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Water Budget Development for SGMA Compliance, Case Study: Ukiah Valley Groundwater Basin

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Abstract: The Sustainable Groundwater Management Act (SGMA) is the first comprehensive legislative effort to reform groundwater management in the state of California after years of uncoordinated and voluntary governance of this resource. The objective of this study is to a) describe the 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 (UVGB). An estimated water budget, done on a monthly time step from 1991 to 2015, was developed in order to characterize the UVGB. Results suggest that the groundwater basin is not in 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, lateral groundwater movement is identified through the groundwater mass balance. Based on previous work and the results of this study, the observed later groundwater losses signify connectivity between the UVGB and the Sanel Valley Groundwater Basin (SVGB). Local groundwater managers and users can use this information to inform proposed action plans and monitoring protocols that will allow them to achieve and maintain groundwater sustainability in the UVGB by the year 2040.

Keywords: *groundwater budget, California, groundwater management, SGMA, water budget, sustainability, water management, water resources management*

Prior to 2014, California did not have a comprehensive plan for managing its groundwater resources. It was not until 2014 that the Sustainable Groundwater Management Act (SGMA) was adopted in California. The SGMA aims to promote groundwater sustainability by preventing these six undesirable conditions: 1) chronic lowering of the water table resulting from the depletion of groundwater storage; 2) groundwater overdraft; 3) reduction in stream flows due to groundwater-surface water disconnections; 4) groundwater quality degradation; 5) land subsidence; and 6) salt water intrusion into groundwater basins (Lund and Harter 2013). The present study introduces a water budget method that helps groundwater managers create some, but not all, necessary baseline measures from which to develop a Groundwater Sustainability Plan (GSP) so as to achieve groundwater sustainability in areas required to comply with the SGMA. More information on this method can be found in Flores Marquez (2017). This proposed method accounts primarily for water accounting and does not address the following three undesirable effects of SGMA: 1) groundwater quality degradation, 2) land subsidence, and 3) salt water intrusion into the groundwater basin.

Water budgets are a helpful evaluation tool for effective water resources management and environmental planning. A water budget utilizes the continuity equation to account for all water that flows in and out of a control volume, resulting in

a change in storage. All of the groundwater and surface water that enters and leaves the system is accounted for in this process and ultimately accounts for any change in water storage over time. A water budget evaluates the availability and sustainability of water supplies and provides a simple way to assess the impacts of climate change and human influence on water resources (Healy et al. 2007). Water budgets have previously been done for groundwater basins in California (Ruud et al. 2002; Foglia et al. 2013; DWR 2016). Some water budgets have been created with programs such as the California Central Valley Groundwater-Surface Water Simulation Model (C2VSIM) and the Integrated Water Flow Model (IWFM, that consider surface water and groundwater) or the Soil and Water Assessment Tool (SWAT, a program capable of doing water balances in the root zone). The water budget method proposed in this study is unique among these because it estimates a surface water balance while explicitly considering each individual water user, as opposed to lumping all of them together as one larger surface water user (C2VSIM, IWFM, and SWAT). This is not a fully integrated surface water and groundwater model as are C2VSIM and IWFM, because it does not account for runoff and infiltration processes. However, for planning purposes, it meets the requirements for estimating an overall water balance by month, accounting for seasonal and interannual variability. While the method used to estimate groundwater budget for this study is novel in the peer-reviewed literature, a similar method was used to estimate the economic feasibility of groundwater banking in agricultural land by Rodriguez Arellano (2015).

Background

Groundwater in California

In California, 515 alluvial groundwater basins and subbasins exist that cover 42% of the state (DWR 2015). From these groundwater basins, an estimated 16.5 MAF (million acre-feet) of groundwater is extracted annually, accounting for 38% of the water supply in the state (DWR 2015). Of the 16.5 MAF of groundwater pumped annually, 39% is used for agriculture, 41% is used in urban areas, and 18% is 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).

Several types of long standing groundwater issues exist throughout the state of California. For example, groundwater degradation is observed in the Tulare Basin because of nitrate contamination from dairies, fertilizers, and septic tanks found in the Central Valley (Lund and Harter 2013). Along the coast, seawater intrusion may occur. Coastal basins in the Salinas and Pajaro Valleys have experienced seawater intrusion because of agriculture development (Garza Diaz 2016).

Prior to 2014, not all regions in the state practiced groundwater management. In order to reform groundwater management throughout the state, California Water Code 10933 and 12924 (SGMA 2014) required the California Department of Water Resources (DWR) to prioritize all groundwater basins and subbasins and do groundwater basin assessments, an effort known as the CASGEM (California Statewide Groundwater Elevation Monitoring) Groundwater Basin Prioritization Process (DWR 2014b). Through this effort, the groundwater basins and subbasins were classified as high, medium, low, or very low priority by quantifying the following criteria: a) the population overlying the groundwater basin (an area with underlying permeable material that can store water); b) the projected growth of the population overlying the groundwater basin; c) the number of public supply wells that draw from the groundwater basin; d) the total number of wells that draw from the groundwater basin; e) the irrigated acreage overlying the groundwater basin; f) the degree to which the overlying community relies on groundwater as the primary source of water; g) any documented impacts on the groundwater (e.g., groundwater overdraft, land subsidence, saline intrusion, and water quality degradation); and h) any other information determined to be relevant by the DWR.

Through 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 361 basins as very low priority, as of May 2014 (DWR 2014b). The high and medium

priority basins are responsible for 96% of the annual groundwater pumping that occurs in the state of California and provide water supply to 88% of the people residing over those groundwater basins (DWR 2014b). This prioritization analysis identified areas that require the implementation of sustainable groundwater management practices.

Introduction of the Sustainable Groundwater Management Act (SGMA)

In September of 2014, California Governor Jerry Brown signed the SGMA, a piece of legislation intended to manage California's groundwater in a sustainable manner for the first time in history. As part of the timeline for this legislation, groundwater sustainability agencies (GSAs) needed to form by June 2017 and develop groundwater sustainability plans (GSPs) by the year 2020 for critical medium and high priority basins and 2022 for the remaining medium and high priority basins (Christian-Smith and Abhold 2015). Once the GSP has been approved, the GSA has until the year 2040 or 2042 to achieve and maintain groundwater sustainability (Christian-Smith and Abhold 2015). A groundwater basin will be defined as sustainable if none of the six undesirable groundwater related conditions listed by the DWR (SGMA 2014) are evident at the time of evaluation.

Case Study: Ukiah Valley Groundwater Basin (UVGB)

A case study on the UVGB was completed to describe the development of a water budget and to illustrate its utility for water managers developing elements of a sustainable groundwater management plan in a specific basin. This section presents the methodology for estimating a water budget in tandem with how data was collected for each variable. The UVGB was selected since it was classified as a medium priority groundwater basin. According to Bulletin 118, the UVGB has had a relatively stable water table (DWR 2004). Despite there being no evidence of a decrease in the water table, the UVGB is considered medium priority because a value of 15.8 was obtained during the CASGEM groundwater basin prioritization process, in which a basin value greater than or equal to 13.43 but lower than 21.08 determined medium priority status (Figure 1). The high well concentration in the area influenced the UVGB's score of 15.8 (Figure 1). Ultimately, this case study will serve as a generalized example on how water budgets can be done for any groundwater basin since the method presented shows the components of the water budget and the sources of data used.

The UVGB is in Mendocino County in the Russian River Watershed (Figure 2). A GSA has been formed for the UVGB and consists of a group of agencies and individuals representing different stakeholder groups, along with a technical advisory committee. Prior to the formation of the GSA, the stakeholders involved agreed that there was a need to develop a water budget to characterize the groundwater basin and assess the status of the UVGB. The resulting water budget serves as the foundation to create a GSP, inform the GSA on integrated water management strategies to avoid the six undesirable groundwater conditions, and aid in developing monitoring protocols to comply with SGMA expectations.

Water Sources

Surface water and groundwater are used to meet the agricultural and municipal water demands in the UVGB. Surface water sources flow primarily 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) (Cardwell 1965). Groundwater sources derive primarily from the UVGB. Communities in Ukiah Valley are groundwater dependent, whereas the communities in Redwood Valley are not. For the purposes of this study, the area in Redwood Valley County Water District is identified as Redwood Valley, whereas the remaining portion of the study area is referred to as Ukiah Valley (Figure 2).

Water Entities

The UVGB has seven major water utilities that provide water supplies to the community: the City of Ukiah, Calpella County Water District, Millview County Water District, Redwood Valley County Water District, Willow County Water District, Rogina Water Company, and the Russian River Flood Control and Water Conservation Improvement District (RRFC) (Figure 3).

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**

Overall Basin Priority: Medium

Very Low Ranking Range	Low Ranking Range	Medium Ranking Range	High Ranking Range
Range < 5.75	5.75 ≥ Range < 13.42	13.43 ≥ Range < 21.08	Range ≥ 21.08

Figure 1. Summary of the results obtained for the Ukiah Valley Groundwater Basin as a result of the CASGEM (California Statewide Groundwater Elevation Monitoring) Groundwater Basin Prioritization Process (DWR 2014a).

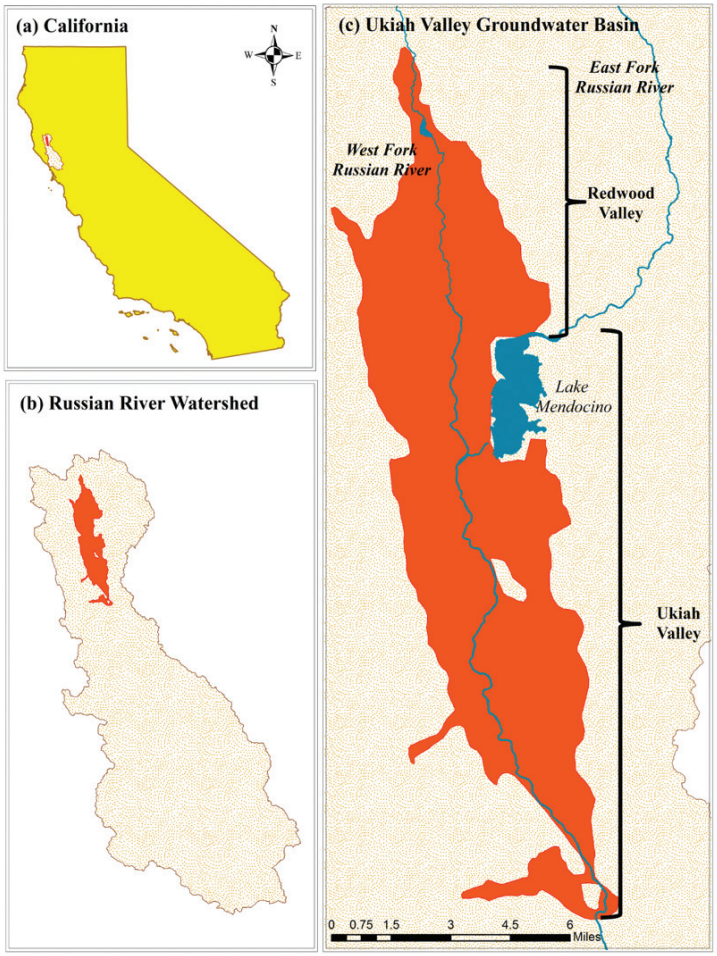


Figure 2. The Ukiah Valley Groundwater Basin (c) located in California (a) and within the Russian River Watershed (b).

Methodology

As a result of data availability, a water budget for the UVGB was developed on a monthly time step from 1991 to 2015. The interactions that occur between the water sources and water supplies in the UVGB are captured in the framework used to develop the water budget (Figure 4). A schematic of the interactions that occur between the water sources and water supplies was developed for the UVGB (Figure 5). Creating the water budget requires four steps. First, calculations associated with the agricultural water demands 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 continuity equation to estimate the surface water gains and losses. Third, the change in groundwater storage from 1991 to 2015 is estimated. Fourth, a groundwater mass balance is completed using the continuity 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.

Agricultural Water Demand Calculations

The monthly agricultural water demand for the UVGB is determined in a monthly time step from 1991 to 2015 (Equation [1]).

$$WD_{ij} = \sum_{k=1}^{K} \left(\frac{(Kc_{jk} * ETo_{ij}) - p_{ij}}{AE_{ik}} * A_{ik} \right) \quad [1]$$

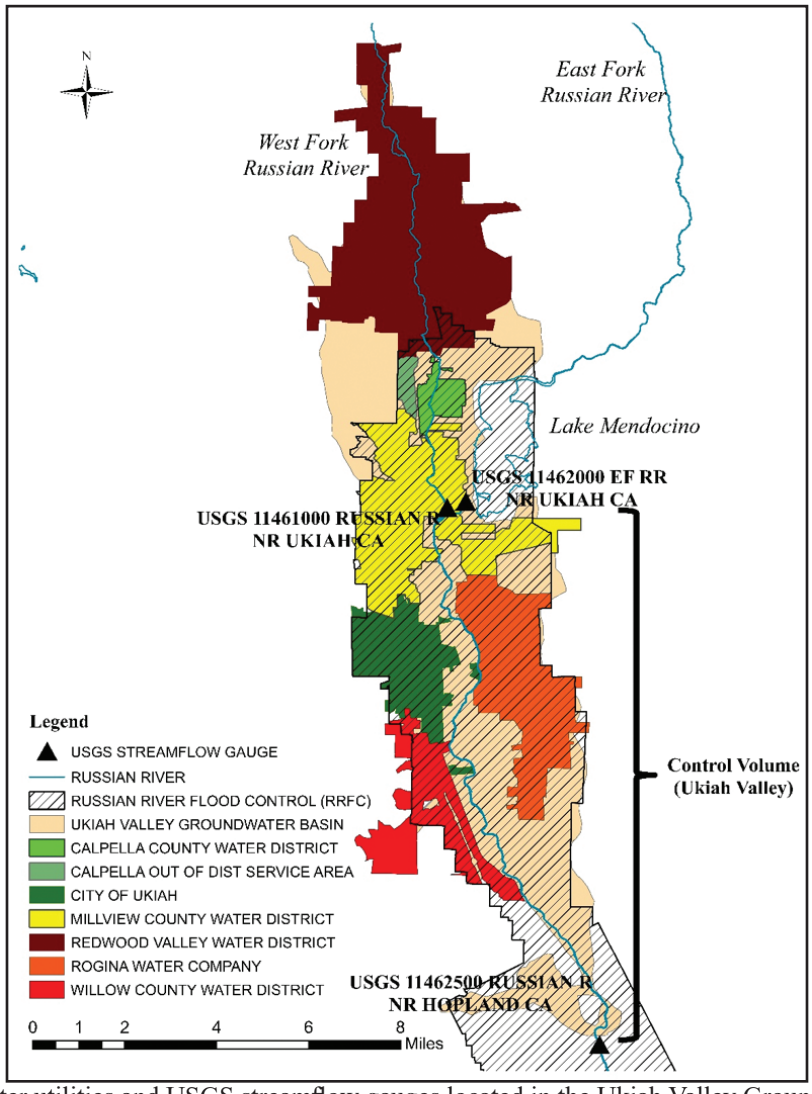


Figure 3. Water utilities and USGS streamflow gauges located in the Ukiah Valley Groundwater Basin.

To estimate the water demand WD_{ij} (AF/month) for a month j and given year i for a crop k, the following inputs were used: acreage A_{ik} (acres), crop coefficients Kc_{jk} (unitless) and application efficiency estimates AE_{ik} (unitless) for each crop, reference evapotranspiration ETo_{ij} (ft), and precipitation p_{ij} (ft). The A_{ik} was obtained from expert consultation (Morse, personal communication 2016). The Kc_{jk} values were obtained from Schwankl et al. (2010) and through expert advice from county advisors of the University of California Cooperative Extension system (Lewis, Harper, and McGourty, personal communication 2016). Reference evapotranspiration (ETo_{ij}) was obtained from the California Irrigation Management Information System (CIMIS) Station 106 in Sanel Valley. Precipitation (p_{ij}) was spatially distributed using the Thiessen Polygon Method using data from the California Data Exchange Center (CDEC) and CIMIS. Application efficiencies (AE_{ik}) were determined using values suggested by Sandoval-Solis et al. (2013) and Lewis et al. (2008). Furthermore, based on expert consultation (Elkins, personal communication 2016), it is assumed that the walnut orchards are dry irrigated and 90% of the grapes are irrigated (Lewis et al. 2008).

The runoff r'_{ij} (ft) that results from a storm event for a given month j and year i, is determined (Equation [2]) and the runoff that results from irrigation r''_{ij} (AF/month) is determined (Equation [3]) in monthly time steps. In both equations, a runoff factor α_{ij} (unitless) of 3% is assumed based on expert consultation (McGourty, personal communication 2016) and from the amount of runoff that was observed during the extent of the project (Fall 2015 to Spring 2017) in the UVGB.

$$r'_{ij} = (p_{ij} - (Kc_{jk} * ETo_{ij})) * \alpha_{ij} \quad [2]$$

$$r''_{ij} = [WD_{ijk} * (1 - AE_{ik})] * \alpha_{ij} \quad [3]$$

For this study, the soil moisture content is not considered; thus, after the crop water requirement is met and runoff has been generated,

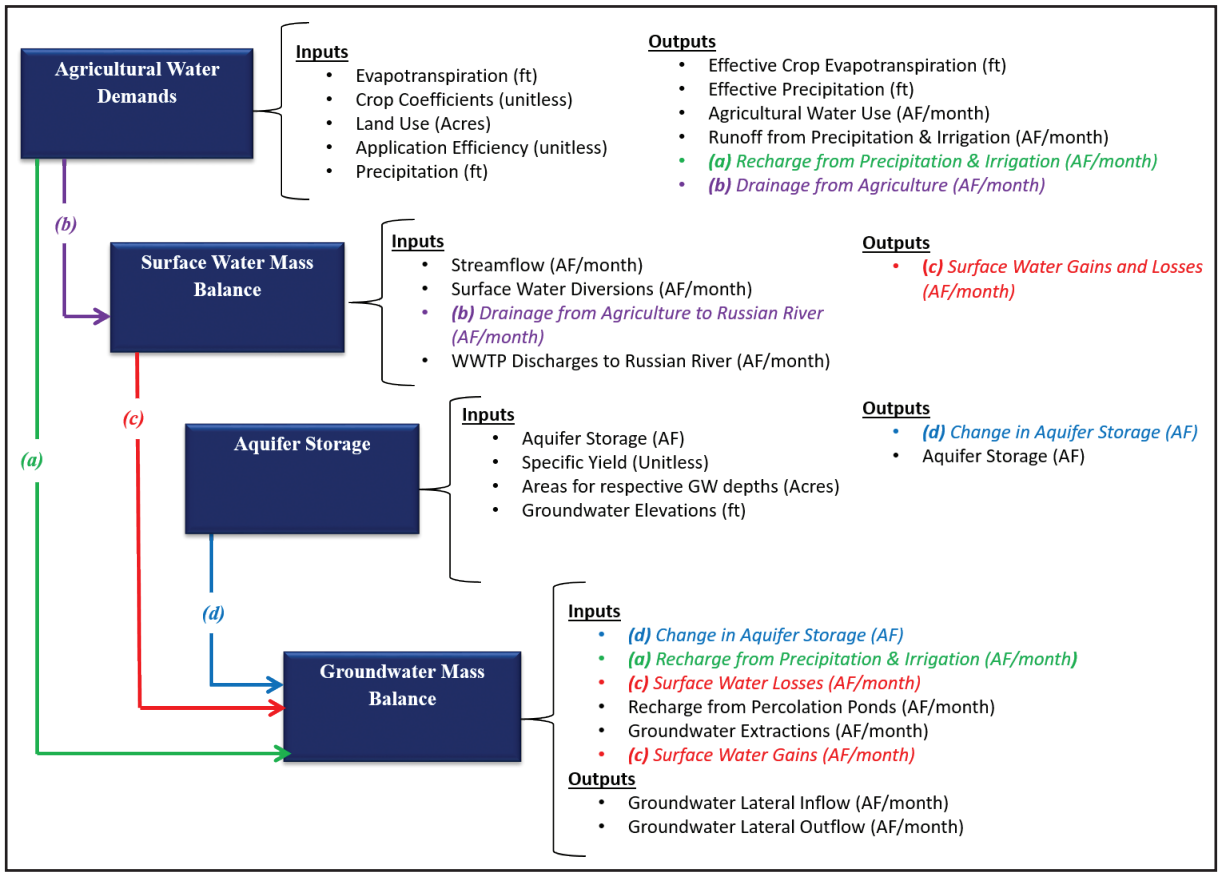


Figure 4. Framework for constructing the water budget.

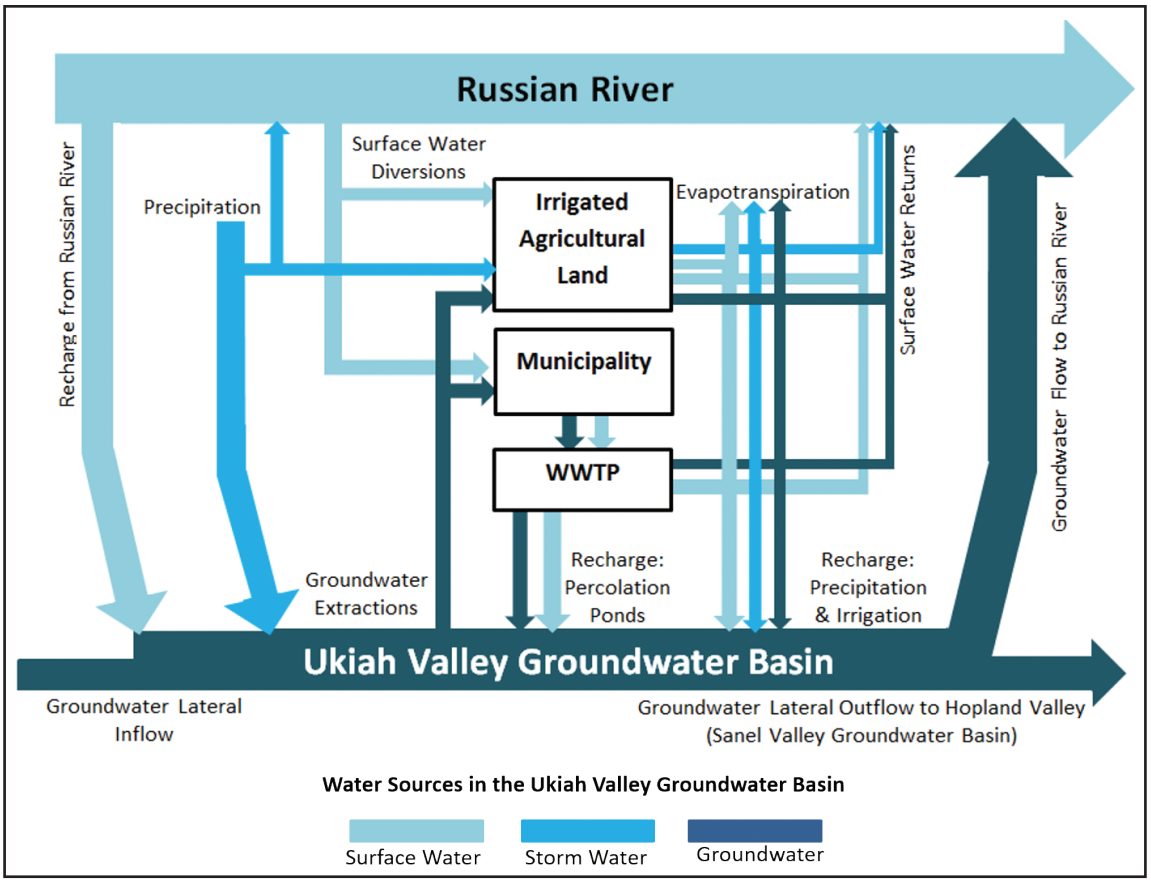


Figure 5. Surface water – groundwater conceptual model for the Ukiah Valley Groundwater Basin.

the precipitation that is in excess percolates into the aquifer. The recharge that occurs because of precipitation RP_{ij} (AF/month) is determined (Equation [4]). Similarly, the recharge from irrigation RI_{ij} (AF/month) is determined (Equation [5]). To estimate the total recharge that results from irrigation and precipitation (R_{ij}) for a given month *j* and year *i* Equation [6] is referenced.

$$RP_{ij} = (p_{ij} - (Kc_{jk} * ETo_{ij}) - r'_{ij}) * A_{ik} \quad [4]$$

$$RI_{ij} = \sum_{k=1}^{K} [WD_{ijk} * (1-AE_{ik})] - r''_{ij} \quad [5]$$

$$R_{ij} = RP_{ij} + RI_{ij} \quad [6]$$

In addition, 3% of the water applied to meet frost protection, post-harvest applications, and heat protection is also assumed to become agricultural drainage, for consistency with runoff from storms and irrigation. The surface water used for frost protection, post-harvest applications, and heat protection is estimated using the information from Lewis et al. (2008).

Surface Water Mass Balance

A surface water mass balance was done to estimate the groundwater–surface water interactions that occurred 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], in other words the Ukiah Valley (Figure 3).

For this study, the water budget was done only for the Ukiah Valley portion of the UVGB and not for the entire groundwater basin because there is no streamflow gauge station 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.

The surface water mass balance was used to estimate the surface water gains and losses in Ukiah Valley using the continuity equation. The surface water storage that occurs in a determined control volume because of the surface water inflows and outflows is described with Equation [7]. Since no surface water reservoir is considered within the control volume, Equation [7] simplifies to Equation [8]. The term Δt in Equation [7] is change in time. The surface water inflows and outflows in the project area are identified with Equations [9] and [10], respectively. The surface water gains and losses are determined using Equation [12].

$$\Delta Storage_t^{SW} = [Inflow_t^{SW} - Outflow_t^{SW}]\,\Delta t \quad [7]$$

$$Inflow_t^{SW} = Outflow_t^{SW} \quad [8]$$

$$Inflow_t^{SW} = Q_t^{WF} + Q_t^{EF} + Return_t^{SW} + Return_t^{GW} + Gains_t^{SW} \quad [9]$$

$$Outflow_t^{SW} = Q_t^{Hopland} + \sum_{i=1}^{i=1} User_t^{SW,i} + Losses_t^{SW} \quad [10]$$

$$\sum_{i=1}^{i=1} User_t^{SW,i} = CityUkiah_t^{SW} + Willow_t^{SW} + Millview_t^{SW} + Calpella_t^{SW} + Rogina_t^{SW} + RRFC_t^{SW} + PrivateUsers_t^{SW} \quad [11]$$

$$Gains_t^{SW} - Losses_t^{SW} = [Q_t^{Hopland} + \sum_{i=1}^{i=1} User_t^{SW,i}] - [Q_t^{WF} + Q_t^{EF} + Return_t^{SW} + Return_t^{GW}] \quad [12]$$

For the surface water mass balance, the surface water inflows are the West Fork of the Russian River Q_t^{WF} (AF/month) and the East Fork of the Russian River Q_t^{EF} (AF/month). Data from the East Fork of the Russian River were complete up to the year 2011; hence, the remaining monthly values were filled with streamflow data obtained from the CDEC COY station near Lake Mendocino. The surface water returns ($Return_t^{SW}$ and $Return_t^{GW}$) considered are the agricultural drainage and the discharge from the City of Ukiah's Wastewater Treatment Facility (AF/month). The City of Ukiah provided monthly discharge data from 2001-2015 for the Wastewater Treatment Facility, whereas the remaining data from 1991-2000 were estimated using the median value for each month. Finally, the surface water gains $Gains_t^{SW}$ (AF/month), are considered an inflow in the surface water mass balance and an unknown value until solved for (Equation [12]).

For the surface water mass balance, a surface water outflow was the stream flow at Hopland $Q_t^{Hopland}$ (AF/month). Surface water diversions ($\sum_{i=1}^{i=1} User_t^{SW,i}$) resulting from 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 with their own water right to divert water for municipal and agricultural water demands were considered a large outflow in the surface water mass balance (Equation [11]). The monthly surface water diversions that occur by each surface water diverter $User_t^{SW,i}$ (AF/month) were either obtained directly from each water entity or were estimated using the median monthly value from the available data records. Finally, the surface water losses $Losses_t^{SW}$ (AF/month) were considered an outflow in the surface water mass balance, an unknown value until solved for (Equation [12]).

Aquifer Storage

Using water table elevations 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 the CASGEM and DWR monitoring wells found in the UVGB from 1991-2015. Groundwater depth contours lines were calculated in GIS in 20-feet increments (*m).* Maps of contour lines were developed from 1991 to 2015 for the months in which there were water table measurements available, usually twice a year. The storage in the UVGB was thus determined (Equation [13]).

$$S_t = \sum_{m=20}^{M} [A_{im} * (d_{mi} - Z)] * \gamma \quad [13]$$

The S_t term represents the aquifer storage (AF) for the given time step. The term A_{im} is the resulting area (acres) for a given groundwater depth for a given time step. The term Z is an arbitrary reference datum proposed by the authors used to represent the bottom of the aquifer in feet and was proposed to be 490 feet (Rodriguez Arellano 2015). The term d_{mi} (ft) is the groundwater surface elevation with respect to sea level. The obtained soil porosity was assumed to be representative of the whole groundwater basin. The term γ (unitless) is the specific yield, which was assumed to be a

value of 8%, a value obtained from Bulletin 118 (DWR 2004) for the UVGB. Once the aquifer storage from 1991-2015 was estimated, the respective change in aquifer storage through time was also determined and ultimately fed into the groundwater mass balance (Equation [17]).

Groundwater Mass Balance

A groundwater mass balance was done to estimate the lateral groundwater inflows and outflows that occur monthly from 1991-2015 in the control volume by using the continuity equation. The obtained results are relevant to Ukiah Valley but are extrapolated to the whole groundwater basin. The groundwater storage that occurs because of groundwater inflows and outflows is described with Equation [14]. The term Δt in Equation [14] is change in time. The groundwater inflows and outflows in the groundwater basin are identified by Equation [15] and Equation [16], respectively. The lateral groundwater gains and losses are determined using Equation [17].

The groundwater inflows considered are the recharge that occurs from precipitation $Recharge_t^{Precipitation}$ (AF/month) and irrigation $Recharge_t^{Irrigation}$ (AF/month), the surface water losses $Losses_t^{SW}$ (AF/month) obtained from the surface water mass balance, tributary recharge $Recharge_t^{Tributary}$ (AF/month) obtained from Flint et al. (2015) for the reach near Hopland, and the recharge that results from the percolation ponds $Recharge_t^{PercolationPonds}$ (AF/month). For this last term, data from the City of Ukiah's Wastewater Treatment Plant and Calpella County Water District's Wastewater Treatment Plant were obtained. Calpella County Water District's Wastewater Treatment Plant percolation rates were calculated given effluent discharge values. The City of Ukiah's Wastewater Treatment Plant percolation rates were obtained from the City of Ukiah for 2009-2015, whereas the percolation rates from 1991-2008 were estimated using the median value for each month. Finally, the lateral groundwater gains $Gains_t^{GW}$ (AF/month) were considered an inflow in the groundwater mass balance and an unknown until solved for (Equation [17]).

For the groundwater mass balance, groundwater outflows include the portion of the agricultural water demands met with groundwater sources $AW_t^{GW,\ crop\ i}$ (AF/month), surface water gains $Gains_t^{SW}$ (AF/month), and groundwater extractions for municipal water demands $GE_t^{Municipal}$ (AF/month) for the City of Ukiah and Calpella County Water District. The municipal groundwater extractions were obtained from the City of Ukiah and from Calpella County Water District. Lastly, the lateral groundwater losses $Losses_t^{GW}$ (AF/month) were also considered an outflow in the groundwater mass balance and an unknown until solved for (Equation [17]).

$$\Delta Storage_t^{GW} = [Inflow_t^{GW} - Outflow_t^{GW}]\,\Delta t \qquad [14]$$

$$Inflow_t^{GW} = Recharge_t^{Precipitation} + Recharge_t^{Irrigation} + Losses_t^{SW} + Recharge_t^{PrecipitationPonds} + Recharge_t^{Tributary} + Gains_t^{GW} \qquad [15]$$

$$Outflow_t^{GW} = \sum_{i=1}^{i=1} AW_t^{GW,crop\ i} + Gains_t^{SW} + GE_t^{Municipal} + Losses_t^{GW} \qquad [16]$$

$$Gains_t^{GW} - Losses_t^{GW} = \Delta Storage_t^{GW} - [Recharge_t^{Precipitation} + Recharge_t^{Irrigation} + Losses_t^{SW} + Recharge_t^{PrecipitationPonds} + Recharge_t^{Tributary}] + [\sum_{i=1}^{i=1} AW_t^{GW,crop\ i} + Gains_t^{SW} + GE_t^{Municipal}] \qquad [17]$$

Results and Discussion

Ukiah Valley Groundwater Basin Agricultural and Municipal Water Demands

From the land use data obtained, the most dominant crops in the UVGB are red wine grapes, white wine grapes, and Bartlett Pears (Morris, personal communication 2016). On average, 8,772 acres of agricultural land are planted each year in the UVGB. The agricultural water demand is on average 10,181 AF/yr. A fraction of this agricultural water demand is applied to meet the crop water needs (8,641 AF/yr) and the remaining fraction is applied for other beneficial uses, such as frost protection, post-harvest application, and heat protection (1,541 AF/yr). The municipal water demand for the UVGB is estimated to be 5,755 AF/yr. The average agricultural and municipal water demand supplied by groundwater is estimated to be 3,411 AF/yr. In contrast, the aquifer recharge from irrigation and precipitation is about 23,011 AF/yr. This number is greater than the total average water demands (municipal and agricultural) supplied with groundwater (3,411 AF/yr) (Table 1).

Table 1. Average groundwater recharge and extractions observed in the Ukiah Valley Groundwater Basin.

Type of Recharge or Extraction	(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**

In the Ukiah Valley, the agricultural water demand is about 7,789 AF/yr, where 6,635 AF/yr are supplied to meet the crop water needs and 1,154 AF/yr are applied for other beneficial uses such as frost protection, post-harvest application, and heat protection. The total agricultural water demand in Ukiah Valley (7,789 AF/yr) is met with 5,321 AF/yr from surface water and 2,468 AF/yr from groundwater, on average. The municipal water demand in Ukiah Valley is 6,685 AF/yr on average, of which 5,755 AF/yr is met with surface water sources and 930 AF/yr from groundwater sources.

For Redwood Valley, the agricultural water demand is approximately 2,393 AF/yr where 2,006 AF/yr are supplied to meet the crop water needs and 387 AF/yr are applied for other beneficial uses such as frost protection, post-harvest, and heat protection. The municipal water demand in Redwood Valley is 415 AF/yr, on average. The total water demand in Redwood Valley (municipal and agricultural) is met with 2,795 AF/yr from surface water and 13 AF/yr from groundwater, on average. The small groundwater supply in Redwood Valley of 13 AF/yr, came from an intertie well to meet the domestic water demands in Redwood Valley County Water District in the year 2015.

Surface Water Mass Balance

Surface water gains and losses are the primary results from the surface water mass balance. The distribution of the surface water gains and losses varies from month to month (Figure 6). Surface water gains (values above zero, mostly from November to June) 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/yr, on average. Surface water gains in the Russian River 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 experiences surface water losses of approximately 393 AF/yr from July to October. The 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. These results suggest that releases from Lake Mendocino are recharging the UVGB. Given that water from the Eel River is imported into the East Fork of the Russian River via the PVHP, and this water is stored in Lake Mendocino, it is likely that a portion of these water transfers is recharging the UVGB during parts of the year.

Aquifer Storage

Aquifer storage was determined using the water table elevation data for the UVGB from 1991-2015 (Figure 7). In 2003 and 2009, there are dips in the dataset due to questionable water table data records that were available for those given years. Despite the questionable data points, the overall groundwater storage appears stable with time.

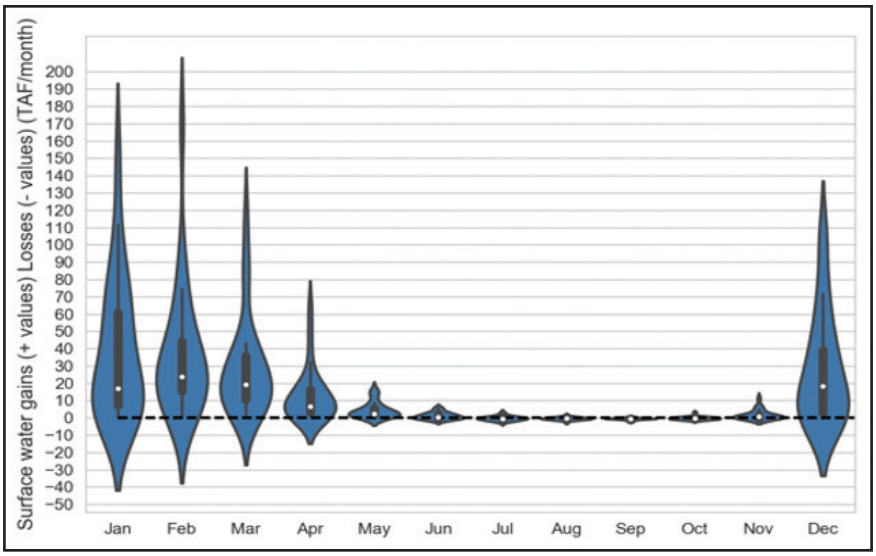


Figure 6. Seasonal distribution of the surface water gains and losses, distribution by year.

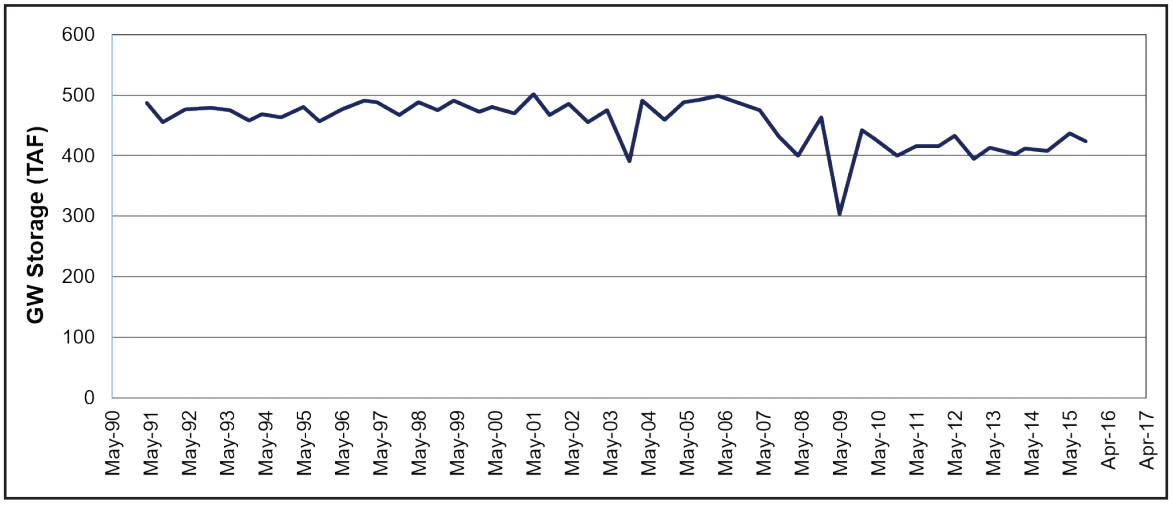


Figure 7. Estimated aquifer storage for the Ukiah Valley Groundwater Basin from 1991-2015.

In the years from 2011 to 2015 there is a subtle decline in storage, but this could be attributed to the drought that occurred from the period of 2012-2015 and from the addition of more water table data.

By plotting the changes in storage (positive and negative) that the aquifer experienced in the time span from 1991 to 2015, a cumulative distribution function from the change in storage observed in the groundwater basin was constructed (Figure 8). Results show that 50% of the time the aquifer experiences a negative change in storage, whereas the other 50% of the time the aquifer experiences a positive change in storage. Ultimately, this means that for the number of times there is a net increase in groundwater storage, there is about an equal number of times there is a net decrease in groundwater storage. Since there is no groundwater storage decline and there is an equal number of times of positive and negative changes of storage occurring, these two observations suggest that the groundwater basin appears to be in balance, concluding, there is no groundwater overdraft in the UVGB. It appears that the amount of groundwater leaving the aquifer is in balance with the amount of water that is recharging the aquifer. These results can be supported with the water table measurements found from the monitoring wells in

the UVGB. From those records, it is seen that the water table has been consistently stable with time, showing no evidence of water table lowering.

Groundwater Mass Balance

The lateral groundwater inflows and outflows were estimated through the groundwater mass balance. Given that the groundwater elevation data was available at an interval of approximately every six months, with a measurement recorded in the spring and another in the fall of each year, the lateral groundwater inflows and outflows were calculated at the time interval in which the monitoring well data were available (Figure 9). Results show that 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

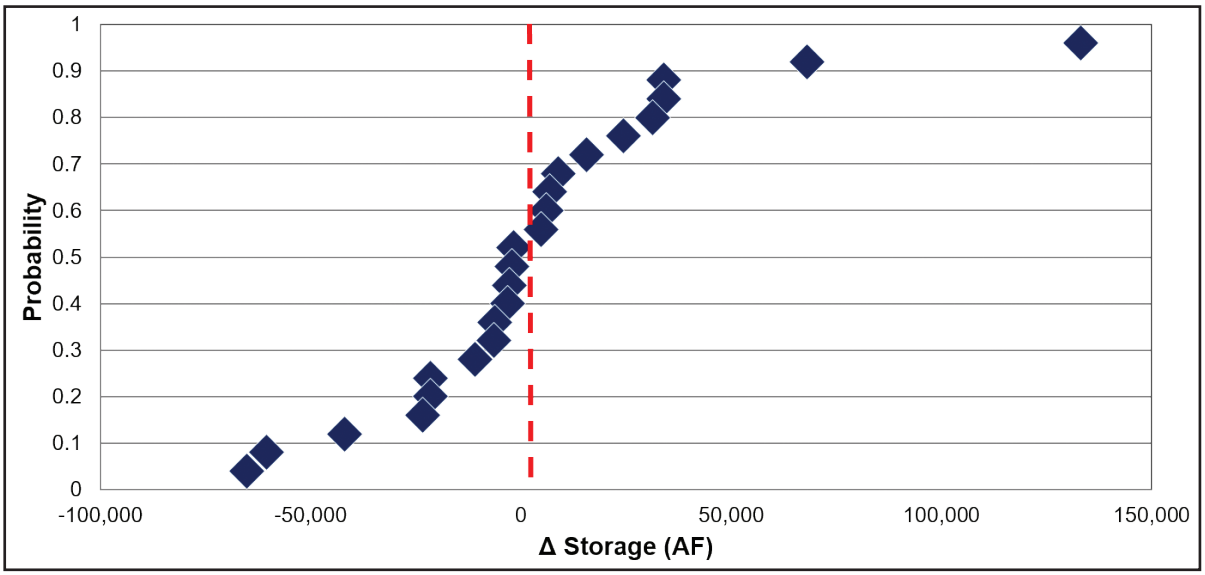


Figure 8. Cumulative distribution function demonstrating the probability of obtaining a particular change in aquifer storage.

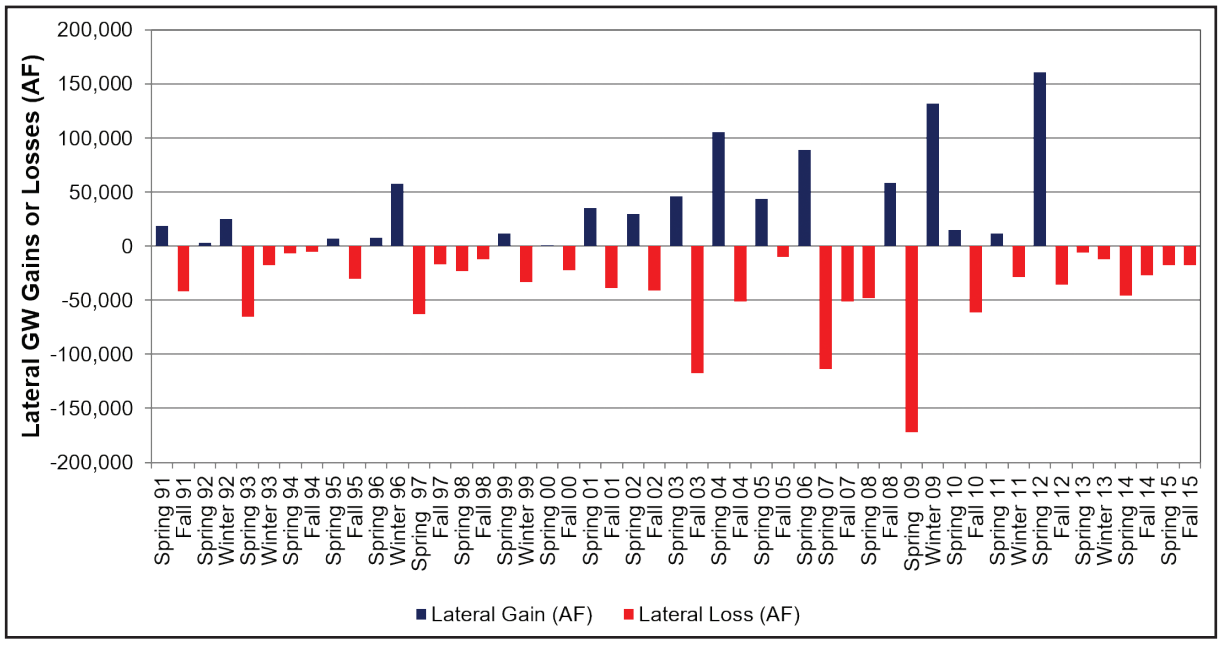


Figure 9. Seasonal lateral groundwater gains and losses in the spring and fall from 1991-2015.

gains observed are assumed to flow from tributary streamflow that recharges the UVGB or from groundwater contributions, such as 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 the result of tributary influence, as suggested by other reports (e.g., Russian River Independent Science Review Panel (RRISRP) 2016). In addition, lateral groundwater losses are occurring. In Farrar (1986) it was outlined that groundwater flows downgradient from the UVGB towards the Russian River, moving from the north to the south end of the groundwater basin. Given the trends previously observed in groundwater movement, the lateral groundwater losses observed are representative of groundwater flowing from the UVGB into the SVGB.

Limitations

Developing a water budget to characterize a groundwater basin is simple, but the quality of the water budget is dependent on the availability and quality of data. The main limitations of this study are related to the control volume used. The control volume centered around Ukiah Valley and not the whole UVGB 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 UVGB 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 the water inflows and outflows. Data gaps were present in some water records, so the missing values were estimated using the median of the data that was available.

Conclusions

Since the UVGB was deemed medium priority, a water budget was established to set baselines for comparison against the six undesirable groundwater conditions the SGMA legislation seeks to prevent. The water budget assessed the status of the UVGB and results indicate that the groundwater basin is not experiencing a decrease in groundwater storage or a lowering of the water table. Surface water-groundwater interactions exist because the Russian River is a gaining river from November to June, gaining on average 18,952 AF/yr, and conversely, a losing river from July to October, losing on average 393 AF/yr. Seawater intrusion is irrelevant to the UVGB since it is inland without risk of saline water entering the fresh water aquifer. Groundwater quality is outside the scope of this study; however, Bulletin 118 (DWR 2004) mentions that the UVGB groundwater quality is generally in good condition. Land subsidence cannot be measured with the results of the water budget but it is assumed that no land subsidence is occurring since the water table has remained stable through time. In addition, groundwater connectivity is observed between the UVGB and the SVGB as a result of lateral groundwater losses identified through the groundwater budget and supported by the work previously done by Farrar (1986). Lateral groundwater gains are also observed to occur, potentially from the SVGB or tributaries. Given these results, it is assumed that tributaries may be the driving force but confirmation of this assumption will require further research.

Overall, the UVGB does not appear to be experiencing any of the six undesirable signs of stress outlined by the DWR. Thus, the basin is in a unique position in which the GSA will have to be proactive in maintaining current basin conditions while also developing an integrated water resources management plan and detailed monitoring protocol for measuring and preventing the six undesirable characteristics that define a groundwater basin as unsustainable.

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