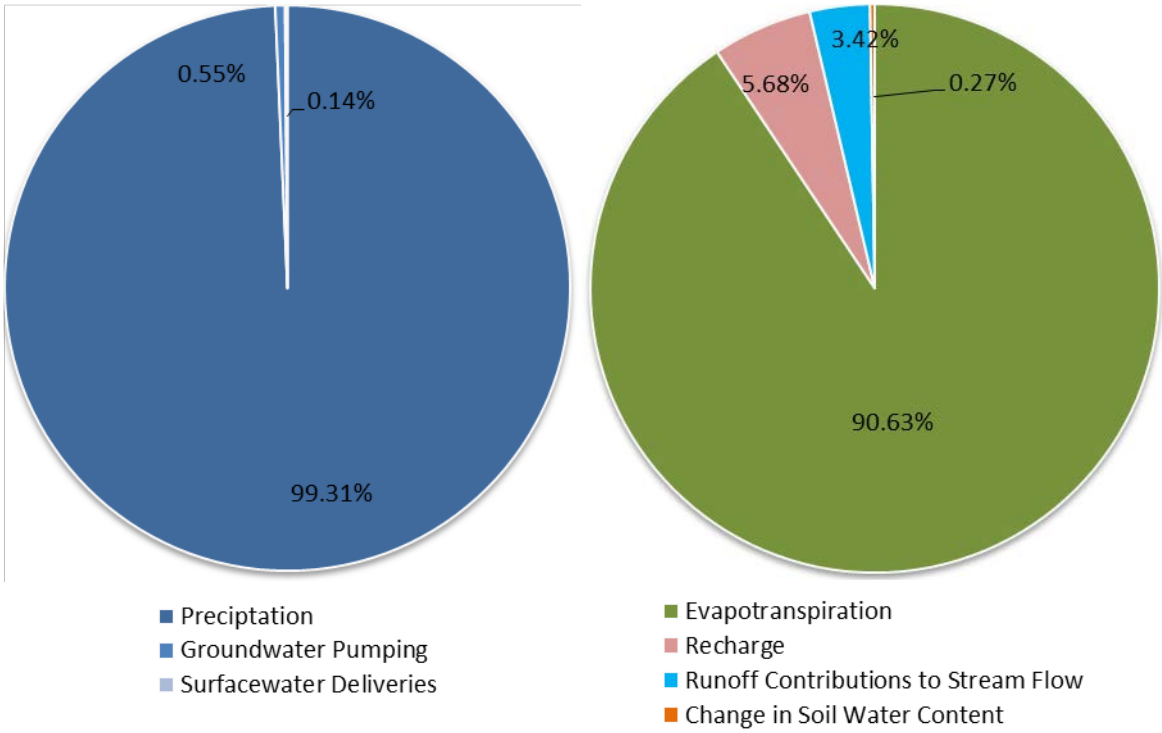


Figure 78. Sources of 18.98 in/ac of total available water and partitioned total available water within runoff zone 2 of the UNWNRD model; High No Action.

5.3.6 Runoff Zone 3

The results within runoff zone 3 show the same general pattern as the basin as whole when compared among the climate scenarios (Figures 79-81). Increases in precipitation led to increases in evapotranspiration, recharge, and runoff contributions to stream flow (Table 20). Runoff zone 3 provides an opportunity to investigate effect of not only the depth but the timing of precipitation events. Despite an increase in precipitation, groundwater pumping also increased. There are many possible reasons for this outcome. The most likely reason is while the precipitation increased 6.78% the effective precipitation[13] remained constant or even decreased. This leads to the precipitation running off the field and water being forced out the bottom of the soil profile; making the precipitation unavailable for crop production.

Table 20. Average Percent Change in Water Balance Parameters in Runoff Zone 3 of the UNWNRD Model; Baseline No Action

Climate Scenario	Precipi-tation	Ground-water Pumping	Surface Water Deliveries	Total Applied Water	ET	Recharge	Runoff Contributions to Streamflow
Climate 1	–15.77%	12.42%	3.05%	–14.97%	–14.22%	–22.68%	–22.84%
Climate 2	6.78%	0.50%	26.76%	6.71%	6.22%	12.19%	14.69%
Climate 3	19.46%	–6.41%	35.12%	18.87%	16.53%	53.60%	48.67%

[13] The portion of precipitation which infiltrates into the soil and remains in the soil for crops' use.

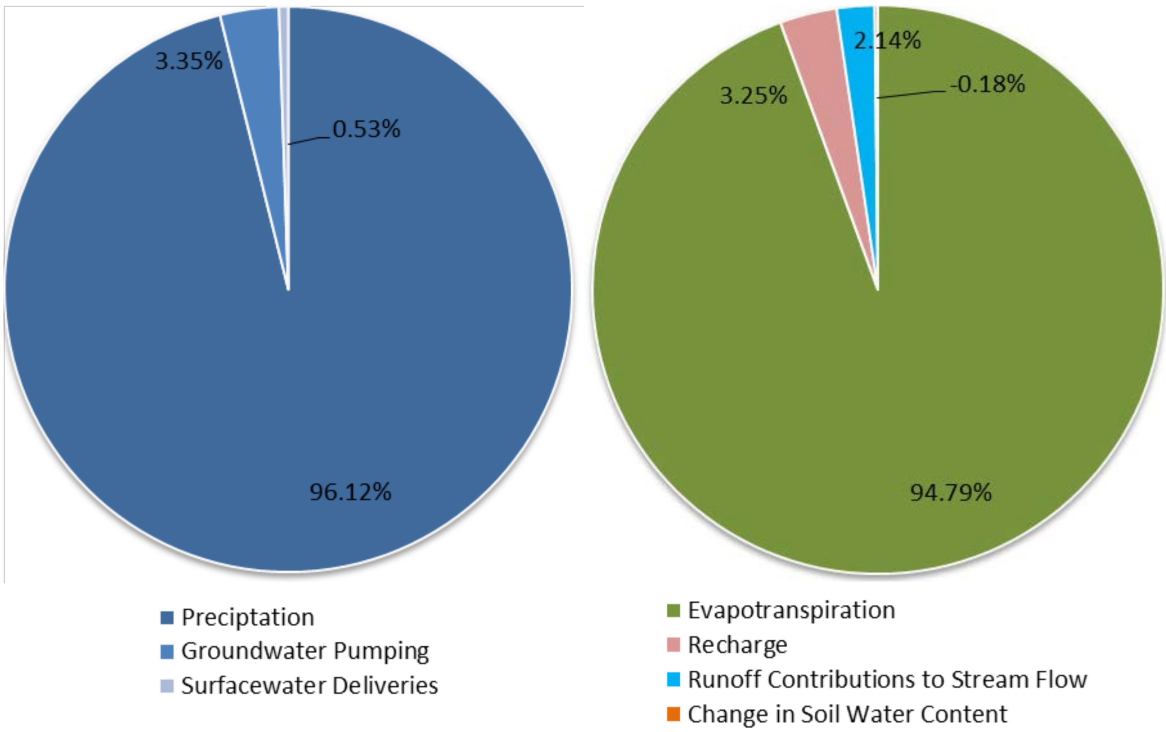


Figure 79. Sources of 13.06 in/ac of total available water and partitioned total available water within runoff zone 3 of the UNWNRD model; Low No Action.

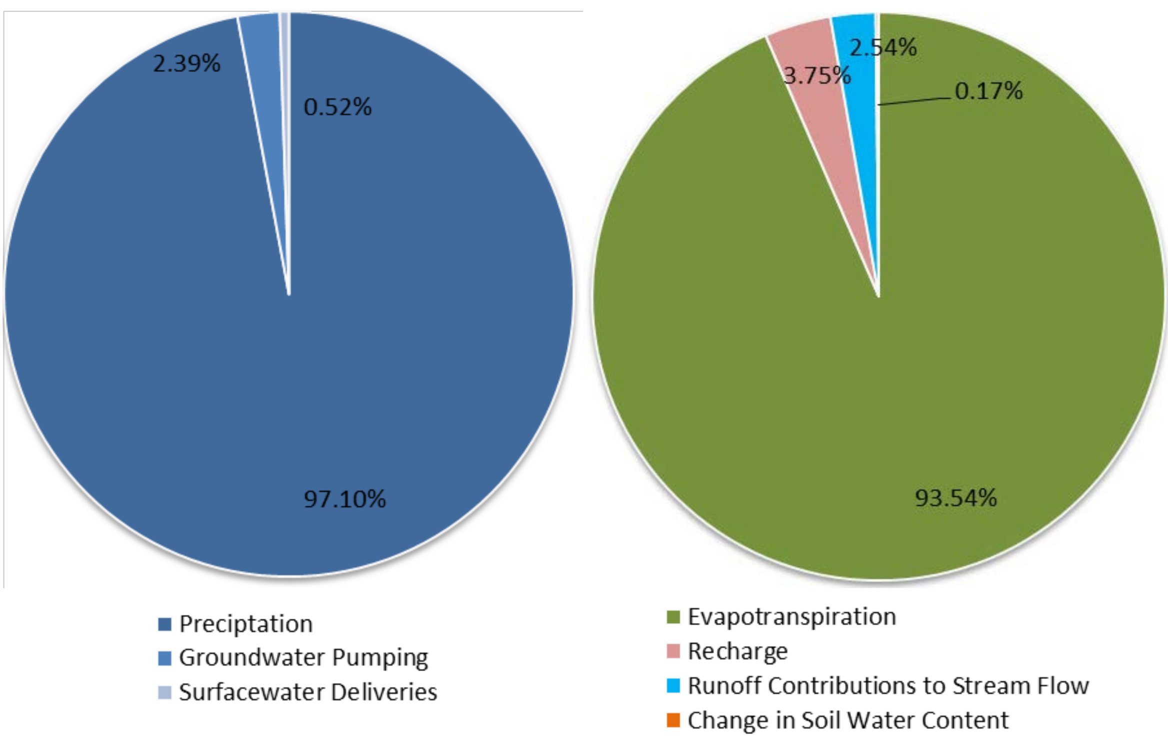


Figure 80. Sources of 16.39 in/ac of total available water and partitioned total available water within runoff zone 3 of the UNWNRD model; CT No Action.

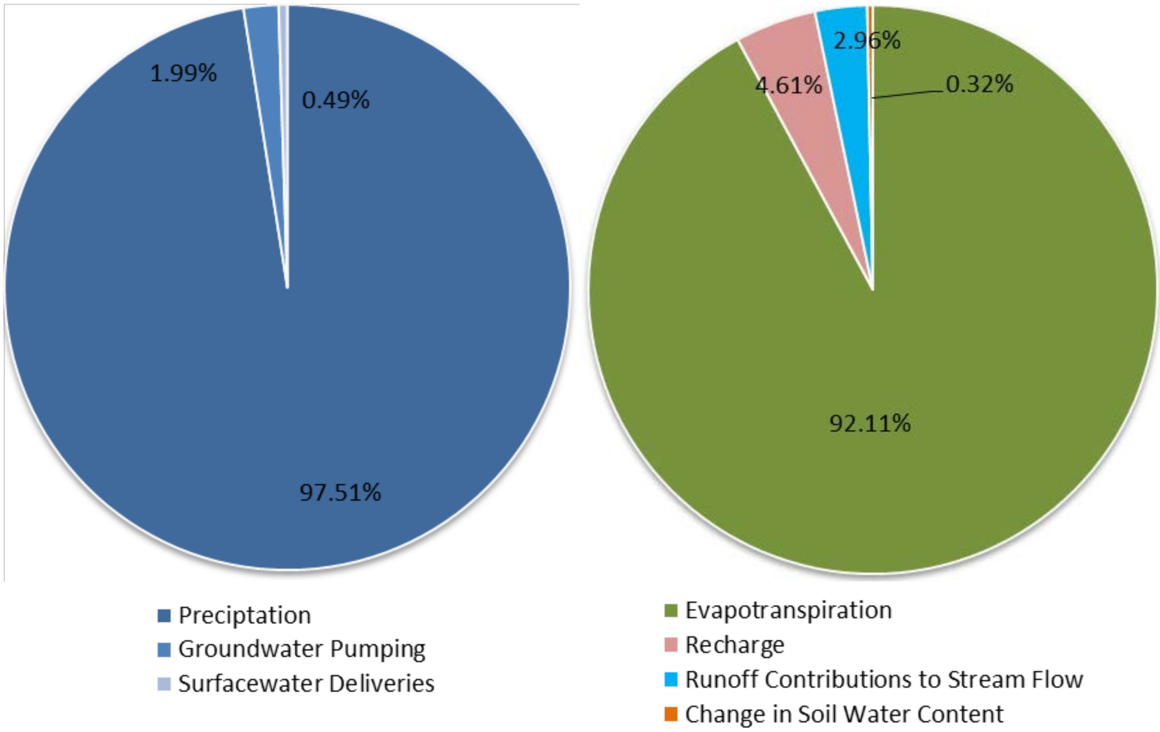


Figure 81. Sources of 18.26 in/ac of total available water and partitioned total available water within runoff zone 3 of the UNWNRD model; High No Action.

5.3.7 Runoff Zone 4

Runoff zone 4's results continue the pattern exhibited by the basin as a whole (Figures 82-84). Increases in precipitation yield more water available for surface water deliveries and reduce the need for groundwater pumping. Additionally, more precipitation leads to greater rates of evapotranspiration, recharge, and runoff contributions to stream flow (Table 21).

Table 21. Average Percent Change in Water Balance Parameters in Runoff Zone 3 of the UNWNRD Model; Baseline No Action

Climate Scenario	Precipi-tation	Ground-water Pumping	Surface Water Deliveries	Total Applied Water	ET	Recharge	Runoff Contributions to Streamflow
Climate 1	–16.47%	13.56%	–16.14%	–14.58%	–14.54%	–20.39%	–22.08%
Climate 2	7.21%	–1.67%	16.64%	6.69%	5.63%	22.06%	13.73%
Climate 3	19.28%	–10.26%	47.80%	17.53%	14.54%	62.97%	46.43%

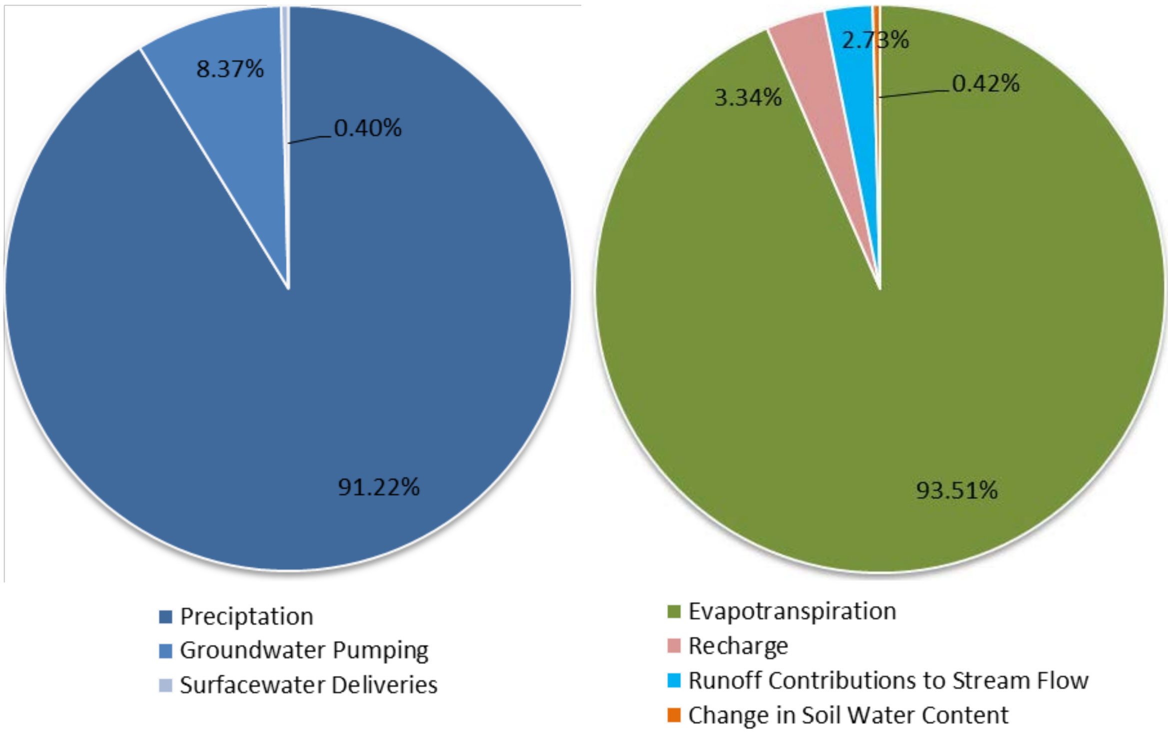


Figure 82. Sources of 14.67 in/ac of total available water and partitioned total available water within runoff zone 4 of the UNWNRD model; Low No Action.

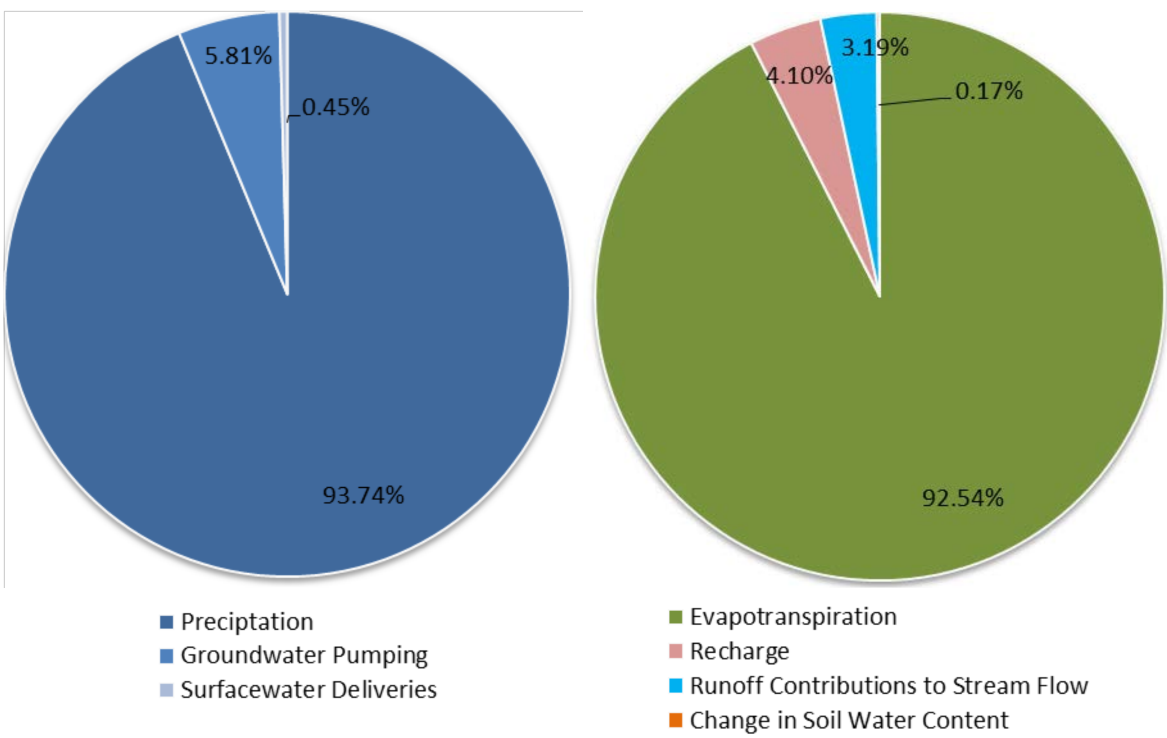


Figure 83. Sources of 18.33 in/ac of total available water and partitioned total available water within runoff zone 4 of the UNWNRD model; CT No Action.

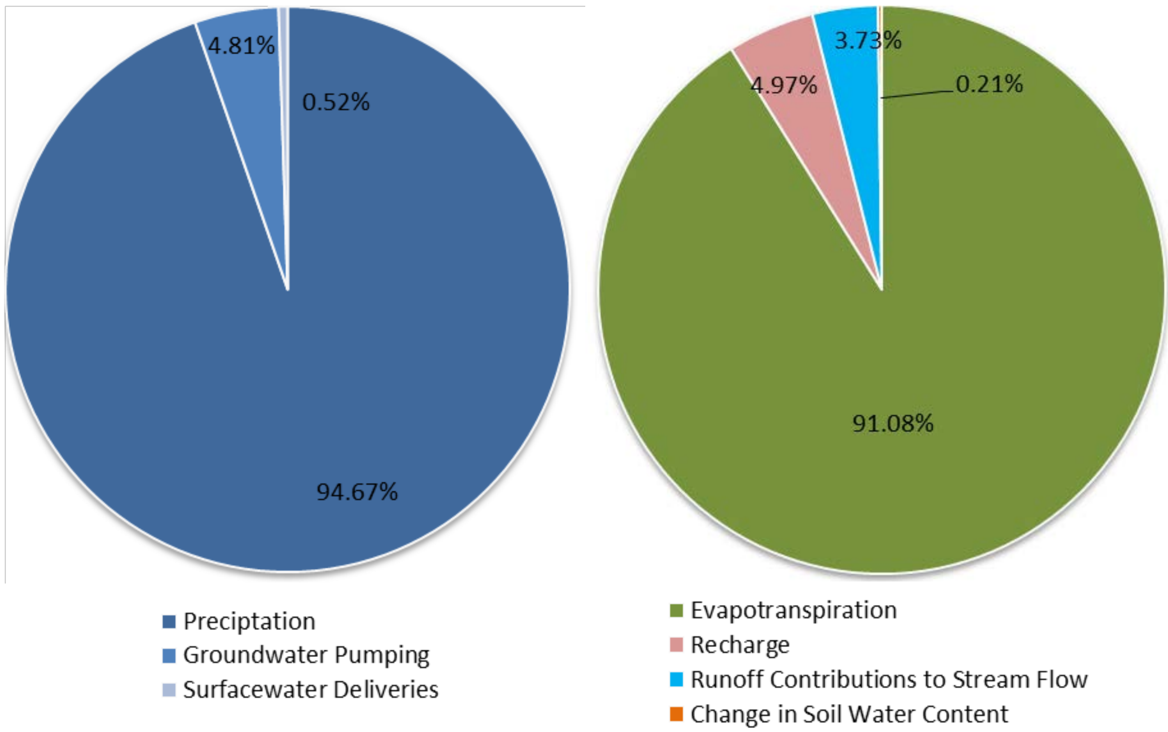


Figure 84. Sources of 20.19 in/ac of total available water and partitioned total available water within runoff zone 4 of the UNWNRD model; High No Action.

5.3.8 Runoff Zone 5

Within runoff zone 5, the results continue to exhibit the pattern of the basin as a whole (Figures 85-87). Increases in precipitation increase available surface water and decrease the need for groundwater pumping. Furthermore, they lead to increases in evapotranspiration, recharge, and runoff contributions to stream flow (Table 22).

Table 22. Average Percent Change in Water Balance Parameters in Runoff Zone 3 of the UNWNRD Model; Baseline No Action

Climate Scenario	Precipi-tation	Ground-water Pumping	Surface Water Deliveries	Total Applied Water	ET	Recharge	Runoff Contributions to Streamflow
Climate 1	–16.33%	8.74%	–15.31%	–14.08%	–13.43%	–26.42%	–21.38%
Climate 2	5.83%	–4.91%	15.06%	4.89%	4.13%	14.80%	7.10%
Climate 3	18.25%	–11.93%	46.04%	15.60%	12.14%	62.91%	40.20%

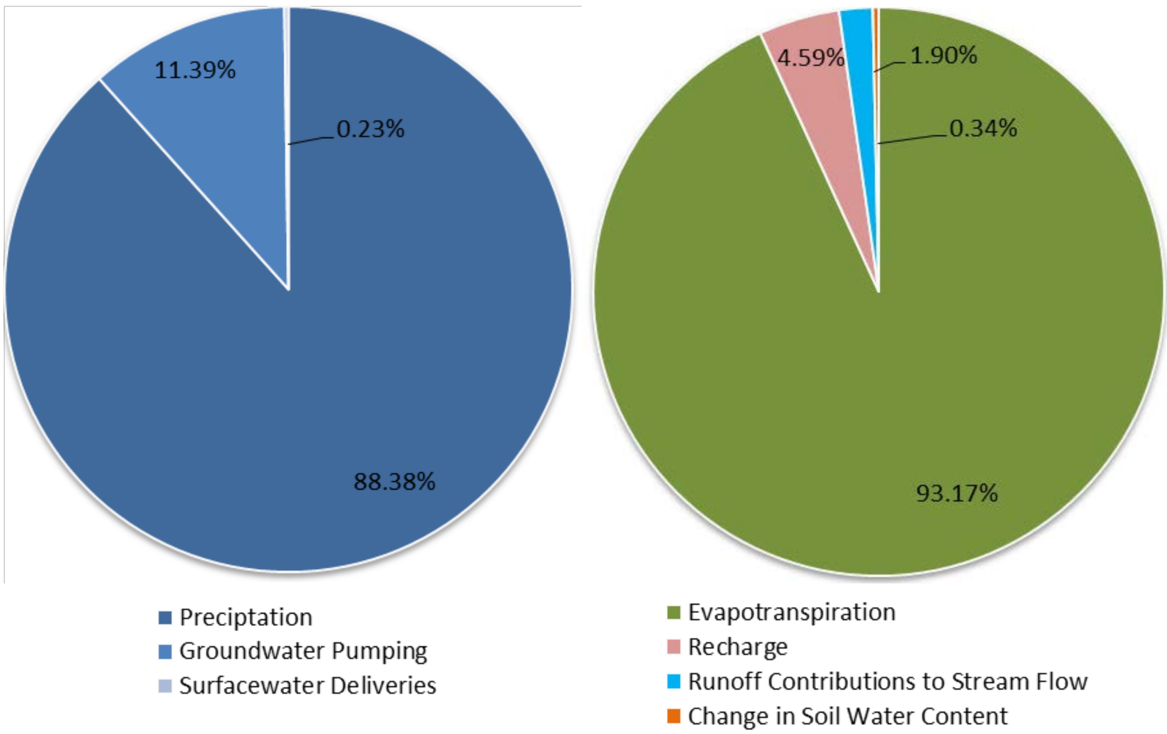


Figure 85. Sources of 15.46 in/ac of total available water and partitioned total available water within runoff zone 5 of the UNWNRD model; Low No Action.

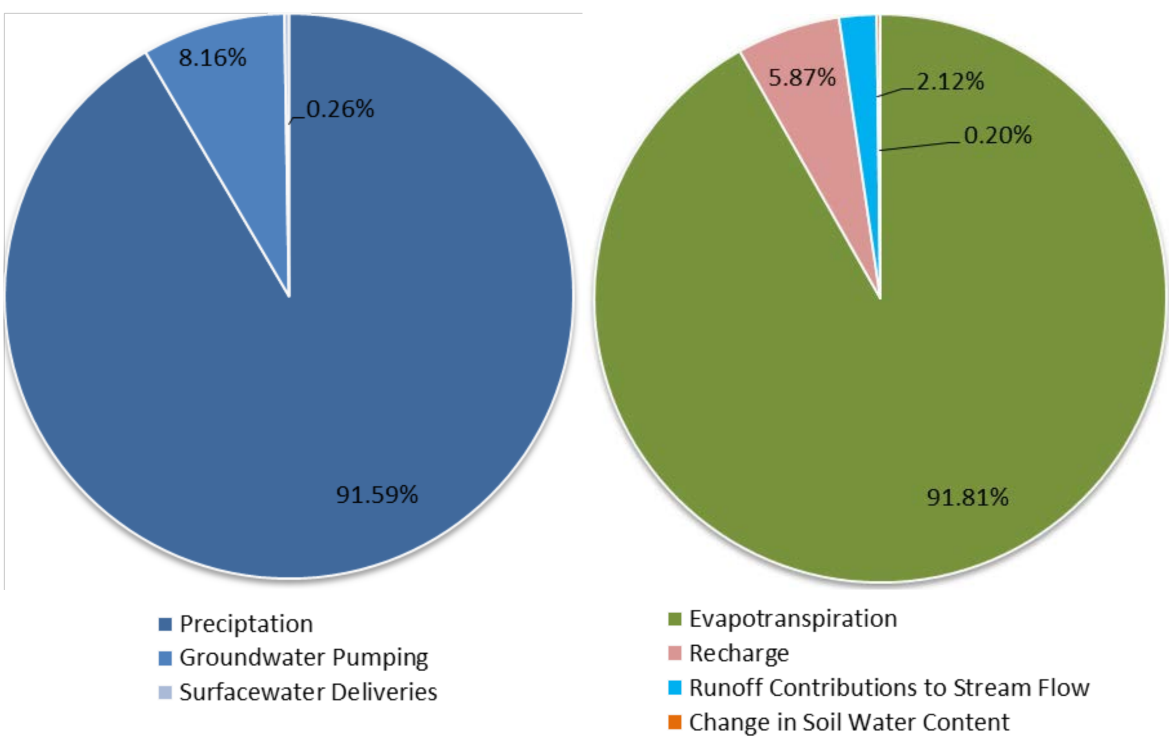


Figure 86. Sources of 18.88 in/ac of total available water and partitioned total available water within runoff zone 5 of the UNWNRD model; CT No Action.

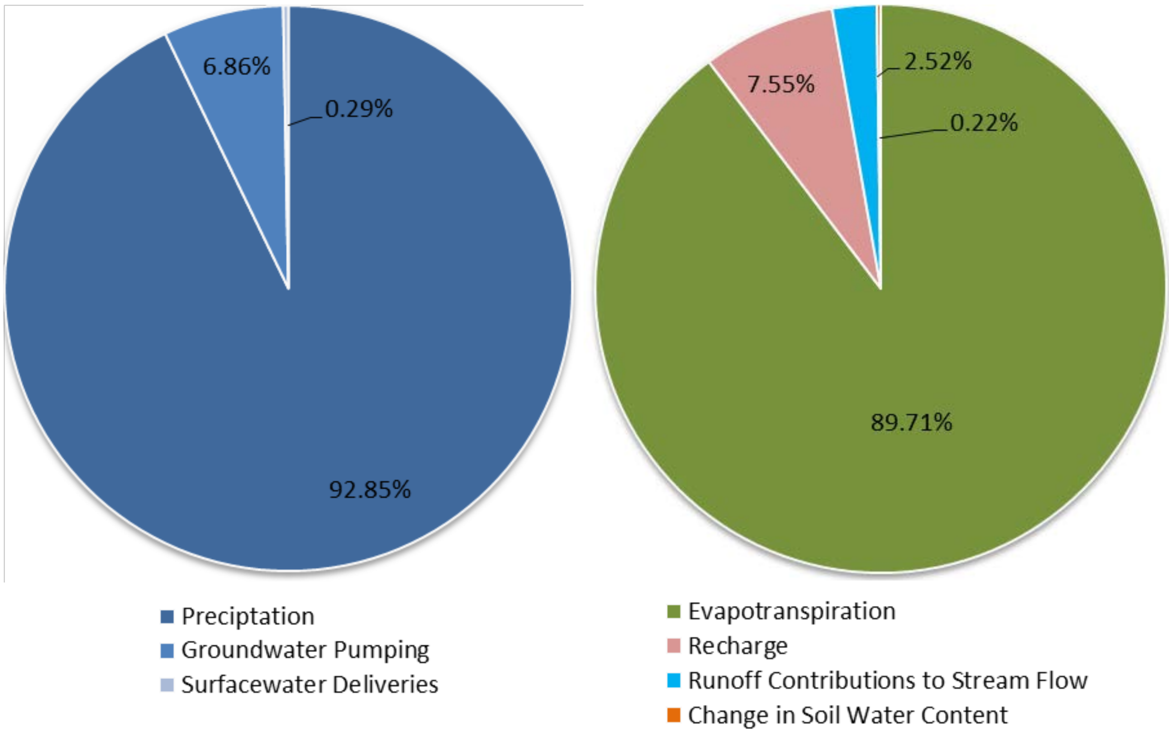


Figure 87. Sources of 20.80 in/ac of total available water and partitioned total available water within runoff zone 5 of the UNWNRD model; High No Action.

5.3.9 Gaps in Surface Water Irrigation Group's Water Availability

Irrigation water is a vital tool for agricultural producers in the Niobrara Basin to improve crop production and their economic viability. There are two sources of irrigation water available; surface water and groundwater. Surface water is diverted from the Niobrara River. Unfortunately, there is insufficient available water in the Niobrara River to meet crop demands. This has led many irrigators to supplement their irrigation with groundwater pumping on co-mingled lands. Figures 88-123 depict the deficit of surface water irrigation and how irrigators respond to the deficit with co-mingled pumping.

Generally speaking, irrigation demands decreased as the climate conditions got wetter. The wetter climates also contained more surface water for diverting for irrigation. These two items combined to reduce the supplemental co-mingled pumping. That being said, the timing of precipitation influences the crop demands. This is illustrated when for example in (Figure 89) 1986 for surface water irrigation group 1 in which the demand in climate scenario 2 exceeded the demand in climate scenario 1. While there was more precipitation, the timing of the precipitation and conditions with which it fell resulted in less effective precipitation, thus a higher demand for irrigation. Whereas, the surface water deliveries show the volume of water the system can deliver, which were developed within the surface water operations model.

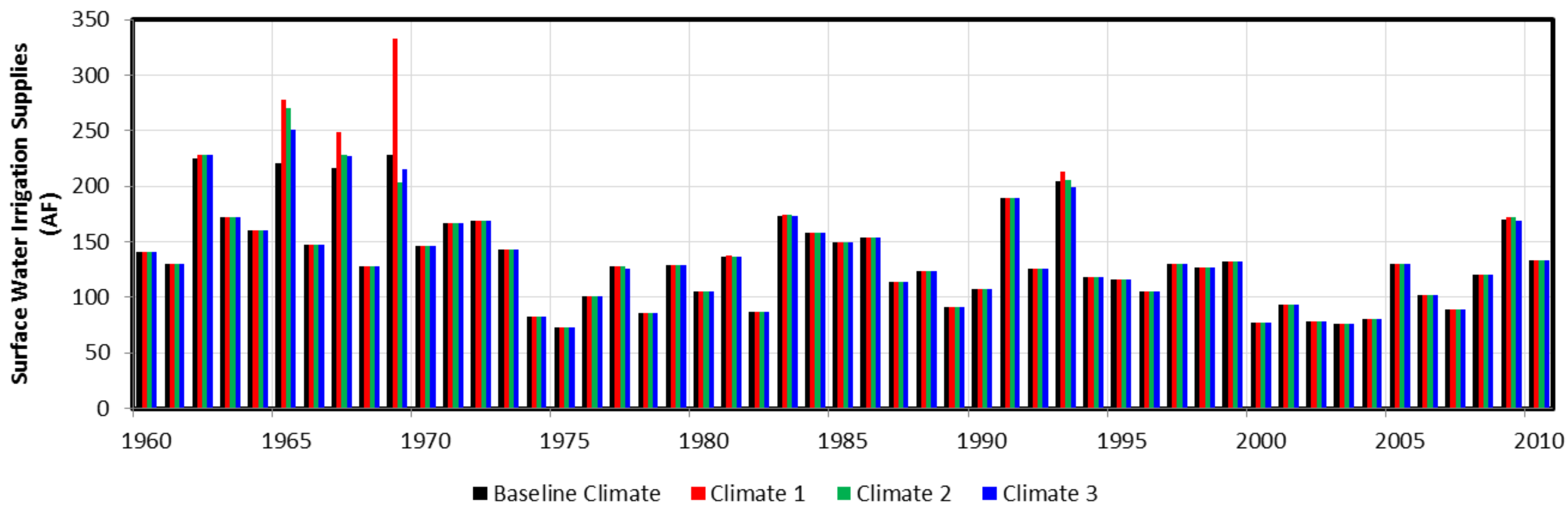


Figure 88. Comparison of surface water deliveries for surface water irrigation group 1 under the various climate scenarios.

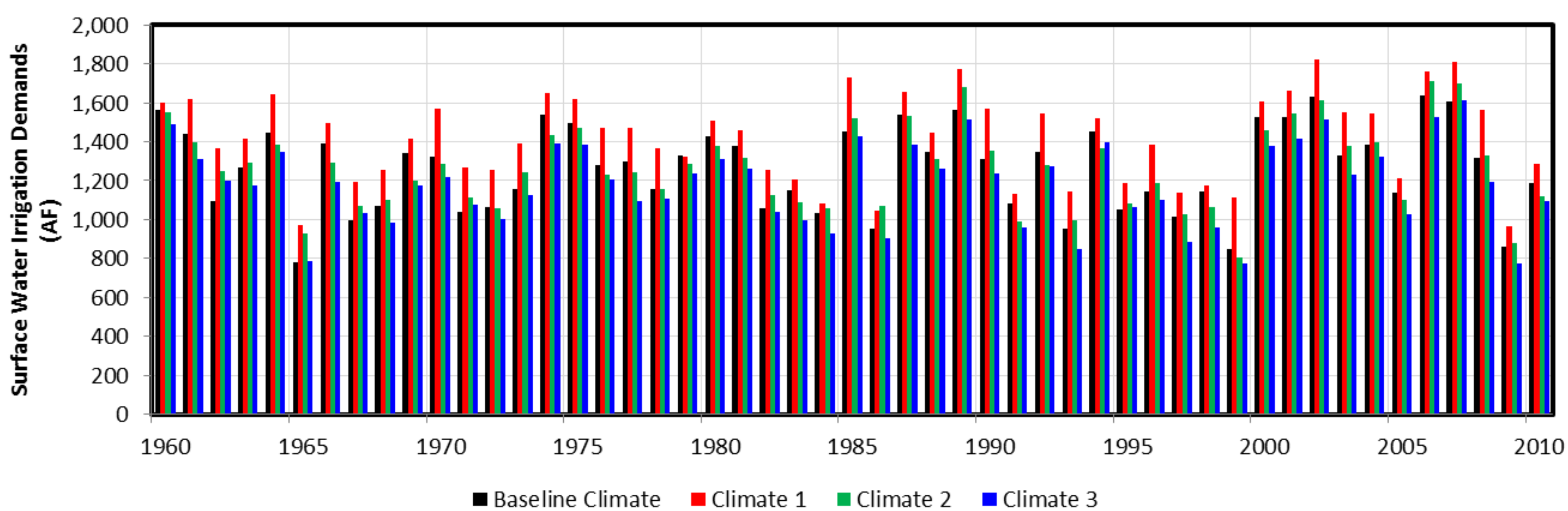


Figure 89. Comparison of surface water demands for surface water irrigation group 1 under the various climate scenarios.

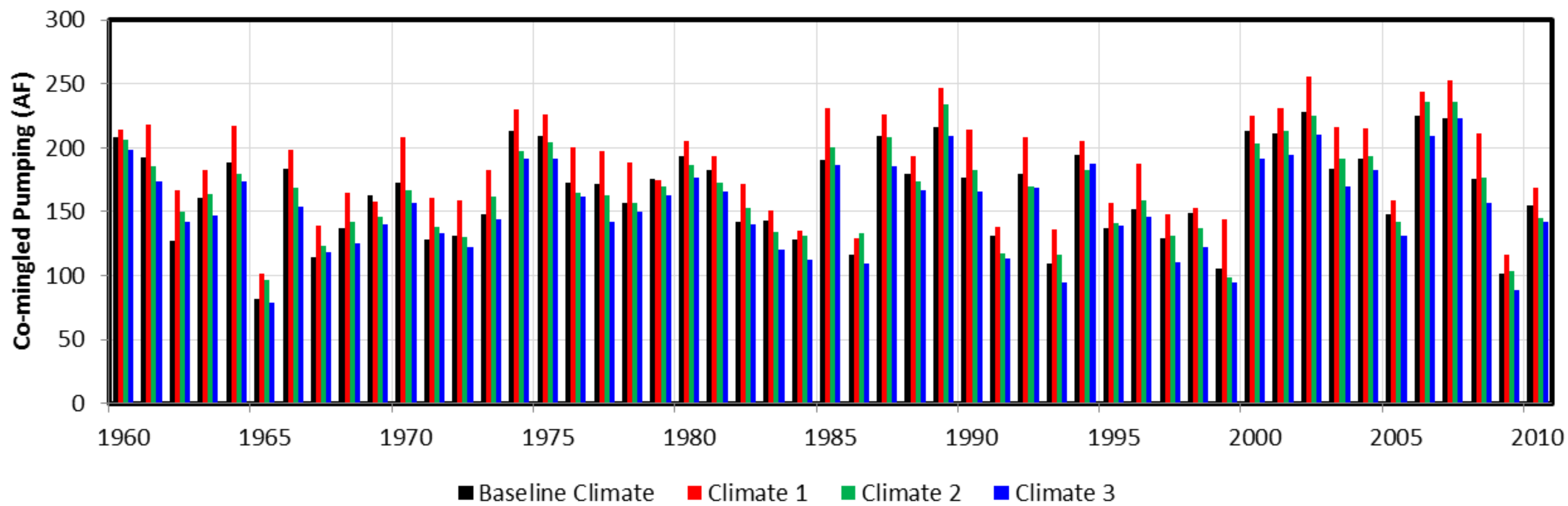


Figure 90. Comparison of supplemental co-mingled pumping for surface water irrigation group 1 under the various climate scenarios.

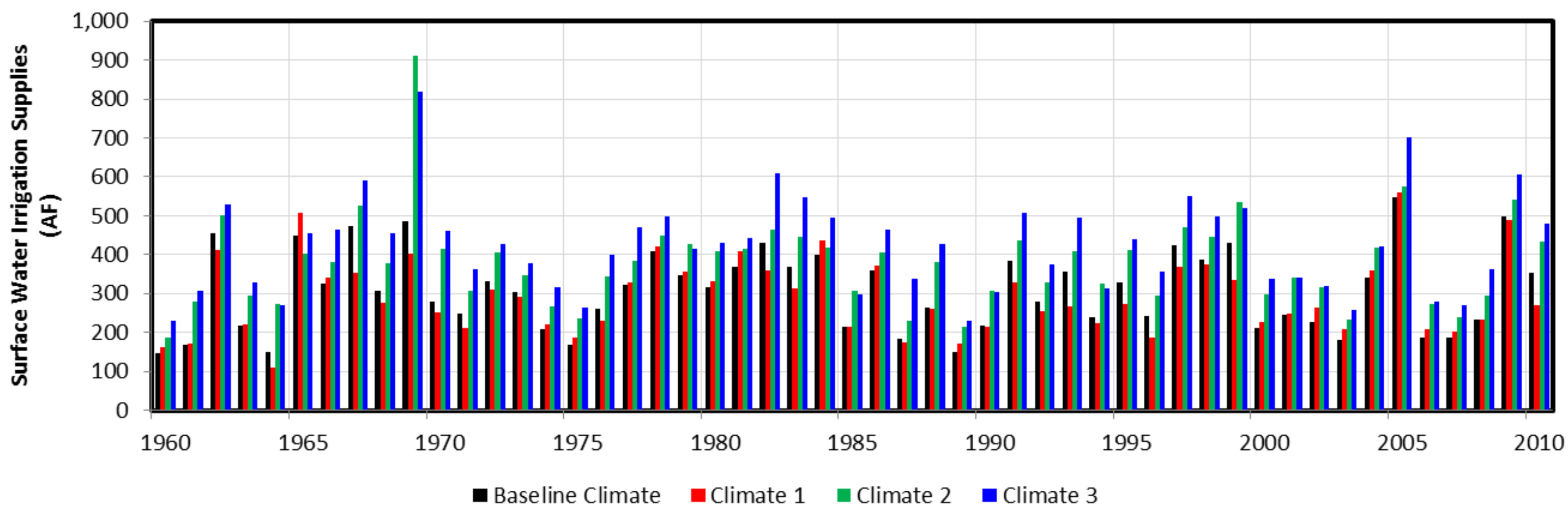


Figure 91. Comparison of surface water deliveries for surface water irrigation group 2 under the various climate scenarios.

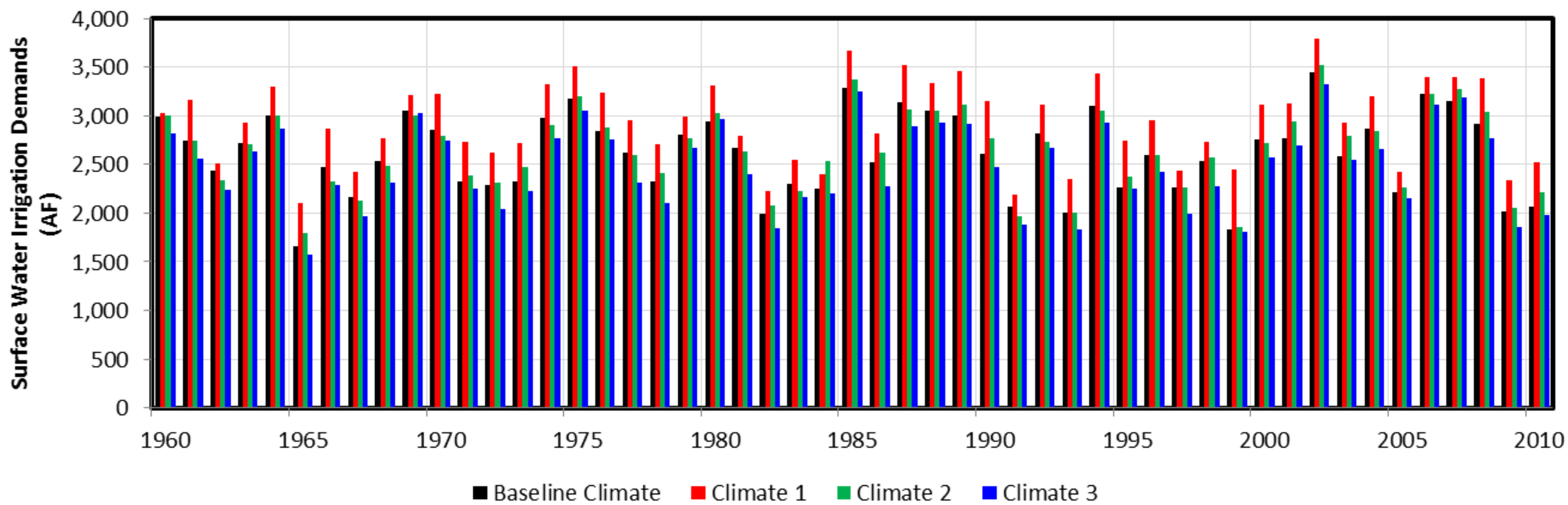


Figure 92. Comparison of surface water demands for surface water irrigation group 2 under the various climate scenarios.

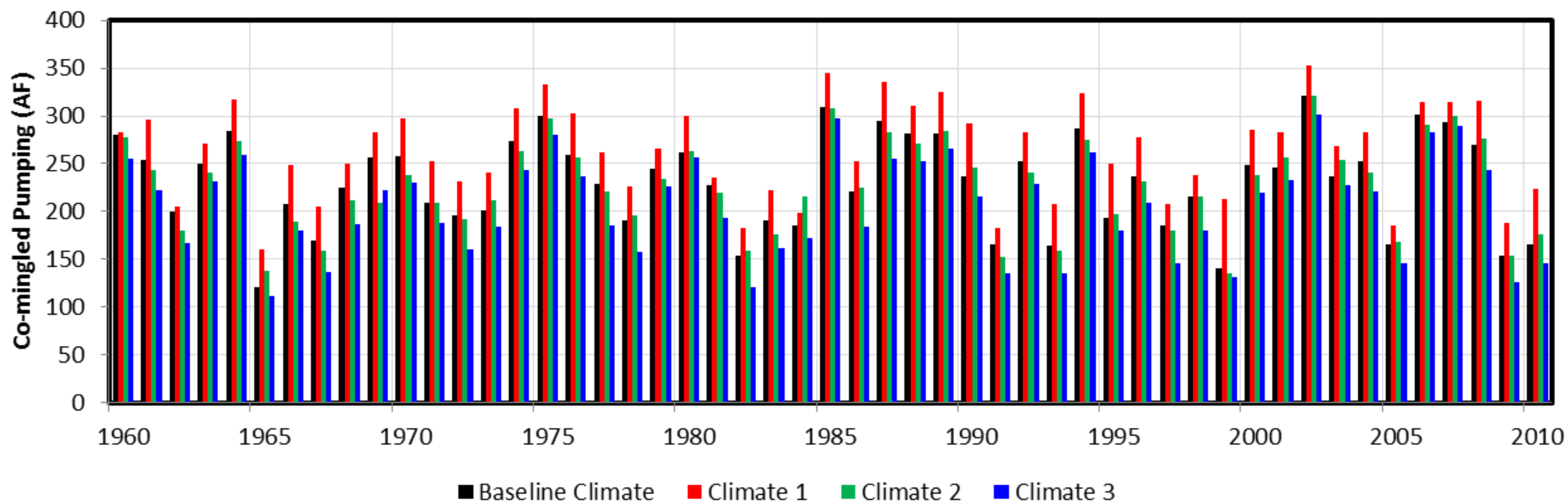


Figure 93. Comparison of supplemental co-mingled pumping for surface water irrigation group 2 under the various climate scenarios.

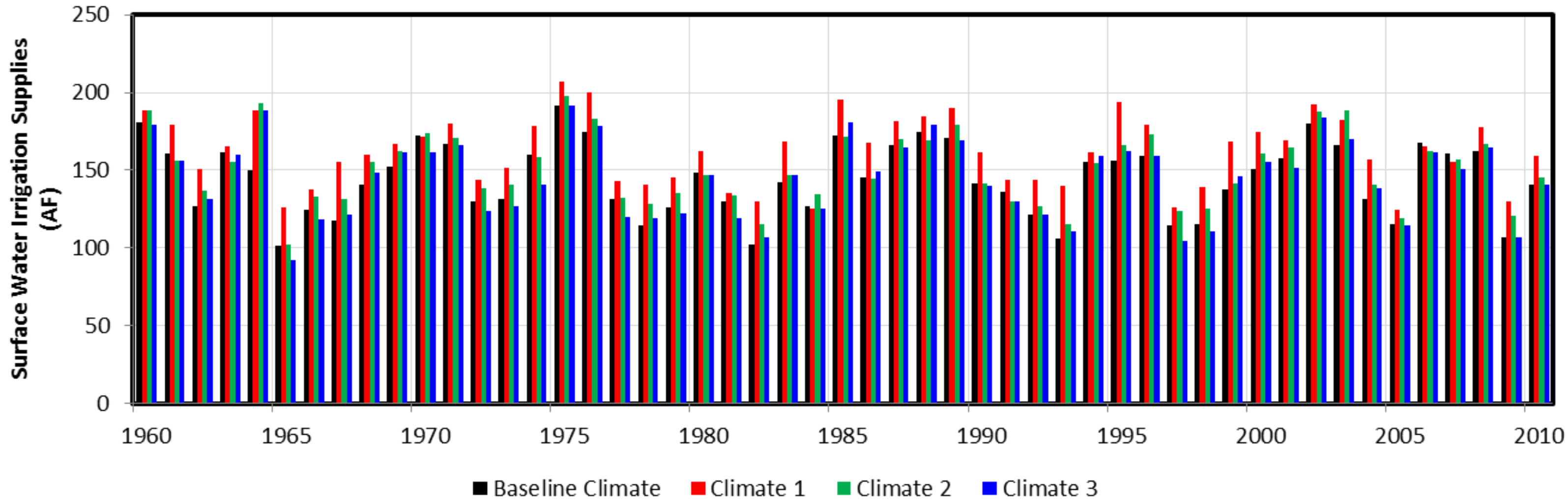


Figure 94. Comparison of surface water deliveries for surface water irrigation group 3 under the various climate scenarios.

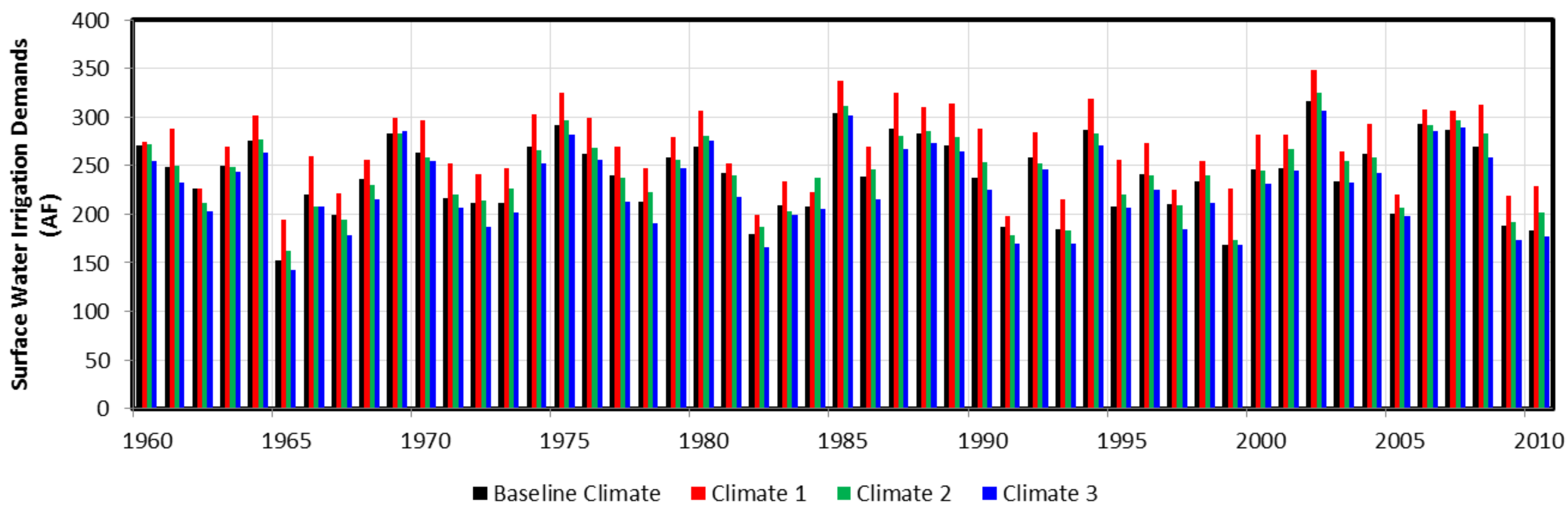


Figure 95. Comparison of surface water demands for surface water irrigation group 3 under the various climate scenarios.

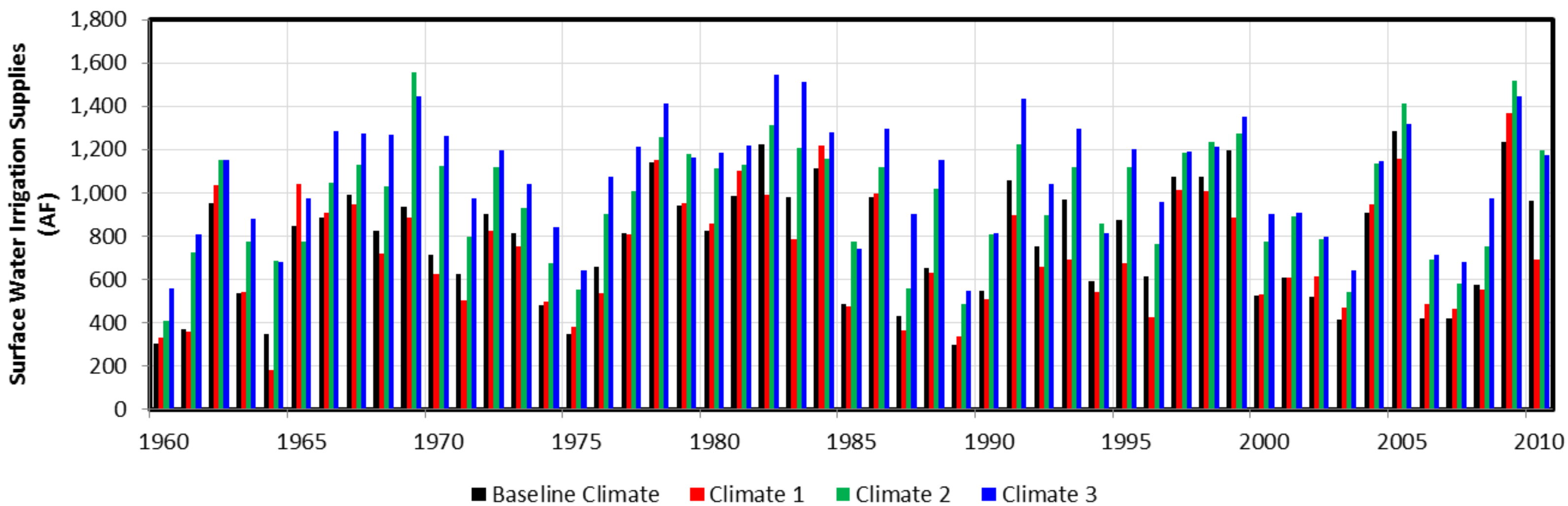


Figure 96. Comparison of surface water deliveries for surface water irrigation group 4 under the various climate scenarios.

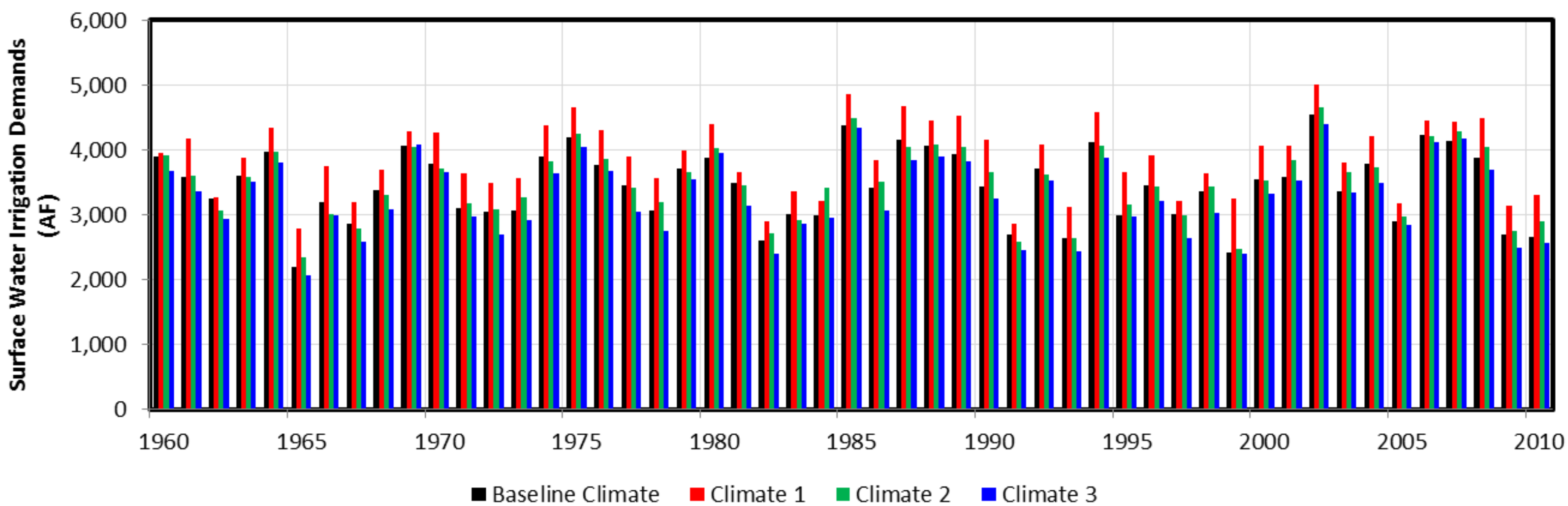


Figure 97. Comparison of surface water demands for surface water irrigation group 4 under the various climate scenarios.

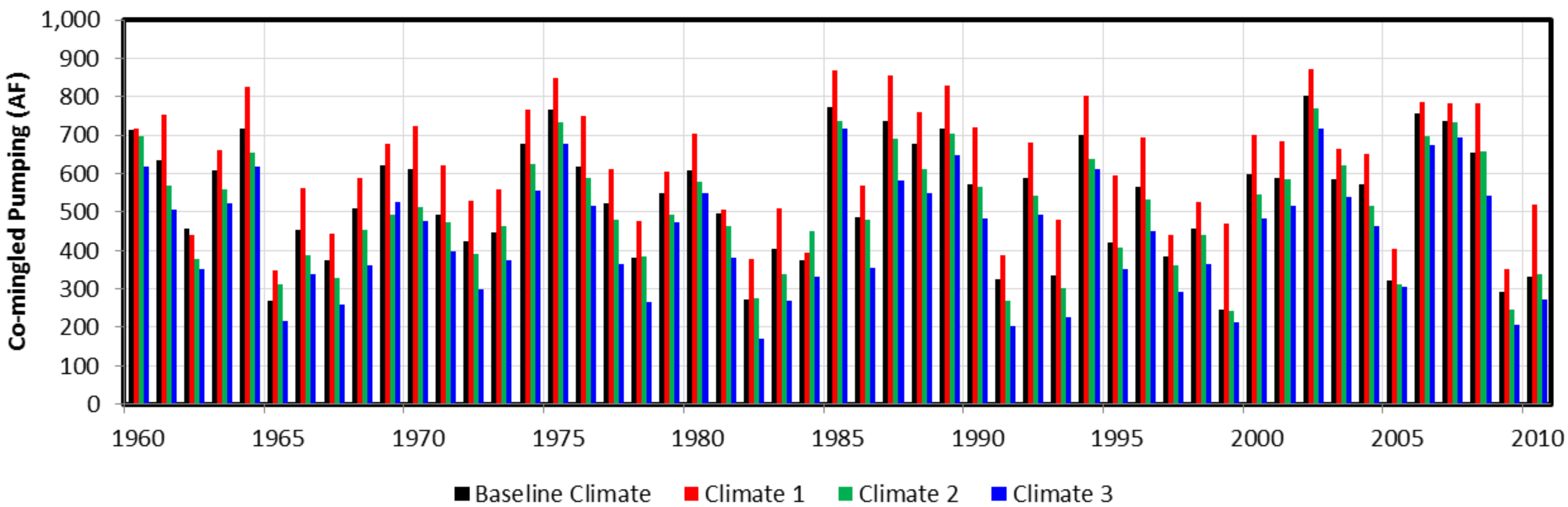


Figure 98. Comparison of supplemental co-mingled pumping for surface water irrigation group 4 under the various climate scenarios.

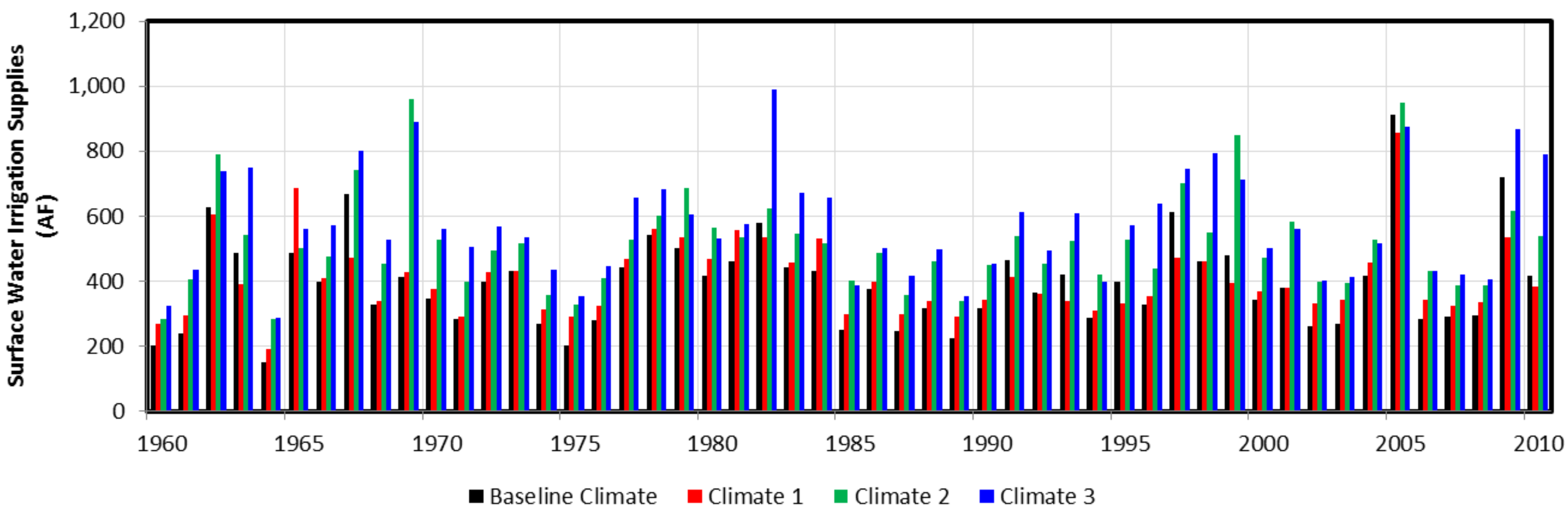


Figure 99. Comparison of surface water deliveries for surface water irrigation group 5 under the various climate scenarios.

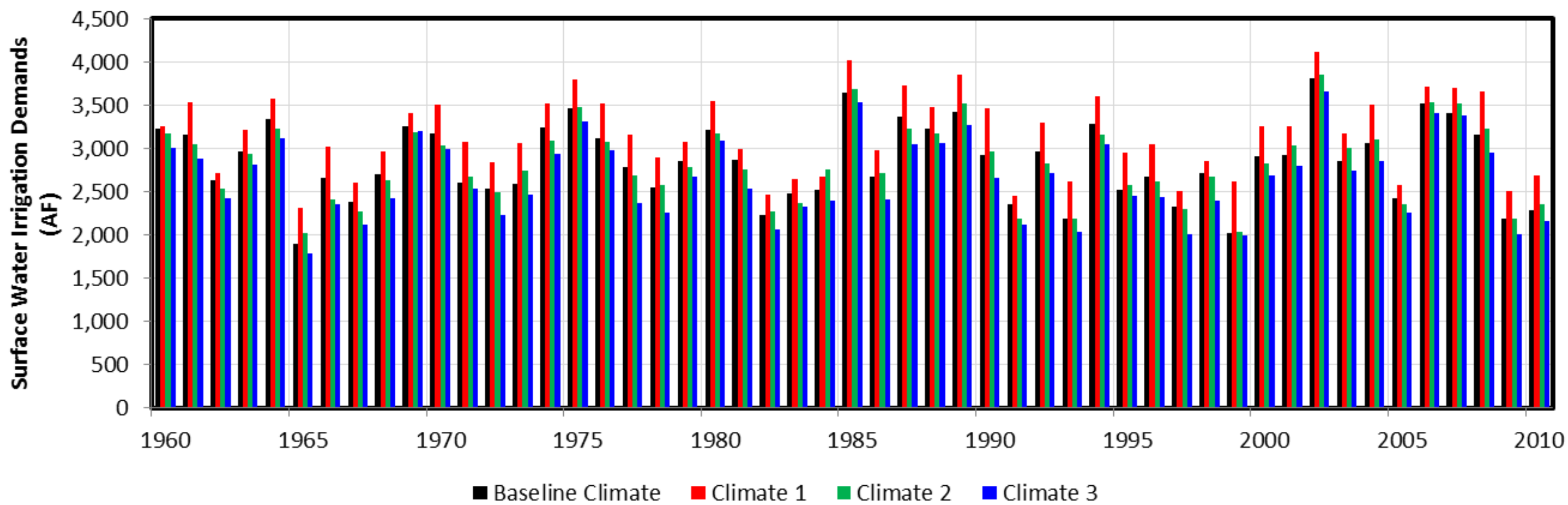


Figure 100. Comparison of surface water demands for surface water irrigation group 5 under the various climate scenarios.

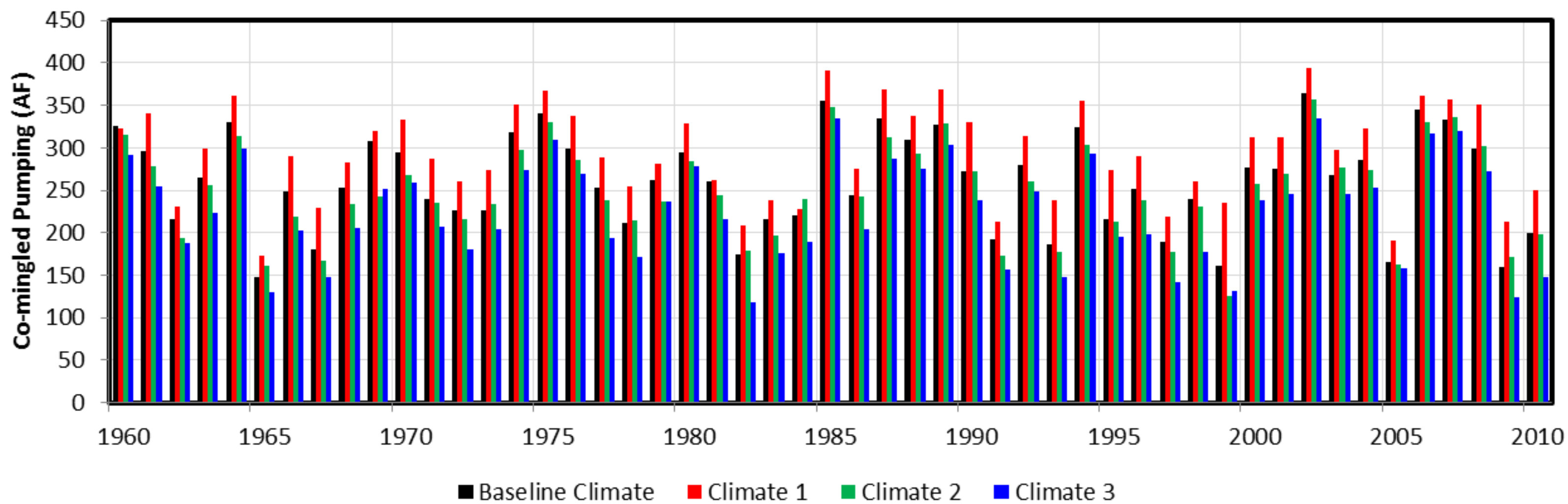


Figure 101. Comparison of supplemental co-mingled pumping for surface water irrigation group 5 under the various climate scenarios.

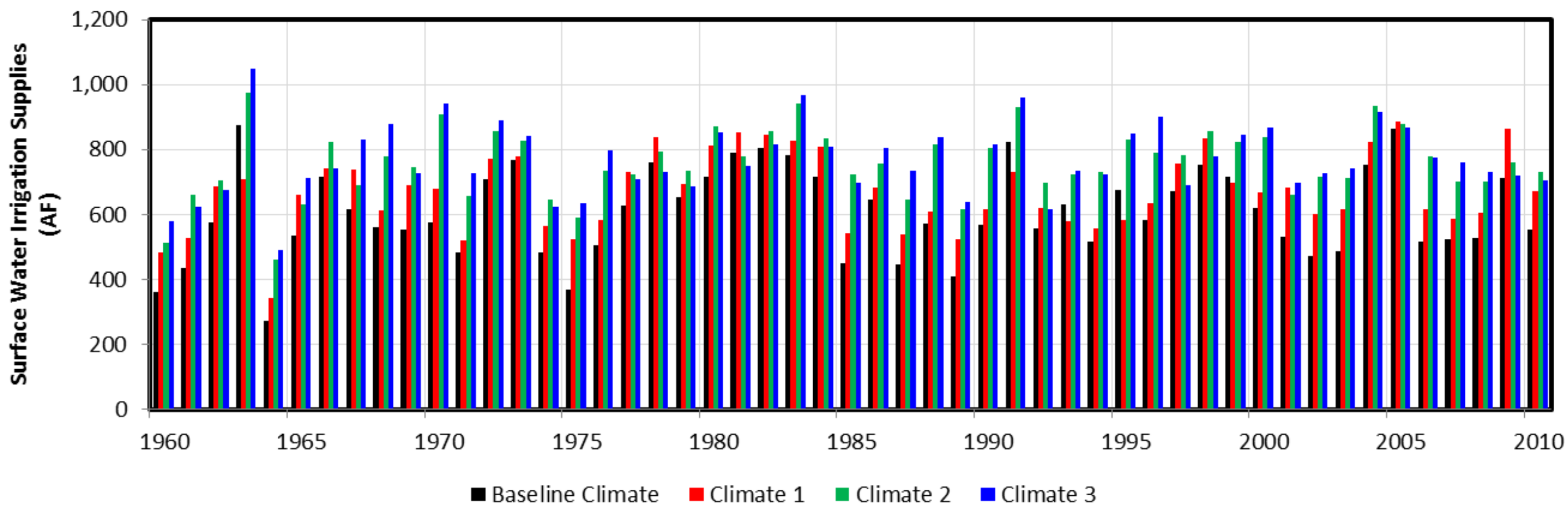


Figure 102. Comparison of surface water deliveries for surface water irrigation group 6 under the various climate scenarios.

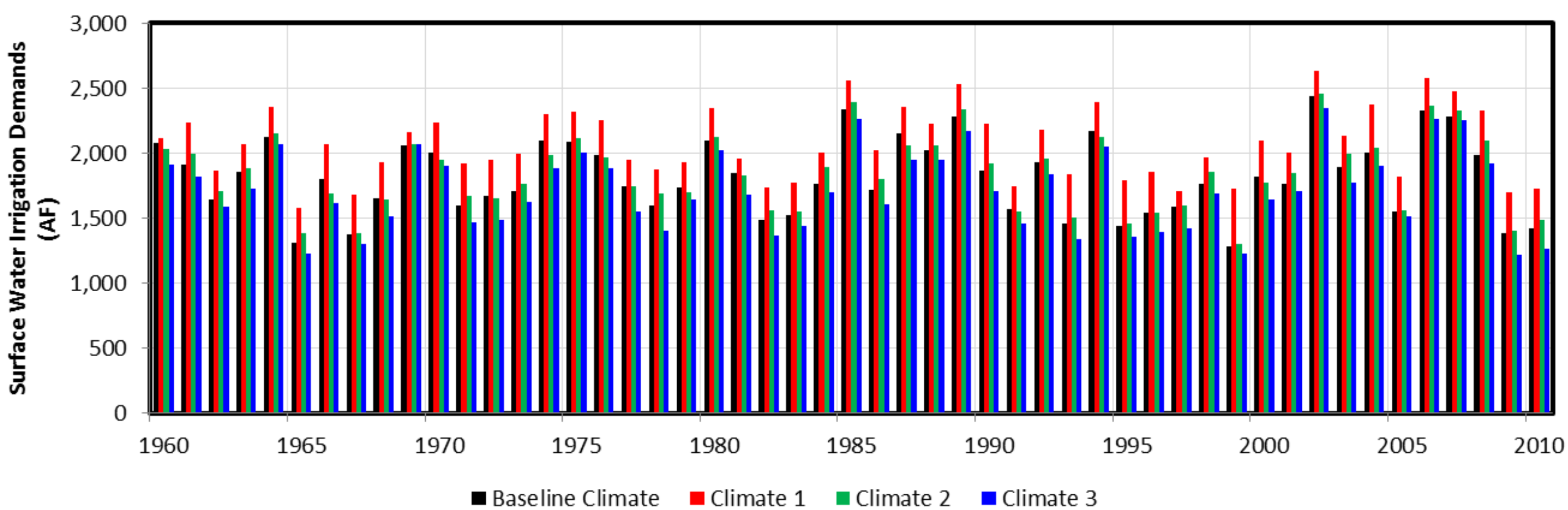


Figure 103. Comparison of surface water demands for surface water irrigation group 6 under the various climate scenarios.

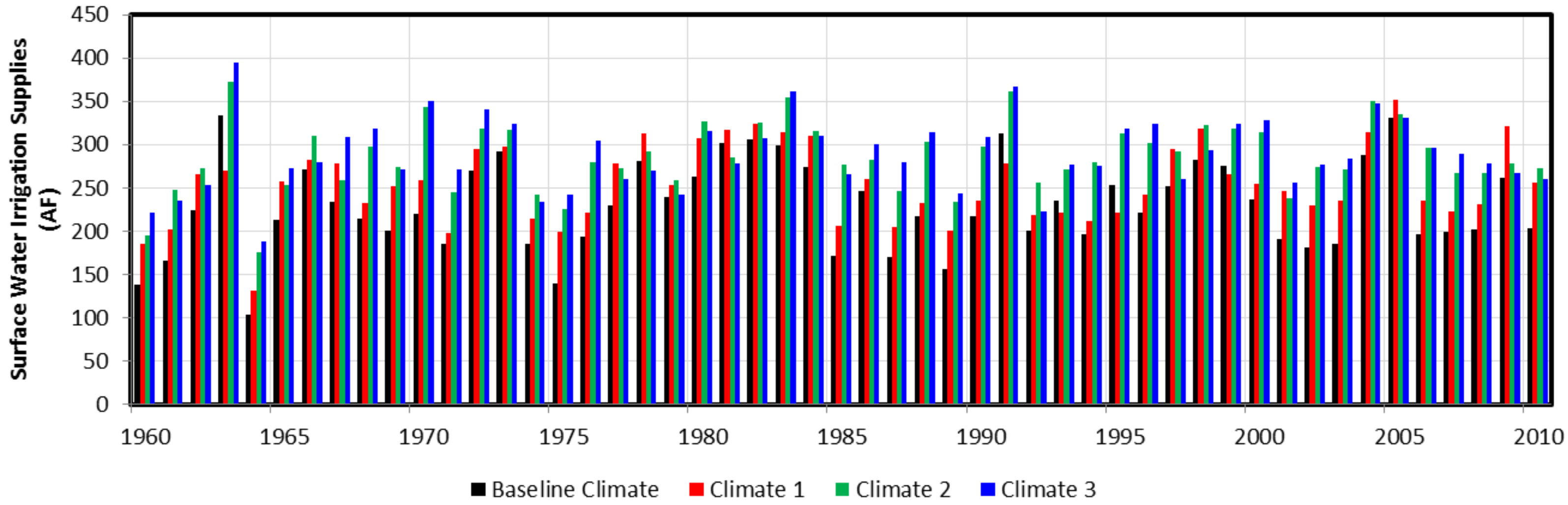


Figure 104. Comparison of surface water deliveries for surface water irrigation group 7 under the various climate scenarios.

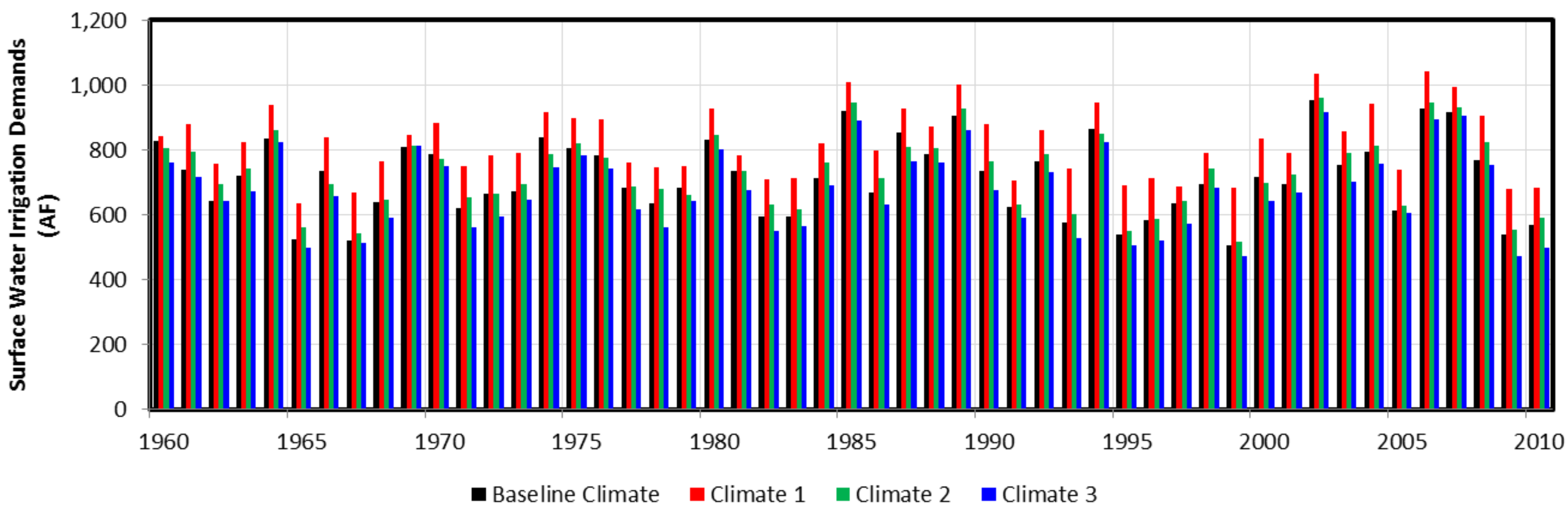


Figure 105. Comparison of surface water demands for surface water irrigation group 7 under the various climate scenarios.

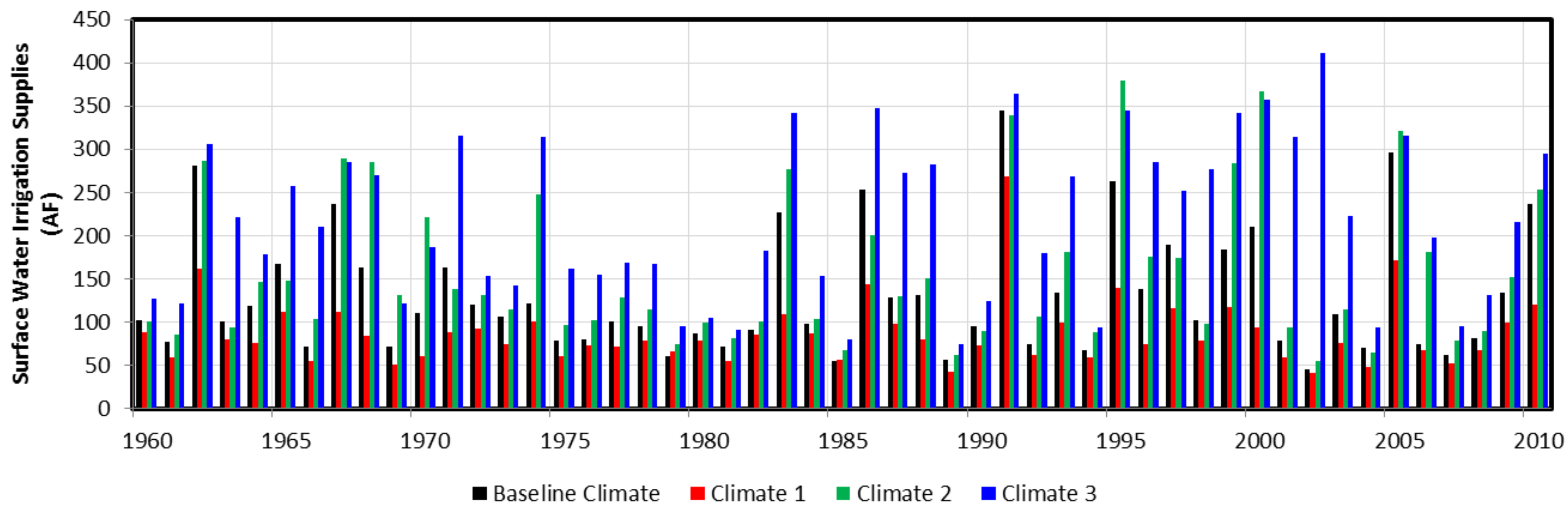


Figure 106. Comparison of surface water deliveries for surface water irrigation group 8 under the various climate scenarios.

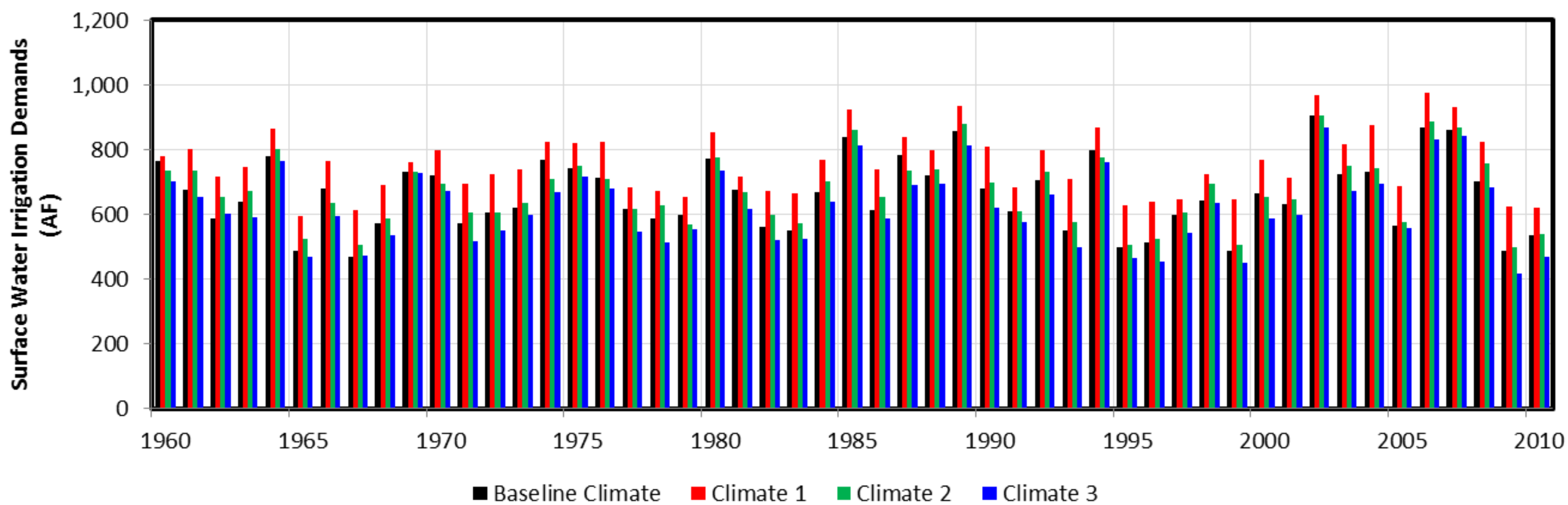


Figure 107. Comparison of surface water demands for surface water irrigation group 8 under the various climate scenarios.

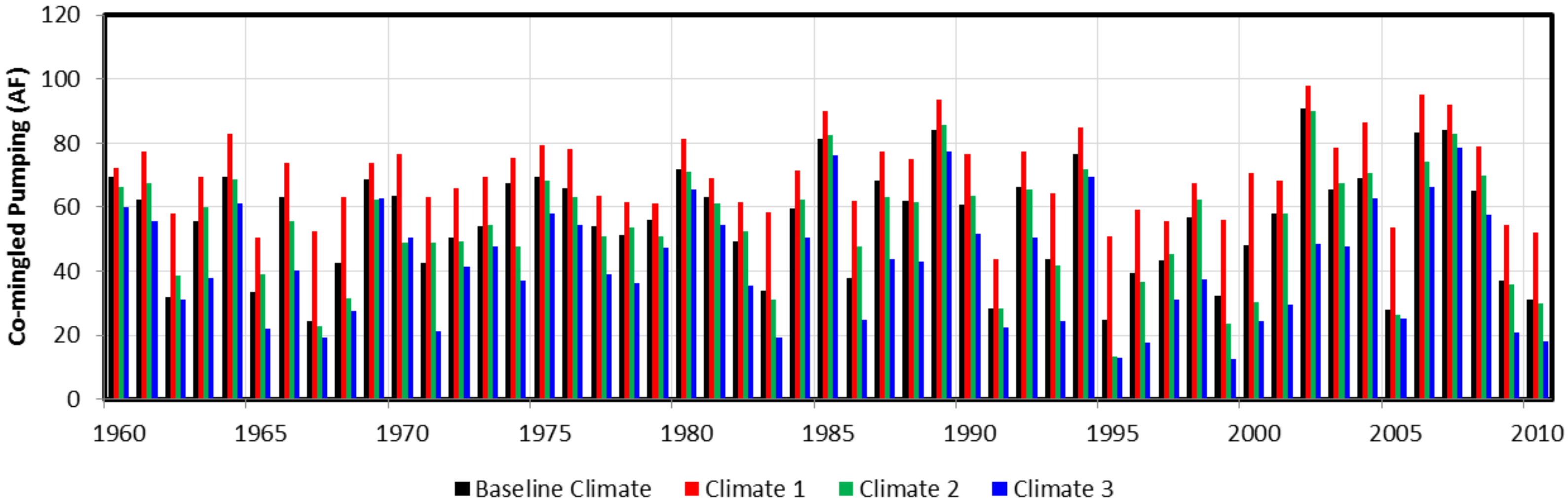


Figure 108. Comparison of supplemental co-mingled pumping for surface water irrigation group 8 under the various climate scenarios.

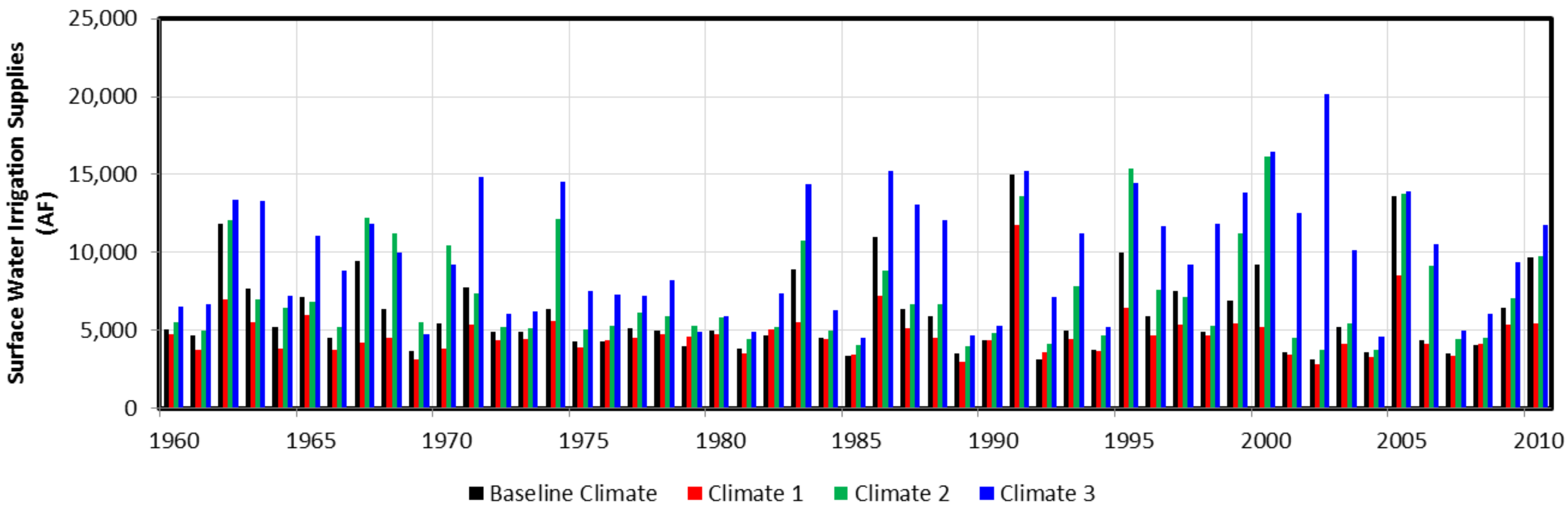


Figure 109. Comparison of surface water deliveries for surface water irrigation group 9 under the various climate scenarios.

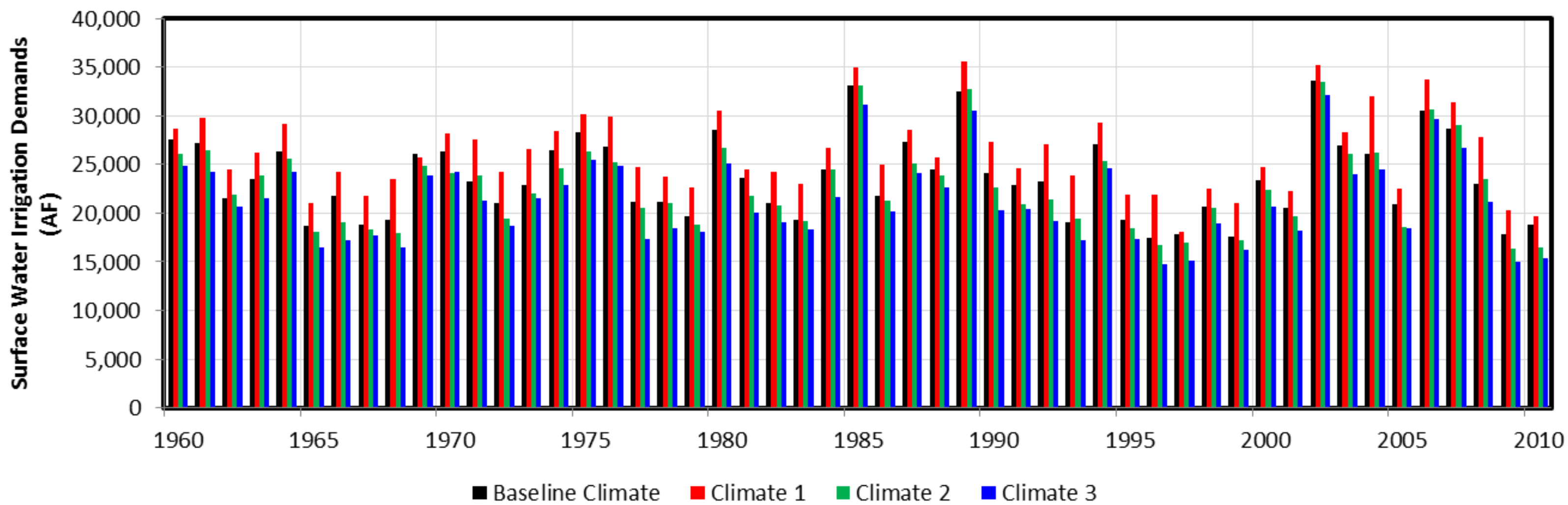


Figure 110. Comparison of surface water demands for surface water irrigation group 9 under the various climate scenarios.

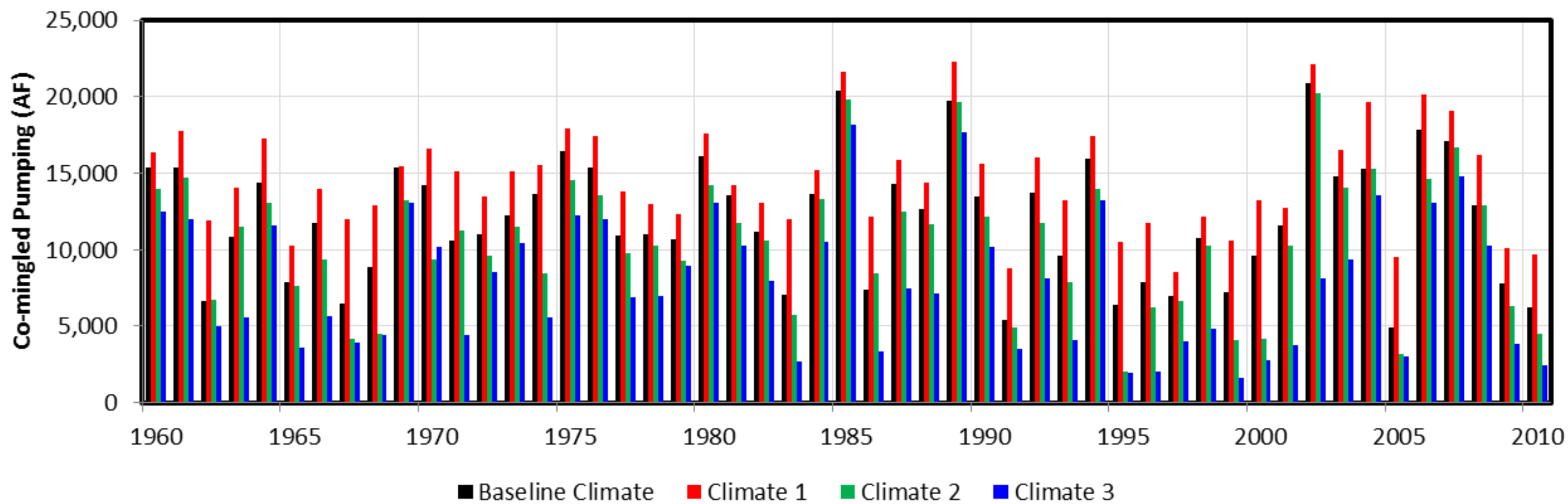


Figure 111. Comparison of supplemental co-mingled pumping for surface water irrigation group 9 under the various climate scenarios.

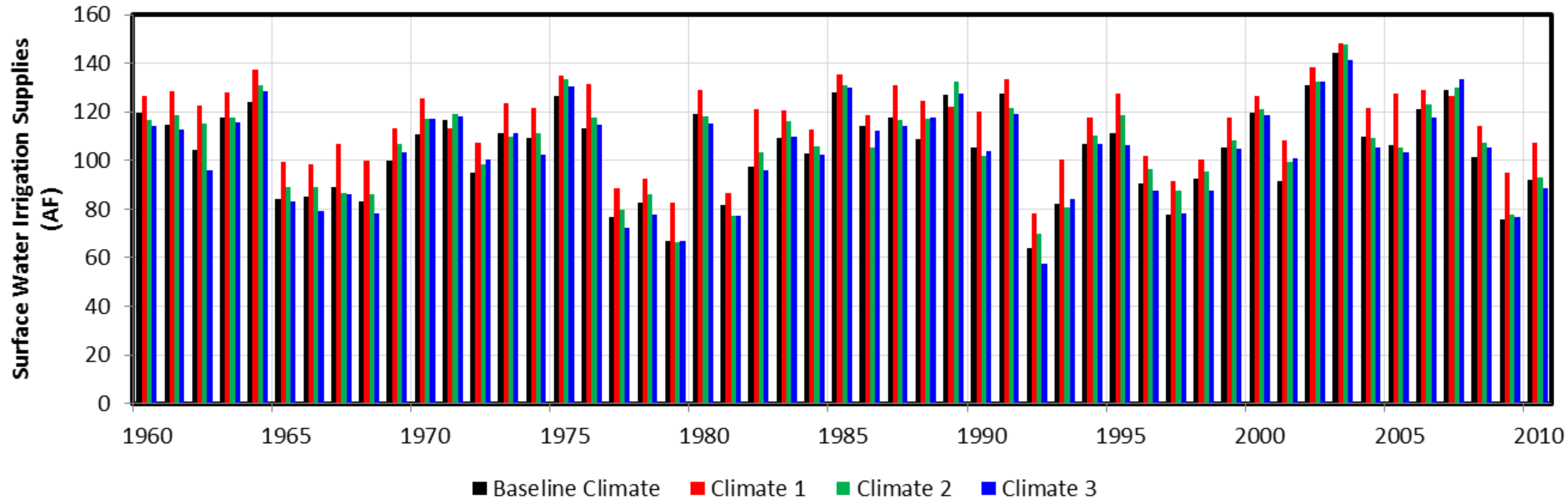


Figure 112. Comparison of surface water deliveries for surface water irrigation group 10 under the various climate scenarios.

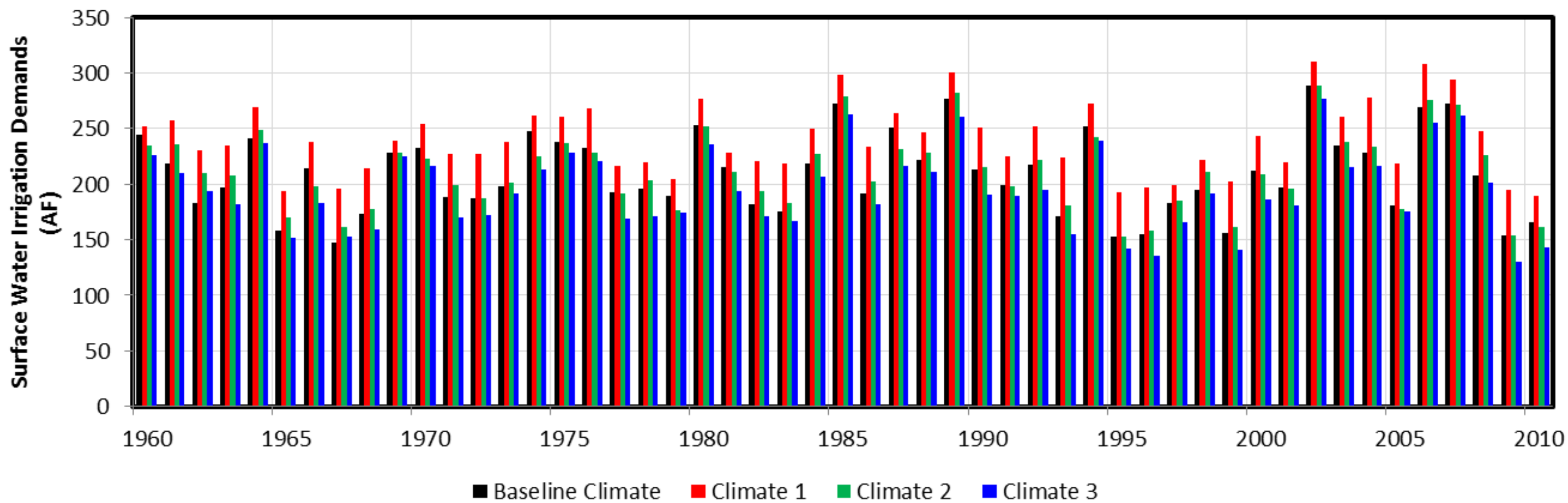


Figure 113. Comparison of surface water demands for surface water irrigation group 10 under the various climate scenarios.

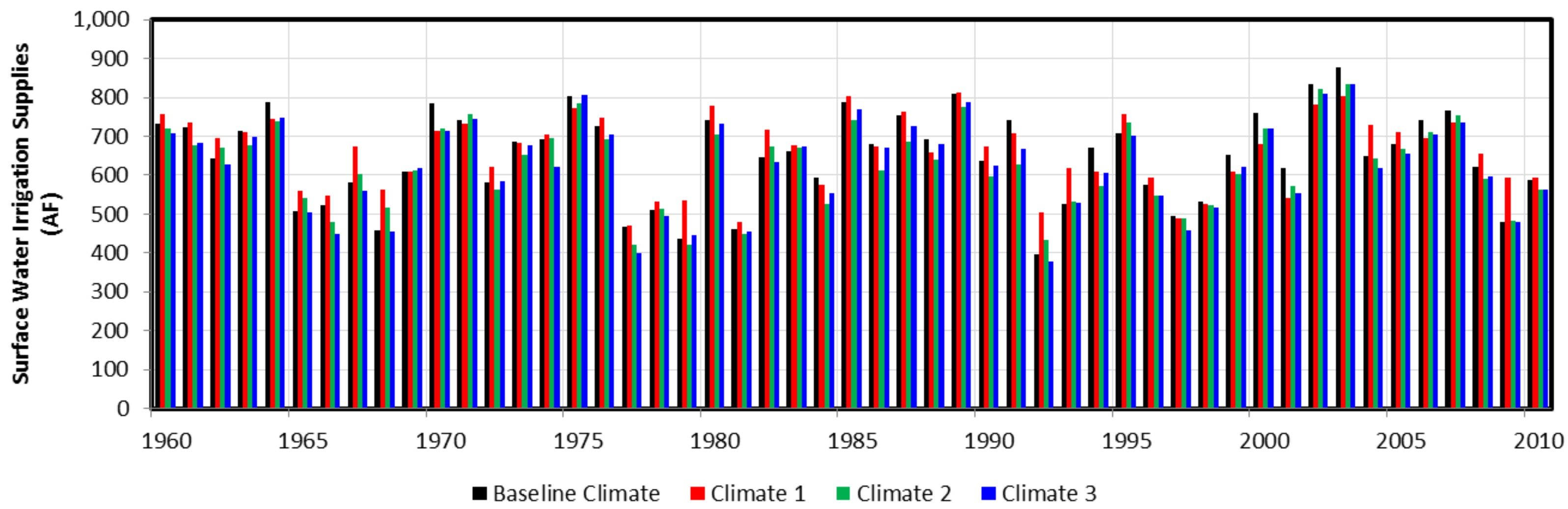


Figure 114. Comparison of surface water deliveries for surface water irrigation group 11 under the various climate scenarios.

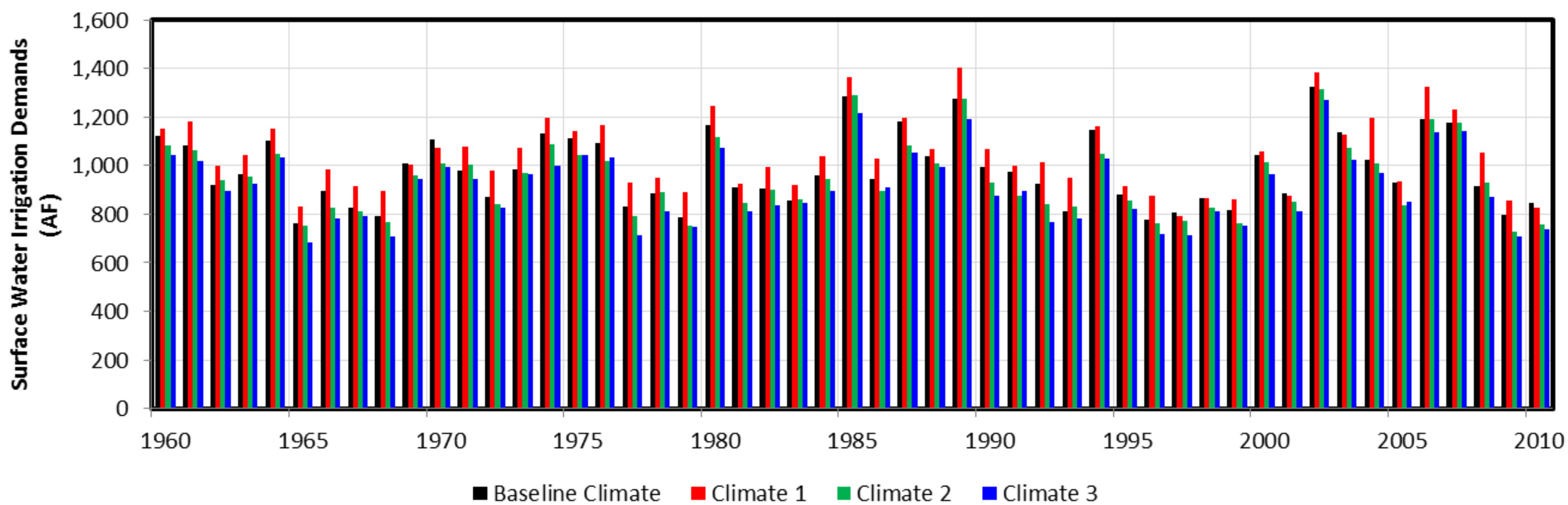


Figure 115. Comparison of surface water demands for surface water irrigation group 11 under the various climate scenarios.

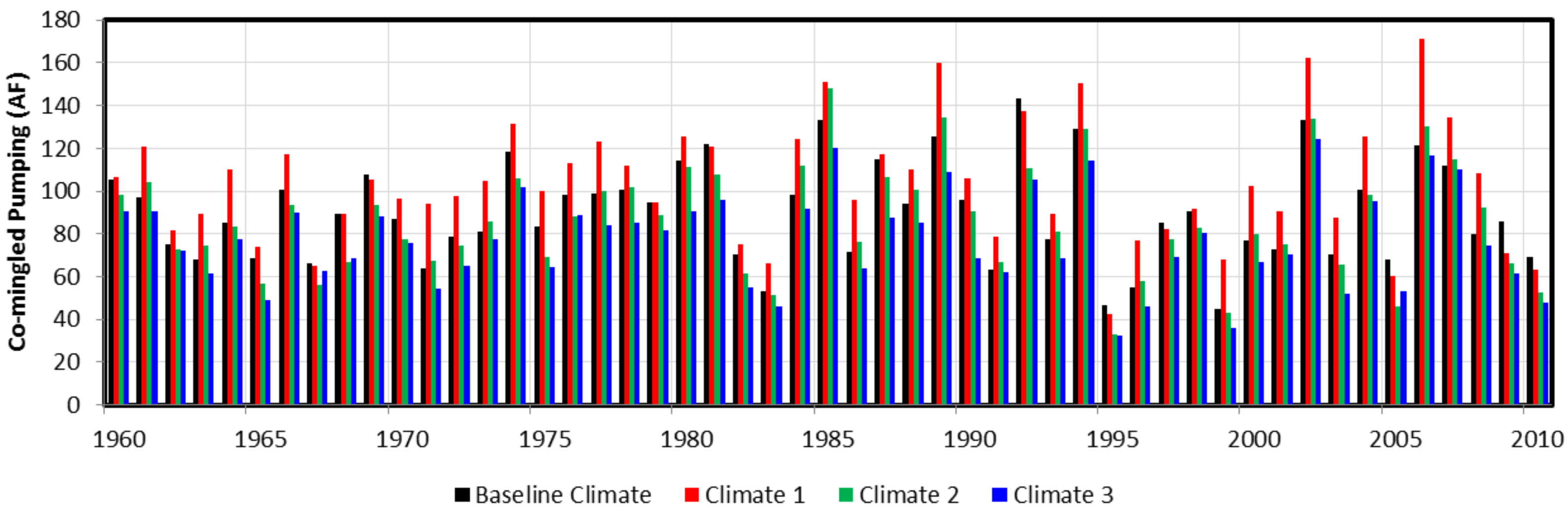


Figure 116. Comparison of supplemental co-mingled pumping for surface water irrigation group 11 under the various climate scenarios.

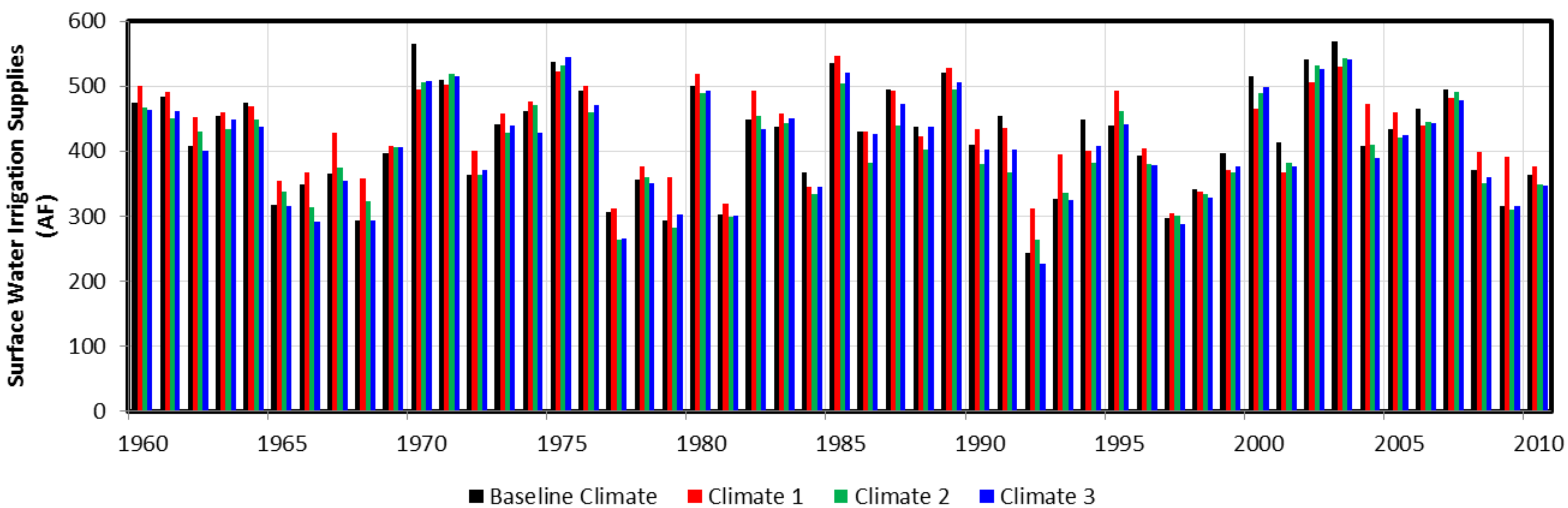


Figure 117. Comparison of surface water deliveries for surface water irrigation group 12 under the various climate scenarios.

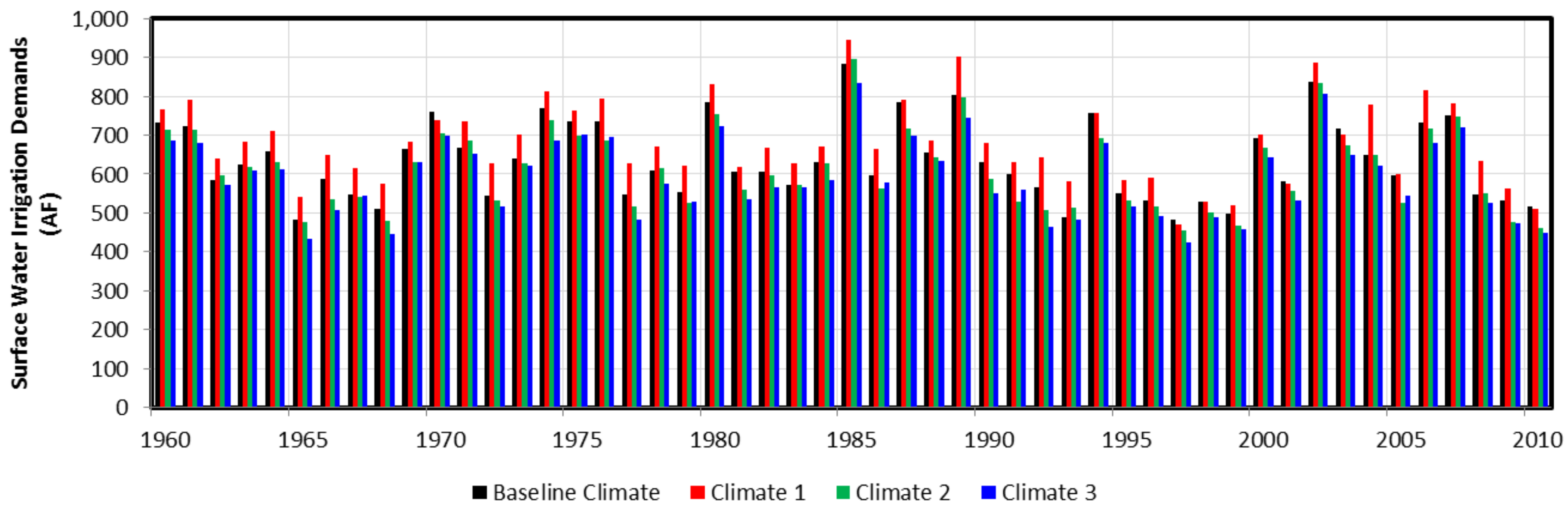


Figure 118. Comparison of surface water demands for surface water irrigation group 12 under the various climate scenarios.

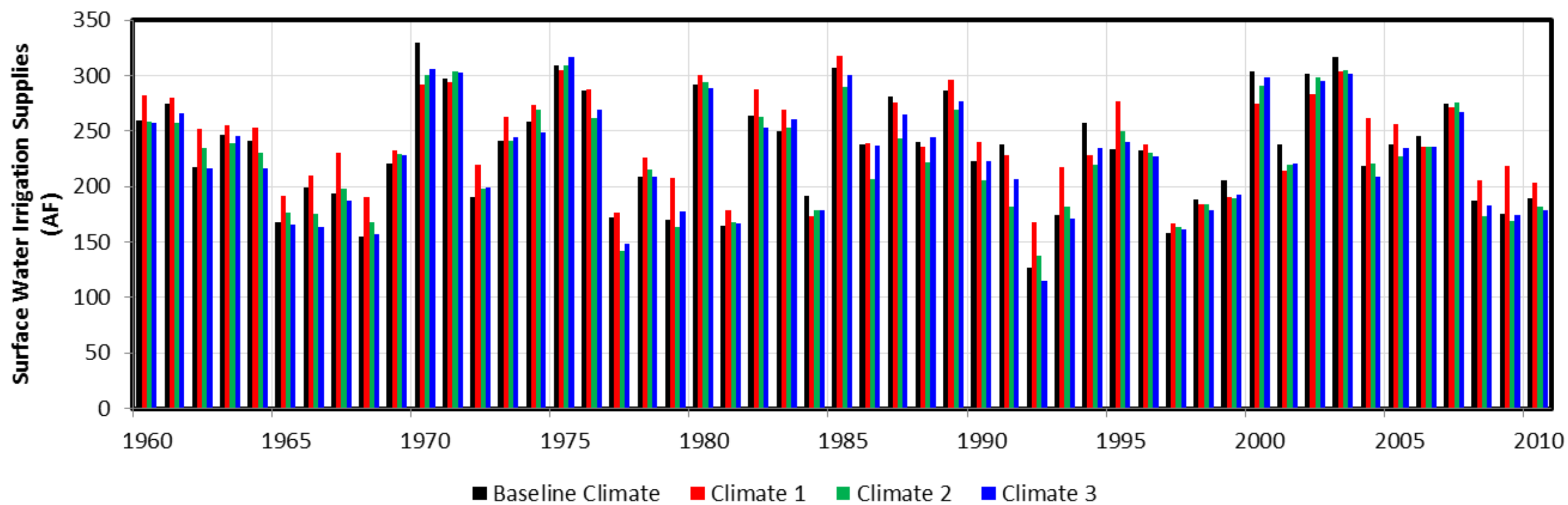


Figure 119. Comparison of surface water deliveries for surface water irrigation group 13 under the various climate scenarios.

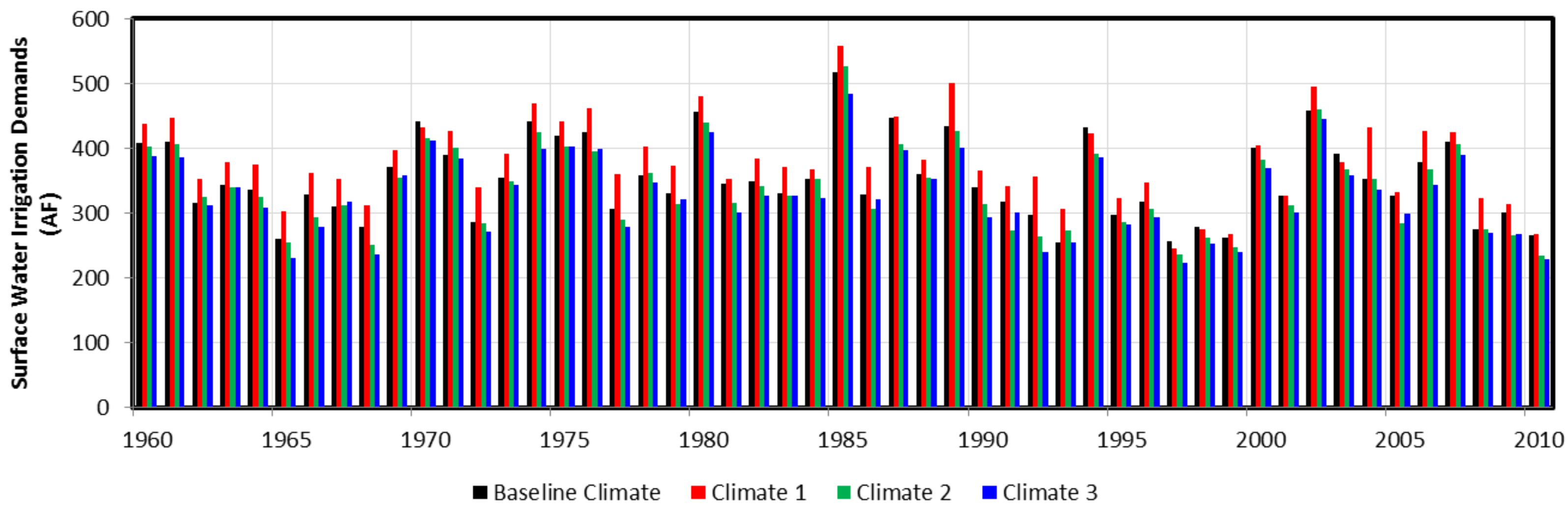


Figure 120. Comparison of surface water demands for surface water irrigation group 13 under the various climate scenarios.

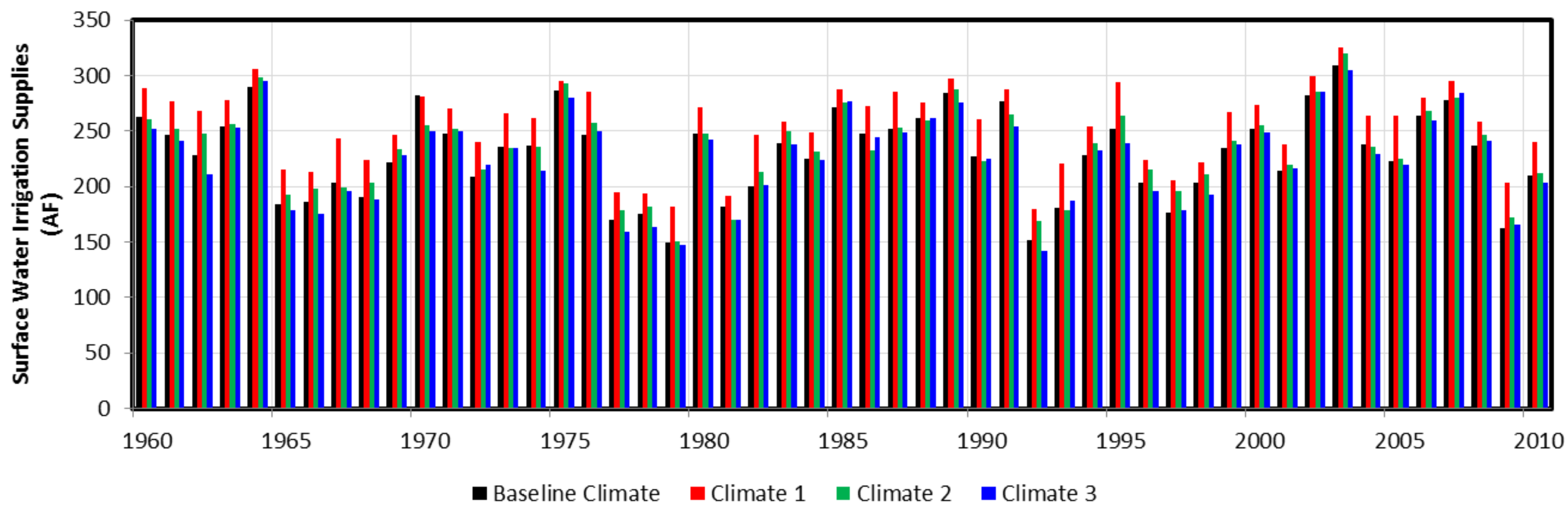


Figure 121. Comparison of surface water deliveries for surface water irrigation group 14 under the various climate scenarios.

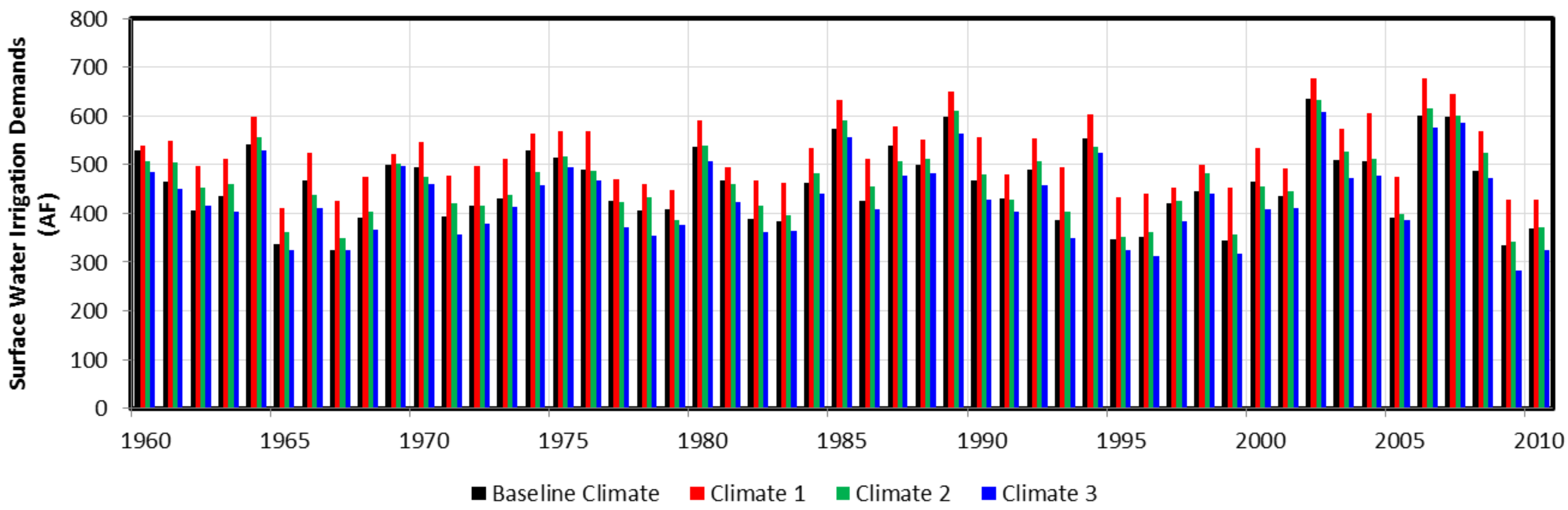


Figure 122. Comparison of surface water demands for surface water irrigation group 14 under the various climate scenarios.

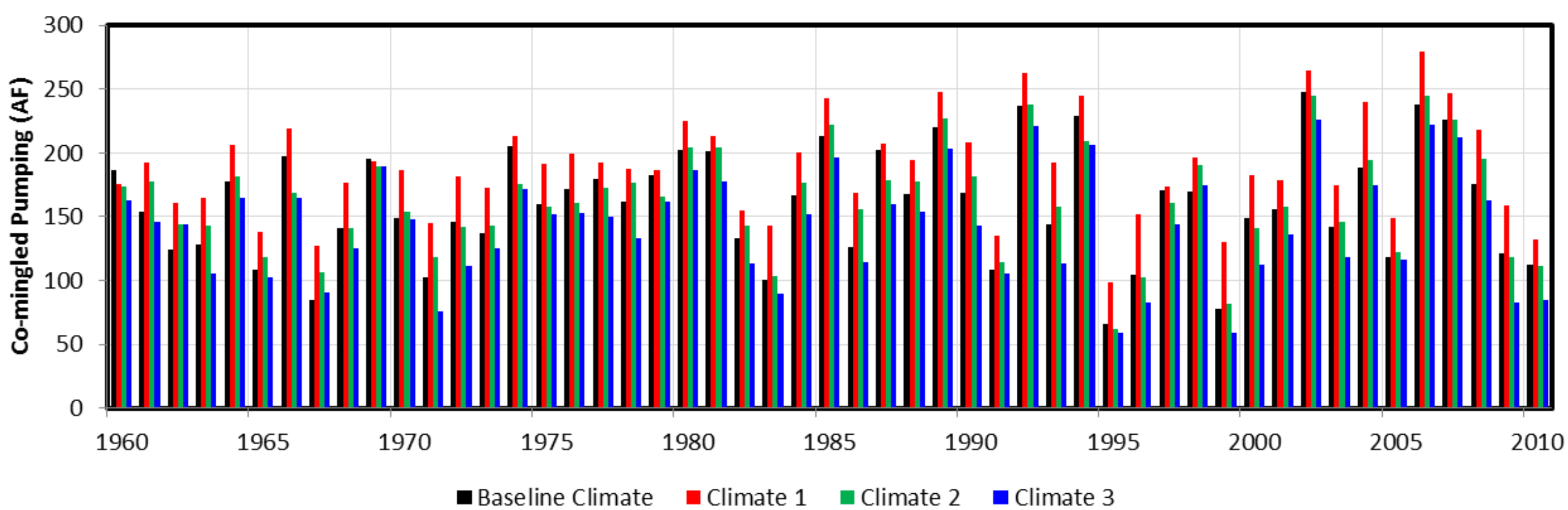


Figure 123. Comparison of supplemental co-mingled pumping for surface water irrigation group 14 under the various climate scenarios.

5.3.10 Mirage Flats Irrigation District

Within the Mirage Flats Irrigation District, the results continue to exhibit the pattern of the basin as a whole (Figures 124-126). Increases in precipitation increase the available surface water and decrease the need for supplemental groundwater pumping. Furthermore, they lead to increases in evapotranspiration, recharge, and runoff contributions to stream flow (Table 23). The annual effect of the climate change on irrigation demands, supplies, and supplemental co-mingled pumping is located in Figures 109-111.

Table 23. Average Percent Change in Water Balance Parameters in the Mirage Flats Irrigation District; Baseline No Action

Climate Scenario	Precipi-tation	Ground-water Pumping	Surface Water Deliveries	Total Applied Water	ET	Recharge	Runoff Contributions to Streamflow
Climate 1	–16.33%	8.74%	–15.31%	–14.08%	–13.43%	–26.42%	–21.38%
Climate 2	5.83%	–4.91%	15.06%	4.89%	4.13%	14.80%	7.10%
Climate 3	18.25%	–11.93%	46.04%	15.60%	12.14%	62.91%	40.20%

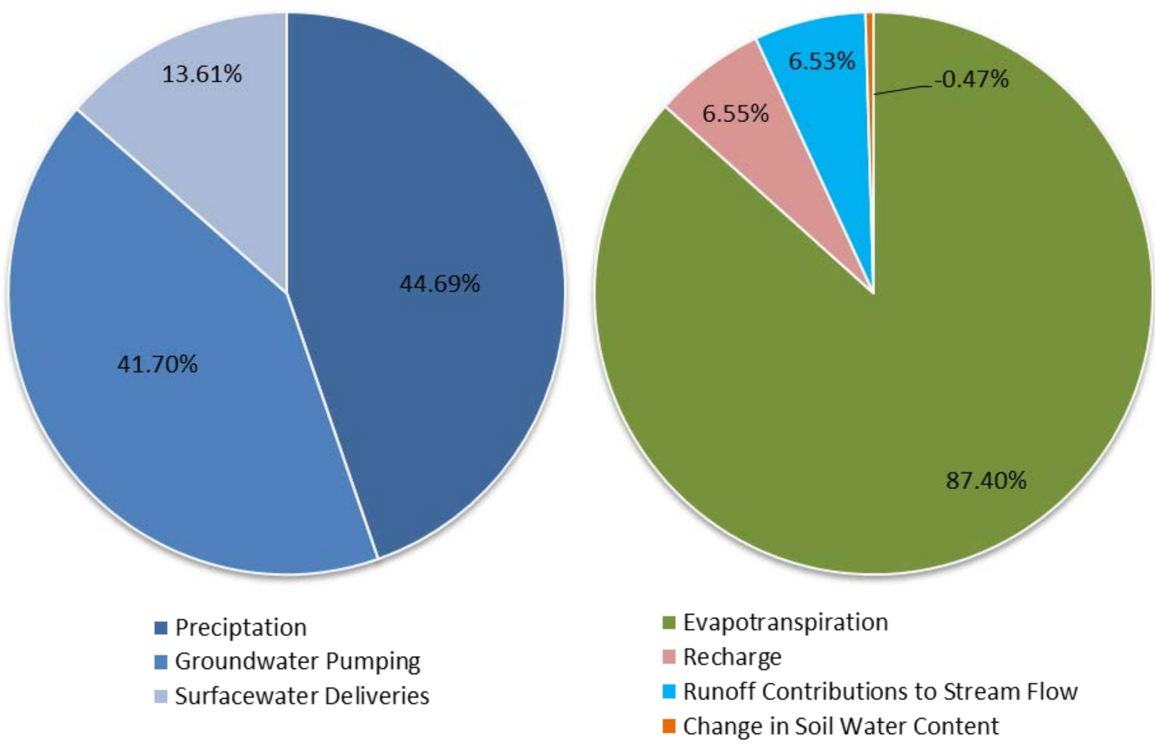


Figure 124. Sources of 31.24 in/ac of total available water and partitioned total available water for the Mirage Flats Irrigation District within the UNWNRD model; Low No Action.

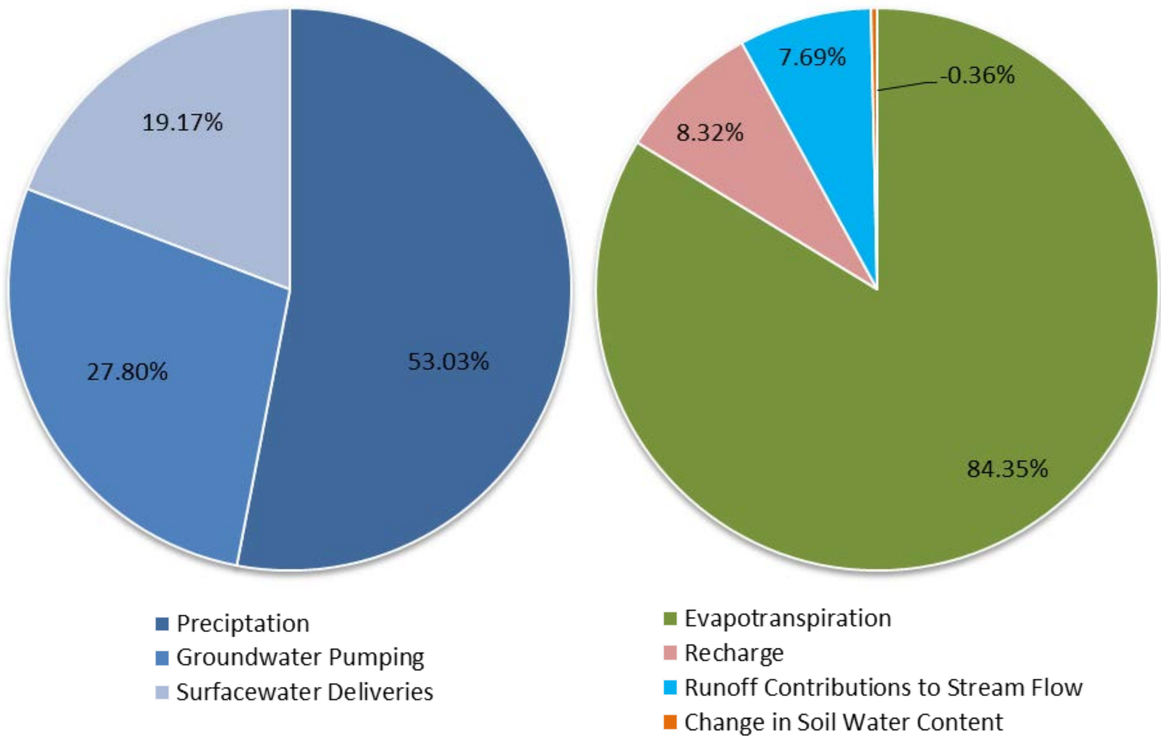


Figure 125. Sources of 33.79 in/ac of total available water and partitioned total available water for the Mirage Flats Irrigation District within the UNWNRD model; CT No Action.

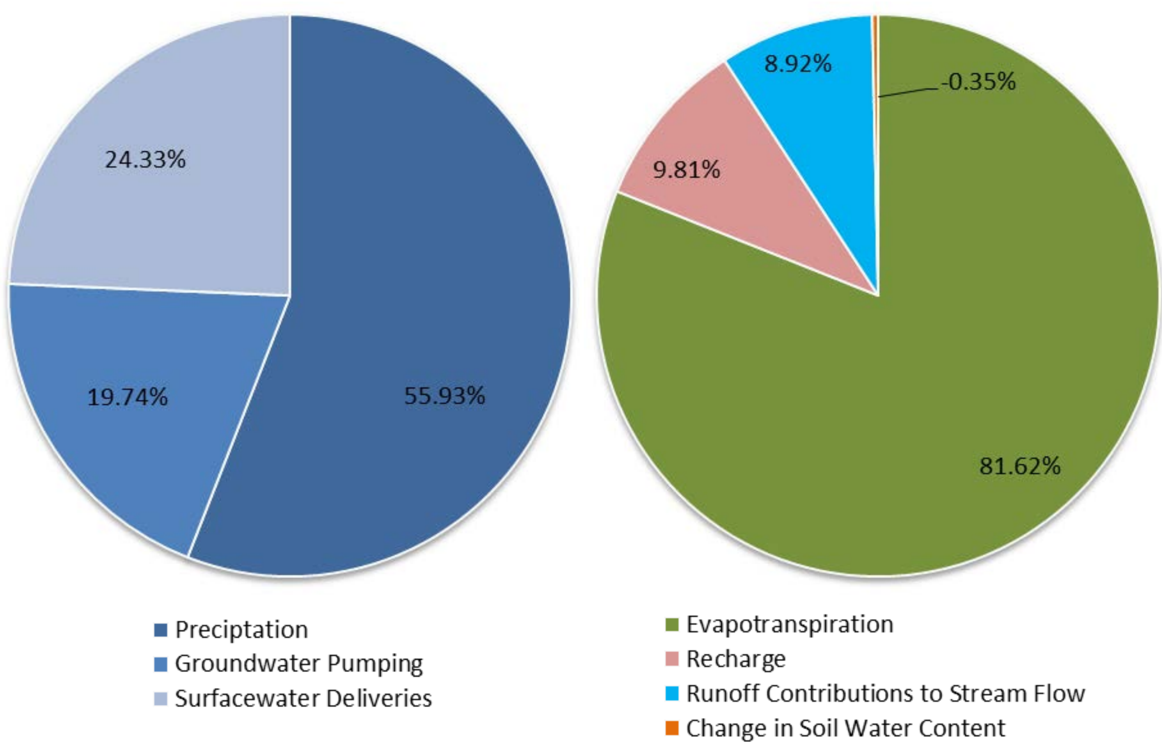


Figure 126. Sources of 35.49 in/ac of total available water and partitioned total available water for the Mirage Flats Irrigation District within the UNWNRD model; High No Action.

5.3.11 Box Butte County

The results in Box Butte County exhibited much of the same pattern as the basin as a whole (Figures 127-129). The principle deviation is the increase in surface water deliveries in climate scenario 1. Otherwise, as precipitation increases the available surface water for irrigation increases and groundwater pumping totals decreased (Figure 130). Furthermore, evapotranspiration, recharge, and runoff contributions to stream flow also increased as precipitation increased (Table 24).

Table 24. Average Percent Change in Water Balance Parameters in Box Butte County; Baseline No Action

Climate Scenario	Precipi-tation	Ground-water Pumping	Surface Water Deliveries	Total Applied Water	ET	Recharge	Runoff Contributions to Streamflow
Climate 1	–16.28%	8.14%	2.57%	–12.19%	–12.30%	–20.29%	–22.15%
Climate 2	5.50%	–4.84%	24.86%	3.78%	3.37%	8.35%	3.28%
Climate 3	18.54%	–11.66%	34.00%	13.50%	11.36%	40.54%	33.77%

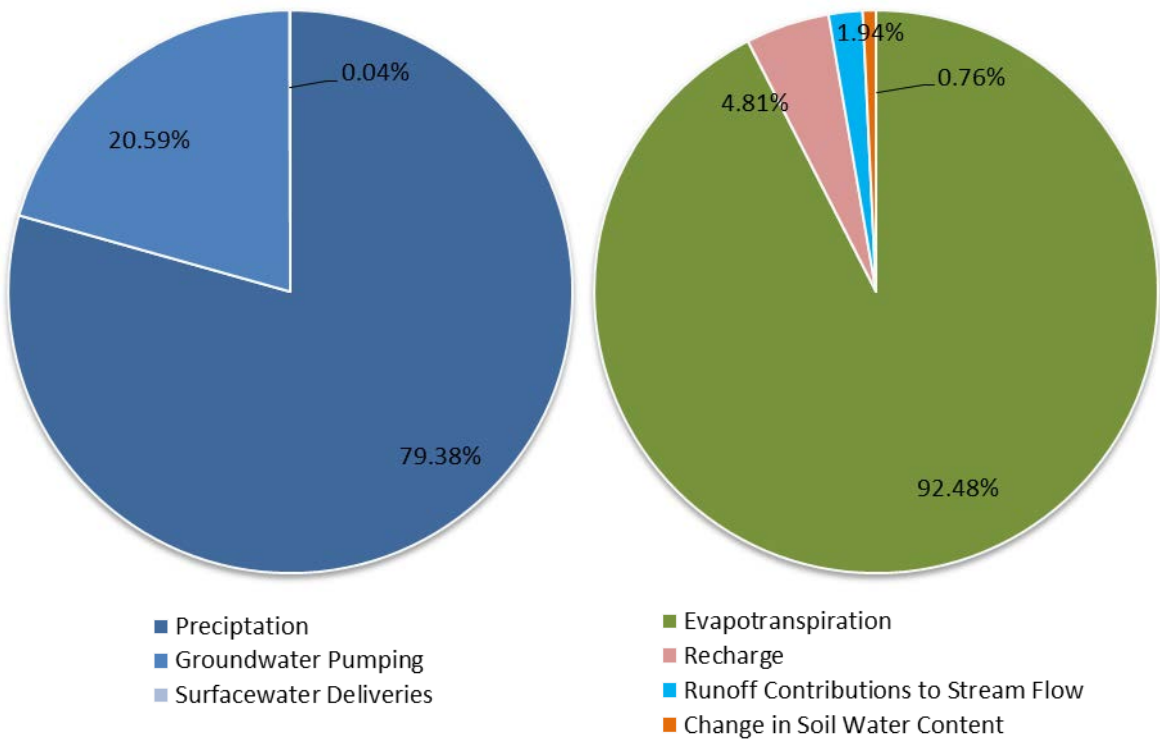


Figure 127. Sources of 16.64 in/ac of total available water and partitioned total available water within Box Butte County; Low No Action.

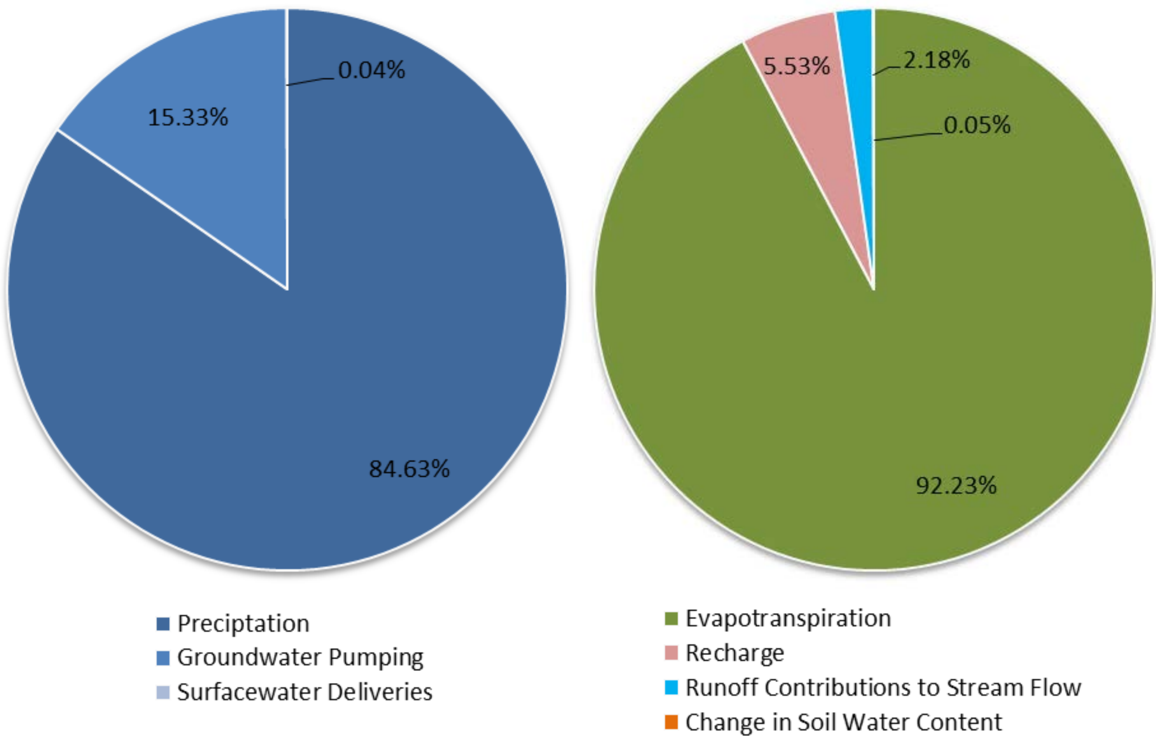


Figure 128. Sources of 19.67 in/ac of total available water and partitioned total available water within Box Butte County; CT No Action.

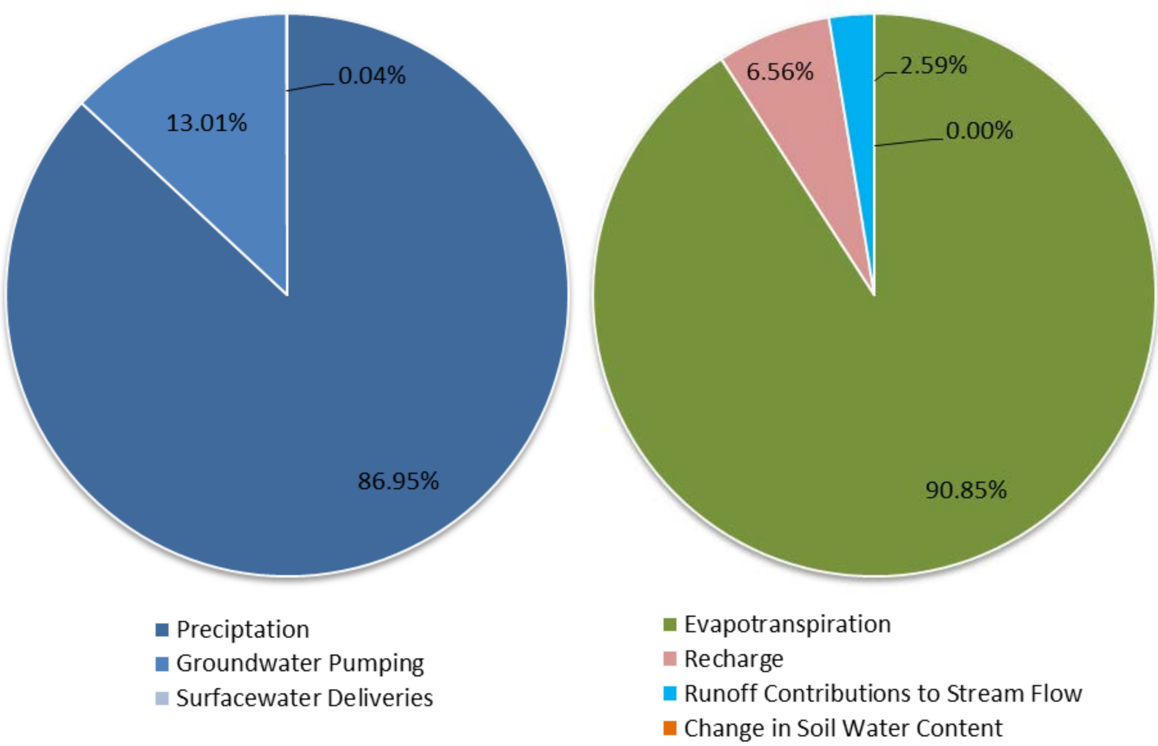


Figure 129. Sources of 21.51 in/ac of total available water and partitioned total available water within Box Butte County; High No Action.

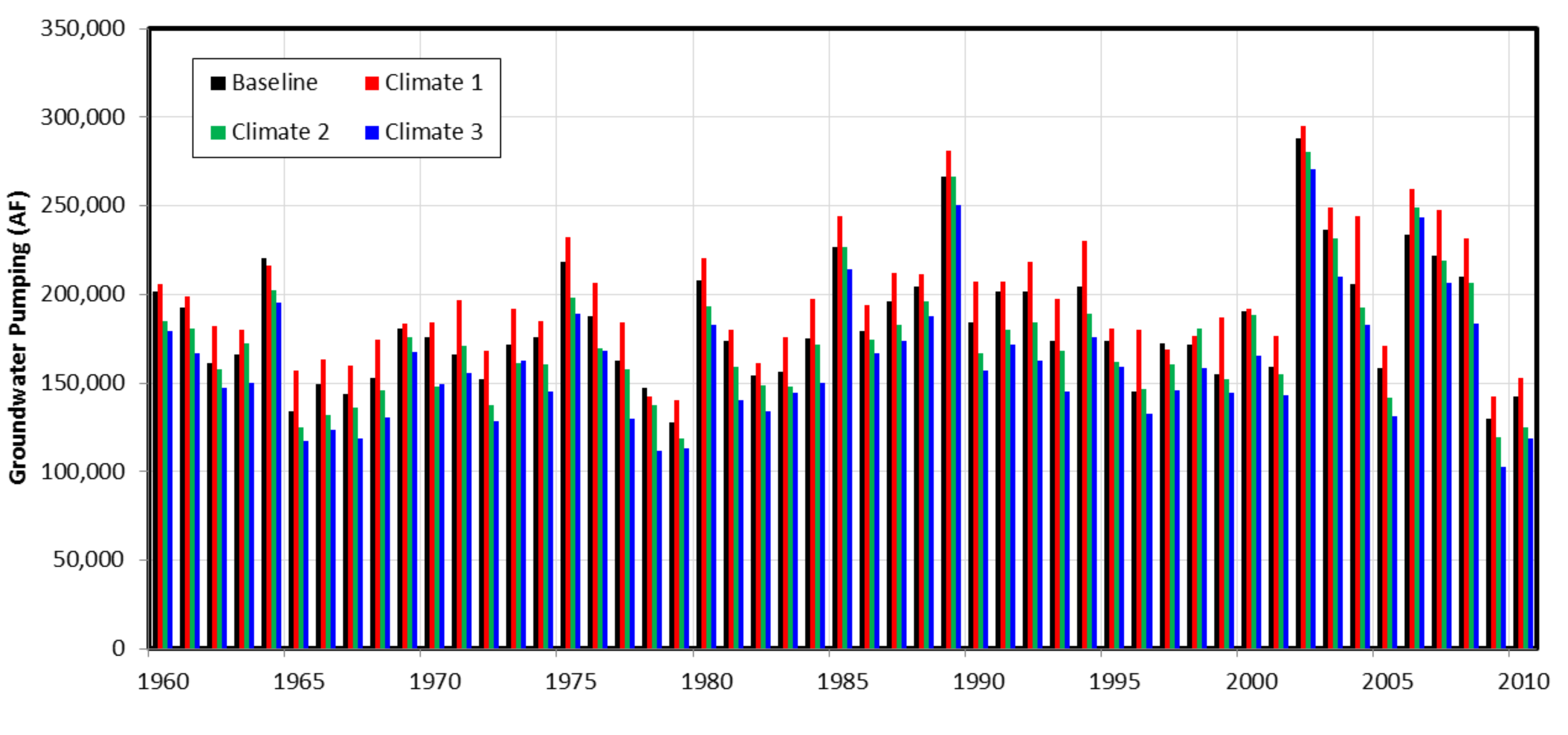


Figure 130. Comparison of annual groundwater pumping in Box Butte County under the various climate scenarios.

5.4 CENEB Model – Climate Scenarios

Upon completion of the base line run, each of the three climate scenarios was applied to the watershed model. Figures 131-133 provide the source and ultimate destination of the total applied water for each of the three climates for the entire Niobrara Drainage Basin upstream of the gauge near Spencer, NE within the CENEB model domain. The water balance within the CENEB model behaves in much the same way as the UNWNRD model; increase in precipitation lead to decreases in groundwater pumping and increases in evapotranspiration, recharge, and runoff contributions to stream flow. However, with the virtual deliveries method for surface water irrigated land, surface water deliveries react similar to groundwater pumping; declining in magnitude as precipitation increases (Table 25).

Table 25. Average percent change in water balance parameters in the Niobrara Drainage Basin within the CENEB model area upstream of the stream gauge near Spencer, NE; Baseline No Action

Climate Scenario	Precipi-tation	Ground-water Pumping	Surface Water Deliveries	Total Applied Water	ET	Recharge	Runoff Contributions to Streamflow
Climate 1	–9.36%	–0.37%	–0.37%	–9.17%	–8.69%	–13.40%	–3.34%
Climate 2	7.03%	–5.21%	–5.06%	6.77%	4.17%	24.22%	12.40%
Climate 3	13.49%	–6.41%	–6.27%	13.07%	7.31%	52.10%	26.07%

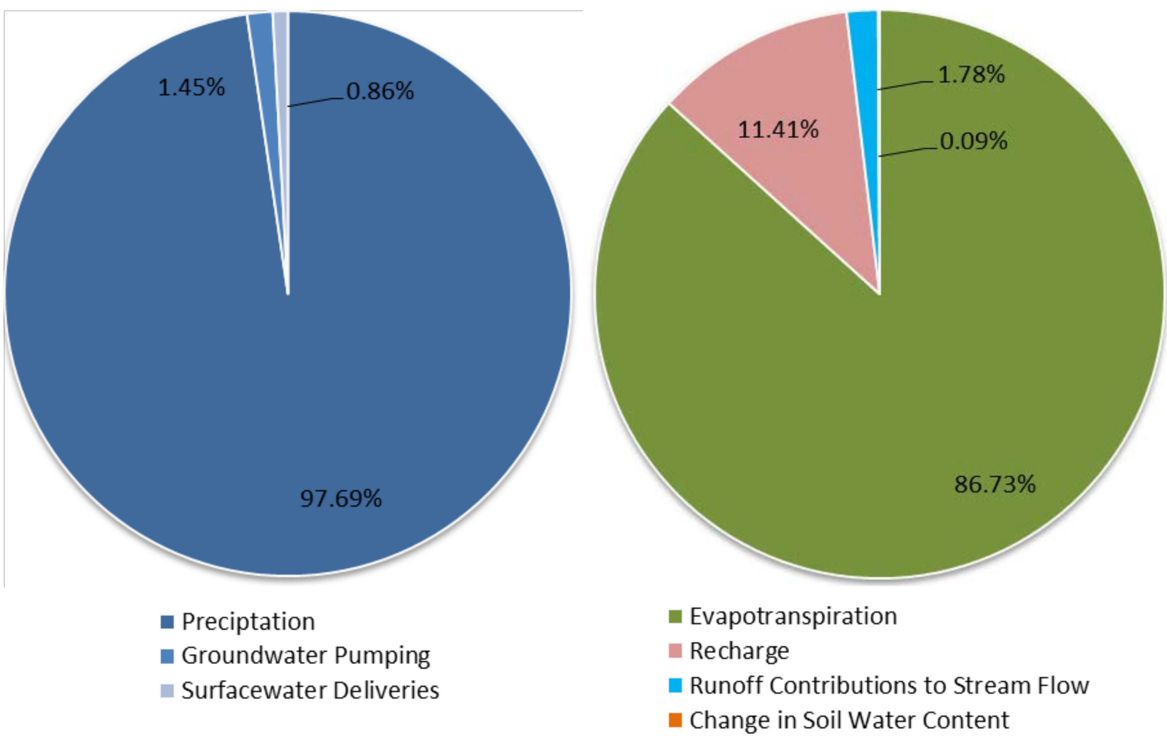


Figure 131. Sources of 19.39 in/ac of total available water and partitioned total available water for the Niobrara River Basin upstream of Spencer, NE within the CENEB model; Baseline No Action.

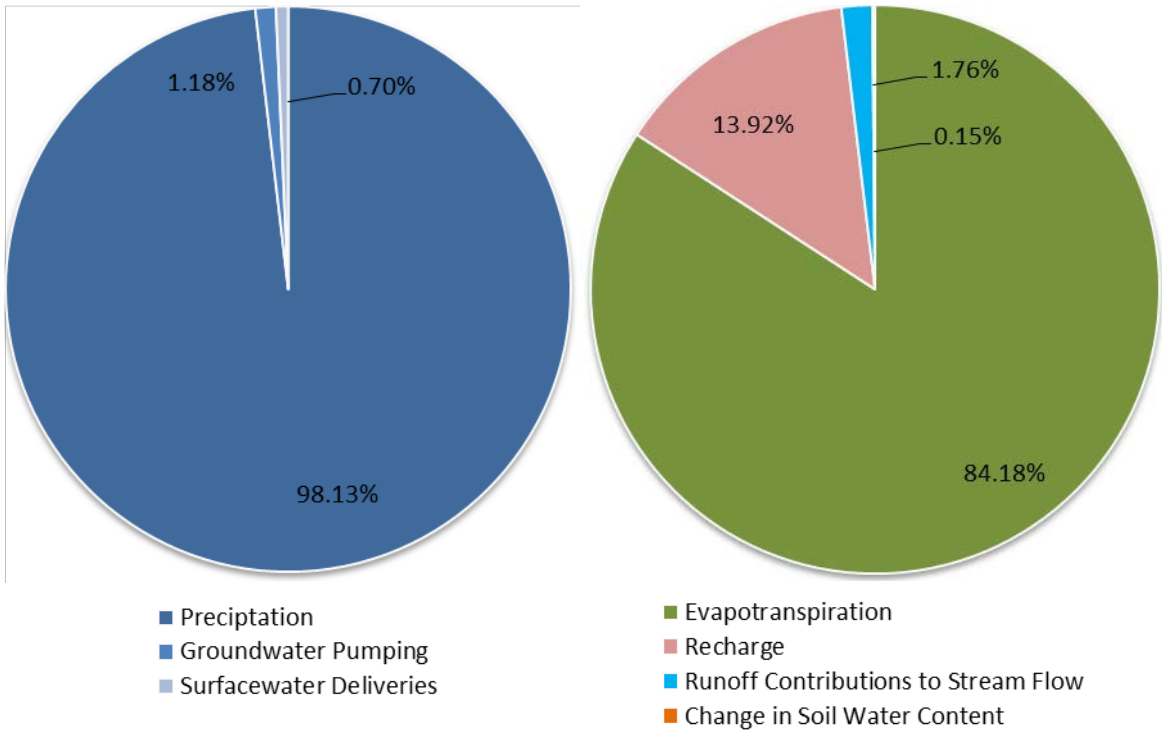


Figure 132. Sources of 22.79 in/ac of total available water and partitioned total available water for the Niobrara River Basin upstream of Spencer, NE within the CENEB model; Baseline No Action.

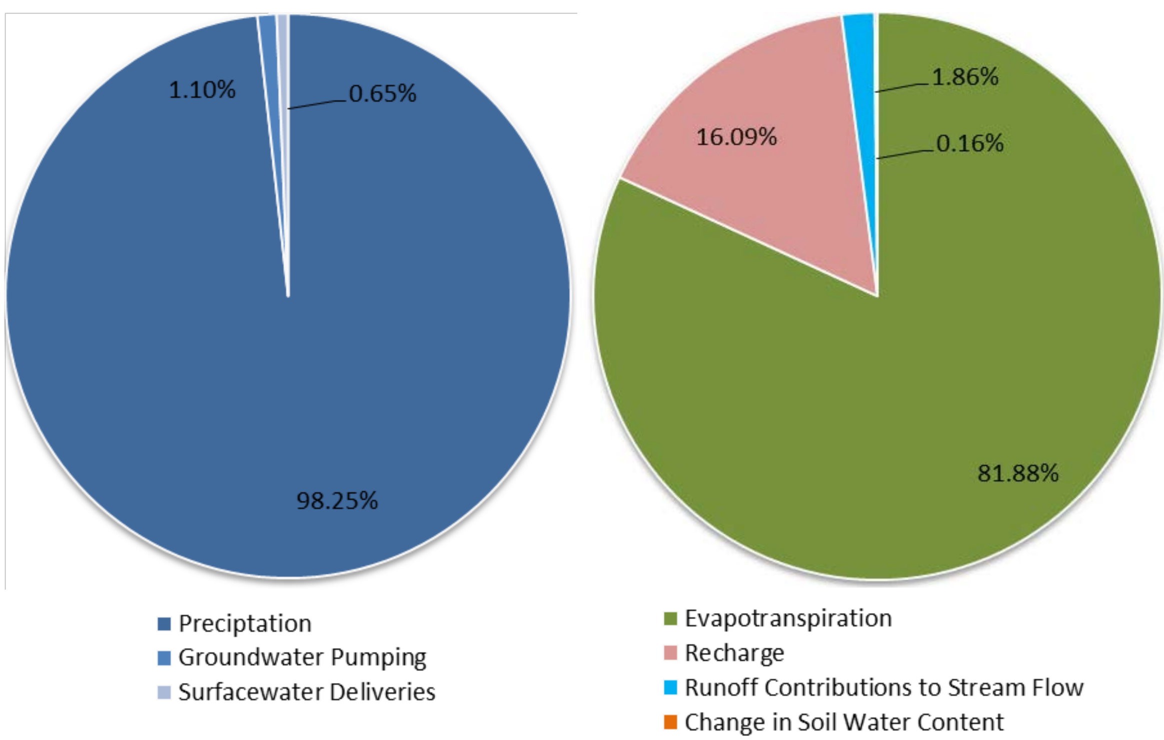


Figure 133. Sources of 24.13 in/ac of total available water and partitioned total available water for the Niobrara River Basin upstream of Spencer, NE within the CENEB model; Baseline No Action.

5.4.1 Average Annual Recharge

Annual average recharge in the CENEB model area was compare to the average annual recharge in the baseline climate scenario (Baseline No Action). Figures 134-139 depict the change in recharge for the various climate scenarios. For all three climates, recharge values tend to be relatively higher where there is higher precipitation, sandier soils, and irrigated crops.

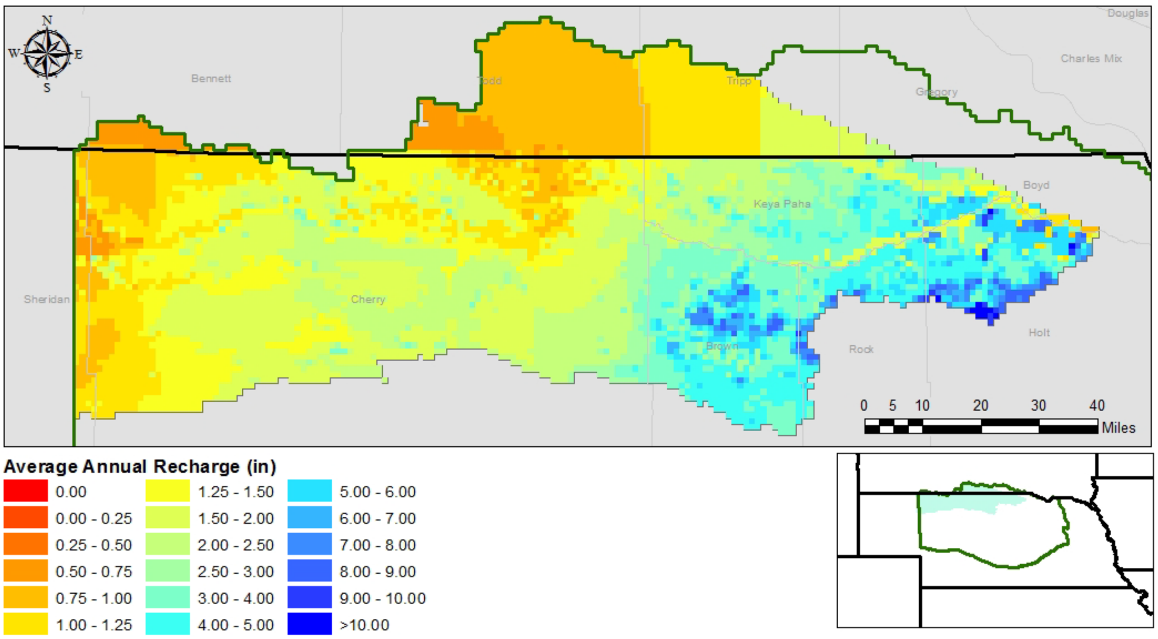


Figure 134. Average annual recharge for the Niobrara Drainage Basin in the CENEB model area; Low No Action.

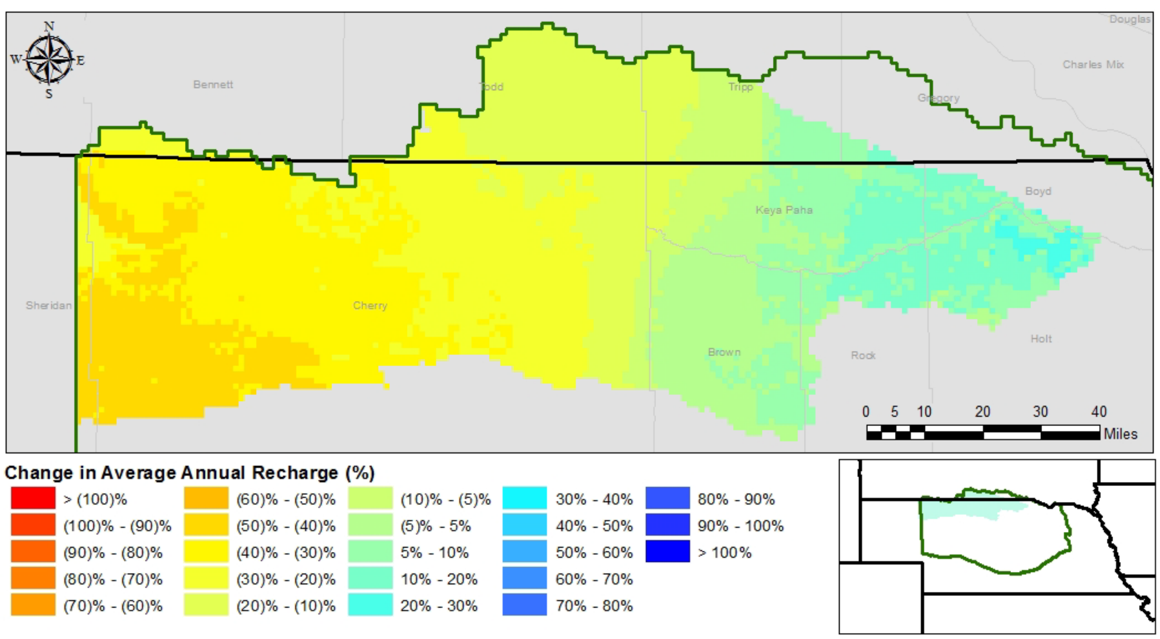


Figure 135. Percent change in average annual recharge within the CENEB model; between Low No Action and Baseline No Action.

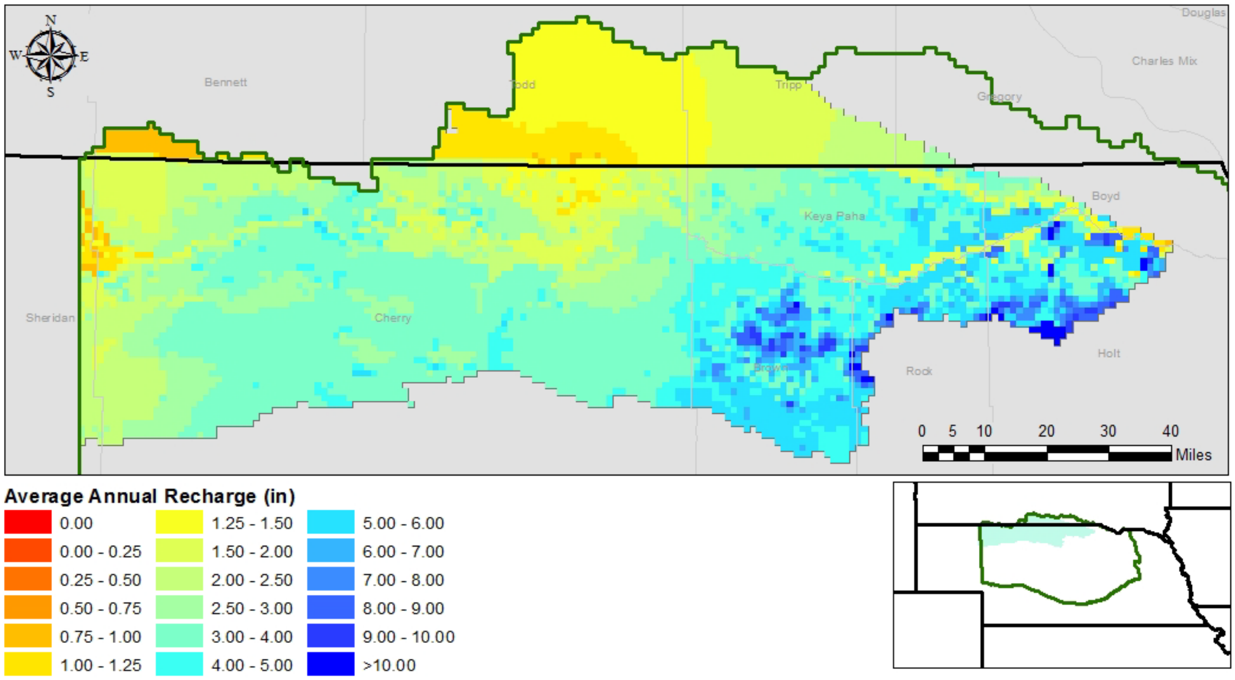


Figure 136. Average annual recharge for the Niobrara Drainage Basin in the CENEB model area; CT No Action.

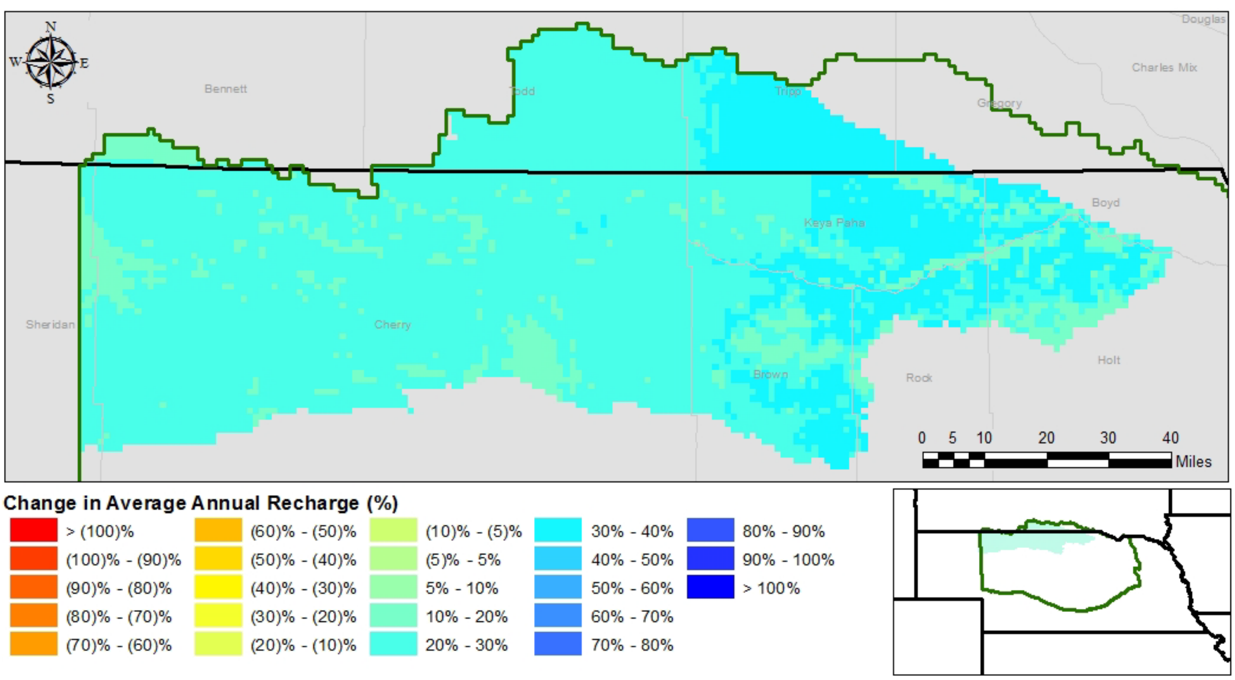


Figure 137. Percent change in average annual recharge within the CENEB model between; CT No Action and Baseline No Action.

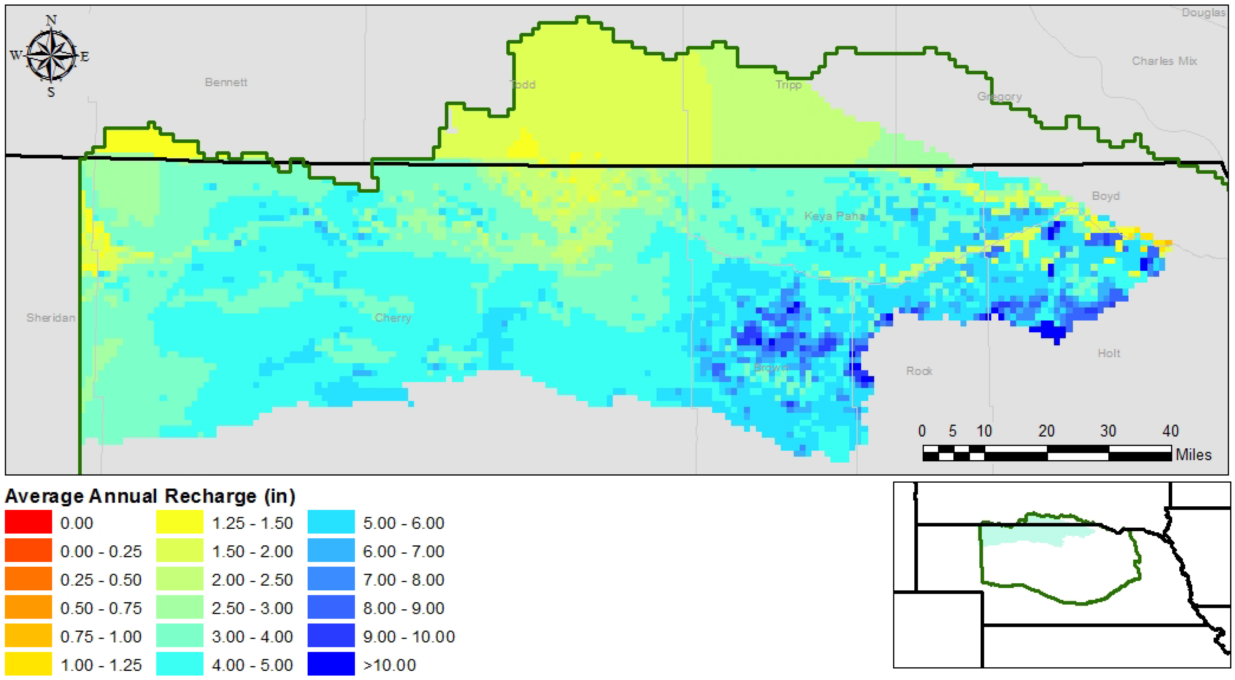


Figure 138. Average annual recharge for the Niobrara Drainage Basin in the CENEB model area; High No Action.

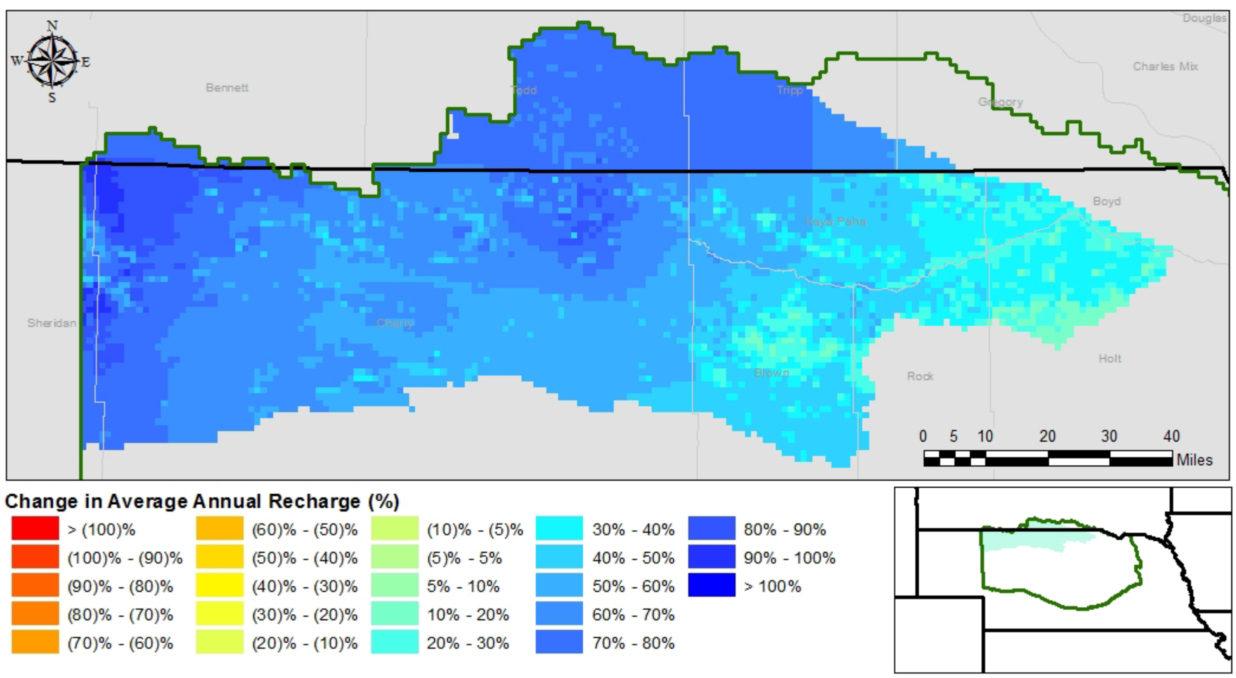


Figure 139. Percent change in average annual recharge within the CENEB model; between High No Action and Baseline No Action.

5.4.2 Runoff Zone 1

Runoff zone 1 followed the same general patterns as the basin as a whole (Figures 140-142). The notable exception being the relative change in surface water deliveries compared to change in precipitation between climates 2 and climate 3 (Table 26). This difference highlights the influence of timing on irrigation demand.

Table 26. Average Percent Change in Water Balance Parameters in Runoff Zone 1 within the CENEB Model; Baseline No Action

Climate Scenario	Precipi-tation	Ground-water Pumping	Surface Water Deliveries	Total Applied Water	ET	Recharge	Runoff Contributions to Streamflow
Climate 1	–14.89%	–1.34%	–0.42%	–14.84%	–11.46%	–37.27%	–16.71%
Climate 2	7.07%	–8.56%	–8.62%	7.01%	4.77%	21.57%	8.36%
Climate 3	15.58%	–8.02%	–7.83%	15.49%	8.17%	63.97%	24.23%

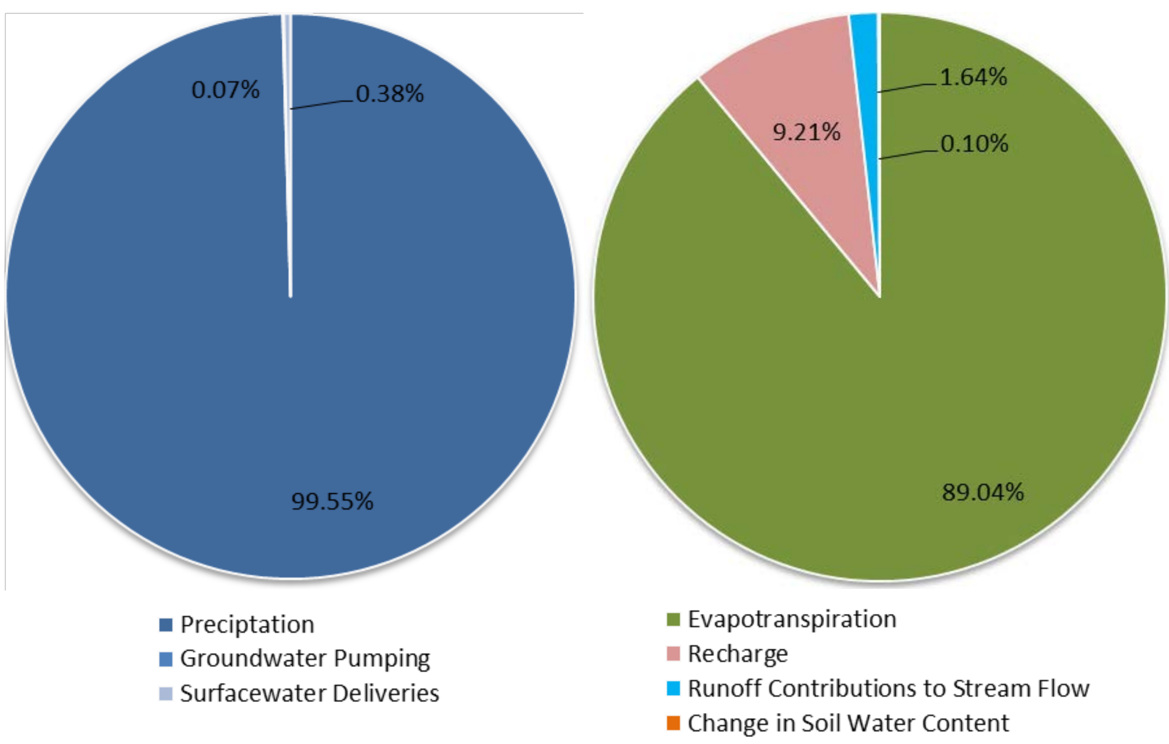


Figure 140. Sources of 17.35 in/ac of total available water and partitioned total available water within runoff zone 1 in the CENEB model; Low No Action.

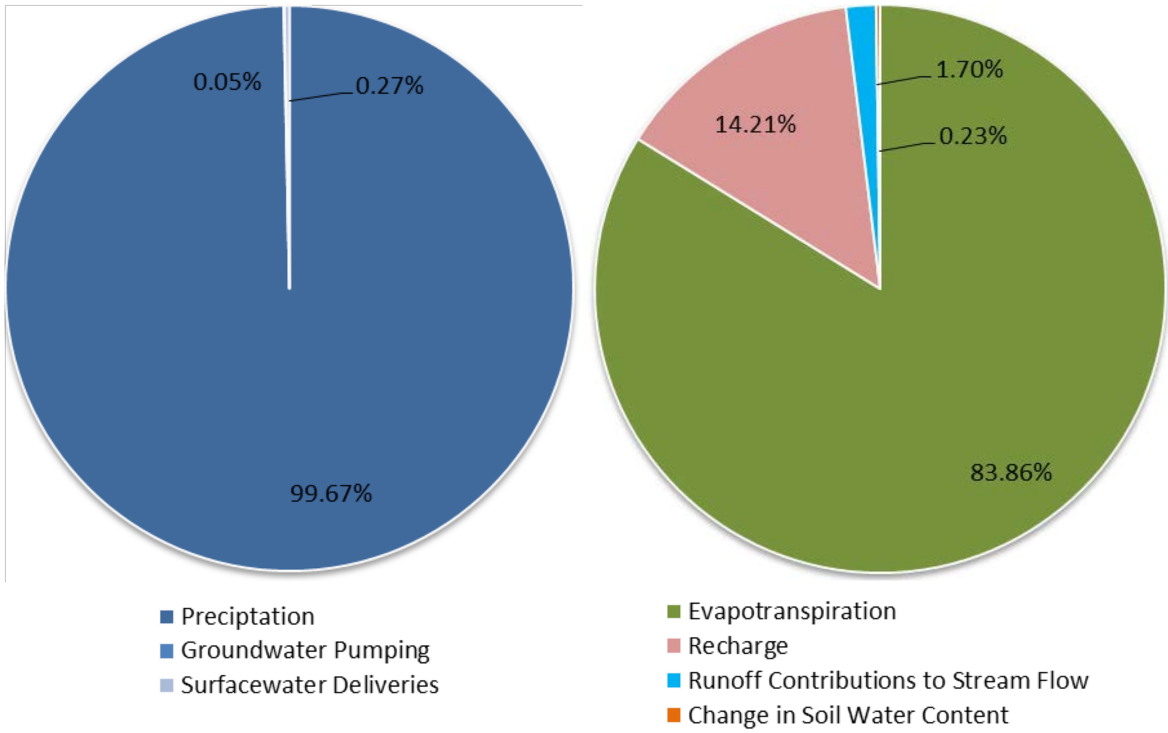


Figure 141. Sources of 21.80 in/ac of total available water and partitioned total available water within runoff zone 1 in the CENEB model; Baseline No Action.

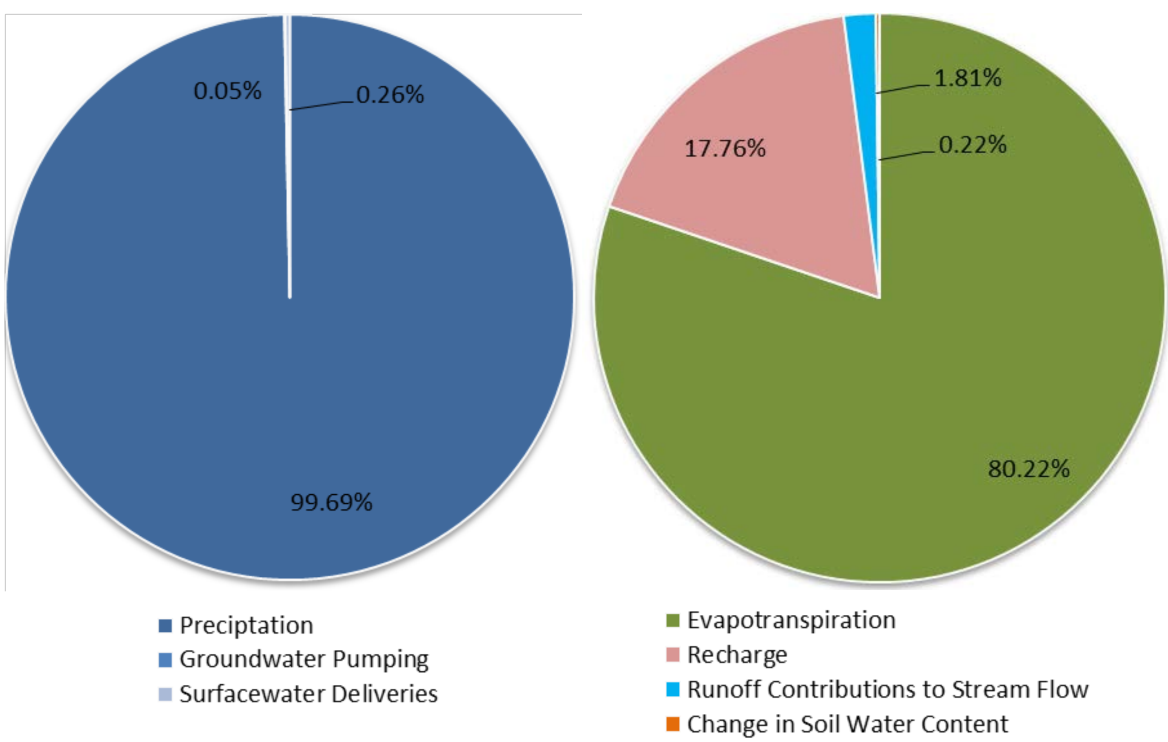


Figure 142. Sources of 23.53 in/ac of total available water and partitioned total available water within runoff zone 1 in the CENEB model; Baseline No Action.

5.4.3 Runoff Zone 2

Runoff zone 2 followed the same general patterns as the basin as a whole (Figures 143-145). The notable exception being the relative change in irrigation compared to change in precipitation between climates 2 and climate 3 (Table 27). This difference highlights the influence of timing on irrigation demand.

Table 27. Average Percent Change in Water Balance Parameters in Runoff Zone 2 within the CENEB Model; Baseline No Action

Climate Scenario	Precipi-tation	Ground-water Pumping	Surface Water Deliveries	Total Applied Water	ET	Recharge	Runoff Contributions to Streamflow
Climate 1	–14.27%	–0.90%	–1.25%	–14.16%	–11.71%	–33.34%	–14.72%
Climate 2	7.12%	–9.26%	–8.77%	6.98%	5.06%	21.41%	10.76%
Climate 3	15.52%	–8.90%	–8.18%	15.32%	8.77%	65.47%	30.71%

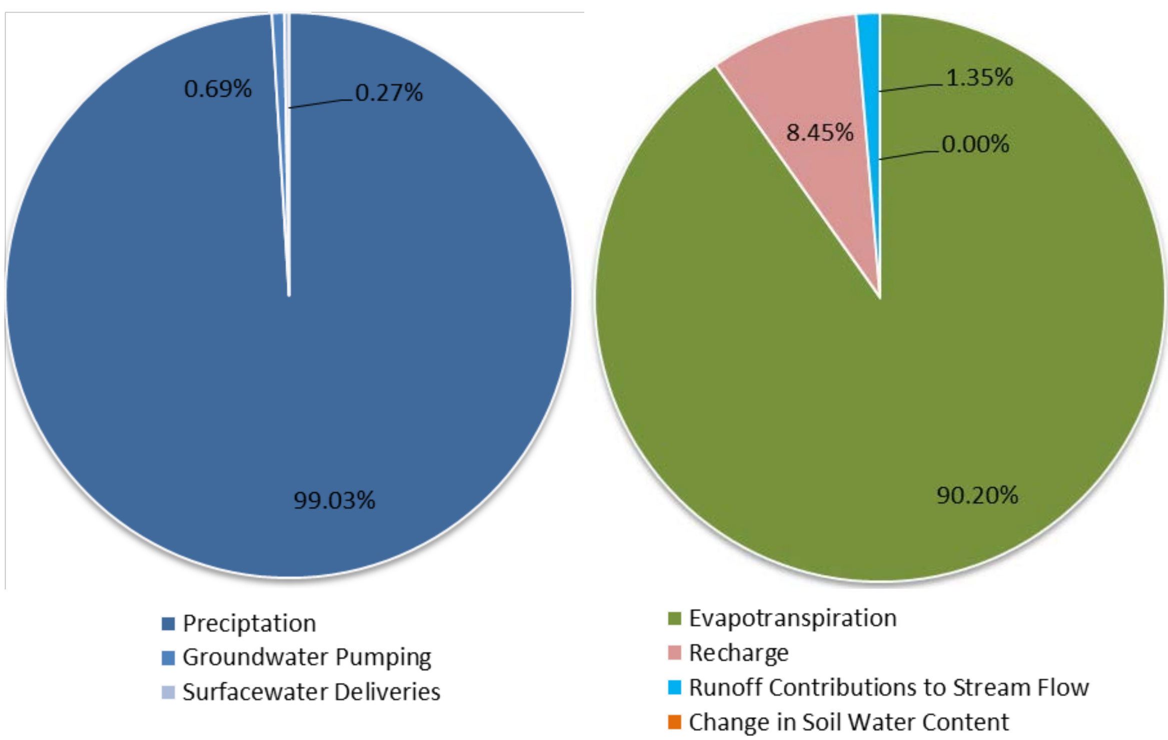


Figure 143. Sources of 17.17 in/ac of total available water and partitioned total available water within runoff zone 2 in the CENEB model; Baseline No Action.

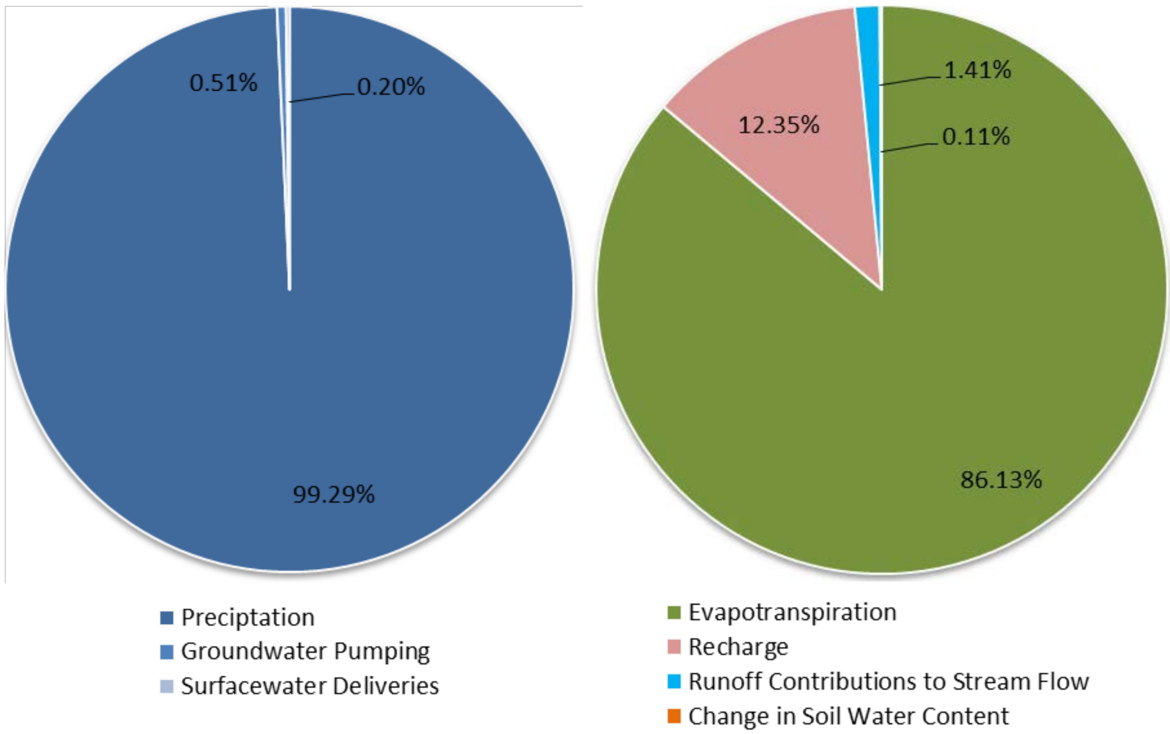


Figure 144. Sources of 21.40 in/ac of total available water and partitioned total available water within runoff zone 2 in the CENEB model; Baseline No Action.

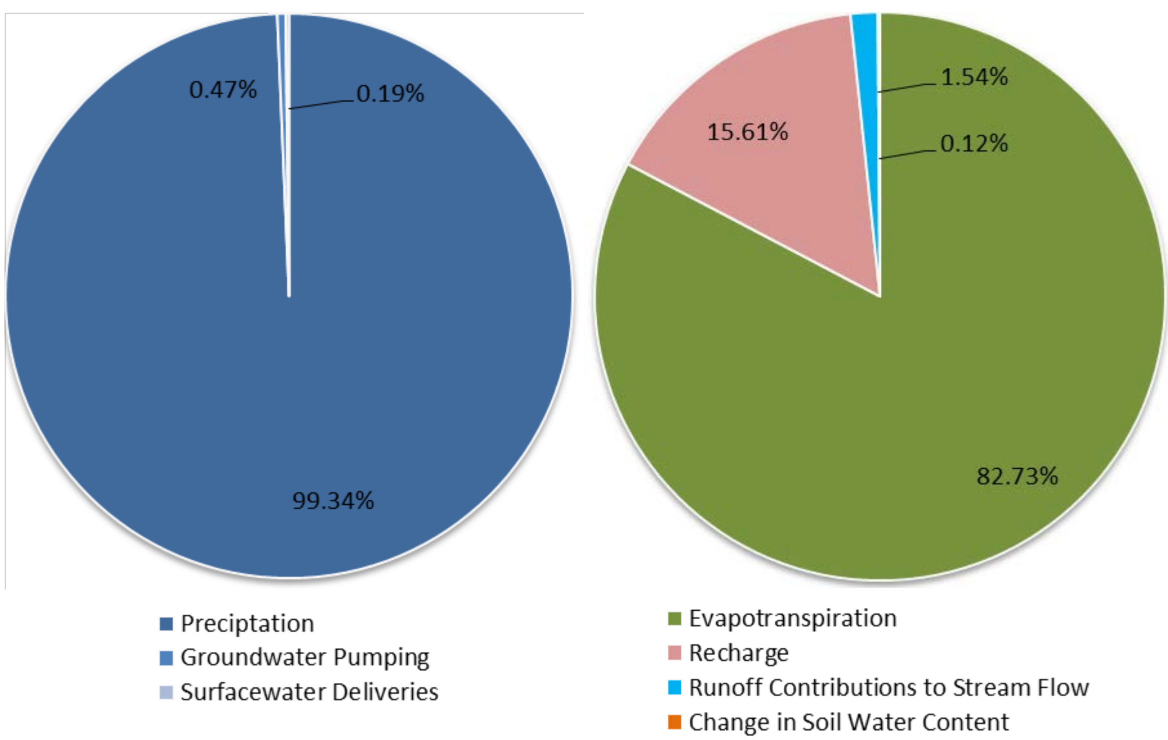


Figure 145. Sources of 23.07 in/ac of total available water and partitioned total available water within runoff zone 2 in the CENEB model; Baseline No Action.

Runoff Zone 3

Runoff zone 3 followed the same general patterns as the basin as a whole (Figures 146-148). Increases in precipitation reduces applied irrigation while increasing evapotranspiration, recharge, and runoff contributions to stream flow (Table 28). This difference highlights the influence of timing on irrigation demand.

Table 28. Average Percent Change in Water Balance Parameters in Runoff Zone 3 within the CENEB Model; Baseline No Action

Climate Scenario	Precipi-tation	Ground-water Pumping	Surface Water Deliveries	Total Applied Water	ET	Recharge	Runoff Contributions to Streamflow
Climate 1	–5.30%	–0.26%	–0.26%	–5.14%	–6.29%	1.02%	3.67%
Climate 2	6.96%	–4.38%	–4.45%	6.60%	3.50%	26.16%	13.65%
Climate 3	11.83%	–5.89%	–23.75%	11.27%	6.21%	42.95%	24.04%

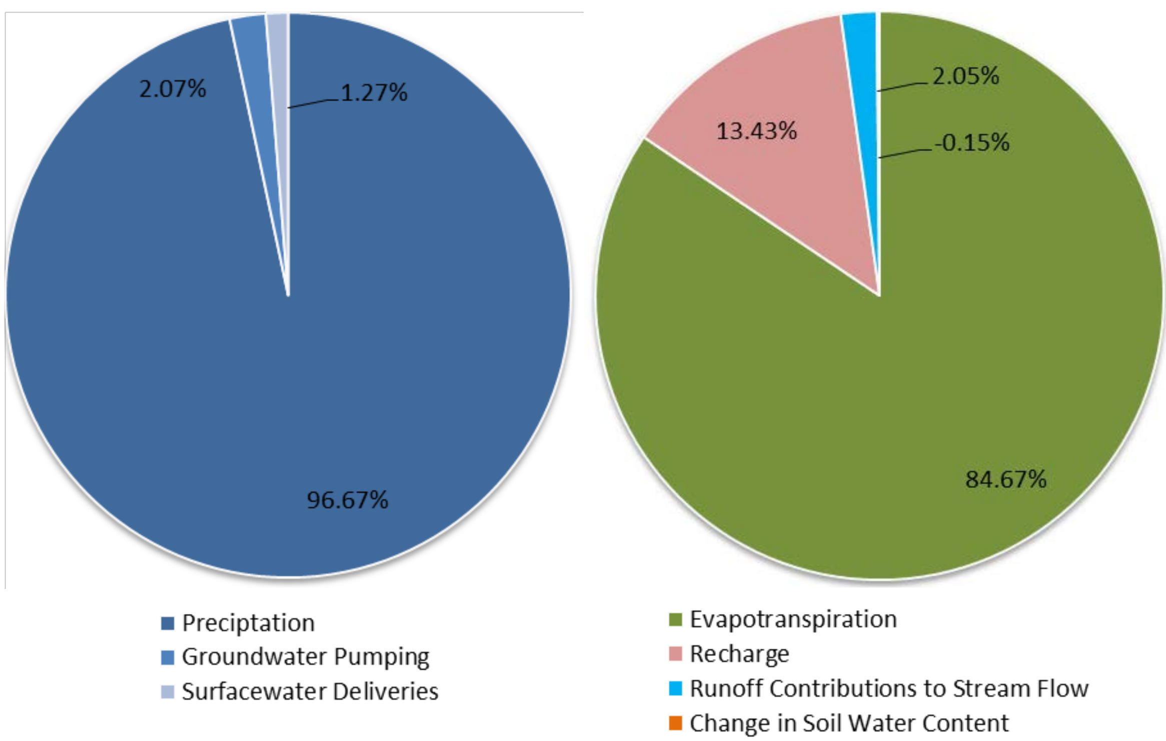


Figure 146. Sources of 21.32 in/ac of total available water and partitioned total available water within runoff zone 3 in the CENEB model; Baseline No Action.

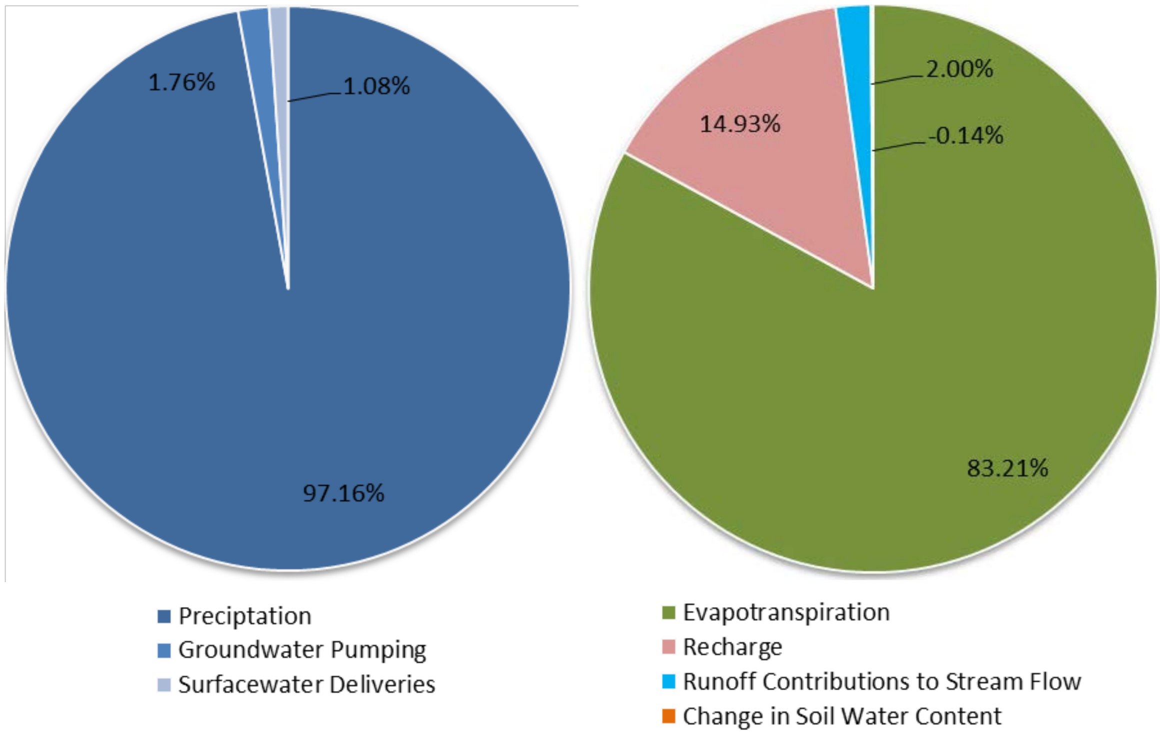


Figure 147. Sources of 23.96 in/ac of total available water and partitioned total available water within runoff zone 3 in the CENEB model; Baseline No Action.

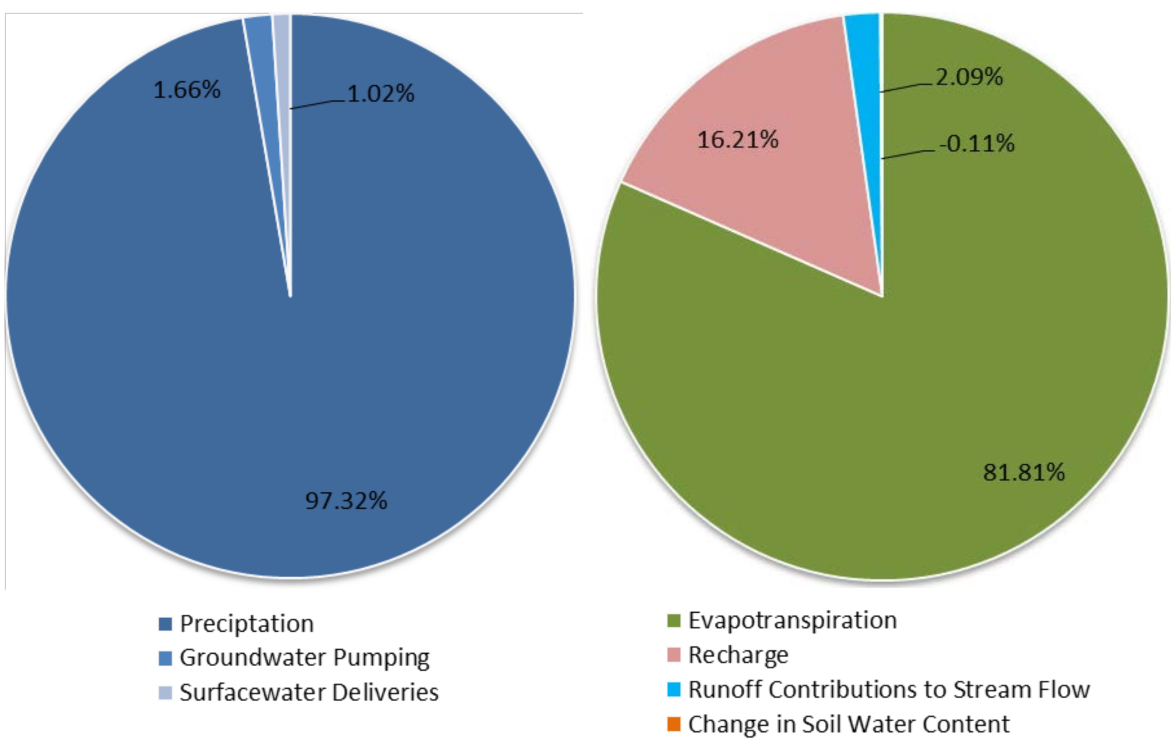


Figure 148. Sources of 25.01 in/ac of total available water and partitioned total available water within runoff zone 3 in the CENEB model; Baseline No Action.

5.5 Alternative 1 – Pumping station

5.5.1 Niobrara Drainage Basin

On a model wide scale, there was limited change to the water balance; yielding only a couple hundredths of a percent change (Figure 149) from the no action alternative. This is expected as the changes for the alternative were concentrated in a small portion of the watershed model. This characteristic persists in the climate scenarios as well.

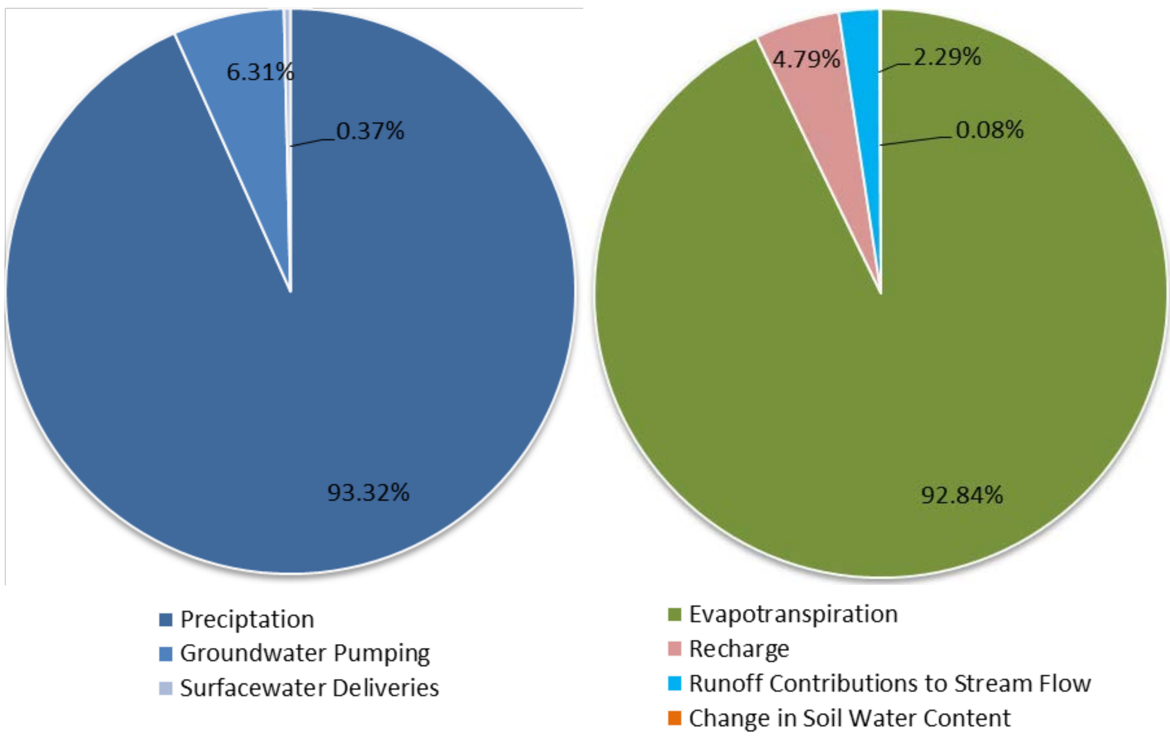


Figure 149. Sources of 17.22 in/ac of total available water and partitioned total available water for the pumping station alternative within the Niobrara Drainage Basin within the UNWNRD model; Baseline No Action.

5.5.2 Average Annual Recharge

The percent change in average aquifer recharge between the No Action and Alternative 1 for all four climate scenarios are shown in Figures 150-153. As expected, the change in recharge is concentrated around the Mirage Flats Irrigation district. The lack of seepage along the canal greatly reduced the recharge in those cells, while the irrigated land saw small increase resulting from the increased deliveries.

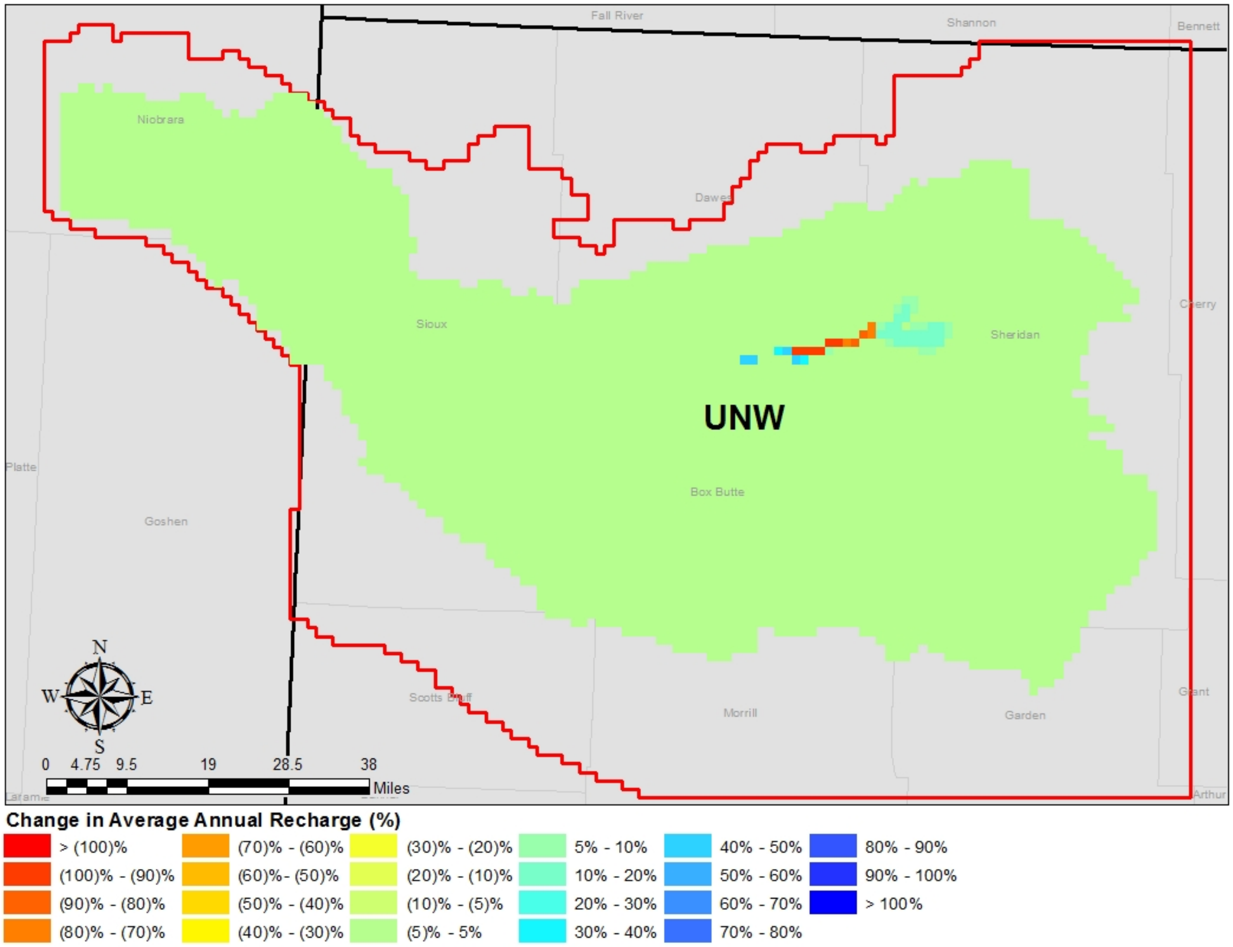


Figure 150. Percent change in average annual recharge within the UNWNRD model between the No Action and Pumping Station Alternative; Baseline No Action.

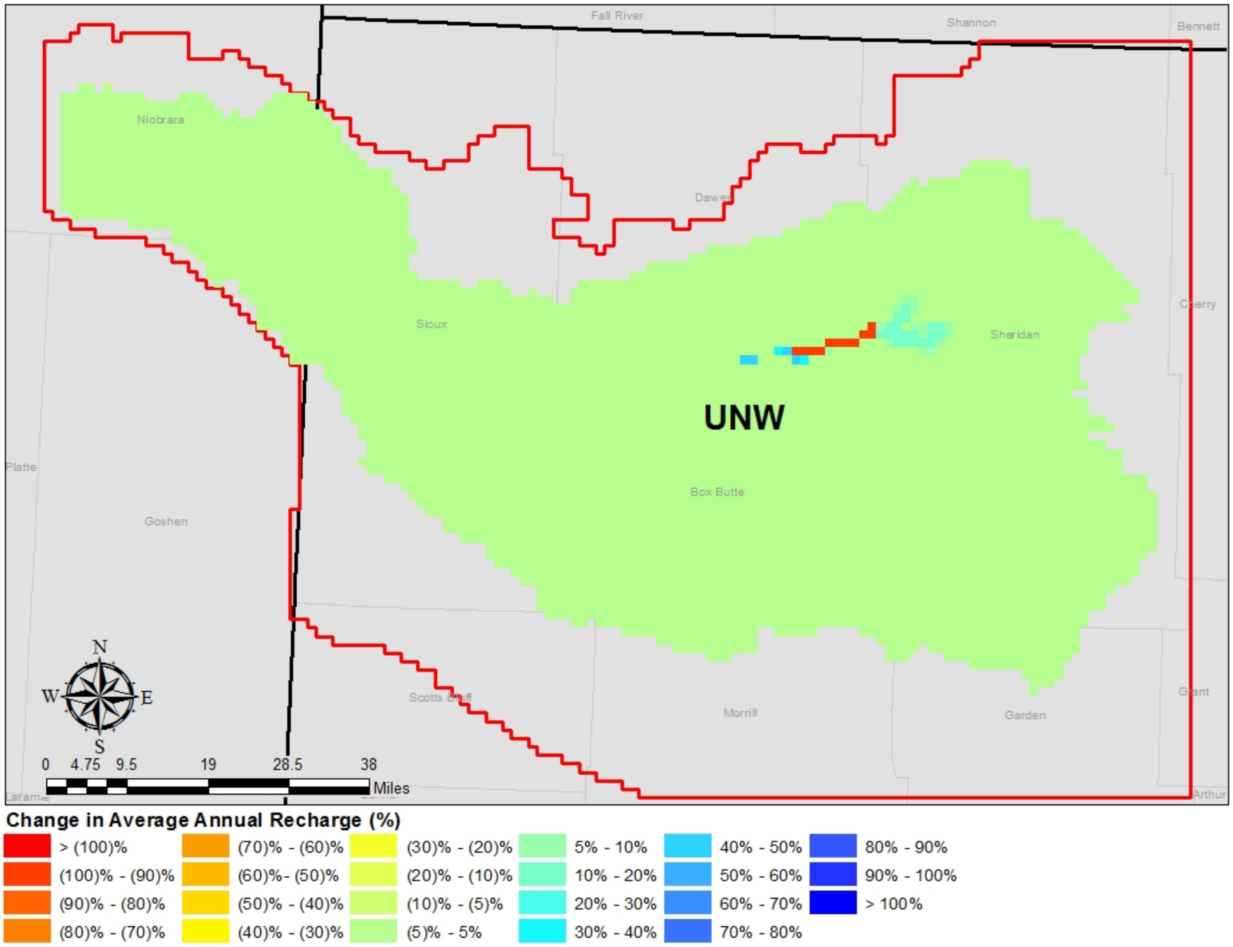


Figure 151. Percent change in average annual recharge within the UNWNRD model between the No Action and Pumping Station Alternative; CT No Action and Alt 1 CT.

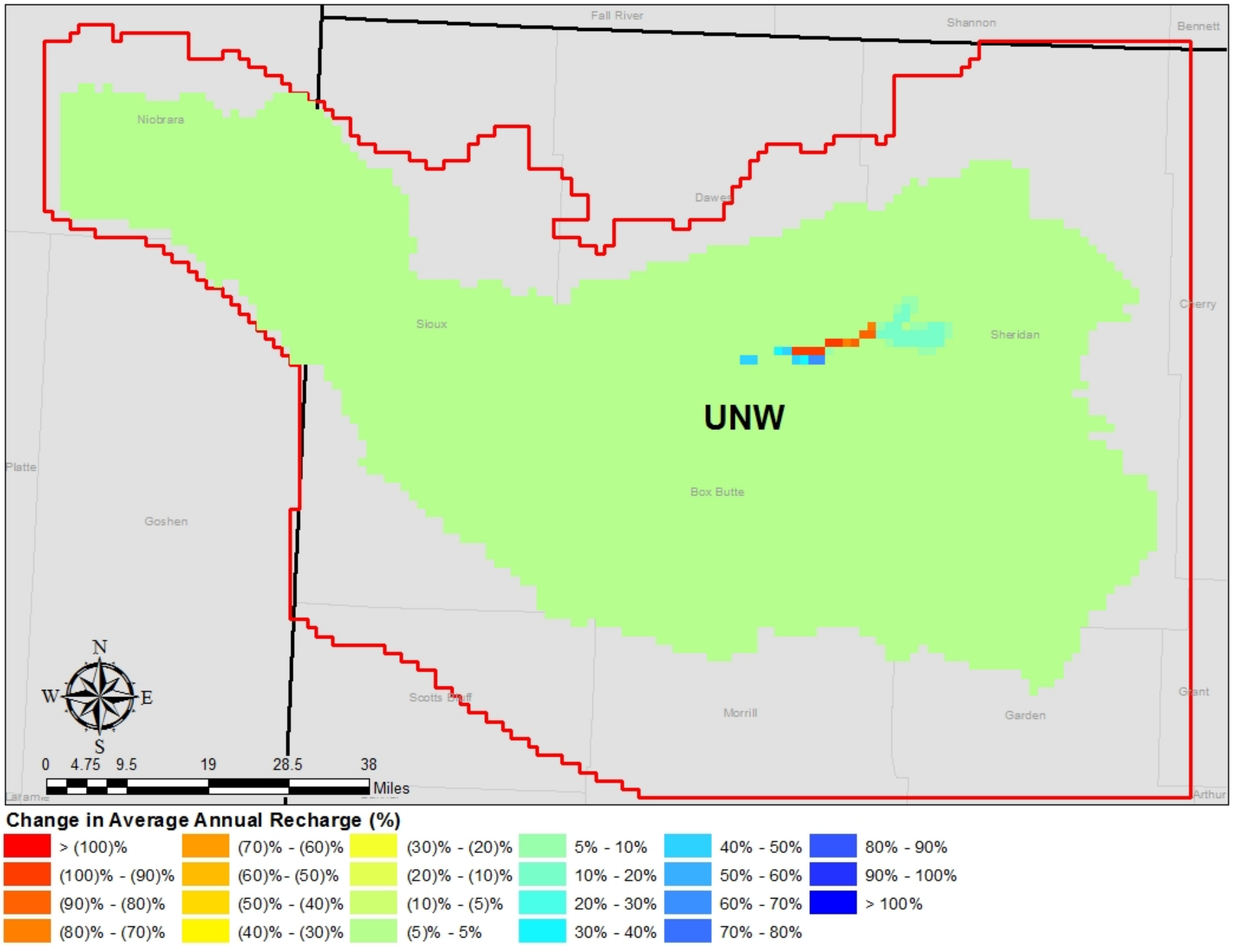


Figure 152. Percent change in average annual recharge within the UNWNRD model between the No Action and Pumping Station Alternative; CT No Action and Alt 1 CT.

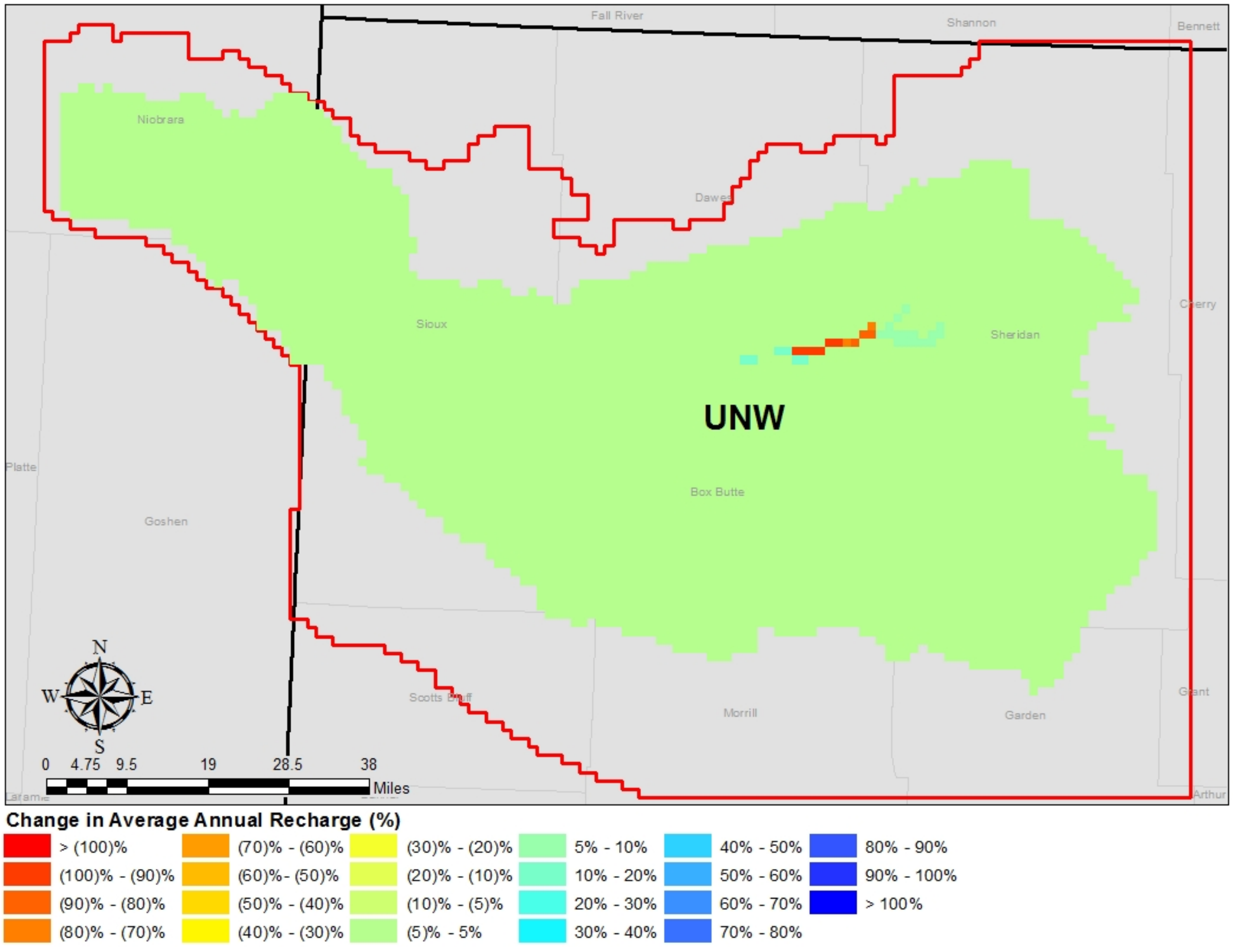


Figure 153. Percent change in average annual recharge within the UNWNRD model between the No Action and Pumping Station Alternative; High No Action and Alt 1 High.

5.5.3 Runoff Zones

As runoff zones 1-3 were all upstream of the Mirage Flats Irrigation District, there were no changes to the water balances within these zones. Within runoff zones 4 (Figure 154) and 5 (Figure 155), the water balance changes become more pronounced, but are still dwarfed by the size of the runoff zone relative to the size of the alternative. This property holds true in the climate scenarios as well.

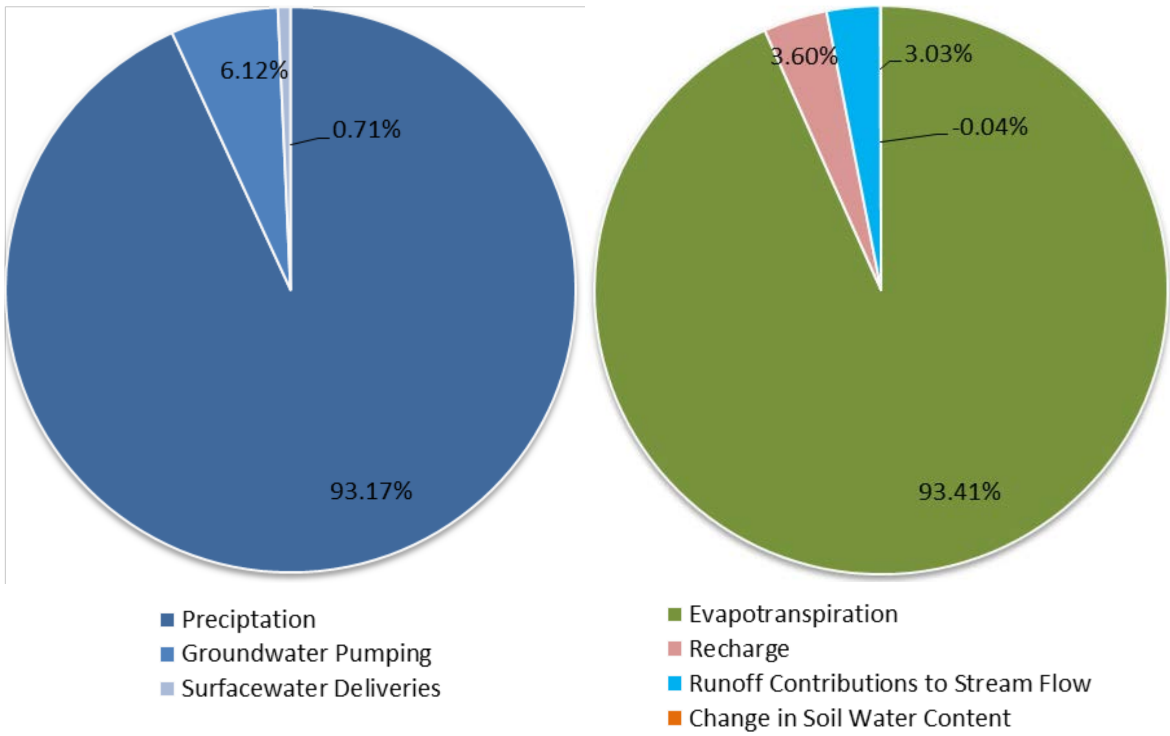


Figure 154. Sources of 17.20 in/ac of total available water and partitioned total available water for the pumping station alternative within runoff zone 4 the UNWNRD model; Baseline No Action.

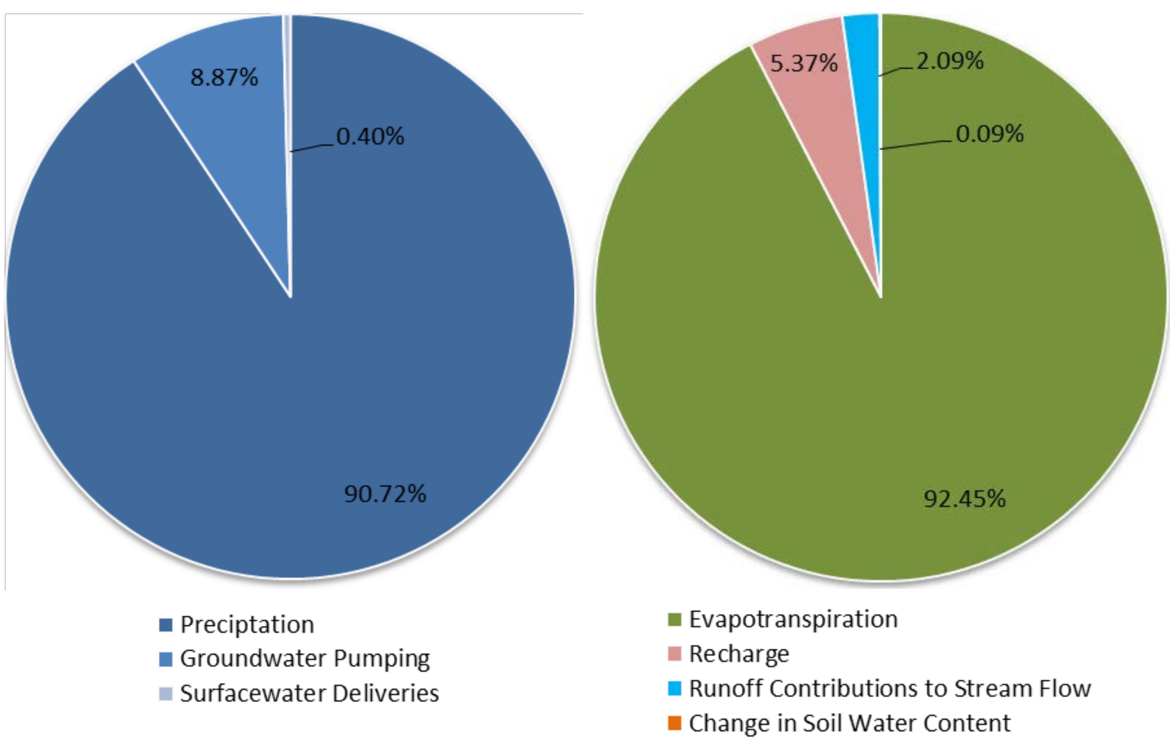


Figure 155. Sources of 18.01 in/ac of total available water and partitioned total available water for the pumping station alternative within runoff zone 5 the UNWNRD model; Baseline No Action.

5.5.4 Mirage Flats Irrigation District

Within the Mirage Flats Irrigation District, the pumping station delivers the desired effect. For each climate, the pumping station was able to increase the volume of surface water delivered to irrigators and reduce the need for supplemental co-mingled pumping (Table 29, Figures 156-159).

Table 29. Percent Change in the Average Water Balance between the No Action and Pumping Station Alternatives under the Various Climate Scenarios

Climate Scenario	Precipi-tation	Ground-water Pumping	Surface Water Deliveries	Total Applied Water	ET	Recharge	Runoff Contributions to Streamflow
Baseline	–	–32.43%	93.96%	4.83%	2.48%	16.95%	19.03%
Climate 1	–	–22.86%	102.08%	4.37%	2.33%	17.28%	17.78%
Climate 2	–	–40.75%	86.17%	5.20%	2.64%	17.15%	19.47%
Climate 3	–	–25.14%	29.69%	2.26%	1.19%	6.74%	7.02%

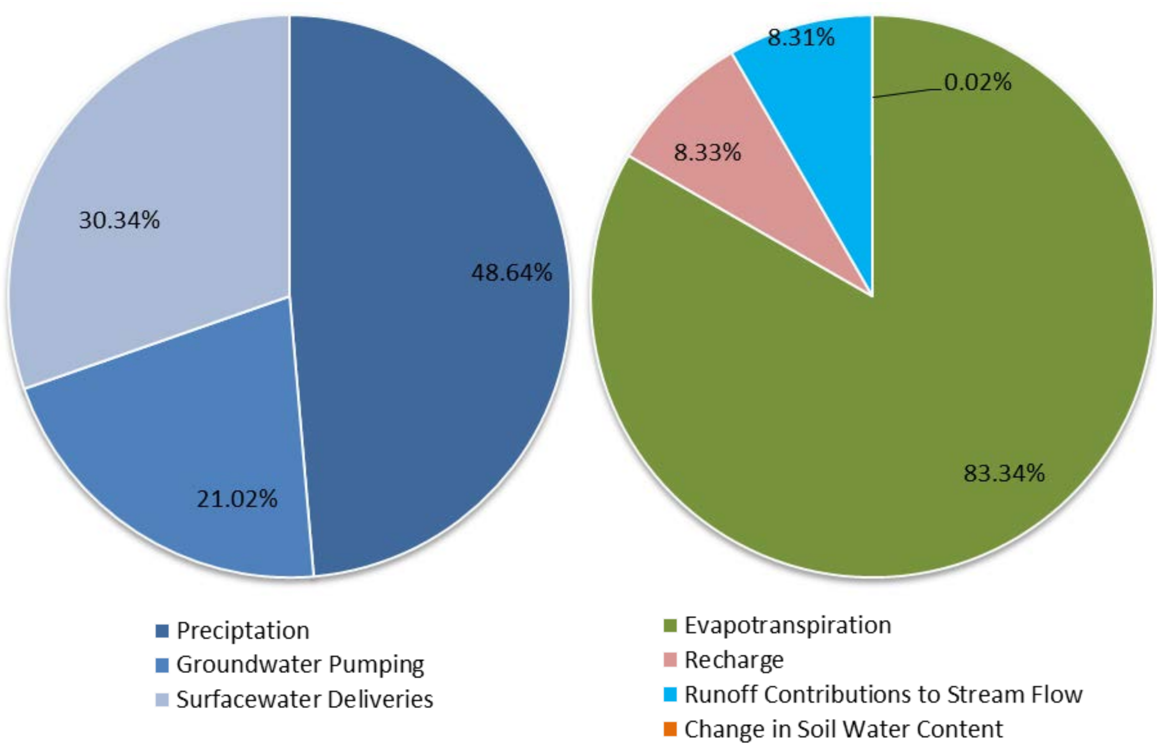


Figure 156. Sources of 34.39 in/ac of total available water and partitioned total available water for the pumping station alternative within the Mirage Flats Irrigation District; Baseline No Action.

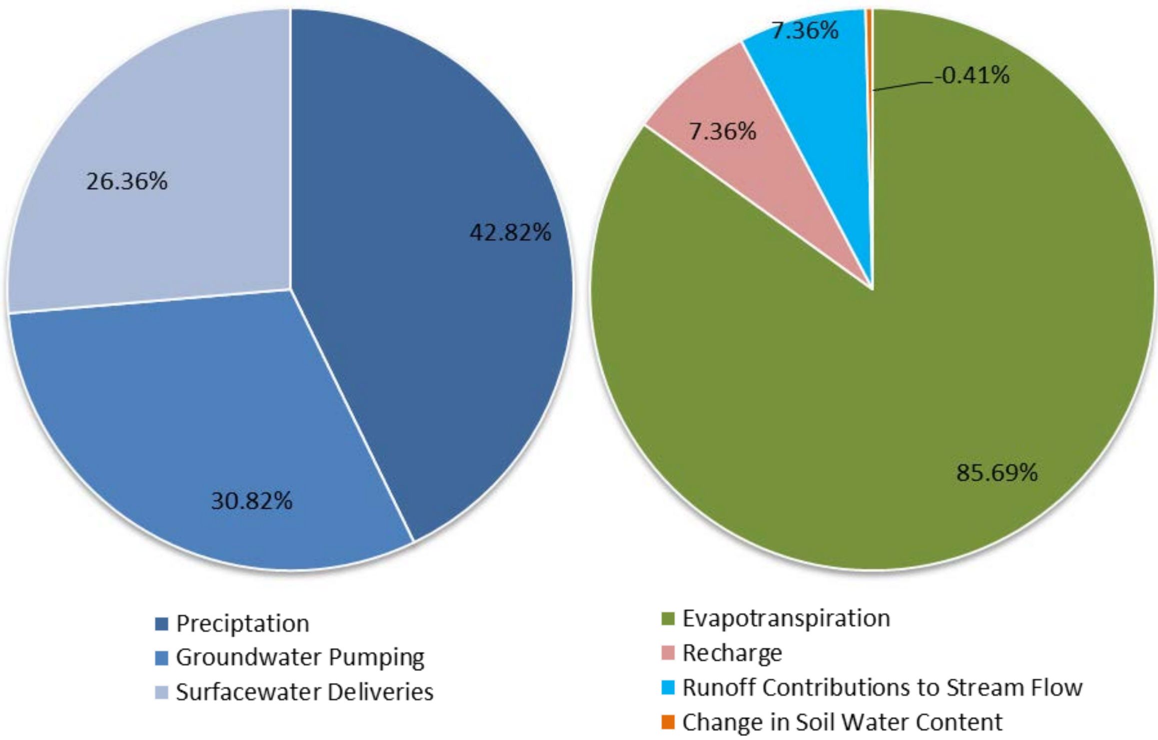


Figure 157. Sources of 32.61 in/ac of total available water and partitioned total available water for the pumping station alternative within the Mirage Flats Irrigation District; Alt 1 Low.

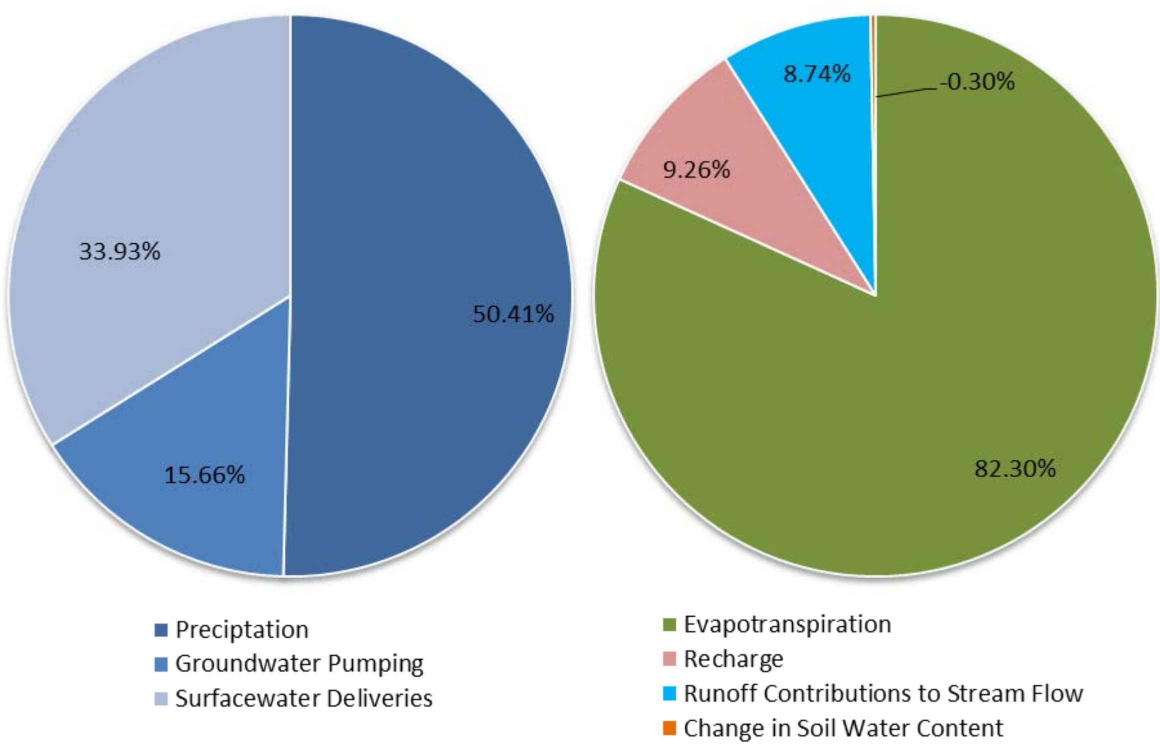


Figure 158. Sources of 35.54 in/ac of total available water and partitioned total available water for the pumping station alternative within the Mirage Flats Irrigation District; Alt 1 CT.

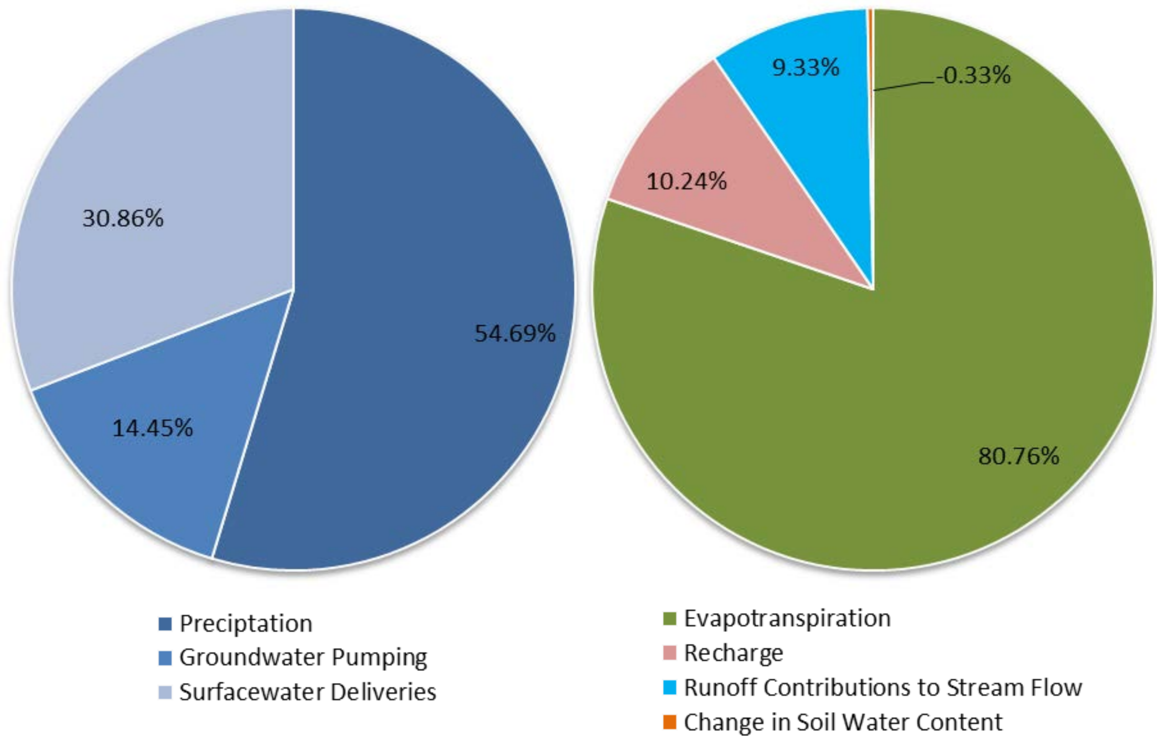


Figure 159. Sources of 36.29 in/ac of total available water and partitioned total available water for the pumping station alternative within the Mirage Flats Irrigation District; Alt 1 High.

5.5.5 Gaps in Surface Water Irrigation Groups Water Availability

Within the Mirage Flats Irrigation District (Group 9), the pumping station generally increased the volume of surface water delivered to irrigators while decreasing the need for supplemental co-mingled pumping (Figures 160-167). This holds for true for the baseline (Baseline No Action) and climate scenario 1 (Alt 1 Low). For climate scenario 2 (Alt 1 CT) & 3 (Alt 1 High), the observation holds true for a majority of the time; but, there are year in which the pumping station would not improve the delivery efficiency. Within climate 3, there are even years when the pumping station delivers less than the no action alternative.

Surface Water Irrigation Group 8 is the only other group which experienced consistent changes in surface water deliveries and co-mingled pumping. Typically, surface water deliveries increased and co-mingled pumping decreased. However, the deviation that existed for the Mirage Flats Irrigation District also occurred within surface water irrigation group 8.

5.5.6 Canal Recharge

While the pumping station alternative generally succeeded in improving the surface water delivery efficiency to the Mirage Flats Irrigation District, it also greatly reduced the volume of canal seepage in the system. For all climate scenarios, several thousand acre-feet of canal seepage are no longer in the system (Figures 176-179).

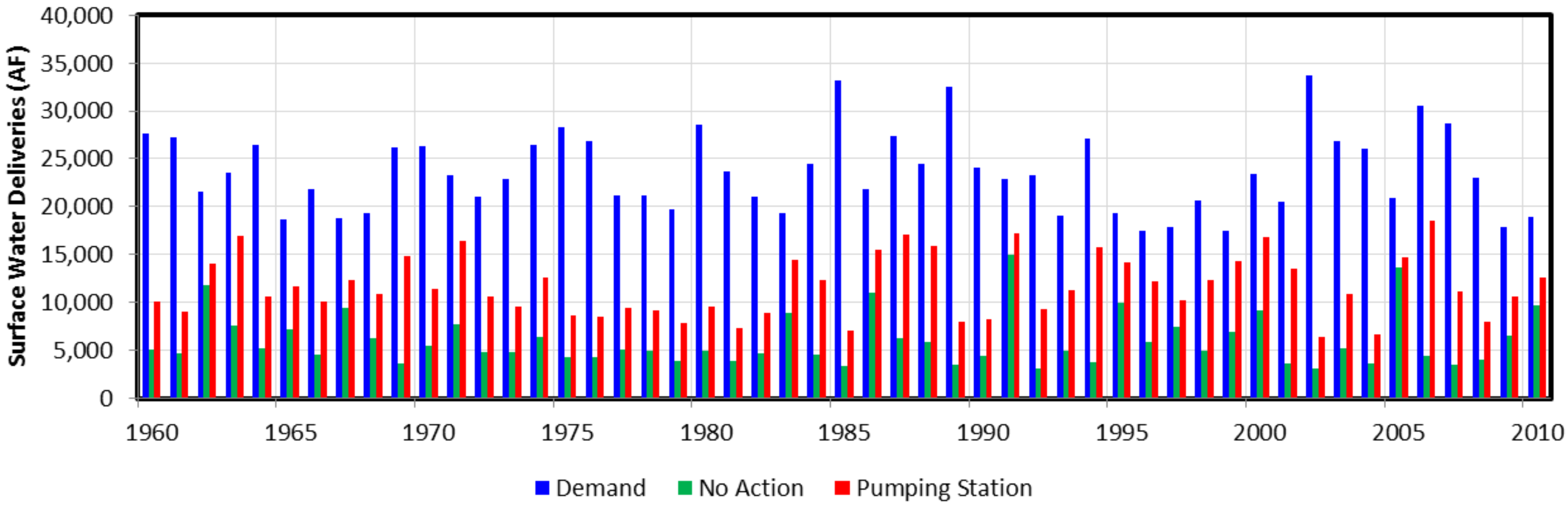


Figure 160. Comparison of the annual surface water demands and deliveries for the pumping station alternative for Group 9; Baseline No Action.

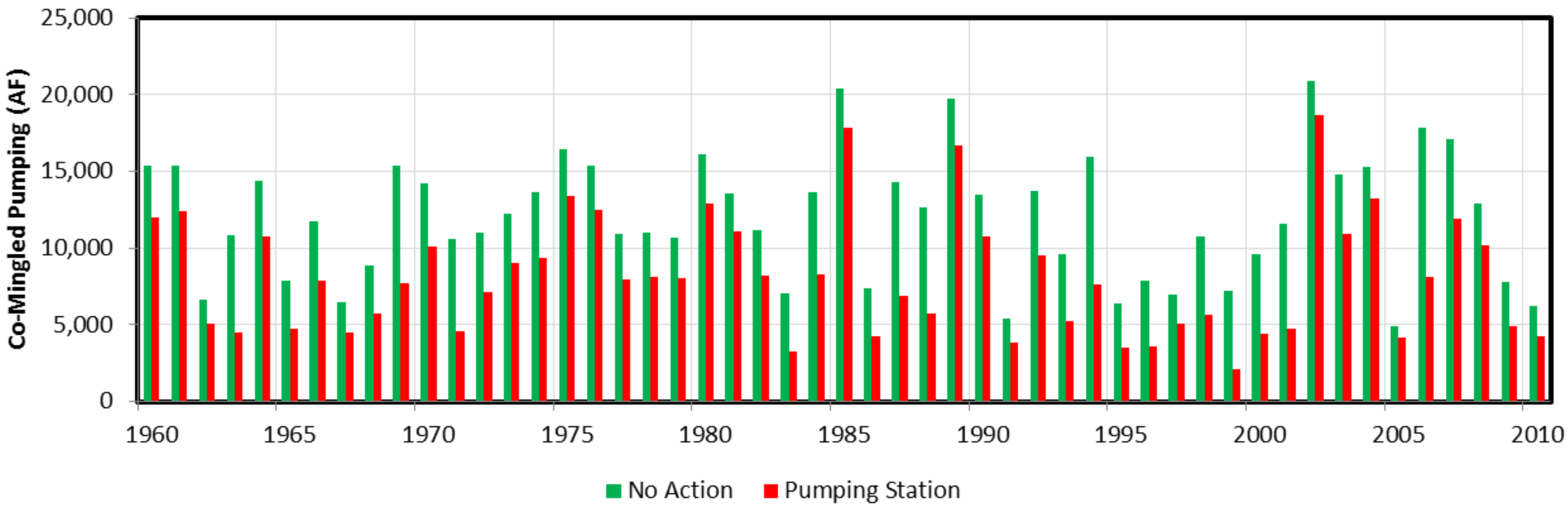


Figure 161. Comparison of the annual co-mingle pumping volumes for the pumping station alternative for Group 9; Baseline No Action.

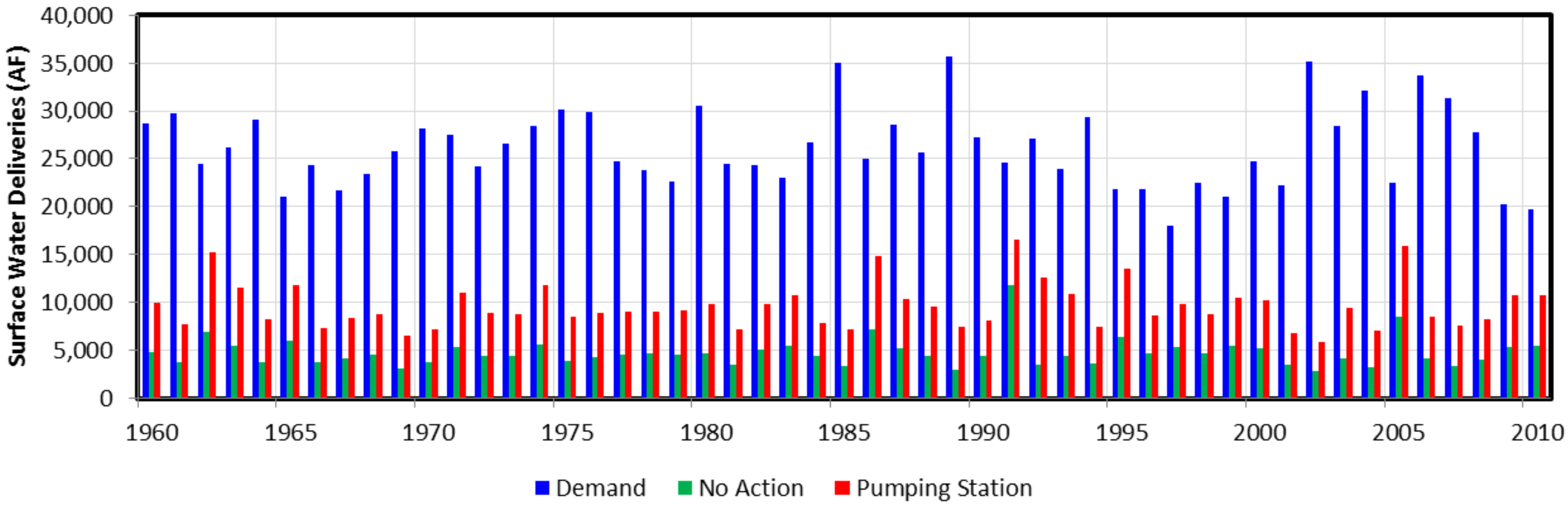


Figure 162. Comparison of the annual surface water demands and deliveries for the pumping station alternative for Group 9; Alt 1 Low.

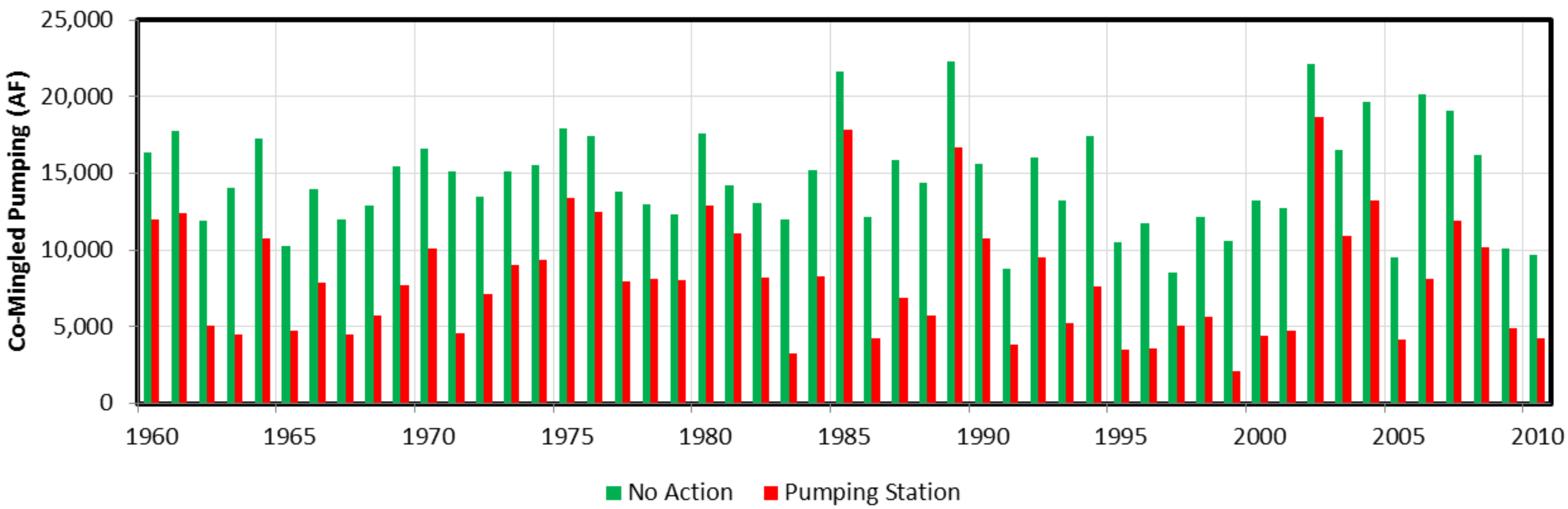


Figure 163. Comparison of the annual co-mingle pumping volumes for the pumping station alternative for Group 9; Low No Action.

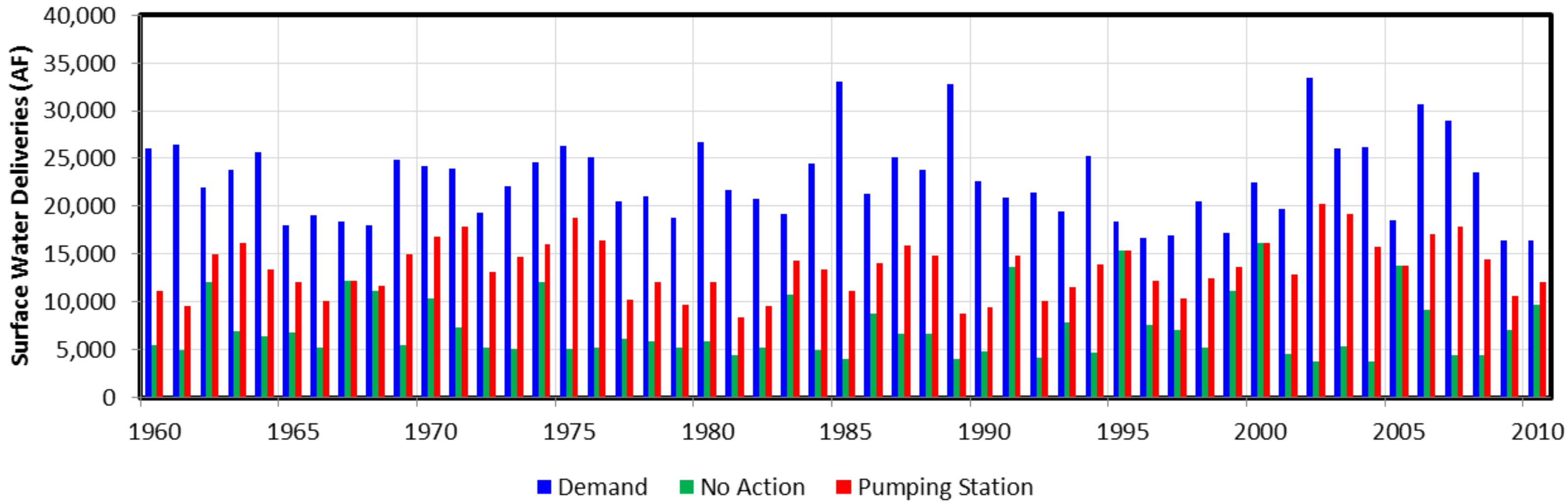


Figure 164. Comparison of the annual surface water demands and deliveries for the pumping station alternative for Group 9; Alt 1 CT.

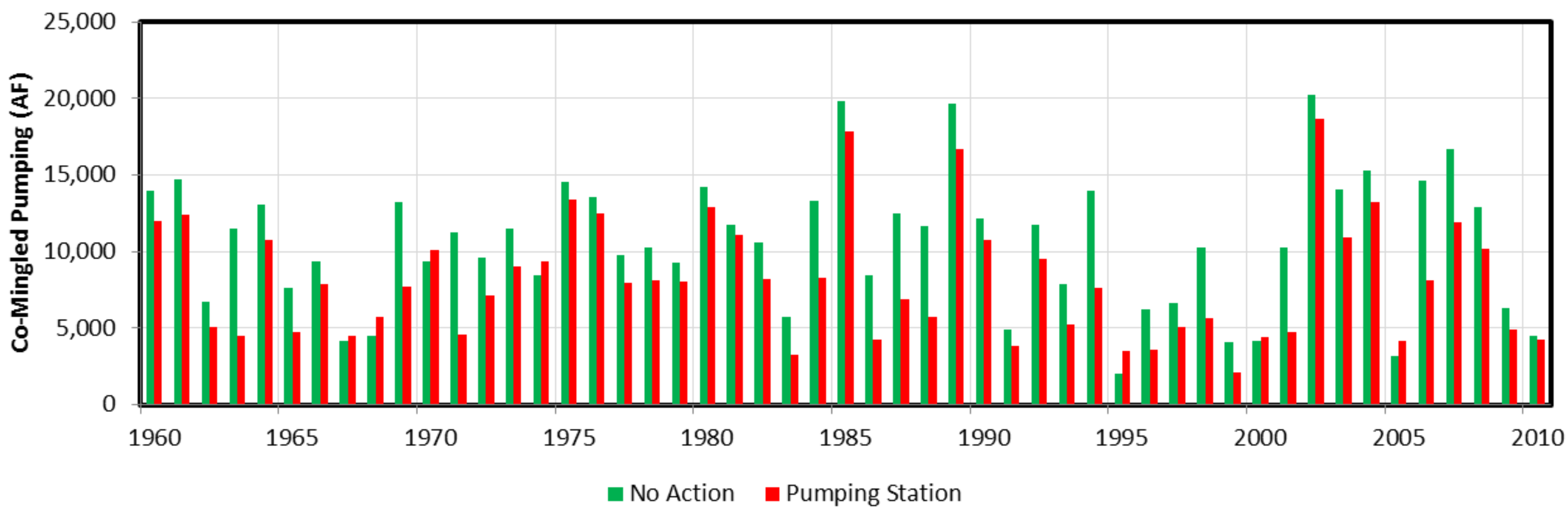


Figure 165. Comparison of the annual co-mingle pumping volumes for the pumping station alternative for Group 9; CT No Action.

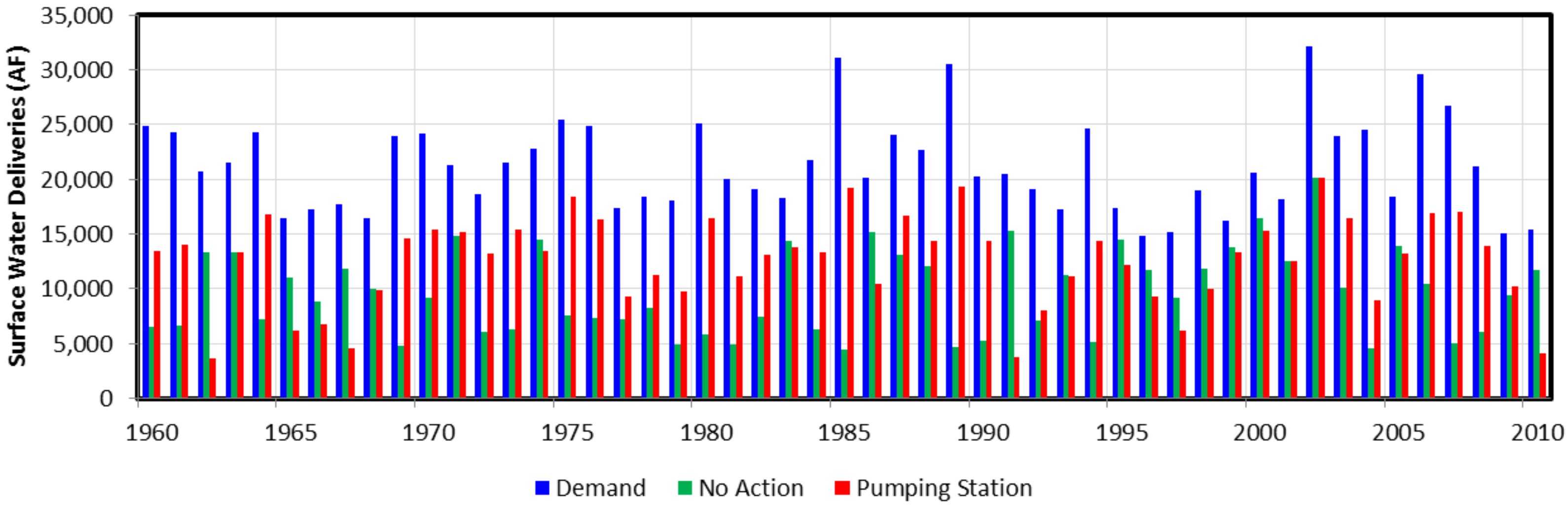


Figure 166. Comparison of the annual surface water demands and deliveries for the pumping station alternative for Group 9; Alt 1 High.

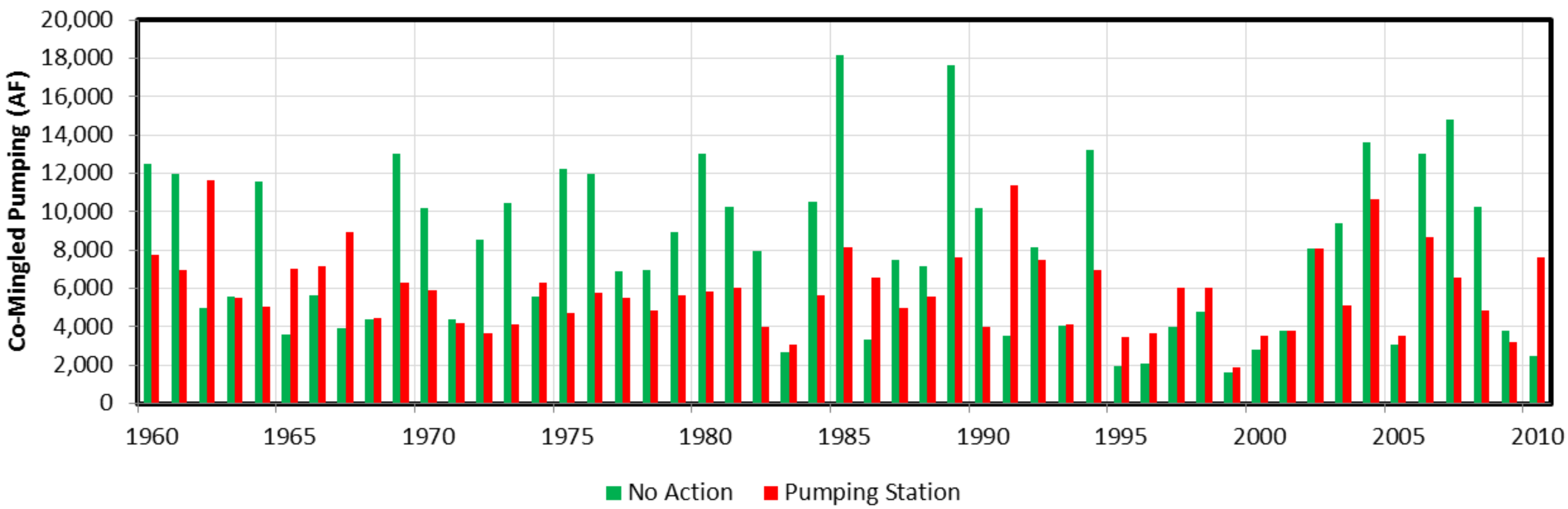


Figure 167. Comparison of the annual co-mingle pumping volumes for the pumping station alternative for Group 9; High No Action.

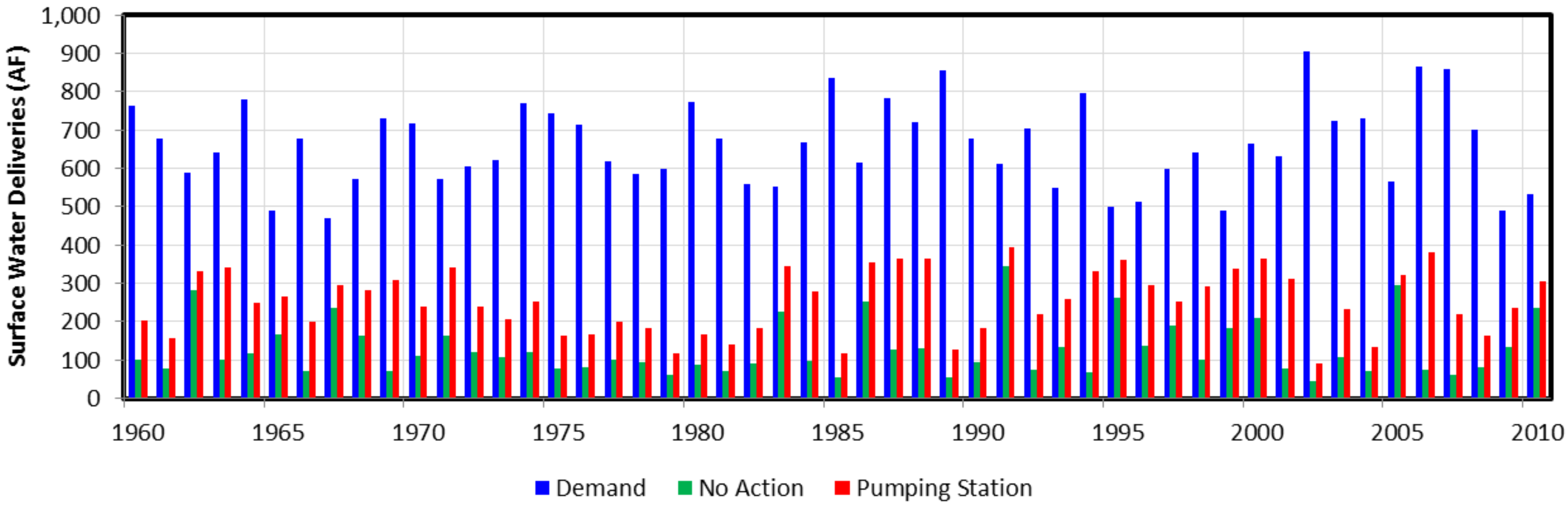


Figure 168. Comparison of the annual surface water demands and deliveries for the pumping station alternative for Group 8; Baseline No Action.

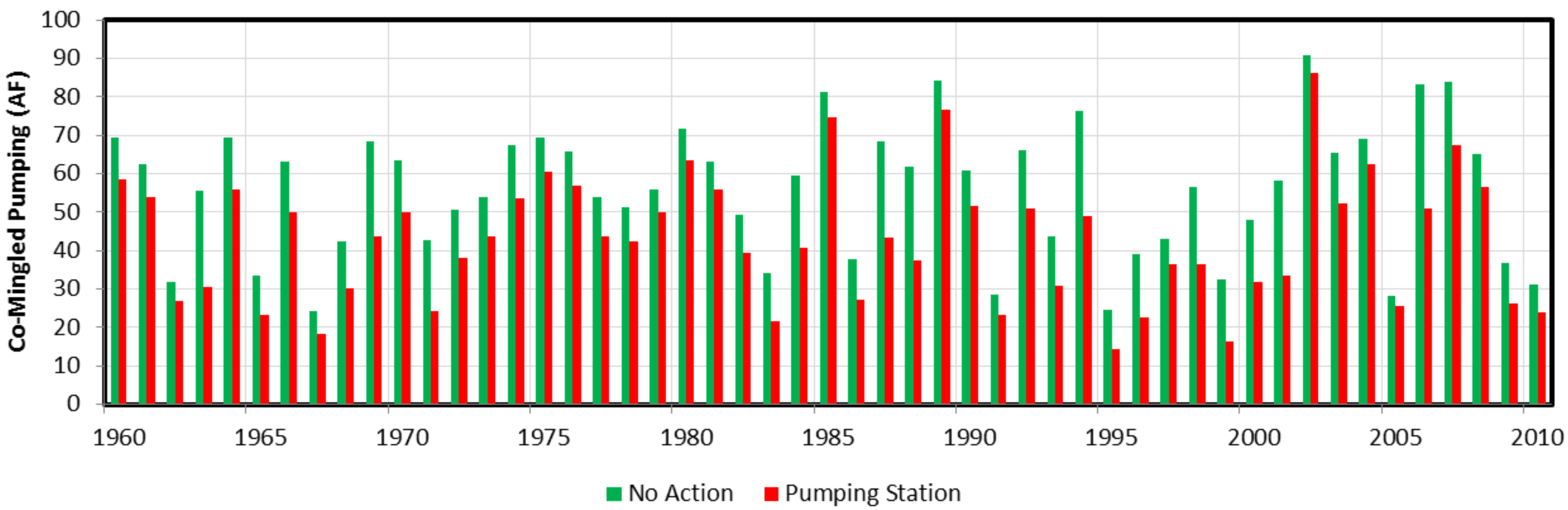


Figure 169. Comparison of the annual co-mingle pumping volumes for the pumping station alternative for Group 8; Baseline No Action.

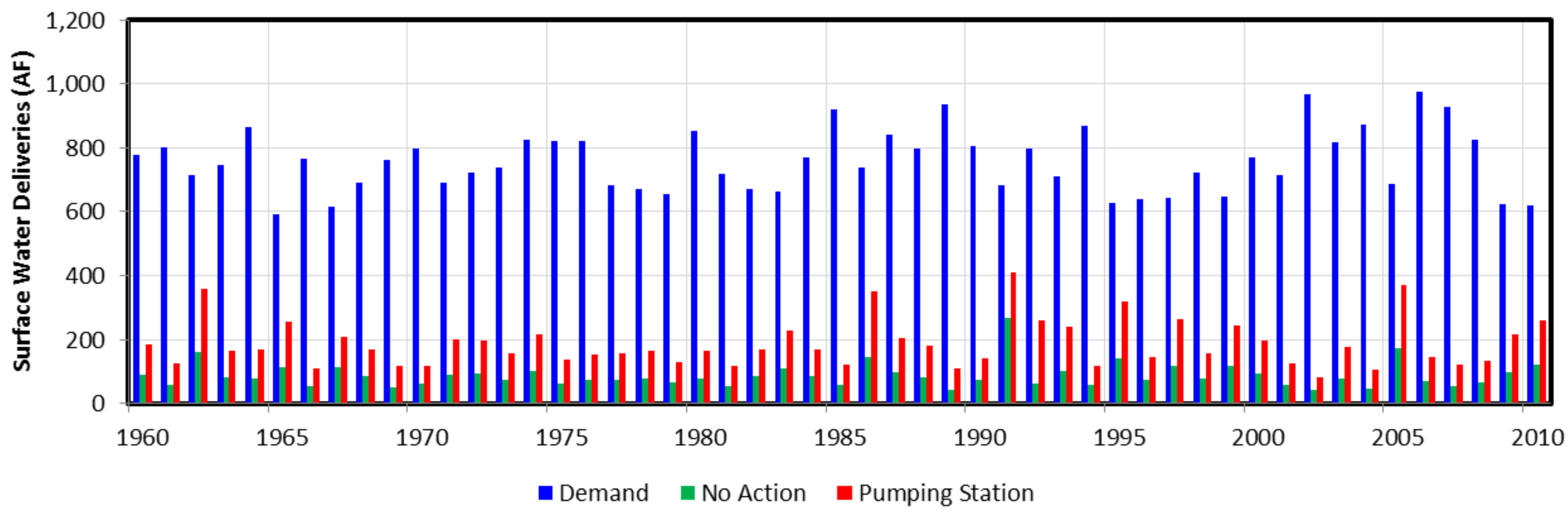


Figure 170. Comparison of the annual surface water demands and deliveries for the pumping station alternative for Group 8; Alt 1 Low.

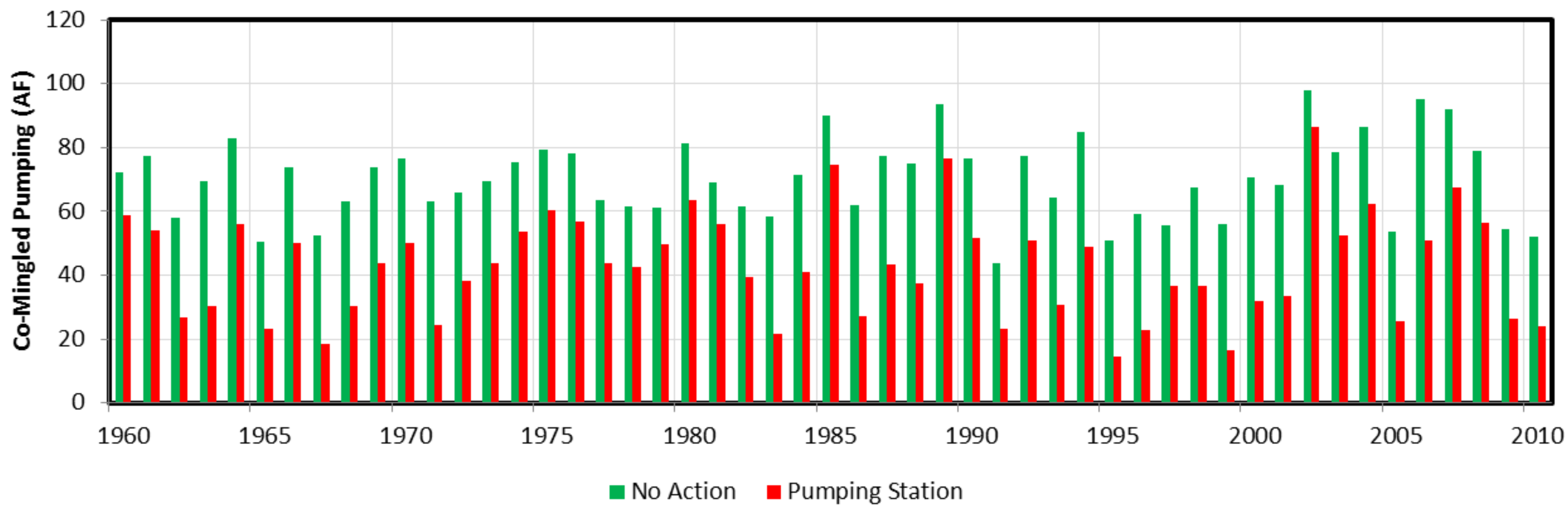


Figure 171. Comparison of the annual co-mingle pumping volumes for the pumping station alternative for Group 8; Low No Action.

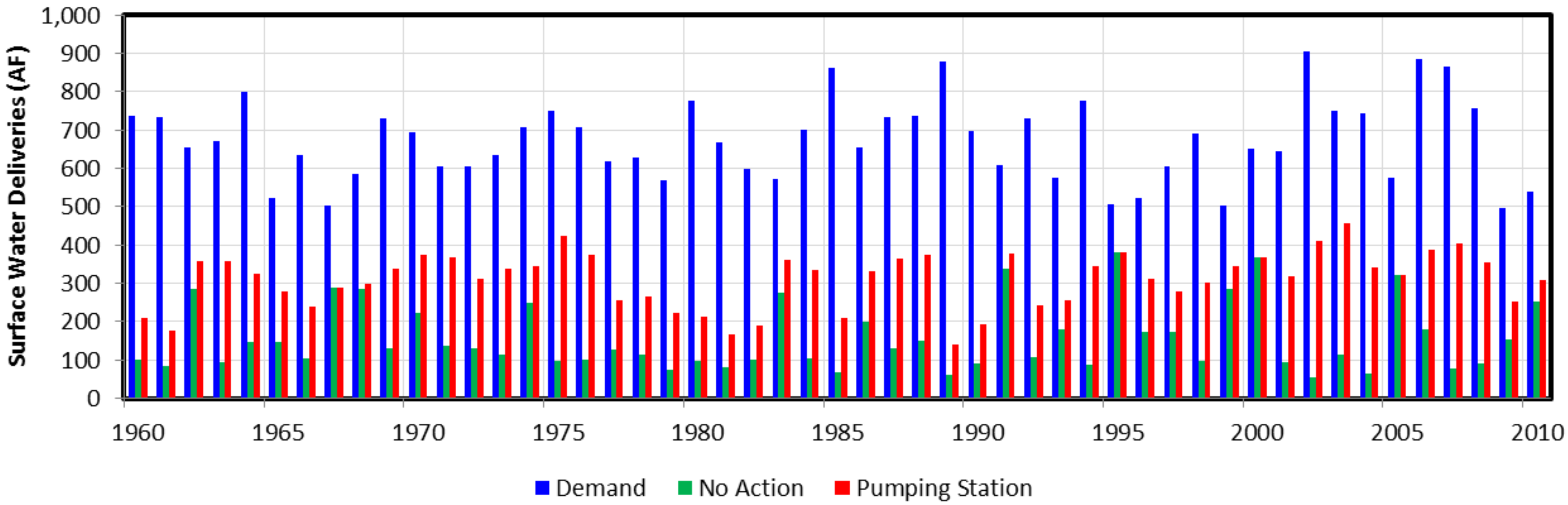


Figure 172. Comparison of the annual surface water demands and deliveries for the pumping station alternative for Group 8; Alt 1 CT.

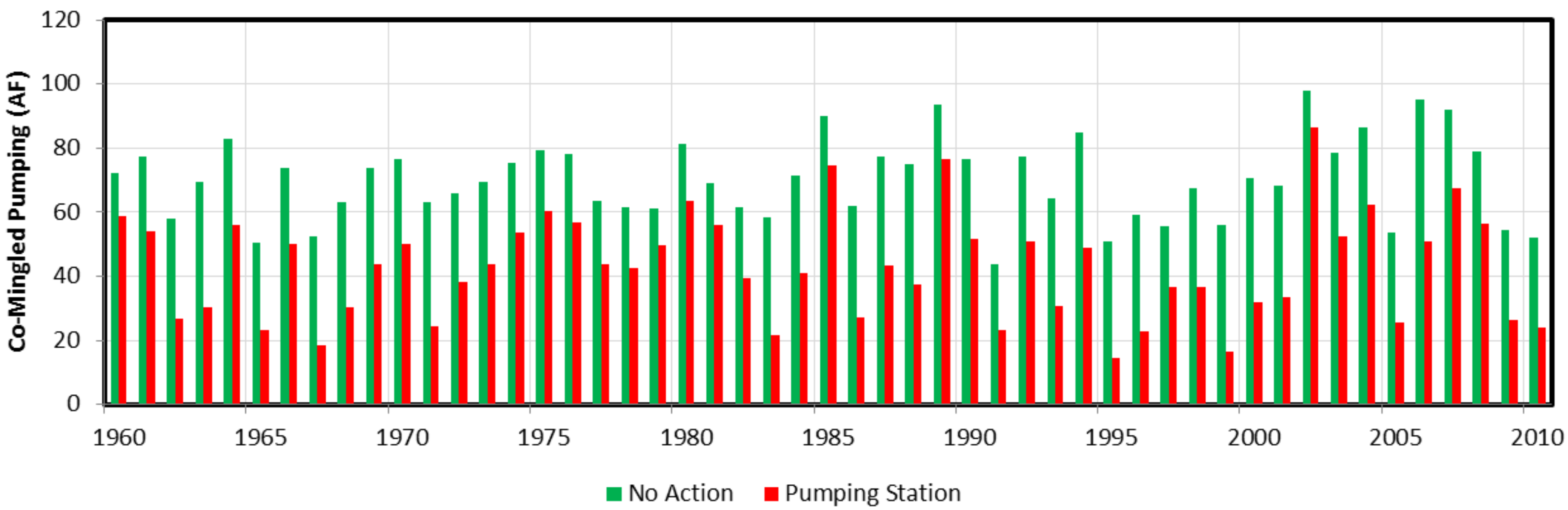


Figure 173. Comparison of the annual co-mingle pumping volumes for the pumping station alternative for Group 8; CT No Action.

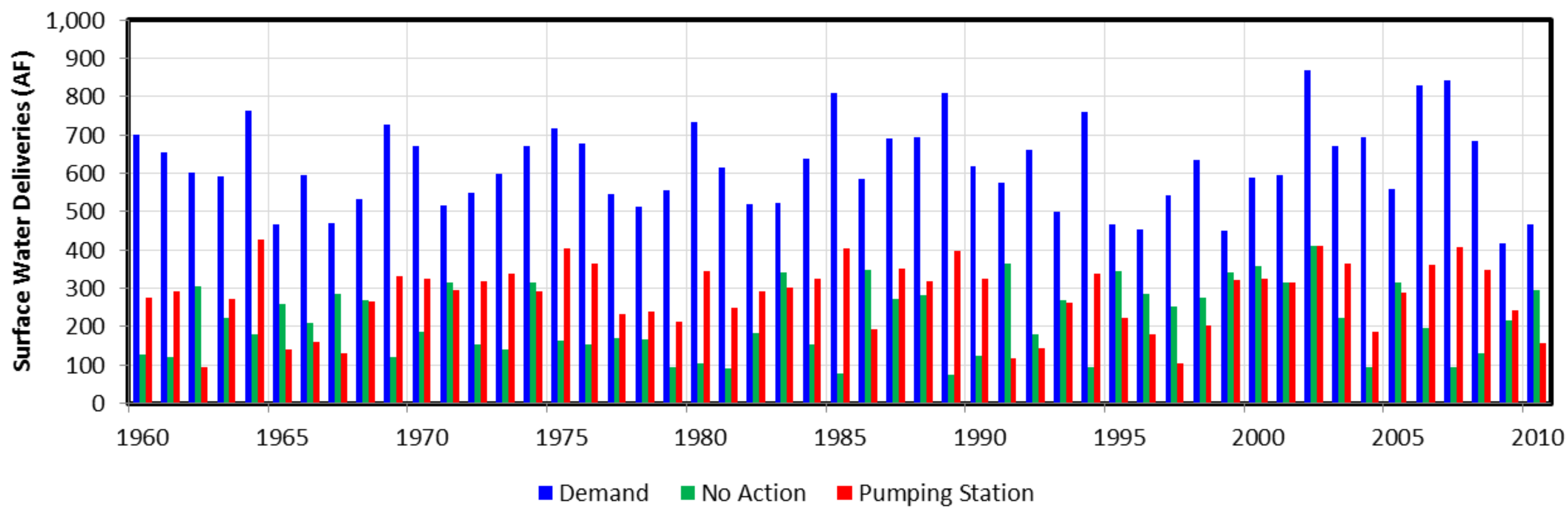


Figure 174. Comparison of the annual surface water demands and deliveries for the pumping station alternative for Group 8; Alt 1 High.

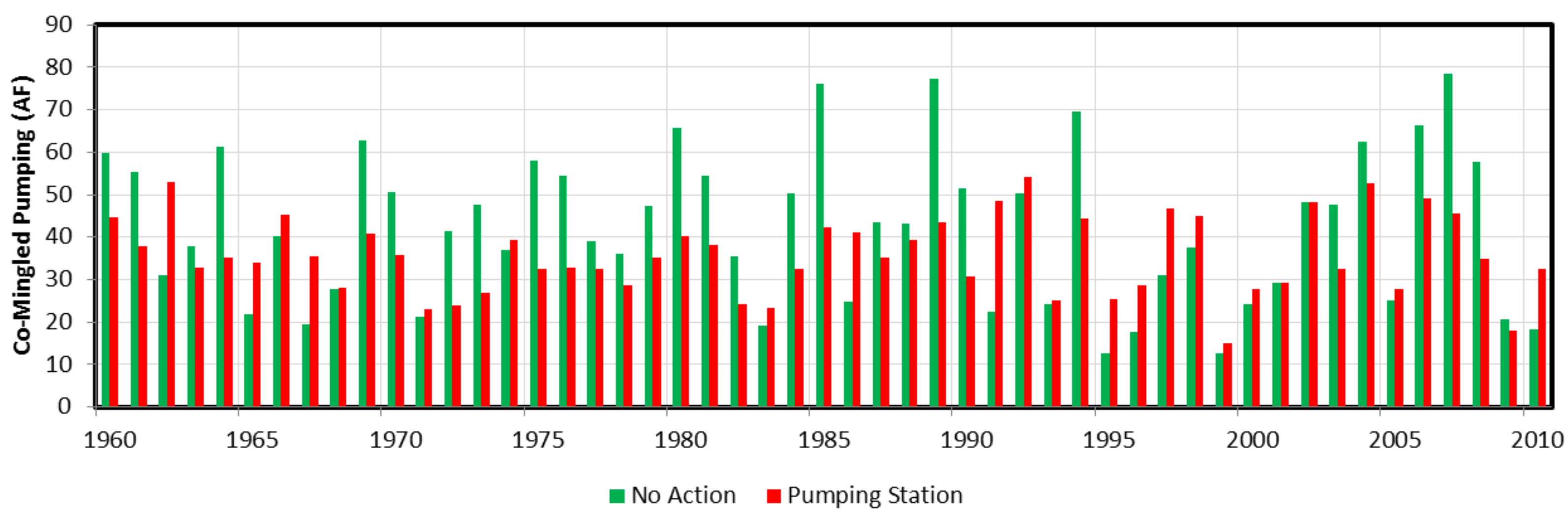


Figure 175. Comparison of the annual co-mingle pumping volumes for the pumping station alternative for Group 8; High No Action.

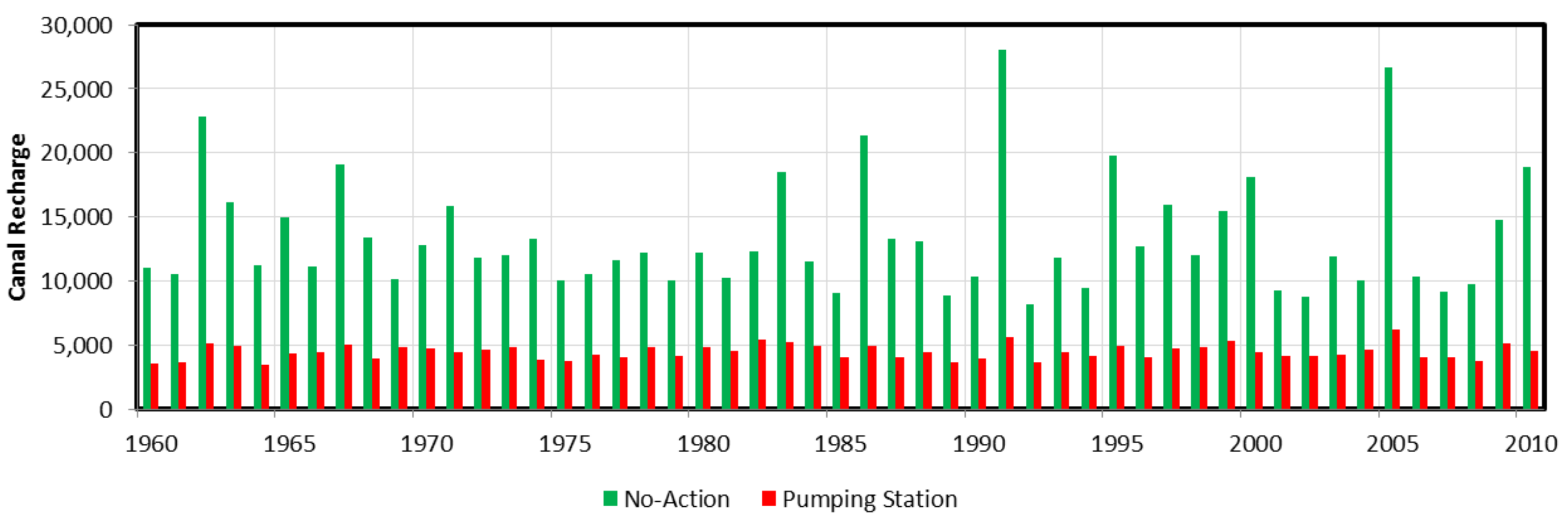


Figure 176. Comparison of annual basin wide canal recharge for the pumping station alternative; Baseline No Action.

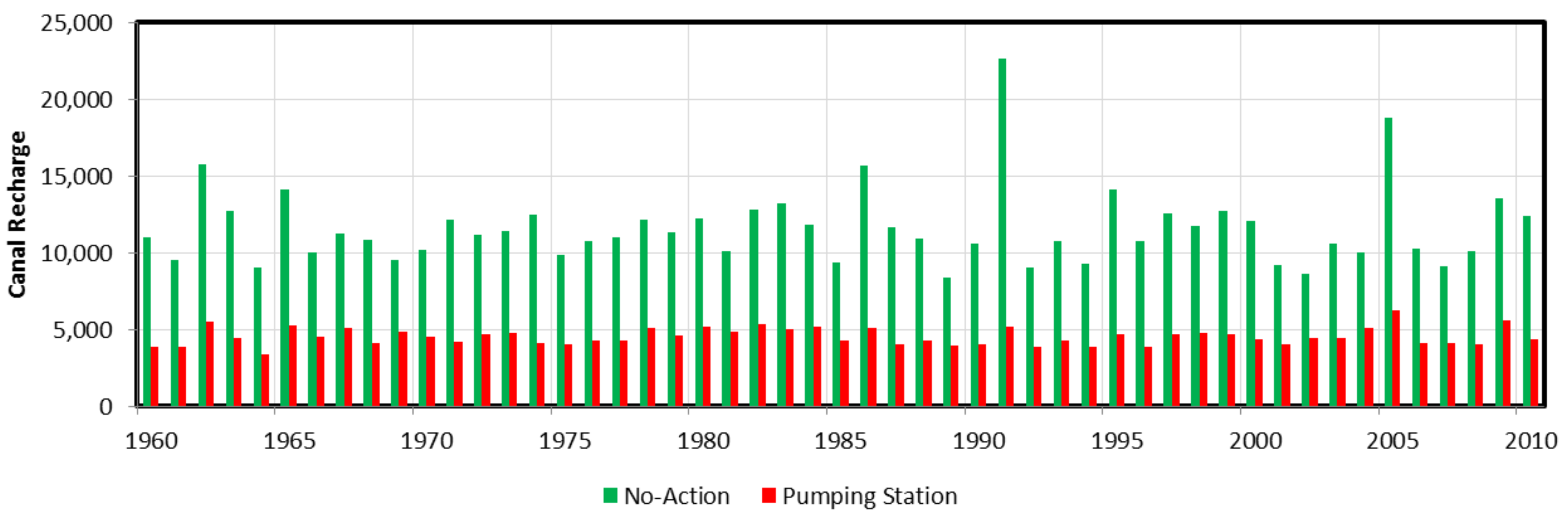


Figure 177. Comparison of annual basin wide canal recharge for the pumping station alternative; Alt 1 Low.

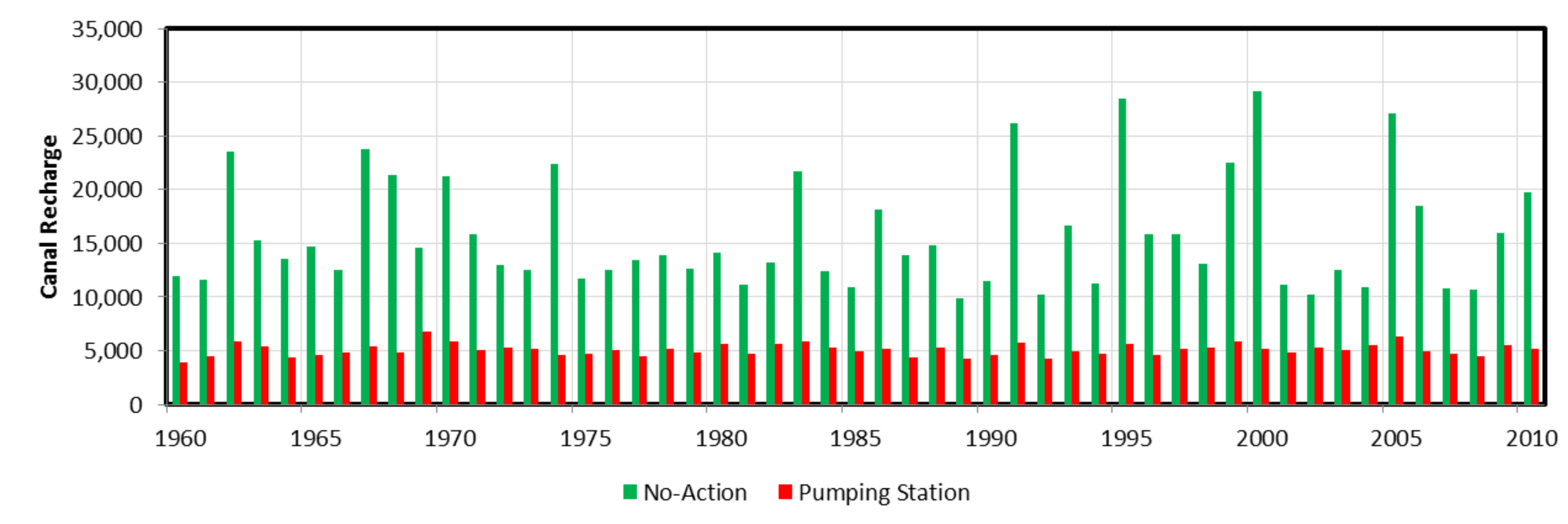


Figure 178. Comparison of annual basin wide canal recharge for the pumping station alternative; Alt 1 CT.

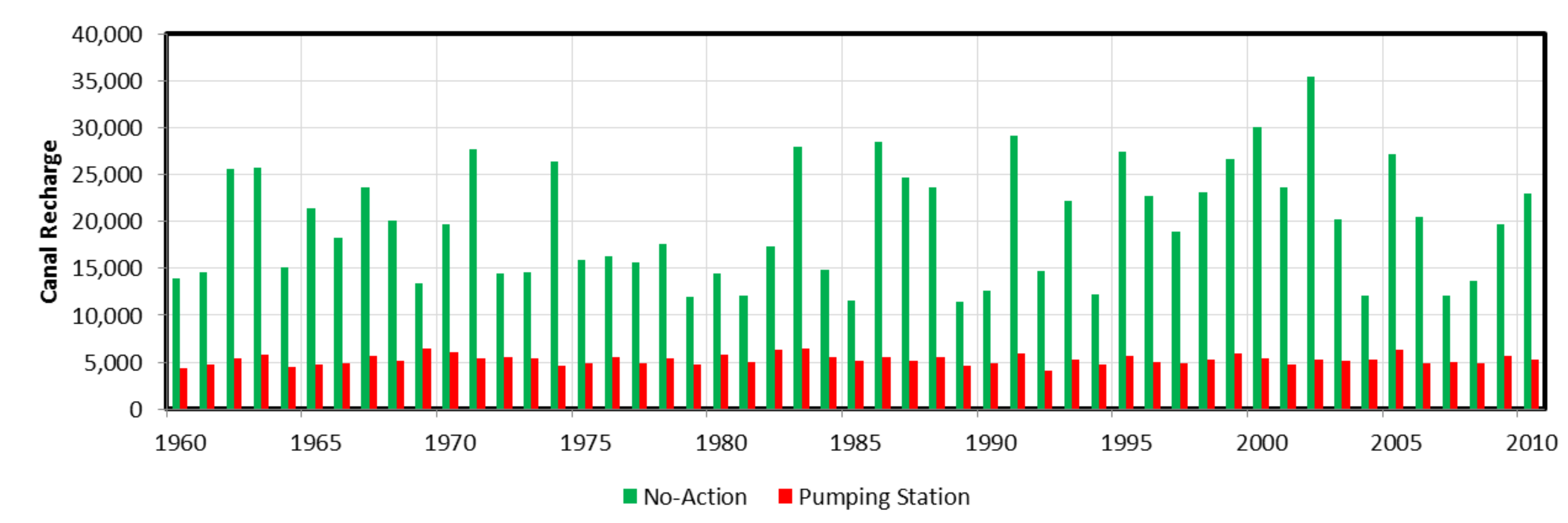


Figure 179. Comparison of annual basin wide canal recharge for the pumping station alternative; Alt 1 High.

5.6 Alternative 2 – Canal Recharge

5.6.1 Niobrara Drainage Basin

On a model wide scale there was limited change to water balance; yielding only a couple hundredths of a percent change () from the no action alternative. This is expected as the changes for the alternative were concentrated in a small portion of the watershed model. This characteristic persists in the climate scenarios as well.

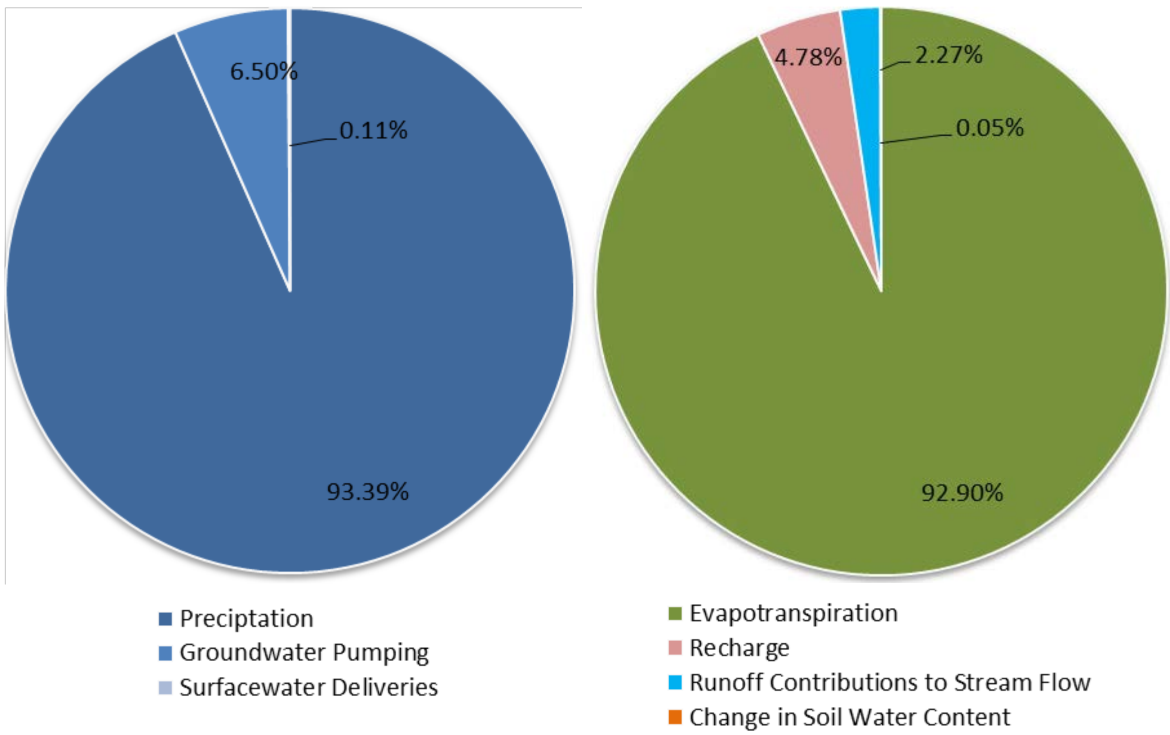


Figure 180. Sources of 17.20 in/ac of total available water and partitioned total available water for the canal recharge alternative within the Niobrara Drainage Basin within the UNWNRD model; Baseline No Action.

5.6.2 Average Annual Recharge

The percent change in average aquifer recharge between the No Action and Alternative 1 for all four climate scenarios are shown in Figures 181-184. As expected the change in recharge is concentrated around the Mirage Flats Irrigation district and canal. All four climate scenarios saw a significant increase in the recharge within the Mirage Flats Irrigation District; while three of the climate scenarios saw a small decrease in recharge along the canal.

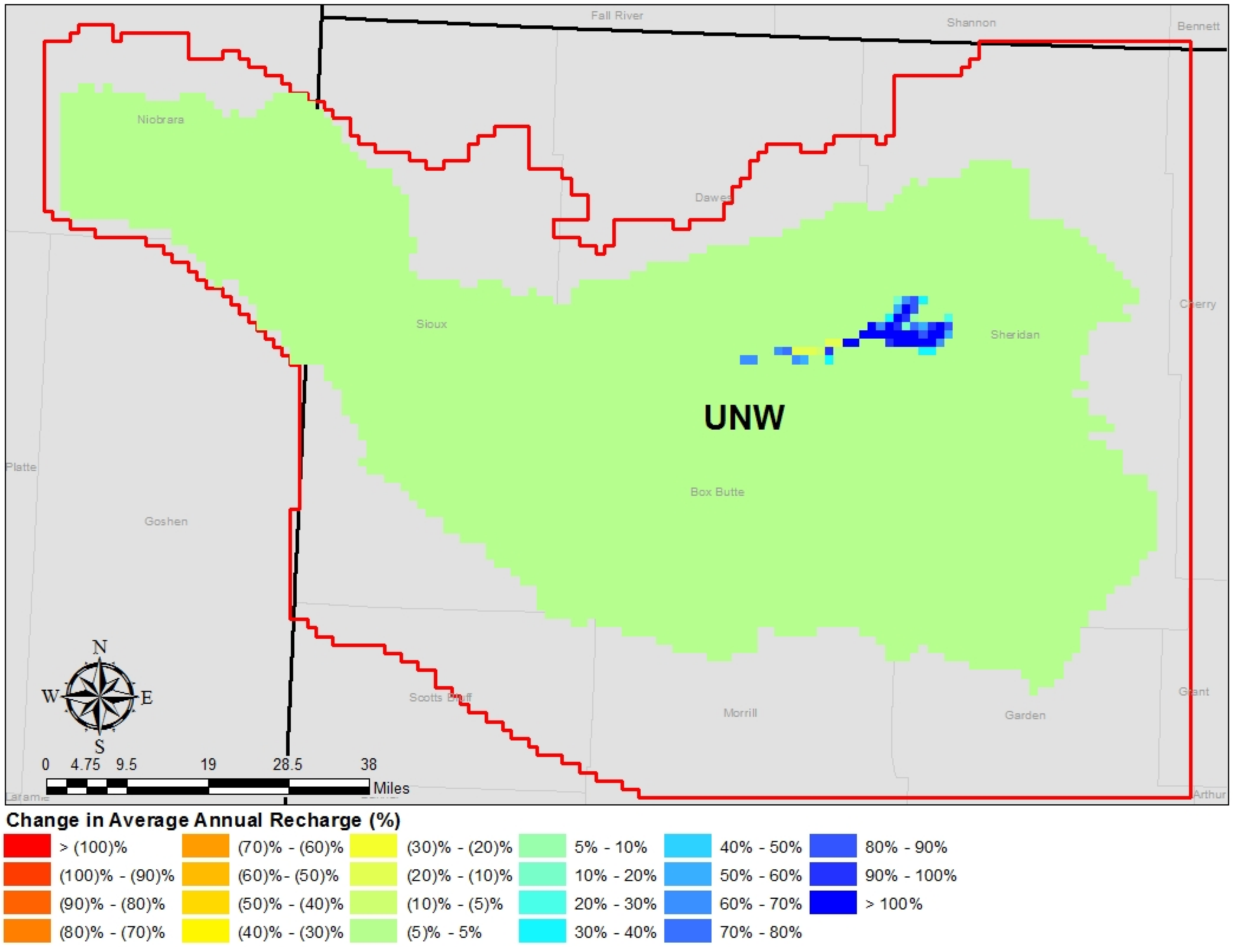


Figure 181. Percent change in average annual recharge within the UNWNRD model between the No Action and Canal Recharge Alternative; Baseline No Action.

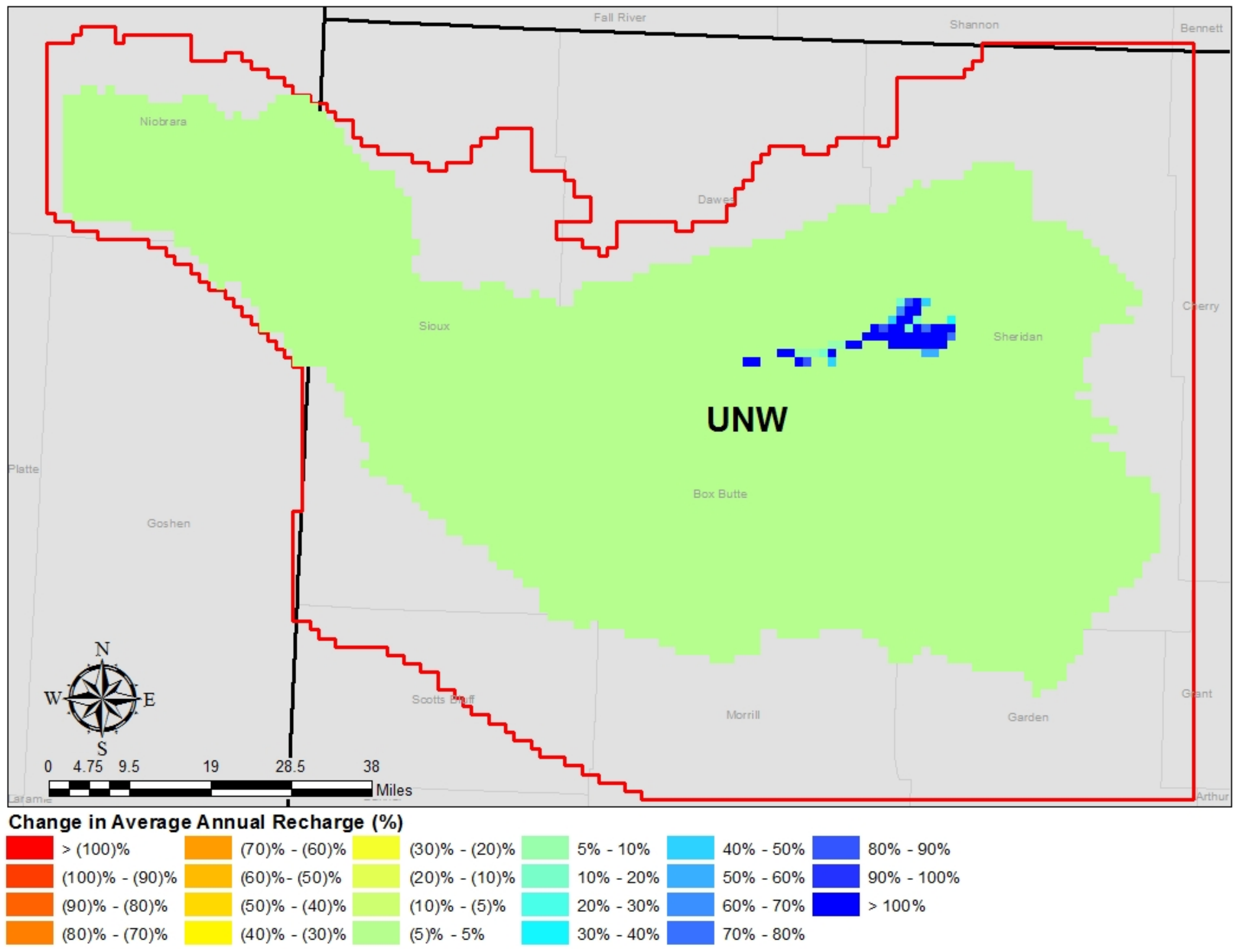


Figure 182. Percent change in average annual recharge within the UNWNRD model between the No Action and Canal Recharge Alternative; Low No Action and Alt 2 Low.

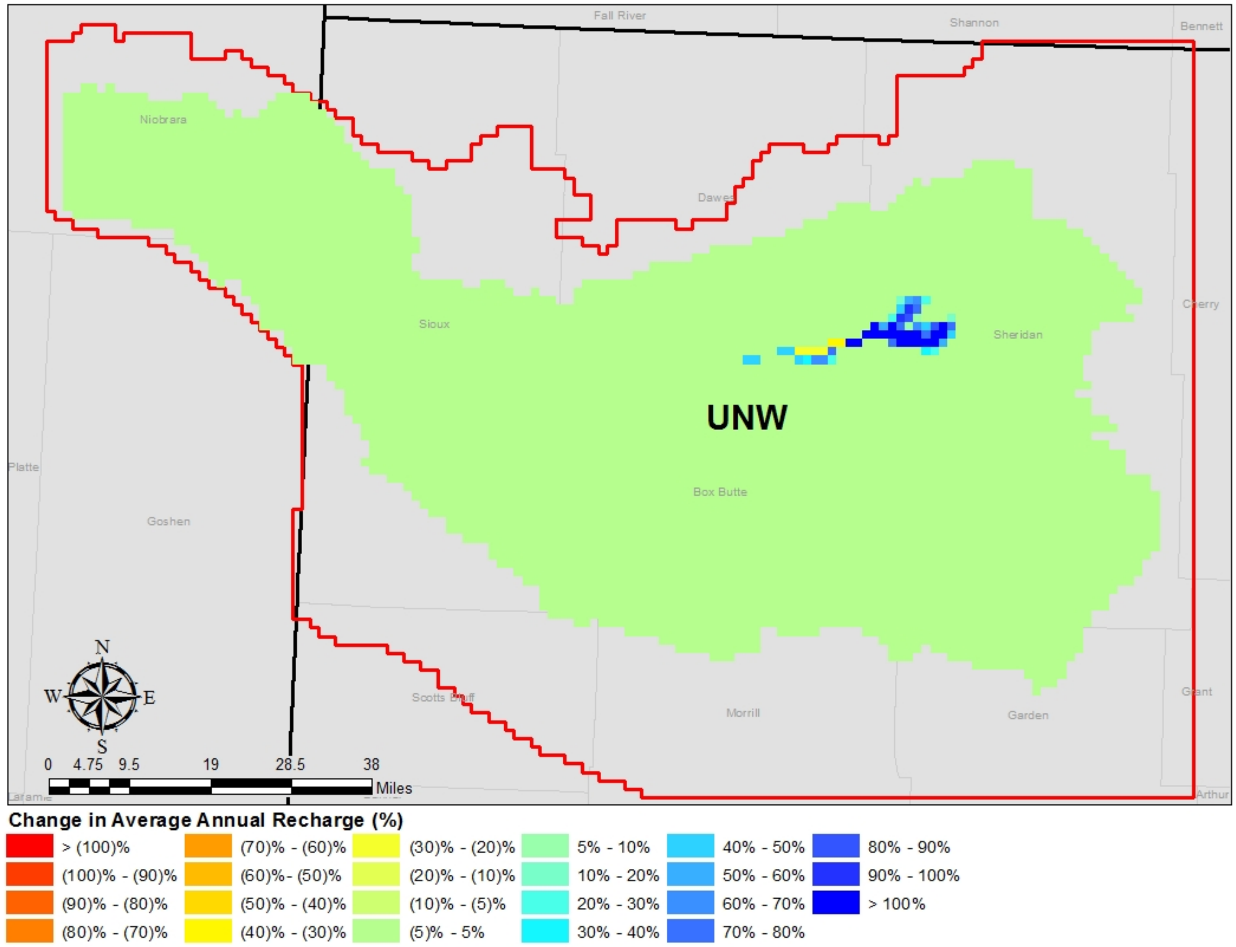


Figure 183. Percent change in average annual recharge within the UNWNRD model between the No Action and Canal Recharge Alternative; CT No Action and Alt 2 CT.

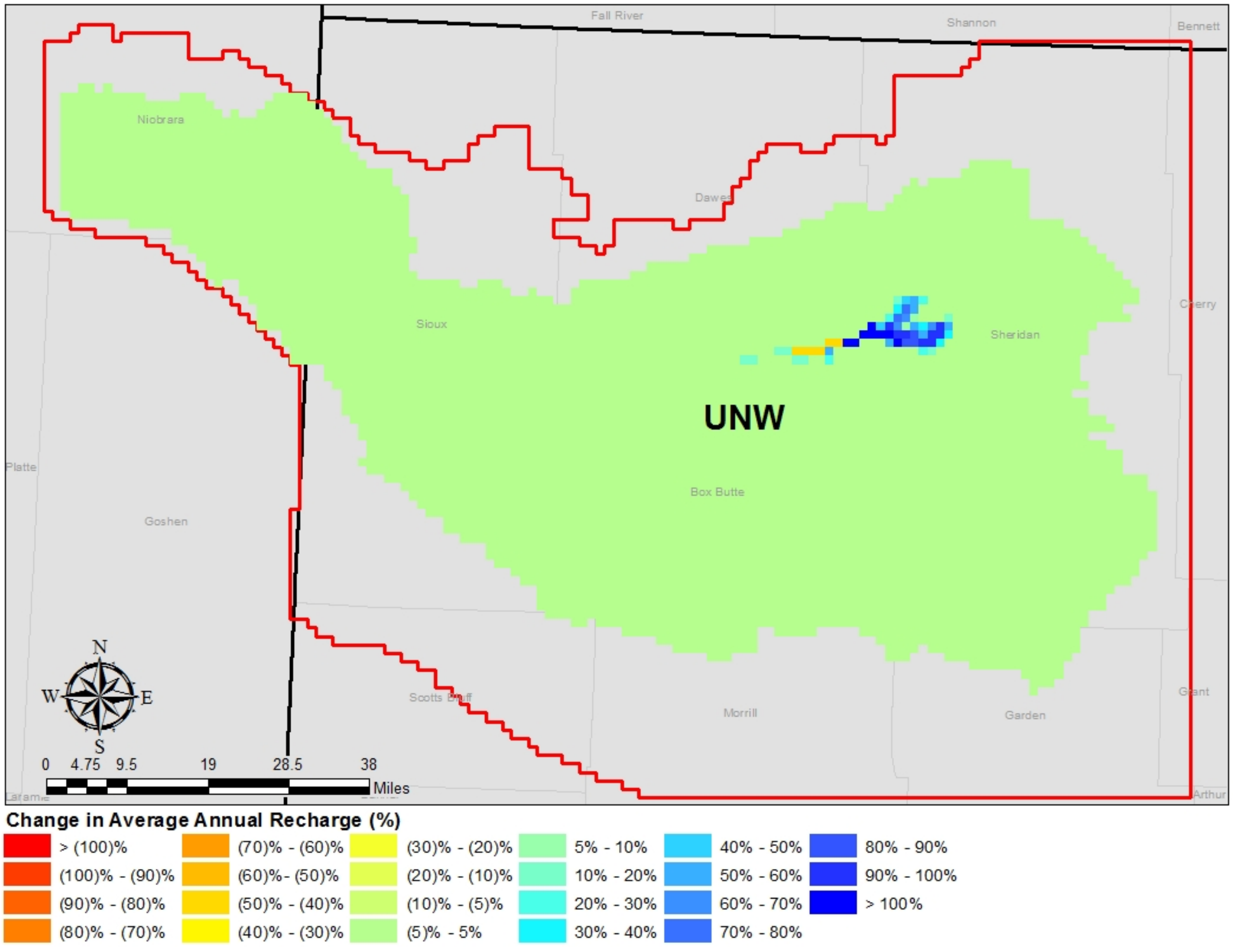


Figure 184. Percent change in average annual recharge within the UNWNRD model between the No Action and Canal Recharge Alternative; High No Action and Alt 2 High.

5.6.3 Runoff Zones

As runoff zones 1-3 were all upstream of the Mirage Flats Irrigation District, there were no changes to the water balance within these zones. Within runoff zone 4 (Figure 185) and 5 (Figure 186), the water balance changes become more prevalent, but are still dwarfed by the size of the runoff zone relative to the size of the alternative. This property holds true for the climate scenarios as well.

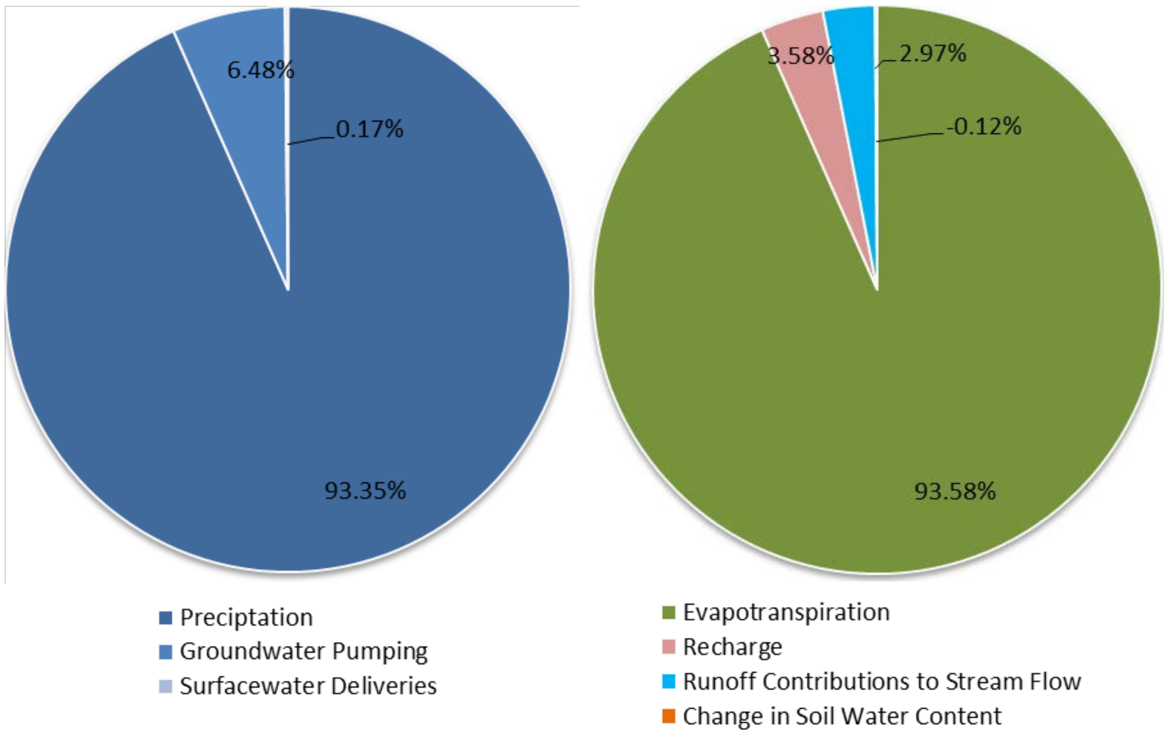


Figure 185. Sources of 17.16 in/ac of total available water and partitioned total available water for the canal recharge alternative within runoff zone 4 the UNWNRD model; Baseline No Action.

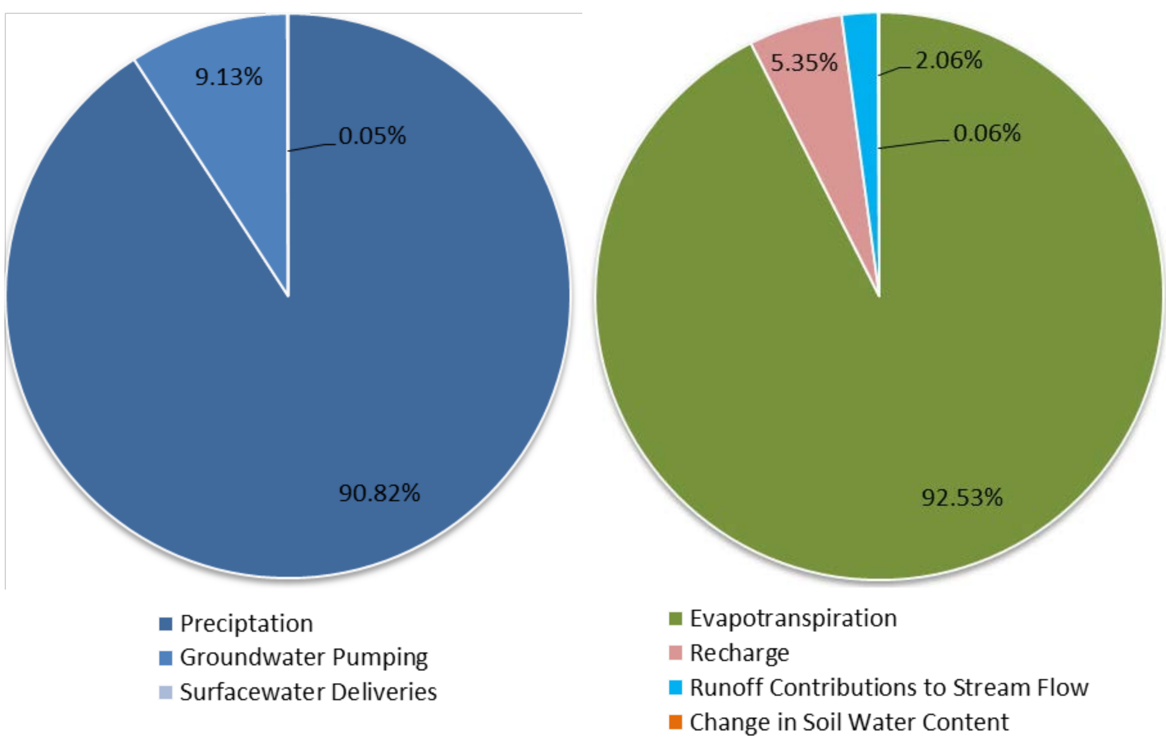


Figure 186. Sources of 17.99 in/ac of total available water and partitioned total available water for the canal recharge alternative within runoff zone 5 the UNWNRD model; Baseline No Action.

5.6.4 Mirage Flats Irrigation District

Within the Mirage Flats Irrigation District, the canal recharge alternative eliminates all surface water deliveries, increases pumping, while decreasing recharge and stream flow contributions. The effect on evapotranspiration was mixed (Table 30, Figures 187-190).

Table 30. Percent Change in the Average Water Balance Between the No Action and Canal Recharge Alternatives under the Various Climate Scenarios

Climate Scenario	Precipi-tation	Ground-water Pumping	Surface Water Deliveries	Total Applied Water	ET	Recharge	Runoff Contributions to Streamflow
Baseline	-	34.40%	-100.00%	-5.18%	0.32%	-15.82%	-20.18%
Climate 1	-	22.39%	-100.00%	-4.27%	0.96%	-16.06%	-17.91%
Climate 2	-	47.21%	-100.00%	-6.05%	-0.45%	-16.68%	-23.18%
Climate 3	-	84.37%	-100.00%	-7.68%	-1.46%	-17.82%	-26.51%

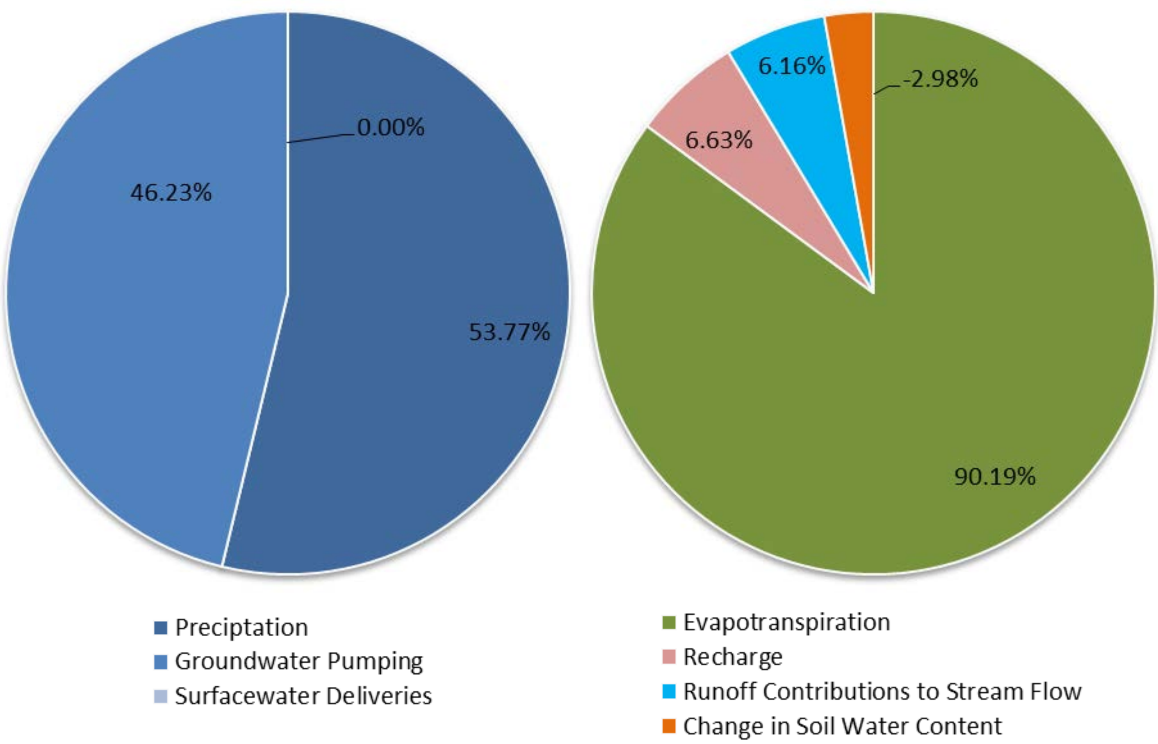


Figure 187. Sources of 31.11 in/ac of total available water and partitioned total available water for the canal recharge alternative within the Mirage Flats Irrigation District; Baseline No Action.

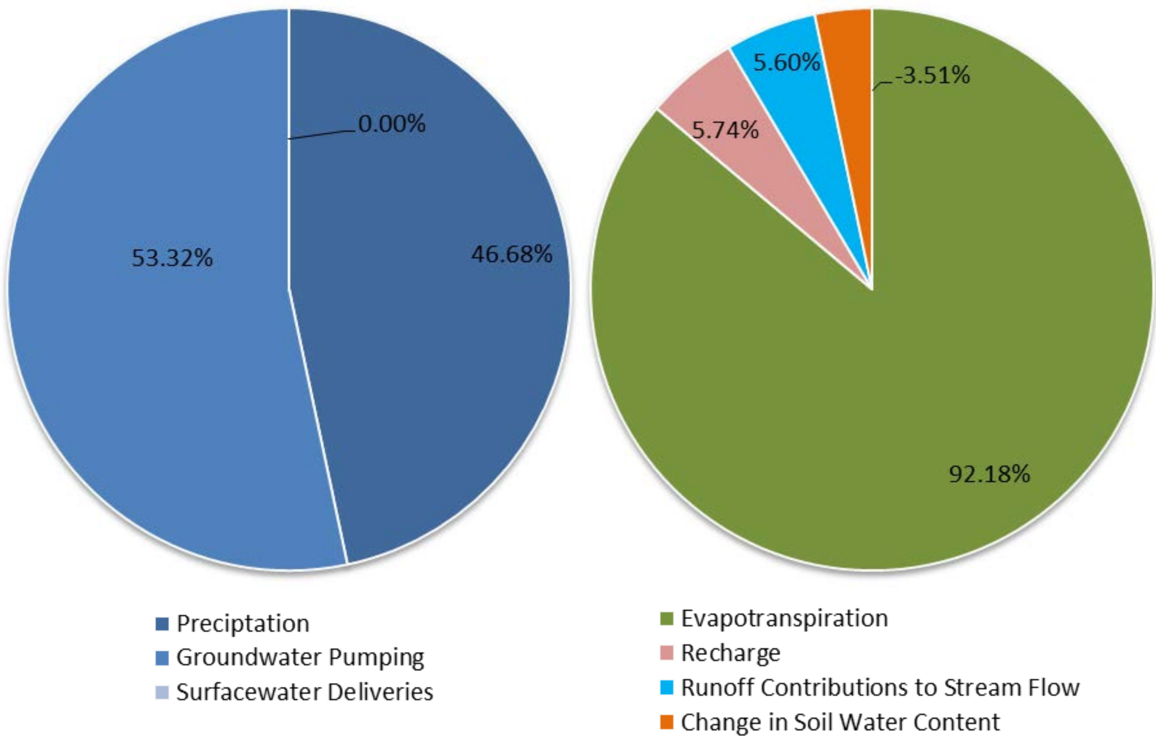


Figure 188. Sources of 29.91 in/ac of total available water and partitioned total available water for the canal recharge alternative within the Mirage Flats Irrigation District; Alt 2 Low.

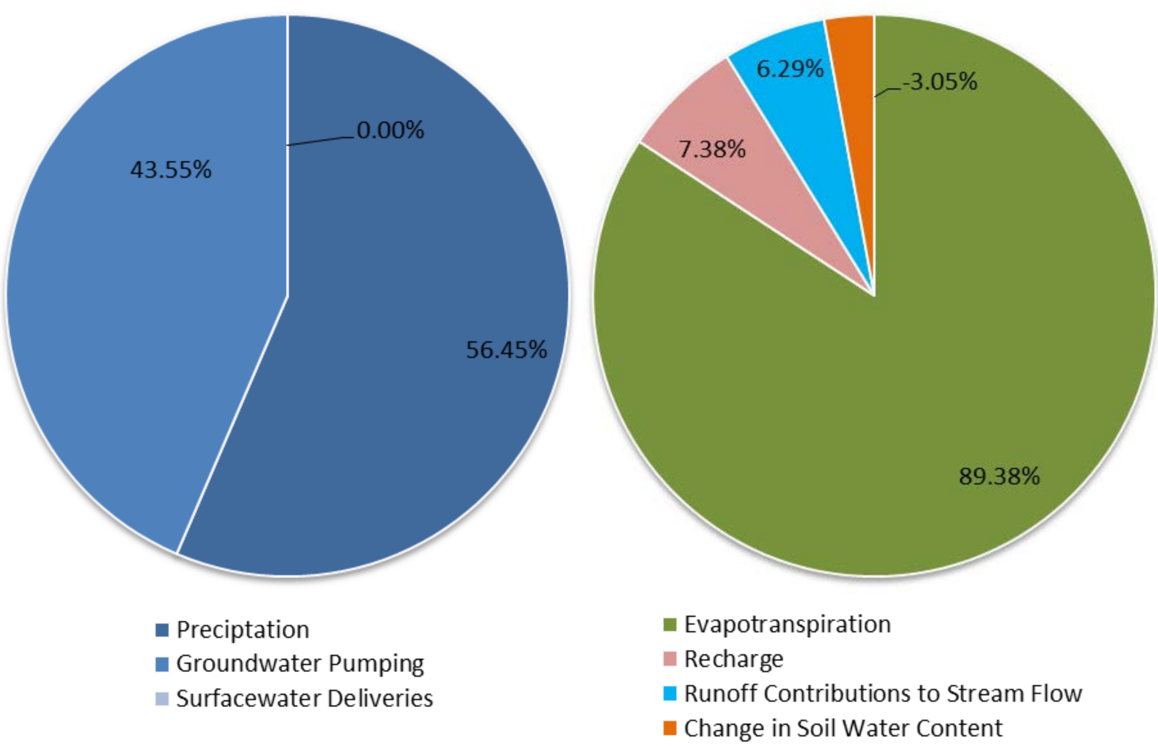


Figure 189. Sources of 31.74 in/ac of total available water and partitioned total available water for the canal recharge alternative within the Mirage Flats Irrigation District; Alt 2 CT.

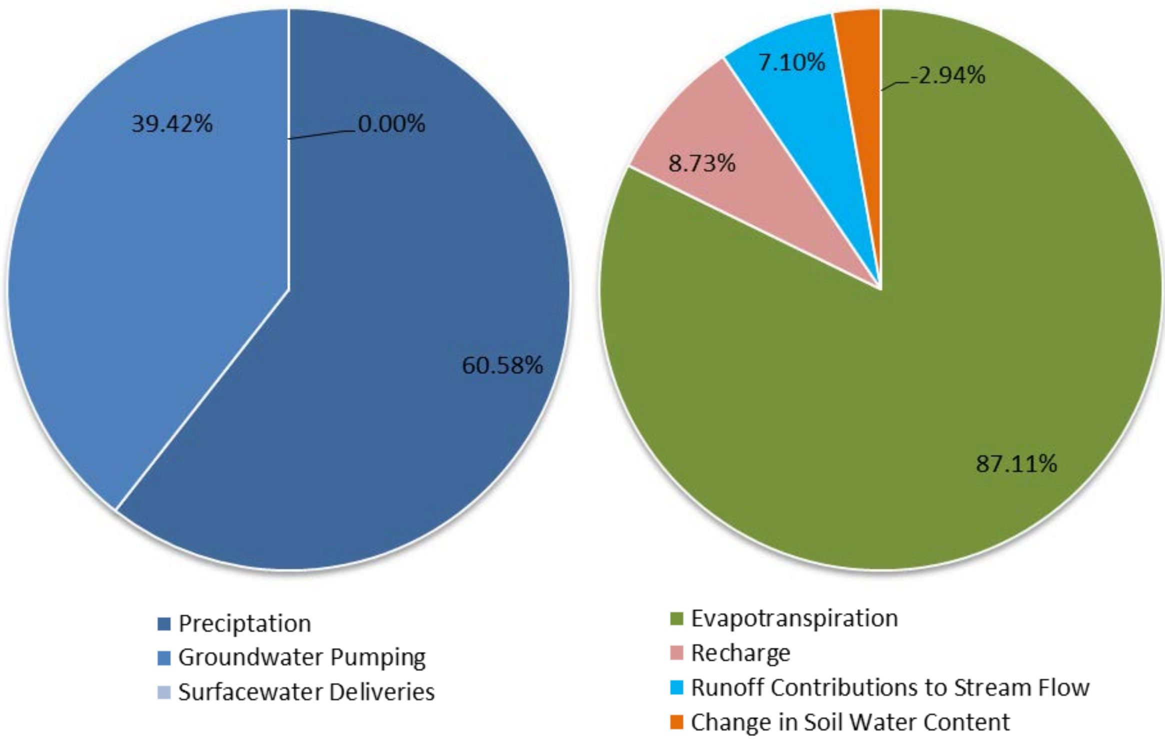


Figure 190. Sources of 31.74 in/ac of total available water and partitioned total available water for the canal recharge alternative within the Mirage Flats Irrigation District; Alt 2 High.

5.6.5 Gaps in Surface Water Irrigation Groups Water Availability

Within the Mirage Flats Irrigation District (Group 9), surface water deliveries ceased for all climate scenarios. Naturally, this led to an increase in supplemental co-mingled pumping (Figures 191-198).

Surface Water Irrigation Group 8 is the only other group which experienced consistent changes in surface water deliveries and co-mingled pumping. Generally, there is more surface water available to group 8. The additional surface water increase surface water deliveries and decreases supplemental co-mingled pumping (Figures 199-206).

5.6.6 Canal Recharge

The canal seepage within the Canal Recharge Alternative experienced increases in the annual canal recharge when compared to the no action alternative for all climate scenarios (Figures 207-210). Furthermore, a more consistent level of seepage occur from year to year.

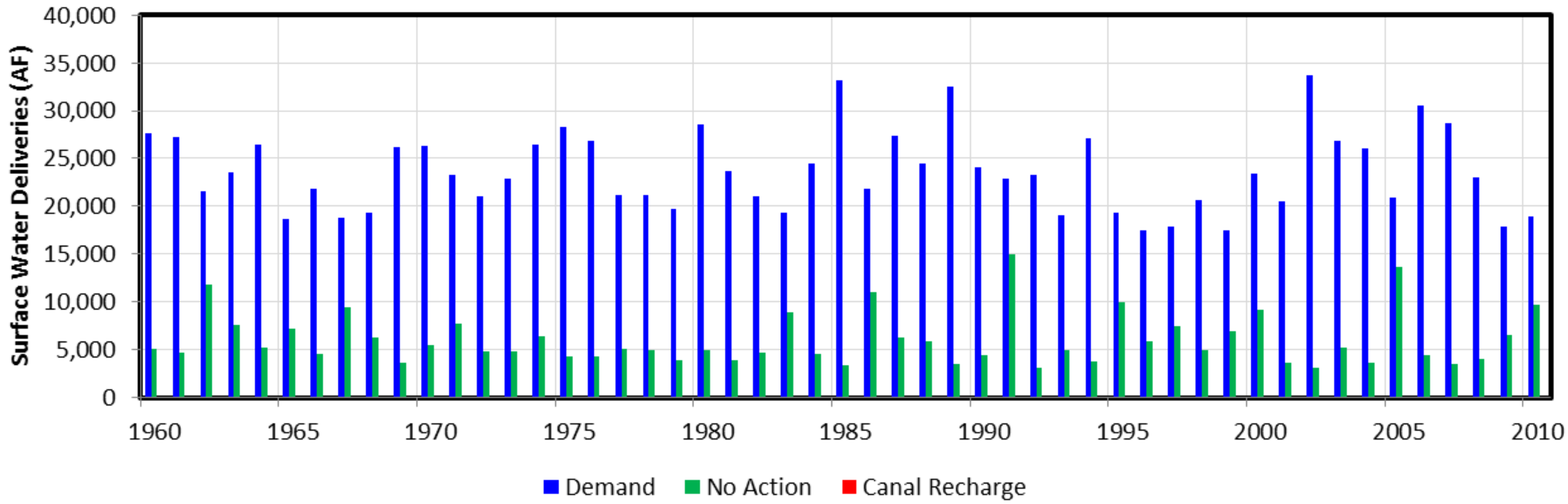


Figure 191. Comparison of the annual surface water demands and deliveries for the canal recharge alternative for Group 9; Baseline No Action.

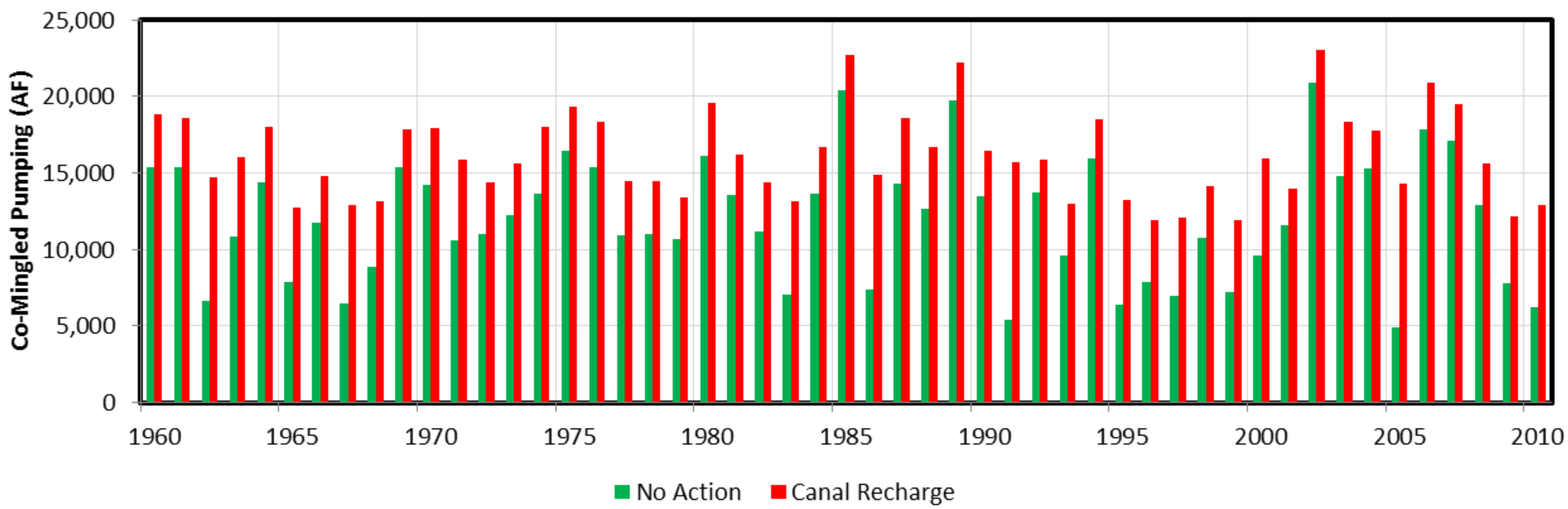


Figure 192. Comparison of the annual co-mingle pumping volumes for the canal recharge alternative for Group 9; Baseline No Action.

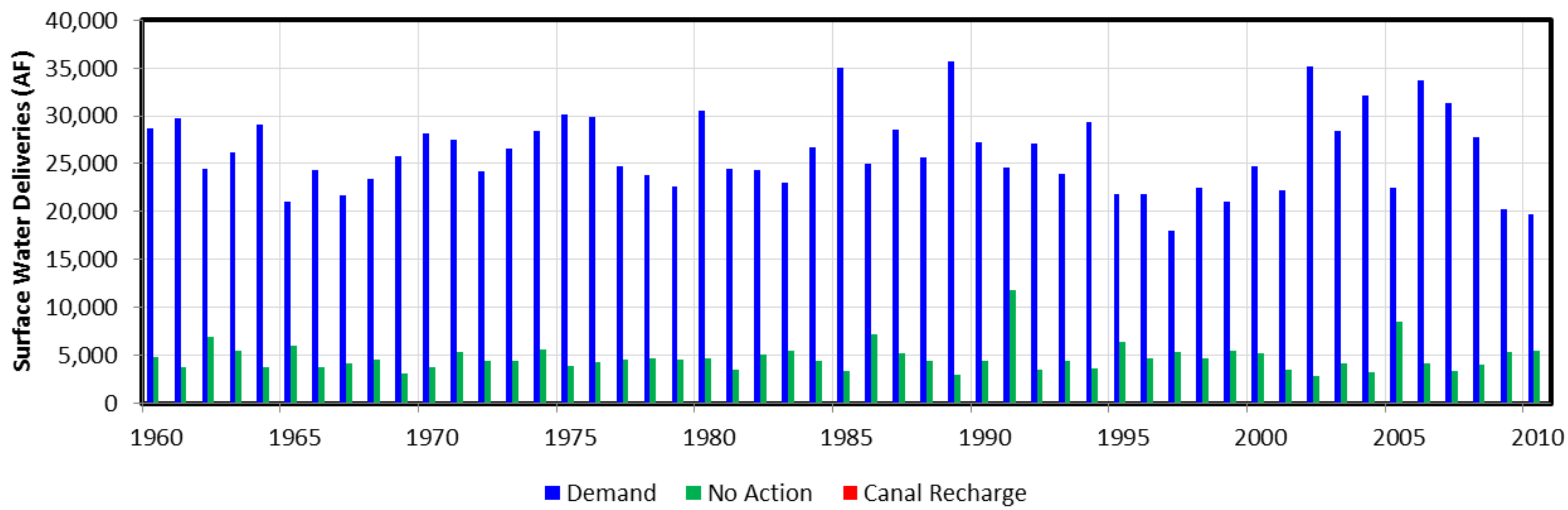


Figure 193. Comparison of the annual surface water demands and deliveries for the canal recharge alternative for Group 9; Alt 2 Low.

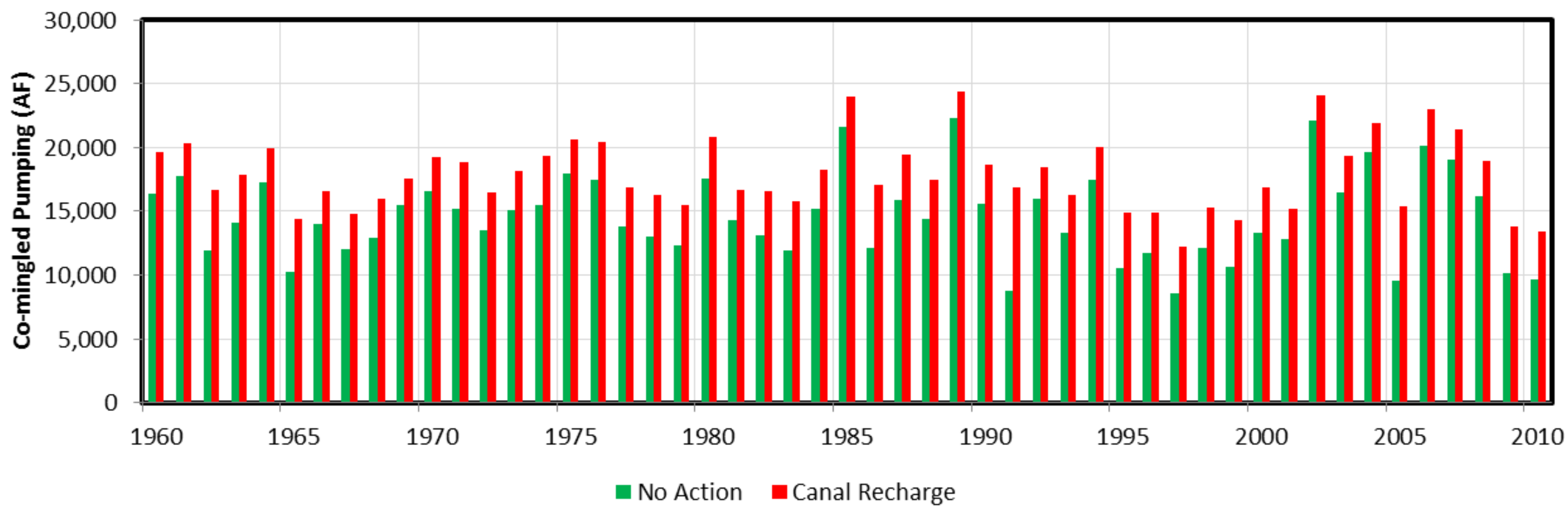


Figure 194. Comparison of the annual co-mingle pumping volumes for the canal recharge alternative for Group 9; Low No Action.

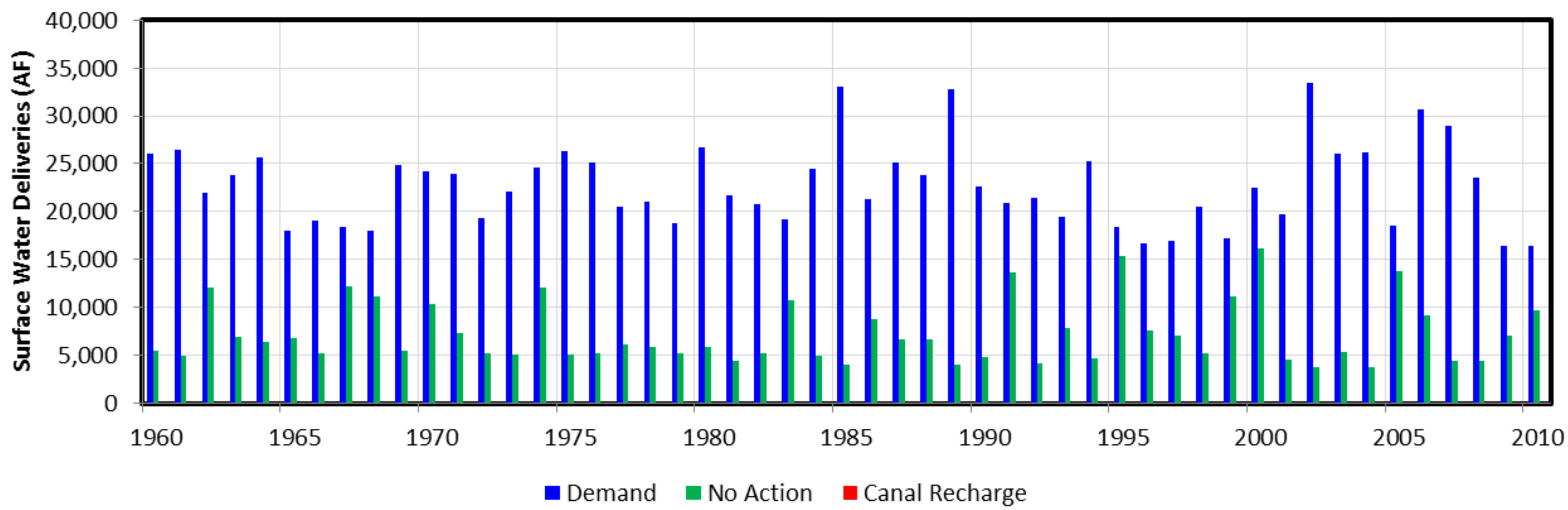


Figure 195. Comparison of the annual surface water demands and deliveries for the canal recharge alternative for Group 9; Alt 2 CT.

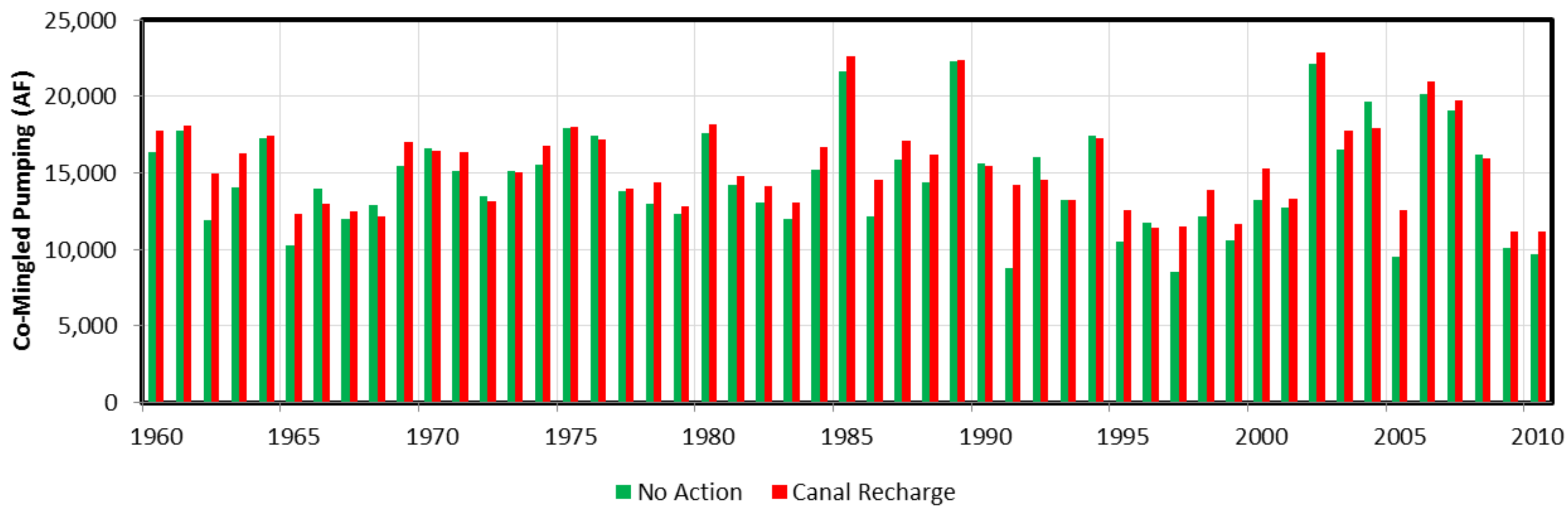


Figure 196. Comparison of the annual co-mingle pumping volumes for the canal recharge alternative for Group 9; CT No Action.

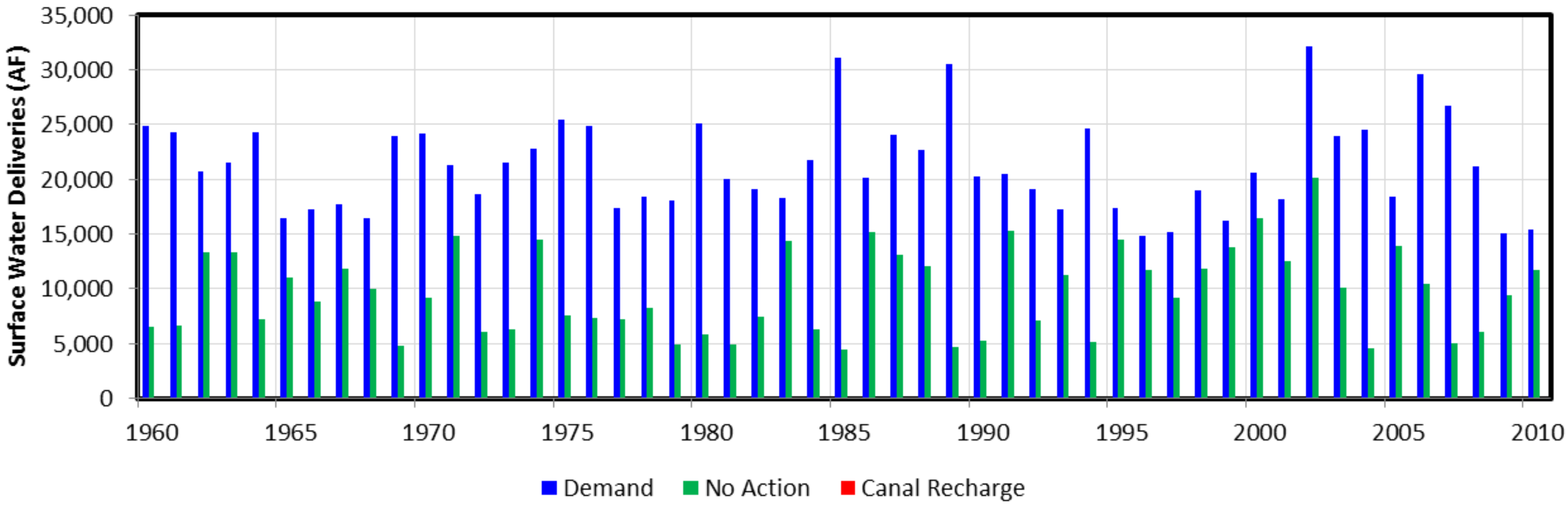


Figure 197. Comparison of the annual surface water demands and deliveries for the canal recharge alternative for Group 9; Alt 2 High.

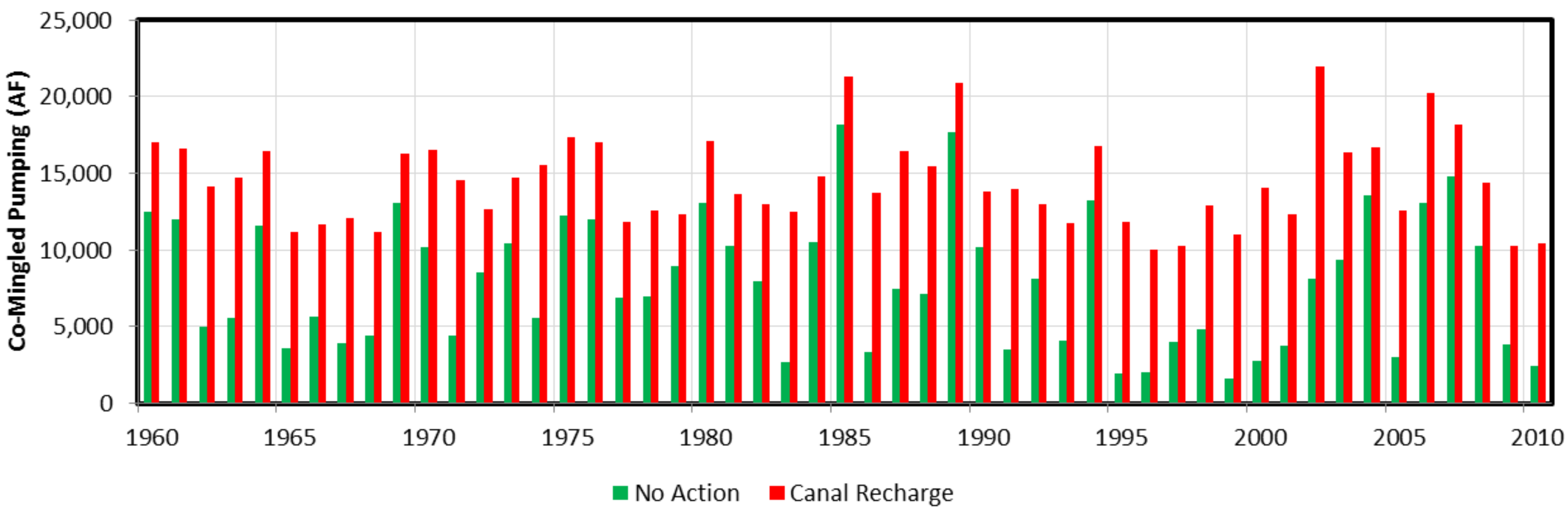


Figure 198. Comparison of the annual co-mingle pumping volumes for the canal recharge alternative for Group 9; High No Action.

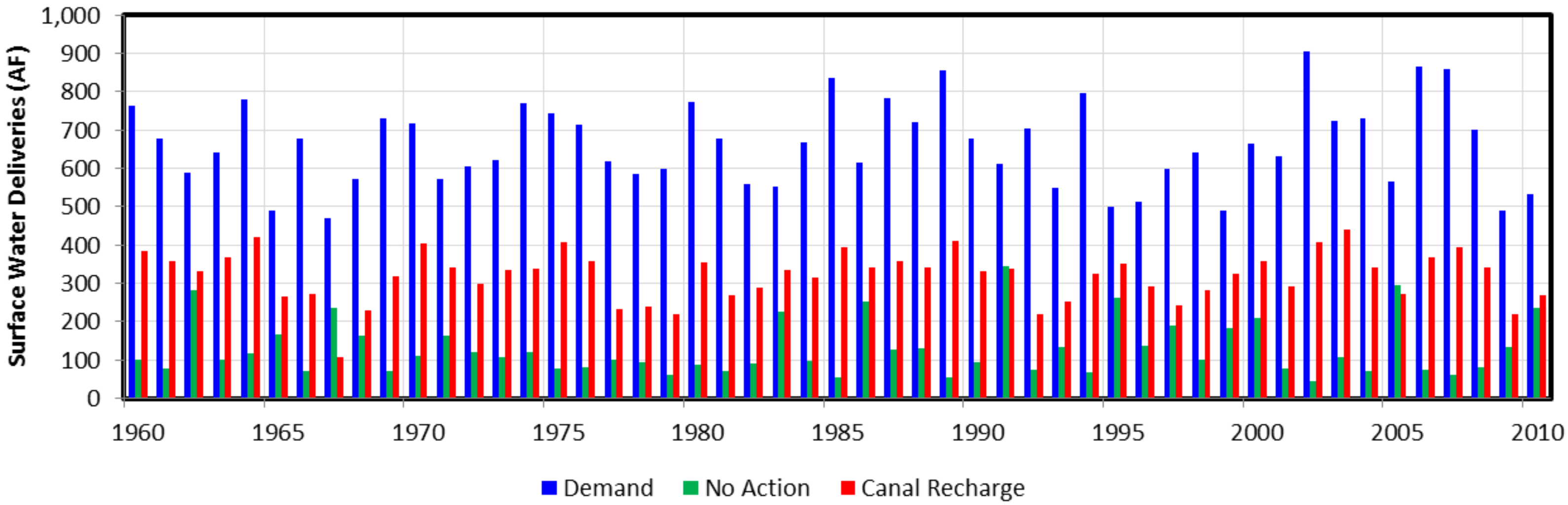


Figure 199. Comparison of the annual surface water demands and deliveries for the canal recharge alternative for Group 8; Baseline No Action.

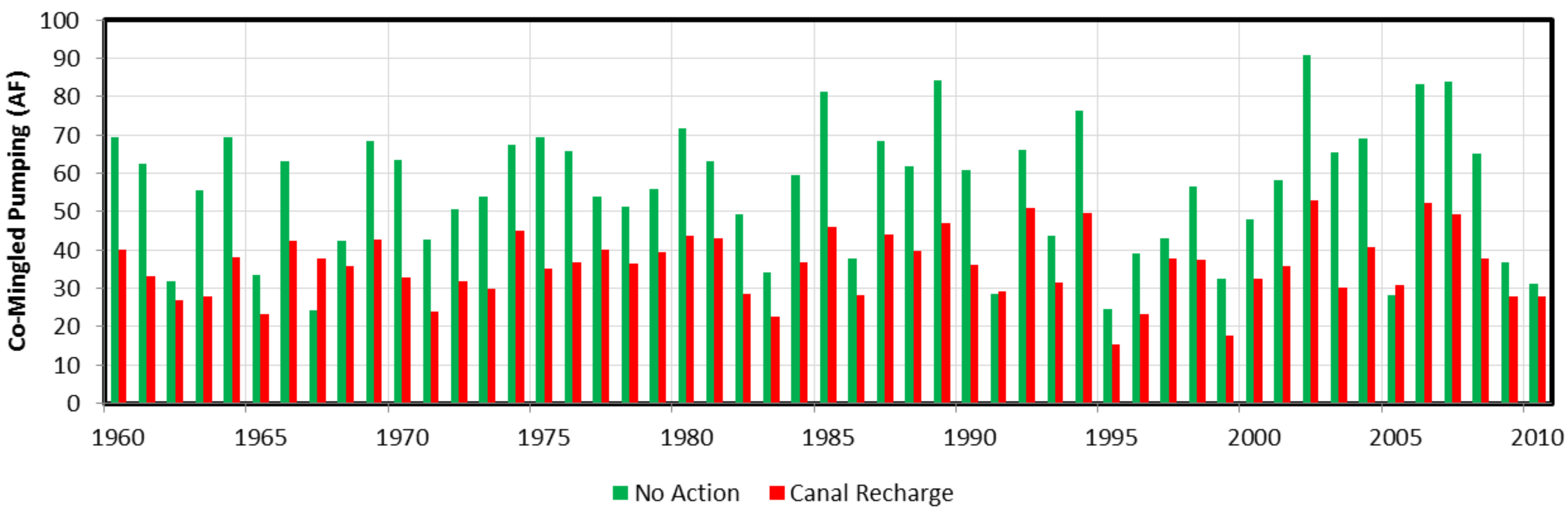


Figure 200. Comparison of the annual co-mingle pumping volumes for the canal recharge alternative for Group 8; Baseline No Action.

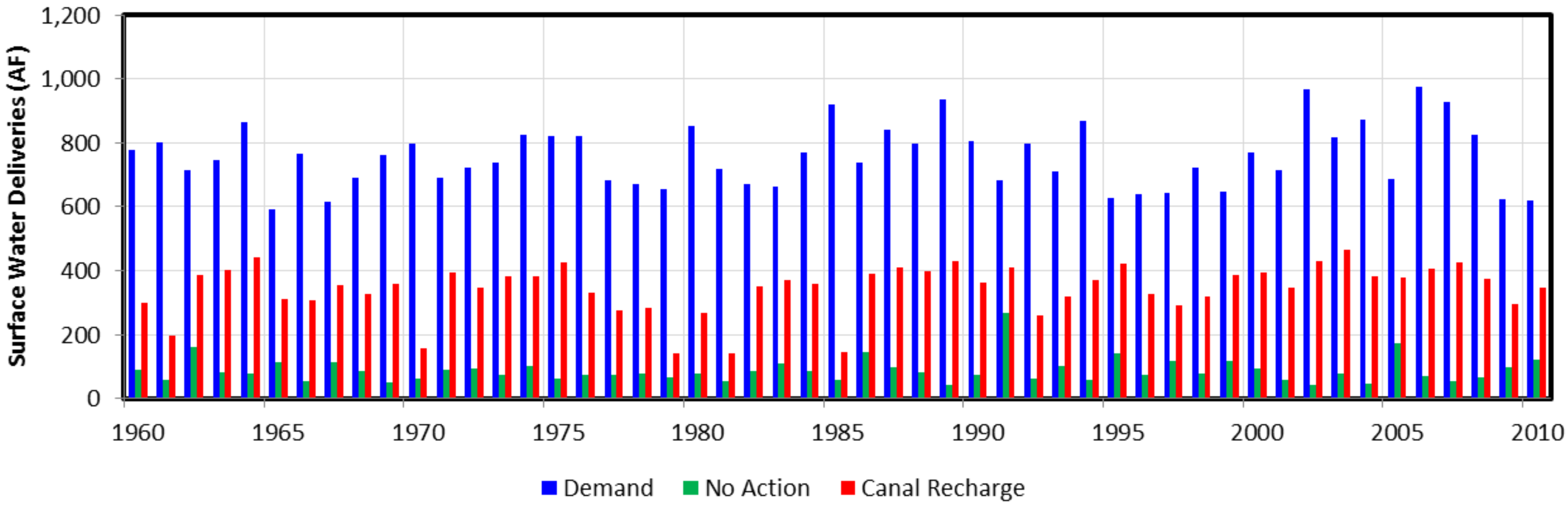


Figure 201. Comparison of the annual surface water demands and deliveries for the canal recharge alternative for Group 8; Alt 2 Low.

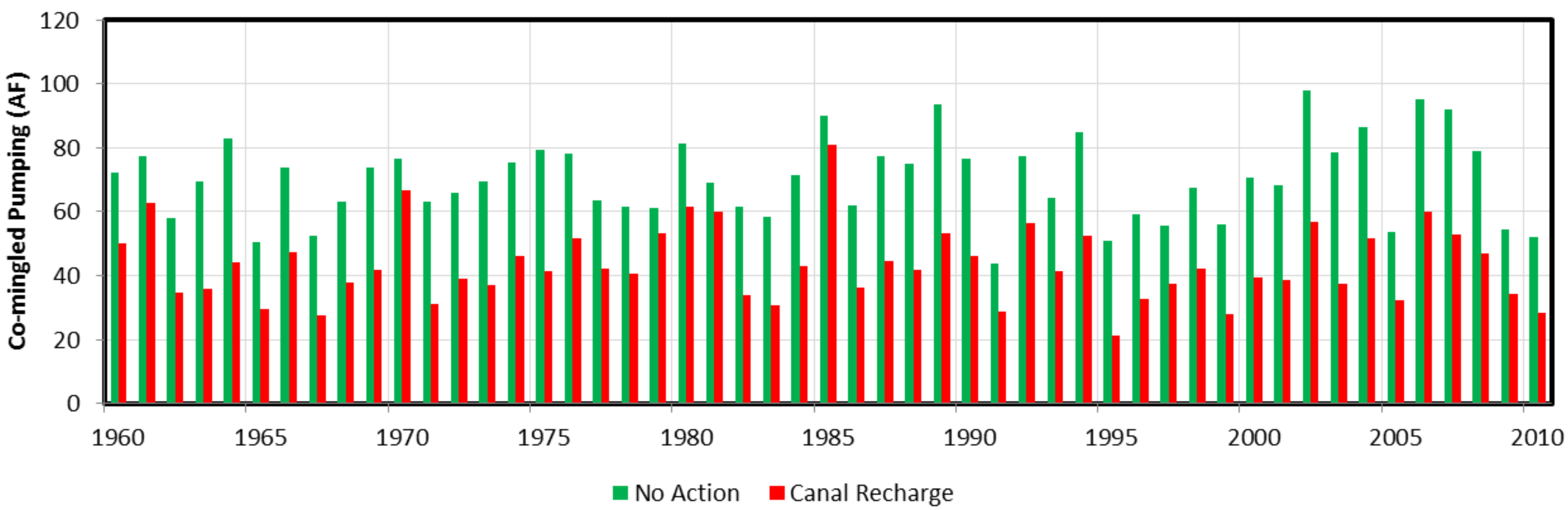


Figure 202. Comparison of the annual co-mingle pumping volumes for the canal recharge alternative for Group 8; Low No Action.

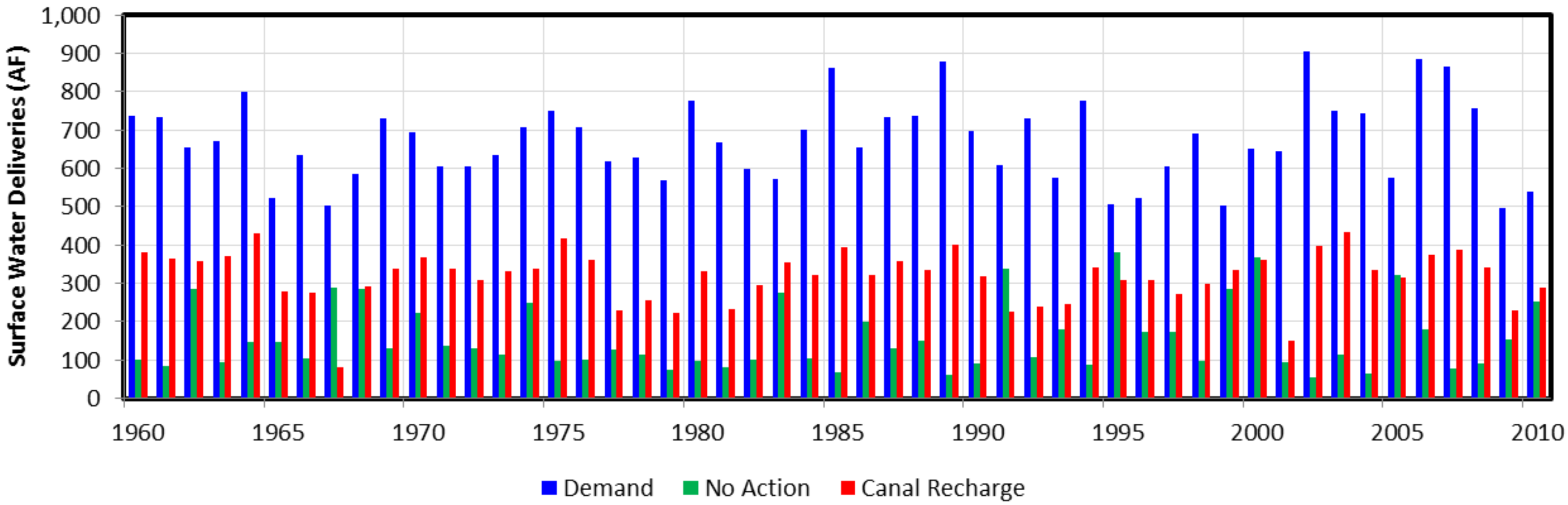


Figure 203. Comparison of the annual surface water demands and deliveries for the canal recharge alternative for Group 8; Alt 2 CT.

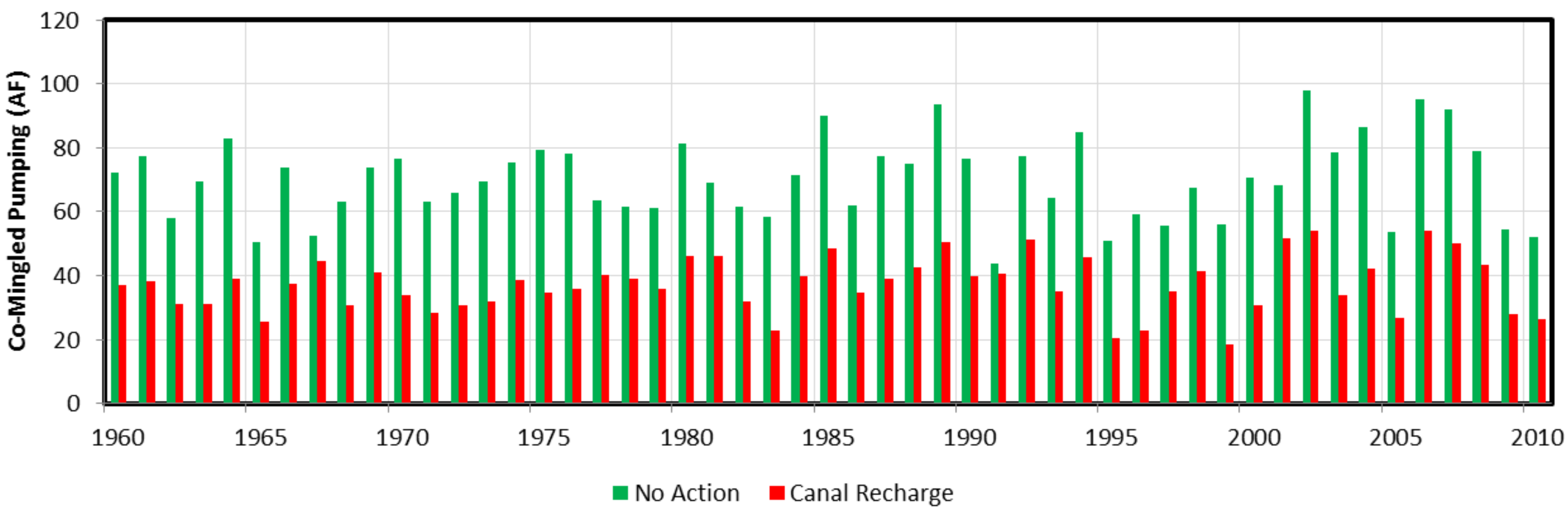


Figure 204. Comparison of the annual co-mingle pumping volumes for the canal recharge alternative for Group 8; CT No Action.

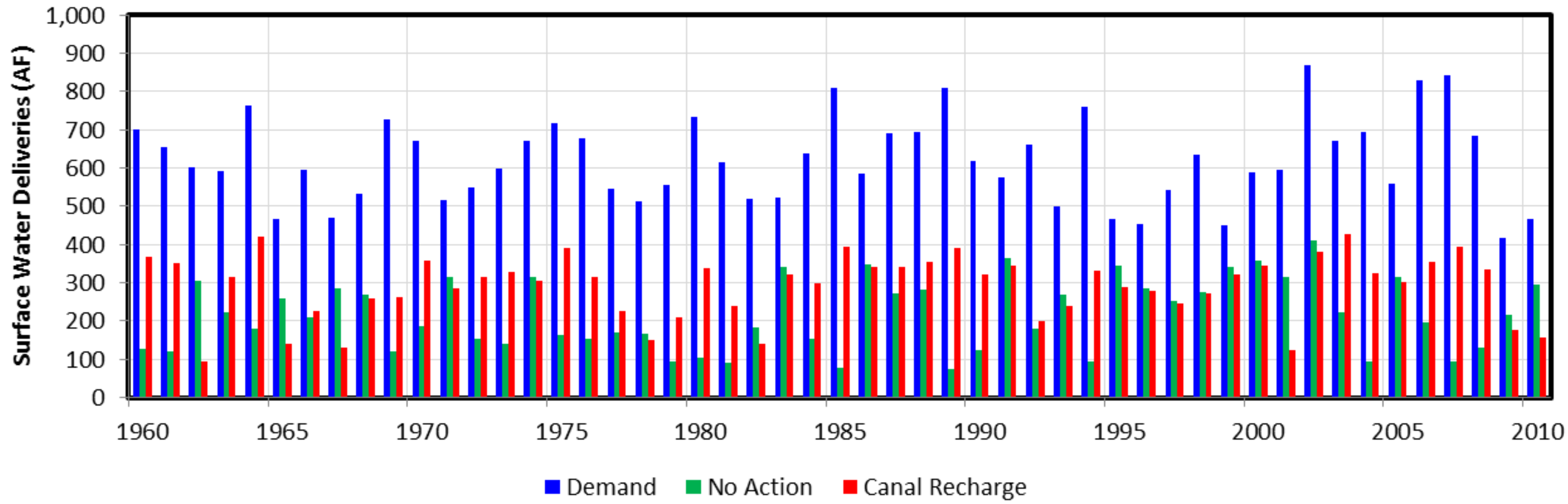


Figure 205. Comparison of the annual surface water demands and deliveries for the canal recharge alternative for Group 8; Alt 2 High.

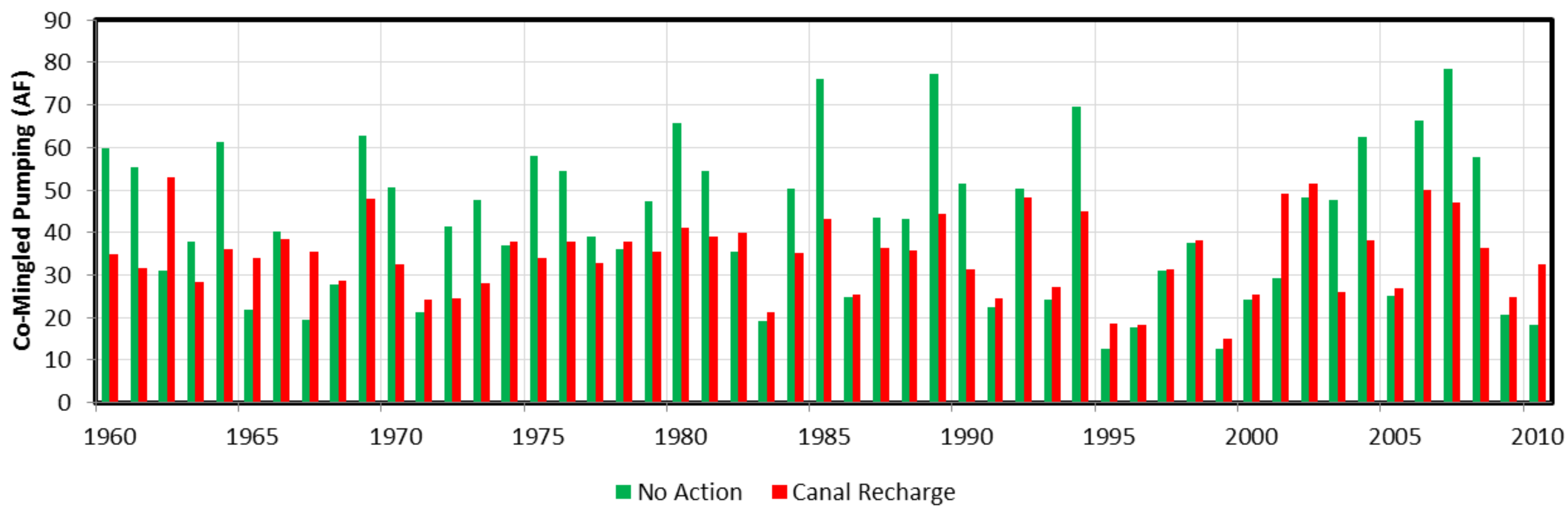


Figure 206. Comparison of the annual co-mingle pumping volumes for the canal recharge alternative for Group 8; High No Action.

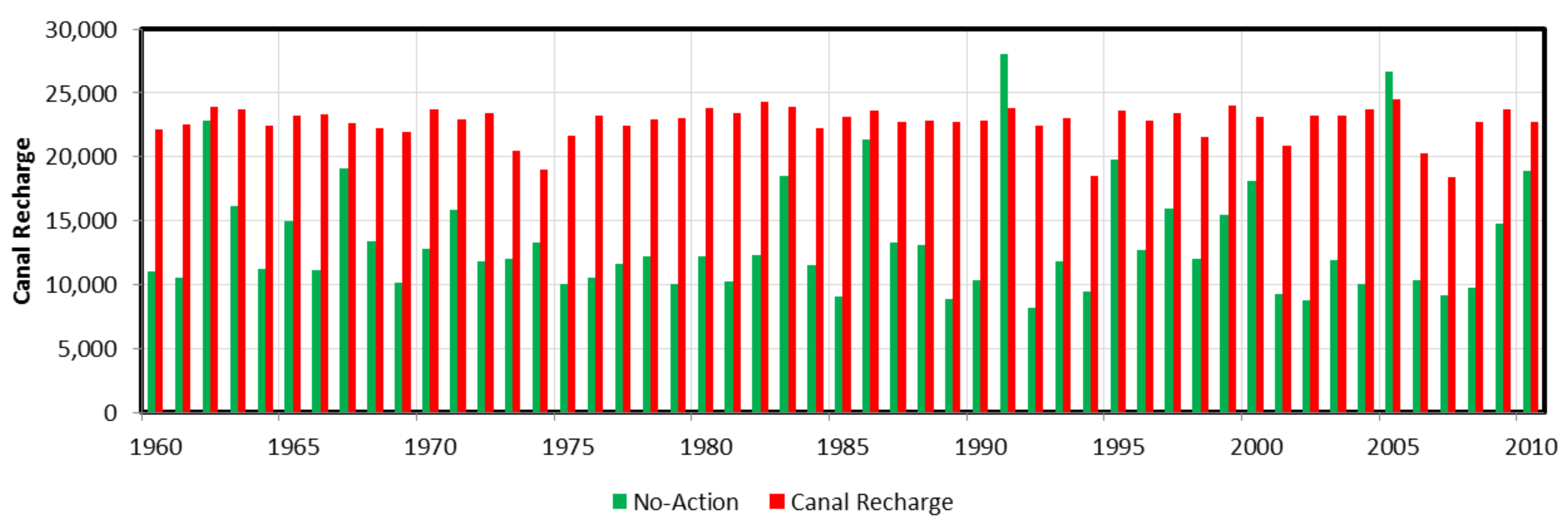


Figure 207. Comparison of annual basin wide canal recharge for the canal recharge alternative; Baseline No Action.

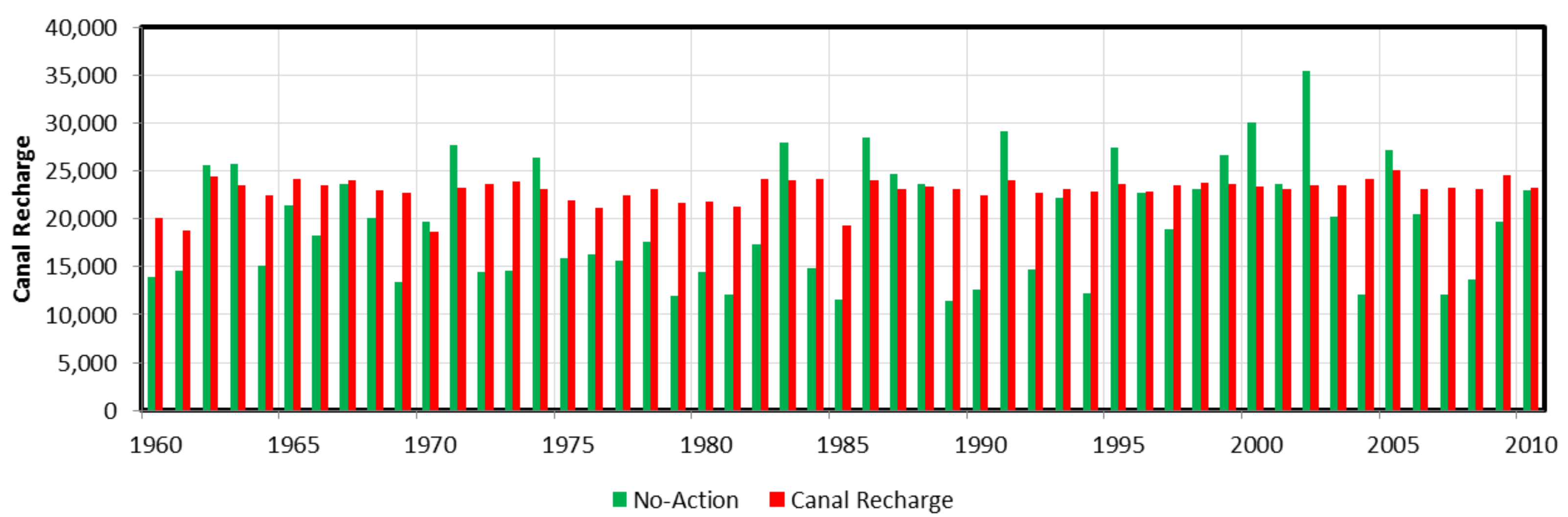


Figure 208. Comparison of annual basin wide canal recharge for the canal recharge alternative; Alt 2 Low.

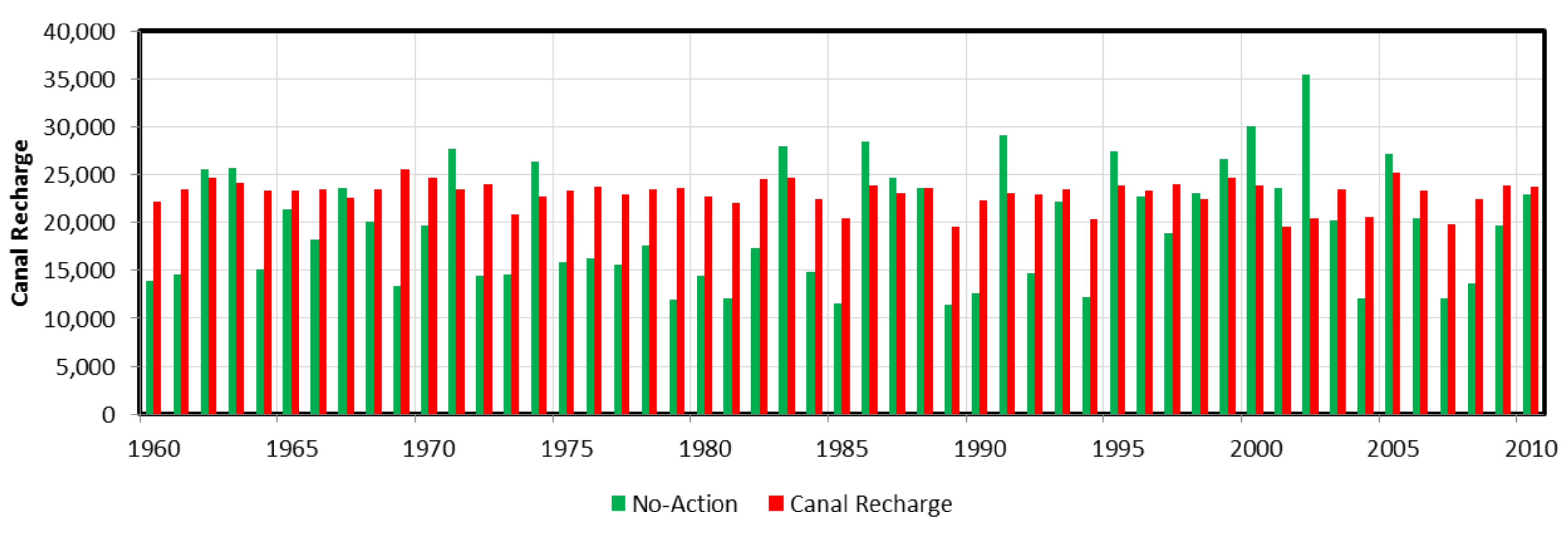


Figure 209. Comparison of annual basin wide canal recharge for the canal recharge alternative; Alt 2 CT.

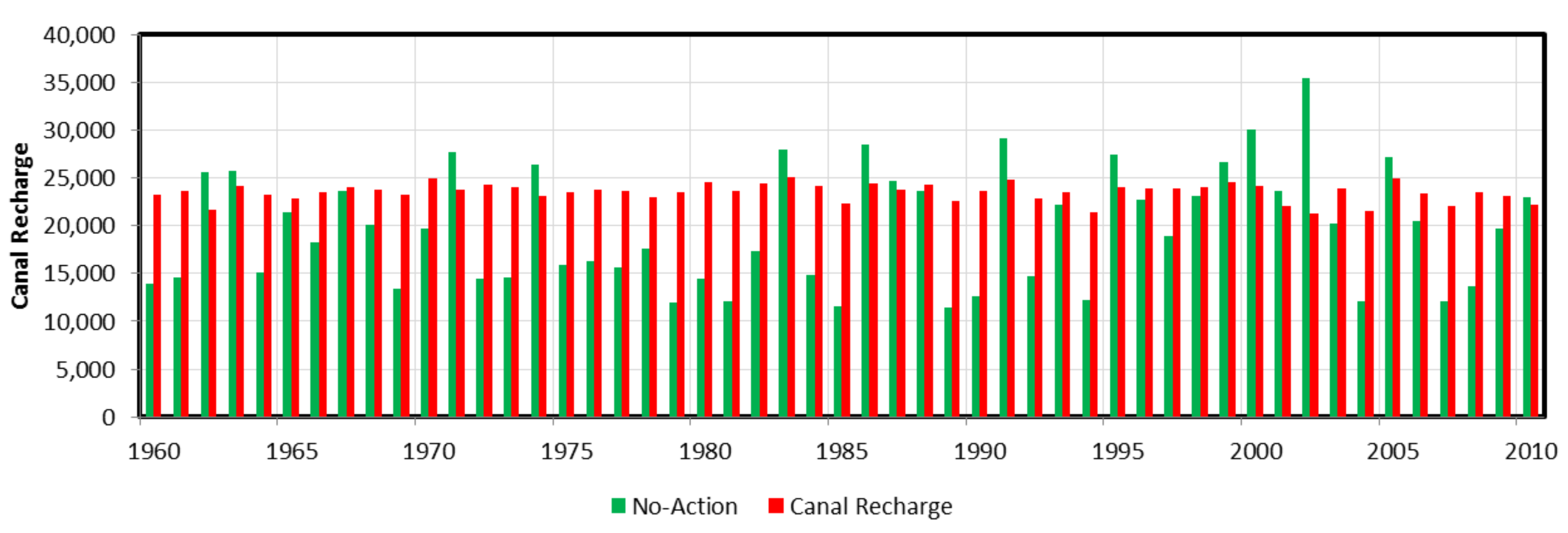


Figure 210. Comparison of annual basin wide canal recharge for the canal recharge alternative; Alt 2 High.

6 Modeling Assumptions and Constraints

The watershed models are regionalized models intended to interface with and support the surface water operations models and groundwater models. The intent of the watershed model is to provide the most accurate estimations of the water balance within the watershed; however, the model is limited by the amount of available information describing the system. Efforts are taken to assemble and incorporate the best available data but given the temporal domain of the study and the input requirements of the model, a robust dataset may not be available. Irrigation efficiency has improved immensely over this time period as irrigators become more efficient and adopt new technology and management techniques. Farming practices and cropping patterns have also changed. The watershed model attempts to account for these variations, but is limited on scope and resolution of the data. Additionally there are characteristics within the system that are improbable to predict and exhibit high variability both spatially and temporally. Examples include insect damage, fire, hail, nutrient deficiencies, disease, to name a few. The watershed model attempts to account for these items through an iterative calibration process with the groundwater model. Limited calibration has been undertaken in both model areas, and further calibration is necessary.

Furthermore, the watershed model is intended to assist in large scale planning projects. The use of characteristic soils, crop, management techniques and systems may be inaccurate in a specific location but are intended to represent the system as a whole and regional areas. End users of this information should not rely solely on absolute values from a specific run, but consider the trends and relative changes between runs.

After the completion of the modeling, a small error was detected in the application of canal recharge in the UNWNRD model. Contradicting values within the canal recharge files, from the surface water operations model and not detected in either the watershed or groundwater models, resulted in canal recharge occurring east of column 100 being applied 100 miles (columns) west of their intended location within the .RCH files. This error persists across all model runs which should allow a majority of the error to fall out as the changes between runs are evaluated. This error did not affect canal seepage for the Mirage Flats Irrigation District which is the dominant source of canal seepage within the model.

Relatively speaking the magnitude of the recharge is small. Roughly, 1,000 AF were omitted from runoff zone 5. Of this omission, 400 AF per year of recharge were added to runoff zone 2. The additional recharge is located on the periphery of zone 2, as opposed to next to the river; an aspect which should lessen any influence the error may cause. The other 600 AF missing from zone 5 was applied outside the Niobrara Drainage Basin.

7 References

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