HB16-1256
SOUTH PLATTE STORAGE STUDY

Final Report

Prepared for the Colorado General Assembly, in coordination with the Colorado Water Conservation Board, the Colorado Division of Water Resources, and the South Platte Basin and Metro Roundtables

December 15, 2017

Stantec

LeonardRice ENGINEERS, INC.

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1. EXECUTIVE SUMMARY

1.1 INTRODUCTION

The South Platte Storage Study (SPSS) was initiated as a result of House Bill 16-1256 titled "South Platte Storage Study." It authorizes the Colorado Water Conservation Board, in collaboration with the State Engineer and the South Platte Basin and Metro Roundtables, to identify multi-purpose water storage options along the lower South Platte River to capture flows leaving Colorado in excess of the minimum legally required amounts. The study area for identifying storage options was the lower South Platte Basin between Greeley and the Nebraska State line. Water storage possibilities include new reservoirs, the enlargement/rehabilitation of existing reservoirs, and alternative storage mechanisms (e.g., underground storage).

The study tasks are summarized in **Figure 1-1**. Study methods and preliminary results were reviewed by and coordinated with members of the Colorado Water Conservation Board, Colorado Division of Water Resources, and South Platte Basin and Metro Roundtables through a series of three workshops and informal reviews. Members of these groups reviewed and commented on draft technical memoranda and the final project report.

The SPSS study was conducted by Stantec Consulting Services Inc., with support from Leonard Rice Engineers, Inc. Funding for the study was provided from the Colorado Water Conservation Board Water Supply Reserve Fund.

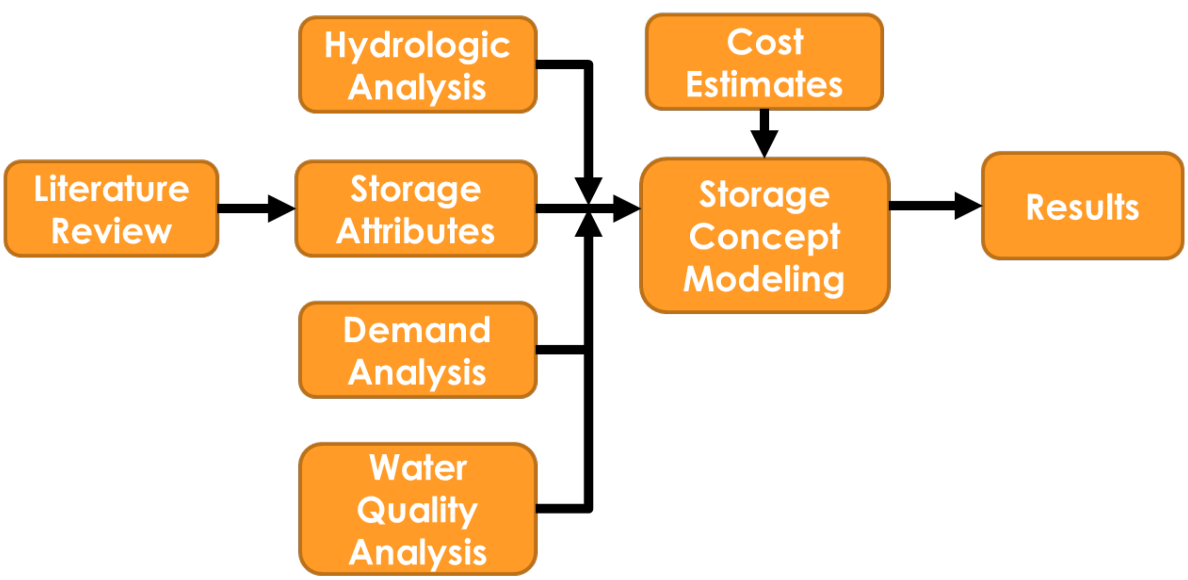


Figure 1-1 – South Platte Storage Study Approach

1.2 LITERATURE REVIEW

Past studies of storage options in the South Platte Basin were reviewed, and a database of storage options identified in these past studies was assembled. Storage options were categorized as new surface storage, existing surface storage enlargement, existing surface storage restoration, existing surface storage rehabilitation, gravel pit storage, and aquifer storage. After eliminating sites outside the SPSS study area and combining similar storage concepts, 73 surface storage options (excluding gravel pits) and 22 aquifer storage options were selected for evaluation.

1.3 LEGAL AND REGULATORY OVERVIEW

Federal, state and local regulations and permits that could affect the feasibility of storage options in the SPSS study area were reviewed and summarized. Key regulations and permits to consider during project development include: U.S. Army Corps of Engineers 404 permit, National Environmental Policy Act, Endangered Species Act, Platte River Recovery Implementation Program, South Platte River Compact, Colorado water rights administration, and local 1041 regulations.

1.4 HISTORICAL FLOW ANALYSIS

The historical flows at the Nebraska State line for the period 1996-2015 (water years) were analyzed to estimate the total amount of water leaving Colorado and the amount of water leaving Colorado in excess of the South Platte River Compact. Table 1-1 shows statistics for total water leaving Colorado and water delivered to Nebraska in excess of the Compact for this 20-year period.

Table 1-1. Historical Annual Flow for 1996-2015 at Nebraska State Line

Statistic	Physical Water Leaving Colorado (Julesburg Gage)	Water Delivered to Nebraska in Excess of the Compact (1)(2)
Annual Median (ac-ft/yr)	331,000	293,000
Annual Average (ac-ft/yr)	436,000	397,000
Minimum Year (ac-ft/yr)	29,000	10,000
Maximum Year (ac-ft/yr)	1,957,000	1,904,000
Total for 20-yr Period 1996-2015 (ac-ft)	8,728,000	7,939,000

(1) Storable flow Julesburg gage
(2) Future environmental flow obligations could reduce legally available water.

1.5 AVAILABLE WATER FOR STORAGE

A daily point flow model was used to compute the amount of water that would be physically and legally available for storage in a new SPSS storage project. Available water was computed for two hydrologic conditions: (1) historical conditions for the 1996-2015 period of record in the point flow model; and (2) future conditions using the same basic hydrology. Future hydrology was estimated by reducing the historical point flow model results by an allowance for Identified Projects and Processes (IPPs) in Colorado's Water Plan and an allowance for existing conditional exchange water rights that have not been executed to date. Statistics defining water available for storage at five locations in the SPSS study area are given in **Table 1-2**. Estimated future median annual available water is 20-30 percent less than median annual available water in the 20 years between 1996 and 2015. The median is a better statistic to describe typical conditions because there are a few high flow years that skew the average in the study period.

Table 1-2. Available Water for Selected Locations Based on Historical and Future Hydrology

Location	Median Annual Available Water (ac-ft)	Average Annual Available Water (ac-ft)	Available Water in Wet Year (ac-ft)	Available Water in Normal Year (ac-ft)	Available Water in Dry Year (ac-ft)
	All Years	All Years	1999	2010	2002
Historical Hydrology (1996-2015)					
South Platte River near Kersey	165,000	262,000	707,000	378,000	14,000
South Platte River near Weldona	179,000	281,000	731,000	411,000	18,000
South Platte River near Balzac	185,000	297,000	771,000	440,000	18,000
Lowline Ditch/Henderson Smith Ditch	200,000	314,000	799,000	476,000	33,000
South Platte River at Julesburg	289,000	397,000	951,000	627,000	79,000
Future Hydrology Based on IPP and Conditional Water Right Adjustments					
South Platte River near Kersey	116,000	214,000	580,000	275,000	6,000
South Platte River near Weldona	127,000	231,000	601,000	303,000	9,000
South Platte River near Balzac	144,000	246,000	641,000	326,000	9,000
Lowline Ditch/Henderson Smith Ditch	154,000	261,000	666,000	357,000	15,000
South Platte River at Julesburg	232,000	332,000	815,000	494,000	54,000

1.6 WATER DEMAND

Maximum potential water demands in the SPSS study area were estimated for use in the subsequent analysis to determine feasible sizes for conceptual SPSS storage projects. Agricultural and municipal & industrial (M&I) demands were estimated for four water districts and counties in the SPSS study area between Denver and Julesburg based on data from the Statewide Water Supply Initiative (SWSI 2010). Maximum demands on SPSS reservoirs were assumed to be equal to the future water supply gap or shortage (difference between demand and supply) for the lower South Platte Basin as reported in SWSI 2010. For purposes of the storage analysis, demands were aggregated at the five key locations on the South Platte River at which available water was estimated. **Figure 1-2** summarizes available supply and maximum potential demand values used for the SPSS analysis. Total median available supply is less than the total shortages in the upper part of the study area; for example, at the Denver gage the median available supply is 5,000 ac-ft compared to total M&I and agricultural water shortages of 106,000 ac-ft. In the lower part of the study area the median available water is greater than the total M&I and agricultural water shortages (232,000 ac-ft median available supply compared to 18,000 ac-ft shortages at the Julesburg gage).

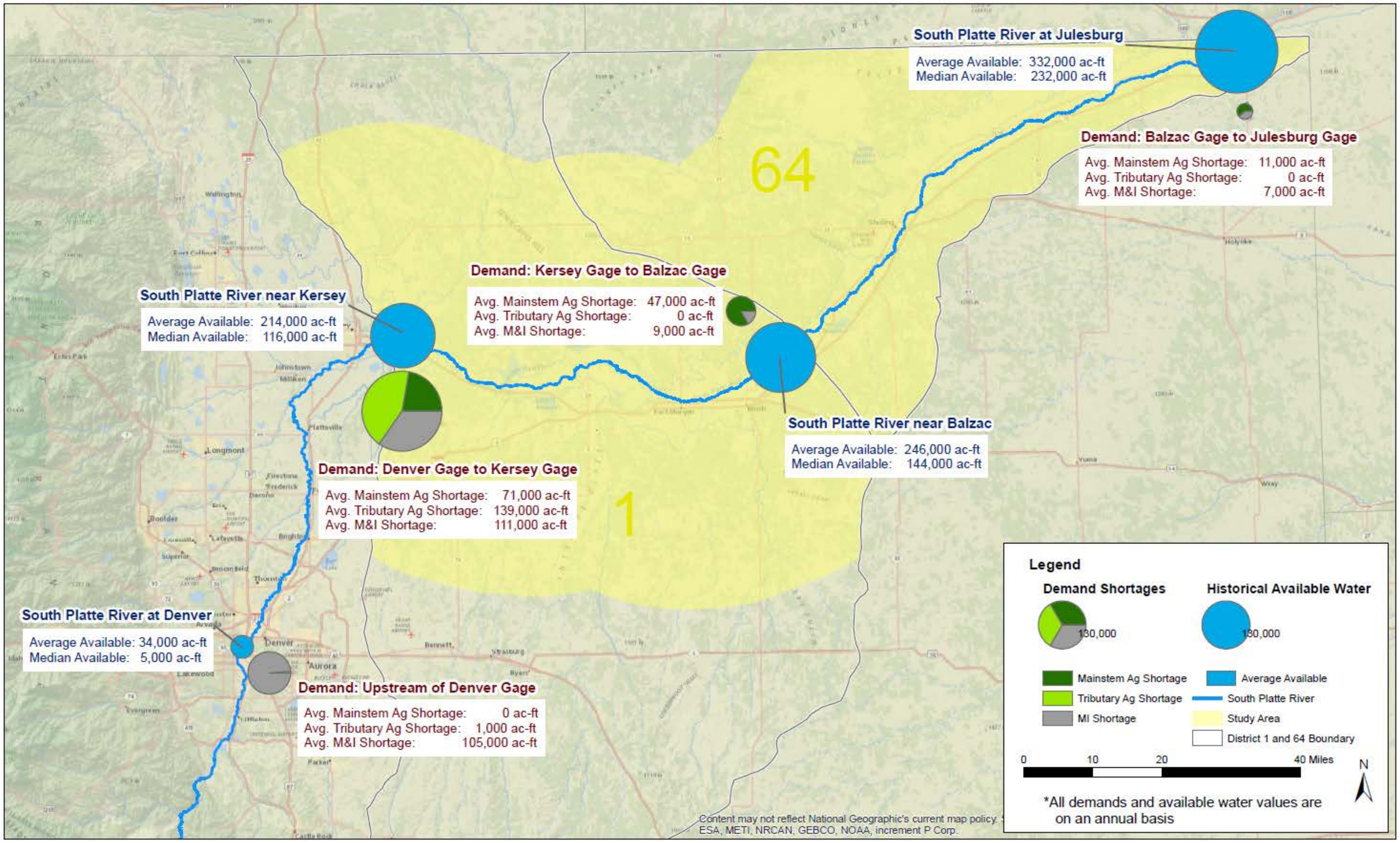


Figure 1-2. Summary of Available Water and Maximum Potential Demands at Key Locations in SPSS Study Area

1.7 WATER QUALITY

The quality of water available for a new storage project in the lower South Platte Basin could affect the feasibility of putting that water to beneficial use. Similarly, enlarging or rehabilitating existing reservoirs would only be feasible if water quality would be appropriate with treatment for the intended uses.

Existing water quality data for stream segments and reservoirs was reviewed and impaired water bodies based on the state's water quality assessment were identified. Water diverted for storage in the SPSS study area would be adequate quality for irrigation use, as these sources are currently widely used for agricultural purposes. However, if used directly as a drinking water supply, water from any new SPSS storage project would require a high level of treatment (e.g., reverse osmosis, ion exchange) to remove a number of problematic constituents including arsenic, selenium, sulfate, total dissolved solids, and uranium. In addition, water used for aquifer storage in managed groundwater basins would have to be treated prior to recharge to protect existing groundwater quality.

1.8 STORAGE OPTIONS

The SPSS evaluation process involved analyzing storage options (individual reservoir or aquifer storage facilities) and more comprehensive storage concepts or solutions. Storage concepts include individual storage options or combinations of storage options integrated with all other infrastructure required to have an operational storage project. Storage options were analyzed first, and the most promising options were incorporated into storage concepts. The overall storage evaluation process is summarized in **Figure 1-3**.

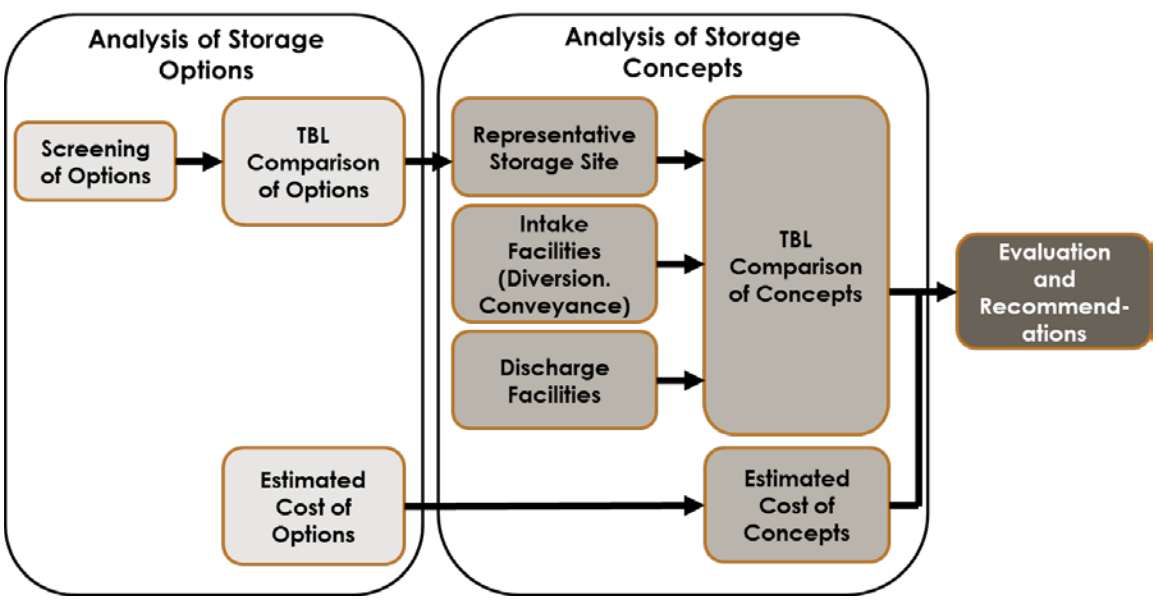


Figure 1-3. SPSS Storage Evaluation Process Overview

The long-list of possible storage sites in the SPSS study area was screened to identify those with the most potential for incorporating into SPSS storage concepts. Storage options not selected for use in creating storage concepts are not necessarily infeasible or inferior, depending on the particular application, and should be retained for consideration in any future studies. The storage site screening process is summarized in **Figure 1-4**. Surface and aquifer storage options remaining after the screening process are shown in **Figure 1-5**.

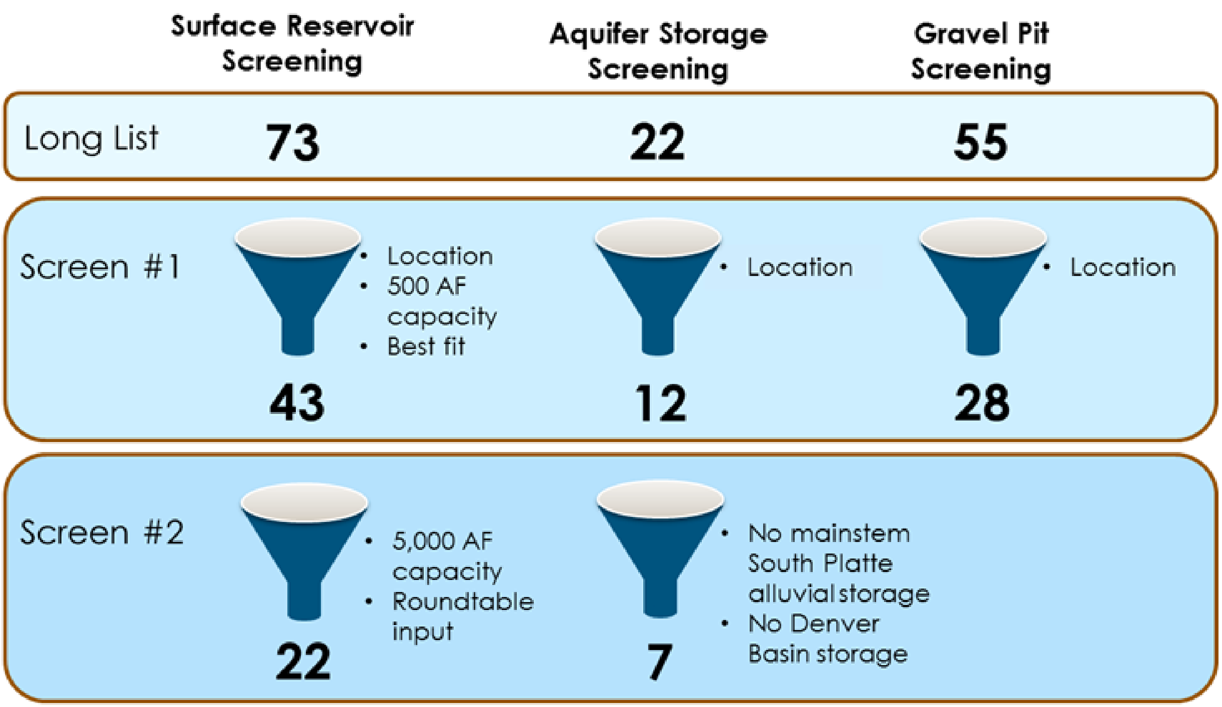


Figure 1-4. Summary of Storage Site Screening Process

Storage options were evaluated for 25 technical, environmental and social criteria based on available information on the sites and experience of the project team. Using this triple bottom line (TBL) type of evaluation process usually involves weighting categories of criteria in different ways to explore different value systems of stakeholder groups. For this study three criteria weighting scenarios were tested: equal weights, higher weighted technical criteria, and higher weighted environmental criteria. Most storage options ranked similarly regardless of the weighting scenario. **Table 1-3** lists the average of the scores under the three weighting scenarios. Because storage categories have different characteristics in terms of how they would be developed and operated, it is appropriate to compare sites within categories but not necessarily between categories.

Current cost estimates for surface storage options were developed based primarily on past studies supplemented by additional work by the consultant team. Costs were expressed in 2017 dollars and include permitting, design, land acquisition, and construction, with an accuracy of -50% to +100%. Results are summarized in **Table 1-3**. Costs were not estimated for certain storage options that were not included in storage concepts described later in this report.

Aquifer storage concepts were assumed to be supplemental supply projects that would either work in conjunction with a surface reservoir or be smaller stand-alone projects. To standardize the comparative analysis they were assumed to have infiltration basins with 5,000 ac-ft/month (82 cfs) capacity for recharge and extraction wellfields with 4,000 ac-ft/month (65 cfs) capacity for recovery.

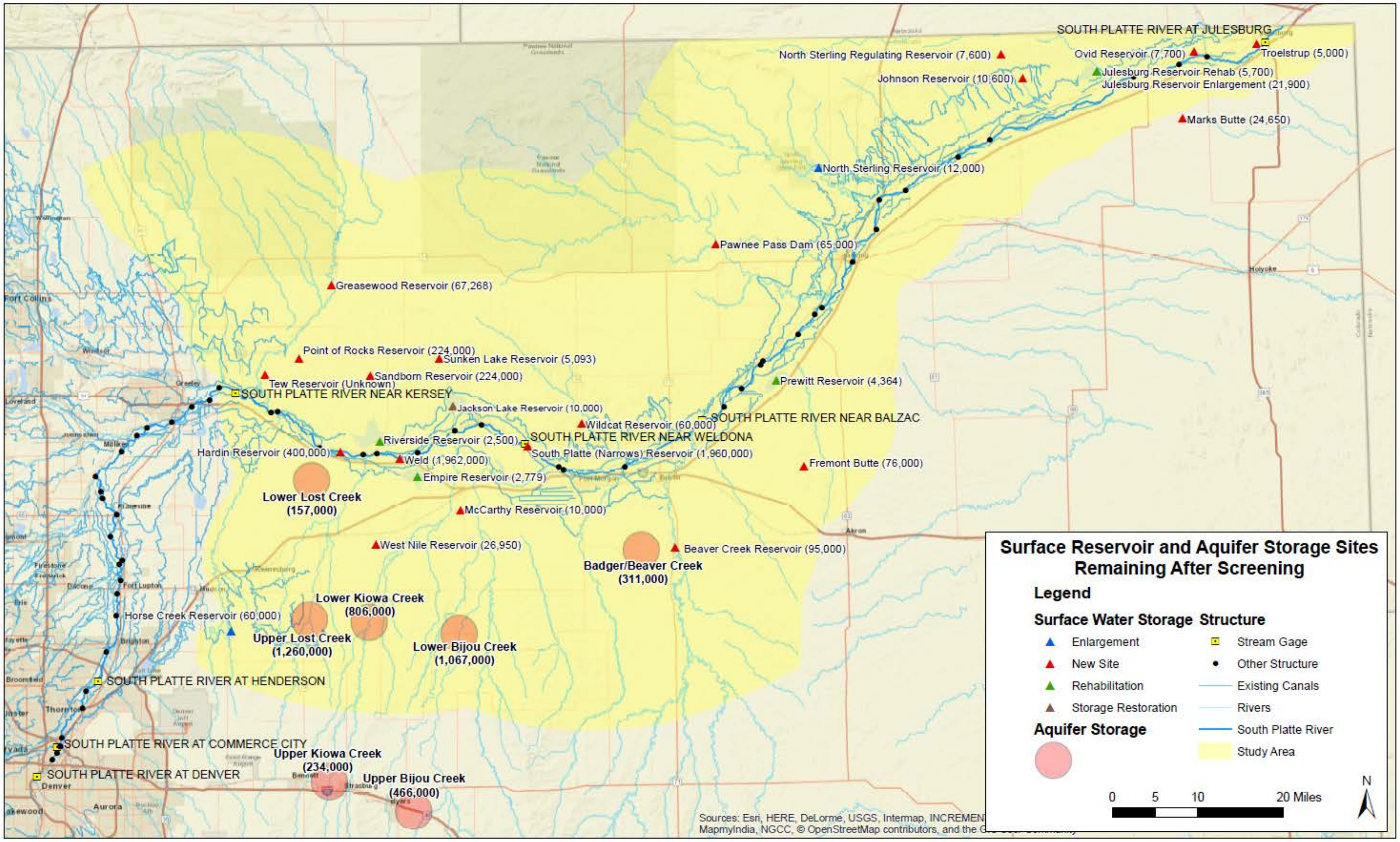


Figure 1-5. Surface Reservoir and Aquifer Storage Sites Remaining After Screening

Table 1-3. Storage Option Costs and Scores

Storage Type/Name	Storage Capacity (ac-ft)	Estimated 2017 Cost ($ million)	Unit Cost ($/ac-ft)	Average of Scores for 3 Weighting Scenarios (1)
New Site - Mainstem				
South Platte (Narrows) Reservoir	1,960,000	$145	$74	11.2
Hardin Reservoir	400,000	-	-	8.7
New Site – Off Chann				
Sandborn Reservoir	224,000	$131	$580	11.0
West Nile Reservoir	26,950	$59	$2,100	8.5
McCarthy Reservoir	10,000	$27	$2,500	9.3
Wildcat Reservoir	60,000	$79	$1,300	14.3
Pawnee Pass Dam	75,000	$254	$3,400	10.7
Fremont Butte Reservoir	76,000	$74	$980	11.2
North Sterling Regulating Reservoir	7,600	$38	$5,000	11.7
Johnson Reservoir	10,600	$24	$2,300	11.7
Ovid Reservoir	7,700	$24	$3,100	10.8
Troelstrup Reservoir	5,000	$19	$3,700	10.8
Beaver Creek Reservoir	95,000	$66	$690	13.2
Point of Rocks Reservoir	224,000	-	-	13.5
Sunken Lake Reservoir	5,100	-	-	10.2
Greasewood Reservoir	67,300	-	-	9.8
Enlargement				
North Sterling Reservoir Enlargement	12,000	$22	$1,800	11.7
Julesburg Reservoir Enlargement	21,900	$44	$2,000	13.7
Rehabilitation				
Empire Reservoir Rehab	2,779	$14	$5,000	16.0
Prewitt Reservoir Rehab	4,364	$5.5	$1,300	14.3
Julesburg Reservoir Rehab	5,700	$31	$5,400	17.8
Jackson Lake Reservoir Rehab	10,000	$37	$3,700	15.2
Riverside Reservoir Rehab	2,500	$13	$5,200	16.0

Storage Type/Name	Storage Capacity (ac-ft)	Estimated 2017 Cost ($ million)	Unit Cost ($/ac-ft)	Average of Scores for 3 Weighting Scenarios (1)
Aquifer Storage				
Lower Lost Creek Basin	157,000	$39	N/A(2)	19.2
Upper Lost Creek Basin	1,260,000	$39	N/A(2)	16.7
Lower Bijou Creek Basin	1,067,000	$39	N/A(2)	17.5
Upper Bijou Creek Basin	466,000	$39	N/A(2)	13.5
Lower Kiowa Creek Basin	806,000	$39	N/A(2)	16.0
Upper Kiowa Creek Basin	234,000	$39	N/A(2)	13.5
Badger/Beaver Creek Basin	311,000	$39	N/A(2)	15.8

(1) Range of possible scores is 0 – 34.
(2) Not applicable. Cost is a function of recharge and extraction hydraulic capacities, not storage capacity.

1.9 STORAGE CONCEPTS

Storage concepts were organized based on the reach of the lower South Platte River in which a storage project would be located, the reach from which water would be diverted, and whether storage would be achieved in a surface reservoir or groundwater basin. Storage concepts consisted of a specific storage option, an approach to capture water from the South Platte River, and an approach to deliver water to meet demands. While hundreds of possible storage concepts could be envisioned in the lower South Platte Basin, eight representative storage concepts were selected to investigate the range of practical storage projects in the region.

Each storage concept was simulated using a MODSIM water resources model developed for this project. To simplify the analysis and focus on differences due to storage options, surface storage concepts had the following consistent features:

- A representative storage option at the maximum physical capacity.
- New dedicated 800 cfs (520 mgd) river diversion with 10,000 ac-ft gravel pit for regulating storage. Although existing irrigation canals could be used to assist in filling some storage options, a detailed analysis of this opportunity was outside the SPSS scope.
- 400 cfs (260 mgd) bi-directional conveyance from intake to storage.
- Release back to river in the bi-directional pipeline to meet downstream demands or exchange to Kersey demand location.
- 150 cfs (100 mgd) conveyance to the Brighton area to meet demands in the Denver metro area.

ASR concepts were limited to a combined inflow rate of 82 cfs (54 mgd) based on the assumed recharge capacity and an outflow rate of 65 cfs (43 mgd) based on the assumed recovery wellfield capacity. All storage concepts were simulated to release water from storage to meet demands as follows.

- First, release to the South Platter River to meet downstream demands.
- Second, exchange to Kersey to meet northern Front Range demands.
- Third, pump to Brighton to meet Denver metro area demands.

No attempt was made in this study to optimize infrastructure or operational assumptions for any of the concepts. The new MODSIM model was used to estimate the firm yield for the eight selected storage concepts. Table 1-4 provides a short description of each storage concept, and the annual firm yield (yield that can be delivered every year) with and without a pipeline to Brighton. This pipeline is an expensive component of any solution so firm yield with and without this component was computed.

Table 1-4. Storage Concept Annual Yield for Maximum Capacity of Representative Storage Sites

Storage Concept	Representative Storage Site(s)	Diversion Reach	Limiting Capacity	Annual Firm Yield with Pipeline to Brighton (ac-ft/yr)	Annual Firm Yield without Pipeline to Brighton (ac-ft/yr)
Surface Reservoir Concepts					
Mainstem Storage	South Platte (Narrows)	Greeley-Weldona	1,960,000 ac-ft	62,000	47,000
Upper Basin Storage	Sandborn	Greeley-Weldona	224,000 ac-ft	22,000	20,000
Mid Basin Storage North	Wildcat	Weldona-Balzac	60,000 ac-ft	9,000	7,000
Mid Basin Storage South	Beaver Creek	Weldona-Balzac	95,000 ac-ft	11,000	8,000
Lower Basin Storage	Julesburg, Ovid, Troelstrup	Balzac-Julesburg	40,300 ac-ft	24,000	24,000
Existing Reservoir Improvements	Riverside, Jackson, Prewitt, Julesburg, North Sterling	Greeley-Weldona Weldona-Balzac Balzac-Julesburg	56,464 ac-ft	17,000	15,000
Aquifer Storage Concepts					
Groundwater Basin Storage West – Recharge Limited	Lower Lost Creek Aquifer	Greeley-Weldona	5,000 ac-ft/month recharge	8,400	8,400
Groundwater Basin Storage East – Recharge Limited	Beaver/Badger Aquifer	Weldona-Balzac	5,000 ac-ft/month recharge	8,000	8,000

Similar to the evaluation of storage options, storage concepts were evaluated for 20 TBL criteria based largely on the criteria listed in HB16-1256, and total costs for all components included in the concepts. Table 1-5 summarizes storage concept costs and TBL scores. Cost estimates include the following assumptions:

- No water treatment costs are included for water delivered to the Brighton or Kersey demand nodes for M&I use.
- Additional infrastructure needed to convey water from Brighton or Kersey to ultimate project beneficiaries is not included.
- All concepts only make use of new diversion structures and intakes. Any potential for use of existing irrigation canals is not considered.
- All concepts include an expensive pipeline and pumping system to Brighton in order to maximize the yield and allow for an even comparison of storage options. Eliminating the pipeline reduces firm yield by 0 to 15,000 ac-ft/yr, and reduces total storage concept cost by $280M - $780M.

Table 1-5. Summary of Storage Concept Costs for Maximum Representative Storage Sites

Storage Concept (Representative Sites)	Storage Capacity (ac-ft)	Storage Cost ($M)	Intake System Cost ($M) (Diversion, Gravel Pits, Pipes, Pump)	Delivery System Cost ($M) (Pipe to Brighton, Kersey Gravel Pits)	Total Storage Concept Cost ($M)	Total Unit Cost ($/AFY Firm Yield)	TBL Score (Range: 0-20)
Surface Reservoir Concepts							
Mainstem Dam (Narrows)	1,960,000	$145	$0	$380	$525	$8,500	11.5
Upper Basin Storage (Sandborn)	224,000	$131	$168	$322	$621	$28,000	12
Mid Basin Storage North (Wildcat)	60,000	$79	$141	$433	$652	$72,000	11
Mid Basin Storage South (Beaver)	95,000	$66	$407	$437	910	$83,000	11
Existing Reservoirs (Riverside, Jackson, Prewitt, Julesburg, North Sterling)	40,300	$121	$221	$322	$662	$39,000	10
Lower Basin Storage (Julesburg, Ovid, Troelstrup)	56,464	$118	$92	$826	$1,037	$43,000	8
Aquifer Storage Concepts							
Groundwater Storage West (Lost Creek) – Recharge Limited	157,000	$39	$238	$158	$435	$52,000	12
Groundwater Storage East (Badger/Beaver) – Recharge Limited	311,000	$39	$160	$270	$469	$59,000	10.5

1.10 CONCLUSIONS AND RECOMMENDATIONS

1.10.1. Conclusions

1.10.1.1 Available Water, Demand and Water Quality

The following conclusions relate to available water in the SPSS study area.

1. A large supply of water is available for beneficial use in the lower South Platte Basin. Between 1996 and 2015, an annual median of approximately 293,000 ac-ft/yr of water was delivered to Nebraska in excess of the South Platte Compact. Excess available water varied between 10,000 ac-ft/yr and 1,904,000 ac-ft/yr over this period.
2. Under future conditions, average annual water available for diversion to a new storage project would vary from approximately 214,000 ac-ft/yr at Kersey to 332,000 ac-ft/yr at Julesburg. Median annual available water would vary from approximately 116,000 ac-ft/yr at Kersey to 232,000 ac-ft/yr at Julesburg, highlighting the influence of a few high runoff years on streamflow statistics in the South Platte Basin.
3. Annual streamflows in the study area are characterized by a few very high flow years. A large mainstem dam or several off-stream dams with large diversion structures would be required to capture a large portion of the available streamflow.
4. Available water at Kersey is much less than at Julesburg due to return flows in the lower basin. A large lower basin reservoir(s) would be required as part of a storage scheme to capture a large portion of available flow upstream of the state line.
5. Because the vast majority of storage options are located off the main South Platte River channel, physically available water is constrained by the diversion capacity and the capacity of conveyance facilities from the river to the storage reservoir. Large diversion and conveyance structures would be needed to capture and convey water from the river to off-channel storage. At the Balzac gage near the middle of the SPSS study area, a diversion capacity of 550 cfs would be needed to capture 85 percent of the available water.
6. Future water shortages in the lower South Platte Basin based on the water supply gap estimated in SWSI 2010 are significant, and exceed the estimated available water in the future. Annual municipal and agricultural demands that could potentially be served by water from a SPSS storage project total over 502,000 ac-ft/yr for the Denver Metro Area, the Northern Front Range Region, and the lower South Platte basin below Greeley.
7. Water quality throughout the SPSS study area is adequate for agricultural use but would require advanced water treatment for direct municipal use.

1.10.1.2 Storage Options and Concepts

Conclusions related to the SPSS analysis of storage opportunities in the lower South Platte Basin are summarized as follows.

1. Many off-channel storage options are feasible and can be combined in a wide variety of water supply concepts.
2. Firm yields of 9,000 ac-ft/yr to 62,000 ac-ft/yr were estimated for the representative storage concepts analyzed for this study.
3. Capital costs for storage concepts range from $7,400 to $78,200/ac-ft/yr, exclusive of treatment costs, with a pipeline to Brighton. Without the pipeline to Brighton the concept costs range from $3,300 to $47,000/ac-ft/yr exclusive of treatment costs. The upper end of this range greatly exceeds the cost of recent water development projects in Colorado.
4. Not surprisingly, a large mainstem reservoir has the best performance in terms of putting the state's water to beneficial use. However, permitting obstacles may be insurmountable.
5. Aquifer storage projects are more limited by recharge and recovery rates rather than storage volume. Typical aquifer storage projects are designed as supplemental supply sources, not as projects to recharge large volumes of water diverted during peak spring snowmelt periods. This results in lower firm yield, and does not attempt maximize use of potential storage capacity as occurs with surface reservoirs. However, a related benefit is that aquifer storage projects are relatively low cost and can be scaled up over time (not constructed all at once). These unique characteristics make aquifer storage projects difficult to compare to surface water storage projects.
6. Storage options lower in the basin tend to be more efficient (better storage:yield ratio) because there is more water available. However they are further from the main demand centers.
7. Combinations of storage options working conjunctively can provide significantly more benefit than individual options. A combination of upper basin and lower basin storage concepts rivals the large mainstem dam option for firm yield benefits. However, there will be reduction in efficiency as the number of projects goes up, and even with multiple storage project a large amount of available water would leave Colorado.
8. No feasible storage concepts or reasonable combinations of concepts are capable of putting all the available flow in the lower South Platte River to beneficial use. This is shown in **Table 1-6**. Therefore as a general principle, more storage will always be "better" in this region in terms of maximizing available supply for basin water users.

Table 1-6. Water Leaving the State under Future Hydrology for Simulated Storage Concepts

Storage Concept	Median Annual Water Leaving State (ac-ft)	Percentage of Available Water Contributing to Beneficial Use (1)
No Storage	249,000	-
Mainstem Storage	150,000	51%
Upper Basin Storage	210,000	19%
Mid Basin Storage North	196,000	21%
Mid Basin Storage South	192,000	22%
Lower Basin Storage	78,000	44%
Existing Reservoir Improvements	100,000	50%
Groundwater Basin Storage West	213,000(2)	18%
Groundwater Basin Storage East	196,000(2)	21%

(1) Includes evaporation losses and other losses which would not be beneficial uses
(2) Assumes maximum size to capture peak spring runoff. Actual projects would be smaller and leave more water at the state line.

9. Because nearly all concepts require off-channel storage and diversion from the South Platte River, intake capacity constraints can be important and there are benefits to having multiple off-channel storage projects to minimize the effects of these constraints.
10. Enlargements and rehabilitations of existing reservoirs tend to score higher than new reservoirs in the multi-criteria ranking process.
11. Triple bottom line scores for the storage sites analyzed in this study were fairly similar at this level of analysis without specific information on how the sites would be used in a water supply strategy; thus the triple bottom line scoring process should not be used to eliminate options at this time.
12. Any of the storage concepts could be candidates for further study in the future under the right circumstances. However, concepts with more storage higher in the basin generally offer a greater potential for benefits and could be more attractive to a broader variety of potential participants.
13. Multiple large storage projects, including one low in the basin, would be required to capture a substantial amount of the available water above the state line.
14. Even a combination of conjunctively operated storage projects would not be capable of addressing the majority of the combined overall M&I and agricultural water supply gaps in the South Platte Basin.

1.10.2. Recommendations

The SPSS team developed the following recommendations for future work.

1. Better estimates of future hydrology should be developed to refine the anticipated available water under future basin operations. Completion of the South Platte Decision Support System would facilitate further hydrologic and operational studies.
2. Exchanges will be important to making storage work cost effectively for many applications. A more robust method of estimating future exchange potential may be needed to refine this important aspect of the analysis.
3. Site-specific and owner-specific analyses will be needed when particular project opportunities are identified in the future. The work in the SPSS is a starting point for more specific alternative investigations, but substantial additional analysis will be required to test the feasibility of specific storage options based on points of diversion, intake systems, and methods of operating to meet demands.
4. Aquifer storage and recovery projects will require site specific aquifer characterization and pilot testing. Pilot testing and preliminary design can begin at a relatively low cost due to the scalability of ASR systems.
5. Using existing irrigation canals to fill storage sites could significantly reduce infrastructure costs for some concepts. Partnerships with irrigation companies and available canal capacities should be investigated further.
6. Cooperative storage projects with multiple users, multiple components and multiple purposes would have the best chance of success. The state, Roundtables and water users should continue to explore opportunities for cooperative multi-use storage projects in the lower South Platte Basin.
7. Gravel pit storage opportunities were not considered in detail in this study. Gravel pits have been used extensively for storage along the South Platte River upstream of Greeley. An investigation of gravel pit storage opportunities downstream of Greeley may be warranted.
8. Use of water from SPSS storage projects directly for M&I use would require advanced water treatment. Recharge into aquifer storage would also require treatment. Additional investigation is required into the feasibility of available advanced treatment processes on water quality from the study area, particularly in the further downstream reaches of the South Platte River.
9. Investigation is warranted into how storage could support future implementation of alternative transfer method (ATM) projects per recommendations in the South Platte Basin Implementation Plan. Most or even all ATM project would need storage to increase yield and project efficiency. Investigation is needed into how new storage projects could be utilized in combination with ATMs to efficiently store and deliver available water as well as water provided from ATM projects. This combination could potentially make both new storage and ATM projects more feasible and help meet the water supply gaps in the basin.
10. Future storage projects would have an impact on Colorado's water obligation to the PRRIP. Membership in SPWAP in addition to coordination with the State of

Colorado and SPWAP would be necessary to comply with all PRRIP mitigation requirements for new South Platte water storage projects. Further investigation into SPWRAP effects of new storage projects is recommended.

11. This study did not simulate conjunctive operation of a large surface storage project with an ASR project. Benefits of conjunctive use should be investigated.
12. This study did not evaluate potential supplies or storage opportunities upstream of Kersey on the South Platte River or Poudre River. Extending the water availability study and the investigation of potential storage options upstream of Kersey on the South Platte River and Cache la Poudre River should be considered.

2. INTRODUCTION

The South Platte Storage Study (SPSS) was initiated as a result of House Bill 16-1256 titled "South Platte Storage Study." HB16-1256, provided in **Appendix A**, was signed into law by the Governor on June 9th, 2016. It authorizes the Colorado Water Conservation Board (CWCB), in collaboration with the State Engineer (SEO) and the South Platte Basin and Metro Roundtables, to identify multi-purpose water storage options along the lower South Platte River to capture flows leaving the state in excess of the minimum legally required amounts. The study area for identifying storage options was the lower South Platte Basin between Greeley and the state line. The study area is shown in **Figure 2-1**. Water storage possibilities include new reservoirs, the enlargement/rehabilitation of existing reservoirs, and alternative storage mechanisms (e.g., underground storage).

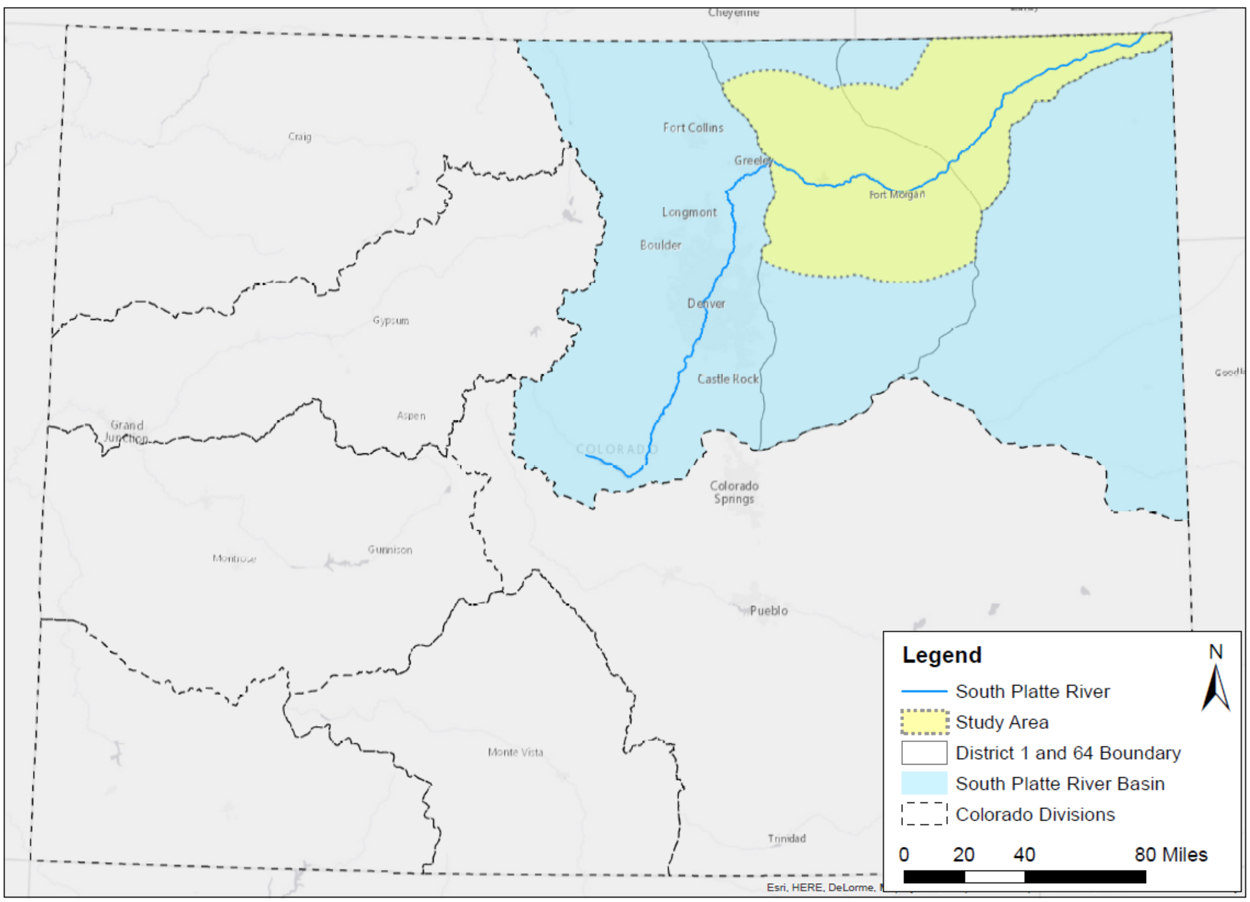


Figure 2-1. Study Area for South Platte Storage Study

This report presents a summary of the analysis and results of the SPSS. Detailed descriptions of technical approaches and preliminary results for specific topics were provided in technical memoranda (TM) during the course of the project. These TMs are included as appendices to this report. The study approach is summarized in **Figure 2-2**.

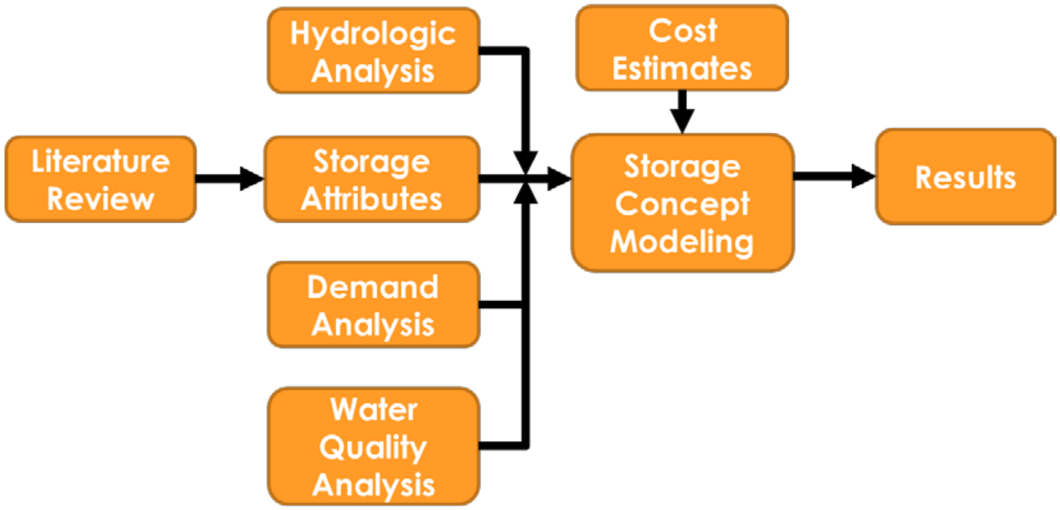


Figure 2-2. South Platte Storage Study Approach

Study methods and preliminary results were reviewed by and coordinated with representatives of the Colorado Water Conservation Board (CWCB), Colorado Division of Water Resources (CDWR), and the South Platte Basin and Metro Roundtables. Three workshops were held with representatives of these groups to present preliminary findings and receive direction on future tasks. They also provided reviews of draft technical memoranda and the final project report.

The SPSS study was conducted by Stantec Consulting Services Inc., with support from Leonard Rice Engineers, Inc. Funding for the study was provided from the Colorado Water Conservation Board Water Supply Reserve Fund.

3. PREVIOUS STUDIES

3.1 INTRODUCTION

Storage opportunities in the South Platte Basin have been studied by a variety of different agencies, including the state and individual water users. Some of these past studies sought to address broad regional water needs (e.g., the South Platte Basin Implementation Plan (HDR/West Sage, 2015)), while others were conducted by individual water users to meet their own storage needs. In some cases, those storage opportunities were part of water users' long term plans and are included in Colorado's Water Plan (CWCB, 2015) as Identified Projects and Processes (IPPs). In other cases, storage opportunities were ruled out by the water user that studied them because they did not meet the needs of the water user. These storage opportunities previously ruled out have been included herein because they could be an opportunity for others.

3.2 SOURCES OF INFORMATION

The sources of information reviewed for this study are listed in **Appendix B**. Pertinent information for storage sites was extracted from a variety of reports and databases. Reports covering areas throughout the basin were reviewed, but the emphasis was on storage options in the designated SPSS study area between Greeley and the state line.

3.3 STORAGE SITE CLASSIFICATION

Storage sites found in the literature review were separated into three main categories: surface storage sites, aquifer storage sites, and gravel pit sites. Gravel pit storage was separated from the surface storage category because it was treated differently in this study, as described below. For the purpose of this study, gravel pit storage was evaluated based on general geographic location, not as individual sites.

3.3.1. Surface Storage Sites

Surface storage sites were classified into four sub-categories to help identify opportunities for this project. Sub-categories for surface storage opportunities were enlargements of existing reservoirs, identified new reservoir sites, existing reservoirs with rehabilitation potential, and existing reservoirs with storage restoration potential. These categories are defined in **Table 2-3**.

Storage sites identified as IPPs in Colorado's Water Plan are included in the inventory. Although the water users promoting these IPPs may be planning to use all the potential storage capacity, there may be opportunities for further enlargements of these reservoirs to incorporate the needs of additional partners. Additional analysis will need to be performed to determine if IPP sites can potentially be enlarged for use by others.

Storage projects identified in other studies that were screened out for that project purpose could still be feasible for this study and were included in the inventory.

Table 2-3. Surface Storage Category Definitions

Category	Description
Enlargement	This group includes existing reservoirs that have been previously studied to determine feasibility of an enlargement. If available, information such as enlarged capacity and enlargement feasibility from previous enlargement studies was captured for use in this investigation.
New Site	These are sites where a new surface storage facility could be feasible. Information such as potential reservoir capacity and feasibility from previous studies is usually available.
Rehabilitation	These sites are existing reservoirs that have a storage restriction imposed by the State of Colorado Dam Safety Branch. By rehabilitating the dams at these locations, the storage restrictions could be removed and additional storage would then become available.
Storage Restoration	Sites in this category include existing reservoirs that have reduced storage capacity due to sedimentation. Storage capacity at these sites could be recovered by dredging the sediment and disposing it.

3.3.2. Aquifer Storage Sites

This group of storage sites includes options that use deep confined or shallow unconfined aquifers to store water. For this summary these sites are represented by a single point on a map, but in reality aquifer storage could occur over a broad area in the aquifer porous space underground. These options require points of recharge and extraction that were analyzed when formulating the storage concepts.

3.3.3. Gravel Pit Storage

Gravel pit storage sites were separated from the surface water storage category because they were treated differently than the larger surface reservoir options in this study. The individual gravel pit storage options are small and were not considered for long term storage on their own; however, groups of individual gravel pits in the same general area could be combined into a larger storage complex that could provide sufficient capacity to meet the needs of this study. In addition, these sites may be used to support other storage solutions, for example by providing temporary storage to hold exchange water until it can be exchanged further upstream. For purposes of this storage site inventory, gravel pit locations were mapped separately from other surface reservoir options so locations of possible gravel pit complexes could be considered later in the project.

3.4 SUMMARY OF REVIEWED STORAGE SITES

The potential surface storage sites in the South Platte River Basin cataloged in this literature review are listed in **Appendix B**.

Figure 3-1 shows potential new, enlarged, rehabilitated and restored surface storage sites in the SPSS study area. **Figure 3-2** shows cataloged aquifer storage options for the SPSS study area. Locations indicated on the map are representative of the general aquifer locations; aquifer spatial boundaries are not depicted. **Figure 3-3** shows active permitted sand, gravel, sand and gravel, or construction borrow material mines in the SPSS study area that could be developed as gravel pit storage.

A total of 73 surface storage options (excluding gravel pits) and 22 aquifer storage options were found in the SPSS study area through the Literature Review. Individual surface storage options in the study area vary from 3 ac-ft to 1,962,000 ac-ft of additional storage capacity, and include sites on the South Platte mainstem, on primary tributaries, and in tributary drainage areas. The inventory includes:

- 62 new reservoir sites
- 6 existing reservoir enlargements
- 4 existing reservoir rehabilitations
- 1 existing reservoir restoration
- 22 aquifer storage options
- 55 permitted gravel mining sites

Some of these options are similar (e.g., different nearby reservoir sites on the same tributary) and were filtered into a single option during the storage site evaluation.

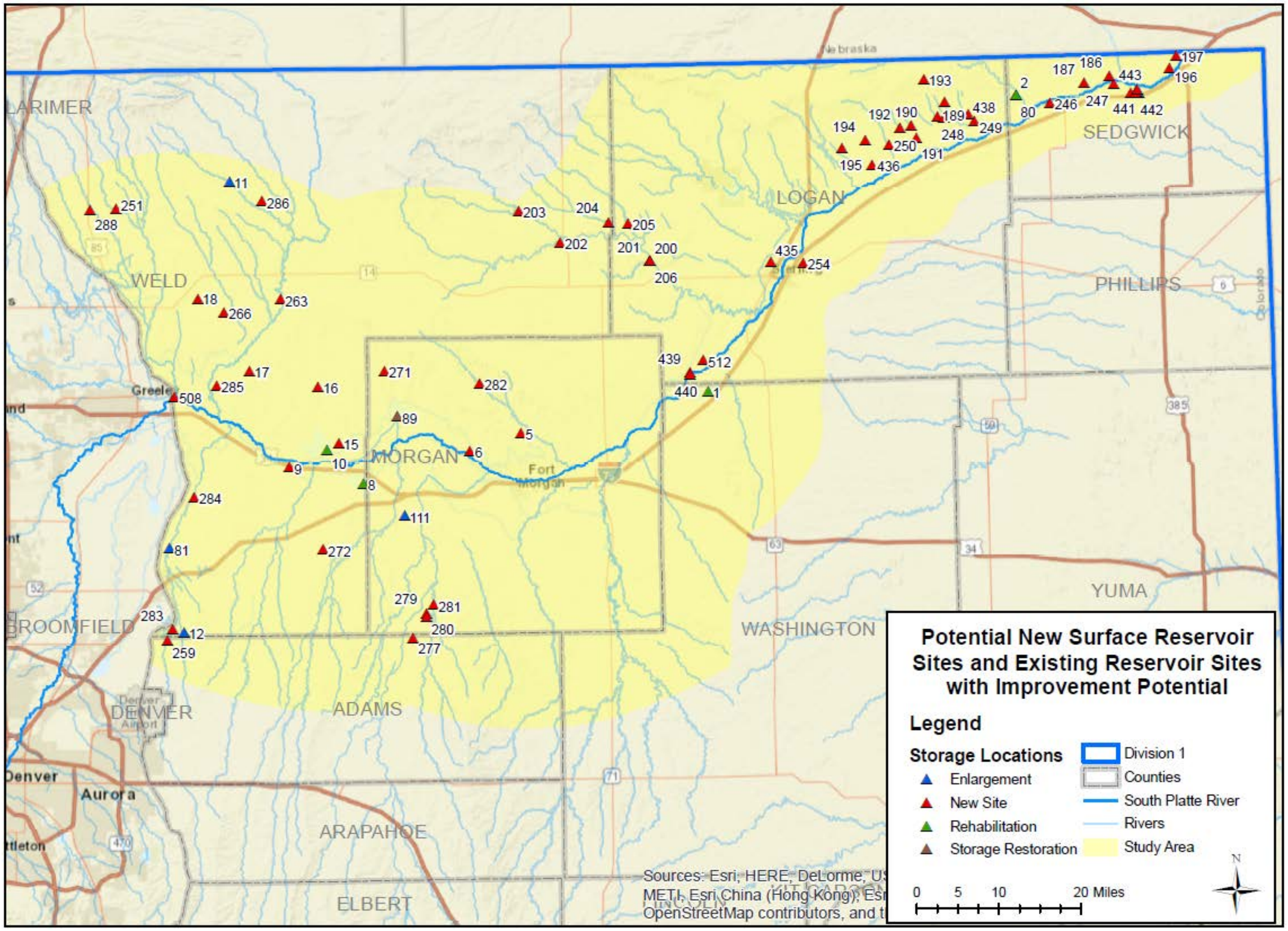


Figure 3-1. Cataloged Sites Where New Surface Storage Could be Developed in the Study Area

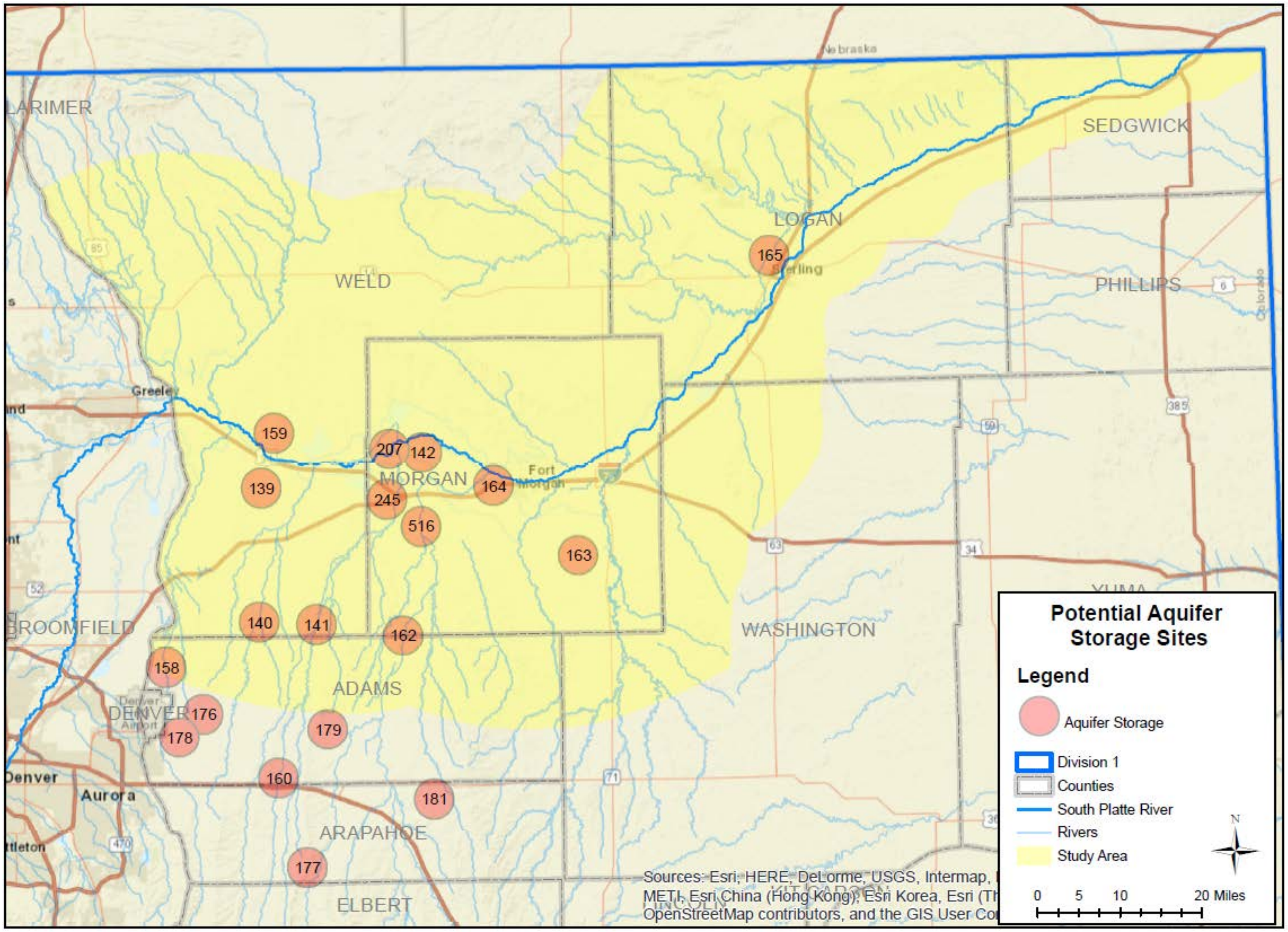


Figure 3-2. Cataloged Aquifer Storage Sites in or Near the Study Area

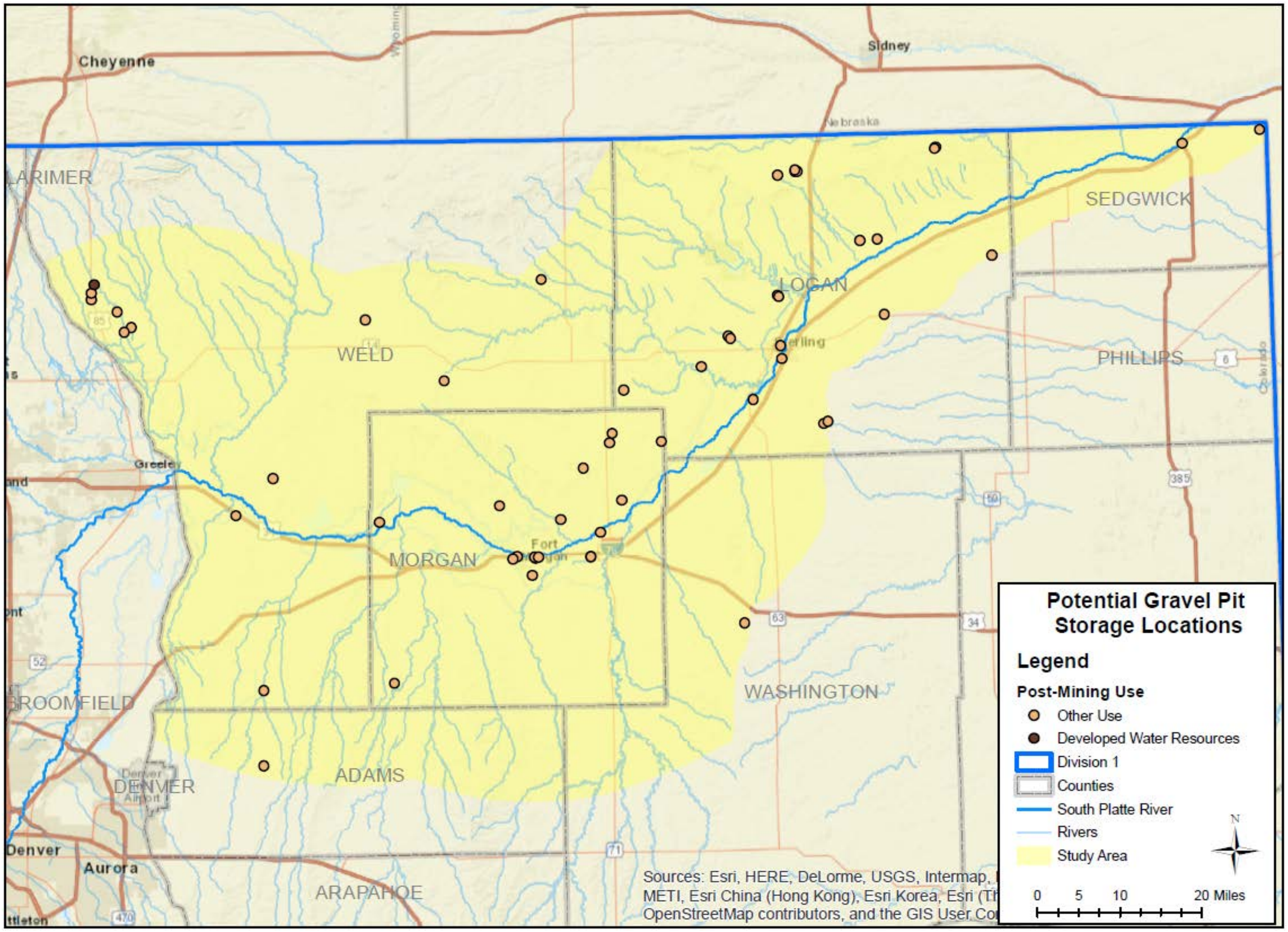


Figure 3-3. Potential Gravel Pit Storage Sites in the Study Area

4. LEGAL AND REGULATORY OVERVIEW

A review was performed of legal and regulatory factors affecting planning and implementation of potential water storage projects in the South Platte Basin. The review focused on how federal, state and local laws and regulations influence SPSS planning. Results are presented in detail in **Appendix C** and summarized below.

4.1 FEDERAL LAWS AND REGULATIONS

National Environmental Policy Act (NEPA) – NEPA requires environmental impact review and mitigation for projects involving a federal action. Several types of activities associated with development of storage projects can require federal actions triggering review under NEPA. These include the U.S. Army Corps of Engineers (USACE) issuing a 404 permit (see below); impacts to federally-listed threatened or endangered species requiring action by the U.S. Fish and Wildlife Service (USFWS); constructing projects on federal lands such as those managed by Bureau of Land Management (BLM) or the U.S. Forest Service (USFS); and connecting to federally owned facilities. An EIS can have significant impacts on project implementation schedule and budget, and in some extreme cases can render a project infeasible due to the inability to receive required federal permits.

Endangered Species Act (ESA) and Section 7 Consultation – Projects with a federal nexus require review for compliance with the ESA. Federal actions resulting in depletions to flows in the Platte River system are likely to jeopardize the continued existence of one or more federally-listed threatened or endangered species and adversely modify critical habitat. Analysis and mitigation of impacts would be required.

Platte River Recovery Implementation Program (PRRIP) – The PRRIP is a cooperative program between Colorado, Wyoming, Nebraska and the U.S. Department of Interior to provide streamlined ESA compliance for impacts of depletions in the Platte River Basin. In Colorado the South Platte Water Related Activities Program, Inc. (SPWRAP) is responsible for the operational costs of projects providing supplemental streamflows at the state line. SPWRAP would not cover a mainstem reservoir over 2,000 ac-ft, significantly complicating environmental permitting of a mainstem dam alternative.

Clean Water Act/Section 404 – Section 404 of the Clean Water Act regulates placement of dredge and fill material in waters of the US. The South Platte River and its tributaries are waters of the US, and construction of new dams or diversion structures on these water bodies would require 404 permits. The 404 review process triggers NEPA and ESA compliance as well as requiring its own permit review and mitigation.

National Historic Preservation Act – Archaeological and cultural surveys and management plans would be required for storage locations and other infrastructure.

South Platte River Compact – The Compact sets a minimum flow target at the Interstate Station (Julesburg gage) of 120 cfs between April 1 and October 15. This effectively limits new diversions in Water District 64 in this period such that a minimum of 120 cfs is left in the river.

4.2 STATE LAWS AND REGULATIONS

Water Right Determination and Administration Act – Water storage and diversion rights for a new SPSS project would have to be adjudicated per Colorado's water rights system.

Colorado Department of Public Health and Environment (CDPHE) – The CDPHE Water Quality Control Division would require compliance with Section 401 of the Clean Water Act prohibiting degradation of the state's water quality. This would involve an anti-degradation review and 401 certification from CDPHE.

Colorado Groundwater Management Act – This act regulates management of groundwater basins that could be used for groundwater storage in the South Platte Basin. Specific regulations apply to the designated basins considered for aquifer storage and recovery in the SPSS. Groundwater management policies require that aquifer storage projects not recharge or inject water that would degrade the water quality of the aquifer.

4.3 LOCAL

1041 Regulations - 1041 regulations allow local governments to describe and designate areas and activities which may be of state interest and encourages local governments to establish criteria for the administration of these areas and activities. 1041 regulations allow local governments to put permit conditions on water projects including reservoirs and pipelines. Local governments located within the SPSS study area known to have 1041 regulations in place include Adams County, Larimer County, Morgan County, and Weld County. A state or local government may choose to adopt 1041 regulations and guidelines for administration of matters of state interest at any time.

A host of other local regulations related to construction and floodplain administration would apply to water infrastructure projects such as those considered for the SPSS.

4.4 SUMMARY OF KEY LEGAL AND REGULATORY EFFECTS

Legal and regulatory issues could affect the feasibility of storage options in the SPSS study area in the following key ways.

- Environmental permitting for on-channel reservoirs would be extremely difficult, particularly for reservoirs on the mainstem of the South Platte River. Past permitting efforts for a mainstem dam at the Narrows site were unsuccessful, and environmental regulations and policies are more challenging now than they were then. Permitting obstacles may be a fatal flow for mainstem storage options.

- Compatibility with the PRRIP and SPWRAP would greatly simplify regulatory compliance for any new storage project. Off-channel dams could be covered under these programs but not mainstem dams.
- Federal and state environmental compliance would be a significant cost and schedule driver for any new storage project.
- Cooperative, multi-purpose projects that have support of and create partnerships between local, state and federal agencies would be more likely to receive the necessary regulatory approvals.

5. HISTORICAL FLOW ANALYSIS

5.1 INTRODUCTION

HB 16-1256 included a requirement to determine historical flow that could have been captured and stored in the South Platte River at the state line. Specifically, the Bill states:

"The Board, in collaboration with the State Engineer, shall conduct or commission a hydrology study of the South Platte River Basin to estimate, for each of the previous twenty years, the volume of water that:

i. Has been delivered to Nebraska in excess of the amount required to be delivered by the South Platte River Compact, Article 65 of this title; and

ii. Could have otherwise been stored in the Lower South Platte River Basin."

The South Platte Point Flow Model (PFM) was used to complete those two tasks. The PFM evaluates the historical daily flow passing structures on the mainstem of the South Platte River between the Burlington Ditch diversion (Henderson area) and the Nebraska State line based on hydrologic data, diversion records and reconstructed call records using a detailed point flow modeling approach. The point flow analysis calculates ungaged gains and losses between measured points by simple mass balance and estimates physical flow at 62 points along the river by redistributing the gains and losses according to their spatial distribution. The model does not account for existing conditional water rights that could be used more fully in the future as they are perfected nor does it consider unused reusable return flows that might be utilized in the future. The version of the PFM used in the South Platte Basin Implementation Plan was updated for this study to include a 20-year period of daily flow records from 1996 to 2015 (water years). Details of the PFM update process are provided in the "South Platte River Hydrologic Analysis TM" in **Appendix E**. Results of the historical flow analysis were presented previously in "Summary of South Platte River Historical Flow Leaving the State and Storable Water," which is provided in **Appendix D**.

5.2 FINDINGS

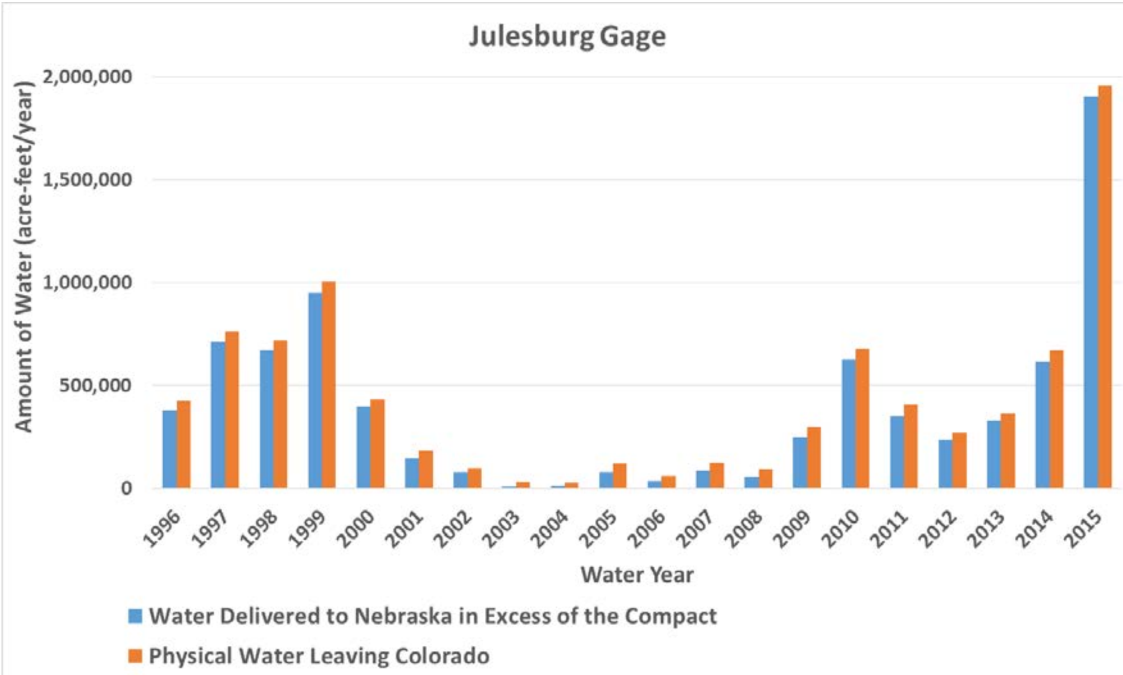
Flow records and Point Flow Model results were analyzed at the South Platte River at Julesburg stream gage near the Nebraska State line to estimate: (1) physical flow in the river; and (2) water that could have been legally stored subject to South Platte River Compact requirements (referred to herein as "storable flow" or "available water"). Storable flow is the maximum potential water that could have been stored by a reservoir on the mainstem of the South Platte River. Storable flow in an off-channel reservoir that would depend on diversions and conveyance facilities similar to the current lower basin reservoirs and irrigation canals would be significantly less.

Figure 5-1 displays annual historical flow for the 20 years from 1996 to 2015 that was delivered to Nebraska. It shows the physical flow in the river ("Water Leaving Colorado"), and the water leaving the state that could have been physically and legally stored or put to beneficial use in Colorado ("Water Delivered to Nebraska in Excess of the Compact"). It is noted that legally available flow does not account for possible environmental flow obligations for mitigation of future Colorado water development projects, so actual available flow may be less than described in this section. Figure 5-1 shows that physical and storable flow vary significantly from year to year. Table 5-1 gives selected statistics for physical flow leaving the state and storable flow at the Julesburg gage for the 20-year period from 1996 to 2015. The large difference between the median and average statistics shows the effect of a few high flow years in the study period.

Table 5-1. Historical Annual Flow for 1996-2015 at Nebraska State Line

Statistic	Physical Water Leaving Colorado (Julesburg Gage)	Water Delivered to Nebraska in Excess of the Compact (1)(2)
Annual Median (ac-ft/yr)	331,000	293,000
Annual Average (ac-ft/yr)	436,000	397,000
Minimum Year (ac-ft/yr)	29,000	10,000
Maximum Year (ac-ft/yr)	1,957,000	1,904,000
Total for 20-yr Period 1996-2015 (ac-ft)	8,728,000	7,939,000

(1) Storable flow Julesburg gage
(2) Future environmental flow obligations could reduce legally available water.



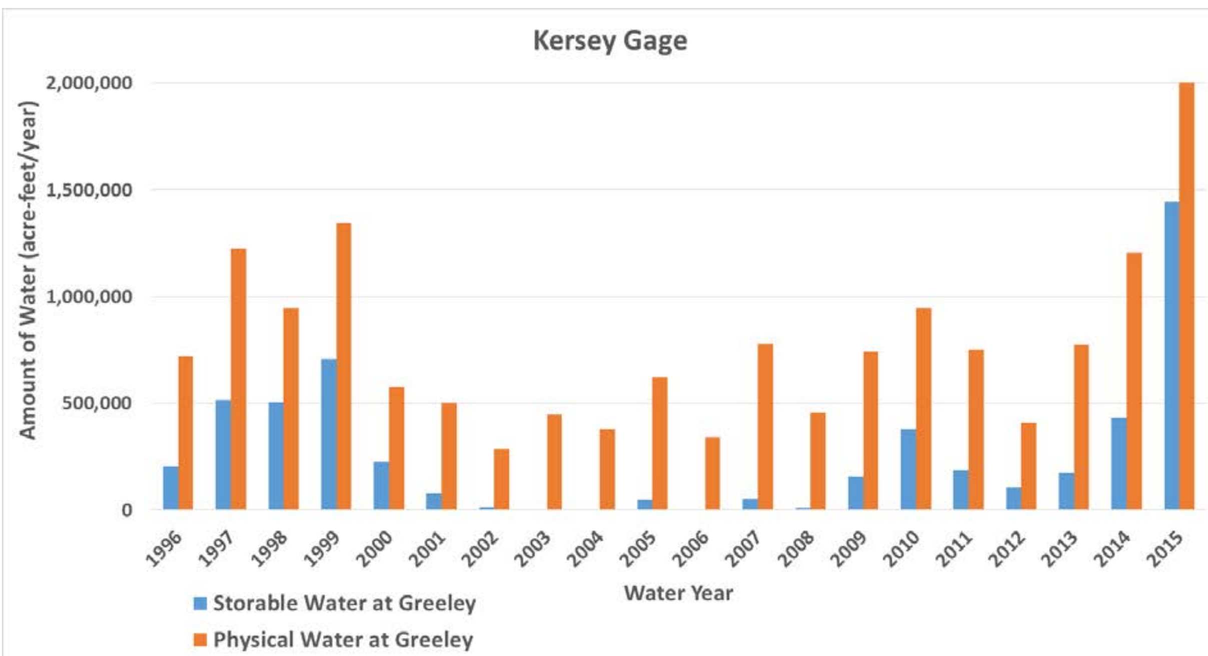
Note: Future environmental flow obligations could reduce legally available water.

Figure 5-1. South Platte River Water Delivered to Nebraska (Julesburg Gage), 1996-2015

Figure 5-2 displays the annual physical flow and storable flow at the South Platte River at Kersey stream gage from 1996 to 2015. **Table 5-2** summarizes statistics for this data. This location is below the confluence of the South Platte River and the Cache la Poudre River in Greeley, and is the upstream end of the Lower South Platte River Basin as defined in the South Platte Storage Study. As with the analysis at the Julesburg gage, storable flow is the maximum potential storable flow assuming a mainstem reservoir that could capture all available water. Although physical flow in the river at Kersey is larger than at the state line due to the lack of major downstream tributaries and the significant diversions for lower South Platte Basin water users, storable flow is a smaller percentage of total flow at the Kersey gage compared to storable flow at the Julesburg gage because of the need to satisfy downstream water rights within Colorado. As with the analysis at the Julesburg gage, potential future environmental flow obligations are not accounted for in the estimate of storable water at Greeley.

Table 5-2. Historical Annual Flow for 1996-2015 at Greeley

Statistic	Physical Water at Greeley (Kersey Gage) (ac-ft/yr)	Storable Water at Greeley (Kersey Gage) (ac-ft/yr)
Annual Median	732,000	165,000
Annual Average	773,000	262,000
Minimum Year	285,000	0
Maximum Year	2,001,000	1,447,000



Note: Future environmental flow obligations could reduce legally available water.

Figure 5-2. Physical and Storable Flow at Greeley (Kersey Gage), 1996-2015

6. AVAILABLE WATER FOR STORAGE

6.1 INTRODUCTION

This section describes the analysis of water legally and physically available for storage in the lower South Platte River basin under future conditions. It represents water that could be stored in a mainstem dam or diverted from the mainstem for off-channel storage. The analysis was based on adjustments to the historical PFM described previously. Adjustments were made to estimate approximate storable flows under possible future hydrologic conditions based on discounting factors such as conditional water rights and the implementation of IPPs identified in Colorado's Water Plan.

Methods and results of the available water analysis are presented in detail in the "South Platte River Hydrologic Analysis TM" in **Appendix E**.

6.2 HISTORICAL HYDROLOGIC ANALYSIS AND RESULTS

Available water for the historical period 1996 to 2015 was calculated for all locations in the PFM by the following steps.

1. Daily historical flow that did not have a calling water right (available flow greater than 0), was reduced by the bypass flow required to satisfy downstream uses. With input from Division 1 staff, bypass flows in **Table 6-1** were adopted as reasonable estimates of the requirements.

Table 6-1. Bypass Flows Applied to Available Water Analysis

Month	Burlington to Upstream of St. Vrain Creek (cfs)	Downstream of St. Vrain Creek to Riverside Canal (cfs)	Bijou Canal to State Line (cfs)
April - October	15	20	10
November - March	15	10	5

2. The South Platte River Compact requires flow at the state line to be 120 cubic feet per second (cfs) (238 ac-ft/day) or greater between April 1 and October 15. The available flow at the state line and at points throughout District 64 was reduced by 120 cfs during these dates. The Compact affects available flows in District 64 only.

3. Available water calculations were reduced by historically unused reusable return flows. These values were obtained from Aurora Water and Denver Water. It was assumed that both entities would reclaim all their reusable water supplies in the future and thus this water would not be available for downstream storage.

4. Available flow at any point along the South Platte River is affected by downstream water rights that must be satisfied. Sufficient water must be left in the river at any point to meet all downstream water rights and delivery obligations, including the South Platte River Compact.

Available water was compared between wet years, normal years, and dry years. Water year 1999 was chosen as a representative wet year, water year 2002 was chosen as a representative dry year, and water year 2010 was chosen as a representative normal year. For seasonal evaluations, February was chosen to be representative of the winter season, June was chosen to be representative of the runoff season, and August was chosen to be representative of the irrigation season.

Additionally, five locations along the South Platte River were chosen for further analysis. Four locations - South Platte River at Kersey, South Platte River at Weldona, South Platte River near Balzac, and South Platte River near Julesburg – are stream gage locations. The fifth location is the Lowline Ditch/Henderson Smith Ditch diversion, which is representative of flow in the river at Sterling. **Figure 6-1** shows these five points and their locations within the SPSS study area.

Figure 6-2 shows historical average daily available water at all points in the Point Flow Model based on hydrologic year type. Available water increases in the downstream direction for all year types.

Table 6-2 shows the average and median annual available water for the 1996-2015 historical period for the selected locations. The average annual available water is given as an average of all years and for a representative wet, normal, and dry year, and the median annual available water is given for all years. The significant differences between available water in wet and dry years and the significant differences between average and median statistics indicate the great variability in available water from year to year based on hydrologic conditions. These differences point to the value of storage in meeting regional demands from South Platte River flows, but also suggest that large storage capacities would be needed to generate substantial sustained yield from storage.

Figure 6-3 and **Figure 6-4** are exceedance plots that show the percentage of time a given magnitude of available flow is equaled or exceeded in the Point Flow Model period of record for historical conditions. A daily flow exceedance plot for the Julesburg gage is shown in **Figure 6-3** , and an annual flow exceedance plot is shown in **Figure 6-4**. **Figure 6-3** shows the extreme variability in available water across the PFM period of record. On roughly half the days there is no available water at Julesburg. **Figure 6-4** shows that annual available water varies widely during the PFM period, with some years producing almost no available water. The average monthly physical flow is shown in **Figure 6-5**, which demonstrates the strong seasonality of South Platte flows.

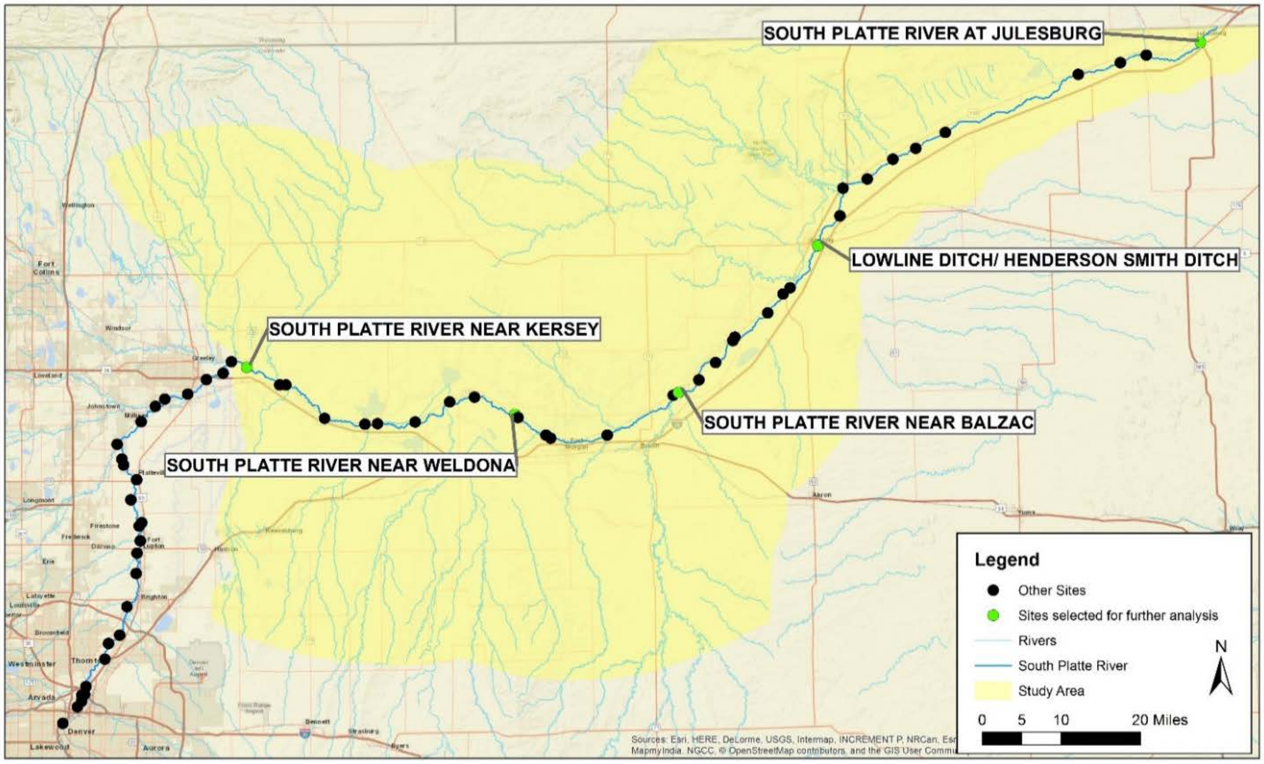


Figure 6-1. Selected Locations for Additional Analysis

Table 6-2. Annual Available Water for Selected Locations Based on Historical Hydrology

Location	Median Annual Available Water (ac-ft)	Average Annual Available Water (ac-ft)	Available Water in Wet Year (ac-ft)	Available Water in Normal Year (ac-ft)	Available Water in Dry Year (ac-ft)
	All Years	All Years	1999	2010	2002
South Platte River near Kersey	165,000	262,000	707,000	378,000	14,000
South Platte River near Weldona	179,000	281,000	731,000	411,000	18,000
South Platte River near Balzac	185,000	297,000	771,000	440,000	18,000
Lowline Ditch/ Henderson Smith Ditch	200,000	314,000	799,000	476,000	33,000
South Platte River at Julesburg	289,000	397,000	951,000	627,000	79,000

Notes: Based on 1996-2015 historical streamflows and river operations, adjusted to remove Denver Water and Aurora Water reusable return flows and account for all existing water rights and South Platte River Compact obligations. Available water" is water physically and legally available to be diverted to a new water supply project like SPSS.

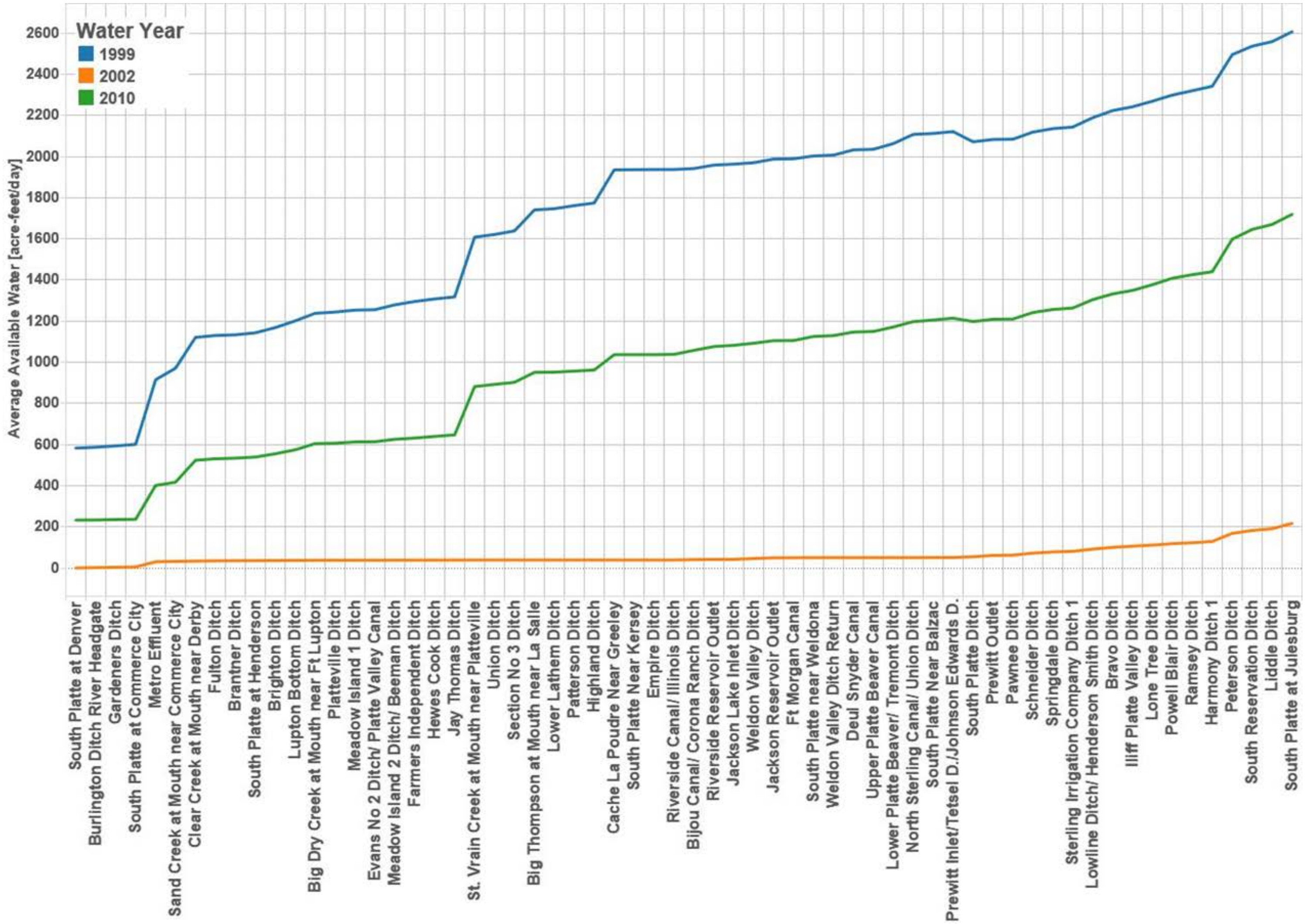


Figure 6-2. Historical Daily Average Available Water for Representative Wet, Normal, and Dry Years

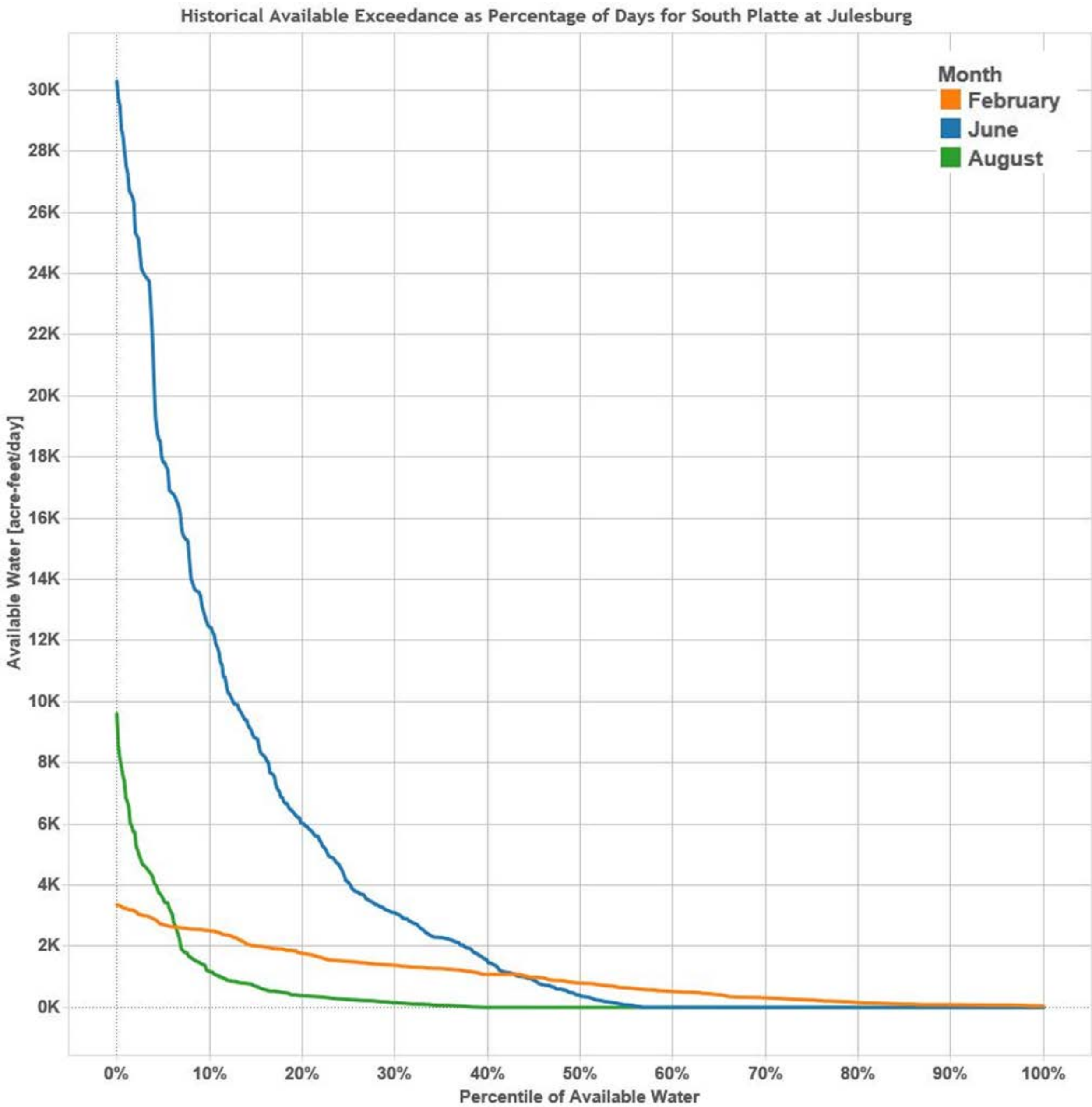


Figure 6-3. Historical Daily Available Water Exceedance for Representative Months, South Platte at Julesburg

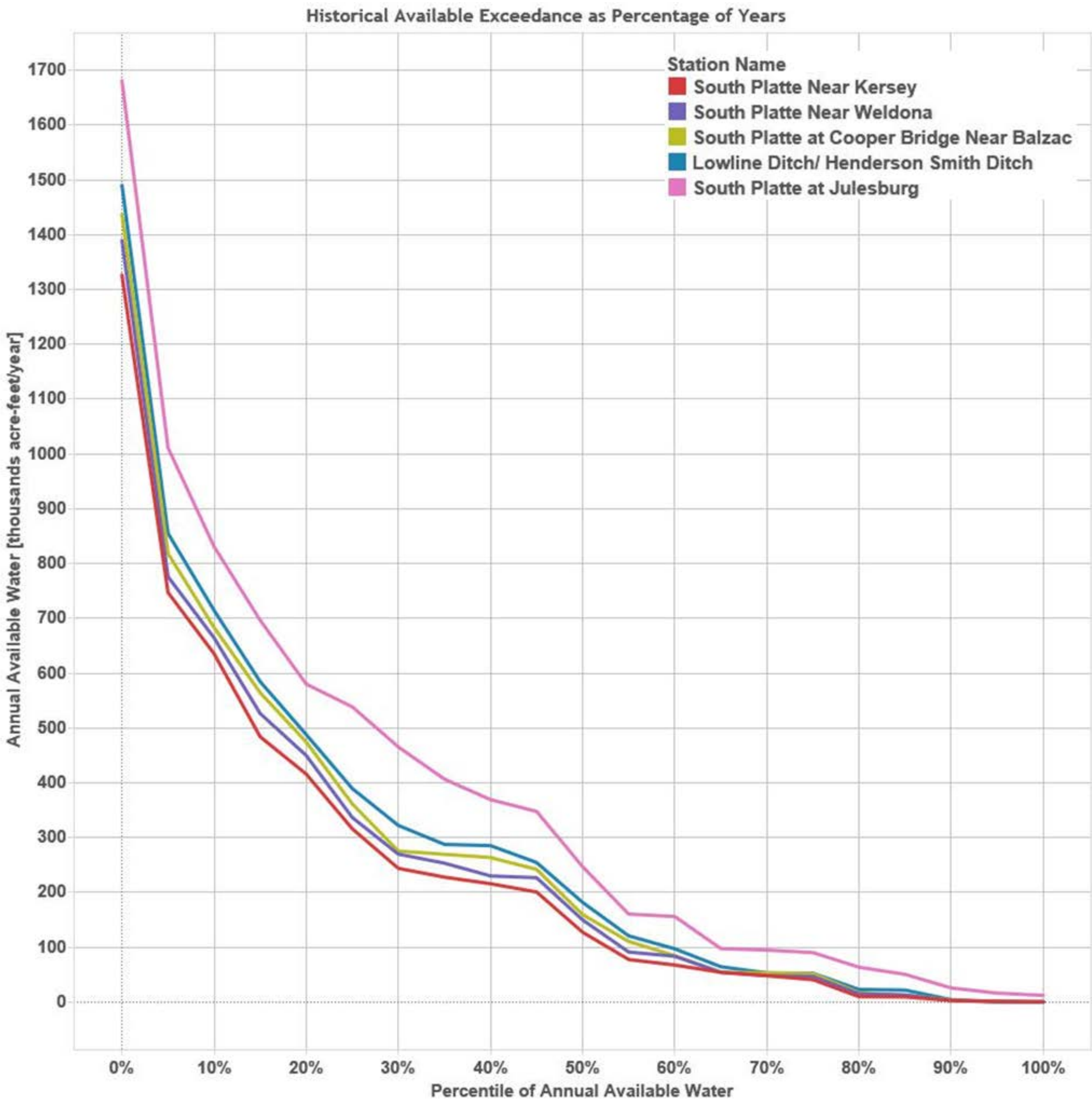


Figure 6-4. Historical Annual Available Water Exceedance at Five Key Locations

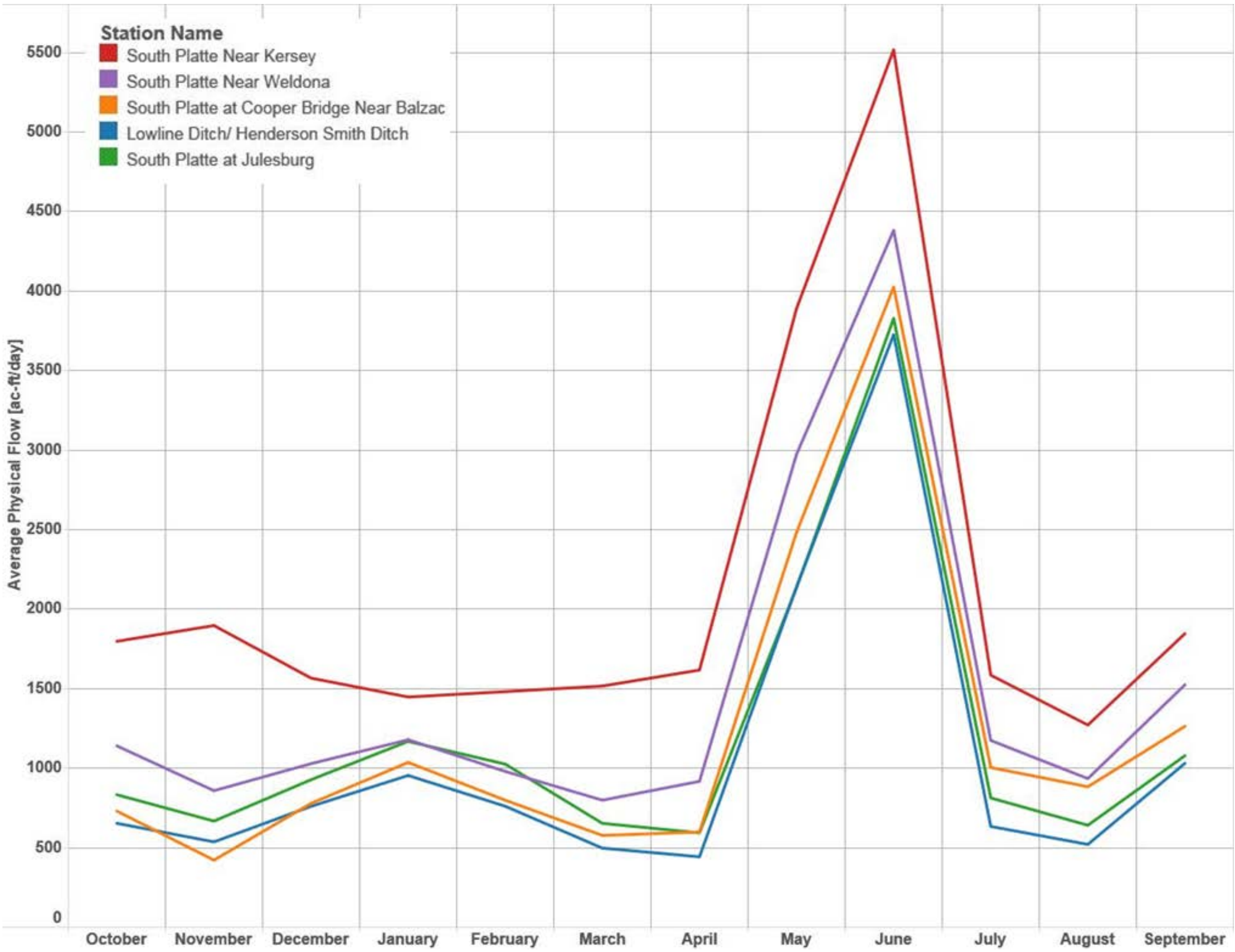


Figure 6-5. Average Monthly Physical Flows

6.3 FUTURE HYDROLOGIC ANALYSIS AND RESULTS

HB 16-1256 specified that this storage study should be based on historical hydrology to answer the question, "How much water could we have stored in recent years if storage had been in place?" However, it is recognized that future hydrologic conditions will not be the same as historical conditions due to development of conditional water rights, implementation of proposed IPPs from Colorado's Water Plan, changed operations by water users, and a host of other factors. Based on direction from the CWCB, CDWR and Roundtables, SPSS planning was performed using future hydrology.

The SPSS used similar methods for adjusting historical hydrology to represent future conditions as were applied in the South Platte Basin Implementation Plan (BIP). In the BIP a routine was developed to reduce historical flows by diversions anticipated from

IPPs in Colorado's Water Plan. This routine used estimates of IPP annual yields obtained from the IPP proponents, and reduced available water equally in all months. The routine allowed the user to select individual IPPs or all IPPs for inclusion in the analysis, since the BIP acknowledges that not all IPPs are likely to be ultimately implemented.

For the SPSS the method of reducing available flows to account for implementation of IPPs from the BIP was modified by assuming a distribution of diversions between peak runoff months and the rest of the year for those proposed projects that would increase future diversions. It is recognized that many factors can affect the magnitude and timing of diversions for future projects, and detailed analyses of specific IPPs was not contemplated for this project. Estimates in this study were only developed to provide a rough order of magnitude of the effect of IPPs on water available for a new South Platte storage project. IPPs which are expected to reduce future demands were not considered in the adjustment of available flows. The IPPs, their estimated yield from the BIP, and the assumed distribution of their diversions between the peak runoff months of May/June and the rest of the year are listed in **Table 6-3**.

Table 6-3. Assumed Seasonal Distribution of Future Diversions for IPPs

IPP Project	Provider	Annual Yield (ac-ft/yr)	May-June Diversions	July-April Diversions
ACWWA Reuse Flow Project	ACWWA, SMWSA	3,520	N/A	N/A
Alternative Northern Water Supply Project	Town of Castle Rock	2,500	80%	20%
ASR Future Storage	Town of Castle Rock	N/A	-	-
ASR Pilot Phase Storage	Town of Castle Rock	N/A	-	-
Chatfield Pump Station	Denver Water	3,000	50%	50%
Chatfield Reservoir Storage Reallocation Project	Colorado Water Conservation Board, Centennial Water and Sanitation District, Central Colorado Water Conservancy District, Castle Pines North Metro District, Colorado Parks and Wildlife, Castle Rock, Center of Colorado Water Conservancy District, Castle Pines Metro District	8,500	80%	20%
Conservation	Centennial Water and Sanitation District	1,764	N/A	N/A

IPP Project	Provider	Yield (ac-ft/yr)	May-June Diversions	July-April Diversions
Conservation	City of Greeley	3,000	N/A	N/A
Conservation	City of Northglenn	600	N/A	N/A
Conservation	City of Thornton	3,500	N/A	N/A
Conservation	Longmont	3,500	N/A	N/A
Conservation	Town of Castle Rock	3,350	N/A	N/A
Consolidated Mutual Water District Reservoir Construction	Consolidated Mutual Water Company	N/A	-	-
Denver Water Reuse	Denver Water	1,750	N/A	N/A
Downstream Reservoir Exchanges	Denver Water	12,000	70%	30%
Halligan Reservoir Enlargement	City of Fort Collins	7,000	80%	20%
Highway 93 Lakes	Arvada	500	80%	20%
Milton Seaman Reservoir Enlargement	City of Greeley	6,600	80%	20%
New Storage Projects	City of Northglenn	1,500	70%	30%
Northern Integrated Supply Project	Town of Erie, City of Lafayette, Left Hand Water District, City of Fort Morgan, City of Dacono, Town of Eaton, Town of Windsor, City of Fort Lupton, Fort Collins - Loveland Water District, Central Weld County Water District, Town of Evans, Morgan County Water Quality District, Town of Severance, Town of Frederick, Town of Firestone	40,000	70%	30%
Plum Creek Diversion & WPF Upgrades	Town of Castle Rock	4,100	80%	20%
Prairie Waters Project	Aurora	15,700	50%	50%
Reclaimed Water	Erie	5,390	N/A	N/A
Reuse	City of Thornton	2,000	N/A	N/A
Reuse Plan	City of Northglenn	700	N/A	N/A
Rueter Hess Reservoir Enlargement	Parker Water and Sanitation District, Castle Rock, Castle Pines North, Stonegate	14,810	80%	20%

IPP Project	Provider	Yield (ac-ft/yr)	May-June Diversions	July-April Diversions
South Platte and Beebe Draw Well Project - Reuse	City of Brighton	3,200	N/A	N/A
South Platte Protection Plan	Denver Water	N/A	-	-
Thornton Northern Project	City of Thornton	13,500	50%	50%
Union Pumpback Pipeline	Longmont	4,950	50%	50%
Union Reservoir Enlargement	Longmont	1,770	80%	20%
Westminster Agreement	City of Brighton	2,000	50%	50%
Westminster Gravel Storage	Westminster	N/A	-	-

Notes: Projects with N/A in the Diversions fields reduce future demand rather than increasing future diversions. Projects with N/A in Yield field did not have yield estimates available from the BIP. Projects with blanks in the Diversions fields did not have adequate yield information. Any potential influences of these IPPs on future storable flow was not accounted for in the SPSS analysis.

Future flows were also adjusted to account for conditional exchange rights that were not utilized in the historical period in the PFM but could be utilized in the future. Conditional water rights were tabulated and allocated to the major reaches in the SPSS study area. Based on input from the Division Engineer it was assumed 33 percent of conditional exchanges were not duplicative and would likely be perfected upstream of Kersey, and 25 percent of conditional exchanges were not duplicative and would likely be perfected downstream of Kersey. These are rough approximations but were considered adequate for this analysis. Daily flow reductions to reflect conditional exchange rights being perfected and exercised in the future are summarized in Table 6-4.

Table 6-4. Reduction in Historical Daily Flows to Account for Conditional Exchange Rights

Reach	Total Conditional Exchanges (cfs)	Reductions to Daily Historical Flows	
		Conditional Exchanges Assuming 25% are Made Absolute and Operated Concurrently (cfs)	Conditional Exchanges Assuming 33% are Made Absolute and Operated Concurrently (cfs)
Above Denver	1,900	-	630
Denver to Kersey	7,600	-	2,500
Kersey to Balzac	1,100	280	-
Balzac to Julesburg	1,200	300	-

Table 6-5 shows historical average annual and median annual available water adjusted for IPP diversion estimates. These results assume all IPPs for which yield information was available in the BIP are implemented, while all IPPs without yield information in the BIP are not implemented. This is conceptually consistent with the scenario in Colorado's Water Plan that assumes 60 percent of all IPPs will ultimately be implemented. **Table 6-5** also shows the reduction in available water compared to the results of the historical hydrology analysis. Future average annual available water is 16-18 percent less than average annual available water in the 20 years between 1996 and 2015.

Figure 6-6 gives a comparison of the daily available water exceedance between the historical hydrology and the future hydrology adjusted for IPPs and conditional exchanges. **Figure 6-7** shows the future average and median physical flow and available flow throughout the SPSS study area; these PFM results were used in the analysis of SPSS alternatives.

Table 6-5. Future Available Water for Selected Locations Based on Historical Hydrology and Adjustments

Location		Median Annual Available Water (ac-ft)	Average Annual Available Water (ac-ft)	Available Water in Wet Year (ac-ft)	Available Water in Normal Year (ac-ft)	Available Water in Dry Year (ac-ft)
		All Years	All Years	1999	2010	2002
South Platte River near Kersey	With IPP Adjustment	116,000	214,000	580,000	275,000	6,000
	Difference from Historical	-49,000	-48,000	-127,000	-103,000	-8,000
South Platte River near Weldona	With IPP Adjustment	127,000	231,000	601,000	303,000	9,000
	Difference from Historical	-52,000	-50,000	-130,000	-108,000	-9,000
South Platte River near Balzac	With IPP Adjustment	144,000	246,000	641,000	326,000	9,000
	Difference from Historical	-41,000	-51,000	-130,000	-114,000	-9,000
Lowline Ditch/Henderson Smith Ditch	With IPP Adjustment	154,000	261,000	666,000	357,000	15,000
	Difference from Historical	-46,000	-53,000	-133,000	-119,000	-18,000
South Platte River at Julesburg	With IPP Adjustment	232,000	332,000	815,000	494,000	54,000
	Difference from Historical	-57,000	-65,000	-136,000	-133,000	-25,000

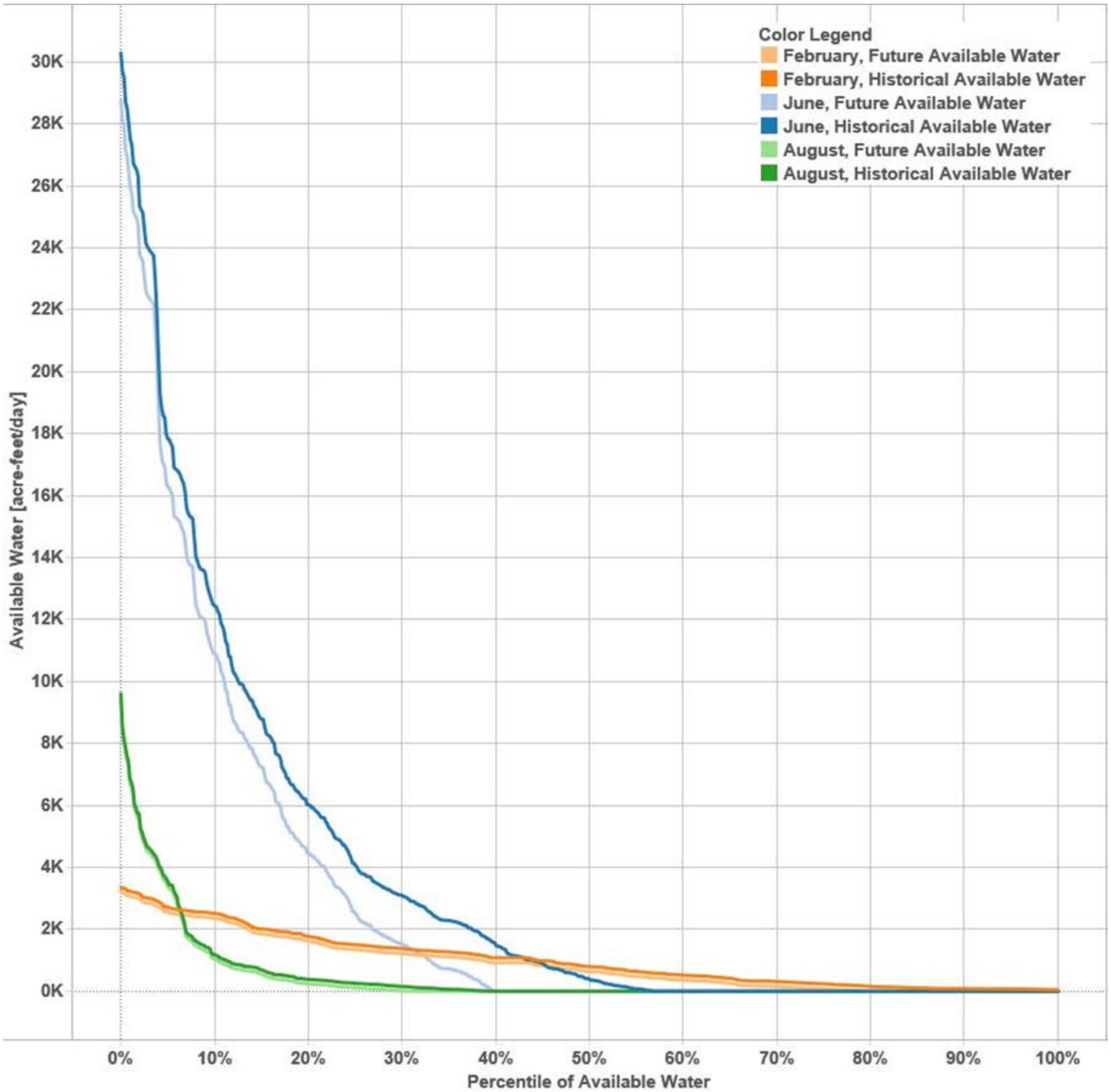


Figure 6-6. Historical and Future Available Water by Month for South Platte at Julesburg Gage

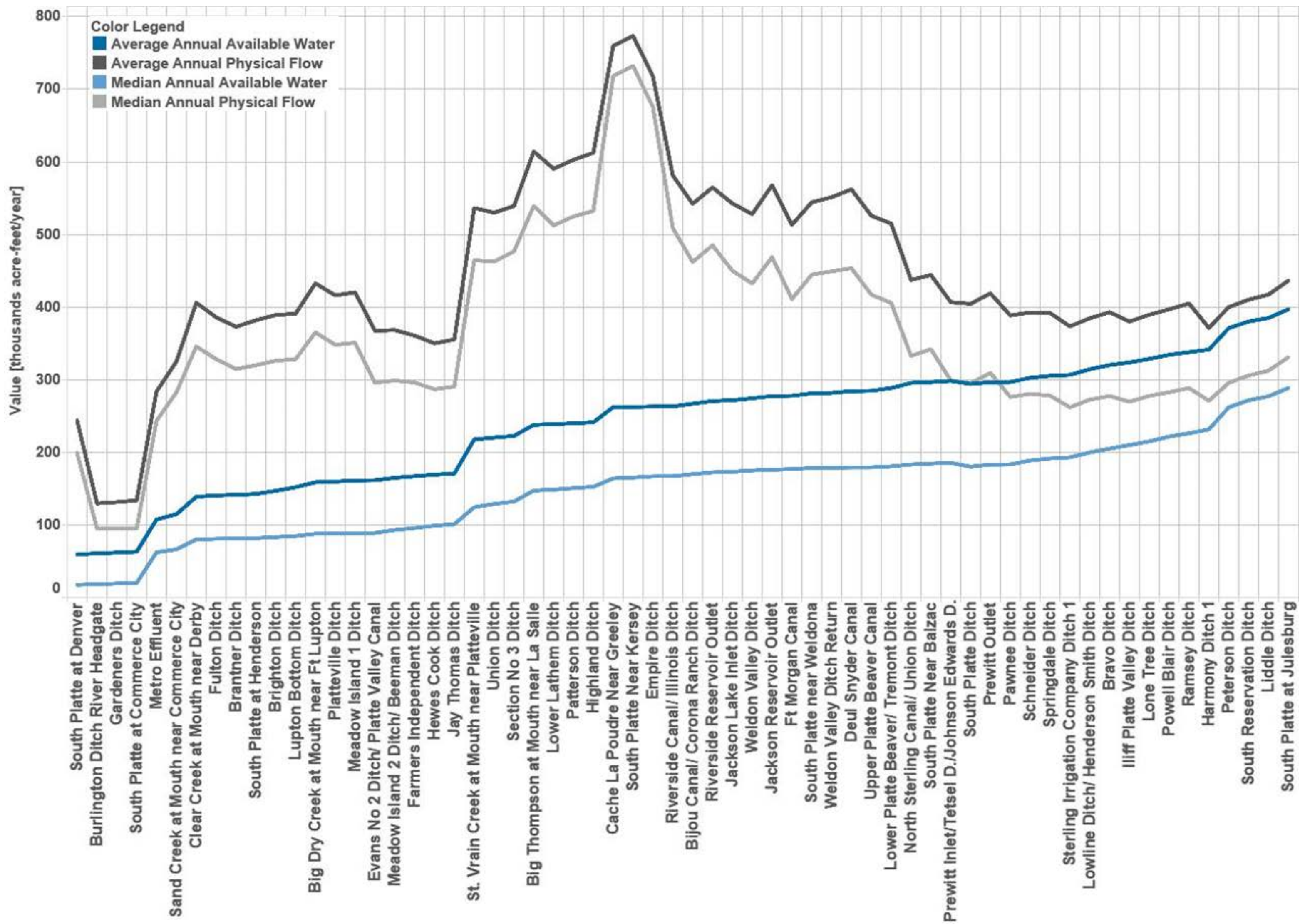


Figure 6-7. Future Average and Median Physical Flow and Available Water

6.4 DIVERSION CAPACITY CONSTRAINTS ON AVAILABLE WATER

Because nearly all potential SPSS storage options would be located off the mainstem of the South Platte River, effective available water would be constrained by the capacity of the diversion system conveying water from the river to storage. Future daily flows based on the adjusted 1996-2015 hydrology were analyzed to estimate the maximum potential volume of water that could be conveyed to storage as function of diversion capacity from three key points in the SPSS study area: the Kersey gage, the Balzac gage and the Julesburg gage. Results are shown in **Table 6-6**, and indicate that large diversion and conveyance facilities would be required to capture significant portions of available water when storage is located off-channel. For example, at the Balzac gage a diversion capacity of 650 cfs would be needed to capture an average of 100,000 ac-ft/yr. Capturing 85 percent of available water would require diversion capacities from 450 cfs at Kersey to 800 cfs at Julesburg. These are large diversion capacities, but are within the range of existing diversion structures on the South Platte River.

Table 6-6. Diversion-Constrained Potential Yield to Off-Channel Storage Site

Percentage of Time the Full Daily Streamflow could be Diverted to Storage	Diversion Point					
	Kersey Gage		Balzac Gage		Julesburg Gage	
	Diversion Capacity (cfs)	Average Annual Yield (AFY)	Diversion Capacity (cfs)	Average Annual Yield (AFY)	Diversion Capacity (cfs)	Average Annual Yield (AFY)
85	450	75,300	550	93,800	800	162,900
90	700	97,600	900	124,600	1,100	189,400
95	1,100	118,100	1,400	149,800	1,700	219,400
97	1,900	140,300	2,100	168,000	2,400	238,500
98	3,100	161,100	3,500	191,700	3,800	262,900
99	5,500	186,300	6,400	220,700	7,400	299,300

7. DEMANDS

7.1 INTRODUCTION

Analysis of SPSS options required an assumption about demands the storage projects would potentially be operated to meet. A simplified approach for estimating water demands was adopted for the SPSS. Because no specific users of SPSS water have been identified, and because many different storage options were investigated, a standardized approach to determining demands for storage scenarios was needed. This approach allowed for a consistent comparison of storage scenarios on the basis of their ability to meet demands in the South Platte Basin.

For the purpose of the SPSS, total potential water demand for future storage projects is defined as the future agricultural and M&I gap or shortage in the lower South Platte Basin, assuming implementation of IPPs. Future demands were used rather than existing demands to match with the use of future condition hydrology for the SPSS supply analysis. The State of Colorado's 2010 Statewide Water Supply Initiative (SWSI 2010) (CDM, 2011) was utilized as the basis for information about the water demands within the SPSS study area.

To simplify the demand analysis, future demand estimates were aggregated by stream reach along the South Platte. From upstream to downstream, the demand reaches utilized for the SPSS were:

- Upstream of the South Platte River at Denver Gage (Upstream of Denver Gage)
- South Platte River at Denver gage to South Platte River Near Kersey gage (Denver to Kersey)
- South Platte River Near Kersey gage to South Platte River at Cooper Bridge near Balzac gage (Kersey to Balzac)
- South Platte River at Cooper Bridge near Balzac gage to South Platte River at Julesburg gage (Balzac to Julesburg)

Detailed documentation of the methods used to estimate demands is provided in **Appendix F**.

7.2 DEMAND ESTIMATION METHODS

Estimation of maximum potential demands that could be met by a SPSS storage project were developed using the approach shown in **Figure 7-1**. Derivation of the SPSS agricultural demands was based on the SWSI 2010 analysis of estimated 2050 agricultural demand, which includes assumptions for reduction in irrigated acreage. The future agricultural shortage was assumed to be the maximum potential agricultural demand that could be met by a SPSS option. SWSI 2010 defines agricultural shortage as the difference between the water supply-limited consumptive use and the irrigation water requirement of the irrigated lands.

Agricultural shortages for the recent 10-year historical period were computed by Water District in the SPSS study area. These were then adjusted to 2050 conditions based on the SWSI 2010 assumptions for reduced irrigated acreage. Shortages by Water District were then allocated to the four SPSS demand points.

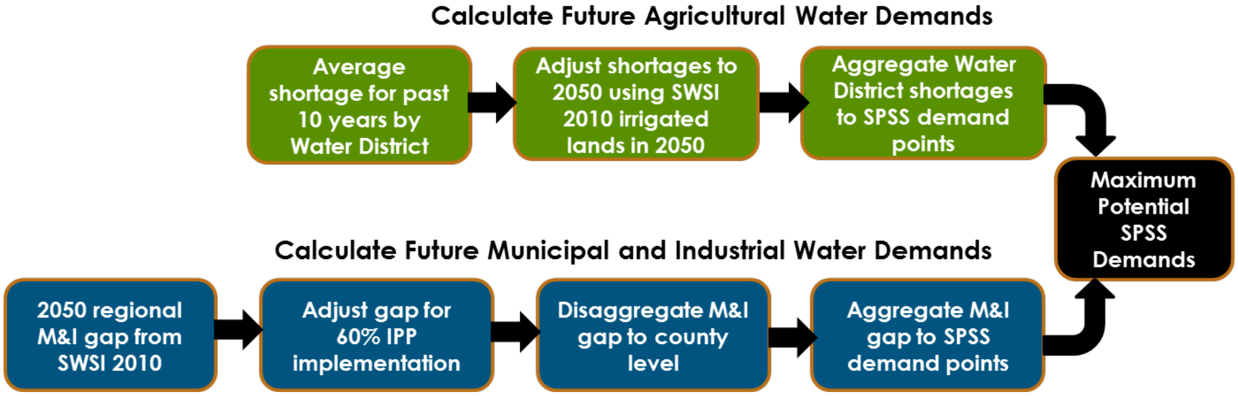


Figure 7-1. Demand Estimate Approach

Derivation of the SPSS municipal demands was based on the SWSI 2010 analysis of the 2050 M&I water supply gap. The SPSS adopted the 2050 M&I gap assuming the median demand forecast and 60 percent implementation of IPPs. SWSI 2010 data presented by region was disaggregated to the county level, then re-aggregated at each of the SPSS demand points.

7.3 RESULTS OF DEMAND ANALYSIS

Table 7-1 presents the results of the SPSS demand analysis. It lists the maximum potential demand that would be applied to storage options to assess their effectiveness in reducing excess flows at the state line and putting Colorado's water resources to beneficial use. Spatial distribution of the demands is shown in **Figure 7-2**, which also shows spatial distribution of available water in the SPSS study area.

In addition to total annual demand, the SPSS analysis required a monthly distribution of demand since both M&I and agricultural demands vary substantially throughout the year. M&I weekly demands as a percentage of total annual demand were taken from data available from Aurora Water; this was assumed to be representative of other municipal entities in the South Platte Basin. A monthly agricultural demand pattern was developed from historical data for applied water from both surface and groundwater sources since SPSS water could be used to augment well depletions. The weekly demand patterns for agricultural and M&I demands are shown in **Figure 7-3**.

The maximum potential demand exceeds the available water supply, particularly if the supply is limited by diversion capacity to off-channel storage projects. Thus the sizing of storage options is supply limited rather than demand limited on a basin-wide basis.

Table 7-1. Maximum Potential Demand Applied to SPSS Options

Reach	Ag Future Shortage			M&I Future Shortage		Total
	Water District	Mainstem	Tributary	County	Total	Demand
Upstream of Denver Gage	WD8		1,115	Denver	18,726	
	WD9		267	Arapahoe	40,439	
				Jefferson	15,215	
				Douglas	27,545	
				Elbert	3,516	
	Reach Total	-	1,382	*Reach Total*	105,441	**106,823**
Denver to Kersey	WD2	71,388		Weld	42,950	
	WD3		65,435	Adams	21,847	
	WD4		28,744	Larimer	28,122	
	WD5		29,394	Boulder	14,828	
	WD6		15,131	Broomfield	3,511	
	WD7		90			
	Reach Total	71,388	138,794	*Reach Total*	111,259	**321,441**
Kersey to Balzac	WD1	46,644		Morgan	9,486	
	Reach Total	46,644	-	*Reach Total*	9,486	**56,130**
Balzac to Julesburg	WD64	11,374		Logan	7,114	
				Sedgwick	0	
				Washington	0	
	Reach Total	11,374	-	*Reach Total*	7,114	**18,488**
BASIN TOTALS		**129,406**	**140,176**		**233,300**	**502,882**

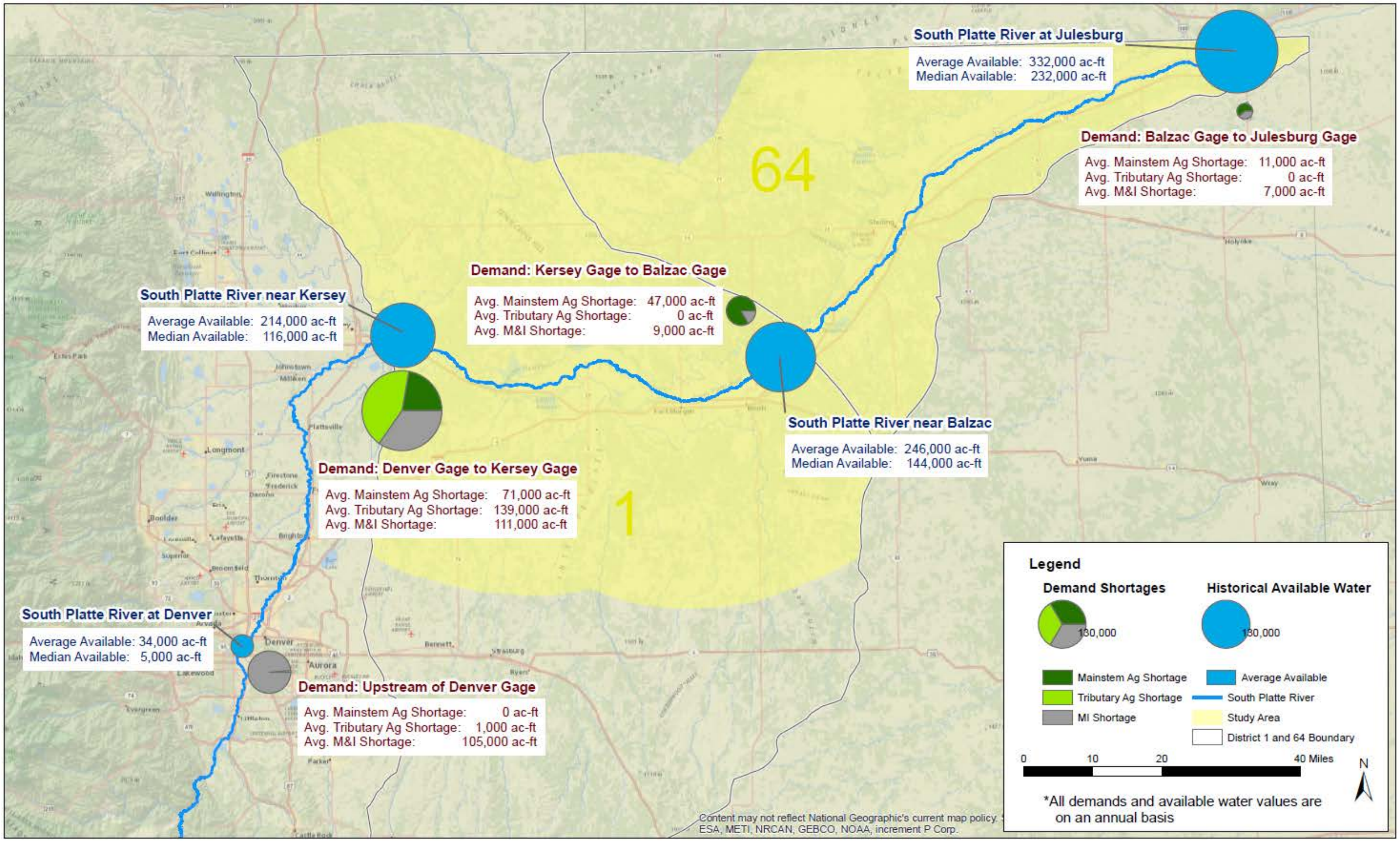


Figure 7-2. Summary of Available Water and Demands at Key Locations in SPSS Study Area

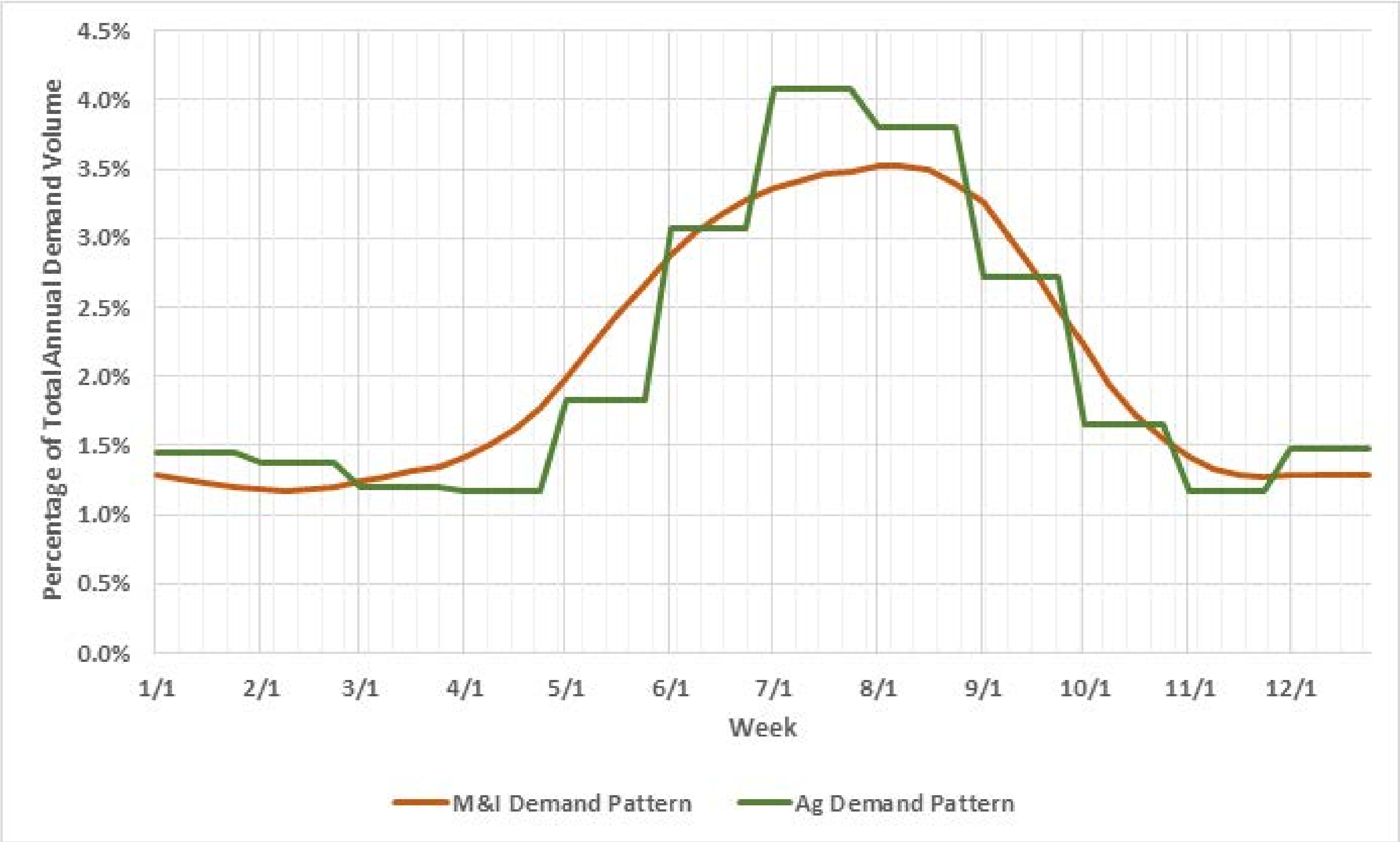


Figure 7-3. Weekly Distribution of Annual Demand

8. WATER QUALITY

The quality of water available for a new storage project in the lower South Platte Basin could affect the feasibility of putting that water to beneficial use. Similarly, enlarging or rehabilitating existing reservoirs would only be feasible if water quality would be appropriate for the intended uses.

Existing water quality data for stream segments and reservoirs was reviewed and impaired water bodies based on the state's water quality assessment were identified. Results of the water quality review are provided in **Appendix G**.

Table 8-1 summarizes the results of the water quality review for key parameters. Water diverted for storage in the SPSS study area would be adequate quality for irrigation use, as these sources are currently widely used for agricultural purposes. However, if used directly as a drinking water supply, water from any new SPSS storage project would require a high level of treatment (e.g., reverse osmosis, ion exchange) to remove a number of problematic constituents including arsenic, selenium, sulfate, total dissolved solids, and uranium. This level of treatment would add significant cost and complexity to a storage concept associated with construction of the treatment process itself, disposal of residuals, operational costs, and energy requirements. In addition, groundwater non-degradation policies would require treatment of any water delivered from the South Platte River below Greeley prior to performing aquifer recharge and underground storage to avoid adversely affecting existing groundwater quality.

Table 8-1. Summary of Water Quality Issues Affecting Storage Options

Key Parameter	Assumed Method of Use	Reach Impaired for Use	Potential Treatment Alternatives and Regulatory Needs
Arsenic	*Domestic Water Supply* – Direct feed to WTP	COSPMS01B	High Level Treatment Methods – High Cost Residuals Treatment and/or Disposal – High Cost
Dissolved Oxygen	*Agriculture, Aquatic Life, Recreation* – Surface water discharge to receiving water for direct use, augmentation use, or exchange *Domestic Water Supply* – Direct feed to WTP	COSPLS03 (North Sterling Reservoir)	Conventional Treatment Methods – Low Cost
E. Coli	*Recreation** – Surface water discharge to receiving water for direct use, augmentation use, or exchange	COSPMS01B	Conventional Treatment Methods – Low Cost
Manganese	*Domestic Water Supply* – Direct feed to WTP	COSPMS01B COSPLS01	Medium Level Treatment Methods – Medium Cost (e.g., green sand filters, enhanced coagulation, etc.)

Key Parameter	Assumed Method of Use	Reach Impaired for Use	Potential Treatment Alternatives and Regulatory Needs
pH	*Aquatic Life* –* Surface water discharge to receiving water for direct use, augmentation use, or exchange *Domestic Water Supply –* Direct feed to WTP	COSPLS03 (Jackson Reservoir)	Conventional Treatment Methods – Low Cost
Selenium	*Domestic Water Supply –* Direct feed to WTP	COSPLS01 COSPLS03 (North Sterling Reservoir)	High Level Treatment Methods – High Cost Residuals Treatment and/or Disposal – High Cost
Sulfate	*Domestic Water Supply –* Direct feed to WTP	COSPMS01B COSPLS01	High Level Treatment Methods – High Cost
Total Dissolved Solids	*Domestic Water Supply –* Direct feed to WTP	COSPMS01B COSPLS01	High Level Treatment Methods – High Cost Residuals Treatment and/or Disposal – High Cost
Uranium	*Domestic Water Supply –* Direct feed to WTP	COSPLS01	High Level Treatment Methods – High Cost Residuals Treatment and/or Disposal – High Cost

Notes: COSPMS01B - Mainstem of the SPR from confluence with St Vrain Creek to the Weld/Morgan County Line
COSPLS01 - Mainstem of the SPR from the Weld/Morgan County line to the CO/NE border
High Level Treatment Needs could include reverse osmosis, ion exchange, activated alumina, etc.
Residuals Treatment and/or Disposal could include permitted discharge to sewer, deep well injection, evaporation pond, land application, zero liquid discharge, etc.
** Initial recommendation – obtain legal determination as to whether the use of water constitutes and "exercise of water rights"*

9. STORAGE OPTIONS

The SPSS evaluation process involved analyzing storage options (individual reservoir or aquifer storage facilities) and more comprehensive storage concepts or solutions (individual storage options or combinations of storage options integrated with all other infrastructure required to have an operational storage project). Storage options were analyzed first, and the most promising options were incorporated into storage concepts. The overall storage evaluation process is summarized in Figure 9-1.

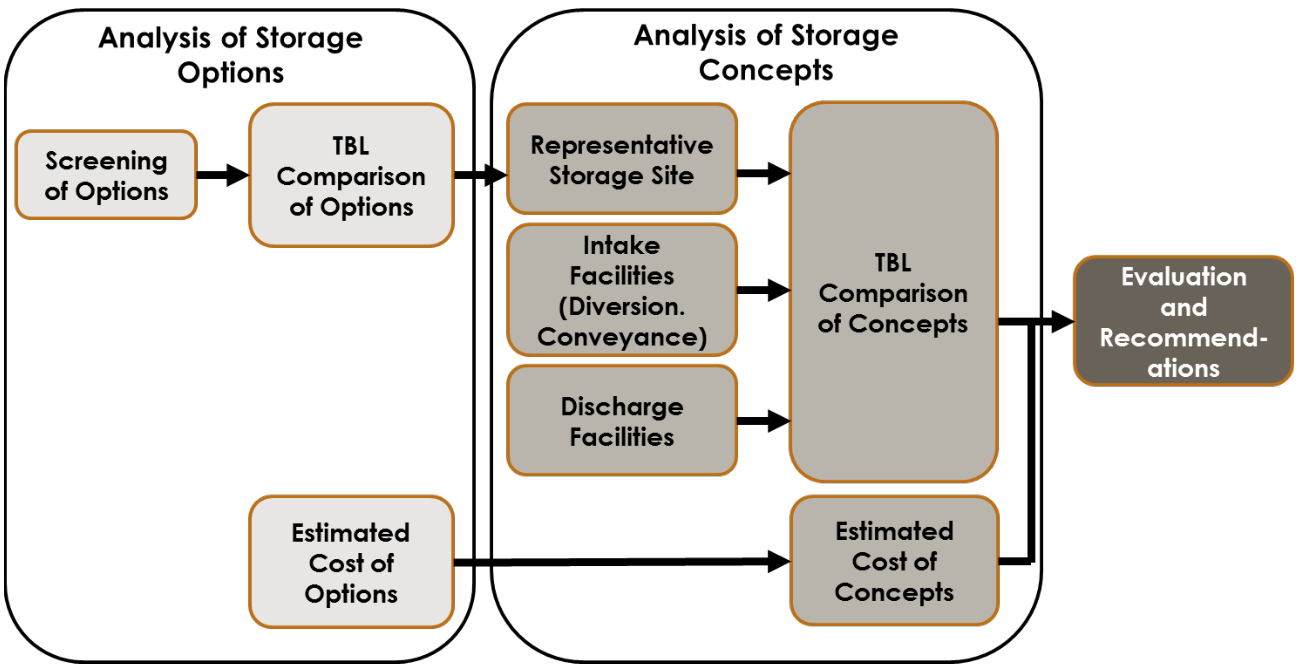


Figure 9-1. SPSS Storage Evaluation Process Overview

This section summarizes the process used to identify and evaluate individual storage options for the SPSS. It includes:

- Screening of storage options to eliminate infeasible and clearly inferior options
- Comparison of storage options based on technical and environmental criteria
- Estimation of cost of storage options

A more detailed discussion of the storage option analysis is provided in **Appendix H**. **Section 10.0** describes how individual storage options were incorporated into overall storage concepts for analysis.

Aquifer storage options are different from surface storage options. While many surface storage projects a designed to capture peak flows by diverting high flow rates for short periods of time, aquifer storage projects are limited by recharge capacity and thus cannot directly store high flows. They are often combined with reservoir projects and operated conjunctively so the reservoir can feed water at a managed rate to the recharge area. Aquifer storage is often seen as a supplemental water source rather than a source for peaking or meeting high sustained demands. For this reason they were analyzed separately from surface reservoir options.

9.1 SCREENING OF STORAGE OPTIONS

Storage options were screened starting with a long-list resulting from the literature review to eliminate those options with fatal flaws or that did not meet minimum criteria related to SPSS project goals. The objective of this process was not to identify the best storage options, but to eliminate clearly inferior options that would not meet SPSS objectives. The storage option screening process was conducted collaboratively in a workshop attended by members of the South Platte and Metro Basin Roundtables and the Stantec consultant team. Subsequent refinements were made by the consultant team with concurrence of the CWCB, CDWR and Roundtables.

Figure 9-2 summarizes the storage site screening process for surface reservoirs, aquifer storage and gravel pits. Sites were screened out if they were located too far from the South Platte mainstem; did not meet minimum capacity criteria; were clearly inferior to other similar options; or were considered impractical for purposes of SPSS by the Roundtable members. Results of the storage site screening process are shown in Figure 9-3.

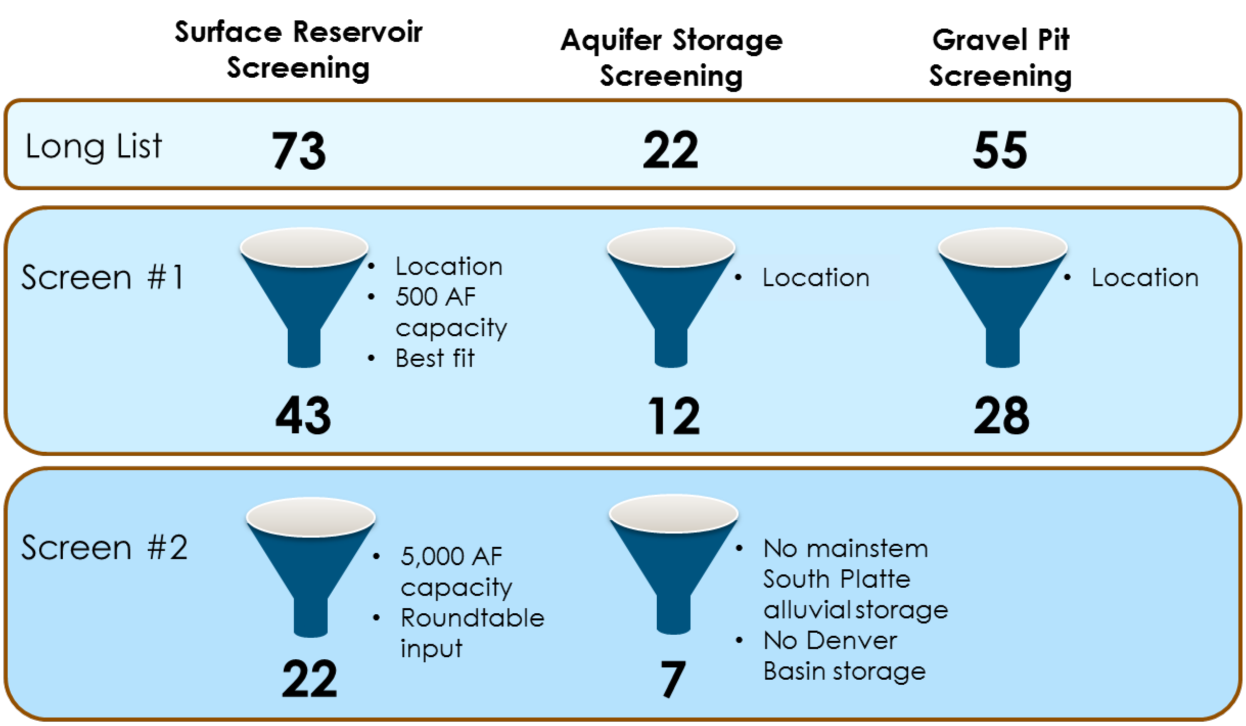


Figure 9-2. Summary of Storage Site Screening Process

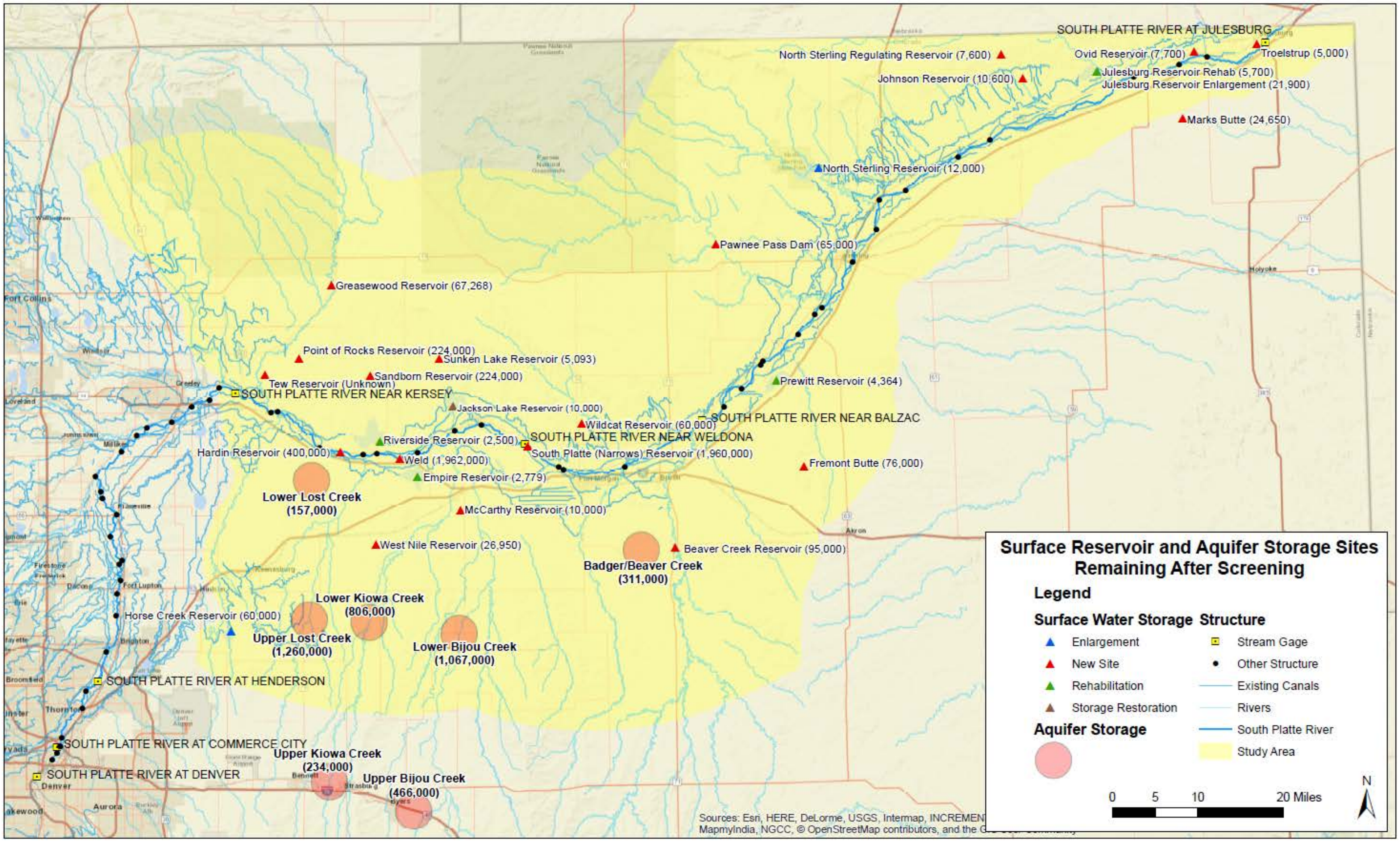


Figure 9-3. Surface Reservoir and Aquifer Storage Sites Remaining After Screening

9.2 COMPARISON OF STORAGE OPTIONS – SITE EVALUATION FRAMEWORK

Individual SPSS storage options were evaluated and compared based on technical, cost, and environmental factors. Technical and environmental data for all storage options remaining after the initial screening process were collected from the available sources described in **Appendix B**. Data were compiled in a Site Evaluation Framework (SEF) database. Database attributes (parameters, data types) and qualifiers (values, ratings) for the SEF are defined in **Appendix H**.

Where possible, data were collected from previous studies and reports. The SPSS study team used the best available maps, aerial photography and other resources to fill in the database attributes for each storage option. Professional judgment was used where necessary. For each surface reservoir storage option the descriptive data were based on the maximum storage capacity reported for that site in previous reports or based on a feasible dam alignment determined by the consultant team. ASR site characteristics were obtained from previous reports and combined with theoretical conceptual design for recharge and recovery facilities. Database entries for each storage option are shown in **Table 9-1**.

Table 9-1. Database Entries for Storage Options

Site Name	Features									Benefits		
	Partnerships-Consumptive	Partnerships-Non-Consumptive	Regional Integration	Existing Water Quality	Source Water Quality	Construct-ability	Scalability	Use Existing Infrastructure	Ease To Use Existing Infrastructure	Flood Control Benefit	Migratory Bird Habitat	Solution Compatibility
Prewitt Reservoir Rehab	Yes	Unknown	Yes	No	Yes	High	Low	Yes	Easy	Low	Yes	Yes
Julesburg Reservoir Enlarge	Unknown	Unknown	Yes	Unknown	Yes	High	Low	Yes	Easy	Low	Yes	No
Wildcat Reservoir	Yes	Yes	Yes	N/A	Yes	High	Low	Yes	Medium	Low	Yes	Yes
South Platte (Narrows) Reservoir	Yes	Unknown	Yes	N/A	Yes	Low	Low	Yes	Easy	High	Yes	Yes
Hardin Reservoir	Unknown	Unknown	Yes	N/A	Yes	Low	Low	Yes	Easy	High	Yes	Yes
Riverside Reservoir Rehab	Unknown	Unknown	Yes	No	Yes	High	Low	Yes	Easy	Low	Yes	Yes
Empire Reservoir Rehab	Unknown	Unknown	Yes	No	Yes	High	Low	Yes	Easy	Low	Yes	Yes
Sandborn Reservoir	Unknown	Unknown	Yes	N/A	Yes	High	Low	Yes	Difficult	Low	Yes	Yes
Point of Rocks Reservoir	Unknown	Unknown	Yes	N/A	Yes	High	Low	Yes	Medium	Low	Yes	Yes
Julesburg Reservoir (Rehab)	Unknown	Unknown	Yes	Unknown	Yes	High	Low	Yes	Easy	Low	Yes	No
Jackson Lake Reservoir	Yes	Unknown	Yes	Yes	Yes	High	Low	Yes	Easy	Low	Yes	Yes
North Sterling Reservoir Enlarge	Unknown	Unknown	Yes	Yes	Yes	High	Low	Yes	Easy	Low	Yes	No
McCarthy Reservoir	Yes	Unknown	Yes	N/A	Yes	High	Low	No	N/A	Low	Yes	Yes
Upper Lost Creek	Unknown	Unknown	No	N/A	No	High	Medium	No	N/A	Low	No	Yes
Lower Lost Creek	Unknown	Unknown	Yes	No	No	High	Medium	No	N/A	Low	No	Yes
Upper Kiowa Creek	Unknown	Unknown	No	N/A	Yes	High	Medium	No	N/A	Low	No	Yes
Lower Kiowa Creek	Unknown	Unknown	Yes	Yes	Yes	High	Medium	No	N/A	Low	No	Yes
Upper Bijou Creek	Unknown	Unknown	No	N/A	Yes	High	Medium	No	N/A	Low	No	Yes
Lower Bijou Creek	Unknown	Unknown	Yes	Unknown	Unknown	High	Medium	No	N/A	Low	No	Yes
Badger/Beaver Creek	Unknown	Unknown	No	No	No	High	Medium	No	N/A	Low	No	Yes
Ovid Reservoir	Unknown	Unknown	Yes	N/A	Yes	High	Low	Yes	Medium	Low	Yes	No
Johnson Reservoir	Unknown	Unknown	Yes	N/A	Yes	High	Low	Yes	Medium	Low	Yes	No
North Sterling Regulating Res	Unknown	Unknown	Yes	N/A	Yes	High	Low	Yes	Difficult	Low	Yes	No
Troelstrup	Unknown	Unknown	Yes	N/A	Yes	High	Low	Yes	Medium	Low	Yes	No
Pawnee Pass Dam	Unknown	Unknown	Yes	N/A	Yes	High	Low	Yes	Difficult	Medium	Yes	Yes
Greasewood Reservoir	Unknown	Unknown	Yes	N/A	Yes	High	Low	No	N/A	Medium	Yes	Yes
Sunken Lake Reservoir	Unknown	Unknown	Yes	N/A	Yes	High	Low	No	N/A	Low	Yes	Yes
West Nile Reservoir	Unknown	Unknown	Yes	N/A	Yes	High	Low	No	N/A	Low	Yes	Yes
Fremont Butte	Yes	Unknown	Yes	N/A	Yes	High	Low	No	N/A	High	Yes	Yes
Beaver Creek Reservoir	Unknown	Unknown	Yes	N/A	Yes	High	Low	No	N/A	Medium	Yes	Yes

Site Name	Environmental							Permitting	
	National Wetland Inventory	Critical Habitat -ESA	Wildlife Habitat Impact	Wildlife Species Impact	Migratory Bird Impact	Bald Eagle Nests Impacts	Oil And Gas Wells	Federal Nexus	SPWRAP Potential
Prewitt Reservoir Rehab	Medium	No	Negative	Negative	Negative	Low	None	Yes	Yes
Julesburg Reservoir Enlarge	Medium	No	Negative	Negative	Negative	Low	None	Yes	Yes
Wildcat Reservoir	Medium	No	Negative	Negative	Negative	Low	None	Yes	Yes
South Platte (Narrows) Reservoir	High	No	Negative	Negative	Negative	Low	None	Yes	No
Hardin Reservoir	High	No	Negative	Negative	Negative	High	High	Yes	No
Riverside Reservoir Rehab	Medium	No	Neutral	Neutral	Neutral	High	Low	Yes	Yes
Empire Reservoir Rehab	Medium	No	Neutral	Neutral	Neutral	High	Low	Yes	Yes
Sandborn Reservoir	Low	No	Negative	Negative	Negative	Low	Low	Yes	Yes
Point of Rocks Reservoir	Low	No	Negative	Negative	Negative	Low	High	No	Yes
Julesburg Reservoir (Rehab)	High	No	Neutral	Neutral	Neutral	Low	None	Yes	Yes
Jackson Lake Reservoir	Low	No	Negative	Negative	Neutral	Medium	None	Yes	Yes
North Sterling Reservoir Enlarge	Medium	No	Negative	Negative	Negative	Low	None	Yes	Yes
McCarthy Reservoir	Low	No	Negative	Negative	Negative	Low	None	Yes	Yes
Upper Lost Creek	Low	No	Neutral	Neutral	Neutral	Low	None	Yes	No
Lower Lost Creek	Low	No	Neutral	Neutral	Neutral	Low	Low	No	No
Upper Kiowa Creek	Low	No	Neutral	Neutral	Neutral	Low	None	Maybe	No
Lower Kiowa Creek	Low	No	Neutral	Neutral	Neutral	Low	None	Yes	No
Upper Bijou Creek	Low	No	Neutral	Neutral	Neutral	Low	None	Maybe	No
Lower Bijou Creek	Medium	No	Neutral	Neutral	Neutral	Low	None	Yes	No
Badger/Beaver Creek	Low	No	Neutral	Neutral	Neutral	Low	Low	Yes	No
Ovid Reservoir	High	No	Negative	Negative	Negative	Low	None	Yes	Yes
Johnson Reservoir	Low	No	Negative	Negative	Negative	Low	None	Yes	Yes
North Sterling Regulating Res	Low	No	Negative	Negative	Negative	Low	None	Yes	Yes
Troelstrup	High	No	Negative	Negative	Negative	Low	None	Yes	Yes
Pawnee Pass Dam	Medium	No	Negative	Negative	Negative	Low	None	Yes	Yes
Greasewood Reservoir	Low	No	Negative	Negative	Negative	Low	None	Yes	Yes
Sunken Lake Reservoir	Medium	No	Negative	Negative	Negative	Low	None	Yes	Yes
West Nile Reservoir	Low	No	Negative	Negative	Negative	Low	None	Yes	Yes
Fremont Butte	Low	No	Negative	Negative	Negative	Low	None	Yes	Yes
Beaver Creek Reservoir	High	No	Neutral	Neutral	Neutral	Low	None	Yes	Yes

The information in the SEF was used to select the representative storage sites for modeling each storage concept as described in **Section 10.0** of this report. Representative sites were the sites that provided the best balance of technical feasibility and size while avoiding difficult environmental and social impacts to the extent possible. While the representative sites were selected as the "best fit" among the potential sites in each portion of the SPSS study area, further study could determine that other sites are as good or better. The data in the SEF can provide the starting point for future studies if desired.

Criteria and data from the SEF were used to compare short-listed storage sites using a simple scoring system. The purpose of the scoring system was to provide a means of identifying the more feasible storage options. At this level the comparison of sites is not a precise assessment, and results should be used only to identify overall trends or large differences between options.

Appendix H lists numerical values assigned to each of the qualifiers for the attributes. Assigning values to the qualifiers allowed for calculation of a triple bottom line evaluation score for each option.

Evaluation of alternatives using a triple bottom line scoring system with multiple criteria required assumptions for the weight of each of the criteria. For this analysis three weighting scenarios were tested:

- Equal Weights; all criteria received an equal weight of 1.
- Technical Weights; all criteria related to technical feasibility of the storage option (e.g., scalability, constructability, ability to use existing infrastructure) were given a weight of 3 and all other criteria were given a weight of 1.
- Environmental Weights; all criteria related to environmental parameters (e.g., wetlands, habitat impacts, permittability) were given a weight of 3 and all other criteria were given a weight of 1.

Table 9-2 summarizes the results of the triple bottom line site evaluation process applied to the storage options for the three criteria weighting scenarios. The table shows the numerical score for the storage options separated by storage category. Because each type of storage project is different, it is most appropriate to compare scores within each category. In addition, the average of the scores was computed across the 3 weighting scenarios for each storage option to assess how the sites performed across all weightings. This is shown in **Table 9-3**, which again is separated by storage category. **Figure 9-4** shows the range of scores for combined surface reservoirs and aquifer storage sites for each of the weighting scenarios as well as the maximum possible score for each scenario.

Table 9-2. Summary of Storage Site Evaluation Scores for Different Criteria Weighting Scenarios

Name	Storage Category	Site Score-Equal Weighting	Site Score-Feasibility Weighting	Site Score-Environmental Weighting
Range of Possible Scores (Min / Max)		**0 / 20.5**	**0 / 43.5**	**0 / 37.5**
New Reservoirs				
Beaver Creek Reservoir	New Site	8.5	18.5	12.5
Fremont Butte	New Site	7.5	18.5	7.5
Greasewood Reservoir	New Site	6.5	16.5	6.5
Hardin Reservoir	New Site	6	20	0
Johnson Reservoir	New Site	7	21	7
McCarthy Reservoir	New Site	6	16	6
North Sterling Reg Res	New Site	7	21	7
Ovid Reservoir	New Site	6.5	21.5	4.5
Pawnee Pass Dam	New Site	7	19	6
Point of Rocks Reservoir	New Site	8.5	21.5	10.5
Sandborn Reservoir	New Site	7	19	7
South Platte (Narrows) Res	New Site	7.5	22.5	3.5
Sunken Lake Reservoirs	New Site	6.5	18.5	5.5
Troelstrup	New Site	6.5	21.5	4.5
West Nile Reservoir	New Site	5.5	14.5	5.5
Wildcat Reservoir	New Site	9	26	8
Modified Existing Reservoirs				
Jackson Lake Reservoir	Rehabilitation	9.5	25.5	10.5
Julesburg Reservoir (Enlrg)	Enlargement	8	25	8
Julesburg Reservoir (Rehab)	Rehabilitation	10.5	27.5	15.5
North Sterling Reservoir	Enlargement	7	22	6
Prewitt Reservoir	Rehabilitation	9	26	8
Riverside Reservoir	Rehabilitation	10	25	13
Empire Reservoir	Rehabilitation	10	25	13
Aquifer Storage				
Badger/Beaver Creek	Aquifer	9.5	24.5	13.5
Lower Bijou Creek	Aquifer	10.5	28.5	13.5
Lower Kiowa Creek	Aquifer	10	26	12
Lower Lost Creek	Aquifer	11.5	28.5	17.5
Upper Bijou Creek	Aquifer	8.5	20.5	11.5
Upper Kiowa Creek	Aquifer	8.5	20.5	11.5
Upper Lost Creek	Aquifer	10	26	14

Table 9-3. Average of Scores across Three Weighting Scenarios for Reservoir Storage Options

Storage Options Sorted by Average Score	Storage Category	Average of Scores for 3 Weighting Scenarios (1)
New Reservoirs		
Wildcat Reservoir	New – Off Channel	14.3
Point of Rocks Reservoir	New – Off Channel	13.5
Beaver Creek Reservoir	New – Off Channel	13.2
Johnson Reservoir	New – Off Channel	11.7
North Sterling Regulating Reservoir	New – Off Channel	11.7
Fremont Butte	New – Off Channel	11.2
South Platte (Narrows) Reservoir	New - Mainstem	11.2
Sandborn Reservoir	New – Off Channel	11.0
Ovid Reservoir	New – Off Channel	10.8
Troelstrup	New – Off Channel	10.8
Pawnee Pass Dam	New – Off Channel	10.7
Sunken Lake Reservoir	New – Off Channel	10.2
Greasewood Reservoir	New – Off Channel	9.8
McCarthy Reservoir	New – Off Channel	9.3
Hardin Reservoir	New – Mainstem	8.7
West Nile Reservoir	New – Off Channel	8.5
Modified Existing Reservoirs		
Julesburg Reservoir (Rehabilitation)	Rehabilitation	17.8
Riverside Reservoir	Rehabilitation	16.0
Empire Reservoir	Rehabilitation	16.0
Jackson Lake Reservoir	Rehabilitation	15.2
Prewitt Reservoir	Rehabilitation	14.3
Julesburg Reservoir (Enlargement)	Enlargement	13.7
North Sterling Reservoir	Enlargement	11.7
Aquifer Storage		
Lower Lost Creek	Aquifer	19.2
Lower Bijou Creek	Aquifer	17.5
Upper Lost Creek	Aquifer	16.7
Lower Kiowa Creek	Aquifer	16.0
Badger/Beaver Creek	Aquifer	15.8
Upper Bijou Creek	Aquifer	13.5
Upper Kiowa Creek	Aquifer	13.5

(1) Range of possible averaged scores is 0 – 34

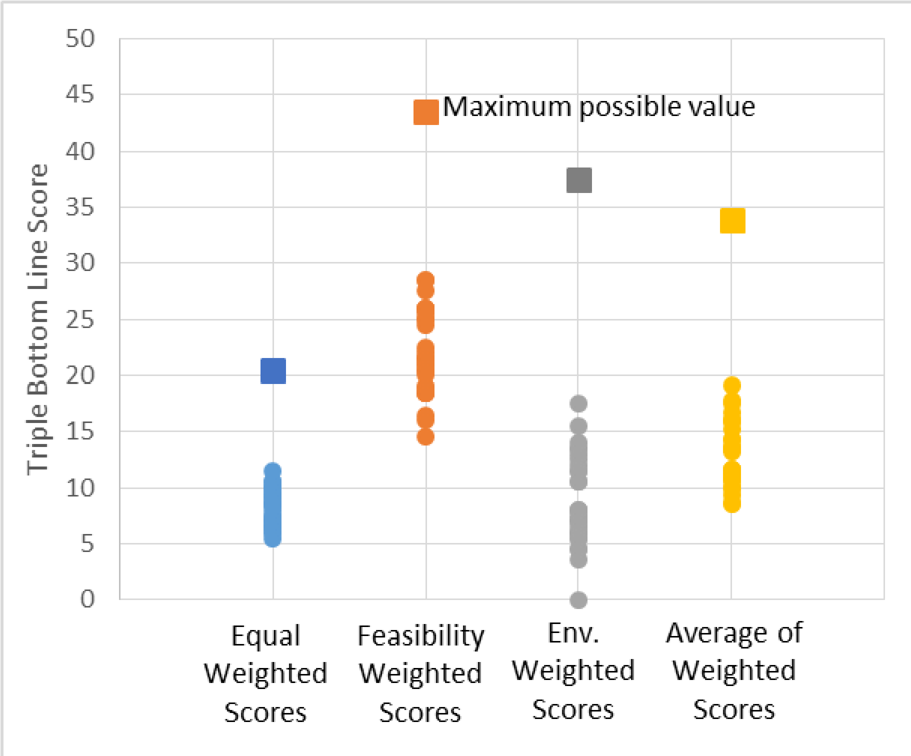


Figure 9-4. Range of Storage Site Scores for Different Weighting Scenarios

Results of the multi-criteria comparison of sites can be summarized as follows:

- Sites that tend to rise to the top of the scoring process tend to do so regardless of the weights assigned to the criteria. Similarly, sites that tend to fall to the bottom of the scoring process tend to do so regardless of the weights assigned to the criteria. This is helpful in that the relative scoring of most sites is fairly independent of the weight assigned to the criteria in the SEF.
- As expected, the on-channel storage options (Narrows Reservoir and Hardin Reservoir) score poorly relative to most other options.
- Of the new off-channel reservoir options, the sites with the most promise appear to be Wildcat, Point of Rocks, Beaver Creek, Johnson, North Sterling Regulating, and Sandborn.
- Of the aquifer storage sites, Lower Lost Creek and Lower Bijou Creek score better than the other sites because of their closer proximity to the South Platte (simplifying diversions into storage and releases back to the river) and closer proximity to the major demand centers at Denver and Kersey.
- Scores are clustered over a relatively narrow range compared to the maximum possible score for each weighting scenario, and no storage options had a score close to the maximum possible score. Differences among storage options are small, and at this level of analysis the triple bottom line scoring process should not be used to eliminate options.

At this level of analysis, the storage option scoring process is very approximate and is based on conceptual information and considerable professional judgment. Significant information about individual sites was unknown at this stage. Refinement of site specific data could change scores of options significantly. In addition, sites were scored without regard for how they could be used in a specific solution that could be formulated by a specific water user. When considering how storage sites would be incorporated into a particular alternative and integrated into the operations of a particular water user, results for the scoring process could vary considerably from this generic approach.

9.3 STORAGE COST ESTIMATES

Conceptual (ACEE Class V) construction cost estimates were prepared for the remaining surface reservoir sites and for two of the aquifer storage sites with the most potential for SPSS storage. Details of the cost estimating process for dams and other infrastructure are contained in **Appendix I**. Where possible cost estimates from past studies were adopted for this study and were escalated to 2017 dollars using accepted construction cost indexes. For new sites or sites for which no data were available, unit costs ($/ac-ft) were estimated based on unit costs of other reservoir storage projects in the SPSS study area.

Surface reservoir costs are summarized in **Table 9-4**. These include costs for permitting, design, land acquisition and construction. The reservoirs with the lowest unit cost are the most cost-effective in terms of storage provided per dollar spent. For new surface reservoirs, unit cost is generally inversely correlated with capacity such that the largest reservoirs have the lowest unit cost. This is shown in **Figure 9-5**; data in the figure include design and construction but not permitting costs. Enlarged or rehabilitated existing reservoirs have more variable unit costs because the type of work required to achieve the additional storage varies considerably from site to site.

Table 9-4. Summary of Surface Reservoir Costs

Dam Type/Name	Storage Capacity (ac-ft)	Estimated 2017 Cost ($ million)	Unit Cost ($/ac-ft)
New Site			
Sandborn Reservoir	224,000	$131	$580
West Nile Reservoir	26,950	$59	$2,100
McCarthy Reservoir	10,000	$27	$2,500
South Platte (Narrows) Reservoir	1,960,000	$145	$74
Wildcat Reservoir	60,000	$79	$1,300
Pawnee Pass Dam	75,000	$254	$3,400
Fremont Butte	76,000	$74	$980
North Sterling Regulating Reservoir	7,600	$38	$5,000
Johnson Reservoir	10,600	$24	$2,300
Ovid Reservoir	7,700	$24	$3,100
Troelstrup	5,000	$19	$3,700
Beaver Creek	95,000	$66	$690
Enlargement			
North Sterling Reservoir Enlargement	12,000	$22	$1,800
Julesburg Reservoir Enlargement	21,900	$46	$2,100
Rehabilitation			
Empire Reservoir Rehab	2,779	$14	$5,000
Prewitt Reservoir Rehab	4,364	$5.5	$1,300
Julesburg Reservoir Rehab	5,700	$31	$5,400
Jackson Lake Reservoir Rehab	10,000	$37	$3,700
Riverside Reservoir Rehab	2,500	$13	$5,200

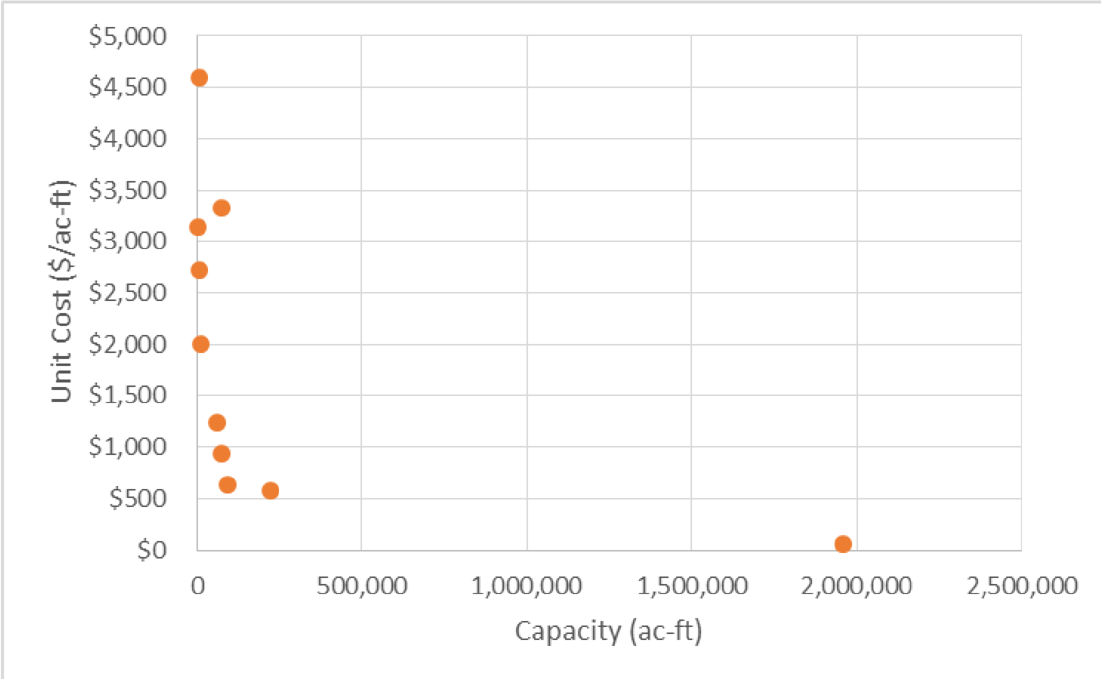


Figure 9-5. Unit Cost of Surface Storage vs Capacity for New Reservoirs

Aquifer storage costs were based on conceptual designs for infiltration basin recharge and recovery within an alluvial aquifer. Conceptual designs included components required to recharge and recover water at a site, but not the conveyance to and from the site.

Aquifer storage and recovery concept costs are more correlated to recharge and recovery rates than total storage volumes. Because of this, Table 9-5 presents the same total cost estimate for Lower Lost Creek Basin and Badger/Beaver Basin. These costs were developed on a unit basis so future cost estimates can be scaled to different recharge and recovery scenarios.

Table 9-5. Aquifer Storage and Recovery Costs

Storage Concept	Storage Capacity (ac-ft)	Recharge Rate (ac-ft per month)	Recovery Rate (ac-ft per month)	Estimated 2017 Cost ($ million)	Unit Cost ($/ac-ft/month)
Lower Lost Creek Aquifer	157,000	5,000	4,000	$39	$9,750
Beaver/Badger Aquifer	311,000	5,000	4,000	$39	$9,750

The aquifer storage cost estimates were based on SPSS delivery and demand scenarios with 10,000 ac-ft of gravel pit regulating storage near the river diversion (see discussion of concepts in the next section). Aquifer storage concepts were modeled with a capacity of 5,000 ac-ft per month of inflow/recharge and 4,000 ac-ft per month of outflow/recovery. It is possible that these scenarios would not represent achievable rates of alluvial aquifer recharge and recovery for all alluvial ASR sites, but these rates were used to provide a reasonable scale for ASR site components and associated costs. It was assumed that land availability and hydrogeologic conditions would not constrain site construction or operations for recharge or recovery. Comparison to surface water storage options is challenging because of fundamental differences in how ASR sites would be constructed and operated.

9.4 SUMMARY OF STORAGE OPTION ANALYSIS

The analysis of storage options was necessarily high level at this stage of analysis, but supports the following conclusions.

- Many feasible surface and aquifer storage options exist in the lower South Platte Basin.
- Cost of surface reservoir storage varies widely, and is very dependent on the specific site being considered and its size based on the needs of the particular application. Nonetheless, many potentially cost-effective reservoir storage options exist in the study area.
- Aquifer storage projects are more limited by recharge and recovery rates rather than storage volume. Typical aquifer storage projects are designed as supplemental supply sources, not as projects to recharge large volumes of water diverted during peak spring snowmelt periods. This results in lower firm yield, and does not attempt to maximize use of potential storage capacity as occurs with surface reservoirs. However, a related benefit is that aquifer storage projects are relatively low cost and can be scaled up over time (not constructed all at once). These unique characteristics make aquifer storage projects difficult to compare to surface water storage projects.
- Factors besides cost such as environmental impacts, permittability, land requirements, infrastructure conflicts, etc. will be important in evaluating specific storage options. These would need to be reviewed in the context of a particular storage project to determine how they could affect project feasibility.
- Based on the high level evaluation in this study it is not recommended that any potential storage options be eliminated from further consideration. However, mainstem dams may prove infeasible due to insurmountable permitting obstacles.
- Mainstem dam options (e.g., Narrows and Hardin sites) are technically feasible and cost-effective but would face significant new permitting challenges and present extensive social challenges related to property acquisition and landowner impacts.

10. STORAGE CONCEPTS

Storage sites cannot be evaluated in a vacuum, but must be integrated with assumed basin water supply, demand and operations to assess their potential effectiveness. The SPSS used the term “storage concept” or “storage solution” to describe how individual storage options would be tied to the overall basin operations in the South Platte River. Conceptual storage solutions were generalized approaches to developing additional storage of South Platte River water in the SPSS study area below Greeley.

Storage concepts were organized based on the reach of the lower South Platte River in which a storage project would be located, the reach from which water would be diverted, and whether storage would be achieved in a surface reservoir or groundwater basin. Each concept was required to have at least one actual storage site identified in the inventory of storage options described in **Section 2.0**. Storage concepts consisted of a specific storage option, an approach to capture water from the South Platte River, and an approach to deliver water to meet demands.

Aquifer storage concepts were fit to the aquifer recharge and recovery capacities described previously. For purposes of comparison with similar surface storage concepts, alternate aquifer storage concepts were also evaluated with similar intake and discharge assumptions, even though in most cases designing and operating aquifer storage projects under those conditions would be extremely challenging.

Surface reservoir storage concepts were modeled using a simplified MODSIM water resources model of the SPSS study area developed for this project. The features of storage concepts and the assumptions used to model them are described below. Aquifer storage options were not simulated in the same way because they would typically be used in conjunction with surface reservoirs and not as stand-alone projects; modeling of surface-groundwater conjunctive use concepts was beyond the scope of this study.

While hundreds of possible storage concepts could be envisioned in the lower South Platte Basin, a manageable number of representative storage concepts was selected to investigate the range of possible storage opportunities in the region.

10.1 SELECTION OF STORAGE CONCEPTS

The following eight representative storage concepts were selected for analysis. Evaluating these concepts will give the state an indication of the range of alternatives, feasibility issues, costs, etc. associated with a new storage project in the SPSS study area.

1. Mainstem Storage – surface reservoir on the mainstem of the South Platte River
2. Upper Basin Storage – surface storage with a reservoir and river diversion between Greeley and the South Platte River near Weldona stream gage
3. Mid Basin Storage North – surface storage with a reservoir and river diversion on the north side of the river between the South Platte River near Weldona stream gage and the South Platte River near Balzac stream gage
4. Mid Basin Storage South – surface storage with a reservoir and river diversion on the south side of the river between the South Platte River near Weldona stream gage and the South Platte River near Balzac stream gage
5. Lower Basin Storage – surface storage with a reservoir and river diversion downstream of the South Platte River near Balzac stream gage
6. Existing Reservoir Improvements – enlargements or rehabilitations of existing reservoirs anywhere in the study area
7. Groundwater Storage Basin West – groundwater aquifer storage and recovery in a groundwater basin in the western portion of the study area
8. Groundwater Storage Basin East – groundwater aquifer storage and recovery in a groundwater basin in the eastern portion of the study area

10.2 DEFINITION OF COMPONENTS ASSOCIATED WITH STORAGE CONCEPTS

In order to analyze the relative benefits of the identified storage concepts, the common components necessary to implement the concepts were defined at a conceptual level. These components are described below and include storage, diversion, intake, and outlet infrastructure. Standard assumptions were adopted for surface storage concepts and another set of standard assumptions were adopted for groundwater storage concepts so as to avoid biasing the results. No optimization or other special consideration was given to any of the storage concepts.

10.2.1. Storage Components

Table 10-1 lists the specific surface and groundwater storage options remaining after the previously described screening process and connects them with each storage concept. Representative storage sites used for analysis are highlighted in bold.

Table 10-1. Specific Storage Options Linked to Generalized Storage Solution Concepts

Storage Solution Concepts	Potential Storage Sites and Maximum Capacities
Mainstem Storage	**South Platte (Narrows) Reservoir Site (1.960,000 ac-ft)** Hardin Reservoir Site (400,000 ac-ft)
Upper Basin Storage	**Sandborn Reservoir Site (224,000 ac-ft)** Point of Rocks Reservoir Site (224,000 ac-ft) Sunken Lake Reservoir Site (5,093 ac-ft) Greasewood Reservoir Site (67,268 ac-ft) Jackson Lake Reservoir Rehabilitation (10,000 ac-ft)
Mid Basin Storage North	**Wildcat Reservoir Site (60,000 ac-ft)** Pawnee Pass Reservoir Site (75,000 ac-ft)
Mid Basin Storage South	**Beaver Creek Reservoir Site (95,000 ac-ft)** Fremont Butte Reservoir Site (75,000 ac-ft) West Nile Reservoir Site (26,950 ac-ft) McCarthy Reservoir Site (10,000 ac-ft)
Lower Basin Storage	**Julesburg Reservoir Enlargement/Rehabilitation (27,600 ac-ft)** **Ovid Reservoir Site (7,700 ac-ft)** **Troelstrup Reservoir Site (5,000 ac-ft)** North Sterling Reservoir Enlargement (12,000 ac-ft) North Sterling Regulation Reservoir (7,600 ac-ft) Johnson Reservoir (10,600 ac-ft)
Existing Reservoir Improvements	**Julesburg Reservoir Enlargement/Rehabilitation (27,600 ac-ft)** **North Sterling Reservoir Enlargement (12,000 ac-ft)** **Prewitt Reservoir Rehabilitation (4,364 ac-ft)** **Riverside Reservoir Rehabilitation (2,500 ac-ft)** **Jackson Lake Reservoir Rehabilitation (10,000 ac-ft)** Empire Reservoir Rehabilitation (2,779 ac-ft)
Groundwater Basin Storage West	Upper Lost Creek Aquifer (1,260,000 ac-ft) **Lower Lost Creek Aquifer (157,000 ac-ft)** Upper Kiowa Creek Aquifer (234,000 ac-ft) Lower Kiowa Creek Aquifer (806,000 ac-ft) Upper Bijou Creek Aquifer (466,000 ac-ft) Lower Bijou Creek Aquifer (1,067,000 ac-ft)
Groundwater Basin Storage East	**Beaver/Badger Aquifer (311,000 ac-ft)**

Note: Representative storage sites used for analysis are highlighted in bold.

Representative storage options were selected for use in each of the storage concepts. This allowed realistic elevation-area-capacity data, evaporation data, and diversion and delivery configurations to be used in the simulations. The study team performed a best-fit evaluation to select a representative storage option for each storage concept. The best-fit option was selected based on data in the Site Evaluation Framework described previously, including physical, environmental and social attributes of the candidate reservoir and groundwater sites in each region of the SPSS study area.

Table 10-1 highlights the representative storage options selected for simulating each storage concept. The locations of these representative storage options are shown in **Figure 10-1**. **Figures 10-2** through **Figures 10-9** present maps of the representative storage options used for each storage concept, and the location of conceptual inlet-outlet facilities (intake pipelines, use of existing irrigation canals, or both).

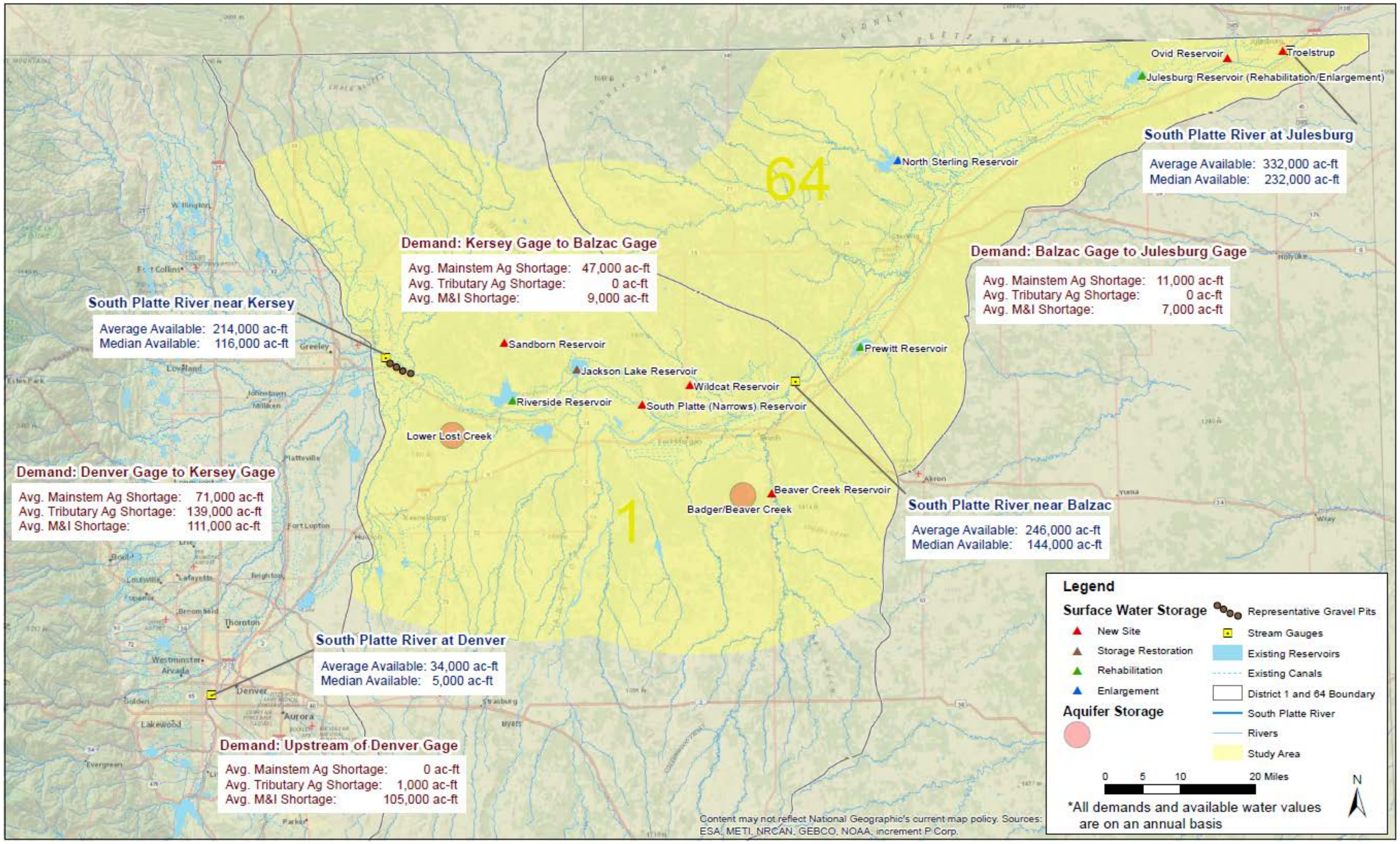


Figure 10-1. Representative Storage Options Used to Model Storage Concepts

Figure 10-2. Upper Basin Storage Conceptual Design for Sandborn Reservoir

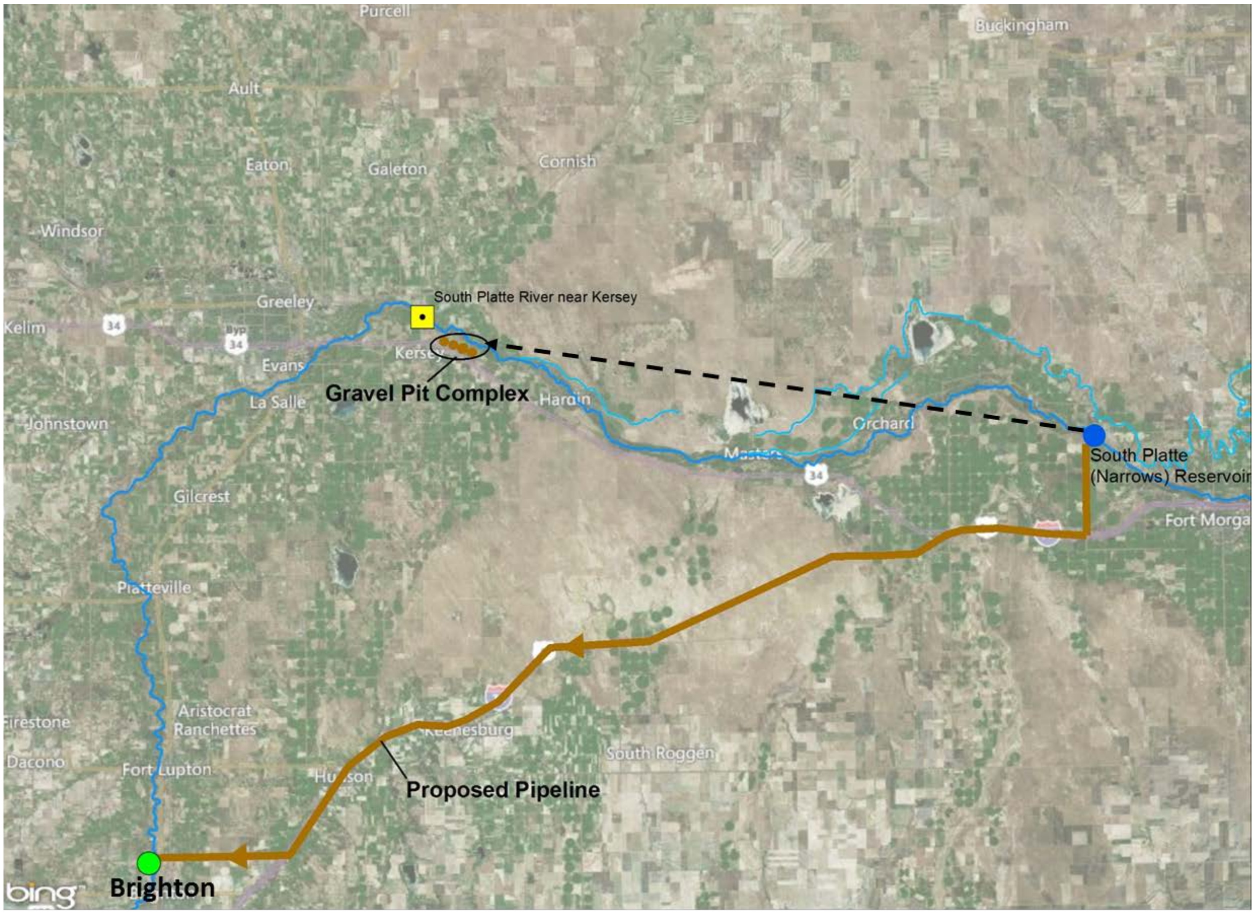


Figure 10-3. Mainstem Storage Conceptual Design for South Platte (Narrows) Reservoir

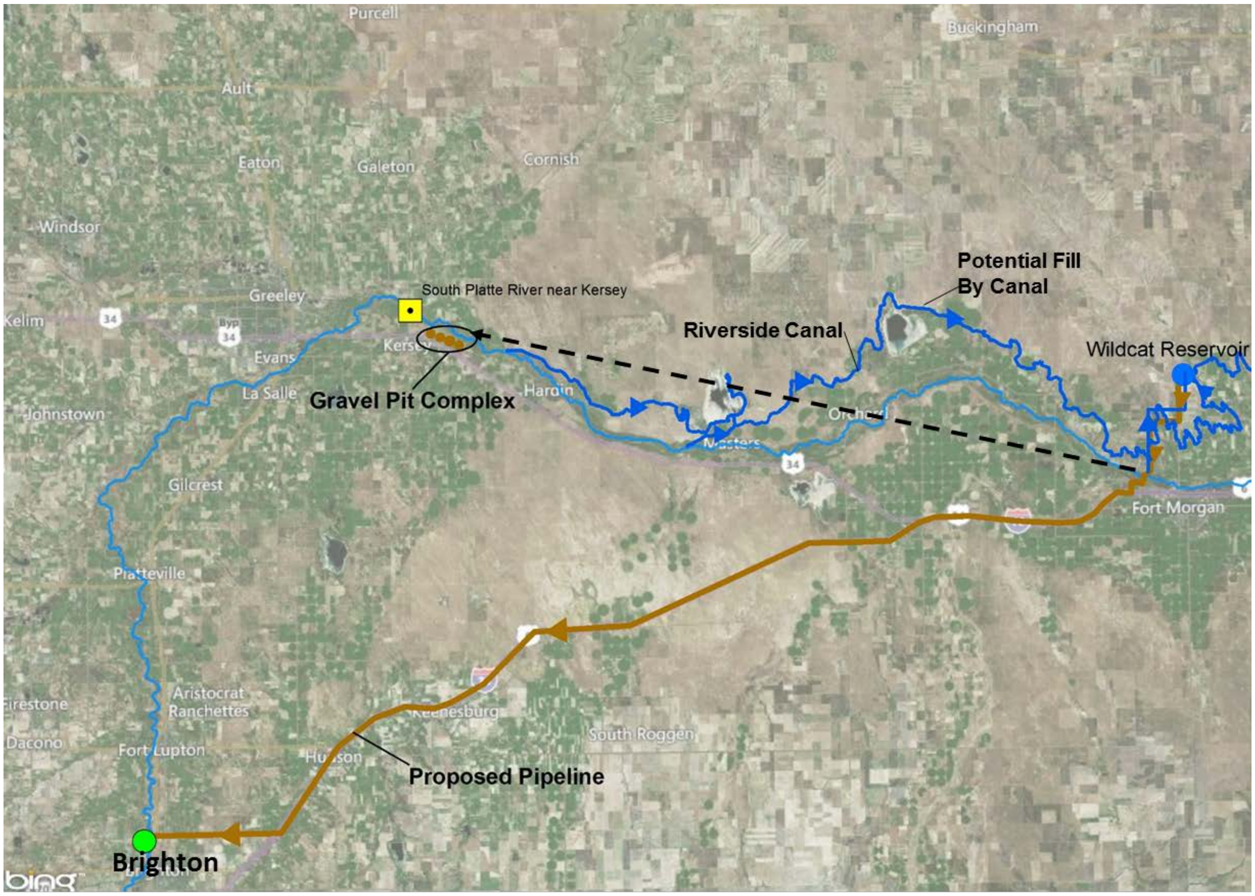


Figure 10-4. Mid Basin North Conceptual Design for Wildcat Reservoir

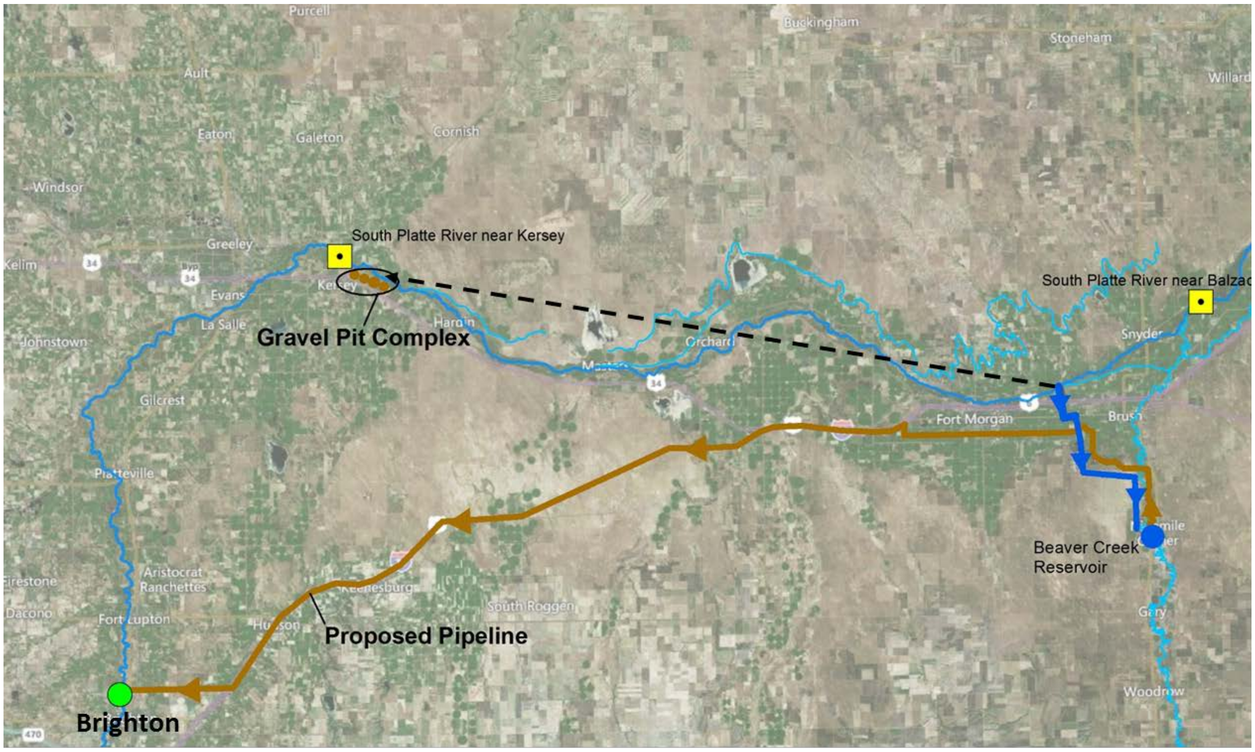


Figure 10-5. Mid Basin South Conceptual Design for Beaver Creek Reservoir

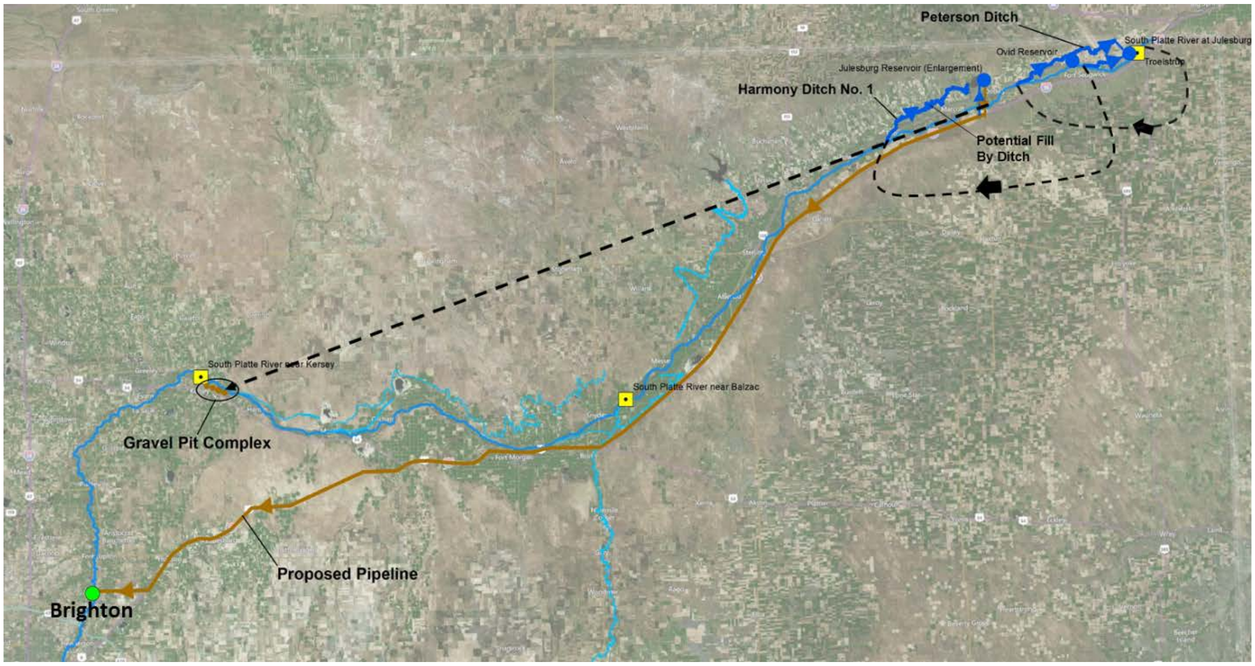


Figure 10-6. Lower Basin Storage Conceptual Design for Julesburg, Ovid, Troelstrup Reservoirs

Figure 10-7. Existing Reservoir Improvements Conceptual Design for Julesburg, North Sterling, Prewitt, Jackson Lake, and Riverside Reservoirs

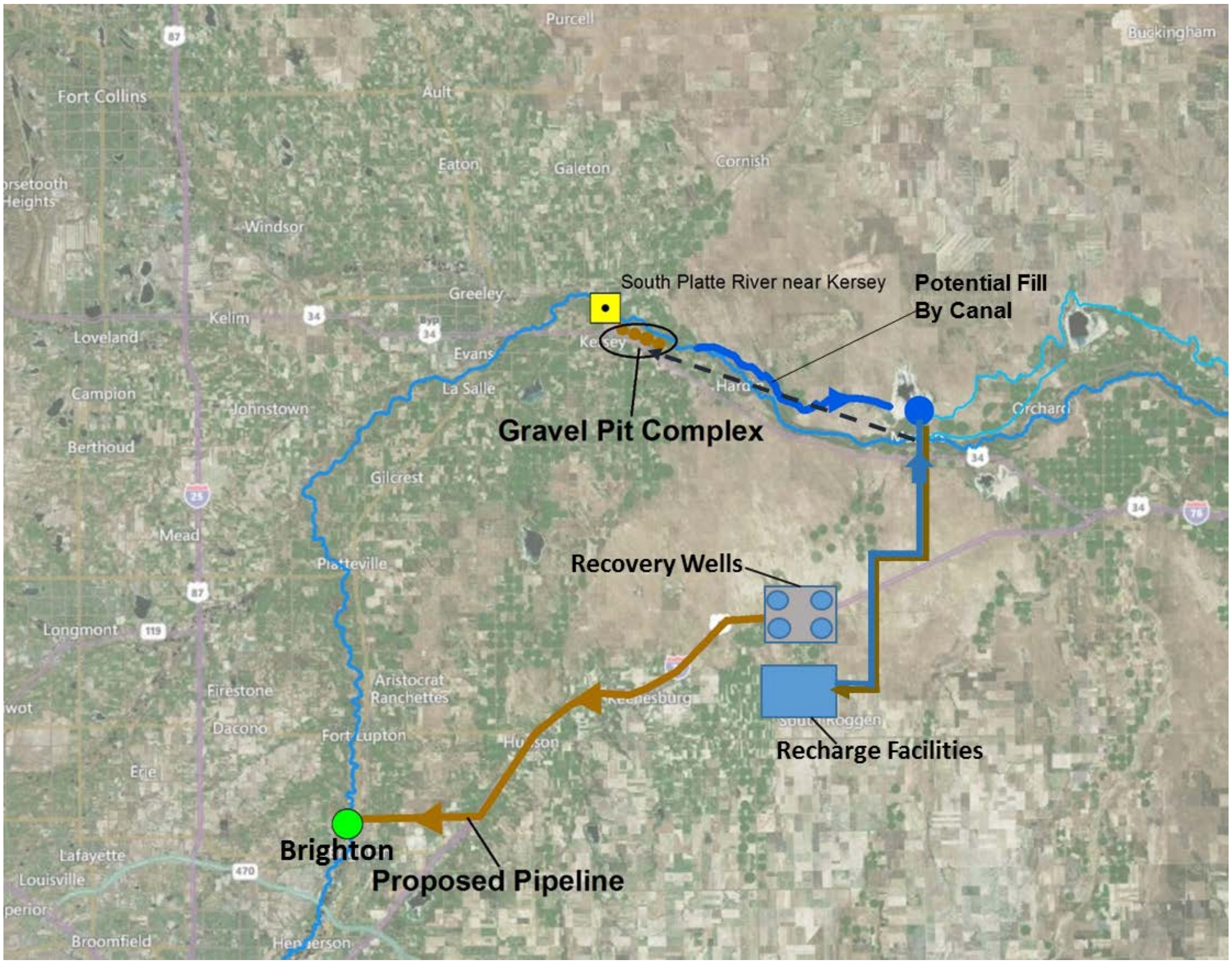


Figure 10-8. Groundwater Storage Basin West Conceptual Design for Lower Lost Creek Basin

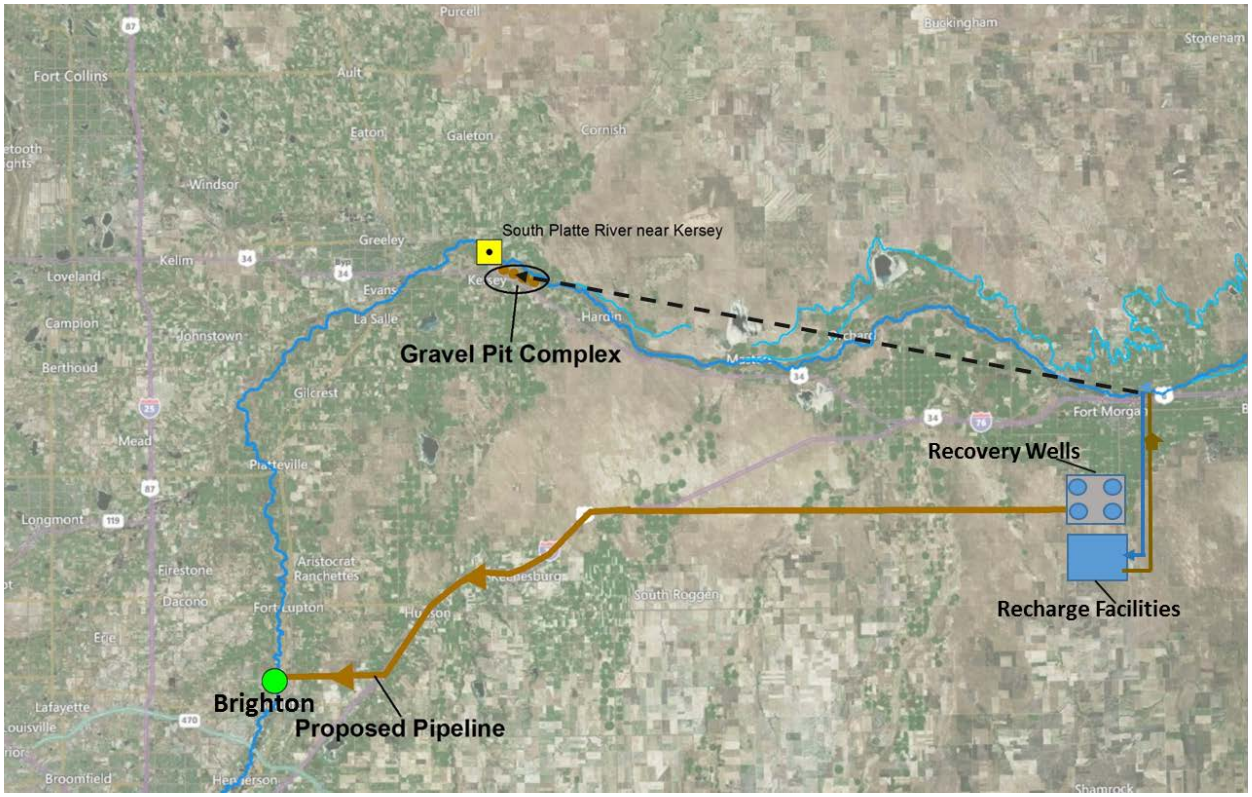


Figure 10-9. Groundwater Basin East Conceptual Design for Badger/Beaver Creek Basin

10.2.2. Surface Reservoir Concept Components

10.2.2.1 River Diversion and Intake Components

With the exception of the Mainstem Storage concept, all concepts require diversion of water from the South Platte River and conveyance to an off-channel storage facility. For any off-channel storage option, the water supply yield would be constrained by the capacity of the diversion and conveyance facilities used to fill the reservoir. Based on review of historical diversion data and conceptual engineering analysis of potential conveyance options, standard assumptions were made for analyzing storage concepts. All storage concepts included the following diversion and intake components.

- *A new 800 cfs (520 mgd) diversion structure on the South Platte River at a location close to the storage option.* This is close to the maximum historical river diversion and balances size and cost of the structure against frequency of bypassing potentially divertable flows due to limited diversion capacity (see **Section 6.4**). Available divertable flow in the South Platte River would exceed this capacity about 8-15 percent of the time, depending on the location.
- *A 10,000 ac-ft gravel pit complex at the diversion point.* This would allow the capacity of the intake conveyance facilities to be sized at 50 percent of the river diversion capacity. This was an estimated size for regulating storage; it was not simulated in the modeling of storage concepts or optimized.
- A new 96-inch pipeline and system of pump stations from the diversion structure to the reservoir or aquifer recharge area with a capacity of 400 cfs (260 mgd). It is possible that existing irrigation diversion structures and canals could be used to fill new storage sites depending on their location and available capacity at the time SPSS water rights would be in priority. Because of the great uncertainty around use of existing irrigation systems for new storage when the owner/operator is not defined, this study assumed new infrastructure would be required.

10.2.2.2 Outlet Components

For purposes of comparing SPSS storage concepts, it was assumed that any storage project would be operated to meet demands in three ways: (1) make releases to the South Platte and exchange up to Kersey to meet demands in the Northern Front Range area; (2) make releases to the South Platte River to meet demands downstream of the discharge point; and (3) make releases to a new pipeline to Brighton to meet demands in the Denver Metro/Northern Front Range area. To make these releases each storage concept included the same standard outlet components:

- Release of water back to the South Platte in the same pipeline used to fill the reservoir (bi-directional pipeline), with an unconstrained capacity.
- 100 mgd pipeline to Brighton. A capacity of 100 mgd (150 cfs) was selected because it is similar to the ultimate capacity of the Prairie Waters pipeline that delivers water from the Brighton area to Aurora and WISE participants.
- A 20,000 ac-ft gravel pit complex near Kersey to serve as the exchange-to point for the exchange alternative. The size of this storage was not optimized but was standard for all storage concepts.

10.2.3. Aquifer Storage Concept Components

The ASR site components were conceptually designed to recharge alluvial aquifers through surface infiltration basins with downgradient recovery wells. The ASR site components included associated instrumentation/controls, conveyance piping, and site excavation costs. ASR sites will also require similar intake components (diversion structure, gravel pit storage, pipeline) and outlet components (pipeline, gravel pit storage), as those described above.

10.3 ASSUMED OPERATIONS FOR STORAGE CONCEPT ANALYSIS

In order to simulate operation of each surface reservoir storage concept to estimate the water supply yield it could produce, a MODSIM operations model was constructed for the Lower South Platte River. The model used the infrastructure components described in the previous section. This section describes the other input data and assumptions used to create the MODSIM model and perform that analysis.

10.3.1. Hydrology

The MODSIM operations model used the daily estimate of available water under future river conditions for the period 1996-2015 from the Point Flow Model. The estimates of future available water account for effects of full use of reusable water by Denver Water and Aurora Water; IPPs from Colorado's Water Plan; and decreed but unexercised exchanges that would not have been reflected in the historical data in the Point Flow Model.

10.3.2. Demands

The same demands were applied to each storage concept, regardless of where it was located in the SPSS study area. This provided a standard basis of comparison for all the storage concepts. The maximum potential demands as well as their temporal distribution through the year were described in **Section 6.0** based on the SWSI gap analysis for the lower South Platte Basin.

All storage concepts were simulated to concurrently meet the three demand scenarios according to the following logic.

1. Priority 1: Exchange to Kersey. Water was exchanged to the assumed 20,000 ac-ft gravel pit complex at Kersey to meet the M&I and agricultural demands aggregated at the Kersey gage. Demands at the Kersey gage represent M&I and agricultural shortages for areas primarily east and north of this point. It is recognized that infrastructure would be required to deliver water from Kersey to M&I or agricultural customers upstream of this point. That infrastructure has not been conceptualized and has not been included in the SPSS costs described in this report.
2. Priority 2: Release to River. Water was released back to the South Platte River to meet downstream agricultural and municipal demands. This would include use of the SPSS water to meet augmentation commitments.
3. Priority 3: Pipe to Brighton. Water delivered by pipeline to the Brighton area could meet demands for municipal customers upstream of the Denver gage and municipal and agricultural customers upstream of the Kersey gage. This was given the lowest priority among the demand scenarios because it would have the highest capital and operating costs. It is recognized that infrastructure would be required to deliver water from Brighton to M&I or agricultural customers upstream of this point. That infrastructure has not been conceptualized and has not been included in the SPSS costs described in this report.

10.3.3. System Losses

Losses in pipelines and pump stations were set at 5 percent of the flow conveyed. Net evaporation at all the reservoir sites was set at 34 inches/year, based on a typical value for the lower South Platte Basin.

10.3.4. Groundwater Storage Options

To simplify the initial comparison of options, all groundwater storage options were assumed to be operated in an aquifer storage and recovery mode in which recharge would occur in surface infiltration basins and recovery would occur through a gallery of extraction wells.

The primary assumptions used to simulate groundwater storage options were developed based on review of available documentation for hydrogeologic characteristics and are listed in **Table 10-2**. Year-to-year carryover storage was allowed as it would be in a surface reservoir. Deliveries from the river were assumed to occur from new river diversions and dedicated pipelines including10,000 ac-ft of regulating storage (e.g., gravel lakes), similar to operation of the surface storage options.

10.3.5. Reservoir Operations

Reservoir storage could be operated in many different ways depending on the needs of the owners. Conceptually, water from storage could be:

- used as a base supply with a constant amount taken every year;
- used as a supplemental dry year supply with water withdrawn only in drought periods;
- used as a primary supply with water taken whenever it is available; or
- used as a mitigation supply to augment diversions from other sources.

Table 10-2. Aquifer Storage Modeling Assumptions

Characteristic	Lower Lost Creek Basin	Badger/Beaver Basin
Storage Capacity (ac-ft)	157,000	311,000
Storage per Acre (ac-ft/ac)	5.7	4.4
Maximum Inflow (ac-ft/month)	5,000	5,000
Maximum Outflow (ac-ft/month)	4,000	4,000
Dominion and Control / Residence Time	Challenging	Challenging
Multi-year Storage	Challenging	Challenging
Infiltration Rate (ft/day)	1.0	1.0
Extraction Well Capacity (gpm)	500	500
Approximate Well Count	60	60
Losses in Aquifer (% of inflow)	10	10

Because SPSS reservoir ownership is unknown and the demands the reservoir could be operated to meet are unknown, a standard operating approach was adopted for each storage concept such that the performance of the concepts could be compared against the same set of conditions. Two operating approaches were considered.

1. Firm Yield Analysis. Firm yield is the maximum yield that could be delivered in every year, for all years of the simulation. In this approach the firm yield for each concept was determined by varying the total demand on a trial-and-error basis until the maximum demand that could be met in every year was determined.
2. As-Available Analysis. This approach estimated the yield that could be delivered if the water would be taken from the river into storage whenever available and delivered from storage to a demand center whenever there is demand. It assumes SPSS water would the primary supply for the user and would be taken whenever it is available.

Results from simulations of storage concepts using both approaches to reservoir operations were investigated to assure that the selection of a particular operating assumption would not bias the comparison of storage concepts.

10.4 STORAGE CONCEPT WATER SUPPLY ANALYSIS RESULTS

10.4.1. Basic Firm Yield Analysis

The firm yield for each of the storage concepts was estimated for the maximum capacity of the representative storage options. Results are shown in Table 10-3. As an example of the firm yield simulations, Figure 10-10 shows a plot of daily MODSIM model results for the Upper Basin – Sandborn Reservoir simulation. The figure shows the demand met on a daily basis by a 224,000 ac-ft reservoir diverting from the Upper Basin portion of the SPSS study area. The firm yield is met on almost every day of the simulation; the shortages are due to the tolerance in the iterative routine used to estimate firm yield in the MODSIM model. The plot shows the reservoir emptying during the critical drought in the model period.

Table 10-3. Storage Concept Firm Yield for Maximum Capacity of Representative Storage Sites

Storage Concept	Representative Storage Site(s)	Reservoir Capacity (ac-ft)	Firm Yield with Pipeline to Brighton (ac-ft/yr)	Firm Yield without Pipeline to Brighton (ac-ft/yr)
Mainstem Storage	South Platte (Narrows)	1.960,000	62,000	47,000
Upper Basin Storage	Sandborn	224,000	22,000	20,000
Mid Basin Storage North	Wildcat	60,000	9,000	7,000
Mid Basin Storage South	Beaver Creek	95,000	11,000	8,000
Lower Basin Storage	Julesburg, Ovid, Troelstrup	40,300	24,000	24,000
Existing Reservoir Improvements	Riverside, Jackson, Prewitt, Julesburg, North Sterling	56,464	17,000	15,000

Figure 10-11 plots the demand locations receiving deliveries of firm yield for each of the storage concepts. Recall that the Kersey demand is met through a combination of exchange and pipeline deliveries, the Denver demand is met through pipeline deliveries alone, and the Balzac and Julesburg demands are met by direct releases to the South Platte. Kersey demands receive the majority of the firm yield for most concepts. Exchanges have the highest priority in the model when attempting to satisfy demands, so those are exercised first and remaining water is released to the river or piped to Brighton. For concepts with some or all of the storage in the lower basin (Lower Basin Storage, Existing Reservoir Improvements), direct releases are the primary mechanism for meeting demands because of the constraints of limited exchange potential. Different reservoir operation assumptions would give different results for distribution of demands being met; for this analysis, the total firm yield is the most important parameter for comparing storage concepts.

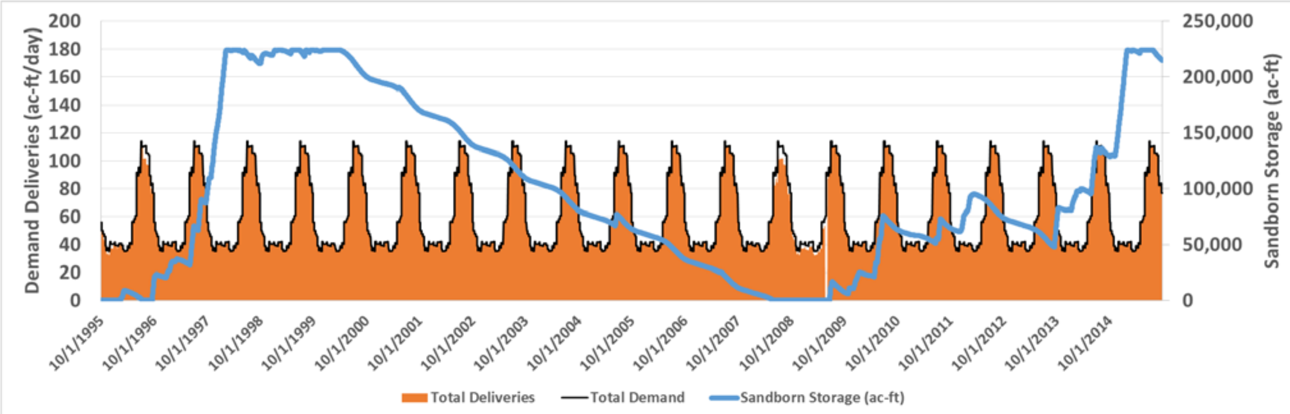


Figure 10-10. Demand Met and Storage Contents for Sandborn Reservoir Firm Yield Analysis

It is noted that any concept in which water is exchanged or piped to Brighton would benefit greatly from terminal storage at the delivery point. As noted previously, this SPSS analysis did not evaluate infrastructure needed to store or convey water beyond Kersey or Brighton.

Note: Groundwater storage concepts were simulated based on sizing to capture large peak flows from South Platte River for purposes of comparing to surface reservoirs. Feasible recharge constraints would produce much smaller firm yields.

Figure 10-11. Distribution of Firm Yield to Demand Points for Storage Concepts with Maximum Capacity of Representative Storage Site

The results depicted in Figure 10-11 show that for the firm yield simulation most storage concepts do not utilize the Brighton Pipeline to meet demands at the Denver demand node because they do not have water remaining after the higher priority demands are satisfied. This raises the question of how much the Brighton Pipeline is being used in the simulations. The water delivered in the Brighton Pipeline can meet demands at the Denver demand node but can also be discharged to the South Platte River to meet demands at the Kersey demand node that could not be met through exchanges due to limited exchange potential. **Table 10-4** summarizes the average annual water conveyed in the Brighton Pipeline for each surface reservoir concept. The Mainstem Storage concept makes significant the most use of the Brighton Pipeline. **Figure 10-12** is a plot of the daily flow in the Brighton Pipeline for the firm yield simulation of the Upper Basin storage concept with Sandborn Reservoir. This shows that the pipeline is used at a high flow rate only infrequently. As shown later in this section, this pipeline is a very expensive infrastructure component. For comparison the firm yields without the pipeline are shown in **Table 10-3**.

Table 10-4. Average Flow through Brighton Pipeline for Firm Yield Simulations

Solution Name	Representative Storage Site(s)	Average Annual Flow through Pipeline to Brighton (AF/Y)
Mainstem Storage	Narrows	15,000
Upper Basin Storage	Sandborn	2,000
Mid Basin Storage North	Wildcat	2,000
Mid basin Storage South	Beaver Creek	3,000
Lower Basin Storage	Julesburg, Ovid, Troelstrup	0
Existing Reservoir Improvements	Riverside, Jackson, Prewitt, Julesburg, North Sterling	2,000

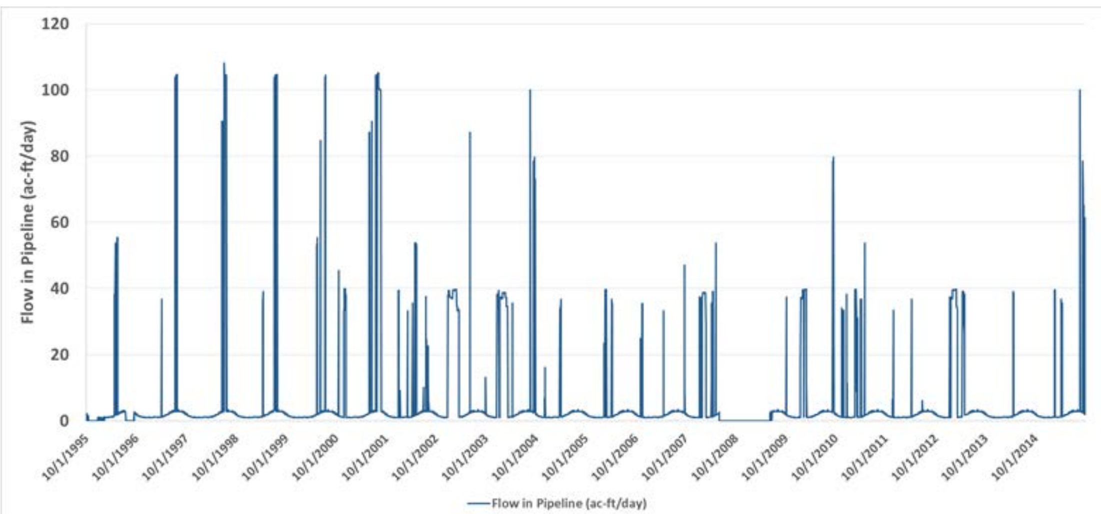


Figure 10-12. Daily Flow in Brighton Pipeline for Upper Basin Storage Concept (Sandborn Reservoir) Firm Yield Simulation

10.4.2. Firm Yield Sensitivity Analyses

A firm yield sensitivity analysis was performed in which selected alternative sizes of storage capacity for certain storage concepts were simulated to assess the effect of capacity on firm yield.

Mainstem Storage Concept. Table 10-5 and Figure 10-13 compare firm yield at the South Platte (Narrows) Dam site for reservoir capacities of 1,960,000 ac-ft, 500,000 ac-ft and 250,000 ac-ft. Results show firm yield is strongly correlated to reservoir capacity. Although the storage efficiency (storage-to-yield ratio) is better for the smaller reservoir, in general bigger is better for the mainstem dam sizes investigated.

Table 10-5. Mainstem Storage Concept Sensitivity Analysis Results

Reservoir Capacity (ac-ft)	Firm Yield (ac-ft/yr)	Storage:Yield Ratio
1,960,000	61,700	16:1
500,000	38,000	13:1
250,000	20,300	12:1

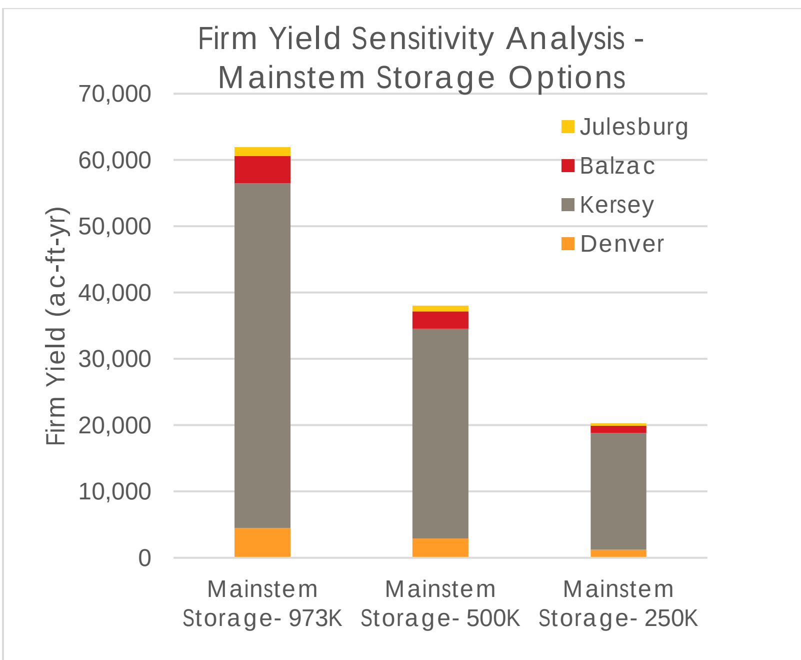


Figure 10-13. Mainstem Storage Concept Sensitivity Analysis Results

Mid Basin Storage Concept. A larger storage capacity than the two identified Mid Basin sites was simulated to estimate potential benefits from additional storage in this region. A 150,000 ac-ft capacity was simulated at the Wildcat Reservoir location. Results are shown in Table 10-6. A larger storage capacity provides a significant increase in firm yield in this region even with off-channel storage options. Because of the high variability in annual flow the storage:yield ratio is better for smaller reservoir sizes.

Table 10-6. Mid Basin Concept Sensitivity Analysis

Storage Site	Capacity (ac-ft)	Firm Yield (ac-ft/yr)	Storage:Yield Ratio
Wildcat	60,000	9,300	6:1
Beaver Creek	95,000	10,700	9:1
Wildcat	150,000	17,200	9:1

Aquifer Storage vs Surface Storage. To compare relative benefits of surface storage and aquifer storage for similar operations, the Upper Basin Storage Concept using Sandborn Reservoir was simulated with a capacity of 150,000 ac-ft, and the Groundwater Basin West aquifer storage option was simulated with the Lost Basin ASR capacity of 157,000 ac-ft. To be comparable to the surface reservoir options, in this case the Lost Creek Basin concept was expanded such that the inflow/outflow facilities would be similar to those used for surface reservoirs; this would not only require the large intake and delivery pipelines and pump stations but also extremely large recharge basins and extraction wellfields. Results are shown in Table 10-7. The ASR concept gives a higher firm yield and better storage:yield ratio for essentially the same storage capacity. This is likely due primarily to the elimination of evaporation losses in the aquifer storage concept (although the simulation does include some groundwater losses). However, it is noted that designing and operating an aquifer storage project in this manner on such a large scale would be extremely challenging and may be infeasible.

Table 10-7. Surface Storage vs Aquifer Storage Comparison in Upper Basin

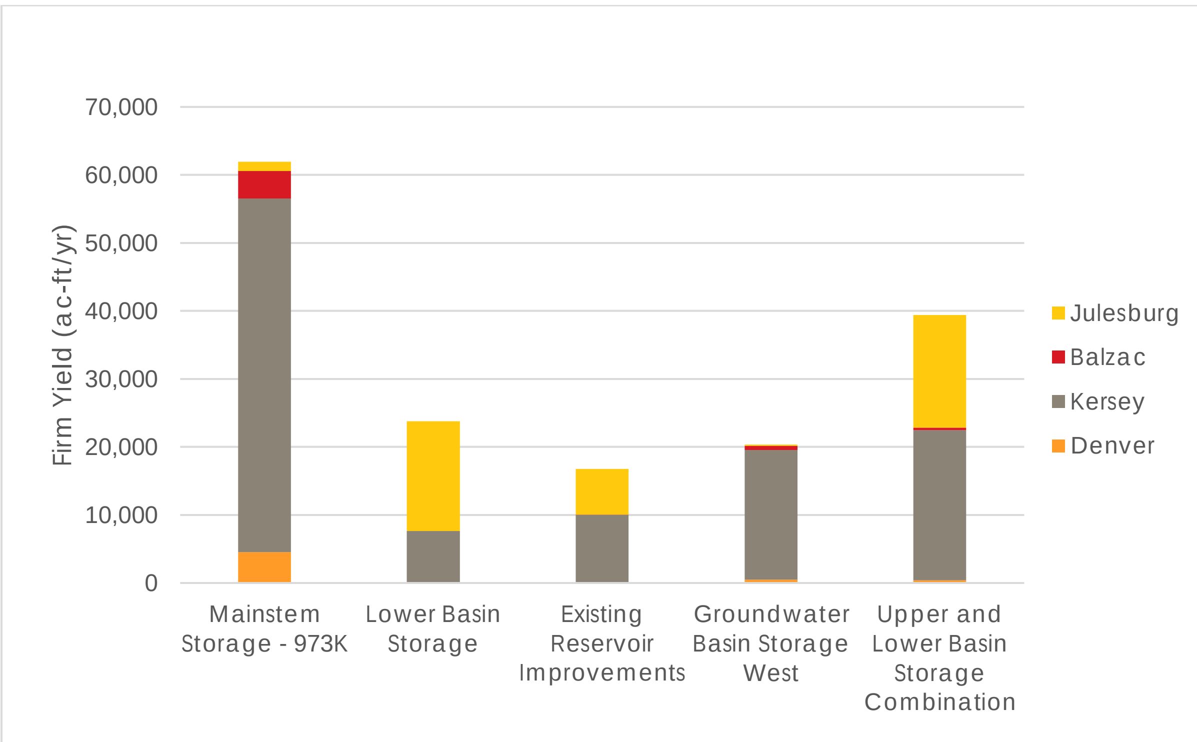
Storage Option	Capacity (ac-ft)	Firm Yield (ac-ft/yr)	Storage:Yield Ratio
Upper Basin Surface Storage	224,000	22,200	10:1
Upper Basin Surface Storage	150,000	16,200	9:1
Upper Basin Aquifer Storage	157,000	20,100	8:1

Note: Recharge and extraction capacities would be extremely large in this concept compared to most ASR projects in Colorado and may be infeasible.

Combination of Upper Basin + Lower Basin Concepts. Benefits of combining an Upper Basin project with a Lower Basin project were investigated by simulating a combination of Lost Creek ASR in the Upper Basin with the three surface reservoirs in the Lower Basin Storage concept. Results are shown in Table 10-8 and Figure 10-14. The benefits are significant; firm yield of this combination is exceeded only by the large Mainstem Dam concept.

Table 10-8. Firm Yield for Combined Upper and Lower Basin Storage Concepts

Storage Concept	Storage Options Simulated	Total Capacity (ac-ft)	Firm Yield (ac-ft/yr)	Storage:Yield Ratio
Lower Basin Storage Alone	Julesburg Enlargement/ Rehabilitation, Ovid, Troelstrup	40,300	23,500	2:1
Upper Basin Storage Alone	Lower Lost Creek ASR	157,000	20,100	8:1
Combined Upper and Lower Basin Storage	All of above	197,300	39,200	5:1



Note: Groundwater basin concepts with displayed in this chart were sized to capture peak flows from the South Platte River. Yield is greater than simulated for the more feasible aquifer storage concepts.

Figure 10-14. Comparison of Firm Yield for Combined Upper and Lower Basin Storage Concept with Other Concepts

10.4.3. As-Available Analysis of Storage Concepts

As noted previously, actual operations of any of the SPSS storage concepts are unknown because the ownership is unknown. Reservoir owners could choose to operate their storage in something other than a firm yield approach. To test the sensitivity of the comparison of storage concepts to operating assumptions, two other operational scenarios were simulated that assumed the storage would be operated to meet as much demand as possible whenever that demand occurred. These scenarios varied only in the amount of demand applied to the storage reservoirs.

- Scenario 1 – Demand on the reservoir was set to the total demand estimated based on the future M&I and agricultural South Platte Basin gap at the four demand centers as described in **Section 7.0** (annual demand = 502,900 AFY).
- Scenario 2 – Gap demand was scaled-back to force reservoirs to hold more water in storage during wet periods (annual demand = 97,000 AFY).

Modeling results are summarized in **Table 10-9** for the maximum potential capacities at each of the representative storage sites for the SPSS storage concepts. The average annual deliveries under this kind of operating assumption are much higher than the firm yields shown in **Table 10-3**. However, the reliability (percentage of days the full applied demand was completely satisfied) was very low. For the Upper Basin Storage simulation in **Figure 10-15**, the reliability is only 1 percent. For the Mainstem Storage concept the reliability is higher – 9 percent – because the storage volume is larger and there are no constraints in diversion and intake capacities. (Recall firm yield has a reliability of 100 percent.) **Figure 10-15** also shows that the storage is rarely used because demands are so high water is moved directly from the river to the demand centers. The simulation of this type of operation does not highlight the value of storage, but does demonstrate that there is a large amount of available water in the river to meet high demands on a very infrequent basis.

Table 10-9. Yield of Storage Concepts Based on As-Available Operations

Solution Name	Representative Storage Site(s)	Reservoir Capacity (AF)	Full Gap Demand (502,882 AFY) – Average Annual Delivery (AF/Y)	Scaled Demand (97,000 AFY) – Average Annual Delivery (AF/Y)
Mainstem Storage	Narrows	1,960,000	118,000	81,000
Upper Basin Storage	Sandborn	224,000	74,000	48,000
Mid Basin Storage North	Wildcat	60,000	82,000	43,000
Mid Basin Storage South	Beaver Creek	95,000	85,000	46,000
Lower Basin Storage	Julesburg, Ovid, Troelstrup	40,300	129,000	48,000
Existing Reservoir Improvements	Riverside, Jackson, Prewitt, Julesburg, North Sterling	56,464	143,000	59,000

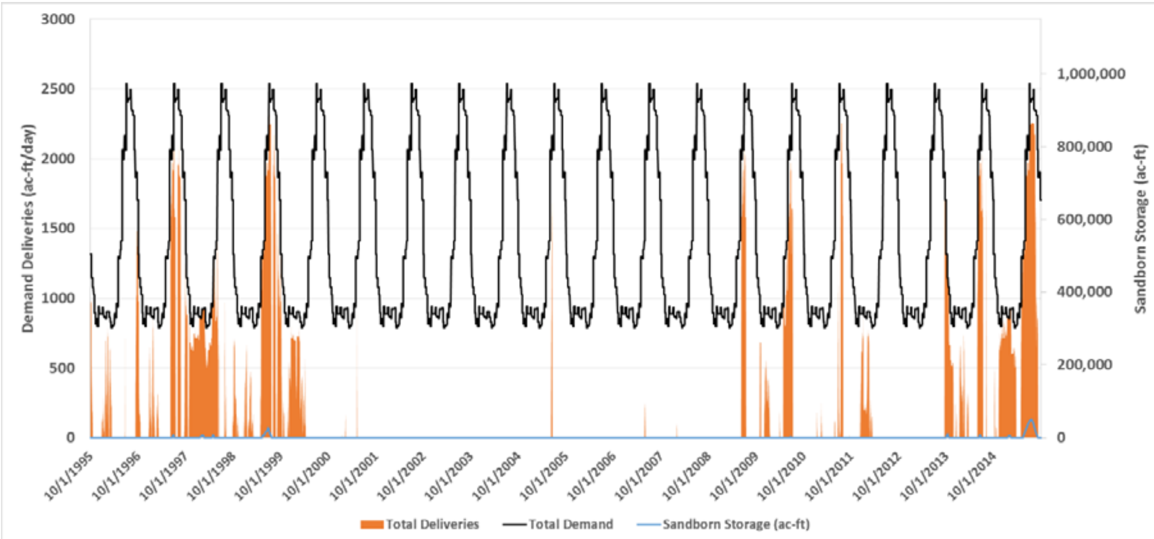


Figure 10-15. Simulation of Sandborn Reservoir with Full Gap Demand Applied in As-Available Operation Mode

Simulation of the scaled-back demands is summarized for each concept in **Table 10-9**, and is displayed for the Upper Basin (Sandborn) concept in **Figure 10-16**. The scaled-back demands are 97,000 ac-ft/yr compared to 502,900 ac-ft/yr for the full gap demands. Average annual deliveries are less than for the full gap scenario (because less water is demanded) and the benefits of storage are more evident. In addition, **Figure 10-16** shows that the reliability for this condition is approaching 50 percent, which is much better than when the full gap demands were applied.

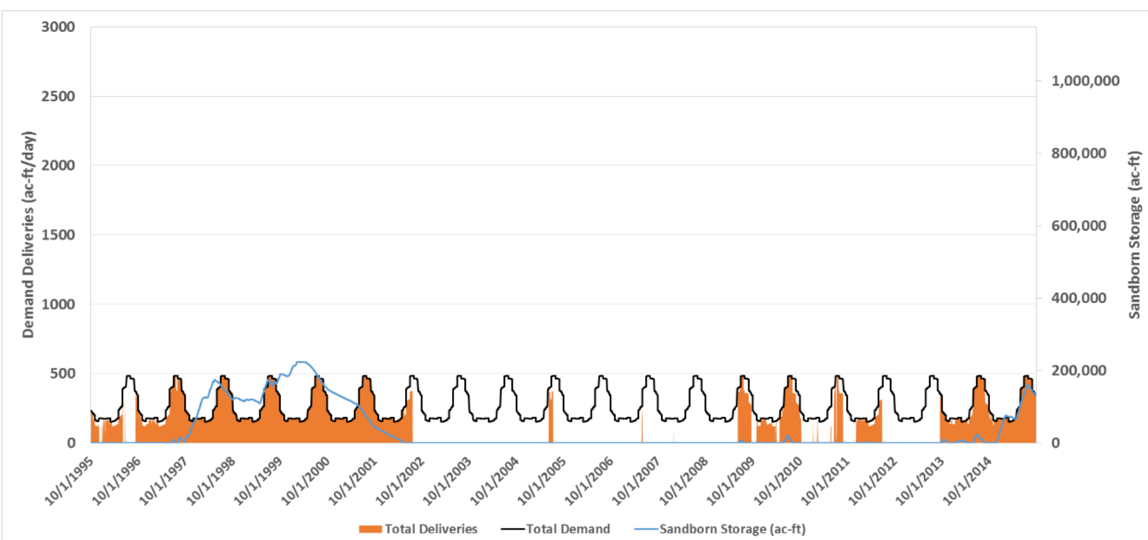


Figure 10-16. Simulation of Sandborn Reservoir with Scaled-Back Demand Applied in As-Available Operation Mode

10.5 SUMMARY OF STORAGE CONCEPT SIMULATIONS

The key findings of the storage concept simulation analysis are as follows.

1. The Firm Yield results are the most useful for this analysis and have an easier message to convey. Thus the firm yield results will be used to draw conclusions.
2. Firm yields of 9,000 ac-ft/yr to 62,000 ac-ft/yr were estimated for the representative storage concepts analyzed for this study.
3. Not surprisingly, the large mainstem reservoir has the best performance. Smaller mainstem reservoirs have significantly less firm yield and are comparable to other off-channel options.
4. Aquifer storage projects are more limited by recharge and recovery rates rather than storage volume. Typical aquifer storage projects are designed as supplemental supply sources, not as projects to recharge large volumes of water diverted during peak spring snowmelt periods. This results in lower firm yield, and does not attempt to maximize use of potential storage capacity as occurs with surface reservoirs. However, a related benefit is that aquifer storage projects are relatively low cost and can be scaled up over time (not constructed all at once). These unique characteristics make aquifer storage projects difficult to compare to surface water storage projects.
5. Average annual available water under future conditions varies from about 160,000 ac-ft/yr at Greeley to about 290,000 ac-ft/yr at Julesburg. Firm yields are much less than these values even for the large storage options due to the significant year-to-year variability in streamflow. Substantially more storage would be required to significantly increase firm yields from the alternatives.
6. Storage options lower in the basin tend to be more efficient (better storage:yield ratio) because there is more water available. This is biased by the fact that the lower basin concepts simulated in this study have multiple storage buckets and hence multiple inlets, so there is more diversion capacity, but the additional water is still an important factor in performance of storage options.
7. A combination of upper basin and lower basin storage concepts rivals the large mainstem dam for firm yield benefits.
8. No feasible storage concepts or reasonable combinations of concepts are capable of putting all the available flow in the lower South Platte River to beneficial use. Therefore as a general principle, more storage will always be "better" in this region in terms of maximizing available supply for basin water users.
9. Because nearly all concepts require off-channel storage and diversion from the South Platte River, intake capacity constraints can be important and there are benefits to having multiple off-channel storage projects to minimize these effects.

10.6 SUMMARY OF COSTS BY STORAGE CONCEPT

Conceptual (ACEE Class V) cost estimates were prepared for the surface reservoir storage concepts including components for storage (maximum size), intake system (new 800 cfs diversion structure, new 10,000 ac-ft gravel pit, new 400 cfs bi-directional conveyance system), and delivery system (conveyance system to Brighton, 20,000 ac-ft Kersey gravel pits). Aquifer storage concept costs were estimated based on the assumptions described earlier with recharge capacities of 5,000 ac-ft/month and extraction wellfield capacities of 4,000 ac-ft/month.

Table 10-10 summarizes capital costs for SPSS storage concepts. These costs are based on the largest feasible storage capacity for the surface reservoir, and the assumed modest size of an ASR project. No alignment studies or cost optimization were performed for this analysis. It is noted that cost estimates assume construction of all new intake and delivery system components; the ability to utilize existing diversion structures or irrigation canals to some degree for certain storage options would reduce the estimated cost. Use of SPSS water directly for M&I purposes at any of the demand centers in the analysis would require advanced water treatment; the cost of facilities to provide this treatment is not included in the storage concept costs. Storage concept costs do not include O&M costs for items such as energy for pumping or maintenance and replacement of mechanical equipment. Energy costs could be significant for pumpback components and aquifer storage and recovery projects.

Table 10-10. Summary of Storage Concept Costs for Maximum Representative Storage Site Including Pipeline to Brighton

Storage Concept (Representative Site)	Storage Capacity (ac-ft)	Storage Cost ($M)	Intake System Cost ($M) (Diversion, Gravel Pits, Pipes, Pump)	Delivery System Cost ($M) (Pipe to Brighton, Kersey Gravel Pits)	Total Storage Concept Cost ($M)	Firm Yield (AFY)	Total Unit Cost ($/AFY)
Surface Reservoir Storage Concepts							
Mainstem Dam (Narrows)	1,960,000	$145	-	$380	$525	62,000	$8,500
Upper Basin Storage (Sandborn)	224,000	$131	$168	$322	$621	22,000	$28,000
Mid Basin Storage North (Wildcat)	60,000	$79	$141	$433	$652	9,000	$72,000
Mid Basin Storage South (Beaver)	95,000	$66	$407	$437	$910	11,000	$83,000
Existing Reservoirs	40,300	$121	$221	$322	$664	17,000	$39,000
Lower Basin Storage	56,464	$118	$92	$826	$1,037	24,000	$43,000

Storage Concept (Representative Site)	Storage Capacity (ac-ft)	Storage Cost ($M)	Intake System Cost ($M) (Diversion, Gravel Pits, Pipes, Pump)	Delivery System Cost ($M) (Pipe to Brighton, Kersey Gravel Pits)	Total Storage Concept Cost ($M)	Firm Yield (AFY)	Total Unit Cost ($/AFY)
Groundwater Storage Concepts							
Groundwater Storage West (Lost Creek)	157,000	$39	$238	$ 158	$435	8,400	52,000
Groundwater Storage East (Badger/Beaver)	311,000	$39	$160	$270	$469	8,000	59,000

Note: Aquifer storage concepts are smaller than surface reservoir concepts, consistent with common existing projects.

As described in the discussion of storage concept modeling results, the pipeline to Brighton is used infrequently when it has lowest priority after exchanges and releases to the river have been performed. This pipeline is a very expensive component of any storage concept in the lower South Platte River. **Table 10-11** shows storage concept costs without the pipeline to Brighton. It is noted that without the pipeline the performance of any storage concept is very dependent on exchange potential in the South Platte River. While exchange potential was simulated in the reaches below Kersey, many factors could reduce this exchange potential in the future. In addition, the exchange potential between Kersey and Denver is very limited, and substantial demands at the Denver location could only be met using direct conveyance.

Table 10-11. Summary of Storage Concept Costs for Maximum Potential Storage Site without Pipeline to Brighton

Storage Concept (Representative Site)	Storage Capacity (ac-ft)	Storage Cost ($M)	Intake System Cost ($M) (Diversion, Gravel Pits, Pipes, Pump)	Delivery System Cost ($M) (Kersey Gravel Pits)	Total Storage Concept Cost ($M)	Firm Yield (AFY)	Total Unit Cost ($/AFY)
Surface Reservoir Storage Concepts							
Mainstem Dam (Narrows)	1,960,000	$145	-	$45	$190	58,000	$ 3,300
Upper Basin Storage (Sandborn)	224,000	$131	$168	$45	$344	21,000	$26,000
Mid Basin Storage North (Wildcat)	60,000	$79	$141	$45	$265	9,000	$29,000
Mid Basin Storage South (Beaver)	95,000	$66	$407	$45	$518	11,000	$47,000
Existing Reservoirs	40,300	$121	$221	$45	$387	17,000	$23,000
Lower Basin Storage	56,464	$118	$92	$45	$255	24,000	$11,000
Aquifer Storage Concepts							
Groundwater Storage West (Lost Creek)	157,000	$39	$238	$45	$322	8,400	$38,000
Groundwater Storage East (Badger/Beaver)	311,000	$39	$160	$45	$244	8,000	$31,000

Note: Aquifer storage concepts are smaller than surface reservoir concepts, consistent with common existing projects.

10.7 COMPARISON OF STORAGE CONCEPTS

The SEF for the SPSS contains many attributes that apply to the overall solutions and storage concepts. Many of the storage concept attributes are based on the specific criteria listed in HB 16-1256 for evaluating SPSS alternatives. Others were developed by the study team to assist in comparing the storage concepts on a relative basis.

Table 10-12 shows the attribute values for the eight SPSS storage concepts considered in this study. It also lists the cumulative scores for each storage concept when numerical values are assigned to the attribute qualifiers (e.g., 1.0, 0.5, 0). For many of the attributes, particularly those associated with the HB 16-1256 criteria, the storage concepts have very similar performance. They were formulated to meet demands in a variety of locations in the basin and thus have similar capabilities of providing water supply benefits listed in HB 16-1256. The storage concepts relying on reservoirs lower in the South Platte basin (e.g., Lower Basin Storage, Existing Storage) have lower scores due to the relatively greater difficulty in providing water supply and flood management benefits for large portions of the basin when storage is located downstream.

It is noted that this comparison is based on the storage concepts and representative storage sites simulated in the MODSIM model. For the SPSS analysis it was necessary to select a limited number of concepts for analysis. Many variations of these concepts would be feasible, including use of different storage options, increased storage capacity, and different operating assumptions. Variations in these storage concept definitions could result in substantial differences in scores exceeding the variability in the scores in **Table 10-12**. Furthermore, none of the concepts or individual site designs were optimized at this level because ownership of storage projects is not known. Results in this table should be used only for a high-level comparison of storage concepts. The fact that the comparison produces fairly similar scores for all of the storage concepts suggests that none should be eliminated based on this analysis.

It was not possible to monetize project benefits at this level of analysis to support a numerical benefit-cost comparison of storage concepts. Information in **Table 10-11**and **Table 10-11** allows for qualitative comparisons of benefits and costs of the limited number of storage concepts analyzed in this study. Storage concepts developed to meet the needs of specific water users could have very different costs and benefits based on their particular application and the ability to optimize size and performance to meet the specific project needs.

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Table 10-12. Site Evaluation Framework Attribute Values for Storage Concepts

Attribute	Description	Mainstem Dam	Upper Basin Storage	Mid Basin Storage - North	Mid Basin Storage - South	Lower Basin Storage	Existing Storage	Aquifer Storage West	Aquifer Storage East	Comments
Water Supply Gap Solution	The storage solution could capture water to meet demands in the basin.	High	Medium	Low	Medium	Medium	Medium	Medium	Medium	Based on firm yield
Reduce TransBasin Diversions	The storage solution could yield additional supplies from in-basin sources, reducing the need for future transbasin diversions.	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Any in-basin yield substitutes for transbasin diversions
Multiple Users Supply	The storage solution could supply water to various municipal, industrial, environmental, and agricultural water users in the basin.	High	High	High	High	Low	Medium	High	Medium	Upstream is good. Far downstream with no pipeline is bad.
Augmentation Plan Operation Enhancement	The storage solution could be used to optimize the operation of existing or future augmentation plans.	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Any storage concept can release to river so all those above Lower Basin could be operated for augmentation

Attribute	Description	Mainstem Dam	Upper Basin Storage	Mid Basin Storage - North	Mid Basin Storage - South	Lower Basin Storage	Existing Storage	Aquifer Storage West	Aquifer Storage East	Comments
Aquifer Recharge Operations	The storage solution is an aquifer recharge facility, directly delivers water to aquifer recharge facilities, or facilitates conjunctive use.	Medium	Medium	Medium	Medium	Low	Medium	High	High	Lower Basin would be below aquifer recharge facilities
ATM Partnership	A storage solution would have available storage for temporary leased water to be stored to help the ATM operations and partnerships.	High	High	High	High	High	High	High	High	All could do this
Exchange Potential Enhancement	The storage solution adds storage capacity for interim storage or "leap-frogging" exchanges, or could add streamflows that would increase exchange potential in the river.	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes for all except Lower Basin
Recreation Benefit	The storage solution would increase recreational opportunities.	Positive	Positive	Positive	Positive	Positive	Neutral	Neutral	Neutral	Positive for new surface sites; neutral for GW and existing storage sites

Attribute	Description	Mainstem Dam	Upper Basin Storage	Mid Basin Storage - North	Mid Basin Storage - South	Lower Basin Storage	Existing Storage	Aquifer Storage West	Aquifer Storage East	Comments
Enhance Streamflow	The storage solution could deliver water to downstream users via natural channels, enhancing stream flow.	Medium	High	High	High	Medium	Medium	High	High	All could release to South Platte; some could release to tribs
Compact Compliance	The storage solution could increase low flows at the state line and reduce frequency of compact calls.	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	All would do this
Increase Ag Production	The storage solution could help meet the agricultural demand gap in the basin.	Low	Low	Low	Low	High	Low	Low	Low	
Reduce Buy&Dry	The storage solution could yield additional M&I supplies from in-basin sources, reducing the pressure to buy Ag water rights.	High	Medium	Low	Medium	Medium	Medium	Medium	Medium	Based on firm yield and applicability to potential M&I users

Attribute	Description	Mainstem Dam	Upper Basin Storage	Mid Basin Storage - North	Mid Basin Storage - South	Lower Basin Storage	Existing Storage	Aquifer Storage West	Aquifer Storage East	Comments
Delivery Water Quality	The storage solution would deliver raw water requiring advance treatment to achieve primary and/or secondary drinking water standards.	Low	Low	Low	Low	Low	Low	Low	Low	All water in SPSS study area would need advanced treatment for potable use
Permitting Feasibility	The potential permitting feasibility of site and solution.	Low	Medium	Medium	Medium	Medium	High	High	High	On channel is worst; existing dams and GW are best
Water Rights	Measure of the perceived ease in obtaining the water rights/decrees required to operate the solution.	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Set all to medium. All will have some issues.
Combined Permitting	Captures the potential increase in permitting complexity for the solutions compared to storage sites alone.	Same	Same	Same	More	More	More	Same	More	Used "More" for concepts requiring longer pipelines to Brighton
Estimated Permit Timeline	The probability that permits would be secured quickly.	Low	Medium	Medium	Medium	Medium	High	Medium	Medium	Mainstem dam is longest. Modifications to existing reservoirs is shortest.

Attribute	Description	Mainstem Dam	Upper Basin Storage	Mid Basin Storage - North	Mid Basin Storage - South	Lower Basin Storage	Existing Storage	Aquifer Storage West	Aquifer Storage East	Comments
Combined Impact	Captures the potential increase in environmental impacts for the solutions compared to individual sites alone.	More	More	More	More	More	More	More	More	All require facilities outside the storage footprint
River Reach	River reach where the solution is predominantly located.	Kersey-Balzac	Kersey-Balzac	Kersey-Balzac	Kersey-Balzac	Balzac-Julesburg	Balzac-Julesburg	Kersey-Balzac	Balzac-Julesburg	
Meet Demands	Ability of a solution to meet demands, either upstream or downstream	US and DS	US and DS	US and DS	US and DS	US and DS	US and DS	US and DS	US and DS	All concepts were formulated to meet demands throughout Basin
Total Score (Unweighted)		**11.5**	**12**	**11**	**11**	**8**	**10**	**12**	**10.5**	

10.8 BENEFICIAL USE OF COLORADO'S AVAILABLE SOUTH PLATTE WATER

The ability of the simulated storage concepts to put Colorado's South Platte River water to beneficial use is summarized in **Table 10-13**. This analysis used future hydrology, and shows that while a significant amount of water that would otherwise leave Colorado could contribute to in-state beneficial uses, considerably more storage would be required to use all the state's available South Platte water resources. A plot of daily flows at the state line for the Upper Basin Storage Concept is shown in **Figure 10-17**. Similar plots for all of the storage concepts are contained in **Appendix J**.

Table 10-13. Water Leaving the State under Future Hydrology for Simulated Storage Concepts

Storage Concept	Average Annual Water Leaving State (ac-ft)	Median Annual Water Leaving State (ac-ft)	Percentage of Available Water Contributing to Beneficial Use (1)
No Storage	343,000	249,000	-
Mainstem Storage	169,000	150,000	51%
Upper Basin Storage	279,000	210,000	19%
Mid Basin Storage North	272,000	196,000	21%
Mid Basin Storage South	269,000	192,000	22%
Lower Basin Storage	193,000	78,000	44%
Existing Reservoir Improvements	173,000	100,000	50%
Groundwater Basin Storage West (sized and operated similar to surface reservoirs)	280,000	213,000(2)	18%
Groundwater Basin Storage East (sized and operated similar to surface reservoirs)	271,000	196,000(2)	21%

(1) Includes evaporation losses and other losses which would not be beneficial uses.
(2) Assumes maximum size to capture peak spring runoff. Actual projects would be smaller and leave more water at the state line.

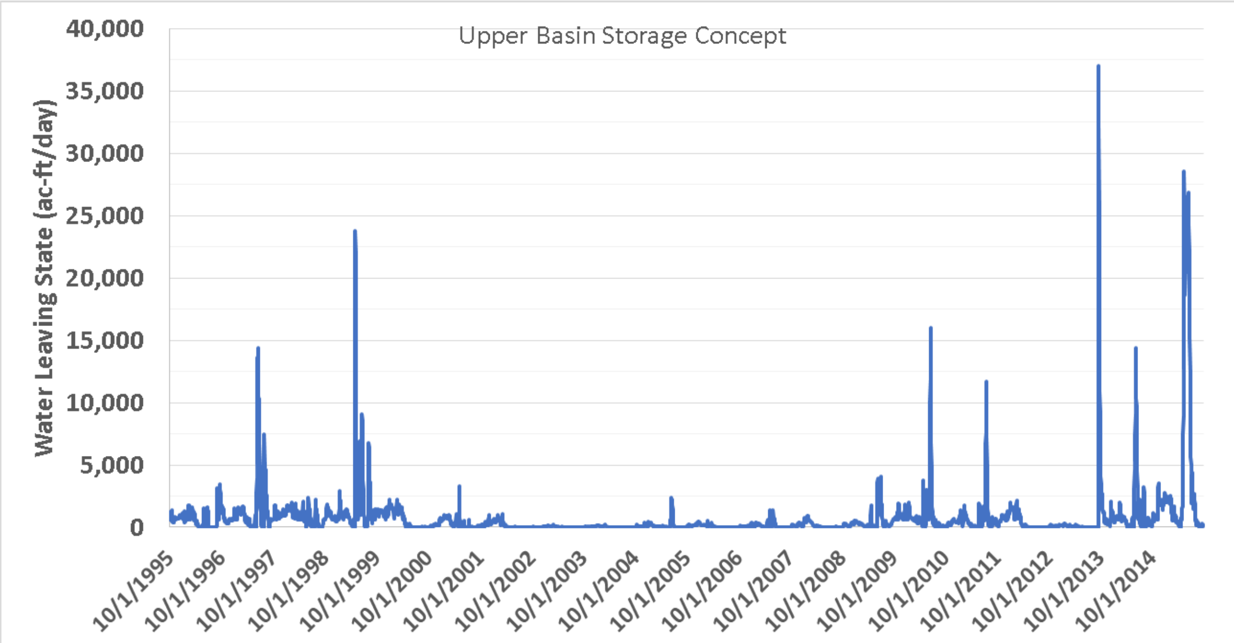

Figure 10-17. Timeseries of Water Leaving the State for Upper Basin Storage Concept under Future Hydrology

11. CONCLUSIONS AND RECOMMENDATIONS

11.1 CONCLUSIONS

11.1.1. Available Water, Demand and Water Quality

The following conclusions relate to available water in the SPSS study area.

1. A large supply of water is available for beneficial use in the lower South Platte Basin. Between 1996 and 2015, an annual median of approximately 293,000 ac-ft/yr of water was delivered to Nebraska in excess of the South Platte Compact. Excess available water varied between 10,000 ac-ft/yr and 1,904,000 ac-ft/yr over this period.
2. Under future conditions, average annual water available for diversion to a new storage project would vary from approximately 214,000 ac-ft/yr at Kersey to 332,000 ac-ft/yr at Julesburg. Median annual available water would vary from approximately 116,000 ac-ft/yr at Kersey to 232,000 ac-ft/yr at Julesburg, highlighting the influence of a few high runoff years on streamflow statistics in the South Platte Basin.
3. Annual streamflows in the study area are characterized by a few very high flow years. A large mainstem dam or several off-stream dams with large diversion structures would be required to capture a large portion of the available streamflow.
4. Available water at Kersey is much less than at Julesburg due to return flows in the lower basin. A large lower basin reservoir(s) would be required as part of a storage scheme to capture a large portion of available flow upstream of the state line.
5. Because the vast majority of storage options are located off the main South Platte River channel, physically available water is constrained by the diversion capacity and the capacity of conveyance facilities from the river to the storage reservoir. Large diversion and conveyance structures would be needed to capture and convey water from the river to off-channel storage. At the Balzac gage near the middle of the SPSS study area, a diversion capacity of 550 cfs would be needed to capture 85 percent of the available water.
6. Future water shortages in the lower South Platte Basin based on the water supply gap estimated in SWSI 2010 are significant, and exceed the estimated available water in the future. Annual municipal and agricultural demands that could potentially be served by water from a SPSS storage project total over 502,000 ac-ft/yr for the Denver Metro Area, the Northern Front Range Region, and the lower South Platte basin below Greeley.
7. Water quality throughout the SPSS study area is adequate for agricultural use but would require advanced water treatment for direct municipal use.

11.1.2. Storage Options and Concepts

Conclusions related to the SPSS analysis of storage opportunities in the lower South Platte Basin are summarized as follows.

1. Many off-channel storage options are feasible and can be combined in a wide variety of water supply concepts.
2. Firm yields of 9,000 ac-ft/yr to 62,000 ac-ft/yr were estimated for the representative storage concepts analyzed for this study.
3. Capital costs for storage concepts range from $7,400 to $78,200/ac-ft/yr, exclusive of treatment costs, with a pipeline to Brighton. Without the pipeline to Brighton the concept costs range from $3,300 to $47,000/ac-ft/yr exclusive of treatment costs. The upper end of this range greatly exceeds the cost of recent water development projects in Colorado.
4. Not surprisingly, a large mainstem reservoir has the best performance in terms of putting the state's water to beneficial use. However, permitting obstacles may be insurmountable.
5. Aquifer storage projects are more limited by recharge and recovery rates rather than storage volume. Typical aquifer storage projects are designed as supplemental supply sources, not as projects to recharge large volumes of water diverted during peak spring snowmelt periods. This results in lower firm yield, and does not attempt maximize use of potential storage capacity as occurs with surface reservoirs. However, a related benefit is that aquifer storage projects are relatively low cost and can be scaled up over time (not constructed all at once). These unique characteristics make aquifer storage projects difficult to compare to surface water storage projects.
6. Storage options lower in the basin tend to be more efficient (better storage:yield ratio) because there is more water available. However they are further from the main demand centers.
7. Combinations of storage options working conjunctively can provide significantly more benefit than individual options. A combination of upper basin and lower basin storage concepts rivals the large mainstem dam option for firm yield benefits. However, there will be reduction in efficiency as the number of projects goes up, and even with multiple storage project a large amount of available water would leave Colorado.
8. No feasible storage concepts or reasonable combinations of concepts are capable of putting all the available flow in the lower South Platte River to beneficial use. This is shown in **Table 11-1**. Therefore as a general principle, more storage will always be "better" in this region in terms of maximizing available supply for basin water users.

Table 11-1. Water Leaving the State under Future Hydrology for Simulated Storage Concepts

Storage Concept	Median Annual Water Leaving State (ac-ft)	Percentage of Available Water Contributing to Beneficial Use (1)
No Storage	249,000	-
Mainstem Storage	150,000	51%
Upper Basin Storage	210,000	19%
Mid Basin Storage North	196,000	21%
Mid Basin Storage South	192,000	22%
Lower Basin Storage	78,000	44%
Existing Reservoir Improvements	100,000	50%
Groundwater Basin Storage West	213,000(2)	18%
Groundwater Basin Storage East	196,000(2)	21%

(1) Includes evaporation losses and other losses which would not be beneficial uses
(2) Assumes maximum size to capture peak spring runoff. Actual projects would be smaller and leave more water at the state line.

10. Because nearly all concepts require off-channel storage and diversion from the South Platte River, intake capacity constraints can be important and there are benefits to having multiple off-channel storage projects to minimize the effects of these constraints.
11. Enlargements and rehabilitations of existing reservoirs tend to score higher than new reservoirs in the multi-criteria ranking process.
12. Triple bottom line scores for the storage sites analyzed in this study were fairly similar at this level of analysis without specific information on how the sites would be used in a water supply strategy; thus the triple bottom line scoring process should not be used to eliminate options at this time.
13. Any of the storage concepts could be candidates for further study in the future under the right circumstances. However, concepts with more storage higher in the basin generally offer a greater potential for benefits and could be more attractive to a broader variety of potential participants.
14. Multiple large storage projects, including one low in the basin, would be required to capture a substantial amount of the available water above the state line.
15. Even a combination of conjunctively operated storage projects would not be capable of addressing the majority of the combined overall M&I and agricultural water supply gaps in the South Platte Basin.

11.2 RECOMMENDATIONS

The SPSS team developed the following recommendations for future work.

1. Better estimates of future hydrology should be developed to refine the anticipated available water under future basin operations. Completion of the South Platte Decision Support System would facilitate further hydrologic and operational studies.
2. Exchanges will be important to making storage work cost effectively for many applications. A more robust method of estimating future exchange potential may be needed to refine this important aspect of the analysis.
3. Site-specific and owner-specific analyses will be needed when particular project opportunities are identified in the future. The work in the SPSS is a starting point for more specific alternative investigations, but substantial additional analysis will be required to test the feasibility of specific storage options based on points of diversion, intake systems, and methods of operating to meet demands.
4. Aquifer storage and recovery projects will require site specific aquifer characterization and pilot testing. Pilot testing and preliminary design can begin at a relatively low cost due to the scalability of ASR systems.
5. Using existing irrigation canals to fill storage sites could significantly reduce infrastructure costs for some concepts. Partnerships with irrigation companies and available canal capacities should be investigated further.
6. Cooperative storage projects with multiple users, multiple components and multiple purposes would have the best chance of success. The state, Roundtables and water users should continue to explore opportunities for cooperative multi-use storage projects in the lower South Platte Basin.
7. Gravel pit storage opportunities were not considered in detail in this study. Gravel pits have been used extensively for storage along the South Platte River upstream of Greeley. An investigation of gravel pit storage opportunities downstream of Greeley may be warranted.
8. Use of water from SPSS storage projects directly for M&I use would require advanced water treatment. Recharge into aquifer storage would also require treatment. Additional investigation is required into the feasibility of available advanced treatment processes on water quality from the study area, particularly in the further downstream reaches of the South Platte River.
9. Investigation is warranted into how storage could support future implementation of alternative transfer method (ATM) projects per recommendations in the South Platte Basin Implementation Plan. Most or even all ATM project would need storage to increase yield and project efficiency. Investigation is needed into how new storage projects could be utilized in combination with ATMs to efficiently store and deliver available water as well as water provided from ATM projects. This combination could potentially make both new storage and ATM projects more feasible and help meet the water supply gaps in the basin.
10. Future storage projects would have an impact on Colorado’s water obligation to the PRRIP. Membership in SPWAP in addition to coordination with the State of

Colorado and SPWAP would be necessary to comply with all PRRIP mitigation requirements for new South Platte water storage projects. Further investigation into SPWRAP effects of new storage projects is recommended.

11. This study did not simulate conjunctive operation of a large surface storage project with an ASR project. Benefits of conjunctive use should be investigated.
12. This study did not evaluate potential supplies or storage opportunities upstream of Kersey on the South Platte River or Poudre River. Extending the water availability study and the investigation of potential storage options upstream of Kersey on the South Platte River and Cache la Poudre River should be considered.

12. REFERENCES

CDM. Statewide Water Supply Initiative. Prepared for Colorado Water Conservation Board and Colorado Department of Natural Resources. January 2011.

Colorado Water Conservation Board. Colorado's Water Plan. 2015.

HDR/West Sage. South Platte Basin Implementation Plan. Prepared for South Platte and Metro Basin Roundtables. 2015