Investigation of Interaction Between Surface and Groundwater of Ball Ranch in the Upper San Joaquin River Watershed

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***Abstract*-The interaction between surface water and groundwater was investigated by monitoring and analyzing the groundwater table's fluctuation in the study area, Ball Ranch of California. Based on the observed data and computer modeling results, this paper studied how groundwater was affected by the flux of the nearby San Joaquin River, precipitation, and evapotranspiration. The site is also bordered and highly influenced by the San Joaquin River located to the west of the site. The flux of the river is reflected in the monitoring wells with a noticeable lag time that was measured using a data logger. This lag time varied based upon the distance of the monitoring well from an open surface water feature such as the main pond. The water table is also affected by the recharge effects of precipitation on the site. These effects along with evapotranspiration have been taken into account while developing the mathematical model for this site. The groundwater flow direction for most of the parts was consistent with the initial hypothesis. The groundwater model can fairly describe the observed data and can be used for the groundwater prediction.**

***Keywords*- Interaction; Water Table; Modeling; Groundwater; Surface Water**

I. INTRODUCTION

Aquifers generally have been experiencing a decline in their water level due to significant use by humans at these days. As a relatively clean and reliable resource, groundwater plays an important role as drinking water and for irrigation. Groundwater also largely maintains surface water systems through flows into lakes and base flow to rivers. The decline of water table in many aquifers due to natural conditions or human factors has caused more and more attention of the investigators [1]. How we manage our water including both groundwater and surface water in the next two decades will have a large impact on the availability and the supply for many more decades to come [2].

Groundwater and surface water are greatly affected by urbanization [3]. As development of land and water resources increases, development of either of these resources affects the quantity and quality of the other and nearly all surface-water features (streams, lakes, reservoirs, wetlands, and estuaries) interact with ground water [4]. With an increase in population and by extension of relatively impermeable surfaces, storm runoff reaches most streams and rivers much quicker. This is much harder for the environment to cope with naturally because infiltration and evapotranspiration do not have the appropriate amount of time to react to the surge of water. Generally, peak flow rates increase and lag times decrease for most areas where urbanization takes place. Further studies must be designed in order to gather the necessary information on the influence of urbanization on the water cycle. The main setback for a study to address this problem is the uncertainty of different variables in each specific scenario. Different scenarios must be taken into account, such as the amount of paved surfaces, land use, and surrounding area. These factors can vary greatly from study to study and are therefore hard to correlate with one another [5]. Surface water bodies and groundwater systems can gain water and be source of each other. For example, withdrawal of water from streams can deplete ground water or conversely, pumpage of ground water can deplete water in streams, lakes, or wetlands [4]. Therefore, it is very important to understand the linkages between ground water and surface water as it applies to any given hydrologic setting for an effective land and water management.

In addition, the interface between surface water and groundwater is especially important when it comes to the transport of contaminants in the water. The relationship between these two is based upon many factors such as geology and topography of the surrounding area. There are several different approaches to estimate the transmission between these interfaces, such as in-stream gauging systems, assessment of water mass balance and the use of piezometers placed throughout the study area. This interaction can also be a source of error if a mathematical model is used for a study where this type of interface is present [6]. On a global scale, the health of many aquifers has degraded sharply due to human interaction with the environment. For example, the use of fertilizers in agriculture has largely introduced contaminants into local aquifers. Water used for agriculture infiltrates into the soil, transporting sulfates and nitrates along with it. These two contaminants change the chemistry of the groundwater by affecting pH and oxygen levels which have adverse effects on the water quality [7]. Another cause for concern is the amount of sediment that has eroded due to agriculture. The sediment negatively impacts the environment as well as the global carbon cycle [8].

Different methods have been used to study the exchange flux between groundwater and surface water systems [9, 10]. Examples of these methods include pumpage method and seepage meters method, which measure groundwater–surface water exchange directly [11, 12]. The groundwater that is pumped out of an aquifer is slowly recharged as surface water percolates through the soil. This process is generally slow, and in many areas of the world, unsustainable. Pumping groundwater near rivers is a sustainable method for contaminant removal [13]. As long as the pumping station is at a lower gradient than that of the river, the groundwater will flow towards the well. As it moves slowly through the soil, it loses many of its impurities. This method is economical and requires no new technology in order to be implemented; furthermore, this would offset the cost of a traditional water purification plant which would require many chemicals as well as much more energy to operate. This process has led to many studies and useful data into the interaction of rivers and streams with the surrounding water table. The only caveats to this process is the unnatural interaction needed to stimulate a higher permeability in the river through dredging, and many areas throughout the country may not have a surface water source that could support this type of operation [14].

The investigation of interactions between groundwater and surface water is especially important for the hyporheic zone like this research, which are the aquifers beside a surface water system such as streams, rivers, lakes and wetlands where groundwater and surface water actively mix and exchange [9, 15, 16]. The hydrologic processes in the hyporheic zone are variable in space and time on relatively small scales [9, 17]. A number of studies on the relationship between surface water and groundwater have been performed under several different conditions [18]. The data has been correlated with nearby water features such as streams and rivers in order to determine whether or not these features were gaining or losing water due to the ground water conditions. Monitoring wells staggered throughout a site with calculated readings help determine the direction and depth of a particular groundwater flow [19]. Knowing this type of information would ultimately aid in future restoration efforts for ground and surface water remediation by native plant species. The typical investigation in this area involves multidisciplinary knowledge and needs combining spatially and temporally resolved field or laboratory data with physically based numerical models to identify key dynamics and to improve process understanding [20, 21].

The objective of this research is to investigate interaction between surface water and groundwater by monitoring and analyzing the groundwater table's fluctuation in the study area, followed by mathematic modeling. Studying infiltration and the water transportation pathways have helped to provide information on how to best manage aquifers in the years to come. This paper studied how groundwater was affected by the flux of the nearby San Joaquin River, precipitation, and evapotranspiration. The detailed task of this project is to accurately portray the subsurface water conditions on the research site so that they can be of use to the San Joaquin River Conservancy and their future use of the site. This will consist of creating a model of the subsurface water conditions at Ball Ranch. Surface water elevation maps will also be created using ArcGIS from the geo-referenced data collected in the field.

II. DESCRIPTION OF STUDY AREA

This research was conducted in Fresno, California at the Ball Ranch site under the jurisdiction of the San Joaquin River Conservancy. Ball Ranch located in the upper San Joaquin River watershed was used as the study area for the investigation of interaction between groundwater and surface water. This area is in Fresno County, adjacent and north of Little Dry Creek, and between Friant Road and the San Joaquin River (Fig. 1). In the past, Ball Ranch was a popular recreational place privately operated for public fishing. The planning participants recognized the need to continue to allow fishing at Ball Ranch, both at the largest of the ponds and along the river. The goals of the Ball Ranch restoration include: protect and enhance the environmental values of the property; develop a spectrum of public access and recreation features consistent with the protection and enhancement of the environmental values; develop public access and recreation features that can be self-supporting to the extent possible. To achieve these goals, it is necessary to assess the site environment by studying the water environment especially the interaction between groundwater and surface water before any restoration measures are carried out.

The site is approximately 358 acres owned by the Upper San Joaquin River Conservancy, and approximately 91 acres owned by the California Department of Fish and Game, which are part of the Willow Unit of the San Joaquin River Ecological Reserve, and located between Friant Road and the San Joaquin River [22]. The boundaries of this study area include the Friant Road, Vulcan mining, and the northern bordering fence. The monitoring data of groundwater table were collected from the ten wells (Fig. 1) between December 2011 and May 2012. Eighty-seven (87) readings of water table elevation for each well were recorded during the period.

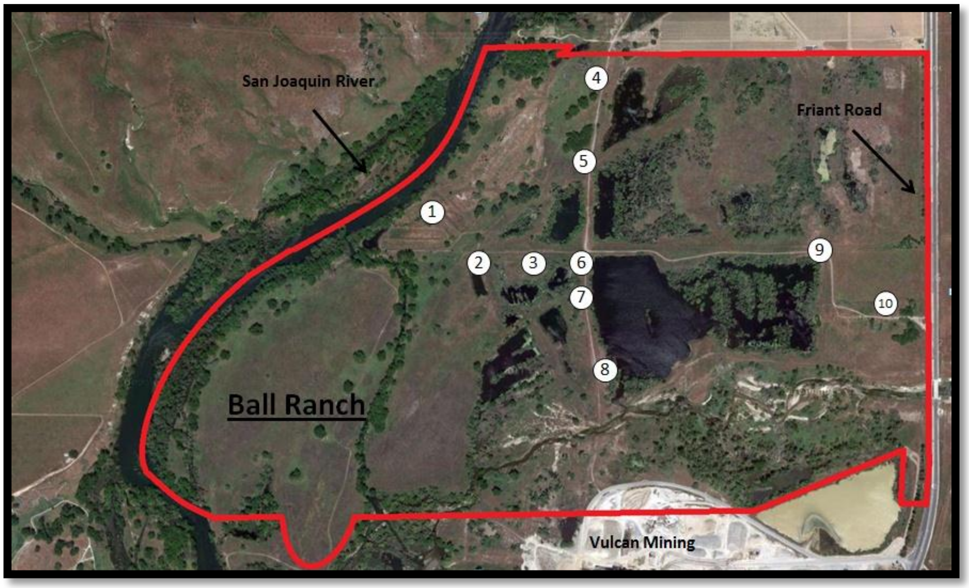
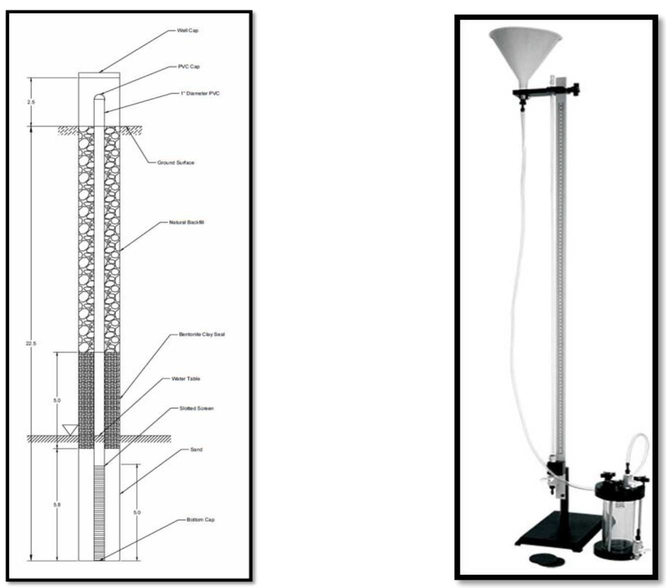


Fig. 1 Satellite map of the investigation domain

III. METHODOLGY

The method used in this research included data analysis, field monitoring, and mathematical modeling. Groundwater table in the Ball Ranch was monitored through ten piezometers installed within the study domain by using air hammer drill rig (Fig. 1). The 20-foot-long PVC pipe with one-inch diameter was joined to a 5-foot-long slotted screen with the same diameter and inserted down to the borehole (Fig. 2a). The slotted screen was fitted with a cap to prevent sediment from filling up the screen from below. After the pipe was inserted, sand was then poured in the exterior of the screen. One to two feet past the screen was filled with the sand, acting as a filter from surrounding sediments, then it was followed by a 5-foot-deep bentonite clay layer. This layer acted as a plug which would prevent surface water from directly seeping down from the casing located above the ground surface. This would prevent any inconsistencies from unwanted seepage from surface water. The piezometric readings were recorded between January 20^{th} and April 16^{th} of 2012.



(a) (b)

Fig. 2 (a) Cross section of Monitoring wells, and (b) Falling Head Permeameter

Groundwater movement during the monitoring period was simulated by using a mathematical model developed using software Groundwater Vistas. Modflow in the Groundwater Vistas was used to create the groundwater model for this project. The governing equations used in this model are as follows,

$$\frac{\partial}{\partial x}(K_{xx}\frac{\partial h}{\partial x})+\frac{\partial}{\partial y}(K_{yy}\frac{\partial h}{\partial y})+\frac{\partial}{\partial z}(K_{zz}\frac{\partial h}{\partial z})+W=S_s\frac{\partial h}{\partial t} \quad (1)$$

where, K_{xx}, K_{yy}, and K_{zz} are hydraulic conductivity along the x, y, and z directions; h is the potentiometric head; W is the volumetric flux per unit volume representing sources and/or sinks of water, with $W<0.0$ and $W>0.0$ for flow out and into the groundwater; S_s is the specific storage of the porous material; t is time. The average hydraulic conductivity was determined by using a permeameter as follows (Fig. 2)

$$K=\left(\frac{aL}{At}\right)\ln\left(\frac{h_0}{h_1}\right) \quad (2)$$

where K is hydraulic conductivity; a is area of water container; L is length of sample; A is area of Permeameter; h_0 is initial head; h_1 is final head; t is time.

The model domain was delineated using a satellite image overlay using the western boundary of the San Joaquin River, the eastern boundary of Friant road, the southern boundary of vulcan mining, and the northern boundary was selected as the fence bordering the site.

IV. RESULTS AND DISCUSSION

A. Hydraulic Conductivity

After the field data were collected, soil samples taken from the Ball Ranch were analyzed in the lab to determine the hydraulic conductivity of the aquifer in this area.

TABLE 1 HYDRAULIC CONDUCTIVITY

	Units	Sample #1	Sample #2	Sample #3	Sample #4
Time, t	days	0.79	0.85	0.50	0.69
Length of Sample, L	ft	1.00	2.00	3.00	4.00
Area of Permeameter, A	ft^2	0.000314	0.000314	0.000314	0.000314
Area of Water Container, a	ft^2	0.049087	0.049087	0.049087	0.049087
Initial Head, h_o	ft	4.95	4.95	4.95	4.95
Final Head, h_1	ft	4.80	4.87	4.90	4.91
Hydraulic Conductivity, K	ft/day	6.073	5.961	9.518	7.376

The falling hydraulic conductivity test was performed using a falling head permeameter shown in **错误!未找到引用源。**. This equipment was provided by Fresno State and used to test four samples taken from the Ball Ranch site. These four samples (see Table 1) were used to compare to the iterative model output, which was 7 ft/day.

B. Hydrologic Data

The interaction between groundwater and surface water was studied by analyzing the water table elevation collected from the monitoring wells and other hydrologic data at the Ball Ranch including, evapotranspiration, transpiration, river stage and discharge of the SJR obtained from the California Data Exchange Center (CDEC) and the California Irrigation Management Information System (CIMIS).

Basically, this region lacked of precipitation during the spring season, when the data were collected (Fig. 3a). The water loss caused by the evapotranspiration increased as summer approached (Fig. 3b). Stages at different gage stations around the study area including downstream Friant dam (Fig. 4b), high way 41 (Fig. 4c), and Ball Ranch (Fig. 4d) are consistent with the discharge of the SJR (Fig. 4a).

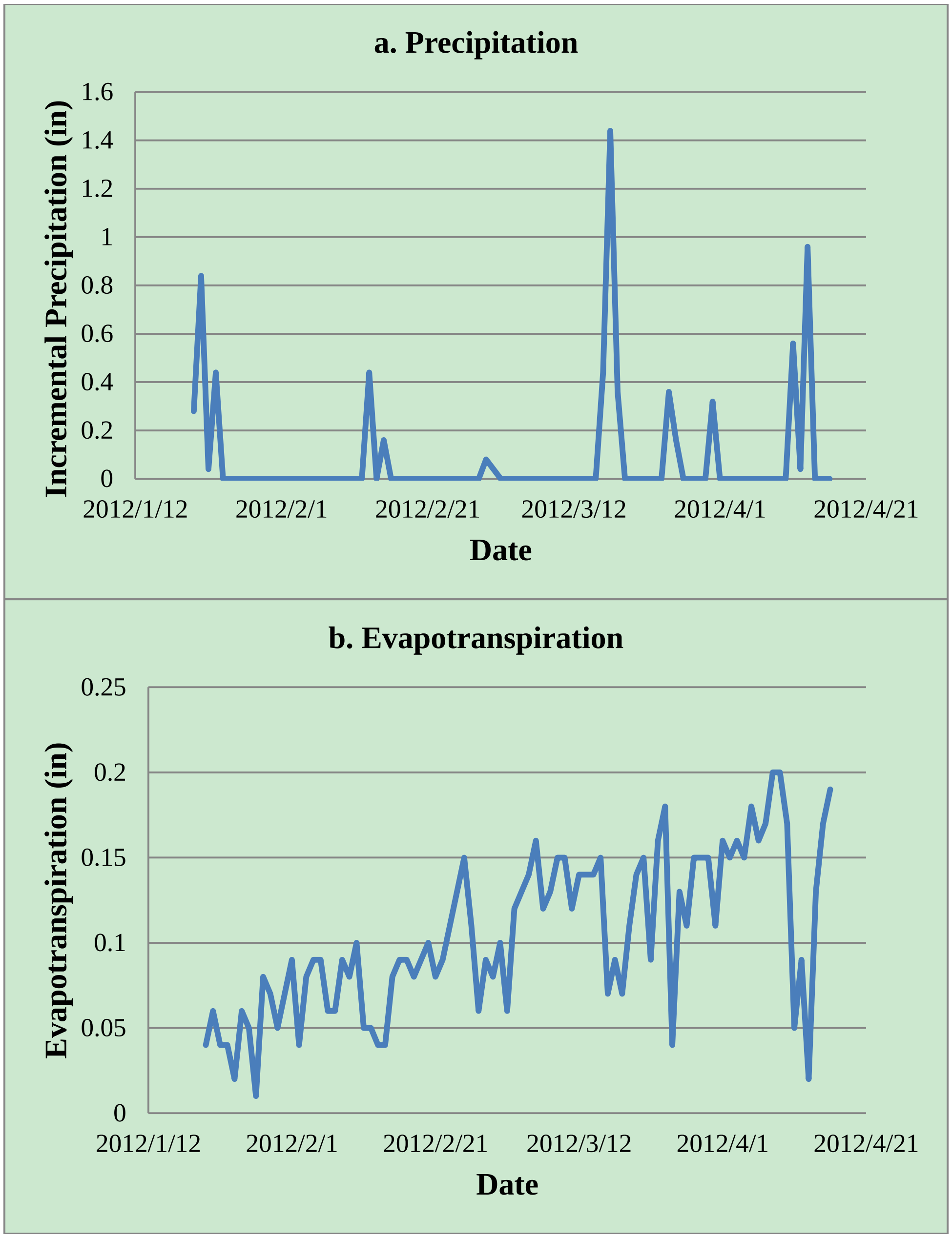


Fig. 3 Hydrologic data of (a) Precipitation; and (b) Evapotranspiration data at the Ball Ranch region

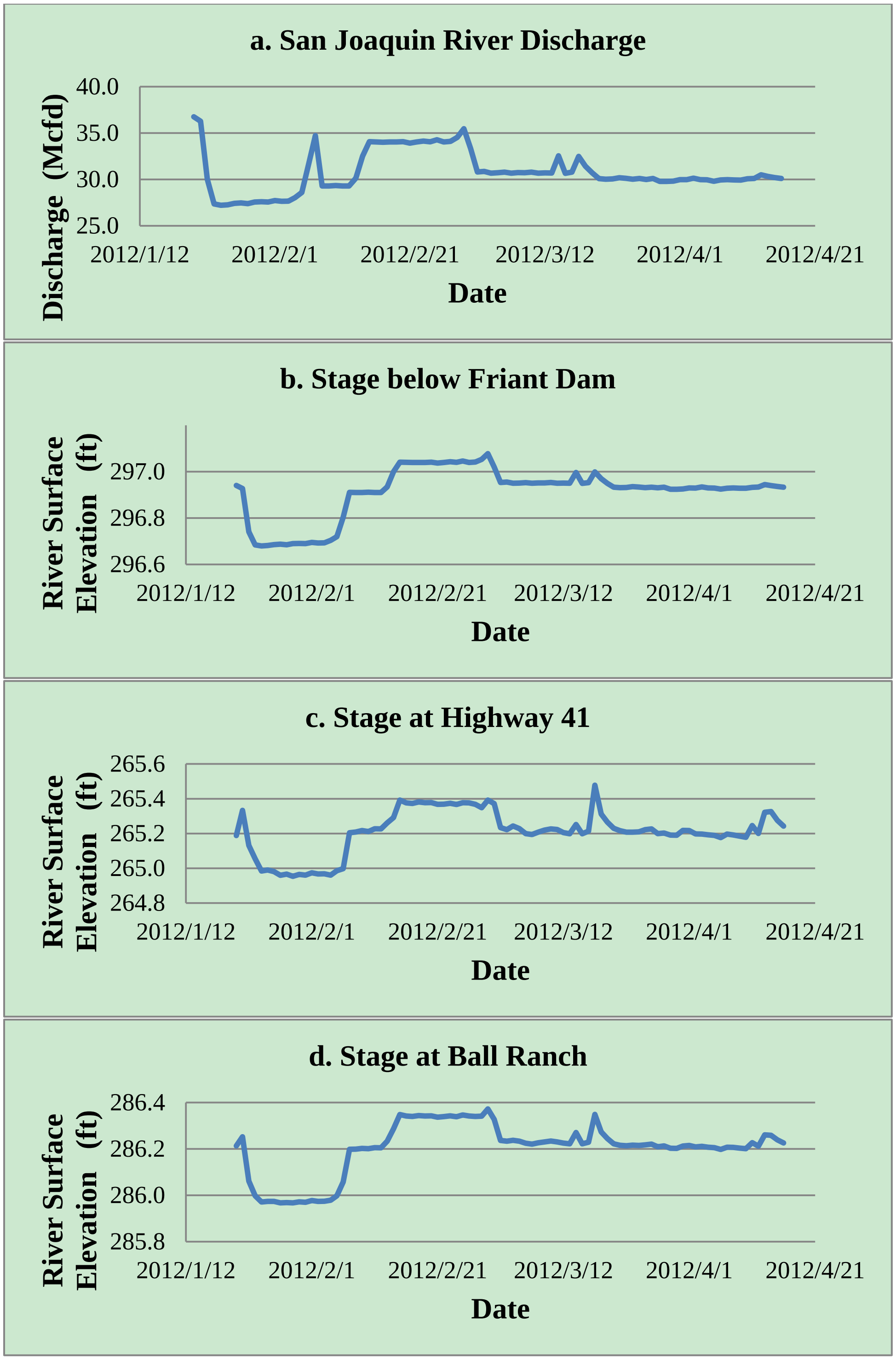


Fig. 4 Hydrologic data of (a) flowrate of the SJR (Mcfd: Million cubic feet per day); (b) stage below Friant Dam; (c) stage at highway 41; and (d) stage at Ball Ranch Piezometric data

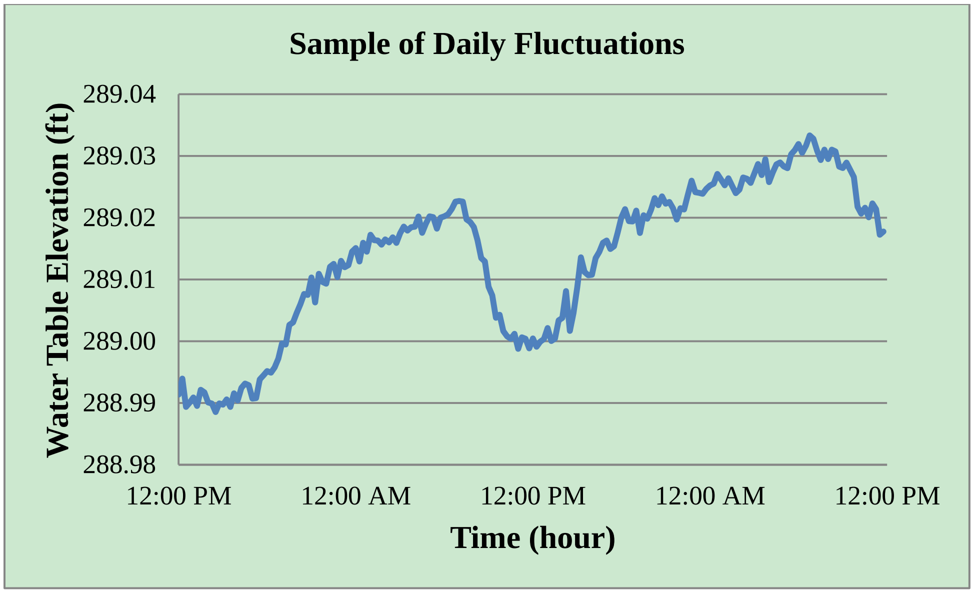


Fig. 5 Sample daily fluctuation

The data logger provided a high time resolution dataset. These readings (Fig. 5) show an increase during the day time which peak daily around 9 am and they reach their local minimums around 12 pm each day. This cycle can be seen if the data is analyzed on an hourly scale. The San Joaquin River is the main influence of the groundwater as displayed in the data of the piezometers. It can be seen from the data that the water table rises in response to flux in the river, notably in those wells closest to the river. Fig. 6 shows the variation of the groundwater table elevation with respect to time at different wells. The elevation decreased gradually from Well 10 to Well 1 (locations shown in Fig. 1) in Fig. 6. It indicated that the groundwater flow direction was from the Friant Road to the San Joaquin River. The water table at each well rose up during this period due to the precipitation in the wet season (Fig. 7). Fig. 8 shows the comparisions between the San Joaquin River discharge or river stage, and the groundwater table elevation at Well 1 and Well 4 in Figs. 8a and 8b, respectively. The discharge variation with time presented a typical hydrograph in a wet season with a peak flowrate of around 34 million cubic feet per day (Mcfd) between Feburary and March of 2012, resulting in the increasing elevation of the water surface in the river. The variations of the water surface elevation and discharge in the river were faily consistent (lines of Ball Ranch Stage (BRS) and the San Joaquin Franit Flowrate (SJFF) in Fig. 8). The constant ascent of the groundwater table reflected the aquifer recharging process and the increase of the base flow to the river during this period. As a resault, the overall trend of both the river stage and discharge was upward between Feburary and April at the Ball Ranch.

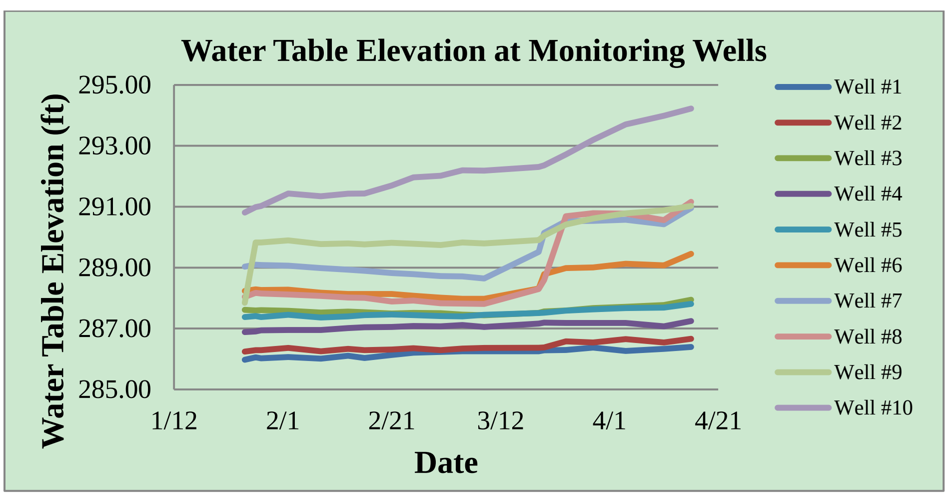


Fig. 6 Piezometric readings from the monitoring wells

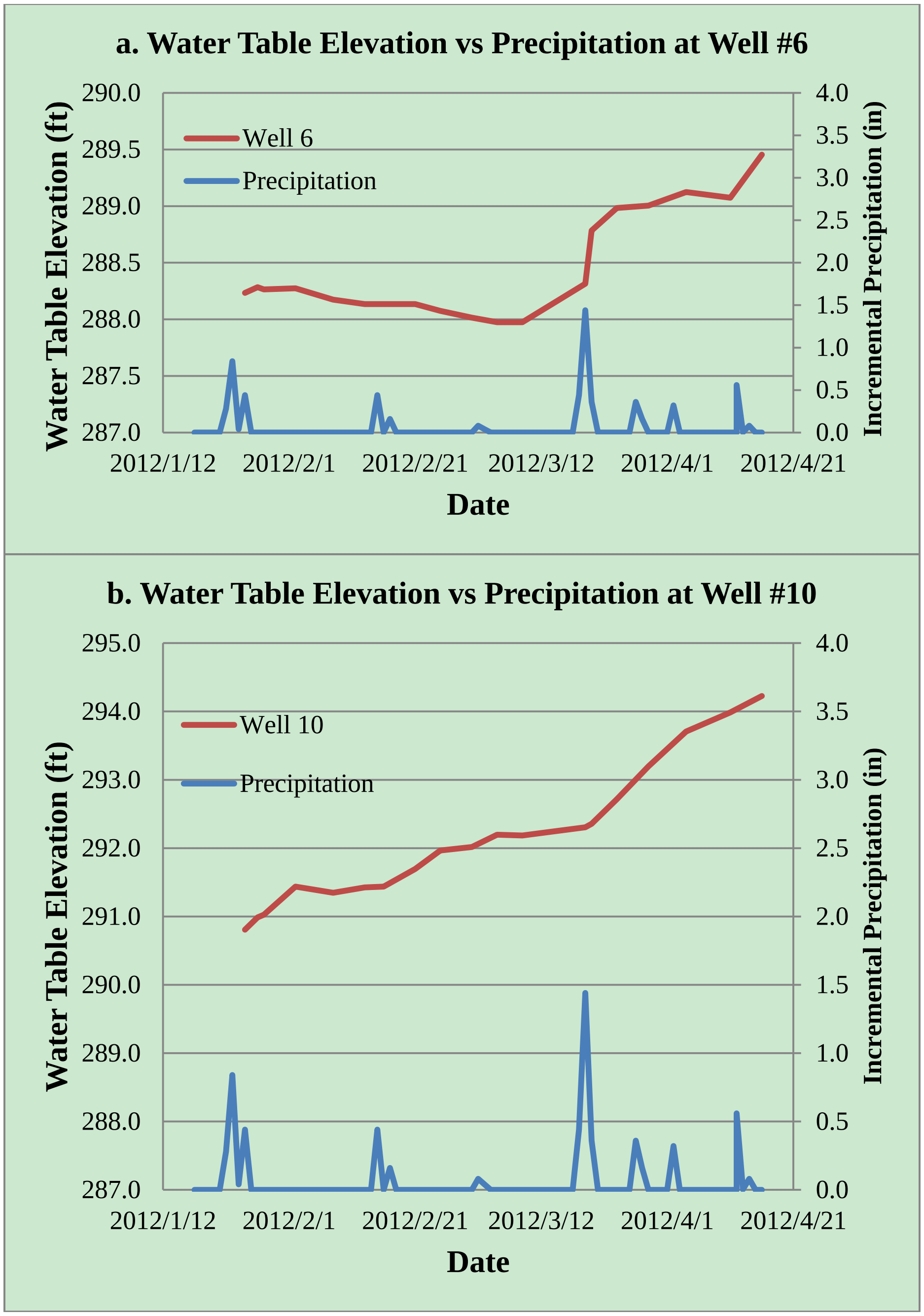


Fig. 7 Water table elevation with precipitation overlay: (a) Water Table Elevation vs Precipitation at Well #6; (b) Water Table Elevation vs Precipitation at Well #10

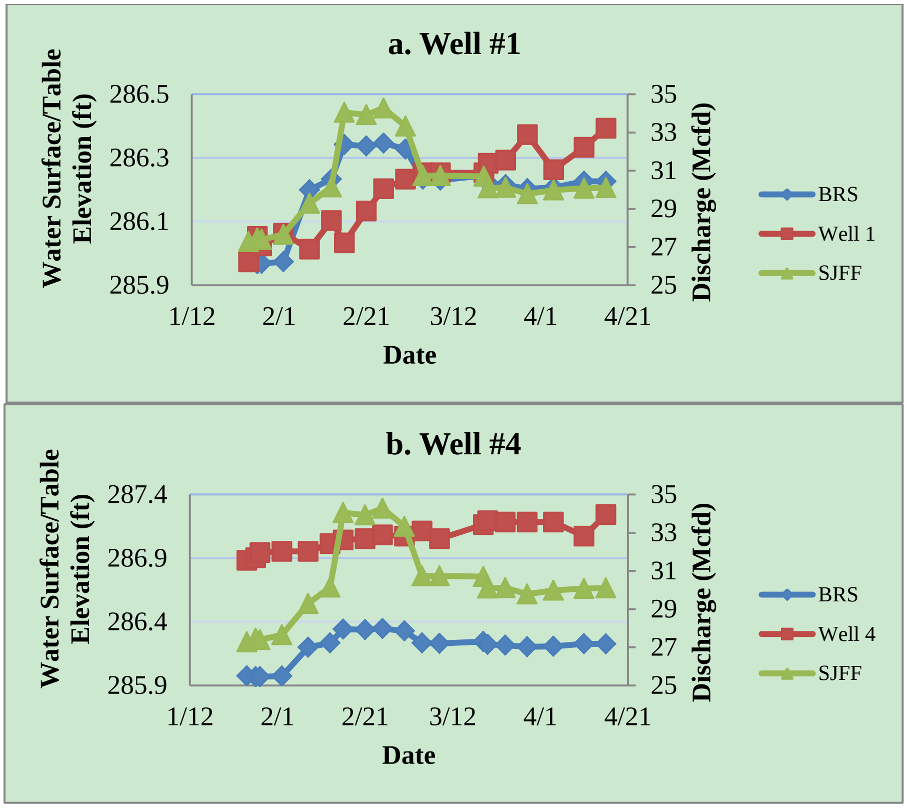


Fig. 8 Comparisons of discharge and water surface elevation in San Joaquin River with groundwater table in the study area: (a) at Well #1, and (b) at Well #4. (BRS: Ball Ranch station Stage reading; SJFF: San Joaquin river Fraint Station Flowrate (discharge))

The developed mathematical model was used to simulate the groundwater table. Fig. 9 shows the correlation between the observed data and the modeling results. The high correlation coefficient between the observed data and the modeling results (0.9) and the fair matches shown in Figs. 10a, 10b, and 10c indicate that the model can reasonably describe the groundwater in the study region.

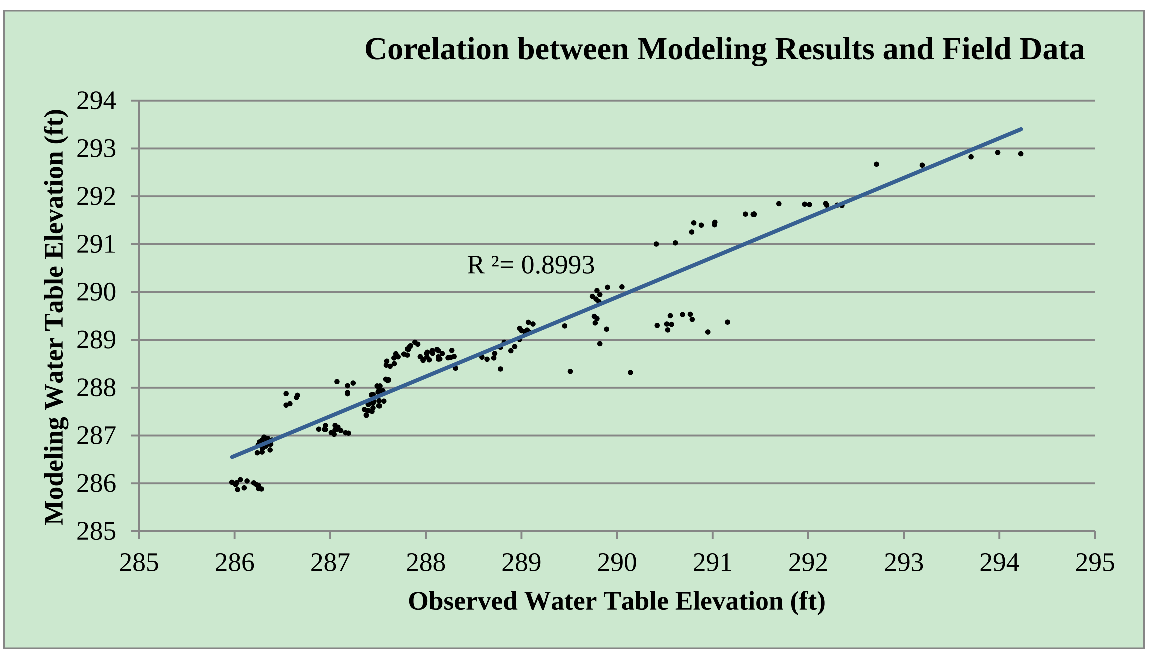


Fig. 9 Correlation between the observed data and modeling results

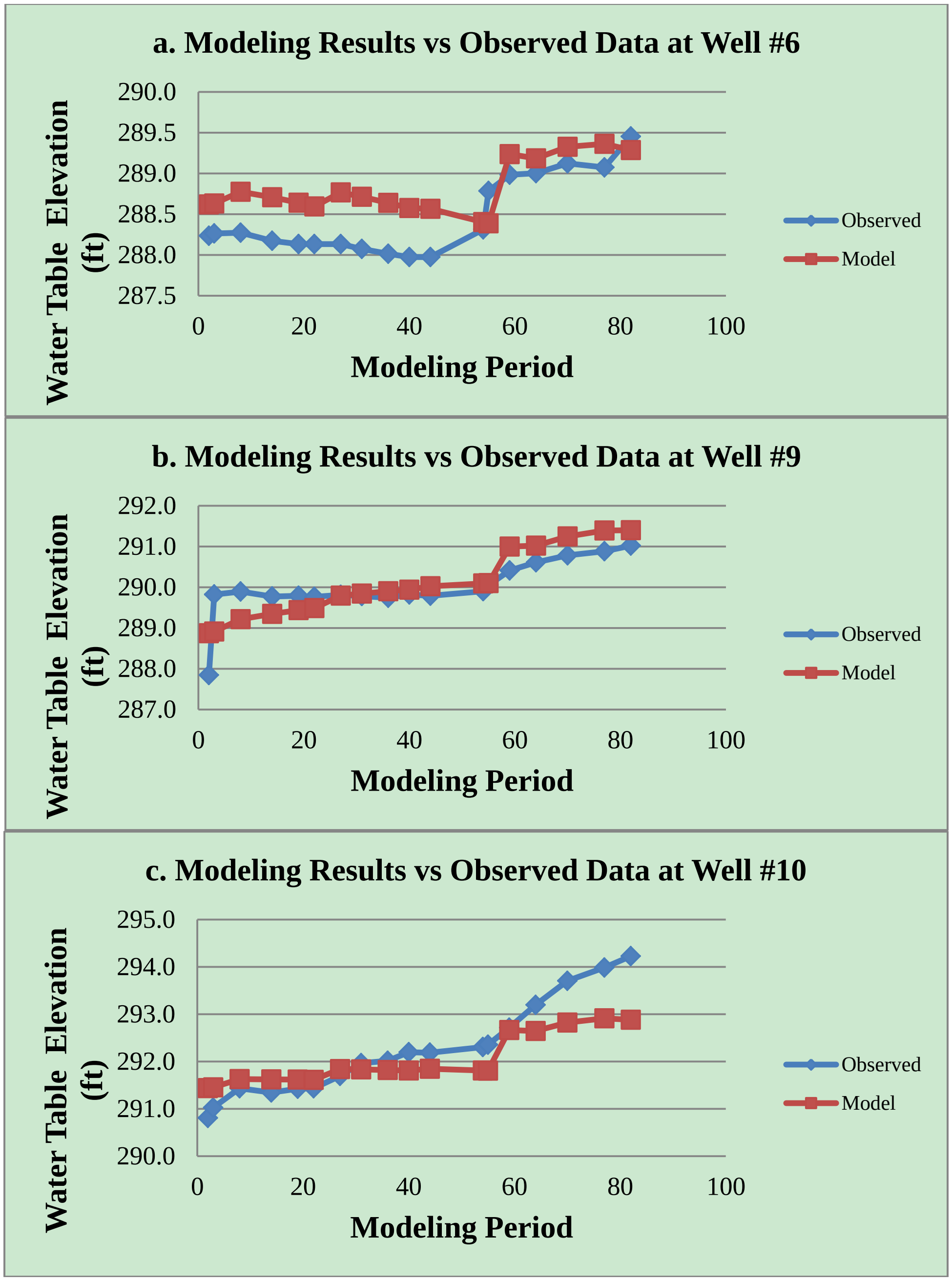


Fig. 10 Comparison between the observed and modeling water table elevations at: (a) Well 6; (b) Well 9; and (c) Well 10

V. CONCLUSIONS

The site is bordered and highly influenced by the San Joaquin River located to the west of the site. The influence of evapotranspiration, precipitation and river flux was based on the observed data and computer modeling results of the Ball Ranch. The flux of the river is reflected in the monitoring wells with a noticeable lag time that was measured using a data logger. This lag time varied with respect to the distance of the monitoring well from an open surface water feature such as the main pond. The water table is also affected by the recharge effects of precipitation on the site. These effects along with evapotranspiration have been taken into account while developing the working model for this site. The groundwater flow direction for the most part was consistent with the initial hypothesis correct. The bend of the river was not initially taken into account. This bend gave a north-eastern direction to the flow, rather than an east to west direction which was predicted in the hypothesis.

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