PREPARED FOR
Colorado River Water Conservation District

Colorado River Water Bank Feasibility Study

PHASE 1 | June 2012

FINAL DRAFT REPORT

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Prepared for:

Colorado River Water Conservation District
201 Centennial, Suite 200
Glenwood Springs, CO 81601

COLORADO RIVER WATER BANK FEASIBILITY STUDY – PHASE 1

Final Draft Report

June 2012

Prepared by:

MWH Americas, Inc.
1801 California Street, Suite 2900
Denver, Colorado 80202

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1.0 INTRODUCTION

1.1 Project Objective

Under the Colorado River Compact of 1922, the States of the Upper Division (Colorado, New Mexico, Utah and Wyoming) are obligated not to cause the flow of the Colorado River at Lees Ferry, Arizona to be depleted below 75,000,000 acre-feet during any consecutive 10-year period. The recent drought has demonstrated that curtailment of some uses of Colorado River water in the Upper Division states may become a possibility, if the flow in the river ever becomes so low that the Upper Division could not meet its obligations under the Colorado River Compact. Within the Upper Division and within any Upper Division state, all parties agree that a curtailment would cause significant social and economic disruption. An informal group composed of representatives of the Colorado River Water Conservation District, Colorado Water Conservation Board (CWCB), Front Range Water Council, Southwestern Water Conservation District, and The Nature Conservancy (collectively, the Water Bank Group) is investigating the development of a "Water Bank" that may allow continued water use in the event that a drought significantly reduces flows in the river and the Upper Division States could not supply all of their demands and meet the Upper Division's non-depletion obligation. The Water Bank would seek to provide a means for pre-Compact water rights (pre-1929 water rights not subject to curtailment) and post-Compact reservoir storage to be used to allow critical water rights that are not 'present perfected rights' under the Compact to continue to be diverted rather than be curtailed.

At a conceptual level, the Water Bank could operate as follows. Willing agricultural participants in the Water Bank could temporarily fallow or deficit irrigate certain lands that are irrigated by pre-Compact water rights. These willing participants would be compensated while normal irrigation is reduced, and the saved consumptive use would be available to a Water Bank. Post-Compact water users would "subscribe" to the bank, and thereby gain access to pre-Compact water that would offset or replace water use that might otherwise be curtailed. It is anticipated that any land that is fallowed or deficit irrigated may be done so on a rotational basis, in conjunction with other irrigated lands. This approach may avoid permanent irrigation dry-up, and minimize the economic and environmental impacts that can occur in surrounding communities and economies. This study recognizes that a Water Bank could also use consumptive use associated with post-Compact water rights that are stored in certain years, for use in subsequent years; however, that concept is outside of the scope of this workgroup and this report.

This report presents results from Phase 1 of the overall Colorado River Water Bank Feasibility Study (Water Bank Study), which will be completed in three phases. Phase 1 provides a conservative estimate of the amount of water supplies that may be associated with a Water Bank, and the potential demand for these supplies. Phase 2 will assess the actual on-farm implementation of the Water Bank for representative pre-Compact irrigation systems. Phase 3, if pursued, will assess regional economic and environmental considerations. Of course, the continuation of this work through the various phases will be dependent upon funding and continued dedication of resources of the funding partners.

1.2 Project Scope of Work

Phase 1 of the Water Bank Study consisted of the following main tasks:

- Estimate water uses on the East Slope and West Slope that are met with water rights that are not 'present perfected rights' under the Compact (i.e. not "pre-Compact water rights").
- Estimate water supply available to the Water Bank from pre-Compact West Slope agricultural water rights
- Estimate the potential magnitude and frequency of shortages that might result in a curtailment that could be mitigated through use of the Water Bank
- Develop and evaluate regional water supply and water use scenarios, and develop and apply a Scenario Analysis Tool to investigate feasible supply-use combinations.

1.3 Project Authorization

MWH Americas, Inc., in association with Natural Resources Consulting Engineers, Inc., performed Phase 1 of the Water Bank Study under contract to the Colorado River Water Conservation District. The District was the contracting entity on behalf of the entire Water Bank Group. Financing was provided by the Water Bank Group members and an Alternatives to Agricultural Water Transfer grant from the Colorado Water Conservation Board.

1.4 Project Coordination

The Water Bank Group provided input to the MWH study team on study methods and assumptions. The Water Bank Group also reviewed draft technical memoranda presenting preliminary study results. In addition, a larger management oversight team comprised of Water Bank Group members and representatives from other Front Range municipal water providers and West Slope agricultural districts received presentations at project milestones and provided input to the study team.

2.0 POTENTIAL WATER BANK USES

Potential use of, or "withdrawals from," the Water Bank would be made to avoid or minimize curtailments of diversions from post-Compact water rights. The *Categories of Existing West Slope and East Slope Water Uses Technical Memorandum*, prepared by the Water Bank Group, describes the derivation of estimates of potential water use for the Water Bank. The technical memorandum is contained in **Appendix A.** Estimates of potential water use were developed by the Water Bank Group based on data on historical average annual water use in the following categories:

- West Slope municipal and industrial (M&I) water use supplied by post-Compact water rights (note: in this report, "West Slope" refers to the area within the Colorado River Basin in Colorado)
- East Slope M&I water use supplied by transbasin diversions from the West Slope of post-Compact water rights
- West Slope agricultural water use for crop types supplied by post-Compact water rights that would suffer irreparable damage if irrigation water was not available for an irrigation season, and include orchards and vegetables

Replenishment of evaporation of post-Compact water stored in non-Colorado River Storage Project (CRSP) reservoirs was not assumed to represent a potential use of the Water Bank for this analysis.

The current estimated average annual use by water use category is shown in **Table 1**, recognizing that annual use varies due to physical and legal water availability, hydrology, and other factors. Water use in specific years, particularly during extended wet or dry periods, will likely be more or less than the values in **Table 1** in any given year. No assumption has been made at this phase of the project about the effect of demand management strategies that might be used to reduce water use in the M&I categories during drought periods in advance of a curtailment situation, or during years when curtailments might otherwise be imposed but for these reductions. It is assumed for purposes of this analysis that entities withdrawing water from the Water Bank would be able to use that water to meet any categories of use listed in **Table 1**.

Table 1 – Potential Categories of Water Bank Use

Water Use Category	Current Average Annual Water Use (AFY)
West Slope Post-Compact M&I Depletions	
Residential Indoor	1,390
Residential Outdoor	16,675
Commercial/Industrial	4,210
Self Supplied Industrial	32,940
Subtotal	**55,215**
East Slope Post-Compact M&I Depletions	
Residential Indoor	107,930
Residential Outdoor	82,375
Commercial/Industrial	105,170
Self Supplied Industrial	-
Subtotal	**295,475**
Total Post-Compact M&I Depletions	
Residential Indoor	109,320
Residential Outdoor	99,050
Commercial/Industrial	109,380
Self Supplied Industrial	32,940
Total	**350,690**
West Slope Post-Compact Agricultural Depletions Not Readily Deficit Irrigated or Fallowed	
Vegetables	3
Orchards (cover and no cover)	2,155
Total	**2,158**
Source: "Categories of Existing West Slope and East Slope Water Uses – Task 1.2," Water Bank Group, November 18, 2011	

3.0 POTENTIAL WATER BANK SUPPLY

Potential supplies for, or "deposits to," the Water Bank would come from voluntary curtailments of diversions from users of pre-Compact water rights. The resulting reduction in consumptive use from pre-Compact water rights would allow a like amount of depletions from post-Compact water users. It is assumed that the source of water for the Water Bank would come from West Slope agricultural water users with pre-Compact water rights. No assumptions were made as to transit losses from the original point of depletion to the exchanged potential new point of depletion, but this issue would have to be addressed.

The supply available to the Water Bank was estimated based on the following three factors: potential supply, level of participation by qualifying irrigators, and level of fallowing or deficit irrigation on participating irrigated lands. Each of these three factors is described in the following sections.

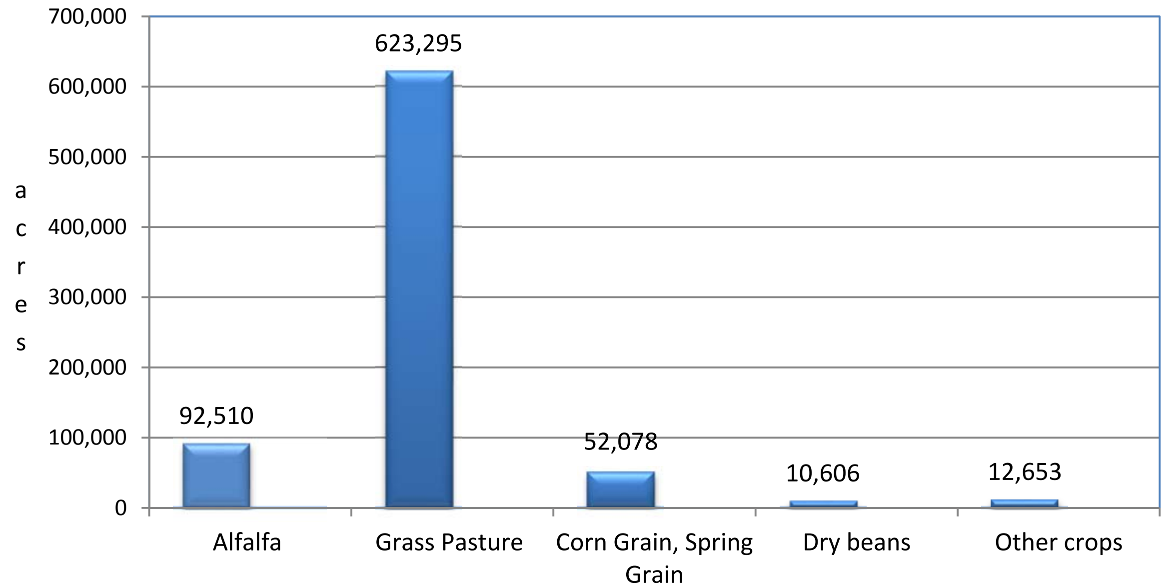
3.1 Potential Supply

The potential supply of water to the Water Bank was represented by the consumptive use of pre-Compact agricultural water rights held by water users in the Upper Colorado River Basin in Colorado. The consumptive use of pre-Compact agricultural water rights was estimated by crop type in the *Colorado River Compact Colorado Water Bank Feasibility Study Water Supply Technical Memorandum* by NRCE. See **Appendix B** for the full technical memorandum. It is important to note that actual use could be much higher if the crops were not supply limited, or if climatic conditions change, as further described below and within this technical report. Due to concerns about overstating the amount of consumptive use that could be available in any particular year for Water Bank purposes, several conservative assumptions were used to estimate the potential supply. Assumptions and methods for determining irrigated acreage served by pre-Compact water rights and estimating supply-limited consumptive use for that irrigated acreage were purposely conservative for this study. The results, therefore, are lower than other estimates created for other purposes.

Consumptive irrigation use for the Water Bank study was derived from the consumptive irrigation requirement of irrigated areas in the Basin, which was estimated with the State of Colorado's Consumptive Use Model (StateCU) (Colorado Division of Water Resources, 2008). The model uses specific crop water requirements combined with climate and temperature data from weather stations in the Basin to estimate the consumptive irrigation use for each irrigated parcel.

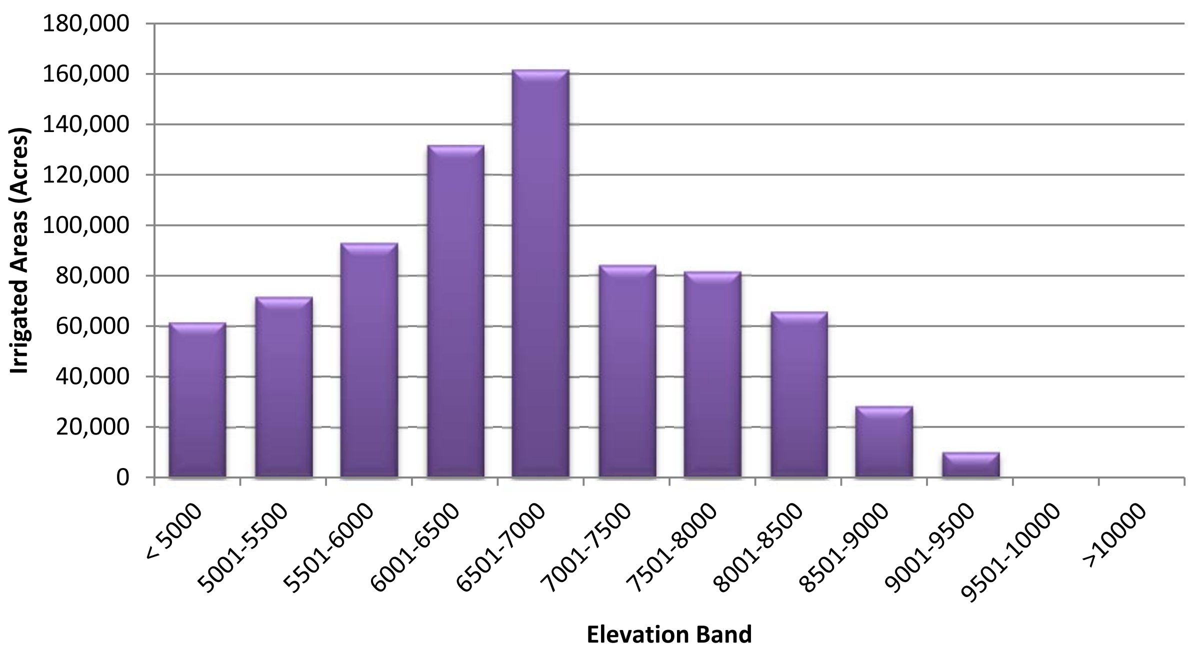
Information on the type of crops grown in the Basin was obtained from a geographic information system (GIS) coverage of Colorado State Water Divisions 4, 5, 6, and 7 obtained from the Colorado State Engineers Office. Major crop types and characteristics of major crop types in Water Divisions 4-7 in Colorado are alfalfa, bluegrass, corn grain, dry beans, grass pastures, orchard with and without ground cover, small grains, sod farm, and vegetables. Consumptive irrigation requirements were evaluated in the StateCU model for alfalfa, corn, dry beans, grass pasture, orchards with cover, orchards without cover, spring or small grains, and vegetables. **Figure 1** shows the combined crop distribution of the irrigated areas.

Figure 1 – Irrigated Areas by Crop Type in Water Divisions 4-7



Irrigated areas were organized by crop types and grouped into 500-foot elevation bands. Elevation bands started at 4,500 feet and progressed to 10,500 feet. **Figure 2** shows the total irrigated areas of crops in each division for each elevation band used.

Figure 2 – Total Irrigated Areas in Water Divisions 4-7 by Elevation Band



Temperature and precipitation vary with elevation resulting in differences in crop evapotranspiration, effective precipitation, and consumptive irrigation requirement. The StateCU model was used with data from weather stations at different elevations to determine the relationship of consumptive irrigation requirement to elevation. On a crop-by-crop basis the consumptive irrigation requirement was calculated from climate data to determine the relationship between consumptive irrigation requirement and elevation.

Consumptive irrigation requirements at different elevations were obtained for Divisions 4, 5, 6, and 7. By multiplying irrigated areas by the appropriate consumptive irrigation requirement values obtained from StateCU based on elevation, the potential irrigation water consumed by crops was estimated.

Because consumptive irrigation requirements were calculated assuming a full supply of water is available, the amount of water historically available (i.e., the water supply limited use) was also considered. The irrigation water supply limitation information was obtained from reports prepared by Leonard Rice Engineers, Inc. (2009 a-d) for the State of Colorado. These Historic Crop Consumptive Use Analysis reports developed for the Colorado, Gunnison, Yampa, and San Juan divisions were used to estimate the supply-limited consumptive irrigation use. These analyses considered available water supply in addition to the estimated consumptive irrigation requirement, and were based on limitations in normal hydrologic years. In dry years, the limitation associated with available water supply could be substantially greater in some areas, further constraining the amount of water available to the Water Bank. Nonetheless, the consideration of irrigation shortage allows a more accurate estimate of consumptive use and depletions in water supply than the full supply crop irrigation requirement.

Water rights data for irrigated lands in the Basin was obtained from the State of Colorado's HydroBase online water rights database. Water rights for agricultural lands were categorized based on appropriation and adjudication dates relative to the Colorado River Compact. Two potential Compact administration dates were considered: November 24, 1922, the effective date of the original Compact, and June 25, 1929, the effective date of the Boulder Canyon Project Act. The water rights categories based on appropriation or adjudication prior to these two dates are described in **Table 2**.

Table 2 – Description of Water Rights Categories Relative to Colorado River Compact Dates

Water Right Category	Appropriation Date	Adjudication Date
A	< 11/24/1922	< 11/24/1922
	OR	
	< 11/24/1922	>= 11/24/1922 Original Adjudication
B	< 11/24/1922	>= 11/24/1922 Supplemental Adjudication
C	>= 11/24/1922 and < 6/25/1929	>= 11/24/1922 and < 6/25/1929
	OR	
	>= 11/24/1922 and < 6/25/1929	>= 6/25/1929 Original Adjudication
D	>= 11/24/1922 and < 6/25/1929	> = 6/25/1929 Supplemental Adjudication
	OR	
	>= 11/24/1922 and < 6/25/1929	unknown
Post Compact Water Rights	Water rights appropriated after 6/25/1929	
No Appropriation Data	A parcel of land where no water rights information is available.	

Specific water rights were linked to each of the parcels of irrigated land in the GIS database based on headgate location. Irrigated areas for crops were summed and organized into the above water rights categories. In many cases, a single irrigated parcel receives water from more than one water right. In this case, the irrigated acreage was allocated equally to each water right; for example, if there were 3 water rights associated with a 99 acre parcel, 33 acres would be assigned to each water right.

Table 3 shows the supply limited consumptive irrigation use by water rights category for the total basin.

Table 3 – Supply Limited Consumptive Irrigation Use by Water Rights Category

Total for Basin				
Water Rights Category ▶	**No Data[1]**	**Pre-Compact Water Rights**	**Post Compact Water Rights**	**Total**
Crop Type ▼	**Supply Limited Consumptive Irrigation Use (acre-feet/year)**			
Alfalfa	43,219	110,164	25,368	178,750
Corn Grain	1,492	34,504	3,476	39,473
Dry Beans	4,618	6,905	137	11,660
Grass pasture	80,233	794,074	195,451	1,069,759
Orchard with Cover	565	1,496	345	2,406
Orchard without Cover	3,160	5,574	582	9,317
Spring Grains	2,809	27,830	3,192	33,830
Vegetables	895	549	28	1,472
Others	1,616	5,320	2,161	9,097
Totals	**138,607**	**986,416**	**230,740**	**1,355,763**
Percent of Total	**10.20%**	**72.80%**	**17.00%**	**100%**

[1] "No Data" refers to land where no water rights information is available. The irrigated acreage probably includes some pre-Compact water rights associated with the Tribal federal reserved rights and other pre-Compact water rights associated with parcels that could not be linked to the CDSS Hydrobase, which contains priority dates.

Based on these results, basic pre-Compact water rights suitable for use in the Water Bank were assumed to consist of the following:

- Water rights with appropriation or adjudication date prior to 1929.
- Water rights associated with alfalfa and grass pasture crop types and small grains/corn/dry beans. For purposes of further analysis, only water use associated with alfalfa and grass pasture was considered because these crop types constitute the majority of agricultural water use on the West Slope, and because they can withstand occasional fallowing or deficit irrigation without significant long-term effects.
- Water right consumptive use based on water supply limited consumptive use estimates (i.e., crop consumptive water use adjusted for historical shortages in water deliveries) for conditions in average hydrologic years.

Table 4 summarizes the irrigated lands on the West Slope with pre-Compact water rights and crop types that could occasionally sustain deficit irrigation. **Table 5** summarizes the potential water supply available to a Water Bank from these sources.

Table 4 – Irrigated Lands Potentially Contributing Supply to the Water Bank

Description	Total Basin (ac)	Irrigated with Pre-Compact Water Rights (ac)	Pre-Compact % of Total
Alfalfa and Grass Pasture	715,805	513,119	72%
Small Grain, Corn Grain, and Dry Beans	62,685	48,482	77%
Total	**778,490**	**561,601**	**72%**

1) About 10 percent of the irrigated land could not be matched with water right appropriation data. Thus, the number of acres associated with the pre-Compact water rights is likely higher than reported in the table.
2) Source: "Colorado River Compact Colorado Water Bank Feasibility Study Water Supply Technical Memorandum," NRCE, February 3, 2012.

Table 5 – Potential Sources of Water Bank Supply Based on Average Year Water Supply Limited Consumptive Use

Crop	Total Basin (AFY)	Pre-Compact (AFY)	Pre-Compact % of Total[1]
Alfalfa and Grass Pasture	1,248,509	904,238	72%
Small Grain, Corn Grain, and Dry Beans	84,963	69,239	81%
Total	**1,333,472**	**973,477**	**73%**

[1] Subsequent more detailed calculations by the State of Colorado determined that the Pre-Compact supply limited consumptive use could be as high as 94% of the total consumptive use.

The potential water sources in **Table 5** were adjusted for the following three factors to estimate maximum potential supply available to the Water Bank.

- **Table 5** does not include Tribal reserved water rights held by the Ute Mountain Ute and Southern Ute Tribes. Tribal reserved water rights for both Tribes combined are 56,470 AF. These are generally considered to be pre-Compact, but the amount to be administered as pre-Compact has not been determined. For purposes of this Water Bank analysis, the potential consumptive use from these rights was estimated to be 33,000 AFY. This amount was added to the pre-Compact water shown in **Table 5**.
- In some areas of Division 7 post-Compact water stored in reservoirs is released to meet irrigation demands on irrigated areas also supplied with pre-Compact water. The consumptive use associated with this water would not be available as a supply to the Water Bank. The average annual volume of this water was estimated to be 37,741 AFY by the Water Bank Group. This volume was subtracted from the pre-Compact water shown in **Table 5**.
- It was assumed that water administration principles would be adopted to shepherd curtailed depletions to Lees Ferry. However, because the consumptive use values in **Table 5** are "on farm" values, a transit loss of 10 percent was applied to all supplies to estimate the benefit of curtailed on-farm depletions to Compact accounting.

Table 6 shows the maximum potential water supply for the Water Bank incorporating the above three adjustment factors.

Table 6 – Adjusted Maximum Potential Water Supply Available for the Water Bank

Crop	Total Basin (AFY)	Pre-Compact (AFY)	Pre-Compact % of Total[1]
Alfalfa and Grass Pasture	1,101,684	791,840	72%
Small Grain, Corn Grain, and Dry Beans	79,646	65,494	82%
Total	**1,181,330**	**857,335**	**73%**

[1] Subsequent more detailed calculations by the State of Colorado determined that the Pre-Compact supply limited consumptive use could be as high as 94% of the total consumptive use.

3.2 Level of Participation by Qualified Irrigators

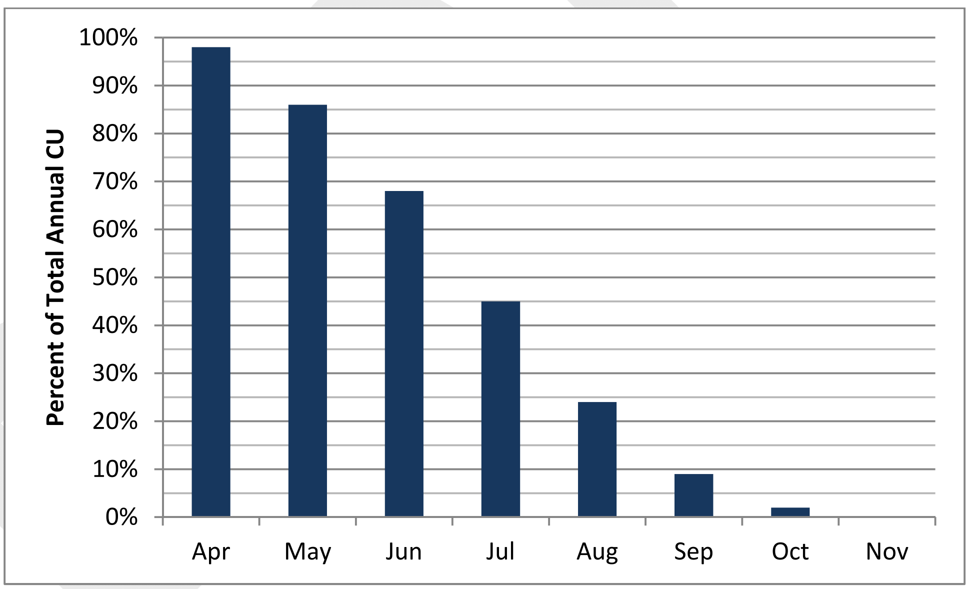
The number of irrigators with pre-Compact water rights who would be interested in supplying water to a Water Bank would be a function of a number of influences including contract terms, price, regional hydrologic conditions, and numerous other factors. Research into the possible level of interest in a Water Bank by West Slope agricultural interests was not performed as part of Phase 1 of the Water Bank feasibility study. Thus, the potential level of participation (or market penetration) has not been estimated for this study, but is treated as a variable in the scenario analysis described in the following portion of this report. The level of participation was represented as a percentage of the irrigated land of a given crop type that would be fallowed or deficit irrigated to provide water to the Water Bank. For purposes of the scenario analysis it was assumed that up to 50 percent of qualifying irrigators would agree to participate in the Water Bank (see **Section 5**).

3.3 Level of Deficit Irrigation on Participating Irrigated Lands

Reductions in consumptive use would be achieved through various levels of fallowing or deficit irrigation. As part of its assessment of potential water supplies for the Water Bank, NRCE investigated the feasibility of deficit irrigation for the crops and irrigation conditions in the study area. The details of this study can be found in **Appendix B.** The NRCE study indicated that deficit irrigation is feasible and best suited for grass pasture and alfalfa. Deficit irrigation (irrigating for only part of the season or irrigating with less than a full supply during any season) can be implemented for a single year or on a continuing basis without significantly impacting future production. Fallowing (not irrigating at all during any season) may be more feasible for annual crops like small grain, corn, and beans. Vegetables and orchards are not considered feasible for deficit irrigation or fallowing, and were not considered as potential sources of consumptive use savings for Water Bank supplies.

Actual water savings through deficit irrigation are difficult to determine without on-farm analyses. For purposes of this conceptual analysis, it was assumed that consumptive use savings through deficit irrigation would be equal to the average monthly consumptive use in months during which irrigation would be curtailed. This is shown in **Figure 3** for the Delta, Colorado climatic zone. In this region, for example, curtailing irrigation after July 1 would save 45 percent of the average annual consumptive use. The level of deficit irrigation adopted by Water Bank participants would vary by irrigator, crop type, hydrologic conditions, compensation, and numerous other factors. This was treated as a variable from 0 percent to 100 percent (no irrigation) in the scenario analysis described in **Section 5**.

Figure 3 – Consumptive Use Saved by Stopping Irrigation at the Beginning of Given Month (Delta, CO)



4.0 POTENTIAL MAGNITUDE AND FREQUENCY OF WATER BANK NEED

The Upper Colorado River Basin Model (Basin Model) developed by Leon Basdekas of Colorado Springs Utilities for the Front Range Water Council was used to provide a rough estimate of the potential frequency with which Colorado River drought conditions (locally or for all of the Upper Colorado River Basin) could create a need for the Colorado Water Bank. The objective was to estimate the magnitude and frequency of potential shortage conditions in the Upper Colorado River system that may result in the need to curtail some diversions in Colorado in order to meet the Upper Basin's non-depletion obligations under the Compact. Federal regulations that govern operation of Lake Powell require annual minimum objective releases from Lake Powell, and those releases and the natural inflow between Lake Powell and the Paria River are measured at the Lees Ferry gaging station. This will be referred to as "Lees Ferry flows" throughout this report. The Basin Model was used to evaluate the frequency of different magnitudes and durations of diversion limitations that would necessitate activation of the Water Bank under various assumptions for Colorado River flows at Lees Ferry, Upper Basin water diversions, and Upper Basin hydrology.

4.1 Upper Colorado River Basin Model

The Basin Model is a simplified spreadsheet model of the Upper Colorado River Basin. Part of the Colorado River Water Availability Study (CRWAS) methodology included using the U.S. Bureau of Reclamation's (Reclamation) 2007 Hydrologic Determination. This Hydrologic Determination by Reclamation was based on natural inflow from 1906-2000, which is the period of record for the Basin Model. The model runs on an annual time step.

The Basin Model is based on the Hydrologic Determination using annual data reported in tabular format by Reclamation for Run 6. Run 6 in the Hydrologic Determination utilized an Upper Colorado River Basin flow of 8.25 MAF/year at Lees Ferry, and annual Upper Basin demand of 5.98 MAF/year. These specific values were used for model QA/QC purposes, but Lees Ferry flows and Upper Basin demands were made to be user defined in the model to allow for evaluation of different demand and Lees Ferry flow scenarios. Further details regarding the Hydrologic Determination can be found in the official Reclamation documentation.

The Basin Model is essentially a dynamic version of the Hydrologic Determination with the ability to perturb system demands, starting storage, Lees Ferry flow targets and inflow volumes, which are detailed on the input sheet of the model. One hundred stochastic streamflow sequences were derived from the 95 years of historical data (1906-2000) using the K-NN methods described in Sharma et.al, 1997. The Basin Model is considered useful in coarse planning level studies that focus on overall conditions in the Upper Colorado River Basin.

The Basin Model uses the following key assumptions for simulating operation of the Upper Colorado River Basin system.

- All Upper Basin annual demands are lumped into a single demand node. Demands are not differentiated between states or diversion points. Annual demand can be specified by the user, but is constant for all years of simulation.
- All Upper Basin reservoirs in the Hydrologic Determination are lumped into a single storage bucket totaling approximately 33.8 MAF after adjustments for sedimentation - principally at Lake Powell. Only total system storage is computed.
- The Upper Basin Colorado River flows (8.25 MAF/year or 7.50 MAF/year) are specified at Lees Ferry, and include the inflows from Paria River.

- The flows at Lees Ferry and deliveries to Upper Basin demands are derived first from natural river flows, then from the combined Upper Basin storage reservoirs.
- Two methods of dealing with present perfected water rights in the Upper Basin can be simulated: not curtailing present perfected uses, and treating all water rights as having the same priority. The model uses a value of 2.26 MAF/year for present perfected rights but it is understood that this number may be substantially different from the appropriate value for present perfected rights (Table A, Bureau of Reclamation, from estimates used in Compact negotiations). The non-curtailment option for present perfected rights was used in this study. In this case, the model first makes deliveries to present perfected water users, then meets the Lees Ferry flow target, then meets the remaining post-Compact Upper Basin demands. Upper Basin deliveries will not rise above the present perfected level until any deficit to the Lower Basin is repaid due to improved hydrologic conditions.
- Shortages are computed in any year in which the full Upper Basin demand cannot be met. Shortages are not declared until all system reservoir storage is emptied because demands are met from storage and there is no minimum allowable storage level in the system reservoir storage account. This differs from how the system would actually be operated, but allows for comparison between hydrologic scenarios.
- Model hydrology consisted of 100 sequences of 95 annual flows with the same statistical properties (mean, standard deviation) as the historical period of record in Reclamation's Hydrologic Determination model.
- The initial reservoir storage was modeled such that the ending reservoir storage for one sequence is adopted as the starting reservoir storage for the next sequence.
- Historical hydrology can be adjusted to reflect the effects of climate change or other influences by applying a user-defined factor that adjusts all annual natural flow values up or down by the same percentage.

The Basin Model contains important simplifications that affect the interpretation of the results. In particular, the model does not simulate operation of storage in individual reservoirs, does not operate the system exactly as specified in the Compact, does not separate out Colorado streamflows and demands, and does not adjust water use downward in drought periods or in response to potential curtailment conditions. Nonetheless, the Basin Model was considered to be a reasonable tool to use at this early conceptual phase of the Water Bank feasibility evaluation.

To evaluate effects on Colorado's Compact allotment, model output was post-processed and 51.75 percent of Upper Basin demands and shortages were allocated to Colorado. The Upper Basin States may not actually develop their Colorado River water in the same time frames or in the full allocated amounts, so the distribution of demand and shortage may be different than the 51.75 percent assumed in this report. No attempt is made to account for Arizona's 50 KAF allotment under the Upper Basin Compact or to apply any other specific Compact mechanisms.

Fourteen scenarios of Upper Basin demands, Lees Ferry flow obligations, and basin hydrology were evaluated using the Basin Model to evaluate potential Water Bank implementation conditions. Upper Basin demands were set at the following amounts:

- 5.98 MAF/year – one of the values used in the Hydrologic Determination
- 4.50 MAF/year – an estimate of current Upper Basin depletions (from Colorado River Water Conservation District presentation, January 2005)
- 5.20 MAF/year – mid-range between 5.98 and 4.50 MAF/year

Lees Ferry flow targets were set at the following amounts:

- 8.25 MAF/year – the value used in the Hydrologic Determination
- 7.50 MAF/year – the value that can be assumed to demonstrate compliance with the Upper Division States' obligation not to deplete the flow of the river at Lees Ferry over 75 MAF during any consecutive 10 year period.

Hydrologic conditions were simulated at 90 percent and 100 percent of historical for all scenarios, and at 80 percent of historical for selected scenarios to further test the sensitivity of the system to altered hydrology.

Table 7 defines the attributes of the 14 scenarios evaluated in this study. The Water Bank Group selected Scenario 12 as a representative scenario to describe possible future conditions.

Table 7 – Upper Basin Scenarios Evaluated in Basin Model

Scenario	Upper Basin Demands (ac-ft)	Flows at Lees Ferry (ac-ft)	Basin Hydrology (% of Historical)	Colorado Demands (% of Total Upper Basin Demands)
Scenario 1	5,980,000	8,250,000	100	51.75
Scenario 2	5,980,000	8,250,000	90	51.75
Scenario 3	5,980,000	8,250,000	80	51.75
Scenario 4	5,980,000	7,500,000	100	51.75
Scenario 5	5,980,000	7,500,000	90	51.75
Scenario 6	4,500,000	8,250,000	100	51.75
Scenario 7	4,500,000	8,250,000	90	51.75
Scenario 8	4,500,000	7,500,000	100	51.75
Scenario 9	4,500,000	7,500,000	90	51.75
Scenario 10	4,500,000	7,500,000	80	51.75
Scenario 11	5,200,000	8,250,000	100	51.75
Scenario 12	5,200,000	8,250,000	90	51.75
Scenario 13	5,200,000	7,500,000	100	51.75
Scenario 14	5,200,000	7,500,000	90	51.75

4.2 Estimation of Magnitude and Frequency of Water Bank Need

Demand shortages were used to evaluate the frequency with which the Water Bank could be called upon to mitigate potential changes in Upper Division State diversions in order to meet non-depletion obligations and Upper Divison State demands. The model logic meets all present perfected Upper Basin demands, then meets Colorado River flow targets at Lees Ferry, then delivers water to meet the remaining Upper Basin demands. Water is provided from annual runoff and from Upper Basin reservoir system storage. Shortages in meeting demands are not declared until all reservoir system storage is depleted.

Using demand shortages alone as a trigger for implementing the Water Bank would likely underestimate the frequency with which the Water Bank could be used because in practice water agencies would not wait until all reservoir storage is depleted to implement mitigation measures. In this approach the Water Bank would be used in a reactive mode, and would not be activated until there is a potential need for additional water supplies to meet non-depletion obligations and Upper Division State demands.

The following sections describe the evaluation of the magnitude and frequency of Water Bank need based on demand shortages.

4.2.1 Demand Shortage Assessment

This modeling approach simulated the frequency with which the Water Bank may be called on as a reactive strategy to mitigate the effects of modifying diversions to meet non-depletion obligations. For each scenario, 9,500 years of model results were analyzed (100 sequences of 95 years each). Two criteria were used to analyze the results related to shortages in meeting Colorado demands from Upper Basin sources: magnitude of shortage and duration of shortage. Colorado's share of Upper Basin shortages was estimated as 51.75% of total Upper Basin shortages, based on Colorado's share of Upper Basin supplies. Shortage magnitudes for multi-year dry periods were computed as the average shortage over all the consecutive short years. The following five categories of magnitudes of Colorado demand shortages were considered for this assessment:

- >0-200,000 ac-ft
- 200,001-400,000 ac-ft
- 400,001-800,000 ac-ft
- 800,001-1,400,000 ac-ft
- >1,400,000 ac-ft

Shortage duration was computed as the number of consecutive dry years in which the entire Upper Basin demand was not met. The following five shortage duration categories were considered:

- 1 yr
- 2-3 yr
- 4-6 yr
- 7-10 yr
- ≥ 11 yr

The two criteria are based upon yearly target flows as measured at Lees Ferry of 7.5 or 8.25 MAF per year. However, the model tracks streamflow against the accumulated river flow deficit. This approach did not consider the current operations under the 2007 Interim Guidelines that allow for releases from Glen Canyon Dam to drop to 7.0 MAF, among other issues. Post-Compact users are curtailed in the model until the accumulated deficit is eliminated.

The annual shortage results were analyzed with respect to each shortage magnitude category and each shortage duration category. This resulted in 25 different shortage magnitude/duration combinations for each scenario. The percent of years with each combination of shortage magnitude and duration was calculated. **Table 8** presents the results for Scenario 12. The results for all the scenarios are shown in **Appendix C**.

Table 8 – Scenario 12 Magnitude, Duration and Frequency of Shortages

Duration of Shortage (yr)	0-200,000 AFY Shortage		200,001-400,000 AFY Shortage		400,001-800,000 AFY Shortage		800,001-1,400,000 AFY Shortage		> 1,400,000 AFY Shortage	
	Average Annual Shortage (AFY)	% Years of Shortage	Average Annual Shortage (AFY)	% Years of Shortage	Average Annual Shortage (AFY)	% Years of Shortage	Average Annual Shortage (AFY)	% Years of Shortage	Average Annual Shortage (AFY)	% Years of Shortage
0-1	110,000	0.3%	320,000	0.2%	580,000	0.4%	1,060,000	0.4%	1,510,000	0.3%
2-3	170,000	0.1%	290,000	0.1%	630,000	0.4%	1,060,000	1.5%	1,500,000	1.1%
4-6	-	-	-	-	640,000	0.2%	1,170,000	3.0%	1,480,000	1.0%
7-10	-	-	-	-	-	-	1,190,000	2.0%	1,490,000	0.9%
≥11	-	-	-	-	-	-	1,310,000	1.4%	1,450,000	1.3%

The exceedance probability of annual shortages in the Colorado River Basin deliveries to Colorado water users was also calculated. These results are shown in **Figure 4.** The exceedance probabilities were used to estimate the probability that the shortage in any given year would be greater than 500,000 AF. The threshold of 500,000 AF was selected assuming the Water Bank would likely not be activated for small shortage amounts. **Table 9** summarizes these results.

Figure 4 – Exceedance Probability of Annual Shortages in Colorado River Basin Deliveries to Colorado Water Users

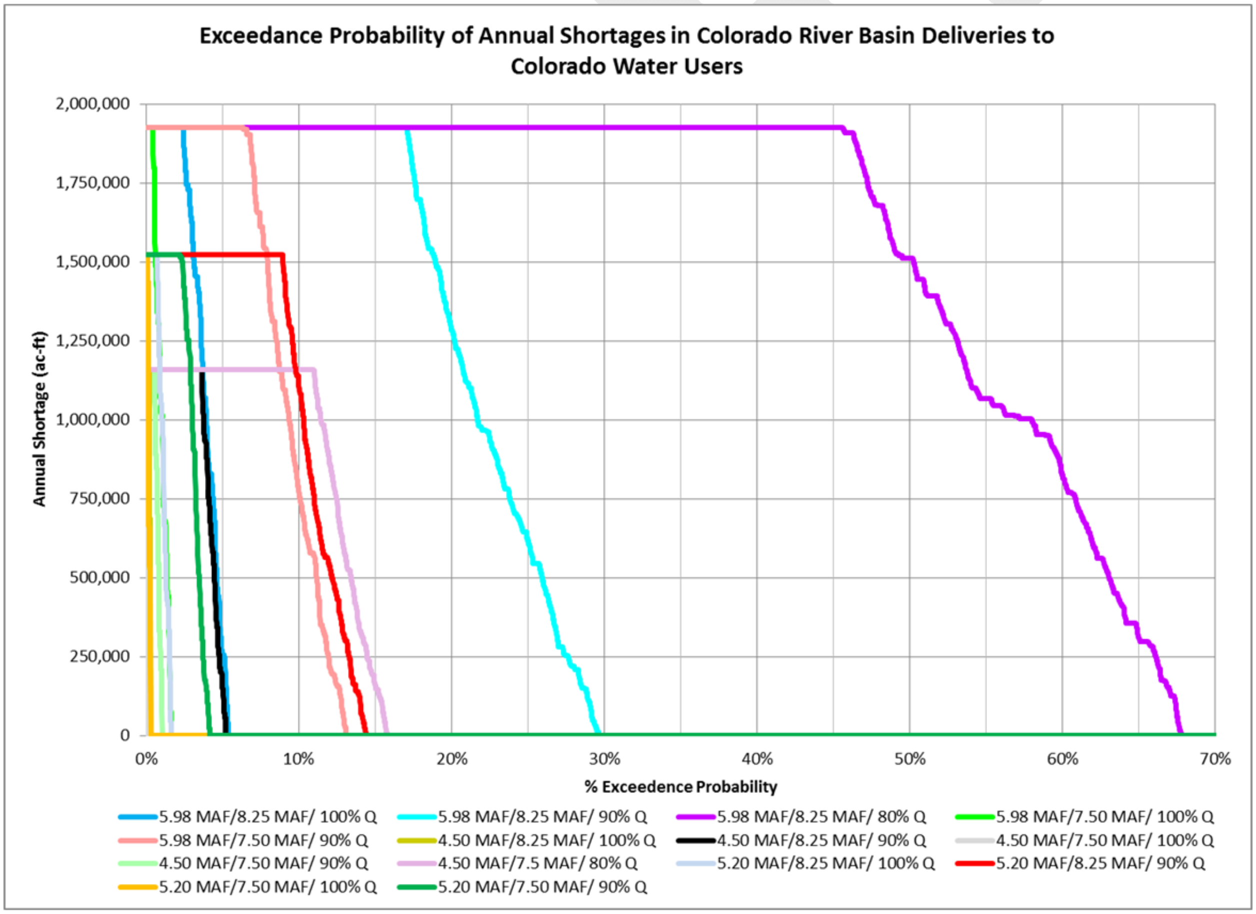


Table 9 – Probability that the Colorado Shortage in Meeting Upper Basin Demands will be Greater than 500,000 AF in Any Year

Scenario	Scenario Description (Upper Basin Demands / Lees Ferry Flows / Hydrology)	Probability
1	5.98 MAF / 8.25 MAF / 100% Q	4.6%
2	5.98 MAF / 8.25 MAF / 90% Q	25.9%
3	5.98 MAF / 8.25 MAF / 80% Q	63.0%
4	5.98 MAF / 7.50 MAF/ 100% Q	1.4%
5	5.98 MAF / 7.50 MAF / 90% Q	11.1%
6	4.50 MAF / 8.25 MAF / 100% Q	0.3%
7	4.50 MAF / 8.25 MAF / 90% Q	4.5%
8	4.50 MAF / 7.50 MAF / 100% Q	0.0%
9	4.50 MAF / 7.50 MAF / 90% Q	0.8%
10	4.50 MAF / 7.50 MAF / 80% Q	13.4%
11	5.20 MAF / 8.25 MAF / 100% Q	1.3%
12	5.20 MAF / 8.25 MAF / 90% Q	12.2%
13	5.20 MAF / 7.50 MAF / 100% Q	0.2%
14	5.20 MAF / 7.50 MAF / 90% Q	3.5%

The following observations can be drawn from these Basin Model simulation results.

- The most frequently occurring durations of shortages, including shortages greater than 500,000 AFY, are in the 2-3 year and 4-6 year categories for all of the scenarios.
- Shortage periods of 11 or more years can occur for the highest assumptions for Upper Basin demands (5.98 MAF and 5.2 MAF) and Lees Ferry flows (8.25 MAF).
- No shortages occur for the best case conditions for Upper Basin demands (4.50 MAF), Lees Ferry flows (7.50 MAF) and hydrology (100 percent of historical).
- Very few shortages occur for any of the scenarios with Upper Basin demands at 4.50 MAF and hydrology at 90 percent or 100 percent of historical, or with full historical hydrology and Lees Ferry flow obligations at less than 8.25 MAF. The need for a Water Bank may be triggered only if future water demands increase substantially and a concurrent reduction in historical hydrology occurs.
- Relatively few shortage periods have an average annual magnitude of less than 500,000 AF, so most shortage periods would trigger the need for the Water Bank.
- There are substantial differences in shortage conditions over the ranges simulated for Upper Basin demands, Lees Ferry flow obligations, and hydrologic conditions. For example, the frequency of years with shortages of any magnitude varies from 0 to 60 percent depending on the scenario.

4.2.2 Sensitivity Analysis

Results for the 14 scenarios were used to evaluate sensitivity of triggering the need for the Water Bank to model assumptions. Sensitivity of demand shortages to changes in hydrology are shown in **Figure 5** and **Figure 6.** Reductions in streamflow due to climate change or other factors have a significant impact on the frequency with which the Water Bank could be required. In general, the impact is not linear, with larger streamflow reductions causing disproportionally larger demand shortages.

Figure 5 – Sensitivity of Shortages and Storage to Hydrology (4.50 MAF UB Demand / 7.50 MAF Lees Ferry Flows)

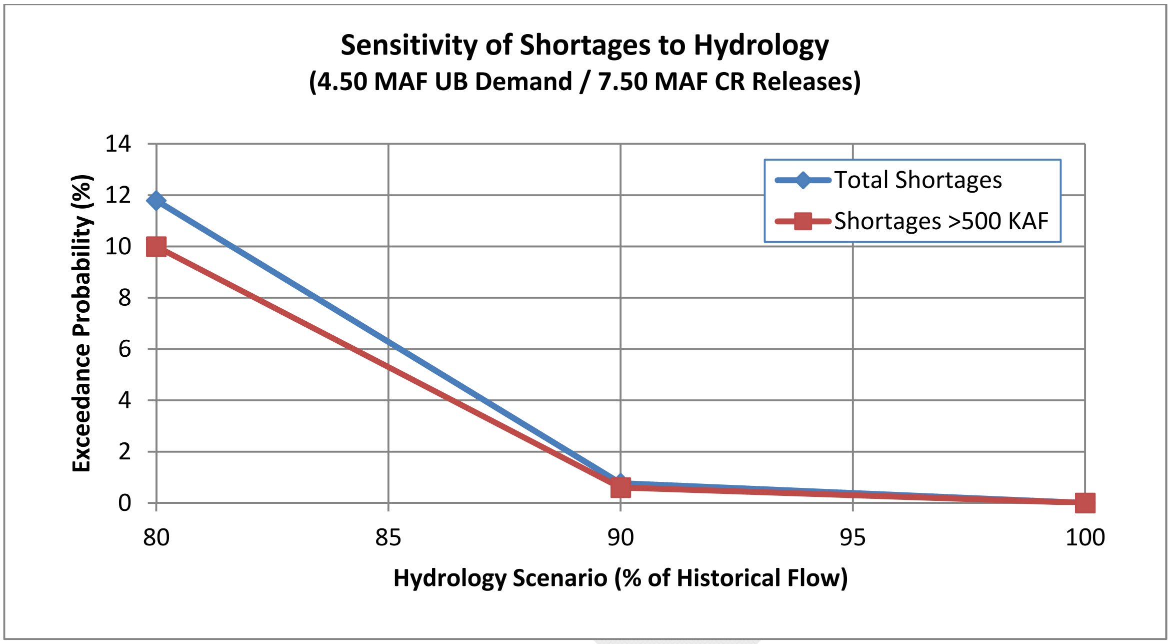
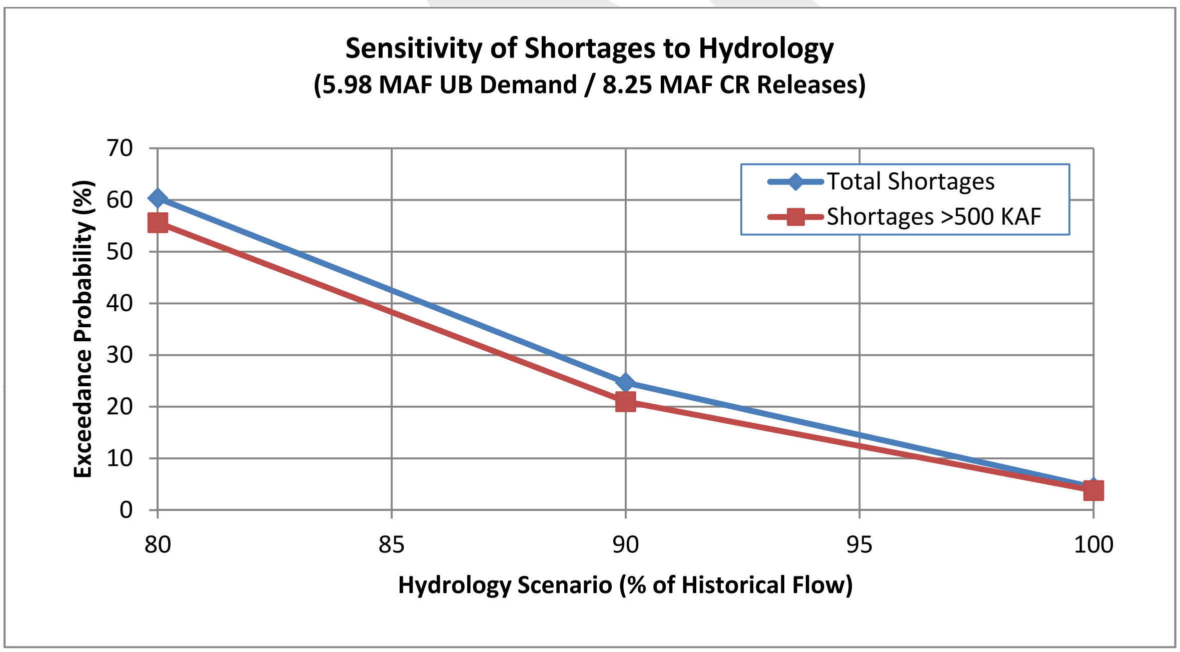


Figure 6 – Sensitivity of Shortages and Storage to Hydrology (5.98 MAF UB Demand / 8.25 MAF Lees Ferry Flows)



Sensitivity of demand shortages to changes in Upper Basin demands is summarized in **Figure 7** and **Figure 8.** The frequency with which the Water Bank could be needed does not increase dramatically when the Upper Basin demand is increased from 4.50 MAF to 5.20 MAF, but the frequency increases more significantly when the demand increases to 5.98 MAF.

Figure 7 – Sensitivity of Shortages and Storage to Upper Basin Demand (8.25 MAF Lees Ferry Flows / 100% Hydrology)

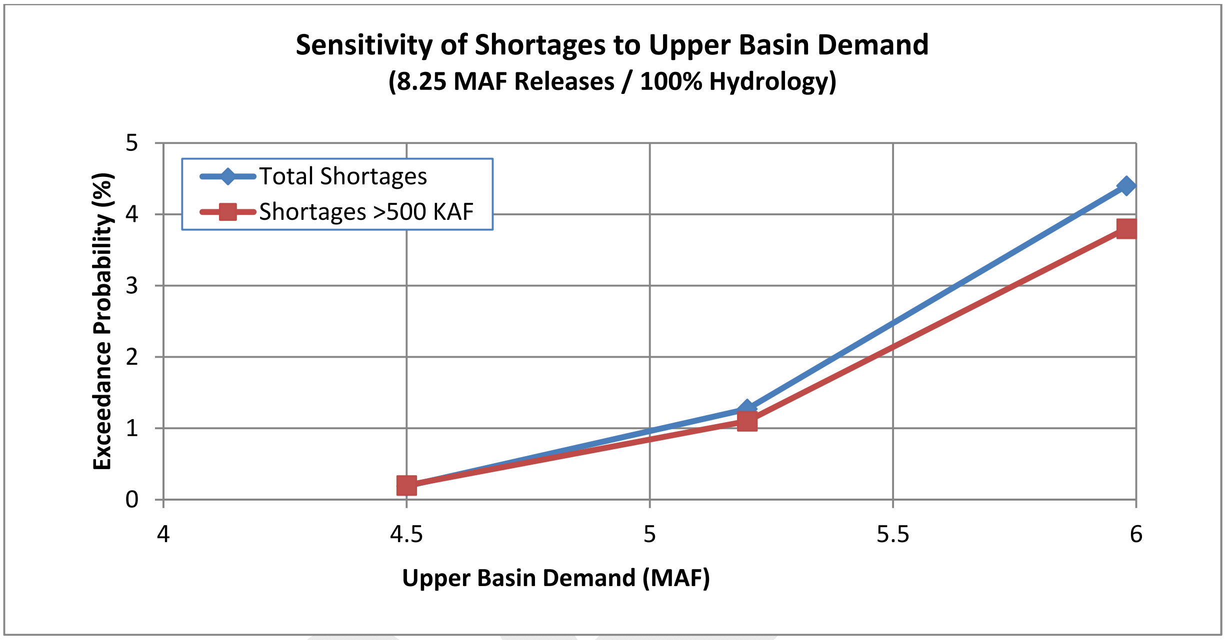
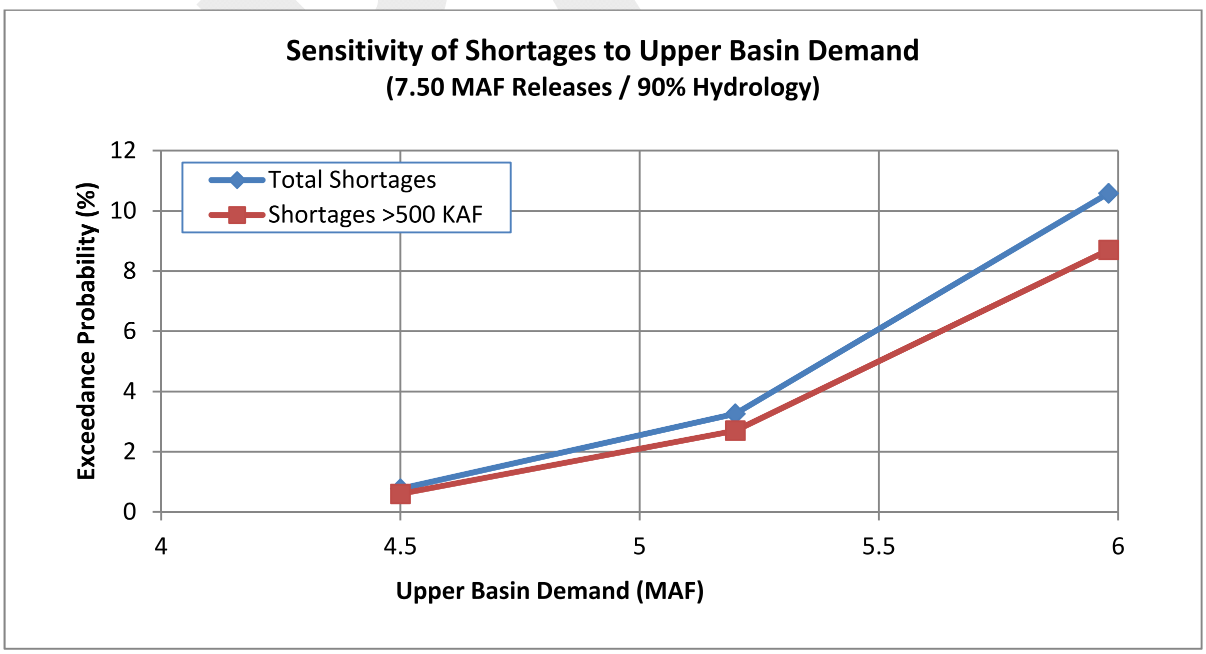


Figure 8 – Sensitivity of Shortages and Storage to Upper Basin Demand (7.5 MAF Lees Ferry Flows / 90% Hydrology)



4.3 Curtailment Analysis Conclusions

Results of the curtailment analysis using the Basin Model must be treated carefully due to the simplifying assumptions used in creating the model. Basin Model results are likely useful in comparing relative system performance between demand and hydrology scenarios. However, results are not recommended for use in estimating specific statistics of potential curtailments of diversions in Upper Division States to meet the non-depletion obligation because the model does not simulate individual reservoirs or their operations, individual water rights, or the complexity of water rights administration procedures, particularly during shortage periods. Moreover, this model does not reflect current operations of Glen Canyon Dam under the 2007 Interim Guidelines. Definitions used for triggers for curtailments are not necessarily how water users and state and federal agencies would operate their systems during drought periods, and longer periods of synthetic hydrology are needed to develop better estimates of shortage statistics.

With these caveats and many others not stated here, the following conclusions were drawn related to the frequency with which conditions could trigger use of the Water Bank by Colorado water users.

- The frequency of potential Water Bank use varies over the range of scenarios evaluated from 0 percent to over 50 percent of the years.
- Durations of shortages that could trigger use of the Water Bank vary from 1 year to over 15 years, with typical values of 6 to 10 years when based on system reservoir storage less than 25 percent of total reservoir capacity.
- The majority of average shortage magnitudes exceed a trigger amount of 500,000 AFY; the frequency of Water Bank use is not significantly affected by setting the minimum trigger at 500,000 AF rather than 0 AF.
- The ultimate impact of climate change on runoff in the Colorado River Basin will significantly affect the frequency with which the Water Bank could be used. In the Basin Model simulations, a 10 percent reduction in long-term streamflow increased the percentage of years with a shortage >1,400,000 AF from 3.4% to 20% with 5.98 MAF Upper Basin demand and 8.25 MAF Lees Ferry flows.
- Growth in Upper Basin demands will increase the frequency of potential Water Bank use. In the Basin Model simulations, scenarios with 4.50 MAF Upper Basin demand had a frequency of potential Water Bank use of 0 to 41 percent depending on the Lees Ferry flow and hydrology assumptions. Scenarios with 5.98 MAF Upper Basin demand had a frequency of potential Water Bank use of 7 to 96 percent.
- The need for the Water Bank would increase significantly under future conditions with a substantial increase in demand and a concurrent substantial reduction in long-term hydrology. Need for a Water Bank and additional water development in the basin may be interdependent. Without additional water development a Water Bank may not be needed, and conversely a Water Bank may be a strategy for mitigating the risk of additional water development. However, firm predictions are not possible based on the level of analysis described in this report.
- The frequency of using the Water Bank would be greater if used as a proactive management strategy compared to use as a reactive mitigation strategy.
- Without the ability to make firm predictions, the technical review committee of the Water Bank Group agreed that the length and depth of diversion limitations that would necessitate use of a Water Bank in Scenario 12 represented a reasonable range of future conditions that was sufficient for evaluating the feasibility of water banking at this phase of the Water Bank study. Thus Scenario 12 was selected for study in greater detail. Shortage conditions similar to those shown in Scenario 12 would occur under several other combinations of demand, Lees Ferry flows and future hydrology. As such, the results based on Scenario 12 are generally transferrable to other scenarios that exhibit the magnitude and duration of shortages that may occur in the future.

5.0 WATER BANK SUPPLY-USE SCENARIOS

5.1 Scenario Analysis Tool

A Scenario Analysis Tool (SAT) was created to allow for rapid evaluation of water supply and water use scenarios. The SAT was developed in Visual Basic. Input data for potential water uses and sources of supply is stored in a Microsoft Access database.

The SAT has two windows – one for water supplies and one for water uses. The water supply window allows the user to make the following choices for defining scenarios:

- Water rights used to supply water to the Water Bank (pre-1922 or pre-1929)
- Crop types contributing water to the Water Bank
- Water Divisions contribute water to the Water Bank
- Level of participation from irrigators in each Water Division
- Level of deficit irrigation on all irrigated areas

The water use window allows the user to make the following choices for defining scenarios:

- Types of demands to be met from Water Bank supplies (West Slope M&I, East Slope M&I or West Slope agriculture not readily deficit irrigated or fallowed)
- Percent of each type of demand to be met from Water Bank supplies
- Percent of demands that would be met from local supplies or other non-Water Bank sources

The SAT allows the user to estimate:

- the irrigated acreage and percent of deficit irrigation needed to meet assumed demands
- the categories of demands that could be met by assumed Water Bank supplies from various sources

Screen shots of the water supply and water use windows are shown in **Figure 9** and **Figure 10**.

Figure 9 – Scenario Analysis Tool Water Supply Window

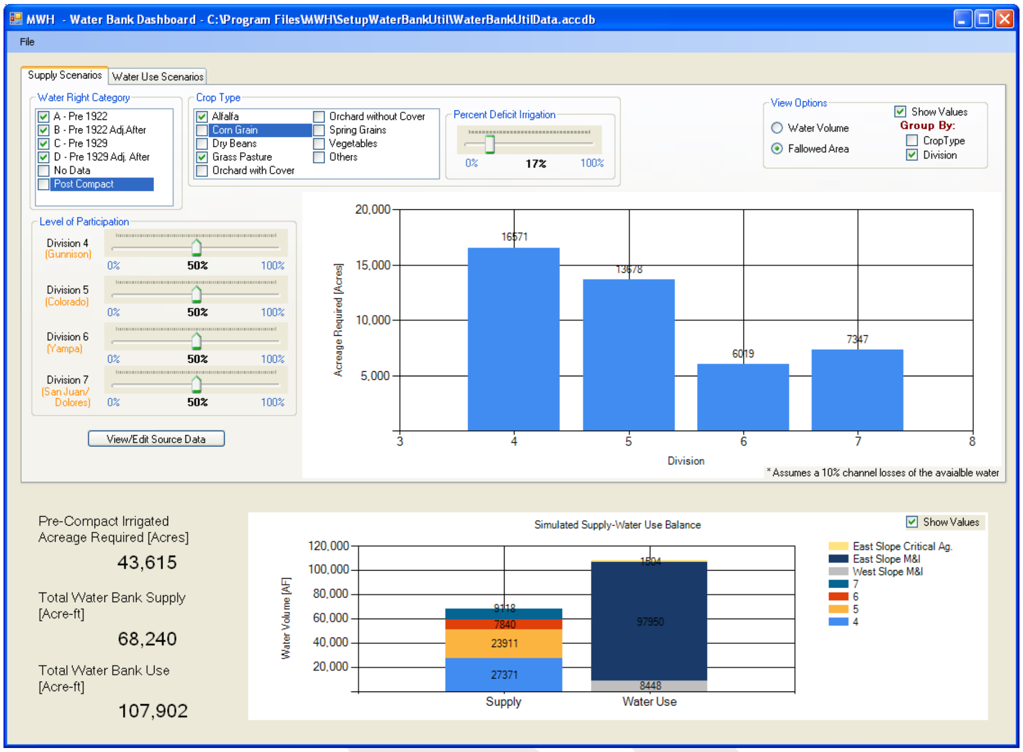
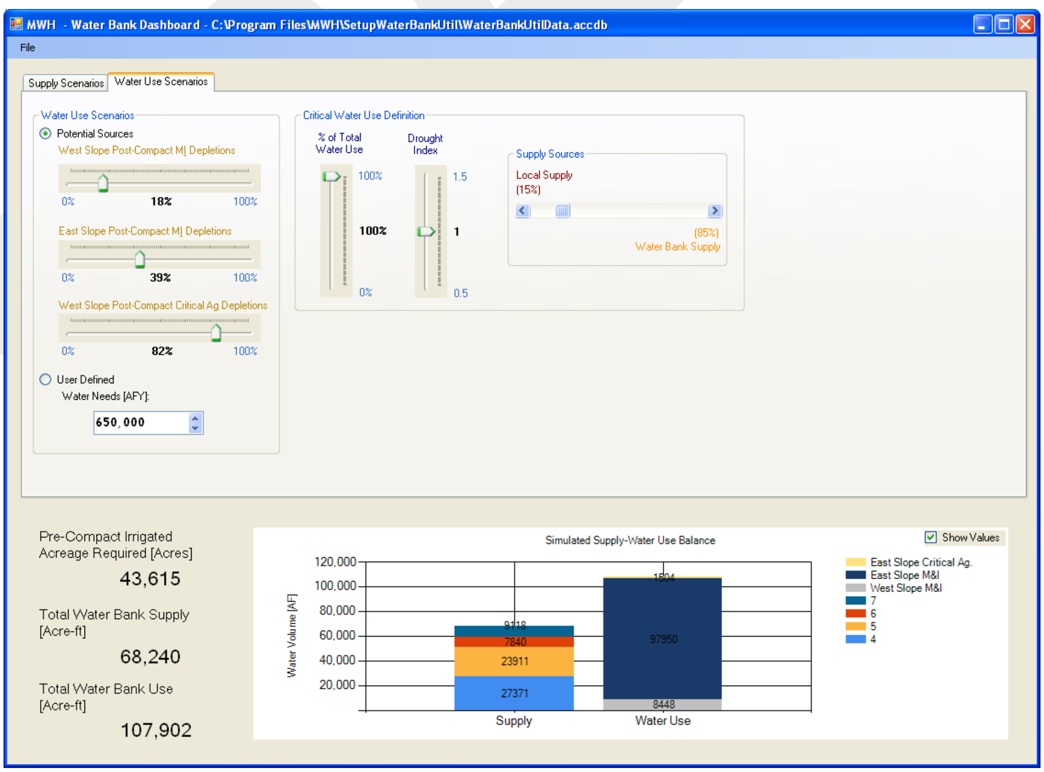


Figure 10 – Scenario Analysis Tool Water Use Window



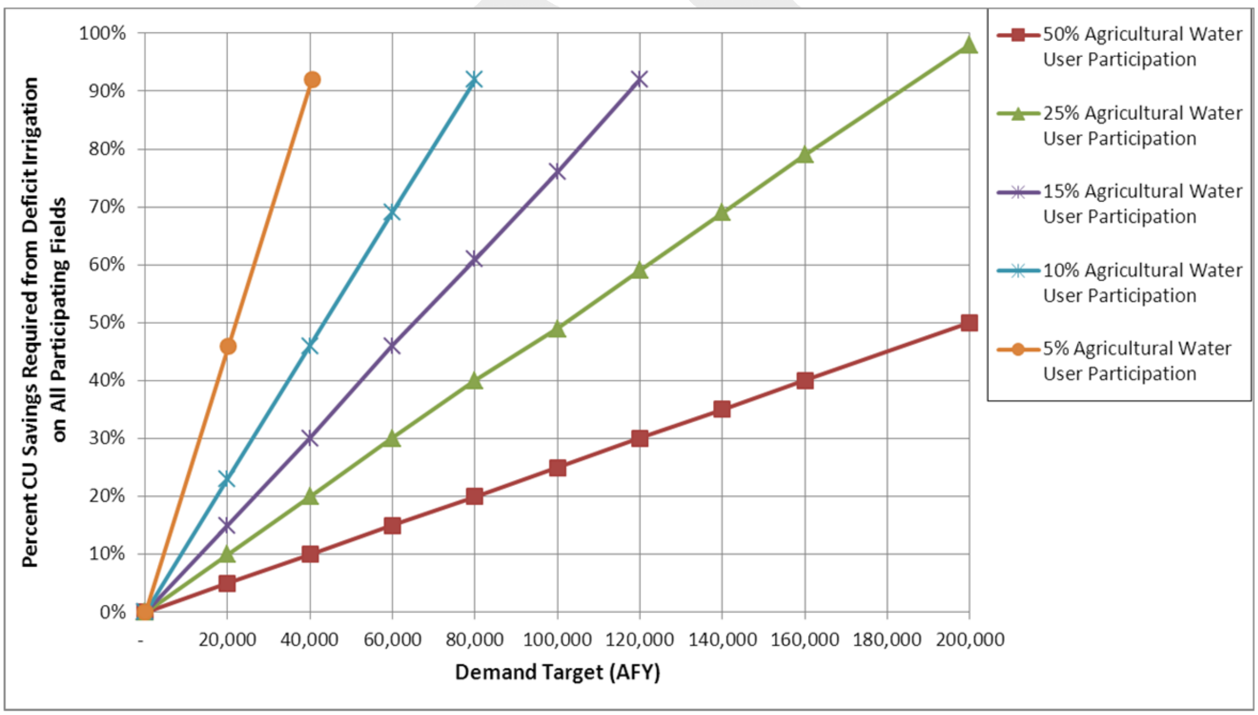
The SAT will be posted on the Colorado River Water Conservation District web site.

5.2 Results of Scenario Analysis

In the *Basic Supply and Water Use Comparison Scenarios for the Colorado River Compact Water Bank Feasibility Study Technical Memorandum* a range of supply and use scenarios was developed for potential Water Bank utilization to test the feasibility of the Water Bank for meeting Colorado's water needs during droughts that significantly reduce flows in the river and limit the Upper Division States' ability to supply all of its demands and meet the Upper Division's non-depletion obligation. The TM is included in **Appendix D**. Scenarios were prepared by assuming a level of use generated primarily from East Slope and West Slope post-Compact M&I users (Section 2.0), then showing how that use could be met from various combinations of supply from West Slope pre-Compact agricultural water users (Section 3.0). For this analysis, only water uses for individual years were considered; complexities of multi-year shortages or pro-actively banking water in reservoir space prior to a curtailment condition were not considered at this level.

Results of the scenario analysis for potential Water Bank uses met from deficit irrigation of pre-Compact water rights applied to alfalfa and grass pasture in all West Slope water divisions are shown in **Table 11** and **Figure 11**. Alfalfa and grass pasture were selected for this analysis because they comprise the majority of irrigated crops in the study area.

Figure 11 – Percent Deficit Irrigation on Participating Alfalfa and Grass Pasture Acreage Required to Meet Assumed Water Bank Water Use



Several conclusions can be drawn from this simple comparison of potential supply and use for the Water Bank.

- An estimate of the maximum annual use that could potentially be met from the Water Bank under a range of feasible assumptions is about 100,000 AFY. This could be met with either: 25 percent deficit irrigation on 50 percent of the qualifying alfalfa and grass pasture lands; 50 percent deficit irrigation on 25 percent of the qualifying alfalfa and grass pasture lands; or full deficit irrigation on 12 percent of the qualifying alfalfa and grass pasture lands.
- Total current post-Compact depletions in Colorado (excluding reservoir evaporation) are an average of about 350,000 AFY. The Water Bank alone could not feasibly compensate for all potential curtailments of uses of Colorado River and tributary water. As population growth and post-Compact water use increase in Colorado, this shortfall will become larger.
- The scenario analysis assumes pre-1929 water rights would be administered as pre-Compact water rights. The scenario analysis assumes only acreage supporting alfalfa and grass pasture would be deficit irrigated to contribute consumptive use to the Water Bank. If acreage irrigating small grain, corn and dry beans also supplied water to the Water Bank, the maximum potential supply could be increased by up to about 8 percent.
- To provide quantities of supply that are large enough to meet a substantial portion of the curtailed post-Compact demands of Water Bank users, it is likely that a significant percentage of qualifying irrigators on the West Slope would have to be willing to provide supplies by deficit irrigating or fallowing cropland. The level of participation required to meet this level of use could be in the range of 25 to 50 percent. Based on **Table 4**, this would result in deficit irrigation or fallowing on 130,000 to 260,000 acres on the West Slope.

6.0 SUMMARY OF CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The potential average annual water use associated with East Slope and West Slope post-Compact M&I depletions could be up to approximately 350,000 AFY. These values are based on current water use estimates provided by the Water Bank technical group and do not include reservoir evaporation obligations.

The NRCE study indicated that deficit irrigation is feasible and best suited for grass pasture and alfalfa. Deficit irrigation can be implemented for a single year or on a rotating basis without significantly impacting future production. Fallowing may be more feasible for annual crops like small grain, corn, and beans. Vegetables and orchards are not considered feasible for deficit irrigation or fallowing.

Grass pasture and alfalfa represent over 90 percent of the irrigated acreage in the study area and would provide virtually all of the Water Bank supply. The small grains, grain corn, and dry beans comprise about 8 percent of the total irrigated acreage in the study area. The acreage of irrigated lands with alfalfa, grass pasture, small grain, corn grain, and dry beans with pre-1929 water rights is approximately 568,900 acres.

The potential water supply generated from deficit irrigation or fallowing of lands irrigated with pre-Compact water rights was estimated. The maximum potential consumptive use available from full deficit irrigation of irrigated lands with pre-1929 water rights is approximately 973,500 AFY[1]. Maximum potential supply is based on estimates of water supply limited consumptive use. The estimated maximum potential supply available was adjusted to add 33,000 AFY allocated for Tribal Rights, subtract 37,700 ACY for post-Compact reservoir releases, and apply a reduction of 10 percent for transit losses.

Supply-use scenarios for a Water Bank were developed by assuming supply comes from deficit irrigation of alfalfa and grass pasture in all four Upper Colorado River water divisions and by varying the level of participation by West Slope irrigators and the level of deficit irrigation to meet the use target. Scenarios were developed to meet uses of up to 200,000 AFY from the Water Bank. However, the total current post-Compact depletions in Colorado (excluding CRSP reservoir evaporation) are presently on the order of 350,000 AFY. The Water Bank alone could not compensate for all the potential curtailments of uses Colorado River and tributary water. The level of participation required to meet significant East and West Slope uses could be in the range of 25 to 50 percent, requiring partial or full deficit irrigation on 130,000 to 260,000 acres on the West Slope but these are just coarse assumptions for purposes of this study.

The frequency of potential Water Bank use varies over the range of Upper Basin demand and hydrology scenarios evaluated from 0 percent to over 50 percent of the years. Durations of shortages that could be mitigated by use of the Water Bank vary from 1 year to over 15 years, with most common values of 2 to 6 years. The frequency of Water Bank usage would be affected by whether it is used proactively to try to avoid flow shortages leading to mandatory depletion curtailments, or only reactively after depletion curtailments have been mandated. Future reductions in average annual Colorado River Basin streamflow and/or growth in Upper Basin demand would increase the frequency of potential Water Bank use.

[1] Based on subsequent more detailed analyses by the State of Colorado, this value could be as high as 1,250,000 AFY.

6.2 Recommendations

1. Phase 1 of the Water Bank Feasibility Study has found that there appear to be conditions under which the Water Bank could be a feasible strategy for mitigating the effects reduced flow in the Colorado River that may otherwise require curtailment of Colorado River and tributary water. Therefore, it is recommended that Phase 2 be initiated to test the on-farm feasibility of deficit irrigation and fallowing and approaches for documenting consumptive use savings.
2. The feasibility of deficit irrigation is critical to long-term success and viability of the Water Bank. Additional research is needed on the feasibility and practical limits of deficit irrigation in the climate zones and for the crop types prevalent on the West Slope.
3. The Basin Model used in this feasibility study is not robust enough to accurately estimate the magnitude and frequency of potential shortages on the Colorado River that would call for mitigation through use of the Water Bank. More detailed modeling, for example using the "Big River" model of the Colorado River basin, will eventually be needed to answer the important question of how often the Water Bank could be needed.
4. The feasibility of the Water Bank is dependent on the participation of a significant portion of West Slope irrigators. An outreach program is needed to educate them on the potential Water Bank operations, long-term effects of deficit irrigation, and the importance of a mitigation strategy for Colorado to deal with potential future shortages on the Colorado River.
5. A number of complex legal and water right administration questions will eventually need to be resolved before a Water Bank could be implemented. For example:

    - How will reduced consumptive use at the farm be shepherded to the state line and ultimately to Lees Ferry?
    - What is the appropriate managing entity and governance structure?
    - How will participating farmers be compensated?
    - How will the Colorado Water Bank operation be coordinated with Compact mitigation strategies used by other Upper Basin states?
    - How will operation of federal reservoirs in the Upper Colorado River Basin be coordinated with Water Bank operations?

A strategy for addressing these issues should be developed soon, as negotiations to resolve these issues will likely be long and time-consuming.

7.0 REFERENCES

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Leonard Rice Engineers, Inc. (2009d). Historic Crop Consumptive Use Analysis - Gunnison River Basin; Final Report. Denver, Colorado: s.n., October 2009.

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Water Bank Work Group Technical Committee. 2011. Categories of Existing West Slope and East Slope Water Uses – Task 1.2. November 18.

APPENDIX A

Categories of Existing West Slope and East Slope Water Uses

WATER BANK WORK GROUP
TECHNICAL SUBCOMMITTEE

Memorandum

Date: November 18, 2011 (final draft)

To: Chip Paulson, MWH

From: Water Bank Work Group – Technical Committee

Subject: Categories of Existing West Slope and East Slope Water Uses – Task 1.2

Task 1.2 of the Phase 1 Scope of Work (SOW) in the contract between with the Colorado River Water Conservation District (on behalf of the Water Bank Work Group) and MWH requires the Water Bank Work Group through its Technical Committee to provide to MWH categories of existing water uses. This memo is to provide that information to MWH.

West Slope Water Uses

The West Slope water use of 117,000 AF is based on Table 4-3 of SWSI 2010, column titled "Water Demand 2008", see attached. The water use includes commercial, institutional, light industrial, but not heavy or self supplied industrial such as coal power plants.

Of the 117,000 AF, 95% is assumed to be residential - 116,218 AF - and of that amount, half is assumed in-house 55,575 AF and half is assumed outside irrigation. The 55,575 AF of in-house use has an estimated consumptive use of 5% based on using a central sewer system. The 55,575 AF of outside irrigation is estimated to have a consumptive use of 60%.

Of the 117,000 AF, 5% (5,850 AF) is assumed to be commercial, institutional, and industrial (light) referenced as CII. The consumptive use is 80%.

The Self Supplied Industrial (SSI) demands were obtained from Table ES-2 of the SWSI 2010 Report. The total for the four western Colorado basins is 36,640 AF per year with the break down by basin being: Colorado – 5,480 AF, Gunnison – 260 AF, Southwest – 2,310 AF, and Yampa – 28,590 AF. The SSI water is assumed to be 100% consumed.

Table-I summarizes the west slope diversion and consumptive use by category.

TABLE I - WEST SLOPE EXISTING WATER USE CATEGORIES

	In-Door (Ac-Ft)	Out-Door (Ac-Ft)	CII (Ac-Ft)	SSI (Ac-Ft)	Total (Ac-Ft)
Water Diversion for Each Category of Use	55,575	55,575	5,850	36,640	184,741
Consumptive Use Factor	0.05	0.6	0.8	1.0	
Consumptive Use Volume	2,780	33,345	4,680	36,640	77,445

East Slope Water Uses

The existing water uses for the east slope are derived from information provided by Kerry Sundeen (of Grand River Consulting) on behalf of the Front Range Water Council (FRWC). The FRWC provided one page with Tables 1,2,3 and a second page with Table A, which are attached. The amounts in Tables 1,2,3 were adjusted slightly in Table A. The Table A data is included in Tables II and III below. East Slope water uses are considered 100% consumptive because no return flow accrues to the Colorado River system.

TABLE II - EAST SLOPE EXISTING WATER USE CATEGORIES

	In-Door	Out-Door	CII	Total
	(Ac-Ft)	(Ac-Ft)	(Ac-Ft)	(Ac-Ft)
Water Diversion for Each Category of Use	131,464	100,337	128,512	360,313
Consumptive Use Factor	100%	100%	100%	
Consumptive Use Volume	131,464	100,337	128,512	360,313

Summary Table-III

Table-III summarizes the west and east slope depletions and the amount that is estimated to be pre and post Compact, based on planning level depletions. The west slope data is from Table-I and the agriculture amount is from Table 4-12 of SWSI 2010 (attached). The east slope data is from Table -III.

TABLE III

Category of Use	(1) Average Annual Depletion	(2) Pre-Compact Rights - Average Depletion	(3) Post-Compact Rights - Average Depletion	(4) Range in Annual Depletions
West Slope				
SSI	36,640	3,700 (10%)	32,940 (90%)	
Residential - Indoor	2,780	1,390 (59%)	1,390 (50%)	
Residential - Irrigation	33,345	16,670 (50%)	16,675 (50%)	
Com / Ind.	4,680	470 (10%)	4,210 (90%)	
Sub-Total =	**77,445**	**22,230**	**55,215**	?
East Slope				
Agriculture	180,486	8,091	172,395	
SSI	-	?	?	
Residential - Indoor	131,464	23,534	107,930	
Residential - Irrigation	100,337	17,962	82,375	
Com / Ind.	128,512	23,341	105,170	
Sub-Total =	**540,799**	**72,928**	**467,870**	215,000 to 763,000
Evaporation	**117,000**			
Grand Total =	**735,224**			

Table 4-3 M&I Forecast by River Basin

Basin	No. Utilities in Database	No. Updated since SWSI	SWSI GPCD	GPCD based on Update	Water Demand (AF) 2008	Baseline Water Demands (AFY)				Water Demands with Passive Conservation (AFY)			
						2035	2050 Low	2050 Medium	2050 High	2035	2050 Low	2050 Medium	2050 High
Arkansas	65	40	214	185	196,000	299,000	327,000	349,000	380,000	273,000	298,000	320,000	352,000
Colorado	55	46	244	182	63,000	115,000	135,000	150,000	174,000	106,000	125,000	140,000	164,000
Gunnison	21	18	226	174	20,000	36,000	40,000	43,000	46,000	33,000	36,000	39,000	43,000
Metro	100	35	191	155	437,000	627,000	695,000	717,000	785,000	557,000	620,000	642,000	709,000
North Platte	1	1	267	310	500	600	700	800	900	600	700	700	800
Rio Grande	9	4	332	314	18,000	24,000	26,000	27,000	30,000	22,000	24,000	26,000	28,000
South Platte	60	53	220	188	206,000	338,000	377,000	397,000	430,000	311,000	347,000	367,000	401,000
Southwest	16	9	246	183	22,000	38,000	42,000	47,000	52,000	35,000	39,000	43,000	49,000
Yampa-White	10	8	230	230	12,000	21,000	25,000	31,000	41,000	20,000	23,000	30,000	40,000
Statewide	**337**	**214**	**210**	**172**	**974,500**	**1,498,600**	**1,667,700**	**1,761,800**	**1,938,900**	**1,357,600**	**1,512,700**	**1,607,700**	**1,786,800**

Notes: Forecast is produced by aggregating the county forecast. If a county falls within two basins, the demand is split according to the portion of population in each basin.

Table ES-2 Summary of Self-Supplied Industry Demands by Basin (AFY)

Basin	Sub-Sector	2008	2035	2050 Low	2050 Med	2050 High
Arkansas	Energy Development	—	—	—	—	—
	Large Industry	49,400	49,400	49,400	49,400	49,400
	Snowmaking	—	—	—	—	—
	Thermoelectric	9,000	14,700	15,400	18,400	22,100
	Total	58,400	64,100	64,800	67,800	71,500
Colorado	Energy Development	2,300	500	200	4,700	10,700
	Large Industry	—	—	—	—	—
	Snowmaking	3,180	4,740	4,740	4,740	4,740
	Thermoelectric	—	—	—	—	—
	Total	5,480	5,240	4,940	9,440	15,440
Gunnison	Energy Development	—	—	—	—	—
	Large Industry	—	—	—	—	—
	Snowmaking	260	650	650	650	650
	Thermoelectric	—	—	—	—	—
	Total	260	650	650	650	650
Metro	Energy Development	—	—	—	—	—
	Large Industry	52,400	52,400	52,400	52,400	52,400
	Snowmaking	—	—	—	—	—
	Thermoelectric	12,000	12,000	12,600	15,000	17,900
	Total	64,400	64,400	65,000	67,400	70,300
Rio Grande	Energy Development	—	600	1,200	1,500	2,000
	Large Industry	—	—	—	—	—
	Snowmaking	—	—	—	—	—
	Thermoelectric	—	—	—	—	—
	Total	—	600	1,200	1,500	2,000
South Platte	Energy Development	—	—	—	—	—
	Large Industry	6,600	6,600	6,600	6,600	6,600
	Snowmaking	320	320	320	320	320
	Thermoelectric	21,400	35,400	37,200	44,400	53,100
	Total	28,320	42,320	44,120	51,320	60,020
Southwest	Energy Development	—	—	—	—	—
	Large Industry	—	—	—	—	—
	Snowmaking	410	410	410	410	410
	Thermoelectric	1,900	3,900	4,100	4,900	5,900
	Total	2,310	4,310	4,510	5,310	6,310
Yampa-White	Energy Development	2,000	6,000	3,900	7,500	41,800
	Large Industry	6,100	9,500	9,500	9,500	9,500
	Snowmaking	290	570	570	570	570
	Thermoelectric	20,200	38,300	36,700	40,500	44,000
	Total	28,590	54,370	50,670	58,070	95,870
Total All Basins		**187,760**	**235,990**	**235,890**	**261,490**	**322,090**

TABLE 1

DRAFT Summary of Colorado River Basin Transbasin Depletions (Acre Feet)

(Exports adjusted for Reservoir Storage)

	Grand River Ditch	Berthoud Pass Ditch	Ewing Ditch	Columbine Ditch	Wurtz Ditch	Adams Tunnel (Divs)	Granby Reserolvr EOM Storage	Granby Reservoir Storage (Diff)	Adams Tunnel (Adjusted)	Moffat Tunnel	Straight Creek Tunnel	Vidler Tunnel	Roberts Tunnel (Divs)	Dillon Reservoir EOM Storage	Dillon Reservoir Storage (Diff)	Roberts Tunnel (Adjusted)	Hoosier Tunnel	Homestake Tunnel (Divs)	Homestake Reservoir EOM Storage	Homestake Reservoir Storage (Diff)	Homestake Tunnel (Adjusted)	Busk-Ivanhoe Tunnel	Boustead Tunnel	Twin Lakes Tunnel	Annual Depletion Total (AF)
1990							295,856							253,907					9,943						
1991	18,379	624	872	1,596	2,263	199,237	336,465	40,609	239,846	64,904	272	1,241	66,041	252,328	(1,579)	64,462	12,357	587	35,795	25,851	26,439	5,702	61,135	42,984	543,073
1992	21,330	1,009	929	1,612	1,651	198,280	339,886	3,421	201,701	49,890	335	1,146	85,529	248,927	(3,401)	82,128	11,653	26,909	33,625	(2,170)	24,739	5,211	57,064	41,967	502,363
1993	24,731	1,258	1,631	2,474	4,129	206,359	447,244	107,358	313,717	34,468	285	761	124,160	237,837	(11,090)	113,070	11,036	28,107	42,480	8,856	36,962	4,977	88,737	62,672	700,907
1994	17,838	874	794	1,474	2,078	233,224	413,786	(33,458)	199,766	43,314	304	465	73,822	239,949	2,112	75,934	9,161	24,246	40,281	(2,200)	22,047	4,097	55,045	42,852	476,044
1995	20,043	815	1,421	2,391	4,245	239,844	525,264	111,478	351,322	24,216	316	760	52,007	247,404	7,455	59,462	4,706	34,763	42,881	2,600	37,363	5,997	91,264	32,227	636,548
1996	22,806	1,529	1,440	2,499	4,209	207,887	499,605	(25,659)	182,228	51,053	264	268	36,917	[illegible]	(1,709)	35,208	11,492	38,686	40,893	(1,989)	36,697	2,453	38,537	34,852	425,535
1997	18,316	2,593	1,350	1,727	4,180	214,594	532,524	32,919	247,513	52,090	391	420	56,769	[illegible]	7,794	64,563	7,698	37,129	42,814	1,922	39,051	4,644	79,379	34,186	558,098
1998	21,106	1,490	775	1,668	2,075	202,198	495,539	(36,985)	165,213	35,622	302	423	[illegible]	[illegible]	(1,513)	29,029	10,684	24,937	41,617	(1,197)	23,739	4,127	53,997	47,450	397,699
1999	19,410	-	618	933	1,234	192,727	521,901	26,362	219,089	38,531	381	580	[illegible]	[illegible]	2,024	42,407	9,484	31,425	42,172	555	31,980	5,073	43,141	16,580	429,440
2000	18,539	-	1,024	1,742	2,684	228,811	463,088	(58,813)	169,998	54,454	388	332	[illegible]	[illegible]	(14,800)	79,172	10,365	24,137	42,129	(43)	24,094	5,232	50,695	42,060	460,778
2001	16,486	532	936	1,789	2,231	236,171	374,229	(88,859)	147,312	68,139	322	[illegible]	[illegible]	241,000	1,800	107,447	5,018	35,766	32,419	(9,710)	26,056	5,332	50,529	45,651	478,149
2002	9,373	247	192	780	647	270,697	176,676	(197,553)	73,144	33,814	191	[illegible]	[illegible]	153,000	(88,000)	42,512	3,398	26,509	17,054	(15,365)	11,145	2,683	15,782	20,574	214,801
2003	5,031	584	1,027	1,938	2,404	173,547	372,043	195,367	368,914	72,440	[illegible]	[illegible]	71,623	246,400	93,400	165,023	7,438	9,933	35,978	18,924	28,857	5,085	57,989	45,236	762,774
2004	14,604	401	499	1,212	1,585	241,535	275,991	(96,052)	145,483	61,215	[illegible]	[illegible]	90,644	218,400	(28,000)	62,644	6,477	23,155	34,900	(1,078)	22,077	5,273	28,588	35,554	386,311
2005	21,174	801	784	1,530	2,298	181,327	426,629	150,638	331,965	56,273	[illegible]	518	59,233	242,300	23,900	83,133	10,036	23,916	39,100	4,200	28,116	5,166	55,811	50,163	648,144
2006	19,484	839	963	1,942	2,925	293,359	382,095	(44,534)	248,825	[illegible]	[illegible]	627	111,405	246,600	4,300	115,705	13,260	32,489	41,200	2,100	34,589	4,828	62,336	54,674	646,570
2007	20,398	719	1,042	1,830	2,358	234,478	376,356	(5,739)	228,739	[illegible]	442	715	41,392	248,500	1,900	43,292	6,122	20,878	42,400	1,200	22,078	4,311	55,223	54,473	485,104
2008	22,921	703	1,443	87	1,278	287,657	408,329	31,973	[illegible]	[illegible]	547	1,060	76,913	252,100	3,600	80,513	10,964	26,823	42,000	(400)	26,423	4,883	90,790	64,535	697,473
2009	19,039	728	1,202	78	2,924	243,550	475,044	66,715	[illegible]	[illegible]	519	1,285	57,286	242,800	(9,300)	47,986	8,453	50,510	21,384	(20,616)	29,894	3,319	83,842	58,741	612,729
2010	13,309	533	919	352	1,690	226,648	492,044	17,000	243,648	31,034	503	953	54,281	229,800	(13,000)	41,281	10,066	9,011	37,297	15,913	24,924	3,254	56,658	46,813	475,936
min	5,031	-	192	78	647	173,547	176,676	(197,553)	73,144	24,216	191	268	30,542	153,000	(88,000)	29,029	3,398	587	17,054	(20,616)	11,145	2,453	15,782	16,580	214,801
max	24,731	2,593	1,631	2,499	4,245	293,359	532,524	195,367	368,914	85,028	547	1,285	130,512	254,000	93,400	165,023	13,260	50,510	42,881	25,851	39,051	5,997	91,264	64,535	762,774
mean (2001-2010)	16,182	609	901	1,154	2,034	238,897	375,944	2,896	241,792	56,746	412	668	79,894	232,090	(940)	78,954	8,123	25,899	34,373	(483)	25,416	4,413	55,755	47,641	540,799
mean (1991-2010)	18,216	814	993	1,483	2,454	225,606	416,737	9,809	235,416	50,800	368	654	72,954	239,585	(1,205)	71,748	8,993	26,496	37,421	1,368	27,863	4,582	58,827	43,712	526,924

PROVISIONAL

Table 2

Draft Approximate Allocation of Current Exports (...)

		Denver Water	Aurora Water	Colorado Springs Utilities
Agricultural Demand[1] =	32%	0%	0%	0%
Residential Demand[2] =	44%	65%	70%	58%
In-House Single Family Residential = 39%		33%	40%	45%
In-House Multi-Family Residential = 17%		12%	27%	13%
Residential Irrigation = 43%		55%	33%	42%
Commercial and Industrial Demand[3] =	24%	35%	30%	42%
Total Export =	100%	100%	100%	100%

[1] 60% of C-BT and 49% of Fry-Ark

[2] 64% of Total Export minus Ag Demand

[3] 36% of Total Export minus Ag Demand

Table 3

Draft Attempt to Allocate Colorado River Basin Consumption by Category (Sept 8, 2011)

		West Slope	East Slope	Total
Agriculture		1,553,000	173,120	1,726,120
SSI		138,000	-	138,000
Residential		46,000	236,669	282,669
	(In)	*(4,000)*	*(134,225)*	*(138,225)*
	(Out)	*(42,000)*	*(102,444)*	*(144,444)*
Com / Ind.		6,000	131,211	137,211
Evaporation		92,000	25,000	117,000
	TOTAL =	1,835,000	566,000	2,401,000

Slightly modified in Table A

APPENDIX B

Colorado River Compact Colorado Water Bank Feasibility Study Water Supply Technical Memorandum

COLORADO RIVER COMPACT
COLORADO WATER BANK FEASIBILITY STUDY
WATER SUPPLY TECHNICAL MEMORANDUM

Prepared by:

Natural Resources Consulting Engineers, Inc.
131 Lincoln Avenue, Suite 300
Fort Collins, Colorado 80524
(970) 224-1851 / Fax (970) 224-1885

June 21, 2012

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1 INTRODUCTION

Fallowing and deficit irrigation are being considered as possible methods to protect some important uses of Colorado River and tributary water in Colorado in an extended drought or supply shortage, when water rights that were put into use after the Colorado River Compact became effective might otherwise be subject to curtailment. Colorado's uses of Colorado River and Colorado River tributary water is governed in part by the Colorado River Compact of 1922 and the Compact requires the states of the Upper Division (Colorado, New Mexico, Utah and Wyoming) not to cause the flow at Lee Ferry, Arizona to be depleted below 75,000,000 acre-feet during any consecutive 10-year period. The Compact also protects water uses that existed at the time of the Compact (referred to as "present perfected rights" in the Compact) by stating these rights are unimpaired by the Compact. The recent drought has demonstrated that the Upper Division states may not be able to meet both its non-depletion obligation and supply all of the Upper Division states' existing Colorado River uses, which may result in some Upper Division states' curtailing some post-Compact uses of Colorado River water to meet the Upper Division's non-depletion obligation. An informal group composed of representatives of the Colorado River Water Conservation District, Colorado Water Conservation Board, Front Range Water Council, Southwestern Water Conservation District, and The Nature Conservancy is investigating the development of a Colorado River Water Bank (Water Bank) that may prevent a curtailment of uses of Colorado River water, or allow continued critical water use in the event of a curtailment.

MWH Americas, Inc. (MWH) has contracted with the Colorado River Water Conservation District (CRWCD) to provide consulting services associated with the Water Bank. Natural Resources Consulting Engineers, Inc. (NRCE) is a subconsultant to MWH in the study. This report discusses the methodology and procedures used to estimate crop irrigation consumptive use for irrigated areas in the Colorado River Basin of Colorado (Basin) which is located in the western portion of Colorado. The reduced consumptive irrigation use from fallowing or deficit irrigation is the potential water supply for the Water Bank. A separate analysis was conducted to determine the agronomic feasibility and costs associated with fallowing and deficit irrigation of certain crops in the Basin (Allen, 2011). Fallowing or deficit irrigation can reduce overall consumptive water use in a basin and thereby provide a water supply for the Water Bank. The effectiveness of fallowing or deficit irrigation will determine the amount of water use that can be provided to the Water Bank. This report presents estimated consumptive irrigation requirements of various crops found in the Basin and determines potential water supply for the Water Bank. The general river basins and Colorado water divisions to be evaluated include the Gunnison River Basin (Division 4), Colorado River Basin (Division 5), Yampa River Basin (part of Division 6), and San Juan/Dolores River Basin (Division 7). This report does not consider the acceptance or willingness of growers to participate in a fallowing or deficit irrigation program.

2 METHODOLOGY

2.1 DEFINITIONS

The following are definitions of terms as used in this report.

Consumptive Irrigation Requirement - The consumed quantity of irrigation water that is required for full crop production. It is calculated as crop evapotranspiration (ET) minus effective precipitation. In this report consumptive irrigation requirement is limited to the field level. Consumptive irrigation requirement differs from consumptive irrigation use; consumptive irrigation use is the amount of irrigation water that is actually used accounting for shortages and other factors that decrease water use below calculated theoretical requirements. In this report the consumptive irrigation requirement is calculated using the Colorado StateCU model. The StateCU model uses the modified Blaney-Criddle equation with an adjustment for elevation to calculate crop ET. For grass pasture above 6,500 feet the original Blaney-Criddle with calibrated crop coefficients for high altitude option in the StateCU model was use. Effective precipitation is calculated in the StateCU model using the Natural Resource Conservation Service procedure describe in Technical Release 21 (SCS, 1970).

Consumptive Use - Use of water that renders it no longer available because it has been evaporated, transpired by plants, incorporated into products or crops, consumed by people or livestock, or otherwise removed from water supplies.

Consumptive Irrigation Use - The quantity of water that is absorbed by the crop and transpired or used directly in the building of plant tissue, together with that evaporated from the cropped area. In this report the consumptive irrigation use quantification is limited to the field level. At the field level consumptive water use does not include runoff or deep percolation.

Crop ET - Called Evapotranspiration (ET) or crop consumptive use. The amount of water used by vegetative growth in a given area by transpiration and that evaporated from adjacent soil or intercepted precipitation on the plant foliage in any specified time. Crop ET can be expressed in acre-feet/acre or in depth such as inches or feet.

Deep Percolation - Water that percolates below the crop root zone and cannot be used by plants.

Depletion - The water consumed within a service area and therefore is no longer available as a source of supply; that part of a withdrawal that has been evaporated, transpired, incorporated into crops or products, consumed by man or livestock, or otherwise removed.

Irrigation Distribution System - A system of ditches or pipelines and their appurtenances which convey irrigation water from the main canal or water source to the farm fields.

Diversion - A structure or pump from a river, lake, reservoir, or groundwater to another watercourse such as a canal, lateral, ditch or pipeline which conveys water to another location.

Effective Precipitation - That portion of precipitation which remains on the foliage or in the soil that is available for evapotranspiration, and reduces the withdrawal of soil water by a like amount. The portion of the precipitation falling on an irrigated area that is effective in meeting the crop ET.

Evapotranspiration (ET) — (1) The process by which plants take in water through their roots and then give it off through the leaves as a by-product of respiration; the loss of water to the atmosphere from the earth's surface by evaporation and by transpiration through plants. (2) The quantity of water transpired, retained in plant tissues, and evaporated from plant tissues and surrounding soil surfaces. (3) The sum of evaporation and transpiration from a unit land area.

On-farm Irrigation Efficiency - The percentage of irrigation water diverted at the farm level used for crop ET, leaching, germination, land preparation, etc.

Irrigation - The controlled application of water for agricultural purposes through man-made systems to supply water requirements for crop production or for turf, shrubbery, or wildlife food and habitat not satisfied by rainfall or applying water to soil when rainfall is insufficient to maintain desirable soil moisture for plant growth.

Irrigation Diversion Requirement - The amount of irrigation diversion from stream, river, reservoir, and/or groundwater required to meet the irrigation requirement. It includes crop irrigation requirement, conveyance and distribution losses, on-farm losses, and drainage system losses.

Irrigation Return Flow — Applied water which is not consumptively used and returns to a surface or ground water supply. In cases of water rights litigation, the definition may be restricted to measurable water returning to the stream from which it was diverted.

On-farm Irrigation Water Requirement - The quantity of water, exclusive of effective precipitation, that is required for crop production; it includes crop ET, leaching requirements, and on-farm losses.

Supply Limited Consumptive Irrigation Use – The actual consumptive use by irrigation at the field level based on the availability of water supply. This value accounts for irrigation shortages resulting from inadequate water supplies.

2.2 METHODOLOGY

The water supply for a potential Colorado River Water Bank is reduced consumptive irrigation use. Consumptive irrigation use for the Water Bank study was derived from consumptive irrigation requirements of crops in the Basin, which was estimated with the State of Colorado's Consumptive Use Model (StateCU) (Colorado Division of Water Resources, 2008). The model uses climate and temperature data from weather stations in the Basin. The monthly crop evapotranspiration (ET) for all crops except pasture was estimated using the SCS TR-21 Modified Blaney-Criddle method with an upward adjustment of crop coefficients for high elevation (10 percent increase per 1,000 meters of elevation). This adjustment was used by Leonard Rice Engineers, Inc. in their historic consumptive use analyses of Colorado River basins (Leonard Rice Engineers, 2009). The elevation adjustment was recommended in the *American Society of Civil Engineers Manuals and Reports on Engineering Practice No. 70, Evapotranspiration and Irrigation Water Requirements* (1990). For pasture above 6,500 feet in elevation the original Blaney-Criddle method with crop coefficients calibrated from ET data from lysimeter studies at high elevations was used. This method known as the Denver Water High Altitude is an option in the StateCU model. Effective precipitation is defined as the amount of precipitation available to meet consumptive use of a crop. A portion of the total precipitation is not available for crop use due to runoff and deep percolation below the root zone. The effective precipitation was estimated using the SCS TR-21 method and monthly precipitation data from the weather stations in the Basin.

Information on the type of crops grown in the Basin was obtained from a geographic information system (GIS) coverage of Colorado State Water Divisions 4, 5, 6, and 7 provided by MWH (Paulson & Sanadhya, 2011). The crop type classifications were based on various remote sensing techniques and are explained in South Platte Decision Support System (SPDSS) Memorandum 89.2 (Schneider, et al., 2006). Major crop types and characteristics of major crop types in Water Divisions 4-7 in Colorado are listed as follows:

<u>Alfalfa</u> - A flowering plant cultivated as an important forage crop in Colorado. It usually greens up during April and early May and is harvested 3-4 times during the growing season that ends in early October.

<u>Bluegrass</u> - A lawn grass, which comprises less than 2% of total irrigated area in Water Divisions 4-7 in Colorado.

<u>Corn Grain</u> -This includes corn used for grain or silage. Planted between late April to early May and harvested from September through November.

<u>Dry Beans</u> - This category includes pinto beans, white beans, and others. Planted between May to early June and harvested from late August to late September.

Grass Pastures - This includes pastures with cultivated grass and hay. It greens up in spring and early summer

Orchard w/ and w/o Ground Cover - Apples, peaches, plums, and grapes are the major crops grown in orchards the region.

Small Grains - Includes winter wheat, spring wheat, oats, barley, rye, and millet. Winter wheat is planted in September of the previous year and is harvested around early July. Oats and barley are planted in March or early April and harvested in July.

Sod Farm - Sod or turf is grass used to establish lawns. This comprises a negligible portion of the irrigated areas in Water Divisions 4-7 in Colorado.

Vegetables - Includes a variety of crops such as potatoes, squash, onions, pumpkins, lettuce, spinach, and broccoli.

Consumptive irrigation requirements for the following crops were evaluated in the StateCU model:

- Alfalfa
- Corn
- Dry Beans
- Grass Pasture
- Orchards with Cover
- Orchards without Cover
- Spring or Small Grains
- Vegetables

Other crops in the Basin included bluegrass, grapes, and sod. These crops represent a small percentage of the total cropped acreage. The crops were assigned consumptive irrigation requirement values based on the consumptive irrigation requirement values of similar crops (i.e. bluegrass and sod as grass pasture and grapes as orchards with cover).

Temperature and precipitation vary with elevation resulting in differences in crop ET, effective precipitation, and consumptive irrigation requirement. The StateCU model was used with data from weather stations at different elevations to determine the relationship of consumptive irrigation requirement to elevation. On a crop-by-crop basis the consumptive irrigation requirement was calculated from climate data to determine the relationship between consumptive irrigation requirement and elevation.

Consumptive irrigation requirements at different elevations were obtained for Divisions 4, 5, 6, and 7. By multiplying irrigated areas by the appropriate consumptive irrigation requirement values obtained from StateCU based on elevation, the potential irrigation water consumed by crops was estimated.

Because consumptive irrigation requirements are calculated based on a full supply of water, the amount of water historically available was also considered. The irrigation water supply limitations information was obtained from reports prepared by Leonard Rice Engineers, Inc. (2009 a-d) for the State of Colorado. These Historic Crop Consumptive Use Analysis reports developed for the Colorado, Gunnison, Yampa, and San Juan divisions were used to estimate the supply-limited consumptive irrigation use. These analyses considered available water supply in addition to the estimated consumptive irrigation requirement. The consideration of irrigation shortage allows a more accurate estimate of consumptive use and depletions in water supply.

3 DATA

The parcel cropping, water right, elevation, and location data for the analysis was obtained from the GIS database of irrigated parcels prepared by the State of Colorado. The data set is based on 2005 aerial photography, which is the most recent data set of irrigated acreage available from the State of Colorado. The acreage from this 2005 aerial photography is less than acreage determined from analysis of 1993 and 2000 aerial photography. The 2010 Statewide Water Supply Initiative (SWSI) analysis of agricultural consumptive use adopted the irrigated acreage values from the 1993 mapping, because that data was subject to better field verification than the more recent data. Different data sets of irrigated acreage from different time periods rarely agree, due to differences in accounting methodologies, accuracy of mapping, and actual differences in irrigated area. The 2002 drought in western Colorado and the recent economic downturn are believed to have resulted in some previously irrigated lands being taken out of production. In addition, SWSI forecasts a decline in irrigated acreage in the Colorado River Basin between 2010 and 2050. As a result of these factors, the 2005 irrigated acreage data available from the State of Colorado was used for this analysis. This provides a conservative estimate for current conditions and reflects the downward trend predicted for irrigated agriculture in Colorado.

The climate data used to calculate Crop ET and effective precipitation was obtained from weather stations in the Basin. This data coupled with the estimated consumptive irrigation requirement provides information to determine potential water supplies from fallowing or deficit irrigation.

3.3 DATA ANALYSIS

A database of irrigated parcels was developed for each division using Microsoft Access. The database allows development of consumptive irrigation requirement reports by criteria that include crop, diversion, priority date, location, or elevation. The database also includes the consumptive irrigation requirements for crops by 500-foot elevation band. This database can be used to identify potential water supplies for proposed Water Bank demand scenarios. The parcel table includes the following attributes:

- Parcel identification,
- Crop type,
- Irrigation type,
- Area,
- Elevation,
- Diversion,
- Appropriation date,
- Adjudication date,

- Location coordinates,
- Water use type, and
- Comments

3.4 IRRIGATED AREAS

The acreage, crop, and elevation used to determine consumptive irrigation requirements in each division were provided to NRCE by MWH as GIS database files (Paulson & Sanadhya, 2011). Plate 1 shows the location and crop type (grain includes corn) of the irrigated lands in the Basin. Consumptive irrigation water use within these divisions affects the water supply available for the Water Bank. There is a portion of Division 6 located in the northeast corner that does not contribute flow to the Colorado River. This area which includes Jackson County is part of the North Platte River basin and was omitted from the study.

The GIS databases contained information for irrigated parcel in each division. Deficit or non-irrigation of alfalfa and grass pasture, along with fallowing of corn, spring grains, and dry beans were identified as providing the best opportunities for providing water for the Water Bank. Figure 1 shows the combined crop distribution of the irrigated areas.

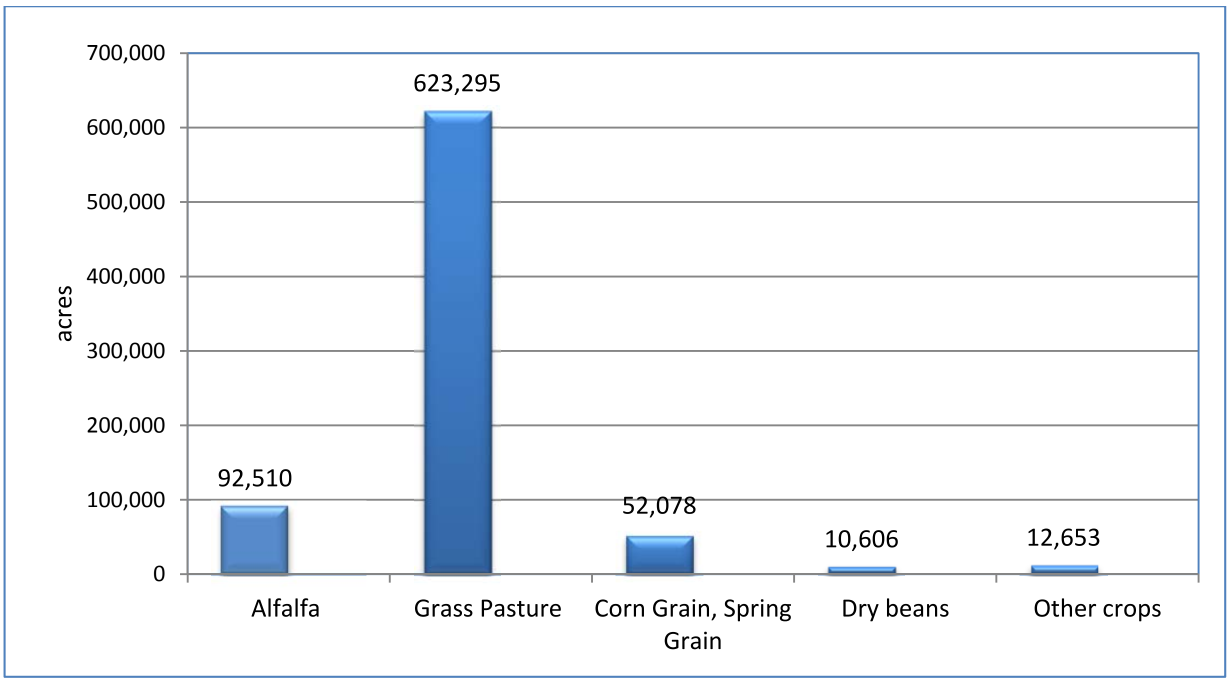

Figure 1: Irrigated Areas by Crop Type (Acres)

Irrigated areas were organized by crop types and grouped into 500-foot elevation bands. The appropriate consumptive irrigation requirement value for each crop type at each elevation could be multiplied by the areas to determine consumptive use. Elevation bands started at 4,500 feet and progressed to 10,500 feet. Figure 2 shows the total irrigated areas of crops in each division for each elevation band used. Irrigated areas by elevation band and crop type are summarized individually for each division in Appendix A.

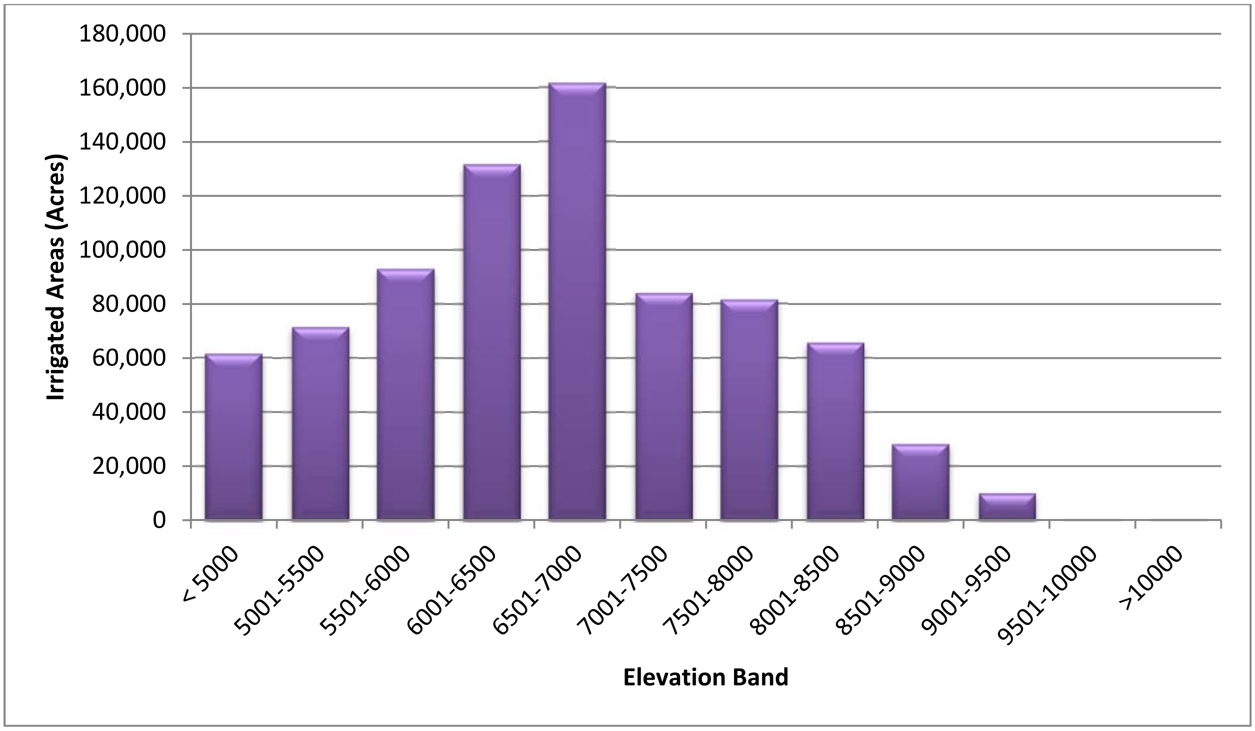

Figure 2: Total Irrigated Areas by Elevation Band

3.5 WATER RIGHTS CATEGORIES

Parcels of land in the databases provided by MWH were categorized based on appropriation and adjudication dates. The water rights categories provided are described in Table 1. Irrigated areas for crops were summed and organized into the above water rights categories. The memorandum prepared by MWH describing the method of assigning water rights to irrigated areas is provided in Appendix B.

Table 1: Description of Water Rights Categories

Water Right Category	Appropriation Date	Adjudication Date
A	< 11/24/1922	< 11/24/1922
	OR	
	< 11/24/1922	>= 11/24/1922 Original Adjustment
B	< 11/24/1922	>= 11/24/1922 Supplemental Adjustment
C	>= 11/24/1922 and < 6/25/1929	>= 11/24/1922 and < 6/25/1929
	OR	
	>= 11/24/1922 and < 6/25/1929	>= 6/25/1929 Original Adjustment
D	>= 11/24/1922 and < 6/25/1929	> = 6/25/1929 Supplemental Adjustment
	OR	
	>= 11/24/1922 and < 6/25/1929	unknown
Post Compact Water Rights	Water rights appropriated after 6/25/1929	
No Appropriation Data	A parcel of land where no water rights information is available.	

Table 2 shows the irrigated areas by crop type in each water rights category for each division. The appropriation date is the most significant date. Categories A and B are pre-Compact water rights because these water uses existed as of November 24, 1922, the date on which the Colorado River Compact was signed, and, categories C and D are also considered pre-Compact because although the Colorado River Compact was signed on November 24, 1922, it did not become effective until June 25, 1929, the effective date of the Boulder Canyon Project Act. There was some irrigated land from the database of irrigated lands that could not be matched to the Colorado Decision Support System (CDSS) Hydrobase water rights information. These parcels and acreage are listed as having no appropriation data. The Colorado River Compact protects use of pre-Compact water rights, which are referred to in the Compact as Present Perfected Rights, by stating that present perfected rights are not impaired by the Compact. The pre-Compact water rights (A, B, C, and D) compose 80.6 percent of the total acreage in the Colorado's Colorado River Basin with known appropriation dates and 71.9 percent of the total irrigated acreage. The "No Appropriation Data" irrigated acreage likely includes some pre-Compact water rights associated with tribal and federal reserved rights and other pre-Compact water rights associated with parcels that could not be linked to the CDSS Hydrobase, which contains priority dates. Plate 2 shows the location of the irrigated lands based on water right priority data.

The analysis in this report assumes that all crop water demand on a given parcel is met by water associated with the water right assigned to the parcel's diversion structure. In some cases, pre-Compact lands may receive supplemental water from reservoirs that was stored under post-Compact rights. At this time the potential quantity of this type of water use has not been determined, and thus it has been ignored for this analysis. If it is later found that supplemental post-Compact water delivered to pre-Compact lands is a significant factor in meeting crop irrigation requirements, results of the analysis in this report may be adjusted when estimating potential agricultural water supplies available to the Water Bank.[1]

Table 2: Irrigated Areas by Crop Type and Water Rights Category

Division 4 - Gunnison							
Water Rights Category → Appropriation/ Adjudication	No Data	Pre-Compact				Post Compact Water Rights	Total
		Pre-1922/ Pre-1922	Pre-1922/ Post 1922	1922-29/ Pre-1929	1922-29/ Post 1929		
Crop Type ↓	Irrigated Areas (Acres)						
Alfalfa	1,366	11,834	3,402	32	201	2,150	**18,984**
Corn Grain	792	14,309	1,180	8	39	561	**16,889**
Dry Beans	40	4,509	124	0	0	95	**4,768**
Grass Pasture	10,559	119,996	51,201	1,351	6,935	29,629	**219,671**
Orchard with Cover	31	279	162	0	0	58	**530**
Orchard without Cover	16	1,936	825	0	6	260	**3,043**
Spring Grains	959	12,870	4,547	17	789	2,258	**21,441**
Vegetables	0	235	0	0	0	8	**243**
Others	87	408	36	0	0	160	**691**
Totals	**13,849**	**166,376**	**61,476**	**1,409**	**7,971**	**35,178**	**286,259**

Division 5 - Colorado							
Water Rights Category → Appropriation/ Adjudication	No Data	Pre-Compact				Post Compact Water Rights	Total
		Pre-1922/ Pre-1922	Pre-1922/ Post 1922	1922-29/ Pre-1929	1922-29/ Post 1929		
Crop Type ↓	Irrigated Areas (Acres)						
Alfalfa	1,698	17,074	9,390	0	374	6,550	**35,086**
Corn Grain	185	3,084	2,367	0	0	1,417	**7,054**
Dry Beans	0	0	0	0	0	0	**0**
Grass Pasture	9,374	98,589	31,252	0	4,234	30,048	**173,498**
Orchard with Cover	138	98	36	0	0	17	**289**
Orchard without Cover	1,528	366	167	0	2	41	**2,103**
Spring Grains	21	2,253	1,266	0	0	492	**4,031**
Vegetables	647	199	47	0	0	12	**905**
Others	552	1,435	502	0	42	882	**3,413**
Totals	**14,144**	**123,098**	**45,026**	**0**	**4,652**	**39,459**	**226,379**

[1] Steve Harris, Southwestern Colorado Water Conservancy District, recently estimated that about 17% of pre-1922 demands in Division 7 are met with releases of post-1922 water from reservoir storage, and that negligible per-1922 demands are met with post-1922 reservoir releases in Divisions 4, 5 and 6.

Division 6 - Yampa							
Water Rights Category → Appropriation/ Adjudication	**No Data**	**Pre-Compact**				**Post Compact Water Rights**	**Total**
		Pre-1922/ Pre-1922	**Pre-1922/ Post 1922**	**1922-29/ Pre-1929**	**1922-29/ Post 1929**		
Crop Type ↓	**Irrigated Areas (Acres)**						
Alfalfa	622	2,698	1,093	0	47	1,711	**6,172**
Corn Grain	0	0	0	0	0	0	**0**
Dry Beans	0	0	0	0	0	0	**0**
Grass Pasture	3,517	43,065	21,999	0	1,914	24,903	**95,398**
Orchard with Cover	0	1	0	0	0	1	**2**
Orchard without Cover	0	0	0	0	0	39	**39**
Spring Grains	0	6	15	0	0	29	**50**
Vegetables	0	0	0	0	0	0	**0**
Others	0	228	13	0	22	122	**386**
Totals	**4,139**	**45,999**	**23,120**	**0**	**1,983**	**26,805**	**102,047**

Division 7- San Juan/Dolores							
Water Rights Category → Appropriation/ Adjudication	**No Data**	**Pre-Compact**				**Post Compact Water Rights**	**Total**
		Pre-1922/ Pre-1922	**Pre-1922/ Post 1922**	**1922-29/ Pre-1929**	**1922-29/ Post 1929**		
Crop Type ↓	**Irrigated Areas (Acres)**						
Alfalfa	23,114	5,802	743	0	317	2,293	**32,268**
Corn Grain	42	73	0	0	0	18	**133**
Dry Beans	5,438	310	0	0	74	15	**5,839**
Grass Pasture	22,482	66,010	10,488	104	2,972	32,671	**134,728**
Orchard with Cover	126	98	40	0	0	120	**384**
Orchard without Cover	22	27	7	0	0	23	**79**
Spring Grains	1,773	636	2	0	4	64	**2,480**
Vegetables	0	2	0	0	0	2	**3**
Others	300	121	0	0	0	121	**543**
Totals	**53,297**	**73,080**	**11,279**	**104**	**3,368**	**35,328**	**176,457**

Note: The Reservations of the Ute Mountain Ute and Southern Ute Tribes are located in Division 7. There are 8,641 acres of irrigated land on the Reservations, most of which have pre-Compact water rights. These irrigated lands are about a 50 percent alfalfa and 50 percent pasture. Plates 1 and 2 show the locations of these Reservations.

Division 7- San Juan/Dolores							
Water Rights Category → Appropriation/ Adjudication	**No Data**	**Pre-Compact**				**Post Compact Water Rights**	**Total**
		Pre-1922/ Pre-1922	**Pre-1922/ Post 1922**	**1922-29/ Pre-1929**	**1922-29/ Post 1929**		
Crop Type ↓	**Irrigated Areas (Acres)**						
Alfalfa	26,800	37,407	14,629	32	939	12,703	**92,510**
Corn Grain	1,019	17,466	3,547	8	39	1,996	**24,075**
Dry Beans	5,479	4,819	124	0	74	110	**10,606**
Grass Pasture	45,932	327,662	114,939	1,456	16,055	117,251	**623,295**
Orchard with Cover	295	477	237	0	0	195	**1,205**
Orchard without Cover	1,566	2,329	998	0	8	364	**5,265**
Spring Grains	2,752	15,765	5,829	17	794	2,844	**28,002**
Vegetables	647	435	47	0	0	21	**1,152**
Others	939	2,192	551	0	65	1,285	**5,033**
Totals	**85,429**	**408,553**	**140,902**	**1,513**	**17,974**	**136,770**	**791,142**
Percent by Category	10.8%	51.6%	17.8%	0.2%	2.3%	17.3%	

3.6 CLIMATE STATIONS

To estimate consumptive irrigation requirement values at different elevations using the StateCU model, a number of different climate stations at different elevations were selected and run in the model. Climate stations containing greater than 25 years of data were used. A complete list of climate stations used is shown in Tables 3 through 6 (some were not used). A map showing the locations of these climate stations and their elevations is shown in Figure 3.

Table 3: Climate Stations Used for Division 4.

Station Name	Elevation
GATEWAY 1 SE	4595
DELTA	4930
URAVAN	5021
PARADOX	5282
PAONIA 1 SW	5576
MONTROSE 1	5786
MONTROSE NO 2	5789
CEDAREDGE	6244
CIMARRON	7011
NORWOOD	7020
BLUE MESA LAKE	7568
GUNNISON 3 SW	7622
OURAY	7840
COCHETOPA CREEK	8002
TELLURIDE 4 WNW	8647
LAKE CITY	8667
CRESTED BUTTE	8865
TAYLOR PARK	9179
PITKIN	9199
TROUT LAKE	9699

Table 4: Climate Stations Used for Division 5.

Station Name	Elevation
PALISADE	4751
GRAND JUNCTION 6 ESE	4760
GRAND JUNCTION WALKER FIELD	4858
RIFLE	5435
COLORADO NATL MONUMENT	5781
GLENWOOD SPGS #2	5895
COLLBRAN	5980
EAGLE COUNTY AP	6497
BOND	6706
KREMMLING	7460
GREEN MT DAM	7740
ASPEN	7936
GRAND LAKE 6 SSW	8288
GRAND LAKE 1 NW	8720
WINTER PARK	9108
BONHAM RESERVOIR	9852
INDEPENDENCE PASS	10557

Table 5: Climate Stations Used for Division 6.

Station Name	Elevation
RANGELY 1 E	5285
BROWNS PARK REFUGE	5354
SUNBEAM 7 SW	5863
MAYBELL	5944
MEEKER 3 W	6229
CRAIG	6280
CRAIG 4 SW	6496
STEAMBOAT SPRINGS	6866
MARVINE	7200
YAMPA	7857
WALDEN	8056
SPICER	8385
RAND	8630
GOULD 4 SE S F S P	9000

Table 6: Climate Stations Used for Division 7.

Station Name	Elevation
CORTEZ	6167
IGNACIO 1 N	6460
NORTHDALE	6680
DURANGO	6761
YELLOW JACKET 2 W	6860
MANCOS	6897
MESA VERDE NP	7087
PAGOSA SPRINGS	7221
FORT LEWIS	7640
LEMON DAM	8365
RICO	8800
SILVERTON	9285

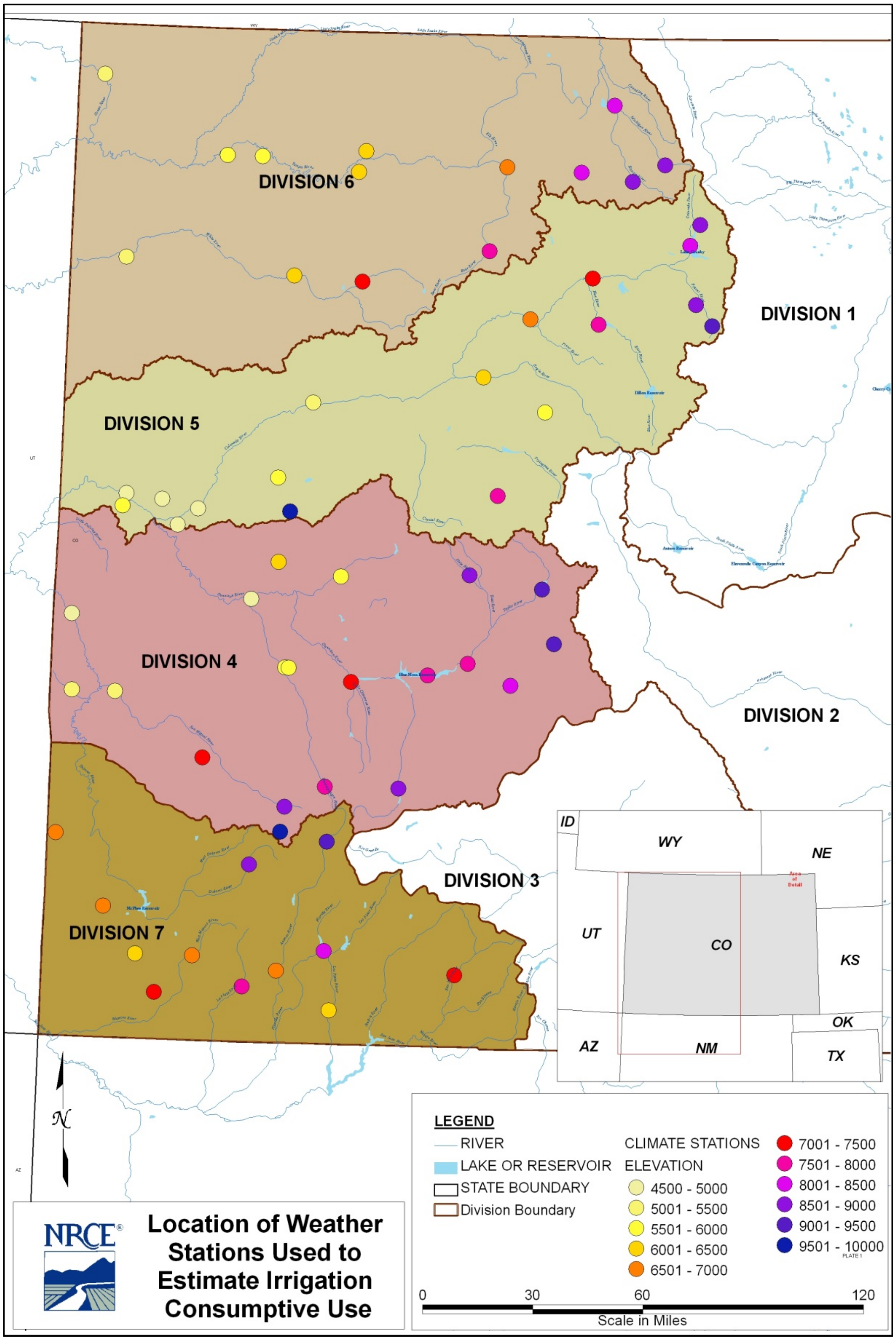

Figure 3: Location Map of Climate Stations Used for Consumptive Use Calculations

4 RESULTS

4.1 CONSUMPTIVE IRRIGATION REQUIREMENTS

The StateCU model was used to estimate annual ET, effective precipitation, and consumptive irrigation requirement values for crops using climate stations with 25 years or more of temperature and precipitation data. For grass pasture ET was determined using the SCS Modified Blaney-Criddle consumptive use methodology with TR-21 crop coefficients with elevation adjustment for acreage below 6,500 feet elevation and the Original Blaney-Criddle consumptive use methodology with high-altitude crop coefficients developed for Denver Water for acreage above 6,500 feet elevation. For all other crops the SCS Modified Blaney-Criddle consumptive use methodology with TR-21 crop coefficients with elevation adjustment was used. The elevation adjustment was used as recommended in the ASCE Manuals and Reports on Engineering Practice No. 70, Evapotranspiration and Irrigation Water Requirements (1990). The elevation adjustment increases the crop coefficients and corresponding ET 10% for each 1,000 meters above sea level. These methods are used by Leonard Rice, Inc. in the Historical Consumptive Use Analysis Basin Reports. The SCS effective rainfall method outlined in the SCS publication Irrigation Water Requirement Technical Release No. 21 (TR-21) was used to determine the amount of water available from precipitation, resulting in irrigation water requirement.

These results were imported into an Excel spreadsheet and summarized for each station. The averages of ET, effective precipitation, and consumptive irrigation requirements for crops were calculated based on data obtained from each weather station. Consumptive irrigation requirements for crops at each climate station were plotted against the corresponding elevations for that particular climate station. These plots were used to determine the relationship of consumptive irrigation requirements to elevation changes for crops. Figures 4 and 5 provide examples of the relationships between consumptive irrigation requirement and elevation for grass pastures. As illustrated in the Figures 4 and 5 there is an abrupt change in the data trends between the modified SCS Blaney-Criddle method with elevation adjusted TR-21 crop coefficients used for elevations below 6,500 feet and the original Blaney-Criddle method with crop coefficients for high altitude developed for Denver Water. However, using a regression analysis with data from both methods appear to make reasonable estimates except for Division 6. For Division 6 the grass pasture ET regression analysis was based on using the all the data from both methods because the results from using the elevation corrected modified SCS Blaney-Criddle method below 6,500 feet elevation and the DWHA method for weather stations above 6,000 feet elevation were not reasonable.

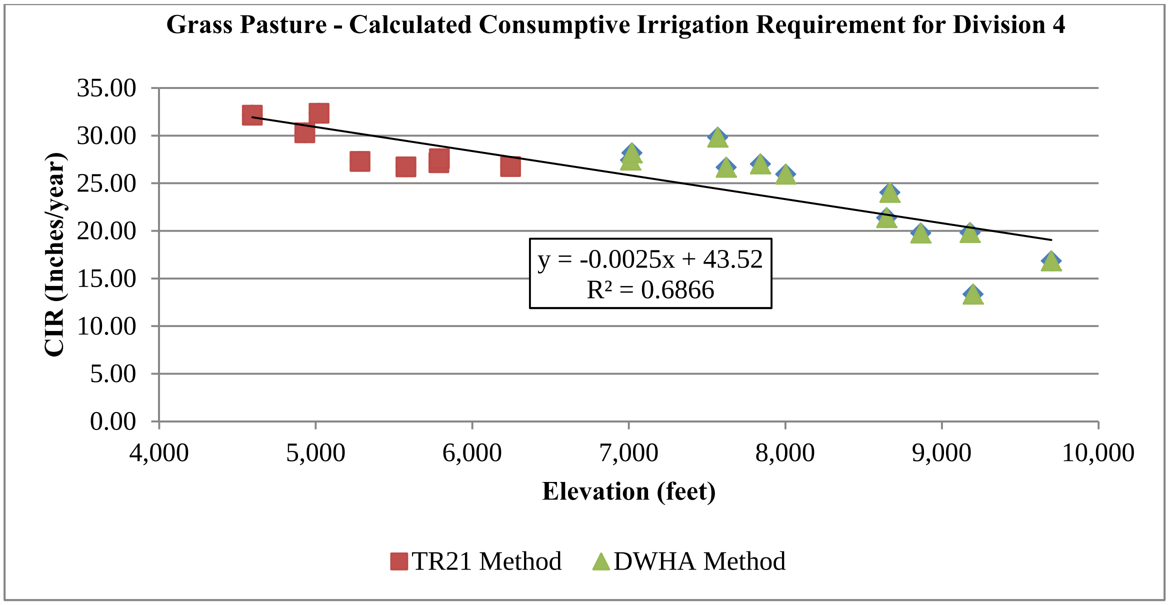

Figure 4: Consumptive Irrigation Requirement for Grass as a Function of Elevation for Gunnison Water Right Division 4

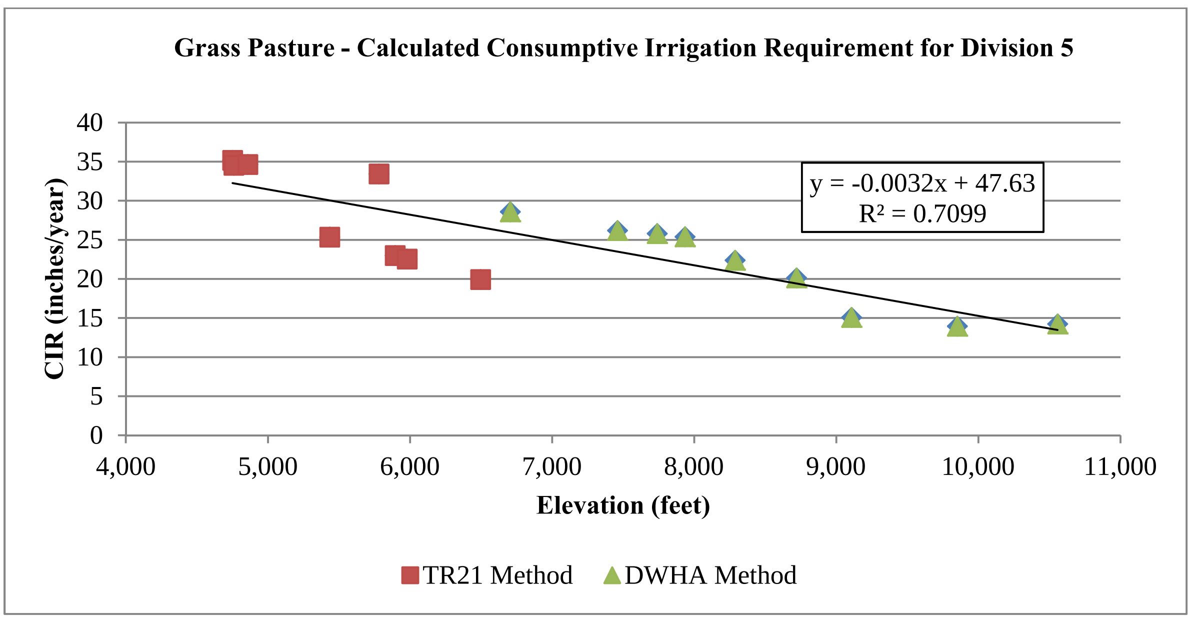

Figure 5: Consumptive Irrigation Requirement for Grass as a Function of Elevation for Colorado Water Right Division 5.

After plotting the consumptive irrigation requirements versus their corresponding elevations, a linear relationship was observed. Using this linear relationship, consumptive irrigation requirement values were assigned to 500-foot elevation bands for every crop. Irrigated areas for each crop in every division were then organized into these elevation bands and the total areas for each elevation band were multiplied by the appropriate consumptive irrigation requirement to obtain irrigated volumes of water required. Elevation bands started at 4,500 feet and continually increased to 10,500 feet. The following table shows the consumptive irrigation requirement values for every elevation band used in this study.

Table 7: Consumptive Irrigation Requirements by Elevation Band

DIVISION 4 - GUNNISON												
Elevation Band →	**4500-5000**	**5001-5500**	**5501-6000**	**6001-6500**	**6501-7000**	**7001-7500**	**7501-8000**	**8001-8500**	**8501-9000**	**9001-9500**	**9501-10000**	**10001-10500**
Crop Type ↓	**CIR (inches/year)**											
Alfalfa	37.1	33.9	30.7	27.5	24.3	21.1	17.9	14.7				
Corn Grain	25.7	23.2	20.6	18.1	15.5	13.0						
Dry Beans	23.1	20.9	18.6									
Grass pasture	31.6	30.4	29.1	27.9	26.6	25.4	24.1	22.9	21.6	20.4	19.1	17.9
Orchard with Cover	37.4	34.4	31.4	28.4	25.4							
Orchard without Cover	27.5	25.3	23.1	20.9	18.7	16.5						
Spring Grains	21.2	19.6	18.0	16.4	14.8	13.2	11.6	10.0	8.4			
Vegetables	20.0	18.2	16.4									
DIVISION 5 - COLORADO												
Elevation Band →	**4500-5000**	**5001-5500**	**5501-6000**	**6001-6500**	**6501-7000**	**7001-7500**	**7501-8000**	**8001-8500**	**8501-9000**	**9001-9500**	**9501-10000**	**10001-10500**
Crop Type ↓	**CIR (inches/year)**											
Alfalfa	37.7	34.2	30.8	27.3	23.9	20.4	17.0	13.5				
Corn Grain	25.5											
Dry Beans												
Grass pasture	32.4	30.8	29.2	27.6	26.0	24.4	22.8	21.2	19.6	18.0	16.4	14.8
Orchard with Cover	38.1	34.8	31.5	28.2								
Orchard without Cover	28.1	25.7	23.3	20.9								
Spring Grains	21.1	19.4										
Vegetables	20.2											

DIVISION 6 - YAMPA												
Elevation Band →	**4500-5000**	**5001-5500**	**5501-6000**	**6001-6500**	**6501-7000**	**7001-7500**	**7501-8000**	**8001-8500**	**8501-9000**	**9001-9500**	**9501-10000**	**10001-10500**
Crop Type ↓	**CIR (inches/year)**											
Alfalfa	29.6	26.8	24.0	21.2	18.4	15.6	12.8					
Corn Grain												
Dry Beans												
Grass pasture	30.1	28.2	26.3	24.4	22.5	20.6	18.7	16.8	14.9	13.0		
Orchard with Cover	30.6	28.1	25.6	23.1	20.6							
Orchard without Cover	22.8	20.9	19.0	17.1								
Spring Grains	19.7	17.9	16.0	14.2								
Vegetables												

DIVISION 7 - SAN JUAN												
Elevation Band →	**4500-5000**	**5001-5500**	**5501-6000**	**6001-6500**	**6501-7000**	**7001-7500**	**7501-8000**	**8001-8500**	**8501-9000**	**9001-9500**	**9501-10000**	**10001-10500**
Crop Type ↓	**CIR (inches/year)**											
Alfalfa	39.4	35.8	32.3	28.7	25.2	21.6						
Corn Grain	27.9	25.0	22.1	19.2								
Dry Beans	24.8	22.2	19.6	17.0	14.4	11.8						
Grass pasture	34.1	32.4	30.7	29.0	27.3	25.6	23.9	22.2	20.5			
Orchard with Cover	39.8	36.3	32.9	29.4	26.0							
Orchard without Cover	29.4	26.8	24.2	21.6	19.0							
Spring Grains	25.8	23.5	21.2	18.9	16.6							
Vegetables	22.2	19.9										

Notes:

1. *Climate at higher elevations is not suitable for the growth of all crops.*
2. *CIR values for Grapes, Sod, and Bluegrass not shown. CIR for Grapes assumed to equal CIR for Orchards with Cover and CIR for Bluegrass and Sod was assumed to equal CIR for Grass pasture.*

4.2 ET Verification

The Penman-Monteith method is also used in estimating evapotranspiration requirements of crops. However, the Colorado Agricultural Metrological network (CoAgMet) can be used to estimate crop evapotranspiration requirements using the Penman-Monteith method (Andales, Bauder & Doeskan, 2009). The CoAgMet weather stations near the weather stations used for the StateCU model are the following:

- Cortez Climate Station
- Delta Climate Station
- Mancos Climate Station
- Yellow Jacket Climate Station

ET values were calculated using the CoAgMet website and were then compared to ET values that resulted at similar climate stations in the StateCU model. Typically, ET values calculated from the Penman-Monteith method were higher than the values from the Blaney-Criddle method. However, since the actual historical consumptive irrigation use is the water available for the Water Bank, the consumptive irrigation requirement values from the StateCU coupled with the historic crop consumptive use analysis results from the Basin modeling (described below) are appropriate for the analysis.

4.3 Historical Consumptive Irrigation Use

After running the StateCU model and determining consumptive irrigation requirement values at different elevations for each division, the values were multiplied by the corresponding irrigated areas for a particular elevation band and the totals were summarized. The consumptive irrigation requirement values estimated from the procedures described above assume full irrigation supply. The Basin's water supply in terms of water availability and timing of flows in relationship to irrigation demands does not meet all the irrigation demands. The water supply limited consumptive irrigation water uses were estimated by using percentage shortages calculated and listed in the Historic Crop Consumptive Use Analysis reports written for divisions of the Colorado River Basin (Leonard Rice Engineers, Inc., 2009 a-d). The percent shortages given in these reports demonstrate the average percent shortage between 1950 and 2006. Shortage information by water district within the divisions was not used. Table 8 lists the percent shortages of available water supply by Division. The shortages are not evenly distributed over priority dates, crops, years, and locations within a division. In most areas the shortages are less for pre-1922 water rights due to priority calls. Applying the basin wide average shortage for all water rights to the more senior pre-1922 rights provides a conservative estimate of water available to the Water Bank. The irrigation water requirements shown in this table only include the eight crops evaluated in this report and no other crops that may also be found in any particular division, such as grapes, sod, or bluegrass. A more detailed analysis would be conducted on a case-by-case and site specific basis when a particular parcel is being considered for deficit irrigation or fallowing. The consumptive losses are at the field level; consumptive use in irrigation conveyance, distribution and drainage systems are not considered. The SWSI 2010 report assumed these losses to be 10 percent of total diversions in the Colorado River Basin (State of Colorado, 2011). If an entire diversion system is shutdown then these consumptive conveyance losses could be considered for the Water Bank.

Table 8: Supply-Limited Consumptive Irrigation Use for Each Division

Division	Irrigation Water Requirement (acre-feet)	Percent Shortage (1)	Supply-Limited Consumptive Use (acre-feet)
Division 4 - Gunnison	605,133	0.17	502,261
Division 5 - Colorado	504,380	0.13	438,811
Division 6 - Yampa	189,106	0.21	149,393
Division 7 - San Juan/Dolores	390,144	0.32	265,298
Total	**1,688,764**		**1,355,763**

(1) Information from Leonard Rice Engineers, 2009.

The following tables summarize the consumptive irrigation requirements by crop in acre-feet for each division, as well as the supply-limited consumptive use after accounting for the percent shortages listed in Table 8. Tables 9 and 10 show the volumes according to water rights categories as described in Table 1. Table 11 shows the volumes according to the 500-foot elevation bands.

Table 9: Consumptive Irrigation Requirement by Water Rights Category

Division 4 - Gunnison							
Water Rights Category → Appropriation/ Adjudication	No Data	Pre-Compact				Post Compact Water Rights	Total
		Pre-1922/ Pre-1922	Pre-1922/ Post 1922	1922-29/ Pre-1929	1922-29/ Post 1929		
Crop Type ↓	Consumptive Irrigation Requirement (acre-feet/year)						
Alfalfa	3,333	31,525	8,461	82	458	5,147	49,005
Corn Grain	1,313	26,945	2,283	14	72	1,002	31,627
Dry Beans	37	7,718	216	0	0	150	8,120
Grass pasture	24,126	265,698	107,354	3,160	14,329	62,175	476,842
Orchard with Cover	80	705	404	0	1	136	1,326
Orchard without Cover	29	3,799	1,566	0	12	517	5,924
Spring Grains	1,325	19,340	5,952	26	959	2,826	30,427
Vegetables	0	347	0	0	0	11	358
Others	159	991	70	0	0	284	1,503
Totals	**30,402**	**357,068**	**126,305**	**3,281**	**15,830**	**72,248**	**605,133**

Division 5 - Colorado							
Water Rights Category → Appropriation/ Adjudication	No Data	Pre-Compact				Post Compact Water Rights	Total
		Pre-1922/ Pre-1922	Pre-1922/ Post 1922	1922-29/ Pre-1929	1922-29/ Post 1929		
Crop Type ↓	Consumptive Irrigation Requirement (acre-feet/year)						
Alfalfa	4,953	43,234	25,392	0	743	16,820	91,142
Corn Grain	394	6,566	5,039	0	0	3,017	15,016
Dry Beans	0	0	0	0	0	0	0
Grass pasture	22,149	210,960	69,390	0	9,548	64,434	376,480
Orchard with Cover	438	296	110	0	0	45	889
Orchard without Cover	3,575	845	385	0	3	92	4,900
Spring Grains	36	3,968	2,230	0	0	867	7,101
Vegetables	1,029	218	80	0	0	20	1,347
Others	1,242	3,162	1,204	0	91	1,807	7,505
Totals	**33,815**	**269,249**	**103,829**	**0**	**10,385**	**87,102**	**504,380**

Division 6 - Yampa							
Water Rights Category → Appropriation/ Adjudication	No Data	Pre-Compact				Post Compact Water Rights	Total
		Pre-1922/ Pre-1922	Pre-1922/ Post 1922	1922-29/ Pre-1929	1922-29/ Post 1929		
Crop Type ↓	Consumptive Irrigation Requirement (acre-feet/year)						
Alfalfa	1,048	4,768	2,117	0	103	3,302	11,339
Corn Grain	0	0	0	0	0	0	0
Dry Beans	0	0	0	0	0	0	0
Grass pasture	6,798	78,652	40,621	0	3,469	47,379	176,918
Orchard with Cover	0	2	0	0	0	2	3
Orchard without Cover	1	0	0	0	0	57	59
Spring Grains	0	9	19	0	0	38	67
Vegetables	0	0	0	0	0	0	0
Others	0	422	25	0	44	229	720
Totals	**7,847**	**83,853**	**42,782**	**0**	**3,616**	**51,008**	**189,106**

Division 7 – San Juan/Dolores							
Water Rights Category → Appropriation/ Adjudication	No Data	Pre-Compact				Post Compact Water Rights	Total
		Pre-1922/ Pre-1922	Pre-1922/ Post 1922	1922-29/ Pre-1929	1922-29/ Post 1929		
Crop Type ↓	Consumptive Irrigation Requirement (acre-feet/year)						
Alfalfa	51,935	13,152	1,855	0	663	5,666	73,271
Corn Grain	87	117	0	0	0	29	233
Dry Beans	6,747	380	0	0	91	18	7,236
Grass pasture	52,307	148,312	22,615	240	6,404	74,057	303,936
Orchard with Cover	173	231	92	0	0	282	777
Orchard without Cover	36	45	12	0	0	40	133
Spring Grains	2,467	880	3	0	7	91	3,448
Vegetables	0	3	0	0	0	3	6
Others	593	255	0	0	0	255	1,104
Totals	**114,346**	**163,375**	**24,577**	**240**	**7,166**	**80,441**	**390,144**

Note: The Reservations of the Ute Mountain Ute and Southern Ute Tribes are located in Division 7. There are 8,641 acres of irrigated land on the Reservations that have mostly pre-Compact water rights. Plates 1 and 2 show the locations of these Reservations.

Total for Basin							
Water Rights Category → Appropriation/ Adjudication	No Data	Pre-Compact				Post Compact Water Rights	Total
		Pre-1922/ Pre-1922	Pre-1922/ Post 1922	1922-29/ Pre-1929	1922-29/ Post 1929		
Crop Type ↓	Consumptive Irrigation Requirement (acre-feet/year)						
Alfalfa	61,269	92,678	37,824	82	1,968	30,936	**224,757**
Corn Grain	1,795	33,627	7,321	14	72	4,048	**46,876**
Dry Beans	6,784	8,098	216	0	91	168	**15,356**
Grass pasture	105,380	703,623	239,979	3,400	33,750	248,045	**1,334,178**
Orchard with Cover	690	1,234	606	0	1	465	**2,996**
Orchard without Cover	3,642	4,689	1,964	0	15	707	**11,016**
Spring Grains	3,828	24,197	8,204	26	966	3,822	**41,043**
Vegetables	1,029	568	80	0	0	34	**1,710**
Others	1,994	4,830	1,299	0	135	2,574	**10,832**
Totals	**186,409**	**873,544**	**297,492**	**3,522**	**36,997**	**290,798**	**1,688,764**
Percent of Total	11.0%	51.7%	17.6%	0.2%	2.2%	17.2%	

Table 10: Supply Limited Consumptive Irrigation Use by Water Rights Category

Division 4 - Gunnison							
Water Rights Category → Appropriation/ Adjudication	No Data	Pre-Compact				Post Compact Water Rights	Total
		Pre-1922/ Pre-1922	Pre-1922/ Post 1922	1922-29/ Pre-1929	1922-29/ Post 1929		
Crop Type ↓	Supply Limited Consumptive Irrigation Use (acre-feet/year)						
Alfalfa	2,766	26,165	7,022	68	380	4,272	**40,674**
Corn Grain	1,090	22,364	1,895	11	60	831	**26,251**
Dry Beans	31	6,406	179			125	**6,740**
Grass pasture	20,025	220,530	89,104	2,623	11,893	51,606	**395,779**
Orchard with Cover	67	585	336		1	113	**1,101**
Orchard without Cover	24	3,153	1,300		10	429	**4,917**
Spring Grains	1,100	16,052	4,940	21	796	2,345	**25,255**
Vegetables	0	288				9	**297**
Others	132	823	58			235	**1,248**
Totals	**25,234**	**296,366**	**104,833**	**2,724**	**13,139**	**59,966**	**502,261**

Division 5 - Colorado							
Water Rights Category → Appropriation/ Adjudication	No Data	Pre-Compact				Post Compact Water Rights	Total
		Pre-1922/ Pre-1922	Pre-1922/ Post 1922	1922-29/ Pre-1929	1922-29/ Post 1929		
Crop Type ↓	Supply Limited Consumptive Irrigation Use (acre-feet/year)						
Alfalfa	4,309	37,613	22,091		647	14,634	**79,293**
Corn Grain	343	5,712	4,384			2,625	**13,064**
Dry Beans							**0**
Grass pasture	19,270	183,535	60,369		8,307	56,057	**327,538**
Orchard with Cover	381	258	96			39	**773**
Orchard without Cover	3,110	735	335		2	80	**4,263**
Spring Grains	31	3,452	1,940			755	**6,178**
Vegetables	895	190	69			18	**1,172**
Others	1,080	2,751	1,048		79	1,572	**6,529**
Totals	**29,419**	**234,246**	**90,332**	**0**	**9,035**	**75,779**	**438,811**

Division 6 - Yampa							
Water Rights Category → Appropriation/ Adjudication	**No Data**	**Pre-Compact**				**Post Compact Water Rights**	**Total**
		Pre-1922/ Pre-1922	**Pre-1922/ Post 1922**	**1922-29/ Pre-1929**	**1922-29/ Post 1929**		
Crop Type ↓	Supply Limited Consumptive Irrigation Use (acre-feet/year)						
Alfalfa	828	3,767	1,672		82	2,609	**8,957**
Corn Grain							**0**
Dry Beans							**0**
Grass pasture	5,370	62,135	32,090		2,740	37,429	**139,765**
Orchard with Cover	0	1				1	**3**
Orchard without Cover	1					45	**46**
Spring Grains	0	7	15			30	**53**
Vegetables							**0**
Others		334	20		35	181	**569**
Totals	**6,199**	**66,244**	**33,798**	**0**	**2,857**	**40,296**	**149,393**

Division 7 - San Juan/Dolores							
Water Rights Category → Appropriation/ Adjudication	**No Data**	**Pre-Compact**				**Post Compact Water Rights**	**Total**
		Pre-1922/ Pre-1922	**Pre-1922/ Post 1922**	**1922-29/ Pre-1929**	**1922-29/ Post 1929**		
Crop Type ↓	Supply Limited Consumptive Irrigation Use (acre-feet/year)						
Alfalfa	35,316	8,943	1,261		451	3,853	**49,825**
Corn Grain	59	79				20	**158**
Dry Beans	4,588	258			62	12	**4,920**
Grass pasture	35,569	100,852	15,378	163	4,355	50,359	**206,677**
Orchard with Cover	117	157	62			192	**529**
Orchard without Cover	25	31	8			27	**91**
Spring Grains	1,678	598	2		5	62	**2,345**
Vegetables		2				2	**4**
Others	403	174				174	**751**
Totals	**77,755**	**111,095**	**16,712**	**163**	**4,873**	**54,700**	**265,298**

Note: The Reservations of the Ute Mountain Ute and Southern Ute Tribes are located in Division 7. There are 8,641 acres of irrigated land on the Reservations that have mostly pre-Compact water rights. Plates 1 and 2 show the locations of these Reservations.

Total for Basin							
Water Rights Category → Appropriation/ Adjudication	No Data	Pre-Compact				Post Compact Water Rights	Total
		Pre-1922/ Pre-1922	Pre-1922/ Post 1922	1922-29/ Pre-1929	1922-29/ Post 1929		
Crop Type ↓	Supply Limited Consumptive Irrigation Use (acre-feet/year)						
Alfalfa	43,219	76,489	32,047	68	1,560	25,368	**178,750**
Corn Grain	1,492	28,155	6,278	11	60	3,476	**39,473**
Dry Beans	4,618	6,664	179	0	62	137	**11,660**
Grass pasture	80,233	567,052	196,941	2,786	27,295	195,451	**1,069,759**
Orchard with Cover	565	1,001	494	0	1	345	**2,406**
Orchard without Cover	3,160	3,919	1,643	0	12	582	**9,317**
Spring Grains	2,809	20,110	6,898	21	801	3,192	**33,830**
Vegetables	895	480	69	0	0	28	**1,472**
Others	1,616	4,081	1,125	0	114	2,161	**9,097**
Totals	138,607	707,951	245,674	2,887	29,904	230,740	**1,355,763**
Percent of Total	10.2%	52.2%	18.1%	0.2%	2.2%	17.0%	

Table 11: Supply Limited Consumptive Irrigation Use by Elevation Band

DIVISION 4 - GUNNISON													
Elevation Band →	**4500-5000**	**5001-5500**	**5501-6000**	**6001-6500**	**6501-7000**	**7001-7500**	**7501-8000**	**8001-8500**	**8501-9000**	**9001-9500**	**9501-10000**	**10001-10500**	**Totals**
Crop Type ↓	Supply Limited Consumptive Irrigation Use (acre-feet/year)												
Alfalfa	3,501	15,389	13,675	4,365	3,279	184	230	51					**40,674**
Corn Grain	2,630	15,490	7,683	388	53	7							**26,251**
Dry Beans	223	5,275	1,242										**6,740**
Grass pasture	8,543	50,906	71,180	44,841	40,652	47,938	49,453	41,523	27,017	13,201	189	337	**395,779**
Orchard with Cover	0	188	426	374	113								**1,101**
Orchard without Cover	373	879	3,045	467	145	7							**4,917**
Spring Grains	1,046	8,961	6,716	3,050	2,917	1,733	62	527	242				**25,255**
Vegetables	0	213	84										**297**
Others	9	0	861	0	0	0	0	0	174	205			**1,248**
Totals	**16,325**	**97,302**	**104,912**	**53,486**	**47,158**	**49,868**	**49,745**	**42,101**	**27,433**	**13,405**	**189**	**337**	**502,261**

DIVISION 5 - COLORADO													
Elevation Band →	**4500-5000**	**5001-5500**	**5501-6000**	**6001-6500**	**6501-7000**	**7001-7500**	**7501-8000**	**8001-8500**	**8501-9000**	**9001-9500**	**9501-10000**	**10001-10500**	**Totals**
Crop Type ↓	Supply Limited Consumptive Irrigation Use (acre-feet/year)												
Alfalfa	51,728	575	3,629	8,063	7,597	4,098	3,020	583					**79,293**
Corn Grain	13,064												**13,064**
Dry Beans													**0**
Grass pasture	45,206	22,057	45,448	50,905	39,585	32,436	46,310	33,840	11,348	325	56	22	**327,538**
Orchard with Cover	658	13	80	23									**773**
Orchard without Cover	4,204	2	15	42									**4,263**
Spring Grains	6,161	17											**6,178**
Vegetables	1,172												**1,172**
Others	2,563	60	441	939	270	264	632	616	443	271	31		**6,529**
Totals	**124,755**	**22,724**	**49,613**	**59,972**	**47,452**	**36,797**	**49,963**	**35,039**	**11,791**	**596**	**87**	**22**	**438,811**

DIVISION 6 - YAMPA													
Elevation Band →	**4500-5000**	**5001-5500**	**5501-6000**	**6001-6500**	**6501-7000**	**7001-7500**	**7501-8000**	**8001-8500**	**8501-9000**	**9001-9500**	**9501-10000**	**10001-10500**	**Totals**
Crop Type ↓	Supply Limited Consumptive Irrigation Use (acre-feet/year)												
Alfalfa	0	2,340	1,530	3,277	1,685	103	23						**8,957**
Corn Grain													**0**
Dry Beans													**0**
Grass pasture	0	1,674	13,805	52,110	36,527	13,189	10,944	10,069	1,314	134			**139,765**
Orchard with Cover	0	0	0	0	3								**3**
Orchard without Cover	0	7	0	39									**46**
Spring Grains	0	29	0	23									**53**
Vegetables													**0**
Others	0	0	0	122	330	116							**568**
Totals	**0**	**4,049**	**15,335**	**55,571**	**38,544**	**13,409**	**10,967**	**10,069**	**1,314**	**134**			**149,392**

DIVISION 7 - SAN JUAN													
Elevation Band →	**4500-5000**	**5001-5500**	**5501-6000**	**6001-6500**	**6501-7000**	**7001-7500**	**7501-8000**	**8001-8500**	**8501-9000**	**9001-9500**	**9501-10000**	**10001-10500**	**Totals**
Crop Type ↓	Supply Limited Consumptive Irrigation Use (acre-feet/year)												
Alfalfa	40	7,795	3,186	7,351	30,560	892							**49,825**
Corn Grain	0	59	0	99									**158**
Dry Beans	0	0	0	1,036	3,827	58							**4,920**
Grass pasture	890	7,073	5,365	52,242	83,876	33,048	15,769	8,274	140				**206,677**
Orchard with Cover	0	0	28	302	199								**529**
Orchard without Cover	0	0	0	37	54								**91**
Spring Grains	0	0	0	133	2,212								**2,345**
Vegetables	0	3											**3**
Others	0	11	0	0	76	83	581						**751**
Totals	**930**	**14,942**	**8,579**	**61,198**	**120,804**	**34,080**	**16,351**	**8,274**	**140**	**0**	**0**	**0**	**265,298**

BASIN TOTALS													
Elevation Band →	**4500-5000**	**5001-5500**	**5501-6000**	**6001-6500**	**6501-7000**	**7001-7500**	**7501-8000**	**8001-8500**	**8501-9000**	**9001-9500**	**9501-10000**	**10001-10500**	**Totals**
Crop Type ↓	Supply Limited Consumptive Irrigation Use (acre-feet/year)												
Alfalfa	55,269	26,100	22,020	23,056	43,121	5,277							**178,750**
Corn Grain	15,694												**39,473**
Dry Beans													**11,660**
Grass pasture	54,639	81,709	135,798	200,097	200,640	126,611	122,477	93,706	39,820				**1,069,759**
Orchard with Cover	658	201	534	698									**2,406**
Orchard without Cover	4,577	888	3,060	586									**9,317**
Spring Grains	7,207	9,008											**33,830**
Vegetables	1,172												**1,472**
Others	2,572	71	1,302	1,061	675	463	1,214	616	616				**9,095**
Totals	**142,010**	**139,017**	**178,439**	**230,227**	**253,958**	**134,155**	**127,026**	**95,483**	**40,678**	**14,135**	**276**	**358**	**1,355,762**

5 WATER BANK WATER SUPPLY

This section summarizes the potential water bank water supply, provides a short discussion on water costs, and discusses determination of water supply. The information is general in nature and implementation would require legal, contractual, administrative, and pilot studies.

5.1 WATER SUPPLY

Ninety-eight percent (777,500 acres) of the irrigated acreage in the Colorado River basin of Colorado is pasture, alfalfa, corn, small grain, and dry beans. The balance of the irrigated cropped acreage includes orchard, bluegrass, sod farms, and vineyards. Because the acreage of orchard, bluegrass, sod farms, and vineyards is small in relationship to the total acreage and due to higher value crops, this acreage is not considered a primary source of water for the Water Bank. Fallowing is suitable for small grains, grain corn, and dry beans. Deficit irrigation is available for all crops, but is best suited for perennial forage crops of alfalfa and pasture for two reasons (see Appendix C).

- First, alfalfa and pasture are drought tolerant. During a drought, alfalfa and pasture enter a stressed or dormant condition without significant loss of plant population or long-term crop damage. In most of the basin, alfalfa and pasture can still produce harvestable yields or can be grazed with limited or no irrigation.
- Second, the majority of irrigation consumptive use in the western divisions of Colorado is from grass pasture and alfalfa. These two crops together occupy 90% of the irrigated land in western Colorado and contribute 92% of the total water consumed for irrigation purposes in the western divisions of Colorado; approximately 1.56 million acre-feet of the total 1.69 million acre-feet (1.25 million acre-feet and 1.36 million acre-feet after accounting for the percent shortage).

Because alfalfa and grass pasture have the most significant impact on the depletion of water due to agriculture in the western divisions of Colorado, deficit irrigation and/or non-irrigation of grass pasture and alfalfa are the best supply of water for the Water Bank. While deficit irrigation and/or fallowing of grass pasture and alfalfa appears to be the most practical application to conserve water supply in western Colorado, the actual acceptance and costs of this procedure will need to be evaluated further.

5.2 WATER COST

The value or cost of the water for the Water Bank is complex due to the market for water, supply of water, and specific water needs based on location and demand. A White Paper concerning the economic and technical feasibility of fallowing and deficit irrigation is in Appendix C. While the cost of water is undetermined, it is expected to range from about $35 to over $200 per acre-foot based on recent costs of agricultural water in Colorado (CRWCD, 2011). Growers in Imperial

Irrigation District in California are paid $85 per acre-foot for fallowing based on historical field deliveries. The value of water is based on lost production from deficit irrigation of alfalfa, estimated from the cost of deficit irrigation, which can be estimated by the value of the loss in production, plus added costs to growers and incentive to participate, minus reduced irrigation and production costs. For forages the estimated loss of production for reduced consumptive use is 1.8 tons of forage per acre-foot. The value of 1.8 tons of alfalfa has been as high as $295 in 2008 ($164 per ton). October 2011 Colorado premium hay prices are over $200 per ton (over $360 per acre-foot). The value of the lost pasture production from deficit irrigation would generally be less because of the lower value of the pasture. However, during a drought the value of irrigated pasture can be similar to that of alfalfa.

5.3 DETERMINATION OF WATER SUPPLY

Determining the decrease in consumptive use and water savings from fallowing or deficit irrigation is site specific. The water savings from deficit or no irrigation ranges from about 1 acre-feet per acre in the higher elevation pastures to 3.2 acre-feet per acre in the lower elevation alfalfa fields. Deficit irrigation reduces crop evapotranspiration resulting in a decrease in yield and reduced income to the grower. Deficit and non-irrigation of grass pasture and alfalfa will need to be determined by grower input and perhaps a pilot program to determine a more accurate cost/benefit ratio that will result from deficit and non-irrigation of these crops.

There are two deficit irrigation options in providing the supply for the water bank; one is no irrigation for the entire year with the other being no irrigation during a portion of the year. The amount of water that could be provided to a water bank through deficit irrigation would be affected by the deficit irrigation cutoff date. The StateCU model uses a monthly time step, but the data presented in this report is based on annual consumptive irrigation requirement. To illustrate the options available from deficit irrigation, an analysis was conducted on monthly consumptive irrigation requirement data from two weather stations in Division 4. Table 12 is an example of the amount of water that could be provided through deficit irrigation on a monthly time basis. For the example shown in Table 12, if the irrigation was cutoff on July 1 the reduction of consumptive irrigation requirement would be 21.92 inches, or 45% of the total annual consumptive irrigation requirement. If irrigation was cutoff on August 1 the reduction in consumptive irrigation requirement would be 14.47 inches, or 24% of the total annual consumptive irrigation requirement.

Table 12 - Grass and Alfalfa Average of selected years for Delta, Colorado (elevation 4,930 feet).

Month	Month Cumulative CIR (in)	% Cumulative CIR Used	% CIR Remaining	% CIR month	CIR Month (in)	CIR Reduction (in)
Apr	0.68	2%	98%	2%	0.68	32.27
May	4.42	14%	86%	11%	3.74	31.59
Jun	10.34	32%	68%	18%	5.93	27.85
Jul	17.79	55%	45%	23%	7.45	21.92
Aug	24.70	76%	24%	21%	6.91	14.47
Sep	29.45	91%	9%	15%	4.75	7.57
Oct	31.63	98%	2%	7%	2.18	2.81
Nov	32.27	100%	0%	2%	0.63	0.63

CIR – Consumptive Irrigation Requirement.

The values in the tables are good estimates, but in reality it is much more complicated than using the consumptive irrigation requirement values. The following are factors to consider.

- The reduction in diversions would include the irrigation efficiencies.
- The actual timing and reduction in depletions would likely require some kind of return flow modeling.
- The crop water use would continue for a few weeks (2 to 4 weeks) as the available soil moisture is depleted by the grass and/or alfalfa.
- It may be typical to stop irrigation near the end of September to finish up the growing season on stored available soil moisture.
- In general, irrigations lag the calculated consumptive irrigation requirement because the irrigations are to replace water used by crops (i.e. the soil moisture reservoir has to be depleted to make soil moisture storage space for the irrigation). The exception is if a dry up period occurs at the end of the season when the soil moisture is not replaced until winter precipitation and/or spring irrigation occurs.
- Late season irrigation shortage based on water supply may already be occurring in some area based on water supply.

In the example provided in Table 12 for Delta, Colorado about 1.5 acre-feet per acre could be provided to a water bank by stopping irrigation July 1 and about 1 acre-foot per acre could be provided to a water bank by stopping irrigation on August 1.

6 CONCLUSIONS

Grass pasture and alfalfa are the best suited crops for deficit irrigation. Small grains, grain corn, and dry beans are the crops that are the most feasible for fallowing. Grass pasture and alfalfa constitute over 90 percent of the irrigated acreage in the Basin. Small grains, grain corn, and dry beans constitute another 8 percent of the irrigated acreage in the Basin. These crops combined account for over 98 percent of the acreage, irrigation consumptive requirement, and supply-limited consumptive use. About 69 percent of the total irrigated acreage has pre-1922 water rights and 72 percent has pre-1929 water rights. This estimate is likely conservative, because some of the land listed as "no appropriation data" may also be pre-Compact water rights. Tables 13 through 16 provide a summary of estimated irrigated acreage, consumptive irrigation requirement, and water supply limited consumptive use in the Basin. Most of the irrigation water use in the Basin is associated with pre-1922 and pre-1929 water rights. The estimated irrigation water requirement and supply limited water use for pre-Compact water rights based on a 1929 Compact effective date is 1,211,555 and 986,416 acre-feet per year, respectively (72 and 73 percent of the total consumptive irrigation water use in the Basin). The supply-limited consumptive use associated with pre-Compact (includes pre-1929) water rights are recommended for use in evaluating Water Bank scenarios.

Table 13: Irrigated Acreage in the Basin

Description	Total Basin (ac)	Pre-1922 (ac)	Pre-1922 % of total	Pre-1929 (ac)	Pre-1929 % of Total
Alfalfa	92,510	52,036	56%	53,007	57%
Grass Pasture	623,295	442,601	71%	460,112	74%
Total Alfalfa and Grass Pasture	**715,805**	**494,637**	**69%**	**513,119**	**72%**
Small Grain, Corn Grain, and Dry Beans	62,685	47,550	76%	48,482	77%
All Irrigated Crops	**791,142**	**549,455**	**69%**	**568,942**	**72%**

Table Note: About 10 percent of the irrigated land could not be matched with water right appropriation data. Thus, the number of acres associated with the pre-Compact water rights is likely higher than reported in the table.

Table 14: Consumptive Irrigation Requirements and Water Supply Limited Consumptive Irrigation Use.

Description	Total Basin (ac-ft/yr)	Pre-1922 (ac-ft/yr)	Pre-1922 % of total	Pre-1929 (ac-ft/yr)	Pre-1929 % of Total
Total Consumptive Irrigation Requirement	1,688,763	1,171,036	69%	1,211,555	72%
Total Supply-limited Consumptive Irrigation Use	1,355,763	953,625	70%	986,416	73%

Table Note: About 10 percent of the irrigated land could not be matched with water right appropriation data. Thus, the consumptive irrigation requirements associated with the pre-Compact water rights is likely higher than reported in the table.

Table 15: Consumptive Irrigation Requirements for Alfalfa, Grass Pasture, Small Grains, Corn Grain and Dry Beans.

Crop	Total Basin (ac-ft/yr)	Pre-1922 (ac-ft/yr)	Pre-1922 % of total	Pre-1929 (ac-ft/yr)	Pre-1929 % of Total
Alfalfa	224,757	130,502	58%	132,552	59%
Grass Pasture	1,334,178	943,602	71%	980,752	74%
Total Alfalfa and Grass Pasture	**1,558,935**	**1,074,104**	**69%**	**1,113,304**	**71%**
Small Grain, Corn Grain, and Dry Beans	103,275	81,663	79%	82,832	80%
Total	**1,662,210**	**1,155,767**	**70%**	**1,196,136**	**72%**

Table Note: About 10 percent of the irrigated land could not be matched with water right appropriation data. Thus, the consumptive irrigation requirements associated with the pre-Compact water rights is likely higher than reported in the table.

Table 16: Water Supply Limited Consumptive Irrigation Use for Alfalfa, Grass Pasture, Small Grains, Corn Grain and Dry Beans.

Crop	Total Basin (ac-ft/yr)	Pre-1922 (ac-ft/yr)	Pre-1922 % of total	Pre-1929 (ac-ft/yr)	Pre-1929 % of Total
Alfalfa	178,750	108,536	61%	110,164	62%
Grass Pasture	1,069,759	763,993	71%	794,074	74%
Total Alfalfa and Grass Pasture	**1,248,509**	**872,529**	**70%**	**904,238**	**72%**
Small Grain, Corn Grain, and Dry Beans	84,963	68,284	80%	69,239	81%
Total	**1,333,472**	**940,813**	**71%**	**973,477**	**73%**

Table Note: About 10 percent of the irrigated land could not be matched with water right appropriation data. Thus, the consumptive irrigation use associated with the pre-Compact water rights is likely higher than reported in the table.

There is potential from a water supply aspect to provide several hundred thousand of acre-feet per year to the Water Bank. The actual amount available for the Water Bank depends on willingness of growers to fallow or deficit irrigate. The willingness of grower participation is a function of price paid for water saved from fallowing or deficit irrigation. The cost for fallowing based on established lease rates and loss of production is estimated to cost from $35 to over $200 per acre-foot. High rates of fallowing or deficit irrigation will likely result in higher cost of water, because not all growers will be willing to lease water for the lower rates. Additionally as high percentages of fallow or deficit irrigation occur the local and regional economies are impacted to a greater degree. No analysis has been conducted to consider economic impacts beyond the individual grower.

The greatest source of water for the Water Bank is from deficit irrigation of alfalfa and pasture. The amount of water saved from deficit irrigation is site specific and based on consumptive irrigation requirement or consumptive irrigation use estimates. The cost of water for the Water Bank is unknown without additional work that would be based on market surveys and discussions with growers. The farmers, growers, and ranchers acceptance and willingness to participate is unknown. Additionally water accounting procedures would need to be developed to estimate the reduced consumptive use of irrigation water that could be made available for the Water Bank. Fallowing and deficit irrigation programs have been implemented in other areas with success and could provide a model for implementation.

The water supply values provided in the previous tables will need to be adjusted when developing specific Water Bank scenarios. Necessary adjustments include:

- Account for transit losses between the field and the Lee Ferry accounting point for Compact compliance
- Account for water administration factors that could affect benefits of fallowing or deficit irrigation relative to Compact accounting
- Account for use of post-1922 reservoir storage releases to meet irrigation requirements on pre-1922 lands in Division 7
- Account for assumptions regarding full fallowing versus partial deficit irrigation
- There are 1,470 and 7,171 acres respectively on the Southern Ute and Ute Mountain Ute Reservations that are not included the database of irrigated lands with appropriation data. These lands as well as others likely have pre-Compact appropriation dates.

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Appendix A - Irrigated Areas by Elevation Bands

Table A17: Division 4 – Gunnison: Irrigated Areas by Elevation Bands

Elevation Band →	4500-5000	5001-5500	5501-6000	6001-6500	6501-7000	7001-7500	7501-8000	8001-8500	8501-9000	9001-9500	9501-10000	10001-10500	Totals
Crop Type ↓	**Irrigated Areas (Acres)**												
Alfalfa	1,365	6,566	6,443	2,296	1,952	126	186	50					**18,984**
Corn Grain	1,478	9,661	5,384	310	49	8							**16,889**
Dry Beans	139	3,650	963	16									**4,768**
Grass pasture	3,903	24,214	35,310	23,241	22,058	27,292	29,612	26,221	18,046	9,358	143	272	**219,671**
Orchard with Cover		79	196	190	64								**530**
Orchard without Cover	196	502	1,904	323	112	6							**3,043**
Spring Grains	714	6,618	5,401	2,693	2,854	1,901	78	764	418				**21,441**
Vegetables		169	74										**243**
Others	4		427						116	145			**691**
Totals	**7,799**	**51,459**	**56,101**	**29,070**	**27,089**	**29,333**	**29,876**	**27,035**	**18,580**	**9,503**	**143**	**272**	**286,259**

Table A2: Division 5 – Colorado: Irrigated Areas by Elevation Bands

Elevation Band →	4500-5000	5001-5500	5501-6000	6001-6500	6501-7000	7001-7500	7501-8000	8001-8500	8501-9000	9001-9500	9501-10000	10001-10500	Totals
Crop Type ↓	**Irrigated Areas (Acres)**												
Alfalfa	18,944	232	1,627	4,072	4,391	2,769	2,456	595					**35,086**
Corn Grain	7,054												**7,054**
Dry Beans													**0**
Grass pasture	19,227	9,868	21,446	25,412	20,976	18,313	27,979	21,986	7,974	249	47	20	**173,498**
Orchard with Cover	238	5	35	11									**289**
Orchard without Cover	2,065	1	9	28									**2,103**
Spring Grains	4,019	12											**4,031**
Vegetables	801							104					**905**
Others	1,090	27	208	469	143	149	382	400	311	207	26		**3,413**
Totals	**53,439**	**10,146**	**23,325**	**29,992**	**25,510**	**21,231**	**30,817**	**23,085**	**8,285**	**456**	**73**	**20**	**226,379**

Table A18: Division 6 – Yampa: Irrigated Areas by Elevation Bands

Elevation Band →	4500-5000	5001-5500	5501-6000	6001-6500	6501-7000	7001-7500	7501-8000	8001-8500	8501-9000	9001-9500	9501-10000	10001-10500	Totals
Crop Type ↓	**Irrigated Areas (Acres)**												
Alfalfa		1,328	970	2,352	1,394	101	27						**6,172**
Corn Grain													**0**
Dry Beans													**0**
Grass pasture		903	7,988	32,504	24,712	9,748	8,913	9,130	1,344	157			**95,398**
Orchard with Cover					2								**2**
Orchard without Cover		5		35									**39**
Spring Grains		25		25									**50**
Vegetables													**0**
Others				76	223	86							**386**
Totals	**0**	**2261**	**8958**	**34992**	**26331**	**9935**	**8940**	**9130**	**1344**	**157**	**0**	**0**	**102,047**

Table A19: Division 7 - San Juan/Dolores: Irrigated Areas by Elevation Bands

Elevation Band →	4500-5000	5001-5500	5501-6000	6001-6500	6501-7000	7001-7500	7501-8000	8001-8500	8501-9000	9001-9500	9501-10000	10001-10500	Totals
Crop Type ↓	**Irrigated Areas (Acres)**												
Alfalfa	18	3,840	1,742	4,516	21,423	728							**32,268**
Corn Grain		42		91									**133**
Dry Beans				1,073	4,680	86							**5,839**
Grass pasture	461	3,857	3,088	31,834	54,298	22,817	11,663	6,589	121				**134,728**
Orchard with Cover			15	181	135	53							**384**
Orchard without Cover				30	50								**79**
Spring Grains				124	2,356								**2,480**
Vegetables		3											**3**
Others		6			49	57	430						**543**
Totals	**479**	**7,749**	**4,845**	**37,850**	**82,991**	**23,742**	**12,092**	**6,589**	**121**	**0**	**0**	**0**	**176,457**

Table A20: Basin Total: Irrigated Areas by Elevation Bands

Crop	Elevation Band												Total Acres
	< 5000	5001-5500	5501-6000	6001-6500	6501-7000	7001-7500	7501-8000	8001-8500	8501-9000	9001-9500	9501-10000	>10000	
Alfalfa	20,327	11,967	10,782	13,237	29,159	3,724	2,669	646	0	0	0	0	**92,510**
Corn Grain	8,532	9,702	5,384	401	49	8	0	0	0	0	0	0	**24,075**
Dry Beans	139	3,650	963	1,089	4,680	86	0	0	0	0	0	0	**10,606**
Grass pasture	23,591	38,843	67,832	112,991	122,044	78,170	78,166	63,925	27,486	9,764	190	292	**623,295**
Orchard with Cover	238	84	246	382	201	53	0	0	0	0	0	0	**1,205**
Orchard without Cover	2,262	508	1,912	415	161	6	0	0	0	0	0	0	**5,265**
Spring Grains	4,733	6,655	5,401	2,843	5,210	1,901	78	764	418	0	0	0	**28,002**
Vegetables	801	172	74	0	0	0	0	104	0	0	0	0	**1,152**
Others	1,094	33	635	545	416	293	812	400	428	352	26	0	**5,033**
Totals	**61,717**	**71,614**	**93,229**	**131,903**	**161,920**	**84,240**	**81,724**	**65,839**	**28,331**	**10,116**	**217**	**292**	**791,142**

Appendix B – MWH Americas Memorandum - GIS Layers and Water Rights Updates Memorandum, September 28, 2011

MWH

BUILDING A BETTER WORLD

MEMORANDUM

TO:	Niel Allen and Jordan Lanini, NRCE, Inc.	DATE:	September 28, 2011
FROM:	Chip Paulson and Pranay Sanadhya	CC:	Enrique Triana
SUBJECT:	GIS Layers and Water Rights updates	REF:	Project No. 1011690

Introduction

This memo provides information related to the categorization of water rights for Water Divisions 4-7 based on their priority date relative to the Colorado River Compact, along with the steps performed to create GIS coverages for the associated irrigated areas. This information is provided based on the discussion with NRCE on 15 September, 2011.

Methodology

Step 1: Initially, a table that had records of all the water rights transactions was exported from the Colorado Decision Support System (CDSS) Hydrobase for each of the four Water Divisions and was sorted in Microsoft Access based on the following criteria relative to the Compact:

- Appropriation date <11/24/1922 and Adjudication date <11/24/1922 or Appropriation <11/24/1922 and Adjudication date * >= 11/24/1922 (* refers to only those Adjudication Dates where the previous adjudication date (Padj_date field) is null because that indicates it is an original Adjudication). This is categorized as “A” in the WR field in the attribute table and databases.

- Appropriation date <11/24/1922 and Adjudication date* >=11/24/1922 (* refers to only those Adjudication dates where the previous adjudication date (Padj_date field) is not null because that indicates it is a supplemental Adjudication) or Appropriation date <11/24/1922 and Adjudication date = “Null”. This is categorized as “B” in the WR field in the attribute table and databases.

- Appropriation date >=11/24/1922 and <6/25/1929 and Adjudication date >=11/24/1922 and <6/25/1929 or Appropriation date >=11/24/1922 and <6/25/1929 and Adjudication date* >=6/25/1929 (* refers to only those Adjudication dates where the previous adjudication date (Padj_date field) is null). This is categorized as “C” in the WR field in the attribute table and databases.

- Appropriation date >=11/24/1922 and <6/25/1929 and Adjudication date >=6/25/1929* (* refers to only those Adjudication dates where the previous adjudication date (Padj_date field) is not null) or Appropriation date >=11/24/1922 and <6/25/1929 and Adjudication date = "Null". This is categorized as "D" in the WR field in the attribute table and databases.

- Any water right not meeting any of the above criteria was categorized as "None" in the WR field in the attribute table and databases. This means there are no assumed conditions under which the water right would not be called out during a Compact call.

  Note: The 1929 cut-off is June 25, 1929, the effective date of the Boulder Canyon Project Act, which became the basis for the apportionment of the lower mainstem in Arizona v. California. The 1922 cut-off is November 24, 1922, the date that the 1922 Compact was signed.

Step 2: The database table obtained as a result of the previous operation was then selected as the master table and the diversion dataset from the CDSS website was linked to it. A common field in the two tables which acts as a unique identifier to the diversion structure was selected to create a link between the tables. The field is represented as "wdid" in the table from Step 1 and "ID_Label7" in the diversion dataset. This task was performed in order to link the water rights to diversion structures. It also helps in representation and categorization of water rights in GIS which otherwise would not be possible since there is no available information in terms of latitude and longitude of water diversion structures in Hydrobase.

Note: Tables corresponding to Step 1 and Step 2 are provided in the database and are named as: Division name_Step1 (example: Gunnison_Step1) and Division name_Step2 (example: Gunnison_Step2) for all the four divisions separately.

Step 3: A polygon shapefile obtained from the CDSS website representing irrigated areas based on 2005 Landsat Imagery and 2005 NAIP imagery was used to prepare maps of irrigated areas by crop type and also to compute the distribution of different crop types based on total division area and irrigated area. This is shown in Table 1 provided with this memo.

The irrigated area shapefile was updated with minimum, maximum, and average elevation corresponding to each polygon based on the "**Zonal Statistics**" toolbox available under Spatial Analyst tools in ArcMap. A "**Join**" operation was also performed between the shapefile and the table obtained from Step 2 based on the "**SW_WDID1**" field available in the shapefile and the "**WDID**" field available in the table in order to link irrigated areas to water rights.

List of items provided with this memo:

1. A database that provides all the available water rights records in terms of net amounts (division name_NetAmts) and transactions (division name_Transacts) of water rights for the four divisions.

Note: the database contains information for all the water rights based on different usage like irrigation, industrial, municipal, domestic, etc. and therefore should be filtered accordingly based on the goal of analysis.

2. A brief documentation providing a description of different attributes in the database.
   Note: HBGuest.pdf provides a description of all the attributes that are in the water rights database provided by MWH. Please refer to overviews on Tables 8 (vw_HBGuest_NetAmts) and 42 (vw_HBGuest_Transact) for information on water rights in terms of net amounts and total transactions, respectively.
3. Updated polygon shapefiles representing irrigated areas for the four divisions.
4. Table 1 representing crop type distribution for the four divisions.

Appendix C – Natural Resources Consulting Engineers, Inc.

DRAFT WHITE PAPER – Colorado River Water Bank

Date: June 22, 2012 (Update of November 28, 2011 Draft)
To: Mr. Chip Paulson, P.E.
MWH Americas, Inc.
From: L. Niel Allen, Ph.D., P.E.
RE: Agronomic and Economic Feasibility of Fallowing and Deficit Irrigation in Colorado's Colorado River Basin

Natural Resources Consulting Engineers, Inc.
131 Lincoln Ave, Suite 300
Fort Collins, CO 80524
Phone: (970) 224-1851/Fax: (970) 224-1885

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To: Mr. Chip Paulson, P.E.
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From: L. Niel Allen, Ph.D., P.E.

RE: Agronomic and Economic Feasibility of Fallowing and Deficit Irrigation in Colorado's Colorado River Basin

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Summary of Findings

This paper discusses the agronomic feasibility and costs associated with fallowing and deficit irrigation to provide water for a potential Colorado River water bank for Colorado (Water Bank). The paper is updated from the November 28, 2011 based on utilization of the high altitude method of calculating consumptive irrigation use for pasture. Fallowing is not planting and not irrigating land that would normally be used for production of an annual corp. Deficit irrigation is irrigating a crop less than the crop irrigation requirements; this could be decreased irrigations or no irrigation during a year. Ninety-eight percent (778,500 acres) of the irrigated acreage in the Colorado River basin of Colorado is pasture, alfalfa, corn, small grain, and dry beans. The balance of the irrigated cropped acreage includes orchard, blue grass, sod farms, and vineyards. The acreage of orchard, beans, blue grass, sod farms, and vineyards is small in relationship to the total acreage. Orchards and vineyards are permanent crops that are very expensive to establish and orchards generally last over 30 years and vineyards last over 50 years. Additionally, deficit irrigation on orchards and vineyards not only impacts yields in the year of deficit irrigation, but also has a negative impact on the next year's production. In general these crops are higher value crops the acreage is small so they are not considered as a primary source of water for the Water Bank.

Fallowing is feasible for small grains and grain corn. Deficit irrigation is available for all crops, but is best suited for perennial forage crops of alfalfa and pasture which comprise 91 percent of the irrigated land in the Colorado River basin of Colorado. Alfalfa and pasture are drought tolerant and by deficit or non-irrigation will reduce consumptive irrigation use and yield. Once established alfalfa can be deficit irrigated every year without shorting the life of the alfalfa stand. Pasture can be deficit irrigated every year without significant long-term impacts. Alfalfa and pasture enter a stressed or dormant condition without significant loss of plant population or long-term crop damage. In some arid areas pastures and alfalfa are grown successfully for many years without irrigation. In most of the basin, alfalfa and pasture will produce harvestable yields with limited or no irrigation. However, deficit irrigation or no irrigation results in a significant decrease in yields. For example under no irrigation, the alfalfa may produce one cutting verses three or four with irrigation.

Determining the decrease in consumptive irrigation use and water savings is site specific. The water savings from deficit or no irrigation ranges from 1.2 acre-feet per acre in the higher elevation pastures to 3.3 acre-feet per acre in the lower elevation alfalfa fields. Deficit irrigation reduces crop evapotranspiration resulting in a decrease in yield and reduced income to the grower. Yields with no irrigation are expected to decrease from 2 ton to 5 tons per acre depending on the elevation of the fields. The highest elevations are colder have a shorter growing season than the lower elevations, resulting in lower yields. Higher elevations are not well suited for alfalfa. There is about 7,000 acres of alfalfa grown at elevations over 7,000 feet.

There is about 258,000 acres of irrigated pasture over 7,000 feet in elevation. The annual yields at higher elevation are much lower than yields at lower elevations.

The amount and timing of deficit irrigation has a direct impact on yield. The greatest water savings occurs from no irrigation for the entire season. However, not irrigating during the latter part of the growing season has less of a reduction in yield per unit of water saved.

The value or cost of the water for the Water Bank is complex due to the market for water, supply of water, and specific water needs based on location and demand. While the cost of water is undetermined, it is expected to range from about $35 to over $200 per acre-foot (CRWCD, 2011). The value of water based on lost production from deficit irrigation of alfalfa can be estimated by the value of the loss in production, plus added costs to growers and incentive to participate, minus reduced irrigation and production costs. For forages the estimated loss of production for reduced consumptive irrigation use is 1.8 tons of forage per acre-foot. The value of 1.8 tons of alfalfa has been as high as $295 in 2008 ($164 per ton). October 2011 Colorado premium hay prices are over $200 per ton (over $360 per acre-foot). The value of the lost pasture production from deficit irrigation would generally be less because of the lower value of the pasture. However, during a drought the value of irrigated pasture can be similar to that of alfalfa.

Introduction

The 1922 Colorado River Compact Article III states that the Upper Basin may not deplete Lee Ferry flows below an aggregate of 75,000,000 acre-feet over a period of 10 consecutive years. The Colorado River Compact Article VIII states that the present perfected water rights are unimpaired by this compact. To meet the non-depletion obligation of the compact and other potential water needs a Colorado River Compact Water Bank Study has been initiated by the Water Bank Group. Fallowing or deficit irrigation can reduce consumptive water use and supply water for the Water Bank. The location and water right priority of Colorado's Colorado River basin agricultural water is shown in Plate 1. The location and major crops of Colorado's Colorado River basin agricultural water is shown in Plate 2.

Fallowing and deficit irrigation in the Colorado River basin are methods considered for Colorado to meet the 1922 Colorado River Compact non-depletion obligation during an extended drought, while protecting important post-compact water uses. Under the Colorado River Compact of 1922, the states of the Upper Division (Colorado, New Mexico, Utah and Wyoming) are required to not cause the flow at Lee Ferry, Arizona to fall below 75,000,000 acre-feet during any consecutive 10-year period, which may, under certain circumstances, cause the Upper Division States to limit their post compact consumptive water uses. The recent drought has demonstrated that the Upper Division states may need to develop mitigation plans if the flow in the Colorado River ever becomes so low that the Upper Division States could not supply all of their depletions and still meet the their non-depletion obligation to the Lower Division States (Arizona, California and Nevada) under the Colorado River Compact. An informal group composed of representatives of the Colorado River Water Conservation District, Colorado Water Conservation Board (CWCB), Front Range Water Council, Southwestern Water Conservation District, and The Nature Conservancy (collectively, the Water Bank Group) is investigating the development of a "Water Bank" that would allow continued water use in the event that a drought significantly reduces flows in the river and the Upper Division States could not supply all of their depletions and still meet their non-depletion obligation. The Water Bank would seek to provide a means for pre-Compact (not subject to the non-depletion obligation) water rights and post-Compact reservoir storage to be used to allow post-Compact water rights that are not 'present perfected rights' under the Compact to continue to be diverted.

Literature Review

Alfalfa Deficit Irrigation

Deficit irrigation of alfalfa is agronomically feasible based on numerous studies in the western United States. Alfalfa is a perennial crop well adapted to dry climates; it goes dormant during the winter and during drought. Field studies by researchers at Colorado State University have shown that alfalfa, under deficit irrigation or non-irrigation (precipitation only), did not experience reduced stands when compared to fully irrigated alfalfa or detrimental impacts on production during the following years (Hansen, 2009). Alfalfa is grown for 4 to 8 years because stands (plant population density) decline with time based on variety, management, and climate. The field is then rotated to a different crop or briefly fallowed before being replanted. The literature review did not indicate that alfalfa rotations would be changed due to deficit irrigation, except in areas such as the Imperial Valley of California where alfalfa is cropped the entire year. In the Basin, deficit irrigation can occur without decreasing the productive years of alfalfa fields.

One complication to deficit irrigation or non-irrigation is that alfalfa develops a deep root system and can extract water from saturated groundwater levels that are even as deep as 20 feet (Hansen, 2011). Thus, the determination of reduced consumptive water use is site specific and can be more complicated than just simply accounting for reduced irrigation. The reduction in consumptive irrigation use rather than reduced irrigation diversion is needed because the water budget is on a basin level. Alfalfa is a suitable crop for deficit irrigation provided an accurate water budget can be established. Alfalfa water budgets are best established when groundwater levels are greater than 25 feet and do not contribute to crop ET. In some fallowing programs such as those on the Arkansas River in Colorado alfalfa cannot be grown as a cover crops because of its deep root system and the impacts that it may have return flows to the river.

Lindenmayer et. al (2011) did a review and analysis of research literature concerning deficit irrigation of alfalfa for water savings in the Great Plains and Intermountain West. One of the findings is that the water use efficiency of alfalfa is less (requires more consumptive use of water per unit of production) during the mid to late growing seasons. This finding provides the ability for growers to efficiently produce alfalfa early in the season from soil moisture accumulated during the winter and spring and from limited irrigation, and then to terminate irrigation. For example, research conducted by Hansen (2009) in Berthoud, Colorado showed that stopping irrigation after the first cutting reduced yields by 3.1 tons per acre and reduced CU by 16.5 inches (5.32 acre-inches per ton, 0.19 tons per acre-inch) and that by stopping irrigation after the second cutting reduced yields by 1.2 tons per acre and reduced CU by 11 inches (9.17 acre-inches per ton, 0.11 tons per acre-inch). Thus, a significant savings in irrigation can occur in relation to the lost production by not irrigating late in the season. Many of the studies were for multiple consecutive years and indicate that, in most cases, deficit irrigation has no long term impacts on the fields.

Grass Deficit Irrigation

Irrigated grass comprises the greatest acreage of water rights in the Colorado River basin of Colorado. Perennial grasses grown in the Colorado River Basin of Colorado are winter hardy and generally drought tolerant. The most critical time to provide adequate water to grasses for maintaining a healthy crop is the early spring through the first harvest (Kirkpatrick, et. al, 2006). The management of pasture in deficit irrigation conditions is needed to maintain the health of the pasture. It is important that the pasture not be over-grazed during stress period to protect the crowns of the grasses which are important for plant recovery. There has not been as much research on deficit or non-irrigation of grasses as for alfalfa, but the crops are similar in their use of water and hardiness. Deficit irrigation of irrigated grasses has the potential to be a significant part of a water banking program because 1) pasture root systems are shallower than alfalfa thus there would be more areas that are not complicated by groundwater contribution to crops and, 2) the large acreage of irrigated grasses in the basin. Water use efficiency of pasture is similar to alfalfa and ranges from 0.15 to 0.2 tons per acre-inch.

Fallowing of Corn and Small Grain

Fallowing of annual irrigated crops such as corn and small grain is commonly used in the western United States to provide water for leases or temporary transfers. Once the water lease or transfer arrangements are made, the process is relatively easy. Requirements are generally provided so the fallowed land is not subject to soil erosion by wind and water and weeds and pests controlled. The majority of the acreage of annual irrigated crops in the basin is planted to corn and small grain. The other annual irrigated crops are dry beans and vegetables which have a higher per acre value than corn or small grain. Due to the acreage and value, only corn and small grains should be considered for fallowing as part of the Water Bank in this initial assessment.

Fallowing of Dry Beans

Dry beans like other annual crops can be fallowed. However, the costs of fallowing dry beans is expected to be higher than fallowing of small grains or corn. This is because the net return from dry beans is usually higher than for wheat and corn. However, like all crops the price received for dry beans can vary from year to year significantly affecting impacts. For example, since 2000 the average price of dry has ranged from $15.60 per cwt. in 2000 to $35.80 in 2008. Fallowing of dry beans could provide a portion of the water supply of the Water Bank if growers are willing to fallow land at prices that compete with other growers of other crops that use more water and usually have a smaller net return per acre.

Fallowing of Vegetables

Vegetables like other annual crops can be fallowed. The acreage of vegetables is 1,152 acres, about 0.15 percent of the total acreage. The consumptive irrigation requirement of vegetables averages about 1.6 acre-foot per acre per year. Fallowing all the vegetable acreage would provide about 1,800 acre-feet per year for the Water Bank. This is the consumptive irrigation requirement because vegetables would not generally be deficit irrigated. It is not expected that vegetables would be fallowed because of their high value.

Deficit Irrigation of Orchards and Vineyards

There are 6,469 acres of orchard and 770 acres of vineyards in the Basin, less than 1 percent of the total acreage. Orchards and vineyards are permanent crops that are very expensive to establish and orchards generally last over 30 years and vineyards last over 50 years. Additionally, deficit irrigation on orchards and vineyards not only impacts yields in the year of deficit irrigation, but also has a negative impact on the next year's production. For these reasons orchards and vineyards are not considered for fallowing or deficit irrigation.

Analysis

The analysis of deficit irrigation and fallowing includes an estimation of consumptive irrigation requirements and use and economic considerations. In addition to the consumptive irrigation requirement, the consumptive irrigation use was estimated based on water supply availability. The water supply limited consumptive irrigation use is less than estimated consumptive irrigation requirements.

Consumptive Irrigation Requirement/Use and Acreage

The consumptive irrigation requirement and use are used to determine the water that could be made available for the Water Bank. Using a model developed for the State of Colorado (StateCU), consumptive irrigation requirements were calculated for the Colorado River basin of Colorado by 500-foot elevation bands and by Colorado Water Right Divisions (See Appendix A). The StateCU model is described and can be obtained from the Colorado Division of Water Resources (CDWR, 2011). For this analysis, consumptive irrigation use is a depletion of water in the basin at the field level. Therefore, reducing consumptive irrigation in the basin increases the water available to other users. The water supply limited consumptive water use is based on basin water use analysis conducted by Leonard Rice Engineers for the State of Colorado (Leonard Rice Engineers, 2009)

Alfalfa

The average annual consumptive irrigation requirement for alfalfa ranges from about 3.3 acre-feet per acre in the lower elevations and drier areas to about 1.0 acre-foot per acre in the higher elevations with higher precipitation. The total acreage of alfalfa in the Colorado River basin of Colorado is about 92,500 acres. The total average annual water supply limited consumptive irrigation use of alfalfa is 180,000 acre-feet. The extent of participation in deficit irrigation or non-irrigation by growers of alfalfa is unknown and is highly dependent on compensation provided to participate. For example, if 10 percent of the acreage was not irrigated, approximately 18,000 acre-feet of water per year could be made available for the Water Bank.

Grass Pasture

The average annual consumptive irrigation requirement for grass pastures ranges from about 2.8 acre-feet per acre in the lower elevations and drier areas to about 1.2 acre-feet per acre in the higher elevations with higher precipitation. The total acreage of pasture in the Colorado River basin of Colorado is about 623,000 acres. The total average annual supply limited consumptive irrigation requirement of pasture is about 1,070,000 acre-feet. As with alfalfa, the extent of participation in deficit irrigation or non-irrigation by growers of pasture is unknown and is highly dependent on compensation provided to participate. For example, if 10 percent of the acreage was not irrigated approximately 107,000 acre-feet of water per year could be made available for the Water Bank.

Corn and Small Grains

The average annual consumptive irrigation requirement for corn and small grain ranges from about 2.3 acre-feet per acre in the lower elevations and dryer areas to about 1.0 acre-feet per acre in the higher elevations with higher precipitation. The total combined acreage of corn and small grain in the Colorado River basin of Colorado is only about 52,000 acres. The combined total average annual water supply limited consumptive irrigation use of corn and small grain is 73,400 acre-feet. The extent of participation by growers to fallow corn and grain is unknown and is highly dependent on compensation provided to participate. If 10 percent of the acreage was fallowed approximately 7,300 acre-feet of water per year could be made available for the Water Bank.

Dry Beans

The acreage of dry beans is 10,606 acres, about 1.3 percent of the total acreage. The consumptive irrigation requirement of dry beans averages about 1.5 acre-feet per acre. Fallowing all the dry bean acreage would provide about 15,400 acre-feet for the Water Bank (based on water supply limitation about 11,700 acre-feet per year).

Economic Considerations

The yield of alfalfa produced by one acre-foot of consumptive water use ranges from about 1.2 to 2.4 tons. During the mid-summer months the yield is about 1.8 tons per acre-foot of consumed water in the Upper Colorado River Basin. Crop yield is a factor of many inputs and conditions. There is a nearly linear relationship between yield of forage crops and crop evapotranspiration (ET), all other things being constant. This occurs because the entire plant is harvest for forage crops and the yield does not depend on the full maturity of the crop. The water use efficiency (yield per unit of crop ET) is usually higher in the spring and early summer than later in the season when temperatures and crop ET are higher (summarized by Bauder, et al, 2010).

For this analysis alfalfa yield versus ET relationships are for both alfalfa and pasture because there are fewer studies relating pasture ET to yield. Alfalfa yield relationships are suitable for this analysis because 1) pasture potential ET and yield are very close to potential alfalfa yield and ET, 2) there are many studies concerning alfalfa yield and ET, and 3) like alfalfa, all the pasture growth can be harvested either by grazing or mechanical harvest. Table 1 provides a summary of relationships between yield and ET for alfalfa and pasture.

Table 1 - Range of yield in tons per acre per inch of ET.

Study	Yield Factor (tons/ac per inch of ET)	Reference
Alfalfa Yield and Water Use in Commercial Fields	0.243	(Hill, 1983)
Daily and Seasonal Evapotranspiration and Yield of Irrigated Alfalfa in Southern Idaho	0.2	(Wright, 1988)
Yield Response to Water - FAO 33	0.17	(Doorenbos and Kasam, 1979)
Yield Response to Water - FAO 33	0.226	(Doorenbos and Kasam, 1979)
Water Use and Yield of Alfalfa in Northwestern New Mexico	0.2015	(Smeal, 1991 & 1994)
Consumptive Use and Yields of Crops in New Mexico (Alfalfa)	0.1572	(Sammis T.W. 1979 & 1981)
Water use by crops and pastures in southern NSW (Pasture)	0.2035	(A. Bowman and B. Scott, 2009)
Limited Irrigation of Alfalfa in the Great Plains and Intermountain West	0.177	(T. Bauder, N. Hansen, B. Lindenmeyer, J. Bauder, and J. Brummer, 2011)
Implications of Deficit Irrigation Management on Alfalfa (California Study)	0.16-0.09	(S. Orloff, D. Putnam, B. Hanson, and H. Carlson, 2005)

Hansen (2010) stated: “there has been much work done in the past to determine the relationship between consumptive water use and alfalfa yield (Daigger, *et al*, 1970; Bauder *et al*, 1978; Retta and Hanks, 1980; Sammis, 1981; Guitjens, 1982; Carter and Sheaffer, 1983; Undersander, 1987; and Smeal *et al*, 1991). Studies of alfalfa water use conducted across a range of climates and geographic areas in the United States illustrate a linear relationship of yield to ET with the slope of this line indicating alfalfa yield per unit of consumed water. The slope of this relationship is 0.18 tons/ac-in can also be interpreted that it requires an average of 5.6 in of ET per ton of alfalfa hay produced. This result corresponds well with a rule of thumb among Colorado irrigators that it takes 6” of water to produce a ton of hay.”

Costs Associated with Fallowing and Deficit Irrigation

The costs associated with deficit irrigation, non-irrigation, and fallowing can be determined by value of reduced yields and/or market values of leased or banked water. The actual value of this water is dependent on many factors that are unknown until a market is established and transactions occur. As with other commodities, the supply and demand has a large impact on the price and value.

The cost of reduced alfalfa and pasture forage resulting from deficit irrigation can be estimated by two methods. First, the cost to replace the feed which includes a purchase cost plus any additional cost for feeding, minus costs that may decrease, which could include labor, fuel, and equipment operation costs. Because many of the irrigated alfalfa and grazed pasture are used in cattle or cow-calf operations, the loss of feed may lead to a reduction in the herd size if replacement feed is not purchased. This reduces profits and/or increases cost to re-establish the full herd size. For producers that use forage as a cash crop, the value is based on the reduced production and changes in costs.

From 2000 through 2009, the average annual price of alfalfa in Colorado ranged from $85 per ton in 2004 to $164 per ton in 2008 (NASS, 2011). Based strictly on the replacement value of lost production, it is as high as $295 per acre-foot (1.8 tons per acre feet times $164 per ton). The current (October 2011) price of premium quality alfalfa is over $200 per ton. The value to the growers would generally be less due to reduced production and harvest costs. However, the grower would likely need an incentive to limit his irrigation and change his production operation. Growers in the lower Colorado River basin are being paid about $200-$230 per acre-foot for water being leased by municipal water purveyors (See Market Value of Leased Water Section). Many of the growers' costs such as equipment, land, and infrastructure are fixed and will not be reduced by deficit irrigation. Other annual growing costs such as some harvest and irrigation will decrease with deficit irrigation.

The loss of forage production from deficit irrigation is estimated to range from approximately 2 to 5 tons per acre, depending on the location of the fields. The corresponding water savings range from 1.2 to 3.3 acre-feet per acre. The higher elevation will experience the lowest decrease in yield and water savings, due to lower forage crop consumptive irrigation use and production rate. The highest elevations are colder have a shorter growing season than the lower elevations, resulting in lower yields. Higher elevations are not well suited for alfalfa. There is about 7,000 acres of alfalfa grown at elevations over 7,000 feet. There is about 258,000 acres of irrigated pasture over 7,000 feet in elevation. The yields are higher elevation are much lower than yields elevations. Providing flexibility concerning the amount of deficit irrigation of pasture and alfalfa may increase the participation by growers. For example, one option could be to irrigate through June and then no irrigation from July until the end of the season. The water savings could be based on baseline irrigations or estimation of reduced consumptive irrigation use based on ET estimates. No irrigation of alfalfa and pasture would likely be more suitable for the higher elevations and partial season deficit irrigation for the lower elevations.

The value of irrigated grass would include the value of hay produced if the pastures are mechanically harvested or the grazing value for grazed pastures. A producer is likely dependent on the grazed pasture for his livestock operation and would need to replace the lost production by leasing grazing lands or purchase of feed to replace the lost production.

As previously discussed, there is opportunity to fallow land that would normally be planted to small grains or corn grain. The opportunity is more limited due to the smaller acreage base, but the costs are thought to be similar. As with forage crops the value of the loss of grain production is not the only consideration to the growers. The value of the water to growers would generally be less than gross revenues due to reduced costs. However, the grower would need enough water lease payment to cover fixed costs, profits, plus an incentive to limit his irrigation and change his production operation. Fallowing of small grains can provide water savings that range from 1.0 to 2.1 acre-feet per acre based on location and effective precipitation. Fallowing of corn can save about 1.2 to 2.3 acre-feet per acre.

Alfalfa is a suitable crop for deficit or no irrigation provided an accurate water budget can be established. As discussed in the literature review section, alfalfa water budgets are best established when groundwater levels are greater than 25 feet and do not contribute to crop ET. Criteria would need to be established for deficit or no irrigation of alfalfa to ensure that water savings to the Basin do occur.

Market Value of Leased Water

The market value of the water to potential users in large part determines price of the water. Water leased for agricultural purposes may be $50 per acre-foot or less depending on the availability and use of the water. Water used for municipal and industrial purposes can be over $200 per acre-foot, primarily due to the ability to pay and the critical needs experienced by some water purveyors. For example, the April 19, 2011 Water Marketing Policy of the Colorado River Water Conservation District's Colorado River Water Projects Enterprise lists supply pricing from $35.28 to $1,407.24 per acre-foot depending on the water source, location, and purpose of use (CRWCD, 2011). Water made available from fallowing would be for downstream users generally making location of existing uses and supplies less significant of an issue. However, if the water available from the water bank was used to supply post-compact water in exchanges, the location would be more important and could significantly impact water prices.

If there is an established water market the value of the water is based on the market conditions, requiring a willing buyer, a willing seller, and an agreeable price. For these transactions, the price the buyer is willing to pay depends greatly on the availability of the water (location and conveyance facilities) and the use of the water.

NRCE was an active participant in two fallowing/forbearance agreements concerning temporary transfers of agriculture water to municipal water on the lower Colorado River. The Moapa Band of Paiute Indians lease water to Southern Nevada Water District for $210 per acre-foot consumptive use (2009 dollar basis) adjusted for inflation. This is a 5 year agreement for annual lease of up to 3,400 acre-feet per year. The Quechan Tribe of the Fort Yuma Indian Reservation receives $125 per acre-feet of decreased diversion (equivalent to about $200 per acre-foot of consumptive use) to Metropolitan Water District of Southern California (MWD) as part of a fallowing/forbearance of agreement. The Quechan Tribe agreement is in place from 2005 until

2035 with an annual increase in rate of 2.5 percent with a lease of up to 13,000 acre-feet per year.

Short term emergency water leases from fallowing from Palo Verde Irrigation District (PVID) to MWD are $1,665 per acre with an additional $35 to the PVID. The equivalent water use rate is about $400 per acre-foot. The long term agreements (based on PIVD 2004 agreement) include an initial payment of $3,170 per acre, with annual payments of $602 per year increased by greater of 2.5 percent compounded each year or consumer price index. The 2011 annual lease payment is $698 per acre or about $230 per acre-foot. The Imperial Irrigation District has a 10 year old fallowing program to provide a water supply for San Diego County Water Authority (IID, 2011). The program is voluntary is provided on a first-come first-served basis. The farmer payments for 2012 are published as $85 per acre-foot based on the field’s baseline water use history or a 6 acre-feet per acre cap.

Conclusion

Deficit irrigation and/or non-irrigation of grass pasture and alfalfa are the best supply of water for the Water Bank. Deficit irrigation is best suited for grass pasture and alfalfa and can quickly be implemented for a single year or on a continuing basis without significantly impact the future production. Deficit irrigation of alfalfa can reduce yield by about one ton per acre in the high elevations to 5 tons per acre in the lower elevation. There is a similar reduction of forage production for well managed pastures.

Fallowing of annual crops can also provide a water supply for the Water Bank. Acreage normally planted to small grain and corn is the most feasible to fallow. Fallowing of acreage that would be planted to dry beans can also be used but the acreage is more limited and the costs are usually higher based on the loss of net return per acre-foot of water saved. Other annual crops such as vegetables are not considered for fallowing due to their small acreage and high value.

Orchards and vineyards are permanent crops that are very expensive to establish and have a long production cycle. Deficit irrigation of orchards and vineyards would result in high economic losses due to decreases in yields and production impacts can extend for several years. For these reasons orchards and vineyards are not considered for fallowing or deficit irrigation.

The consumptive irrigation requirement in the Basin is estimated to be 1,430,000 acre-feet per year, with the supply limited consumptive irrigation use estimated to be about 1,250,000 acre feet per year. There is potential to bank several hundred thousand of acre-feet per year from deficit irrigation of pasture and alfalfa. The acceptance and costs of the deficit and non-irrigation of grass pasture and alfalfa are unknown and will need to be determined by grower input and perhaps a pilot program.

The cost of water produced from deficit irrigation or fallowing would range from about $50 per acre-foot (based on irrigation water lease rates) to over $200 per acre–foot (based on feed replacement or loss of income costs). The amount of water available would be a function of the price paid for water. Higher prices provide more incentives for grower participation.

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Appendix A

Colorado River Basin of Colorado

Consumptive Irrigation Requirements

Irrigated Acreage of Alfalfa, Corn, Grass Pasture, and Small Grains

Average Annual Consumptive Irrigation Requirement

Average Consumptive Irrigation Requirement (inches per year).

Elevation Band (ft) → Division/Crop ↓	<5000	5001-5500	5501-6000	6001-6500	6501-7000	7001-7500	7501-8000	8001-8500	8501-9000	9001-9500	9501-10000
Division 4											
Alfalfa	37.1	33.9	30.7	27.5	24.3	21.1	17.9	14.7			
Corn	25.7	23.2	20.6	18.1	15.5	13.0					
Grass Pasture	31.6	30.4	29.1	27.9	26.6	25.4	24.1	22.9	21.6	20.4	19.1
Spring Grain	21.2	19.6	18.0	16.4	14.8	13.2	11.6	10.0	8.4		
Division 5											
Alfalfa	37.7	34.2	30.8	27.3	23.9	20.4	17.0	13.5			
Corn	25.5										
Grass Pasture	32.4	30.8	29.2	27.6	26.0	24.4	22.8	21.2	19.6	18.0	16.4
Spring Grain	21.1	19.4									
Division 6											
Alfalfa	29.6	26.8	24.0	21.2	18.4	15.6	12.8				
Corn											
Grass Pasture	30.1	28.2	26.3	24.4	22.5	20.6	18.7	16.8	14.9	13.0	
Spring Grain	19.7	17.9	16.0	14.2							
Division 7											
Alfalfa	39.4	35.8	32.3	28.7	25.2	21.6					
Corn	27.9	25.0	22.1	19.2							
Grass Pasture	34.1	32.4	30.7	29.0	27.3	25.6	23.9	22.2	20.5		
Spring Grain	25.8	23.5	21.2	18.9	16.6						

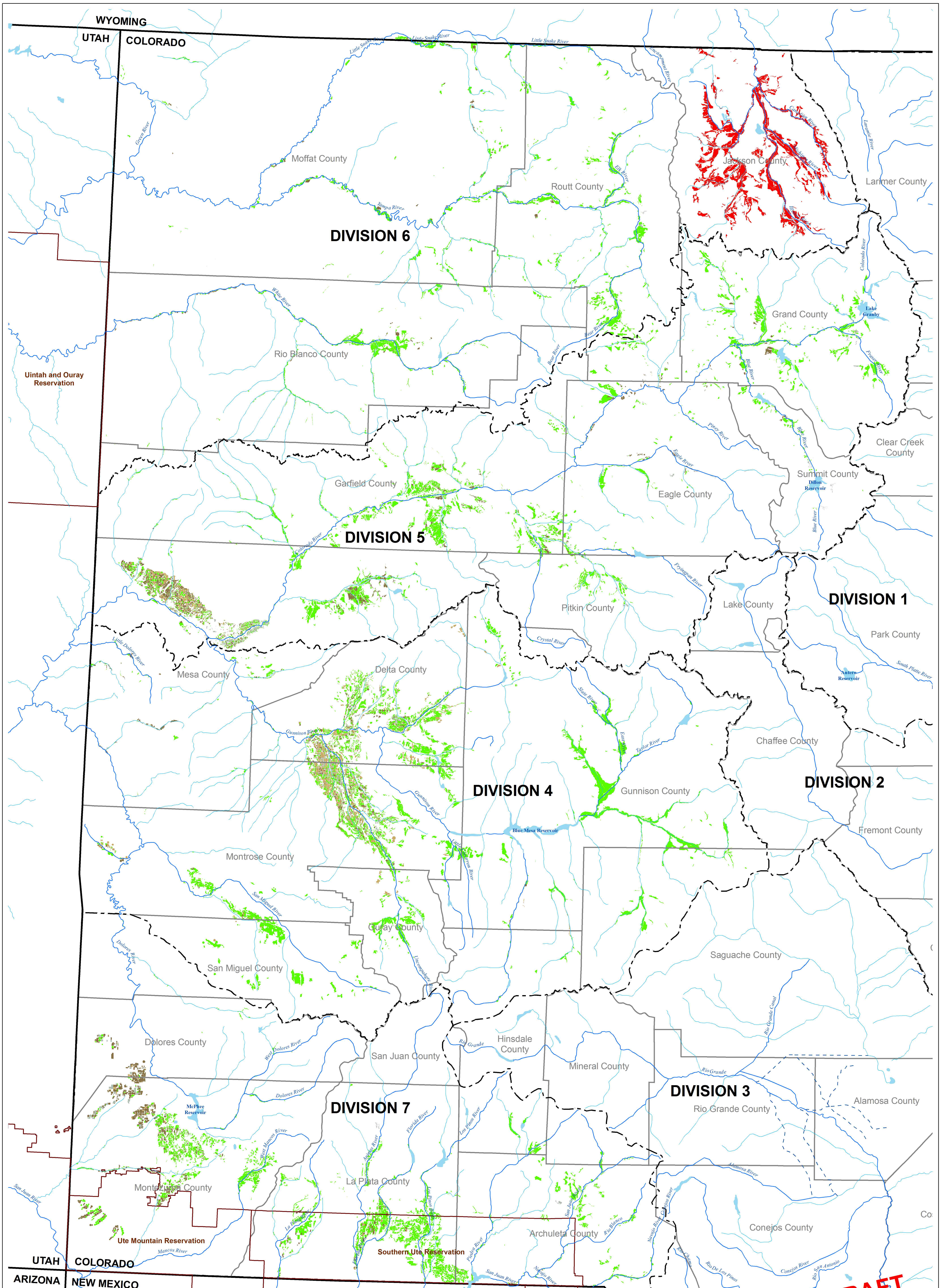
Area of Irrigated Land based on 2005 Survey (acres).

Elevation Band (ft) → Division/Crop ↓	<5000	5001-5500	5501-6000	6001-6500	6501-7000	7001-7500	7501-8000	8001-8500	8501-9000	9001-9500	9501-10000
Division 4											
Alfalfa	1,365	6,566	6,443	2,296	1,952	126	186	50			
Corn	1,478	9,661	5,384	310	49	8					
Grass Pasture	3,903	24,214	35,310	23,241	22,058	27,292	29,612	26,221	18,046	9,358	143
Spring Grain	714	6,618	5,401	2,693	2,854	1,901	78	764	418		
Division 5											
Alfalfa	18,944	232	1,627	4,072	4,391	2,769	2,456	595			
Corn	7,054										
Grass Pasture	19,227	9,868	21,446	25,412	20,976	18,313	27,979	21,986	7,974	249	47
Spring Grain	4,019	12									
Division 6											
Alfalfa		1,328	970	2,352	1,394	101	27				
Corn											
Grass Pasture		903	7,988	32,504	24,712	9,748	8,913	9,130	1,344	157	
Spring Grain		25		25							
Division 7											
Alfalfa	18	3,840	1,742	4,516	21,423	728					
Corn		42		91							
Grass Pasture	461	3,857	3,088	31,834	54,298	22,817	11,663	6,589	121		
Spring Grain				124	2,356						
Totals											
Alfalfa	20,327	11,967	10,782	13,237	29,159	3,724	2,669	646			
Corn	8,532	9,702	5,384	401	49	8					
Grass Pasture	23,591	38,843	67,832	112,991	122,044	78,170	78,166	63,925	27,486	9,764	190
Spring Grain	4,733	6,655	5,401	2,843	5,210	1,901	78	764	418		

Average Annual Consumptive Irrigation Requirement (acre-feet).

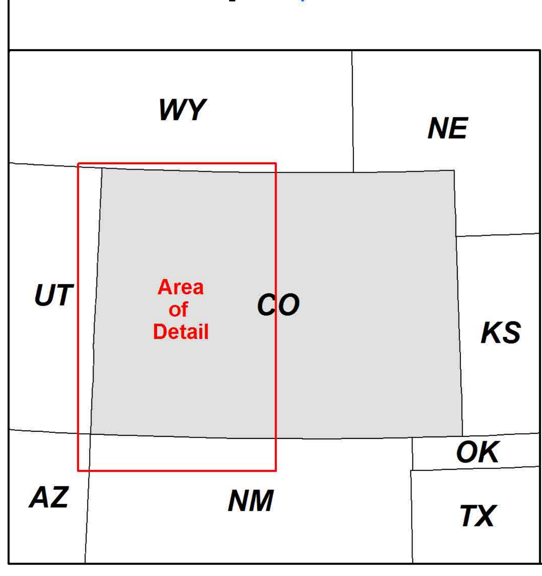
Elevation Band (ft) → Division/Crop ↓	<5000	5001-5500	5501-6000	6001-6500	6501-7000	7001-7500	7501-8000	8001-8500	8501-9000	9001-9500	9501-10000
Division 4											
Alfalfa	4,219	18,548	16,482	5,263	3,953	221	278	62			
Corn	3,165	18,677	9,242	467	63	8					
Grass Pasture	10,279	61,342	85,627	54,036	48,895	57,768	59,470	50,038	32,483	15,909	228
Spring Grain	1,261	10,810	8,101	3,681	3,520	2,091	75	637	292		
Division 5											
Alfalfa	59,516	663	4,176	9,264	8,744	4,708	3,479	670			
Corn	14,989										
Grass Pasture	51,913	25,329	52,186	58,448	45,448	37,236	53,160	38,841	13,024	373	64
Spring Grain	7,067	20									
Division 6											
Alfalfa		2,966	1,941	4,155	2,137	131	29				
Corn											
Grass Pasture		2,123	17,506	66,091	46,335	16,734	13,889	12,782	1,669	170	
Spring Grain		37		32							
Division 7											
Alfalfa	61	11,457	4,689	10,802	44,988	1,311					
Corn		87		146							
Grass Pasture	1,309	10,415	7,899	76,932	123,529	48,677	23,228	12,189	208		
Spring Grain				196	3,259						
Totals											
Alfalfa	63,796	33,634	27,288	29,484	59,823	6,370	3,785	732			
Corn	18,155	18,764	9,242	613	63	8					
Grass Pasture	63,500	99,208	163,219	255,506	264,207	160,415	149,747	113,851	47,384	16,453	293
Spring Grain	8,328	10,867	8,101	3,909	6,779	2,091	75	637	292		

Total of 1,646,614 acre-feet per year.



LEGEND

RIVER	INDIAN RESERVATION
STREAM	ALFALFA
CANAL	GRASS PASTURE
LAKE OR RESERVOIR	GRAINS / CORN
DIVISION BOUNDARY	OTHER
STATE BOUNDARY	IRRIGATED LAND NOT IN BASIN
COUNTY BOUNDARY	



N

0 10 20 40
Scale in Miles

PLATE 1

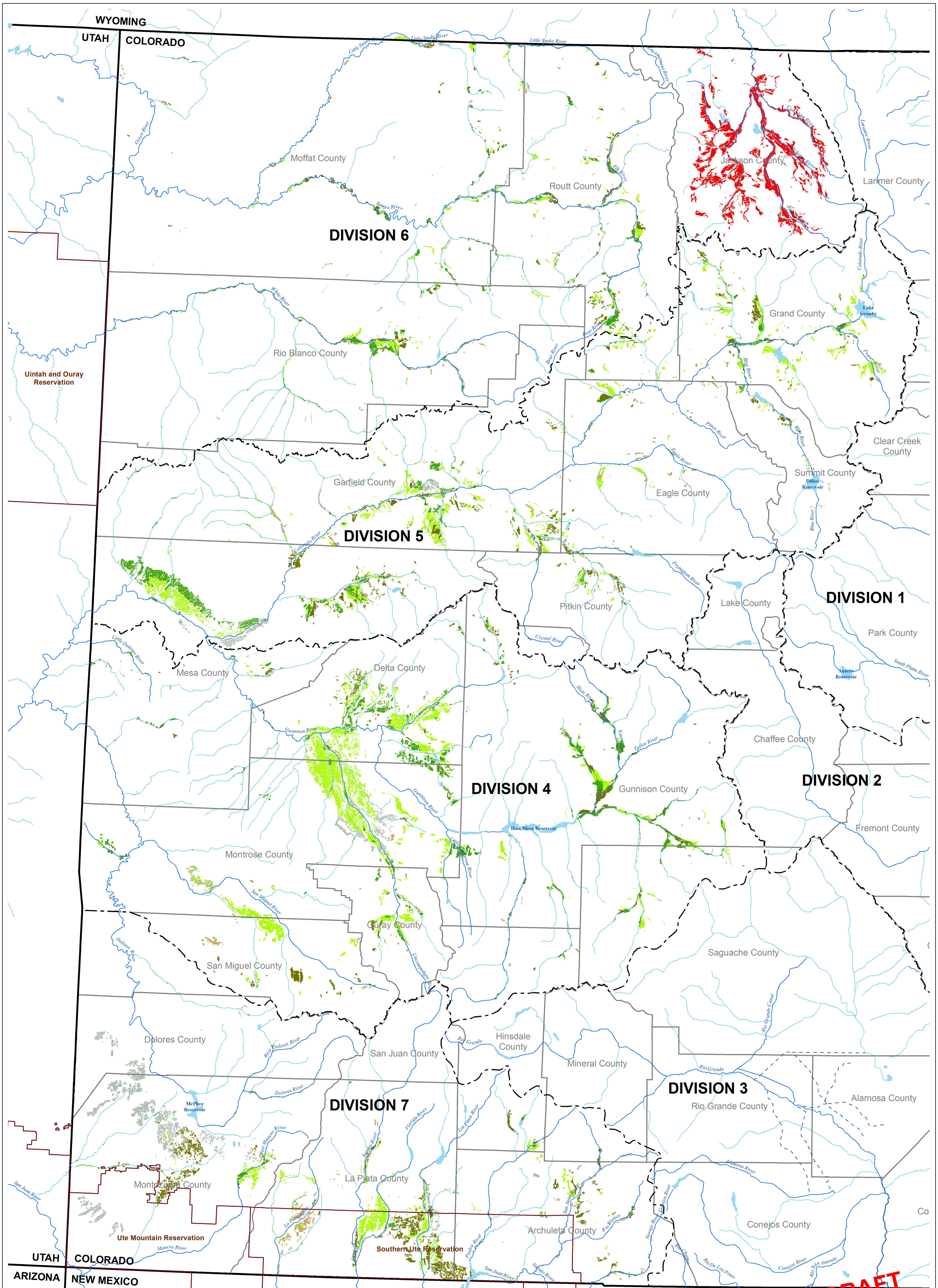
NOVEMBER 2011

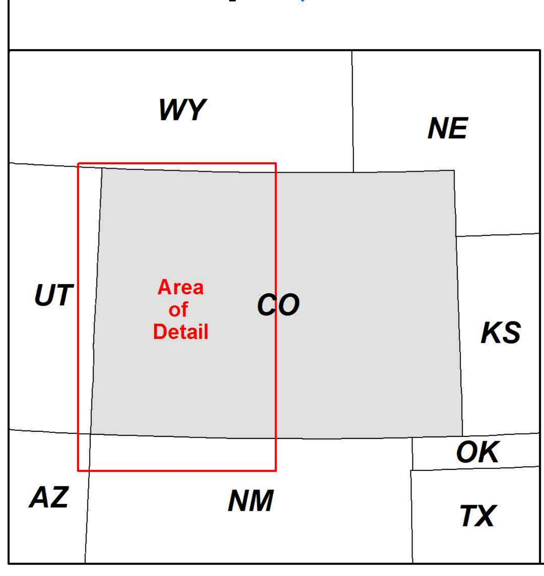
COLORADO WATER BANK CROP TYPE MAP

NRCE

NATURAL RESOURCES CONSULTING ENGINEERS, INC.

Fort Collins, CO Asmara, ERITREA Oakland, CA





LEGEND

- RIVER
- STREAM
- CANAL
- LAKE OR RESERVOIR
- DIVISION BOUNDARY
- STATE BOUNDARY
- COUNTY BOUNDARY
- INDIAN RESERVATION
- PRE - 1922 APPROPRIATION AND ADJUDICATION
- PRE - 1922 APPROPRIATION
- 1922 - 1929 APPROPRIATION AND ADJUDICATION
- 1922 - 1929 APPROPRIATION
- POST 1929 APPROPRIATION
- NO APPROPRIATION DATA
- IRRIGATED LAND NOT IN BASIN

N

0 10 20 40
Scale in Miles

PLATE 2 JANUARY 2012

COLORADO WATER BANK APPROPRIATION DATE MAP

NRCE

Natural Resources Consulting Engineers, Inc.

Fort Collins, CO Asmara, ERITREA Oakland, CA

APPENDIX C

Evaluation of Colorado River Compact Water Bank Hydrologic Scenarios Using the Upper Colorado River Basin Model

TECHNICAL MEMORANDUM

MWH
BUILDING A BETTER WORLD

TO:	Dan Birch	DATE:	June 13, 2012
FROM:	Chip Paulson	REFERENCE:	1011690

SUBJECT: *Evaluation of Colorado River Compact Water Bank Hydrologic Scenarios Using the Upper Colorado River Basin Model*

1.0 INTRODUCTION

The Upper Colorado River Basin Model (Basin Model) developed by Leon Basdekas of Colorado Springs Utilities for the Front Range Water Council was used to determine the potential frequency with which Colorado River drought conditions (locally or for all of the Upper Colorado River Basin) could create a need for the Colorado River Compact Water Bank (Water Bank). The objective was to determine the magnitude and frequency of potential shortage conditions in the Upper Colorado River system that may result in the need to curtail some diversions in Colorado in order to meet the Upper Basin's non-depletion obligations under the Colorado River Compact. Federal regulations that govern operation of Lake Powell require annual minimum objective releases from Lake Powell, and those releases and the natural inflow between Lake Powell and the Paria River are measured at the Lee Ferry gaging station. This will be referred to as "Lee Ferry flows" throughout this TM. The Basin Model was used to evaluate the frequency of different magnitudes and durations of potential diversion shortages and low reservoir levels under various assumptions for Colorado River flows at Lee Ferry, Upper Basin water diversions, and Upper Basin hydrology.

2.0 BASIN MODEL SUMMARY

2.1 BASIN MODEL DESCRIPTION

The Basin Model is a simplified spreadsheet model of the Upper Colorado River Basin. Part of the CRWAS methodology included using the U.S. Bureau of Reclamation's (Reclamation) 2007 Hydrologic Determination (Determination). This Determination by Reclamation was based on natural inflow from 1906-2000. The model runs on an annual time step.

The Basin Model is based on the Determination using annual data reported in tabular format by Reclamation for Run 6. Run 6 in the Determination utilized an Upper Colorado River Basin flow of 8.25 MAF/year at Lee Ferry, and annual Upper Basin demand of 5.98 MAF/year. These specific values were used for model QA/QC purposes, but Lee Ferry flows and Upper Basin demands were made to be user defined in the model to allow for evaluation of different demand and Lee Ferry flow scenarios. For further details regarding the Determination can be found in the official Reclamation documentation.

The Basin Model is essentially a dynamic version of the Determination with the ability to perturb system demands, starting storage, Lee Ferry flow targets and inflow volumes, which are detailed on the input sheet of the model. One hundred stochastic streamflow sequences were derived from the 95 years of historical data (1906-2000) using the K-NN methods described in Sharma et.al, 1997. The Basin Model is considered useful in coarse planning level studies that focus on overall conditions in the Upper Colorado River Basin.

The Basin Model uses the following key assumptions for simulating operation of the Upper Colorado River Basin system.

- All Upper Basin annual demands are lumped into a single demand node. Demands are not differentiated between states or diversion points. Annual demand can be specified by the user, but is constant for all years of simulation.
- All Upper Basin reservoirs in the Hydrologic Determination are lumped into a single storage bucket totaling approximately 33.8 MAF after adjustments for sedimentation - principally at Lake Powell. Only total system storage is computed.
- The Upper Basin Colorado River flows (8.25 MAF/year or 7.50 MAF/year) are specified at Lee Ferry, and include the inflows from Paria River.
- The flows at Lee Ferry and deliveries to Upper Basin demands are derived first from natural river flows, then from the combined Upper Basin storage reservoirs.
- Two methods of dealing with present perfected water rights in the Upper Basin relative to the Compact can be simulated: not curtailing present perfected uses to meet the flow requirements at Lee Ferry, and treating all water rights as having the same priority. The model uses a value of 2.26 MAF/year for present perfected rights (Table A, Bureau of Reclamation, from estimates used in Compact negotiations). The non-curtailment option for present perfected rights was used in this study. In this case, the model first makes deliveries to present perfected water users, then meets the Lee Ferry flow target, then meets the remaining post-Compact Upper Basin demands. Upper Basin deliveries will not rise above the present perfected level until any deficit to the Lower Basin is repaid due to improved hydrologic conditions.
- Shortages are computed in any year in which the full demand cannot be met. Because demands are met from storage and there is no minimum allowable storage level in the

system reservoir storage account, shortages are not declared until all system reservoir storage is emptied. This differs from how the system would actually be operated, but allows for comparison between hydrologic scenarios.

- The model allows for two methods of assigning initial reservoir storage: (1) all reservoirs start full in the analysis, or other user defined value, for each of the 100 hydrologic sequences; and (2) sequences can be “looped” such that the ending reservoir storage for one sequence is adopted as the starting reservoir storage for the next sequence. This analysis uses the “looped” approach.
- Historical hydrology can be adjusted to reflect the effects of climate change or other influences by applying a user-defined factor that adjusts all annual natural flow values up or down by the same percentage.
- 100 95-yr stochastic sequences are analyzed and statistics are summarized for the entire 9,500-year data set.

The Basin Model lumps all Upper Basin demands together. To evaluate effects on Colorado’s Compact allotment, model output was post-processed and 51.75 percent of Upper Basin demands and shortages were allocated to Colorado. The Upper Basin States may not actually develop their Colorado River water in the same time frames or in the full allocated amounts, so the distribution of demand and shortage may be different than the 51.75 percent assumed in this report. No attempt is made to account for Arizona’s 50 KAF allotment under the Upper Basin Compact or to apply any other specific Compact mechanisms.

2.2 MODEL SCENARIOS

Fourteen scenarios of Upper Basin demands, Lee Ferry flow obligations, and basin hydrology were evaluated using the Basin Model to evaluate potential curtailment conditions. Upper Basin demands were set at the following amounts:

- 5.98 MAF/year – the value used in the Hydrologic Determination
- 4.50 MAF/year – an estimate of current Upper Basin depletions (from Colorado River Water Conservation District presentation, January 2005)
- 5.20 MAF/year – mid-range between 5.98 and 4.50 MAF/year

Lee Ferry flow obligations were set at the following amounts:

- 8.25 MAF/year – the value used in the Hydrologic Determination
- 7.50 MAF/year – the value from the original Compact computations

Hydrologic conditions were simulated at 90 percent and 100 percent of historical for all scenarios, and at 80 percent of historical for selected scenarios to further test the sensitivity of the system to altered hydrology.

Model input parameters defining the scenarios are summarized in **Table 1**.

TABLE 1
SCENARIOS EVALUATED

Scenario	Upper Basin Demands (ac-ft)	Flows at Lee Ferry (ac-ft)	Basin Hydrology (% of Historical)	Colorado Demands (% of Total Upper Basin Demands)
Scenario 1	5,980,000	8,250,000	100	51.75
Scenario 2	5,980,000	8,250,000	90	51.75
Scenario 3	5,980,000	8,250,000	80	51.75
Scenario 4	5,980,000	7,500,000	100	51.75
Scenario 5	5,980,000	7,500,000	90	51.75
Scenario 6	4,500,000	8,250,000	100	51.75
Scenario 7	4,500,000	8,250,000	90	51.75
Scenario 8	4,500,000	7,500,000	100	51.75
Scenario 9	4,500,000	7,500,000	90	51.75
Scenario 10	4,500,000	7,500,000	80	51.75
Scenario 11	5,200,000	8,250,000	100	51.75
Scenario 12	5,200,000	8,250,000	90	51.75
Scenario 13	5,200,000	7,500,000	100	51.75
Scenario 14	5,200,000	7,500,000	90	51.75

3.0 MODEL RESULTS

Two model output parameters were used to evaluate the frequency with which the Water Bank could be called upon to mitigate the impact of shortages in the Colorado River and tributaries. The first is shortages in meeting the assumed Upper Basin demands. The model logic meets all present perfected Upper Basin demands, then Colorado River flows at Lee Ferry of either 7.5 maf or 8.25 maf, then delivers water to meet the remaining Upper Basin demands. Water is provided from annual runoff and from Upper Basin reservoir system storage. Shortages in meeting demands are not declared until all reservoir system storage is depleted.

Using demand shortages alone as a trigger for implementing the Water Bank would likely underestimate the frequency with which the Water Bank could be used because water agencies would not wait until all reservoir storage is depleted to implement mitigation measures. Therefore, system-wide Upper Basin reservoir storage as a percentage of total storage capacity was also evaluated as a potential Water Bank trigger. For each scenario, the demand shortages and reservoir storages were analyzed and are described in the following sections.

3.1 EVALUATION OF DEMAND SHORTAGES

For each scenario 9,500 years of model results were analyzed (100 sequences of 95 years each). Two criteria were used to analyze the results related to shortages in meeting Colorado demands from Upper Basin sources: magnitude of shortage and duration of shortage.

Colorado's share of Upper Basin shortages was estimated as 51.75% of total Upper Basin shortages, based on Colorado's share of Upper Basin supplies. Shortage magnitudes for multi-year dry periods were computed as the average shortage over all the consecutive short years. The following five categories of magnitudes of Colorado demand shortages were considered for this assessment:

- >0 – 200,000 ac-ft
- 200,001 – 400,000 ac-ft
- 400,001 – 800,000 ac-ft
- 800,001 – 1,400,000 ac-ft
- >1,400,000 ac-ft

Shortage duration was computed as the number of consecutive dry years in which the entire Upper Basin demand was not met. The following five shortage duration categories were considered:

- 1 yr
- 2 – 3 yr
- 4 – 6 yr
- 7 – 10 yr
- ≥ 11 yr

The two criteria are based upon a yearly flow to the Lower Basin of 7.5 or 8.25 MAF per year. However, the model tracks streamflow against river target flow deficit. Post-Compact users are curtailed in the model until the accumulated deficit is eliminated.

A third shortage criterion is also possible but not evaluated because it is very difficult to define. Due to the many variables in defining and implementing the conditions for potential curtailment of post-Compact water rights described in the Colorado and Upper Colorado River Compacts, those conditions may not be enforced until the 10-year deficit is well below the 75 or 82.5 MAF threshold. This situation was not analyzed due to the complexities and lack of guidance for administering multi-year curtailments. Whether this will worsen or lessen the length and amount of the curtailment in the model could not be determined.

The annual shortage results were analyzed with respect to each shortage magnitude category and each shortage duration category. This resulted in 25 different shortage magnitude/duration combinations for each scenario.

To calculate the percent of years with each combination of shortage magnitude and duration, the number of years that met both criteria was divided by the total number of years analyzed (9,500). The average magnitude of shortages that met the criteria was calculated. Results are shown in **Figure 1** and in the tables and plots in **Attachment A**.

The exceedance probability of annual shortages in the Colorado River Basin deliveries to Colorado water users was also calculated. The exceedance probabilities were used to estimate the probability that the shortage in any given year would be greater than 500,000 ac-ft. These results are shown in **Table 2**. The threshold of 500,000 ac-ft was selected assuming that the Water Bank would likely not be activated for small shortage amounts.

The following observations can be drawn from these results.

- The most frequently occurring durations of shortages, including shortages of greater than 500,000 ac-ft/yr, are in the 2-3 year and 4-6 year categories for all of the scenarios.

- Shortage periods of 11 or more years can occur for the highest assumptions for Upper Basin demands (5.98 MAF and 5.2 MAF) and Lee Ferry flows (8.25 MAF).

- No shortages occur for the best case conditions for Upper Basin demands (4.50 MAF), Lee Ferry flows (7.50 MAF) and hydrology (100% of historical).

- Very few shortages occur for any of the scenarios with Upper Basin demands at 4.50 MAF and hydrology at 90% or 100% of historical, or with full historical hydrology and Upper Basin demands and Lee Ferry flow obligations at less than 8.25 MAF. The need for a Water Bank may be triggered only if future water demands increase substantially and a concurrent reduction in historical hydrology occurs.

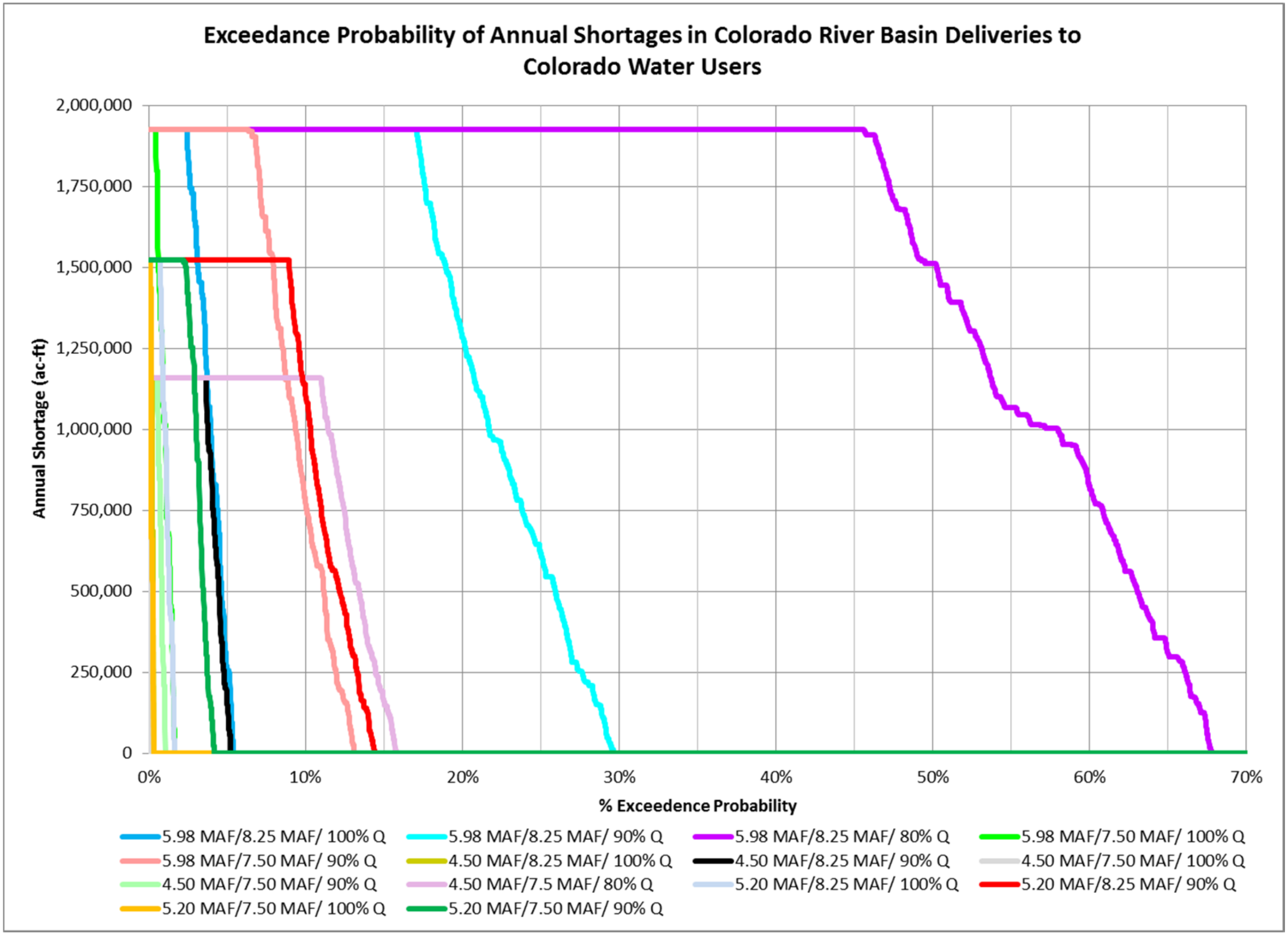
- Relatively few shortage periods have an average annual magnitude of less than 500,000 ac-ft, so most shortage periods would trigger the need for the Water Bank.

- There are substantial differences in shortage conditions over the ranges simulated for Upper Basin demands, Lee Ferry flow obligations, and hydrologic conditions. The frequency of years with shortages of any magnitude varies from 0% to 60% depending on the scenario.

TABLE 2
PROBABILITY THAT THE COLORADO SHORTAGE IN MEETING UPPER BASIN DEMANDS WILL BE GREATER THAN 500,000 AC-FT IN ANY YEAR

Scenario	Scenario Description (Upper Basin Demands / Lee Ferry Flows/ Hydrology)	Probability
1	5.98 MAF / 8.25 MAF / 100% Q	4.6%
2	5.98 MAF / 8.25 MAF / 90% Q	25.9%
3	5.98 MAF / 8.25 MAF / 80% Q	63.0%
4	5.98 MAF / 7.50 MAF/ 100% Q	1.4%
5	5.98 MAF / 7.50 MAF / 90% Q	11.1%
6	4.50 MAF / 8.25 MAF / 100% Q	0.3%
7	4.50 MAF / 8.25 MAF / 90% Q	4.5%
8	4.50 MAF / 7.50 MAF / 100% Q	0.0%
9	4.50 MAF / 7.50 MAF / 90% Q	0.8%
10	4.50 MAF / 7.50 MAF / 80% Q	13.4%
11	5.20 MAF / 8.25 MAF / 100% Q	1.3%
12	**5.20 MAF / 8.25 MAF / 90% Q**	**12.2%**
13	5.20 MAF / 7.50 MAF / 100% Q	0.2%
14	5.20 MAF / 7.50 MAF / 90% Q	3.5%

FIGURE 1


Exceedance Probability of Annual Shortages in Colorado River Basin Deliveries to Colorado Water Users
Annual Shortage (ac-ft)
2,000,000
1,750,000
1,500,000
1,250,000
1,000,000
750,000
500,000
250,000
0
0%
10%
20%
30%
40%
50%
60%
70%
% Exceedence Probability
5.98 MAF/8.25 MAF/ 100% Q
5.98 MAF/8.25 MAF/ 90% Q
5.98 MAF/8.25 MAF/ 80% Q
5.98 MAF/7.50 MAF/ 100% Q
5.98 MAF/7.50 MAF/ 90% Q
4.50 MAF/8.25 MAF/ 100% Q
4.50 MAF/8.25 MAF/ 90% Q
4.50 MAF/7.50 MAF/ 100% Q
4.50 MAF/7.50 MAF/ 90% Q
4.50 MAF/7.5 MAF/ 80% Q
5.20 MAF/8.25 MAF/ 100% Q
5.20 MAF/8.25 MAF/ 90% Q
5.20 MAF/7.50 MAF/ 100% Q
5.20 MAF/7.50 MAF/ 90% Q

3.2 STORAGE ASSESSMENT

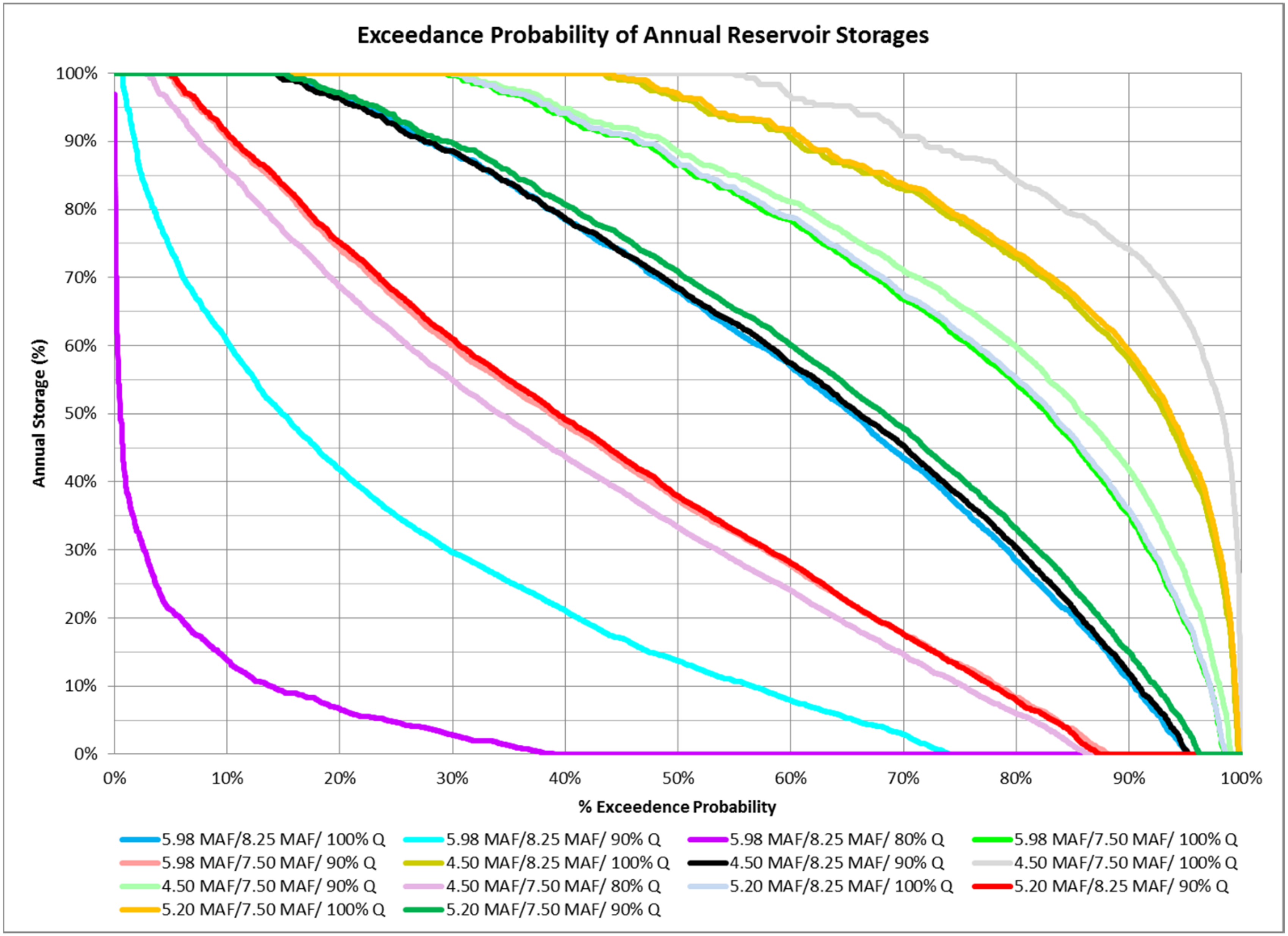
The system-wide reservoir storage volumes for the 9,500 years of simulation were also analyzed for each scenario. The annual end-of-year storage for each year was divided by the total storage capacity to calculate the percent of reservoir storage for each year.

The annual exceedance probability of the percent of reservoir storage was calculated for each scenario. Results of the storage probability analysis are shown in **Figure 2**. The probability that the reservoir storage will be less than 25% was estimated for each scenario based on the exceedance probability results and is shown in **Table 3**. The threshold of 25% of total system storage was selected as an estimate of the point at which mitigation measures such as the Water Bank would be considered by water users to mitigate potential future shortages. It is recognized that water users would not accept the risk of operating with system reservoir storage near empty, and would proactively implement mitigation measures like the Water Bank to prevent a condition in which no carryover storage exists.

TABLE 3
PROBABILITY THAT THE RESERVOIR SYSTEM STORAGE WILL BE LESS THAN 25% FULL IN ANY YEAR

Scenario	Scenario Description (Upper Basin Demands / Lee Ferry Flows/ Hydrology)	Probability
1	5.98 MAF / 8.25 MAF / 100% Q	18%
2	5.98 MAF / 8.25 MAF / 90% Q	65%
3	5.98 MAF / 8.25 MAF / 80% Q	96%
4	5.98 MAF / 7.50 MAF / 100% Q	7%
5	5.98 MAF / 7.50 MAF / 90% Q	38%
6	4.50 MAF / 8.25 MAF / 100% Q	2%
7	4.50 MAF / 8.25 MAF / 90% Q	17%
8	4.50 MAF / 7.50 MAF / 100% Q	0%
9	4.50 MAF / 7.50 MAF / 90% Q	5%
10	4.50 MAF / 7.50 MAF / 80% Q	41%
11	5.20 MAF / 8.25 MAF / 100% Q	6%
12	**5.20 MAF / 8.25 MAF / 90% Q**	**37%**
13	5.20 MAF / 7.50 MAF / 100% Q	1%
14	5.20 MAF / 7.50 MAF / 90% Q	15%

FIGURE 2

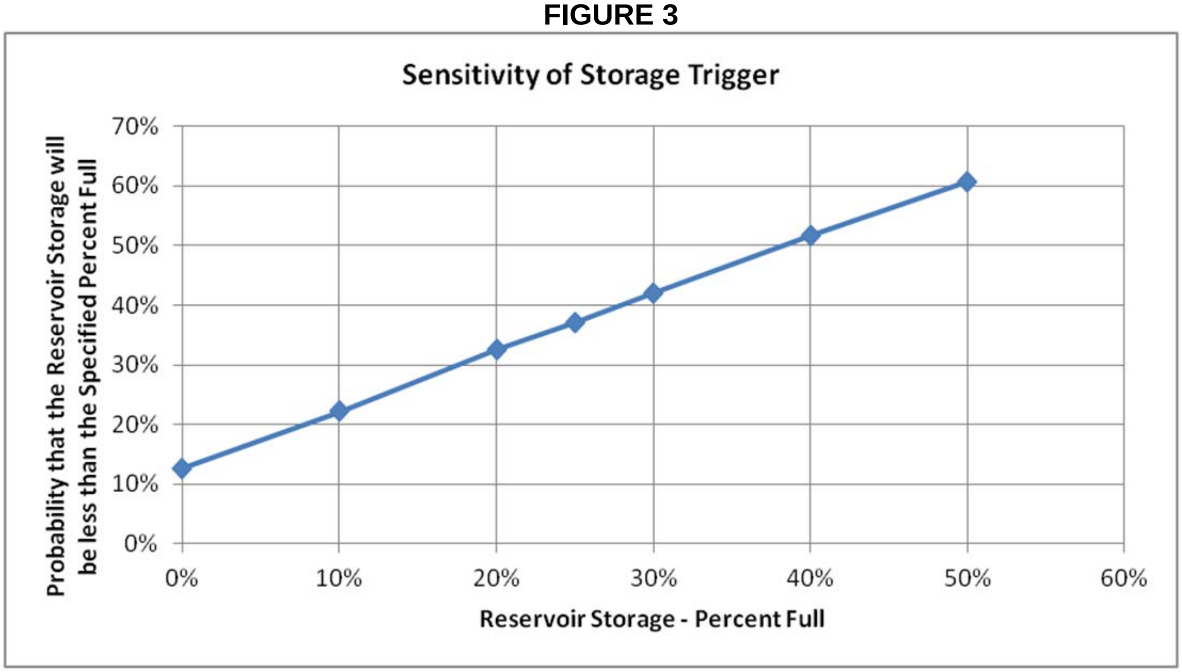

Exceedance Probability of Annual Reservoir Storages
Annual Storage (%)
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
% Exceedence Probability
5.98 MAF/8.25 MAF/ 100% Q
5.98 MAF/8.25 MAF/ 90% Q
5.98 MAF/8.25 MAF/ 80% Q
5.98 MAF/7.50 MAF/ 100% Q
5.98 MAF/7.50 MAF/ 90% Q
4.50 MAF/8.25 MAF/ 100% Q
4.50 MAF/8.25 MAF/ 90% Q
4.50 MAF/7.50 MAF/ 100% Q
4.50 MAF/7.50 MAF/ 90% Q
4.50 MAF/7.50 MAF/ 80% Q
5.20 MAF/8.25 MAF/ 100% Q
5.20 MAF/8.25 MAF/ 90% Q
5.20 MAF/7.50 MAF/ 100% Q
5.20 MAF/7.50 MAF/ 90% Q

To analyze the sensitivity of the 25% minimum system storage assumption, the probabilities that the reservoir storage volume would be less than 10%, 20%, 25%, 30%, 40%, and 50% of full were estimated for Scenario 12. Scenario 12 was selected for further evaluation by the Water Bank Technical Team. The results of the sensitivity analysis are shown in **Table 4** and **Figure 3**. There is no "knee of the curve" in **Figure 3** that would suggest that there is an optimal minimum storage level to balance risk of shortage versus use of reservoir storage to meet demands during extended droughts.

TABLE 4
SENSITIVITY ANALYSIS OF RESERVOIR SYSTEM STORAGE TRIGGER – SCENARIO 12

Reservoir System Storage - Percent Full	Reservoir System Storage Volume (MAF)	Probability that Reservoir Storage will be less than the Specified Percent Full in Any Year
0%	0.0	13%
10%	3.4	22%
20%	6.8	33%
25%	8.5	37%
30%	10.2	42%
40%	13.5	52%
50%	16.9	61%

FIGURE 3



Comparison of **Table 2** and **Table 3** indicates that using the assumed storage criteria to estimate the frequency with which the Water Bank could be used results in higher frequency of use than using the assumed shortage criteria. Selected periods of model results were extracted from the 100 simulated sequences during which shortages and low reservoir storage levels occurred. These are shown in **Attachment B**. As expected, periods of system reservoir storage less than 25% precede and follow shortage years of at least 500,000 ac-ft. On average, using the storage criteria rather than the shortage criteria increases the duration of potential Water Bank use by 3-4 years for each major drought period (typically 2 years earlier and 1-2 years later).

3.3 SENSITIVITY ANALYSIS

Results for the 14 scenarios can be used to evaluate sensitivity of triggering the need for the Water Bank to model assumptions. Sensitivity of demand shortages and reservoir storage to changes in hydrology is summarized in **Figure 4** and **Figure 5.** Reductions in streamflow due to climate change or other factors have a significant impact on the frequency with which the Water Bank could be required. In general the impact is not linear, with larger streamflow reductions causing disproportionally larger demand shortages.

FIGURE 4

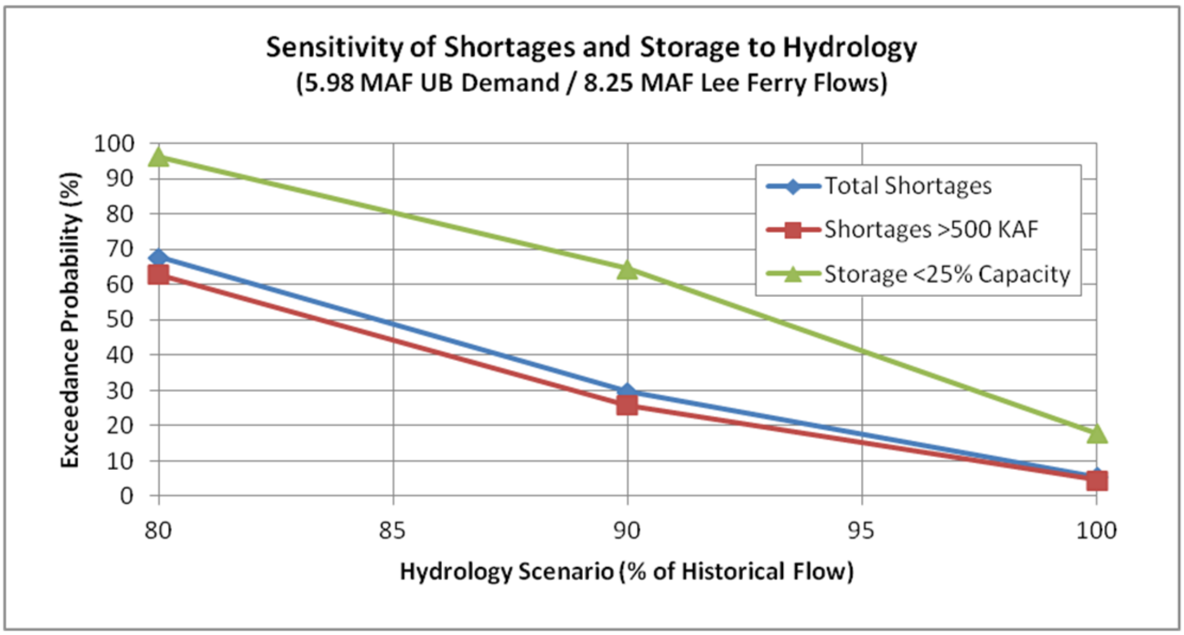
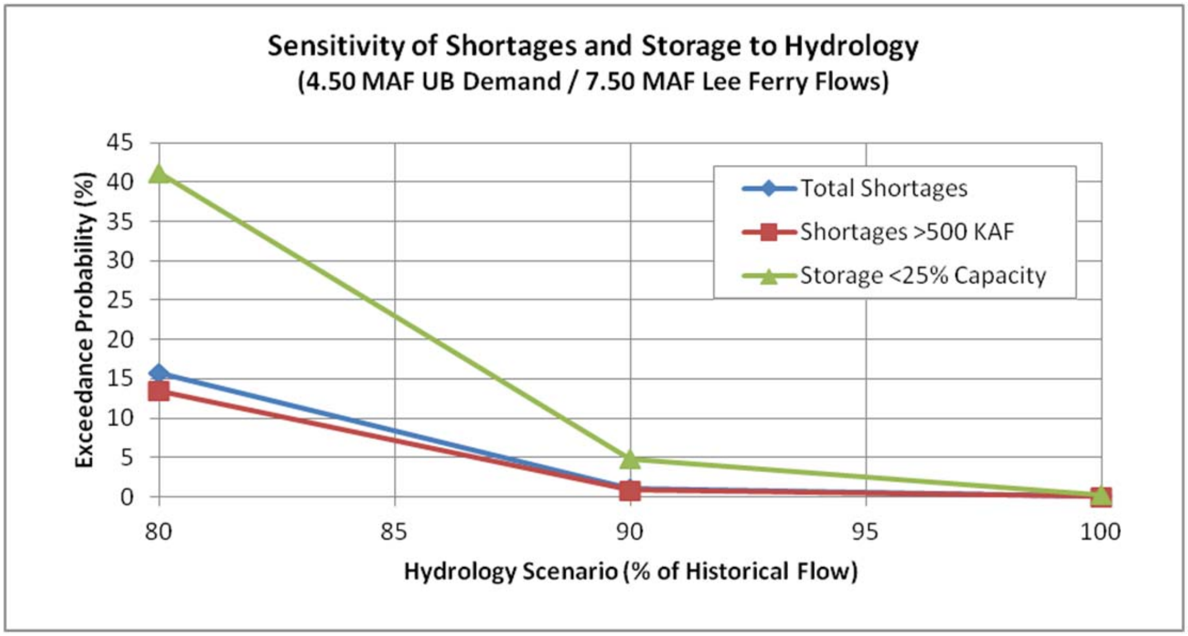


FIGURE 5



Sensitivity of demand shortages and reservoir storage to changes in Upper Basin demands is summarized in **Figure 6** and **Figure 7.** The frequency with which the Water Bank could be needed does not increase dramatically when the Upper Basin demand is increased from 4.50 MAF to 5.20 MAF, but the frequency increases more significantly when the demand increases to 5.98 MAF.

FIGURE 6

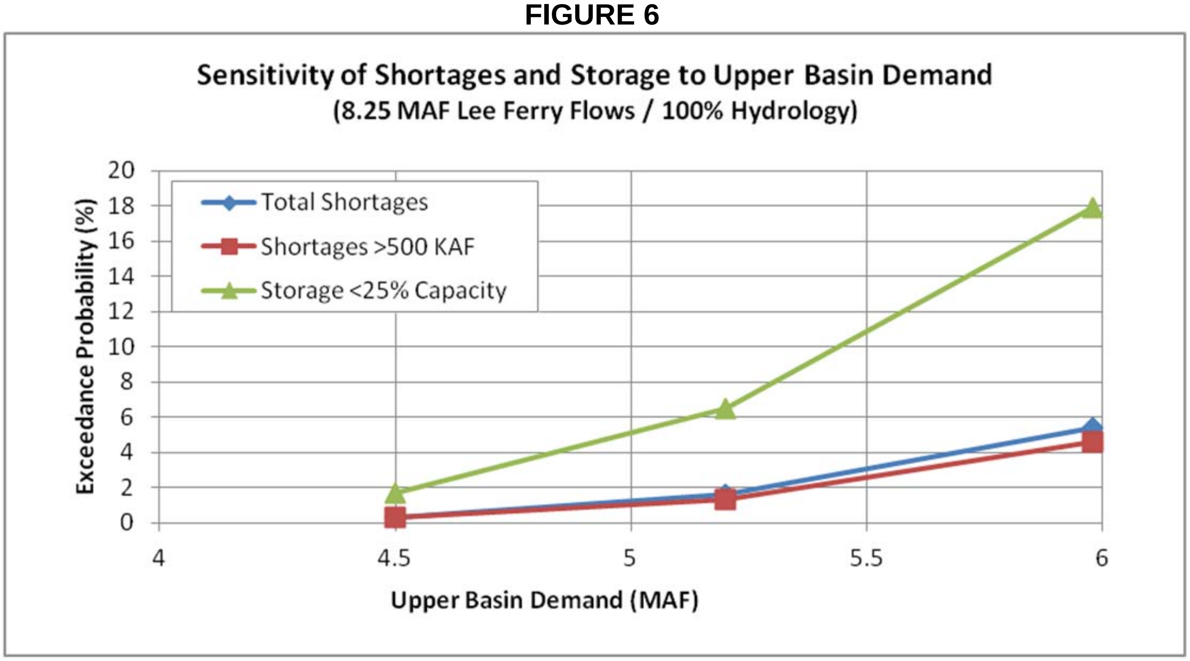
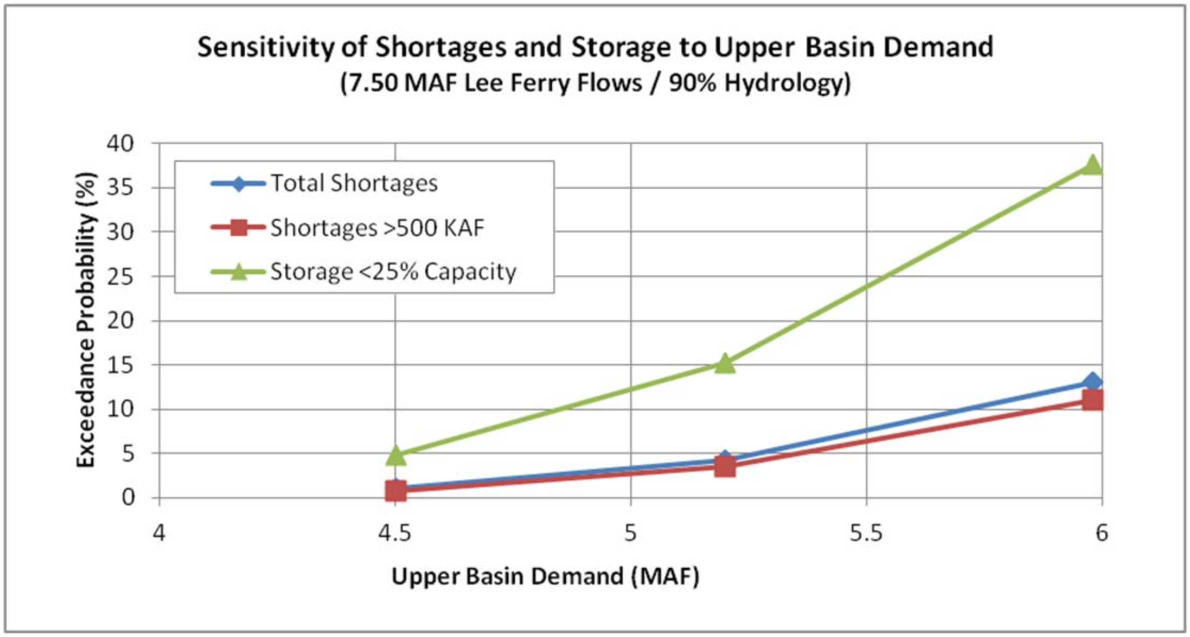


FIGURE 7



4.0 CONCLUSIONS

Results of the analysis using the Basin Model lead to the following conclusions related to the frequency with which conditions could trigger use of the Water Bank by Colorado water users.

1. The condition of Upper Basin system reservoir storage is a more conservative indicator than Upper Basin water shortages of when the Water Bank could be used.

2. The frequency of potential Water Bank use varies over the range of scenarios evaluated from 0 percent to over 50 percent of the years.

3. Durations of shortages that could trigger use of the Water Bank vary from 1 year to over 15 years, with typical values of 6 to 10 years when based on system reservoir storage less than 25 percent of total reservoir capacity.

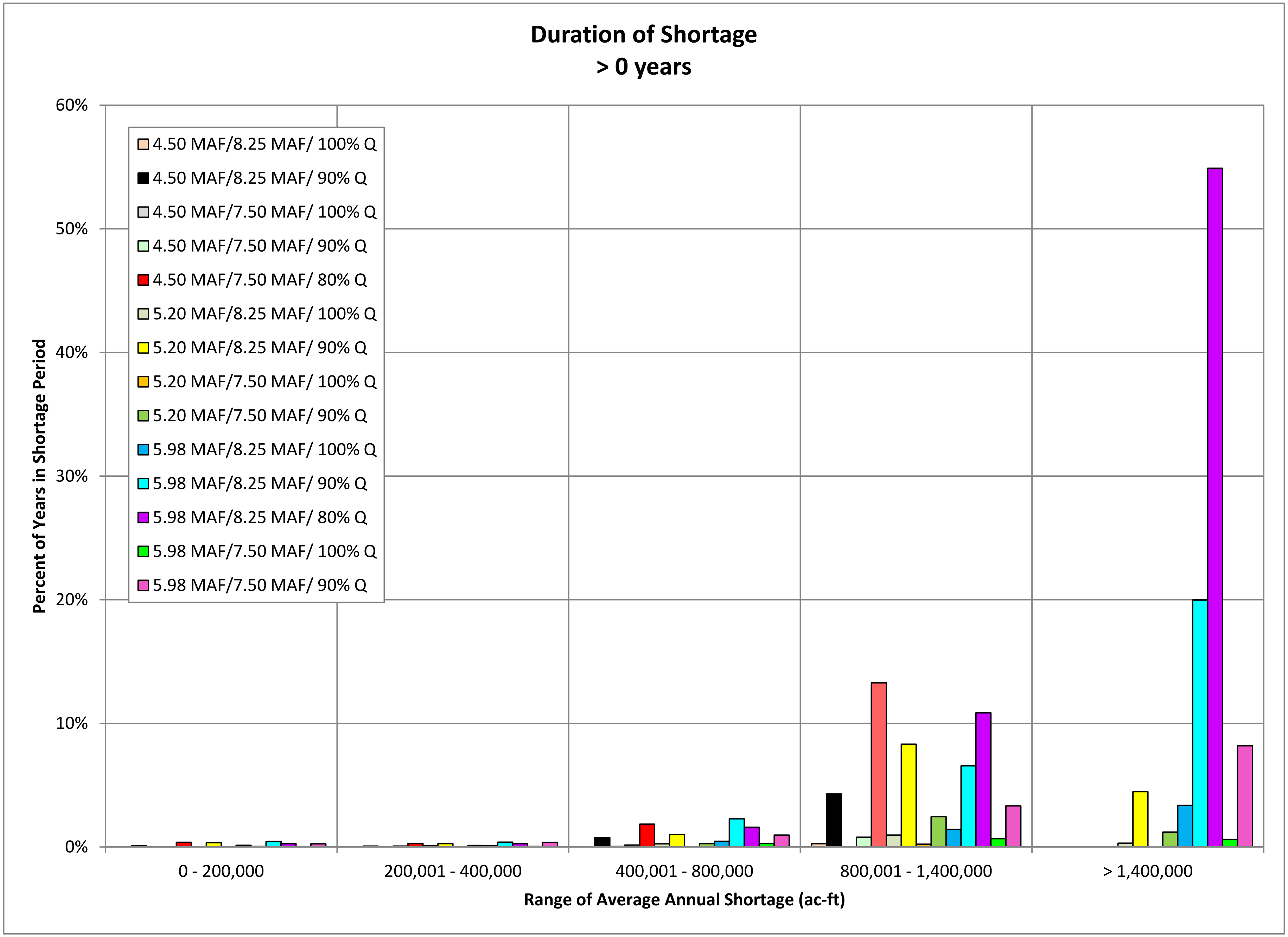
4. The majority of average shortage magnitudes exceed a trigger amount of 500,000 ac-ft/yr; the frequency of Water Bank use is not significantly affected by setting the minimum trigger at 500,000 ac-ft rather than 0 ac-ft.

5. Growth in Upper Basin demands will increase the frequency of potential Water Bank use. Scenarios with 4.50 MAF Upper Basin demand have a frequency of potential Water Bank use of 0 to 41 percent depending on the Lee Ferry flow and hydrology assumptions. Scenarios with 5.98 MAF Upper Basin demand have a frequency of potential Water Bank use of 7 to 96 percent.

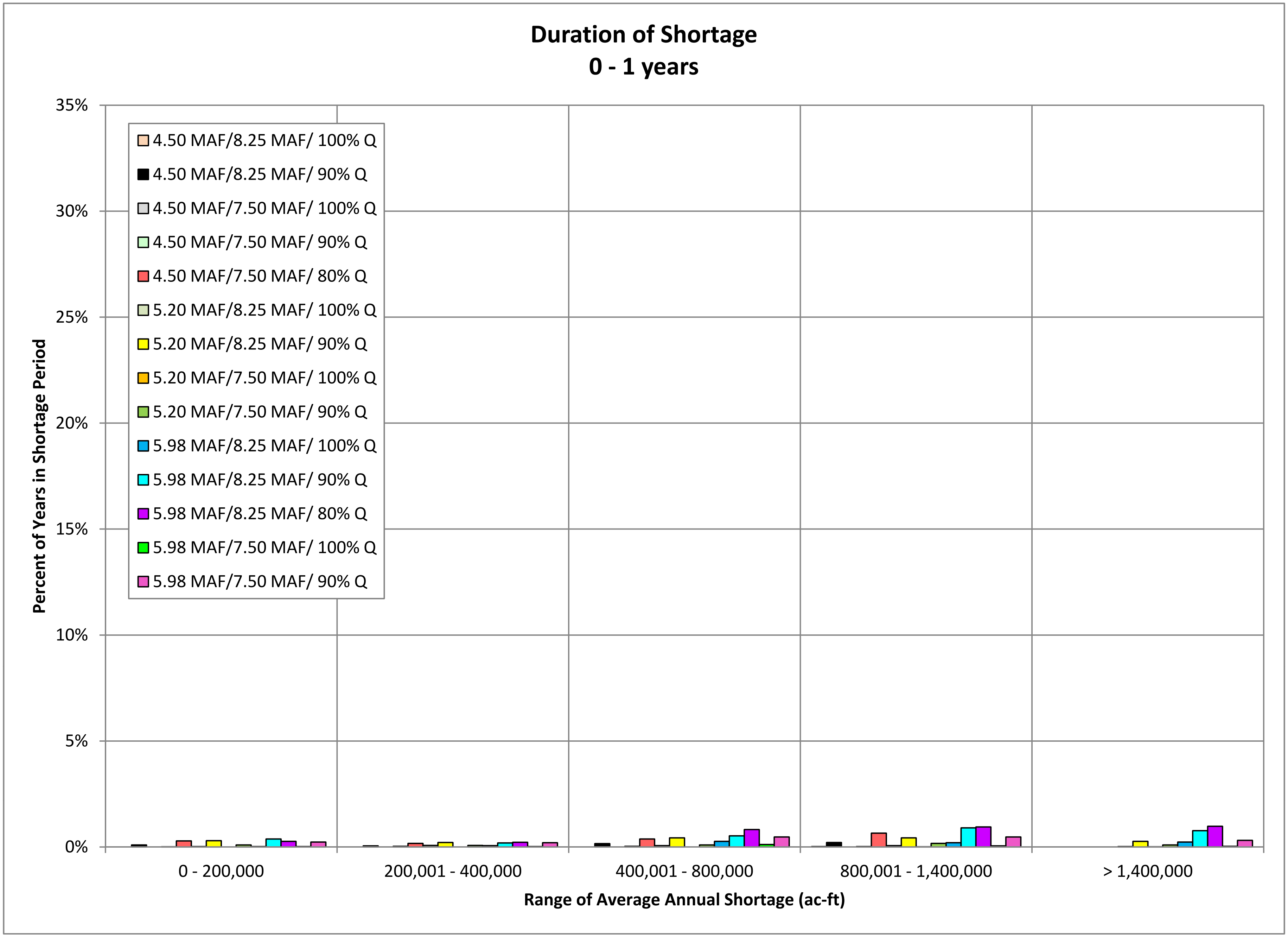
6. The Water Bank may only be needed under future conditions with a substantial increase in demand and a concurrent substantial reduction in long-term hydrology. Need for a Water Bank and additional water development in the basin may be interdependent. Without additional water development a Water Bank may not be needed, and conversely a Water Bank may be a strategy for mitigating the risk of additional water development. However, firm predictions are not possible based on the level of analysis described in this report.

Attachment A

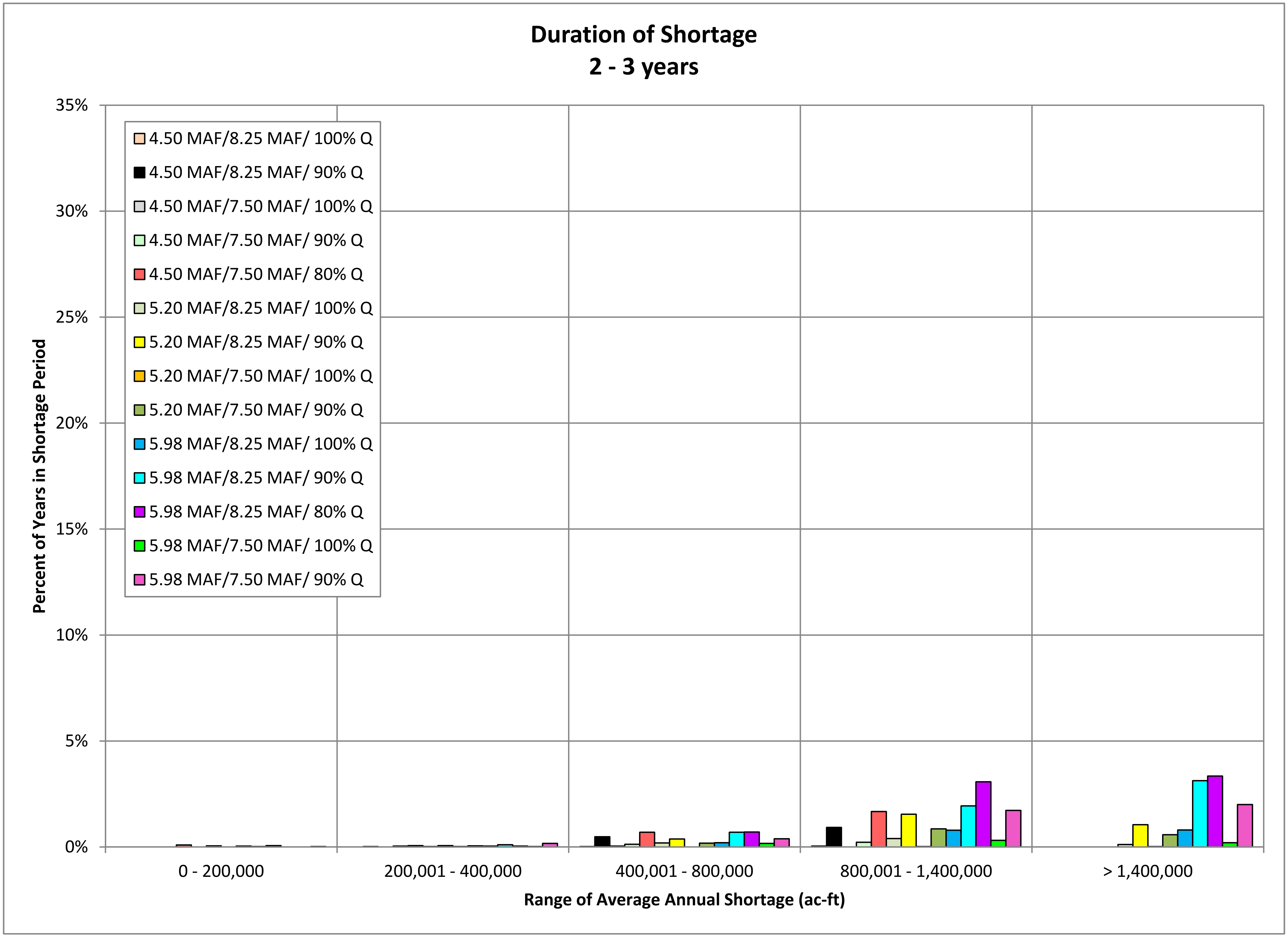
Shortage Results

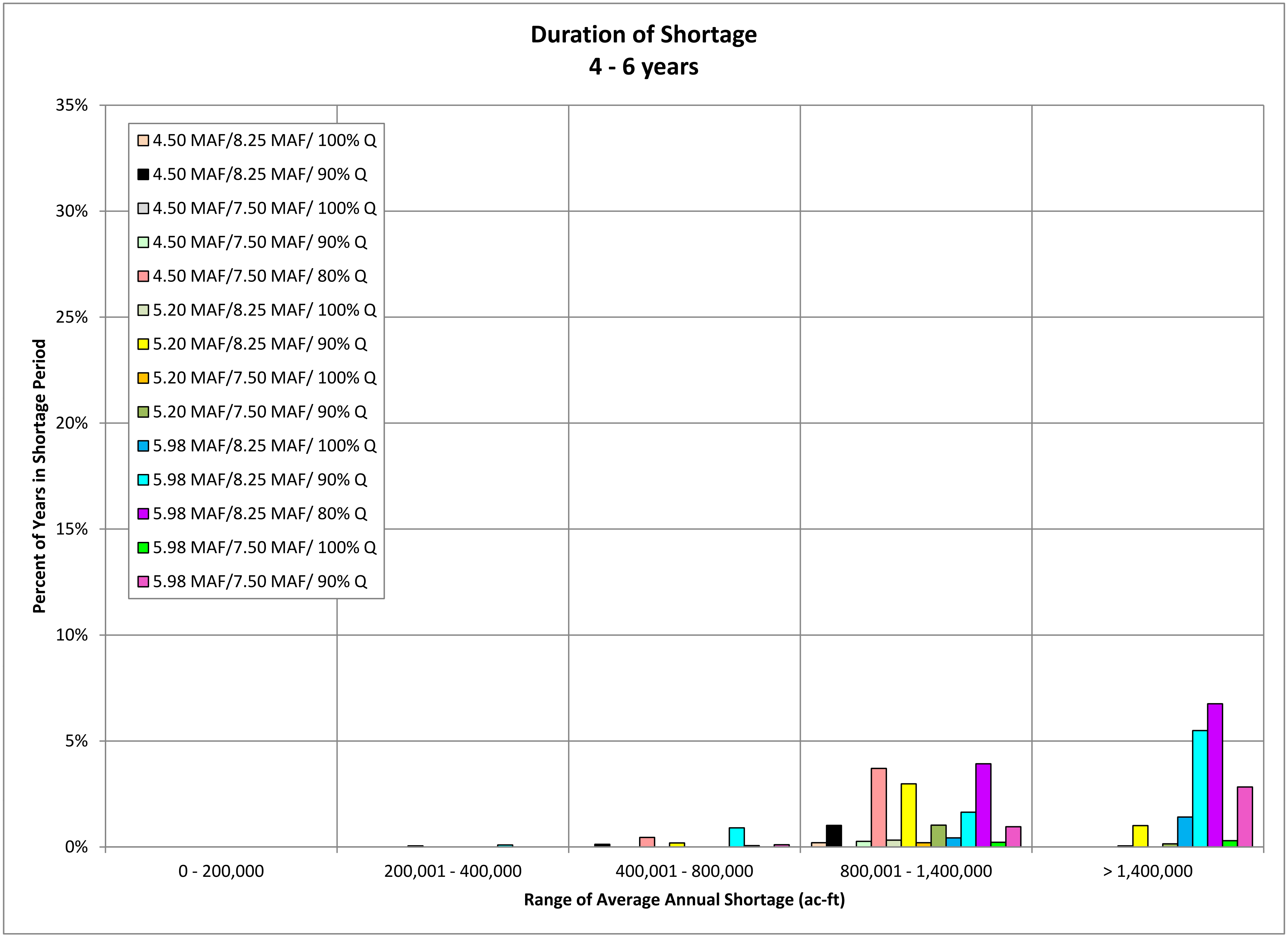


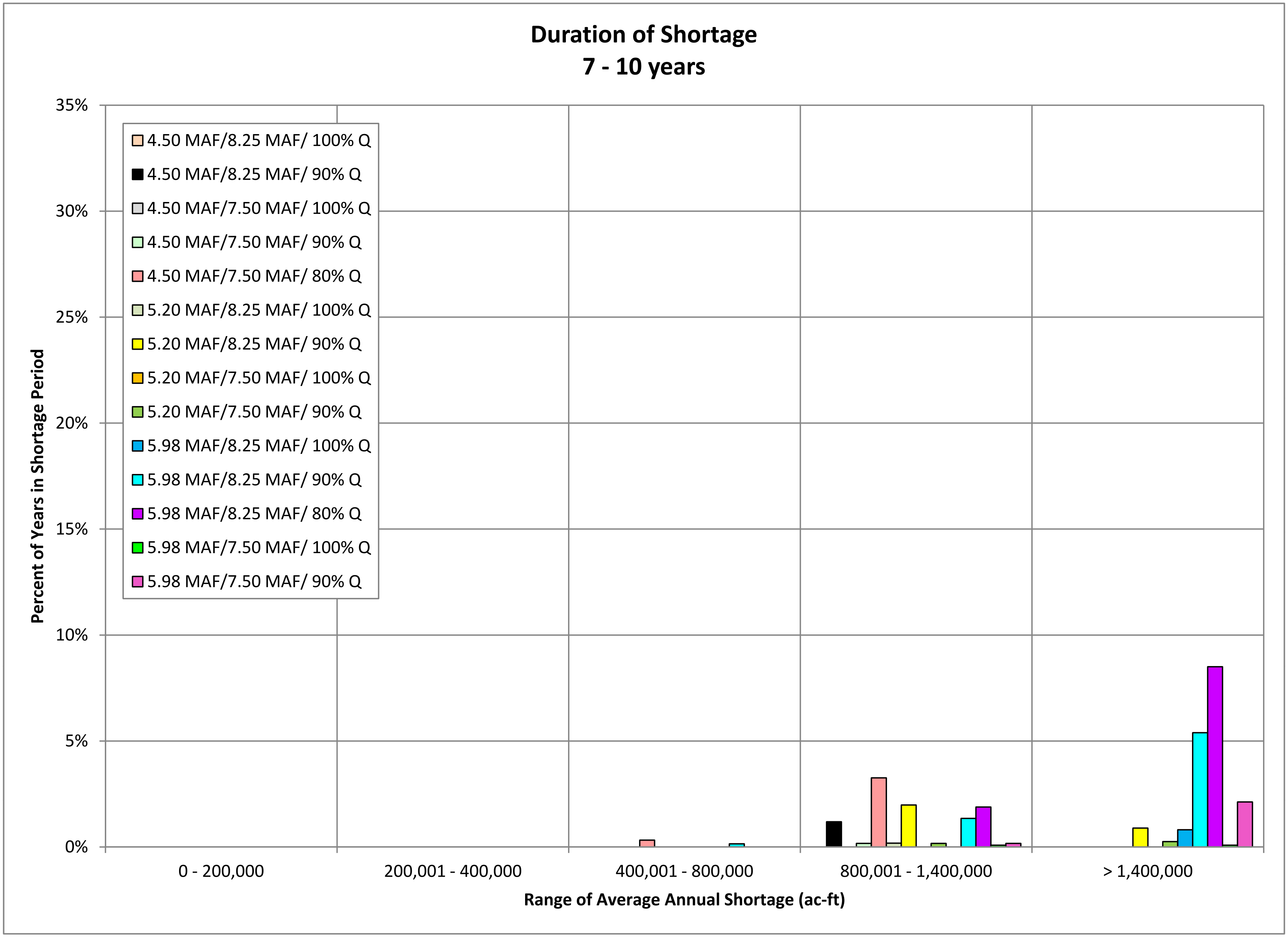
Duration of Shortage
> 0 years
60%
50%
40%
30%
20%
10%
0%
Percent of Years in Shortage Period
4.50 MAF/8.25 MAF/ 100% Q
4.50 MAF/8.25 MAF/ 90% Q
4.50 MAF/7.50 MAF/ 100% Q
4.50 MAF/7.50 MAF/ 90% Q
4.50 MAF/7.50 MAF/ 80% Q
5.20 MAF/8.25 MAF/ 100% Q
5.20 MAF/8.25 MAF/ 90% Q
5.20 MAF/7.50 MAF/ 100% Q
5.20 MAF/7.50 MAF/ 90% Q
5.98 MAF/8.25 MAF/ 100% Q
5.98 MAF/8.25 MAF/ 90% Q
5.98 MAF/8.25 MAF/ 80% Q
5.98 MAF/7.50 MAF/ 100% Q
5.98 MAF/7.50 MAF/ 90% Q
0 - 200,000
200,001 - 400,000
400,001 - 800,000
800,001 - 1,400,000
> 1,400,000
Range of Average Annual Shortage (ac-ft)



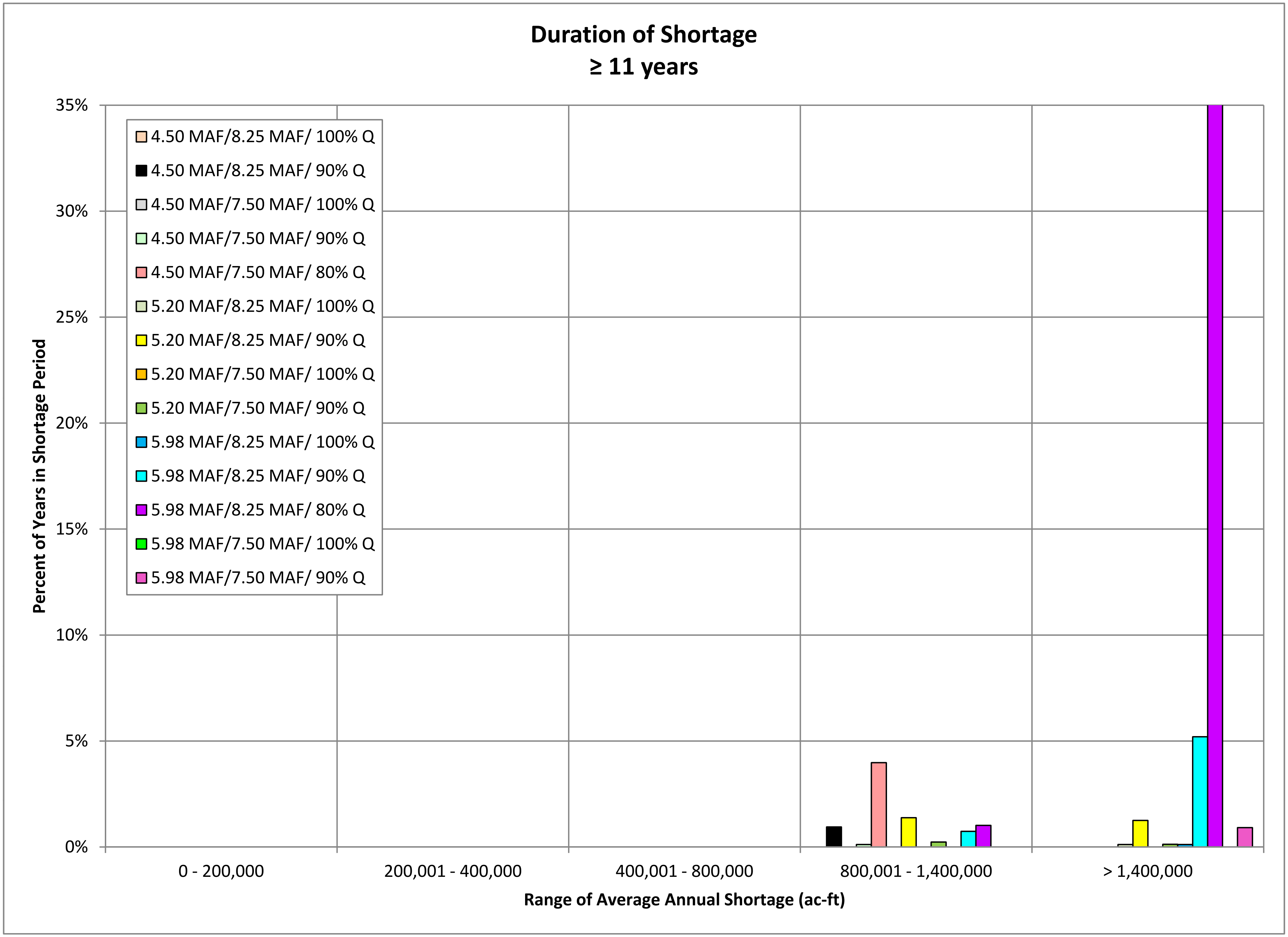
Duration of Shortage
0 - 1 years
Percent of Years in Shortage Period
35%
30%
25%
20%
15%
10%
5%
0%
4.50 MAF/8.25 MAF/ 100% Q
4.50 MAF/8.25 MAF/ 90% Q
4.50 MAF/7.50 MAF/ 100% Q
4.50 MAF/7.50 MAF/ 90% Q
4.50 MAF/7.50 MAF/ 80% Q
5.20 MAF/8.25 MAF/ 100% Q
5.20 MAF/8.25 MAF/ 90% Q
5.20 MAF/7.50 MAF/ 100% Q
5.20 MAF/7.50 MAF/ 90% Q
5.98 MAF/8.25 MAF/ 100% Q
5.98 MAF/8.25 MAF/ 90% Q
5.98 MAF/8.25 MAF/ 80% Q
5.98 MAF/7.50 MAF/ 100% Q
5.98 MAF/7.50 MAF/ 90% Q
0 - 200,000
200,001 - 400,000
400,001 - 800,000
800,001 - 1,400,000
> 1,400,000
Range of Average Annual Shortage (ac-ft)


Duration of Shortage
2 - 3 years
Percent of Years in Shortage Period
35%
30%
25%
20%
15%
10%
5%
0%
4.50 MAF/8.25 MAF/ 100% Q
4.50 MAF/8.25 MAF/ 90% Q
4.50 MAF/7.50 MAF/ 100% Q
4.50 MAF/7.50 MAF/ 90% Q
4.50 MAF/7.50 MAF/ 80% Q
5.20 MAF/8.25 MAF/ 100% Q
5.20 MAF/8.25 MAF/ 90% Q
5.20 MAF/7.50 MAF/ 100% Q
5.20 MAF/7.50 MAF/ 90% Q
5.98 MAF/8.25 MAF/ 100% Q
5.98 MAF/8.25 MAF/ 90% Q
5.98 MAF/8.25 MAF/ 80% Q
5.98 MAF/7.50 MAF/ 100% Q
5.98 MAF/7.50 MAF/ 90% Q
0 - 200,000
200,001 - 400,000
400,001 - 800,000
800,001 - 1,400,000
> 1,400,000
Range of Average Annual Shortage (ac-ft)


Duration of Shortage
4 - 6 years
35%
30%
25%
20%
15%
10%
5%
0%
Percent of Years in Shortage Period
4.50 MAF/8.25 MAF/ 100% Q
4.50 MAF/8.25 MAF/ 90% Q
4.50 MAF/7.50 MAF/ 100% Q
4.50 MAF/7.50 MAF/ 90% Q
4.50 MAF/7.50 MAF/ 80% Q
5.20 MAF/8.25 MAF/ 100% Q
5.20 MAF/8.25 MAF/ 90% Q
5.20 MAF/7.50 MAF/ 100% Q
5.20 MAF/7.50 MAF/ 90% Q
5.98 MAF/8.25 MAF/ 100% Q
5.98 MAF/8.25 MAF/ 90% Q
5.98 MAF/8.25 MAF/ 80% Q
5.98 MAF/7.50 MAF/ 100% Q
5.98 MAF/7.50 MAF/ 90% Q
0 - 200,000
200,001 - 400,000
400,001 - 800,000
800,001 - 1,400,000
> 1,400,000
Range of Average Annual Shortage (ac-ft)



Duration of Shortage
7 - 10 years
35%
30%
25%
20%
15%
10%
5%
0%
Percent of Years in Shortage Period
4.50 MAF/8.25 MAF/ 100% Q
4.50 MAF/8.25 MAF/ 90% Q
4.50 MAF/7.50 MAF/ 100% Q
4.50 MAF/7.50 MAF/ 90% Q
4.50 MAF/7.50 MAF/ 80% Q
5.20 MAF/8.25 MAF/ 100% Q
5.20 MAF/8.25 MAF/ 90% Q
5.20 MAF/7.50 MAF/ 100% Q
5.20 MAF/7.50 MAF/ 90% Q
5.98 MAF/8.25 MAF/ 100% Q
5.98 MAF/8.25 MAF/ 90% Q
5.98 MAF/8.25 MAF/ 80% Q
5.98 MAF/7.50 MAF/ 100% Q
5.98 MAF/7.50 MAF/ 90% Q
0 - 200,000
200,001 - 400,000
400,001 - 800,000
800,001 - 1,400,000
> 1,400,000
Range of Average Annual Shortage (ac-ft)



Duration of Shortage
≥ 11 years
35%
30%
25%
20%
15%
10%
5%
0%
Percent of Years in Shortage Period
4.50 MAF/8.25 MAF/ 100% Q
4.50 MAF/8.25 MAF/ 90% Q
4.50 MAF/7.50 MAF/ 100% Q
4.50 MAF/7.50 MAF/ 90% Q
4.50 MAF/7.50 MAF/ 80% Q
5.20 MAF/8.25 MAF/ 100% Q
5.20 MAF/8.25 MAF/ 90% Q
5.20 MAF/7.50 MAF/ 100% Q
5.20 MAF/7.50 MAF/ 90% Q
5.98 MAF/8.25 MAF/ 100% Q
5.98 MAF/8.25 MAF/ 90% Q
5.98 MAF/8.25 MAF/ 80% Q
5.98 MAF/7.50 MAF/ 100% Q
5.98 MAF/7.50 MAF/ 90% Q
0 - 200,000
200,001 - 400,000
400,001 - 800,000
800,001 - 1,400,000
> 1,400,000
Range of Average Annual Shortage (ac-ft)

Summary of Potential Curtailments in Colorado Depletions Due to Colorado River Compact Risks and Drought Conditions Assuming Protection of Pre-compact Water Rights

Scenario 1

Upper Basin Demands (AF)	**5,980,000**
Lee Ferry Flows (AF)	**8,250,000**
Basin Hydrology (% of Historical)	**100**
Colorado Demands (% of Total Upper Basin Demands)	**51.75**

Duration of Shortage (yr)	0 - 200,000 AF Shortage		200,001 - 400,000 AF Shortage		400,001 - 800,000 AF Shortage		800,001 - 1,400,000 AF Shortage		> 1,400,000 AF Shortage		Percent of Years in Shortage Period
	Average Annual Shortage (MAF)	% Years of Shortage	Average Annual Shortage (MAF)	% Years of Shortage	Average Annual Shortage (MAF)	% Years of Shortage	Average Annual Shortage (MAF)	% Years of Shortage	Average Annual Shortage (MAF)	% Years of Shortage	
0 - 1	0.03	0.02%	0.31	0.06%	0.59	0.26%	1.06	0.20%	1.68	0.23%	0.78%
2 - 3	0.19	0.02%	0.23	0.04%	0.55	0.20%	1.18	0.79%	1.74	0.80%	1.85%
4 - 6	-	-	-	-	-	-	1.21	0.43%	1.64	1.41%	1.84%
7 - 10	-	-	-	-	-	-	-	-	1.67	0.81%	0.81%
≥ 11	-	-	-	-	-	-	-	-	1.91	0.12%	0.12%
Percent of Years within Range of Shortage Volumes	-	0.04%	-	0.11%	-	0.46%	-	1.42%	-	3.37%	5.40%

Scenario 2

Upper Basin Demands (AF)	**5,980,000**
Lee Ferry Flows (AF)	**8,250,000**
Basin Hydrology (% of Historical)	**90**
Colorado Demands (% of Total Upper Basin Demands)	**51.75**

Duration of Shortage (yr)	0 - 200,000 AF Shortage		200,001 - 400,000 AF Shortage		400,001 - 800,000 AF Shortage		800,001 - 1,400,000 AF Shortage		> 1,400,000 AF Shortage		Percent of Years in Shortage Period
	Average Annual Shortage (MAF)	% Years of Shortage	Average Annual Shortage (MAF)	% Years of Shortage	Average Annual Shortage (MAF)	% Years of Shortage	Average Annual Shortage (MAF)	% Years of Shortage	Average Annual Shortage (MAF)	% Years of Shortage	
0 - 1	0.08	0.38%	0.30	0.19%	0.59	0.53%	1.07	0.91%	1.79	0.77%	2.77%
2 - 3	0.16	0.06%	0.30	0.11%	0.58	0.69%	1.17	1.94%	1.73	3.13%	5.93%
4 - 6	-	-	0.37	0.09%	0.61	0.91%	1.22	1.64%	1.69	5.49%	8.14%
7 - 10	-	-	-	-	0.63	0.15%	1.15	1.35%	1.69	5.39%	6.88%
≥ 11	-	-	-	-	-	-	1.26	0.74%	1.74	5.20%	5.94%
Percent of Years within Range of Shortage Volumes	-	0.44%	-	0.39%	-	2.27%	-	6.57%	-	19.98%	29.65%

Scenario 3

Upper Basin Demands (AF)	**5,980,000**
Lee Ferry Flows (AF)	**8,250,000**
Basin Hydrology (% of Historical)	**80**
Colorado Demands (% of Total Upper Basin Demands)	**51.75**

Duration of Shortage (yr)	0 - 200,000 AF Shortage		200,001 - 400,000 AF Shortage		400,001 - 800,000 AF Shortage		800,001 - 1,400,000 AF Shortage		> 1,400,000 AF Shortage		Percent of Years in Shortage Period
	Average Annual Shortage (MAF)	% Years of Shortage	Average Annual Shortage (MAF)	% Years of Shortage	Average Annual Shortage (MAF)	% Years of Shortage	Average Annual Shortage (MAF)	% Years of Shortage	Average Annual Shortage (MAF)	% Years of Shortage	
0 - 1	0.11	0.26%	0.26	0.22%	0.58	0.82%	1.10	0.95%	1.76	0.98%	3.23%
2 - 3	-	-	0.34	0.04%	0.64	0.71%	1.10	3.07%	1.73	3.35%	7.17%
4 - 6	-	-	-	-	0.69	0.06%	1.15	3.93%	1.70	6.76%	10.75%
7 - 10	-	-	-	-	-	-	1.24	1.88%	1.73	8.51%	10.39%
≥ 11	-	-	-	-	-	-	1.29	1.02%	1.76	35.31%	36.33%
Percent of Years within Range of Shortage Volumes	-	0.26%	-	0.26%	-	1.59%	-	10.85%	-	54.89%	67.86%

Scenario 4

Upper Basin Demands (AF)	**5,980,000**
Lee Ferry Flows (AF)	**7,500,000**
Basin Hydrology (% of Historical)	**100**
Colorado Demands (% of Total Upper Basin Demands)	**51.75**

Duration of Shortage (yr)	0 - 200,000 AF Shortage		200,001 - 400,000 AF Shortage		400,001 - 800,000 AF Shortage		800,001 - 1,400,000 AF Shortage		> 1,400,000 AF Shortage		Percent of Years in Shortage Period
	Average Annual Shortage (MAF)	% Years of Shortage	Average Annual Shortage (MAF)	% Years of Shortage	Average Annual Shortage (MAF)	% Years of Shortage	Average Annual Shortage (MAF)	% Years of Shortage	Average Annual Shortage (MAF)	% Years of Shortage	
0 - 1	0.11	0.02%	0.27	0.02%	0.59	0.12%	1.12	0.05%	1.60	0.03%	0.24%
2 - 3	-	-	0.34	0.02%	0.64	0.17%	1.07	0.32%	1.75	0.20%	0.71%
4 - 6	-	-	-	-	-	-	1.24	0.22%	1.63	0.29%	0.52%
7 - 10	-	-	-	-	-	-	1.40	0.08%	1.54	0.08%	0.17%
≥ 11	-	-	-	-	-	-	-	-	-	-	0.00%
Percent of Years within Range of Shortage Volumes	-	0.02%	-	0.04%	-	0.28%	-	0.67%	-	0.61%	1.63%

Scenario 5

Upper Basin Demands (AF)	**5,980,000**
Lee Ferry Flows (AF)	**7,500,000**
Basin Hydrology (% of Historical)	**90**
Colorado Demands (% of Total Upper Basin Demands)	**51.75**

Duration of Shortage (yr)	0 - 200,000 AF Shortage		200,001 - 400,000 AF Shortage		400,001 - 800,000 AF Shortage		800,001 - 1,400,000 AF Shortage		> 1,400,000 AF Shortage		Percent of Years in Shortage Period
	Average Annual Shortage (MAF)	% Years of Shortage	Average Annual Shortage (MAF)	% Years of Shortage	Average Annual Shortage (MAF)	% Years of Shortage	Average Annual Shortage (MAF)	% Years of Shortage	Average Annual Shortage (MAF)	% Years of Shortage	
0 - 1	0.12	0.23%	0.29	0.20%	0.64	0.47%	1.08	0.47%	1.77	0.32%	1.69%
2 - 3	0.18	0.02%	0.29	0.17%	0.63	0.39%	1.16	1.73%	1.71	2.00%	4.31%
4 - 6	-	-	-	-	0.56	0.11%	1.24	0.96%	1.66	2.83%	3.89%
7 - 10	-	-	-	-	-	-	1.32	0.17%	1.68	2.13%	2.29%
≥ 11	-	-	-	-	-	-	-	-	1.69	0.92%	0.92%
Percent of Years within Range of Shortage Volumes	-	0.25%	-	0.37%	-	0.97%	-	3.33%	-	8.19%	13.11%

Scenario 6

Upper Basin Demands (AF)	**4,500,000**
Lee Ferry Flows (AF)	**8,250,000**
Basin Hydrology (% of Historical)	**100**
Colorado Demands (% of Total Upper Basin Demands)	**51.75**

Duration of Shortage (yr)	0 - 200,000 AF Shortage		200,001 - 400,000 AF Shortage		400,001 - 800,000 AF Shortage		800,001 - 1,400,000 AF Shortage		> 1,400,000 AF Shortage		Percent of Years in Shortage Period
	Average Annual Shortage (MAF)	% Years of Shortage	Average Annual Shortage (MAF)	% Years of Shortage	Average Annual Shortage (MAF)	% Years of Shortage	Average Annual Shortage (MAF)	% Years of Shortage	Average Annual Shortage (MAF)	% Years of Shortage	
0 - 1	-	-	-	-	-	-	1.16	0.02%	-	-	0.02%
2 - 3	-	-	-	-	0.57	0.02%	1.16	0.04%	-	-	0.06%
4 - 6	-	-	-	-	-	-	1.02	0.20%	-	-	0.20%
7 - 10	-	-	-	-	-	-	-	-	-	-	0.00%
≥ 11	-	-	-	-	-	-	-	-	-	-	0.00%
Percent of Years within Range of Shortage Volumes	-	0.00%	-	0.00%	-	0.02%	-	0.26%	-	0.00%	0.28%

Scenario 7

Upper Basin Demands (AF) **4,500,000**
Lee Ferry Flows (AF) **8,250,000**
Basin Hydrology (% of Historical) **90**
Colorado Demands (% of Total Upper Basin Demands) **51.75**

Duration of Shortage (yr)	0 - 200,000 AF Shortage		200,001 - 400,000 AF Shortage		400,001 - 800,000 AF Shortage		800,001 - 1,400,000 AF Shortage		> 1,400,000 AF Shortage		Percent of Years in Shortage Period
	Average Annual Shortage (MAF)	% Years of Shortage	Average Annual Shortage (MAF)	% Years of Shortage	Average Annual Shortage (MAF)	% Years of Shortage	Average Annual Shortage (MAF)	% Years of Shortage	Average Annual Shortage (MAF)	% Years of Shortage	
0 - 1	0.09	0.09%	0.29	0.05%	0.63	0.16%	1.12	0.21%	-	-	0.52%
2 - 3	-	-	0.25	0.02%	0.63	0.48%	1.07	0.93%	-	-	1.43%
4 - 6	-	-	-	-	0.59	0.13%	1.06	1.02%	-	-	1.15%
7 - 10	-	-	-	-	-	-	1.05	1.19%	-	-	1.19%
≥ 11	-	-	-	-	-	-	1.04	0.95%	-	-	0.95%
Percent of Years within Range of Shortage Volumes	-	0.09%	-	0.07%	-	0.77%	-	4.29%	-	0.00%	5.23%

Scenario 8

Upper Basin Demands (AF) **4,500,000**
Lee Ferry Flows (AF) **7,500,000**
Basin Hydrology (% of Historical) **100**
Colorado Demands (% of Total Upper Basin Demands) **51.75**

Duration of Shortage (yr)	0 - 200,000 AF Shortage		200,001 - 400,000 AF Shortage		400,001 - 800,000 AF Shortage		800,001 - 1,400,000 AF Shortage		> 1,400,000 AF Shortage		Percent of Years in Shortage Period
	Average Annual Shortage (MAF)	% Years of Shortage	Average Annual Shortage (MAF)	% Years of Shortage	Average Annual Shortage (MAF)	% Years of Shortage	Average Annual Shortage (MAF)	% Years of Shortage	Average Annual Shortage (MAF)	% Years of Shortage	
0 - 1	-	-	-	-	-	-	-	-	-	-	0.00%
2 - 3	-	-	-	-	0.60	0.04%	-	-	-	-	0.04%
4 - 6	-	-	-	-	-	-	-	-	-	-	0.00%
7 - 10	-	-	-	-	-	-	-	-	-	-	0.00%
≥ 11	-	-	-	-	-	-	-	-	-	-	0.00%
Percent of Years within Range of Shortage Volumes	-	0.00%	-	0.00%	-	0.04%	-	0.00%	-	0.00%	0.04%

Scenario 9

Upper Basin Demands (AF) **4,500,000**
Lee Ferry Flows (AF) **7,500,000**
Basin Hydrology (% of Historical) **90**
Colorado Demands (% of Total Upper Basin Demands) **51.75**

Duration of Shortage (yr)	0 - 200,000 AF Shortage		200,001 - 400,000 AF Shortage		400,001 - 800,000 AF Shortage		800,001 - 1,400,000 AF Shortage		> 1,400,000 AF Shortage		Percent of Years in Shortage Period
	Average Annual Shortage (MAF)	% Years of Shortage	Average Annual Shortage (MAF)	% Years of Shortage	Average Annual Shortage (MAF)	% Years of Shortage	Average Annual Shortage (MAF)	% Years of Shortage	Average Annual Shortage (MAF)	% Years of Shortage	
0 - 1	0.07	0.01%	0.28	0.03%	0.56	0.03%	0.98	0.02%	-	-	0.09%
2 - 3	-	-	0.27	0.04%	0.60	0.13%	1.02	0.22%	-	-	0.39%
4 - 6	-	-	-	-	-	-	0.96	0.26%	-	-	0.26%
7 - 10	-	-	-	-	-	-	1.01	0.17%	-	-	0.17%
≥ 11	-	-	-	-	-	-	1.16	0.12%	-	-	0.12%
Percent of Years within Range of Shortage Volumes	-	0.01%	-	0.07%	-	0.16%	-	0.79%	-	0.00%	1.03%

Scenario 10

Upper Basin Demands (AF)	**4,500,000**
Lee Ferry Flows (AF)	**7,500,000**
Basin Hydrology (% of Historical)	**80**
Colorado Demands (% of Total Upper Basin Demands)	**51.75**

Duration of Shortage (yr)	0 - 200,000 AF Shortage		200,001 - 400,000 AF Shortage		400,001 - 800,000 AF Shortage		800,001 - 1,400,000 AF Shortage		> 1,400,000 AF Shortage		Percent of Years in Shortage Period
	Average Annual Shortage (MAF)	% Years of Shortage	Average Annual Shortage (MAF)	% Years of Shortage	Average Annual Shortage (MAF)	% Years of Shortage	Average Annual Shortage (MAF)	% Years of Shortage	Average Annual Shortage (MAF)	% Years of Shortage	
0 - 1	0.10	0.28%	0.30	0.17%	0.58	0.38%	1.07	0.65%	-	-	1.48%
2 - 3	0.14	0.09%	0.34	0.06%	0.63	0.69%	1.04	1.67%	-	-	2.53%
4 - 6	-	-	0.39	0.05%	0.69	0.45%	1.01	3.71%	-	-	4.21%
7 - 10	-	-	-	-	0.70	0.33%	1.04	3.26%	-	-	3.59%
≥ 11	-	-	-	-	-	-	1.09	3.98%	-	-	3.98%
Percent of Years within Range of Shortage Volumes	-	0.38%	-	0.28%	-	1.85%	-	13.27%	-	0.00%	15.79%

Scenario 11

Upper Basin Demands (AF)	**5,200,000**
Lee Ferry Flows (AF)	**8,250,000**
Basin Hydrology (% of Historical)	**100**
Colorado Demands (% of Total Upper Basin Demands)	**51.75**

Duration of Shortage (yr)	0 - 200,000		200,001 - 400,000		400,001 - 800,000		800,001 - 1,400,000		> 1,400,000		Percent of Years in Shortage Period
	Average Annual Shortage (AFY)	% Years of Shortage	Average Annual Shortage (AFY)	% Years of Shortage	Average Annual Shortage (AFY)	% Years of Shortage	Average Annual Shortage (AFY)	% Years of Shortage	Average Annual Shortage (AFY)	% Years of Shortage	
0 - 1	0.04	0.02%	0.30	0.07%	0.50	0.06%	1.03	0.06%	1.47	0.02%	0.24%
2 - 3	-	-	0.25	0.02%	0.61	0.19%	1.09	0.40%	1.51	0.12%	0.73%
4 - 6	-	-	-	-	-	-	1.26	0.33%	1.44	0.05%	0.38%
7 - 10	-	-	-	-	-	-	1.31	0.18%	-	-	0.18%
> 11	-	-	-	-	-	-	-	-	1.43	0.12%	0.12%
Percent of Years within Range of Shortage Volumes	-	0.02%	-	0.09%	-	0.25%	-	0.97%	-	0.31%	1.64%

Scenario 12

Upper Basin Demands (AF)	**5,200,000**
Lee Ferry Flows (AF)	**8,250,000**
Basin Hydrology (% of Historical)	**90**
Colorado Demands (% of Total Upper Basin Demands)	**51.75**

Duration of Shortage (yr)	0 - 200,000		200,001 - 400,000		400,001 - 800,000		800,001 - 1,400,000		> 1,400,000		Percent of Years in Shortage Period
	Average Annual Shortage (AFY)	% Years of Shortage	Average Annual Shortage (AFY)	% Years of Shortage	Average Annual Shortage (AFY)	% Years of Shortage	Average Annual Shortage (AFY)	% Years of Shortage	Average Annual Shortage (AFY)	% Years of Shortage	
0 - 1	0.11	0.29%	0.32	0.21%	0.58	0.43%	1.06	0.43%	1.51	0.26%	1.63%
2 - 3	0.17	0.05%	0.29	0.06%	0.63	0.38%	1.06	1.55%	1.50	1.05%	3.09%
4 - 6	-	-	-	-	0.64	0.19%	1.17	2.98%	1.48	1.01%	4.18%
7 - 10	-	-	-	-	-	-	1.19	1.98%	1.49	0.89%	2.87%
> 11	-	-	-	-	-	-	1.31	1.38%	1.45	1.25%	2.63%
Percent of Years within Range of Shortage Volumes	-	0.35%	-	0.27%	-	1.00%	-	8.32%	-	4.47%	14.41%

Scenario 13

Upper Basin Demands (AF) **5,200,000**
Lee Ferry Flows (AF) **7,500,000**
Basin Hydrology (% of Historical) **100**
Colorado Demands (% of Total Upper Basin Demands) **51.75**

Duration of Shortage (yr)	0 - 200,000 AF Shortage		200,001 - 400,000 AF Shortage		400,001 - 800,000 AF Shortage		800,001 - 1,400,000 AF Shortage		> 1,400,000 AF Shortage		Percent of Years in Shortage Period
	Average Annual Shortage (MAF)	% Years of Shortage	Average Annual Shortage (MAF)	% Years of Shortage	Average Annual Shortage (MAF)	% Years of Shortage	Average Annual Shortage (MAF)	% Years of Shortage	Average Annual Shortage (MAF)	% Years of Shortage	
0 - 1	-	-	-	-	-	-	0.84	0.01%	1.52	0.01%	0.02%
2 - 3	-	-	0.38	0.02%	-	-	1.09	0.02%	1.48	0.02%	0.06%
4 - 6	-	-	-	-	-	-	1.03	0.20%	-	-	0.20%
7 - 10	-	-	-	-	-	-	-	-	-	-	0.00%
≥ 11	-	-	-	-	-	-	-	-	-	-	0.00%
Percent of Years within Range of Shortage Volumes	-	0.00%	-	0.02%	-	0.00%	-	0.23%	-	0.03%	0.28%

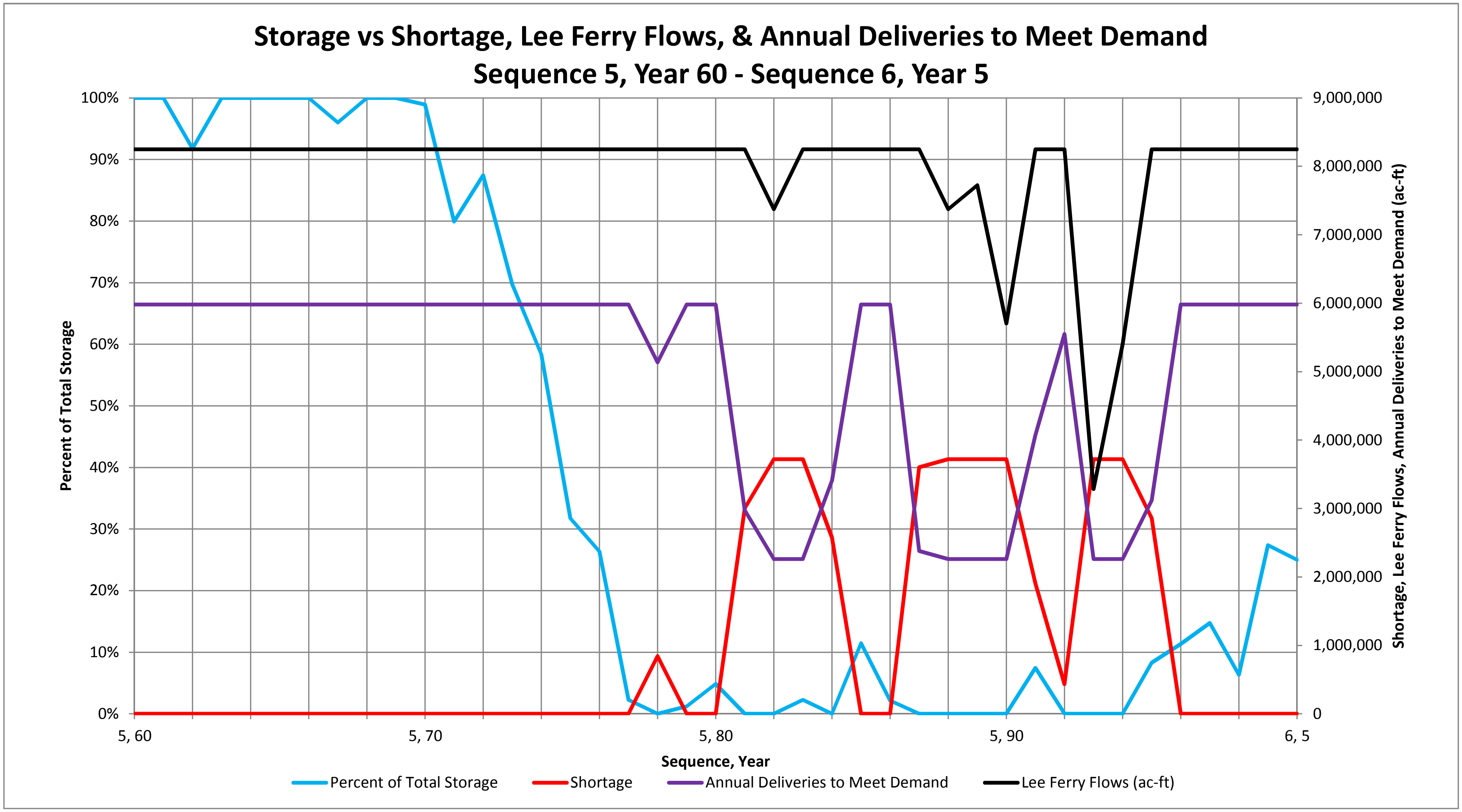
Scenario 14

Upper Basin Demands (AF) **5,200,000**
Lee Ferry Flows (AF) **7,500,000**
Basin Hydrology (% of Historical) **90**
Colorado Demands (% of Total Upper Basin Demands) **51.75**

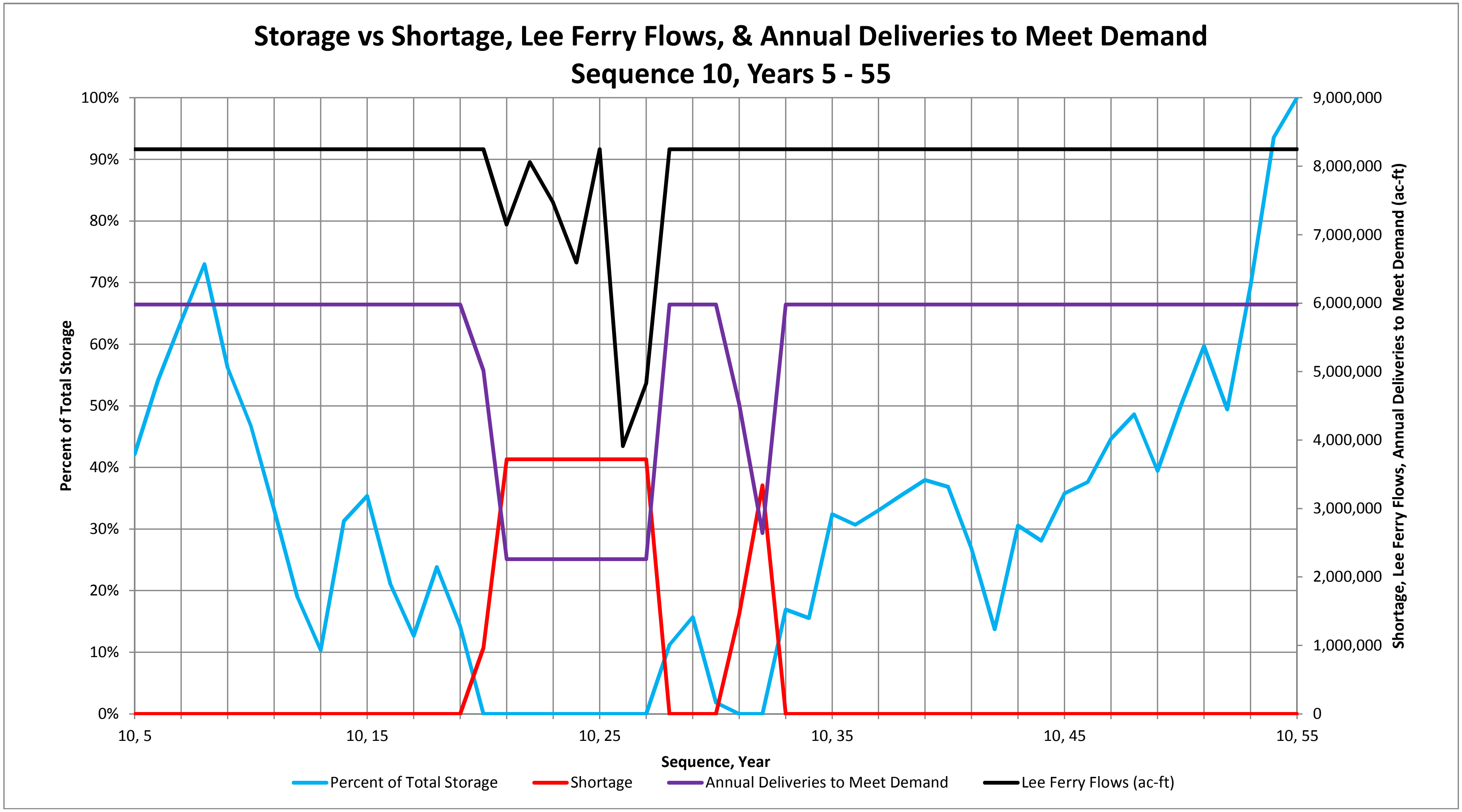
Duration of Shortage (yr)	0 - 200,000 AF Shortage		200,001 - 400,000 AF Shortage		400,001 - 800,000 AF Shortage		800,001 - 1,400,000 AF Shortage		> 1,400,000 AF Shortage		Percent of Years in Shortage Period
	Average Annual Shortage (MAF)	% Years of Shortage	Average Annual Shortage (MAF)	% Years of Shortage	Average Annual Shortage (MAF)	% Years of Shortage	Average Annual Shortage (MAF)	% Years of Shortage	Average Annual Shortage (MAF)	% Years of Shortage	
0 - 1	0.08	0.09%	0.29	0.07%	0.56	0.09%	1.13	0.17%	1.50	0.09%	0.53%
2 - 3	0.16	0.04%	0.32	0.05%	0.63	0.18%	1.08	0.85%	1.50	0.58%	1.71%
4 - 6	-	-	-	-	-	-	1.27	1.03%	1.46	0.15%	1.18%
7 - 10	-	-	-	-	-	-	1.27	0.17%	1.44	0.25%	0.42%
≥ 11	-	-	-	-	-	-	1.18	0.23%	1.52	0.13%	0.36%
Percent of Years within Range of Shortage Volumes	-	0.14%	-	0.13%	-	0.27%	-	2.45%	-	1.20%	4.19%

Attachment B

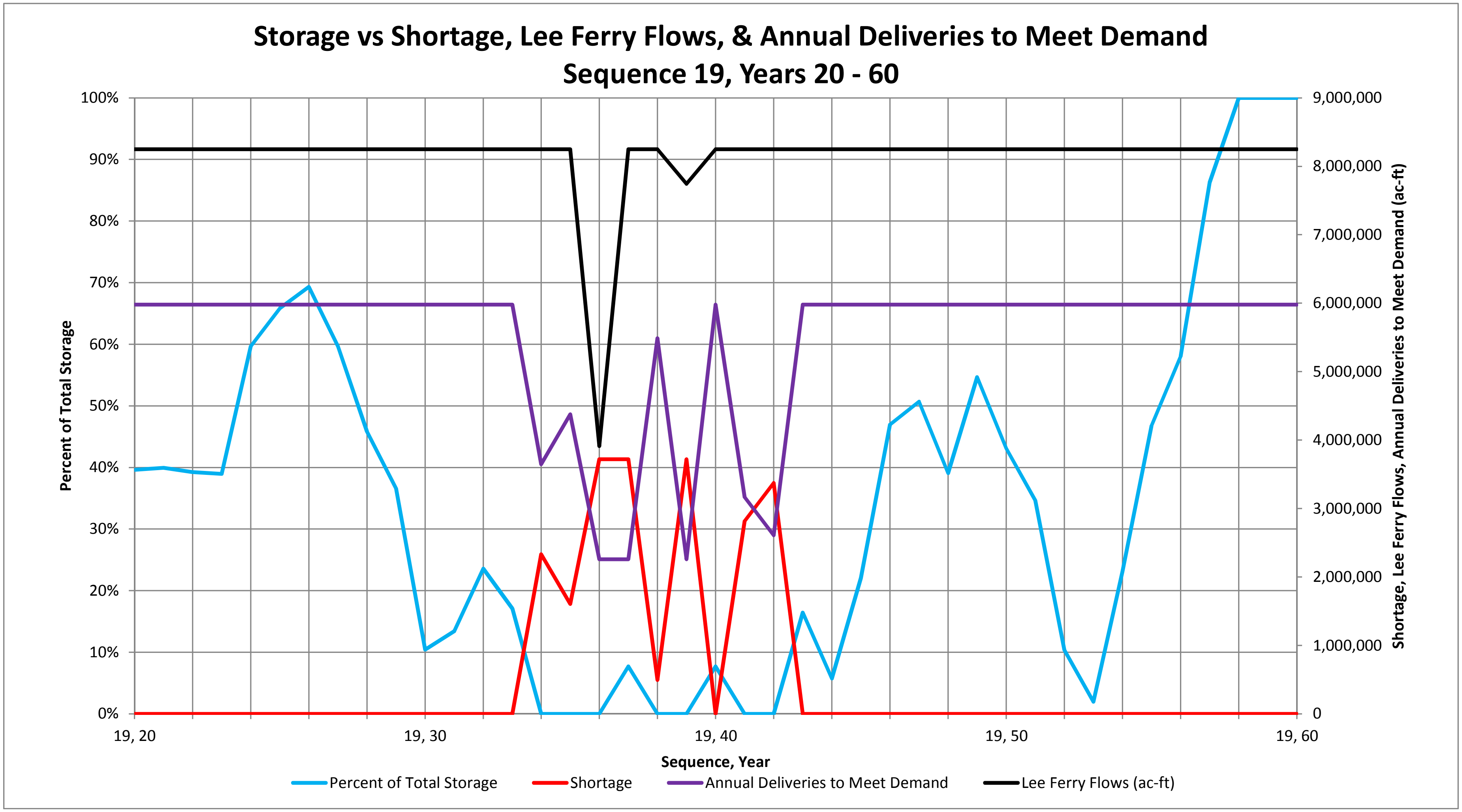
Storage Results



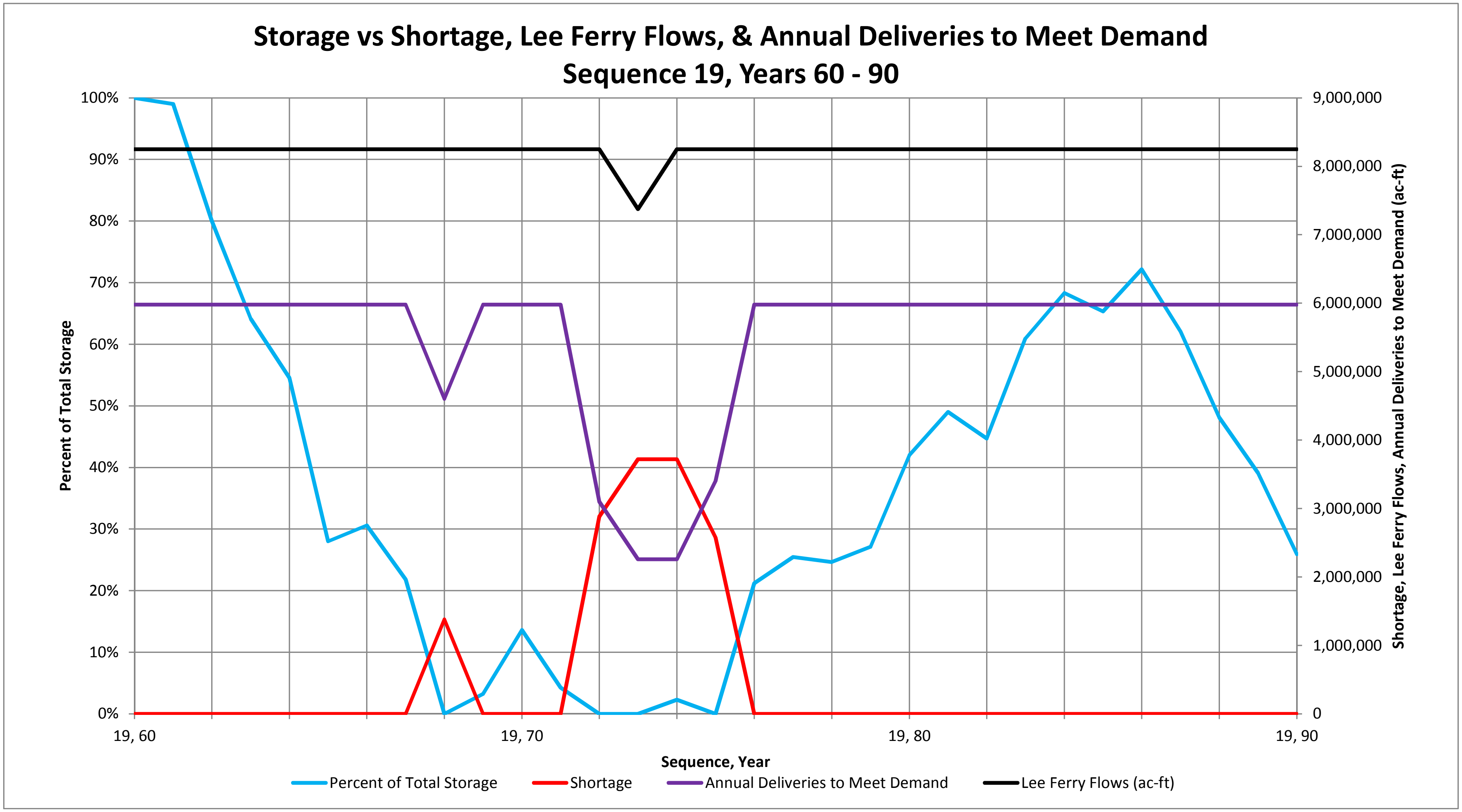
Storage vs Shortage, Lee Ferry Flows, & Annual Deliveries to Meet Demand
Sequence 5, Year 60 - Sequence 6, Year 5
Percent of Total Storage
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Shortage, Lee Ferry Flows, Annual Deliveries to Meet Demand (ac-ft)
9,000,000
8,000,000
7,000,000
6,000,000
5,000,000
4,000,000
3,000,000
2,000,000
1,000,000
0
5, 60
5, 70
5, 80
5, 90
6, 5
Sequence, Year
Percent of Total Storage
Shortage
Annual Deliveries to Meet Demand
Lee Ferry Flows (ac-ft)



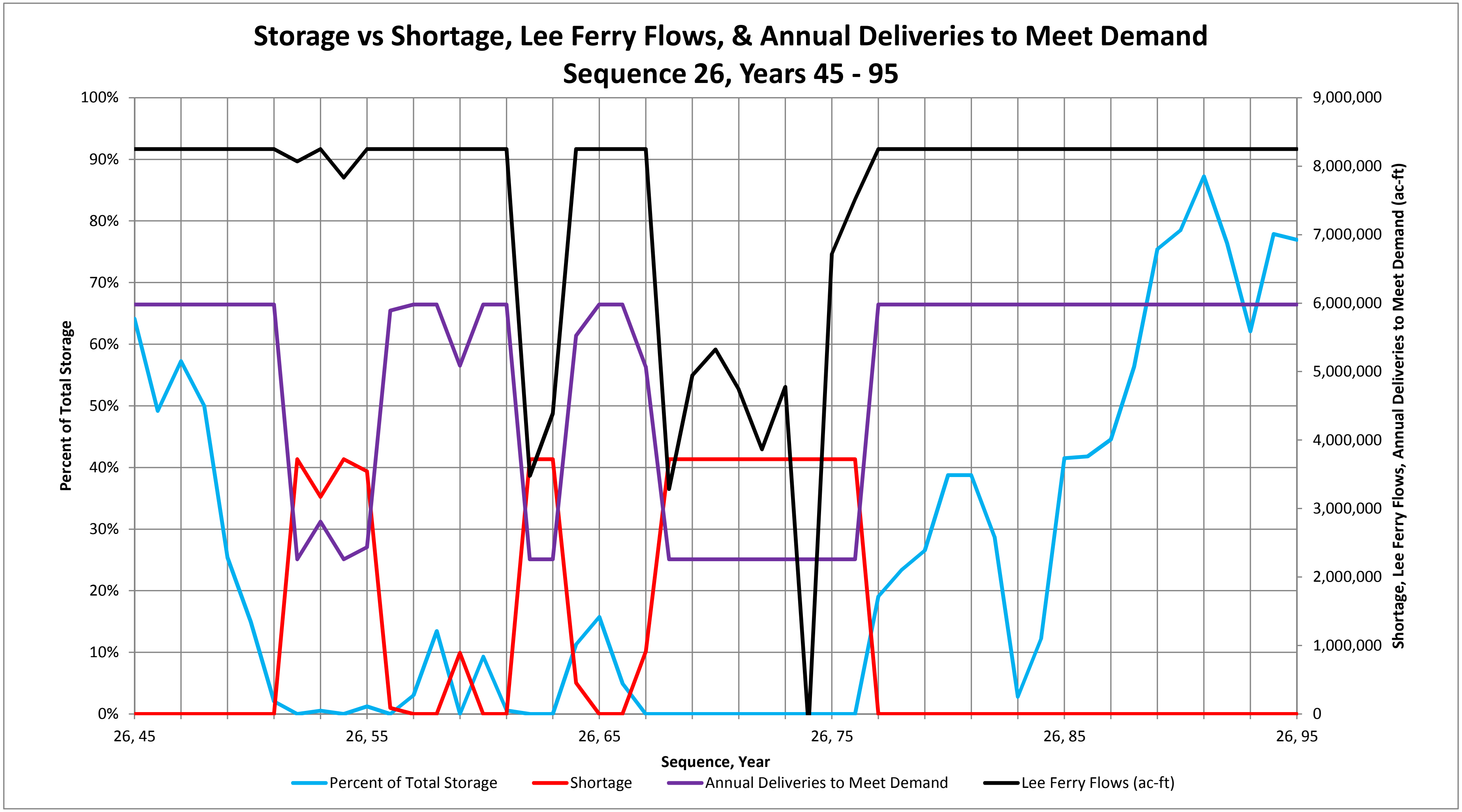
Storage vs Shortage, Lee Ferry Flows, & Annual Deliveries to Meet Demand
Sequence 10, Years 5 - 55
Percent of Total Storage
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Shortage, Lee Ferry Flows, Annual Deliveries to Meet Demand (ac-ft)
9,000,000
8,000,000
7,000,000
6,000,000
5,000,000
4,000,000
3,000,000
2,000,000
1,000,000
0
10, 5
10, 15
10, 25
10, 35
10, 45
10, 55
Sequence, Year
Percent of Total Storage
Shortage
Annual Deliveries to Meet Demand
Lee Ferry Flows (ac-ft)



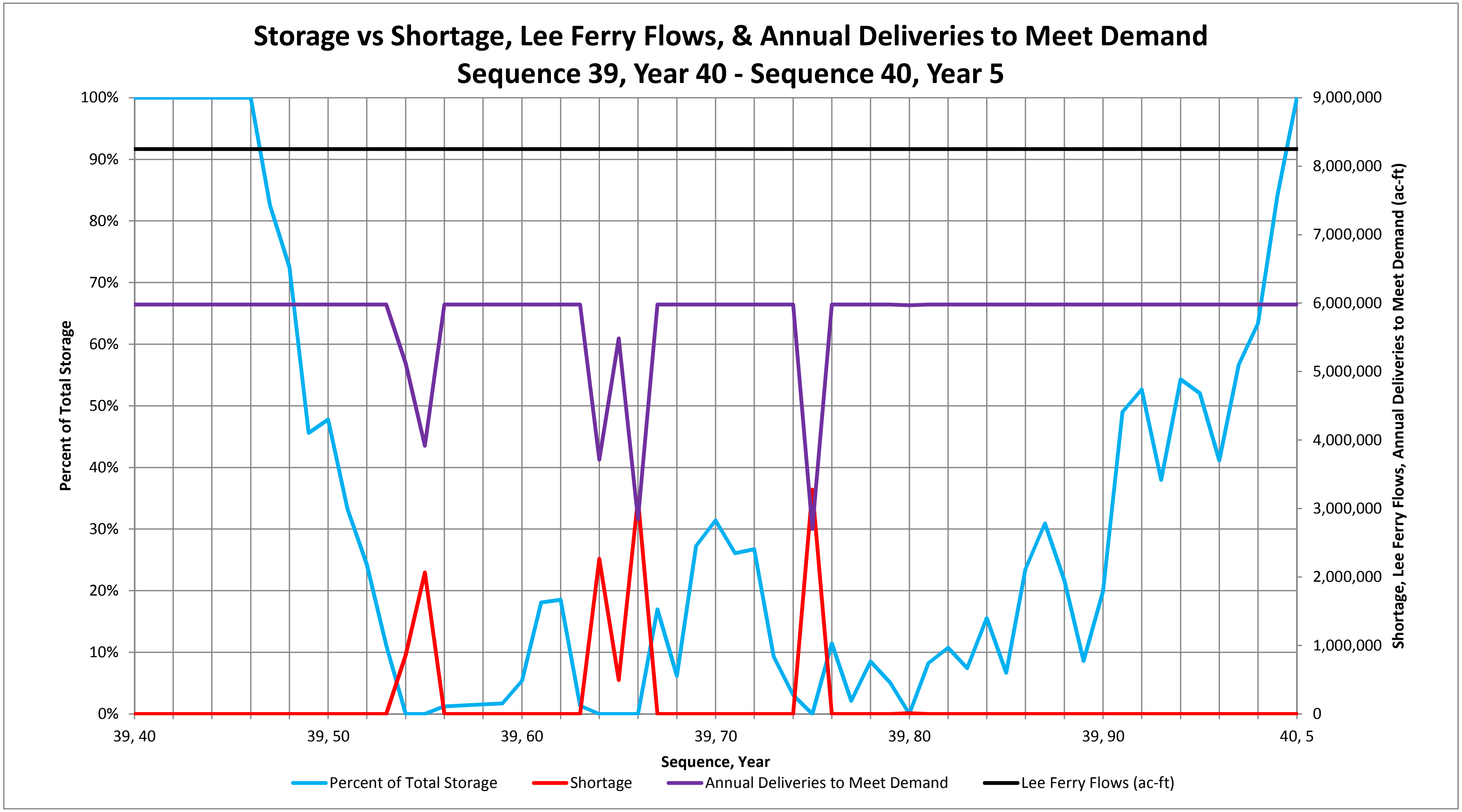
Storage vs Shortage, Lee Ferry Flows, & Annual Deliveries to Meet Demand
Sequence 19, Years 20 - 60
Percent of Total Storage
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Shortage, Lee Ferry Flows, Annual Deliveries to Meet Demand (ac-ft)
9,000,000
8,000,000
7,000,000
6,000,000
5,000,000
4,000,000
3,000,000
2,000,000
1,000,000
0
19, 20
19, 30
19, 40
19, 50
19, 60
Sequence, Year
Percent of Total Storage
Shortage
Annual Deliveries to Meet Demand
Lee Ferry Flows (ac-ft)

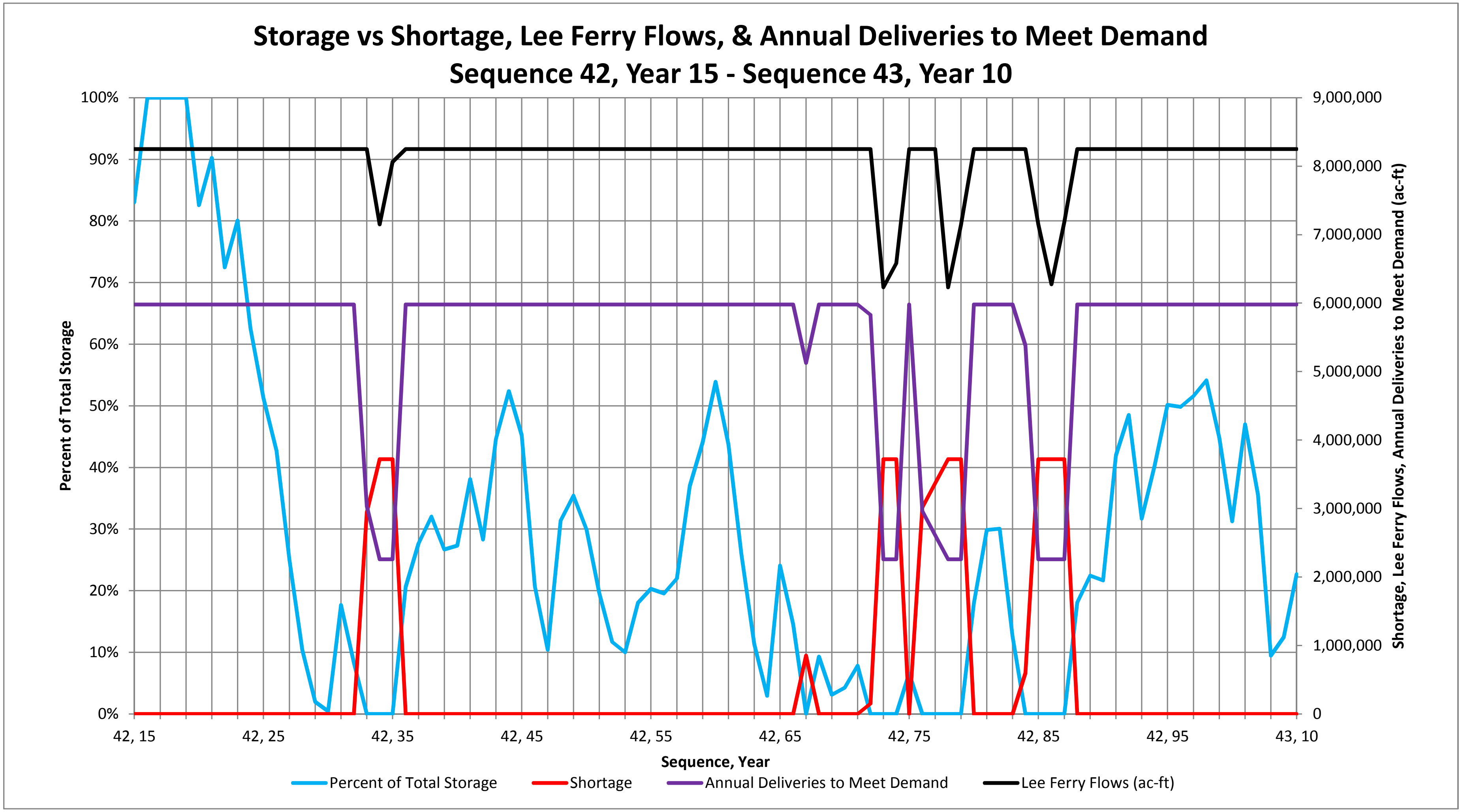


Storage vs Shortage, Lee Ferry Flows, & Annual Deliveries to Meet Demand
Sequence 19, Years 60 - 90
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Percent of Total Storage
9,000,000
8,000,000
7,000,000
6,000,000
5,000,000
4,000,000
3,000,000
2,000,000
1,000,000
0
Shortage, Lee Ferry Flows, Annual Deliveries to Meet Demand (ac-ft)
19, 60
19, 70
19, 80
19, 90
Sequence, Year
Percent of Total Storage
Shortage
Annual Deliveries to Meet Demand
Lee Ferry Flows (ac-ft)

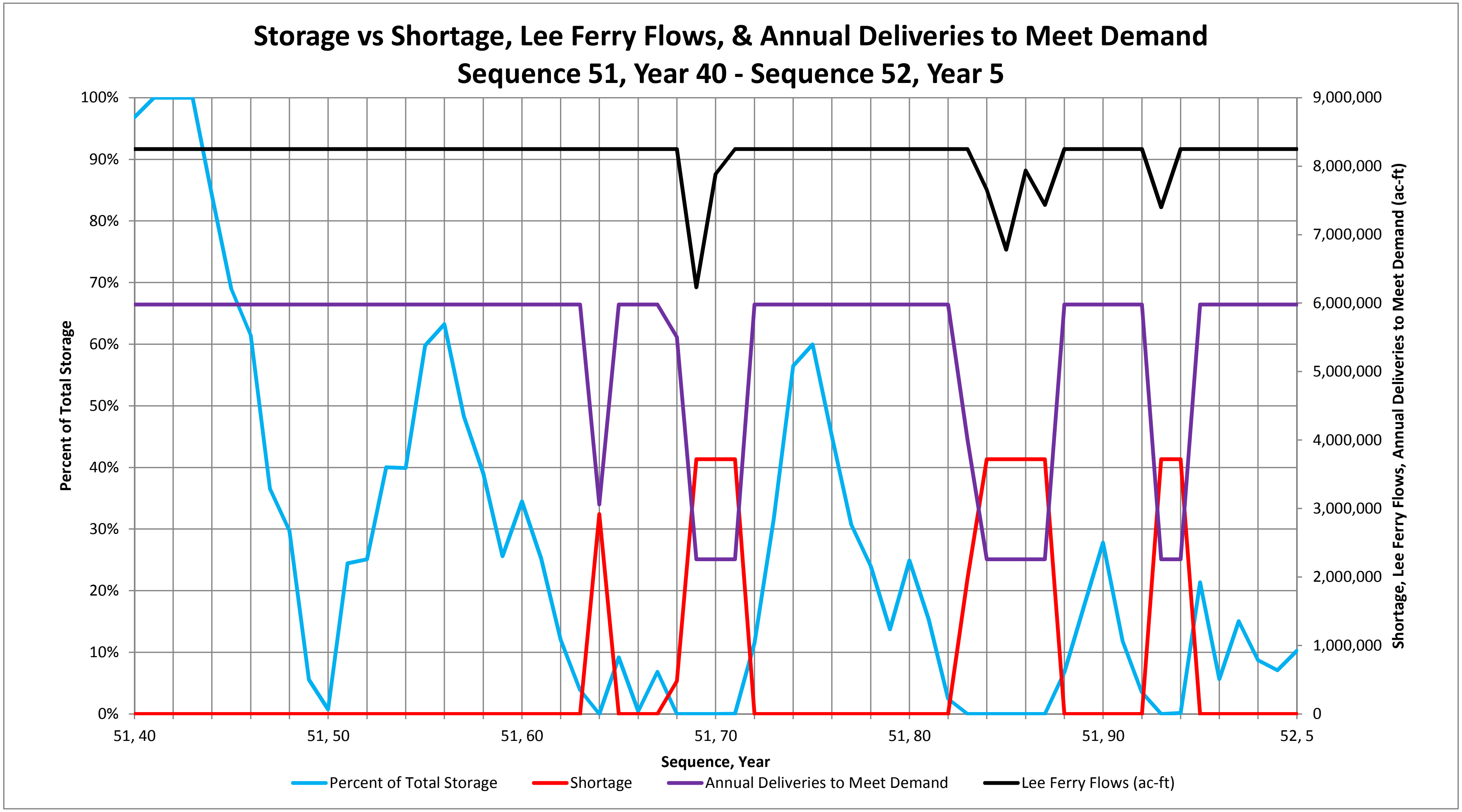


Storage vs Shortage, Lee Ferry Flows, & Annual Deliveries to Meet Demand
Sequence 26, Years 45 - 95
Percent of Total Storage
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
9,000,000
8,000,000
7,000,000
6,000,000
5,000,000
4,000,000
3,000,000
2,000,000
1,000,000
0
Shortage, Lee Ferry Flows, Annual Deliveries to Meet Demand (ac-ft)
26, 45
26, 55
26, 65
26, 75
26, 85
26, 95
Sequence, Year
Percent of Total Storage
Shortage
Annual Deliveries to Meet Demand
Lee Ferry Flows (ac-ft)


Storage vs Shortage, Lee Ferry Flows, & Annual Deliveries to Meet Demand
Sequence 39, Year 40 - Sequence 40, Year 5
Percent of Total Storage
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Shortage, Lee Ferry Flows, Annual Deliveries to Meet Demand (ac-ft)
9,000,000
8,000,000
7,000,000
6,000,000
5,000,000
4,000,000
3,000,000
2,000,000
1,000,000
0
39, 40
39, 50
39, 60
39, 70
39, 80
39, 90
40, 5
Sequence, Year
Percent of Total Storage
Shortage
Annual Deliveries to Meet Demand
Lee Ferry Flows (ac-ft)



Storage vs Shortage, Lee Ferry Flows, & Annual Deliveries to Meet Demand
Sequence 42, Year 15 - Sequence 43, Year 10
Percent of Total Storage
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Shortage, Lee Ferry Flows, Annual Deliveries to Meet Demand (ac-ft)
9,000,000
8,000,000
7,000,000
6,000,000
5,000,000
4,000,000
3,000,000
2,000,000
1,000,000
0
42, 15
42, 25
42, 35
42, 45
42, 55
42, 65
42, 75
42, 85
42, 95
43, 10
Sequence, Year
Percent of Total Storage
Shortage
Annual Deliveries to Meet Demand
Lee Ferry Flows (ac-ft)



Storage vs Shortage, Lee Ferry Flows, & Annual Deliveries to Meet Demand
Sequence 51, Year 40 - Sequence 52, Year 5
Percent of Total Storage
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Shortage, Lee Ferry Flows, Annual Deliveries to Meet Demand (ac-ft)
9,000,000
8,000,000
7,000,000
6,000,000
5,000,000
4,000,000
3,000,000
2,000,000
1,000,000
0
51, 40
51, 50
51, 60
51, 70
51, 80
51, 90
52, 5
Sequence, Year
Percent of Total Storage
Shortage
Annual Deliveries to Meet Demand
Lee Ferry Flows (ac-ft)

APPENDIX D

Basic Supply and Water Use Comparison Scenarios for the Colorado River Compact Water Bank Feasibility Study Technical Memorandum

MWH

BUILDING A BETTER WORLD

TECHNICAL MEMORANDUM

TO:	Dan Birch	DATE:	May 22, 2012
FROM:	Chip Paulson	REFERENCE:	1011690

SUBJECT: *Basic Supply and Water Use Comparison Scenarios for the Colorado River Compact Water Bank Feasibility Study*

1.0 INTRODUCTION

This Technical Memorandum describes basic comparisons of potential supply and potential water use for the Colorado River Compact Water Bank (Water Bank). This TM was prepared as part of Phase 1 of the Water Bank Feasibility Study performed by MWH for the Water Bank Group. The analysis is based on assumptions intended to provide an overall comparison of the Water Bank supply and water use at a basin scale. A scenario analysis tool is being prepared to allow for more detailed investigations of supply and water use scenarios at the Water Division level and for a range of assumptions for participation in the Water Bank by irrigators and municipal water users.

2.0 METHODS AND DATA USED

Methods and data used in this analysis rely heavily on previous analyses of potential Water Bank supply and water use developed for Phase 1 of the Water Bank feasibility study.

2.1 POTENTIAL WATER BANK WATER USE

Potential use of, or "withdrawals from," the Water Bank would be made to avoid curtailments of diversions from post-Compact water rights. Estimates of potential use were developed by the Water Bank Group (TM, November 18, 2011) based on data on historical average annual water use in the following categories:

- West Slope municipal and industrial (M&I) water use supplied by post-Compact water rights (note: in this TM, "West Slope" refers to the area within the Colorado River Basin in Colorado)
- East Slope M&I water supplied by transbasin diversions from the West Slope of post-Compact water rights
- West Slope agricultural water use for critical crop types supplied by post-Compact water rights

Replenishment of evaporation of post-Compact water stored in non-CRSP reservoirs was not assumed to represent a potential use of the Water Bank for this analysis.

The current average annual use by water use category is shown in Table 1. Water use in specific years, particularly those during extended wet or dry periods, could be more or less than the values in Table 1. It is assumed that entities withdrawing water from the Water Bank would be free to use that water to meet any type of water use within their systems.

2.2 POTENTIAL WATER BANK SUPPLIES

Potential supplies for, or "deposits to," the Water Bank would come from voluntary curtailments of diversions from users of pre-Compact water rights. The resulting reduction in consumptive use from pre-Compact water rights would allow a like amount of depletions from post-Compact water users. It is assumed that the source of water for the Water Bank would come from West Slope agricultural water users with pre-Compact water rights.

The supply available to the Water Bank was estimated based on the following three factors: maximum potential supply, level of participation by qualifying irrigators, and level of deficit irrigation on participating irrigated lands. Each of these three factors is described in the following sections.

Table 1. Potential Sources of Water Bank Use (Current Average Annual Use)

Water Use Category	Water Use (AFY)
West Slope Post-Compact M&I Depletions	
Residential Indoor	1,390
Residential Outdoor	16,675
Commercial/Industrial	4,210
Self Supplied Industrial	32,940
Subtotal	55,215
East Slope Post-Compact M&I Depletions	
Residential Indoor	107,930
Residential Outdoor	82,375
Commercial/Industrial	105,170
Self Supplied Industrial	-
Subtotal	295,475
Total Post-Compact M&I Depletions	
Residential Indoor	109,320
Residential Outdoor	99,050
Commercial/Industrial	109,380
Self Supplied Industrial	32,940
Total	350,690
East Slope Post-Compact Critical Agricultural Depletions	
Vegetables	3
Orchards (cover and no cover)	2,155
Total	2,158

Source: "Categories of Existing West Slope and East Slope Water Uses – Task 1.2," Water Bank Group, November 18, 2011

2.2.1 Maximum Potential Supply

The maximum potential supply of water to the Water Bank is represented by the total of all pre-Compact agricultural water rights held by water users in the Upper Colorado River Basin in Colorado. Pre-Compact agricultural water rights were estimated by crop type in a report for the Water Bank Group by NRCE (February 3, 2011). Basic pre-Compact water rights suitable for use in the Water Bank were assumed for the analysis in this TM to consist of the following:

- Appropriation or adjudication prior to 1929 (there is only a 2 percent difference between the volume of water associated with pre-1922 and pre-1929 agricultural water rights).

- Alfalfa and grass pasture crop types and small grains/corn/dry beans. For purposes of further analysis in this TM, only water use associated with alfalfa and grass pasture was considered because these crop types constitute the majority of agricultural water use on the West Slope.

- Water accounting for the Water Bank is based on water supply limited consumptive use estimates (i.e., crop consumptive water use adjusted for historical shortages in water deliveries).

Table 2 summarizes the irrigated lands on the West Slope with pre-Compact water rights and crop types that could occasional sustain deficit irrigation. Table 3 summarizes the maximum potential water supply available from these sources.

Table 2. Irrigated Lands Potentially Contributing Supply to the Water Bank

Description	Total Basin (ac)	Pre-1922 (ac)	Pre-1922 % of total	Pre-1929 (ac)	Pre-1929 % of Total
Alfalfa and Grass Pasture	715,805	494,637	69%	513,119	72%
Small Grain, Corn Grain, and Dry Beans	62,685	47,550	76%	48,482	77%
All Irrigated Crops	791,142	549,455	69%	568,942	72%

Source: "Colorado River Compact Colorado Water Bank Feasibility Study Water Supply Technical Memorandum," NRCE, February 3, 2012.

Table 3. Potential Sources of Water Bank Supply

Crop	Total Basin (ac-ft/yr)	Pre-1922 (ac-ft/yr)	Pre-1922 % of total	Pre-1929 (ac-ft/yr)	Pre-1929 % of Total
Alfalfa and Grass Pasture	1,248,509	872,529	70%	904,238	72%
Small Grain, Corn Grain, and Dry Beans	84,963	68,284	80%	69,239	81%
Total	**1,333,472**	**940,813**	**71%**	**973,477**	**73%**

Source: "Colorado River Compact Colorado Water Bank Feasibility Study Water Supply Technical Memorandum," NRCE, February 3, 2012.

The water sources in Table 3 were adjusted for the following three factors to estimate maximum potential supply available to the Water Bank.

- Table 3 does not include Tribal reserved water rights held by the Ute Mountain Ute and Southern Ute Tribes. Tribal reserved water rights for both Tribes combined are 56,470 AF. Some portion of these rights may be administered as pre-Compact, but that has not yet been determined. For purposes of this Water Bank analysis, the potential consumptive use from these rights was estimated to be 33,000 AFY. This amount was added to the pre-Compact water shown in Table 3.

- In some areas of Division 7 post-Compact water stored in reservoirs is released to meet irrigation demands on pre-Compact irrigated areas. The consumptive use associated with this water would not be available as a supply to the Water Bank. The average annual volume of this water was estimated to be 37,741 AFY by the Water Bank Group. This volume was subtracted from the pre-Compact water shown in Table 3.

- It was assumed that water administration principles would be adopted to shepherd potential curtailed depletions to Lee Ferry. However, because the consumptive use values in Table 3 are “on farm” values, a transit loss of 10 percent was applied to all supplies to estimate the benefit of curtailed on-farm depletions to Compact accounting.

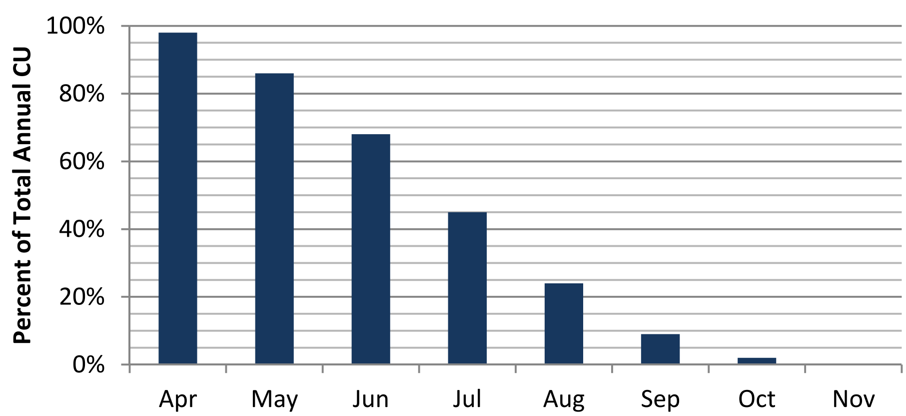
2.2.2 Level of Participation by Qualified Irrigators

The number of irrigators with pre-1929 water rights who would be interested in supplying water to a Water Bank would be a function of a number of influences including contract terms, price, regional hydrologic conditions, and numerous other factors. Research into the possible level of interest in a Water Bank by West Slope agricultural interests was not performed as part of Phase 1 of the Water Bank feasibility study. Thus the potential level of participation (or market penetration) has not been estimated for this study, but is treated as a variable in the scenario analysis described in the following portion of this TM. The level of participation was represented as a percentage of the irrigated land of a given crop type that would be fallowed or deficit irrigated to provide water to the Water Bank. For purposes of the scenario analysis it was assumed that up to 50 percent of qualifying irrigators would agree to participate in the Water Bank.

2.2.3 Level of Deficit Irrigation on Participating Irrigated Lands

Reductions in consumptive use would be achieved through various levels of deficit irrigation. Actual water savings through deficit irrigation are difficult to determine without on-farm analyses. This is discussed in the NRCE Water Bank water supply TM. For purposes of this conceptual analysis, it was assumed that consumptive use savings through deficit irrigation would be equal to the average monthly consumptive use in months during which irrigation would be curtailed. This is shown in Figure 1 for the Delta, Colorado climatic zone. In this region, for example, curtailing irrigation after July would save 45 percent of the average annual consumptive use. The level of deficit irrigation adopted by Water Bank participants would vary by irrigator, crop type, hydrologic conditions, compensation, and numerous other factors. This was treated as a variable from 0 percent to 100 percent (full fallowing) in the scenario analysis described below.

Figure 1. Consumptive Use Saved by Stopping Irrigation at End of Given Month (Delta, CO)



2.3 SCENARIO ANALYSIS

A range of supply and demand scenarios was developed for potential Water Bank utilization to test the feasibility of the Water Bank for meeting Colorado's water needs during a curtailment of uses of Colorado River and tributary water. Scenarios were prepared by assuming a level of demand generated primarily from East Slope and West Slope post-Compact M&I users (Section 2.1), then showing how that demand could be met from various combinations of supply from West Slope pre-Compact agricultural water users (Section 2.2). For this analysis only demands for individual years were considered; complexities of multi-year shortages or pro-actively banking water in reservoir space prior to a curtailment condition were not considered at this level. A separate analysis has been performed as part of the Phase 1 Water Bank Feasibility Study to estimate the magnitude, duration and frequency of hydrologic conditions in the Upper Colorado River Basin that could trigger curtailments of depletions of Colorado River and tributary water and resulting in the need for a mitigation strategy such as the Water Bank ("Evaluation of Colorado River Compact Water Bank Hydrologic Scenarios Using the Upper Colorado River Basin Model," MWH, February 2012).

MWH is developing a more robust scenario analysis tool to test scenarios of use and supply. It will allow the user to interactively select individual West Slope water divisions and crop types as supply sources, estimate the amount of irrigated land required to supply the needed consumptive use savings, and vary the level of participation and level of deficit irrigation.

3.0 RESULTS

Results of the scenario analysis for potential Water Bank uses met from deficit irrigation of pre-1929 water rights applied to alfalfa and grass pasture in all West Slope water divisions are shown in Table 4 and Figure 2. Alfalfa and grass pasture were selected for this analysis because they represent the largest use of pre-Compact water in the study area and because they are most resilient at surviving occasional deficit irrigation.

Several conclusions can be drawn from this simple comparison of potential supply and use for the Water Bank.

1. An estimate of the maximum annual use that could potentially be met from the Water Bank under a range of feasible assumptions is about 200,000 AFY. This demand could be met from 50 percent of the qualifying irrigators implementing deficit irrigation to reduce CU by 50 percent, or from 25 percent of qualifying irrigators implementing full fallowing.

2. A more reasonable planning-level estimate of the feasible potential supply available from the Water Bank may be about 100,000 AFY. This could be met with either: 25 percent deficit irrigation on 50 percent of the qualifying alfalfa and grass pasture lands; 50 percent deficit irrigation on 25 percent of the qualifying alfalfa and grass pasture lands; or full fallowing on 12 percent of the qualifying alfalfa and grass pasture lands.

3. Total current post-Compact depletions in Colorado (excluding reservoir evaporation) are on the order of 350,000 AFY. The Water Bank alone could not feasibly compensate for all Colorado River depletion curtailments.. As population growth and post-Compact water use increase in Colorado, this shortfall will become larger.

4. The analysis presented above assumes pre-1929 water rights would be administered as pre-Compact water rights. If pre-1922 water rights are administered as pre-Compact, the

Water Bank supply would be reduced by less than 5 percent compared to the 1929 cut-off date, so results would be similar to those presented previously.

5. The analysis presented above assumes only acreage supporting alfalfa and grass pasture would be deficit irrigated to contribute consumptive use to the Water Bank. If acreage irrigating small grain, corn and dry beans also supplied water to the Water Bank, the maximum potential supply could be increased by up to about 8 percent.

6. To provide quantities of supply that are large enough to meet a substantial portion of the curtailed post-Compact depletions of Water Bank users, it is likely that a significant percentage of qualifying irrigators on the West Slope would have to be willing to provide supplies by deficit irrigating or fallowing cropland. The level of participation required to meet this level of use could be in the range of 25 to 50 percent. Based on Table 2, this would result in deficit irrigation or fallowing on 130,000 to 260,000 acres on the West Slope.

Table 4. Percent Deficit Irrigation on Participating Alfalfa and Grass Pasture Acreage Required to Meet Assumed Water Bank Water Use

Water Bank Water Use (AFY)	50% Agr Water User Participation	25% Agr Water User Participation	15% Agr Water User Participation	10% Agr Water User Participation	5% Agr Water User Participation
	Percent CU Savings Required Through Deficit Irrigation of Alfalfa and Grass Pasture				
0	0%	0%	0%	0%	0%
20,000	5%	10%	15%	23%	46%
40,000	10%	20%	30%	46%	92%
60,000	15%	30%	46%	69%	-
80,000	20%	40%	61%	92%	-
100,000	25%	49%	76%	-	-
120,000	30%	59%	92%	-	-
140,000	35%	69%	-	-	-
160,000	40%	79%	-	-	-
200,000	50%	98%	-	-	-

Figure 2. Percent Deficit Irrigation on Participating Alfalfa and Grass Pasture Acreage Required to Meet Assumed Water Bank Water Use