Water Mass Balance for the Ukiah Valley Groundwater Basin

By

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To my mom and dad, Carmen and Pedro, for their unconditional support throughout the years.

Garcias por todo a través de los años.

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Abstract

The Sustainable Groundwater Management Act (SGMA) is the first legislative effort of its form in California geared towards reforming groundwater management throughout the state after years of uncoordinated and voluntary management of groundwater. SGMA will enforce the management and monitoring of groundwater resources at a local scale by requiring medium and high priority groundwater basins to form a Groundwater Sustainability Agency (GSA). GSAs are required to submit a Groundwater Sustainability Plan (GSP) addressing how their groundwater resources will be managed to achieve groundwater sustainability by the year 2040 by avoiding the six undesirable results listed by the California Department of Water Resources (DWR). The objective of this study is to (a) describe the implementation of SGMA in California, (b) describe a method for estimating a water budget, and (c) present the implementation of this method for the Ukiah Valley Groundwater Basin. To characterize the Ukiah Valley Groundwater Basin, a water budget was developed on a monthly time step from 1991 to 2015 in collaboration with local stakeholders and scientists. Results suggest that the Ukiah Valley Groundwater Basin is not in groundwater overdraft, and that a portion of the Russian River is a gaining river approximately 18,952 AF/y from November to June, and a losing river approximately 393 AF/y from July to October. Furthermore, groundwater connectivity is observed to occur between the Ukiah Valley Groundwater Basin and the Sanel Valley Groundwater Basin through lateral groundwater movement. Local groundwater managers and users will use this information to inform proposed action plans and monitoring protocols that will allow them to achieve and maintain groundwater sustainability by the year 2040 and onward.

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1. Introduction

In California, groundwater is not merely part of the hydrologic cycle, but a key component that supports the state's economy, contributes towards environmental stewardship, and supports communities that may range from being partially dependent to solely dependent on groundwater. Groundwater in California has supported urban development, irrigation for intensive agriculture, and has functioned as an alternative water source during periods of drought. Given the importance of groundwater in the state, California pumps more groundwater than any other state in the nation, roughly 16% of all the groundwater pumped by the United States (DWR 2015). Despite the importance of groundwater, California has forgone establishing a comprehensive plan for managing its groundwater resources. As a result, some groundwater basins have been deemed unsustainable because they have experienced one or more of the following conditions: chronic lowering of the water table, a reduction in groundwater storage, saline intrusion, a degradation of water quality, land subsidence, and depletion in groundwater-surface water interactions. In 2014, the Sustainable Groundwater Management Act (SGMA) was introduced in California to encourage groundwater management and monitoring at a local scale through the formation of Groundwater Sustainability Agencies (GSAs). With the goal of obtaining groundwater sustainability the year 2040, GSA formations were formed in areas where the groundwater basins were identified as medium and high priority by the California Department of Water Resources (DWR). Given the challenges that some groundwater basins are experiencing, there is a critical need to hydrologically analyze them to begin managing them and make them sustainable.

1.1 Research Objectives

The objectives of this research study are: 1) describe the implementation of SGMA in California, 2) describe the method and framework used for estimating a water budget, and 3) describe the implementation of SGMA and the construction of a water budget for the Ukiah Valley Groundwater Basin. The development of this water budget will provide a characterization of the Ukiah Valley Groundwater Basin for the formed GSA which will contribute towards the efforts of developing a Groundwater Sustainability Plan (GSP). The development of this water budget also will be the starting point for more detailed water management projects for this region.

SGMA provides a mandate to make all groundwater basins in California sustainable. Analysis of groundwater basins in critical condition begins with constructing a water budget. A well-constructed water budget can inform in the decision making process when it comes time to design water management strategies for an area that needs improvement. The water budget will provide a historical and a current summary of the groundwater basin that was otherwise unknown or controversial.

This study presents a method for estimating a water budget for a groundwater basin identified to be of concern by DWR. The method consists of developing a water mass balance for the project area. The framework consist of four main components that included 1) performing agricultural water use calculations, 2) constructing a surface water mass balance, 3) estimating aquifer storage, and 4) constructing a groundwater mass balance. The presented framework considers the historical association between the water sources, water supplies, and water uses for the groundwater basin of interest.

Background in California’s groundwater management and SGMA are covered in Chapter 2. In Chapter 3, the Case Study on the Ukiah Valley Groundwater Basin is presented. Chapter 4 describes the development of the water budget for the Ukiah Valley Groundwater Basin. Chapter 5 presents the results and Chapter 6 is a discussion on the results. Chapter 7 concludes with closing comments, an overall summary of what was accomplished through this study, and a brief outline of some of the limitations encountered in this study.

2. Background

2.1 Groundwater in California

The state of California relies on groundwater from either alluvial or fractured rock aquifers. The alluvial aquifers have fine grained sediments, sand and/or gravel that contains water stored within its pore spaces (DWR 2015). Fractured rock aquifers store much less water and are made of impermeable granitic, metamorphic, volcanic, or sedimentary rocks that hold groundwater within the fractures or void spaces. Typically, fractured rock aquifers are in mountainous and foothill areas (DWR 2015).

In California, 515 alluvial groundwater basins and subbasins exist that cover 42% of the state (DWR 2015). From the groundwater basins it is estimated that 16.5 MAF or 20,352 Mm^3 of groundwater are extracted annually, which accounts for 38% of the water supply in the state (DWR 2015). Despite the number of basins in the state, each basin is somewhat unique but, have been regionalized into the Central Valley aquifer system, the coastal aquifers, the Northern California basin-fill aquifers, and the eastern Sierra Nevada and the California Desert aquifers (DWR 2015). In Figure 1, the location of the groundwater basins and subbasins in California have been identified as the areas shaded in green.

California Groundwater Basins and Subbasins

Source: Department of Water Resources, CWP 2013

Figure 1. Areas shaded in green are the groundwater basins and subbasins found in California (DWR 2015).

Of the 16.5 MAF of groundwater pumped annually in the state of California, 39% is used for agriculture, 41% in the urban areas, and 18% used for the state's wetlands (DWR 2015). The Central Valley alone uses 74% of all extracted groundwater, where the Tulare Lake Hydrologic Region is the greatest groundwater user (DWR 2015). Topography, precipitation, and hydrologic conditions vary throughout the state. Some areas lack access to enough water to meet water demands, so state and federal water projects offer help with imported water. When the amount of surface water from the state and federal water projects does not fully meet local water demands, water users typically rely on groundwater to cover the deficit. The total amount of water used in each hydrologic region is found in Figure 2, along with the amount of groundwater used by each region. The Tulare Lake Hydrologic Region is by far the greatest groundwater consumer. The North Lahontan Hydrologic Region is the smallest groundwater consumer in California.

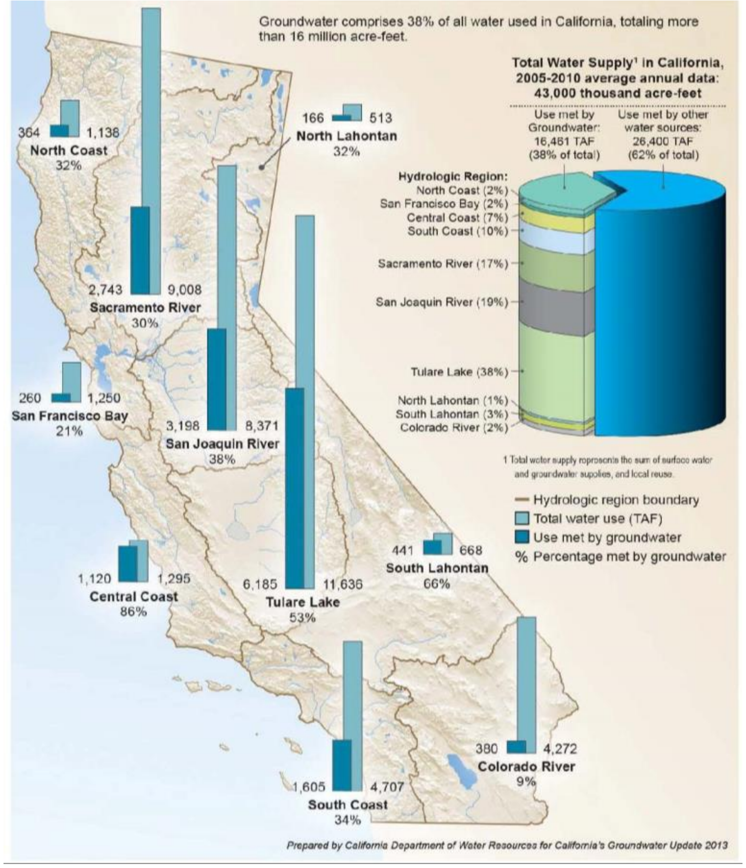


Figure 2. Total water supply and the percent of groundwater supply for each hydrologic region for the years 2005-2010 (DWR 2015).

2.2 Concerns Regarding California Groundwater Resources

California has long forgone establishing a comprehensive plan for managing its groundwater resources. The lack of groundwater oversight has introduced concerns that need to be mitigated and better addressed. Some groundwater basins throughout the state are not sustainable due to overdraft, reduced stream flows, potential to lose ecosystems, depletion in groundwater quality, land subsidence, or salt water intrusion.

Conjunctive use seeks to manage both groundwater and surface water simultaneously. California's Water Plan Update 2013, defines conjunctive use as "a coordinated and planned use and management of both surface water and groundwater resources to maximize the availability and reliability of water supplies in a region to meet various management objectives" (DWR 2013). Through conjunctive use, groundwater is essentially stored and used for future needs mostly during drought periods. Through this management scheme users can rely on stored groundwater during dry periods, and surface water during wet periods.

Many areas in California lack an integrated water resources management system that integrates surface water and groundwater management. Groundwater overdraft is an example of the many groundwater issues that have resulted from the unregulated groundwater use, water demand increase, change in cropping patterns, an increase in population, and or change in irrigation systems. Groundwater overdraft is the point at which the quantity of groundwater extracted from the aquifer exceeds the amount of groundwater recharging the aquifer (Moran et al. 2014). Groundwater overdraft is a prominent problem in the Central Valley where several communities rely on groundwater resources to meet agricultural and municipal water demands. Coastal basins and some basins in the southern portion of the state have also been known to be susceptible to groundwater overdraft (Lund and Harter 2013). It is estimated that 500,000 AF to 1.5 million AF of overdraft occur throughout the state (Lund and Harter 2013). The Tulare Lake Basin is the highest groundwater consumer as a result of intensive agriculture, making this area, particularly susceptible to 0.7 to 1.5 million AF/y of groundwater overdraft (Lund and Harter 2013). In general, groundwater overdraft leads to decreasing groundwater storage and chronic lowering of the groundwater table as a function of time. This in turn, threatens water security in communities and leads to more expensive pumping and drilling costs to access groundwater in areas that lack reliable sources of surface water.

With the depletion of groundwater resources and lowering of the water table, surface water and groundwater interactions may also be lost. In most cases, the surface water and groundwater systems are connected. Through the streambed, groundwater may flow into the surface water, providing surface water gains or surface water may flow through the streambed to recharge the groundwater system (Vandas et al. 2002). For surface water to recharge groundwater, the groundwater water table must be lower than the free surface of the surface water (Vandas et al. 2002). For surface water to gain groundwater, the water table must be higher than the free surface of the surface water (Vandas et al. 2002). Since both systems are hydrologically connected it is important to try to maintain them connected by monitoring the amount of groundwater pumped. Maintaining these surface water and groundwater interactions assures that there is chemical and thermal buffering, the formation and maintenance of habitat, refuge areas for aquatic species that are endangered, and assures base flows in rivers during times in which there is no snowmelt or rain (Gardner 1999).

Many groundwater basins have experienced degradation of groundwater quality. In California, some regions have water quality concerns regarding nitrates and salinity that stem from agricultural irrigation practices mainly. Excess surface water used for irrigation, transports nitrates and salts to the groundwater, polluting local water supplies. The Tulare and Salinas Basins are examples of sites that have been affected from nitrate contamination (Lund and Harter 2013). Their groundwater sources have become impacted from crop fertilizer, nitrates from dairies, and nitrates from septic tanks (Lund and Harter 2013). The Tulare Lake Basin and the

San Juaquin Basin are also susceptible to salinity problems (Lund and Harter 2013). High concentrations of salts have been found in their groundwater supplies which stem from the soils and aquifers, irrigation water, animal farming, and waste from industry and communities (Lund and Harter 2013). The high presence of nitrates and salinity has led to the closure of several wells within these groundwater basins.

With an unmanaged groundwater system, land subsidence has also been a problem in some regions. Land subsidence is the gradual sinking of the Earth's surface (USGS 2016). Areas of concern include the Tulare Lake Basin and the San Juaquin basin, with land subsidence of up to 30ft due to groundwater overdraft (Lund and Harter 2013). Land subsidence can be a threat locally because of the damage it can cause to infrastructure, canals, bridges, and sewers. Figure 3 demonstrates how dire the results may be from land subsidence. Figure 3 is an image demonstrating how much land subsidence has occurred in the Central Valley, near the area of Mendota California. In the image it can be seen how the land has significantly dropped with time as a result of the large amounts of groundwater that have been withdrawn from the aquifer.

R. Ireland, U.S. Geological Survey

Figure 3. Historical land subsidence observed in the Central Valley near Mendota, California (USGS 2000).

Lastly, sea water intrusion has also been a concern for some groundwater basins. During sea water intrusion, sea water will flow into fresh water aquifers which may contaminate the drinking water supply. This can occur from excessive groundwater pumping or naturally, a physical process that is seen commonly in the coastal aquifers. For sea water intrusion to occur, the groundwater levels must be lower that the sea level. The amount of sea water intrusion will vary depending on the rate at which groundwater is extracted and the amount of fresh water that is being recharged into the groundwater basin (Barlow and Reichard 2010). Other factors affecting sea water intrusion may include the distance that exists between the groundwater wells and the source of saltwater, the geologic structure of the aquifer, and the presence of confining units that may prevent the movement of saltwater into the aquifer (Barlow and Reichard 2010). In coastal Los Angeles, sea water intrusion has been a problem as a result of excessive groundwater development that began in the middle of the 19th century (Nishikawa et al. 2009). With time, the amount of groundwater pumping increased as the population grew. The use of turbine pumps eventually decreased the water level lower than that of sea level which lead to seawater intrusion, since then sea water intrusion problems have continued to be addressed (Nishikawa et al. 2009). The Salinas and Pajaro Valleys have also been areas that have been recognized to experience occasional seawater intrusion as a result of agriculture development (Garza Diaz 2016).

2.3 Prior the Sustainable Groundwater Management Act (SGMA)

Up to 2014, there had been little coordinated effort on managing groundwater in California. This widely used water resource lacked detailed groundwater law or policies governing its use. Indirectly, money regulated groundwater use. Groundwater hydrologic characteristics and the costs of pumping and drilling drove how much groundwater was used. However, the most common groundwater management practices involved water districts with groundwater management programs or having adjudicated groundwater basins. The groundwater rights in the state have been correlative rights, appropriative rights, mutual prescription, and notions of equitable appointment (Weatherford et al. 1982).

Through correlative rights, overlying users are limited to a feasible amount of groundwater that will not cause detrimental impacts to other users depending on the aquifer. The doctrine of correlative rights is formed from the idea that the overlying owners have equal rights per acre to reasonably pump groundwater from a common source (Cox 1982). In addition, overlying users have greater priority than non-overlying users. Non-overlying users may only have access to the water not needed by the overlying users (Weatherford et al. 1982).

The rights of overlying and non-overlying users were redefined by the 1949 court case of the City of Pasadena vs. City of Alhambra (Weatherford et al. 1982). This Supreme Court case established the doctrine of mutual prescription. Under the doctrine of mutual prescription "groundwater withdrawals could be judicially limited to safe yield by proportionally reducing the pumping of all parties, using five-year periods of highest continuous use following the beginning of overdraft as the measure for the amount of water to which the reduction would apply" (Weatherford et al. 1982). When groundwater overdraft was experienced, private pumpers would "acquire rights against one another by the continued act of pumping, without regard to seniority or the location of use" (Weatherford et al. 1982). However, this doctrine raised several questions and problems. A problem that arose involved public entities being able to acquire prescriptive rights from private users, but private users would not be able to acquire prescriptive rights from public entities such as cities and water districts. Another problem that arose was that unnecessary groundwater pumping was encouraged (Weatherford et al. 1982). It was not until the case of the City of Los Angeles vs. City of San Fernando, that the doctrine of mutual prescription was limited. This case excluded municipalities from prescription and required owners to be put on notice of the adversity caused by the commencement of the overdraft (Getches et al. 2015). This court case also defined overdraft as “the condition when withdrawals exceed both safe yield and temporary surplus,” but more importantly, it declared that equitable appointment was more important than mutual prescription (Weatherford et al. 1982). In other words, all water rights “must be subject to reasonable conditions and priorities” (Weatherford et al. 1982).

California groundwater law has been diverse. Aside from groundwater laws, the concept of adjudicated basins has been a way to manage groundwater. In adjudicated basins, the court has jurisdiction, watermasters are appointed, local management districts exist, and it is the economics of groundwater pumping that determines the behavior of groundwater users (DWR 2015). Adjudicated basins can form when people or cities go to court to address groundwater issues. In this process the court appoints a watermaster or a group responsible to purchase water and manage water storage (Weatherford et al. 1982). The objective of groundwater adjudications has been to provide an equal share of available groundwater available to the users while simultaneously not causing detrimental effects on groundwater supplies as groundwater is pumped to meet water demands. Since the publication of *California’s Groundwater Update 2013,* there have been a total of 24 adjudicated groundwater basins located mainly in southern California (DWR 2015). For many of the adjudicated basins, extraction limits and management actions are imposed when groundwater levels and water quality levels are declining.

To address emerging groundwater concerns, some innovative solutions have occasionally resulted. Groundwater overdraft eventually led to the creation of the Central Valley and the State

Water Project, and in 1975 interests in groundwater management peaked and encouraged conjunctive use along with better management practices (Weatherford et al. 1982). In 1980, special legislation, SB 1391, was passed to address groundwater overdraft (Weatherford et al. 1982). The Sierra Valley and Long Valley Groundwater Basin Act allowed several counties to form groundwater management districts by joint powers agreements and to "require the registration of groundwater extraction, to purchase, condemn, import, store, reclaim, and/or exchange water; to enjoin well inference; to require permits before groundwater can be exported; and to levy extraction and management charges" (Weatherford et al. 1982).

In 1992, the state increased support for groundwater management through passage of the Groundwater Management Act, AB 3030, which has since then been modified. Through this legislation groundwater management was adopted as "the planned and coordinated monitoring, operation, and administration of a groundwater basin, or portion of a basin, with the goal of long term groundwater resource sustainability" (DWR 2015). This act encouraged local water entities to work together in managing their groundwater resources and to develop groundwater management plans. In 2002 The Groundwater Management Act was modified so public agencies seeking funds from the state to finance groundwater management projects must provide groundwater management plans. In 2011, the Assembly Bill 359 modified the Groundwater Management Act again to require local agencies to provide a copy of their groundwater management plan to the DWR (DWR 2015).

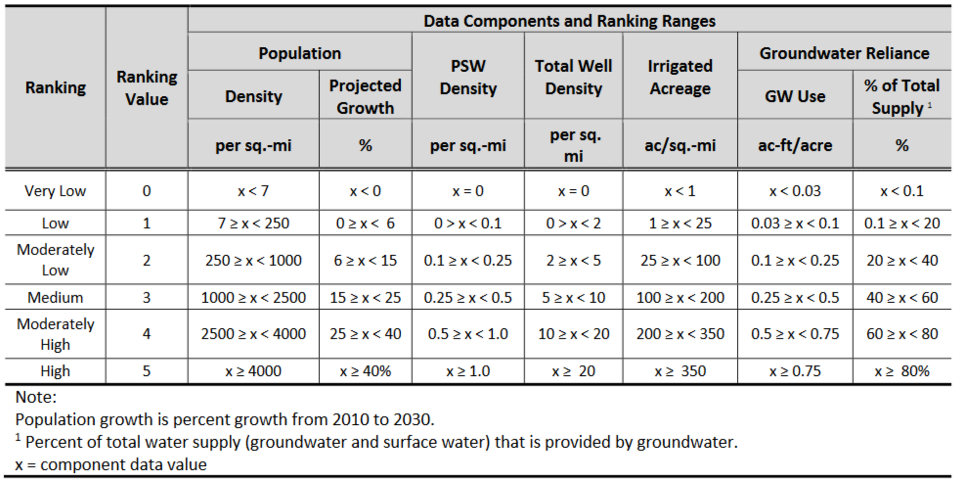
Groundwater resources management has been attempted through the State Water Code and Government Code. If a city or county sought financial support for groundwater management, a water management plan must be constructed as mandated by the codes (Green 2014). However, these groundwater management plans failed to limit groundwater use. To better monitor groundwater conditions, the state created the California Statewide Groundwater Elevation Monitoring Program (CASGEM).

The goal of CASGEM in 2009 was to improve the monitoring of groundwater conditions by allowing local management agencies the responsibility to monitor and report groundwater levels. CASGEM was put into effect as a result of legislation enacted in California's 2009 Comprehensive Water Package (DWR 2014). In essence, CASGEM established collaboration between local monitoring parties and DWR to monitor groundwater levels statewide. In efforts to shed light on the need to reform groundwater management, California Water Code 10933 and 12924 required the DWR to prioritize all 515 alluvial groundwater basins and subbasins and do groundwater basin assessments which became known as the CASGEM Groundwater Basin Prioritization Process (DWR 2014). This effort ranked groundwater basins as high, medium, low, or very low priority.

2.3.1 CASGEM Groundwater Basin Prioritization

The 515 alluvial groundwater basins and subbasins were classified as high, medium, low, or very low priority by considering the following variables (DWR 2014): (a) the population overlying the basin, an area with underlying permeable material that can store water; (b) the rate of current and projected growth of the population overlying the basin; (c) the number of public supply wells that draw from the basin; (d) the total number of wells that draw from the basin; (e) the irrigated acreage overlying the basin; (f) the degree to which persons overlying the basin rely on groundwater as their primary source of water; (g) any documented impacts on the groundwater, which may include groundwater overdraft, land subsidence, saline intrusion, and water quality degradation; and (h) any other information determined to be relevant by the DWR.

In classifying each groundwater basin and subbasin a score from 0-5 was assigned to each variable listed above. To determine the score, the information in Figure 4 was referenced. After each variable had an assigned score, the total wells data was reduced by 25 % as a result of data confidence (DWR 2014). The resulting scores for each variable were then input into Equation [1] to obtain a rank value for each groundwater basin.



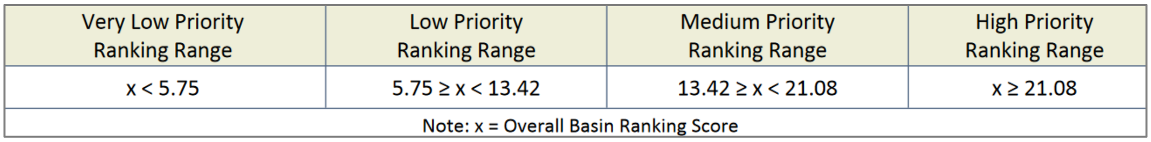
Ranking	Ranking Value	Data Components and Ranking Ranges						
		Population		PSW Density	Total Well Density	Irrigated Acreage	Groundwater Reliance	
		Density	Projected Growth				GW Use	% of Total Supply [1]
		per sq.-mi	%	per sq.-mi	per sq. mi	ac/sq.-mi	ac-ft/acre	%
Very Low	0	x < 7	x < 0	x = 0	x = 0	x < 1	x < 0.03	x < 0.1
Low	1	7 ≥ x < 250	0 ≥ x < 6	0 > x < 0.1	0 > x < 2	1 ≥ x < 25	0.03 ≥ x < 0.1	0.1 ≥ x < 20
Moderately Low	2	250 ≥ x < 1000	6 ≥ x < 15	0.1 ≥ x < 0.25	2 ≥ x < 5	25 ≥ x < 100	0.1 ≥ x < 0.25	20 ≥ x < 40
Medium	3	1000 ≥ x < 2500	15 ≥ x < 25	0.25 ≥ x < 0.5	5 ≥ x < 10	100 ≥ x < 200	0.25 ≥ x < 0.5	40 ≥ x < 60
Moderately High	4	2500 ≥ x < 4000	25 ≥ x < 40	0.5 ≥ x < 1.0	10 ≥ x < 20	200 ≥ x < 350	0.5 ≥ x < 0.75	60 ≥ x < 80
High	5	x ≥ 4000	x ≥ 40%	x ≥ 1.0	x ≥ 20	x ≥ 350	x ≥ 0.75	x ≥ 80%

Note:
Population growth is percent growth from 2010 to 2030.
[1] Percent of total water supply (groundwater and surface water) that is provided by groundwater.
x = component data value

Figure 4. CASGEM Groundwater Basin Prioritization Process score assignment table (DWR 2014).

$$Overall\ Basin\ Ranking = Population + Population\ Growth + Public\ Supply\ Wells + (Total\ Wells\ x\ .75) + Irrigated\ Acreage + [(Groundwater\ Use + \%\ of\ Total\ Supply)/2] + Impacts + Other\ information \quad [1]$$

After each basin obtained a rank value, the basin rankings were divided into four ranges to identify the threshold under which a basin would be identified as very low, low, medium, or high priority. The resulting thresholds (Figure 5) were used to classify each basin into very low, low, medium, or high priority.

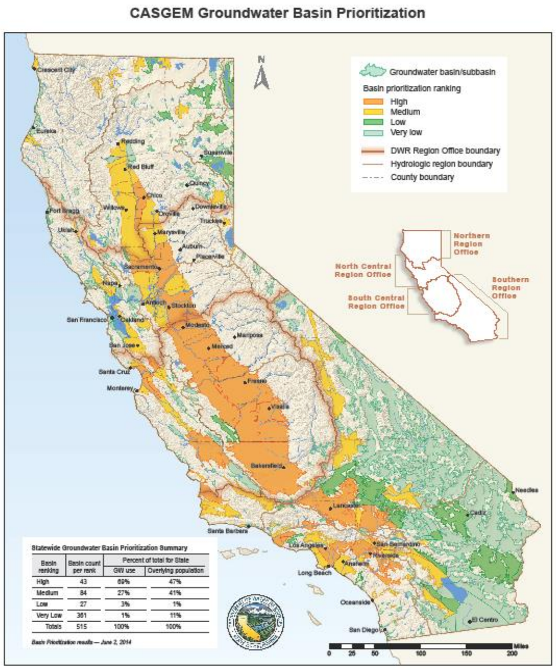


Very Low Priority Ranking Range	Low Priority Ranking Range	Medium Priority Ranking Range	High Priority Ranking Range
x < 5.75	5.75 ≥ x < 13.42	13.42 ≥ x < 21.08	x ≥ 21.08

Note: x = Overall Basin Ranking Score

Figure 5. Table used to classify each groundwater basin and subbasin as high, medium, low or very low priority (DWR 2014).

From the CASGEM Groundwater Basin Prioritization Process 43 groundwater basins were classified as high priority, 84 basins as medium priority, 27 basins as low priority, and the remaining basins from the 515 as low priority as of May 2014 (DWR 2014). Of the basins classified as high and medium priority, they are responsible for 96% of the annual groundwater pumping in California and provide water supply to 88% of the people residing over those groundwater basins (DWR 2014). The results from the CASGEM groundwater basin prioritization helped DWR identify areas that need implementation of sustainable groundwater management practices throughout the state. Figure 6 demonstrates the basins and subbasins in the state classified as high, medium, low, or very low priority through the CASGEM Groundwater Basin Prioritization Process. Areas of great concern are in the Central Valley, where much of the water demands are met through groundwater.



Statewide Groundwater Basin Prioritization Summary

Basin ranking	Basin count per rank	Percent of total for State	
		GW use	Overlying population
High	43	69%	47%
Medium	84	27%	41%
Low	27	3%	1%
Very Low	361	1%	11%
Totals	515	100%	100%

Basin Prioritization results — June 2, 2014

Figure 6. Basins and subbasins classified as high, medium, low, or very low priority (DWR 2014).

2.4 Introduction of the Sustainable Groundwater Management Act (SGMA)

The goal of the Sustainable Groundwater Management Act (SGMA) is for the groundwater basins in California to meet sustainable yield by the year 2040. California's Governor Jerry Brown signed the legislation into law in September of 2014 as an attempt to manage California's groundwater for the first time in history. Through this legislation, the State Water Resources Control Board (SWRCB) and the DWR have established a timeline with deadlines to comply with SGMA. By June of 2017, groundwater sustainability agencies (GSAs) will need to form and provide groundwater sustainability plans (GSP) by the year 2020 or 2022 for groundwater basins classified as medium or high priority respectively (Christian-Smith and Abhold 2015). Once the GSP has been approved, the GSA implement it to maintain or achieve groundwater sustainability by the year 2040 or 2042 (Christian-Smith and Abhold 2015). A groundwater basin will have reached sustainability if it has avoided six undesirable results listed by DWR. A sustainable groundwater basin will: (1) not have chronic lowering of the groundwater table, (2) not have a reduction in groundwater storage, (3) not experience seawater intrusion, (4) not experience degradation of water quality, (5) not experience land subsidence, and (6) not have depletion in groundwater/surface water interactions (DWR 2017).

The GSPs to be submitted will be more thorough and stringent than past groundwater management plans submitted to the state. Previous groundwater management plans were voluntary and unenforceable, which caused some to not improve the conditions of the groundwater basins. For some regions, groundwater users pumped as much as they wanted without regard to how stressed the aquifers were or how they would impact other groundwater users because local water agencies did not have the authority to regulate groundwater pumping. To avoid detrimental conditions, SGMA requires the GSPs to set measurable objectives aimed at reaching groundwater sustainability, including descriptions of how the objectives will be met, a physical description of the basin, monitoring and management provisions, paperwork about how the plan will include other county/city plans, as well as documentation of how the planning will encourage the involvement of various interest groups (Christian-Smith and Abhold 2015).

After the GSPs have been submitted for groundwater basins of medium or high priority, the GSPs will be reviewed within 2 years and corrections may be suggested by DWR. However, if DWR and the SWRCB see that a water plan will be insufficient or discover that the GSP is not being followed, intervention by the state may result (Christian-Smith and Abhold 2015).

2.5 Water Budgets

Water budgets are helpful for evaluating water resources management and environmental planning. A water budget utilizes the conservation of mass equation to account for all water inflows, outflows and changes in storage in a control volume. Through this process all groundwater and surface water entering and leaving the system is accounted for and ultimately leads to accounting for the change in water storage as a function of time (Joseph et al. 2016). By using a water budget, the availability and sustainability of water supplies also can be evaluated in the area of interest (Healy et al. 2007).

A water budget was used in the Beaverdam Creek Basin in Maryland to determine the proportion of rain distributed between the recharge, runoff, groundwater evapotranspiration, and groundwater storage (Healy et al. 2007). To complete the water budget, data was collected extensively for 2 years. Within this time span the water table was measured weekly, stream discharge was monitored with a sharp crested weir, the change in water storage of the ponds found in the watershed were calculated based off stage readings, precipitation data was collected from precipitation gauges, pan evaporation was measured, and soil moisture content was determined weekly by electrical resistance (Healy et al. 2007). With the abundance of data, a detailed water budget was developed in which the apportionment of precipitation was estimated. From the detailed accounting it was found that 60% of the rainfall became evapotranspiration, 37% of the rainfall left the watershed as streamflow, and only 3% of rainfall increased the surface and subsurface storage (Healy et al. 2007). Furthermore, the resulting recharge in the watershed was estimated by using the water table data collected from the monitoring wells. It was determined that in the time span of 2 years, 42.5 inches of recharge occurred, where 21.5 inches contributed to base flow, 1.7 inches increased the groundwater storage, and 19.5 inches became evapotranspiration of groundwater (Healy et al. 2007). A water budget done on a small scale basin can provide a lot of insight on where water is coming from and where it ends up.

With respect to water management, a water budget has been constructed in the past for the Arroyo Seco Watershed to evaluate water use in the area and to determine ways that water management can be improved upon. The Arroyo Seco Watershed is located in Southern California in which its water sources come from precipitation, imported water (the Eastern Sierra Nevada, the Colorado River, and the Sacramento River), and the Raymond Basin (Brick 2003). The water budget created for the Arroyo Seco Watershed was developed using a spreadsheet model that included data available for precipitation, infiltration, runoff, and water supply studies and plans for the region from agencies such as the U.S. Geological Survey and the Los Angeles Department of Water and Power (Brick 2003). For the water budget, the water inflows considered included imported water supplies, septic tank recharge, recharge from applied water, and precipitation. For the water outflows, the items considered included surface water diversions, outflow to the Los Angeles River, water production and sales, subsurface flow, and evapotranspiration. By quantifying all water inflows and outflows of the Arroyo Seco Watershed the interaction between the water sources and water demands could be evaluated to generate a preliminary understanding of the area. The creation of the water budget can help create awareness in the community of each component of the hydrologic cycle while simultaneously providing a characterization of the watershed that supports strategic water management plans. As a result of the water budget study, items were recommended that included expanding on the water conservation and water recycling programs as well as promoting conjunctive use in the region.

With respect to SGMA, developing a water budget will provide understanding on how the water supply, water demand, hydrology, climate, land use, and population of the groundwater basin relate to the six sustainability objectives (Joseph et al. 2016). Its main purpose will be to evaluate the conditions of the groundwater basin, identify undesirable results, help set sustainability criteria, guide in creating monitoring networks, and suggest future projects for improving water management to maintain and achieve groundwater sustainability when drafting the GSP (Joseph et al. 2016).

3. Case of Study: Ukiah Valley Groundwater Basin

The Ukiah Valley Groundwater Basin is in Mendocino County, in the Russian River Watershed (Figure 7). This groundwater basin is approximately 37,531 acres, overlies the Redwood and Ukiah Valley, and is the largest groundwater basin on the Russian River (DWR 2004).

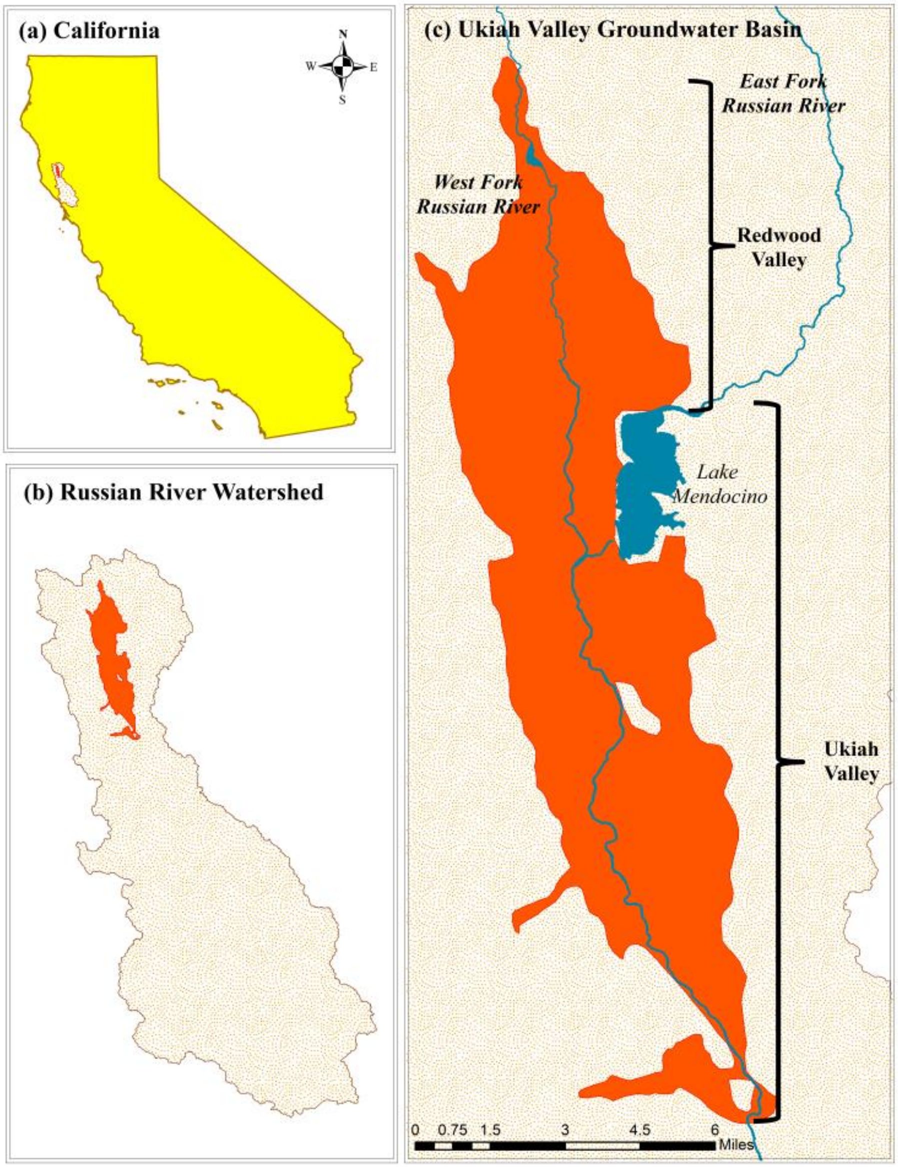
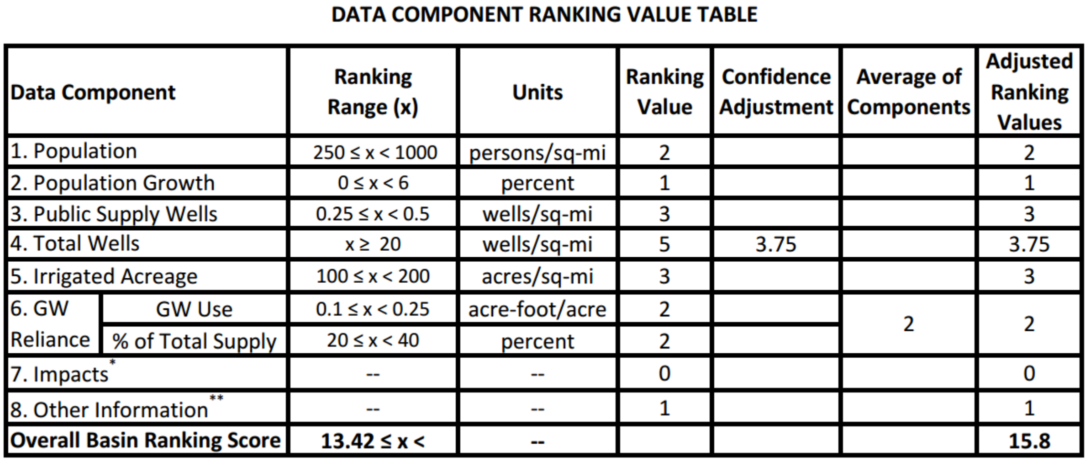


Figure 7. The Ukiah Valley Groundwater Basin (c) located in (a) California and (b) within the Russian River Watershed.

From the CASGEM groundwater basin prioritization process, the Ukiah Valley Groundwater Basin was classified as medium priority. The classification as a medium priority basin resulted because a ranking of 15.8 was obtained from the scores that the groundwater basin received when it was evaluated based on the variables listed in section 2.3.1 (Figure 8).



DATA COMPONENT RANKING VALUE TABLE

Data Component		Ranking Range (x)	Units	Ranking Value	Confidence Adjustment	Average of Components	Adjusted Ranking Values
1. Population		250 ≤ x < 1000	persons/sq-mi	2			2
2. Population Growth		0 ≤ x < 6	percent	1			1
3. Public Supply Wells		0.25 ≤ x < 0.5	wells/sq-mi	3			3
4. Total Wells		x ≥ 20	wells/sq-mi	5	3.75		3.75
5. Irrigated Acreage		100 ≤ x < 200	acres/sq-mi	3			3
6. GW Reliance	GW Use	0.1 ≤ x < 0.25	acre-foot/acre	2		2	2
	% of Total Supply	20 ≤ x < 40	percent	2			
7. Impacts*		--	--	0			0
8. Other Information**		--	--	1			1
Overall Basin Ranking Score		**13.42 ≤ x <**	**--**				**15.8**

Figure 8. Summary of the results obtained for the Ukiah Valley Groundwater Basin as a result of the CASGEM Groundwater Basin Prioritization Process (DWR 2014).

Since the Ukiah Valley Groundwater Basin was classified as medium priority, it must comply with implementing SGMA. Consequently, a GSA structure has been proposed in which it will consist of 6 members representing different stakeholder groups and agencies (Figure 9). It will also have a technical advisory committee. This GSA will consist of the Upper Russian River Water Agency, the Russian River Flood Control and Water Conservation Improvement District, the City of Ukiah, the County of Mendocino, an agricultural seat, and a Tribal seat. The technical advisory committee will consist of Sonoma County Water Agency, the Mendocino County Resource Conservation District, and representatives from each stakeholder and agency making up the GSA. Following the formation of the GSA, the next step is to create a GSP, but before the GSP can be constructed it is necessary to characterize the groundwater basin by estimating a water budget. Ultimately, the water budget will provide insight on the historical and current groundwater trends, in addition to identifying the degree to which the groundwater basin may or may not be in balance. The results from this water budget will provide the foundation for future water management projects, while also providing an initial direction on how the GSA will advance in developing monitoring protocols and integrated water resources management strategies to achieve and maintain groundwater sustainability. The following describes the water resources of the region and the major water entities that supply water for municipal and agricultural water demands.

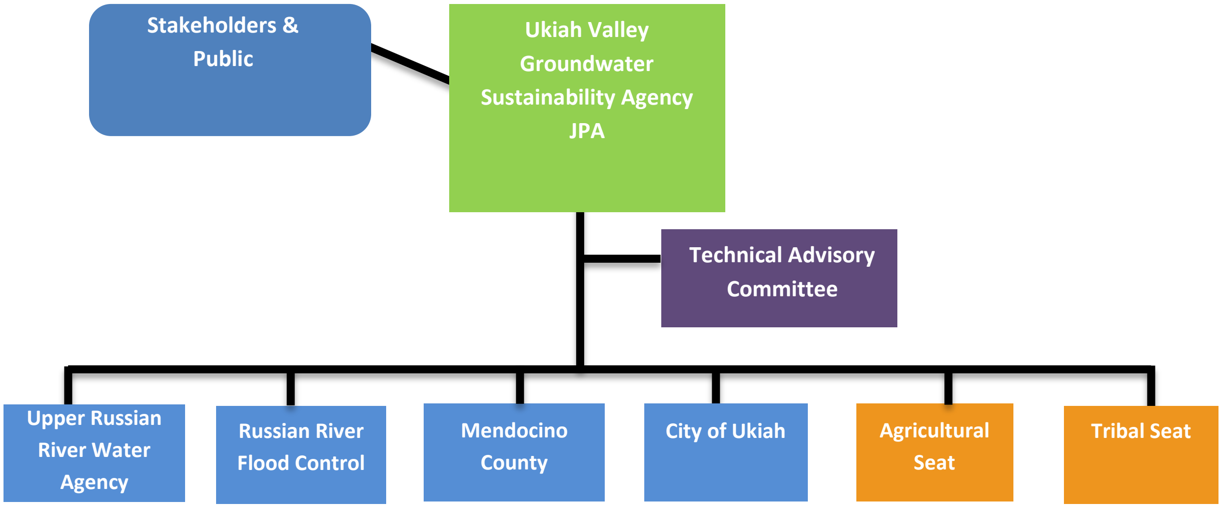


Figure 9. GSA structure for the Ukiah Valley Groundwater Basin.

3.1 Water Sources

3.1.1 Precipitation

Most of the precipitation in the Ukiah Valley Groundwater Basin falls from November to April. The climate is Mediterranean, where the summers are hot and the winters are cold and wet.

3.1.2 Surface Water

The surface water supply is from the Russian River, surface water stored in Lake Mendocino, and from water imported from the Eel River through the Potter Valley Hydroelectric Project (PVHP). The Russian River flows over the groundwater basin where the East Fork and the West Fork of the Russian River converge near the City of Ukiah. As the Russian River flows over the groundwater basin, several tributaries feed into it. As a result of the PVHP, diversions from the Eel River to the East Fork of the Russian River occur through a tunnel. Diversions began in 1908, and since then this water has flowed into Lake Mendocino (Cardwell 1548). Lake Mendocino and Coyote Valley Dam are located on the East Fork of the Russian River and they provide flood control, water supplies, recreation, water storage, and power generation, but ultimately Coyote Valley Dam regulates the flow of the East Fork of the Russian River (MCWA 2010).

3.1.3 Groundwater

The groundwater supply comes from the Ukiah Valley Groundwater Basin. Communities in Ukiah Valley are groundwater dependent, whereas the communities in Redwood Valley depend on surface water. The controversial aspect is whether the groundwater is classified as underflow from the Russian River (DWR 2014).

Overall, the Ukiah Valley Groundwater Basin has a reported storage capacity of 324,000 AF, with 90,000 AF of available storage recharged each year primarily from precipitation (MCWA 2010). From historical groundwater elevation measurements, the groundwater basin has been relatively stable since the 1960's (MCWA 2010). Seasonally, fluctuations have been observed in which the water table will be at its highest in March or April and at its lowest during October (MCWA 2010).

3.2 Water Entities

The Ukiah Valley Groundwater Basin is comprised of seven water entities that supply water to the region (Figure 10). The following is a description of each water entity.

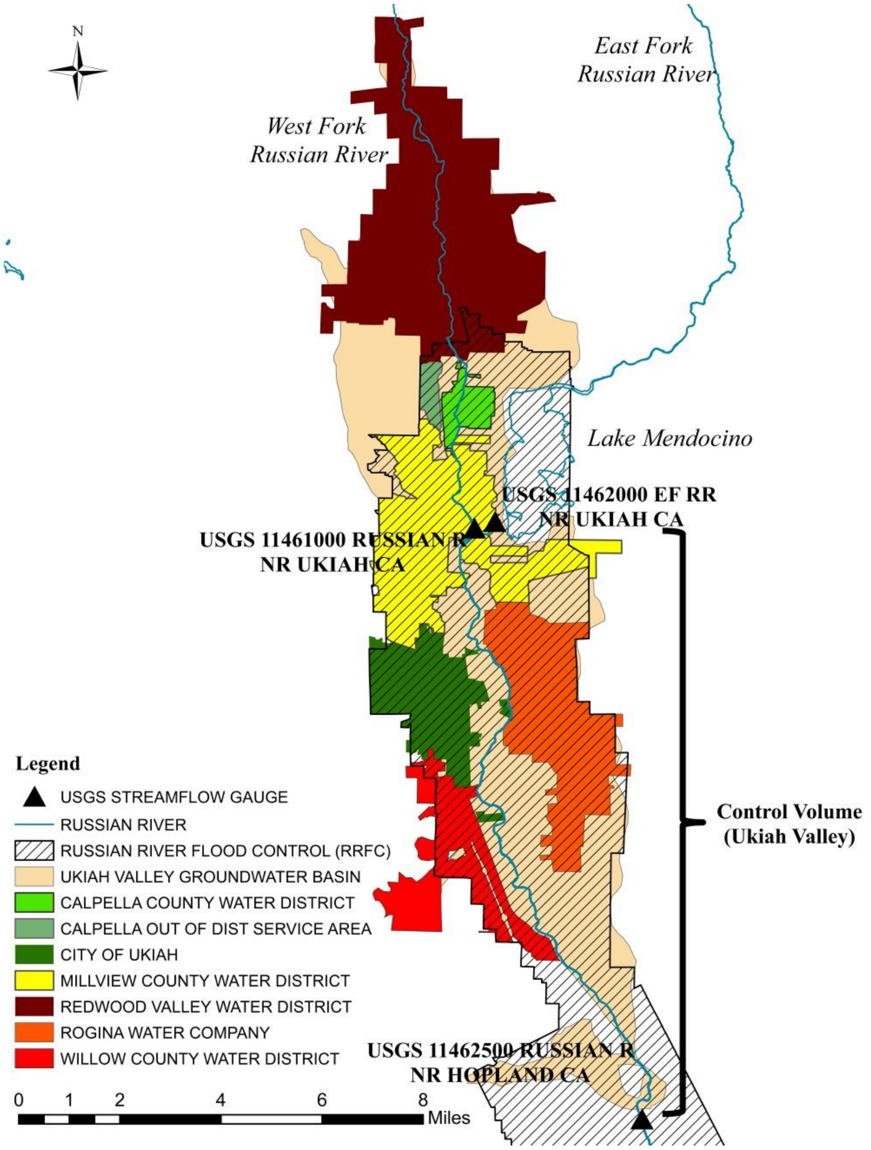


Figure 10.Water entities and USGS streamflow gauges located in the Ukiah Valley Groundwater Basin.

3.2.1 Calpella County Water District

Calpella County Water District is the smallest water district in the area that serves about 140 residential and 25 commercial connections (MCWA 2010). The water supplied to the community of Calpella and the surrounding areas comes from a groundwater well with a capacity of 25 gallons per minute, whereas the remaining water supplies are from a Russian River Flood Control and Water Conservation Improvement District (RRFC) contract to purchase 51 AF/y of surface water (MCWA 2010). Millview County Water District will obtain the surface water from RRFC and transfer it to Calpella County Water District.

3.2.2 City of Ukiah

The City of Ukiah is a public water service provider to approximately 5,800 connections (MCWA 2010). Its water is from groundwater and surface water. For groundwater, the city currently has 4 active wells (WYA 2016). For surface water, 800 AF/y of surface water can be purchased from RRFC under a contract and the remaining surface water supplies are obtained through the City’s water right (MCWA 2010). In some cases, the City of Ukiah may obtain emergency water supplies from the Millview and Willow interties (MCWA 2010). The City’s water right is to divert 14,480 AF/year from the Russian River between January 1 to December 31 at a maximum diversion rate of 20 cfs (MCWA 2010).

3.2.3 Millview County Water District

Millview County Water District serves to about 1,300 residential connections and 210 commercial connections (MCWA 2010). In addition, it wheels RRFC surface water to Calpella County Water District (MCWA 2010). The water supply for Millview County Water District comes from RRFC or from water rights. From the water rights, approximately 1,522 AF/y of surface water and underflow can be obtained (LAFCO 2016). These are junior water rights, so during drought Millview County Water District may lack water due to low flow in the Russian River. From RRFC Millview County Water District can purchase up to 1,520 AF/y of surface water (MCWA 2010).

3.2.4 Redwood Valley County Water District

Redwood Valley County Water District provides water for residential, commercial and agricultural uses. About a third of all water use is for municipal and commercial water demands. Redwood Valley County Water District supplies surface water from diversions from Lake Mendocino or from surplus water sold to them from the Russian River Flood Control and Water Conservations Improvement District (MCWA 2010). Redwood Valley County Water District has also obtained water from other sources. From 2005 to 2010 surface water was obtained through a contract with Sonoma County Water Agency and in 2015 to meet domestic water demands, groundwater from well 6, near Millview County Water District, was obtained. Through their own water right, up to 4,900 AF/y of surface water may be diverted from Lake Mendocino from November 1 to April 30 when the flow at the confluence of the East Fork and West Fork of the Russian River is above 150 cfs and the storage in Lake Mendocino is greater than 72,000 AF (MCWA 2010). Essentially, Redwood Valley County Water District has a relatively un-exercisable water right.

3.2.5 Rogina Water Co.

Rogina Water Company is a private water company that provides water to a small service area of about 990 connections (MCWA 2010). The water supply obtained is from a RRFC contract to purchase 400 AF/y of surface water while the rest of their water supplies comes from their groundwater wells (MCWA 2010). However, the water pumped may actually be underflow from the Russian River.

3.2.6 Russian River Flood Control and Water Conservation Improvement District

The Russian River Flood Control and Water Conservation Improvement District (RRFC) serves a great portion of the Ukiah Valley Groundwater Basin. RRFC along with Sonoma County Water Agency sponsored the development of Coyote Valley Dam and Lake Mendocino (MCWA 2010). As a result of the water right permit 12947B, the RRFC can divert 8,000 AF/y within the RRFC service area to provide water for domestic, municipal, irrigation and recreational use (MCWA 2010). Although, the RRFC has access to 8,000 AF/y of surface water, rarely will it use its full water allocation. RRFC sells raw water to the City of Ukiah, Redwood Valley County Water District, Millview County Water District, Calpella County Water District, Rogina Water Co, Willow County Water District and other contractors for municipal water demands, irrigation, and frost protection.

3.2.7 Willow County Water District

Willow County Water District provides water to a service area of 990 residential connections and 60 commercial connections (MCWA 2010). The water supply comes from a water contract with the RRFC where 515 AF/y of surface water can be purchased, whereas the remaining water supply is from appropriative water rights (MCWA 2010). Under one water right, up to 1,400 AF/y of surface water may be diverted between November 1 and July 1 at a maximum rate of 3 cfs when the stream flow in the Russian River is or exceeds 150 cfs at the point where the diversion occurs (MCWA 2010). Under the second water right, 728 AF/y of surface water may be diverted from January 1 to December 31 at a maximum rate of 1 cfs (MCWA 2010). In dry years, Willow County Water District may find it difficult to exercise its water rights since they are junior water right holders. During dry years, the Russian River may not have the flow needed for Willow County Water District to divert surface water.

4. Method

4.1 Introduction

A water budget was developed on a monthly time step from 1991 to 2015 for the Ukiah Valley Groundwater Basin. For the purposes of this study the area that lies in the Redwood Valley County Water District is identified as Redwood Valley, whereas the area south is referred to as Ukiah Valley (Figure 7).

The interactions that occur between the water sources and water supplies in the Ukiah Valley Groundwater Basin (Figure 11) are captured in the framework used to develop the water budget (Figure 12). First, calculations associated with the agricultural water use are estimated to obtain the water use and drainage from agricultural water use, and the recharge resulting from precipitation and irrigation. Second, a surface water mass balance is completed using the conservation of mass equation to estimate the surface water gains and losses. Third, the change in groundwater storage is estimated from 1991 to 2015. Fourth, a groundwater mass balance is completed using the conservation of mass equation to obtain the lateral groundwater inflows and outflows. The groundwater mass balance utilizes the already calculated variables of recharge from precipitation and irrigation, surface water gains and losses, and the change of groundwater storage.

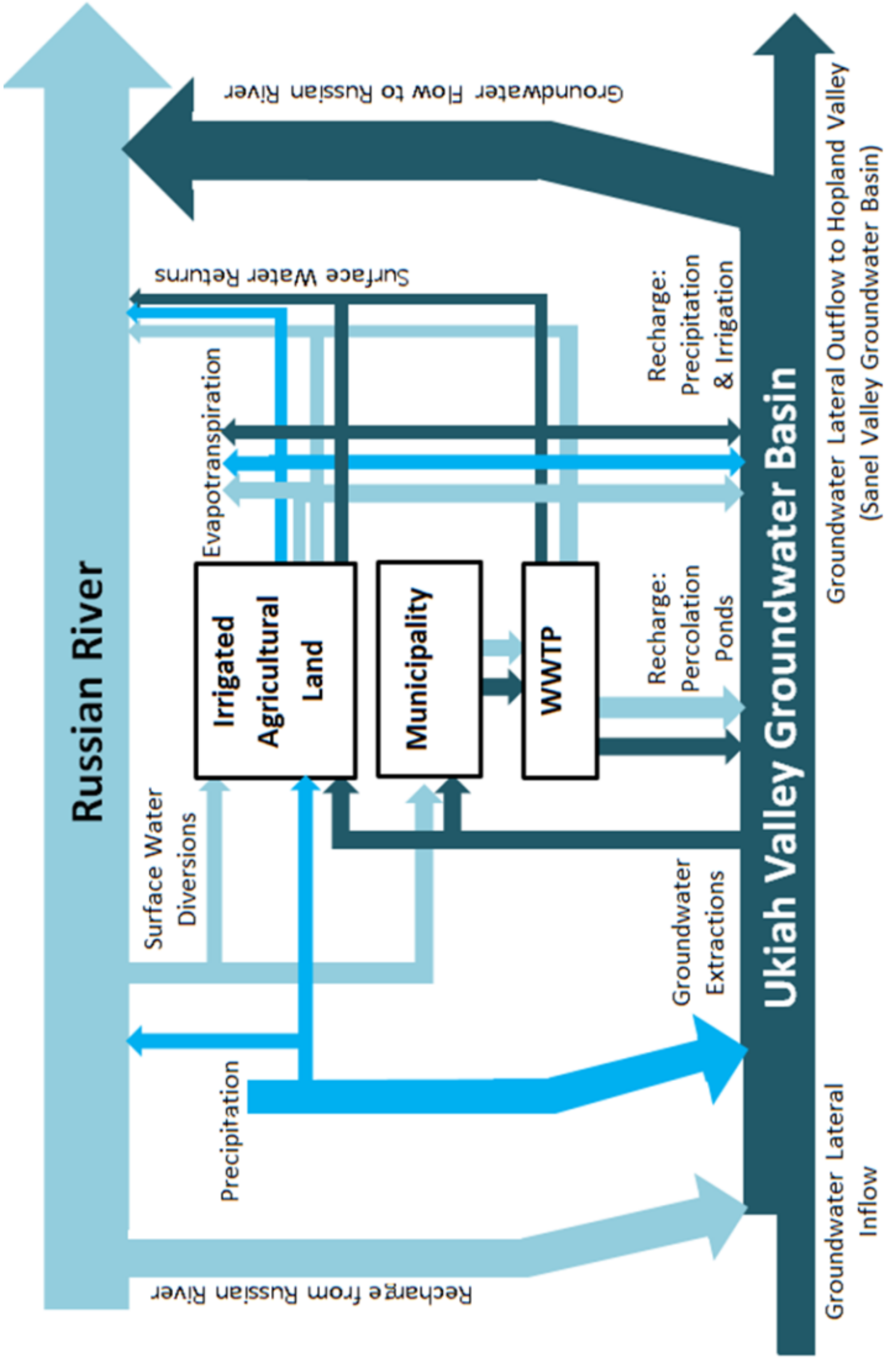


Figure 11.Surface water-groundwater conceptual model for the Ukiah Valley Groundwater Basin.

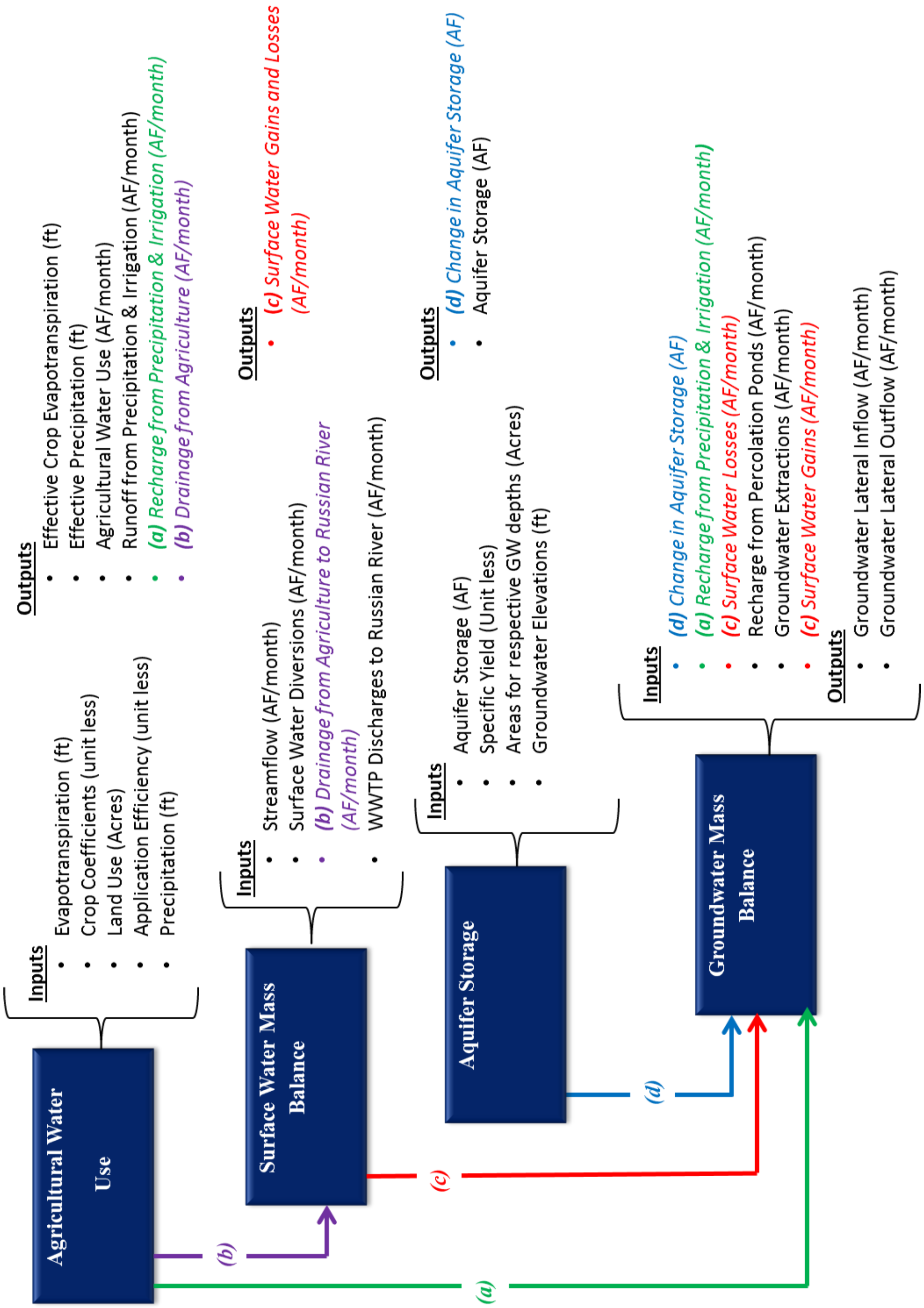


Figure 12. Framework followed for constructing the water budget.

4.2 Agricultural Water Use

4.2.1 Inputs

4.2.1.1 Land Use

The land use overlying the Ukiah Valley Groundwater Basin was obtained from Mendocino County’s Agricultural Commissioner and County Sealer of Weights and Measures (Chuck Morse, personal communication, 2016). From annual records, land use data was obtained from 1991-2015 for Redwood Valley and Ukiah Valley. For the year 2001 there was no data available and so the average between the land use values found in the years 2000 and 2002 was taken and used to represent the missing data. In receiving the land use data, two separate datasets were obtained that had slight differences on the number of crop acres reported. One data set contained data from 1990-2012 whereas the second data set contained data from 2006-2015. To address the discrepancy between the reported acres of grapes (red wine and white wine grapes), acres of pears (Bartlett), acres of pears (other), and acres of olives in the Ukiah Valley, the acreage in the 1990-2012 dataset was used for the years 1990 to 2005, whereas the 2006-2015 dataset was used for the years 2006 to 2015. The assumption was that the values reported on the latest dataset contained the updated acreage. For Redwood Valley, the discrepancy between the reported acres of grapes (white wine and red wine grapes) and acres of olives was addressed similarly. Appendix C, D, and E shows the land use data that was used in the study.

4.2.1.2 Crop Coefficients

A crop coefficient is the ratio of the evapotranspiration observed for a crop over the reference evapotranspiration of a well-watered grass maintained under standards conditions (NRMED). For this study crop coefficients were required for apples, cherries, red wine grapes, white wine grapes, grapes (rootstock), olives, Bartlett Pears, pears (other), pistachios, walnuts, pasture, and raisins. The crop coefficients used for the white wine grapes, red wine grapes, raisins, and grapes (rootstock) were obtained from Glenn McGourty, a University of California Division of Agriculture and Natural Resources Adviser that specializes in Viticulture and Plant Science. For walnuts, pistachios, olives, apples, and pears the crop coefficients used were obtained from Schwankl et al. (2010). For the few cherries present, the crop coefficient values found for stone fruit (Schwankl et al. 2010) were applied. For pasture, the initial crop coefficient value of 0.95 stemmed from the Consumptive Use Program PLUS (CUP+). After contacting John Harper, a Strategic Initiative Leader-Sustainable Natural Ecosystems, Livestock and Natural Resources Adviser for the University of California Cooperative Extension, the time frame under which the crop coefficient was applied was adjusted to be from May to October. After determining the applied water required for each crop (AF/acre), the calculated values for pasture, vineyards, and pear orchards was compared to the published values in Lewis et al. (2008). First, the applied water values that were calculated for vineyards and pear orchards was in agreement with the values published in Lewis et al. (2008), meaning that the crop coefficients from Schwankl et al. (2010) and the crop coefficient values suggested through expert consultation (Glenn McGourty, personal communication, 2016) were adequate to use. Second, to further verify the validity of the chosen crop coefficients, the applied water values estimated for all the crops was compared with Mendocino County values that are reported to the state (DWR 2017). The applied water values estimated agreed with the values reported by the county to the state further suggesting the crop coefficients used were acceptable. For pasture, the applied water estimated was higher than what was published in Lewis et al. (2008) and the values reported by the county to the state. The crop coefficient value of 0.95 for pasture was thus adjusted to 0.8

until the estimates of applied water for pasture were close to the values reported by the county and in Lewis et al. (2008). The crop coefficients used in the study are found in Appendix B.

4.2.1.3 Evapotranspiration

Evapotranspiration is the process that involves transpiration and evaporation of a determined crop to meet its water needs. In transpiration plants lose water to the atmosphere, whereas evaporation is the process by which the land surfaces and bodies of water loose water into the atmosphere. For this study Equation [2] was used to estimate monthly evapotranspiration of the various crops found in the Ukiah Valley Groundwater Basin. In calculating the evapotranspiration, the crop coefficients identified and the reference evapotranspiration of the study area is used.

$$ET_{ijk} = Kc_{jk} \times ETo_{ij} \qquad [2]$$

In Equation [2], ET_{ijk} signifies the evapotranspiration in feet for a given crop k in a given month j in year i. The term Kc_{jk} represents the crop coefficient a dimensionless term for a given crop k in a given month j. The term ETo_{ij} represents the reference evapotranspiration in feet for a given month j in a given year i. In using this method, crop growth and the evapotranspiration that stems from salinity stress, crop density, pests, disease, weed infestation or low fertility was not limited (NRMED). The reference evapotranspiration values used for this study were obtained monthly from the California Irrigation Management Information System (CIMIS) Station 106 in Sanel Valley from February 1991 to December 2015. To obtain the January 1991 value, the median of the January values from 1992 to 2015 was taken. The reference evapotranspiration values used can be found in Appendix A.

4.2.1.4 Precipitation

Precipitation can be classified as effective rainfall or net rainfall. Effective rainfall is the amount of rain that can be used by crops to meet their agricultural water demands. If the amount of precipitation from a given storm event is not enough to meet the agricultural water demands, additional water through irrigation must be applied. Net rainfall is defined to be the total amount of water available from a given storm event.

Since precipitation in the Ukiah Valley Groundwater Basin varies from the northern portion of the basin (45 in) to the southern portion of the basin (35 in), the Thiessen polygons method for precipitation was used (DWR 2004). Through the Thiessen polygons method for precipitation and the use of Geographic Information System (GIS) software, the average rainfall found monthly over the Ukiah Valley Groundwater Basin was obtained.

For the Thiessen polygon method, monthly precipitation data from 1991 to 2015 was obtained from the CIMIS Sanel Valley Station 106, the California Data Exchange Center (CDEC) weather station found near Lake Mendocino (COY), and from the CDEC weather station located near the City of Ukiah (UKH). Data from these weather stations was obtained because they had complete data sets from 1991 to 2015 and because they are all found in the valley at an elevation lower than 1000 ft. Data from weather stations at higher elevations was not considered since it could skew the generated precipitation results and thus not provide an accurate representation of the average rainfall over the valley. The resulting precipitation data used in the study can be found in Appendix F. Although the average rainfall over the Ukiah Valley Groundwater Basin was estimated, it should be noted that the values estimated are averages and may not truly represent the actual rainfall trends throughout the whole groundwater basin. It is assumed that the estimated rainfall occurs throughout the whole groundwater basin when there is a possibility that some areas may not have received as much rain for a given time period.

4.2.1.5 Application Efficiency

Application efficiency is the ratio of the average water depth to the water depth targeted during an irrigation event (Sandoval-Solis et al. 2013). The application efficiency values used for this study were based off Lewis et al. (2008). From Lewis et al. (2008), system uniformity values for grape vineyards and pear orchards are provided (Table 1). The average value provided for grape vineyards, 88.8%, was used to describe the application efficiency for vineyards occurring in 1991. This value was interpolated linearly and annually until a value of 92% was obtained for the year 2015. This was done since the irrigation systems used are expected to become more efficient with time. For the past three decades, farmers have significantly conserved water in the Mendocino County portion of the Russian River Watershed where the Ukiah Valley Groundwater Basin is nestled. This has been the case because they have relied on more efficient irrigation systems that include drip irrigation for vineyards and under canopy sprinkler systems for pear orchards (Lewis et al. 2008). Given the efficient irrigation practices in the area, the application efficiency for pear orchards was estimated similarly. The average value provided for the pear orchards, 88.4% (Table 1), was used to describe the application efficiency for pear orchards in 1991. This value was interpolated linearly and annually until a value of 90% was obtained for the year 2015. The application efficiency values for pasture were also estimated given that gravity type underground pipe and valve sprinkler delivery systems are used to irrigate pasture (Lewis et al. 2008). Sandoval-Solis et al. (2013), estimated application efficiency values for various crops in different counties by using the 2001 and 2010 irrigation surveys. Using the data provided for Mendocino County (Table 2) the average value of 69.3% from the 2010 irrigation survey was used to describe the application efficiency for pasture in the year 1991. This value was interpolated linearly and annually until the maximum application efficiency value of 78 % (Table 2) was obtained for the year 2015.

Once a set of annual application efficiency values was obtained for grape vineyards, those values were applied to the white wine grapes, red wine grapes, grapes (rootstock), and grapes for raisins to describe their irrigation trends. Similarly, the annual application efficiency values found for pear orchards was applied to the few apple, cherry, olive, and pistachio orchards in the area. It was thus assumed that all the grape vineyards in the region have the same application efficiency trends, while all the orchards in the area were assumed to all share the same application efficiency trends. Given the amount of assumptions done to estimate the application efficiency of the crops in the Ukiah Valley Groundwater Basin, the authors from Lewis et al. (2008) were contacted to review and improve upon the original assumptions made to obtain a set of application efficiency values representative of the area. The application efficiency values used for this study can be found in Appendix G.

Table 1. Application efficiency values for grape vineyards and pear orchards (Lewis et al. 2008)

Crop	Mean	Standard Deviation	Minimum	Maximum
Grapes	88.8	7.5	64.3	96.0
Pears	88.4	5.5	81.9	94.3

Table 2. Application efficiency values for pasture obtained for Mendocino County (Sandoval-Solis et al. 2013) .

Year	Crop	Mean AE %	Low AE %	High AE %
2001	Pasture	73	60.6	83
2010	Pasture	69.3	58.4	78

4.2.2 Outputs

4.2.2.1 Effective Crop Evapotranspiration

The effective crop evapotranspiration represents the irrigation water requirement or the depth of water that a crop requires. It is defined as the difference between the crop water requirement, the quantity of water needed to compensate for the losses that result from evapotranspiration, and the effective precipitation (Allen et al. 1998). Using expression [3] the effective crop evapotranspiration is estimated for each crop on a monthly time step for Ukiah Valley and Redwood Valley.

$$ET_{ijk} - p_{ij} \qquad [3]$$

ET_{ijk} is the evapotranspiration in feet for a given crop k in a given month j in year i, whereas the term p_{ij} represents precipitation in feet in a given month j and year i.

4.2.2.2 Effective Precipitation

The effective precipitation is the amount of precipitation used to meet the crop water requirement. Expression [4] is used to determine the effective precipitation for Ukiah Valley and Redwood Valley. The term p_{ij} represents precipitation in feet in a given month j and year i and the term ET_{ijk} represents the evapotranspiration in feet for a given crop k in a given month j in year *i*.

$$p_{ij} - ET_{ijk} \tag{4}$$

4.2.2.3 Agricultural Water Use

The agricultural water use was estimated for Ukiah Valley, Redwood Valley, and ultimately for the entire Ukiah Valley Groundwater Basin. By estimating the agricultural water use, the applied water required to meet the agricultural water use is estimated. To estimate the monthly agricultural water use Equation [5] is used, whereas to estimate the annual agricultural water use Equation [6] is used.

$$WD_{ij} = \sum_{k=1}^{K} \left(\frac{ET_{ijk} - p_{ij}}{AE_{ik}} \times \ A_{ik}\right) \tag{5}$$

$$WD_i = \sum_{j=1}^{J} WD_{ij} \tag{6}$$

For this set of equations, WD_{ij} represents the water use of irrigation in acre feet for a given month j and year i for every crop k. The term WD_i represents the annual water use in acre feet in a year i that is representative of the sum of all of the agricultural water use obtained for each crop for a given water year. The term A_{ik} represents the area in acres of a given crop k found in year i. The term ET_{ijk} is the evapotranspiration in feet for crop k in a given month j and year i, whereas p_{ij} represents the precipitation in feet in a given month j and year i. Lastly, AE_{ik} represents the application efficiency for crop k in a given year i. In estimating the agricultural water use, it was assumed that no land use changes occurred for the given year.

In estimating the agricultural water use for the crops found in the Ukiah Valley Groundwater Basin, it was assumed that only 90% of the grapes are irrigated (Lewis et al. 2008). This assumption was confirmed with expert consultation (Glenn McGourty, personal communication, 2016).

Based on personal communication with Rachel Elkins, a University of California Division of Agriculture and Natural Resources Pomology Adviser in Lake and Mendocino County, it was also assumed that the few walnut orchards in the region are dry irrigated.

4.2.2.4 Runoff from Precipitation and Irrigation

To estimate the amount of runoff that results from a storm event in Ukiah Valley and Redwood Valley, Equation [7] is used. The term r'_{ij} represents the runoff that results from precipitation in a given month *j* and year *i*. The term ET_{ijk} represents the evapotranspiration in feet for a given crop k in a given month *j* in year *i*, whereas the term p_{ij} represents precipitation in feet in a given month *j* and year *i*. The term α_{ij} is the runoff factor that occurs in month *j* in year *i*. The runoff factor was assumed to be 3% based on expert consultation (McGourty, personal communication, 2016) and by the amount of runoff that was observed during the extent of the project (Fall 2015 to spring 2017) in the Ukiah Valley Groundwater Basin.

$$r'_{ij} = \left(p_{ij} - ET_{ijk}\right) \times \alpha_{ij} \qquad [7]$$

Similarly, runoff that results from irrigation r''_{ij} in acre feet is estimated using Equation [8]. As defined earlier WD_{ijk} is the agricultural water use resulting for a given month *j* and year *i* and crop k, whereas AE_{ik} represents the application efficiency for crop *k* in a given year *i*. Term α_{ij} holds the same definition and value as defined for Equation [7].

$$r''_{ij} = \left[WD_{ijk} \times (1 - AE_{ik})\right] \times \alpha_{ij} \tag{8}$$

4.2.2.5 Recharge from Precipitation and Irrigation

For this study, the soil moisture content is not considered, thus after the crop water requirement has been met and runoff has been generated, the precipitation that is in excess will percolate into the aquifer. Equation [9] describes the recharge that may occur in Redwood Valley and Ukiah Valley as a result of precipitation.

$$RP_{ij} = \left(p_{ij} \;-\; ET_{ijk} \;- r'_{ij}\right) \times A_{ik} \tag{9}$$

The term RP_{ij} represents the recharge that occurs from precipitation in acre feet in a given month j and given year i. The term p_{ij} represents the amount of precipitation in feet that is present in a given month j and given year i. The term A_{ik} is representative of the area in acres of a given crop k in a given year i. The term ET_{ijk} is the evapotranspiration in acre feet for a crop k in a month j and in year i, whereas the term r'_{ij} is the surface runoff that occurs as a result of precipitation for a given month j and year i.

Similarly, Equation [10] is used to estimate the recharge in Redwood Valley and Ukiah Valley that results from irrigation. The term WD_{ijk} is the water use in acre feet that results for a given crop k in a given month j and given year i, whereas the term AE_{ik} represents the application efficiency of a given crop k in a specific year i. Lastly, the term r''_{ij} represents the surface runoff that results from irrigation for a given month j and given year i.

$$RI_{ij} = \sum_{k=1}^{K} \left[WD_{ijk} \times \; (1 - AE_{ik})\right] - r''_{ij} \tag{10}$$

To estimate total recharge from irrigation and precipitation for a given month *j* and year *i*, Equation [11] is used. To estimate total annual recharge from precipitation and irrigation Equation [12] is used. From the expressions the term R_{ij} is the total recharge that results in acre feet in a given month *j* and year *i*. The term R_i represents the total recharge in acre feet in a given year *i*, whereas the terms RP_{ij} and RI_{ij} are representative of the recharge, in acre feet, respectively from precipitation and irrigation for a given month *j* and year *i*.

$$R_{ij} = RP_{ij} + RI_{ij} \tag{11}$$

$$R_i = \sum_{j=1}^{J} R_{ij} \tag{12}$$

4.2.2.6 Agricultural Drainage

Agricultural drainage is the excess water removed from irrigated agricultural land by surface ditches and/or subsurface permeable pipes (Busman and Sands 2002). For the Ukiah Valley Groundwater Basin it was assumed that 3% of the water that is applied to meet agricultural water use, whether it stems from groundwater or surface water sources, results in agricultural drainage for consistency with runoff from storms and irrigation. In addition, 3% of water applied to meet frost protection, post-harvest applications, and heat protection also became agricultural drainage. The agricultural drainage that results in Ukiah Valley and Redwood Valley is estimated from 1991 to 2015 on a monthly time step.

4.3 Frost Protection, Post Harvest Application, and Heat Protection

In the Ukiah Valley Groundwater Basin, surface water is used for frost protection, post-harvest applications, and heat protection. For orchards and vineyards located at an elevation lower than 700 ft, water is applied for frost protection during times of radiant frost which usually occurs from March to May (Lewis et al. 2008). To increase the carbohydrate storage and to germinate the cover crop seed bank, post-harvest water applications can be applied to vineyards from September to October (Lewis et al. 2008). In times of extreme heat, usually July and August, water can be applied to vineyards for heat protection (Lewis et al. 2008). Although frost protection, post-harvest application, and heat protection occur in the Ukiah Valley Groundwater Basin, it is unclear how often farmers use water for frost protection, post-harvest application, and heat protection it depends on the irrigation systems and the availability of surface water that farmers have access to (Lewis et al. 2008). For this study the amount of water used for frost protection, post - harvest application, and heat protection was estimated and accounted for in the water budget.

To estimate the quantity of water used for frost protection in Ukiah Valley, Redwood Valley and ultimately in the Ukiah Valley Groundwater Basin, the number of frost events was identified by (Silva-Jordan 2016), who estimated the number of frost events in Redwood Valley and in Hopland from historical meteorological data. Frost events in Hopland were assumed to occur in Ukiah Valley. It was then assumed that 2,155 acres of vineyards required frost protection annually in Ukiah Valley and 548 acres of vineyards in Redwood Valley required frost protection annually since the actual number of acres is unknown from year to year. In addition, the application rate of 50 gallons/min/acre was assumed. These assumptions were obtained from Lewis et al. (2008) for Ukiah Valley and Redwood Valley. Frost protection is also applied to pear orchards so it was assumed that 649 AF/y of water is applied for frost protection in Ukiah Valley and 55 AF/y in Redwood Valley. The 649 AF/y value was divided evenly between the number of frost events occurring in Ukiah Valley and the 55 AF/y value was divided evenly between the number of frost events seen in Redwood Valley. The frost protection applied to pear orchards was derived from Lewis et al. (2008).

To estimate the annual quantity of water used for post-harvest application, it was assumed that only one post harvest event occurred each year and that the resulting water used in Ukiah Valley and Redwood Valley was 60 AF/y and 149 AF/y, respectively. These assumptions resulted from Lewis et al. (2008). For this study it was assumed that the post-harvest application event always occurred in September of every year.

Finally, to estimate the annual quantity of water used for heat protection, it was assumed that 5 heat events occurred where the total water used was 149 AF/y in Ukiah Valley and 57 AF/y in Redwood Valley. These assumptions resulted from Lewis et al. (2008). For this study it was assumed that the heat events occurred in July of every year with the assumption that July is the warmest month of the year.

Given the assumptions, a time series of how much water may be used annually for frost protection, post-harvest application, and heat protection was estimated for Ukiah Valley and Redwood Valley. After comparing the water use and water supplies in Ukiah Valley, it was seen that the estimates of frost protection, post-harvest application, and heat protection could be covered with the water supplies available. The resulting quantities of frost protection, post harvest application, and heat protection were thus considered in the water budget analysis. For Redwood Valley, there were some years, year 2013 and 2014, that the water supplies was not be enough to cover the frost protection, post-harvest application, and heat protection. For those years, it was assumed that no frost protection, post-harvest application, and heat protection occurred. This assumption can be supported by the fact that there was a drought during that time frame and it is likely that Redwood Valley County Water District and private water users in Redwood Valley did not have access to as much surface water in those years to meet frost protection, post-harvest application, and heat protection water demands.

The Ukiah Valley Groundwater Basin has limited data available on the quantity of water used annually for frost protection, post-harvest application, and heat protection. To estimate the amount of water used annually, Lewis et al. (2008) was referenced. In this study it was assumed that the quantity of water used for frost protection, post-harvest application, and heat protection in Ukiah Valley and Redwood Valley remained the same from year to year, as well as the time frame under which the water was used each year. In reality, these estimates have an associated uncertainity because they may not represent reality. The amount of water used depends on the micro climate, the crops, water availability, and ultimately the farmers. To gain more knowledge on the amount of water used by each farmer, farmers may be encouraged to report their water use to the GSA.

4.4 Surface Water Mass Balance

A surface water mass balance was done to estimate the groundwater–surface water interactions monthly from 1991-2015 in a control volume. For this study, the *control volume* is the space located between the confluence of the East and West forks of the Russian River near the City of Ukiah [United States Geological Survey (USGS) streamflow gauges for the East Fork and West Fork of the Russian River] and the southern portion of the groundwater basin located near Hopland [USGS stream flow gauge near Hopland] (Figure 10).

For this study, the water budget is only for the Ukiah Valley portion of the Ukiah Valley Groundwater Basin and not for the entire groundwater basin because there is no streamflow gauge upstream of Redwood Valley. For the control volume proposed for Ukiah Valley, the surface water inflows (streamflow gauges at the East and West forks of the Russian River) and the outflow (USGS streamflow gauge at Russian River at Hopland) are well defined.

Although, this water budget is calculated only in Ukiah Valley, the obtained results from the water budget will still be useful in characterizing the Ukiah Valley Groundwater Basin. The reason for that is because within the specified control volume majority of the groundwater pumping that occurs in the Ukiah Valley Groundwater Basin is captured because Ukiah Valley is groundwater dependent and Redwood Valley is not. In addition, most of the surface water diversions from the Russian River in the Ukiah Valley Groundwater Basin are captured within the defined control volume.

The surface water mass balance was used to estimate the surface water gains and losses using conservation of mass. The surface water storage in a determined control volume varies with surface water inflows and outflows described with Equation [13]. Since Lake Mendocino is outside the control volume, Equation [13] simplifies to Equation [14]. The term Δt in Equation [13] is change in time. The surface water inflows and outflows in the project area are identified with Equation [15] and [16] respectively. The surface water diverters in the in the control volume are defined with Equation [17]. The surface water gains and losses are estimated using Equation [18].

$$\Delta Storage_t^{SW} = [Inflow_t^{SW} - Outflow_t^{SW}]\,\Delta t \qquad [13]$$

$$Inflow_t^{SW} = Outflow_t^{SW} \qquad [14]$$

$$Inflow_t^{SW} = Q_t^{WF} + Q_t^{EF} + Return_t^{SW} + Return_t^{GW} + Gains_t^{SW} \qquad [15]$$

$$Outflow_t{}^{SW} = Q_t{}^{Hopland} + \sum_{i=1}^{i=1} User_t{}^{SW,i} + Losses_t{}^{SW} \qquad [16]$$

$$\sum_{i=1}^{i=1} User_t{}^{SW,i} = CityUkiah_t^{SW} + Willow_t^{SW} + Millview_t^{SW} + Calpella_t^{SW} + Rogina_t^{SW} + RRFC_t^{SW} + PrivateUsers_t^{SW} \qquad [17]$$

$$Gains_t{}^{SW} - Losses_t{}^{SW} = \left[Q_t{}^{Hopland} + \sum_{i=1}^{i=I} User_t{}^{SW,i}\right] - \left[Q_t{}^{WF} + Q_t{}^{EF} + Return_t{}^{SW} + Return_t{}^{GW}\right] \qquad [18]$$

4.4.1 Surface Water Mass Balance Inflows

4.4.1.1 Streamflow

The flow from the West Fork of the Russian River is a surface water inflow in the surface water mass balance represented with the term $Q_t{}^{WF}$ in AF/month in Equation [15]. Data for the West Fork of the Russian River was obtained monthly from 1991 to 2015 from the stream flow gauge USGS 11461000.

The flow from the East Fork of the Russian River is another surface water inflow represented by the term $Q_t{}^{EF}$ in AF/month in equation [15]. Data for the East Fork of the Russian River was obtained monthly from 1991-2011 from the stream flow gauge USGS 11462000. Since the acquired data only went up to the year 2011, flow records from 2012-2015 were filled with data obtained from CDEC from the station COY located near Lake Mendocino. The reservoir outflow was thus assumed to be representative of the stream flow occurring in the East Fork of the Russian River.

4.4.1.2 Surface Water Returns

A surface water return is water that may have originated from surface water or groundwater sources that ultimately returns into the surface water system, the Russian River. The surface water returns are surface water inflows represented in Equation [15] with the terms $Return_t{}^{SW}$ and $Return_t{}^{GW}$. The agricultural drainage described in Section 4.1.2.6 is a surface water return as well as the waste water that is treated and discharged into the Russian River from the City of Ukiah's Waste Water Treatment Facility. The amount of effluent discharged into the Russian River was obtained from a personal communication with Sean White, director of water and sewer for the City of Ukiah. Monthly discharge data was obtained from 2001-2015 and the data from 1991-2000 was estimated using the median value for each month. Since the discharge was estimated from 1991 to 2000, a small degree of uncertainty may be present in the water budget during that time frame.

4.4.1.3 Surface Water Gains

A surface water gain is the combined amount of surface water from tributaries and the groundwater that flows through the streambed into the surface water system. It is an inflow in the surface water mass balance that is represented with the term $Gains_t{}^{SW}$ in AF/month in Equation [15]. This value is unknown until solved for monthly from 1991-2015 using Equation [18].

4.4.2 Surface Water Mass Balance Outflows

4.4.2.1 Streamflow

The stream flow, flowing out of the southern end of the groundwater basin is a surface water outflow in the surface water mass balance and is represented using the term $Q_t{}^{Hopland}$ in

AF/month in Equation [16]. Data was obtained monthly from 1991-2015 from the stream flow gauge USGS 11462500.

4.4.2.2 Surface Water Diversions

The surface water diversions in Ukiah Valley were identified as a surface water outflow in the surface water mass balance and described with Equation [17]. The surface water diversions are the City of Ukiah, Willow County Water District, Millview County Water District, Calpella County Water District, Rogina Water Co, RRFC contractors, and surface water users that have their own water right to divert water for municipal and agricultural water demands. The monthly surface water diversions that occur by each surface water diverter i is represented in Equation [16] with the term $User_t^{SW,i}$ in the units of AF/month.

The surface water diverted annually and monthly by the City of Ukiah was obtained from the City of Ukiah (Sean White, personal communication, 2016). The amount of surface water diverted monthly and annually by the water districts was obtained from the personal communication with Bill Koehler, general manager of Millview County Water District and Redwood Valley County Water District.

The amount of surface water diverted by users that have their own water right was obtained from the SWRCB 2010-2013 Average Demand Dataset (SWRCB 2017). In this dataset monthly diversions from 2010-2013 are reported. Data was obtained for Ukiah Valley using a series of hydrologic unit code 12 values (HUC12), the values used were 180101100403, 180101100404, 180101100401, 180101100407, 180101100402, and 180101100405. To avoid double counting, diversions reported by the water districts, water sold by RRFC, and water diverted from RRFC contractors was removed from the SWRCB dataset. A list of the 2010-2013

RRFC contractors was obtained through personal communication with RRFC General Manager Tamara Alaniz to identify surface water diversions that needed to be removed to avoid double counting. Since the data obtained from the HUC12 value of 180101100407 covered regions in Hopland Valley, an area outside of the Ukiah Valley Groundwater Basin, information found online for the surface water diverters was used to determine whether or not they were in Ukiah Valley. If a diversion was found to occur outside of the groundwater basin that particular data set was removed. With a final monthly data set obtained for 2010-2013, the monthly average water use was obtained and used to fill in the missing years from 1991-2009 and 2014-2015. Although Redwood Valley is not considered in the water budget, the surface water diversions occurring from users that have their own water right was still determined. These estimated surface water diversions may have some degree of uncertainty considering that there was not a full data set and the unknown years were estimated off the available records.

As noted in Section 3.2.5, Rogina Water Co. is completely surface water dependent, with water supplies stemming from a RRFC contract to purchase surface water and the rest of the their water supplies stemming from underflow (surface water). Since no data was obtained from Rogina Water Co., monthly surface water diversions were estimated. Information on monthly surface water quantities obtained from RRFC from 1991-2015 was obtained from RRFC records (Tamara Alaniz, personal communication, 2016) and the remaining monthly surface water supplies from underflow was estimated. By using the groundwater production records from the City of Ukiah and Calpella County Water District, a time series of the percentage of groundwater produced monthly for a given year was obtained from 1991-2015 and assumed to represent the amount of underflow used in Rogina Water Co. The urban water use for Rogina Water Co. was estimated from 1991-2015, the annual water production from 2009-2013 was obtained from

(SCWA 2015), and the annual water production from 2000-2009 reported in MCWA (2010). From the monthly RRFC quantities, the annual surface water supply from RRFC is known. By taking the difference between the annual urban water use and the annual RRFC quantities, the difference can be assumed to be the underflow used annually by Rogina Water Co. Similarly, given the annual water production records found from SCWA (2015) and MCWA (2010), the estimated annual use of underflow could be estimated for the years of 2000-2013. For the years in which there were two estimated annual underflow quantities, the average between them was taken and assumed to be the total underflow quantity for that year. With estimated annual underflow values, the time series for the percentage of underflow assumed to be used monthly was applied to estimate the monthly quantity of underflow used by Rogina Water Co. Finally, the total monthly surface water diversions occurring in Rogina Water Co. were estimated by taking the sum of the monthly RRFC values and the estimated monthly underflow values. The estimated surface water use by Rogina Water Co. may have some degree of uncertainty given their water use was estimated off the reports available and the records available from the RRFC. To improve upon this, monthly records from Rogina Water Co. would have to be obtained.

Another major source of surface water diversions that occur in Ukiah Valley results from the contractors that purchase surface water from RRFC. The assumption in this study was that the RRFC water not already used by the water districts, the City of Ukiah, and the Hopland Public Utility District (PUD), would be used in Ukiah Valley to meet the agricultural water use. The total surface water sold annually by RRFC and the monthly water quantities sold to the water districts, City of Ukiah, and Hopland PUD was obtained (Tamara Alaniz, personal communication, 2016) and was used to estimate the water monthly available from RRFC to meet the agricultural water use in Ukiah Valley. The resulting monthly quantities were identified as

RRFC surface water purchased by contractors, diverted and used to meet agricultural water demands in Ukiah Valley. RRFC records prior the year 2000 do not have a clear record of how much water was sold to each contractor. As a result, some uncertainty arises given that the amount of water sold to each contractor was estimated and thus it may have had a slight effect on the amount of water that was actually used for agriculture from RRFC in Ukiah Valley from 1991 to 2000.

4.4.2.3 Surface Water Losses

A surface water loss is surface water that flows through the streambed to recharge the aquifer. They are a surface water outflow in the surface water mass balance represented with the term ${Losses_t}^{SW}$ in AF/month in Equation [16]. This value is unknown until solved for from 1991-2015 on a monthly time step using Equation [18].

4.5 Aquifer Storage

Using water table elevations derived from monitoring wells, groundwater depth contours were created in GIS by using Inverse Distance Weighted Interpolation (Rodriguez Arellano 2015). The water table elevations were obtained from DWR monitoring wells found in the Ukiah Valley Groundwater Basin (DWR 2017). The data was obtained from DWR’s water data library from 1991 to 2015 where most water table measurements were provided at 6 month intervals, with measurements taken in the fall and spring (DWR 2017). The groundwater depths are contours generated in GIS in 20 ft increments, m, in an analysis from 1991 to 2015 for the months when water table measurements are available. The resulting groundwater depth contour maps can be found in Appendix H. The aquifer storage underlying the study area was found using Equation [19]. The S_t term represents the aquifer storage in acre feet for the given time step. The term A_{im} is the resulting area in acres for a given groundwater depth for a given time step. The term Z is a reference datum used to represent the bottom of an idealized one bucket aquifer system; this value was proposed to be 490 ft. For simplification, the one bucket aquifer system was considered to represent the aquifer system of the Ukiah Valley Groundwater Basin (Rodriguez Arellano 2015). The term d_{mi} is the groundwater surface elevation with respect to sea level in feet. The term γ is the specific yield, which was assumed to be 8%, a value obtained from Bulletin 118 for the Ukiah Valley Groundwater Basin.

$$S_t = \sum_{m=20}^{M} [A_{im} \times (d_{mi} - Z)] \times \gamma \qquad [19]$$

To estimate the change in aquifer storage, storage found from a previous time step is subtracted from the storage at the current time step. The initial aquifer storage used to estimate the change in aquifer storage was 324,000 AF, the approximate groundwater storage capacity reported in Bulletin 118 for the Ukiah Valley Groundwater Basin (DWR 2004). Ultimately, the derived values for the change in aquifer storage are fed into the groundwater mass balance (Equation [23]).

4.6 Groundwater Mass Balance

A groundwater mass balance estimates the lateral groundwater inflows and outflows monthly from 1991-2015 in the control volume using the conservation of mass equation. The groundwater storage that occurs as a result of groundwater inflows and outflows is described with Equation [20], where the term Δt represents the change in time. The groundwater inflows and outflows in the groundwater basin are identified by Equation [21] and Equation [22] respectively. The lateral groundwater gains and losses are estimated using Equation [23].

$$\Delta Storage_t{}^{GW} = [Inflow_t{}^{GW} - Outflow_t{}^{GW}]\Delta t \tag{20}$$

$$Inflow_t{}^{GW} = Recharge_t{}^{Precipitation} + Recharge_t{}^{Irrigation} + Losses_t{}^{SW} + Recharge_t{}^{Percolation\ Ponds} + Recharge_t{}^{Tributary} + Gains_t{}^{GW} \tag{21}$$

$$Outflow_t{}^{GW} = \sum_{i=1}^{i=1} AW_t{}^{GW,crop\ k} + Gains_t{}^{SW} + GE_t{}^{Municipal} + Losses_t{}^{GW} \tag{22}$$

$$Gains_t{}^{GW} - Losses_t{}^{GW} = \Delta Storage_t{}^{GW} - \left[Recharge_t{}^{Precipitation} + Recharge_t{}^{Irrigation} + Losses_t{}^{SW} + Recharge_t{}^{Percolation\ Ponds}\right] + \left[\sum_{i=1}^{i=1} AW_t{}^{GW,crop\ k} + Gains_t{}^{SW} + GE_t{}^{Municipal}\right] \tag{23}$$

4.6.1 Groundwater Mass Balance Inflows

4.6.1.1 Recharge from Precipitation and Irrigation

The recharge from precipitation and irrigation is described in Section 4.1.2.5 for Ukiah Valley as a groundwater inflow in the groundwater mass balance. The recharge that results from precipitation is represented by the term $Recharge_t{}^{Precipitation}$ in AF/month while the recharge from irrigation is represented by the term $Recharge_t{}^{Irrigation}$ in AF/month in Equation [21].

4.6.1.2 Surface Water Losses

The surface water losses from the surface water mass balance, Section 4.3.2.3, are a groundwater inflow for the groundwater mass balance. In Equation [21] the surface water losses are represented by the term $Losses_t{}^{GW}$ with the units of AF/month.

4.6.1.3 Recharge from Percolation Ponds

The recharge from percolation ponds is a groundwater inflow in the groundwater mass balance defined by the term $Recharge_t^{Percolation\ Ponds}$ in Equation [21] in the units of AF/month. The percolation ponds in Calpella County Water District and in the City of Ukiah are considered in the analysis.

The waste water treatment facility located in the community of Calpella, is located in the south end of the community along the west banks of the Russian River in which it serves the community of Calpella and the surrounding areas (MC 2010). In personal communication with David Redding, General Manager of Willow County Water District, the facility provides secondary treatment with aerated lagoons and all of the generated effluent is discharged into one of three percolation ponds that are 47,900 ft^2 each. The monthly discharge into a percolation pond was obtained from 1991-2015 (David Redding, personal communication, 2016). However, since there is only one reliable meter to measure influent, the values provided were influent values assumed to be the effluent values. To estimate monthly percolation rates, the monthly rain (Section 4.1.1.4) was considered along with the evaporation that may occur on the percolation ponds. Pan evaporation values from the CDEC COY station at Lake Mendocino were obtained and assumed to represent the amount of evaporation from the percolation ponds found in the waste water treatment facility in Calpella. The monthly percolation rate for one percolation pond was found by summing the effluent and the precipitation and subtracting the evaporation. The resulting percolation rates were the values used in this study. To improve upon the estimated monthly percolation rates, a meter should be placed in the waste water treatment facility to measure effluent discharge.

For the rest of Ukiah Valley, the Ukiah Valley Sanitation District and the City of Ukiah provide most sanitary sewer services. The Ukiah Valley Sanitation District and the City of Ukiah have collection systems for sewage taken to the City of Ukiah Waste Water Treatment Facility. Treated effluent is discharged into the Russian River or sent to percolation ponds. Monthly data from 2001-2015 was obtained (Sean White, personal communication 2016) showing the effluent quantities that are discharged monthly into the Russian River and to the percolation ponds. The percolation rates used in this study originated from work done by Carollo Engineers for the City of Ukiah's Waste Water Treatment Facility who estimated monthly percolation rates from 2009-2015 (Carollo Engineers, unpublished excel sheet, 2016). The remaining percolation rates from 1991-2008 were estimated using the median value for each month. Since the percolation rates were estimated from 1991 to 2008, a small degree of uncertainty may be present in the water budget during that time frame.

4.6.1.4 Tributary Recharge

The recharge resulting from tributary influence was represented with the term ${Recharge_t}^{Tributary}$ in Equation [21] in the units of AF/month. Tributary data was obtained from (Flint et al. 2015) for the reach near Hopland.

4.6.1.5 Lateral Groundwater Gains

The lateral groundwater gains are a groundwater inflow in the groundwater mass balance. This term ${Gains_t}^{GW}$in Equation [21] is representative of the amount of water that is flowing latterly into the groundwater basin and is in the units of AF/month. This term is unknown until solved for using Equation [23].

4.6.2 Groundwater Mass Balance Outflows

4.6.2.1 Applied Groundwater for Agricultural Water Use

The groundwater pumped for agricultural water use for a given crop k, is represented with the term $AW_t^{GW,crop\ k}$ in AF/month in Equation [22]. This value is estimated as the difference between the monthly agricultural water use in Ukiah Valley (Section 4.1.2.3) and the surface water available monthly for agricultural water use. The surface water available to meet the agricultural water use stems from RRFC or from private water users that have their own water right to divert water. To estimate the amount of water diverted from private users to irrigate, data was obtained from the SWRCB 2010-2013 Average Demand Dataset, as explained before (SWRCB 2017).

4.6.2.2 Surface Water Gains

The surface water gains identified in Section 4.3.1.3 from the surface water mass balance are an outflow in the groundwater mass balance. The surface water gains are represented by the term $Gains_t^{SW}$ in AF/month in Equation [22].

4.6.2.3 Groundwater Extractions for Municipal Water Use

In the Ukiah Valley Groundwater Basin, the City of Ukiah and Calpella County Water District are both partially dependent on groundwater supplies to meet municipal water use. Monthly groundwater production values for the City of Ukiah from 1991 to 2015 were obtained from the City of Ukiah (Sean White, personal communication, 2016). In addition, monthly groundwater production values for Calpella County Water District from 1991-2015 were obtained (Bill Koehler, personal communication, 2016). The groundwater production values are an outflow in the groundwater mass balance represented by the term $GE^{Municipal}$ in AF/month in Equation [22].

4.6.2.4 Lateral Groundwater Losses

The lateral groundwater losses are an outflow in the groundwater mass balance and are represented by the term ${Losses_t}^{GW}$ in AF/month in Equation [22]. This term is unknown until solved for monthly from 1991 to 2015 with Equation [23].

5. Results

5.1 Ukiah Valley Groundwater Basin Characterization

An overview of the crops in the Ukiah Valley Groundwater Basin was developed from land use data from Mendocino County (Chuck Morse, personal communication, 2016). In Ukiah Valley (Figure 13) the prominent crops are red wine grapes, white wine grapes, and Bartlett pears. The region also has some cherry orchards, olive orchards, other types of pear orchards, pistachio orchards, walnut orchards, and pasture. Since there are only a few acres of these crops they were classified as other in Figure 13. On average, 6,368 acres of agricultural land exists in Ukiah Valley. In Redwood Valley (Figure 14) the prominent crops are red wine grapes and white wine grapes with a few acres of Bartlett pears, apple orchards, grapes (rootstock), olive orchards, pistachio orchards, pasture, walnut orchards, and raisin grapes. A few crops in Redwood Valley are classified as other in Figure 14. On average, 2,404 acres of agricultural land exists in Redwood Valley. Overall in the Ukiah Valley Groundwater Basin (Figure 15) the major crops are red wine grapes, white wine grapes, and Bartlett Pears, averaging 8,772 acres of agricultural land.

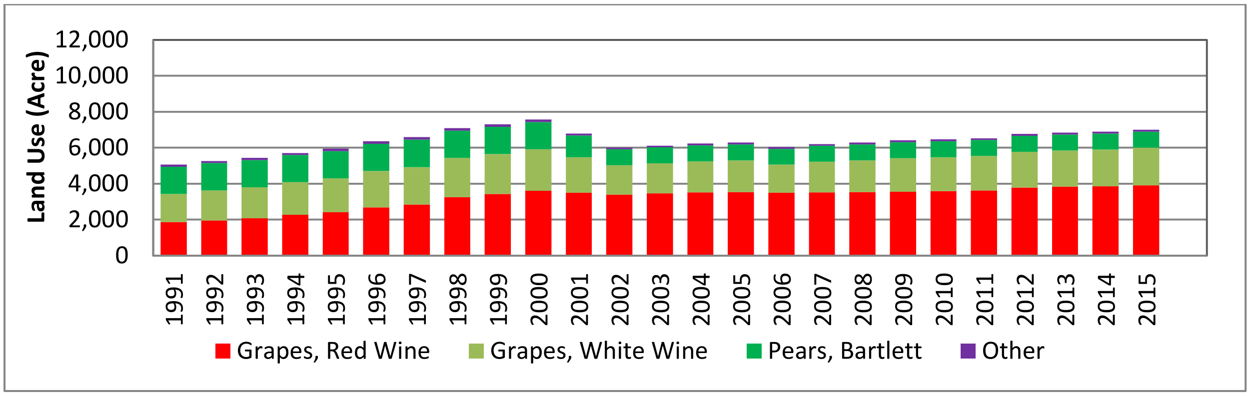


Figure 13.Land use trends for Ukiah Valley.

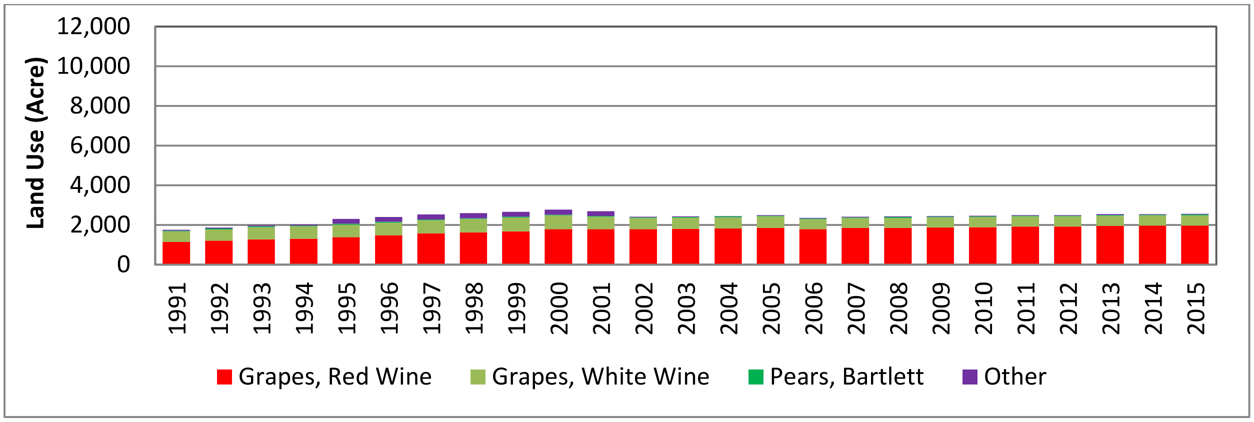


Figure 14. Land use trends for Redwood Valley.

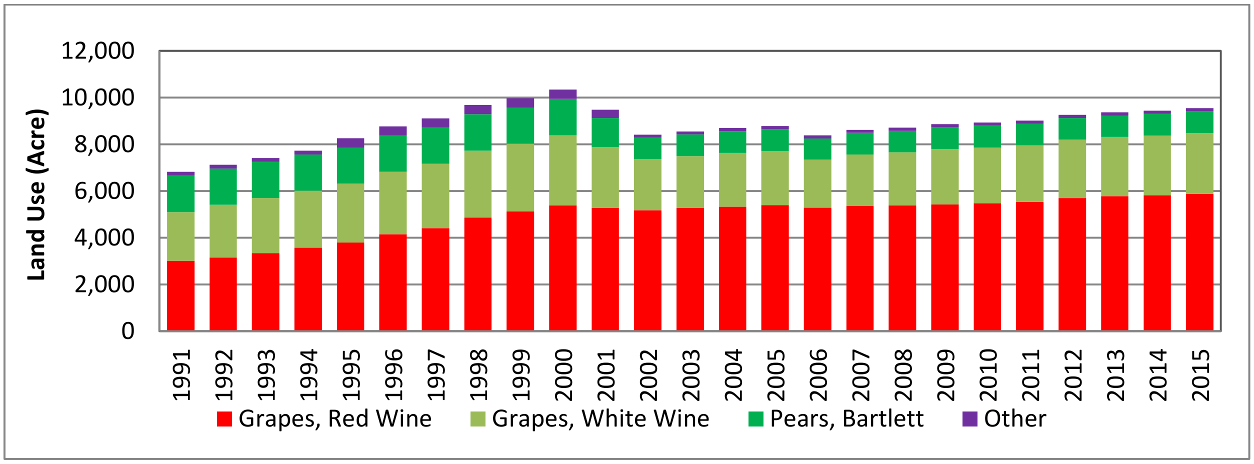


Figure 15. Land use trends for the Ukiah Valley Groundwater Basin.

Given the land use trends in Ukiah Valley, Redwood Valley, and the Ukiah Valley Groundwater Basin, total agricultural water use was estimated. In Ukiah Valley (Figure 16) the average agricultural water use is 7,789 AF/y where 6,635 AF/y stems from the water applied to meet the crop water requirements and the remaining 1,154 AF/y stems from the water applied for frost protection, post-harvest application, and heat protection. In Redwood Valley (Figure 17) the average agricultural water use is 2,393 AF/y, the quantity of water required to meet the crop water requirements is 2,006 AF/y, and the remaining 387 AF/y is representative of the amount of water applied for frost protection, post-harvest application, and heat protection. For the Ukiah

Valley Groundwater Basin (Figure 18) average agricultural water use is 10,181 AF/y. In combing the results obtained from Ukiah Valley and Redwood Valley, average water required to meet the crop water use is 8,641 AF/y, whereas the estimated annual amount of water that may be used in the Ukiah Valley Groundwater Basin for frost protection, post-harvest application, and heat protection averages approximately 1,541 AF/y. These water use estimates were compared with Lewis et al. (2008) and discussed with expert consultation (David Lewis & Glenn McGourty, personal communication, 2016). The resulting agricultural water use in this study agrees with the results published in Lewis et al. (2008) suggesting that the estimated quantities are representative of the Ukiah Valley Groundwater Basin.

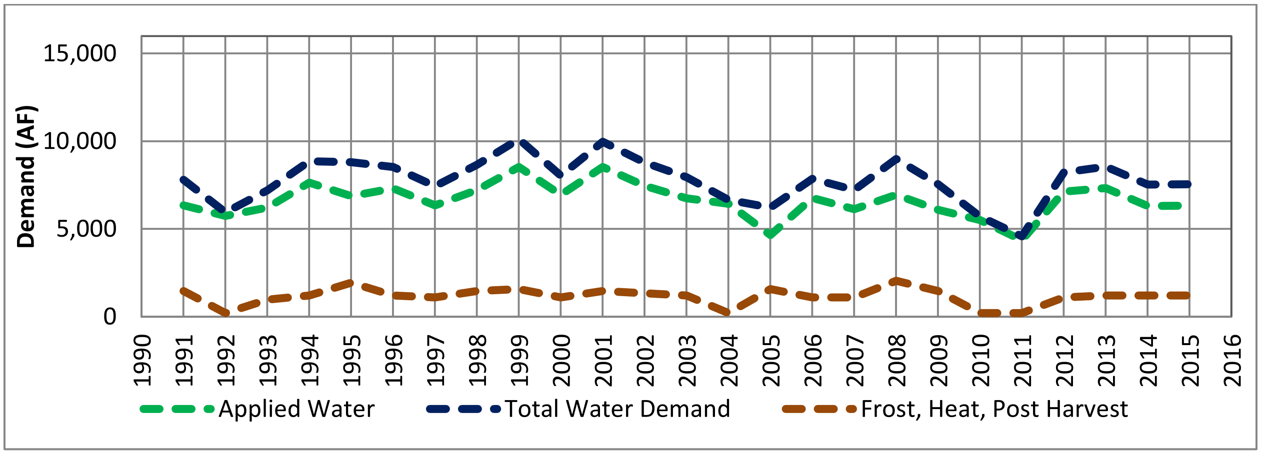


Figure 16. Total agricultural water use in Ukiah Valley.

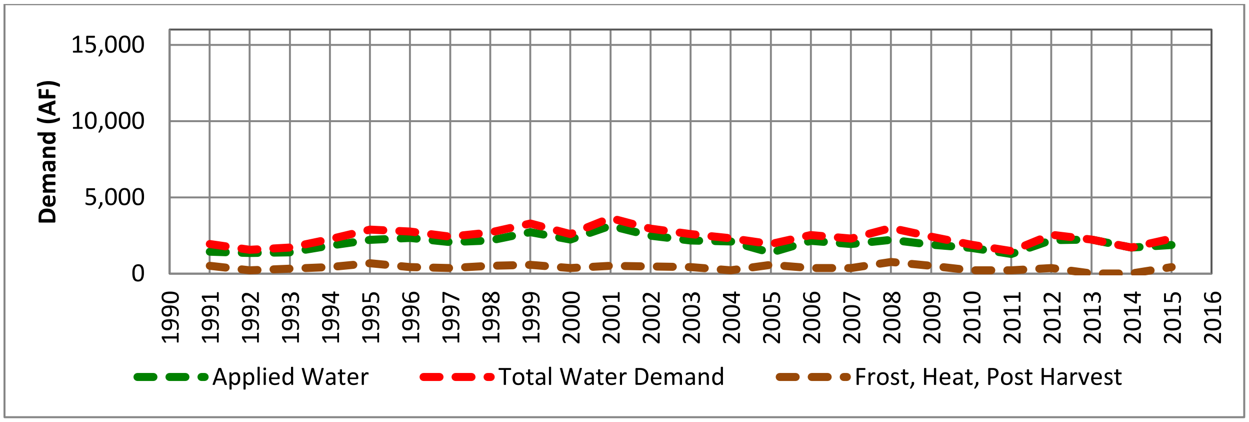


Figure 17. Total agricultural water use in Redwood Valley.

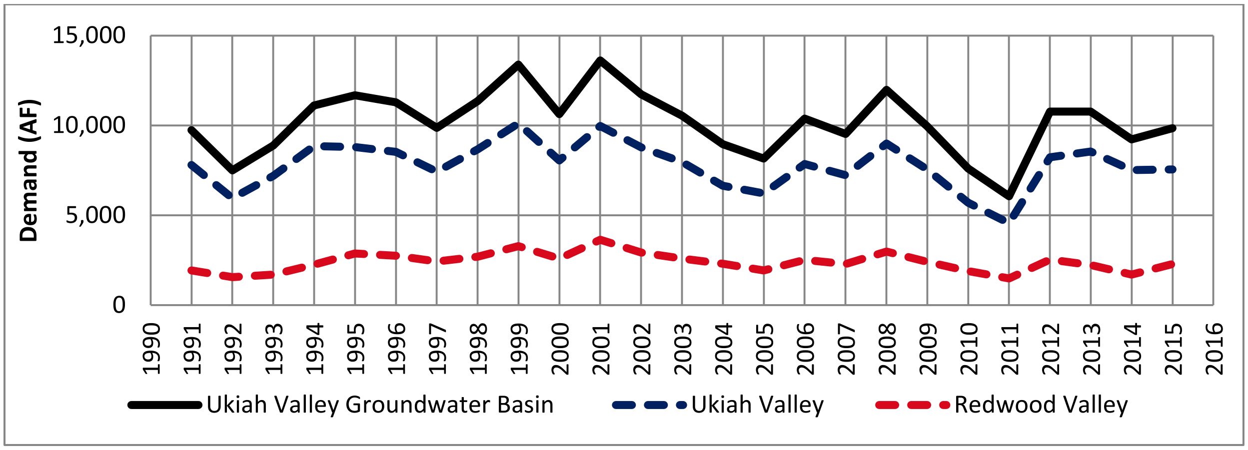


Figure 18.Total agricultural water use in the Ukiah Valley Groundwater Basin.

For Ukiah Valley, Redwood Valley, and the Ukiah Valley Groundwater Basin the recharge from irrigation and precipitation was estimated. The annual recharge from irrigation and precipitation is 23,011 AF/y on average for the Ukiah Valley Groundwater Basin (Figure 19). For Ukiah Valley annual recharge from precipitation and irrigation averages 16,681 AF/y, and in Redwood Valley the annual recharge from precipitation and irrigation on average is 6,330 AF/y.

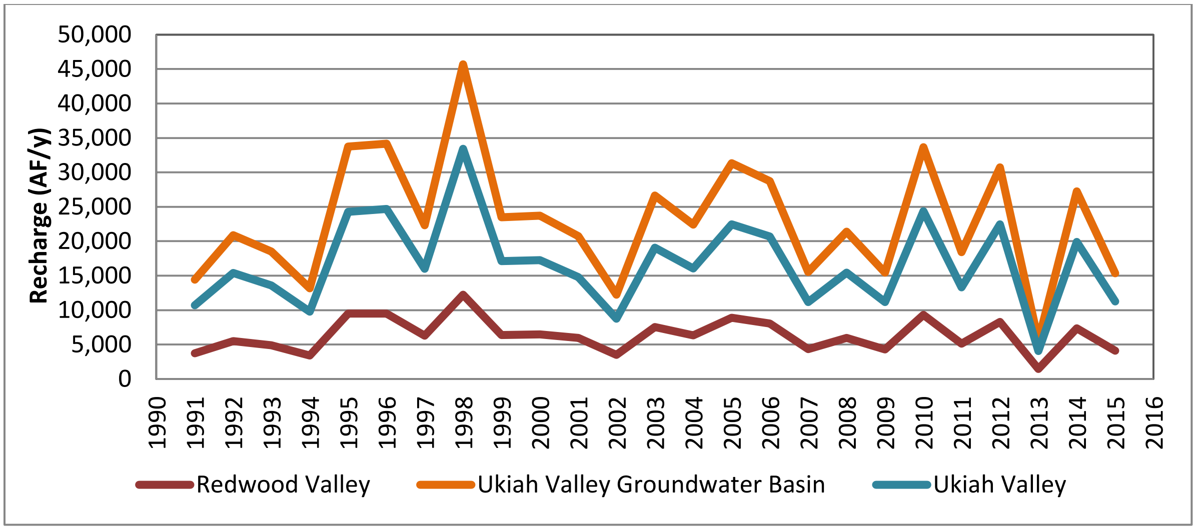


Figure 19. Groundwater recharge in Redwood Valley, Ukiah Valley, and the Ukiah Valley Groundwater Basin occurring from precipitation and irrigation from 1991-2015

All major water supplies and water use in Ukiah Valley were identified for the water budget. The total agricultural water use in Ukiah Valley (Figure 20) is 7,789 AF/y on average and can be divided into categories: (1) the applied water for crop water use and (2) for frost protection, post-harvest application, and heat protection. This agricultural water use is met with surface water and groundwater supplies, on average 2,468 AF/y is supplied from groundwater and 5,321 AF/y is supplied from surface water. For the surface water supplies, on average 2,940 AF/y comes from RRFC contracts and the remaining 2,381 AF/y comes from individual water right holders. Figure 21 shows the quantity of surface water and groundwater used annually to meet the agricultural water use in Ukiah Valley.

Of the estimated agricultural water use in Ukiah Valley, the greatest source of uncertainty stems from the frost, post harvest, and heat protection, as explained in Section 4.3. Although it may have some uncertainty, this quantity only makes up 15% of the total agricultural water use.

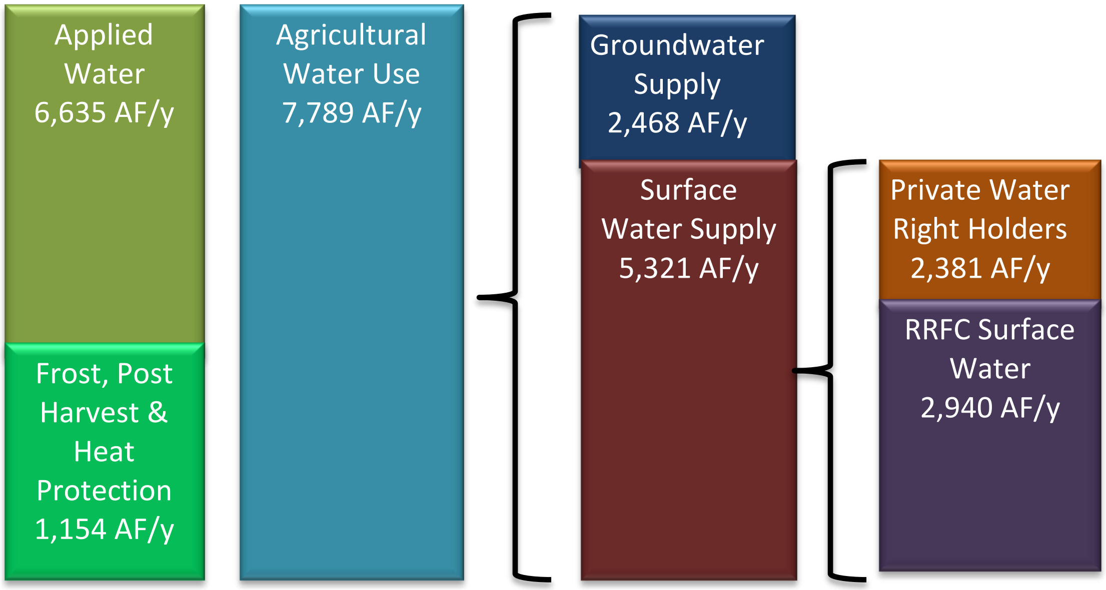


Figure 20.Identification of the average agricultural water use found in Ukiah Valley and the associated water supplies used on average to meet the agricultural water use.

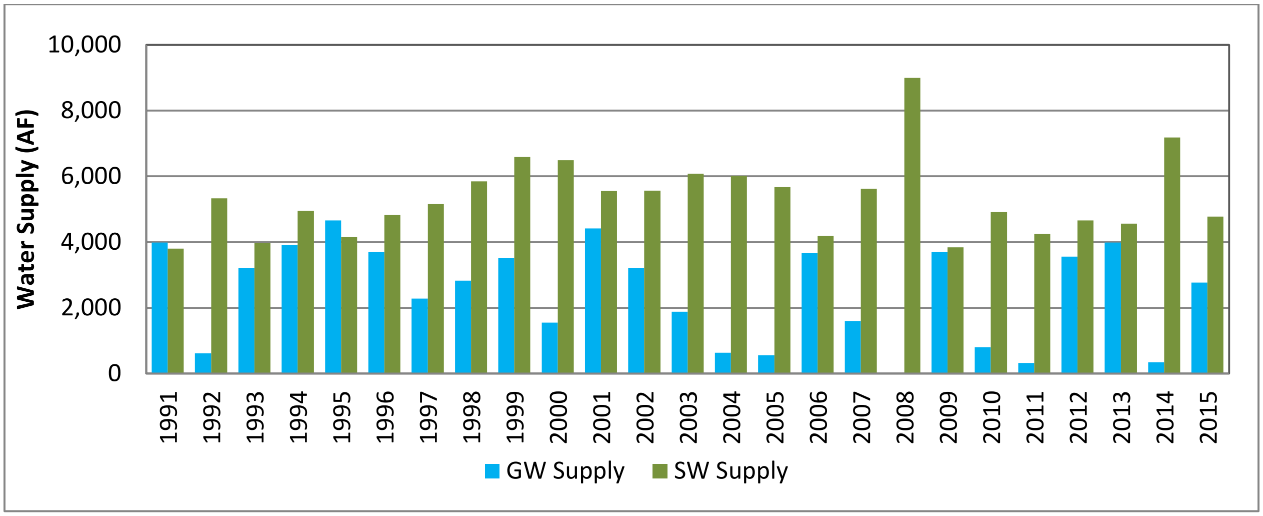


Figure 21. Groundwater and surface water used annually to meet the agricultural water use in Ukiah Valley.

Municipal water use in Ukiah Valley (Figure 22) averages 6,685 AF/y. Supplies include 930 AF/y from groundwater and 5,755 AF/y of surface water. Communities that partially depend on groundwater are the City of Ukiah and Calpella County Water District. On average, the City of Ukiah will use approximately 897 AF/y of groundwater, whereas Calpella County Water District pumps on average about 33 AF/y. For surface water sources to meet the municipal water use, an average of 1,708 AF/y comes from RRFC and 4,047 AF/y from underflow, surface water from a water right held by the City of Ukiah or the water districts, or surface water obtained by a user with a water right to divert water for domestic purposes. Figure 23 shows the annual water use of surface water sources for the City of Ukiah, Millview County Water District, Willow County Water District, Rogina Water Co, and private water right users. Figure 24 shows the annual groundwater production for the City of Ukiah and Calpella County Water District. Unlike the agricultural water use in Ukiah Valley, the municipal water use is less uncertain since most of the water use records were collected directly from the City of Ukiah and the water districts.

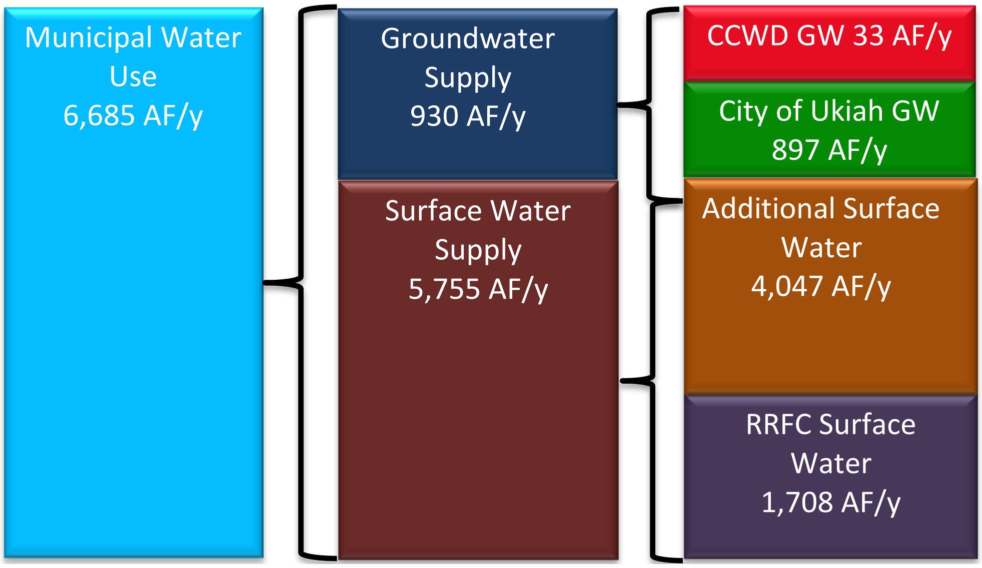


Figure 22. Identification of the average municipal water use found in Ukiah Valley and the associated water supplies used on average to meet the municipal water use.

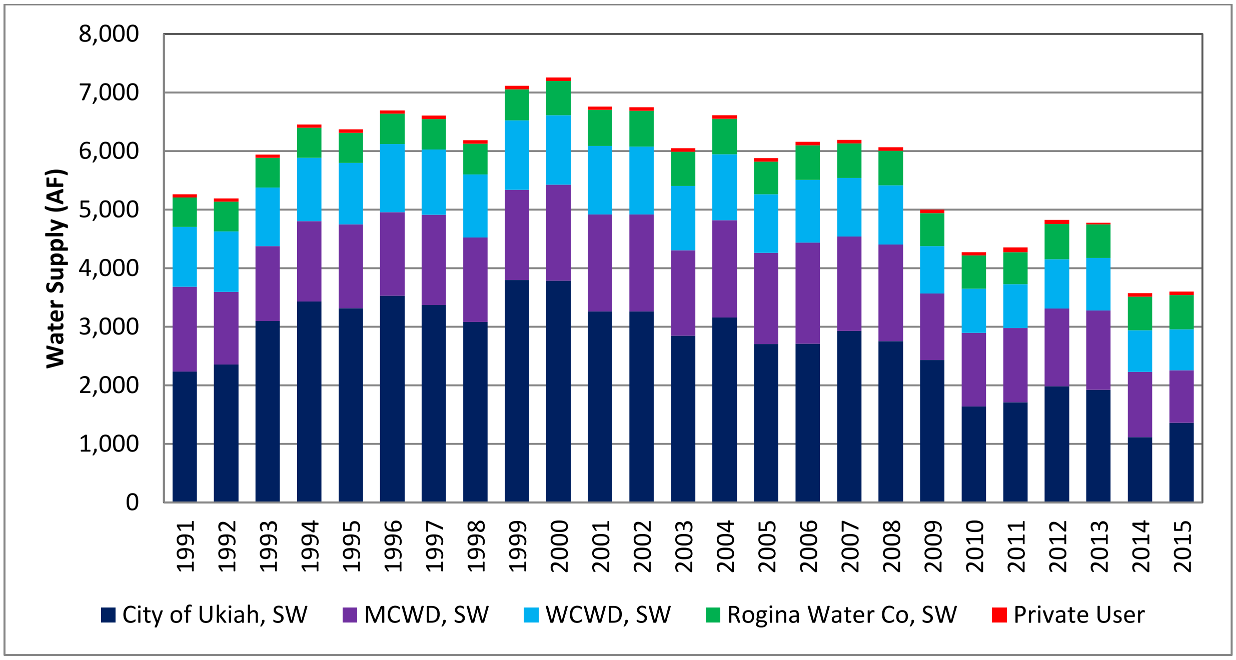


Figure 23.Surface water supplies used annually by each water entity in Ukiah Valley to meet municipal water use. The water quantity shown for Millview County Water District is representative of the surface water Millview County Water District uses, but also the amount of surface water that is purchased by Calpella County Water District from RRFC that is wheeled to them by Millview County Water District.

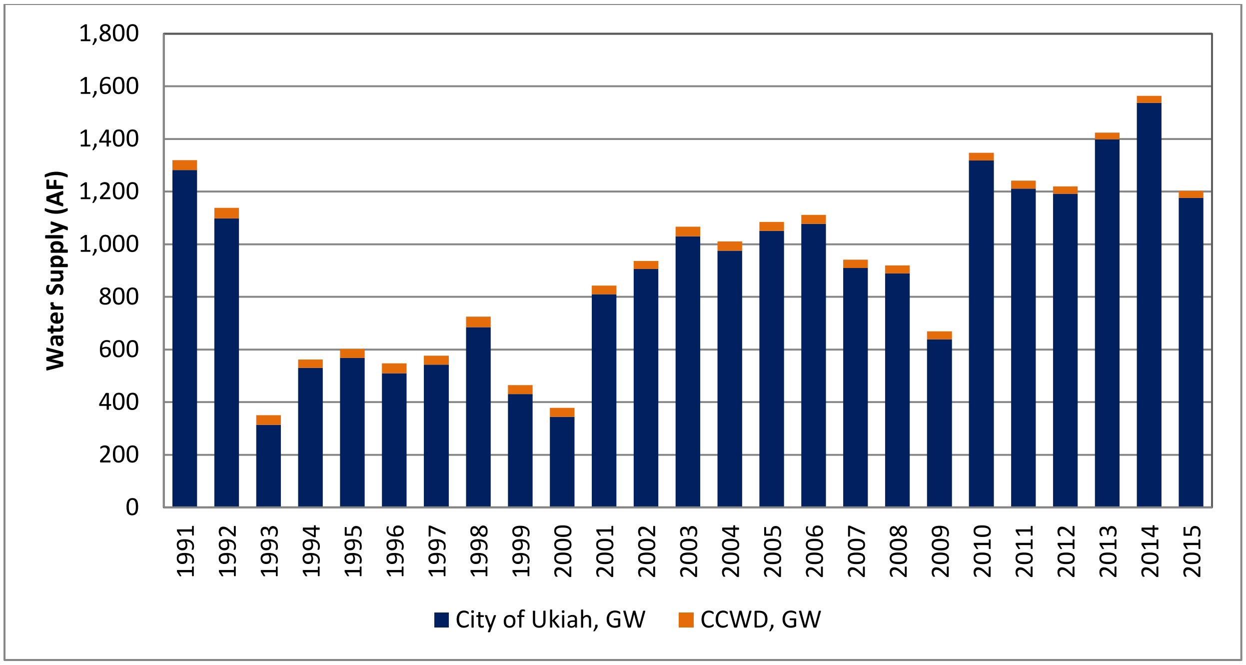


Figure 24.Annual groundwater production by the City of Ukiah and the Calpella County Water District used to meet municipal water use.

Although Redwood Valley was not included in the water budget, the water use and water supplies in the area were still identified (Figure 25). The agricultural water use in the region is about 2,393 AF/y on average and can be divided in two categories: (1) the amount of water required for crops in the region, and (2) the water estimated for frost protection, post-harvest application, and heat protection. On average, the municipal water use is about 415 AF/y. To meet the municipal and agricultural water use 2,795 AF/y of surface water and 13 AF/y of groundwater will be used on average. Redwood Valley is completely surface water dependent and in 2015 groundwater from well 6, an intertie well found near Millview County Water District, was used to help supply domestic water use for that year. The average annual water supply in Figure 25 was obtained by considering all annual water supplies available to Redwood Valley from 1991-2015. From 1991-2015, surface water came from RRFC 1,557 AF/y on average, Redwood Valley County Water District’s water right 252 AF/y on average, and Sonoma

County Water Agency (SCWA) 102 AF/y on average when there was a water contract with this agency from 2005-2010. Finally, water supplies in Redwood Valley can come from water diverted by users that have their own water right, 884 AF/y on average. The annual water supply for Redwood Valley is presented in Figure 26. Once more, the greatest source of uncertainty in the amount of water used by Redwood Valley stems from frost, post harvest, and heat protection (Section 4.3). Although it may have some uncertainty, this quantity only makes up 16% of the total agricultural water use.

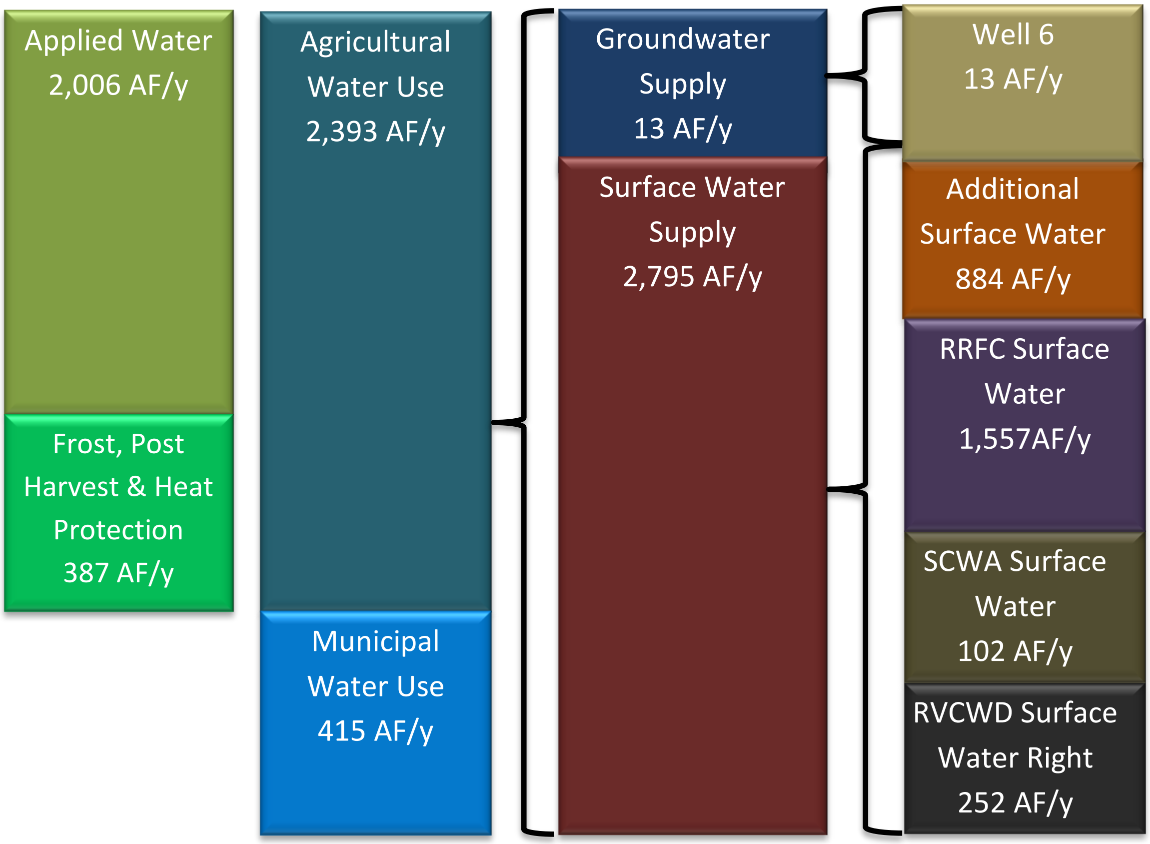


Figure 25.The average agricultural and municipal water use found in Redwood Valley and the water supplies used on average to meet the agricultural and municipal water use.

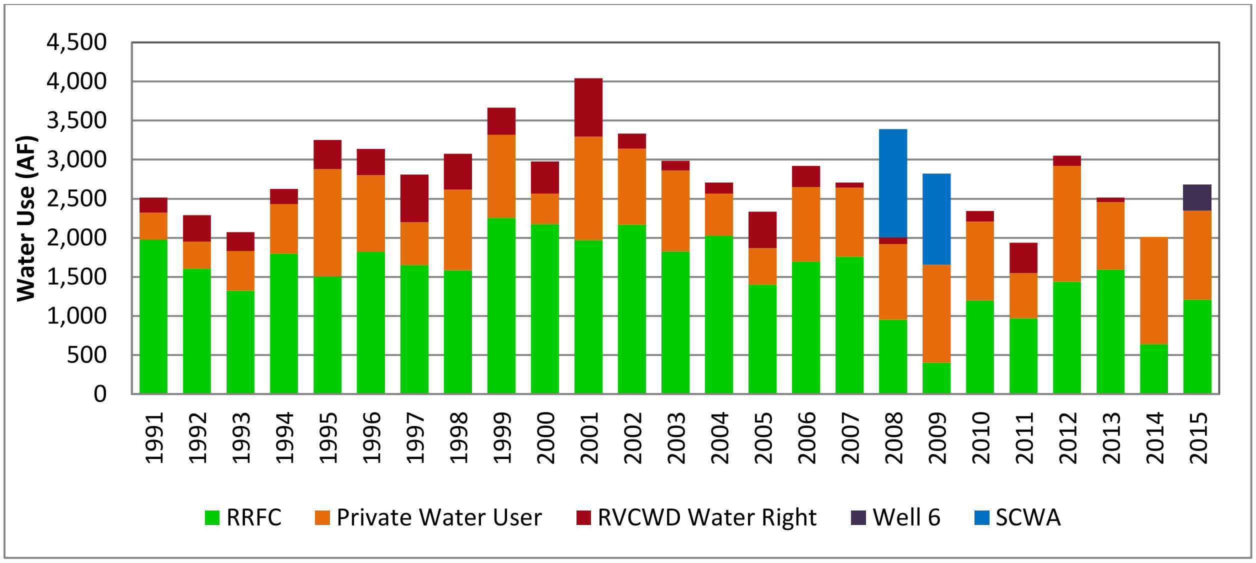


Figure 26.Annual water supplies for Redwood Valley.

Figure 27 summarizes the total water used in the Ukiah Valley Groundwater Basin and water use by type and water source, on average from 1991 to 2015. A total of 17,947 AF/y of water was used for the entire Ukiah Valley Groundwater Basin (Ukiah Valley and Redwood Valley), of which 7,100 AF/y (40%) and 10,182 AF/y (57%) was used to meet municipal and agricultural water use, respectively, and 665 AF/y (3%) of surface water was used to meet water requirements for fire protection, fish and wildlife preservation and enhancement, recreation, and aquaculture (SWRCB 2017). In terms of water sources, 3,411 AF/y (19%) and 14,536 AF/y (81%) was supplied from groundwater and surface water, respectively.

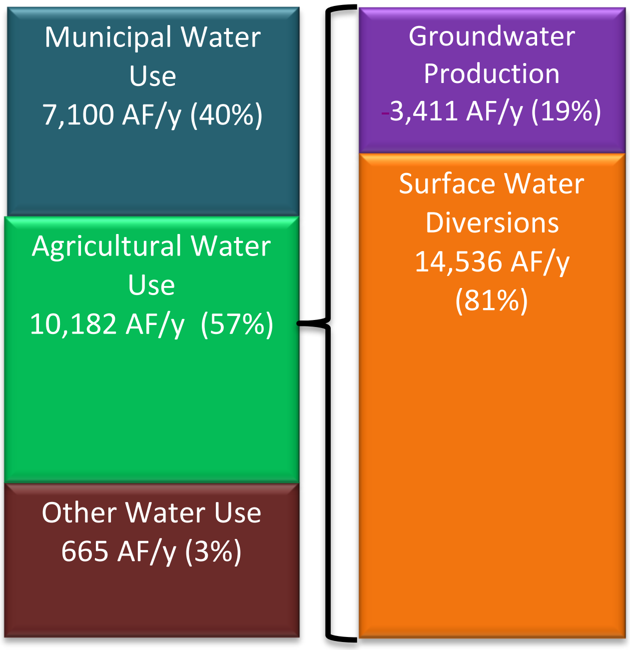


Figure 27.Areas to which water is used in the Ukiah Valley Groundwater Basin, and the total amount of groundwater and surface used for those allocations identified.

5.2 Surface Water Mass Balance Results

Figure 28 shows the monthly distributions of surface water net gains and losses. Surface water gains (values above zero) occur mostly from November to June and are highly variable. Surface water losses (values below zero) occur mostly from July to October. In general, the Russian River mainstem, from the confluence of the East and West fork to Hopland, is a gaining river from November to June, gaining approximately 18,952 AF/y, on average. Surface water gains are from: (1) groundwater discharge into the river mainstem when the groundwater table is higher than the surface of the Russian River, and (2) tributary runoff from creeks in the upper watershed and foothills feeding into the Russian River.

In contrast, the Russian River has net surface water losses, approximately 393 AF/y, from July to October. Surface water losses occur when the groundwater table is lower than the free surface of the Russian River, and recharge from surface water to the aquifer occurs. From July to

October, water in the mainstem mostly comes from Lake Mendocino releases, which in turn is filled with imported water from the Eel River through the Potter Valley Hydropower Project. These results suggest that releases from Lake Mendocino are recharging the Ukiah Valley Groundwater Basin and it is likely that a portion of Lake Mendocino releases come from the water transfers from the Eel River through PVHP and may end up recharging the Ukiah Valley Groundwater Basin during parts of the year. Figure 29 shows the monthly time series data of surface water gains and losses from 1991-2015. In general, surface water gains are more frequent and greater in magnitude than surface water losses. Of the surface water gains, 88% comes from tributaries and 12% comes from groundwater influence (Figure 30).

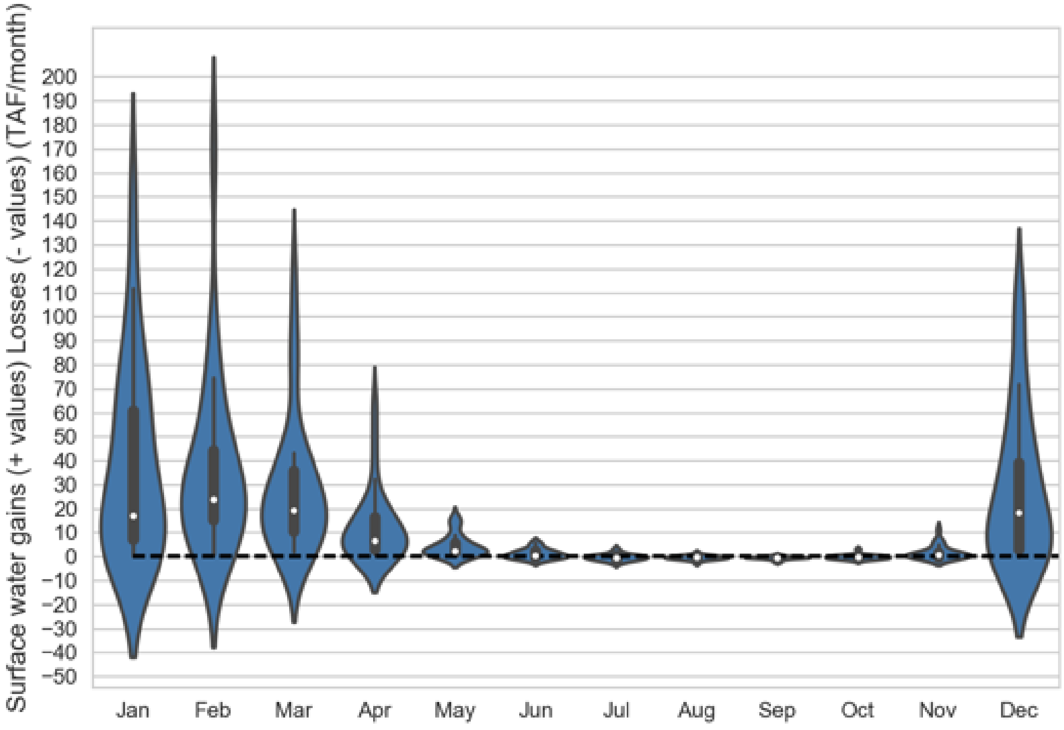


Figure 28. Seasonal distribution of surface water losses and surface water gains, distributions by year.

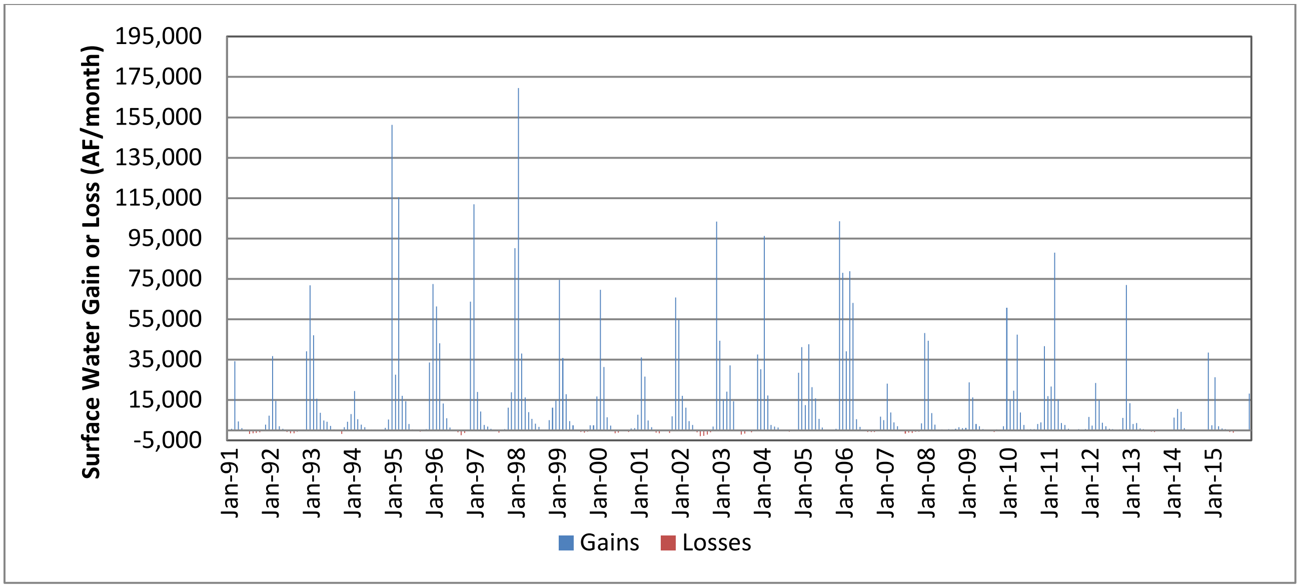


Figure 29. Monthly time series of the surface water losses and gains.

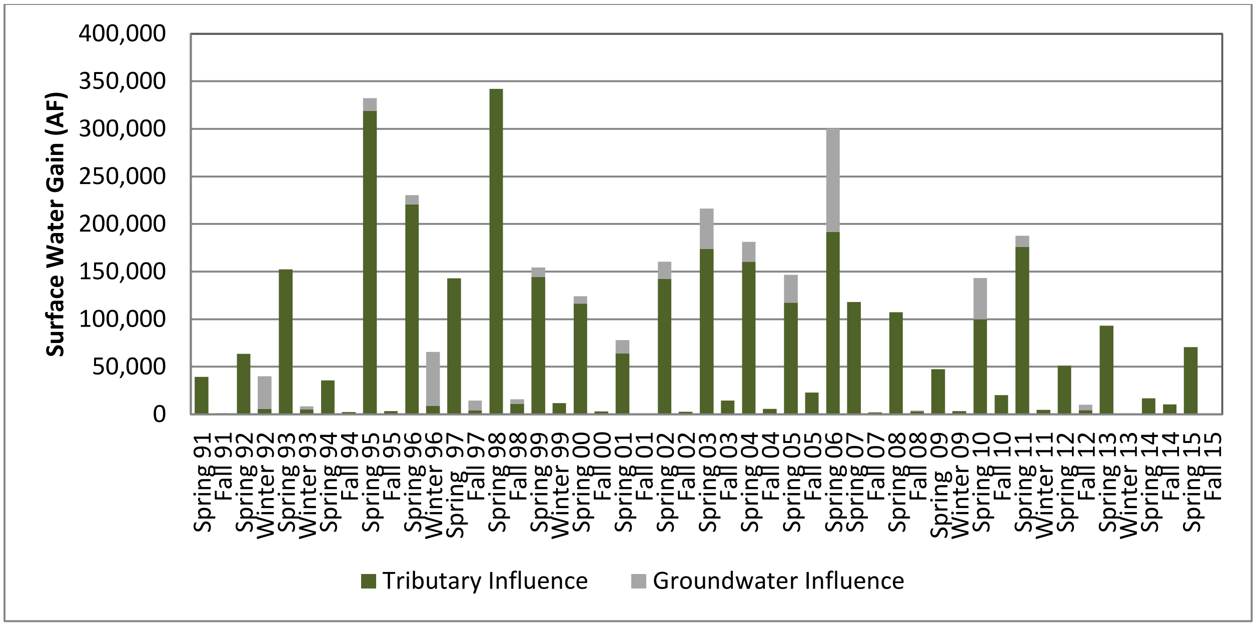


Figure 30. Surface water gains partitioned between groundwater and tributary influence.

5.3 Aquifer Storage Results

Aquifer storage was estimated using the water table elevation data (DWR 2017) and the procedure described in section 4.5. Figure 31 shows estimated aquifer storage and its seasonal fluctuation. The years 2003 and 2009 have kinks in the plot because the water table becomes lower than usual in some parts of the groundwater basin. These lower than normal water table records can be seen in Appendix H for November 2003 and May 2009. Overall the groundwater storage is stable (no chronic decline) with time. In the years from 2011 to 2015 there is a subtle decline in storage, attributable to the 2012 – 2015 drought. Despite the subtle decline in the storage, the storage does stabilize from 2012-2015. In addition, an alternative explanation as to why the storage decreases subtly but then stabilizes in the time span from 2011 to 2015 is because more monitoring wells were introduced starting in the year 2012. With an increase in monitoring wells, more water table data was available to refine estimates of groundwater storage. The conclusion that the groundwater storage is stable is also supported by long term monitoring wells within the basin that do not show a decline in the water levels.

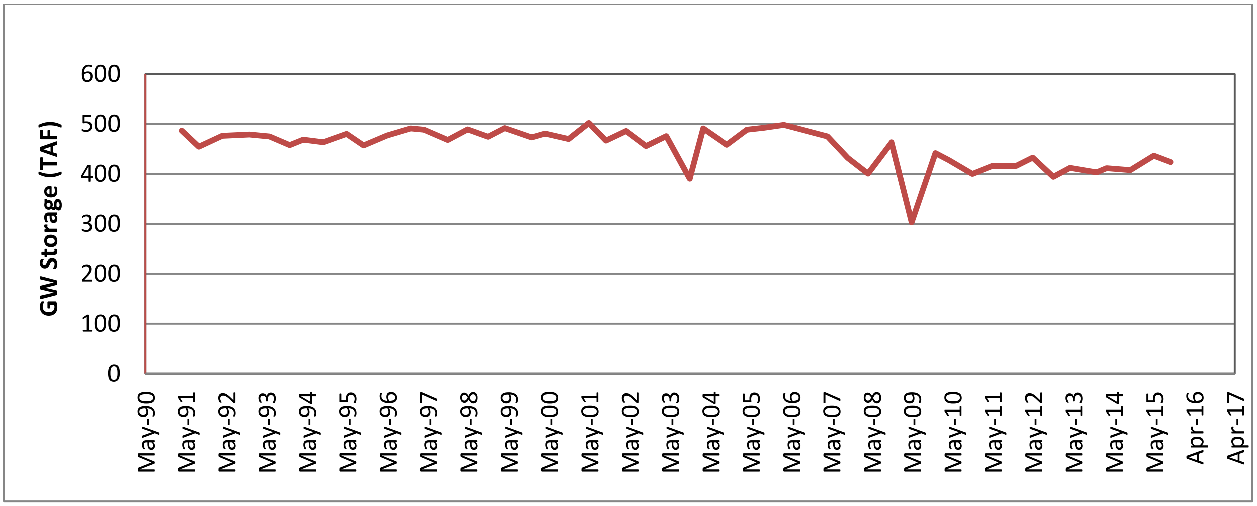


Figure 31.Estimated groundwater storage for the Ukiah Valley Groundwater Basin from 1991-2015.

Change in aquifer storage was calculated from 1991-2015. Figure 32 shows the cumulative distribution of the change in storage (positive and negative) of the aquifer during the 1991 to 2015 period. The cumulative distribution expresses the probability that the change of storage is equal or less than that determined value (ESH). Results show that 50% of the time the aquifer has declining storage, whereas the other 50% of the time the aquifer has increasing storage. There is about an equal number of times there is a net decrease and increase in groundwater storage. These observations suggest that the groundwater basin is roughly in balance, without groundwater overdraft in the Ukiah Valley Groundwater Basin. These conclusions are supported with the water table measurements found in the monitoring wells found in the Ukiah Valley Groundwater Basin. Records show the water table has been consistently stable with time, showing no evidence of water table lowering.

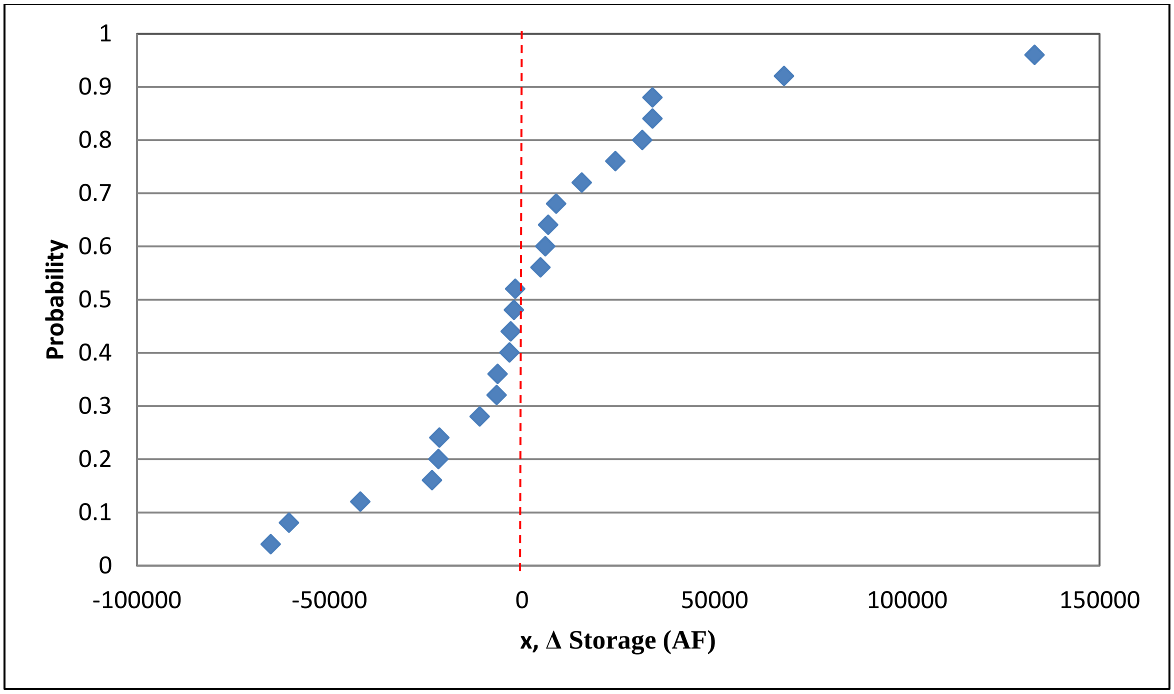


Figure 32. Cumulative distribution showing the probability of obtaining a particular change in storage.

5.4 Groundwater Mass Balance Results

Lateral groundwater inflows and outflows were calculated through the groundwater mass balance. The groundwater elevation data was available at an interval of approximately every 6 months, with a measurement recorded in the spring and another in the fall of each year. Figure 33 shows the lateral groundwater inflows and outflows calculated for the hydrologic period of analysis. The magnitude and occurrence of the lateral groundwater inflows are about equal to the magnitude and occurrence of the lateral groundwater outflows. The lateral groundwater gains observed are assumed to come from tributary streamflow that recharges the Ukiah Valley Groundwater Basin and/or from groundwater contributions, mostly from perched aquifers in the foothills and tributaries of the mainstem. However, it is believed that the driving physical process of the lateral groundwater gains is from tributary influence, as suggested by other reports (RRISRP 2016). In addition, lateral groundwater losses are occurring from downgradient groundwater flow from the Ukiah Valley Groundwater Basin towards the Russian River, and overall moving from the northern end to the southern end of the groundwater basin (Farrar 1986). Given these trends in groundwater movement, the lateral groundwater losses observed are from groundwater moving from the Ukiah Valley Groundwater Basin into the Sanel Valley Groundwater Basin (also known as the Hopland Valley Groundwater Basin).

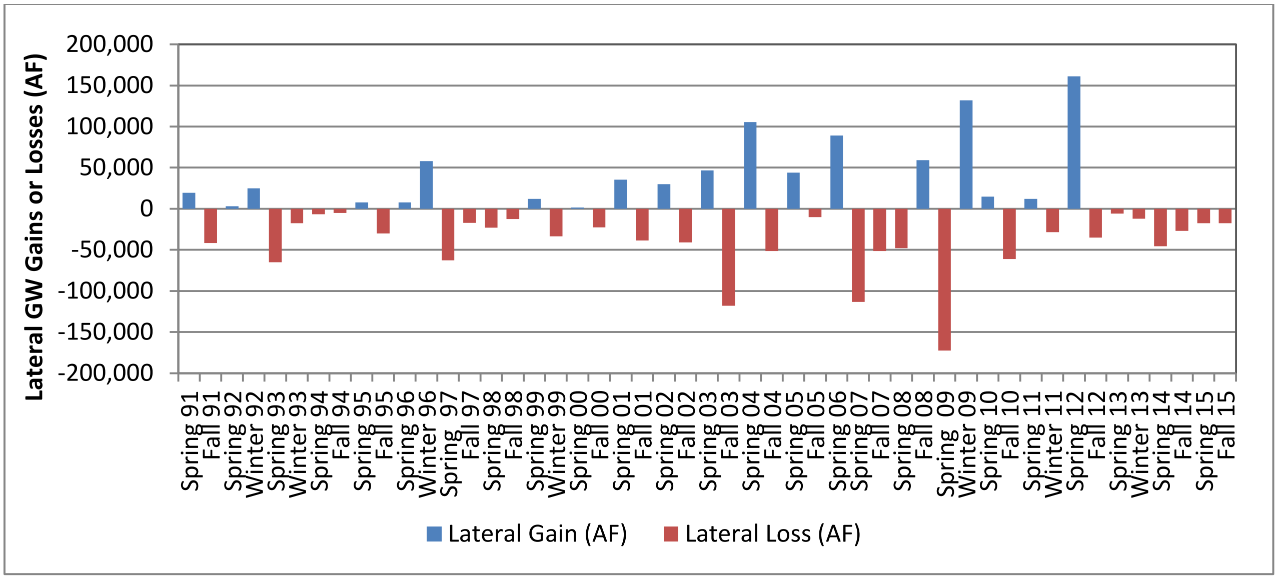


Figure 33. Seasonal lateral groundwater gains and losses in the spring and fall from 1991-2015.

Figure 34 shows the monthly time series of lateral groundwater gains and losses estimated in the Ukiah Valley Groundwater Basin. The monthly time series was estimated by correlating the decrease in storage with groundwater extractions, whereas the increase in storage was correlated with the amount of rainfall experienced in the area. The calculated monthly lateral groundwater gains and losses further show that the lateral groundwater gains and losses have similar magnitudes.

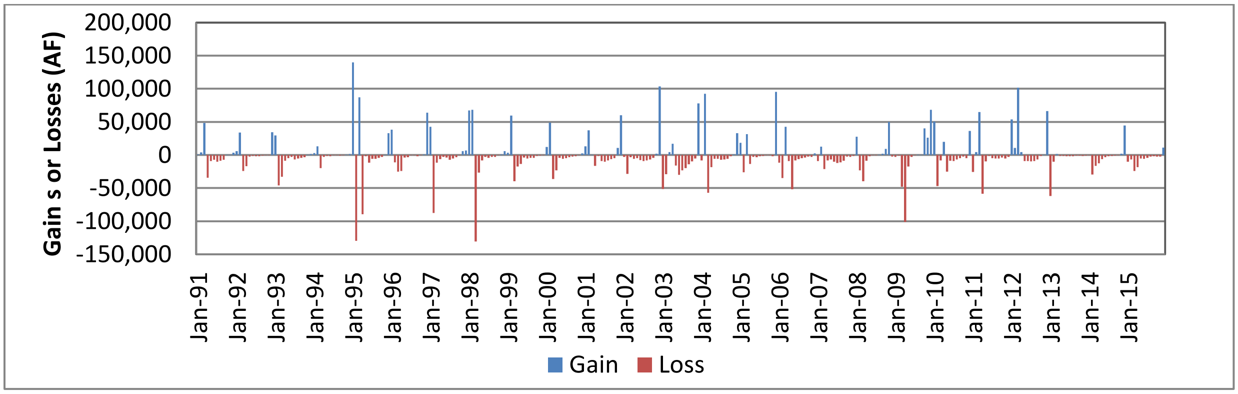


Figure 34. Observed monthly lateral groundwater gains and losses.

6. Discussion

SGMA requires that six undesirable results be avoided: (1) chronic lowering of the groundwater table, (2) reduction in groundwater storage, (3) seawater intrusion, (4) degradation of water quality, (5) land subsidence, and (6) depletion in groundwater-surface water interactions (DWR 2017). According to the data analyzed and the results of the water budget analysis, the Ukiah Valley Groundwater Basin is not experiencing any of these undesirable results. However, this does not mean that there may not be any problems today or in the near future related to groundwater management. For instance, a determined well extracting groundwater may decrease the water table elevation affecting neighboring wells, but not for the whole region. This local issue should be considered when managing the Ukiah Valley Groundwater Basin. Currently, there is no evidence suggesting a chronic decrease in groundwater storage, the water table declining, land subsidence, and disconnection between surface water-groundwater interactions.

Seawater intrusion is irrelevant to the Ukiah Valley Groundwater Basin since it is inland without risk of salt ocean water entering the fresh water aquifer. Groundwater quality is outside the scope of this study, however Bulletin 118 (DWR 2004) mentioned that groundwater quality here is generally in good condition. Regardless of Bulletin 118, the Ukiah Valley Groundwater Basin will have to test its water at regular intervals to comply with SGMA and confirm the quality of the groundwater. In addition, the interval at which water samples are taken and the number of water quality sampling points will have to be increased.

In accounting for the water and water use in the Ukiah Valley Groundwater Basin, groundwater dependence is relatively small relative to surface water use. Figure 27 shows that of all water used in the Ukiah Valley Groundwater Basin, only 19 % is from groundwater, mostly for agriculture. Despite the quantity of groundwater used to meet municipal and agricultural water use, the amount of recharge in the Ukiah Valley Groundwater Basin exceeds groundwater extractions, on average (Table 3). Even though the largest uncertainty in this study is in the estimation of frost, post-harvest, and heat protection (15% in Ukiah Valley and 16% in Redwood Valley, see Section 4.3), this uncertainty does not change the result that the recharge is greater than the amount of groundwater extracted in the Ukiah Valley Groundwater Basin (Table 3).

Table 3. Average groundwater recharge and extractions observed in the Ukiah Valley Groundwater Basin.

	(AF/year)
Precipitation & Irrigation Recharge	23,011
Percolation Pond Recharge, City of Ukiah	2,264
Percolation Pond Recharge, Calpella County WD	42
Average Aquifer Recharge	**25,317**
Ag Water Pumping	2,468
Municipal GW Use	943
Average Aquifer Extractions	**3,411**

The Ukiah Valley Groundwater Basin has surface water – groundwater interactions. A strategy to keep this interaction should focus on two main tasks. First, protect and enhance recharge zones so the current level of recharge is maintained. Some strategies for achieving this may include: protecting the upper watershed (tributaries) so water can reach the mainstem and recharge the aquifer, enhance aquifer recharge in urban and agricultural land, among other strategies. Second, keep the current levels of water use and/or avoid increasing groundwater extractions, which will keep the interaction between the aquifer and the river in the future. If groundwater pumping is not managed, excessive pumping may lower the water table and lead to disconnecting the surface water and groundwater systems. Thus, the water tables should continue to be monitored with additional monitoring wells throughout the groundwater basin. This effort of identifying additional monitoring wells has been initiated by LACO Associates, a consulting firm offering engineering, geology, and environmental planning services to Mendocino County to draft an initial groundwater sustainability plan for the Ukiah Valley Groundwater Basin. To protect the upper watershed tributaries, wells should be managed and monitored, so streamflow from the headwater and foothills continues to provide gains and recharge to the Ukiah Valley Groundwater Basin. If there was to be a drastic decrease in water from the foothills via the tributaries, it may reduce aquifer recharge and the surface water-groundwater interactions since much of the surface water gains result from tributaries. In monitoring the tributaries LACO Associates have also initiated an effort to identify locations to place streamflow and tributary gauges in the Ukiah Valley Groundwater Basin. A way to manage the tributaries can be by preserving the natural terrain in the foothills.

Groundwater may be moving laterally from the Ukiah Valley Groundwater Basin to the Sanel Valley Groundwater Basin. Monitoring wells may have to be placed in the northern end of the Sanel Valley Groundwater Basin and on the southern end of the Ukiah Valley Groundwater Basin to confirm this observation. Field work will also have to be done to estimate groundwater flow from the Ukiah Valley Groundwater Basin to the Sanel Valley Groundwater Basin. With the addition of new monitoring wells groundwater contour maps can be generated and provide greater insight on the seasonal groundwater movement.

7. Conclusions

This study presented a water budget for a groundwater basin classified as medium priority by DWR by looking into the water sources, water supplies, and water use. For the Ukiah Valley Groundwater Basin it was identified that the groundwater basin is not in groundwater overdraft. Surface water – groundwater interactions were identified, it was determined that the Russian River is a gaining river from November to June, gaining on average 18,952 AF/y; and conversely, the Russian River is a losing river from July to October, losing on average 393 AF/y. In addition, it was determined that there is groundwater connectivity between the Ukiah Valley Groundwater Basin and the Sanel Valley Groundwater Basin, where groundwater is flowing laterally from the Ukiah Valley Groundwater Basin to the Sanel Valley Groundwater Basin. Furthermore, it was determined that lateral groundwater gains are occurring which may result from the Sanel Valley Groundwater Basin or tributaries, although it is assumed that tributaries may be the driving force but cannot confirm with the results of this study.

Overall, the groundwater basin does not appear to experience any undesirable results given the criteria outlined by the SWRCB. Given the conditions of the groundwater basin, it is in a unique position where the GSA will have to be proactive in maintaining the current condition under which it is and develop an integrated water resources management plan and detailed monitoring protocol of measuring and thus preventing against the six undesirable results that deem a groundwater basin unsustainable when constructing the GSP.

Multiple efforts are on the horizon for broadening the understanding of the Ukiah Valley Groundwater Basin and the Russian River Watershed. Results from this study are the stepping stone for future efforts for improving water management and for broadening knowledge in the area. LACO Associates will now use the results of this study to improve upon the water budget and aid in the construction of the GSP. Ultimately, this work and LACO's efforts will better inform the work to be done in the future by the USGS when a model of the Russian River Watershed is created.

It will take decades before the progress of SGMA can be evaluated. However, SGMA is the most promising piece of legislation that has resulted, aimed specifically in improving the framework in which groundwater is managed throughout the state. Although, many questions and concerns have arisen since its introduction, it holds promise for establishing a new perspective and practices geared at achieving groundwater sustainability. The successful implementation of SGMA will increase water security in communities, maintain environmental stewardship, and improve water quality statewide. For the Ukiah Valley Groundwater Basin, SGMA is the driving force pushing this region towards establishing a comprehensive, integrated water resources management scheme that will promote water security.

7.1 Limitations

The concept of developing a water budget to characterize a groundwater basin is relatively simple, but the quality of the water budget is dependent on the availability and quality of data. The limitations of this study are summarized in this section.

- For this study, the water budget centered around Ukiah Valley and not the whole Ukiah Valley Groundwater Basin. This occurred because there was no active streamflow gauge on the West Fork of the Russian River North of Redwood Valley County Water District. Without an accurate account of the surface water entering the Ukiah Valley Groundwater Basin from the north via the West Fork of the Russian River, the next best alternative was to center the water budget in an area that could effectively account for all of the water inflows and outflows.

- There was no annual data available for the amount of water used for frost protection, post harvest application, and heat protection, so the water quantities were estimated based off the work presented in Lewis et al. (2008).
- Rogina Water Co. did not share their water production records and thus the amount of water used within its service area was estimated based off the data available from RRFC, SCWA (2015), and MCWA (2010).
- To determine aquifer storage, the one-bucket model is used. To obtain more accurate results of aquifer storage a more robust groundwater model is required.
- Surface water diversions are known to occur by users that have their own water right. To capture these diversions in the analysis data from the SWRCB 2010-2013 Average Demand Dataset was obtained. This data provided insight on the diversions occurring from 2010-2013 in Ukiah Valley and Redwood Valley, but for the remaining years of analysis from 1991-2009 and from 2014-2015 monthly averages were used to fill in the data gaps. Records of all surface water diversions from all users would be ideal to have an improved water budget.
- The number of wells and annual production of each well is unknown. The groundwater used for to meet the water use for the City of Ukiah and Calpella County Water District are known, but for the few tribes and families that have their domestic supply well, the groundwater production is unknown. Likewise, the amount of groundwater pumped to meet the crop water requirements is unknown and was estimated given the agricultural water use present in the area and the surface water supply available to meet them.

- There were data gaps presented in some of the water records obtained so the missing values were estimated using the median of the data that was available. Doing this may not be ideal, but was considered a good option in seeking to fill in missing data records.

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Appendices

Appendix A. Monthly evapotranspiration (in) values obtained from Sanel Valley, CIMIS station 106.

Monthly Evapotranspiration (in)												
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
1991	1.27	2.12	2.56	4.85	6.25	7.21	7.94	6.77	5.57	3.79	1.86	1.13
1992	1.21	1.84	2.94	4.73	7.02	6.26	7.66	6.83	4.80	2.79	1.39	0.65
1993	0.93	1.37	2.82	4.48	5.41	7.25	8.01	7.44	5.56	3.42	2.02	1.32
1994	1.58	2.02	4.15	5.59	5.71	6.96	8.23	7.54	5.49	3.72	1.66	1.12
1995	1.40	2.13	2.84	4.34	5.85	6.91	7.40	7.06	4.88	3.52	1.48	0.60
1996	0.79	1.29	3.40	4.22	6.15	7.78	8.32	7.52	5.45	3.61	1.58	0.89
1997	1.05	2.26	3.87	4.80	7.09	7.37	8.27	6.61	5.27	3.23	1.27	1.31
1998	0.68	0.98	2.82	4.30	4.37	5.99	8.18	7.47	5.16	3.64	1.27	1.30
1999	1.35	1.20	2.77	5.19	6.08	7.77	8.26	6.73	5.42	3.64	1.39	1.48
2000	0.85	1.18	3.64	4.82	6.21	7.49	7.74	6.93	4.94	3.21	1.53	1.19
2001	1.27	1.60	3.66	4.82	7.44	7.89	8.16	7.27	5.39	3.66	1.21	0.84
2002	1.27	1.85	3.44	4.39	6.99	8.20	8.25	6.96	5.61	3.75	1.81	0.80
2003	1.11	1.92	3.64	3.21	6.16	7.57	8.01	6.81	5.22	3.98	1.20	0.75
2004	1.07	1.47	4.02	4.93	6.57	7.53	7.82	7.03	5.50	3.06	1.46	1.03
2005	1.05	1.56	3.16	4.37	5.30	6.26	8.24	6.92	5.10	3.38	1.54	0.70
2006	0.98	2.00	2.12	3.30	6.34	7.12	8.32	6.97	5.39	3.30	1.36	1.14
2007	1.62	1.47	3.94	4.83	6.74	7.59	8.07	7.21	4.93	2.65	1.72	1.10
2008	0.81	1.84	3.36	4.92	5.95	7.54	8.19	7.31	5.23	3.46	1.49	1.14
2009	1.63	1.59	3.62	5.28	6.46	7.11	8.58	7.14	5.53	3.72	1.69	0.95
2010	1.66	2.12	3.48	3.88	5.44	7.51	7.86	6.85	5.15	2.85	1.55	0.73
2011	1.45	1.78	2.15	4.20	5.27	5.91	7.12	6.59	5.31	3.37	1.42	1.42
2012	1.45	2.10	2.33	4.39	7.01	7.21	7.82	7.34	5.58	3.41	1.38	0.93
2013	1.44	2.42	3.31	6.06	7.16	7.49	8.58	7.22	5.21	3.95	2.19	1.60
2014	1.91	1.75	3.44	5.28	7.22	7.90	7.05	6.79	5.26	3.45	1.64	1.15
2015	1.88	2.70	3.91	5.31	6.29	7.80	7.38	6.72	5.13	3.84	1.90	0.96

Appendix B. Crop Coefficients

Crop Coefficients												
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
Apples	0	0	0	0	0.63	0.80	0.96	1	1	0.96	0.30	0
Cherries	0	0	0.59	0.70	0.82	0.87	0.87	0.87	0.85	0.84	0	0
Grapes, Red Wine	0	0	0	0.15	0..30	0.30	0.30	0.30	0.30	0.30	0	0
Grapes, White Wine	0	0	0	0.15	0..30	0.30	0.30	0.30	0.30	0.30	0	0
Grapes, Rootstock	0	0	0	0.15	0..30	0.30	0.30	0.30	0.30	0.30	0	0
Olives	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80
Pears, Bartlett	0	0	0	0	0.28	0.67	0.83	0.87	0.87	0.87	0.81	0.68
Pears, Other	0	0	0	0	0.28	0.67	0.83	0.87	0.87	0.87	0.81	0.68
Pistachios	0	0	0	0.25	0.81	1.13	1.19	1.16	0.93	0.59	0.18	0
Walnuts, English	0	0	0.06	0.61	0.83	0.97	1.14	1.14	1.03	0.70	0.14	0
Pasture	0	0	0	0	0.80	0.80	0.80	0.80	0.80	0.80	0	0
Grapes, Raisin	0	0	0	0.15	0.30	0.30	0.30	0.30	0.30	0.30	0	0

Appendix C. Land use time series for Ukiah Valley

Ukiah Valley Land Use (Acres)									
Year	**Cherries**	**Grapes, Red Wine**	**Grapes, White Wine**	**Pears, Bartlett**	**Olives**	**Pears, Other**	**Pistachios**	**Walnut, English**	**Pasture**
1990	1.8	1,760	1,497	1,514	0	98	0.2	1	0
1991	1.8	1,873	1,553	1,514	0	114	0.2	1	0
1992	1.8	1,956	1,675	1,514	0	114	0.2	1	0
1993	1.8	2,081	1,725	1,514	0	116	0.2	1	0
1994	1.8	2,275	1,804	1,514	0	116	0.2	1	0
1995	1.8	2,409	1,885	1,514	4	126	0.2	1	10
1996	1.8	2,673	2,030	1,516	4	126	0.2	1	10
1997	1.8	2,840	2,086	1,516	4	126	0.2	1	10
1998	1.8	3,247	2,188	1,516	4.2	126	0.2	1	10
1999	1.8	3,436	2,216	1,516	4.2	126	0.2	1	10
2000	1.8	3,603	2,315	1,516	4.2	126	0.2	1	10
2001	1.1	3,497	1,974	1,201	5.2	101	0.2	5.4	10
2002	0.4	3,391	1,632	886	6.1	77	0.2	9.7	0
2003	0.4	3,464	1,668	886	6.2	83	0.2	9.7	0
2004	0.4	3,510	1,739	886	6.3	89	0.2	9.7	0
2005	0.4	3,538	1,758	886	6.9	89	0.2	9.7	0
2006	0.4	3,496	1,560	878	9.1	80	0.2	9.7	0
2007	0.4	3,522	1,702	883	9.3	80	0.2	9.7	0
2008	0.4	3,535	1,761	888	9.3	80	0.2	9.7	0
2009	0.4	3,548	1,877	888	9.3	80	0.2	9.7	0
2010	0.4	3,592	1,887	888	9.3	80	0.2	9.7	0
2011	0.4	3,626	1,909	888	9.3	80	0.2	9.7	0
2012	0.4	3,788	1,989	888	9.3	83	0.2	9.7	0
2013	0.4	3,829	2,017	888	9.3	83	0.2	9.7	0
2014	0.4	3,862	2,036	888	9.3	83	0.2	9.7	0
2015	0.4	3,908	2,095	888	9.3	83	0.2	11	0

Appendix D. Land use time series for Redwood Valley

Redwood Valley Land Use (Acres)										
Year	**Apples**	**Grapes, Red Wine**	**Grapes, White Wine**	**Grapes, Rootstock**	**Pears, Bartlett**	**Olives**	**Pistachios**	**Pasture**	**Walnuts, English**	**Grapes, Raisin**
1990	0.8	1,088	480	0	40	0	12.4	0	32.4	0
1991	0.8	1,142	530	0	40	2	12.4	0	32.4	0
1992	0.8	1,199	577	0	40	2	12.4	0	32.4	0
1993	0.8	1,264	624	0	40	2	12.4	0	32.4	0
1994	0.8	1,299	631	1.7	40	2	12.4	0	32.4	0
1995	0.8	1,388	631	1.7	40	2	12.4	200	32.4	0
1996	1	1,478	636	1.7	40	2	12.4	200	32.4	0
1997	1	1,570	666	1.7	40	2	12.4	200	32.4	0
1998	1	1,621	675	1.7	40	2	12.4	200	32.4	0
1999	1	1,680	690	1.7	40	2	12.4	200	32.4	0
2000	1	1,783	690	7.2	40	2	12.4	200	32.4	0
2001	1.6	1,783	627	3.6	39	4.4	12.4	200	19.6	0
2002	2.2	1,784	564	0	38	6.7	12.4	0	6.7	0
2003	2.2	1,805	564	0	38	8.0	12.4	0	6.7	0
2004	2.2	1,823	564	0	38	8.1	12.4	0	6.7	0
2005	2.2	1,853	570	0	38	8.1	12.4	0	6.7	0
2006	2.2	1,794	489	0	38	10.1	12.4	0	6.7	0
2007	2.2	1,847	496	0	38	11.2	12.4	0	6.7	0
2008	2.2	1,855	504	0	38	11.2	12.4	0	6.7	0
2009	2.2	1,872	505	0	38	11.2	12.4	0	6.7	0
2010	3.2	1,887	505	0	38	11.2	12.4	0	6.7	0
2011	3.2	1,913	512	0	38	11.2	12.4	0	6.7	0
2012	3.2	1,914	512	0	38	11.2	12.4	0	6.7	0.1
2013	3.2	1,951	515	0	38	11.2	12.4	0	6.7	0.1
2014	3.2	1,961	515	0	38	11.2	12.4	0	6.7	0.1
2015	3.2	1,967	516	0	38	11.2	12.4	0	6.7	0.1

Appendix E. Land use time series for the Ukiah Valley Groundwater Basin

Ukiah Valley Groundwater Basin Total Land Use (Acres)												
Year	**Apples**	**Cherries**	**Grapes, Red Wine**	**Grapes, White Wine**	**Grapes, Rootstock**	**Olives**	**Pears, Bartlett**	**Pears, Other**	**Pistachios**	**Walnut, English**	**Pasture**	**Grape, Raisin**
1990	0.80	1.80	2,849	1,977	0	0	1,554	98.40	12.60	33.40	0	0
1991	0.80	1.80	3,015	2,083	0	2.00	1,554	114.40	12.60	33.40	0	0
1992	0.80	1.80	3,155	2,251	0	2.00	1,554	114.40	12.60	33.40	0	0
1993	0.80	1.80	3,345	2,349	0	2.00	1,554	116.40	12.60	33.40	0	0
1994	0.80	1.80	3,574	2,435	1.70	2.00	1,554	116.40	12.60	33.40	0	0
1995	0.80	1.80	3,797	2,516	1.70	6.00	1,554	125.90	12.60	33.40	210	0
1996	1.00	1.80	4,151	2,666	1.70	6.00	1,556	125.90	12.60	33.40	210	0
1997	1.00	1.80	4,410	2,752	1.70	6.00	1,556	125.90	12.60	33.40	210	0
1998	1.00	1.80	4,868	2,864	1.70	6.20	1,556	125.90	12.60	33.40	210	0
1999	1.00	1.80	5,117	2,906	1.70	6.20	1,556	125.90	12.60	33.40	210	0
2000	1.00	1.80	5,386	3,005	7.20	6.20	1,556	125.90	12.60	33.40	210	0
2001	1.60	1.10	5,280	2,601	3.60	9.50	1,240	101.40	12.60	24.90	210	0
2002	2.20	0.40	5,175	2,196	0	12.80	924	76.90	12.60	16.40	0	0
2003	2.20	0.40	5,268	2,232	0	14.20	924	83.30	12.60	16.40	0	0
2004	2.20	0.40	5,333	2,303	0	14.40	924	89.30	12.60	16.40	0	0
2005	2.20	0.40	5,392	2,328	0	15.00	924	89.30	12.60	16.40	0	0
2006	2.20	0.40	5,290	2,049	0	19.20	916	79.80	12.60	16.40	0	0
2007	2.20	0.40	5,370	2,198	0	20.50	921	79.80	12.60	16.40	0	0
2008	2.20	0.40	5,389	2,265	0	20.50	926	79.80	12.60	16.40	0	0
2009	2.20	0.40	5,420	2,382	0	20.50	926	79.80	12.60	16.40	0	0
2010	3.20	0.40	5,479	2,391	0	20.50	926	79.80	12.60	16.40	0	0
2011	3.20	0.40	5,539	2,421	0	20.50	926	79.80	12.60	16.40	0	0
2012	3.20	0.40	5,702	2,502	0	20.50	926	82.50	12.60	16.40	0	0.10
2013	3.20	0.40	5,781	2,532	0	20.50	926	82.50	12.60	16.40	0	0.10
2014	3.20	0.40	5,823	2,551	0	20.50	926	82.50	12.60	16.40	0	0.10
2015	3.20	0.40	5,875	2,611	0	20.50	926	82.50	12.60	17.70	0	0.10

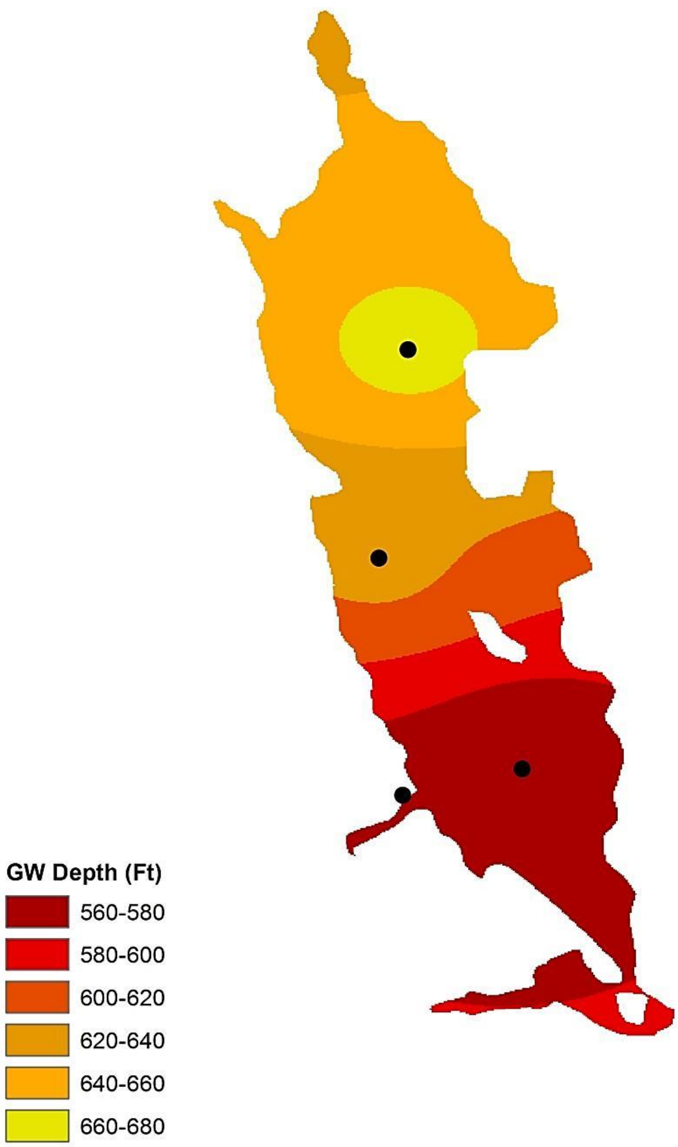
Appendix F. Monthly precipitation (in) values obtained through the Thiessen Polygon Method for precipitation.

Monthly Precipitation(in)												
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
1991	0.97	3.40	14.06	0.97	0.45	0.50	0.04	0.00	0.01	2.02	2.50	3.13
1992	4.01	9.67	4.30	1.03	0.30	1.26	0.01	0.00	0.00	3.10	1.09	13.80
1993	10.08	7.94	2.59	2.17	3.24	1.19	0.00	0.00	0.00	0.45	1.90	4.27
1994	2.18	5.95	0.26	2.31	0.53	0.02	0.01	0.00	0.00	0.38	5.81	4.07
1995	18.97	0.39	12.72	2.83	1.62	0.53	0.00	0.00	0.01	0.00	0.44	14.24
1996	12.21	9.03	3.09	2.96	1.65	0.00	0.00	0.00	0.17	1.60	4.12	15.69
1997	10.77	1.48	2.09	1.07	0.78	0.78	0.00	0.92	0.68	2.15	9.50	4.05
1998	16.26	20.31	6.82	2.43	4.33	0.12	0.00	0.00	0.00	1.57	6.70	2.02
1999	2.92	12.15	5.71	1.42	0.05	0.02	0.00	0.51	0.07	1.09	5.19	1.18
2000	7.31	10.88	2.41	2.50	1.64	0.62	0.02	0.03	0.19	2.83	1.65	1.77
2001	5.48	7.69	3.18	0.85	0.02	0.27	0.00	0.00	0.08	0.33	4.18	4.83
2002	1.89	1.30	0.95	0.31	0.35	0.03	0.08	0.02	0.00	0.02	2.59	10.05
2003	1.71	2.62	4.27	9.69	0.86	0.07	0.01	0.00	0.14	0.03	4.62	14.97
2004	3.06	11.61	1.37	0.67	0.27	0.19	0.00	0.00	0.11	4.51	1.90	9.54
2005	6.02	3.45	5.87	2.57	3.81	2.19	0.00	0.00	0.01	0.91	6.15	17.56
2006	8.16	5.09	10.58	7.42	0.47	0.01	0.00	0.00	0.00	0.23	3.87	6.71
2007	0.50	9.23	0.57	2.40	0.90	0.13	0.09	0.00	0.08	1.86	0.75	7.65
2008	13.74	4.74	1.21	0.26	0.00	0.00	0.02	0.02	0.22	1.03	6.31	3.36
2009	0.44	8.10	3.39	0.33	2.92	0.02	0.01	0.00	0.04	2.71	1.83	4.61
2010	12.48	4.25	4.61	6.13	2.32	0.24	0.00	0.00	0.10	6.22	3.71	9.46
2011	1.91	4.15	12.08	1.09	2.37	1.68	0.02	0.00	0.02	3.66	2.65	0.19
2012	5.68	2.02	9.66	1.56	0.27	0.10	0.00	0.00	0.00	1.36	8.24	13.27
2013	1.47	0.47	2.23	1.07	0.51	0.25	0.09	0.01	0.88	0.02	1.04	0.97
2014	0.70	9.41	6.19	1.64	0.19	0.14	0.11	0.17	1.03	1.28	4.54	13.07
2015	0.62	4.61	0.71	2.00	0.57	0.43	0.44	0.53	0.58	0.12	2.21	9.82

Appendix G. Application efficiency values.

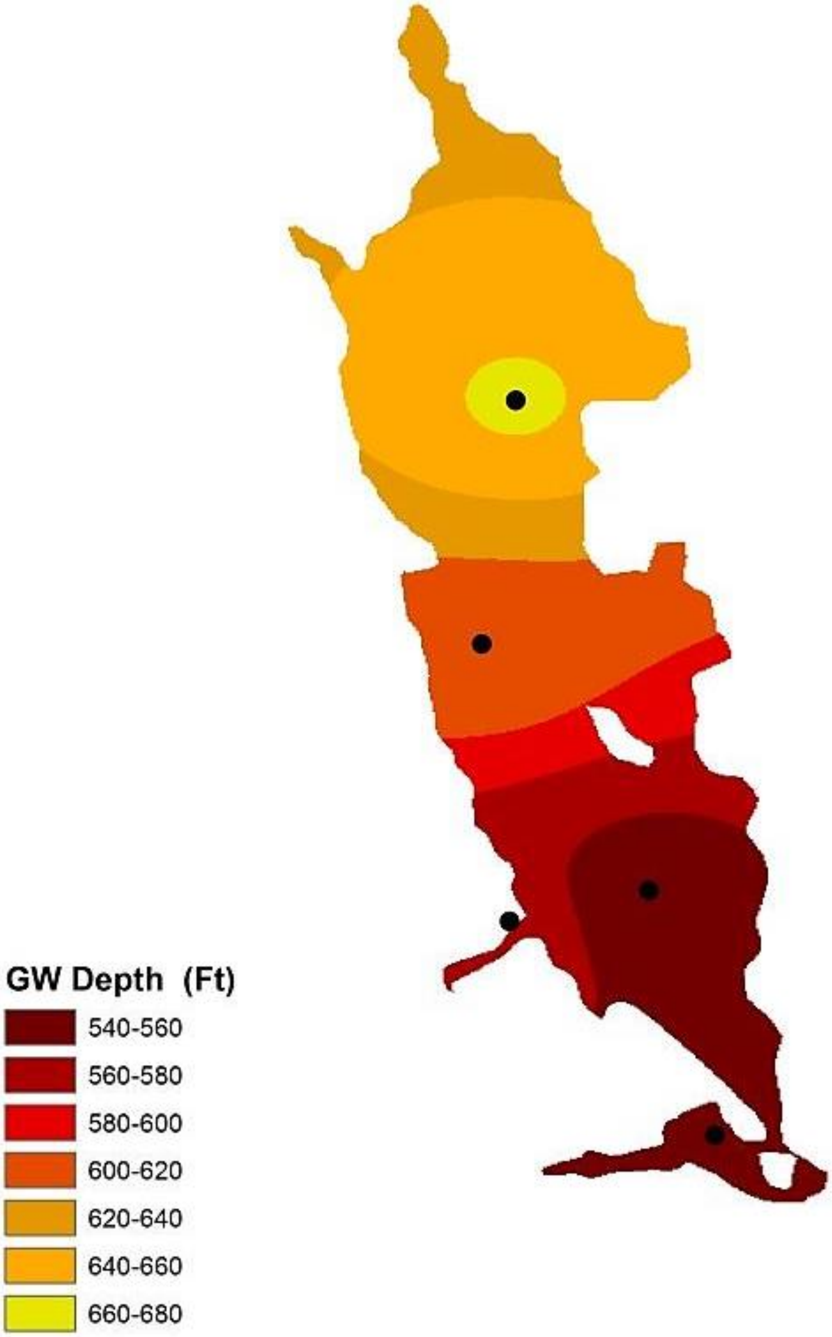
	Apples, Cherries, Olives, Bartlett Pears, Pears (Other), & Pistachios	**White Wine Grapes, Red Wine Grapes, Grapes (Rootstock), & Raisin Grapes**	**Pasture**
1991	0.884	0.888	0.693
1992	0.885	0.889	0.697
1993	0.885	0.891	0.700
1994	0.886	0.892	0.704
1995	0.887	0.893	0.708
1996	0.887	0.895	0.711
1997	0.888	0.896	0.715
1998	0.889	0.897	0.718
1999	0.889	0.899	0.722
2000	0.890	0.900	0.726
2001	0.891	0.901	0.729
2002	0.891	0.903	0.733
2003	0.892	0.904	0.737
2004	0.893	0.905	0.740
2005	0.893	0.907	0.744
2006	0.894	0.908	0.747
2007	0.895	0.909	0.751
2008	0.895	0.911	0.755
2009	0.896	0.912	0.758
2010	0.897	0.913	0.762
2011	0.897	0.915	0.766
2012	0.898	0.916	0.769
2013	0.899	0.917	0.773
2014	0.899	0.919	0.776
2015	0.900	0.920	0.780

Appendix H. GIS generated groundwater depth contours based off water table elevations derived from monitoring wells through DWR's water data library found online. The black dots represent the monitoring well location from which the water table data was obtained. The color scheme represents the water table elevations with respect to sea level that were generated using Inverse Distance Weighted Interpolation.

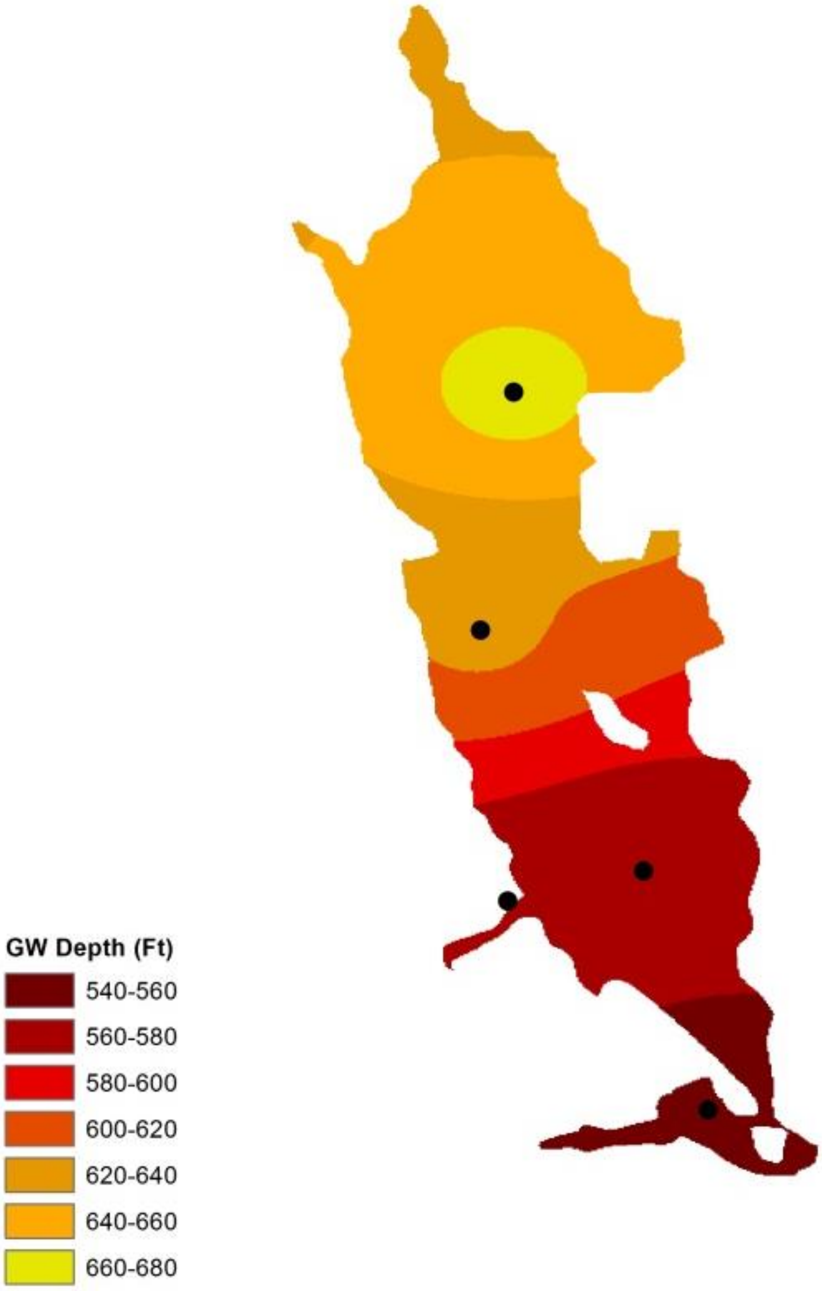


April 1991

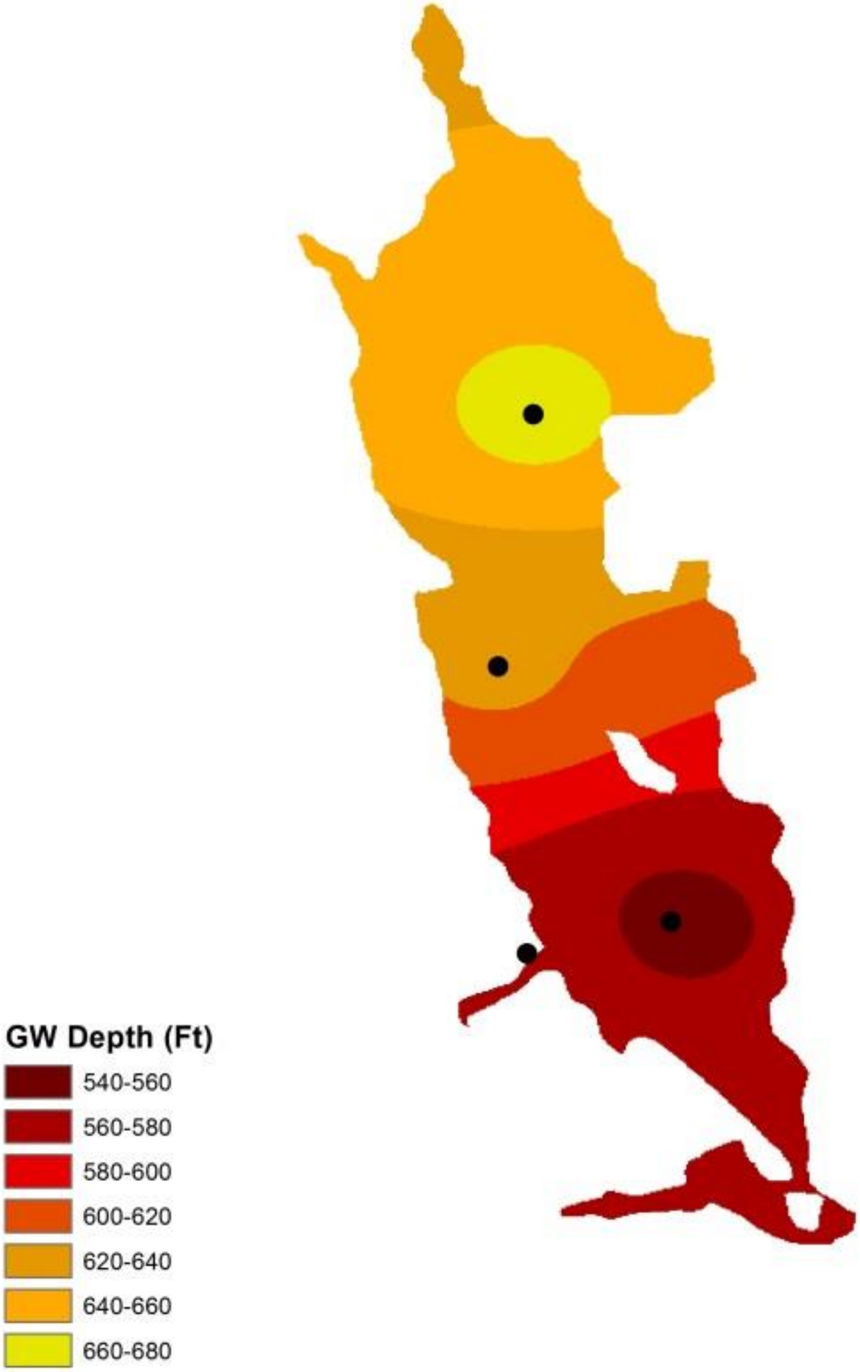
September 1991



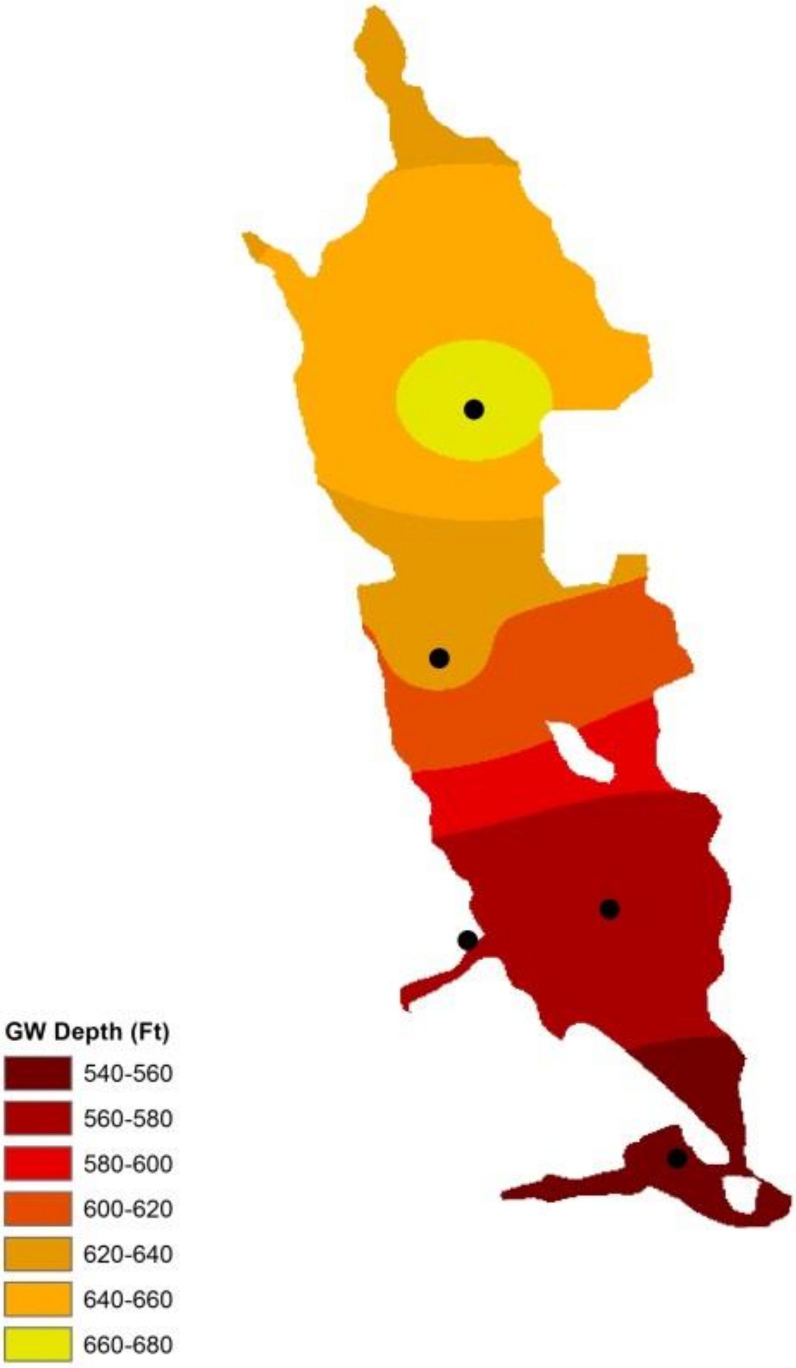
April 1992


GW Depth (Ft)
540-560
560-580
580-600
600-620
620-640
640-660
660-680

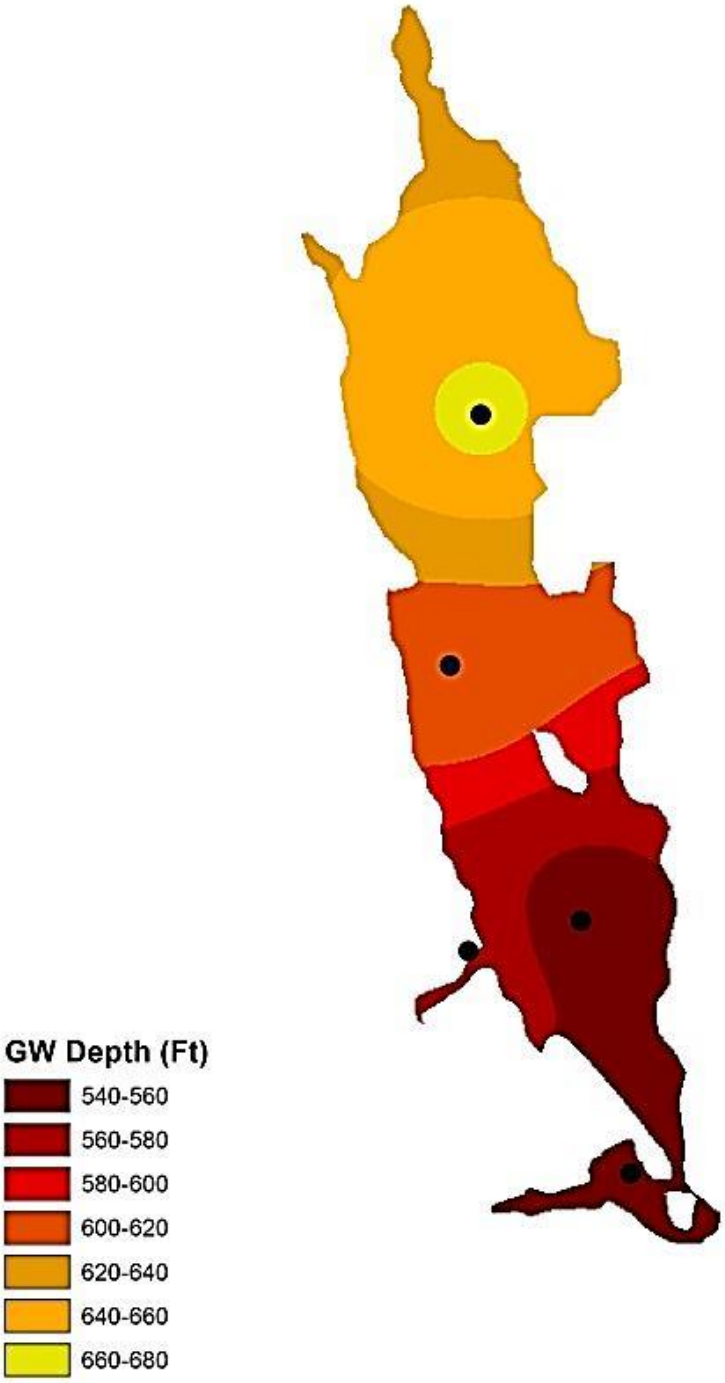
December 1992



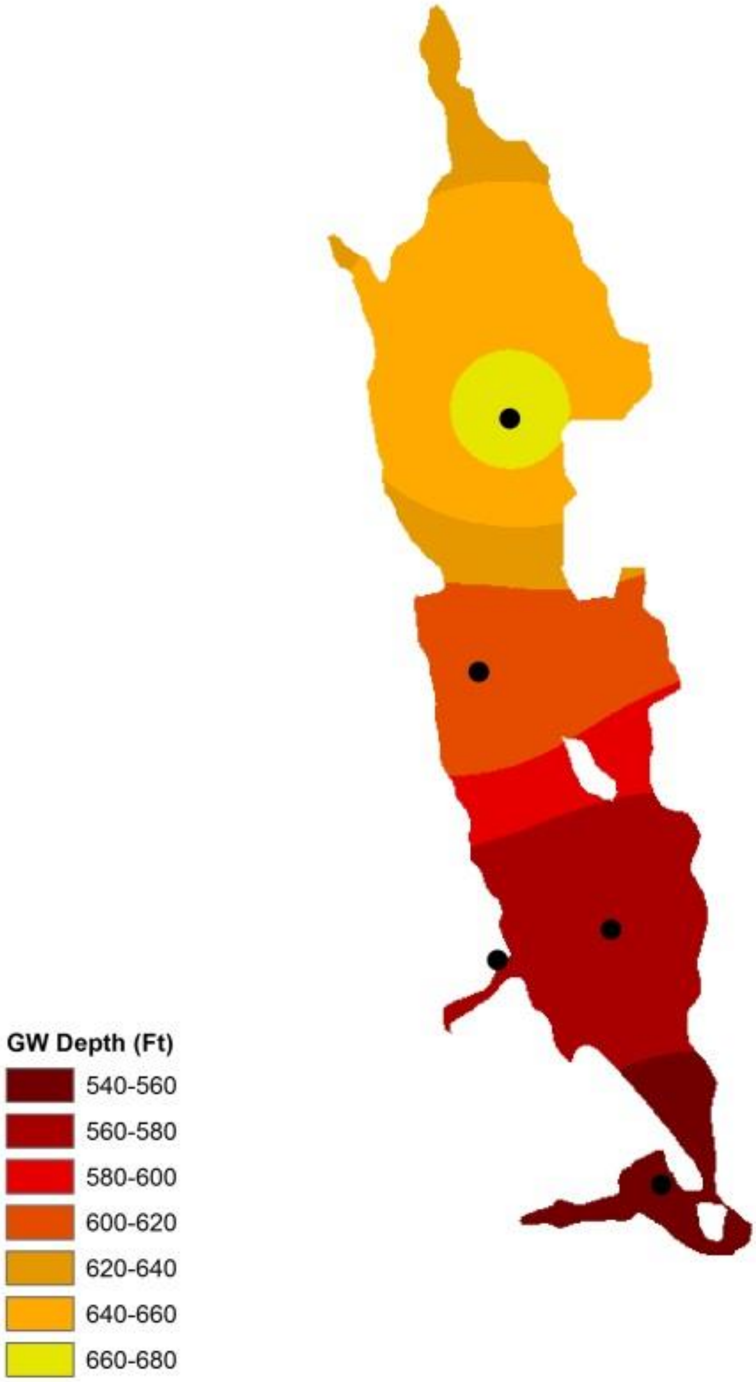
June 1993


GW Depth (Ft)
540-560
560-580
580-600
600-620
620-640
640-660
660-680

December 1993

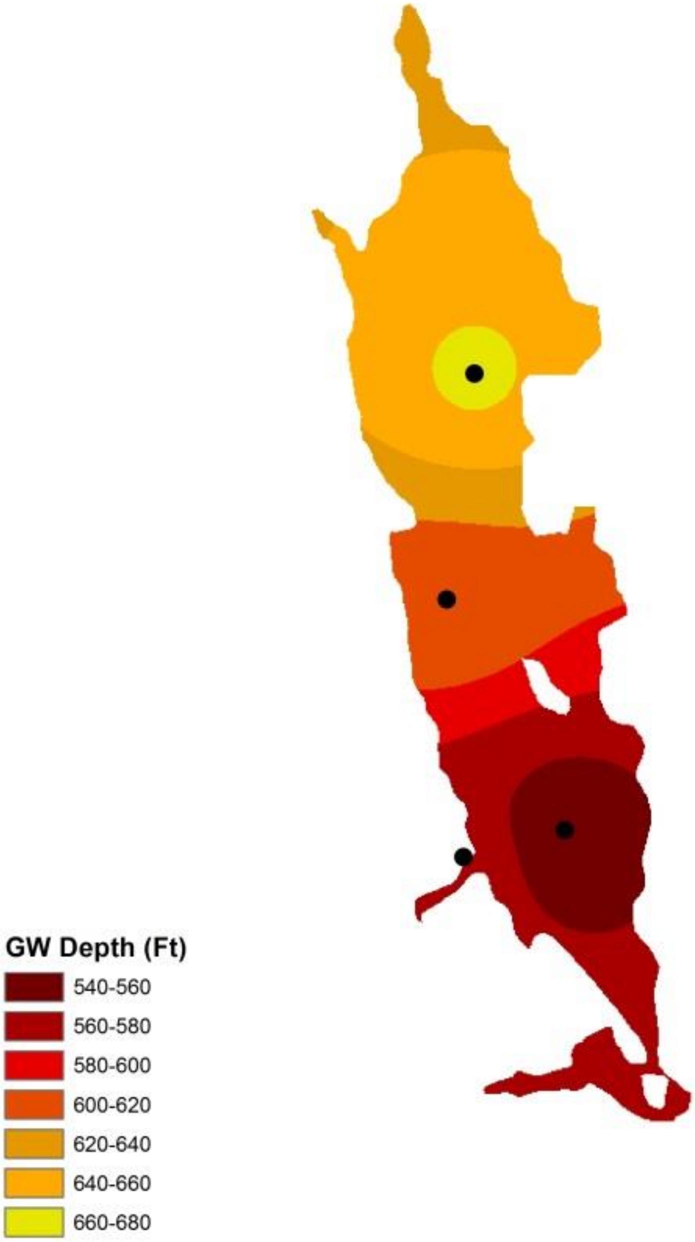


April 1994

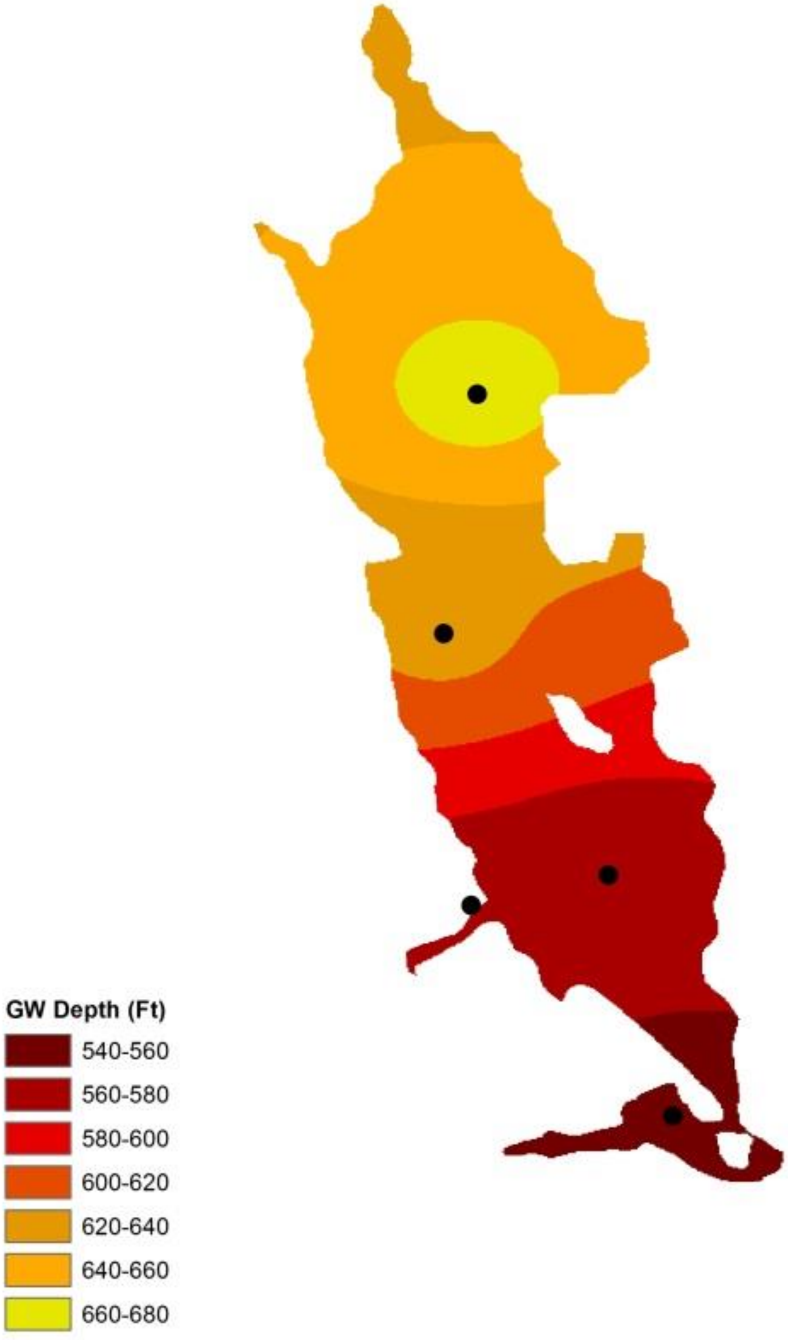


GW Depth (Ft)
540-560
560-580
580-600
600-620
620-640
640-660
660-680

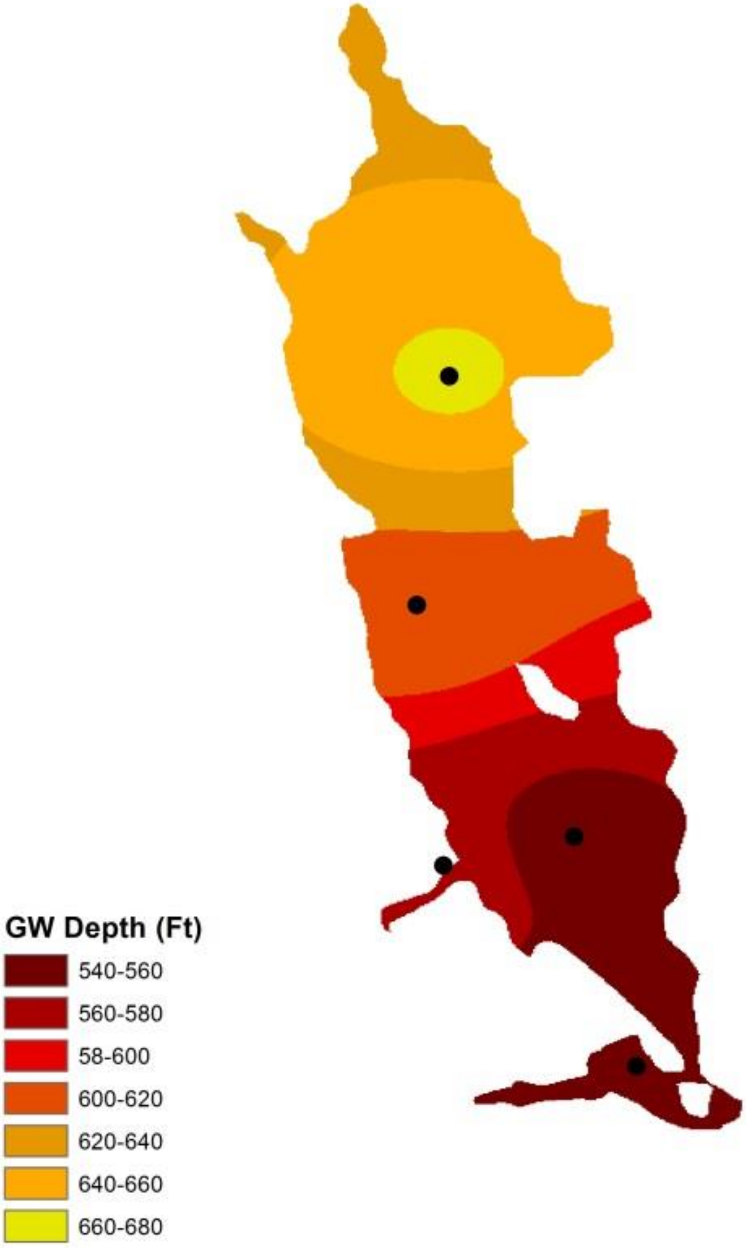
October 1994



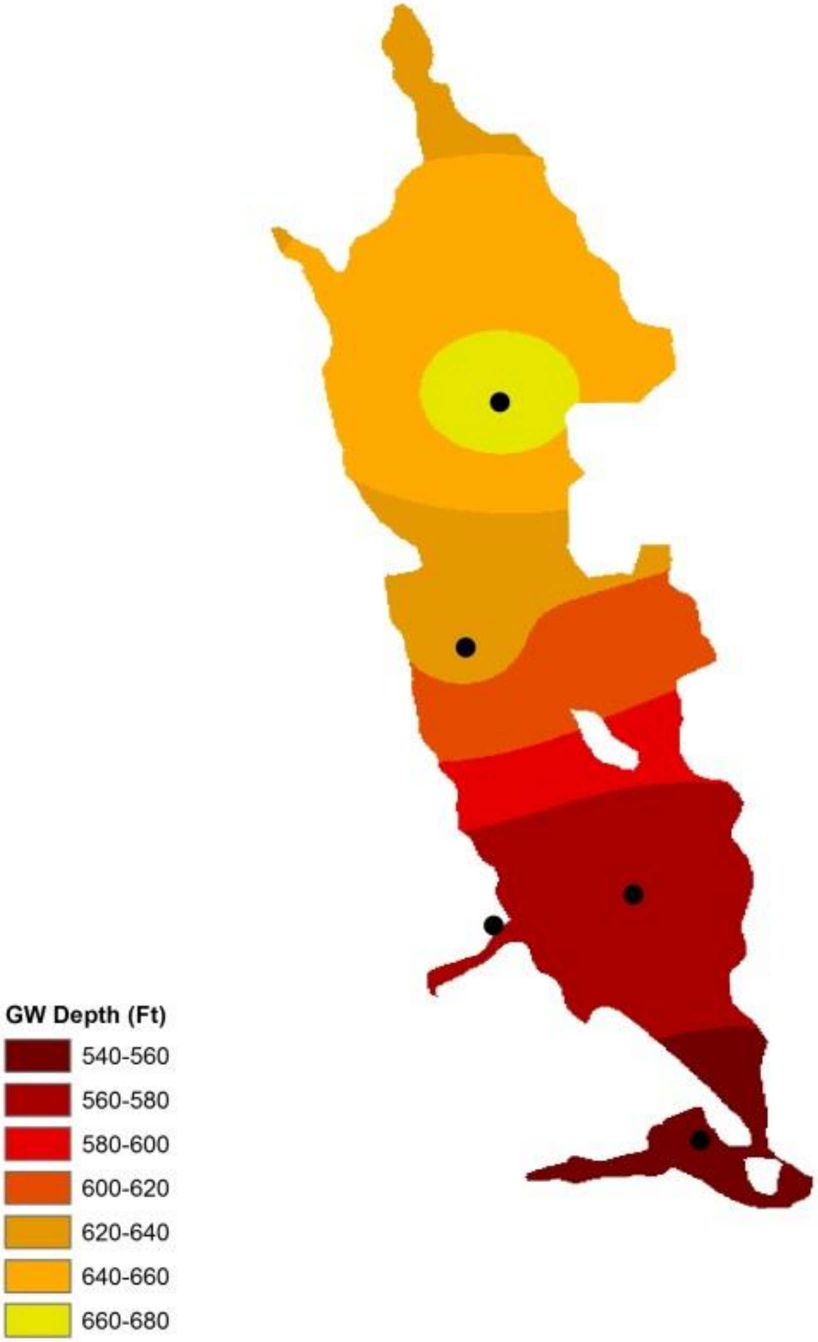
May 1995


GW Depth (Ft)
540-560
560-580
580-600
600-620
620-640
640-660
660-680

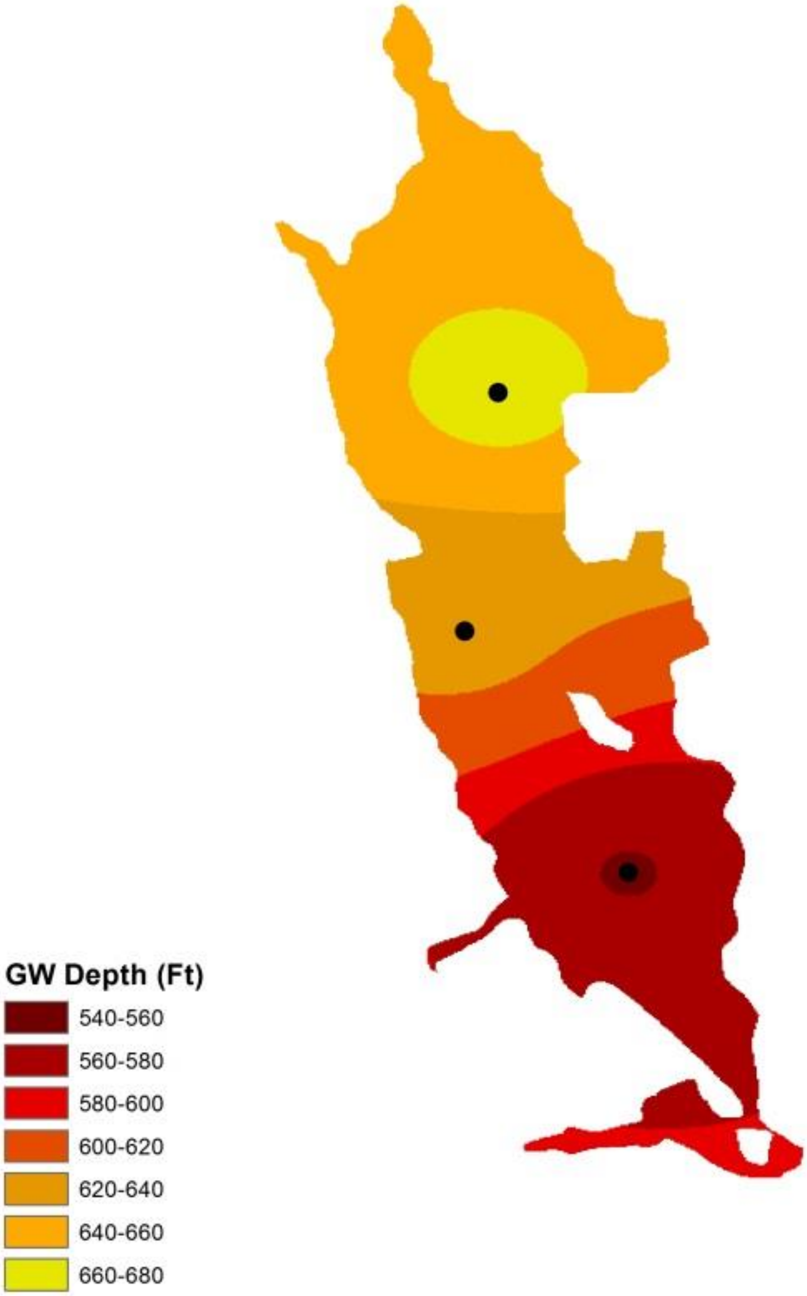
October 1995



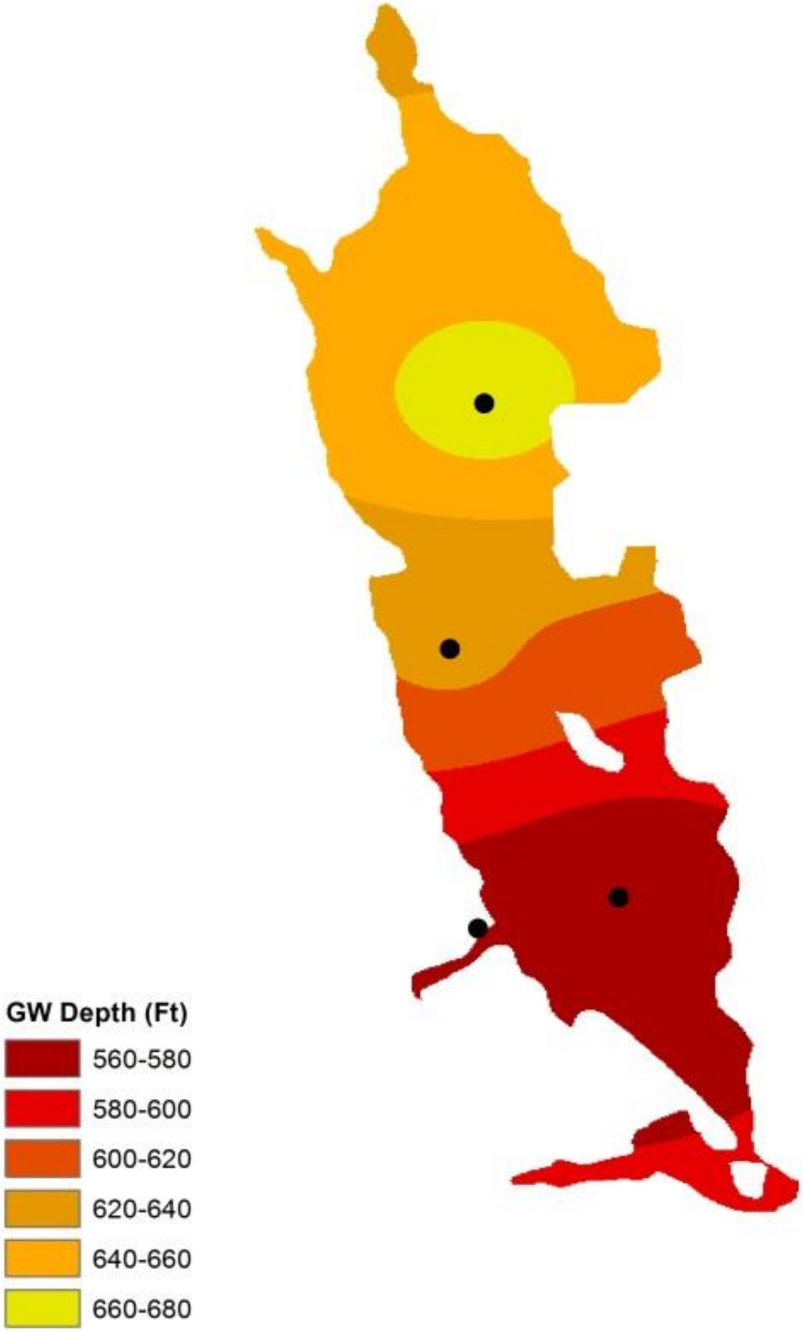
May 1996


GW Depth (Ft)
540-560
560-580
580-600
600-620
620-640
640-660
660-680

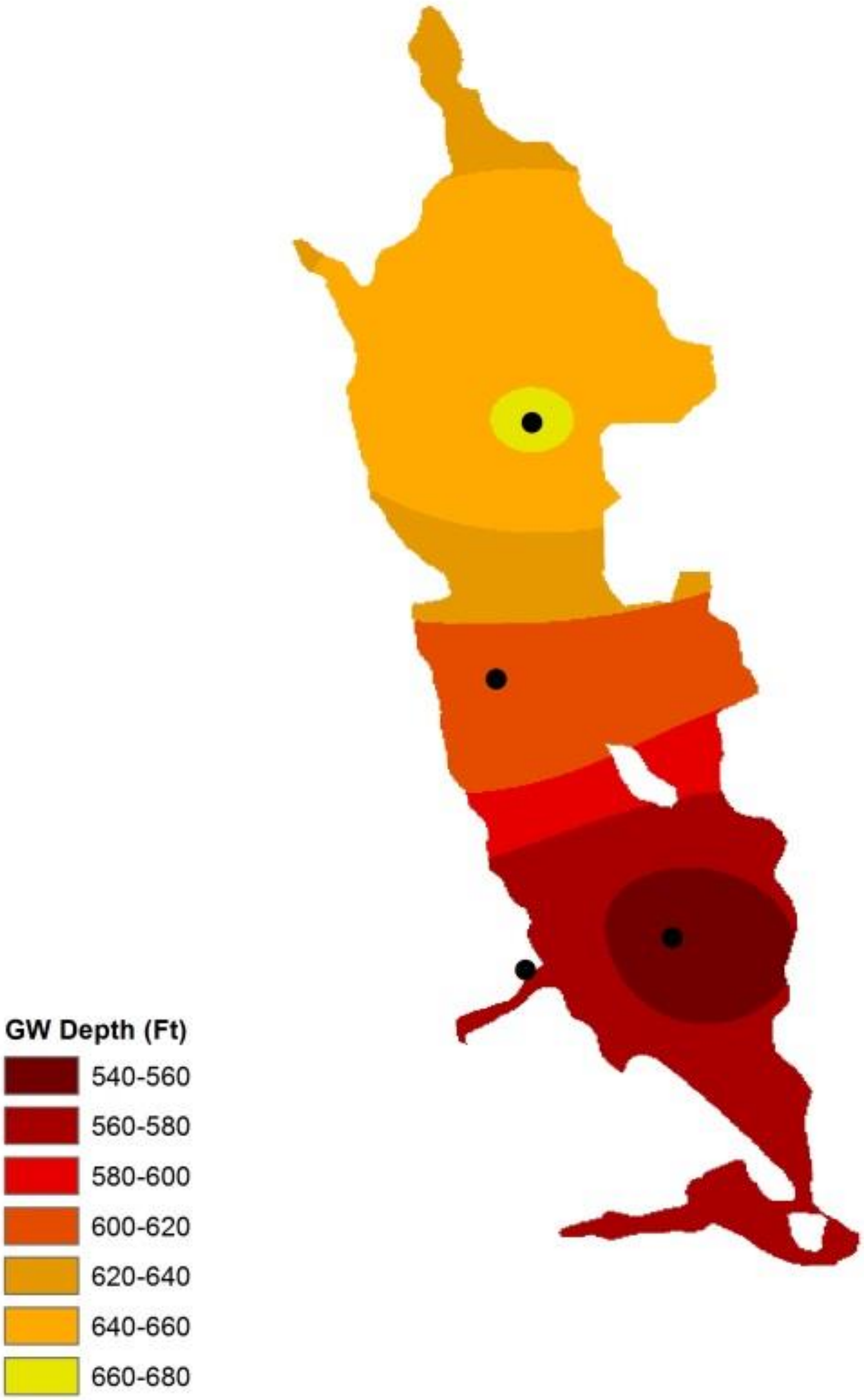
December 1996



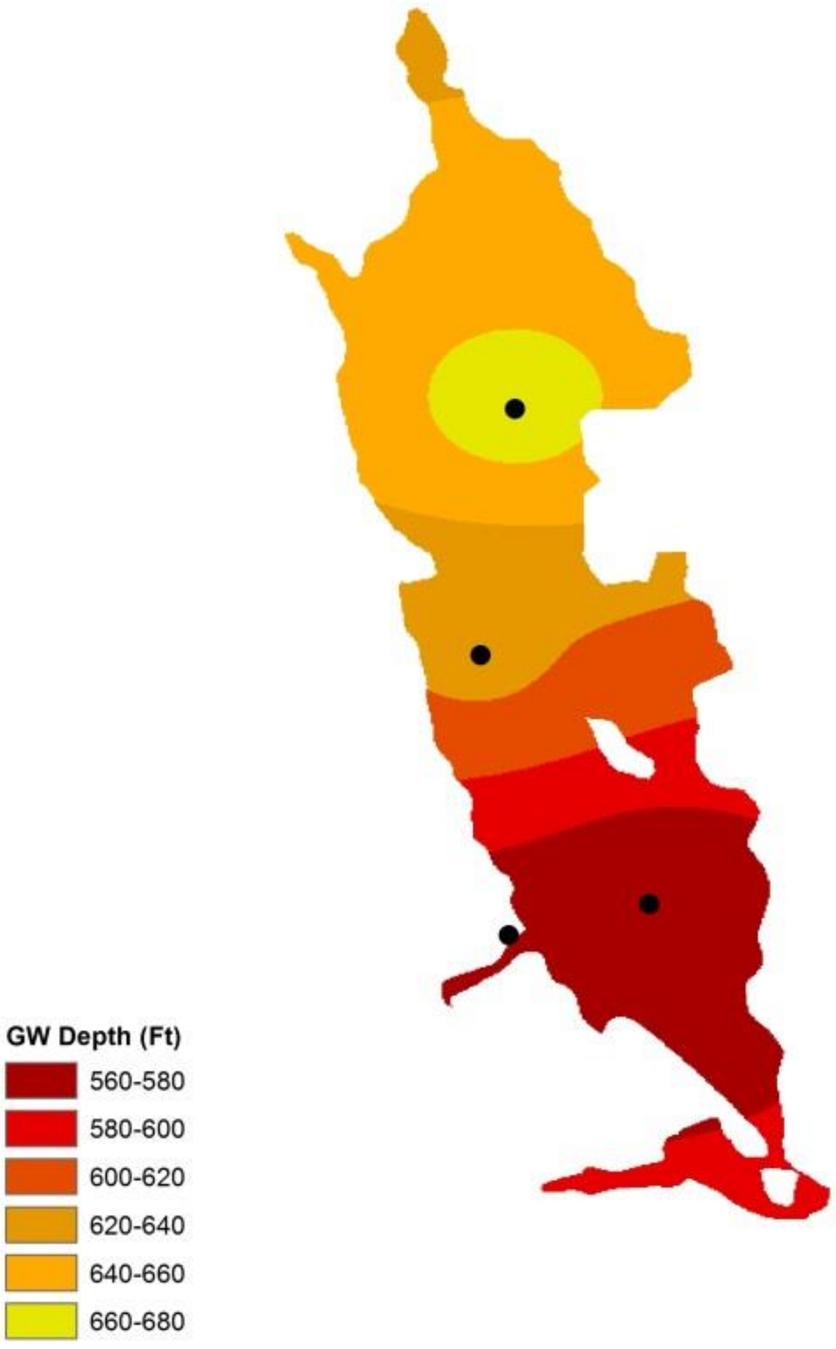
April 1997

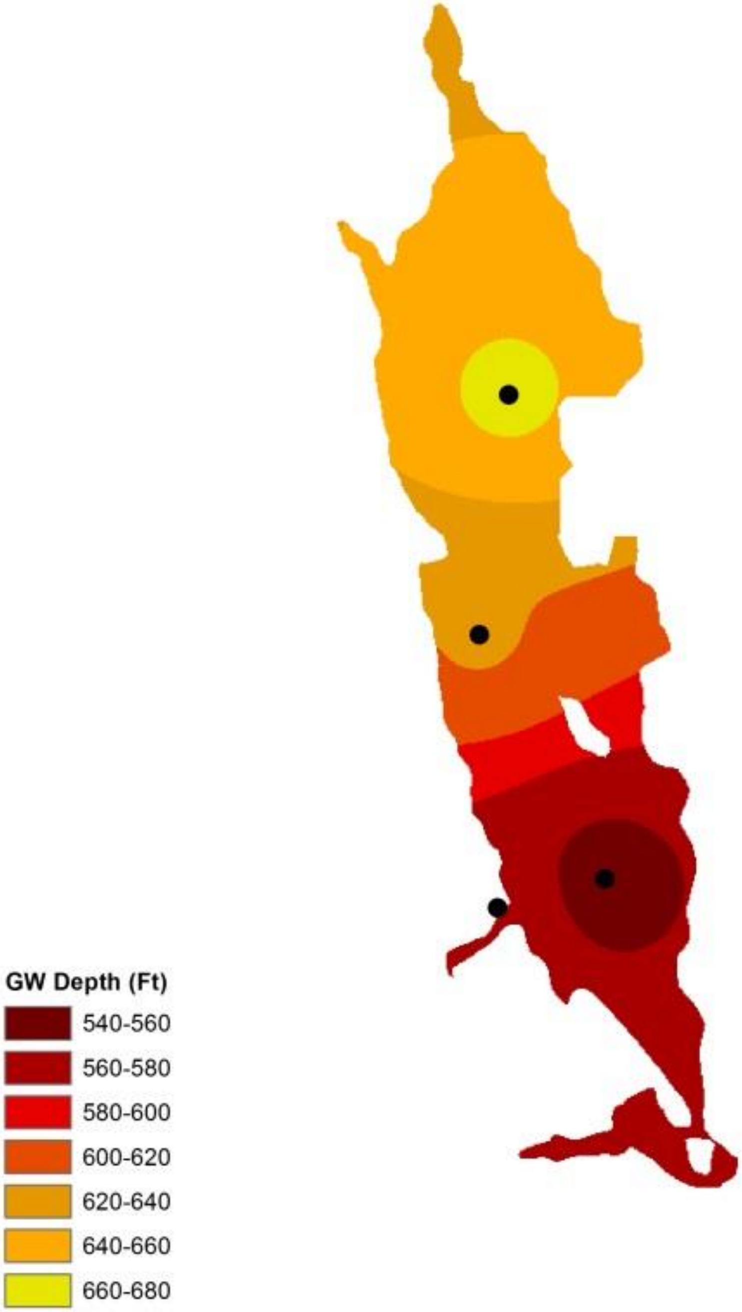


November 1997



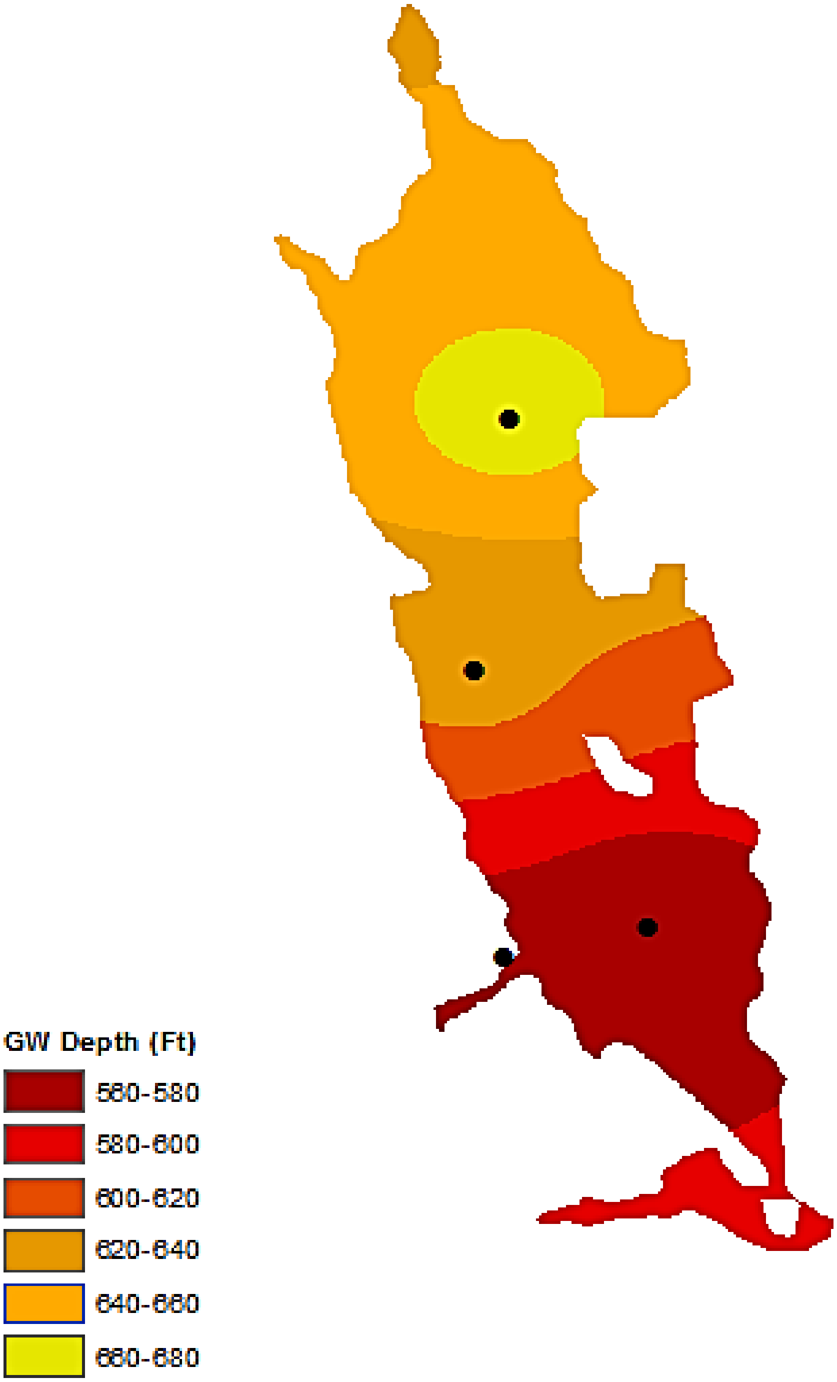
May 1998





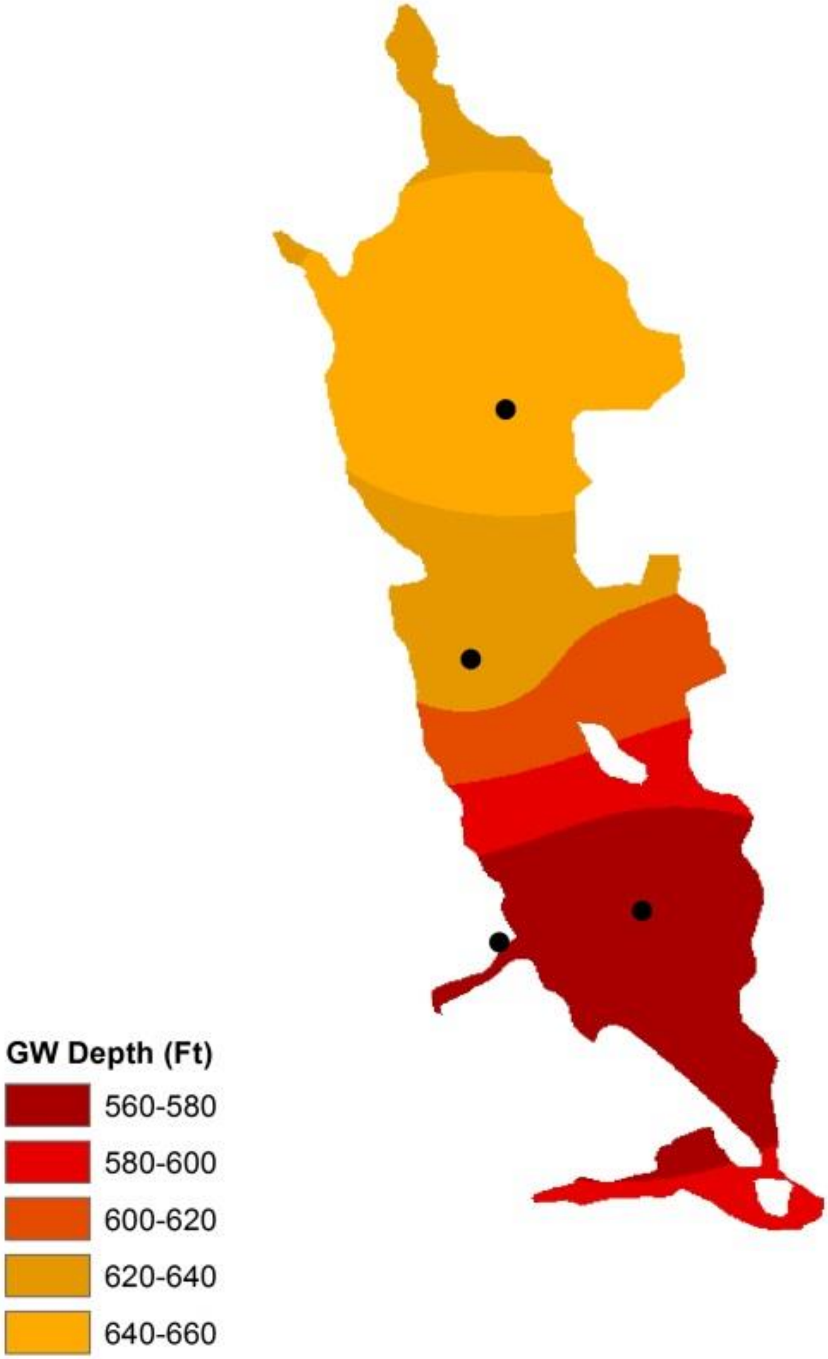
November 1998

April 1999



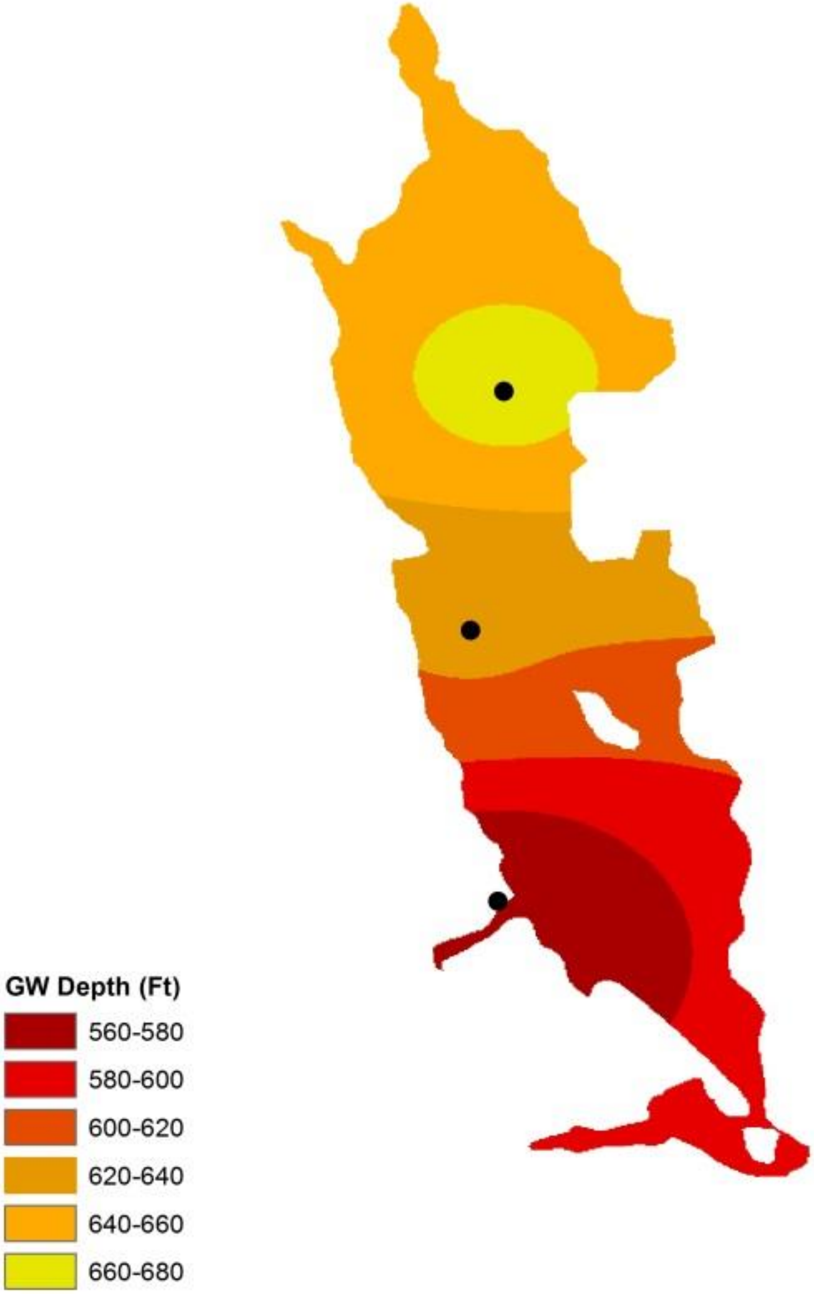
December 1999

April 2000



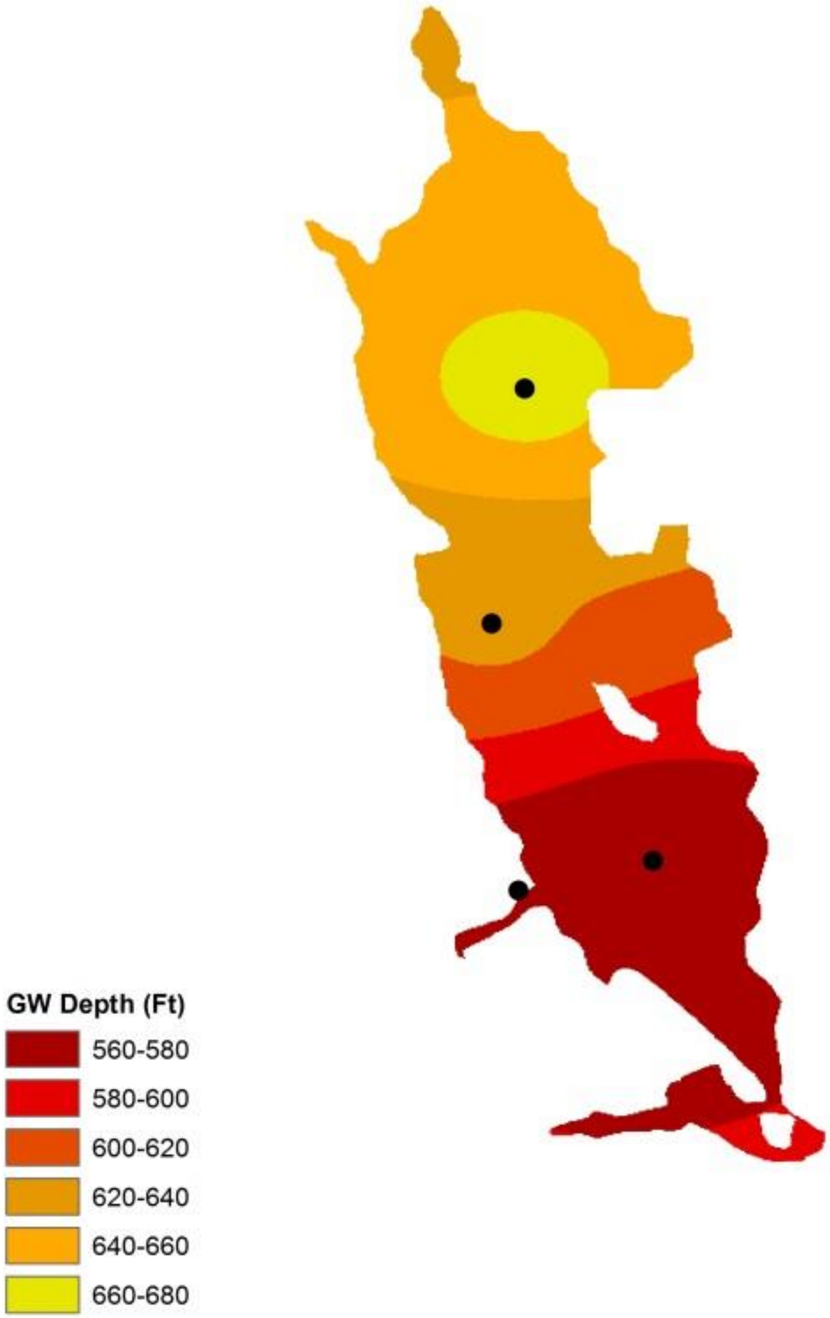
November 2000

May 2001

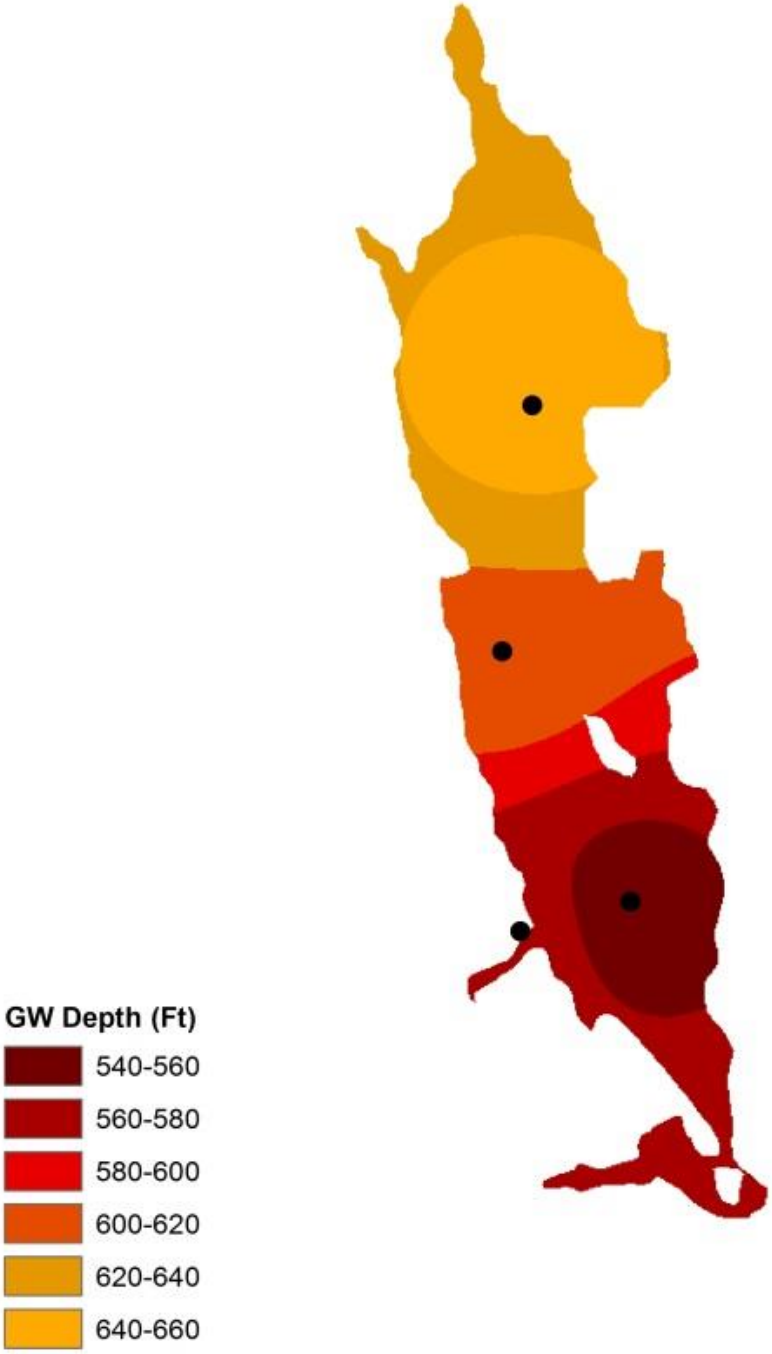


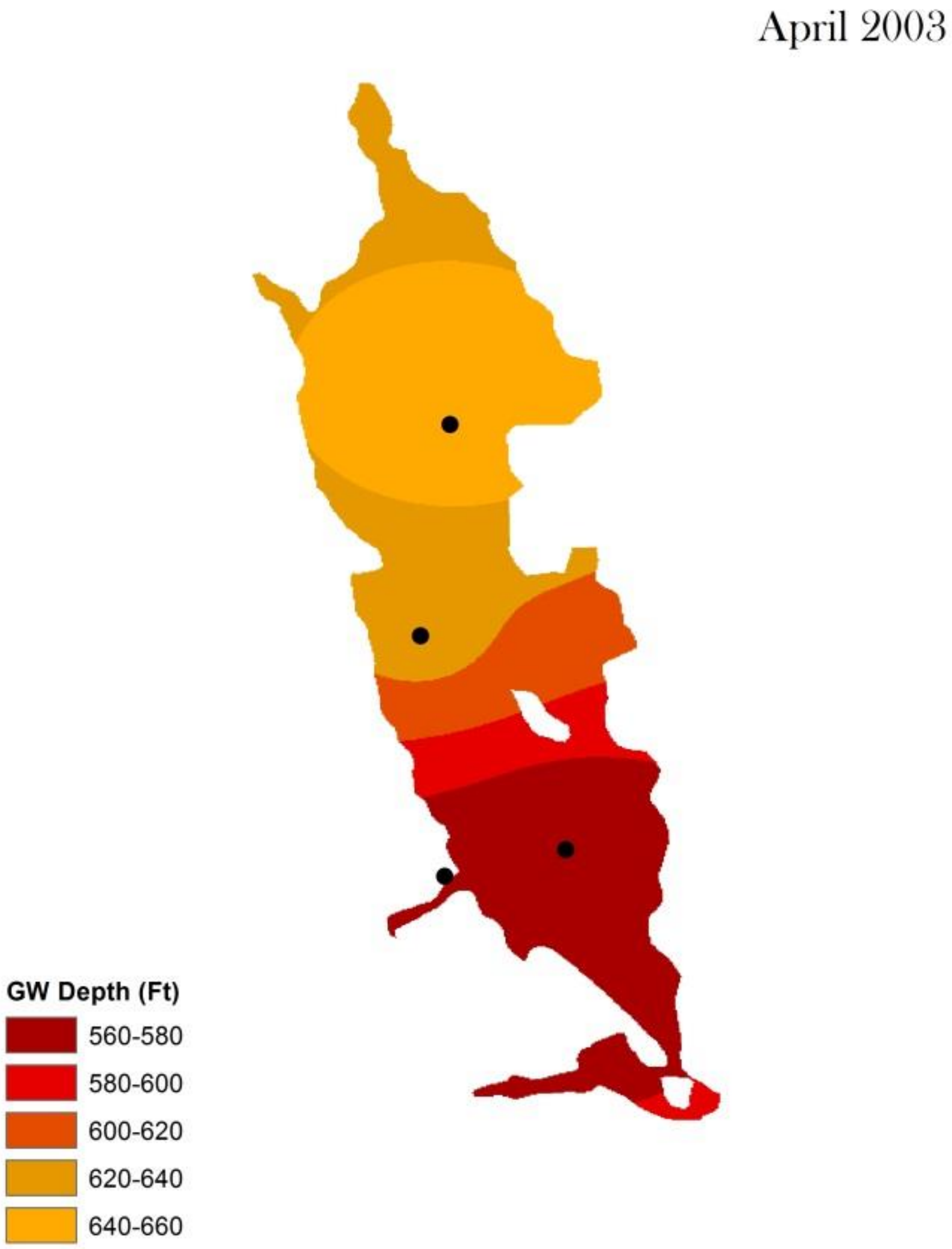
October 2001

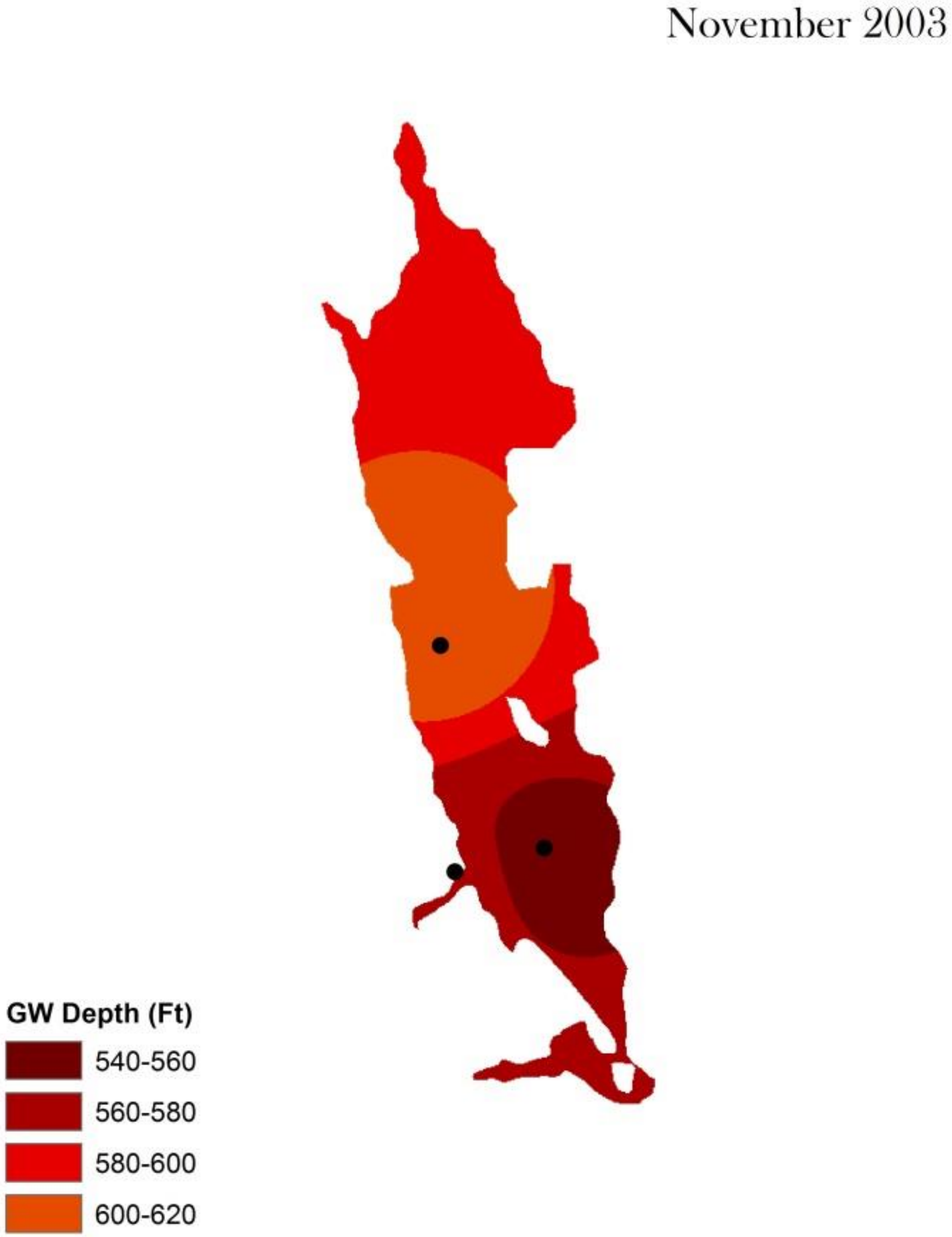
April 2002



October 2002

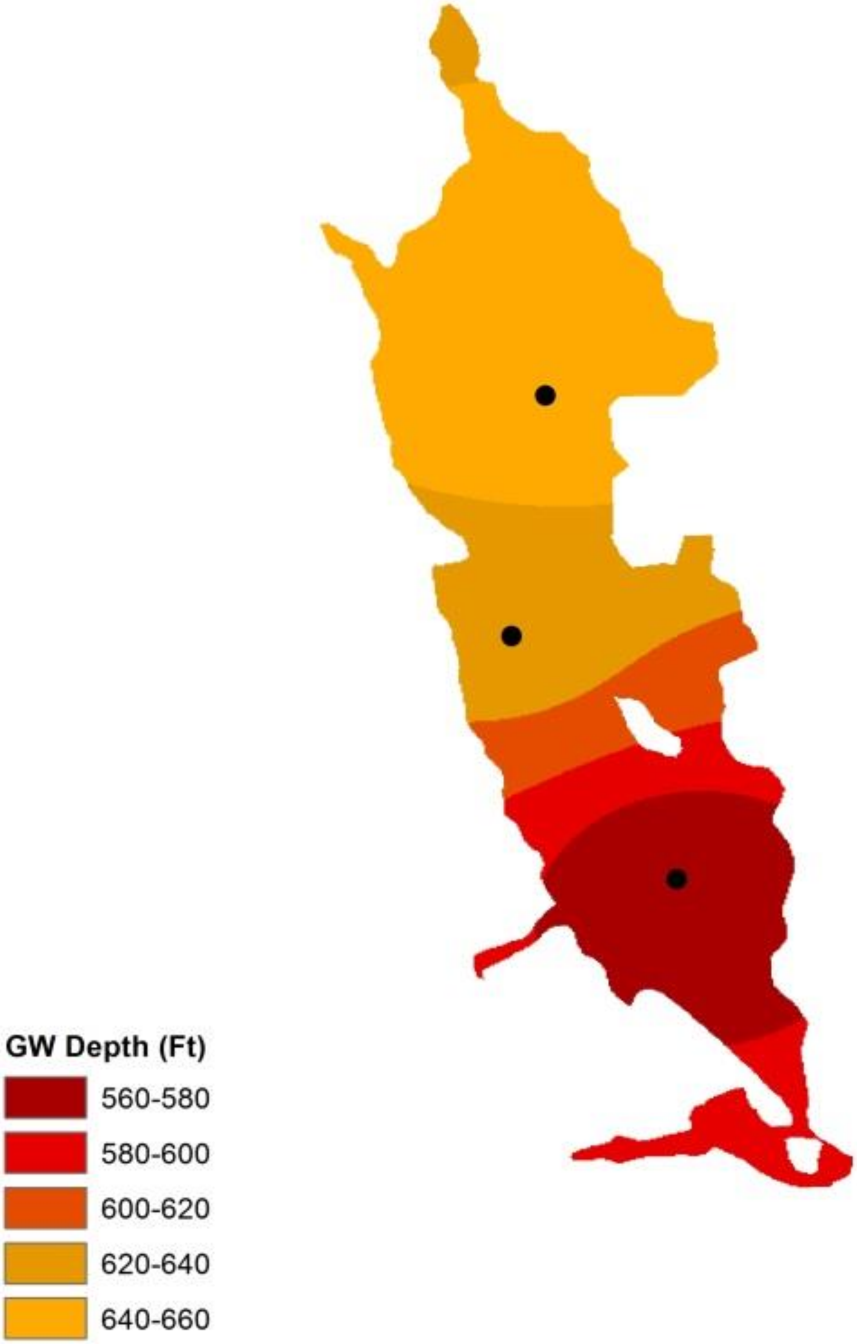



April 2003
GW Depth (Ft)
560-580
580-600
600-620
620-640
640-660

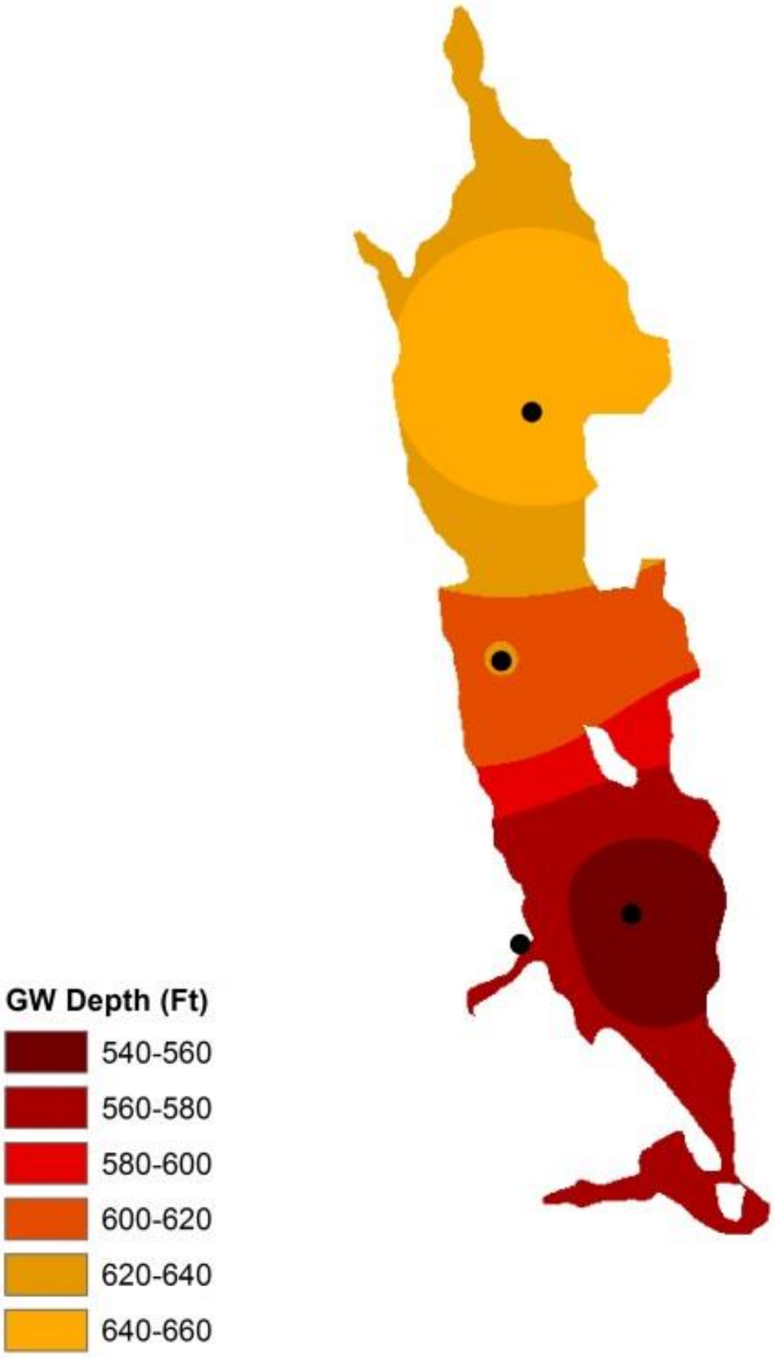


For November of 2013, only three monitoring wells had data available. The southern end of the basin had water table measurements in the low range of 540-560 ft with respect to sea level. This data is what is responsible for the kink seen in Figure 31 for the year 2003.

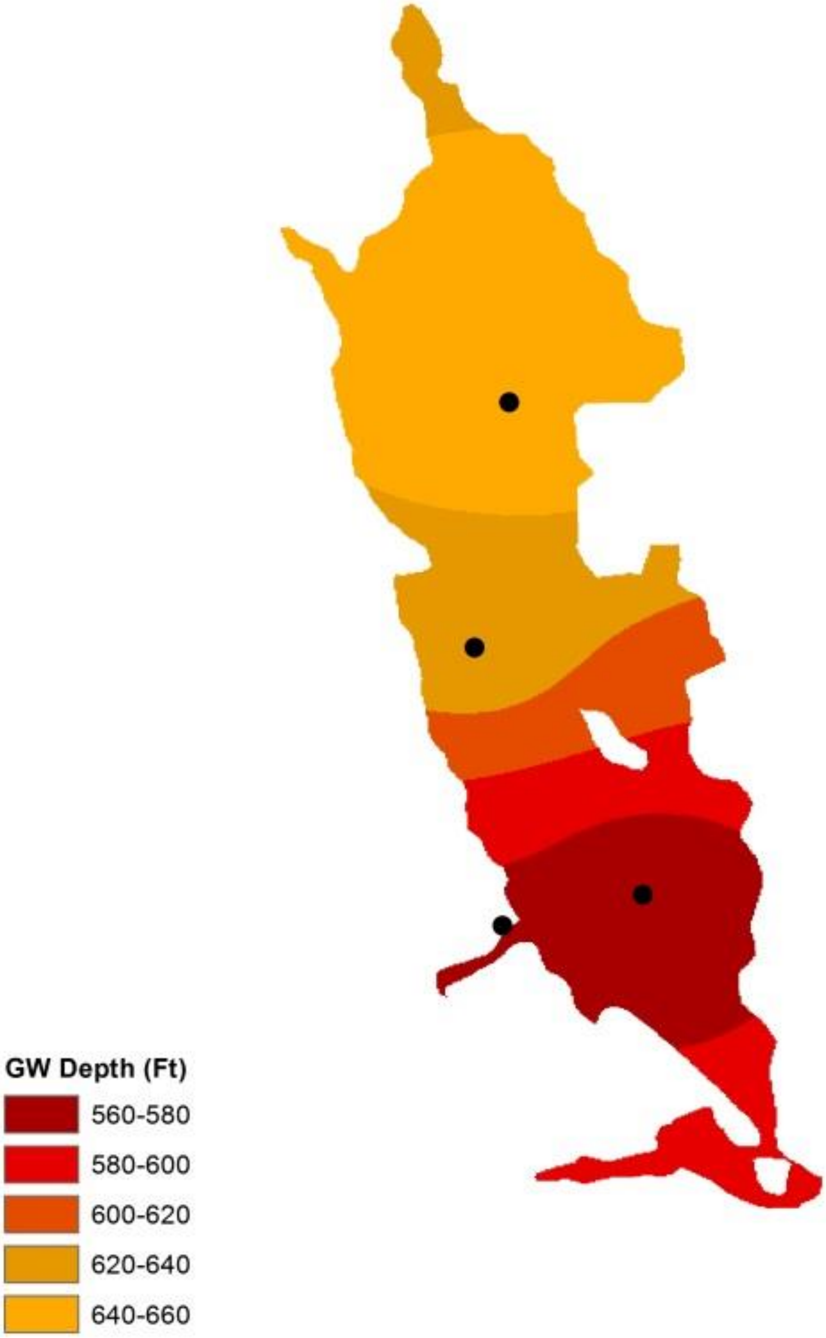
March 2004



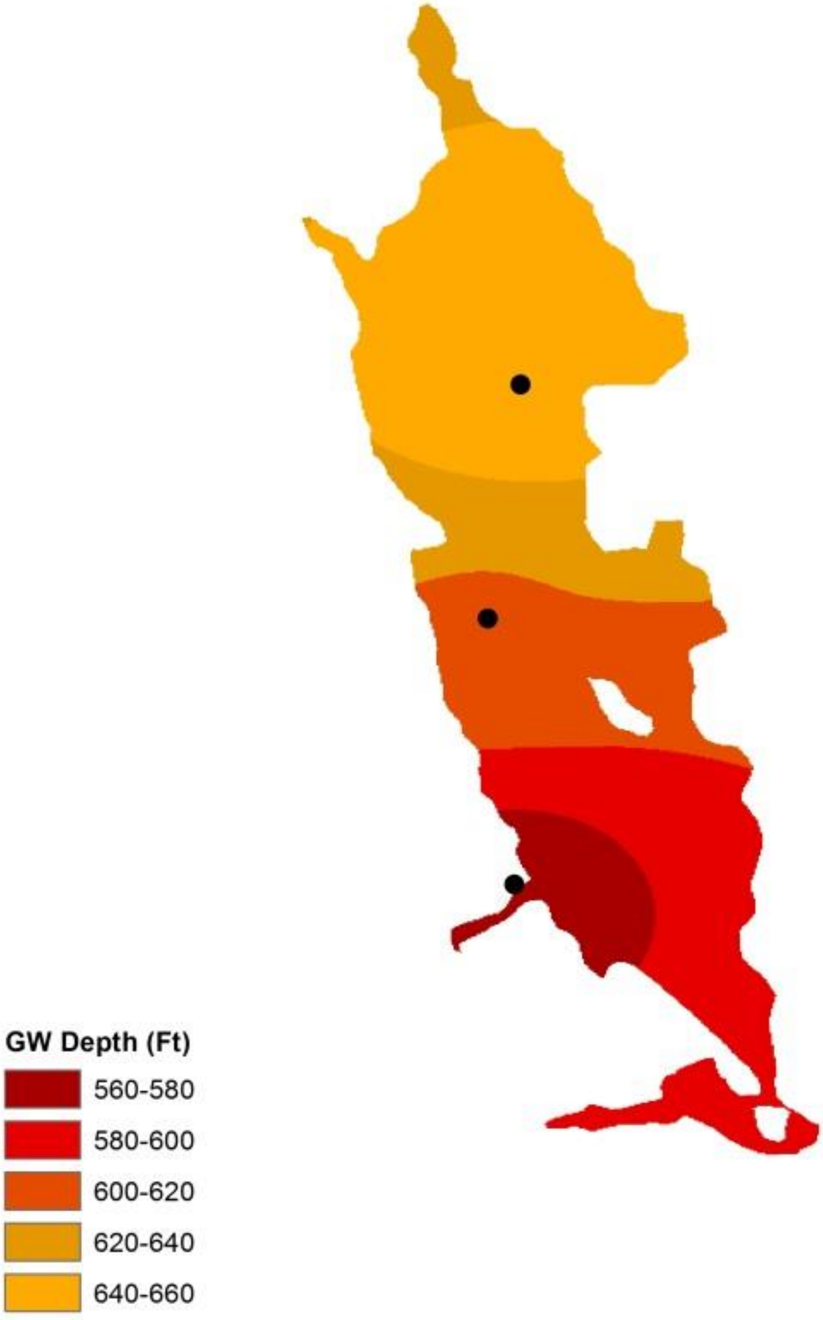
October 2004



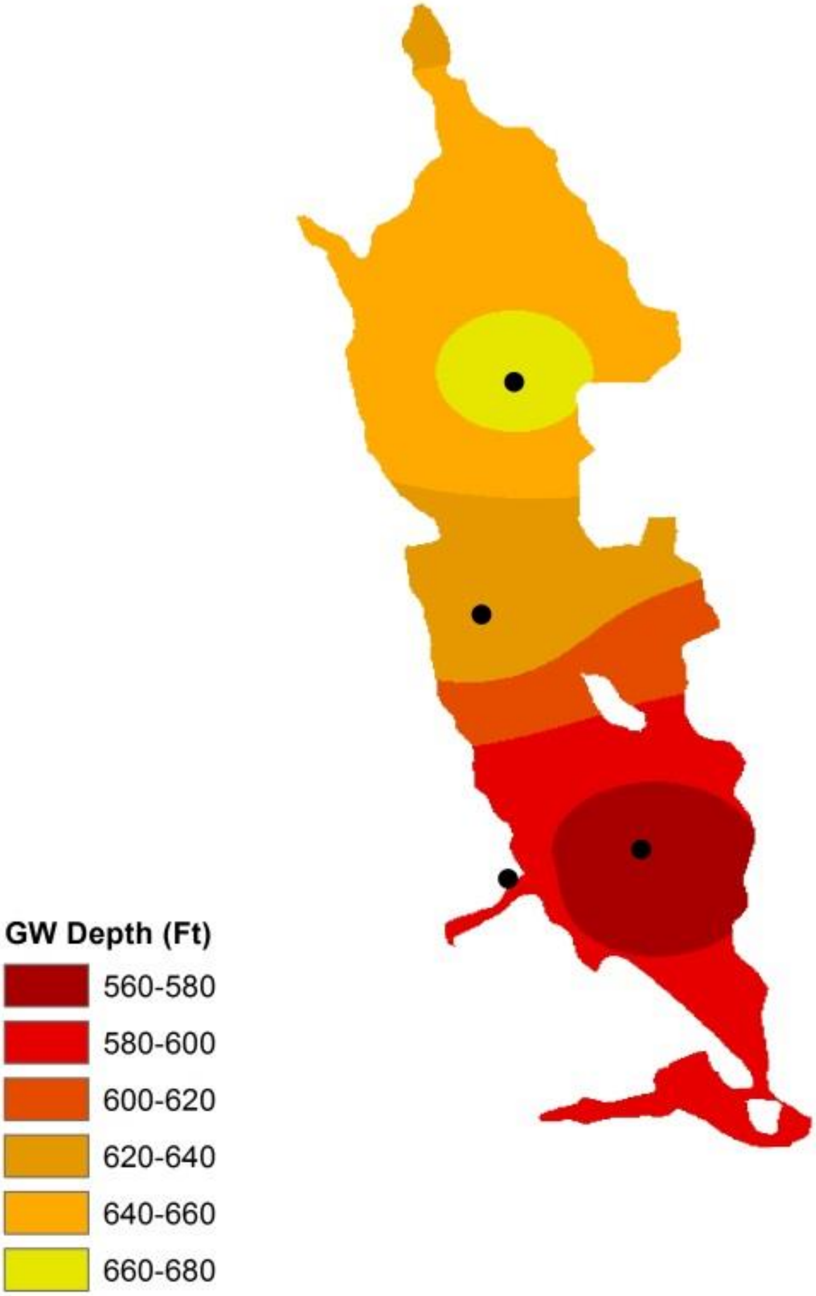
April 2005

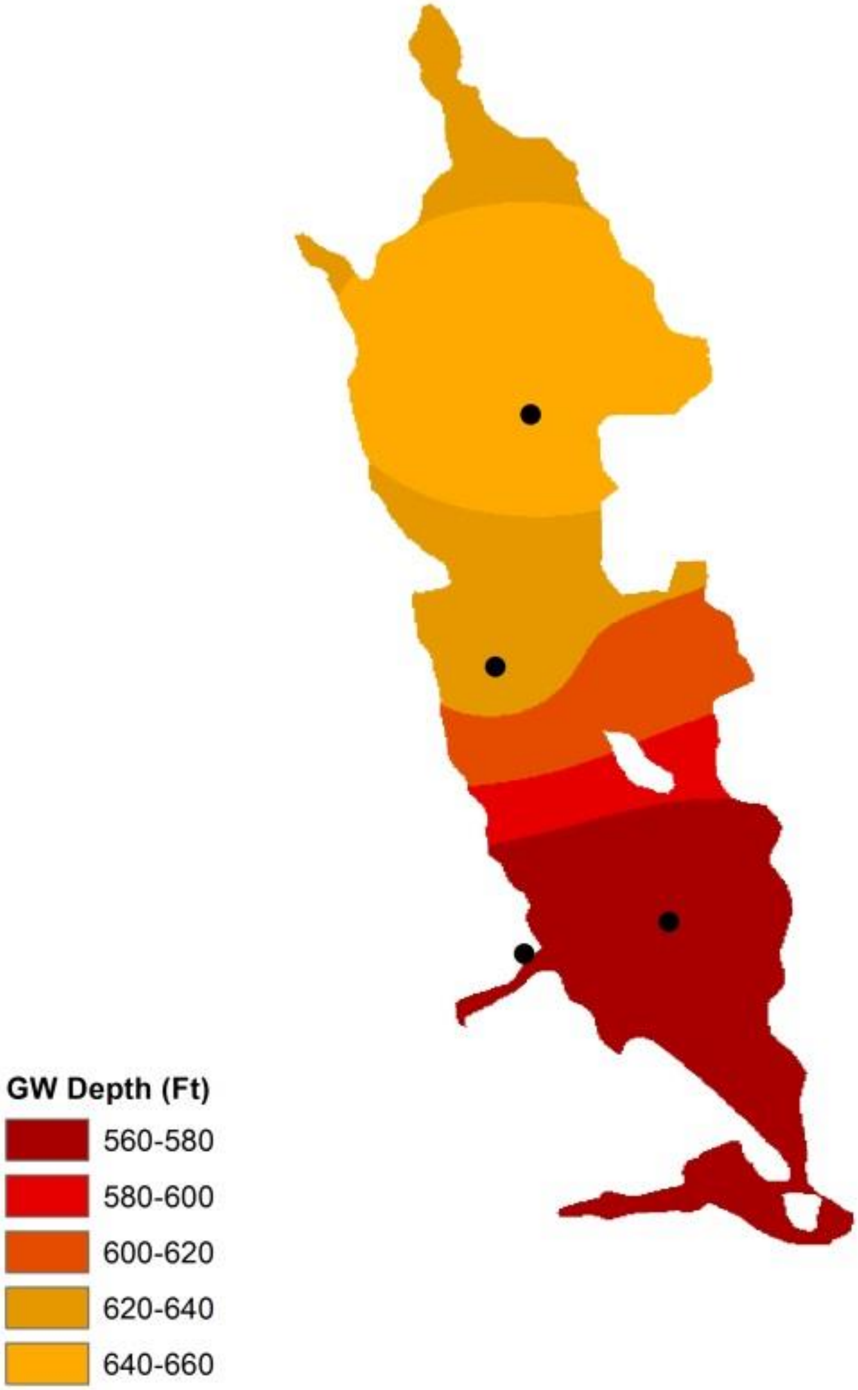


September 2005



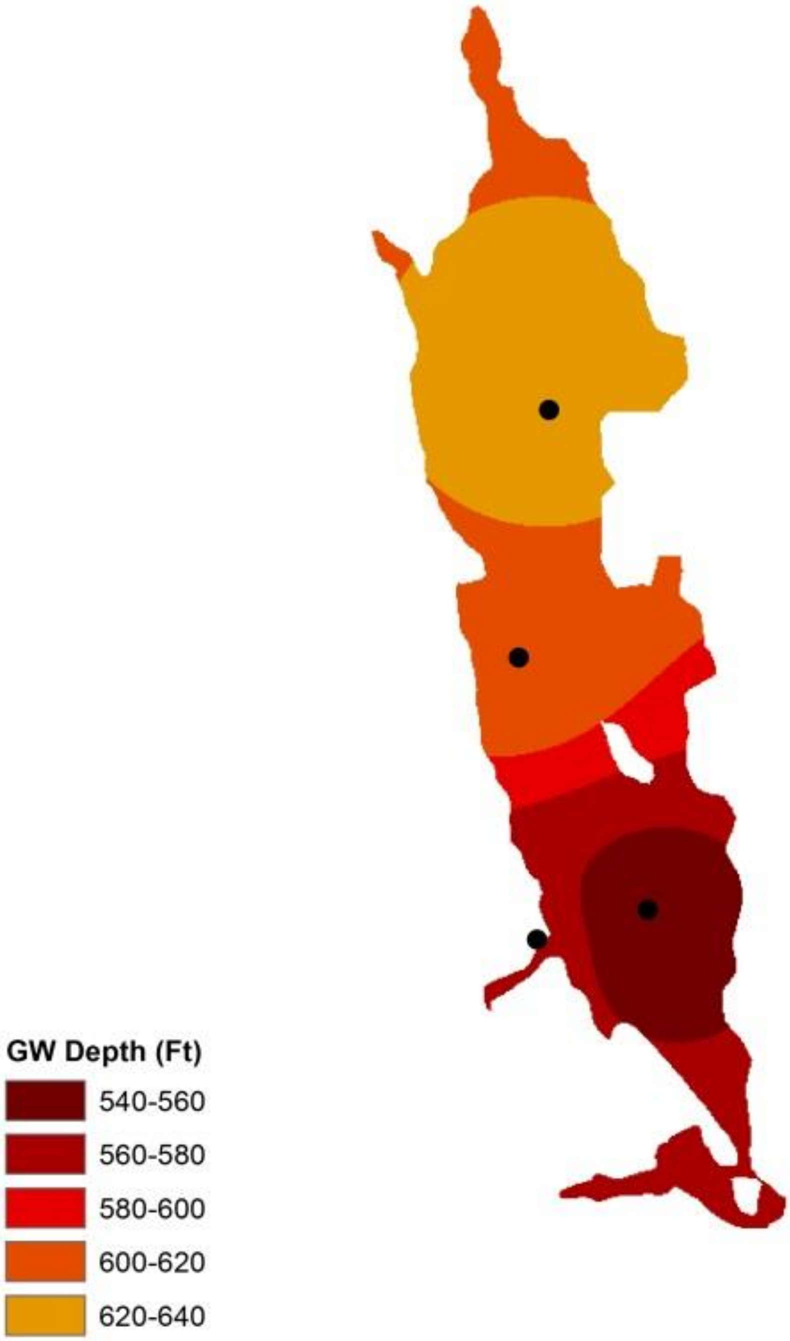
March 2006





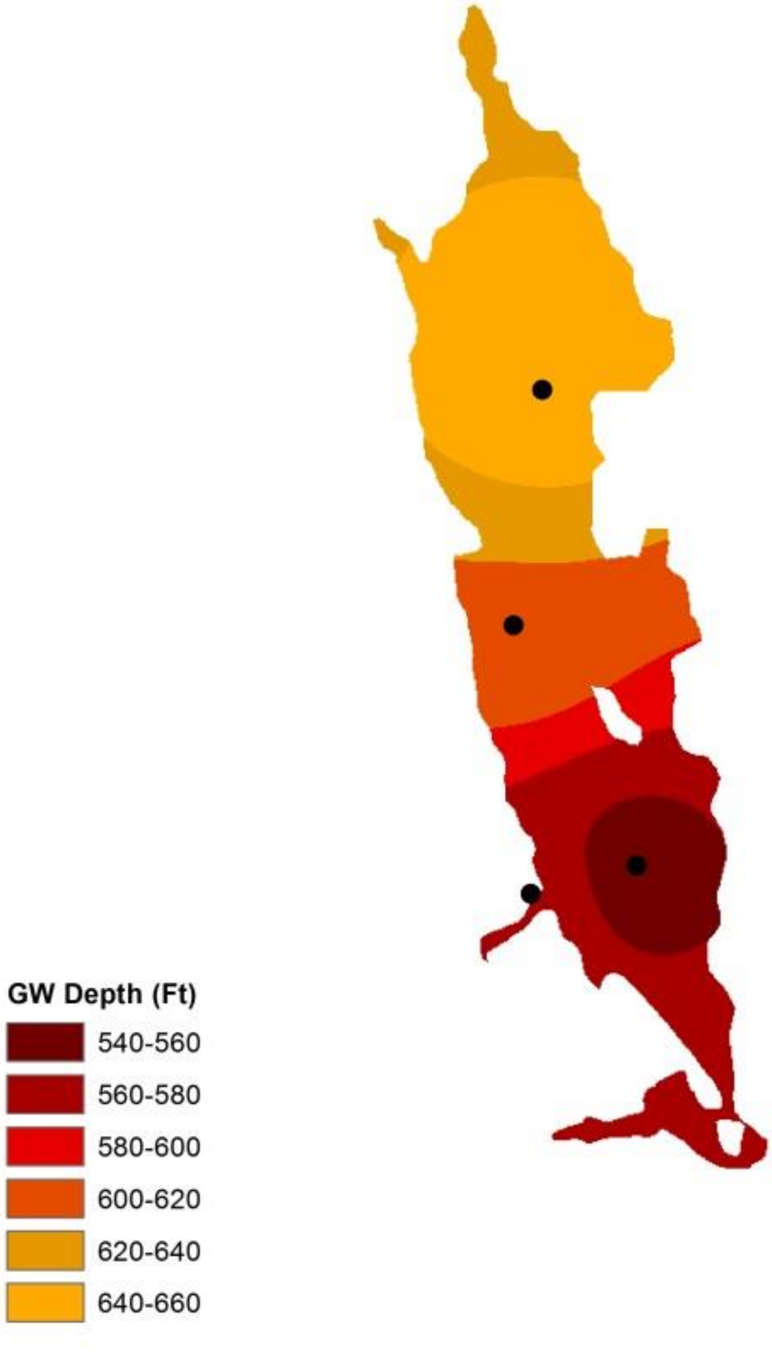
April 2007

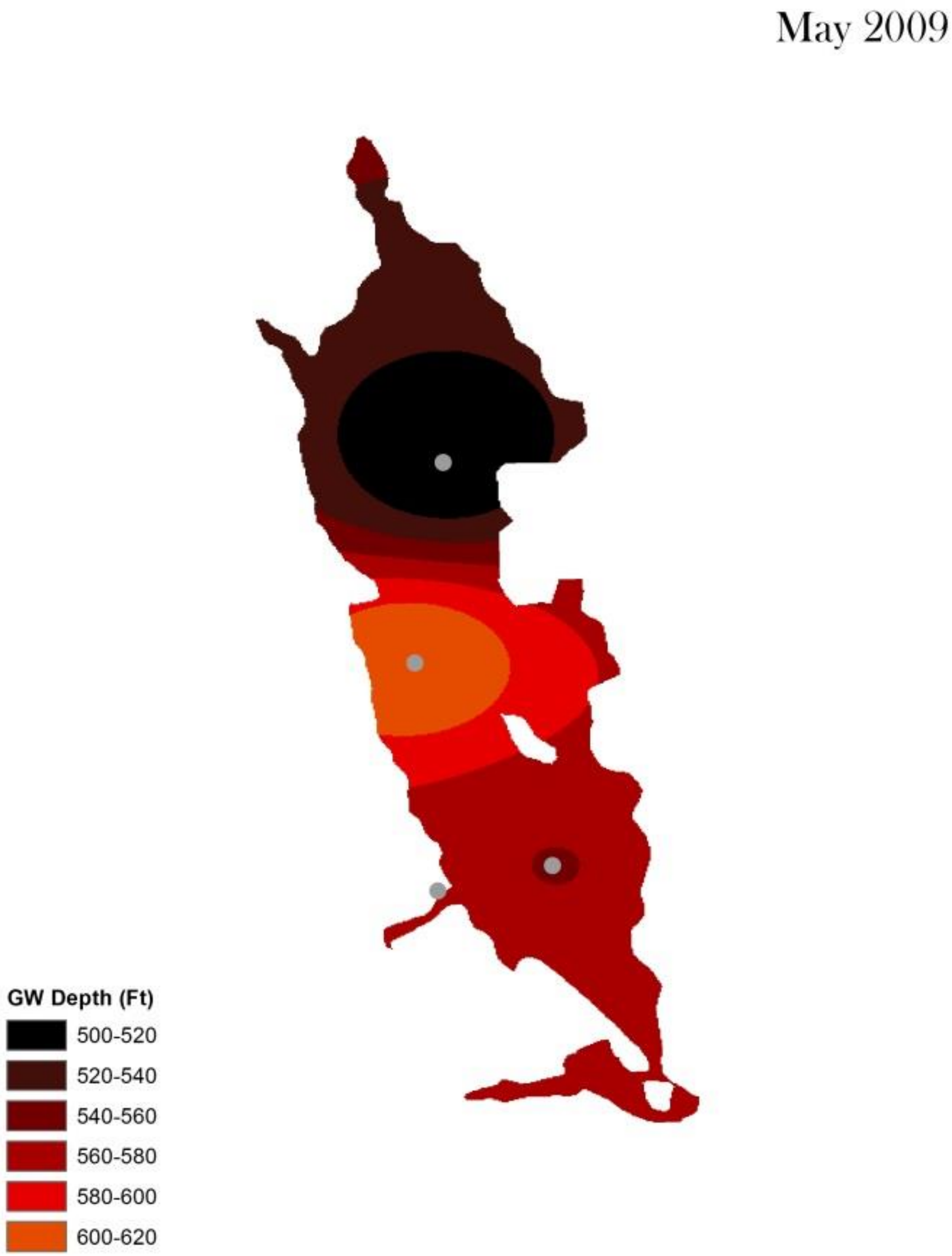
October 2007



April 2008

November 2008

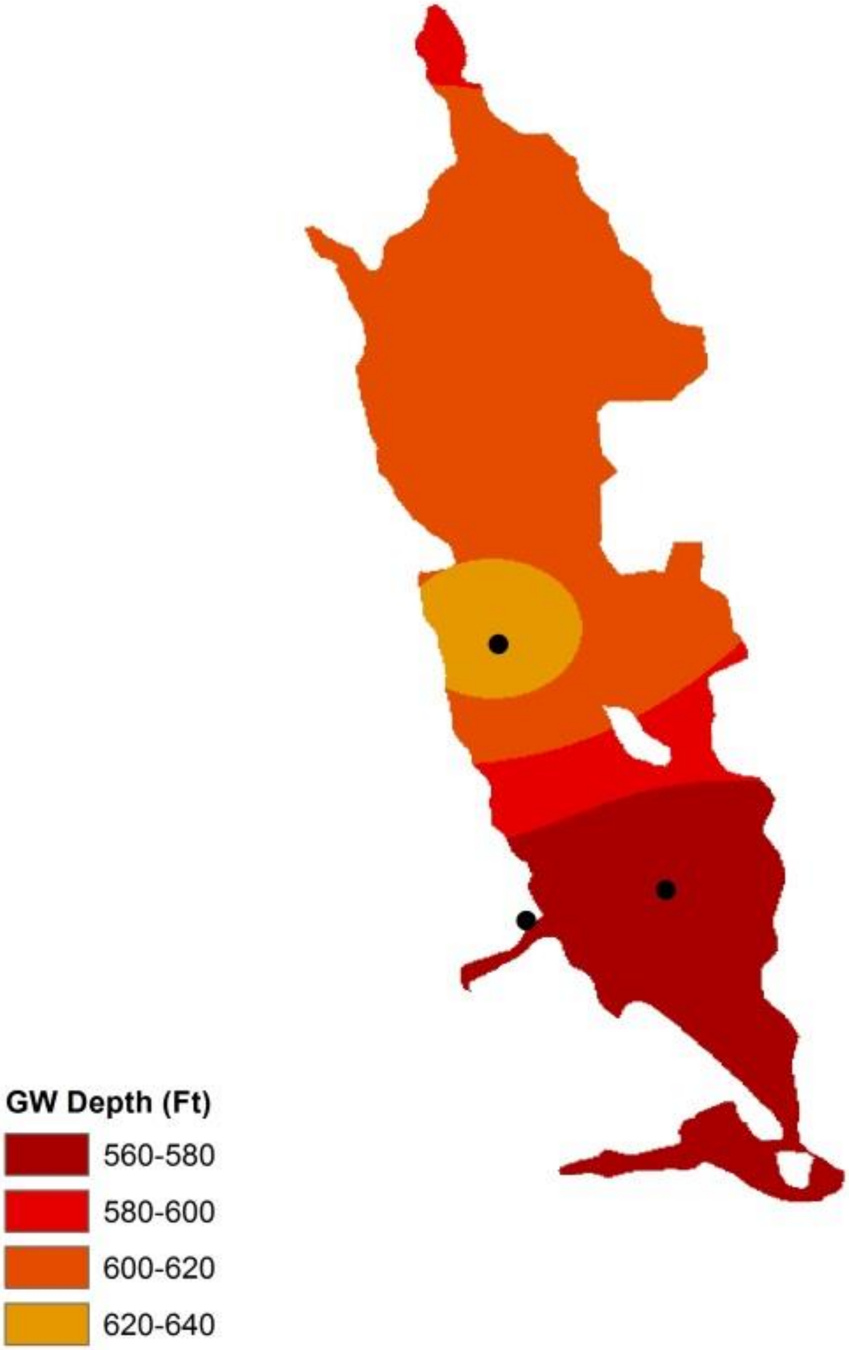




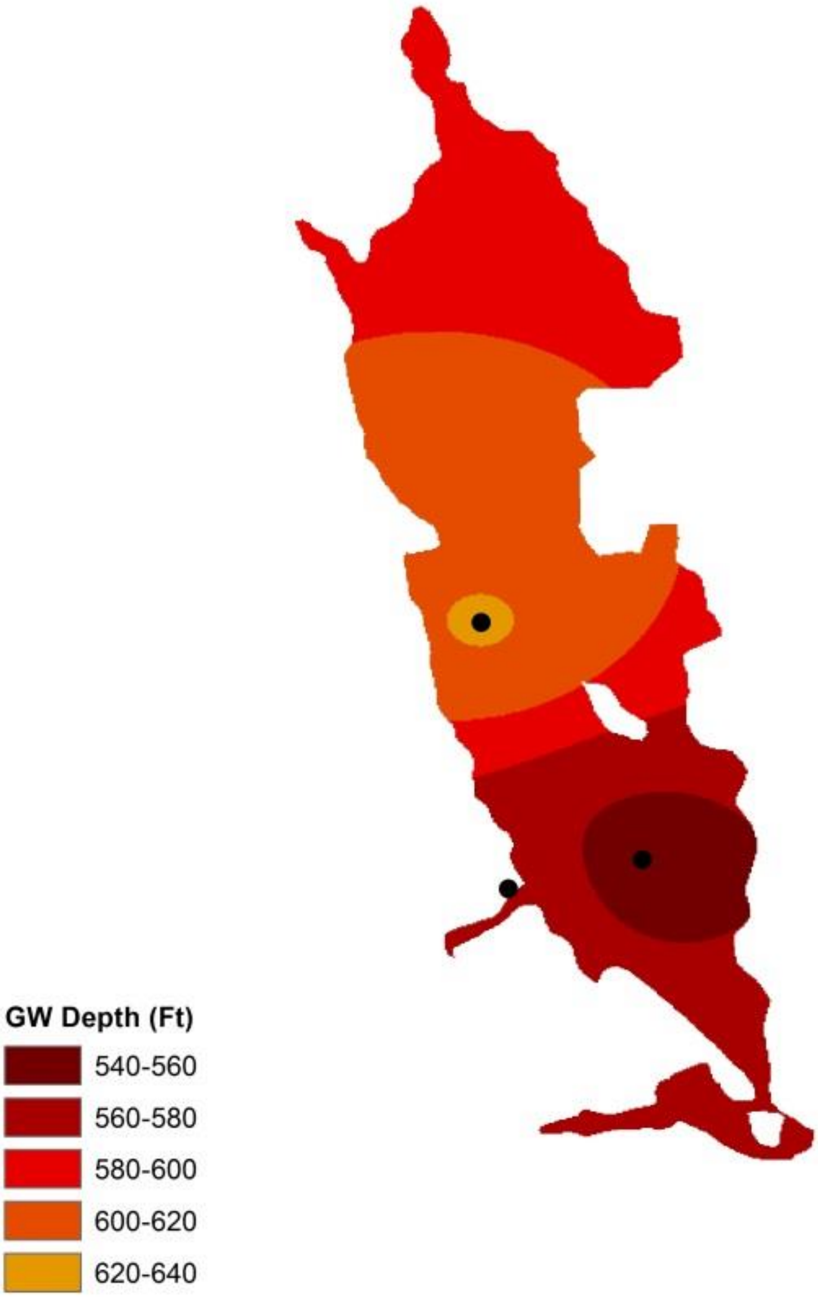
For May of 2009, the water table measurement taken in the northern end of the groundwater basin was abnormally low in range of 500-520 ft with respect to sea level. As a result of the water table data obtained at this point, the kink presented in Figure 31 results.

December 2009

April 2010

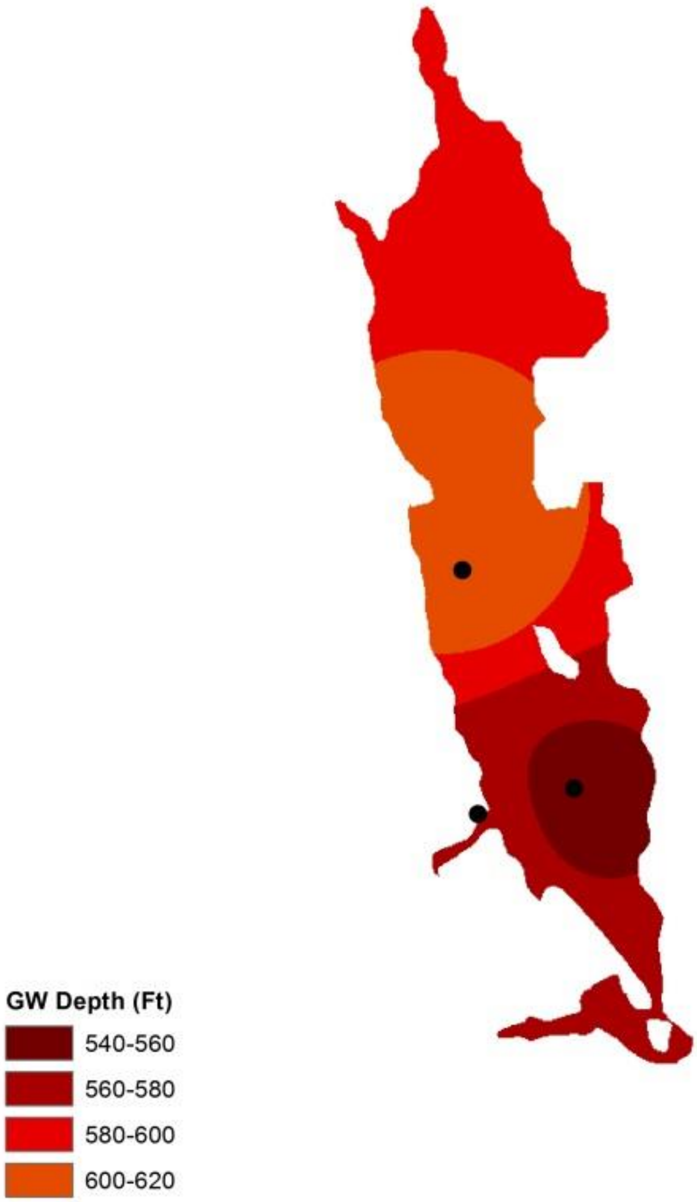


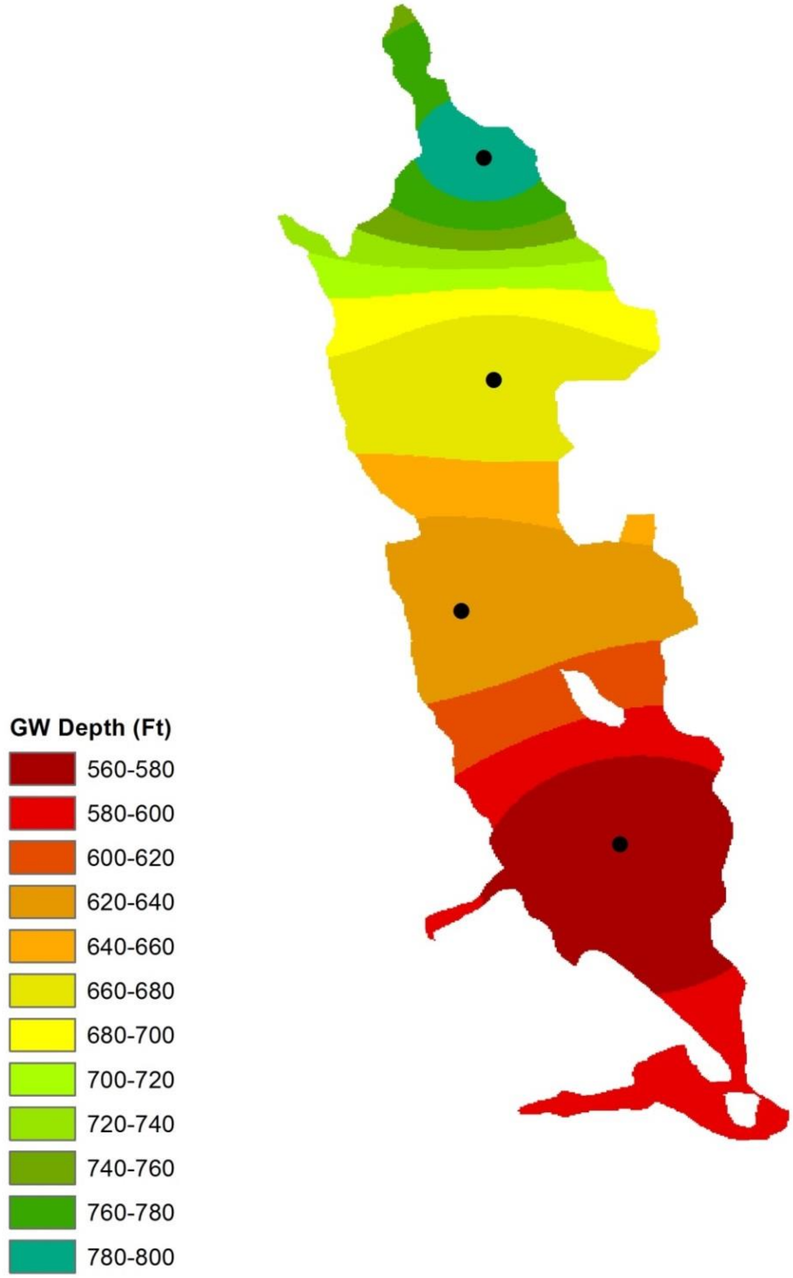
November 2010



May 2011

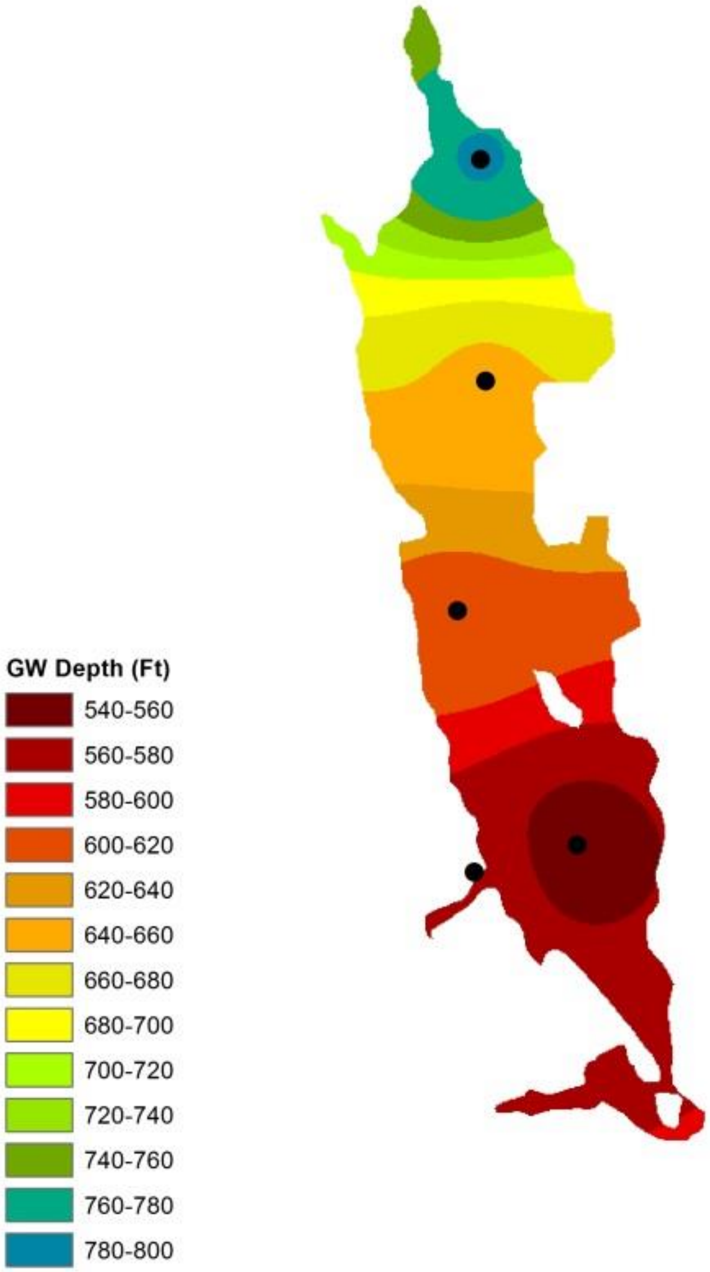
December 2011



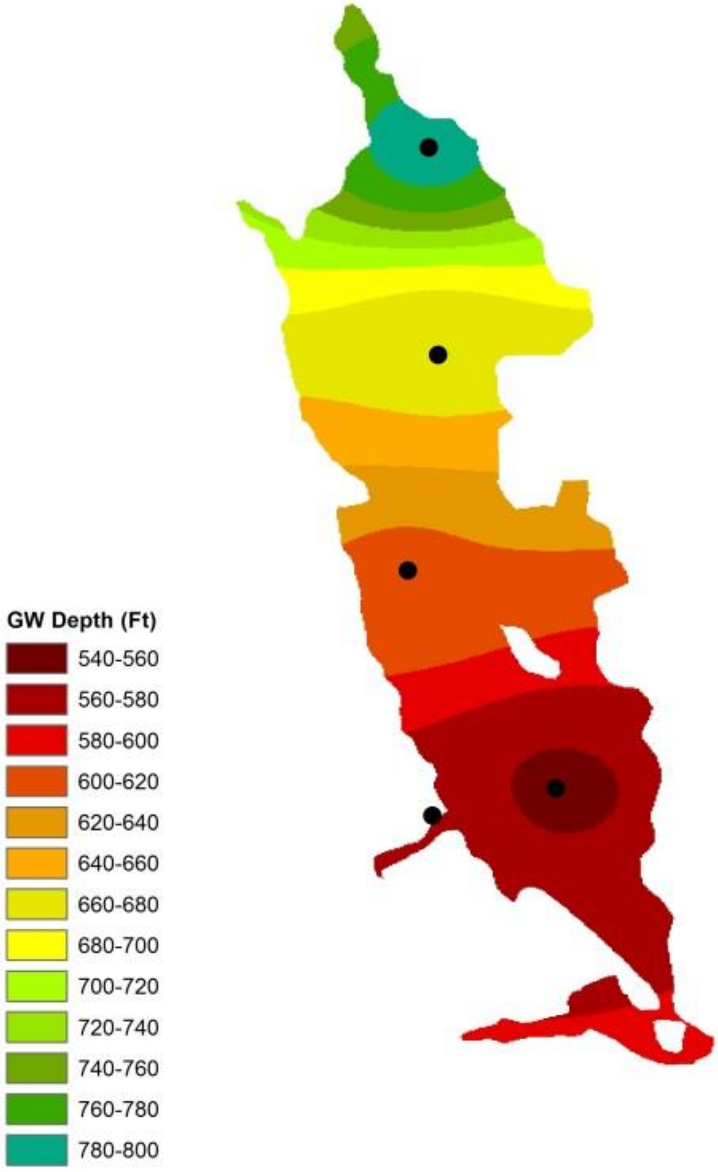

May 2012

In May of 2012 a monitoring well found on the northern end of the groundwater basin began recording data.

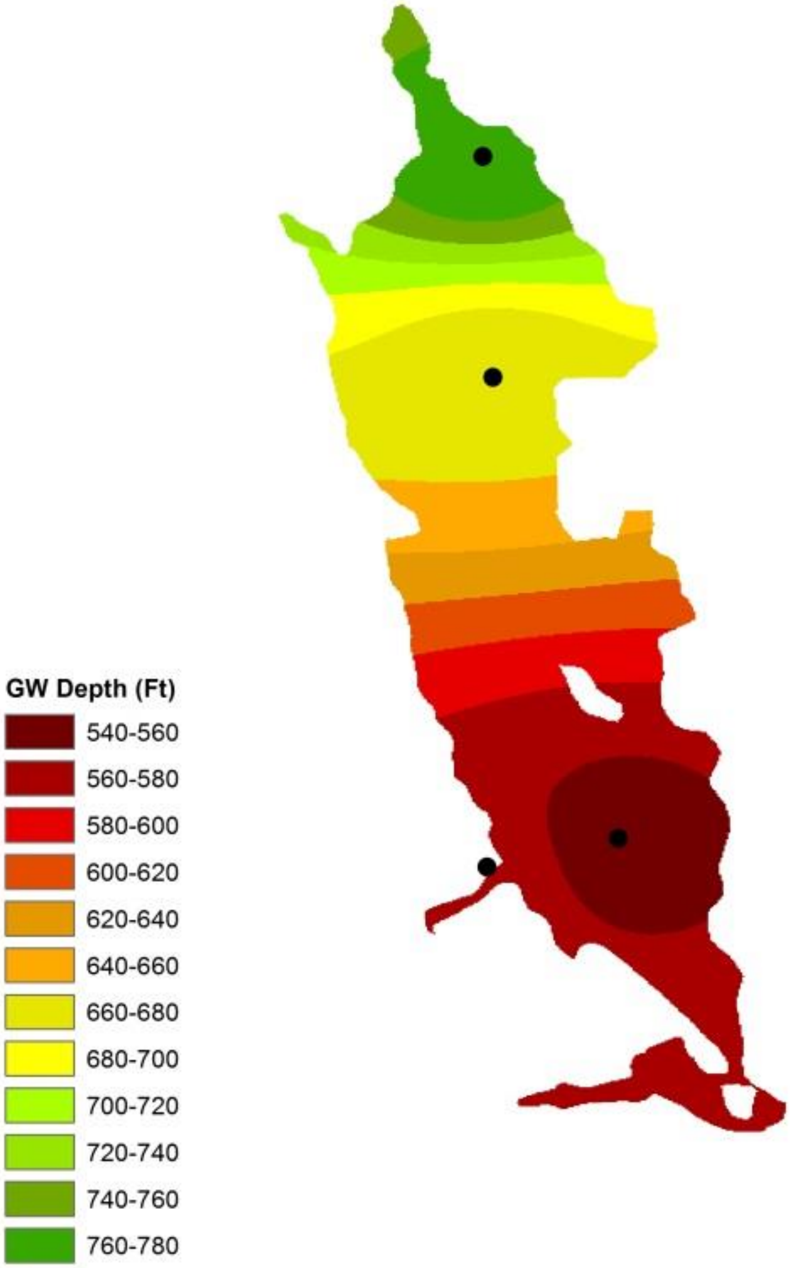
November 2012



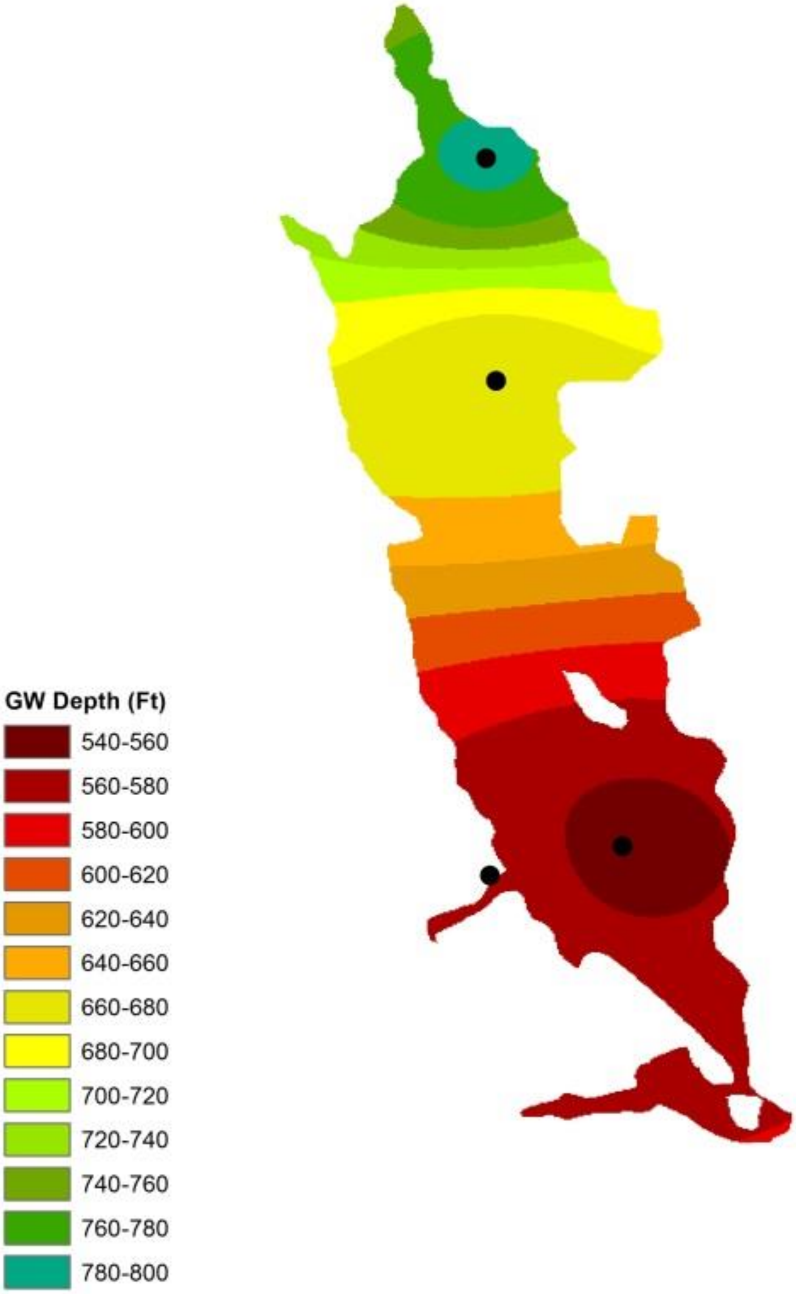
April 2013

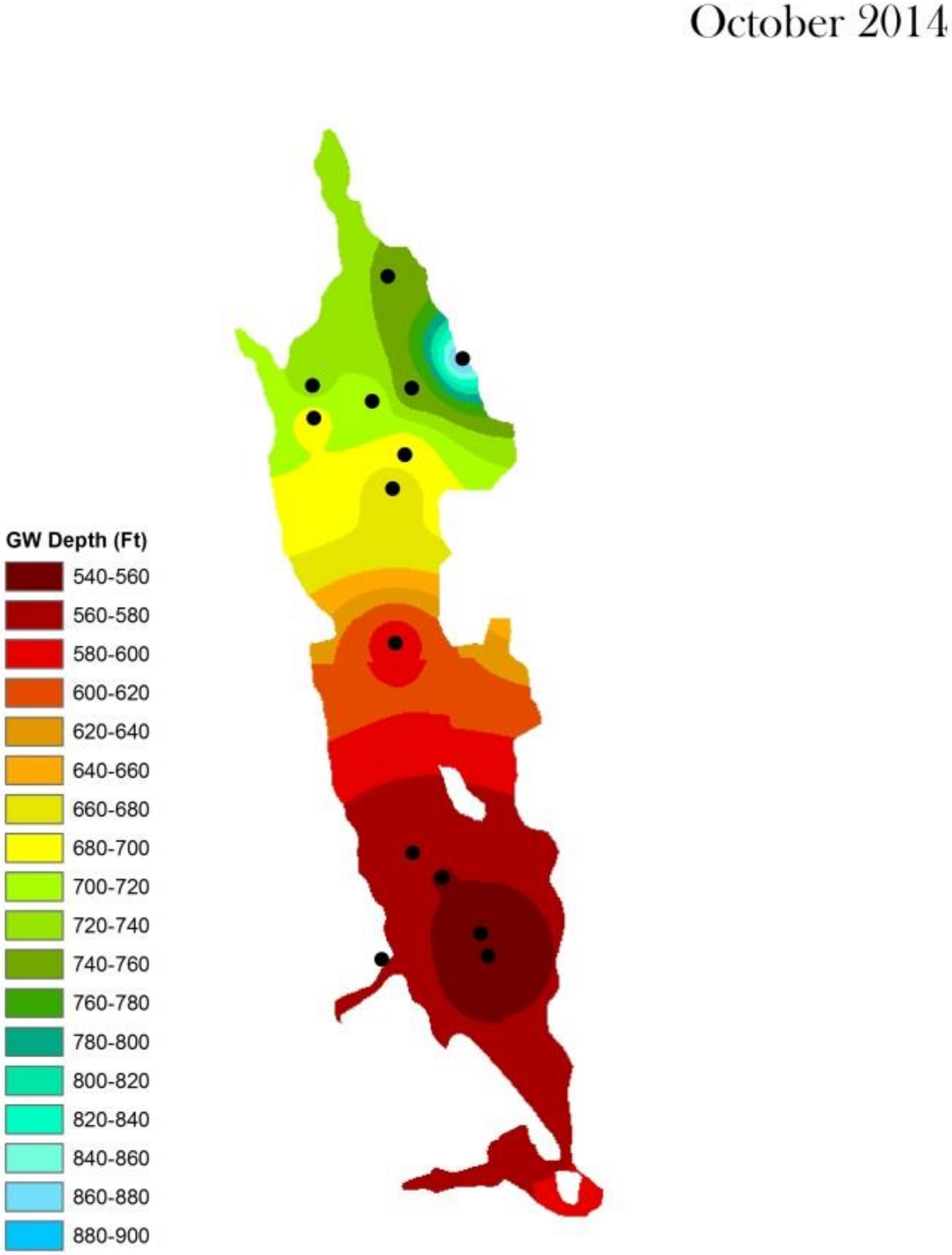

GW Depth (Ft)
540-560
560-580
580-600
600-620
620-640
640-660
660-680
680-700
700-720
720-740
740-760
760-780
780-800

December 2013



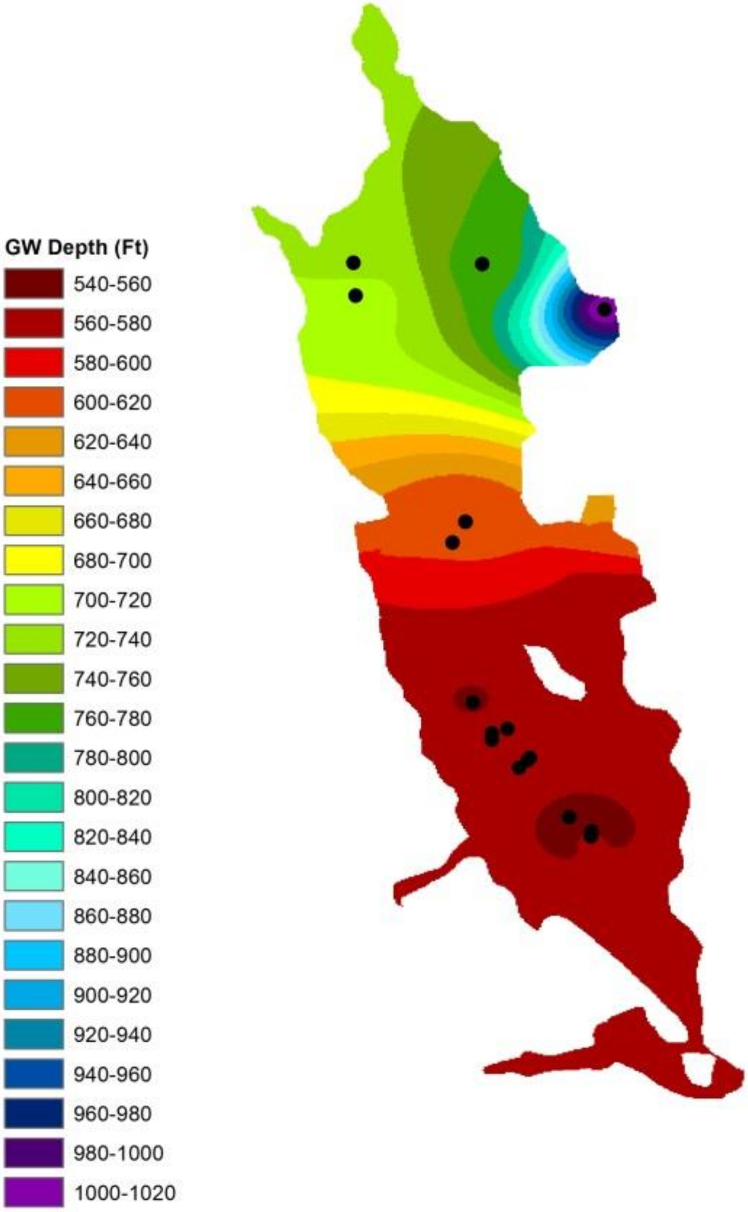
March 2014


GW Depth (Ft)
540-560
560-580
580-600
600-620
620-640
640-660
660-680
680-700
700-720
720-740
740-760
760-780
780-800



The number of monitoring wells significantly increased in the fall of 2014.

May 2015


GW Depth (Ft)
540-560
560-580
580-600
600-620
620-640
640-660
660-680
680-700
700-720
720-740
740-760
760-780
780-800
800-820
820-840
840-860
860-880
880-900
900-920
920-940
940-960
960-980
980-1000
1000-1020

October 2015