WWUM Model Historical Consumptive Use & Pumping Estimates

To: Thad Kuntz, North Platte NRD

From: Mark Mitisek and Kara Sobieski, Leonard Rice Engineers, Inc.

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Subject: Use of StateCU to Develop Historical Consumptive Use and Pumping Estimates

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The State of Colorado's 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 (WWUM) Model, only the water balance portion of StateCU was used, as the potential crop consumptive use and the 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 was adapted 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, irrigation application efficiencies, historical pumping records when available, and multiple methodologies to apply ground water supplies.
- 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 for use in the ground water model.

This memorandum 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 Model area. In addition, this memorandum will compare the estimated well pumping information to actual well pumping information collected by the North Platte Natural Resource District (NPNRD). This memorandum is not attended to thoroughly document the approach, rather highlight the important modeling decisions used to develop the StateCU analysis and resulting information.

Use of Data & Model Extent

The primary use of information from the StateCU analysis is to determine a preliminary estimate of historical well pumping on co-mingled 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 data will be used during the calibration phase of the surface and ground water modeling efforts, and will be superceded by data from the StateMod surface water model as the model becomes calibrated.

Due to the primary use of information, the StateCU analysis included the irrigated lands served entirely or in part by North Platte River diversions of surface water within the Lewellen Dam to Lake McConaughy river reach, and a selection of ground water only lands that are located in close

proximity to the river. The lands included in the analysis are located either in Wyoming or in the North Platte NRD area in Nebraska , with only a small portion of the lands located in the Pumpkin Creek Basin.

StateCU Input File Approach

Several input files are required to perform the water balance analysis in StateCU. These input files, which are discussed in more detail below, include a structure file, NIR file, efficiency file, and historical diversion file. The information used to create these input files was generated using an Access database, which contains NIR information, well information, acreage information, and diversion information. Data management interfaces, including TSTool and StateDMI, were used to format the data into the correct input file format.

There are also several input files required by StateCU to perform the crop consumptive use analysis, however since this portion of the program was not used, blank input files were used as placeholders.

Structure File (WWUM2012.str)

The structure file provides a master list of structures that will be included in the StateCU analysis. Each structure represents a model ID in the surface water model, and may represent a group of irrigated lands served by surface and/or ground water, or a carrier structure that conveys water to irrigated land. The irrigated lands are grouped by *URF Zone*, or a group of irrigated lands operating in a similar fashion that experiences a similar return flow pattern (i.e. *U*nit *R*esponse *F*unction). This one-for-one correlation between structures in the StateCU model and the surface water model is necessary, as the StateCU output will be read directly into the surface water model. There are 97 structures that receive surface water and 87 ground water only structures in the WWUM Model representing both the Wyoming and Nebraska lands in the model.

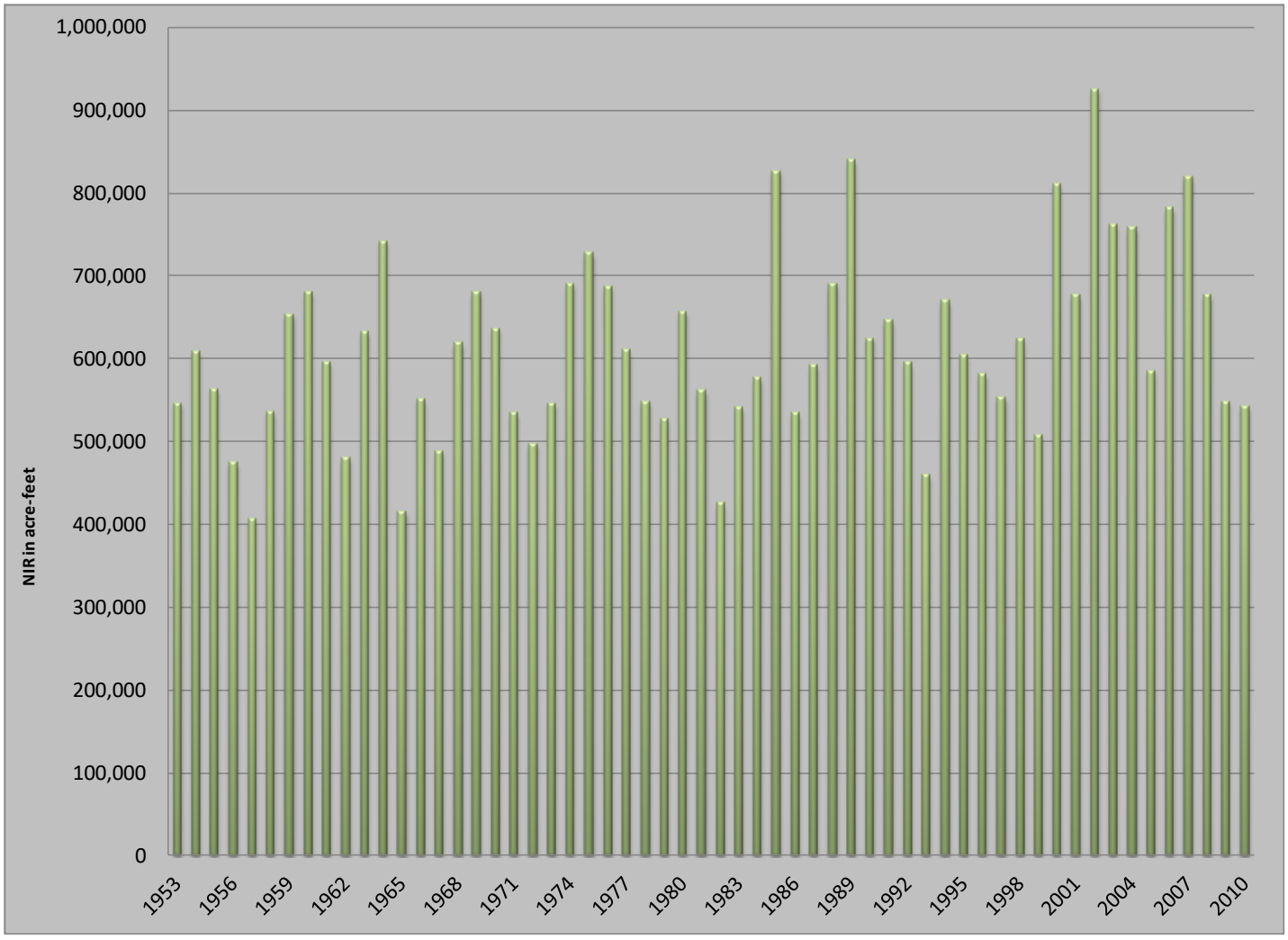
The structure file also contains soil moisture capacity information for each structure. Available water capacity (AWC) information is used by StateCU to determine the volume of the soil moisture zone available to the lands associated with each structure. AWC information, in the form of a spatial soils coverage, was provided by The Flatwater Group. For Nebraska structures, the 2005 irrigated lands was intersected with the soils coverage to determine the AWC by parcel. 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. The representative AWC values in Wyoming were confirmed by the U.S.G.S. Soils Survey data. Overall, AWC values in the structure file ranged from 0.080 to 0.150 inches per inch.

Additional information in the structure file is generally used by StateCU to perform the crop consumptive analysis. This information is present in the structure file, but not used in the water balance analysis.

Net Irrigation Requirement File (WWUM2012.rcr)

The development of the historical NIR by parcel using CropSim was completed by The Flatwater Group for lands in both the Nebraska and Wyoming portion of the model area. Monthly NIR estimates were provided by parcel in inches for each year 1953 through 2010. These monthly NIR values were stored in the master Access database, and parcel IDs were used as the primary key to join monthly NIR estimates to each parcel in the acreage coverage. Monthly NIR in acre-feet, as required by StateCU, was then calculated by first converting NIR from inches to feet, and then multiplying the NIR by the corresponding parcel acreage. Monthly NIR by parcel was then aggregated by WWUM Model structure (i.e. *URF Zone*) for each year. This resulted in a monthly time series of NIR in acre-feet by structure for the 1953 to 2010 period. **Figure 1** shows the average annual NIR (1953-2010) for the entire WWUM Model area.

Figure 1
WWUM Model Average Annual NIR (1953-2010)



Efficiency File (WWUM2012.ipy)

The annual efficiency file (a.k.a. *I*rrigation *P*arameter *Y*early file) is an annual time series of efficiency and well information by structure required to run the water balance simulation, and includes parameters discussed in more detail below. StateDMI was used to create the annual efficiency file using list files generated from structure specific information in the master Access database.

Conveyance Efficiencies

The conveyance efficiency represents the portion of the total diversion that reaches the farm headgate. The inverse of the efficiency is the percent loss, accounting for the loss between the river headgate and the farm headgate, and represents losses through canals, ditches and laterals. A summary of conveyance efficiencies and the data source used to develop the loss factor is tabulated in **Table 1**.

Table 1
WWUM Model Maximum Conveyance Efficiencies

Model ID	Irrigation District	Conveyance Efficiency	Source*
00064	Alliance	55%	BBA
00165	Burbank	60%	USBR
00187	Torrington	58%	USBR
00283	Beerline	59%	USBR
00417	Blue Creek	75%	LRE
00424	Lucerne	58%	USBR
00534	Belmont	62%	USBR
00589	Browns Creek	58%	USBR
00746	Castle Rock	60%	BBA
00754	Central	58%	USBR
00794	Chimney Rock	58%	USBR
01295	Empire	75%	BBA
01311	Enterprise	58%	USBR
01362	Farmers	51%	USBR
01590	Gering-Ft. Laramie	58%	USBR
01591	Gering	56%	USBR
01600	Graf	75%	LRE
02353	Hooper	75%	LRE
02359	Narrows	75%	BBA
03162	Lisco	63%	BBA
03563	Minatare	55%	BBA
03578	Mitchell	73%	Dr. Martin
03778	Ninemile	55%	BBA
03805	Northport	47%	USBR
03845	Wright	62%	USBR
03940	Paisley	75%	LRE

03966	Pathfinder	46%	Dr. Martin
04397	Midland-Overland	75%	BBA
04803	Shortline	75%	BBA
05313	Union	75%	LRE
05701	Winters Creek	55%	BBA
05867	Meredith-Ammer	75%	LRE
05920	Murphy	59%	BBA
07853	Grattan	58%	USBR
07859	North Platte	60%	BBA
07870	Rock Ranch	59%	USBR
07881	Pratt Ferris	60%	BBA
18544	Goshen	62%	USBR

* BBA: North Platte River Return Flow Model Documentation, Bishop Brogden Associates, Inc.
Dr. Martin: *Post-Decree Changes in the Water Supply and Irrigation Development in the North Platte River Valley from Whalen, Wyoming to Lewellen, Nebraska* by Dr. Darrel Martin
LRE: Estimated using engineering judgment and anecdotal information.
USBR: Average convey. efficiency for irrigation district (1946 -2005), from in the *npdiv-del.xls* spreadsheet.

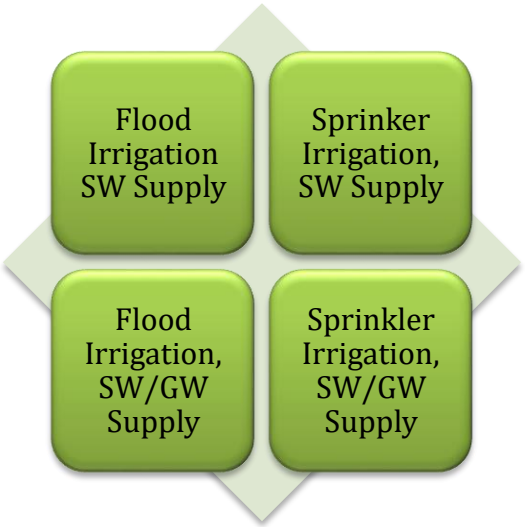
Maximum Irrigation Efficiencies

The maximum flood irrigation and sprinkler efficiencies account for application losses between the farm headgate or well and the crops. The maximum flood irrigation efficiency is estimated to be 65 percent (i.e. loss of 35 percent of the farm delivery through application of irrigation supplies) throughout the study period. Sprinkler irrigation efficiencies were set to 70 percent prior to 1975 and linearly interpolated to 85 percent until 1995, then set to 85 percent after 1995.

Acreage flood or sprinkler irrigated with surface and/or ground water supplies

The total acreage assigned to each 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 2** summarizes the four land use categories.

Figure 2
StateCU Land Use Categories



These land use categories are used by StateCU to determine which efficiencies should be used for each portion of the land assigned to a WWUM Model structure. Note that the land use categories that include surface and ground water supplies reflect co-mingled parcels. Ground water only parcels were included in separate structures to ensure that they did not receive surface water supplies. The attribution of surface and ground water supplies in the WWUM Model acreage assessment allowed for the summation of each structure's irrigated land in each land use category.

As noted above, the efficiency file is a time series and can reflect changes to efficiencies over time. An example is that it was more likely that acreage assigned to a structure in 1955 was served by surface water supplies and flood irrigated. Over time, the

same structure may have more acreage assigned to the sprinkler irrigation with surface and ground water supplies land use category, due to the increase in sprinkler technology and supplemental supplies. The change in flood to sprinkler acreage and surface water to co-mingled supplied acreage is discussed in more detail in the *Western Water Use Management Model Irrigation and Dryland Acreage Assessment,* completed by LRE.

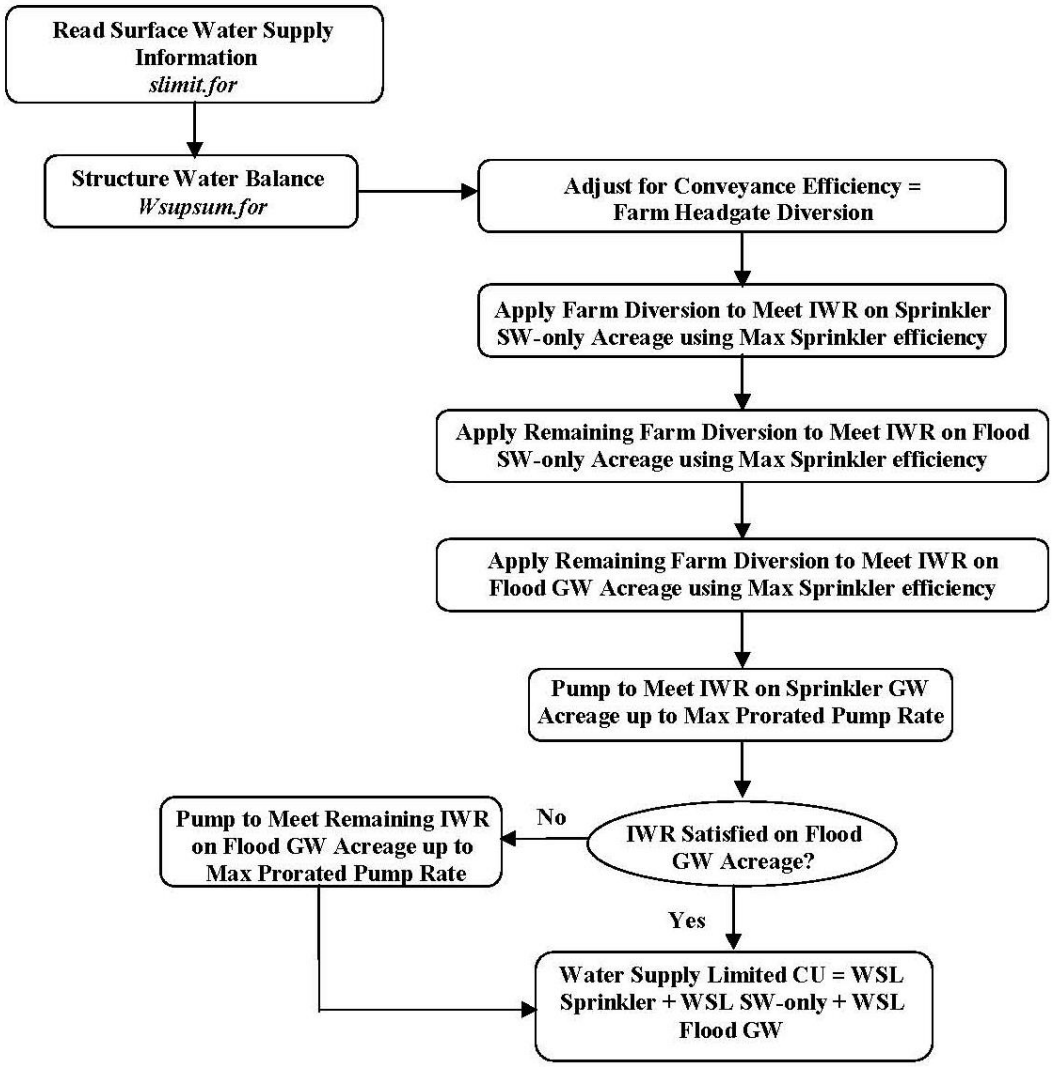
Maximum Monthly Pumping Volume

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 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.

Ground Water Use Mode

The ground water use mode determines how surface water and ground water are used to meet the NIR demand for each structure. There are two approaches available in StateCU that represent the irrigation practices in the WWUM Model study area. The "Mutual Ditch" (GWMode = 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" (GWMode = 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 3** below is a flow chart from the StateCU documentation that summarizes how the water supplies are accounted for using this approach.

Figure 3
Water Balance Procedure with "Maximize Supply" Approach



Scenarios using both of these approaches were completed, and the results from 2009 and 2010 were compared to actual pumping records from the North Platte NRD (see the Sensitivity Analysis below). 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 2** were modeled using the Mutual Ditch approach; all others were modeled using the Maximize Supply approach.

Table 2
Irrigation Districts Modeled with a Mutual Ditch Approach

Model ID	Irrigation District
01362	Farmers
01590	Gering-Ft. Laramie*
01591	Gering
01600	Graf
03966	Pathfinder*
04397	Midland-Overland

*Irrigation Districts in Wyoming served prior to these districts were also modeled with a Mutual Ditch Approach; despite no available pumping information for comparison

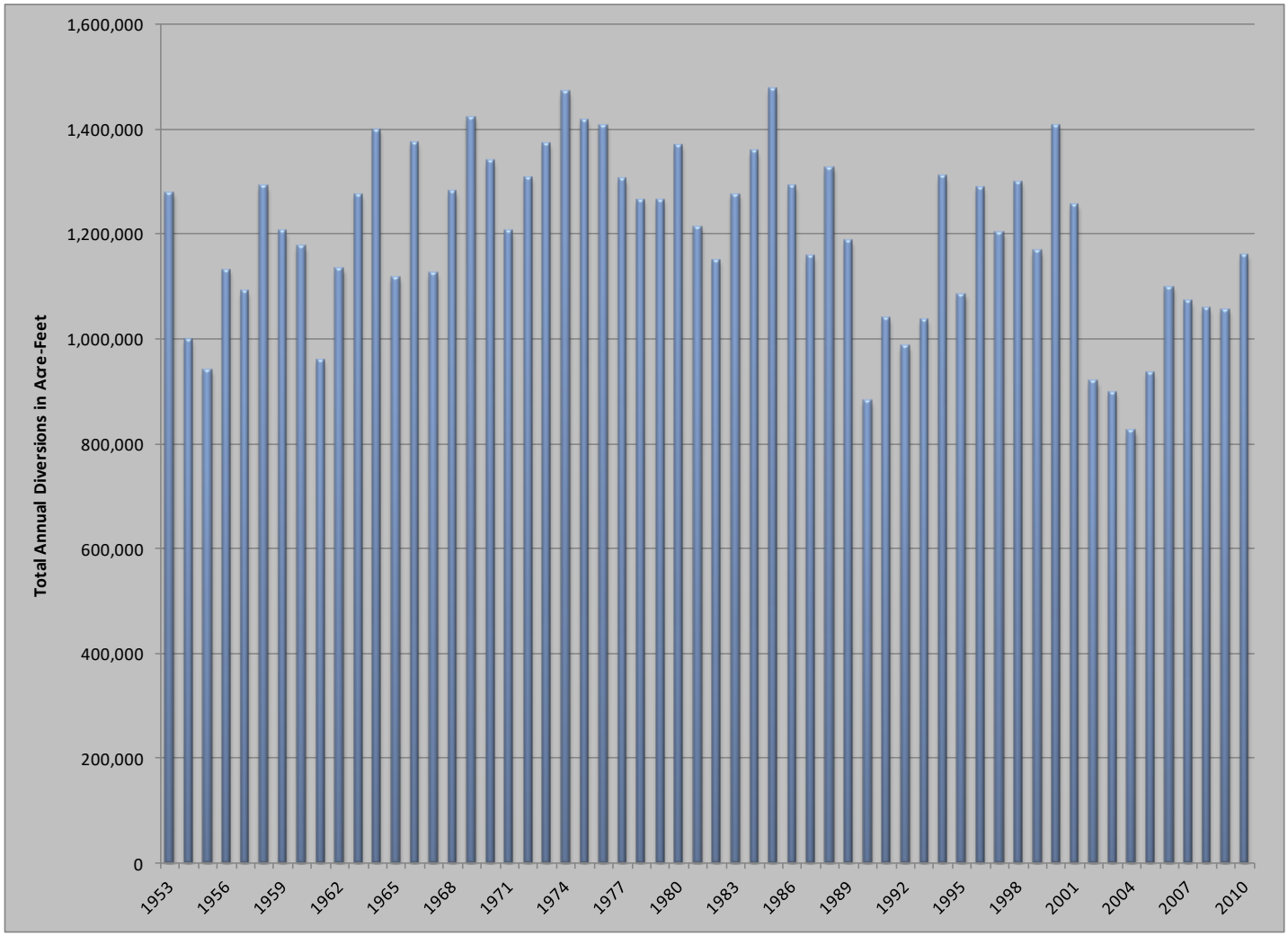
Note that irrespective of the approach, StateCU estimates ground water pumping required to satisfy the NIR not met by surface water. These pumping estimates include water pumped to offset the inefficiencies associated with ground water application. Also, the amount of ground water pumped is limited by the acres served by wells and permitted capacity.

Historical Diversion File (WWUM2012.ddh)

The historical diversion file provides surface water supply information required to estimate actual (supply-limited) consumptive use. Monthly irrigation diversions, based on information from the U.S. Bureau of Reclamation (Reclamation) and the Nebraska Division of Natural Resources (NDNR), were developed for each carrier structure in the model. Diversion data generally reflects canal diversions from the North Platte River, however also includes diversions from smaller tributaries such as Winters Creek or Blue Creek.

Figure 4 shows how surface water diversions for irrigation in the basin have changed over time. Surface water diversions for irrigation averaged approximately 1,195,000 acre-feet over the 1953 through 2010 study period. The variation seen in **Figure 4** is due to water supply limitations, highlighted by the decreased diversions in the drought years of 1954, 1955, and 1990, 2004 and the increased diversions during the wet years of 1975, 1985, and 2000.

Figure 4
WWUM Model Total Annual Diversions (1953-2010)



In the consumptive use and surface water model, carrier structures do not have a NIR demand; rather they "carry" surface water to meet NIR demands based on groupings of land in a *URF Zone*. As a carrier structure generally serves more than one *URF Zone,* it was necessary for the diversions from the carrier structures to be divided up and assigned to the structures with irrigation demand in the consumptive use model (these operations are simulated automatically in the surface water model). Two approaches to dividing up the diversions to each *URF Zone* were investigated; pro-rating diversions based on the acreage in each *URF Zone* or pro-rating based on the total NIR in each *URF Zone.* The consumptive use analysis was simulated using both approaches, and the results, in terms of shortages and estimated ground water pumping, were more reasonable using the NIR approach. In practice, this approach mirrors the situation whereby crops with a higher NIR are using more supplemental ground water supplies. The pro-ration of the total diversions was performed using the master Access database.

For all but Interstate Canal, it was assumed that the total diversions were used solely for irrigation. Likewise, it was assumed that storage releases from the upstream Reclamation reservoirs were

included in the total diversions at the carrier structures. Special consideration was given to Interstate Canal, as it diverts both for irrigation on several thousand acres, and for storage in the "Inland Lakes", including Lake Alice, Little Lake Alice, Lake Minatare, and Winters Creek Reservoir. Therefore, *URF Zones* served by Interstate Canal do not receive a pro-rated amount of the total diversions; rather they receive only a portion of the diversions to irrigation and some downstream *URF Zones* also receive releases from the Inland Lakes. Using end-of-month contents from Inland Lakes, considered as an aggregate for simplification purposes, the amount stored and released each month could be estimated. The total diversions at Interstate Canal less diversions to storage, including diversions that are lost to reservoir evaporation, equal the diversions to irrigation. These diversions to irrigation were divided up based on NIR among all *URF Zones* served by Interstate Canal, including those in Wyoming. The amount of water released from Inland Lakes was divided up among the *URF Zones* located downstream of the Inland Lakes. This resulted in the correct amount of water to be used by StateCU to determine actual (supply-limited) consumptive use, shortages and pumping.

Table 3 summarizes the carrier structures, *URF Zone* structures and the average annual diversion applied to each *URF Zone* structure based on the NIR pro-ration approach.

Table 3
WWUM Model Carrier Structures, URF Zone Structures and Associated Average Annual Diversions (1953-2010)

Model ID	Irrigation District	URF Zone	Average Annual Diversion (ac-ft)
00064	Alliance	00064_80	8,548
		00064_86	8,791
00165	Burbank Canal	00165	609
00187	Torrington Canal	00187	7,880
00283	Beerline	00283	2,187
00417	Blue Creek	00417_130	3,385
		00417_132	4,242
00424	Lucerne Canal	00424	13,971
00534	Belmont	00534_203	5,220
		00534_204	5,133
		00534_88	3,608
		00534_97	14,799
	Empire	01295	8,263
00589	Browns Creek	00589_105	6,889
		00589_96	7,710
00746	Castle Rock	00746_50	968
		00746_55	1,529
		00746_63	11,433
		00746_72	7,535
00754	Central	00754_39	4,436
		00754_41	1,385
		00754_50	256
00794	Chimney Rock	00794	16,368
01311	Enterprise	01311_16	11,214
		01311_207	771
		01311_30	11,698
01362	Farmers	01362_13	3,861
		01362_208	5,113
		01362_209	6,523
		01362_21	221
		01362_25	2,836
		01362_58	22,955
		01362_66	7,971
		01362_7	3,293
		01362_74	15,662
		01362_84	16,775

01590	Gering-Fort Laramie	01590_14	27,194
		01590_15	24,499
		01590_26	12,129
		01590_38	40,777
		01590_8	22,960
	Wright & Murphy Canals	03845 & 05920	24
	Goshen Irrigation District	18544	158,595
01600	Graf	01600_131	1,962
		01600_136	429
02353	Hooper	02353	2,193
02359	Narrows Canal	02359	129
03162	Lisco	03162	9,315
03563	Minatare	03563_43	564
		03563_46	6,177
		03563_52	5,438
		03563_53	1,572
		03563_56	2,374
		03563_58	1,114
		03563_61	3,556
03578	Gering	01591_41	18,803
		01591_50	9,379
		01591_59	830
	Mitchell	03578_17	8,935
		03578_23	18,048
		03578_6	7,530
03778	Ninemile	03778_61	11,767
		03778_68	9,576
		03778_76	5,872
03805	Northport	03805_84	22,221
		03805_86	2,121
		03805_94	48,615
03940	Paisley	03940	3,021
04397	Midland-Overland	04397	1,869
04803	Shortline	04803_73	5,618
		04803_76	2,783
05313	Union	05313_129	2,142
		05313_131	227
07853	Grattan Canal	07853	2,516
07870	Rock Ranch Canal	07870	8,598
07881	Pratt and Ferris Canal	07881	2,299

03966	Pathfinder	03966_11	44,961
		03966_19	24,138
		03966_21	20,977
		03966_25	2,278
		03966_28	17,667
		03966_36	58,674
		03966_4	43,780
		03966_44	18,518
		03966_49	19,275
		03966_54	36,853
		03966_69	15,342
		03966_70	27,802
		03966_84	16,694
		03966_WY	58,215
05701	Winters Creek	05701_201	3,141
		05701_202	9,322
		05701_29	1,469
07859	North Platte Irrigation Ditch	07859	8,251
Total Average Diversions			**1,195,167**

Historical Pumping File (WWUM2012_NRD.gwp)

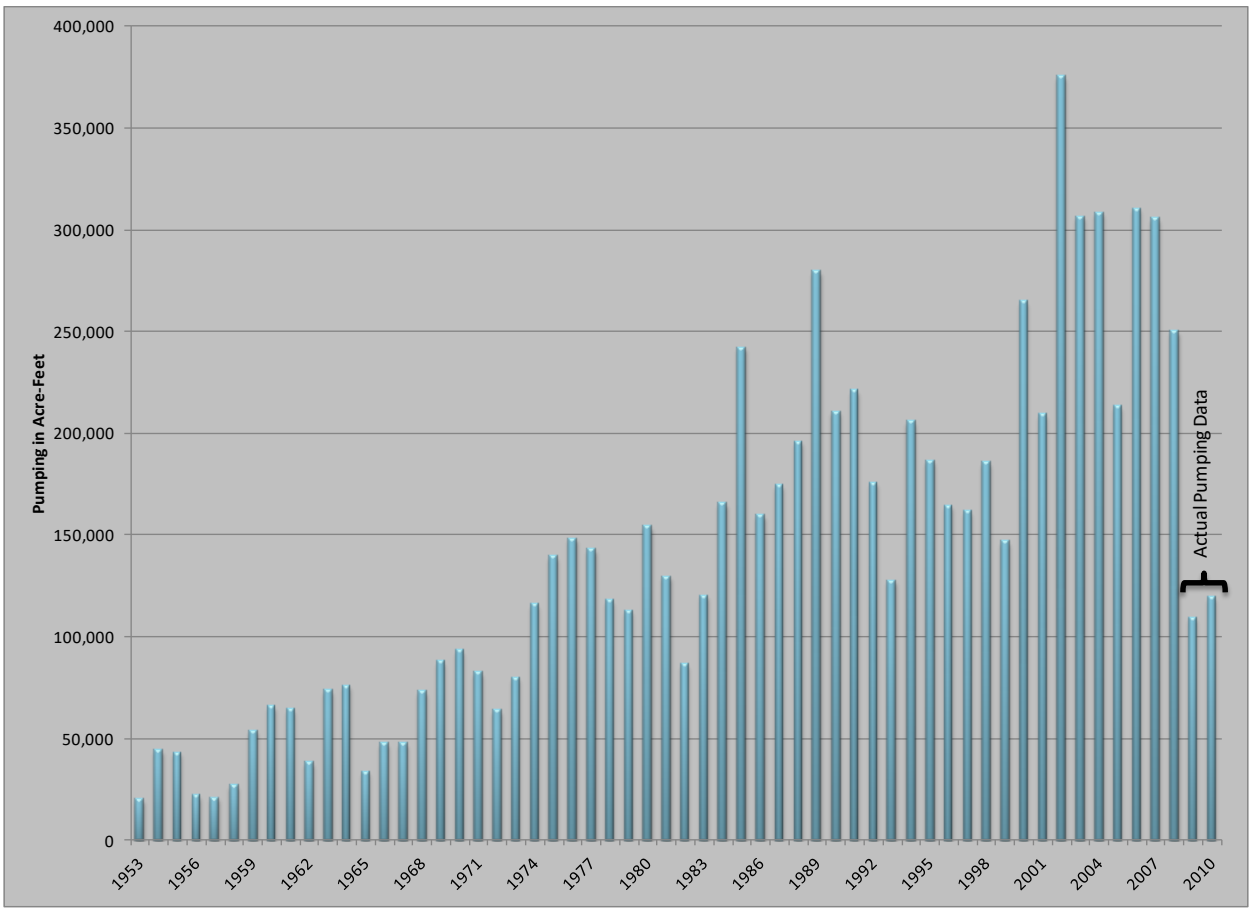
The historical pumping file provides ground water supply information that, in addition to surface water diversions, are used to estimate actual (supply-limited) consumptive use. The historical pumping file consists of monthly pumping information for each *URF Zone* that contains irrigated land that is served by either co-mingled or ground water only supplies. The historical pumping file reflects actual pumping records when available, or estimated pumping based on NIR. Actual pumping records were available in 2009 and 2010 on an annual basis for each certificate ID located in an *Over Appropriated* area. The individual pumping records for each certificate ID were first aggregated by *URF Zone*, then multiplied by a monthly distribution pattern. Four monthly distribution patterns were developed using 2009 and 2010 StateCU model output; they estimate the different distribution between 2009 and 2010, and co-mingled lands and ground water only lands. **Table 4** summarizes the four monthly patterns, and the pattern used for each type of *URF Zone*. Pumping records were not available prior to 2009, therefore the remaining years, from 1953 through 2008, in the historical pumping file were estimated by StateCU using ground water efficiencies, ground water approach and NIR.

Table 4
WWUM Model Monthly Pumping Distributions

Pattern Type	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2009 Co-mingled URF Zones	0%	0%	0%	1%	7%	2%	24%	42%	23%	1%	0%	0%
2009 Ground Water Only URF Zones	0%	0%	0%	2%	12%	2%	32%	34%	18%	0%	0%	0%
2010 Co-mingled URF Zones	0%	0%	0%	2%	2%	6%	26%	58%	6%	0%	0%	0%
2010 Ground Water Only URF Zones	0%	0%	0%	1%	3%	9%	35%	44%	8%	0%	0%	0%

Figure 5 reflects the estimated StateCU pumping and the actual NRD pumping associated with the co-mingled and ground water only parcels included in this model. As discussed above, not all ground water only lands in the North Platte NRD are included in the model; therefore **Figure 5** does not represent total pumping in the North Platte NRD area.

Figure 5
WWUM Model Annual Pumping (1953-2010)



Results

The WWUM Model StateCU water balance analysis provides modelers with an estimate of actual (supply-limited) consumptive use, shortages, canal leakage, irrigation return flow and pumping for the 1953 to 2010 period. **Table 5** serves as a scenario-wide summary of the WWUM Model water balance analysis, averaged annually over the 1953 to 2010 period. Review of the model results on a monthly basis and for specific structures may provide additional perspective as to where and why shortages and pumping is occurring.

Table 5
WWUM Model Scenario-wide Water Balance Analysis Results
Average Annual for 1953-2010 (acre-feet)

NIR	Surface Water Diversion Accounting					
	River Diversion	Conv. Loss	Diversion to Farm	Surface Water Diversion to:		
				CU	Soil Zone	Non-consumed
614,147	1,195,167	547,477	647,690	350,786	43,022	253,882

Ground Water Accounting				Estimated Crop CU			Total Non-Consumed	Shortages
Pumping	CU	Soil Zone	Non-Consumed	From SW & GW	From Soil	Total		
141,122	98,196	6,418	36,508	448,982	49,440	498,422	290,390	115,725

Sensitivity Analysis

There are several inputs and parameters, as discussed above, available in StateCU that are used to simulate actual practices in the field. Many of the parameters are "known" or have been reasonably estimated based on industry-approved techniques, including acreage, NIR, and diversions. Other factors are "unknown", including co-mingled pumping, pumping approach and efficiencies, and these factors were further investigated to determine if the estimated data or approach taken resulted in values that are similar to recorded values.

Figures 6, 7, 8 and **9** below show the pumping results in 2009 and 2010 of various StateCU simulations compared to actual pumping as recorded by the NRD. The various StateCU simulations reflected modifications to certain "unknown" factors, with the goal of determining how sensitive these factors were and how they impacted the pumping estimates. The results of these simulations, as compared to the actual pumping records, ultimately guided the decision behind how these factors would be used in the StateCU analysis discussed herein.

As illustrated in the figures, adjusting efficiency information had very little impact on the overall pumping. The pumping estimates, however, were very sensitive to the ground water mode 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 2 above.

Figure 6
2009 WWUM Model Co-mingled Pumping Comparison by Irrigation District

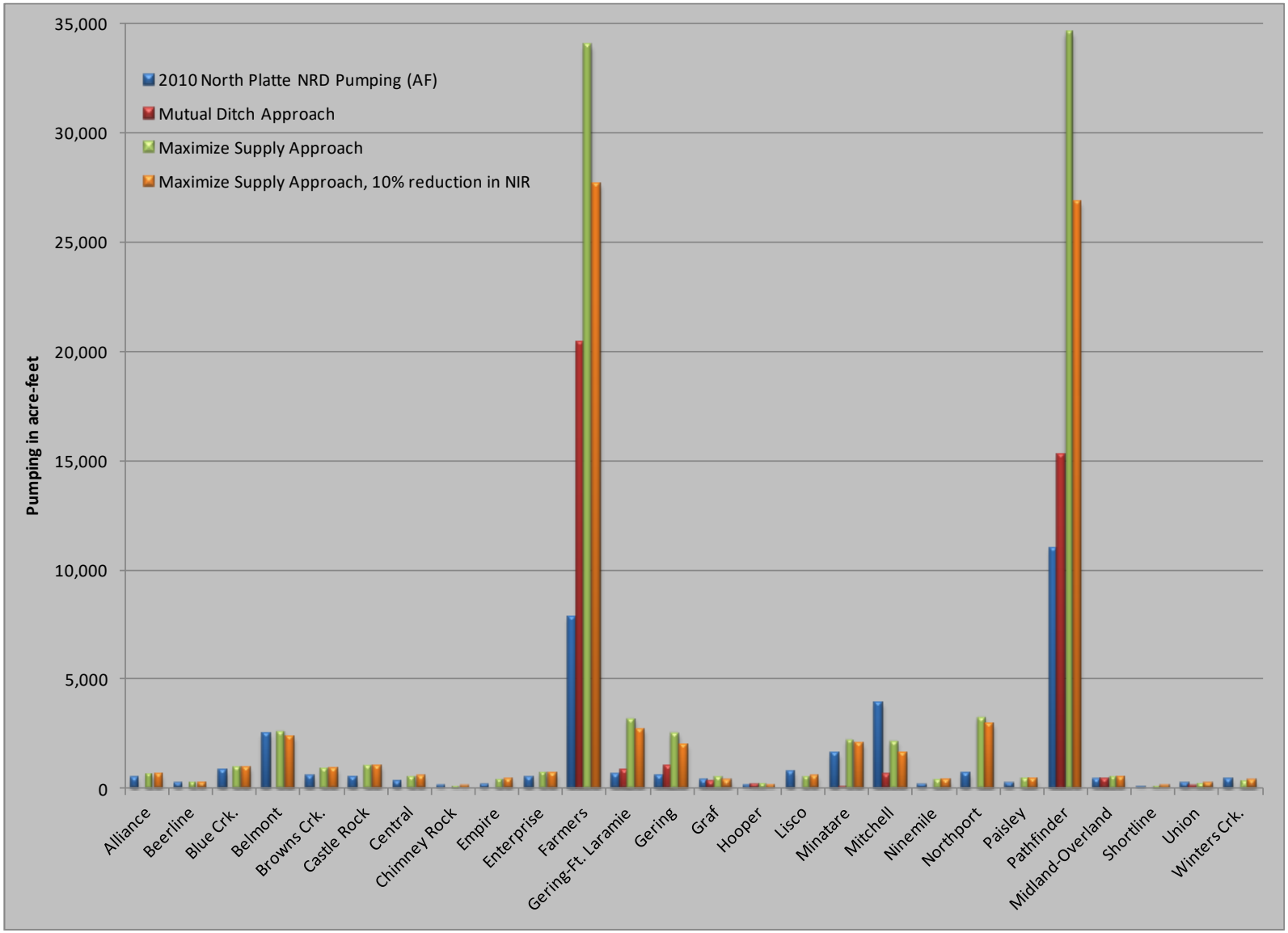


Figure 7
2009 WWUM Model Co-mingled Pumping Comparison by Irrigation District
Excluding Farmers and Pathfinder Irrigation District

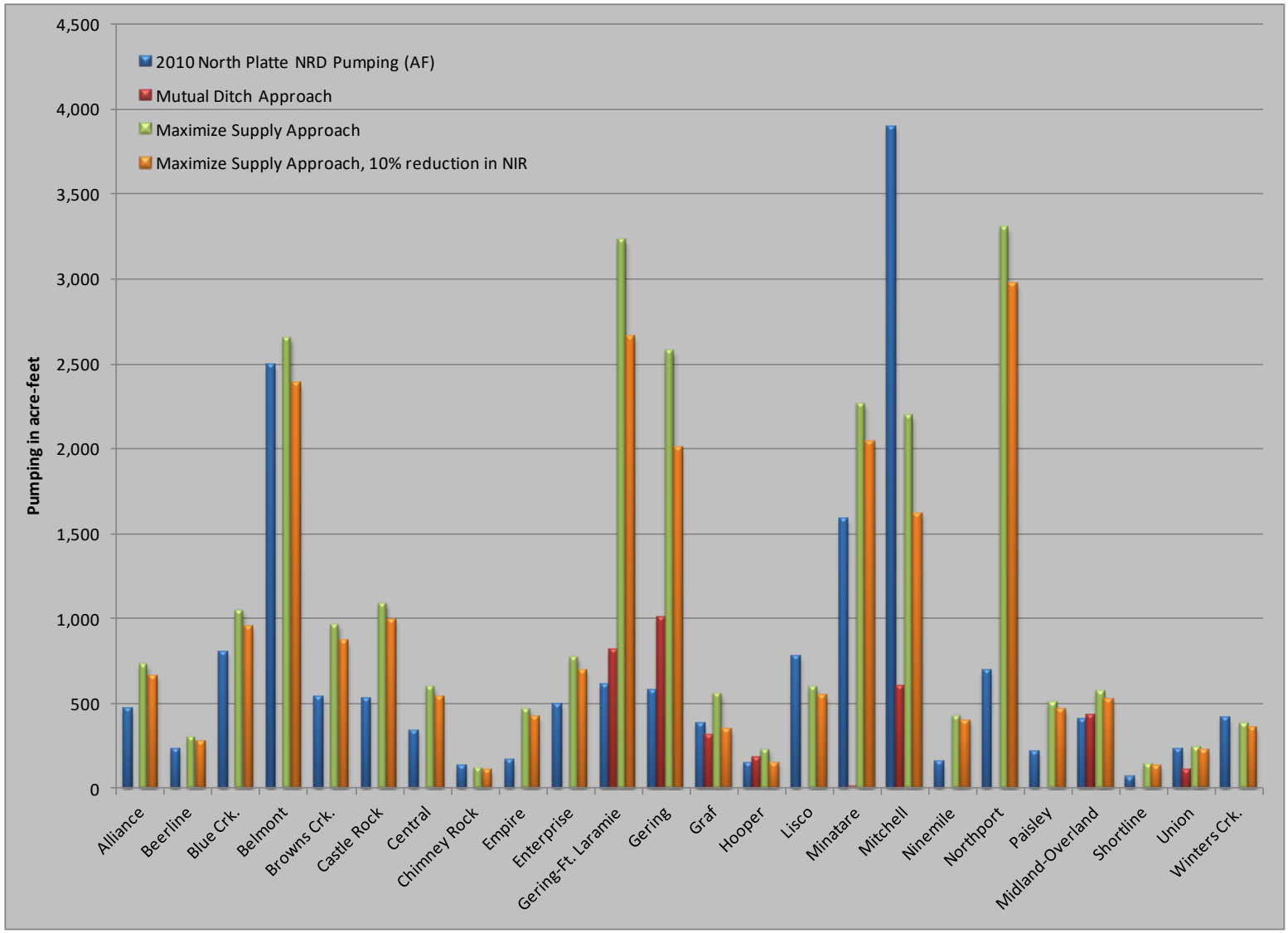


Figure 8
2010 WWUM Model Co-mingled Pumping Comparison by Irrigation District

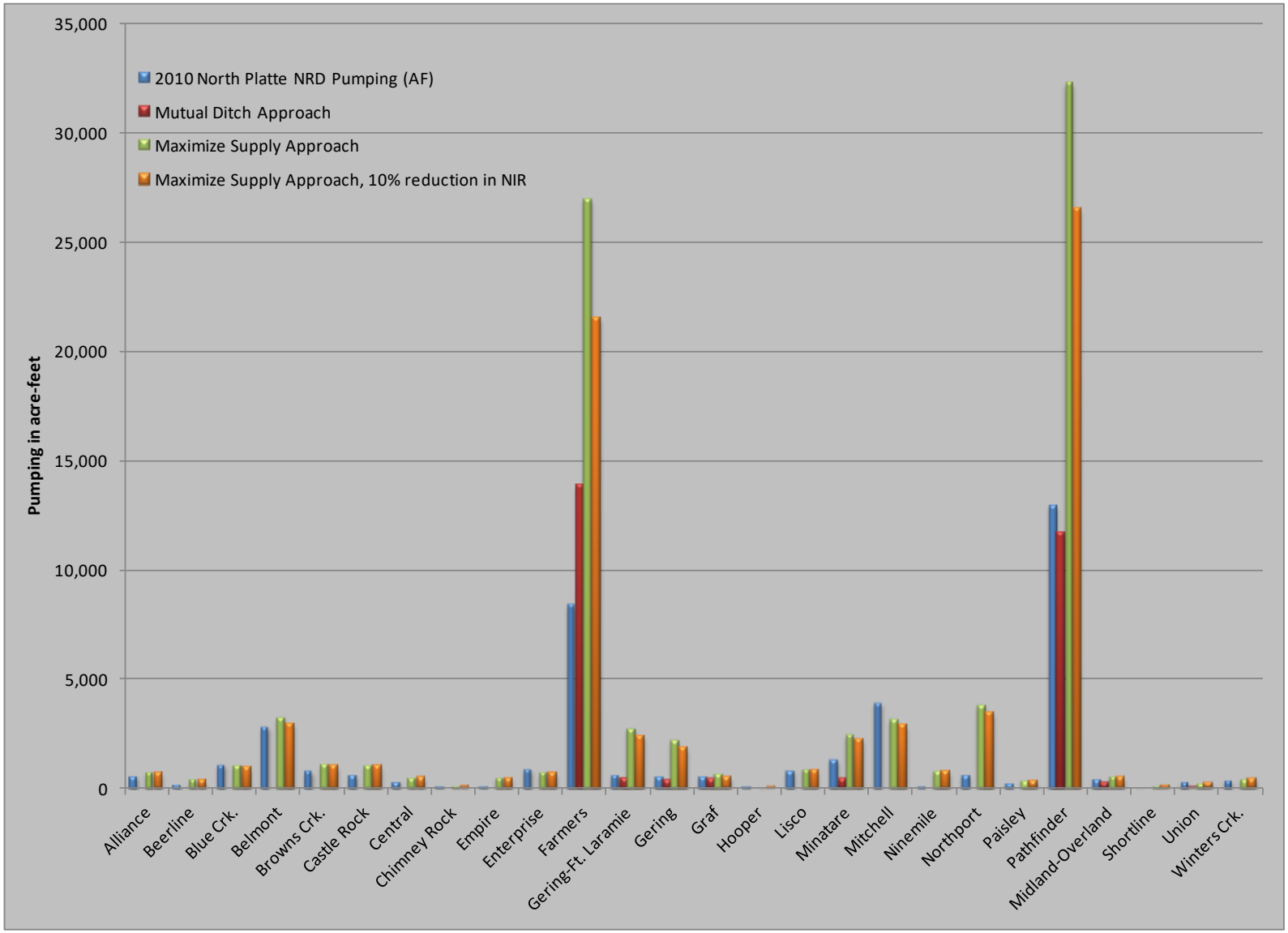


Figure 9
2010 WWUM Model Co-mingled Pumping Comparison by Irrigation District
Excluding Farmers and Pathfinder Irrigation District