Brown AND Caldwell

FINAL REPORT

Prepared for
The State of Colorado, Department of Natural Resources

Sterling and Gilcrest/LaSalle High Groundwater Analysis

July 2015

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Colorado Water Conservation Board and Colorado Division of Water Resources

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List of Abbreviations and Terms

AF	acre- feet
ASCE	American Society of Civil Engineers
Basin	South Platte River Basin
BC	Brown and Caldwell
CGS	Colorado Geological Survey
CU	consumptive use
CCWCD	Central Colorado Water Conservancy District
CWCB	Colorado Water Conservation Board
DWR	Colorado Division of Water Resources
ET	evapotranspiration
ft	foot/feet
GASP	Groundwater Appropriators of the South Platte River Basin
GMS	Groundwater Management Subdistrict
GW	groundwater
HydroBase	DWR's water resources database
in.	inch(es)
Lo/L	ratio between the length of the ditch within the study area and the total length
mi	mile(s)
NCWCD	Northern Colorado Water Conservancy District
NOAA	National Oceanic and Atmospheric Administration
SPDSS	South Platte Decision Support System
U:1	irrigation use
U:R	recharge
USGS	U.S. Geological Survey
WAS	Well Augmentation Subdistrict
WDID	water district identifier
WY	water year

Executive Summary

Water management in the South Platte River Basin (Basin) is subject to a wide variety of drivers. Demand by agricultural, municipal, industrial, and environmental users exceeds supply in most years and forces us to maximize the beneficial use of our water to support as many uses as possible.

Relatively recent changes in surface and groundwater management, along with a number of recent years with above-average precipitation, have impacted the water budget in various parts of the Basin. Real and perceived impacts of hydrologic and management drivers have gained recent attention in the vicinity of Sterling and in the area surrounding Gilcrest and LaSalle along the South Platte River. The attention to these drivers has come as the result of high water table conditions in the Sterling and Gilcrest/LaSalle areas.

The Colorado Division of Water Resources (DWR) initiated detailed data collection and monitoring of the hydrologic conditions and drivers in the Sterling and Gilcrest/LaSalle areas in spring 2012 with the intent of hiring a third-party consultant to analyze the data, quantify the drivers of water table change, and identify relationships among the drivers.

The overall goal of the project described in this report was to create a water budget that can help describe the hydrologic and hydrogeologic influences that may be causing high groundwater in the Sterling and Gilcrest/LaSalle areas.

Data Collection and Water Budget Development

The data collected for this study came from a variety of sources. Where possible, data acquired by DWR as a part of its ongoing investigations in the study areas were used. Data stored in DWR's water resources database (HydroBase), augmentation plan accounting, and outputs from South Platte Decision Support System (SPDSS) models made up most of the remaining data needs.

The water budget focused on the regional alluvial aquifer and all components are defined relative to the aquifer. In other words, inflow refers to components that recharge the aquifer and outflow refers to components that drain the aquifer. For example, surface water flow occurring as streamflow, flow in ditches, or runoff was not quantified. However, seepage into the alluvial aquifer resulting from flow in ditches or contributions of alluvial groundwater to flow in the South Platte River was quantified. The components of the water budget are described in the following table.

Table ES-1. Water Budget Components

Inflow Components	Outflow Components	Storage Components
Ditch seepage	Groundwater consumptive use from pumping	Change in aquifer storage
Recharge from ponds	Groundwater contribution to streamflow	
Recharge from precipitation	Direct phreatophyte consumption	
Recharge from irrigation	Direct crop consumption	
Subsurface inflow	Subsurface outflow	

Study area boundaries were developed to quantify regional drivers and isolate key water budget components. The figures below show the delineation of the Gilcrest/LaSalle and Sterling study areas, major features in and around the study areas, and groundwater level contours.

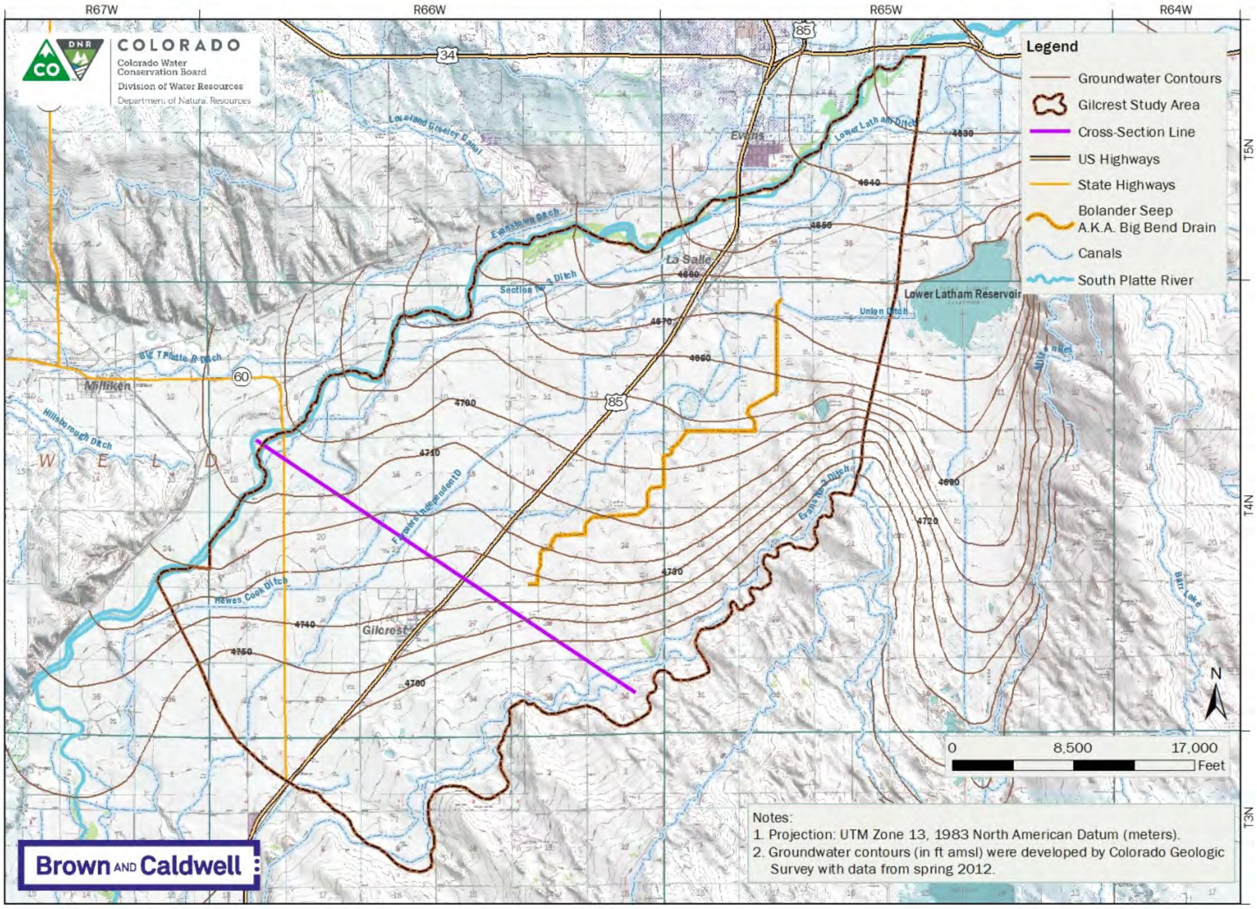

Figure ES-1. Gilcrest/LaSalle study area

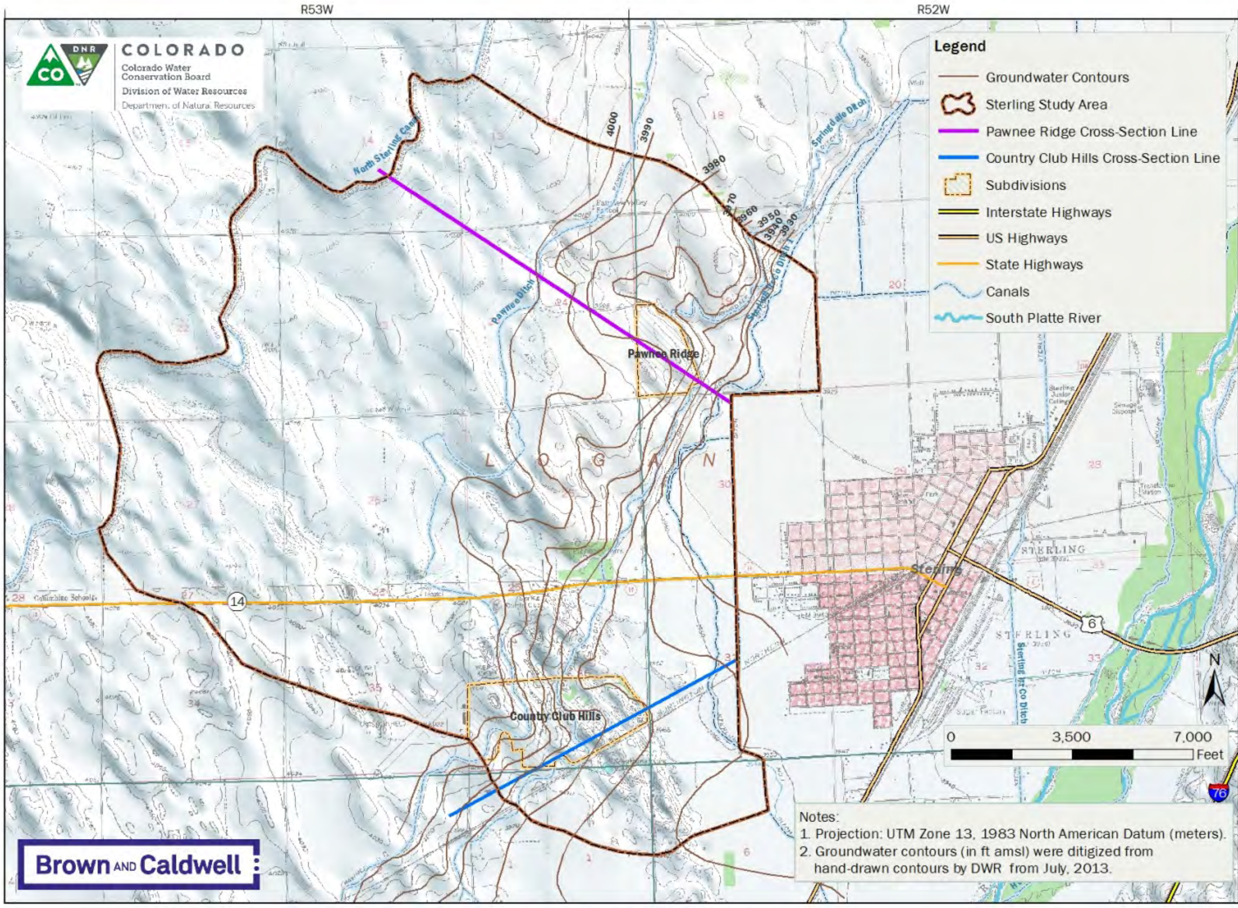

Figure ES-2. Sterling study area

Components of the water balance were quantified according to the study area boundaries shown above. A wide variety of methods were used to quantify the various components, and in most cases, a consistent method was used in both study areas for specific components. Components of the water budget, and the water budget itself, were quantified on a monthly time step during the study period. The study period corresponded to the range of time over which DWR conducted their data gathering activities and spanned from November 2011 through October 2014

Water Budget Quantification

Gilcrest/LaSalle Study Area

The water budget for the Gilcrest/LaSalle study area was quantified and is described in detail in the report. Observations on the water budget for the Gilcrest/LaSalle study area are summarized below.

- Ditch seepage and recharge from surface water irrigation were the largest components of inflow to the aquifer during each year of the study period.
- While representing a smaller overall contribution to the water budget, recharge from recharge ponds showed the largest increase from the beginning to the end of the study period on a volumetric basis and percentage-wise.
- Groundwater contribution to streamflow was, by far, the largest component of outflow.
- Total outflows in 2012 were more than total inflows, and aquifer storage was reduced. Conversely, in 2013 and 2014, aquifer inflows were greater than aquifer outflows and aquifer storage increased.

- The estimated monthly change in groundwater storage was used to estimate the relative change in the regional water table elevation during the study period. The results were compared with measured changes in the water table at monitoring wells in the study area. Estimated and measured changes in the water table matched very closely during the study period (Figure ES-3).

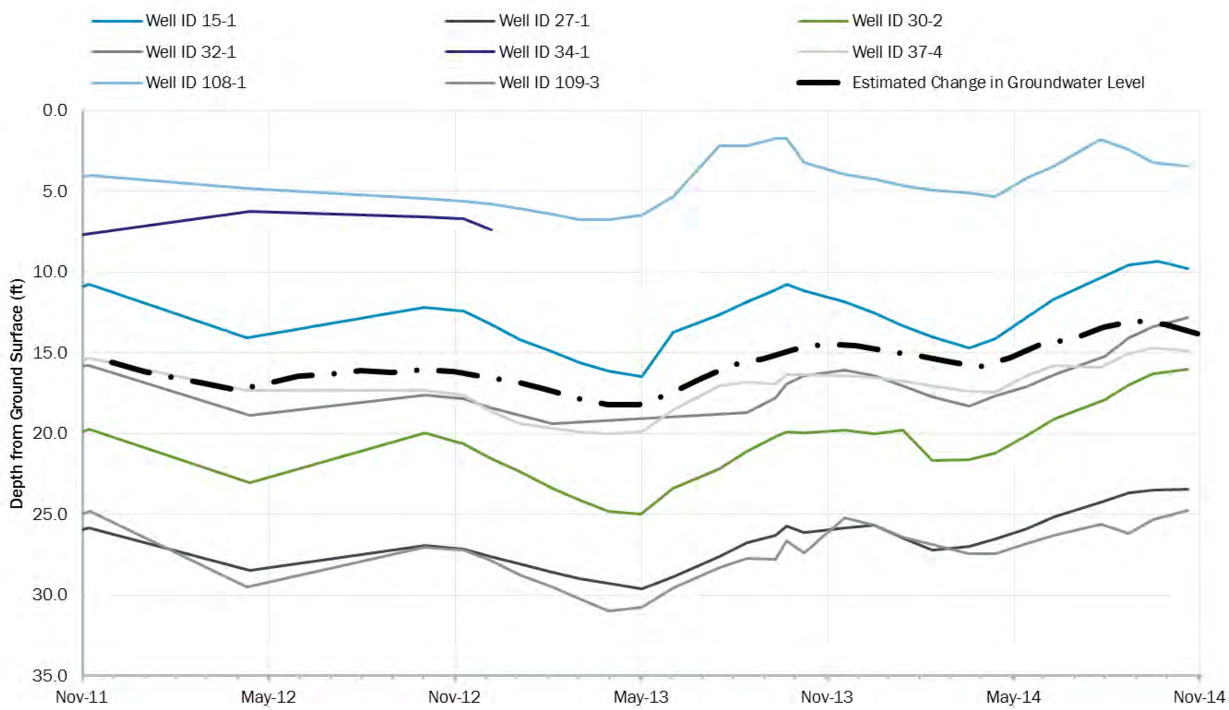

Figure ES-3. Estimated and measured groundwater level comparison: Gilcrest/LaSalle study area

Sterling Study Area

The water budget for the Sterling study area was quantified and is described in detail in the report. Observations on the water budget for the Sterling study area are summarized below.

- On a regional basis, ditch seepage was the largest inflow component during the study period in the Sterling area, and it increased during the study period
- Recharge from recharge ponds was the second largest component, and it also increased during the study period
- The largest outflow component in the Sterling study area was subsurface outflow (i.e. groundwater flow out of the study area).
- Consumptive use of groundwater from pumping for irrigation was the second largest outflow component.
- Total outflows in 2012 were more than total inflows, and aquifer storage was reduced. In 2013, outflows were slightly higher than inflows, but they were generally balanced. Conversely, in 2014, aquifer inflows were greater than aquifer outflows and aquifer storage increased.
- The estimated monthly change in groundwater storage was used to estimate the relative change in the regional water table during the study period. The results were compared with measured changes in the water table at monitoring wells in the Country Club Hills and Pawnee Ridge subdivisions.

- Estimated regional changes in water tables generally followed changes measured in the Country Club Hills subdivision, but several inconsistent patterns were observed (Figure ES-4). Local drivers likely caused the inconsistent patterns.

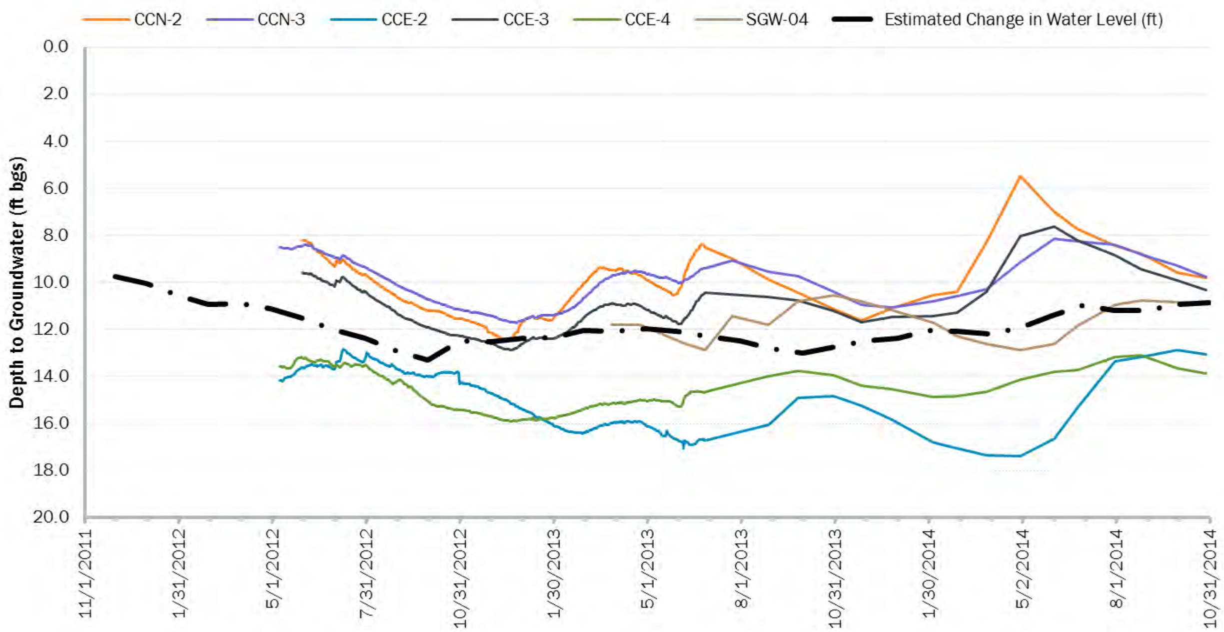

Figure ES-4. Estimated and measured groundwater level comparison near Country Club Hills

- Estimated regional changes in the water table closely matched nearly all of the measured water levels in the Pawnee Ridge study area (Figure ES-5).

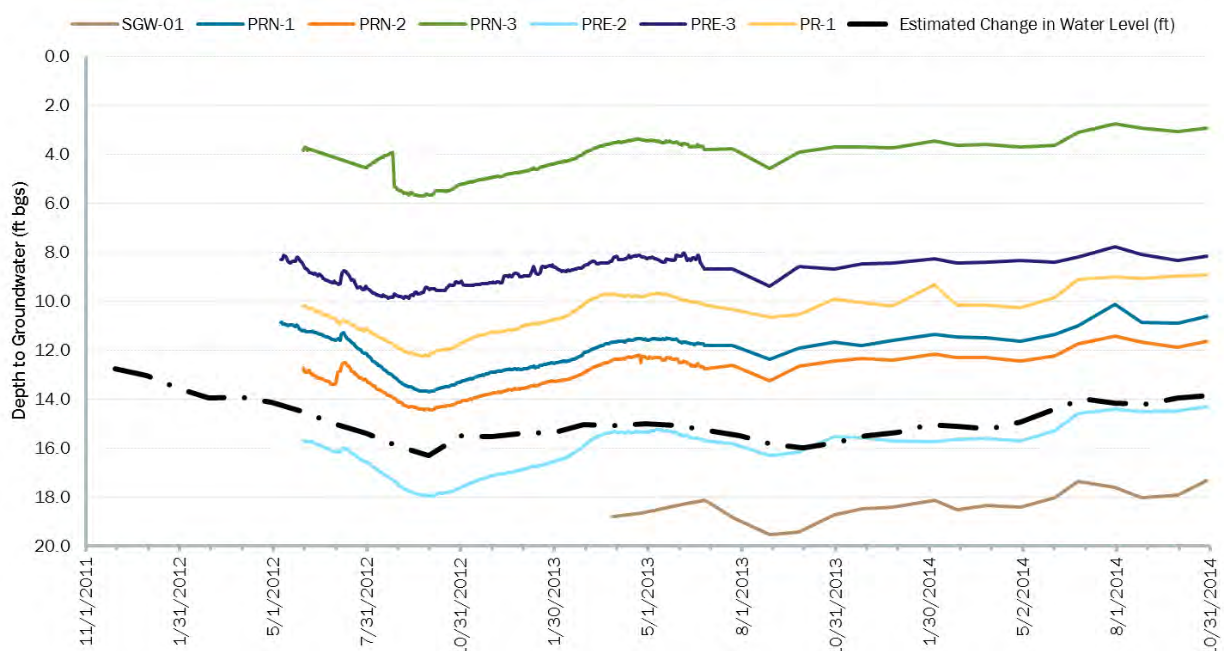

Figure ES-5. Estimated and measured groundwater level comparison near Pawnee Ridge

Hydrologic Relationships, Observations, and Conclusions

The overall water budgets and water balance components in each study area were analyzed to identify relationships among the components and to develop observations and conclusions that will be useful in developing conceptual approaches for mitigating high groundwater issues. The following is a summary of the relationships, observations and conclusions described in the report.

Gilcrest/LaSalle Study Area

- Based on the results of the water budget analysis, the regional water table during the study period responded to the balance of total inflows and outflows. The water budget components influencing water table changes during the study period were driven by diverse factors, and the components of total inflows and outflows varied in magnitude and changed in magnitude from year to year. Some of the components are driven primarily by natural phenomena and some are driven by human decision-making. The water budget and estimated changes in regional water table suggest that an imbalance in the water budget of around 5,000 acre-feet will result in about a 1-foot average change in the regional water table. This relationship is sensitive to the estimated specific yield of the aquifer.
- Drivers of regional water table change varied during the study period. The water budget components that drove increases and decreases in the water table changed during the study period. No single water budget component stands out as a consistent and primary driver of water table change. Rather, the combined effects of the various components tended to drive water table changes.
- Rainfall is an important factor. Rainfall plays a very important role in how the water budget components vary. Certainly, recharge from precipitation is directly influenced by the amount of rainfall that occurs. However, other components such as recharge from recharge ponds, consumptive use of groundwater from pumping for irrigation, and recharge from surface water irrigation are all impacted by changes in water demand and water management due to wet and dry hydrologic cycles.
- The water budget can be a useful tool for estimating regional changes that could occur based on the various drivers. The water budget also provides information on interrelationships among the water budget components that should be considered when developing concepts to mitigate regional high water table conditions.

Sterling Study Area

- Based on the results of the water budget analysis, the regional water table during the study period responded to the balance of total inflows and outflows. The water budget analysis estimated changes in the regional water table that generally reflected monitoring well data. The monitoring wells that did not show an obvious correlation to the regional water budget were likely influenced by local drivers such as nearby ditches or recharge ponds or by heterogeneity in local aquifer characteristics.
- Water levels in Country Club Hills and Pawnee Ridge monitoring wells respond to different drivers depending on location and local hydrogeologic characteristics. Monitoring well hydrographs in the Country Club Hills and Pawnee Ridge subdivisions show a variety of patterns. Some hydrographs appear to mimic seasonal rises and falls in the regional water table. Other hydrographs show abrupt changes that could be driven by local structures such as recharge ponds or ditches. A statistical analysis was conducted to identify correlations between drivers of groundwater level change and observed groundwater levels in monitoring wells.
    - In the Country Club Hills subdivision, several strong correlations were observed between water levels in specific wells and individual hydrologic drivers. Statistically significant but

moderate correlations were identified among several hydrologic drivers for many of the monitoring wells.
   - In the Pawnee Ridge subdivision, water levels in most of the monitoring wells were strongly correlated to regional changes in water table elevations rather than local hydrologic drivers.
- Local topographic and geologic characteristics can make some areas more vulnerable to high groundwater problems than others. Lower areas in the rolling topography of the Country Club Hills subdivision may be more vulnerable to high water table issues than higher areas. A local rise in the bedrock underneath the aquifer below the Pawnee Ridge subdivision may be restricting groundwater flow.

Recommendations

Several recommendations are included in the report. Below is a summary of recommendations.

- The water budget and groundwater levels in both study areas should continue to be monitored. Continued monitoring will be useful in evaluating the success of regional or local high water table mitigation strategies.
- The water budget can be a useful tool for developing regional high water table mitigation strategies. Local dewatering strategies should continue to be developed, though the regional water budget may be of limited value.
- The updated SPDSS Alluvial Groundwater Model, when completed, will be a useful tool for conducting more detailed evaluations of high water table mitigation strategies.
- Detailed water budgets, developed for earlier time periods, could provide useful insights into the magnitudes of various hydrologic drivers during a time period when high water table conditions were not a problem.

Section 1

Introduction

Water management in the South Platte River Basin (Basin) is subject to a wide variety of drivers. Demand by agricultural, municipal, industrial, and environmental users exceeds supply in most years and forces us to maximize the beneficial use of our water to support as many uses as possible. Colorado's legal system dictates that senior water users (in general, surface water users) be provided their supply before junior users (in general, alluvial groundwater [GW] users). With constantly and sometimes widely varying hydrologic conditions, the stage is set for these drivers to create complicated water management issues that need to be informed by sound science.

1.1 Water Management and Hydrologic Changes

Relatively recent changes in surface and groundwater management, along with hydrologic drivers, have impacted the water budget in various parts of the Basin. During and after the drought of the early 2000s, and in response to various water court rulings, administration of alluvial groundwater pumping became stricter, and wells that were not covered by augmentation plans (e.g., former Groundwater Appropriators of the South Platte River Basin (GASP) wells) were shut down. In addition, some augmentation plans have not been able to acquire sufficient replacement supply, which has also resulted in pumping curtailments. Pumping curtailments have impacted District 2 more severely than in other reaches of the river because augmentation supplies are more difficult to acquire. In other areas of the Basin, pumping has been curtailed less because replacement supplies are more plentiful. In lower reaches of the South Platte River, several augmentation plans have been conducting alluvial groundwater recharge programs since the 1970s. In recent years, many more recharge programs have been initiated throughout the Basin to supply augmentation plans with replacement supply. The Background section in the HB12-1278 report (Study of the South Platte Alluvial Aquifer; Colorado State University, 2013) provides more detail regarding water management changes that have occurred in recent years.

In addition to water management changes, changes in the hydrology in recent years have impacted streamflows, farming operations, and augmentation plan operations. Excluding the drought in 2012, the Basin has experienced a series of wetter-than-average years dating back to the mid-2000s. This has led to increased flow in the river that in turn has eased the call regime and allowed junior users to divert more frequently, including junior recharge rights. Additionally, the wetter climate acts to reduce irrigation demand, which can lead to lower levels of pumping. The impact from major events such as the heavy precipitation and flooding in September 2013 is less clear. However, the flow in the South Platte River was likely increased for several months by the release of bank storage.

1.2 High Groundwater Issues

Real and perceived impacts of hydrologic and water management drivers described above have gained recent attention in the vicinity of Sterling and in the area surrounding Gilcrest and LaSalle along the South Platte River. In recent years, homeowners in the Sterling area have experienced negative impacts associated with high groundwater tables (e.g., water in basements, etc.). The impacts have centered on the Country Club Hills and Pawnee Ridge subdivisions. Recent high water table conditions in the Gilcrest/LaSalle area have led to negative impacts such as crop damage, basement flooding, and septic system failure. The contexts for the water management challenges in these areas are somewhat different but, in both situations, high groundwater tables have been observed in recent years and have caused concern among water users and local citizens.

1.3 Historical Context

The changes in water management and hydrology have the potential to impact groundwater levels. The potential relationship among these factors and the high groundwater issues in the affected areas can be explained in part by a review of historical records. The charts below show historical depth to groundwater measurements compared to various hydrologic components.

1.3.1 Gilcrest/LaSalle Region

Historical groundwater level readings were retrieved from a select number of wells throughout the region surrounding Gilcrest and LaSalle. The monitoring well locations are shown on Figure 1-1 below.

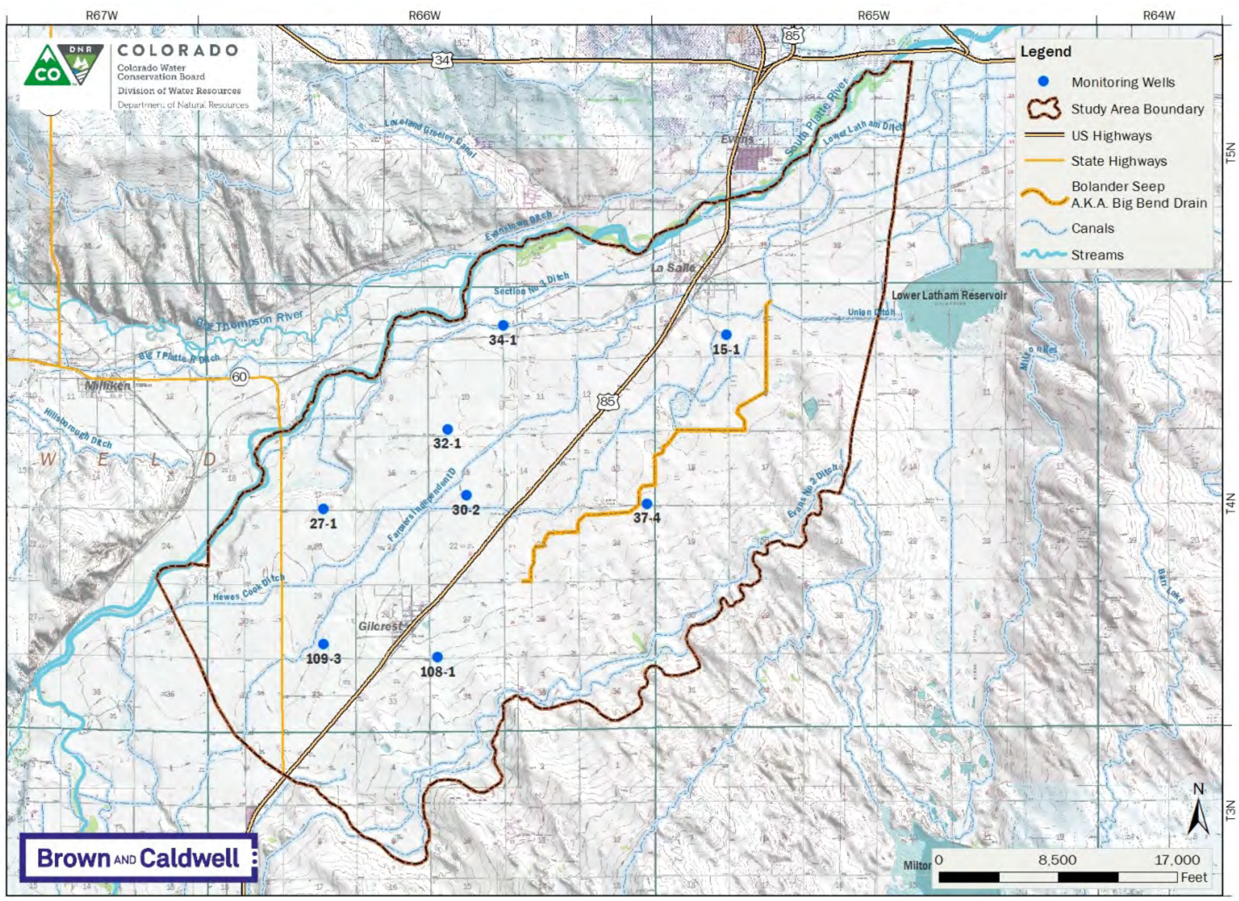

Figure 1-1. Historical groundwater monitoring sites near Gilcrest/LaSalle

The monitoring sites were selected based on the availability of historical water level data and location. The majority of the sites have data that are available from 1994 – 2014.

Figures 1-2 through 1-5 below compare the historical groundwater levels from the wells shown in Figure 1-1 to various regional hydrologic components, including pumping, precipitation, ditch diversions, and groundwater contribution to streamflow.

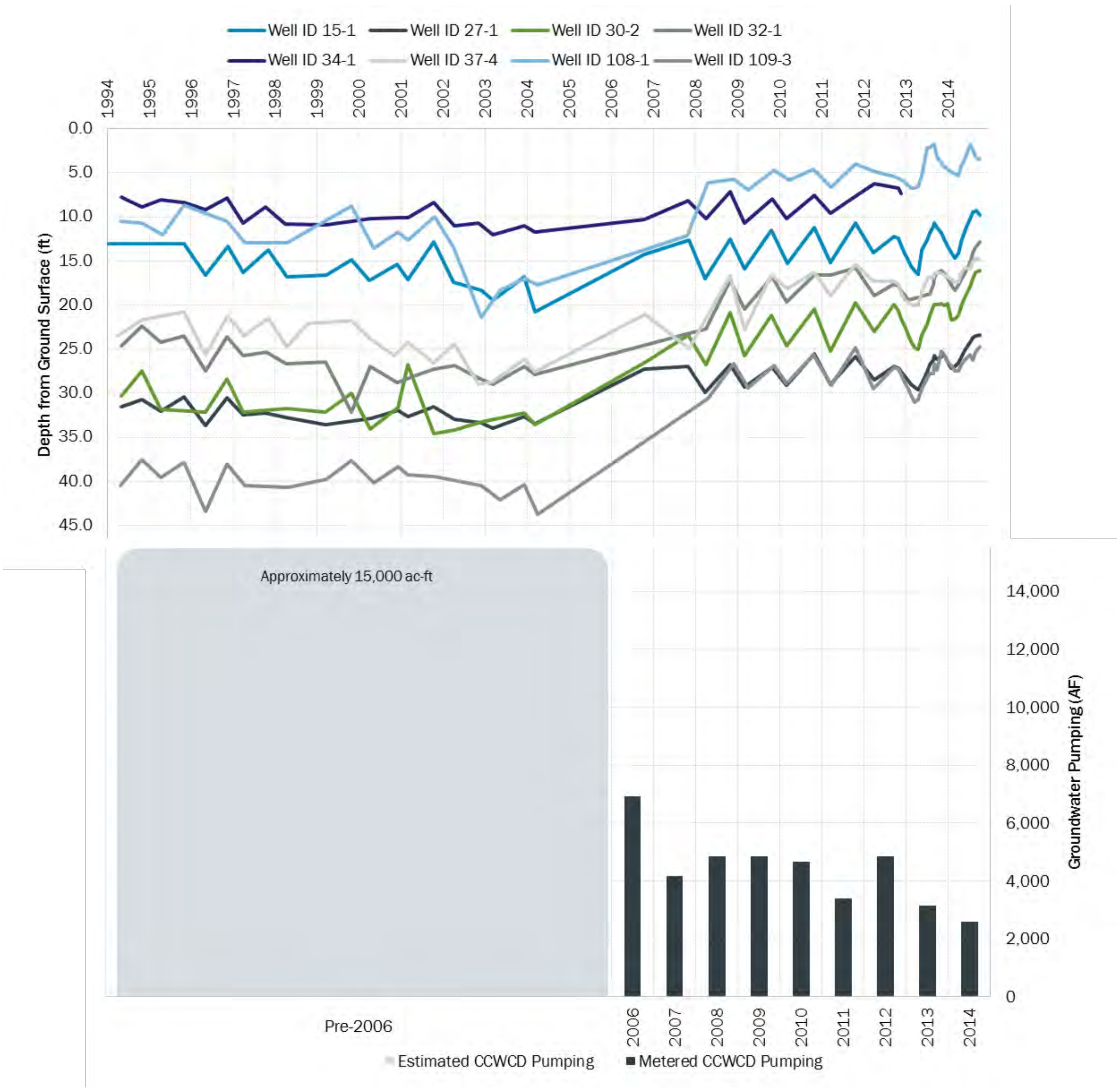

Figure 1-2. Historical groundwater levels and pumping near Gilcrest/LaSalle

The pumping data shown in Figure 1-2 are from records provided by the Central Colorado Water Conservancy District (CCWCD) for wells near Gilcrest and LaSalle. Metered data were available from 2006 – 2014. Pre-2006 pumping rates, estimated by CCWCD, were approximately 15,000 acre feet annually but varied based on irrigation demand and other factors. Curtailment of pumping covered by CCWCD's augmentation plans began in 2006.

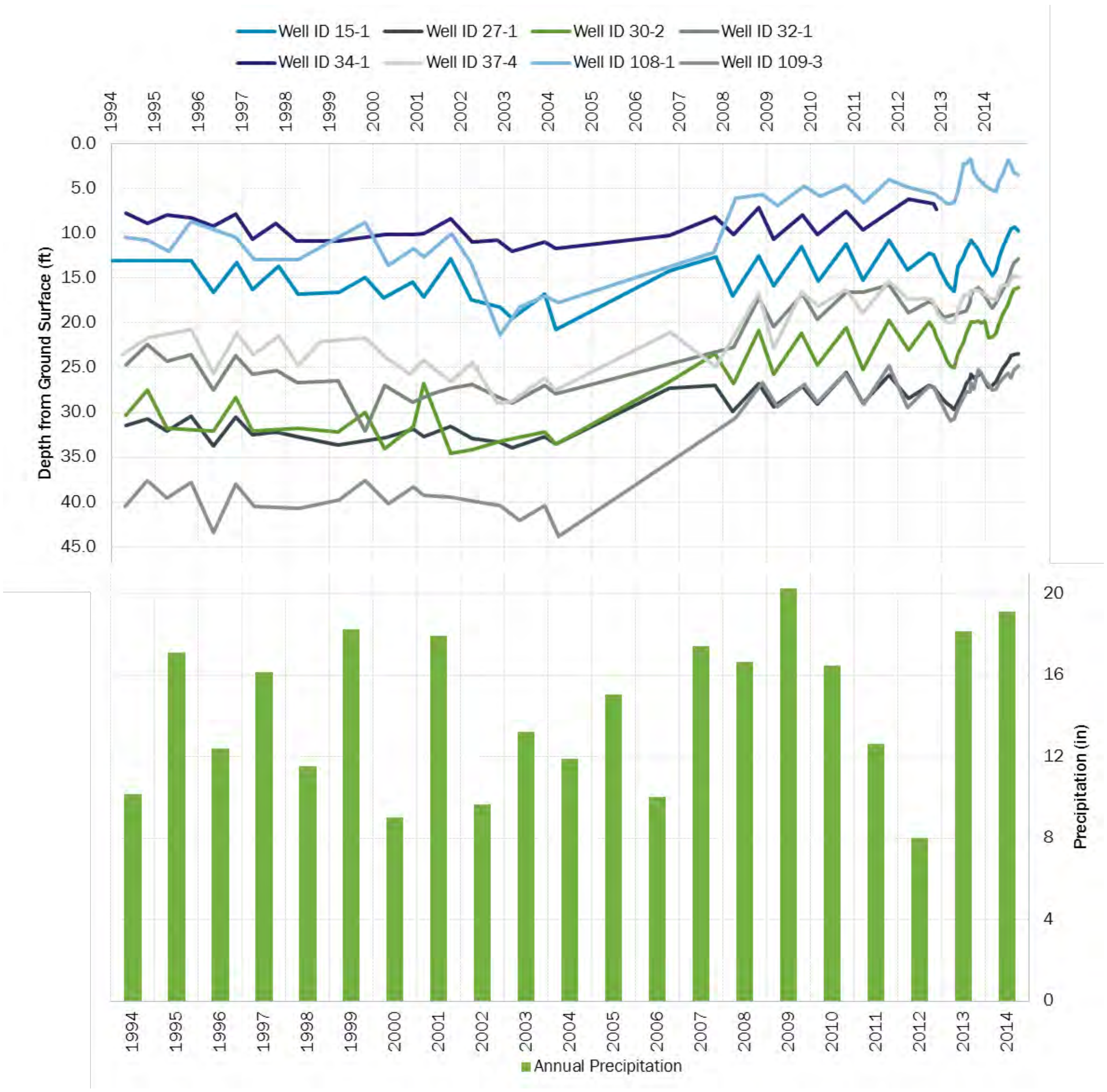

Figure 1-3. Historical groundwater levels and precipitation near Gilcrest/LaSalle

Figure 1-3 compares historical groundwater levels and annual precipitation values collected from the National Oceanic and Atmospheric Administration (NOAA) weather station near Greeley. The average annual rainfall from 1994 – 2014 was 14.3 inches per year. In 6 out of the 9 years from 2006 to 2014, the average value was exceeded.

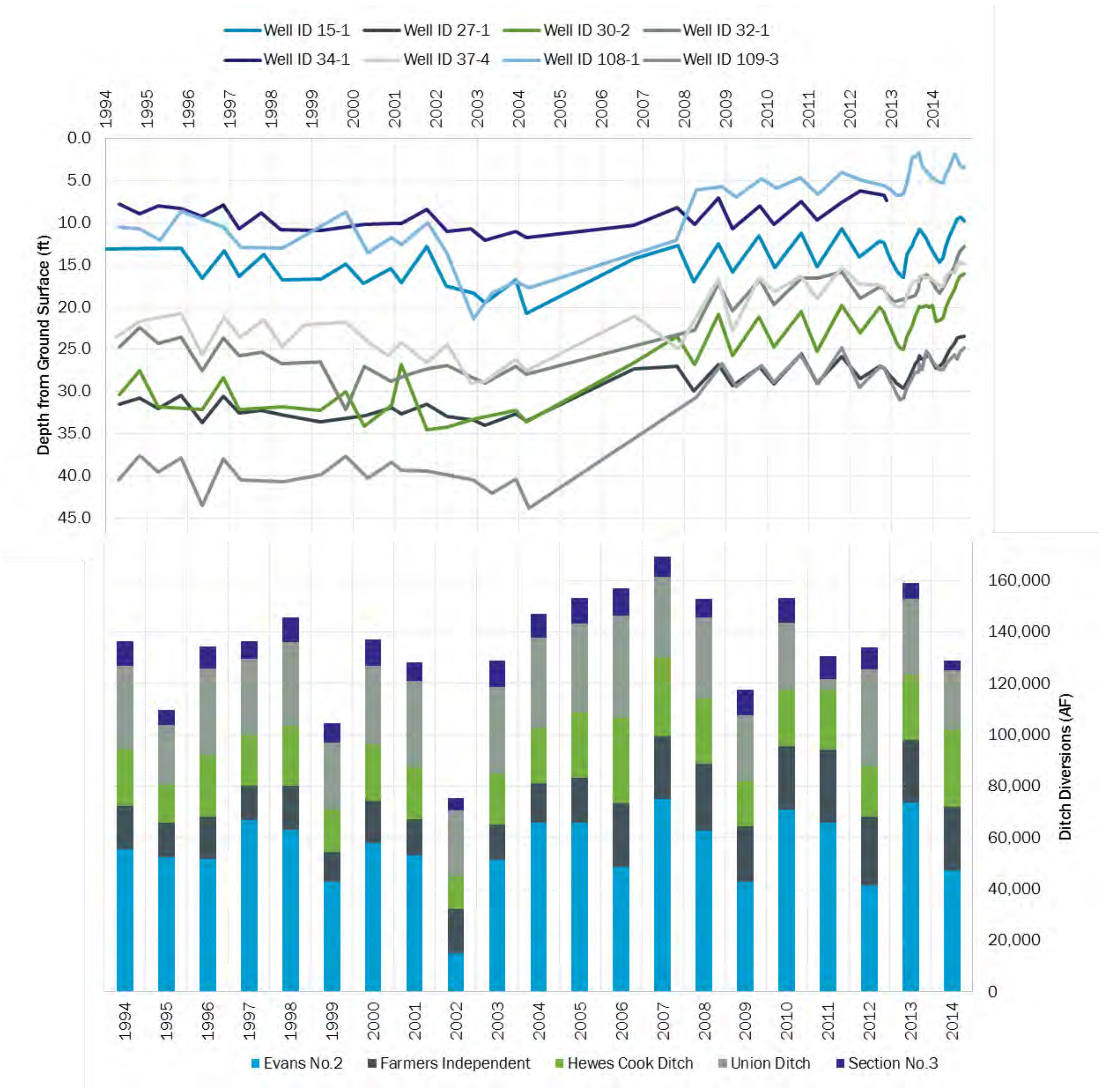

Figure 1-4. Historical groundwater levels and annual ditch diversions near Gilcrest/LaSalle

Annual diversions for ditches near Gilcrest and LaSalle show mixed trends on a ditch-by-ditch basis. Evans No. 2 is more volatile because of a relatively junior water right and does not show a strong trend. Increases were observed in the Farmers Independent and Hewes Cook ditches. Union and Section No. 3 ditches were fairly steady.

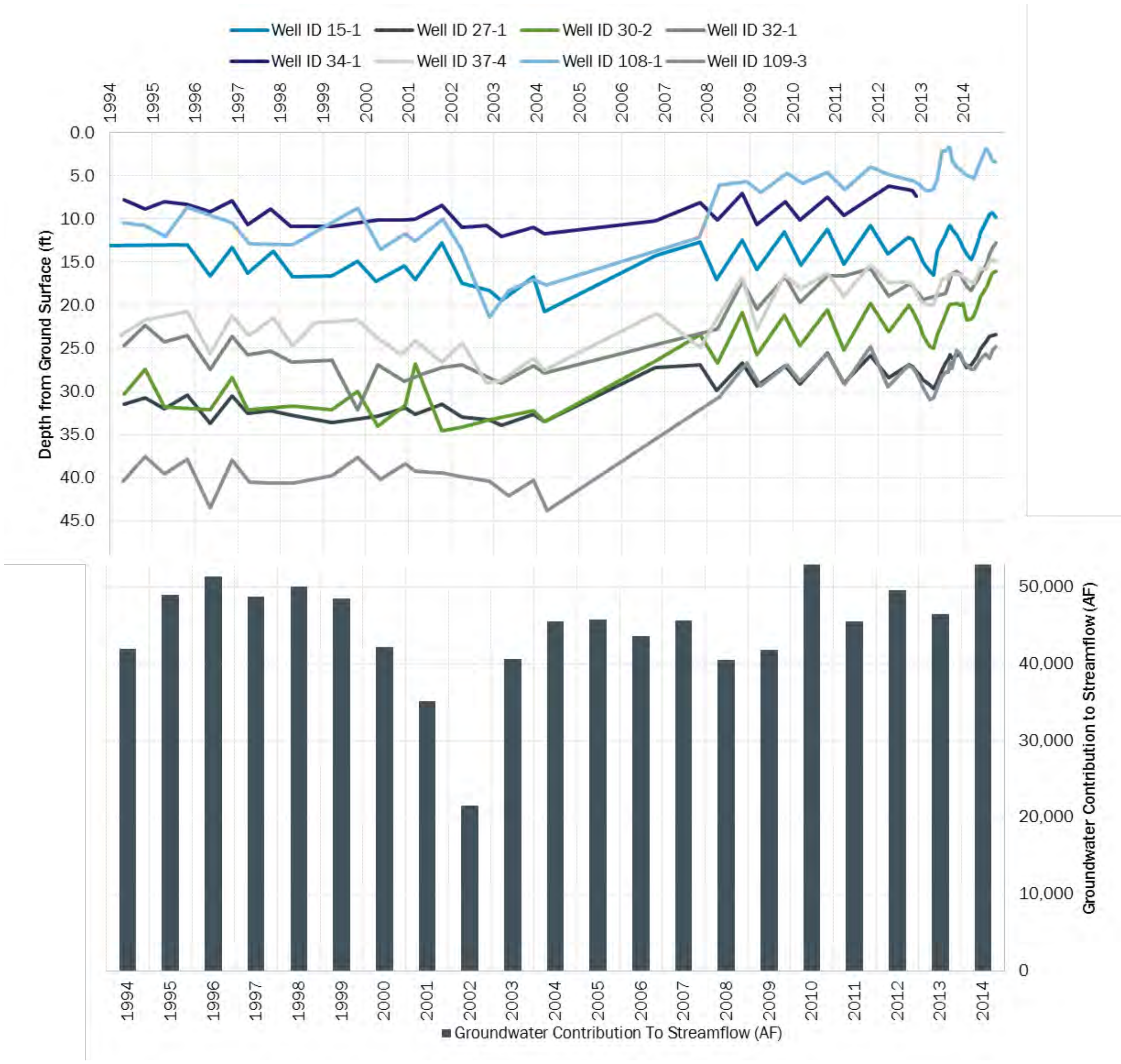

Figure 1-5. Historical groundwater levels and groundwater contribution to streamflow near Gilcrest/LaSalle

Groundwater contribution to streamflow represents the subsurface flow leaving the study area defined for the Gilcrest/LaSalle region and entering the South Platte River. The methodology for determining the values is explained in Section 3.2.2.5 of this report. Since 2002, the groundwater contribution to streamflow shows a slightly increasing trend.

1.3.2 Sterling Region

There are a limited number of monitoring wells with historical data in the Sterling region. Figure 1-6 shows the wells that had records dating back to at least 2006. Figures 1-7 through 1-9 below compare the historical groundwater levels from the wells shown in Figure 1-6 to various regional hydrologic components, including pumping, precipitation, and ditch diversions.

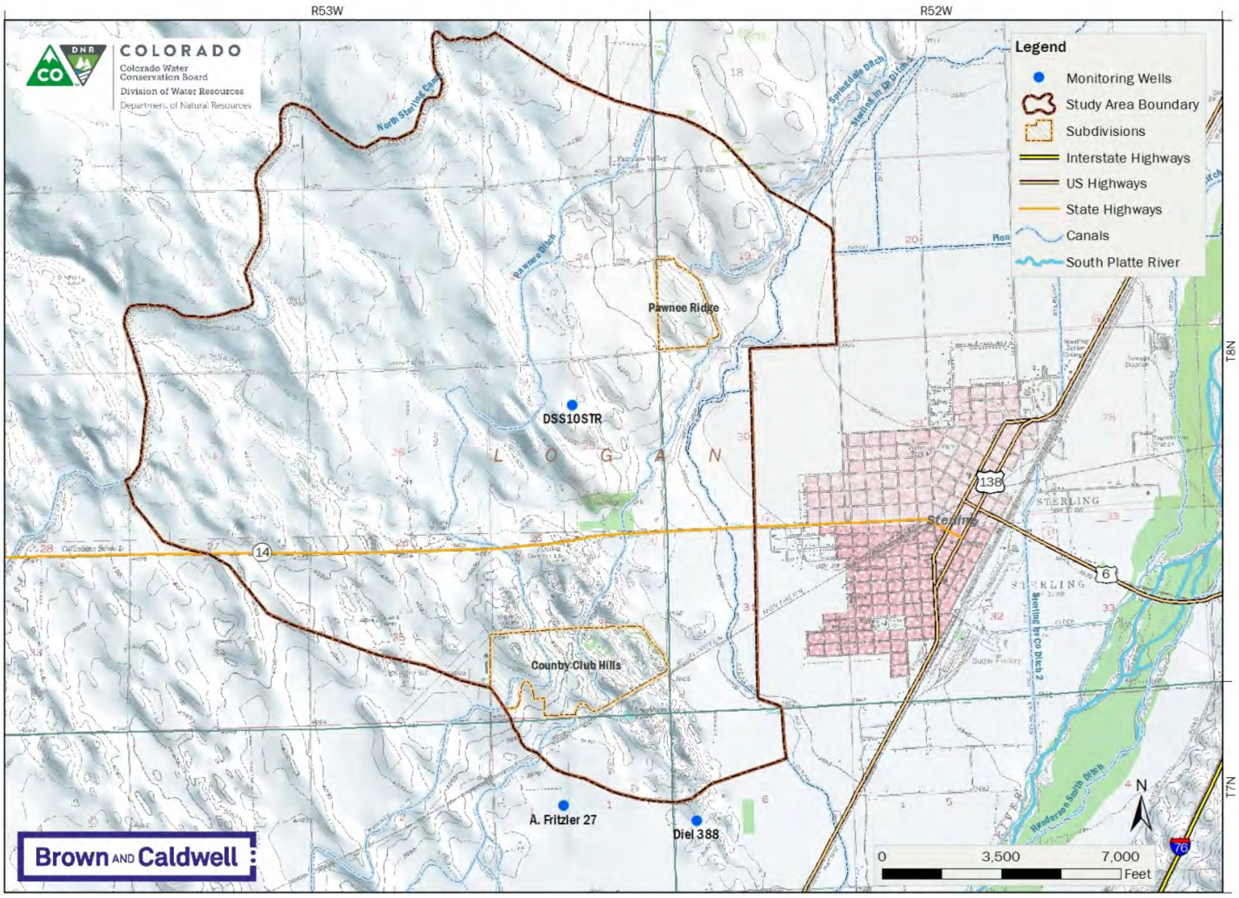

Figure 1-6. Historical groundwater monitoring sites near Sterling

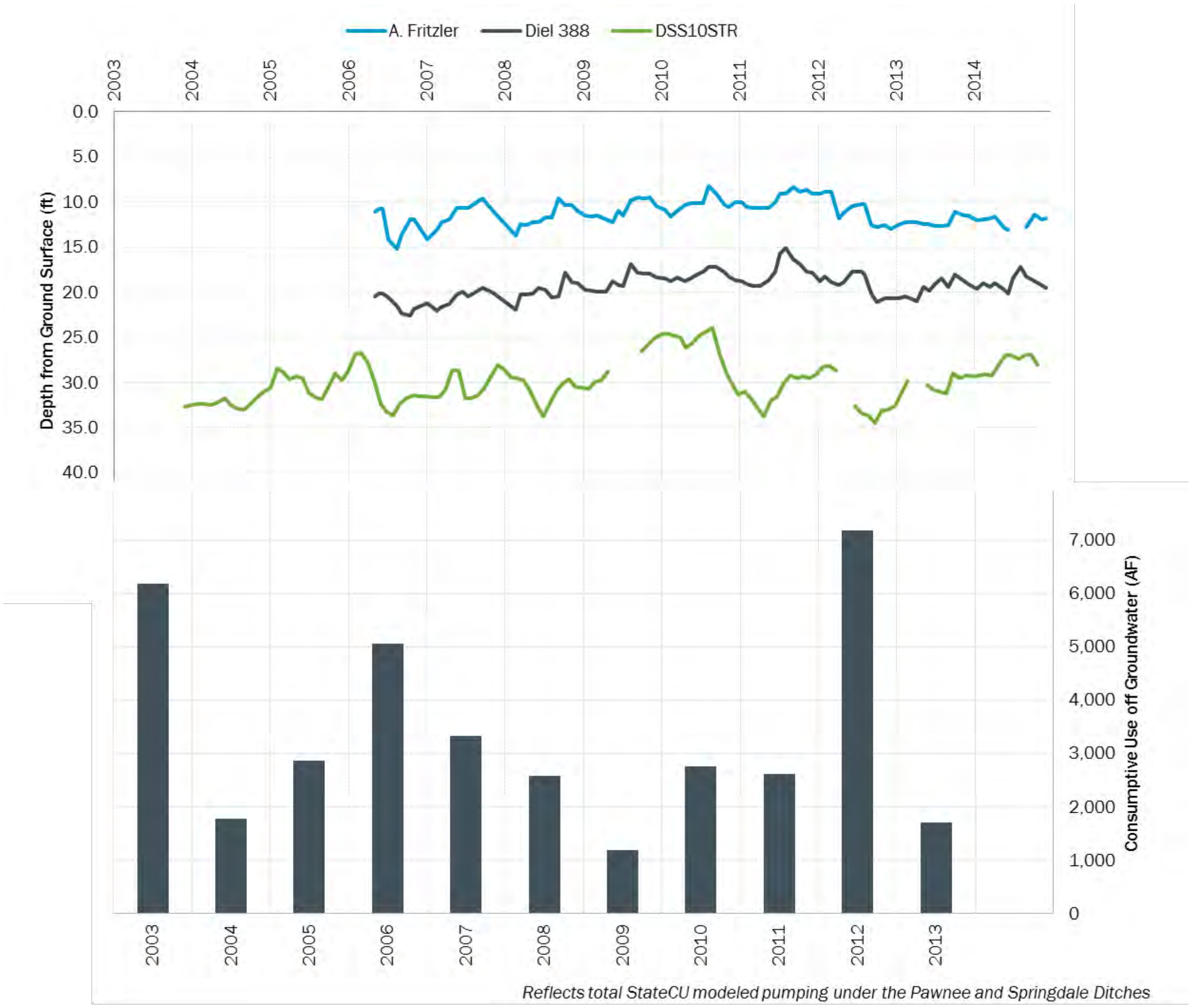

Figure 1-7. Historical groundwater levels and groundwater consumptive use from pumping near Sterling

Groundwater consumptive use from pumping represents simulated pumping from the StateCU model less irrigation return flows. The model runs through 2013, so 2014 values were not available. The values shown in Figure 1-7 reflect estimated groundwater consumptive use under the Pawnee and Springdale Ditches, and are not intended to be a comprehensive accounting of all groundwater consumptive use near Sterling. Because the majority of the pumping in the area is supplemental to surface water supplies, the amount of pumping is closely related to the hydrologic conditions. Wet years generally bring a decrease in pumping and dry years are accompanied by an increase in pumping. The values shown for 2003 and 2012 are good examples of dry-year groundwater consumptive use from pumping. The years 2009 and 2011 represent wetter than average years and show lower groundwater consumptive use from pumping. The well curtailment that occurred in 2006 in the Basin did not impact the Sterling area to the same degree as the Gilcrest/LaSalle area. The lower groundwater consumptive use values post-2006 are likely due to changing hydrologic conditions.

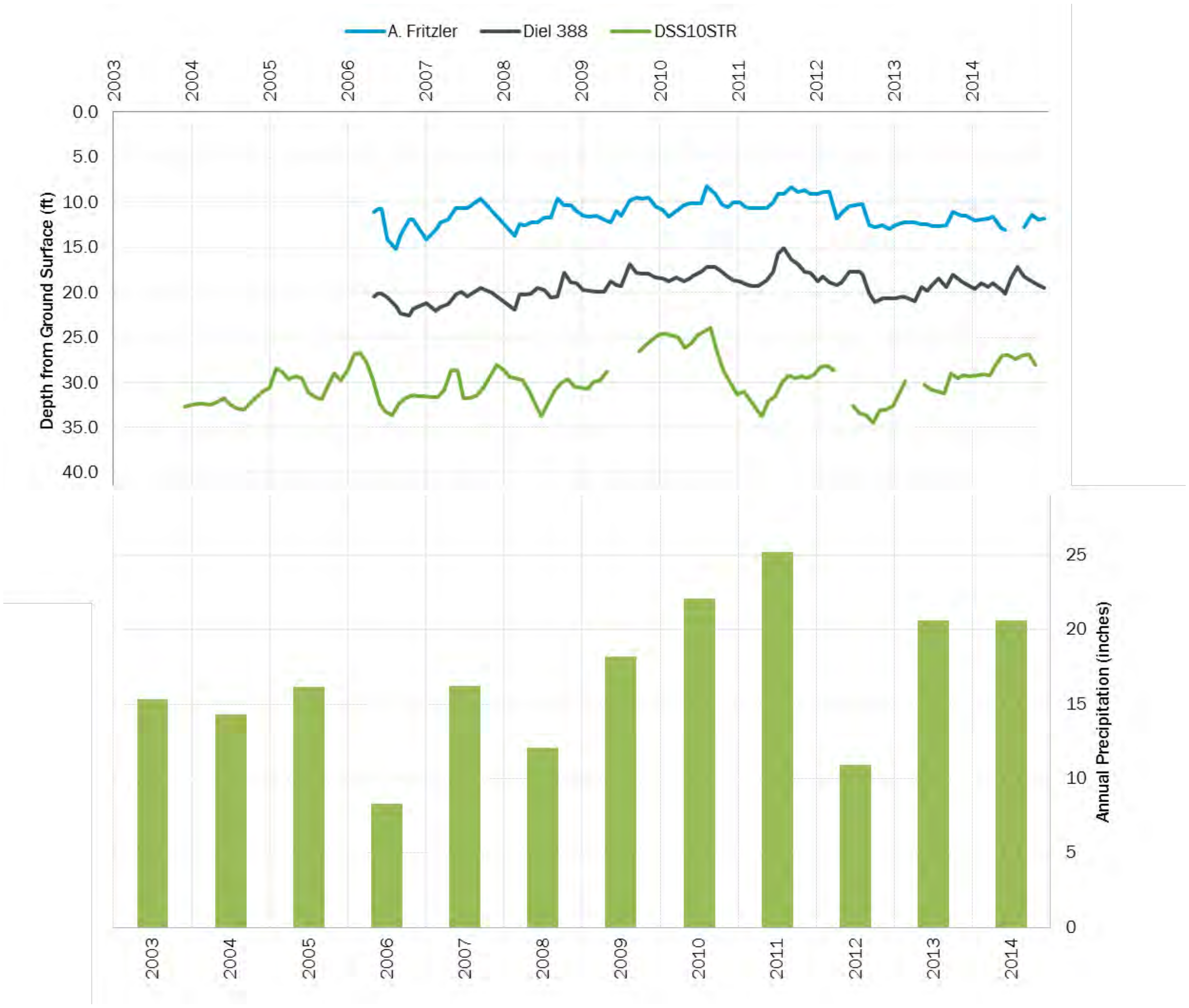

Figure 1-8. Historical groundwater levels and annual precipitation near Sterling

Annual precipitation totals were collected from a combination of NOAA weather stations near Sterling. The average precipitation from 2003 – 2014 was 16.7 inches. That average was exceeded five times during the period of interest, with all instances occurring in the last six years.

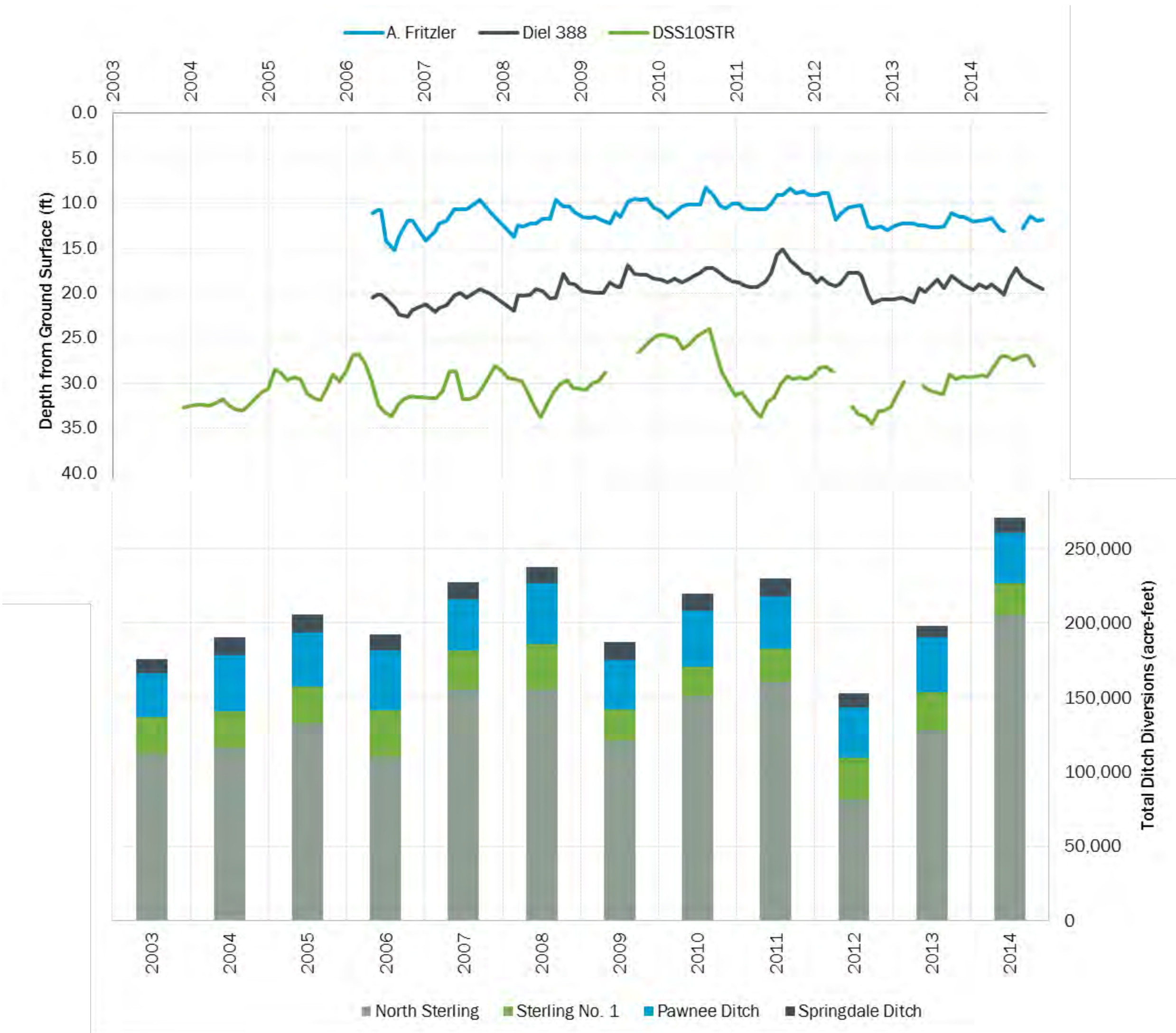

Figure 1-9. Historical groundwater levels and annual ditch diversions near Sterling

Between 2003 and 2014, the annual ditch diversions for ditches near Sterling have generally been increasing, The North Sterling Canal has shown the largest increase during that time period. The Sterling No. 1, Pawnee, and Springdale ditches have been relatively steady on an annual basis.

1.4 Investigation and Analysis

The Colorado Division of Water Resources (DWR) initiated detailed data collection and monitoring of the hydrologic conditions and drivers in the Sterling and Gilcrest/LaSalle areas in spring 2012. An overview of the study area locations within the Basin is shown on Figure 1-10.

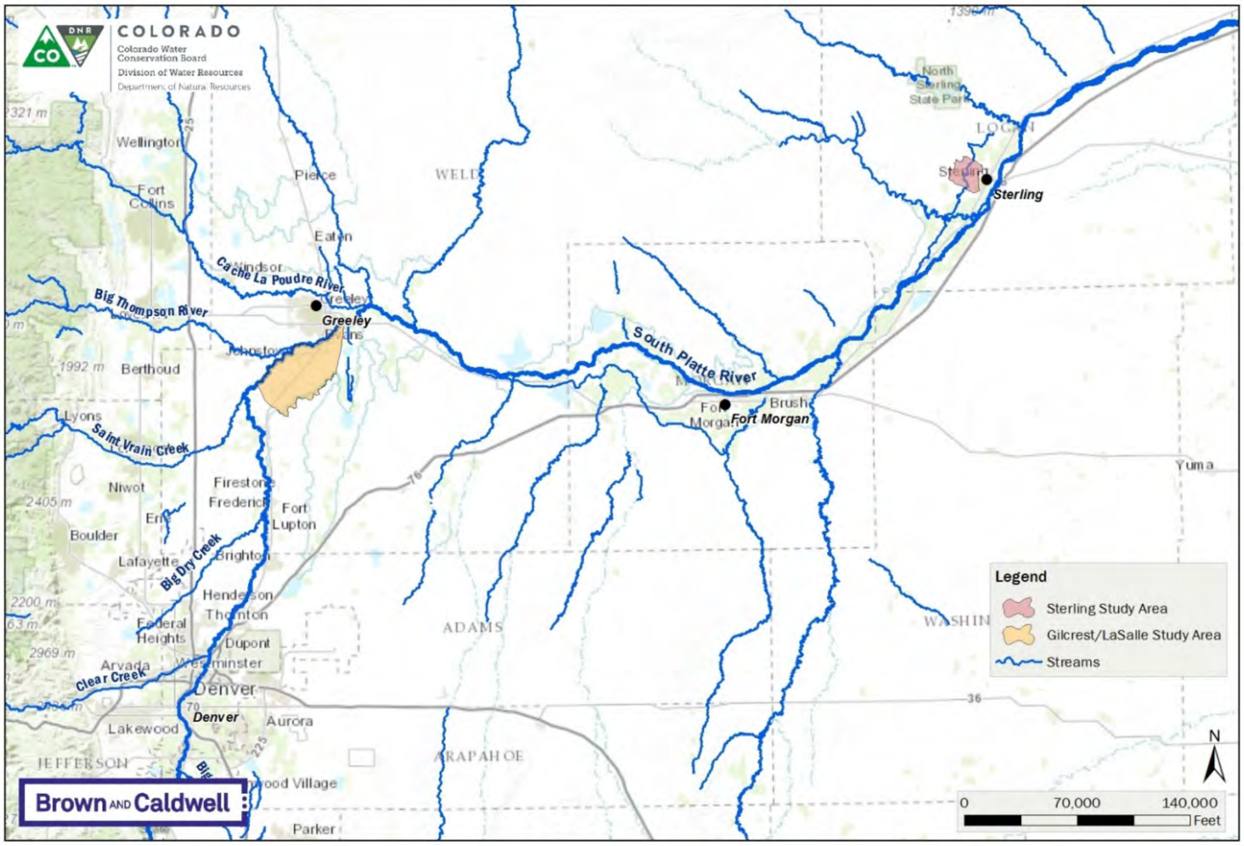

Figure 1-10. Regional overview

The data collection and monitoring focused on various components of the water budget in the areas. Ditch diversions, climatological parameters (primarily rainfall), groundwater levels, and hydrogeologic characteristics are among the data and information acquired and compiled during this effort. However, DWR has not conducted analyses of the data, nor has it made recommendations regarding mitigation strategies for the negative impacts of high groundwater tables. Brown and Caldwell (BC) was retained to conduct an independent review and analysis of the data and develop causal relationships where possible that explain the reasons for high groundwater tables.

1.4.1 Scope of Work

The overall goal of the project was to create a water budget that can help describe the hydrologic and hydrogeologic influences that may be causing high groundwater in the Sterling and Gilcrest/LaSalle areas. The analysis was focused on the geographic areas where problems with high groundwater have been reported. The general tasks include:

- Identifying and acquiring the relevant geologic and historical water use data for the study areas
- Quantifying the components of the water budget using standard scientific methods
- Establishing water budgets for the two study areas

- Analyzing the water budgets to identify and describe the interrelationship of all hydrologic factors that influence the hydrogeology in the study areas
- Completing a report of the analysis

Section 2

Identify and Acquire Relevant Historical Data in Study Area

The purpose of this task was to identify the relevant individual components of the water budgets, select appropriate sources for the necessary data, determine a period of record for the investigation, and acquire the historical data. A similar approach for identifying and acquiring data was used in both the Gilcrest/LaSalle and Sterling study areas.

The data collected for this study came from a variety of sources. Where possible, data acquired by DWR as a part of its ongoing investigations in the study areas were used. Data stored in DWR's water resources database (HydroBase), augmentation plan accounting, and outputs from South Platte Decision Support System (SPDSS) models made up most of the remaining data needs. Some of the components of the water budget could not be represented by data that can be directly measured. In these cases, BC developed methods for estimating historical values using standard scientific methods using various groundwater modeling and spreadsheet-based tools.

For background, SPDSS is a joint effort by the Colorado Water Conservation Board (CWCB) and DWR to develop data sets and models that describe the hydrologic and hydrogeologic conditions in the Basin and provide support for water resources planning and management. The modeling efforts include consumptive use (CU) modeling, groundwater modeling, and surface water modeling. Modeling and data collection efforts for SPDSS are ongoing and the data are publicly available. The SPDSS Alluvial Groundwater Model was initially developed with data through 2006, and it is currently being updated with data through 2012; the update is expected to be completed later this year.

Prior to initiating data collection efforts, the historical period of record for the water budget was established. BC reviewed the available data and met with DWR and CWCB and determined that a period beginning in water year (WY) 2012 (starting in November 2011) and running through the end of WY 2014 (October 2014) was appropriate. The selected period is consistent with the scope of work and coincides with the wide availability of DWR-collected water level data in the study areas during that time frame.

The following sections provide an overview of the historical data collection organized by source.

2.1 Data Acquired from DWR

The data collected from DWR came primarily from HydroBase. In some cases, BC used spreadsheets provided by DWR where HydroBase data had previously been compiled as a part of the ongoing monitoring efforts within the study areas. These data included ditch diversion records and diversions to recharge ponds. Published HydroBase diversion data were not available for WY 2014, so provisional diversion records collected and maintained by the Division 1 Engineer's office were used.

In addition to the historical time series data acquired from DWR, certain spatial data were obtained and used to quantify components of the water budget. These spatial data include canal locations, irrigated parcel snapshots, recharge pond locations, and irrigation well locations. Additional spatial data were acquired from DWR for mapping purposes (e.g., reservoir locations, city boundaries, and roads), but were not used in the quantification of water budget components and are not summarized in the report. Table 2-1 shows the data that were obtained from DWR, specific sources of the data, and which water budget components quantified with the data.

Table 2-1. Data Obtained from DWR			
Data Type	**Data Source**	**Data Format**	**Water Budget Components**
Ditch diversions	HydroBase and provisional workbooks	Monthly time series/daily time series	Ditch seepage, recharge from irrigation, groundwater contribution to streamflow
Diversions to recharge	HydroBase and provisional workbooks	Monthly time series	Recharge from ponds
Streamflow	HydroBase	Daily time series	Groundwater contribution to streamflow
Irrigated area snapshots	HydroBase	Geodatabase	Recharge from irrigation, direct crop GW consumption
Canal locations	HydroBase	ESRI shapefile	Ditch seepage
Recharge pond locations	Division 1 engineer	ESRI shapefile	Recharge from ponds
Irrigation well locations	Division 1 engineer	ESRI shapefile	Consumptive use of groundwater from pumping
Groundwater levels	DWR Gilcrest and Sterling database	Tabular data	Verification of change in storage

In cases where existing data sets needed to be supplemented, BC modified these data (e.g., completed mapping of recharge structures) using information from outside sources or through consultation with DWR staff.

2.2 Data Acquired from Other Sources

A number of water budget components were quantified using data from outside sources or using modeling output generated and processed by BC. These data include monthly well pumping, consumptive use model output (StateCU), SPDSS groundwater model output, precipitation data, municipal discharge data, and depth-to-water mapping. A summary of the data collected from non-DWR sources is shown in Table 2-2.

Table 2-2. Data Acquired from Other Sources				
Data Type	**Data Provider**	**Data Source**	**Data Format**	**Water Budget Components**
Well pumping	City of Sterling, Logan well users, North Sterling, Pawnee well users, Central GMS, and Central WAS	Augmentation plan accounting	Monthly time series	Consumptive use from groundwater pumping
Precipitation	Northern Colorado Water Conservancy District	NCWCD Climate Station Network	Monthly time series/daily time series	Recharge from precipitation, groundwater contribution to streamflow
Non-consumed irrigation deliveries	StateCU model	StateCU water budget file	Monthly time series	Recharge from irrigation, ditch seepage
Subsurface flows	SPDSS groundwater model	MODFLOW cell-by-cell flow file	Monthly time series	Subsurface inflow, subsurface outflow
Municipal discharges to stream	Environmental Protection Agency	EPA ECHO database	Monthly time series	Groundwater contribution to streamflow
Depth-to-water mapping and water table contours	Colorado Geological Survey	Gilcrest/LaSalle Pilot Project Hydrogeologic Characterization Report	Geodatabase	Direct crop GW consumptive use

The StateCU model output used in this study is from the basin-wide consumptive use model developed in conjunction with the SPDSS surface water modeling and groundwater modeling projects and has a period of record from 1950 through 2012. Because the period of record does not cover the period for the water budget completely, data for components extracted from the StateCU model (e.g., recharge from irrigation) for 2013 and 2014 were quantified using a combination of HydroBase records and historical average relationships from the model. The SPDSS Alluvial Groundwater Model output is from a version of the model constructed during the initial modeling effort, and has a period of record of 1950 through 2006. As a result, model output data used in this study are monthly average values. The SPDSS groundwater model is currently being updated with data through 2012; the update is expected to be completed later this year.

Section 3

Apply Standard Scientific Methods and Practices to Quantify the Various Hydrologic Inputs Influencing Groundwater Levels and Flow

The purpose of this task was to delineate appropriate study areas for each water budget and quantify the hydrologic inputs that make up the water budget. The methods and approaches used to quantify each component of the water budget are discussed in detail in the following sections.

The water budget focused on the alluvial aquifer and all components are defined relative to the aquifer. That is to say that inflow refers to components that recharge the aquifer and outflow refers to components that drain the aquifer. Surface water flow occurring as streamflow, flow in ditches, or runoff was not quantified. However, seepage into the alluvial aquifer resulting from flow in ditches or contributions of alluvial groundwater to flow in the South Platte River was quantified. Additionally, the study area boundaries were drawn to align with groundwater flow paths where possible and focus the study on the areas most affected by high groundwater. Aligning the boundary with the groundwater flow paths serves to minimize subsurface flow entering and leaving the study area. These components are difficult to measure and could represent a significant portion of the water budget. Furthermore, the subsurface flows are relatively consistent over time and show a lagged response to changes in the hydrologic inputs. Also, regions that do not have a large influence on the areas most affected by high groundwater were excluded from the study areas. For example, the Beebe Draw region was excluded from the Gilcrest/LaSalle study area because a large amount of water flows through it, but water levels have been relatively stable, and it does not contribute to the problem areas near Gilcrest. Table 3-1 shows a list of the water budget components that were quantified in Task 2.

Table 3-1. Water Budget Components

Inflow Components	Outflow Components	Storage Components
Ditch seepage	Groundwater consumptive use from pumping	Change in storage
Recharge from ponds	Groundwater contribution to streamflow	
Recharge from precipitation	Direct phreatophyte consumption	
Recharge from irrigation	Direct crop consumption	
Subsurface inflow	Subsurface outflow	

Note that seepage from reservoirs was not considered in either study area because all nearby reservoirs fell outside of the study area boundaries. Additionally, groundwater contribution to streamflow was not considered in the Sterling study area because the study area boundary was not adjacent to the river.

3.1 Delineation of Study Areas

The study area boundaries were developed to quantify regional drivers and isolate key water budget components. A summary of the approaches taken to delineate each study are provided in the following sections.

3.1.1 Gilcrest/LaSalle Study Area

The Colorado Geological Survey (CGS) delineated a study area that was used to spatially constrain the collection of hydrogeologic data as part of the Gilcrest/LaSalle Pilot Project (CGS, 2014). While the study area was appropriate for compiling data and for development of a regional conceptual model, the boundaries do not necessarily conform to natural hydrologic or hydrogeologic features. If the CGS study area boundary were adopted for this study, fluxes either into or out of the study area would be more difficult to quantify and would have higher levels of uncertainty.

To address this issue, BC refined the study area so that boundaries conformed to hydrologic or hydrogeologic features. The study area proposed by BC is smaller than the one delineated by CGS but still includes areas impacted by high groundwater. The BC study area boundaries were selected as follows:

- On the east and west sides of the study area, boundaries are generally parallel to historical groundwater flow directions, which limits groundwater flow into or out of the study area along these boundaries.
- To the north, the boundary is the South Platte River. Groundwater from the alluvial aquifer discharges to the South Platte River along this boundary.
- Along the southern extent of the BC study area, the boundary is formed by the Platte Valley Canal, which is near the edge of the mapped alluvial aquifer.

Figure 3-1 shows the delineation of the Gilcrest/LaSalle study area, major features in and around the study area, and groundwater level contours. These features indicate the basic aspects of the hydrogeologic setting and formed the basis for the boundary positioning.

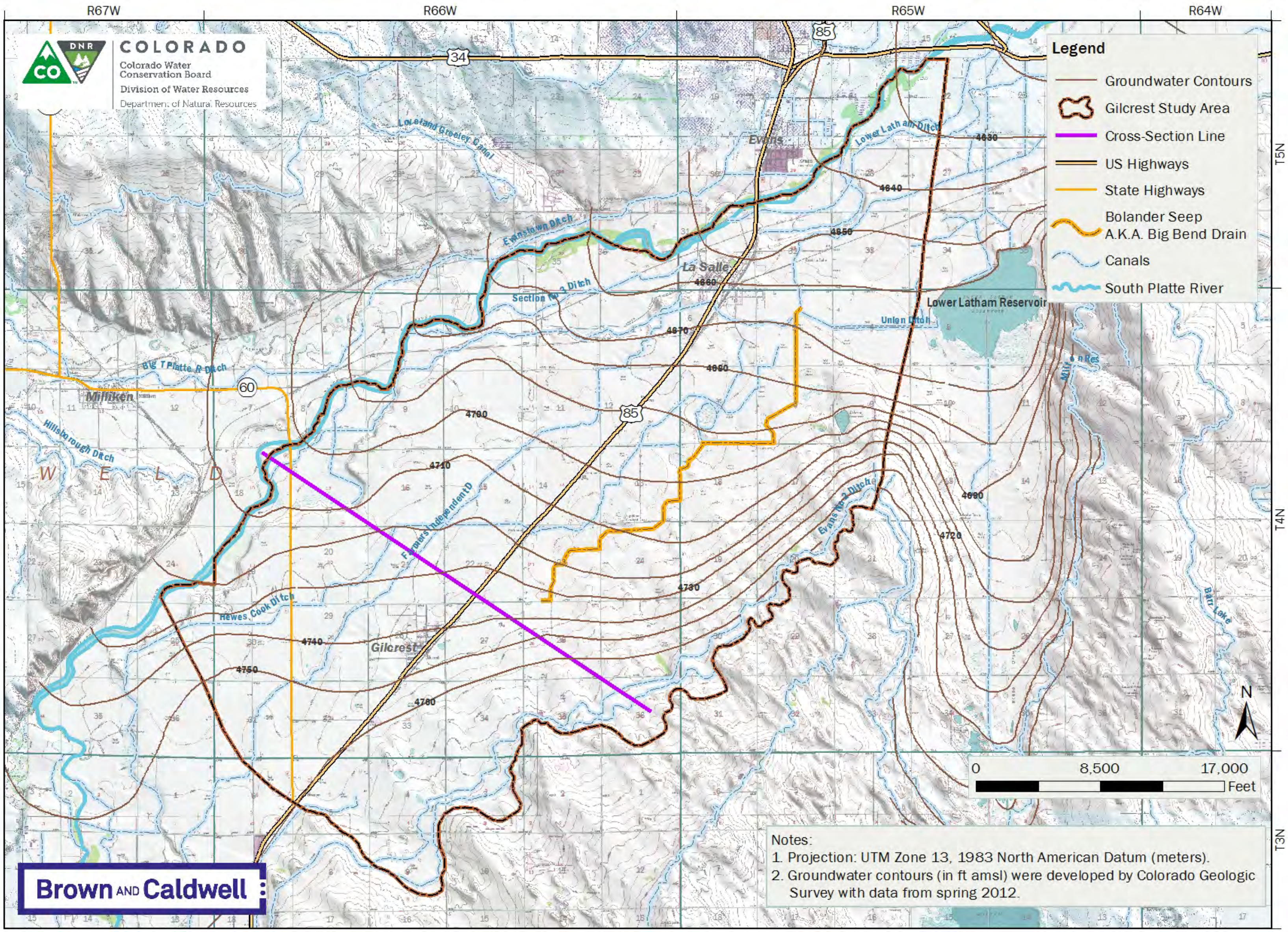

Figure 3-1. Gilcrest/LaSalle study area

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3.1.2 Sterling Study Area

In contrast with the Gilcrest/LaSalle area, no previous study area boundary has been proposed for the Sterling area. The study area boundary proposed by BC near Sterling is defined by the N. Sterling Canal along the northwest boundary. The southwest and northeast boundaries are generally oriented parallel to historical groundwater flow directions, which limits the amount of groundwater flux across these boundaries. The eastern boundary coincides with the Pioneer Drain.

Figure 3-2 shows an overview of the Sterling study area with estimated groundwater elevation contours.

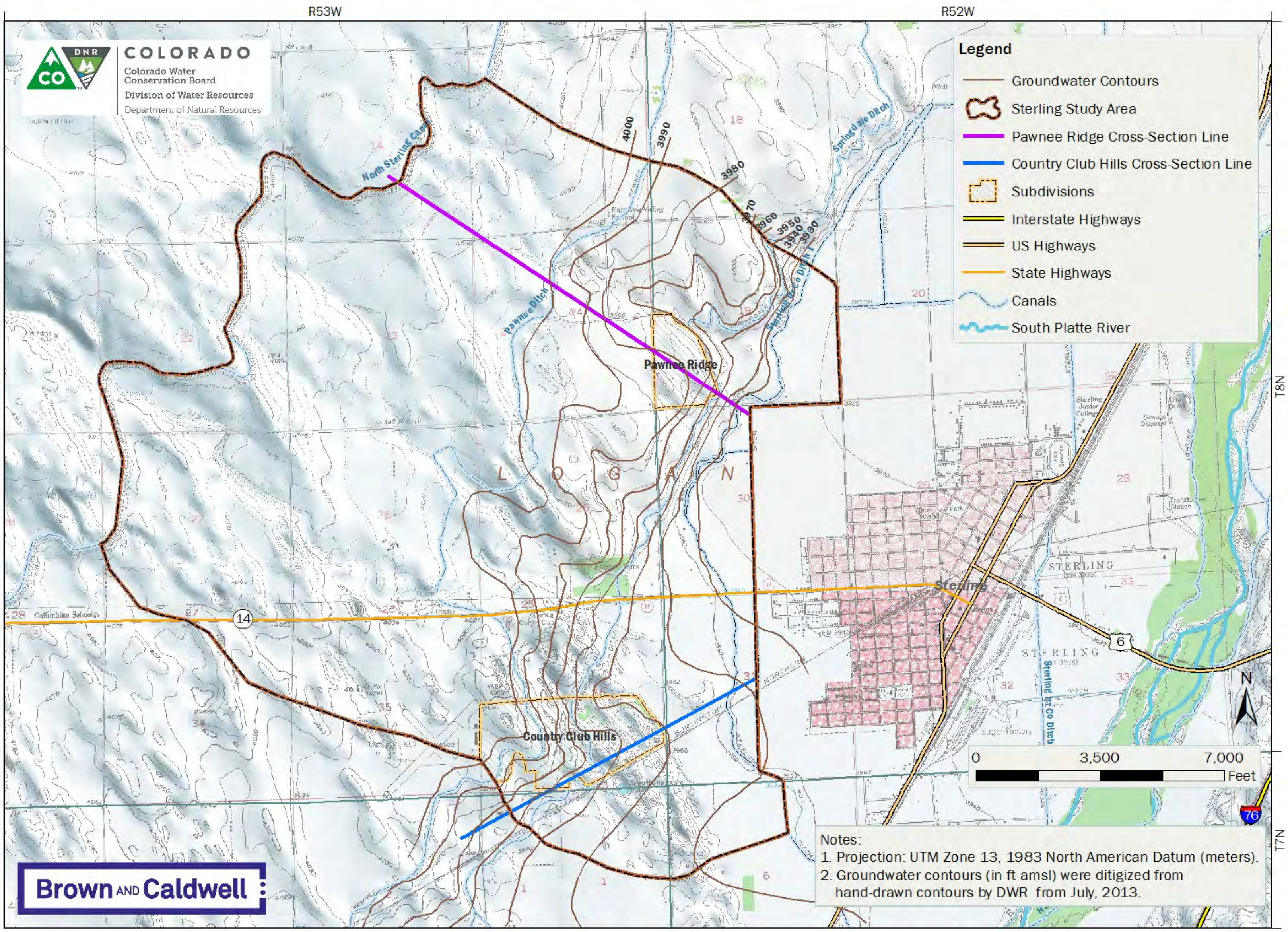

Figure 3-2. Sterling study area

3.2 Quantification of Water Budget Components

The following sections provide a detailed description of the data inputs, approach, and methods used to quantify each of the water budget components. In most cases, similar methods were used to quantify the components in each study area, and the discussion applies to each area. Differences in the methods and approach are noted specifically. A summary of the complete water budget is provided in the next section.

3.2.1 Inflows

This section presents inflows used to quantify the water budget, including ditch seepage; recharge from recharge ponds, precipitation, and irrigation; and subsurface inflow.

3.2.1.1 Ditch Seepage

Direct measurements of seepage for the ditches in the study area do not widely exist, so monthly seepage amounts were estimated using diversion records, conveyance efficiencies, and the lengths of the ditches within the study areas. BC compiled daily diversion records for the ditches within the two study areas using data from HydroBase and provisional spreadsheets maintained by DWR. The daily records were summed into a monthly time series for the final estimate of ditch seepage. The ditch conveyance efficiency values were obtained from the current basin-wide consumptive use modeling data set as well as through personal communication with members of various ditch boards. The values are generally consistent with the values presented in the SPDSS Task 56 memorandum, with a number of exceptions. Several of the conveyance efficiency values have been updated since the Task 56 memorandum was completed. BC used the most recent values. Efficiency values obtained from personal communications were also slightly different from the Task 56 values. The "Div1_Canals" shapefile obtained from DWR was the basis for calculating ditch lengths, both total and within the study area. The ratio between the length of the ditch within the study area and the total length, referred to as Lo/L in Figures 3 and 4, was used to scale the seepage for the study areas. The general equation for computing ditch seepage is as follows:

$$\text{Seepage} = \text{total diversions} * (1\text{-efficiency}) * \text{length of ditch in study area} / \text{total length of ditch} \qquad (3\text{-}1)$$

The total diversion values used in the seepage calculations, typically measured at the river headgate, represent the total flow in the ditch prior to any seepage/evaporation loss or delivery to farms. For some of the ditches in the Sterling study area, the diversion records during the non-irrigation season (November–March) were coded explicitly as recharge (U:R) with the seepage already incorporated into the recorded values. Therefore, no efficiency factor was applied to the U:R-coded records. Diversions from April through October were recorded at the river headgate in the typical fashion and were multiplied by the efficiency factor to estimate seepage according to Equation 3-1.

The seepage from the North Sterling Canal was estimated differently from that of the other canals within the Sterling study area. The seepage was calculated as the difference in flow measured at the river headgate and flow measured at the inlet to North Sterling Reservoir. There are no intervening diversions between the headgate and the reservoir inlet, so all losses were assumed to be from seepage. The seepage calculations were made using monthly data, so travel time between the headgate and reservoir was not a significant issue. The calculated seepage loss was prorated for the Sterling study area as shown in Equation 3-1.

Structures such as the Union Seep and Lower Latham Drain were not considered in the estimate of ditch seepage in the Gilcrest/LaSalle study area based on the assumption that the flows in those waterways are the result of interception of groundwater flow and represent a loss from the aquifer. Union Seep flow diverted into the Union Ditch was counted in the seepage calculation.

Tables 3-2 and 3-3 show the efficiencies, lengths, and proration factors for the ditches considered in the Gilcrest/LaSalle and Sterling study areas, respectively.

Table 3-2. Ditch Efficiency and Length Proration Factors: Gilcrest/LaSalle Study Area

Ditch System	Evans No. 2 [a]	Farmers Independent	Hewes Cook (Western)	Union Ditch	Godfrey/Section 3	Lower Latham
WDID	0200817	0200824	0200825	0200828	0200830	0200834
Conveyance efficiency (%)	76	73	90	70	75	88
Total length (mi)	31.0	14.3	17.7	29.7	4.3	32.8
Length in study area (mi)	11.6	9.4	11.0	13.9	4.3	3.8
Proration factor	0.37	0.66	0.62	0.47	1.00	0.12

a. *Evans No. 2 calculations are inclusive of the Platte Valley Canal. The System is treated as a single ditch.*

Table 3-3. Ditch Efficiency and Length Proration Factors: Sterling Study Area

Ditch System	Springdale	Pawnee	North Sterling	Sterling Lateral #1
WDID	6400530	6400533	0100687	6400528
Efficiency (%)	60	78	NA	77
Total length (mi)	17.5	34.0	60.3	32.4
Length in study area (mi)	4.6	5.1	4.9	4.4
Proration factor	0.26	0.15	0.08	0.14

The total monthly ditch seepage values for the Gilcrest/LaSalle and Sterling study areas are shown in Tables 3-4 and 3-5, respectively.

Table 3-4. Monthly Ditch Seepage Estimates (AF): Gilcrest/LaSalle Study Area

Water Year	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Total
2012	104	2	96	30	521	2,168	2,306	2,340	2,930	2,668	2,132	1,715	17,011
2013	596	196	505	988	668	525	2,032	3,316	3,560	3,085	2,021	1,725	19,217
2014	300	95	133	166	521	1,645	1,727	2,140	3,366	3,075	1,710	663	15,542

Table 3-5. Monthly Ditch Seepage Estimates (AF): Sterling Study Area

Water Year	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Total
2012	917	264	5	43	519	419	383	550	600	434	329	1,602	6,064
2013	586	644	511	660	488	477	580	582	538	550	222	854	6,692
2014	995	817	1,079	492	519	923	1,025	965	696	769	931	797	10,007

Figures 3-3 and 3-4 show the ditches considered in the seepage calculations and the length ratios for the Gilcrest/LaSalle and Sterling study areas, respectively.

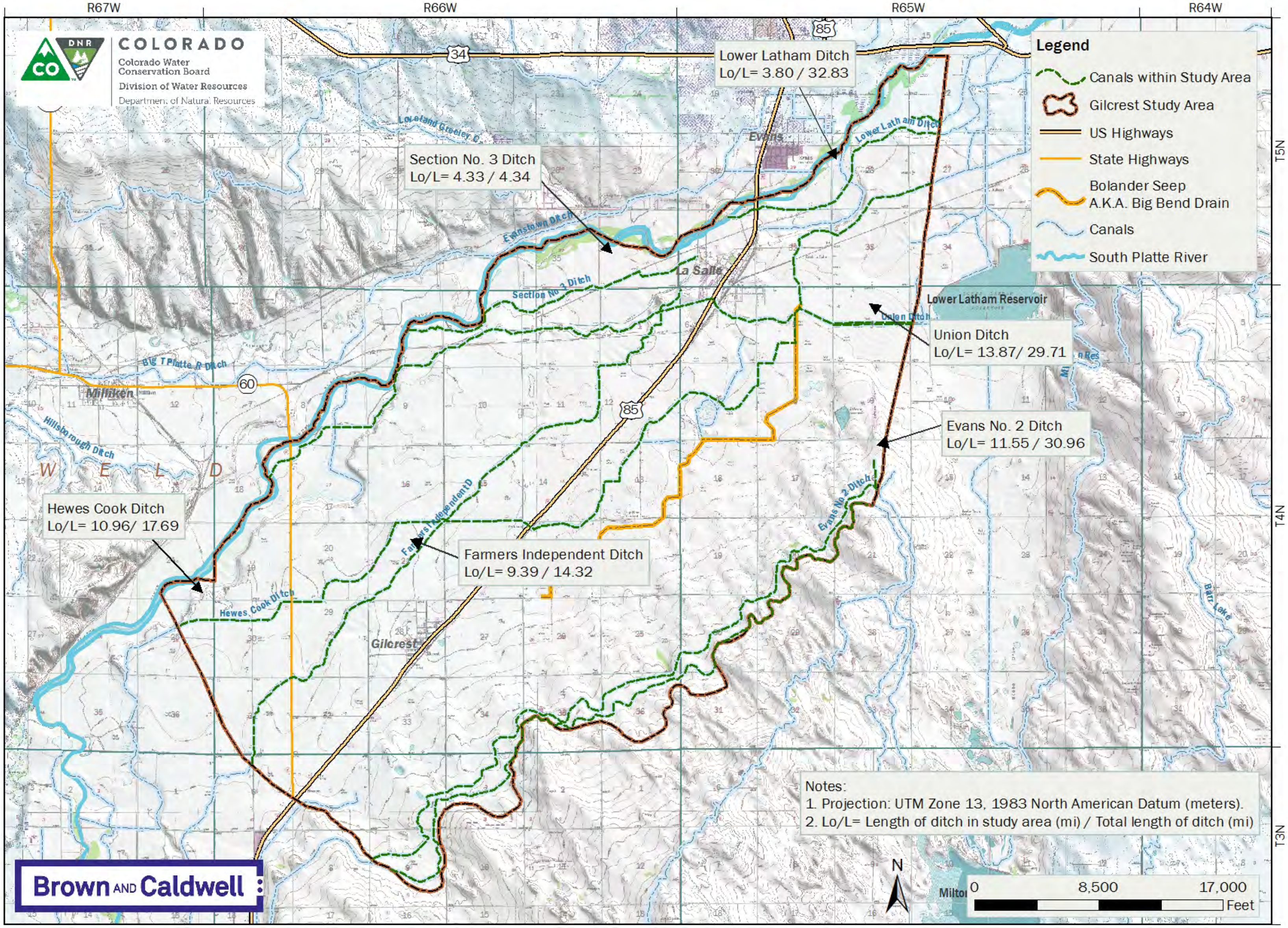

Figure 3-3. Gilcrest/LaSalle study area: ditch seepage

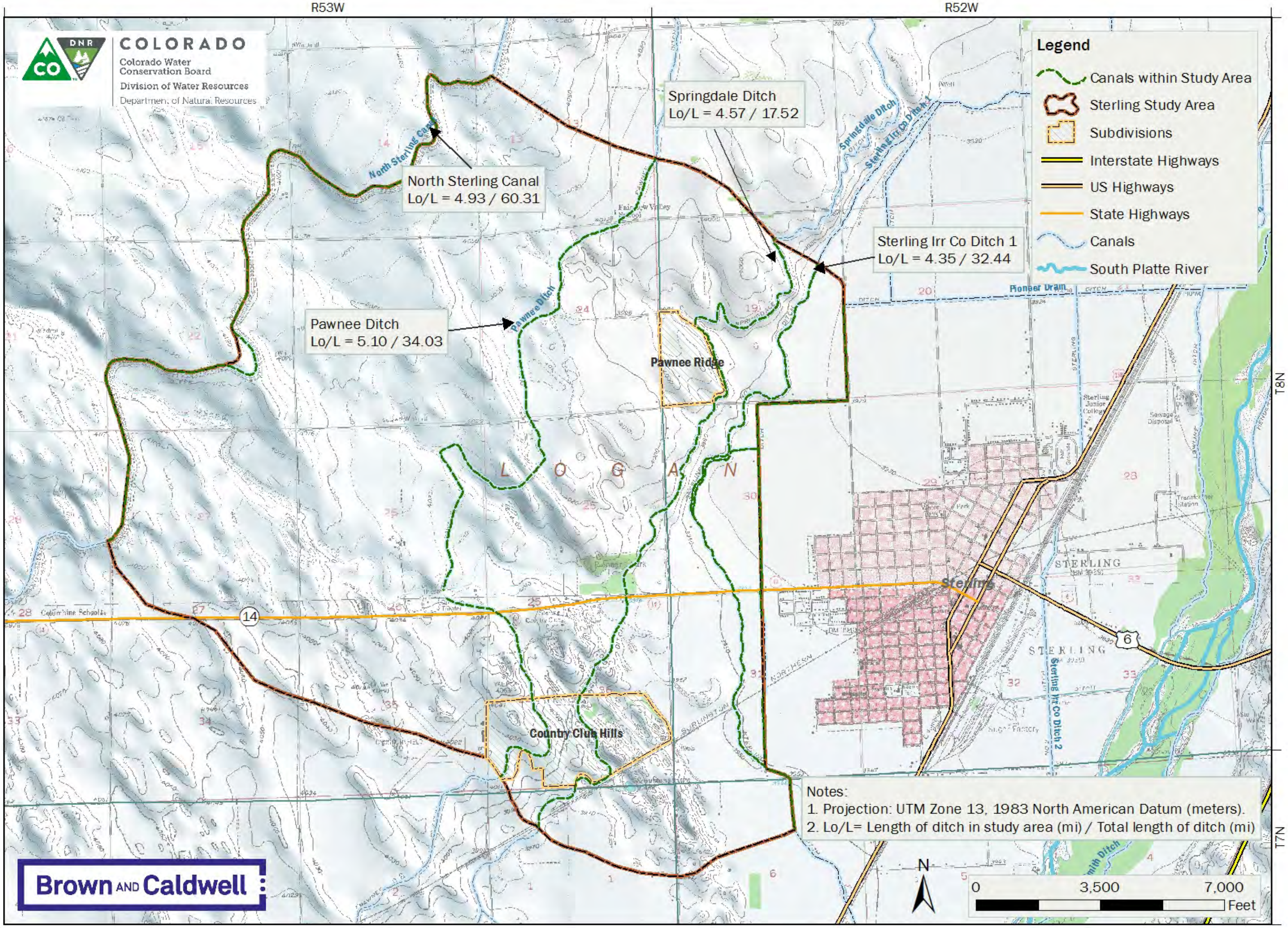

Figure 3-4. Sterling study area: ditch seepage

3.2.1.2 Recharge from Recharge Ponds

Much like ditch seepage, recharge from ponds is rarely measured directly, so the quantification was based on monthly pond deliveries and an estimate of evaporation loss. Because of the lack of specific data, month-to-month carryover storage in the recharge ponds was ignored. Therefore, the general approach for estimating recharge from ponds is based on the following equation:

Recharge = pond deliveries – evaporation (3-2)

Daily pond deliveries were compiled from HydroBase records and provisional records provided by DWR. Evaporation was estimated by using calculated reference evapotranspiration (ET) reported at the Northern Colorado Water Conservancy District (NCWCD) weather stations at Gilcrest and Sterling. Reference ET (alfalfa-based) is calculated at each station by NCWCD using the American Society of Civil Engineers (ASCE) Standardized Reference ET equation. The daily reference ET value calculated at the weather station was converted to an estimate of pan evaporation by multiplying the ET value by 1.2. The pan value was then converted to an estimate of open–water evaporation by multiplying by 0.7. The evaporation equation is as follows:

*Open water evaporation (in.) = reference ET (alfalfa) * 1.2 * 0.7* (3-3)

The daily evaporation values were compiled into monthly values and multiplied by the surface area of the recharge ponds to develop the volumetric evaporation estimates. The pond surface areas were determined from the shapefile provided by DWR based on the full area of the pond. This method likely leads to overestimation of evaporative losses because the recharge ponds are not always full. However, because no month-to-month carry-over storage is accounted for, the estimate of recharge based solely on deliveries is likely to be greater than actual recharge. The overestimates of both recharge and evaporation act as offsetting factors. Some ponds in the Gilcrest/LaSalle study area were not in the DWR shapefile, so their areas either were based on augmentation decrees or were traced using 2014 aerial photography provided in Google Earth. A total of 30 recharge ponds were considered within the Gilcrest/LaSalle study area. The DWR shapefile was completed for the Sterling study area, and eight recharge ponds are located in this study area.

Tables 3-6 and 3-7 show the monthly recharge values for the Gilcrest/LaSalle and Sterling study areas, respectively.

Table 3-6. Monthly Recharge from Ponds Estimates (AF): Gilcrest/LaSalle Study Area

Water Year	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Total
2012	89	0	38	0	25	43	67	215	154	152	8	5	797
2013	0	0	0	0	0	15	71	240	347	378	932	998	2,981
2014	1,296	31	138	436	1,252	1,117	987	1,307	493	961	1,118	1,022	10,158

Table 3-7. Monthly Recharge from Ponds Estimates (AF): Sterling Study Area

Water Year	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Total
2012	121	42	0	28	236	35	10	0	0	0	0	183	655
2013	18	202	211	334	166	240	27	0	0	0	153	131	1,485
2014	48	61	64	51	34	86	325	390	86	237	344	104	1,829

Figures 3-5 and 3-6 show the locations and relative size of the recharge ponds considered in the water budget for the Gilcrest/LaSalle and Sterling study areas, respectively.

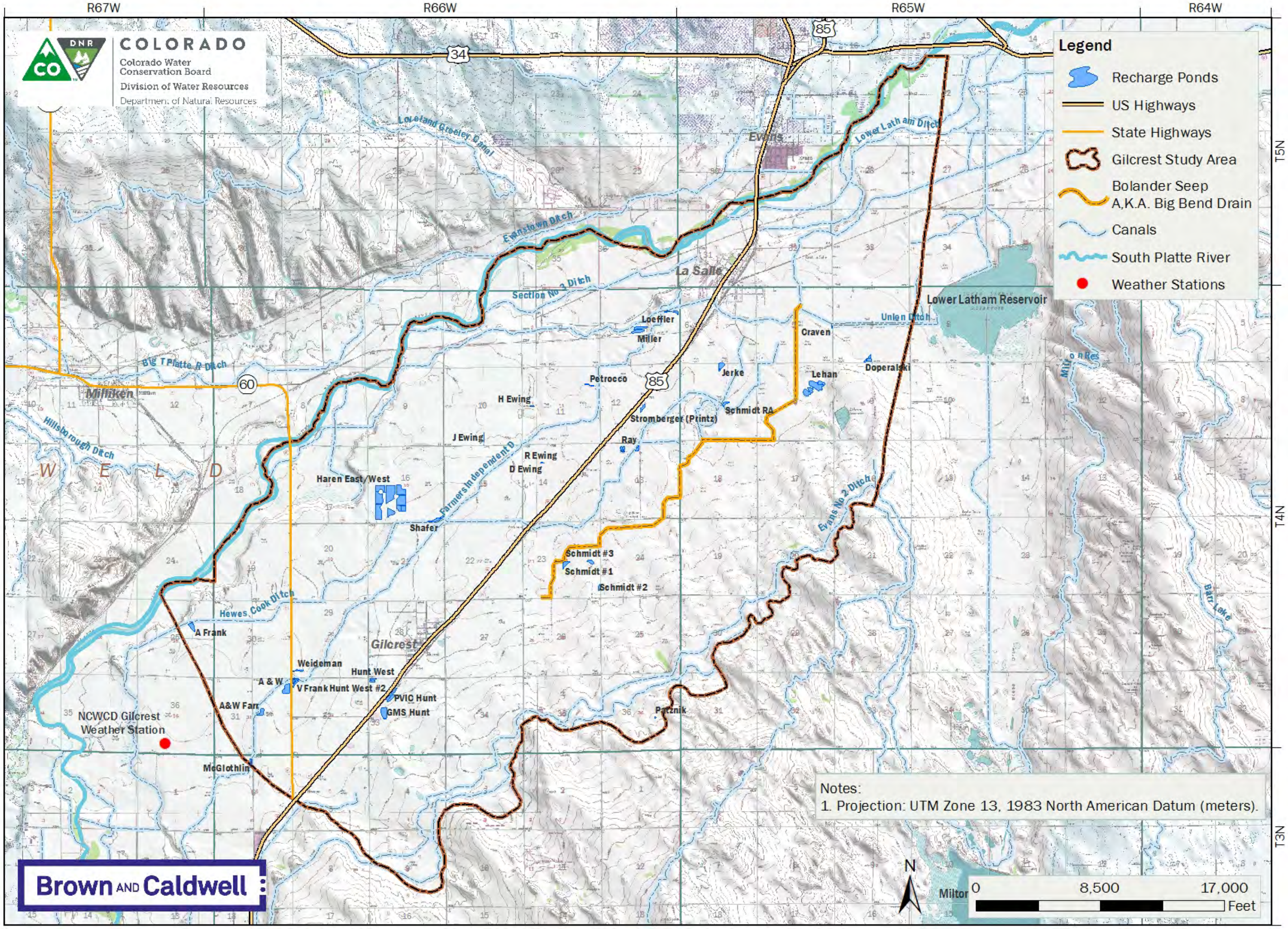

Figure 3-5. Gilcrest/LaSalle study area: recharge pond locations

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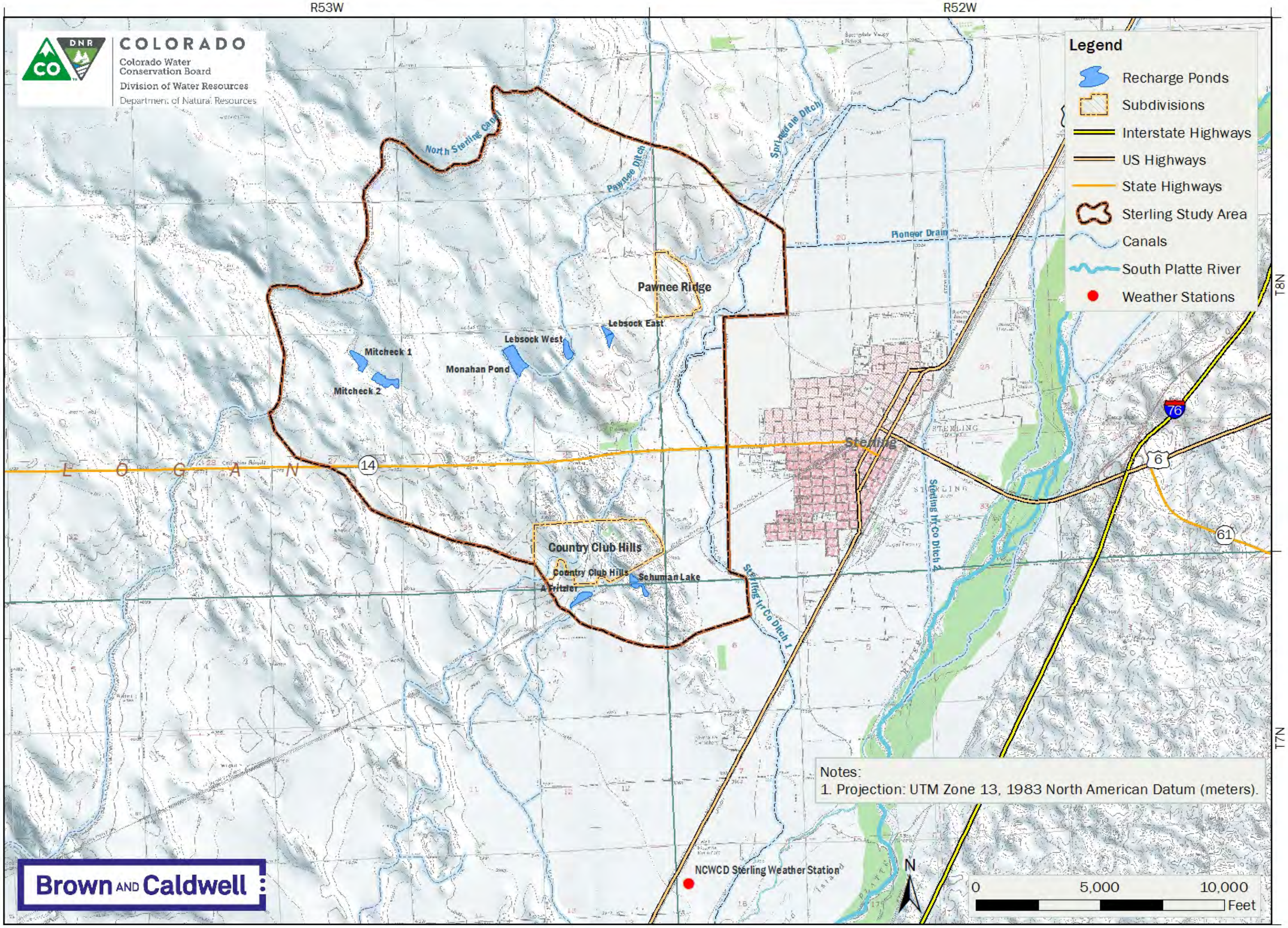

Figure 3-6. Sterling study area: recharge pond locations

3.2.1.3 Recharge from Precipitation

The estimate for recharge from precipitation was determined using a methodology that was originally developed to estimate precipitation recharge for input into the SPDSS groundwater model. The method uses monthly precipitation values from a nearby weather station and then applies a seasonal recharge factor based on land use and soil types to convert the precipitation to recharge. For this study, precipitation data from the Gilcrest and Sterling NCWCD weather stations were used.

The percentage of precipitation that becomes aquifer recharge was based on recharge factors that consider the land use/ground cover and soil type. Soil types were aggregated by their hydrologic soil group value (A, B, C, or D). The recharge factors were then assigned to the land cover types for each soil grouping. For example, irrigated alfalfa grown in soil group A was given a recharge factor of 23 percent during the irrigation season, alfalfa grown in soil group B is 14 percent, 4 percent for group C, and 2 percent for group D. In general, all irrigated fields were assigned the same recharge factor for similar soil groups. Irrigated fields were assigned a recharge factor of 3 percent in the non-irrigation season (November–March). All native vegetation areas, urban areas, wetlands, and forested areas were given a recharge factor of 3 percent. The recharge factor for open-water areas was set to 0 percent. These factors are consistent with the SPDSS groundwater model. The recharge factors are summarized in Table 3-8.

Table 3-8. Precipitation Recharge Factors

Land Use Type	Season	Hydrologic Soil Groups			
		A	B	C	D
Irrigated crops	Irrigation (Apr–Oct)	23%	14%	4%	2%
	Non-Irrigation (Nov–Mar)	3%	3%	3%	3%
Other/native	Irrigation (Apr–Oct)	3%	3%	3%	3%
	Non-Irrigation (Nov–Mar)	3%	3%	3%	3%

The monthly precipitation recharge values for the Gilcrest/LaSalle and Sterling study areas are shown in Tables 3-9 and 3-10, respectively.

Table 3-9. Monthly Recharge Precipitation (AF): Gilcrest/LaSalle Study Area

Water Year	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Total
2012	55	42	6	39	4	261	388	174	532	289	658	354	2,803
2013	38	24	17	59	75	596	460	311	372	507	2,073	339	4,870
2014	25	37	93	28	90	221	1,122	498	965	220	433	250	3,983

Table 3-10. Monthly Recharge Precipitation (AF): Sterling Study Area

Water Year	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Total
2012	5	4	2	11	4	35	27	13	78	1	16	29	223
2013	3	7	6	9	7	48	34	30	143	30	165	35	516
2014	6	1	11	9	10	56	52	101	115	65	33	11	469

3.2.1.4 Recharge from Irrigation

Recharge from irrigation represents the excess or non-consumed water that was applied to crops within the study areas. The amount of non-consumed water is a function of the irrigation method, soil type, root profile of the crop, and field conditions (e.g., field slope, etc.). For the beginning of the study period, recharge values were extracted directly from the basin-wide StateCU model. The model period of record currently ends in 2012 so, for 2013 and 2014, the irrigation recharge was estimated using diversion records and the average historical relationship between the volume of farm deliveries and non-consumed water from the StateCU model.

The average monthly ratio of farm headgate deliveries to the non-consumed surface water from the StateCU model was calculated for each ditch system in the study areas. That ratio was applied to the estimated farm headgate deliveries for the ditch systems to determine the non-consumed deliveries in 2013 and 2014. For the purposes of quantifying irrigation recharge, the farm headgate deliveries are estimated by identifying the diversions at the river headgate that correspond to deliveries to irrigation, which are often less than total river headgate diversions, and multiplying the diversions by the ditch efficiency to remove the seepage loss. The same ditch efficiency values were used in these calculations as in the ditch seepage calculations and are shown in Tables 3-2 and 3-3.

The farm headgate delivery estimates for 2013 were based on diversion records retrieved from HydroBase. The specific diversion time series that were compiled for each ditch system were consistent with the diversions used in the StateCU model input files and were generally coded as irrigation use (U:1).

HydroBase diversion records were not available for 2014 so the provisional diversion data from DWR were used instead. The river headgate values recorded in the provisional data were reduced by deliveries to recharge and recorded tail water exiting the ditch. The water commissioners for Districts 2, 1, and 64 were consulted to verify which values to subtract from the river headgate total.

Once the estimate of non-consumed water was compiled, those results were prorated by the ratio of the irrigated area in each ditch that were in the Gilcrest/LaSalle and Sterling study areas to the total irrigated area in the ditch systems. The irrigated area is based on the 2010 SPDSS snapshot. Table 3-11 shows the portion of the irrigated area for each ditch considered for the Gilcrest/LaSalle study area. Table 3-12 shows similar information for the ditches in the Sterling study area.

Table 3-11. Irrigated Area in Gilcrest/LaSalle Study Area (acres)

Ditch Name	Ditch ID	Total Irrigated Area (2010)	Irrigated Area in Study	Ratio
Platteville	0200813	3,686	161	0.044
Evans No. 2	0200817	13,526	9,369	0.693
Farmers Independent	0200824	5,243	3,351	0.639
Hewes Cook	0200825	5,287	4,276	0.809
Union	0200828	4,578	2,593	0.566
Section 3	0200830	1,184	1,184	1.000
Lower Latham	0200834	9,508	309	0.032
FRICO-Barr Lake	0203837	19,795	168	0.008

Table 3-12. Irrigated Area in Sterling Study Area (acres)				
Ditch Name	Ditch ID	Total Irrigated Area (2010)	Irrigated Area in Study	Ratio
Sterling #1	6400528	7,729	334	0.043
Springdale	6400530	3,254	194	0.060
Pawnee	6400533	8,034	410	0.051

In the Gilcrest/LaSalle study area, the irrigation recharge attributable to the Platteville, Lower Latham, and FRICO-Barr Lake ditches was small relative to the other ditches, so the average non-consumed deliveries from the StateCU model from 2011 and 2012 were used to fill the 2013 and 2014 values.

Although the North Sterling Canal forms the northwestern boundary of the Sterling study area, no parcels within the study area are irrigated with surface water from North Sterling, and therefore there is no contribution to recharge from irrigation.

Tables 3-13 and 3-14 show the estimate of monthly recharge from irrigation for the Gilcrest/LaSalle and Sterling study areas, respectively.

Table 3-13. Recharge From Irrigation (AF): Gilcrest/LaSalle Study Area													
Water Year	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Total
2012	0	0	0	0	0	3,202	3,815	3,036	3,669	3,725	3,654	2,308	23,408
2013	0	0	0	0	0	660	3,724	6,013	6,281	5,318	2,305	651	24,952
2014	0	0	0	0	0	2,448	3,484	4,027	6,156	5,436	2,768	581	24,900

Table 3-14. Recharge From Irrigation (AF): Sterling Study Area													
Water Year	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Total
2012	0	0	0	0	0	45	92	172	155	157	84	10	715
2013	0	0	0	0	0	2	82	176	174	169	66	0	668
2014	0	0	0	0	0	21	83	78	194	146	82	17	621

Figures 3-7 and 3-8 show the irrigated areas, grouped by ditch system in the Gilcrest/LaSalle and Sterling study areas, respectively.

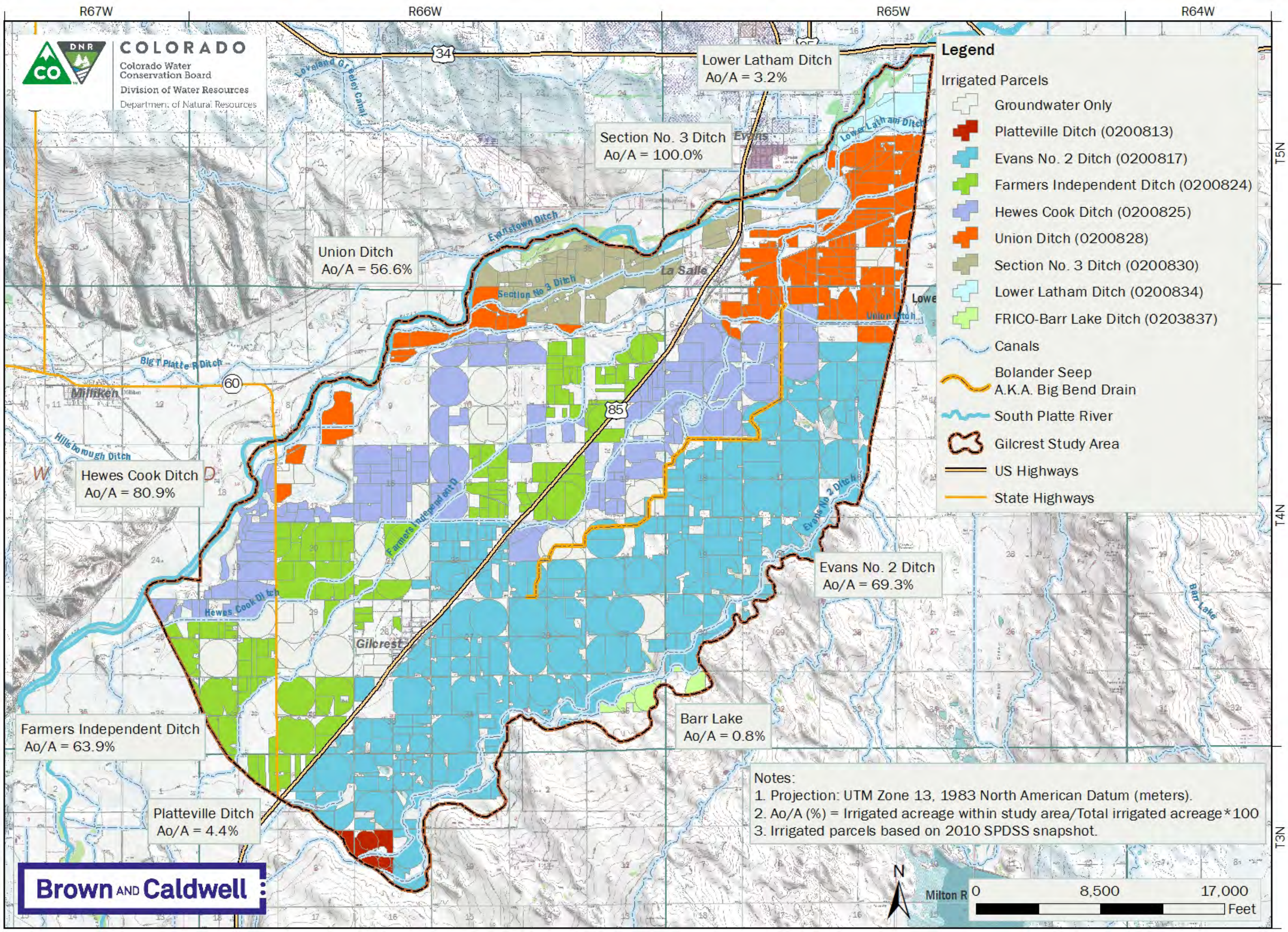

Figure 3-7. Gilcrest/LaSalle study area: irrigated area

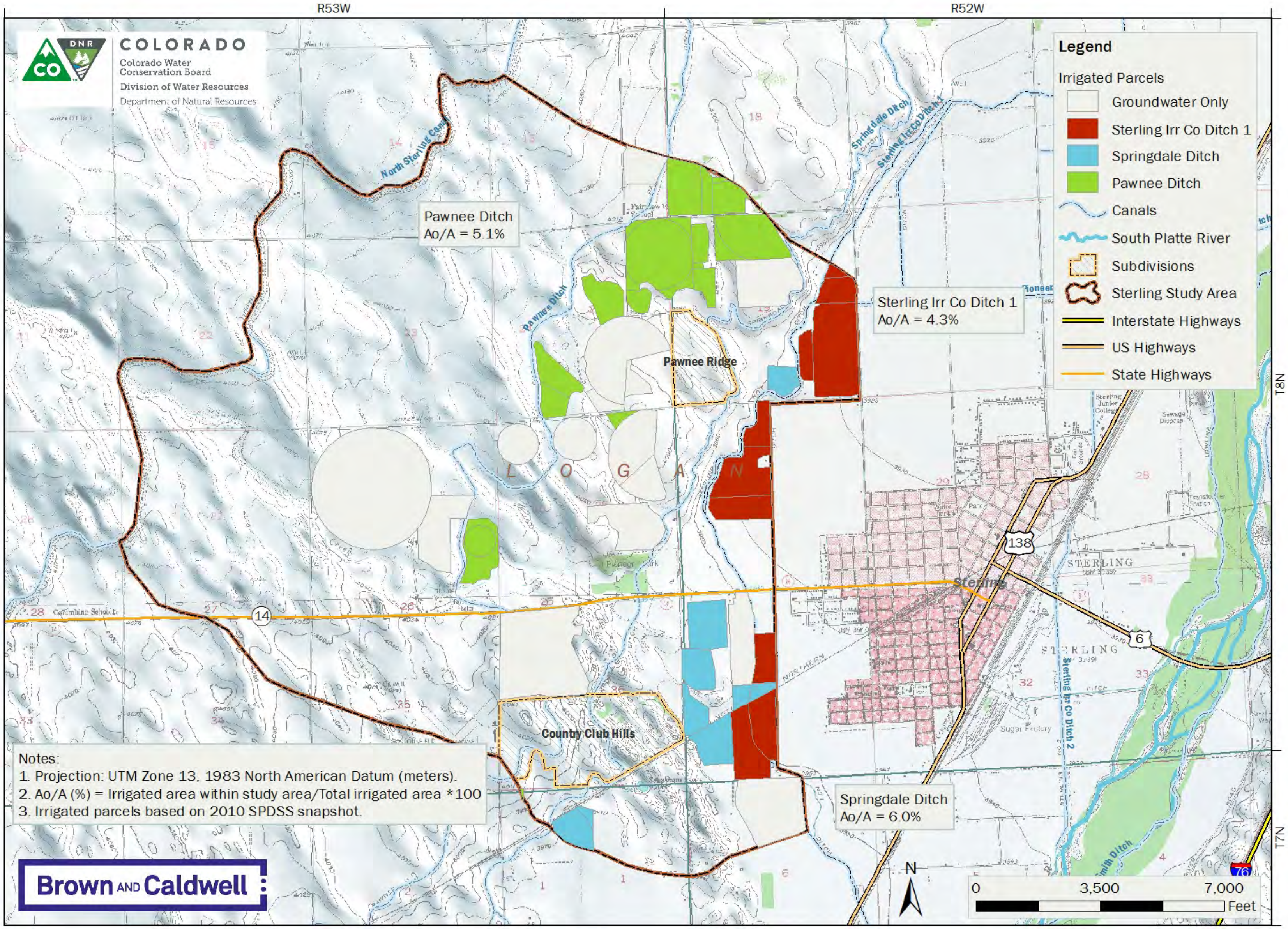

Figure 3-8. Sterling study area: irrigated area

3.2.1.5 Subsurface Inflow

Subsurface inflow values represent alluvial groundwater flow that enters a study area at the boundaries. The study area boundaries were chosen to minimize this portion of the water budget by aligning with the groundwater flow paths. The subsurface inflow was estimated using the SPDSS groundwater model. Cell-by-cell flow values along the study area boundaries were extracted from the model for the Gilcrest/LaSalle and Sterling study areas using the U.S. Geological Survey (USGS) Zone Budget tool. Because the study period for the groundwater model currently ends in 2006, monthly average subsurface inflow values for the entire model study period (1950–2006) were used in the water budget. As a result, the monthly values are the same each year. The historical model output shows that the subsurface flow conditions are very steady on an annual basis, but show attenuated seasonal fluctuations.

From a hydrologic standpoint, the subsurface inflow in the Sterling study area represents some groundwater flow resulting from ambient aquifer conditions (e.g., gradients) and seepage from irrigation and precipitation occurring outside the alluvium. The subsurface flow estimated in the Gilcrest/LaSalle study area is primarily from ambient aquifer conditions.

The average monthly subsurface inflows are shown in Table 3-15.

Table 3-15. Monthly Subsurface Inflow (AF)

Study Area	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Total
Gilcrest/LaSalle	1,328	1,367	1,371	1,237	1,369	1,337	1,393	1,353	1,403	1,403	1,349	1,384	16,295
Sterling	35	37	37	33	37	36	37	36	37	37	35	37	433

3.2.2 Outflows

This section presents outflows used to quantify the water budget, including groundwater consumptive use from pumping; direct consumption of groundwater by crops and phreatophytes, subsurface outflow and groundwater contribution to streamflow, and groundwater contribution to streamflow.

3.2.2.1 Groundwater Consumptive Use from Pumping

Groundwater consumptive use from pumping values used in the water budget were based on pumping records from wells that are covered by the major augmentation plans in each study area. In Gilcrest, the pumping data corresponded to wells in the CCWCD Groundwater Management Subdistrict (GMS) and Well Augmentation Subdistrict (WAS) augmentation plans. Pumping records for wells operating under the City of Sterling, Logan Wells Users, North Sterling, and Pawnee Wells Users augmentation plans were used in the Sterling study area. The records were retrieved from the monthly accounting forms submitted to DWR for the period of record of the water budget.

The pumping data received from GMS and WAS represented actual groundwater withdrawal. When used for irrigation, a portion of the pumped water is not consumed by the crops and returns to the aquifer, and therefore does not represent outflow from the aquifer. For this study, only the portion consumed by the crops was considered. To determine how much of the total pumping was consumed, the metered pumping values were multiplied by a well depletion factor. Nearly all of the GMS and WAS wells had their own pumping depletion factors. When none were available, the assumed factor was 70 percent. The pumping records reported in the Sterling study area already represented consumptive use, so no additional well depletion factors were necessary.

Not all wells covered by the augmentation plans listed above fell within the study area boundaries. Using a shapefile of wells in the augmentation plans provided by DWR, the relevant wells were clipped out for each study area. The water district identifiers (WDIDs) for the clipped wells were used to query the pumping records from the monthly accounting.

Tables 3-16 and 3-17 show the monthly consumptive use of groundwater from pumping in the Gilcrest/LaSalle and Sterling study areas, respectively.

Table 3-16. Consumptive Use of Groundwater from Pumping (AF): Gilcrest/LaSalle Study Area

Water Year	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Total
2012	11	0	58	59	131	261	206	266	760	1,146	642	208	3,749
2013	88	24	16	31	41	26	92	226	404	683	134	96	1,863
2014	3	8	4	33	103	0	134	143	404	292	536	139	1,800

Table 3-17. Consumptive Use of Groundwater from Pumping (AF): Sterling Study Area

Water Year	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Total
2012	71	53	39	17	51	180	361	716	612	570	269	83	3,024
2013	4	1	0	0	13	12	161	366	397	518	161	30	1,663
2014	0	0	0	0	8	40	81	207	602	519	323	107	1,888

Figures 3-9 and 3-10 show the locations of the wells considered in each study area and the corresponding augmentation plans.

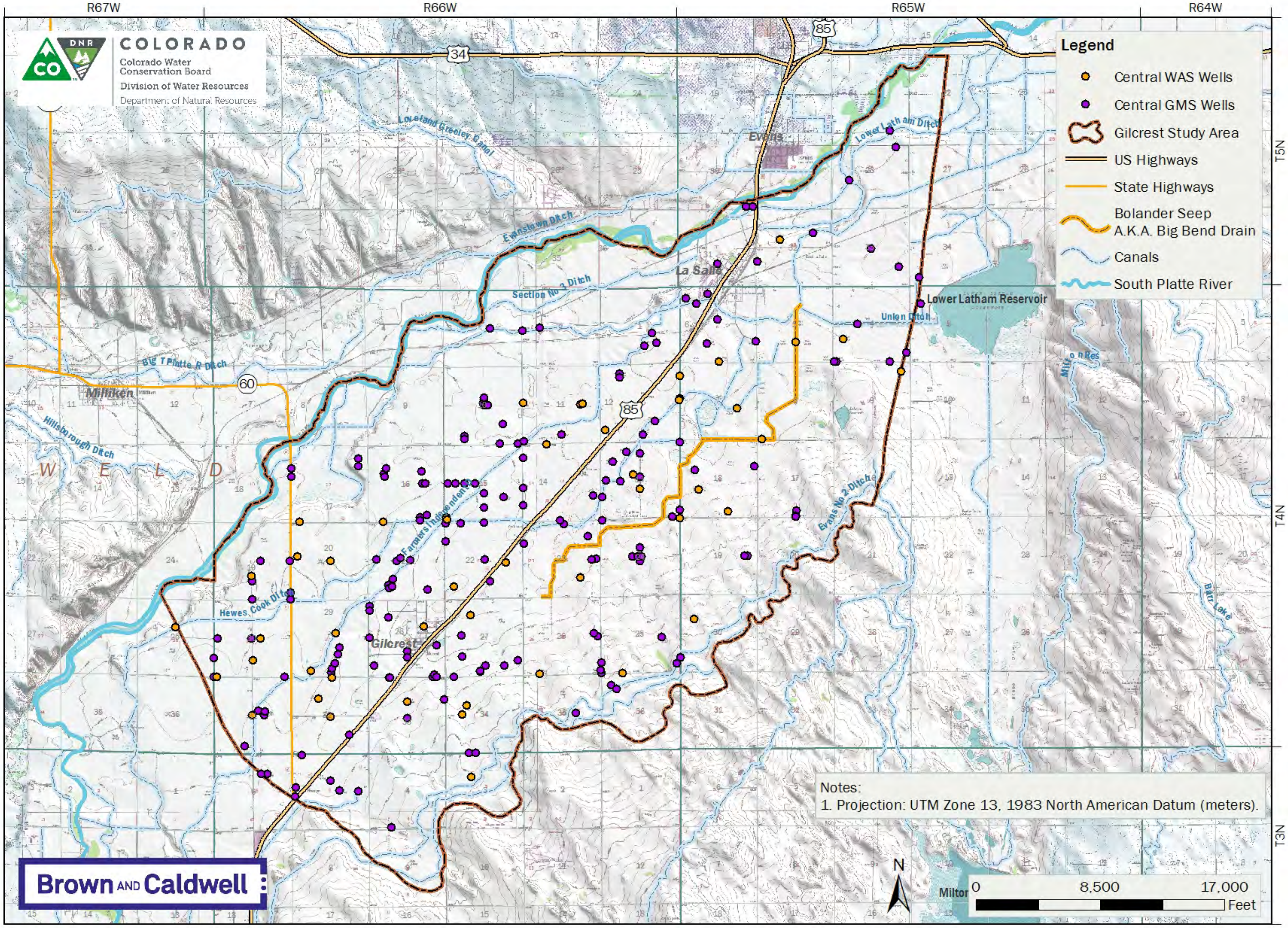

Figure 3-9. Gilcrest/LaSalle study area: well locations

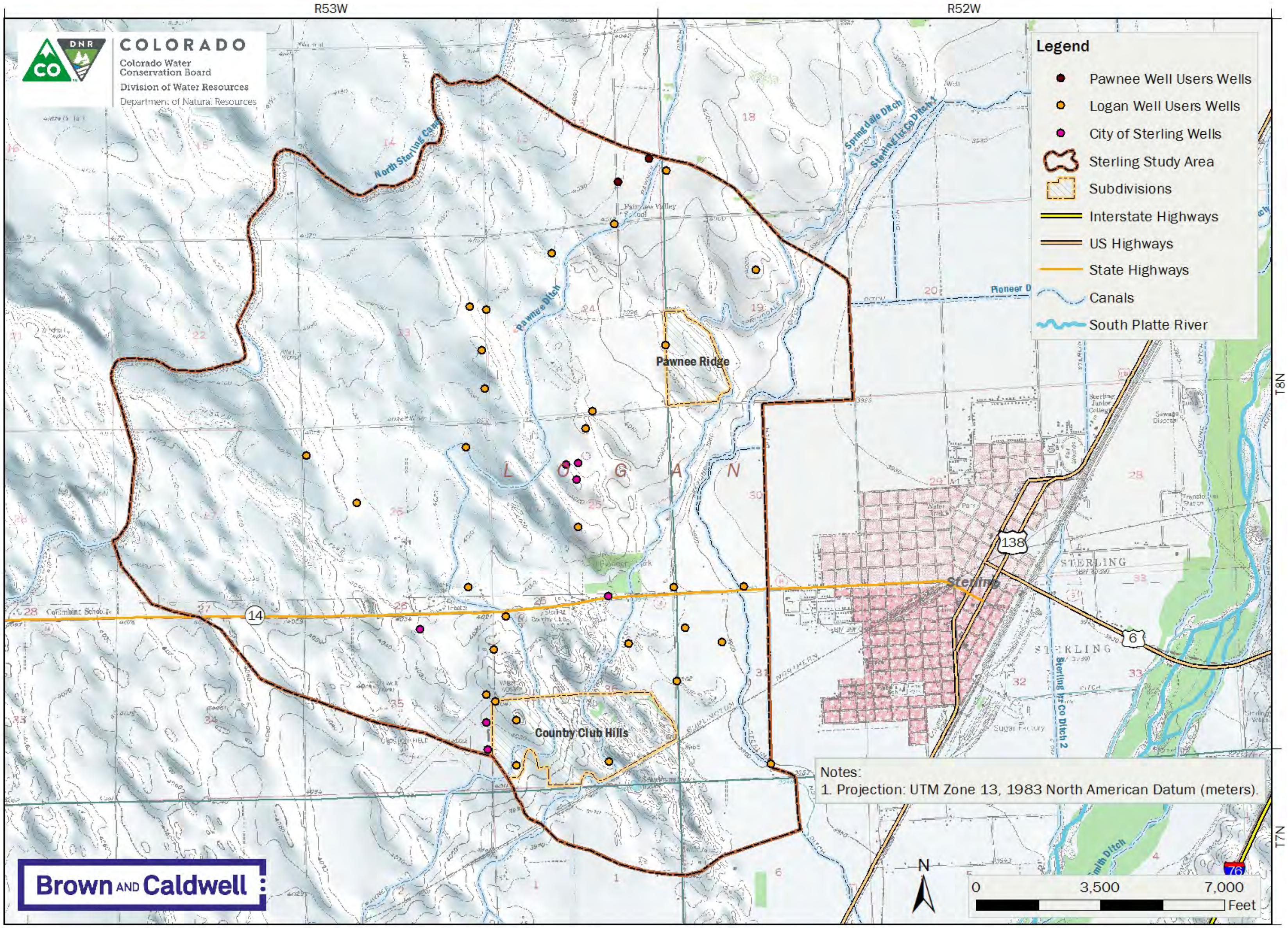

Figure 3-10. Sterling study area: well locations

3.2.2.2 Direct Consumption of Groundwater by Crops

The direct consumption of groundwater by crops represents the portion of consumptive crop demands that are met by groundwater through the root zone instead of the irrigation supply. Rate of consumption of groundwater is dependent on the root profile of the crop and the depth to saturated soil zone. Most irrigated crops have shallow to intermediate root zones and lack a deep tap root that is capable of accessing the local groundwater table. Alfalfa and pasture grass have deep root systems and are capable of consuming groundwater directly.

The amount of groundwater that a crop can consume is dependent on the depth to the groundwater table. A study of native grass and alfalfa in South Park, Colorado, developed percentages of consumptive demand that can be met with groundwater at varying depths (Walter et al. 1990). Nearly all of the consumptive demand can be met with very shallow groundwater (1–2 feet deep), but the percentage drops off quickly as depth increases and is essentially zero at 10 feet for alfalfa and 8 feet for native grass.

Accordingly, the alfalfa and grass pasture parcels, as indicated by the 2010 SPDSS snapshot, were compared to the depth to water in both study areas. For mapped alfalfa fields where the groundwater was within 5 feet of the surface, the percentage of consumptive use supplied by groundwater was set to 75 percent. For alfalfa fields with depths to groundwater between 5 and 10 feet, the consumptive use percentage was set to 10 percent. Similarly, for grass pasture fields with depth-to-groundwater levels within 5 feet of the ground surface, the percentage of consumptive use supplied by groundwater was set to 75 percent. When the groundwater depth was between 5 and 8 feet under grass pasture fields, the consumptive use percentage was set to 10 percent. For groundwater depths greater than 10 feet for alfalfa and 8 feet for pasture grass, direct consumptive use of groundwater was zero.

Groundwater depth information for the Gilcrest/LaSalle study area was taken from the CGS hydrogeologic characterization report and represented conditions in spring 2012 and spring 2013. The average areas for each crop type and groundwater depth condition were used for the calculations. For the Sterling study area, a depth-to-water coverage was created using the hand-drawn contours of water levels from July 2013 provided by DWR.

Estimates of consumptive use demand for alfalfa and grass pasture were developed using StateCU. The model was set up to calculate potential consumptive use using only weather station inputs and was not supply-limited. A separate model was developed for each study area. The Gilcrest/LaSalle study area model used the NCWCD Gilcrest climate station and the upper South Platte calibrated Blaney-Criddle crop coefficients. The Sterling study area model used the NCWCD climate station at Sterling and the Lower South Platte calibrated Blaney-Criddle coefficients. The calibrated Blaney-Criddle crop coefficients were developed as a part of the SPDSS basin-wide consumptive use modeling and groundwater modeling efforts. The methods and results of the calibration are described SPDSS Task 59.1 memorandum.

The potential consumptive use values were multiplied by the total area of alfalfa and grass pasture that met the depth-to-groundwater criteria and then multiplied by the corresponding consumptive use percentage. The following is a sample calculation for the direct consumption of groundwater by alfalfa:

$$\text{Direct groundwater CU} = \text{potential CU} * \text{area of alfalfa with depth to GW 5 ft or less} * 0.75 \qquad (3\text{-}4)$$

Similarly, the potential consumptive use was multiplied by the total area of alfalfa and grass pasture crops with groundwater depths between 5 and 10 feet and 5 and 8 feet, respectively, and then multiplied by 10 percent. The values from both groundwater level conditions were summed to estimate the total direct consumption of groundwater in the study areas. The Sterling study area did not have mapped grass pasture fields, so all calculations are based on alfalfa only.

Tables 3-18 and 3-19 show the monthly total direct consumption of groundwater in the Gilcrest/LaSalle and Sterling study areas, respectively.

Table 3-18. Direct Consumption of Groundwater by Crops (AF): Gilcrest/LaSalle Study Area

Water Year	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Total
2012	0	0	0	0	55	142	162	235	219	172	136	67	1,188
2013	0	0	0	0	0	29	157	218	195	173	138	57	967
2014	0	0	0	0	0	95	145	189	186	112	113	84	923

Table 3-19. Direct Consumption of Groundwater by Crops (AF): Sterling Study Area

Water Year	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Total
2012	0	0	0	0	0	5	8	13	9	7	5	1	48
2013	0	0	0	0	0	0	8	11	8	7	5	2	40
2014	0	0	0	0	0	2	8	10	8	6	5	3	41

Figures 3-11 and 3-12 show the locations of the alfalfa and grass pasture fields along with the average depth to groundwater under each parcel for the Gilcrest/LaSalle and Sterling study areas, respectively.

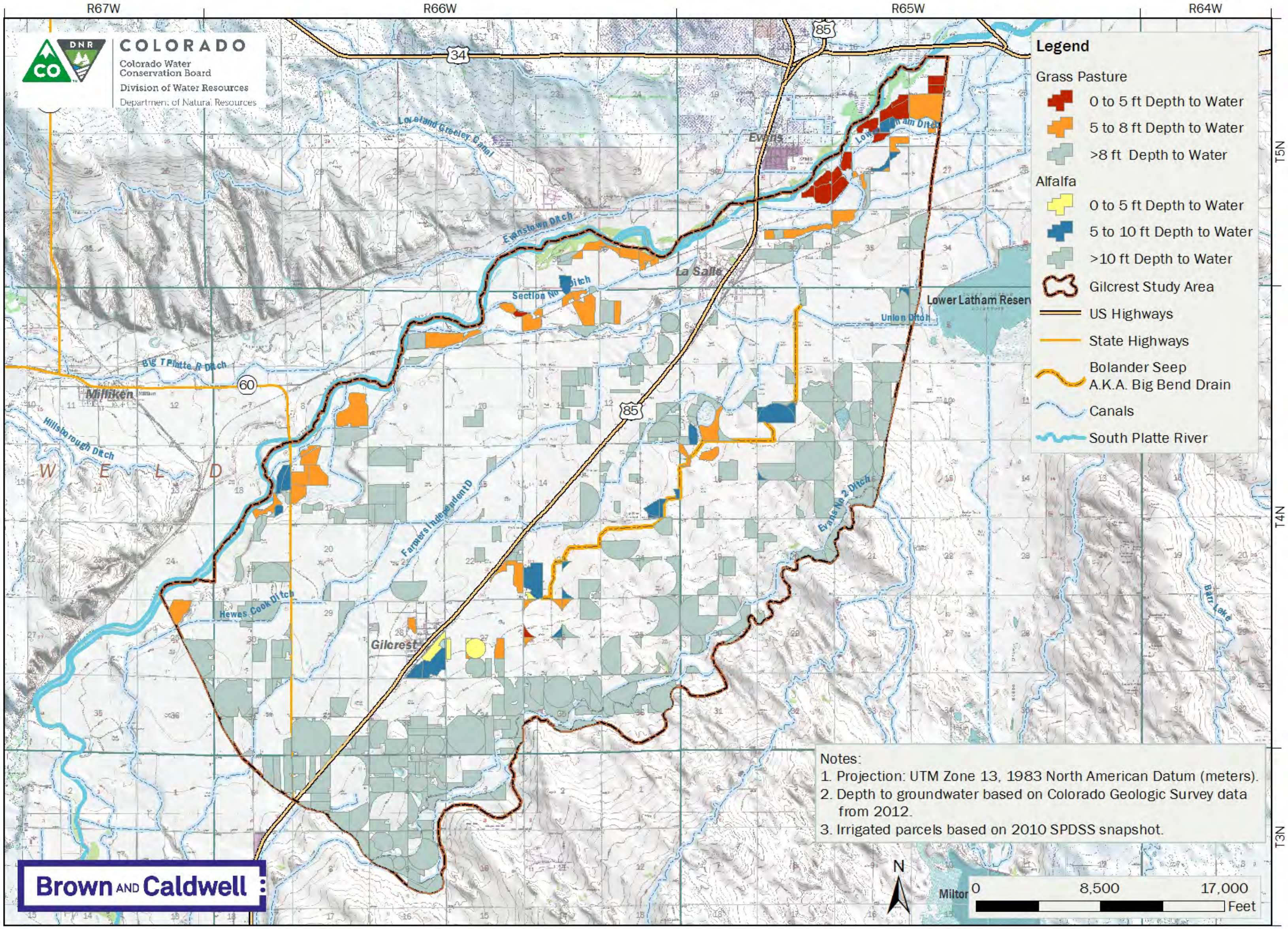

Figure 3-11. Gilcrest/LaSalle study area: locations of direct groundwater consumption from crop evapotranspiration

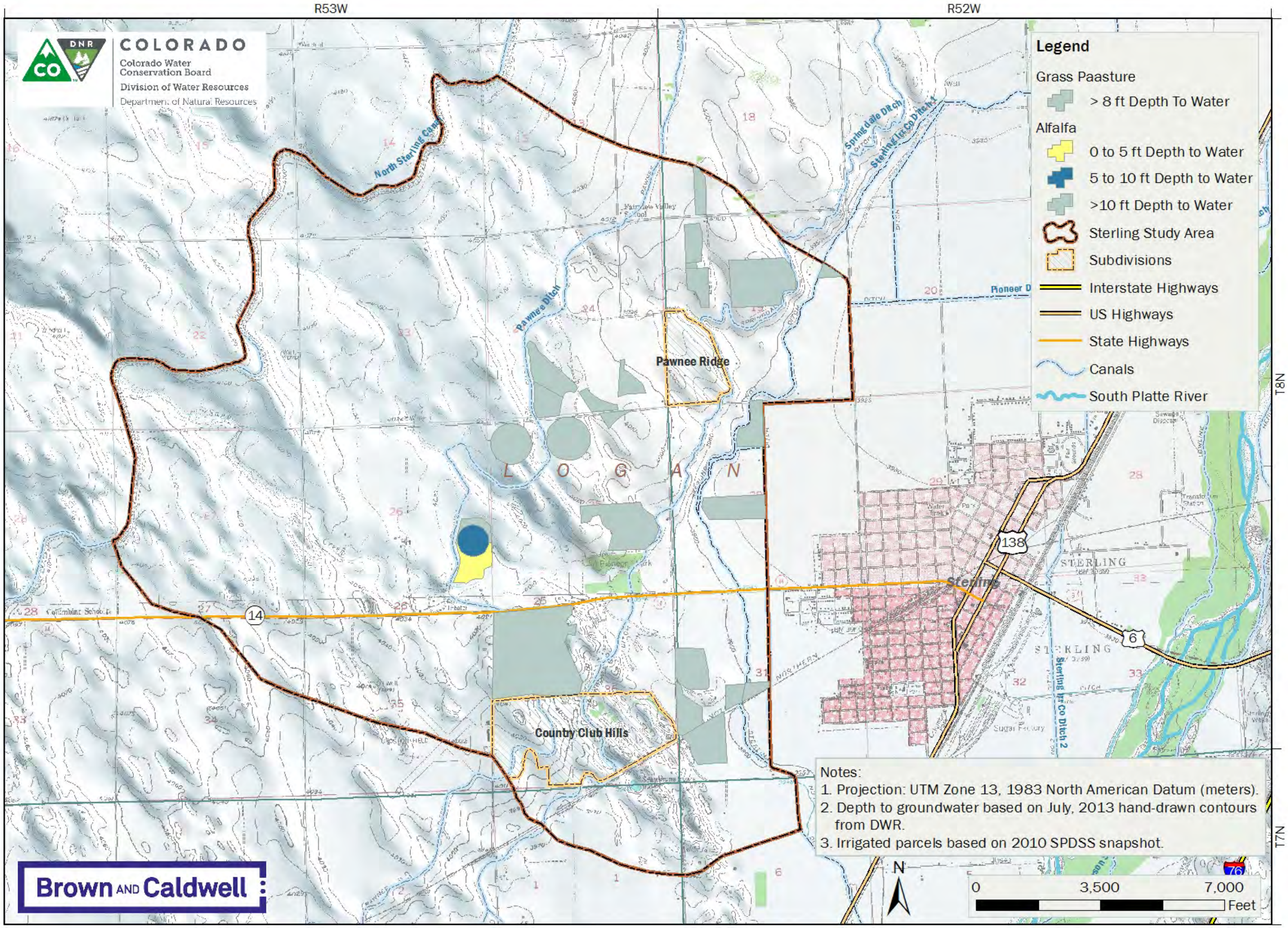

Figure 3-12. Sterling study area: locations of direct groundwater consumption from crop evapotranspiration

3.2.2.3 Direct Consumption of Groundwater by Phreatophytes

Phreatophytes are plants that have deep roots that typically grow in wetland and riparian settings and that receive a majority of their water supply from groundwater. To estimate the direct consumption of groundwater by phreatophytes for the water budget, the areas with likely phreatophyte growth were identified and quantified, and an estimate of the potential consumptive use of phreatophytes was developed.

The total area of phreatophyte growth within the study areas was estimated using a wetland delineation map supplied by the Colorado Natural Heritage Program at Colorado State University. These wetland delineations are based in part on independent field investigations and the National Wetland Inventory mapping program from the U.S. Fish and Wildlife Service. The wetland types were analyzed and areas indicated as open water ponds were eliminated. All other types, including freshwater emergent wetlands, freshwater forested wetlands, and riverine wetlands, were assumed to be areas with phreatophyte growth. The wetland types and their respective areas within each study area are shown in Tables 3-20 and 3-21.

Table 3-20. Wetland Type Summary: Gilcrest/LaSalle study area

Wetland Type	Acres
Freshwater emergent wetland	356
Freshwater forested/shrub wetland	598
Riverine	355
Total	1,309

Table 3-21. Wetland Type Summary: Sterling Study Area

Wetland Type	Acres
Freshwater emergent wetland	13
Riverine	42
Total	55

The potential consumptive use of phreatophytes was estimated using a daily analysis based on the ASCE Standardized Reference ET equation and using crop coefficients for cattails developed for climates that experience annual frosts (Allen, 1998). The NCWCD climate stations at Gilcrest and Sterling were used in the analysis for each study area, respectively. The monthly volumes of direct groundwater consumption by phreatophytes in the study areas were calculated by multiplying the monthly potential consumptive use values (in feet) by the total area of the wetlands. The values are summarized below in Tables 3-22 and 3-23.

Table 3-22. Direct Consumption of Groundwater by Phreatophytes (AF): Gilcrest/LaSalle study area

Water Year	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Total
2012	0	0	0	0	0	104	381	893	713	662	375	0	3,128
2013	0	0	0	0	0	0	175	623	649	578	106	0	2,132
2014	0	0	0	0	0	0	0	370	515	528	55	0	1,469

Table 3-23. Direct Consumption of Groundwater by Phreatophytes (AF): Sterling Study Area

Water Year	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Total
2012	0	0	0	0	0	0	14	66	72	76	48	0	276
2013	0	0	0	0	0	0	16	58	44	50	21	5	194
2014	0	0	0	0	0	0	3	27	46	44	35	0	155

Figures 3-13 and 3-14 show the wetland areas, identified by type, in each study area. Note that the wetland shapefile may not reflect the locations of all current wetland areas, and wetlands classified as freshwater ponds have been excluded from Figure 14 because those areas were not considered in the calculation of groundwater consumption by phreatophytes. This includes some of the wetlands near the Country Club Hills and Pawnee Ridge subdivisions in the Sterling study area.

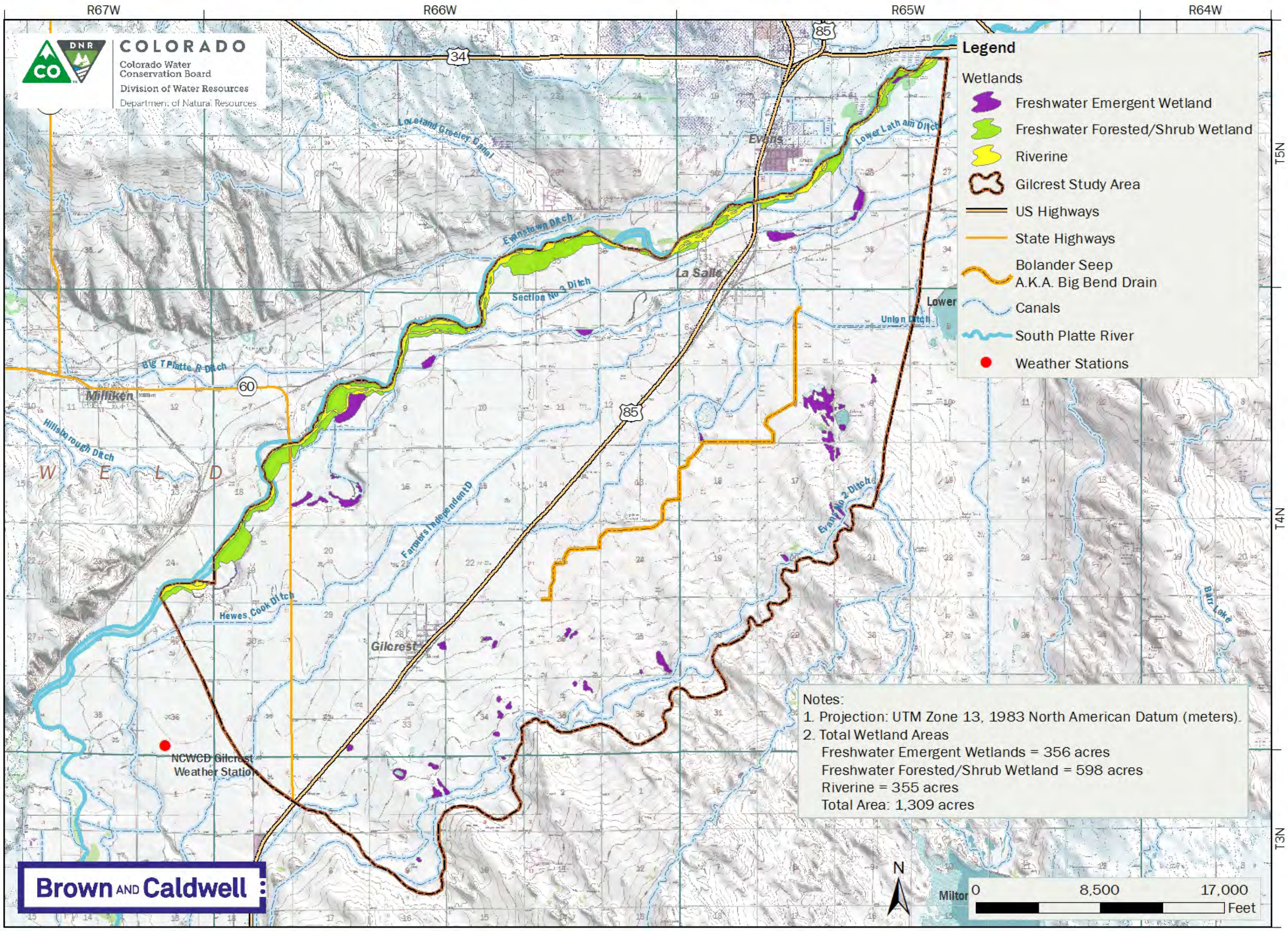

Figure 3-13. Gilcrest/LaSalle study area: wetland areas

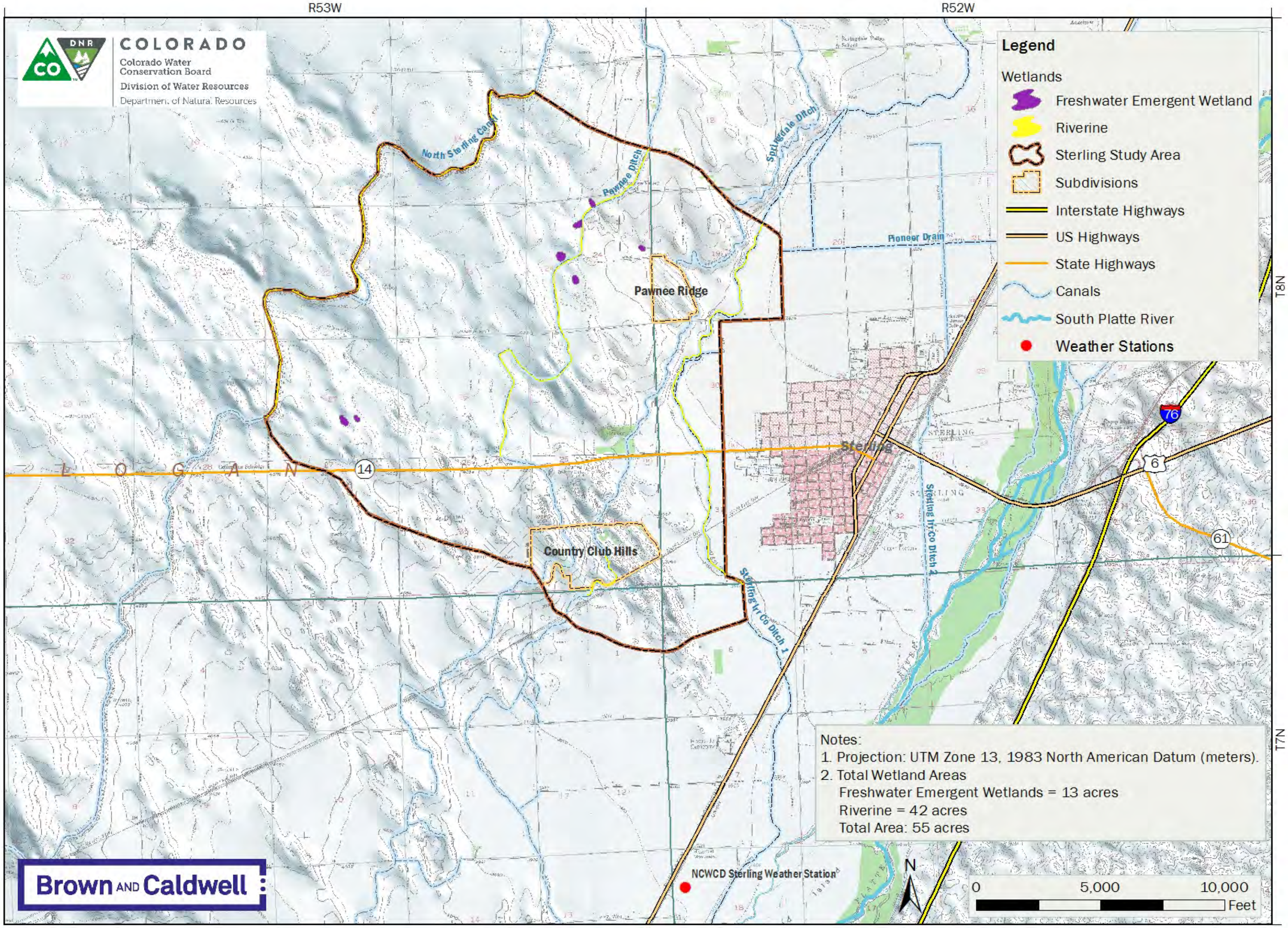

Figure 3-14. Sterling study area: wetland areas

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3.2.2.4 Subsurface Outflow

Subsurface outflow, similar to the subsurface inflow component discussed previously, represents groundwater flow that exits the study areas at the boundaries. Groundwater flow that exits the study area directly into a stream was considered separately from other subsurface outflow. Subsurface outflow not directly contributing to streamflow was estimated using the SPDSS groundwater model and USGS Zone Budget tool. As with the subsurface inflow, monthly average values from the groundwater model were used because the current period of record does not cover the water budget study period.

Using monthly average values from the groundwater model generates the same outflow from year to year (with monthly variation). For the Gilcrest/LaSalle study area, subsurface outflow not contributing to streamflow was a relatively small component of the overall water budget, so year-to-year similarity did not have a large impact on the final results. The majority of the subsurface outflow occurred along the boundary with the South Platte River.

In the Sterling study area, the subsurface outflow component composed a significant portion of the total estimated outflows. As a result, the average monthly values were scaled based on estimated changes in saturated thickness from year to year to better approximate changing aquifer conditions. The changes in saturated thickness were estimated based on changes in annual average water levels at select monitoring wells and the saturated thickness mapping from the SPDSS groundwater model. The scale factors apply to the whole year, so the fluctuations in the average monthly patterns remain; however, the actual monthly values have been modified. The annual scale factors are shown in Table 3-24.

Table 3-24. Subsurface Outflow Scale Factors: Sterling Study Area

Year	Scale Factor (%)
2012	-3.4
2013	-1.9
2014	3.2

The subsurface outflow values for the Gilcrest/LaSalle and Sterling study areas are shown in Tables 3-25 and 3-26, respectively.

Table 3-25. Average Monthly Subsurface Outflow (AF): Gilcrest/LaSalle Study Area

Water Year	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Total
2012-2014	579	597	598	541	599	580	596	577	606	610	589	604	7,076

Table 3-26. Monthly Subsurface Outflow (AF): Sterling Study Area

Water Year	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Total
2012	668	692	695	628	696	673	695	669	687	684	662	688	8,137
2013	678	702	705	637	706	683	705	679	697	694	672	698	8,254
2014	714	740	742	671	743	719	742	715	734	730	707	735	8,691

3.2.2.5 Groundwater Contribution to Streamflow

The groundwater contribution to streamflow was calculated using a spreadsheet-based method for estimating stream gains and losses that was used in the calibration of the SPDSS groundwater model. The method is based on the daily balance of streamflow measured at the upstream and downstream gages of a particular reach, surface diversions, discharges, gaged tributary inflow, and ungaged runoff from precipitation events within the reach. The basic mass balance equation is as follows:

$$\text{Gain/loss} = \text{downstream flow} - \text{upstream flow} + \text{diversions} - \text{tributary inflow} - \text{runoff} - \text{discharge} \quad (3\text{-}5)$$

The daily gain/loss terms are constrained by multiple factors including the travel time of streamflow within the reach, capacity of the stream to recharge the alluvial aquifer, and capacity of the aquifer to discharge to the stream. Final daily gain/loss values are also smoothed by calculating multi-day moving averages. These constraints are in place to filter out extreme daily variations that are not indicative of groundwater contributions, but likely caused by runoff. The daily gain/loss terms are accumulated over the month and the net gain/loss is used in the water budget.

Groundwater contribution to streamflow was calculated for the Gilcrest/LaSalle study area only along the boundary with the South Platte River. The Sterling study area boundary does not coincide with the South Platte River, so all groundwater flows leaving the Sterling study area are represented by the subsurface outflow term discussed in the previous section. Table 3-27 shows the groundwater contribution to streamflow for the Gilcrest/LaSalle study area.

Table 3-27. Monthly Groundwater Contribution to Streamflow (AF): Gilcrest/LaSalle Study Area

Water Year	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Total
2012	4,033	3,602	3,045	2,451	3,175	3,967	4,244	4,471	5,147	6,216	5,304	5,354	51,010
2013	3,117	2,643	3,859	4,335	3,569	2,303	3,316	4,757	5,824	6,520	4,765	2,699	47,707
2014	2,770	2,840	2,556	3,132	4,232	3,049	3,529	6,484	6,919	7,505	7,172	6,133	56,320

Section 4

Use Data from Sections 2 and 3 to Establish Water Budget

The purpose of this task was to incorporate the data collected and quantified in Sections 2 and 3 into a comprehensive water budget for each study area. Throughout the process of establishing the water budget, the various inflow and outflow components were evaluated and amended as necessary in an effort to incorporate the best available data and reduce the magnitude of error in the results.

The water budget was set up so that components on the inflow side represented hydrologic inputs that contribute to increases in groundwater storage. Outflow components represent inputs that decrease groundwater storage. The difference between the inflow and outflow components is the change in storage and is described by the following equation:

$$\textit{Inflow} - \textit{outflow} = \textit{change in storage} \qquad (4\text{-}1)$$

Positive change in storage corresponds to a rise in the water table elevation and negative change in storage corresponds to a decline in water table elevation. The magnitude of the changes to the water table elevation for a specific amount of change in storage is a function of the aquifer properties and size of the region where the change in storage was computed.

This section includes a summary of monthly inflows, outflows, and change in storage with accompanying graphics for each study area. Also included are annual water budget summaries and corresponding graphics. The full monthly water budget for the Gilcrest/LaSalle and Sterling study areas, showing each component, is included in Appendices A and B, respectively.

4.1 Gilcrest/LaSalle Water Budget

The Gilcrest/LaSalle study area covers a region where the hydrologic inputs are dominated by surface water irrigation and groundwater interactions with the South Platte River. Numerous groundwater wells that typically provide supplemental irrigation supply are also located within the study area. Over the last decade, an increasing amount of augmentation recharge ponds, fed via irrigation canals, have been installed throughout the region. These components compose a large part of the water budget for the Gilcrest/LaSalle study area.

4.1.1 Monthly Water Budget Results

Table 4-1 (below) provides a summary of total inflow, total outflow, and change in storage on a monthly basis. Figure 4-1 shows a graphical representation of the data from Table 4-1. Total inflow values are shown as positive (bars rising above the zero-line) and total outflow values are negative and shown as descending bars below the zero-line. The change in storage is the difference between the inflow and outflow and is shown as a line. A strong seasonal response for the inflow components is driven by recharge from surface water irrigation and ditch seepage. The outflows also show a seasonal pattern, primarily because of variations in groundwater discharge to the South Platte River. Pumping also contributes to the seasonal pattern that is visible in the outflow components.

Table 4-1. Monthly Water Budget Summary: Gilcrest/LaSalle Study Area

Date	Total Inflow	Total Outflow	Change in Storage
Nov-11	1,577	4,624	-3,047
Dec-11	1,411	4,199	-2,788
Jan-12	1,511	3,701	-2,191
Feb-12	1,306	3,051	-1,745
Mar-12	1,920	3,959	-2,039
Apr-12	7,012	5,054	1,958
May-12	7,969	5,590	2,379
Jun-12	7,118	6,442	676
Jul-12	8,688	7,446	1,242
Aug-12	8,236	8,806	-570
Sep-12	7,802	7,047	755
Oct-12	5,765	6,232	-468
Nov-12	1,962	3,785	-1,822
Dec-12	1,587	3,264	-1,677
Jan-13	1,892	4,473	-2,581
Feb-13	2,284	4,906	-2,622
Mar-13	2,112	4,209	-2,097
Apr-13	3,134	2,938	196
May-13	7,680	4,337	3,343
Jun-13	11,232	6,401	4,831
Jul-13	11,963	7,678	4,285
Aug-13	10,690	8,564	2,126
Sep-13	8,680	5,733	2,947
Oct-13	5,098	3,456	1,641
Nov-13	2,949	3,353	-403
Dec-13	1,530	3,445	-1,914
Jan-14	1,735	3,159	-1,425
Feb-14	1,866	3,705	-1,839
Mar-14	3,233	4,933	-1,700
Apr-14	6,769	3,724	3,045
May-14	8,713	4,404	4,309
Jun-14	9,326	7,763	1,562
Jul-14	12,383	8,629	3,754
Aug-14	11,094	9,047	2,047
Sep-14	7,379	8,465	-1,085
Oct-14	3,900	6,960	-3,059

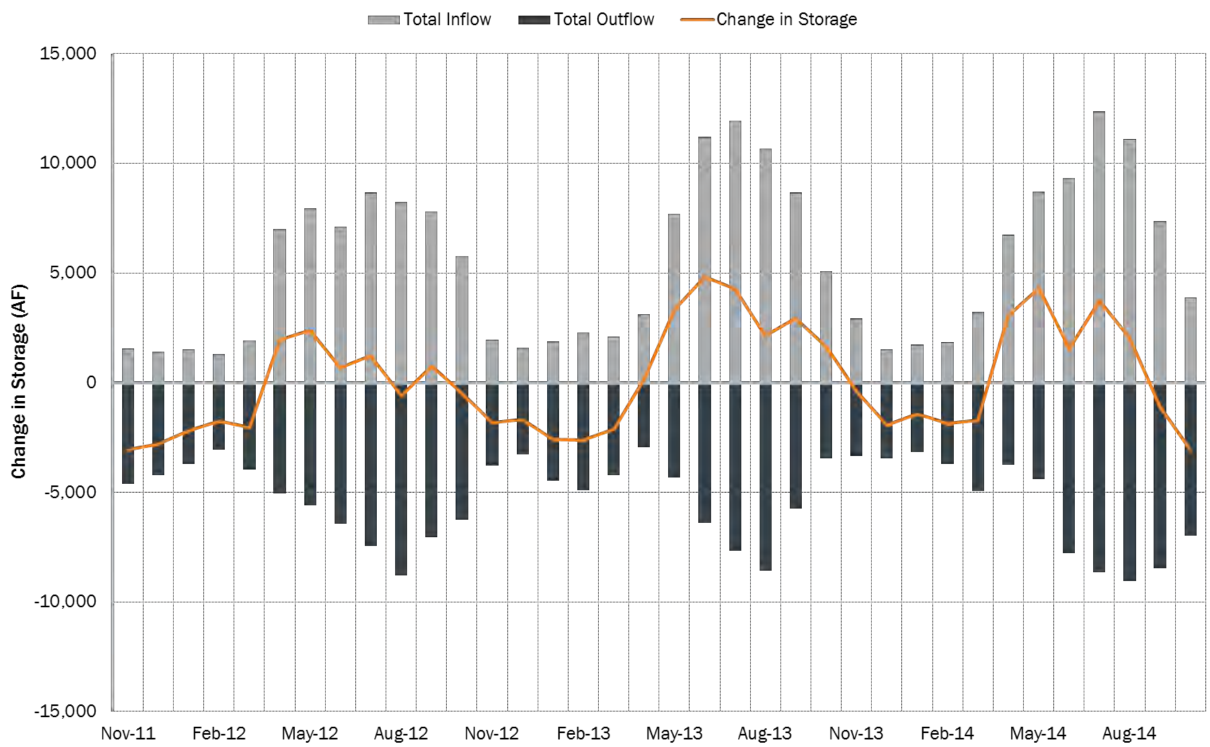

Figure 4-1. Change in storage summary: Gilcrest/LaSalle study area

Figures 4-2 and 4-3 show the magnitudes of the monthly inflow and outflow components for the Gilcrest/LaSalle study area relative to total inflow and outflow, respectively. The top of the stacked area graph represents the total inflow or total outflow. The same seasonal patterns are visible, as well as changes in individual components throughout the study period. For the inflows, there is a sharp increase in recharge from precipitation in September 2013 and a steady increase in recharge from recharge ponds from 2012 through 2013. The outflows are more steady, but show gradual decline in pumping (shown as consumptive use of groundwater from pumping) and phreatophyte consumption. Those declines are likely a result of increases in precipitation lessening the demand for supplemental irrigation and providing a larger supply of water to phreatophytes.

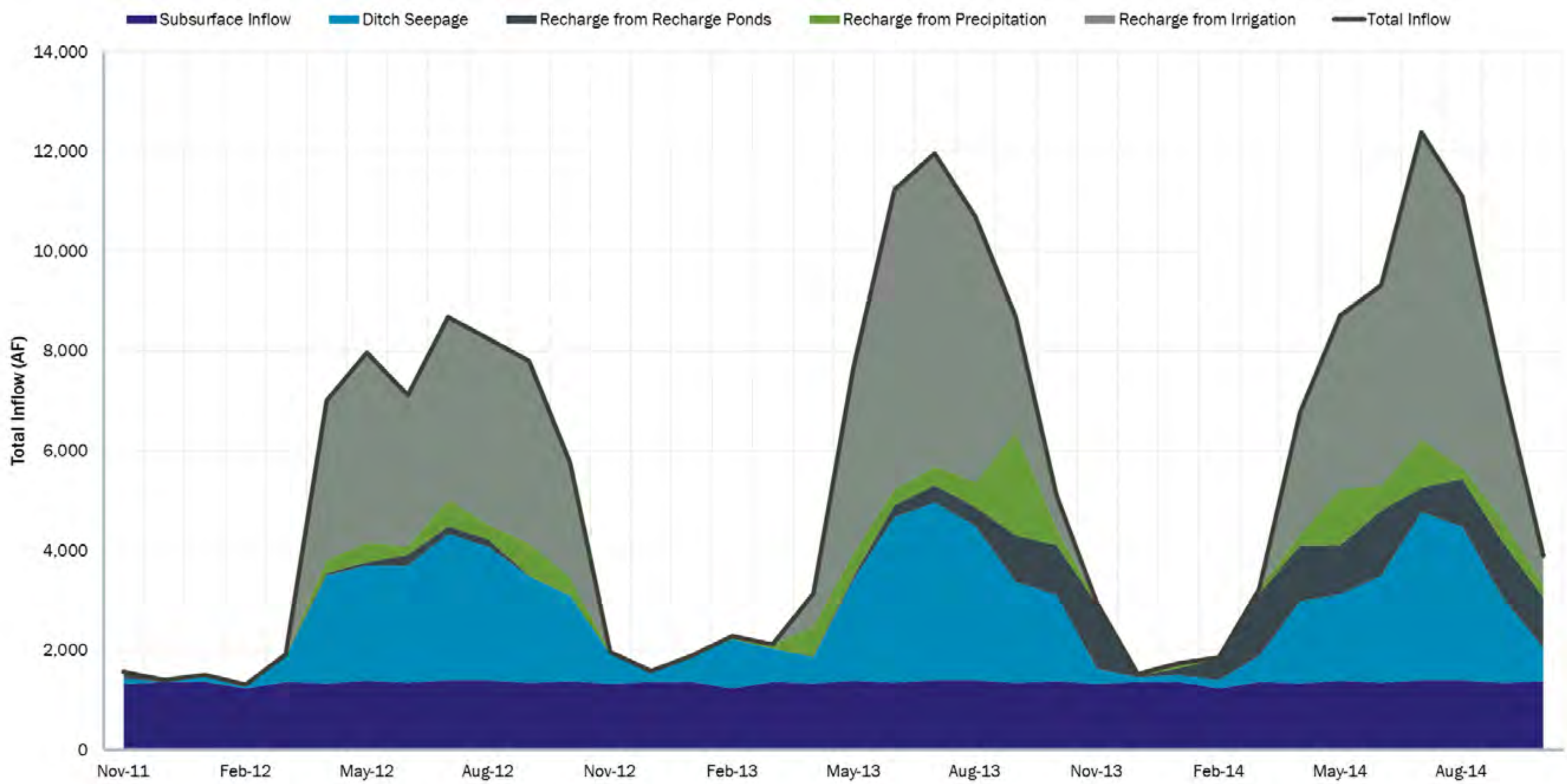

Figure 4-2. Monthly inflow summary: Gilcrest/LaSalle study area

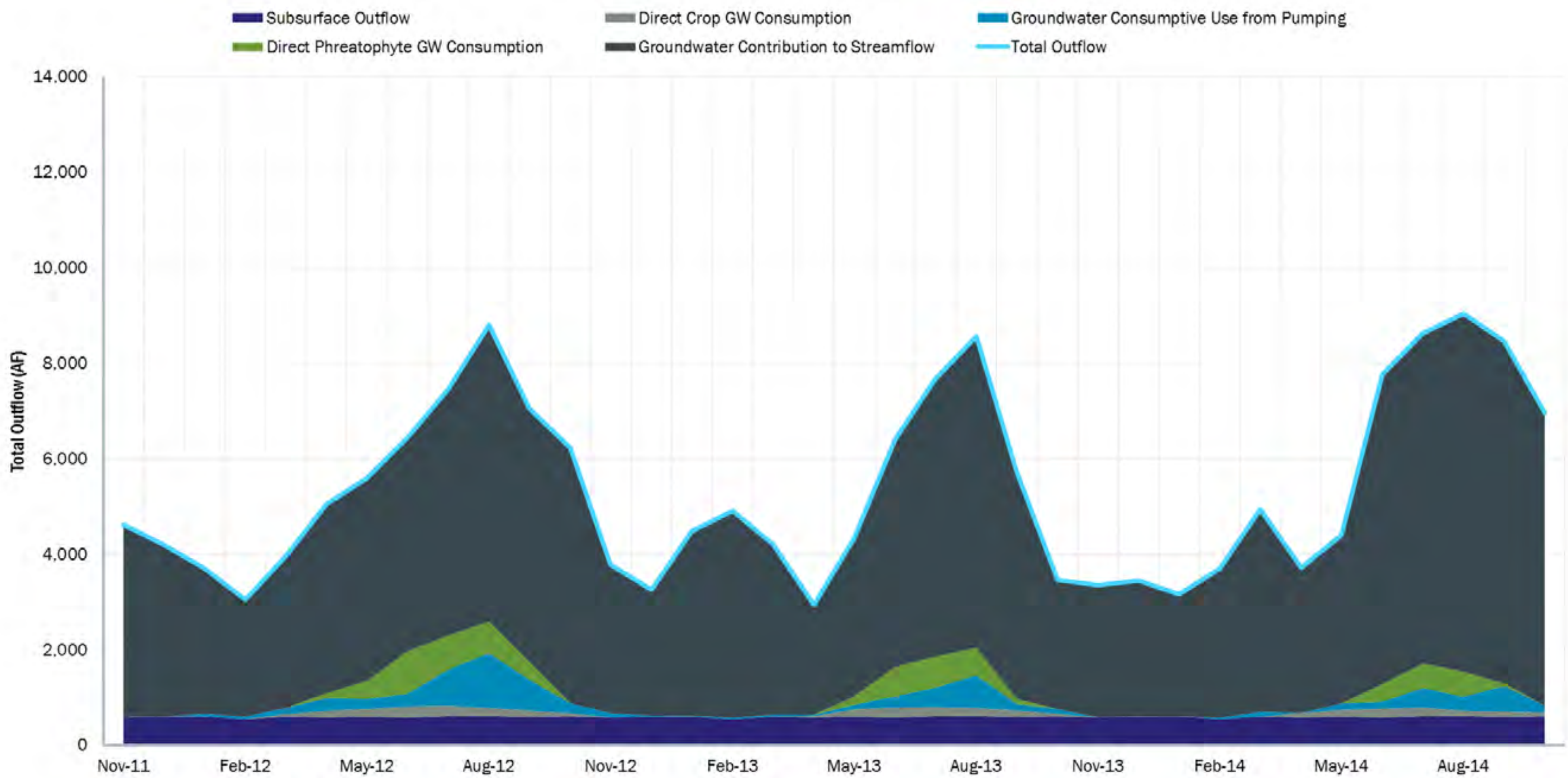

Figure 4-3. Monthly outflow summary: Gilcrest/LaSalle study area

4.1.2 Annual Water Budget Results

Looking at the water budget components for the Gilcrest/LaSalle study area on an annual basis shows how the various inputs and outputs are changing throughout the study period. The annual values were calculated based on a water year basis.

4.1.2.1 Inflow Summary

The annual inflow components are summarized in Figure 4-4. The bars show the magnitude of each component grouped by water year. The chart below shows the percentage of total inflow that each component represents for that year.

Figure 4-4. Annual inflow component summary: Gilcrest/LaSalle study area

The annual inflow values can be grouped by component to highlight year-to-year changes in a particular component. Those results are shown in Figure 4-5.

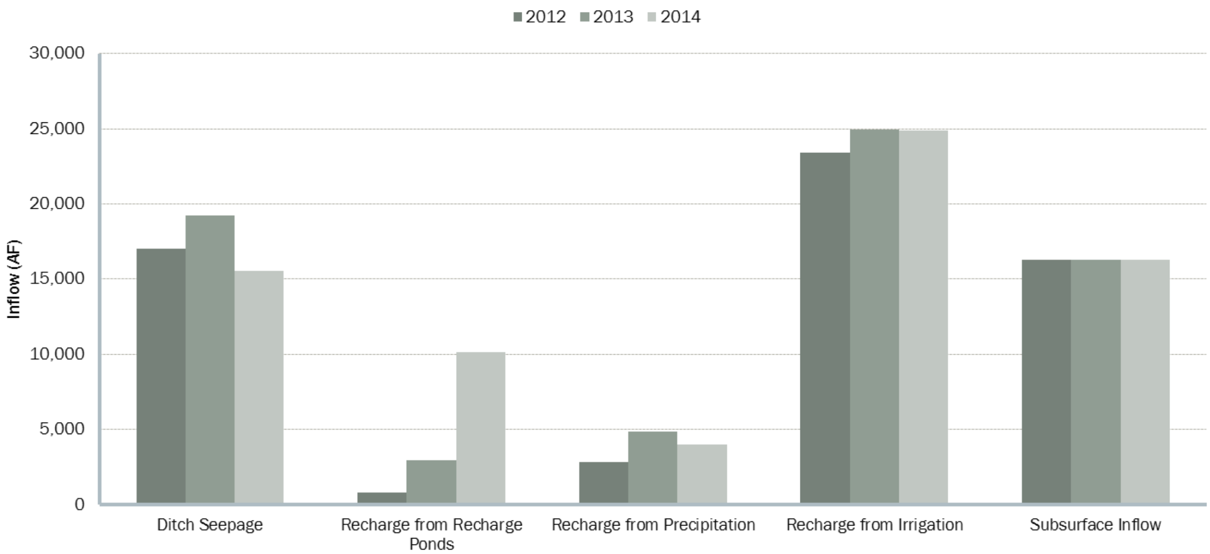

Figure 4-5. Annual inflow component values: Gilcrest/LaSalle study area

The component showing the largest increase during the study period on a volumetric basis and percentagewise is recharge from recharge ponds. Precipitation recharge shows a jump up from 2012 values in both 2013 and 2014. The drop in ditch seepage in 2014 is a result of fewer winter diversions than what occurred in 2013, thus fewer annual diversions, and a redistribution of which ditches were diverting. Ditches that were represented as being more efficient were taking a larger portion of the diversions in 2014, so the changes in total diversions throughout the Gilcrest/LaSalle study area were not necessarily analogous to changes in calculated ditch seepage.

4.1.2.2 Outflow Summary

The annual outflow values for the Gilcrest/LaSalle study area are shown in Figure 4-6.

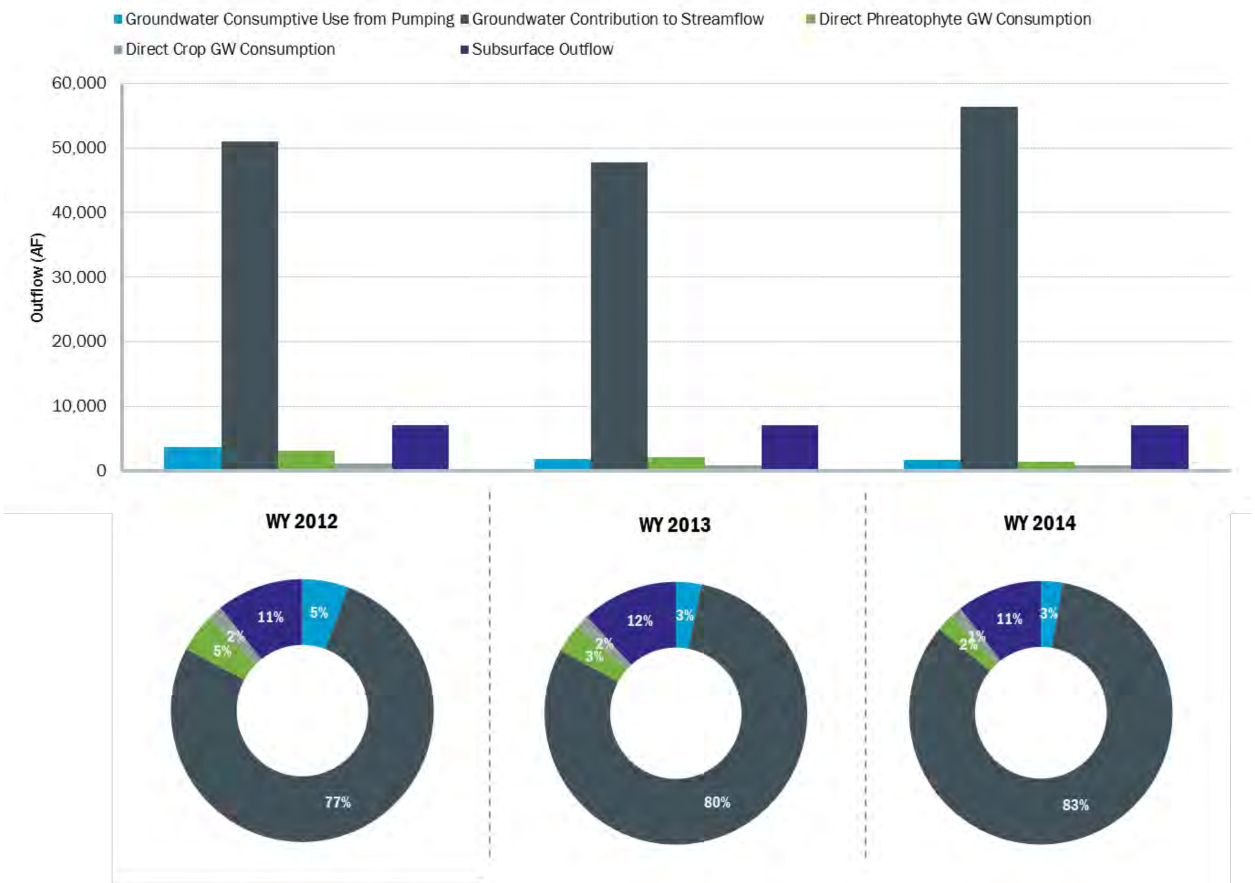

Figure 4-6. Annual outflow component summary: Gilcrest/LaSalle study area

Figure 4-7 shows the annual outflow values grouped by component.

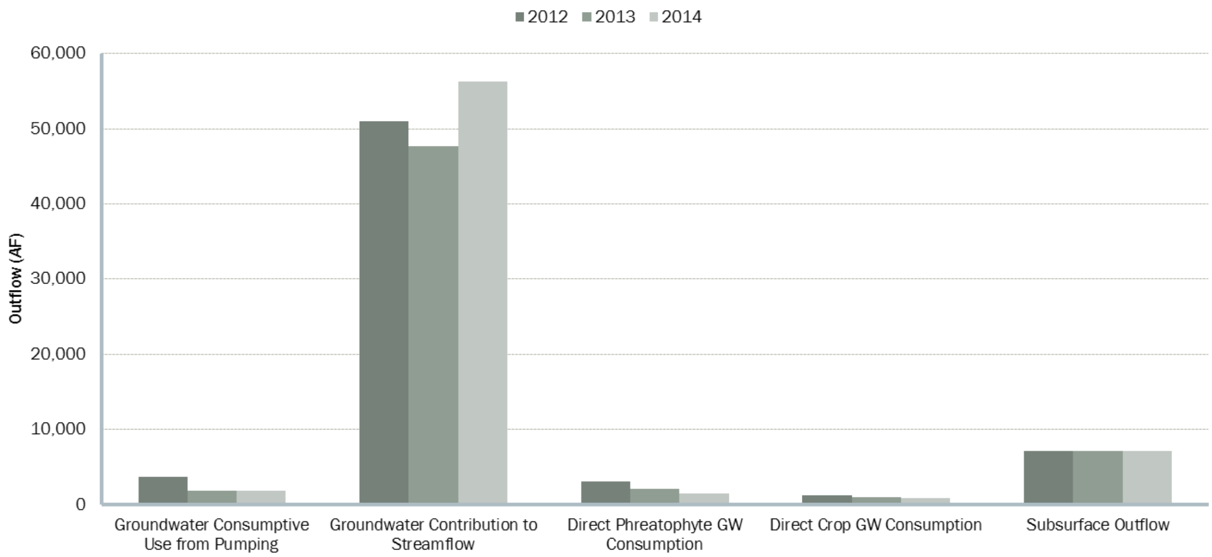

Figure 4-7. Annual outflow component values: Gilcrest/LaSalle study area

In general, the outflow components are steadier on a year-to-year basis than the inflow components. However, the groundwater contribution to streamflow makes up such a large percentage of the total outflow that changes in other components do not have a significant impact on the water budget.

4.1.2.3 Change in Storage Summary

The total inflow and outflow values for each water year are shown in Figure 4-8.

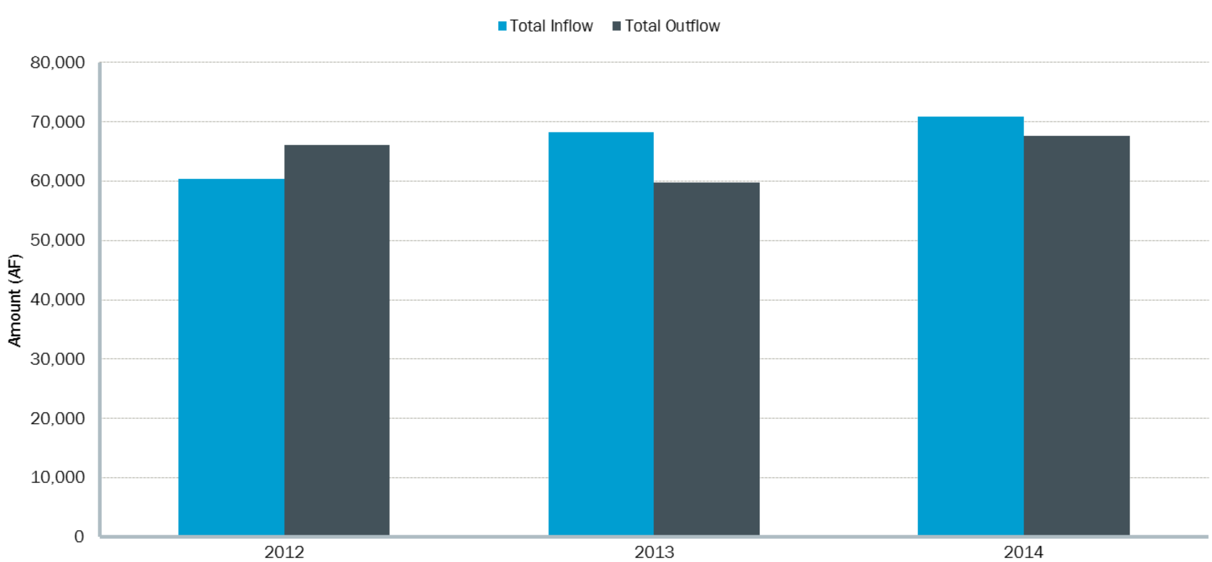

Figure 4-8. Summary of annual inflows and outflows: Gilcrest/LaSalle study area

The annual total inflow and outflow values show that in 2012, outflows were greater than inflows, indicating a decline in water table elevation at the beginning of the study period. In the subsequent years, the inflows are greater than outflows, which correspond to a rise in water table elevation.

4.1.2.4 Estimated change in groundwater level

The estimated change in storage was used to develop an estimate of the regional change in groundwater level, which assumes the change in storage is distributed evenly across the entire study area. This estimated relative change in groundwater level is calculated using the following equation:

*Change in groundwater level = change in storage/ (area * specific yield)* (4-2)

The area in Equation 4-2 is based on the study area boundaries; for the Gilcrest-LaSalle study area, it is about 34,350 acres. Specific yield represents the percentage of a volume of the aquifer that can yield or store water due to gravity. For the Gilcrest/LaSalle study area, the specific yield was assumed to be 15 percent. That value was obtained from the Gilcrest/LaSalle Pilot Project Hydrogeologic Characterization Report (Barkmann et al, 2014). The report provides specific yield estimates at various locations around the Gilcrest/LaSalle study area, some of which reflect semi-confined aquifer conditions, and some of which reflect unconfined conditions. For the purposes of this study, BC adopted the specific yield estimates that reflect unconfined conditions. The assumption of unconfined conditions tended to be verified given how well the estimated change in water table matched monitoring well records.

Monthly estimates of water level change were developed using Equation 4-2. Figure 4-9 shows the estimated change in groundwater level based on the water budget compared to measured groundwater levels at various locations with the study area (see Figure 1-1 for well locations).

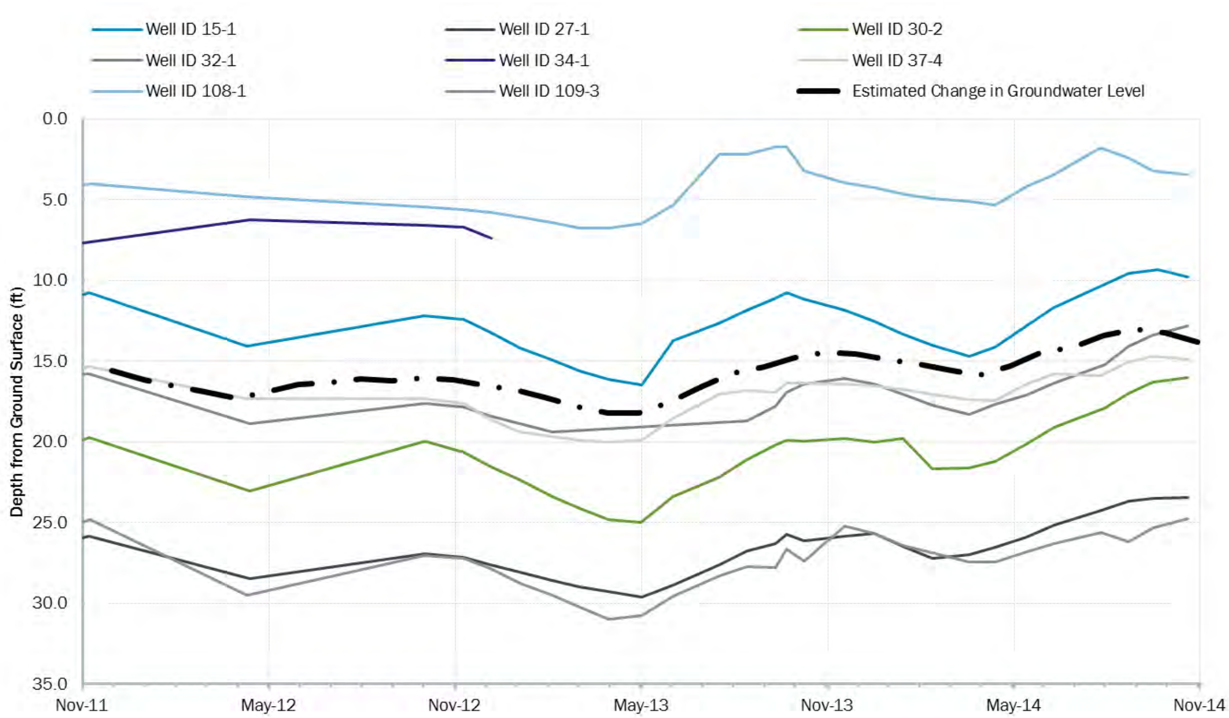

Figure 4-9. Estimated and measured groundwater level comparison: Gilcrest/LaSalle study area

The magnitude and trend of the monthly change in estimated groundwater level are the important features to compare to those of the measured groundwater levels; the numerical value for the estimated groundwater level is irrelevant. Therefore, for illustrative purposes in Figure 4-9, the estimated change in groundwater level was placed along the vertical axis so that it highlighted the comparison with the measured groundwater levels.

Figure 4-9 shows that the estimated change in groundwater level reflected by the water budget closely resembles the pattern and magnitude of water level change seen in the monitoring wells.

4.2 Sterling Water Budget

The Sterling study area covers a region that has a mix of residential and agricultural areas that is upland from the South Platte River. The agricultural areas represent a mix of surface water irrigated areas and groundwater irrigated areas. A number of recharge ponds and wells are located within the study area. Most of these facilities were in place prior to the water budget study period.

4.2.1 Monthly Water Budget Results

A summary of total inflow, total outflow, and change in storage on a monthly basis is shown in Table 4-2. Figure 4-10 shows a graphical representation of the data from Table 4-2. Total inflow values are shown as positive (bars rising above the zero-line) and total outflow values are negative and shown as descending bars below the zero-line. The change in storage is the difference between the inflow and outflow and is shown as a line. A strong seasonal response is not shown in the inflows, particularly in the second half of the study period. The outflows show a more predictable seasonal pattern, driven primarily by pumping.

Table 4-2. Monthly Water Budget Summary: Sterling Study Area			
Date	Total Inflow	Total Outflow	Change in Storage
Nov-11	1,078	740	338
Dec-11	346	746	-399
Jan-12	44	734	-690
Feb-12	116	645	-529
Mar-12	796	747	49
Apr-12	569	859	-290
May-12	549	1,078	-529
Jun-12	770	1,463	-692
Jul-12	870	1,380	-511
Aug-12	629	1,336	-708
Sep-12	464	985	-521
Oct-12	1,860	772	1,088
Nov-12	642	682	-40
Dec-12	890	703	186
Jan-13	765	705	60
Feb-13	1,036	637	399
Mar-13	699	719	-20
Apr-13	804	695	109
May-13	761	890	-129
Jun-13	823	1,114	-291
Jul-13	892	1,146	-254
Aug-13	786	1,268	-482
Sep-13	641	859	-218
Oct-13	1,057	735	322
Nov-13	1,083	714	370
Dec-13	916	740	177
Jan-14	1,191	742	449
Feb-14	584	671	-87
Mar-14	599	751	-152
Apr-14	1,121	761	359
May-14	1,522	833	689
Jun-14	1,569	959	611
Jul-14	1,128	1,390	-262
Aug-14	1,254	1,299	-45
Sep-14	1,425	1,070	355
Oct-14	966	845	121

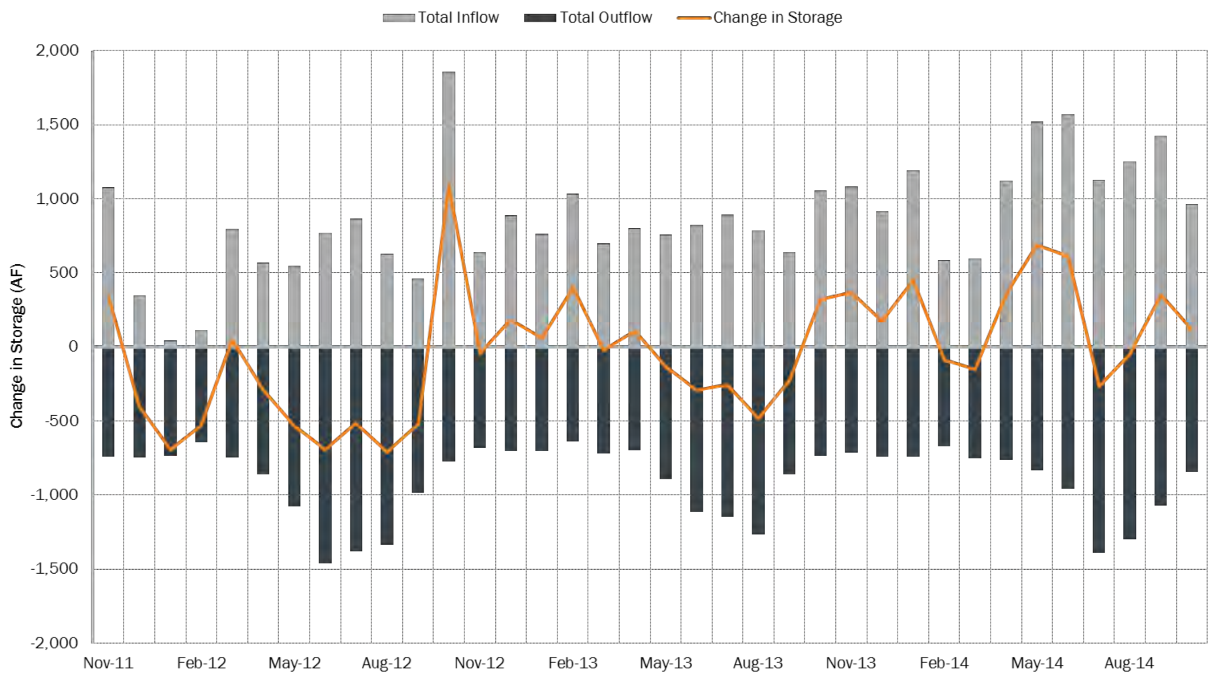

Figure 4-10. Change in storage summary: Sterling study area

Figures 4-11 and 4-12 show the magnitudes of the monthly inflow and outflow components for the Sterling study area relative to total inflow and outflow. The top of the stacked area graph represents the total inflow or total outflow. The lack of an overall seasonal pattern is visible on the inflows, as well as a general increase in ditch seepage. The outflows are dominated by subsurface outflows (flows leaving the study area at the boundary), with distinct seasonal patterns from pumping.

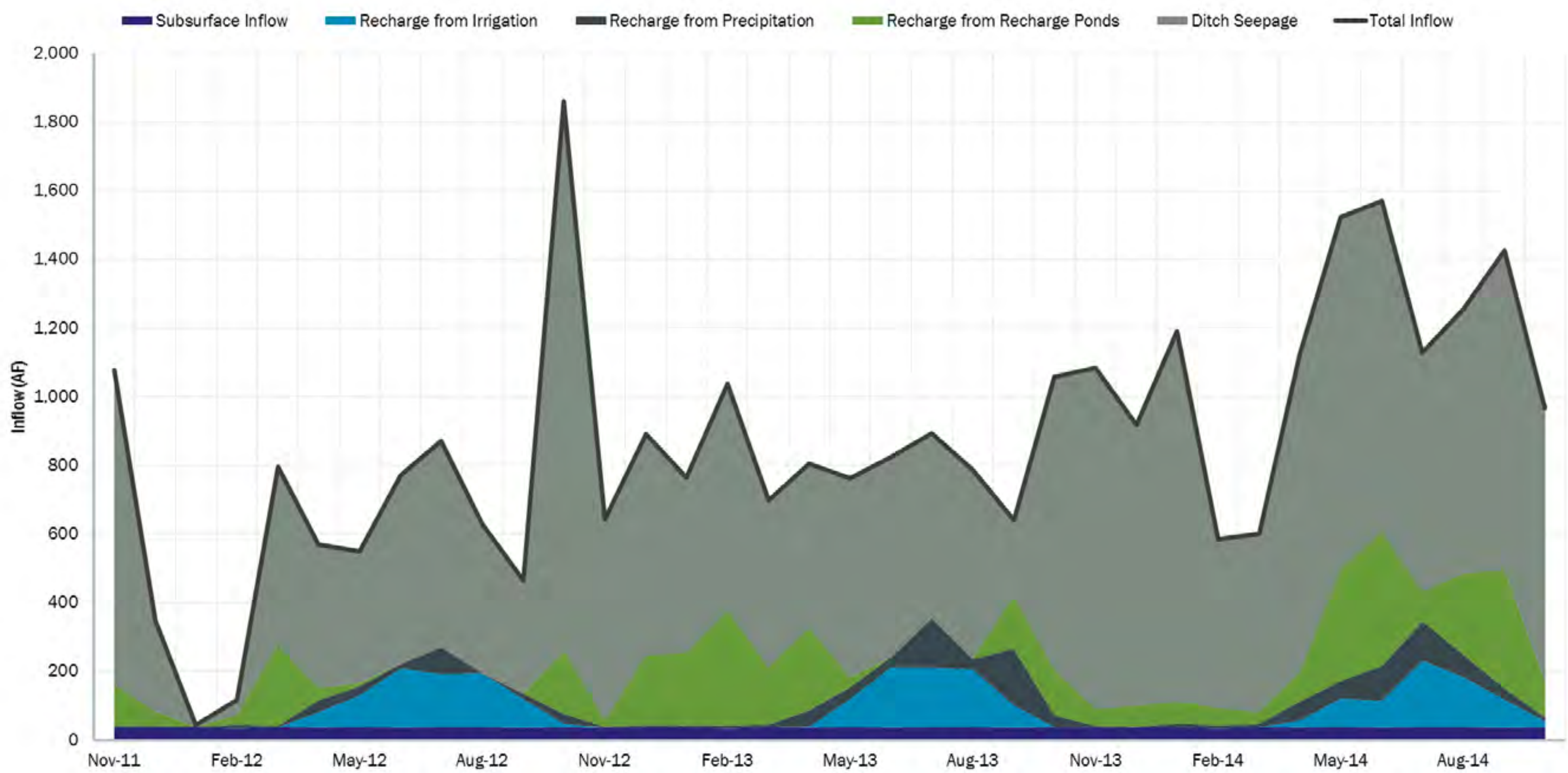

Figure 4-11. Monthly inflow summary: Sterling study area

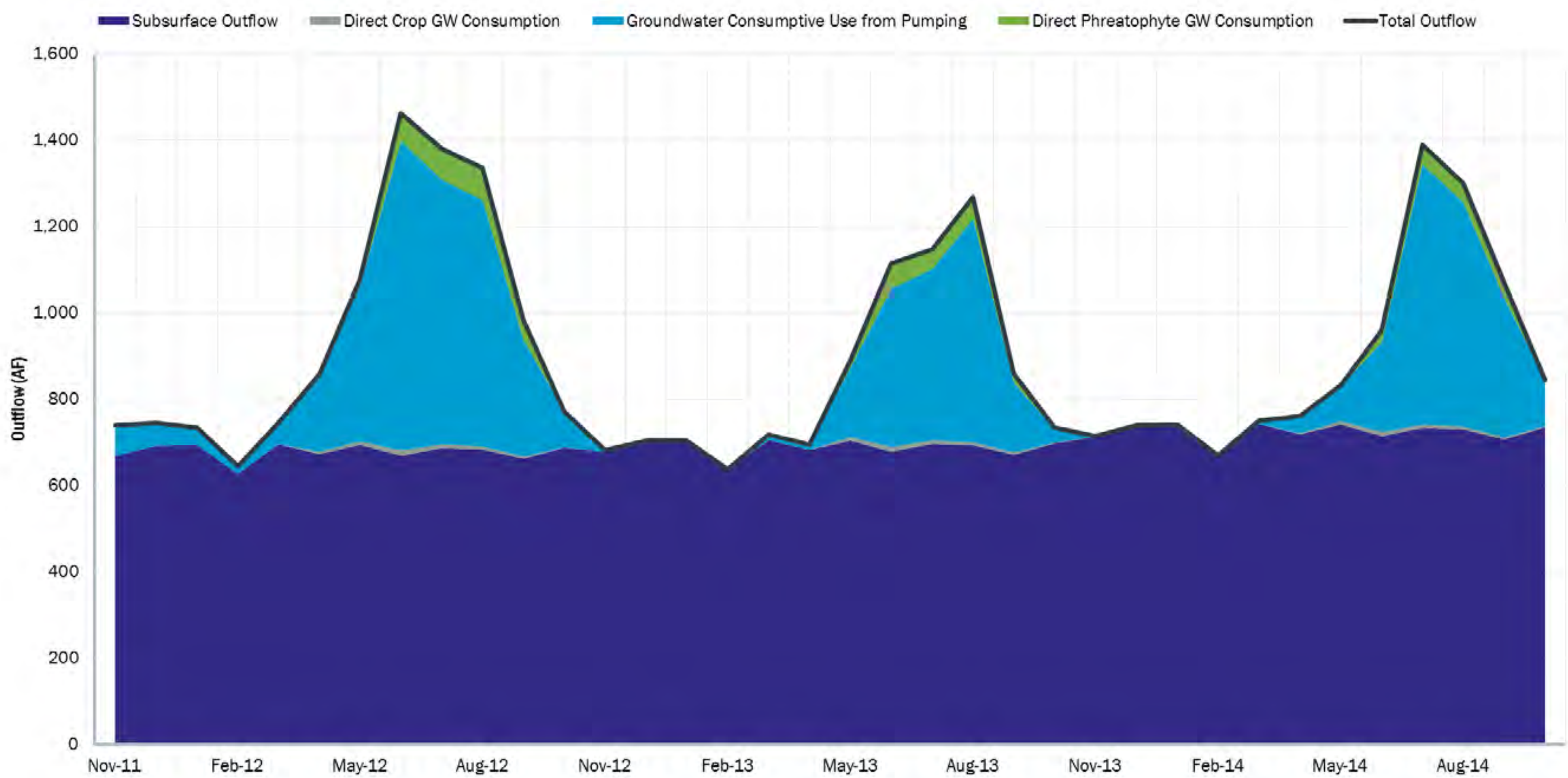

Figure 4-12. Monthly outflow summary: Sterling study area

4.2.2 Annual Water Budget Results

The following sections provide a summary of the water budget components on an annual basis for the Sterling study area. The annual values were calculated based on water year.

4.2.2.1 Inflow Summary

The annual inflow components are summarized in Figure 4-13. The bars show the magnitude of each component grouped by water year. The chart below shows the percentage of total inflow that each component represents for that year.

Figure 4-13. Annual inflow component summary: Sterling study area

The annual inflow values grouped by component are shown in Figure 4-14.

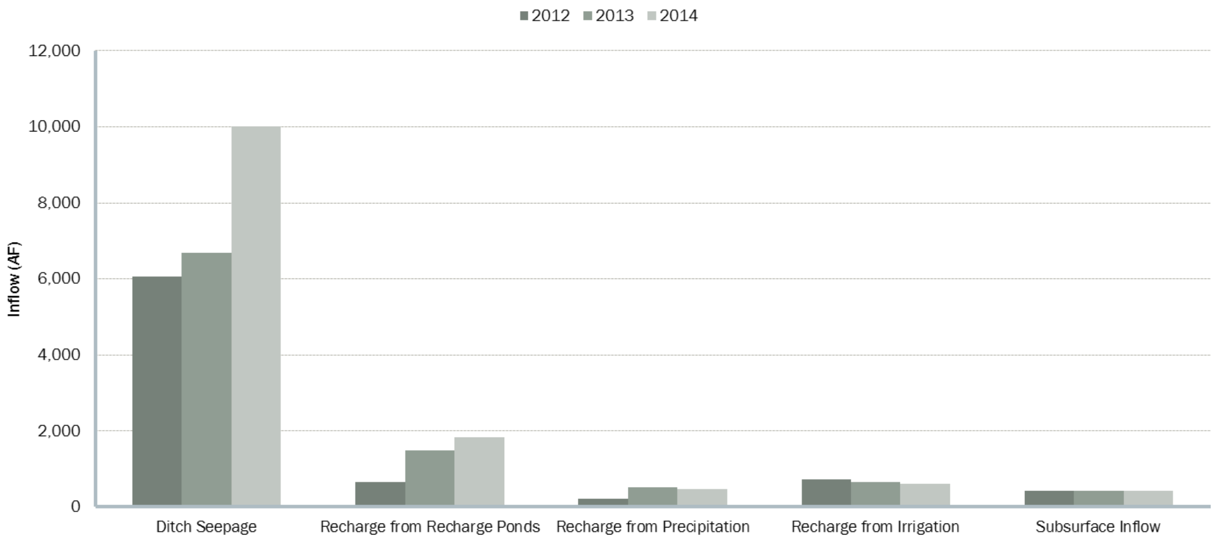

Figure 4-14. Annual inflow component values: Sterling study area

The component showing the largest increase from the beginning to the end of the study period on a volumetric basis is ditch seepage. There is an increase each year in recharge from recharge ponds. The other components were relatively steady from year to year.

4.2.2.2 Outflow Summary

The annual outflow values for the Sterling study area are shown in Figure 4-15.

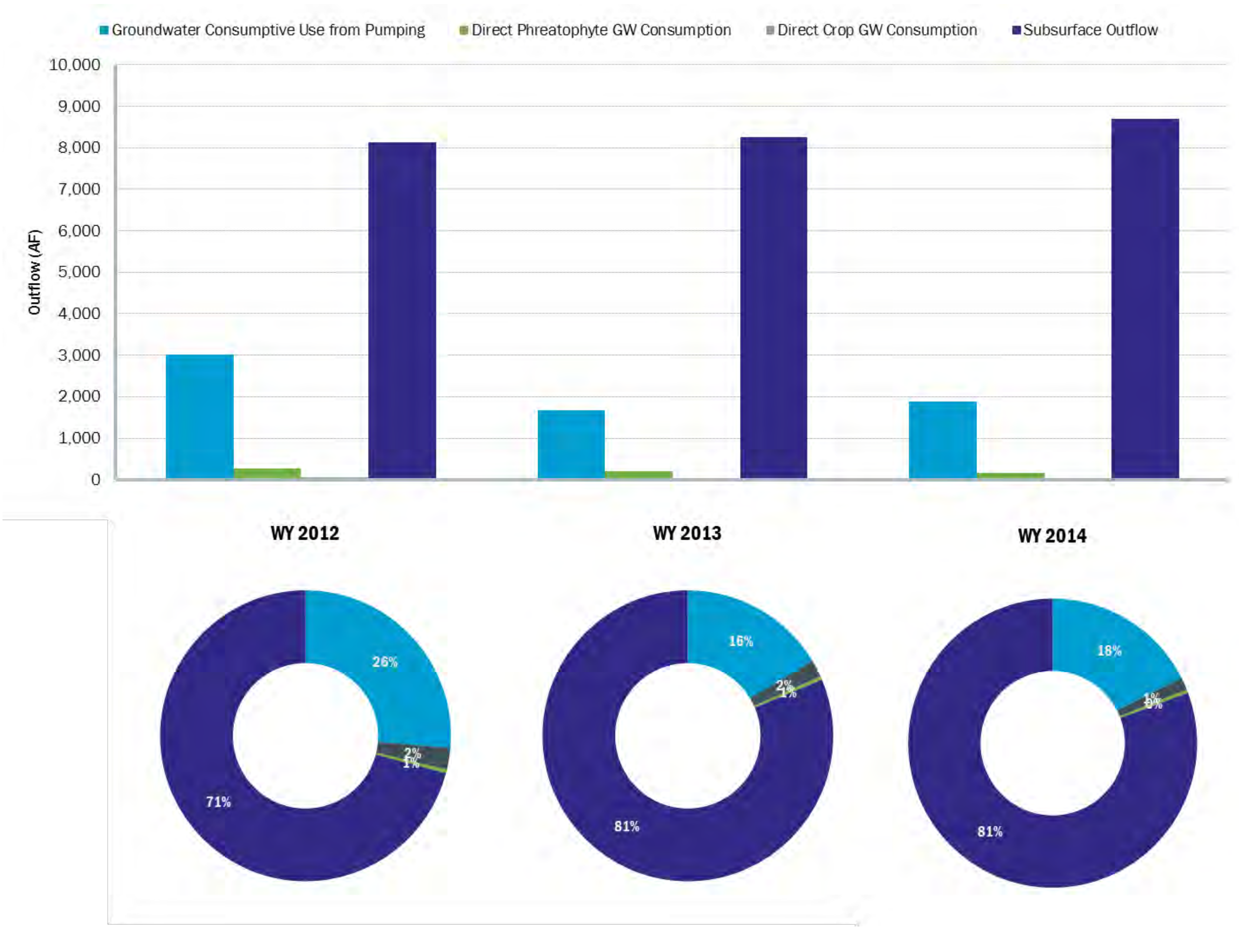

Figure 4-15 Annual outflow component summary: Sterling study area

Figure 4-16 shows the annual outflow values grouped by component.

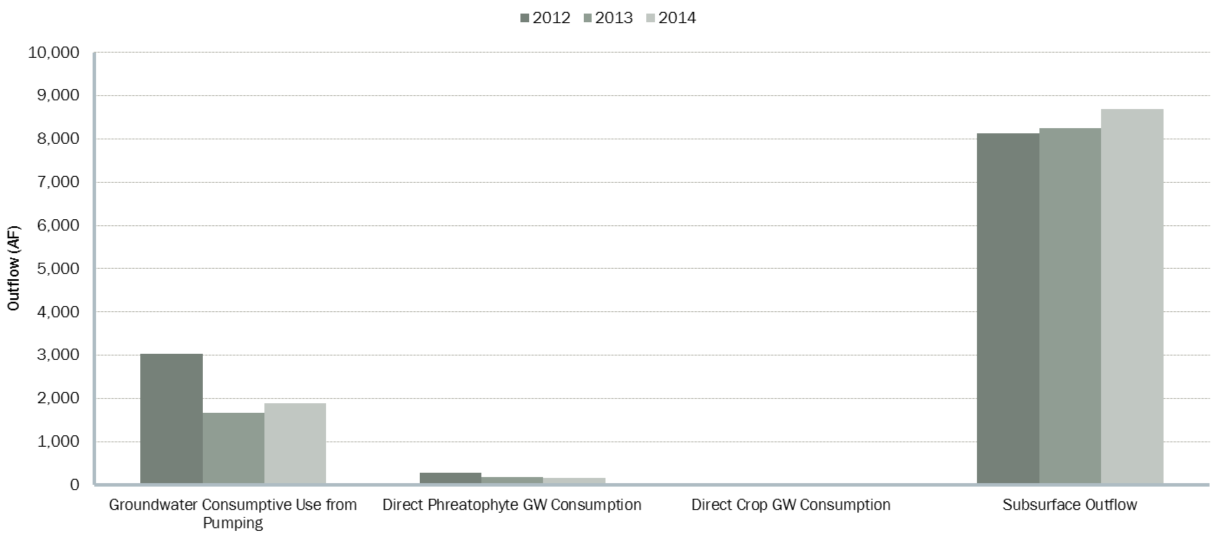

Figure 4-16. Annual outflow component values: Sterling study area

There is a drop in pumping from 2012 to 2013 and 2014. The decrease in pumping is likely a result of increases in precipitation leading to reduced irrigation demand. Subsurface outflow rises each year, which is related to the changing water level in the study area.

4.2.2.3 Change in Storage Summary

The total inflow and outflow values for each water year are shown in Figure 4-17.

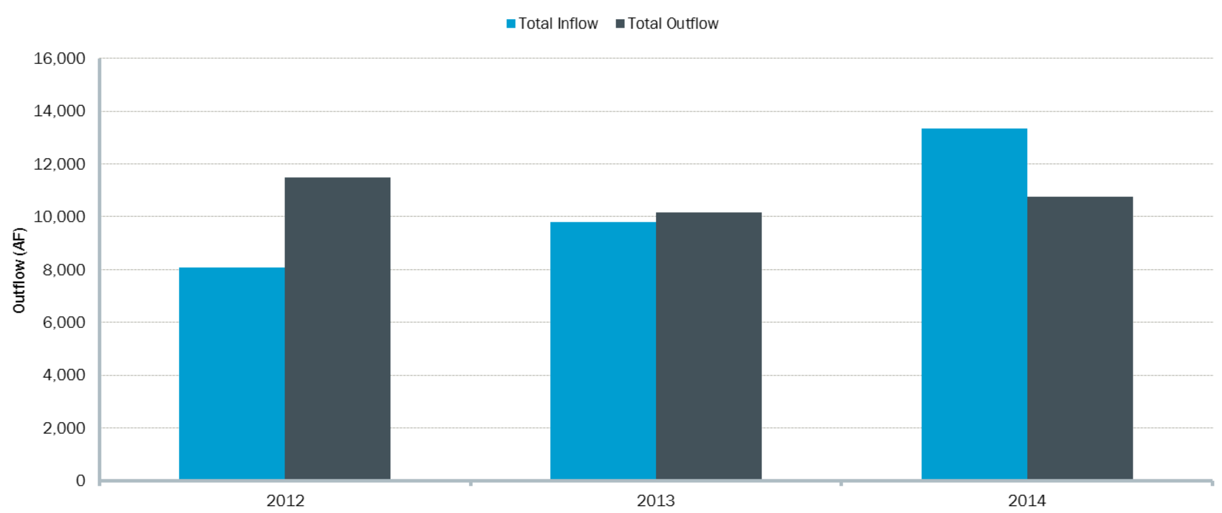

Figure 4-17. Summary of annual inflows and outflows: Sterling study area

Similar to the Gilcrest/LaSalle study area, the annual total inflow and outflow values show that in 2012 outflows were greater than inflows, indicating a decline in water table elevation at the beginning of the study period. Outflows were also greater in 2013, but to a lesser extent than in 2012. Halfway through 2013, the trend of greater outflow than inflow is reversed and remains in place for 2014.

4.2.2.4 Estimated change in groundwater level

The estimated change in storage was used to develop a monthly estimate of the regional change in groundwater level using Equation 4-2. This calculation assumes the estimated change in storage is distributed evenly across the entire study area, which is approximately 6,800 acres in size. Specific yield was set at 20 percent for the Sterling study area. Figures 4-18 and 4-19 show the estimated change in groundwater level compared to measured groundwater levels at piezometers installed near the Country Club Hills and Pawnee Ridge subdivisions, respectively. (See Figure 5-1 below for well locations.)

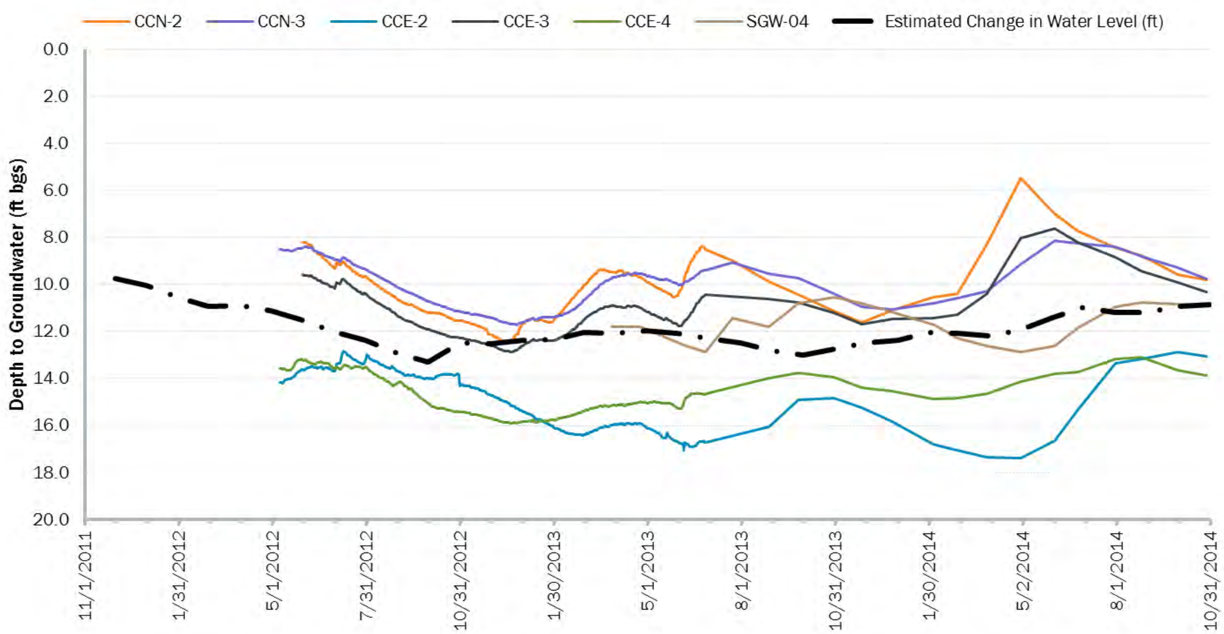

Figure 4-18. Estimated and measured groundwater level comparison at Country Club Hills

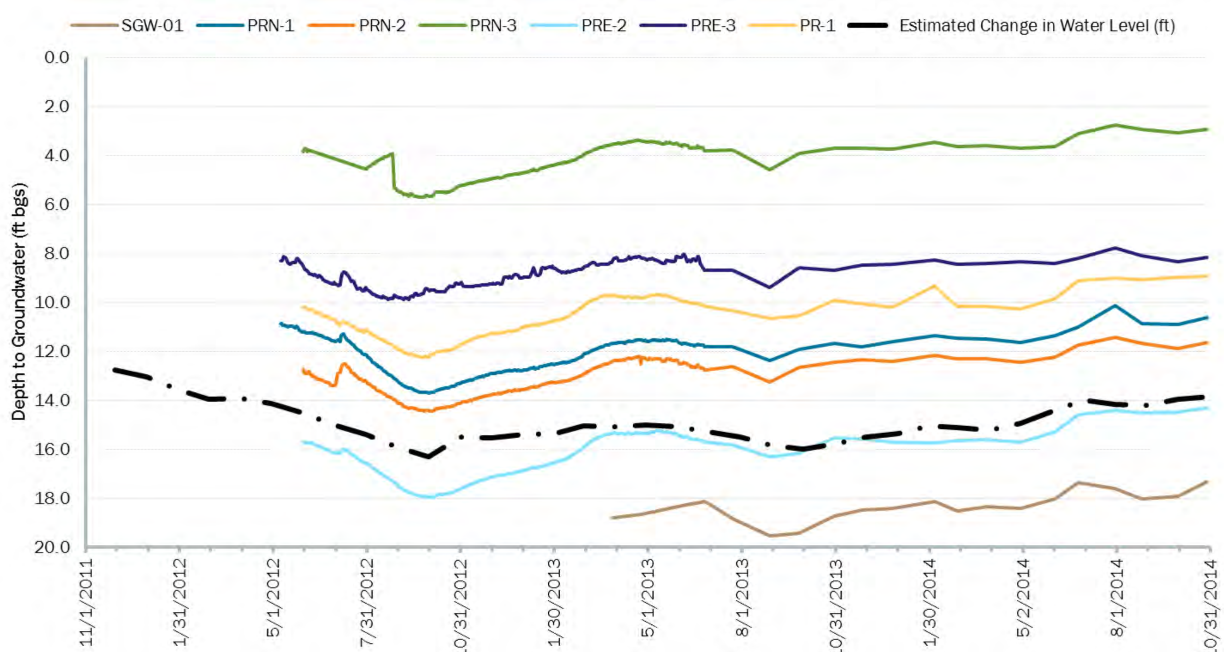

Figure 4-19. Estimated and measured groundwater level comparison at Pawnee Ridge

The magnitude and trend of the monthly change in estimated groundwater level are the important features to compare to those of the measured groundwater levels; the numerical value for the estimated groundwater level is irrelevant. Therefore, for illustrative purposes in Figures 4-18 and 4-

19, the estimated change in groundwater level was placed along the vertical axis so that it highlighted the comparison with the measured groundwater levels

Figure 4-18 shows that the estimated change in groundwater level estimated by the water budget resembles the trends in the measured groundwater level changes near the Country Club Hills subdivision. However, the magnitudes of change in some of the measured data are greater than what the water budget estimated. This is likely the result of inputs (e.g., seepage from nearby ditches) that have a strong local influence, but do not have a large impact on the overall study area. Some wells, such as CCE-2, do not match the estimated change in groundwater level, showing trends opposite of those that were estimated.

The estimated change in groundwater level shows good agreement in both trend and magnitude of change with the measured groundwater levels near the Pawnee Ridge subdivision, as shown on Figure 4-19.

Section 5

Apply Scientific Methods to Identify and Describe Hydrologic Relationships between All Factors

The following are conclusions and observations for the Gilcrest/LaSalle and Sterling study areas. The recommendations for the Gilcrest/LaSalle and Sterling study areas are described separately.

5.1 Conclusions

This section presents the conclusions of this groundwater analysis for the Gilcrest/LaSalle and Sterling study areas.

5.1.1 Gilcrest/LaSalle Study Area

Based on the results of the water budget analysis, the regional water table responded to the balance of total inflows and outflows during the study period.

As shown in Figure 4-9, the estimated changes in regional water table elevation based on the water budget followed water level trends observed in groundwater monitoring wells very closely. This correlation indicates that the water budget for the Gilcrest/LaSalle study area was developed appropriately and strongly suggests that the estimated magnitude and timing of inflows and outflows reflect field conditions.

During the study period, the water table responded to the balance of inflows and outflows:

- Through the first year of the analysis period (November 2011 through October 2012), most of the monitoring wells showed an overall downward trend. As shown in Figure 4-8, estimated total outflows were greater than estimated inflows in 2012, and therefore the water budget reflects a decrease in aquifer storage, resulting in a lowering of the regional water table.
- In 2013 and 2014, the reverse situation was calculated in the water budget. Estimated total inflows in 2013 and 2014 to the study area were greater than estimated total outflows. As a result, a general increase in aquifer storage was estimated and a regional water table increase was reflected by the water budget. Monitoring well water-level trends verify this result.

The water budget components influencing water table changes during the study period were driven by diverse factors. As shown in Figures 4-4 and 4-6, the components of total inflows and outflows varied in magnitude from year to year. Some of the components are driven primarily by natural phenomena and others are driven by human activities. For example, recharge from precipitation is driven primarily by precipitation amounts and soil types, while land use (a human-induced influence) is also a key factor. Other components are highly influenced by human activities such as recharge from recharge ponds. Deliveries to recharge ponds with junior water rights are subject to the call on the river and can occur only when the junior rights are in priority. Because both natural phenomena and human activities influence water budget components from year to year, it is difficult to develop precise relationships among all the components. However, as is described in other conclusions, more generalized relationships and trends do exist.

The water budget and estimated change in the regional water table suggest that a change in the water budget of approximately 5,000 acre-feet (AF) will result in about a 1-foot average change in the regional water table. This relationship is sensitive to the estimated specific yield of the aquifer. A specific yield of 15 percent was used for the purposes of this study.

The regional water budget and relationship between change in aquifer storage and water table elevation reflect total system changes and should be used with caution when evaluating individual and specific problems with high water tables at a local scale, where nearby wells, recharge ponds, ditches, etc., can influence local water table elevations and can have more impact than regional drivers. In addition, local conditions can vary in terms of the combination of drivers impacting the water table and the degree of impact. Local hydrogeologic characteristics and aquifer properties are also important. For example, clay lenses in an aquifer may lead to a perched water table that is higher than the regional groundwater elevation.

Drivers of regional water table change varied during the study period.

As described earlier, the regional water table exhibited an overall decline during WY 2012 but showed an overall increase during both WY 2013 and WY 2014. The water budget components that drove increases in the water table changed during the study period as shown in Figures 5-1 and 5-2 and as described below:

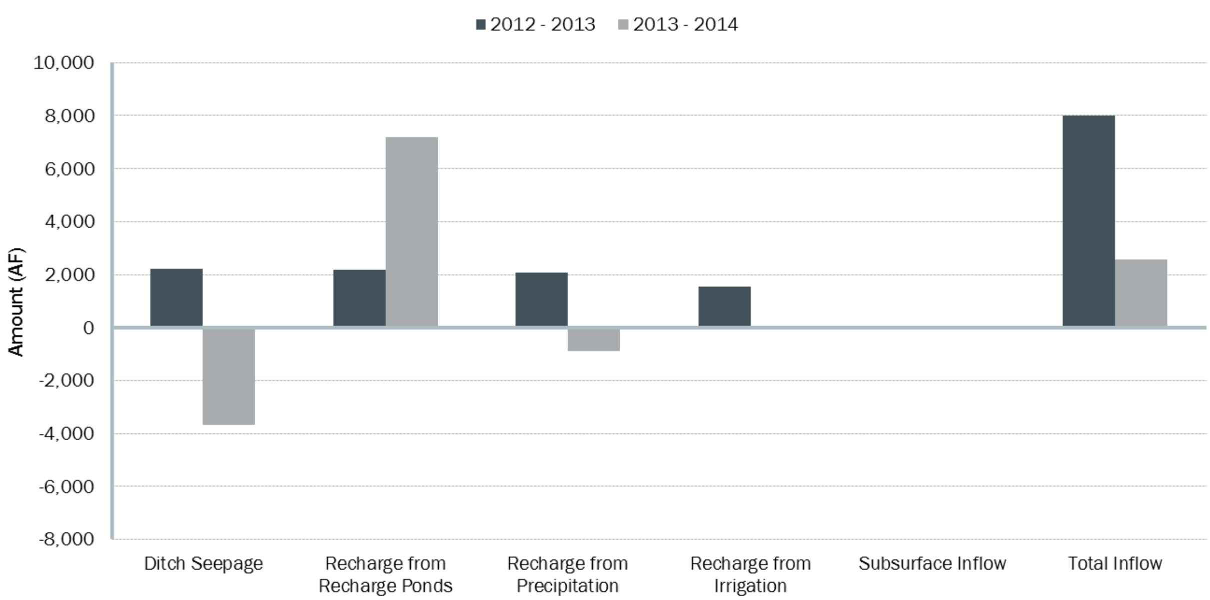

Figure 5-1. Year-to-year change in inflow components: Gilcrest/LaSalle study area

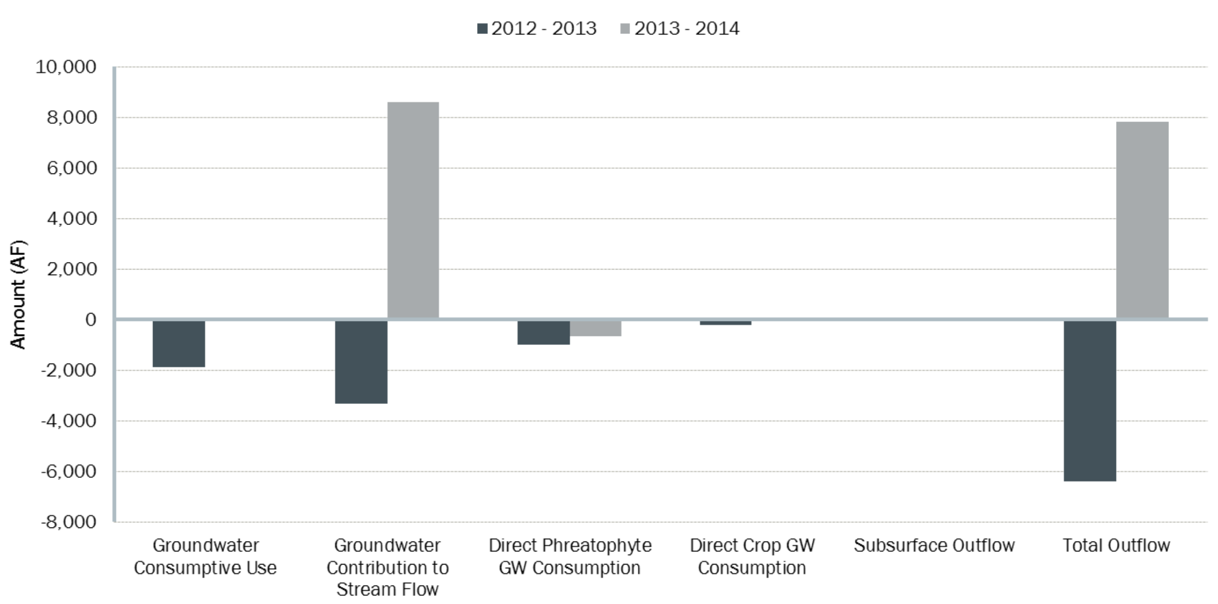

Figure 5-2. Year-to-year change in outflow components: Gilcrest/LaSalle study area

- Change from 2012 to 2013: Figure 5-1 shows the difference in annual 2012 and 2013 totals for the various water budget inflow components, and Figure 5-2 shows the difference for water budget outflow components. In 2013, ditch seepage, recharge from recharge ponds, recharge from precipitation, and recharge from surface water irrigation were all higher than in 2012, and the increases in these components were of very similar magnitudes. Outflows in 2013 were lower than those in 2012 and were driven primarily by reductions in consumptive use of groundwater for irrigation and groundwater contributions to streamflow.
- Change from 2013 to 2014: In WY 2014, the drivers of water table increases shifted. Ditch seepage in 2014 was less than in 2013, but recharge from recharge ponds was higher in 2014 than in 2013. Groundwater contributions to streamflow increased in 2014 relative to 2013, and partially offset the increases in inflow.

The analysis of annual changes in the water budget components illustrates the dynamic nature of water table drivers. During the study period, no single water budget component stands out as a consistent and primary driver of water table change. Rather, the combined effects of the various components tended to drive water table changes.

Rainfall is an important factor.

Rainfall plays a very important role in how the water budget components vary. Certainly, recharge from precipitation is directly influenced by the amount of rainfall that occurs. However, other components such as recharge from recharge ponds, consumptive use of groundwater from irrigation, and recharge from surface water irrigation are all impacted by rainfall. Below are examples of how the various water budget components relate to one another under different rainfall scenarios:

- Wet conditions: During periods of above-average rainfall, aquifer recharge from precipitation is higher. Demands for groundwater irrigation would likely be lower, so less groundwater would be pumped and consumed by irrigated crops. The call regime may allow junior water rights to divert if demand for surface water is lower and/or river flows are high. As a result, deliveries of water to recharge ponds would likely increase. Recharge from surface water irrigation could potentially increase if surface water irrigators with relatively junior water rights can divert longer. However, demand for surface water irrigation would be lower during wetter conditions and could lead to lower amounts of recharge from surface water irrigation if less diversion occurs.

- Dry conditions: Dry conditions drive irrigation demands higher, which potentially result in higher levels of groundwater consumption for irrigation, though pumping quotas limit the amount of groundwater that can be pumped. Recharge from precipitation is lower during dry conditions. Recharge from surface irrigation may increase because of higher irrigation demands. Conversely, recharge from surface irrigation could decrease if conditions are dry enough that relatively junior surface water rights are curtailed. During dry conditions, it is likely that recharge from recharge ponds would decrease given the junior priority of their water rights. However, some augmentation plans in the study area allow recharge of ditch shares in ponds and, therefore, dry-year deliveries of water to recharge ponds could still occur at some level.

In summary, rainfall is an important factor that drives many of the water budget components either directly or indirectly. However, as the above examples show, the relationship of precipitation to various drivers and the relationships among the various drivers are dynamic and can be complicated by factors such as pumping quotas, the call on the river, and other influences that are human-induced and can vary based on surface water availability.

The water budget can be a useful tool for estimating regional changes that could occur based on the various drivers.

The water budget can provide conceptual-level information to help evaluate alternatives for addressing regional high water table issues. The water budget can also provide information on the interrelationships among the water budget components that should be considered. The following scenario illustrates this use of the water budget.

Consider a scenario in which pumping could be increased so that consumptive use of groundwater for irrigation would be increased by approximately 5,000 AF/year in the study area via an increase in augmentation plan quota. This scenario assumes that the streamflow depletions from the increased pumping would be augmented using replacement sources that do not include additional recharge from recharge ponds in the study area. As a result of the increased pumping, it is possible that less surface water would be needed on average to provide for irrigation needs in the study area. Assuming that 5,000 AF less surface water is needed for crop consumptive use, there would also be a reduction in the recharge from surface water irrigation and ditch seepage loss components of the water budget. If on-farm irrigation efficiency is around 70 percent on average, approximately 7,100 AF of surface water would need to be provided at the farm headgate (5,000 AF of CU divided by 70 percent irrigation efficiency); therefore, 2,100 AF less recharge of surface water irrigation would occur (7,100 AF farm headgate delivery less 5000 AF crop CU). Further, if ditch conveyance efficiency is around 75 percent, then approximately 9,500 AF of surface water would have been diverted at the river headgate (7,100 AF divided by 75 percent conveyance efficiency). Without this diversion, there would be 2,400 AF less ditch seepage (9,500 diversion less 7,100 AF farm headgate delivery), which, when combined with the 2,100 AF less irrigation recharge, results in 4,500 AF less inflow in the water budget due to the reduction in surface water diversion.

In summary, by increasing consumptive use of groundwater by 5,000 AF and reducing the surface water diversion that would have met that irrigation demand, the total reduction in storage in the water budget would be around 9,500 AF/year (5,000 AF more outflow due to CU of groundwater plus 4,500 less inflow due to less surface water diversion). This in turn, using a specific yield of 15 percent would result in around a 2-foot reduction in the regional water table. Again, this scenario assumes that the other components of the water budget do not change.

In another example scenario, perhaps conveyance efficiencies could be improved by lining either ditches or earthen laterals with a goal of reducing ditch seepage by 5,000 AF/year. Note that ditches or sections of ditches used as recharge structures would likely not be good candidates for efficiency improvements. If ditch seepage losses were reduced by 5,000 AF/year, then a 1-foot reduction in average regional water table elevation could potentially be achieved. It is possible that reductions in the water table would vary spatially with higher reductions in the immediate vicinity of lined ditches and less reduction in areas that are not near lined ditches or in areas near ditches that are not lined.

Local topographic and geologic characteristics can make some areas more vulnerable to high groundwater problems than others.

The Town of Gilcrest is located in a topographically low area and above a likely paleo-channel (Barkmann et al, 2014). The water table near Gilcrest generally slopes down to the northwest toward the South Platte River. If the water table beneath the town rises, the topographically low areas are likely be the first to experience high water table problems. Figure 5-3 illustrates this issue.

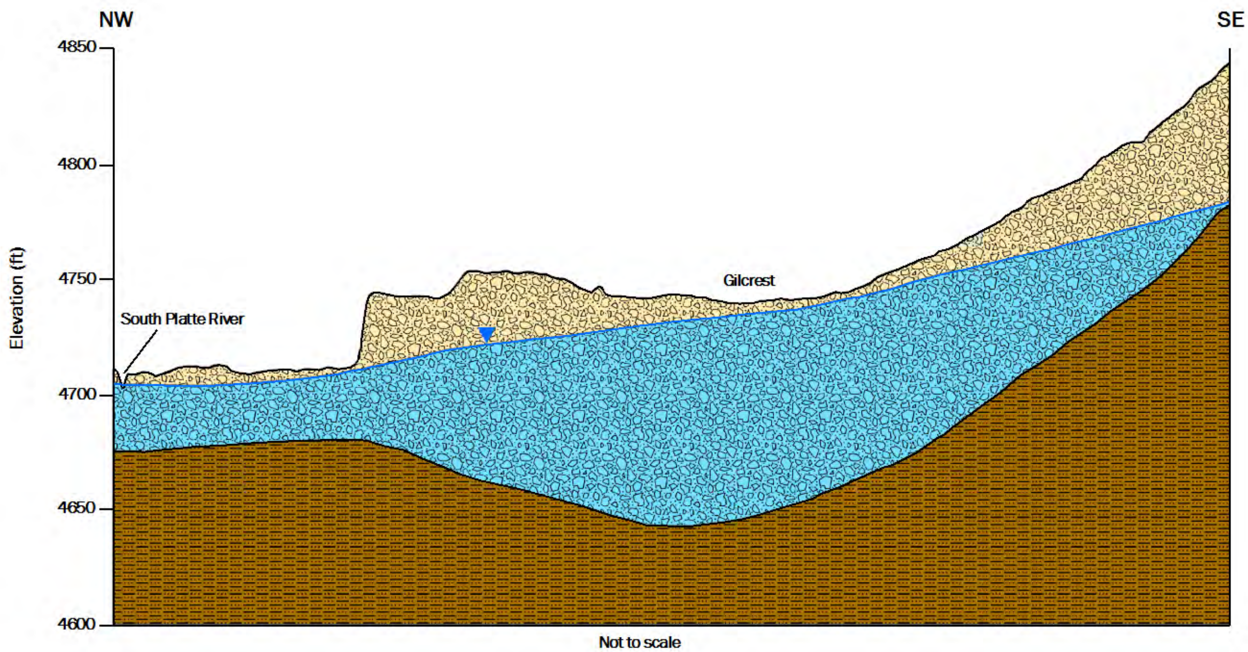

Figure 5-3. Subsurface profile at Gilcrest

The location of the cross-section line is shown on Figure 3-1.

5.1.2 Sterling Study Area

Based on the results of the water budget analysis, the regional water table during the study period responded to the balance of total inflows and outflows.

Figures 4-18 and 4-19 show that the water budget analysis estimated changes in the regional water table that reflected monitoring well water level data. While water levels in some monitoring wells did not show obvious correlation to the regional water budget, many did, and these closely mimicked changes predicted by the study area water budget based on changes in aquifer inflows and outflows during the study period. The monitoring wells that did not show an obvious correlation to the regional water budget were likely influenced significantly by local drivers such as nearby ditches or recharge ponds or by heterogeneity in local hydrogeologic characteristics.

The regional water budget and water table elevations responded to the balance of aquifer inflows and outflows during the study period:

- Water levels in monitoring wells in the Pawnee Ridge and Country Club Hills areas that mimic the estimated regional changes in water table were at their lowest level during the study period in WY 2012. As shown in Figure 4-17, total aquifer outflows were greater than aquifer inflows in 2012, resulting in a net loss of water stored in the aquifer. The net loss in water stored in the aquifer was reflected in lower water table elevations in monitoring wells.
- In WY 2013, inflows and outflows were approximately the same. In a corresponding manner, the water budget predicted similar water levels at the end of both 2012 and 2013 (with seasonal changes in between). Many of the monitoring wells showed a slight overall increase in water level from the end of 2012 to 2013. However, the water budget showed trends that were very similar to water levels in monitoring wells during the period between the end of 2012 and 2013.
- Overall inflows were greater than outflows during WY 2014. The resulting increase in the water table reflected by the water budget was shown in monitoring well water levels. The magnitude and pattern of water table increase reflected by the water budget were very similar to the patterns exhibited in monitoring wells that follow regional trends.

As shown in Figure 4-13, ditch seepage contributed the majority of inflow to the alluvial aquifer in the study area during the study period. The most significant outflow component, other than subsurface outflow, was consumptive use of groundwater for irrigation.

Water levels in Country Club Hills and Pawnee Ridge monitoring wells respond to different drivers depending on location and local hydrogeologic characteristics.

Monitoring well hydrographs in the Country Club Hills and Pawnee Ridge subdivisions show a variety of patterns (see Figure 5-4 for the locations of these wells). Some hydrographs appear to mimic seasonal rises and falls in the regional water table. Other hydrographs show abrupt changes that could be driven by local structures such as recharge ponds or ditches.

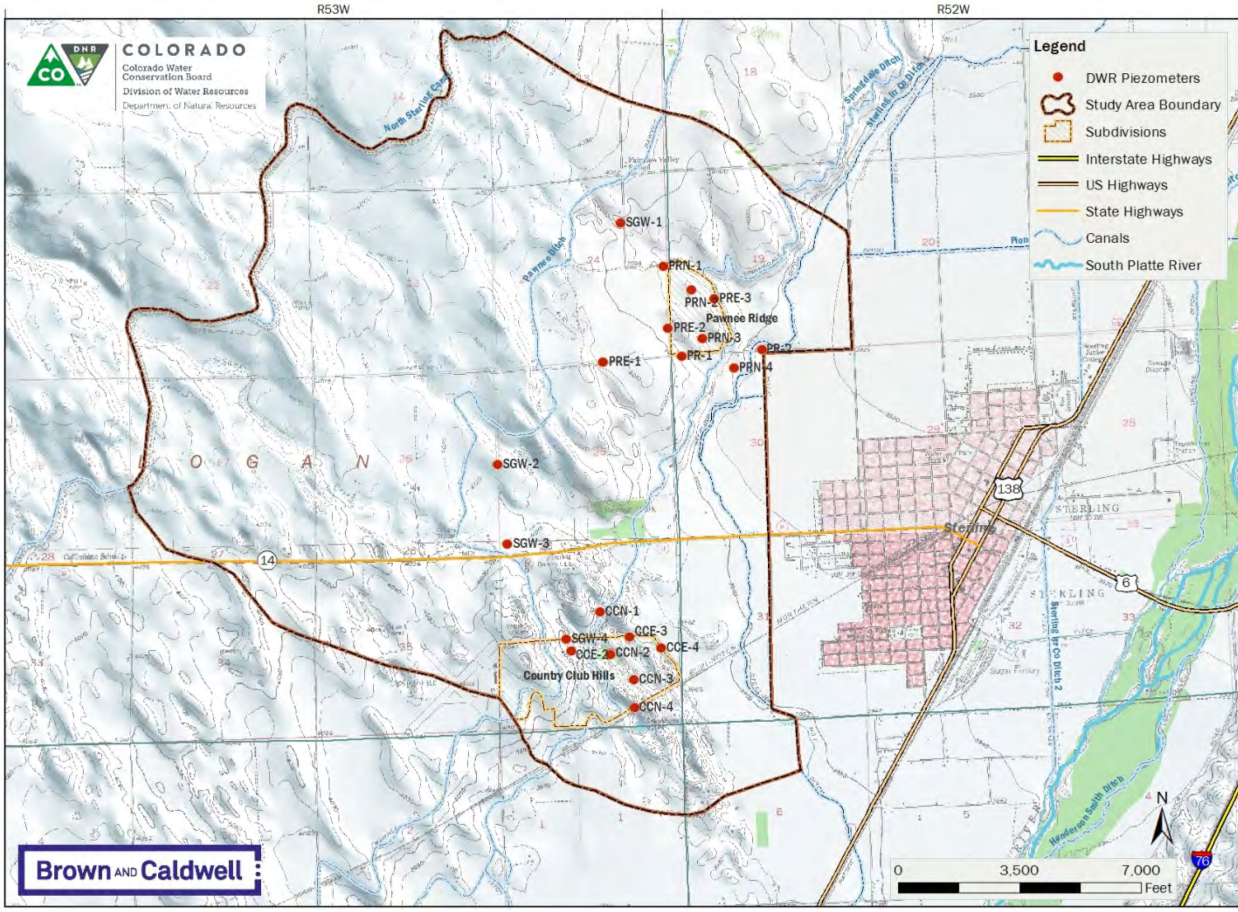

Figure 5-4. DWR piezometer locations: Sterling study area

Hydrographs for monitoring wells located within the Country Club Hills and Pawnee Ridge subdivisions were plotted alongside monthly ditch diversions, recharge pond deliveries, and precipitation amounts to visually investigate water level patterns in wells that seem to mimic hydrologic drivers. The hydrographs and monthly amounts of diversion, recharge pond delivery, and precipitation are shown in Appendix C.

Water level data for each of the monitoring wells were shown as the water table elevation above mean sea level. In spring 2015, CWCB surveyed the monitoring wells in the subdivisions so that more precise evaluations of relative water elevations could be conducted.

General observations from the hydrographs are described below for each subdivision. It should be noted that water levels in monitoring wells can sometimes be influenced by very localized hydrogeologic conditions, well depth and construction characteristics, etc., and that some of the observations below could potentially be affected by these types of considerations. Note that some of the monitoring well locations included nested wells completed at different depths within the alluvium, and the nested wells demonstrated some vertical differences in groundwater levels likely due to local geologic variation. The differences in groundwater levels in the nested wells generally indicate a downward gradient.

5.1.2.1 Country Club Hills

The following general observations from the hydrographs were made for the Country Club Hills subdivision:

- Water levels in wells with the CCN designation were at similar elevations during the study period, but they exhibited differing patterns, as described below:
    - Water levels in CCN-1 and CCN-4 showed abrupt changes during certain times.
    - Most of the time, the water level in CCN-4 was the highest and CCN-1 was the lowest of the CCN wells.
    - The water level in CCN-2 was generally slightly higher than CCN-1 and CCN-3, but not always. Well CCN-2 is located between wells CCN-1 and CCN-3.
- Water levels in wells with the CCE designation were at different elevations during the study period. The westernmost CCE well was highest and the easternmost CCE well was the lowest, suggesting generally west-to-east groundwater flow directions. Water levels in the CCE wells did not exhibit abrupt changes during the study period.
- Visual inspection of the hydrographs and monthly values of ditch diversions, recharge pond deliveries, and precipitation suggest some correlations. For example, water levels in CCN-4 appear to react to recharge deliveries to the Schuman and Country Club Hills recharge ponds (which is expected given the location of the CCN-4 well). Water levels in CCN-1, which is located right beside the Springdale Ditch, appear to respond to Springdale Ditch diversion patterns.
- Many hydrographs show fluctuating water levels throughout the study period, but it is difficult to draw conclusions regarding the specific driver of fluctuation based solely on visual inspection.
- A relatively abrupt and large water level increase in spring 2014 was observed in wells CCN-1 and CCN-2, and somewhat in CCE-3. The water level increase occurred during a period when the Springdale Ditch experienced a blockage just to the north (or down-gradient on the ditch) of these wells. It is possible that abnormally high water levels in the ditch due to the blockage (the ditch did not breach) led to increased seepage that in turn increased water levels in the monitoring wells.

5.1.2.2 Pawnee Ridge

The following general observations from the hydrographs were made for the Pawnee Ridge subdivision:

- Water levels in three of the wells with the PRN designation showed an very high level of similarity during the study period, and one of the wells showed a much different pattern, as described below:
    - Water levels in wells PRN-1, PRN-2, and PRN-3 were at nearly identical levels throughout the study period.
    - The water level in well PRN-4 was approximately 40 feet lower than the water level in the other PRN wells, and the water level in this well showed fluctuations that appeared to mimic diversions in the Springdale and Sterling No. 1 ditches. This well is between these two ditches at a location where the ditches are close to one another.
- Water levels in wells with the PRE designation were at different elevations during the study period. The westernmost PRE well was highest and the easternmost PRE well was the lowest, suggesting a west-to-east groundwater flow direction. Water levels in the PRE-1 well exhibited somewhat abrupt changes periodically, while water levels in wells PRE-2 and PRE-3 did not.
- Water levels in wells with the PR designation were at different elevations. Water levels in PR-1 were around 50 feet higher than in PR-2, indicating an easterly groundwater flow direction.

  - Water levels in PR-2 appear to mimic the seasonal patterns of diversions in the Sterling No. 1 Ditch.
  - Water levels in PR-1 do not exhibit abrupt changes.
- Water levels in PRE-3 were relatively steady through the study period and showed only 1 or 2 feet of fluctuation. It is located very close to the Springdale Ditch, on the up-gradient side, but did not appear to fluctuate in response to flows in the ditch. The water level in PRE-3 was approximately 10 feet lower than that in PRN-2 and PRN-3, which suggests that the water table in the eastern side of the Pawnee Ridge development slopes to the east.
- Water levels in wells PRE-2 and PR-1 mimicked the patterns of change (though slight) in wells PRN-2 and PRN-3. However, the water levels in PRE-2 and PR-1 were only slightly higher (1 to 2 feet) than those in PRN-2 and PRN-3. These patterns suggest that groundwater in the western half of the Pawnee Ridge subdivision may be impacted by a bedrock high that reduces the alluvial aquifer thickness and potentially restricts the west-to-east flow of groundwater.

5.1.2.3 Statistical Analysis

As described above, visual inspection of the hydrographs and monthly ditch diversions, recharge deliveries, and precipitation amounts revealed some apparent correlations, but they were not conclusive. A statistical analysis was conducted to evaluate potential correlations between water levels in wells and the various potential drivers of groundwater level change.

The Kendall rank correlation test was used to identify correlations among water levels in monitoring wells and the various potential drivers of water level change. The Kendall rank correlation test is non-parametric, and it measures how strongly two variables depend on one another. In addition, the analysis evaluated whether the correlations among variables were statistically significant.

Statistical analyses were conducted for the group of monitoring wells and local hydrologic drivers in both the Country Club Hills and Pawnee Ridge subdivisions. The results of the statistical analyses and observations regarding each analysis are described below for each subdivision.

5.1.2.3.1 Country Club Hills

Table 5-1 is a matrix showing the relative strength of statistical correlations among water levels in monitoring wells, monthly diversion totals for the Pawnee and Springdale Ditches, recharge deliveries to the A. Fritzler Pond and combined deliveries to the Schuman and Country Club Hills Ponds, precipitation, and regional water level changes estimated by the water budget. Notes on the data in Table 5-1 are below. Observations on the data are included below Table 5-1.

- The Kendall's Tau Correlation Coefficient measures the strength of dependence between two variables. As the Tau value approaches 1.0, direct correlations strengthen (i.e., as the value of one variable increases, the value of the other variable tends to increase as well). As the Tau value approaches -1.0, inverse correlations strengthen (i.e., as the value of one variable increases, the value of the other variable tends to decrease).
- Cells in Table 5-1 colored in light blue indicate that a statistically significant correlation was found (at 95 percent confidence) between variables.
- Cells in Table 5-1 colored in dark blue indicate that a statistically significant correlation was found between variables and the correlation was relatively strong (Tau > 0.5).
- The monitoring well data and changes in water levels estimated using the water budget were in terms of depth to water below ground surface. Therefore, as the water table rises, the depth to water measured at monitoring wells decreases. As a result, if water levels in a monitoring well rise because, for example, ditch seepage or recharge deliveries are occurring, then the

correlation will be negative (i.e., depth to groundwater decreases as a result of increases in another parameter like ditch seepage).

Table 5-1. Country Club Hills Correlation Matrix

	CCN-1	CCN-2	CCN-3	CCN-4	CCE-2	CCE-3	CCE-4
CCN-1	1						
CCN-2	0.646	1					
CCN-3	0.407	0.743	1				
CCN-4	0.375	0.333	0.186	1			
CCE-2	-0.228	-0.103	0.090	-0.320	1		
CCE-3	0.503	0.775	0.802	0.172	0.057	1	
CCE-4	0.255	0.425	0.600	-0.094	0.324	0.623	1
Pawnee Ditch	-0.140	-0.338	-0.476	0.099	-0.200	-0.352	-0.398
Springdale Ditch	-0.522	-0.453	-0.297	-0.264	0.145	-0.310	-0.163
Sum of Schuman and Country Club Hills Ponds	-0.287	-0.172	-0.085	-0.586	-0.237	-0.103	0.002
A. Fritzler Pond	-0.232	0.011	0.209	-0.444	0.062	0.113	0.195
Recharge from Precipitation (AF)	-0.140	-0.384	-0.531	-0.011	0.002	-0.434	-0.361
Water Budget Estimated Water Level	0.430	0.407	0.333	0.329	-0.007	0.411	0.182

Dark blue shading indicates relatively strong statistically significant correlations; light blue indicates correlations that are statically significant but less so than dark blue shaded cells. Cells without shading indicate no statistically significant correlation.

- Pawnee Ditch diversions showed a statistically significant correlation with water level changes in monitoring wells CCN-2, CCN-3, CCE-3, and CCE-4, though the correlations were of moderate strength. It is possible that the correlation results from seasonal similarities in general timing of ditch diversions and patterns in water level decline and fall.
- Springdale Ditch diversions showed a statistically significant correlation with water level changes in monitoring wells CCN-1, CCN-2, CCN-3, CCN-4, and CCE-3. The strongest correlation to Springdale Ditch diversions was in CCN-1, which is sited alongside the Springdale Ditch on the up-gradient side. The other monitoring wells are also in relatively close proximity and are just down-gradient from the ditch, though the strength of their correlation is not as great as CCN-1 and is similar to correlations with the Pawnee Ditch.
- The Schuman and Country Club Hills recharge ponds showed a strong correlation to monitoring well CCN-4, which is located just north of ponds. Recharge from those ponds also showed a statistically significant correlation to well CCN-1 (though relatively weak), but it is likely that the

correlation occurs because the ponds are filled from the Springdale Ditch and CCN-1 is located right beside the Springdale Ditch.

- The A. Fritzler pond showed a statistically significant correlation only to monitoring well CCN-4, the well located closest to the pond.
- Water levels in several monitoring wells showed statistically significant correlations to recharge from precipitation. Well CCN-3 showed a relatively strong correlation, and monitoring wells CCN-2, CCE-3, and CCE4 showed moderately strong correlations. All of these wells are sited near low points in the topography of Country Club Hills or near wetlands. It is very possible that recharge occurring from the concentration of runoff after storm events (either in a wetland or a drainage way) contributes to the correlations observed in the data.
- Water level changes in several monitoring wells, including CCN-1, CCN-2, CCN-3, CCN-4, and CCE-3, showed statistically significant correlations to regional water level changes estimated using the water budget.
- Water level changes in most of the monitoring wells were correlated to changes in other monitoring wells. Some of the correlations were stronger than others. On the contrary, water levels in CCE-2 were not strongly correlated to other monitoring wells or any of the hydrologic drivers included in the analysis. This is potentially due to more influence from the Pawnee Ditch compared to the other Country Club Hills wells.
- In summary, the statistical analysis suggests that several drivers influence water levels in many of the monitoring wells in the Country Club Hills subdivision. Monitoring wells with the strongest correlations to hydrologic drivers are as follows:
  - CCN-1 and Springdale Ditch diversions
  - CCN-4 and the sum of recharge deliveries to the Schuman and Country Club Hills ponds
  - CCN-3 and recharge from precipitation

5.1.2.3.2 Pawnee Ridge

Table 5-2 is a matrix showing the relative strength of correlations among water levels in monitoring wells; monthly diversion totals for the Pawnee, Springdale, and Sterling No. 1 ditches; recharge deliveries to the Lebsock East, Lebsock West, and Monahan ponds; precipitation recharge; and regional water level changes estimated by the water budget. The explanation of Kendall's Tau, table formatting, and sign conventions in Section 5.1.2.3.1 for Country Club Hills are also applicable to the data in Table 5-2 below. Observations on the data are included following Table 5-2.

Table 5-2. Pawnee Ridge Correlation Matrix

	PRN-1	PRN-2	PRN-3	PRN-4	PRE-1	PRE-2	PRE-3	PR-1	PR-2
PRN-1	1								
PRN-2	0.775	1							
PRN-3	0.720	0.862	1						
PRN-4	0.223	0.067	0.085	1					
PRE-1	0.595	0.678	0.697	0.085	1				
PRE-2	0.683	0.784	0.793	0.126	0.802	1			
PRE-3	0.660	0.743	0.789	0.039	0.697	0.710	1		
PR-1	0.687	0.807	0.844	0.067	0.825	0.894	0.770	1	
PR-2	0.237	0.117	0.126	0.830	0.080	0.177	0.071	0.117	1
Pawnee Ditch	-0.108	-0.007	-0.053	-0.683	-0.071	-0.067	-0.007	-0.025	-0.678
Springdale Ditch	-0.195	-0.067	-0.067	-0.329	-0.076	-0.071	-0.159	-0.067	-0.251
Sterling No.1 Ditch	-0.071	0.094	0.039	-0.664	-0.007	-0.048	0.025	0.021	-0.628
Lebsock West	-0.168	-0.237	-0.264	-0.136	-0.398	-0.310	-0.338	-0.329	-0.071
Lebsock East	-0.287	-0.352	-0.356	-0.080	-0.568	-0.416	-0.379	-0.416	-0.021
Monahan	-0.301	-0.366	-0.352	-0.094	-0.526	-0.384	-0.384	-0.393	-0.044
Recharge from Precipitation (AF)	-0.255	-0.274	-0.237	-0.453	-0.255	-0.269	-0.283	-0.228	-0.476
Water Budget Estimated Water Level	0.664	0.554	0.582	0.099	0.637	0.577	0.618	0.600	0.067

Dark blue shading indicates relatively strong statistically significant correlations; light blue indicates correlations that are statically significant but less so than dark blue shaded cells. Cells without shading indicate no statistically significant correlation.

- Pawnee Ditch diversions showed a statistically significant correlation with water level changes in monitoring wells PRN-4 and PR-2. It is likely that, given the distance between the Pawnee Ditch and these monitoring wells, the correlation results from seasonal similarities in general timing of ditch diversions and patterns in water level decline and fall.
- Springdale Ditch diversions showed a statistically significant correlation only to water levels in PRN-4, which is located just west of the Springdale Ditch.
- Sterling No. 1 Ditch diversions showed a statistically significant correlation to water levels in PRN-4 and PR-2, which are located very near the ditch.

- The Lebsock West pond showed statistically significant correlations to water levels in several monitoring wells including PRN-3, PRE-1, PRE-2, PRE-3, and PR-1 though the correlations were somewhat weak to moderate.
- The Lebsock East pond showed statistically significant correlations to water levels in the same wells as the Lebsock West ponds but also PRN-1 and PRN-2. The correlation with water levels in PRE-1 was fairly strong and likely due to the monitoring well's close location to the north of the pond.
- The Monahan pond showed a very similar set of correlations as the Lebsock East pond.
- Recharge from precipitation showed statistically significant correlations to water levels in several monitoring wells including PRN-1, PRN-2, PRN-4, PRE-1, PRE-2, PRE-3, and PR-2 though the correlations were somewhat weak to moderate.
- Water levels in several monitoring wells, including PRN-1, PRN-2, PRN-3, PRE-1, PRE-2, PRE-3, and PR-1, showed strong and statistically significant correlations to estimated regional water level changes from the water budget. All of the wells that exhibited this strong correlation were west and up-gradient of the Springdale and Sterling No. 1 ditches.
- All of the monitoring wells west and up-gradient of the Springdale and Sterling No. 1 ditches showed strong correlations with one another and with regional water level changes estimated by the water budget.

Local topographic and geologic characteristics can make some areas more vulnerable to high groundwater problems than others.

The topography of the Country Club Hills subdivision is rolling and varied. The monitoring well data acquired during the study period suggest that the water table is somewhat planar and slopes to the east, though ditches and recharge ponds can sometimes create local high points. If the water table beneath the subdivision rises, lower areas in the rolling topography in the subdivision would likely be the first to experience high water table problems. Figure 5-5 illustrates this issue.

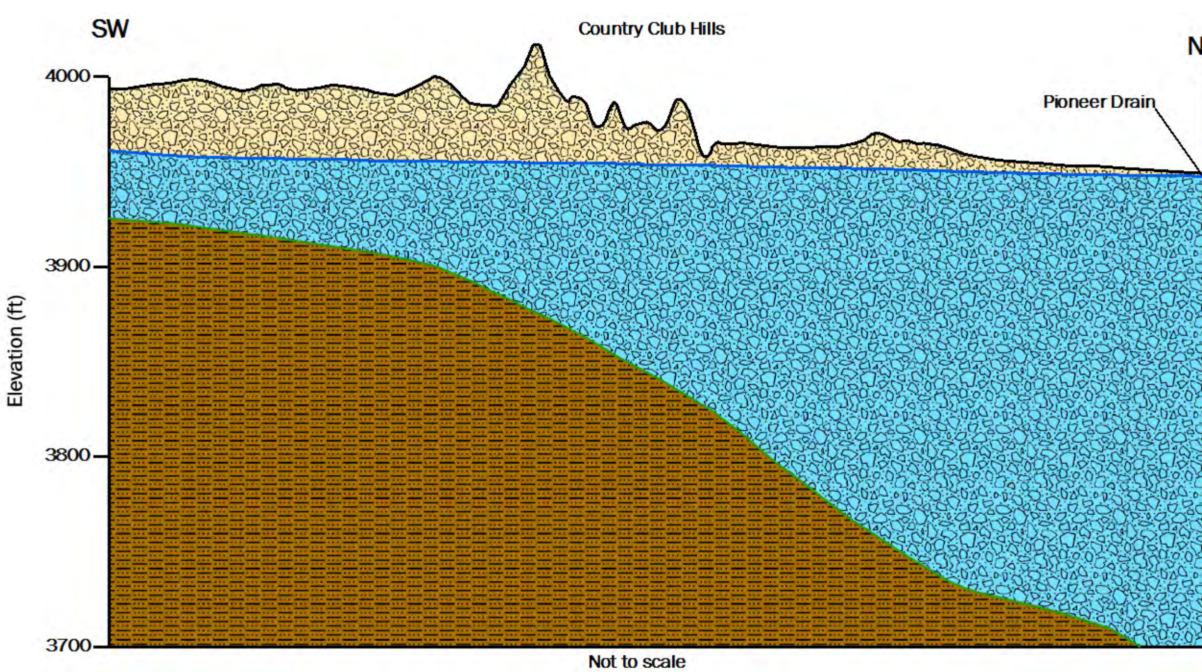

Figure 5-5. Subsurface profile at Country Club Hills

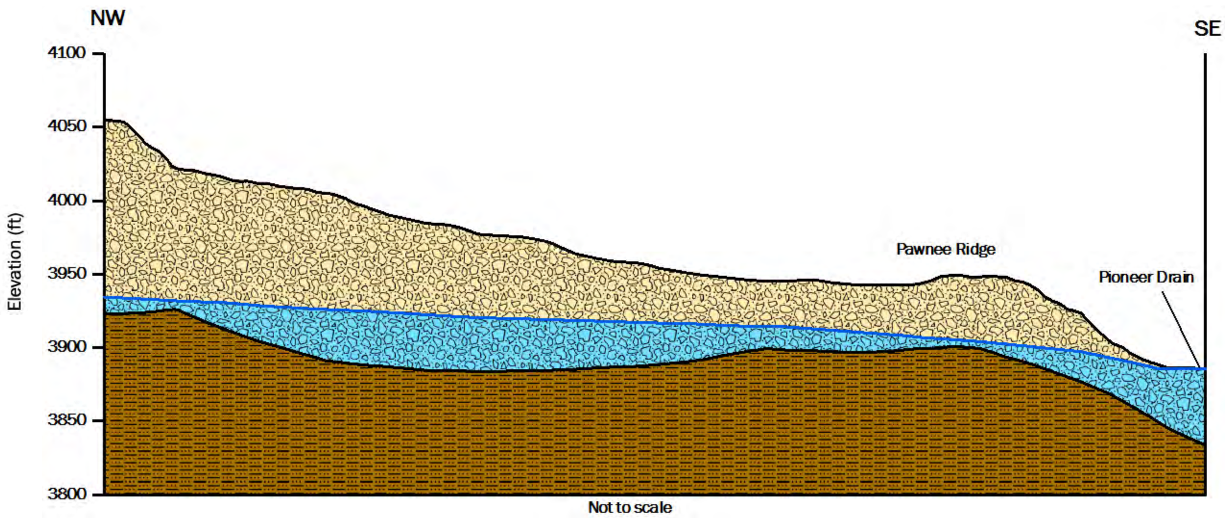

Figure 5-6. Subsurface profile at Pawnee Ridge

The locations of the cross-sections for Country Club Hills and Pawnee Ridge are shown on Figure 3-2.

5.2 Recommendations

This section presents the recommendations resulting from this groundwater analysis for the Gilcrest/LaSalle and Sterling study areas.

5.2.1 Gilcrest/LaSalle Study Area

The following are recommendations with respect to the Gilcrest/LaSalle study area:

- The water budget should be maintained and should continue to be monitored. The water budget developed for the purposes of this study was very successful in reflecting general changes in the regional water table compared to observed water levels in monitoring wells. Given the relatively short study period, additional years of data input, water budget computation, and subsequent comparisons of estimated versus actual water table changes will help to verify, and potentially improve, the performance of the water budget.
- Conceptual water management scenarios for addressing regional water table issues in the Gilcrest/LaSalle study area could be developed using the water budget. These scenarios should be developed carefully to ensure that the relationships among water budget components are properly addressed. For example, changes in groundwater pumping regimes will likely impact ditch diversions, seepage amounts, and recharge from surface water irrigation.
  - Groundwater modeling should be used to refine water management scenarios and evaluate local impacts that may not be evident from the water budget alone.
- Stakeholders have expressed interest in extending the time period of the water budget to earlier years, especially years when water management practices in the study area were different. This extended budget time period could be a useful exercise that could increase our understanding of the magnitude and timing of water budget drivers during times when water table issues were not as severe. It should be noted that the SPDSS Alluvial Groundwater Model, once updated, could be a useful tool for this exercise.
- Local efforts to provide dewatering and relief from high water table issues should continue. When dewatering efforts are initiated, as much data from monitoring wells, well discharge data, etc., as possible should be collected to better evaluate local aquifer conditions and the

performance of dewatering efforts. These evaluations could be performed with two methods: analytically with traditional aquifer test analysis methods; and numerically with the SPDSS Alluvial Groundwater Model. Additionally, any existing drainage ditches or other structures (such as the Big Bend Drain) should be cleaned and maintained to maximize drainage of excess shallow groundwater.

5.2.2 Sterling Study Area

The following are recommendations with respect to the Sterling study area:

- The water budget should be maintained and should continue to be monitored. Given the relatively short study period, additional years of data input, water budget computation, and subsequent comparisons of estimated versus actual water table changes will help to verify, and potentially improve, the performance of the water budget. Extending the time period of the water budget to earlier could also increase our understanding of the water budget drivers.
- Reported problems with high water tables in the Country Club Hills and Pawnee Ridge subdivisions have been focused on a few specific locations, some of which may be particularly vulnerable to high water table issues because of topographic or geologic conditions. Local dewatering efforts for affected properties that have been proposed in the past could be effective in mitigating specific problems.
- The existing monitoring wells in the Country Club Hills and Pawnee Ridge subdivisions should continue to be maintained and water levels in these wells should continue to be measured and recorded. This will be especially important if dewatering or other mitigation projects are undertaken so that the effectiveness of these measures can be evaluated. The water level measurements could also be useful to local homeowners in tracking either upward or downward trends and potentially mitigating high water table issues before they become a problem.
- The Pioneer Drain should be cleaned and maintained to allow maximum drainage of excess shallow groundwater through this existing structure.
- Additional investigations into the characteristics of the base of the shallow aquifer in the Pawnee Ridge subdivision should be conducted to evaluate the significance of the rise in high water table issues in this area.

Section 6

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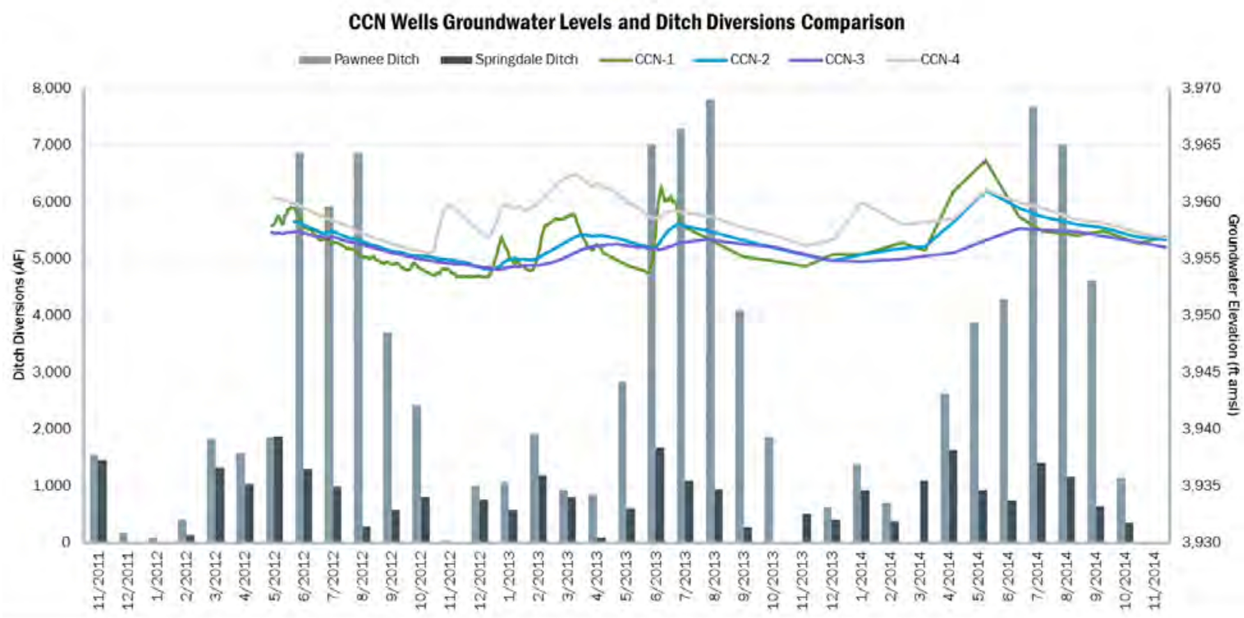
Appendix A: Gilcrest/LaSalle Study Area Water Budget

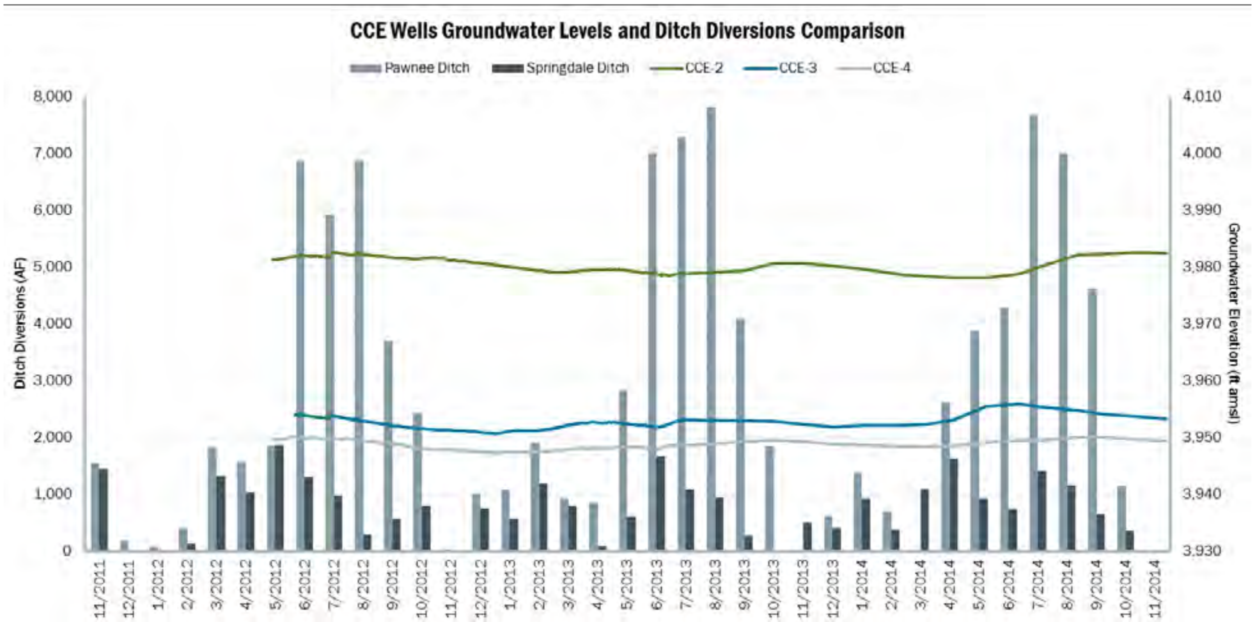
GILCREST	Inflow (all values in acre-feet)						Outflow (all values in ac-ft)						ΔS (ac-ft)
Month	Ditch Seepage	Recharge from Recharge Ponds	Recharge from Precipitation	Recharge from Irrigation	Subsurface Inflow	**Total Inflow**	Groundwater Consumptive Use from Pumping	Groundwater Contribution to Streamflow	Direct Phreatophyte GW Consumption	Direct Crop GW Consumption	Subsurface Outflow	**Total Outflow**	Change in Storage
Nov-11	104	89	55	0	1,328	1,577	11	4,033	0	0	579	4,624	-3,047
Dec-11	2	0	42	0	1,367	1,411	0	3,602	0	0	597	4,199	-2,788
Jan-12	96	38	6	0	1,371	1,511	58	3,045	0	0	598	3,701	-2,191
Feb-12	30	0	39	0	1,237	1,306	59	2,451	0	0	541	3,051	-1,745
Mar-12	521	25	4	0	1,369	1,920	131	3,175	0	55	599	3,959	-2,039
Apr-12	2,168	43	261	3,202	1,337	7,012	261	3,967	104	142	580	5,054	1,958
May-12	2,306	67	388	3,815	1,393	7,969	206	4,244	381	162	596	5,590	2,379
Jun-12	2,340	215	174	3,036	1,353	7,118	266	4,471	893	235	577	6,442	676
Jul-12	2,930	154	532	3,669	1,403	8,688	760	5,147	713	219	606	7,446	1,242
Aug-12	2,668	152	289	3,725	1,403	8,236	1,146	6,216	662	172	610	8,806	-570
Sep-12	2,132	8	658	3,654	1,349	7,802	642	5,304	375	136	589	7,047	755
Oct-12	1,715	5	354	2,308	1,384	5,765	208	5,354	0	67	604	6,232	-468
Nov-12	596	0	38	0	1,328	1,962	88	3,117	0	0	579	3,785	-1,822
Dec-12	196	0	24	0	1,367	1,587	24	2,643	0	0	597	3,264	-1,677
Jan-13	505	0	17	0	1,371	1,892	16	3,859	0	0	598	4,473	-2,581
Feb-13	988	0	59	0	1,237	2,284	31	4,335	0	0	541	4,906	-2,622
Mar-13	668	0	75	0	1,369	2,112	41	3,569	0	0	599	4,209	-2,097
Apr-13	525	15	596	660	1,337	3,134	26	2,303	0	29	580	2,938	196
May-13	2,032	71	460	3,724	1,393	7,680	92	3,316	175	157	596	4,337	3,343
Jun-13	3,316	240	311	6,013	1,353	11,232	226	4,757	623	218	577	6,401	4,831
Jul-13	3,560	347	372	6,281	1,403	11,963	404	5,824	649	195	606	7,678	4,285
Aug-13	3,085	378	507	5,318	1,403	10,690	683	6,520	578	173	610	8,564	2,126
Sep-13	2,021	932	2,073	2,305	1,349	8,680	134	4,765	106	138	589	5,733	2,947
Oct-13	1,725	998	339	651	1,384	5,098	96	2,699	0	57	604	3,456	1,641
Nov-13	300	1,296	25	0	1,328	2,949	3	2,770	0	0	579	3,353	-403
Dec-13	95	31	37	0	1,367	1,530	8	2,840	0	0	597	3,445	-1,914
Jan-14	133	138	93	0	1,371	1,735	4	2,556	0	0	598	3,159	-1,425
Feb-14	166	436	28	0	1,237	1,866	33	3,132	0	0	541	3,705	-1,839
Mar-14	521	1,252	90	0	1,369	3,233	103	4,232	0	0	599	4,933	-1,700
Apr-14	1,645	1,117	221	2,448	1,337	6,769	0	3,049	0	95	580	3,724	3,045
May-14	1,727	987	1,122	3,484	1,393	8,713	134	3,529	0	145	596	4,404	4,309
Jun-14	2,140	1,307	498	4,027	1,353	9,326	143	6,484	370	189	577	7,763	1,562
Jul-14	3,366	493	965	6,156	1,403	12,383	404	6,919	515	186	606	8,629	3,754
Aug-14	3,075	961	220	5,436	1,403	11,094	292	7,505	528	112	610	9,047	2,047
Sep-14	1,710	1,118	433	2,768	1,349	7,379	536	7,172	55	113	589	8,465	-1,085
Oct-14	663	1,022	250	581	1,384	3,900	139	6,133	0	84	604	6,960	-3,059

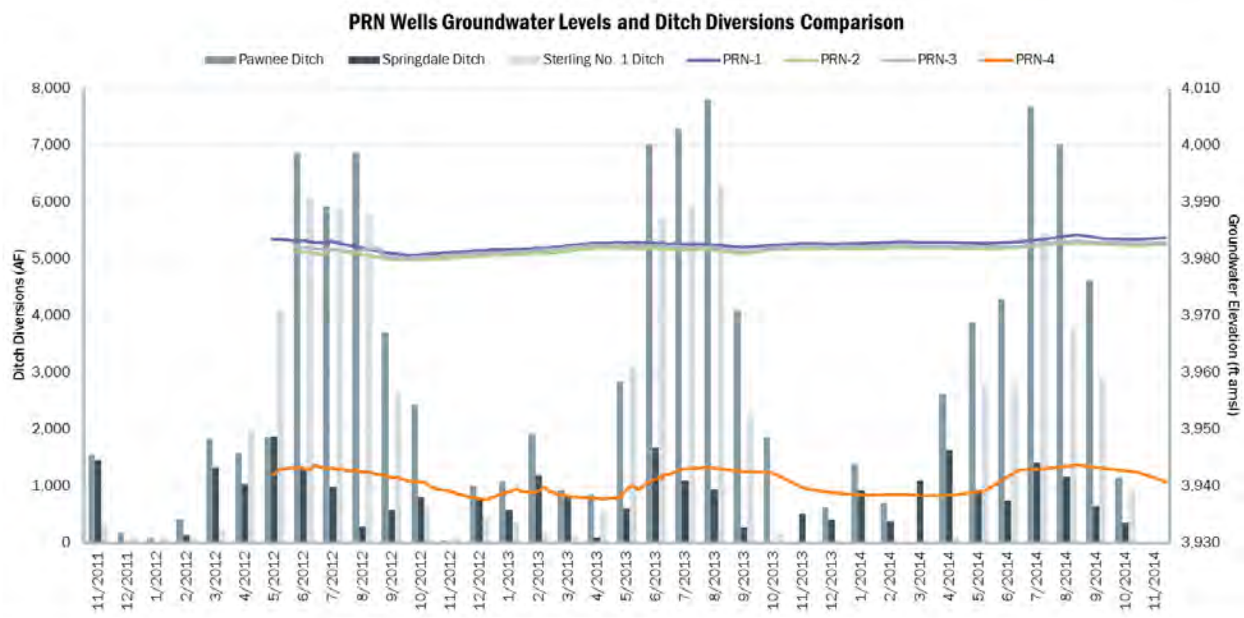
Appendix B: Sterling Study Area Water Budget

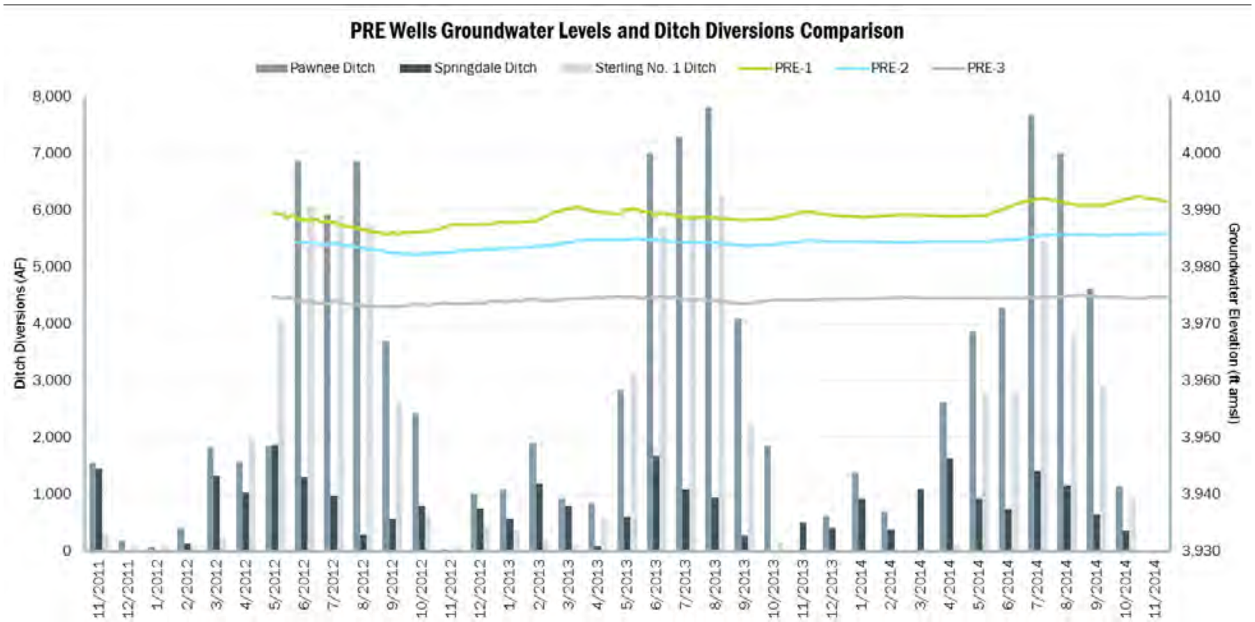
STERLING	Inflow (all values in acre-feet)						Outflow (all values in acre-feet)					ΔS (ac-ft)
Month	Ditch Seepage	Recharge from Recharge Ponds	Recharge from Precipitation	Recharge from Irrigation	Subsurface Inflow	Total Inflow	Groundwater Consumptive Use from Pumping	Direct Phreatophyte GW Consumption	Direct Crop GW Consumption	Subsurface Outflow	Total Outflow	Change in Storage
Nov-11	917	121	5	0	35	1,078	71	0	0	668	740	338
Dec-11	264	42	4	0	37	346	53	0	0	692	746	-399
Jan-12	5	0	2	0	37	44	39	0	0	695	734	-690
Feb-12	43	28	11	0	33	116	17	0	0	628	645	-529
Mar-12	519	236	4	0	37	796	51	0	0	696	747	49
Apr-12	419	35	35	45	36	569	180	0	5	673	859	-290
May-12	383	10	27	92	37	549	361	14	8	695	1,078	-529
Jun-12	550	0	13	172	36	770	716	66	13	669	1,463	-692
Jul-12	600	0	78	155	37	870	612	72	9	687	1,380	-511
Aug-12	434	0	1	157	37	629	570	76	7	684	1,336	-708
Sep-12	329	0	16	84	35	464	269	48	5	662	985	-521
Oct-12	1,602	183	29	10	37	1,860	83	0	1	688	772	1,088
Nov-12	586	18	3	0	35	642	4	0	0	678	682	-40
Dec-12	644	202	7	0	37	890	1	0	0	702	703	186
Jan-13	511	211	6	0	37	765	0	0	0	705	705	60
Feb-13	660	334	9	0	33	1,036	0	0	0	637	637	399
Mar-13	488	166	7	0	37	699	13	0	0	706	719	-20
Apr-13	477	240	48	2	36	804	12	0	0	683	695	109
May-13	580	27	34	82	37	761	161	16	8	705	890	-129
Jun-13	582	0	30	176	36	823	366	58	11	679	1,114	-291
Jul-13	538	0	143	174	37	892	397	44	8	697	1,146	-254
Aug-13	550	0	30	169	37	786	518	50	7	694	1,268	-482
Sep-13	222	153	165	66	35	641	161	21	5	672	859	-218
Oct-13	854	131	35	0	37	1,057	30	5	2	698	735	322
Nov-13	995	48	6	0	35	1,083	0	0	0	714	714	370
Dec-13	817	61	1	0	37	916	0	0	0	740	740	177
Jan-14	1,079	64	11	0	37	1,191	0	0	0	742	742	449
Feb-14	492	51	9	0	33	584	0	0	0	671	671	-87
Mar-14	519	34	10	0	37	599	8	0	0	743	751	-152
Apr-14	923	86	56	21	36	1,121	40	0	2	719	761	359
May-14	1,025	325	52	83	37	1,522	81	3	8	742	833	689
Jun-14	965	390	101	78	36	1,569	207	27	10	715	959	611
Jul-14	696	86	115	194	37	1,128	602	46	8	734	1,390	-262
Aug-14	769	237	65	146	37	1,254	519	44	6	730	1,299	-45
Sep-14	931	344	33	82	35	1,425	323	35	5	707	1,070	355
Oct-14	797	104	11	17	37	966	107	0	3	735	845	121

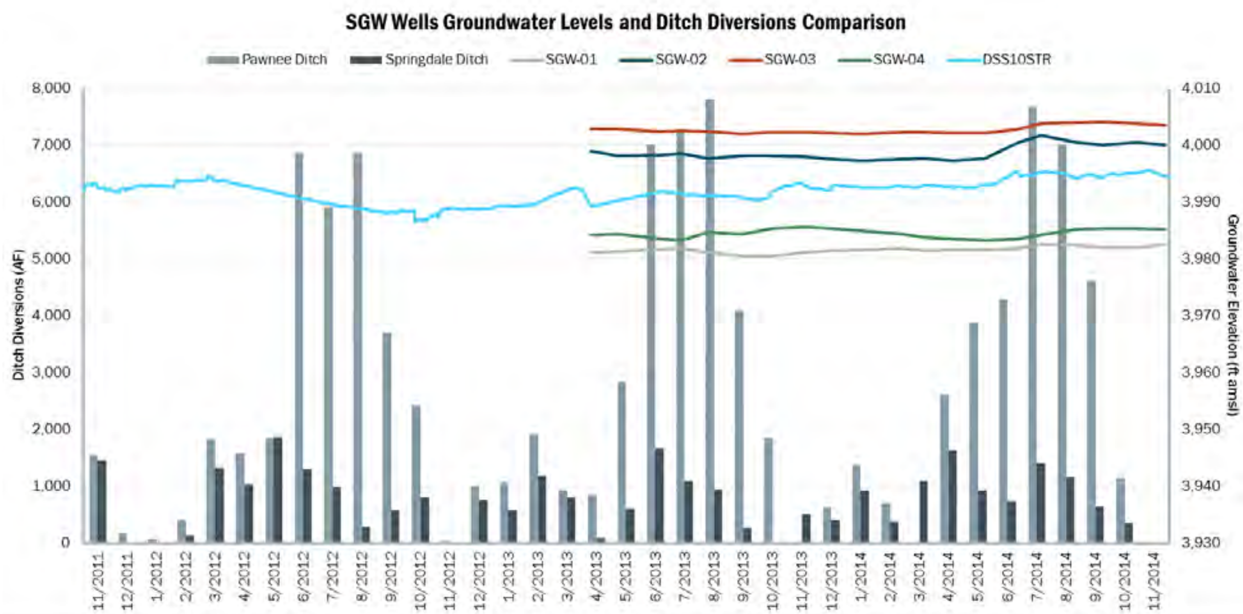
Appendix C: Country Club Hills and Pawnee Ridge Water Level Analysis

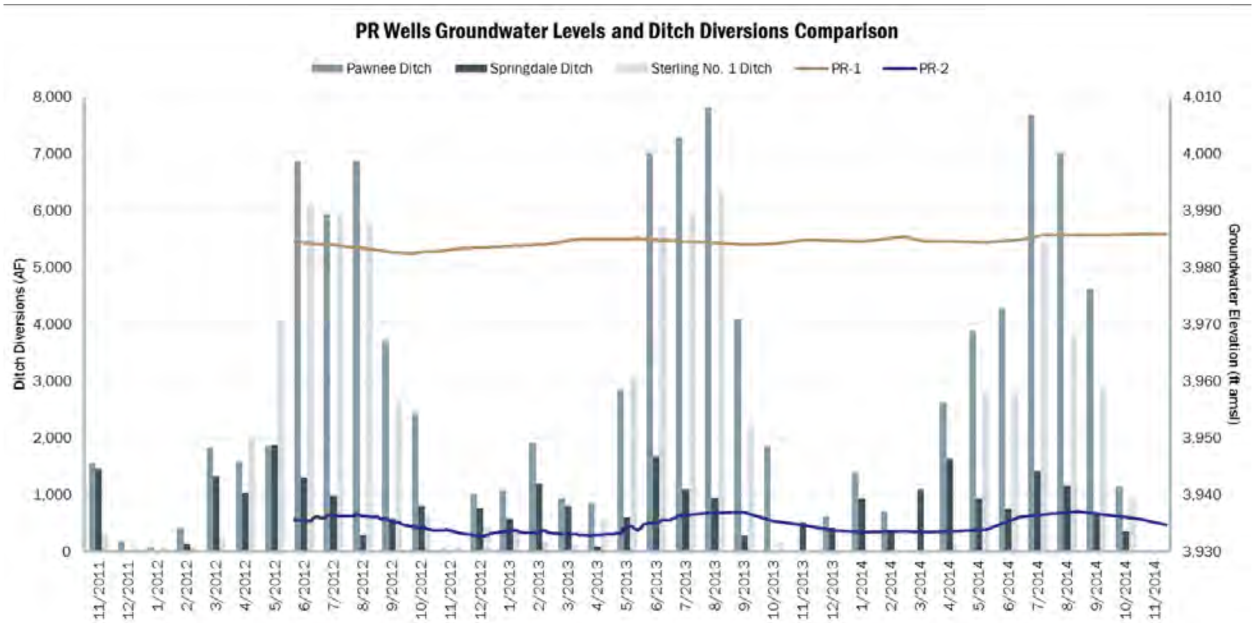

CCN Wells Groundwater Levels and Ditch Diversions Comparison
Pawnee Ditch
Springdale Ditch
CCN-1
CCN-2
CCN-3
CCN-4
Ditch Diversions (AF)
Groundwater Elevation (ft amsl)
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
3,970
3,965
3,960
3,955
3,950
3,945
3,940
3,935
3,930
11/2011 12/2011 1/2012 2/2012 3/2012 4/2012 5/2012 6/2012 7/2012 8/2012 9/2012 10/2012 11/2012 12/2012 1/2013 2/2013 3/2013 4/2013 5/2013 6/2013 7/2013 8/2013 9/2013 10/2013 11/2013 12/2013 1/2014 2/2014 3/2014 4/2014 5/2014 6/2014 7/2014 8/2014 9/2014 10/2014 11/2014

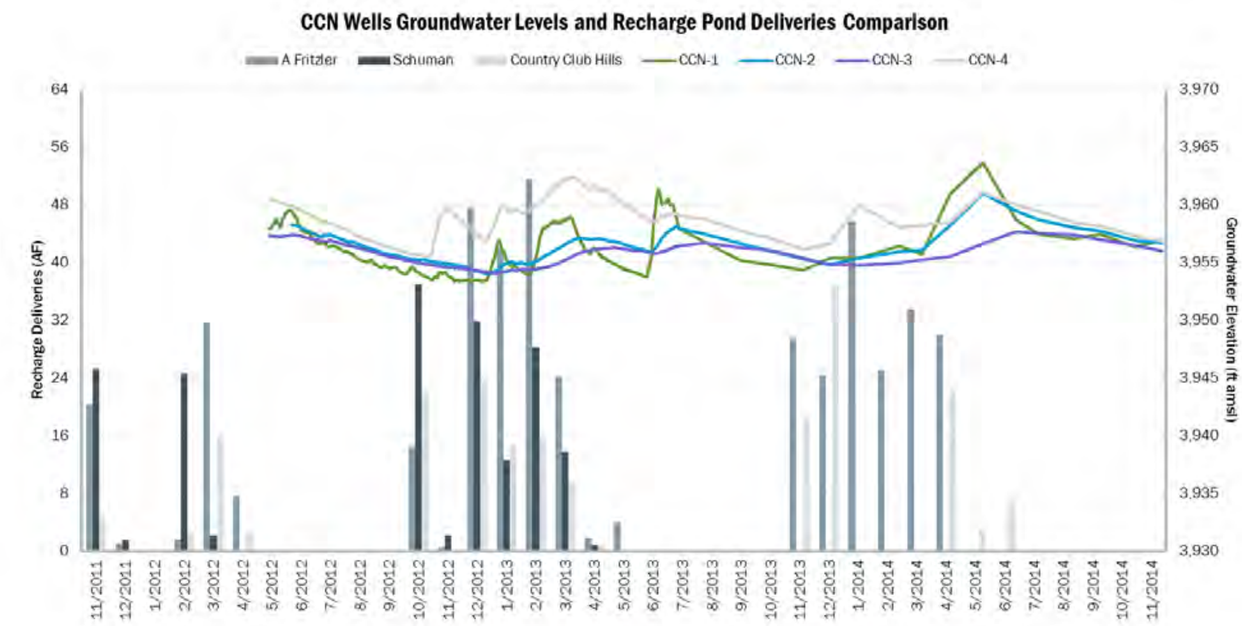

CCE Wells Groundwater Levels and Ditch Diversions Comparison
Pawnee Ditch
Springdale Ditch
CCE-2
CCE-3
CCE-4
Ditch Diversions (AF)
Groundwater Elevation (ft amsl)
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
4,010
4,000
3,990
3,980
3,970
3,960
3,950
3,940
3,930
11/2011 12/2011 1/2012 2/2012 3/2012 4/2012 5/2012 6/2012 7/2012 8/2012 9/2012 10/2012 11/2012 12/2012 1/2013 2/2013 3/2013 4/2013 5/2013 6/2013 7/2013 8/2013 9/2013 10/2013 11/2013 12/2013 1/2014 2/2014 3/2014 4/2014 5/2014 6/2014 7/2014 8/2014 9/2014 10/2014 11/2014


PRN Wells Groundwater Levels and Ditch Diversions Comparison
Pawnee Ditch
Springdale Ditch
Sterling No. 1 Ditch
PRN-1
PRN-2
PRN-3
PRN-4
Ditch Diversions (AF)
Groundwater Elevation (ft amsl)


PRE Wells Groundwater Levels and Ditch Diversions Comparison
Pawnee Ditch
Springdale Ditch
Sterling No. 1 Ditch
PRE-1
PRE-2
PRE-3
Ditch Diversions (AF)
Groundwater Elevation (ft amsl)


SGW Wells Groundwater Levels and Ditch Diversions Comparison
Pawnee Ditch
Springdale Ditch
SGW-01
SGW-02
SGW-03
SGW-04
DSS10STR
Ditch Diversions (AF)
Groundwater Elevation (ft amsl)


PR Wells Groundwater Levels and Ditch Diversions Comparison
Pawnee Ditch
Springdale Ditch
Sterling No. 1 Ditch
PR-1
PR-2
Ditch Diversions (AF)
Groundwater Elevation (ft amsl)


CCN Wells Groundwater Levels and Recharge Pond Deliveries Comparison
A Fritzler
Schuman
Country Club Hills
CCN-1
CCN-2
CCN-3
CCN-4
Recharge Deliveries (AF)
Groundwater Elevation (ft amsl)
0
8
16
24
32
40
48
56
64
3,930
3,935
3,940
3,945
3,950
3,955
3,960
3,965
3,970
11/2011
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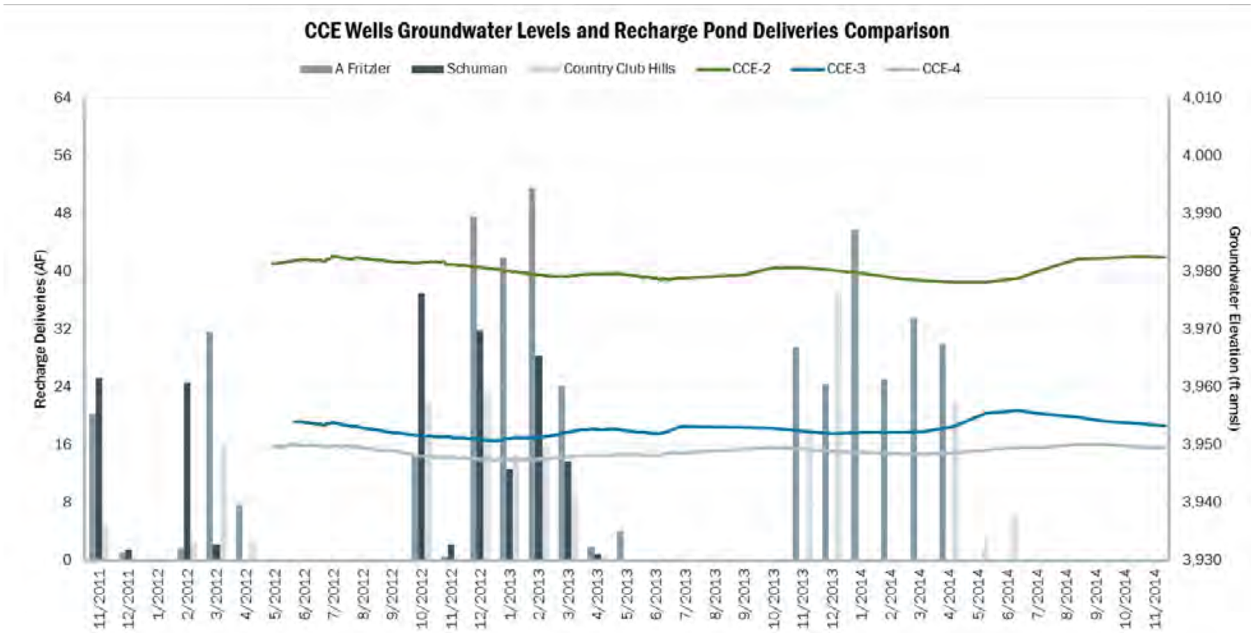
CCE Wells Groundwater Levels and Recharge Pond Deliveries Comparison
A Fritzler
Schuman
Country Club Hills
CCE-2
CCE-3
CCE-4
Recharge Deliveries (AF)
Groundwater Elevation (ft amsl)
0
8
16
24
32
40
48
56
64
3,930
3,940
3,950
3,960
3,970
3,980
3,990
4,000
4,010
11/2011
12/2011
1/2012
2/2012
3/2012
4/2012
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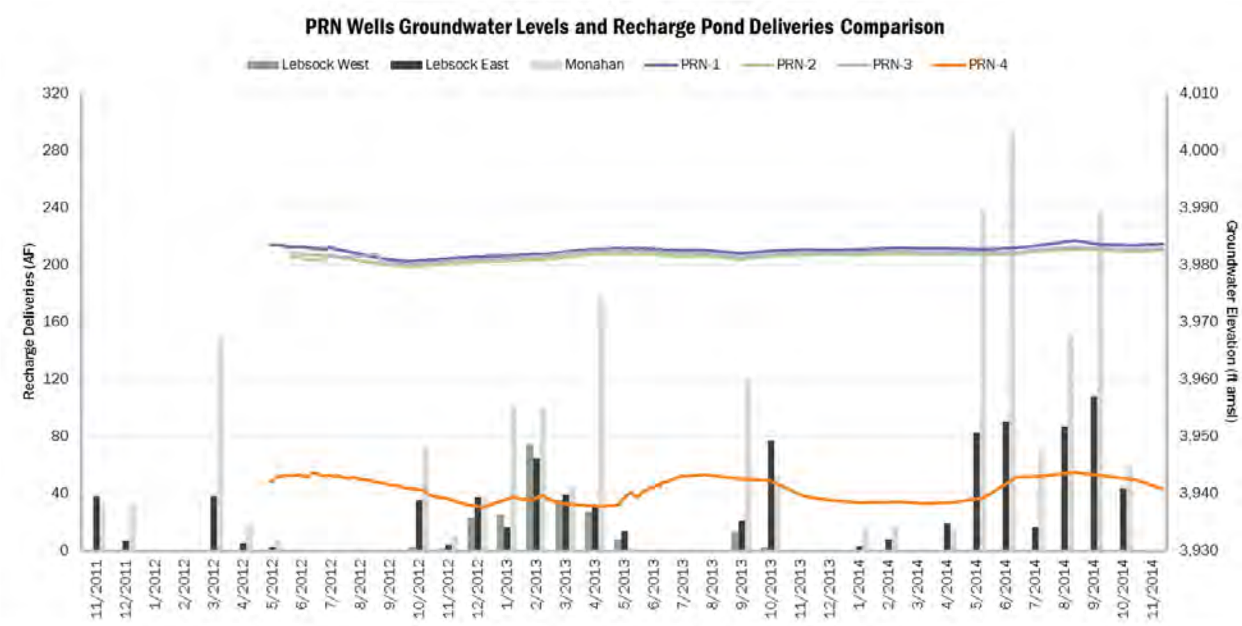
PRN Wells Groundwater Levels and Recharge Pond Deliveries Comparison
Lebsock West
Lebsock East
Monahan
PRN-1
PRN-2
PRN-3
PRN-4
Recharge Deliveries (AF)
Groundwater Elevation (ft amsl)
320
280
240
200
160
120
80
40
0
4,010
4,000
3,990
3,980
3,970
3,960
3,950
3,940
3,930
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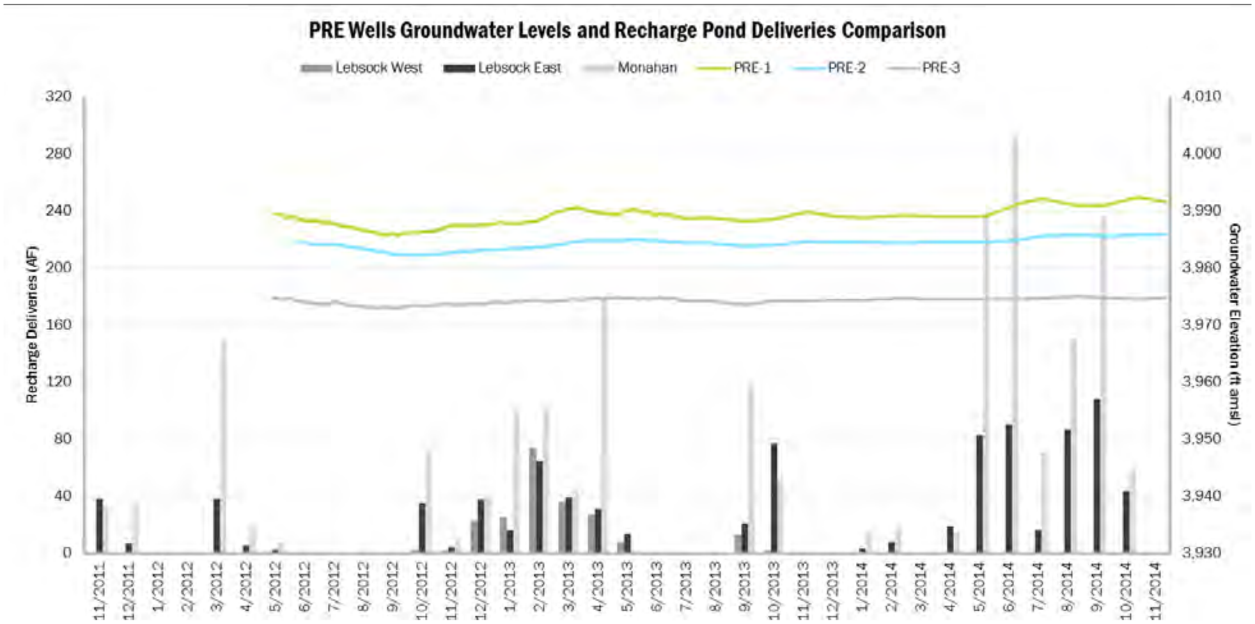
PRE Wells Groundwater Levels and Recharge Pond Deliveries Comparison
Lebsock West
Lebsock East
Monahan
PRE-1
PRE-2
PRE-3
Recharge Deliveries (AF)
Groundwater Elevation (ft amsl)
320
280
240
200
160
120
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0
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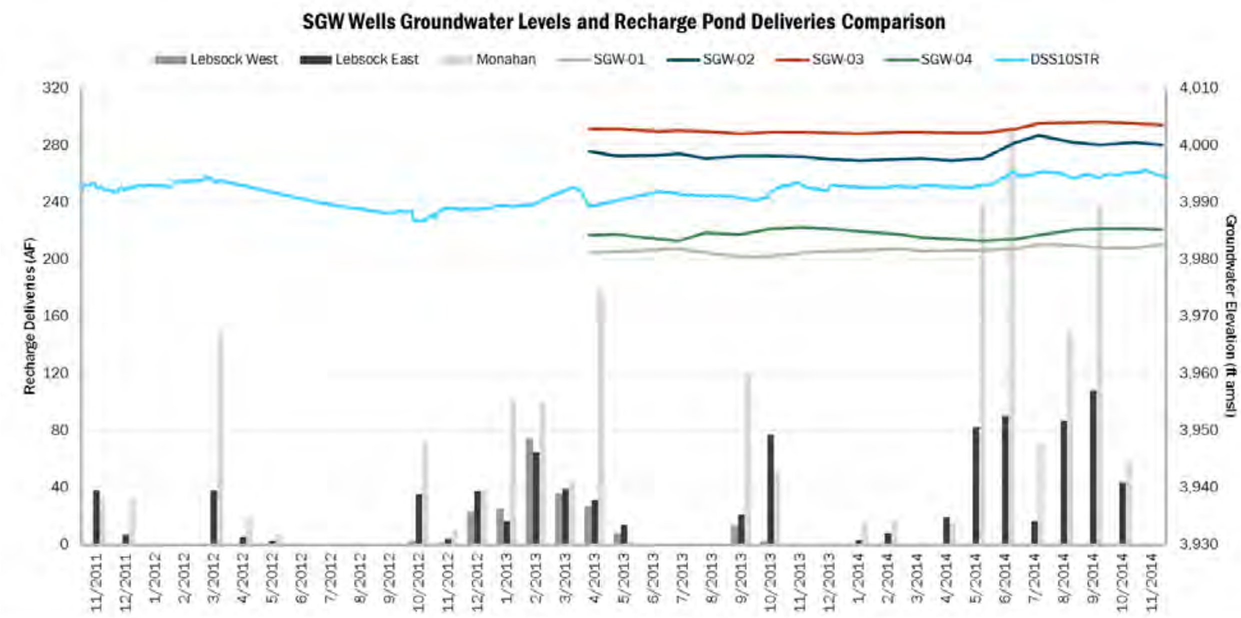

SGW Wells Groundwater Levels and Recharge Pond Deliveries Comparison
Lebsock West
Lebsock East
Monahan
SGW-01
SGW-02
SGW-03
SGW-04
DSS10STR
Recharge Deliveries (AF)
Groundwater Elevation (ft amsl)
320
280
240
200
160
120
80
40
0
4,010
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3,990
3,980
3,970
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3,940
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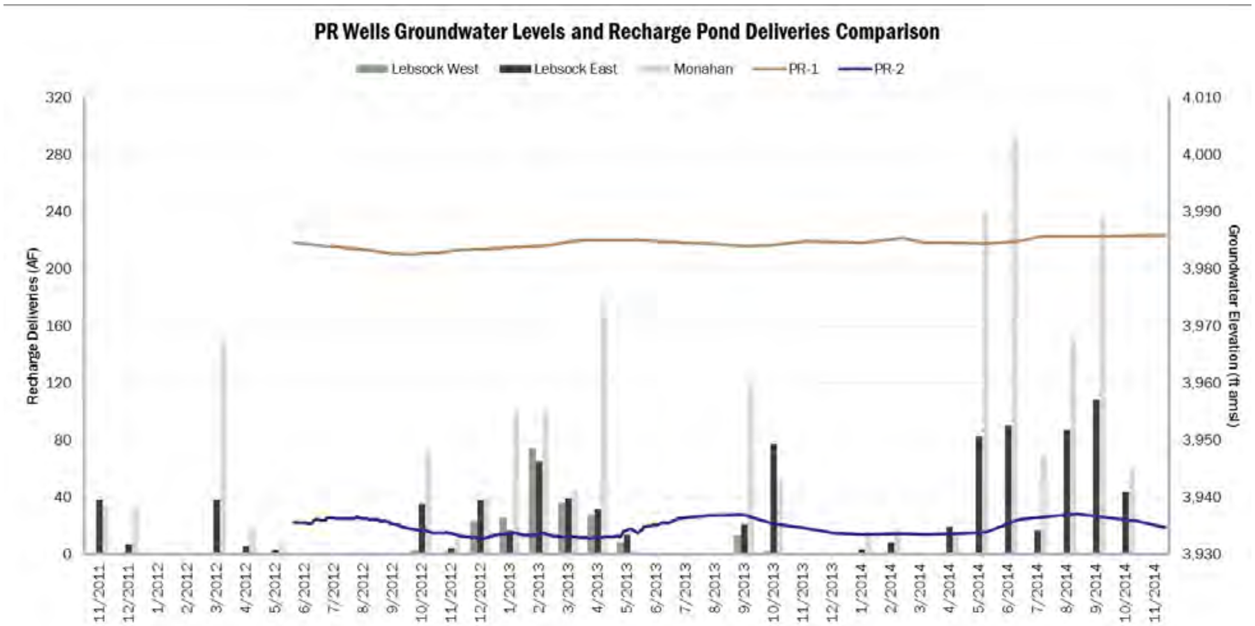

PR Wells Groundwater Levels and Recharge Pond Deliveries Comparison
Lebsock West
Lebsock East
Monahan
PR-1
PR-2
Recharge Deliveries (AF)
Groundwater Elevation (ft amsl)
320
280
240
200
160
120
80
40
0
4,010
4,000
3,990
3,980
3,970
3,960
3,950
3,940
3,930
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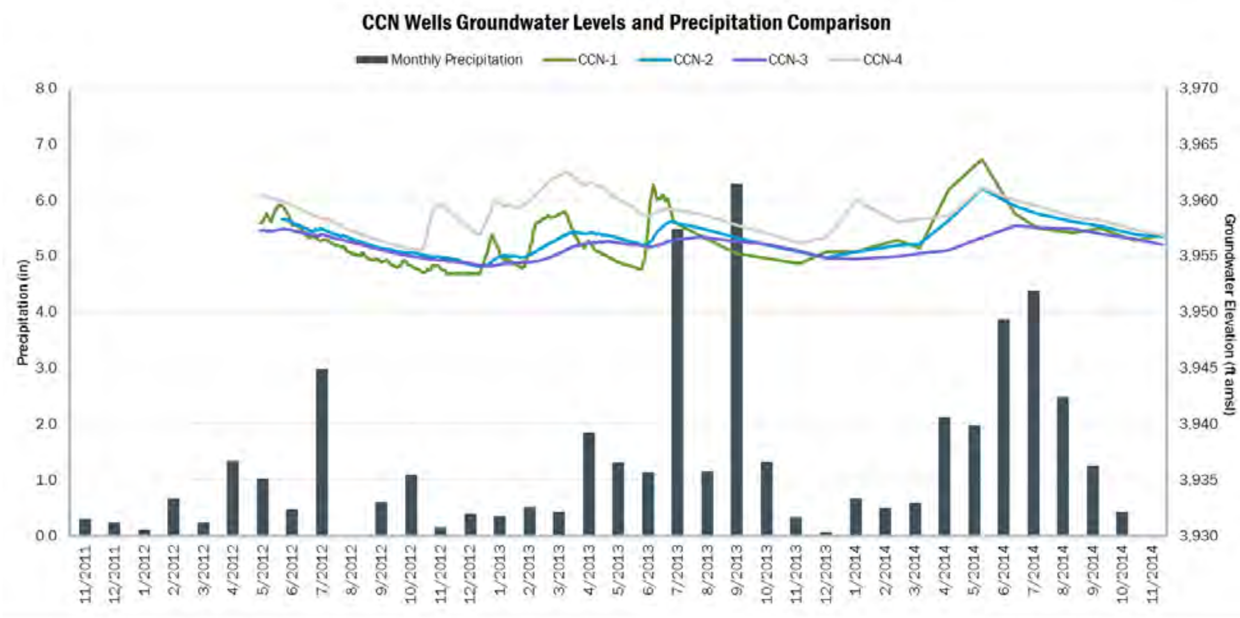
CCN Wells Groundwater Levels and Precipitation Comparison
Monthly Precipitation
CCN-1
CCN-2
CCN-3
CCN-4
Precipitation (in)
Groundwater Elevation (ft amsl)
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
3,930
3,935
3,940
3,945
3,950
3,955
3,960
3,965
3,970
11/2011
12/2011
1/2012
2/2012
3/2012
4/2012
5/2012
6/2012
7/2012
8/2012
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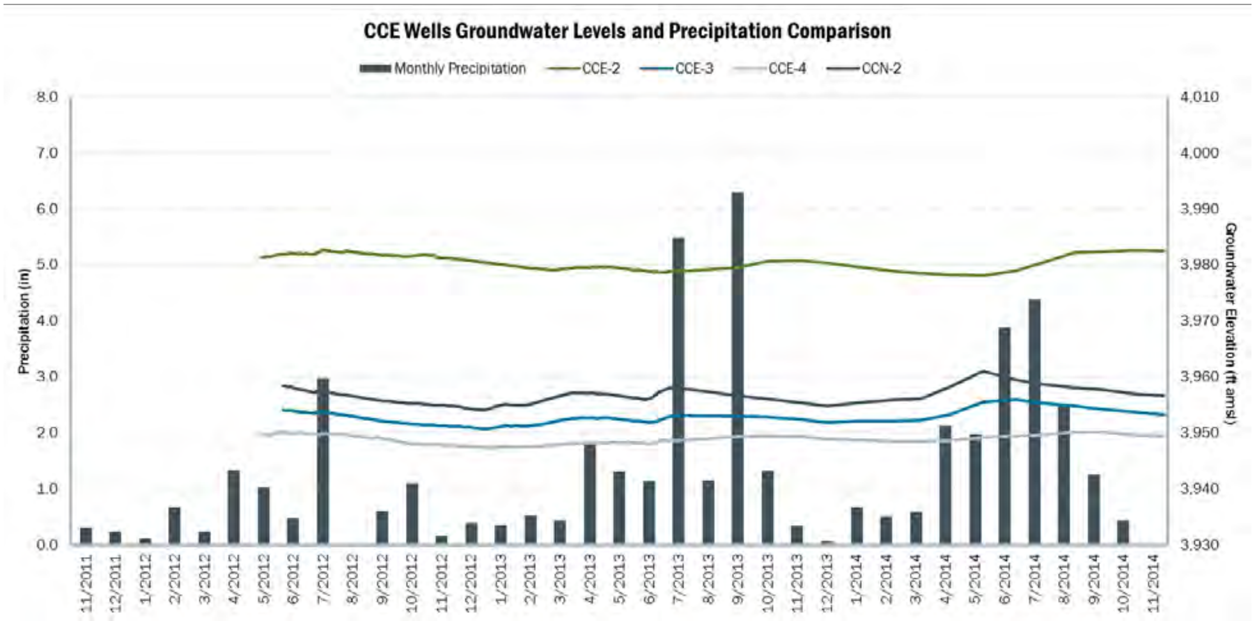
CCE Wells Groundwater Levels and Precipitation Comparison
Monthly Precipitation
CCE-2
CCE-3
CCE-4
CCN-2
Precipitation (in)
Groundwater Elevation (ft amsl)
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
3,930
3,940
3,950
3,960
3,970
3,980
3,990
4,000
4,010
11/2011
12/2011
1/2012
2/2012
3/2012
4/2012
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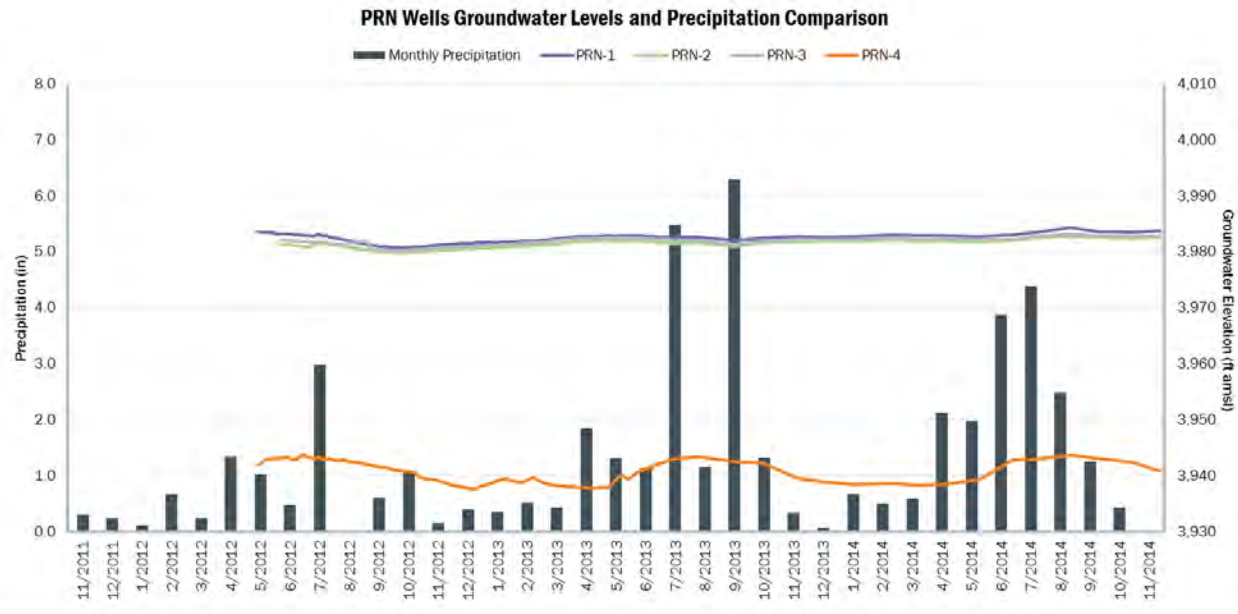
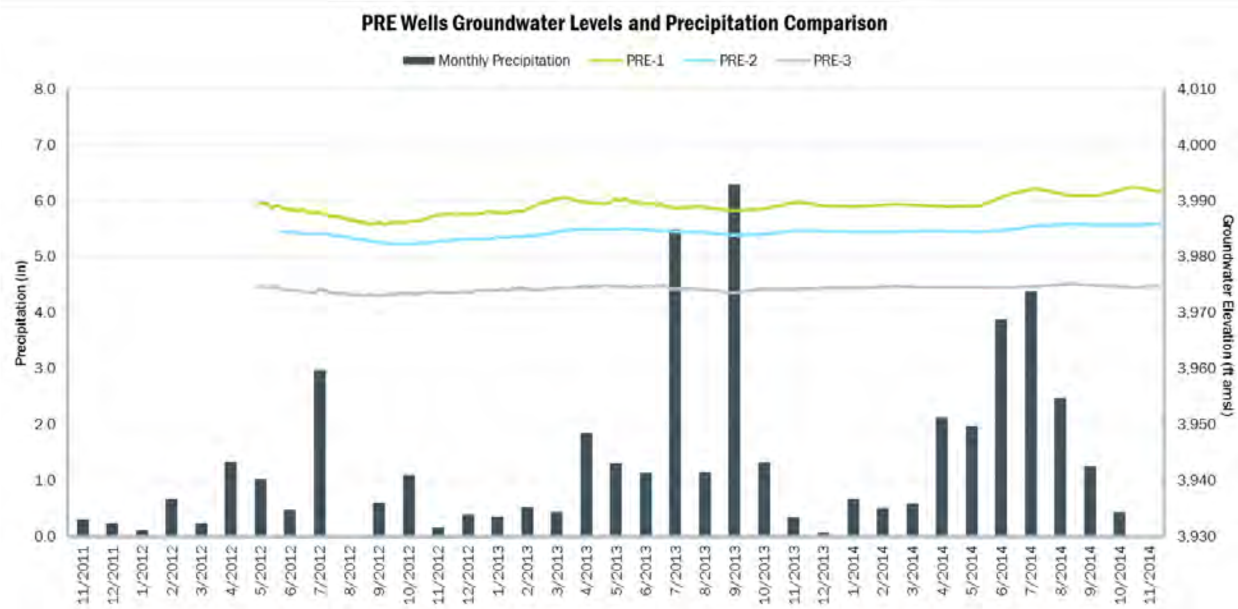
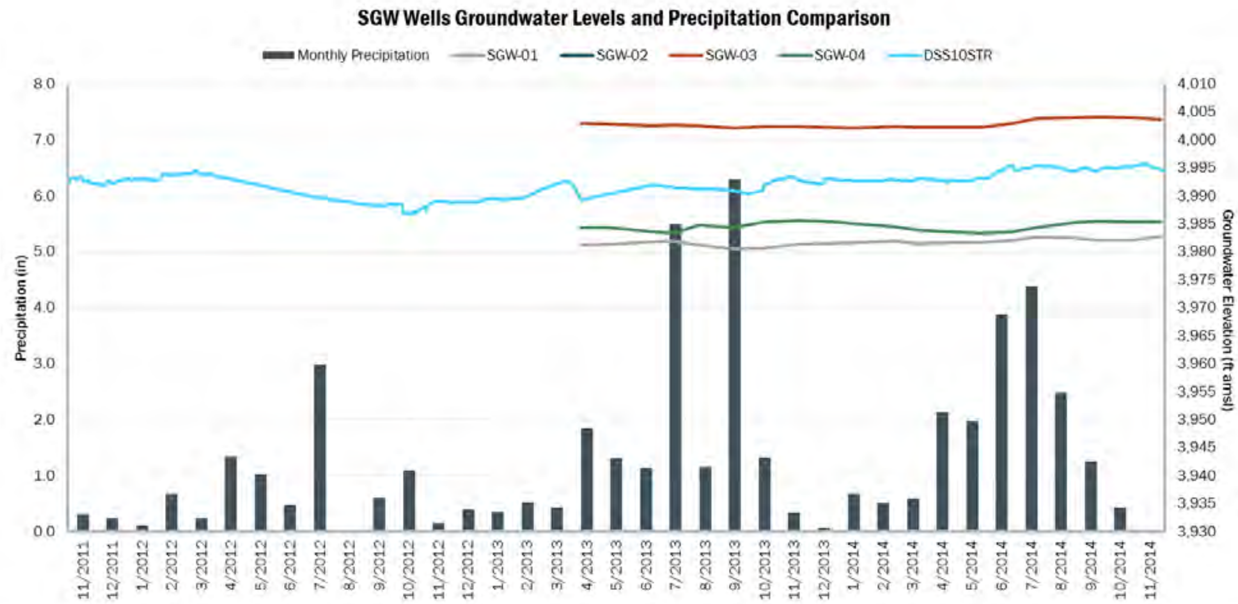

PRN Wells Groundwater Levels and Precipitation Comparison
Monthly Precipitation
PRN-1
PRN-2
PRN-3
PRN-4
Precipitation (in)
Groundwater Elevation (ft amsl)


PRE Wells Groundwater Levels and Precipitation Comparison
Monthly Precipitation
PRE-1
PRE-2
PRE-3
Precipitation (in)
Groundwater Elevation (ft amsl)


SGW Wells Groundwater Levels and Precipitation Comparison
Monthly Precipitation
SGW-01
SGW-02
SGW-03
SGW-04
DSS10STR
Precipitation (in)
Groundwater Elevation (ft amsl)
0.0
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3,950
3,955
3,960
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3,970
3,975
3,980
3,985
3,990
3,995
4,000
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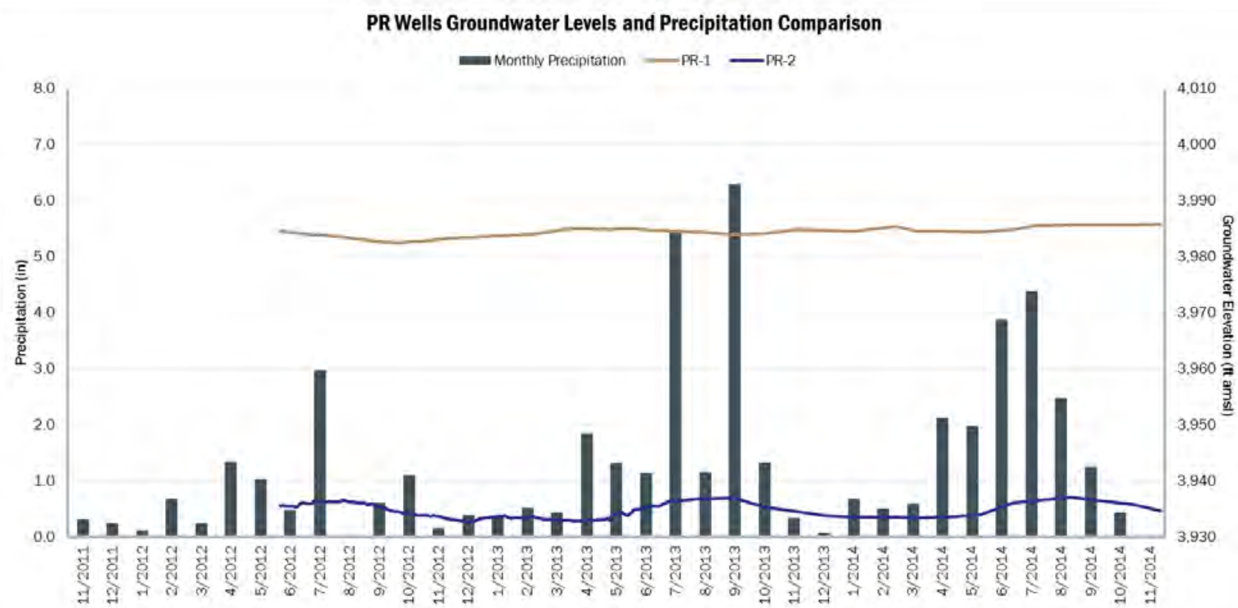
PR Wells Groundwater Levels and Precipitation Comparison
Monthly Precipitation
PR-1
PR-2
Precipitation (in)
Groundwater Elevation (ft amsl)
0.0
1.0
2.0
3.0
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