HB12-1278 Study of the South Platte River Alluvial Aquifer

December 2013

Completion Report No. 226

Colorado Water Institute

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Acknowledgements

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Additional copies of this report can be obtained from the Colorado Water Institute, E102 Engineering Building, Colorado State University, Fort Collins, CO 80523-1033 970-491-6308 or email: cwi@colostate.edu, or downloaded as a PDF file from http://www.cwi.colostate.edu.

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Completion Report

HB12-1278 *Study of the South Platte River Alluvial Aquifer*

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Reagan M. Waskom
Colorado Water Institute
Colorado State University
Fort Collins, CO 80523-1033
http://cwi.colostate.edu

http://www.cwi.colostate.edu/southplatte

EXECUTIVE SUMMARY

In 2012 session, the Colorado Legislature passed HB12-1278, entitled *Concerning The Authorization of a Study of The South Platte River Alluvial Aquifer*, directing the Colorado Water Institute (CWI) at Colorado State University to conduct a study of the South Platte alluvial aquifer with funding provided by the Colorado Water Conservation Board (CWCB). CWI was required under the Act to present a final report to the General Assembly by December 31, 2013.

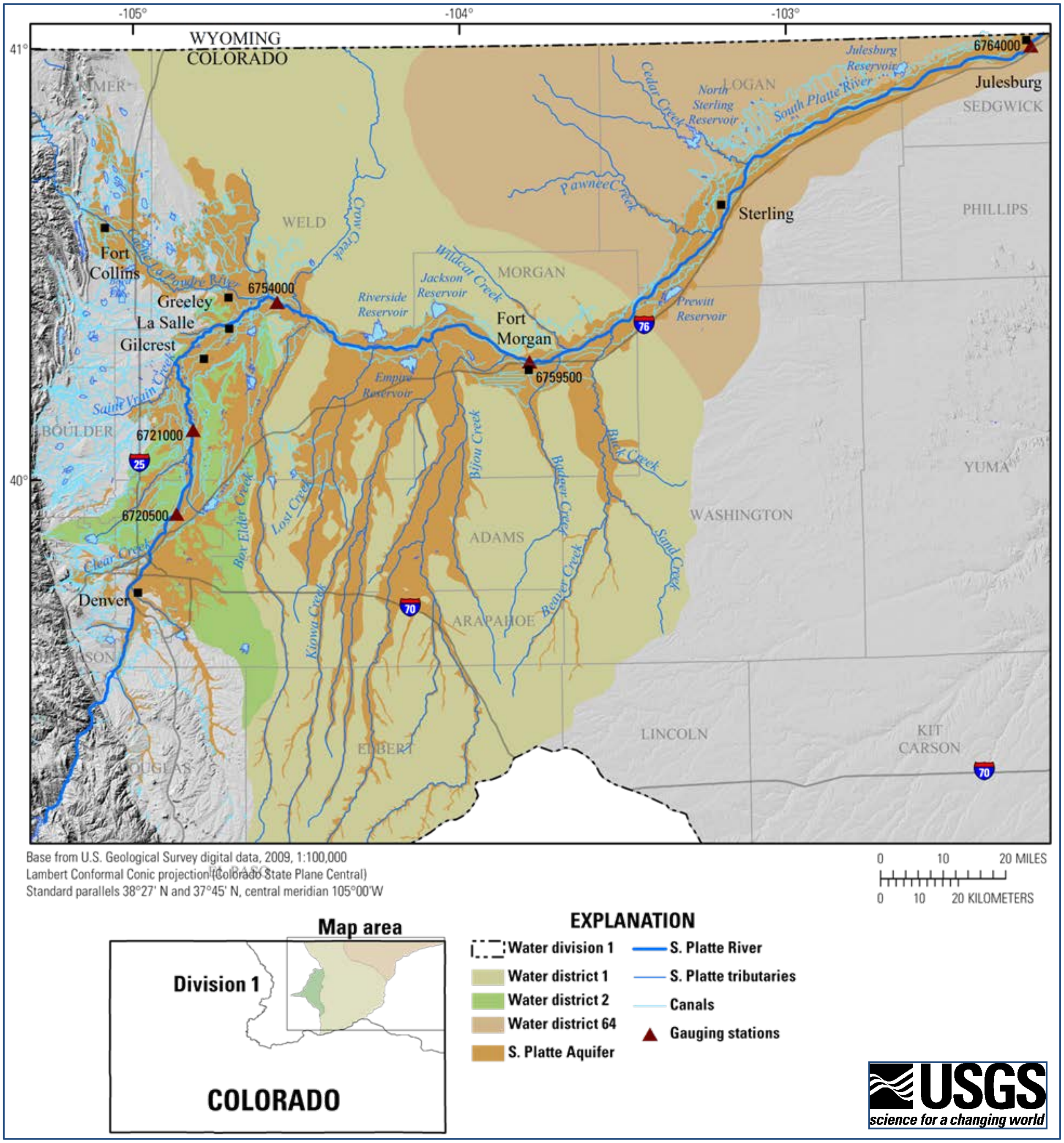
Background on the HB1278 Study

HB1278 was a result of a decade of debate that initially concerned wells that lacked court adjudicated augmentation plans to replace out-of-priority depletions. Coincident with the development of recharge structures to allow wells to operate, concerns began to arise regarding property adversely impacted by high groundwater levels. In 2008 there were homeowner reports of high groundwater levels in the Pawnee Ridge and the Country Club Hills subdivisions of Sterling. Above average precipitation in 2009, 2010, and 2011 in the lower basin increased the frequency and locations of these complaints. Homeowners reported failed septic systems and flooded basements that had not previously been a concern. Meanwhile, farmers and homeowners in the Gilcrest/LaSalle area also began relaying concerns that high groundwater levels were damaging crops and flooding basements and septic systems. Parties concerned about curtailment of wells and those concerned about high water levels appealed to the Legislature, asking if there were a way to provide mechanisms to mitigate high groundwater and create more flexibility and opportunity for agricultural water users by utilizing the aquifer more effectively. Eventually, legislators passed HB1278 to study the problem and propose solutions. The sponsors of the bill sought further information about planned utilization of the groundwater resource as a basis for improving the system of water administration in the South Platte.

This report, with its associated appendices and online material, describes and evaluates the history and current status of groundwater use and water level trends, surface water use and trends, the spread of phreatophytes, and the climate of the S. Platte basin in order to better understand the potential opportunities for improved surface/alluvial groundwater conjunctive use in the basin.

The Basin

The S. Platte basin of northeast Colorado has 150 years of water management history and some 18,600 decreed points of diversion. The average annual river flow over the past four decades at Julesburg (since 1969), near the Nebraska border, is approximately 478,000 acre-feet (AF), but within this period there has been tremendous variation in average annual flow, ranging from 55,000 to 2.1 million AF/yr. Return flows from irrigation make a large contribution to stabilizing river flows. A century and a half of water supply development in the basin has resulted in an extensive network of diversion ditches, canals, and reservoirs, all of which seep large amounts of water into the alluvial aquifer, creating a gaining river downstream of Denver for almost the entire year. By 1970 there were over 8,200 high capacity wells in the S. Platte alluvium pumping approximately 500,000 AF of water annually, resulting in declining groundwater levels. Strict administration of well augmentation requirements after the year 2000 led to curtailment and eventual abandonment of some wells coincident with the development of recharge projects to augment out-of-priority groundwater depletions for many other wells.



Area of the HB1278 Investigation in the South Platte Alluvial Aquifer in Water Districts 2, 1, and 64, Extending Approximately From Denver to Greeley to Julesburg.

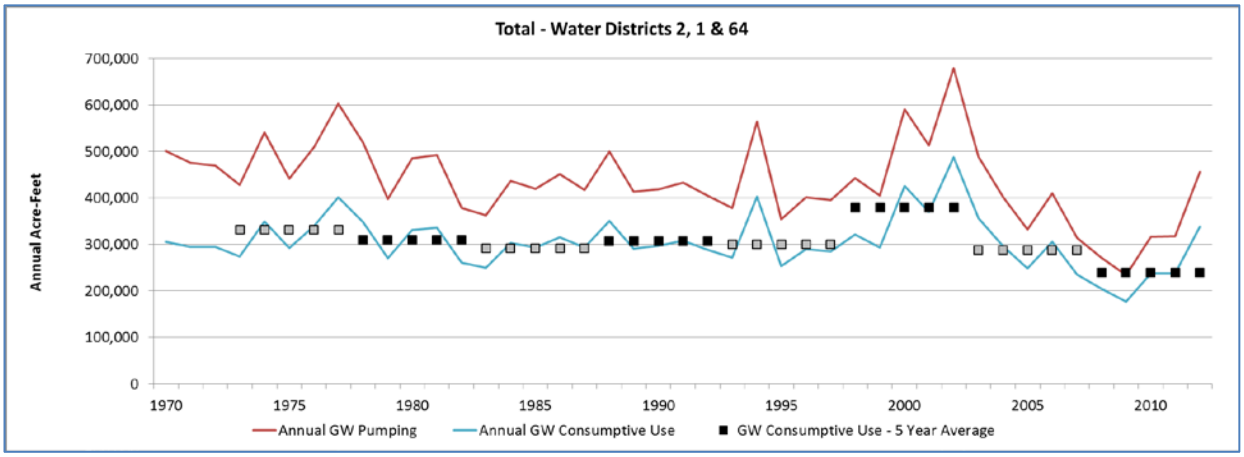
HB1278 Study Approach

The problem of surface and groundwater interaction is difficult to accurately measure or model. HB1278 did not authorize the development of new models to study the system, but rather an evaluation of the available data to address the objectives of the Act. Our general plan of work for this study was to use the existing data tools in the South Platte Decision Support System (SPDSS) developed for the CWCB. The groundwork laid by the SPDSS was extremely valuable to the HB1278 study. However, we did not use the SPDSS groundwater model, which was released during the course of the HB1278 study and at this time is only calibrated up to 2006. We used the SPDSS to develop datasets on groundwater levels, surface and groundwater diversions, river flow, call records, stream gain and loss, augmentation, artificial recharge, phreatophytes, and other factors for analysis. Our general approach was to compare these factors on a multi-year basis to smooth out annual variation in climate and hydrologic conditions in order to detect long-term trends, looking most closely at trends since 2000, when we entered the current era of stricter administration of groundwater. Colorado State University (CSU) conducted trend analyses on observation well levels to determine if groundwater levels were changing in response to recent management. U.S. Geological Survey (USGS) simultaneously conducted an independent analysis of groundwater trends using data from 1,670 wells that included more than 150,000 observations for calendar years 1953-2012 and developed a proposed long-term monitoring well network to improve future understanding of groundwater conditions. We determined at the outset to focus on publically available data from HydroBase, the USGS National Water Information System, the National Oceanic and Atmospheric Administration, the Colorado Agricultural Meteorological Network, and LandSat data that could be accessed and replicated by any interested party.

Summary of Findings

The S. Platte basin is subject to a number of variable climate, hydrologic, geologic, and human factors interacting to create an extremely complicated set of conditions impacting the alluvial aquifer. In almost all years there is inadequate water in the river to meet all of the demands, and the excess flows that do occur occasionally are not always predictable in place and time. The data record, particularly groundwater levels, pumping volumes, and climate is irregular, and it must be understood that there remain unknowns and uncertainties in the findings. While variations in the data record introduce uncertainty in exact values of basin-wide parameters, various trends are apparent that allow us to make a number of observations, which taken together reveal certain generalizable findings. In summary:

- Combined groundwater consumptive use for irrigation in Water Districts 2, 1, and 64 has varied with snowpack and precipitation over the past three decades. Since 2008, the combined three water districts have been pumping an average of approximately 320,000 AF/yr, with local areas of well curtailment gradually being offset by new or expanded pumping as augmentation supplies are developed over time. Agricultural pumping has decreased by the highest percentage in Water District 2, from a recent high of 120,000 AF in 2002 to 40,000 AF in 2012 as augmentation sources remain difficult to acquire, limiting pumping in that district. Long-term average groundwater consumptive use in Water District 1 is relatively stable since the 1980s at 180,000 AF/yr with some relocation due to curtailment and development of new augmentation supplies. Long-term average groundwater consumptive use in Water District 64 has increased by approximately 10,000 AF to an average of 110,000 AF/yr as development of augmentation water supplies has allowed increased pumping. Curtailment and abandonment of wells in Water Districts 2 and 1 is reflected in lower pumping amounts in Water District 2 and slightly lower pumping amounts in areas of Water District 1, potentially affecting local groundwater levels in recent years.



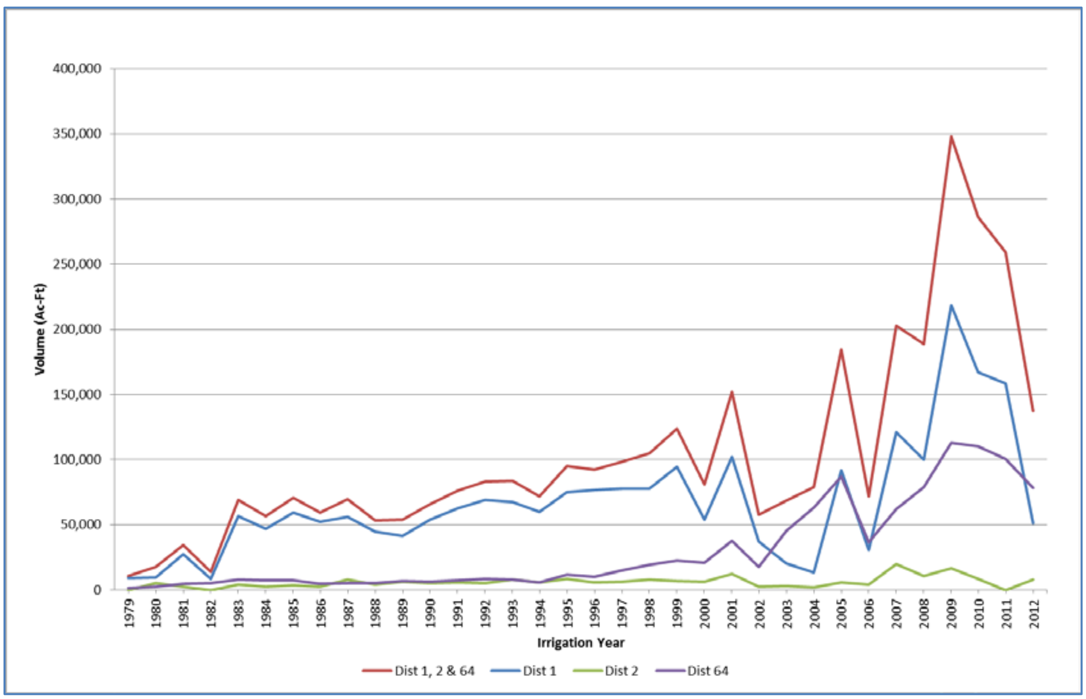
Estimated Total Annual Pumping and Groundwater Consumptive Use in Water Districts 2, 1, and 64.

Average Annual Surface Diversions, Pumping, Consumptive Use Groundwater Pumping, and Augmentation for Water Districts 2, 1, and 64, for the Period of 2008-2012.

	WD 2	WD 1	WD 64	Total
	---------- Average (2008-2012) in AF/yr ----------			
Total Surface Diversion	376,583	673,869	257,766	1,308,217
Total Pumping	31,195	177,490	110,612	319,298
CU GW Pumping	23,138	134,872	80,781	238,791
Surface Augmentation	18,487	6,067	5,493	30,047
Recharge Augmentation	11,166	131,287	91,819	234,271
Total Augmentation	29,653	137,354	97,312	264,318

- Well pumping curtailments have shifted irrigation water demands to more reliance on surface water, particularly in Water District 2, likely resulting in more canal and ditch seepage coincident with reduced groundwater pumping.

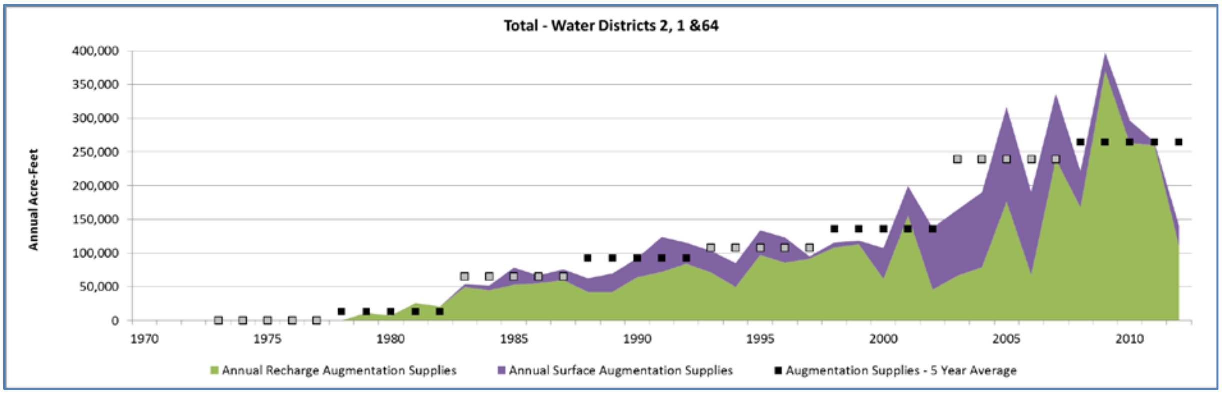
- The number of days of administrative call on the river has increased since the late 1990s from an average of 102 to 305 days annually in Water District 2, from 55 to 271 days annually in Water District 1, and from 72 to 177 days annually in Water District 64, increasing augmentation requirements and decreasing free river periods when augmentation supplies can be diverted.
- Many recharge facilities have been built recently in the S. Platte basin as part of augmentation plans. Water Districts 2, 1, and 64 combined have developed over 230,000 AF of augmentation supplies based on five-year averages, reflecting the increase in recharge site construction, and some higher runoff flows available to divert for recharge. Large spatial and temporal variation in annual augmentation supplies is observed, with excess in some areas and deficiencies in other areas.



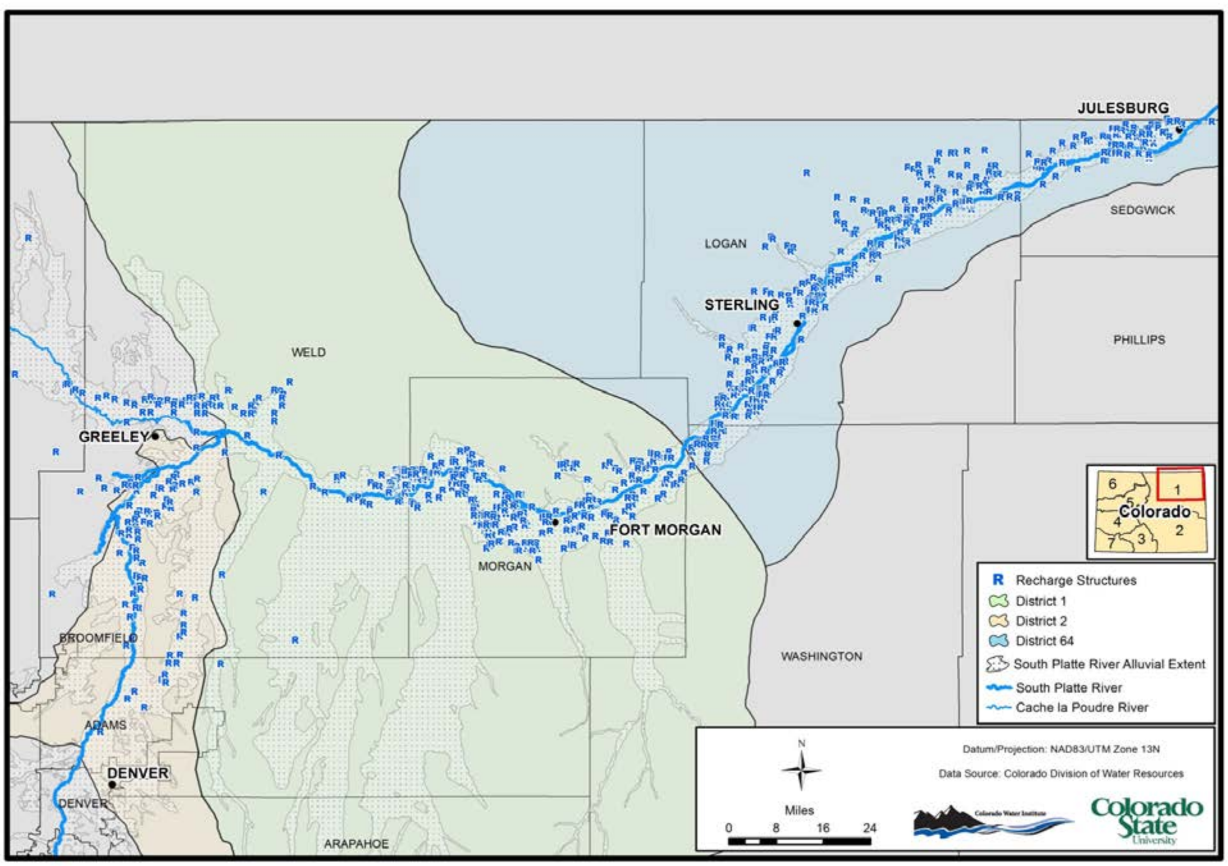
Artificial Groundwater Recharge Diversions in Water Districts 2, 1, and 64.

- Augmentation plan operators may only divert recharge water when in priority and augmentation plans may recharge more water than required for some part of the year to meet the minimum needed in other months.
- Extensive development of recharge ponds and lined gravel pit storage projects in the past decade have likely changed local groundwater gradients. While prolonged wet weather contributes to groundwater recharge, it does not explain the rising groundwater levels

observed throughout the basin since 2002, or the lack of a rising trend during the wet periods of the 1980s or 1990s.

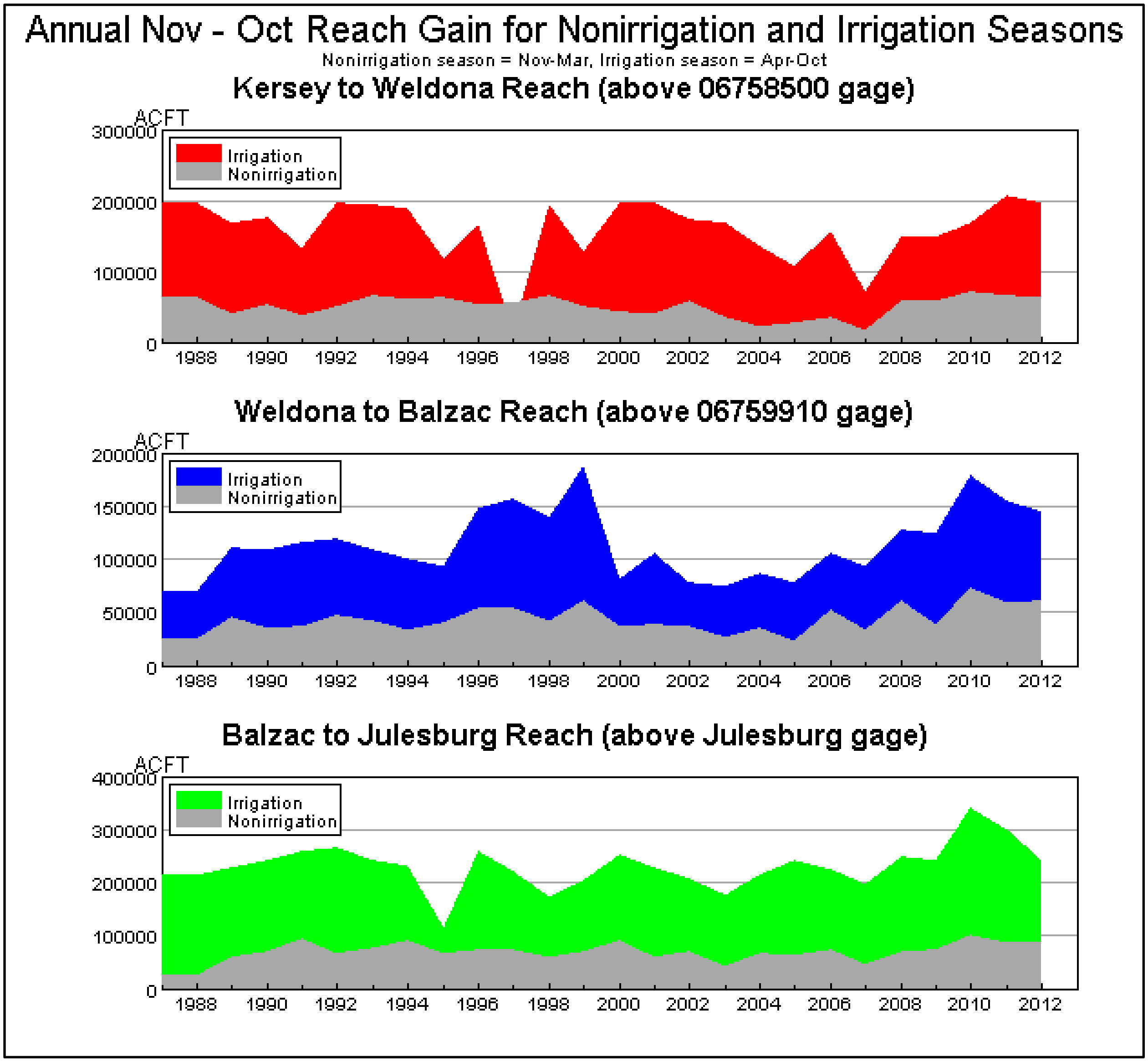


Total Annual Surface and Groundwater Supplies Developed to Meet Augmentation Plan Requirements in Water Districts 2, 1, and 64.

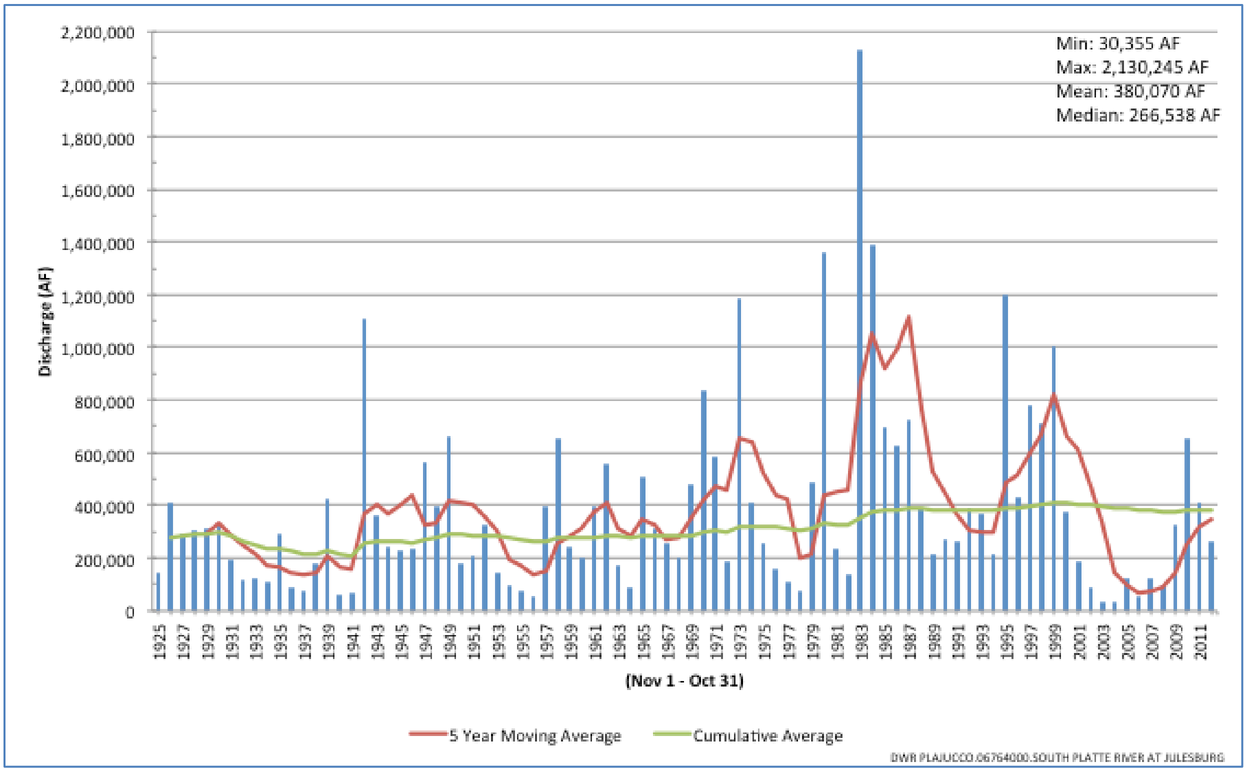


Location of Existing Recharge Structures in the S. Platte Basin.

- A point flow analysis tool was developed for the HB1278 study to quantify the historical monthly, seasonal, annual, and decadal stream reach gains and losses between mainstem streamflow gages located in Water District 1 and 64. Stream gains are highest in the S. Platte during the irrigation season and the lowest in November and December, ranging from approximately 3-9 cfs/mi, consistent with previous studies. Reuse of return flows and accretions increases downstream, with the surface diversions in the lower reach being nearly equal to available stream gains. A rising trend in stream gain can be observed in recent years.

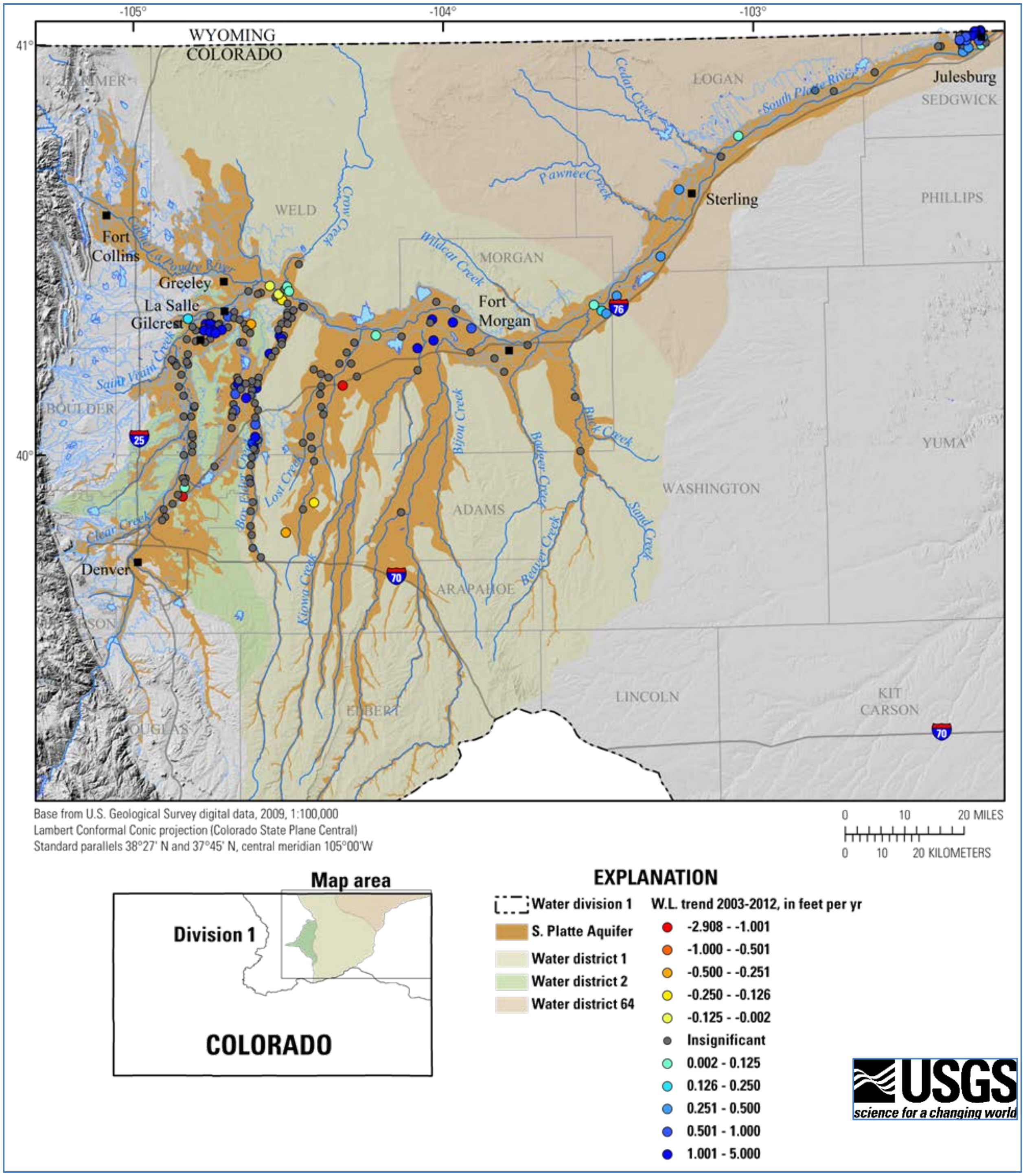


Calculated Annual River Gain Summary in AF for the Period of 1987-2012 Showing Irrigation and Off-Season Gain by Reach.

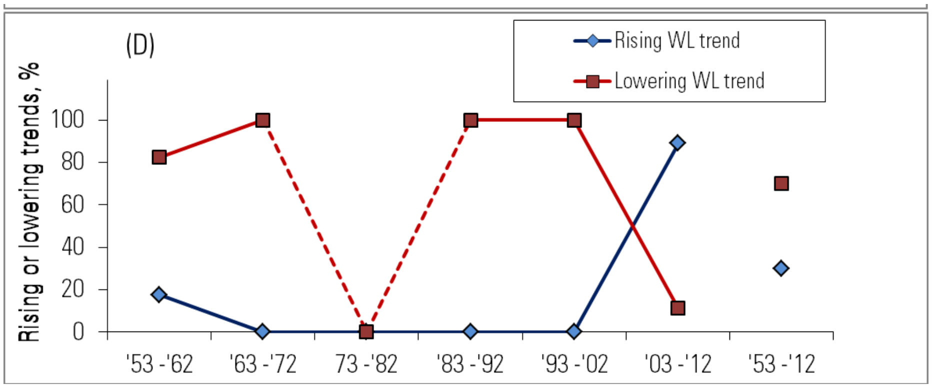


Annual Flow at the Julesburg Gage, 1925-2012.

- The long-term annual flow at the Julesburg gage near the state line averages 478,261 AF for the period of 1969-2012. The average annual flow for the period of 2000-2012 was 213,446 AF, due mainly to drought conditions in 2001-2008, and 2012.
- While there is still water available to be developed on the S. Platte in Colorado, the location and timing of that available water is highly variable. No statistically significant annual flow trends were detected at the Kersey or Julesburg gages over the past decade.
- Phreatophytes continue to increase in the basin, resulting in large quantities of non-beneficial consumptive use, perhaps as much as 250,000AF/yr.
- Localized areas of high groundwater have occurred in regions of the aquifer over the period of record and in some cases, high groundwater is commonplace. Groundwater levels have increased over the last decade (2003-2012), during which time a large number of observation wells indicate trends of rising water. The CSU and USGS analyses independently corroborated this trend of rising water levels in the recent decade. While the data do not allow direct attribution of cause, the weight of the current evidence indicates that rising groundwater is a response to curtailment of pumping after 2002 and increased recharge in the recent decade. The main areas of groundwater rise occur near Gilcrest, Fort Morgan, Sterling, and Julesburg.



Water Level Trends at Wells with Acceptable Records from 2003 to 2012. Positive Values Indicate Increasing Water Levels and Negative Values Indicate Decreasing Water Levels.



Percentage of Wells by Decade Having Rising or Lowering Water Level Trends. (insufficient data for the decade of '73-'82)

<u>Conclusions</u>

These findings lead us to the conclusion that changes in water administration in the past decade, specifically curtailment of wells and increased augmentation, have served to further protect senior surface water rights from injury. Changed water administration practices have also led to increasing groundwater levels in the basin, and in some cases, these rising levels are impacting homes and property. Presently, high groundwater conditions impacting landowners appear to be localized and thus, local solutions are recommended. In contemplating any of the recommendations offered herein, it should be acknowledged that senior water rights must be protected in any adjustments to the system and that wells cannot be relieved from the obligation to replace out-of-priority depletions that cause material injury to senior surface water rights.

Water users in the basin have expended significant effort and resources in recent years to comply with the law of the river, leading to the observation that current administration of groundwater in the basin works for most water users. However, some groundwater users in Water District 2 and parts of District 1 have been adversely impacted by the shortage of affordable augmentation supplies to offset pumped depletions, limiting their ability to use the aquifer.

There are over 500 recharge projects now in place in the S. Platte basin. According to Division 1 staff, as many as 800 total recharge structures are planned in existing augmentation plans, so there are potentially many more facilities yet to be constructed. Future groundwater recharge projects should be designed, located, constructed, and managed so as to avoid creating groundwater mounds that cause harm to third parties. When the court currently evaluates a recharge project, it is primarily determining whether it will offset out-of-priority depletions, with no explicit determination if recharge might cause property damage to others in the flow path of recharged groundwater. Given the urban and suburban development occurring in the basin, the construction and operation of new recharge structures should be given further scrutiny.

HB1278 required an evaluation of whether the use of water in the basin could be improved by affording the State Engineer additional flexibility in the administration of water rights. The

Colorado Division of Water Resources (DWR) has instrumented two areas in the S. Platte basin with known high groundwater levels (Sterling and Gilcrest/LaSalle). With two years of data collected (2012-2013) to characterize water level behavior, these areas are primed for implementing pilot tests to evaluate alternative strategies for groundwater management. Pilot approaches may include permitted pumping or decreased recharge as determined to be locally appropriate to test alternative management strategies. Groundwater levels and surface diversions in the pilot areas must be accurately monitored in real time to determine impacts from the pilot management approach, and a plan to offset any injurious depletions must be established. Calibrated numerical groundwater models should be developed and tested along with analytical models in the pilot project areas. The S. Platte Decision Support System should also be employed to help evaluate the impact of management scenarios.

Developments in water court and administrative practice have diminished the Division Engineer's ability to play a management role in the distribution of water supplies. As we have already adjudicated most of the augmentation plans for high capacity irrigation wells likely to be developed within Water Districts 2, 1 and 64, the mass movement of irrigation wells into augmentation plans is widely considered to be nearly completed. The decrees are considered final and to the extent there is room for adjustment in augmentation requirements, it has to do with the administrative call. Augmentation plans respond to the administrative call, and it is the one moving part that is not fixed in the decrees. Reducing the number of days of administrative call on the river system will allow more days of free river whereby well users can acquire recharge supplies. In the past, water users worked with the Division Engineer to reduce the call period. Reestablishing this flexibility could benefit water users in the basin.

In an age when water is becoming increasingly scarce and supplies uncertain, robust data networks and decision support tools are critically needed for day-to-day operations and to build a long-term data archive to serve the needs of the people of the State of Colorado. The HB1278 study has revealed that the existing groundwater monitoring data collection network is irregular and incomplete but could rather easily be substantially upgraded. Better management decisions require higher quality and more easily accessible data. We need to install, instrument, and maintain a groundwater level monitoring network that can be used for real time management decisions. Additionally, water management organizations in the basin should be strongly encouraged to share data and collaborate on data collection.

The Division 1 Engineer has incurred significant additional duties and responsibilities as a result of the many adjudicated augmentation plans now in operation and new rules for well metering. Reported data must be taken in, checked, loaded, analyzed and provided to the public in short order if management is to be implemented based upon better information. Concurrently, we need to upgrade the data collection technology in the basin through more robust information systems, monitoring, and telemetry. Water Division 1 has 6.5 FTEs (full-time equivalents) in the Hydrographic Unit, and it has been estimated that they need 10 to 12 FTEs to do the job currently assigned to them. There is a demonstrated need for two additional fulltime FTEs in Division 1 to focus on the technical aspects of surface and groundwater tabulation and administration and one new senior staff position in DWR to provide leadership for services focused on water rights tabulation, diversion records, structure location, and electronic workflow processes.

Given that all active tributary irrigation wells in the S. Platte alluvial aquifer are now in court approved augmentation plans, the challenge before us is to determine if there are further mechanisms and innovations to improve groundwater utilization within the context of current law. Replaced pumping depletions that result in waterlogging of agricultural fields or residential neighborhoods do not replace depletions at the river, nor do they meet the true intent of augmentation plans. Continuing to foster rising groundwater levels will inevitably salinize valuable agricultural lands and increase non-beneficial evapotranspiration (ET) by phreatophytes and evaporative upflux, wasting precious water. To the extent possible, groundwater levels should be managed to avoid waterlogging and salinization of fields.

New water storage, both above and below ground, is needed to maximize the potential of the S. Platte system and allow more alluvial groundwater utilization. Municipal and industrial demands in the basin are projected to increase by 340,000 to 510,000 AF/yr by 2050. Given the certainty that water demands will outstrip supplies in the near future, new management tools are needed to allow more effective use of the alluvial aquifer for the benefit of Colorado. Better monitoring, data management, models, and common technical platforms are needed if water management in the S. Platte is to benefit from better science. The South Platte Decision Support System is positioned to facilitate the integration of science in planning and decision-making, but the basin must also be organized to utilize the science. The HB1278 study leads us to the conclusion that the best institutional mechanism for attaining sustainable conjunctive use of surface and groundwater in the S. Platte basin is the formation of a basin-wide authority with the ability to work with all water management organizations, using comprehensive data and the best available science for the good of the entire basin. The recent flood damage in the S. Platte and the recovery challenges water users face in 2014 points to the need for more comprehensive water management that can enable basin-wide cooperative solutions.

HB1278 asked whether management of the system could be improved while respecting senior water rights. In addition to developing information on surface and groundwater use and water levels, HB1278 directed CWI to:

- Provide information to use as a base for implementation of measures to mitigate adverse impacts in areas experiencing high groundwater levels.
- Provide information to the General Assembly, CWCB, and the State Engineer to facilitate the long-term sustainable use of South Platte water supplies.
- Determine whether additional usage of the alluvial aquifer could be permitted in a manner consistent with protecting senior surface water rights.
- Determine whether, and to what extent, the use of water in the basin could be improved or maximized by affording the State Engineer additional authority to administer water rights while ensuring protection of senior surface water rights.

In that context, our recommendations fall into four broad categories: 1. Mitigation of localized high water table conditions; 2. Increasing augmentation plan efficiency; 3. Implementation of basin-wide management; and 4. Recommendations for the State of Colorado, DWR, and CWCB. We recommend that any changes in groundwater management in Division 1 should occur through an inclusive and open process. Further explanation of the recommendations is found beginning on page 177 of the report.

<u>Recommendations</u>

1. Mitigation of localized high water table conditions

   A. *The State Engineer or the Colorado Geological Survey should be delegated responsibility by the General Assembly to provide a consultation to the water court regarding new recharge structures before construction and recommend changes in design or operation when a recharge plan is deemed likely to cause or is causing harm.*

   B. *Two pilot projects should be authorized and funded by the General Assembly to allow the State Engineer to track and administer high groundwater zones for a specified period of time to lower the water table at Sterling and Gilcrest/LaSalle while testing alternative management approaches.*

2. Increasing augmentation plan efficiency

   A. *The State Engineer should be directed by the General Assembly to promulgate new rules for the S. Platte to:*

      1) *Establish a framework for the voluntary movement of excess water supplies between augmentation plans, facilitated by the office of the Division Engineer, including a water bank or pool available for use by augmentation plan users.*

      2) *Establish basin specific guidelines for the implementation of administrative curtailment orders pursuant to 37-92-502(2)(a), C.R.S. that reduce waste and facilitate efficient management and distribution of available water supplies to storage and recharge water rights in the time and place of their need, in accordance with priority and historic practice. The guidelines should:*

         a. *Allow the Division Engineer to use the administrative call as a management tool to increase system efficiency, decrease waste and maximize diversions for beneficial use;*
         b. *Provide for storing water out-of-priority at higher elevation, and managing deliveries to downstream reservoirs as necessary;*
         c. *Minimize seniority, frequency and duration of administrative calls to the full extent consistent with the fulfillment of decreed water rights;*
         d. *Make use of all available data regarding water supply, including ground water levels, to determine the necessary administrative call date for each reach or sub-reach of the river and the alluvial aquifer system.*

3) Develop uniform and transparent reporting standards for augmentation plan accounting designed to integrate with basin data collection, modeling and management.

B. Funding should be authorized to provide the Division 1 Engineer with two additional FTEs and greater annual investment in technology upgrades. Additionally, Colorado DWR needs one additional FTE to focus on data and information services.

3. Implementation of basin-wide management

   A. *The General Assembly should authorize the establishment of a pilot basin-wide management entity with a defined sunset date.*

   B. *The CWCB, CDA and DWR should work with USGS to implement the basin-wide groundwater monitoring network outlined in this report.*

   C. *The State should cooperate with the S. Platte Basin Roundtable and water organizations in the basin to fund and conduct a helicopter electromagnetic and magnetic survey to produce detailed hydrogeological maps of the S. Platte alluvial aquifer.*

   D. *The State should continue strong support for the development and implementation of the SPDSS and strive to improve accessibility, scope, and robust stakeholder processes.*

   E. *The State should aggressively begin working with water users and other stakeholders in the S. Platte basin to develop multiple-benefit water storage options.*

4. Recommendations to the Colorado DWR and the CWCB for improved data collection, data management, and data access

   A number of specific recommendations for improving data capture, management, and display are offered to the State based upon our experience on the HB1278 study beginning on page 185 of the report.

The recommendations offered in this report carry fiscal impacts that should be weighed in consideration of their implementation. However, the S. Platte basin faces significant water shortages that will potentially impact Colorado's economic, agricultural and environmental future. The planned conjunctive use of surface and groundwater has the potential to offer benefits in terms of economic, environmental, and social outcomes through increased drought protection, water use efficiency, and the control of shallow groundwater levels and consequent soil salinity. Retrofitting conjunctive use into a prior appropriation system that favors surface water use is made difficult by the many layers of management and local interests that have evolved over time. It is important to acknowledge that most of our water management system is working well. The challenge lies in whether we can move to an even higher level of sustainable utilization. Well users must replace injurious out-of-priority depletions – that is not a matter of question. The question is whether we are protecting senior rights while utilizing groundwater in a way that optimizes the entire system.

The S. Platte alluvial aquifer provides a storage vessel that far surpasses anything that could feasibly be built in the modern era. However, to avoid over-appropriation of the groundwater resource, the sustainable use of the S. Platte alluvial aquifer requires us to find the right balance between long-term recharge and diversion by pumping. The economic and population growth expected in the S. Platte basin over the next several decades and the anticipated water shortages should compel us to get better organized to capture and store excess flows, reduce waste from nonbeneficial consumptive use, and put the alluvial aquifer to optimum sustainable use.

The data, full report and all appendices for the HB1278 study can be found online at: http://www.cwi.colostate.edu/southplatte.

TABLE of CONTENTS

EXECUTIVE SUMMARY 1
LIST of FIGURES 18
LIST of MAPS 21
LIST of TABLES 22
INTRODUCTION 24
BACKGROUND 27
Basin Description *27*
Brief History of Groundwater Development in the South Platte *31*
Problems Leading to HB1278 ..... *40*
GROUNDWATER PUMPING 41
Description of the South Platte Alluvial Aquifer *41*
Groundwater Use *47*
Aquifer Recharge *50*
Meeting Irrigation Water Requirement *50*
Groundwater Pumping and Crop Consumptive Use *53*
AUGMENTATION 57
Stream Depletion Modeling *63*
Augmentation Plan Accounting *67*
Augmentation Requirements and Augmentation Supplies *69*
GROUNDWATER LEVELS IN THE ALLUVIAL AQUIFER 86
Observation Well Data *89*
DWR Groundwater Monitoring Pilot Studies *100*
USGS Analysis of Groundwater Levels *101*
Proposed Groundwater Monitoring Network *108*
STREAMFLOW, DIVERSIONS and RIVER ADMINISTRATION 119
Stream Gages and Flow Trends *120*
Surface Water Diversions and River Administration *124*
Reservoirs and Transbasin Diversions *132*
Stream Gain and Loss *137*
Call Records *148*

CLIMATE 155
PHREATOPHYTES 162
SUMMARY of KEY FINDINGS 172
RECOMMENDATIONS 176
CONCLUSIONS 193
REFERENCES 195
APPENDIX (found online at http://www.cwi.colostate.edu/southplatte/findings.shtml)

LIST of FIGURES

Figure 1. Estimated Groundwater Pumping for Irrigation from the S. Platte Alluvial Aquifer, 1950 – 2006. 45

Figure 2. Estimated Irrigated Acreage in the S. Platte Basin 52

Figure 3. Consumptive Use from Surface and Groundwater, 1950-2006 53

Figure 4. Estimated Pumping and Groundwater Consumptive Use in Water District 2 54

Figure 5. Estimated Pumping And Groundwater Consumptive Use In Water District 1 55

Figure 6. Estimated Pumping and Groundwater Consumptive Use in Water District 64 55

Figure 7. Total Estimated Annual Pumping and Groundwater Consumptive Use in Water Districts 2, 1, and 64 56

Figure 8. Hypothetical Single Pumping Year SDF Method Calculated Lagged Depletions to the River (In cfs) Over a 60-Month Period For 30, 90, 180 and 360 Day SDF 64

Figure 9. Hypothetical Single Year Pumping Glover Method Calculated Lagged Depletions to the River in cfs for Four Well Locations Over a 60-Month Period Using the AWAS Alluvial Aquifer Mode Assuming Pumping for 2 Months at 1000 gpm 65

Figure 10. Hypothetical Lagged Depletions to the River for a 25-Year Pumping Simulation Using the Glover Method for a Single Well Located 5,000 Feet trom The River Using the AWAS Alluvial Aquifer Mode Assuming Pumping for 2 Summer Months at 1000 gpm 66

Figure 11. Potential Annual Augmentation Requirements, Groundwater Consumptive Use and Five-Year Average Potential Augmentation Requirements in Water District 2 70

Figure 12. Potential Annual Augmentation Requirements, Groundwater Consumptive Use and Five-Year Average Potential Augmentation Requirements in Water District 1 71

Figure 13. Potential Annual Augmentation Requirements, Groundwater Consumptive Use and Five-Year Average Potential Augmentation Requirements in Water District 64 71

Figure 14. Total Annual Potential Augmentation Requirements, Groundwater Consumptive Use and Five-Year Average Potential Augmentation Requirements in Water Districts 2, 1 and 64 72

Figure 15. Annual Surface and Groundwater Supplies Used to Meet Estimated Potential Augmentation Requirements, and Five-Year Average Augmentation Supplies in Water District 2. 73

Figure 16. Annual Surface and Groundwater Supplies Used to Meet Estimated Potential Augmentation Requirements, and Five-Year Average Augmentation Supplies in Water District 1. 73

Figure 17. Annual Surface and Groundwater Supplies Used to Meet Estimated Potential Augmentation Requirements, and Five-Year Average Augmentation Supplies in Water District 64. 74

Figure 18. Total Annual Surface and Groundwater Supplies Used to Meet Estimated Potential Augmentation Requirements, and Five-Year Average Augmentation Supplies in Water Districts 2, 1 and 64. 74

Figure 19. Annual Surface and Groundwater Augmentation Supplies Versus Estimated Potential Augmentation Requirements, and Five-Year Average Augmentation Supplies Less Potential Augmentation Requirement in Water District 2. 77

Figure 20. Annual Surface and Groundwater Augmentation Supplies Versus Estimated Potential Augmentation Requirements, and Five-Year Average Augmentation Supplies Less Potential Augmentation Requirement in Water District 1 77

Figure 21. Annual Surface and Groundwater Augmentation Supplies Versus Estimated Potential Augmentation Requirements, and Five-Year Average Augmentation Supplies Less Potential Augmentation Requirement in Water District 64 78

Figure 22. Total Annual Surface and Groundwater Augmentation Supplies Versus Estimated Potential Augmentation Requirements, and Five-Year Average Augmentation Supplies Less Potential Augmentation Requirement in Water Districts 2, 1, and 64 78

Figure 23. Artificial Groundwater Recharge Diversions in Water Districts 2, 1, and 64 79

Figure 24. Example Calculated Lagged Depletions from Wells Pumping Under the Weldon Valley Ditch and the Harmony No. 2 Ditch Using the AWAS Glover Method 80

Figure 25. Calculated Example of Pumped Depletion Timing Compared to Accretion Timing from a Recharge Pond 82

Figure 26. Example Hydrographs for Three Observation Wells in the CCWCD Network 96

Figure 27. Example Hydrograph for One Continuous Monitoring Well in the SPDSS Network. 98

Figure 28. Plots A And B Show the Number of Observations and Frequency of High Water Conditions Given as Depth to Groundwater of Less Than or Equal To 5 and 10 Feet Below Land Surface, Respectively. Plots C and D Show the Total and Eligible Number of Wells to Examine Trends and the Proportion of Trends Having Rising or Lowering Water Levels, Respectively. 106

Figure 29. Results from Well Network Optimization Analysis for the "Unstressed" Monitoring Network Showing the Reduction in Average Error (Uncertainty) Achieved by Adding Additional Wells To A Starting Well Network (Backbone) Composed Of 52 SPDSS And USGS NAWQA Wells 116

Figure 30. Annual S. Platte River Flows at Kersey, CO, 1915-2012 123

Figure 31. Annual S. Platte River Flows at Julesburg, CO, 1925-2012 123

Figure 32. Diversion Record for the Union Ditch in Water District 2 for 1950-2012 Showing Irrigation Season and Off-Season Annual Diversion Amounts 126

Figure 33. Diversion Record for the Bijou Canal in Water District 1 for 1950-2012 Showing Irrigation Season and Off-Season Annual Diversion Amounts 127

Figure 34. Diversion Record for the Springdale Ditch in Water District 64 for 1950-2012 Showing Irrigation Season and Off-Season Annual Diversion Amounts 128

Figure 35. Diversion Record for the Harmony #1 Ditch in Water District 64 for 1950-2012 Showing Irrigation Season And Off-Season Annual Diversion Amounts 129

Figure 36. Total Annual Transbasin Diversions, 1950-2012 136

Figure 37. Monthly Gain/Loss (AF) in the Kersey to Weldona Reach, 1987-2013 141

Figure 39. Monthly Gain/Loss (AF) in the Balzac to Julesburg Reach, 1987-2013 143

Figure 40. Calculated Annual Gain Summary in AF for the period of 1987-2012 showing Irrigation and Off-Season Gain by Reach. 145

Figure 41. November to October Annual Reach Gain 146
Figure 42. On and Off-Season River Calls Affecting Water District 2, 1982-2012 151
Figure 43. On and Off-Season River Calls Affecting Water District 1, 1982-2012 151
Figure 44. On and Off-Season River Calls Calls Affecting Water District 64, 1982-2012 152
Figure 45. Total and Post-1970 River Calls Affecting Water District 2, 1982-2012. 153
Figure 46. Post-1970 River Calls Affecting Water District 1, 1982-2012 154
Figure 47. Post-1970 River Calls Affecting Water District 64, 1982-2012 154
Figure 48. Annual S. Platte Basin Precipitation as a Percent of Average for 1950-2013 160
Figure 49. Annual Percent of Average Snowpack Accumulated on April 1 for the Water Years 1968-2013 161
Figure 50. The Alluvial Extent, Reaches, and Weather Stations in the S. Platte Basin 164
Figure 51. Examples of the Four Different Types of Images for River Reach 13: Landsat 5, ANIP Natural Color, NAPP Black and White, and NAPP Color Infrared Used to Track the Changes of Phreatophytic Vegetation 165
Figure 52. Thirty-Year Average Annual and Seasonal ET and Precipitation Data from 81 Weather Stations (1981-2010) 166
Figure 53. Average Annual and Seasonal ET and Precipitation Interpolated from Weather Station Data 167
Figure 54. Annual and Seasonal Phreatophyte ETg (AF) for the Years: 1990, 2001, and 2010 169
Figure 55. Example Stretch of the River with the Application of Grouping Tool Techniques to Classify Vegetation 171

LIST of MAPS

Map 1. Digital Elevation Model of Northeast Colorado Showing the S. Platte Drainage 28

Map 2. Outline of the S. Platte Alluvial Aquifers in Northeast Colorado showing Division 1 Water Districts 2, 1, and 64 30

Map 3. High Capacity Wells in the S. Platte Alluvial Aquifer 43

Map 4. Aquifer Depths Across the S. Platte Alluvial Aquifer Showing Greatest Depths at the Channel Center to the East and Central Regions Near Fort Morgan and Along Lower Sections of the Lost Creek Tributary 44

Map 5. Aquifer Cross-Sections at Five Locations along the S. Platte River 47

Map 6. Irrigated Lands in the S. Platte Basin of Colorado. 52

Map 7. Designated Groundwater Basins in Proximity to the S. Platte Alluvial Aquifer in Northeast Colorado 59

Map 8. Location of Existing Recharge Structures in the S. Platte Basin 76

Map 9. High Groundwater Locations Self-Reported by S. Platte Stakeholders. 88

Map 10. Calculated Depth to Groundwater in the S. Platte Alluvial Aquifer 90

Map 11. Location of Observation Wells in the Six Networks Used for HB1278 Study 92

Map 12. Depth to Groundwater Table in the S. Platte River Alluvial Aquifer using latest Measurements from the Six Observation Well Networks 94

Map 13. Groundwater Depth Trends Over 2000-2012 for Observation Wells With Complete Records for the Period, Where Red Dots Indicate Statistically Significant Rising Water Levels Over the Past Decade 99

Map 14. Complete Set of 1,670 Wells Used for Groundwater Level Analysis Defined by Use Type 102

Map 15. Well Locations with High Water Conditions Within the S. Platte Alluvial Aquifer for the 60-Year Record (1953-2012) 105

Map 16. Water Level Trends At Wells With Acceptable Records From 2003 To 2012. Positive Values Indicate Increasing Water Levels And Negative Values Indicate Decreasing Water Levels. 107

Map 17. Monitoring Well Candidates for the Unified Monitoring Well Network of S. Platte Alluvial Aquifer. 115

Map 18. Proposed “Unstressed” Monitoring Network Composed of 96 Monitoring Wells. 117

Map 19. Major Streamflow Gages on the S. Platte Mainstem Below Denver 122

Map 20. Major Ditches on the Mainstem S. Platte River in Northeastern Colorado 125

Map 21. Location of Division 1 Lakes and Reservoirs 133

Map 22. Transbasin Diversions to the S. Platte Basin 135

Map 23. Percentage of Complete Data for S. Platte COOP Stations Since 2000. 158

Map 24. Locations of Active Snotel and COOP Weather Stations in the S. Platte Basin 159

LIST of TABLES

Table 1. Estimated Storage Volumes in the S. Platte River Basin Alluvium 45

Table 2. High Capacity Irrigation Well Count in Hydrobase by Water District in Division 1 Before and After Adjudication of the 2010 Abandonment List 48

Table 3. Division 1 Average Annual Water Budget, 1950-2006 51

Table 4. Division 1 Historical Irrigated Acreage by Water Source for 1956-2005 51

Table 5. Major Augmentation Plans in Division 1 61

Table 6. Calculated Timing and Acreage for 75 Percent of the Depletions to Impact the Stream 81

Table 7. Average Surface Diversions, Pumping, Consumptive Use Groundwater Pumping, and Augmentation for Water Districts 2, 1, and 64, for the Period of 2008-2012 83

Table 8. Average Surface Diversions, Pumping, Consumptive Use Groundwater Pumping, and Augmentation for Water Districts 2, 1, and 64, for the Period of 1999-2004 83

Table 9. Monitoring Wells by Agency in the Complete Data Set (Total), Network Backbone (Backbone), Optimized Unstressed Subnetwork (Unstressed Subnetwork), Optimized Target Subnetwork for Diversion Structures (Diversion Subnetwork), and Optimized Target Subnetwork for High Water Conditions or Trends in Water Levels (Hydrologic Subnetwork). 113

Table 10. Average Flows at Major Streamflow Gages on the Mainstem of the S. Platte River 122

Table 11. Average Total Annual Diversions for 56 Major Ditches in Water Districts 2, 1, and 64 129

Table 12. Mann-Kendall Trend Test for 56 S. Platte ditches average annual irrigation year diversions for 3 periods of record 130

Table 13. Total Reservoir Capacity by Water District in the S. Platte Basin. 132

Table 14. Largest 25 Reservoirs in the S. Platte River Basin. 134

Table 15. Annual (Nov – Oct) Transbasin Diversions, 1950-2012. 136

Table 16. SPDSS Task Memo 46.2 Estimated Baseflow by River Reach, 1991-1994 139

Table 17. Average Daily Gain by Decade. 144

Table 18. Five-Year Average Gain-Loss Estimate for Water District 2, 2008-2012 147

Table 19. Days of Call per Irrigation Year in Water Districts 2, 1, and 64, 1982-2012 150

Table 20. Monthly and Annual Precipitation in the S. Platte Basin 156

Table 21. Monthly and Annual Reference Evapotranspiration in the S. Platte Basin. 157

Table 22. Annual and Seasonal Reference ET and Precipitation 165

Table 23. Comparison of the Annual and Seasonal Phreatophyte ET from Groundwater in AF for the years 1990, 2010, and 2011. 168

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INTRODUCTION

In 2012 the Colorado Legislature passed HB12-1278, entitled *Concerning The Authorization Of a Study of The South Platte River Alluvial Aquifer*. The Act directed the Colorado Water Institute (CWI) at Colorado State University to conduct a study of the South Platte alluvial aquifer with funding provided by the Colorado Water Conservation Board (CWCB). CWI was required under the Act to prepare and present a report to the General Assembly by December 31, 2013.

HB1278 was a result of a decade of debate in the S. Platte basin that initially concerned wells that lacked court adjudicated augmentation plans to repay out-of-priority depletions. Later, concerns arose regarding property adversely impacted by high groundwater levels. The sponsors of the bill sought further information about planned utilization of the groundwater resource as a basis for improving the system of water administration in the S. Platte.

This report describes water use in the S. Platte basin – more specifically, groundwater use and water table level trends, surface water use and trends, phreatophytes, and the climate of the S. Platte basin – in order to better understand the current status and potential opportunities for alluvial groundwater utilization in the basin. HB1278 directed CWI to:

- Evaluate whether current laws and rules that guide water administration in the South Platte River basin achieve the dual goals of protecting senior water rights and maximizing the beneficial use of both surface water and groundwater within the basin.
- Identify and delineate areas within the basin adversely impacted by high groundwater levels and to conduct a feasibility-level evaluation of the causes of high groundwater levels in the affected area.
- Provide information to use as a base for implementation of measures to mitigate adverse impacts in areas experiencing high groundwater levels.
- Provide information to the General Assembly, CWCB, and the State Engineer to facilitate the long-term sustainable use of South Platte water supplies.

In addition, CWI was directed to evaluate and report its findings and conclusions regarding:

- To what extent augmentation plans are preventing injury to other water rights holders or potentially causing over-augmentation of well depletions;
- Whether additional usage of the alluvial aquifer could be permitted in a manner consistent with protecting senior surface water rights; and
- Whether, and to what extent, the use of water in the basin could be improved or maximized by affording the State Engineer additional authority to administer water rights while ensuring protection of senior surface water rights.

The problems of groundwater management are complex and controversial from a number of viewpoints. The challenge of sustainably using groundwater without impairing the senior rights of surface water diverters is made more difficult by the lack of comprehensive and readily available data, models that accurately simulate actual conditions, and a common technical platform used by all water managers in the S. Platte basin. Due to the time lags involved with detecting groundwater movement and change, it is difficult to react in real time to excess depletions or accretions, sometimes resulting in undesirable third-party impacts such as fluctuating groundwater levels. In the S. Platte, concerns have arisen in recent years from conflicting viewpoints about over-pumping, as well as loss of the ability by some to utilize groundwater, excess augmentation leading to high water tables, and augmentation water not adequately replacing depletions. Often times, the problems observed are localized, and care must be exercised not to over-reach when applying solutions. While the system is working well for many water users, the question remains as to whether we can improve the system for the good of Colorado while maintaining our commitments to preventing injury to senior water users, the 1923 South Platte Compact, and the Platte River Endangered Species Recovery and Implementation Program.

HB1278 did not authorize or contemplate the development of new models to study the system, but rather an evaluation of the available data to address the objectives of the Act. High groundwater was not explicitly defined in HB1278 and thus we choose to define it as a depth to water below land surface of 10 feet or less based on discussions with research colleagues and the Colorado Division of Water Resources. Our general plan of work for this study was to use the existing data tools in the South Platte Decision Support System (SPDSS) developed for CWCB as part of the Colorado DSS (CDSS) but not the SPDSS groundwater model, which was released during the HB1278 study. The South Platte Decision Support System (SPDSS) has been under development over the past decade and provides a wealth of data, data tools, and data synthesis through the many Technical Memoranda that may be accessed online at http://cdss.state.co.us/basins/Pages/SouthPlatte.aspx. These memos were invaluable to the HB1278 study and are referenced many times in this report. In addition, the SPDSS contains GIS data and map layers, software products such as the TSTools, online tools such as map viewer, and modeling data and software.

The SPDSS groundwater model was developed and calibrated for the CWCB by CDM-Smith using MODFLOW-2000, a finite-difference groundwater flow model. The groundwater model currently simulates the period from 1950-2006 and is in the process of being updated to the present. The SPDSS will also include a surface water model, which is currently under development. The large geographic extent of the basin necessitated development of a regional planning model based upon 1,000 x 1,000 foot grid cells (~23 acres per cell). Because of the grid size, the model is most appropriately used for regional scale planning rather than local investigations or decision-making. The SPDSS groundwater model simulates a very complex system and is extremely data intensive, requiring extensive computer processing time and capacity. While the groundwater model was released during the course of the HB1278 study, it was not used for our analysis but should prove helpful in the future as regional scale changes are considered for implementation. We used the SPDSS tools to develop datasets on groundwater levels, surface and groundwater diversions, river flow, call records, stream gain and loss, augmentation, artificial recharge, phreatophytes, and other factors for analysis. Our approach was to use these tools to generate data products we could use to compare factors on a decadal basis to smooth out annual variation in climate and hydrologic conditions to detect long-term trends, looking most closely at trends since 2000 when we entered the current era of stricter administration of groundwater. The groundwork laid by the SPDSS was extremely useful for the HB1278 study. We determined at the outset to focus on publically available data from HydroBase, the National Water Information System (NWIS), the National Oceanic and Atmospheric Administration, the Colorado Agricultural Meteorological Network (CoAgMet), and LandSat that could be accessed and replicated by any interested party. We also accessed key groundwater monitoring data from the Central Colorado Water Conservancy District and the Lower South Platte Water Conservancy District. It is acknowledged that many other S. Platte water management entities hold their own datasets that provide additional information; however, we chose to focus primarily on the publically available data and the SPDSS tools to conduct our analysis.

BACKGROUND

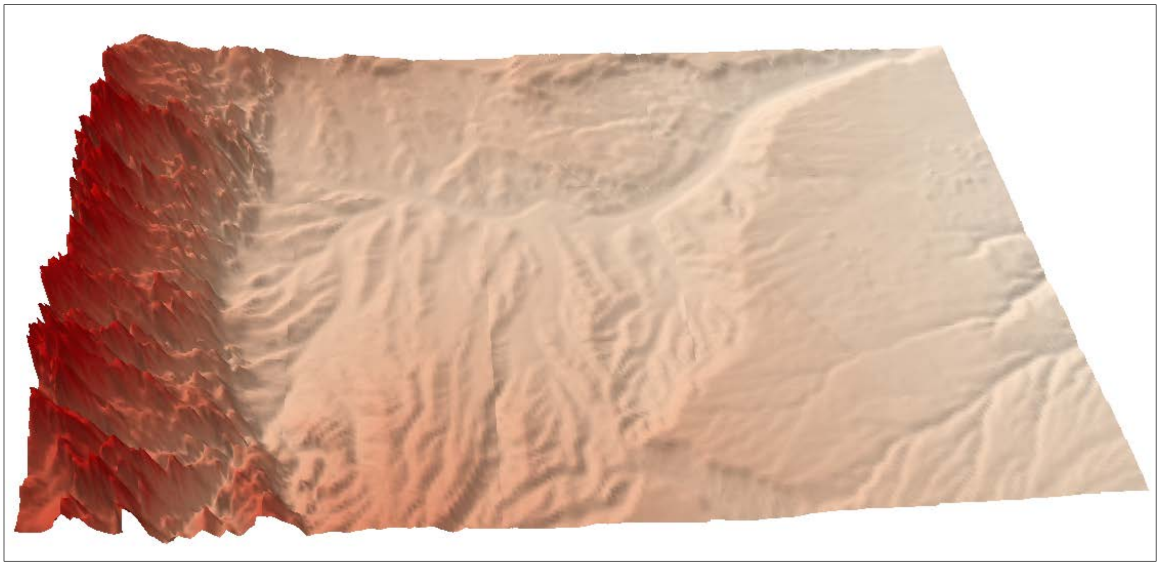
Key Points

- The S. Platte is a return flow dominated system. It is over-appropriated and thus governed by senior surface calls.
- Virtually all irrigation wells in the basin were developed after 1920 and are junior to senior calling rights.
- Wells were integrated into the prior appropriation system through the Water Right Determination and Administration Act of 1969, which allowed groundwater to be taken out-of-priority if injurious depletions could be mitigated through a court approved augmentation plan.
- In 2000 the Empire Lodge Homeowner's Association v. Moyer case affirmed the water court's decision that the State Engineer did not have legal authority to approve Substitute Water Supply Plans indefinitely. Two large well user organizations in the S. Platte, the Ground Water Management Subdistrict (Central GMS) and Groundwater Appropriators of the S. Platte (GASP) were using this mechanism to receive annual approval for their augmentation plans.
- In 2002-03 Colorado entered into a prolonged drought that resulted in the curtailment of approximately 5,000 junior groundwater wells that were pumping S. Platte River tributary groundwater without court approved augmentation plans.
- In 2008 reports of high groundwater levels began to surface in the Sterling and Gilcrest/LaSalle areas.

Basin Description

The South Platte basin is one of the most complex water use and administration basins in Colorado, with a long management history and some 18,600 decreed points of diversion. The S. Platte River flows eastwards out of the Rocky Mountains to Denver then turns northeast and flows to Nebraska. Its altitude varies from over 14,000 feet at the headwaters to 3,400 feet at the state line (Map 1). The plains begin at about 6,000 feet above sea level east of the foothills and gradually slope to the east. The climate is highly variable, with average rainfall varying from 10-17 inches. The average annual flow in the S. Platte at Julesburg (since 1969), near the Nebraska border, is approximately 478,000 acre-feet (AF), but within this period there has been variation in average annual flow between 55,000 and 2.1 million AF. Flows are bolstered by annual transfers of approximately 400,000 AF in transbasin diversions, mostly from the Colorado River. Return flows from irrigation may make an even larger contribution to stabilizing river flows. The S. Platte River basin includes all or part of 14 counties and comprises about 20% of the state's land area. CWCB estimates that approximately 830,000 acres are irrigated within the S. Platte basin (2011). The alluvial groundwater system covers about 4,000 square miles according to the

Colorado Geological Survey (Map 2). Due to the magnitude of surface and groundwater diverted for irrigation, agricultural water use exerts a large influence on groundwater flow conditions. A century and a half of irrigation development in the basin has resulted in an extensive network of diversion ditches, canals, and reservoirs, all of which seep large amounts of water into the alluvial aquifer. More recently, particularly in the last 20 years, there has been extensive development of recharge projects that are used to augment out-of-priority groundwater diversions or withdrawals.



Map 1. Digital Elevation Model of Northeast Colorado Showing the S. Platte Drainage.

Prior to widespread irrigation, most of the stream system experienced peak flow during the spring and early summer months from snowmelt runoff, declining to low baseflow levels for most of the remaining annual cycle. Irrigation development over time increased available water supplies by increasing surface water return flow and the water table elevation of the alluvial aquifer. Streamflow hydrographs increased from the early period of development in the 1860s to the late 1950s as transbasin diversions, reservoirs, and other water projects were developed. Since that time the flow trend has stabilized but with large interannual variability. Large ditches with senior rights sweep the entire flow of the river at certain places and times, yet the river regains flow from groundwater and return flows just below these dry-up points to serve the next downstream water right. Irrigation remains the dominant use of water in the basin today and the river is a return flow dependent system administered in priority of appropriation and decree.

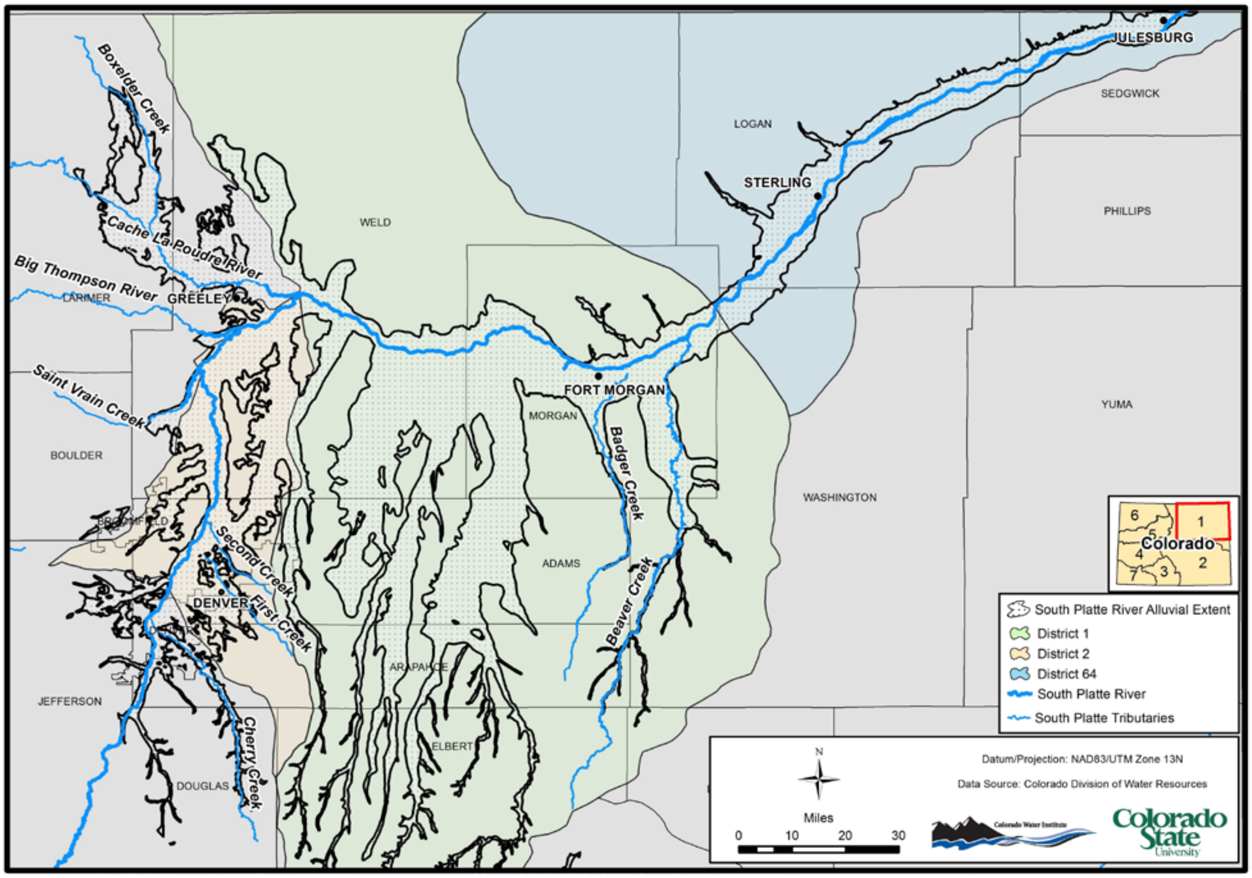
The 2010 population of the basin was approximately 3.4 million people and is expected to increase to an estimated 6 million by 2050. Seventy percent of Colorado’s total employment is in the S. Platte basin. Approximately 40% of Colorado's agricultural production occurs in the S. Platte (Thorvaldsen and Pritchett, 2005). In 2002 the annual value of sales and services in the S.

Platte equaled $251 billion, of which agricultural production directly accounted for $2.2 billion. Although agriculture's share of the basin's total economic output is relatively small, any reduction of irrigated cropland in these areas has an impact on the economy in counties east of the Front Range. In 2005, irrigated agriculture accounted for over two thirds of water use in the S. Platte basin. Rapid growth of population and urban water demand is leading to increasing competition for water (Thorvaldsen and Pritchett, 2007).

Groundwater pumping from high capacity alluvial wells located along the S. Platte River was estimated to be nearly 500,000 AF annually prior to 2002 from approximately 8,200 wells (Thorvaldsen and Prittchett, 2007). Currently, it is estimated that closer to 450,000 AF are pumped annually in the basin from 6,500 high capacity wells. Total decreed water rights in the basin equal approximately 4,000,000 AF, resulting from multiple uses of return flows from upstream diversions of native water, reservoir deliveries, as well as imported transbasin water (Jones, 2010).

The history of irrigation in the S. Platte basin has been a cycle of over-appropriation followed by adjustment and supply enhancement. New canals, reservoirs, transbasin diversions, and wells were developed over time to deal with shortage and to firm up water rights and irrigable acreage, but the result was always quickly back to a fully appropriated system. Water development generally proceeded from an upstream to downstream progression, with the first significant diversion occurring in 1870 in the vicinity of Greeley. Development proceeded at a rapid pace, and by the late 1890s to early 1900s, a more stable water supply based on return flows was available in the lower river, leading to the development of more extensive irrigation works in that region. By the 1930s, water shortage and drought led to the development of the Colorado Big Thompson project, which imports approximately 280,000 AF annually into the basin.

Return flows have been an integral part of the S. Platte water supply since the 1880s. The river valley from Kersey to Julesburg stretches approximately 158 miles, providing many opportunities to pick up and use return flows for irrigation and augmentation (Hurr and Scheider, 1972b). A 1951 Reclamation study for the Narrows project noted that the total return flow in the Kersey to Julesburg stretch of the river averaged 552,400 AF during the 1925-1945 period. Inadequate drainage following canal and ditch development has historically caused localized waterlogging and subsequent abandonment of some irrigated lands in the basin, and is documented in the Reclamation Narrows study (1951) to have occurred in the Sterling area.



Map 2. Outline of the S. Platte Alluvial Aquifers in Northeast Colorado Showing Division 1 Water Districts 2, 1, and 64.

The S. Platte River is over-appropriated and thus governed by senior surface calls. Though there are times of free river (water flow in surplus of the amount subject to diversion by water rights) in the spring and early summer runoff months and following large storm events, for most of the irrigation season, the river serves only water rights with priority dates pre-dating 1900 (Jones, 2010). In the winter months, the river is dedicated to filling reservoirs with priority dates pre-dating 1915 (Howe 2008). It is important to note that virtually all the irrigation wells in the basin were developed after 1915, and water rights junior to the senior calling rights take water on an as-available basis during times of free river resulting from high flow and/or low demand. The solution provided in the Water Right Determination and Administration Act of 1969 allowed groundwater to be taken out-of-priority if injurious lagged depletions could be mitigated through a court approved augmentation plan.

In 2002-03 Colorado entered into a prolonged drought that resulted in the curtailment of many junior groundwater wells that were pumping S. Platte River tributary groundwater. In *Simpson v. Bijou* (Colo. 2003), the Colorado Supreme Court held that the General Assembly through the 1969 Act had required the wells to be integrated into the priority system. Forty-four years after the 1969 Act, the desire to integrate surface and groundwater management has proven a formidable task in virtually every water basin in the state. Today, there are those who want to know if the current approach is over-protecting the river, resulting in high groundwater and restricting the maximum beneficial use of the groundwater resource.

The planned conjunctive use of groundwater and surface water has been touted to offer benefits in terms of economic, environmental, and social outcomes through increased water use efficiency and the control of shallow groundwater levels and consequent soil salinity. However, retrofitting conjunctive use into a prior appropriation system that heavily favors surface water users is made difficult by the many layers of management and local interests that have evolved over time. It is important to acknowledge that most of our water administration is functioning well – the challenge lies in whether we can move to an even higher level of sustainable utilization. The S. Platte alluvial aquifer provides a huge storage vessel, far surpassing anything that could feasibly be built in the modern era. Conjunctive use of surface and groundwater has been shown to increase the economic output of a basin and to provide a buffer against drought (Shah, Darghouth & Dinar, 2006). However, to avoid over-appropriation of the groundwater resource, the measure of sustainable development must be the balance of long-term recharge and diversion by pumping. It is critically important to the long-term sustainability of crop production in the basin to acknowledge that water table control and drainage is the key to salinity management in any river basin system in an arid region. High water tables inevitably lead to non-beneficial evaporative upflux and salinization, a slow but sure death for soil productivity. Bredehoeft (2011) stressed that strict administration by prior appropriation and conjunctive use are not compatible; integration of surface and groundwater management into a single administrative framework is needed to achieve sustainable conjunctive management. If it is any consolation to Colorado, there are few, if any, examples of how to retrofit a basin such as the S. Platte without harming existing water rights.

Brief History of Groundwater Development in the South Platte

The S. Platte basin has experienced continual change from the 1860s to the present, resulting in additional supplies, uses, and changes of use over time. The era of irrigation development on the S. Platte began in earnest in the early 1860s, and the first large-scale irrigation project was initiated with the Union Colony in 1870 near Greeley. Chronologically speaking, the use of groundwater for irrigation was not far behind, as the first irrigation well of record was excavated in 1886 in the Lone Tree alluvium east of Eaton.

As early as 1896, it was documented that the S. Platte River was being augmented by canal seepage and irrigation return flow, benefitting those downstream. In the 1913 *Comstock v Ramsay* case, the Colorado Supreme Court clarified that return flows are tributary to the river and that the water right holder has no right to redirect return flows, thus the single use rule. In its 1913 ruling, the Court stated that all of the waters of the S. Platte were appropriated, and that the entire normal flow was inadequate to supply the decreed irrigated lands. Additionally, the ruling stated that almost every decree except possibly only the very early ones were dependent upon return flows, which is what enabled enlarged use of the stream.

It was not until the 1930s when modern drilling technology and electrical pumps became available that well yields became sufficient for large-scale irrigated crop production. By 1930 there were approximately 300 high capacity wells in the S. Platte basin, and the drought of the 1930s resulted in an additional 1,400 wells constructed in the basin. William Code's 1943 report entitled *Use Of Ground Water For Irrigation In The South Platte Valley Of Colorado* documented that there were 1,957 irrigation wells pumping an estimated 220,000 AF in 1940. Code (1943) determined that over 80% of the irrigation wells at that time were used to supplement the surface water rights owned by irrigators. Following World War II, the rural electrical associations brought electric power to rural areas and turbine pump technology became available, making diversions of groundwater more feasible. Severe drought during the 1950s resulted in the construction of an additional 1,200 wells. By this point, there was growing concern in the basin about the impact of unbridled well pumping on river flows. The legislature took the first step toward regulating tributary groundwater when it passed Senate Bill 120 in 1953. The 1953 Act, entitled "Underground Water" required well drillers to be licensed, the filing of advance notice of well drilling, and the filing of well logs after drilling, all under the supervision of CWCB. In 1956, Colorado State University (CSU) Professor Ralph Parshall observed that seepage return flow in 1956 was nil partly due to the fact that more than 4,000 irrigation wells pumped 584,000 AF during the irrigation season of 1955. This coincided with severely reduced senior surface water diversions during extended periods from 1955 to 1957.

Compared to some of the other western states, Colorado was relatively slow to enact legislation governing groundwater withdrawals. Several other western states addressed the groundwater issue in some form early in their development (Territory of Dakota, 1866; Kansas 1891, 1910; Idaho, 1899; Utah, 1903; Nevada and California, 1913; Arizona, 1919). The Colorado General Assembly took no meaningful action until 1957. By 1957 there was recognition of the need to regulate groundwater development in the state. The Colorado Ground Water Law of 1957 established that a permit from the State Engineer was a prerequisite to drilling a well and obtaining a water right, but the permit was administrative only with no evaluation standards and therefore no basis to deny. The 1957 Act also established that a well permit "shall not have the effect of granting or conferring a groundwater right upon the user," and that the newly established Commission shall identify critical groundwater areas that "have approached, reached or exceeded the normal annual rate of replenishment" (1957 Colo. Sess. Laws, Ch. 289, 863-73).

The General Assembly, in 1965, put groundwater within the regulatory authority of the State Engineer and for the first time allowed the State Engineer to deny a well permit application if the State Engineer found that there was no unappropriated water available or that the proposed well would materially injure other vested water rights. Although the 1965 Act subjected new wells to an injury analysis, it did not require wells to get a decreed water right, and did not provide for administration in priority of permitted wells (Hannay 1980; Hobbs 1999).

During the mid-1960s, dry conditions and low streamflows resulted in more complaints by senior surface water rights on the S. Platte and Arkansas River, claiming wells were causing depletions and should be regulated within the priority system like surface water rights. In June 1966, the Division Engineer in the Arkansas River basin attempted to regulate a limited number of wells, in response to complaints by holders of senior surface water rights (Simpson 2006). This led to the 1968 Colorado Supreme Court decision in *Fellhauer v. People*. In Fellhauer, the Supreme Court held that any regulation of wells must be preceded by the promulgation of reasonable rules and regulations, and that wells should only be regulated to the extent that it resulted in a reasonable lessening of material injury to senior water rights. Fellhauer contained the now famous statement by Justice Groves that "as administration of water approaches its second century, the curtain is opening upon the new drama of maximum utilization and how constitutionally that doctrine can be integrated into the law of vested rights."

In 1967, the Legislature passed Senate Bill 407, authorizing a two-year investigation of the relationship between surface and groundwater to evaluate the need for additional legislation to effectuate integrated administration of surface and groundwater. Morton W. Bittinger & Associates and Wright Water Engineers conducted the SB407 studies (1968). The 1968 report by Bittinger and Wright concluded:

- The 20-year moving average at Julesburg was showing a very slight downward trend caused by the cumulative effect of many wells.
- Shutting off wells to satisfy senior surface rights is a negative approach which does not allow utilization of stored water when needed and increased beneficial use can be attained through planned integrated management and the use of surface and groundwater.
- Fully integrated management of groundwater and surface water should be planned for the entire basin to achieve maximum benefits.
- Planned utilization of 10% to 15% of the groundwater storage capacity can provide more efficient utilization of the total resources of the basin, reduce shortages, and minimize conflicts between water users. This planned utilization in conjunction with surface water supplies would basically involve a heavier draft upon the groundwater supplies during low runoff years with provision for replenishment of those supplies during years of surplus runoff.
- Surface water right owners should be allowed to obtain alternate points of diversion at wells.
- Immediate steps were needed to improve the completeness, accuracy, storage, and retrieval of water measurements and records, utilizing automatic data processing methods wherever possible.
- The State Engineer should be granted administrative power to grant or deny changes in point of diversions, alternate points of diversion and transfers of water between uses and users, provided that investigations indicate that such changes or transfers will not materially injure the vested rights of others. Such decisions should be subject to court review. Water rights should be quantified in terms of acre-feet on the basis of beneficial use.
- Legislation was needed to allow the integrated management and administration of groundwater and surface water on an overall S. Platte River basin basis through the establishment of basin water management. A basin authority should be financed by a

small ad valorem tax on all real property within the district boundaries and should be given specific powers to own and operate well fields, reservoirs, and other facilities.

Following the Bittinger/Wright Study (1968) and the Fellhauer decision, the Legislature repealed House Bill 1066 and enacted comprehensive legislation entitled the Water Right Determination and Administration Act of 1969 (the "1969 Act"). The 1969 Act was the Legislature's attempt to integrate surface and groundwater use. The Act intentionally brought all alluvial groundwater into administration based on the prior appropriation doctrine. The legislative declaration of the 1969 Act provides that "it is the policy of this state to integrate the appropriation, use, and administration of underground water tributary to a stream with the use of surface water in such a way as to maximize the beneficial use of all of the waters of this state." The 1969 Act introduced the concept of a "plan for augmentation," by which a well or other junior water right could divert or operate out-of-priority so long as replacement water was supplied in time, location, and amount sufficient to prevent injury to senior water rights (MacDonnell, 1988a, 1988b).

Though the 1969 Act called for adjudication of all augmentation plans by the water court, in order to ease the transition, the 1969 Act further provided the ability for the State Engineer to approve temporary augmentation plans pending court adjudication of the final plans (MacDonnell, 1988a, 1988b; Jones, 2010). The State Engineer's approval of temporary plans would eventually cause a major crisis in 2002. In the wake of the 1969 Act, most S. Platte well users adjudicated their wells and received priority dates. Some sought court approval of augmentation plans, but the vast majority of S. Platte wells sought shelter in State Engineer approved substitute water supply plans (SWSP) — annual administrative approvals that allowed ongoing pumping. Because of the high cost of obtaining the replacement water necessary for the adjudication of permanent plans, two major well augmentation groups formed on the S. Platte — one under the auspices of the GASP (Groundwater Appropriators of the S. Platte) was established in 1972 (approximately 4,000 wells), and the Central Colorado Water Conservancy District's (CCWCD) Ground Water Management Subdistrict ("Central GMS") was formed in 1973 (approximately 1,000 wells). Neither GMS nor GASP sought court approved augmentation plans in the 1970s, '80s, or '90s (MacDonnell, 1988a; Jones, 2010).

In 1974, the Legislature adopted Senate Bill 7, authorizing the State Engineer to grant temporary approval while applications for augmentation plans were pending in water court. Only three years later, the Legislature passed Senate Bill 4 in 1977, which repealed Senate Bill 7 and revoked the State Engineer's authority to temporarily approve augmentation plans. However, the State Engineer continued to approve annual temporary Substitute Water Supply Plans for these entities (Strawn, 2004). Some S. Platte water users became increasingly dissatisfied with the approval process, accusing GMS and GASP of providing inadequate replacement of depletions. However, from 1980 to 2000, the S. Platte enjoyed 20 relatively wet years, masking supply shortages.

GMS and GASP took different paths. While both continued to enjoy temporary administrative approvals, GMS set its sights on obtaining augmentation plans approved by water court, and worked towards assembling permanent supplies. GASP opted for arranging temporary leases and shorter-term supplies that supported the annual approvals, but were less useful in a permanent augmentation plan. GASP had almost 4,000 wells covered under their plan from south Denver all the way to Julesburg (Strawn, 2004). Central's advantage over GASP was that it was a taxing district, while GASP relied solely on annual assessments on each well owner based on AF-feet of groundwater pumped (MacDonnell, 1988b).

In 2000, litigation was initiated in the Arkansas River basin between the Empire Lodge Homeowners Association and the Moyers. The dispute involved access issues, but a fight over water also developed, and the issue was the State Engineer's approval of an SWSP under C.R.S. § 37-80-120 that allowed a pond to be filled by exchange out of the Arkansas River up a small tributary. The water judge ruled that the Legislature had not given the State Engineer authority to approve SWSPs. This ruling was appealed to the Colorado Supreme Court, and in December 2001, the Court's decision in *Empire Lodge Homeowner's Association v. Moyer* (Colo. 2001) affirmed the water court's decision that the State Engineer did not have legal authority to approve SWSPs under the statute C.R.S. § 37-80-120 that had historically been relied upon. The Empire Lodge case had a direct and immediate impact on the administration of water rights in the S. Platte River basin, since the State Engineer no longer had authority to approve SWSPs, including the large plans covering thousands of wells that were operated by Central GMS and GASP. The Colorado Supreme Court held that through the 1969 Act: (1) the General Assembly created a new statutory authorization for water uses that, when decreed by the court, are not subject to curtailment by priority administration, (2) this statutory authorization be for out-of-priority diversions for beneficial use that operate under the terms of decreed augmentation plans, (3) plans for augmentation allow diversions of water out-of-priority while ensuring the protection of senior water rights through a replacement water supply that offsets injurious out-of-priority depletions, and (4) injurious depletions not adequately replaced shall result in curtailment of the out-of-priority diversions. The Empire Lodge case affirmed that augmentation plans are a legislatively created device to provide replacement water for senior water rights and thereby allow junior appropriators to divert water when they otherwise would be curtailed under strict prior appropriation administration. Depletions not adequately replaced result in curtailment of out-of-priority diversions, a nondiscretionary duty the water administration officials must discharge (Hobbs 2012).

During the 2002 session, the General Assembly responded to Empire Lodge by enacting HB 02-1414 (C.R.S. § 37-92-308). This legislation granted the State Engineer specific authority to review and approve SWSPs under four circumstances: (1) all previously approved SWSPs could be reapproved for 2002 only, § 37-92-308(3); (2) augmentation plans filed with the water court could be approved as SWSPs while the water court adjudication was pending, § 37-92-308(4); (3) short duration water uses (not exceeding five years) could be approved as SWSPs without water court adjudication, § 37-92-308(5); and (4) water use necessitated by a public health and safety emergency could be approved as SWSPs without water court adjudication for a period not to exceed 90 days, § 37-92-308(7). HB 02-1414 acknowledged the pre-existing rulemaking authority of the State Engineer under § 37-92-501, but it did not address the question of whether that rulemaking authority was broad enough to include annual approval of out-of-priority depletions without water court adjudication (Shimmin, 2003; Simpson, 2006; Hobbs, 2012).

State Engineer Hal D. Simpson filed proposed new rules for the S. Platte basin in May 2002. The rules, which were patterned after the rules promulgated successfully in the Arkansas River basin in 1996, would have allowed the State Engineer to annually approve replacement plans under much more stringent standards. 2002 also brought one of the worst drought years in recorded history. The call by senior water rights began in June and stayed on throughout the rest of the year. The calls in 2003 lasted nearly the entire year, and in 2004 the situation was similar. As a result, replacement of depletions caused by wells required considerably more augmentation water, and GASP ultimately went out of business in 2006. Central GMS had to scramble to lease additional water in order to obtain approval of its SWSP during those years. With the drought as a backdrop, more than thirty water user entities and individuals opposed the State Engineer's proposed rules. In separate rulings, the Division 1 Water Court held that the rules must be dismissed in their entirety because the State Engineer lacked statutory authority to review and approve annual replacement plans outside the statutory framework of express authorization granted by §37-92-308 (Strawn, 2004; Simpson, 2006).

The Colorado Supreme Court ruled on April 30, 2003 regarding the rules proposed by State Engineer Simpson in May 2002. In *Simpson v. Bijou Irrigation Co.* (Colo. 2003), the Supreme Court agreed with the Division 1 Water Court that there was no statutory authority for this type of rules for well administration. The Court remanded the rules back to the water court for consideration of the portion of the rules that pertained to an interstate compact. The majority of the *Simpson v. Bijou* decision was devoted to analysis of the scope of State Engineer authority under the water rule power of C.R.S. §37-92-501. After detailed analysis of existing statutes and legislative history, the Supreme Court concluded that the replacement plans contemplated by the proposed rules were the functional equivalent of temporary augmentation plans, that the State Engineer did not have legal authority to review and approve such plans, and that review and approval of augmentation plans is within the exclusive jurisdiction of the water court (Simpson, 2006).

On the same day that *Simpson v. Bijou* (Colo. 2003) was decided, the Governor signed SB 03-73, giving well organizations in the S. Platte River basin three years to file a plan for augmentation with the Division 1 Water Court, and allowing the State Engineer to annually approve an SWSP after conducting a hearing. The basic structure was patterned after the SWSP process already contained in §37-92-308. However, changes in the water market in the basin following the 2002 drought limited the availability of water and many of the well owners were unable to find sufficient replacement water at an affordable price to take advantage of the Legislature's authorization. SB03-73 included 37-92-308(3) which stated that "Beginning January 1, 2006, groundwater diversions from all such wells shall be continuously curtailed unless the wells are included in a plan for augmentation approved by the water judge for Water Division 1, are included in an SWSP approved pursuant to subsection (4) of this section, or can be operated under their own priorities without augmentation." This allowed for a well user to obtain an SWSP without having to first file in water court. This allowance was made explicitly for the years 2003, 2004, and 2005 "to provide sufficient time to fully integrate certain wells into the water court adjudication process for augmentation plans." But, such plans were still required to "replace all out-of-priority stream depletions in time location and amount." During 2006, the Central Well Augmentation Subdistrict ("Central WAS") had an SWSP application before the

State Engineer for approval that was heavily reliant on recharge from spring runoff and augmentation wells. During that spring, the forecast for runoff was extremely pessimistic. This caused an even greater reliance on augmentation wells, creating more future obligations that required replacement. With the prospect of the SWSP application being denied because of a lack of sufficient augmentation water, Central WAS withdrew its application, impacting 449 wells.

In 2003, GASP filed for approval of an SWSP under SB 03-73. The plan was approved to allow for replacement of ongoing stream depletions that resulted from past pumping, but did not allow any new pumping in 2003. GASP went out of business shortly thereafter, leaving hundreds of wells without augmentation coverage. As the need for recharge credits increased, the downstream reservoirs were no longer willing to gamble on whether they would fill. The "gentlemen's agreement" that had existed for many years was discontinued. In addition, the pressure on well owners to reduce their depletions to the river resulted in many ditches starting river diversions earlier than had occurred previously, when wells were used to provide the early season irrigation water.

In GASP's place other groups were formed to develop and file augmentation plans. The "South Platte Well Owners" filed two applications for augmentation plans with the Water Court and sought approval of an SWSP for 380 wells in June 2003. This group was composed of former members of GASP. In 2004, CCWCD established the Central WAS, which included the above 380 wells and 61 additional wells, for a total of 441 wells (Simpson, 2006). Meanwhile, the Central GMS application (Case No. 02CW335) was being prepared for a 2005 trial in the Water Court. In May of 2005, the Central GMS case settled on the eve of trial. The resulting consent decree was the result of extensive settlement negotiations and contained numerous restrictive terms and conditions for the protection of senior water rights. The Central GMS decree utilized a projection tool to forecast future depletions and anticipated replacement of Central GMS member wells. After lengthy multi-party negotiations, GMS, the largest and oldest of the remaining augmentation groups, settled out of court with water users opposing its plan, and presented a stipulated augmentation plan to the judge. The GMS plan did not have enough water supplies to cover depletions from pumping its member wells at 100% capacity (Jones, 2010). As a result, there was a need to limit pumping such that depletions would never exceed replacement supply. Depletions are calculated for each well to establish the impact on surface flows. The wells are required to replace the calculated depletions in the time and amount that the Glover analysis dictates, at a location set forth in the decree. For supply, GMS is allowed to project deliveries of senior rights it owns based on a dry year yield. It may project deliveries from surface storage to the extent that there is water in storage at the time of the projection. Similarly, it may predict groundwater accretions to the extent that water has already been delivered to recharge sites for aquifer percolation. It may not assume any additional future deliveries of junior recharge rights. The length of the GMS projection is seven years. This time period is intended to match the approximate time it takes for the bulk of delayed depletions from pumping the member wells to affect the river. The projection is updated annually by April 15. This Projection Tool methodology was also applied successfully to GASP orphan groups located downstream of Fort Morgan. Since its inception, it has been refined in a series of S. Platte decrees and has become the de facto standard for S. Platte augmentation plans. Since the entry of its decree, GMS has been able to declare quotas ranging from 15% to 40% of calculated demand (Jones, 2010).

During the spring of 2006, Central WAS engaged in an increasingly contentious effort to secure the ability of its member wells to pump during the 2006 irrigation season. Central WAS's struggles during this period illustrate the challenges involved in the operation of a large-scale augmentation plan during a period of extended drought. Central WAS initially submitted a request for approval of an SWSP for 449 wells with a proposed pumping quota of 20% (of average historical pumping), based on a projected annual call period of 70% of the days of the year. By May 1 of that year, the snowpack was below average and the State Engineer's anticipated number of days of no call was reduced to nearly zero. State Engineer Simpson informed CCWCD on May 5, 2006, that he could not approve the Central WAS SWSP as proposed, and suggested that if the plan was denied, Central WAS could appeal it to the Division 1 Water Court to be considered together with the appeals of the approvals of the 2003 and 2004 SWSPs that were set begin on May 8, 2006 (Simpson, 2006).

The Central Board decided to withdraw the 2006 SWSP request. The result was that barely a month into the 2006 irrigation season, the Central WAS wells were ordered not to pump until further notice. Consistent with the withdrawal of the 2006 SWSP and the Water Court's order, the Division 1 Engineer ordered all of the 449 Central WAS member wells to cease pumping. Notification was done primarily via certified mail. Division 1 staff posted notices on the well sites when certified mail was not accepted. Division 1 staff field inspected the great majority of Central WAS wells, collecting power meter and flow meter information to verify compliance with the stop-pumping order. As with other wells, Division 1 staff has continued to monitor these wells and have filed complaints with the water court when a user has violated the order.

As the February 2007 trial date neared in the Central WAS augmentation plan cases, Central WAS dropped 230 wells from the applications, leaving approximately 219 wells in the plan. The Central WAS plan was unable to settle out of court with senior surface rights owners opposing the application, principally because the opposers believed that WAS did not have enough augmentation supplies to justify the entry of a decree. WAS wells did not receive temporary approval to operate in 2006, and were curtailed. This curtailment was an extreme hardship on well owners, and drew attention from national media (Jones, 2010). The most immediate economic impact of well curtailment fell on farmers who relied disproportionately on alluvial groundwater for irrigation. These producers had little recourse but to fallow or convert formerly irrigated acres to dryland farming. Higher value crops did not decline in acreage as a result of changing administration – these acres shifted elsewhere within the basin. Lower value, less water using crops such as wheat were grown on affected acres. Local business adapted to changing conditions for the most part, but some allied business in eastern Weld County and western Morgan County suffered declines in revenues. Value-added industries (ethanol, feedlots, dairies) were still able to source inputs, and the high prices they paid were the result of national price conditions rather than local price conditions. In aggregate, agribusiness remained healthy in the S. Platte basin but some individual operations were devastated, as debt could no longer be serviced (Thorvaldsen and Pritchett, 2007).

Whereas GMS had been assembling permanent supplies for 30 years, WAS had only four years and limited means. Faced with relatively small amounts of permanent supply, and the reality that available funding was insufficient to allow the large scale purchase of senior water rights, WAS developed an aggressive program of groundwater recharge designed to capture free river water during times of surplus and re-time it to replace well depletions. WAS's recharge program consists of a series of shallow infiltration basins, generally located on existing ditch systems. When water is available, it is delivered via agreement with the ditch company to the recharge sites, where it is allowed to infiltrate into the alluvial aquifer. The same analytical equations that are used to calculate depletions are then used to calculate accretions and predict when these accretions will supplement river flows. In addition, many of the projects involve the use of alluvial wells to take water from the aquifer and deliver it to the river to supplement river flows (augmentation wells) or take water from the river and deliver it to recharge sites (headgate wells) (Jones, 2010). Operated together, these facilities give WAS the ability to take water when it is available and re-time it to match the pattern of groundwater depletions caused by the member wells used for irrigation.

From 1995 to 2007 the number of augmentation decrees went from 400 to over 750. During this same period the number of mainstem call changes went from less than 100 days to essentially year round. This change in the call regime resulted in reduced use of groundwater and increased reliance on surface rights during the summer. From 1995 to 2007 the number of water rights for which daily diversions are recorded went from 3,250 to almost 4,900. This increase in surface water diversion was in large part a result of junior recharge projects coming online and decreed augmentation plans and changes of water rights that require daily recording of diversions. The historical lack of river calls from November through March has ceased as reservoir managers place calls to assure that they can fill their reservoirs and not have to compete for the water that otherwise would be diverted by junior recharge water rights and storage rights.

In 2009 the Colorado General Assembly passed HB 09-1174, exempting new augmentation plans from having to replace for out-of-priority well pumping depletions that occurred prior to 1974. In 2013 the Division 1 Water Court approved the *Rules Governing the Measurement of Tributary Ground Water Diversions by Wells Located in the South Platte River Basin within Water Division No. 1,* requiring all nonexempt tributary wells to be metered by an approved method and provide an annual report of monthly total well diversions by December 1 for the previous 12 month period (Nov 1 through Oct 31).

(More detail on the history of groundwater development and regulation can be found in the Appendix II to this document.)

Problems Leading to HB1278

In 2008 there were homeowner reports of high groundwater levels in the Pawnee Ridge and the Country Club Hills subdivisions of Sterling. Subsequent wet years in 2009, 2010, and 2011 increased the frequency and locations of these complaints. Homeowners reported failing septic systems and flooding basements that had not previously been a concern (Ganser, 2010). Local attempts to address flooding concerns were not successful, as inadequate information existed to precisely isolate the cause of the waterlogging. Meanwhile, farmers and homeowners in the Gilcrest/LaSalle area also began relaying concerns that high groundwater levels were damaging crops and flooding basements and septic systems locally. Additionally, seep ditches and low areas not wet in recent years were reported as a problem to landowners.

Some well owners who had been curtailed due to lack of adjudicated augmentation plans believed the high water table was symptomatic, telling us that recent changes in groundwater management led to these problematic groundwater levels. While they acknowledge that augmentation plans are working well for some groundwater users, fields in Weld, Morgan, and Logan Counties near the river that previously grew good crops were becoming increasingly waterlogged. Some believe the 500-800 curtailed wells in Weld and Morgan Counties affecting 20,000 to 30,000 acres mainly in the BeeBe Draw, Prospect Valley, Box Elder, Badger, Beaver, and Wiggins Hill areas were overly restricted and faced unfair circumstances in water court as they adjudicated augmentation plans in the modern era. These parties appealed to the state Legislature, asking if there was a way to insert some institutional mechanisms to create more flexibility and opportunity for agricultural water users. Homeowners with flooded basements asked why recharge structures continued to their operations when the local water table was near the surface. Eventually, the Legislature passed HB12-1278 to study these problems and propose solutions.

GROUNDWATER PUMPING

Key Points

- The SB06-193 study conducted by the Colorado Water Conservation Board (CWCB) estimated 10 MAF of water is stored in the S. Platte alluvial aquifer.
- Prior to 2003, approximately 8,200 high capacity wells pumped on average nearly 500,000 AF/yr from the alluvial aquifer. There are now approximately 6,500 high capacity wells in the alluvial aquifer, and total annual groundwater pumping in the basin is now closer to 450,000 AF/yr, with agricultural pumping estimated in the 400,000 AF/yr range.
- In 2005, 60% of the 830,000 irrigated acres in the basin were watered solely with surface water, 18% solely with groundwater, and 22% with a mix of surface and groundwater.
- Most of the irrigation wells in adjudicated augmentation plans now have full or near full allocations in most years, however, the Central Colorado Water Conservancy District has approximately 1,200 wells in the WAS and GMS plans that are on a restricted quota and not able to pump 100% of full crop ET.
- The greatest groundwater pumping occurs in Water District 1, which correlates with the large amount of acreage served only by groundwater. The greatest percentage reduction in pumping has occurred in Water District 2 as Central WAS and GMS and other augmentation plans work to develop reliable augmentation supplies. Water District 64 has the most recharge and surface augmentation sources due to their downstream position in the basin. Pumping amounts have returned to previous levels in District 64.
- Groundwater pumping has shown a rebound in Water Districts 2, 1, and 64 since 2009 as additional augmentation supplies have been acquired and adjudicated.
- Groundwater pumping and consumptive use estimates were developed for the HB1278 study by the Wilson Water Group in collaboration with Leonard Rice Engineers. The well metering rules enacted in 2013 will enhance future pumping analyses.

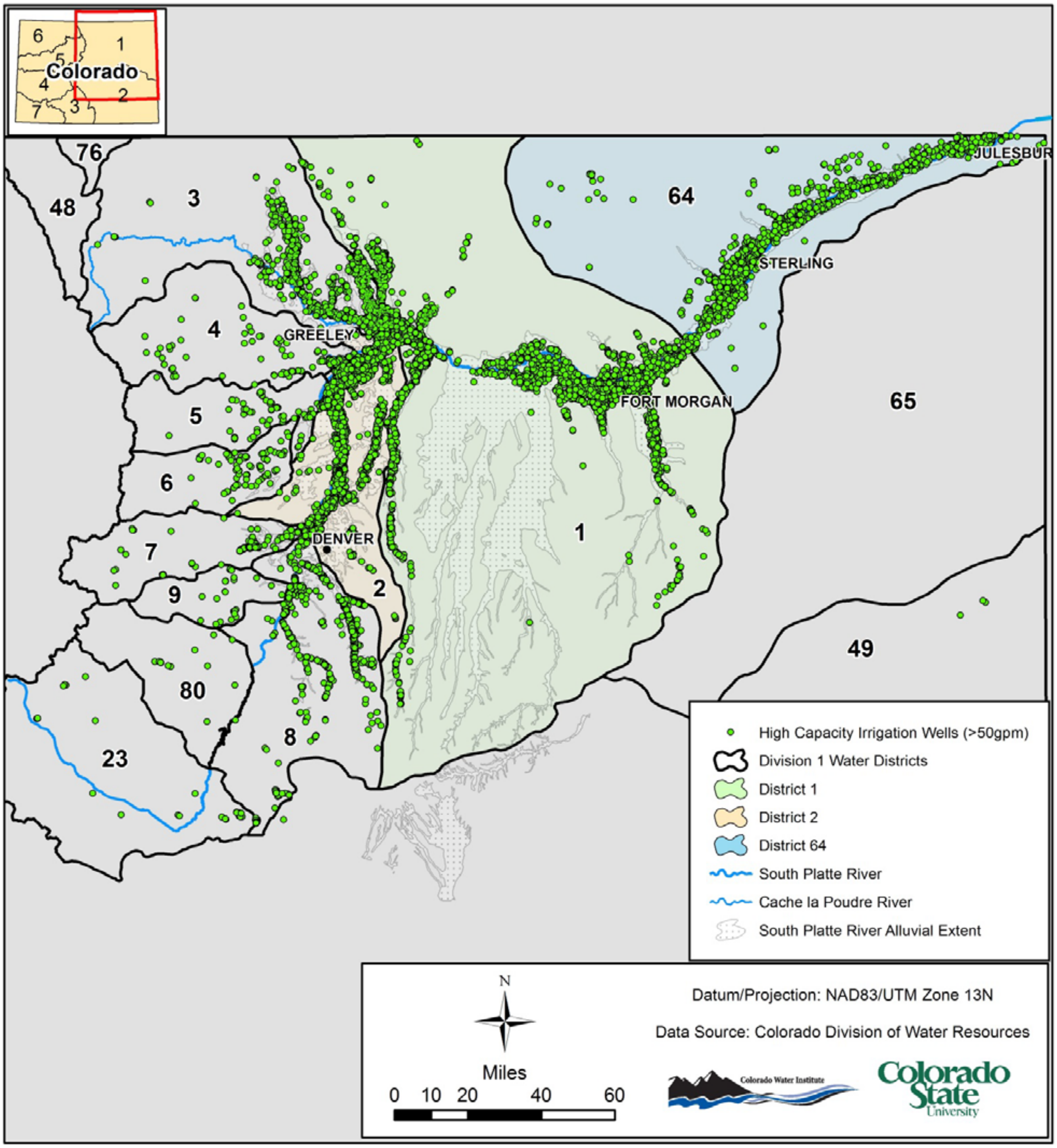
Description of the South Platte Alluvial Aquifer

The S. Platte alluvial aquifer consists primarily of silt, sand, and gravel deposits of alluvial and aeolian origin that cover an area of over 4,000 square miles. Drilling logs indicate the deposits near the base of the alluvium are coarsest and become finer towards the surface, with considerable heterogeneity in the aquifer materials, particularly with respect to clay and silt. Clay layers are common throughout the basin, both laterally and vertically, and although clay layers may not be laterally continuous over great distances, they can affect pathways of groundwater movement. In addition, the aquifer grades from coarsest material in the west to finer material in the east. The ancient S. Platte River and its tributaries, swollen with snowmelt at the end of the last ice age (Pleistocene), left extensive alluvial deposits ranging in width from two to six miles wide and up to 200 feet deep in the main river channel (Lindsey, Langer & Knepper Jr., 2005).

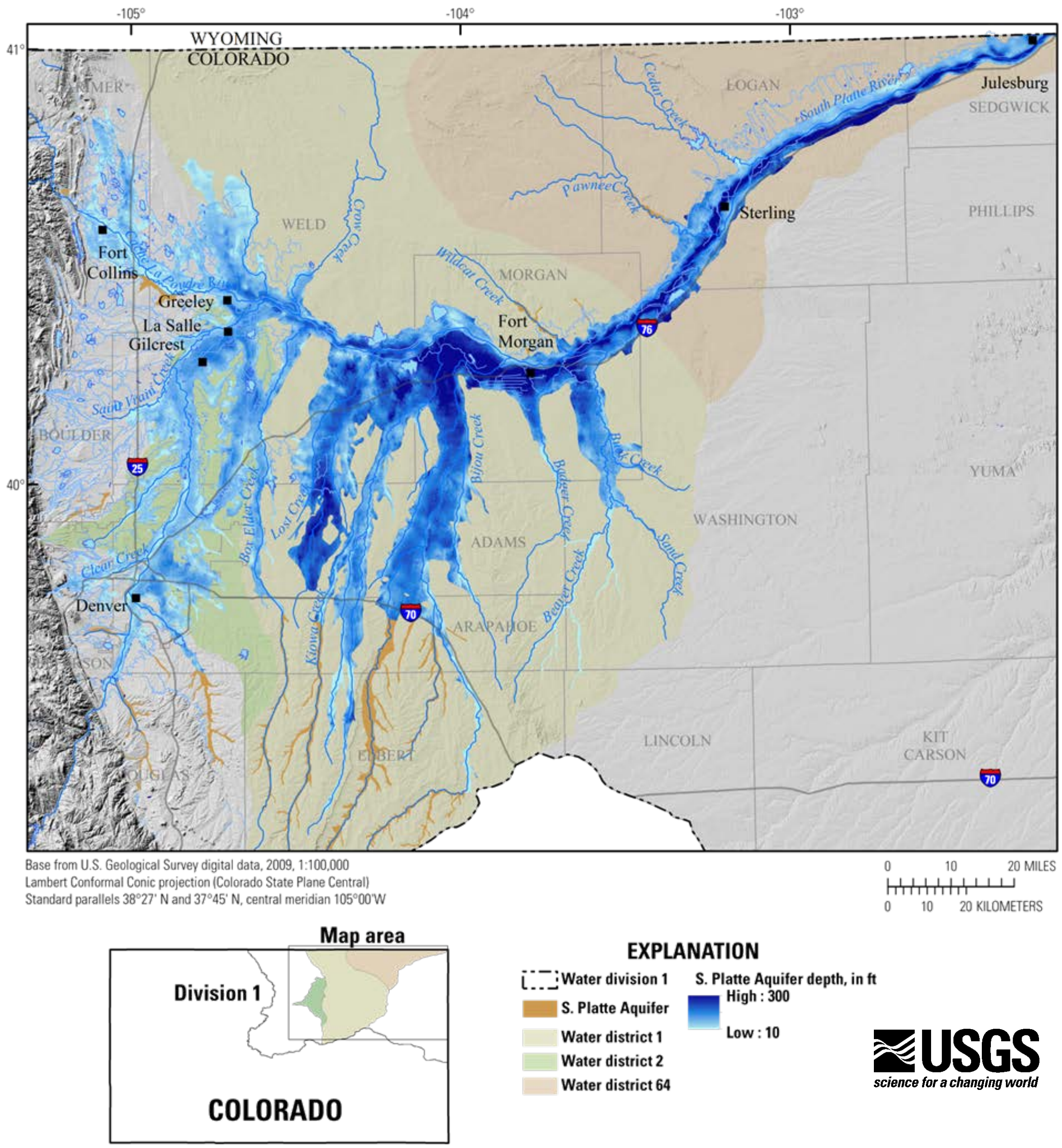
The flood plain of the S. Platte River east of the Front Range averages about a mile in width and has an irregular surface that consists of swamps, oxbow lakes, abandoned meander scars, and low, indistinct terraces (Smith et al., 1964). The overall surface drainage in the region is toward the northeast. Surface topography consists of many terraces and subtle changes in topographic relief that can make differences in water table depth over short horizontal distances. The major perennial tributaries of the S. Platte River in the project area are Clear Creek, Big and Little Dry Creeks, St. Vrain Creek, the Big Thompson River, Cache la Poudre River, Lone Tree Creek, and Crow Creek. Several intermittent streams also enter the river below Kersey, including Kiowa, Bijou, Badger, Wildcat, Beaver, Pawnee and Cedar Creeks.

The alluvial aquifer is in hydraulic communication with the surface water system throughout the basin, and the extensive development of irrigation, reservoirs, transbasin diversions, and wells has resulted in gaining conditions for the majority of the river since application of irrigation water results in deep percolation, and resulting return flows to the river (Barlow and Leake, 2012). The maximum thickness of the alluvial deposits increases in a downstream direction on the mainstem with saturated thickness of 20 to 40 feet in the upstream region near Denver to more than 200 feet near Julesburg (Map 4). Well depths in the lower S. Platte River basin alluvium average about 75 feet below ground surface (Lindsey, Langer & Knepper Jr., 2005; Pottorff, 2008). The hydraulic characteristics of the aquifer are such that high-capacity irrigation wells may yield 1,200 to 2,000 gallons per minute. Hydraulic conductivity is the main physical parameter that governs the rate of groundwater flow, varying considerably within relatively small areas in the alluvial aquifer. Hydraulic conductivity (K) values in the S. Platte alluvial aquifer range from approximately 20 to 2,000 feet per day (with a median value near 500 ft/day) depending on the materials present (Wellman, 2014 in press). Infiltration from precipitation, irrigation, canal seepage, and pond seepage recharge the alluvial aquifers whereas groundwater tends to discharge to the main channel of the river. Groundwater discharge to the river channel creates baseflow for the river.

All groundwater in Water Division 1 that is not either Designated groundwater or Denver Basin groundwater is presumed to be tributary groundwater, in direct hydraulic connection to the surface stream system. However, there are a number of water right decrees in Water Division 1, generally entered from 1910 to 1970 that specifically declare the groundwater to be nontributary. The almost 500 so-called Coffin Wells in Water District 1 and 3 were decreed as non-tributary by Judge Coffin in 1953, although today we know they are in the alluvial aquifer and are indeed tributary to the S. Platte River.



Map 3. High Capacity Wells in the S. Platte Alluvial Aquifer.
Data Source: CO DWR HydroBase Version 20130710



Map 4. Aquifer Depths Across the S. Platte Alluvial Aquifer Showing Greatest Depths at the Channel Center to the East and Central Regions Near Fort Morgan and Along Lower Sections of the Lost Creek Tributary.

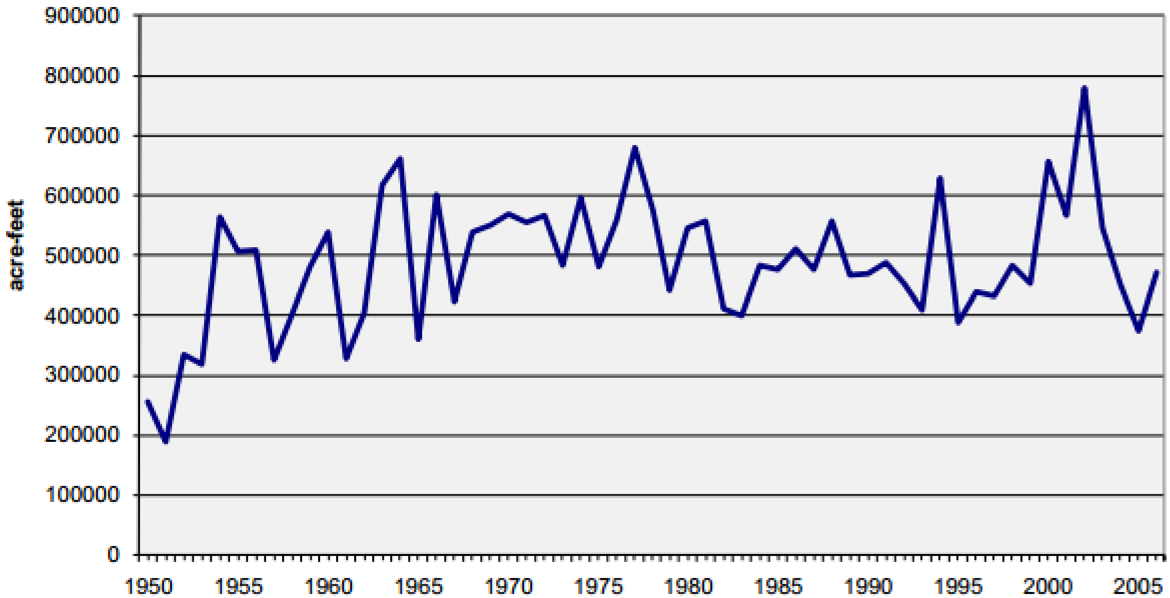


Figure 1. Estimated Groundwater Pumping for Irrigation from the S. Platte Alluvial Aquifer, 1950 – 2006.
Source: Leonard Rice Engineers, Inc. (2010:44)

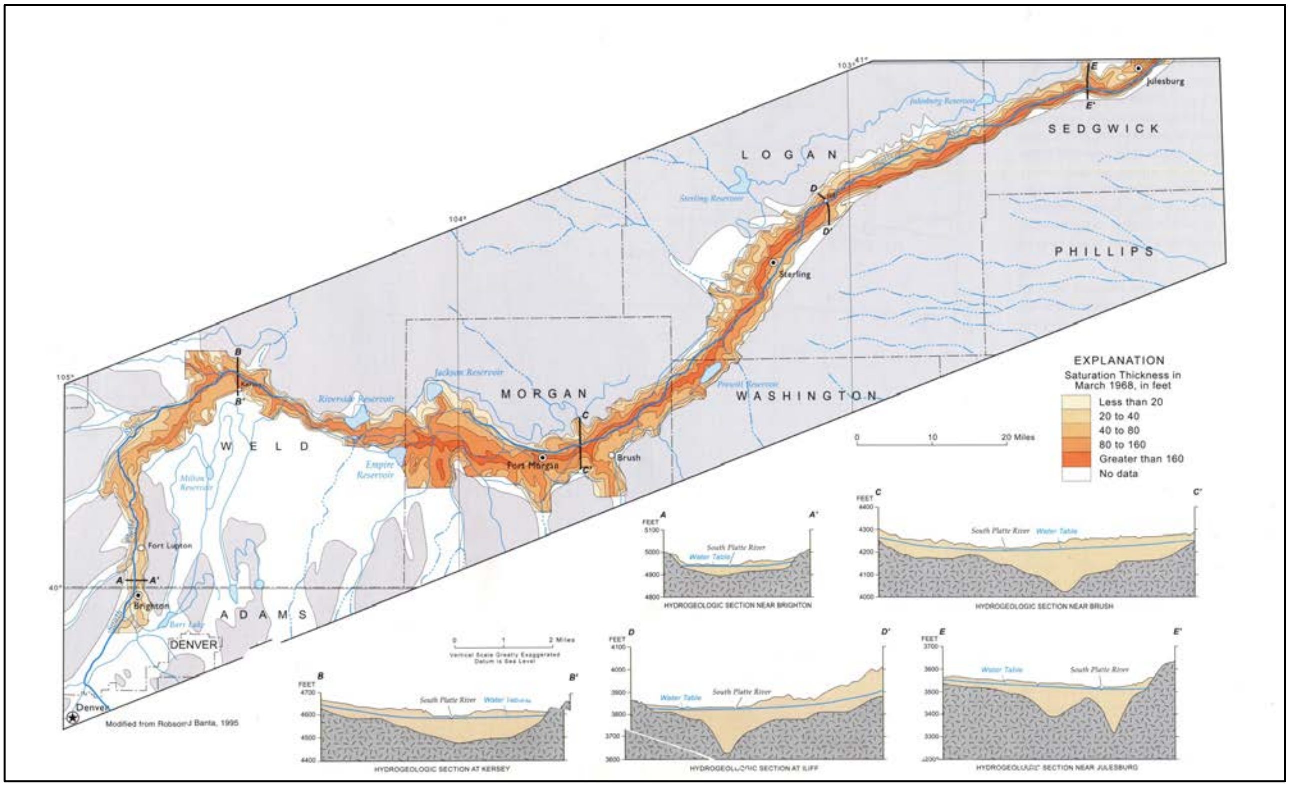
A number of studies have examined the alluvial aquifer of the S. Platte River and its tributaries. Stratigraphy of the alluvial deposits was originally described by Hunt (1954) and Scott (1960) and later by Scott (1963a). Several workers developed maps of the S. Platte alluvial aquifer extent, thickness, and depth to water beginning in the 1950s (Bjorklund and Brown, 1957; Smith et al., 1964; Duke and Longenbaugh, 1966; Nelson et al., 1967; Hurr and Schneider et al., 1972a, 1972b, 1972c; Hurr et al., 1975; Konikow, 1975; Nadler and Schumm, 1981; Robson, 1996; and Robson, Arnold, and Heiny, 2000a, 2000b; Robson, Heiny, and Arnold, 2000a, 2000b). The South Platte Decision Support System (SPDSS) compiled selected maps of these features into Geographic Information System (GIS) data sets. Robson (1989) described the interconnection between bedrock and alluvial aquifers in the study area.

The SB06-193 study conducted by the CWCB (2007) revealed that there is an estimated 10 MAF of stored water in the S. Platte alluvial aquifer; 14 MAF if the designated basins are included. The study also estimated there is some 7 MAF of unsaturated alluvium that some fraction of which would be available for aquifer storage (Table 1).

Table 1. Estimated Storage Volumes in the S. Platte River Basin Alluvium[1].

Mainstem	Unsaturated Volumes[3]	Saturated Volumes[4]
Denver Metro	353,000	479,000
Metro to Greeley	169,000	920,000
Greeley to Ft. Morgan	94,000	1,143,000
Ft. Morgan Area	968,000	2,055,000
Balzac to State Line	890,000	4,058,000
Total	**2,474,000**	**8,655,000**
Tributaries		
Cache la Poudre River	291,000	859,000
Upper Beebe/Box Elder	268,000	494,000
Lower Beebe/Box Elder	61,000	259,000
Badger/Beaver Creek	311,000	600,000
Total	**931,000**	**2,212,000**
Designated Basins		
Upper Lost Creek	1,260,000	925,000
Lower Lost Creek	157,000	348,000
Upper Kiowa Creek	234,000	298,000
Lower Kiowa Creek	806,000	580,000
Upper Bijou Creek	466,000	450,000
Lower Bijou Creek	1,067,000	1,406,000
Total	**3,990,000**	**4,007,000**
Total Volume	7,395,000	14,874,000
Total Volume minus Designated Basins	3,405,000	10,867,000

Source: Based on data from Brown & Caldwell, et. al (2001) & CWCB (2007)
1. Volumes rounded to the nearest 1,000 AF.
2. Sub-Regions defined in Figure 4 of SB06-193 Study
3. Unsaturated volumes exclude the upper 10 feet; from Table 2 of SB06-193 Study.
4. Saturated volumes are from average water table surface to base of alluvium.



Map 5. Aquifer Cross-Sections at Five Locations along the S. Platte River.
Source: Topper et. al (2003). *Colorado Groundwater Atlas (Special Publication 53). Denver, CO: Colorado Geological Survey.*

Groundwater Use

Prior to 2003, on average nearly 500,000 AF of groundwater was pumped annually in the S. Platte basin from approximately 8,200 high capacity wells (Figure 1 and Map 3). Agricultural pumping between the years 1950 to 2000 was calculated to average 438,000 AF/yr with municipal and industrial pumping growing to approximately 50,000 AF/yr during this same period. There are now approximately 6,500 high capacity wells in the basin and total annual groundwater pumping in the basin is now closer to 450,000 AF/yr with agricultural pumping in the 400,000 AF/yr range (Table 2). Approximately 1,000 high capacity wells were abandoned through the 2010 Abandonment List, many of these were former GASP wells and of these, many had low pumping rates and were supplemental for drought insurance. Central Colorado Water Conservancy District has approximately 1,200 wells in the WAS and GMS plans that are on a quota system and not able to pump anywhere near 100% of full crop ET (GMS quota has been in the 35% range since 2006; WAS quotas have been even less). Most of the other irrigation wells in adjudicated augmentation plans have full or near full allocations in most years. While rules now require well owners to meter and provide pumping records, it will likely be several years before we have accurate accounting of wells metering records to determine exactly how much individual wells are pumping and how much water is extracted from the various reaches of the alluvium in the basin.

For the purposes of augmentation plans, two methods are generally used to determine the amount of stream depletion caused by well pumping: 1. crop potential consumptive or 2. presumed depletive factor. The crop potential consumptive method involves determining the potential crop consumptive use for the land irrigated by the wells in the plan. Any available surface water is subtracted from the potential consumptive use and the remainder is assumed to be the stream depletion caused by wells. This method was commonly used prior to 2003 but is not generally used in recent augmentation plans. The second and currently most commonly used method for estimating stream depletion is the presumed depletive factor (PDF). In this method, well volume is recorded or calculated and a specified percentage of that pumping is assumed to be consumptively used by the crop depending upon irrigation method (and hence the streamflow depletive amount). In most plans, sprinkler irrigation is assumed to have an 80% PDF and surface irrigation is assumed to have a 60% PDF (Jenkins, 1968, 1968b; Miller, 2007).

Table 2. High Capacity Irrigation Well Count in Hydrobase by Water District in Division 1 Before and After Adjudication of the 2010 Abandonment List.

Water District	Wells Needing Augmentation Before 2010	Wells Needing Augmentation After 2010	Coffin Wells	Total Wells After 2010
WD 01	2279	2092	236	2328
WD 02	1939	1613	0	1613
WD 03	800	695	211	906
WD 04	112	77	0	77
WD 05	82	48	0	48
WD 06	91	25	0	25
WD 07	156	132	0	132
WD 08	591	456	0	456
WD 09	31	26	0	26
WD 23	24	24	0	24
WD 48	0	0	0	0
WD 49	4	4	0	4
WD 64	980	944	0	944
WD 65	0	0	0	0
WD 76	0	0	0	0
WD 80	13	12	0	12
Total for Div. 1	7102	6148	447	6595

Numerous scientific and engineering studies have established that high capacity groundwater wells pumping from an alluvial aquifer can lower the water table locally (e.g. Meinzer 1923 and 1959; Glover and Balmer, 1954; McGuinness, 1963). Well pumping can also reduce surface flows, either by interception of groundwater that would have discharged to the surface or by changing the gradient from the stream to the aquifer. Stated another way, groundwater pumping causes a cone of depression around the well as water is initially removed from aquifer storage. The cone of depression creates a localized gradient that captures water that would have eventually discharged to the stream as baseflow. As the cone of depression moves closer to the stream it causes water to flow from the stream to the aquifer, diminishing streamflow. Over time, a new equilibrium is established where the streamflow is diminished by an amount equivalent to the rate of pumping. The amount, timing, and location of stream depletion due to pumping depend on proximity of the well to the stream, the pumping rate and duration, the direction and rate of groundwater flow, the amount of groundwater recharge, and hydraulic properties of the aquifer. Whether a pumped depletion causes injury depends on if it impacts the stream while under administration and if senior diverters are thereby shorted by the out-of-priority pumped depletion (Winter et al., 1998; Barlow and Leake, 2012).

Since direct measurements of well production across the basin are not yet available, the best available estimates for agricultural pumping are currently based on potential crop consumptive use and available surface water. The Division 1 Engineer indicates that the new well measuring rules should be fully implemented and pumping data available within the next five to six years. Until that time, estimates based upon crop ET or electrical power coefficients are the best available methods. These data are also discussed in the SPDSS historical crop consumptive use analysis (Leonard Rice Engineers, Inc., 2010).

The method used for the HB1278 analysis for estimating agricultural pumping where groundwater is the sole source is based upon crop consumptive use and an estimation of irrigation efficiency using 80% for sprinkler irrigation and 60% for flood irrigation. For irrigated lands that receive both surface and groundwater, it was assumed that consumptive use is first met through surface water diversions with the remainder of crop demand made up through pumping, with well pumping limited by their decreed rate. The average annual agricultural pumping demand for the period of 1991 to 1994 is estimated at 432,838 AF per year. Annual pumping rates are known to vary as a function of streamflow, precipitation, and ET; thus, modeled estimates attempt to incorporate these variables. Well curtailments since 2005 have resulted in agricultural pumping somewhere in the neighborhood of 400,000 AF for Division 1, as estimated by the Division 1 Engineer. Pumping rates for agricultural wells ranges from zero during the non-growing season months, generally November through March, and reach peak values in July of each year. Annual agricultural pumping values range from 176,000 AF in 1951 to 714,000 AF in 2002 in Division 1. There were 15 years in the 56-year period from 1950 to 2006 in which agricultural wells were estimated to pump more than 500,000 AF. High pumping years include 1963, 1964, 1977, 2000, and 2002. The month of July has the highest average pumping rate of 127,000 AF followed by August, June, and September.

Municipal and industrial pumping was estimated for the purposes of the SPDSS groundwater model. Fifty municipal/industrial entities in the S. Platte pumped an estimated 49,600 AF per year during the period of 1991 to 1994 in Division 1. Municipal and industrial pumping amounts increased steadily from 1950-1980 to approximately 50,000 AF and have remained relatively constant rates since that time, however, there is large annual and monthly variability due to demand fluctuations.

Augmentation and recharge wells are estimated to pump 10,700 AF per year in Division 1 according to the SPDSS groundwater model documentation developed by CDM. Augmentation wells pump alluvial groundwater directly to surface water to replace out-of-priority depletions. These wells typically have a long stream depletion factors. Recharge wells are wells that supply groundwater to recharge basins that re-time groundwater flow back to the stream so as to replace out-of-priority depletions.

Aquifer Recharge

The SPDSS consumptive use studies (Leonard Rice Engineers, Inc., 2008 and 2010) determined that approximately 3% of total precipitation that falls on native vegetation in the basin becomes recharge to the alluvial aquifer system. Thus, the average annual recharge rate for native vegetation areas is 0.43 inches per year. Higher percentages of precipitation tend to infiltrate on irrigated lands during the irrigation season due to antecedent soil moisture. Canal seepage calculated by StateCU for the SPDSS ranges from 10 to 50%, averaging 23%. Given the magnitude of water diversion through the canals overlying the aquifer (2.4 MAF annually on average in Division 1), aquifer recharge from canals, ditches and lateral is estimated to be in excess of 500,000 AF/yr (Table 3). Additionally, deep percolation from irrigation creates large amounts of recharge to the aquifer.

The 2002 *Park County v. Sportsmen's Ranch* case established that the public, not the overlying landowner, owns the water-bearing capacity of Colorado's aquifers throughout the state as part of the public's water resource. This capacity may be used to store and convey water appropriated by both public agencies and private persons and is not considered trespass. Accordingly, the Colorado Supreme Court held that the natural water bearing formations may be used for the transport and retention of appropriated water. The Court held in Sportsmen's Ranch that the applicant for an underground storage and recharge appropriative right must meet certain conditions, including that the storage will not interfere with overlying landowners' use and enjoyment of their property (Hobbs, 2012).

Meeting Irrigation Water Requirement

Under unconstrained conditions, well pumping is a function of precipitation and surface water availability coupled with crop demand. Irrigation water requirement varies by year based upon evapotranspiration (ET) demand and precipitation. For Division 1, the estimated average annual irrigation water requirement for the 56 year period from 1950 to 2006 was an estimated 1,544,000 AF, while the average annual water limited consumptive use was approximately 1,171,000 AF, indicating about 24% of the irrigation water requirement is not satisfied in an average year (Table 3). Based on 2001 figures, approximately 44% of irrigated acreage in the basin has the ability to meet either the entire demand or part of the demand with groundwater (Table 4). The average annual consumptive use of surface water from 1950 to 2006 was approximately 858,000 AF, while the average annual consumptive use of groundwater was approximately 312,000 AF. The supply obtained from groundwater historically increases in years when surface water supplies are limited.

Table 3. Division 1 Average Annual Water Budget, 1950-2006.

Irrigation Water Requirement	Surface Water Diversion Accounting, AF							
	River Headgate Diversions	Conv Loss	Diversion to Recharge	Diversion to Farm	Surface Water Diversion to:			Calculated Application Efficiency
					CU	Soil	Non-Consumed	
1,544,302	2,425,410	652,412	26,172	1,746,826	749,505	109,564	887,758	49%

Source: Adapted from *Historic Crop Consumptive Use Analysis South Platte Decision Support System* (Final Report), p.37, by Leonard Rice Engineers, Inc., 2010, Denver, CO.

Table 4. Division 1 Historical Irrigated Acreage by Water Source for 1956-2005.

	1956 Acres	%	1976 Acres	%	1987 Acres	%	2001 Acres	%	2005 Acres	%
Groundwater	111,673	11	176,598	17	179,365	18	165,738	18	146,843	18
GW + SW	198,894	20	235,190	23	224,986	23	234,182	26	186,399	22
Surface	664,216	68	600,290	59	580,770	59	510,599	56	497,305	60
Total	974,784	100	1,012,078	100	985,122	100	910,519	100	830,546	100

Source: SP 2008 StateCU Historical Consumptive Use Analysis, March 2010. Leonard Rice Engineers, Inc., 2010.

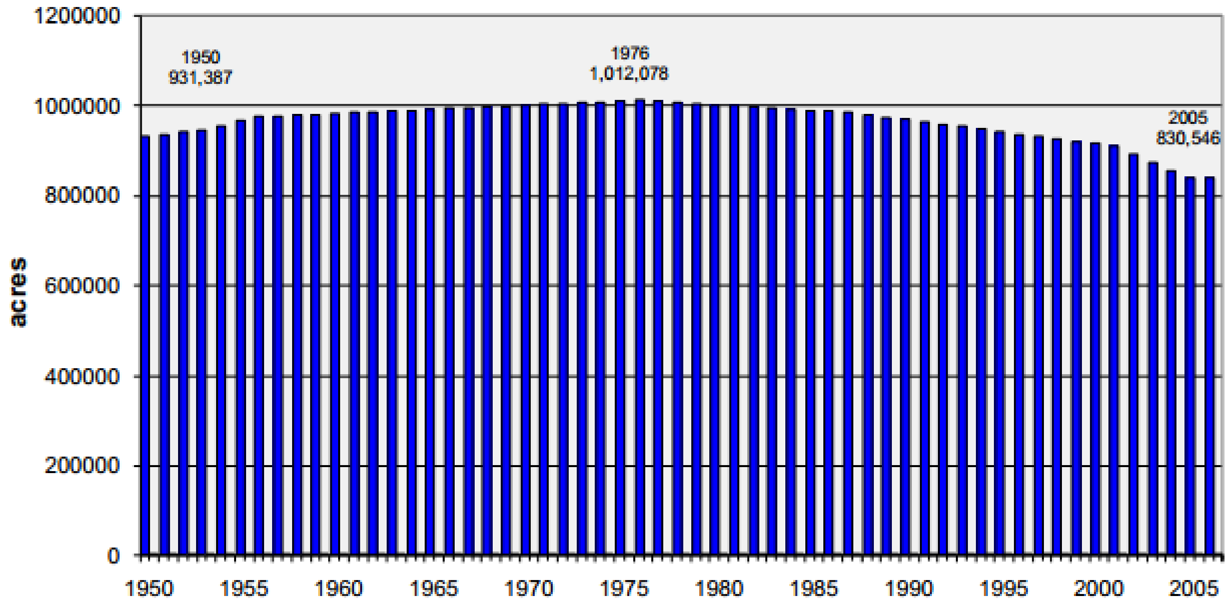
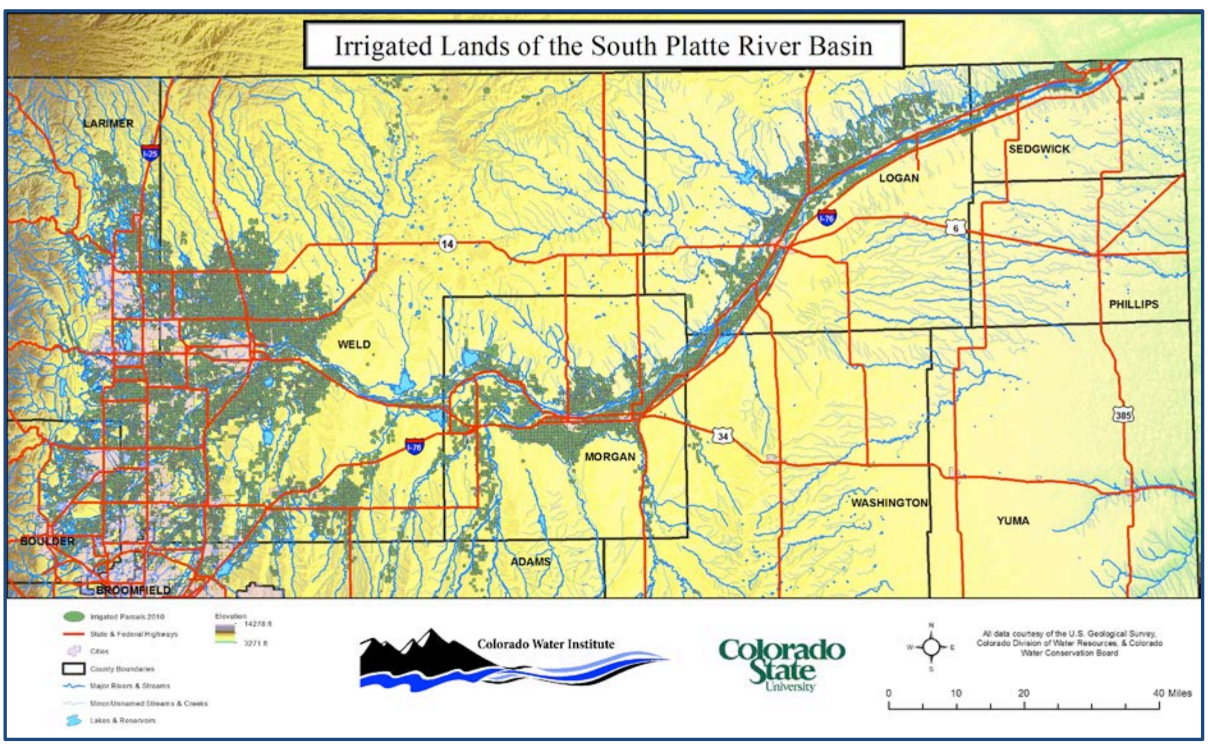


Figure 2. Estimated Irrigated Acreage in the South Platte Basin.
Source: Adapted from *Historic Crop Consumptive Use Analysis S. Platte Decision Support System* (Final Report), p.24, by Leonard Rice Engineers, Inc., 2010, Denver, CO.



Map 6. Irrigated Lands in the S. Platte Basin of Colorado.

Irrigated lands have decreased in the S. Platte basin since reaching a peak of slightly over one million acres in the mid-1970s to approximately 830,000 acres presently (Figure 2). Much of this loss of irrigated lands is a result of urban growth over agricultural lands along the Front Range / I25 corridor, but some of it can also be attributed to the purchase of senior agricultural surface water rights and the subsequent dry up of these lands (Map 6). Figure 3 below shows the almost inverse relationship between consumed groundwater and surface water, indicating the interdependence of the resource and the need to utilize groundwater in dry periods where surface water is limited.

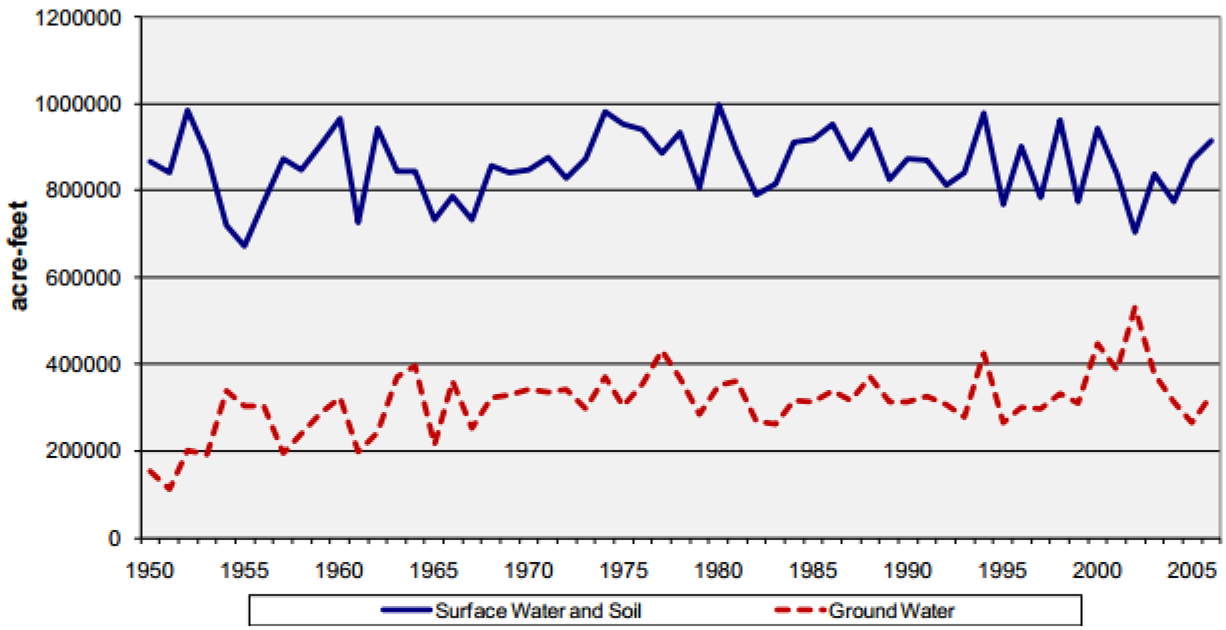


Figure 3. Consumptive Use from Surface and Groundwater, 1950-2006.
Source: Adapted from Historic Crop Consumptive Use Analysis South Platte Decision Support System (Final Report), p.6, by Leonard Rice Engineers, Inc., 2010, Denver, CO.

Groundwater Pumping and Crop Consumptive Use

The total groundwater crop consumptive use is defined as the portion of pumping that is consumed by crops, including the portion temporarily stored in the soil moisture reservoir prior to being consumed by crops. For the HB1278 analysis, groundwater crop consumptive use was considered in two ways:

Non-depletive groundwater is the portion of groundwater crop consumptive use that is estimated not to deplete flows in the S. Platte or is decreed as non-depletive. Non-depletive groundwater is further divided into two categories:

- Groundwater consumptive use in designated basins
- Groundwater consumptive use from Coffin Well pumping

Groundwater depletions are the portion of total groundwater crop consumptive use that is estimated to deplete flows in the S. Platte. These groundwater depletions generate augmentation requirements when the depletions impact the river at the time when there is a senior call. For this trend analysis, the lagged timing of the depletions and the call regime is not considered; instead, monthly depletions are summed on an annual basis and assumed to require full augmentation. Groundwater depletions were further divided for the analysis into two categories:

- Depletions that are associated with an augmentation plan
- Depletions that could not be readily tied to an augmentation plan

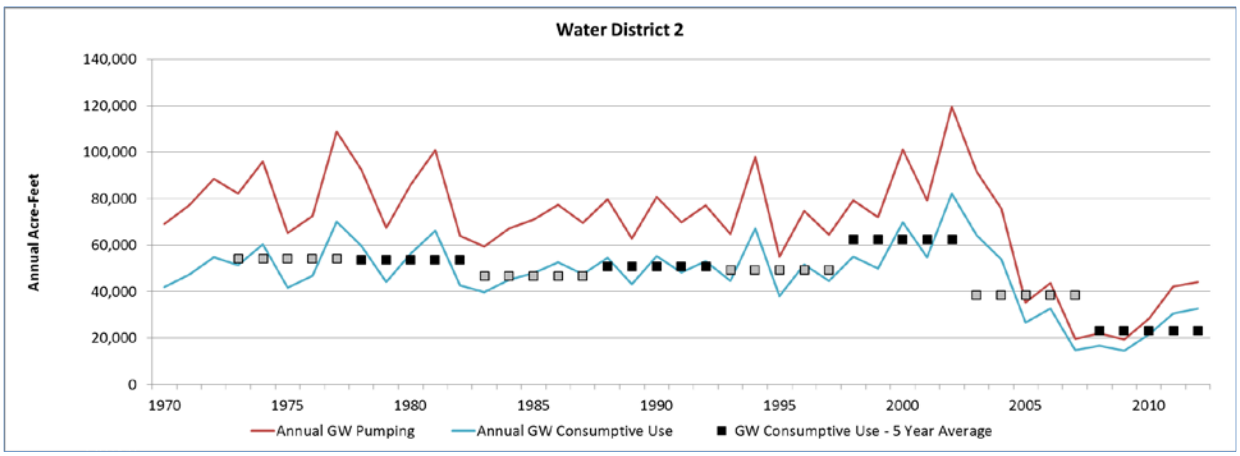


Figure 4. Estimated Pumping and Groundwater Consumptive Use in Water District 2.
Data Source: CO DWR HydroBase Version 20130710.

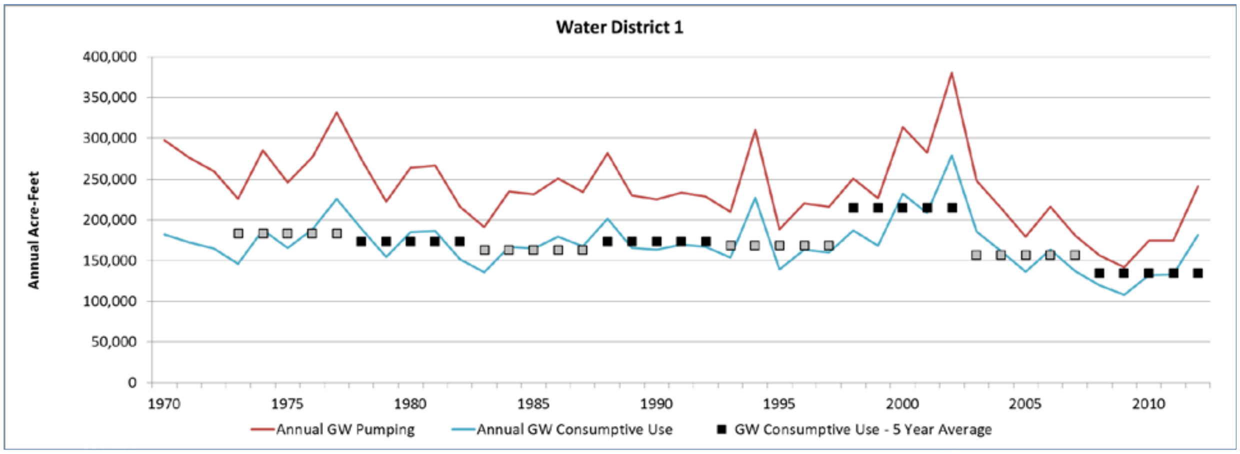


Figure 5. Estimated Pumping And Groundwater Consumptive Use In Water District 1.
Data Source: CO DWR HydroBase Version 20130710.

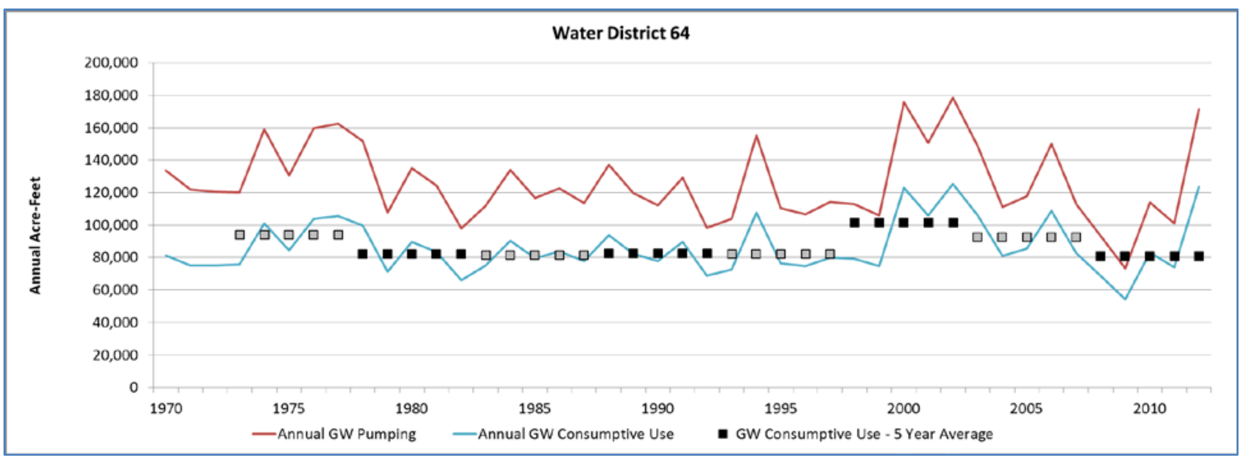


Figure 6. Estimated Pumping and Groundwater Consumptive Use in Water District 64.
Data Source: CO DWR HydroBase Version 20130710.

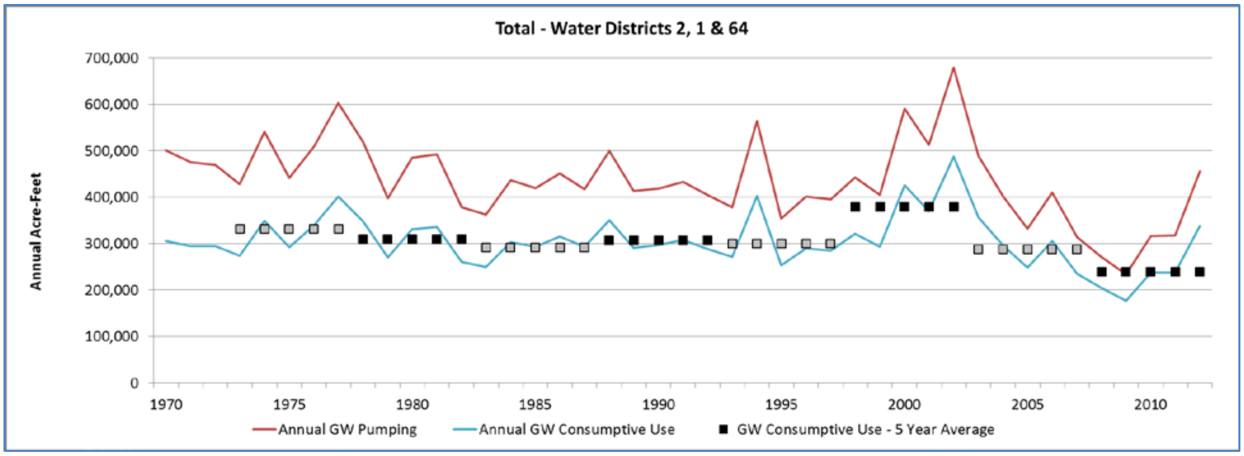


Figure 7. Total Estimated Annual Pumping and Groundwater Consumptive Use in Water Districts 2, 1, and 64.
Data Source: CO DWR HydroBase Version 20130710.

We estimated pumping amounts based on crop irrigation water requirements plus an on-farm application efficiency value associated with flood and sprinkler application methods less any surface water supplies, as estimated by the StateCU analysis developed for the SPDSS (Figures 4-7). Estimated pumping for wells included in CCWCD's WAS and GMS augmentation plans, generally in Water Districts 1 and 2, were reduced based on annual quotas, ranging from zero to 50% over the 2005 to 2012 period. The difference between pumping and consumptive use reflects the portion of the pumping that is not consumed by the crops and returns to the river or aquifer. The difference between annual pumping and consumptive use generally decreases over time, reflecting the gradual increase in sprinkler irrigation over the past several decades.

Annual variability of the pumping volumes can be attributed primarily to varying climate conditions, plus some changes in irrigated acreage. In each of the three water districts, irrigated acreage peaked in the mid-1980s and began to decrease thereafter. Acreage has decreased the least in Water District 64; therefore, the variability and increased pumping for the 2000 through 2012 average seen in Water District 64 can be attributed primarily to climate variability. The greatest pumping and consumptive use occurs in Water District 1, which correlates with the large amount of acreage served only by groundwater in that district. Reduced pumping in Water District 2 after the 2002 drought occurred because many wells were not fully covered under augmentation plans and were forced to reduce pumping. Water District 64 has the most recharge and surface augmentation sources, and increased pumping reflects limited surface water due to drier conditions. It is important to note that consumptive use values shown in these graphs do not take into account the lagged depletive impact at the river. Five-year averages are used to smooth out the data and indicate the effect of lagged depletions as shown above in Figures 4-7. Note that groundwater pumping has shown an increase since 2009 as additional augmentation supplies have been acquired and adjudicated.

AUGMENTATION

Key Points

- Plans for augmentation allow wells to pump water out-of-priority while ensuring the protection of senior water rights. The S. Platte River basin is fully appropriated and thus the presumption of injury accompanies all out-of-priority depletions by tributary wells.
- The most cost effective method of augmentation is to develop recharge structures that can take surface water during times of free river and allow the water to seep into the aquifer and back to the river during times when injurious depletions occur. These structures may be ponds, unlined ditches, or low lying areas that overlie the alluvium and are hydraulically connected to the river.
- The timing of stream depletion impacts on the river are most frequently calculated using methods and assumptions for applying the analytical method described by Glover, which is usually specified in the decree.
- Augmentation plans adjudicated since 2003 determine adequacy of replacement supply through the use of a projection tool. The purpose of the projection is to compare future depletions from current and past pumping to future replacement supplies.
- Augmentation from recharge in excess of requirements may occur because junior recharge rights are only in priority for short windows of time, so augmentation plan operators must recharge as much as possible when they are in priority. Since recharge operators cannot know when the next drought period will occur, they are compelled to operate in a manner that assumes that drought could occur next year, or for the next six years, depending upon their court decree.
- The Northeastern Colorado Water Cooperative has been proposed to facilitate more efficient use of excess augmentation water in the lower S. Platte basin through quantification and trading. Preliminary studies for the Cooperative found that annual amounts of unused recharge credits in District 64 varied from 5,000 to 10,000 AF, and annual amounts of unused recharge credits in District 1 varied from 6,000 AF in 2008 up to 50,000 AF in 2010. It is expected that during drought unused recharge credits will be greatly reduced, if not eliminated.
- Augmentation supplies and requirement estimates were developed for the HB1278 study by the Wilson Water Group in collaboration with Leonard Rice Engineers.

Plans for augmentation allow diversions of water out-of-priority while ensuring the protection of senior water rights. Decreed water rights receive a replacement water supply that offsets the out-of-priority depletions caused by well pumping. Replacement water can come from any legally available source of water such as mutual ditch company shares, reservoir storage releases, successive use of transbasin water, nontributary water, augmentation wells, and/or artificial recharge of aquifers to generate augmentation credits. Where surface water is fully appropriated, Colorado law presumes that groundwater depletions through well pumping will result in injury to senior appropriators absent a showing to the contrary (*Simpson v. Bijou*, Colo. 2003). The S. Platte River basin is fully appropriated and thus the presumption of injury accompanies all out-of-priority depletions by tributary wells.

Elements of a well augmentation plan typically include:

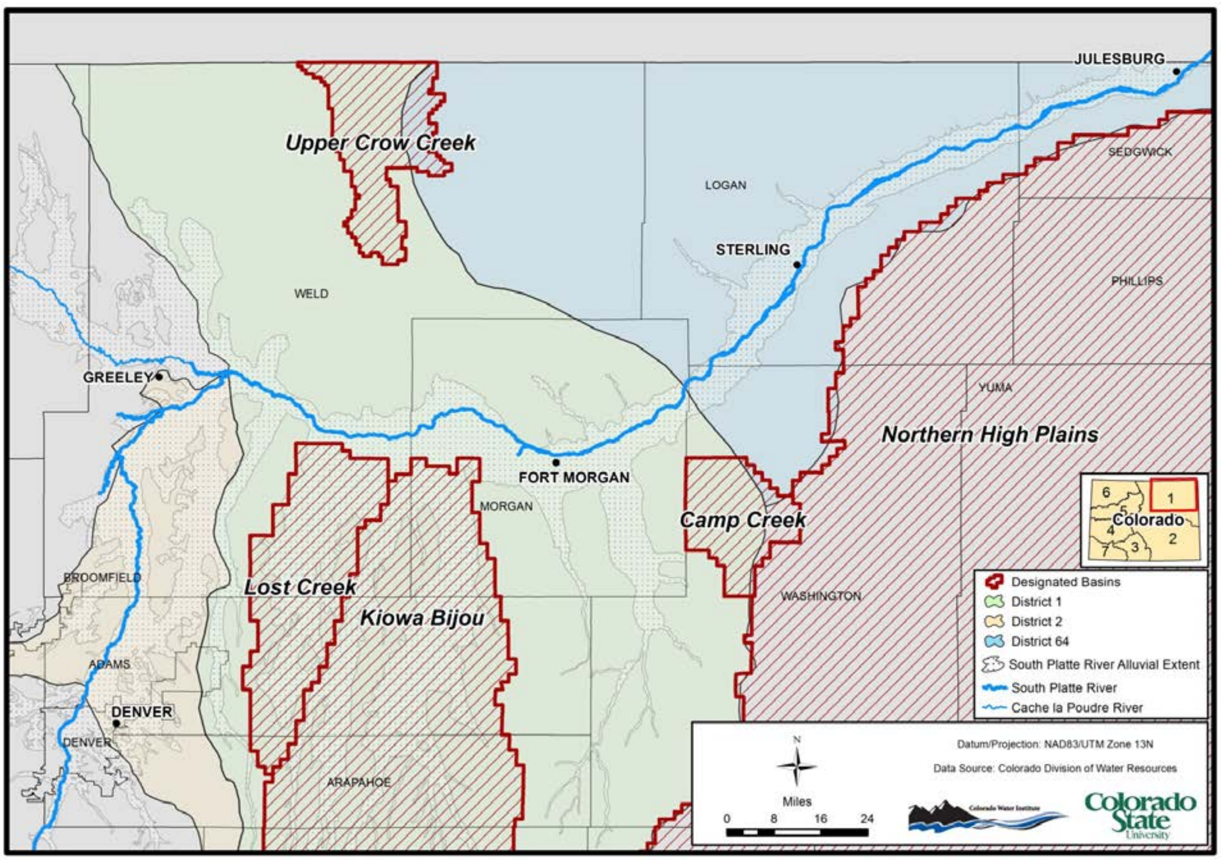
- Accounting of river depletions in time, amount, and location due to well pumping
- Replacement/augmentation sources for all injurious depletions
- The plan for operation of augmentation water to cover depletions

Augmentation plans are decreed based on the same non-injury analysis that applies in change of water right proceedings (*Simpson v. Yale Invs., Inc*., Colo. 1994). Accordingly, determining the absence of injury is crucial to the success of an augmentation plan, which shall only be approved "if such change or plan will not injuriously affect the owner of or persons entitled to use water under a vested water right or a decreed conditional water right." §37-92-305(3).

Before applicants can establish an absence of injury to satisfy an augmentation plan, they must first establish the timing and location of depletions, as well as the availability of replacement water to prevent injury from those depletions. Well augmentation plans are administered based upon terms and conditions adjudicated by the water court. Once adjudicated, it is generally presumed that the engineering and operational elements of the decree are acceptable and that operation within these terms is sufficient to avoid future injury to other water rights. The system is not set up to easily alter the terms, conditions, and operations based upon any future analysis of augmentation plan sufficiency or effectiveness, although the court does retain jurisdiction over the plan for a specified period to ensure effectiveness. The purpose of retained jurisdiction is to address injurious effects that may result from the operation of a decreed augmentation plan, and may be invoked to cause the court to reconsider injury once an augmentation plan is operating. The State Engineer's Office (SEO) or parties to the case may request the court to exercise its retained jurisdiction, but this action is rare. It is important to note that all of the court approved augmentation plans in the S. Platte basin were stipulated agreements and only one plan went all the way to trial – the Central WAS Plan.

The most cost effective method of augmentation is to develop recharge structures that can take surface water during times of free river and allow the water to seep into the aquifer and back to the river. These structures may be ponds, unlined ditches or low lying areas that overly the alluvium and are hydraulically connected to the river, are permeable, and have enough unsaturated material above the water table to allow recharge. The concept is to time the recharge so that it will flow underground back to the river coincident with the timing of injurious well depletions hitting the river. The returned recharge water is then available to senior surface water rights in lieu of the river baseflow that was taken out-of-priority by well pumping. The siting of recharge structures is of necessity dependent on many factors, not the least of which is available land near a surface water source, but for the recharge to actually satisfy the augmentation needs it should be located at an optimal distance from the river such that the timing of lagged return flows meets the timing of well depletions. The accuracy of calculating the timing of this recharge water return flow to the river is important as it determines whether the recharge suitably replaces water in the river at the time it is needed by senior water rights.

Wells in the designated groundwater basins of District 1, including Camp Creek, Kiowa Bijou, Lost Creek and Upper Crow Creek Designated basins, do not require augmentation since they are not considered tributary to the S. Platte (Map 7). The so-called Coffin Wells, adjudicated as non-tributary wells in 1953 by Judge Coffin, also do not require augmentation under the terms of their decree. Wells decreed as alternate points of diversion to surface water rights do not require augmentation when pumped based upon the surface water rights priority dates of their original decrees. The Division 1 APOD database (alternative points of diversion) identifies these wells.



Map 7. Designated Groundwater Basins in Proximity to the S. Platte Alluvial Aquifer in Northeast Colorado.

All other nonexempt tributary wells in Division 1 require court-approved augmentation plans. The Division 1 office has associations for approximately 570 augmentation plans. According to SPDSS Task Memo 7.2 (Leonard Rice Engineers, Inc., 2010), the top 25 augmentation plans represents approximately 93% of the total well acreage associated with plans in HydroBase and 78% of total well acreage requiring augmentation. The SPDSS Task 7.2 effort consisted of an in-depth review of large-scale augmentation plans in the S. Platte River basin in order to develop a modeling approach for overall SPDSS modeling efforts. The in-depth review for the large-scale plans consisted of mapping of wells and associated acreage, interviewing plan representatives, reviewing decrees for the history and operational details of the plans, and comparison of wells included in the decree versus those reflected in the HydroBase Structure Association Table (from 2006) and tied to CDSS 2001 irrigated acreage. The memorandum also developed recommendations for representing the augmentation plan components in future consumptive use and surface water modeling efforts.

The Structure Association Table associates augmentation plans with structures that are included in their decrees at the time the table was queried from HydroBase (Table 5). This table provides a snapshot of the wells, recharge areas, impact reaches, etc. associated with an augmentation plan on a specific date (i.e. when the table was queried from HydroBase). The Division of Water Resources makes changes daily, as necessary, based on water court actions and decrees for the augmentation plans keeping the Structure Association Table in HydroBase current. Therefore, several lists or snapshots are necessary to understand general trends of changes to augmentation wells over time. Available lists for the comparison summarized herein were from November of 2006 and September of 2013 (referred to by their years in the table).

Well counts in Table 5 may appear high because some wells are associated with more than one augmentation plan. For example, due to the quotas assigned to Central GMS and WAS augmentation plans, well users have also sought augmentation supplies from other augmentation plans and their wells are now associated with more than one plan. This one-to-many association was carried forward into this summary as well, as an indicator to the size of each augmentation plan. This summary, however, does not limit the well counts based on their association with irrigated acreage, primarily due to the complication of which irrigated acreage assessment is representative of which association table list (e.g. 2001, 2005, 2012 acreage assessments vs. 2006, 2007, 2013 lists). An additional complication is the fact that the irrigated acreage assessments, particularly the subset of wells assigned to acreage served by groundwater, is currently under review at the DWR. Therefore, any comparison to irrigated acreage will be quickly outdated, as the acreage assessments will be revised in the future.

The general increase in total wells associated with augmentation plans throughout Division 1 is a result of more strict administrative of augmentation plans after the early 2000s drought, and subsequent water court action and decrees reflecting revisions to augmentation plans. It may also be a result of wells seeking more than one augmentation supply due to quotas put in place by the Central augmentation plans. Many augmentation plans, primarily those with sufficient supplies, have maintained the same number of wells throughout the 2006 to 2013 period.

Table 5. Major Augmentation Plans in Division 1.

No.	Plan Name	Plan ID	2006 Well List	2013 Well List
1	Central GMS Aug	0203334		
2	Central WAS Aug	0203394		
3	Logan Well Users Aug	6402539		
4	Bijou Aug Plan	0103339		
5	Poudre Plan	0303336		
6	Lower Logan Well Users A	6402536		
7	Lower Platte Beaver Aug	0102535		
8	Sedgwick Cty Wl Users A	6402517		
9	Upper Platte Beaver Aug	0102529		
10	Ft Morgan Cnl Aug Plan	0102528		
11	Lower Latham Res Co Aug	0103332		
12	Riverside Aug	0102522		
13	Orphan Wells Of Wiggins Aug	0102557		
14	Harmony Ditch Co Aug	6402518		
15	Rothe Aug	0102513		
16	New Cache Aug	0103397		
17	LSLWCD Aug	6402542		
18	Union Ditch Aug	0202539		
19	Pioneer Aug Plan	0102518		
20	Low Line Ditch Co Aug	6402540		
21	North Sterling Aug	6403392		
22	Dinsdale Aug	6402519		
23	Condon Aug	6402525		
24	National Hog Farms Aug	0102624		
25	Water Supply Strg Aug	0303399		
		TOTALS*	**4,169**	**4,102**
26 to 125	Smaller Plans Associated To Wells In HydroBase	**Various**	**5,388**	**7,713**
		TOTALS*	**9,557**	**11,815**

Notes: *Well totals reflect wells and well fields associated with augmentation plans in Division 1, not limited based on irrigated acreage or other considerations. Wells included in Plan IDs are not unique since multiple wells may be associated with multiple plans in HydroBase.

Efforts have been made in recent years to clean up augmentation plan decrees, and wells have been removed or added to more accurately reflect the wells that are currently operational under the plan. Note that augmentation plans can include wells used to meet other uses, including municipal or industrial. Although trends can be gleaned from this summary, additional lists back in time or annual lists between 2006 and 2013 would be beneficial in providing a more complete picture of the wells associated with augmentation plans. An additional aspect of the SPDSS Task 7.2 memorandum is the identification of augmentation plan supply structures and water rights. A quantitative analysis based on a comparison of associated structures between the 2006 and 2013 lists is difficult to conduct due to a more detailed coding approach reflected in 2013 (e.g. more explicit WDID assignment to recharge areas and impact reaches) and due to the format of the Task 7.2 summary of supplies. The following general observations were made based on a qualitative review:

- The number of associated recharge areas for each augmentation plan has generally increased from 2006 to 2013, correlating with the number of new structures constructed.
- The quantity associated with direct rights changed for augmentation has a seen a smaller increase.
- Based on recent diversion coding, it appears that more reusable effluent is being used as an augmentation supply.
- There has been more short-term or intermittent leasing of excess augmentation supplies.
- Based on discussions with DWR staff, augmentation plan operators have increased the options associated with their supplies, including filing for exchange of unused augmentation credits for re-diversion into recharge areas.
- New leasing markets for augmentation credits, and the prospect of rotational fallowing programs, will likely change the amount of augmentation supplies in the future.

The 1969 Act provided that approval of augmentation plans was expressly vested in the water court. Interestingly, a proposed early version of the 1969 Act would have granted the State Engineer rather than the Water Court the authority to approve augmentation plans. C.R.S. 37-92-501.5(10) states that the state and division engineers shall exercise the broadest latitude possible in the administration of waters under their jurisdiction to encourage and develop augmentation plans and voluntary exchanges of water and may make such rules and regulations and shall take such other action as may be necessary in order to allow the continuance of existing uses and to assure maximum beneficial utilization of the waters of the state. Conjunctive management is used to refer to actions other than water rights administration that can be taken to optimize the benefits and value of the water resource through maintenance of a sustainable supply in basins where there is a hydraulic connection between surface and groundwater. There are statutes that allow, in fact, require, the State Engineer to exercise broad latitude and discretion in carrying out his administrative duties so as to maximize the beneficial use of waters of the State. See also §37-92-502(4) ("Each plan for augmentation shall be administered to accomplish the maximum economic use of and benefit from the water which may be available or developed for such administration if persons owning, or entitled to use water under, water rights or conditional water rights will not be injuriously affected thereby.")

Stream Depletion Modeling

It is widely accepted that tributary groundwater pumping can impact surface flows; when and how much reduction actually occurs depends upon: (1) distance of the well from the river, (2) transmissivity of the aquifer, (3) depth of the well, (4) time and volume of pumping, and (5) so-called boundary conditions, including other inputs and withdrawals, water table gradient, etc. The problem of quantifying river depletions due to pumping has vexed engineers for decades. The most common approaches for estimating the effects of groundwater pumping on streamflow are the Glover solution (Glover 1968, 1975; Glover and Balmer, 1954), the stream depletion factor method (Jenkins, 1968a, 1968b; Hurr and Schneider, 1972a-d; Schroeder, 1987), and numerical methods such as MODFLOW (McDonald and Harbaugh, 1988). Both the Glover and SDF methods have been widely used in developing augmentation plans for adjudication in Colorado's water court process. While these analytical methods have been widely accepted in water rights cases, it is recognized that they simplify physical conditions such as vertical and horizontal aquifer properties (Fox, DuChateau and Durnford, 2004; Miller et al., 2007).

Jenkins (1968a and 1968b) defined the stream depletion factor (SDF) expressed as units of time, typically days. Jenkins noted that the stream depletion factor is equal to the time at which streamflow depletion is equal to 28% of the volume pumped for a given location. An important aspect of the SDF is that it can be calculated for every location in an aquifer. Many decrees entered prior to 2003 used the calibrated SDF maps developed by U.S. Geological Survey (USGS), but this method is not commonly used in new decrees. Alternative approaches to the SDF methodology have been developed to map aquifer locations having equal effect on streamflow depletion, called unit response-functions.

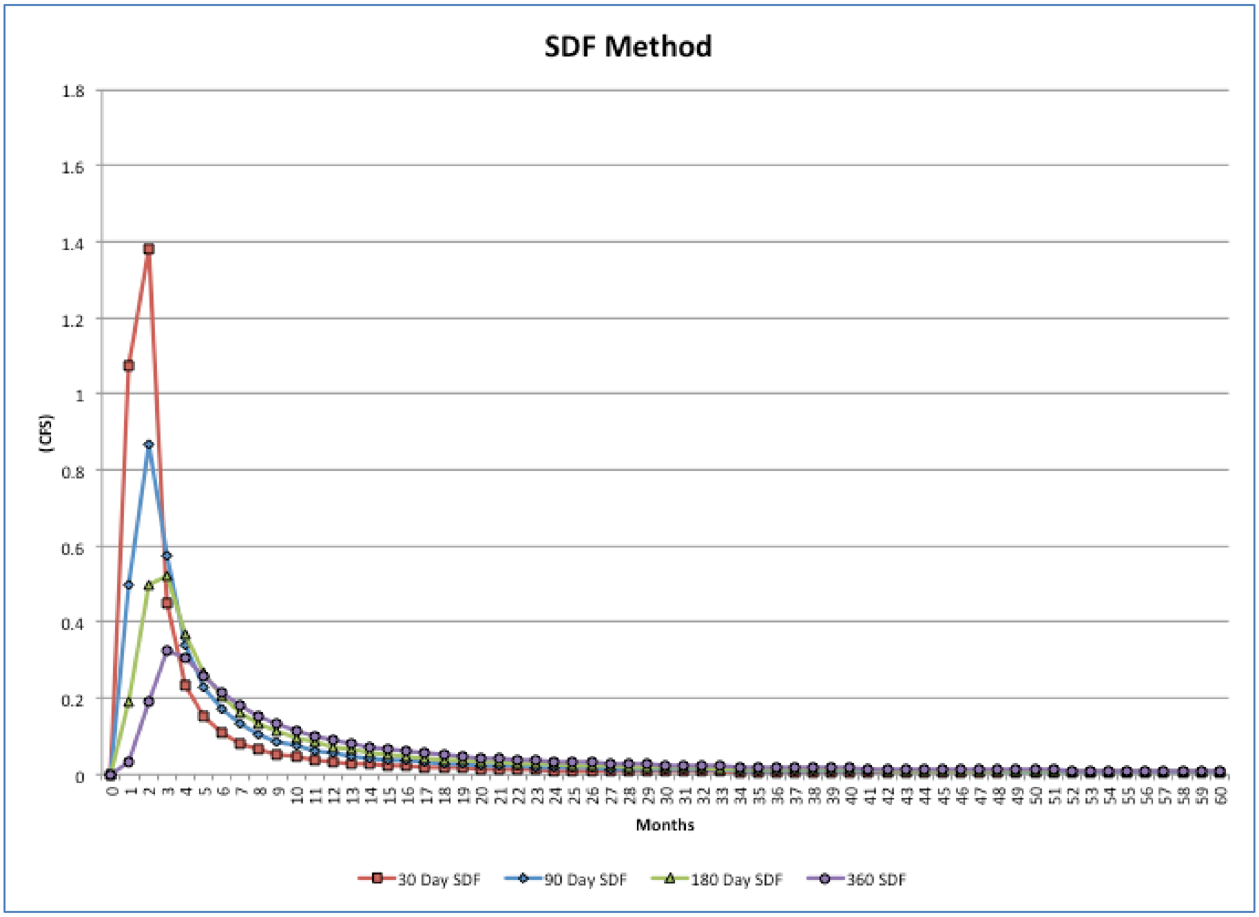


Figure 8. Hypothetical Single Pumping Year SDF Method Calculated Lagged Depletions to the River (in cfs) Over a 60-Month Period for 30, 90, 180 and 360 Day SDF. Calculated with pumping rate at 1000 gpm for the first 2 months (total 268.8 AF) of the simulation and no pumping thereafter.

Figures 8 and 9 show hypothetical calculated depletion timing back to the river for SDF and Glover methods for two months of pumping during a single year and display how the majority of pumped depletions are estimated to impact the river during the first year, and the pattern of lagged depletions thereafter. Figures 8 and 9 show that after about 36 months both Glover and SDF calculated lagged depletion from a single well become diminishingly small and would be virtually undetectable in the stream system given the currently accuracy of stream gaging. Figure 10 shows AWAS Glover simulated annual summertime pumping over 25 years and that the lagged depletions reach steady state after some period of time (about 20 years in this simulation), assuming pumping volume and timing remain the same each year.

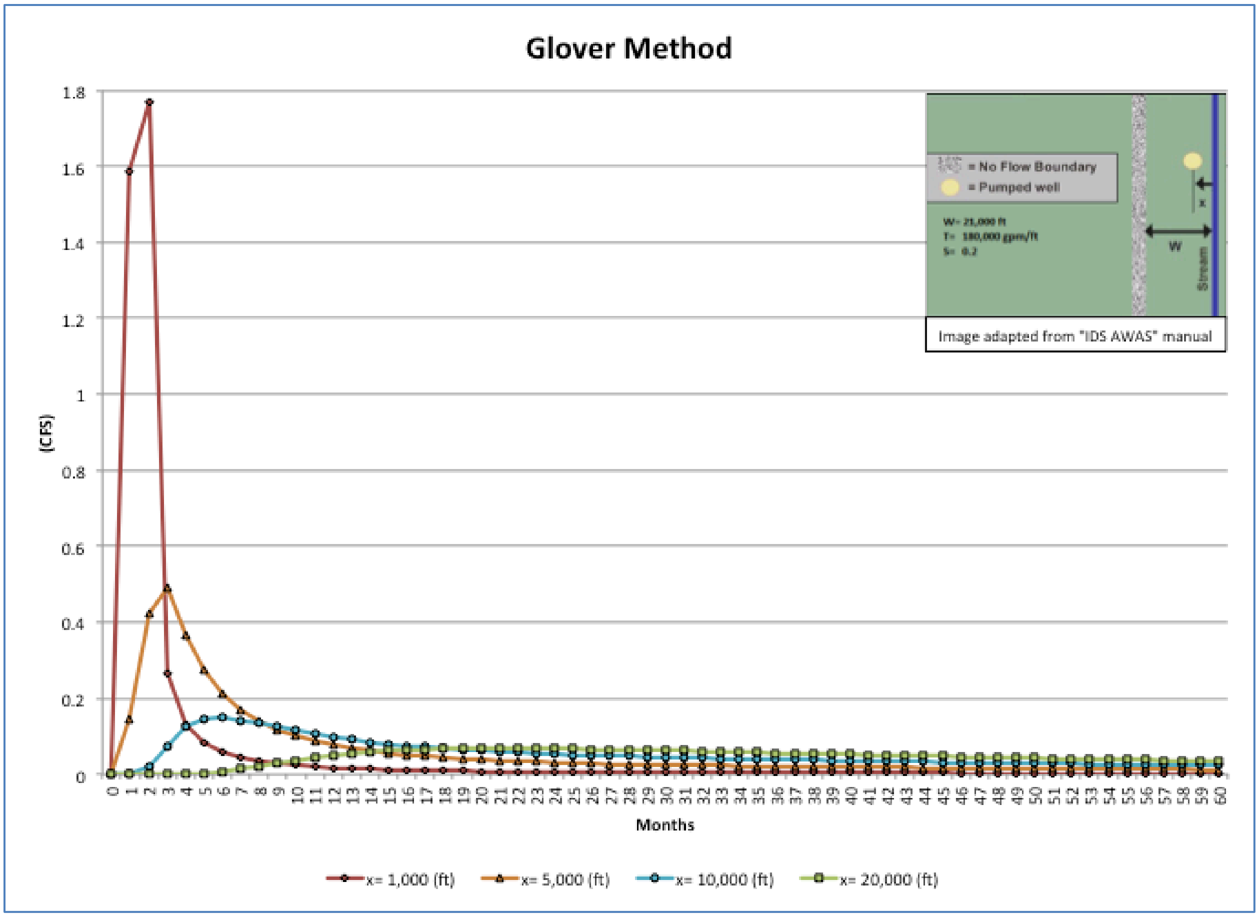


Figure 9. Hypothetical Single Year Pumping Glover Method Calculated Lagged Depletions to the River in cfs for Four Well Locations Over a 60-Month Period Using the AWAS Alluvial Aquifer Mode Assuming Pumping for 2 Months at 1000 gpm. Where X = distance in feet from pumped well to the river, from 1000 to 20,000 ft; W= 21000 ft (distance of no-flow boundary from the stream); Harm T= 180.0 GPD/ft; S= 0,2.

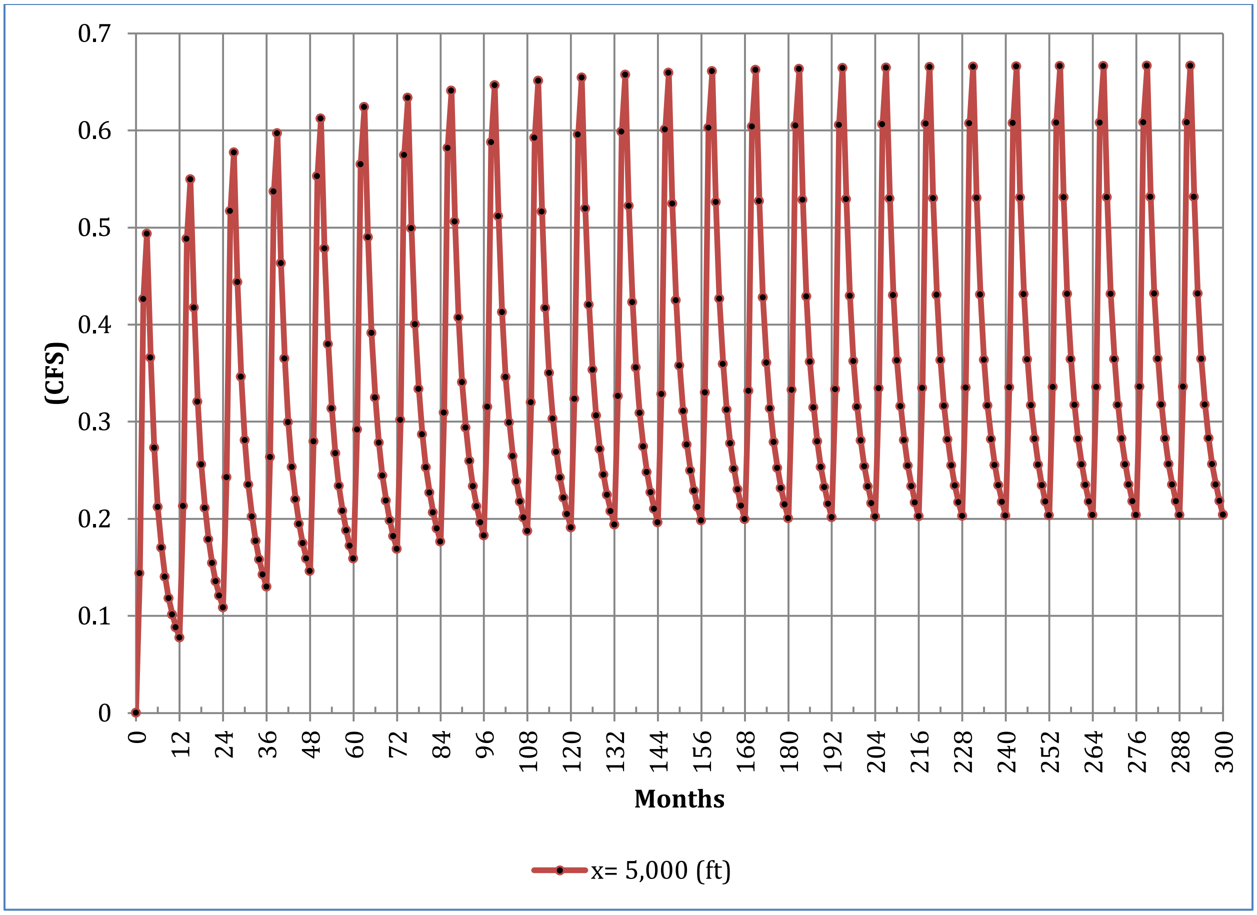


Figure 10. Hypothetical Lagged Depletions to the River for a 25-Year Pumping Simulation Using the Glover Method for A Single Well Located 5,000 Feet from the River Using the AWAS Alluvial Aquifer Mode Assuming Pumping for 2 Summer Months at 1000 gpm. Where X = 5,000 feet from a pumped well to the river; W= 21000 ft (distance of no-flow boundary from the stream); Harm T= 180.000 GPD/ft; S= 0,2.

Much work has been done to extend the applicability of analytical solutions to conditions that are typically found in the field, however, these solutions cannot adequately address many of the complicating factors that affect streamflow depletion by wells, such as aquifer heterogeneity (Sophocleous et al, 1995; Kollet and Zlotnik, 2003). Aquifer heterogeneity, complex stream geometry, streambed hydraulic conductivity, and finite-width aquifers with complex geometry can have substantial effects on streamflow depletion that limit the reliability of analytical solutions for many practical applications, particularly basin-wide analyses in which multiple wells pump simultaneously. To model these complex conditions, numerical-modeling methods are needed. MODFLOW is a numerical-modeling method that is widely utilized in scientific studies, providing more accurate simulation of streamflow impact where adequate data is available to calibrate the model, as it is capable of simulating three-dimensional flow in systems that are horizontally and vertically heterogeneous and have complex boundary conditions (McDonald and Harbaugh, 1988). However, the construction, calibration, and validation of numerical models for each augmentation plan is considered too expensive and data intensive at this time to be feasible for farmers needing to use groundwater as an irrigation source and it has not been proven that widespread adoption of this method would result in better management of the S. Platte system. Despite recent advancements in numerical solutions for stream depletion analysis, it is likely that the established Glover methods will continue to be widely used in existing and new augmentation plans, particularly as they are accepted by both the court and opposers. The SPDSS includes a single-layer MODFLOW groundwater simulation model on a coarse grid resolution, useful for regional scale analysis, but not sufficient for determining the impacts from single wells or even small groups of wells. Finer resolution MODFLOW models have been constructed for other reaches of the S. Platte such as the Tamarack Ranch State Wildlife Area, the Lower Logan Well Users and others. The MODFLOW model is not currently used in the actual administration of augmentation plans, but rather to develop Unit Response Functions (URF) for each well. The URFs are then used in the actual plan administration.

The assumptions regarding aquifer properties and boundary conditions commonly employed for solving analytical methods such as Glover result in approximations of stream depletions and accretions in timing and amount. These approximations are generally considered conservative in the sense that they tend to avoid under-estimation of impacts on the stream, and hence may be seen as protective of the aquifer. As wells or recharge sites are located further from the river, the error associated with these simplifications increases due to heterogeneous aquifer conditions. There are cases, however, where Glover matches the MODFLOW simulations quite well and even underestimates aquifer-stream interaction. Sophocleous et al. (1995) compared Glover to MODFLOW and found in all cases he evaluated, the Glover solution overestimated stream depletion. The State requires that the same method be used to determine accretions as depletions in order to preclude augmentation plans from cherry-picking the most favorable methods. In spite of concerns about the absolute accuracy of modeled depletions and accretions, analytical and numerical models remain the best available tools to estimate stream impacts from alluvial groundwater pumping and are widely accepted and utilized in augmentation decrees and accounting.

Augmentation Plan Accounting

Court approved augmentation plans are designed to provide for replacement of out-of-priority depletions to the extent necessary to prevent material injury to senior vested water rights. These stream depletions caused by wells are typically calculated upon crop consumptive use values determined by the modified Blaney-Criddle method and a water budget approach. The CSU Integrated Decision-Support CU computer program developed by the IDS group at CSU is often used to calculate consumptive use of water by wells, as is the StateCU model. (http://www.ids.colostate.edu).

The timing of stream depletion impacts on the river is most frequently calculated using methods and assumptions for applying the analytical method described by Glover (1968, 1975), which are usually specified in the decree. Aquifer conditions are also frequently specified in the decree and are often based on the USGS publication entitled, *Hydrogeologic Characteristics Of The Valley Fill Aquifer (*Hurr and Schneider, 1972a-d). The CSU Integrated Decision-Support AWAS program (Alluvial Water Accounting System) is commonly used to complete the calculations of stream depletions and recharge using the Glover equation or SDF method. AWAS utilizes the no-flow boundary method of the Glover equation based upon the analytical stream depletion model of the office of the State engineer, which was developed in 1987 to compute stream depletion or accretions caused by well pumping or recharge. Some S. Platte augmentation plans have decreed URFs (unit response functions). Response functions may be thought of as values that express the response at a specific location to aquifer recharge or discharge at another location. Since the response changes with time, a different value is required not only for each pair of locations, but also for each time period of interest. Some augmentation plans carry past pumping depletions to two or three significant digits for 30 or more years after initial pumping. Pumping volumes are multiplied by efficiency factors to calculate consumptive use values; typically 50-60% for flood irrigation and 75-80% for sprinkler irrigation. For mixed surface and groundwater irrigation systems, it is commonly assumed the crop irrigation requirement not satisfied by surface water is met by groundwater. Local weather station data, often from the Northern Colorado Water Conservancy District (NCWCD) network, is used for calculating ET and effective precipitation.

Wells operating under more recently approved augmentation plans are now required to submit well pumping data based upon actual pumping records from flow meter readings as specified by the well metering rules approved by the Division 1 Water Court in 2013. The determination of the adequacy of replacement water is evaluated when the decree is entered or the substitute water supply plan is approved. Since 2003, adequacy of replacement supply is determined as an on-going part of the plan operation through the use of an agreed upon projection tool or method. These projections generally assume the river will be continuously under call for the specified period of future projection. The purpose of the projection is to compare future depletions from current and past pumping to future replacement supplies. Typically, projections are based on stipulated or decreed one to seven year scenarios of minimal replacement supplies, and maximum call periods. Augmentation decrees may allow exchange or substitution of excess recharge water. Some plans also require annual well pumping quotas that specify an AF pumping limit based on augmentation projections for that year.

Augmentation plan decrees typically specify an assumed period of senior call that must be protected from injury, often all of the irrigation season. The plan may also be required to demonstrate that depletions from irrigation, augmentation, and recharge wells can all be replaced, if necessary, for the entire year. Plan operators are required to submit monthly reports of their daily depletion and accretion accounting to the Division Engineer. Net out-of-priority well depletions are calculated by multiplying the sum of net depletion by the percentage of time the wells were out-of-priority. Shortfalls in accretions to cover net depletions necessitate replacement with alternative augmentation water or curtailing well pumping to the extent needed to avoid a deficit. Augmentation plan operators are bound by the terms and conditions of the decree and the Division Engineer has the nondiscretionary responsibility to enforce the terms and conditions of the decree upon the wells and the lands included in the decree, as well as the successors and assignees until all obligations under the decree has been fulfilled.

Augmentation Requirements and Augmentation Supplies

Augmentation supplies are the water supplies associated with augmentation plans used to cover augmentation requirements when there is a senior call on the river. These supplies include accretions from recharge sites as well as alternative supplies such as fully consumable water and reusable effluents, pumped water from augmentation wells and surface water adjudicated for release as augmentation water (McMahon, 1976). For the HB1278 analysis, total supplies, some of which include lagged recharge, are summed on an annual basis. Note that augmentation plans that are primarily used to augment municipal or industrial depletions were not included herein. Augmentation supplies are divided into two general categories:

- Recharge Augmentation Supplies include water diverted for in-ditch recharge or to recharge ponds. The lagged timing of these recharge supplies is not specifically considered. Instead, the monthly diversions to recharge are summed on an annual basis, and trends are considered based on a five-year average. Note that recharge augmentation supplies accrue to the river regardless of whether a call requires augmentation during that time period.
- Surface Augmentation Supplies include controlled water released from a storage reservoir; water diverted and released to the river via an augmentation station; and reusable effluent. Surface augmentation supplies only are released to the river when a call requires augmentation.

Graphical comparisons of potential augmentation requirements and associated augmentation supplies are shown below by water district and include the larger augmentation plans (Figures 11-14).

Recharge structures in the S. Platte are designed to introduce water into the alluvium that will result in water accretions to the river. The structures are optimally sited at a distance from the river that most efficiently covers lagged pumping depletions that are incurred during the summer growing season, but may hit the river days, months or years later during a period when the river is under administration. A recharge structure may be a designated section of unlined ditch or canal, or a pond or group of ponds that receive water designated for recharge or augmentation. Flow into and out of each recharge structure must be metered and equipped with a continuous flow recorder or similar approved equipment. All recharge ponds must have a staff gage that registers the lowest water level in the pond. Recharge areas must be maintained free of or with minimal vegetation as a requirement of the decree. Recharge water must be deemed fully consumable and accretions are calculated as inflow minus evaporation plus consumptive use by vegetation plus water retained and outflow. Recharge accounting is done on a daily time step with monthly summations provided to the Division Engineer within 30 days of the end of the month. The Division Engineer files these reports on Laserfiche once they are checked and approved.

Augmentation Requirements (Groundwater Depletions)

Potential augmentation requirements were determined for the HB1278 study by summing the depletions from wells associated with an augmentation plan based on the HydroBase association table from 2007. The 2007 table is more representative of the wells assigned to the 2005 irrigated acreage assessment, used to represent the 2000 to 2012 decade. As discussed above, not all groundwater pumping causes depletions to the river and depletions do not require augmentation if there is not a senior call on the river. The annual potential augmentation requirements shown in Figures 11-14 below do not represent lagging; nor are they reduced for times when there is not a senior call. The result is that the lack of lagging underestimates depletion, while the assumption of 100% call overestimates the owed depletions. A calibrated groundwater model is needed to more precisely quantify lagged augmentation requirements at this scale.

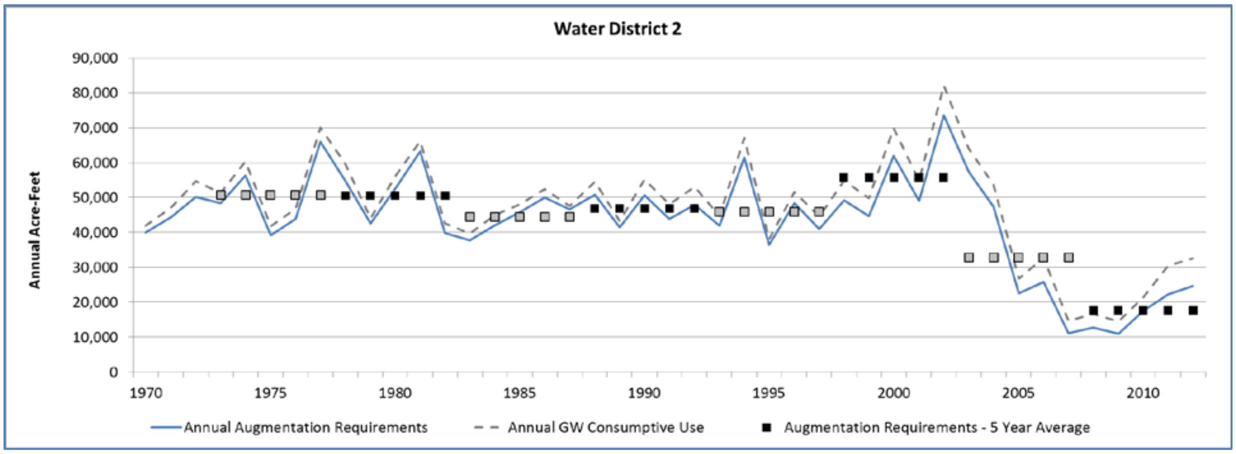


Figure 11. Potential Annual Augmentation Requirements, Groundwater Consumptive Use and Five-Year Average Potential Augmentation Requirements in Water District 2.
Data Source: CO DWR HydroBase Version 20130710.

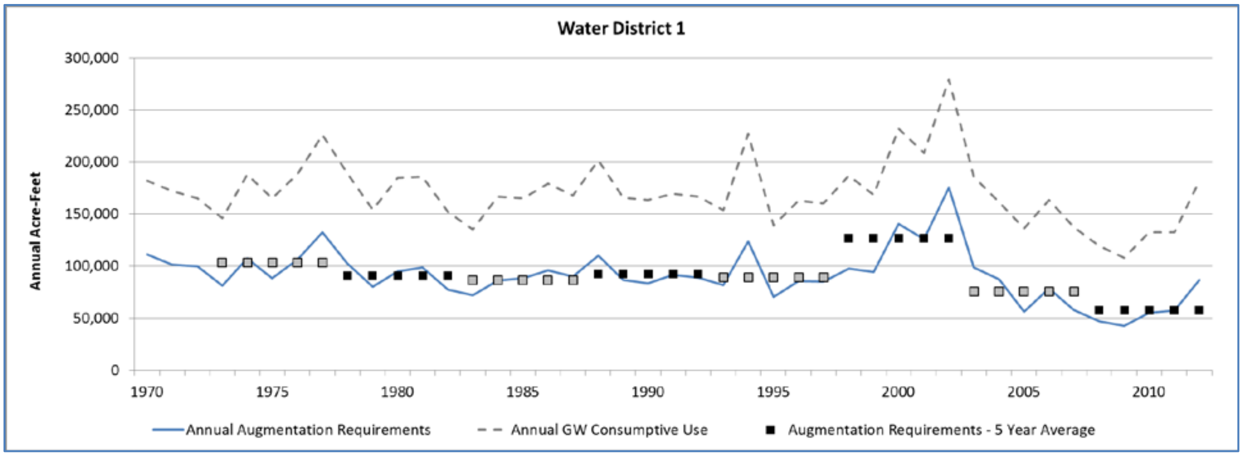


Figure 12. Potential Annual Augmentation Requirements, Groundwater Consumptive Use and Five-Year Average Potential Augmentation Requirements in Water District 1.
Data Source: CO DWR HydroBase Version 20130710.

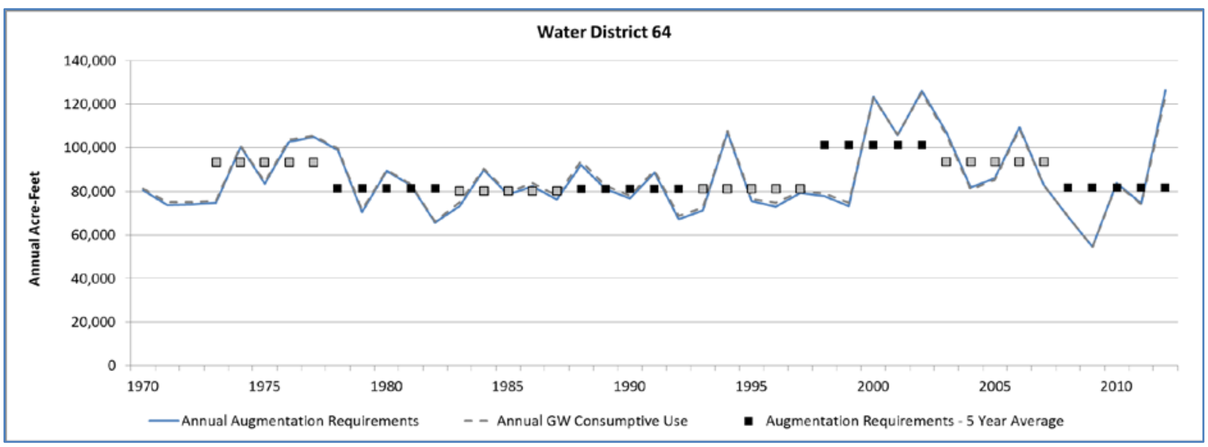


Figure 13. Potential Annual Augmentation Requirements, Groundwater Consumptive Use and Five-Year Average Potential Augmentation Requirements in Water District 64.
Data Source: CO DWR HydroBase Version 20130710.

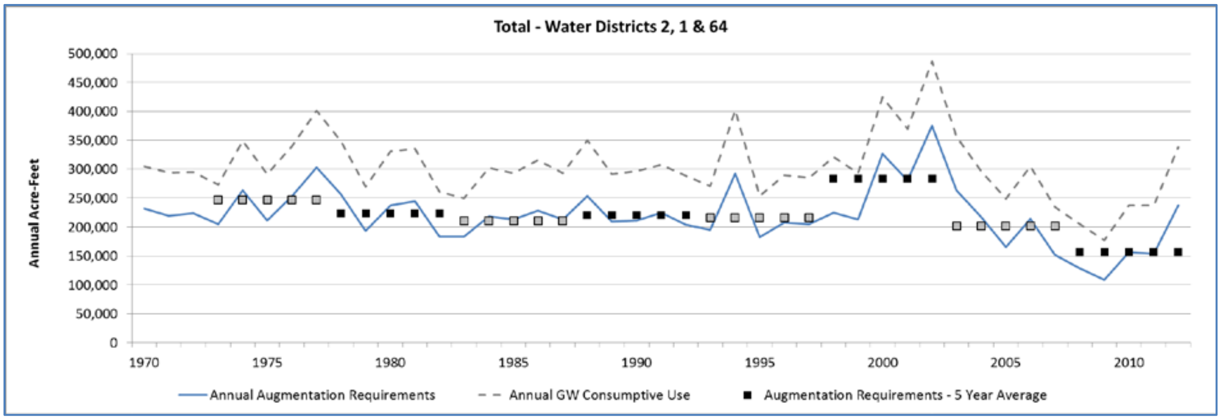


Figure 14. Total Annual Potential Augmentation Requirements, Groundwater Consumptive Use and Five-Year Average Potential Augmentation Requirements in Water Districts 2, 1 and 64.
Data Source: CO DWR HydroBase Version 20130710.

Consumptive use from designated basin wells, nontributary Denver Basin wells, and Coffin Wells does not require augmentation. Consumptive use associated with these wells accounts for the difference between total consumptive use and potential augmentation requirements in the figures above. As shown in Figure 12 above, Water District 1 has the largest differential between total consumptive use and potential augmentation requirements, corresponding to the large amount of acreage located in designated groundwater basins in that water district. Potential augmentation requirements in Water District 64 correspond to a greater percentage of acreage supplied by groundwater in the basin than other water districts. Potential augmentation requirements increased in Water District 64 after 2000, likely corresponding to the recent drier conditions and reduced available surface water to meet irrigation needs. They decrease in the late 2000s during wetter than average years where pumping was reduced.

Augmentation Supplies

Based on discussions with Colorado DWR staff, diversions to recharge areas are designated in HydroBase diversion and release classes using a Use Type = Recharge (R). Recharge augmentation supplies are a lagged or timed source of augmentation plan supply measured at the recharge area site, whereby the diversions are made in advance of the depletions and timed such that the recharge accretions are available to offset future depletions. Based on discussions with DWR staff, augmentation released directly to the river (Surface Augmentation Supply) is designated in diversion and release classes using a Use Type = Augmentation (A). Direct augmentation can be considered a controlled and more immediate type of augmentation plan supply, as opposed to lagged recharge structure seepage that accrues to the river even if it is in excess of an augmentation demand. Figures 15-18 show trends in surface water and recharge augmentation supplies by Water District.

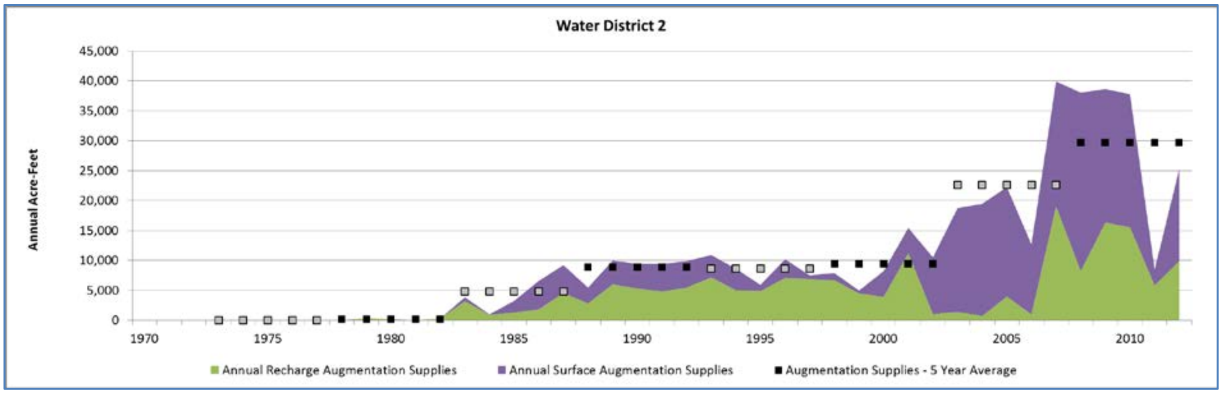


Figure 15. Annual Surface and Groundwater Supplies Used to Meet Estimated Potential Augmentation Requirements, and Five-Year Average Augmentation Supplies in Water District 2.

Data Source: CO DWR HydroBase Version 20130710.

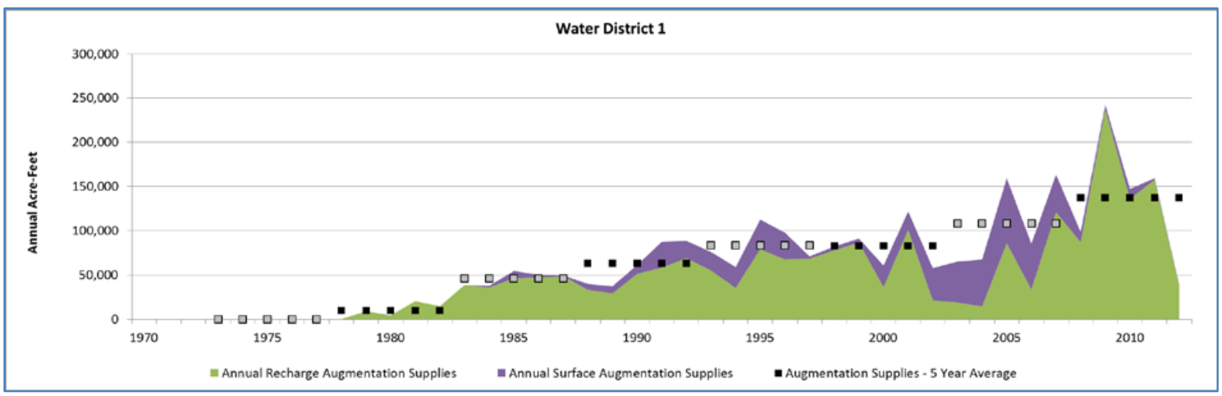


Figure 16. Annual Surface and Groundwater Supplies Used to Meet Estimated Potential Augmentation Requirements, and Five-Year Average Augmentation Supplies in Water District 1.

Data Source: CO DWR HydroBase Version 20130710.

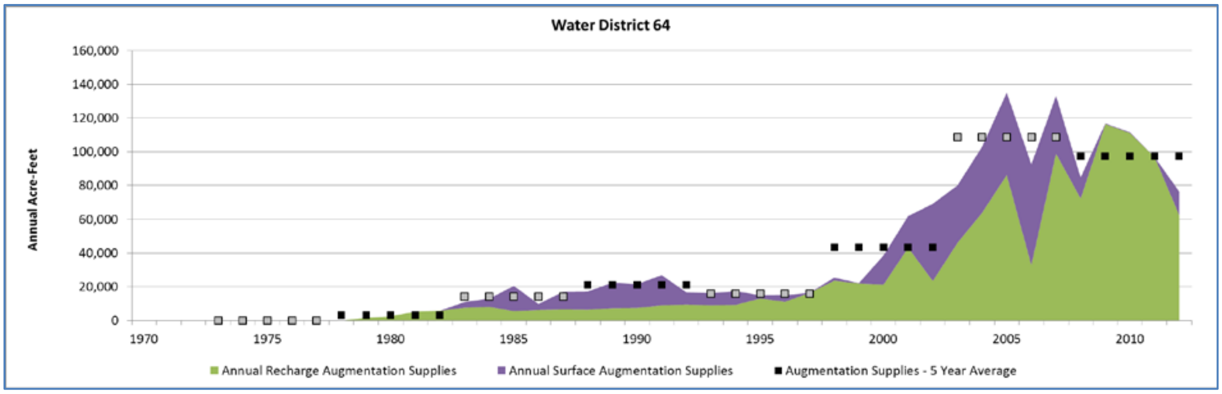


Figure 17. Annual Surface and Groundwater Supplies Used to Meet Estimated Potential Augmentation Requirements, and Five-Year Average Augmentation Supplies in Water District 64.
Data Source: CO DWR HydroBase Version 20130710.

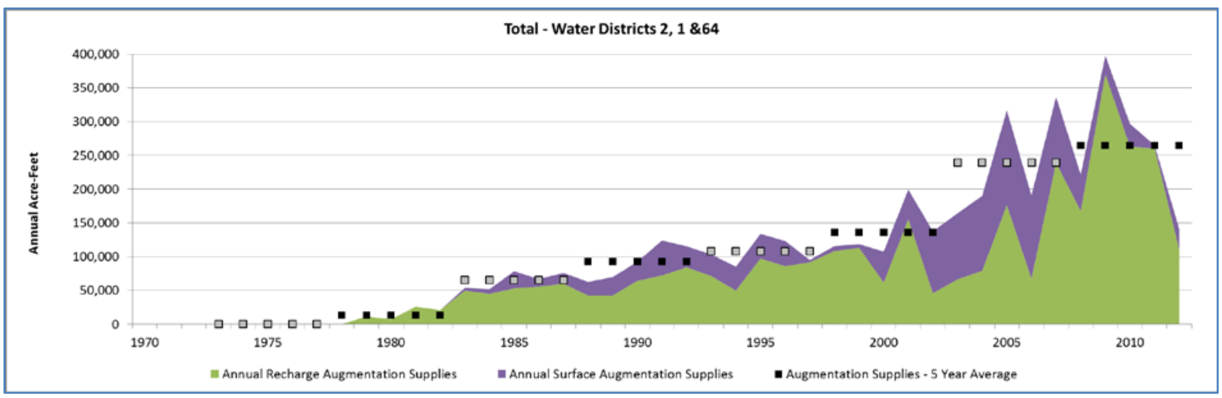
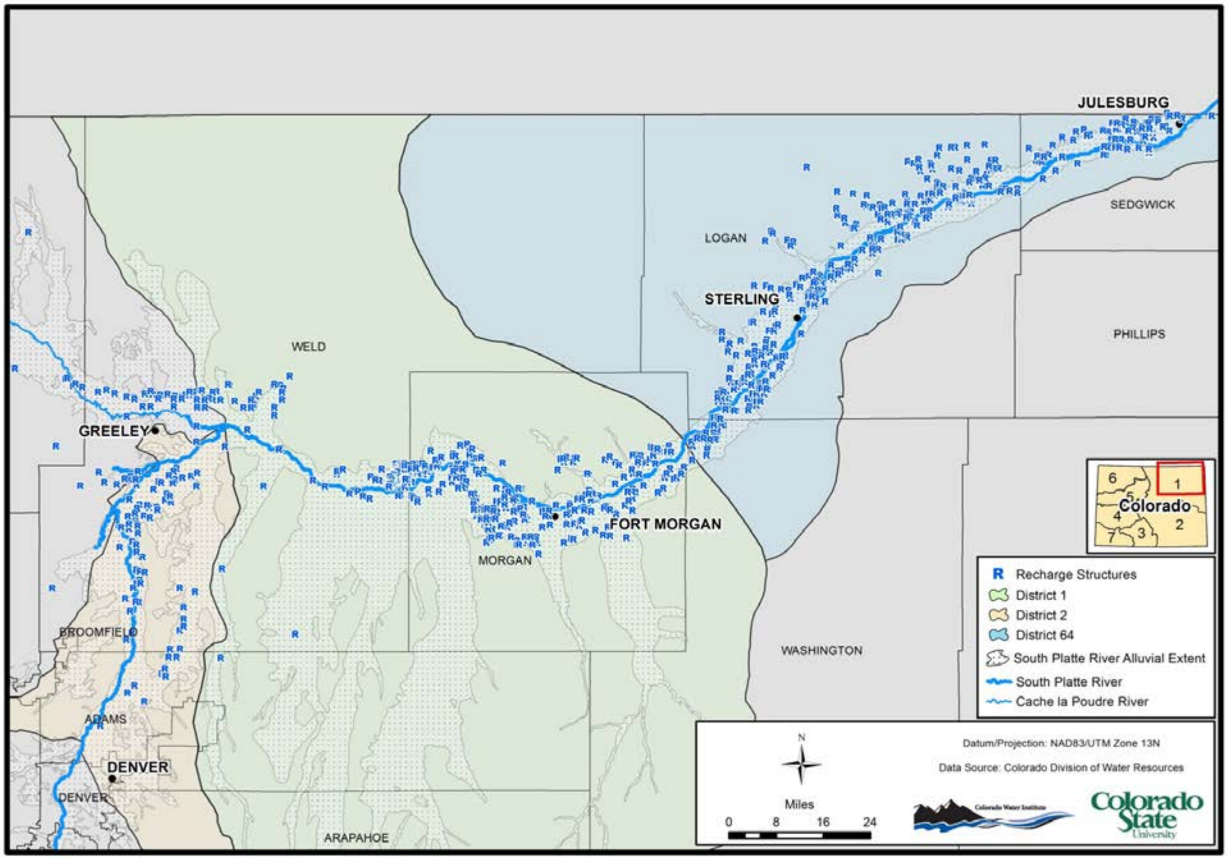


Figure 18. Total Annual Surface and Groundwater Supplies Used to Meet Estimated Potential Augmentation Requirements, and Five-Year Average Augmentation Supplies in Water Districts 2, 1 and 64.
Data Source: CO DWR HydroBase Version 20130710.

The graphical display of recharge augmentation supply is the result of querying HydroBase for water classes with U:R coding, assigning these classes to augmentation plans, then aggregating this augmentation supply by water district (Figures 15-18). As noted above, augmentation plans used primarily to augment municipal and industrial depletions were not included herein, as the potential augmentation requirements reflected in this analysis are based on agricultural depletions. Water classes were assigned an augmentation plan based on the Group ID included in the water class, the associated augmentation plan based on the HydroBase association table, or the From ID included in the water class if it was in an augmentation plan. Because each water class was assigned to an augmentation plan, the diversions could be appropriately assigned to more than one augmentation plan. For those diversions to recharge not tied to a specific augmentation plan, the diversion was evenly split between the multiple augmentation plans identified in the HydroBase association table.

The graphical display of surface augmentation supply is the result of querying for water classes with U:A coding, assigning these classes to augmentation plans, then aggregating this augmentation supply by water district. As with recharge augmentation supply, augmentation plans used primarily to augment municipal and industrial depletions were not included. Water classes were assigned an augmentation plan based on the augmentation plan the class was recorded under, the Group ID included in the water class, the associated augmentation plan based on the HydroBase association table. These estimates of recharge supply queried directly from HydroBase were reasonably correlated to annual estimates provided by DWR staff. Deviations from the DWR estimates are generally caused by lack of Group ID designation in water classes.

The increase in recharge augmentation supply in the 2000s is a result of an increase in recharge areas constructed in the basin, specifically in Water District 64 and to a slightly lesser degree in Water District 1(Map 8). District 2 has seen the development of many lined gravel pits which may or may not provide augmentation water, but do not serve as a source of recharge. Augmentation supplies in District 2 are inadequate to serve the needs, thus wells remain on restricted quotas. Surface augmentation supply reflects releases for augmentation from reservoirs such as Jackson Lake and Prewitt Reservoir that are able to release directly back to the river, groundwater diversions from augmentation/recharge wells, bypassed diversions measured at augmentation stations, reusable effluent, and other sources of direct augmentation. The increase in surface augmentation supply from the 1990s to the 2000s is likely a combination of more complete recording of classes with U:A coding and the increased administration after the drought of the early 2000s.



Map 8. Location of Existing Recharge Structures in the S. Platte Basin.
Data Source: CO DWR HydroBase Version 20130710.

Total Augmentation Supply vs. Estimated Potential Augmentation Requirements

The five-year averages shown on Figures 19-22 show that potential estimated augmentation requirements exceeded augmentation supply in Water Districts 2 and 64 prior to more strict administration beginning after the drought in the early 2000s. However, since days of administrative call were considerably less in these water districts prior to 2000, the actual augmentation requirement would have been much less than the potential maximum requirement based upon consumptive groundwater pumping. Well curtailments and quotas in Water District 2 have reduced pumping and thus requirements, but in reality, there is a demand for more augmentation water in the district. Augmentation supply shown in Figure 20 appears greater than potential augmentation requirements in Water District 1 based on the late 2000 five-year average. This likely reflects both the increase in recharge site construction, and some higher runoff flows available to divert for recharge during this period. However, it is important to note that lagged depletions from previous years can amount to significant amounts of water in large augmentation plans and cannot be accurately tracked by this method.

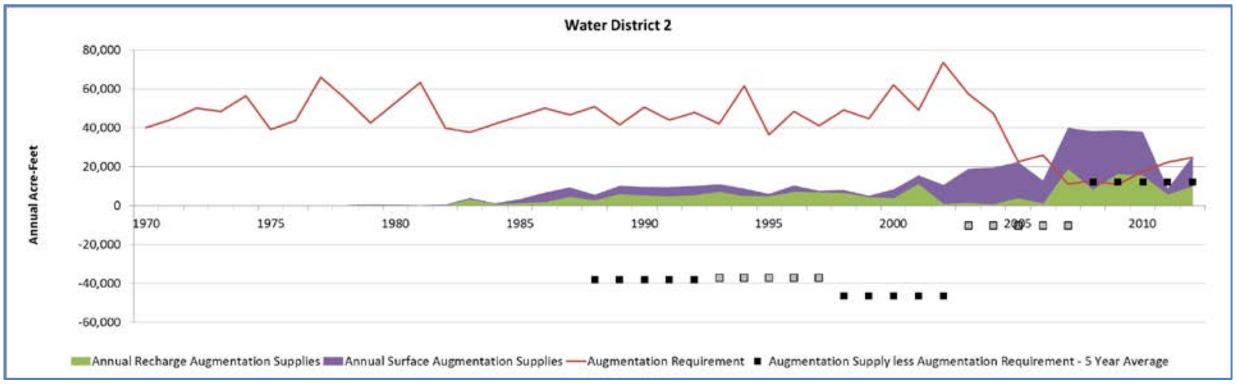


Figure 19. Annual Surface and Groundwater Augmentation Supplies Versus Estimated Potential Augmentation Requirements, and Five-Year Average Augmentation Supplies Less Potential Augmentation Requirement in Water District 2.
Data Source: CO DWR HydroBase Version 20130710.

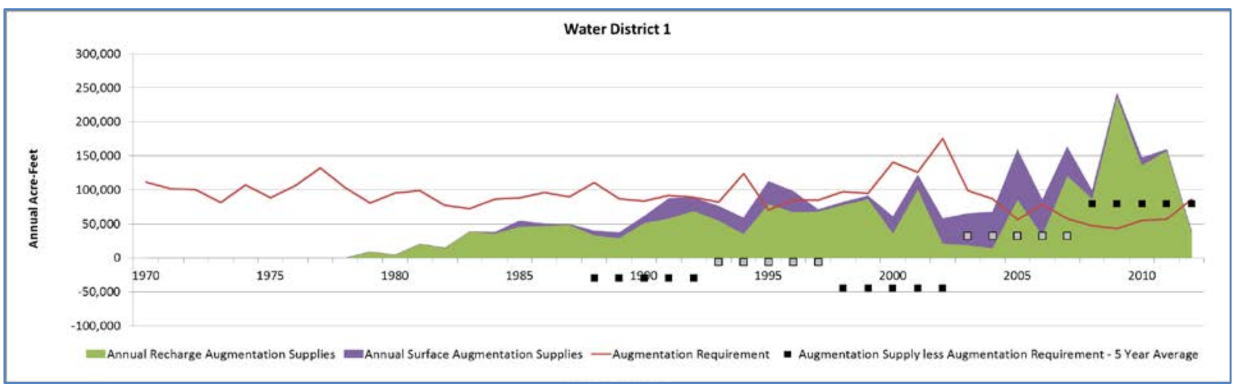


Figure 20. Annual Surface and Groundwater Augmentation Supplies Versus Estimated Potential Augmentation Requirements, and Five-Year Average Augmentation Supplies Less Potential Augmentation Requirement in Water District 1.
Data Source: CO DWR HydroBase Version 20130710.

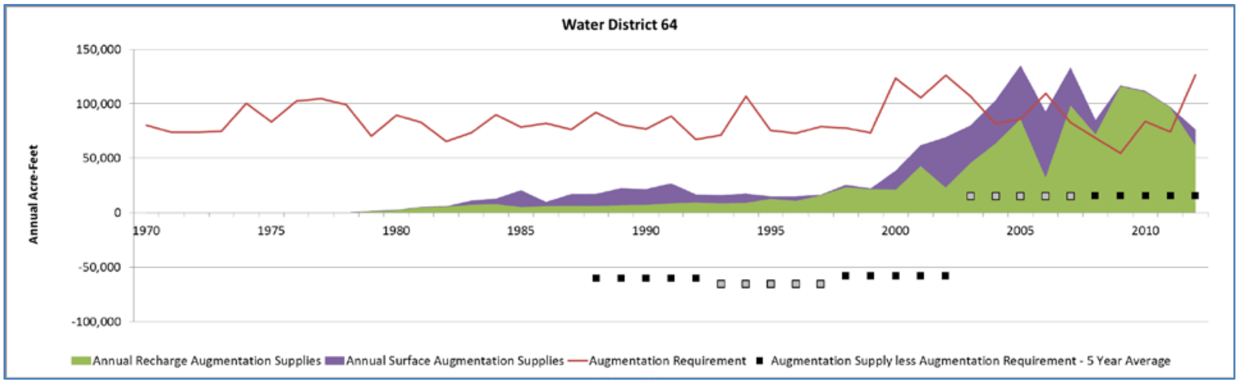


Figure 21. Annual Surface and Groundwater Augmentation Supplies Versus Estimated Potential Augmentation Requirements, and Five-Year Average Augmentation Supplies Less Potential Augmentation Requirement in Water District 64.
Data Source: CO DWR HydroBase Version 20130710.

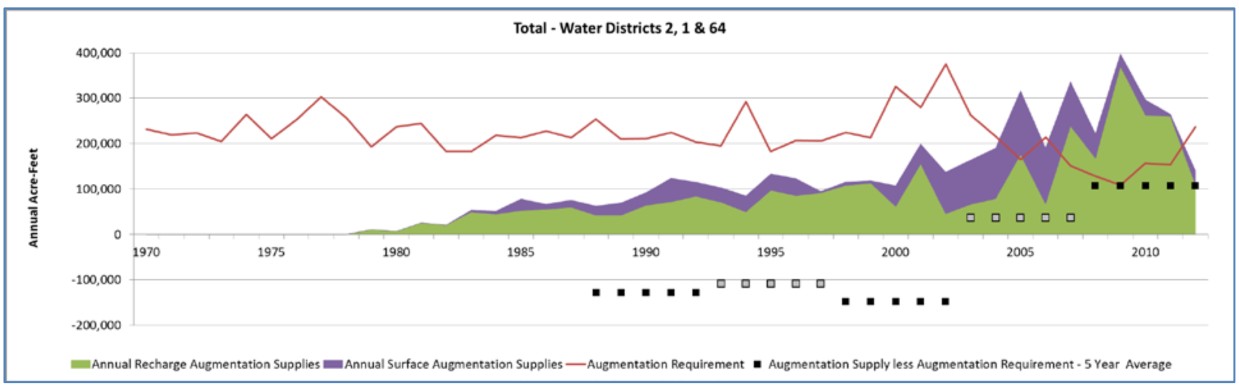


Figure 22. Total Annual Surface and Groundwater Augmentation Supplies Versus Estimated Potential Augmentation Requirements, and Five-Year Average Augmentation Supplies Less Potential Augmentation Requirement in Water Districts 2, 1, and 64.
Data Source: CO DWR HydroBase Version 20130710.

The early and late 2000s five-year average for Water District 64 reflects a more closely balanced augmentation supply and potential requirement and a drop in surface augmentation supply, likely indicating the recharge supply is sufficient to meet the lagged augmentation requirements in years of average or above average hydrologic conditions. Fewer days of administrative call in Water District 64 compared to Water District 2 or Water District 1 also help recharge structures to take needed supplies. Particularly in Water District 2, augmentation plans appear to augment both agricultural and municipal/industrial depletions, and it is more difficult to isolate supplies used to meet agricultural augmentation requirements shown in the graphs. Surface augmentation is more widely used as a supply in Water District 2, likely due to the availability and prevalence of reusable effluent compared to other districts. The number of days of call in Water District 2 reduces periods of time where junior recharge rights can divert. Additionally, due to the urban growth in this area there is a lack of suitable sites for recharge structures.

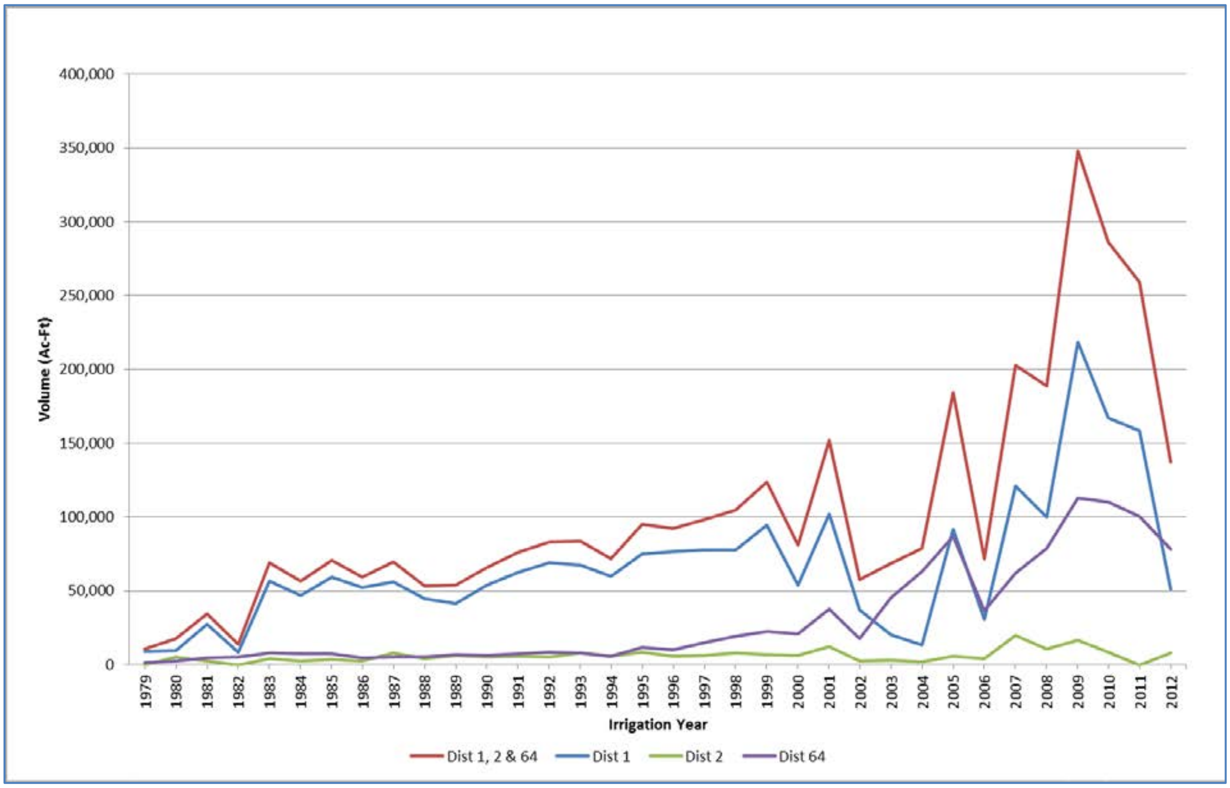


Figure 23. Artificial Groundwater Recharge Diversions in Water Districts 2, 1, and 64.
Data Source: CO DWR HydroBase Version 20130710.

Lagged Depletion Patterns in Water Districts 1 and 64

As stated above, the estimated potential augmentation requirements depicted in Figures 19-22 do not include lagged depletions from previous years of pumping. To investigate the lagged depletion patterns for irrigation wells in the S. Platte basin, the Wilson Water Group used the depletion/return flow patterns developed for the SPDSS Lower South Platte StateMod model. A Glover analysis was performed using the AWAS modeling tool at points representing the general centroid of each irrigation district or aggregate of groundwater only lands (Figure 24). Glover parameters, including transmissivity, specific yield, distance to the aquifer boundary, and distance to the stream were collected from individual SPDSS modeling efforts (SPDSS Task 43.3 - South Platte Alluvium Region Aquifer Property Technical Memorandum and SPDSS Task 42.3 South Platte Alluvium Region Aquifer Configuration Technical Memorandum) and through spatial mapping analyses. The maximum number of months for the patterns was set to 120 months or the number of months necessary to achieve 95% of the full depletion. The last 5% of depletions were normalized over the pattern to result in patterns that equal 100%. Patterns range from 9 to 120 months, with a maximum of 76.5% depleting the river in the first month.

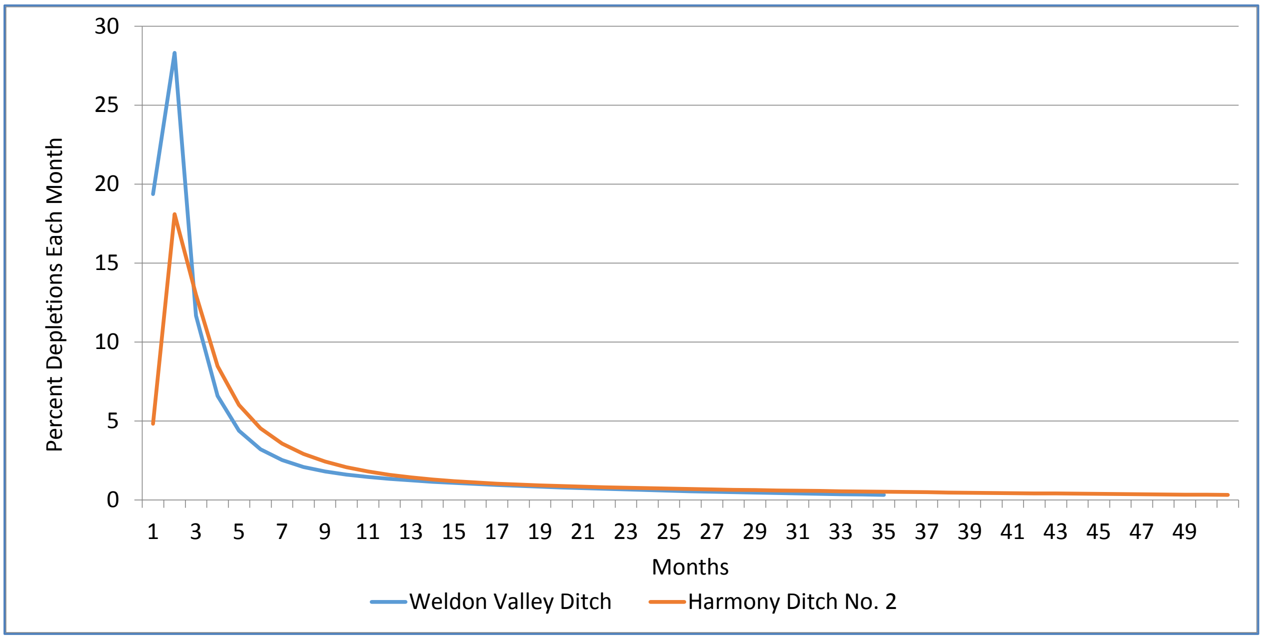


Figure 24. Example Calculated Lagged Depletions from Wells Pumping Under the Weldon Valley Ditch and the Harmony No. 2 Ditch Using the AWAS Glover Method.

For this analysis, the patterns were assigned to each irrigation structure found in the SPDSS modeling effort to assess how quickly the depletions from the groundwater pumping would impact the nearest live stream (the S. Platte River mainstem in most instances). Of the 356,246 acres of irrigated land in Water Districts 1 and 64 (SPDSS 2001 Irrigated Acreage Assessment), approximately 17% is located in Designated Ground Water Basins. The remaining 296,606 acres of irrigated land receive either a sole or supplemental supply of groundwater that can be considered depletive to the river. Although statistical analysis could be performed on all of the patterns to determine the average, maximum and minimum patterns in the basin, this analysis would not reflect the fact that some patterns are associated with very little acreage. For example, the pattern for North Sterling Irrigation District can be applied to the depletions from supplemental pumping on over 36,000 acres, whereas the pattern for Harmony Irrigation District can be applied to the depletions from supplemental pumping on only 11,000 acres. To "weight" the patterns, two thresholds (50% and 75%) were selected to reflect the sum of the depletions that occur in a given time frame (i.e. three months, six months, one year and three years) within each threshold. For example, 75% of the depletions associated with 17,869 acres of irrigated land impact the river in the first three months. This acreage amount corresponds to 6% of the total acreage in the S. Platte basin outside of Designated Ground Water Basins. If a 50% threshold is applied, 50% of the depletions associated with 43,881 acres of irrigated land impact the river in the first three months. Table 6 summarizes the information in the 75% depletion example above and expands the assessment into further time frames, showing that the majority of pumped depletions impact the stream within three years.

Table 6. Calculated Timing and Acreage for 75 Percent of the Depletions to Impact the Stream.

Timing of Impact	3 Months	6 Months	1 Year	3 Years
Acres Associated with Impact	17,869	28,939	66,121	285,056
Percent of WD 1 + 64 Acreage	6%	10%	22%	96%

Timing of depletions is an important component when analyzing streamflow in the S. Platte River. The conclusion that can be drawn from this assessment is that for much of the acreage in the basin, the depletions do not fully reach the river within the first irrigation season or even in the same year. A large majority of the depletions, however, do impact the river within 3 years, which supports the 5-year average assessment periods we have used to compare augmentation plan supply sufficiency.

Another analysis was performed to investigate the use of recharge pits that have the same lagged return flow pattern as well depletions. Figure 25 provides an illustration of the following example:

- Users pump 100 AF each irrigation season based on a typical pumping pattern, causing depletions = 60 AF (equal to crop consumptive use, example assumes flood irrigation at 60% efficiency).
- The lagged depletion pattern used for this example returns less than 1% in the first month of pumping. This pattern is representative of approximately 59% of the acreage irrigated in Water Districts 1 and 64.
- Recharge sites with the same depletion pattern require junior diversions totaling 80 AF during the runoff months (assume water is available only in May and June) to meet the winter depletions obligations once a steady-state pattern has been reached (approximately 4 years).

This example assumes that recharge ponds in the same vicinity as the irrigated lands cover all depletions and that there is always a call on the river. It ignores the other important “direct augmentation” options including augmentation wells and surface reservoir releases. This analysis points to the unavoidable timing differences that are inherent in augmentation plans relying on recharge to cover pumped depletions (Figure 25).

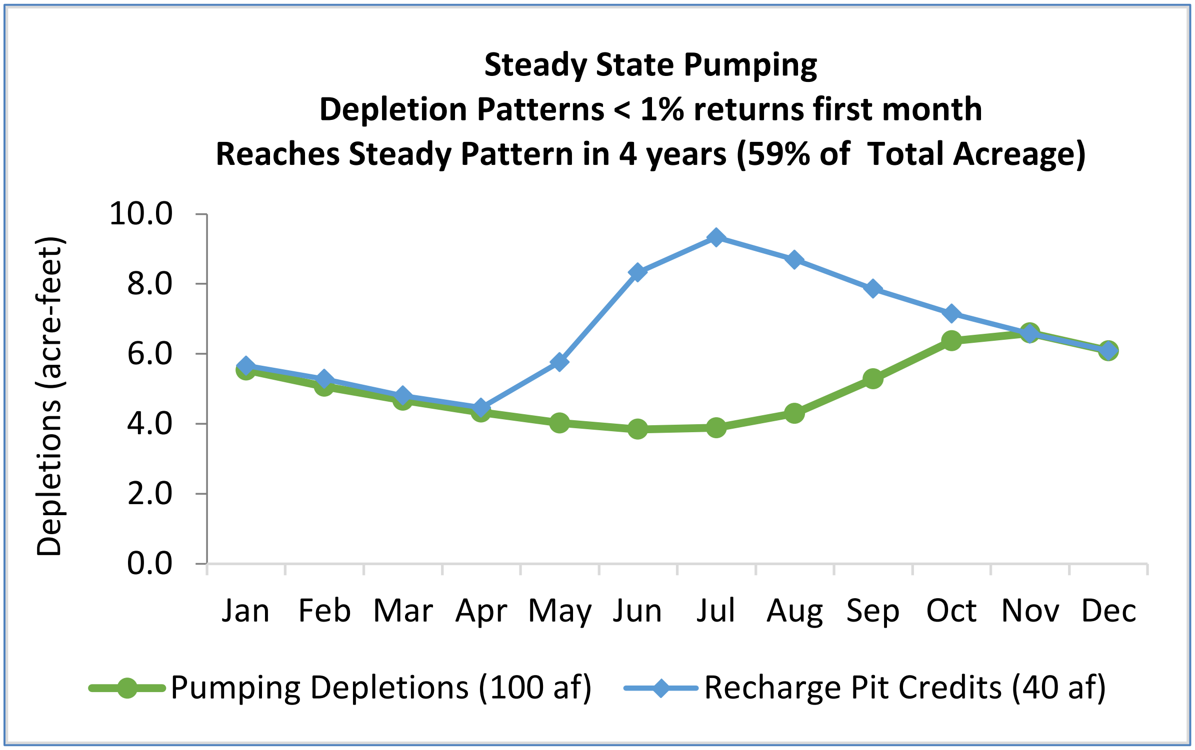


Figure 25. Calculated Example of Pumped Depletion Timing Compared to Accretion Timing from a Recharge Pond.

Augmentation from recharge in excess of requirements may occur because junior recharge rights are only in priority in short windows of time and thus augmentation plan operators must recharge as much as possible when they are in priority. Since recharge operators cannot know when the next drought period will occur, they are compelled to operate in a manner that assumes that drought could occur next year, or for the next six years, depending upon their court decree. Additionally, the timing of when the recharge rights are in priority may not match the lagged timing of when water is needed from the wells to irrigate crops. The locations of recharge ponds and other recharge facilities relative to irrigation wells also may present timing difficulties for augmentation plans. For example, if recharge structures are located closer to the river than the irrigation wells in an augmentation plan, the recharge credits reach the river more quickly than the depletions. In these cases it is difficult to recharge only the amount of water ultimately needed to offset the well depletions. As a result, many augmentation plans have excess capacity to provide adequate supplies to cover depletions year round. A good augmentation plan must have a blend of recharge structures close to the river for use following dry periods and structures further away to provide much longer recharge credits for protection during prolonged drought periods. When added up, the many augmentation plans in the S. Platte can generate excess recharge credits in normal and wet years. However, dry years such as 2012 result in very little water available for recharge, as the river is seldom free of administration during these years. When averaged over the period of 2008 to 2012 (Table 7), which include three wet years and one drought year, total augmentation supply exceeded consumptive groundwater pumping, but not by a wide margin. Table 8 provides a comparison to the recent period and shows how much recharge has been developed in the basin over the last decade and what has happened to well pumping. The period of 1999- 2004 encompassed exceptional drought and corresponding reduction in surface diversions, which were offset by groundwater pumping.

Table 7. Average Surface Diversions, Pumping, Consumptive Use Groundwater Pumping, and Augmentation for Water Districts 2, 1, and 64, for the period of 2008-2012.

	WD 2	WD 1	WD 64	Total
	----- Average (2008-2012) in AF/yr ----------			
Total Surface Diversion	376,583*	673,869	257,766	1,308,217
Total Pumping	31,195	177,490	110,612	319,298
CU GW Pumping	23,138	134,872	80,781	238,791
Surface Augmentation	18,487	6,067	5,493	30,047
Recharge Augmentation	11,166	131,287	91,819	234,271
Total Augmentation	29,653	137,354	97,312	264,318

*2011 diversion data not included for WD 2
Source: HydroBase Version 20130710.

Table 8. Average Surface Diversions, Pumping, Consumptive Use Groundwater Pumping, and Augmentation for Water Districts 2, 1, and 64, for the period of 1999-2004.

	WD 2	WD 1	WD 64	Total
	------ Average (1999-2004) in AF/yr -----------			
Total Surface Diversion	397,916	573,433	209,553	1,180,902
Total Pumping	89,840	277,685	145,095	512,620
CU GW Pumping	62,418	205,907	102,630	370,954
Surface Augmentation	9,105	30,961	25,861	65,927
Recharge Augmentation	3,786	46,432	36,653	86,871
Total Augmentation	12,891	77,393	65,514	152,798

Source: HydroBase Version 20130710.

A new water cooperative (commonly called the South Platte Cooperative or the Northeastern Colorado Water Cooperative) has been proposed to facilitate more efficient use of excess augmentation water in the lower S. Platte basin through quantification and trading. The proposed Cooperative would create a mechanism for temporarily moving augmentation credits from plans with unused credits to plans that need additional credits. The Cooperative anticipates being operational in 2014 and aspires to eventually serve as a water bank for the lower river where any source of tradable water can be deposited and transferred on a temporary basis. Preliminary studies for the Cooperative found the following:

- Amounts of unused recharge credit vary annually
- The amount of unused recharge credit appears to be less variable in District 64
- Annual amounts of unused recharge credits in District 64 varied from 5,000 to 10,000 AF
- Annual amounts of unused recharge credits in District 1 varied from 6,000 AF in 2008 up to 50,000 AF in 2010
- It is expected that during drought unused recharge credits will be greatly reduced if not eliminated

A similar effort or water bank is likely needed for Water District 2 to help provide inexpensive augmentation water to well users in wet and average years. In dry years it could also provide water to municipalities.

<u>Alluvial Aquifer Accretion/Depletion Analysis Tool</u>

Currently, the DWR relies on accounting from augmentation plan operators to determine whether or not a sufficient amount of accretions are provided at the time and location required to cover out-of-priority depletions. Such accounting is typically not submitted until at least 30 or more days after the depletion has impacted the river. An operational planning tool is under development by the CWCB and DWR to track supplies, demands, and deliveries in Districts 1 and 64. The Alluvial Aquifer Accretions and Depletions Tool (AAADAT) has been conceived to provide augmentation plan holders and water commissioners with a timely way to assess and agree upon availability of excess accretions in the river. Excess accretions are defined as a surplus of inputs to a surface water source from a single augmentation plan, occurring when the total replacements to the stream in a day exceed the total depletions to the stream for that plan. The AAADAT planning tool includes the following:

- Supplies in each reach
- Demands in each reach
- Reservoir storage and recharge structures in each reach
- Exchange water
- Transit losses for water passed to downstream reaches
- Water balance in each reach

Individual plan holders calculate their daily net impacts to the river and usually know when they are generating excess accretions. It is difficult for individuals to leverage this excess as a resource because that would require verification by the State, and the modeled (not measured) lagged impacts calculations are typically not available to water commissioners until 30 to 60 days after the impacts have affected the river. Individual accounting practices vary considerably between plans, and insufficient Division 1 staff is available to review and verify the daily data generated by the many plans operating in the basin. With the AAADAT tool, the water commissioners will have a way to verify plan holder claims on a daily time step, and potentially administer requests for use of excess accretions while ensuring that vested water rights are not being impacted by un-replaced out-of-priority lagged diversions. Initial development of AAADAT is focused on Division 1, with the intent that the tool will be adaptable to other divisions. AAADAT will pull information from HydroBase to calculate daily lagged impacts of the augmentation plans to the relevant water sources. AAADAT users will have access to web-based tools to upload to HydroBase the components from their augmentation plan necessary to make this possible, including daily diversions for lagged impact structures (recharge ponds, wells, etc.), lagging functions, and historical lagged impacts.

GROUNDWATER LEVELS IN THE ALLUVIAL AQUIFER

Key Points

- The HB1278 study conducted two independent analyses of groundwater level data – one by Colorado State University (CSU) and one by the U.S. Geological Survey (USGS). Concurrently, the Colorado Division of Water Resources (DWR) implemented a detailed groundwater monitoring program in Sterling and in the Gilcrest/LaSalle areas.
- The typical annual cycle of water level fluctuation observed was that the water table is generally at its highest in the fall and lowest in the spring. During the winter, the river serves as a drain lowering the water table built up from seepage during the previous irrigation season.
- Localized high groundwater levels have been reported in the basin going back to the early 1900s, and at one time, there were a number of drainage districts in the S. Platte to keep fields from waterlogging.
- Water level data from 1953 to 2012 indicate approximately 28% of groundwater levels recorded during the 60 year record show conditions of high groundwater, as defined by a depth to groundwater below land surface of less than or equal to 10 feet.
- Groundwater levels in wells having significant trends appear to have been mostly in a state of decline for five decades from 1953-2002. Since 2002 there has been a reversal in groundwater levels where about 89% of wells indicate rising groundwater levels.
- As a part of the HB1278 study, the USGS developed a proposed optimum groundwater monitoring network to enable better understanding of groundwater reaction to water management in the basin. The proposed monitoring network is intended to provide a foundation for informed decision making and hydrologic analysis.

Prior to the development of irrigation, the S. Platte River was reportedly an intermittent stream that was often dry during late summer. As irrigation became widespread by the late 1870s, the river became a perennial stream, as the riverbed lies below what became the new water table. USGS Water Supply Paper 1378 (Bjorklund, 1957) mapped groundwater levels in basin. The study began in 1947 and was published in 1957 using data derived from 189 observation wells, 62 of which were from the CSU network established by W.E. Code. Drilling logs were obtained for 1,767 additional existing wells. Water Supply Paper 1378 reported that the alluvium varies in thickness from a foot at the edge of the valley to 293 feet deep. The water table in the basin generally slopes diagonally downstream and toward the river. Groundwater discharges to the river, making it a gaining stream for most of the year and for most of the distance downstream of Denver to Julesburg. During low flow periods, virtually all of the streamflow is groundwater baseflow to the stream. Coarseness and thickness of alluvium and the underlying bedrock surface and slope affect the water table depth and flow vectors. Lack of uniformity of bedrock and overlying alluvium are reflected in the variation of water table shape and slope.

The Bittinger 1968 progress report stated that long-term observation well records collected by CSU showed a stable water table over the 35-year period from 1933 to 1968. The typical annual cycle of fluctuation observed was such that the water table was generally at its highest in the fall and lowest in the spring. Bittinger (1968) concluded this pattern indicated that surface water additions from ditches, reservoirs, and irrigated fields during the irrigation season exceeded the net withdrawal of water from wells at that time. During the winter, the river serves as a drain lowering the water table built up during the previous crop season.

The water table is not a stationary surface but rises and falls with recharge (from irrigation, canal and reservoir seepage, precipitation) and discharge (withdrawal by pumping and baseflow). In parts of the basin, such as Prospect Valley, Bijou, Badger, and Beaver Creek drainages, the water table is lowered during the pumping season and recovers in the off-season. In areas that are chiefly watered by canals, such as between Brush and Sterling or near Goodrich and Weldona, the water table rises during the irrigation season and declines during the off-season as it drains back to the river. Periods of above average precipitation may cause local water table rises, while periods of drought generally cause it to decline. Heavy pumping in Bijou, Beaver, and Kiowa drainages has caused a long-term trend of declining water levels that appears different than most of the other reaches of the S. Platte and its tributaries.

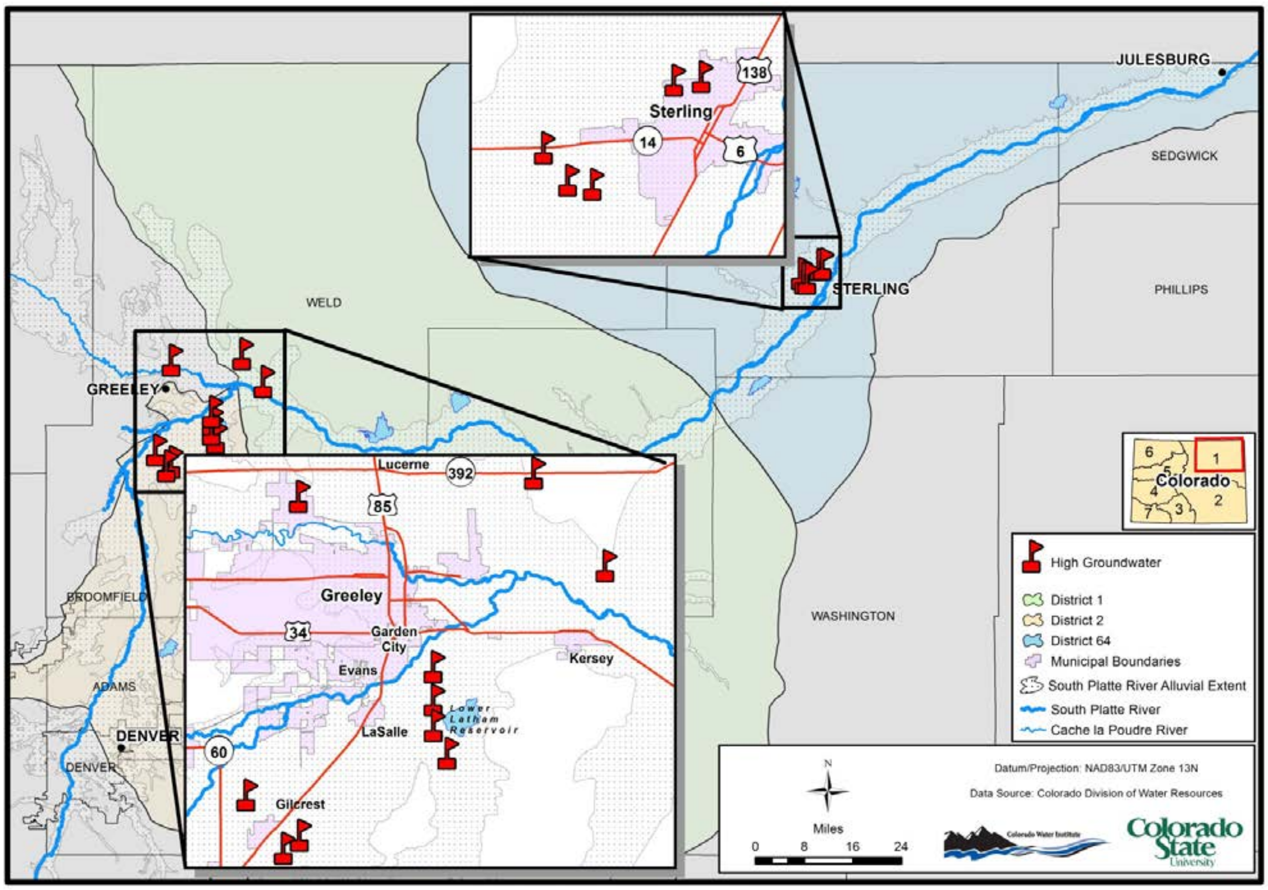
An argument can be made that we have already conducted a basin-wide experiment on the S. Platte. Large volumes of groundwater were pumped from the 1930s to 1972 without augmenting depletions. We partially augmented depletions from 1972 to 2002, as many wells operated under GASP and CCWCD's SWSPs during the period of the gentlemen's agreement with reduced calls. We moved into the period of full augmentation and curtailment of wells lacking court adjudicated augmentation plans following the Empire Lodge Case and the drought of 2002 and corresponding increase in the number of days of call on the river. The question arose as to whether we can detect the impact of these three periods in the groundwater level records.

The ability to detect and interpret changes in groundwater levels is essential for sound management of groundwater resources (Scanlon, Healy and Cook, 2002). Most trend detection techniques operate on the assumption that groundwater trends are linear or best represented by short linear segments. In general, it is difficult to detect statistically significant trends for periods shorter than a decade. As groundwater levels change, the area of groundwater discharge may also change, dynamically feeding back and altering the trend rate of change. While the short-term trend of groundwater may be linear, long-term trends of rising groundwater may be observed that are nonlinear. Three types of long-term trends may be observed according to Ferdowsian and Pannell (2009):

1. A rising trend that flattens out over time (curvilinear). In these cases as groundwater levels rise, the hydraulic gradient and the rate of flow discharge both increase. The result is that the rate of groundwater rise decreases over time.

2. There are cases where the long-term trend is linear. This usually occurs in regional aquifers that have relatively higher recharge to discharge ratios, very little hydraulic gradient to generate significant flow, and groundwater levels that tend to be well below the surface.
3. Occasionally, we may observe an increasing rate of groundwater rise that is nonlinear. In these cases, localized groundwater will rise until the area of discharge has increased or groundwater finds a convenient flow path to spill into the lower part of the aquifer.

Although the S. Platte alluvial aquifer contains an estimated 10 MAF of stored water, the volume is not the key consideration in sustainable utilization of the aquifer. It is the hydraulic head that drives the flux of water to river that matters most for sustaining groundwater levels and surface flows over the long-term.

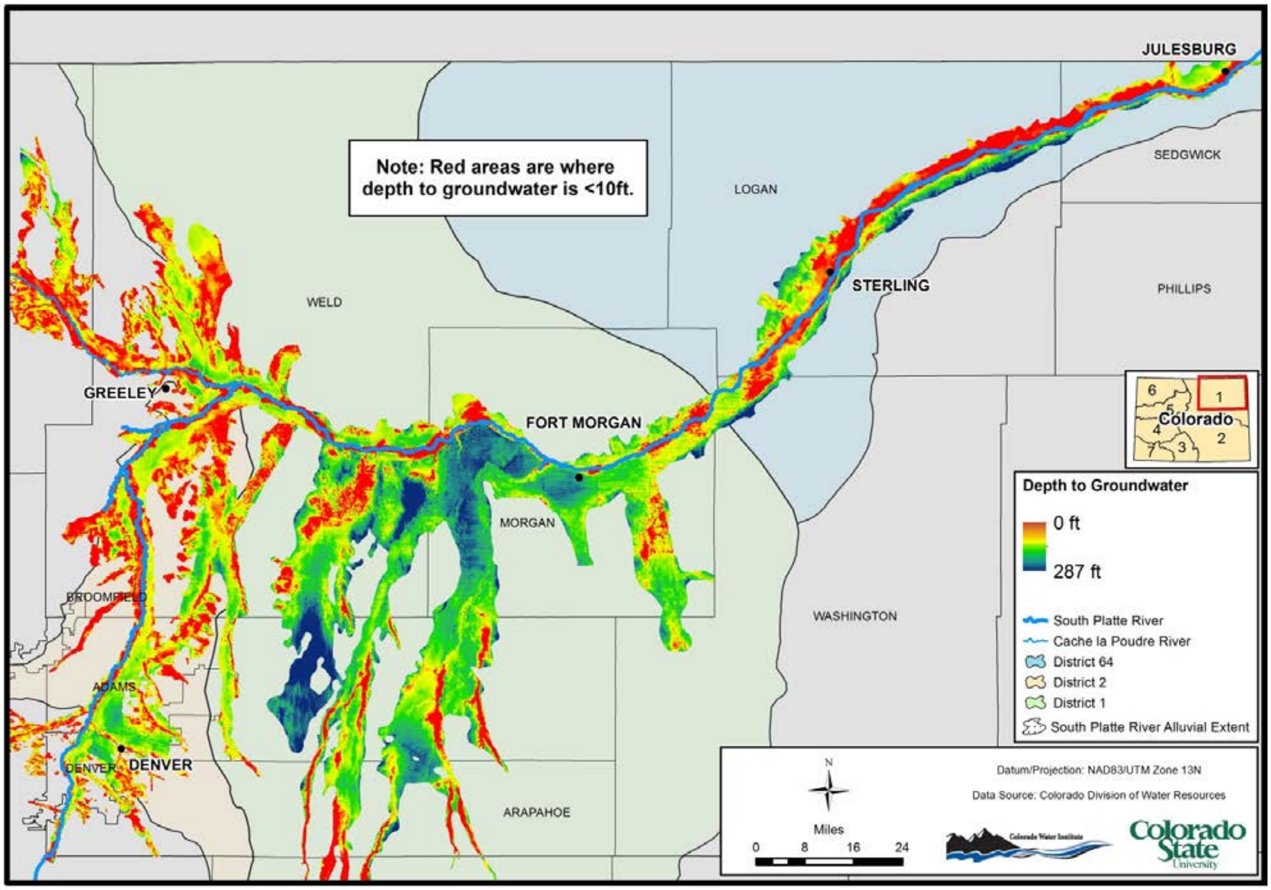


Map 9. High Groundwater Locations Self-Reported by S. Platte Stakeholders.

Observation Well Data

The HB1278 study conducted two analyses of groundwater level data – one conducted by CSU and an independent analysis by the USGS. Concurrently, the Colorado Division of Water Resources (DWR) implemented a detailed monitoring program in Sterling and in the Gilcrest/ LaSalle areas. The USGS and DWR studies are detailed later in this section. CSU's analysis utilized publicly available data from six groundwater observation networks that are currently active in the basin. These include: CCWCD, CSU, Colorado Division of Water Resources (DWR), SPDSS, USGS National Water Quality Assessment (NAWQA), and the Lower S. Platte Water Conservancy District (LSPWCD).

We obtained data for each of these six networks and checked it in detail to determine if there were missing values, duplicates or values that needed verification. In addition, at public meetings and via the media, we asked stakeholders in the basin to self-report on our website and via paper forms handed out at public meetings to tell us where they were experiencing adverse impacts of high groundwater such as waterlogging and flooded basements. The self-reported impact results are shown in Map 9 above and are consistently in vicinity of Greeley and Sterling. Localized high groundwater levels have been reported in the basin going back to the early1900s and at one time there were a number of drainage districts in the S. Platte to keep fields from waterlogging. High groundwater and adverse impacts were not explicitly defined in HB1278 and are a subjective determination, depending on site and use. We used a depth to water below land surface of 10 feet or less to delineate high groundwater levels based on discussions with our academic colleagues and the Colorado Division of Water Resources. Map 10 below shows approximate depth to the water table calculated by subtracting groundwater elevation data in the SPDSS from surface elevation and reveals many areas where groundwater reaches within ten feet of the surface.



Map 10. Calculated Depth to Groundwater in the S. Platte Alluvial Aquifer.
Data Source: The depth to groundwater raster file was created by subtracting groundwater elevation (raster file qalw1106r27) from surface elevation (raster file qalgs1106). Both qalw1106r27 and qalgs1106 are from the CDSS Division 1 GIS data site found at http://cdss.state.co.us/GIS/Pages/Division1SouthPlatte.aspx. All data is from November 2006.

The six groundwater observation networks shown in Map 11 include:

CCWCD Network

- 154 wells (138 irrigation and 16 dedicated monitoring)
- Most of them have a span of measurements from mid 1990s to present. Some observations go back to the 1930s and 1940s
- Well level measurements were provided by CCWCD staff as an Excel spreadsheet
- HB-1278 staff reviewed the data with CCWCD personnel in order to rectify any discrepancies

CSU Network

- 150 irrigation wells (109 listed with CSU as data source in HydroBase)
- Most of the wells have a span of measurements from the early 1960s till present. Some of the observations go back to the 1930s and 1940s
- Well levels were queried from HydroBase version 20130710 and field notes

DWR Network

- 58 wells in total, of which 4 are dedicated monitoring wells and 54 are irrigation wells
- Well levels were queried from HydroBase version 20130710
- The majority have measurements beginning in 1940s through the 1960s
- Some overlap with the CSU and CCWCD networks

SPDSS Network

- 38 dedicated monitoring wells with continuous data loggers that are within the area of study. Of these, at least 21 wells represent the alluvial aquifer in the S. Platte mainstem, 4 are associated with gaging stations, while several of the other wells may not be representative of the alluvial aquifer for various reasons.
- Well levels were queried from HydroBase version 20130710
- The majority have measurements spanning 2003 or 2004 till present

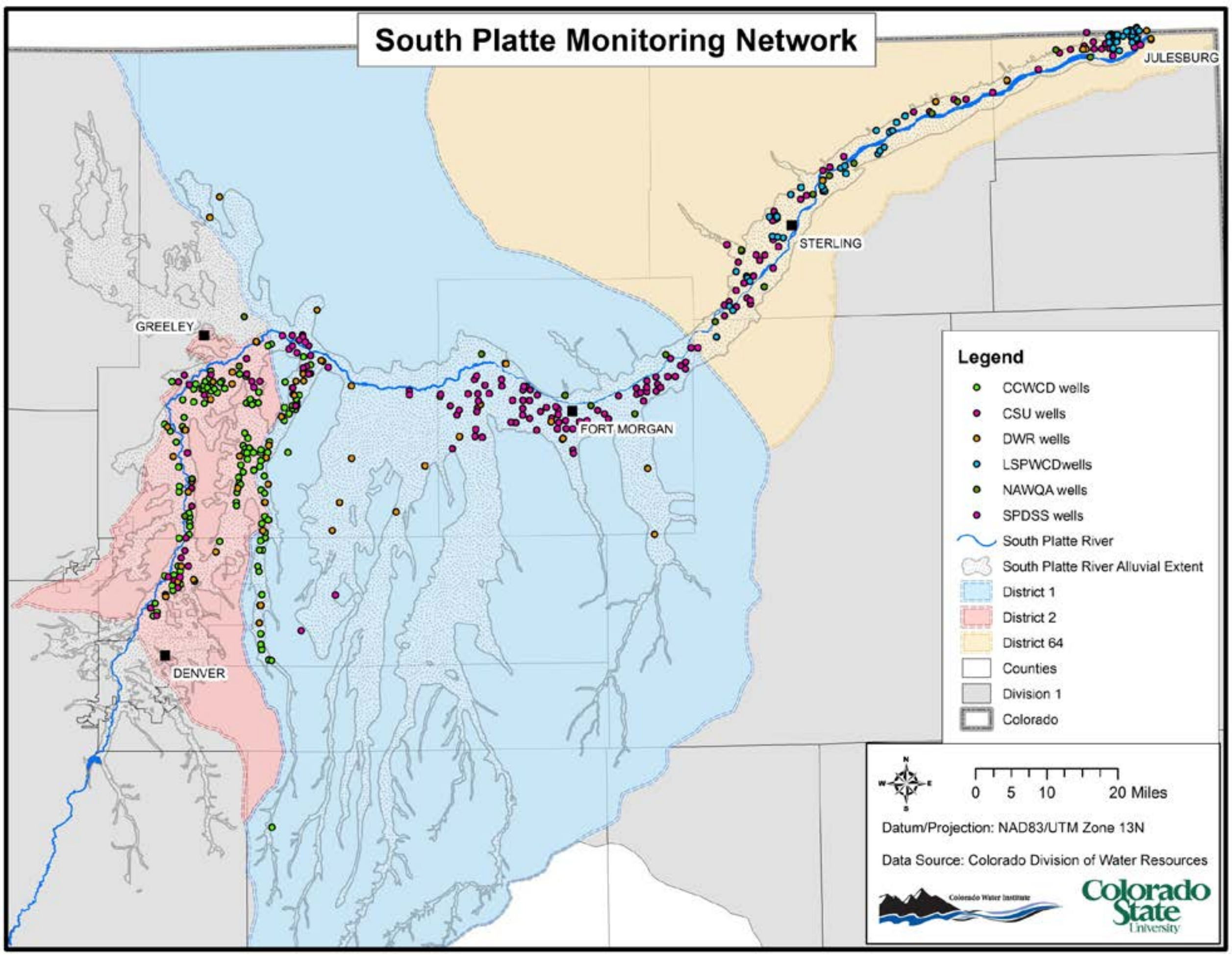
USGS NAWQA Network

- 19 dedicated monitoring wells (5 completed in Denver Basin) as part of the USGS National Water-Quality Assessment Program
- Well levels were queried from HydroBase version 20130710
- The majority have measurements spanning 1994 till present

LSPWCD Network

- 82 wells (33 in Julesburg, 39 in LWU and LLWU and 10 in Pawnee Ridge)
- 26 are dedicated monitoring wells, 19 are irrigation wells, 20 are recharge structure monitoring wells, and 17 of unspecified type
- Well levels were queried from LSPWCD Excel spreadsheet
- HB-1278 staff conferred with LSPWCD personnel in order to verify and avoid some discrepancies in the data
- The majority of Julesburg wells have measurements after 2002
- The majority of LWU and LLWU wells have measurements after 2006
- All the wells in Pawnee Ridge starting measuring after 2009

In general, while the spatial extent of the nearly 400 observation wells in the six groundwater level monitoring networks covered the mainstem of the S. Platte, they were not aligned temporally in terms of the period of record nor the number and frequency of observations, making it difficult to easily draw inferences across the six networks. Additionally, the network had spatial and temporal data gaps (some very large) as well as missing and duplicate observations that had to be reconciled and dealt with. Only the irrigation wells in the CSU, DWR, and CCWCD networks had records that reached back prior to 1969. Irrigation wells provide the least reliable data, particularly when sampled only once or twice a year, as individual observations are likely to be skewed by recent pumping, recovery and recharge. In spite of these limitations, the six observation networks provide valuable data on water levels in the basin over time. Due to space limitations, the observation well data and hydrographs are housed in Appendix III to this document and online at http://www.cwi.colostate.edu/southplatte.

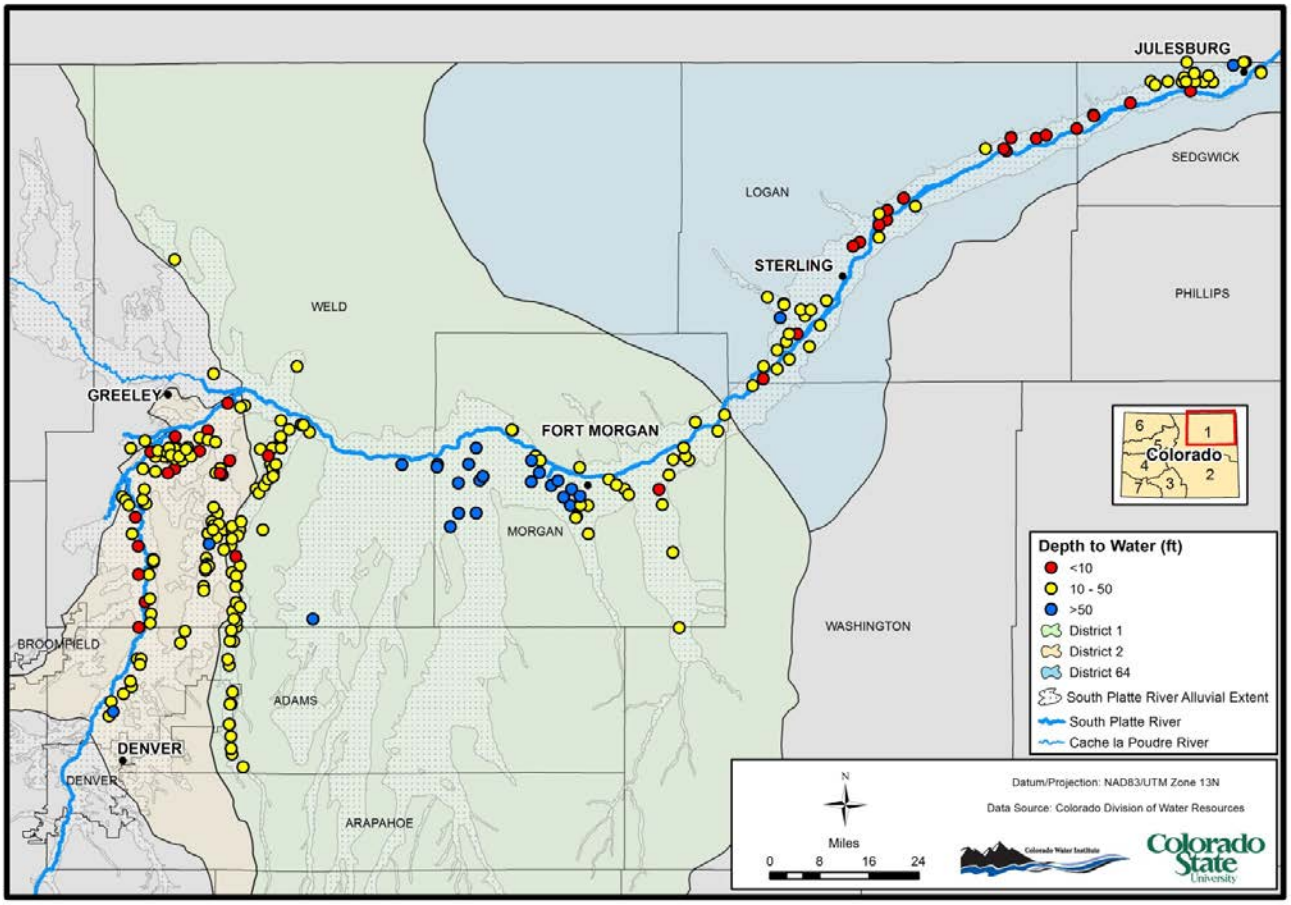


Map 11. Location of Observation Wells in the Six Networks Used for HB1278 Study.

Statistical Analysis of Groundwater Levels in the South Platte

A preliminary approach to investigate possible groundwater level changes in the S. Platte was to investigate for monotonic trends in the observation well hydrographs that had been collected from HydroBase and S. Platte water agencies. The wells investigated for trends are part of six major networks, including: the CCWCD network, the LSPWCD network, the DWR network, the USGS NAWQA network, and the CSU network. The wells that were included in the analysis were those that had a consistent record of measurements in the time period of 2000-2012 and at least one measurement in the last two years. The data do not allow for a longer period of analysis due to the lack of systematic measurements during earlier years.

Analysis was performed based on bi-annual (spring and winter) data to determine if systematic trends existed by utilizing the non-parametric Mann-Kendall (Kendall, 1975; Mann, 1945) test with a significance level of 5%. A non-parametric trend test was chosen because the data are not required to follow a normal distribution. The other assumption that Mann-Kendall test requires is that the data are not serial correlated. Serial correlation can influence the accuracy of the Mann-Kendall test resulting in statistical errors (Wang et al., 2005). If the data are not independent the results of the Mann-Kendall are not accurate, resulting in statistical errors. As Wang and Swail (2001) have shown, prewhitened data reduces the magnitude of trend. The method used to avoid this problem was proposed by Zhang et al. (2000) and refined by Wang and Swail (2001) and gives almost unbiased estimates of lag-1 autocorrelation coefficient and slope.



Map 12. Depth to Groundwater Table in the S. Platte River Alluvial Aquifer using latest Measurements from the Six Observation Well Networks.

Data Source: This layer was created by extracting the last water depth measurement for 2012 for each well in the observation well network and characterizing water depth as <10ft (red), 10 – 50ft (yellow), or >50ft (blue) from surface elevation. Water depth and well location data were obtained from HydroBase_20130404.

The interpolated map created from the SPDSS data layers (Map 11) and the result of mapping current depth to water in the observation well network (Map 12) show that high groundwater levels are common in the S. Platte mainstem and tributaries areas. Indeed, high groundwater has been reported for almost a century. The question we sought to answer is whether the trend data indicate a rising water table, and whether this trend could be connected to current management.

Although each observation well network has its own limitations, we attempted to analyze each set of data for recent trends to address the question of whether recent changes in surface and groundwater management were driving groundwater levels upwards, as was required under HB1278. First, it was important to determine whether we observed statistically significant trends in water levels. If this is the case, the secondary question of causation can then be addressed.

The CCWCD network, contained within Water Districts 2 and 1, consists largely of irrigation wells sampled in the spring and fall of the year, similar to the CSU and DWR networks. These wells exhibit unique water level patterns influenced by local conditions, and variation across years and seasons, but a similar pattern visually emerges for many of the well hydrographs. In general, a low point can be observed around or after the 2002 drought, with an upward trend until the drought of 2012 (Fig 25). This is likely due to return of closer to average patterns of snowpack and precipitation between 2003 and 2011, but is also likely influenced by localized well curtailment and increased augmentation, as evidenced in Figure 23 above showing the increase in recharge in the basin over this time period. It is important to note that not all wells exhibited this pattern and in many cases where an upward trend is observed, we did not detect a statistically significant trend. More time and more data will be needed to verify if this trend results in the establishment of a new post-2002 equilibrium, or whether this upward trend will continue. Some wells show that water levels have risen within ten feet of the ground surface, a point at which non-beneficial evaporative up-flux can occur. Additionally, waterlogged soils from high water levels eventually result in soil salinization and lost productivity. The CCWCD observation network included a total of 154 wells, but 18 wells were excluded from our analysis because they did not have measurements the last two years (2011 or 2012). We used a time series of two measurements per year, and the average percentage of missing measurements in the 136 remaining wells was about 32%. Our evaluation indicated that of the 136 wells, 69 wells had no statistically detected trend, 12 wells had a significant decreasing trend (p-value 5%), and 55 wells had a significant rising trend (p-value <5%). Thus, for the CCWCD network, 40% of the wells showed a rising trend over the past twelve years while 50% showed no statistically significant trend.

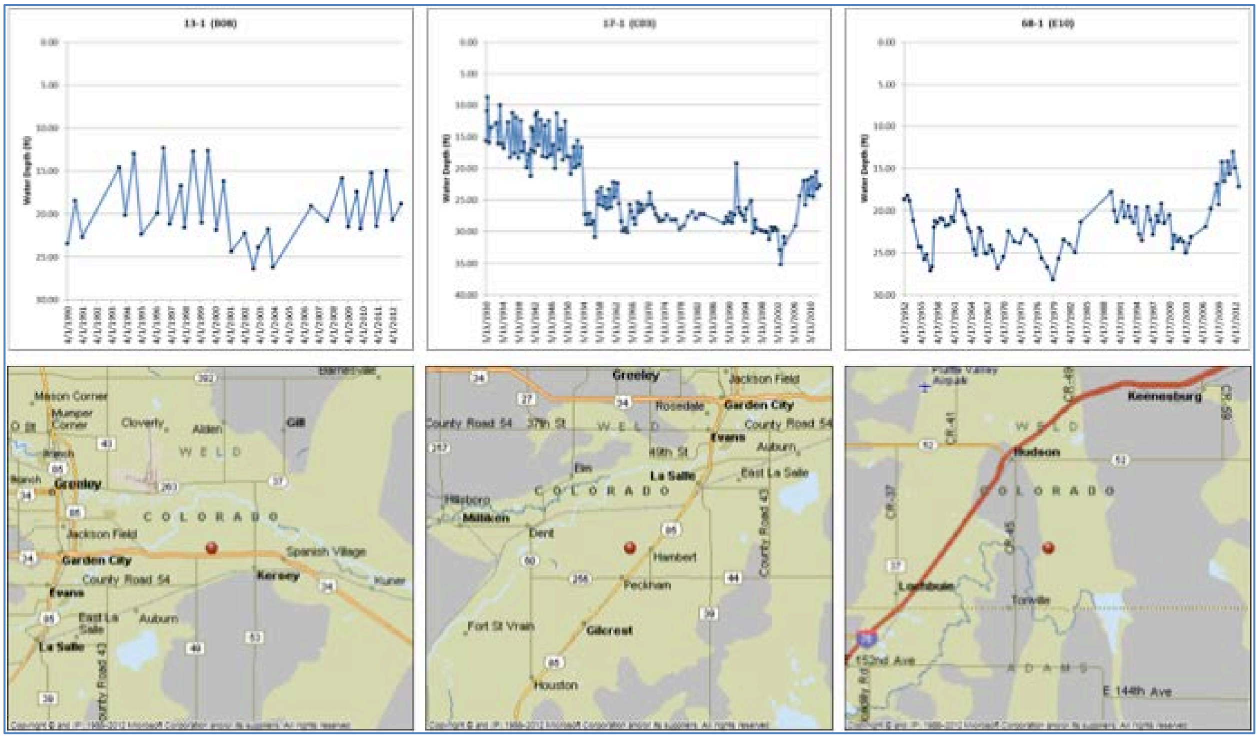


Figure 26. Example Hydrographs for Three Observation Wells in the CCWCD Network.

(All observation well hydrographs can be found in Appendix III to this document.)

Both the DWR and CSU networks, which overlap to a degree, contain the longest record of water levels and thus provide information over a longer period of groundwater development and administration. In reviewing water level data going back to the 1920s, 1930s, and 1940s before extensive development and pumping occurred in the basin, it is apparent that high groundwater levels existed at that time after some 50-70 years of surface water development. Unfortunately, large gaps appear in these records in the 1960s through the 1990s as interest in long-term monitoring waned. Within these networks, visual inspection of the hydrographs appears to show upward trends, downward trends, and wells with no apparent trend, with large intra-annual variation. A post 2002 upward trend can be visually observed within the data for many of these wells, but it cannot be said that they are all at record high levels and that all wells exhibit this upward trend (Figure 26). The DWR observation network contains 58 wells, but only 42 wells were used in trend analysis for the period of 2000-2012. Sixteen wells were excluded because they did not have measurements for the last two years (2011 or 2012). Again the time series used had two measurements per year and the average percentage of missing measurements in the 42 wells was 22.5%. Of the 42 wells tested, 26 wells had no statistically detected trend, two wells had a significant decreasing trend (p-value 5%), and 14 wells had a significant rising trend (p-value <5%). Thus, for the DWR network, 33% of the wells show a rising trend and 62% show no detectable trend for the past twelve years.

The CSU observation well network is the oldest of the six networks, containing 150 wells, but it also has some of the most significant data gaps. Of the 150 wells only 81 were used in the 2000-2012 trend analysis (2000-2012) due to the gaps in the data. The time series used had two measurements per year and the average percentage of missing measurements in the 81 wells was 68.5%. A majority of the CSU wells have a measurement gap from winter 2003 till spring 2009, making our statistical analysis much less powerful. Due to these data gaps we found that 79 of the 81 wells showed no statistically detected trend and only two wells in this network could be shown to have a statistically significant rising trend (p-value <5%) for the past twelve years.

The LSPWCD observation network in Logan and Sedgwick Counties has a total of 33 wells. We were able to construct a time series for 2002-2012 for 31 of these wells. Two wells were excluded because they did not have measurements over the last two years (2011 or 2012). Note that we could not begin this time series with the year 2000, as the wells did not have observations prior to 2002. This resulted in a time series that started and ended with drought. The time series for the wells included had 12 monthly minimum measurements per year with an average of 8.7% missing measurements in the 31 wells. Of the wells included, six wells had no statistically detected trend, no wells showed a significant decreasing trend (p-value 5%) and 25 wells had a significant rising trend (p-value <5%) for a total of 80% of the wells showing a rising trend. Caution is warranted in this evaluation as the data show that shallow observation wells in the basin react to drought and 2002 is a low point in most of the recent data.

The dedicated monitoring wells of the SPDSS network installed by CWCB make up a much more recent network than the CCWCD, CSU, or DWR networks, but provide continuous monitoring of water levels, allowing better understanding of the daily, monthly, and annual patterns as they are perturbed by pumping, recharge from seepage, and drainage back to the river. Many of these wells exhibit a pattern of decline during the spring and summer followed by a rise in the fall as irrigation and ditch seepage returns back to the river and well pumping declines. Several of the wells are in close proximity to the river in areas with very high water tables and show a slight upward trend, as they were installed around 2003. Virtually all of the dedicated monitoring wells across the networks in the alluvial aquifer responded to both wet and dry years, likely reflecting annual changes in natural recharge, ditch diversion amounts, and resulting canal and irrigated lands seepage. Figure 27 below shows an example of both the annual fluctuation as well as the perturbations from nearby high capacity wells during the irrigation season.

Our analysis of the SPDSS monitoring wells utilized 36 of the 38 wells, excluding two wells from the analysis for the period of 2003-2012 because they did not have complete data for the last two years (2011 or 2012). The time series used 12 monthly minimum measurements per year, and the average percentage of missing measurements in the 36 wells was 24.2%. Twenty-four wells had no statistically detected trend, while three wells had strong significant decreasing trend (p-value 5%) and nine wells had strong significant rising trend (p-value <5%), for a total of 25% of the wells showing a rising trend. Due to the period of record for the SPDSS wells it is not possible to know what trends they may have exhibited prior to 2003.

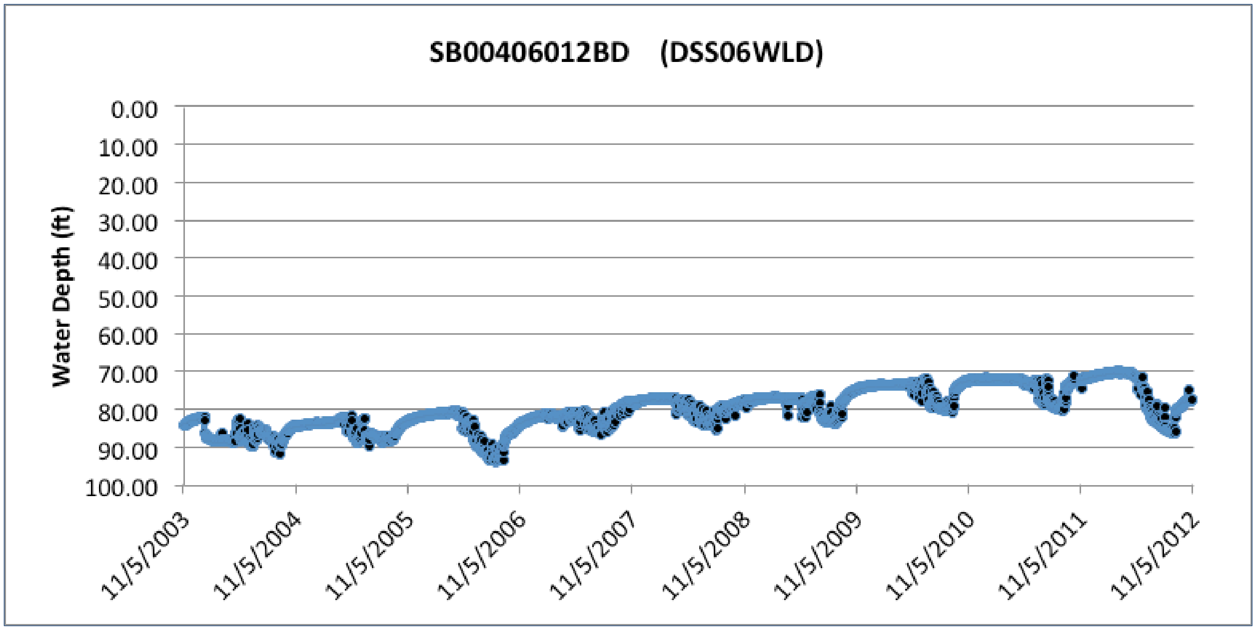
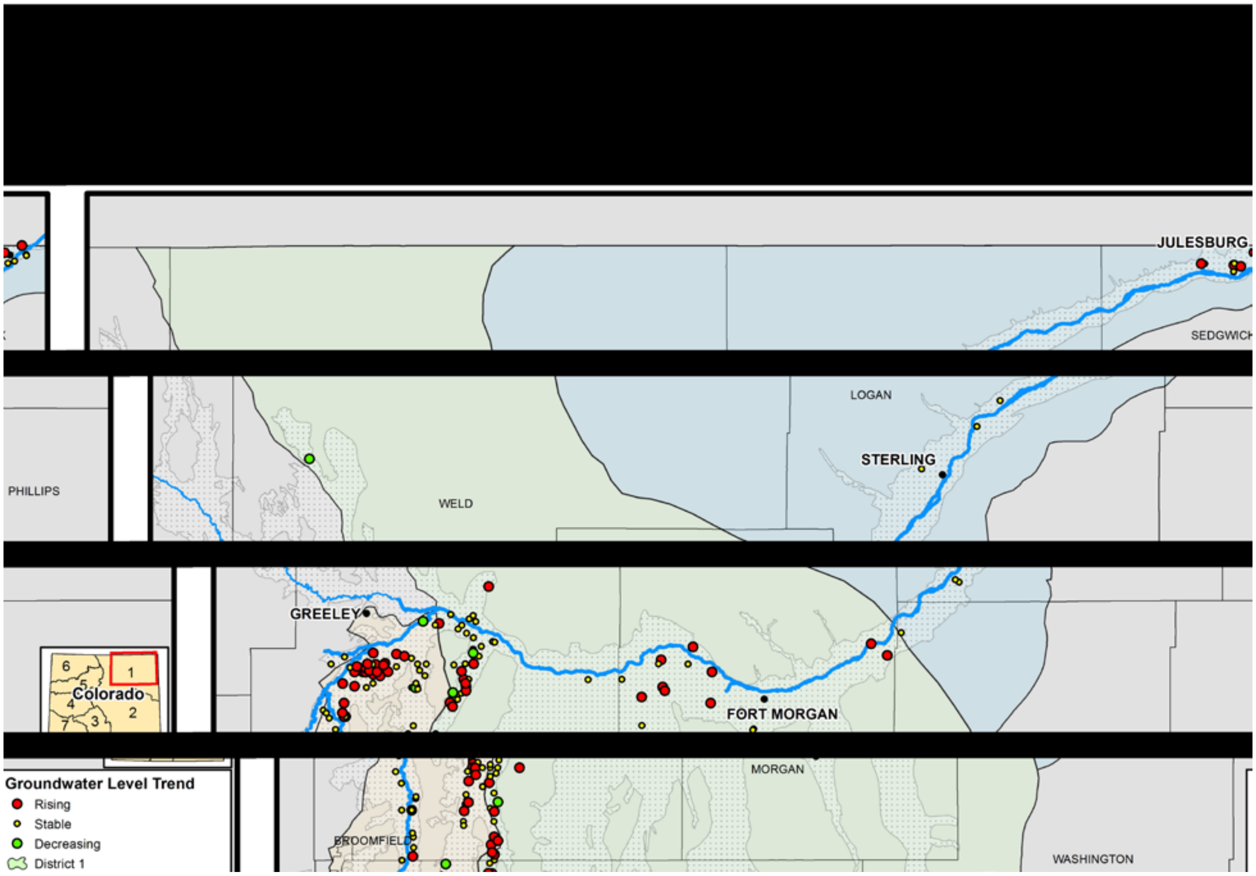


Figure 27. Example Hydrograph for One Continuous Monitoring Well in the SPDSS Network.

The USGS NAWQA network of 19 dedicated monitoring wells was installed in 1994 for the S. Platte NAWQA study. These wells exhibited an upward trend since 1994, but this observation must be taken in the context of a discontinuous record of measurement. Again, these dedicated monitoring wells showed sensitivity to the 2012 drought, particularly in the lower river in Sedgwick County. Given the incomplete period of record for these wells we did not include them in our analysis or on Map 13 below.



Map 13. Groundwater Level Trends Over 2000-2012 for Observation Wells with Complete Records eor rhe Period, Where Red Dots Indicate Statistically Significant Rising Water Levels Over the Past Decade.

The 2012 drought provided a valuable observation year for the HB1278 study, as many observation wells showed a decline that year and did not continue the rising trend observed over the past decade, indicating that unusually large lagged return flows were not in transit back to the river or to unfortunate homeowners' basements, at least on a regional scale. On the whole, the majority of the observation wells either did not have an adequate data record or there was too much noise in the data to detect a statistically significant trend. However, a much greater percentage of observation wells show increased water levels over the recent decade than declining water levels. This is not surprising, as we know this period started at a drought induced low point, and recharge increased at the same time there was an increased reliance on surface water due to well curtailment. Indeed, it would be a surprise if groundwater levels did not react to these changes.

DWR Groundwater Monitoring Pilot Studies

Homeowners in the Sterling area and landowners in the Gilcrest/LaSalle area relayed concerns to state officials about high groundwater levels in 2010 and 2011. Subsequently, the DWR and CWCB have undertaken an effort to compile historical groundwater level data, monitor current groundwater levels, and characterize the hydrogeology within these two areas of interest. The objective of these two groundwater investigations is to identify relationships between the climate, geology, hydrologic conditions, and water management of the area and groundwater levels.

Sterling

In 2011, homeowners in the Sterling area notified state officials of undesirable impacts related to high groundwater levels specifically in the Country Club Hills and Pawnee Ridge subdivisions in Sterling. In response, the CWCB allocated funding for the Division of Water Resources (DWR) to undertake a multi-year project to gather the relevant data necessary to identify the factors contributing to the high groundwater levels in these areas and ultimately to commission an independent analysis and interpretation of the potential causal relationships leading to recommendations to mitigate those impacts. Piezometers were installed in the Country Club Hills and Pawnee Ridge subdivisions and equipped with electronic data loggers that record water levels at hourly intervals. DWR staff have undertaken an effort to monitor groundwater levels; compile climate, diversion, and recharge data; and characterize the hydrogeology within the areas of interest to understand the groundwater system. Preliminary information and data collected from this investigation are updated regularly online at http://water.state.co.us/DivisionsOffices/Div1SPlatteRiverBasin/Pages/GroundwaterSterling.aspx to provide access to the data and keep the stakeholders informed. The study area that encompasses both the Country Club Hills and Pawnee Ridge subdivisions contains a number of recharge ponds and diversion ditches. Seepage from both the ponds and ditches influences groundwater recharge and thus the groundwater levels.

Preliminary review of the groundwater level data collected from the Sterling area piezometers indicates that prolonged rainfall events of several inches or more are required to detect a response in the water table. For example, the resultant recharge effect of 2-3 inches of rainfall during the first week of July 2012 is evident in most hydrographs. The storm of July 19, 2012 also produced a response of the water table. Smaller rainfall events have not produced a hydrologic response that could be correlated. In the Country Club Hills area, groundwater levels vary from approximately 6 feet below ground surface to greater than 27 feet. The overall hydrograph trends are similar between all wells with declining water levels since early summer 2012 through mid-December, then slowly rising or relatively stable water levels. The water level trends at CCN-4 and CCN-1, however, differ. Water levels in those wells fluctuate much more in response to neighboring recharge events like the Country Club Hills recharge pond or flow in the Springdale Ditch. In the Pawnee Ridge subdivision area groundwater levels follow two distinct trends. The hydrograph trends in wells west of the Springdale ditch and north of County Road 30 show declining water levels through end of September 2012 with rising water levels thereafter. These water levels peaked in early May 2013 and have been slowly declining since then.

Groundwater levels in the O'Connell well near Pioneer Park also continued to rise until May 2013, and most recently appear to be stable or declining.

Gilcrest/LaSalle Area

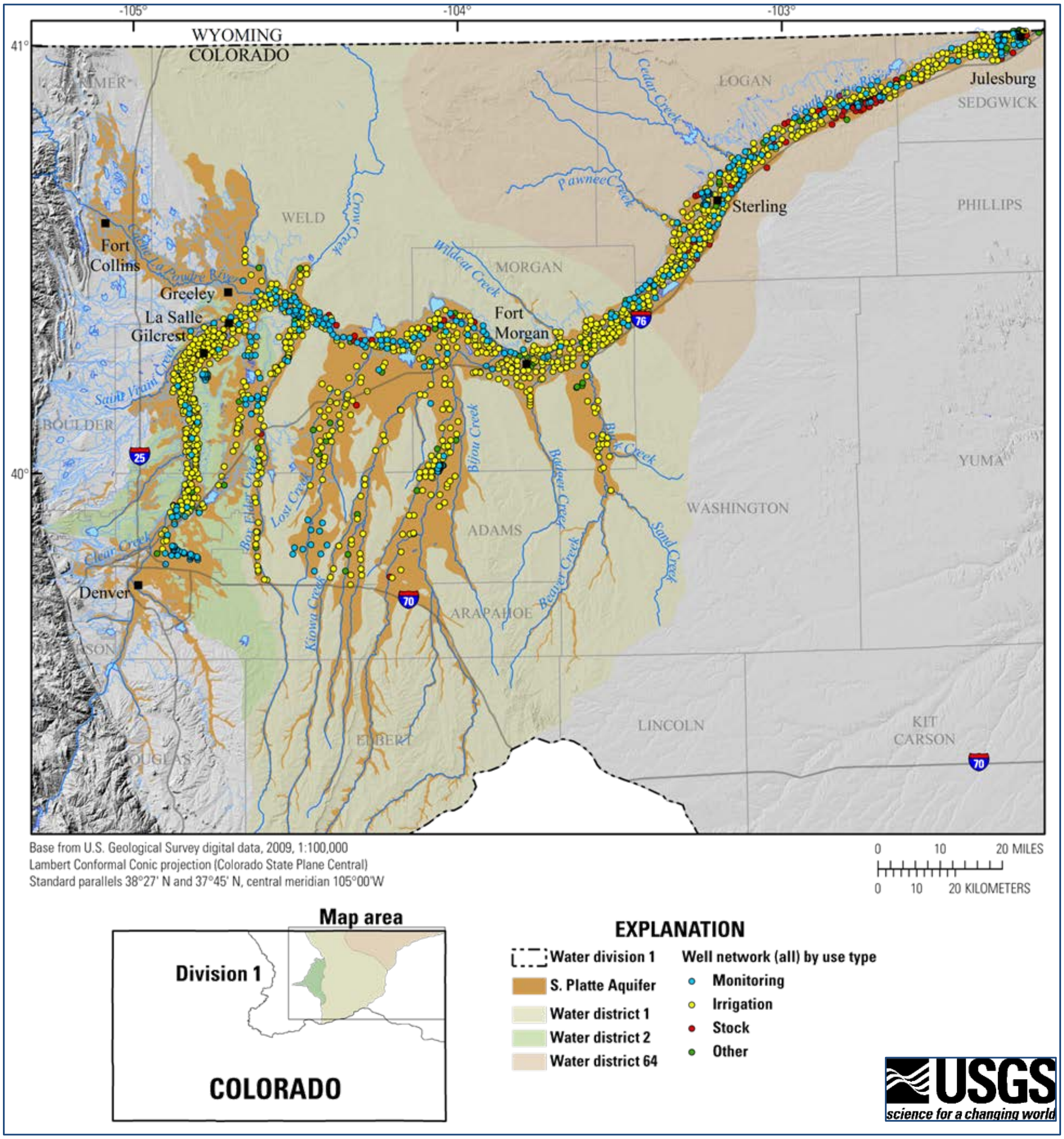
Due to previous work in the Gilcrest area, long-term observation well networks are already installed and available for analysis of groundwater levels over time. The DWR sought to acquire existing water level data and identify wells suited for continued, high intensity monitoring. DWR's approach was to implement a two-year water level monitoring plan and to compile existing aquifer properties data, conduct new pump tests to characterize the hydrogeology of the alluvial aquifer in the area. After the two-year data collection, DWR will contract with consultants to identify causal relationships for water levels and produce a report of findings and recommendations.

USGS Analysis of Groundwater Levels

USGS conducted an independent analysis of groundwater level data for the HB1278 study for the years 1953 through 2012. Water levels were evaluated at point locations (at each well) and over aggregate areas defined by subwatershed boundaries in the study area. Temporal and spatial relations of high groundwater levels were examined using ArcGIS and algorithms developed specifically for this study. Based on results of the analyses, a groundwater monitoring plan was proposed for the basin that accounts for statistical relations and could be used to test potential conditions (or hypotheses) that cause high groundwater levels in the future.

The Kendall line and least trimmed squares regression methods, each resistant to statistical outliers, were used to determine linear trends in observed groundwater levels at 1,670 wells in the S. Platte alluvial aquifer (Map 14). The decision to use two statistical approaches versus a single approach was justified as a way to verify results and identify cases where discrepancies exist, either from artifacts in the data sets or assumptions inherent to the method. The Kendall line is a simple and widely recognized non-parametric method used to fit a linear trend to the data. The slope of the Kendall line is computed by comparing each data pair (time, groundwater levels) to all others in a pairwise fashion. A data set of n data pairs will result in $n(n-1)/2$ pairwise comparisons. For each of these comparisons, groundwater level change is computed. The median of all possible pairwise slopes is taken as the nonparametric slope estimate, and the trend is then applied to a linear fit relation. Least trimmed squares is a more advanced method both mathematically and computationally, and was recently developed for studies in data mining. It involves a criterion for analyzing multiple regression data sets in which there may be outliers. The method consists of finding a subset of cases whose deletion from the data set would lead to the regression with the smallest residual sum of squares. It is used as a general-purpose high breakdown method, and also has some inferential motivation in that it gives the maximum likelihood estimator of the regression under an outlier model. The algorithm takes random starting trial solutions and refines each to the local optimum satisfying this necessary condition.

Repeated analysis by using different starting sets provides the global optimum with arbitrarily high probability for sufficiently many random starts.



Map 14. Complete Set of 1,670 Wells Used for Groundwater Level Analysis Defined by Use Type.

Trend evaluation

To test whether a trend is significant, both type I and type II errors were evaluated. The significance, α, is used to evaluate type I error. Type I error is the probability of rejecting the null hypothesis when it is true. The significance level for the current study was set to a value of 0.01. Type I errors were evaluated using p-values and the Kendall Tau correlation coefficient to evaluate monotonic relations in the groundwater level data. Methods of nonparametric trend analysis such as those based on Kendall's coefficient are widely used to test for the presence of monotonic trends in environmental time series data. The type II error, β, is a measure of statistical power (1- β). Type II error is the probability of failing to reject the null hypothesis when it is false. The power threshold value used to define acceptable accuracy was a value of 0.8, which is commonly used as a minimum threshold in statistical studies. Power cannot be evaluated directly, however, but may be approximated numerically through Monte Carlo simulation (Kulkarni & Von Storch, 1995). Two thousand independent normally distributed time series were generated numerically and evaluated for a range of different sample sizes to estimate Type II errors. Power can be calculated as the number of experiments that fall in the confidence region in relation to the total number of experiments conducted. In the case of power equal to 0.80, this implies 80% of cases meet this criterion. Considering both Type II errors and I adds reliance to rejecting the null hypothesis when it is either true or false, as opposed to considering only Type I error, which is commonly implemented.

In addition to examining for Type I and II errors, trend predictions from the Kendall line and least trimmed squares regression approaches were compared. In about 99% of cases, predicted trends of the 1,670 wells examined showed agreement in trend magnitude within 1ft/yr. A 1ft/yr threshold was used as a metric to identify anomalies in the data. Differences in predicted trends in the majority were substantially less than 1ft/yr in magnitude. For the remaining ~1% of cases, differences in trend magnitudes were greater than 1 ft/yr. In some instances, particularly with small trend magnitudes, the signs of the trends were opposed.

Predicted trends in groundwater levels were ultimately evaluated based on several criteria. These criteria include: (a) Type I and Type II errors, (b) sufficient trend agreement between methods, and (c) sufficient data record over the defined period. For the latter, for a time series to be considered as having a sufficient data record there must be at least 70% data coverage over the evaluated time range (i.e. data range of at least 7 years per 10 year period) and 50% data coverage using bi-annual time divisions (i.e. 10 of 20 divisions per decade must have data observations). For records of groundwater levels that meet these conditions, the average trend estimate between the Kendall line and least trimmed squares regression was used for further analysis.

Multiple tasks related to data compilation, quality control, evaluation, and analysis were performed as components of the project. The study is focused on examining historical groundwater level data from calendar year 1953 through 2012. External data that includes information from various state and federal sources was combined with existing USGS records. Nonfederal sources of the groundwater level data identified include wells managed by: (a) South Platte Decision Support System (SPDSS), (b) Central Colorado Water Conservancy District

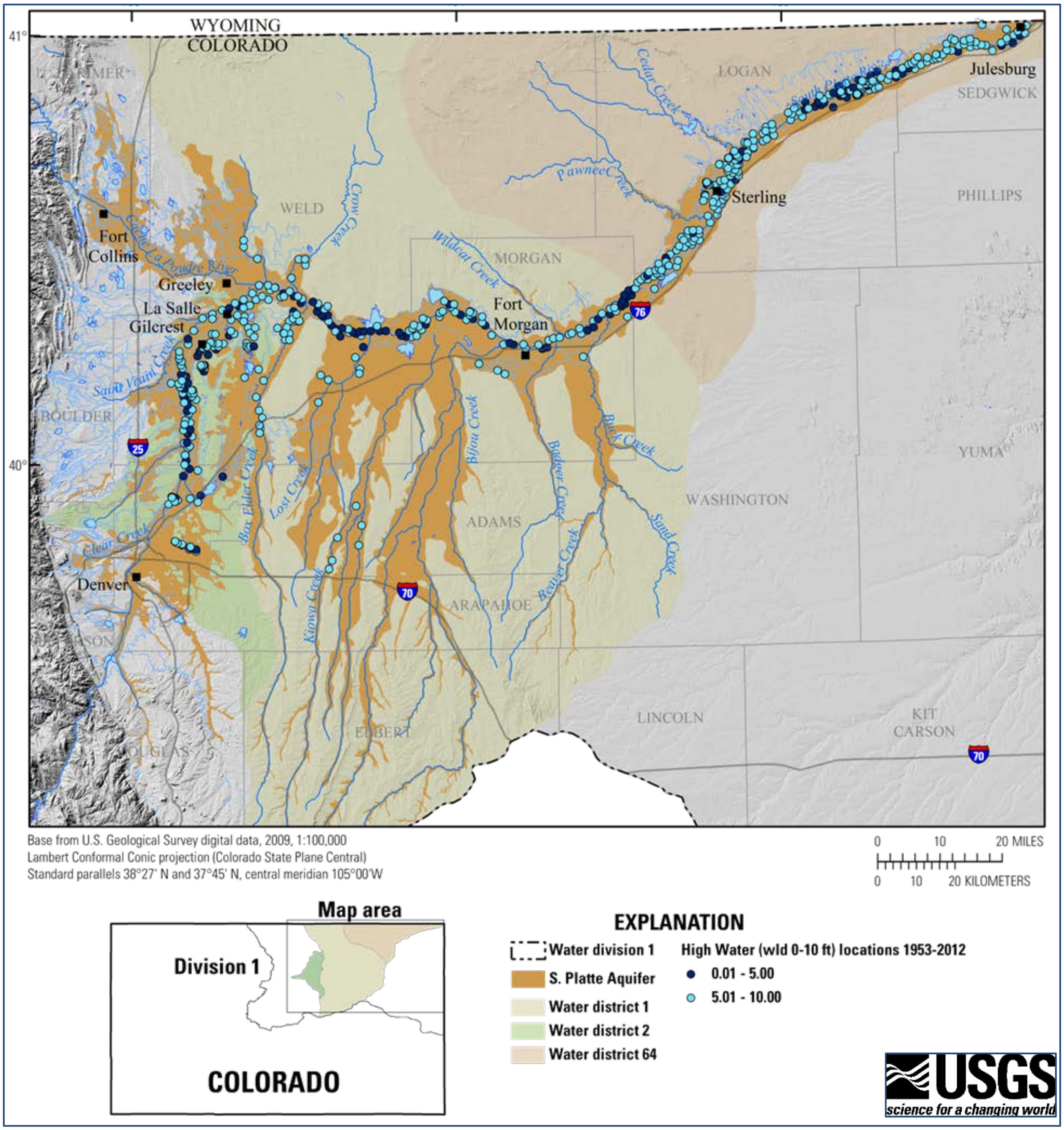
(CCWCD), (c) Lower South Platte Water Conservancy District (LSPWCD), and Colorado State University (CSU), and other agencies and owners. The compiled data set includes 1,670 wells that include more than 150,000 water level observations. An assessment of data completeness, correctness, and coverage both spatially and temporally was used to constrain the analyses of high water conditions that the data can support. Quality-assured data was integrated within ESRI ArcGIS coverages and/or geodatabases either as direct input or embedded metadata. The coverages and/or geodatabases will serve as the primary data archive for the project. Water level monitoring sites and water level data will also be entered into NWIS web (USGS online data repository) to provide public access to groundwater level data.

Summary Statistics for Groundwater Levels

Summary statistics for groundwater levels were calculated by decade and for the complete period of record from 1953 to 2012, for the entire set of 1,670 wells. Data indicate that about 24% of recorded groundwater levels per decade, on average, and approximately 28% of groundwater levels recorded during the 60 year record show conditions of high groundwater, as defined by a depth to groundwater below land surface of less than or equal to 10 feet, with the number of available data varying per decade (Figure 28A and 28B). Near-surface groundwater levels of less than or equal to 5 feet below land surface occur less frequently in about 8% of cases. Overall, there has been an increase in the frequency of high groundwater levels occurring over the last decade to near historic levels observed from1963-1992 (Figure 28B).

The number of eligible well sites suitable for trend analysis by decade varies from 7 to 255. For decades 1973-1982 and 1983-1992 there are relatively few eligible well sites for trend analysis bringing to question the reliability of results for these periods. On average, approximately 14% of wells have validated trends at the decadal time scale (Figure 28C). The most recent decade, 2003-2012, has the highest percentage of wells with significant trends at 33%. Of the 49 well sites suitable for trend analysis for the entire 60-year record, about 60% of them show a significant trend in groundwater levels. Groundwater levels in wells having significant trends appear to have been mostly under a state of decline for five decades from 1953-2002 (Figure 28D). Since 2002 there has been a reversal in groundwater levels where about 89% of wells indicate rising groundwater levels, and the remaining 11% show a decline (Maps 15 and 16).

To examine potential causes of high groundwater conditions in the S. Platte alluvial aquifer, correlations were examined between frequencies of high groundwater levels observed in wells from years 2003 to 2012 and 41 attributes that describe characteristics of the aquifer and diversion structures. Of the 13 geographic attributes evaluated, 9 attributes show statistically significant correlations. Strongest positive correlations were identified for well elevation and the relative position of wells within local subwatersheds and S. Platte alluvial aquifer. In terms of surface water, wells located closer to the S. Platte River show greater frequencies of high groundwater levels, while those closer to tributaries of the S. Platte River show lower frequencies of high groundwater levels. Of the 28 attributes of diversion structures examined, 20 attributes show statistically significant relations. The greatest positive correlations occur for wells or well fields. The results indicate that areas near pumping wells or areas where the decree rate of pumping is relatively high tend to experience lower frequencies of high groundwater levels. Other significant positive correlations occur for reservoirs and ditches, but at lower magnitudes than wells or well fields. The greatest negative correlations to high groundwater levels occur for number of wells, well fields, and augmentation plans. In this case, where there are more structures there tend to be lower frequencies of high groundwater levels.



Map 15. Well Locations With High Water Conditions Within the S. Platte Alluvial Aquifer for the 60-Year Record (1953-2012).

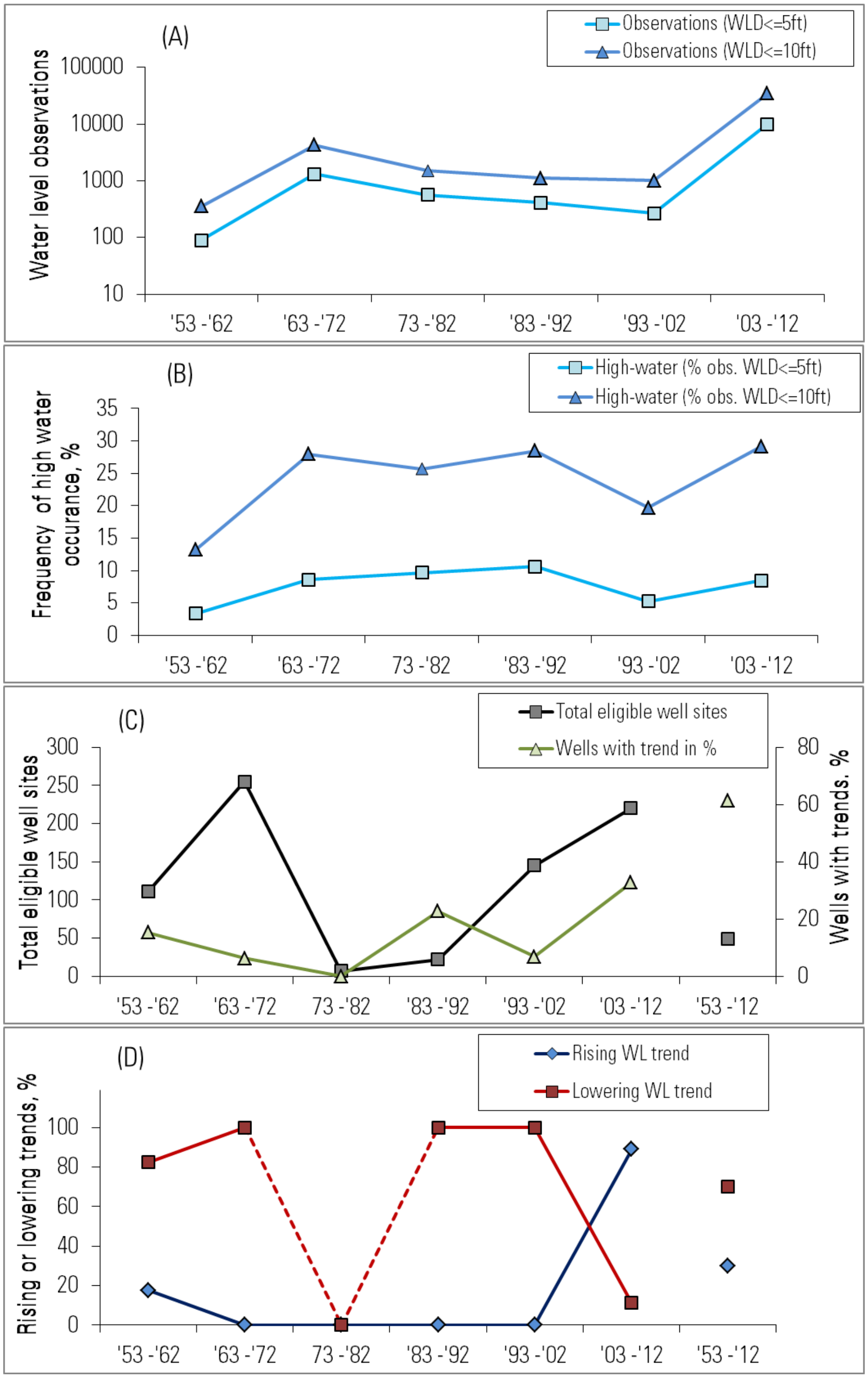
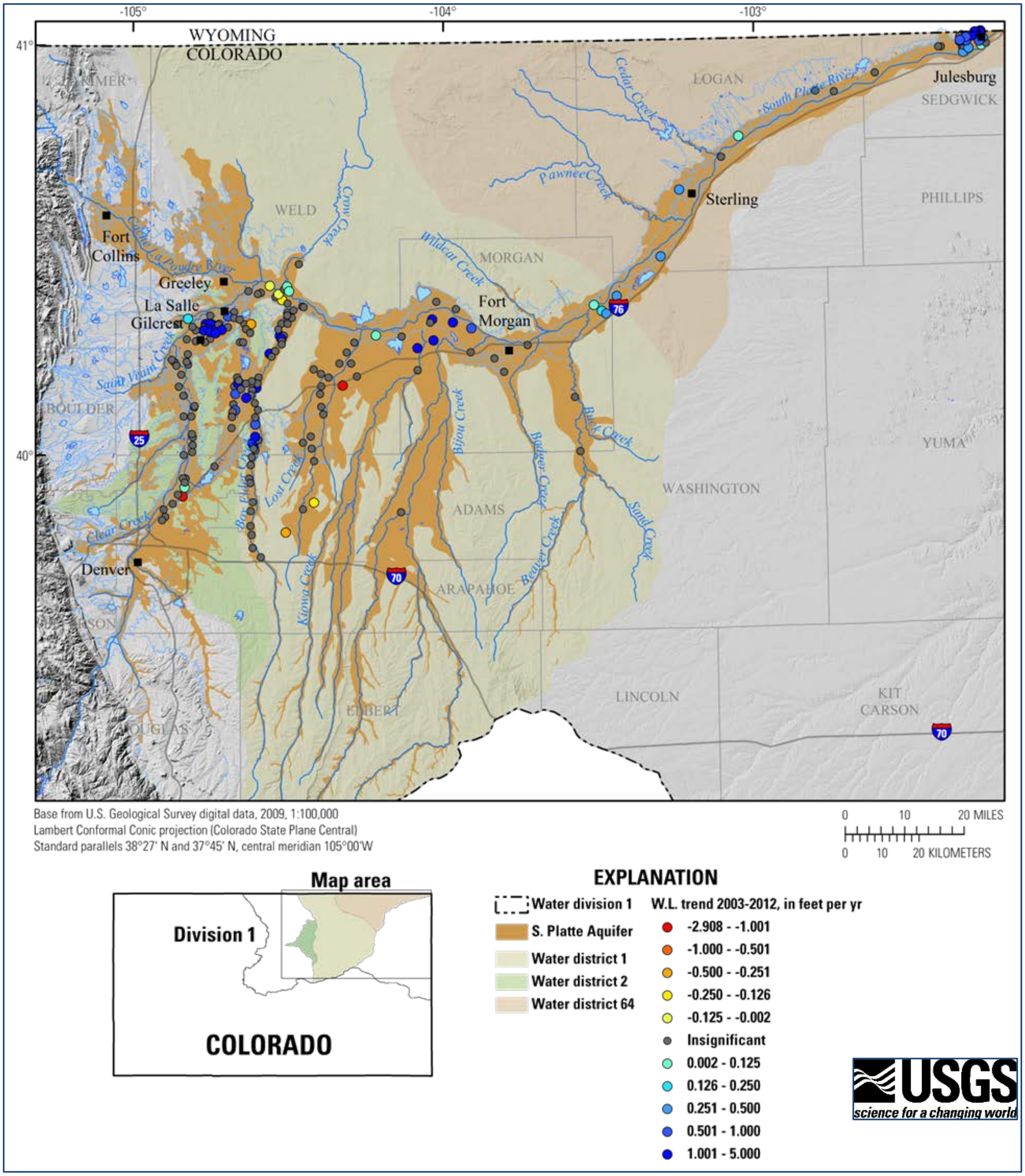


Figure 28. Plots A and B Show the Number of Observations and Frequency of High Water Conditions Given ts Depth To Groundwater of Less Than or Equal To 5 and 10 Feet Below Land Surface, Respectively. Plots C And D Show the Total and Eligible Number of Wells to Examine Trends and the Proportion of Trends Having Rising or Lowering Water Levels, Respectively.



Map 16. Water Level Trends at Wells with Acceptable Records from 2003 to 2012. Positive Values Indicate Increasing Water Levels and Negative Values Indicate Decreasing Water Levels.

Proposed Groundwater Monitoring Network

As a part of the HB1278 study, the USGS developed a proposed optimum groundwater monitoring network to enable better understanding of groundwater reaction to water management in the basin. Groundwater level measurements from observation wells are the primary source of information used to evaluate hydrologic stresses from natural and anthropogenic sources that act on an aquifer. Long-term, systematic measurements of water levels provide essential data that are critical to evaluate changes in the aquifer over time, to develop and calibrate groundwater models, forecast trends, and to design, implement, and monitor the effectiveness of groundwater management and resource protection programs. Ideally, wells chosen for a monitoring well network will provide data that are representative of various physiographic and land-use environments. The primary purposes of a groundwater level monitoring network are to measure (1) ambient groundwater conditions, or the effects of natural, climatic related hydrologic stresses, and (2) other influences on the aquifer that are often societal related.

Because the aquifer resource is important regionally, water districts and other agencies have monitored local water levels and/or water quality at several locations across the S. Platte over certain periods of time with specific goals in mind, often at relatively small scales. Projects conducted by various agencies that measure water levels often involve different objectives, monitoring designs, protocols, and reporting requirements. In some instances, wells used as observation sites are not fully devoted to monitoring groundwater level observations and reflect, at least in part, other influences such as local domestic water use or irrigation. In other instances, as in the case of the South Platte Decision Support (SPDSS) network or USGS NAWQA network, wells are devoted primarily to monitoring groundwater levels and instrumented with transducers for high precision measurements. Although groundwater levels are monitored by several agencies in the S. Platte, at present, there is no single monitoring network sufficient to characterize the water table (potentiometric surface) across the aquifer in its entirety, and there is no network in place that targets the influence of diversion structures on water levels at the same scale. In aggregate, the existing well networks do not have unifying objectives or reporting requirements needed for a comprehensive aquifer water monitoring plan. A regional groundwater level monitoring network was developed to provide a basis for aquifer scale characterization that includes examining potential influences from diversion structures. The network is intended to provide a foundation for informed decision making and hydrologic analysis in future studies.

An optimization approach was used for the design of the monitoring network. The method combines use of Kriging of groundwater level data and evaluation of monitoring well characteristics in the selection process. Kriging is performed on water levels given as depth to groundwater below land surface in order to be most applicable to high water conditions defined as levels that are less than or equal to 10 feet below the land surface. The Kriging procedure first requires de-trending the data to achieve second-order stationarity and performing variogram analysis to estimate a model variogram, which is then used in the interpolation procedure. Kriging variance is a product of the interpolation and can be interpreted as a measure of uncertainty (error). It is used to evaluate the benefit of incorporating a candidate monitoring well into the monitoring network design. Wells considered for monitoring ambient “unstressed” groundwater levels are ranked as a combination of the importance of the location in the Kriging process and relative degree the well is located in a low-stress area of the aquifer with fewer anthropogenic influences that may influence hydrologic conditions. Wells targeted for other purposes are ranked as a combination of the importance of the well location and relative rank of a site for the intended goal using a defined set of criteria. Partially weighting well location in the selection procedure to a sufficient degree in addition to considering defined criteria helps to disperse selections of monitoring wells across the aquifer extent, which is desirable for a representative sampling of the aquifer.

Decisions in selecting monitoring well candidates are defined according to the intended purpose of the network. The main “unstressed” network of monitoring wells will be used for sampling water level trends and surveillance. This network was developed by considering well location in the Kriging process and the degree that a well site may be affected by diversion structures, which can affect hydrologic processes and introduce artifacts into the data set. Again, weighting interpolations of water levels along with the primary constraint, e.g. avoiding diversion structures, is beneficial to limit or prevent the selection of wells in isolated clusters and to better sample across the aquifer extent, depending on the weighting that is used. The second type of network developed targets wells with high-water conditions and those that show strong trends in water level change over the last decade. This entails selecting monitoring wells that are useful with respect to their location in delineating water levels and have greater frequencies of high-water conditions or water level change over the last decade. The third type of network targets the effects of diversion structures. This entails selecting monitoring wells that are useful with respect to their location in delineating water levels and prioritizing wells in close proximity to diversion structures and/or areas with high average decree rates of all diversion structures in the local neighborhood where there is the greatest potential to affect water levels, herein defined as structures within a 10 km radius from each well location.

Ranking criteria are used to evaluate the candidate pool of monitoring wells and optimize the design of the intended monitoring networks. This was done in a manner that balances the importance of well location as determined by the Kriging variance at each iteration of each selected well location as a metric of uncertainty along with other defined criteria, as described. For simplicity, attributes considered in selecting monitoring wells are normalized over the interval 0 to 1. This ensures that the proportion of weight (importance), ω, given to each attribute is defined as intended. The associated weights and group-normalized attributes using multiple criteria are used to produce ranks that also made to range over the interval 0-1. The highest rank under the proposed convention indicates the best candidate well in the candidate pool.

Rank coefficients are used to select monitoring well candidates for the unstressed monitoring network (unstressed), structural target monitoring networks for each diversion (div), and hydrologic target monitoring networks emphasizing high groundwater levels (HW) and trends in groundwater levels.

Monitoring Network Design Components

Unstressed Subnetwork

The unstressed component of a monitoring network includes monitoring wells that provide data from unstressed (or least stressed) parts of an aquifer. Under optimal protocols and design the unstressed subnetwork ensures that a consistent group of wells is regularly monitored to generate water level data from areas of the aquifer reflecting ambient conditions. It is, however, expected that total network-wide isolation from land use, diversions, and development is not absolutely possible. In practice, "unstressed" regions are those that either have limited stress or have been least affected by human activities.

Targeted Subnetwork

The targeted component of a monitoring network includes monitoring points that provide data from aquifers that are affected by human activities of some form. This includes areas that are known to be heavily pumped or have undergone substantial land use change, or those with managed groundwater resources.

Baseline Monitoring

In the event that historical records do not exist, then an initial baseline monitoring period for up to five years is recommended for new monitoring wells to define hydrologic conditions and to account for natural variability. Once baseline data are available, data should be reviewed to determine whether the monitoring well should be assigned to the surveillance or trend monitoring classifications, or whether the baseline phase should be extended. When baseline monitoring is completed, wells are available for surveillance and trend monitoring. Over time, as conditions change, wells should be critically evaluated to assure they remain in the proper subnetwork.

Surveillance Monitoring

Surveillance monitoring is used to periodically report on the overall water level conditions in the aquifer at a point in time. Surveillance monitoring can be thought of as a periodic census of groundwater levels across the aquifer extent. It may not be possible to regularly monitor all surveillance wells due to cost limitations, but an aquifer census could be taken in a rotating program over different areas. Over time, surveillance monitoring can be thought of as a series of discrete snapshots of aquifer conditions. The frequency of surveillance monitoring generally is much less than trend monitoring.

Trend Monitoring

Trend monitoring requires frequent water level measurements for a manageable number of wells given budgetary constraints and aquifer requirements. A subset of the wells used for trend analyses of groundwater levels are designated as the backbone of the monitoring network. These are carefully selected sites that are fully supported for continued data collection over the duration of the program. Every consideration must be given to continuing the long-term record from the backbone of the monitoring network for a continuous historical record. Measurement frequencies for trend monitoring must be appropriate to determine long-term trends and seasonal variability in water levels at selected locations.

South Platte Alluvial Aquifer Network Design

The proposed water level monitoring network for the S. Platte alluvial aquifer consists of a primary ("unstressed") subnetwork and two secondary ("target") subnetworks. The primary monitoring network will focus on representing the least stressed parts of the S. Platte alluvial aquifer for defining baseline conditions and performing surveillance and trend monitoring. The primary monitoring network requires wells that are less affected by well pumping, diversions, and land uses that affect groundwater recharge. A secondary target-monitoring network (structural target) will focus on potential locations where diversion structures affect water levels. Another secondary target network (hydrologic target) will focus on areas of notable "high water" conditions or those with appreciable changes in groundwater levels occurring over the recent decade (2003-2012). Subnetworks should include a logical subset of available monitoring wells sufficient for the intended purpose. SPDSS and U.S Geological Survey NAWQA wells installed with pressure transducers recording daily or sub-daily measurements were selected as the logical backbone of the primary monitoring network. Well sites suitable for trend analyses include those with water level data recorded on at least a seasonal frequency. Subnetworks for trends or surveillance monitoring may be composed of wells managed by different agencies that will require shared strategies and guidelines for data collection. The term "network-of-networks" can be used to describe combining well networks of difference agencies operated over smaller areas to form an inclusive network. There are also small-scale pilot studies in Gilcrest, La Salle, Sterling, and other areas along the S. Platte alluvial aquifer conducted by the Colorado Division of Water Resources and other agencies that will complement the proposed monitoring network aimed at an aquifer-scale characterization.

Frequency of Groundwater level Measurements

The frequency of groundwater level measurements is among the most important components of a groundwater level monitoring program. Although often influenced by economic constraints, the frequency of measurements should be determined according to the anticipated variability of groundwater level fluctuations in the observation wells and the data resolution or degree of detail needed to fully characterize the hydrologic behavior of the aquifer. Systematic, long-term collection of groundwater level data offers the greatest likelihood that groundwater level fluctuations caused by variations in climatic conditions and groundwater level trends caused by changes in land use or water management practices will be "sampled." Moreover, long-term groundwater level records greatly enhance the ability to forecast future water levels.

Multiple factors considered for the S. Platte alluvial aquifer point to the need of frequent groundwater level measurements. The aquifer is unconfined in most locations and composed mainly of permeable sediment with moderate to large variations in thickness. Each of the conditions examined for the S. Platte alluvial aquifer point toward the need for a "more frequent" data collection program. It is suggested that all monitoring wells selected for the trend network be instrumented with continuous recorders that record water levels at least on a 4-hour frequency, and that accompanying surveillance monitoring in the unstressed network be performed, at least, on a seasonal frequency.

Monitoring Well Candidates

All of the wells considered for the proposed water level monitoring network are completed in the S. Platte Alluvial aquifer. Wells are indicated as dedicated for monitoring purposes either in state or federal data records or were stated as such in personal communication with agencies or affiliate group members of HB1278. The focus on using dedicated monitoring wells is to reduce local influences on the water table such as pumping or artificial recharge. The total pool of monitoring well candidates consists of 397 wells (Table 9 and Map 17). The SPDSS network contains 37 monitoring wells but is not optimized for aquifer scale evaluation, which is apparent by examining that several wells are clustered in proximity to one another at the expense of spatial gaps extending over large areas. There are 15 additional monitoring well candidates managed by the Division of Water Resources in addition to the SPDSS network. The USGS NAWQA network contains 23 monitoring wells dispersed along the S. Platte River and compliments SPDSS well locations in the majority of instances. Both the SPDSS and USGS NAWQA networks have a known construction history, were carefully selected, produce reliable results, and have current data collection programs in place. For these reasons the two networks were considered for the backbone of the monitoring network. Other major contributions to the candidate pool of monitoring wells come from conservancy districts. The Central Colorado Water Conservancy District (CCWCD) has 15 monitoring wells considered in the study, while the Lower South Platte Water Conservancy District (LSPWCD) has 45 wells considered in the study. Additional monitoring wells considered for the unified network include: 15 wells managed by the Colorado Division of Agriculture with recent data records, 2 wells as part of the CSU network, 33 wells with miscellaneous ownership, and 7 tentative wells without a known data history. The majority of monitoring wells considered for the unified monitoring network are used regularly by managing agencies and the level of reliance is considered high. Other wells with miscellaneous ownership and those denoted as tentative possess the greatest uncertainty of accessibility and suitability. The nearest suitable monitoring well from the remaining candidate pool is suggested if a replacement well is necessary. For wells listed as tentative, new monitoring wells may be required or well selections ignored if a viable alternative is not identified. The suitability of the proposed unified monitoring network should be evaluated by direct field reconnaissance and by other means as part of the implementation phase.

Table 9. Monitoring Wells by Agency in the Complete Data Set (Total), Network Backbone (Backbone), Optimized Unstressed Subnetwork (Unstressed Subnetwork), Optimized Target Subnetwork for Diversion Structures (Diversion Subnetwork), and Optimized Target Subnetwork for High Water Conditions or Trends in Water Levels (Hydrologic Subnetwork). "Other" Sites Indicate Miscellaneous Sources With Data and "Tentative" Sites Have No Known Data History and Require Additional Evaluation.

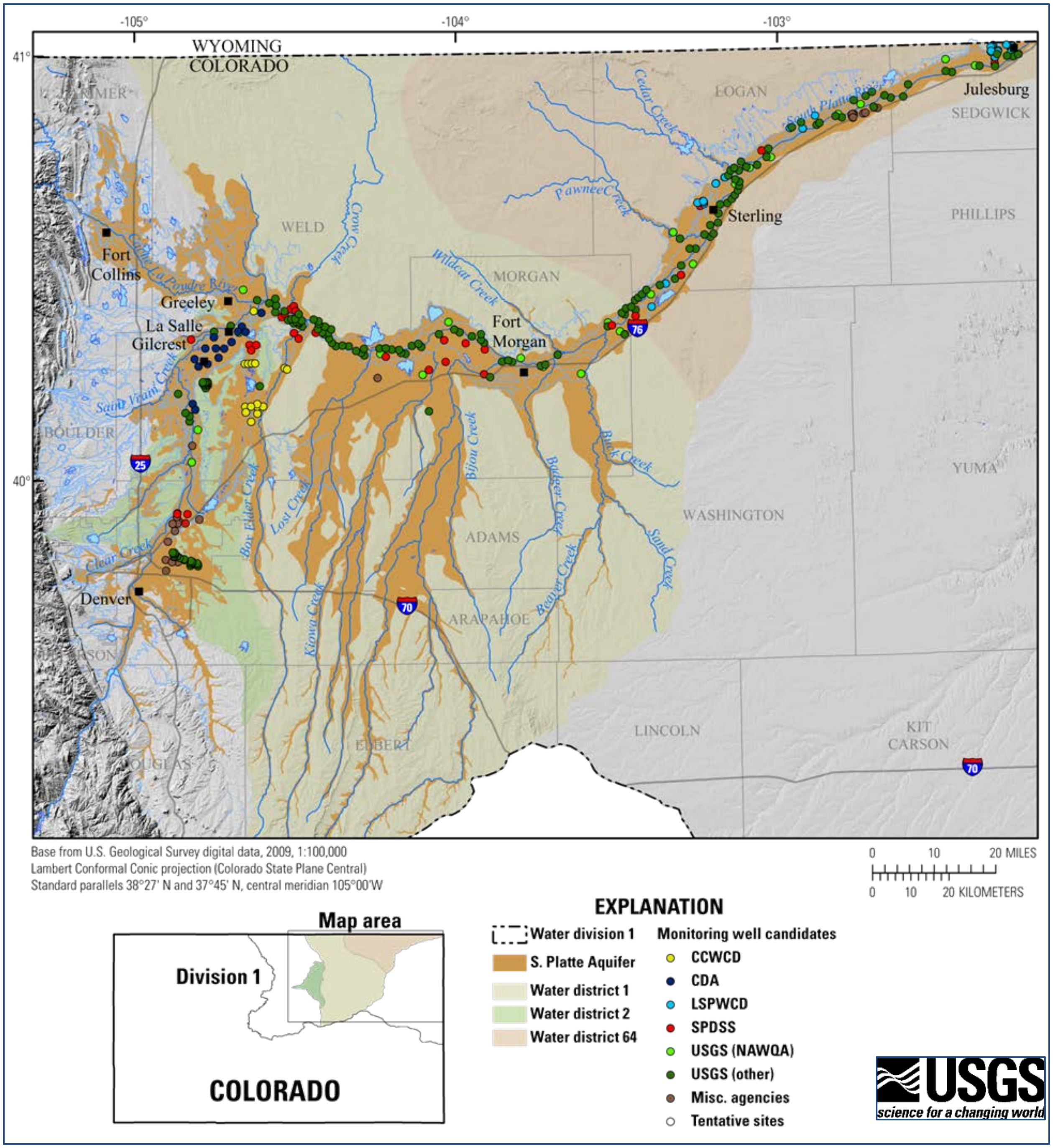
Source Agency	Total	Backbone	Unstressed Subnetwork	Diversion Subnetwork	Hydrologic Subnetwork
CCWCD	15	0	3	5	4
CDA	15	0	2	2	0
CSU	2	0	0	1	0
DWR	15	0	0	1	0
LSPWCD	45	0	1	8	4
SPDSS	37	29	31	7	29
USGS	228	23	46	45	3
Other	33	0	6	11	0
Tentative	7	0	7	0	0
Total	397	52	96	80	40

Monitoring Well Network Optimization

The initial step in optimizing the monitoring network design was to de-trend groundwater level data and approximate a depth to water surface of the S. Platte alluvial aquifer. Ordinary Kriging assumes that non-stationary artifacts (trends) in the data have been removed in order for the underlying mathematical assumptions to remain valid. The complete groundwater level data set with records between 1953-2012 consisting of 1,670 wells (exhaustive data set) used for monitoring, irrigation, domestic, stock, and other miscellaneous purposes was evaluated to approximate a representative potentiometric surface across the S. Platte alluvial aquifer. A broad averaging was viewed as a practical option in this instance given that monitoring wells with different periods of records are considered in the analysis and hydrologic stresses have changed over time. Locally weighted scatterplot smoothing was performed for each well site in the exhaustive data set to first smooth temporal fluctuations in groundwater levels. The data were then spatially averaged and de-trended using a second order polynomial surface layer to make the data field second order stationary. The best-fit exponential variogram model indicates a nugget of 357.4 ft^2 (33.2 m^2), sill of 3,460.6 ft^2 (321.5 m^2), and range of 33,399.9 feet (10,180.3 m, ~10 km) using 30 counts of 3,280.8 ft. (1,000 m) lag steps. The most important of these parameters for the network design is considered the correlation scale (range), which indicates that average well spacing for the designed monitoring network should be substantially less than about 33,400 ft. (~10 km) to enable an overlap in the spatial correlation in groundwater levels between well locations.

Cross validation of kriging estimates of the exhaustive data set was performed on the predictions of water level depth at each well location. Cross validation involves an iterative removal of one data point (well) from the complete data set and using the remaining data to compute an estimate at the location of the removed data point. Residuals between estimated and known values provide an assessment of error in terms of equivalent units of the data and are optimal near zero.

Optimization of the unstressed (primary) monitoring subnetwork was performed using an initial starting network consisting of the proposed backbone where data recording is continuous, sites are reasonably distributed, and measurements are accurate. Initial ranking of proximity to each nearest diversion structure considered in the analysis (reservoirs, recharge areas, ditches, wells and well fields) and average decree rate of structures within a 10 km radius of each candidate monitoring well were used to refine the backbone of the network. By excluding the top 10 monitoring wells per diversion structure category showing the largest potential influences on local water levels from consideration, all 23 USGS NAWQA wells and 29 of the 37 SPDSS wells were chosen to form the backbone. The resulting backbone network is therefore composed of 52 monitoring wells. Design of the unstressed monitoring subnetwork was automated using the starting backbone of 52 monitoring wells as an initial condition and adding wells to the network iteratively. The average Kriging variance was used to evaluate the optimal number of wells that should be adopted. As additional monitoring wells were added to the subnetwork the average Kriging error (uncertainty) in the interpolated water levels was reduced and observed to follow a power-law relation with an R^2 fit of 0.91, which if extended to additional iterations beyond those examined would suggest little benefit is gained from adding additional monitoring wells to the subnetwork (Figure 29). The optimal number of wells was chosen at the 32nd iteration, which is beyond the maximum curvature of the power-law by a few wells at the observed error minima. In total, 84 wells were selected from the automated optimization process. It is noted that 2 additional SPDSS wells were added to the subnetwork because of their ideal locations as determined through the Kriging process bring the total SPDSS wells to 31 (Figure 29).



Map 17. Monitoring Well Candidates for the Unified Monitoring Well Network of S. Platte Alluvial Aquifer.

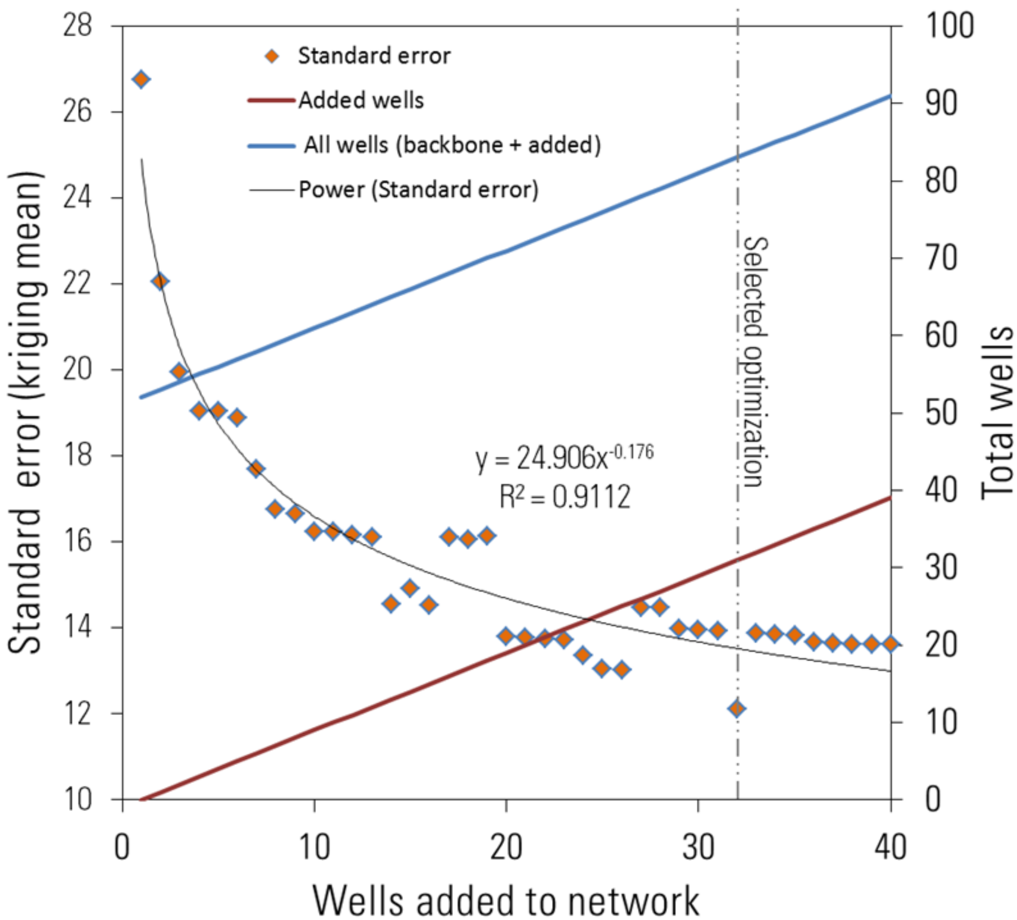
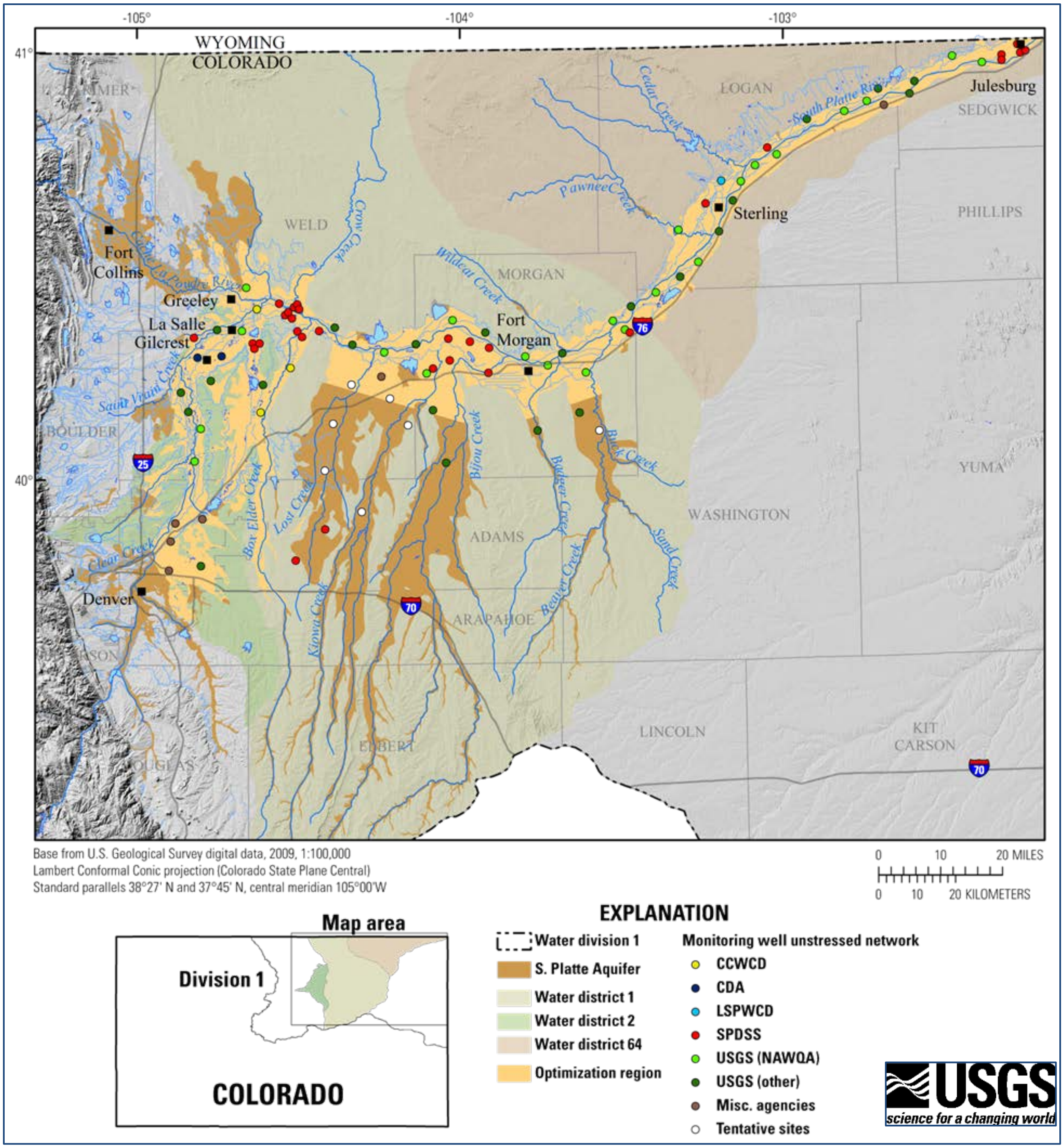


Figure 29. Results from Well Network Optimization Analysis for the "Unstressed" Monitoring Network Showing the Reduction in Average Error (Uncertainty) Achieved by Adding Additional Wells to a Starting Well Network (Backbone) Composed of 52 SPDSS and USGS NAWQA Wells. The Dashed Line Indicates the Stopping Point of Optimization Equivalent to 84 Total Wells Along the Main Stem of the S. Platte River.

Tributaries south of the main stem of the S. Platte alluvial aquifer that reside beyond the optimization region were examined manually. Twelve additional wells were selected in tributaries south of the main stem of the river and adjacent areas within the optimization region where no monitoring wells were located in the evaluated data set. The complete unstressed monitoring subnetwork has 96 monitoring wells dispersed across the aquifer. The network includes wells from USGS, SPDSS, CDA, CSU, DWR, LSPWCD, and other sources demonstrating the need to gather community resources in order to characterize water levels across the S. Platte alluvial aquifer (Map 18).



Map 18. Proposed “Unstressed” Monitoring Network Composed of 96 Monitoring Wells.

The hydrologic monitoring subnetwork includes wells to examine high water conditions or change in groundwater levels using data over the recent decade (2003-2012). During optimization each candidate monitoring well is ranked as a function of location as determined by the kriging process, and either the frequency of groundwater levels or trends in groundwater levels as the second metric. Only sites that meet quality control criteria are used in the analysis. Twenty monitoring wells were identified to evaluate areas with high groundwater and those with appreciable water levels trends. It is recommended that a subset of the proposed well groups be adopted based on direct field reconnaissance to assess additional factors evident from physical inspection of the site. The optimal monitoring wells for each component are dispersed from Greeley to Julesburg along the main stem of the S. Platte River. There are primary groupings of wells identified east of Greeley, La Salle, and Gilcrest and west of Fort Morgan. Other selected wells are more isolated and located mainly between Sterling and Julesburg.

The structural monitoring subnetwork is composed of wells to evaluate whether diversion structures could be affecting groundwater levels. The diversion structures considered in the analysis are reservoirs, recharge areas, ditches, and wells and well fields. During optimization each candidate monitoring well was ranked as a function of location as determined by the kriging process, proximity to diversion structures, and average decree rate within a 10 km radius of the well. Twenty monitoring well candidates were determined for each of four structures (ditch, recharge area, reservoir, and well or well field). It is recommended that a subset of the proposed well groups be adopted based on direct field reconnaissance to assess additional factors evident from physical inspection of the site. The optimal monitoring wells for each component are dispersed all along the main stem of the S. Platte River. There are primary groupings of wells identified midway between Greely and Fort Morgan at the confluence of Lost Creek with the S. Platte River near Riverside reservoir and midway between Fort Morgan and Sterling along the S. Platte River. Locations of wells selected for each structure type are both isolated and grouped. Influences from multiple types of diversion structures appear to occur more frequently at selected monitoring wells, however, as evidenced by data overlap in most regions. Areas with the most potential influence on groundwater levels also vary by structure type. Most monitoring wells identified to examine the effects from wells or well fields occur in the eastern section of the study area, while most monitoring wells identified to examine the effects from reservoirs occur in the western section of the study area. Monitoring wells to examine the influence of ditches and recharge areas are more disperse along the S. Platte alluvial aquifer.

The proposed monitoring plan consisting of the network design and unified data collection strategy should be finalized through future discussion with federal, state and local agencies to provide for an improved foundation to interpret groundwater data from various data-collection efforts in the S. Platte alluvial aquifer. The network will generate an ongoing time series of groundwater levels to evaluate the status and trends of one of Colorado's most important water resources. The network will provide data that can be used to answer questions at a variety of scales, though the primary focus will be on the aquifer scale along with targeted wells being used to examine high groundwater areas in future studies. Establishment of a consistent data collection program and standards of data collection will allow for consistent comparisons between monitoring wells managed by different agencies.

(For more detail on the proposed monitoring network see Appendix XIV to this document.)

STREAMFLOW, DIVERSIONS and RIVER ADMINISTRATION

Key Points

- The annual flow at the Julesburg gage near the state line averages 380,070 AF for the entire period of record from 1924-2012. The average annual flow for the period of 1967-1999 was 589,313 AF. In contrast, the average annual flow for the period of 2000-2012 was 213,446 AF, due mainly to drought conditions in 2001-2008, and 2012, and increased diversions for recharge. Julesburg flow trends over the past decade provide no evidence to indicate reduced water utilization, to the contrary if anything. No statistically significant monthly or annual trend, either positive or negative, was detected in flows measured at the Kersey gage from the period of 2000-2012.
- There are 56 major surface water diversion canals along the mainstem of the S. Platte in Water Districts 2, 1, and 64. The largest change that can be observed in surface water diversions over this period is the post-1969 diversions in the November to March period, when canals are taking water for reservoir filling and augmentation purposes. Comparing mean annual canal diversions for the 1950-2012 period to the 2000-2012 period, we observe that about a third of surface water diversions show some increase in mean annual diversion amounts between the periods. In Water Districts 1 and 64 these increases can mostly be attributed to increased reservoir fill season (Nov – March) diversions for the purpose of augmentation accretions. However, additional irrigation season diversions can be detected in several canals in Water Districts 2, 1 and 64. Total annual surface diversions in Water Districts 2, 1, and 64 have increased by an average of 278,381 AF/yr when comparing 2000-2012 to 1969-1999. Of that increase, 192,433 AF/yr is diverted during the winter months.
- S. Platte water users benefit from an average of 386,000 AF/yr of transbasin diversions and 2.3 MAF of reservoir storage.
- A point flow analysis tool was developed by the Open Water Foundation for the HB1278 study to quantify the historical monthly, seasonal, annual, and decadal reach gains and losses between mainstem streamflow gages located in Water District 1 and 64. Stream gains are highest in the S. Platte during the irrigation season and the lowest in November and December, ranging from approximately 9-3 cfs/mi, consistent with earlier studies. Reuse of return flows and accretions increases downstream, with the surface diversions in the lower reach being nearly equal to available stream gains. A rising trend in stream gain can be observed in recent years.
- The number of days of administrative call on the river has increased since the late 1990s from an average of 102 to 305 days annually in Water District 2, from 55 to 271 days annually in Water District 1, and from 72 to 177 days annually in Water District 64, increasing augmentation requirements and decreasing free river periods when augmentation supplies can be diverted.

Stream Gages and Flow Trends

The flow on the mainstem of the S. Platte from Denver to Julesburg is measured by ten principal stream gages maintained by the USGS and DWR, and there a number of other gages on the system maintained by other entities such as the USGS, USACE, NCWCD, LSPWCD, and various diverters (Map 19). Stream gaging generally involves (1) obtaining a continuous record of stage – the height of the water surface at a location along a stream or river, (2) obtaining periodic measurements of discharge (the quantity of water passing a location along a stream), (3) defining the natural but often changing relation between the stage and discharge, and (4) using the stage-discharge relation to convert the continuously measured stage into estimates of streamflow or discharge. Stream gage accuracy is rated as "good" when 95% of daily discharges are within 10% of true value.

Many developments have altered flow trends over the period of time that gage records have been kept on the S. Platte, including new reservoirs, transbasin diversions, and well pumping. The Colorado-Big Thompson project came on line in the 1950s, resulting in a quantitative change in District 3 and 4 flows that were observed all the way to Julesburg (Table 10).

Ken Wright's 1968 Senate Bill 207 study report showed that the average annual river flow at Kersey during the 50-year period from 1917 to 1966 was approximately 516,700 AF. During the same period, the average annual flow measured at Balzac was approximately 261,100 AF. The 255,600 AF average difference represents an apparent average annual depletion or consumption of river water within the reach. To convert this to actual average annual consumption one must also consider return flows from irrigation; inflows from tributaries in response to precipitation events; outflows of ditches that divert water from District 1 to District 64, principally the North Sterling inlet and the Pruitt inlet; and changes in storage of water in the alluvial aquifer.

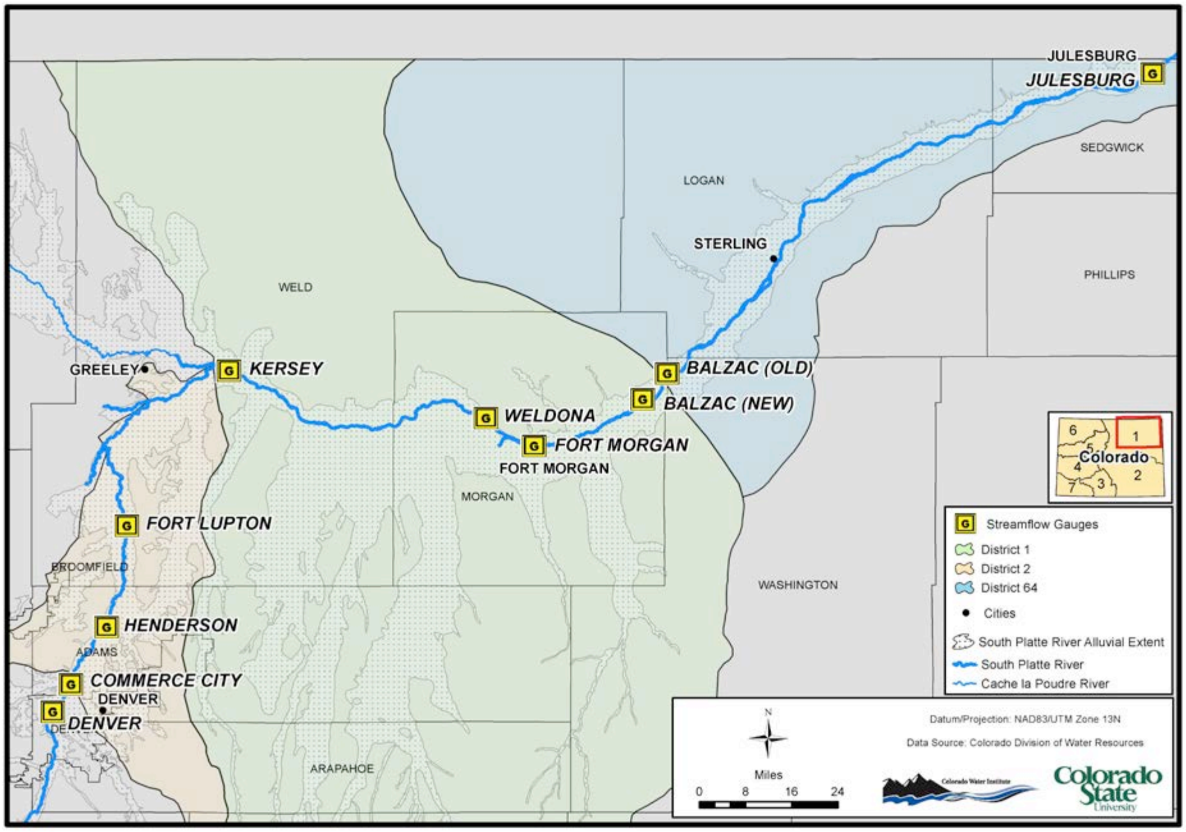
We conducted a statistical analysis of streamflows for the Kersey and Julesburg gages over five time periods to detect trends in flow records and to determine if the observed trends were statistically significant. In order to identify any possible changes of streamflow in the S. Platte, we investigated monotonic trends of discharges, without accounting for either climatic or anthropogenic variation. Two key streamflow gages at Kersey and Julesburg were chosen and trend testing for five time periods was performed. The decision to test for multiple time periods was based on water management shifts in the S. Platte basin.

Trend analysis for the annual (irrigation year Nov 1 – Oct 31) and monthly streamflow was performed by utilizing the non-parametric Mann-Kendall (Kendall, 1975; Mann, 1945) test and a significance level of 5%. A non-parametric trend test was chosen because the data do not have to be normally distributed for the test to be valid. The other assumption that Mann-Kendall test requires is that the data are not serial correlated. Serial correlation can influence the accuracy of the Mann-Kendall test, resulting in statistical errors (Wang et al., 2005). It is common method in the literature to remove the influence of autocorrelation by prewhitening the time series (Von Storch, 1995). As Wang and Swail (2001) have shown, prewhitened data reduces the magnitude of trend. The method used to avoid this problem was proposed by Zhang et al. (2000) and refined by Wang and Swail (2001) and gives almost unbiased estimates of lag-1 autocorrelation coefficient and slope.

The stream gage data retrieved from HydroBase (2013) confirmed Wright's finding that average annual river flow at Kersey during the 50-year period from 1917 to 1968 was approximately 516,969 AF (Table 10). We found that from 1969 to 1999, the average annual river flow at Kersey was 927,323 AF, primarily due to very big flow years in 1970, 1973, 1980, 1981,1983, 1984, 1985, 1995, and 1987, all of which exceeded one million AF (Figure 30). The average annual river flow at Kersey from 2000 – 2012 was 553,773 AF, close to the long-term average observed by Wright. Interestingly, the annual flow at Kersey in the drought year of 2012 (394,588 AF) was 45% higher than the drought year of 2002 (272,075 AF). However, it should be noted that nearly 500,000 AF of groundwater was pumped in Water Districts 2 and 1 in 2002 with 80,000 AF of augmentation, compared to 290,000 AF of pumping and 185,000 AF of augmentation in 2012. Statistical analysis of the monthly and annual flow at Kersey for the 1917-2012 period of record showed a positive trend that was significant at the 0.05 confidence level. This result is expected, since a number of reservoir and transbasin diversion projects came on during this period of time. No statistically significant monthly or annual trend, either positive or negative, was detected in flows measured at the Kersey gage from the period of 2000-2012.

The average annual flow at the Julesburg gage near the state line averages 380,070 AF for the entire period of record from 1924-2012 (Table 10). Large variation in flow occurs within and between years (Figure 31). No statistically significant trend in flow at Julesburg was detected over the entire period. For the period of 1967-1999, a positive but non-significant trend was observed over the period, with a significant positive trend (at $p<.05$) during August, September, and October. The average annual flow for the period of 1967-1999 was 589,313 AF. In contrast, the average annual flow for the period of 2000-2012 was 213,446 AF, due mainly to drought conditions in 2001-2008, and 2012, and increased diversions for recharge. These data provide no evidence that Julesburg flow trends in the past decade are increasing. It should be noted that in 1997, Colorado, Nebraska, and the US Department of the Interior made a cooperative agreement to develop and implement a recovery program for four endangered species: the whooping crane, the least tern, the piping plover, and the pallid sturgeon. Colorado has committed to making 10,000 AF of water available between April and September of each year by adjusting the timing of water flows using an augmentation scheme managed at the Tamarack Ranch State Wildlife Area (Freeman, 2011). Correspondingly, we detected a positive trend for the months of July and August in the 2000-2012 period.

(More detail on the streamflow data can be found in the Appendix VI to this document.)



Map 19. Major Streamflow Gages on the S. Platte Mainstem Below Denver.

Table 10. Average Flows at Major Streamflow Gages on the Mainstem of the S. Platte River.

	Streamflow Gages								
	Denver	**64th Ave, Commerce City**	**Henderson**	**Fort Lupton**	**Kersey**	**Weldona**	**Fort Morgan**	**Combined Balzac Gages**	**Julesburg**
Period of Record	1896 - 2012	1983 - 2012	1929 - 2012	1930 - 2012	1915 - 2012	1953 - 2012	1944 - 2012	1950 - 2012	1925 - 2012
	-- Average AF/yr --								
Start - 2012	250,501	161,270	320,504	330,891	651,657	503,522	323,878	427,307	380,070
Start - 1968	240,347	N/A	235,968	236,178	516,969	304,706	306,915	258,803	281,878
1969 - 2012	267,347	N/A	397,355	433,961	816,956	575,819	N/A	500,070	478,261
1969 - 1999	292,701	N/A	430,887	452,794	927,323	673,488	N/A	610,086	589,313
2000 - 2012	206,888	99,215	317,393	361,320	553,773	342,917	347,627	237,724	213,446

Data Source: CO DWR HydroBase Version 20130710.

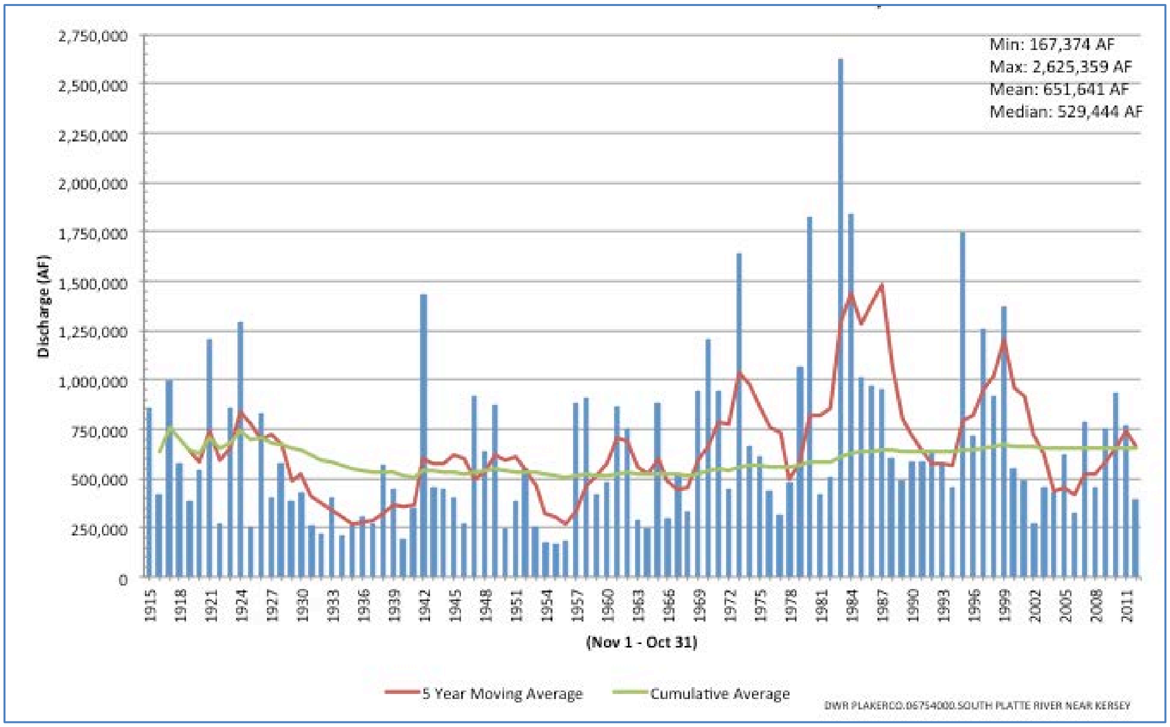


Figure 30. Annual S. Platte River Flows at Kersey, CO, 1915-2012.
Data Source: CO DWR HydroBase Version 20130710.

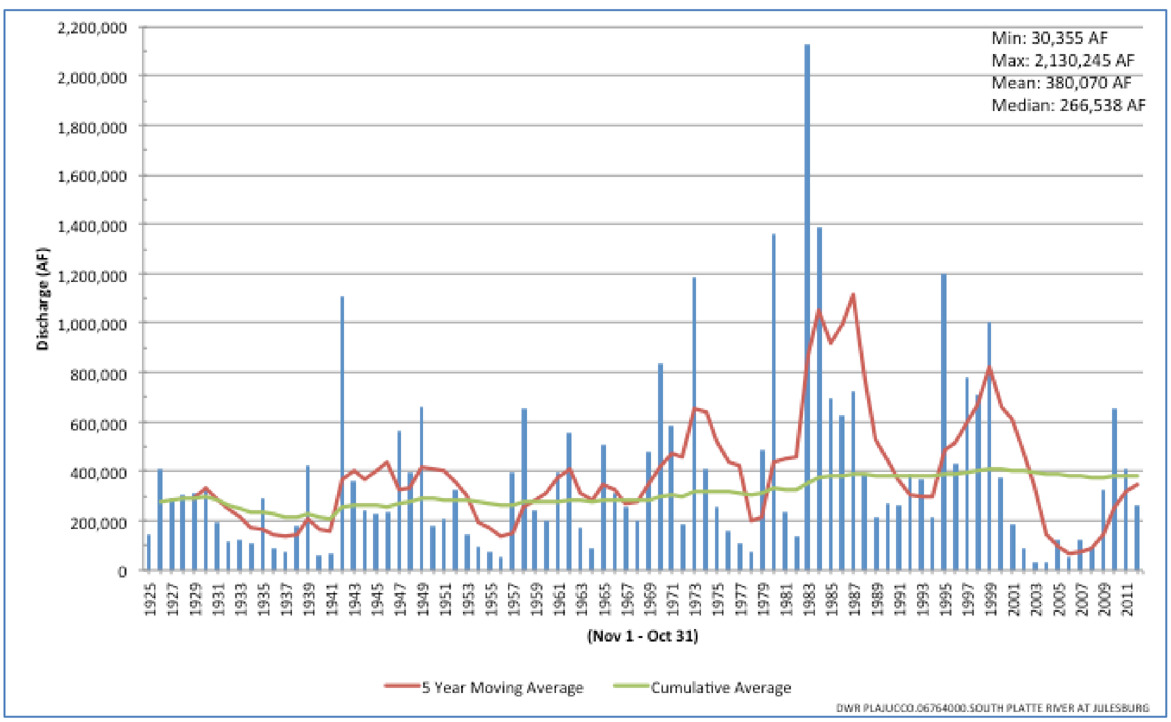


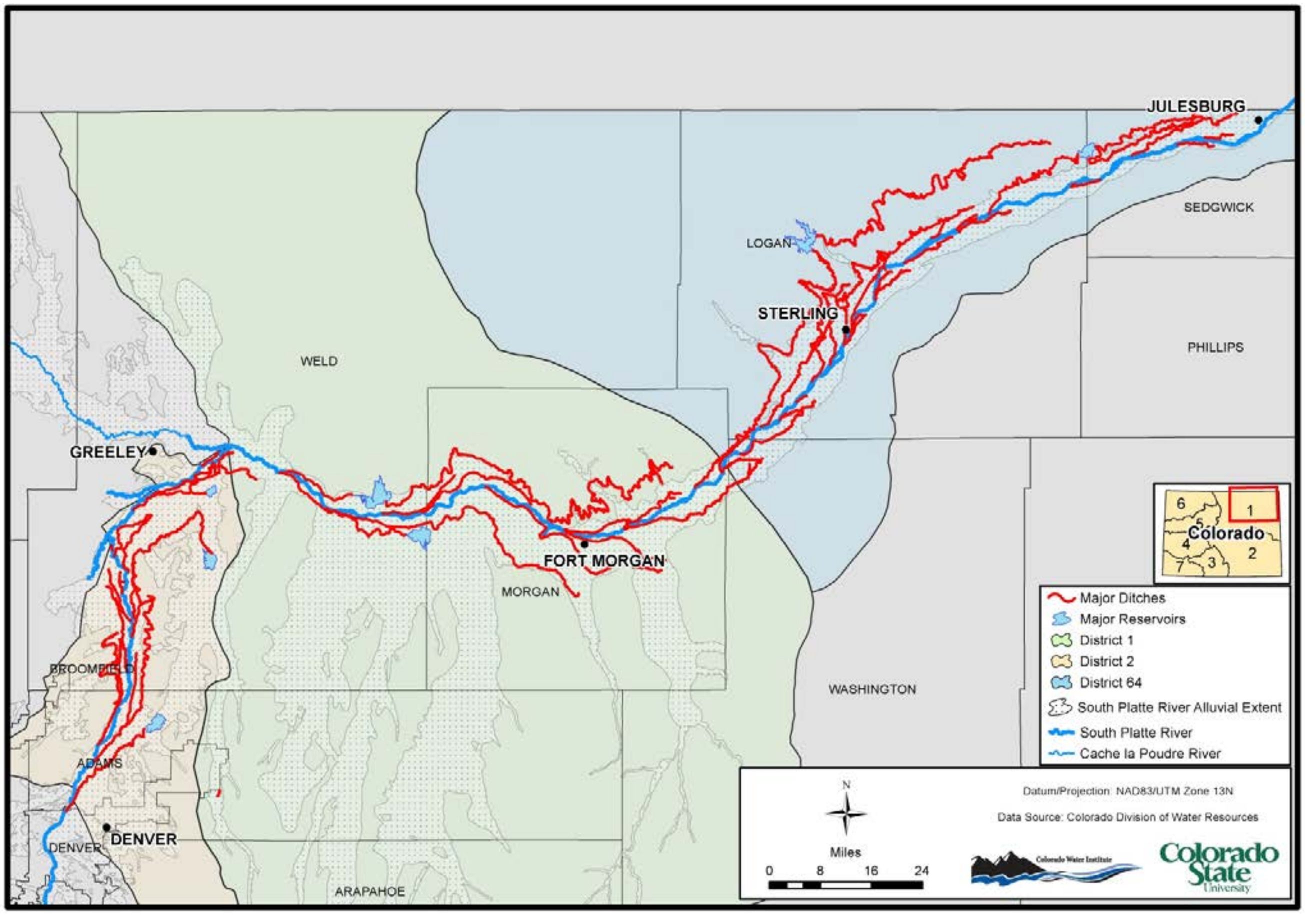
Figure 31. Annual S. Platte River Flows at Julesburg, CO, 1925-2012.
Data Source: CO DWR HydroBase Version 20130710.

Surface Water Diversions and River Administration

There are 56 major surface water diversion canals along the mainstem of the S. Platte in Water Districts 2, 1, and 64 (Map 20). Minor ditches, alternative points of diversion and augmentation structures are not included in this number. Appendix VII shows the main canal and diversion points for these 56 structures as well as the irrigation season and reservoir season diversion trends from 1950 to 2012. The largest change that can be observed in surface water diversions over this period is the post-1969 diversions in the November to March period, when canals are taking water for reservoir filling and augmentation purposes (examples provided in Figures 32-35 and Table 11). We analyzed mean annual diversion records, irrigation season and reservoir season diversion records for the periods of 1950-1968, 1969-1999, 2000-2012, as well as 1950-2012 and 1969-2012 to detect the presence or absence of trends, either positive or negative, and used the Mann-Kendall test to determine if the trends are significant (Table 12).

Most canal system diversion records contain large inter-annual variation as a function of variable snowpack and precipitation, making it difficult to detect statistically significant trends. The decade of the 1950s included severe drought in the 1954-1957 period, as well as new transbasin diversions from the Adams tunnel. The Roberts tunnel diversion began in 1964, also bringing large quantities of transbasin water to the S. Platte and return flows lower in the basin. Comparing mean annual canal diversions for the 1950-2012 period to the 2000-2012 period, we observe that about a third of surface water diversions show some increase in mean annual diversion amounts between the periods. In Water Districts 1 and 64 these increases can mostly be attributed to increased reservoir fill season (Nov – March) diversions for the purpose of augmentation accretions. It is important to note that prior to the 1980s, river commissioners were not uniformly kept on the job year around and off-season diversion records are incomplete. A significant increase in off-season diversions has occurred in the past decade. However, additional irrigation season diversions can be detected in several canals in Water Districts 2, 1 and 64. In District 2 in the recent period, small diversion increases during the irrigation season are detected in the Brantner, Platteville, Farmers Independent, Lower Latham, Highland and Patterson ditches. In District 1, the Fort Morgan, Deuel & Snyder, Lower Platte & Beaver, Tremont, North Sterling, Union, and Tetsel show some increase in diversion amounts in comparing the recent decade to the sixty-year average. The South Platte Ditch, Farmers Pawnee, Schneider, Iliff & Platte, Powell & Blair, and Settlers, and Patterson ditches in Water District 64 also show increases in irrigation season diversions. For the most part, these increases in irrigation season diversions are not large amounts and they are not sustained through drier years such as 2012. In some cases this can be explained by the reported fact that surface water is now diverted where in the past many producers would have pumped groundwater. Only a few ditches showed a statistically significant downward trend in the recent period – the Brighton ditch most notably. A few systems showed a decrease in irrigation season diversions with a corresponding increase in off-season diversions.

Historically, when surface supplies were the main supply, diversions could be broken into two seasons: the irrigation season (April-October) and storage season (October-March). Although most storage decrees begin November 1, historical storage diversions occurred whenever there were no irrigation demands and water was available. Today, operations occur year round and diversions can be broken into three seasons. The irrigation season (April-October), storage season (October-March), and recharge season. Recharge season occurs year round, whenever recharge rights are in priority and there is no irrigation or storage demand. Recharge (and recharge calls) happen primarily in the spring and fall when neither direct use nor storage are at their peak, or in the dead of winter when diversions down very long ditches to storage can be problematic due to icing, but running water for in-ditch recharge and over shorter distances to recharge ponds can be done with less difficulty. These changes make it difficult to generalize a relationship between changed diversion patterns and changed river administration, as each ditch has unique circumstances and associated decrees.



Map 20. Major Ditches on the Mainstem S. Platte River in Northeastern Colorado.

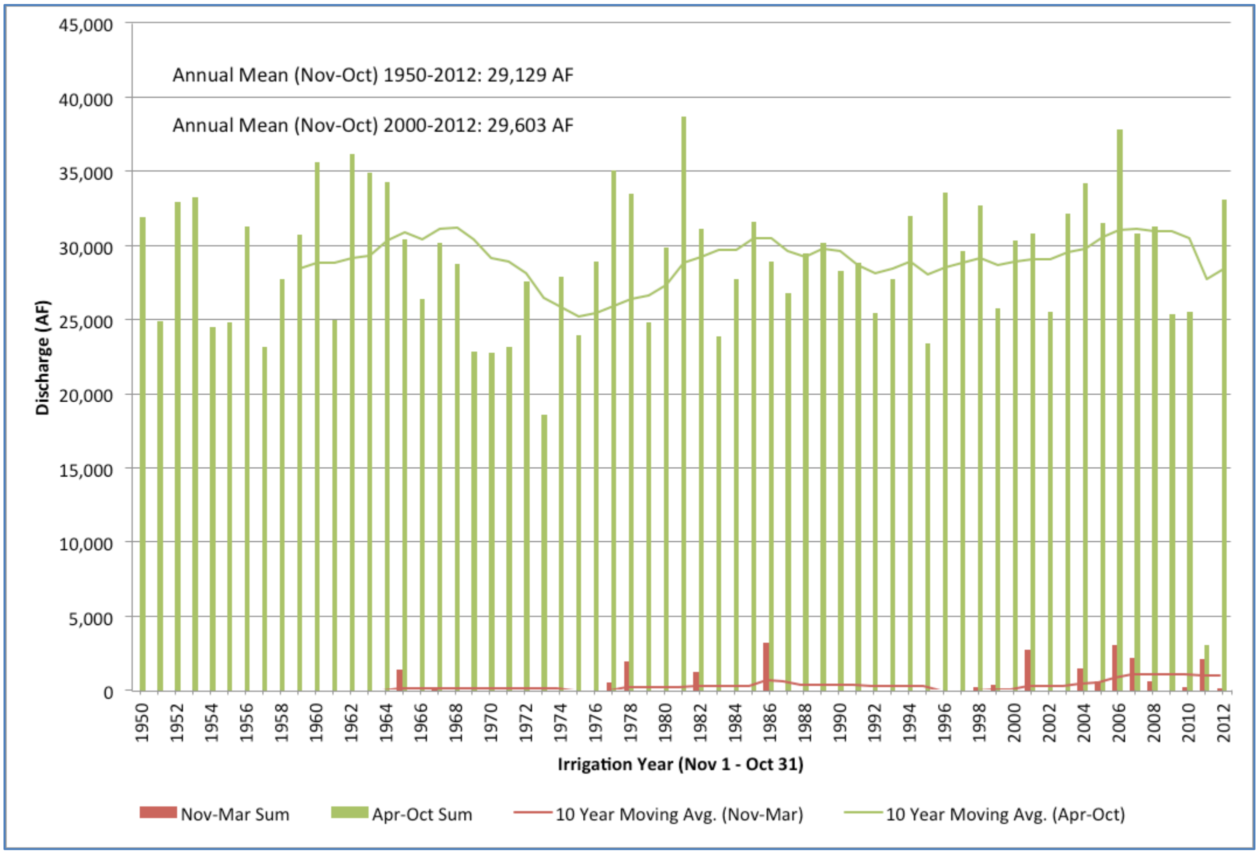


Figure 32. Diversion Record for the Union Ditch in Water District 2 for 1950-2012 Showing Irrigation Season and Off-Season Annual Diversion Amounts.
Data Source: CO DWR HydroBase Version 20130710.

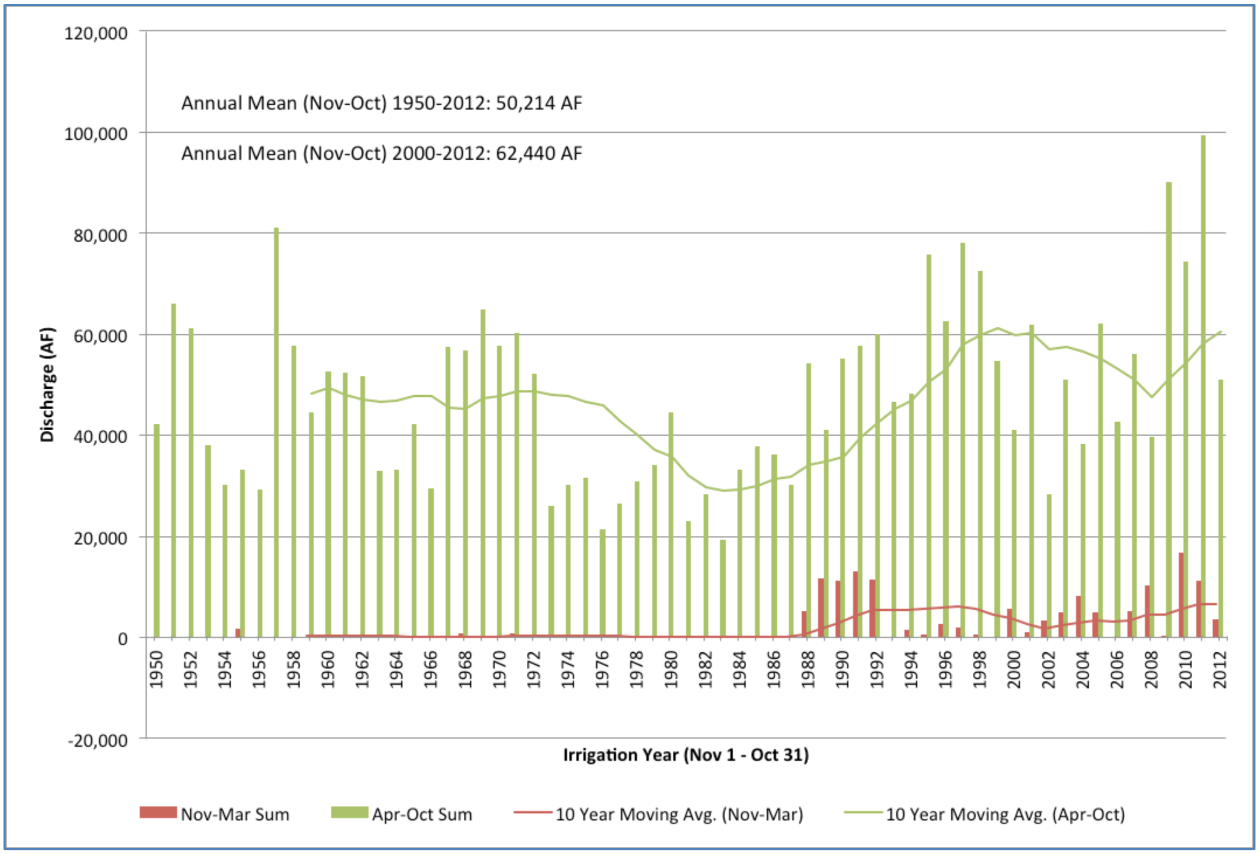


Figure 33. Diversion Record for the Bijou Canal in Water District 1 for 1950-2012 Showing Irrigation Season and Off-Season Annual Diversion Amounts.
Data Source: CO DWR HydroBase Version 20130710.

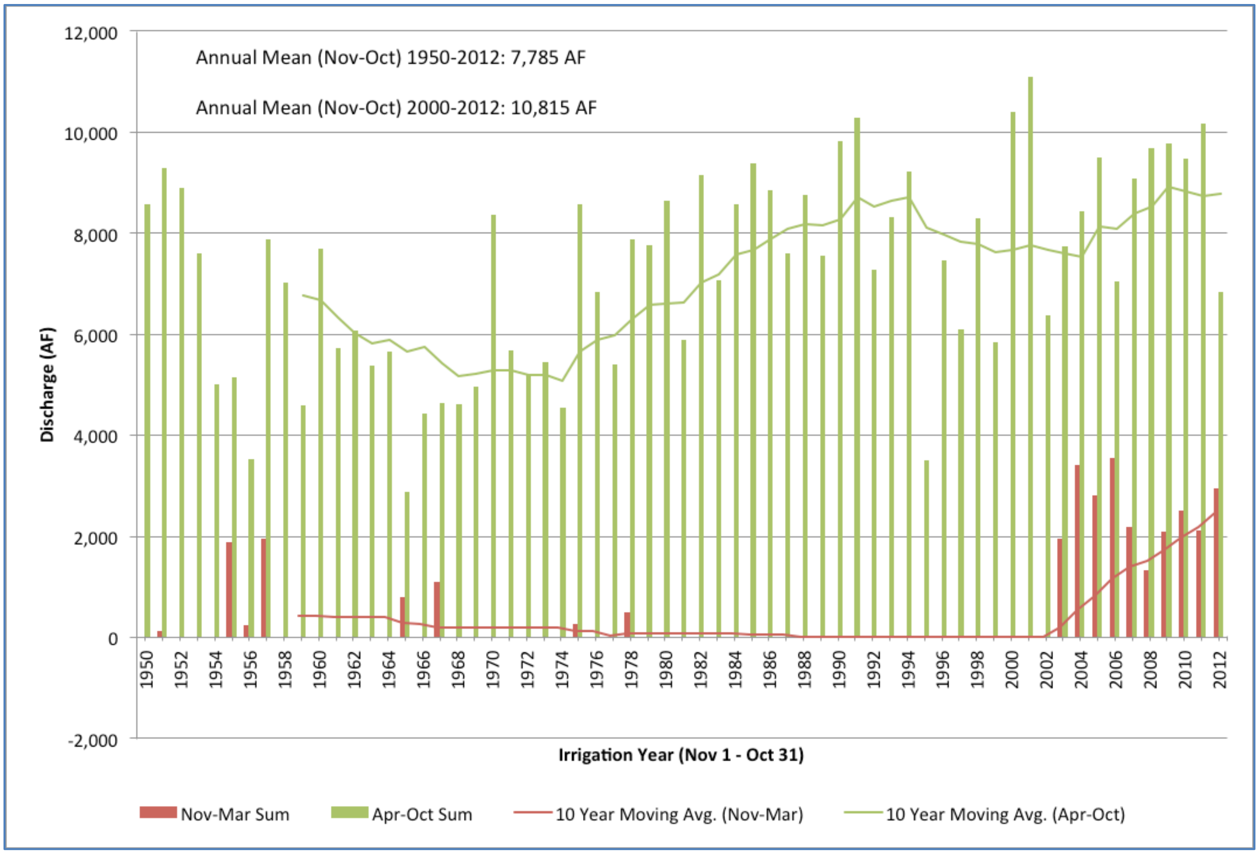


Figure 34. Diversion Record for the Springdale Ditch in Water District 64 for 1950-2012 Showing Irrigation Season and Off-Season Annual Diversion Amounts.
Data Source: CO DWR HydroBase Version 20130710.

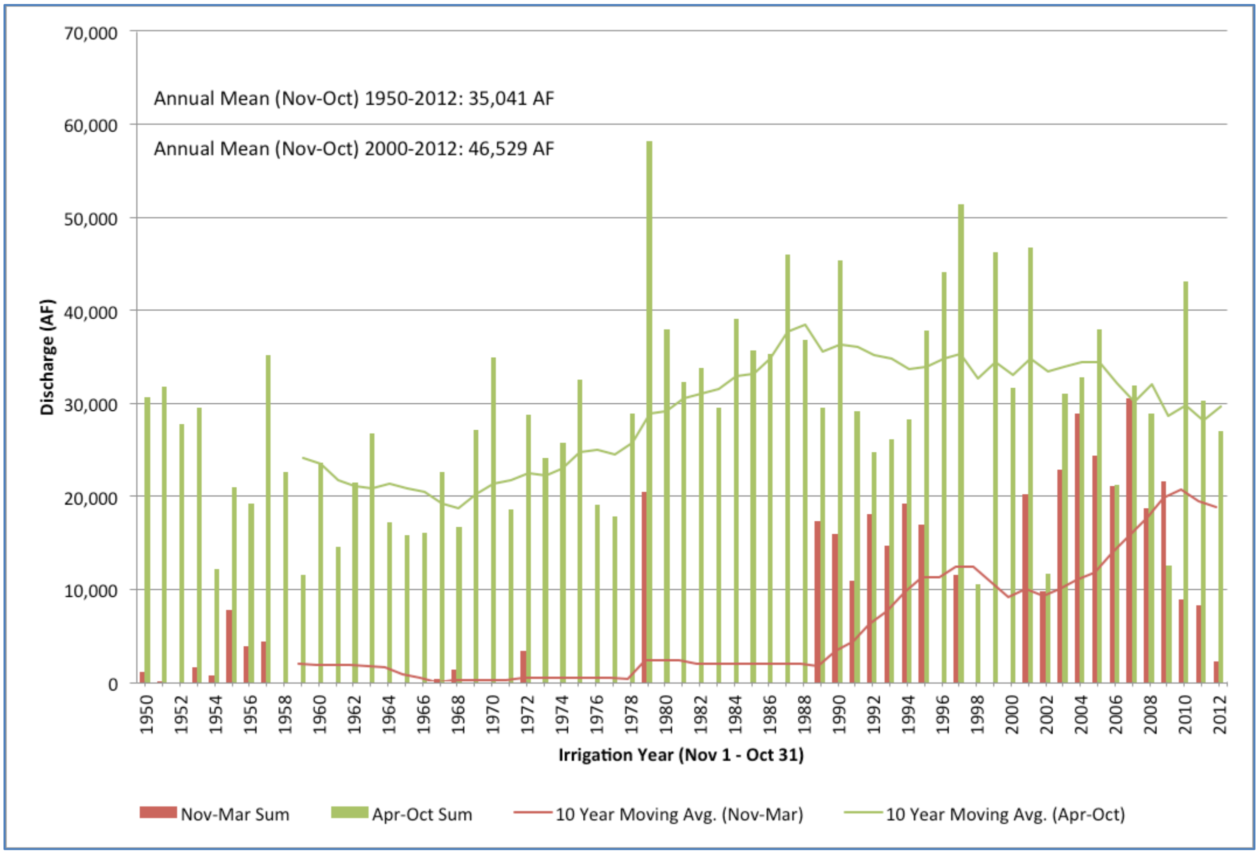


Figure 35. Diversion Record for the Harmony #1 Ditch in Water District 64 for 1950-2012 Showing Irrigation Season and Off-Season Annual Diversion Amounts.
Data Source: CO DWR HydroBase Version 20130710.

Table 11. Average Total Annual Diversions for 56 Major Ditches in Water Districts 2, 1, and 64.

Period	**Irrigation Season (Apr-Oct)**	**Off-Season (Nov-Mar)**	**Irrigation Year (Nov-Oct)**
	------------------------------------	AF/yr	------------------------------------
1950-1968	614,397	13,337*	627,733
1969-1999	818,151	151,479	969,630
2000-2012	901,600	343,912	1,245,512

Data Source: CO DWR HydroBase Version 20130710.
*Early Off-season records are not complete

Table 12. Mann-Kendall Trend Test for 56 S. Platte Ditches Average Annual Irrigation Year Diversions for 3 Periods of Record. Blue Shaded Areas are Significant Positive Trends at p< 0.05.

Ditch Name	1950-1968		1969-1999		2000-2012	
	Slope	p-value	Slope	p-value	Slope	p-value
BURLINGTON DITCH	343.2	0.54	1438.0	0.04	-860.4	0.63
GARDENERS DITCH	39.8	0.26	6.1	0.53	23.2	1.00
FULTON DITCH	-226.6	0.40	376.6	<0.01	-229.4	0.47
BRANTNER DITCH	-114.6	0.08	184.1	<0.01	129.7	0.47
BRIGHTON DITCH	-49.6	0.36	64.8	0.15	-279.6	<0.01
LUPTON BOTTOM DITCH	-228.2	0.06	91.0	0.04	-122.3	0.72
PLATTEVILLE DITCH	-174.1	0.16	234.9	0.04	-381.9	0.16
MEADOW ISLAND DITCH #1	10.6	0.65	56.1	<0.01	37.4	0.67
EVANS NO 2 DITCH	-41.3	0.94	452.4	0.05	229.6	0.84
MEADOW ISLAND DITCH #2	-19.2	0.89	18.1	0.59	307.9	0.45
FARMERS INDEPENDENT DITCH	-344.5	<0.01	20.3	0.54	1392.3	0.03
HEWES COOK DITCH	-82.0	0.82	61.8	0.31	573.4	0.59
JAY THOMAS DITCH	-5.0	0.92	-29.8	0.52	94.5	1.00
UNION DITCH	110.9	0.62	106.5	0.28	-568.9	0.15
SECTION #3 DITCH	126.2	0.40	-14.7	0.78	15.6	0.88
LOWER LANTHAM DITCH	317.7	0.45	283.3	<0.01	635.8	0.72
PATTERSON DITCH	-41.2	0.32	-9.6	0.75	162.9	0.06
HIGHLAND DITCH	-24.6	0.78	10.5	0.83	112.2	0.86
EMPIRE DITCH	NA	NA	1893.0	0.02	1930.9	<0.01
RIVERSIDE CANAL	-1234.7	0.30	4311.5	<0.01	1854.6	0.58
BIJOU CANAL	-299.5	0.70	1135.1	0.05	3354.6	0.02
JACKSON LAKE INLET DITCH	NA	NA	204.4	0.55	-935.9	0.36
WELDON VALLEY DITCH	-187.6	0.82	439.4	0.13	-336.9	0.30
FT MORGAN CANAL	-388.1	0.70	1057.5	<0.01	2061.1	0.09
DEUEL & SNYDER CANAL	-85.2	0.26	35.2	0.15	661.3	<0.01
UPPER PLATTE BEAVER CNL	-56.1	0.88	368.0	<0.01	1907.2	<0.01
LOWER PLATTE BEAVER DITCH	-281.2	0.65	537.7	<0.01	762.2	0.16
TREMONT DITCH	-6.7	0.62	294.3	<0.01	213.8	0.67
NORTH STERLING CANAL	NA	NA	4092.1	0.06	4813.0	0.06
UNION DITCH	NA	NA	-144.4	<0.01	422.5	0.02
TETSEL DITCH	-22.6	0.65	12.6	0.66	-126.4	0.20
PREWITT INLET CANAL	NA	NA	-48.1	0.73	-241.3	0.43
JOHNSON & EDWARDS DITCH	-93.0	0.02	80.8	0.08	-70.3	0.86
SOUTH PLATTE DITCH	-267.6	0.02	70.4	0.34	20.8	0.95
FARMERS PAWNEE DITCH	-531.2	0.15	151.4	0.08	394.5	0.54
DAVIS BROS DITCH	-144.1	0.01	159.5	<0.01	NA	NA

Ditch Name	1950-1968		1969-1999		2000-2012	
	Slope	p-value	Slope	p-value	Slope	p-value
SCHNEIDER DITCH	-209.6	0.04	-55.7	0.28	112.5	0.43
SPRINGDALE DITCH	-235.8	<0.01	57.1	0.15	200.8	0.15
STERLING IRR CO DITCH 1	-321.1	0.11	-50.2	0.69	-199.6	0.76
HENDERSON SMITH DITCH	-7.5	0.88	-20.5	0.20	-64.4	0.13
STERLING IRR CO DITCH 2	-241.4	<0.01	32.9	0.03	NA	NA
LOWLINE DITCH	-211.7	0.03	19.5	0.64	356.5	<0.01
BRAVO & FARMERS PEOPLE D	36.8	0.67	-85.4	0.03	-274.2	0.37
ILIFF & PLATTE VALLEY D	-135.1	0.29	75.3	0.52	-447.6	0.95
JUD BRUSH DITCH	-4.6	0.62	NA	NA	NA	NA
LONE TREE DITCH	-54.3	0.82	-18.6	0.47	NA	NA
POWELL & BLAIR DITCH	-59.7	0.23	40.3	0.10	-98.2	0.63
RAMSEY DITCH	17.0	0.82	-17.1	0.30	-53.7	0.16
CHAMBERS DITCH	26.8	0.37	3289.3	0.20	NA	NA
HARMONY #1 DITCH	-775.4	0.02	879.9	<0.01	-1614.8	0.43
RED LION DITCH	-109.7	<0.01	180.8	0.11	NA	NA
HIGHLINE DITCH	NA	NA	NA	NA	721.6	0.54
SETTLERS DITCH	-46.1	0.64	194.6	0.22	908.8	0.01
PETERSON DITCH	-286.3	0.03	180.6	0.16	1275.5	0.05
SOUTH RESERVATION D	-116.2	0.03	-9.9	0.40	-152.8	0.03
LIDDLE DITCH	-58.6	0.06	-44.6	<0.01	-65.4	0.19
JULESBURG	-59.0	0.66	-107.4	0.83	-2275.7	1.00

*If Mann Kendall p value is greater than 0.05 the trend is declared non-significant or no trend.

(All 56 major ditch diversion records can be found in the Appendix VII to this document.)

Reservoirs and Transbasin Diversions

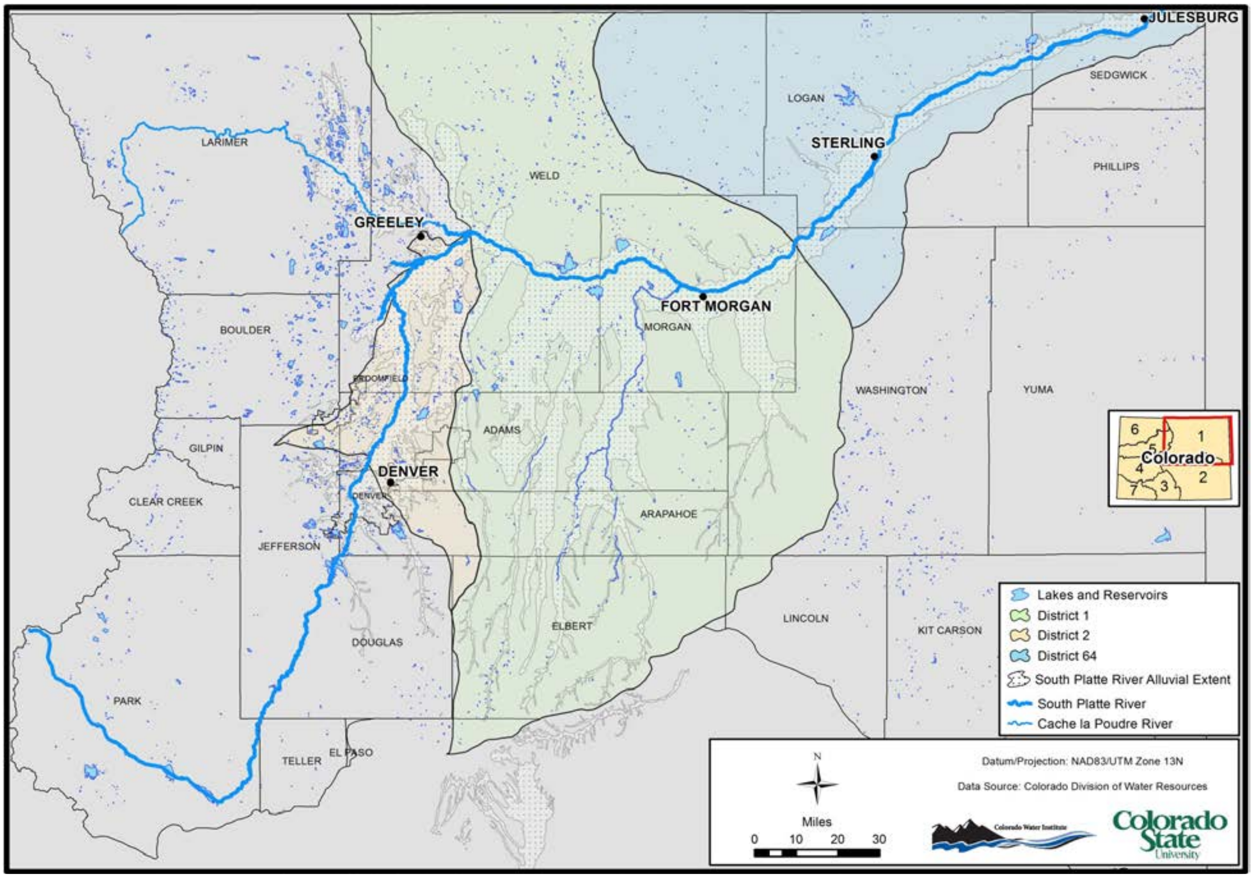
Water management organizations in the S. Platte basin have developed an extensive system of reservoirs throughout the basin to enable storage of spring runoff and winter water. Table 13 shows the total reservoir storage capacity by water district in the basin, some two million AF of capacity. Large reservoirs are located in the mountains and foothills, as well as in the lower river (Map 21 and Table 14). These reservoirs tend to fill during average years and years of plentiful snowpack. In addition, S. Platte water users benefit from some 14 transbasin diversions that import an average of 386,000 AF annually during the period from 1969-2012 (Map 22). The amount was slightly larger in the past dozen years as an average of 420,000 AF of transbasin were brought into the basin during the period of 2000-2012 (Table 15 and Figure 36).

Table 13. Total Reservoir Capacity by Water District in the S. Platte Basin.

Water District	Approx. Storage Capacity	Approx. Decreed Volume Absolute	Total Volume Lost from Dam Restrictions
	(AF)		
WD 1	161,828	332,511	0
WD 2	67,243	100,732	0
WD 3	490,223	344,454	2,650
WD 4	216,173	214,925	0
WD 5	150,365	87,785	0
WD 6	79,472	104,428	0
WD 7	42,734	41,565	0
WD 8	620,770	50,365	0
WD 9	23,100	19,995	0
WD 23	296,873	403,725	6,500
WD 64	108,768	124,657	9,495
WD 80	87,227	158,128	0
TOTAL	2,344,776	1,983,270	18,645

Source: SPDSS Task 5 Key Structures (by Reservoir/System Name) documents from Laserfiche Weblink

(All Division 1 major reservoirs can be found in the Appendix VIII to this document.)

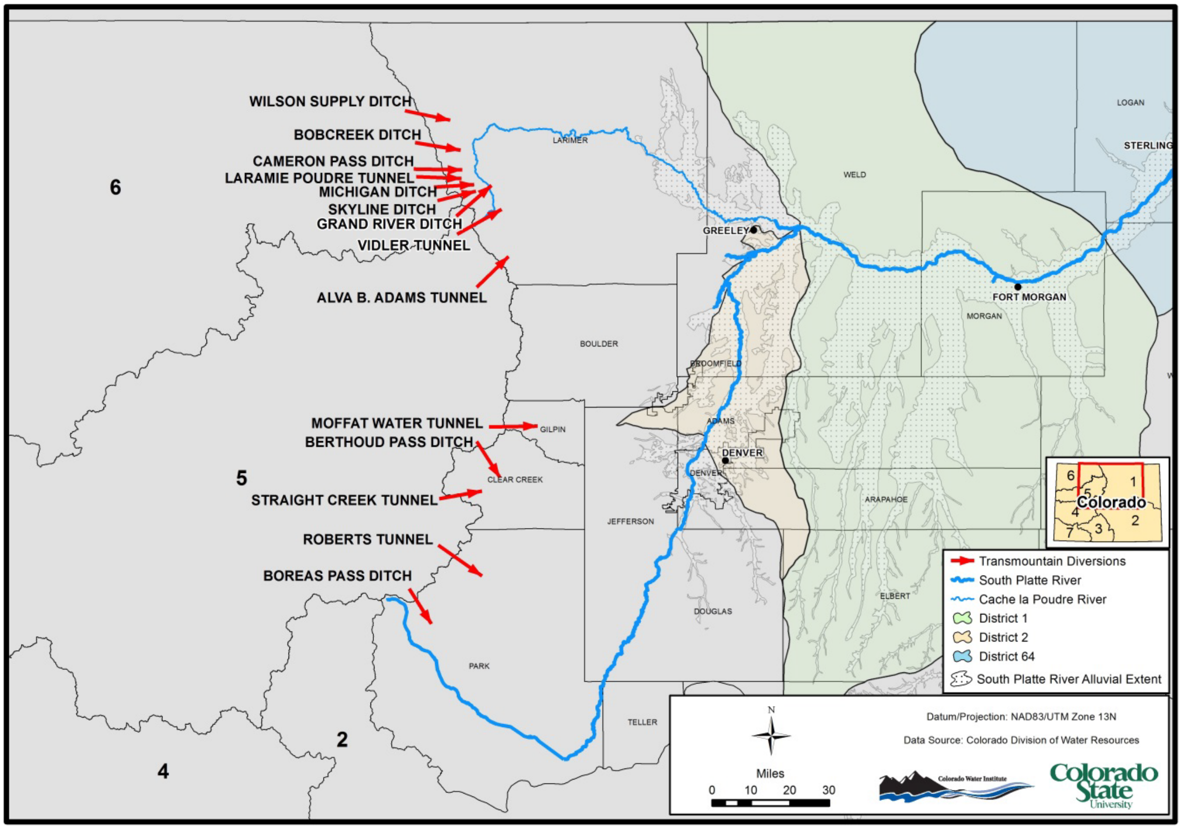


Map 21. Location of Division 1 Lakes and Reservoirs.

Table 14. Largest 25 Reservoirs in the S. Platte River Basin.

Reservoir Name	Water District	Storage Capacity (AF) *
Chatfield Reservoir	8	355,000
Cherry Creek Reservoir	8	265,770
Horsetooth Reservoir	3	156,700
Twin Lakes Reservoir	3	141,000
Eleven Mile Reservoir	23	128,000
Antero Reservoir	23	115,000
Carter Lake Reservoir	4	112,200
Cheesman Reservoir	80	87,227
North Sterling Reservoir	64	80,590
Riverside Reservoir	1	65,008
Boyd Lake	4	49,048
Standley Lake	7	42,734
Gross Reservoir	6	41,920
Jackson Lake Reservoir	1	34,937
Empire Reservoir	1	34,483
Prewitt Reservoir	64	32,164
Barr Lake	2	32,000
Milton Lake	2	29,031
Cobb Lake Reservoir	3	22,300
Marston Reservoir	9	21,100
Windsor Reservoir (aka Big Windsor Reservoir)	3	17,689
Ralph Price Reservoir (Button Rock Reservoir)	5	16,197
Ralston Creek Reservoir	6	15,900
Horse Creek Reservoir	1	15,000
Boulder Reservoir	5	13,100

Source: SPDSS Task 5 Key Structures (by Reservoir/System Name) documents from Laserfiche Weblink



Map 22. Transbasin Diversions to the S. Platte Basin.

(Division 1 transbasin diversion records can be found in the Appendix IX to this document.)

Table 15. Annual (Nov – Oct) Transbasin Diversions, 1950-2012.

Nov-Oct Year	Adams Tunnel	Berthoud Pass Ditch	Boreas Pass Ditch	Grand River Ditch	Moffat Water Tunnel	Roberts Tunnel	Straight Cr. Tunnel	Vidler Tunnel	Cameron Pass Ditch	Michigan Ditch	Bobcreek Ditch	Laramie Poudre Tunnel	Skyline Ditch at Chambers Lake	Wilson Supply Ditch	Total
	AF/yr														
Min	26361	0	0	4980	14956	0	18	12	0	0	0	5547	0	256	96648
Max	315787	2608	475	25196	90734	136983	396	1285	407	6586	705	19688	4927	5260	534503
Mean (1950-2012)	223122	684	106	17599	51934	56743	299	520	101	2314	71	15776	1157	2018	360352
Mean (1950-1968)	206340	645	133	17170	46267	33045	N/A	N/A	86	953	109	15143	2377	2498	303286
Mean (1969-2012)	230928	702	94	17798	54569	60601	299	520	109	2947	54	16070	590	1795	386894
Mean (2000-2012)	242162	611	138	15756	54954	82796	287	627	114	3862	180	16218	55	2189	419950

Data Source: CO DWR HydroBase Version 20130710.

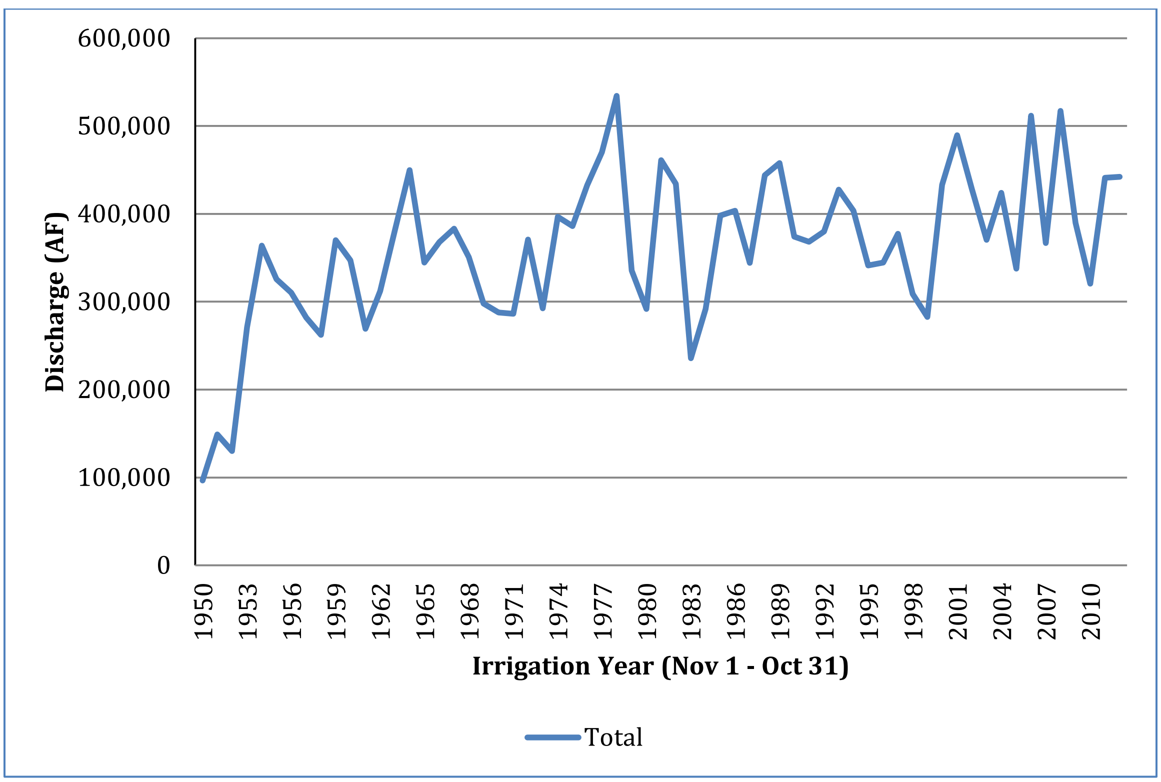


Figure 36. Total Annual Transbasin Diversions, 1950-2012.
Data Source: CO DWR HydroBase Version 20130710.

Stream Gain and Loss

Baseflow is defined as the groundwater contribution to streamflow. Since it is very difficult to directly measure baseflow over a given stream reach, it is estimated by various methods. There are two general methods employed for estimating baseflow in river systems – the mass balance and pilot point flow methods. The mass balance method sums all known inflows and subtracts outflows over a specified period of time, leaving the remainder as stream gain from groundwater or stream loss to the aquifer. A positive remainder indicates a gaining reach of river while a negative remainder indicates a losing reach. The pilot point method is based upon a daily mean mass balance of all inflows to and outflows from a stream reach but constrains extreme values through a smoothing function based on moving averages. Capesius and Arnold (2012) compared these methods on the S. Platte and found similar patterns but different magnitudes of values due to the smoothing in the pilot point approach. Results using daily mean flows are highly variable due to swings in river administration and ungaged inflows or outflows, for example during precipitation events.

CSU irrigation engineer Louis Carpenter published AES Bulletin 33 in 1896 entitled, *Seepage Or Return Waters From Irrigation.* At that time, the phenomenon of return flows had been little studied. Carpenter described measurements made on the Cache la Poudre and on the S. Platte. In his 1896 study, Carpenter measured stream gain and loss in Water Districts 1 and 64. All of the measurements taken in the fall of 1889 indicated the river was a gaining stream with only a few exceptions, and typical gain per mile varied from 0.59 cfs to as high as 9.46 cfs. Slight river losses were observed at Weldona, above Merino, above Crook, and at Julesburg. In averaging October monthly data from 1889 to 1895, the river was shown to be a gaining stream from the mouth of the Poudre to Iliff. From Iliff to the state line, the river lost slightly less than 1 cfs per mile. Data published in the 1896 Bulletin 33 indicated that the river was a gaining stretch from Denver to the mouth of the Poudre. Carpenter (1896) concluded that surface irrigation was responsible for the increase in the volume of flows measured in the river, and the increase grows as the irrigated area increases. He concluded that rainfall had little influence on stream gain. At the time, Carpenter noted that the amount of seepage was slowly but constantly increasing and predicted that it may increase for some years to come, particularly as more land was brought under cultivation. He predicted that return flows from seepage would make the lower portions of the S. Platte more reliable for irrigation in the future.

In 1913, the *Comstock v Ramsay* case clarified that return flows are tributary to the river and that the water right holder has no right to redirect these flows – thus the single use rule. Of interest in the facts of the case, was description of a drainage ditch in the LaSalle area that produced 6 cfs/mile. Also noted in the ruling was that all of the waters of the S. Platte were appropriated at that time and that the entire normal flow was inadequate to supply the decreed irrigated lands. Additionally, the court stated that almost every decree, except possibly only the very early ones, were dependent upon return flows, which is what enables enlarged use of the stream. To permit later claimants to capture and appropriate water naturally tributary to the river that are in fact return flows upon which older priorities depend, would reverse the ancient doctrine of “First in time, first in right” and substitute “Last in time, first in right” according to the court opinion.

Ralph Parshall's 1922 Agricultural Experiment Station Bulletin 279, entitled *Return Of Seepage Water To The Lower South Platte River*, evaluated stream gain and loss during 1919 and 1920 from Kersey to Julesburg, a distance of 158 river miles, and found that the average return flow is 5.26 cfs per mile over the entire reach, with a measured range from 1.99 to 8.50 cfs per mile. Parshall concluded these river gains were due in large part to the development of surface irrigation, canal systems and reservoirs.

In the State Engineers 24th Biennial Report published in 1927, seepage reports for November 1926 showed positive river gains for the entire reach from Denver to Julesburg, with an average seepage rate of 6.31 cfs per mile for the river below Waterton, a distance of 235 miles. In the 25th Biennial report, seepage investigations were reported for April 1930 from Kersey to Julesburg. Again, each of the stretches showed a positive seepage gain to the river, averaging slightly over 6 cfs per mile.

The Bureau of Reclamation Narrows study published in 1976 showed the area between the proposed Narrows project near Weldona and the state line was a gaining stream at that time. The earlier 1951 reconnaissance study observed the riverbed had aggraded from Ft. Morgan to state line, possibly causing high groundwater in places.

SPDSS Task Memo 46.2 (Camp Dresser and McKee Inc., 2008) estimated stream gain or loss for seven reaches along the S. Platte based upon the availability of streamflow gauges (Table 16). The process used in Task Memo 46.2 for estimating stream gains and losses involved compiling surface water data on the inflows and outflows for a specified stream reach and time period, then converting the flows into estimates of monthly gain or loss between the surface water system and the hydrologically connected aquifer system. Stream gain or loss was defined as the recharge from or discharge to the alluvial aquifer that is in hydrologic communication with the overlying stream system. Inflows include the streamflow into the stream reach defined by the upstream flow gauge, streamflows from tributaries, industrial and municipal discharge, and reservoir releases. Outflows include irrigation and other diversions within the reach. To account for streamflow travel time within each reach and help smooth the results, a one to two day averaging was applied to the mass balance data for each reach in Task Memo 46.2. The lag was one day for each reach, except the reach from Balzac to Julesburg, which had a two-day lag. Stream losses from the S. Platte River and its tributaries typically occur during peak flow events when the stream stage is higher than average. Peak flows typically occur during snowmelt periods and during localized precipitation events. For the study period of 1950 to 2005, the average annual baseflows are generally positive for the mainstem of the S. Platte, indicating that on an annual basis the river is gaining flow from the alluvial aquifer. The one exception is the Kersey to Weldona stretch that tends to be a losing stretch on average over this period. Estimated baseflow ranged from 6.3 cfs per mile in the Ft. Lupton to Kersey reach to 3.0 cfs per mile in the Balzac to Julesburg reach.

Table 16. SPDSS Task Memo 46.2 Estimated Baseflow by River Reach, 1991-1994.

Reach	Estimated Baseflow (cfs)	Estimated Baseflow Per River Mile (cfs/mi)
Waterton to Denver	94.1	5.4
Denver to Henderson	87.7	5.5
Henderson to Fort Lupton	62.8	3.7
Fort Lupton to Kersey	245.3	6.3
Kersey to Weldona	173.3	4.0
Weldona to Balzac	132.3	5.3
Balzac to Julesburg	293.1	3.0

Source: SPDSS Spatial System Integration Component Task 46.2 Stream Gain/Loss Estimates Technical Memorandum, p.15, Table 9. Riverside Technology et al., 2007.

Task Memo 46.2 indicated that the magnitude of both measured and modeled stream gain and loss varies annually with generally larger gains occurring during the summer months. The Denver to Henderson reach is observed to be primarily a gaining reach in the SPDSS Task Memo 46, except during some summer months. The Henderson to Fort Lupton reach is a losing reach during the winter and early spring but gains the rest of the year. The Fort Lupton to Kersey reach is gaining throughout the year. The Kersey to Weldona reach is primarily a gaining reach except for occasional periods during the non-irrigation season. The Weldona to Balzac reach is a gaining reach virtually all time. The Balzac to Julesburg reach is a gaining reach at most times of the year.

It is interesting to note that the recent analysis conducted for the SPDSS shows lower stream gains than previous analyses. Several possibilities exist that might explain a physical cause for this, including expansion of phreatophyte ET along the riparian corridor and the shift from surface to center pivot irrigation, thereby reducing return flows.

HB1278 Baseflow Analysis

A point flow analysis was performed for the HB1278 study to quantify the historical monthly, seasonal, annual, and decadal reach gains and losses between mainstem streamflow gages located in Water District 1 and 64 using a very simple and transparent modeling approach to determine if trends could be detected that relate to groundwater pumping, recharge or groundwater levels. To conduct this analysis, a point flow tool was developed within the TSTool software to analyze historical data from various sources and compute daily and monthly reach gains and losses based on a node balance approach. A monthly and daily analysis was completed for the 1987 to 2012 period to reflect the current location of the Balzac gage and was broken into three segments or reaches for analysis: Kersey to Weldona, Weldona to Balzac, and Balzac to Julesburg.

Stream gain or loss was calculated on a mass balance approach for a daily and monthly time step as described above. Stream gains may be a result of surface water return flows, surface inflows from ungaged drainages, or groundwater inflows from irrigation, precipitation or recharge. Stream losses could include lagged groundwater depletions, or incidental losses due to phreatophyte consumptive use or river bank storage.

<u>Kersey to Weldona</u> –The Kersey to Weldona reach is 42.6 river miles in length and was a gaining segment over 93% of months during the 1987-2012 period. The average daily gains calculated for the period are 291 cfs (6.83 cfs/mi) and the average monthly calculated gains are 15,324 AF. Figure 37 below shows monthly gains for the period of 1987-2012. Large losses tend to be associated with wet periods of high river where water is lost between reaches due to bank storage and overflow. This reach receives substantial inflows from Water District 2 and 3 and irrigation return flows and accretions from the upstream irrigated acreage. This reach has an average annual diversion of 31,500 AF or 740 AF/mile. Gains in this reach are observed primarily during the irrigation season of April through October, with the highest gains seen in July and the lowest gains in November. The highest gains in the 1987-2012 period of study were seen during the 1995-1999 and 2010-2012 periods (Table 17). The least amount of gains in this reach was observed during the 2005-2009 period. The highest average daily gains that occur during the irrigation and non-irrigation seasons occur in the 2010-2012 period. The lowest average daily gains that occurred during the irrigation seasons occur in the 1987-1989 and 2005-2009 periods. The lowest average daily gains that occurred during the non-irrigation seasons occur in the 2000-2004 period. The same general trends are observed with the monthly data. Average monthly gains during the irrigation season within this reach range from 17,080 to 20,319 AF and average 19,000 AF. During the non-irrigation season the average monthly gains range from 8,311 to 12,994 AF with an average of 10,437 AF. This reach has an average decadal gain of 291 cfs (15,505 AF) with an average of 6.8 cfs/mi (364 AF/mi) over the reach. The 1980s show the lowest daily gains and the 2000s show the lowest monthly gains. The 2010s (2010-2012) show the highest daily and monthly gains.

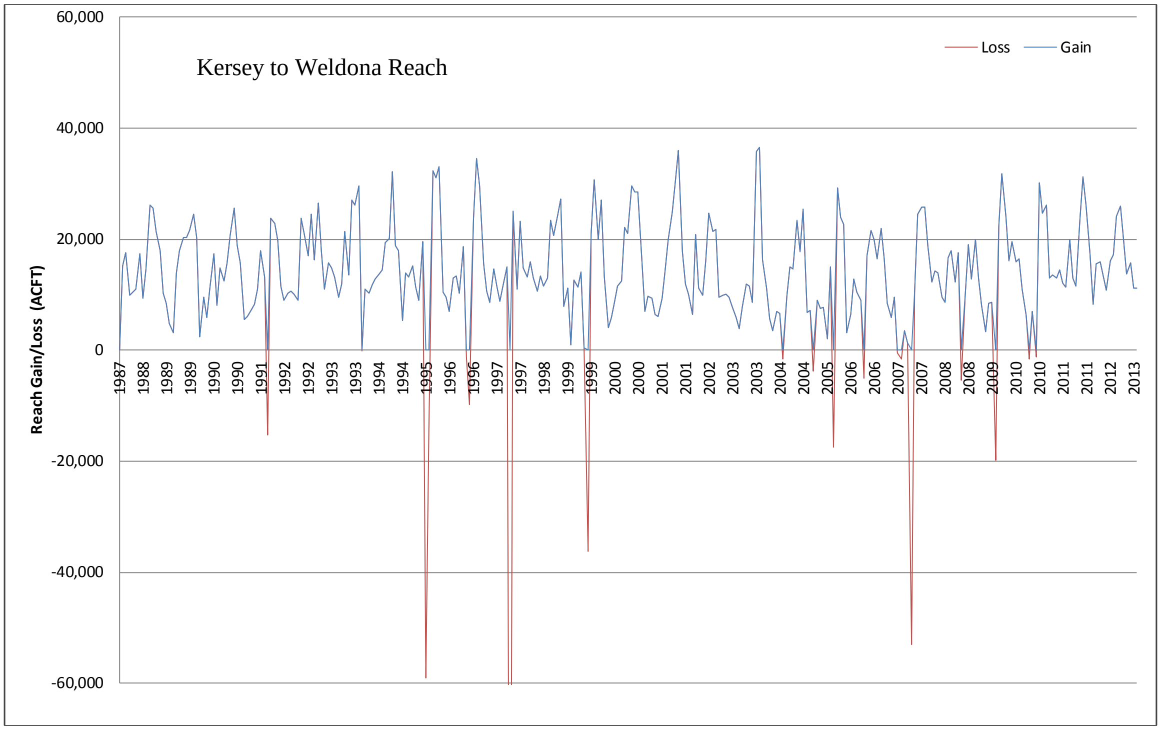


Figure 37. Monthly Gain/Loss (AF) in the Kersey to Weldona Reach, 1987-2013.

<u>Weldona to Balzac</u> – The Weldona to Balzac reach is 24.7 river miles long and was a gaining segment over 96% of months during the 1987-2012 period. The average daily gains calculated for the period are 192 cfs (7.77 cfs/mi) and the average monthly calculated gains are 10,191 AF. Figure 38 below shows monthly gains for the period of 1987-2012. This reach experiences the lowest amount of gains with six diverting structures that have an average annual diversion of 17,132 AF or 693 AF/mile. This reach is also the shortest reach distance between streamflow nodes and the majority of irrigated acreage is close to the river. Gains in this reach are observed primarily during April through July, with the highest gains seen in June and the lowest gains in December. The highest gains were seen during the 1995-1999 and 2010-2012 periods (Table 17). The least amount of gain in this reach was observed during the 2000-2004 period. Average daily gains during the irrigation season within this reach range from 151 to 303 cfs and average 213 cfs. During the non-irrigation season the average daily gains range from 125 to 210 cfs with an average of 163 cfs. The highest average daily gains that occur during the irrigation seasons occur in the 1995-1999 period. The highest average daily gains that occur during the non-irrigation season occurred in the 1987-1989 period. The lowest average daily gains that occurred during the irrigation and non-irrigation seasons occur in the 2000-2004 period. The same general trends are observed with the monthly data. Average monthly gains during the irrigation season within this reach range from 7,456 to 15,041 AF and average 10,887 AF. During the non-irrigation season the average monthly gains range from 6,933 to 12,724 AF with an average of 9,234 AF. This reach has an average decadal gain of 201 cfs (10,808 AF) with a decadal average of 8.1

cfs/mi (438 AF/mi) over the reach. The 2000s decade shows the lowest daily and monthly gains. The 2010s show the highest daily and monthly gains.

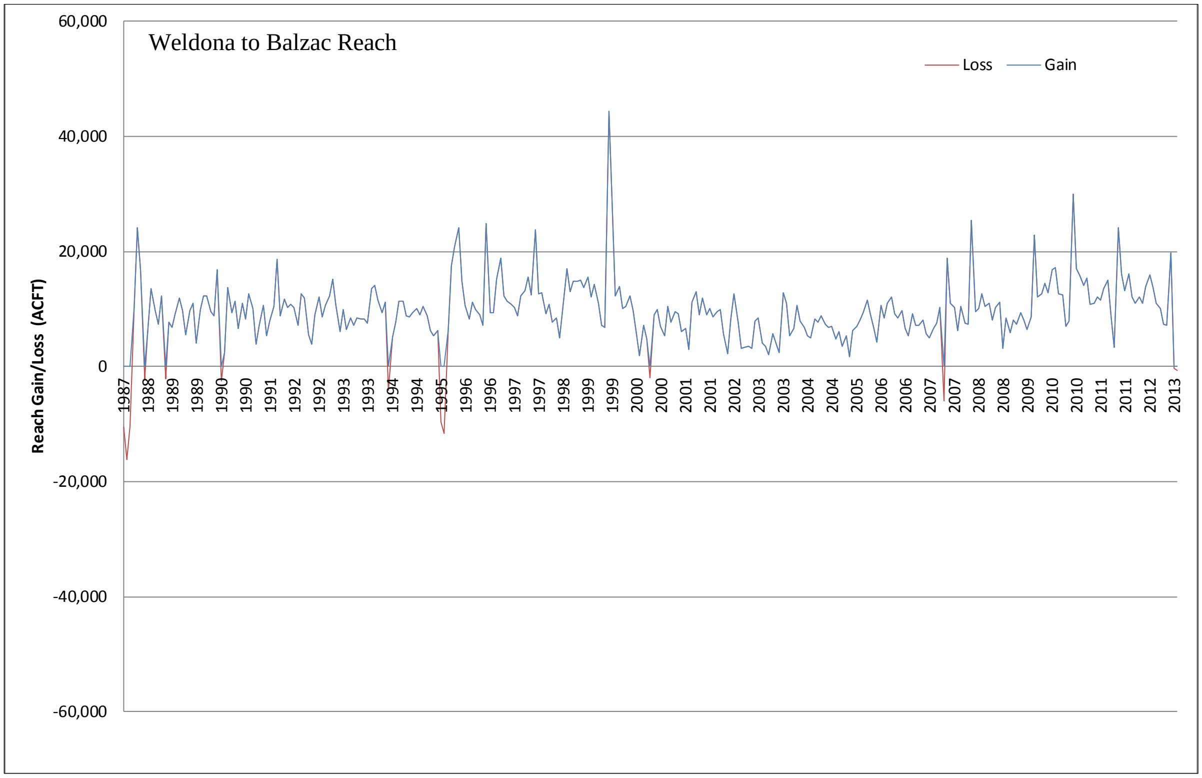


Figure 38. Monthly Gain/Loss (AF) in the Weldona to Balzac Reach, 1987-2013.

<u>Balzac to Julesburg</u> – The Balzac to Julesburg reach is 90.1 river miles long and was a gaining segment over 97% of months during the 1987-2012 period. The average daily gains calculated for the period are 391 cfs (4.34 cfs/mi) and the average monthly calculated gains are 20,171 AF. Figure 39 below shows monthly gains for the period of 1987-2012. This reach is the longest reach with the most recharge structures. The total average annual diversions in this reach are 20,120 AF or 223 AF/mile. Gains in this reach are observed primarily during April through July with the highest gains seen in June and the lowest gains in December. The highest gains were seen during the 1995-1999 and 2010-2012 periods (Table 17). The least amount of gain in this reach was observed during the 2000-2004 period. Average daily gains during the irrigation season within this reach range from 366 to 591 cfs and average 463 cfs. During the non-irrigation season the average daily gains range from 232 to 347 cfs with an average of 285 cfs. The highest average daily gains that occur during the irrigation and non-irrigation seasons occur in the 2010-2012 period. The lowest average daily gains that occur during the irrigation and non-irrigation seasons occur in the 2000-2004 period. The same general trends are observed with the monthly data. Average monthly gains during the irrigation season within this reach range from

21,202 to 28,747 AF and average 24,316 AF. During the non-irrigation season the average monthly gains range from 13,132 to 18,029 AF with an average of 14,535 AF. This reach has an average decadal gain of 410 cfs (20,994 AF) with an average of 4.6 cfs/mi (233 AF/mi) over the reach. The 2000s show the lowest daily and monthly gains. The 2010s show the highest daily and monthly gains.

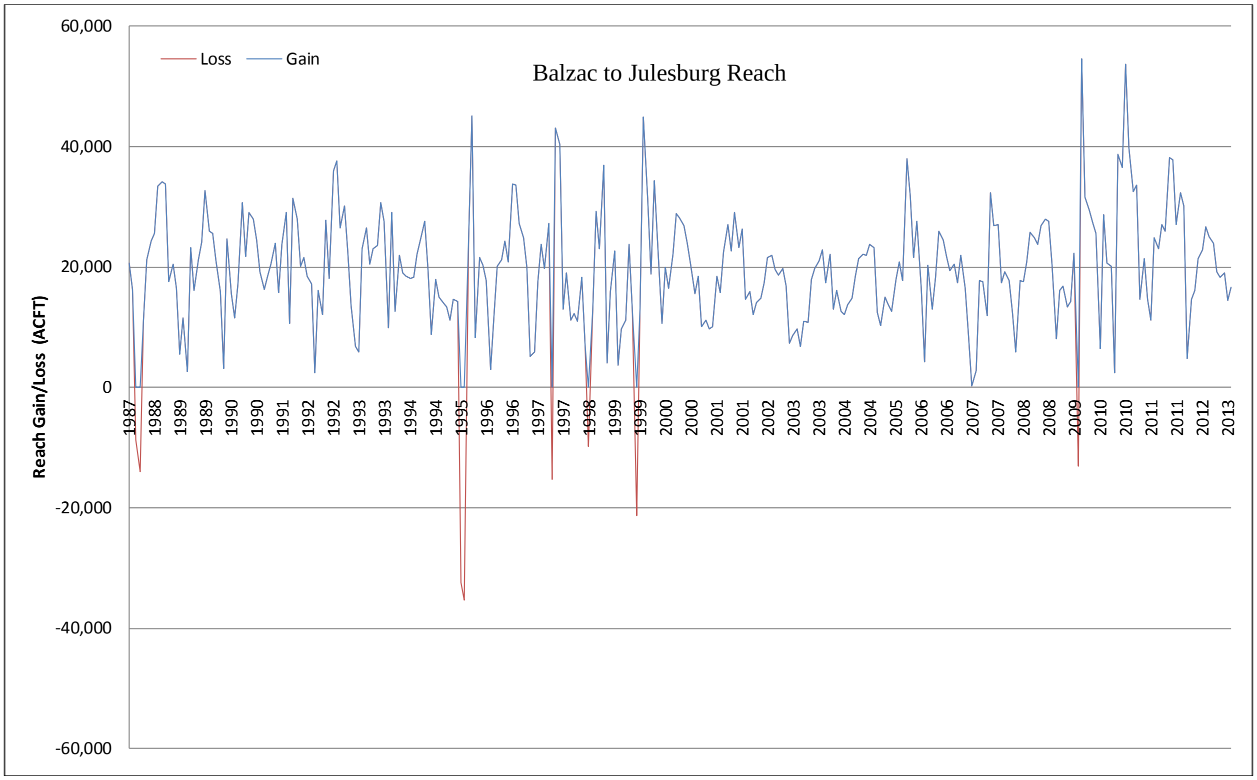


Figure 39. Monthly Gain/Loss (AF) in the Balzac to Julesburg Reach, 1987-2013.

Table 17. Average Daily Gain by Decade.

Period	Kersey to Weldona	Weldona to Balzac	Balzac to Julesburg
	---------------- Average Daily Gain, cfs --------------		
1987 - 1989	266.4	193.6	403.7
1990 - 1999	304.2	214.9	414.1
2000 - 2009	274.3	155.0	338.7
2010 - 2012	320.1	240.6	485.0
Average	291.2	201.0	410.4
	------------- Average Daily Gain, cfs/mi --------------		
1987 - 1989	6.3	7.8	4.5
1990 - 1999	7.1	8.7	4.6
2000 - 2009	6.4	6.3	3.8
2010 - 2012	7.5	9.7	5.4
Average	6.8	8.1	4.6

Overall, the S. Platte River remains a gaining river for most of the year in Water Districts 1 and 64 with calculated gains in each reach over 90% of the time. The calculated gain data generally followed earlier observed trends for the lower river. Specifically, the Weldona to Balzac reach had the highest gain per river mile, followed by Kersey to Balzac then Balzac to Julesburg. The decadal average gain in the period of 2000-2009 was lower than average, and the recent period of 2010-2012 was higher than average (Table 17). The 1990s were wetter than the decade of the 2000s, as reflected in the gain data. The analysis is not sensitive enough to separate surface hydrologic conditions from groundwater return flow provided by augmentation plans but certainly does not contradict the observed increase in developed recharge below Kersey in the late 2000s.

The majority of calculated losses occurred during single time-steps, but appear significant on graphs. The negative gains were evaluated to determine the cause of the sharp downward spikes and were found to often be a result of high flow events causing in increased bank storage and overflow of the main channel into areas near the river resulting in gaged loss during the time step in question. There also are likely timing issues between upstream and downstream gages in a reach during high flow events. There are a few prolonged periods of calculated losses, representing periods when diversions exceed the gains in the reach, often likely due to data errors and lack of precision. The negative gains (losses) were left in the analysis data in order to reflect overall water balance and preserve annual volumes for irrigation years November 1 through October 31.

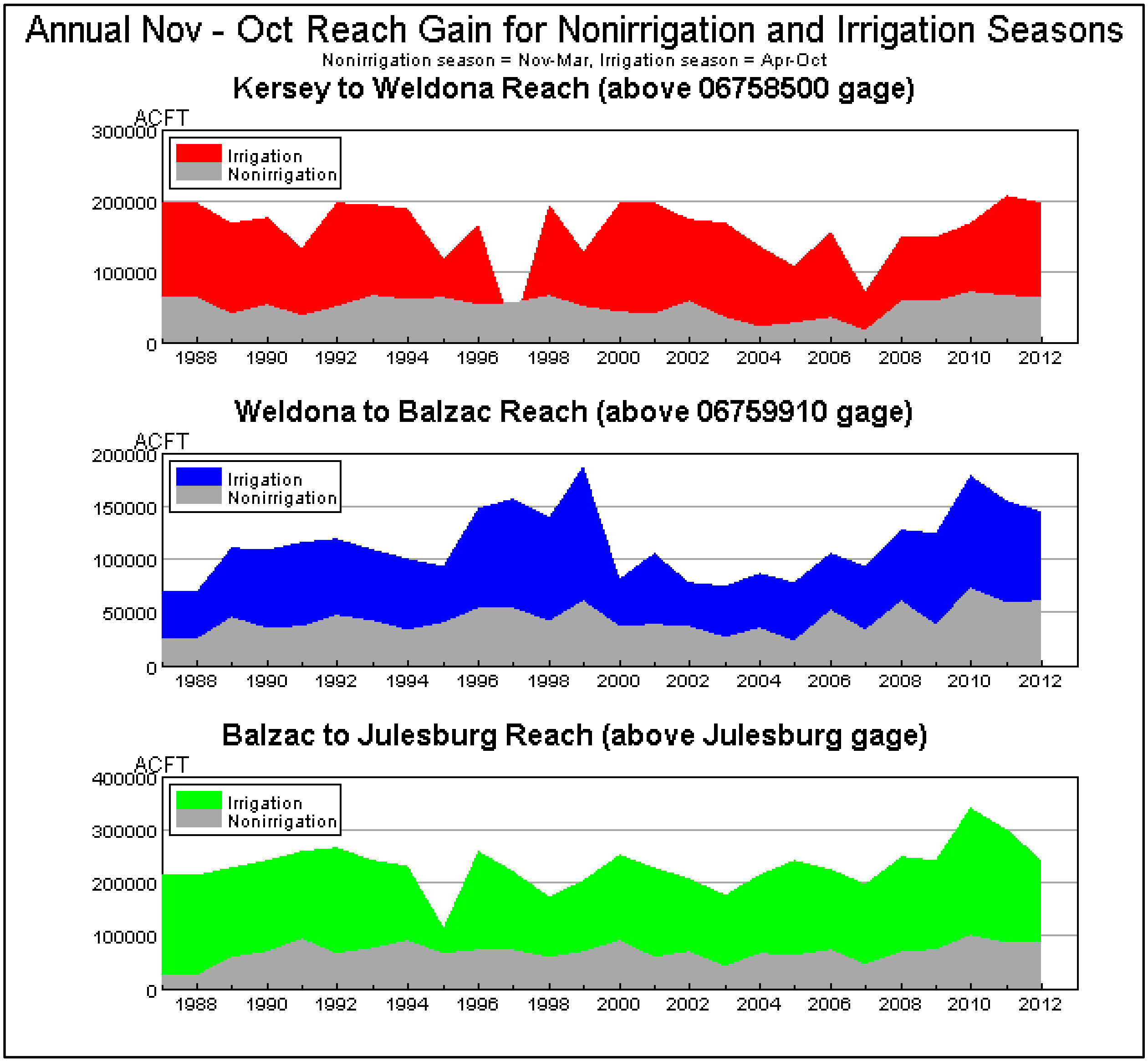


Figure 40. Calculated Annual Gain Summary in AF for the period of 1987-2012 Showing Irrigation and Off-Season Gain by Reach.

Gains and losses are more variable below the Balzac gage. The Kersey to Balzac reach has the most constant gains and losses and is the least affected by hydrologic variations between wet and dry years. From Kersey to Weldona the average total monthly diversion is approximately 32,000 AF while the average total monthly pumping in that reach is much lower. Because surface water use dominates the river it is difficult to separate surface water returns and groundwater returns using this approach. However, increases in river gain can be observed in all three river reaches over the past decade (Figure 40).

Large amounts of water is re-diverted and reused in each reach of the river. As an example, in June 2005, the streamflow at the Kersey gage was 72,667 AF and the streamflow at Weldona was 42,361 AF, a decrease of 30,305 AF. Within the Kersey to Weldona reach there was 45,267 AF of diversions. This means that 14,961 AF of diversions was met from return flows and accretions. These additions to the reach are primarily in the form of immediate and lagged surface water and groundwater returns that are re-diverted by the downstream users. Reuse of return flows and accretions increases downstream, with the surface diversions in the lower reach being nearly equal to available gains. The Balzac to Julesburg reach has seen an approximately 100,000 AF increase in annual gain between the start of the drought in the early 2000s and 2010. A rising trend in stream gain can be observed over this same period beginning after 2002 (Figure 41).

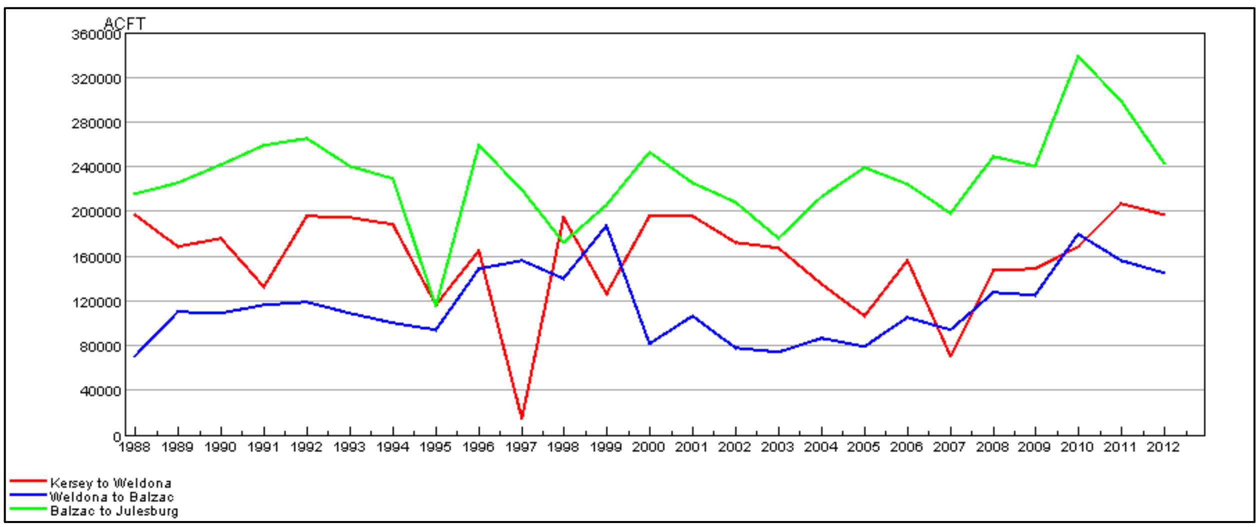


Figure 41. November to October Annual Reach Gain.

The point flow tool built for the HB1278 analysis did not include the river reaches in Water District 2. This District, as well as the tributaries, can be added to the tool over time. To compensate for this, we computed simple mass balance gain losses for the 5-year period of 2008-2012 using the gage data in HydroBase. The Henderson to Ft Lupton reach showed average gains over the period of 2.8 cfs/mi, which is slightly lower than the analysis of 1991-1994 conducted for the SPDSS. The Henderson to Kersey reach averaged 6.8 cfs/mi, slightly higher than calculated for 1991-1994 (Table 18).

Table 18. Five-Year Average Gain-Loss Estimate for Water District 2, 2008-2012.

WDID or Abbreviation	Structure Name	5-year Average* (2008-2012)	Reach Length	Reach Gain-Loss	Reach Gain-Loss	Gain-Loss per Mile	Gain-Loss per Mile
		AF	Miles	AF	cfs	AF	cfs
PLAHENCO	HENDERSON GAGE*	322,622					
0200810	BRIGHTON DITCH	-7,038					
BIGDAFCO	BIG DRY CREEK AT MOUTH NEAR FORT LUPTON	+28,924					
0200812	LUPTON BOTTOMS DITCH	-18,351					
0200813	PLATTEVILLE DITCH	-21,329					
PLALUPCO	FORT LUPTON GAGE	338,840	17.1	34,012	47.0	1,994	2.8
0200821	MEADOW ISLAND #1 DITCH	-5,930					
0200817	EVANS #2 DITCH	-53,156					
0200822	MEADOW ISLAND #2 DITCH	-11,543					
0200824	FARMERS INDEPENDENT DITCH	-24,712					
0200825	WESTERN MUTUAL DITCH AKA HEWES COOK	-20,966					
0200826	JAY TOMAS DITCH	-345					
SVCPLACO	ST VRAIN CREEK at PLATTEVILLE	+154,903					
0200828	UNION DITCH	-24,298					
0200830	SECTION NO 3 DITCH	-8,977					
BIGLASCO	BIG THOMPSON at LASALLE	+45,947					
0200834	LOWER LATHAM DITCH	-42,716					
0200836	PATTERSON DITCH	-6,334					
0200837	HIGHLAND DITCH	-4,636					
CLAGRECO	CACHE LAPOUDRE at GREELEY	+132,804					
PLAKERCO	KERSEY GAGE	659,022	38.7	190,141	262.6	4,917	6.8

Source: HydroBase Version 20130710.
*Blue = Stream gage; Red = Inflows; Black = Diversions

Currently, high-resolution data is not readily available to help determine surface and groundwater splits between gains and losses seen in the S. Platte. This data could be mined from augmentation plan accounting but this would be very laborious and time intensive for a single snapshot in time. The underlying simplifications in our analysis, such as distributing gain/loss over the reach, and not lagging or routing, limits the use of the analysis to a basic understanding of water balance and changes of water balance over time. Attempting to draw too much from this point flow analysis may result in invalid interpretation. Obtaining more refined analysis results, such as impacts of return flows over time, requires using a more complex approach such as the

CDSS models. While trends can be detected in this analysis, the point flow mass balance approach is driven by surface hydrologic conditions and diversions and is not sensitive enough to draw direct relationships to groundwater pumping, recharge or groundwater levels. However, the analysis does not contradict the observed increase in developed recharge below Kersey in the late 2000s.

(More detail on the gain loss analysis can be found in the Appendix X to this document.)

Call Records

As noted earlier, alluvial groundwater users are responsible to repay injurious river depletions taken out-of-priority during times the river is under senior call or administration. One of many changes that have occurred in the basin over time has been the percentage of time during which the river is under administration, particularly outside of the typical irrigation season. At one time there was a so-called "gentlemen's agreement" in the S. Platte for how surface reservoirs would be filled during the off-season. That agreement held that following the normal irrigation season, surface reservoirs would begin storing river flows from the top of the basin down, and lower river seniors would avoid making a priority call. This resulted in there being minimal wintertime call on the river and thus the wintertime stream depletions caused by pumping from the previous years did not have to be replaced by irrigation well owners. This was a major benefit for well augmentation plans and particularly for GASP and CCWCD. The gentlemen's agreement began to break down in the late 1990s as more artificial recharge projects were developed for augmentation plans, taking advantage of free river periods when reservoirs were filling under the gentlemen's agreement. The loss of the agreement increased the period of time the river was under call, and hence, the depletions owed back to the river system by well users. Division 1 staff still attempts to facilitate upstream reservoir fill by working with water users to encourage cooperation and efficiency in the spirit of the gentlemen's agreement, but this only works if adequate water is available in the river.

SPDSS Task Memo 7.1 prepared by Leonard Rice Engineers and dated November 15, 2006, characterizes the historical call regime over time. Water commissioners set the location and priority date of a valid river call based upon the flow of water in the river and the demand for that water from senior water rights. Under the administration of a call, upstream water right holders junior to the calling water right priority date are curtailed. Multiple calls can be active in the river at the same time; upstream calls are always more senior than downstream calls. In the S. Platte basin there are two basic types of calls – standard and bypass. A bypass call occurs when an upstream junior water right can divert a portion of its water right while bypassing a sufficient amount passed its head gate to satisfy the downstream senior calling right. Bypass calls allow more beneficial use from the river than if only the senior downstream ditch was calling and upstream junior rights were completely curtailed. Exchange of water rights is important to the optimal utilization of the river. Under this practice, decreed water from one source on the river is passed downstream in exchange for water at some other point, usually higher in the system. This is allowed only if there is no injury to other users.

The Water District 2 administration is typically controlled by the Jay Thomas 1865 18 cfs and the Western Mutual 1866 and 1871 rights, both of which are above the confluence with the St. Vrain. A number of ditches in Water District 1 have water rights with 1882 priority dates or 1882 and 1888 priority dates (Bijou Canal, Fort Morgan Canal, Upper Platte and Beaver Canal, Lower Platte and Beaver Canal). These water rights, in particular the 1882 rights, are frequently operated as bypass calls to the Sterling No. 1. Administration of the lower river is typically controlled by the senior right at the Sterling No. 1 (July 15, 1873 for 113 cfs).

The absence of the call indicates free river conditions. However, free river conditions do not automatically imply water is available for diversion by a junior appropriator. For example, there are numerous instances when a ditch may not have made a call because there was no upstream user with a junior right that could be called out or a user with a senior right decided it was not necessary to call out a junior diverter. Additional diversions by a junior upstream appropriator may have triggered a call.

The S. Platte Compact (1923) with Nebraska was settled in 1923. Between April 1 and Oct 15 of each year Colorado has full use of the river except in District 64 where the right of the Western Canal to divert 120 cfs under its 1897 right is recognized. Thus, Colorado is required by the compact to curtail all diversions in District 64 junior to June 14, 1897 when the Julesburg gage falls below 120 cfs during the irrigation period. Times when the river falls below 120 cfs during this period are registered as a S. Platte Compact call. The provisions of the compact have not been difficult to meet as times when the flow at the state line is below 120 cfs often already have water rights junior to 1897 called out. Flows less than 120 cfs are not uncommon during summer. The annual period subject to the compact is 198 days and the lower river is currently under compact administration an average of 116 days per year over the past decade (Table 19).

Analysis of the call data from 1982 to 2012 show that administration of the river has changed in the recent decade (Table 19). In the past, the number of days the river was under administration was typically a function of water supply from snowpack and precipitation, as can be shown comparing the slightly dry 1982 when there were more calls than normal, to the extremely wet 1983 water year when the river was free the entire year. Prior to water year 2000, the S. Platte compact call days were the same as the days of call in Water District 64. This changed sharply beginning in 2000 when additional calls were put on the river in the irrigation season and the reservoir filling season. Table 19 below shows the average days under call in the period of 2002-2012 has tripled in District 2, quadrupled in District 1, and more than doubled in District 64 when compared to the 1982-2001 period. Off-season calls account for much, but not all of this change in administration (Figures 42-44). The net impact is a double whammy of more days that well depletions must be repaid and fewer days of free river when junior augmentation rights can be exercised.

Table 19. Days of Call per Irrigation Year in Water Districts 2, 1, and 64, 1982-2012.

Irrigation Year	District 2	District 1	District 64	Compact
1982	129	24	108	108
1983	0	0	0	0
1984	3	2	15	15
1985	45	13	65	65
1986	57	0	53	53
1987	46	28	38	38
1988	80	67	80	80
1989	165	124	116	116
1990	75	35	117	117
1991	129	106	94	94
1992	113	36	56	56
1993	149	110	92	92
1994	187	98	155	155
1995	86	23	26	26
1996	189	43	70	70
1997	62	20	37	37
1998	91	34	72	72
1999	58	51	3	2
2000	186	170	130	129
2001	199	120	104	83
2002	300	196	195	184
2003	362	362	216	178
2004	363	362	282	197
2005	329	324	193	93
2006	362	356	224	166
2007	276	282	193	115
2008	324	328	211	170
2009	300	258	98	10
2010	162	138	90	4
2011	322	160	53	0
2012	260	219	193	158
Average 1982-2001	102	55	72	70
Average 2002 - 2012	305	271	177	116

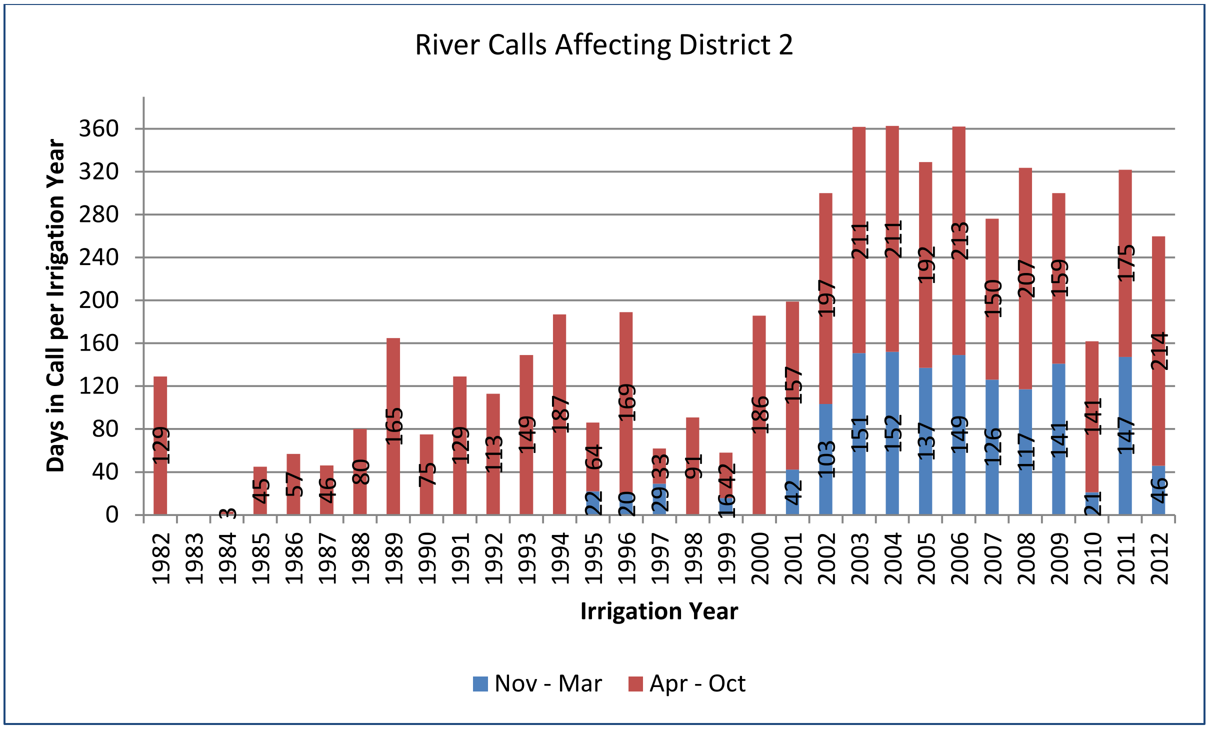


Figure 42. On and Off-Season River Calls Affecting Water District 2, 1982-2012.
Data Source: CO DWR HydroBase Version 20130710.

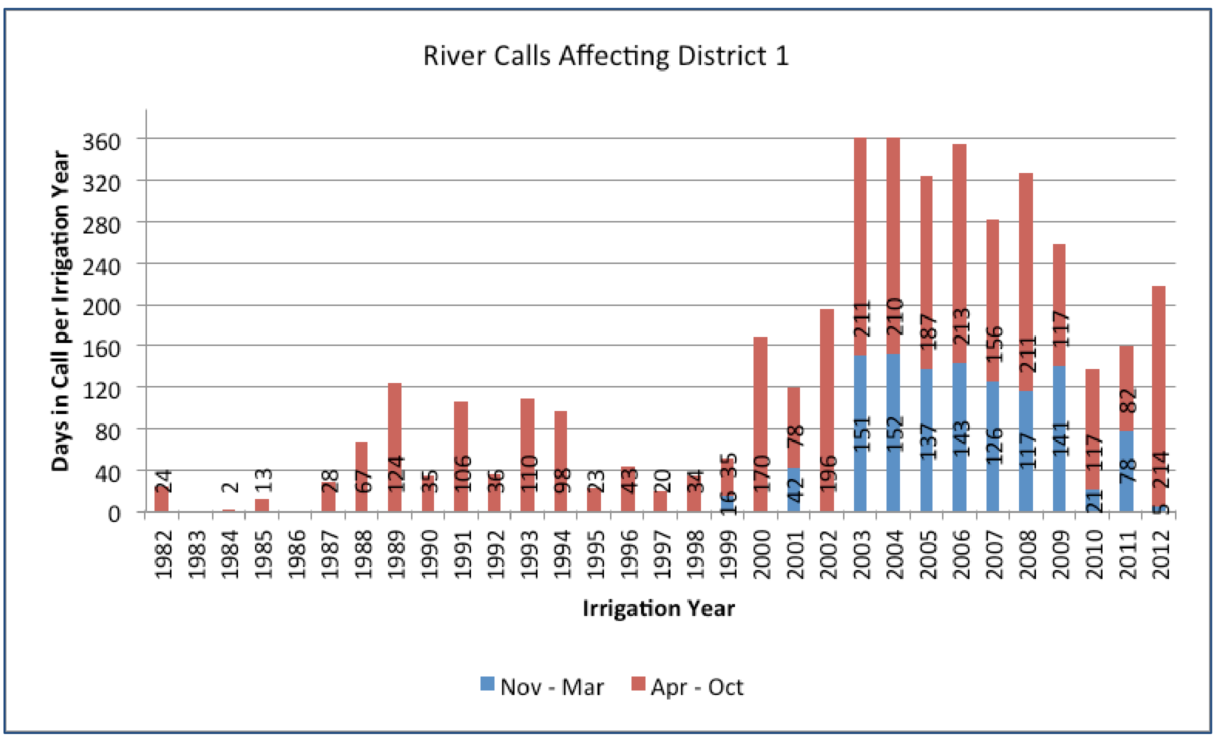


Figure 43. On and Off-Season River Calls Affecting Water District 1, 1982 – 2012.
Data Source: CO DWR HydroBase Version 20130710.

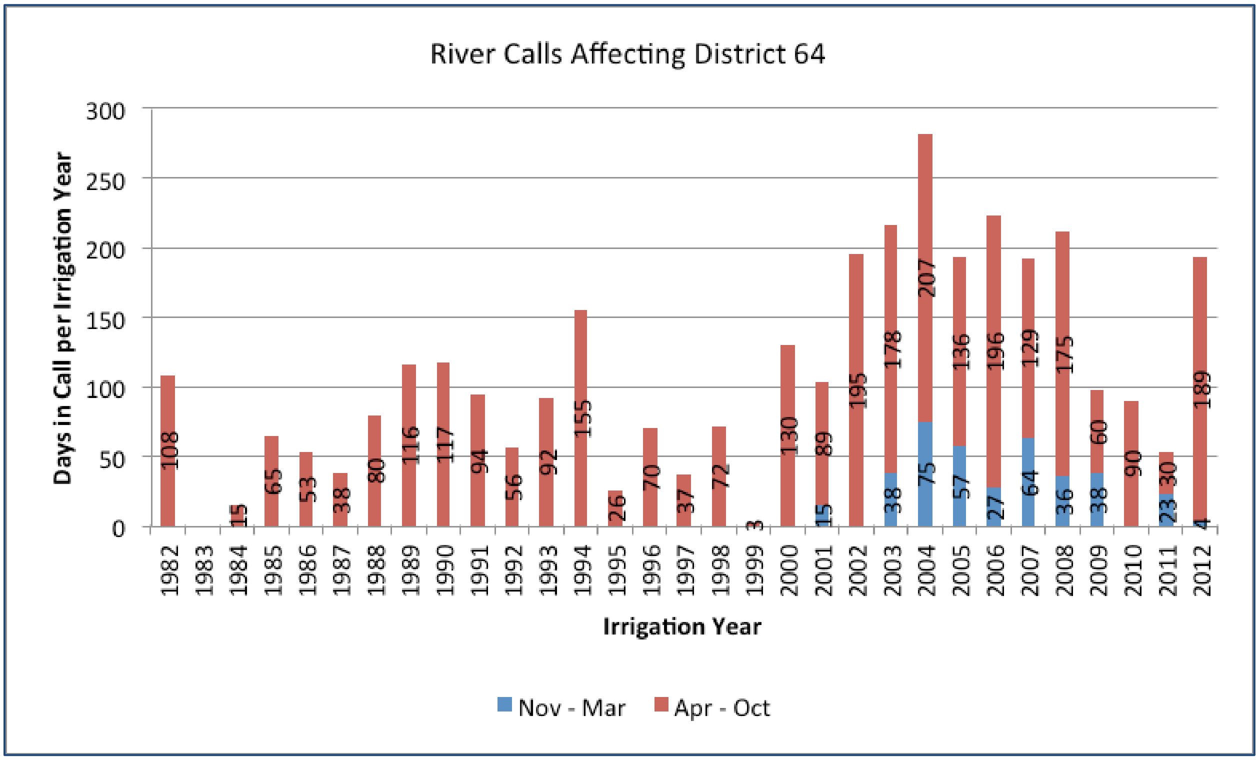


Figure 44. On and Off-Season River Calls Calls Affecting Water District 64, 1982-2012.
Source: CO DWR HydroBase Version 20130710.

It should be noted that not all calls impact irrigation wells. Most of the high capacity irrigation wells in the basin have 1930s-1960s adjudication dates. Any call junior to a well's adjudicated priority date would not trigger augmentation requirements for those depletions. The oldest augmentation calling right on the river is the 1972 Fort Morgan Plan. Post-1972 augmentation plans include recharge rights that occasionally are in priority as the calling right – wells senior to that date do not have to replace these depletions called by augmentation plans. In most cases, these operate as by-pass calls to senior users. Recharge calls almost all operate as bypass calls to rights senior to most wells when there was enough water to meet the senior demand, but not enough to go to free river. These calls maximize beneficial use by allowing the well depletions to be in priority and not require augmentation, but keep the most junior rights out of the river so that the call does not yo-yo between senior calls and free river. The Division 1 Engineer estimates there are approximately 6,000 cfs of decreed water rights in Districts 1 and 64 for recharge and augmentation with post-1972 priority dates. Figures 45-47 show annual days of post-1970 (and hence recharge structure calls) call compared to total days of annual call. Recharge and recharge calls happen primarily in 2 periods – the spring and fall shoulder months, when neither direct use nor storage are at their peak, or in the dead of winter, when diversions down very long ditches to storage can be problematic due to icing (reducing storage demand) but running water for in-ditch recharge and over shorter distances to recharge ponds can be done with less difficulty.

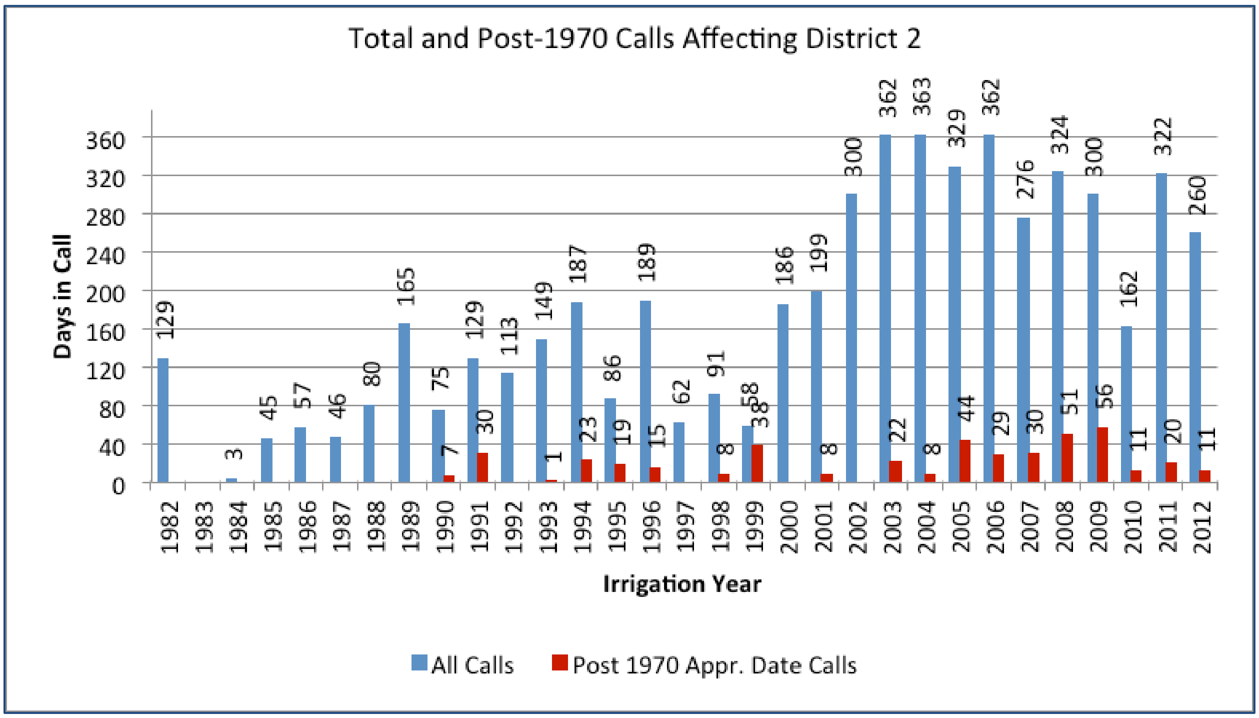


Figure 45. Total and Post-1970 River Calls Affecting Water District 2, 1982-2012.
Source: CO DWR HydroBase Version 20130710.

(More detail on the call records can be found in the Appendix XI to this document.)

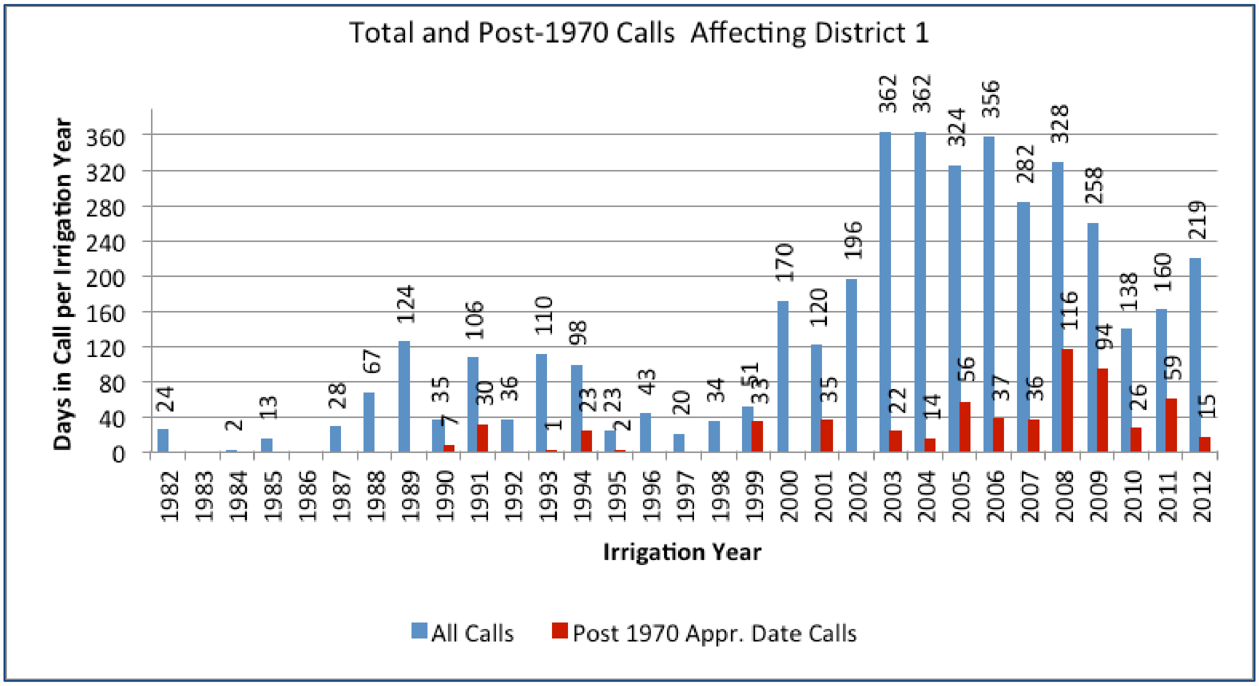


Figure 46. Post-1970 River Calls Affecting Water District 1, 1982-2012.
Source: CO DWR HydroBase Version 20130710.

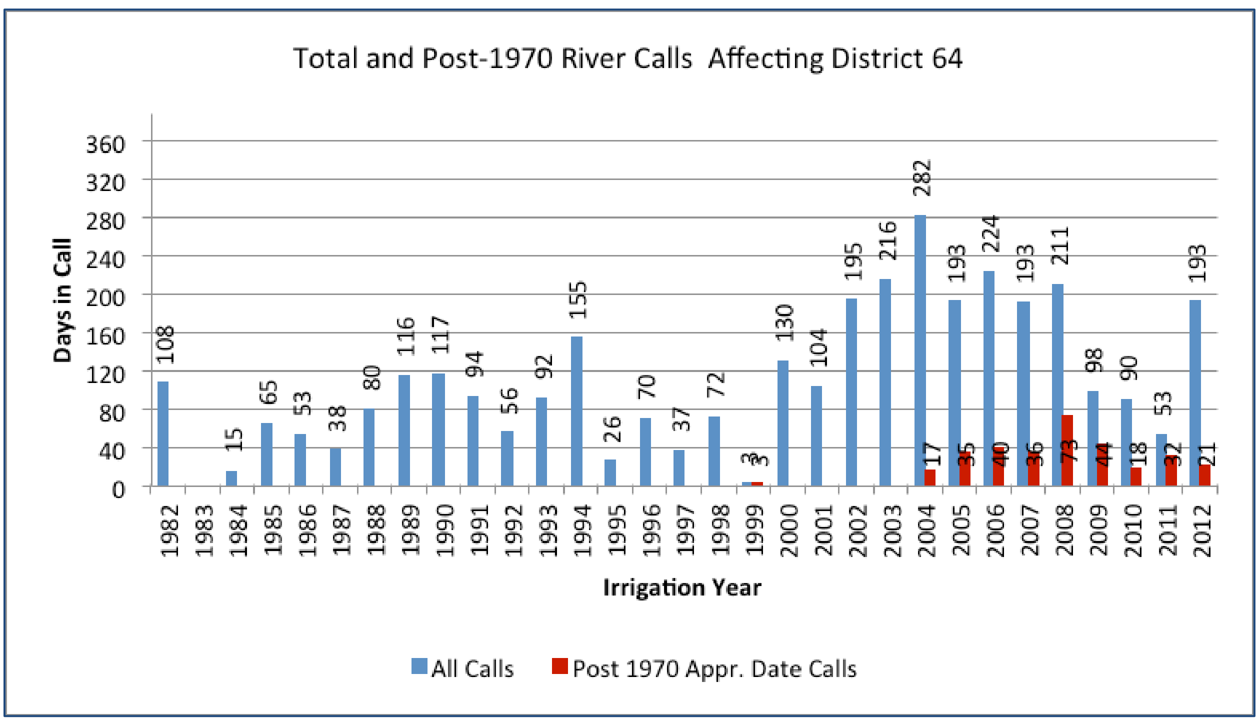


Figure 47. Post-1970 River Calls Affecting Water District 64, 1982-2012.
Source: CO DWR HydroBase Version 20130710.

CLIMATE

Key Points

- Precipitation data for the Sterling area show that 2009, 2010, and 2011 were wetter than average, contributing to the problems homeowners were experiencing with high water levels. The years 1990, 1992, 1997, and 1998 were also wetter than average, but we are unable to show rising groundwater levels during those years.
- Precipitation data for the Gilchrest/LaSalle areas were close to average for the years 2009, 2010, and 2011, making it difficult to attribute localized precipitation as the cause for higher than normal water tables in this area. Higher than average ditch diversions in 2011 due to plentiful snowpack likely increased seepage amounts.
- In the sixteen years since 1998, only four winter snowpacks have exceeded the 30-year average in the S. Platte basin.
- The current status of climate data collection in the S. Platte is problematic. A more robust and adequately funded network of weather stations with high spatial representation should be considered to ensure Colorado can meet the data needs of stakeholders.
- The Colorado Climate Center at Colorado State University developed climate information for the HB1278 study.

The South Platte River basin is characterized by a continental type climate with moderately cold winters and warm summers and irregular patterns of seasonal and annual precipitation. The climate of the S. Platte basin is inherently variable. The highest elevations of the basin provide the majority of water supply to the lower portion of the basin through snowmelt from frequent winter storms. These storms originate in the Pacific, bringing orographic precipitation to the high mountains. The higher elevations where snow accumulates during the winter season receive on average about 32 inches of precipitation per year, in contrast to the lower portions of the basin, which on average receives less than 19 inches annually (Table 20). The area just between the foothills and eastern plains receives even less on average due to the mountain rain shadow limiting annual precipitation to 13-15 inches as storms come off the mountains, descend, and dry out. The mountains receive the majority of their precipitation in mid-winter and spring, while the foothills/urban corridor receive most during the spring and early summer. Spring storms are important in the mountains, foothills and eastern plains for water supply.

Summers on the eastern plains are characteristically hot and dry with abundant sunshine, but are also the time when the eastern plains receive the majority of their annual precipitation. On the plains, annual precipitation can vary from 50% of normal in a dry year to 200% of normal in a wet year, with most years falling in the 70-140% of normal range. The difference between a wet and dry year can simply be the presence or absence of a few major storms. Hot and dry years inevitably lead to surface water shortages and reduced groundwater recharge. SPDSS Task Memo 64 reviewed precipitation recharge estimates as an input parameter the groundwater model and estimated that recharge from precipitation in the S. Platte ranges from approximately 15% of total precipitation along the foothills down to as low as 2% in the lower basin. Antecedent moisture conditions at the time of precipitation and soil texture greatly influence the amount of deep percolation reaching the aquifer. Evapotranspiration rates in the basin are high due to warm summer temperatures, low relative humidity, high solar radiation and wind, averaging from 45-55 inches of potential or reference ET for the eastern plains (Table 21).

Table 20. Monthly and Annual Precipitation in the S. Platte Basin.

Stations	Precipitation												
	Jan	**Feb**	**Mar**	**April**	**May**	**June**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**	**Annual**
	Inches												
AKRON 1 N	0.3	0.4	0.9	1.7	2.9	2.5	2.6	2.3	1.2	1.1	0.6	0.4	16.7
AKRON 4 E	0.4	0.4	0.9	1.4	2.7	2.5	2.5	2.6	1.1	1.1	0.6	0.4	16.5
BRIGHTON 3 SE	0.4	0.4	1.2	1.7	2.3	1.9	1.5	2.1	1.1	1.0	0.8	0.5	14.7
CROOK	0.3	0.4	1.1	1.7	2.6	3.0	3.3	2.2	1.2	1.1	0.5	0.5	17.8
FT MORGAN	0.2	0.2	0.7	1.3	2.2	2.4	2.3	1.9	1.3	1.0	0.4	0.3	14.2
GREELEY UNC	0.5	0.4	1.1	1.8	2.4	1.9	1.7	1.5	1.1	1.0	0.7	0.6	14.7
JULESBURG	0.5	0.4	1.2	1.7	2.8	3.0	2.5	2.6	1.4	1.3	0.5	0.3	18.2
LEROY 9 WSW	0.3	0.4	1.0	1.6	2.7	2.8	3.0	2.3	1.3	1.1	0.6	0.4	17.5
LINDON 5 WNW	0.3	0.3	0.8	1.4	2.2	2.4	2.9	2.3	0.9	1.0	0.6	0.3	15.4
LONGMONT 2 ES	0.5	0.4	1.4	1.9	2.2	1.8	1.1	1.6	1.2	0.8	0.7	0.6	14.2
NEW RAYMER 21	0.3	0.4	1.0	1.7	2.7	2.6	2.3	2.2	1.4	1.2	0.6	0.4	16.8
NEW RAYMER	0.2	0.3	0.9	1.3	2.4	2.7	2.5	2.1	1.4	1.1	0.5	0.3	15.6
NORTHGLENN	0.4	0.4	1.2	1.8	2.2	1.7	1.9	1.5	1.0	1.0	0.7	0.6	14.3
NUNN 7 NNE	0.3	0.3	1.2	1.7	2.2	2.0	2.2	1.9	1.4	1.0	0.6	0.5	15.3
NUNN	0.2	0.3	1.0	1.6	2.1	2.2	2.0	1.7	1.2	1.1	0.6	0.3	14.2
STERLING	0.3	0.3	1.1	1.3	2.3	2.8	2.6	1.8	1.2	1.2	0.6	0.4	15.9

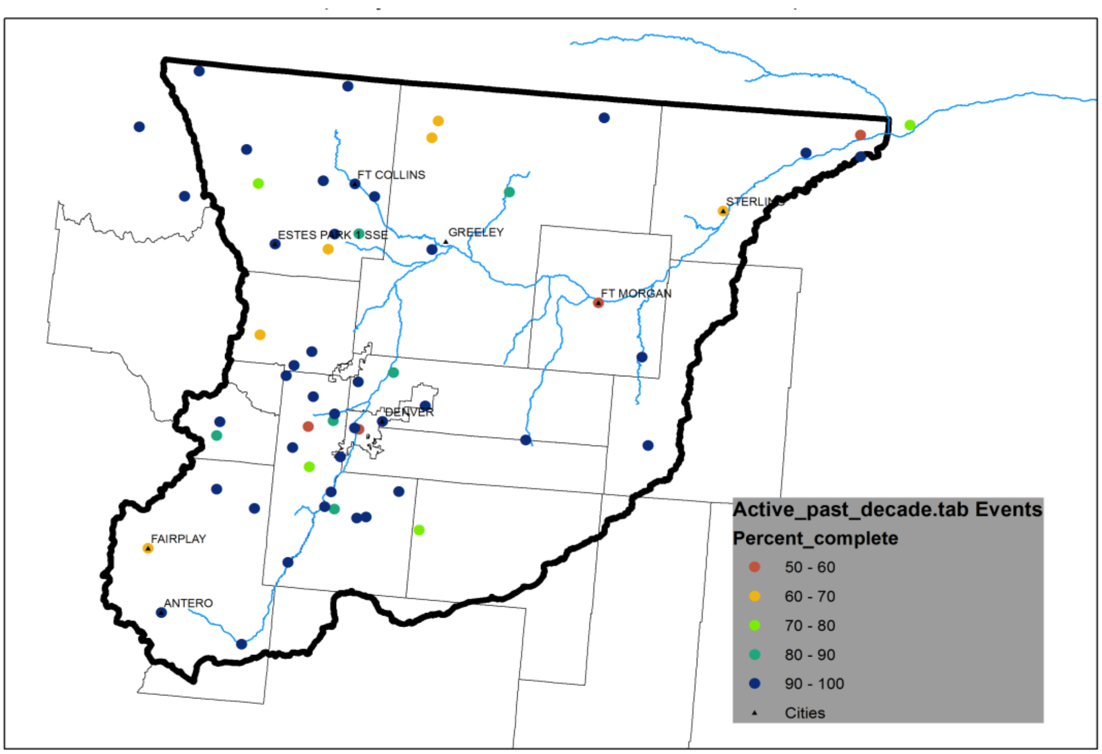
Source: Colorado Climate Center.

Table 21. Monthly and Annual Reference Evapotranspiration in the S. Platte Basin.

Stations	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual
	Reference Evapotranspiration (Inches)												
AKRON 1 N	1.9	2.1	3.2	4.2	5.6	6.8	7.5	6.9	5.3	3.9	2.5	1.8	51.7
AKRON 4 E	1.9	2.1	3.3	4.2	5.6	6.8	7.6	6.9	5.3	3.9	2.5	1.8	51.7
BRIGHTON 3 SE	2.0	2.1	3.3	4.3	5.7	6.8	7.5	6.8	5.2	3.9	2.5	1.8	52.0
CROOK	2.0	2.1	3.3	4.3	5.7	7.0	7.7	7.0	5.3	4.0	2.5	1.8	52.8
FT MORGAN	1.6	1.9	3.1	4.2	5.6	6.8	7.5	6.8	5.2	3.7	2.3	1.6	50.3
GREELEY UNC	2.1	2.3	3.6	4.6	6.0	7.1	7.8	7.1	5.5	4.1	2.6	2.0	54.8
JULESBURG	1.9	2.2	3.4	4.4	5.8	7.0	7.7	7.0	5.4	4.0	2.6	1.9	53.4
LEROY 9 WSW	1.9	2.1	3.2	4.2	5.6	6.8	7.6	6.9	5.2	3.9	2.5	1.8	51.6
LINDON 5 WNW	1.8	2.0	3.2	4.1	5.5	6.8	7.5	6.8	5.2	3.8	2.4	1.8	50.8
LONGMONT 2 ES	1.8	2.0	3.2	4.1	5.5	6.7	7.3	6.7	5.1	3.7	2.4	1.8	50.3
NEW RAYMER 21	1.6	1.7	2.7	3.6	5.0	6.1	6.9	6.3	4.7	3.4	2.1	1.5	45.5
NEW RAYMER	1.8	2.0	3.1	4.1	5.5	6.7	7.4	6.8	5.1	3.8	2.3	1.7	50.2
NORTHGLENN	2.3	2.4	3.5	4.4	5.8	7.0	7.6	7.0	5.4	4.0	2.7	2.1	54.2
NUNN 7 NNE	1.8	2.0	3.0	4.0	5.3	6.5	7.2	6.6	5.0	3.6	2.3	1.7	48.9
NUNN	1.8	1.9	3.1	4.0	5.4	6.6	7.3	6.7	5.1	3.6	2.3	1.7	49.7
STERLING	1.9	2.1	3.4	4.4	5.9	7.1	7.8	7.1	5.4	3.9	2.5	1.8	53.3

Source: Colorado Climate Center.

The National Weather Service Cooperative (COOP) Network serves as the backbone for long-term climate monitoring for nearly all areas of the United States. This network has been in existence since the late 19th Century and provides baseline climate monitoring for most of the country. Colorado has just under 300 of these stations statewide. Unfortunately, there have only been a handful of stations in the COOP network along and near the S. Platte from just downstream of Denver to the Nebraska state line. This region has been covered by fewer COOP stations per unit area than most regions of the U.S. The number of stations has been adequate to capture some of the broader trends and general patterns in temperature, but inadequate for documenting local conditions and the more highly variable precipitation of the region. The climate of the S. Platte River basin is such that the large majority of annual precipitation occurs during spring and summer, the months when spatial variability in precipitation is greatest due to local thunderstorm behavior. In the past decade, most of the key stations along the mainstem of the lower S. Platte have been discontinued or interrupted due to lack of observers and budgets to maintain the network. Map 23 shows the spatial distribution of stations in northeastern Colorado and the percentage of complete data from this network since 2000 that have 50% or greater data completeness.



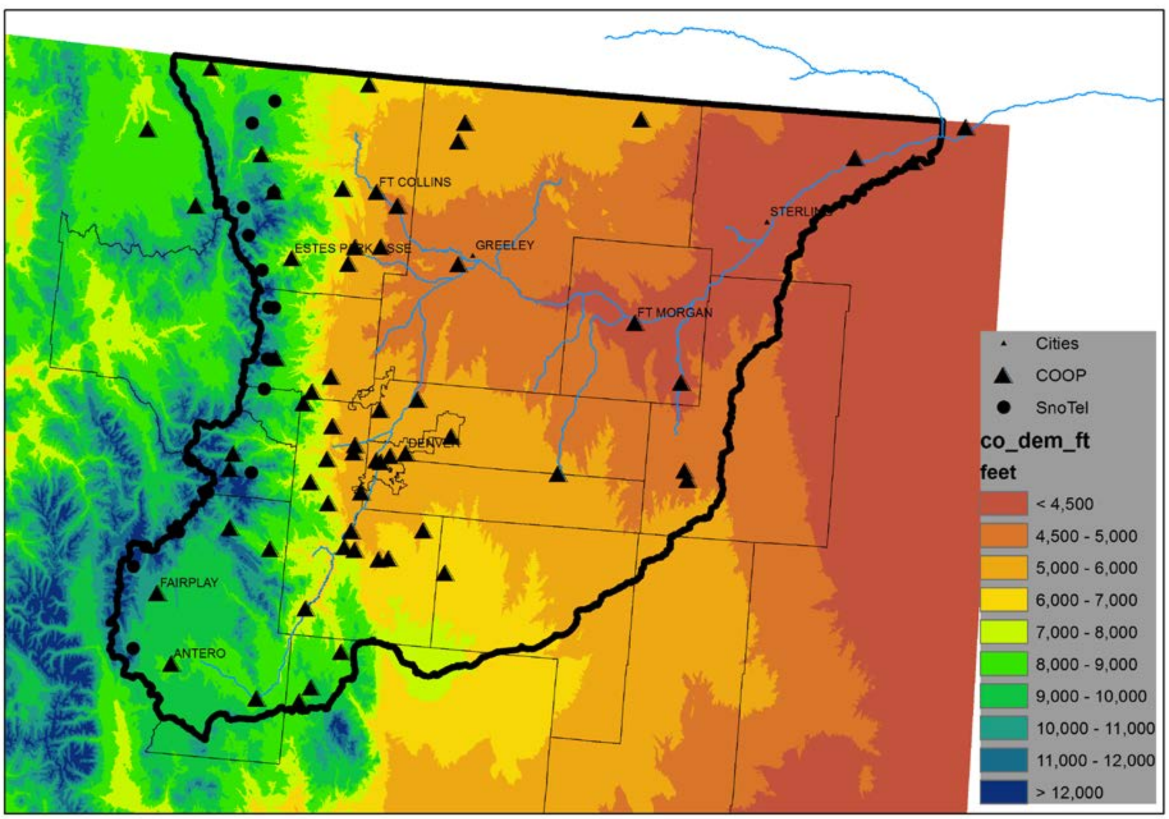
Map 23. Percentage of Complete Data for S. Platte COOP Stations Since 2000.
Source: Colorado Climate Center.

Areas near the Front Range have continued to collect reliable and nearly complete datasets since 2000. Areas farther east on the plains have seen long-term stations closed, leaving records with very low spatial resolution that have varying degrees of incomplete data (Map 23). The areas in the S. Platte with the most intensive agricultural practices have seen the sharpest decline in station data and reliability. Agriculture is one of the largest users of climate data for a variety of purposes, spanning irrigation scheduling to crop insurance claims. This lack of long-term, reliable data is detrimental to the agricultural sector of the basin and the water resources community.

The NWS COOP network is not the only data source available in the basin, but it does provide the only long-term records for comparison to historical conditions in the basin. In the early 1990s, the Colorado Climate Center along with the USDA Agricultural Research Service started the CoAgMet network. Beginning at about the same time, the Northern Colorado Water Conservancy District (NCWCD) initiated a network of similar stations. The purpose of these stations is to provide reference ET data based on physical models like Kimberly-Penman and the ASCE Standardized Penman equations during the growing season. These are automated stations that collect temperature, humidity, solar radiation, wind, soil temperature, and precipitation.

CoAgMet stations utilize tipping bucket rain gages that do not allow year round precipitation monitoring, since snow is not represented well. NCWCD has transitioned most of their stations to weighing gages that handle year-round precipitation much better; however, all of these stations have climatically short records.

SnoTel stations are used to measure meteorological parameters in the high mountains. These data aid in streamflow forecasting and water supply planning. Map 24 shows the current locations of active COOP and SnoTel stations. These networks achieve fairly good coverage over the mountains; however, the foothills zone (7,000-9,000 feet) is poorly represented both by COOP and SnoTel, particularly in Larimer and Boulder counties. This zone is very important for identifying the snow line and how much snow can contribute to runoff. Some years have very little low elevation snow, while the snowfall in other years greatly affects subsequent streamflow. The accuracy of seasonal streamflow forecasts for the S. Platte basin based on April 1 conditions tends to be less skillful than other basins in Colorado due, in part, to these data limitations.



Map 24. Locations of Active Snotel and COOP Weather Stations in the S. Platte Basin.
Source: Colorado Climate Center.

The COOP network below the elevation contour of 5,000 feet is very data sparse. There is no longer a Sterling site, which creates a large gap from Ft. Morgan all the way to Crook with no monitoring stations. There is also a large gap from Greeley upstream to Brighton and downstream to Ft. Morgan. Given the nature of convective storms in these areas during the summertime, these gaps leave much of the area unmonitored.

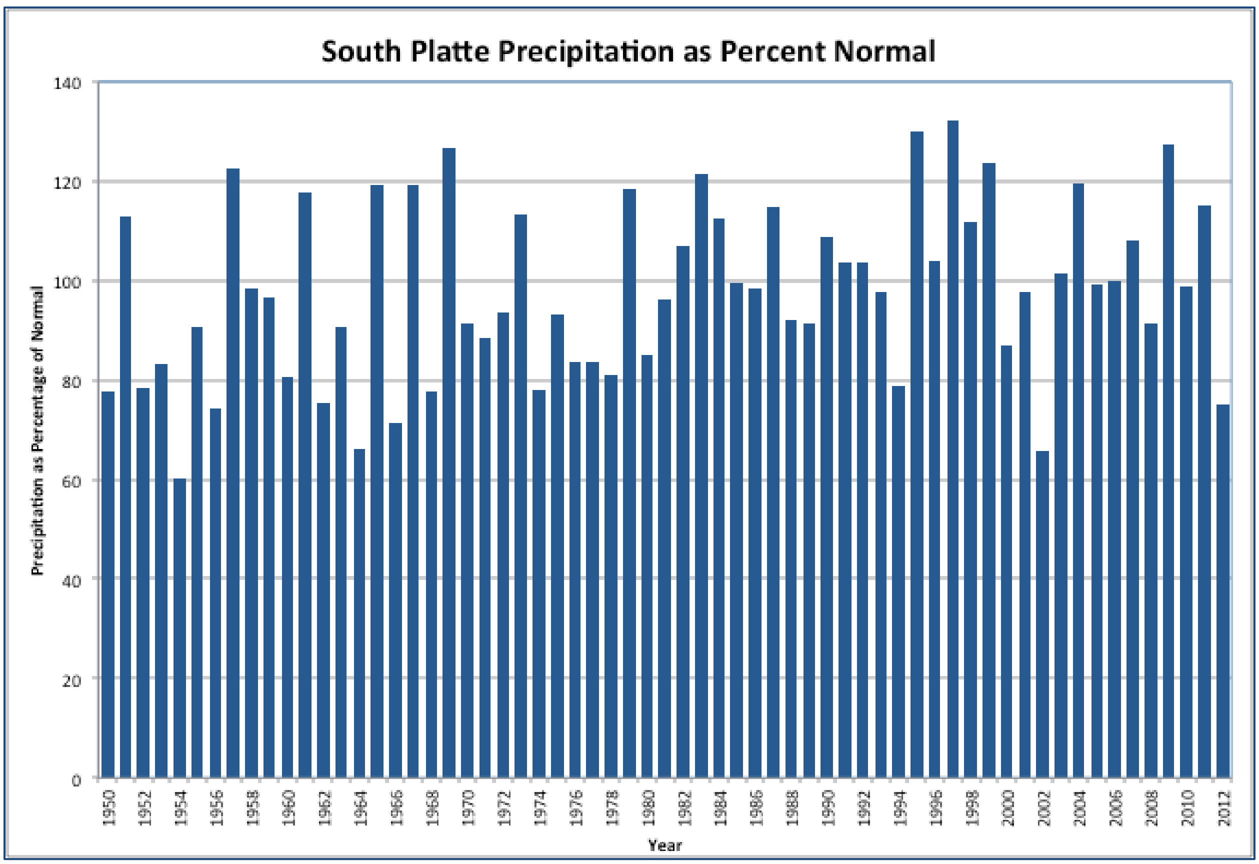


Figure 48. Annual S. Platte Basin Precipitation as a Percent of Average for the Water Years 1950 – 2013.
Source: Colorado Climate Center.

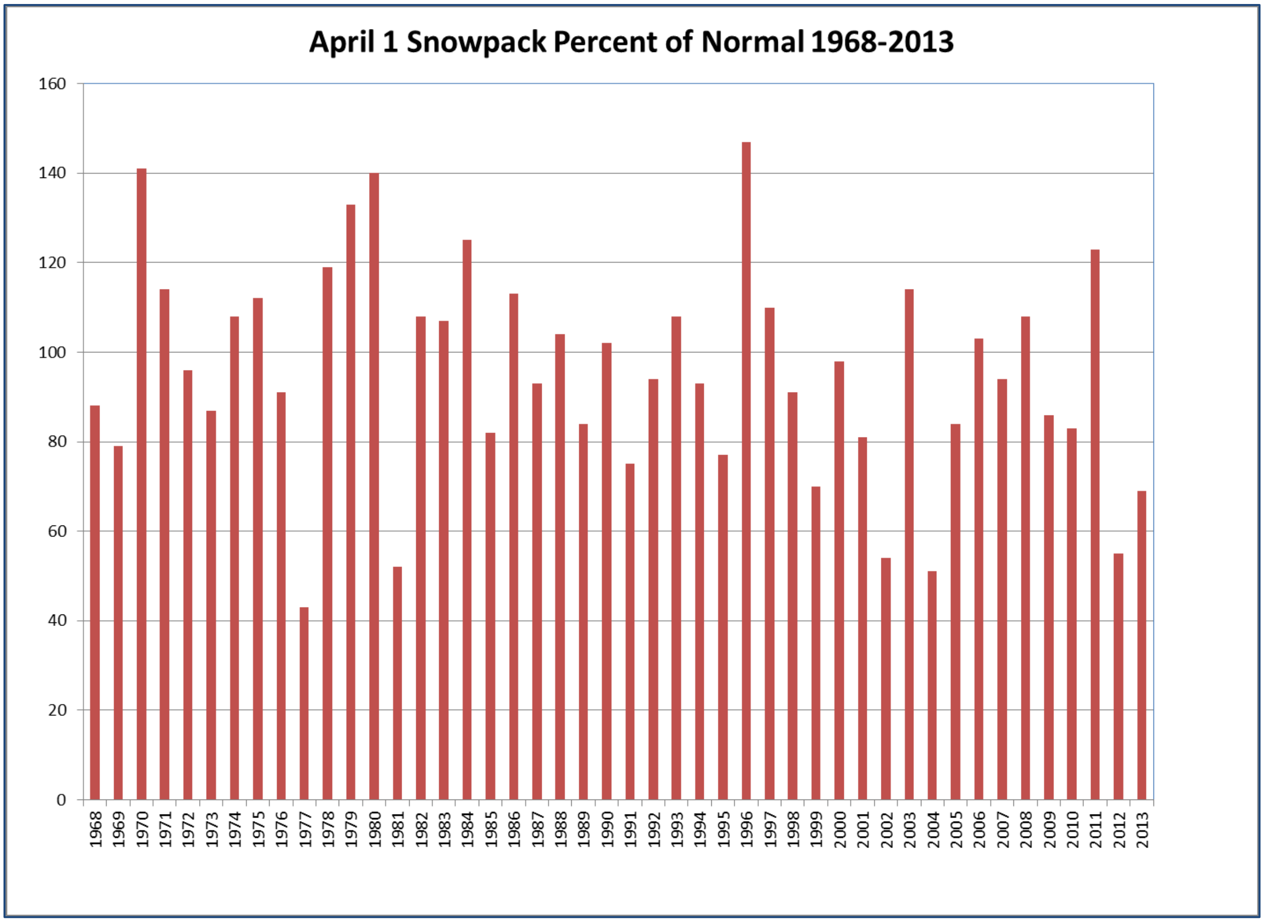


Figure 49. Annual Percent of Average Snowpack Accumulated on April 1 for the Water Years 1968 – 2013. Source: Colorado Climate Center.

Precipitation data for the Sterling area shows that 2009, 2010, and 2011 were wetter than average, no doubt contributing to the problems homeowners were experiencing with high water tables (Figure 48). The years of 1990, 1992, 1997, and 1998 were also wetter than average, but we are not able to locate reports indicating these years resulted in flooded basements in the area, nor does the groundwater level data indicate rising water levels during those years. Precipitation data for the Gilchrest/LaSalle Gilcrest/LaSalle areas were close to average for the years 2009, 2010, and 2011, making it difficult to attribute localized precipitation as the cause for higher than normal water tables in this area. In the sixteen years since 1998, only four winter snowpacks have exceeded the 30-year average in the S. Platte basin (Figure 49). The above average snowpack in 2011 led to increased surface water diversions and hence greater recharge in the basin. Conversely, the low 2012 snowpack and summer precipitation and above average 2012 temperatures increased crop ET and subsequently increased the need for pumping and resulted in reduced recharge, as is reflected in the observation well data.

(More detail on the S. Platte basin climate can be found in the Appendix XII to this document.)

PHREATOPHYTES

Key Points

- Phreatophytes are a good indicator of high groundwater levels, as their occurrence is governed by the presence of groundwater within their maximal rooting depth.
- We replicated a previous study by Groeneveld and Prescott who developed estimations of phreatophyte ET from groundwater in the S. Platte basin for the baseline year of 2001. We extended this methodology forward to 2010 and back to 1990 to evaluate the expansion of phreatophytes up to the current period.
- Phreatophytes continue to increase in the basin, resulting in large quantities of non-beneficial consumptive use, perhaps as much as 250,000 AF/yr. We found a 35% increase in phreatophyte ET over the 20-year period from 1990 to 2010.
- We were unable to link expanded phreatophyte ET to changed groundwater management in the basin as the data do not show an increase in phreatophyte ET in areas outside the river floodplain, but instead indicated a densification of phreatophytes within the same areas of the floodplain.
- The analysis of phreatophyte ET was conducted for the HB1278 study by Dr. Ahmed Eldeiry of Colorado State University.

HB1278 stated that the analysis of groundwater conditions in the basin should include an evaluation of the relationship between high groundwater levels and nonbeneficial consumptive use by phreatophytes. Phreatophytes are trees and other deep-rooted perennial vegetation types that derive some part of their ET demand from groundwater. They are typically a good indicator of high groundwater levels, as their occurrence is governed by the presence of groundwater within its maximal rooting depth. South Platte DSS Task Memo 65 by David Groeneveld and Michael Prescott dated January 30, 2007 developed estimations of phreatophyte ET from groundwater in the S. Platte basin for the baseline year of 2001. The method used Landsat data and a derivation of the Normalized Difference Vegetation Index (NDVI). Total annual phreatophyte ET estimated for their study area, which included the tributaries to the S. Platte, was approximately 255,000 AF per year within the riparian zones along the river and the tributaries in basin. The total annual phreatophyte ET estimated by Groeneveld for the riparian corridor along Water Districts 2, 1, and 64 was 123,686 AF for the year 2001.

By far, the largest proportion of phreatophyte ET occurs during the growing season along the mainstem of the S. Platte in the floodplain. Groeneveld's ET estimations were based on annual totals and included reaches not considered in the HB1278 study, specifically the mountain front to the Henderson gage, the Cache la Poudre basin, and portions of the tributaries including the Beaver, Badger, Bijou, Sand Creek, Box Elder Creek, First and Second Creek, and portions of Cherry Creek (Figure 50). Pixels within Landsat imaging have an area of 0.2 acres, so

Groeneveld's ET estimations were derived on this scale. A single Landsat image may be used because the presence of a high water table confers a reasonably steady state condition of water availability, and thus phreatophyte vegetation is generally not water limited. Given that the phreatophytic vegetation in the S. Platte is predominantly deciduous trees, most of the plant transpiration occurs during the growing season from May 1 to September 30. Additionally, given the topography and amount of run-on that occurs in the floodplain, Groeneveld reasonably considered all of the precipitation that occurred during the growing season to be effective, thus his calculation for phreatophyte ET from groundwater was essentially reference ET – total precipitation.

We replicated Groeneveld's 2001 results independently and then extended a slightly corrected method that used 30-year average precipitation and reference ET back to 1990 and forward to 2010 using the stretched normalized difference vegetation index (NDVI*) developed from Landsat 5 satellite images and the weather station data (reference ET and precipitation) in order to estimate the annual and seasonal phreatophyte ET from groundwater in the mainstem of the S. Platte. Landsat 5 satellite images with a 30 meter resolution were acquired for the years: 1990, 2001, and 2010. The resolution of the Landsat 5 images makes it difficult to differentiate between the annual and perennial vegetation; therefore, aerial photos with high resolution were also collected (Figure 51). Color aerial photos were acquired for the years 2005 and 2011 from the National Agricultural Imagery Program (NAIP) with one meter resolution. Weather station data were collected from 81 weather stations scattered over the S. Platte to develop a thirty year average (1980-2010) of both annual and seasonal ET and precipitation (Table 22 and Figure 52). The seasonal (May 1 through Sept 30) and the annual weather data were used with the NDVI* to estimate the annual and perennial phreatophyte ET in a raster map formats. The result of this work shows increases in phreatophyte ET from groundwater from 1990 to 2010 from 115,438 AF annually in 1990 to 156,601 AF annually in 2010, a 35% increase over the 20-year period. Because the riparian corridor is constrained by development and agricultural fields for most of the river through Districts 2, 1, and 64, the majority of the increase in ET is due to increased density of the canopy within the existing riparian corridor. Due to the constrained area of phreatophyte growth, we were unable to draw any relationship between changes in high water areas and phreatophytes.

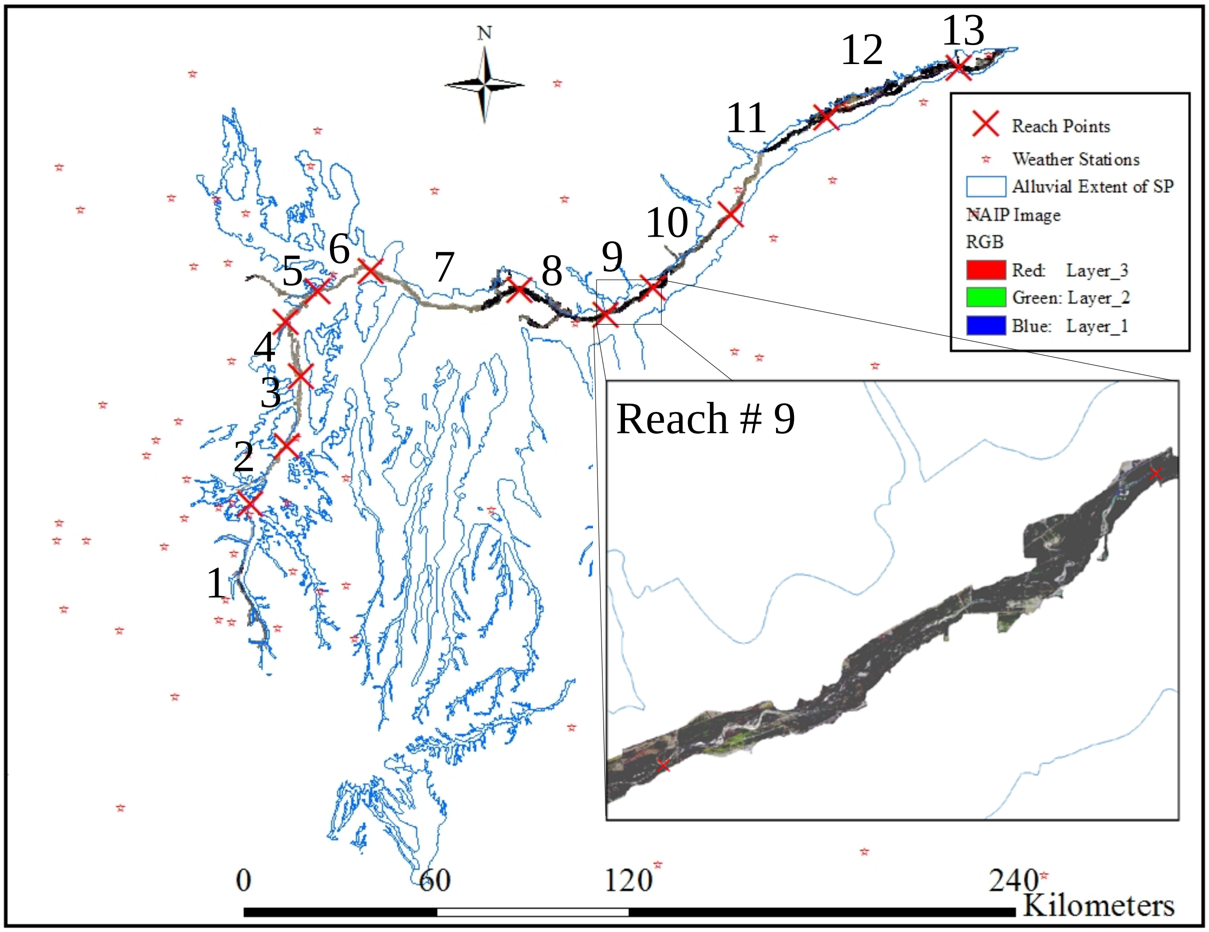


Figure 50. The Alluvial Extent, Reaches, and Weather Stations in the S. Platte Basin.

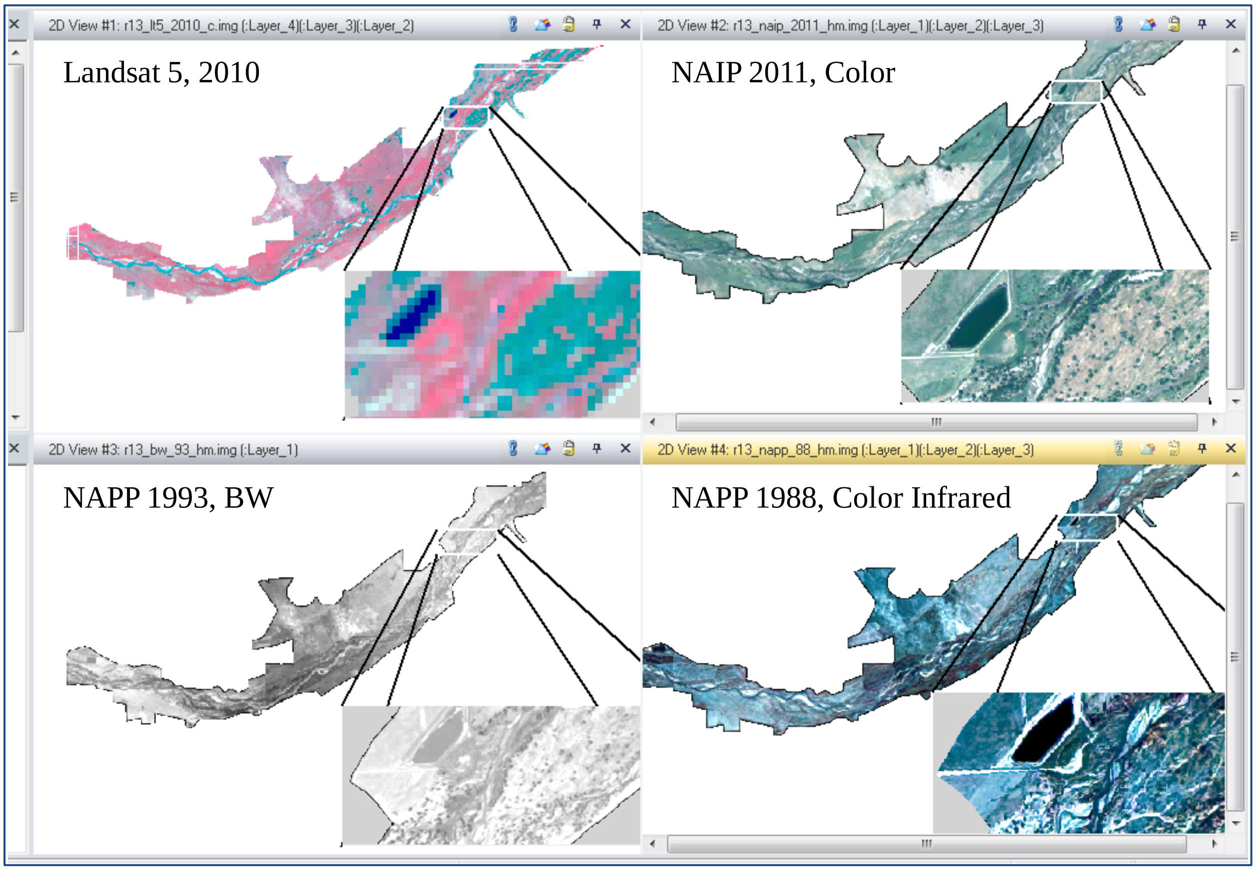


Figure 51. Examples of the Four Different Types of Images for River Reach 13: Landsat 5, ANIP Natural Color, NAPP Black and White, and NAPP Color Infrared Used to Track The Changes of Phreatophytic Vegetation.

Table 22. Annual and Seasonal Reference ET and Precipitation.

Dataset	Min. (in)	Max. (in)	Mean (in)	Std. Dev (in)	Median (in)
Annual ET	34.75	54.78	49.34	4.79	50.94
Annual Precipitation	10.86	30.82	17.41	3.09	17.12
Seasonal ET	22.65	33.47	30.60	2.69	31.60
Seasonal Precipitation	7.43	14.18	10.65	1.49	10.66

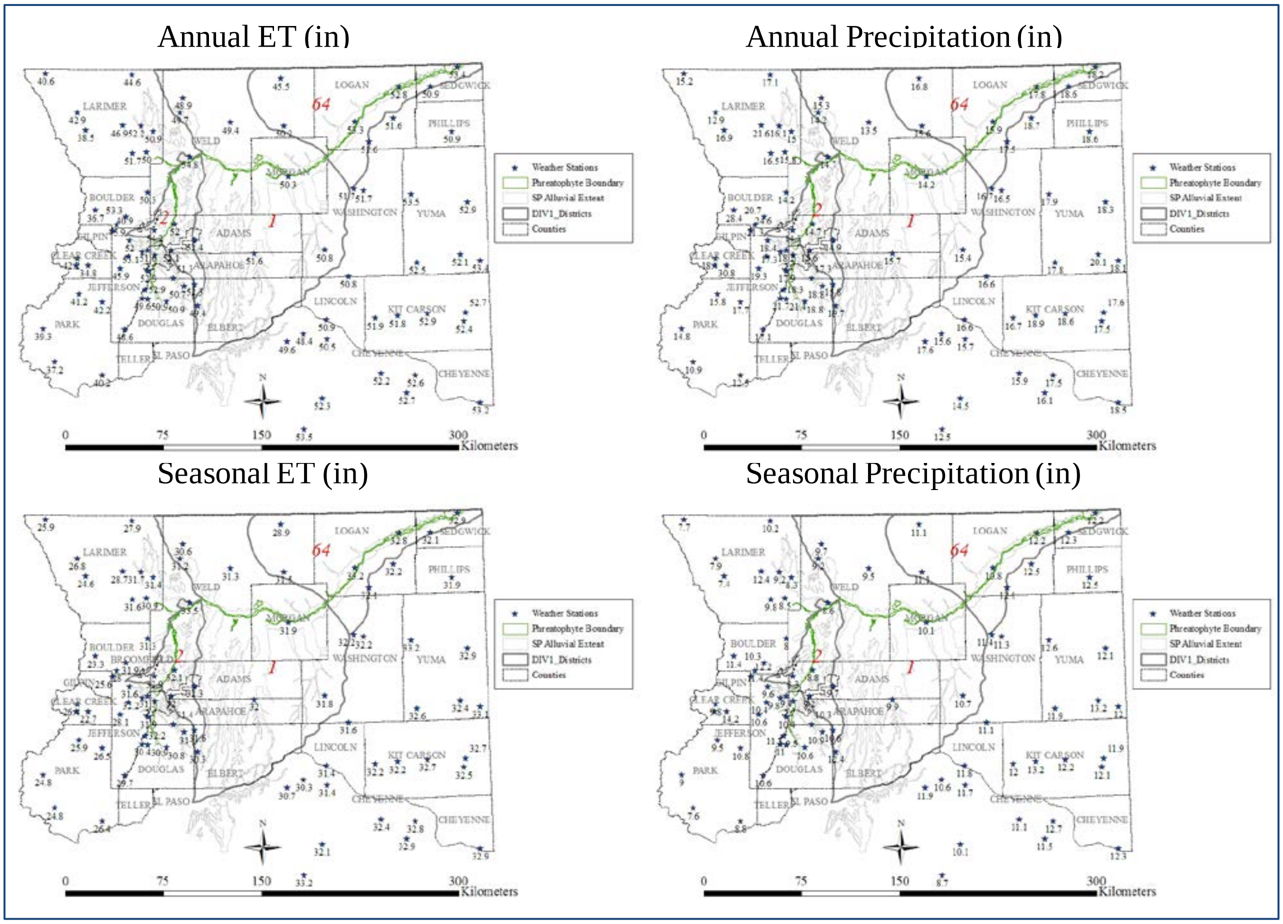


Figure 52. Thirty-Year Average Annual and Seasonal ET and Precipitation Data from 81 Weather Stations (1981-2010).
Data Source: Data acquired from the National Climate Center Data (NCDC).

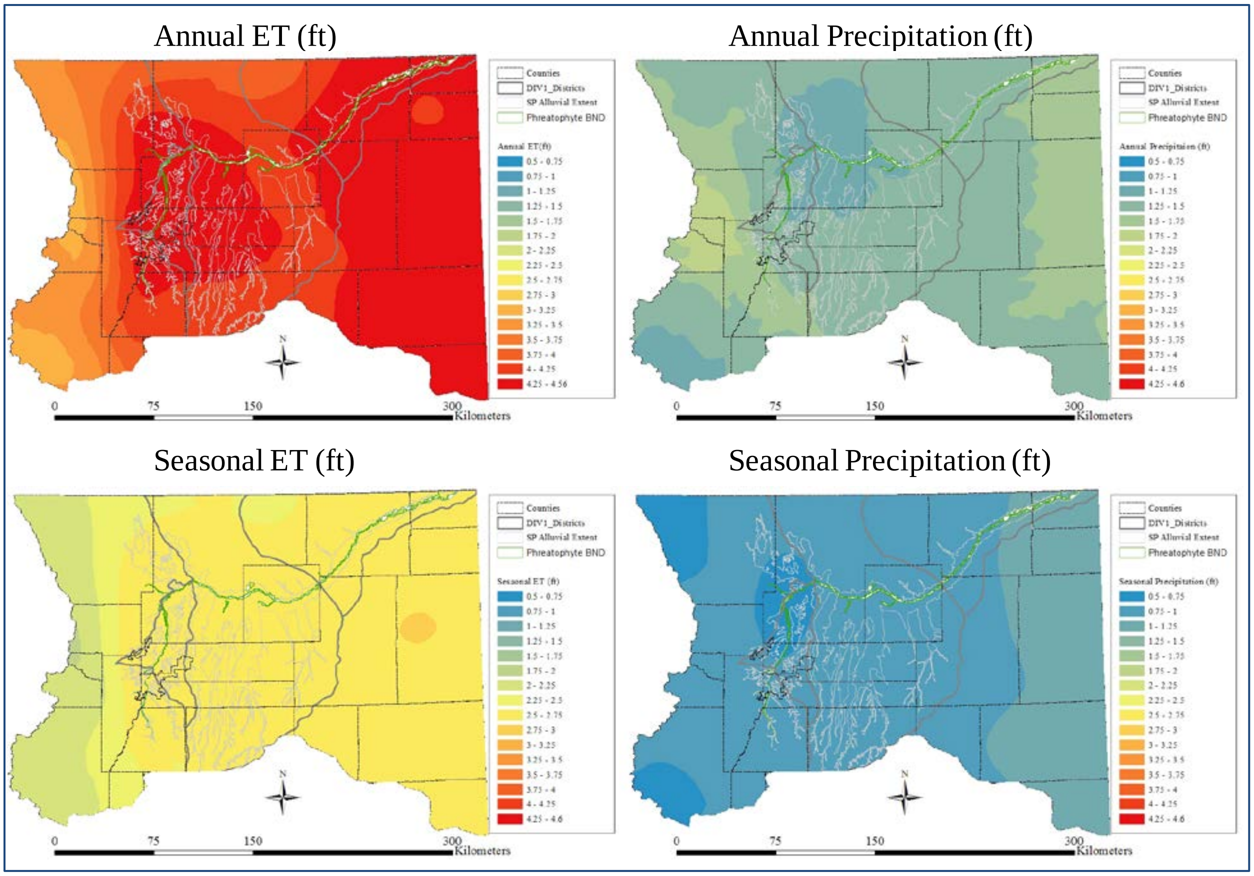


Figure 53. Average Annual and Seasonal ET and Precipitation Interpolated from Weather Station Data.

Data Source: Data acquired from the National Climate Center Data (NCDC).

Figure 53 shows both the annual and seasonal ET after subtracting the precipitation generated from the weather station data. The annual ET after subtracting the precipitation is in the range between 2.00 to 3.50 ft., the seasonal ET after subtracting the precipitation is between 1.25 to 2.25 ft., and the range of the NDVI* is between 0 to 1.00. To generate the final ET, each annual and seasonal ET after subtracting the precipitation is multiplied by the NDVI*.

Table 23. Comparison of the Annual and Seasonal Phreatophyte ET from Groundwater in AF for the years 1990, 2010, and 2011.

River Reach	1990		2001		2010	
	Annual phreatophyte ET (AF)	Seasonal phreatophyte ET (AF)	Annual phreatophyte ET (AF)	Seasonal phreatophyte ET (AF)	Annual phreatophyte ET (AF)	Seasonal phreatophyte ET (AF)
1	5246	3403	7479	4852	8230	5337
2	1081	686	1298	822	1555	985
3	2825	1750	3404	2109	4056	2513
4	4633	2897	5124	3203	6370	3986
5	4941	3137	5581	3542	7481	4749
6	2692	1697	3061	1929	4030	2540
7	19634	11947	22163	13481	24464	14876
8	9714	5861	11396	6876	15413	9301
9	6193	3726	6401	3851	6792	4087
10	11407	6808	11390	7110	13921	8317
11	13118	7903	13110	8890	20531	12363
12	26937	14297	23000	17000	34425	20612
13	7017	4192	7000	5577	9333	5577
Total	115,438	68303	120,406*	79,242	156,601	95,241

*Groeneveld et al., 2007, Annual phreatophyte ET for the 13 river reaches in 2001 was 123,686 AF using data from only 4 weather stations.

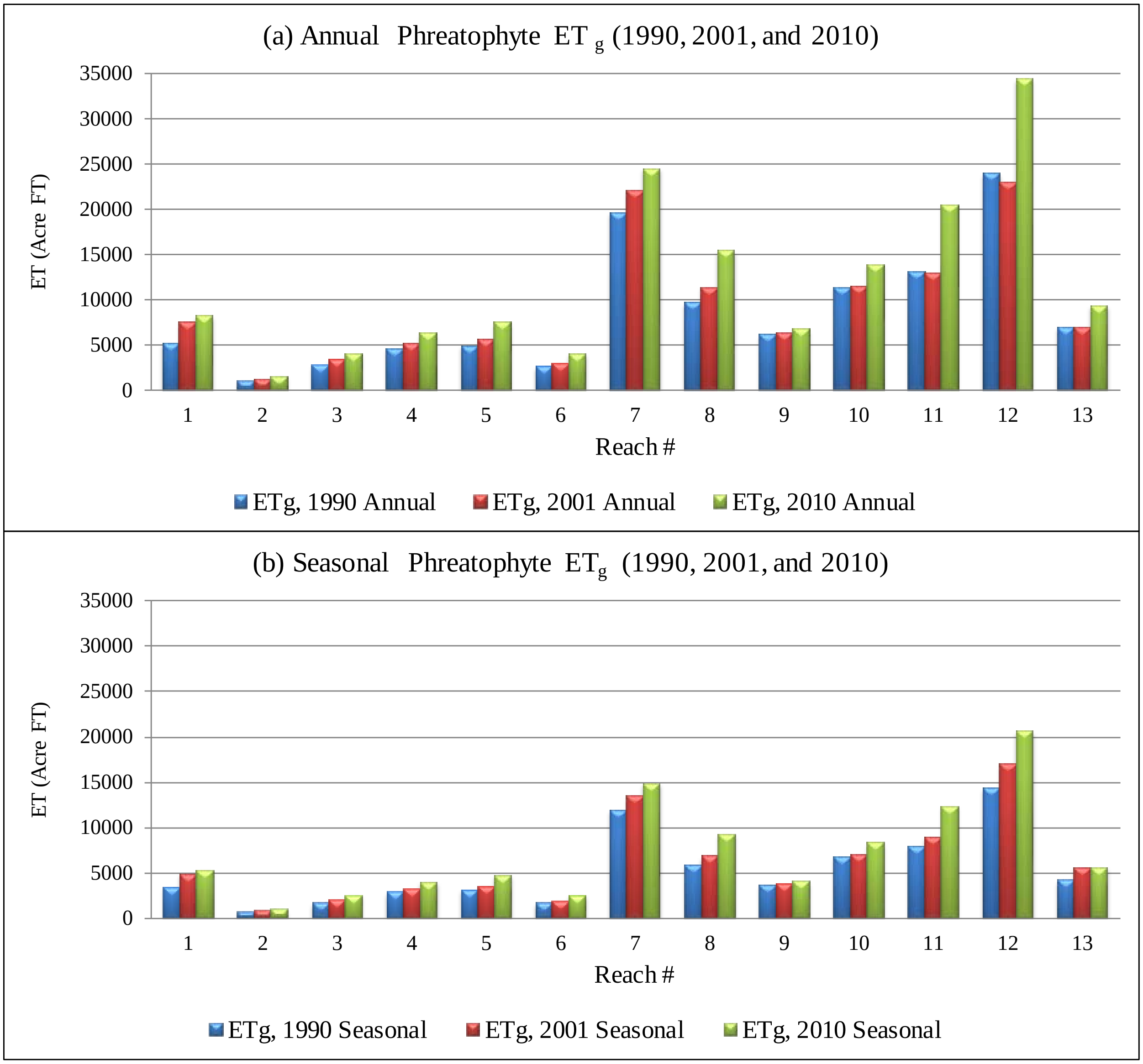


Figure 54. Annual and Seasonal Phreatophyte ET_g (AF) for the Years: 1990, 2001, and 2010.

Figure 54 and Table 23 above show a comparison among the years 1990, 2001, and 2010 of the annual and seasonal phreatophyte ET (AF). There is a clear trend of increasing of phreatophytes from 1990 to 2001 to 2010. In most cases, this increase is slight except few cases such as reaches 11 and 12. The total estimated ET_g (evapotranspiration from groundwater) for the years 1990, 2001, and 2010 are: 115,438, 120,406, and 156,601 respectively. Figure 54 above shows that most of the phreatophyte ET_g is consumed during the growing season. The rate of increase from 2001 to 2010 is higher than that from 1990 to 2001. In a comparison of our work to Groeneveld's 2001 study, we found the ET estimations were very close and the differences are mainly due to the number of weather stations used in the two studies. We find that Groeneveld's 2001 estimate of phreatophyte ET in the mainstem of the river below Denver of 123,686 AF/yr was reproducible and that total annual ET by phreatophytes had increase by approximately 35% in the past decade. It is likely that similar scale increases have occurred throughout the basin. However, we observe these increases vary by river reach and time from very slight to considerable.

We attempted to further refine ET estimates by classifying the vegetation types, separating annual plants from perennial trees (Figure 55). As there is no crop coefficient developed yet for phreatophytes, it is difficult to accurately estimate ET using methods that rely on Landsat images, which have 30m by 30m resolution, and relatively few weather stations. The low resolution of the Landsat images does not allow for an accurate estimate of phreatophyte types, whereas using aerial photos in conjunction with the Landsat images allows separation of perennial and annual phreatophytes. We found that there is a reduction in the estimation of phreatophyte ET_g when areas with only annual plants are subtracted from the total ET_g.

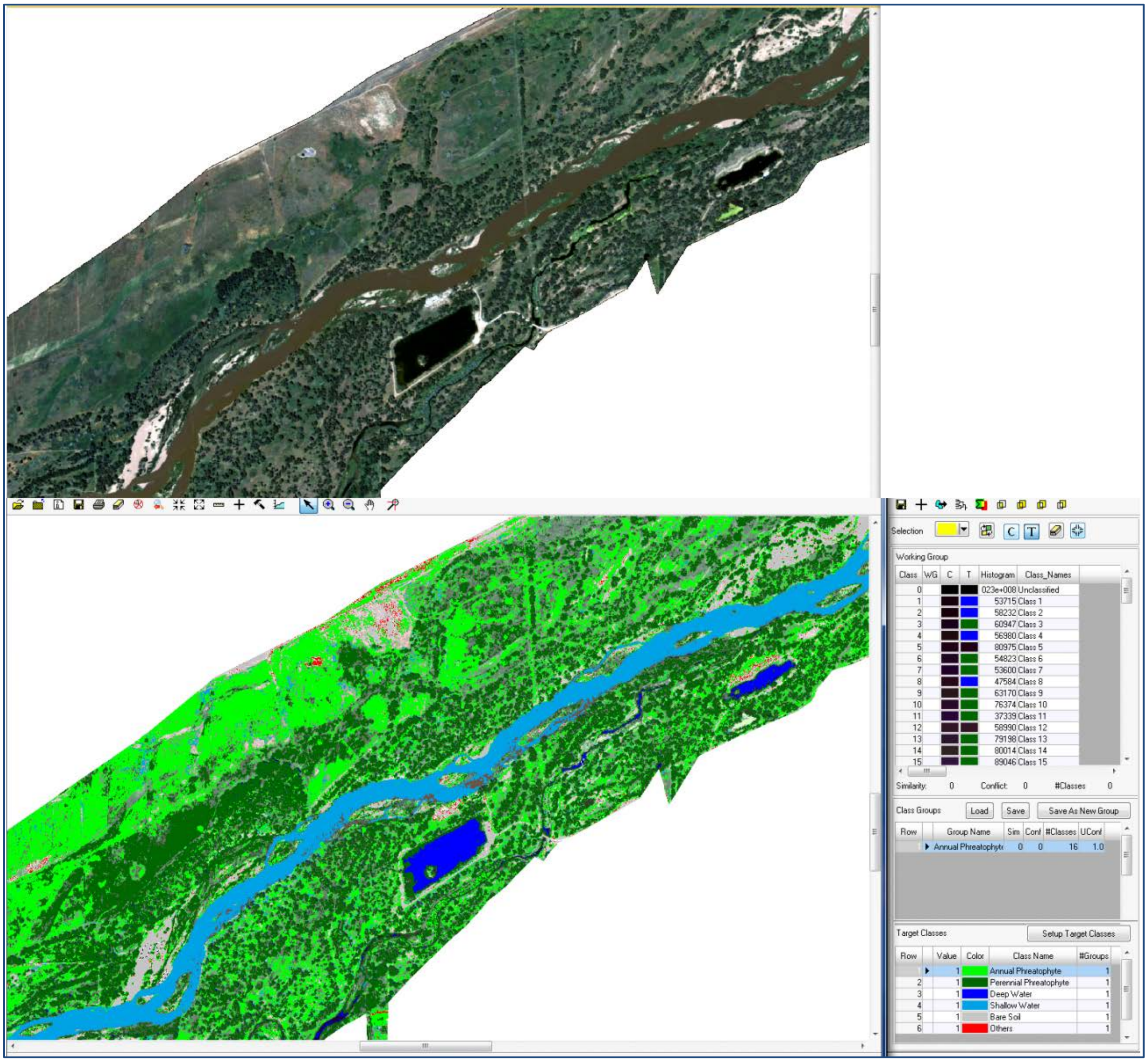


Figure 55. Example Stretch of the River with the Application of Grouping Tool Techniques to Classify Vegetation.

(More detail on the method used to calculate phreatophyte ET using remote sensed NDVI and RESET are contained in the Appendix XIII to this document.)

SUMMARY of KEY FINDINGS

The S. Platte basin has been in a state of flux since the early settlers began diverting flows for mining and agriculture in 1859. A number of variable climate, hydrologic, and human factors interact to create an extremely complicated set of conditions impacting the alluvial aquifer. The complexity of interacting factors in the basin makes it challenging to attribute the effect of single factors, such as reduced pumping or increased augmentation on groundwater levels. Additionally, the data record, particularly groundwater levels and pumping volumes, is incomplete and irregular. While variations in the data record introduce some uncertainty in exact amounts of pumping or other parameters, various trends are apparent that allow us to make a number of observations, which taken together reveal certain generalizable findings.

Groundwater Levels:

- The observation well record shows a large number of wells with observed rising water levels in the past decade, particularly near Greeley along the mainstem, and in Morgan, Logan and Sedgwick Counties.
- Localized areas of high groundwater have occurred in most regions of the aquifer over the period of record and in some cases high groundwater is commonplace. Our results show that about 28% of groundwater level observations recorded over the last 60 years show conditions of high groundwater. As a likely response to curtailment of pumping after 2002 and increased recharge, groundwater levels have increased over the last decade (2003-2012), during which time a significant fraction of the observation wells evaluated indicate trends of rising water. Over the complete period since 1953, however, about 60% of evaluated wells with significant trends in groundwater levels indicate a lowering of water levels, particularly near the river. This implies that the aquifer is now returning to higher levels, but as of 2012 had not reached equilibrium.
- Combined groundwater consumptive use for irrigation in Water Districts 2, 1, and 64 has varied with snowpack and precipitation over the past three decades. Since 2008, the combined three water districts have been pumping an average of approximately 320,000 AF/yr, with local areas of well curtailment gradually being offset by new or expanded pumping as augmentation supplies are developed over time. Agricultural pumping has decreased by the highest percentage in Water District 2, from a recent high of 120,000 AF in 2002 to 40,000 AF in 2012 as augmentation sources remain difficult to acquire, limiting pumping in that district. The greatest pumping and consumptive use of groundwater occurs in Water District 1. Long-term average groundwater consumptive use in Water District 1 is relatively stable since the 1980s at 180,000 AF/yr with some relocation due to curtailment and development of new augmentation supplies. Long-term average groundwater consumptive use in Water District 64 has increased by approximately 10,000 AF to an average of 110,000 AF/yr as development of augmentation water supplies has allowed increased pumping. Curtailment and abandonment of wells in Water Districts 2 and 1 is reflected in lower pumping amounts

in Water District 2 and slightly lower pumping amounts in areas of Water District 1, potentially affecting local groundwater gradients in recent years.

- The data show that the water table is responsive to wet and dry climate conditions.
- DWR's monitoring efforts in the Sterling and Gilcrest areas similarly show that the water table reacts to large precipitation or drought events, and localized pumping or artificial recharge in close proximity to observation wells.

Recharge/Augmentation Operations:

- Increases in the number of groundwater augmentation plans and the number of recharge sites have occurred since the mid-1990s.
- Augmentation supply has caught up with potential augmentation requirements in Water Districts 1 and 64 based on the recent five-year average. The combined Water Districts 2, 1, and 64 have developed over 230,000 AF of augmentation supplies based on five-year averages, reflecting the increase in recharge site construction, and some recent higher runoff flows available to divert for recharge. Large spatial and temporal variation in annual augmentation supplies is observed, but there is an increase of approximately 100,000 AF of augmentation water in recent years from recharge and correspondingly use of surface water supplies to meet augmentation requirements has declined recently.
- Reduced pumping in Water District 2 after the 2002 drought occurred because many wells were not fully covered under augmentation plans and were required to reduce pumping. Water District 2 has fewer opportunities to meet augmentation requirements through recharge as the district is often under administration, reducing ability to exercise junior water rights. Additionally, there are fewer suitable places in District 2 for the optimum placement of recharge structures.
- Water District 64 has the greatest rate of increase in recharge and surface augmentation sources since 2003.
- Augmentation plan operators appear to be taking recharge water when available due to future uncertainty, court decree requirements, and inefficient augmentation plans (e.g. plans that replace more water than necessary in certain months to meet the minimum in other months) may recharge more water than required for some part of the year.

Agricultural Changes:

- Irrigated acreage in the basin peaked around 1980; acreage has decreased the least in Water District 64.
- Increased irrigation application efficiency has occurred as sprinkler irrigation acreage went from essentially 0% in 1956 to over 40% of irrigated acres in 2005, altering historical patterns of deep percolation, runoff and return flows.

Hydrologic Changes Over the Recent Period:

- Two major droughts occurred in 2002 and 2012, while 2009, 2010, and 2011 were wet years in the basin.
- In the sixteen years since 1998, only four winter snowpacks have exceeded the 30-year average in the S. Platte basin. Precipitation data for the Sterling area show that 2009, 2010, and 2011 were wetter than average, contributing to the problems homeowners were experiencing due to high water tables.
- The annual flow at the Julesburg gage near the state line averages 478,261 AF for the period of 1969-2012. The average annual flow for the period of 2000-2012 was 213,446 AF, due mainly to drought conditions in 2001-2008, and 2012. No significant annual trend was detected at the Julesburg gage over the period of 2000-2012, although the months of July and August did show a significant positive trend.
- Comparing mean annual surface water diversions for the 1950-2012 period to the 2000-2012 period indicate that about a third of the major ditch systems show some increase in mean annual diversion amounts between the periods. In Water Districts 1 and 64 these increases can mostly be attributed to increased off season (Nov – March) diversions for the purpose of additional augmentation credits. However, additional irrigation season diversions can be detected in several canals in Water Districts 2, 1, and 64, but for the most part these increases in irrigation season diversions are not large amounts and they are not sustained through drier years such as 2012.
- Phreatophytes continue to increase in the basin resulting large quantities of non-beneficial consumptive use, perhaps as much as 250,000AF/yr. We found a 35% increase in phreatophyte ET over the 20-year period from 1990 to 2010.
- Extensive recent development of recharge ponds and lined gravel pit storage projects have likely changed local groundwater gradients in recent years.
- Curtailment and abandonment of wells in Water Districts 2 and 1 is reflected in lower pumping amounts in Water District 2 and slightly lower pumping amounts in areas of Water District 1, again potentially changing local groundwater gradients in recent years.

Municipal Changes:

- Transbasin supplies increased until the mid-1960s and have been relatively stable since that time at 386,000 AF/yr. The period of 2000-2012 had slightly above average importation from these projects at 420,000 AF/yr.
- Over time there has been conversion of single-use transbasin Colorado-Big Thompson shares from agricultural use (>50% consumed) vs. municipal use (<50% consumed).
- In recent years there has been an increasing trend in reuse of supplies from fully reusable, transbasin diversions in the Metro area that will likely continue. As municipalities continue to develop and capture their reusable return flows, the S. Platte flow regime will only get tighter, making it even more difficult to find augmentation supplies and increasing the period of administrative call.

- In recent years there has been an increasing trend in construction and use of lined gravel pits (particularly in WD 2), including increase in exchanged supplies.

Administration:

- The number of days of administrative call on the river has increased since the late 1990s as the gentlemen's agreement on winter calls was discontinued with the advent of increasing off-season augmentation. The river is under administrative call for the majority of the year in the past decade, increasing augmentation requirements.

RECOMMENDATIONS

In addition to developing information on surface and groundwater use and water levels, HB1278 directed CWI to:

- Provide information to use as a base for implementation of measures to mitigate adverse impacts in areas experiencing high groundwater levels.
- Provide information to the General Assembly, CWCB, and the State Engineer to facilitate the long-term sustainable use of South Platte water supplies.
- Determine whether additional usage of the alluvial aquifer could be permitted in a manner consistent with protecting senior surface water rights.
- Determine whether, and to what extent, the use of water in the basin could be improved or maximized by affording the State Engineer additional authority to administer water rights while ensuring protection of senior surface water rights.

Our evaluation of the data leads us to the conclusion that current administration of groundwater in the basin works well for the majority of water users, and that senior surface water users are for the most part protected from injury due to well pumping by current administration. Groundwater users in Water District 2 and parts of District 1 have been adversely impacted by the shortage of affordable augmentation supplies to offset pumped depletions. Changes in water administration in the past decade have led to increasing groundwater levels that in some cases impact land and homes. Presently, high groundwater conditions impacting landowners appear to be localized and thus, local solutions are recommended. In the consideration of the recommendations offered herein, it should be acknowledged that senior water rights must be protected in any adjustments to the system and that wells cannot be relieved from the obligation to replace out-of-priority depletions that cause material injury to surface water rights. HB1278 asked whether management of the system could be improved while still respecting augmentation decrees and the work accomplished to bring wells into compliance. In that context, our recommendations fall into four broad categories: 1. Mitigation of localized high water table conditions, 2. Increasing augmentation plan efficiency, 3. Implementation of basin-wide management, and 4. Recommendations for the State of Colorado, DWR and CWCB. We recommend that any changes in groundwater management in Division 1 should occur through an inclusive and open process.

1. Mitigation of Localized High Water Table Conditions

Several areas on the S. Platte mainstem, most notably Sterling and the Gilcrest/LaSalle regions, are experiencing high groundwater conditions that should be mitigated to prevent further damage to property and loss of water through non-beneficial consumptive use. HB1278 required that CWI provide information to use as a base for implementation of measures to mitigate adverse impacts in areas experiencing high groundwater levels. Our evaluation leads to the finding that while high groundwater can be found throughout the basin, adverse impacts are localized at this time. The first category of recommendations proposes strategies to address these local issues in the short to mid-term.

Additional State Engineer Duties

1A. The State Engineer or the Colorado Geological Survey should be delegated responsibility by the General Assembly to provide a consultation to the water court regarding new recharge structures before construction and recommend changes in design or operation when a recharge plan is deemed likely to cause or is causing harm.

There are over 500 recharge projects now in place in the S. Platte basin. According to Division 1 staff, as many as 800 total recharge structures are planned in existing augmentation plans, so there are potentially many more facilities yet to be constructed. Future groundwater recharge projects should be designed, located, constructed, and managed so as to avoid creating groundwater mounds that cause harm to third parties. When the State Engineer and the water court currently evaluate a recharge project, they are primarily determining whether it will offset out-of-priority depletions, with no explicit responsibility to determine if recharge is at risk of causing property damage to others in the flow path of recharged groundwater.

Recharge structures should be only be located near urbanizing areas after an analysis of potential impact to down gradient properties. In some cases, more complete geotechnical analysis is warranted to identify aquitards, perched water tables, confining layers or clay lenses, and consideration of flow paths that may affect return time to the river. A spacing interval between recharge structures may need to be established to avoid cumulative impacts. The SEO should be authorized to work with local parties to establish remedies that allow augmentation plans to continue operating without causing impact from high groundwater levels.

Pilot Projects in Areas with High Groundwater Levels

1B. Two pilot projects should be authorized and funded by the General Assembly to allow the State Engineer to track and administer high groundwater zones for a specified period of time to lower the water table at Sterling and Gilcrest/LaSalle while testing alternative management approaches.

The Colorado DWR has instrumented the two areas in the S. Platte basin with known high groundwater levels (Sterling and Gilcrest/LaSalle). With two years of data collected (2012-2013) to characterize water level behavior, these areas are primed for implementing pilot tests to evaluate alternative strategies for groundwater management. Pilot approaches may include permitted pumping or decreased recharge as determined to be locally appropriate to test alternative management strategies. Groundwater levels and surface diversions in the pilot areas must be accurately monitored in real time to determine impacts from the pilot management approach, and a plan to augment any injurious depletions must be established. Calibrated numerical groundwater models should be developed and tested against analytical methods in the pilot project areas.

The SEO should be authorized to work with recharge site operators in pilot project areas with mounded groundwater to replace injurious groundwater depletions in ways that will achieve the goals of augmentation plans without further raising water levels. Additionally, a stakeholder group should be authorized to develop local input to the SEO for alternative management in the pilot project areas. The pilot projects should sunset after a three to five year period and an analysis of what was learned should be provided to the Legislature.

2. Improving Augmentation Plan Administration and Efficiency

<u>South Platte Rulemaking</u>

2A. The State Engineer should be directed by the General Assembly to promulgate new rules for the S. Platte to:

> **1) Establish a framework for the voluntary movement of excess water supplies between augmentation plans, facilitated by the office of the Division Engineer, including a water bank or pool available for use by augmentation plan users.**
>
> **2) Establish basin specific guidelines for the implementation of administrative curtailment orders pursuant to 37-92-502(2)(a), C.R.S. that reduce waste and facilitate efficient management and distribution of available water supplies to storage and recharge water rights in the time and place of their need, in accordance with priority and historic practice. The guidelines should:**
>
> - **a. Allow the Division Engineer to use the administrative call as a management tool to increase system efficiency, decrease waste and maximize diversions for beneficial use;**
> - **b. Provide for storing water out of priority at higher elevation, and managing deliveries to downstream reservoirs as necessary;**
> - **c. Minimize seniority, frequency and duration of administrative calls to the full extent consistent with the fulfillment of decreed water rights;**
> - **d. Make use of all available data regarding water supply, including ground water levels, to determine the necessary administrative call date for each reach or sub-reach of the river and the alluvial aquifer system.**
>
> **3) Develop uniform and transparent reporting standards for augmentation plan accounting designed to integrate with basin data collection, modeling and management.**

HB1278 required an evaluation of whether the use of water in the basin could be improved by affording the State Engineer additional authority to administer water rights. Developments in water court and administrative practice have diminished the Division Engineer’s ability to play a management role in the distribution of water supplies. As we have already adjudicated most of the augmentation plans for high capacity irrigation wells likely to be developed within Water Districts 2, 1 and 64, the mass movement of irrigation wells into augmentation plans is widely considered to be nearly completed. The decrees are considered final and to the extent there is any room for adjustment in augmentation requirements, it has to do with the administrative call. Augmentation plans respond to the administrative call, and it is the one moving part that is not fixed in the decrees. Reducing the number of days of administrative call on the river system will allow for additional groundwater use and allow more days of free river whereby well users can acquire recharge supplies. Reducing the winter call period was once accomplished in the S. Platte under the gentlemen's agreement. The goal was to fill all the reservoirs and use Colorado's full compact entitlement, but avoid putting a call on so that upstream reservoirs could fill with an agreement to keep North Sterling, Empire, Jackson, and Jumbo whole if water ran short. The call regime is often governed by water rights low in the basin, which does not maximize opportunities for efficiency. However, downstream senior rights cannot be shorted and must have guarantees that they will not be harmed if they operate without placing a priority call.

Development of criteria for implementation of increased management will require the Division Engineer to rely heavily upon available real time data and forecasts. Some monitoring of key basin elements is in place and can be utilized immediately. The HB1278 study recommends specific additional monitoring and data management measures. Data sets related to both surface and groundwater should be used by the Division Engineer to guide the development of an annual management plan, which could then be adjusted throughout the season in response to changing conditions. For areas in the basin experiencing damaging high groundwater conditions, there is the potential for rules to establish standards to determine when portions of the alluvial aquifer are "full" and additional augmentation or curtailment is wasteful. In these regions, it is likely that the aquifer's accretive contributions to the river have reached maximum potential and additional replacement or curtailment merely contributes to evaporation or evapotranspiration losses without any increase in water supply for senior rights. At such times, the Division Engineer could set the administrative call affecting the augmentation plan so that additional replacement is not required and/or authorize pumping to mitigate damaging conditions and return the aquifer to optimal accretive levels.

The Legislature granted the State Engineer discretionary administrative authority to enact rules and regulations to assist in the performance of his 501 duties to administer, distribute, and regulate the waters of the state. This authority to adopt rules and regulations is referred to as the State Engineer's water rule power. See, for example, *Simpson v. Cotton Creek Circles, LLC* (Colo. 2008), and *Simpson v. Bijou*, (Colo. 2003). The State Engineer's discretionary water rule power is constrained by statute. When promulgating rules and regulations using its water rule power, the Legislature mandates that the State Engineer be guided by certain principles and considerations and set forth in subsections 501(2) and 502(2) of the Act (C.R.S. § 37-92-501(2)). The Legislature may provide additional guidance regarding rulemaking for a specific basin in the form of statutory amendments. As is always the case with a statutory amendment, it must conform to the constitution, and when construed by a court it will be considered in the context of the statutory scheme. The Legislature amended section 501 of the Act in 2004 to provide the State Engineer "wide discretion to permit the continued use of underground water [in Division 3] consistent with preventing material injury to senior surface water rights" and therein provided guidance in the exercise of such discretion in the form of further principles that the State Engineer must apply when regulating the aquifers in Division 3, C.R.S. § 37-92-501(4)(a) and in the form of required considerations when conducting rule-making in that Division, C.R.S. § 37-92-501(4)(b). In accordance with this newly granted statutory authority, the State Engineer subsequently adopted rules for Division 3, which were upheld by the Supreme Court, in *Simpson* *v. Cotton Creek Circles, LLC* (Colo. 2008). Review of the 2004 amendment to section 501 of the Act reveals there is similarity between the recommendations stemming from the HB1278 study and the legislative guidance and grant of discretion to the State Engineer in Division 3.

Recommendation 2A1 of the HB1278 study is that the Legislature should direct the State Engineer to establish a framework for the voluntary movement of excess water supplies between augmentation plans, facilitated by the office of the Division Engineer, including a water bank available for use by augmentation plan users. Like the legislative directive in C.R.S. § 37-92-501(4)(b)(I), recommendation 2A1 recognizes the potential for cooperative solutions to current water supply problems.

Recommendation 2A2 of the HB1278 study is that the Legislature should direct the State Engineer to efficiently manage and distribute available water supplies to groundwater, storage and recharge water rights in accordance with priority and historic practice by 1) storing water out-of-priority at higher elevation, and managing deliveries to downstream reservoirs as necessary, and 2) minimizing frequency and severity of administrative calls increasing opportunity for wells and junior rights to deplete the river in priority. Further, there is additional statutory support for the State Engineer's administrative authority to allow out-of-priority storage of water, which could be targeted such that water is stored at higher elevations as recommended by the study. Particularly, section 37-80-120, allows the State Engineer to permit out-of-priority reservoir storage, provided the water is made available to satisfy a senior call. New rules could direct the Division 1 Engineer to develop an annual fill plan prior to November 1 based upon current conditions with triggers to increase or decrease out-of-priority fill under call forbearance.

Subsection 37-92-502(2)(a) provides power for the State Engineer to curtail diversions to ensure supplies to senior priorities "at the time and place of their need." Subsection 502(2)(a) provisions on administrative curtailment are relevant to augmentation plan administration because 1) the majority of Division 1 augmentation plans replace depletions in response to administrative calls senior to the priority date of the well, and 2) many augmentation plans rely at least in part upon junior recharge or storage diversions for augmentation supply. When the Division Engineer places an administrative call senior to the priority date of the wells or the junior rights, diversions by the wells under the augmentation plans is reduced because more augmentation is required, and less augmentation supply is available. To the extent that curtailment provides additional supplies to senior water rights at the time or place of their need, it is necessary and appropriate. However, empirical data suggests that the 'fit' between the senior demand and the replacement provided by the current administrative call regime is not perfect, and, as a result, water use is not maximized.

We observed two phenomena that contribute to this recommendation. First, Division 1 augmentation plans are providing more water than is necessary to offset depletive effects of well pumping during certain periods. Second, strict non-irrigation season call regimes requiring delivery to downstream reservoirs are compressing the opportunity for diversions to junior recharge and storage rights to narrow time frames and thereby reducing the amount diverted, even as excess water is discharged from the system. Historical practice suggests that the downstream reservoirs may be filled in many years without the necessity of administrative calls through the non-irrigation season.

Subsection 502(2)(a) recognizes the variables present in South Platte administration and encourages the State and Division Engineer to establish the administrative call based on these factors; however, strict administration practice in recent years has removed all discretionary elements. Basin specific rules could affirm the Division Engineer's authority to set the administrative call to maximize beneficial use and establish parameters for the consideration of the 502(2)(a) factors.

The Water Court and Division Engineer need an ongoing process to evaluate how augmentation plans interact and if they are appropriately covering river depletions, and additional authority to play an active management role in the distribution of water supplies. One step in this direction is the development of uniform and transparent reporting standards for augmentation plan accounting to facilitate greater transparency in the day-to-day operation of plans (recommendation 2A3). The S. Platte system is unique and needs tailored rules to maximize beneficial use and protection of decreed rights. A rulemaking process would provide all parties a full and fair opportunity to participate in the development of additional management policies.

<u>Additional Division 1 and DWR Personnel</u>

2B. Funding should be authorized to provide the Division 1 Engineer with two additional FTEs and greater annual investment in technology upgrades. Additionally, Colorado DWR needs one additional FTE to focus on data and information services.

The Division 1 Engineer has incurred additional duties and responsibilities as a result of the many adjudicated augmentation plans now in operation and new rules for well metering. Reported data must be taken in, checked, loaded, analyzed, and provided to the public in short order if management is to be implemented based upon better information. Concurrently, we need to upgrade the data collection technology in the basin through more robust information systems, monitoring, and telemetry. Headgate gages need to be upgraded to achieve more accurate diversions and diversion records. Currently, Division 1 has 6.5 FTEs in the Hydrographic Unit, and it has been estimated that they need 10 to 12 FTEs to do the job currently assigned to them. We believe there is a demonstrated need for two additional fulltime FTEs in Division 1 to focus on the technical aspects of surface and groundwater tabulation and administration and one new senior staff position in DWR to provide leadership for services focused on water rights tabulation, diversion records, structure location, and electronic workflow processes.

3. Implementation of Basin-Wide Management and Planning

HB1278 required CWI to provide information to the General Assembly, CWCB, and the State Engineer to facilitate the long-term sustainable use of S. Platte water supplies. Achieving optimum conjunctive use of surface and groundwater in the S. Platte that is sustainable over the long-term is best accomplished through implementation of a basin-wide approach that would have the goal of fuller utilization of the river and the alluvial aquifer for all water users' benefit. Presently, no one organization in the basin has the responsibility of managing the whole system for the benefit of all. Admittedly, there are many political, jurisdictional and funding impediments to implementing basin-wide management in the S. Platte but it must be understood that this basin faces the most critical water supply gap in the future and meeting the gap requires us to optimize the use of the resource. Water lost downstream in the recent flood of 2013 and the inability to more effectively use the aquifer during the 2012 drought demonstrates that we are not best positioned to deal with extreme hydrologic events or future shortages.

Basin-wide Management Entity

3A. The General Assembly should authorize the establishment of a pilot basin-wide management entity with a defined sunset date.

A new entity such as a South Platte Water Conservation District with a mandate to work with water users across the entire basin could work towards augmenting water supplies and facilitating more flexible management in the basin. The basin-wide entity could be charged to work toward determining the sustainable yield of the aquifer, making a plan for the distribution of sustainable yield by priority, determining how we could operate recharge more effectively in certain areas, and developing water not committed to a specific water right for a water bank or spot market. It could capture and store groundwater and put it in the river in times of drought and replenish it in times of plenty. A regional authority for basin-wide water management is not a new or original idea. Members of the Governor's 2007 South Platte Task Force (Colorado Farm Bureau, 2010) proposed it, as did the Bittinger/Wright study in 1968. Perhaps the time is right to give this concept more serious consideration as we prepare for the future water supply gap in the basin.

All potential solutions to increase management effectiveness involve greater recognition and use of the alluvial aquifer and development of true conjunctive use. One possible pathway is to define sustainable yield and distribute it according to priority using surface diversions and widespread groundwater withdrawals to insure against hydrologic variability. Alternatively, we could develop provisions to use the sustainable yield of the aquifer for drought only, not to exceed two or three years out of ten within a certain zone or withdrawal rate. Another possible approach is to develop provisions for emergency use of the aquifer during drought with accountability to repay future injurious depletions. A management entity could assess these scenarios, as well as others, in an effort to identify strategies to protect existing rights and maximize beneficial use.

The management entity could operate the real time monitoring network, continue the HB1278 study, build a home for real time management of the system, and this institution could become the champion for the SPDSS. Water users would run the organization and tasks could include:

- Build and operate new storage projects, including underground storage
- Serve as the water banker and develop a fully operating spot market for the basin
- Develop more augmentation water supplies
- Create a basin-wide augmentation bank
- Provide ongoing data collection, analysis and display
- Provide SPDSS oversight
- Develop an annual river forecast and operating plan that determines sustainable yield
- Develop annual plans for distribution of sustainable yield by priority, using surface and groundwater withdrawals
- Work with the SEO to keep the call period minimized through cooperation and communication
- Find and protect environmental flows
- Implement phreatophyte management
- Provide coordination and communication among water users

If the pilot period is successful, water users could move ahead with support for legislation to establish the entity as a conservation district. The experimental entity could conduct a simulation of a permanent institution to show how it would operate. The simulation should be allowed to run for at least three years. The pilot entity would have an engineering committee that would develop an annual water supply plan for the basin that would show how additional water could be made available through alternative management approaches. The pilot entity would operate the first year as a dummy, second year as dummy or experimental, and a third year as experimental. The management entity should be governed by a board composed of members representing all major categories of water use, with attention to geographical distribution. An engineering committee would be appointed to evaluate the annual operating plan. It is our opinion that this simulation should not be delegated to any existing water management organization in the basin, as there are too many jurisdictional and political divisions for the pilot to have the basin-wide support needed to have a reasonable chance of success.

Better Data and Models

3B. The CWCB, CDA and DWR should work with USGS to implement the basin-wide groundwater monitoring network outlined in this report.

In an age when water is becoming increasingly scarce and supplies uncertain, robust data networks and decision support tools are critically needed for day-to-day operations and to build a long-term data archive to serve the needs of the people of the State of Colorado. The HB1278 study has revealed that our groundwater monitoring data collection network is irregular and incomplete but could rather easily be substantially upgraded. Better management decisions require higher quality and more easily accessible data. We need to install, instrument and maintain a groundwater level monitoring network that can be used for real time management decisions. Additionally, water management organizations in the basin should share data and collaborate on data collection. The USGS has developed a statistically robust groundwater monitoring network as part of the HB1278 study based on existing monitoring wells that can greatly improve our ability to track and manage groundwater for very low initial cost. The proposed monitoring well network is composed of three subnetworks designed to measure groundwater levels in the South Platte alluvial aquifer. The primary subnetwork consisting of 96 monitoring wells was designed to measure ambient groundwater conditions. Two additional monitoring subnetworks were designed to target areas of hydrologic interest (two targets, 20 wells) and areas that could be affected by diversion structures (four targets, 80 wells). The complete network consists of the three subnetworks and includes wells managed by federal, state, and local agencies, demonstrating the need to gather community resources collaboratively in a unifying manner to establish an optimal network for the region.

3C. The State should cooperate with the S. Platte Basin Roundtable and water organizations in the basin to fund and conduct a helicopter electromagnetic and magnetic survey to produce detailed hydrogeological maps of the S. Platte alluvial aquifer.

Detailed mapping and characterization is necessary to accurately delineate aquifer geology, assess hydrologic connection with streams and other aquifers, and better model surface and groundwater interactions. Higher resolution hydrogeological parameters are needed to improve groundwater models in order to accurately represent the aquifer system. The USGS has recently been using a helicopter electromagnetic (HEM) system and surface nuclear magnetic resonance (SNMR) to map properties directly related to the water in the subsurface. This method allows for low-cost quantitative estimates of hydraulic parameters and has recently been used to evaluate the subsurface mapping application eastern Nebraska. Airborne geophysical studies have also been effectively used by the USGS in a variety of groundwater resource projects and programs around the USA. Airborne geophysical data are collected by a private contractor using a HEM system under contract to the USGS. The digital airborne geophysical data are collected along flight lines and then processed to produce digital maps of the aquifer. These map layers will be very useful to supplement the SPDSS efforts, basin-wide efforts to improve water management, and individual water user groups as we move to more precise delineation of surface and groundwater interactions. Results will also be helpful in evaluating water leakage from ditches and reservoirs.

3D. The State should continue strong support for the development and implementation of the SPDSS and strive to improve accessibility, scope, and robust stakeholder processes.

We need a basin-wide model and a common technical platform that all water users in the basin agree to employ. The SPDSS is the best mechanism to provide this over time. However, CWCB needs to work with basin water interests to develop stakeholder ownership of the SPDSS to ensure it continues to improve and meet the needs of basin water users. In addition, the current status of climate data collection in the S. Platte is also problematic. Long-term stations are simply too few and too far apart. In light of current federal budgets, relying on NWS and NRCS to fill these gaps and bring back records to some locations is likely not feasible. A more robust and adequately funded network of weather stations with high spatial representation across the state should be considered to ensure Colorado meets the data needs of stakeholders across the state. Improving this network is in the interest of all water users and could be coordinated under the basin-wide entity or the CWCB as part of the SPDSS.

Develop Additional Water Supply

3E. The State should aggressively begin working with water users and other stakeholders in the S. Platte basin to develop multiple-benefit water storage options.

Stored surface water offers the most certain method for assuring senior surface water rights are protected at the time pumped depletions impact the river. Additionally, meeting the water supply gap in the S. Platte basin depends upon multiple strategies, including capture and storage of water during wet periods. Opportunities remain on the S. Platte to develop storage that could provide more augmentation water and more management flexibility. These opportunities must be identified and vigorously pursued with support from the State. Gaining support for new storage will require broad inclusion of stakeholders in the development of projects that can meet environmental, recreational, agricultural and urban goals. Removing silt from existing reservoirs may help, but is expensive relative to yield. Small but potentially significant amounts of water can be obtained by rehabilitating restricted reservoirs in the basin.

It is recommended that the State work aggressively with water users to expand or build a reservoir such as the proposed Ovid Reservoir at the lower end of basin to sustain the Three States Agreement, the S. Platte Compact, and to better regulate water supplies. Storage projects are also needed higher in the basin for the purpose of capturing excess water when available, storing and exchanging excess augmentation credits upstream, and water banking. The Northeastern Colorado Water Cooperative study indicates there may be in the neighborhood of 100,000 AF of excess water in the basin, just not in a convenient place or time. Lost Creek designated basin and certain other areas within the S. Platte alluvial aquifer could be used as a place to store water underground and move water into and out of that basin.

4. Specific recommendations for the Colorado Division of Water Resources and the CWCB for Improved Data Collection, Data Management, and Data Access

In the course of assembling and analyzing the large volume of data relevant to this study, the study team identified a number of improvements that could be made to the existing SPDSS product that would increase accessibility and utility and ensure that the SPDSS achieves its potential as a management tool. The issues related to data collection and data management are interrelated and are discussed together, primarily because these topics are highly dependent on State of Colorado information technology (IT) resources.

It is important to recognize the value of the existing CDSS platform. The data provided by HydroBase and the functionality of various software tools allows access to tremendous amounts of data. However, it is also important to recognize limitations in the existing system, in particular related to new user requirements that are being identified beyond the original system requirements.

A general recommendation is that any data available on the web should be made available using a REST (Representational State Transfer) web service API (application programming interface). In simple terms, this means that data resources should be available via a URL, with no need for intermediate navigation of web forms. Forms are fine for helping to determine the URL, but once the URL for a data resource is known, it should be usable without going through the form. With this approach and standard naming conventions for data resources in URLs, it is possible to automate data retrieval and implement efficient data processes.

A. Update data access and software for new diversion record coding:

- HydroBase currently is being distributed with older diversion coding (SFUTG); therefore, access to new, more detailed accounting (SFUTG2) is not available and consequently cannot be used in analysis or modeling. Instead, the older coding is being used, which limits understanding the details of water administration.
- CDSS software tools such as StateDMI and TSTool need to be updated to provide access to the new diversion coding data, as well as being backward compatible with older versions of HydroBase.
- Data analysis processes including those for preparing CDSS model data sets need to be updated to utilize the new diversion coding, including dealing with a change in diversion coding from old to new standard.

B. Improve access to augmentation plan data to facilitate review and analysis:

- Augmentation plan reporting spreadsheets are published by the State in Laserfiche Weblink. However, this system does not provide an open API to data. For example, the general query tool is available on the DWR website (main page is http://water.state.co.us/DWRDocs/ImagedDocs/Pages/default.aspx), but only an interactive query is available. The following URL can be used to access the main query for a structure, but individual files cannot be accessed in an automated way to facilitate bulk downloads and processing. For example, for WDID 0103339 there are 344 data files to download, which if done manually would require a prohibitive amount of time.
- It is recommended that an approach be evaluated to provide access to individual files using a URL, so that downloads can be automated. Additional functionality such as retrieving the list of files via a URL is also desirable so that users are not forced to interactively navigate Laserfiche (although interactive access is desirable when searching for information).
- The data files that can be downloaded are often complex and data are difficult to extract. It is recommended that standards for Excel data forms include using named ranges to identify the contents of data cells. For example, a named range could be defined that

matches the diversion coding for that cell. This will allow software to automate extraction and help with review of the data.

- Standards for naming data files would help in accessing data submission Excel files. For example, files could be named DWR_DIV1_DiversionFiling_0103339_YYYYMMDD.xlsx
- Without this standardization, it is laborious to handle individual files with different naming conventions.
- Where augmentation plans include the collection of water level data, this information should be publicly accessible.

C. Improve data design to help understand the history of augmentation:

- A history of augmentation is needed for historical analysis to understand the impacts of changes in administration (e.g., full augmentation being evaluated in HB1278). For example, for every historical irrigation year, it is useful to know which structures were active in a plan so that data for those structures can be retrieved. The “associated WDID” table in HydroBase is a dynamic table that only represents the current snapshot and cannot be used for historical analysis. It is recommended that this data be time-stamped to understand the change in data over time.
- It may be possible to use new diversion record coding to retrieve this information; however, there is not enough data using the new standard to confirm.
- The above changes would facilitate historical analysis of augmentation plans, including processing data for model data sets.

D. Add metered well pumping to HydroBase:

- For the HB1278 analysis, as well as the current SPDSS analysis, pumping and augmentation requirements have been estimated based on a full supply, because metered pumping is generally not available in HydroBase. For this analysis alone, it was necessary to estimate the portion of pumping assigned to each well based on its assignment to irrigated acreage and the crop irrigation requirement, and then estimate the portion of the total depletions that may be attributable to more than one augmentation plan. Each level of estimation introduces error, which may be partially alleviated by the availability of pumping records.
- It is recommended that metered pumping be made available in HydroBase as soon as possible in order to more accurately reflect total pumping and augmentation requirements.

E. Improve access to documents in Laserfiche:

- Although the system allows for keyword search, it is often possible to miss finding a document because the title or keywords are not known. It is recommended that a general search similar to Google be enabled to make it easier to find documents. This search would utilize content in the documents.
- Providing a REST API to access individual documents by URL (permalink) would allow documents to be retrieved without navigating a form. This appears to be enabled for some documents but not others.

- Providing access to the original Word or PDF document is recommended. Laserfiche appears to regenerate PDFs from images for some documents, which is slow and can result in huge PDFs.
- Allowing direct access to Laserfiche resources would allow better integration with CDSS tools, such as AAADAT, and model data sets. Users could be presented with a link directly to a document or data file in Laserfiche.

F. Address technical issues related to distributing and accessing HydroBase:

- HydroBase contains a wealth of information and is being utilized on numerous projects, but can be challenging to access, even to those with technical expertise. Ideally, as more users access HydroBase, effort should be taken to make its use easier.
- The web-based query tools do not provide a web service API to access resources. It is recommended that important data (such as diversion records) be made available using a REST API so that data resources can be accessed directly with a URL. It is also recommended that record limits on queries be removed in as many cases as possible. These improvements could further minimize the need for a local installation of HydroBase.
- The HydroBase DVD is useful to improve performance and to freeze the dataset; however, a number of improvements could be considered:
    - Place HydroBase installer on the DWR or CDSS website for download.
    - Place HydroBase database files on the DWR or CDSS website for download and provide more frequently than one time per year. Providing access to multiple versions of HydroBase is useful for troubleshooting.
    - Perform additional testing to support HydroBase installations in other configurations (Windows 7, Windows 8, etc.). It is difficult for consultants and other HydroBase users to adhere to specific operating system requirements. Progress has been made in this area and it is recommended that resources continue to be allocated to support various operating systems.
    - Consider distributing read-only HydroBase in other formats that may be more conducive to third-party users, such as open source databases mySQL, SQLite, or PostgreSQL. This could alleviate issues with SQL Server compatibility. It should be possible to automate transfer of key HydroBase tables from SQL Server to these databases. Stored procedures will require additional effort but may not be needed for general HydroBase use.
- HydroBase releases sometimes have data issues, in particular for third-party data, and additional quality control is recommended prior to releases, for example using TSTool or other automation software:
    - Automate HydroBase tests to confirm expected data (number of stations, period of record, data types).
    - Automate comparison of HydroBase and web service results.

G. Improve Satellite Monitoring System (SMS) data access:

- The DWR website pages for SMS data do not provide specific information about the available period of record. For example, the graphs sometime indicate the number of years of record, but do not specify the specific period. In some cases, no indication of historical period is provided. The “Station Description” page appears to have a placeholder for the period but the information is not available. It is recommended that the available period be clearly indicated in output displays.

- Often for a historical analysis it is necessary to process time series from multiple sources and consequently it would be useful if in addition to the ABBREV identifier, station information could include the related USGS gage identifier or structure WDID. This would help ensure that identifiers for real-time and historical data are properly matched.

H. Continue and improve integration of third-party data, in particular for data that currently have limited availability:
   - Third-party data are already collected and managed by the State. For example, various water districts pay for equipment to measure flows for their structures, and this information flows into the Satellite Monitoring System. These efforts should continue and data access should be continued and improved (for example, the above recommendations for improving Laserfiche and SMS will make such data more accessible).
   - Coordinating user supplied groundwater level data sharing with the USGS has pitfalls. Unlike streamflow data, which are well associated with a gage identifier, groundwater levels are often associated with locations that do not have well-recognized identifiers. As part of HB1278, the USGS assigned new USGS site identifiers to some locations in order to load data into the USGS NWIS database. To avoid confusion, it is recommended that clear guidelines are developed to describe how well data are shared, in particular in cases where the State and USGS are defining new metadata for the same locations.
   - A crowdsourcing or citizen scientist approach could be used for data necessary to fill in gaps. For example, groundwater level measurements currently are made using automated readers and infrequent manual readings. The manual readings have limited value because the groundwater levels at the location may rise and fall at different times based on conditions at the site, and snapshots are not guaranteed to represent minimum or maximum in a year or help indicate a trend. An approach to collecting additional data is to provide guidelines for measurement and then allow the public to take measurements. This is similar to the CoCoRaHS approach for collecting precipitation data. The results may have somewhat limited accuracy; however, for the data types and uses being considered, this is likely acceptable. It is recommended that this concept be evaluated and if appropriate, initiate a pilot study that leverages CoCoRaHS and other existing infrastructure and experience to demonstrate the merit of the concept.

I. Provide spatial data in open formats, with attributes that can be related to other data:
   - Geodatabases that only Esri and other costly software can use limits access to the data.
   - Shapefiles, while not always the best format, are supported by many programs.
   - KML files are supported by many programs and would be useful.
   - For point data, simple CSV files are useful.
   - In all cases, basic attributes such as location identifiers and coordinate system should be provided. If possible, provide geographic coordinates in addition to projected

coordinates. All data providers should be careful to ensure that fundamental data are properly represented (e.g., WDID should be a zero-padded string, not an integer).

Recommendations for Improved Tools for Water Management

Issues related to data collection, management, and access were discussed in the previous section. Core system features that provide data access can be leveraged to implement analysis tools. The following recommendations are made for higher-level applications and the overall system:

1. Minimize confusion about what is HydroBase in order to improve understanding and efficiency:
   - It is recommended that DWR summarize database names and configurations for DWR staff and external users. For example HydroBase CDSS" may refer to the published HydroBase that is familiar to consultants, but DWR staff may not use this version. Such documentation will become increasingly important as various users access different types of State data. For example, AAADAT will require forecasts of depletions and augmentation, information that is useful for real-time operations, but which is not appropriate for the published HydroBase. It is important that tool developers and data users understand how data move through the system.
   - Document how various users connect to HydroBase and other databases with various software tools, such as ODBC connections, TSTool datastores, website, etc.
   - Develop and post online standard procedures for acquiring data from HydroBase and example output tables.
   - The above clarifications will help with data discussions and troubleshooting because it will be clearer which database is being used and consequently what contents are available.

2. Improve DWR staff efficiency with increased utilization of CDSS tools and data products:
   - For example, the TSTool software simplifies accessing and processing historical diversion records, in particular for bulk visualization and quality control. However, TSTool generally is not used by DWR staff because DWR staff utilize administrative tools or direct database queries. Although existing DWR administrative tools are appropriate for some tasks, CDSS tools could help staff with other tasks. CDSS tool access and training could be provided to appropriate DWR staff and support provided.
   - The CDSS data-centered approach has been implemented to automate data processing for model data sets. The same approach could be utilized for DWR data processing and quality control. It is recommended that DWR needs be evaluated to determine whether CDSS tools and data-centered approach can help meet these needs.

3. Consider broader data use in DWR business processes and work products:
   - Although DWR performs administration as per its mission, administrative data (diversion records, calls, etc.) increasingly are being used for DSS projects and other studies, and DWR is being asked to help use its data in new ways. It is recommended that a mechanism be considered for how to address broader data needs while not

burdening DWR staff. In many cases, relatively minor changes are needed and such changes can also benefit DWR's efficiency (see previous item about using CDSS tools). Perhaps the DWR's DSS group is appropriate for these discussions.

- Any request for data from DWR management or others that results in a manual data gathering and formatting exercise should be evaluated to determine whether tools are available to automate and streamline the effort. Although effort must be spent up front to configure a response, executing the analysis again in the future will be more efficient, and will be repeatable. For example, TSTool has been used with the HydroBase web services to automate retrieval of historical diversion record data.

4. Coordinate overall AAADAT/Water Administration/SPDSS integration:
   - Projects such as SPDSS and the AAADAT project arise because of specific needs that have been articulated. However, in many cases, those needs are focused on a specific problem at hand and the solution does not consider broader implications. It is difficult to step back and evaluate the broader system and how multiple efforts integrate. It is recommended that a small technical group discuss integration of the various efforts to ensure that the overall solution is synergistic and avoids reinventing the wheel.
   - There is a need for open data standards to ensure that data exchange between various products and software tools is streamlined and avoids misinterpreting data. It is recommended that data exchange formats be evaluated and that open data standards be developed and published. In particular, sharing of time series data involving diversion coding should be standardized.

5. Provide a point flow tool, or perhaps multiple tools depending on requirements:
   - The Water Information Sheet (WIS) tool developed as part of the Colorado Water Rights Administration Tool was developed in the early 2000s, used for several years (for example District 64 has 684 sheets for period 2000-10-02 to 2003-12-31) and then abandoned. See Figures 2-4. The purpose of this tool was to allow water commissioners to perform a point flow analysis for the current day, using real-time streamflow data and representing all river releases and diversions. The results were saved in HydroBase and could be viewed as time series graphs and tables. Technical issues with this tool included slow Internet, implementation in custom software rather than Excel (at that time Excel did not have required data access features), and operational issues such as coordinating upstream district administration with lower district administration (impacted by slow Internet). The installation of additional gages on diversion structures also made use of real-time data more straightforward in administration. The data from the WIS have not been used in the HB1278 study. It is recommended that the WIS requirements and functionality be reexamined to evaluate its use in Division 1. Rather than using the tool again, it may be appropriate to leverage the work that was done to implement a new tool (see below).
   - The Excel Visual South Platte tool performs a point flow analysis and provides other useful information for daily administration. However, the tool was developed by the Lower South Platte Water Conservancy District, and its operation is hosted by that

organization. Although useful for understanding the river in real-time, there is quite a bit of data processing going on under the hood that may not be transparent to users including the State.

- As part of HB1278, the CDSS TSTool software was enhanced to include the AnalyzeNetworkPointFlow() command, specifically to perform a historical point flow analysis. This allows the data processing features of TSTool to be leveraged, for example to access data from USGS and DWR web services and HydroBase and to fill and manipulate data for any analysis period. This tool may not be useful for real-time administration and management but is intended to use the input from real-time tools.
- It is recommended that WIS, Visual South Platte, TSTool, AAADAT, and other tools to evaluated to determine how best to provide accessible and transparent tools that meet the needs of the State and third parties in administering and managing the S. Platte. The result may be more than one tool in order to meet the needs of specific users; however, it is likely that improvements in data sharing and visualization can be shared between tools.

In addition to the new coding standards, the DWR as well as CWCB through their CDSS modeling efforts have improved the accuracy, availability, and detail of information in HydroBase and CDSS products. This includes, but is not limited to, more accurate locations of wells due to GPS measurements, more accurate assignments of surface and groundwater supplies to irrigated acreage in the CDSS acreage assessments, and more detailed identification and coding of augmentation plan impact reaches and other recharge structures. It is recommended that these improvements continue in order to support improved analysis.

CONCLUSIONS

Colorado's prior appropriation system has served us well over the past 150 years for the allocation of limited surface water resources. It has provided certainty. It has adapted to changing conditions and human needs. Beneficial use without waste or injury to senior water rights is the foundation of Colorado water law and administration. Our water law and administration continues to evolve, particularly in regard to groundwater. The legacy of rules and legislation, court cases, and multi-layered management jurisdictions often causes impediments to innovations that might serve to more comprehensively address the emerging water supply challenges that face us. A pure prior appropriation system does not allow full realization of the potential of groundwater aquifers for conjunctive management of surface and groundwater resources in a basin such as the S. Platte, as groundwater development occurred relatively late, and wells will always be junior diverters. Times of surface water shortage naturally coincide with times when the groundwater resource is most valuable, but not fully unusable under current law and practice. Given that our water law is a product of human ingenuity, the adjustments needed to find methods to sustainably use groundwater should be within our ability to identify and address.

Mass movement of high capacity irrigation wells into augmentation plans is largely complete in the S. Platte basin. Most groundwater users have stipulated their augmentation plan decrees and more or less accept the terms and conditions of their decrees; the terms may not be perfect, but well users know what they have to do to use groundwater. The decrees institutionalize scientific uncertainty, but create another form of certainty that benefits many water users.

New water storage, both above and below ground, is needed to maximize the potential of the S. Platte system and allow more groundwater utilization. Municipal and industrial demands in the basin are projected by the State to increase by 340,000 to 510,000 AF by 2050. If new water supplies and projects fail to be built, the continued dry-up of irrigated agriculture is inevitable in the S. Platte basin, and Water Districts 1 and 64 are very likely sources for new municipal and industrial supplies. Given the certainty that water demands will outstrip supplies in the near future, new tools and approaches are needed to allow more effective use of the alluvial aquifer for the benefit of Colorado. Further, continuing to foster a system of rising groundwater levels will inevitably salinize valuable agricultural lands in the basin and increase non-beneficial ET by phreatophytes and evaporative upflux. This fact is not a matter of debate, as it has proven out numerous times around the world in semi-arid river valleys where diversion for surface irrigation resulted in high groundwater levels and waterlogging.

The surface water and alluvial groundwater in the S. Platte basin is in reality a single resource. Diverted surface water recharges the aquifer, which later discharges to the stream, only to be diverted and applied once again lower in the system further recharging the aquifer, and so on. Yet many think of these as separate resources, pitting users against each other. Planned conjunctive use of surface and groundwater represents an avenue to maximize economic output in the S. Platte basin and provide protection against drought (Winter et al., 1998; Office of the Colorado State Engineer, 1978). The massive storage volume in the alluvial aquifer creates a huge reservoir for our use. However, it must be recognized that groundwater pumping creates a depletion that can injure senior surface water rights; the full impact of pumping may not be realized for years. The challenge is that timescales at which water moves through the stream versus the aquifer are significantly different, requiring improved planning and coordination, better data collection, and greater basin-wide cooperation. The impact of a single well is not likely to produce depletions that are measurable in a river system the size of the S. Platte; it is the sum total of streamflow effects caused by pumping from many wells that must be properly managed, one augmentation plan at a time.

The S. Platte alluvial aquifer is an underground reservoir that can provide agriculture, municipalities, and the environment with additional water, particularly during drought, if we measure and manage the resource. Improved monitoring, data management, models, and common technical platforms are needed if water management in the S. Platte is to benefit from better science. The S. Platte Decision Support System is positioned to facilitate the integration of science in planning and decision-making, but the basin must also be organized to utilize the science. This is a long-term challenge – the S. Platte basin will always be in state of flux, and we need to continue developing innovative tools and approaches to better manage surface and groundwater for the benefit of future Colorado citizens and water users.

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APPENDIX

(Online at http://www.cwi.colostate.edu/southplatte/findings.shtml)

I. HB1278 DOCUMENTS

   a. Colorado House Bill 12-1278

   b. HB1278 Project Team

   c. Independent Scientific Panel

   d. Scope of Work

II. SOUTH PLATTE WELL DEVELOPMENT TIMELINE

III. GROUNDWATER DATA

   a. High Groundwater Areas

   b. Observation Well Hydrographs

IV. AUGMENTATION PLAN REQUIREMENTS AND SUPPLIES

V. EXAMPLE AUGMENTATION PLANS

VI. STREAMFLOW GAGES

VII. MAJOR DITCH DIVERSIONS

VIII. MAJOR RESERVOIRS & RESTRICTED DAMS

IX. TRANSBASIN DIVERSIONS

X. GAIN LOSS ANALYSIS

XI. CALL RECORDS

XII. CLIMATE DATA

XIII. PHREATOPHYTES

XIV. USGS ANALYSIS OF GROUNDWATER LEVELS AND PROPOSED MONITORING NETWORK

XV. COMMUNITY OUTREACH AND EDUCATION

XVI. TSTOOL CODE