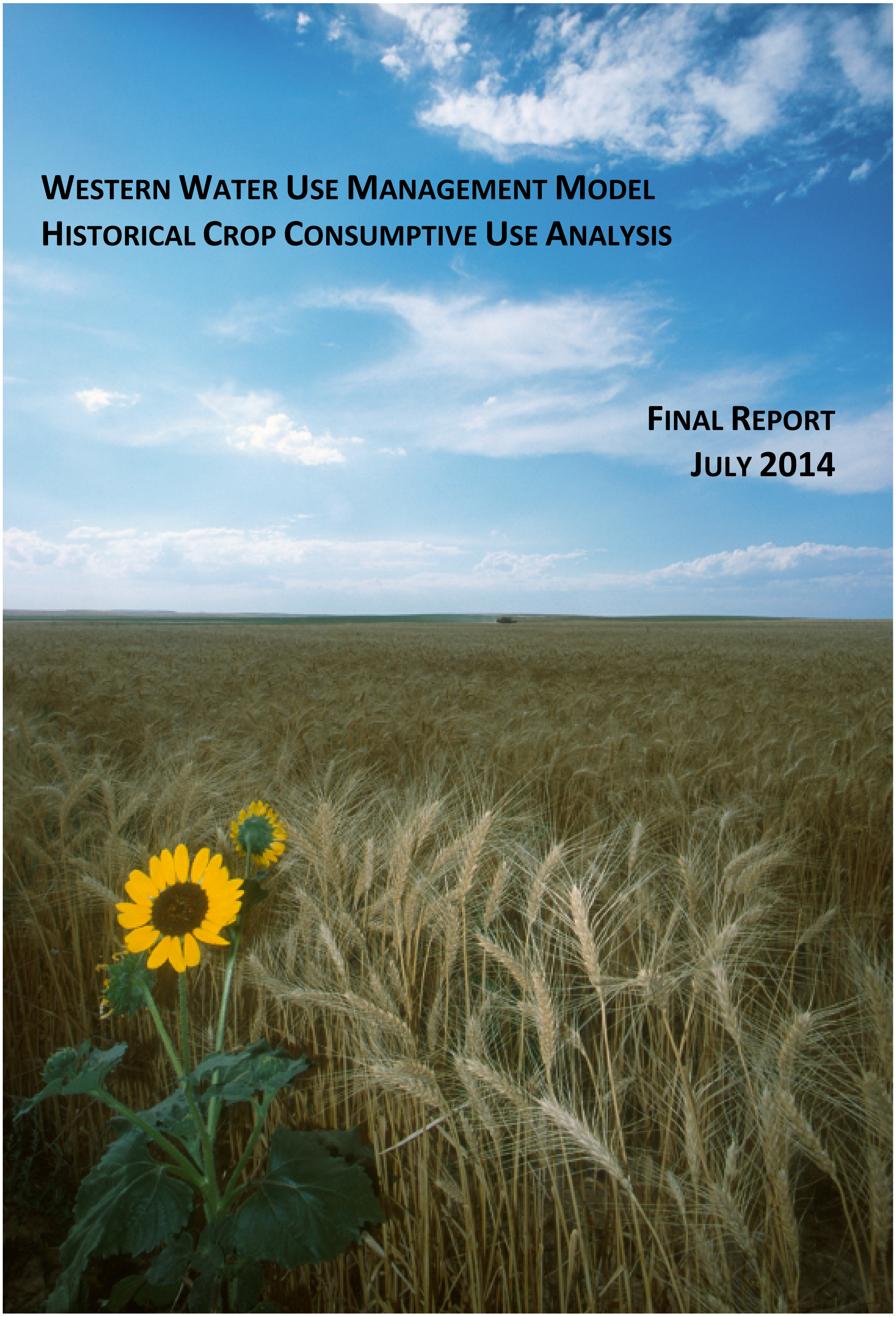
Western Water Use Management Model
Historical Crop Consumptive Use Analysis

Final Report
July 2014



ACKNOWLEDGMENTS

This report was prepared for the North Platte and South Platte Natural Resource Districts. Funding for this effort was provided by the North Platte and South Platte Natural Resource Districts (NPNRD and SPNRD), and the Nebraska Department of Natural Resources (NDNR) as part of the Western Water Use Management Modeling (WWUM) efforts. An original modeling effort was completed and documented in June of 2013 for the 1953 through 2010 study period. The modeling effort and study period was extended through 2013 and the results of that extended effort are documented herein. The model extension effort was directed by Thad Kuntz of Adaptive Resources Inc. with technical support provided from Kara Sobieski of Wilson Water Group; Heath Kuntz and Kyle Liebig of Adaptive Resources Inc.; and Marc Groff, Shane Dolph, and Isaac Mortensen of The Flatwater Group.

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1.0 INTRODUCTION

The publically available Consumptive Use Model (StateCU) uses several different methods to estimate potential crop consumptive and irrigation water requirement, then performs a water balance to estimate the actual crop consumptive use of surface and ground water supplies. For the Western Water Use Management Model (WWUM), only the water balance portion of StateCU was used, as the potential crop consumptive use and the net irrigation water requirement (NIR) was estimated by The Flatwater Group using the CropSim program. StateCU was used to perform the water balance for the WWUM Model for the following reasons:

- StateCU has the capability to directly read in CropSim-estimated NIR.
- StateCU can estimate the portion of NIR met from surface water supplies using historical diversion records, conveyance efficiency and irrigation application efficiencies.
- StateCU can estimate the portion of NIR met from ground water supplies using well capacities and irrigation application efficiencies. Historical pumping records are used in the water balance calculation when available.
- Output generated from the StateCU analysis is correctly formatted for direct input into the surface water model.
- StateCU can provide a preliminary estimate of historical pumping and non-consumed water from canal leakage and irrigation application in a format that can be easily used in the ground water model.

This report discusses the input files and modeling decisions made to develop the StateCU analysis in order to estimate historical consumptive use, well pumping, canal leakage, and irrigation return flows for the WWUM area. In addition to the information found herein, information regarding the estimation of historical crop consumptive use in the North Platte and South Platte River Basin and the tool used to perform the analysis is also documented in five major reports as follows:

1. The *WWUM Irrigated and Dryland Acreage Assessment* report describes the development of the 1953, 1975/77, 1984, 1993, 1997, 2001, 2005 and 2010 irrigated lands coverages, including the process used to determine irrigated acreage, associated crop type, irrigation method (sprinkler or flood), and surface water source. The same general approach was used to extend the assessment through 2013; and the report may be revised to reflect results of this extended assessment in 2011 through 2013.

2. The *WWUM Regionalized Soil Water Balance Model (CropSim)* report describes the development of the climate data and soil moisture parameters, as well as the effective precipitation and consumptive use methodologies used to estimate potential consumptive use and net irrigation requirement for the entire WWUM study area.

3. *WWUM Water Resources Planning Model User's Manual* describes the development of the North Platte River Basin StateMod surface water model. This document, currently in development, summarizes the process and results of developing the structure list and historical diversions for the historical consumptive use analysis.

4. The *Ground Water Flow Model for the Southern Half of the Nebraska Panhandle* describes the development of MODFLOW ground water model for the North Platte and South Platte NRD areas. This document summarizes the process of integrating historical pumping and recharge information, as well as the model development process and the results from the model.

5. The *StateCU Documentation* describes the consumptive use model and graphical user interface used to perform all consumptive use analyses and is available on the Colorado Decision Support System website (cdss.state.co.us).

For More Information:

- The *Post-Decree Changes in the Water Supply and Irrigation Development in the North Platte River Valley from Whalen, Wyoming to Lewellen, Nebraska* report by Dr. Darrel Martin provides more information on major irrigation districts discussed in this report.

1.1 EXTENT OF ANALYSIS AREA

The primary information used from this analysis is a preliminary estimate of historical well pumping on co-mingled (i.e. lands that receive surface and ground water supplies) lands for the surface and ground water models, and a preliminary estimate of canal leakage and irrigation return flows for the ground water model. This analysis included the irrigated lands served by North Platte River and Blue Creek diversions within the Whalen Dam to Lake McConaughy river reach. This analysis also included lands irrigated by ground water only, located within the North Platte River Alluvium, and in relatively close proximity to the river valley.

As shown in **Figures 1 through 4**, the lands included in the analysis are generally located in the North Platte River Valley in Wyoming and the North Platte NRD area in Nebraska, with only a small portion of the lands located in the Pumpkin Creek Basin. Note that the acreage subset included in this analysis and referred herein as "WWUM" acreage represents only a portion of the irrigated acreage identified in the larger *WWUM Irrigated and Dryland Acreage Assessment*.

Figure 1: Modeled Irrigated Acreage in Nebraska, Garden County

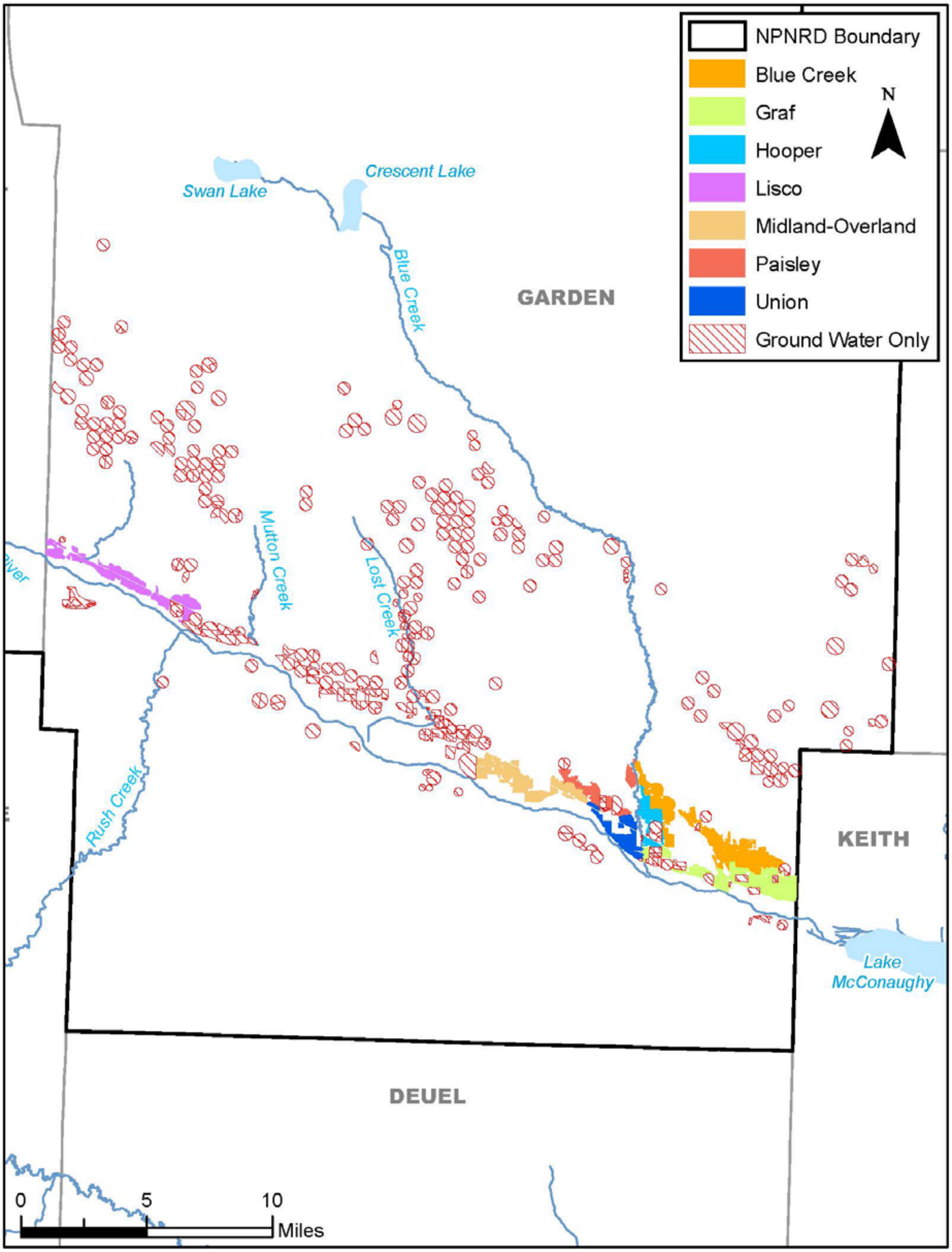


Figure 2: Modeled Irrigated Acreage in Nebraska, Morrill County

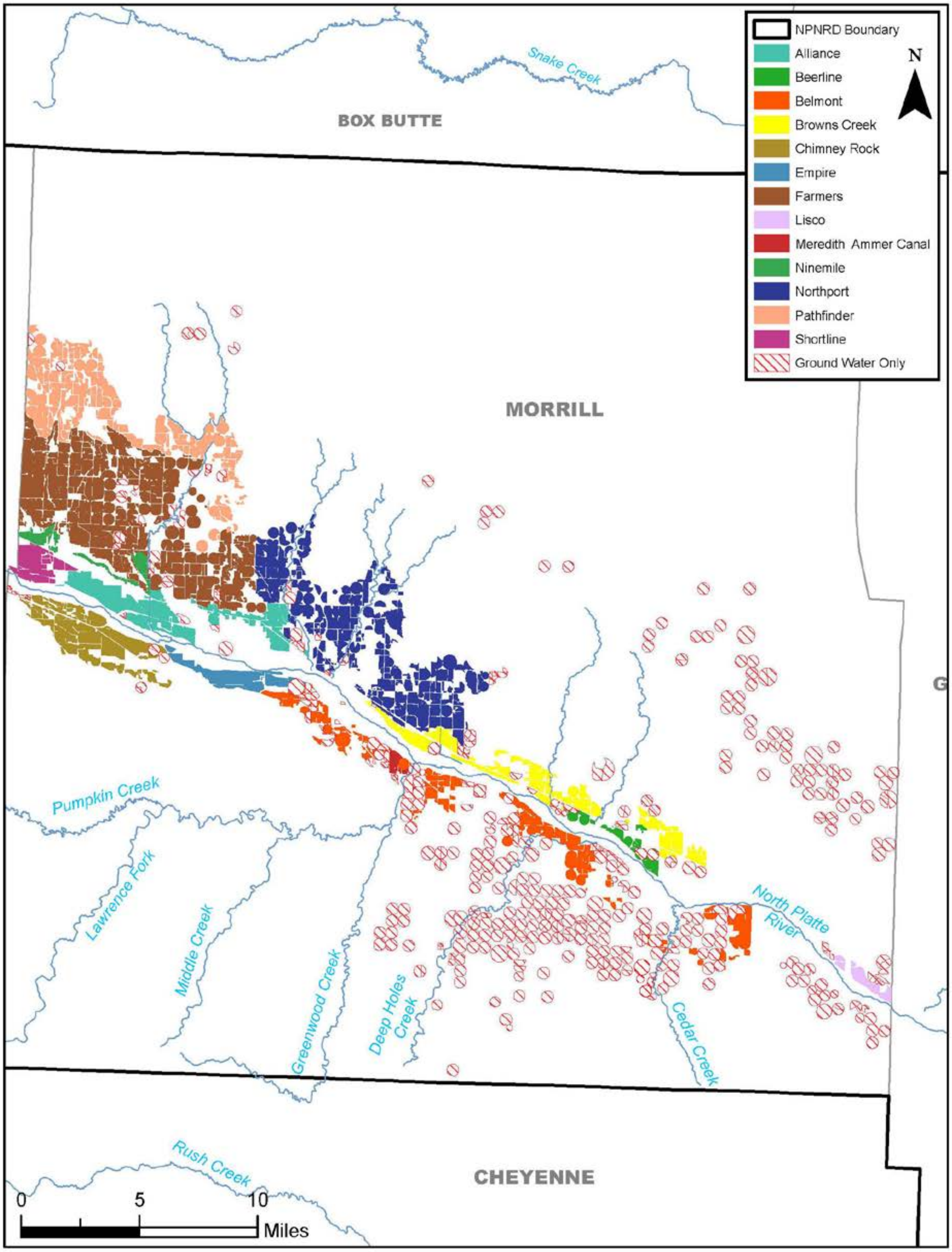


Figure 3: Modeled Irrigated Acreage in Nebraska, Sioux & Scotts Bluff Counties

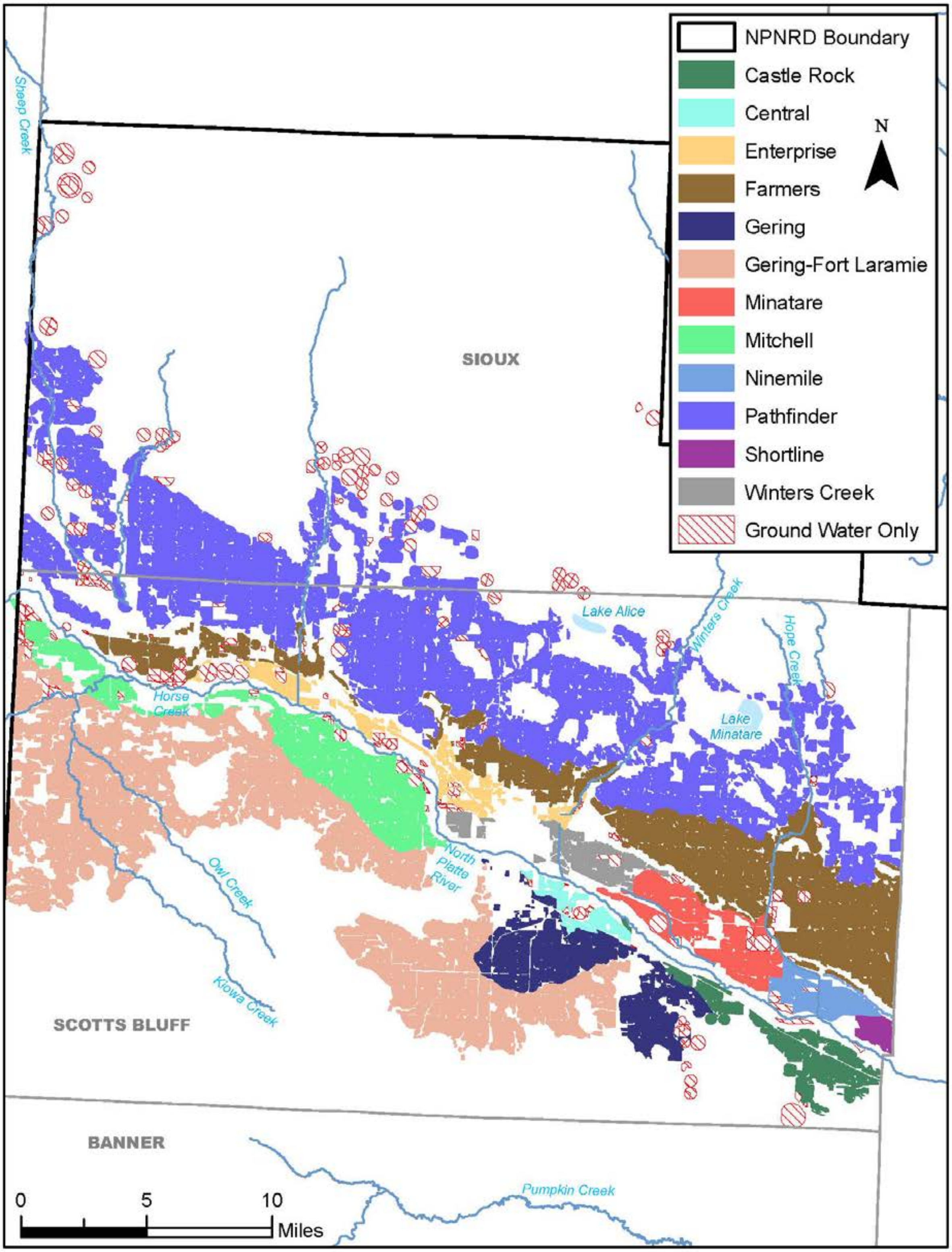
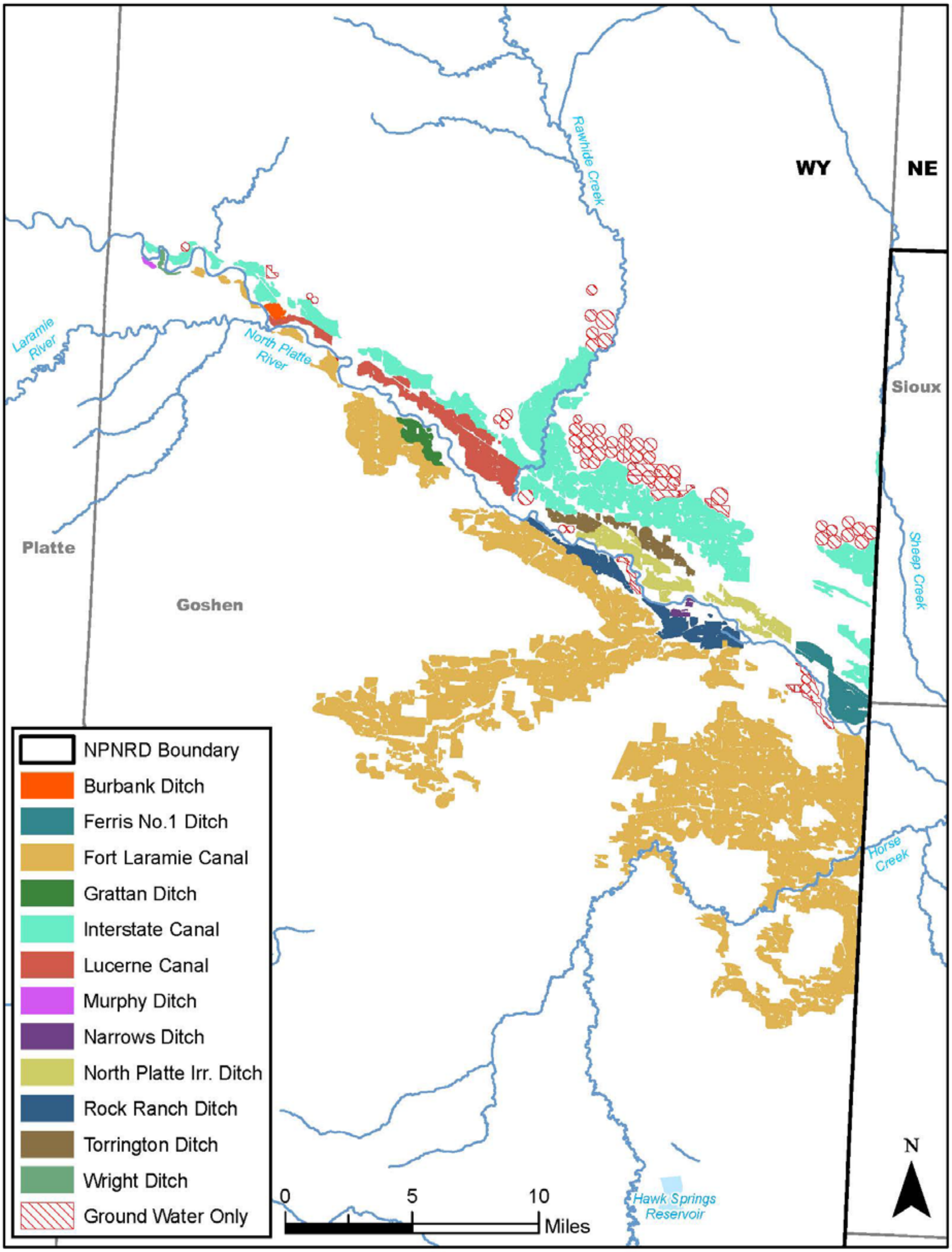


Figure 4: Modeled Irrigated Acreage in Wyoming



1.2 DEFINITIONS

Several terms used in this report have been broadly used in other studies, the following terms are defined for this report and the WWUM modeling effort.

Potential Evapotranspiration (ET) The total amount of water that would be used for crop growth if provided with an ample water supply, also called potential consumptive use.

Effective Precipitation The portion of precipitation falling during the crop-growing season that is available to meet the evapotranspiration requirement of the crop.

Net Irrigation Water Requirement (NIR) The amount of water required from a surface water diversion or ground water pumping irrigation to meet crop consumptive needs. Calculated as potential evapotranspiration less effective precipitation and stored winter precipitation.

Water Supply-Limited Consumptive Use The amount of water actually used by the crop, limited by water availability; also called actual consumptive use.

Irrigated Parcel An irrigated "field" having a common crop mix (up to four crop types), irrigation method (sprinkler or flood), and water source (surface and/or ground water). Irrigated parcels were defined in the *WWUM Irrigated and Dryland Acreage Assessment*, and aggregated based on location and water source for the StateCU analysis discussed herein.

Ditch Service Area The area of land that a ditch system has either the physical ability or the legal right to irrigate. Note that a ditch service area often includes farmhouses, roads, ditches, fallow fields and undeveloped lands. Therefore a ditch service area is typically greater than the land irrigated under that ditch.

Diversion Structure A ditch system that is modeled explicitly in both the StateCU historical consumptive use model and the StateMod water resources planning model. Diversion structures may be carriers to other structures or have an associated irrigation demand.

Demand Structure An irrigation demand structure is used to represent lands that are:

- served by several surface water sources (i.e. diversions from the North Platte River and diversions from tributaries to the North Platte River), or
- located within a similar Unit Response Function (URF) zone based on the ground water model.

Ground Water Only Structure A group of irrigated parcels without a surface water source. Ground water only lands were aggregated based on their location within a similar Unit Response Function (URF) zone based on the ground water model.

URF Zone An area used to define the aggregation of irrigated parcels, whereby the irrigated lands within a zone operate in a similar fashion, and whose irrigation recharge experiences similar return flow pattern (i.e. *U*nit *R*esponse *F*unction) and reach the river at a similar location. A URF Zone map was originally developed by Richard Luckey of High Plains Hydrology, included in the *Documentation of Unit Response Functions created for Western Water Use Model of the Nebraska Panhandle*, and used to assign a URF Zone to each irrigated parcel in the assessment.

Certified Parcels, **Certificates** A group of parcels that are served by one or more assigned well, and are assigned a unique certificate number to facilitate NRD management.

Data Management Interface (DMI) Programs, including StateDMI and TSTool, that allow data to be read in, filled if necessary, and formatted for use in StateCU using an automated data-centered approach.

StateMod The water allocation model used to analyze historical and future water management policies.

2.0 MODEL DEVELOPMENT

The WWUM historical crop consumptive use analysis was performed using StateCU, a generic data driven consumptive use model and graphical user interface. Only the water balance portion of StateCU is used for this analysis; the potential ET and NIR portions of this analysis were provided by other WWUM technical consultants. The objective of this WWUM analysis is to use externally-processed NIR information to develop monthly supply-limited consumptive use estimates, and estimates of pumping for periods without historical records. This information will be provided to the surface and ground water models, assess historical and future water management policies.

2.1 MODELING APPROACH

The general methodology used to estimate historical consumptive use for the North Platte River Valley is as follows:

1. A WWUM structure scenario was developed that includes 100% of the 1953 through 2013 irrigated acreage in the North Platte River valley using diversion, demand and ground water only structures and their associated acreage and crop patterns.
2. Potential ET was calculated by CropSim using the Hargreaves consumptive use methodology and factors calibrated to the ASCE Penman-Montheith method based on daily climate data from the High Plains Regional Climate Center and the National Weather Service. CropSim accounts for varying soil conditions that impact soil moisture, and uses soil moisture along with effective precipitation to estimate NIR on a daily basis for each irrigated parcel in the NPNRD area. NIR for each irrigated parcel was then aggregated by structure and by month and read directly into StateCU.

3. Water supply-limited consumptive use was calculated by StateCU by considering diversion records, conveyance efficiencies, application efficiencies, soil moisture interactions, and supplemental ground water supplies to meet NIR. Historical pumping records in the basin are only available in more recent years; therefore it was necessary to estimate historical pumping through the model analysis. The model approach to estimating ground water pumping, either "mutual ditch" or "maximize supply", dictates which order surface water, soil moisture and ground water supplies are used to satisfy NIR. The ground water pumping approach was determined for each structure based on a comparison of modeled pumping to metered pumping, when available.

The remainder of this report summarizes specific information on how input data was developed, which model analysis options were used, and the results from the analysis. Details on how to make changes to the input file data using the DMIs or how to simulate the StateCU model using the GUI can be found in the StateCU Documentation, available on the CDSS website.

3.0 DATA DESCRIPTION

The following sections provide a description of each input file, the source of the data contained in the input file, and the procedure for generating the input file.

- StateCU Response File ***Section 3.1***
- StateCU Control File ***Section 3.2***
- StateCU Structure File ***Section 3.3***
- Crop Distribution File ***Section 3.4***
- Annual Irrigation Parameter File ***Section 3.5***
- Historical Diversion File ***Section 3.6***
- Historical Ground Water Pumping File ***Section 3.7***
- Crop Characteristics File ***Section 3.8***
- Replacement Crop Requirement ***Section 3.9***

As discussed above, CropSim was used to perform the potential ET and NIR calculations for the NPNRD. These calculations took into account historical climate data and other information used in the consumptive use equations. Although StateCU is not performing these calculations, the files containing these types of information are still required to execute the program. The Climate Station Information File (*.cli), Climate Data Files (temperature *.tmp, precipitation *.prc, frost dates *.fd), Blaney-Criddle Crop Coefficient File (*.kbc) are included in the analysis but are filled with null data. See the *StateCU Documentation* for information on the content and format of these files.

3.1 STATECU RESPONSE FILE (WWUM2012_GWP.RCU)

The StateCU response file contains the names of input files used for a StateCU analysis. The StateCU response file was created using a text editor for the WWUM analysis.

3.2 STATECU MODEL CONTROL FILE (WWUM2012.CCU)

The StateCU Model control file contains the following information used in the historical consumptive use analysis; note only control options that apply to the supply-limited portion of the analysis are discussed below.

- Beginning and ending year for simulation – The simulation period for the analysis was 1953 through 2013.
- Scenario type – The analysis was defined as a "structure" scenario.
- Water supply/rights consideration – The water supply/rights consideration switch was set to "4" which specifies that water supply-limited consumptive use was calculated considering both surface and ground water sources.
- Soil moisture consideration – The soil moisture switch was set to "2" indicating the analysis should include soil moisture accounting and run a "pre-simulation" to set initial soil content to simulated ending soil content for each structure
- Output options – The output summary switch was set to "3" indicating a detailed water budget output should be generated.

The StateCU model control file was created using a text editor for the WWUM analysis.

3.3 STATECU STRUCTURE FILE (WWUM2012.STR)

The structure file provides a master list of structures that will be included in the StateCU analysis, and contains physical information and structure-specific information that does not vary over time (e.g. location information and available soil capacity values). Each structure included in this file represents a model ID in the surface water model; this one-for-one correlation between structures in StateCU and the surface water model is necessary as the StateCU output is read directly into the surface water model.

Structures were classified as either diversion structures, demand structures, or ground water only structures. The classification process was based on the type of supply available to each irrigated parcel and the location of the parcel with respect to the river, tributaries, diversion points, and streamflow gages. The URF Zone (see description in the Definitions section) assignment, along with the water supply information (i.e. SW/GW flags) and surface water facility assignment (i.e. SW_FAC) in the acreage assessment was used to aggregate lands into structure types.

For More Information:

- The *Documentation of Unit Response Functions created for Western Water Use Model of the Nebraska Panhandle* report developed by Richard Luckey of High Plains Hydrology provides additional information on the development of URF Zones.
- The *WWUM Irrigated and Dryland Acreage Assessment* report provides additional information on the assignment of surface water facility, water supply information, and URF Zones.

Demand Structures

Irrigated lands that receive surface water from more than one source and/or receive a co-mingled supply were grouped into demand structures based on surface water facility assignment and URF Zone assignment. Demand structures in the model are generally designated with a five-digit model ID that corresponds to the model ID of the diversion structure that carries water to the grouped land and a numeric suffix that corresponds to the URF Zone the land is located in. For example, two URF Zones were delineated for the lands served by Browns Creek Canal (Model ID: 00589), therefore there are two demand structures associated with Browns Creek Canal (Model IDs: 00589_96 and 00589_106).

Note that if only one URF Zone was delineated for a surface water facility, a separate demand structure was not created. Rather, the irrigated land was represented under the diversion structure model ID. The URF Zone map only encompassed the irrigated land in Nebraska, therefore many of the Wyoming diversion structures were represented in the model with an associated irrigation demand, not separate demand structures.

There are 81 demand structures represented in the WWUM consumptive use analysis. Four are located in Wyoming, with the remaining structures located in Nebraska.

Diversion Structures

Diversion structures divert surface water to serve one or more irrigation demands. As discussed above, diversion structures that divert surface water to a single irrigation demand are represented in the model with that associated irrigation demand. Diversion structures that carry water to multiple demand structures do not have an associated irrigation demand and are included in the consumptive use model as a place-holder for the surface water modeling efforts. Diversion structures are designated in the model with a five-digit model ID, and may also include a “C” suffix if the diversion structure is a secondary carrier structure. For example, the main diversion structure for Winters Creek Canal from the North Platte River is designated by model ID 05701, and the secondary diversion structure from Winters Creek is designated by model ID 05701_C1.

There are 46 diversion structures in the WWUM consumptive use analysis, of which 14 have associated irrigation demands. Eight of these are located in Wyoming, the remaining are located in Nebraska.

Ground Water Aggregates

Irrigated lands that receive ground water only were grouped into aggregate structures based on URF Zone assignment. Ground water aggregates are designated in the model by a two-letter State identifier and a numeric suffix that generally corresponds to the URF Zone the land is located in. For example, irrigated lands served by ground water only located in URF Zone 209 were designated as NE_GW209. The WWUM consumptive use model includes 81 ground water aggregates located in Nebraska, and 6 in Wyoming.

Table 1 shows the number of each structure type and their associated acreage in the WWUM consumptive use analysis.

Table 1: Structure Type Summary

Structure Type	2005 Acres	Number of Structures	Percent of Total Acreage
Diversion Structures with Irrigation Demand	25,046	14	5%
Carrier Diversion Structures	N/A	32	N/A
Demand Structures	367,175	81	74%
Aggregated Ground Water Structures	102,779	87	21%
Total Structures	**495,000**	**214**	**100%**

Available Soil Moisture Capacities

Available water capacity (AWC) information is used by StateCU to determine the volume of the soil moisture zone available to store excess irrigation for each structure. AWC values in Nebraska were estimated through a spatial intersection between the 2005 irrigated lands coverage and a soil coverage provided by the The Flatwater Group.

The average AWC of the irrigated land assigned to the structure was used in the structure file. The soil coverage did not cover the entire Wyoming portion of the model area, therefore the portion that did extend into Wyoming was used to estimate a representative AWC for the lands to the north and south of the river. An AWC value of 0.1458 inches per inch was used for the structures with land to the south of the river, and an AWC value of 0.1250 inches per inch was used lands to the north of the river in Wyoming. The representative AWC values in Wyoming were confirmed by the Natural Resources Conservation Service (NRCS) Soils Survey data. Overall, AWC values in the structure file ranged from 0.080 to 0.150 inches per inch.

The structure file used in the historical consumptive use model was created using **StateDMI**, and external text files containing location information and available water capacities were read directly into the DMI during the creation of the file. Note that the structure file also contains information used by the potential consumptive use calculations, however that information, although provided, was not used in the water supply limited analysis.

3.4 CROP DISTRIBUTION FILE (WWUM2012.CDS)

The crop distribution file contains acreage and associated crop types for each structure for every year in the analysis period (1953 through 2013). The information provided in the crop distribution file is primarily used by StateCU to determine potential consumptive use and irrigation water requirement. Although this portion of StateCU is not used in the WWUM analysis, the crop and acreage information is still used in the water balance analysis to determine the volume of soil moisture available to each structure.

The crop and acreage information used in the WWUM historical crop consumptive use analysis is based on the 1953 through 2013 irrigated acreage assessment, as originally documented in *WWUM Irrigated and Dryland Acreage Assessment* report. The acreage assessment for the extended period of 2011 through 2013 was performed by Adaptive Resources Inc. and followed the same general approach as documented for the original assessments. In this assessment, parcels were identified as irrigated based on aerial imagery interpretation and analysis of water supply information. This assessment resulted in 1953, 1975, 1984, 1993, 1997, 2001, 2005, 2010, 2011, 2012, and 2013 irrigated lands coverages for the entire North Platte NRD area. Complex algorithms that included information about when parcels with wells were first irrigated were used to estimate acreage in between the coverages. These algorithms are documented in Appendix C and D of the *WWUM Irrigated and Dryland Acreage Assessment* report.

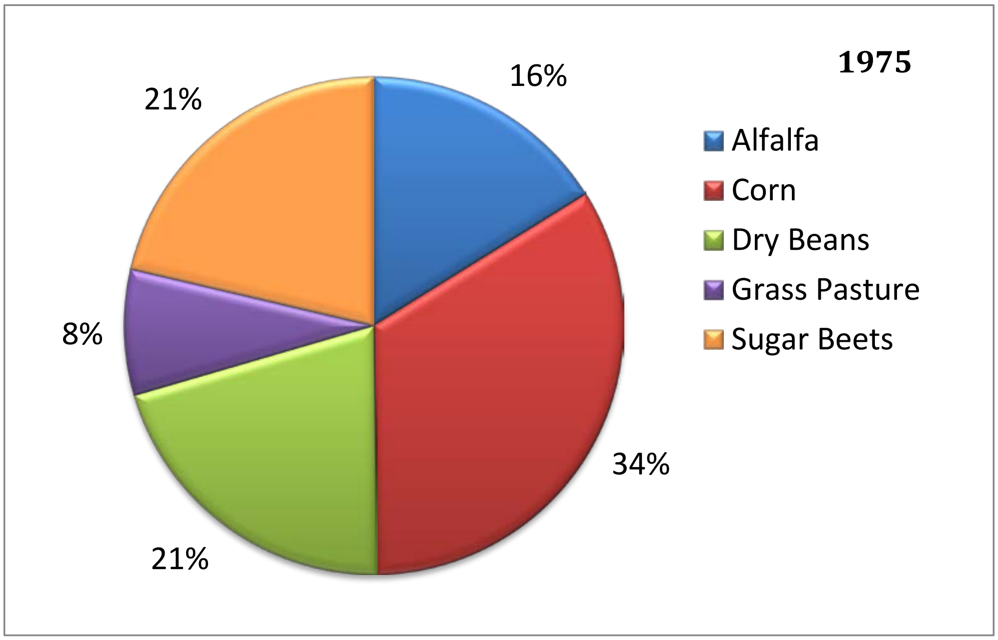
Crop information was assigned to irrigated acreage in each coverage based on a variety of sources, both spatial and tabular in nature, in order to use the best available crop information. In general, Nebraska crop information was based on the following sources and used during the years noted below:

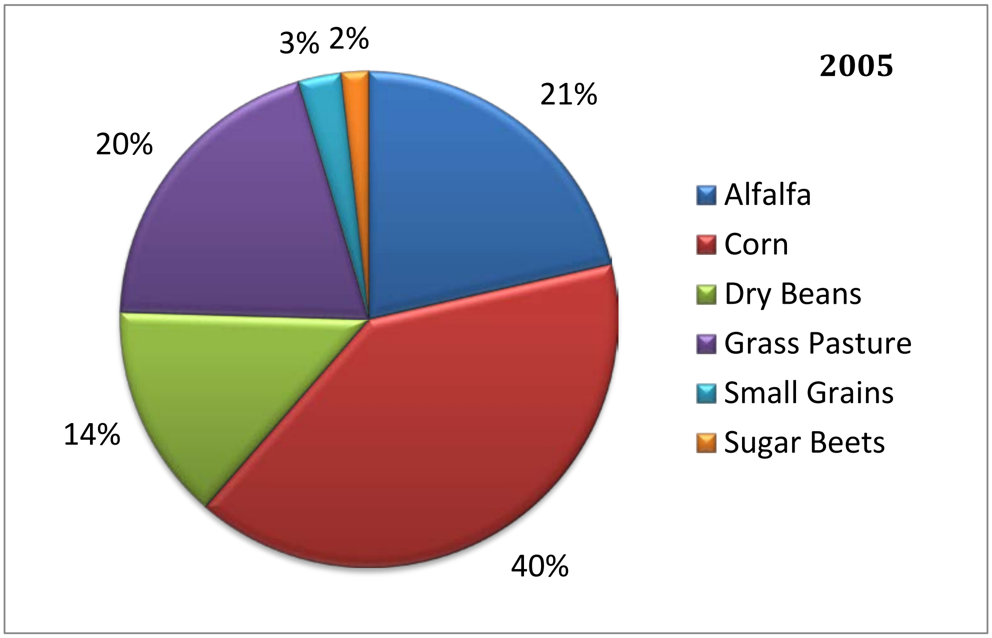
- 2010, 2011, 2012, 2013 – NPNRD field-verified crop information and USDA CropScape
- 2005, 2001, 1997, 1993 – Land Use coverages provided by the Center for Advanced Land Management Information Technologies (CALMIT) at the University of Nebraska Lincoln (UNL)
- 1984, 1975, 1953 – Cropping information provided in the *Post-Decree Changes in the Water Supply and Irrigation Development in the North Platte River Valley from Whalen, Wyoming to Lewellen, Nebraska* report by Dr. Darrel Martin (Dr. Martin report) and County Agricultural Statistics

Cropping information for Wyoming was also assigned based on information from the Dr. Martin report, specifically the Wyoming Government Irrigation Districts crop summary was limited to the four majority crops. Due to lack of more recent reliable spatial crop information, the crop information assigned in 1994 was carried forward through to 2013. A full discussion of the assignment of crop information in both Wyoming and Nebraska can be found in *Appendix C* of the *WWUM Irrigated and Dryland Acreage Assessment* report.

Figure 5 summarizes the average cropping pattern, as a percentage of total acreage, for the 1975 and 2005 irrigated acreage included in the WWUM historical consumptive use analysis. As shown, the overall crop mix in the model area has not changed significantly, with the predominant crops of dry beans, corn and alfalfa remaining relatively consistent over the years. More variability is seen with grass pasture and sugar beets; which may be attributed to the difference in crop classifications between data sources and the changing economic factors associated with producing certain crops in the North Platte River valley.

Figure 5: WWUM Crop Types 1975 vs. 2005



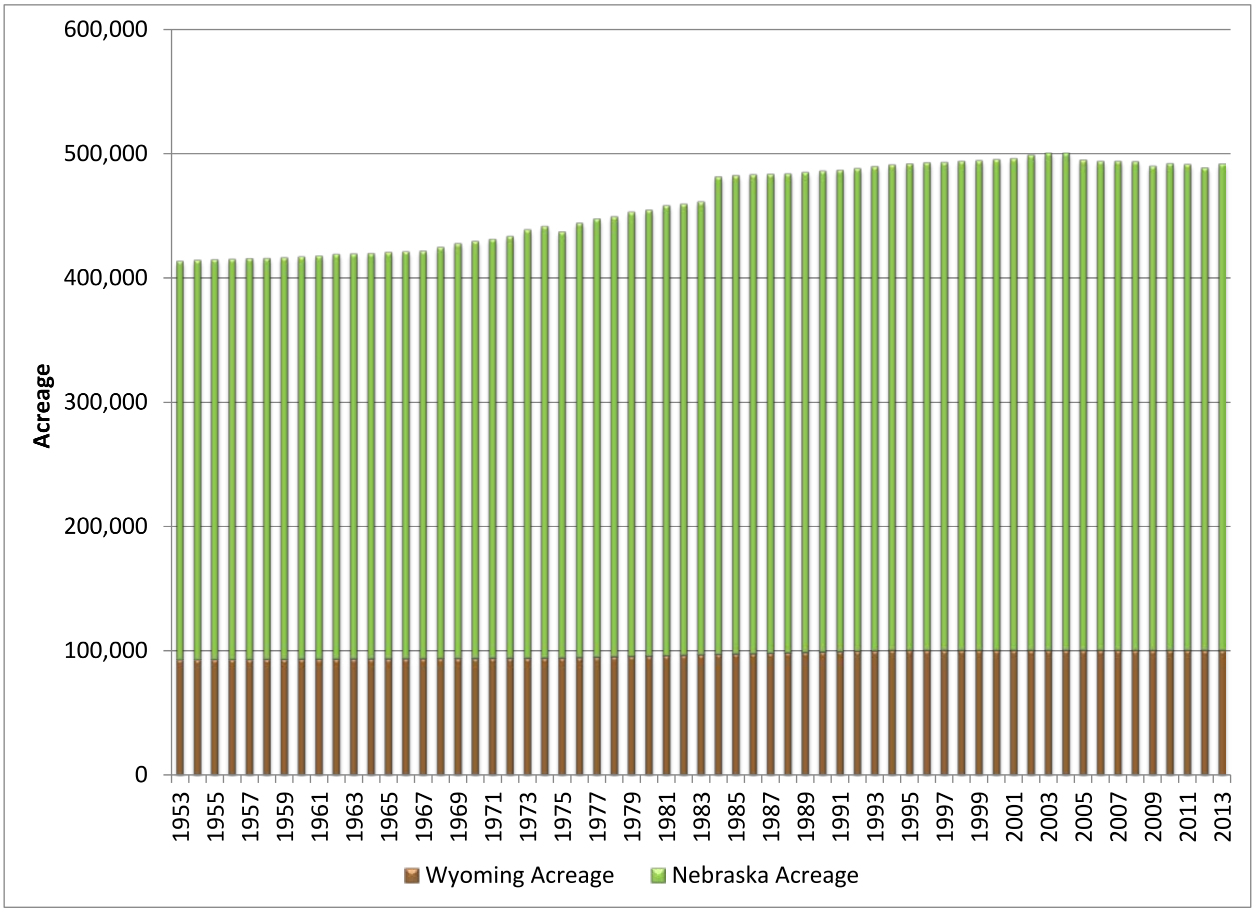


As discussed above, acreage for diversion structures, demand structures and ground water aggregates was based on the grouped acreage based on URF Zone mapping. As shown in **Figure 6,** irrigated acreage was estimated to steadily increase from approximately 413,660 acres in 1953 to 491,910 in 2013. Of this total, acreage in Wyoming accounted for approximately 20 percent, with the remaining acreage located in Nebraska. The sharp increase in 1984 acreage was in part due to the increased visibility of irrigated acreage in the infrared aerial imagery available that year, as discussed in the acreage assessment report.

For More Information:

- The *WWUM Irrigated and Dryland Acreage Assessment* report provides additional information on the development of acreage in between coverages, the assignment of crop types using best available information, and overall acreage trends.

Figure 6: Wyoming and Nebraska Irrigated Acreage



The crop distribution file used in the historical consumptive use model was created using **StateDMI**, and external text files containing crop and acreage information were read directly into the DMI during the creation of the file.

3.5 ANNUAL IRRIGATION PARAMETER FILE (WWUM2012.IPY)

The annual irrigation parameter file contains yearly (time series) structure information required to run supply-limited consumptive use simulations, including the following:

- Conveyance Efficiencies
- Maximum Irrigation Application Efficiencies (i.e. Flood or Sprinkler)
- Acreage assigned to the Four Land Use Categories:
  - Acreage flood irrigated with surface water only
  - Acreage sprinkler irrigated with surface water only
  - Acreage flood irrigated with ground water only or supplemental (i.e. co-mingled) to surface water
  - Acreage sprinkler irrigated with ground water only or supplemental (i.e. co-mingled) to surface water
- Maximum permitted or decreed monthly pumping capacity
- Pumping Approach (a.k.a. Ground Water Use Mode) of Mutual Ditch or Maximize Supply Approach

Conveyance Efficiencies

The conveyance efficiency is used to determine the portion of the total diversion that reaches the farm turnout. One minus the conveyance efficiency is the percent loss, accounting for the loss between the river headgate and the farm turnout, and represents losses through canals, ditches and laterals.

Published information was available for many of the canals in the WWUM area, primarily from the U.S. Bureau of Reclamation (USBR). For those canals that receive USBR supplies (i.e. Project canals), the long-term average annual conveyance efficiency was used. For non-Project canals, the average conveyance efficiency of smaller Project canals was used in this analysis. Note that a single conveyance efficiency value was used for each irrigation district, and applied to all URF Zone irrigation demands associated with each district. **Table 2** shows the conveyance efficiencies used in the analysis.

Table 2: WWUM Conveyance Efficiency

Model ID	Irrigation District	Conveyance Efficiency	Source
00064	Alliance	59%	USBR Ave.
00165	Burbank	60%	USBR
00187	Torrington	58%	USBR
00283	Beerline	59%	USBR

Model ID	Irrigation District	Conveyance Efficiency	Source
00417	Blue Creek	59%	USBR Ave.
00424	Lucerne	58%	USBR
00534	Belmont	62%	USBR
00589	Browns Creek	58%	USBR
00746	Castle Rock	59%	USBR Ave.
00754	Central	58%	USBR
00794	Chimney Rock	58%	USBR
01295	Empire	59%	USBR Ave.
01311	Enterprise	58%	USBR
01362	Farmers	51%	USBR
01590	Gering-Ft. Laramie	58%	USBR
01591	Gering	56%	USBR
01600	Graf	59%	USBR Ave.
02353	Hooper	59%	USBR Ave.
02359	Narrows	59%	USBR Ave.
03162	Lisco	59%	USBR Ave.
03563	Minatare	59%	USBR Ave.
03578	Mitchell	72%	USBR
03778	Ninemile	59%	USBR Ave.
03805	Northport	47%	USBR
03845	Wright	62%	USBR
03940	Paisley	59%	USBR Ave.
03966	Pathfinder	45%	USBR
04397	Midland-Overland	59%	USBR Ave.
04803	Shortline	59%	USBR Ave.
05313	Union	59%	USBR Ave.
05701	Winters Creek	59%	USBR Ave.
05867	Meredith-Ammer	59%	USBR Ave.
05920	Murphy	59%	USBR Ave.
07853	Grattan	58%	USBR
07859	North Platte	59%	USBR Ave.
07870	Rock Ranch	59%	USBR
07881	Pratt Ferris	59%	USBR Ave.
18544	Goshen	62%	USBR

Maximum Application Efficiencies

The maximum flood irrigation and sprinkler efficiencies account for application losses between the farm turnout and the crops. The maximum sprinkler irrigation efficiency was set to 70 percent from 1953 to 1975, linearly increased over time from 1976 to 1994, and was set to 85 percent from 1995 to 2013. The maximum flood irrigation efficiency was set to 65 percent for entire time period. These efficiency values were selected for the analysis based on discussions with Nebraska Department of Natural Resources (NDNR) staff and on the experience of those on the WWUM technical team.

Land Use Categories

The total acreage assigned to each diversion, irrigation demand or ground water only structure is split into four land use categories, indicating whether the acreage is irrigated by flood or sprinkler practices and served by surface water and/or ground water supplies. **Figure 7** summarizes the four land use categories. The attribution of surface and ground water supplies in the WWUM acreage assessment allowed for the summation of each structure's irrigated land in each land use category.

These land use categories are used to determine which efficiencies should be used for each portion of the land assigned to a structure each year. Note that the land use categories that include surface and ground water supplies reflect co-mingled parcels. Ground water only parcels were represented as separate structures to ensure that they did not receive surface water supplies. **Figure 8** shows the time series of irrigated acreage served by surface water only in contrast to acreage served in part or entirely by ground water. **Figure 9** shows the time series of irrigated acreage served by flood and sprinkler irrigation methods, and highlights the transition to sprinkler irrigation methods over time.

Figure 7: Four Land Use Categories

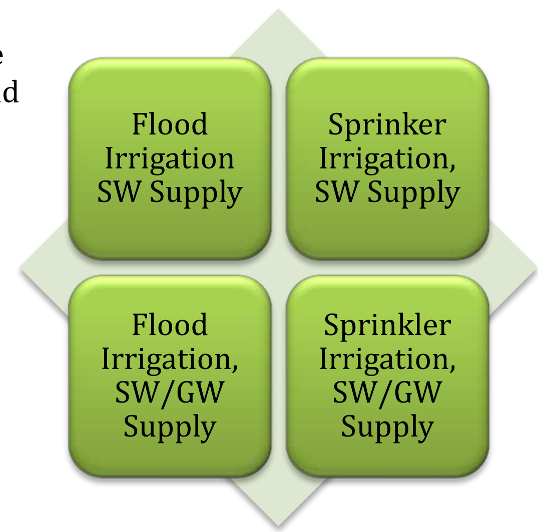


Figure 8: Acreage by Source

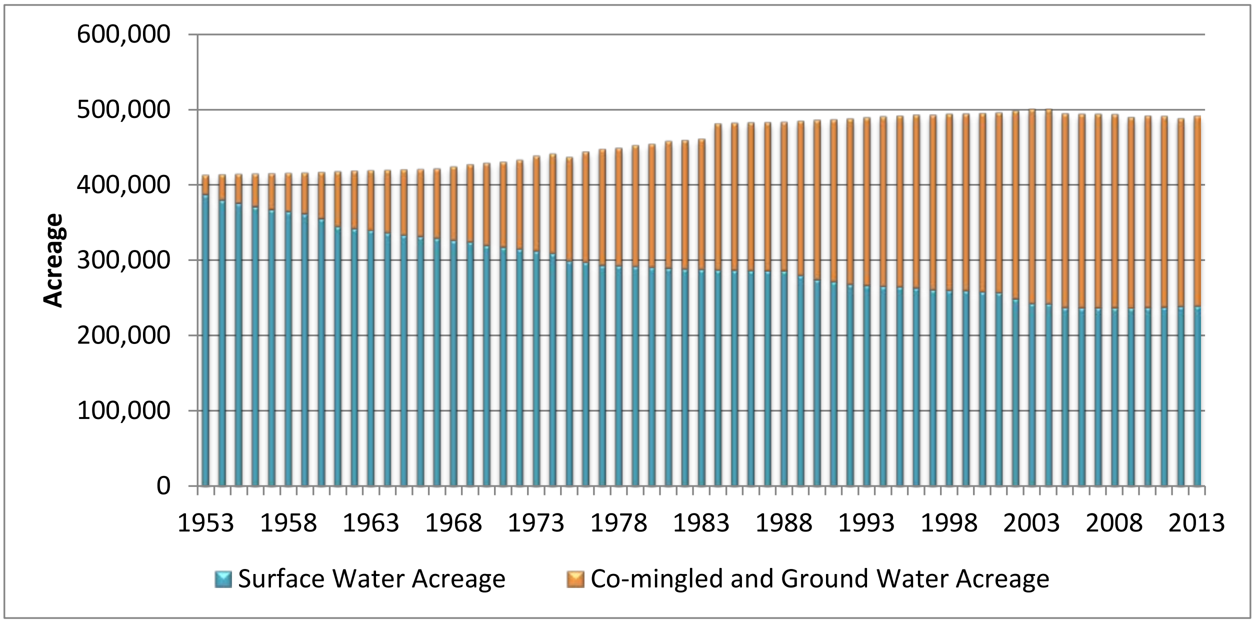
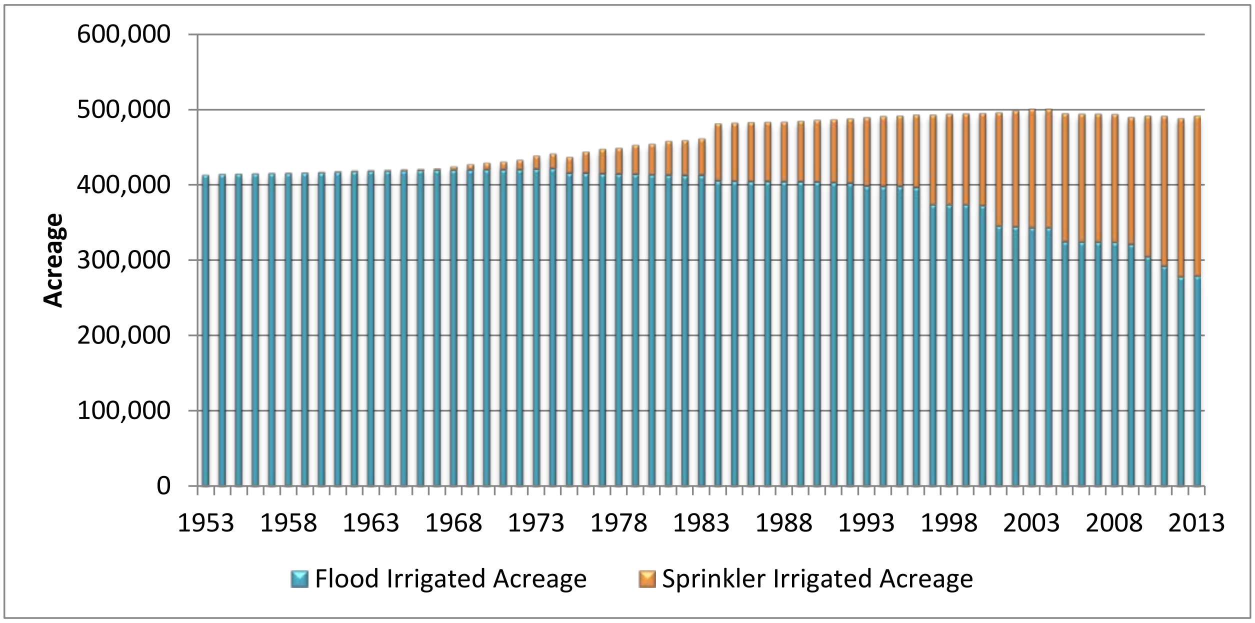


Figure 9: Acreage by Irrigation Method



For acreage in Nebraska, attribution of surface and ground water supplies, as well as irrigation application method, was performed during the development of each of acreage coverages (1953, 1975, 1984, 1993, 1997, 2001, 2005, 2010, 2011, 2012, and 2013). The algorithms used to develop the acreage information in between coverages is documented in Appendix C and D of the *WWUM Irrigated and Dryland Acreage Assessment*

For acreage in Wyoming, a single 1994 coverage was developed and attributed with surface and ground water supplies and irrigation application method. Because multiple coverages were not available to indicate the transition of acreage associated with each of the four land use types through time, these transitions were estimated based on the transitions seen in Nebraska. In general, surface water only acreage was transitioned over to co-mingled supplies in the 1953 to 1975 period, and flood acreage was transitioned over to sprinkler acreage in the 1975 to 1994 period. By 1994 additional transitions of supply or application method were minimal and the 1994 acreage associated with each of the four land use categories was carried forward to 2013.

As noted above, the efficiency file is a time series and can reflect a change to a structure's overall system efficiency over time. Conveyance efficiency data were not adjusted by year, however the maximum application efficiency data varied over time to reflect improved efficiency of sprinkler technologies. Therefore a structure's overall system efficiency may change by year due to the change in sprinkler efficiency, due to changes in the percent of land served by sprinkler or flood application methods, or due to surface water supply in excess of crop requirement.

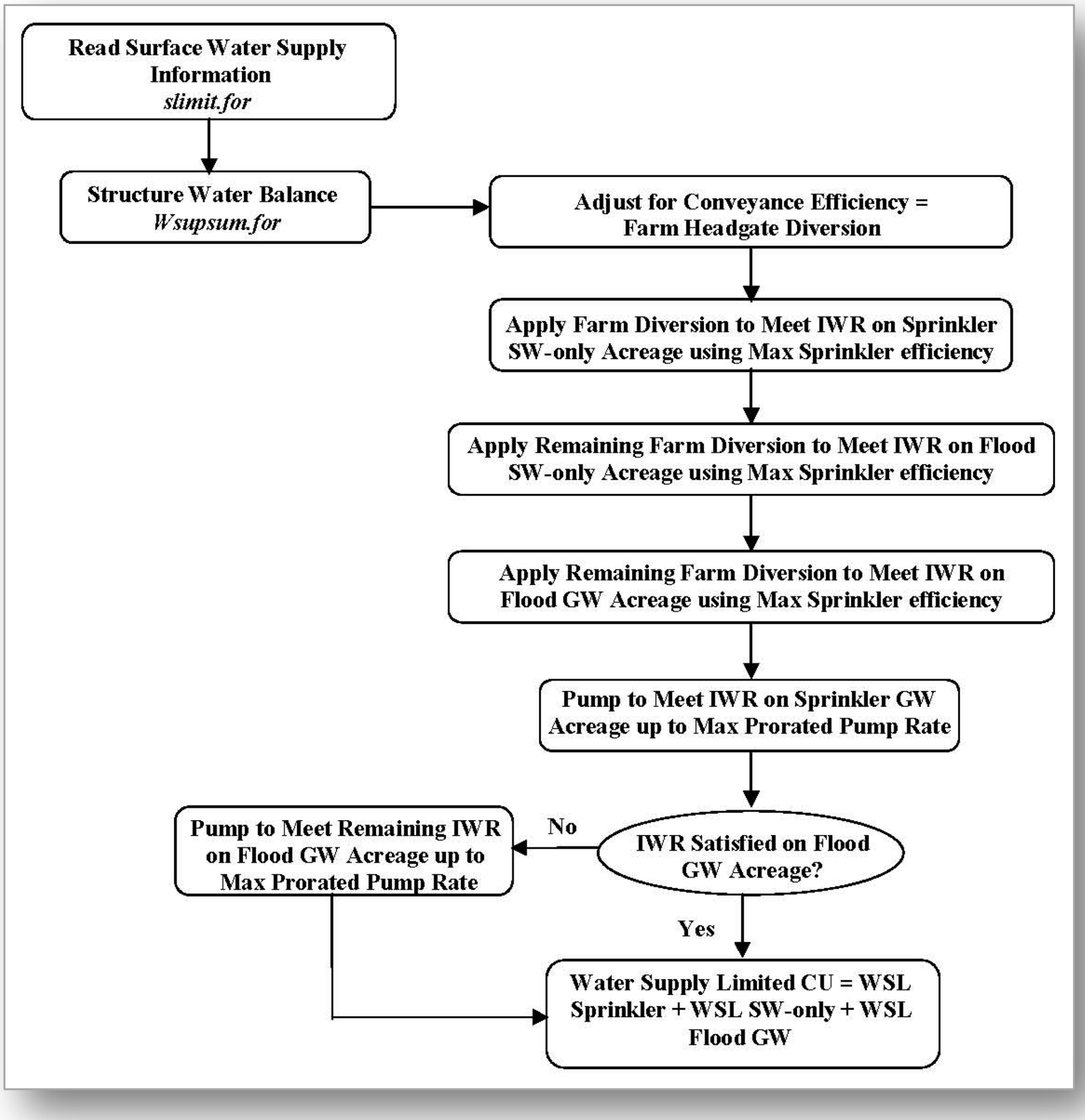
Maximum Monthly Pumping Volume

The maximum monthly pumping volume is the total permitted well pumping rate, converted to acre-feet per month, for the wells that serve irrigated parcels under a structure. For each year, the capacities for active wells associated with irrigated parcels under each structure were summed to determine the total monthly well pumping volume for a structure. The total NIR demand for a structure is generally the limiting factor on a structure's estimated pumping, and the monthly pumping volume does not generally serve as a limitation.

Pumping Approach

The pumping approach determines how surface water and ground water are used to meet the NIR demand for each structure. Two approaches were used in this analysis to represent the irrigation practices in the WWUM area. The "Mutual Ditch" (ground water use mode = 2) approach evenly divides the surface water diversions across all surface water only and co-mingled lands, then pumps ground water to meet the remaining deficit on co-mingled lands. The "Maximize Supply" (ground water use mode = 1) approach applies surface water diversions to sprinkler and flood surface water only lands first. Remaining surface water diversions then are available to meet NIR on co-mingled flood lands. Ground water is pumped to meet the NIR on co-mingled sprinkler lands, and any remaining deficit on co-mingled flood lands. **Figure 10** below is a flow chart from the StateCU documentation that summarizes how the water supplies are accounted for using this approach.

Figure 10: Water Balance Procedure with "Maximize Supply" Approach



A calibration analysis was performed to determine which pumping approach should be used to represent the irrigation demand structures in each irrigation district. Scenarios using both of the pumping approaches were completed, and the results from 2009 through 2013 were compared to metered pumping records from the North Platte NRD. A summary and results from the Calibration Analysis are provided in Appendix A. Based on this comparison, it was evident that some irrigation districts operated according to the Mutual Ditch approach, whereas other district pumping more closely aligned with the Maximize Supply approach. The structures in **Table 3** were modeled using the Mutual Ditch approach; all others were modeled using the Maximize Supply approach. Note that the Calibration Analysis was performed for irrigation districts in Nebraska only, all irrigation districts in Wyoming were modeled using the Mutual Ditch approach as shown in **Table 3**. Although there are more irrigation districts modeled using the Maximize Supply approach as compared to those modeled using the Mutual Ditch approach, the vast majority of the pumping in the WWUM area is associated with Mutual Ditch approach irrigation districts. More than 80% of the co-mingled pumping on average over the 1953 to 2013 period is associated with Mutual Ditch approach irrigation districts.

Table 3: Irrigation Districts Modeled with a Mutual Ditch Approach

Model ID	Irrigation District
00165	Burbank
00187	Torrington
00424	Lucerne
01590	Gering-Ft. Laramie
01591	Gering
01600	Graf
02359	Narrows
03805	Northport
03845	Wright
03966	Pathfinder
04397	Midland-Overland
05313	Union
05920	Murphy
07853	Grattan
07859	North Platte
07870	Rock Ranch
07881	Pratt-Ferris
18544	Goshen

Note that irrespective of the approach, StateCU estimates ground water pumping required to satisfy the NIR not met by surface water. These pumping estimates include water pumped to offset the inefficiencies associated with ground water application. Also, the amount of ground water pumped is limited by NIR associated with the acres served by wells and DNR-reported capacity. **StateDMI** was used with external test files to create the annual irrigation parameter file.

For More Information:

- The *WWUM Modeling Project Summary, Data Integration, and Calibration Plan* report provides additional information on WWUM Technical Consultants calibration efforts.

3.6 HISTORICAL IRRIGATION DIVERSION FILE (WWUM2012.DDH)

The historical diversion file provides surface water supply information required to estimate supply-limited consumptive use. Irrigation diversions are provided for each modeled structure that has an irrigation demand met at least in part by surface water (i.e. diversion structure with irrigation demand and irrigation demand structures).

The development of surface water supply information by structure, discussed in more detail below, was made more complex because of:

- diversions and releases to the off-channel Inland Lakes;
- diversions from both the North Platte River and tributaries; and
- pro-rata amount of diversions for irrigation demand structures.

The first step in developing surface water supply information by structure was to collect monthly diversion data at the point of diversion. Daily historical diversion data was generally available for the entire study period (1953 – 2013) from NDNR and USBR for many points of diversion in Nebraska and Wyoming. Daily data from NDNR was used as the primary source of diversion data in Nebraska, and USBR monthly data was used as the primary source of diversion data for Wyoming.

- Daily diversion data was accessed from the NDNR Stream Gaging Data Bank (http://dnr.ne.gov/docs/hydrologic.html) or obtained directly from NDNR staff, visually reviewed for errant data points, and aggregated into monthly data using **TSTool**. A threshold of 5 days was used to aggregate daily data to monthly time series; if less than 5 days is missing in a month, the daily diversion data was aggregated into a monthly value. If greater than 5 days in a month was missing, the entire month was set to missing and filled. Daily USBR HydroMet Site diversion data was used to supplement NDNR daily data when available.

- Monthly diversion data was digitized from USBR Water Distribution Reports and visually reviewed for errant data points using **TSTool**.

Many of the structures have relatively complete diversion data records over the period of record especially in recent years. Missing data was filled using a wet/dry/average pattern according to an "indicator" gage. Each month of the streamflow at the indicator gage was categorized as a wet/dry/average month through a process referred to as "streamflow characterization". Months with gage flows at or below the 25th percentile for that month are characterized as "dry", while months at or above the 75th percentile are characterized as "wet", and remaining months are characterized as "average". Using this characterization, missing data points were filled based on the wet, dry, or average pattern. For example, a data point missing for a wet March was filled with the average of other wet Marches in the partial time series, rather than all Marches. The pattern streamflow gage used is the North Platte River near WY-NE Stateline (06674500). If missing data still existed after filling with a pattern file, historical monthly averages were used to fill the remaining data.

A complete point of diversion list, including the source of diversion data, NDNR and USBR gage ID if available, the years when diversion data was generally available within the 1953 to 2013 study period, is provided in **Appendix B**. Once the monthly diversion data for irrigation was completed for each diversion point, the irrigation diversions, or a portion thereof, were assigned to each structure. For diversion structures with an irrigation demand as shown in **Table 4**, the full amount of monthly irrigation diversions were assigned to these structures. As discussed above, this corresponds directly to the fact that the full irrigation demand under the diversion structure is assigned to the structure. Note that carrier diversion structures do not have an associated irrigation demand and their diversions are applied to irrigation demand structures as summarized below. **Table 4** identifies the diversion structures with irrigation demand including model ID and the 1953 to 2013 average annual diversion amount based on the filled diversion data.

Table 4: Diversion Structures with Irrigation Demand Diversion Summary

Model ID	Diversion Structure	Ave. Annual Diversion (ac-ft)
00165	Burbank	614
00187	Torrington	7,753
00283	Beerline	2,184
00424	Lucerne	13,953
00794	Chimney Rock	16,631
02353	Hooper	2,126
02359	Narrows	126
03162	Lisco	9,403
03940	Paisley	2,952
04397	Midland-Overland	1,817
07853	Grattan	2,487
07859	North Platte	8,118
07870	Rock Ranch	8,666
07881	Pratt Ferris	2,281
	Total	**79,111**

For carrier diversion structures that carry to irrigation demand structures, the diversion data was set to zero and assigned to the associated irrigation demand structures. For irrigation demand structures, only a portion of the acreage served by a canal is assigned to the structure, therefore only a portion of the diversions are available to the structure. The following approach was used to assign the irrigation diversions to each irrigation demand structure.

1. Determine the annual NIR assigned to the irrigation demand structure.

2. Sum the annual NIR for all irrigation demand structures served by an irrigation district.
3. Divide the individual irrigation demand structure's annual NIR by the total NIR to determine the percentage of the NIR attributable to the irrigation demand structure. This percentage serves as the annual NIR factor for each irrigation demand structure.
4. Multiply the NIR factor by monthly diversion data to determine the pro-rata amount of irrigation diversions that are used in the consumptive use analysis as surface water supplies for the irrigation demand structure.

Note that for structures met by supplies from both the North Platte River and tributaries, the diversions were summed prior to manipulation with the NIR factor. Additional data manipulation was required for the diversions via Interstate Canal as they represent diversions to both irrigation in the Pathfinder Irrigation District and to storage. The portion of the diversions that were destined for storage was estimated by using the change in the reservoir's end-of-month contents and monthly evaporation. When the reservoir's change in end-of-month contents, less evaporation, reflected that the reservoir stored, the estimated stored amount was subtracted from the total Interstate Canal diversions to reflect only diversions to irrigation, which were assigned to all of the irrigation demand structures served by Interstate Canal (i.e. Pathfinder Irrigation District in Wyoming and Nebraska) based on their NIR factors. When the reservoir's change in end-of-month contents, less evaporation, reflected that the reservoir released, the estimated released amount was assigned to the Pathfinder Irrigation District irrigation demand structures located downstream of the reservoir based their NIR factors. The pro-rata share of the direct diversions to irrigation and the reservoir releases were summed for each irrigation demand structure to represent their full surface water supplies. Operationally Pathfinder Irrigation District has flexibility with how surface water supplies are distributed to their users. The approach of distributing surface water supplies used in this analysis is an attempt to represent these historically dynamic operations using a single static approach. The good correlation between NPNRD pumping records and estimated pumping on a district-wide basis, as summarized in the Calibration Analysis, provided confidence in using this static approach.

During the development of this analysis two approaches to pro-rating the diversions to each irrigation demand structure were investigated; pro-rating diversions based on acreage and pro-rating based on NIR. The consumptive use analysis was simulated using both approaches, and the results, in terms of shortages and estimated ground water pumping, resulted in better calibration using the NIR approach. In practice, this approach mirrors the situation whereby crops with a higher NIR are using more supplemental ground water supplies.

Table 5 identifies the irrigation demand structures including Model ID, the source of diversion data including NDNR gage ID if available, the years when diversion data was generally available within the 1953 to 2013 study period, and the 1953 to 2013 average annual diversion amount based on the filled diversion data.

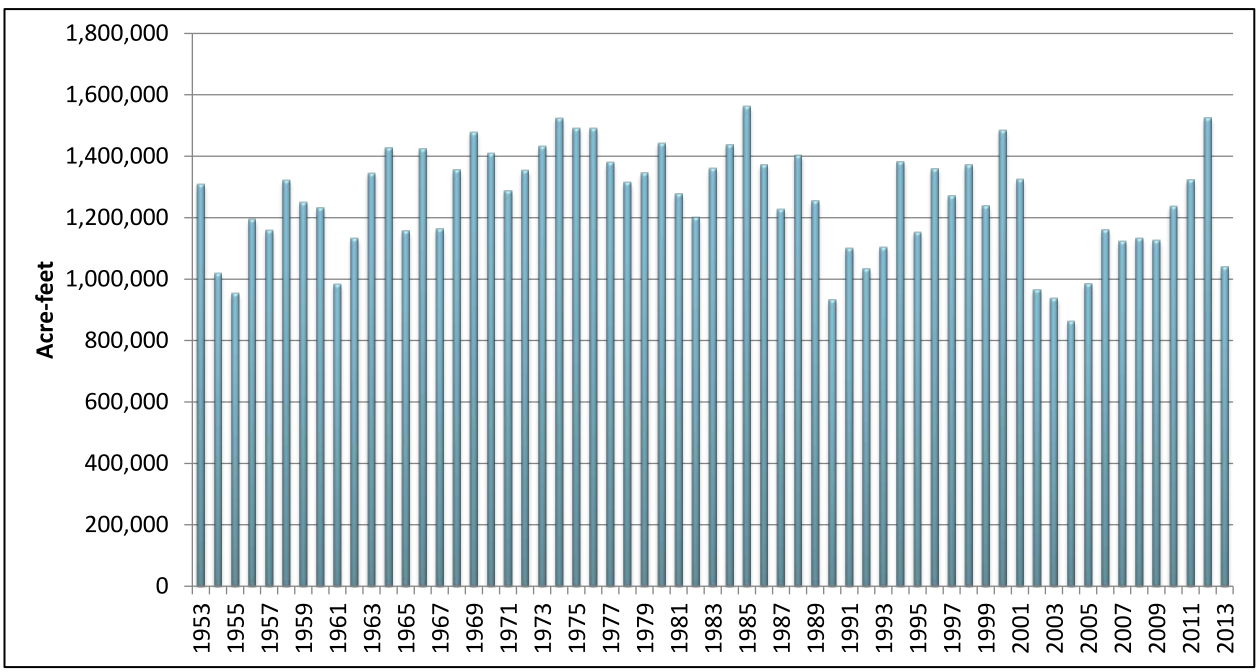
Table 5: Irrigation Demand Structure Diversion Summary

Irrigation District	Demand Structure	Ave. Ann. Diversion (acre-feet)	Irrigation District	Demand Structure	Ave. Ann. Diversion (acre-feet)
Alliance	00064_80	8,656	Gering-Fort Laramie	01590_14	27,468
	00064_86	8,775		01590_15	24,669
Blue Creek	00417_130	3,375		01590_26	12,097
	00417_132	4,251		01590_38	40,624
Belmont	00534_203	5,203		01590_8	23,096
	00534_204	5,137	Gering	01591_41	19,057
	00534_88	3,609		01591_50	9,524
	00534_97	14,705		01591_59	881
Empire	01295	8,303	Graf	01600_131	1,613
Browns Creek	00589_105	7,030		01600_136	353
	00589_96	7,734	Minatare	03563_43	565
Castle Rock	00746_50	957		03563_46	6,226
	00746_55	1,557		03563_52	5,501
	00746_63	11,441		03563_53	1,596
	00746_72	7,560		03563_56	2,389
Central	00754_39	4,450		03563_58	1,128
	00754_41	1,442		03563_61	3,619
	00754_50	305	Mitchell	03578_17	9,135
Enterprise	01311_16	11,635		03578_23	18,431
	01311_207	809		03578_6	7,672
	01311_30	11,988	Ninemile	03778_61	11,708
Farmers	01362_13	7,571		03778_68	9,601
	01362_208	9,977		03778_76	5,934
	01362_209	12,624	Northport	03805_84	15,538
	01362_21	434		03805_86	1,428
	01362_25	5,506		03805_94	33,977
	01362_58	44,592	Shortline	04803_73	5,700
	01362_66	15,487		04803_76	2,785
	01362_7	6,475	Union	05313_129	2,114
	01362_74	30,445		05313_131	218
	01362_84	32,974	Goshen	18544	158,206
Wright & Murphy Canals	03845 & 05920	24			

Irrigation District	Demand Structure	Ave. Ann. Diversion (acre-feet)
Pathfinder (Interstate Canal)	03966_11	44,936
	03966_19	24,064
	03966_21	20,881
	03966_25	2,368
	03966_28	17,565
	03966_36	58,577
	03966_4	44,021
	03966_44	18,443
	03966_49	19,362
	03966_54	37,268
	03966_69	15,468
	03966_70	27,807
	03966_84	16,799
	03966_WY	58,021
Winters Creek	05701_201	3,090
	05701_202	9,368
	05701_29	1,508
Total		**1,177,430**

Figure 11 shows how surface water diversions for irrigation in the basin have changed over time. Variation is due to hydrology; for example, total annual diversions in the early 2000's reflect below average streamflow. Surface water diversion for irrigation averaged approximately 1,256,540 acre-feet per year over the 1953 through 2013 study period.

Figure 11: Total Annual Surface Water Irrigation Diversions



TSTool was used to review, fill, and aggregate diversion data and reservoir end-of-month content data from NDNR and USBR, and manipulate that data to develop surface water supply data for demand structures. See the *WWUM Water Resources Planning Model User's Manual* for more information on the development of diversion data.

3.7 HISTORICAL PUMPING FILE (WWUM2012_NRD.GWP)

The historical pumping file provides ground water supply information that, in addition to surface water diversions, are used to estimate supply-limited consumptive use. The historical pumping file consists of monthly pumping information for each structure that represents irrigated land that is served by either co-mingled or ground water only supplies. For the WWUM analysis, the historical pumping file was developed in two steps.

First, the complete StateCU analysis is run to estimate the ground water pumping required to satisfy crop consumptive demands not met by surface water (WWUM2012.gwp) for the 1953 to 2013 period. These pumping estimates include inefficiencies associated with ground water application (flood or sprinkler) and are limited by capacity.

Second, StateCU estimated pumping for 2009 through 2013 was overwritten with metered pumping records when available. Metered pumping records were available in 2009 through 2013 on an annual basis for certified parcels (see description in the Definitions section) in the NPNRD area. The individual pumping records for each certificate were first aggregated by structure, then multiplied by a monthly distribution pattern in order to estimate the amount of annual pumping that occurred in each month. The results from the StateCU analysis simulated in the first step were used to determine the estimated pumping, both in quantity and monthly distribution, for 2009 through 2013. Specifically, the monthly and annual pumping for each year from the first step analysis was averaged across structures types and the average monthly pumping was divided by the average annual pumping to provide an estimated percentage of pumping each month for 2009 through 2013. This analysis resulted in ten monthly distribution patterns that estimated the different monthly distribution between 2009 through 2013, and co-mingled lands and ground water only lands. **Table 6** summarizes the four monthly patterns, and the pattern used for each type of structure.

Table 6: 2009 and 2010 Monthly Pumping Distributions

Pattern Type	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2009 Co-mingled Structures	0%	0%	0%	1%	7%	2%	24%	42%	23%	1%	0%	0%
2009 GW Only Structures	0%	0%	0%	2%	12%	2%	32%	34%	18%	0%	0%	0%
2010 Co-mingled Structures	0%	0%	0%	2%	2%	6%	26%	58%	6%	0%	0%	0%
2010 GW Only Structures	0%	0%	0%	1%	3%	9%	35%	44%	8%	0%	0%	0%
2011 Co-mingled Structures	0%	0%	0%	2%	2%	3%	22%	62%	9%	2%	0%	0%
2011 GW Only Structures	0%	0%	0%	2%	3%	5%	30%	49%	11%	1%	0%	0%
2012 Co-mingled Structures	0%	0%	0%	3%	7%	17%	42%	28%	2%	0%	0%	0%
2012 GW Only Structures	0%	0%	0%	3%	9%	21%	39%	26%	2%	0%	0%	0%
2013 Co-mingled Structures	0%	0%	0%	3%	9%	24%	32%	26%	6%	0%	0%	0%
2013 GW Only Structures	0%	0%	0%	2%	6%	17%	37%	34%	4%	0%	0%	0%

TSTool was used to multiply the annual pumping records by the monthly distribution patterns; overwrite the estimated pumping records for 2009 through 2013; and create the final monthly historical pumping file used in the WWUM analysis.

3.8 CROP CHARACTERISTIC FILE (CROPSIM.CCH)

The crop characteristic file contains information on planting, harvesting, and root depth. A majority of the information in this file is used for calculating potential ET and NIR equations, however the rooting depth information in this file is used to determine the volume of soil moisture available to each structure. Root zone depth information was provided by The Flatwater Group based on CropSim rooting depths. **Table 7** summarizes the rooting zone depths for crops used in the WWUM consumptive use analysis.

Table 7: Rooting Zone Depths by Crop Type

Crop Type	Root Zone Depth (in)	Root Zone Depth (ft)
Alfalfa	84	7.0
Corn Grain	60	5.0
Dry Beans	54	4.5
Grass Pasture	60	5.0
Potatoes	36	3.0
Small Grains	72	6.0
Sorghum	60	5.0
Sugar Beets	60	5.0
Sunflower	72	6.0

3.9 REPLACEMENT CROP REQUIREMENT FILE (WWUM2012.RCR)

The replacement crop requirement file provides monthly NIR information for each structure in the analysis for the 1953 to 2013 period. This file is used when the potential ET and NIR functionality in StateCU is bypassed, and the NIR information is provided from an external source. For the WWUM consumptive use analysis, CropSim used the Hargreaves consumptive use methodology and factors calibrated to the ASCE Penman-Montheith method based on daily climate data to estimate potential ET. CropSim then accounts for varying soil conditions that impact soil moisture, and uses soil moisture along with effective precipitation to estimate NIR on a daily basis for each irrigated parcel in the NPNRD area. NIR for each irrigated parcel was then aggregated by structure and by month resulting in the replacement crop requirement file. CropSim was not completed for the entire Wyoming portion of the study area, therefore NIR was extrapolated from the western-most edge of the CropSim boundary for use with Wyoming irrigated acreage.

4.0 RESULTS

The WWUM historical crop consumptive use results are a product of the input files described in **Section 3**. This section provides a summary of historical crop consumptive use of surface and ground water, system efficiencies, non-consumed water, and historical ground water pumping. Results presented herein summarize information for structures in the WWUM analysis, additional summaries and structure-specific information can be accessed by obtaining the StateCU input files and StateCU model.

4.1 STATECU MODEL RESULTS

Table 8 shows the average annual basin consumptive use water budget accounting in average annual acre-feet for the period 1953 through 2013. The individual component results are discussed in detail in the following sections.

Table 8: 1953 through 2013 Average Annual Model Results

NIR
612,917

Surface Water Accounting					
River Headgate Diversion	Conveyance Loss	Diversion to Farm	To CU	To Soil Moisture	Irrigation Returns [1]
1,256,540	584,194	672,346	366,328	49,736	256,282

Ground Water Accounting		
Pumping	To CU	Irrigation Returns [1]
151,347	111,401	39,946

Crop CU Accounting			
From SW + GW	From Soil	Total	Shortage
477,728	55,310	533,038	79,879

[1] Represents irrigation return flows; the portion of the Diversion to Farm that is non-consumed and returns to the stream.

4.2 HISTORICAL CROP CONSUMPTIVE USE

Table 9 presents the historical crop consumptive use analysis results for the 1953 to 2013 study period. NIR in the WWUM area is satisfied from surface and ground water diversions, resulting in an estimate of water supply limited consumptive use. The WWUM area averages 533,038 acre-feet of water supply-limited consumptive use annually with an average annual shortage of 13 percent. Note the supply-limited consumptive use from surface water includes excess surface water stored in the soil moisture and then subsequently used by crops.

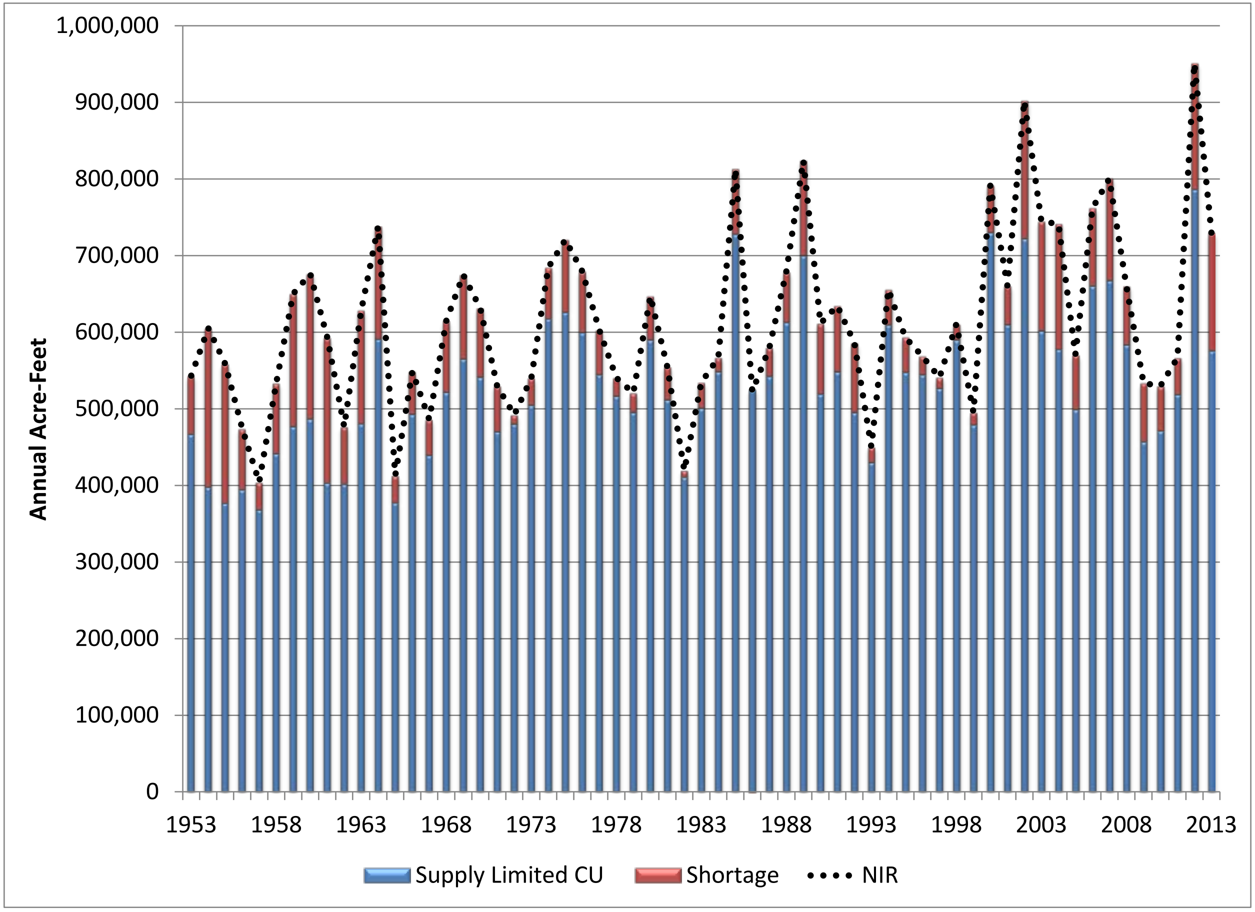
Table 9: 1953 through 2013 Average Annual Consumptive Use Results

Acres	NIR (acre-feet)	Supply-Limited CU (acre-feet)	Percent Short
460,507	612,917	533,038	13%

Figure 12 presents basin crop consumptive use results by year and shows that the percent of NIR is directly related to water supply. The variability for NIR depicted on the graph is due to the annual variability of temperature and precipitation conditions seen in the WWUM area; the overall upward trend on NIR is due to the increase of irrigated acreage in the area over the 1953 to 2013 period. Greater shortages from 1953 through 1961, averaging 23 percent, represent limited water supply due to well development levels and

below average stream flows. Shortages averaging 4 percent from 1993 through 1999 are consistent with advanced well development and normal to above average stream flows.

Figure 12: Irrigation Water Requirement and Supply Limited CU



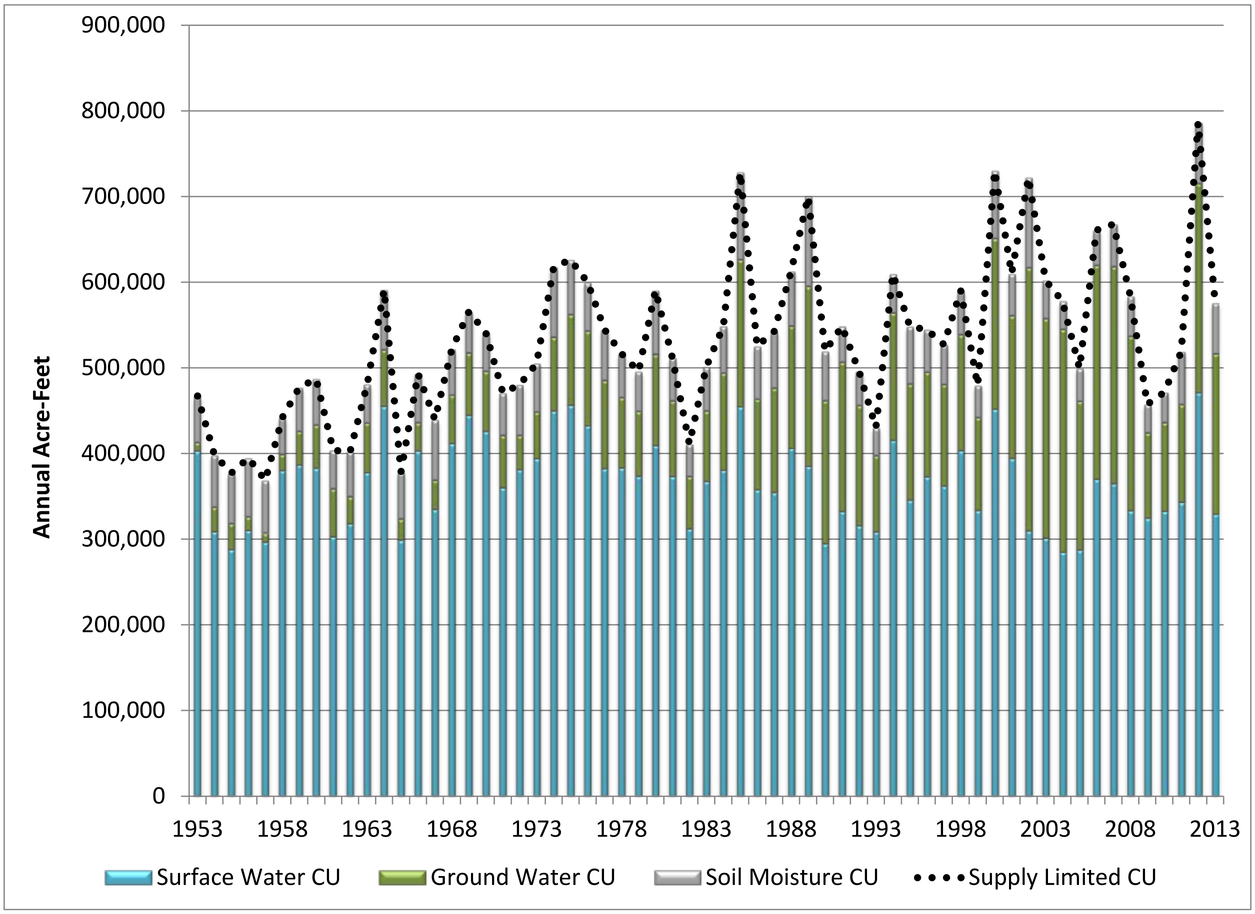
Average monthly shortages for the study period vary from a low of 11 percent in June and September to a high of 38 percent in October, as shown in **Table 10**. Late season shortages can be attributed to both a decreased surface water supply, and irrigation practices whereby users choose to stop irrigating due to individual harvesting practices.

Table 10: Average Monthly Shortages (1953 – 2013)

Apr	May	Jun	Jul	Aug	Sep	Oct
27%	15%	11%	12%	14%	10%	38%

NIR in the WWUM area is satisfied from surface water, available from natural flow and storage releases, and from ground water pumping. **Figure 13** shows the consumptive use attributable to surface and ground water and soil moisture in the WWUM area. As shown, consumptive use from ground water tends to be higher in years when consumptive use from surface water is less (i.e. in years of short surface water supply), and ground water consumptive use has generally increased over time due to the increase in acreage served by ground water only. In 1960, ground water supplied approximately 12 percent of the total consumptive use. By 1980, this percentage was approximately 22 percent, and by 2005, ground water supplies met more than 39 percent of the total consumptive use. Note the consumptive use from surface water includes excess surface water stored in the soil moisture and then subsequently used by crops. Ground water, as modeled, does not contribute to soil moisture storage.

Figure 13: Consumptive Use from Surface and Ground Water and Soil Moisture

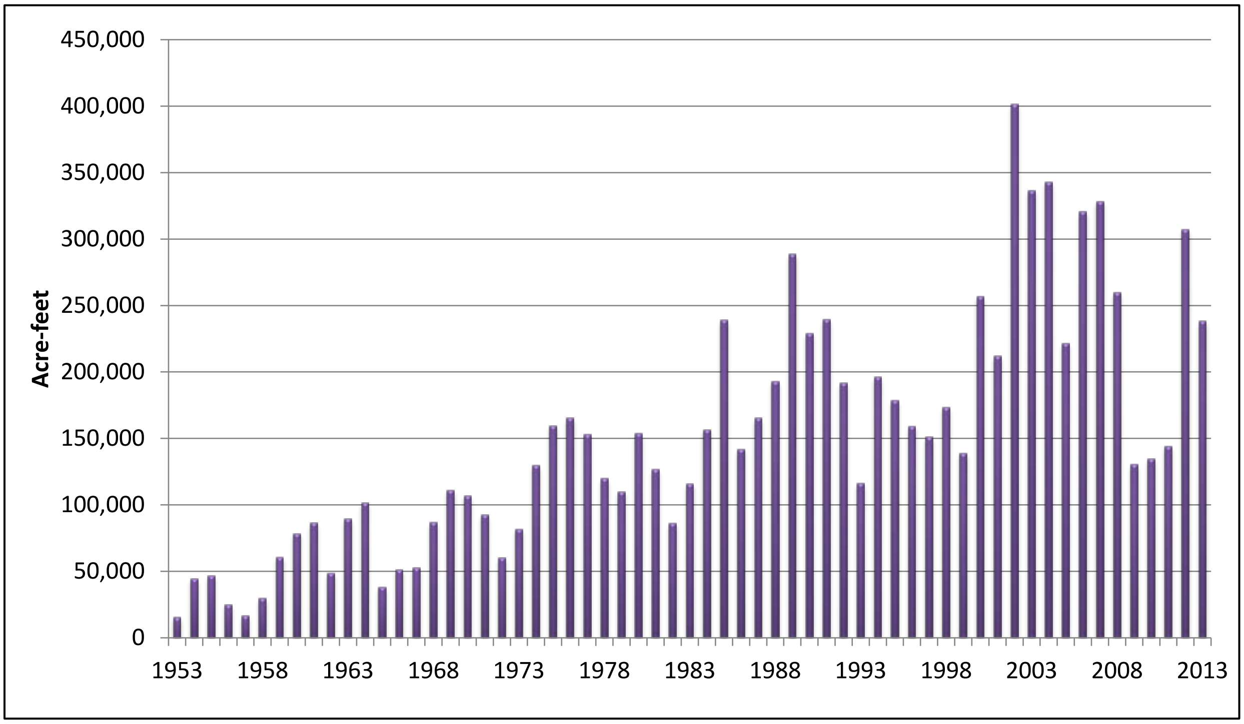


4.4 GROUND WATER PUMPING ESTIMATES

StateCU estimates ground water pumping required to satisfy crop consumptive demands not met by surface water when metered pumping records are not available. These pumping estimates include water pumped to offset the inefficiencies associated with ground water application (flood or sprinkler). Also, the amount of ground water pumped is limited by the acres served by wells and the DNR-reported capacity for each month.

As pumping records are available in 2009 through 2013, metered pumping was used for these years and StateCU estimated pumping for the 1953 to 2008 period. **Figure 14** reflects the amount of annual pumping represented in the WWUM consumptive use analysis. The variability of ground water pumping shown in the graph can be attributed to both the variability of NIR due to climatic conditions, and the increase in co-mingled and ground water only acreage in the area over time. As shown, the metered pumping in 2009 through 2013 is lower than the recent estimated average due to individual irrigation practices by land owners and implementation of the NPNRD ground water pumping allocation system. As discussed in Appendix A, the pumping approach selected for each structure greatly impacts the amount of pumping estimated by StateCU and the pumping records from 2009 through 2013 were used to calibrate the pumping approach used in the previous years.

Figure 14: Ground Water Pumping



4.5 ESTIMATED ACTUAL EFFICIENCIES

As described in the *StateCU Documentation*, the amount of surface water available to meet the crop demand is the river headgate diversion less conveyance losses and application losses. If the surface water supply to the crop exceeds the irrigation water requirement, water can be stored in the soil moisture up to its water holding capacity. Note that ground water is only pumped to meet the irrigation water requirement and associated application losses, according to the pumping approaches discussed in **Section 3.5.** Therefore, ground water does not contribute to soil moisture storage.

Maximum efficiencies for surface water and ground water diversions are provided as input to StateCU, as described in **Section 3.5**. Actual efficiencies are calculated based on the amount of water available to meet crop demands and the application method (e.g. flood or sprinkler).

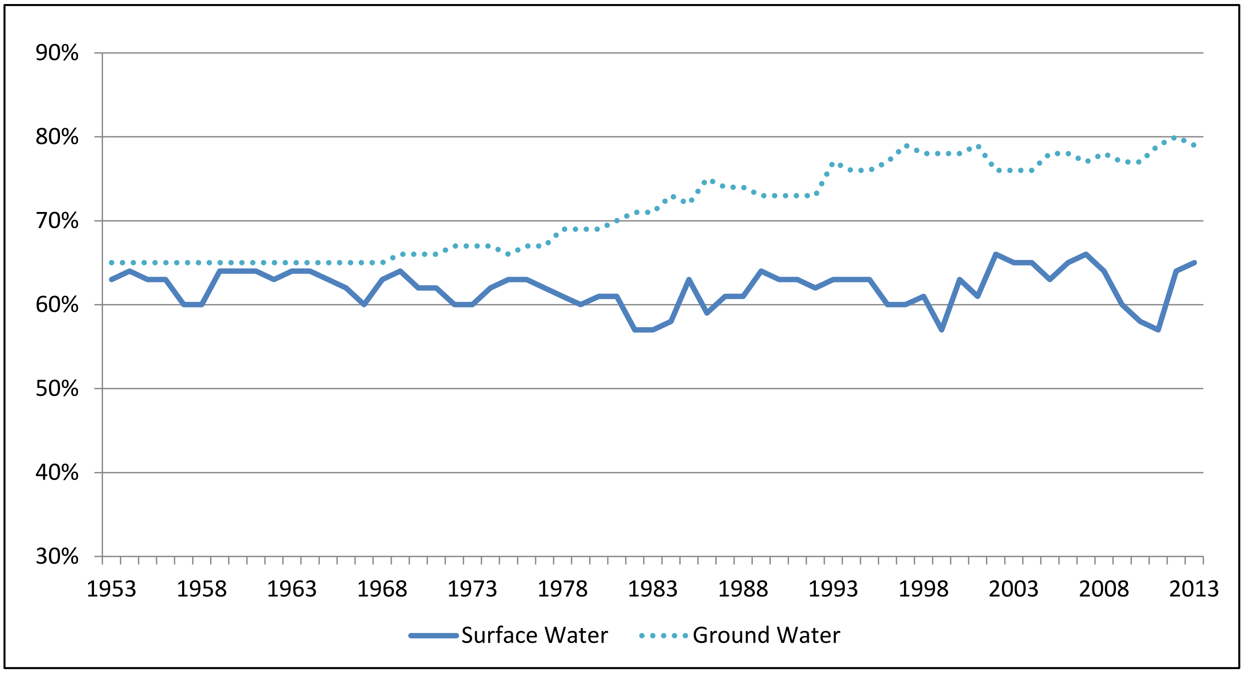
Table 11 provides the average monthly calculated application efficiencies for surface water and ground water supplies. Efficiencies in April, September and October are lower, indicating water is diverted in excess of crop needs (i.e. to fill the soil reservoir). During the typically high runoff months of May and June, application efficiencies are slightly lower than in mid to late summer when less surface water is available for diversion.

Table 11: Average Monthly Calculated Application Efficiencies (1953 – 2010)

Diversion Type	Apr	May	Jun	Jul	Aug	Sep	Oct
Surface Water	53%	59%	60%	64%	64%	60%	44%
Ground Water	72%	74%	75%	74%	73%	73%	69%

Figure 15 shows the efficiency information annually for surface and ground water. Ground water efficiencies have increased primarily because the application efficiencies were represented in the model as increasing over time due to improvements to sprinkler technology, from 70 to 85 percent. Ground water efficiency has also increased due to the greater amount of acreage using sprinkler application methods, beginning in the early 1970s. Surface water application efficiencies have remained relatively constant throughout the study period, with the slight variations due to water availability.

Figure 15: Surface and Ground Water On-Farm Efficiency



5.0 COMMENTS AND CONCERNS

The historical crop consumptive use estimates are based on measured and recorded data; information from other studies; information provided by local river administrators and users; and engineering judgment. The results developed for this project are considered appropriate to use for planning efforts in the WWUM area. Areas of potential improvement or concern include:

- *Pumping Approach*: The calibration analysis presented in Appendix A discusses the different pumping approaches (i.e. Mutual Ditch and Maximize Supply), and the process used to determine which pumping approach was used with each irrigation district. The available pumping information was limited to only five years, and many of these years experienced above-average streamflows and upstream storage levels. A single pumping approach may not be representative of operations for an entire irrigation district or for the entire period of record; however information was not available to implement different approaches for different time periods or irrigation demand structures. It is recommended that the calibration analysis be performed again in the future as additional pumping information becomes available to re-evaluate the selected pumping approach.
- *Conveyance Efficiencies*: Conveyance efficiency information was known for several USBR Project canals within the WWUM area, however conveyance efficiency was estimated for the remainder of the canals. Estimates of consumptive use, and co-mingled pumping, could be improved if canal-specific efficiency information was known for the non-Project canals. Incorporating conveyance efficiencies that vary each year and at different points along the canal may also improve consumptive use estimates.
- *Diversion Data*: There are multiple sources of diversion records for many of the ditches in the study area, and they vary from each other in diversion amount, type of record (i.e. daily/monthly) and completeness. The records available from the NDNR were primarily relied upon for this effort, supplemented by records from USBR and other sources. Additionally, an irrigation season was estimated based on years of complete records. This approach is appropriate for a basin-wide analysis such as the WWUM effort. Additional review and reconciliation between these various sources, as well as further investigation into an representative irrigation season, is recommended if these results on used for ditch-level analyses.
- *Water Use*: The results presented are based on an approach that attempts to represent how water is actually applied to crops in the basin. The approach used is based on engineering judgment and informal discussions with water administrators and users. The effort did not include determining surface water shares for each owner under a ditch, determining different application rates based on crop types, or investigating deficit irrigation practices. Instead water was shared equally based on acreage, and pumping was estimated to meet the full NIR. Therefore, this basin-wide historical crop consumptive use analysis is appropriate for planning purposes, and it should be used as a starting point only for a more detailed ditch level analysis.

APPENDIX A: CALIBRATION ANALYSIS

There are several inputs and parameters available in StateCU that are used to simulate actual irrigation practices in the field. Many of the parameters are "known" or have been reasonably estimated based on industry-approved techniques, including acreage, NIR, and historical diversions. Other factors are relatively "unknown", including historical co-mingled pumping, pumping approaches, and efficiency information. These factors were investigated in a calibration analysis to determine if the estimated data or approach taken in the StateCU analysis resulted in co-mingled pumping values that are similar to recorded values.

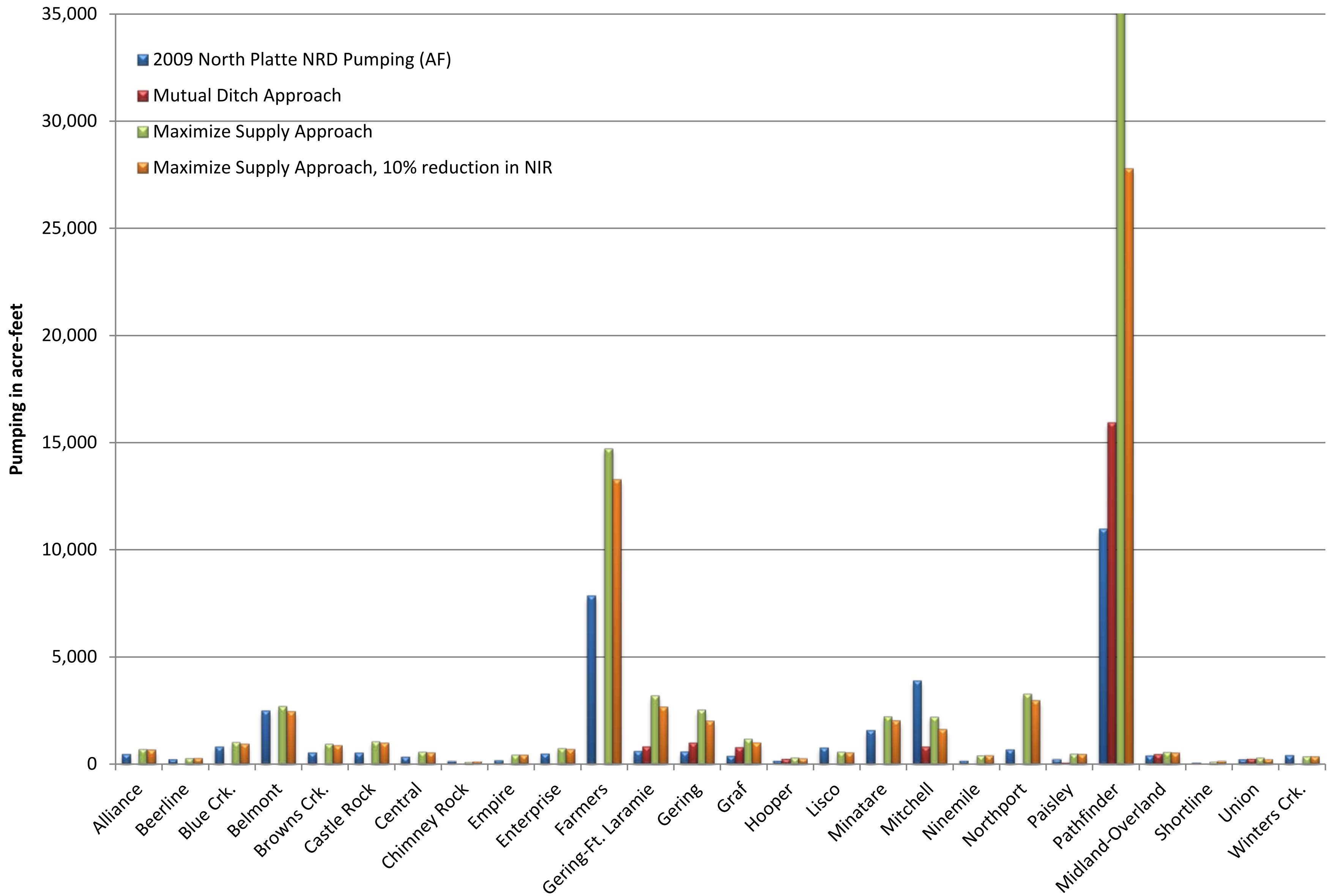
Numerous StateCU scenarios were developed to include different modeling parameters in order to investigate the impact of these modeling parameters on co-mingled pumping results. The following summarizes the list of scenarios investigated and the modeling parameters that were adjusted.

- *Mutual Ditch Scenario*: All structures are modeled using a Mutual Ditch pumping approach (GWMode=2); NIR, historical diversions, and irrigation and application efficiencies remained unchanged.
- *Maximize Supply Scenario*: All structures are modeled using a Maximize Supply pumping approach (GWMode=1); NIR, historical diversions, and irrigation and application efficiencies remained unchanged.
- *Maximize Supply with Reduced NIR*: All structures are modeled using a Maximize Supply pumping approach (GWMode=1) and NIR was reduced by 10%; historical diversions, and irrigation and application efficiencies remained unchanged.

Co-mingled pumping resulting from these analyses were compared to metered pumping records for 2009 through 2013 on a district-wide basis. The goal of the comparison was to determine which modeling parameters should be used to represent which irrigation districts and canal companies, how sensitive these parameters are, and ultimately provide confidence with the model setup as representative of historical conditions. **Appendix Figures 1 through 10** below show the co-mingled pumping results in 2009 through 2013 of these StateCU scenarios compared to metered pumping as recorded by the NRD. Note that if a red bar is not shown, StateCU estimated zero pumping required to meet NIR under the pumping approach for that specific structure for that year.

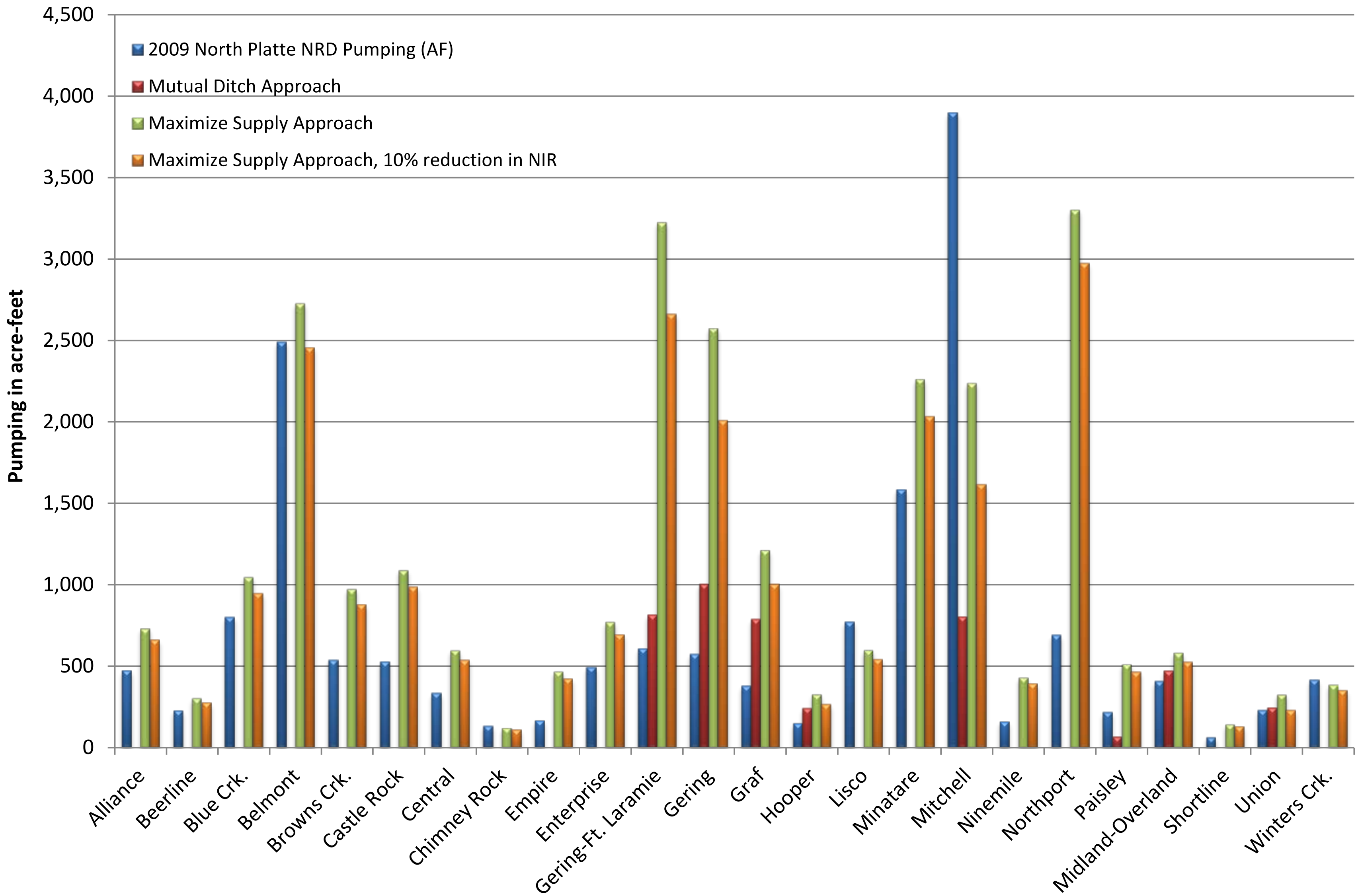
As illustrated in the figures, adjusting NIR information had very little impact on the overall co-mingled pumping. The pumping estimates, however, were very sensitive to the pumping approach selected. It became clear that ground water users in some irrigation districts generally operated according to the "Mutual Ditch Approach", while others appeared to more closely align with the "Maximize Supply Approach". These comparisons were used to determine which structures would ultimately be modeled using these ground modes, as shown in **Table 3** of this report.

Appendix Figure 1: 2009 WWUM Model Co-mingled Pumping Comparison by Irrigation District

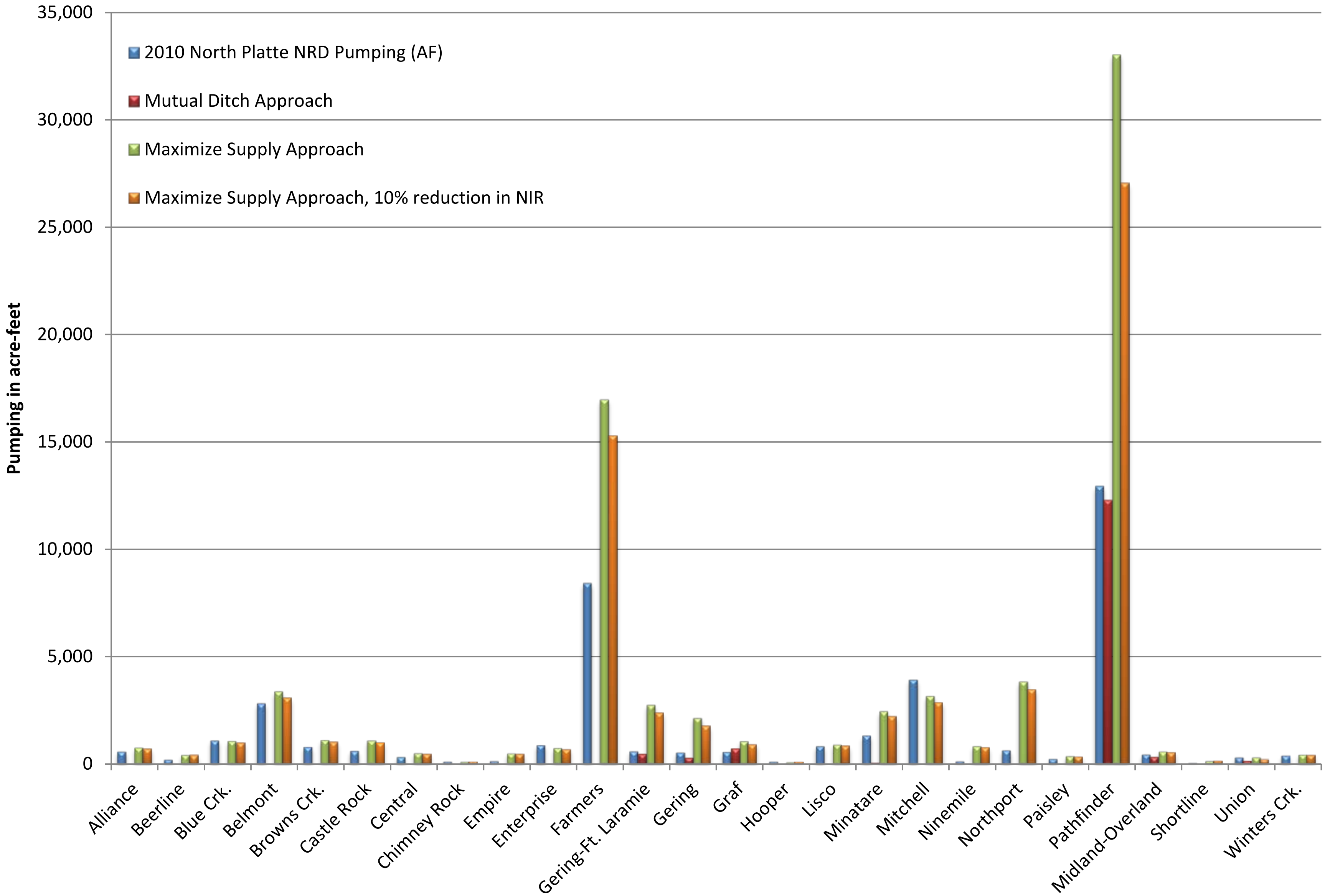


Appendix Figure 2: 2009 WWUM Model Co-mingled Pumping Comparison by Irrigation District

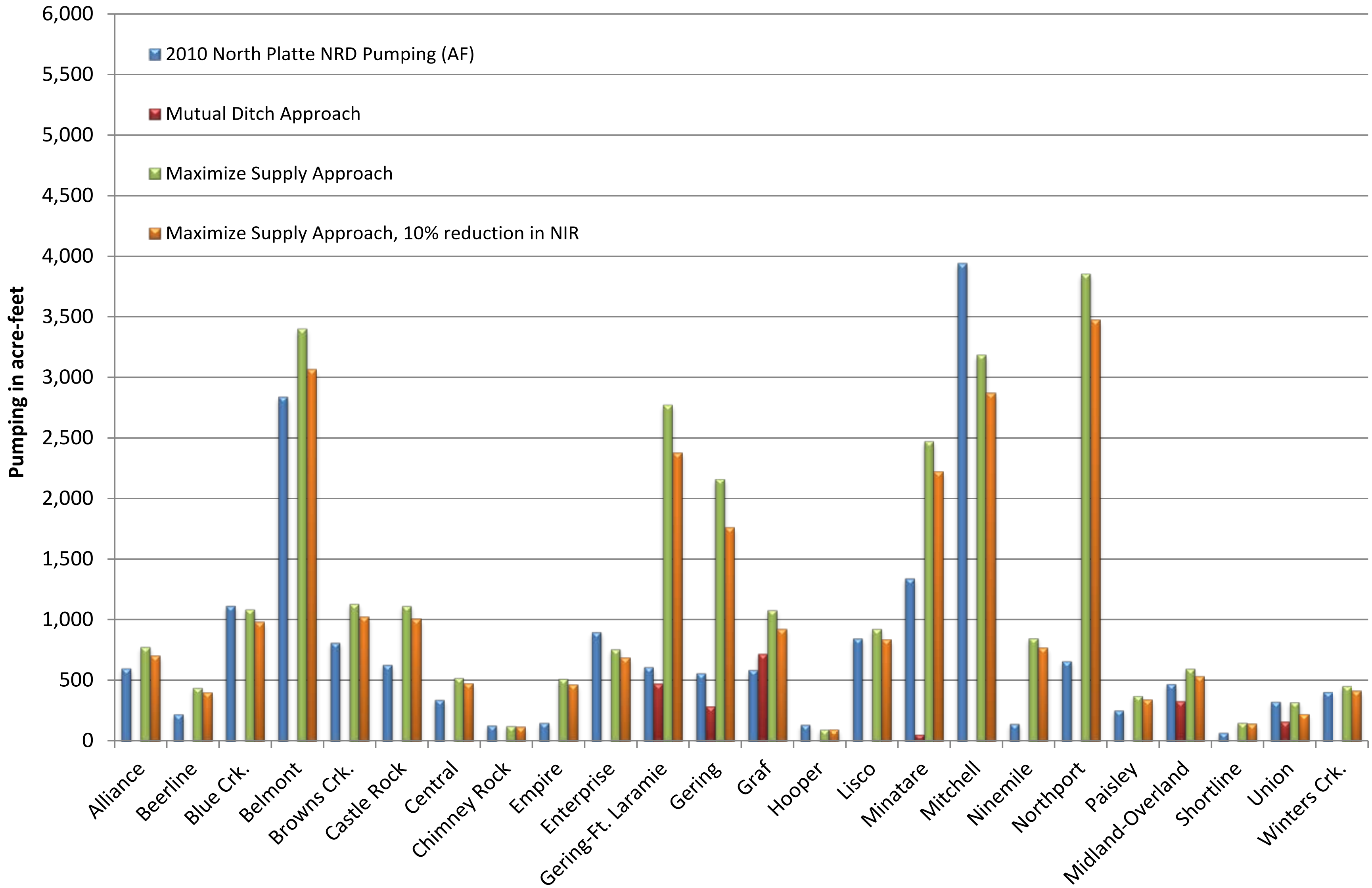
Excluding Farmers and Pathfinder Irrigation District



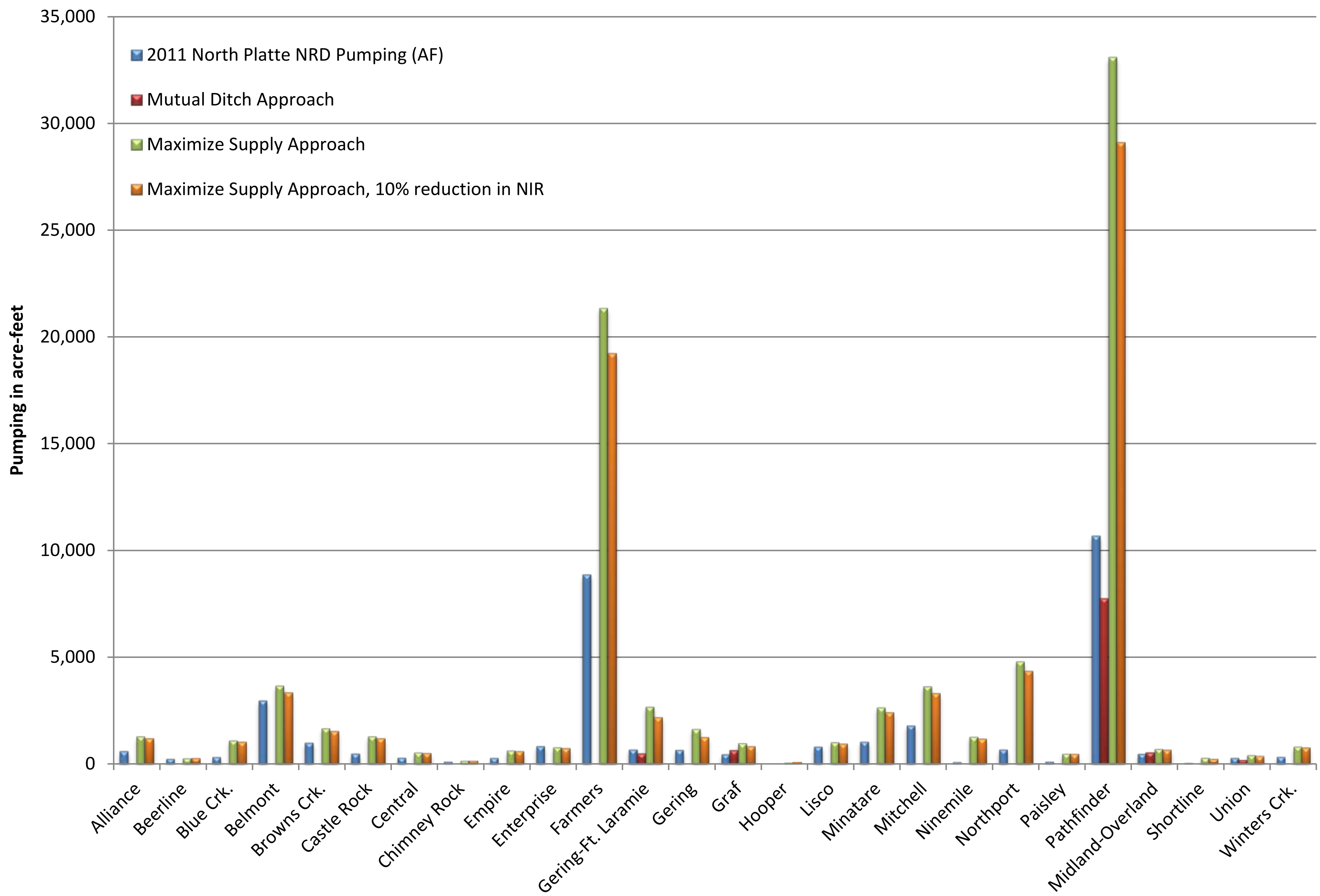
Appendix Figure 3: 2010 WWUM Model Co-mingled Pumping Comparison by Irrigation District



Appendix Figure 4: 2010 WWUM Model Co-mingled Pumping Comparison by Irrigation District Excluding Farmers and Pathfinder Irrigation District

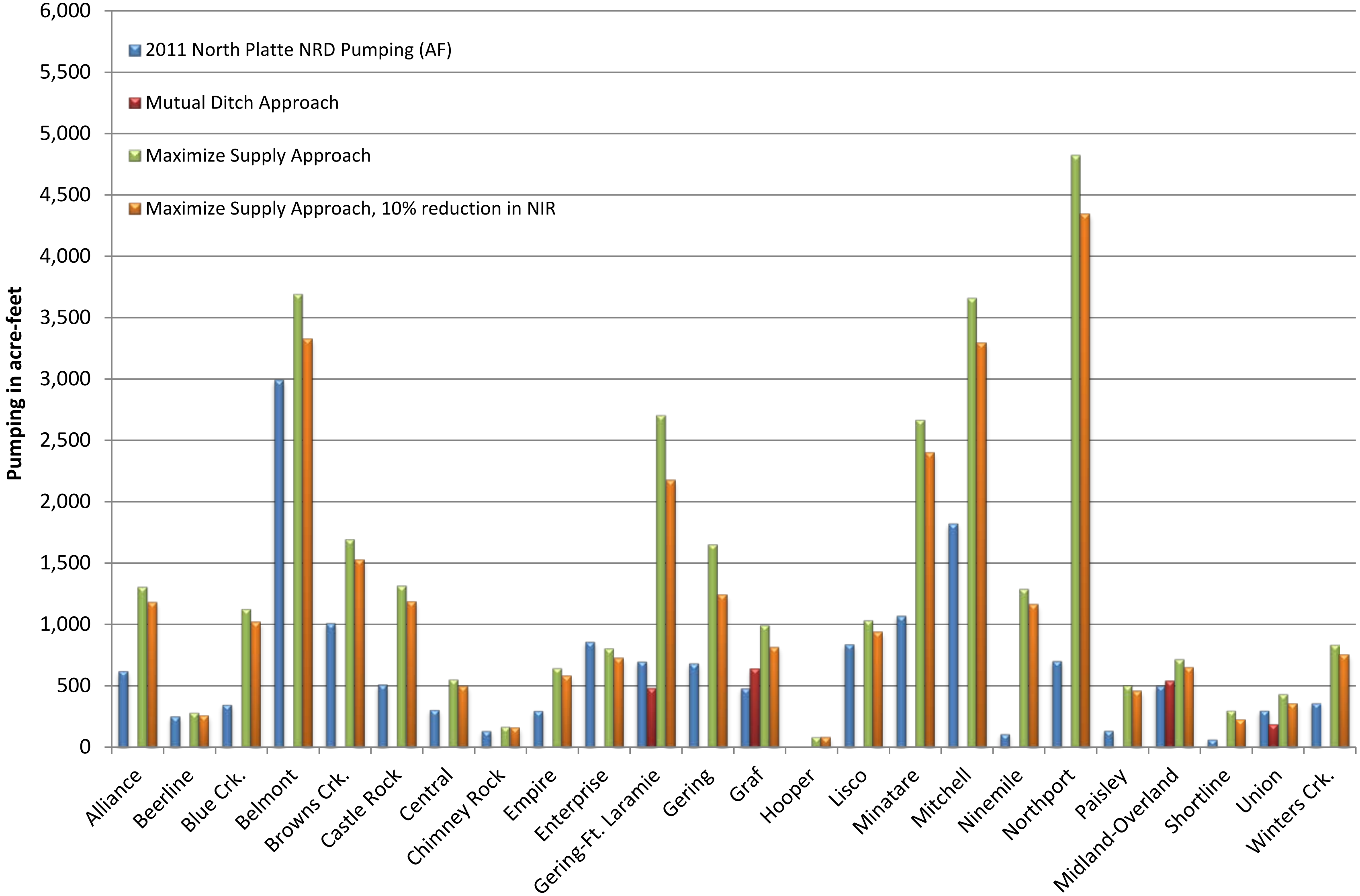


Appendix Figure 5: 2011 WWUM Model Co-mingled Pumping Comparison by Irrigation District

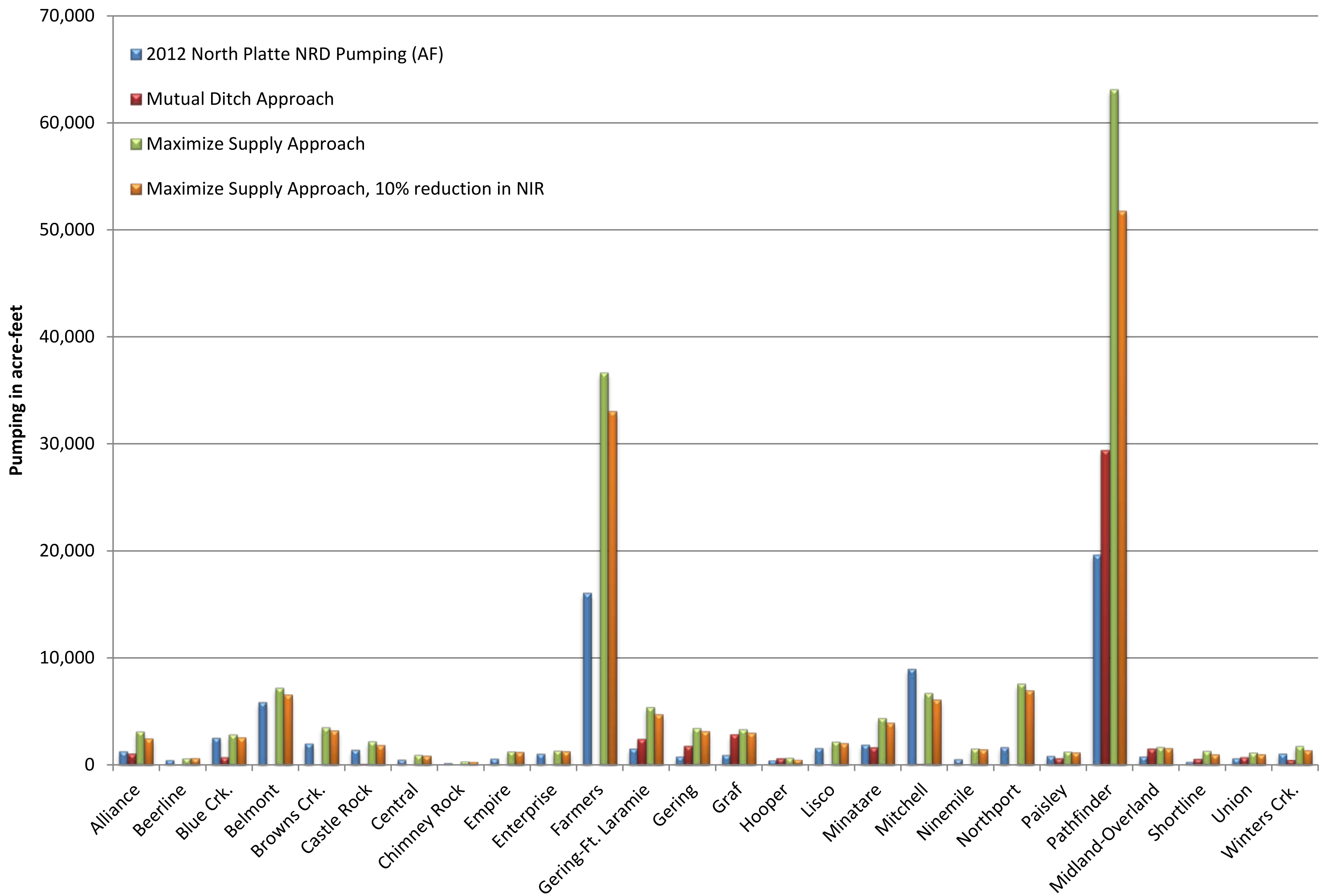


Appendix Figure 6: 2011 WWUM Model Co-mingled Pumping Comparison by Irrigation District

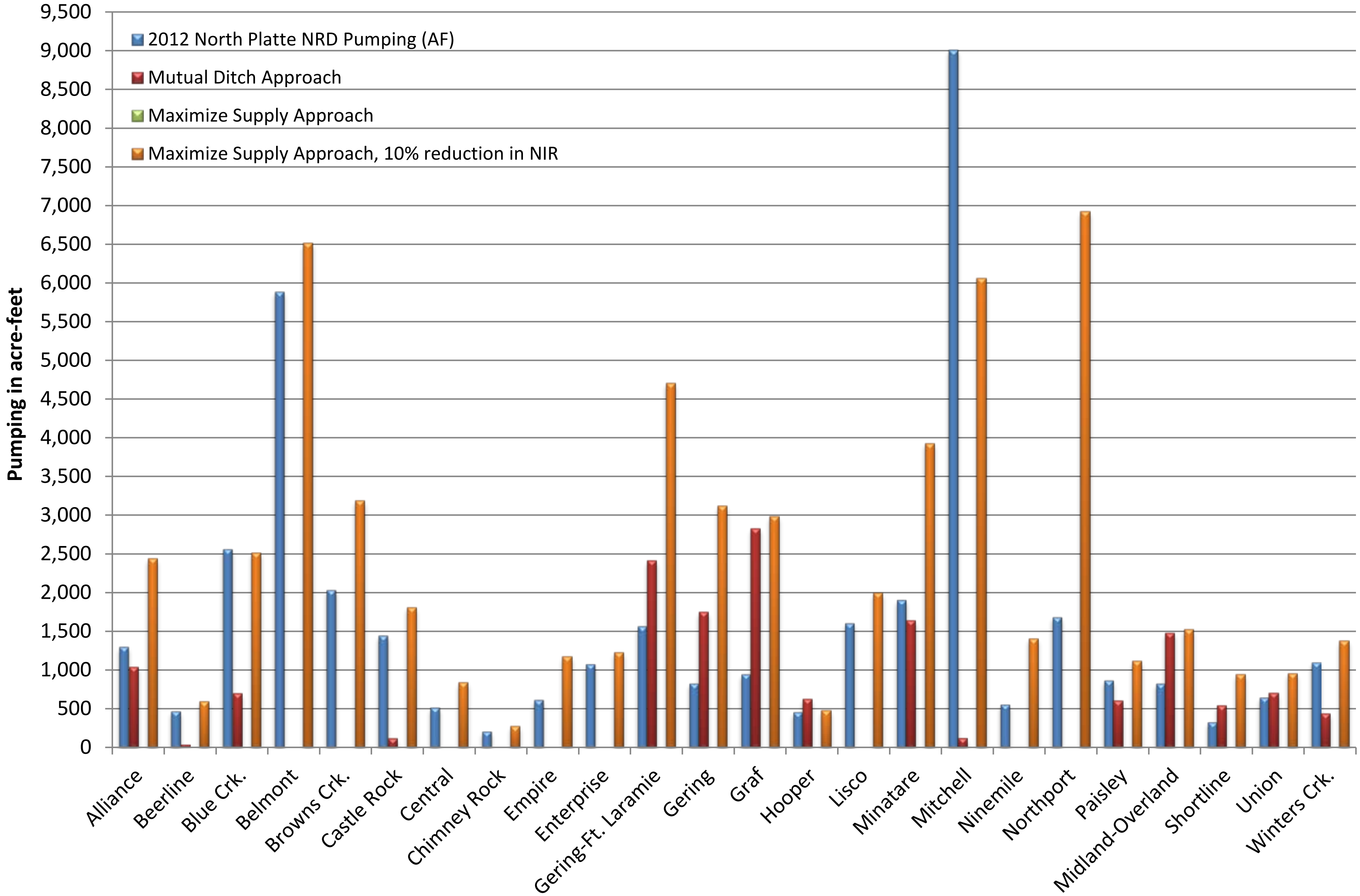
Excluding Farmers and Pathfinder Irrigation District



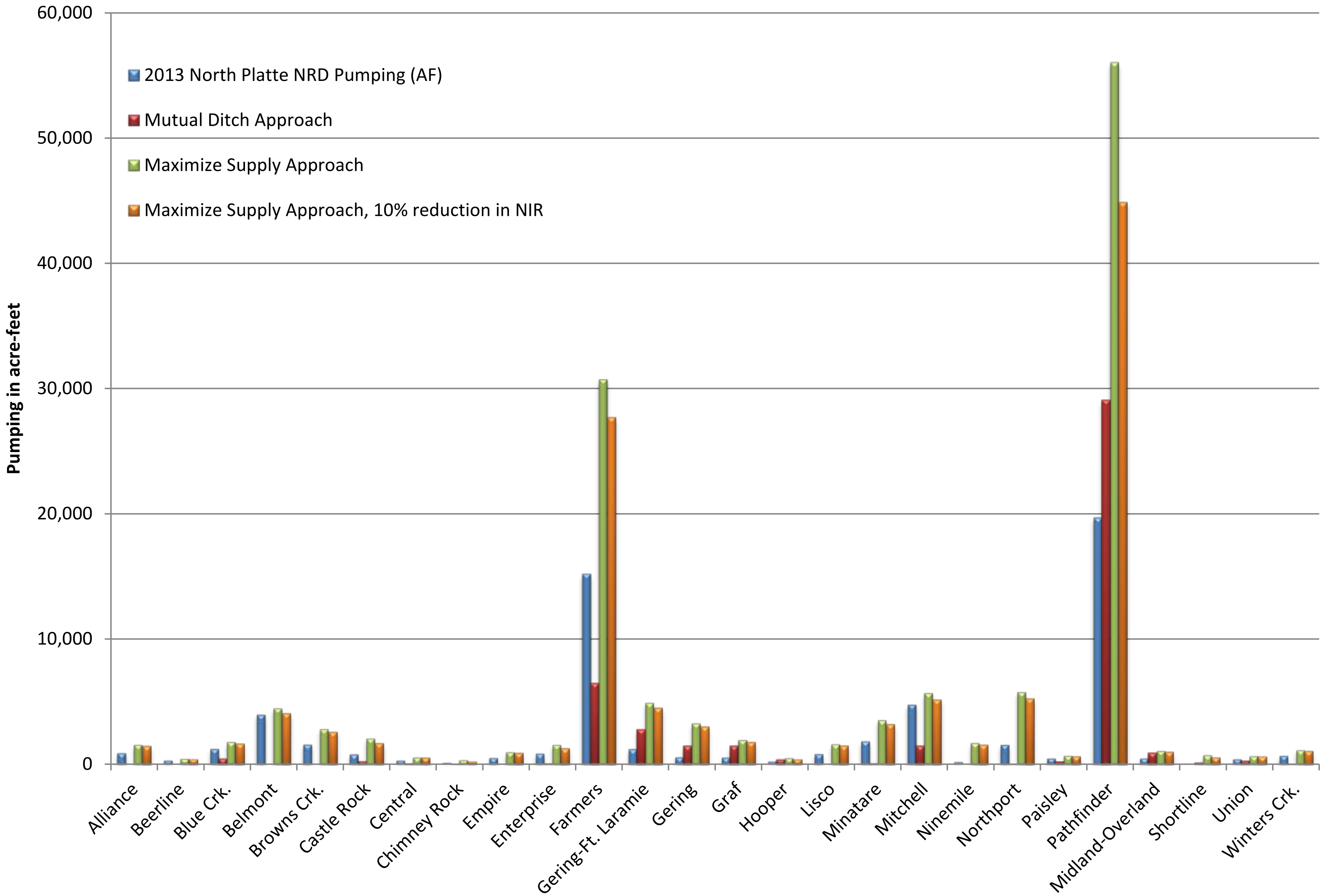
Appendix Figure 7: 2012 WWUM Model Co-mingled Pumping Comparison by Irrigation District

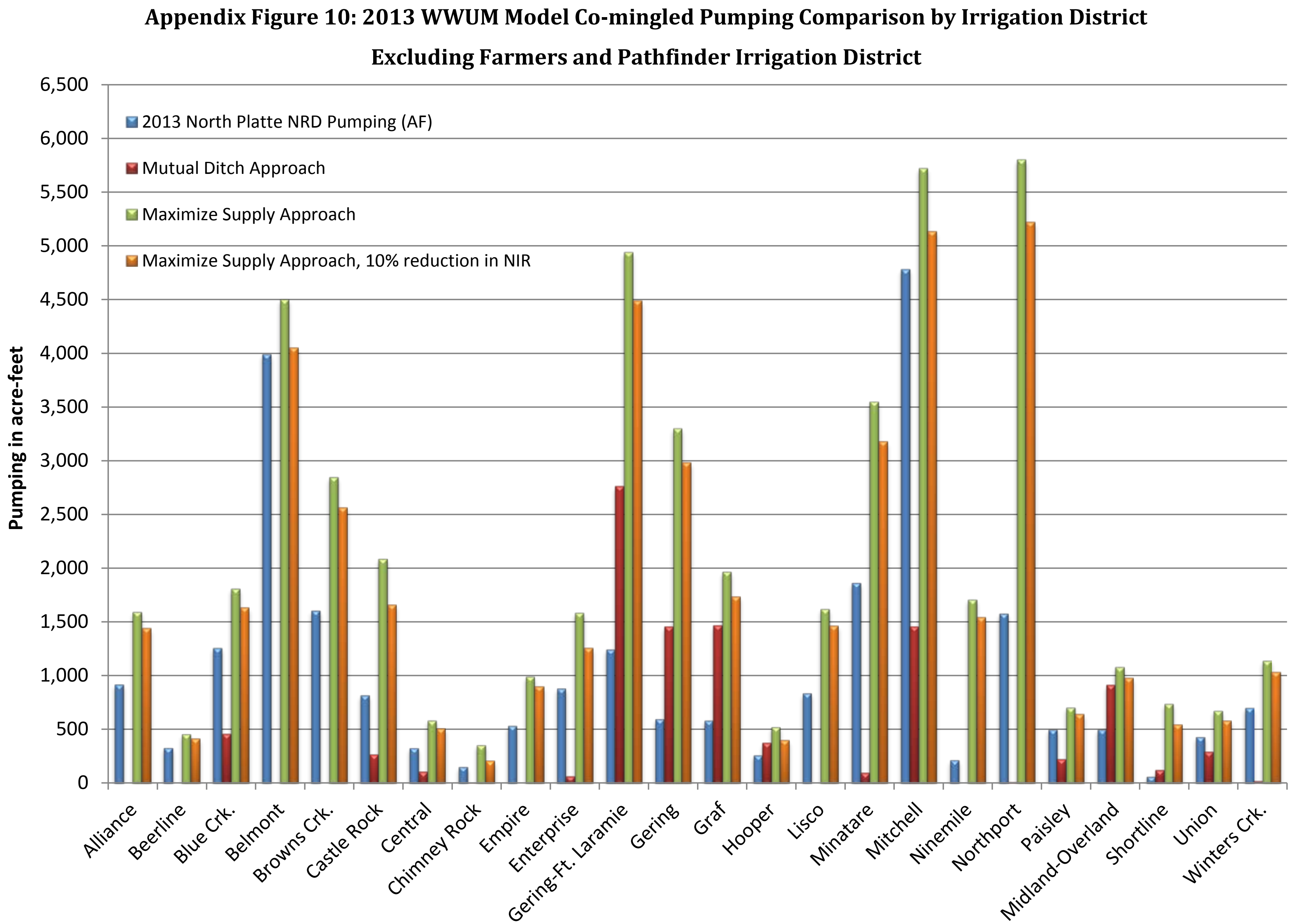


Appendix Figure 8: 2012 WWUM Model Co-mingled Pumping Comparison by Irrigation District Excluding Farmers and Pathfinder Irrigation District



Appendix Figure 9: 2013 WWUM Model Co-mingled Pumping Comparison by Irrigation District




Appendix Figure 10: 2013 WWUM Model Co-mingled Pumping Comparison by Irrigation District
Excluding Farmers and Pathfinder Irrigation District
2013 North Platte NRD Pumping (AF)
Mutual Ditch Approach
Maximize Supply Approach
Maximize Supply Approach, 10% reduction in NIR
Pumping in acre-feet
6,500
6,000
5,500
5,000
4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
Alliance
Beerline
Blue Crk.
Belmont
Browns Crk.
Castle Rock
Central
Chimney Rock
Empire
Enterprise
Gering-Ft. Laramie
Gering
Graf
Hooper
Lisco
Minatare
Mitchell
Ninemile
Northport
Paisley
Midland-Overland
Shortline
Union
Winters Crk.

An additional StateCU scenario, *Mutual Ditch Scenario with Revised Conveyance Efficiency,* was developed in order to investigate the impact of conveyance efficiency on the simulated co-mingled pumping. This scenario represented all structures using the Mutual Ditch pumping approach and was iteratively simulated with revised conveyance efficiencies with the goal of yielding co-mingled pumping results that more closely correlate with metered pumping in 2009 and 2010. This resulted in a set of conveyance efficiencies that would calibrate to results based on a Mutual Ditch pumping approach. Note this analysis was completed during the original modeling effort using 2009 and 2010 pumping data, and not revised using the extended dataset. This set of conveyance efficiencies are provided in **Appendix Table 1** below.

Appendix Table 1: Revised Conveyance Efficiency for Mutual Ditch Approach

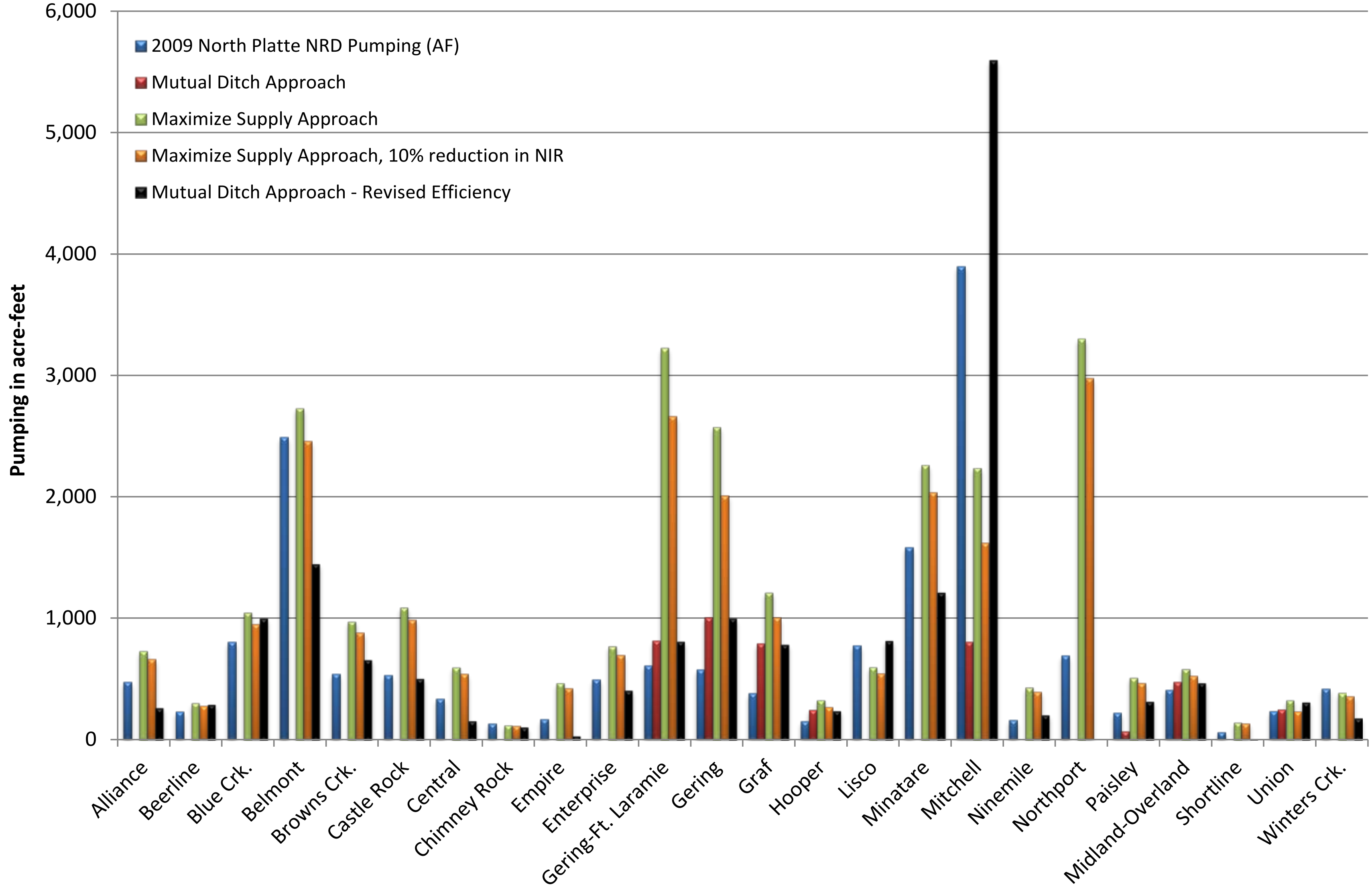
Model ID	Irrigation District	Original Conveyance Efficiency	Revised Conveyance Efficiency
00064	Alliance	59%	35%
00165	Burbank	60%	*Not Rev.*
00187	Torrington	58%	*Not Rev.*
00283	Beerline	59%	30%
00417	Blue Creek	59%	25%
00424	Lucerne	58%	*Not Rev.*
00534	Belmont	62%	20%
00589	Browns Creek	58%	25%
00746	Castle Rock	59%	34%
00754	Central	58%	34%
00794	Chimney Rock	58%	30%
01295	Empire	59%	24%
01311	Enterprise	58%	25%
01362	Farmers	51%	34%
01590	Gering-Ft. Laramie	58%	*Not Rev.*
01591	Gering	56%	*Not Rev.*
01600	Graf	59%	*Not Rev.*
02353	Hooper	59%	*Not Rev.*
02359	Narrows	59%	*Not Rev.*
03162	Lisco	59%	18%
03563	Minatare	59%	35%
03578	Mitchell	72%	47%
03778	Ninemile	59%	33%
03805	Northport	47%	*Not Rev.*
03845	Wright	62%	*Not Rev.*
03940	Paisley	59%	40%

Model ID	Irrigation District	Original Conveyance Efficiency	Revised Conveyance Efficiency
03966	Pathfinder	45%	*Not Rev.*
04397	Midland-Overland	59%	*Not Rev.*
04803	Shortline	59%	50%
05313	Union	59%	47%
05701	Winters Creek	59%	45%
05867	Meredith-Ammer	59%	*Not Rev.*
05920	Murphy	59%	*Not Rev.*
07853	Grattan	58%	*Not Rev.*
07859	North Platte	59%	*Not Rev.*
07870	Rock Ranch	59%	*Not Rev.*
07881	Pratt Ferris	59%	*Not Rev.*
18544	Goshen	59%	*Not Rev.*

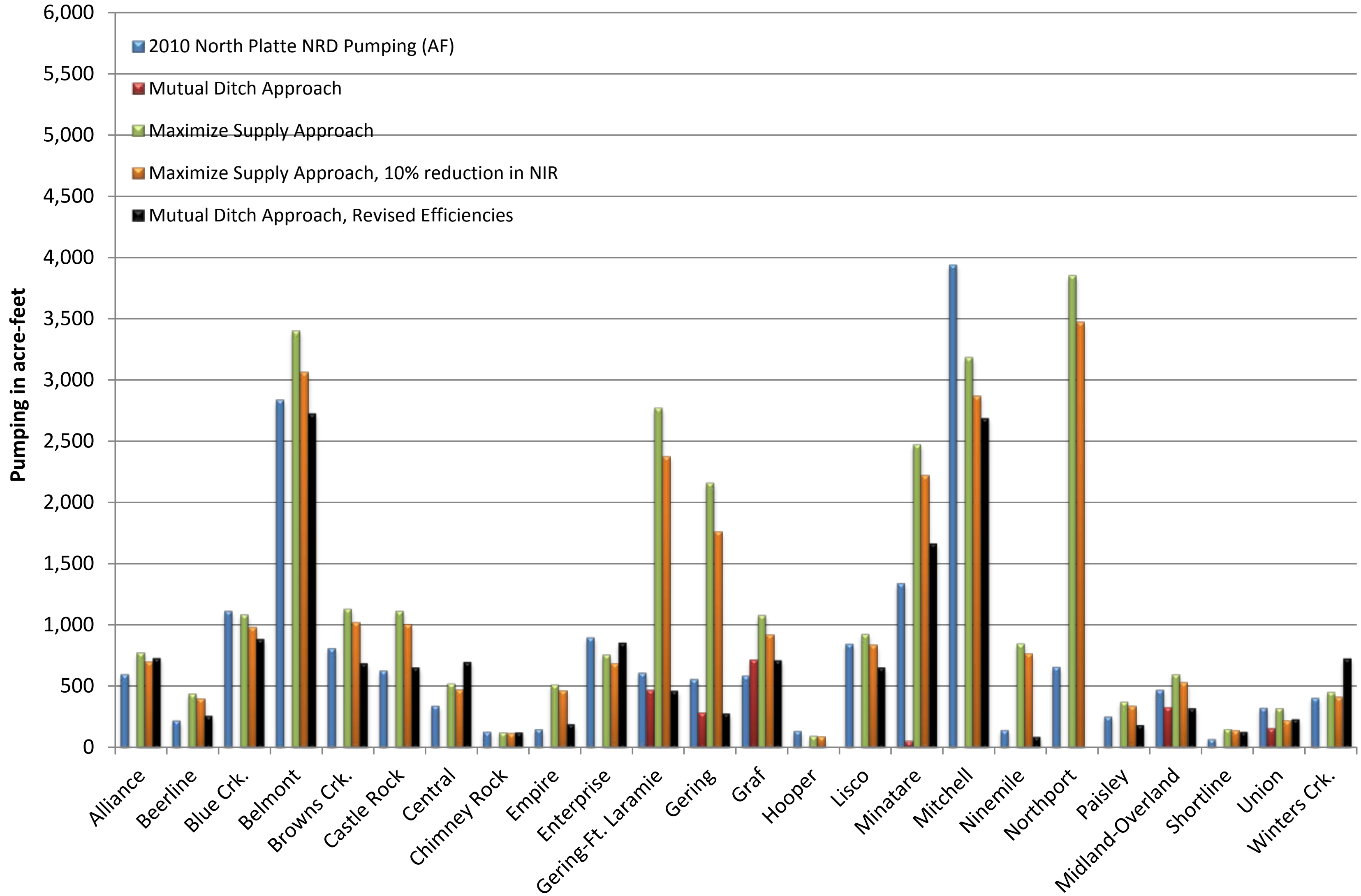
Note that for this analysis the revised conveyance efficiency was used for the entire period. Although StateCU has the capability to vary conveyance efficiency annually, the revised conveyance efficiency presented herein was selected by taking the results of both 2009 and 2010 into consideration. Due to the difference in climatic conditions and water available for diversion in 2009 compared to 2010, the revised conveyance efficiencies generally resulted in co-mingled pumping greater than metered pumping in 2009 and less than metered pumping in 2010. The resulting co-mingled pumping is designated by the black bars on **Appendix Figures 11 and 12** below. Note that the figures exclude Farmers and Pathfinder Irrigation Districts, because these irrigation districts have substantially more pumping making the other comparisons difficult.

As shown in **Appendix Table 1**, many of the revised conveyance efficiencies are low compared to USBR and other sources of estimated efficiency information. No revised conveyance efficiency values were used from this analysis; the analysis provided support towards the sensitivity of the pumping approaches selected for the analysis as opposed to refinements to conveyance efficiencies. Additional calibration and areas of investigation are documented in the *WWUM Modeling Project Summary, Data Integration, and Calibration Plan.*

Appendix Figure 11: 2009 WWUM Model Co-mingled Pumping Comparison by Irrigation District With Revised Efficiency, Excluding Farmers and Pathfinder Irrigation District



Appendix Figure 12: 2010 WWUM Model Co-mingled Pumping Comparison by Irrigation District With Revised Efficiency, Excluding Farmers and Pathfinder Irrigation District



APPENDIX B: POINT OF DIVERSION LIST

Appendix B summarizes the diversion data information used in the consumptive use analysis. Points of diversion were identified within the Whalen Dam to Lake McConaughy reach of the North Platte River. Diversion data associated with these points was found in the following or obtained from following publically available sources:

1. NDNR Stream Gaging Data Bank (http://dnr.ne.gov/docs/hydrologic.html)
2. Directly from NDNR Staff via email exchanges
3. USBR Water Distribution Reports, provided in scanned form for 1953 through 2013

As discussed in **Section 3.6**, daily diversion data was queried from the NDNR website, visually reviewed for errant data points, and aggregated into monthly data using **TSTool.** Likewise, monthly diversion data was digitized from USBR Water Distribution Reports and visually reviewed for errant data points. Data points were considered "errant" if they far exceeded the other diversion data available. See the **TSTool** command files for the specific data points deemed as errant for this analysis. **Appendix Table 2** summarizes the points of diversion, source of data used, and the period of record that data was generally available for each irrigation district.

Additional data manipulation was necessary for the following structures:

- Daily diversion data for the Mitchell-Gering Canal, Fort Laramie Canal and Interstate Canal was supplemented by daily USBR HydroMet Site diversion data obtained from the USBR website prior to monthly aggregation. The HydroMet sites used are noted in the table below.
- No historical data was available for the Gering Ft. Laramie at Owl Creek point of diversion, therefore diversion records for this structure were set to zero for the consumptive use analysis.
- Section 3.6 describes the process for estimating the diversions to irrigation and storage recorded at Interstate Canal.
- Diversion data for the Mitchell-Gering Canal has been recorded under several different gage ID's during the study period. Prior to 1985, Mitchell - Gering Canal diversions were recorded separately under the 101000 and 56000 gages. Diversion data for these gages was added together, and used to fill the 101100 gage data prior to 1985. Post 1985 daily data from the USBR MGNE gage was used to fill the 101100 gage, and then the daily data for the full 1953 to 2013 period was aggregated to monthly data for use in the analysis.
- Tri-State Canal diversions to irrigation for irrigation demand structures under Farmer's Irrigation District and Northport Irrigation District were recorded under several different gage ID's during the study period. Prior to 1985, the following gages and approach were used:
    - The Tri-State Canal diversions were recorded at the 145100 gage, and reflected the diversions from the North Platte River for Farmer's and Northport Irrigation Districts. The recorded diversions to Northport did not include carriage/delivery fees, therefore Northport Irrigation Diversions recorded at 115100 were scaled by 34% and this percentage was added to

the Tri-State Canal diversions. Additionally, the historical Ramshorn Canal diversions recorded at the 125000 were added to the Tri-State Canal diversions. Ramshorn Canal was not modeled explicitly, therefore the historical acreage served by this canal was added to the surrounding Farmer's Irrigation District acreage and the historical diversions were aggregated as well.

- Northport Irrigation Diversions consisted of the North Platte River diversions recorded at 115100 and the Government Drain diversions (see Appendix Table 2 below) separately. These records were scaled by 66% to reflect the carriage/delivery fees, and then added together.
- Farmer's Irrigation Diversions were created by subtracting the Northport Irrigation Diversions from the North Platte River from the total Tri-State Canal diversions.

After 1985, the following gages and approach were used:

- Tri-State Canal diversions recorded at the 145100 gage correctly reflect the diversions from the North Platte River for Farmer's and Northport Irrigation Districts; no adjustment is necessary.
- Northport Irrigation Diversions recorded at 115100 reflect the combined diversions from the North Platte River and Government Drains, and are now measured at the Northport Irrigation District boundary (i.e. post-carriage/delivery fees). No adjustment is necessary.
- Farmer's Irrigation Diversions were created by first removing the Government Drain diversions from the Northport Irrigation Diversions, then subtracting the Northport Irrigation Diversions from the Tri-State Canal diversions.

Appendix Table 2: WWUM Historical Diversion Data Summary

Irrigation District	Model ID	Source	Point of Diversion Name and ID	Available POR
Alliance	00064	NDNR	Alliance Canal from Bayard Creek (2000)	1953 – 2013
	00064_C1	NDNR	Alliance Canal from Red Willow Creek (3000)	1953 – 2013
Beerline	00283	NDNR	Beerline Canal from North Platte River (7000)	1953 – 2013
Belmont, Empire & Meredith-Ammer	00534	NDNR	Belmont Canal from North Platte River (9000)	1953 – 1983 1985 – 2013
	00534_C1	NDNR	Belmont Canal from Cedar Creek (10000)	1954 – 1956 1959 – 1964 1966 – 1982 1984 – 2013

Irrigation District	Model ID	Source	Point of Diversion Name and	Available POR
	05867	NDNR	Meredith-Ammer Canal from Pumpkin Creek (88000)	1953 – 2013
	01295	NDNR	Empire Canal from North Platte River (39000)	1958 – 2013
Blue Creek	00417	NDNR	Blue Creek Canal from Blue Creek and Crescent Lake (17000)	1953 – 1997
Browns Creek	00589	NDNR	Browns Creek Canal from North Platte River (19000)	1953 – 1982 1984 – 2013
Burbank	00165	USBR	Burbank Ditch	1953 – 2013
Castle Rock	00746	NDNR	Castle Rock-Steamboat Canal from North Platte River (21000)	1953 – 2013
Central	00754	NDNR	Central Canal from North Platte River(22000)	1953 – 2013
Chimney Rock	00794	NDNR	Chimney Rock Canal from North Platte River (24000)	1953 – 2013
Enterprise	01311	NDNR	Enterprise Canal from North Platte River (40000)	1953 – 2013
	01311_C1	NDNR	Enterprise Canal from Morrill Drain (42000)	1953 – 1996
	01311_C2	NDNR	Enterprise Canal from Winters Creek (44000)	1961 – 1971 1973 – 1989 1991 – 1996
	01311_C3	NDNR	Enterprise Canal from Tub Springs (43000)	1953 – 2013
	01311_C4	NDNR	Enterprise Canal from Wet Spotted Creek (42700)	1953 – 2013
Farmers	01362	NDNR	Tri-State Canal from North Platte River (145100)	1953 – 2013
		NDNR	Ramshorn Canal from North Platte River (125000)	1953 - 1992
Gering Ft. Laramie, Goshen, Wright & Murphy	01590	NDNR	Ft Laramie Canal from NPR MP 0.8 (52000)	1953 – 2010
		USBR	Ft Laramie Canal from NPR MP 0.8 (FCWY)	1953 - 2013

Irrigation District	Model ID	Source	Point of Diversion Name and	Available POR
	01590_C1	N/A	Gering Ft. Laramie at Owl Creek	N/A
Graf	01600		Graf Canal from Blue Creek (60000)	1953 – 2001
Grattan	07853	USBR	New Grattan Ditch	1953 – 2013
Hooper	02353	NDNR	Hooper Canal from Blue Creek via Blue Creek Canal (67000)	1953 – 2013
Lisco	03162	NDNR	Lisco Canal from North Platte River (82000)	1953 – 1984 1986 – 2013
Lucerne	00424	USBR	Lucerne Canal and Power Co.	1953 – 2013
Midland-Overland	04397	NDNR	Midland-Overland Canal from North Platte River (98000)	1953 – 2002 2004 – 2013
Minatare	03563	NDNR	Minatare Canal from North Platte River (99000)	1953 – 2013
Mitchell & Gering	03578	NDNR	Mitchell & Gering Canal from North Platte River (101100)	1985 – 2013
			Gering Canal from North Platte River via Mitchell-Gering Canal (56000)	1953 – 2013
			Mitchell Canal from the North Platte River (101000)	1953 – 1984
		USBR	Mitchell Gering Canal near State Line, NE (MGNE)	1985 – 2013
Narrows	02359	USBR	Narrows District	1953 – 2013
Nine Mile	03778	NDNR	Nine Mile Canal from North Platte River (106000)	1953 – 2013
	03778_C1	NDNR	Nine Mile Canal from Nine Mile Creek (106100)	1977 1988 – 2013
North Platte	07859	USBR	North Platte Irrigation Ditch	1953 – 2013
Northport	03805	NDNR	Northport Canal from North Platte River (115100)	1953 – 2013
	03805_C1	NDNR	Tri-State Canal from Sheep Creek (144700)	1961 – 2013
	03805_C2	NDNR	Tri-State Canal from Akers Draw near Morrill (144500)	1961 – 2013

Irrigation District	Model ID	Source	Point of Diversion Name and	Available POR
	03805_C3	NDNR	Tri-State Canal from Dry Spotted Tail Creek (144600)	1961 – 2013
	03805_C4	NDNR	Tri-State Canal from Wet Spotted Tail Creek (144900)	1961 – 2013
	03805_C5	NDNR	Tri-State Canal from Tub Springs (144800)	1961 – 2013
Paisley	03940	NDNR	Paisley Canal from Blue Creek (120000)	1953 – 2013
Pathfinder	03966	NDNR	Interstate Canal from North Platte River (71000)	1953 – 2013
		USBR	Interstate Canal at Mile Post 1.0, WY (ICWY)	1953 – 2013
Pratt Ferris	07881	USBR	Pratt Ferris Ditch	1953 – 2013
Rock Ranch	07870	USBR	Rock Ranch District	1953 – 2013
Short Line	04803	NDNR	Short Line Canal from North Platte River (133000)	1953 – 2013
	05313	NDNR	Union Canal from Blue Creek (146000)	1953 – 2013
Torrington	00187	USBR	Torrington District	1953 – 2013
Winters Creek	05701	NDNR	Winters Creek Canal from North Platte River (148000)	1953 – 2013
	05701_C1	NDNR	Winters Creek Canal from Winters Creek (149000)	1953 – 2013