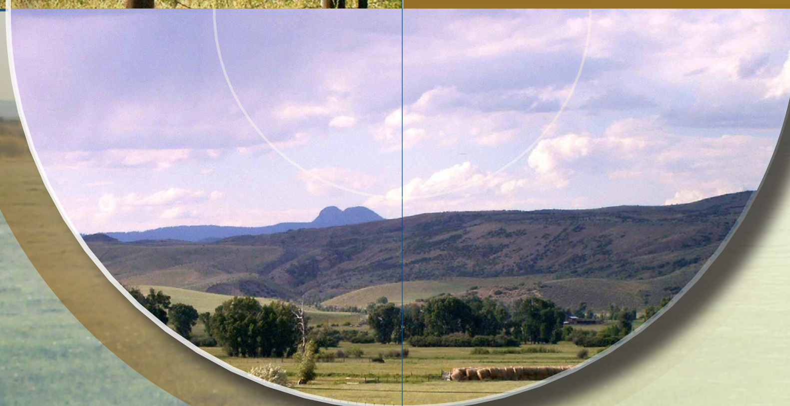
REPORT



Agricultural Water Needs Study

Yampa/White/Green Basin Roundtable

December 2010

CDM

Report Highlights
Agricultural Water Needs Assessment Study
Yampa, White and Green River Basins

While there were seven objectives for the study, the key objectives to the study were: (1) Refine existing shortages using an improved model developed by CDM with CWCB review, (2) Identify new developable irrigable lands, (3) Alternatives to meet shortages/new lands, and (4) Return flows.

The Ag Subcommittee provided invaluable suggestions and critique. This subcommittee really understands water and irrigation in the Yampa, Green and White River basins. They worked with the consultant to evaluate the basin water supply needs and shortages so that the results reflected their knowledge and understanding of the basin. The study area includes the Yampa, Green and White River basins as shown on Figure 1-1 (page 1-4).

Refine Existing Shortages of Ag Water

The use of high altitude crop coefficients increased the Ag demands by 65% over the original model used in CRDSS. This change resulted in greater late summer and fall water shortages after the main runoff season is over. The majority of the study areas experience a typical runoff pattern with peak runoff in June with increasing flow in May and decreasing flow in July. Without reservoir storage to capture excess flows during runoff, the late July, August and October irrigation demands are not met in most years. This runoff pattern causes irrigators to apply as much water as possible during runoff to the fields to maximize soil moisture storage and recharge the alluvial aquifers so that return flows are available to provide for later irrigation demands. This irrigation practice is criticized by some who are uninformed as wasteful but it is the only practical way to capture the excess flows if reservoir storage is not adequate.

The StateMod model was enhanced so that tributaries (B-Aggregates) without a gaging station at the lower end of the tributary were modeled explicitly. Previously in StateMod, these tributary ditch diversions were taken from the main stem where flow was not as limited thus not showing a shortage. The B-Aggregate tributaries have a number of ditches with historic diversion records. StateMod was modified to model the B-Aggregate tributaries using the historic diversions of the ditches as the available supply and any shortages were computed as the irrigation demand that exceeded the available supply based on historic diversions. The use of the B-Aggregates resulted in a larger estimate of consumptive use (CU) shortages than with the original StateMod model, especially in the late season when the tributaries water supply decline as compared to the larger watersheds.

New Developable Irrigation Lands

The study identified two types of irrigable lands that have potential for irrigation if the infrastructure is constructed. The first are areas on upland mesas that could be irrigated if reservoirs and canals were constructed. Previous project studies were reviewed and 35,344 acres were identified as having potential for irrigation if water supply is available. The second are areas located on oxbows along the Yampa River below Craig that could be irrigated with minimal leveling and could be irrigated by a pump in the river serving a ditch or a center-pivot sprinkler system. These areas are estimated to be 14,805 acres.

Alternatives Evaluated for Ability to Meet Shortages or New Demands

Five alternatives were selected after a careful screening process and received considerable input from the Ag Subcommittee especially with respect to meeting agricultural water shortages and meeting future demands related to new irrigated lands.

<u>New or Enlarged Reservoirs</u>

The enlargement of Yamcolo Reservoir was found to not be feasible but the study did reveal that an exchange of irrigation water stored in Stagecoach Reservoir to Yamcolo Reservoir for M&I water in Yamcolo would be feasible and would have a yield of 750 AF. Stagecoach Reservoir is being enlarged by 3185 AF by raising the spillway four feet.

Three new reservoirs were identified from the previous Yampa River Basin Small Reservoir Study. These possible reservoir sites include Monument Butte Reservoir (560 AF) on Morapos Creek, Little Bear (800 AF) and South Fork (1700 AF), both on Fortification Creek. The construction costs of these reservoirs vary from $3,200 to 5,800 per AF of capacity.

<u>Small On-Site Reservoirs</u>

Small non-jurisdictional reservoirs constructed under existing ditches were evaluated as a possible alternative using Morapos Creek as an example due to available data for modeling. It was assumed that 1 AF per irrigated acre could be stored which provided 2,097 AF of additional storage. This amount of storage was able to reduce on average the CU shortage by 1,150 AF. The cost of this storage is estimated to be $500 per AF which is a reasonable cost as compared to costs associated with three reservoirs identified above. This cost came from a rancher on the Ag Committee who had constructed a small dam on his ranch that is filled under a new priority from an existing irrigation ditch. The results for the entire Yampa River basin are shown on Figure 5-20 (page 5-38) and for the White River on Figure 5-21 (page 5-39).

<u>New Irrigated Lands along the Yampa River</u>

The development of new lands along the Yampa River oxbows was evaluated and 14,805 acres were found to be possible for irrigation with pumps from the river and irrigation by ditches or center-pivot sprinklers. The cost per acre ranged from $200 for flood and $800 for sprinkler. There would still be CU shortages in the late summer according to the model runs with the least being 4,786 AF for sprinkler irrigation.

<u>Increased Efficiency on B-Aggregate Ditches</u>

The increased irrigation efficiency on the B-Aggregates ditches was evaluated using the improved model with a sprinkler efficiency of 75% being assumed. This analysis showed that the CU shortage in the Yampa River Basin could be reduced by 34% and the White River Basin by 45% but with serious impacts on late season return flows since less water was applied and at a greater efficiency.

White River Ditch Analysis

The White River Basin was studied at the request of the Ag Subcommittee for the impact of the development of senior conditional water rights by the energy sector on junior water rights on three large ditches in the basin just above Meeker. The study found that additional storage or lining portions of the ditches with high leakage rates could offset the loss of water resulting from exercising the senior energy water rights. The amount of water needed to offset this senior energy right would be about 18,000 AF.

Return Flows

The Ag Subcommittee expressed a concern that the impact on return flows from a conversion to sprinkler irrigation may not be fully understood by most persons and asked that CDM evaluate the impact using the model. The Ag Subcommittee also believed that the value of return flows from irrigation on late season (August, September, and October) stream flows were not fully understood by some of the public.

The impact of increased efficiency was evaluated with the enhanced StateMod model by comparing historical flows with those resulting from increasing the irrigation efficiency to 75%. The resulting changes in flow at six gaging stations within the study area are shown on Figures 6-4 to 6-9 (pages 6-11 to 6-16). The results indicate increased streamflow in the peak runoff season and lower irrigation diversions with an efficiency of 75%. In addition, the return flows are reduced since diversions are less and efficiency is greater. This is especially shown in the late season. The greatest impact on return flows was found to be on the Yampa River above Stagecoach Reservoir where the average flow was reduced in August by 31%.

CDM

Memorandum

To: *Jeff Comstock (Moffat County), Yampa/White/Green Basin Roundtable Agricultural Subcommittee*

From: *Matt Bliss, Mark Hoener (CDM); Hal Simpson (H. D. Simpson Consulting); Ross Bethel (Ross Bethel, LLC)*

Date: *May 28, 2010*

Subject: *Agricultural Water Needs Study: Task 1 Final*

We are pleased to present the final draft of the Yampa/White/Green Agricultural Water Needs Study Task 1 technical memorandum. This task addresses existing agricultural consumptive use shortages. This memo was prepared by CDM staff and reviewed by both Hal Simpson and Ross Bethel. Additionally, the final version incorporates comments the subcommittee has raised at the progress meetings.

Sincerely,

Matt Bliss
Project Manager

1.0 Introduction and Background

In 2005, House Bill 05-1177, the Colorado Water for the 21st Century Act (Penry, Decker, et al., House Bill 05-1177 2005), was signed into law. Among other provisions, the bill provides for the creation of Basin Roundtables (BRT). Each BRT is charged with formulating a water needs assessment, conducting an analysis of available unappropriated water, and proposing projects or methods for meeting those needs.

In 2003, the Colorado Water Conservation Board (CWCB) completed the Statewide Water Supply Initiative (SWSI). That study included estimates of water demands in the White and Yampa River basins through 2030. SWSI concluded there was little gap between projected municipal and industrial water demands and available water supplies in the basins. While SWSI provided a valuable coarse assessment of water demands for the municipal, industrial, and agricultural sectors, concerns were raised at that time that the analysis did not accurately reflect the agricultural water shortages in some of the water districts and especially as it exists on the tributaries. One concern was that the Yampa River Basin analysis of agricultural demand was not based on high-altitude crop coefficients, thus understating the demand for water in the Yampa River Basin.

SWSI also noted that up to an additional 39,000 acres of agricultural lands could be developed in the basins but did not investigate the location or impact of additional agricultural demand in these basins. The Colorado River Water Conservation District Small Reservoir Study (CRWCD 2000) identified sites for additional water supply storage in the Yampa Basin. That study highlighted the need to look at integrating irrigation practices with storage to better meet water demands.

The objectives of the current study are to:

1. Refine and update previous estimates of current agricultural water demands, supplies, and shortages for the Yampa/White/Green River Basin through use of the State of Colorado's Decision Support System (DSS) models and data
2. Identify and evaluate shortages for the future agricultural demands
3. Assess the impacts of climate change on agricultural water availability
4. Assess the impacts of energy sector water supply development on agricultural water availability in the White River Basin
5. Assess water supply development alternatives to satisfy shortages identified in (1), (2), and (3) above
6. Assess the effects on return flows of various irrigation practices or changes in those practices
7. Investigate creative solutions that benefit multiple interests (e.g., agriculture, energy, recreation, environment, etc.)

This technical memorandum addresses the first of those objectives and is the first in a series of technical memoranda that will address each of the objectives. Figure 1-1 shows a map of the study area.

2.0 Agricultural Subcommittee Input

Several of the tasks in this study required input and feedback from the agricultural subcommittee of the Yampa/White/Green Basin (BRT subcommittee). BRT subcommittee members include Dan Birch, Darryl Steele, Dan Smith, Doug Monger, Geoff Blakeslee, Mary Brown, T. Wright Dickenson, Tom Gray, Dan Craig and Jeff Comstock. To date, CDM has met with the BRT subcommittee on multiple occasions to listen to concerns and discuss the approach to addressing these concerns associated with this task. Items related to current agricultural shortages (Task 1) are presented in this technical memorandum.

One of the objectives of Task 1 is to examine the year 2000 irrigated acreage and compare with 2005 aerial photographs for discrepancies. However, through the course of the meetings, all members were satisfied that the 2000 irrigated acreage is an accurate representation of field conditions. The irrigated acreage coverage was developed with the aid of local water commissioners who provided local ground verification of the irrigated areas and is not widely disputed. However, in a meeting with CWCB staff in May 2009, CWCB staff indicated that recent investigations had shown the 1993 irrigated acreage database to be of better quality than the year 2000 irrigated acreage database and recommend the use of the 1993 data for this study. Therefore, the 1993 irrigated acreage dataset was used for all analyses for this project and assumed to represent current irrigated acreage.

The major concerns related to Task 1 expressed by the BRT subcommittee are related to the use of high-altitude crop coefficients, the application and availability of late season water, and the treatment of aggregated ditches in the model. In particular, the subcommittee expressed concern that shortages at smaller ditches diverting from smaller tributary streams with lack of physical supply were not identified in the CDSS model. The BRT subcommittee identified 13 focus ditches throughout the basin that will be tracked in each of the tasks in this study (Table 1-1, Figure 1-1) to better understand d model results by comparing with ditch operations where the BRT subcommittee has working knowledge of the operations.

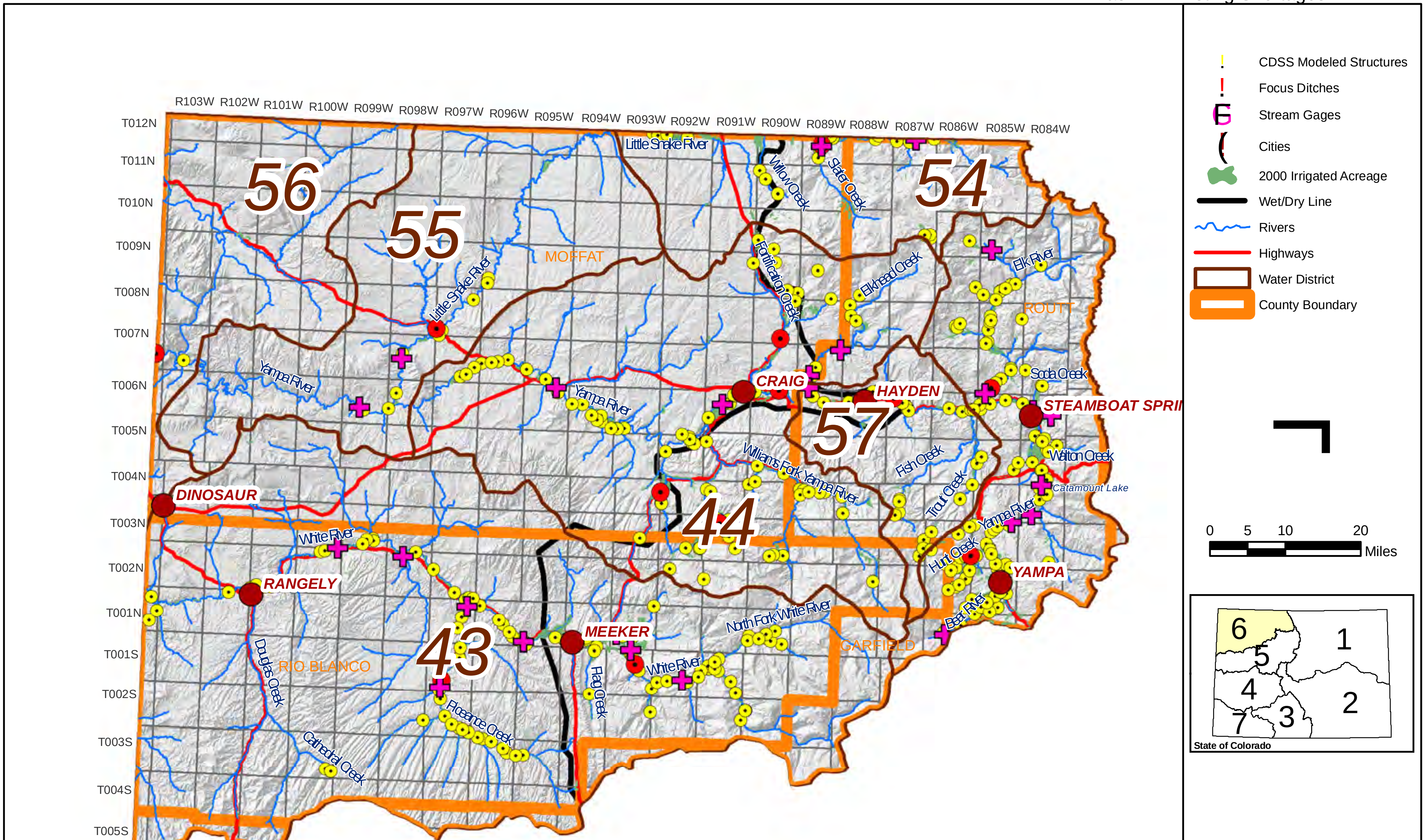


Figure 1-1 - Map of the Study Area

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Table 1-1 Focus Ditches Identified by Agricultural Subcommittee

WD	ID	Name	Water Source
43 – White River	430694	HIGHLAND DITCH[1]	WHITE RIVER
43- White River	430948	SQUARE S CONS D SYS	PICEANCE CK
44 – Lower Yampa	440511	WISCONSIN DITCH	FORTIFICATION CK
44 – Lower Yampa	440589	DEEP CUT IRR D	YAMPA RIVER
44 – Lower Yampa	440651	HIGHLAND DITCH	MORAPOS CK
44 – Lower Yampa	440706	MILK CK DITCH	MILK CK
54 – Slater/Timberlake	540549	MORGAN SLATER DITCH	SLATER CK
55 – Little Snake	550506	MAJORS PUMP NO 2	LITTLE SNAKE RIVER
56 – Green River	56_ADY027	GREEN AGGREGATE	GREEN RIVER
57 – Middle Yampa	570611	WALKER IRRIG DITCH	YAMPA RIVER
58 – Upper Yampa	580783	MORIN DITCH	ELK RIVER
58 – Upper Yampa	580798	NICKELL DITCH	BEAR RIVER
58 – Upper Yampa	580801	NORTH HUNT CREEK DITCH	NORTH HUNT CK

[1] Also known as the White River Highland Ditch

3.0 Irrigation Water Demands

There are many demands for water in the basin, including municipal and industrial use, stock watering, reservoir storage, instream flow water rights, and irrigation use. Irrigation demands can be subdivided into two primary components: irrigation water requirement (IWR) and the headgate demand. The headgate demand is the total amount of water that must be diverted at the stream to deliver a sufficient amount of water to meet the consumptive use (CU) of the crops. The headgate diversion is diminished by conveyance losses (ditch losses) and on-field losses. System efficiency is defined as the consumptive use divided by the headgate diversion. Table 1-2 provides definitions of terms commonly used in this memo. The majority of the water that is not consumed returns to the river as surface and subsurface return flows, but some (~3 percent of return flow) is lost incidentally to non-beneficial consumption such as phreatophytes and evaporation.

Table 1-2—Glossary of terms used in this study

Term	Abbreviation	Definition
potential evapotranspiration	PET	maximum potential volume (or depth) of water that can be consumed by a crop under a full water supply
effective precipitation	P_{eff}	volume (or depth) of water available to meet PET from precipitation
irrigation water requirement	IWR	maximum potential volume (or depth) of irrigation water consumed by a crop under a full water supply (IWR = PET - P_{eff})
water supply limited consumption	WSL	volume (or depth) of water consumed by crops with a given water supply. Under a full irrigation supply, WSL = IWR. Under shortage conditions, WSL < IWR
consumptive use	CU	total volume (or depth) of water consumed by a crop. CU = P_{eff} + WSL. However, CU often refers to only WSL (i.e. the portion of irrigation water that is consumed)
consumptive shortage	N/A	Amount of unmet CU. Equal to IWR - WSL
structure	N/A	Any point of diversion from a stream. Includes ditches, tributary wells and reservoirs
aggregate structure	N/A	Several structures combined into to a single model location. Aggregates are further subdivided into structures that divert from a modeled stream (A-aggregates), and those that divert from a tributary stream that is not modeled (B-aggregates)

3.1 Irrigation in the Study Area

Irrigated acreage in the Yampa/White/Green Basin has varied over the past several decades, fluctuating between 60,000 and 90,000 acres in the Yampa Basin (BBC Reasearch & Consulting

1998) and approximately 26,000 irrigated acres in the White Basins. The primary crop grown in the study area is hay, which has a reputation as being high quality that commands a premium price (BBC Reasearch & Consulting 1998). In addition to hay, there is a significant amount of alfalfa grown, and several other crops make up a small percentage of the total irrigated acreage. According to the State of Colorado 1993 irrigated acreage datasets, there are a total of 119,607irrigated acres in the study area, of which 26,820 are in the White Basin, and 92,787 are in the Yampa and Green basins. Figure 1-2 shows the total irrigated acreage by crop type, and Figure 1-3 shows the irrigated acreage by water district. Irrigated acreage shown in the figures is based on the State of Colorado 1993 irrigated acreage coverage. The State of Colorado developed a year 2000 irrigated acreage coverage, but CWCB staff indicated that this coverage is not as reliable as the 1993 coverage and recommended using only the 1993 acreage (meeting with CWCB staff, May 2009). Average annual agricultural diversions in the study area from 1975 to 2004 are approximately 721,000 AFY, with approximately 284,000 AFY in the White Basin and 436,000 AFY in the Yampa Basin (CDSS 2008). For comparison purposes, Figure 1-4 shows the average annual surface water diversions and associated irrigated acreage and average diversion per irrigated acre in the major river basins in the State (CWCB 2004). Groundwater pumping is not included in the total diversions shown in Figure 1-4.

For this study, each structure in the CDSS StateMod model was identified as either diverting from a mainstem reach or a tributary. Mainstem reaches include the Yampa River, Bear River, Williams Fork River, and the White River (North and South forks). All other streams were considered tributaries. In addition, there are several smaller structures that were grouped together, called aggregates. The aggregates as defined in the CDSS models were refined as described in Section 3.4 and 4.4.

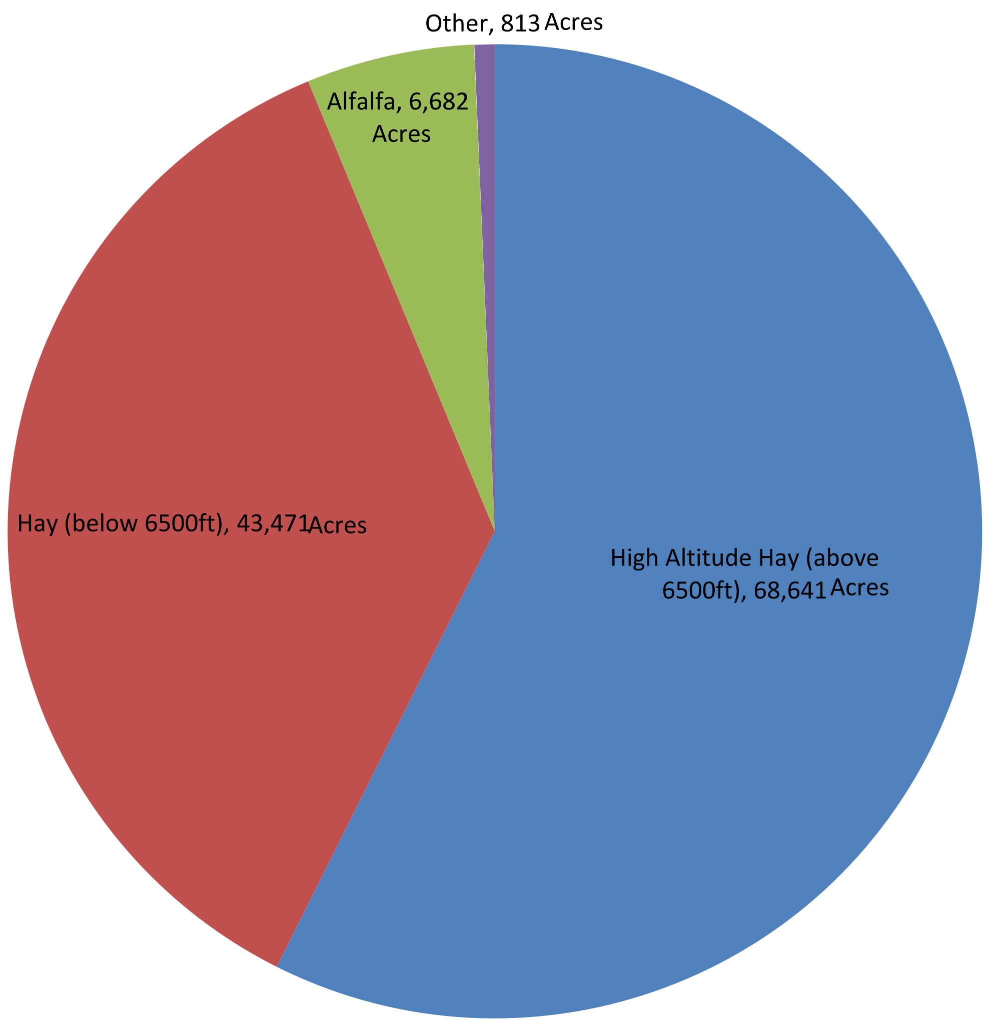
3.2 Consumptive Use Model Background

The State of Colorado has developed several DSS models for many of the major river basins in the state, including the White Basin and the Yampa and Green basins. The DSS consumptive use model is called StateCU. The StateCU documentation (CWCB, StateCU Documentation 2008) describes how crop potential evapotranspiration (ET) is developed:

> StateCU allows either the SCS TR-21 modified Blaney-Criddle or the original Blaney-Criddle procedure to estimate monthly evapotranspiration (ET). The empirical equation relates ET with mean air temperature and mean percentage daytime hours. The SCS TR-21 method was modified from the original Blaney-Criddle method to reasonably estimate short-period consumptive use. The modifications include the use of (1) climatic coefficients that are directly related to the mean air temperature for each of the consecutive short periods which constitutes the growing season and (2) coefficients which reflect the influence of the crop growth rates on consumptive use rates (SCS TR-21).

StateCU generates an estimate of irrigation water requirement (IWR) for the model area. IWR is defined as the portion of potential ET that would come from irrigation water under a full water supply (i.e. the portion of potential ET that is not satisfied by precipitation; Table 1-2). StateCU computes IWR based on temperature, precipitation, acreage, and crop type and optionally elevation. Agricultural demands were computed for the basin using StateCU during the SWSI effort using the latest StateCU model at the time, and

Figure 1-2 - 1993 Crop Distribution in the Study Area
119,607 Total Irrigated Acres



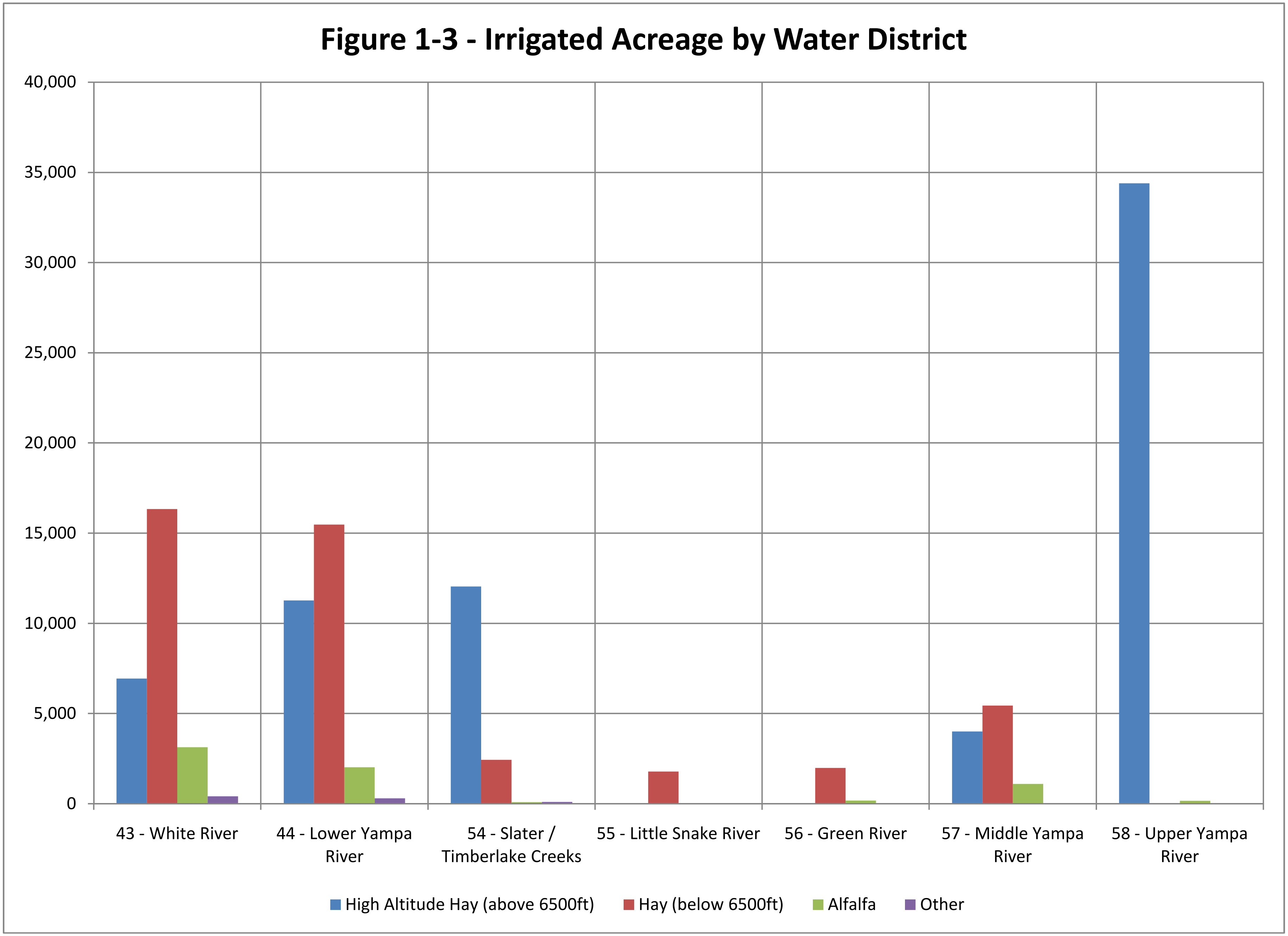


Figure 1-3 - Irrigated Acreage by Water District
40,000
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
43 - White River
44 - Lower Yampa River
54 - Slater / Timberlake Creeks
55 - Little Snake River
56 - Green River
57 - Middle Yampa River
58 - Upper Yampa River
High Altitude Hay (above 6500ft)
Hay (below 6500ft)
Alfalfa
Other

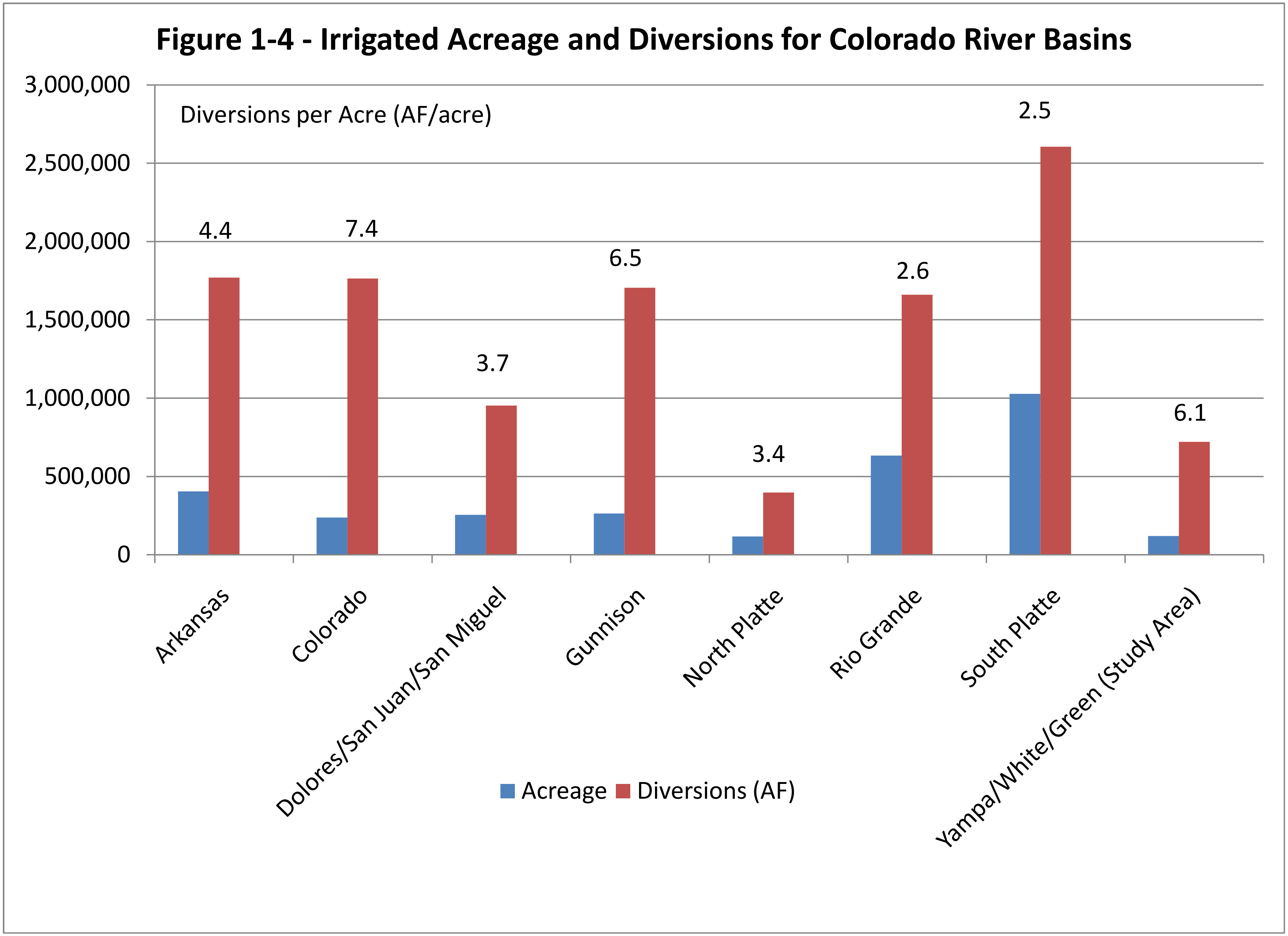


Figure 1-4 - Irrigated Acreage and Diversions for Colorado River Basins
3,000,000
2,500,000
2,000,000
1,500,000
1,000,000
500,000
0
Diversions per Acre (AF/acre)
4.4
7.4
3.7
6.5
3.4
2.6
2.5
6.1
Arkansas
Colorado
Dolores/San Juan/San Miguel
Gunnison
North Platte
Rio Grande
South Platte
Yampa/White/Green (Study Area)
Acreage
Diversions (AF)

again for the 2008 release of the CDSS Yampa and White models. For this study, StateCU was used to refined IWR for the basin using high-altitude crop coefficients for crops above 6,500 feet and a separate elevation adjustment for crops below 6,500 feet.

3.3 IWR with High-Altitude Crop Coefficients and Altitude Adjustment

Model runs of StateCU used in SWSI did not use high-altitude crop coefficients in the Yampa/White/Green Basin. The 2008 release of the Yampa/White/Green Basin StateCU models were refined to incorporate high-altitude crop coefficients for hay and grass pasture at an elevation of 6,500 ft or higher.

Crop coefficients available from the SCS TR21 publication were developed to represent general conditions around the Western United States and may not represent local conditions—particularly hay and grasses at high elevations. Locally calibrated Blaney-Criddle coefficients were developed for the upper South Platte Basin for mountain meadow grass pasture by Denver Water in 1990 (CWCB, SPDSS Task 59.1 2008). These coefficients were reviewed by a panel of experts and were selected for mountain grass pastures in the South Platte Basin. (CWCB, Technical Peer Review Meeting 2008). These same coefficients were applied to the Yampa/White/Green Basin for structures above 6,500 feet.

Lysimeter data are available for the Yampa Basin through a program managed by the Division 6 Division of Water Resources staff, and high-altitude crop coefficients have been calculated using this data. However, data from the Division 6 lysimeters were not considered an accurate measure of potential ET. The lysimeters were filled manually rather than automatically and are often surrounded by large non-irrigated pasture. The conclusion is that these lysimeters likely record actual ET rather than maximum potential ET (CWCB, SPDSS Task 59.1 2008) and therefore were not selected for development of crop coefficients.

An additional and separate elevation adjustment for crop coefficients can be implemented to adjust the Blaney-Criddle SCS TR21 coefficients to maintain consistency with common practice at the State Engineer's Office and the Colorado River Water Availability Study (CRWAS; CWCB in progress). This adjustment is not applied to the crops utilizing the high-altitude coefficients described above. Crops using the SCS TR21 coefficients can be adjusted for elevation in StateCU as reported in the documentation (StateCU Documentation 2008). The StateCU documentation explains that the elevation adjustment of 10% upward for each 1,000 meters increase in elevation above sea level for TR21 crops is handled internally by StateCU and is incorporated into the calculation of IWR:

> The adjustment corrects for lower mean temperatures that occur at higher elevations at a given level of solar radiation (i.e. mean temperatures do not reflect rops' reactions to warm daytime temperatures and cool nights). The adjustment is applied to the potential consumptive use estimate and can be applied to any crop type.

In other words, mean daily temperatures are generally lower in high elevation areas than at lower elevations because of cooler nights, even if the daily high temperature is the same as in a lower elevation area. The adjustment in coefficients accounts for cooler nights and warm daytime temperatures at higher elevations not accounted for in the empirical Blaney-Criddle method.

Note that the elevation adjustment of an increase of 10 percent per 1,000m is not applied to the high-altitude coefficients above 6,500 ft because those coefficients are set to the locally calibrated values as described above.

CWCB staff has indicated that StateCU model runs used for the Colorado River Water Availability Study (CWCB, in progress) have been refined from the 2008 model release to include the second elevation adjustment (meeting with CWCB, May 2009). For the purposes of this study, use of the second elevation adjustment is appropriate and was implemented to calculate the updated IWR. Figure 1-5 shows IWR as calculated in SWSI, in the CDSS 2008 model and in the model used for this study including the 10 percent per 1,000m of elevation coefficient adjustment below 6,500 feet in elevation and high altitude coefficients above 6,500 feet in elevation.

The inclusion of high-altitude crop coefficients and secondary adjustment for elevation have significant effects on IWR. Table 1-3 shows the IWR by basin and water district reported in SWSI, the 2008 CDSS release, and the amount calculated in this study. Inclusion of the high-altitude coefficients increased basin-wide IWR by 54 percent over the amount reported in SWSI. The addition of the secondary elevation adjustment increases IWR to 65 percent above the amount reported in SWSI. The IWR presented in Table 1-3 is presented on a unit basis in Figure 1-5. In Figure 1-5, the impact of the elevation adjustments is evident. The difference between the SWSI model version and the CDSS 2008 version is due to the use of the locally calibrated high-altitude crop coefficients for hay above 6,500 ft. This is evidenced by large increases in IWR in the higher basins where much of the irrigated hay is above 6,500 ft (e.g. Upper Yampa) and relatively little change in the lower basins where much of the irrigated hay is below 6,500 ft (e.g. Little Snake). The difference between the CDSS 2008 version of the Yampa model and the version used in this Study is due to the 10 percent increase in coefficients for every 1,000m in elevation (except to hay above 6,500 which was adjusted with calibrated high-altitude coefficients as mentioned above). This adjustment is evident in the lower basins where the high-altitude coefficients for hay above 6,500 ft were not applied (e.g. Little Snake and Green).

Table 1-3—Average Annual IWR in Different Model Versions (AF)

Basin / *Stream*	SWSI	CDSS 2008	This Study
White	32,634	39,465	45,740
Green	2,878	2,759	3,516
Yampa *(Sub-basins in italics below)*	104,248	170,207	179,762
Study Area	**139,760**	**212,431**	**229,018**
Lower Yampa	*37,924*	*49,828*	*55,003*
Slater / Timberlake	*19,673*	*32,160*	*33,401*
Little Snake	*2,529*	*2,407*	*2,869*
Middle Yampa	*10,136*	*14,449*	*16,556*
Upper Yampa	*33,986*	*71,364*	*71,933*

3.4 Aggregate Ditches

The Yampa/White/Green Basin models have several aggregate structures that are groups of ditches combined into a single modeling node. IWR was calculated for these ditches based on the

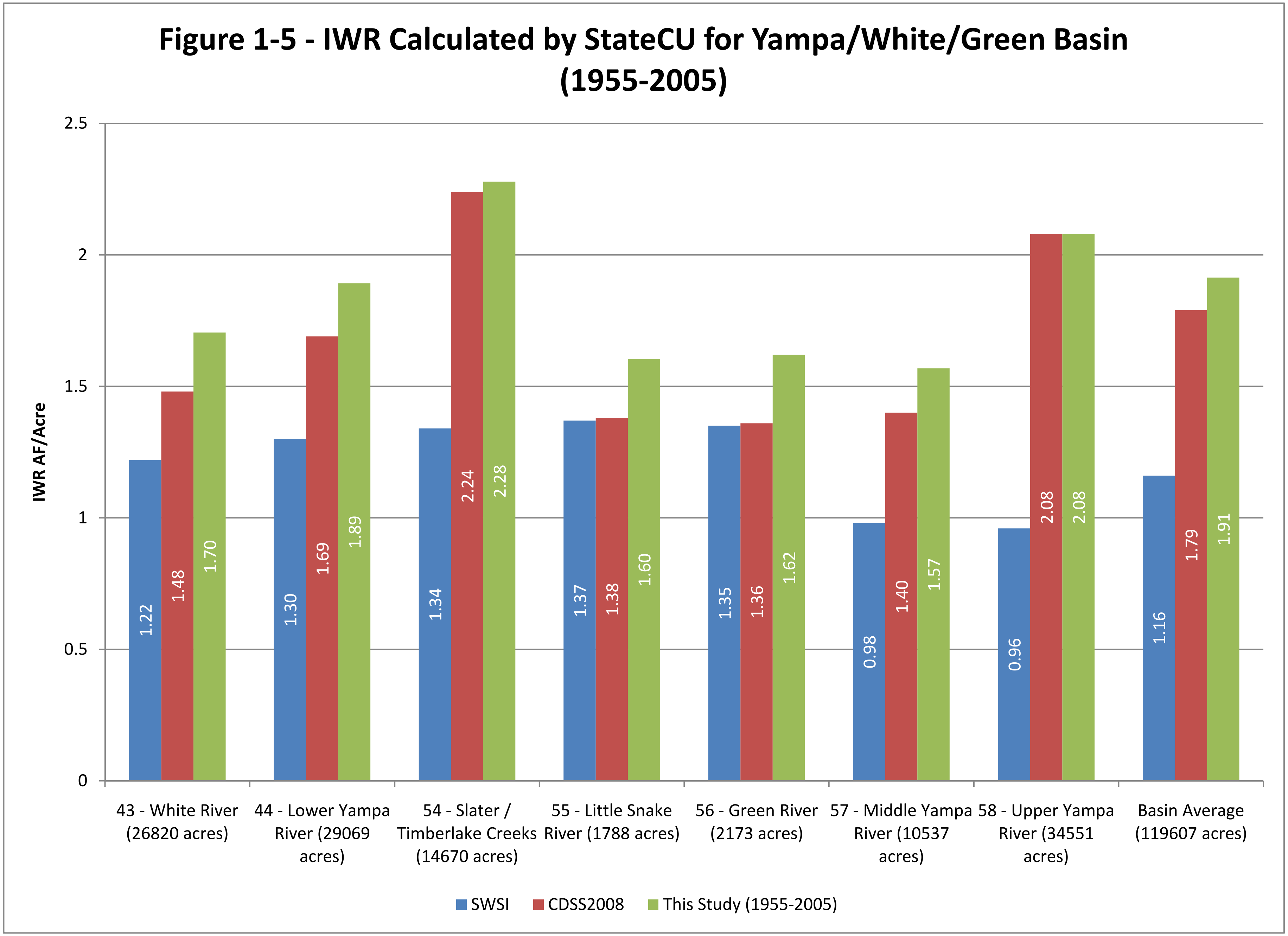


Figure 1-5 - IWR Calculated by StateCU for Yampa/White/Green Basin (1955-2005)
IWR AF/Acre
2.5
2
1.5
1
0.5
0
1.22
1.48
1.70
1.30
1.69
1.89
1.34
2.24
2.28
1.37
1.38
1.60
1.35
1.36
1.62
0.98
1.40
1.57
0.96
2.08
2.08
1.16
1.79
1.91
43 - White River (26820 acres)
44 - Lower Yampa River (29069 acres)
54 - Slater / Timberlake Creeks (14670 acres)
55 - Little Snake River (1788 acres)
56 - Green River (2173 acres)
57 - Middle Yampa River (10537 acres)
58 - Upper Yampa River (34551 acres)
Basin Average (119607 acres)
SWSI
CDSS2008
This Study (1955-2005)

combined acreage and crop type of all ditches in the aggregation. This method is reasonable for calculating IWR. Members of the BRT subcommittee expressed concern that aggregate ditches were not treated properly in the CDSS models. Refinement of water availability and shortage computation at aggregate structures is discussed in more detail in section 4.4 to address those concerns.

The Yampa water allocation model (StateMod) documentation (CWCB, Yampa and White River Basin Water Resources Planning Model User's Manuals 2004 & 2008) describes the process of aggregating irrigation ditches:

> The use associated with irrigation diversions having total absolute rights less than 5.0 cfs were included in the model at "aggregated nodes." These nodes represent the combined historical diversions, demand, and water rights of many small structures within a prescribed sub-basin. The aggregation boundaries were based generally on tributary boundaries, or if on the mainstem, gage location, critical administrative reaches, and instream flow reaches. To the extent possible, aggregations were devised so that they represented no more than 1500 irrigated acres. In the Yampa River model within Colorado, 27 aggregated nodes were identified, representing nearly 25,000 acres of irrigated crops *[See Table 1-4 for actual modeled acreage]*. Generally, these nodes were placed in the model at the most downstream position within the aggregated area.
>
> Aggregated irrigation nodes were attributed all the water rights associated with their constituent structures. Their historical diversions were developed by summing the historical diversions of the individual structures, and their irrigation water requirement is based on the total acreage associated with the aggregation.

A similar approach was used in the White Basin, though a threshold of 4.8 cfs was used.

One of the objectives of this study is to refine the demand, supply and shortage computations at the aggregates. The list of individual structures that comprise the aggregates was analyzed to determine the number and acreage of structures that divert from streams that are modeled in the water allocation model (StateMod) and which divert from unmodeled streams. Unmodeled streams are generally small ungaged tributaries to the larger streams that are modeled in the water allocation model. The water rights tabulation in the State's database (HydroBase) was used to determine the source of water for each structure in each aggregate and was compared to the point of diversion for its associated aggregate node in the water allocation model. Structures whose HydroBase water source matched the modeled point of diversion were categorized as A-aggregates. Structures whose HydroBase water source did not match the modeled point of diversion were categorized as B-aggregates. Table 1-4 presents the number of structures, acreage and IWR for explicitly modeled structures, A-aggregate structures, and B-Aggregate structures. Summing the acreage of the A- and B-aggregates results in the same values used for the aggregates in the 2008 CDSS model release. The acreage of B-aggregates accounts for nearly 75 percent of the acreage in the aggregate nodes. Water District 44 (Lower Yampa River) has the largest acreage in aggregate nodes with 9,960 acres, of which 7,067 acres are included under the B-aggregate nodes. Refinements to the simulation of the supply and shortages at the A- and B-aggregate nodes are discussed in sections 4.4 and 5 of this technical memorandum

Table 1-4 – Acreage and IWR by Location and Structure Type

Water District and Structure Type	Number of Structures	Acreage	Acreage as a Percent of the Study Area Acreage	IWR (Average Annual, AF)	IWR as a Percent of the Study Area IWR
43 - White	370	26,820	22%	45,740	20%
Explicit	103	19,957	17%	32,721	14%
A-Aggregates	84	2,116	2%	3,680	2%
B-Aggregates	183	4,746	4%	9,339	4%
44 - Lower Yampa	310	29,069	24%	55,003	24%
Explicit	80	19,108	16%	34,704	15%
A-Aggregates	71	2,893	2%	5,744	3%
B-Aggregates	159	7,067	6%	14,556	6%
54 - Slater/Timberlake	107	14,670	12%	33,401	15%
Explicit	17	5,886	5%	12,238	5%
A-Aggregates	30	3,260	3%	7,846	3%
B-Aggregates	60	5,524	5%	13,317	6%
55 - Little Snake	19	1,788	1%	2,869	1%
Explicit	7	1,128	1%	1,808	1%
A-Aggregates	10	600	1%	965	0%
B-Aggregates	2	60	0%	97	0%
56 - Green	40	2,173	2%	3,516	2%
Explicit	0	0	0%	0	0%
A-Aggregates	1	157	0%	252	0%
B-Aggregates	39	2,016	2%	3,263	1%
57 - Middle Yampa	94	10,537	9%	16,556	7%
Explicit	23	8,214	7%	12,126	5%
A-Aggregates	25	1,033	1%	1,979	1%
B-Aggregates	46	1,290	1%	2,451	1%
58 - Upper Yampa	339	34,551	29%	71,933	31%
Explicit	96	24,903	21%	51,817	23%
A-Aggregates	29	1,307	1%	2,724	1%
B-Aggregates	214	8,340	7%	17,393	8%
Total Study Area	1279	119,607	100%	229,018	100%
Explicit	326	79,197	66%	145,414	63%
A-Aggregates	250	11,367	10%	23,189	10%
B-Aggregates	703	29,043	24%	60,415	26%

3.5 Late Season Application of Water

Members of the BRT subcommittee stated that there is a need for the application of late season water—generally in late September and October. In many locations in the basin, this does not appear as a crop consumptive demand because IWR is low that time of year. BRT subcommittee members indicated that irrigating a field in the late season will help the field over-winter. CDM interviewed several experts and professionals regarding the issue of late-season irrigation (Dan Smith, Colorado State University agronomy professor; C. J. Mucklow, Routt County Extension Agent; Kathy Boyer, Water Commissioner; Ray Bennett, DWR). The purpose of the interviews was to determine if there is a beneficial use to applying late-season water, even if there is no potential crop IWR to meet, and how this use could be quantified. The consensus was that late-season water applied to fields helps the fields survive the winter, reduces trampling damage from livestock that graze the fields during the winter, and moistens the soil for the following spring. They cited a noticeable difference between a field that had received late-season water, and one that did not. Late-season application of water is a recognized irrigation practice in the basin.

Often, irrigated crops will utilize all moisture remaining in the soil at the end of the growing season (especially if little or no irrigation water is applied), leaving the soil dry entering the winter. Application of late-season water can replenish the soil moisture reservoir and provide the multiple benefits described above. Through discussions with the BRT subcommittee, it was determined that winter precipitation is sufficient to meet this demand in the eastern part of the basin, but soil moisture is not replenished in the western portion of the basin (or is quickly evaporated out of the top several inches of soil by sun and wind). BRT subcommittee members stated that the presence of scrub-oak was a good dividing line between the wetter and drier portions of the basin. Figure 1-1 shows the wet/dry delineation line. Precipitation gages in the east and west portions of the basin were examined to evaluate the reasonableness of this division.

A late-season soil moisture demand was calculated for all structures in the dry portion of the basin by determining the available storage capacity in the soil zone in October. Average available capacity is 6,638 AF. This demand is approximately 9 percent of IWR for the structures in the drier western portion of the study area. The storage capacity is based on an average root zone depth of three feet (as defined in the CDSS model) and the available water content fraction (as estimated from soil types in the CDSS model). This demand was compared to the water allocation model (StateMod) output of available water at each stream in September and October and is discussed in further detail in section 5.

4.0 Water Allocation Modeling Approach

4.1 Water Allocation Model Background

StateMod is the State of Colorado's water allocation model. StateMod has been developed for the Yampa/Green river basins and the White Basin with the latest model update released in late 2008. The purpose of a water allocation model is to allow a user to simulate existing and/or proposed conditions in the basin using historical hydrology. The first step is to estimate the amount of flow, called baseflows, that would be available to the system in the absence of basin operations (e.g. without diversions, storage, imports). Once baseflows are computed, the model goes through a calibration process where simulated streamflows, diversions and reservoir operations are compared to observed data. Once calibrated, a baseline model is developed that simulates current operations using the observed hydrology (e.g. current levels of irrigated acreage and crop patterns, current reservoir size and operations, current municipal and industrial demand, historical hydrology). This allows the user to analyze system response under variable and reasonable hydrologic conditions (e.g. what would happen to the reservoir levels in a new reservoir if we had another drought like in the 1950's?). The baseline model is a point of comparison for other proposed scenarios.

Baseflows are the primary water inflows to the water allocation model. In the absence of all basin operations, baseflow is often referred to as naturalized or virgin flow, since this is the amount of flow that would be expected in the stream absent any use or alteration by man. Baseflows are calculated at multiple locations by StateMod using historical gaged data, diversions, change in storage, return flows, evaporation, imports, exports, and physical characteristics of ungaged basins such as precipitation, area, and elevation.

Changes to IWR of the historical model will result in changes to return flows and therefore require recalculation of baseflows. Generally, an increase in IWR (as was seen in Section 3) will result in higher baseflows. Baseflows were regenerated using the updated IWR values computed using the high-altitude adjustments described in section 3.3. While checking the new baseflows, it became apparent that an older version of the processing tool StateDMI that was used for the 2008 model release incorrectly accounted for diversions at aggregate nodes that resulted in an approximately 50,000 AFY reduction in baseflows. CDM presented the error to the State who acknowledged this problem and provided a more recent version of the StateDMI tool (version 3.0.8). The more recent version was used to regenerate baseflows for all other model runs in this study. CDM recommends that all future refinements of the model use the latest version of StateDMI but should verify backward compatibility for other model files generated with the newer version..

4.2 Model Calibration

Since baseflows were regenerated due to the refinement of IWR, the model calibration was reviewed to ensure the model was able to simulate historical conditions. Simulated flows and diversions were compared against observed flows and diversion and the CDSS 2008 model calibration results using the new baseflows. The simulation using the revised baseflows resulted in a favorable calibration. The differences between observed and simulated streamflow and diversions were comparable to those obtained in the 2008 CDSS calibration. Based on these comparisons, it was determined that the new baseflows were suitable for the baseline scenario and future conditions scenario simulations.

4.3 Baseline Scenario

The baseline model represents current basin conditions and operations, including all reservoirs, water rights, imports, diversions, and return flow patterns while using the historical hydrology and climate. The baseline model is the point of comparison for all proposed scenarios (e.g. supply projects, climate change, energy development etc…) and will be used to quantify the benefits and impacts of the proposed scenarios relative to current conditions.

The baseline scenario uses the IWR from StateCU model output for agricultural demands, and computes a demand at the headgate that accounts for conveyance and on-field losses. Headgate demands are estimated by computing an average monthly structure efficiency based on historical use (efficiency is equal to historical IWR divided by historical diversion), and then dividing the calculated IWR by the efficiency. This headgate demand is referred to in the CDSS Documentation as the 'Calculated Demand'. For example, if IWR for a certain month is 100 AF, and the historical monthly average efficiency is computed at 40%, the headgate demand is set to 250 AF (100AF / 40%).

Using the historical average monthly efficiency can provide useful information about the operating practices of a particular structure, but can also lead to unrealistic estimates of headgate demand if historical irrigated acreage or diversion records are not complete or are inaccurate. In the study area, irrigated acreage at each structure is generally not known with certainty except for 1993, when aerial photography was used to quantify acreage. Irrigated acreage has varied from 60,000 to 90,000 acres in the Yampa basin over the past several decades (see Section 3.1). Diversion records are not always complete and were filled using an automated process that estimates diversions based on recorded diversions during other hydrologically similar years.

To reduce the potential impact of uncertainty related to historical irrigated acreage and diversions, the historical monthly average efficiency was limited to a reasonable minimum of 30 percent and maximum of 50 percent (acreage using sprinklers used a maximum efficiency of 80 percent). The bounded efficiencies were used to generate the headgate demands. During simulation, these bounds on efficiency also apply. The 30 percent floor and 50 percent ceiling on efficiency are reasonable values for flood irrigation in the rugged and mountainous environment of the study area. Experts Hal Simpson (retired State Engineer) and Ross Bethel (water resources consultant and part of original development team of the CDSS models) were contracted by CDM for this study and agreed with these bounds on efficiency in this basin for the purpose of estimating consumptive use shortages. In addition, experts performing the CRWAS have also adopted to the 30 percent and 50 percent efficiency bounds for that study. Bounding the efficiencies in this manner may not exactly capture historical operations, but provides a consistent manner to identify and quantify agricultural shortages based on the best available irrigated acreage information.

4.4 Aggregate Structures

Aggregate structures are model nodes that represent multiple smaller structures that divert from streams that are modeled in StateMod, and smaller tributary streams that are not modeled (see section 3.4 and Table 1-4). In StateMod, aggregate nodes are generally placed at the most downstream location of any structure in the aggregate. IWR is computed based on the total acreage and, using the bounded efficiency as described in section 4.3, provides a reasonable estimate of headgate demands for the aggregate structures. However, as is shown in Table 1-4, there is a large portion of the acreage included in aggregate nodes in the study area that does not divert from the stream where the model node is located. The CDSS models were developed for basin-wide planning purposes which by definition makes some simplifying assumptions for smaller structures and small tributaries. For the purposes of this study, additional refinement was desired to better characterize the location and amounts of shortages particularly at the aggregate nodes under current basin operations. Feedback from subcommittee members suggested that many of these unmodeled tributaries simply do not have physical water available in the later part of the growing season and the streamflows at the larger tributaries can be very different than the smaller unmodeled tributary streams.

For this study, the individual structures that comprise the aggregates in the CDSS models were categorized as structures that divert from the modeled stream (A-aggregates), or structures that divert from an unmodeled tributary (B-aggregates) based on the water source listed in water rights tabulation of the State's database (HydroBase). Each of the A-aggregates and B-aggregates included associated acreage and water rights of its constituent structures in a similar manner as described in the CDSS aggregate node documentation. Since gage data is generally not available for the unmodeled streams (B-aggregates), historical diversions were assumed provide a reasonable estimate of physically available flow. Therefore, headgate demands at the B-aggregates were replaced with the historical diversions associated with those structures. This configuration of aggregate ditches allows structures that divert from the modeled stream (A-aggregates) to continue to simulate demands, diversions and returns in the same manner as an explicitly modeled structure. The configuration limits the structures that cannot divert from a modeled stream (B-aggregates) to a reasonable estimate of physically available flow (i.e. historical diversions). Return flows from B-aggregate structures are routed to the A-aggregate structures since physically, the B-aggregates divert from streams that are tributary to the modeled stream from which the A-aggregates divert and their return flows would eventually reach the modeled stream.

5.0 Shortages

Agricultural water shortages occur when consumptive use demand for water exceeds the supply available to the crops after conveyance and on-field losses. For the purposes of this study, shortages are defined as a consumptive use shortage (CU shortage). Any project or basin operation designed to fulfill the CU shortage must deliver a sufficient amount of water to the point of diversion such that the CU shortage can be met after conveyance and on-field losses.

As discussed in section 4.4, the CDSS aggregate nodes have been split into structures on modeled streams (A-aggregates) and structures not on modeled streams (B-aggregates). Water availability and resulting shortages for the A-aggregates are simulated in the same manner as any other explicitly modeled structure. For the B-aggregates consumptive use shortages will occur any time the historical diversion would not satisfy the IWR.

Table 1-5 presents a detailed breakdown the average annual CU shortage from the refined baseline scenario by water district, stream and structure type (explicitly modeled structures, A-aggregates and B-aggregates). The information is presented as a volumetric shortage, as a percentage of IWR, and as a percentage of the total study area CU shortage, and additionally tabulates the acreage that is critically short. Critically short acreage is defined as structures that are at least 20 percent short in at least 4 of 10 years. The comprehensive nature of the information presented in Table 1-5 serves as a primary data source for shortages in the baseline scenario and serves as a reference for comparisons and analyses for the remainder of the study. Figure 1-6 shows the CU shortage by water district and groups by structures that divert from mainstem reaches (denoted by an asterisk in Table 1-5) or tributaries.

Table 1-5 and Figure 1-6 show that CU shortages are more prevalent and severe for structures on the tributaries than structures on the mainstem. Shortages on tributaries account for 93 percent of the CU shortage, but only 60 percent of the irrigated acreage. Conversely, structures on the mainstem account for 7 percent of the CU shortage on 40 percent of the acres. Critically short acreage is also unevenly distributed between tributary and mainstem structures, with 89 percent of the critically short acreage are on tributary structures. Figure 1-7 shows the amount of critically short acreage on tributaries compared to mainstem reaches. By definition, B-aggregates are structures on tributaries and the ‘Tributary’ and ‘B-aggregate’ bars in Figures 1-6 and 1-7 could be summed to determine the total CU shortage and critically short acreage on the tributaries. However, since the B-aggregates rely on historical diversions as a surrogate for water supply, there is more uncertainty associated with shortages at those structures. Table 1-6 summarizes the results with and without the B-aggregates for the study area for comparison, and shows that the tributary structures represent a large portion of CU shortage and critically short acreage even with the B-aggregates removed. On an average basis, CU shortage is 0.04 AF per acre on mainstem structure, 0.22 AF per acre on tributary structures (excluding B-aggregates), and 0.48 AF per acre on B-aggregate structures.

Table 1-5 - Consumptive Use Shortage and Critically Short Acreage by Location and Structure Type

Location by Water District, Stream and Structure Type	Irrigated Acreage	Average Annual IWR (AF)	Average Annual CU Shortage (AF)	CU Shortage as Percent of IWR	Percentage of Study Area CU Shortage	Critically Short Acreage	Percentage of Study Area Critical Acreage
43 - White River	**26,820**	**45,740**	**1,128**	**2.5%**	**4.4%**	**723**	**2.8%**
Explicit Structures	19,957	32,721	594	1.8%	2.3%	391	1.5%
A-aggregates	2,116	3,680	108	2.9%	0.4%	164	0.6%
B-aggregates	4,746	9,339	426	4.6%	1.7%	168	0.6%
Big Beaver Creek	66	148	10	6.4%	0.0%	0	0.0%
Explicit Structures	66	148	10	6.4%	0.0%	0	0.0%
A-aggregates	0	0	0	n/a	0.0%	0	0.0%
B-aggregates	0	0	0	n/a	0.0%	0	0.0%
Black Sulphur Creek	97	142	3	1.8%	0.0%	0	0.0%
Explicit Structures	97	142	3	1.8%	0.0%	0	0.0%
A-aggregates	0	0	0	n/a	0.0%	0	0.0%
B-aggregates	0	0	0	n/a	0.0%	0	0.0%
Coal Creek	768	1,707	0	0.0%	0.0%	0	0.0%
Explicit Structures	768	1,707	0	0.0%	0.0%	0	0.0%
A-aggregates	0	0	0	n/a	0.0%	0	0.0%
B-aggregates	0	0	0	n/a	0.0%	0	0.0%
Elk Creek	154	345	33	9.7%	0.1%	0	0.0%
Explicit Structures	154	345	33	9.7%	0.1%	0	0.0%
A-aggregates	0	0	0	n/a	0.0%	0	0.0%
B-aggregates	0	0	0	n/a	0.0%	0	0.0%
Evacuation	250	561	36	6.4%	0.1%	0	0.0%
Explicit Structures	0	0	0	n/a	0.0%	0	0.0%
A-aggregates	106	239	0	0.0%	0.0%	0	0.0%
B-aggregates	144	322	36	11.2%	0.1%	0	0.0%
Fawn Creek	67	150	0	0.0%	0.0%	0	0.0%
Explicit Structures	67	150	0	0.0%	0.0%	0	0.0%
A-aggregates	0	0	0	n/a	0.0%	0	0.0%
B-aggregates	0	0	0	n/a	0.0%	0	0.0%
Flag Creek	297	482	2	0.4%	0.0%	0	0.0%
Explicit Structures	297	482	2	0.4%	0.0%	0	0.0%
A-aggregates	0	0	0	n/a	0.0%	0	0.0%
B-aggregates	0	0	0	n/a	0.0%	0	0.0%
Hill Creek/Hill Creek Tributary	130	291	6	2.2%	0.0%	0	0.0%
Explicit Structures	130	291	6	2.2%	0.0%	0	0.0%
A-aggregates	0	0	0	n/a	0.0%	0	0.0%
B-aggregates	0	0	0	n/a	0.0%	0	0.0%
Lake Creek/Douglas Creek	12	35	9	26.4%	0.0%	12	0.0%
Explicit Structures	12	35	9	26.4%	0.0%	12	0.0%
A-aggregates	0	0	0	n/a	0.0%	0	0.0%
B-aggregates	0	0	0	n/a	0.0%	0	0.0%
Marvine Creek	130	264	0	0.0%	0.0%	0	0.0%
Explicit Structures	130	264	0	0.0%	0.0%	0	0.0%
A-aggregates	0	0	0	n/a	0.0%	0	0.0%
B-aggregates	0	0	0	n/a	0.0%	0	0.0%
Miller Creek	125	244	15	6.0%	0.1%	0	0.0%
Explicit Structures	125	244	15	6.0%	0.1%	0	0.0%
A-aggregates	0	0	0	n/a	0.0%	0	0.0%
B-aggregates	0	0	0	n/a	0.0%	0	0.0%
Moose Creek/Cave Creek	301	490	18	3.8%	0.1%	0	0.0%
Explicit Structures	301	490	18	3.8%	0.1%	0	0.0%
A-aggregates	0	0	0	n/a	0.0%	0	0.0%
B-aggregates	0	0	0	n/a	0.0%	0	0.0%
North Fork White River	594	1,328	4	0.3%	0.0%	0	0.0%
* Explicit Structures	206	464	4	0.8%	0.0%	0	0.0%
* A-aggregates	69	155	0	0.0%	0.0%	0	0.0%
B-aggregates	319	709	0	0.0%	0.0%	0	0.0%
Piceance Creek	4,230	7,722	806	10.4%	3.2%	653	2.5%
Explicit Structures	2,437	3,987	451	11.3%	1.8%	321	1.2%
A-aggregates	352	710	108	15.2%	0.4%	164	0.6%
B-aggregates	1,441	3,025	247	8.2%	1.0%	168	0.6%
Soldier Creek/East Douglas/Douglas Creek	57	161	43	27.0%	0.2%	57	0.2%
Explicit Structures	57	161	43	27.0%	0.2%	57	0.2%
A-aggregates	0	0	0	n/a	0.0%	0	0.0%
B-aggregates	0	0	0	n/a	0.0%	0	0.0%
South Fork White River	952	2,137	17	0.8%	0.1%	0	0.0%
* Explicit Structures	684	1,537	0	0.0%	0.0%	0	0.0%
* A-aggregates	66	148	0	0.0%	0.0%	0	0.0%
B-aggregates	201	452	17	3.7%	0.1%	0	0.0%
Ute Creek	61	138	0	0.0%	0.0%	0	0.0%
Explicit Structures	61	138	0	0.0%	0.0%	0	0.0%
A-aggregates	0	0	0	n/a	0.0%	0	0.0%
B-aggregates	0	0	0	n/a	0.0%	0	0.0%
White River	18,528	29,394	126	0.4%	0.5%	0	0.0%
* Explicit Structures	14,363	22,136	0	0.0%	0.0%	0	0.0%
* A-aggregates	1,523	2,427	0	0.0%	0.0%	0	0.0%
B-aggregates	2,642	4,830	126	2.6%	0.5%	0	0.0%

Notes:
Asterisk denotes mainstem reach
A-aggregates include structures that divert from a modeled stream
B-aggregates include structures that divert from an unmodeled tributary
Critically short acreage is at least 20% short in 4 of 10 years

Table 1-5 - Consumptive Use Shortage and Critically Short Acreage by Location and Structure Type

Location by Water District, Stream and Structure Type	Irrigated Acreage	Average Annual IWR (AF)	Average Annual CU Shortage (AF)	CU Shortage as Percent of IWR	Percentage of Study Area CU Shortage	Critically Short Acreage	Percentage of Study Area Critical Acreage
44 - Lower Yampa River	**29,069**	**55,003**	**10,587**	**19.2%**	**41.7%**	**11,235**	**43.3%**
Explicit Structures	19,108	34,704	5,836	16.8%	23.0%	5,319	20.5%
A-aggregates	2,893	5,744	205	3.6%	0.8%	240	0.9%
B-aggregates	7,067	14,556	4,546	31.2%	17.9%	5,676	21.9%
Beaver Creek	150	340	127	37.2%	0.5%	150	0.6%
Explicit Structures	150	340	127	37.2%	0.5%	150	0.6%
A-aggregates	0	0	0	n/a	0.0%	0	0.0%
B-aggregates	0	0	0	n/a	0.0%	0	0.0%
Crystal Creek	30	54	0	0.5%	0.0%	0	0.0%
Explicit Structures	30	54	0	0.5%	0.0%	0	0.0%
A-aggregates	0	0	0	n/a	0.0%	0	0.0%
B-aggregates	0	0	0	n/a	0.0%	0	0.0%
Deer Creek	274	503	1	0.2%	0.0%	0	0.0%
Explicit Structures	274	503	1	0.2%	0.0%	0	0.0%
A-aggregates	0	0	0	n/a	0.0%	0	0.0%
B-aggregates	0	0	0	n/a	0.0%	0	0.0%
Dry Creek	289	665	250	37.6%	1.0%	289	1.1%
Explicit Structures	289	665	250	37.6%	1.0%	289	1.1%
A-aggregates	0	0	0	n/a	0.0%	0	0.0%
B-aggregates	0	0	0	n/a	0.0%	0	0.0%
East Fork Williams Fork	2,680	6,039	1,179	19.5%	4.6%	1,501	5.8%
Explicit Structures	863	1,669	0	0.0%	0.0%	0	0.0%
A-aggregates	317	765	0	0.0%	0.0%	0	0.0%
B-aggregates	1,501	3,606	1,179	32.7%	4.6%	1,501	5.8%
Elkhead Creek	2,070	4,053	561	13.8%	2.2%	703	2.7%
Explicit Structures	1,431	2,520	105	4.2%	0.4%	64	0.2%
A-aggregates	70	158	38	24.4%	0.2%	70	0.3%
B-aggregates	569	1,375	417	30.3%	1.6%	569	2.2%
Fortification Creek	991	1,875	468	25.0%	1.8%	385	1.5%
Explicit Structures	991	1,875	468	25.0%	1.8%	385	1.5%
A-aggregates	0	0	0	n/a	0.0%	0	0.0%
B-aggregates	0	0	0	n/a	0.0%	0	0.0%
James Creek	5	12	1	5.8%	0.0%	0	0.0%
Explicit Structures	5	12	1	5.8%	0.0%	0	0.0%
A-aggregates	0	0	0	n/a	0.0%	0	0.0%
B-aggregates	0	0	0	n/a	0.0%	0	0.0%
Little Bear	1,530	3,119	1,836	58.9%	7.2%	1,530	5.9%
Explicit Structures	1,530	3,119	1,836	58.9%	7.2%	1,530	5.9%
A-aggregates	0	0	0	n/a	0.0%	0	0.0%
B-aggregates	0	0	0	n/a	0.0%	0	0.0%
Little Cottonwood Creek	207	415	213	51.3%	0.8%	207	0.8%
Explicit Structures	207	415	213	51.3%	0.8%	207	0.8%
A-aggregates	0	0	0	n/a	0.0%	0	0.0%
B-aggregates	0	0	0	n/a	0.0%	0	0.0%
Milk Creek	3,796	7,289	1,532	21.0%	6.0%	1,851	7.1%
Explicit Structures	2,175	4,279	337	7.9%	1.3%	373	1.4%
A-aggregates	313	621	164	26.5%	0.6%	170	0.7%
B-aggregates	1,307	2,389	1,031	43.1%	4.1%	1,307	5.0%
Morapose Creek	2,097	4,208	2,130	50.6%	8.4%	2,097	8.1%
Explicit Structures	2,097	4,208	2,130	50.6%	8.4%	2,097	8.1%
A-aggregates	0	0	0	n/a	0.0%	0	0.0%
B-aggregates	0	0	0	n/a	0.0%	0	0.0%
North Fork Elkhead Creek	27	57	7	13.1%	0.0%	0	0.0%
Explicit Structures	27	57	7	13.1%	0.0%	0	0.0%
A-aggregates	0	0	0	n/a	0.0%	0	0.0%
B-aggregates	0	0	0	n/a	0.0%	0	0.0%
Pine Creek	392	699	249	35.6%	1.0%	223	0.9%
Explicit Structures	392	699	249	35.6%	1.0%	223	0.9%
A-aggregates	0	0	0	n/a	0.0%	0	0.0%
B-aggregates	0	0	0	n/a	0.0%	0	0.0%
South Fork Williams Fork	125	262	0	0.0%	0.0%	0	0.0%
* Explicit Structures	125	262	0	0.0%	0.0%	0	0.0%
* A-aggregates	0	0	0	n/a	0.0%	0	0.0%
B-aggregates	0	0	0	n/a	0.0%	0	0.0%
Waddle Creek	217	510	19	3.7%	0.1%	0	0.0%
Explicit Structures	217	510	19	3.7%	0.1%	0	0.0%
A-aggregates	0	0	0	n/a	0.0%	0	0.0%
B-aggregates	0	0	0	n/a	0.0%	0	0.0%
Williams Fork	2,631	6,106	1,120	18.3%	4.4%	1,036	4.0%
* Explicit Structures	274	448	0	0.0%	0.0%	0	0.0%
* A-aggregates	779	1,863	0	0.0%	0.0%	0	0.0%
B-aggregates	1,578	3,795	1,120	29.5%	4.4%	1,036	4.0%
Yampa River	11,557	18,796	895	4.8%	3.5%	1,262	4.9%
* Explicit Structures	8,031	13,068	94	0.7%	0.4%	0	0.0%
* A-aggregates	1,415	2,337	2	0.1%	0.0%	0	0.0%
B-aggregates	2,111	3,391	799	23.6%	3.1%	1,262	4.9%

Notes:
Asterisk denotes mainstem reach
A-aggregates include structures that divert from a modeled stream
B-aggregates include structures that divert from an unmodeled tributary
Critically short acreage is at least 20% short in 4 of 10 years

Table 1-5 - Consumptive Use Shortage and Critically Short Acreage by Location and Structure Type

Location by Water District, Stream and Structure Type	Irrigated Acreage	Average Annual IWR (AF)	Average Annual CU Shortage (AF)	CU Shortage as Percent of IWR	Percentage of Study Area CU Shortage	Critically Short Acreage	Percentage of Study Area Critical Acreage
54 - Slater/Timerlake Creeks	**14,670**	**33,401**	**6,359**	**19.0%**	**25.1%**	**7,884**	**30.4%**
Explicit Structures	5,886	12,238	1,997	16.3%	7.9%	2,360	9.1%
A-aggregates	3,260	7,846	165	2.1%	0.6%	0	0.0%
B-aggregates	5,524	13,317	4,198	31.5%	16.5%	5,524	21.3%
Little Snake	10,250	22,723	3,808	16.8%	15.0%	3,988	15.4%
Explicit Structures	3,153	5,648	144	2.6%	0.6%	0	0.0%
A-aggregates	3,110	7,483	164	2.2%	0.6%	0	0.0%
B-aggregates	3,988	9,592	3,500	36.5%	13.8%	3,988	15.4%
Slater Creek	2,780	6,736	1,156	17.2%	4.6%	2,257	8.7%
Explicit Structures	1,095	2,648	457	17.3%	1.8%	721	2.8%
A-aggregates	150	363	1	0.2%	0.0%	0	0.0%
B-aggregates	1,536	3,725	698	18.7%	2.8%	1,536	5.9%
Willow Creek	1,639	3,942	1,396	35.4%	5.5%	1,639	6.3%
Explicit Structures	1,639	3,942	1,396	35.4%	5.5%	1,639	6.3%
A-aggregates	0	0	0	n/a	0.0%	0	0.0%
B-aggregates	0	0	0	n/a	0.0%	0	0.0%
55 - Little Snake River	**1,788**	**2,869**	**81**	**2.8%**	**0.3%**	**60**	**0.2%**
Explicit Structures	1,128	1,808	63	3.5%	0.3%	0	0.0%
A-aggregates	600	965	0	0.0%	0.0%	0	0.0%
B-aggregates	60	97	18	18.2%	0.1%	60	0.2%
Little Snake	1,680	2,694	63	2.4%	0.3%	0	0.0%
Explicit Structures	1,128	1,808	63	3.5%	0.3%	0	0.0%
A-aggregates	552	886	0	0.0%	0.0%	0	0.0%
B-aggregates	0	0	0	n/a	0.0%	0	0.0%
Yampa River	108	175	18	10.0%	0.1%	60	0.2%
* Explicit Structures	0	0	0	n/a	0.0%	0	0.0%
* A-aggregates	48	78	0	0.0%	0.0%	0	0.0%
B-aggregates	60	97	18	18.2%	0.1%	60	0.2%
56 - Green River	**2,173**	**3,516**	**383**	**10.9%**	**1.5%**	**0**	**0.0%**
Explicit Structures	0	0	0	n/a	0.0%	0	0.0%
A-aggregates	157	252	0	0.0%	0.0%	0	0.0%
B-aggregates	2,016	3,263	383	11.7%	1.5%	0	0.0%
Green River	2,173	3,516	383	10.9%	1.5%	0	0.0%
* Explicit Structures	0	0	0	n/a	0.0%	0	0.0%
* A-aggregates	157	252	0	0.0%	0.0%	0	0.0%
B-aggregates	2,016	3,263	383	11.7%	1.5%	0	0.0%
57 - Middle Yampa River	**10,537**	**16,556**	**437**	**2.6%**	**1.7%**	**632**	**2.4%**
Explicit Structures	8,214	12,126	1	0.0%	0.0%	0	0.0%
A-aggregates	1,033	1,979	47	2.4%	0.2%	0	0.0%
B-aggregates	1,290	2,451	389	15.9%	1.5%	632	2.4%
Fish Creek	595	1,222	0	0.0%	0.0%	0	0.0%
Explicit Structures	595	1,222	0	0.0%	0.0%	0	0.0%
A-aggregates	0	0	0	n/a	0.0%	0	0.0%
B-aggregates	0	0	0	n/a	0.0%	0	0.0%
Trout Creek	2,113	4,350	37	0.9%	0.1%	0	0.0%
Explicit Structures	1,193	2,435	0	0.0%	0.0%	0	0.0%
A-aggregates	575	1,194	0	0.0%	0.0%	0	0.0%
B-aggregates	345	721	37	5.2%	0.1%	0	0.0%
West Fish Creek	387	809	0	0.0%	0.0%	0	0.0%
Explicit Structures	387	809	0	0.0%	0.0%	0	0.0%
A-aggregates	0	0	0	n/a	0.0%	0	0.0%
B-aggregates	0	0	0	n/a	0.0%	0	0.0%
Yampa River	7,442	10,175	399	3.9%	1.6%	632	2.4%
* Explicit Structures	6,039	7,660	1	0.0%	0.0%	0	0.0%
* A-aggregates	458	785	47	6.0%	0.2%	0	0.0%
B-aggregates	945	1,730	351	20.3%	1.4%	632	2.4%

Notes:
Asterisk denotes mainstem reach
A-aggregates include structures that divert from a modeled stream
B-aggregates include structures that divert from an unmodeled tributary
Critically short acreage is at least 20% short in 4 of 10 years

A

Table 1-5 - Consumptive Use Shortage and Critically Short Acreage by Location and Structure Type

Location by Water District, Stream and Structure Type	Irrigated Acreage	Average Annual IWR (AF)	Average Annual CU Shortage (AF)	CU Shortage as Percent of IWR	Percentage of Study Area CU Shortage	Critically Short Acreage	Percentage of Study Area Critical Acreage
58 - Upper Yampa River	**34,551**	**71,933**	**6,390**	**8.9%**	**25.2%**	**5,438**	**20.9%**
Explicit Structures	24,903	51,817	2,283	4.4%	9.0%	2,877	11.1%
A-aggregates	1,307	2,724	37	1.4%	0.1%	0	0.0%
B-aggregates	8,340	17,393	4,070	23.4%	16.0%	2,561	9.9%
Bear River	11,632	24,134	2,177	9.0%	8.6%	2,759	10.6%
* Explicit Structures	8,940	18,517	1,705	9.2%	6.7%	2,759	10.6%
* A-aggregates	451	934	37	3.9%	0.1%	0	0.0%
B-aggregates	2,241	4,683	435	9.3%	1.7%	0	0.0%
Beaver Creek	133	278	2	0.9%	0.0%	0	0.0%
Explicit Structures	133	278	2	0.9%	0.0%	0	0.0%
A-aggregates	0	0	0	n/a	0.0%	0	0.0%
B-aggregates	0	0	0	n/a	0.0%	0	0.0%
Big Creek	74	155	0	0.1%	0.0%	0	0.0%
Explicit Structures	74	155	0	0.1%	0.0%	0	0.0%
A-aggregates	0	0	0	n/a	0.0%	0	0.0%
B-aggregates	0	0	0	n/a	0.0%	0	0.0%
Brinker Creek	194	404	24	6.0%	0.1%	0	0.0%
Explicit Structures	194	404	24	6.0%	0.1%	0	0.0%
A-aggregates	0	0	0	n/a	0.0%	0	0.0%
B-aggregates	0	0	0	n/a	0.0%	0	0.0%
Chimney Creek	736	1,538	65	4.2%	0.3%	0	0.0%
Explicit Structures	0	0	0	n/a	0.0%	0	0.0%
A-aggregates	29	60	0	0.0%	0.0%	0	0.0%
B-aggregates	708	1,478	65	4.4%	0.3%	0	0.0%
Day Creek	350	733	39	5.4%	0.2%	0	0.0%
Explicit Structures	350	733	39	5.4%	0.2%	0	0.0%
A-aggregates	0	0	0	n/a	0.0%	0	0.0%
B-aggregates	0	0	0	n/a	0.0%	0	0.0%
Elk River	9,696	20,226	3,449	17.1%	13.6%	2,561	9.9%
Explicit Structures	4,965	10,373	2	0.0%	0.0%	0	0.0%
A-aggregates	661	1,382	0	0.0%	0.0%	0	0.0%
B-aggregates	4,070	8,471	3,446	40.7%	13.6%	2,561	9.9%
Green Creek	136	283	23	8.0%	0.1%	0	0.0%
Explicit Structures	136	283	23	8.0%	0.1%	0	0.0%
A-aggregates	0	0	0	n/a	0.0%	0	0.0%
B-aggregates	0	0	0	n/a	0.0%	0	0.0%
Harrison Creek	21	43	0	0.0%	0.0%	0	0.0%
Explicit Structures	21	43	0	0.0%	0.0%	0	0.0%
A-aggregates	0	0	0	n/a	0.0%	0	0.0%
B-aggregates	0	0	0	n/a	0.0%	0	0.0%
Hinman Creek	148	311	3	0.9%	0.0%	0	0.0%
Explicit Structures	148	311	3	0.9%	0.0%	0	0.0%
A-aggregates	0	0	0	n/a	0.0%	0	0.0%
B-aggregates	0	0	0	n/a	0.0%	0	0.0%
Hot Springs Creek	96	183	0	0.1%	0.0%	0	0.0%
Explicit Structures	96	183	0	0.1%	0.0%	0	0.0%
A-aggregates	0	0	0	n/a	0.0%	0	0.0%
B-aggregates	0	0	0	n/a	0.0%	0	0.0%
Hunt Creek	63	131	0	0.0%	0.0%	0	0.0%
Explicit Structures	63	131	0	0.0%	0.0%	0	0.0%
A-aggregates	0	0	0	n/a	0.0%	0	0.0%
B-aggregates	0	0	0	n/a	0.0%	0	0.0%
Lawson Creek	133	277	1	0.2%	0.0%	0	0.0%
Explicit Structures	133	277	1	0.2%	0.0%	0	0.0%
A-aggregates	0	0	0	n/a	0.0%	0	0.0%
B-aggregates	0	0	0	n/a	0.0%	0	0.0%

Notes:
Asterisk denotes mainstem reach
A-aggregates include structures that divert from a modeled stream
B-aggregates include structures that divert from an unmodeled tributary
Critically short acreage is at least 20% short in 4 of 10 years

Table 1-5 - Consumptive Use Shortage and Critically Short Acreage by Location and Structure Type

Location by Water District, Stream and Structure Type	Irrigated Acreage	Average Annual IWR (AF)	Average Annual CU Shortage (AF)	CU Shortage as Percent of IWR	Percentage of Study Area CU Shortage	Critically Short Acreage	Percentage of Study Area Critical Acreage
Middle Hunt Creek	769	1,605	1	0.0%	0.0%	0	0.0%
Explicit Structures	769	1,605	1	0.0%	0.0%	0	0.0%
A-aggregates	0	0	0	n/a	0.0%	0	0.0%
B-aggregates	0	0	0	n/a	0.0%	0	0.0%
Mill Creek	131	272	0	0.0%	0.0%	0	0.0%
Explicit Structures	131	272	0	0.0%	0.0%	0	0.0%
A-aggregates	0	0	0	n/a	0.0%	0	0.0%
B-aggregates	0	0	0	n/a	0.0%	0	0.0%
North Hunt Creek	447	875	4	0.5%	0.0%	0	0.0%
Explicit Structures	447	875	4	0.5%	0.0%	0	0.0%
A-aggregates	0	0	0	n/a	0.0%	0	0.0%
B-aggregates	0	0	0	n/a	0.0%	0	0.0%
Oak Creek	766	1,601	31	1.9%	0.1%	0	0.0%
Explicit Structures	766	1,601	31	1.9%	0.1%	0	0.0%
A-aggregates	0	0	0	n/a	0.0%	0	0.0%
B-aggregates	0	0	0	n/a	0.0%	0	0.0%
Sand Creek	341	714	64	9.0%	0.3%	0	0.0%
Explicit Structures	341	714	64	9.0%	0.3%	0	0.0%
A-aggregates	0	0	0	n/a	0.0%	0	0.0%
B-aggregates	0	0	0	n/a	0.0%	0	0.0%
Smith Creek	167	356	1	0.3%	0.0%	0	0.0%
Explicit Structures	167	356	1	0.3%	0.0%	0	0.0%
A-aggregates	0	0	0	n/a	0.0%	0	0.0%
B-aggregates	0	0	0	n/a	0.0%	0	0.0%
Soda Creek	700	1,465	73	5.0%	0.3%	0	0.0%
Explicit Structures	700	1,465	73	5.0%	0.3%	0	0.0%
A-aggregates	0	0	0	n/a	0.0%	0	0.0%
B-aggregates	0	0	0	n/a	0.0%	0	0.0%
South Hunt Creek	776	1,620	14	0.9%	0.1%	0	0.0%
Explicit Structures	776	1,620	14	0.9%	0.1%	0	0.0%
A-aggregates	0	0	0	n/a	0.0%	0	0.0%
B-aggregates	0	0	0	n/a	0.0%	0	0.0%
Walton Creek	2,494	5,216	241	4.6%	0.9%	0	0.0%
Explicit Structures	2,494	5,216	241	4.6%	0.9%	0	0.0%
A-aggregates	0	0	0	n/a	0.0%	0	0.0%
B-aggregates	0	0	0	n/a	0.0%	0	0.0%
Watson Creek	313	654	55	8.4%	0.2%	118	0.5%
Explicit Structures	313	654	55	8.4%	0.2%	118	0.5%
A-aggregates	0	0	0	n/a	0.0%	0	0.0%
B-aggregates	0	0	0	n/a	0.0%	0	0.0%
Willow Creek	91	190	0	0.1%	0.0%	0	0.0%
Explicit Structures	91	190	0	0.1%	0.0%	0	0.0%
A-aggregates	0	0	0	n/a	0.0%	0	0.0%
B-aggregates	0	0	0	n/a	0.0%	0	0.0%
Yampa River	4,145	8,666	123	1.4%	0.5%	0	0.0%
* Explicit Structures	2,658	5,558	0	0.0%	0.0%	0	0.0%
* A-aggregates	166	347	0	0.0%	0.0%	0	0.0%
B-aggregates	1,322	2,761	123	4.5%	0.5%	0	0.0%
Study Area Total	**119,607**	**229,018**	**25,366**	**11.1%**	**100.0%**	**25,972**	**100.0%**
Explicit Structures	79,197	145,414	10,774	7.4%	42.5%	10,947	42.2%
A-aggregates	11,367	23,189	562	2.4%	2.2%	404	1.6%
B-aggregates	29,043	60,415	14,030	23.2%	55.3%	14,621	56.3%

Notes:
Asterisk denotes mainstem reach
A-aggregates include structures that divert from a modeled stream
B-aggregates include structures that divert from an unmodeled tributary
Critically short acreage is at least 20% short in 4 of 10 years

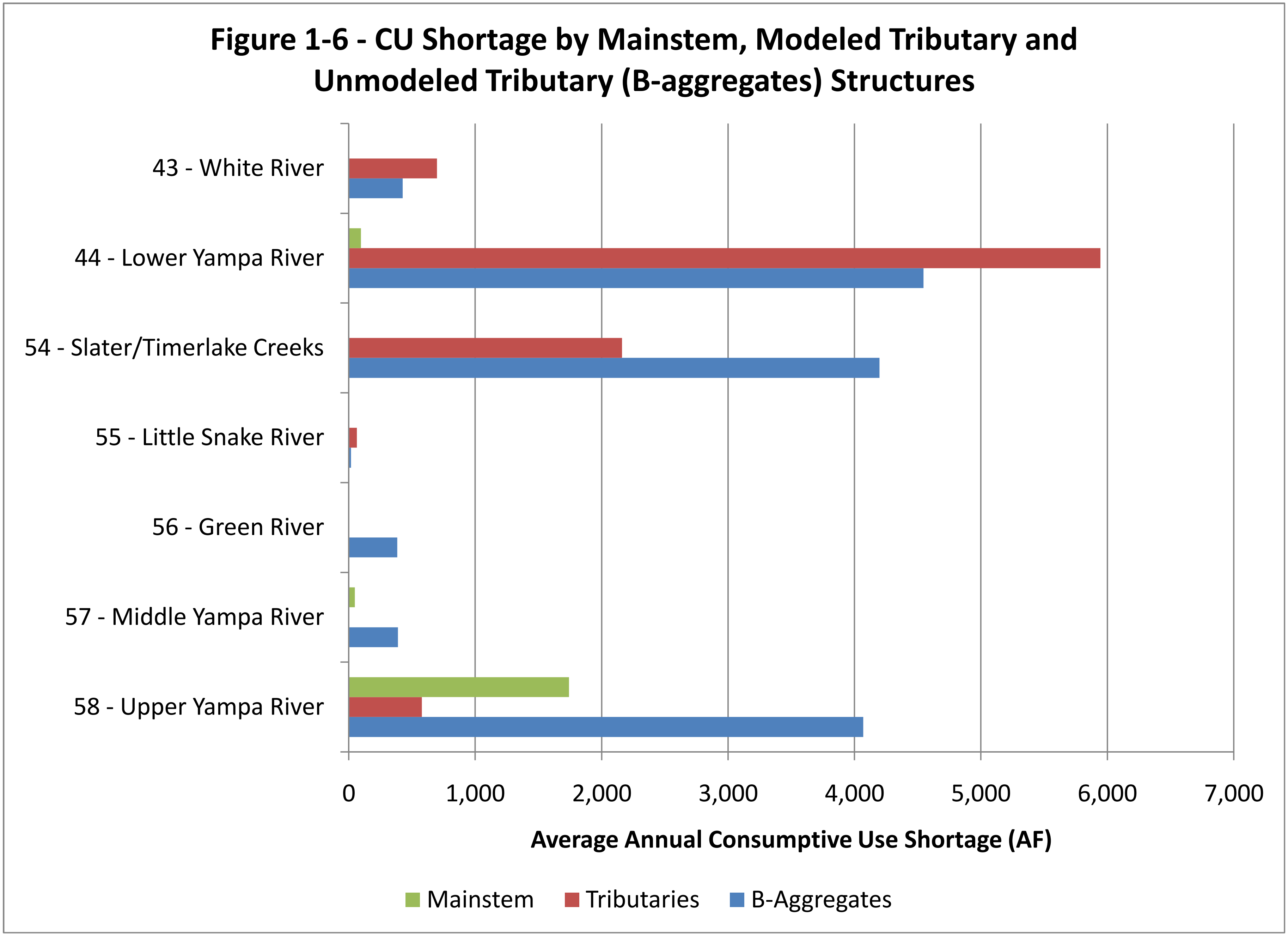
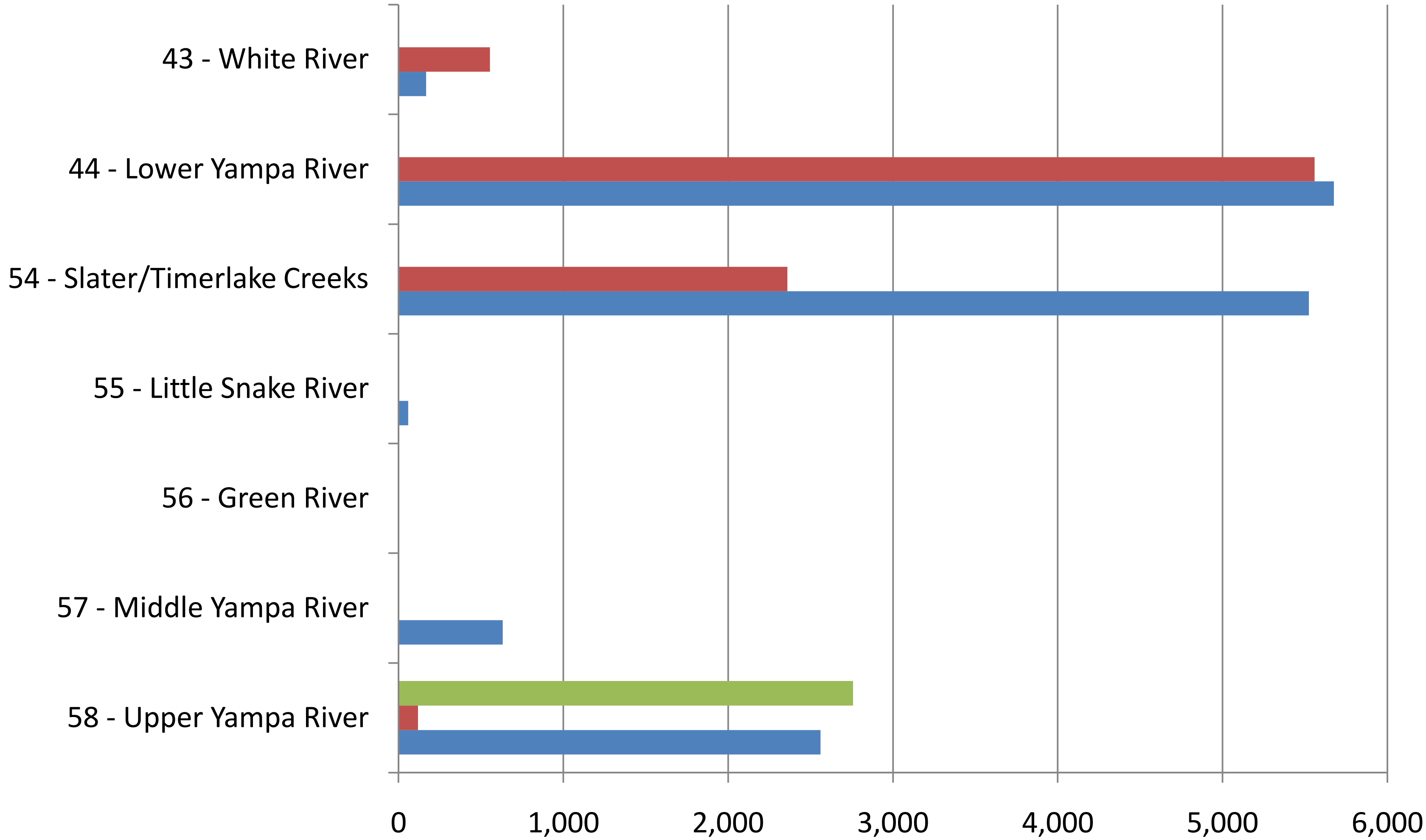


Figure 1-6 - CU Shortage by Mainstem, Modeled Tributary and Unmodeled Tributary (B-aggregates) Structures
43 - White River
44 - Lower Yampa River
54 - Slater/Timerlake Creeks
55 - Little Snake River
56 - Green River
57 - Middle Yampa River
58 - Upper Yampa River
0
1,000
2,000
3,000
4,000
5,000
6,000
7,000
Average Annual Consumptive Use Shortage (AF)
Mainstem
Tributaries
B-Aggregates

Figure 1-7 - Critically Short Acreage by Mainstem, Modeled Tributary and Unmodeled Tributary (B-aggregate) Structures



Note critically short acreage is defined as acreage that has at least a 20% shortage in at least 4 of 10 years

Table 1-6 – Summary of Shortages at Mainstem and Tributary Structures

Structure Location	Irrigated Acreage	Average Annual IWR (AF)	Average Annual CU Shortage (AF)	Critically Short Acreage
Total Study Area	**119,607**	**229,018**	**25,366**	**25,972**
Mainstem	40%	36%	7%	11%
Tributary (excluding B-aggregates)	36%	38%	37%	33%
B-aggregates	24%	26%	55%	56%

Notes:
- B-aggregates are structures that divert from an unmodeled stream and use historical diversions as representative of physical water availability.
- Critically short acreage is defined as acreage that is at least 20% short in at least 4 of 10 years.

Figure 1-8 is a map that shows the average annual CU shortage spatially by severity of the CU shortage and acreage under the structure. Figures 1-8a to 1-8g are close-up views of Figure 1-8 by water district. Figure 1-9 shows the critically short structures that experience more than a 5% CU shortage in at least 4 out of 10 years (critically short structures). Figures 1-9a through 1-9g are close-up views of Figure 1-9.

To help identify watersheds that might be helped most by a supplemental supply project, critically short acreage, amount of average annual CU shortage and the ratio of CU shortage to critically short acreage streams were quantified for each stream and ranked. The ranks for each category were summed together and sorted to give an indication of the streams that are most impacted by shortages and are presented in Table 1-7. Figure 1-10 shows the location of the streams that ranked highest in Table 1-7. This list identifies watersheds that could benefit most from a supplemental supply project. Supply alternatives will be investigated in further detail in a future technical memo (Tasks 5 and 7).

The seasonal component of the shortages is presented in Figure 1-11. The figure shows that consumptive use shortages are most severe on the tributary structures (including B-aggregates) and comparatively minor on the mainstem structures. The increasing shortages for the tributary and B-aggregate structures in July and August correlates well with information provided by the agricultural subcommittee and helps identify the need for supplemental supply for the late summer months on the tributary structures.

Late season demand for soil moisture was quantified in section 3.5 as 6,638 AFY in the drier western portion of the basin. Based on input from the subcommittee and precipitation records, winter precipitation is assumed to fulfill the soil moisture demand in the wetter eastern portion of the basin. This demand is not considered part of IWR since this is near the end of the growing season, and consumptive use shortages do not include this type of demand. The method used to compute headgate demands is based on IWR and irrigation season efficiency and therefore does not include this late season demand. Available water (minimum of physical and legal available water) is computed

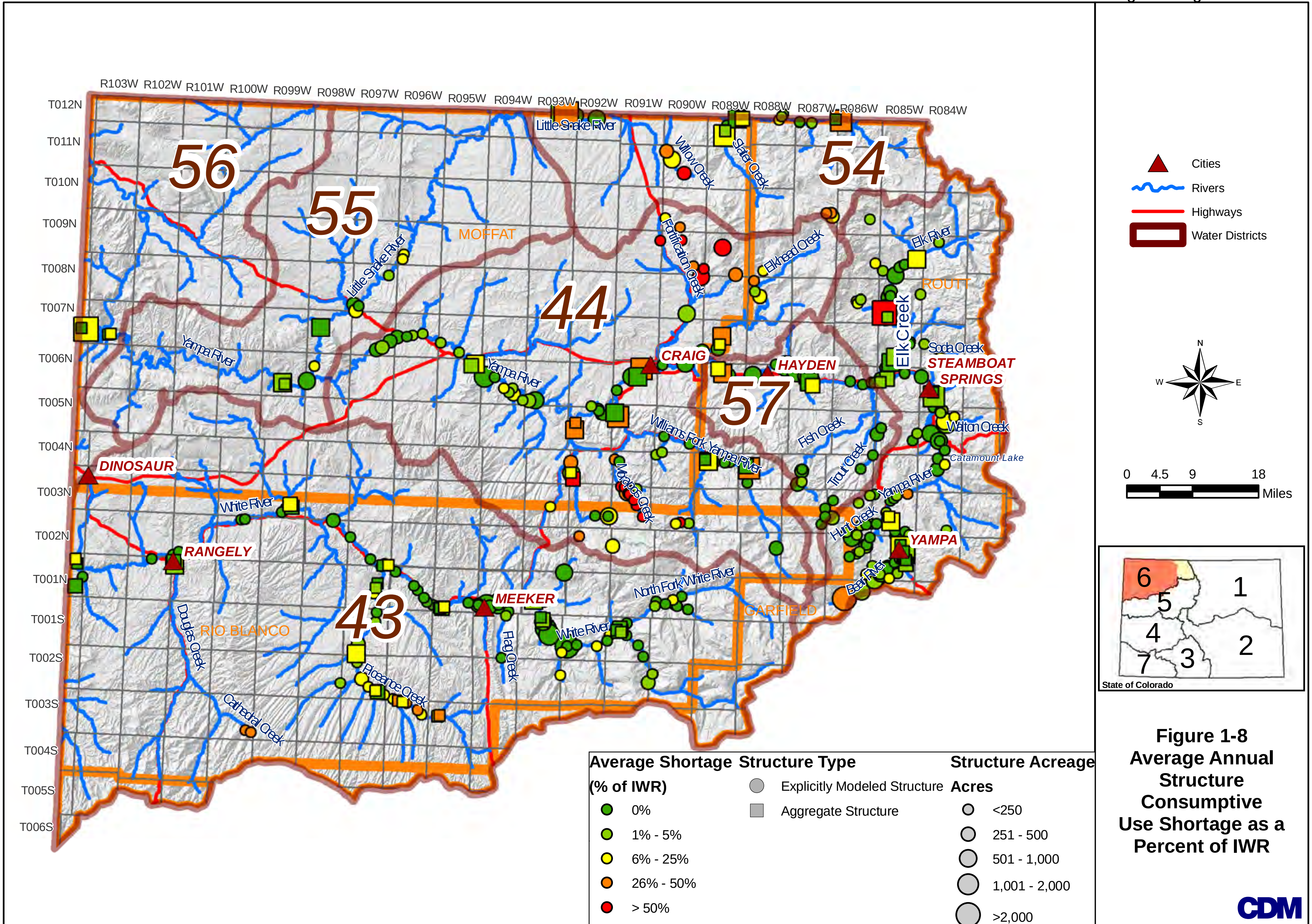


Figure 1-8
Average Annual Structure Consumptive Use Shortage as a Percent of IWR

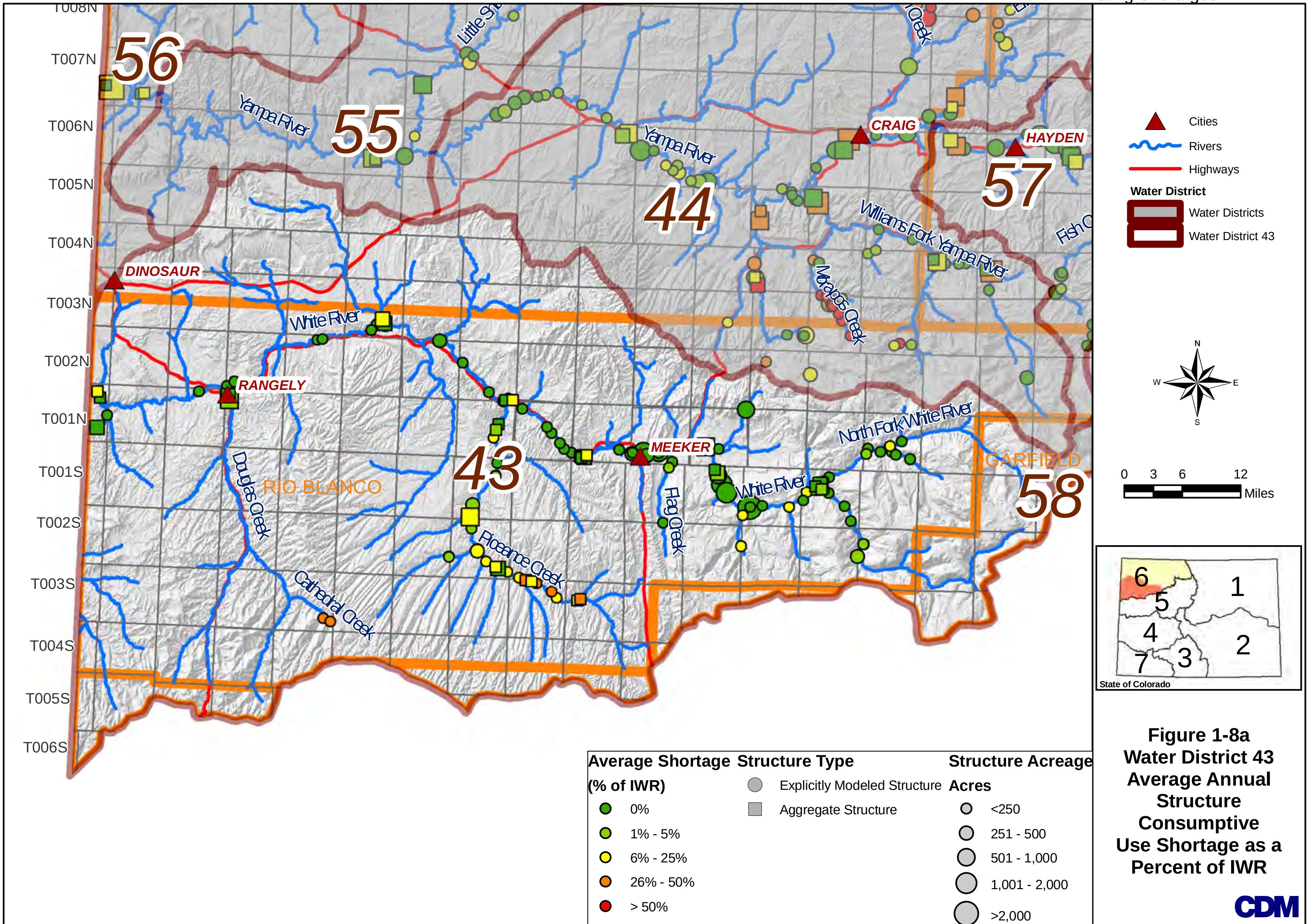


**Figure 1-8a
Water District 43
Average Annual
Structure
Consumptive
Use Shortage as a
Percent of IWR**

CDM

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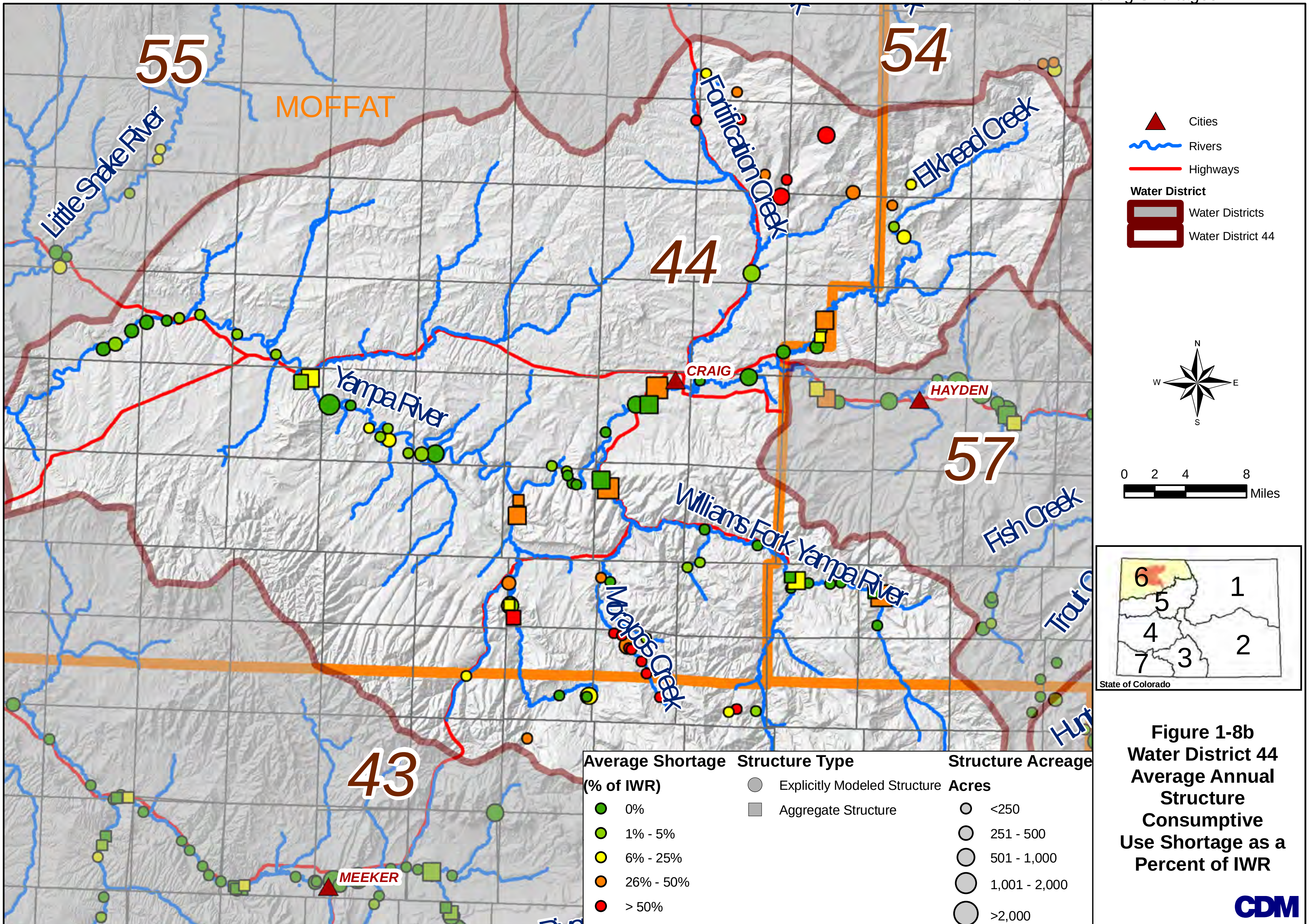

Figure 1-8b
Water District 44
Average Annual Structure Consumptive Use Shortage as a Percent of IWR

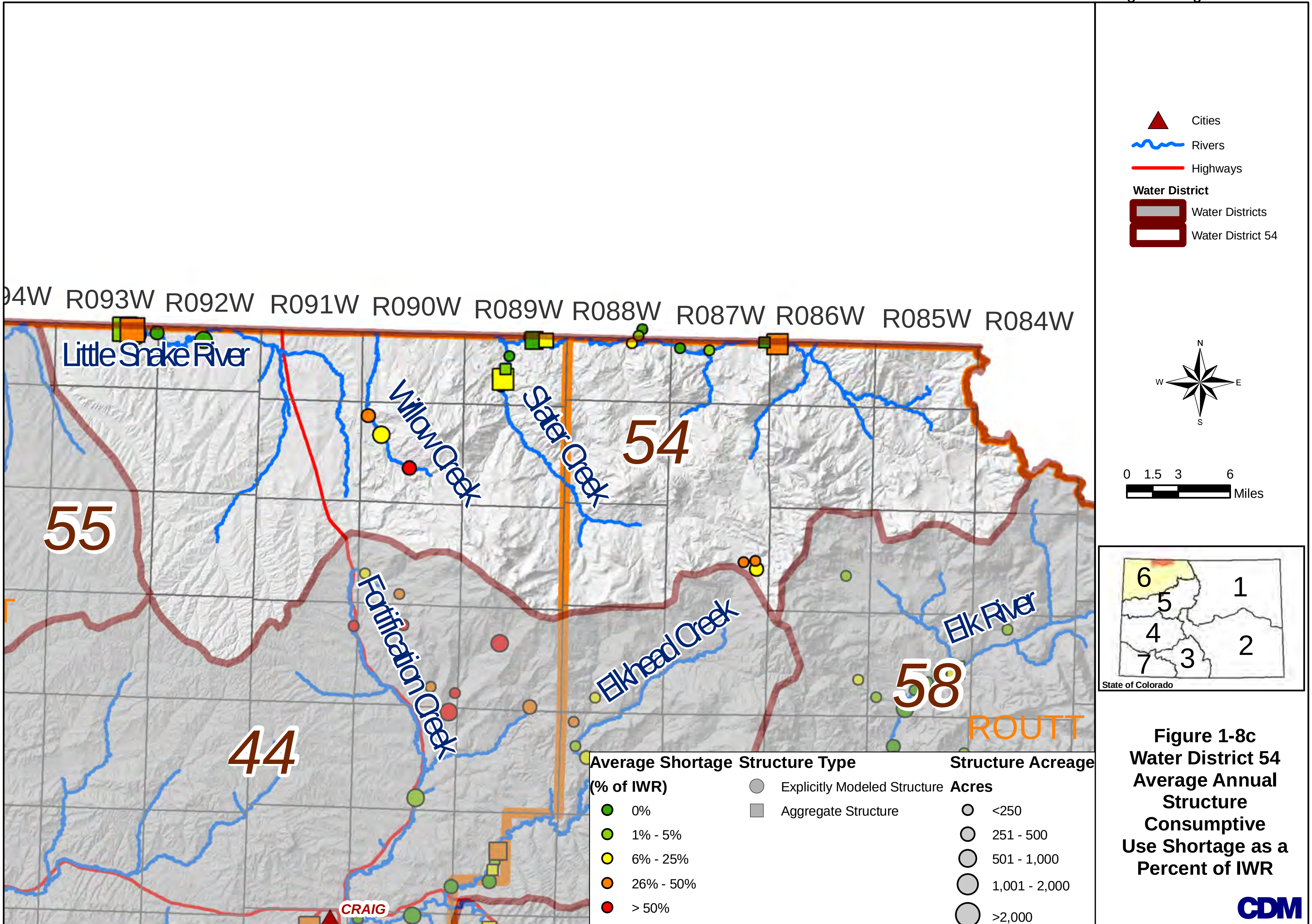

Figure 1-8c
Water District 54
Average Annual Structure Consumptive Use Shortage as a Percent of IWR

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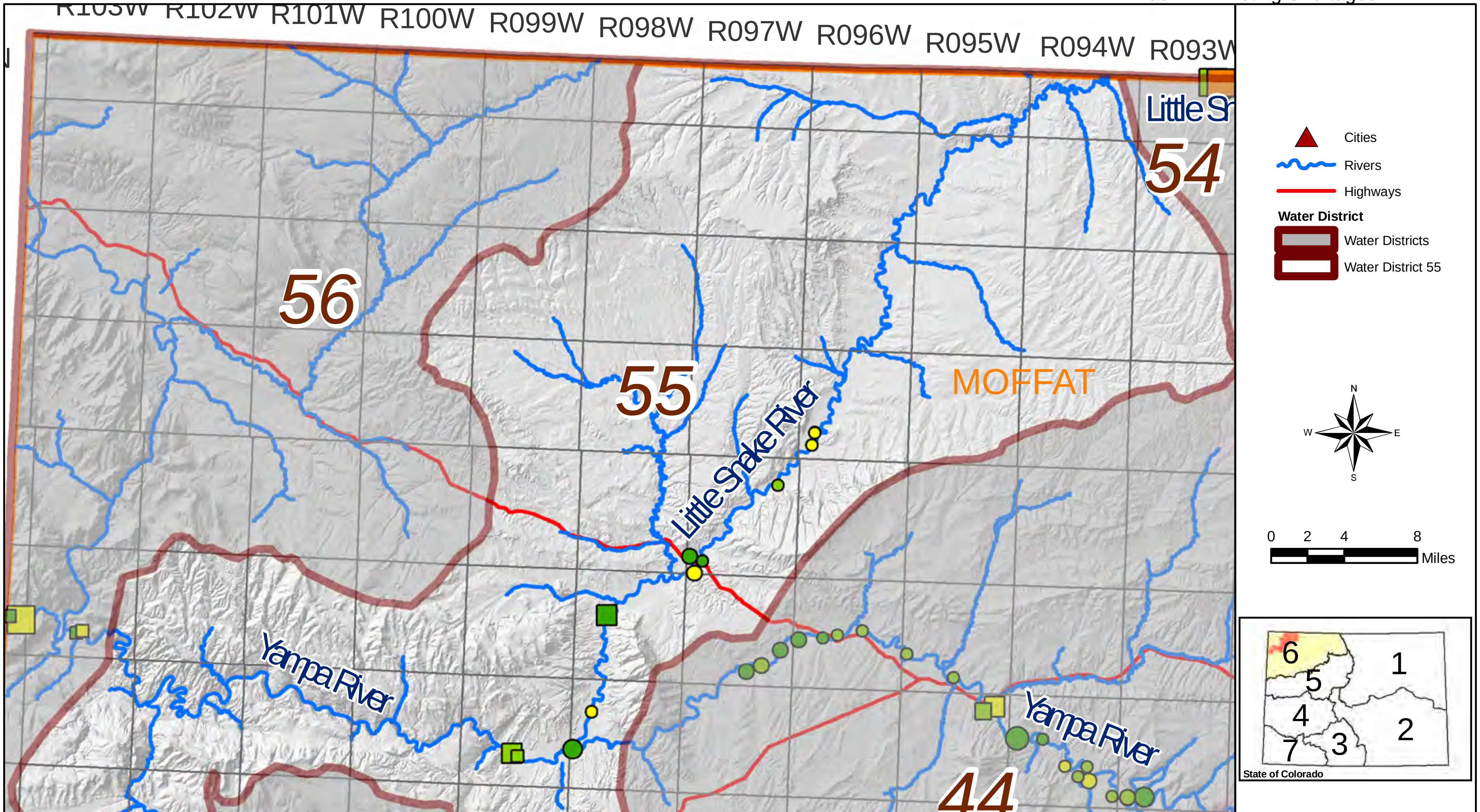

Figure 1-8d
Water District 55
Average Annual Structure Consumptive Use Shortage as a Percent of IWR

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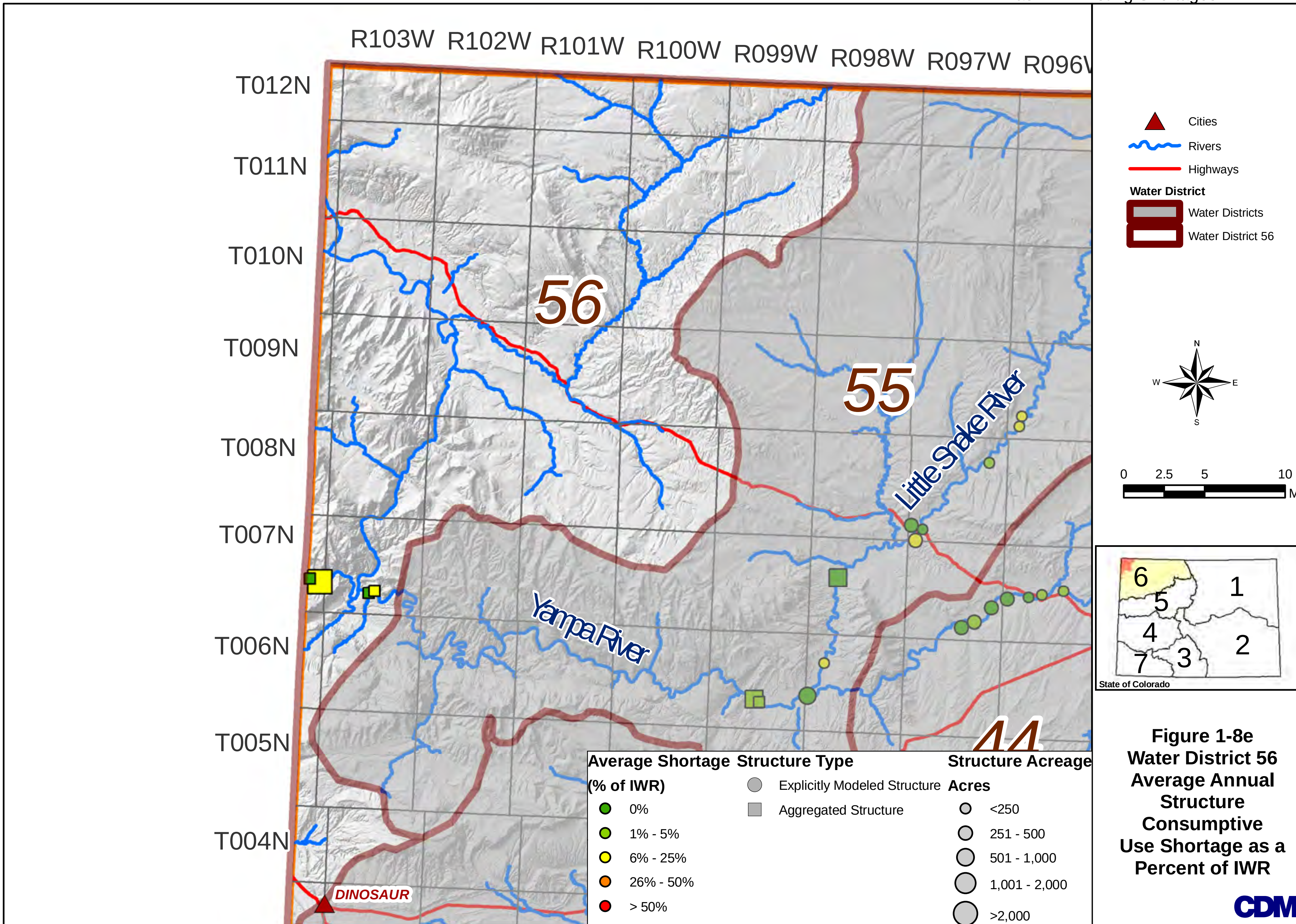

Figure 1-8e
Water District 56
Average Annual Structure Consumptive Use Shortage as a Percent of IWR

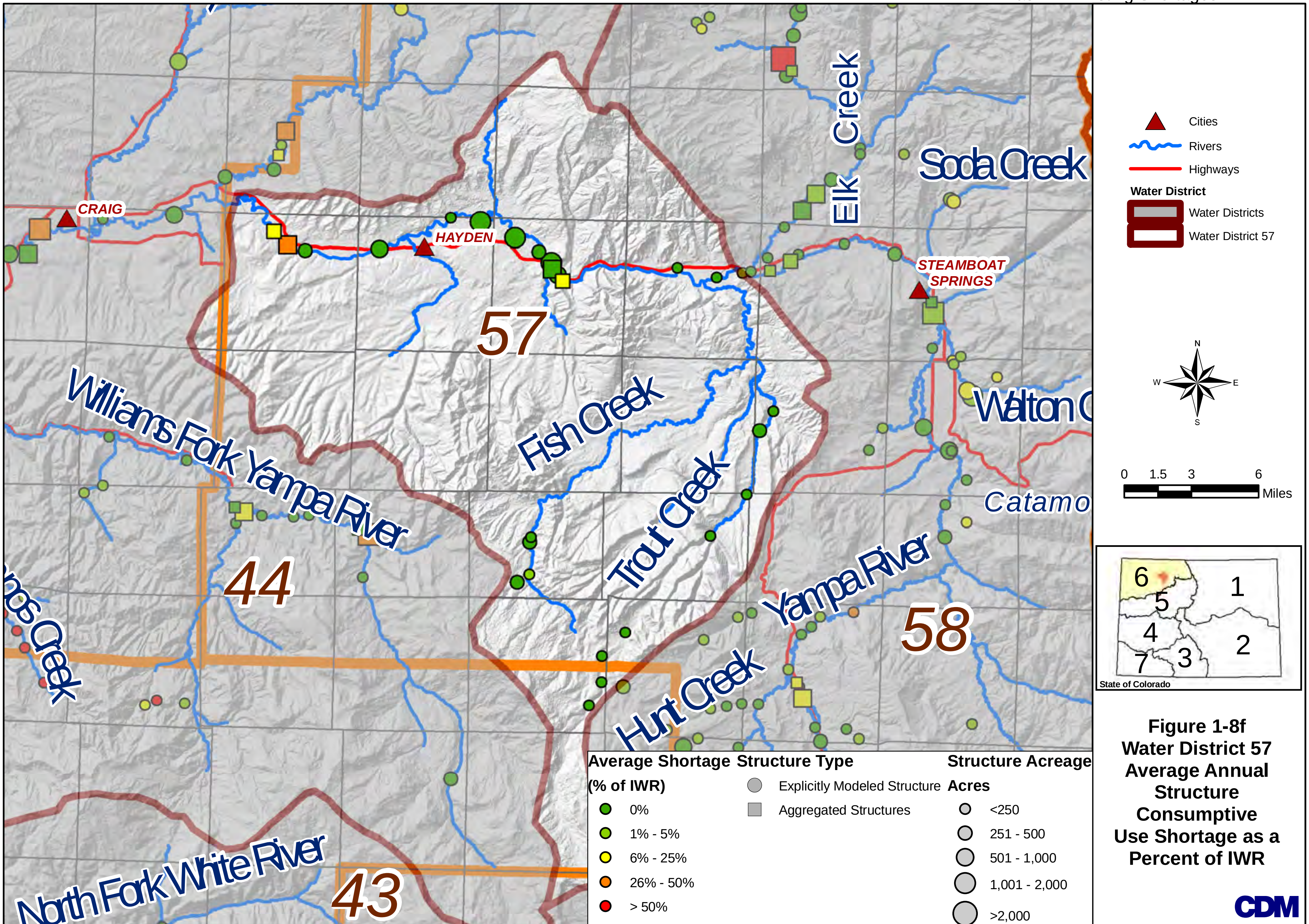

Figure 1-8f
Water District 57
Average Annual Structure Consumptive Use Shortage as a Percent of IWR

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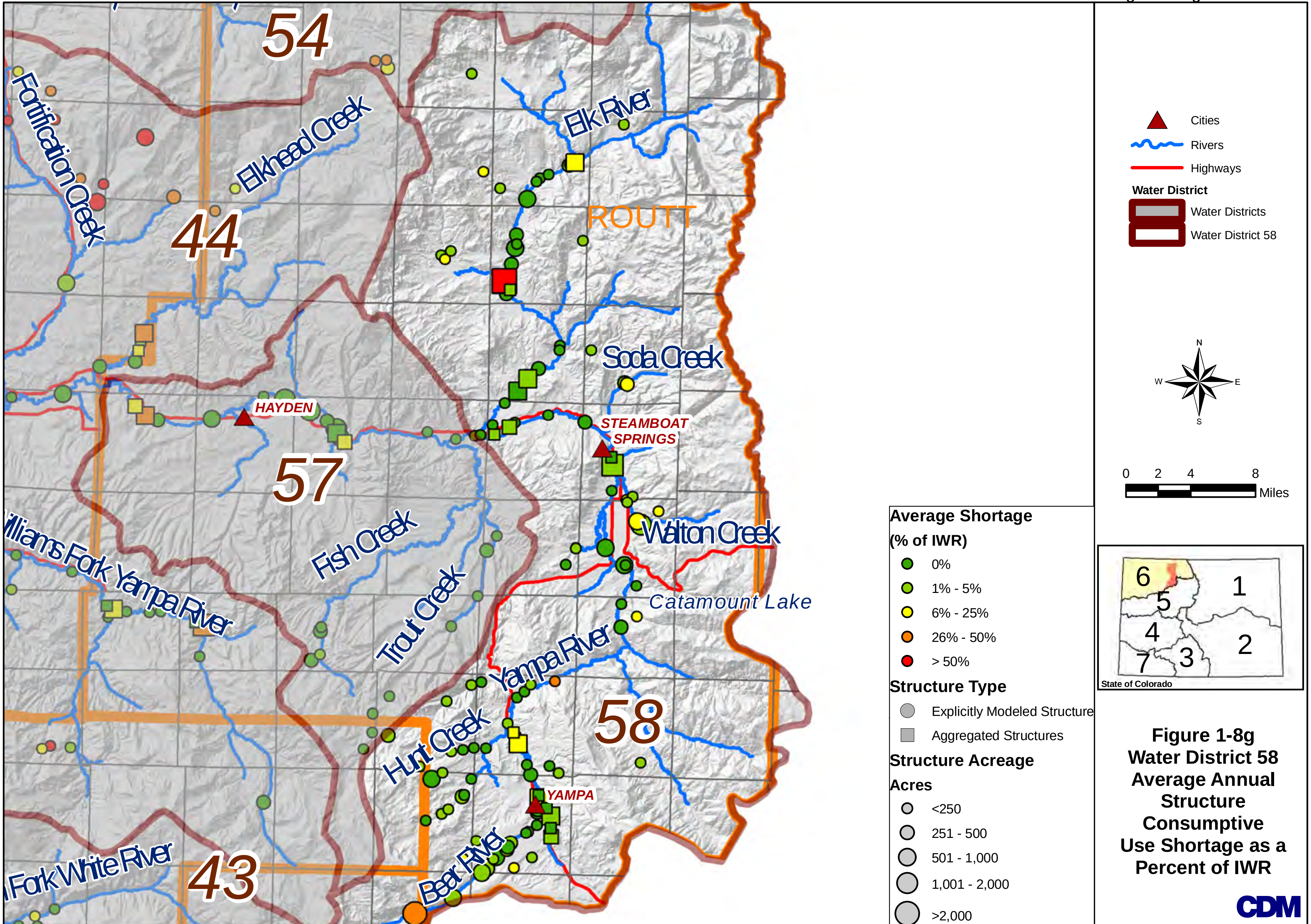

Figure 1-8g
Water District 58
Average Annual Structure Consumptive Use Shortage as a Percent of IWR

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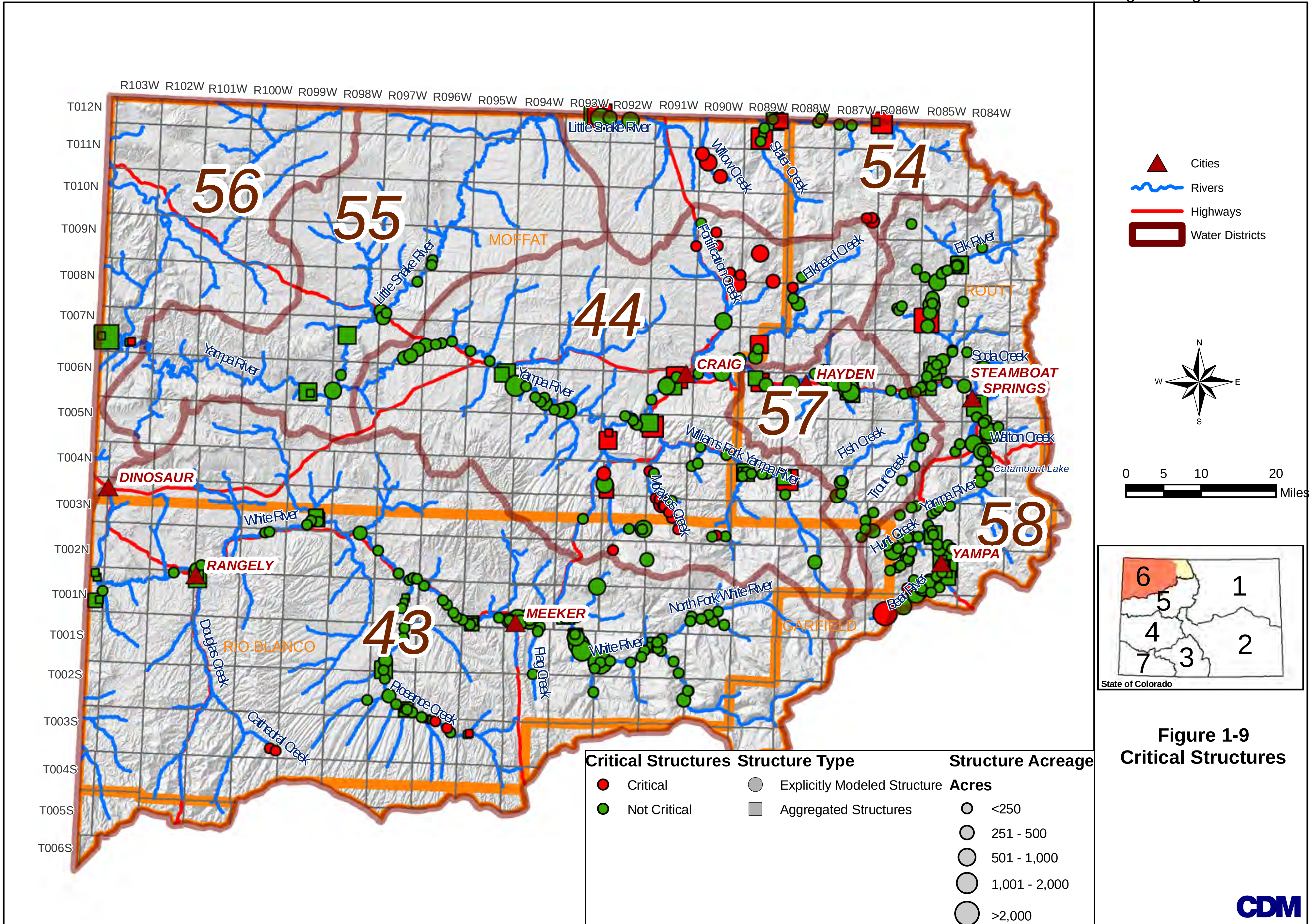

Figure 1-9
Critical Structures

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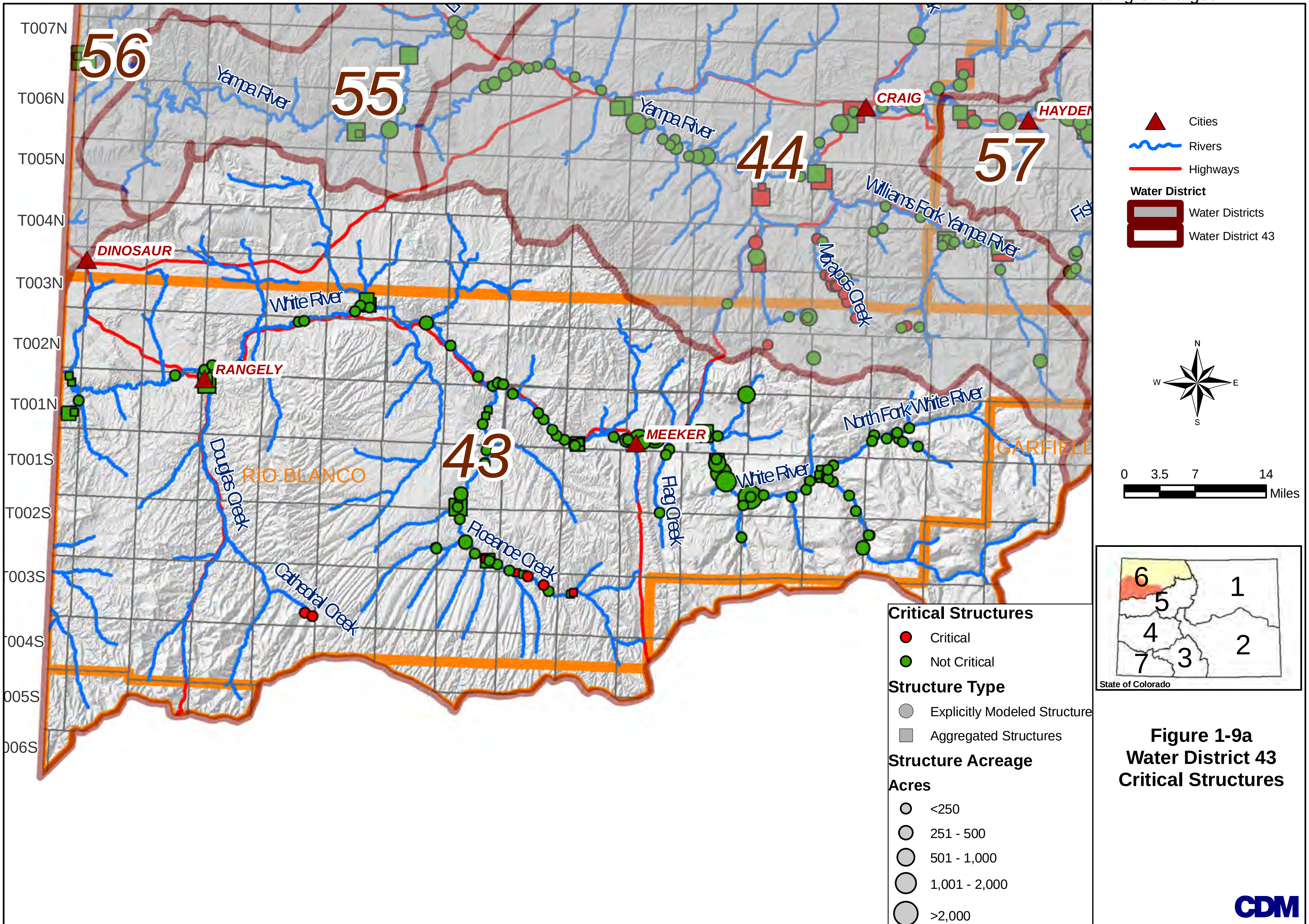

Figure 1-9a
Water District 43
Critical Structures

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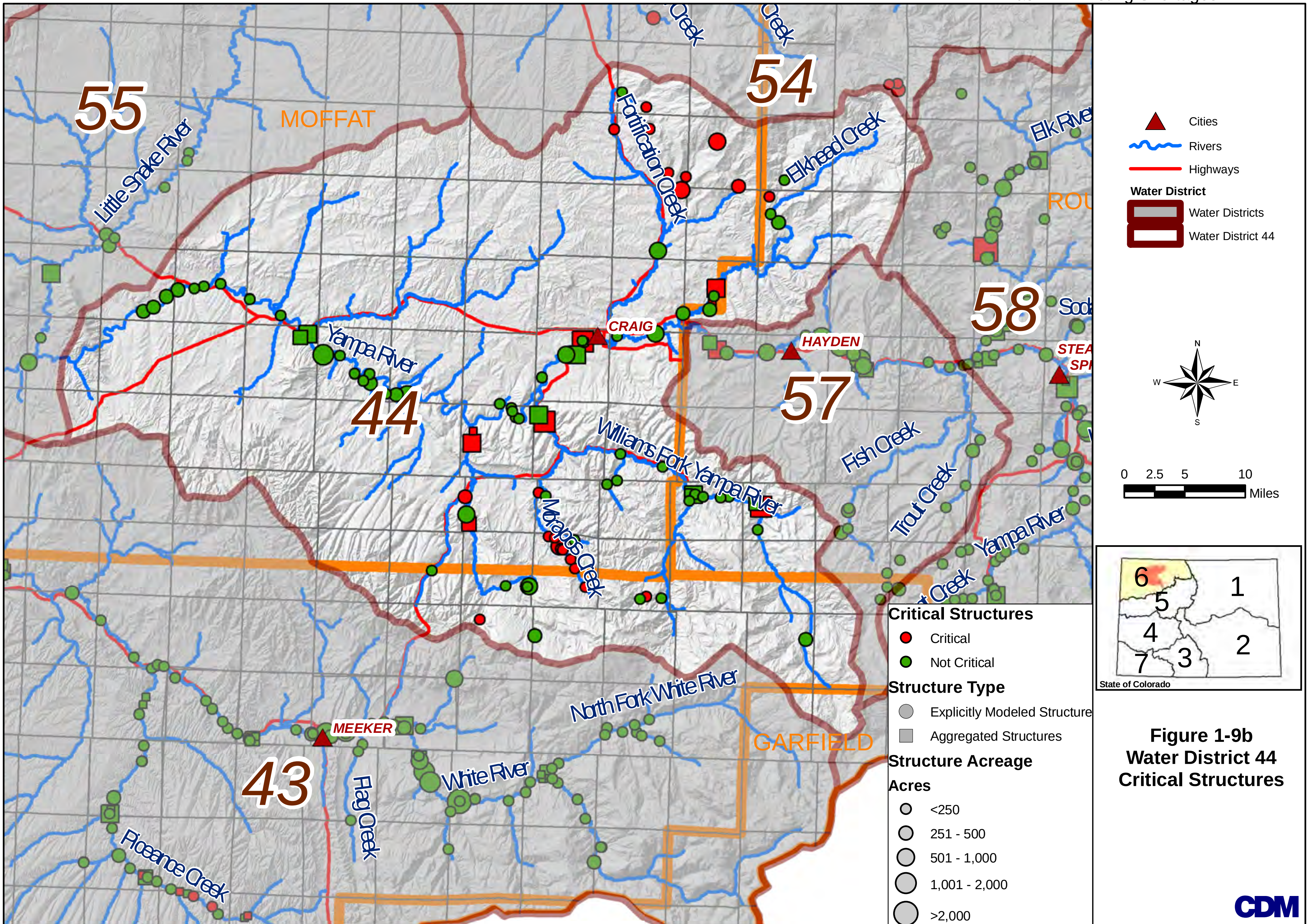

Figure 1-9b
Water District 44
Critical Structures

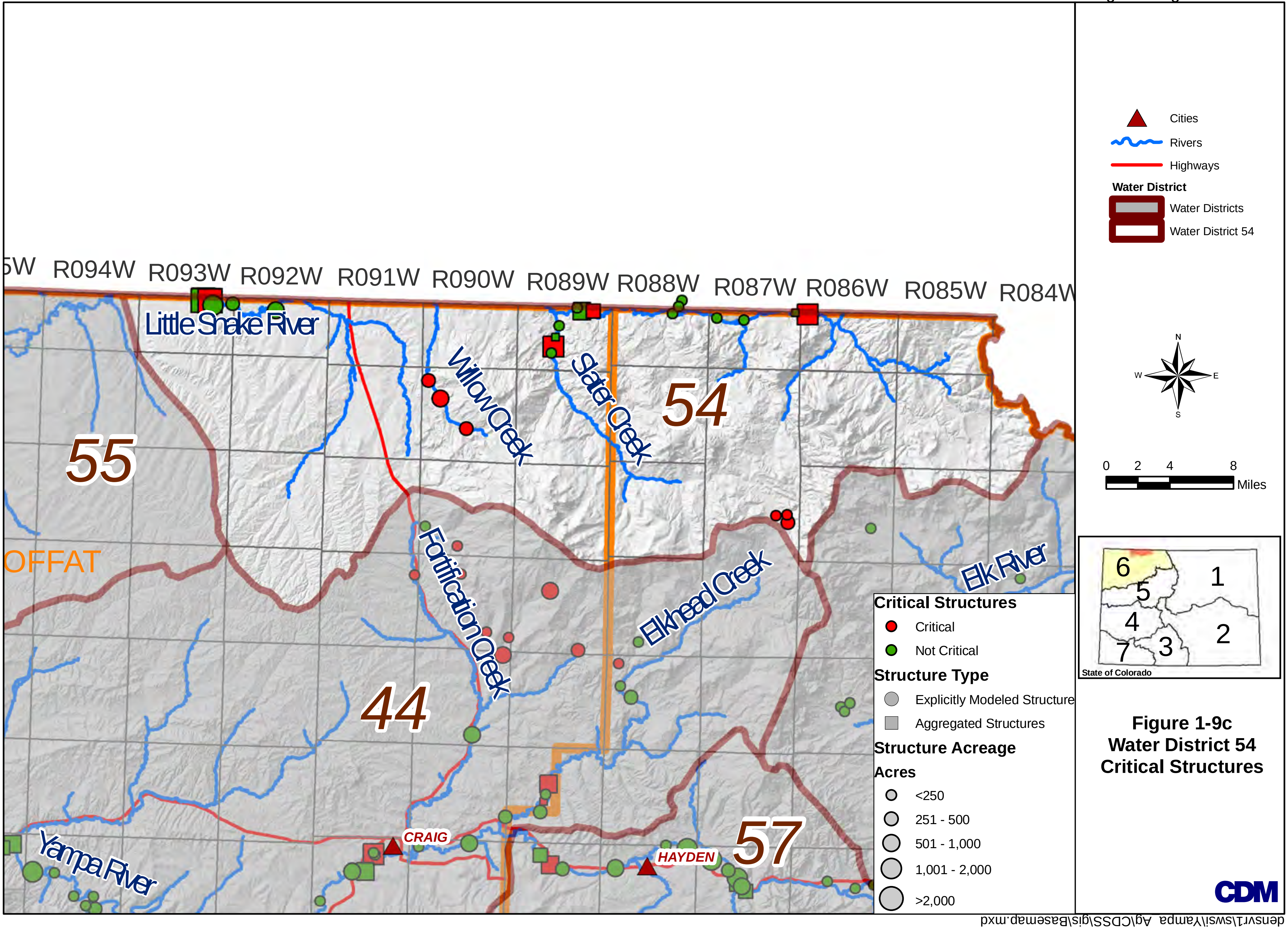

Figure 1-9c
Water District 54
Critical Structures

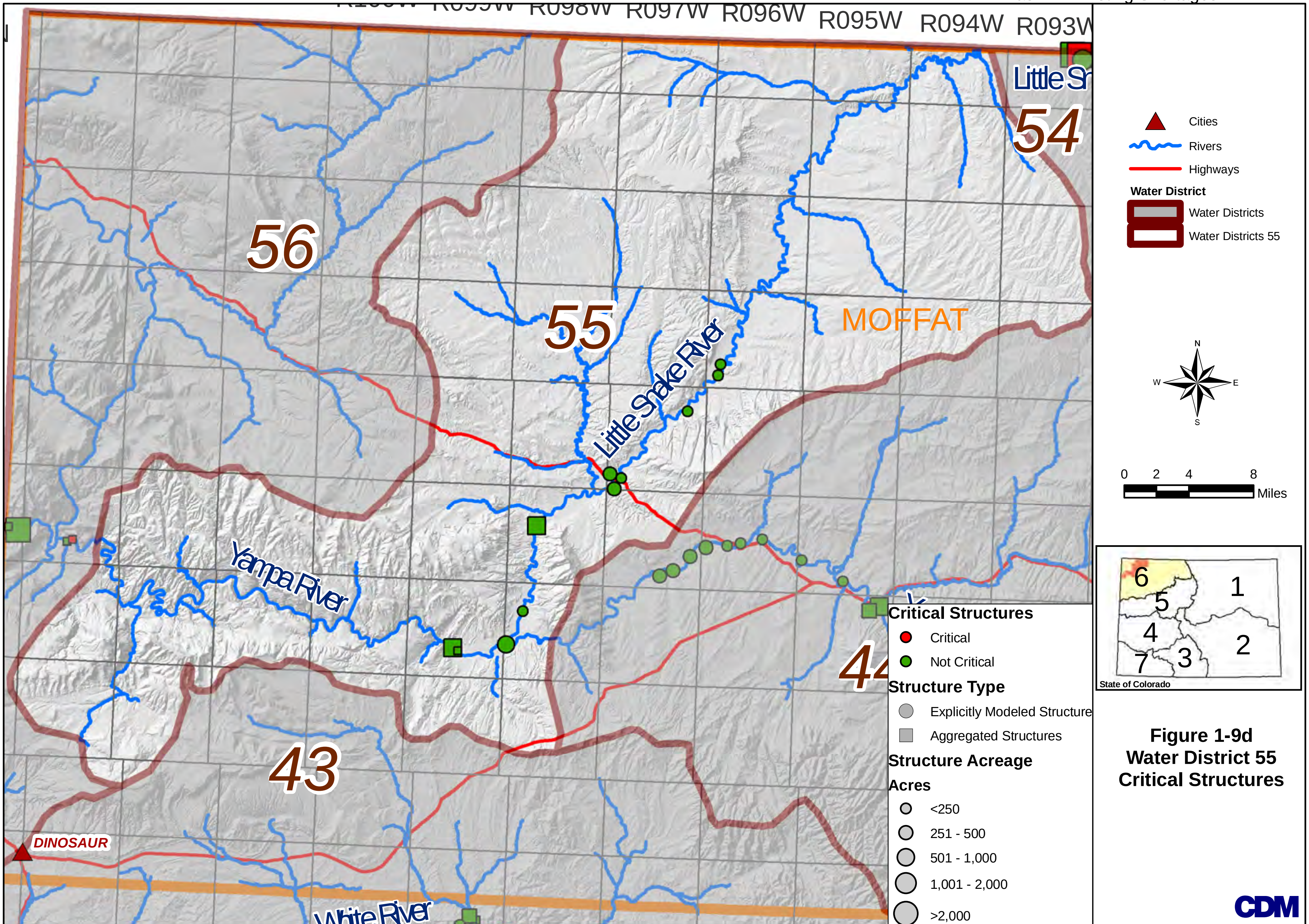

Figure 1-9d
Water District 55
Critical Structures

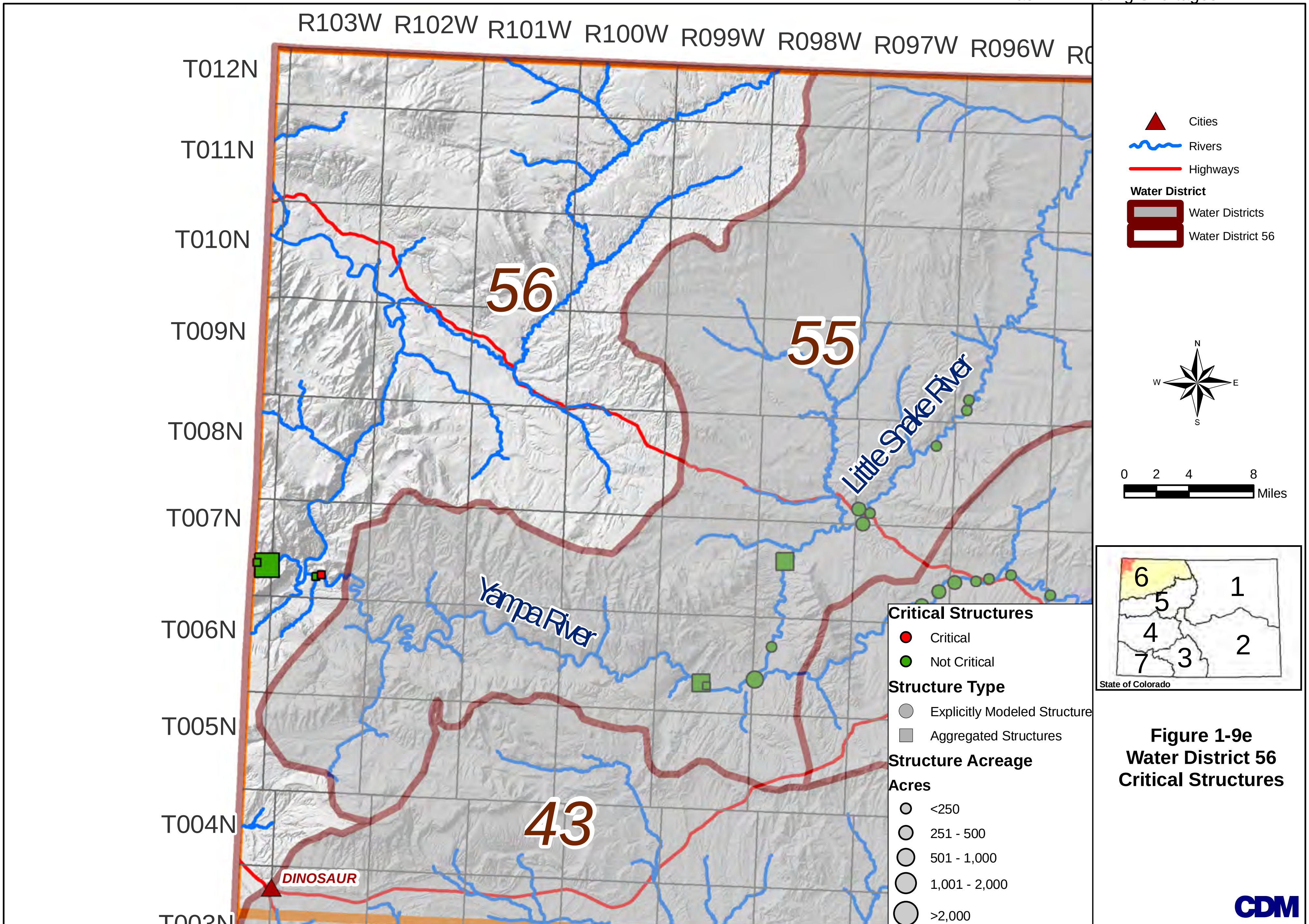

Figure 1-9e
Water District 56
Critical Structures

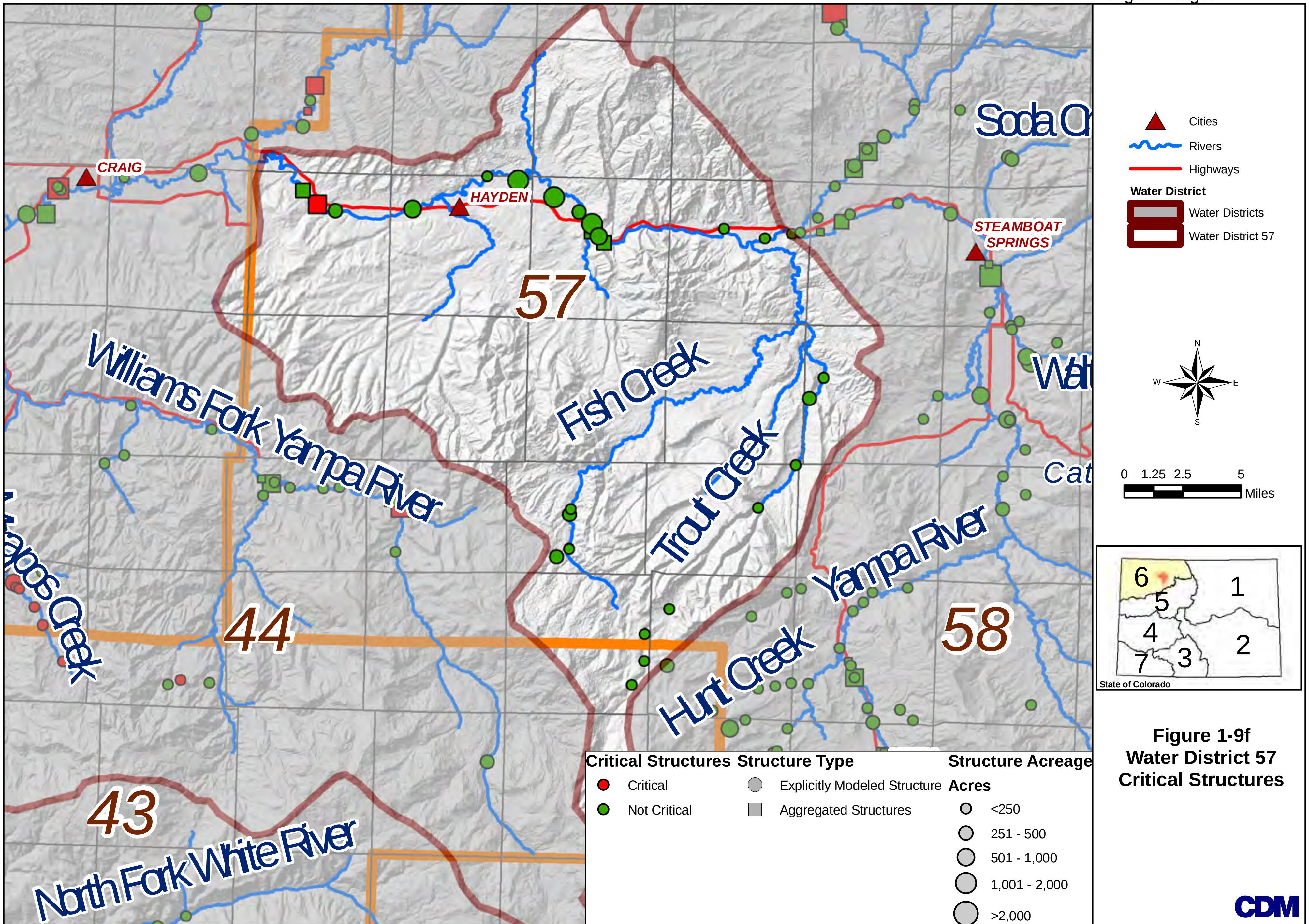

Figure 1-9f
Water District 57
Critical Structures

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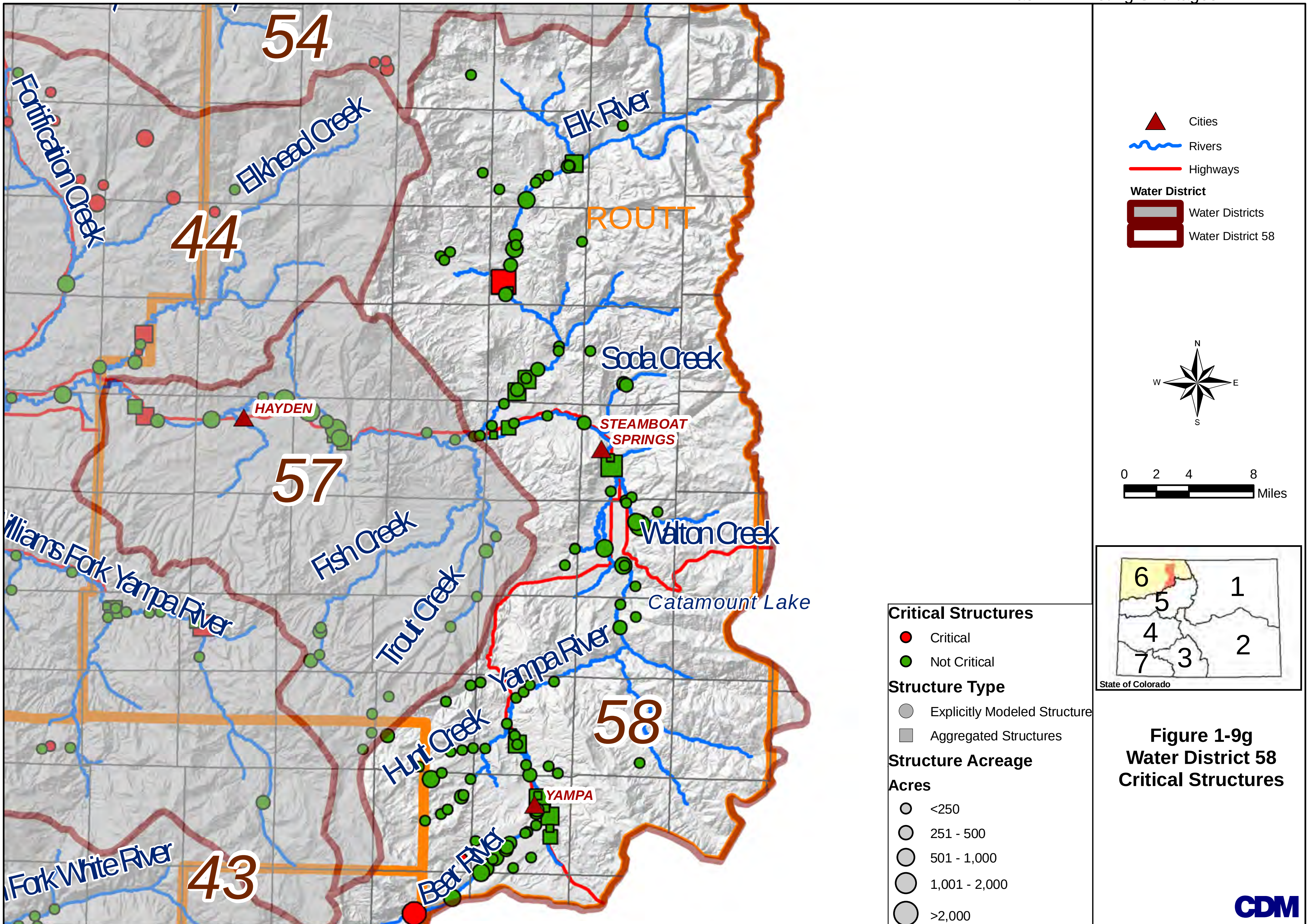

Figure 1-9g
Water District 58
Critical Structures

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Table 1-7 - Streams Sorted by CU Shortage Impact

Water District	Stream	Critically Short Acreage	Average Annual CU Shortage (AF)	CU Shortage per Critically Short Acre (AF/acre)	
58 - Upper Yampa River	Elk River	2,561	3,449	1.35	*
54 - Slater/Timerlake Creeks	Little Snake	3,988	3,808	0.95	*
44 - Lower Yampa River	Little Bear	1,530	1,836	1.20	
44 - Lower Yampa River	Morapose Creek	2,097	2,130	1.02	
58 - Upper Yampa River	Bear River	2,759	2,177	0.79	*
54 - Slater/Timerlake Creeks	Willow Creek	1,639	1,396	0.85	
44 - Lower Yampa River	Milk Creek	1,851	1,532	0.83	*
43 - White River	Piceance Creek	653	806	1.23	*
44 - Lower Yampa River	Williams Fork	1,036	1,120	1.08	*
44 - Lower Yampa River	Fortification Creek	385	468	1.21	
44 - Lower Yampa River	East Fork Williams Fork	1,501	1,179	0.79	*
54 - Slater/Timerlake Creeks	Slater Creek	2,257	1,156	0.51	*
44 - Lower Yampa River	Elkhead Creek	703	561	0.80	*
44 - Lower Yampa River	Pine Creek	223	249	1.12	
44 - Lower Yampa River	Yampa River	1,262	895	0.71	*
44 - Lower Yampa River	Dry Creek	289	250	0.86	
44 - Lower Yampa River	Little Cottonwood Creek	207	213	1.03	
57 - Middle Yampa River	Yampa River	632	399	0.63	*
44 - Lower Yampa River	Beaver Creek	150	127	0.85	
56 - Green River	Green River	0	383	0.00	*
58 - Upper Yampa River	Walton Creek	0	241	0.00	
43 - White River	Soldier Creek/East Douglas/Douglas Creek	57	43	0.75	
58 - Upper Yampa River	Watson Creek	118	55	0.46	
43 - White River	White River	0	126	0.00	*
58 - Upper Yampa River	Yampa River	0	123	0.00	*
58 - Upper Yampa River	Soda Creek	0	73	0.00	
58 - Upper Yampa River	Chimney Creek	0	65	0.00	*
58 - Upper Yampa River	Sand Creek	0	64	0.00	
55 - Little Snake River	Little Snake	0	63	0.00	
58 - Upper Yampa River	Day Creek	0	39	0.00	
57 - Middle Yampa River	Trout Creek	0	37	0.00	*
43 - White River	Evacuation	0	36	0.00	*
43 - White River	Elk Creek	0	33	0.00	

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* Indicates Stream Systems that Include Shortages from B-Aggregates

Table 1-7 - Streams Sorted by CU Shortage Impact

Water District	Stream	Critically Short Acreage	Average Annual CU Shortage (AF)	CU Shortage per Critically Short Acre (AF/acre)
58 - Upper Yampa River	Oak Creek	0	31	0.00
58 - Upper Yampa River	Brinker Creek	0	24	0.00
55 - Little Snake River	Yampa River	60	18	0.29 *
58 - Upper Yampa River	Green Creek	0	23	0.00
43 - White River	Lake Creek/Douglas Creek	12	9	0.74
44 - Lower Yampa River	Waddle Creek	0	19	0.00
43 - White River	Moose Creek/Cave Creek	0	18	0.00
43 - White River	South Fork White River	0	17	0.00 *
43 - White River	Miller Creek	0	15	0.00
58 - Upper Yampa River	South Hunt Creek	0	14	0.00
43 - White River	Big Beaver Creek	0	10	0.00
44 - Lower Yampa River	North Fork Elkhead Creek	0	7	0.00
43 - White River	Hill Creek/Hill Creek Tributary	0	6	0.00
58 - Upper Yampa River	North Hunt Creek	0	4	0.00
43 - White River	North Fork White River	0	4	0.00
58 - Upper Yampa River	Hinman Creek	0	3	0.00
43 - White River	Black Sulphur Creek	0	3	0.00
58 - Upper Yampa River	Beaver Creek	0	2	0.00
43 - White River	Flag Creek	0	2	0.00
58 - Upper Yampa River	Smith Creek	0	1	0.00
44 - Lower Yampa River	Deer Creek	0	1	0.00
44 - Lower Yampa River	James Creek	0	1	0.00
58 - Upper Yampa River	Middle Hunt Creek	0	1	0.00
58 - Upper Yampa River	Lawson Creek	0	1	0.00
44 - Lower Yampa River	Crystal Creek	0	0	0.00
57 - Middle Yampa River	Fish Creek	0	0	0.00
58 - Upper Yampa River	Hot Springs Creek	0	0	0.00
58 - Upper Yampa River	Big Creek	0	0	0.00
58 - Upper Yampa River	Willow Creek	0	0	0.00
43 - White River	Coal Creek	0	0	0.00
43 - White River	Fawn Creek	0	0	0.00
43 - White River	Marvine Creek	0	0	0.00
43 - White River	Ute Creek	0	0	0.00
44 - Lower Yampa River	South Fork Williams Fork	0	0	0.00
57 - Middle Yampa River	West Fish Creek	0	0	0.00
58 - Upper Yampa River	Harrison Creek	0	0	0.00
58 - Upper Yampa River	Hunt Creek	0	0	0.00
58 - Upper Yampa River	Mill Creek	0	0	0.00

* Indicates Stream Systems that Include Shortages from B-Aggregates

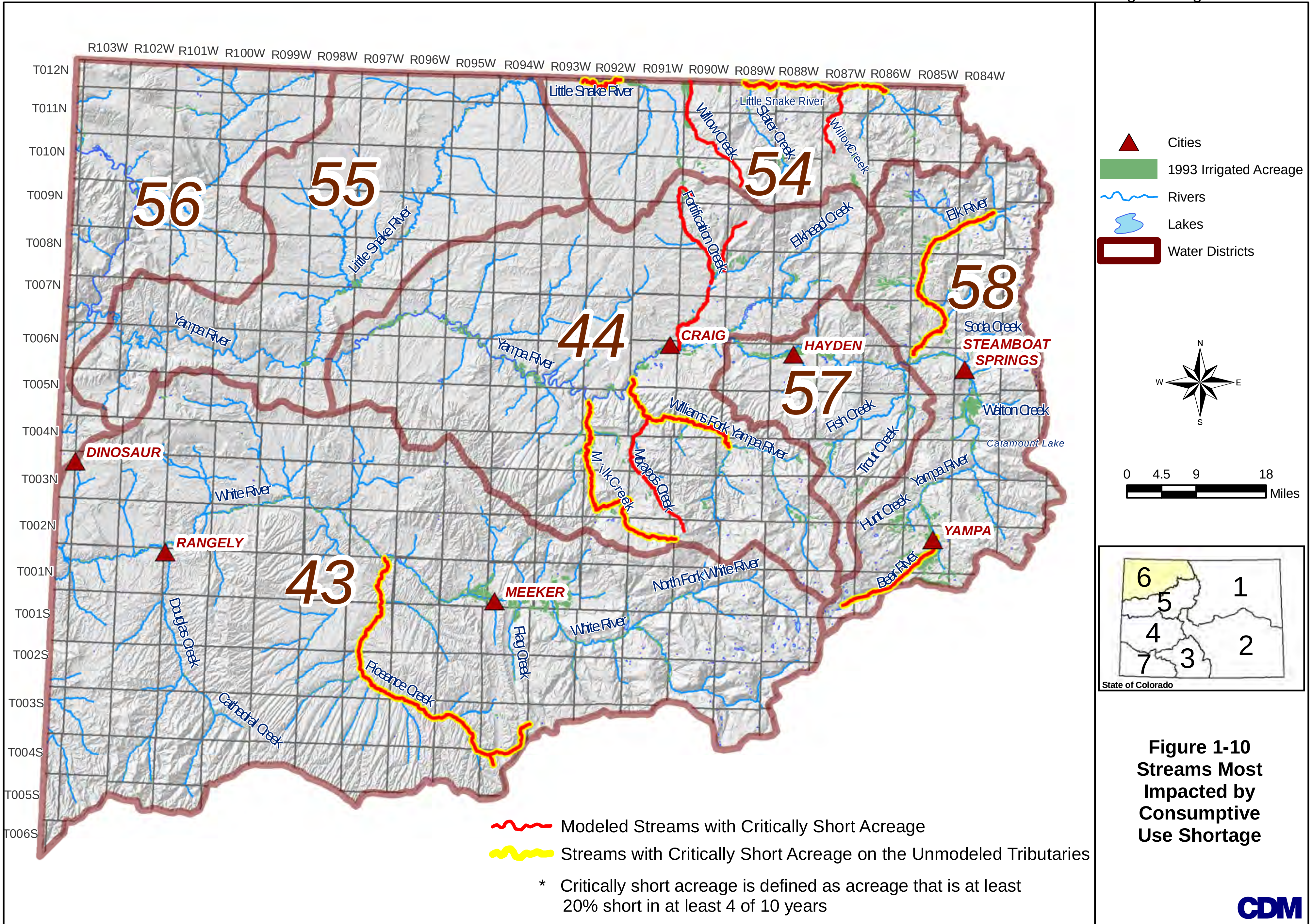

Figure 1-10
Streams Most Impacted by Consumptive Use Shortage

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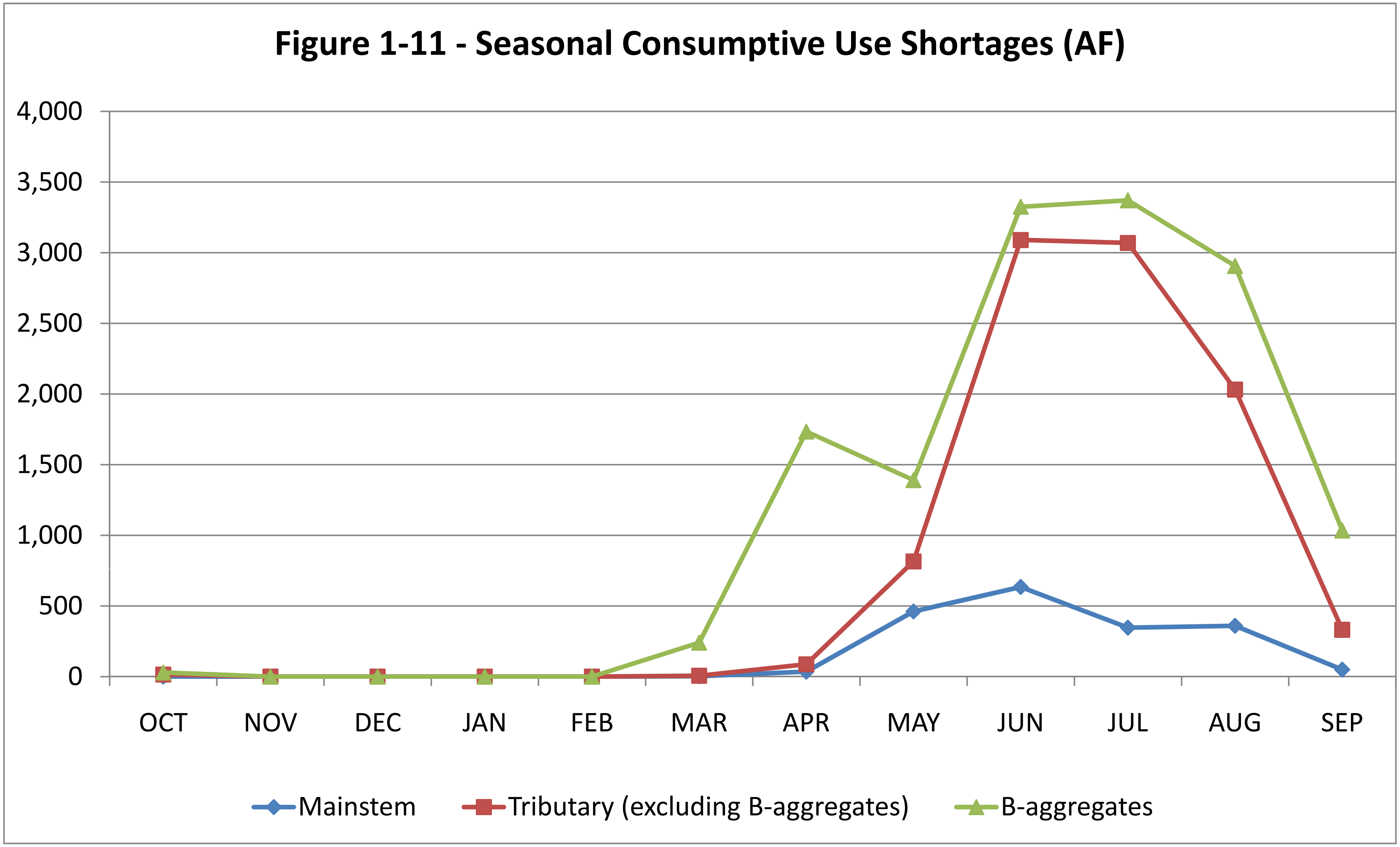
Figure 1-11 - Seasonal Consumptive Use Shortages (AF)
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
Mainstem
Tributary (excluding B-aggregates)
B-aggregates

by StateMod at each model location. Available water in September and October was summed at the most downstream point in each water district. Available water is compared to the Water District level late season demand for a basin level estimate of the demand that could be met by late season diversions and is presented in Fig 1-12. The figure shows that all basins have sufficient water availability to supply the late season demand except the Green River. However, the basin-wide water availability could mask lack of water availability on tributaries, but shows that a supplemental supply project in the basin could help meet the late season soil moisture deficit demand. Due to lack of streamflow data for the B-aggregates on the Green River (which comprise the majority of acreage in District 56), historical diversions in September and October were evaluated with IWR and the soil moisture deficit. This indicates that tributaries in other basins may not be able to meet the soil moisture demand without storage facilities. Water availability on a stream-specific basis for supplemental water supply projects will be evaluated in future technical memoranda (Tasks 5 and 7) and stream-specific late season soil moisture deficit will be evaluated at that time.

Table 1-8 presents the shortages at the focus ditches.

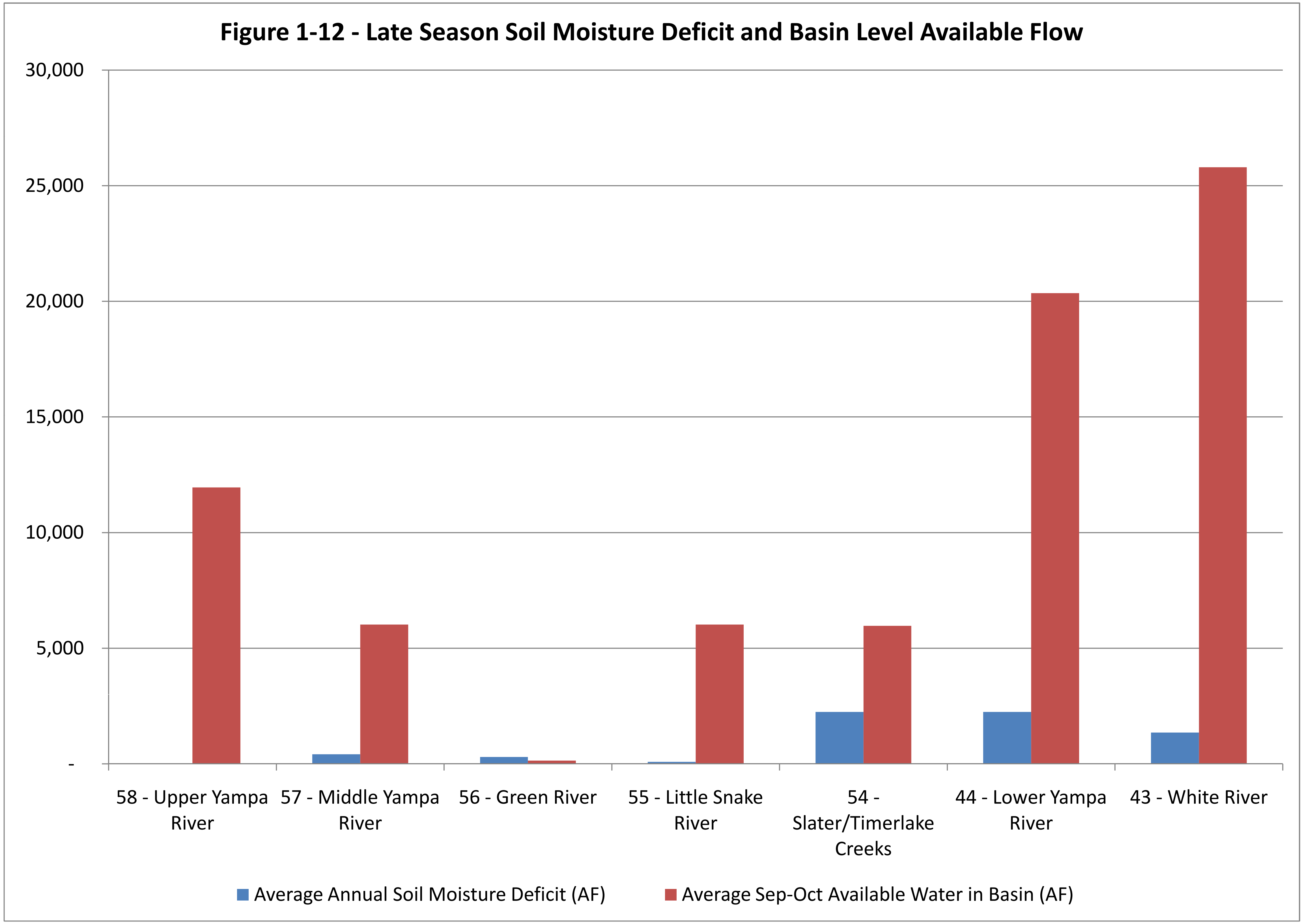
Figure 1-12 - Late Season Soil Moisture Deficit and Basin Level Available Flow
30,000
25,000
20,000
15,000
10,000
5,000
-
58 - Upper Yampa River
57 - Middle Yampa River
56 - Green River
55 - Little Snake River
54 - Slater/Timerlake Creeks
44 - Lower Yampa River
43 - White River
Average Annual Soil Moisture Deficit (AF)
Average Sep-Oct Available Water in Basin (AF)

Table 1-8 - Consumptive Use Shortages at Focus Ditches

Structure Name	Water Source	ID	Irrigated Acreage	Average IWR (AF)	Average CU Shortage (AF)	Average CU Shortage as % of IWR	Idendified as Critically Short
HIGHLAND DITCH[1]	WHITE RIVER	430694	1,851	2,750	0	0.0%	No
SQUARE S CONS D SYS	PICEANCE CK	430948	303	443	1	0.2%	No
WISCONSIN DITCH	FORTIFICATION CK	440511	543	888	14	1.5%	No
DEEP CUT IRR D	YAMPA RIVER	440589	583	953	0	0.0%	No
HIGHLAND DITCH	MORAPOS CK	440651	856	1,455	593	40.7%	Yes
MILK CK DITCH	MILK CK	440706	373	624	156	25.0%	Yes
MORGAN SLATER DITCH	SLATER CK	540549	148	358	0	0.0%	No
MAJORS PUMP NO 2	LITTLE SNAKE RIVER	550506	388	622	0	0.0%	No
GREEN AGGREGATE	GREEN RIVER TRIBUTARIES	56_ADY027b	2,016	3,263	383	11.7%	No
WALKER IRRIG DITCH	YAMPA RIVER	570611	1,298	1,617	0	0.0%	No
MORIN DITCH	ELK RIVER	580783	463	968	0	0.0%	No
NICKELL DITCH	BEAR RIVER	580798	284	593	0	0.0%	No
NORTH HUNT CREEK DITCH	NORTH HUNT CK	580801	131	274	0	0.0%	No

1 - also known as the White River Highland Ditch

Critically short acreage is defined as at least 20% short in at least 4 of 10 years

6.0 Conclusions

6.1 Demands

The CDSS StateCU and StateMod models were refined to include the Denver Water High Altitude crop coefficients for pasture grass (hay) fields above 6,500 feet. For all other crops, an elevation adjustment of 10 percent per 1,000 meters above sea level was used to be consistent with the approach taken in CRWAS and common practice of the State Engineer Office.

The CDSS StateCU and StateMod models were updated to only use the 1993 acreages for the entire study period. As a result, a total of 119,607 irrigated acres were simulated in the study area for all years and were assumed to represent current conditions.

Compared to values reported in SWSI, IWR increased by 54 percent basin-wide when the high-altitude coefficients for the hay/grass above 6,500 feet and are considered, and an increase of 65 percent when the elevation adjustment and high altitude crops were considered (Figure 1-5, Table 1-3).

6.2 Consumptive Use Shortages

The CDSS StateMod model for the Yampa and White Rivers was modified to refine the consumptive use shortage estimates provided in SWSI. Three significant changes to the 2008 release of the models were made.

1) New baseflows (or virgin flows) were computed using updated IWR crop demands. A more recent version of the data management interface (StateDMI version 3.0.8) was provided by the State and used for aggregate nodes to correct a computational error discovered in the 2008 model release. Calibration of the model was checked with new baseflows.

2) To reduce the amount of uncertainty related to historical acreage and missing or incomplete diversion records, the demands computed using the best and most recent most accurate available irrigated acreage aerial photography (year 1993) were used to generate headgate demands in the model. The headgate demands used historical monthly efficiency values to account for conveyance and on-field losses, but were limited to a 30 percent minimum and 50 percent maximum efficiency.

3) To allow more detailed modeling appropriate for this study, each aggregate node was split into two nodes; one for structures that divert from a modeled stream (A-aggregates), and another for structures that divert from a tributary that is not modeled (B-aggregates). Historical diversions were used as a surrogate for physical water supply in the B-aggregates. Splitting the aggregate nodes in this manner prevents simulated available water in a modeled stream to be used at a structure that cannot physically divert from the modeled stream.

Model results show that on a basin-wide scale, consumptive use shortages are larger than reported in SWSI. CU shortages are much more prevalent on the tributaries in the basin due to lack of physical availability on these streams. Approximately 93 percent of the CU shortage in the basin occurs on tributaries that contain only 60 percent of the irrigated acreage (Table 1-6). The disproportionate amount of shortages on tributaries is due to the fact that snowmelt is the primary water source in the basin. In tributaries this causes a high discharge in the spring and very little discharge for the rest of the growing season. In mainstem river reaches of the basin, these peaks are attenuated by a wider range of elevations and associated snowmelt timing resulting in more consistent flow during the early and late part of the growing season. Return flows from irrigation water also play a role in water availability in the late season and will be addressed in more detail in a future technical memo (Task 6).

Critically short acreage, defined as acreage under a structure that is more than 20 percent short in at least 4 of 10 years, was quantified by water district and by structure type (Table 1-6, Figure 1-7). 89 percent of critically short acreage is located on tributary streams while comprising only 60 percent of irrigated acreage in the study area. Of the 89 percent of critically short acreage, 33 percent is located on the modeled tributaries (generally more major streams), and 56 percent is located on smaller, unmodeled tributaries. Average annual CU shortage and critically short acreage are mapped on Figures 1-8 and 1-9.

Consumptive use shortage, critically short acreage and the ratio of the two were computed for each watershed in the basin, and were ranked. The streams were sorted by rank to help identify the watersheds that have a combination of the most CU shortage, most critically short acreage and the most severe shortages on the critically short acres (Table 1-7). This list will aid alternatives analyses by identifying areas where a supplemental supply project might be most beneficial from an agricultural water needs perspective.

The results presented in this technical memorandum will serve as a point of comparison for all future modeling scnenarios (e.g. climate change, energy development, water supply projects, change in return flow patterns). Shortages at the focus ditches are presented in Table 1-8 and will serve as a baseline of comparison for future model scenarios at those particular structures.

SWSI reported consumptive use shortages of more than 10 percent only in Water Districts 44 (Lower Yampa River) and 54 (Slater/Timberlake Creeks). Results from this study show that the District 56 (Green River) also has shortages over 10 percent. More importantly, this study has identified that the shortages disproportionately impact structures on the tributaries and shortages at those structures are generally much higher than 10 percent (Figure 1-6).

7.0 References

BBC Reasearch & Consulting. "Yampa Valley Water Demand Study." Study, Denver, CO, 1998.

CDSS. "Yampa and White Basin StateMod Models." 2008.

CRWCD. "Yampa River basin - Small Reservoir Study." Study, Glenwood Springs, Colorado, 2000.

CWCB. "SPDSS Task 59.1." *Develop Locally Calibrated Blaney-Criddle Crop Coefficients*. 2008.

—. "StateCU Documentation." September 2008.

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Jensen, M. E., R. D. Burman, and R. G. Allen. *Evapotranspiration and Irrigation Water Requirements (ASCE Manuals and Reports on Engineering Practice No. 70).* ASCE, 1990.

Penry, et al. "House Bill 05-1177." *Colorado General Assmbly*. 2005. http://www.state.co.us/gov_dir/leg_dir/olls/sl2005a/sl_314.htm.

—. "House Bill 06-1400." *Colorado General Assembly*. 2006. http://www.state.co.us/gov_dir/leg_dir/olls/sl2006a/sl_279.htm.

CDM

Memorandum

To: *Jeff Comstock (Moffat County), Yampa/White/Green Basin Roundtable Agricultural Subcommittee*

From: *Matt Bliss, Mark Hoener (CDM); Hal Simpson (H. D. Simpson Consulting); Ross Bethel (Ross Bethel, LLC)*

Date: *June 2, 2010*

Subject: *Agricultural Water Needs Study: Task 2 Final*

We are pleased to present the final draft of the Yampa/White/Green Agricultural Water Needs Study Task 2 technical memorandum. This task identifies potential future irrigated acreage in the study area. This memo was prepared by CDM staff and reviewed by both Hal Simpson and Ross Bethel. Additionally, the final version incorporates comments the subcommittee has raised at the progress meetings.

Sincerely,

Matt Bliss
Project Manager

1.0 Introduction and Background

In 2005, House Bill 05-1177, the Colorado Water for the 21st Century Act, was signed into law. Among other provisions, the bill provides for the creation of Basin Roundtables. Each Basin Roundtable is charged with formulating a water needs assessment, conducting an analysis of available un-appropriated water, and proposing projects or methods for meeting those needs.

In 2003, the Colorado Water Conservation Board (CWCB) completed the Statewide Water Supply Initiative (SWSI). That study included estimates of water demands in the White and Yampa River Basin through 2030. SWSI concluded there was little "gap" between projected municipal and industrial water demands and available water supplies in the basins. While SWSI provided a valuable coarse assessment of water demands for the municipal, industrial, and agricultural sectors, concerns were raised at that time that the analysis did not accurately reflect the agricultural water shortages in some of the water districts and especially as it exists on the tributaries. One concern was that the Yampa River Basin analysis of agricultural demand was not based on high altitude crop coefficients, thus understating the demand for water in the Yampa River Basin.

SWSI also noted that up to an additional 40,000 acres of agricultural lands could be developed in the basins but did not investigate the location or impact of additional agricultural demand in these basins. SWSI also indicated a potential of losing 1,200 to 2,600 acres of irrigated land due to transfers or urbanization for a maximum potential net gain in acreage of 39,000 (rounded to nearest 1,000 acres). The Colorado River Water Conservation District Small Reservoir Study identified sites for additional water supply storage in the Yampa Basin. That study highlighted the need to look at integrating irrigation practices with storage to better meet water demands.

The objectives of the current study are to:

1. Refine and update previous estimates of current agricultural water demands, supplies, and shortages for the Yampa/White/Green River Basin through use of the State's Decision Support System (DSS) models and data

2. Identify and evaluate shortages for the future agricultural demands.

3. Assess the impacts of climate change on agricultural water availability

4. Assess the impacts of energy sector water supply development on agricultural water availability in the White River basin.

5. Assess water supply development alternatives to satisfy shortages identified in (1), (2) and (3).

6. Assess the effects on return flows of various irrigation practices or changes in those practices.

7. Investigate creative solutions that benefit multiple interests (e.g., agriculture, energy, recreation, environment, etc.).

This technical memorandum addresses the second of those objectives, and is second in a series of technical memoranda that will address each of the objectives. Figure 2-1 shows a map of the study area.

2.0 Agricultural Subcommittee Input

Several of the tasks in this study required input and feedback from the agricultural subcommittee of the Yampa/White/Green basin (BRT subcommittee). BRT subcommittee members include Dan Birch, Darryl Steele, David Smith, Doug Monger, Geoff Blakeslee, Mary Brown, T. Wright Dickenson, Tom Gray, Dan Craig and Jeff Comstock. To date, CDM has met with the BRT subcommittee on multiple occasions to listen to concerns and discuss the approach to addressing these concerns associated with this task. Items related to future agricultural demands (Task 2) are presented in this section.

One of the objectives of the future demands was to better define the location of the 40,000 of additional irrigated acreage that the BRT identified for SWSI. BRT subcommittee members indicated that the 40,000 acres were identified from National Resource Conservation Service (NRCS) maps along the oxbows of the Yampa River from approximately the Moffat county line to the confluence with the Little Snake. This area is entirely within Water District 44. The original maps used to quantify the 40,000 acres were lost in a fire at the Craig NRCS office.

Through discussions with the BRT Subcommittee, it became apparent that there is a significant amount of potentially irrigable land in the basin outside of the original 40,000 acres along the Yampa as contemplated in SWSI. Subcommittee members requested that acreage in the following categories be evaluated for potential future irrigation demand:

- Aggregation of NRCS mapping of various categories of 'Prime Farmland if Irrigated'. (see Section 4.2 for definition)
- Previously identified projects, such as Juniper Cross, Yellow Jacket, Savery-Pot Hook, Hayden Mesa and Great Northern Projects
- Existing dry-land farms
- Oxbows along the Yampa River between the Moffat County line and the confluence with the Little Snake

3.0 Data Sources

In addition to the input from the BRT Subcommittee, several data sources were referenced to help determine the locations and amount of land that could be brought under irrigation. Potential irrigated acreage and associated irrigation water requirement (IWR) from each data sources is discussed in Section 4.

<u>Agencies</u>

Several governmental agencies were contacted to obtain GIS data of boundaries, soil classifications, and to determine uses of public lands. The CDSS models were developed by the CWCB and CWCB staff was consulted through the modeling process. The following is a listing of agencies whose data was used in this study:

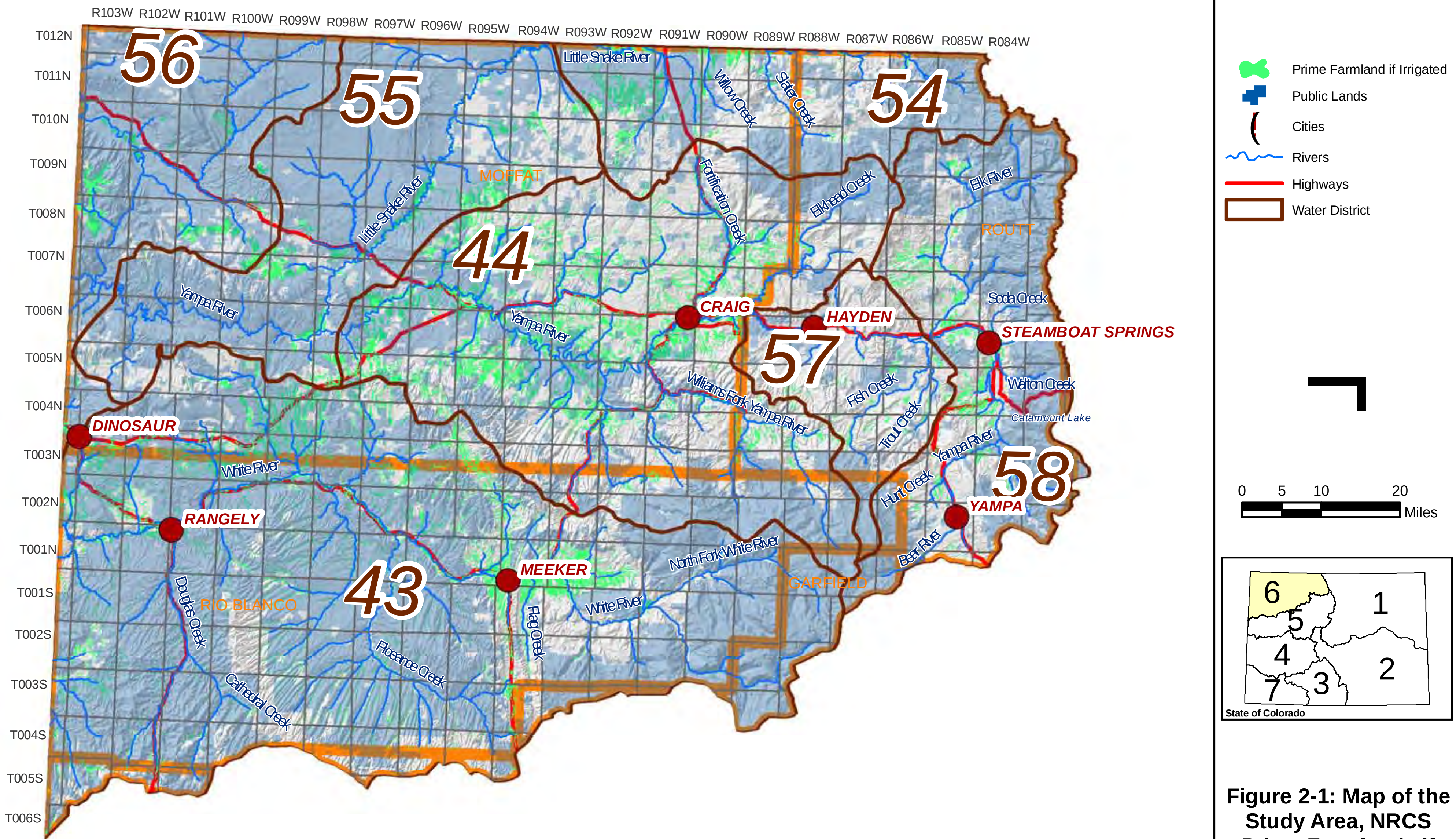

Figure 2-1: Map of the Study Area, NRCS Prime Farmlands if Irrigated and Public Lands

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- National Resources Conservation Service (NRCS)
- Bureau of Land Management (BLM)
- United States Forest Service (USFS)
- United States Department of Agriculture, Farm Service Agency (USDA, FSA)
- Colorado Water Conservation Board (CWCB)
- State of Colorado (State Land Trust, State Wildlife Areas)

Previous Project Investigations
Five previously proposed larger-scale water supply and irrigation projects were reviewed. While project supply availability and feasibility was not reviewed in this Task, the lands identified in the project investigations were considered for potential future acreage:

- Yellow Jacket Project
- Hayden Mesa Project
- Great Northern Project
- Juniper Cross Project
- Savery-Pot Hook Project

Reports
There have been many reports related to water resources in the Yampa and White basin. The following reports were reviewed and data regarding amounts and locations of potential new irrigated acreage was utilized:

- Yampa Valley Water Demand Study (BBC Research & Consulting 1998)
- Small Reservoir Study (Colorado River Water Conservation District, 2000)
- Yampa River Basin Alternative Feasibility Study Draft Executive Summary (Colorado River Water Conservation District et al. 1993)
- Elkhead Reservoir Project Past, Present and Future Report (Colorado River Water Conservation District November 2003)
- Discussion of Legal and Institutional Constraints on Energy-Related Water Development in the Yampa River Basin, Northwestern Colorado (Knudsen and Danielson 1977)
- Summary of Water Resources Development Investigations 1966 - 1986 White River Basin (Morrison-Kundsen Engineers, Inc. 1986)
- Plan for the Water Supply for Development of Oil Shale Industry in the White River Basin, Colorado (Occidental Oil Shale, Inc. et al., 1979)
- SWSI

4.0 Demand Analysis

4.1 Approach
Potential future demands were quantified in two steps. The first is to define the location and amount of potential acreage to be brought under irrigation. Lands identified in the 1993 irrigated acreage coverage developed for the CDSS were excluded for consideration for new irrigated lands wherever there was

overlap with other data sources. The second step is to assign a projected crop distribution and create new datasets for StateCU that include the potential new acreage. Each of the steps is discussed in further detail below.

4.2 Location and Amount of New Irrigated Land

The potential of bringing new land under irrigation is not a new idea in the study area. Projects dating to the 1950s have contemplated construction of reservoirs and canal systems to provide a more reliable supply for irrigators. Future tasks in this study will use three levels of future development when developing alternatives. It is envisioned that a portion of the acreage identified in this analysis will be used to develop the various build-out demands. This analysis began using sources of data that would likely yield the largest number of potential new acres and worked down to projects, reports or concepts that would yield smaller amounts of irrigable acres. Four levels of potential future irrigated acres were selected for IWR calculation and all or portions of these levels will be considered in water supply alternatives to be evaluated in future tasks of this study. Total acreages are provided in Table 2-1, and discussion of each of the levels follows the table.

The four levels identified in Table 2-1 can be considered as four approaches to identifying potentially irrigable lands in the basin. The full acreage, a subset of the acreage or none of the acreage identified in each level will be selected in the alternatives development in future tasks of this study for the future build-out assumptions. Acreage for prior projects, dry-land farms and Yampa River oxbows are assumed to be subsets of the NRCS ‘Prime Farmland if Irrigated’ dataset. Overlap among other layers is possible but not easily quantifiable due to a lack of mapping. Overlap would most likely occur between the prior projects acreage and the dry-land farms acreage in the Fortification Creek (Great Northern Project) and Hayden Mesa areas.

Table 2-1 – Potential New Irrigated Acreage

Data Source	Description	Potential New Irrigated Acres	Screened Acreage[1]	Simulated Acreage[2]
NRCS	Prime farmland if irrigated GIS data layer	512,698	238,774	273,924
Prior Projects	Yellowjacket, Juniper Cross, Savery-Pot, Great Northern, Hayden Mesa	85,505	50,161	35,344
Dry-land Farms	2007 Census of Agriculture, Harvested Cropland less Irrigated Cropland	33,282	0	33,282
Yampa River Oxbows	Subset of NRCS dataset limited to the oxbows along the Yampa River from the Routt County line to the Little Snake confluence	40,000 (SWSI)	0	14,805
Previous Reports	Yampa Water Demand Study Maximum Foreseeable Increase (15%)	13,500	0	0

1. Acreage removed from consideration for further analysis in this study because acreage is on public lands
2. Acreage used to simulate IWR

NRCS Data

The NRCS has mapped soils in the study area and GIS datasets are available from their website. The classifications of mapping appear to be slightly different for Rio Blanco county than for Routt and Moffat counties. The soil classifications of interest to this study are 'Farmland of Statewide Importance', 'Prime Farmland if Irrigated', 'Prime Irrigated and Drained', 'Prime if Irrigated and Reclaimed of Excess Salts'. Prime farmland is defined as land that has the best combination of physical characteristics for producing food, feed, forage, fiber and oil seed crops and is also available for these. (NRCS no date). According to the USDA, FSA office 'Farmland of Statewide Importance' is defined differently for different states and at different times. Based on examination of the GIS datasets, 'Farmland of Statewide Importance' in Moffat and Routt counties appears to be analogous to lands that were classified as 'Prime if Irrigated' in Rio Blanco county. The four soil classifications were merged into a single GIS layer for further analysis and comprised approximately 513,000 acres.

Much of the lands identified in the NRCS dataset are on federal lands managed by the BLM or USFS (Routt National Forest and White River National Forest). There is also a significant presence of State of Colorado owned lands in the basin (State Land Trusts and State Wildlife Areas). GIS datasets for BLM, USFS and State Lands (hereafter public lands) in the study area were obtained from each agency's online resources. Figure 2-1 shows the extent of public lands in the study area. New irrigation is not contemplated on public lands (phone conversation with BLM field office, September 2009). Figure 2-1 shows large amounts of potentially irrigable lands lie in many small valley bottoms throughout the study area, and larger areas primarily in the eastern portion of the Yampa Basin. Lands identified in the NRCS GIS dataset that fall within the public lands were excluded from potential future irrigated acreage in the basin. Approximately 274,000 acres of the 513,000 acres (53%) in the NRCS dataset fall on private lands. The lands that fell within public lands were excluded from further analysis (approximately 240,000 acres, 47%).

Previously Proposed Projects

Several large-scale irrigation and water supply projects have been proposed over the past 50 years in the study area. However, none of the projects have been built due to concerns about economic feasibility and environmental concerns. Although the economic and environmental concerns are still valid (e.g. cost of reservoirs, environmental impacts of on-channel reservoirs), one of the objectives of future tasks of this study is to develop and assess feasibility of developing supplies to meet a potential future demand. In that light, the irrigated acreage associated with these projects was considered as potentially irrigable, and the associated supply development challenges will be evaluated in future tasks of this study.

Five projects were evaluated: Yellow Jacket Project, Hayden Mesa Project, Great Northern Project, Juniper Cross Project, and the Savery-Pot Hook Project. GIS datasets for potential irrigated lands were not available for any of the projects, and the information obtained for each project had varying levels of detail on irrigated acres. Locations of proposed irrigated acreage for each project were estimated from available data and maps, and aggregated by township. The combined total of new irrigated lands identified in the projects is 85,505 acres. Similarly to the NRCS datasets, much of the land identified in the projects is potentially located on federal or state lands. As a screening step, the total acreage of the NRCS 'Prime Farmland if Irrigated' dataset that does not lie within public lands were quantified by township where the projects are located. The minimum of the acreage within a township of either the proposed project acreage or the NRCS 'Prime Farmland if Irrigated' acreage not on public lands was identified as potentially irrigable land. This screening resulted in approximately 35,000 acres (41%) being retained for further evaluation, and removal of approximately 50,000 acres (59%) from further analysis. Figure 2-2 shows the screened distribution of irrigated acreage contemplated by the five projects. This level of screening is potentially conservative since the projects may not have been planned on public lands during their inception. However, the soil types contemplated for the studies may have been of a lower quality than identified by the NRCS as 'Prime Farmland if Irrigated'. The lands associated with previous projects considered in this analysis (approximately 35,000 acres) are only lands identified or estimated from project documents and maps that are considered 'Prime Farmland if Irrigated' and do not lie on public lands.

Existing Dry-land Farms

There is a significant portion of land in the study area that is used for dry-land farming. Table 2-2 summarizes acreages reported in the 2007 Colorado Census of Agriculture (USDA 2009). The Census shows that there is a large amount of land that is used for pasture, but not harvested (i.e. used for grazing or accounts for crop failure), but also shows that 74% of the land that is harvested is irrigated. No further details of location are provided in the document and no GIS datasets are available. The Yampa basin is generally covered by Moffat and Routt Counties, and the White River is covered by Rio Blanco County.

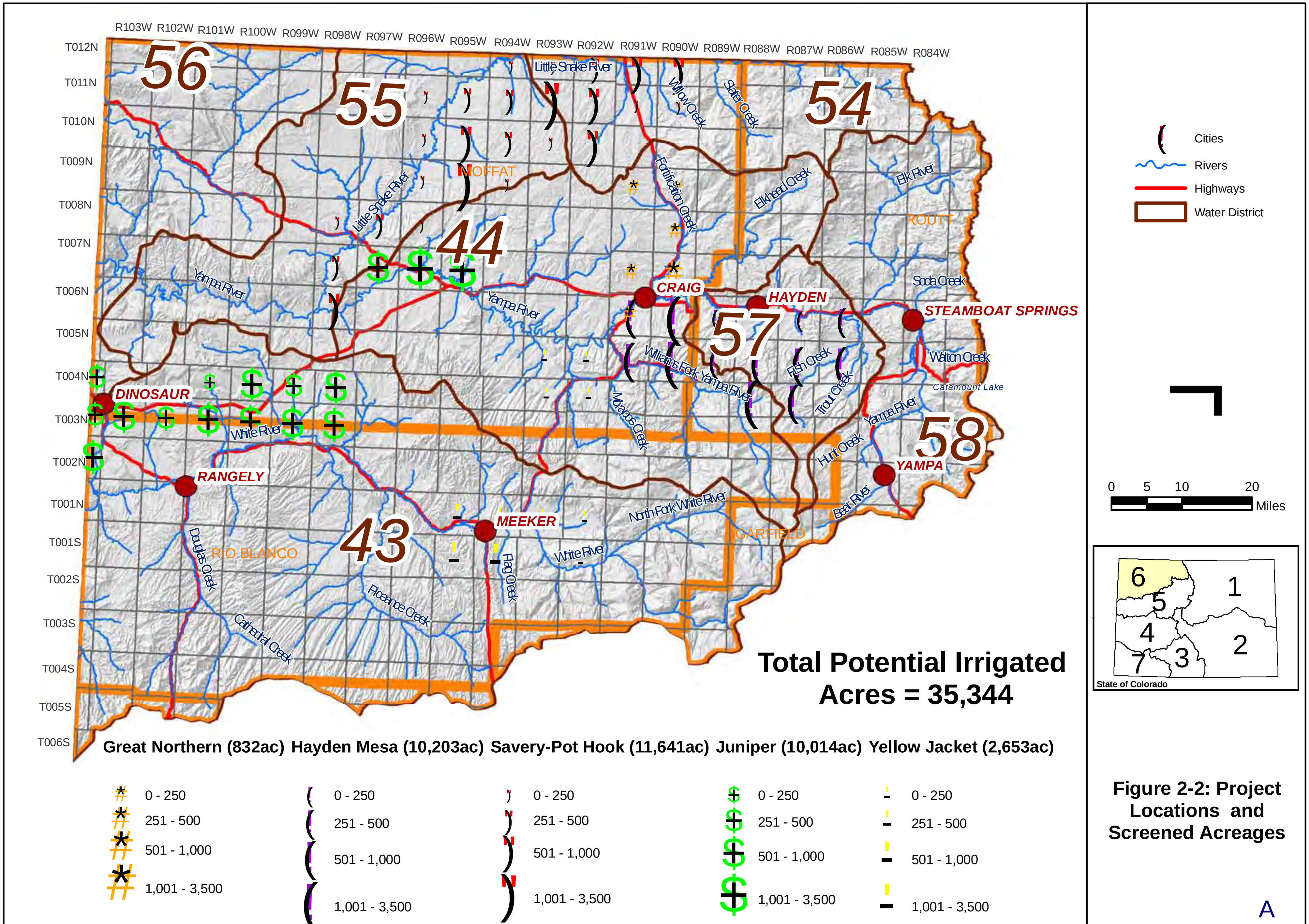

Figure 2-2: Project Locations and Screened Acreages

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Table 2-2 – 2007 Census of Agriculture (USDA 2009)

County	Total Cropland [1]	Harvested Cropland [2]	Irrigated Acres	Harvested Cropland Not Irrigated	Irrigated Acres as % of Harvested Cropland
Routt	129,874	56,636	43,527	13,109	77%
Moffat	135,148	48,645	28,472	20,173	59%
Rio Blanco	55,197	22,393	22,992	0	103% [3]
Total	320,219	127,674	94,991	33,282[4]	74%

1. Total Cropland is defined as cropland that is harvested, used for grazing or crop failure
2. Harvested Cropland is defined as land from which crops were harvested and hay was cut
3. Greater than 100% indicates some irrigated land was not harvested (i.e. used for grazing or crops failed)
4. Total of Routt and Moffat Counties only since Rio Blanco County shows more land irrigated than harvested.

The BRT Subcommittee suggested contacting the FSA offices in Moffat and Craig counties to try to obtain GIS datasets of land that is enrolled in the Conservation Recovery Program (CRP). According to the subcommittee, many of the dry-land farms are enrolled in CRP. However, due to security and privacy concerns, FSA policy is to not release any of the GIS data without individual landowner consent, even if there is no identifying information of the participant.

Without specific location information of dry-land farms, some general assumptions must be made to use this information presented in Table 2-2. First, it is assumed that the total cropland acreage presented in Table 2-2 includes land for grazing that would be less suitable for irrigation since crops on these lands are not currently harvested. Second, it is assumed harvested cropland could be brought under irrigation if a water supply were available. Under these assumptions, a total of 33,282 acres could be brought under irrigation by subtracting the irrigated acreage from the harvested acreage. Lands in Moffat County were generally described by the FSA staff as north of Craig. It was assumed that all Moffat County acreage would be in Water District 44. The FSA staff in Routt County indicated lands were located both south of US Highway 40 near Hayden, and in the southern portion of the county. For this analysis, it was assumed that half of the Routt county acreage would be in Water District 57 (near Hayden), and half in the southern portion of Water District 58 (southern Routt County). It is anticipated that the potentially irrigable dry-land farm acreage are a subset of the NRCS 'Prime Farmland if Irrigated' dataset.

Yampa River Oxbows

BRT Subcommittee members indicated during SWSI that there are approximately 40,000 acres along the Yampa oxbows from the Moffat county line to the confluence with the Little Snake. The maps used to quantify this acreage were lost in a fire at the Craig NRCS office. The acreage of NRCS 'Prime Farmland if Irrigated' GIS dataset was quantified within a half-mile buffer on either side of the Yampa River though this reach. This buffer resulted in identification of 14,805 acres of potentially irrigable lands (Figure 2-3). Due to the close proximity to the river of some of these lands, it is possible that subirrigation would preclude the need for an external irrigation system. However, the level of detail possible in this study makes it difficult to make an elevation determination that would distinguish lands that could benefit from subirrigation and those that would require an external irrigation system. Therefore, as a conservative assumption for potential future demand, it was assumed that none of these lands would benefit from subirrigation. The acreage identified using the GIS buffer resulted in significantly less acreage than was estimated during SWSI, however, members of the Subcommittee that delineated the

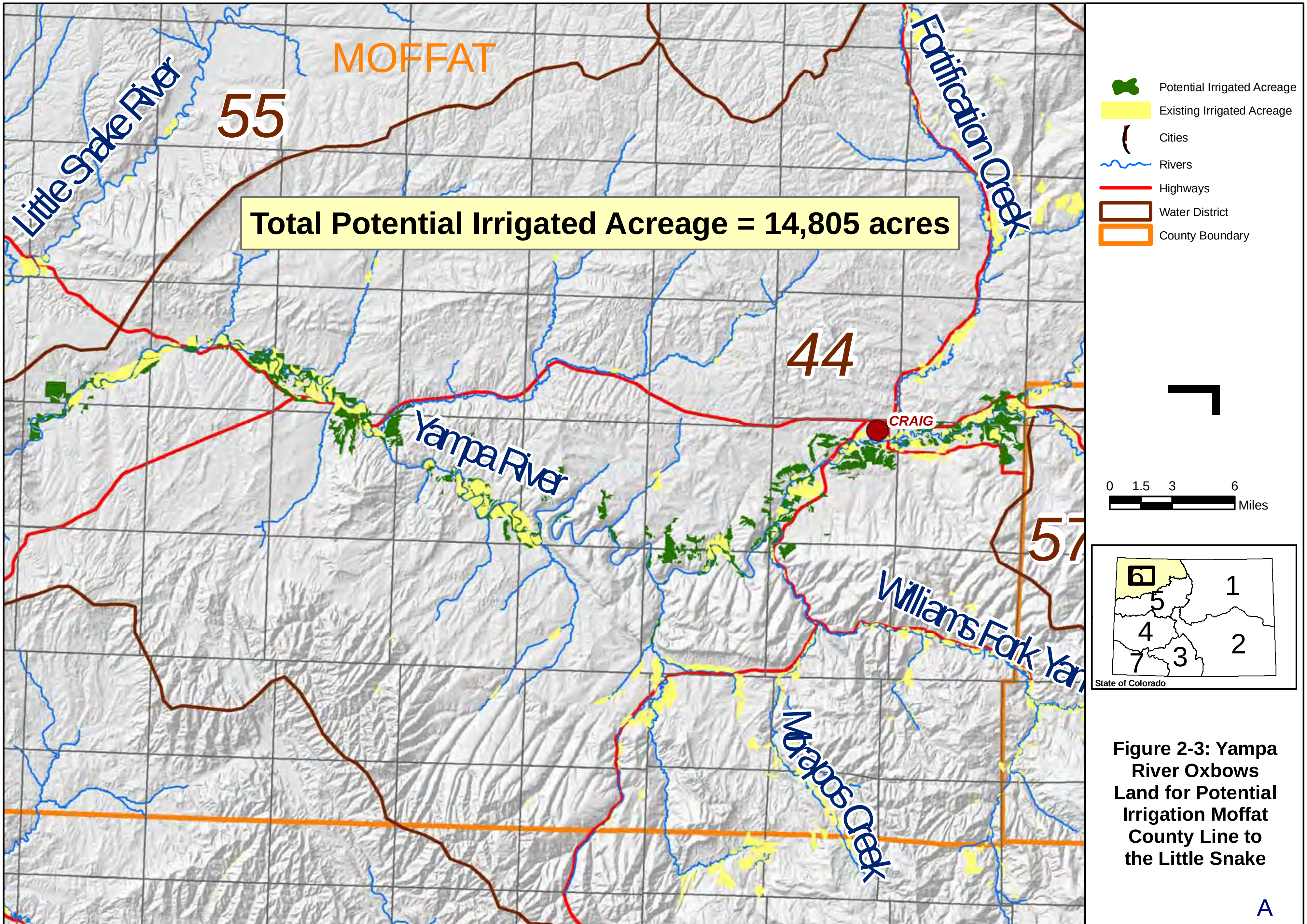

Figure 2-3: Yampa River Oxbows Land for Potential Irrigation Moffat County Line to the Little Snake

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40,000 acres noted that acreage in the Fortification Creek drainage were part of the 40,000 and the 14,805 acres along the Yampa was similar to the amount they had quantified previously.

Other Reports
In addition to the sources identified by the BRT Subcommittee, several other previous reports were reviewed to quantify the extent of additional irrigated acreage that has been considered by others. The reports reviewed are listed in Section 3. Most of the reports indicated no increase in irrigated acreage, but addressed existing irrigated lands. The Yampa Basin Water Demand Study used a maximum foreseeable increase in irrigated acreage of 15% over current levels (~13,500 acres in the Yampa Basin), but indicated this was not likely and used the current irrigated acreage for the majority of their analyses. The Small Reservoir Study discussed several potential reservoir sites in tributary basins of the Yampa, but generally only shortages at existing irrigated lands were considered and new acreage was not. Potential new acreage shown in Table 2-1 shows several potential areas that could be irrigated that would amount to the 15% increase contemplated in the BBC report, and is therefore not identified separately in Table 2-1.

4.3 Crop Distribution and IWR
For this analysis, it was assumed that future crop distributions would remain unchanged from current conditions. Much of the potential new irrigated acreage identified in Table 2-2 does not have a specified location, which could have significant impacts on future IWR. IWR Sensitivity to location in the basin was tested by adding 8 new structures to the StateCU model. These structures were located at approximately the center of each water district near existing irrigated acreage and estimated locations of new irrigated acreage presented in Table 2-1. Two structures were placed in the White River Basin (Water District 43) representing upper and lower portion of the basin to distinguish between higher and lower elevations (Yampa Basin has separate water districts for upper and lower reaches). Each structure was modeled as one acre of land with the average crop hay and alfalfa distribution of the study area (94% hay/pasture_grass, 6% alfalfa). Structures were modeled with the appropriate elevation adjustment (see Technical Memorandum 1, Section 3.3) based on their location (e.g. high altitude crop coefficients and adjustment of SMS TR21 crops). The results of this StateCU model run allow the demand for any number of acres in any region of the study area to be quantified for further analysis. Unit demands were multiplied by the number of acres presented in Table 2-1 based on their estimated locations. Potential future acreage and consumptive demand is shown in Figure 2-4.

Headgate diversions needed to meet the consumptive demand will be approximately 2 to 3 times higher than the IWR, depending on efficiency achieved by the conveyance system and on-field efficiency of the new lands.

5.0 Conclusions

Several data sources were consulted to determine the amounts and location of potentially new irrigable lands within the study area. Incomplete or unavailable GIS datasets associated with each data source make it difficult to identify exact locations of the potentially new irrigable land in the study basin. Four levels of potentially new irrigable land were investigated and the acreages are presented in Table 2-1.

A unit acre of land was simulated in StateCU in eight locations throughout the basin to provide unit estimates of IWR for various locations in the study area. The estimated locations of the new potentially

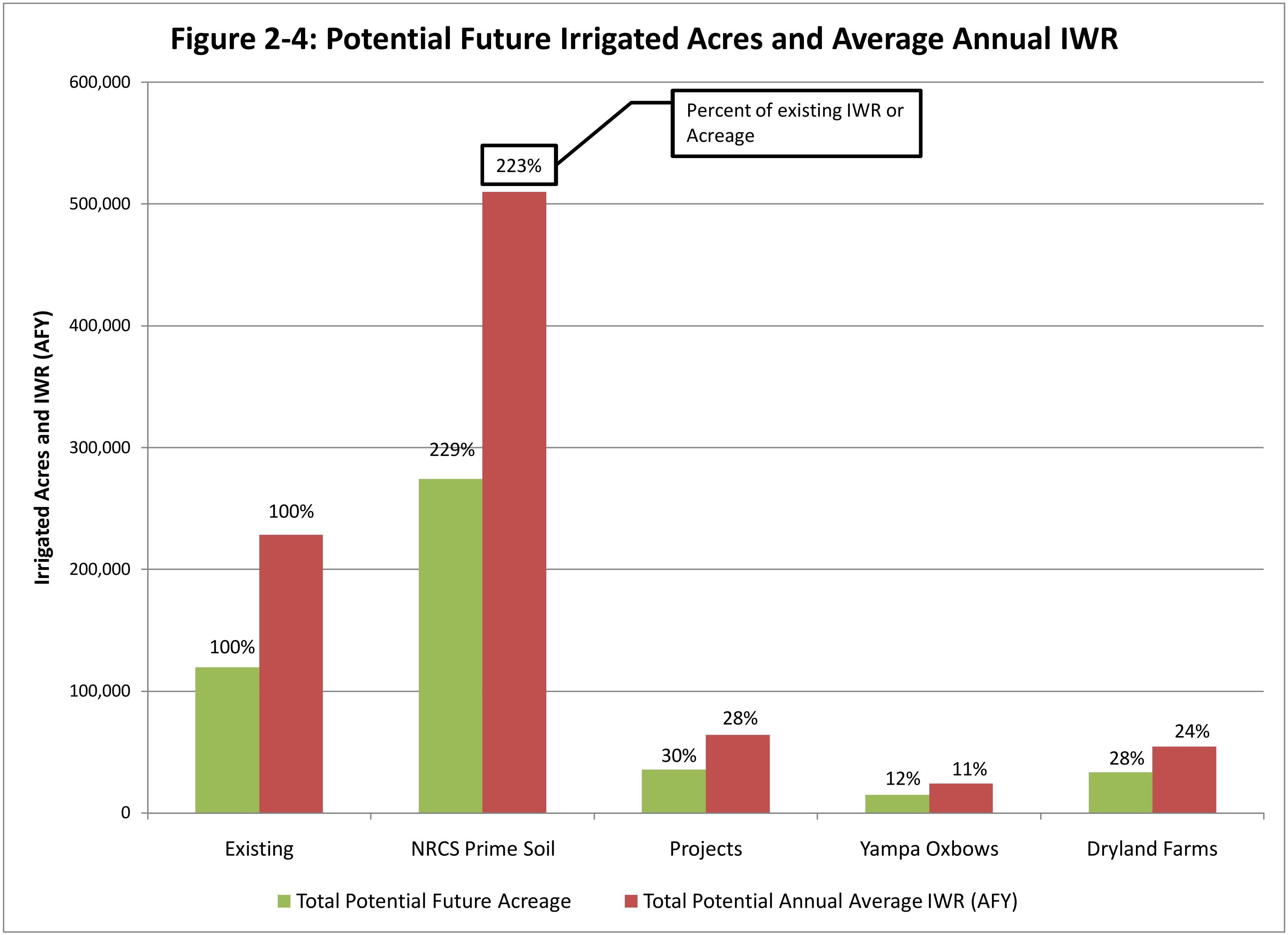


Figure 2-4: Potential Future Irrigated Acres and Average Annual IWR
Irrigated Acres and IWR (AFY)
600,000
500,000
400,000
300,000
200,000
100,000
0
Percent of existing IWR or Acreage
223%
229%
100%
100%
30%
28%
12%
11%
28%
24%
Existing
NRCS Prime Soil
Projects
Yampa Oxbows
Dryland Farms
Total Potential Future Acreage
Total Potential Annual Average IWR (AFY)

irrigable lands identified in Table 2-1 were multiplied by the unit IWR to determine the total potential new IWR associated with the potential new acreage (Figure 2-4)

Table 2-1 shows that a maximum of approximately 274,000 acres could be brought under irrigation in the study area if a source of water could be developed. However, Figure 2-1 shows that the location of these acres falls along multiple valley bottoms of small tributaries within the study area. Most of this acreage would be very difficult to supply with a reliable source of irrigation water. It is anticipated that much of this acreage will not be considered for analysis of water supply alternatives in future tasks of this study.

Table 2-1 shows that there are approximately 35,000 acres of land that were identified as irrigable as part of previous proposed water supply projects. The 35,000 acres limits the lands identified by previous projects to ‘Prime Farmland if Irrigated’ that do not lie on public land. These projects all had identified a source of water and reservoir locations to provide a reliable supply to these lands. Many of the reservoir sites would no longer be feasible due to more recent environmental concerns about on-channel reservoirs. However, it is anticipated that these lands or a subset thereof will be part of the water supply alternatives analysis in future tasks of this study.

Dry-land cropland was also considered as potentially new irrigable land. Table 2-2 shows that approximately 33,000 acreas of existing dry-land farming could be brought under irrigation in Routt and Moffat Counties. No such acreage was identified in Rio Blanco County using the same criteria as Routt and Moffat Counties.

Land near the Yampa River between the Moffat County line and the Little Snake confluence were estimated at 40,000 acres during SWSI, however maps used to estimate this acreage was lost in a fire at the Craig NRCS office. Using GIS datasets, a half-mile buffer on the Yampa River identified approximately 14,000 acres of ‘Prime Farmland if Irrigated’. It is anticipated that most of this land will be considered in the water supply alternatives analysis in future tasks of this study. Given the large amounts of available water on the Yampa mainstem (see Technical Memorandum No. 1), these lands could be supplied with relatively little new infrastructure.

Other reports regarding water resources in the study area revealed little to no information on potential areas of new irrigation. These reports will likely be useful for the supply alternatives analysis in future tasks.

The IWR estimated for the new acreage represents the maximum potential consumption by the irrigated crops. Headgate diversions required to fully supply the new acreage will be approximately two to three times higher than the IWR, depending on conveyance and on-field efficiency achieved on the new lands.

6.0 References

CWCB. *Statewide Water Supply Initiative (SWSI).* 2004

Penry, et al. "House Bill 05-1177." *Colorado General Assmbly.* 2005

USDA. *2007 Census of Agriculture: Colorado.* 2009

CDM

Memorandum

To: *Jeff Comstock (Moffat County), Yampa/White/Green Basin Roundtable Agricultural Subcommittee*

From: *Matt Bliss, Mark Hoener (CDM); Hal Simpson (H. D. Simpson Consulting); Ross Bethel (Ross Bethel, LLC)*

Date: *June 2, 2010*

Subject: *Agricultural Water Needs Study: Task 3 Final*

We are pleased to present the final draft of the Yampa/White/Green Agricultural Water Needs Study Task 3 technical memorandum. This task addresses potential impacts of climate change on existing agricultural uses in the study area. This memo was prepared by CDM staff and reviewed by both Hal Simpson and Ross Bethel. Ray Alvarado at the Colorado Water Conservation Board (CWCB) also reviewed this document as part of the coordination with the Colorado River Water Availability Study. His comments are addressed in this final version. Additionally, this memo incorporates comments the subcommittee has raised at the progress meetings.

Sincerely,

Matt Bliss
Project Manager

1.0 Introduction and Background

In 2005, House Bill 05-1177, the Colorado Water for the 21st Century Act (Penry, et al., House Bill 05-1177, 2005) was signed into law. Among other provisions, the bill provides for the creation of Basin Roundtables (BRT). Each BRT is charged with formulating a water needs assessment, conducting an analysis of available unappropriated water, and proposing projects or methods for meeting those needs.

In 2003, the Colorado Water Conservation Board (CWCB) completed the Statewide Water Supply Initiative (SWSI). That study included estimates of water demands in the White and Yampa River basins through 2030. SWSI concluded there was little gap between projected municipal and industrial water demands and available water supplies in the basins. While SWSI provided a valuable coarse assessment of water demands for the municipal, industrial, and agricultural sectors, concerns were raised at that time that the analysis did not accurately reflect the agricultural water shortages in some of the water districts and especially as they exist on tributaries. Another concern was that the Yampa River Basin analysis of agricultural demand was not based on high-altitude crop coefficients, thus understating the demand for water in the Yampa River Basin.

SWSI also noted that up to an additional 39,000 acres of agricultural lands could be developed in the basins but did not investigate the location or impact of additional agricultural demand in the basins. The Colorado River Water Conservation District Small Reservoir Study (CRWCD, 2000) identified sites for additional water supply storage in the Yampa Basin. That study highlighted the need to look at integrating irrigation practices with storage to better meet water demands.

The objectives of the current study are to:

1. Refine and update previous estimates of current agricultural water demands, supplies, and shortages for the Yampa/White/Green River Basin through use of the State of Colorado's Decision Support System (DSS) models and data
2. Identify and evaluate shortages for the future agricultural demands
3. Assess the impacts of climate change on agricultural water availability
4. Assess the impacts of energy sector water supply development on agricultural water availability in the White River Basin
5. Assess water supply development alternatives to satisfy shortages identified in (1), (2), and (3) above
6. Assess the effects on return flows of various irrigation practices or changes in those practices
7. Investigate creative solutions that benefit multiple interests (e.g., agriculture, energy, recreation, environment, etc.)

This technical memorandum addresses the third objective and is the third in a series of technical memoranda that will address activities and results related to the objectives.

2.0 Agricultural Subcommittee Input

The agricultural subcommittee expressed their desire to analyze the impacts of climate change on agricultural shortages. Some of the members wanted to include the effects of a cooling climate on shortages. However, in coordination with the Colorado River Water Availability Study (CRWAS), only climate warming was considered. CRWAS selected climate warming scenarios based on recent research and global climate model (GCM) results that unanimously show general warming in northwest Colorado. GCMs are multi-layer atmosphere-oceanic global scale models of water circulation patterns under greenhouse gas forcing.

Members of the subcommittee also questioned whether other changes in the basin might have similar or compounding effects on hydrology to climate change, such as the mountain pine beetle infestation or wind blow-down areas.

3.0 Current Hydrology and Climate

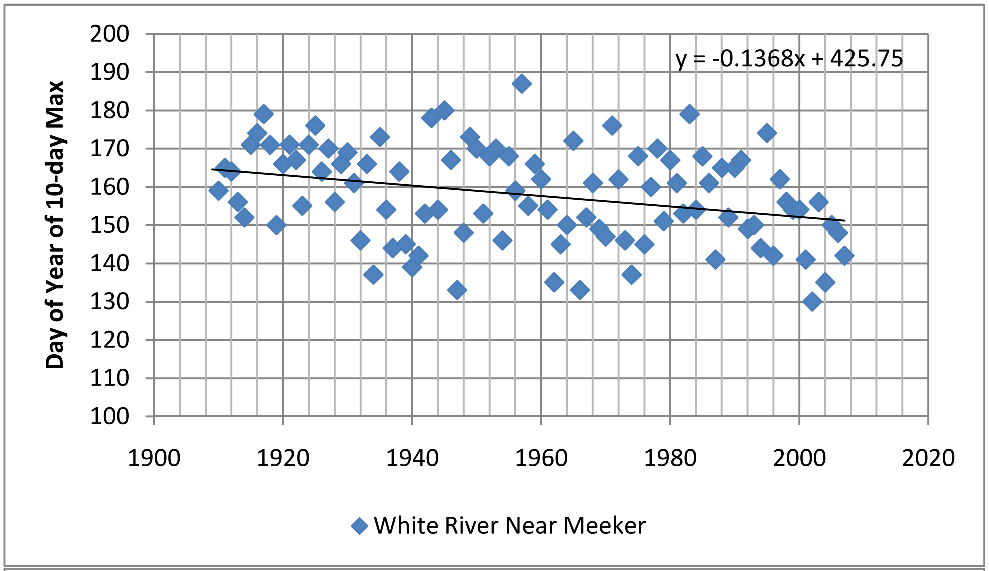
Historical flow and climate data for the Yampa and White River basins (study area) were used in analysis of trends in flow timing and temperatures in recent decades. A ten-day running average of streamflow was computed for several long term flow gages. Mean monthly temperatures from the StateCU model input were evaluated on a seasonal basis for climate stations near the stream gages (gages and climate stations listed in Table 3-1). For streamflows, the day of the year that the maximum of the running average was attained was determined for each year and plotted (Figure 3-1). Mean monthly temperatures from 1950 to 2005 were computed for the whole year, and for the growing season (April to October) and are plotted in Figure 3-2.

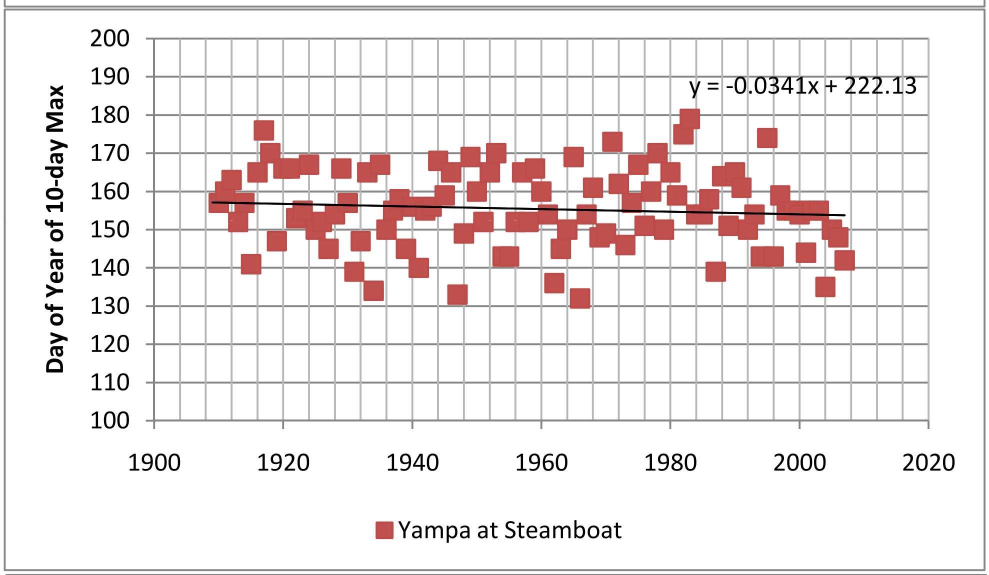
Table 3-1 – Long-Term Gages and Nearby Climate Stations

Streamflow Gage Name	Gage Number	Period of Record	Minimum Flow (AFY)	Median Flow (AFY)	Maximum Flow (AFY)
WHITE RIVER NEAR MEEKER	09304500	1910-2005	199,000	448,000	758,000
YAMPA RIVER AT STEAMBOAT SPRINGS	09239500	1910-2005	122,000	322,000	596,000
YAMPA RIVER NEAR MAYBELL	09251000	1916-2005	345,000	1,078,000	2,196,000
Climate Station Name	**Station ID**	**Average Annual Precipitation (Inches)**		**Average Annual Temperature (°F)**	
MEEKER 3 W	5484	16.15		44.64	
STEAMBOAT SPRINGS	7936	24.15		39.24	
MAYBELL	5446	12.28		42.27	

Figure 3-1 shows that there has been a small shift during the gaged period of record in the maximum flow period at the selected gages to earlier in the year. The figures show that peak runoff timing is quite variable and routinely varies by as much as a month from year to year. A statistical significance analysis was performed and it was determined that the Yampa River trends are not statistically significant (95% confidence intervals). Trends in the White River,

Figure 3-1 - Long Term Gages, Day of Year 10-Day Maximum Flow Attained





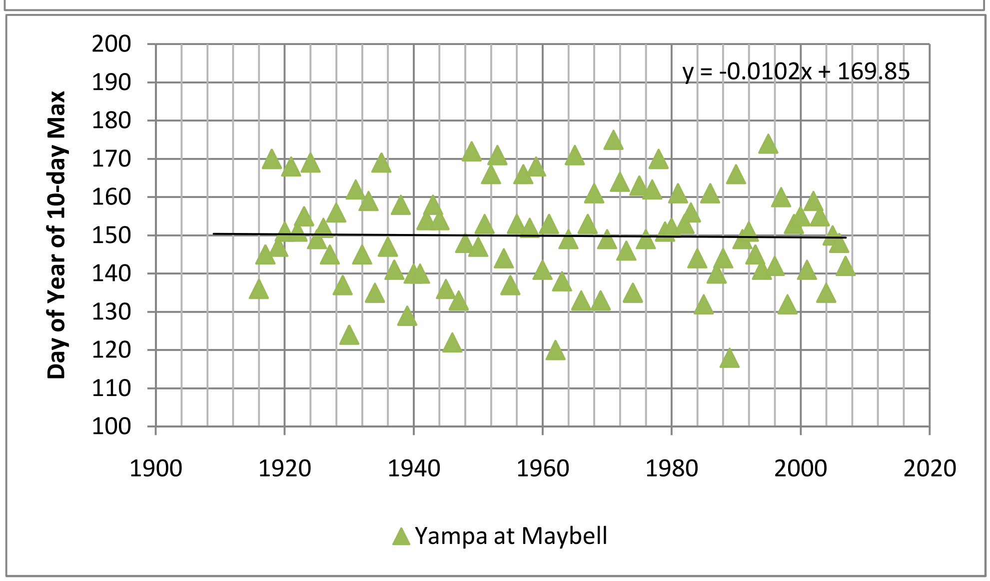
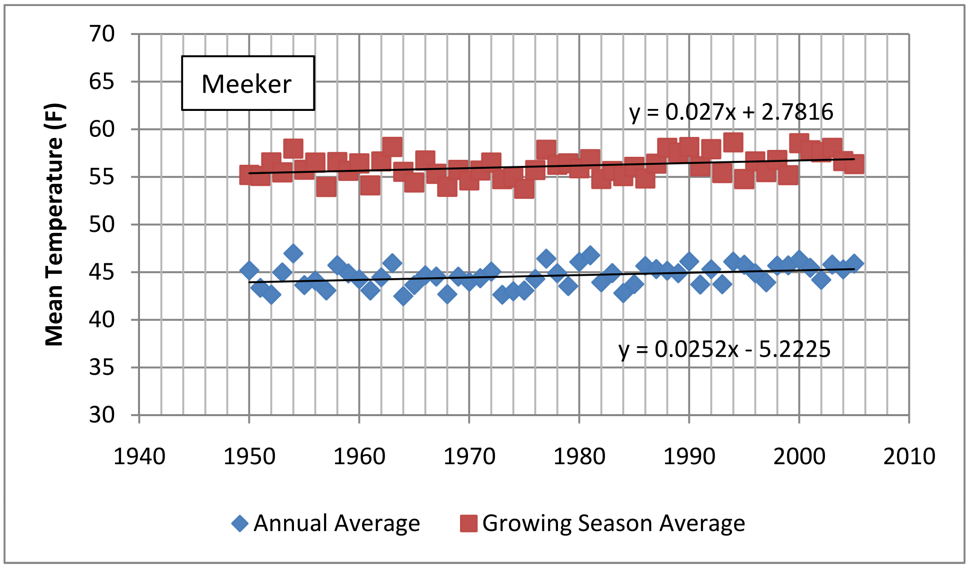
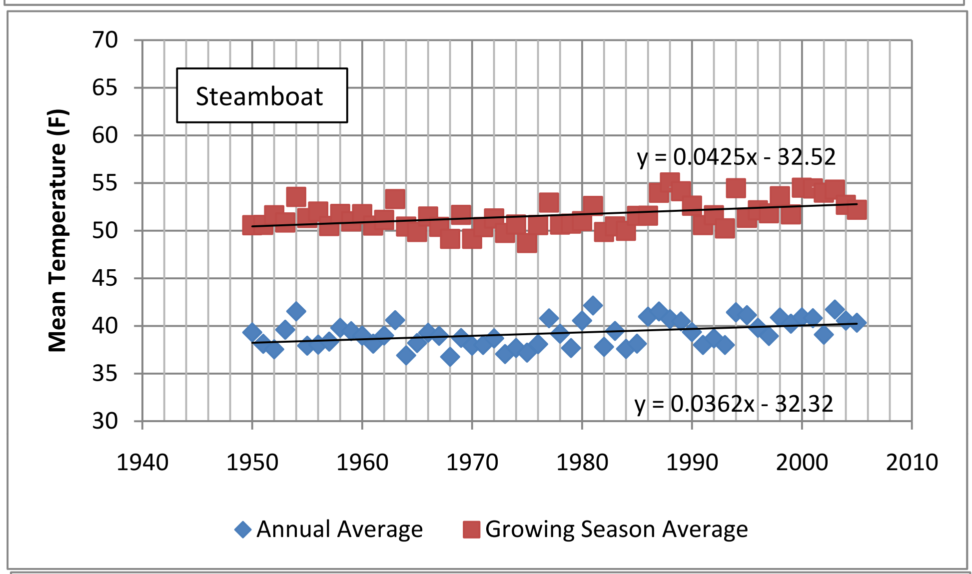
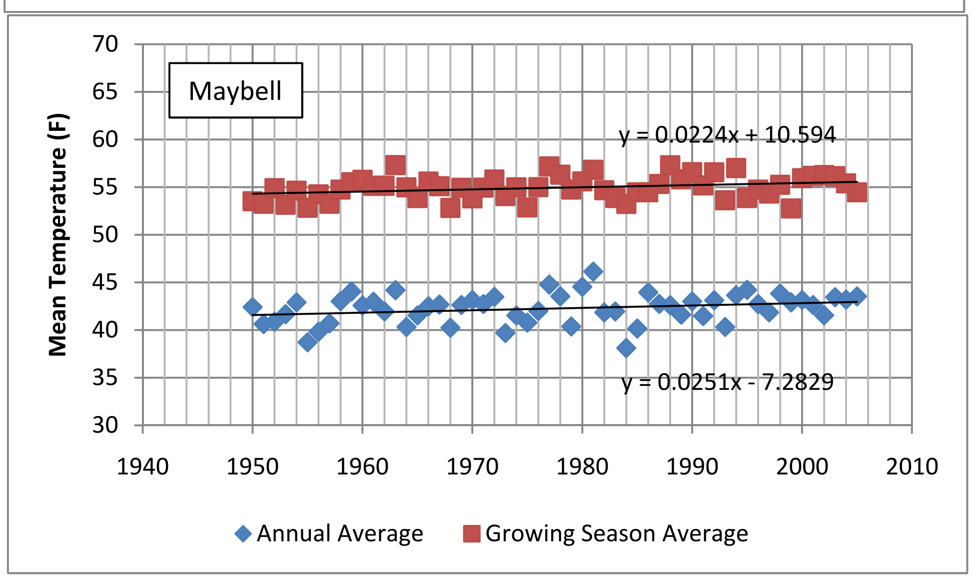


Figure 3-2 - Historical Mean Temperatures at Climate Stations







however, are statistically significant which indicates there is a trend that peak streamflow is shifting earlier in the year on the White River.

The temperature plots shown on Figure 3-2 indicate that temperatures have been very slightly increasing over the past 60 years on both an average annual basis, and during the growing season. The variability is much less than the peak runoff timing shown in Figure 3-1. A statistical significance analysis was performed ad it was determined that temperatures at all stations are statistically significant (95% confidence intervals). The lower year-to-year variability compared to runoff timing makes these trends more apparent. Based on the data shown in Figure 3-2, the mean temperature during the growing season increases 1 degree Fahrenheit every 37.0 years at the Meeker station; 23.5 years at the Steamboat Springs station; and 44.6 years at the Maybell station. These data represent historical conditions and do not reflect the more rapid warming much of the climate change research and GCMs predict and are provided to serve as a historical reference.

4.0 Climate Change Scenario Selection and Modeling

The hydrologic cycle in its most basic form begins as precipitation in a basin. A portion of that precipitation is stored as snow and later melts, infiltrates into groundwater, becomes streamflow, or is consumed (e.g. by native vegetation, irrigated crops, industrial uses etc..). Changes in precipitation and temperature have direct impacts to the amount and timing and type of precipitation (i.e. rain or snow) that becomes streamflow, as well as the amount of water required by vegetation (native or irrigated).

CRWAS selected 10 climate scenarios (five for 2040 conditions and five for 2070 conditions) based on variance in temperature and precipitation from historical mean values predicted by global circulation model (GCM) results and associated climate change research (CWCB 2010). The CRWAS goal was to select scenarios that represent 80 percent of the overall range of the entire suite of 112 GCM model projections. In general, the GCM models all predict an increase in temperature in the study area, but precipitation increases in some models, and decreases in others. Many climate change scenarios result in earlier runoff and increased irrigation water requirement (IWR) throughout the growing season due to increased temperatures. Under existing conditions, late season shortages already exist in the study area (See Technical Memorandum #1), and would be worse if supply shifts earlier, leaving less supply in the late season than under current conditions.

Changes in temperature and precipitation will change existing runoff patterns and the resulting streamflow available to water users. These changes are modeled using a watershed level precipitation-runoff model to produce baseflows (or naturalized flows) under climate change conditions. CRWAS developed a precipitation-runoff model that includes the study area, and results of the model became available for this study in early 2010. In an effort to coordinate with CRWAS, the baseflows (naturalized flows) developed under CRWAS were adopted for the StateMod modeling of this study.

Through coordination with the CRWAS team, it was communicated that the projections selected for 2040 better characterize the range of projected impacts on streamflow from future climate for both 2040 and 2070 than do the projections selected for 2070. Of the five 2040 scenarios, all are considered equally likely to occur. Therefore, for this study, two scenarios of the five 2040 CRWAS scenarios were selected generally representing the greatest baseflow increase during the growing season and greatest baseflow decrease during the growing season at several gages relative to current conditions. CRWAS scenario 'cccma_cgcm3_12' was determined to produce the largest increase in baseflows during the growing season (wet scenario). CRWAS scenario 'miroc3_2_medres1' was determined to produce the largest decrease in baseflows during the growing season at multiple gages (dry scenario) by comparing baseflows during the growing season against the baseline baseflows during the growing season. For the purposes of this study, it was assumed that the scenarios with the largest increase and decrease in growing season baseflows would capture a reasonable range of changes to existing agricultural shortages from baseline conditions. Average monthly temperatures increase relative to current mean temperatures in both of the scenarios selected for this study and in all five of the scenarios selected for CRWAS. Figure 3-3 shows the change in temperature and precipitation for both of the selected scenarios for this study. By selecting the scenarios with the largest increase and decrease in baseflows during the growing season, a range of shortages that can be reasonably expected under climate change conditions can be estimated.

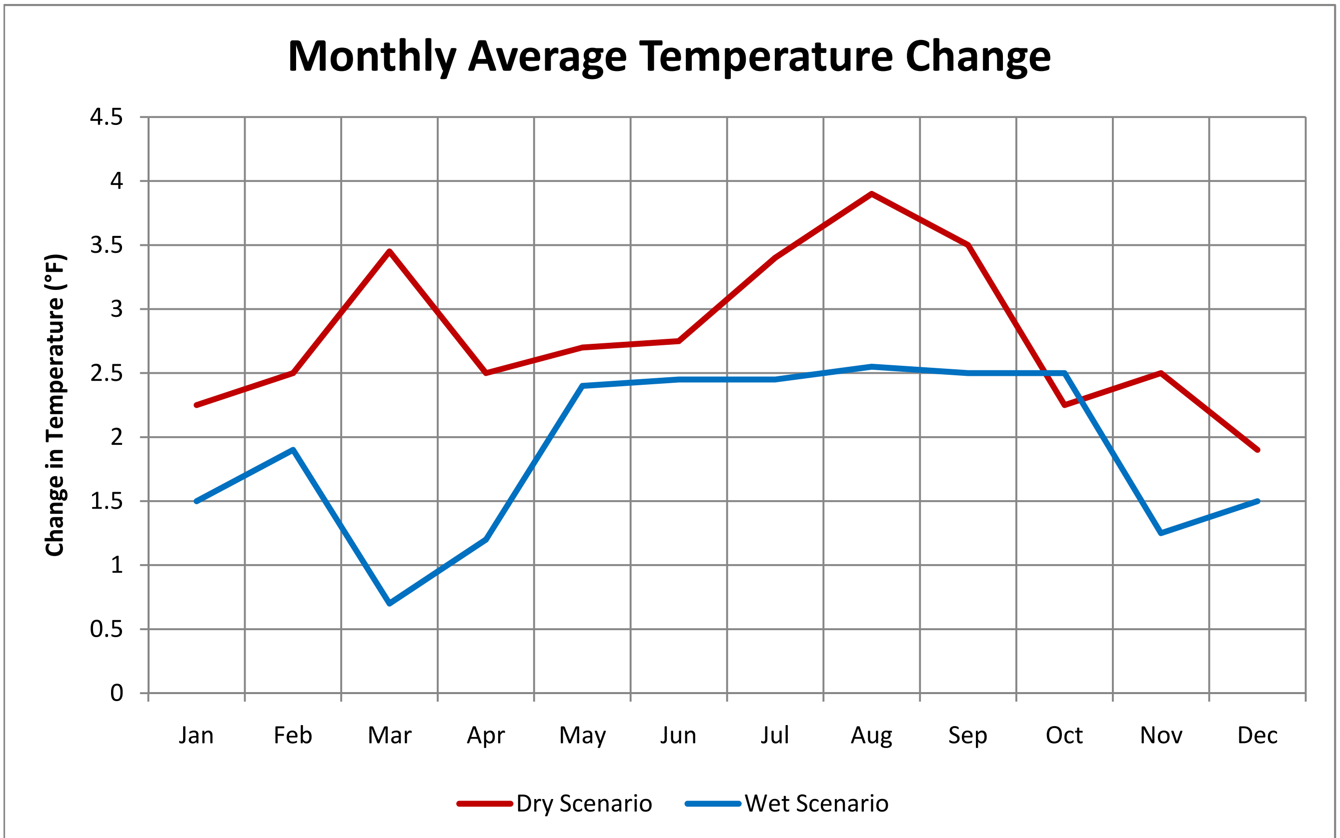
The average monthly changes in precipitation and temperature from both projections were applied to the existing condition consumptive use model (StateCU), resulting in two climate change IWR datasets. The new IWR datasets were then used to develop new headgate demands for the water allocation model (StateMod). The demands were generated using the methodology as used in CRWAS. CRWAS reports IWR for the Yampa basin that includes the North Platte Basin and identifies the minimum, maximum and average IWR from the scenarios used (Table 3-5 in CWCB 2010); so the values are not directly comparable to this study. However, the percentage increase in IWR compared to baseline IWR is consistent with the CRWAS (see Section 5). The new IWR datasets are described in more detail in Section 5, change in water supplies in Section 6 and agricultural shortages in Section 7.

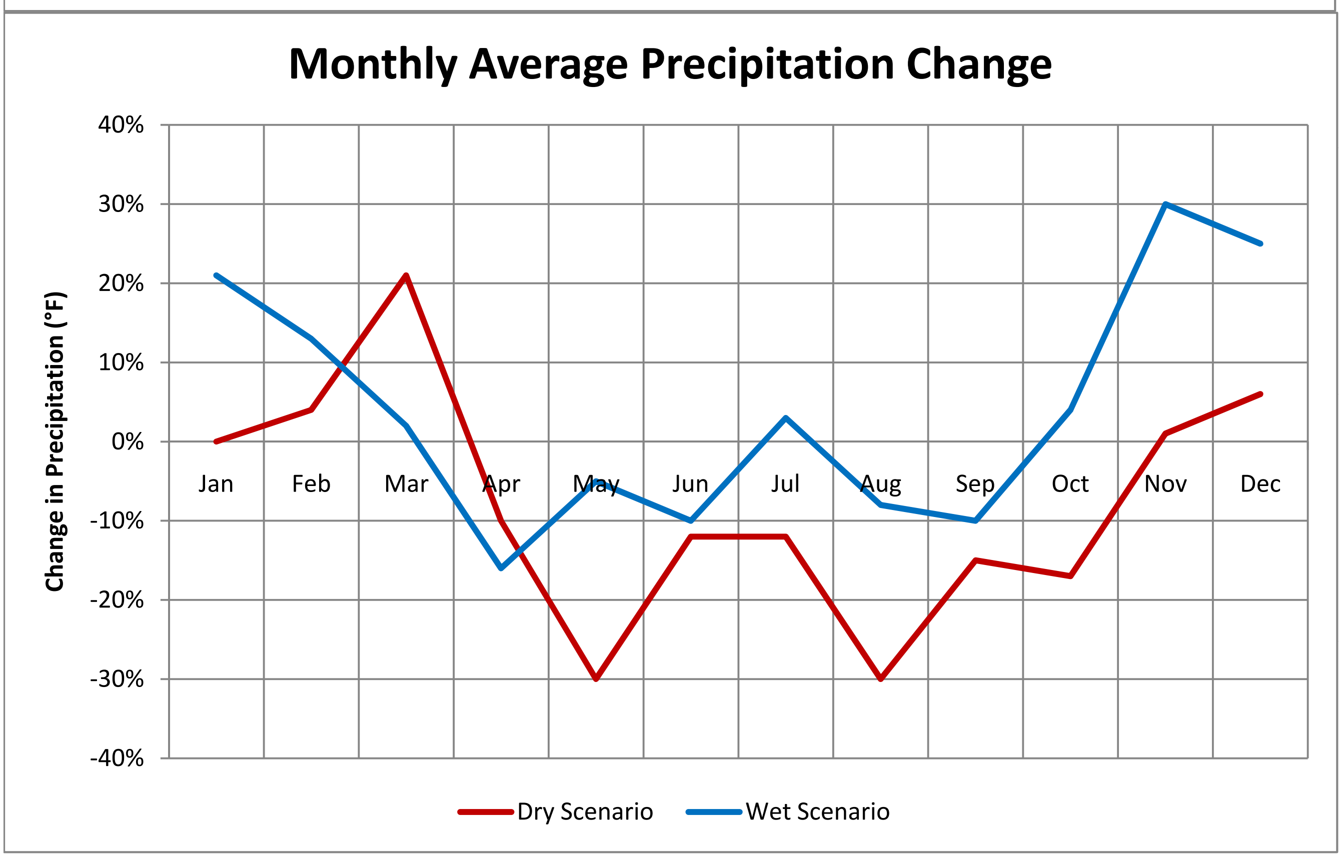
5.0 Demands under Climate Change Scenarios

Compared to existing conditions, increases in temperature and increase or decrease in precipitation will impact IWR. Increased temperatures produce higher potential evapotranspiration, and changes in precipitation will alter the amount of potential ET remaining to be served by irrigation. Change in temperature and precipitation relative to current conditions is predicted by the GCM models (Figure 3-3). There are numerous GCM scenarios that yield different results for a given area of the globe. As discussed above, CRWAS selected 10 such scenarios for their evaluation (five for the year 2040, and five for the year 2070) that were intended to capture 80 percent of the variability seen in all GCM climate models. In an effort to coordinate with that study, two of the five 2040 scenarios were selected that resulted in the largest increase and largest decrease in baseflows during the growing season at key gages. For the purposes of this study, the two selected scenarios will be referred to as the 'wet' (i.e. largest increase in growing season baseflows) and 'dry' (i.e. largest decrease in growing season baseflows) scenarios.

The average monthly change in temperature and precipitation data from the wet and dry scenarios (Figure 3-3) were applied to StateCU model inputs. Historical precipitation for the climate stations was scaled by a monthly average climate change factor that relates historical

Figure 3-3 Climate Change Scenario Changes in Temperature and Precipitation





precipitation to the precipitation predicted by the given GCM scenario. This method is consistent with the methodology used in the CRWAS (personal communication with Leonard Rice Engineering engineer, Erin Wilson 2009) The change in temperature predicted by the given GCM scenario was added to the historical temperature dataset. All other modeling assumptions (e.g. crop distribution, acreage, etc…) from the baseline scenario used in this study remained unchanged (See Technical Memorandum #1, existing shortages).

In both climate change scenarios, the temperature increases lead to higher IWR. Decreased precipitation, particularly in the dry scenario, also contribute to elevated IWR. For the dry scenario, average annual IWR for the study area is 265,456 AF, which represents a 16% increase relative to existing IWR. For the wet scenario, average annual IWR study area is 252,807 AF, which represents a 10% increase in IWR. Average monthly increases of IWR are shown in Figure 3-4. IWR on a per-acre basis by water district is presented in Figure 3-5. In Table 3-5 of the CRWAS report, the IWR in the Yampa basin (including the North Platte basin) increases between 5 and 23 percent, with an average scenario increase of 15 percent. For the White River, CRWAS reports IWR increases between 9 and 35 percent with an average of 23 percent increase. The wet and dry scenarios selected for this study use a 10 and 15 percent increase, respectively, for the Yampa basin and a 13 and 20 percent increase, respectively for the White basin. For the entire study area, IWR increases by 10 and 16 percent, respectively for the wet and dry scenarios. The increases in IWR used in this study fall within the ranges reported by CRWAS.

The water allocation modeling approach assumes that current irrigation practices remain the same under the climate change scenarios. The average monthly efficiencies which were calculated from the existing conditions were applied to the IWR using the same calculation method used previously in the computation of existing shortages (headgate demand = IWR/efficiency, efficiency bounded by 30% and 50%; see Technical Memorandum #1). Headgate demands are increased when the IWR increases.

6.0 Supplies under Climate Change Scenarios

Monthly naturalized flows (or baseflows) represent the amount of flow that would be expected in the stream absent any use or alteration by man, and are computed at several locations within the basin. Baseflows are the primary water inflow to the water allocation model, and higher baseflows represent a larger water supply. Baseflows for the climate change scenarios were generated as part of the CRWAS study using the results of a watershed-level precipitation-runoff model developed for CRWAS. The precipitation-runoff model uses the climate change adjusted temperature and precipitation from the GCMs. Figure 3-6 shows the baseflows under the baseline (current) and the wet and dry climate change scenarios at several locations in the study area. IWR is included on these plots to demonstrate the offset between supply and demand that leads to shortages. On average, the wet scenario annual baseflows are about 15% higher than baseline (ranging from 3% to 19% increase depending on location), and the dry scenario annual baseflows are about 15% lower than baseline (ranging from 3% to 24% decrease depending on location). However, both climate change scenarios predict an earlier runoff peak with increased streamflows in March and April. Peak flow occurs within the same month for most locations as the baseline scenario, but the hydrograph is shifting earlier in the year. There are decreases of flow in June, July and August for the dry scenario, and in July and August for the wet scenario. The wet scenario can be characterized as generally having a larger peak in

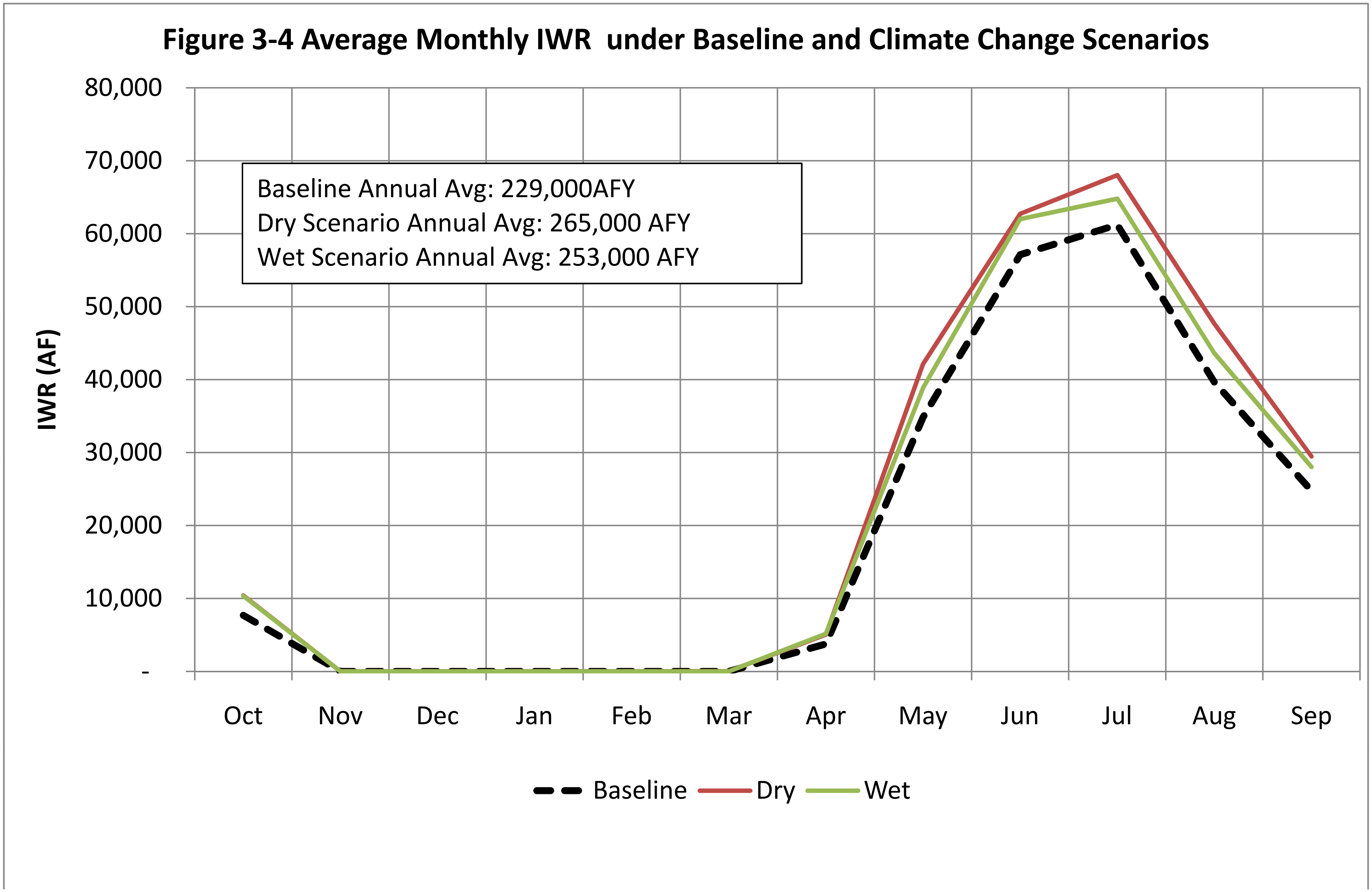


Figure 3-4 Average Monthly IWR under Baseline and Climate Change Scenarios
IWR (AF)
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
-
Baseline Annual Avg: 229,000AFY
Dry Scenario Annual Avg: 265,000 AFY
Wet Scenario Annual Avg: 253,000 AFY
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Baseline
Dry
Wet

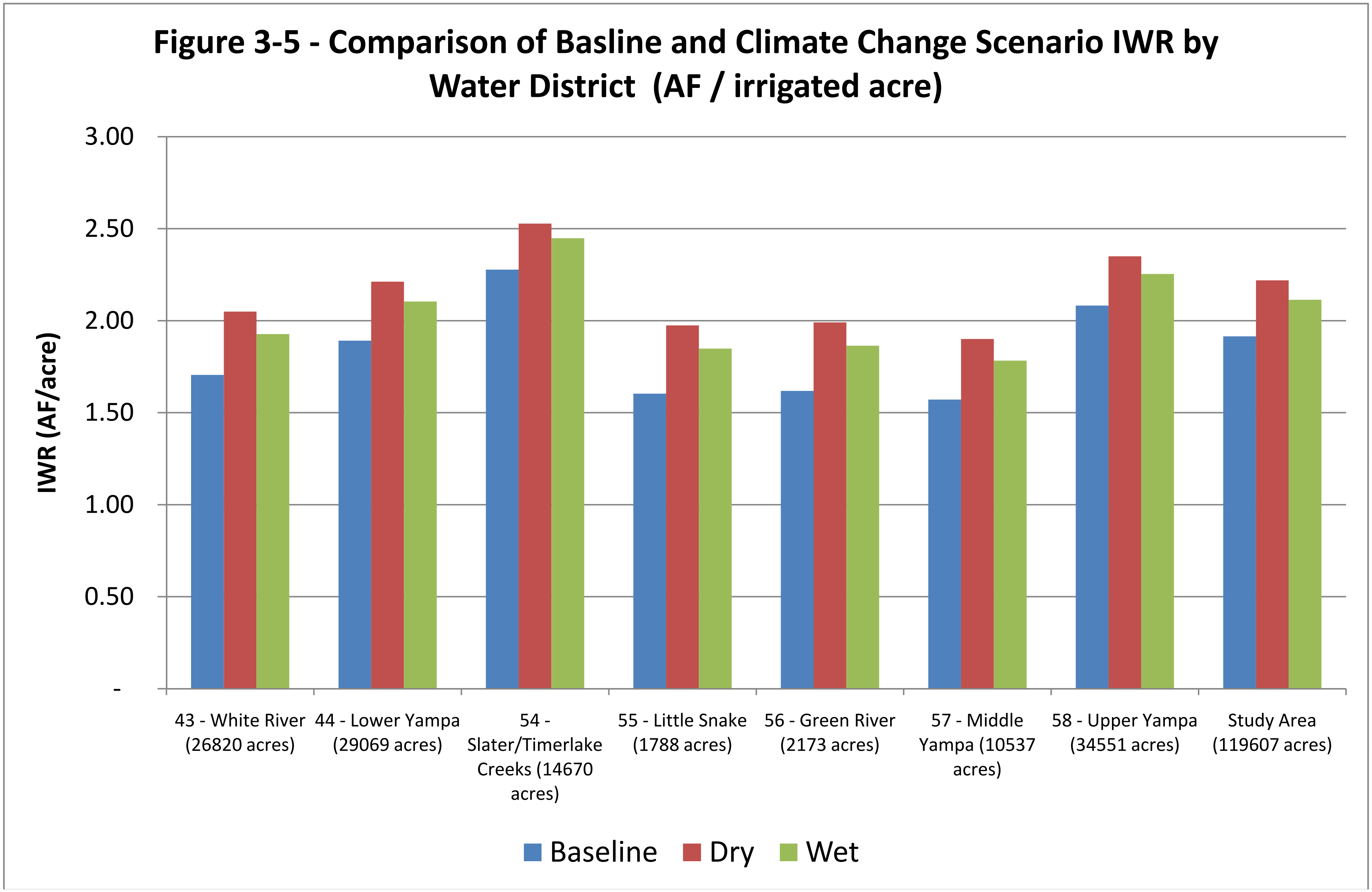
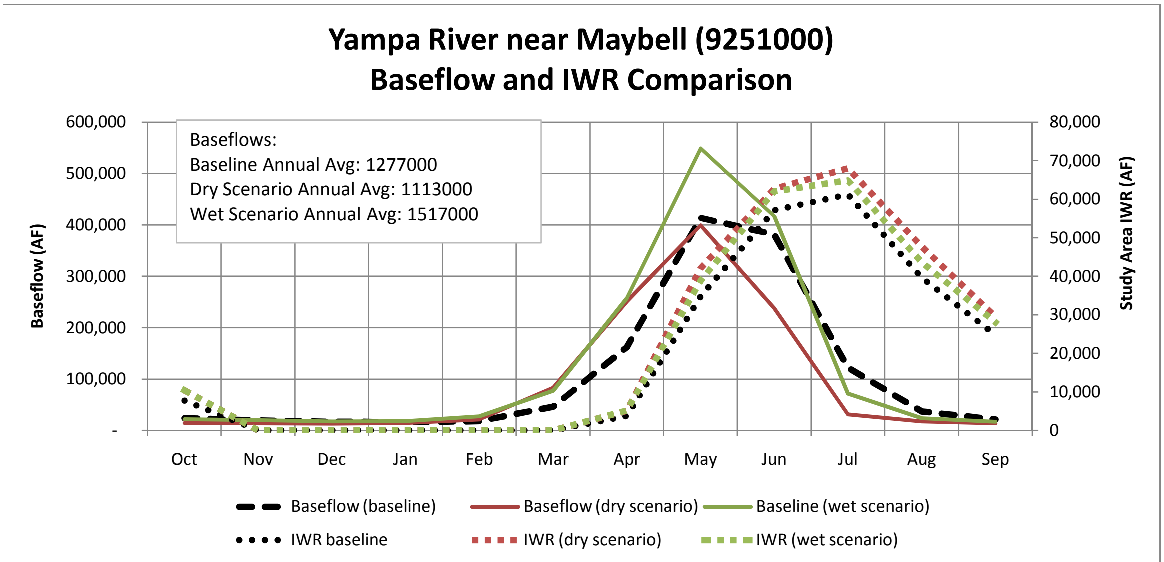
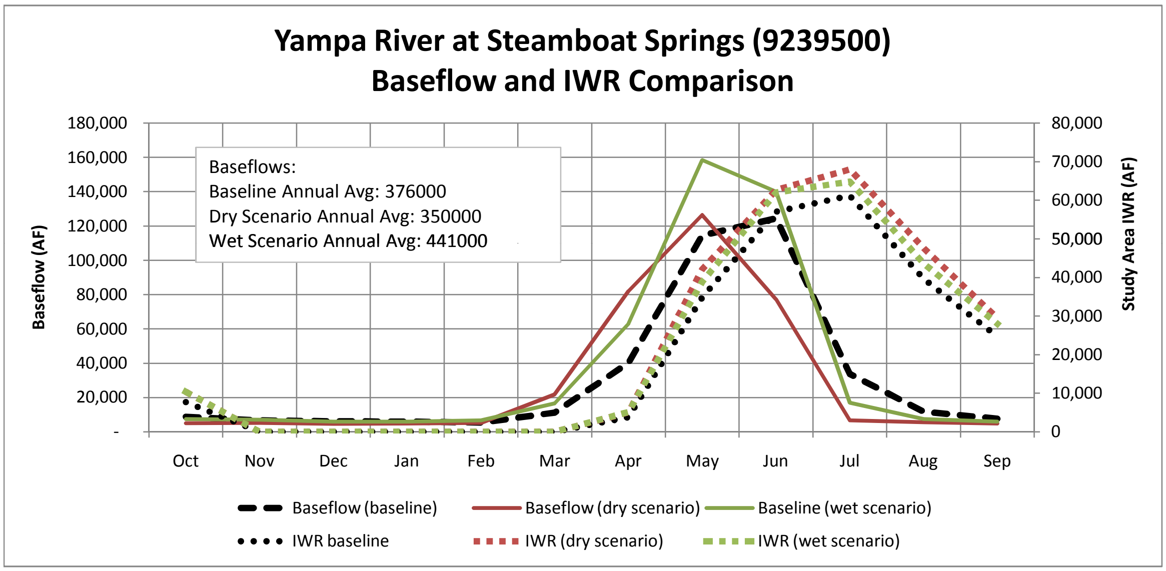


Figure 3-5 - Comparison of Basline and Climate Change Scenario IWR by Water District (AF / irrigated acre)
IWR (AF/acre)
3.00
2.50
2.00
1.50
1.00
0.50
-
43 - White River (26820 acres)
44 - Lower Yampa (29069 acres)
54 - Slater/Timerlake Creeks (14670 acres)
55 - Little Snake (1788 acres)
56 - Green River (2173 acres)
57 - Middle Yampa (10537 acres)
58 - Upper Yampa (34551 acres)
Study Area (119607 acres)
Baseline
Dry
Wet

Figure 3-6 - Baseflows at Several Gages and Basinwide IWR





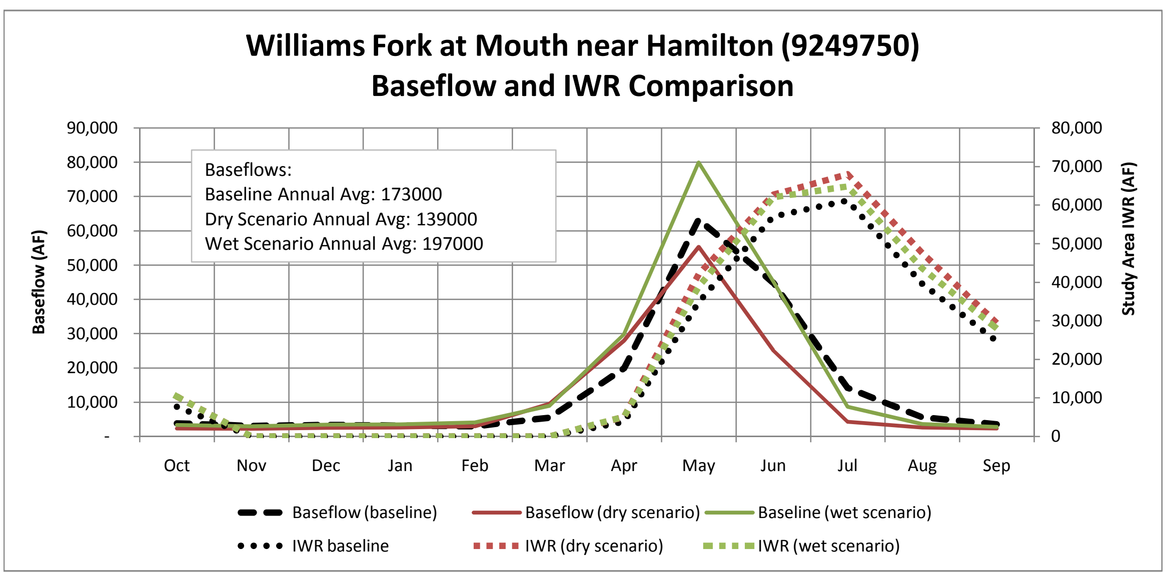
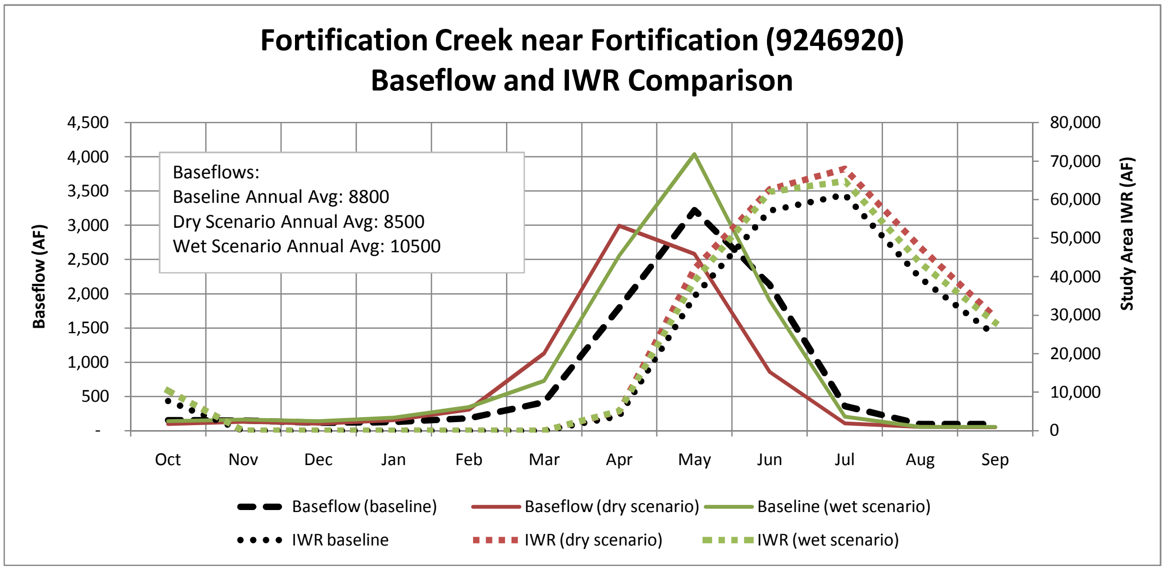
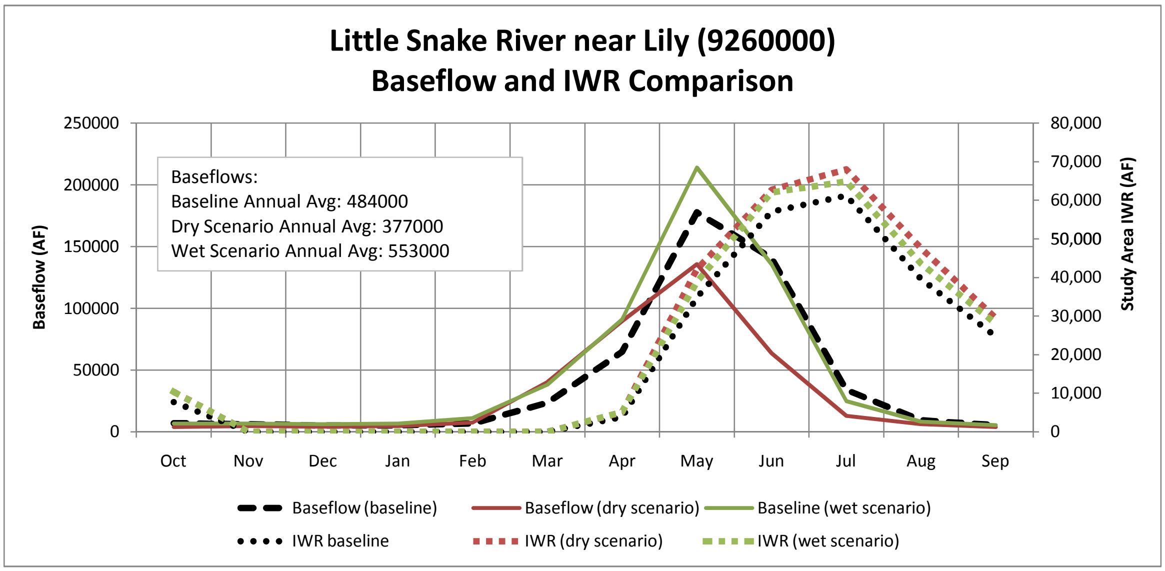
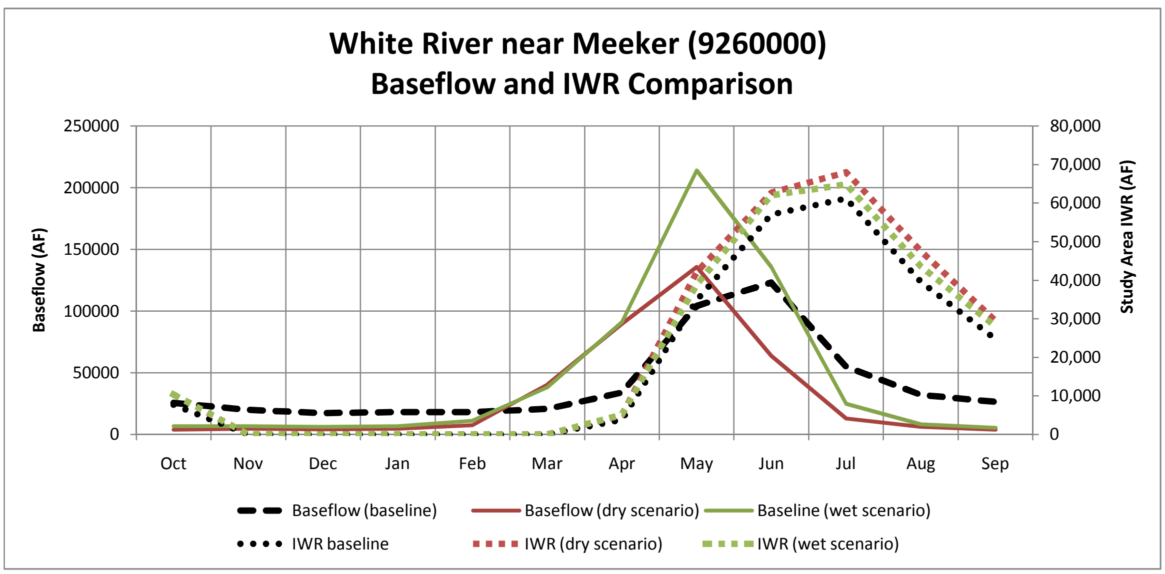


Figure 3-6 - Baseflows at Several Gages and Basinwide IWR







May, with a quicker tailing off as the summer goes on, suggesting a more rapid snowmelt that current conditions. The dry scenario is characterized by a hydrograph that tails off in June, resulting in much lower flows in June as compared to current conditions.

There are several structures in the model that are aggregations of multiple smaller structures. As part of the Task 1 of this study, the CDSS model aggregate nodes were split into two groups, representing those structures that divert from the modeled stream (A-aggregates), and those structures that divert from unmodeled tributaries (B-aggregates). Water available at the B-aggregates was represented by historical diversions. Under the climate change scenarios, historical diversions will not represent available flow due to changes in baseflows under climate change conditions. Available flow was estimated at the B-aggregates by applying a climate change scenario factor to historical diversions. The factor was computed by comparing the gains in a reach that contains B-aggregates in the baseline scenario against the gains in the same reach under the climate change flows. This approach isolates the change in flow for a specific sub-basin that supplies water to the B-aggregate nodes. For example, if a reach with B-aggregates showed an average gain of 1,000 AF in a given month in the baseline scenario, and the average gain was 700 AF in the climate change scenario, the historical diversions at the B-aggregates were multiplied by 70 percent to represent the reduced available flow.

There was a discussion at a project progress meeting regarding the changes in baseflows. It was noted that changes in runoff timing and amounts could be caused by factors other than climate change. For example, a beetle infestation in the White River in the 1940's as well as the current and expanding beetle-kill area causes reduction in precipitation infiltration and transpiration in the study area. This has been shown to increase runoff, and in some instances makes hydrograph peak sharper. Several investigators have reported on changes in runoff due to beetle infestation (Love 1955, Mitchell and Love 1973, Bethlahmy 1974 and 1975) and results are summarized in an article in 'Streamline Watershed Management Bulletin' (Uunila, Guy and Pike, 2006) that include more recent studies in Montana and British Columbia. The baseflows developed by the CRWAS for climate change scenarios did not consider beetle infestation effects or the effects outside of climatic changes. However, the changes in hydrology predicated by CRWAS are similar to those observed and predicted by the beetle infestation investigations. The effects of beetle infestation are relatively short-term (largest impact within 25 years) and were therefore not considered in CRWAS.

7.0 Shortages under Climate Change Scenarios

A combination of increased demands and a supply pattern that has a larger percentage of the flow earlier in the year causes increased shortages in the study area for both climate change scenarios. Figure 3-6 shows water supply (baseflows) and demands (IWR) graphically at several key gages in the study area. The figures show that the largest increases in IWR occur in the late season, and water supply shifts towards earlier runoff, creating an even larger separation between supply and demand than currently exists. Increases in agricultural shortages in the study area under climate change conditions are driven by a combination of the increased demand and the shifting water supply pattern. Under climate change conditions, there are still significant amounts of available water in several streams on an annual basis (especially the larger streams); it is a matter of timing that affects shortages, and the changes in water supply and crop demands under the climate change scenarios exacerbate the existing shortages.

The climate change scenario model runs were updated with the climate change demands and baseflows, with agricultural shortages computed as in Task 1. Table 3-2 presents the CU shortages in the climate change runs compared to the existing shortages by water district and by structure location (mainstem, tributary, B-aggregate). Figure 3-7 shows this information graphically. The shortages presented in Table 3-2 and Figure 3-7 present a range of potential shortages; the table and figure show the existing shortages and predicted shortages under the climate change scenario. Under existing conditions, there are agricultural consumptive use shortages and those shortages increase under climate change scenarios. The baseline scenario has consumptive shortage as 11 percent of IWR. The wet scenario predicts an increase of consumptive shortage to 14 percent of IWR, and the dry scenario predicts a consumptive shortage increase to 21 percent of IWR. The climate change modeling indicates that consumptive use shortage increases by 3 percent of basin IWR in the wet scenario (11 percent to 14 percent) and by 10 percent in the dry scenario (11 percent to 21 percent) The largest increases of shortages (volumetrically) occur on the tributary streams.

As would be predicted from Figure 3-6, shortages increase dramatically in the late summer relative to current conditions for both the wet and dry climate change scenario. Shortages are most severe during this time of year currently, but increased demands and earlier runoff makes shortages in the late season even more severe under climate change scenarios. Figure 3-8 shows the average monthly consumptive use shortages for the wet and dry scenarios compared to the baseline scenario. These shortages will be used to guide alternatives that can help meet these shortages. The subcommittee recommended that higher priority be given to areas that show the most severe shortages currently that also show significant increases to the shortage under the climate change scenarios.

Shortages at B-aggregates also increase. Since water availability at the B-aggregates is not well defined and is represented by adjusting historical diversions, shortages at these structures are more uncertain. However, the relative increase in shortages is consistent with other explicitly modeled structures in the basin.

Figure 3-9 shows the increases in critically short acres under the climate change scenarios. For the purposes of this study, critically short acreage is defined as acreage that is at least 20 percent short in at least 4 of 10 years. In the baseline scenario, approximately 26,000 acres were identified as critically short. Critically short acreage increases to 32,965 acres in the wet scenario (increase of approximately 7,000 acres), and to 46,406 acres in the dry scenario (increase of approximately 20,500 acres).

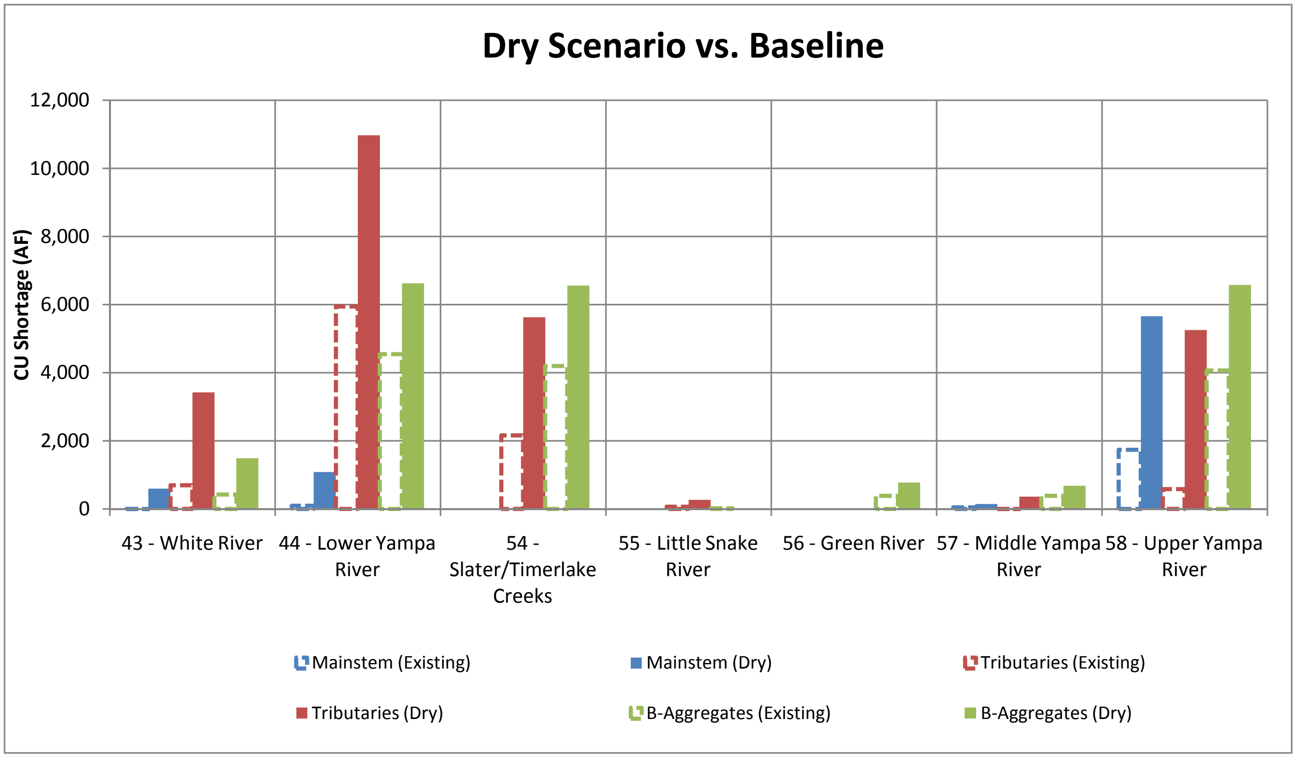
Detailed shortages by stream and structure type are presented in Tables 3-3 (dry scenario) and Table 3-4 (wet scenario) along with baseline shortages for comparison purposes. Shortages at the focus ditches identified by the subcommittee are presented in Table 3-5. Table 3-5 shows that there were increases in shortages at the focus ditches, but CU shortages were severe enough at only one structure (Square S Cons D Sys on Piceance Creek) to change the classification from 'not critically short' in the baseline scenario, to 'critically short' in the dry scenario.

Table 3-2 - Consumptive Use Shortages (AF) by Water District for Baseline and Climate Change Scenarios

Baseline (Existing)	Mainstem	Tributaries	B-aggregates	Total	Shortage as % of IWR
43 - White River	4	698	426	1,128	2%
44 - Lower Yampa River	96	5,946	4,546	10,587	19%
54 - Slater/Timerlake Creeks	0	2,162	4,198	6,359	19%
55 - Little Snake River	0	63	18	81	3%
56 - Green River	0	0	383	383	11%
57 - Middle Yampa River	48	0	389	437	3%
58 - Upper Yampa River	1,742	578	4,070	6,390	9%
Total Study Area (Baseline)	**1,889**	**9,447**	**14,030**	**25,366**	**11%**
Dry Scenario	Mainstem	Tributaries	B-aggregates	Total	Shortage as % of IWR
43 - White River	599	3,431	1,496	5,526	10%
44 - Lower Yampa River	1,090	10,976	6,630	18,696	29%
54 - Slater/Timerlake Creeks	0	5,637	6,568	12,204	33%
55 - Little Snake River	1	272	26	299	8%
56 - Green River	0	0	777	777	18%
57 - Middle Yampa River	147	363	686	1,196	6%
58 - Upper Yampa River	5,660	5,254	6,586	17,500	22%
Total Study Area (Dry)	**7,497**	**25,933**	**22,768**	**56,199**	**21%**
Wet Scenario	Mainstem	Tributaries	B-aggregates	Total	Shortage as % of IWR
43 - White River	21	1,305	713	2,040	4%
44 - Lower Yampa River	302	8,016	5,685	14,002	23%
54 - Slater/Timerlake Creeks	0	3,133	5,249	8,383	23%
55 - Little Snake River	0	90	21	111	3%
56 - Green River	0	0	622	622	15%
57 - Middle Yampa River	69	25	539	633	3%
58 - Upper Yampa River	3,032	2,104	5,065	10,201	13%
Total Study Area (Wet)	**3,424**	**14,673**	**17,895**	**35,993**	**14%**

B-aggregates are structures located on unmodeled tributaries

Figure 3-7 - Comparison of Consumptive Use Shortages



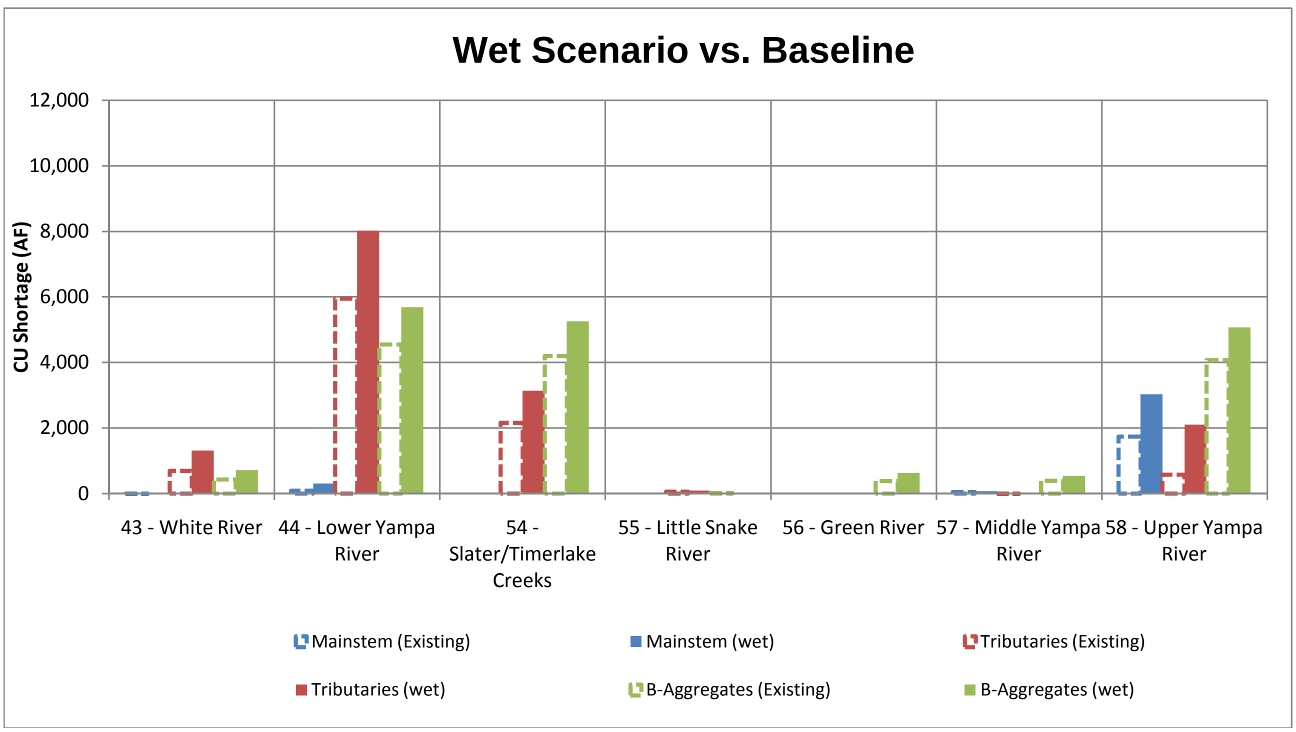
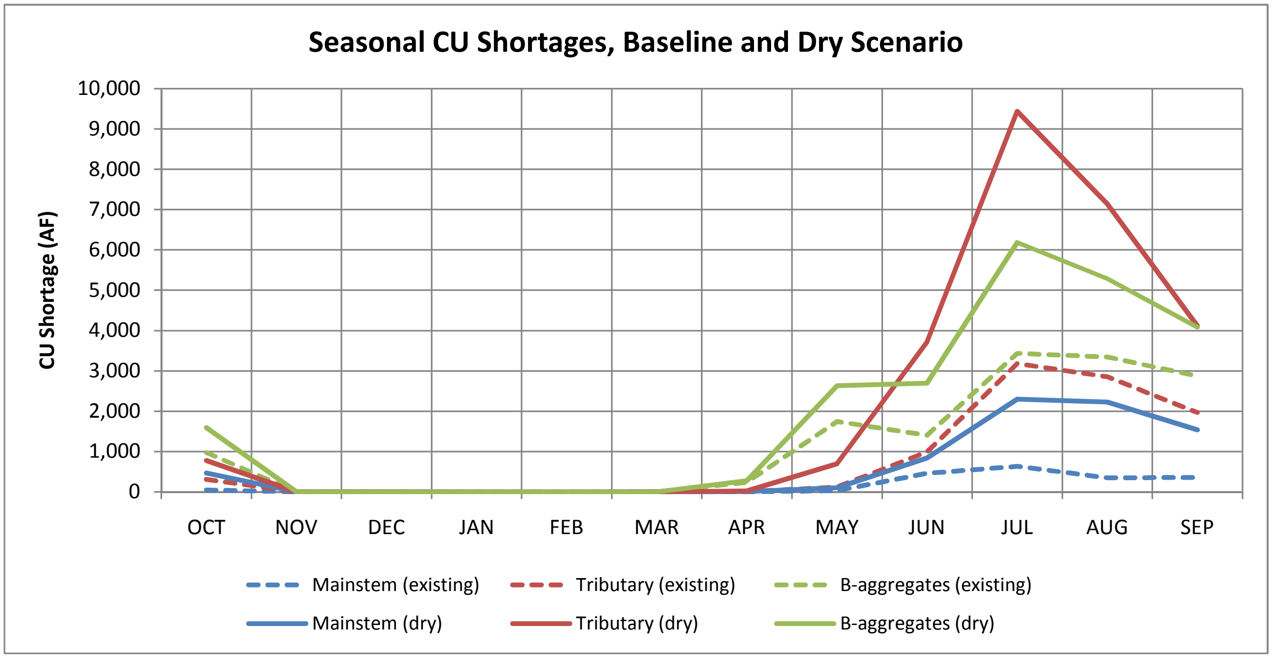
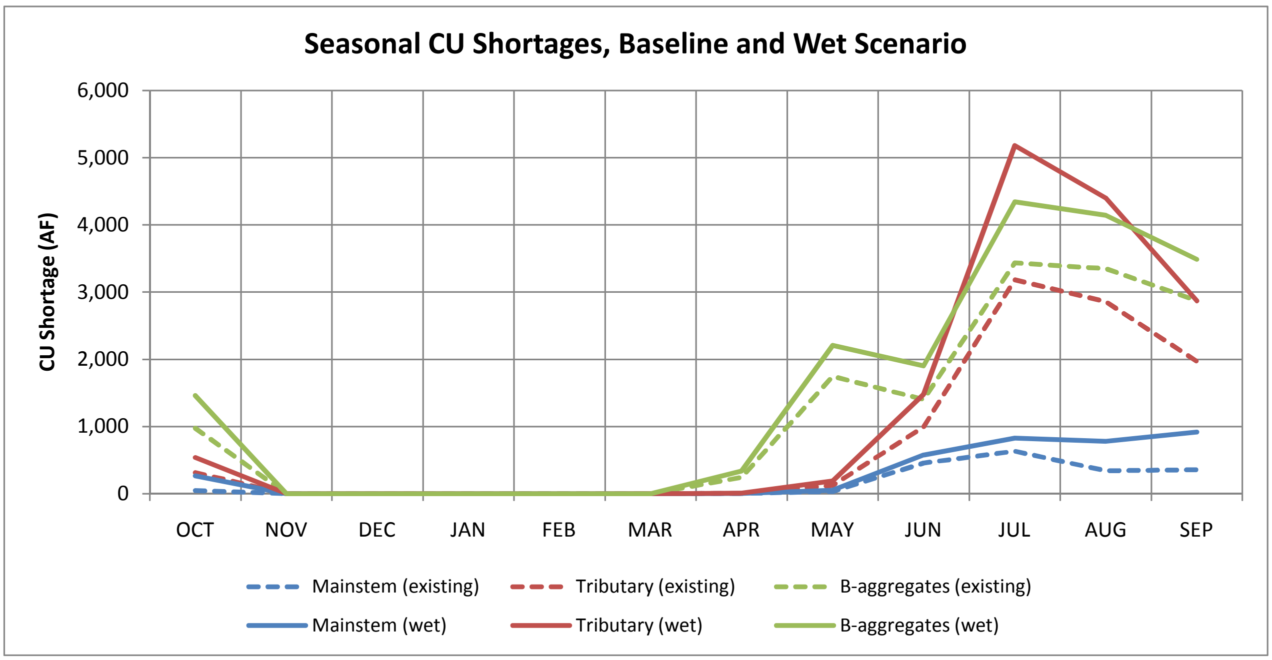


Figure 3-8 - Monthly Comparison of Consumptive Use Shortages

* Note Vertical Scale Differences





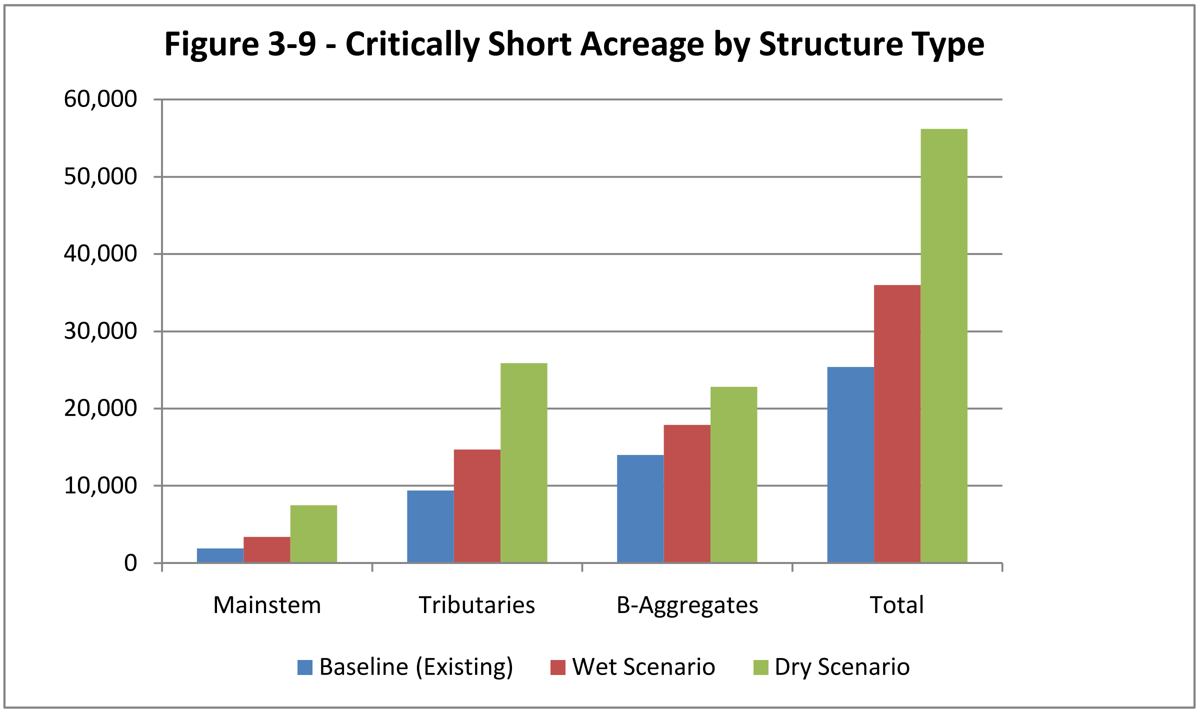


Figure 3-9 - Critically Short Acreage by Structure Type
60,000
50,000
40,000
30,000
20,000
10,000
0
Mainstem
Tributaries
B-Aggregates
Total
Baseline (Existing)
Wet Scenario
Dry Scenario

Table 3-3 - Dry Scenario Consumptive Use Shortage by Location and Structure Type

	Location by Water District, Stream and Structure Type	Irrigated Acreage	Dry Scenario Average Annual IWR (AF)	Dry Scenario Average Annual CU Shortage (AF)	Dry Scenario CU Shortage as Percent of IWR	Baseline Scenario Average Annual IWR (AF)	Baseline Scenario Average Annual CU Shortage (AF)	Baseline Scenario CU Shortage as Percent of IWR
	43 - White River	**26,820**	**54,978**	**5,526**	**10.1%**	**45,740**	**1,128**	**2.5%**
	Explicit Structures	19,957	39,859	3,564	8.9%	32,721	594	1.8%
	A-aggregates	2,116	4,398	466	10.6%	3,680	108	2.9%
	B-aggregates	4,746	10,722	1,496	14.0%	9,339	426	4.6%
	Big Beaver Creek	66	164	28	17.2%	148	10	6.4%
	Explicit Structures	66	164	28	17.2%	148	10	6.4%
	A-aggregates	0	0	0	n/a	0	0	n/a
	B-aggregates	0	0	0	n/a	0	0	n/a
	Black Sulphur Creek	97	178	98	55.3%	142	3	1.8%
	Explicit Structures	97	178	98	55.3%	142	3	1.8%
	A-aggregates	0	0	0	n/a	0	0	n/a
	B-aggregates	0	0	0	n/a	0	0	n/a
	Coal Creek	768	1,896	155	8.2%	1,707	0	0.0%
	Explicit Structures	768	1,896	155	8.2%	1,707	0	0.0%
	A-aggregates	0	0	0	n/a	0	0	n/a
	B-aggregates	0	0	0	n/a	0	0	n/a
	Elk Creek	154	382	101	26.4%	345	33	9.7%
	Explicit Structures	154	382	101	26.4%	345	33	9.7%
	A-aggregates	0	0	0	n/a	0	0	n/a
	B-aggregates	0	0	0	n/a	0	0	n/a
	Evacuation	250	622	138	22.2%	561	36	6.4%
	Explicit Structures	0	0	0	n/a	0	0	n/a
	A-aggregates	106	265	35	13.3%	239	0	0.0%
	B-aggregates	144	357	103	28.8%	322	36	11.2%
	Fawn Creek	67	166	2	1.2%	150	0	0.0%
	Explicit Structures	67	166	2	1.2%	150	0	0.0%
	A-aggregates	0	0	0	n/a	0	0	n/a
	B-aggregates	0	0	0	n/a	0	0	n/a
	Flag Creek	297	585	108	18.4%	482	2	0.4%
	Explicit Structures	297	585	108	18.4%	482	2	0.4%
	A-aggregates	0	0	0	n/a	0	0	n/a
	B-aggregates	0	0	0	n/a	0	0	n/a
	Hill Creek/Hill Creek Tributary	130	323	36	11.2%	291	6	2.2%
	Explicit Structures	130	323	36	11.2%	291	6	2.2%
	A-aggregates	0	0	0	n/a	0	0	n/a
	B-aggregates	0	0	0	n/a	0	0	n/a
	Lake Creek/Douglas Creek	12	37	8	22.4%	35	9	26.4%
	Explicit Structures	12	37	8	22.4%	35	9	26.4%
	A-aggregates	0	0	0	n/a	0	0	n/a
	B-aggregates	0	0	0	n/a	0	0	n/a
	Marvine Creek	130	298	23	7.7%	264	0	0.0%
	Explicit Structures	130	298	23	7.7%	264	0	0.0%
	A-aggregates	0	0	0	n/a	0	0	n/a
	B-aggregates	0	0	0	n/a	0	0	n/a
	Miller Creek	125	283	42	14.9%	244	15	6.0%
	Explicit Structures	125	283	42	14.9%	244	15	6.0%
	A-aggregates	0	0	0	n/a	0	0	n/a
	B-aggregates	0	0	0	n/a	0	0	n/a
	Moose Creek/Cave Creek	301	573	78	13.6%	490	18	3.8%
	Explicit Structures	301	573	78	13.6%	490	18	3.8%
	A-aggregates	0	0	0	n/a	0	0	n/a
	B-aggregates	0	0	0	n/a	0	0	n/a
	North Fork White River	594	1,473	63	4.3%	1,328	4	0.3%
*	Explicit Structures	206	514	63	12.3%	464	4	0.8%
*	A-aggregates	69	172	0	0.0%	155	0	0.0%
	B-aggregates	319	787	0	0.1%	709	0	0.0%
	Piceance Creek	4,230	9,046	3,748	41.4%	7,722	806	10.4%
	Explicit Structures	2,437	4,821	2,248	46.6%	3,987	451	11.3%
	A-aggregates	352	810	413	51.0%	710	108	15.2%
	B-aggregates	1,441	3,416	1,088	31.9%	3,025	247	8.2%
	Soldier Creek/East Douglas/Douglas Creek	57	173	41	23.9%	161	43	27.0%
	Explicit Structures	57	173	41	23.9%	161	43	27.0%
	A-aggregates	0	0	0	n/a	0	0	n/a
	B-aggregates	0	0	0	n/a	0	0	n/a
	South Fork White River	952	2,367	91	3.9%	2,137	17	0.8%
*	Explicit Structures	684	1,703	66	3.9%	1,537	0	0.0%
*	A-aggregates	66	164	0	0.0%	148	0	0.0%
	B-aggregates	201	501	25	5.0%	452	17	3.7%
	Ute Creek	61	153	16	10.2%	138	0	0.0%
	Explicit Structures	61	153	16	10.2%	138	0	0.0%
	A-aggregates	0	0	0	n/a	0	0	n/a
	B-aggregates	0	0	0	n/a	0	0	n/a
	White River	18,528	36,259	749	2.1%	29,394	126	0.4%
*	Explicit Structures	14,363	27,611	451	1.6%	22,136	0	0.0%
*	A-aggregates	1,523	2,988	19	0.6%	2,427	0	0.0%
	B-aggregates	2,642	5,661	280	4.9%	4,830	126	2.6%

Asterisk denotes mainstem reach
B-aggregates are structures located on unmodeled tributaries
Critically Short Acreage is at least 20% short in at least 4 of 10 years

Table 3-3 - Dry Scenario Consumptive Use Shortage by Location and Structure Type

Location by Water District, Stream and Structure Type	Irrigated Acreage	Dry Scenario			Baseline Scenario		
		Average Annual IWR (AF)	Average Annual CU Shortage (AF)	CU Shortage as Percent of IWR	Average Annual IWR (AF)	Average Annual CU Shortage (AF)	CU Shortage as Percent of IWR
44 - Lower Yampa River	**29,069**	**64,315**	**18,696**	**29.1%**	**54,987**	**10,587**	**19.3%**
Explicit Structures	19,108	41,124	11,609	28.2%	34,678	5,836	16.8%
A-aggregates	2,893	6,635	457	6.9%	5,746	205	3.6%
B-aggregates	7,067	16,556	6,630	40.0%	14,563	4,546	31.2%
Beaver Creek	150	376	233	62.0%	340	127	37.2%
Explicit Structures	150	376	233	62.0%	340	127	37.2%
A-aggregates	0	0	0	n/a	0	0	n/a
B-aggregates	0	0	0	n/a	0	0	n/a
Crystal Creek	30	63	11	18.0%	54	0	0.5%
Explicit Structures	30	63	11	18.0%	54	0	0.5%
A-aggregates	0	0	0	n/a	0	0	n/a
B-aggregates	0	0	0	n/a	0	0	n/a
Deer Creek	274	594	74	12.5%	501	1	0.2%
Explicit Structures	274	594	74	12.5%	501	1	0.2%
A-aggregates	0	0	0	n/a	0	0	n/a
B-aggregates	0	0	0	n/a	0	0	n/a
Dry Creek	289	740	448	60.6%	664	250	37.6%
Explicit Structures	289	740	448	60.6%	664	250	37.6%
A-aggregates	0	0	0	n/a	0	0	n/a
B-aggregates	0	0	0	n/a	0	0	n/a
East Fork Williams Fork	2,680	6,703	1,811	27.0%	6,043	1,179	19.5%
Explicit Structures	863	1,919	86	4.5%	1,670	0	0.0%
A-aggregates	317	836	1	0.1%	766	0	0.0%
B-aggregates	1,501	3,948	1,724	43.7%	3,608	1,179	32.7%
Elkhead Creek	2,070	4,662	978	21.0%	4,053	561	13.8%
Explicit Structures	1,431	2,984	306	10.3%	2,519	105	4.2%
A-aggregates	70	176	60	34.1%	157	38	24.5%
B-aggregates	569	1,502	612	40.7%	1,376	417	30.3%
Fortification Creek	991	2,218	907	40.9%	1,876	468	24.9%
Explicit Structures	991	2,218	907	40.9%	1,876	468	24.9%
A-aggregates	0	0	0	n/a	0	0	n/a
B-aggregates	0	0	0	n/a	0	0	n/a
James Creek	5	13	4	33.0%	12	1	6.0%
Explicit Structures	5	13	4	33.0%	12	1	6.0%
A-aggregates	0	0	0	n/a	0	0	n/a
B-aggregates	0	0	0	n/a	0	0	n/a
Little Bear	1,530	3,591	2,584	71.9%	3,120	1,836	58.8%
Explicit Structures	1,530	3,591	2,584	71.9%	3,120	1,836	58.8%
A-aggregates	0	0	0	n/a	0	0	n/a
B-aggregates	0	0	0	n/a	0	0	n/a
Little Cottonwood Creek	207	479	328	68.5%	415	213	51.4%
Explicit Structures	207	479	328	68.5%	415	213	51.4%
A-aggregates	0	0	0	n/a	0	0	n/a
B-aggregates	0	0	0	n/a	0	0	n/a
Milk Creek	3,796	8,459	3,484	41.2%	7,290	1,532	21.0%
Explicit Structures	2,175	4,940	1,690	34.2%	4,279	337	7.9%
A-aggregates	313	716	361	50.4%	621	164	26.5%
B-aggregates	1,307	2,803	1,434	51.1%	2,390	1,031	43.1%
Morapose Creek	2,097	4,872	3,325	68.3%	4,208	2,130	50.6%
Explicit Structures	2,097	4,872	3,325	68.3%	4,208	2,130	50.6%
A-aggregates	0	0	0	n/a	0	0	n/a
B-aggregates	0	0	0	n/a	0	0	n/a
North Fork Elkhead Creek	27	64	19	29.0%	57	7	13.1%
Explicit Structures	27	64	19	29.0%	57	7	13.1%
A-aggregates	0	0	0	n/a	0	0	n/a
B-aggregates	0	0	0	n/a	0	0	n/a
Pine Creek	392	822	486	59.1%	699	249	35.6%
Explicit Structures	392	822	486	59.1%	699	249	35.6%
A-aggregates	0	0	0	n/a	0	0	n/a
B-aggregates	0	0	0	n/a	0	0	n/a
South Fork Williams Fork	125	294	0	0.0%	261	0	0.0%
* Explicit Structures	125	294	0	0.0%	261	0	0.0%
* A-aggregates	0	0	0	n/a	0	0	n/a
B-aggregates	0	0	0	n/a	0	0	n/a
Waddle Creek	217	563	139	24.7%	511	19	3.7%
Explicit Structures	217	563	139	24.7%	511	19	3.7%
A-aggregates	0	0	0	n/a	0	0	n/a
B-aggregates	0	0	0	n/a	0	0	n/a
Williams Fork	2,631	6,749	1,507	22.3%	6,109	1,120	18.3%
* Explicit Structures	274	554	0	0.0%	448	0	0.0%
* A-aggregates	779	2,043	0	0.0%	1,865	0	0.0%
B-aggregates	1,578	4,152	1,507	36.3%	3,796	1,120	29.5%
Yampa River	11,557	23,054	2,357	10.2%	18,775	895	4.8%
* Explicit Structures	8,031	16,039	968	6.0%	13,046	94	0.7%
* A-aggregates	1,415	2,864	36	1.2%	2,337	2	0.1%
B-aggregates	2,111	4,150	1,354	32.6%	3,392	799	23.6%

Asterisk denotes mainstem reach
B-aggregates are structures located on unmodeled tributaries
Critically Short Acreage is at least 20% short in at least 4 of 10 years

Table 3-3 - Dry Scenario Consumptive Use Shortage by Location and Structure Type

	Location by Water District, Stream and Structure Type	Irrigated Acreage	Dry Scenario			Baseline Scenario		
			Average Annual IWR (AF)	Average Annual CU Shortage (AF)	CU Shortage as Percent of IWR	Average Annual IWR (AF)	Average Annual CU Shortage (AF)	CU Shortage as Percent of IWR
	54 - Slater/Timerlake Creeks	**14,670**	**37,081**	**12,204**	**32.9%**	**33,407**	**6,359**	**19.0%**
	Explicit Structures	5,886	13,921	4,320	31.0%	12,235	1,997	16.3%
	A-aggregates	3,260	8,599	1,317	15.3%	7,851	165	2.1%
	B-aggregates	5,524	14,561	6,568	45.1%	13,321	4,198	31.5%
	Little Snake	10,250	25,403	7,082	27.9%	22,726	3,808	16.8%
	Explicit Structures	3,153	6,712	729	10.9%	5,645	144	2.6%
	A-aggregates	3,110	8,202	1,301	15.9%	7,488	164	2.2%
	B-aggregates	3,988	10,488	5,053	48.2%	9,593	3,500	36.5%
	Slater Creek	2,780	7,366	2,619	35.6%	6,737	1,156	17.2%
	Explicit Structures	1,095	2,896	1,088	37.6%	2,646	457	17.3%
	A-aggregates	150	397	16	4.1%	363	1	0.2%
	B-aggregates	1,536	4,073	1,515	37.2%	3,728	698	18.7%
	Willow Creek	1,639	4,312	2,503	58.0%	3,944	1,396	35.4%
	Explicit Structures	1,639	4,312	2,503	58.0%	3,944	1,396	35.4%
	A-aggregates	0	0	0	n/a	0	0	n/a
	B-aggregates	0	0	0	n/a	0	0	n/a
	55 - Little Snake River	**1,788**	**3,531**	**299**	**8.5%**	**2,868**	**81**	**2.8%**
	Explicit Structures	1,128	2,226	267	12.0%	1,808	63	3.5%
	A-aggregates	600	1,187	7	0.6%	964	0	0.0%
	B-aggregates	60	119	26	21.8%	97	18	18.2%
	Little Snake	1,680	3,317	272	8.2%	2,694	63	2.4%
	Explicit Structures	1,128	2,226	267	12.0%	1,808	63	3.5%
	A-aggregates	552	1,091	5	0.5%	887	0	0.0%
	B-aggregates	0	0	0	n/a	0	0	n/a
	Yampa River	108	214	27	12.7%	174	18	10.1%
*	Explicit Structures	0	0	0	n/a	0	0	n/a
*	A-aggregates	48	95	1	1.4%	77	0	0.0%
	B-aggregates	60	119	26	21.8%	97	18	18.2%
	56 - Green River	**2,173**	**4,327**	**777**	**17.9%**	**3,517**	**383**	**10.9%**
	Explicit Structures	0	0	0	n/a	0	0	n/a
	A-aggregates	157	311	0	0.0%	252	0	0.0%
	B-aggregates	2,016	4,016	777	19.3%	3,265	383	11.7%
	Green River	2,173	4,327	777	17.9%	3,517	383	10.9%
*	Explicit Structures	0	0	0	n/a	0	0	n/a
*	A-aggregates	157	311	0	0.0%	252	0	0.0%
	B-aggregates	2,016	4,016	777	19.3%	3,265	383	11.7%
	57 - Middle Yampa River	**10,537**	**20,027**	**1,196**	**6.0%**	**16,557**	**437**	**2.6%**
	Explicit Structures	8,214	14,919	386	2.6%	12,125	1	0.0%
	A-aggregates	1,033	2,280	124	5.5%	1,981	47	2.4%
	B-aggregates	1,290	2,828	686	24.3%	2,451	389	15.9%
	Fish Creek	595	1,382	190	13.7%	1,222	0	0.0%
	Explicit Structures	595	1,382	190	13.7%	1,222	0	0.0%
	A-aggregates	0	0	0	n/a	0	0	n/a
	B-aggregates	0	0	0	n/a	0	0	n/a
	Trout Creek	2,113	4,921	267	5.4%	4,350	37	0.9%
	Explicit Structures	1,193	2,760	158	5.7%	2,434	0	0.0%
	A-aggregates	575	1,349	2	0.1%	1,195	0	0.0%
	B-aggregates	345	812	107	13.2%	721	37	5.2%
	West Fish Creek	387	912	14	1.5%	810	0	0.0%
	Explicit Structures	387	912	14	1.5%	810	0	0.0%
	A-aggregates	0	0	0	n/a	0	0	n/a
	B-aggregates	0	0	0	n/a	0	0	n/a
	Yampa River	7,442	12,812	726	5.7%	10,175	399	3.9%
*	Explicit Structures	6,039	9,865	25	0.3%	7,659	1	0.0%
*	A-aggregates	458	931	122	13.1%	786	47	6.0%
	B-aggregates	945	2,015	579	28.7%	1,730	351	20.3%

Asterisk denotes mainstem reach
B-aggregates are structures located on unmodeled tributaries
Critically Short Acreage is at least 20% short in at least 4 of 10 years

Table 3-3 - Dry Scenario Consumptive Use Shortage by Location and Structure Type

Location by Water District, Stream and Structure Type	Irrigated Acreage	*Dry Scenario* Average Annual IWR (AF)	*Dry Scenario* Average Annual CU Shortage (AF)	*Dry Scenario* CU Shortage as Percent of IWR	*Baseline Scenario* Average Annual IWR (AF)	*Baseline Scenario* Average Annual CU Shortage (AF)	*Baseline Scenario* CU Shortage as Percent of IWR
58 - Upper Yampa River	**34,551**	**81,197**	**17,500**	**21.6%**	**71,953**	**6,390**	**8.9%**
Explicit Structures	24,903	58,500	10,690	18.3%	51,819	2,283	4.4%
A-aggregates	1,307	3,073	224	7.3%	2,725	37	1.4%
B-aggregates	8,340	19,625	6,586	33.6%	17,408	4,070	23.4%
Bear River	11,632	27,293	6,848	25.1%	24,144	2,177	9.0%
* Explicit Structures	8,940	20,955	5,524	26.4%	18,522	1,705	9.2%
* A-aggregates	451	1,056	95	9.0%	935	37	3.9%
B-aggregates	2,241	5,282	1,229	23.3%	4,687	435	9.3%
Beaver Creek	133	313	70	22.2%	278	2	0.9%
Explicit Structures	133	313	70	22.2%	278	2	0.9%
A-aggregates	0	0	0	n/a	0	0	n/a
B-aggregates	0	0	0	n/a	0	0	n/a
Big Creek	74	174	17	9.9%	155	0	0.1%
Explicit Structures	74	174	17	9.9%	155	0	0.1%
A-aggregates	0	0	0	n/a	0	0	n/a
B-aggregates	0	0	0	n/a	0	0	n/a
Brinker Creek	194	456	195	42.7%	404	24	6.0%
Explicit Structures	194	456	195	42.7%	404	24	6.0%
A-aggregates	0	0	0	n/a	0	0	n/a
B-aggregates	0	0	0	n/a	0	0	n/a
Chimney Creek	736	1,735	404	23.3%	1,540	65	4.2%
Explicit Structures	0	0	0	n/a	0	0	n/a
A-aggregates	29	68	0	0.0%	60	0	0.0%
B-aggregates	708	1,668	404	24.2%	1,480	65	4.4%
Day Creek	350	826	260	31.5%	733	39	5.4%
Explicit Structures	350	826	260	31.5%	733	39	5.4%
A-aggregates	0	0	0	n/a	0	0	n/a
B-aggregates	0	0	0	n/a	0	0	n/a
Elk River	9,696	22,813	5,093	22.3%	20,233	3,449	17.0%
Explicit Structures	4,965	11,693	336	2.9%	10,372	2	0.0%
A-aggregates	661	1,558	115	7.4%	1,383	0	0.0%
B-aggregates	4,070	9,561	4,641	48.5%	8,478	3,446	40.7%
Green Creek	136	320	141	44.2%	284	23	8.0%
Explicit Structures	136	320	141	44.2%	284	23	8.0%
A-aggregates	0	0	0	n/a	0	0	n/a
B-aggregates	0	0	0	n/a	0	0	n/a
Harrison Creek	21	49	2	3.3%	43	0	0.0%
Explicit Structures	21	49	2	3.3%	43	0	0.0%
A-aggregates	0	0	0	n/a	0	0	n/a
B-aggregates	0	0	0	n/a	0	0	n/a
Hinman Creek	148	351	78	22.1%	311	3	0.9%
Explicit Structures	148	351	78	22.1%	311	3	0.9%
A-aggregates	0	0	0	n/a	0	0	n/a
B-aggregates	0	0	0	n/a	0	0	n/a
Hot Springs Creek	96	211	30	14.1%	182	0	0.1%
Explicit Structures	96	211	30	14.1%	182	0	0.1%
A-aggregates	0	0	0	n/a	0	0	n/a
B-aggregates	0	0	0	n/a	0	0	n/a
Hunt Creek	63	147	6	4.3%	131	0	0.0%
Explicit Structures	63	147	6	4.3%	131	0	0.0%
A-aggregates	0	0	0	n/a	0	0	n/a
B-aggregates	0	0	0	n/a	0	0	n/a
Lawson Creek	133	312	56	18.0%	277	1	0.2%
Explicit Structures	133	312	56	18.0%	277	1	0.2%
A-aggregates	0	0	0	n/a	0	0	n/a
B-aggregates	0	0	0	n/a	0	0	n/a

Asterisk denotes mainstem reach
B-aggregates are structures located on unmodeled tributaries
Critically Short Acreage is at least 20% short in at least 4 of 10 years

Table 3-3 - Dry Scenario Consumptive Use Shortage by Location and Structure Type

Location by Water District, Stream and Structure Type	Irrigated Acreage	Dry Scenario			Baseline Scenario		
		Average Annual IWR (AF)	Average Annual CU Shortage (AF)	CU Shortage as Percent of IWR	Average Annual IWR (AF)	Average Annual CU Shortage (AF)	CU Shortage as Percent of IWR
Middle Hunt Creek	769	1,810	128	7.1%	1,607	1	0.0%
Explicit Structures	769	1,810	128	7.1%	1,607	1	0.0%
A-aggregates	0	0	0	n/a	0	0	n/a
B-aggregates	0	0	0	n/a	0	0	n/a
Mill Creek	131	307	28	9.3%	273	0	0.0%
Explicit Structures	131	307	28	9.3%	273	0	0.0%
A-aggregates	0	0	0	n/a	0	0	n/a
B-aggregates	0	0	0	n/a	0	0	n/a
North Hunt Creek	447	1,002	175	17.5%	875	4	0.5%
Explicit Structures	447	1,002	175	17.5%	875	4	0.5%
A-aggregates	0	0	0	n/a	0	0	n/a
B-aggregates	0	0	0	n/a	0	0	n/a
Oak Creek	766	1,804	454	25.2%	1,601	31	1.9%
Explicit Structures	766	1,804	454	25.2%	1,601	31	1.9%
A-aggregates	0	0	0	n/a	0	0	n/a
B-aggregates	0	0	0	n/a	0	0	n/a
Sand Creek	341	804	300	37.3%	714	64	9.0%
Explicit Structures	341	804	300	37.3%	714	64	9.0%
A-aggregates	0	0	0	n/a	0	0	n/a
B-aggregates	0	0	0	n/a	0	0	n/a
Smith Creek	167	395	73	18.4%	351	1	0.3%
Explicit Structures	167	395	73	18.4%	351	1	0.3%
A-aggregates	0	0	0	n/a	0	0	n/a
B-aggregates	0	0	0	n/a	0	0	n/a
Soda Creek	700	1,651	376	22.7%	1,466	73	5.0%
Explicit Structures	700	1,651	376	22.7%	1,466	73	5.0%
A-aggregates	0	0	0	n/a	0	0	n/a
B-aggregates	0	0	0	n/a	0	0	n/a
South Hunt Creek	776	1,826	446	24.4%	1,621	14	0.9%
Explicit Structures	776	1,826	446	24.4%	1,621	14	0.9%
A-aggregates	0	0	0	n/a	0	0	n/a
B-aggregates	0	0	0	n/a	0	0	n/a
Walton Creek	2,494	5,878	1,715	29.2%	5,216	241	4.6%
Explicit Structures	2,494	5,878	1,715	29.2%	5,216	241	4.6%
A-aggregates	0	0	0	n/a	0	0	n/a
B-aggregates	0	0	0	n/a	0	0	n/a
Watson Creek	313	736	244	33.1%	653	55	8.4%
Explicit Structures	313	736	244	33.1%	653	55	8.4%
A-aggregates	0	0	0	n/a	0	0	n/a
B-aggregates	0	0	0	n/a	0	0	n/a
Willow Creek	91	215	10	4.5%	191	0	0.1%
Explicit Structures	91	215	10	4.5%	191	0	0.1%
A-aggregates	0	0	0	n/a	0	0	n/a
B-aggregates	0	0	0	n/a	0	0	n/a
Yampa River	4,145	9,769	352	3.6%	8,670	123	1.4%
* Explicit Structures	2,658	6,264	26	0.4%	5,559	0	0.0%
* A-aggregates	166	391	14	3.6%	347	0	0.0%
B-aggregates	1,322	3,114	312	10.0%	2,764	123	4.5%
Study Area Total	**119,607**	**265,456**	**56,199**	**21.2%**	**229,029**	**25,366**	**11.1%**
Explicit Structures	79,197	170,548	30,834	18.1%	145,386	10,774	7.4%
A-aggregates	11,367	26,481	2,596	9.8%	23,199	562	2.4%
B-aggregates	29,043	68,427	22,768	33.3%	60,443	14,030	23.2%

Asterisk denotes mainstem reach
B-aggregates are structures located on unmodeled tributaries
Critically Short Acreage is at least 20% short in at least 4 of 10 years

Table 3-4 - Wet Scenario Consumptive Use Shortage by Location and Structure Type

Location by Water District, Stream and Structure Type	Irrigated Acreage	*Wet Scenario*			*Baseline Scenario*		
		Average Annual IWR (AF)	Average Annual CU Shortage (AF)	CU Shortage as Percent of IWR	Average Annual IWR (AF)	Average Annual CU Shortage (AF)	CU Shortage as Percent of IWR
43 - White River	**26,820**	**51,693**	**2,040**	**3.9%**	**45,740**	**1,128**	**2.5%**
Explicit Structures	19,957	37,321	1,131	3.0%	32,721	594	1.8%
A-aggregates	2,116	4,142	195	4.7%	3,680	108	2.9%
B-aggregates	4,746	10,230	713	7.0%	9,339	426	4.6%
Big Beaver Creek	66	158	10	6.6%	148	10	6.4%
Explicit Structures	66	158	10	6.6%	148	10	6.4%
A-aggregates	0	0	0	n/a	0	0	n/a
B-aggregates	0	0	0	n/a	0	0	n/a
Black Sulphur Creek	97	165	26	15.6%	142	3	1.8%
Explicit Structures	97	165	26	15.6%	142	3	1.8%
A-aggregates	0	0	0	n/a	0	0	n/a
B-aggregates	0	0	0	n/a	0	0	n/a
Coal Creek	768	1,829	2	0.1%	1,707	0	0.0%
Explicit Structures	768	1,829	2	0.1%	1,707	0	0.0%
A-aggregates	0	0	0	n/a	0	0	n/a
B-aggregates	0	0	0	n/a	0	0	n/a
Elk Creek	154	369	42	11.3%	345	33	9.7%
Explicit Structures	154	369	42	11.3%	345	33	9.7%
A-aggregates	0	0	0	n/a	0	0	n/a
B-aggregates	0	0	0	n/a	0	0	n/a
Evacuation	250	600	53	8.8%	561	36	6.4%
Explicit Structures	0	0	0	n/a	0	0	n/a
A-aggregates	106	255	4	1.7%	239	0	0.0%
B-aggregates	144	345	48	14.0%	322	36	11.2%
Fawn Creek	67	161	0	0.0%	150	0	0.0%
Explicit Structures	67	161	0	0.0%	150	0	0.0%
A-aggregates	0	0	0	n/a	0	0	n/a
B-aggregates	0	0	0	n/a	0	0	n/a
Flag Creek	297	549	19	3.4%	482	2	0.4%
Explicit Structures	297	549	19	3.4%	482	2	0.4%
A-aggregates	0	0	0	n/a	0	0	n/a
B-aggregates	0	0	0	n/a	0	0	n/a
Hill Creek/Hill Creek Tributary	130	312	8	2.4%	291	6	2.2%
Explicit Structures	130	312	8	2.4%	291	6	2.2%
A-aggregates	0	0	0	n/a	0	0	n/a
B-aggregates	0	0	0	n/a	0	0	n/a
Lake Creek/Douglas Creek	12	36	8	22.2%	35	9	26.4%
Explicit Structures	12	36	8	22.2%	35	9	26.4%
A-aggregates	0	0	0	n/a	0	0	n/a
B-aggregates	0	0	0	n/a	0	0	n/a
Marvine Creek	130	287	0	0.0%	264	0	0.0%
Explicit Structures	130	287	0	0.0%	264	0	0.0%
A-aggregates	0	0	0	n/a	0	0	n/a
B-aggregates	0	0	0	n/a	0	0	n/a
Miller Creek	125	269	16	6.0%	244	15	6.0%
Explicit Structures	125	269	16	6.0%	244	15	6.0%
A-aggregates	0	0	0	n/a	0	0	n/a
B-aggregates	0	0	0	n/a	0	0	n/a
Moose Creek/Cave Creek	301	545	25	4.6%	490	18	3.8%
Explicit Structures	301	545	25	4.6%	490	18	3.8%
A-aggregates	0	0	0	n/a	0	0	n/a
B-aggregates	0	0	0	n/a	0	0	n/a
North Fork White River	594	1,421	21	1.5%	1,328	4	0.3%
* Explicit Structures	206	496	21	4.3%	464	4	0.8%
* A-aggregates	69	166	0	0.0%	155	0	0.0%
B-aggregates	319	760	0	0.0%	709	0	0.0%
Piceance Creek	4,230	8,582	1,538	17.9%	7,722	806	10.4%
Explicit Structures	2,437	4,531	914	20.2%	3,987	451	11.3%
A-aggregates	352	774	191	24.7%	710	108	15.2%
B-aggregates	1,441	3,277	433	13.2%	3,025	247	8.2%
Soldier Creek/East Douglas/Douglas Creek	57	169	40	23.7%	161	43	27.0%
Explicit Structures	57	169	40	23.7%	161	43	27.0%
A-aggregates	0	0	0	n/a	0	0	n/a
B-aggregates	0	0	0	n/a	0	0	n/a
South Fork White River	952	2,286	23	1.0%	2,137	17	0.8%
* Explicit Structures	684	1,644	0	0.0%	1,537	0	0.0%
* A-aggregates	66	158	0	0.0%	148	0	0.0%
B-aggregates	201	484	23	4.7%	452	17	3.7%
Ute Creek	61	148	0	0.0%	138	0	0.0%
Explicit Structures	61	148	0	0.0%	138	0	0.0%
A-aggregates	0	0	0	n/a	0	0	n/a
B-aggregates	0	0	0	n/a	0	0	n/a
White River	18,528	33,807	209	0.6%	29,394	126	0.4%
* Explicit Structures	14,363	25,655	0	0.0%	22,136	0	0.0%
* A-aggregates	1,523	2,788	0	0.0%	2,427	0	0.0%
B-aggregates	2,642	5,365	209	3.9%	4,830	126	2.6%

Asterisk denotes mainstem reach
B-aggregates are structures located on unmodeled tributaries
Critically Short Acreage is at least 20% short in at least 4 of 10 years

Table 3-4 - Wet Scenario Consumptive Use Shortage by Location and Structure Type

Location by Water District, Stream and Structure Type	Irrigated Acreage	Wet Scenario: Average Annual IWR (AF)	Wet Scenario: Average Annual CU Shortage (AF)	Wet Scenario: CU Shortage as Percent of IWR	Baseline Scenario: Average Annual IWR (AF)	Baseline Scenario: Average Annual CU Shortage (AF)	Baseline Scenario: CU Shortage as Percent of IWR
44 - Lower Yampa River	**29,069**	**61,171**	**14,002**	**22.9%**	**54,987**	**10,587**	**19.3%**
Explicit Structures	19,108	38,910	8,001	20.6%	34,678	5,836	16.8%
A-aggregates	2,893	6,345	316	5.0%	5,746	205	3.6%
B-aggregates	7,067	15,917	5,685	35.7%	14,563	4,546	31.2%
Beaver Creek	150	363	181	49.9%	340	127	37.2%
Explicit Structures	150	363	181	49.9%	340	127	37.2%
A-aggregates	0	0	0	n/a	0	0	n/a
B-aggregates	0	0	0	n/a	0	0	n/a
Crystal Creek	30	60	2	3.2%	54	0	0.5%
Explicit Structures	30	60	2	3.2%	54	0	0.5%
A-aggregates	0	0	0	n/a	0	0	n/a
B-aggregates	0	0	0	n/a	0	0	n/a
Deer Creek	274	563	18	3.3%	501	1	0.2%
Explicit Structures	274	563	18	3.3%	501	1	0.2%
A-aggregates	0	0	0	n/a	0	0	n/a
B-aggregates	0	0	0	n/a	0	0	n/a
Dry Creek	289	715	336	47.0%	664	250	37.6%
Explicit Structures	289	715	336	47.0%	664	250	37.6%
A-aggregates	0	0	0	n/a	0	0	n/a
B-aggregates	0	0	0	n/a	0	0	n/a
East Fork Williams Fork	2,680	6,490	1,421	21.9%	6,043	1,179	19.5%
Explicit Structures	863	1,831	4	0.2%	1,670	0	0.0%
A-aggregates	317	815	0	0.0%	766	0	0.0%
B-aggregates	1,501	3,844	1,416	36.8%	3,608	1,179	32.7%
Elkhead Creek	2,070	4,453	721	16.2%	4,053	561	13.8%
Explicit Structures	1,431	2,819	168	6.0%	2,519	105	4.2%
A-aggregates	70	170	45	26.2%	157	38	24.5%
B-aggregates	569	1,464	509	34.8%	1,376	417	30.3%
Fortification Creek	991	2,099	639	30.4%	1,876	468	24.9%
Explicit Structures	991	2,099	639	30.4%	1,876	468	24.9%
A-aggregates	0	0	0	n/a	0	0	n/a
B-aggregates	0	0	0	n/a	0	0	n/a
James Creek	5	13	2	15.3%	12	1	6.0%
Explicit Structures	5	13	2	15.3%	12	1	6.0%
A-aggregates	0	0	0	n/a	0	0	n/a
B-aggregates	0	0	0	n/a	0	0	n/a
Little Bear	1,530	3,430	2,153	62.8%	3,120	1,836	58.8%
Explicit Structures	1,530	3,430	2,153	62.8%	3,120	1,836	58.8%
A-aggregates	0	0	0	n/a	0	0	n/a
B-aggregates	0	0	0	n/a	0	0	n/a
Little Cottonwood Creek	207	457	263	57.5%	415	213	51.4%
Explicit Structures	207	457	263	57.5%	415	213	51.4%
A-aggregates	0	0	0	n/a	0	0	n/a
B-aggregates	0	0	0	n/a	0	0	n/a
Milk Creek	3,796	8,064	2,449	30.4%	7,290	1,532	21.0%
Explicit Structures	2,175	4,711	909	19.3%	4,279	337	7.9%
A-aggregates	313	685	263	38.5%	621	164	26.5%
B-aggregates	1,307	2,668	1,276	47.8%	2,390	1,031	43.1%
Morapose Creek	2,097	4,645	2,626	56.5%	4,208	2,130	50.6%
Explicit Structures	2,097	4,645	2,626	56.5%	4,208	2,130	50.6%
A-aggregates	0	0	0	n/a	0	0	n/a
B-aggregates	0	0	0	n/a	0	0	n/a
North Fork Elkhead Creek	27	62	11	18.3%	57	7	13.1%
Explicit Structures	27	62	11	18.3%	57	7	13.1%
A-aggregates	0	0	0	n/a	0	0	n/a
B-aggregates	0	0	0	n/a	0	0	n/a
Pine Creek	392	779	341	43.8%	699	249	35.6%
Explicit Structures	392	779	341	43.8%	699	249	35.6%
A-aggregates	0	0	0	n/a	0	0	n/a
B-aggregates	0	0	0	n/a	0	0	n/a
South Fork Williams Fork	125	282	0	0.0%	261	0	0.0%
* Explicit Structures	125	282	0	0.0%	261	0	0.0%
* A-aggregates	0	0	0	n/a	0	0	n/a
B-aggregates	0	0	0	n/a	0	0	n/a
Waddle Creek	217	545	59	10.8%	511	19	3.7%
Explicit Structures	217	545	59	10.8%	511	19	3.7%
A-aggregates	0	0	0	n/a	0	0	n/a
B-aggregates	0	0	0	n/a	0	0	n/a
Williams Fork	2,631	6,549	1,331	20.3%	6,109	1,120	18.3%
* Explicit Structures	274	517	0	0.0%	448	0	0.0%
* A-aggregates	779	1,988	0	0.0%	1,865	0	0.0%
B-aggregates	1,578	4,044	1,331	32.9%	3,796	1,120	29.5%
Yampa River	11,557	21,603	1,450	6.7%	18,775	895	4.8%
* Explicit Structures	8,031	15,019	289	1.9%	13,046	94	0.7%
* A-aggregates	1,415	2,687	9	0.3%	2,337	2	0.1%
B-aggregates	2,111	3,896	1,152	29.6%	3,392	799	23.6%

Asterisk denotes mainstem reach
B-aggregates are structures located on unmodeled tributaries
Critically Short Acreage is at least 20% short in at least 4 of 10 years

Table 3-4 - Wet Scenario Consumptive Use Shortage by Location and Structure Type

Location by Water District, Stream and Structure Type	Irrigated Acreage	Wet Scenario			Baseline Scenario		
		Average Annual IWR (AF)	Average Annual CU Shortage (AF)	CU Shortage as Percent of IWR	Average Annual IWR (AF)	Average Annual CU Shortage (AF)	CU Shortage as Percent of IWR
54 - Slater/Timerlake Creeks	**14,670**	**35,911**	**8,383**	**23.3%**	**33,407**	**6,359**	**19.0%**
Explicit Structures	5,886	13,367	2,795	20.9%	12,235	1,997	16.3%
A-aggregates	3,260	8,367	338	4.0%	7,851	165	2.1%
B-aggregates	5,524	14,178	5,249	37.0%	13,321	4,198	31.5%
Little Snake	10,250	24,544	4,849	19.8%	22,726	3,808	16.8%
Explicit Structures	3,153	6,352	298	4.7%	5,645	144	2.6%
A-aggregates	3,110	7,980	331	4.2%	7,488	164	2.2%
B-aggregates	3,988	10,211	4,220	41.3%	9,593	3,500	36.5%
Slater Creek	2,780	7,169	1,766	24.6%	6,737	1,156	17.2%
Explicit Structures	1,095	2,816	730	25.9%	2,646	457	17.3%
A-aggregates	150	386	7	1.7%	363	1	0.2%
B-aggregates	1,536	3,966	1,030	26.0%	3,728	698	18.7%
Willow Creek	1,639	4,199	1,768	42.1%	3,944	1,396	35.4%
Explicit Structures	1,639	4,199	1,768	42.1%	3,944	1,396	35.4%
A-aggregates	0	0	0	n/a	0	0	n/a
B-aggregates	0	0	0	n/a	0	0	n/a
55 - Little Snake River	**1,788**	**3,306**	**111**	**3.4%**	**2,868**	**81**	**2.8%**
Explicit Structures	1,128	2,084	90	4.3%	1,808	63	3.5%
A-aggregates	600	1,111	0	0.0%	964	0	0.0%
B-aggregates	60	111	21	19.1%	97	18	18.2%
Little Snake	1,680	3,105	90	2.9%	2,694	63	2.4%
Explicit Structures	1,128	2,084	90	4.3%	1,808	63	3.5%
A-aggregates	552	1,022	0	0.0%	887	0	0.0%
B-aggregates	0	0	0	n/a	0	0	n/a
Yampa River	108	200	21	10.7%	174	18	10.1%
* Explicit Structures	0	0	0	n/a	0	0	n/a
* A-aggregates	48	89	0	0.2%	77	0	0.0%
B-aggregates	60	111	21	19.1%	97	18	18.2%
56 - Green River	**2,173**	**4,051**	**622**	**15.4%**	**3,517**	**383**	**10.9%**
Explicit Structures	0	0	0	n/a	0	0	n/a
A-aggregates	157	291	0	0.0%	252	0	0.0%
B-aggregates	2,016	3,761	622	16.5%	3,265	383	11.7%
Green River	2,173	4,051	622	15.4%	3,517	383	10.9%
* Explicit Structures	0	0	0	n/a	0	0	n/a
* A-aggregates	157	291	0	0.0%	252	0	0.0%
B-aggregates	2,016	3,761	622	16.5%	3,265	383	11.7%
57 - Middle Yampa River	**10,537**	**18,785**	**633**	**3.4%**	**16,557**	**437**	**2.6%**
Explicit Structures	8,214	13,916	30	0.2%	12,125	1	0.0%
A-aggregates	1,033	2,174	64	3.0%	1,981	47	2.4%
B-aggregates	1,290	2,695	539	20.0%	2,451	389	15.9%
Fish Creek	595	1,325	13	1.0%	1,222	0	0.0%
Explicit Structures	595	1,325	13	1.0%	1,222	0	0.0%
A-aggregates	0	0	0	n/a	0	0	n/a
B-aggregates	0	0	0	n/a	0	0	n/a
Trout Creek	2,113	4,718	74	1.6%	4,350	37	0.9%
Explicit Structures	1,193	2,644	12	0.5%	2,434	0	0.0%
A-aggregates	575	1,294	0	0.0%	1,195	0	0.0%
B-aggregates	345	780	61	7.9%	721	37	5.2%
West Fish Creek	387	875	0	0.0%	810	0	0.0%
Explicit Structures	387	875	0	0.0%	810	0	0.0%
A-aggregates	0	0	0	n/a	0	0	n/a
B-aggregates	0	0	0	n/a	0	0	n/a
Yampa River	7,442	11,867	547	4.6%	10,175	399	3.9%
* Explicit Structures	6,039	9,072	5	0.1%	7,659	1	0.0%
* A-aggregates	458	880	64	7.3%	786	47	6.0%
B-aggregates	945	1,915	478	25.0%	1,730	351	20.3%

Asterisk denotes mainstem reach
B-aggregates are structures located on unmodeled tributaries
Critically Short Acreage is at least 20% short in at least 4 of 10 years

Table 3-4 - Wet Scenario Consumptive Use Shortage by Location and Structure Type

Location by Water District, Stream and Structure Type	Irrigated Acreage	Wet Scenario			Baseline Scenario		
		Average Annual IWR (AF)	Average Annual CU Shortage (AF)	CU Shortage as Percent of IWR	Average Annual IWR (AF)	Average Annual CU Shortage (AF)	CU Shortage as Percent of IWR
58 - Upper Yampa River	**34,551**	**77,890**	**10,201**	**13.1%**	**71,953**	**6,390**	**8.9%**
Explicit Structures	24,903	56,111	5,067	9.0%	51,819	2,283	4.4%
A-aggregates	1,307	2,948	68	2.3%	2,725	37	1.4%
B-aggregates	8,340	18,831	5,065	26.9%	17,408	4,070	23.4%
Bear River	11,632	26,168	3,695	14.1%	24,144	2,177	9.0%
* Explicit Structures	8,940	20,087	2,976	14.8%	18,522	1,705	9.2%
* A-aggregates	451	1,012	52	5.1%	935	37	3.9%
B-aggregates	2,241	5,069	667	13.2%	4,687	435	9.3%
Beaver Creek	133	300	23	7.8%	278	2	0.9%
Explicit Structures	133	300	23	7.8%	278	2	0.9%
A-aggregates	0	0	0	n/a	0	0	n/a
B-aggregates	0	0	0	n/a	0	0	n/a
Big Creek	74	167	2	1.2%	155	0	0.1%
Explicit Structures	74	167	2	1.2%	155	0	0.1%
A-aggregates	0	0	0	n/a	0	0	n/a
B-aggregates	0	0	0	n/a	0	0	n/a
Brinker Creek	194	437	72	16.4%	404	24	6.0%
Explicit Structures	194	437	72	16.4%	404	24	6.0%
A-aggregates	0	0	0	n/a	0	0	n/a
B-aggregates	0	0	0	n/a	0	0	n/a
Chimney Creek	736	1,665	168	10.1%	1,540	65	4.2%
Explicit Structures	0	0	0	n/a	0	0	n/a
A-aggregates	29	65	0	0.0%	60	0	0.0%
B-aggregates	708	1,600	168	10.5%	1,480	65	4.4%
Day Creek	350	793	131	16.5%	733	39	5.4%
Explicit Structures	350	793	131	16.5%	733	39	5.4%
A-aggregates	0	0	0	n/a	0	0	n/a
B-aggregates	0	0	0	n/a	0	0	n/a
Elk River	9,696	21,889	4,050	18.5%	20,233	3,449	17.0%
Explicit Structures	4,965	11,220	27	0.2%	10,372	2	0.0%
A-aggregates	661	1,496	14	1.0%	1,383	0	0.0%
B-aggregates	4,070	9,174	4,008	43.7%	8,478	3,446	40.7%
Green Creek	136	307	79	25.8%	284	23	8.0%
Explicit Structures	136	307	79	25.8%	284	23	8.0%
A-aggregates	0	0	0	n/a	0	0	n/a
B-aggregates	0	0	0	n/a	0	0	n/a
Harrison Creek	21	47	0	0.2%	43	0	0.0%
Explicit Structures	21	47	0	0.2%	43	0	0.0%
A-aggregates	0	0	0	n/a	0	0	n/a
B-aggregates	0	0	0	n/a	0	0	n/a
Hinman Creek	148	336	16	4.7%	311	3	0.9%
Explicit Structures	148	336	16	4.7%	311	3	0.9%
A-aggregates	0	0	0	n/a	0	0	n/a
B-aggregates	0	0	0	n/a	0	0	n/a
Hot Springs Creek	96	200	4	2.2%	182	0	0.1%
Explicit Structures	96	200	4	2.2%	182	0	0.1%
A-aggregates	0	0	0	n/a	0	0	n/a
B-aggregates	0	0	0	n/a	0	0	n/a
Hunt Creek	63	142	1	0.4%	131	0	0.0%
Explicit Structures	63	142	1	0.4%	131	0	0.0%
A-aggregates	0	0	0	n/a	0	0	n/a
B-aggregates	0	0	0	n/a	0	0	n/a
Lawson Creek	133	300	4	1.3%	277	1	0.2%
Explicit Structures	133	300	4	1.3%	277	1	0.2%
A-aggregates	0	0	0	n/a	0	0	n/a
B-aggregates	0	0	0	n/a	0	0	n/a

Asterisk denotes mainstem reach
B-aggregates are structures located on unmodeled tributaries
Critically Short Acreage is at least 20% short in at least 4 of 10 years

Table 3-4 - Wet Scenario Consumptive Use Shortage by Location and Structure Type

Location by Water District, Stream and Structure Type	Irrigated Acreage	Wet Scenario: Average Annual IWR (AF)	Wet Scenario: Average Annual CU Shortage (AF)	Wet Scenario: CU Shortage as Percent of IWR	Baseline Scenario: Average Annual IWR (AF)	Baseline Scenario: Average Annual CU Shortage (AF)	Baseline Scenario: CU Shortage as Percent of IWR
Middle Hunt Creek	769	1,737	12	0.7%	1,607	1	0.0%
Explicit Structures	769	1,737	12	0.7%	1,607	1	0.0%
A-aggregates	0	0	0	n/a	0	0	n/a
B-aggregates	0	0	0	n/a	0	0	n/a
Mill Creek	131	295	2	0.6%	273	0	0.0%
Explicit Structures	131	295	2	0.6%	273	0	0.0%
A-aggregates	0	0	0	n/a	0	0	n/a
B-aggregates	0	0	0	n/a	0	0	n/a
North Hunt Creek	447	957	30	3.2%	875	4	0.5%
Explicit Structures	447	957	30	3.2%	875	4	0.5%
A-aggregates	0	0	0	n/a	0	0	n/a
B-aggregates	0	0	0	n/a	0	0	n/a
Oak Creek	766	1,731	224	12.9%	1,601	31	1.9%
Explicit Structures	766	1,731	224	12.9%	1,601	31	1.9%
A-aggregates	0	0	0	n/a	0	0	n/a
B-aggregates	0	0	0	n/a	0	0	n/a
Sand Creek	341	772	161	20.9%	714	64	9.0%
Explicit Structures	341	772	161	20.9%	714	64	9.0%
A-aggregates	0	0	0	n/a	0	0	n/a
B-aggregates	0	0	0	n/a	0	0	n/a
Smith Creek	167	379	12	3.1%	351	1	0.3%
Explicit Structures	167	379	12	3.1%	351	1	0.3%
A-aggregates	0	0	0	n/a	0	0	n/a
B-aggregates	0	0	0	n/a	0	0	n/a
Soda Creek	700	1,585	200	12.6%	1,466	73	5.0%
Explicit Structures	700	1,585	200	12.6%	1,466	73	5.0%
A-aggregates	0	0	0	n/a	0	0	n/a
B-aggregates	0	0	0	n/a	0	0	n/a
South Hunt Creek	776	1,752	116	6.6%	1,621	14	0.9%
Explicit Structures	776	1,752	116	6.6%	1,621	14	0.9%
A-aggregates	0	0	0	n/a	0	0	n/a
B-aggregates	0	0	0	n/a	0	0	n/a
Walton Creek	2,494	5,641	848	15.0%	5,216	241	4.6%
Explicit Structures	2,494	5,641	848	15.0%	5,216	241	4.6%
A-aggregates	0	0	0	n/a	0	0	n/a
B-aggregates	0	0	0	n/a	0	0	n/a
Watson Creek	313	706	124	17.5%	653	55	8.4%
Explicit Structures	313	706	124	17.5%	653	55	8.4%
A-aggregates	0	0	0	n/a	0	0	n/a
B-aggregates	0	0	0	n/a	0	0	n/a
Willow Creek	91	206	1	0.4%	191	0	0.1%
Explicit Structures	91	206	1	0.4%	191	0	0.1%
A-aggregates	0	0	0	n/a	0	0	n/a
B-aggregates	0	0	0	n/a	0	0	n/a
Yampa River	4,145	9,376	226	2.4%	8,670	123	1.4%
* Explicit Structures	2,658	6,012	1	0.0%	5,559	0	0.0%
* A-aggregates	166	375	2	0.7%	347	0	0.0%
B-aggregates	1,322	2,989	223	7.4%	2,764	123	4.5%
Study Area Total	**119,607**	**252,807**	**35,993**	**14.2%**	**229,029**	**25,366**	**11.1%**
Explicit Structures	79,197	161,708	17,115	10.6%	145,386	10,774	7.4%
A-aggregates	11,367	25,377	983	3.9%	23,199	562	2.4%
B-aggregates	29,043	65,722	17,895	27.2%	60,443	14,030	23.2%

Asterisk denotes mainstem reach
B-aggregates are structures located on unmodeled tributaries
Critically Short Acreage is at least 20% short in at least 4 of 10 years

Table 3-5 - Shortages at Focus Ditches for Baseline, Dry and Wet Scenarios

Structure Name	Water Source	ID	Scenario	Irrigated Acreage	Average IWR (AF)	Average CU Shortage (AF)	Average CU Shortage as % of IWR	Idendified as Critically Short
HIGHLAND DITCH[1]	WHITE RIVER	430694	Baseline	1,851	2,750	0	0.0%	No
			Dry	1,851	3,458	22	0.6%	No
			Wet	1,851	3,205	0	0.0%	No
SQUARE S CONS D SYS	PICEANCE CK	430948	Baseline	303	443	1	0.2%	No
			Dry	303	555	119	21.4%	Yes
			Wet	303	515	17	3.2%	No
WISCONSIN DITCH	FORTIFICATION CK	440511	Baseline	543	888	14	1.5%	No
			Dry	543	1,097	178	16.2%	No
			Wet	543	1,024	61	6.0%	No
DEEP CUT IRR D	YAMPA RIVER	440589	Baseline	583	953	0	0.0%	No
			Dry	583	1,178	0	0.0%	No
			Wet	583	1,100	0	0.0%	No
HIGHLAND DITCH	MORAPOS CK	440651	Baseline	856	1,456	593	40.7%	Yes
			Dry	856	1,795	1,081	60.2%	Yes
			Wet	856	1,677	830	49.5%	Yes
MILK CK DITCH	MILK CK	440706	Baseline	373	623	156	25.1%	Yes
			Dry	373	764	452	59.2%	Yes
			Wet	373	716	330	46.1%	Yes
MORGAN SLATER DITCH	SLATER CK	540549	Baseline	148	359	0	0.0%	No
			Dry	148	392	2	0.6%	No
			Wet	148	381	0	0.1%	No
MAJORS PUMP NO 2	LITTLE SNAKE RIVER	550506	Baseline	388	622	0	0.0%	No
			Dry	388	765	0	0.0%	No
			Wet	388	716	0	0.0%	No
GREEN AGGREGATE	GREEN RIVER TRIBUTARIES	56_ADY027b	Baseline	2,016	3,265	383	11.7%	No
			Dry	2,016	4,016	777	19.3%	No
			Wet	2,016	3,761	622	16.5%	No
WALKER IRRIG DITCH	YAMPA RIVER	570611	Baseline	1,298	1,617	0	0.0%	No
			Dry	1,298	2,093	0	0.0%	No
			Wet	1,298	1,922	0	0.0%	No
MORIN DITCH	ELK RIVER	580783	Baseline	463	969	0	0.0%	No
			Dry	463	1,091	0	0.0%	No
			Wet	463	1,048	0	0.0%	No
NICKELL DITCH	BEAR RIVER	580798	Baseline	284	593	0	0.0%	No
			Dry	284	669	0	0.0%	No
			Wet	284	642	0	0.0%	No
NORTH HUNT CREEK DITCH	NORTH HUNT CK	580801	Baseline	131	274	0	0.0%	No
			Dry	131	309	0	0.0%	No
			Wet	131	297	0	0.0%	No

1 - Also known as the White River Highland Ditch
Critically short acreage is defined as at least 20% short in at least 4 of 10 years

8.0 Conclusions

Long term records of streamflow in the Yampa do not indicate historical patterns of peak flow beginning earlier in the year; however very clearly show the natural variability from year to year of the river systems. Long term records of streamflow on the White River indicate a wide range of natural variability in streamflow timing, but that peak flow on the White River is shifting earlier in the year. Temperature records dating to the 1950's indicate temperatures have increased at a rate of approximately one degree (F) every 40 years (Figures 3-1 and 3-2).

Two climate change scenarios from the five year 2040 selected scenarios for CRWAS were modeled for this study; 'miroc3_2_medres1' (dry scenario) and 'cccma_cfcm3_12' (wet scenario). Both scenarios have increased temperature. IWR increased in both of the climate change scenarios (Figure 3-5); approximately 10 percent increase over baseline conditions for the wet scenario and 16 percent increase in the dry scenario. The increases in IWR for the two selected scenarios are within the range of increases to IWR presented in CRWAS.

The two scenarios generally produced the largest increase, and largest decrease in baseflows during the growing season relative to current conditions. The increased IWR demand and a shift to earlier runoff creates a larger gap between water supply and crop demand than under current conditions (Figure 3-6). Each of the scenarios is considered to be equally as likely to occur. For the purposes of this study, it was assumed that the scenarios with the largest increase and decrease in growing season baseflows would capture a reasonable range of changes to existing agricultural shortages from baseline conditions.

The climate change hydrology did not consider any non-climatic changes; however changes to hydrology due to the Mountain Pine Beetle infestation has been show to create changes in runoff similar to the changes predicted in the wet climate change scenarios (increased annual runoff and runoff shifting earlier in the year). Near full forest recovery is expected by the 2040 timeframe used in CRWAS so compounding effects of beetle infestation and climate change were not investigated in this study.

Agricultural shortages in the study area increased under both climate change scenarios (Table 3-2, Figure 3-7) as compared to the baseline condition. Under current conditions, consumptive shortage is 11 percent of the study area IWR and increases to 14 percent in the wet scenario and 21 percent in the dry scenario. Seasonal shortages beginning in July worsened under both scenarios due to increased IWR and earlier runoff (Figure 3-8). Critically short acreage increases under both climate change scenarios approximately proportionately to increases in CU shortage amounts. In many watersheds in the study area, there is sufficient water in the basin on an annual basis to meet agricultural demand, but the timing of water supplies and crop demands do not coincide and leads to shortages.

Additional storage could be used to retime supplies to align with demands. Water users in the basin have contemplated additional storage to offset existing shortages. The change in supply and demand patterns under the climate change scenarios exacerbates the timing difference in supply in demand, suggesting that additional storage could help mitigate increases in shortages due to climate change. However, many of the shortages are on smaller tributary streams (including un-modeled tributaries) where a storage project may benefit a smaller number of users. The largest increases in shortages occurred at the modeled tributary and unmodeled tributary structures under climate change scenarios (Figures 3-7 and 3-8). Storage projects aimed to alleviate shortages at the un-modeled tributaries would have a narrower set of beneficiaries than the large modeled tributary streams, but return flows from a storage project may be available to downstream users. Alternatives to shortages are addressed in more detail in future technical memoranda (Tasks 5 and 7).

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CDM

Memorandum

To: *Jeff Comstock (Moffat County), Yampa/White/Green Basin Roundtable Agricultural Subcommittee*

From: *Matt Bliss, Mark Hoener (CDM); Hal Simpson (H. D. Simpson Consulting); Ross Bethel (Ross Bethel, LLC)*

Date: *June 29, 2010*

Subject: *Agricultural Water Needs Study: Task 4 Final*

We are pleased to present the final draft of the Yampa/White/Green Agricultural Water Needs Study Task 4 technical memorandum. This task addresses potential impacts the potential development of conditional water rights associated with the energy industry on existing agricultural uses in the study area. This memo was prepared by CDM staff and reviewed by both Hal Simpson and Ross Bethel. Additionally, this memo incorporates comments the subcommittee has raised at the progress meetings.

Sincerely,

Matt Bliss
Project Manager

1.0 Introduction and Background

In 2005, House Bill 05-1177, the Colorado Water for the 21st Century Act (Penry, et al., House Bill 05-1177, 2005) was signed into law. Among other provisions, the bill provides for the creation of Basin Roundtables (BRT). Each BRT is charged with formulating a water needs assessment, conducting an analysis of available unappropriated water, and proposing projects or methods for meeting those needs.

In 2003, the Colorado Water Conservation Board (CWCB) completed the Statewide Water Supply Initiative (SWSI). That study included estimates of water demands in the White and Yampa River basins through 2030. SWSI concluded there was little gap between projected municipal and industrial water demands and available water supplies in the basins. While SWSI provided a valuable coarse assessment of water demands for the municipal, industrial, and agricultural sectors, concerns were raised at that time that the analysis did not accurately reflect the agricultural water shortages in some of the water districts and especially as it exists on the tributaries. One concern was that the Yampa River Basin analysis of agricultural demand was not based on high-altitude crop coefficients, thus understating the demand for water in the Yampa River Basin.

SWSI also noted that up to an additional 39,000 acres of agricultural lands could be developed in the basins but did not investigate the location or impact of additional agricultural demand in these basins. The Colorado River Water Conservation District Small Reservoir Study (CRWCD, 2000) identified sites for additional water supply storage in the Yampa Basin. That study highlighted the need to look at integrating irrigation practices with storage to better meet water demands.
The objectives of the current study are to:

1. Refine and update previous estimates of current agricultural water demands, supplies, and shortages for the Yampa/White/Green River Basin through use of the State of Colorado's Decision Support System (DSS) models and data
2. Identify and evaluate shortages for the future agricultural demands
3. Assess the impacts of climate change on agricultural water availability
4. Assess the impacts of energy sector water supply development on agricultural water availability in the White River Basin
5. Assess water supply development alternatives to satisfy shortages identified in (1), (2), and (3) above
6. Assess the effects on return flows of various irrigation practices or changes in those practices
7. Investigate creative solutions that benefit multiple interests (e.g., agriculture, energy, recreation, environment, etc.)

This technical memorandum addresses the fourth of those objectives and is the fourth in a series of technical memoranda that will address each of the objectives.

2.0 Agricultural Subcommittee Input

The agricultural subcommittee expressed concern that development of the energy industry in the study area could negatively affect agricultural users. In particular, reference was made to some ditches in the White River basin that enlarged their ditch after many of the conditional energy industry water rights were filed. Additionally, there was concern that ranching or farming water rights that have been bought by energy companies could negatively impact other agricultural users.

3.0 Energy Needs Assessment Report

The Colorado River and Yampa/White/Green Roundtables funded an energy water needs assessment study (URS 2008), and the draft version of the report was made available to CDM for this study (hereafter, energy report). In an effort to coordinate with previous efforts of the roundtable, the results presented in the energy report were used to help determine the energy industry's water needs and probable locations of use within the study area. Within the study area, the energy needs report identified uses primarily in the White River basin (including Piceance Creek). The map of coal and natural gas production showed deposits extending into the Yampa basin. However, conditional water rights for energy development were tabulated only for the Colorado and White River basins, and not for the Yampa basin.

The conditional water rights tabulation for the Yampa River basin was reviewed for water rights owned by energy interests and are described in further detail in Section 4. For the purposes of this study, it was assumed that any additional water use associated with energy development in the Yampa basin would require either a junior water right or the transfer of an existing water right. In either case, existing agricultural uses would not be affected by such a right, provided maintenance of historical return flows is required in the water right change decree or substitute water supply plan.

The energy report investigated four sectors: oil shale, natural gas, coal and uranium. Each of the four sectors were analyzed and different levels of water needs were projected for low, mid, and high levels of production, and for near-term (present to 2017), mid-term (2018 to 2035) and long-term (beyond 2035) timeframes. Water needs were further subdivided by component of use (e.g. direct use, indirect use from thermoelectric demand, operational and maintenance uses etc…). Table 4-1 summarizes the mid-production, mid-term timeframe water needs presented in the energy study. Uranium mining demand (70 AFY) was considered negligible and were not considered in this analysis. The energy study did not provide estimated amounts of production by location within their study area, except for natural gas production. New natural gas wells will be drilled almost exclusively in the White River basin (Rio Blanco County) by 2025. For all other energy sectors, estimates of the proportion of energy industry water demands in the White River basin were made based on the relative amount of mineral deposit area shown in the oil shale, natural gas well and coal maps presented in the energy study. For the purposes of this study, it was assumed that 100% of the oil shale, 100% of natural gas new drilling demands, 50% of natural gas O&M demand, and 50% of coal water demands provided in the energy study would be assigned to the White River basin.

Table 4-1 - Mid-production, Mid-term (2017 to 2035) Energy Industry Water Demands

	Energy Report Study Area Direct Demands (AFY)	Energy Report Study Area Indirect Power Demands (AFY)	Portion of Demand Assigned to White River Basin	Energy Industry Demand in White River Basin (AFY)	Monthly Average Demand (cfs)
Oil Shale	14,200	5,500	100%	**19,700**	27
Natural Gas Drilling	5,754	0	100%	**5,754**	8
Natural Gas O&M	3,836	4,970	50%	**4,403**	6
Coal	2,660	1,040	50%	**1,850**	3
Total	26,450	11,510	n/a	**31,707**	44

The energy study also identified several conditional water rights in the White River basin that are owned by energy companies totaling 83 direct flow rights totaling 2,344 cfs, and 25 storage rights totaling 333,717 AF. Other than two irrigation rights identified in the energy study as energy industry related (presumably owned by energy interests) from the early 1900's totaling 2cfs, the most senior of these conditional rights are two 1955 priority date conditional rights totaling to a 370 cfs diversion from the South Fork of the White River (South Fork Piceance Pipeline and Stillwater Power Plant, same point of diversion). It appears that this water would be piped to the Piceance basin. The amounts and locations of conditional water rights identified in the energy study are presented in more detail in Section 4.

Full utilization of the conditional water rights flow rates and storage amounts far exceed the demands presented in Table 4-1. Under mid-term, mid-production, the conditional water rights would not be fully utilized and amount to an average demand of 44 cfs (Table 4-1). Water use demands increase dramatically for oil shale under a high-production scenario (total 362,000 AFY or 500 cfs average), and would use a much larger amount of water under the conditional water rights.

4.0 Water Rights

The energy study tabulated conditional water rights in the White River Basin, but not in the Yampa River Basin. For this study, the water rights tabulation of the Yampa River Basin was reviewed. There are several conditional water rights associated with the Juniper Power Plant, which was originally intended as an on-channel hydropower plant. On-channel reservoirs most likely will not be built due to environmental concerns so it is unlikely that this water right will be developed for the energy industry. The Juniper Project conditional water rights are junior to 92 percent of the absolute direct flow water rights in the Yampa River basin. In addition, the Juniper Project rights have been subordinated to several absolute junior water rights and would have little impact on existing uses. The Craig Station power plant has a conditional water right for 15 cfs with a 1972 priority date, and there is a conditional storage right of 30,000 AF on Trout Creek for Energy Fuels Reservoir 2 with a 1977 priority date. Due to the relatively junior nature of these water rights, it was assumed that development of conditional water rights in the Yampa would not affect existing agricultural uses and was not considered in further modeling.

The conditional water rights identified in the energy study in the White River Basin were compared to the absolute water rights incorporated into the baseline water allocation model for the White River Basin (StateMod). The most senior energy related conditional water rights total 370 cfs on the South Fork of the White River and have priority dates in the mid 1950's (South Fork Piceance Pipeline and Stillwater Power Plant, same point of diversion). The location of these rights are upstream of most of the irrigated acreage in the White River basin. Approximately 77 percent of all absolute direct flow rights (by total decreed flow rate) in the basin are senior to those water rights. The 1950's conditional water rights are senior to approximately 23 percent of the absolute direct flow rights and are senior to most of the Big Beaver Creek Reservoir, and Taylor Draw Reservoir storage rights. Yields on the water rights senior to the conditional rights would not be affected if the conditional rights were made absolute. The priority dates of other conditional water rights identified in the energy study intermix with absolute rights through recent years. Figure 4-1 shows the township and amount (in cfs) of several of the largest and most senior energy conditional water rights. The direct flow rights are summarized by decade in Table 4-2. Many of the direct flow conditional rights are associated with conditional storage rights. The conditional water rights, if developed, could impact the yield to junior absolute water rights. For example, the 2 conditional water rights listed for 1950 could impact the yield to all absolute rights with 1960's or later priority dates.

Table 4-2 – Conditional and Absolute Water Rights by Decade in the White River Basin

Decade	Count Conditional Energy Direct Flow Rights	Sum of Conditional Energy Decreed Flowrate (cfs)	Count of Absolute Direct Flow Rights	Decadal Sum of Absolute Direct Flow Rights (cfs)	Cumulative Sum of Absolute Direct Flow Rights (cfs)
Pre-1950	2	2	337	1,846	1,846
1950*	2	370	47	330*	2,176
1960	19	1,410	18	147	2,323
1970	14	287	13	127	2,450
1980	17	215	3	3	2,453
1990	26	58	7	45	2,498
2000	0	0	0	0	2,498

*A portion (85 cfs) of the 1950's absolute water rights are senior to the 1955 energy conditional rights, and a portion (245 cfs) are junior

Irrigation water rights owned by energy companies and leased back to agriculture were not identified in the energy report, and no further information was available on the amounts or locations of such practice. Water rights historically used for irrigation or other agricultural uses would have to go through a change of use process through Colorado water court, or through State Engineer administrative proceedings associated with substitute water supply plans (SWSP). In both cases, maintenance of historical return flows (amount, timing and location) can become a requirement if requested by water users who could be injured by such a change. It is recommended that water users in the White River

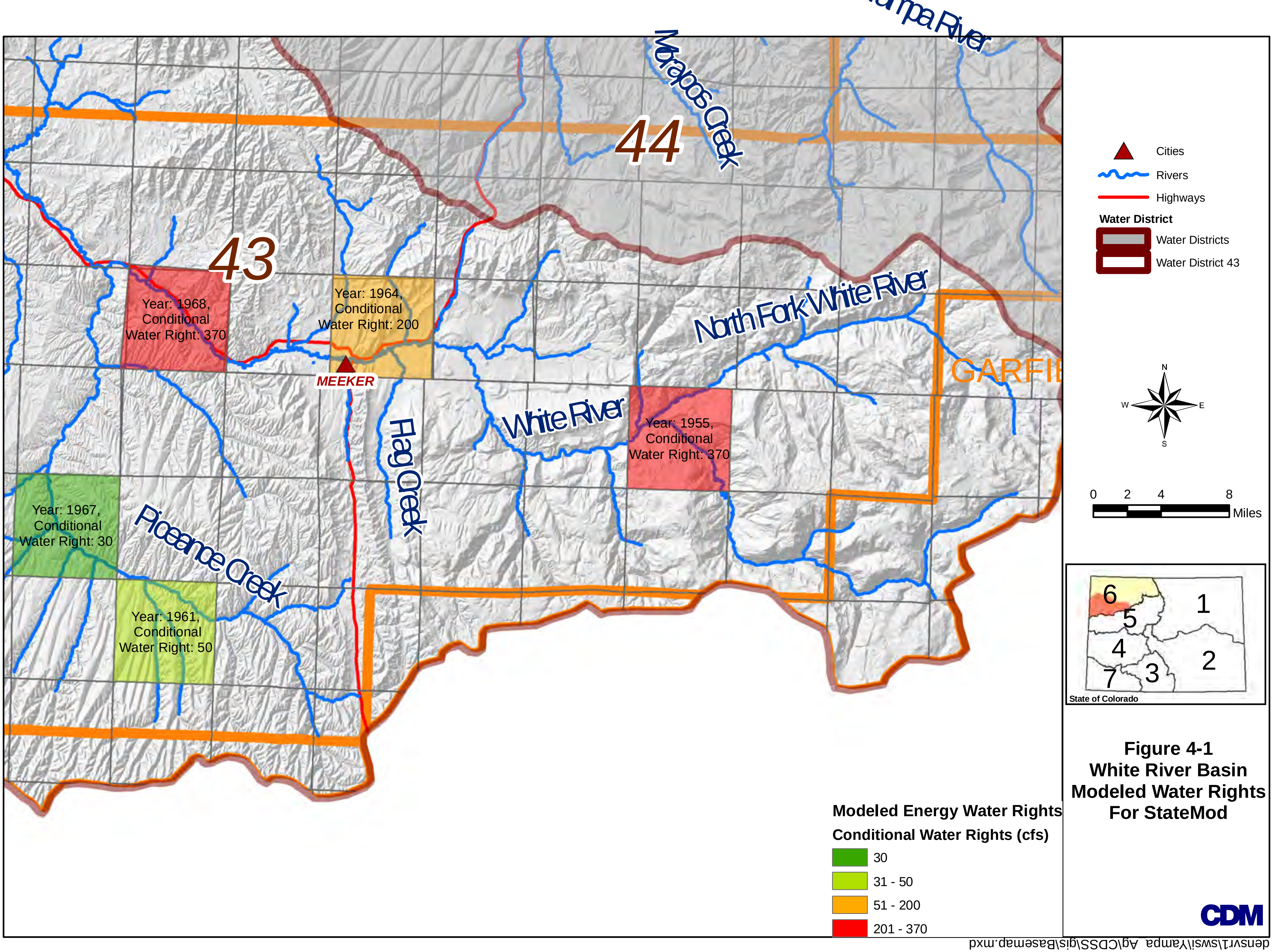


**Figure 4-1
White River Basin
Modeled Water Rights
For StateMod**

Basin keep abreast of such changes in the basin and express their concerns for maintenance of historical return flows. This might best be accomplished through consistent review of water court monthly resumes. In addition, the Roundtable communication channels could be utilized to help notify water users of upcoming change cases or SWSP proceedings.

Subcommittee members expressed concern that some ditches that have expanded acreage and obtained newer water rights junior to many of the conditional energy water rights would experience more severe shortages if the energy water rights were made absolute. As shown in Table 4-2, approximately 23 percent, of the absolute decreed water rights are junior to the 1955 conditional water rights (567 cfs junior to the 1955 conditional water rights of 2,498 cfs total absolute decreed water rights). Using the State's water rights tabulation, it was determined that 42 agricultural structures in the White River Basin have some of their water rights junior to the 1955 conditional energy rights, nine of which have no absolute rights senior to the 1955 conditional energy rights. Table 4-3 lists these structures and tabulates the amount of decreed water rights senior and junior to the 1955 conditional energy rights and shows the irrigated acreage for each structure. Most of the irrigated acreage in the basin is located downstream of these water rights and may not be subject to a water rights call, depending on the flow from other tributaries in the basin downstream of the point of diversion of the conditional water rights. The table is sorted such that structures with the highest percentage and highest decreed rate of water rights junior to the 1955 conditional energy water rights are higher in the list (i.e. structures listed towards the top of the table have a greater chance of being impacted by the development of conditional energy water rights than those lower on the list).

5.0 Modeling Approach and Results

The purpose of modeling energy demands for this study is to assess the impact of potential future energy development on agricultural users. Current agricultural water users divert under absolute water rights that are in large part more senior than the energy industry's conditional water rights (Table 4-2). However, there are several absolute water rights that are junior to significant conditional water rights (Table 4-3). Since only conditional energy water rights in Water District 43 (White River Basin) were tabulated in the energy study, only the White River StateMod model was used for this analysis. Two model runs were executed for this analysis.

The first model run represented energy demands at a mid-level production, mid-term timeframe as presented in Table 4-1 (energy demands scenario). Model nodes were added to the White River StateMod model at the approximate locations of the point of diversion for the conditional water rights and several of the most senior conditional water rights were activated. Figure 4-1 shows the township, priority and amount of the modeled conditional water rights. More detailed information on the location of the point of diversion of the conditional water rights listed in the State's water rights tabulation were used to help identify the location of the conditional water right in the StateMod model network. The model nodes were given the conditional water rights priorities and diversion rates associated with the conditional water rights. A demand was assigned to each node representing the associated energy demands as presented in Table 4-1. The energy demands were assumed to be fully consumptive and were given a uniform monthly distribution.

Table 4-3 - Structures with absolute water rights junior to the 1955 conditional energy water rights

Structure Name	Structure ID	Total of Absolute Rights Senior to 1955 Conditional Energy Rights (cfs)	Total of Absolute Rights Junior to 1955 Conditional Energy Rights (cfs)	Percent of Rights Senior to 1955 Conditional Energy Rights	Irrigated Acreage
GOFF DITCH	431494	0.00	10.20	0%	66
WHIT_ADW WhiteAbPice Modeled Stream Aggregate	43_ADW006a	0.00	10.00	0%	159
GREENSTREET DITCH EXT	430665	0.00	8.90	0%	93
MCDOWELL NO. 1 DITCH	431034	0.00	8.00	0%	131
IVO E SHULTS D & PUMP	430714	0.00	5.00	0%	22
LAWRENCE DITCH NO 1	430758	0.00	5.00	0%	82
JACOBS PUMP & PL	431108	0.00	4.00	0%	99
DORRELL DITCH 2	430605	0.00	2.40	0%	59
SIZEMORE DITCH 1	430929	0.00	2.00	0%	26
California Water Co*	430564	0.31	13.29	2%	0*
RANGELY WATER*	430889	2.60	28.35	8%	0*
THOMAS DITCH	430965	1.00	6.00	14%	76
MARVINE DITCH 1	430790	2.75	7.59	27%	81
Modeled Stream Aggregate	43_ADW014a	13.42	31.78	30%	454
THOMAS DITCH 2	430966	3.67	6.00	38%	70
HIGHLAND DITCH	430694	102.30	146.70	41%	1,851
SKELTON DITCH	430931	3.50	4.80	42%	13
DREIFUSS DITCH	430607	6.39	8.58	43%	75
Unmodeled Stream Aggregate	43_ADW001b	19.49	25.50	43%	319
GEORGE S WITTER DITCH	430653	7.00	7.90	47%	141
CLOHERTY DITCH	430575	3.60	3.65	50%	44
OLDLAND DITCH 2	430851	9.47	9.47	50%	31
OLDLAND DITCH 1	430850	6.90	6.90	50%	120
OAK RIDGE PARK DITCH	430848	66.79	66.21	50%	1,864
MEEKER WELLS*	436045	7.42	6.77	52%	0*
ELK CREEK DITCH	430623	3.92	3.53	53%	154
MOONEY DITCH	430828	5.62	4.60	55%	89
DREYFUSS DITCH	430608	3.40	2.49	58%	77
NIBLOCK DITCH	430842	61.88	37.12	63%	1,384
Unmodeled Stream Aggregate	43_ADW010b	29.96	13.33	69%	723
MEEKER WATER SYS*	430810	7.42	3.00	71%	0*
MARCOTT DITCH	430788	15.33	6.18	71%	236
IMES & REYNOLDS DITCH	430710	16.90	6.75	71%	153
NORT_ADW WhiteNorthF Modeled Stream Aggregate	43_ADW001a	4.84	1.20	80%	69
MILLER CREEK DITCH	430819	100.00	24.00	81%	2,226
POWELL PARK DITCH	430883	67.64	15.00	82%	1,784
WHIT_ADW WhiteBlDoug Modeled Stream Aggregate	43_ADW013a	30.45	3.60	89%	295
CALHOUN DITCH	430563	7.31	0.86	89%	71
Unmodeled Stream Aggregate	43_ADW011b	12.90	1.51	90%	185
Modeled Stream Aggregate	43_ADW012a	28.93	3.00	91%	416
Unmodeled Stream Aggregate	43_ADW003b	23.62	2.00	92%	433
HAY BRETHERTON DITCH	430681	21.50	1.70	93%	265
PEASE DITCH	430867	24.56	1.20	95%	340
BARBOUR NORTH SIDE D	430526	6.70	0.30	96%	23
MEEKER DITCH	430808	25.70	0.25	99%	129
Unmodeled Stream Aggregate	43_ADW012b	28.65	0.06	100%	406

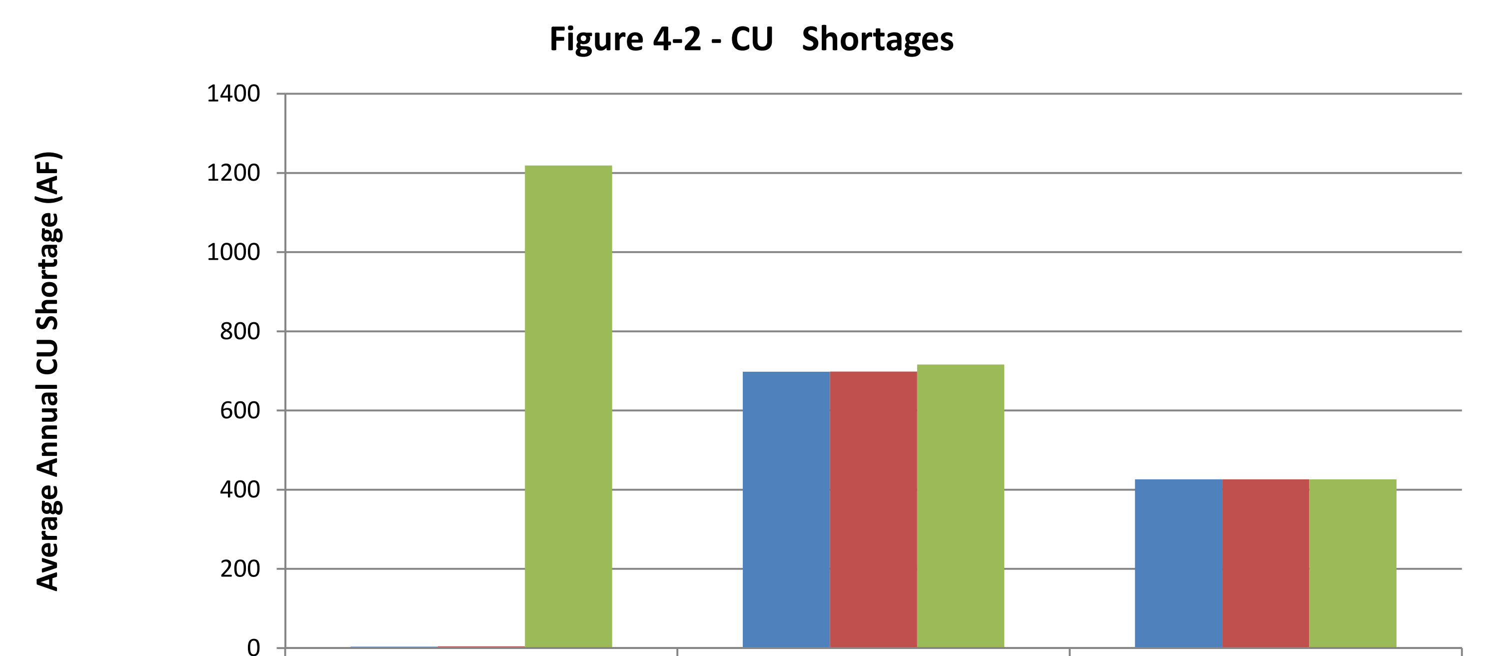
* Asterisk denotes non-agricultural structures

The second model run was a sensitivity test to determine the effects of curtailing existing absolute water rights junior to the 1955 energy conditional water rights (sensitivity scenario). Agricultural shortages computed under this scenario are expected to be more severe than the energy demands scenario since water is not available to any water right junior to the 1955 conditional energy water rights. 'Free River' water rights that allow a water user to divert in excess of its decreed water rights (if there is demand and available flow) were also curtailed. The purpose of the sensitivity scenario was to assess agricultural shortages using only the water supply that cannot be affected by the development of the energy industry's conditional water rights, regardless of the future extent of such development. From a practical standpoint, this model scenario limits agricultural water users more than would be realistic even under high energy demands, and therefore provides an elevated upper bound to agricultural shortages due to any level of development of the energy industry's conditional water rights in the White Basin. To be clear, even under high energy development, many of the agricultural water rights junior to the 1955 conditional energy water rights would likely be able to divert during high flow periods. This model run was designed as a sensitivity test and is not intended to represent actual conditions under a high energy development scenario.

Agricultural consumptive use shortages were computed for the two model runs and are presented in Figure 4-2 for mainstem, tributary and B-aggregates. B-aggregates are defined as structures that divert from smaller tributary streams that are not simulated in the StateMod model (See Technical Memorandum #1 for further details on the development of B-aggregates). In the energy demands scenario, there are no increases in consumptive use shortages to agricultural users relative to the baseline scenario. In the sensitivity scenario, average annual consumptive use shortages increase by 1,215 AF on mainstem structures, 18 AF on tributaries and 0 AF on B-aggregates. Table 4-4 shows the consumptive use shortages at the structures presented in Table 4-3 that have some water rights junior to the 1955 conditional water rights. The increase in consumptive use shortages on the mainstem of 1,215 AF in the sensitivity scenario occur almost exclusively (1,197 AF) at the nine structures with no water rights senior to the 1955 conditional water rights (i.e. unable to divert in the sensitivity scenario, see Table 4-4). Total simulated agricultural diversions in the sensitivity scenario decreased compared to the energy demands scenario and baseline agricultural scenarios. However, the lack of large increases in consumptive use shortages in the sensitivity scenario suggests that while some irrigators currently are able to operate at low ditch efficiencies (some structures at 10 percent or lower during high flows, meaning 10 percent goes to crop consumptive needs and 90 percent becomes return flows), there is a sufficient amount of water to meet most existing consumptive use demands using only water rights senior to the 1955 conditional water rights if ditch efficiencies in the 30 to 50 percent range can be attained.

6.0 Conclusions and Recommendations

Conditional water rights associated with the energy industry were tabulated for the energy industry in the energy report for the White River basin only. The State's water rights tabulation for the Yampa River basin was reviewed for this study.



	Mainstem	Tributaries	B-aggregates
Baseline	4	698	426
Energy Scenario	4	698	426
Sensitivity Scenario	1219	716	426

Table 4-4 - Comparison of CU Shortages for Ditches with Water Rights Junior to the 1955 Conditional Energy Water Rights

Name	ID	Average Annual IWR (AF)	Baseline Average CU Shortage (AF)	Energy Sceanrio Average CU Shortrage (AF)	Sensitiviy Sceanrio Average CU Shortage (AF)	Change in Shortage (Energy Scenario, AF)	Change in Shortage (Sensitivity Scenario, AF)
GOFF DITCH**	431494	171	0	0	171	0	171
WHIT_ADW WhiteAbPice Modeled Stream Aggregate**	43_ADW006a	230	0	0	228	0	228
GREENSTREET DITCH EXT**	430665	93	0	0	92	0	92
MCDOWELL NO. 1 DITCH**	431034	189	0	0	189	0	189
IVO E SHULTS D & PUMP**	430714	25	0	0	25	0	25
LAWRENCE DITCH NO 1**	430758	176	0	0	175	0	175
JACOBS PUMP & PL**	431108	178	0	0	177	0	177
DORRELL DITCH 2**	430605	85	0	0	85	0	85
SIZEMORE DITCH 1**	430929	58	3	4	58	1	54
California Water Co*	430564	512	0	0	290	0	290
RANGELY WATER*	430889	616	0	0	39	0	39
THOMAS DITCH	430965	110	0	0	15	0	15
MARVINE DITCH 1	430790	183	0	0	2	0	2
Modeled Stream Aggregate	43_ADW014a	693	0	0	0	0	0
THOMAS DITCH 2	430966	102	0	0	0	0	0
HIGHLAND DITCH	430694	2750	0	0	0	0	0
SKELTON DITCH	430931	29	0	0	0	0	0
DREIFUSS DITCH	430607	169	0	0	0	0	0
Unmodeled Stream Aggregate	43_ADW001b	709	0	0	0	0	0
GEORGE S WITTER DITCH	430653	204	0	0	0	0	0
CLOHERTY DITCH	430575	99	0	0	0	0	0
OLDLAND DITCH 2	430851	71	31	32	32	0	0
OLDLAND DITCH 1	430850	175	30	30	30	0	0
OAK RIDGE PARK DITCH	430848	2707	0	0	0	0	0
MEEKER WELLS*	436045	0	0	0	0	0	0
ELK CREEK DITCH	430623	345	33	33	48	0	14
MOONEY DITCH	430828	200	0	0	0	0	0
DREYFUSS DITCH	430608	134	8	8	8	0	0
NIBLOCK DITCH	430842	2018	0	0	0	0	0
Unmodeled Stream Aggregate	43_ADW010b	1608	88	88	88	0	0
MEEKER WATER SYS*	430810	0	0	0	0	0	0
MARCOTT DITCH	430788	529	0	0	0	0	0
IMES & REYNOLDS DITCH	430710	222	0	0	0	0	0
NORT_ADW WhiteNorthF Modeled Stream Aggregate	43_ADW001a	155	0	0	0	0	0
MILLER CREEK DITCH	430819	3232	0	0	0	0	0
POWELL PARK DITCH	430883	2590	0	0	0	0	0
WHIT_ADW WhiteBlDoug Modeled Stream Aggregate	43_ADW013a	441	0	0	0	0	0
CALHOUN DITCH	430563	94	0	0	0	0	0
Unmodeled Stream Aggregate	43_ADW011b	273	1	1	1	0	0
Modeled Stream Aggregate	43_ADW012a	628	0	0	0	0	0
Unmodeled Stream Aggregate	43_ADW003b	914	1	1	1	0	0
HAY BRETHERTON DITCH	430681	395	0	0	0	0	0
PEASE DITCH	430867	493	0	0	0	0	0
BARBOUR NORTH SIDE D	430526	22	0	0	0	0	0
MEEKER DITCH	430808	189	0	0	0	0	0
Unmodeled Stream Aggregate	43_ADW012b	588	41	41	41	0	0

* Indicates non-agricultural structure

** Indicates structure with no water rights senior to the 1955 conditional energy water right

Seventy-seven percent of all absolute water rights in the White River Basin are senior to the most senior major conditional water right associated with energy development (a 1955 priority date conditional water right for 370 cfs on the South Fork of the White River).

Ninety-two percent of all absolute water rights in the Yampa River basin are senior to the most senior major conditional water right (The Juniper Project that has a hydropower component). However, the Juniper Project water rights have been subordinated to many existing water rights and would have minimal impact to existing water users if made absolute. Other conditional water rights in the Yampa are sufficiently junior such that existing uses would be largely unaffected. Therefore, no further analysis was undertaken on impacts of energy development in the Yampa basin on existing agricultural water users.

There are nine agricultural structures comprising 736 irrigated acres in the White River Basin that have no water rights senior to the 1955 conditional energy water rights. An additional 33 agricultural structures comprising 14,593 irrigated acres have some water rights junior to the 1955 conditional energy water right (Table 4-3). Ninety-two agricultural structures comprising 11,491 irrigated acres are simulated using absolute water rights senior to the 1955 conditional energy water right.

Agricultural consumptive use shortages do not increase under the energy demands scenario that simulates mid-production level, mid-term timeline (year 2018 to 2035) water demands (Table 4-1, Figure 4-2 and Table 4-4).

Under a sensitivity scenario where all water rights junior to the 1955 conditional energy water right were curtailed, consumptive use shortages increased significantly primarily at structures with no water rights senior to the 1955 conditional water right (Figure 4-2 and Table 4-4). However, at structures with at least some water rights senior to the 1955 conditional rights, agricultural shortages did not significantly increase. This suggests that if ditch efficiencies in the 30 to 50 percent range can be attained, most of the structures in the White Basin will not experience consumptive use shortages regardless of the level of energy conditional water rights development.

Future water use associated with energy development will have little impact to existing agricultural consumptive use shortages. The most significant impacts would occur at structures with only water rights junior to 1955, since those water rights could be subject to a call from energy sector conditional rights developed in the future. Under the mid-level, middle timeframe energy scenario (2017 to 2035), these rights were not impacted, indicating that agricultural shortages at these structures would not be anticipated unless the energy industry develops water rights in excess of the mid-level, mid-term scenario. Such development by the energy industry is not anticipated for several decades at the earliest, and depending on economic and technological factors affecting the energy industry, may never occur.

It is recommended that water users in the White and Yampa River Basins are involved in all water rights change cases and substitute water supply plan proceedings that intend to change water use from agricultural use to any other use to ensure that historical return flows from the agricultural use are maintained. The basin Roundtable could appoint a representative tasked with reviewing the water resume and alert water users to such change cases and proceedings, or request that the legal staff on the Colorado River Water Conservation District assist them in this process.

7.0 References

2004 CWCB Statewide Water Supply Iniative (SWSI)

2008 URS Draft Energy Water Needs Assessment

CDM

Memorandum

To: *Jeff Comstock (Moffat County), Yampa/White/Green Basin Roundtable Agricultural Subcommittee*

From: *Matt Bliss, Mark Hoener (CDM); Hal Simpson (H. D. Simpson Consulting)*

Date: *July 28, 2010*

Subject: *Agricultural Water Needs Study: Task 5 Preliminary Draft and Project Completion Schedule*

We are pleased to present a preliminary draft of the Task 5 technical memo. The purpose of this draft is to invite comments from the roundtable subcommittee members to ensure that the alternatives we have selected align with subcommittee expectations discussed at the last project meeting. In order to expedite completion of the project, I would ask for comments on the five alternatives presented herein by August 6, 2010.

In mid-July, the project team met to outline a strategy and schedule for completion of the project. The following is our proposed scheduled. Please know that we will devote every resource necessary to meet this schedule. In light of past delays, I would like to assure you that this schedule was developed with the entire project team, accounting for each member's availability and a reasonable timeframe for report writing and review period.

Activity	Due Date
Submission of Preliminary T5 Draft	7/30/10
Receive comments from BRT committee	8/6/10
Model setup and execution of T5 Alternatives	8/20/10
Task 5 Draft Memo	9/3/10
Task 6 and 7 Draft Memos	9/17/10
Finalization of Memos and Compilation in Report.	9/30/10
Presentation to Roundtable	After finalization

Assumes one-week for review and comment on draft memos

Please contact me with any questions,

Matt Bliss

1.0 Introduction and Background

In 2005, House Bill 05-1177, the Colorado Water for the 21st Century Act (Penry, Decker, et al., House Bill 05-1177 2005), was signed into law. Among other provisions, the bill provides for the creation of Basin Roundtables (BRT). Each BRT is charged with formulating a water needs assessment, conducting an analysis of available unappropriated water, and proposing projects or methods for meeting those needs.

In 2003, the Colorado Water Conservation Board (CWCB) completed the Statewide Water Supply Initiative (SWSI). That study included estimates of water demands in the White and Yampa River basins through 2030. SWSI concluded there was little gap between projected municipal and industrial water demands and available water supplies in the basins. While SWSI provided a valuable coarse assessment of water demands for the municipal, industrial, and agricultural sectors, concerns were raised at that time that the analysis did not accurately reflect the agricultural water shortages in some of the water districts and especially as it exists on the tributaries. One concern was that the Yampa River Basin analysis of agricultural demand was not based on high-altitude crop coefficients, thus understating the demand for water in the Yampa River Basin.

SWSI also noted that up to an additional 39,000 acres of agricultural lands could be developed in the basins but did not investigate the location or impact of additional agricultural demand in these basins. The Colorado River Water Conservation District Small Reservoir Study (CRWCD 2000) identified sites for additional water supply storage in the Yampa Basin. That study highlighted the need to look at integrating irrigation practices with storage to better meet water demands.

The objectives of the current study are to:

1. Refine and update previous estimates of current agricultural water demands, supplies, and shortages for the Yampa/White/Green River Basin through use of the State of Colorado's Decision Support System (DSS) models and data

2. Identify and evaluate shortages for the future agricultural demands

3. Assess the impacts of climate change on agricultural water availability

4. Assess the impacts of energy sector water supply development on agricultural water availability in the White River Basin

5. Assess water supply development alternatives to satisfy shortages identified in (1), (2), and (3) above

6. Assess the effects on return flows of various irrigation practices or changes in those practices

7. Investigate creative solutions that benefit multiple interests (e.g., agriculture, energy, recreation, environment, etc.)

This technical memorandum addresses the fifth of those objectives and is the fifth in a series of technical memoranda describing activities that address each of the objectives. This technical memorandum draws significantly from technical memoranda numbers 1 through 4, which identified existing shortages (1), potential future irrigable acreage (2), impacts of climate change (3) and impacts of the energy sector impacting existing uses (4).

2.0 Agricultural Subcommittee Input

Several of the tasks in this study required input and feedback from the agricultural subcommittee of the Yampa/White/Green Basin (BRT subcommittee). BRT subcommittee members include Dan Birch, Darryl Steele, Dan Smith, Doug Monger, Geoff Blakeslee, Mary Brown, T. Wright Dickenson, Tom Gray, Dan Craig and Jeff Comstock. To date, CDM staff and Hal Simpson of H. D. Simpson Consulting have met with the BRT subcommittee on multiple occasions to listen to concerns and discuss the approach to addressing these concerns associated with this task. The project team, comprised of CDM, H. D. Simpson Consulting and Ross Bethel of Ross Bethel, LLC reviewed several alternatives and compared the alternative locations to shortages identified in previous tasks for this study. Through a screening process, the project team identified five alternatives to develop in more detail. A description of the screening process and recommendation of the five alternatives was submitted to the BRT for feedback before proceeding with the more in-depth alternatives analysis.

Through the screening process, the project team took into account several of the concerns and ideas that had been discussed by members of the BRT in previous progress meetings, including:

- Addressing shortages at structures located on smaller tributaries that are often limited by physical water availability, especially in the late summer and fall (B-aggregates as defined in Task 1)

- Assess ability to irrigate lands identified in previously proposed projects, such as potential Bureau of Reclamation projects and other lands identified by the BRT subcommittee members along the Yampa mainstem

- Identify potential opportunities with the proposed Yampa pump-back

- Identify potential opportunities to coordinate with the energy sector

3.0 Development of Alternatives

In addition to the concerns and ideas from BRT subcommittee members, the project team reviewed potential alternatives from Identified Projects and Processes (IP&Ps) from the SWSI report (CWCB 2004), increasing irrigation efficiency and proposed projects from previous water resources reports for the basin. Agricultural shortages identified in previous tasks of this study were mapped together with information on potential alternatives and screened based on a high-level assessment of ability to meet shortages. Shortages identified for climate change conditions were similar in location to existing shortages, just more severe. The screening process resulted in five recommended alternatives to analyze in further detail.

3.1 Potential Alternatives

The project team drew on several sources of information to identify potential alternatives that could meet agricultural shortages. These alternatives are presented in Table 5-1. In addition, quantification of potential irrigated lands on the Yampa River oxbows near Craig and increased irrigation efficiency were included in Table 5-1. Sources of information to identify the alternatives are as follows (bracketed text indicate abbreviated name in Table 5-1):

- Statewide Water Supply Initiative, Identified Projects and Processes (SWSI; CWCB 2004) ***[SWSI IP&P]***

- Yampa River Basin Small Reservoir Study – Phase 2 (Montgomery Watson, 2000) ***[Small Reservoir Study]***

- Yampa River Basin Alternatives Feasibility Study (Hydrosphere Resource Consultants, 1993) ***[Yampa Alternatives Study]***

- Multi-Basin Water Supply Investigation (Northern Colorado Water Conservancy District 2006) ***[Yampa Pumpback]***

- Reconnaissance Level Cost Estimates for Agricultural and New Supply Strategy Concepts (CWCB 2010) ***[Yampa Pumpback]***

- Various maps and reports from previously proposed projects considered by the BOR

    - Savery – Pot Hook Conservancy District ***[Savery – Pot Hook]***

    - Yellow Jacket Conservancy District ***[Yellow Jacket]***

    - Hayden Mesa Conservancy District ***[Hayden Mesa]***

    - Great Northern Conservancy District ***[Great Northern]***

    - Juniper Conservancy District ***[Juniper]***

- Plan for the Water Supply for Development of Oil Shale Industry in White River Basin, Colorado (Clifford H. Jex Engineers, Tipton and Kalmbach, Inc. – Engineers, 1979) ***[Oil Shale Development]***

3.2 Comparison of Potential Alternatives with Shortages and Alternatives Screening Process

The first three tasks of this study were focused on quantifying agricultural shortages and demands for potential future irrigated lands. Task 4 showed that development of the energy industry's conditional water rights would have little impact on existing agricultural shortages for existing water users. Existing agricultural shortages were estimated in Technical Memorandum Number 1 of this study, and were also estimated under climate change scenarios in Technical Memorandum Number 3. Demands at potential future irrigated lands were estimated in Technical

Table 5-1. Potential Alternatives

Information Source	Project Type	Project Name	Stream	Yield Analysis Available?
SWSI IP&P	Reservoir Enlargement	Yamcolo Reservoir	Bear River	No
SWSI IP&P,Yampa River Basin Alternatives Feasibility Study	Reservoir Enlargement	Stagecoach Reservoir	Bear River/Yampa River	Yes, Previous alternative analysis looks at shortage decrease from this project.
SWSI IP&P,Yampa River Basin Alternatives Feasibility Study	Reservoir Enlargement	Elkhead Reservoir	Elkhead Creek	Yes, Previous alternative analysis looks at shortage decrease from this project.
Increased Irrigation Efficiency	Non-Storage	n/a	All	n/a
Small Reservoir Study	New Reservoir	Little Bear 1	Fortification Creek	Yes, 4,950 AFY Reservoir Inflow
Small Reservoir Study	New Reservoir	South Fork 2	Fortification Creek	Yes, 1,650 AFY Reservoir Inflow
Small Reservoir Study	New Reservoir	Monument Butte 1	Morapos Creek	Yes, 3,025 AFY Reservoir Inflow
Number 2)	New Irrigated Lands	Yampa Oxbows	Yampa River near Craig	Yes
Yampa Pumpback	New Reservoir	Spring Creek or Sand Creek Reservoir	Yampa River below Maybell	Yes, 300,000 AFY yield at 500,000 AF storage
Yampa Pumpback	Pipeline	Northern Alignment	Fortification Creek, Slater Creek, Willow Creek	n/a
Yampa Pumpback	Pipeline	Center Alignment	Steamboat	n/a
Yampa Pumpback	Pipeline	Southern Alignment	Lower Elk River	n/a
Savery-Pot Hook	New Reservoir	Columbus Mountain Reservoir	Willow Creek/Little Snake River	No
Savery-Pot Hook	New Reservoir	Pot Hook Reservoir	Slater Creek/Little Snake River	No
Savery-Pot Hook	New Reservoir	California Park Reservoir	Little Snake River (From Elkhead)	No
Yellow Jacket	New Reservoir	Warner Point Dam & Reservoir	Big Beaver/ White River	Yes
Yellow Jacket	New Reservoir	Avery Dam & Reservoir	Big Beaver/ White River	Yes
Yellow Jacket	New Reservoir	Sawmill Mountain Dam & Reservoir	Big Beaver/ White River	Yes
Hayden Mesa	New Reservoir	Dunkley Reservoir Site	Fish Creek	No
Great Northern	New Reservoir	Upper Fortication Creek	Fortification Creek	No
Juniper	New Reservoir	Juniper Reservoir	Yampa River	No
Oil Shale Development	New Reservoir	Rangely Project	White River	No, Data for Decreed Reservoir and Diversion Capacity Exists
Oil Shale Development	New Reservoir	Yellow Creek Reservoir	Yellow Creek	No, Data for Decreed Reservoir and Diversion Capacity Exists
Oil Shale Development	New Reservoir	Duck Creek Reservoir	Yellow Creek/Duck Creek	No, Data for Decreed Reservoir and Diversion Capacity Exists
Oil Shale Development	New Reservoir	Ryan Gulch Reservoir	Ryan Gulch/Morapos Creek	No, Data for Decreed Reservoir and Diversion Capacity Exists
Oil Shale Development	New Reservoir	Crooked Wash	Crooked Wash/White River	No, Data for Decreed Reservoir and Diversion Capacity Exists
Oil Shale Development	New Reservoir	Blacks Gulch Reservoir	Blacks Gulch/White River	No, Data for Decreed Reservoir and Diversion Capacity Exists
Oil Shale Development	New Reservoir	Wray Gulch Reservoir	Wray Gulch/White River	No, Data for Decreed Reservoir and Diversion Capacity Exists
Oil Shale Development	New Reservoir	Kellog Gulch Reservoir	Kellog Gulch/White River	No, Data for Decreed Reservoir and Diversion Capacity Exists
Oil Shale Development	New Reservoir	Boies Reservoir	Black Sulphur Creek/White River	No, Data for Decreed Reservoir and Diversion Capacity Exists
Oil Shale Development	New Reservoir	Fourteen Mile Reservoir	Fourteen Mile Creek	No, Data for Decreed Reservoir and Diversion Capacity Exists
Oil Shale Development	New Reservoir	Yellow Jacket Project	Big Beaver/ White River	No, Data for Decreed Reservoir and Diversion Capacity Exists
Oil Shale Development	New Reservoir	Strawberry Creek Reservoir	Strawberry Creek/White River	No, Data for Decreed Reservoir and Diversion Capacity Exists
Oil Shale Development	New Reservoir	Stillwater Reservoir	South Fork White River	No, Data for Decreed Reservoir and Diversion Capacity Exists
Oil Shale Development	New Reservoir	South Fork Reservoir	South Fork White River	No, Data for Decreed Reservoir and Diversion Capacity Exists
Oil Shale Development	New Reservoir	Flattops Project	Park Creek/South Fork White River	No, Data for Decreed Reservoir and Diversion Capacity Exists

Memorandum Number 2. Figure 5-1 is a map that shows the locations of the most severe shortages on existing irrigated acreage, the location of the most feasible future irrigated acreage and the locations of potential alternatives listed in Table 5-1.

Figure 5-1 was used to compare the location of shortages and future demands to locations of project alternatives to identify projects suited for further analysis. Table 5-2 presents the potential alternatives that were screened from further consideration and the reason for the exclusion.

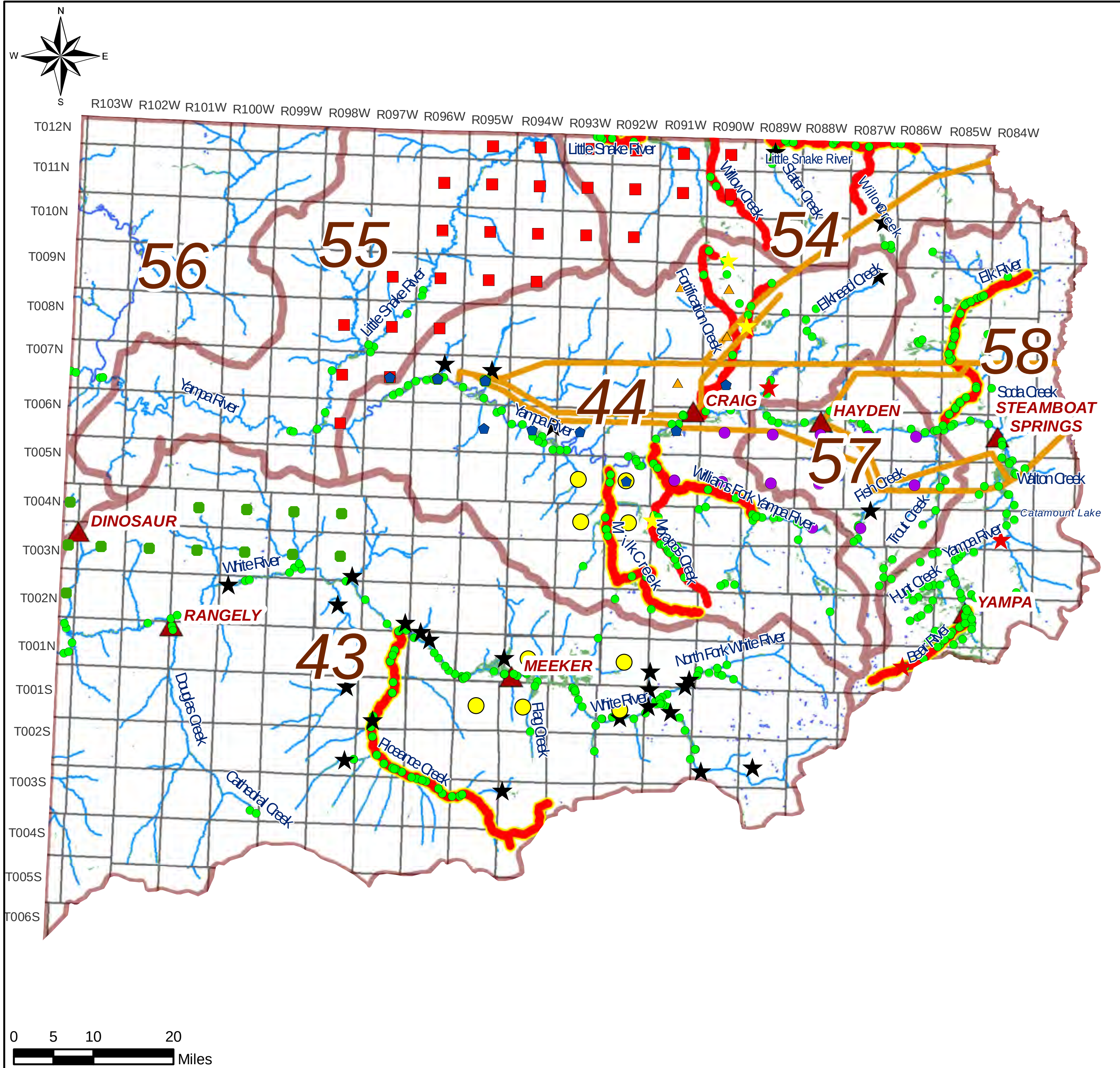
3.3 Alternatives Identified for Further Analysis

After alternatives shown in Table 5-2 were eliminated through screening process, five alternatives remained that were carried forward for further analysis. The alternatives are presented in no order of preference and discussion of the following alternatives should not preclude other alternatives from being considered in the future:

1. New Storage in the basin including Yamcolo, Stagecoach, Small Reservoir Study
2. Development of new irrigated lands on the Yampa River oxbows
3. Small On-Site Storage Facilities
4. Increased Irrigation Efficiency on B-aggregates
5. Evaluation of Ditch Enlargement Options in the White River Basin

4.0 Alternatives Analysis

Each of the alternatives identified above was evaluated in more detail. Each of the following section details this analysis and is divided into an introduction section that identifies the alternative, a description of the modeling process, the ability to meet shortages, the changes in flows due to the alternative, reconnaissance costing and regulatory concerns.



Cities

1993 Irrigated Acreage

Rivers

Lakes

Water Districts

Modeled Structures

Transmountain Pipeline Alignments

Potential New Reservoirs

Recommended in Small Reservoir Study

Enlargements from SWSI IP&P

From Other Projects

Modeled Streams with Critically Short Acreage

Unmodeled Tributaries with Critically Short Acreage

* Critically short acreage is defined as acreage that is at least 20% short in at least 4 of 10 years

Previously Proposed Projects

Savory Pothook

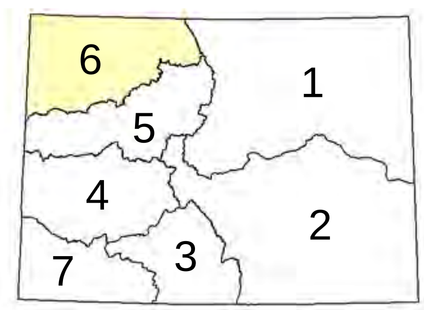
Hayden Mesa

Yellow Jacket

Juniper

Great Northern

Oxbows



State of Colorado

Figure 5-1
Potential Alternatives, Existing Shortages, Future Demands

CDM

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Table 5-2 Potential Alternatives Eliminated from Further Consideration

Screened Potential Alternative	Reason for Exclusion from Further Analysis
Elkhead Reservoir Enlargement	Already constructed
Stagecoach Reservoir Enlargement	River reach below Stagecoach was not identified as one of the most critically short streams in the study
Yampa Pumpback	Large amount of uncertainty on routing and feasibility. Discussed in further detail in Task 7 (Multiple-Benefit Solutions)
Savery-Pothook Project (Columbus, Pot Hook and California Reservoirs)	Pothook Reservoir is downstream of a large number of the critically short structures on the upper Little Snake River. The diversion point for Columbus Reservoir and California Reservoirs are from neighboring basins and would require significant investment in infrastructure. Additionally, Savery Reservoir was constructed in Wyoming and Colorado water users on the lower Little Snake River may be able to obtain water from the project.
Yellow Jacket Project (Warner Point, Avery, Sawmill Mountain Reservoirs)	The Yellow Jacket project diverts from the White River basin and could provide water to new irrigated acreage in the White River Basin, the Yampa River basin (rb-do we need two references to Yampa Basin or just the following?) and to critically short Milk Creek in the Yampa Basin. However, due to the required tunnel and pipeline from the White River basin into the Yampa basin, this alternative is likely more expensive than other potential alternatives (rb- do we need to address why not retained in for new acreage in White River Basin?).
The Hayden Mesa Project (Dunkley Reservoir)	Could provide additional water to Fish Creek which is not a critical stream. Could supply potential future irrigated acreage but likely at a higher cost than other alternatives.
Juniper Project (Juniper Reservoir)	Would not provide a source to existing critically short structures. Could provide a supply to potential future irrigated acreage, but reservoir site was an on-channel reservoir which would most likely not obtain a permit today. New reservoir site would have to be located.
Oil Shale Development except Piceance Creek reservoir sites (Rangely, Yellow Creek, Duck Creek, Crooked Wash, Blacks Gulch, Wray Gulch, Kellog Gulch, Strawberry Creek, Stillwater, South Fork, Flattops Reservoirs)	Would not provide supply to existing critically short acreage. Retained Piceance Creek reservoir sites (Ryan Gulch, Boies, Fourteen-Mile Reservoirs)

4.1.1 New Storage in the Yampa Basin

This alternative evaluates the ability of new storage in the basin to meet shortages or demands on new irrigated acres. New storage locations considered for the purposes of this study were identified from the Small Reservoir Study and from SWSI IP&Ps.

The Small Reservoir Study identified 106 potential reservoir sites of less than 2,000 AF. The study included feasibility studies on several of the sites resulting in three sites recommended for further consideration (Little Bear 1, Monument Butte, South Fork 2 Sites, see Figure 5-1). These reservoir sites can supply some structures that are currently included in the aggregated model nodes in that State's StateMod model. These reservoirs can supply water to portions of the most critically short streams in the study area (Fortification Creek, Morapos Creek). The Monument Butte site on Morapos Creek is located downstream of many of the shortages on Morapos Creek, but could serve acreage on the lower reaches of Morapos Creek and the Williams Fork River, and potentially some acreage in the lower reaches of the Milk Creek drainage.

Enlarging Yamcolo Reservoir was identified as a SWSI IP&P. The reservoir is located on the upper Bear River (see Figure 5-1), has a current capacity of 9,096 AF of which 7,525 AF is for agricultural water, 1,000 AF is for municipal use, and the remainder is a conservation deadpool. The reservoir currently supplies supplemental water to agricultural water users on the Bear River as well as municipal and industrial uses downstream, including an exchange with Stagecoach Reservoir to provide additional water to the Upper Bear River. The Water District 58 water commissioner (Elvis Iocovetto) was contacted to better understand shortages in Bear River area. He stated this reach is under a call during the growing season and there are rarely enough flows to satisfy all the water rights, and that he thought a junior water right at Yamcolo would have a small yield. He also stated that return flows from the Bear River (above the town of Yampa) make up a significant portion of the flow in the Yampa River below the town of Yampa and loss of return flows would discourage conversion to sprinklers. He also stated that return flows from applied reservoir releases on fields above the town of Yampa feed streamflows below the town and increasing efficiency on the upper part of the system could result in lower flows in the lower part of the system in the later part of the growing season. Return flows are discussed in more detail in Technical Memorandum Number 6.

While developing this alternative, members of the project team contacted the UYWCD to determine if any feasibility studies have been performed on a potential enlargement of Yamcolo Reservoir. The District's engineer, Andy Rossi, indicated that enlarging Yamcolo would be very unlikely. He noted that the reservoir is on US Forest Service land and enlargement would require a high level of regulation and permitting. Therefore, the Yamcolo enlargement is likely infeasible and was not considered further for the purposes of this study.

Currently, there is an exchange of 4,000 AF from Stagecoach to Yamcolo where agricultural water in Stagecoach is exchanged for industrial use water in Yamcolo. UYWCD Director, Kevin McBride indicated that an additional 750 AFY of water could be exchanged between the reservoirs to augment agricultural supplies on the Bear River since some municipal stored supplies in Yamcolo are delivered downstream of Stagecoach. Existing conditions modeling showed very little shortage on the Yampa River downstream of Stagecoach. Since agricultural contract water is still available in Stagecoach, an alternative to increase the agricultural pool in Stagecoach to meet existing shortages was not considered further in this study. However, the potential exchange of up to 750 AF from the agricultural pool in Stagecoach to Yamcolo Reservoir was simulated using the baseline model's storage water right yield of the 1,000 AF municipal pool in Yamcolo.

Enlarging Stagecoach Reservoir was also identified as a SWSI IP&P. The reservoir is located on the mainstem of the Yampa River above Steamboat Springs (see Figure 5-1) and is currently being enlarged by the Upper Yampa Water Conservation District (UYWCD) by raising the spillway four feet, increasing the storage capacity from 33,275 AF to 36,460 AF. The UYWCD indicated that the storage decree is for multiple uses, but the water has not yet been contracted nor have prices for irrigation been set. The price for irrigation water out of the existing reservoir is $12.50 per acre foot and not all of the existing agricultural water has been contracted.

Figures 5-2 to 5-6 are maps that show the reservoir locations and irrigated acreage potentially served by the reservoir, and diversion locations in the vicinity of each of the five new reservoir sites. Information on the three sites from the Small Reservoir Study is for proposed locations and sizes. Information on Yamcolo Reservoir is for the existing reservoirs. Irrigated acreage was evaluated downstream of each location to identify structures that could be served by the new storage. In addition, legally and physically available flow (available flow) was evaluated at each of the reservoir locations and is summarized in Table 5-3

Table 5-3: Acreage Served and Annual Available Flow at Reservoirs

Reservoir	Existing Acreage Potentially Served	Number of Structures Potentially Served	Average Available Flow (AF)	Min Available Flow (AF)	Median Available Flow (AF)	Max Available Flow (AF)	Percent of Years with Zero Flow Available
Monument Butte	1,354	9	3,019	756	2,753	8,403	0%
South Fork 2	1,090	6	3,280	653	3,308	6,807	0%
Little Bear 1	874	3	9,959	2,389	10,070	22,614	0%
Yamcolo[1]	6,181	22	750	750	750	750	0

1 – Note Yamcolo available flow indicates additional amount available by exchange from Stagecoach

4.1.2 Modeling Approach

New storage was simulated by assuming a reservoir would be filled with a junior water right (or by exchange in the case of Yamcolo) and would be used for supplemental supply only for existing shortages identified through this study. Simulated reservoir releases would be in addition to water already allocated to the structures in the StateMod baseline model, whether from native supplies or existing storage supplies.

Results from the StateMod baseline model results (see Technical Memorandum Number 1) were used as model input to a spreadsheet water allocation model called SWAM (simplified water allocation model). SWAM is a CDM-developed model (funded in part by the CWCB) that is a simplified tool that uses the same fundamental equations as StateMod, but on a smaller scale with significantly less input required. Three separate SWAM models were developed to simulate

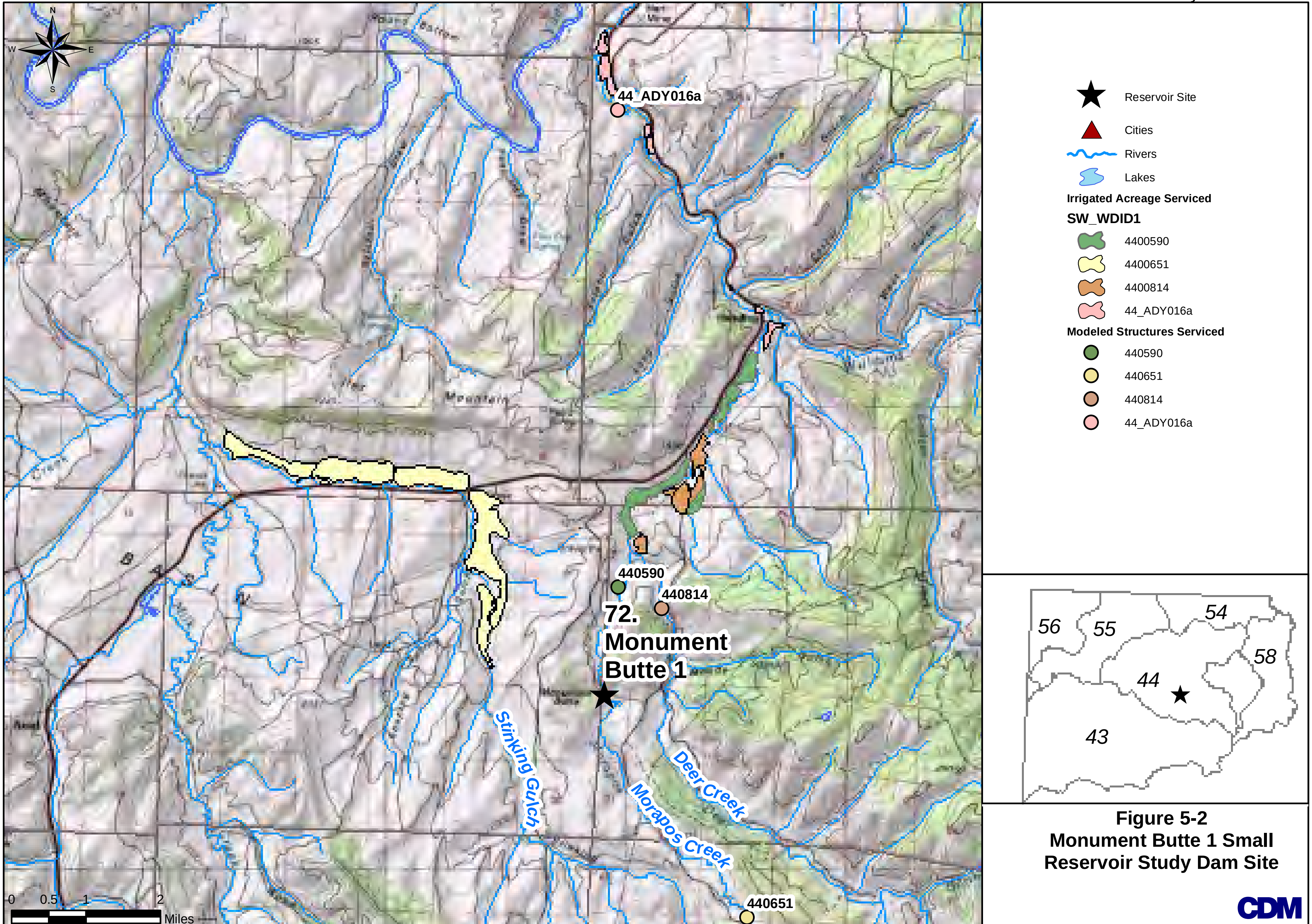

Figure 5-2
Monument Butte 1 Small Reservoir Study Dam Site

densvr1\swsi\Yampa_Ag\CDSS\gis\Basemap.mxd

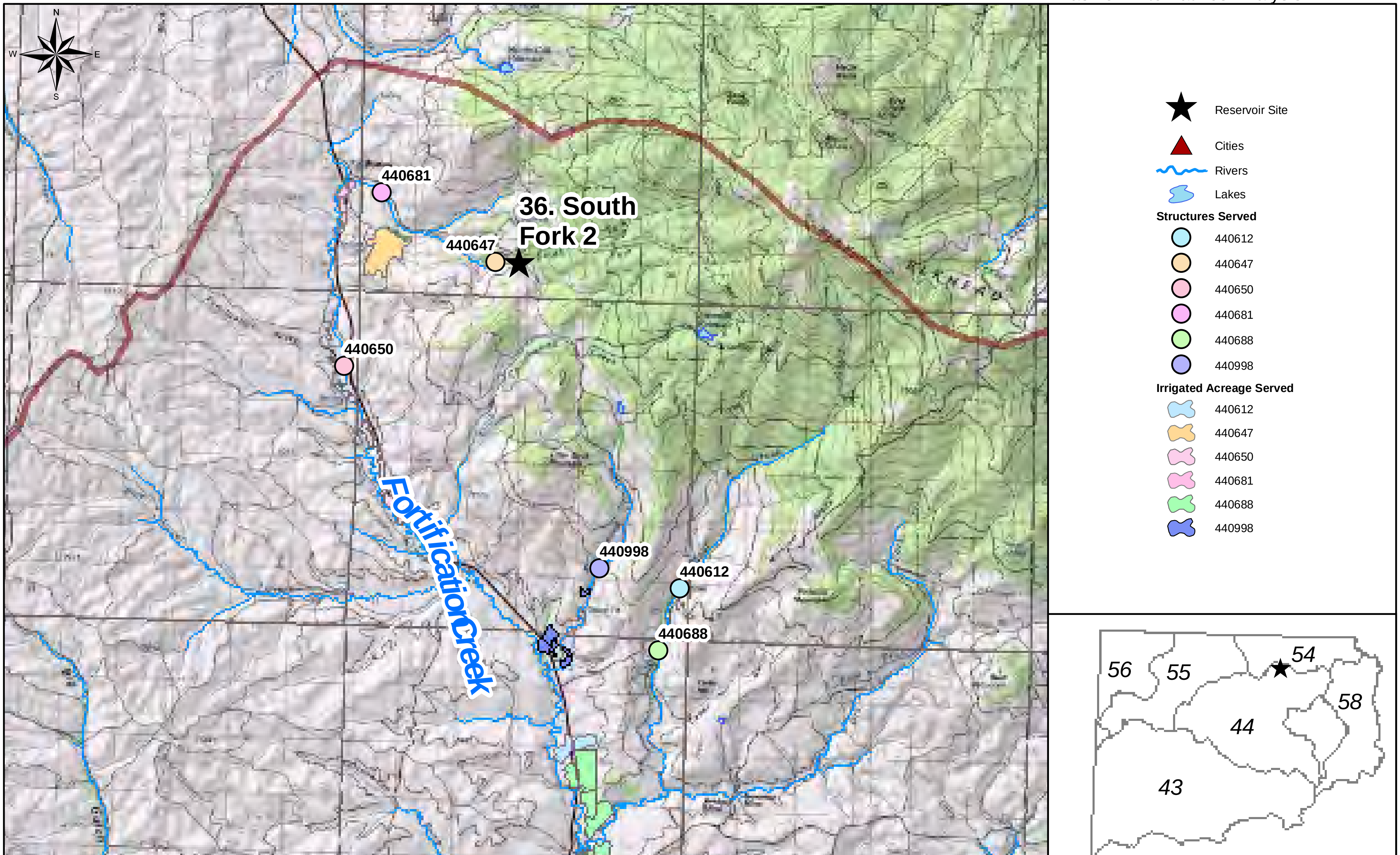

Figure 5-3
South Fork 2 Small Reservoir Study Dam Site

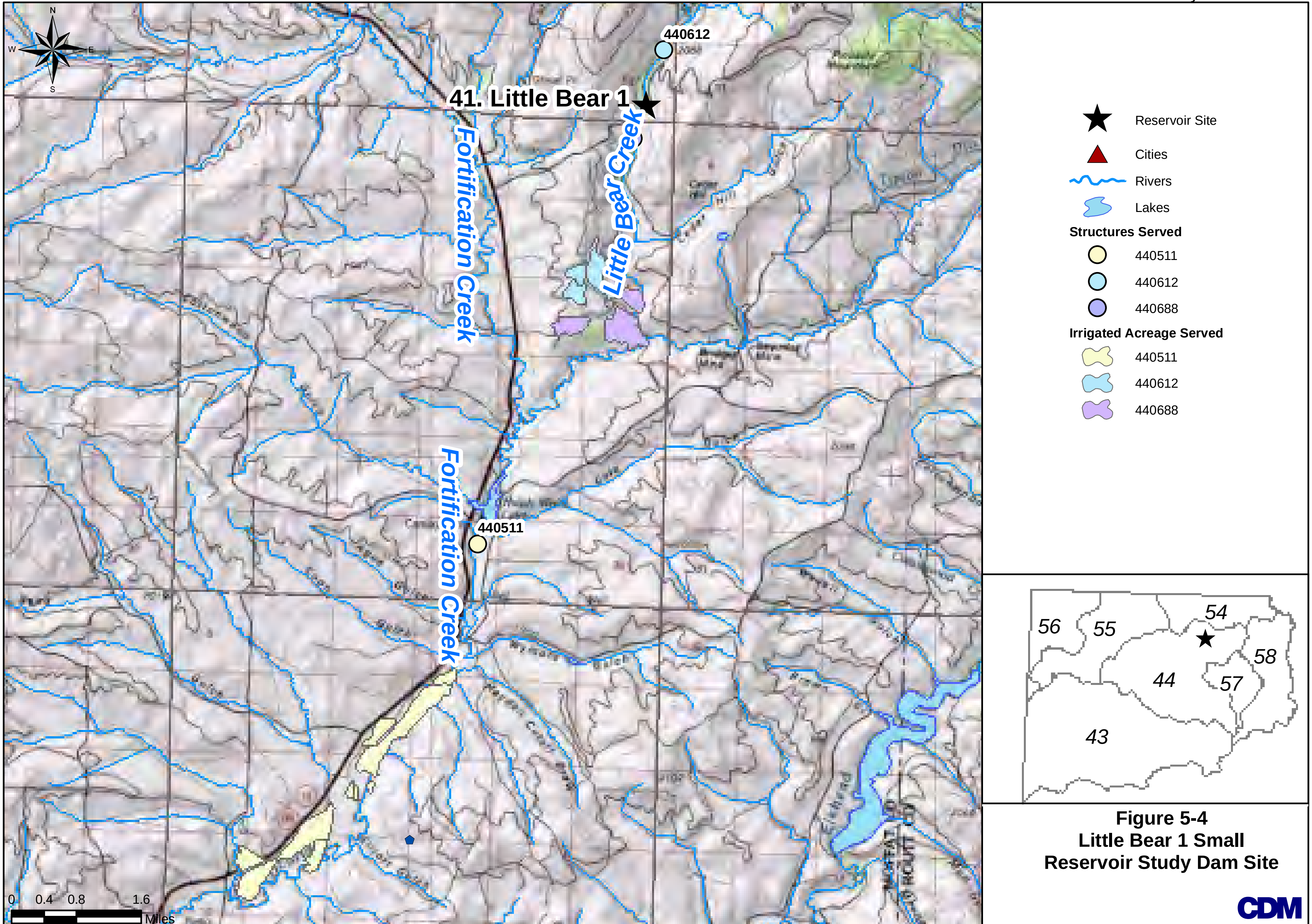

Figure 5-4
Little Bear 1 Small Reservoir Study Dam Site

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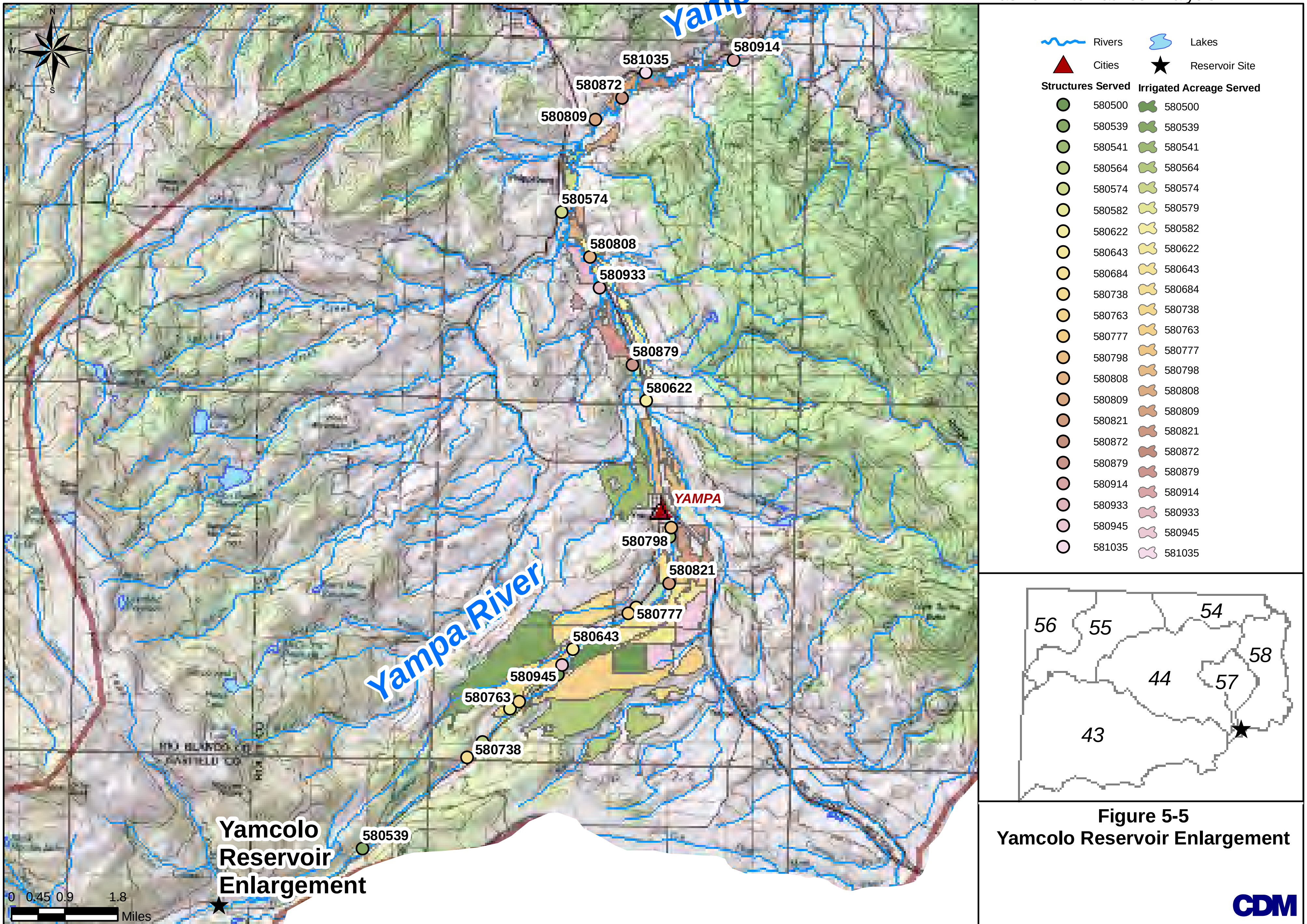

Figure 5-5
Yamcolo Reservoir Enlargement

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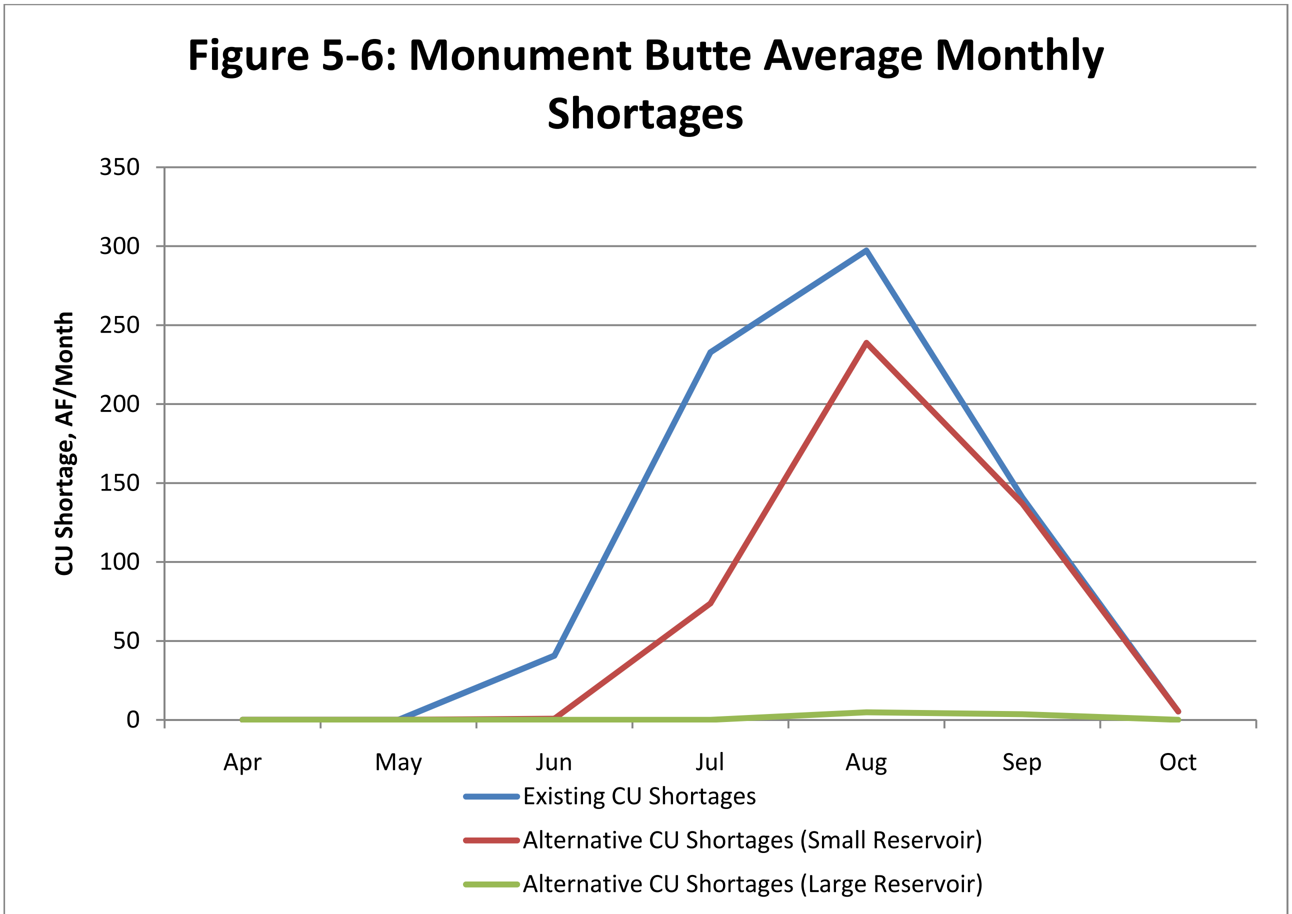
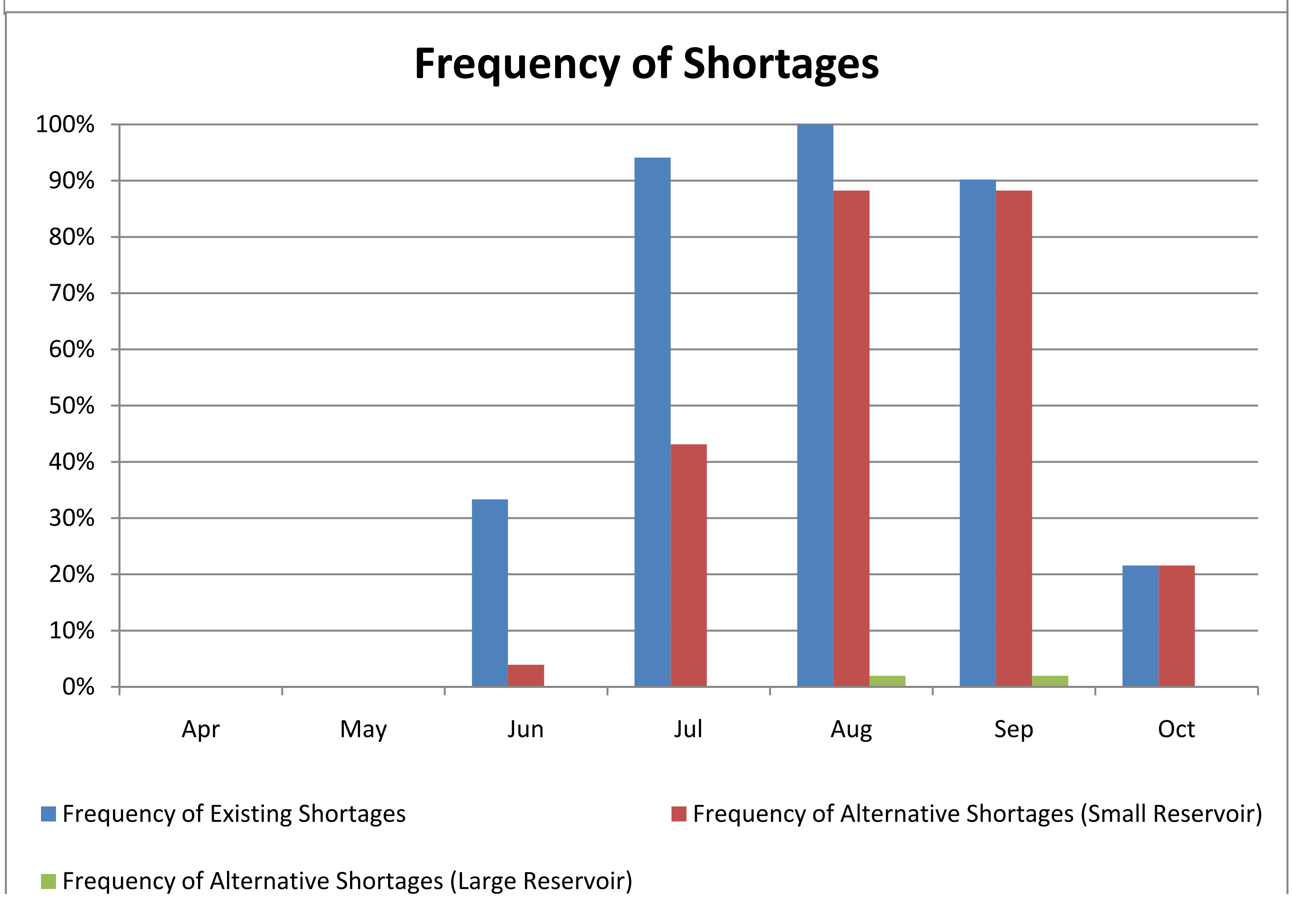


Figure 5-6: Monument Butte Average Monthly Shortages
CU Shortage, AF/Month
350
300
250
200
150
100
50
0
Apr
May
Jun
Jul
Aug
Sep
Oct
Existing CU Shortages
Alternative CU Shortages (Small Reservoir)
Alternative CU Shortages (Large Reservoir)


Frequency of Shortages
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Apr
May
Jun
Jul
Aug
Sep
Oct
Frequency of Existing Shortages
Frequency of Alternative Shortages (Small Reservoir)
Frequency of Alternative Shortages (Large Reservoir)

Monument Butte Reservoir (Morapos Creek), Little Bear 1 and South Fork 2 Reservoirs (Fortification Creek), and an additional 750 AFY of exchanged agricultural water to Yamcolo Reservoir (Bear River). Each model consists of reservoirs and agricultural demands. Available flow output from the nearest upstream StateMod model node was provided as inflow to the reservoirs to simulate the yield of junior water rights. Consumptive use shortages computed in the StateMod baseline model run were queried for structures that could be served by each of the reservoirs. These shortages were aggregated into a single value, divided by the assumed ditch efficiency for the project (50%) and were provided to SWAM as headgate demands for supplemental water. The SWAM models are able to compute the amount and frequency of shortages that can be met by the proposed reservoir and allow for change in flows at key locations to be assessed. Reservoir sizes provided in the Small Reservoir Study and information from UYWCD about the amount of exchange water available at Yamcolo were used in the model configuration.

4.1.3 Ability to Meet Shortages

Model results show that all of the reservoir alternatives are able to reduce agricultural shortages. Figures 5-6 to 5-8 show the average existing agricultural shortages computed for this project and the shortages with the new storage. Note that in the Small Reservoir Study, the Monument Butte Reservoir included two reservoir sizes, and both sizes were evaluated.

Figure 5-6 shows the model results for the Monument Butte Reservoir site. For the structures on Morapos Creek that the Monument Butte Reservoir Site can supply, a 36% average annual reduction in shortages occurs. During very dry years, only a limited reduction of shortages may occur, however, the additional storage is able to reduce shortages to some extent in all years. Using the smaller size Monument Butte Reservoir (560 AF), shortages can be reduced in June and July, but meeting these shortages drains the reservoir. Using the larger size reservoir (4,390 AF), nearly all shortages could be met.

Figure 5-7 shows the model results for the Fortification Creek sites. The Bear Creek and South Fork Reservoirs are able to meet 85% of the shortages on Fortification Creek. The chart shows that existing shortages in the early part of the season can be met every year. Shortages in the late season cannot be met every year, later into the growing season, the ability to meet shortages decreases. The figure shows that currently there are shortages in May through September in nearly every year, and the additional storage would nearly eliminate shortages in April, May and June, and reduce shortages to occurring in approximately 25% of years in August, and 50% of years in September and October.

Figure 5-8 shows the model results for the additional 750 AFY exchange to Yamcolo Reservoir. For structures that could take additional water from Yamcolo, there is a 51% average annual reduction of shortages. The figure also shows that the frequency of shortages is reduced significantly; under current conditions, structures experience shortages in approximately 40% of the years during the growing season. When the exchanged 750 AF is available, the frequency of the shortages falls to 5 to 10% of the years. It is interesting to note that while the frequency of shortages falls significantly, the average July, August and September shortages are still relatively high. This indicates that in the years with shortages, the shortages are quite severe, indicating the water is simply not available at Yamcolo.

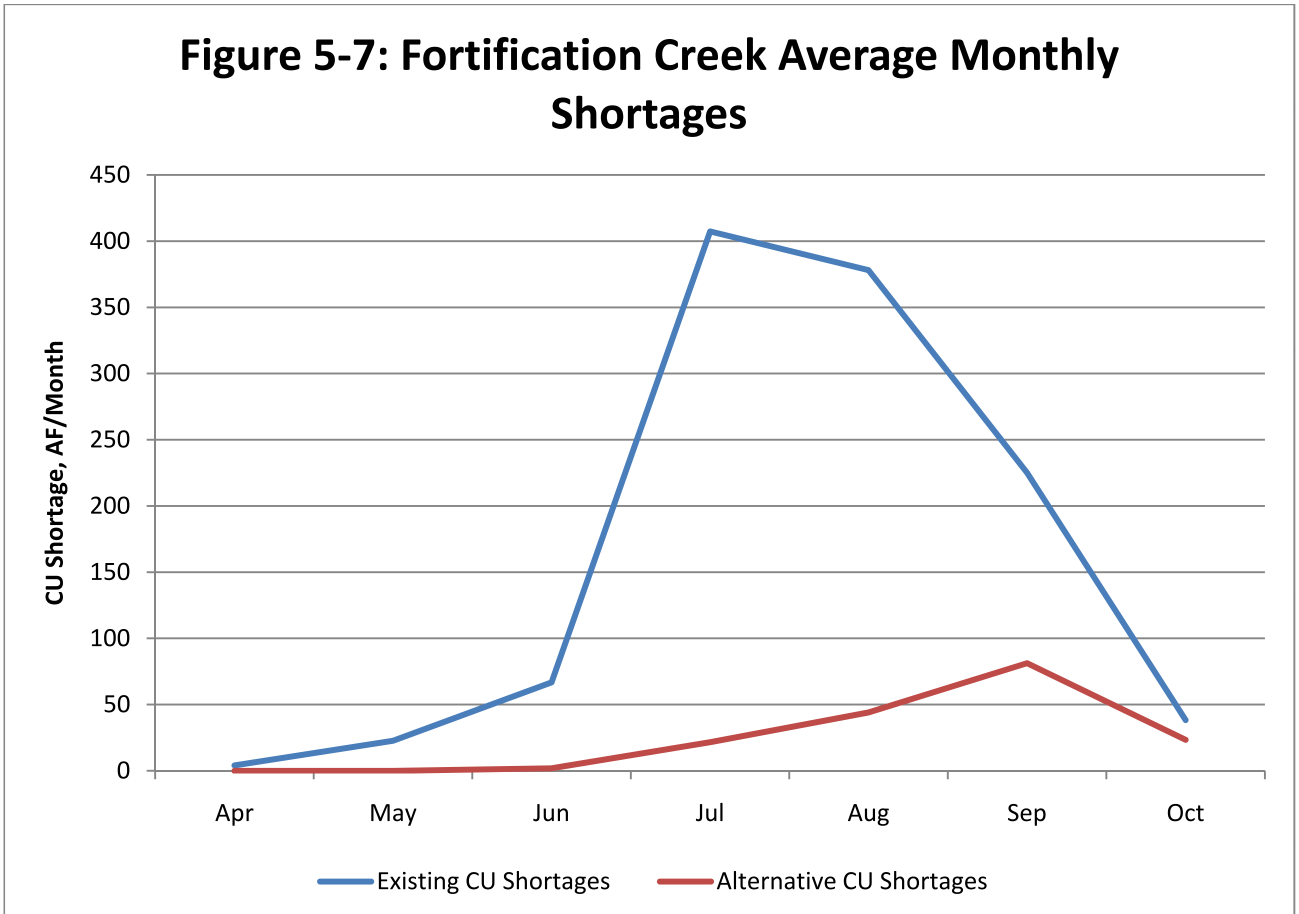


Figure 5-7: Fortification Creek Average Monthly Shortages
CU Shortage, AF/Month
450
400
350
300
250
200
150
100
50
0
Apr
May
Jun
Jul
Aug
Sep
Oct
Existing CU Shortages
Alternative CU Shortages

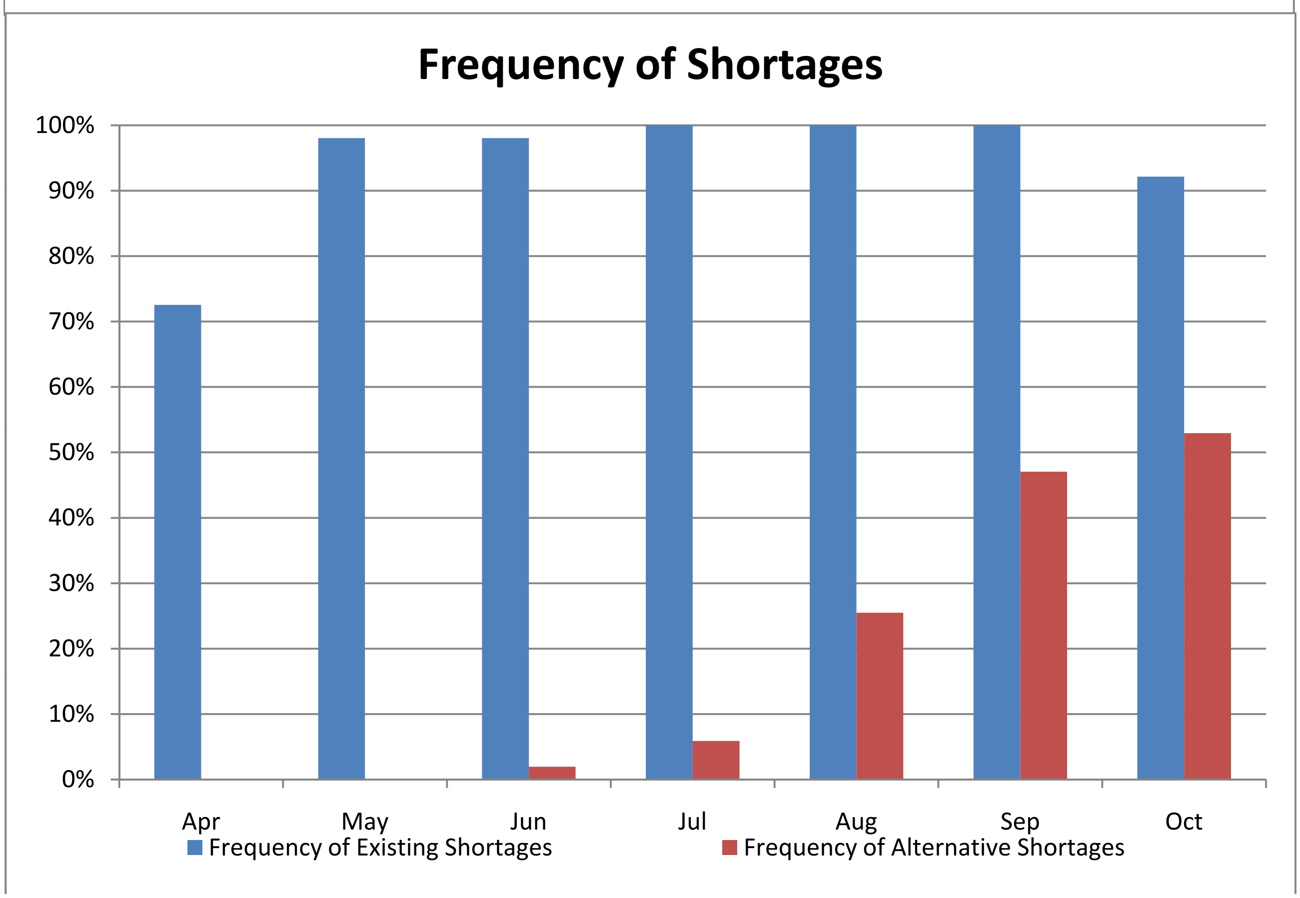
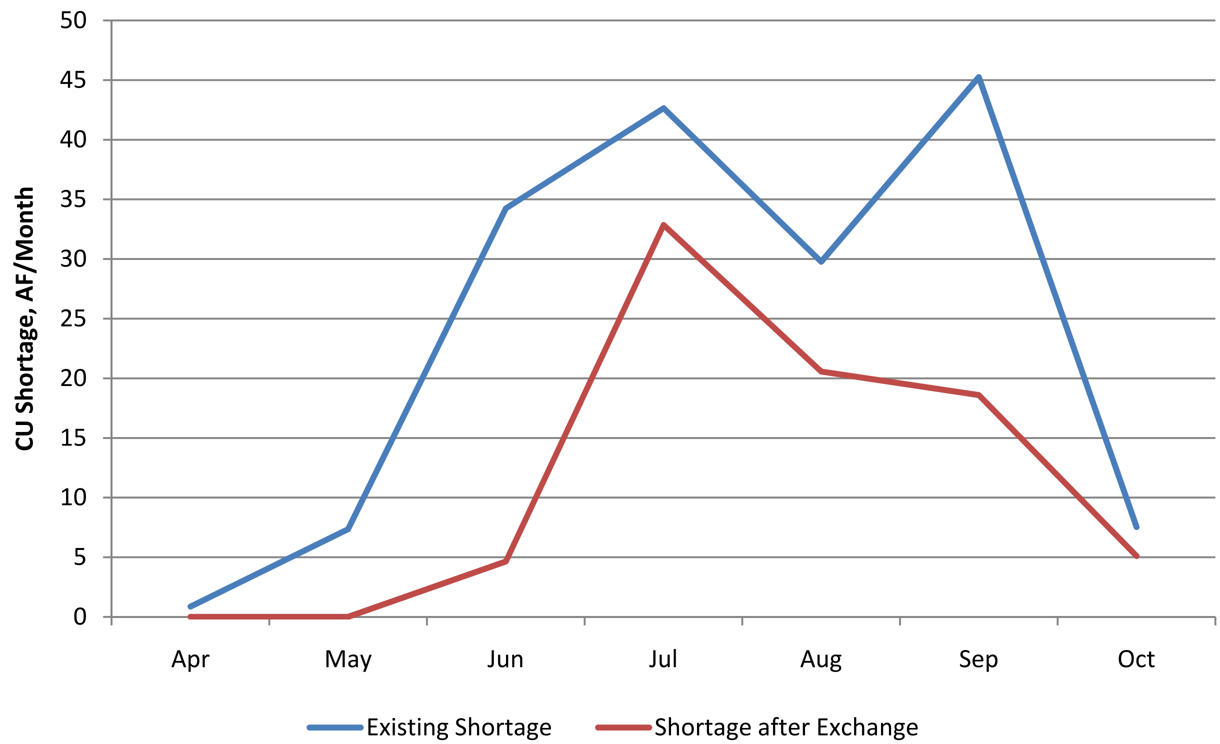
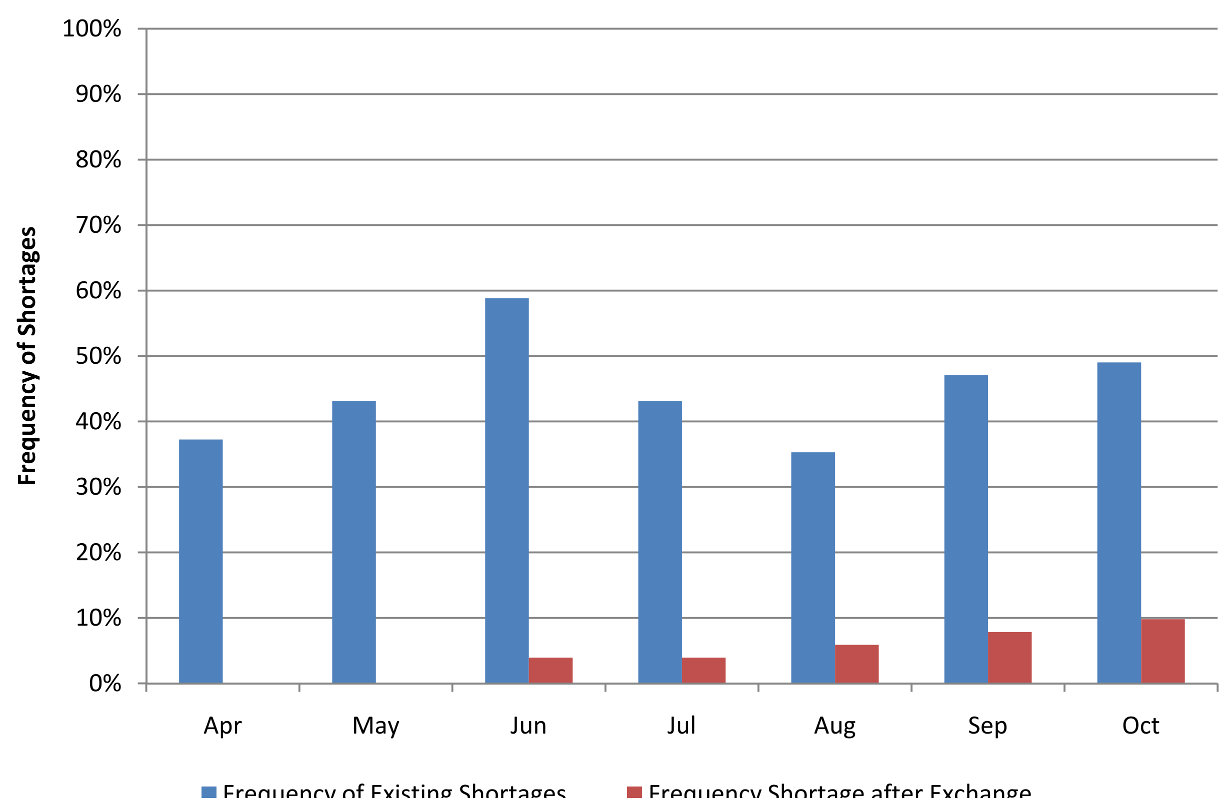

Frequency of Shortages
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Apr
May
Jun
Jul
Aug
Sep
Oct
Frequency of Existing Shortages
Frequency of Alternative Shortages

Figure 5-8: Reduction in CU Shortages From Yamcolo Exchange



Frequency of Shortages



4.1.4 Changes in Flow

The relatively small sizes of the reservoirs analyzed in this alternative create relatively small changes in flows. In general, flows are reduced in the winter and during the peak runoff when the reservoirs are storing water. Flows are increased in the later season when the reservoir makes releases to shorted land, and through delayed return flows of applied reservoir release water. Since consumptive use shortages are met by this additional water, there is a net increase in depletion to the stream. Flows on Morapos Creek and Fortification Creek are very low in the late season (~1 to 10 cfs). Releases of reservoir water in the late season can increase flows significantly from a percentage standpoint, even if the new volumes are not large. Figure 5-9 shows the changes in flows due to the reservoirs. Note that Monument Butte Reservoir can release to acreage in the Morapos Creek drainage, Milk Creek drainage, and to structures on the lower Williams Fork River. Therefore the change in flow due to the reservoir release at Monument Butte is not seen in the Morapos Creek drainage exclusively.

4.1.5 Reconnaissance Level Costs

The small reservoir study provided cost estimates for the three recommended sites. These costs were published in August of 2000. These costs were adjusted using the ENR CCI costs indices for Denver to August 2010 costs. Two dam sizes were discussed in the Small Reservoir Study for Monument Butte, but cost was only estimated for the smaller of the two given sizes due to likely lack of inflow for the larger structure. The larger structure would nearly double the dam height (increase of 50'). The estimated capital costs are summarized in Table 5-4.

Exchange of agricultural water to Yamcolo Reservoir from Stagecoach requires no additional infrastructure and would be available to water users on the Bear River for the current irrigation water price of $12.50/AF. Agricultural subcommittee members confirmed that many agricultural water users are not willing to pay this amount for water.

Table 5-4 Reconnaissance Level Costs for New Storage Alternatives

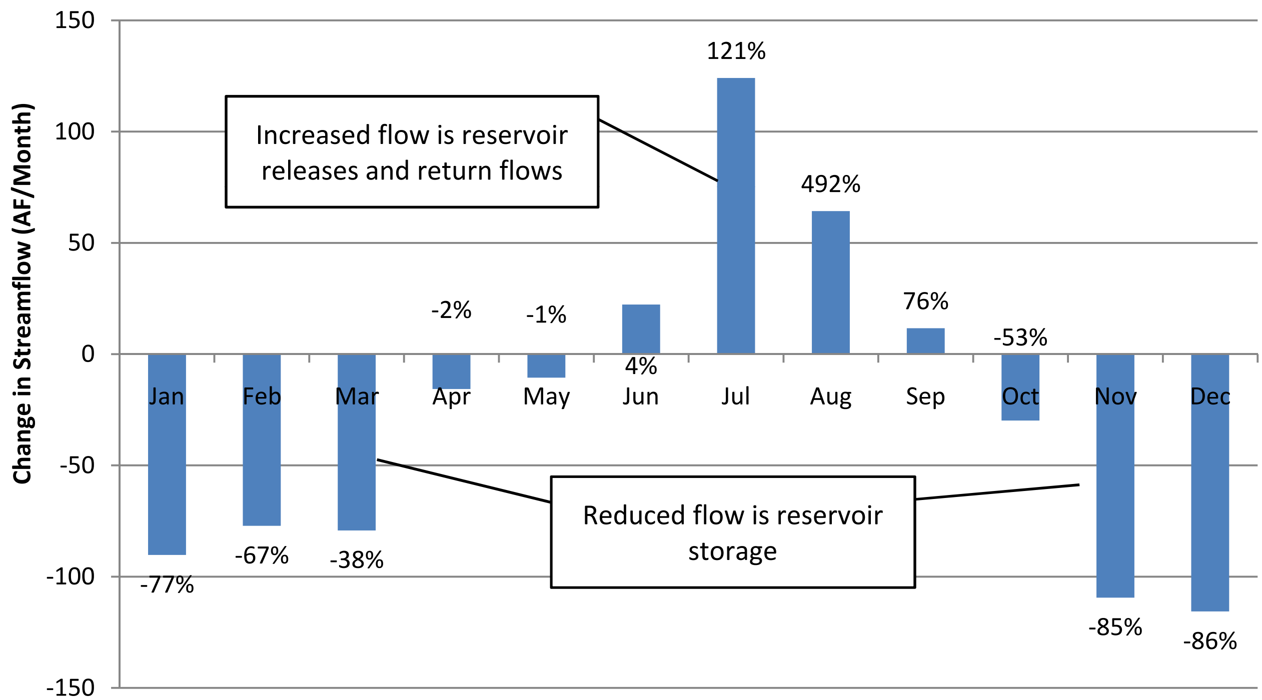
Reservoir	Total Capital Cost ($)	Capital Cost per AF ($/AF)	Average Annual Shortage Met (AF of CU)	Capital Cost per AF of Shortage Met ($/AF of CU)
Monument Butte	$2,430,660	$4,340	261	$9,313
Little Bear	$4,616,183	$5,770	283	$16,311
South Fork	$5,384,186	$3,167	687	$7,837
Yamcolo[1]	$9,375	$12.50	85	$25[2]

1 – Yamcolo costs are average annual lease rate costs based on average amount of water used – there is no additional capital cost associated with the Yamcolo exchange.
2 – Yamcolo cost per AF of shortage met is based on average use of 750 AF exchange (172 AFY average used)

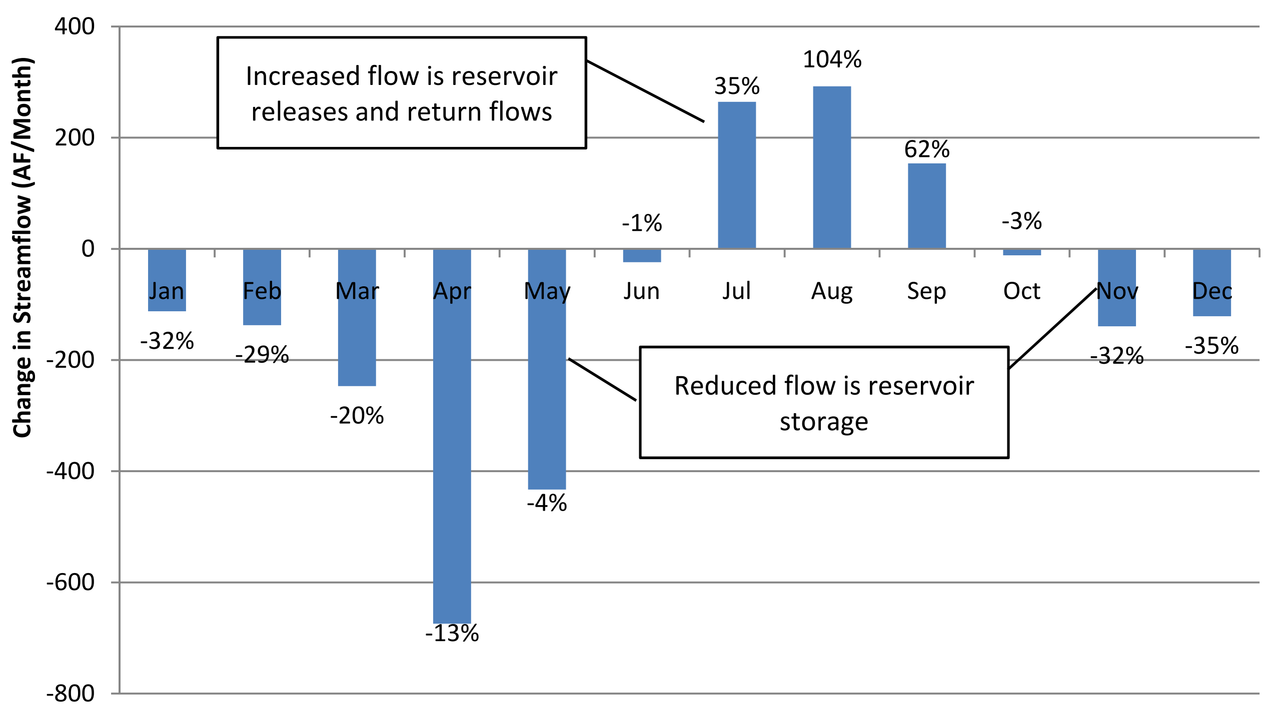
4.1.6 Regulatory Concerns

The reservoirs in the Small Reservoir Study are located on streams that would likely be considered Waters of the United States and would therefore be subject to federal permitting.

Figure 5-9: Changes in Flow at the Confluence of Morapos Creek and Williams Fork



Changes in Flow at the Confluence of Fortification Creek and Yampa River



There is a high level of cost and uncertainty associated with permitting. The reservoirs may fall under the general agricultural exemption in the federal permitting process, but the presence of the Colorado River Endangered Fish Species Recovery Program downstream of all the new reservoir location would likely require closer scrutiny from federal agencies. The cost of permitting is included in the total capital costs in Table 5-4, but the permitting process has become increasingly cumbersome even in the past decade since the Small Reservoir Study was written. Costs in Table 5-4 could increase depending on the level of effort required to obtain a permit.

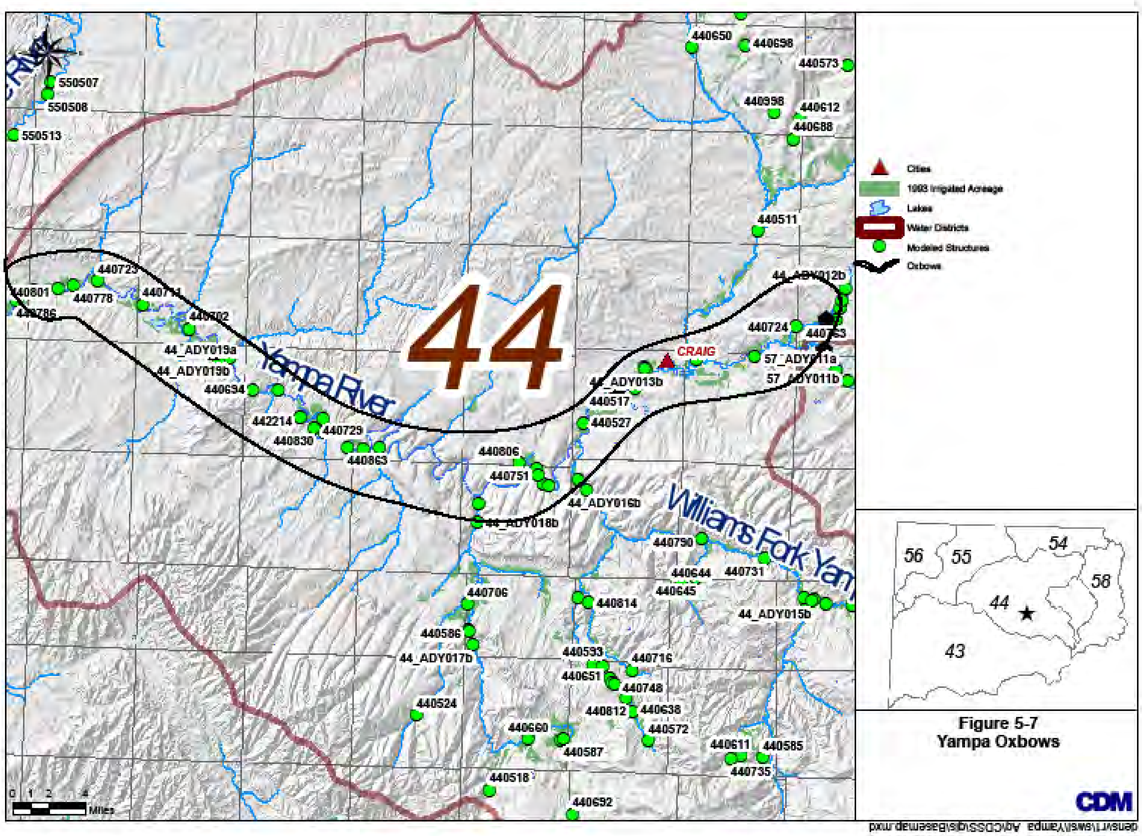
In contrast, the exchange of 750 AF to Yamcolo Reservoir from Stagecoach would not require a federal permit since there would be no new dredge or fill, and minimal change in streamflows below Stagecoach Reservoir.

4.2.1 Development of New Lands on the Yampa River Oxbows

One of the objectives of this study was to identify areas in the basin where new irrigated lands could be developed. In Technical Memorandum Number 2, 14,805 acres of new potentially irrigable land was identified along the Yampa River oxbows in Moffat County. The Yampa Oxbows begin just upstream of Craig, CO and follow the river to above the confluence of the Yampa and Little Snake River. Figure 5-10 shows the region where the new lands would be located. It is assumed that irrigation water supply for these lands would be diverted from the Yampa River under a junior direct flow water right either by pumping from the river and applying with sprinkler or through more traditional ditch diversion and flood irrigation.

Through a portion of the area indicated in Figure 5-10, the Yampa River mainstem is designated for the Management Plan for Endangered Fishes in the Yampa Basin. The program has set target flows of 93 cfs during the summer and 124 cfs during the winter months. These flows were based on historical flows through the reach, with some exceptions for falling below the target with the same frequency as was observed historically. According to the recommended alternative for the Endangered Fishes Management Plan, 7,000 AF of storage will be allocated to helping meet these targeted flows (Roehm, 2004). Development of new irrigated acreage in this region will need to consider the impacts on the Recovery Program.

Figure 5-10 – Location of Potential New Irrigated Lands



4.2.2 Modeling Approach

A spreadsheet model was developed to simulate water supply and the demands associated with the potential new irrigated lands as well as the Endangered Fishes Management Plan target flows. The new lands would be irrigated with a junior direct flow water right from the Yampa River. The Endangered Fishes Management Plan target flows were simulated as senior to the irrigation water right and were provided up to 7,000 AFY of releases from storage. Return flows from the new irrigated lands are made available to meet the Management Plan target flows.

Available flow from the baseline StateMod model for this project represents the yield of a junior water right that could be used to irrigate the new lands. Available flow was considered only at the upstream end of the reach as a conservative assumption. New lands developed below the confluences of Fortification Creek and the Williams Fork would have additional water available to them. Crop distribution on the new lands used the existing basin average distribution (94% grass pasture and 6% alfalfa). The State of Colorado's consumptive use model, StateCU, was used to generate the crop irrigation water requirement (IWR). Figure 5-11 shows the average monthly available flow at this location, the Endangered Fish Recovery Program target flows, and IWR. Headgate demands were generated using different percent structure efficiency values (headgate demand = IWR/efficiency). Model runs were made using 30, 50 and 75 percent efficiencies. The 30 percent represents flood irrigation, 75 percent represents sprinkler irrigation, and 50 percent represent a mixture of irrigation types. .

4.2.3 Ability to Meet New Demands

Modeling results show that IWR for the new lands can be met on average through June, with shortages increasing in July, August and September. Figures 5-12, 5-13 and 5-14 show the average monthly diversions, return flows, IWR and CU shortages and frequency of shortages for the 30%, 50% and 75% efficiency scenarios. The figures show that under all efficiency scenarios, the available flow in the river would be sufficient to meet IWR through June. However, beginning in July, shortages appear and last through October. The frequency of shortages is less as efficiency increases.

As efficiency increases, return flows decrease, and delayed or lagged return flows decrease. Return flows from the new lands area able to help meet the ESA target flows in some years and the frequency that flows fall below the target flows decreases at lower efficiencies.

The models used conservative assumptions for reuse of return flows since the configuration of individual users within the area is unknown at this point. Therefore, new lands irrigated in this reach will likely be able to increases a system-wide efficiency and reduce CU shortages by re-diverting return flows from upstream users. The shortages seen in the late season could be mitigated by contracting for storage water from upstream reservoirs (e.g. Elkhead Creek, Stagecoach).

4.2.4 Changes in Flow

Only flows in the Yampa River below the location of the new lands would be affected by irrigation of the new lands under a junior direct-flow water right. The flow of the Yampa River at this point is fairly large relative to the amount of depletions that would occur if all these lands were irrigated (average annual flow of the Yampa River at Maybell is 1,100,000 AF, average annual IWR of the new irrigated lands is approximately 30,000 AF or 2.7%). In addition, by

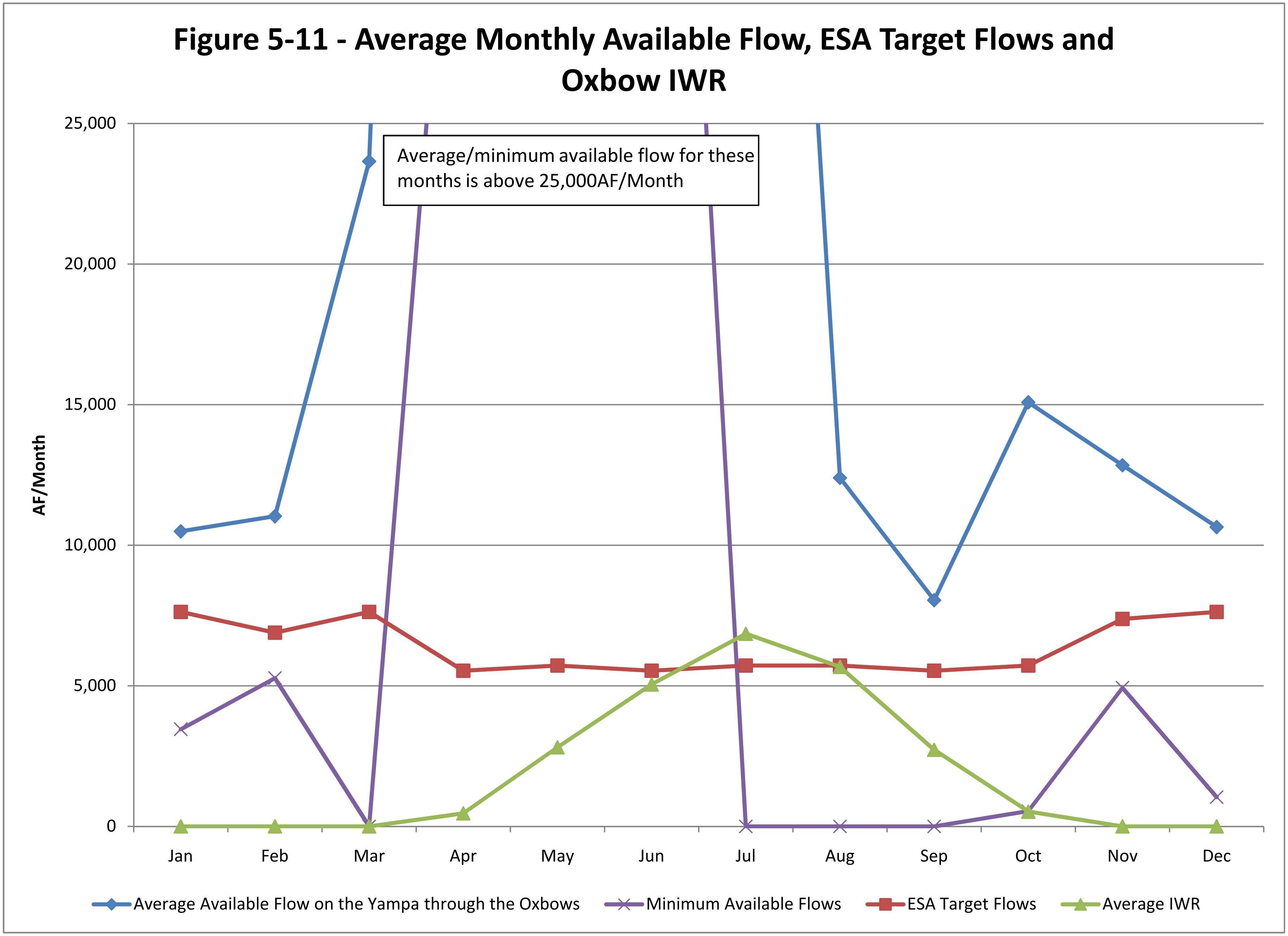


Figure 5-11 - Average Monthly Available Flow, ESA Target Flows and Oxbow IWR
Average/minimum available flow for these months is above 25,000AF/Month
AF/Month
25,000
20,000
15,000
10,000
5,000
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Average Available Flow on the Yampa through the Oxbows
Minimum Available Flows
ESA Target Flows
Average IWR

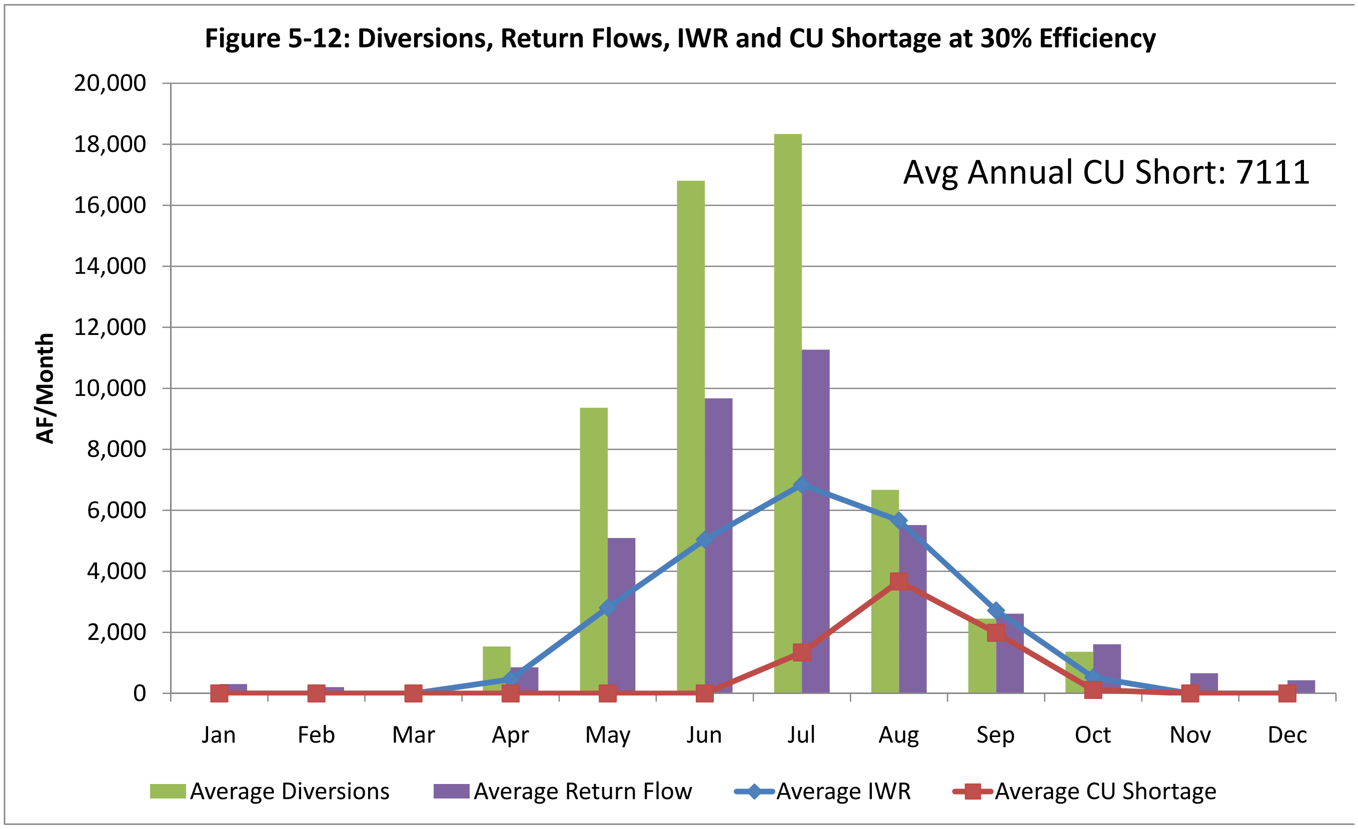
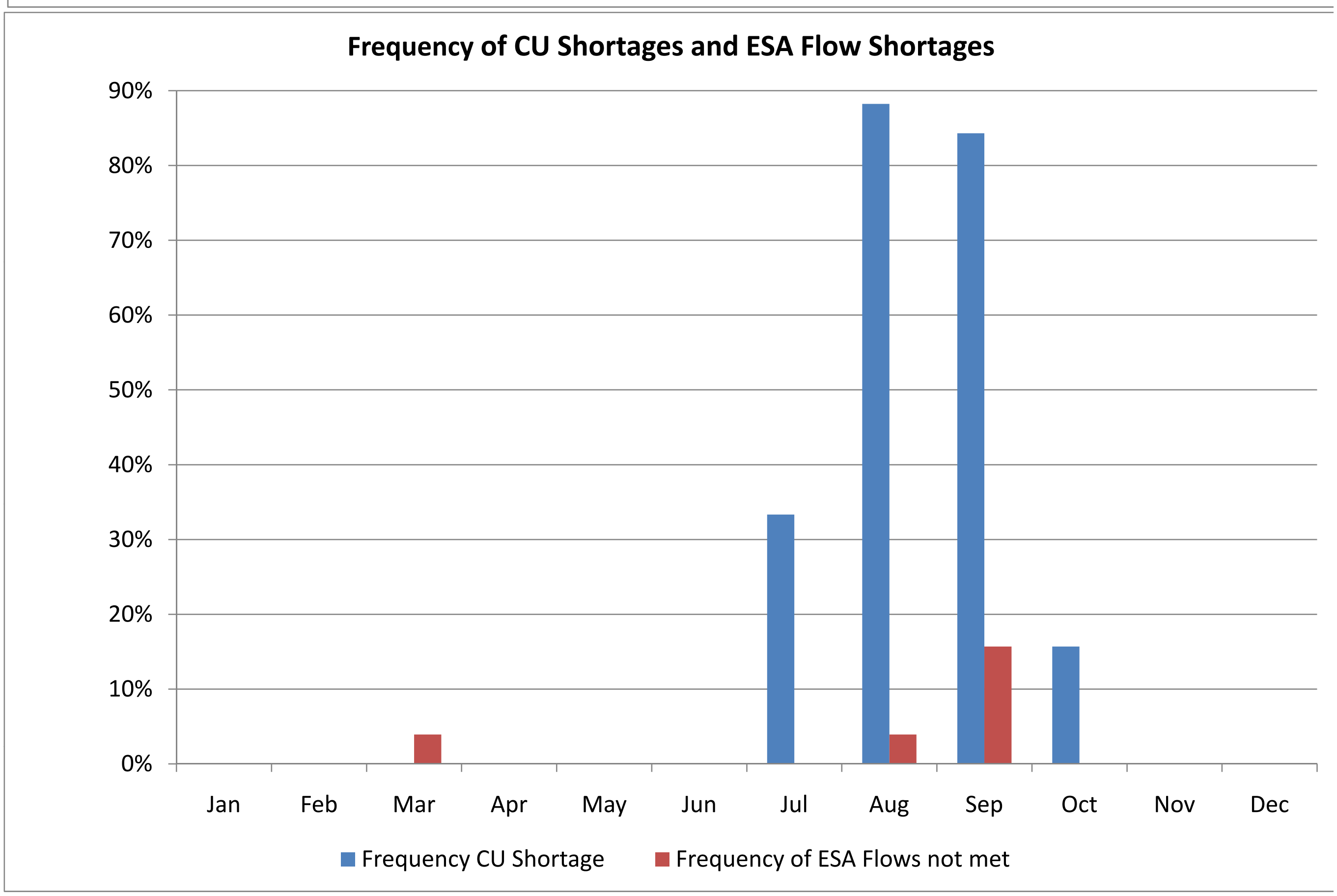


Figure 5-12: Diversions, Return Flows, IWR and CU Shortage at 30% Efficiency
Avg Annual CU Short: 7111
AF/Month
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Average Diversions
Average Return Flow
Average IWR
Average CU Shortage


Frequency of CU Shortages and ESA Flow Shortages
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Frequency CU Shortage
Frequency of ESA Flows not met

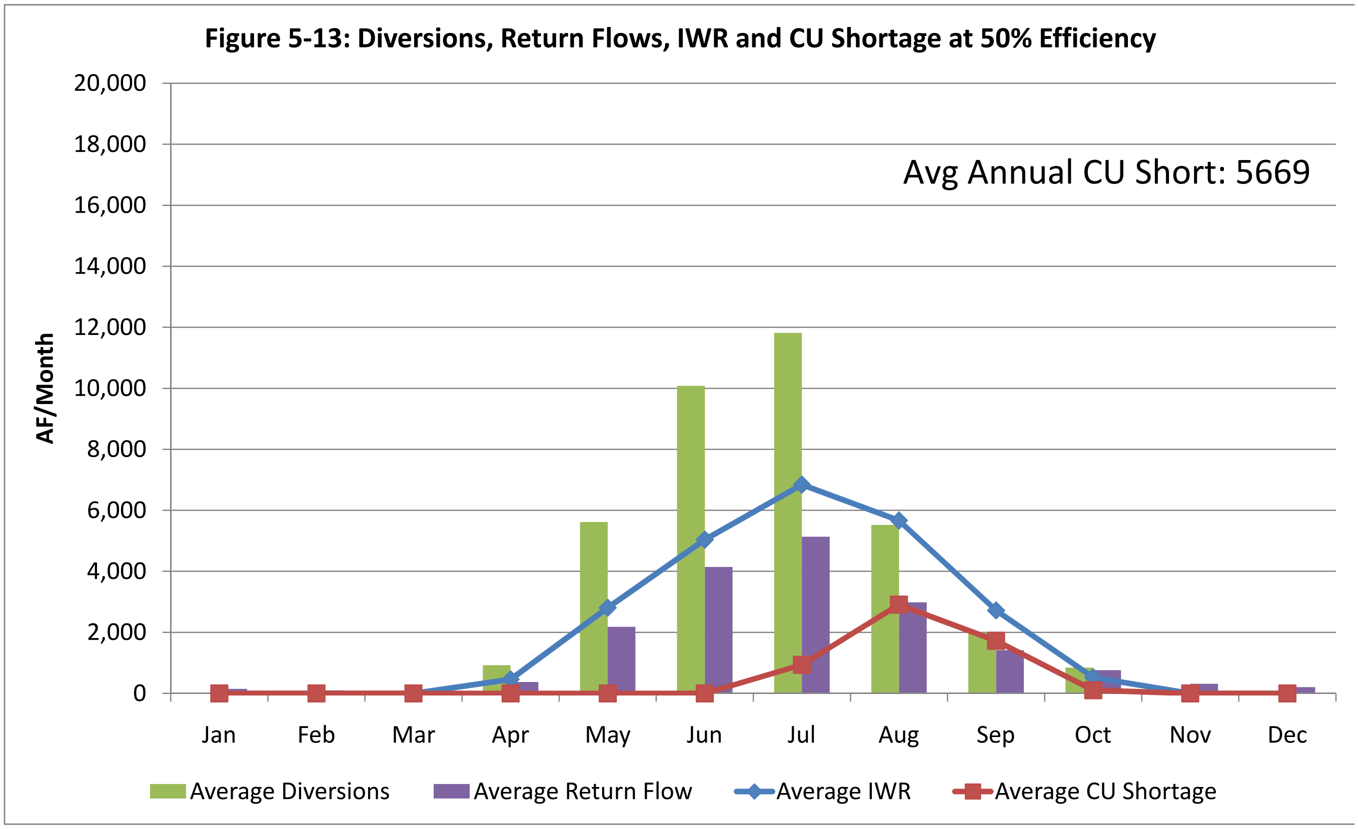
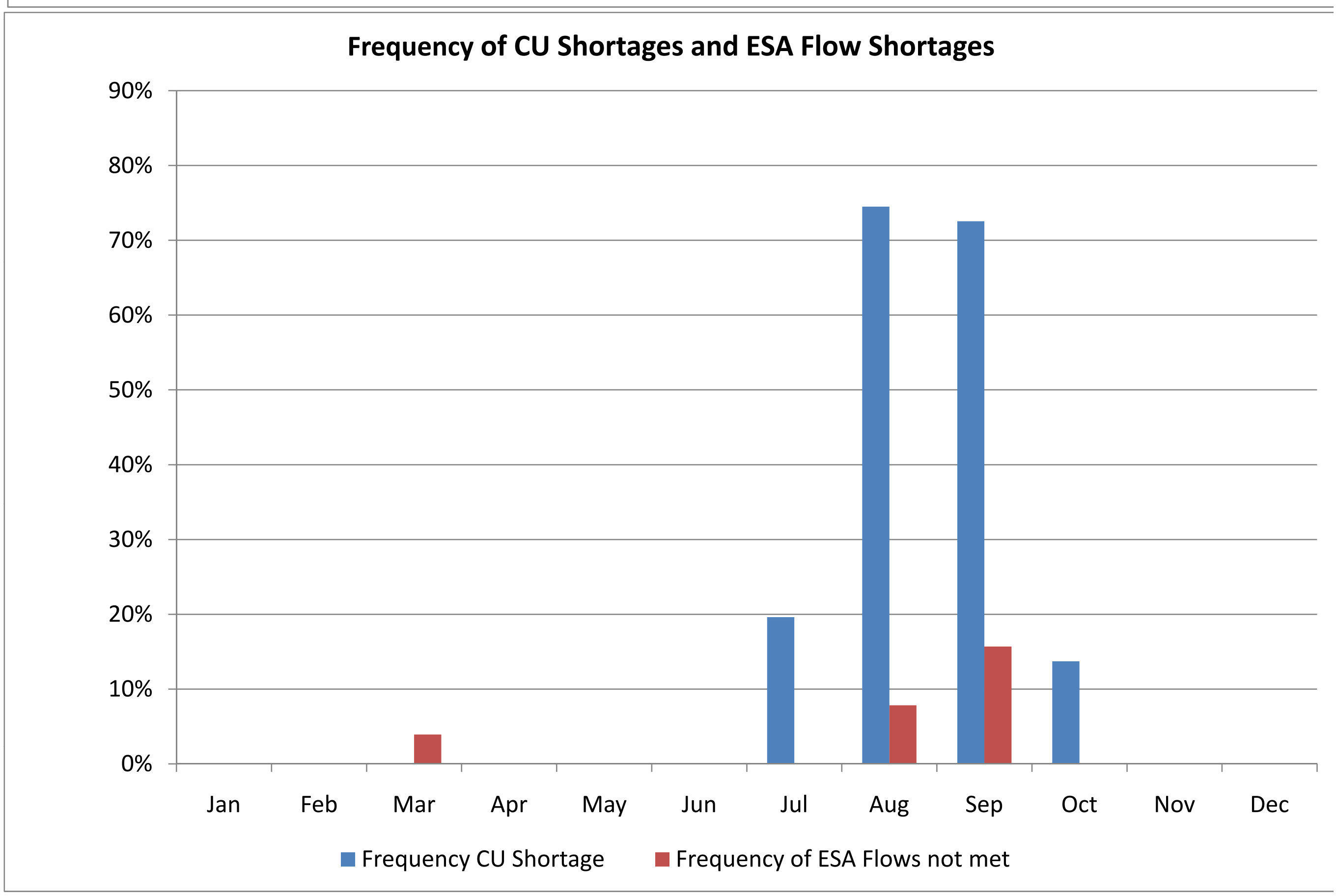


Figure 5-13: Diversions, Return Flows, IWR and CU Shortage at 50% Efficiency
AF/Month
Avg Annual CU Short: 5669
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Average Diversions
Average Return Flow
Average IWR
Average CU Shortage


Frequency of CU Shortages and ESA Flow Shortages
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Frequency CU Shortage
Frequency of ESA Flows not met

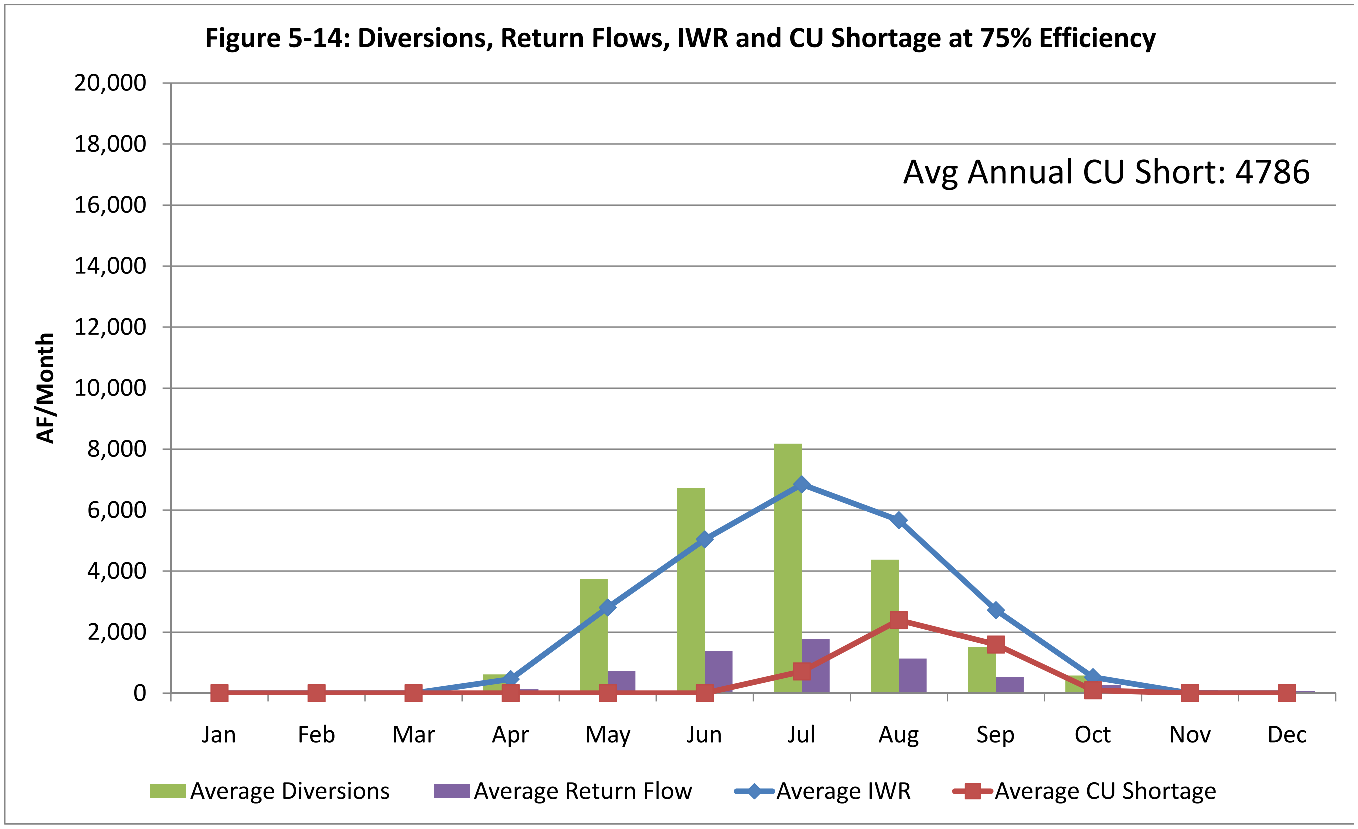
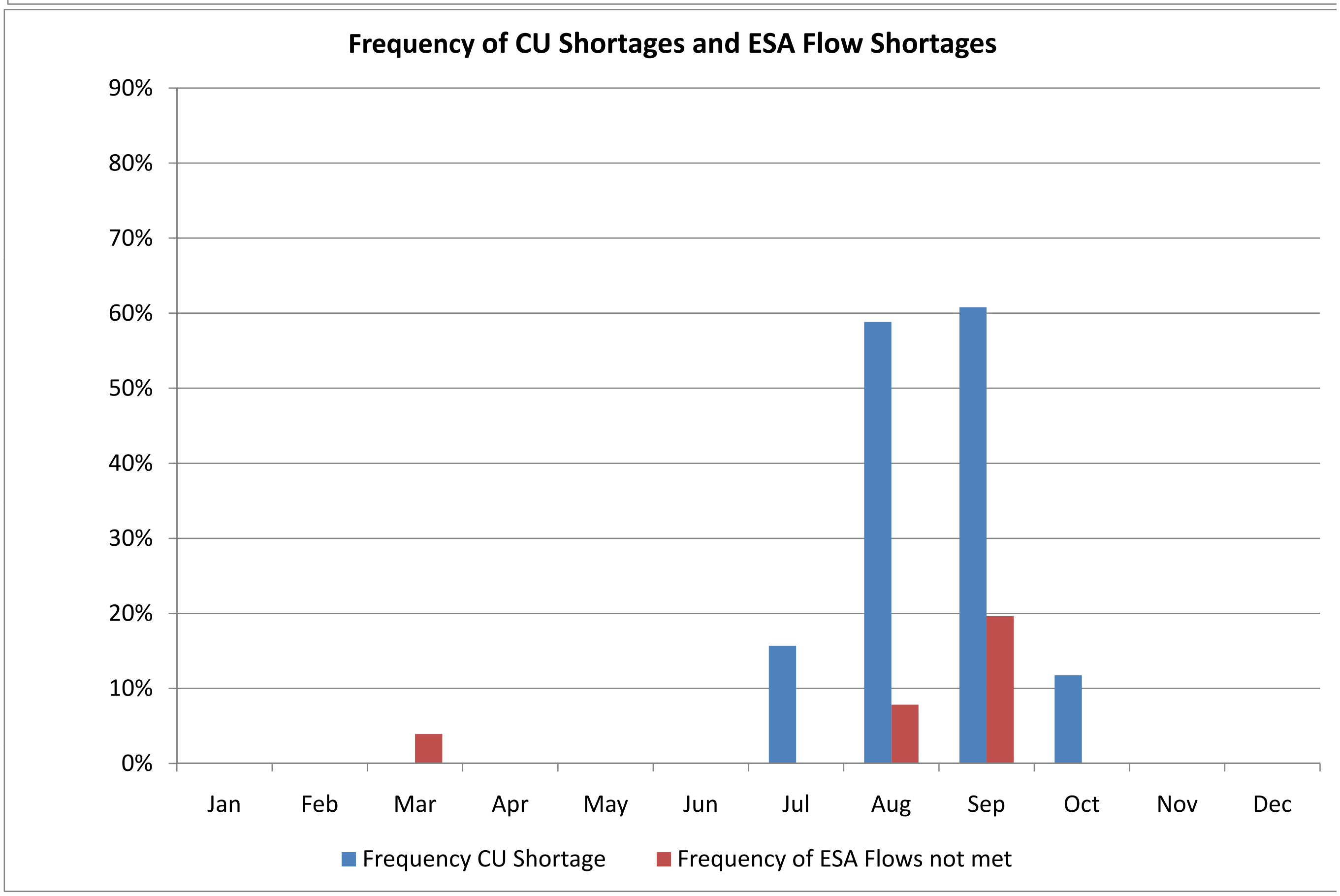


Figure 5-14: Diversions, Return Flows, IWR and CU Shortage at 75% Efficiency
Avg Annual CU Short: 4786
AF/Month
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Average Diversions
Average Return Flow
Average IWR
Average CU Shortage


Frequency of CU Shortages and ESA Flow Shortages
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Frequency CU Shortage
Frequency of ESA Flows not met

modeling the Endangered Fishes Management Plan target flows as senior to the new irrigated lands, the historical frequency of flows below 93 cfs in the summer and 124 cfs in the winter are not altered. Figure 5-15 shows the changes in flow that would occur due to irrigation at the various efficiencies. The percentages shown for each month in the figure compare the change in flow to Yampa at Maybell average monthly flow.The figure shows that the decreases in flow in terms of total change in volume, is greatest in June and July when IWR is greatest. However, flows through this reach are very high in June, and on average there is approximately a 2 percent reduction in flow. However, while volume of change decreases in the late season, the percent change becomes larger since the flows at Maybell decrease fairly rapidly beginning in July. Return flows from the new irrigated lands increase streamflows by small amounts (1 to 2 percent) through the late season. The lower efficiency run shows return flows increasing flows in the river on average in September.

4.2.5 Reconnaissance Level Costs

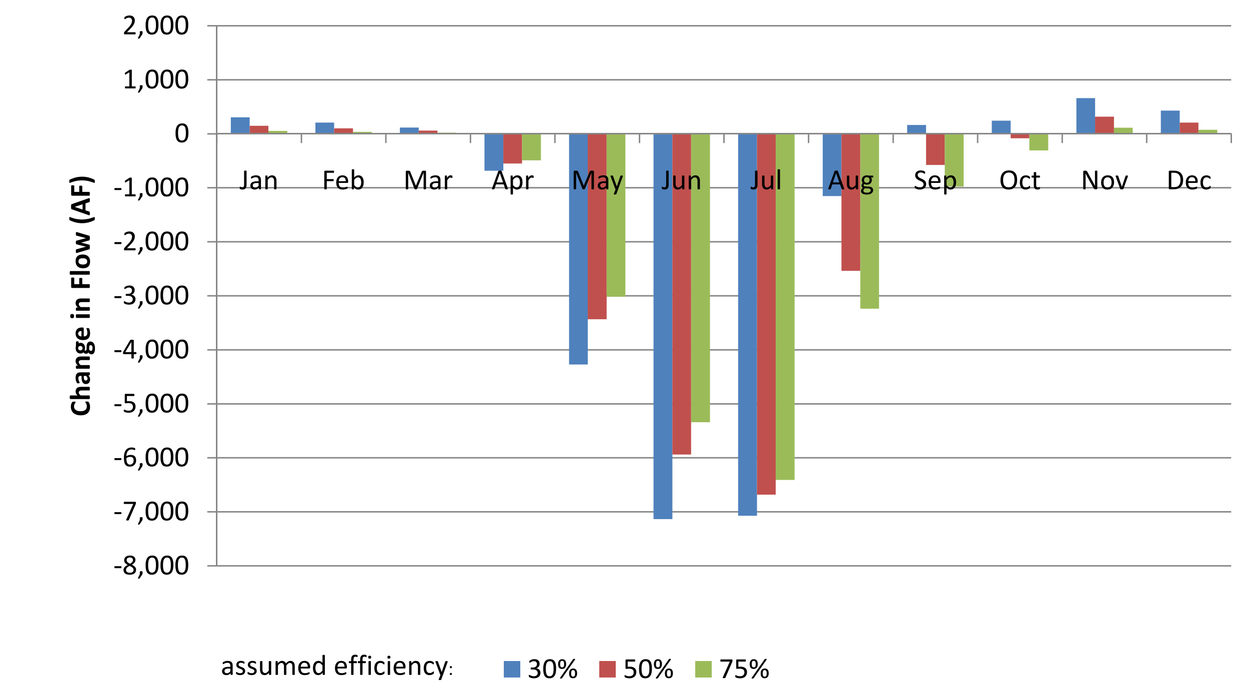
The type of irrigation system required to irrigate these lands would be determined on a site-specific basis. The majority of the existing irrigated lands along the Yampa River through this reach are flood irrigated. However, it is unknown whether the lands not currently irrigated could also be supplied through flood irrigation and gravity diversion. The State Land Board, in a 1999 document regarding crop land rental rates, estimated an average investment of $500 per acre for sprinkler irrigation, and $150 per acre for flood irrigation. Using data from the Bureau of Labor Statistics, there is a 31% adjustment for inflation from 1999 to 2010 dollars. Therefore, the 2010 approximate costs would be $655 per acre for sprinkler irrigation and $197 per acre for flood irrigation. No annual operations and maintenance costs were provided in the document.

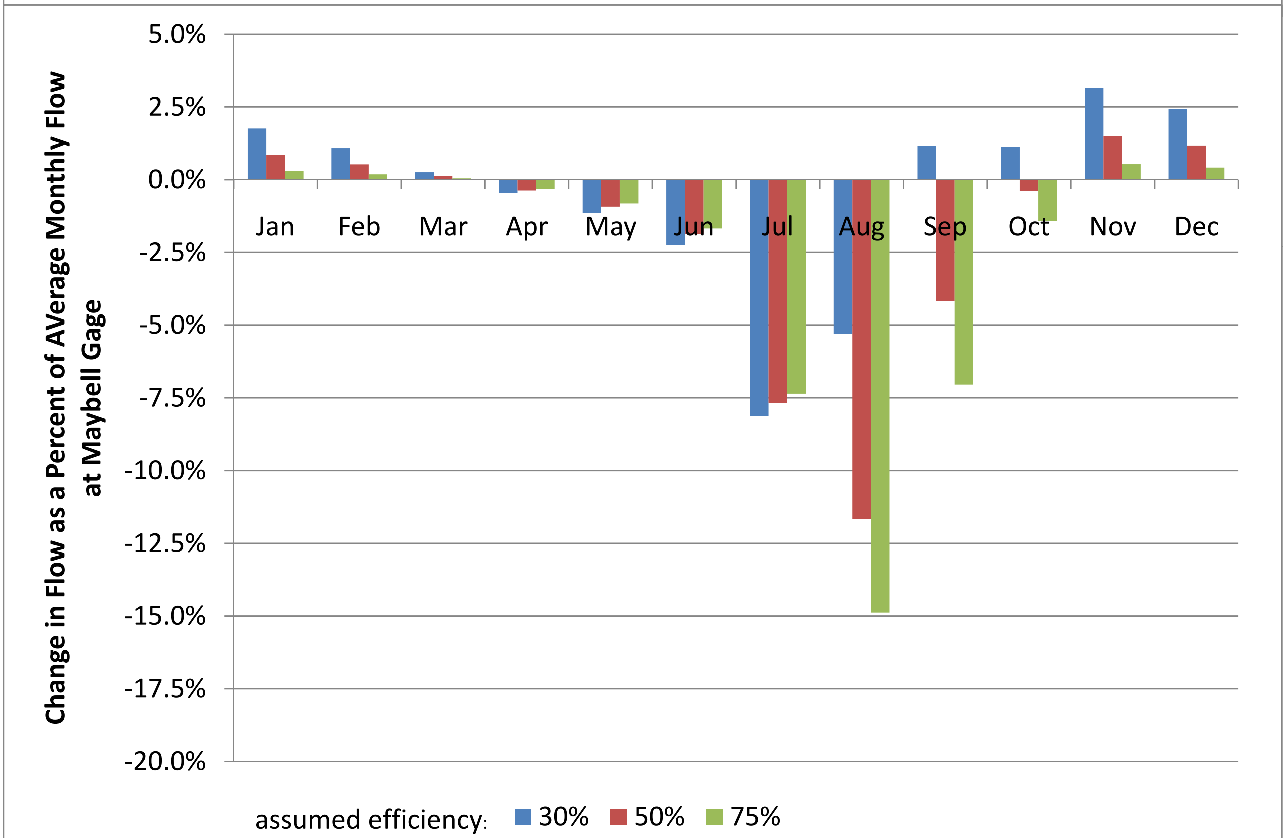
The project team requested a reconnaissance level cost estimate to install a center-pivot sprinkler system with a pump and pump structure from B&B Irrigation, an irrigation supplier in the region. The estimate included a quarter-mile sprinkler, which can irrigate approximately 125 acres (circular area of a quarter-section). The estimate for the irrigation system was approximately $102,000 capital and $4,500 in annual operating costs (electricity for pumping and sprinkler rotation). These costs equate to a per-acre cost of $795 capital costs and $35 per acre annual operating costs.

4.2.6 Regulatory Concerns

It is anticipated that development of new irrigated lands would be undertaken by private landowners rather than through a large-scale publicly funded project. Individual development would likely lessen the regulatory challenges associated with the development of these lands, especially if the lands went under irrigation over time. CDM contacted the US Army Corps of Engineers (Corps) to discuss the potential regulatory implications of developing the new irrigated lands. Federal regulation could be triggered through several mechanisms, including Section 404 for dredge and fill activities associated with the new diversion point, the Endangered Species Act (ESA), or through cultural resources inventory. Exemptions are often available for agricultural activities, but due to the Endangered Fish Recovery Program through the reach, the exemption may be not be honored (recaptured) and further permitting evaluation would be required.

Figure 5-15 - Change in Monthly Average Flows Due to Development of Oxbows Using Different Efficiencies (30%, 50%, 75%)





A new water right would have to be filed with the State of Colorado. Since plentiful water is available at the location of the diversion, little resistance is anticipated to obtain a new water right, provided it was operated as junior to the Recovery Program target flows.

4.3.1 Small On-Site Storage

Many structures in the study area cannot be served by larger reservoirs, such as structures located in the upper reaches of smaller tributary streams (e.g. Morapos Creek), or on small tributaries that are not simulated in the StateMod model (B-aggregates; e.g. irrigated land in the Green River basin on Talamantes Creek). Many structures that have shortages in the late season could benefit from storing water during the peak runoff for release of that water later in the growing season when streamflows are low. This alternative provides a conceptual analysis of the amount of water available under a junior water right during the peak flow that could potentially be stored in smaller on-site storage facilities.

Figure 5-16 shows the average annual distribution of legally and physically available flow (or simply available flow) and the distribution of consumptive use (CU) shortages on Morapos Creek. Morapos Creek is a smaller tributary stream with a significant amount of shortage in the late season. As shown on the figure, on average there is water available in the early season (April, May and June) that could potentially be stored and used for late season irrigation. Morapos Creek serves as an example of what occurs on many smaller tributaries in the basin, including tributaries that are not explicitly modeled in StateMod. More than half of the shortages identified in the study area occur at structures that divert from such unmodeled streams (B-aggregates). Since such a large amount of shortages occur at these types of structures, it was important to evaluate a decentralized alternative that could potentially meet shortages at these structures.

Dams under 10 feet in height, inundate less than 20 acres and store less than 100 AF are considered non-jurisdictional dams and are generally not regulated by the State, subject to dam safety rules and could be built more inexpensively and easily by private landowners. Feasibility of constructing such a structure depends on many site-specific characteristics such as topography, soil and seepage considerations at the specific structure. While site-specific analysis cannot be provided on a basin-wide project such as this, the concept was analyzed on a smaller tributary stream (Morapos Creek) that was modeled explicitly in StateMod (providing a higher level of confidence in modeling results). The results were then applied to the B-aggregates where there is more uncertainty, but provides a reconnaissance level view of the potential to mitigate a large portion of existing CU shortages in the study area.

4.3.2 Modeling Approach

The baseline StateMod model consists of explicitly modeled structures, and aggregate structures. Aggregate structures are groups of several smaller structures that are simulated at the same point in the model. For the purposes of this project, the aggregate structures were further subdivided into structures that divert from the modeled stream (A-aggregates) and those that divert from a smaller, unmodeled stream (B-aggregates). Streamflow data at the B-aggregate structures is unknown, and historical diversion data was used as a proxy for divertible streamflow at the B-aggregates.

The analysis process for evaluating the ability of small on-site storage facilities to reduce agricultural shortages is presented in Figure 5-17. StateMod computes the amount of available flow at all explicitly modeled structures and A-aggregates in the model and at major stream gages. Available flow represents water not allocated to other users and could be stored under a

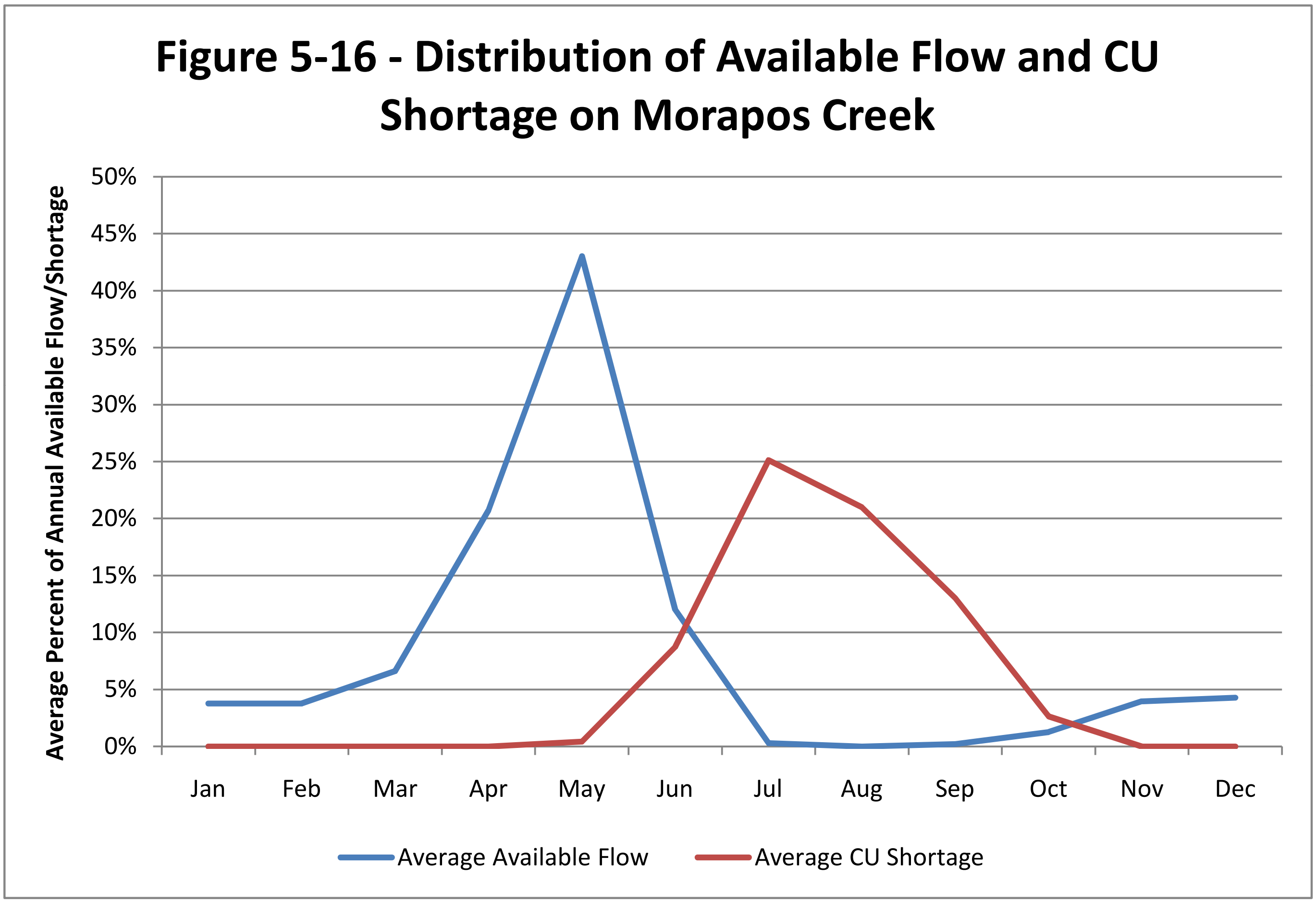
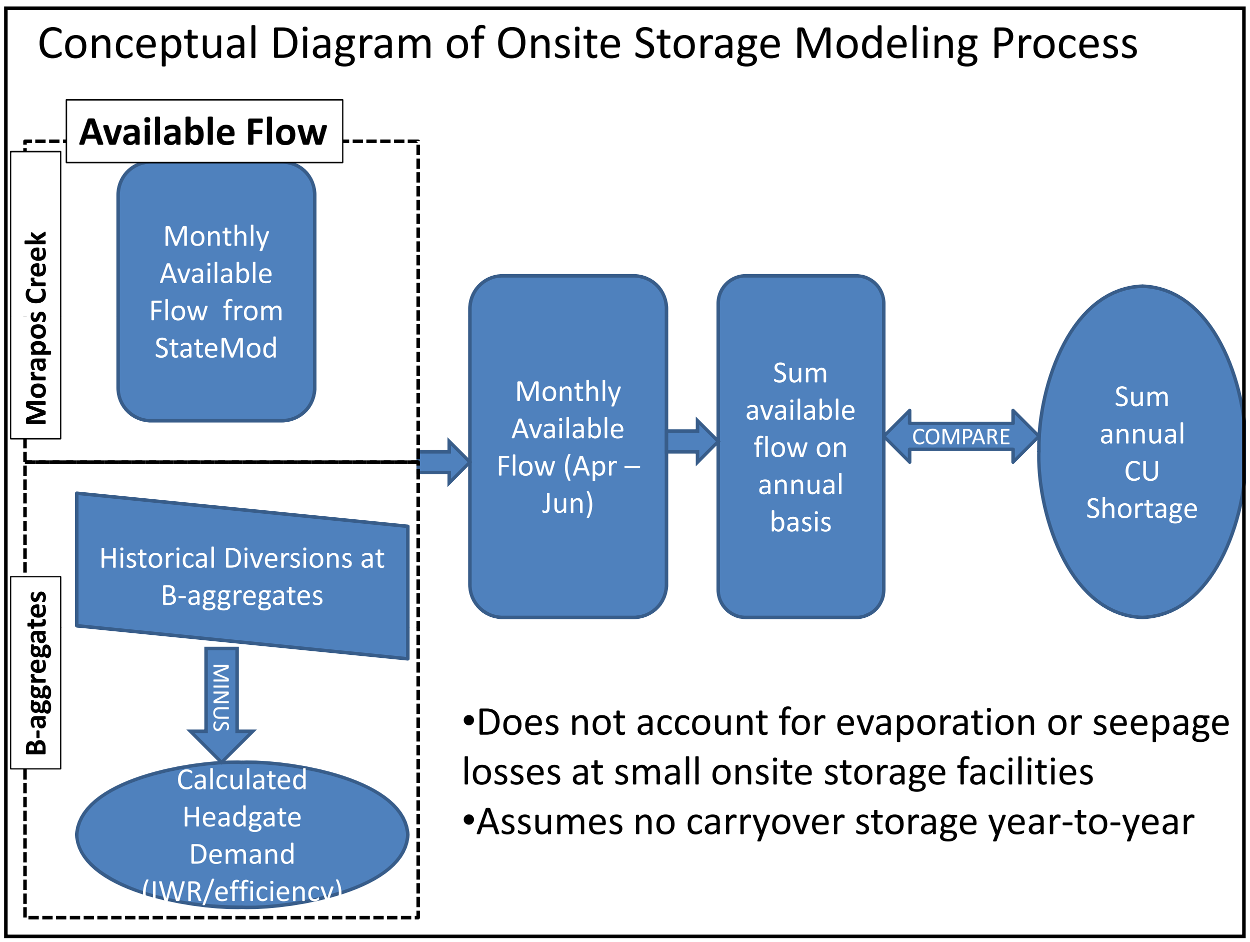


Figure 5-16 - Distribution of Available Flow and CU Shortage on Morapos Creek
Average Percent of Annual Available Flow/Shortage
50%
45%
40%
35%
30%
25%
20%
15%
10%
5%
0%
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Average Available Flow
Average CU Shortage

Figure 5-17 - Schematic of Analysis Process



junior water right without causing injury to other existing water rights. Available flow in April, May and June was then compared to CU shortages that occur primarily in the later part of the year. Available flow was further limited based on an estimated amount of storage available so that tributaries with very high amounts of available flow (more than could be captured using small on-site storage facilities) would not be considered as available to be stored and used later in the season. Estimates of available storage were made by assuming that 1 AF of storage could be built for each irrigated acre. In some cases, this would mean that an individual structure that serves more than 100 acres would construct more than one storage facility. Efficiency on the use of the released stored water was assumed to be 75 percent. This efficiency value is high for flood irrigation, but it is assumed that return flows from application of storage water will be re-diverted by other users and consumed. Re-use of return flows by one downstream user will generate a net 75 percent efficiency if each structure can operate at 50 efficiency, which is reasonable during water-short periods especially for structures that do not have large canal conveyance losses.

There is higher confidence in the data at explicitly modeled structures and A-aggregates since these structures divert from a modeled stream and available flow is simulated at each structure. The concept was evaluated on Morapos Creek to evaluate the concept where there is higher confidence in the available flow calculation. Figure 5-18 shows the average available flow, CU shortage and historical diversions for the structures on Morapos Creek. Note that in some months (e.g. June), the average shows available flow and shortage. This is due to the nature of averages, and indicates that in June in some years there is available flow, and there is shortage in other years. Available flow from the StateMod baseline model was queried at the most upstream structure on Morapos Creek to provide a conservative estimate of water available for storage under a junior water right. Only available flow in April, May and June was considered to fill a new on-site storage facility, and carryover storage year-to-year was not considered. Available flow in the winter months was not considered due to the generally lower amounts of available flow and potential problems with winter operations. The total amount of storable available flow was then limited to the estimated maximum storage amount of 1 AF per irrigated acre for a total of 2,097AF. Model results are presented in Section 4.3.3.

As described above, by definition, B-aggregates are comprised of structures that divert from streams not modeled in StateMod, and therefore available flow is not simulated at these locations. At B-aggregates, available flow was estimated by computing the difference between the historical diversion and the headgate demand. Headgate demand is computed using the IWR for the irrigated acreage and an assumed efficiency of 50% (Headgate demand = IWR/efficiency). Using the historical diversion as a proxy for available flow provides a reasonable estimate of divertible flow. However, due to the unknown configuration of structures that comprise the B-aggregates, it is possible that one structure may rely on return flows from other upstream structures within the B-aggregate. Therefore, available flow computed in this manner may overestimate actual available flow. On the other hand, a structure may not have historically diverted the entire flow in the stream, and therefore available flow could be underestimated at that location. Thus, although there is a higher level of uncertainty for the B-aggregates, the available flow analysis provides a reconnaissance level estimate of the potential impact at the B-aggregates given the proof of concept on the explicitly modeled structures on Morapos Creek.

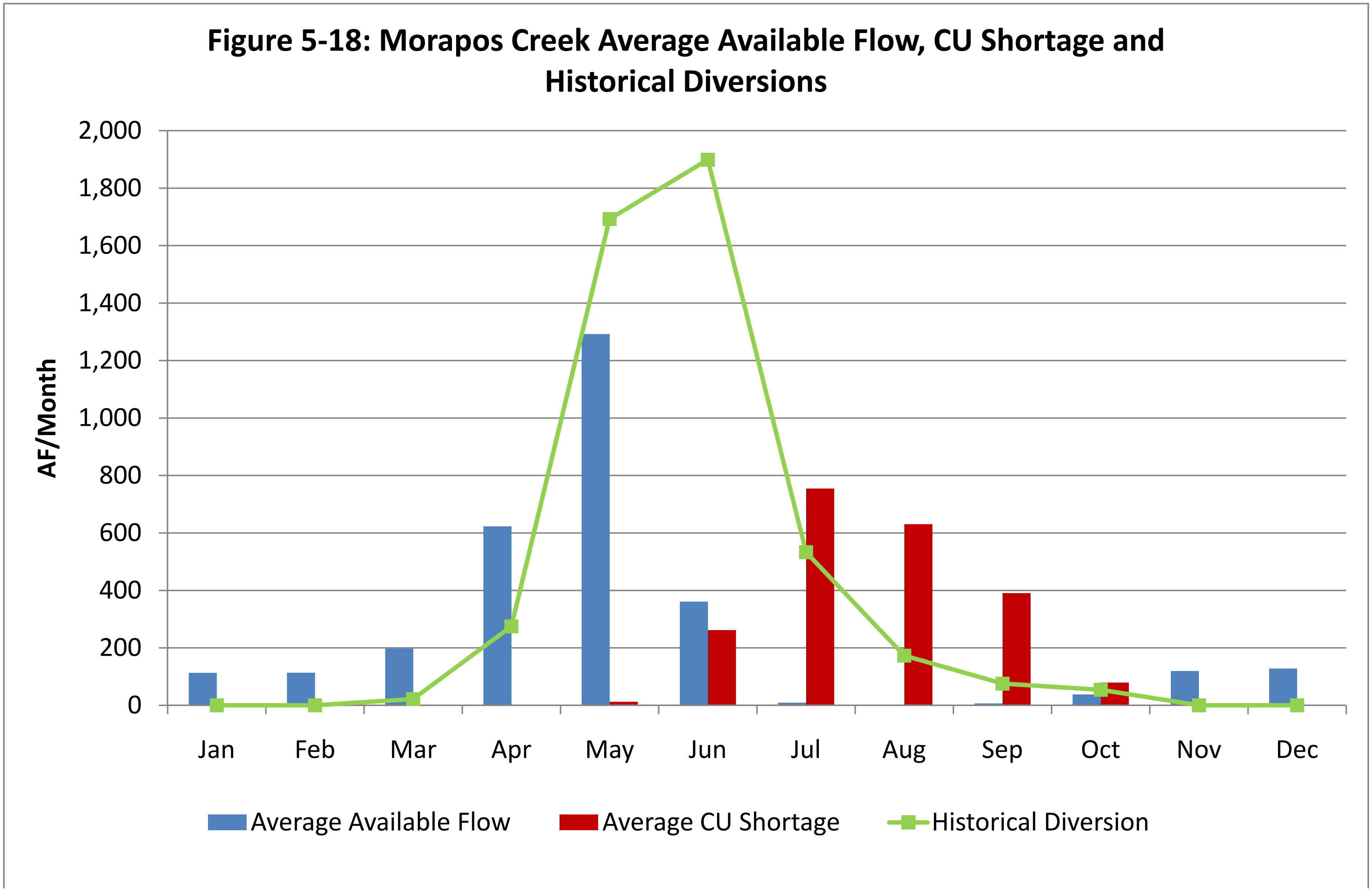


Figure 5-18: Morapos Creek Average Available Flow, CU Shortage and Historical Diversions
AF/Month
2,000
1,800
1,600
1,400
1,200
1,000
800
600
400
200
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Average Available Flow
Average CU Shortage
Historical Diversion

Specific knowledge of the structures that comprise the B-aggregates would reduce the uncertainty. For example, in a B-aggregate in which very few of the structures divert from the same stream, fewer structures rely return flows from upstream users and uncertainty would be lower; the flow in excess of the headgate demand is more representative of available flow. In B-aggregates where several structures divert from the same stream, the effect of relying on upstream return flows becomes more important and flow in excess of headgate demand is less representative of available flow.

4.3.3 Ability to Meet Shortages

Morapos Creek is a tributary stream in the Yampa River basin and has significant shortages at explicitly modeled structures. Using model output from StateMod and assuming on-site storage facilities as described in the previous section, shortages on Morapos Creek were reduced by an average of 63 percent. Evaporation and seepage losses were not considered due to the site specific nature of small on-site storage facilities, but could reduce the ability of such facilities to reduce shortages. Figure 5-19 shows that in years with higher available flow, shortages are lower, and years with less available flow, shortages are higher. Figure 5-19 also shows that on Morapos Creek, there are always shortages and that on-site storage facilities could reduce late season shortages in all years. However, the available flow often exceeds the estimated amount of storage (2,097 AF) and this water does not meet shortages later in the season. The figure also shows that in dry years (e.g. 1977, 2002), there is very little available water to go into storage under a junior water right, and there is correspondingly little reduction in shortages.

The analysis on Morapos serves to demonstrate that there is potential to store excess flows during the peak flow times in the smaller watersheds in the study area. A large portion (55 percent) of the existing shortages in the study area occurs at smaller structures that divert from smaller tributaries not modeled in StateMod (B-aggregates). As described above, uncertainty increases in the analysis of available flows in the B-aggregates due to lack of streamflow and structure configuration data. However, since the concept has been shown to work on a smaller tributary where there is less uncertainty, the analysis on the B-aggregates provides a conceptual level demonstration of the potential benefits of utilizing small on-site storage to meet shortages at the B-aggregates. Site specific data on streamflow availability should be obtained prior to constructing any storage facility.

Figure 5-20 shows the available flow and shortages at B-aggregates for the Yampa River and Figure 5-21 shows the available flow and shortage at the B-aggregates for the White River. In the Yampa basin, CU shortages can be decreased on average by 3,095 AF (21 percent of B-aggregate shortage), and 353 AF (67 percent of B-aggregate shortage) in the White basin. The figures also show that much of the available water cannot be used to meet shortages. This indicates that flow is highly variable throughout the basin and there are areas where there is abundant water in excess of the demand from irrigated lands in some places, and areas where there is not enough water for the irrigated demand even when there is plentiful water in other parts of the basin.

Figures 5-20 and 5-21 also give some indication of the uncertainty with the B-aggregates. For example, 1984 was a very wet year with streamflows well above average throughout the basin.

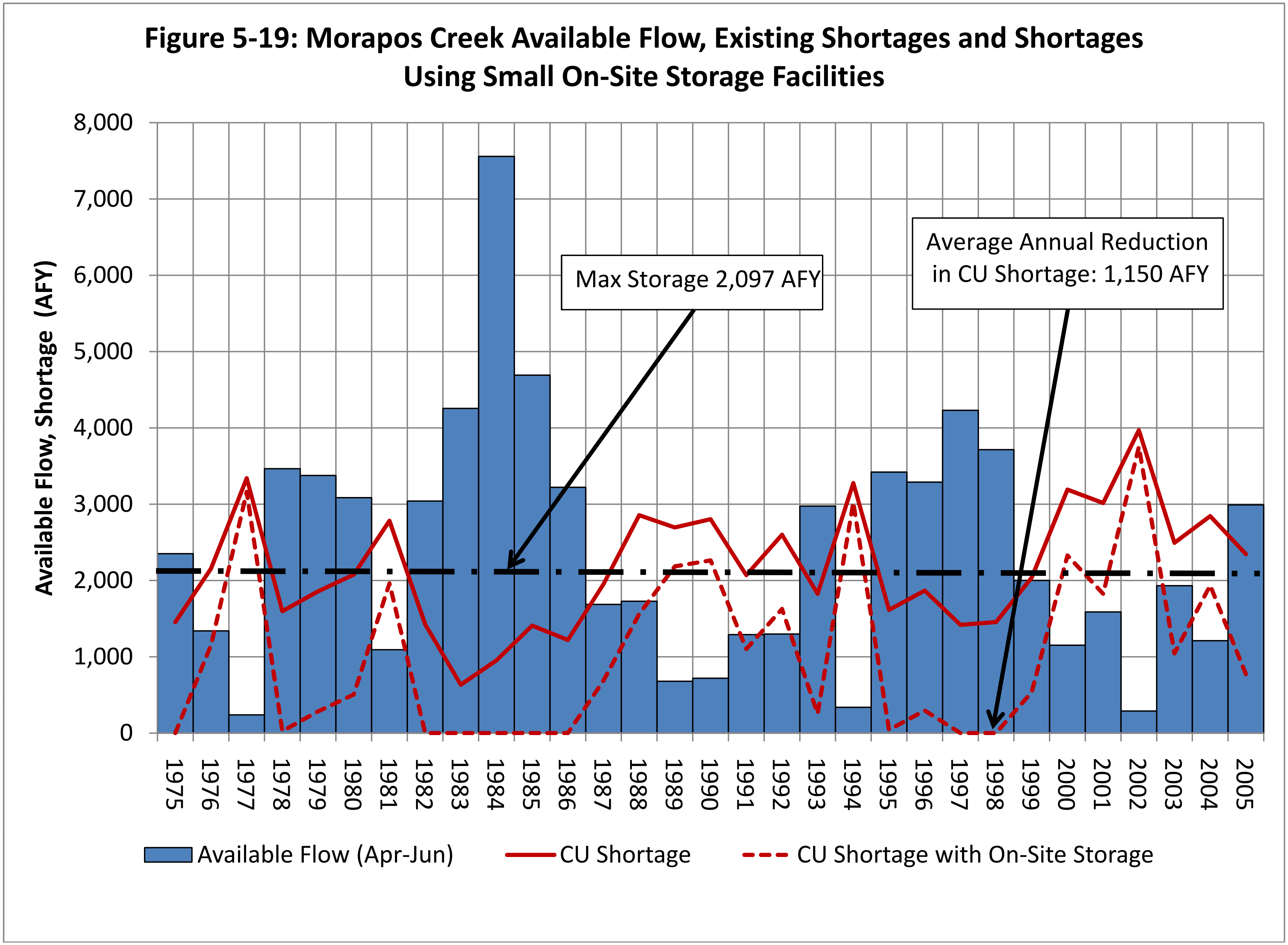


Figure 5-19: Morapos Creek Available Flow, Existing Shortages and Shortages Using Small On-Site Storage Facilities
Available Flow, Shortage (AFY)
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
Max Storage 2,097 AFY
Average Annual Reduction in CU Shortage: 1,150 AFY
1975
1976
1977
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
Available Flow (Apr-Jun)
CU Shortage
CU Shortage with On-Site Storage

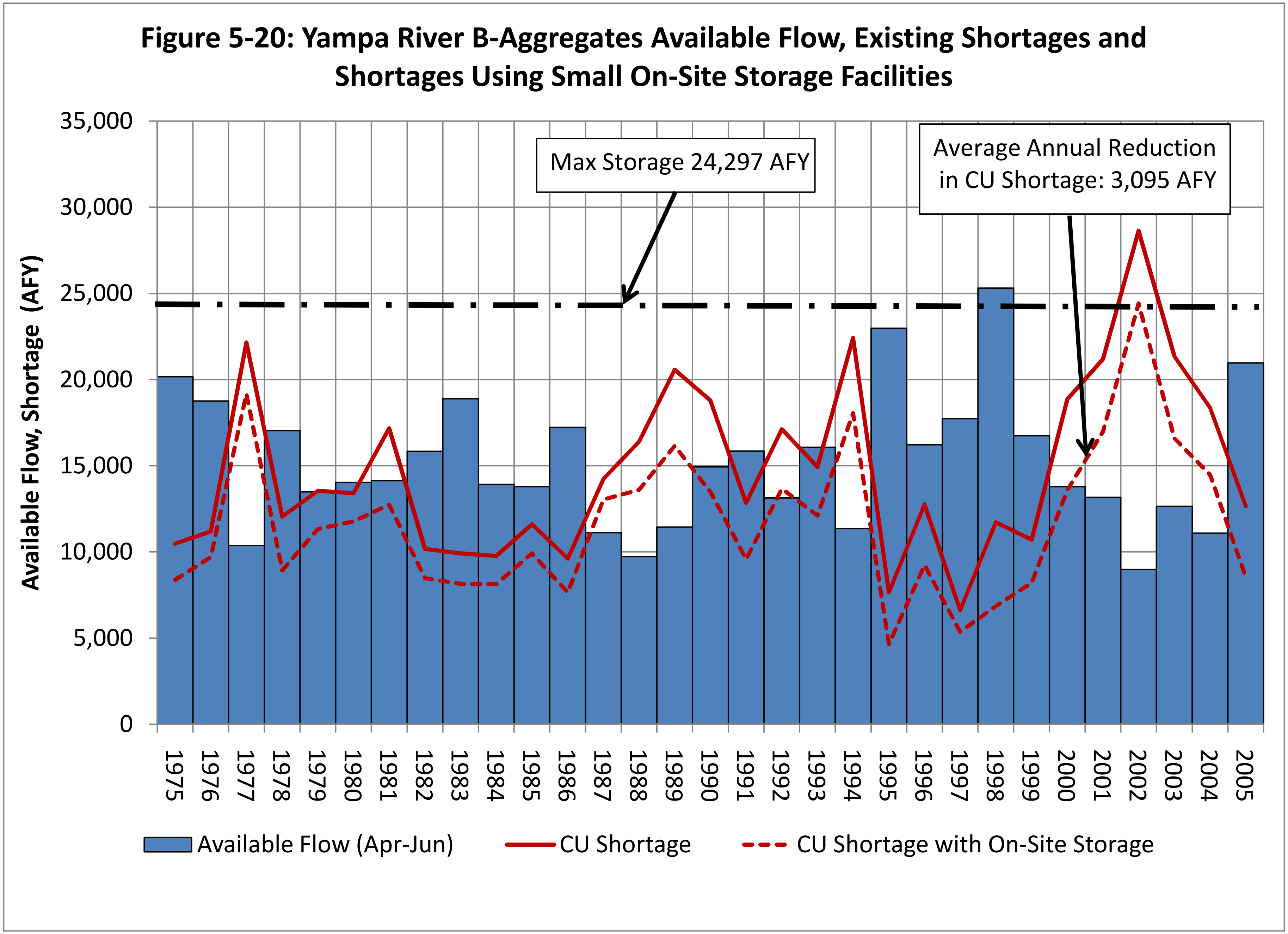


Figure 5-20: Yampa River B-Aggregates Available Flow, Existing Shortages and Shortages Using Small On-Site Storage Facilities
Max Storage 24,297 AFY
Average Annual Reduction in CU Shortage: 3,095 AFY
Available Flow, Shortage (AFY)
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
1975
1976
1977
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
Available Flow (Apr-Jun)
CU Shortage
CU Shortage with On-Site Storage

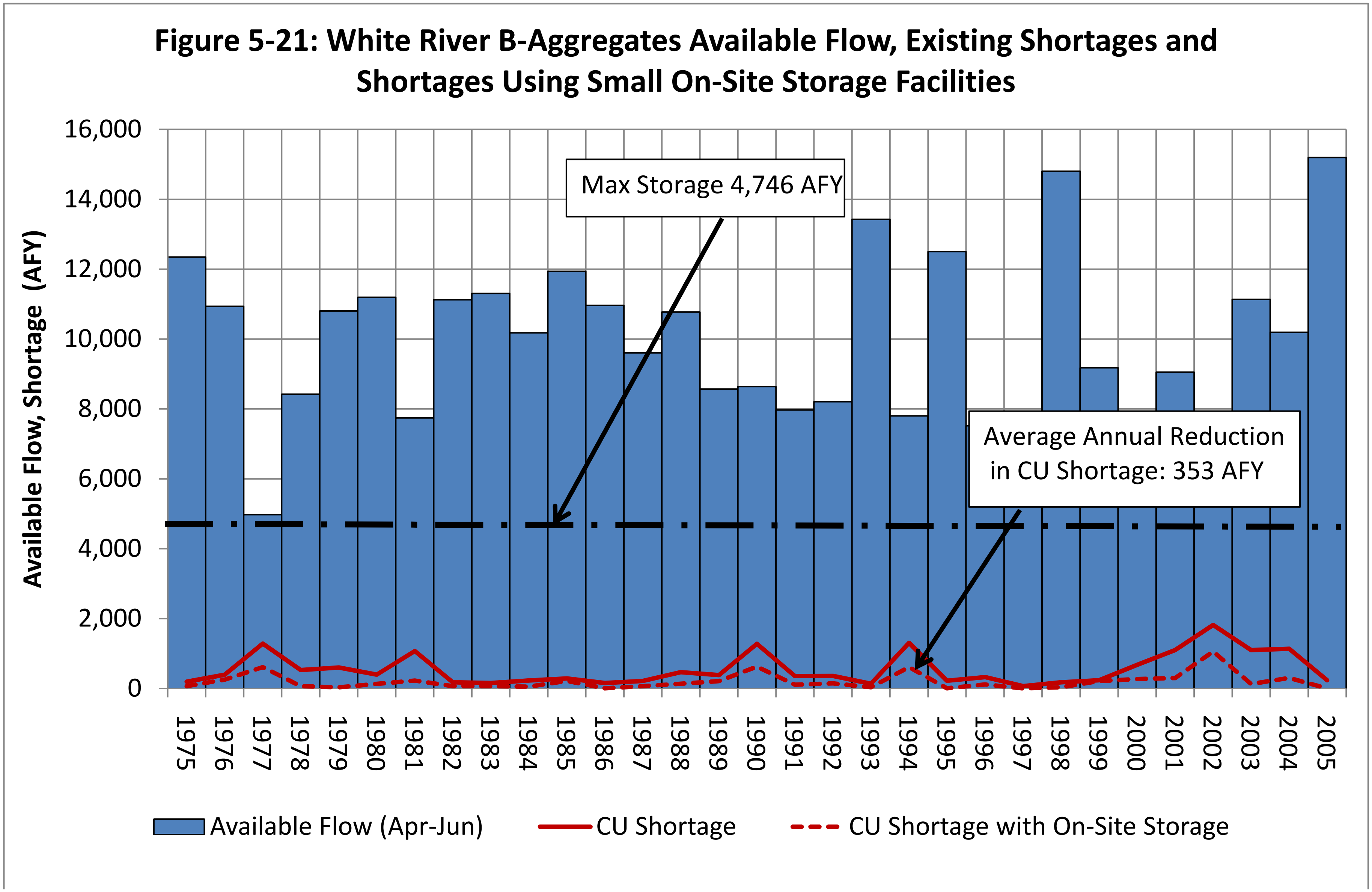


Figure 5-21: White River B-Aggregates Available Flow, Existing Shortages and Shortages Using Small On-Site Storage Facilities
Available Flow, Shortage (AFY)
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
Max Storage 4,746 AFY
Average Annual Reduction in CU Shortage: 353 AFY
1975
1976
1977
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
Available Flow (Apr-Jun)
CU Shortage
CU Shortage with On-Site Storage

Figure 5-19 shows this large increase for Morapos Creek where flows were explicitly modeled in StateMod. However, in Figure 5-20 and 5-21, the available flow in 1984 is not that large. The reason for this is that historical diversions were used as a proxy for divertible flow. In situations like 1984, there was likely a significant amount of water in addition to the historical diversions in the streams that would have been available to go into small on-site storage facilities. This point underscores that while the estimates provided here based on fairly conservative assumptions, the need for site-specific evaluation of available water is needed before any small on-site storage facilities should be constructed.

4.3.4 Changes in Flow

Streamflows would be affected in a similar fashion as in the New Reservoir Storage alternative (Section 4.1.3). Peak streamflows would be reduced as these small on-site storage facilities stored water that previously was not diverted, or was diverted and returned quickly to the system via return flows. Streamflows could increase in the later season somewhat from return flows of small on-site storage releases applied to crops. However, depending on the location of the on-site storage facility, these return flows may be diverted and consumed by downstream users and would therefore cause little increase in flows in the late season outside of the watershed of origin.

Due to the highly uncertain nature of the locations and sizes of on-site storage facilities, streamflow changes cannot be quantified. However, based on Figures 5-20 and 5-21, the average reduction in shortages is 3,095 and 353AFY in the Yampa and White River Basins, respectively. Using the 75 percent efficiency assumption, the minimum amount of water required to be stored would be 4,126 AF in the Yampa and 471 AF in the White. Removing this amount of flow from the Yampa at Maybell gage represents approximately a 0.5% average reduction in the average April through June flow when the reservoir would fill. Assuming the 75 percent net efficiency of the applied reservoir water (includes re-use of return flows by downstream users), approximately 1,032 AF of delayed return flows would come to the river in the late season. These return flow represent approximately 1.8% of the average August through October flows of the Yampa at Maybell. Return flows will be higher if the applied storage water is used at lower efficiencies than 75 percent, but will be determined by actual number and location of small on-site storage facilities.

4.3.5 Reconnaissance Level Costs

Costs for adding storage will vary widely depending on site-specific conditions. A member of the subcommittee stated that he was able to build such a facility for approximately $500 per AF of storage.

4.3.6 Regulatory Concerns

A new junior water would be needed to fill smaller on-site storage facilities. As was shown for Morapos Creek, there is sufficient amount of unappropriated water for such a water right. However, in other parts of the basin such as the upper Yampa River, the available flow is less and such water rights may not be in priority in many years. For example, there is no available flow at Yamcolo Reservoir in more than half of the years in the study period, but there may be water available on smaller tributaries depending on the demands lower in the system. At B-aggregates, where structure configuration and streamflow data is uncertain, a more detailed analysis of available flow is needed to determine the site-specific feasibility of on-site storage facilities.

CDM contacted the US Army Corps of Engineers (Corps) to discuss the potential regulatory implications of developing the new irrigated lands. Federal regulation could be triggered through several mechanisms, including Section 404 for dredge and fill activities associated with the new diversion point, the Endangered Species Act (ESA), or through cultural resources inventory. The Corps noted that the first step in the Section 404 permitting process would be to determine if the proposed on-site storage facility would be located on a water body that would be considered Waters of the United States (WOUS). WOUS is generally any stream (perennial or ephemeral) that connects to another WOUS, but individual determination would be required. The Yampa River and White River are considered WOUS. If a proposed storage location is determined to be on a WOUS, a dam would constitute fill into that WOUS and would require a permit. Exemptions are often available for agricultural activities, but due to the Endangered Fish Recovery Program in the basin, the exemption may be recaptured for further permitting evaluation. Dry tributaries or gulches are generally not considered WOUS and would likely not require a Section 404 permit. Other regulatory challenges include a review of the impact on other endangered species and cultural and anthropological resources in the proposed location.

4.4.1 Increasing Irrigation Efficiency on B-Aggregates

As described in section 4.3.1, the majority of CU shortages for agricultural users in the study area are located at grouped small structures that divert from smaller tributaries that are not explicitly modeled in StateMod, known as B-aggregates. To estimate CU shortages in the baseline model, the historical diversions at these structures was used as a proxy for available flow in the stream, and compared against the computed IWR based on irrigated acreage under each structure. Streamflow peaks typically in May and June in many of these streams, tails off in July and there is significantly less flow in the later season of August through October.

Since the B-aggregates are located upstream of larger regional-scale streams, regional water supply projects such as large reservoirs are not able to serve most of these structures. The previous alternative evaluated the potential of using smaller on-site storage facilities to store excess water during the peak runoff for use later in the season. The analysis showed that while such storage could help reduce shortages, there are many instances where there is abundant water without an associated agricultural demand for the water. Similarly, there are also areas where there is a large agricultural demand without a significant amount of available water to store.

This alternative assesses the potential of using water more efficiently at the B-aggregates to reduce shortages. In instances where there is no water available in the late season, no decrease in shortage will be seen. However, where a small amount of water in the late season is available, higher efficiencies may result in decreased shortages. For this alternative, it is assumed that increased efficiency would be attained by a combination of installation of sprinklers and some level of ditch lining to reduce leakage. Ditch lining and the appropriateness and feasibility of sprinkler installation would be determined on a site-specific basis and may not be feasible at all locations.

It is important to note that increasing efficiency of flood irrigated fields can significantly alter the return flow pattern. By definition, increasing efficiency means that more water is available to the crop to be consumed rather than returning to the stream via return flows. In a water-short system, this leads to increased net depletions to the stream. The majority of return flows return to the river within several days of application through tailwater and runoff. Another portion of return flows, however, returns via deep percolation and the groundwater system and are lagged over the course of several months. Higher efficiency of irrigation water application in June and July (when historically more water is available for diversion often far in excess of IWR) will reduce return flows – and thereby streamflows - in August, September and October. Thus, efficient irrigation early in the season may result in lower available flow in the late season.

As described previously, a higher level of uncertainty exists at the B-aggregates than at explicitly modeled structures and streams. The uncertainty is due to the unknown streamflows and unknown configuration of the individual structures that comprise the B-aggregates. For example, in a B-aggregate that is comprised of 10 structures, it is not known if these structures all divert from the same source (and also rely on each others' return flows) or if they divert from 10 different small streams (and return flows would not affect one another's available supply).

4.4.2 Modeling Approach

Model output from the baseline StateMod model was queried for all B-aggregates. Using the modeled IWR and diversions (recall for the baseline, diversions are the historical diversion at B-aggregates), CU, CU shortage, and return flow amounts were computed. The return flows were then lagged according to the StateMod's return flow pattern to estimate the impact of the B-aggregates under existing conditions. The same analysis was then carried out using 75 percent efficiency, and reducing the headgate demand based on the increased efficiency (headgate demand = IWR/efficiency). Root-zone soil moisture has the ability to meet consumptive demands in months when there is not sufficient water to divert from the stream. However, as a simplification for this analysis, root-zone soil moisture was not considered. Comparing the results of both analyses shows the potential changes if efficiency is increased at the B-aggregates (see section 4.4.3).

Uncertainty with the configuration of the B-aggregates can introduce some error into the results. The baseline model configuration of the B-aggregates lumps all structures into a single diversion point and all return flows from one individual structure within the aggregate are not available to other structures in the same aggregate. Figure 5-22 shows a conceptual schematic of how individual structures within a B-aggregate could be configured. B-aggregates where several structures divert from the same source, are water-short and rely on each-other's return flows may be impacted to a greater extent than shown in this analysis (series scenario). However, the analysis is a better representation for B-aggregates that have a plentiful supply or where several structures divert from different sources (parallel scenario). While there is uncertainty in individual configuration, the analysis provides a reconnaissance level estimate of the impact of increasing efficiencies at the B-aggregates. Site-specific investigations that reveal the local structure configuration and available flow should be carried our prior to installation of sprinklers of lining of ditches.

4.4.3 Ability to Meet Shortages and Changes in Flow

For the analysis on the Yampa basin, Figure 5-23 shows monthly average CU shortages, diversions, lagged return flows to a point below the B-aggregate, the change in CU, and the net depletion (or accretion) to the stream under the baseline and 75 percent efficiency scenarios. For the White basin, Figure 5-24 shows the same information. Both figures show that increasing the efficiency at B-aggregates can reduce shortages significantly; by an average of 34 percent in the Yampa basin and 45 percent in the White basin.

The decrease in CU shortage, however, significantly impacts return flows and diversions. When efficiencies are higher, the headgate demand is less and therefore there are less overall diversions and reduced diversions lead to reduced return flows. Historically, diversions are highest in June, and are also relatively high in May and July. Since a portion of return flows are delayed return flows, the high diversions in the baseline model feed higher return flows in the later part of the growing season (August, September, October). This affect is most clearly seen in the upper-right graph of each figure that shows that under baseline conditions, the B-aggregates deplete the stream more in the early season than in the late season. However, beginning in July or August, this trend switches, and the higher efficiency scenario has a larger net depletion to the river. This

Figure 5-22 – Schematic of Potential Configurations of Individual Structures Within a B-Aggregate Node

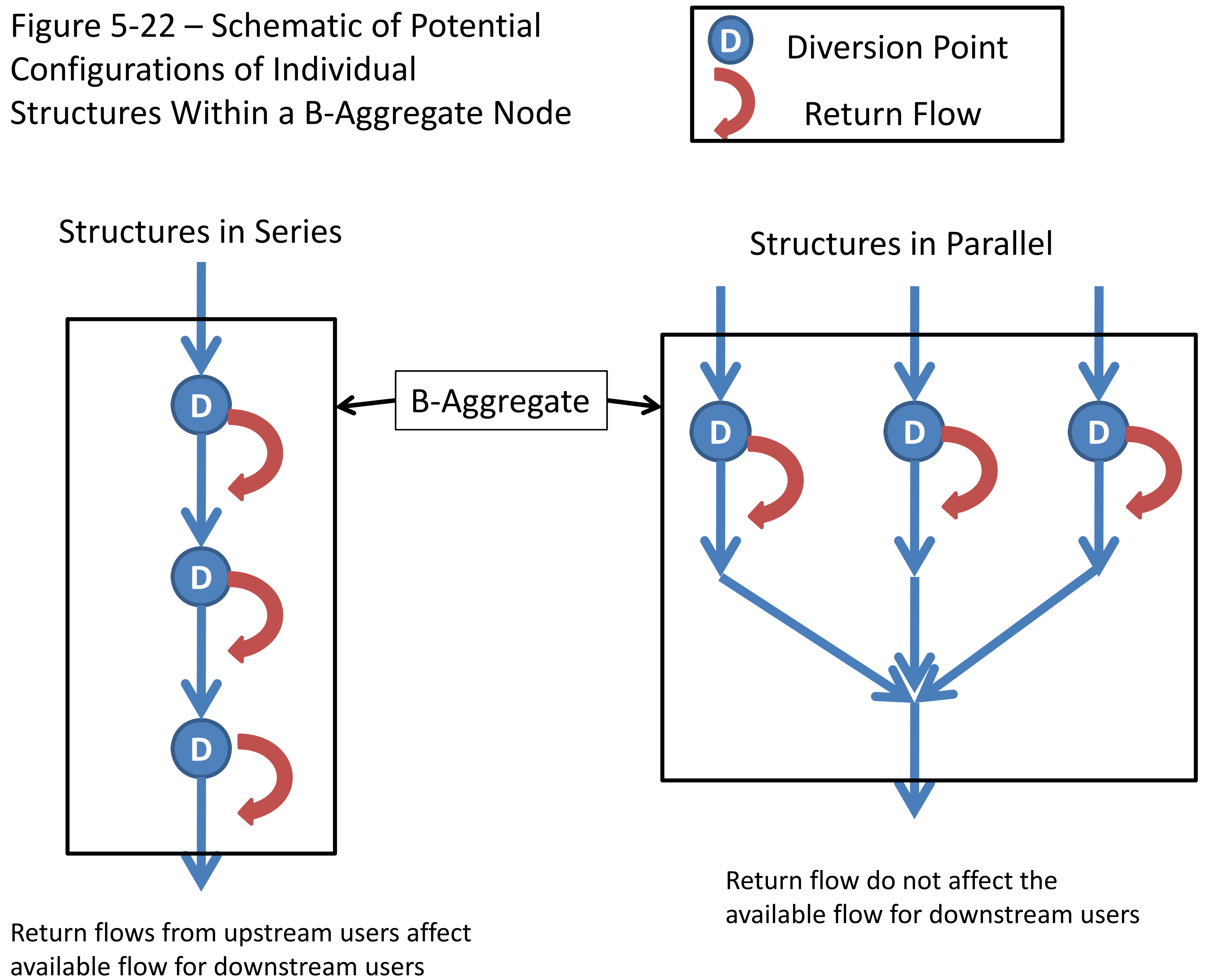
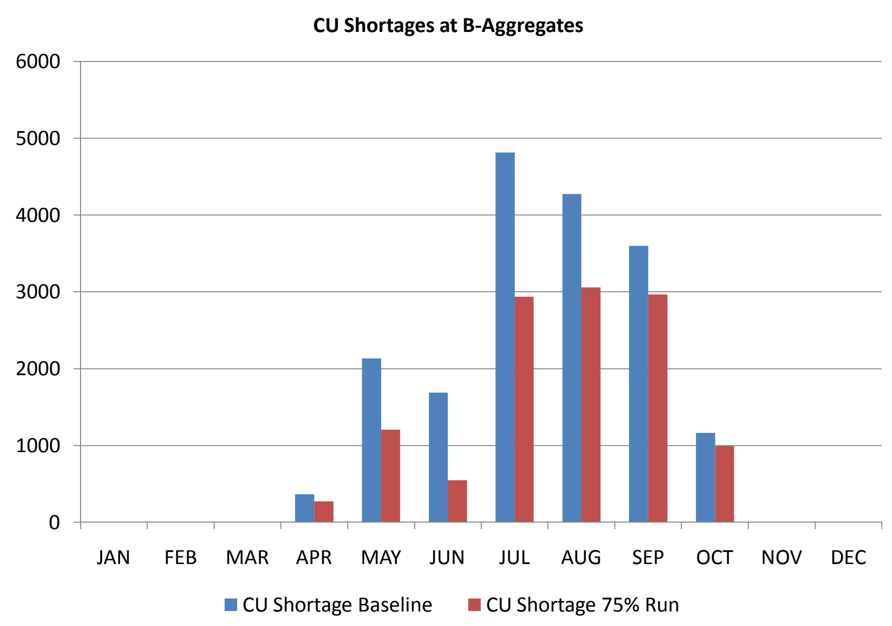
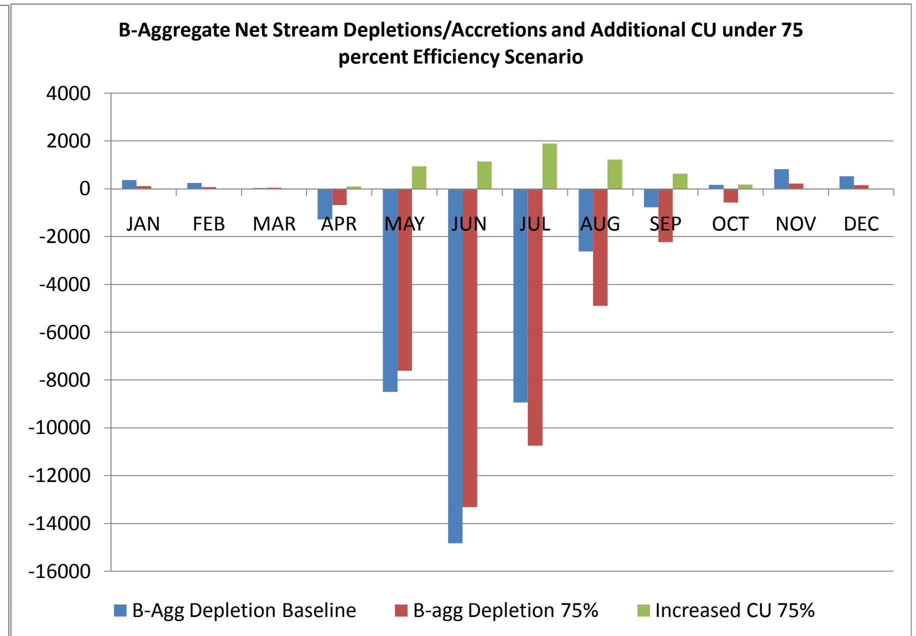
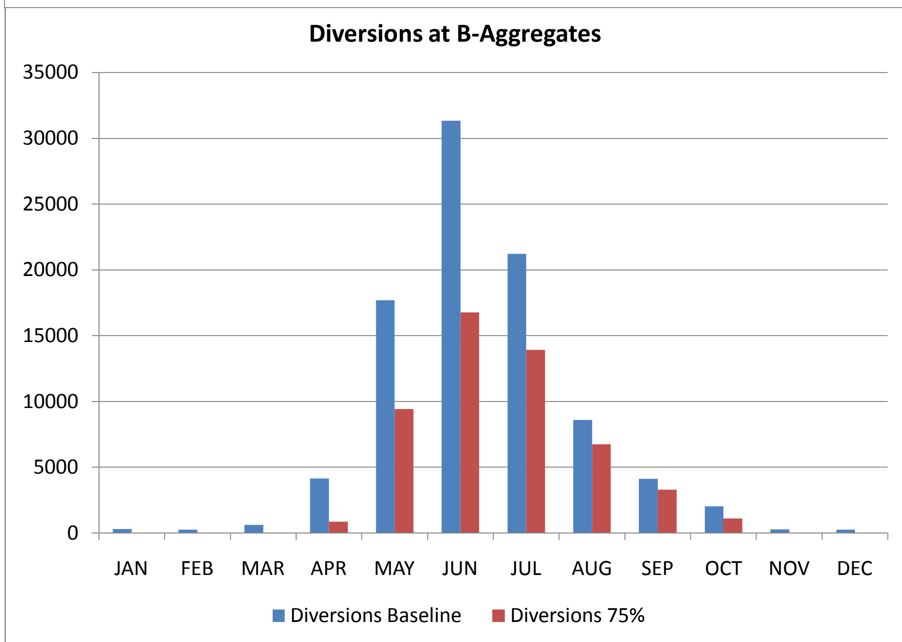


Figure 5-23 - B-aggregate Analysis for Yampa River Basin; CU Shortages, River Depletions, Diversions, Return Flows (All Values in AF)







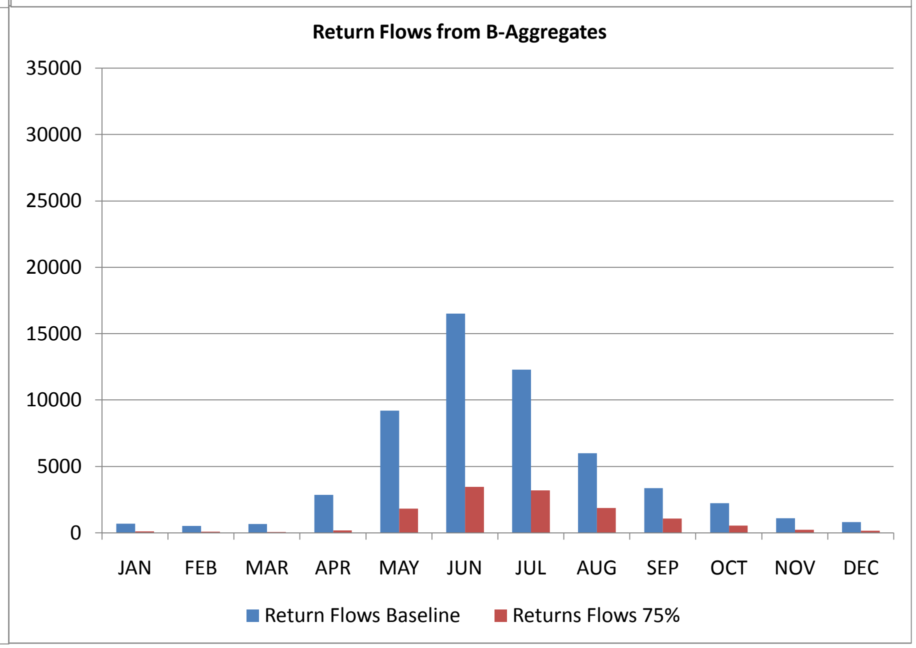
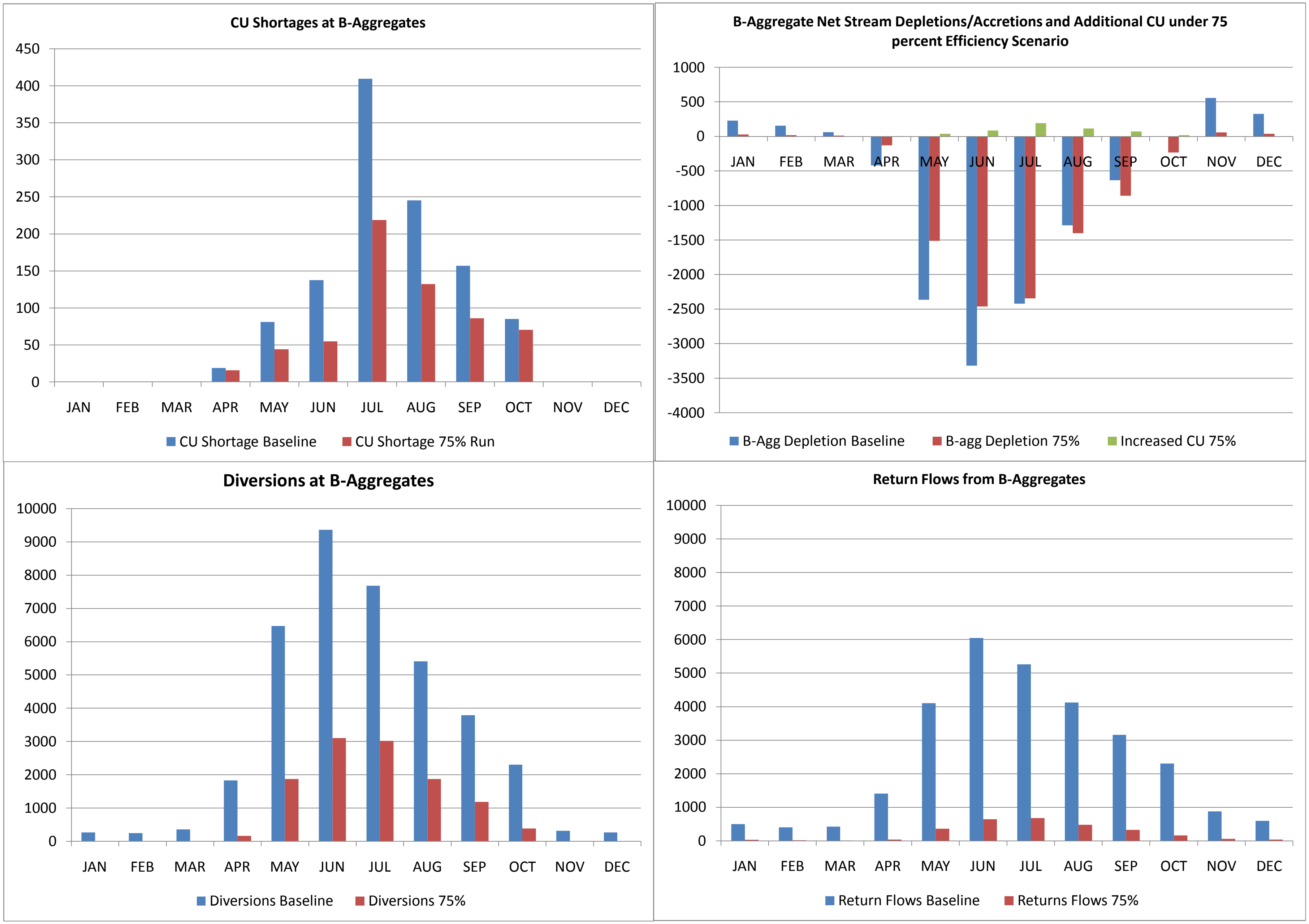


Figure 5-24 - B-aggreate Analysis for White River Basin; CU Shortages, River Depletions, Diversions, Return Flows (All Values in AF)



is due to the fact that return flows are not coming back to the river from the early season diversion to the extent they are in the baseline scenario.

4.4.4 Reconnaissance Level Costs

Cost of installing new sprinklers consists was estimated by the State Land Board at $650 per acre (2010 dollars adjusted from $500 per acre in 2000). Ditch lining estimates are $1 per square foot of canal to be lined. Due to the unknown geographical, geotechnical and topological conditions of each B-aggregate, and the uncertainty regarding the practicality of implementing efficiency increases basin-wide, costing on a basin-wide scale is not possible.

4.4.5 Regulatory Concerns

Under Colorado water law, agricultural water users are not required to obtain a change of use to increase the efficiency of their irrigation system (except in the Arkansas basin where this is governed by the Arkansas River Compact). However, increasing the efficiency of the irrigation system does not permit a water user to expand the historical acreage under the decreed water right.

Lining a ditch could potentially trigger a federal Section 404 permit requirement. CDM contacted the US Army Corps of Engineers (Corps) who said that recent case law has determined in some cases, agricultural ditches can be considered Waters of the United States (WOUS). If such a determination is made, the federal permit may be required if the ditch lining is considered fill material by the Corps. Exemptions are often available for agricultural activities, but due to the Endangered Fish Recovery Program on the Yampa River mainstem, the exemption may be recaptured for further permitting evaluation.

4.5.1 Increased Irrigation Efficiency on the White River and the Yellow Jacket Project

The baseline modeling quantification of shortages showed that there are relatively few agricultural shortages in the White River basin. Existing shortages were determined to exist primarily on Piceanace Creek, but discussions with subcommittee members indicated that these ranches do not represent true shortages since many are owned by energy companies and may not actively irrigate anymore. The subcommittee members expressed concern that three larger ditches above Meeker (Oak Ridge Park Ditch, Highland Ditch and Miller Creek Ditch), while currently not water short, are vulnerable to conditional water right use by the energy companies since the three ditches were expanded significantly after several conditional water rights were filed. Figure 5-25 shows a map of the location of the three structures.

In Technical Memorandum Number 4, an energy development scenario was developed for mid-production within approximately the next 20 years. This scenario showed that if the ditches can attain an efficiency of 30 percent, they will not experience consumptive shortages, even though headgate diversions may decrease. Return flows would decrease from existing conditions if higher efficiencies area attained. The changes in flow from increased efficiencies would be most prevalent in the late season when there would be a decrease in flow due to the higher efficiency.

Ditch lining is an alternative for increasing the efficiency to minimize the potential for shortages. However, if historical irrigation practices are maintained, additional storage may be needed to supply water for the junior expansion water rights if the energy sector develops their conditional rights. The size of such a reservoir was evaluated for this alternative. It is anticipated that this reservoir would be part of the Yellow Jacket project on Big Beaver Creek. The Yellow Jacket Water Conservation District is currently updating the previous planning studies for that project.

4.5.2 Modeling Approach

The three ditches of concern have water rights senior and junior to the energy sector’s most senior conditional water right. The historical diversions under senior and junior water rights were tabulated on a monthly basis. Figure 5-26 shows the average monthly historical diversions, the diversions under senior water rights, junior water rights, and the required diversions to meet IWR at 30 percent efficiency.

If the energy sector develops their conditional water rights, the junior water rights at these three ditches may be curtailed to some extent. A SWAM model was developed to determine the reservoir size required to supply the same amount of water as historically has been diverted under the junior water rights. Inflow to the reservoir was queried from available flow (legally and physically available) on Big Beaver Creek, the diversion point for the Yellow Jacket project reservoir.

Since assuming the energy sector has developed some of its conditional water rights may also curtail the storage right at the Yellow Jacket reservoir. However, depending on the location of the energy sector development, there may be available water on the North and South Forks of the White River such that diversions into the Yellow Jacket reservoir would not be affected. Therefore, two scenarios were developed; the first uses the baseline available flow on Big Beaver Creek and assumes this water could fill the Yellow Jacket reservoir. The second scenario

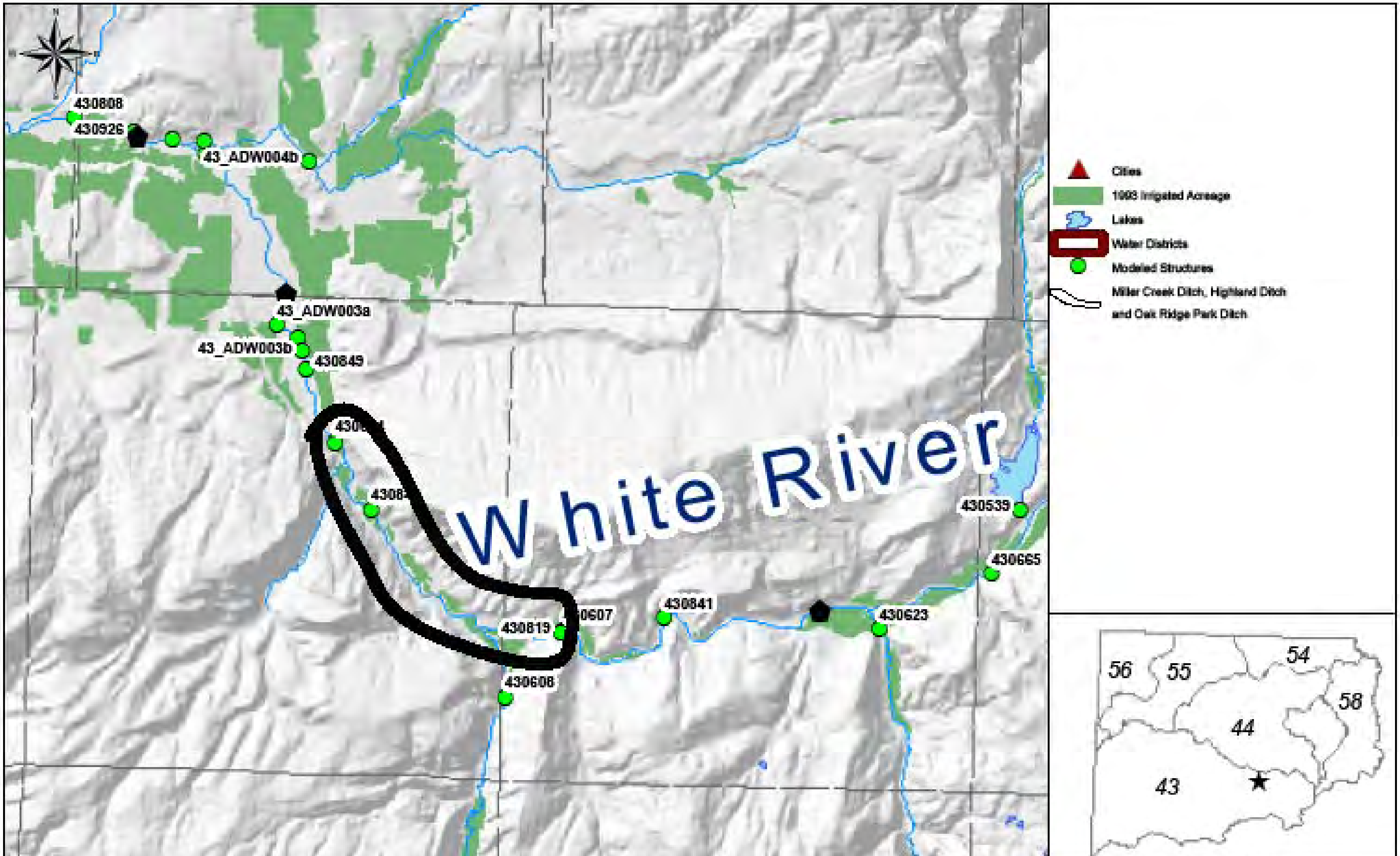
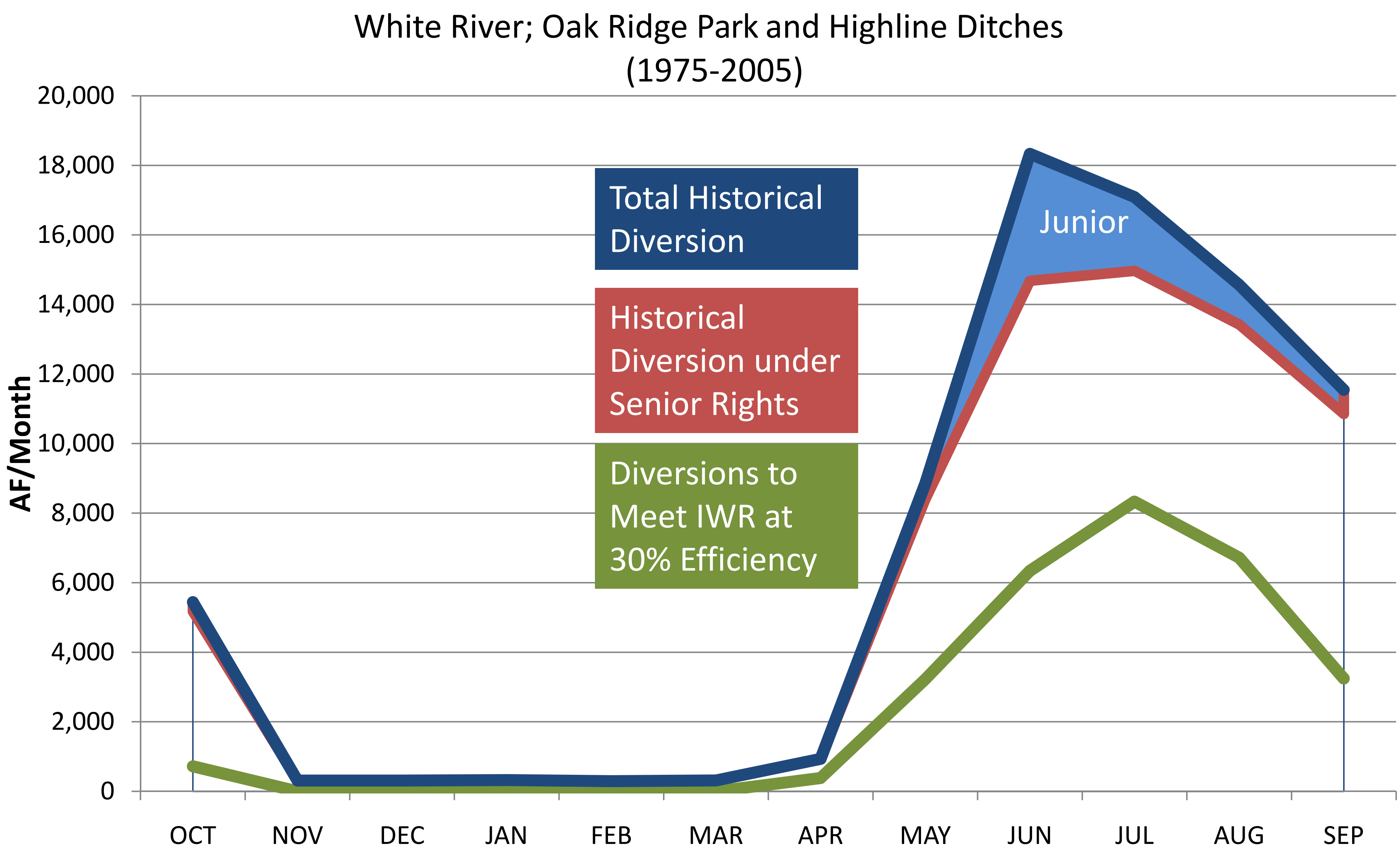


Figure 5-25
White River Ditches

Figure 5-26 – Monthly Average Diversions under Senior and Junior Water Rights and Diversions Required to Meet IWR at 30 Percent Efficiency



uses available flow on the North Fork of the White River and reduces the available flow the available flow by 31,707 AFY (2,642 AF per month), which is the value used for the energy sector's mid-term, mid-production scenario in Technical Memorandum Number 4 (Table 4-X). While not all of the available flow on the North Fork would be available to the Yellow Jacket reservoir, a large portion of the flow could be diverted into a project reservoir via pipeline as shown in the oil shale development study (Occidental Oil Shale Inc., 1979).

Figure 5-27 shows the annual historical diversions under the junior water rights at the three ditches, the available flow at Big Beaver Creek and the available flow on the North Fork after reducing for the energy demand. For each scenario, the size of the reservoir was varied in the SWAM model until it was able to deliver an equal amount of water to the ditches that was historically diverted under their junior water rights.

4.5.3 Ability to Supply Water

The Big Beaver Creek reservoir scenario model results indicate that a reservoir of approximately 18,000 AF would be necessary to supply an equal amount of water as was historically diverted by the junior water rights of the three ditches. However, this reservoir could be reduced to 12,000 AF if it did not meet its delivery targets in two years. If flow from the North Fork were also available to fill the reservoir, the size required drops to 12,000 AF, and could be reduced to approximately 6,000 AF if it did not meet its delivery targets in two years. Figure 5-28 shows the end-of-month contents for the reservoirs for the two scenarios.

Actual storage requirements to be able to supply any gap in diversions from historical use will likely be less than shown above because the junior rights will most likely still be in priority at higher flows or at times where the energy sector demand does call the junior water rights out. The location and amount of energy sector development of conditional water rights will determine this amount. Refinements to total storage needed could be made at such a time as conditional water rights for the energy sector are made absolute.

4.5.4 Changes in Flow

As with other reservoir alternatives, streamflows will decrease during times of diversion into storage, and increase when releases are made. Since this alternative's objective is to maintain historical patterns of water use, there would be no change to the return flow pattern from the application of the reservoir water to the fields. The reductions and increases in flow associated with the reservoir storage and releases are proportional to the final reservoir size needed and would affect flows downstream of the reservoir on Big Beaver Creek and on the White River mainstem. Flow could also be affected below a pipeline intake on the North Fork if such a pipeline is utilized to fill the reservoir.

4.5.5 Reconnaissance Level Costs

Ditch lining is an option that would not require new storage and could be targeted at sections of the ditch that are particularly leaky. Reconnaissance level costing for ditch lining is approximately $1 per square foot. The width and wetted depth of the ditch, then will determine the cost per linear foot of ditch.

Costs for a new reservoir as part of the Yellow Jacket project were estimated in report to the CWCB in 1982 by International Engineering Company, Inc at $875 per AF of storage in Avery Reservoir in 1982

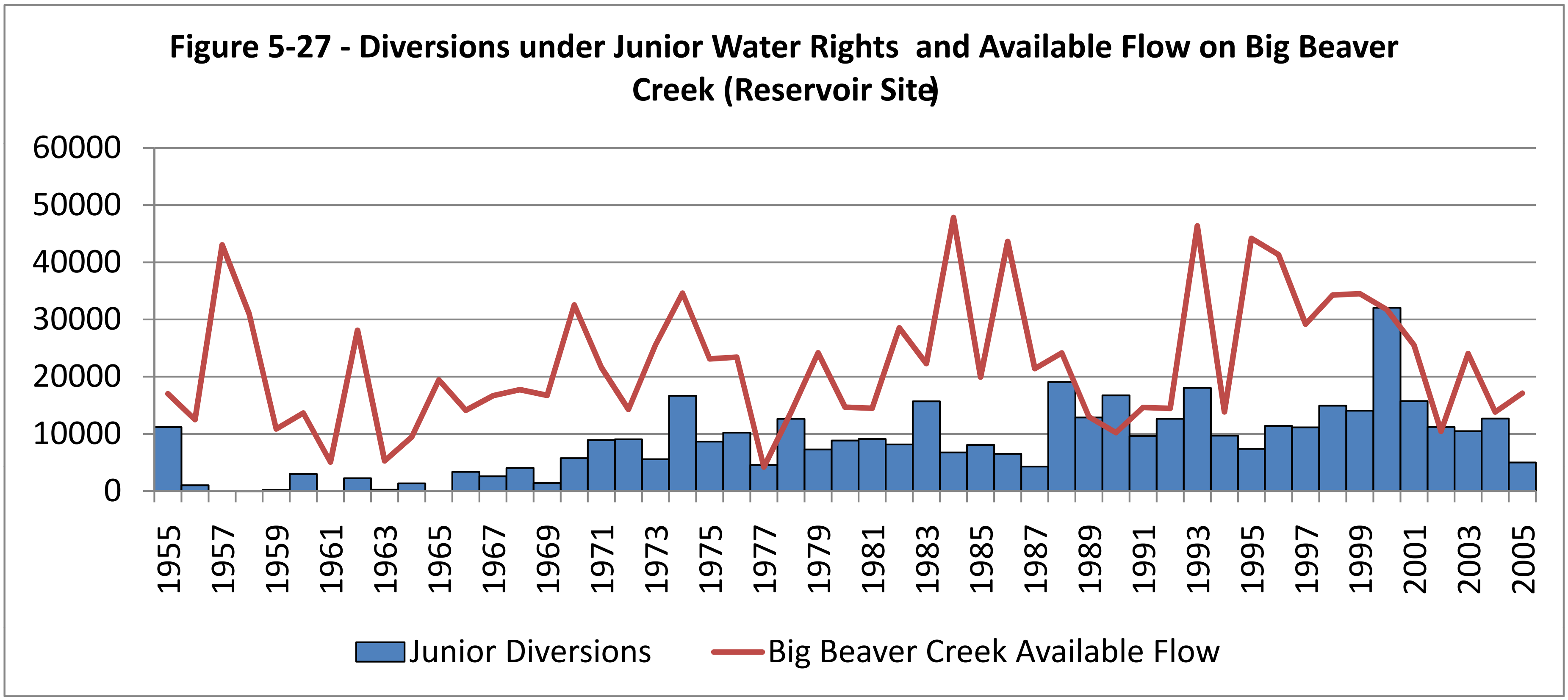
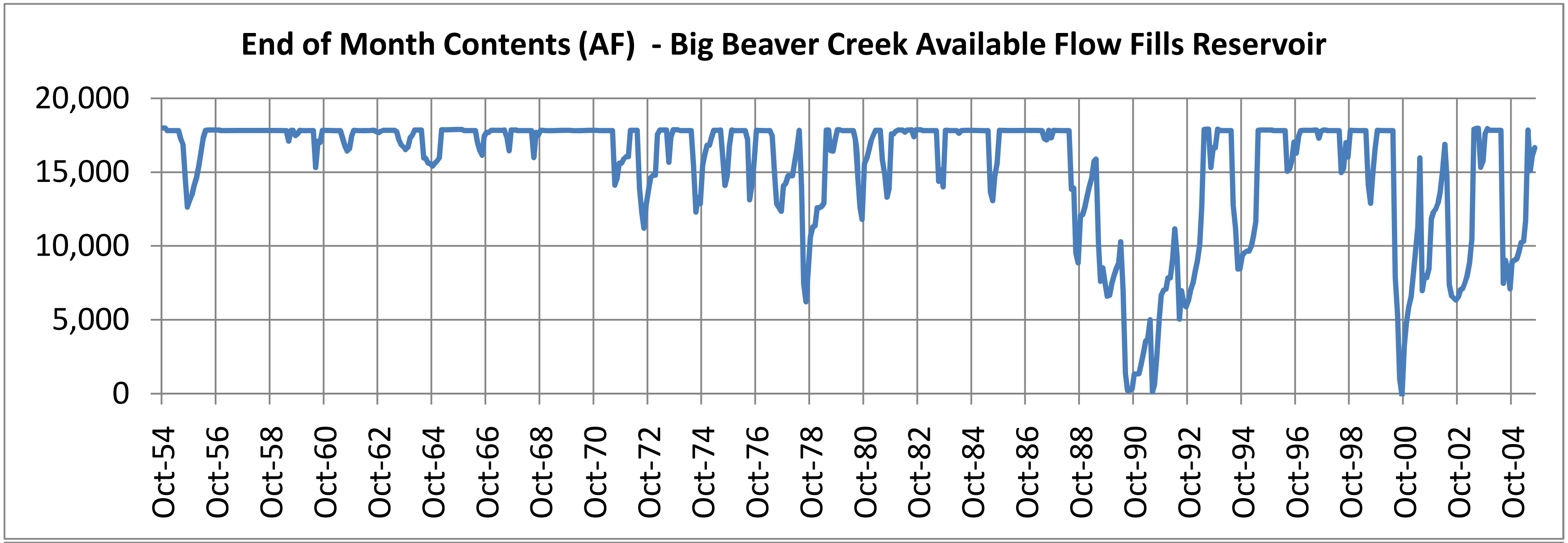
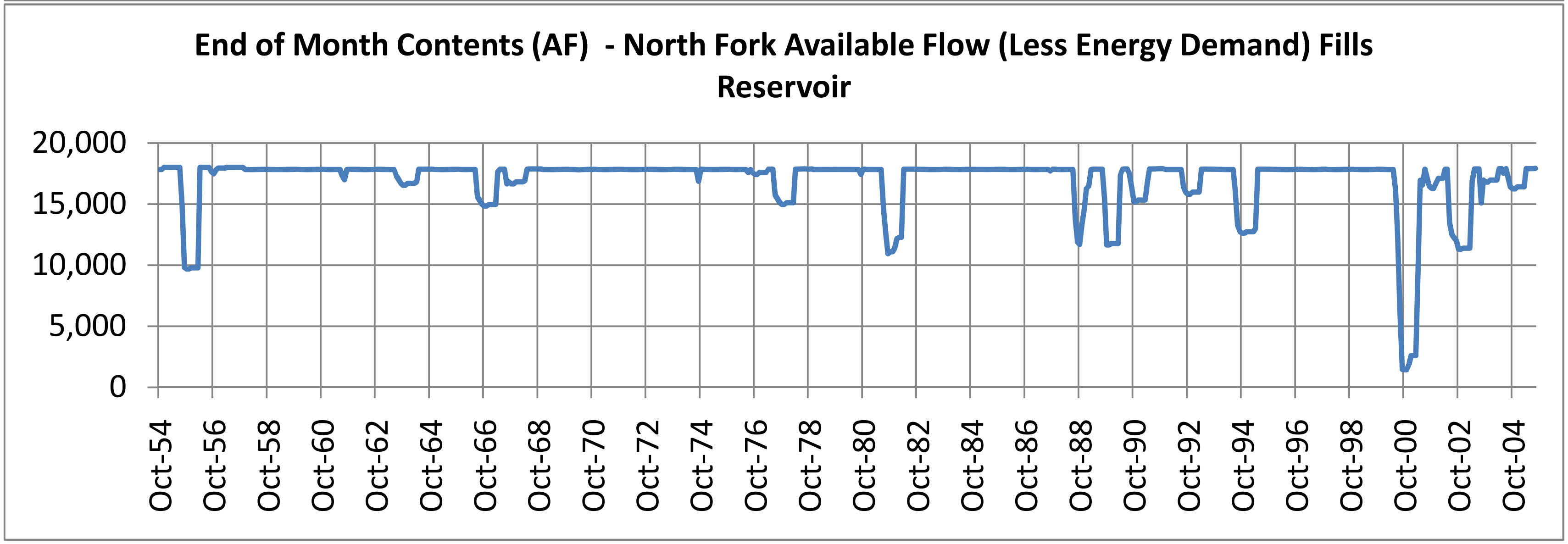


Figure 5-27 - Diversions under Junior Water Rights and Available Flow on Big Beaver Creek (Reservoir Site)
60000
50000
40000
30000
20000
10000
0
1955
1957
1959
1961
1963
1965
1967
1969
1971
1973
1975
1977
1979
1981
1983
1985
1987
1989
1991
1993
1995
1997
1999
2001
2003
2005
Junior Diversions
Big Beaver Creek Available Flow

Figure 5-28 - End of Month Contents for Reservoir Sized to Deliver Equivilant Volume as Historically Diverted Under Junior Water Rights





dollars. Adjusted to 2010 dollars, the cost per AF of storage is approximately $1,625 per AF. The unit cost of Sawmill Mountain Reservoir is nearly three times as high as Avery. No explanation was provided in the portion of the report obtained by CDM, so costs for Avery Reservoir were assumed. Since 1982, permitting requirements have increased significantly, and the adjusted 2010 value is likely low.

4.5.6 Regulatory Concerns

Lining a ditch could potentially trigger a federal Section 404 permit requirement. CDM contacted the US Army Corps of Engineers (Corps) who said that recent case law has determined in some cases, agricultural ditches can be considered Waters of the United States (WOUS). If such a determination is made, the federal permit may be required if the ditch lining is considered fill material by the Corps. Exemptions are often available for agricultural activities, but may be recaptured for further permitting evaluation if detrimental effects to the river are perceived.

Federal permitting for a new reservoir as proposed by the Yellow Jacket project will likely require an Environmental Impact Statement. This is a long process that can last years, cost millions of dollars and is not guaranteed to result in a permit.

5.0 References

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CDM

Memorandum

To: *Jeff Comstock (Moffat County), Yampa/White/Green Basin Roundtable Agricultural Subcommittee*

From: *Matt Bliss, Mark Hoener (CDM); Hal Simpson (H. D. Simpson Consulting); Ross Bethel (Ross Bethel, LLC)*

Date: *10/8/10*

Subject: *Agricultural Water Needs Study, Final Technical Memorandum Number 6.*

We are pleased to present the final draft of the Yampa/White/Green Agricultural Water Needs Study Task 6 technical memorandum. This task addresses return flows from irrigation and impacts to streamflow from changes in return flow patterns. This memo was prepared by CDM staff and reviewed by both Hal Simpson and Ross Bethel. Additionally, the final version incorporates comments the subcommittee has raised at the progress meetings.

Sincerely,

Matt Bliss
Project Manager

1.0 Introduction and Background

In 2005, House Bill 05-1177, the Colorado Water for the 21st Century Act (Penry, Decker, et al., House Bill 05-1177 2005), was signed into law. Among other provisions, the bill provides for the creation of Basin Roundtables (BRT). Each BRT is charged with formulating a water needs assessment, conducting an analysis of available unappropriated water, and proposing projects or methods for meeting those needs.

In 2003, the Colorado Water Conservation Board (CWCB) completed the Statewide Water Supply Initiative (SWSI). That study included estimates of water demands in the White and Yampa River basins through 2030. SWSI concluded there was little gap between projected municipal and industrial water demands and available water supplies in the basins. While SWSI provided a valuable coarse assessment of water demands for the municipal, industrial, and agricultural sectors, concerns were raised at that time that the analysis did not accurately reflect the agricultural water shortages in some of the water districts and especially as it exists on the tributaries. One concern was that the Yampa River Basin analysis of agricultural demand was not based on high-altitude crop coefficients, thus understating the demand for water in the Yampa River Basin.

SWSI also noted that up to an additional 39,000 acres of agricultural lands could be developed in the basins but did not investigate the location or impact of additional agricultural demand in these basins. The Colorado River Water Conservation District Small Reservoir Study (CRWCD 2000) identified sites for additional water supply storage in the Yampa Basin. That study highlighted the need to look at integrating irrigation practices with storage to better meet water demands.

The objectives of the current study are to:

1. Refine and update previous estimates of current agricultural water demands, supplies, and shortages for the Yampa/White/Green River Basin through use of the State of Colorado's Decision Support System (DSS) models and data

2. Identify and evaluate shortages for the future agricultural demands

3. Assess the impacts of climate change on agricultural water availability

4. Assess the impacts of energy sector water supply development on agricultural water availability in the White River Basin

5. Assess water supply development alternatives to satisfy shortages identified in (1), (2), and (3) above

6. Assess the effects on return flows of various irrigation practices or changes in those practices

7. Investigate creative solutions that benefit multiple interests (e.g., agriculture, energy, recreation, environment, etc.)

This technical memorandum addresses the sixth of those objectives and is the sixth in a series of technical memoranda describing activities that address each of the objectives.

2.0 Agricultural Subcommittee Input

Several of the tasks in this study required input and feedback from the agricultural subcommittee of the Yampa/White/Green Basin (BRT subcommittee). BRT subcommittee members include Dan Birch, Darryl Steele, Dan Smith, Doug Monger, Geoff Blakeslee, Mary Brown, T. Wright Dickenson, Tom Gray, Dan Craig and Jeff Comstock. To date, CDM staff and Hal Simpson of H. D. Simpson Consulting have met with the BRT subcommittee on multiple occasions to listen to concerns and discuss the approach to addressing these concerns associated with this task.

The subcommittee emphasized their desire for a clear representation of how return flows impact streamflows, especially in the late season (August, September and October). Based on their observations, return flows from applied irrigation water during the peak runoff increases flows in the late season and in some cases becomes the only water supply for water users to divert in the late season. Concern was raised about the potential decrease in late season flows if more land is converted from flood irrigation to sprinkler irrigation. Concern was also raised about potential change of use of an irrigation water right and how that could change the return flow pattern, particularly in instances where an irrigation right could be dedicated to an instream flow water right and no longer be used for irrigation. To support their arguments, subcommittee members cited examples of years with heavy early season rains that resulted in very low streamflow in the late season because water users did not irrigate during the rainy months thereby reducing the late season return flows. The subcommittee expressed their desire to see what the model would show if the entire study area converted to high efficiency sprinklers.

3.0 Return Flow Concepts

Return flows are defined as the portion of diverted water that is not consumed. Return flows are divided into a surface water and groundwater component. The surface water portion of return flows include water that returns to the stream system via tailwater ditches, direct runoff from fields, and headgate losses. Surface water returns return to the stream system relatively quickly, on the order of hours to a few days. The groundwater component of return flows is often referred to as deep percolation. The local soils, geology and distance to the stream impact how quickly groundwater return flows can return to the stream system. Groundwater return flows are much slower than the surface water return flows and can take several months to return to the stream.

As return flows from upstream users accrue to a stream system, it makes water available for use by downstream users whether consumptive or non-consumptive uses. This phenomenon is evident in many stream systems throughout Colorado. For example, on the South Platte River, irrigation was not viable on the lower reaches of the river until late season flows were sustained by return flows from upstream users.

A single irrigation user may divert water at a lower efficiency (i.e. flood irrigation far in excess of the crop demand), but the return flows from this diversion are diverted again at a lower ditch, and can be re-diverted again multiple times. The delays created by the return flows keeps the water in the system longer and can lead to overall higher efficiency. Based on discussions with Elvis Iocovetto, the Water District 58 water commissioner (upper Yampa River), several ditches in the lower reaches of the Bear River depend on return flows from the upper ditches, including return flows from reservoir releases to the upper ditches. Figure 6-1 shows the total historical diversions for ditches on the Bear River in July for ditches above the Town of Yampa, and for ditches below the Town of Yampa. The figure shows that diversions above the Town of Yampa in July often exceed the total basin supply. This indicates a combination of re-diversion of return flows as well as diversions of reservoir water. The figure also shows the diversions below the Town of Yampa against the basin supply that comes into the river below the Town of Yampa. It shows that diversions exceed the supply in many years, and indicates diversion of return flows from upper basin ditches.

4.0 Modeling of Return Flows

4.1 Representation in StateMod Modeling

StateMod allocates water to demands based on naturalized water supply and priority of the structure's water right and computes a diversion amount for each structure. To account for conveyance and on-field losses, the diversion amount is multiplied by the structure maximum efficiency and that portion of water is made available to meet the consumptive demand of the crop (IWR). StateMod also simulates soil moisture that is stored temporarily in the soil root zone. Water stored in the root zone is different than the groundwater return flow component and is not part of the total return flow. Root zone water can be used to meet crop consumptive demands if there is not enough water diverted. The root zone moisture function simulates times when fields are dry and additional water is needed to moisten the soil profile. The total return flow is then computed as the difference between the diversion amount and the consumptive amount, less any water routed to the root zone soil moisture. The root zone soil moisture volumes are generally small compared to the amount of water diverted in a year and are approximately 0.1 AF per acre based on soil classification, while diversions are normally several AF per acre.

Once the model computes a total return flow for each structure, the return flows are lagged over the course of several months to simulate the groundwater return flow component. The StateMod documentation (CDSS 2004) explains the method for the return flow pattern for irrigated lands:

> The basic return pattern was developed using the Glover analytical solution for parallel drain systems. The State's Analytical Stream Depletion Model (September, 1978), which is widely used in determining return flows for water rights transfers and augmentation plans, permits this option for determining accretion factors….
>
> Regionalized values for the aquifer parameters were determined by selecting ten representative sites throughout the west slope, based partly on the ready availability of geologic data, and averaging them. The analysis estimated generalized trasmissivity as 48,250 gpd/ft, specific yield as 0.13, distance from the stream to the alluvial boundary as 3,500 ft. The Glover analysis was then executed for both a distance of 600 feet from the recharge center to the stream,

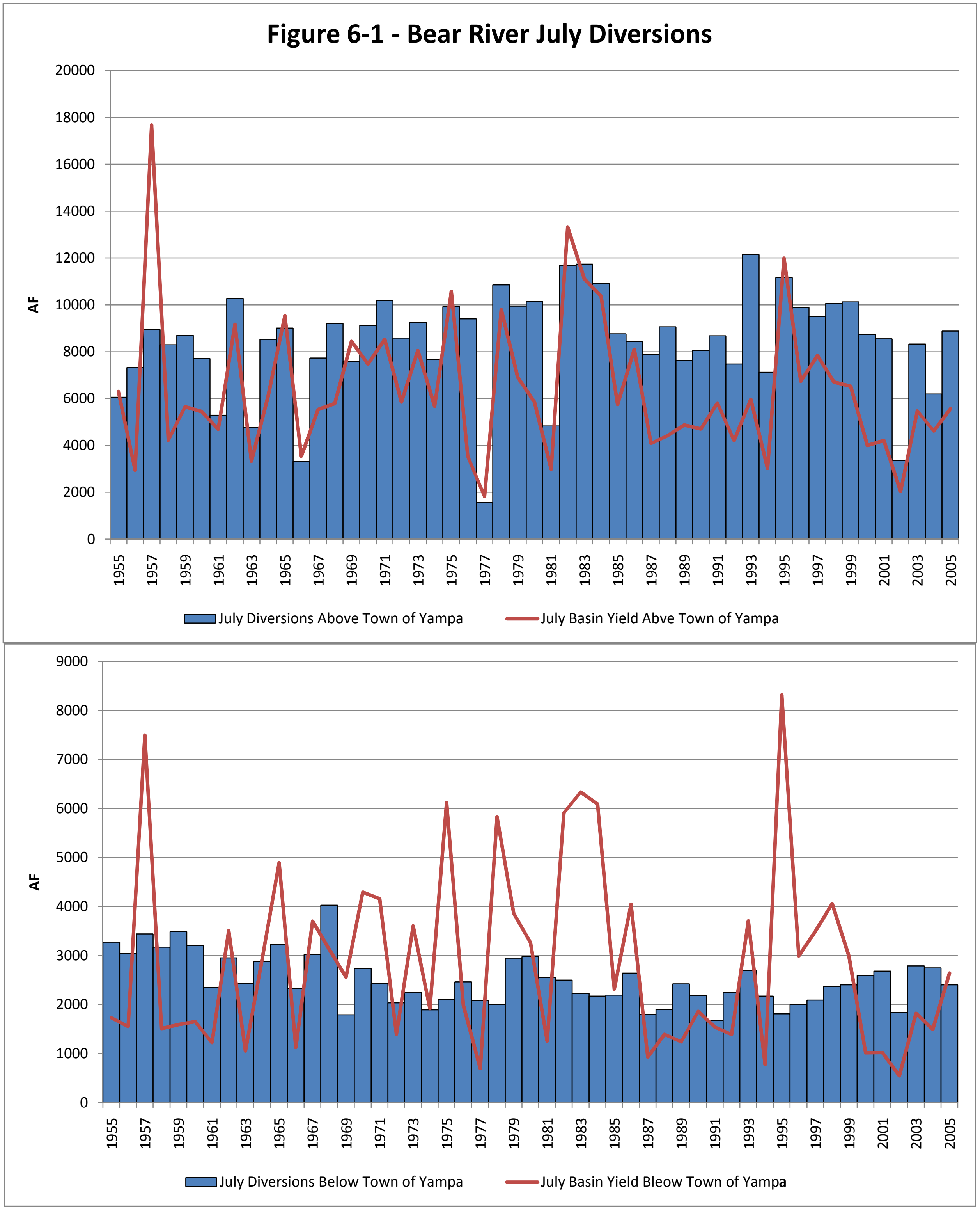


Figure 6-1 - Bear River July Diversions
AF
July Diversions Above Town of Yampa
July Basin Yield Abve Town of Yampa
AF
July Diversions Below Town of Yampa
July Basin Yield Bleow Town of Yampa

> and 1500 feet from the recharge center to the stream. (Currently, the pattern resulting from the shorter distance is used in the model).
>
> It was assumed that the resulting pattern applies to only half of the return flow, and that the other half returns within the month via the surface (tailwater returns, headgate losses, etc.). … the irrigation return patterns supplied to the model reflect combined surface and groundwater returns.

Three return flow patterns are used for irrigation in the study area. The first is used for the majority of the structures in the study area. The second pattern is used for a limited number of structures in the White basin that are located further from the river. The second return flow pattern increases the time it takes for returns to come back to the stream. The third return flow pattern was used for a limited number of structures in the Yampa basin along the lower Little Snake and accounts for a higher incidental loss due to phreatophytes, evaporation and other non-beneficial uses.

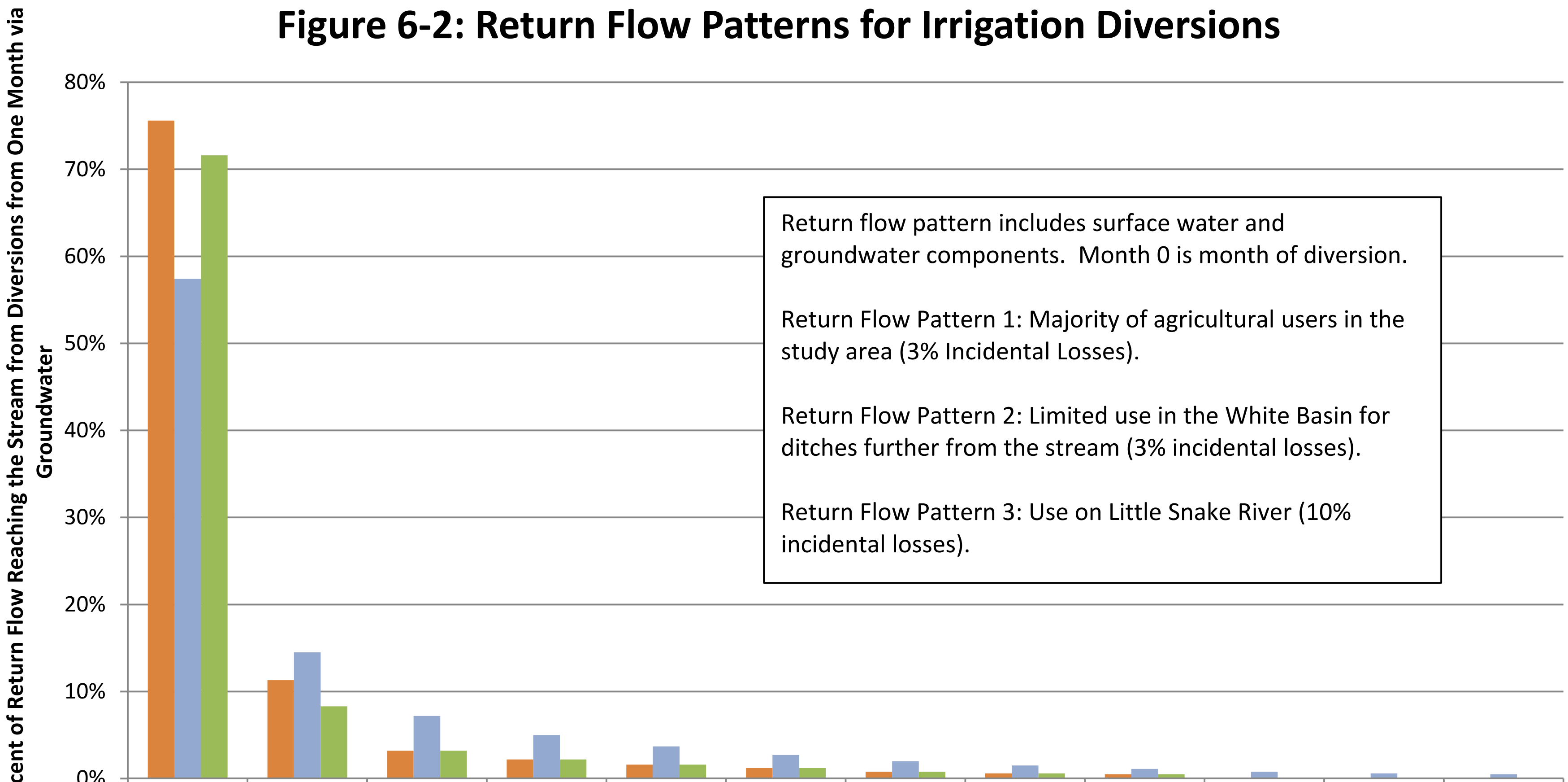
The monthly StateMod model allocates a significant amount of return flows back to the stream in the first month. As the documentation explains, this includes the surface water returns and the first month of the groundwater returns and represents return flows that would return in the first month after diversion. Figure 6-2 shows the three return flow patterns used in the study area StateMod models for agricultural water users. These return flow patterns were used during calibration of the StateMod models. Calibration of the models indicate that the models are able to reasonably reproduce historical observations (e.g. of gage flows and reservoir levels) and gives credibility to the return flow patterns used in the modeling. The purpose of the StateMod models is to provide basin-level planning results. Through the State's development of the models, return flow patterns at individual structures were modified in the study area to the extent necessary for model calibration. Actual return flow patterns at individual structures may vary from the patterns shown in Figure 6-2 and should be evaluated on a site-specific basis for specific concerns related to one area.

4.2 Conceptual Analysis of Return Flow Changes Due to Change in Efficiency

Changes in structure efficiency can significantly impact the amount of return flow. Increasing efficiency leads to lower diversions and lower return flows. Under this scenario, less water is diverted, but return flows are reduced as well. The affect of the reduced return flows is amplified in the late season since flows are much smaller than during the peak runoff. In the late season return flows constitute a much larger percentage of streamflow than during the peak runoff.

A simplified conceptual model was developed to help demonstrate this concept. The model is comprised of a single structure that has demands representative of the monthly IWR distribution in the basin. An inflow pattern that is similar to the runoff pattern seen in the study area was provided to the structure. Using a variety of efficiencies, flows were then computed for a downstream location where the return flows come back to the stream. Table 6-1 summarizes the conceptual model inputs, and Figure 6-3 shows the results for 30, 50 and 75 percent efficiencies. 30 percent efficiency is representative of flood irrigation, 75 percent is representative of sprinkler irrigation, and 50 percent represents a combination of flood and sprinkler. Figure 6-3 shows that under high efficiency, the flows are higher in the early season (fewer diversions), but decrease in

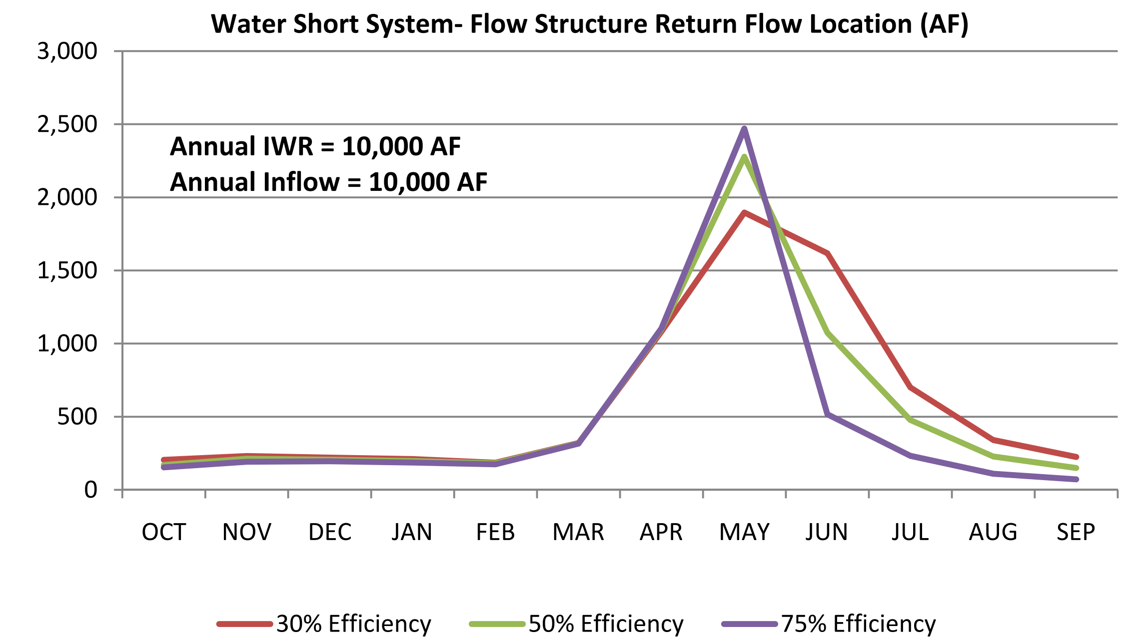
Figure 6-2: Return Flow Patterns for Irrigation Diversions

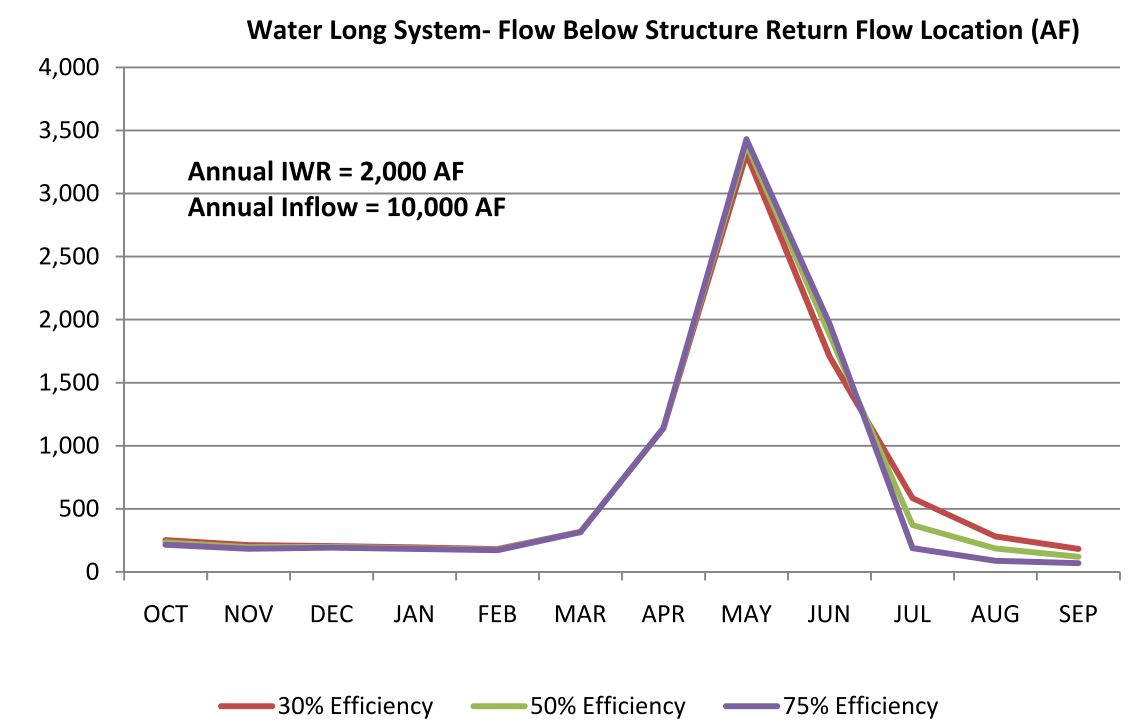


	0	1	2	3	4	5	6	7	8	9	10	11
Pattern 1	76%	11%	3%	2%	2%	1%	1%	1%	1%	0%	0%	0%
Pattern 2	57%	15%	7%	5%	4%	3%	2%	2%	1%	1%	1%	1%
Pattern 3	72%	8%	3%	2%	2%	1%	1%	1%	1%	0%	0%	0%

Months After Diversion

Figure 6-3 - Conceptual Model





the late season (fewer return flows). Figure 6-3 also shows that the effect of the return flows is magnified in a basin where IWR is a large portion of supply (water short basins), and the effect is less apparent when there is less IWR relative to the basin supply (water long basins). In the study area, there are basins that are water long, and some that are water short, and the localized effect of increasing efficiencies will be more evident in basins where IWR approaches the basin supply. In some basins in the study area such as Morapos Creek and Fortification Creek, the basin supply is larger than the IWR, but the supply comes in May and June, and IWR is greater than the basin supply in the late season. Figure 6-3 also shows that a reduction of flow during the peak runoff is a relatively small percentage of the total flow. The reduction in the late season – though a comparable amount volumetrically – is a larger percent of the total flow and the impact to streamflow is magnified.

Table 6-1 – Conceptual Model Inputs

	Water-Short System		Water-Long System	
Month	Inflow (AF)	IWR (AF	Inflow	IWR
OCT	219	84	219	17
NOV	175	0	175	0
DEC	188	0	188	0
JAN	179	0	179	0
FEB	169	0	169	0
MAR	314	0	314	0
APR	1,150	42	1,150	8
MAY	3,670	1,103	3,670	221
JUN	2,595	2,910	2,595	582
JUL	817	2,994	817	599
AUG	323	2,174	323	435
SEP	201	693	201	139
Total	10,000	10,000	10,000	2,000

4.3 Basin-Wide Changes to Efficiency

The efficiency of structures in the StateMod models is based on historical practice and has a set maximum based on irrigation type. However, as described in Technical Memorandum Number 1, for the purposes of this study, the baseline models were modified such that efficiency was set to a minimum of 30 percent and a maximum of 50 percent for flood irrigation. This was done so that shortages could be quantified using a reasonable efficiency target. To test the impact of increasing efficiencies on a basin-wide scale, all flood irrigation structures were set to 75 percent efficiency and the model was run for water years 1955 to 2005.

To achieve 75 percent efficiency, sprinklers would have to be installed on irrigated lands and ditch lining would likely have to occur for ditch sections that are particularly leaky. While this scenario is unlikely to occur due to economic reasons (cost of sprinklers and ditch lining) and geographical reasons (sprinklers may not be feasible on all irrigated fields), it shows the upper range of potential impacts that increasing efficiency could have. As described above, the impact of increasing efficiencies is more evident in basins where the crop demand (IWR) is high relative to the basin supply, and will be less evident where IWR is low relative to the basin supply. For the study area as a whole, IWR is approximately 183,000 AFY in the Yampa basin and 46,000 AFY in the White basin. The estimated naturalized flow (e.g. basin supply) for the Yampa River is 1,732,000 AFY and 516,000 AFY for the White River. Therefore, on a basin-wide scale the impacts of increasing efficiencies will not be as evident as in sub-basins where the ratio of IWR to supply is higher.

Results from the model run with efficiency set to 75 percent for current flood irrigation structures (hereafter, the '75 percent model run') were compared against the baseline model run at several locations in the basin. Figures 6-4 through 6-9 show the average monthly flows, the change in flow and the frequency of the change in flows. The change in flow is also expressed as a percent of the average monthly flow. The frequency chart indicates the percentage of years that flows increased or decreased (e.g. an average monthly change of zero may have a frequency diagram showing 50 percent frequency of flow increases and 50 percent frequency of flow decreases). The plots show the general trend of decreasing flow in the late season when efficiencies are increased. Smaller basins where IWR is a larger portion of total basin supply show a larger impact on a percentage basis (e.g above Stagecoach, Figure 6-4 and Fortification Creek, Figure 6-7) compared to basins where IWR is a smaller portion of total basin supply.

4.4 Reservoirs and Return Flows

Application of reservoir water can also play a significant role in return flows. Generally, reservoir water, if available to a water user, is applied later in the season when native supplies are diminished (or direct-flow water rights are out of priority). Application of reservoir water at low efficiency will result in higher return flows. Elvis Iocovetto, the water commissioner for the upper Yampa River communicated that water users in the upper part of the Bear River above the Town of Yampa own reservoir water and ditches below the Town of Yampa rely on the return flows from the upper ditches, particularly in the late season when return flows are generated from applied reservoir water at the upper ditches. He also estimated that 90 percent of the return flows come back to the river within a month of initial diversion, which is in agreement with the return flow patterns shown in Figure 6-2.

Referring to Figure 6-2, the majority of return flow occur in the same month of diversion, meaning that reservoir water released to a flood irrigation structure will return a large portion of the total release to the stream within a month and this water will be available to other downstream users (both consumptive and non-consumptive users – i.e. this water may be diverted by another irrigator, or could enhance flows for fishing or rafting). The effect of reservoirs can be seen in Figure 6-4, the change in flows above Stagecoach Reservoir. Many of the ditches in the upper reaches of that basin own reservoir water in Yamcolo Reservoir. The releases from Yamcolo create return flows that can augment late season flows. In the 75 percent model run, the headgate demand is lower than in the baseline model (recall headgate demand = IWR/efficiency, so higher efficiency leads to lower headgate demand). Therefore, water is not drawn out of Yamcolo as quickly and in some years is able to make more releases later into the season. For this reason, the 75 percent model run shows some increases in October and winter flows in the basin above Stagecoach Reservoir.

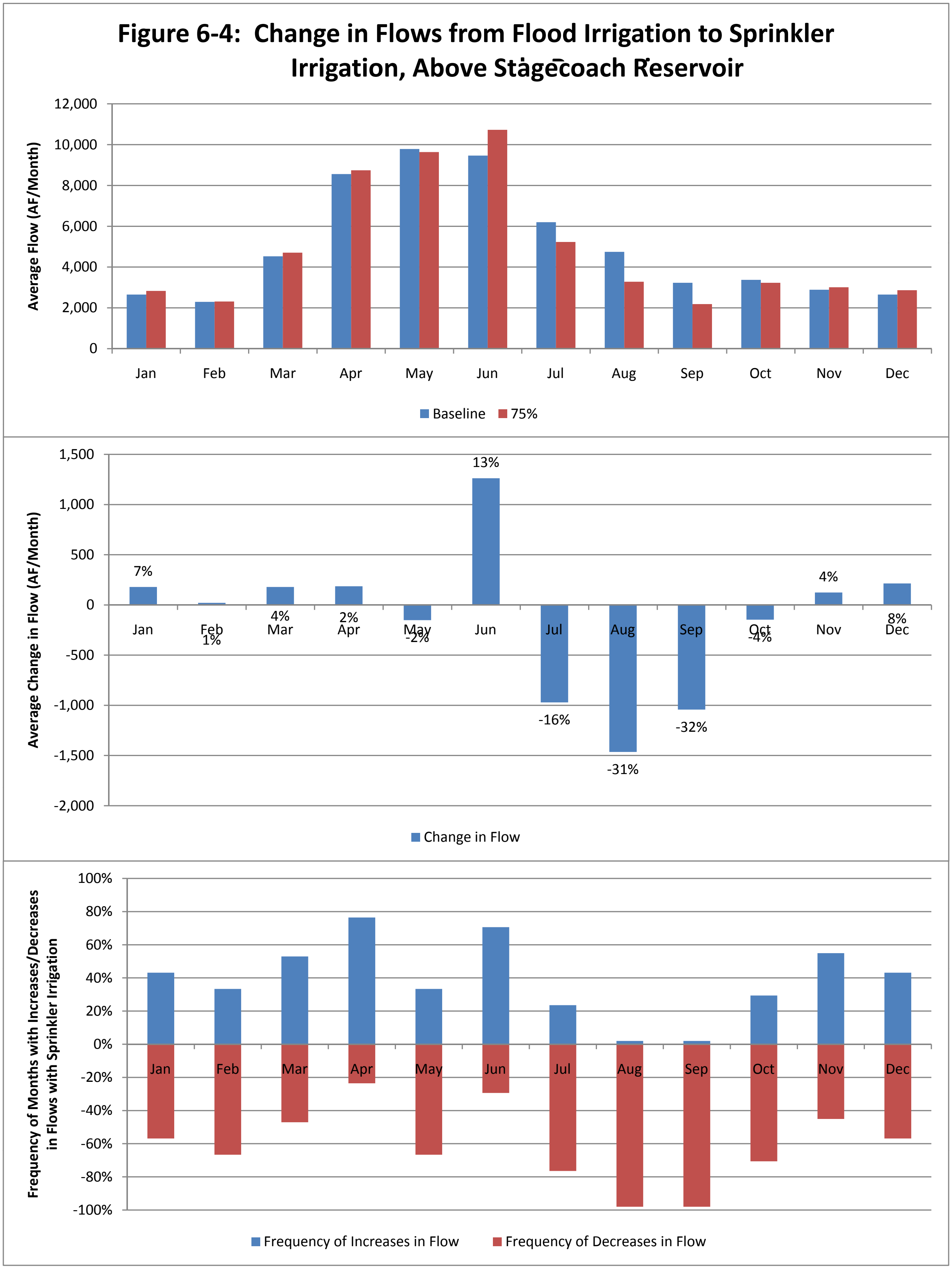
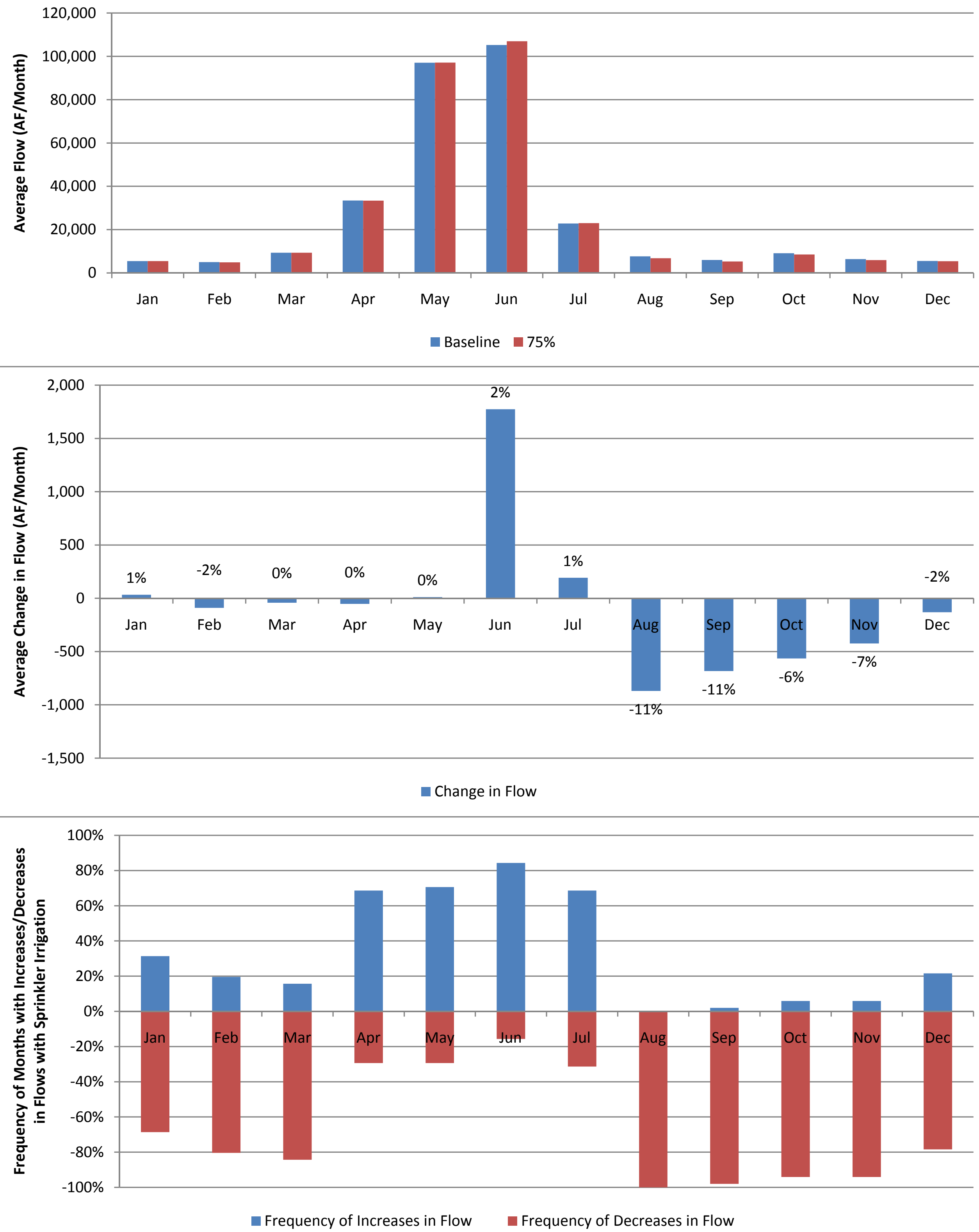


Figure 6-4: Change in Flows from Flood Irrigation to Sprinkler Irrigation, Above Stagecoach Reservoir
Average Flow (AF/Month)
12,000
10,000
8,000
6,000
4,000
2,000
0
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Baseline
75%
Average Change in Flow (AF/Month)
1,500
1,000
500
0
-500
-1,000
-1,500
-2,000
7%
1%
4%
2%
-2%
13%
-16%
-31%
-32%
-4%
4%
8%
Change in Flow
Frequency of Months with Increases/Decreases in Flows with Sprinkler Irrigation
100%
80%
60%
40%
20%
0%
-20%
-40%
-60%
-80%
-100%
Frequency of Increases in Flow
Frequency of Decreases in Flow

Figure 6-5: Change in Flows from Flood Irrigation to Sprinkler Irrigation, Yampa River at Steamboat



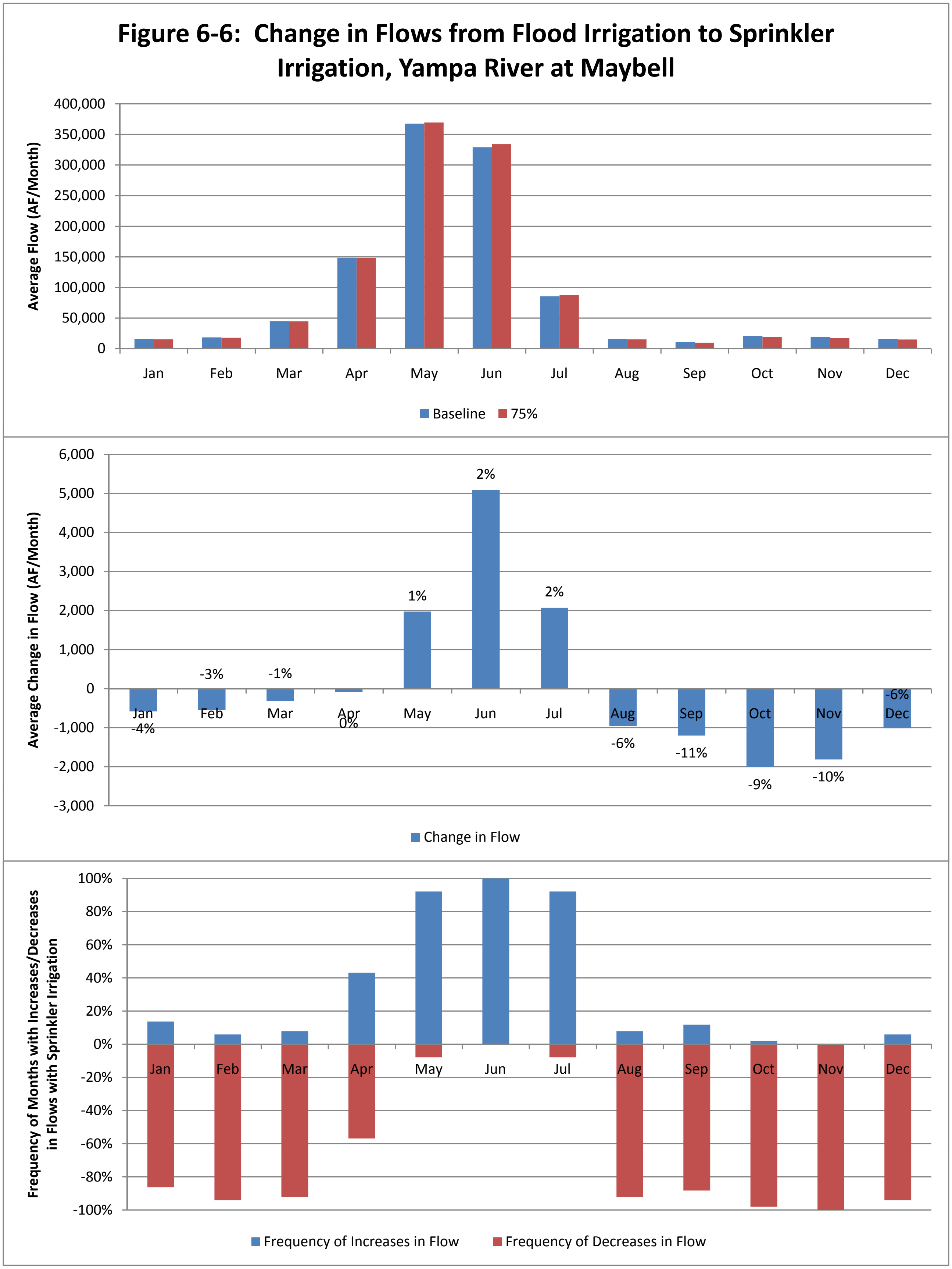


Figure 6-6: Change in Flows from Flood Irrigation to Sprinkler Irrigation, Yampa River at Maybell
Average Flow (AF/Month)
400,000
350,000
300,000
250,000
200,000
150,000
100,000
50,000
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Baseline
75%
Average Change in Flow (AF/Month)
6,000
5,000
4,000
3,000
2,000
1,000
0
-1,000
-2,000
-3,000
-4%
-3%
-1%
0%
1%
2%
2%
-6%
-11%
-9%
-10%
-6%
Change in Flow
Frequency of Months with Increases/Decreases in Flows with Sprinkler Irrigation
100%
80%
60%
40%
20%
0%
-20%
-40%
-60%
-80%
-100%
Frequency of Increases in Flow
Frequency of Decreases in Flow

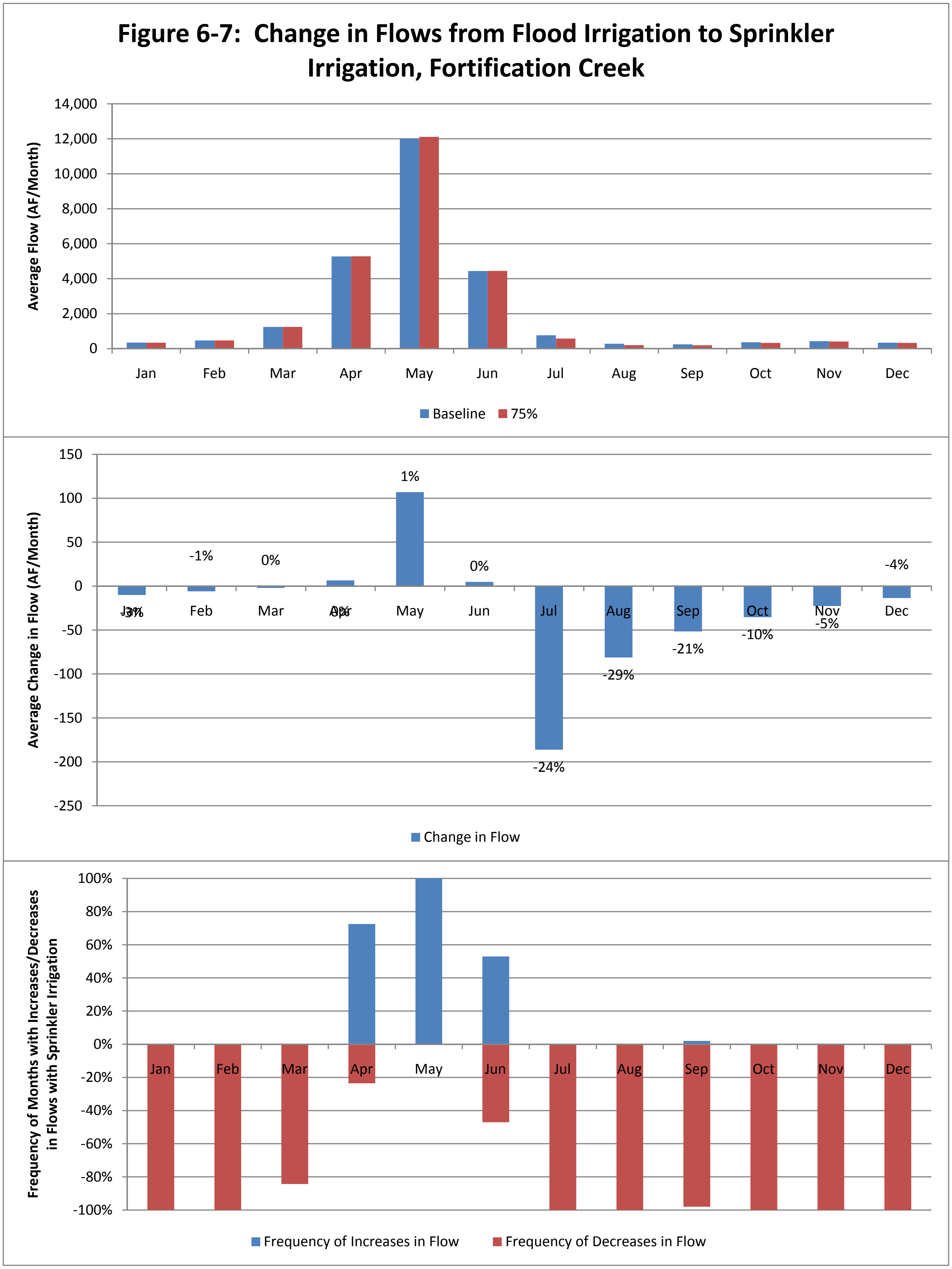
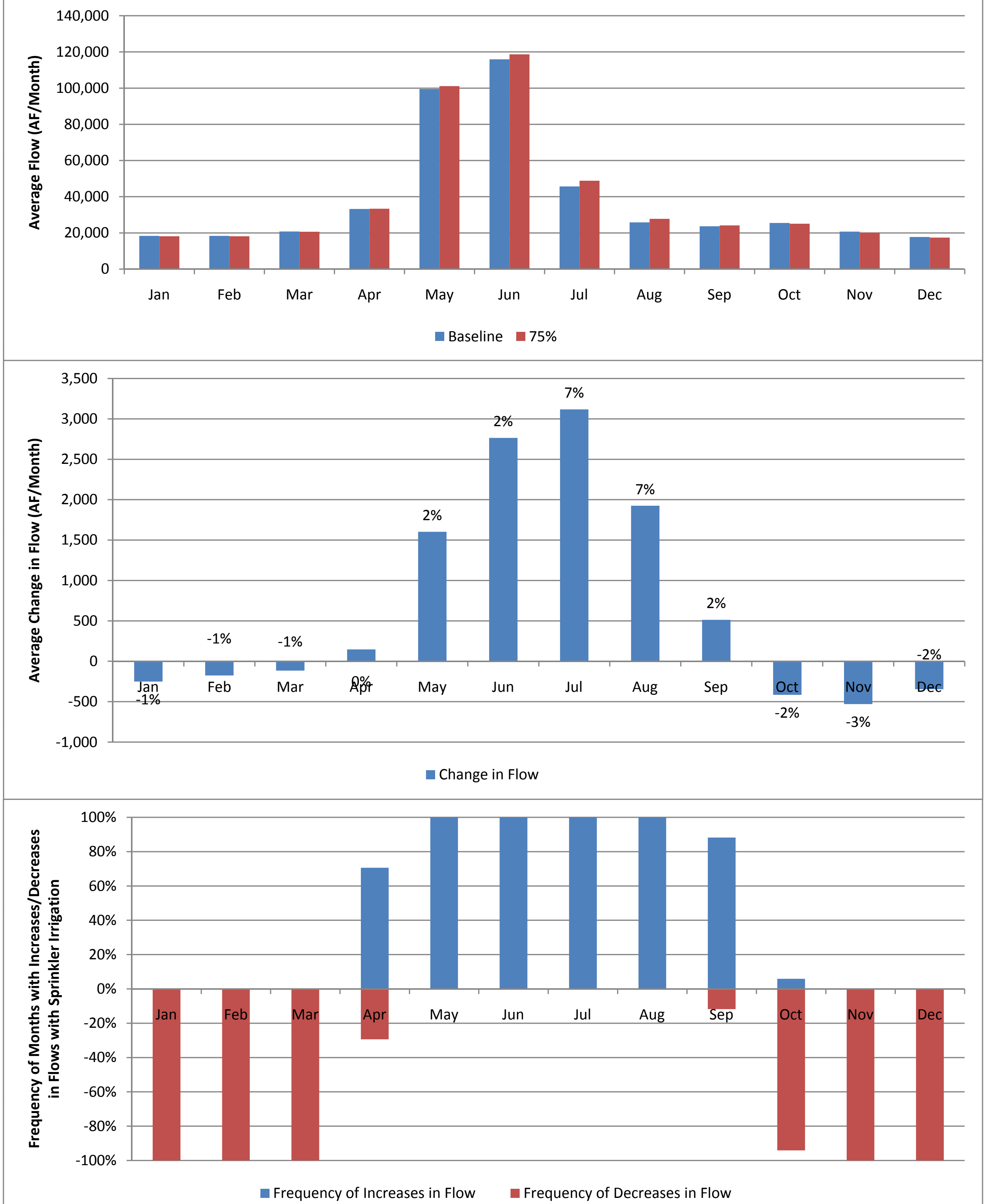


Figure 6-7: Change in Flows from Flood Irrigation to Sprinkler Irrigation, Fortification Creek
Average Flow (AF/Month)
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Baseline
75%
Average Change in Flow (AF/Month)
150
100
50
0
-50
-100
-150
-200
-250
-3%
-1%
0%
0%
1%
0%
-24%
-29%
-21%
-10%
-5%
-4%
Change in Flow
Frequency of Months with Increases/Decreases in Flows with Sprinkler Irrigation
100%
80%
60%
40%
20%
0%
-20%
-40%
-60%
-80%
-100%
Frequency of Increases in Flow
Frequency of Decreases in Flow

A

Figure 6-8: Change in Flows from Flood Irrigation to Sprinkler Irrigation, White River at Meeker



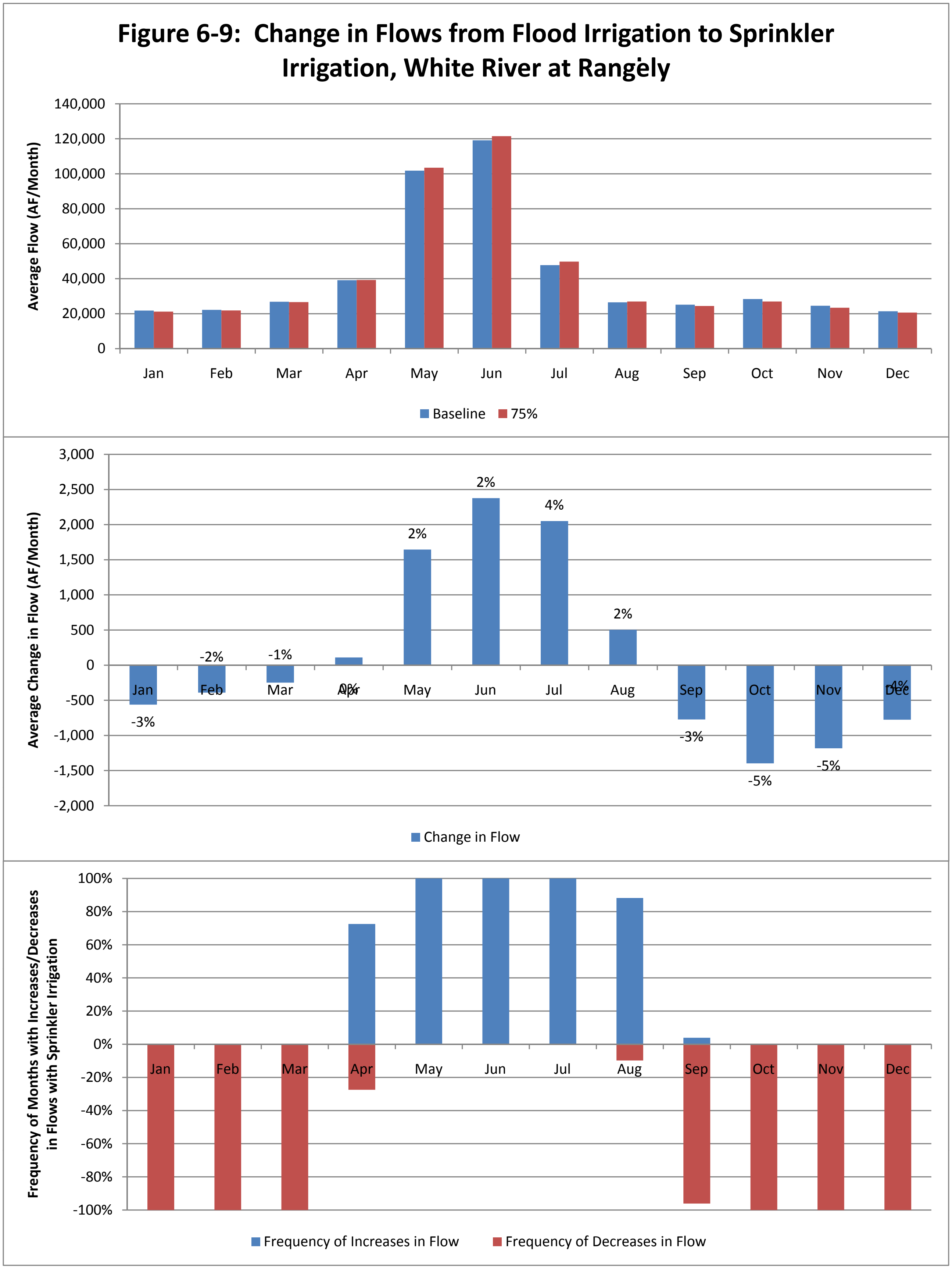


Figure 6-9: Change in Flows from Flood Irrigation to Sprinkler Irrigation, White River at Rangely
Average Flow (AF/Month)
140,000
120,000
100,000
80,000
60,000
40,000
20,000
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Baseline
75%
Average Change in Flow (AF/Month)
3,000
2,500
2,000
1,500
1,000
500
0
-500
-1,000
-1,500
-2,000
-3%
-2%
-1%
0%
2%
2%
4%
2%
-3%
-5%
-5%
-4%
Change in Flow
Frequency of Months with Increases/Decreases in Flows with Sprinkler Irrigation
100%
80%
60%
40%
20%
0%
-20%
-40%
-60%
-80%
-100%
Frequency of Increases in Flow
Frequency of Decreases in Flow

One of the alternatives evaluated for this study (see Technical Memorandum Number 5) includes an alternative to build small on-site storage facilities throughout the basin, primarily for structures that are located on small tributaries that could not be served by larger regional reservoirs. Application of water from such small storage facilities would also increase late season return flows and potentially could increase winter flows over the baseline conditions.

5.0 Conclusions

Return flows from irrigation are a significant part of the existing hydrologic cycle in the study area. Currently, the majority of irrigation is flood irrigation and there is relatively little regulation of flows in the basin by storage. Therefore, during peak runoff, diversions for irrigation are high and generally in excess of the crop requirement. Return flows from these peak runoff diversions help sustain the flow in the late season for use by other irrigators or by non-consumptive needs.

Some general conclusions from the modeling are presented below.

- Increasing irrigation efficiency to 75 percent causes a reduction in return flows and streamflows beginning generally in August and lasting throughout the year in many locations in the study area.
- Increasing irrigation efficiency to 75 percent results in higher streamflows during the peak runoff due to lower headgate diversions.
- The volume of increased streamflows (relative to the baseline model) during the peak runoff is comparable to the reduction in late season flows, but taken as a percent of streamflow, the late season reductions are generally much larger since streamflows are much lower in the late season.
- The reduction in late season flows when irrigation efficiencies are increased is more pronounced in basins that are water-short (i.e. IWR is a larger portion of the total basin supply)
- Application of reservoir water can increase late season flows by providing another source of water in the late season

6.0 References

CWCB "Yampa River Basin Water Resources Planning Model User's Manual." 2004.

Penry, et al. "House Bill 05-1177." Colorado General Assembly. 2005.

CDM

Memorandum

To: *Jeff Comstock (Moffat County), Yampa/White/Green Basin Roundtable Agricultural Subcommittee*

From: *Matt Bliss, Mark Hoener (CDM); Hal Simpson (H. D. Simpson Consulting); Ross Bethel (Ross Bethel, LLC)*

Date: *10/8/10*

Subject: *Agricultural Water Needs Study, Final Technical Memorandum Number 7.*

We are pleased to present the final draft of the Yampa/White/Green Agricultural Water Needs Study Task 7 technical memorandum. This task addresses multiple benefit solutions to meeting existing and potential future shortages in the study area. This memo was prepared by CDM staff and reviewed by both Hal Simpson and Ross Bethel. Additionally, the final version incorporates comments the subcommittee has raised at the progress meetings.

Sincerely,

Matt Bliss
Project Manager

1.0 Introduction and Background

In 2005, House Bill 05-1177, the Colorado Water for the 21st Century Act (Penry, Decker, et al., House Bill 05-1177 2005), was signed into law. Among other provisions, the bill provides for the creation of Basin Roundtables (BRT). Each BRT is charged with formulating a water needs assessment, conducting an analysis of available unappropriated water, and proposing projects or methods for meeting those needs.

In 2003, the Colorado Water Conservation Board (CWCB) completed the Statewide Water Supply Initiative (SWSI). That study included estimates of water demands in the White and Yampa River basins through 2030. SWSI concluded there was little gap between projected municipal and industrial water demands and available water supplies in the basins. While SWSI provided a valuable coarse assessment of water demands for the municipal, industrial, and agricultural sectors, concerns were raised at that time that the analysis did not accurately reflect the agricultural water shortages in some of the water districts and especially as it exists on the tributaries. One concern was that the Yampa River Basin analysis of agricultural demand was not based on high-altitude crop coefficients, thus understating the demand for water in the Yampa River Basin.

SWSI also noted that up to an additional 39,000 acres of agricultural lands could be developed in the basins but did not investigate the location or impact of additional agricultural demand in these basins. The Colorado River Water Conservation District Small Reservoir Study (CRWCD 2000) identified sites for additional water supply storage in the Yampa Basin. That study highlighted the need to look at integrating irrigation practices with storage to better meet water demands.

The objectives of the current study are to:

1. Refine and update previous estimates of current agricultural water demands, supplies, and shortages for the Yampa/White/Green River Basin through use of the State of Colorado's Decision Support System (DSS) models and data

2. Identify and evaluate shortages for the future agricultural demands

3. Assess the impacts of climate change on agricultural water availability

4. Assess the impacts of energy sector water supply development on agricultural water availability in the White River Basin

5. Assess water supply development alternatives to satisfy shortages identified in (1), (2), and (3) above

6. Assess the effects on return flows of various irrigation practices or changes in those practices

7. Investigate creative solutions that benefit multiple interests (e.g., agriculture, energy, recreation, environment, etc.)

This technical memorandum addresses the seventh of those objectives and is the seventh in a series of technical memoranda describing activities that address each of the objectives.

2.0 Agricultural Subcommittee Input

Several of the tasks in this study required input and feedback from the agricultural subcommittee of the Yampa/White/Green Basin (BRT subcommittee). BRT subcommittee members include Dan Birch, Darryl Steele, Dan Smith, Doug Monger, Geoff Blakeslee, Mary Brown, T. Wright Dickenson, Tom Gray, Dan Craig and Jeff Comstock. To date, CDM staff and Hal Simpson of H. D. Simpson Consulting have met with the BRT subcommittee on multiple occasions to listen to concerns and discuss the approach to addressing these concerns associated with this task. The subcommittee expressed interest in considering a potential future pump-back and the development of storage by the energy sector in the White River basin.

3.0 Multiple Interests

The Yampa, Green and White Rivers and their tributaries provide a valuable resource for the region. SWSI describes the rivers as ‘a source of life’ and a precious natural resource and identifies the need to wisely manage water and identified the changing needs of the State from a primarily agricultural society, to a society that now includes technology, tourism, recreation, transportation and other industries. SWSI also identifies the changing attitudes towards environmental concerns, and how the legal structure formed in the early days of the State’s existence was not designed to consider such concerns.

3.1 Non-Consumptive Needs

Through the Roundtable process, CWCB has investigated the non-consumptive needs throughout the state. In 2010, the CWCB completed the non-consumptive needs focus mapping effort (CWCB 2010a). Through that process, non-consumptive focus areas were identified and mapped throughout the study area. Non-consumptive needs were subdivided into recreational and environmental needs. Recreational needs included fishing, rafting, kayaking, and recreational destination lakes and canyons. Environmental needs centered on connectivity between fish populations, critical habitat for endangered species and riparian habitat. Table 7-1 is a reproduction of the non-consumptive needs assessment table for the study area from the CWCB 2010 mapping effort. Figure 7-1 is a reproduction of the mapping generated from that report. In addition, the roundtable is conducting a watershed flow evaluation tool to further quantify environmental and recreational needs. The results of that study can be used to further refine potential multiple-benefit solutions.

3.2 Consumptive Needs

Other than agricultural consumptive needs identified in the previous technical memoranda for this study, additional consumptive needs have been identified for the study area. In July 2010, the CWCB completed an update to municipal and industrial water use projections (CWCB 2010b). Specific to the study area, the report identifies the increasing consumptive needs of thermoelectric power generation and the potential large increases in demand resulting from development of oil-shale. There is a wide range of projected demands from energy development that depend on the rate of development of the energy sector, and oil shale in particular. The CWCB 2010 report summarized the total thermoelectric and direct use water demands for the energy sector for the study area, and those results are shown in Table 7-2. As shown in Table 7-2, the water demand for thermoelectric and direct energy use for the study area increases from 22,200 AFY in 2008 to a range of 40,600 AFY to 85,800 AFY in 2050. The range depends on several uncertainties identified in the report, including economic, political, regulatory and social conditions, the oil shale industry size, oil shale retorting process, and source of electricity. The 2050 projected demands presented in Table 7-2 are not the oil shale industry build-out demands since build-out is not anticipated prior to 2050 (CWCB 2010b). Oil shale build-out demands for Rio Blanco

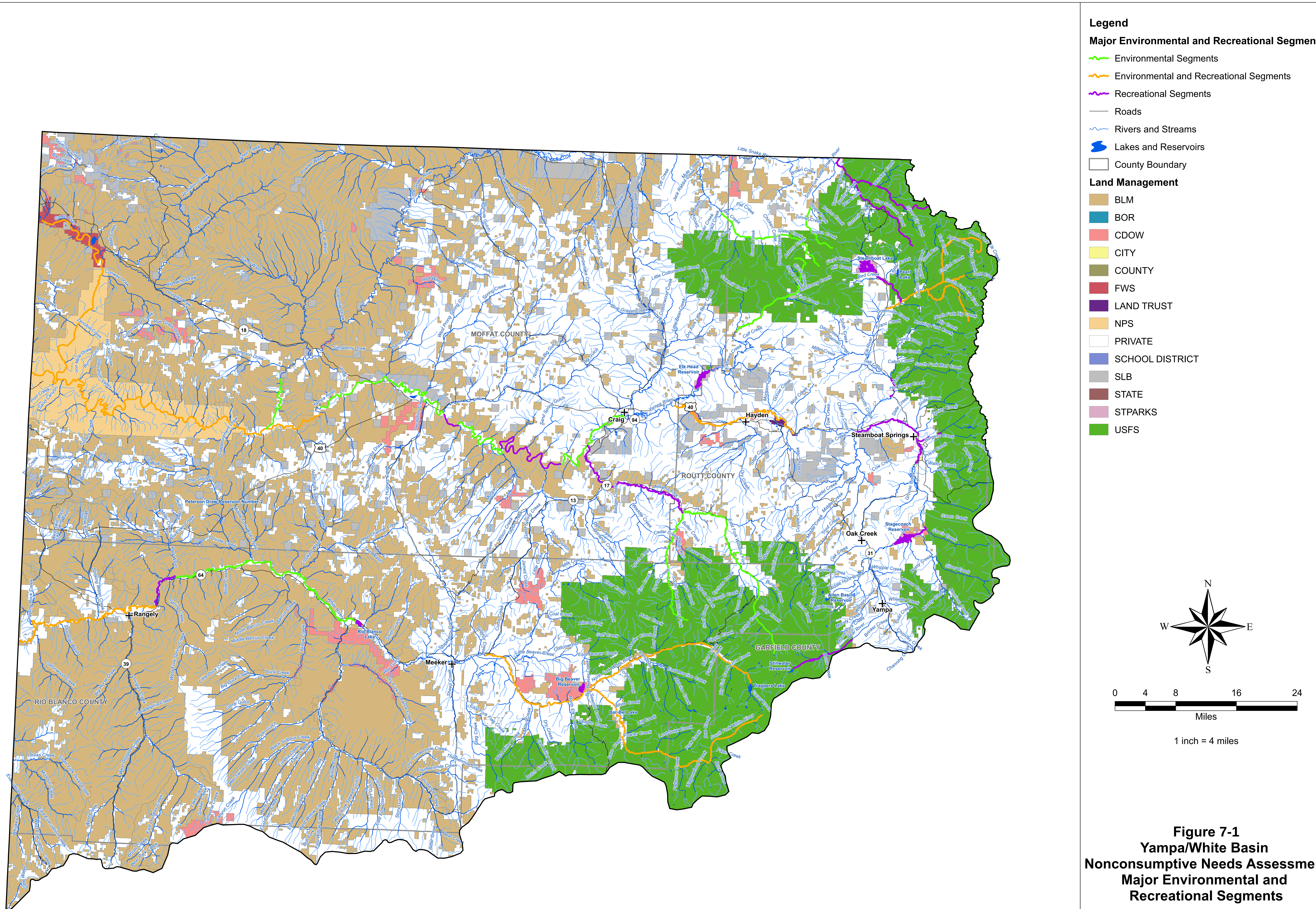


Figure 7-1
Yampa/White Basin
Nonconsumptive Needs Assessment
Major Environmental and Recreational Segments

Refer to Appendix B of the NCNA Mapping Report for a complete list of data sources and Appendix D of the Mapping Report for other basin-specific mapping information.

-10

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Table 7-1 YAMPA/WHITE/GREEN BASIN NON-CONSUMPTIVE NEEDS ASSESSMENT - IDENTIFICATION OFMAJOR STREAM AND LAKE SEGMENTS

No.	STREAM OR LAKE SEGMENT (Based upon segment maps)	ATTRIBUTE CATEGORY	1. Federal Threatened & Endangered Fish	2. State Threatened and Endangered Species	3. Important Riparian Habitat	4. Instream Flows and Natural Lake Levels	5. Fishing	6. Boating	7. Waterfowl Hunting	RATIONALE FOR CONSIDERATION AS A MAJOR SEGMENT	CDSS Nodes	Attributes with Flow Relationships
Major Environmental & Recreational Segments												
1	Yampa River - from entrance of Cross Mountain Canyon (East Cross Mountain) to confluence with Green River		a,b,c,d,e	a,b,c,f,e	a,b		c	a	a	Multiple environmental values including critical habitats for endangered fish plus Yampa's most sought after white water and overnight rafting destination including Dinosaur National Monument	09260050, 440687	Bluehead Sucker, Roundtail Chub, Flannelmouth Sucker, Riparian, Trout, and Whitewater Boating
2	Yampa River - from Pump Station to confluence of Elkhead Creek			a,c,e,f	a,c		c	a	a	Multiple environmental values plus high use boating and fishing includes TNC's the Carpenter Ranch	09244410	Bluehead Sucker, Flannelmouth Sucker, Riparian, Trout, and Whitewater Boating
3	Green River - from Utah State line (Browns Park Wildlife Refuge) to the Utah State line		a,b,d	a,c,e,f	a,b,c		c	a	a	Multiple environmental and recreational values includes Browns park National Wildlife Refuge and rafting in Dinosaur National Monument	56_ADY027	Bluehead Sucker, Flannelmouth Sucker, Riparian, Trout, and Whitewater Boating
4	Elk River - from headwaters to the County Road 129 bridge at Clark; including the North, Middle and South Fork as well as the mainstem of the Elk			d,f,g	b	a	c	a		Multiple environmental and recreational values including high levels of recreation and significant fisheries use, multiple/critical environmental values	09241000	Riparian, Trout, and Whitewater Boating
5	White River - from headwaters to Meeker; including the North and South Fork and mainstem of the White			c,d,f	a,b	a	c	a	a	Multiple environmental and recreational values including most extensive, valuable connectivity of Colorado Cutthroat Trout populations in the Yampa/White/Green basin; G1-G3 plant/wetland communities; valuable private and public water fisheries providing significant economic benefits for the upper White basin	430928, 430881, 09303000, 09303400, 09303500, 09304000, 09304200, 09304500	Flannelmouth Sucker, Trout, Riparian, and Whitewater Boating
6	White River - below Kenney Reservoir dam to Utah State line		b,d,e	a,b,c,f			c	a	a	Multiple environmental and recreational values including critical habitat for endangered fish	434433	Bluehead Sucker, Roundtail Chub, Flannelmouth Sucker, Trout, and Whitewater Boating
Major Environmental Segments												
7	White River - from Rio Blanco Lake Dam to Kenney Reservoir		b,e	a,b,c				a		Multiple environmental and recreational values including critical habitat for Federal endangered species, multiple state aquatic species of concern	430653, 09306222, 09306224, 431033, 09306290, 434433	Bluehead Sucker, Roundtail Chub, Flannelmouth Sucker, and Whitewater Boating
8	Slater Creek - from headwaters to the Beaver Creek confluence			d	b		c	a		Valuable connectivity of Colorado Cutthroat Trout populations, with G1-G3 plant communities and multiple recreational opportunities	540570	Trout, Riparian, and Whitewater Boating
9	Elkhead Creek - from headwaters to confluence of North Fork of Elkhead Creek			a,d	b	a		a		Valuable connectivity of Colorado Cutthroat Trout populations, Boreal toad as well as G1-G3 plant communities and recreational opportunities	9245000	Bluehead Sucker, Trout, Riparian, Whitewater Boating

Table 7-1 YAMPA/WHITE/GREEN BASIN NON-CONSUMPTIVE NEEDS ASSESSMENT - IDENTIFICATION OF MAJOR STREAM AND LAKE SEGMENTS

No.	STREAM OR LAKE SEGMENT (Based upon segment maps)	ATTRIBUTE CATEGORY	1. Federal Threatened & Endangered Fish	2. State Threatened and Endangered Species	3. Important Riparian Habitat	4. Instream Flows and Natural Lake Levels	5. Fishing	6. Boating	7. Waterfowl Hunting	RATIONALE FOR CONSIDERATION AS A MAJOR SEGMENT	CDSS Nodes	Attributes with Flow Relationships
10	South Fork of the Little Snake - from headwaters to confluence of Johnson Creek			a,d		a				Valuable connectivity of Colorado Cutthroat Trout populations	9253000	Blehead Sucker, Trout and Riparian
11	South and East Fork of the Williams Fork - from headwaters to the confluence of the Forks			d,f	b	a	c			Valuable connectivity of Colorado Cutthroat Trout populations	440607, 09249000, 09249200, 440652	Trout and Riparian
12	Litte Snake River - from Moffat County Road 10 to confluence of the Yampa River		c,d	b	a,b					Significant environmental values including occurances of Colorado Pikeminnow and rare collections of Humpback Chub, populations of Roundtail Chub and valuable ripairan plant communities	9260000	Roundtail Chub, Riparian
13	Yampa River - from Craig (Hwy 394 Bridge) to mouth of Cross Mountain Canyon		d,e	b,e,f	b		c	a	a	Critical habitat for Federal endangered species, multiple state aquatic species of concern	09247600, 440694, 09251000	Roundtail Chub, Riparian, Trout, and Whitewater Boating
Major Recreational Segments												
14	Yampa River - from Stagecoach Reservoir "Tailwaters" to northern boundary of Sarvis Creek State Wildlife area			a,c	a	a	c		a	High recreation and fisheries use	09237500	Bluehead Sucker, Flannelmouth Sucker, and Riparian
15	Fish Creek - from Fish Creek Falls to confluence of the Yampa River				a	a		a		Most significant, highest use kayaking "creek run" in basin	09238900	Riparian and Whitewater Boating
16	Yampa River - from Chuck Lewis Wildlife Area to Pump Station			a,c,e,f	b		c	a,b	a	Highest recreation use along entire Yampa River allowing for multiple recreational opportunities; only RICD in entire Yampa/Whte/Green Basin	09239500	Bluehead Sucker, Roundtail Chub, Riparian, Trout, and Whitewater Boating
17	Elk River - at Christina State Wildlife Area			c		a	c			Highest public fishery use on Lower Elk River	None	
18	Willow Creek - below Steamboat Lake to confluence				a		c	a		Valuable kayaking creek and fisheries use	583787	Riparian, Trout, and Whitewater Boating
19	Bear River - from headwaters to USFS boundary			d			c			Cutthroat Trout habitat and significant recreational fishing	09236000	Trout
20	Stagecoach Reservoir			a			c	a	a	High recreation and fisheries use	None	No Relationships for Reservoirs
21	Elkhead Reservoir			a,b,c			c	a	a	High recreation and fisheries use	None	No Relationships for Reservoirs
22	Steamboat Lake			d	a		b	a	a	High recreation and fisheries use including only Gold Medal Water in basin	None	No Relationships for Reservoirs
23	Little Snake River - from headwaters of Middle Fork of the Little Snake River and King Solomon Creek to Wyoming border			a,c,d	b	a	c	a		Important fishery including public access and private waters; significant environmental values	09253000	Bluehead Sucker, Flannelmouth Sucker, Trout, Riparian, and Whitewater Boating
24	Williams Fork - from South Fork to confluence of the Yampa River				a,b	a	c			Important Fishery	09249750	Riparian and Trout
25	Avery Lake						c		a	Important recreational destination	None	No Relationships for Reservoirs
26	Rio Blanco Reservoir				b		c		a	Important recreational destination	None	No Relationships for Reservoirs

Table 7-1 YAMPA/WHITE/GREEN BASIN NON-CONSUMPTIVE NEEDS ASSESSMENT - IDENTIFICATION OF MAJOR STREAM AND LAKE SEGMENTS

No.	STREAM OR LAKE SEGMENT (Based upon segment maps)	ATTRIBUTE CATEGORY	1. Federal Threatened & Endangered Fish	2. State Threatened and Endangered Species	3. Important Riparian Habitat	4. Instream Flows and Natural Lake Levels	5. Fishing	6. Boating	7. Waterfowl Hunting	RATIONALE FOR CONSIDERATION AS A MAJOR SEGMENT	CDSS Nodes	Attributes with Flow Relationships
27	Kenny Reservoir						c	a	a	Important recreational destination	None	No Relationships for Reservoirs
28	Yampa River - Duffy Canyon		d,e	b,e,f	b		c	a	a	Important recreational canyon	440694	Roundtail Chub, Riparian, Trout, and Whitewater Boating
29	Yampa River - Juniper Canyon		d,e	b,e,f	b		c	a	a	Important recreational canyon	440694	Roundtail Chub, Riparian, Trout, and Whitewater Boating
30	Yampa River - Little Yampa Canyon		d,e	b,e,f	b		c	a	a	Important recreational canyon	440694	Roundtail Chub, Riparian, Trout, and Whitewater Boating

KEY TO ATTRIBUTE CODES

Attribute 1 - Federal Threatened & Endangered Fish
- a. Bonytail Chub
- b. Razorback Sucker
- c. Humpback Chub
- d. Colorado Pikeminnow
- e. Federally Listed Critical Habitat

Attribute 2 - State Threatened and Endangered Species
- a. Bluehead Sucker
- b. Roundtail Chub
- c. Flannelmouth Sucker
- d. Colorado River Cutthroat Trout
- e. River Otter
- f. Northern Leopard Frog
- g. Boreal Toad

Attribute 3 - Important Riparian Habitat
- a. Riparian/Wetland - Dependent Rare Plants
- b. Significant Riparian/Wetland Plant Communities
- c. Audubon Important Bird Areas

Attribute 4 - Instream Flows and Natural Lake Levels
- a. CWCB Instream Flow Water Rights
- b. CWCB Natural Lake Level Water Rights

Table 7-1 YAMPA/WHITE/GREEN BASIN NON-CONSUMPTIVE NEEDS ASSESSMENT - IDENTIFICATION OFMAJOR STREAM AND LAKE SEGMENTS

No.	STREAM OR LAKE SEGMENT (Based upon segment maps)	ATTRIBUTE CATEGORY	1. Federal Threatened & Endangered Fish	2. State Threatened and Endangered Species	3. Important Riparian Habitat	4. Instream Flows and Natural Lake Levels	5. Fishing	6. Boating	7. Waterfowl Hunting	RATIONALE FOR CONSIDERATION AS A MAJOR SEGMENT	CDSS Nodes	Attributes with Flow Relationships

Attribute 5 - Fishing
- a. Gold Metal Trout Streams
- b. Gold Medal Trout Lakes
- c. Significant Fishing Waters (based on local knowledge)

Attribute 6 - Boating
- a. Rafting/kayaking/flatwater Reaches
- b. Recreational In-Channel Diversion Structures

Attribute 7 - Waterfowl Hunting
- a. Waterfowl Hunting

Notes (disclaimer verbiage):
1. Non-consumptive environmental and/or recreational attributes exist on virtually all stream and lake segments, whether such attributes are identified herein or not. Exclusion of a segment from this chart does not indicate absence of non-consumptive attributes.
2. Attributes associated with the major segments are commonly dependent on conditions in upstream tributary segments. Therefore, the achievement or maintenance of non-consumptive attributes depends upon achieving or maintaining necessary values in upstream segments as well as within the major segment itself.

Important Riparian Habitats were considered based on the following CNHP rankings:

G/S1 Critically imperiled globally/state because of rarity (5 or fewer occurrences in the world/state; or 1,000 or fewer individuals), or because some factor of its biology makes it especially

G/S2 Imperiled globally/state because of rarity (6 to 20 occurrences, or 1,000 to 3,000 individuals), or because other factors demonstrably make it very vulnerable to extinction throughout

G/S3 Vulnerable through its range or found locally in a restricted range (21 to 100 occurrences, or 3,000 to 10,000 individuals).

Table 7-2 - Energy Sector and Municipal Demand Projections (AFY)

County	Use	2008	2035	2050 Low	2050 Med	2050 High
Moffat	Energy Development Direct Use	800	1,500	400	1,200	2,300
	Thermoelectric	17,500	26,900	24,700	26,200	26,900
	Municipal	3,000	5,000	6,000	6,000	7,000
	Total	*21,300*	*33,400*	*31,100*	*33,400*	*36,200*
Rio Blanco	Energy Development Direct Use	700	4,000	3,000	5,800	37,900
	Thermoelectric	-	-	-	-	-
	Municipal	2,000	4,000	5,000	10,000	17,000
	Total	*2,700*	*8,000*	*8,000*	*15,800*	*54,900*
Routt	Energy Development Direct Use	500	500	500	500	1,600
	Thermoelectric	2,700	11,400	12,000	14,300	17,100
	Municipal	6,000	12,000	14,000	15,000	17,000
	Total	*9,200*	*23,900*	*26,500*	*29,800*	*35,700*
Study Area	*Energy Development Direct Use*	*2,000*	*6,000*	*3,900*	*7,500*	*41,800*
	Thermoelectric	*20,200*	*38,300*	*36,700*	*40,500*	*44,000*
	Municipal	*11,000*	*21,000*	*25,000*	*31,000*	*41,000*
	Total	***33,200***	***65,300***	***65,600***	***79,000***	***126,800***

Source: CWCB 2010b Tables 3-1 and 4-12

are approximately 59,400 AFY higher than the 2050 high demand shown in Table 7-2 (CWCB 2010b; Tables 4-9, 4-10 and 4-11). In addition, water demands could increase by 230,000 AFY if oil shale processing does not rely on on-site electrical generation and *in situ* oil shale production does not use byproduct water to satisfy process needs.

Municipal demand in the study area is projected to increase as well. The findings in SWSI showed that there was no gap for municipal supplies if identified projects and processes (IP&Ps) were implemented. To date, two of the IP&Ps were implemented – enlargement of Elkhead Reservoir, and construction is currently underway for an enlargement of Stagecoach Reservoir. The 2010 SWSI Consumptive Needs updated includes increased municipal demands for the study area related to the development of the energy industry in the county. Municipal demands are projected to increase from 11,000 AFY in 2008 to between 25,000 AFY and 41,000 AFY in 2050 and are also presented in Table 7-2.

Municipal demands in other parts of the state, primarily on the Front Range, however, may impact water use on the West Slope. Several pump-back alternatives have been explored by various entities, and a report providing reconnaissance level cost estimates was developed by the CWCB in June, 2010 (CWCB 2010c). A pump-back is where a pipeline brings water from a West Slope river across the Continental Divide to the Front Range where municipal demands are rapidly growing. One pump-back proposal diverts water from the Yampa River near Maybell and pumps the water to the northern Front Range. Figure 7-2 shows three potential alignments of the Maybell pump-back. There is also a proposed pump-back from Flaming Gorge Reservoir (Green River in Wyoming) to the Front Range that follows the Interstate 80 corridor through Wyoming until reaching the Front Range. While the Flaming Gorge pipeline would not directly impact flows for the majority of the study area (the Green River passes through the westernmost portion of the study area), water taken to the Front Range from this reservoir could impact uses and flows in the Yampa and White Rivers due to the Colorado River Compact obligations.

As identified through the course of this study, agricultural shortages exist in the study area, and the majority of the shortages exist on small tributaries that were not modeled in the State’s basin modeling effort, and other larger tributary streams. There are not generally shortages for agricultural users who divert from the larger regional streams. Peak runoff occurs in May and June, and is generally far in excess of crop demand. Flows drop sharply in late July and remain low through the remainder of the year. Existing reservoirs provide supplemental supply to water users in some basins, but are not able to supply water to many water users on the smaller tributary streams. The cost of constructing new storage is generally more than agricultural users are able to pay for, and would require partnering with other basin interests.

Increasing efficiency on existing agricultural lands (i.e. conversion to sprinklers and ditch lining) was also explored through this study and was shown to help reduce existing shortages. However, increasing efficiencies reduces return flows and often results in lower flows in August, September and October. This time of the year is when flows are already low and could produce undesired environmental and recreational impacts.

Additional irrigated lands could be developed in the study area. In Technical Memorandum Number 2 approximately 14,000 acres were identified along the Yampa River oxbows downstream of Craig, Colorado. Under the alternatives analysis, development of the new irrigated lands using junior direct-flow water rights showed that shortages would exist during the late season. Target flows for the fish recovery program on the Yampa River were met before meeting the new agricultural demand. In some years, return flows from the new lands were able to reduce late season shortages to the target flows for the fish recovery program.

4.0 Potential Multiple-Interest Solutions

The following are several potential multiple-interest solutions that address agricultural shortages in the study area. To reduce agricultural shortages, new storage and increases in irrigation efficiency were evaluated previously. There are positive and negative aspects to both storage and efficiency increases. However, combined with other interests, there is potential to meet other needs identified in the study area, thereby maximizing the positives and minimizing the negatives. The following potential solutions are not intended to be exhaustive or exclusive, and are presented in no order of preference.

4.1 New Storage

Streamflow in the study area peaks in May and June, but agricultural demands are highest in July and August. This offset in supply and demand can be met by storage of water during the peak runoff and releases later in the year. In many locations in the study area, there is a significant amount of available supply during the peak runoff that could be stored for later use. In general, the disadvantages to more storage are environmental impacts at the reservoir site (inundation of riparian habitat, potential obstruction of fish migration) and on the stream directly below the reservoir (reduced flows during times of storage). Permitting for on-channel storage is increasingly difficult and more likely increases in storage would occur off-channel or through enlarging existing reservoirs. More storage provides several advantages, including reduction in agricultural shortages and increased late season flow below the reservoir and below the irrigation structures it serves via return flows. Depending on the location of the reservoir, late season flows may also enhance existing fisheries and enhance flows for rafting and kayaking. Reservoirs themselves often serve as tourist destinations for ‘flat water’ recreation.

4.1.1. Small Reservoir Study Locations and Stagecoach Enlargement

Three proposed reservoir sites were evaluated in Technical Memorandum Number 5 for their ability to meet shortages in their respective basins. In addition to meeting agricultural shortages locally, the reservoirs could be used to supply water to new irrigated lands on the Yampa River. Releases from storage would occur generally in the late season and enhance flows on lower Morapos Creek, Fortification Creek and the Yampa River below their respective confluences. In addition, releases from the enlarged Stagecoach reservoir to new irrigated lands near Craig would also increase flows in the late season from both the reservoir release and the return flows on the Yampa River.

Much of the Yampa River below Stagecoach Reservoir is identified as key environmental and/or recreational segments in Table 7-1 and Figure 7-1 or as critical habitat for federal endangered species and multiple state aquatic species of concern. Increases in flow from releases from storage to irrigated lands can help enhance environmental flows en-route and downstream of the irrigated lands as delayed return flows.

4.1.2 Small On-Site Storage

Small on-site storage facilities for individual agricultural users have the potential to provide small amounts of storage to irrigators located on smaller tributaries (See Technical Memorandum Number 5, Section 4.3.1). These users generally would not be able to receive water from a regional reservoir. Releases of water from such small on-site storage facilities keep water higher in the basin for longer periods of time. Return flows from application of this water would enhance streamflows during the late season. The disperse nature of these structures precludes identification of specific reaches that could receive enhanced late season flows.

The CWCB owns several instream flow water rights in the basin. Many of these instream flow rights are upstream of existing agricultural users. As a modification to the small on-site storage, small storage facilities could be built upstream of the agricultural users in the instream flow reach, and releases made to irrigators in the late season and simultaneously enhance streamflows through a portion of the instream flow reach during the later part of the season when flows normally drop off. Depending on location, such smaller reservoirs could also serve as recreational destination lakes.

4.1.3 Development of the Energy Sector

The energy sector will rely on new storage to provide a reliable water supply to meet increasing demands. In the White River, there are several existing conditional water rights for storage for the energy sector for large amounts of storage. Through the alternatives evaluated for this study (see Technical Memorandum Number 5, Section 4.5.1), it was determined that approximately 6,000 to 12,000 AF of storage for agricultural users would provide an equal amount of water that has historically been diverted under junior irrigation water rights that are vulnerable to energy sector conditional water rights. It is unlikely that the full amount of water historically diverted under junior water rights would be curtailed by the development of the energy sector's conditional water rights, so the amount of storage actually needed for agricultural is likely less. The addition of an agricultural pool in a reservoir built primarily for the energy sector's use could provide opportunity to lower costs of new storage for agriculture. In addition, releases from such a reservoir to agricultural users could enhance flows through reaches of the White River identified in Figure 7-1 and Table 7-1 as valuable environmental and recreational resources.

4.1.4 Compensatory Storage

The effects of a water removed from the basin via a pump-back or other transmountain diversion can be offset with compensatory storage. Storage may be built in any number of locations provided there is sufficient inflow and a site is found that minimizes negative environmental impacts. However, with the proposed alignments of the Yampa pump-back pipeline, as shown in Figure 7-2, there is a potential to develop storage along the pipeline route that could be partially filled from the pipeline. The northern alignment passes through the Fortification Creek drainage and the upper Little Snake River (Water District 54). Both of these drainages were identified through this study as having significant agricultural shortages. Releases of late season reservoir water could also increase late-season streamflows for reaches identified in the non-consumptive needs report (Figure 7-1).

4.2 Efficiency Increases

Due to the impracticability of getting water to many users on small streams in the study area, one alternative evaluated in this study was to increase irrigation efficiency to reduce shortages (see Technical Memorandum Number 5, section 4.4.1). Higher irrigation efficiency can be attained by installing sprinklers and reducing conveyance losses through ditch lining. Irrigation efficiency was shown to reduce total diversions and shortages, but return flows were also reduced in the late season. Since flows are already lowest in the late season, the impact of fewer return flows is magnified.

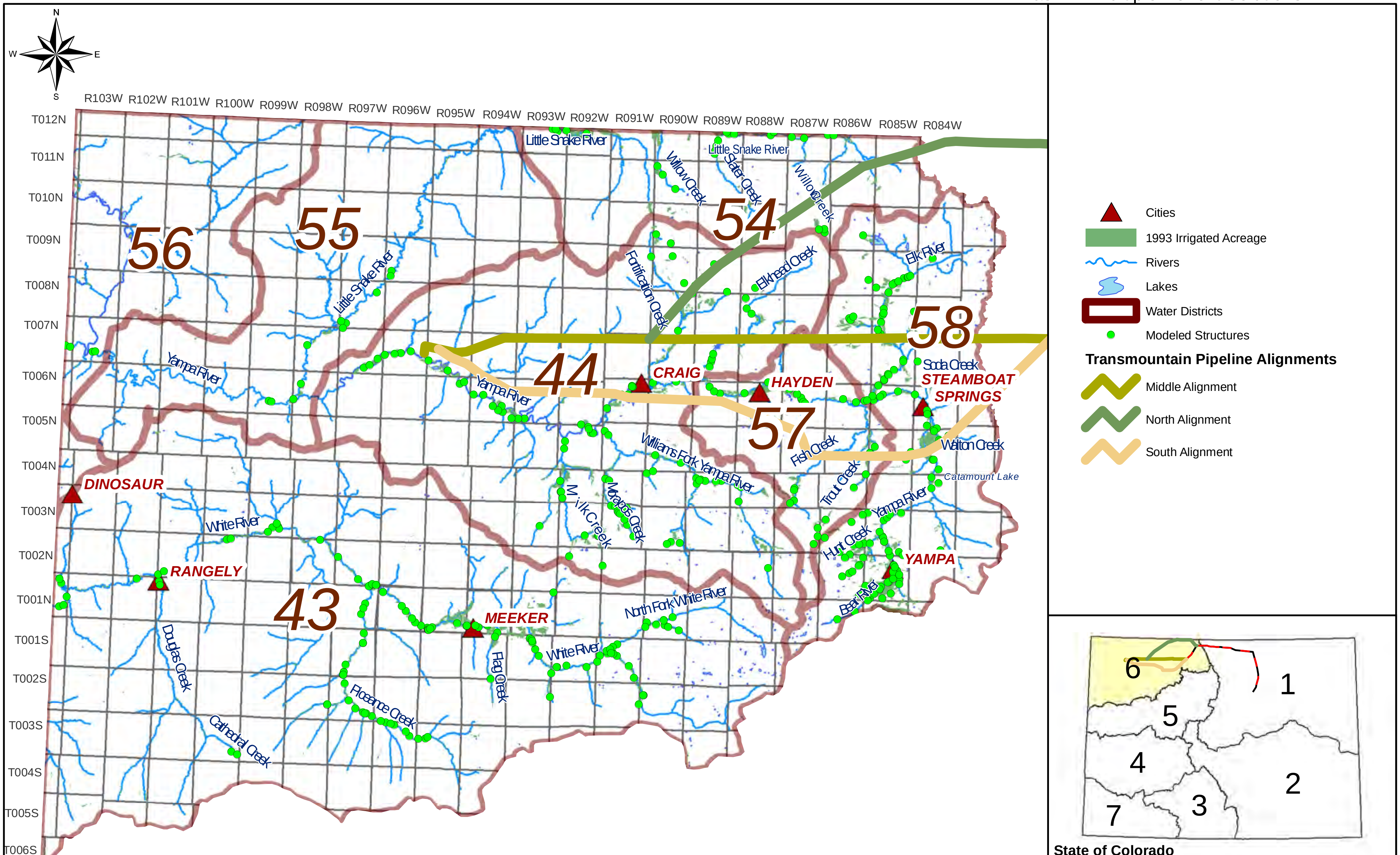

Figure 7-2
Yampa Pumpback Alignments

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One potential solution is to utilize higher efficiency irrigation equipment to reduce agricultural shortages, and utilize storage in regional reservoirs to offset the reduced return flows by releasing water in the late season to meet target environmental flows. While this would not address the reduced streamflows at the local scale, late season flows in the regional streams could be maintained or enhanced while agricultural shortages could be reduced on the tributaries.

4.3 Funding

Through the SWSI process, it has been identified that agriculture does not generally have the ability to pay for many of the enhancements that could further reduce shortages. Funding would likely need to be provided in large part through partnering with the other interests that could benefit from a joint solution. The possibility of creating new recreational destinations could draw on new revenue from tourism. Environmental groups may be able to help fund projects that provide environmental benefits as well as benefits to the agricultural needs. Partnering with sponsors of the pump-back projects or with the energy sector may provide a firmer source of funding. Both the pump-back project and significant development of energy resources would require a large amount of capital investment and the costs of many of the alternatives above would be relatively small compared to the entire project cost. Partnerships to create benefits for agricultural and environmental concerns could play an important role in a project's success.

5.0 References

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