Assessment of Water Table and Water Quality Variations with Respect to River Flow Along Rio Grande Between Garfield NM and Fabens TX

By

Blair Stringam, College Associate Professor

Manoj Shukla, Professor

Benjamin Nana O Kuffour, Graduate Assistant

Technical Completion Report
Account Number ?????????

June 2015

New Mexico Water Resources Research Institute
New Mexico State University

The research on which this report is based was financed in part by the State of New Mexico, through the New Mexico Water Resources Institute.

DISCLAIMER

Abstract

The interaction between the Rio Grande and the ground water in the Lower Rio Grande in New Mexico was studied from May of 2014 to June of 2015. During this period of time, river flow was observed and the water levels were recorded from observations wells located between Hatch, New Mexico down to the New Mexico Texas border. In addition, EC, salts, and SAR were recorded for water samples that were collected from observation wells. The measurements further validate that there is an interaction between the Rio Grande and the shallow ground water aquifer. However, the relationship between the low EC water flow from the river into the aquifer did not seem to have much of an impact on groundwater EC. It is believed that this is likely due to over irrigation where salts are washed from the land into the groundwater or possibly water flow from other aquifers. Further testing is required to determine the source of the salts. Empirical equations were developed for modelling the initial flow from Rio Grande into the ground water aquifers in the Hatch-Rincon valley and the Las Cruces areas. Despite the high correlation values that were determined for the equations, further study is required to validate these equations.

Introduction

New Mexico is facing a severe shortage of surface water for irrigation and the problem is getting worse with continued drought. There is a strong possibility that the drought situation is not going to improve in the near future. Low surface water availability for irrigation is putting increasing pressure on the groundwater resources. New Mexico groundwater aquifers are not contiguous and some are also saline. Resent measurements indicate that the water-table has dropped due to the continuous pumping for irrigation from Hatch and Anthony, NM to areas south of El Paso, TX and the concentrations of salts appear to be increasing. NRCS has recorded a drop in the water level from observation wells in the Hatch area and some of the observation wells in the Las Cruces area were dry when measurements were taken in the May of 2014. Similar drops have been observed by measurements made by PIs along Rio Grande River between Garfield, NM and Fabens, TX. Farmers in the Hatch area complain that in the middle of the irrigation season the well water level is so low that they cannot pump enough to meet crop water demand. In the Las Cruces area, there are mixed concerns about well water. Some water users complain about dropping water levels, while others complain of increasing salt concentrations.

Study Objectives:

1) Measure the fluctuations of water table on a monthly basis throughout the year along Rio Grande south of Garfield, NM and develop a model that describes the influence of the river and canal systems on the water aquifers.
2) Monitor the fluctuations in groundwater quality (salinity and sodicity) by collecting water samples from over 50 observation wells and river water from Garfield NM down to the

Fabens, Texas.

3) Develop a preliminary water budget for the experimental area and identify the influence of surface and groundwater interaction on water quality.

Impacts on New Mexico:

The interaction between surface water and ground water is dynamic and complex. Past research indicates that there is a close interaction between the Rio Grande discharge and groundwater aquifers in the areas south of Hatch. For example, it is believed that pumping water from wells near the river, depletes water in the river. If this is true, the time that is required for water to travel from the river to the ground water needs to be understood. This work should help researchers and water users better understand the surface ground water interaction and provide a model/relationship that will help to manage the water.

In addition, there appears to be an increase in salts in the upper aquifers in this area. The river water has a low salt concentration and could potentially improve groundwater quality. However, there are claims that this is not happening. The data that is being collected appears to support the salt concentrations for some of the aquifers at this point.

LITERATURE REVIEW

Groundwater table depth is a spatio-temporary dynamic variable (Dinka, 2010; Hecker *et al.*, 1998). Comparably, shallow groundwater levels generally fluctuate more frequently than deep levels of groundwater (Helmuth *et al.*, 1997) and this either occurs on daily, monthly, seasonally or over several years depending on the prevailing biotic and abiotic (occurrence of rainfall) conditions and certain anthropogenic activities (irrigation frequency and pumping) (Hecker *et* *al.,* 2010). Thus changes in groundwater depth relate the groundwater system to external factors (Jinglong et al., 2008).

Aslan and Gundogdu (2007) stated that frequent monitoring of the spatio-temporal variations in groundwater depth especially in irrigation areas are highly essential for effective management of groundwater resources. Periodically observing and evaluating groundwater depths in agricultural areas help water managers access the effect of irrigation and precipitation on the changes to groundwater depth. This helps to put better irrigation plans in place and take precautionary measures for the use of groundwater resources. Also, concurrent studies of time and spatial changes in groundwater depth provide insight to the behavioral dynamics of aquifer systems (Kumar and Ahmed, 2003). Furthermore, continuous and periodic measurement of groundwater levels provide the most reliable source of information pertaining to the effect of hydrologic stresses on groundwater systems (Alley and Taylor, 2001).

Related Research

Groundwater levels worldwide have declined over the past decades (Cay and Uyan, 2009). In southern New Mexico, there has been a reported decline in groundwater levels (Sharma et al., 2013). The situation is no different in other parts of the world. In the Konya Close basin of Turkey, groundwater level has observed a 25 meter decline in the last 25 years (Water Authority, 2006; Cay and Uyan, 2009). Kheda in India has seen the water table drop by 0.5 meters to 9.5 meters in recent years (Sharda *et al.,* 2006).

Weeden and Maddock (1999) mentioned that pioneer investigations of water quality and depth-to-water table in the Mesilla and Rincon Valleys, southern New Mexico were done by Slichter (1905) and Lee (1907). In 1954, Conover generated groundwater contour maps to show that the Rio Grande alternate between a gaining and losing stream in the Mesilla and Rincon valleys. The Rio Grande is a gaining stream from Leasburg dam to about 6 miles south and is predominantly a losing stream as it flows down in the Mesilla basin. Overall, the river replenishes the groundwater system rather than receiving groundwater from the river (Weeden and Maddock, 1999). Wilson *et al.,* (1981) reported that "water table in Mesilla Valley is typically 10 to 25 feet below land surface and has a southward gradient of 4.5 feet per mile (Weeden and Maddock, 1999). Seepage investigations in the Rio Grande between Radium Springs, New Mexico and El-Paso, Texas show that during the irrigation season the river is a gaining stream to about 5 miles north of Mesilla dam and changes to a losing stream. This condition occurs predominantly during low flow events (1997 New Mexico Water Year; Nickerson, 1994; Weeden and Maddock, 1999). Maddock and Wright Water Engineers, Inc, (1987); Weeden and Maddock, (1999) stated that the water tables in the Rincon and Mesilla Valleys fluctuates about 2 feet during the irrigation season and rises as the aquifer gets recharged by irrigation water. Sheng *et al.,* (2010) analyzed the river flow, total dissolved solids (TDS) and salt loading at selected segments of the river (Rio Grande) reach and associated underlying aquifers from Caballo Reservoir in NM, continuing through the urbanized areas of Las Cruces, NM and El-Paso, TX to Fort Quitman, TX. They found that salt concentrations continue to increase downstream up to an average of 3,200 mg/L during the irrigation season, and identified patterns of salt exchange between the river and underlying aquifers.

Study Area

The study area includes Garfield, Hatch-Rincon, Radium Springs, Leasburg, Las Cruces, La Mesa, and Anthony located in south-central New Mexico, along the Rio Grande, down to the Fabens, Texas. The Rio Grande flows for 1,900 miles from southern Colorado through New Mexico to the Gulf of Mexico. In southern New Mexico, the river flows through the Dona Ana County, which includes the New Mexico part of the study area. The fertile valley, formed by historical repeated heavy spring floods along the river extends from Hatch, at the northern corner of the Dona Ana County, to the west side of El Paso, Texas (Kammerer, 2008).

The Rio Grande streamflow serves as the primary source of recharge to the aquifer system in the Mesilla Valley. The largest amount of recharge to the aquifer system originate from the Rio Grande seepage in losing reaches of the stream, infiltration of applied irrigation water, seepage from irrigation canals, and recharge from precipitation and interbasin groundwater inflows (Nickerson and Myers, 1993). Portions of the Rio Grande within the Mesilla Valley serve as losing stream, however, there exist a slight river gains from Leasburg dam to 6 miles north of Las Cruces (Wilson *et al.,*, 1981; Nickerson and Myers, 1993), and at the immediate upstream of El-Paso, Texas to the southern end of the basin.

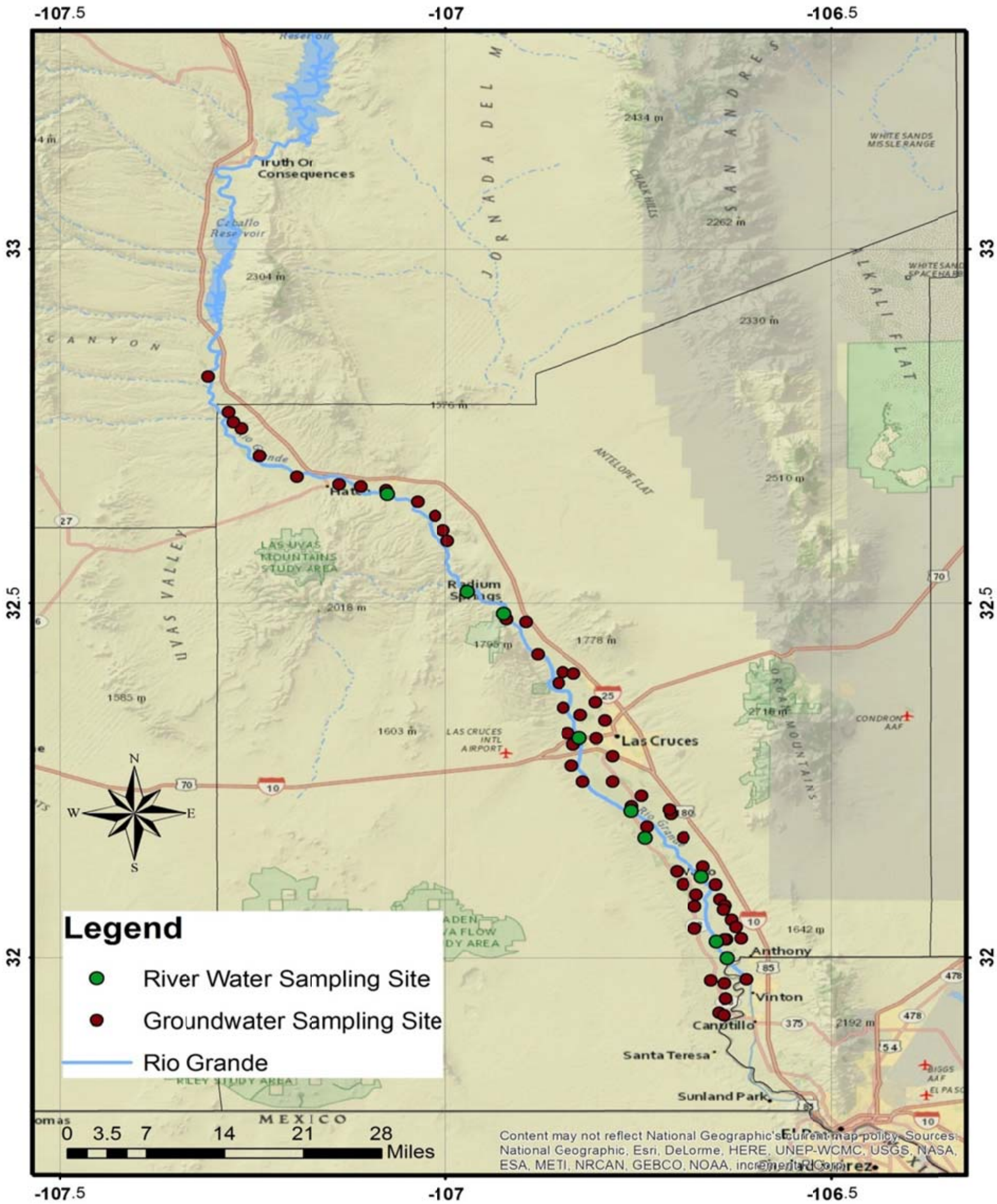

Fig. 1: Map showing sampling sites on the Rio Grande and groundwater sampling sites (study wells) within the area of study from Garfield to Canutillo, NM.

CURRENT EXPERIMENTAL RESULTS

Spatial and Seasonal Variability in Groundwater and River water Characteristics

Monthly fluctuations in the following parameters; groundwater levels, electrical conductivity (EC), and Sodium Adsorption Ratio (SAR), calculated from ion concentrations (Mg^{2+}, Ca^{2+}, and Na^{+}) were observed and calculated for all well locations across the study area from June 2014 to May 2015.

All the wells experienced monthly fluctuations throughout the year in groundwater levels (depth to groundwater table) during periods of river flow and no-flow, and changes occurred irrespective of well distance relative to the river. The changes in groundwater levels obtained from some well measurements during river flow were significantly higher compared to the periods of no river flow ($p \leq 0.10$). These changes or fluctuations followed the trend of reduction in river water levels. Thus as the river water level dropped gradually from June through to September (month in which river flow was last witnessed in the year 2014), the depth in the groundwater table observed in those wells increased (Fig. 2, 3 and 4).

In the areas south of Garfield in the Hatch-Rincon valley, there is a short initial increase in ground water depth observed for the majority of the wells during river flow. After the initial period, continued increases in groundwater depth were observed in 30% of the wells (Fig. 2). These wells were found within 1600 to 4900 feet from the river. However, two wells within the 1600 foot range and one beyond 4900 foot from the river exhibited a decline in the groundwater table when the river was flowing compared to periods of no-flow. Generally the mean estimates of the well depths indicate a decline in the groundwater table during periods of river flow (June to September, 2014) (Table A).

Table A: The Mean River Water Level, Depth to Groundwater table, EC, and SAR estimated in groundwater wells and River during June to September 2014 when the River was flowing and during October 2014 to May 2015 when the River was not flowing, in Hatch-Rincon, south of Garfield, NM.

Well Number	Well Distance from River feet	GWT Depth (feet)	GWT Depth (feet)	GW EC (µS/cm)	GW EC (µS/cm)	SAR	SAR
		River flow	**No River flow**	**River flow**	**No River flow**	**River flow**	**No River flow**
RIN_5R	0 to 1600	19.5 (16.8-22.7)	*16.9 (15.5-21.1)	1757 (1029-2700)	2161 (2020-2420)	3.2 (2.9-3.7)	2.8 (2.6-3.0)
RIN_8R		17.9 (16.7-20.6)	17.7 (17.2-18.8)	1355 (1130-1618)	1370 (1229-1565)	2.0 (1.8-2.2)	2.0 (1.8-2.4)
RIN_1R	>1600 to 3200	23.8 (21.9-28.4)	22.8 (21.4-25.1)	2607 (2290-2890)	2210 (2070-2330)	3.6 (3.3-4.0)	3.6 (3.1-3.9)
RIN_2R		21.7 (19.7-23.9)	*20.2 (19.2-20.6)	1530 (1322-1898)	1867 (1214-2080)	3.8 (3.5-4.0)	3.6 (3.1-3.9)
RIN_4R		23.8 (22.7-25.9)	*22.2 (21.6-23.9)	1262 (976-1724)	1200 (1083-1331)	2.4 (2.0-2.8)	2.6 (2.0-3.1)
RIN_7R		27.7 (24.5-31.1)	23.7 (19.9-29.2)	2352 (2030-2660)	1924 (1726-2490)	1.9 (1.7-2.0)	2.1 (1.8-2.4)
RIN_10R		**16.7 (15.5-18.1)	17.7 (17.5-17.9)	2687 (2600-2800)	2547 (2390-2710)	4.5 (4.4-4.8)	4.7 (4.2-5.4)
RIN_12R		22.5 (22.0-23.0)	*21.5 (21-22.3)	4822 (4650-4940)	4722 (4510-5050)	6.3 (5.9-6.5)	6.5 (6.1-6.9)

RIN_13 R		9.4 (8.5-10.5)	9.4 (9.2-9.8)	3466 (2680-4290)	3292 (3190-3470)	5.5 (4.5-6.2)	5.1 (4.8-5.3)
RIN_3R	>3200 to 4900	20.1 (19.0-21.9)	*18.8 (18.2-19.6)	946 (758-1255)	867 (788-1032)	3.9 (3.8-4.0)	5.8 (4.1-6.8)
RIN_6R		10.9 (10.4-12.1)	11.4 (10.7-13.3)	4292 (3770-5270)	4357 (4280-4470)	6.9 (6.6-7.6)	7.2 (6.7-7.8)
RIN_11 R		23.7 (22.5-24.8)	22.5 (21.4-24.3)	2742 (2670-2810)	2768 (2710-2830)	3.6 (3.4-4.0)	3.7 (3.3-4.0)
RIN_9R	>4900 to 6500	26.6 (26.2-26.9)	*25.3 (24.2-26.1)	4142 (4030-4280)	3840 (3580-4030)	6.5 (6.3-6.9)	6.0 (5.8-6.6)
RIVER		5.5 (3.0-7.5)	0.0	683 (229-878)	0.0	1.7 (0.5-2.9)	0.0

GWT indicates Groundwater table: The mean depths to GWT with * indicates the mean rise in GWT observed in a well during no river flow period was *significant* ($p \leq 0.10$): The mean depths to GWT with ** indicates the mean rise in GWT observed in a well during river flow is *significant* ($p \leq 0.10$).

Table A presents the ranges and the estimated means for the groundwater table depths for each observation well in Hatch-Rincon valley. These depths are for periods of river flow and when no-flow is observed in the river. The estimated means and ranges of EC, SAR for river water and groundwater, river water level, and the distance of well positions from the river are also presented in the table.

The peak depth to groundwater table during river flow was 8.5 feet, which was observed in wells found within 1600 to 3200 feet from the river south of Hatch (The depths were measured from the top of the observation wells.). The deepest water table depth was 31.1 feet. This was observed from a well in the Village of Hatch. The well was within 4900 to 6500 feet of the river. The average depth to the groundwater table in the area during the period of river flow was 20.3 feet. When there was no-flow in the river, the shallowest depth to the groundwater table was 9.2

feet south of Hatch. The greatest depth was 29.2 feet in a well sited in Hatch village with a distance from the river similar to the above. Wells observed an average of 19.2 feet during no-flow periods for the areas south of Garfield to south of Hatch along the Rio Grande.

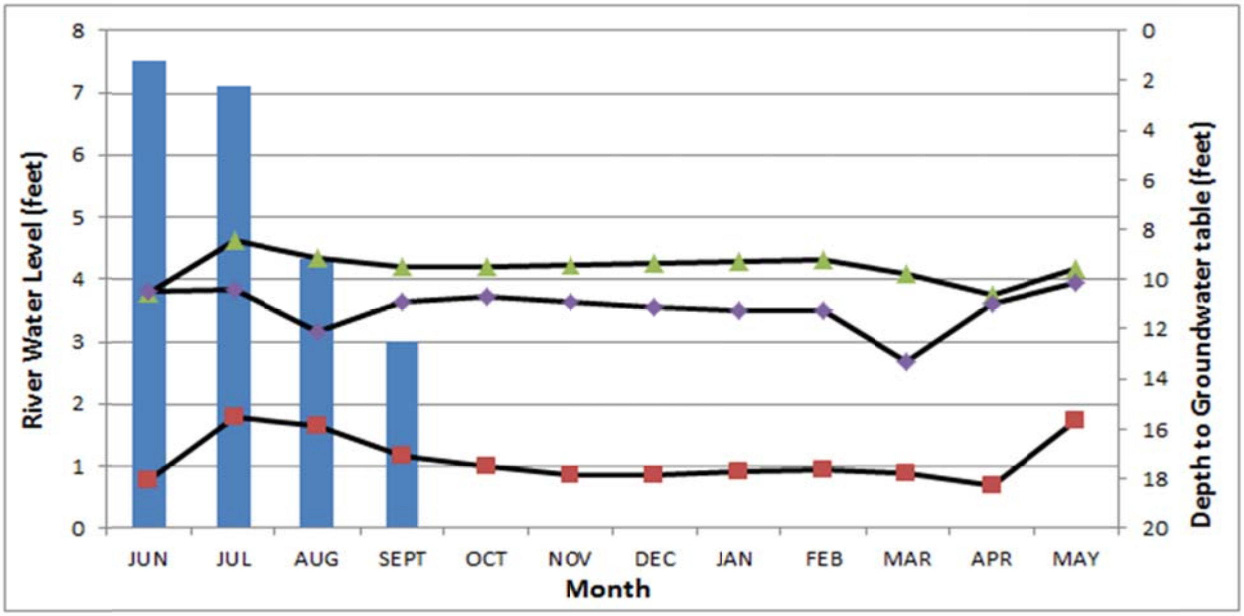

Fig. 2: Average river water level during periods of river flow (June to September) and average depth to groundwater table during periods of river flow and no-flow (June to May) of some wells in the areas of Hatch-Rincon, NM.

The graph above shows an average one foot decline in the groundwater table was observed in some of the wells during periods of no river flow from October to early May. Most wells that saw this drop in groundwater table depth were sited within 1600 to 3200 feet from the river. In general, the depths to groundwater table in this portion of the study area during periods of river flow were between 8.4-31 feet and vary with well distance from river (Table A). During no-flow periods, depths to the groundwater table in wells ranged between 9.2-30 feet.

During river flow periods, the majority of wells exhibited a short initial increase in water level. The average increase in water level was determined for these wells and this value was modeled using the following equation:

$$GDI = 0.1043 + 78.0177 \times \frac{days}{distance} \tag{1}$$

Where GDI = groundwater depth increase (feet), days = number of days that the river is flowing, distance = the distance from the river (feet). This is an empirical equation and only models the initial increase in ground water. The R^2 value for this equation was 0.93.

During the river flow period in the Hatch-Rincon valley, the lowest EC recorded in groundwater was 758 µS/cm and this was for wells within 3200 to 4900 feet from the river in Hatch village. The highest EC of 5270 µS/cm was measured in a well south of Hatch between 1600 to 3200 feet from the river. However, the lowest and highest groundwater EC for no-flow periods were 788 µS/cm (in Hatch village well) and 5050 µS/cm (just south of Hatch) respectively, with wells located within 3200 to 4900 feet and 1600 to 3200 feet from the river in that order (Table A). Moreover, the average EC estimated during river flow and no-flow periods were 2612 µS/cm and 2548 µS/cm respectively. Generally, the EC of river water was found to be lower than that of groundwater in that stretch of the study area (see Table A).

When water was flowing in the Rio Grande, the least SAR of 1.7 was calculated for a groundwater well in Hatch and within 3200 to 4900 feet from the river. The highest SAR of 7.6 was determined for wells south of Hatch within 3200 to 4900 feet from river. The average SAR for groundwater during river flow in the area was found to be 4.16. On the other hand, the least and highest SAR for groundwater at no-flow periods were 1.8 north of Hatch within 1600 feet from river and 7.8 south of Hatch within 4900 feet from river respectively. The area average was 4.28. For over 84% of the wells, the SAR was higher than the river water. Some wells within 1600 feet from the river had an SAR similar to the river water.

For Radium Springs, Leasburg, Las Cruces (LC) to Mesquite in the Mesilla basin, about 50% of the wells in the area witnessed a significant rise in groundwater table when the river was flowing ($p \leq 0.10$). During river flow periods, the majority of wells located between 0 to 4900 feet from the river exhibited a short initial increase in water level. The average increase in water level was determined for these wells and this value was modeled using the following equation:

$$GDI = 0.7674 + 88.8818 \times \frac{days}{distance} \tag{2}$$

Where GDI = groundwater depth increase (feet), days = number of days that the river is flowing, distance = the distance from the river (feet). This is an empirical equation and only models the initial increase in ground water. The R^2 value for this equation was 0.9991.

As mentioned earlier approximately 50% of the wells saw a significant increase in water level. About 17% of the wells were within 1600 feet from the river, 33% were located between 1600 to 3200 feet from the river, 8% were positioned within 3200 to 4900 feet and the rest of the wells were beyond 4900 feet from the river. About 24% of the wells within 1600 to 3200 feet from the river, in addition to about 25% found beyond 4900 feet from the river in Las Cruces and

Mesquite recorded a decline in estimated mean depth in groundwater table during periods of river flow (June to September) compared to the periods when the river was not flowing (October to May) (See Table B below). Most of these wells were located within 3200 to 4900 feet from the Rio Grande River.

Table B: The Mean River Water Level, Depth to Groundwater table, EC, and SAR estimated in groundwater wells and River during June to September 2014 when the River was flowing and during October 2014 to May 2015 when the River was not flowing, in Radium Springs, Leasburg, Las Cruces and Mesquite, NM.

Well Number	Well Distance from River feet	GWT Depth (feet)	GWT Depth (feet)	GW EC (µS/cm)	GW EC (µS/cm)	SAR	SAR
		River flow	No River flow	River flow	No River flow	River flow	No River flow
MES_41R	0 to 1600	18.2 (15.6-20.7)	19.0 (18.8-19.3)	1938 (1636-2120)	1849 (1752-1968)	3.0 (2.6-3.2)	2.9 (2.6-3.2)
MES_43R		14.8 (12.8-18.5)	16.6 (15.4-17.3)	1482 (1086-1949)	1591 (1428-1762)	3.6 (3.2-4.0)	4.3 (3.7-4.6)
MES_15R	>1600 to 3200	19.8 (18.7-23.0)	21.1 (19.3-22.8)	1533 (1456-1573)	1513 (1354-1618)	2.4 (2.2-2.5)	2.4 (2.2-2.8)
MES_11R		14.1 (13.3-15.4)	13.9 (13.4-14.7)	1702 (1612-1799)	1671 (1585-1732)	6.0 (5.7-6.6)	5.9 (5.8-6.2)
MES_12R		16.4 (14.6-18.9)	15.9 (14.9-17.3)	1416 (1165-1616)	1612 (1384-1682)	3.2 (3.1-3.5)	3.8 (3.4-4.6)
MES_13R		22.6 (21.1-24.3)	22.6 (22.2-23.4)	1928 (1425-2300)	1574 (1507-1700)	4.7 (2.9-7.3)	3.7 (2.4-5.5)
MES_16R		22.2 (20.9-23.3	*20.5 (20.1-21.2)	2024 (1828-2320)	2387 (1905-2960)	5.3 (5.1-5.5)	5.1 (4.3-6.4)

MES_48R		**13.4 (10.3-17.6)	16.1 (14.4-16.8)	3365 (1700-4460)	3742 (2830-4290)	5.1 (4.4-6.3)	4.7 (4.2-5.4)
MES_8R		11.9 (11.1-13.3)	12.9 (11.5-14.1)	3245 (3070-3390)	3260 (3080-3380)	6.3 (6.1-6.8)	6.2 (5.2-7.4)
MES_42R	>3200 to 4900	18.8 (17.8-20.1)	18.5 (18.3-19.0)	1736 (1587-1836)	1549 (1473-1692)	3.3 (3.2-3.4)	3.4 (3.0-3.8)
MES_19R		21.5 (19.3-24.5)	19.8 (19.3-20.9)	2250 (2090-2470)	2525 (2170-2790)	4.1 (4.0-4.2)	4.0 (3.7-4.1)
MES_20R		28.7 (28.1-29.2)	*26.2 (25.0-28.2)	1860 (1793-1944)	2398 (1720-2970)	4.0 (3.7-4.4)	3.5 (3.1-4.5)
MES_18R		26.1 (24.8-28.3)	25.7 (24.8-28.5)	1862 (1312-2920)	2405 (2260-2560)	4.0 (3.5-4.9)	4.2 (3.5-4.7)
MES_45R	>4900 to 6500	40.4 (39.6-40.8)	40.1 (39.5-40.9)	2420 (2260-2550)	2430 (2300-2510)	3.5 (2.9-4.0)	3.6 (3.3-4.0)
MES_7R		16.3 (15.5-16.9)	16.7 (16.5-17.0)	2034 (1821-2280)	1314 (986-1748)	2.5 (1.9-3.7)	2.0 (1.1-3.1)
MES_25R		27.5 (27.3-27.8)	*26.6 (26.4-27.6)	841 (707-1252)	640 (558-692)	2.2 (1.2-2.9)	2.1 (1.5-2.7)
MES_6R		22.0 (21.7-22.6)	*21.0 (20.6-21.6)	2109 (1986-2210)	2057 (1869-2220)	3.6 (3.4-3.9)	3.6 (3.3-4.1)
MES_17R	>6500	36.0 (35.6-36.2)	*34.7 (33.9-36.0)	2592 (2460-2720)	2857 (2740-2960)	3.6 (3.4-3.9)	3.5 (3.3-3.7)
MES_26R		28.3 (28.2-28.6)	28.5 (28.0-29.1)	9877 (3450-13500)	5615 (3320-8340)	15.7 (5.8-19.4)	8.0 (5.0-13.1)
MES_44R		**39.8 (39.6-39.9)	40.8 (40.5-41.0)	1839 (1527-2070)	1598 (1459-1673)	3.1 (2.7-3.4)	2.7 (2.4-2.8)
MES_47R		**37.5 (33.0-39.2)	40.1 (39.6-40.9)	588 (519-665)	524 (467-600)	0.5 (0.4-0.7)	0.5 (0.3-0.7)
MES_46R		36.9 (32.1-45.4)	38.6 (38.4-38.7)	1312 (1132-1453)	1508 (1474-1620)	2.6 (2.5-2.6)	2.4 (2.3-2.5)
MES_14R		**35.9	38.7	2150	2112	1.6	1.6

	(31.4-37.6)	(38.2-38.9)	(2120-2190)	(1964-2180)	(1.5-1.7)	(1.4-1.8)
MES_10R	31.1 (30.3-31.8)	31.4 (31.0-32.0)	4935 (4720-5210)	4875 (3860-5720)	12.2 (11.2-13.7)	12.6 (11.4-14.4)
MES_9R	32.1 (30.3-36.6)	30.7 (30.4-31.0)	2835 (2750-2900)	2908 (2820-2960)	6.1 (6.0-6.2)	6.0 (5.5-6.8)
MES_5R	20.5 (19.9-21.5)	*20.0 (19.8-20.3)	2842 (2520-3120)	2415 (1710-2590)	4.4 (3.8-4.8)	4.4 (3.9-4.7)
RIVER	2.4 (0.9-3.6)	0.0	425 (256-554)	0.0	1.9 (0.6-3.0)	0.0

GWT indicates Groundwater table: The mean depths to GWT with * *mean* that the mean rise in GWT observed in a well during no river flow period was *significant* ($p \leq 0.10$): The mean depths to GWT with ** indicates the mean rise in GWT observed in a well during river flow is significant ($p \leq 0.10$).

The shallowest depth to the groundwater table during river flow was 10.3 feet, recorded in wells within 1600 to 3200 feet from river east of Las Cruces and the deepest depth of 45.4 feet for a well located within 4900 to 6500 feet from the river, south of Las Cruces. The average depth to groundwater table in the entire stretch along the Rio Grande for periods of river flow was 22.9 feet. When there was no-flow in the river, the shallowest depth to the groundwater table was 11.5 feet in well located east of Las Cruces within 1600 to 3200 feet from river with greatest depth being 41 feet. The well with the greatest depth to groundwater table was located north of Las Cruces, beyond the 6500 feet range from the river (Table B). The average depth to groundwater table in the area when there was no-flow in the river was about 28 feet.

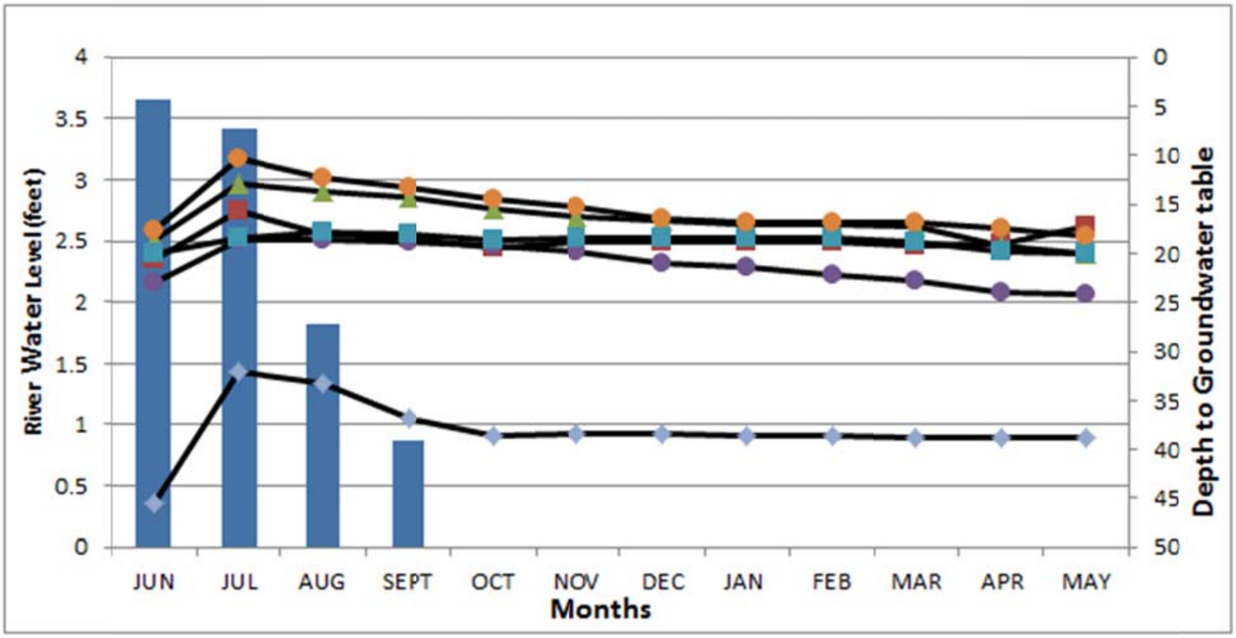

Fig. 3: Average river water level during periods of river flow (June to September) and average depth to groundwater table during periods of river flow and no flow (June to May) of some wells from Radium Springs down to Mesquite, NM.

The average drop of groundwater depth in each of the wells (Fig. 3) during periods of no-flow (October to May) was around 2 feet. The wells beyond 6500 feet from the river of which most were located in Las Cruces had the greatest depth to groundwater table during the study period (Table B). The groundwater table during periods of river flow ranged between 10.3-45.4 feet and the depth to the water table in the area at the times when there was no-flow in the river ranged between 11.5-41 feet. Most wells observed a decline in groundwater table depth when there was no-flow in the river (Table B). However, there were few wells that were found to show a drop in the groundwater table when the river was flowing. Some of these wells were sited north of Las Cruces.

The EC results obtained from this portion of the study area during river flow showed that wells in south west of Las Cruces located beyond 6500 feet from the river recorded the lowest EC values. The lowest EC of 519 µS/cm was measured in well located west of Las Cruces beyond 6500 feet from river. Meanwhile the highest or the peak EC value of 13,500 µS/cm was determined for groundwater in a well beyond 6500 feet from the river, north of Las Cruces. The average EC determined in groundwater during river flow was 2,341.4µS/cm. However, when there was no river flow the wells in the above locations measured the least and highest EC values of 467µS/cm and 8,340 µS/cm respectively, with an area average of 2,266.5 µS/cm. Likewise in other areas the EC measured in river water were low compared to all well positions (Table B).

A lowest SAR of 0.4 was calculated in well 6500 feet beyond the river during river flow west of Las Cruces. The highest SAR of 19.4 was determined for the area north of Las Cruces 6500 feet beyond the river. An average SAR of about 4.5 was calculated for groundwater from this stretch of the study area. At the time when there was no-flow in the river, the wells saw a reduction in SAR to about 0.3 and 14.4 for the lowest and largest values respectively, and an average of 4.12 was computed for the wells in that part of the study area.

For the area below Mesilla dam to Canutillo, all wells within 1600 feet from the river, in addition to about 33% of wells beyond 6500 feet from the river had a rise in the estimated mean of depths to the groundwater table during river flow periods. The average depth to groundwater table in wells between 1600 to 6500 feet had a decline in the depth to the groundwater table when the river was flowing (Table C).

Table C: The mean River Water Level, Depth to Groundwater table, EC, and SAR estimated in groundwater wells and River during June to September 2014 when the River was flowing and during October 2014 to May 2015 when the River was not flowing, below Mesilla Dam to Canutillo, NM.

Well Number	**Well Distance from River feet**	**GWT Depth (feet)**	**GWT Depth (feet)**	**GW EC (µS/cm)**	**GW EC (µS/cm)**	**SAR**	**SAR**
		River flow	**No River flow**	**River flow**	**No River flow**	**River flow**	**No River flow**
MES_2R	0 to 1600	**20.8 (20.2-21.4)	21.6 (21.0-22.0)	993 (962-1046)	1260 (1199-1334)	3.0 (2.8-3.1)	2.9 (2.7-3.3)
MES_27R	>1600 to 3200	20.5 (18.2-26.2)	18.4 (18.2-18.8)	3825 (3480-4100)	4178 (3660-5070)	8.5 (7.5-10.6)	8.4 (7.6-9.4)
MES_1R	>3200 to 4900	18.3 (17.2-19.5)	18.0 (17.6-18.6)	2390 (2180-2920)	2258 (2150-2520)	10.8 (10.2-11.4)	11.0 (9.2-11.6)
MES_3R		19.8 (18.7-20.6)	*18.4 (17.9-19.7)	1379 (1173-1623)	1432 (1225-1932)	3.4 (3.2-3.9)	3.3 (3.1-3.5)
MES_4R		18.0 (17.6-18.6)	*17.3 (17.0-17.8)	2300 (2200-2440)	2422 (2290-2570)	6.8 (6.2-7.6)	6.6 (5.8-7.7)
MES_24R		18.7 (15.7-27.1)	15.9 (15.7-16.0)	2097 (2030-2160)	1996 (1954-2070)	10.0 (8.9-11.1)	8.7 (7.4-10.8)
MES_32R		22.0 (21.2-23.4)	*21.1 (20.7-21.9)	3735 (3320-4080)	3605 (3310-4230)	7.6 (7.1-8.5)	7.9 (7.6-8.7)
MES_39R		23.1 (22.6-23.4)	*22.1 (21.5-23.0)	1862 (1250-3320)	1585 (1293-1930)	4.2 (2.9-7.6)	3.1 (3.0-3.3)
MES_21R	>4900 to 6500	14.9 (14.2-16.2)	14.7 (14.4-15.4)	2867 (1790-3700)	2465 (1897-3060)	9.0 (7.9-10.1)	7.5 (7.3-8.5)
MES_51R		16.3 (15.7-17.0)	*15.5 (15.1-15.9)	1972 (1925-2040)	2150 (1962-2260)	4.9 (4.6-5.7)	5.4 (4.9-5.6)
MES_22R	>6500	**12.9	13.9	3295	2150	15.7	19.2

	(12.6-13.5)	(13.4-14.3)	(2460-3960)	(2020-2320)	(14.0-18.1)	(18.5-20.4)
MES_23R	19.1 (18.3-20.0)	*17.8 (16.4-18.6)	4560 (4350-5000)	4340 (4140-4580)	9.0 (8.3-9.7)	8.7 (8.4-9.2)
MES_30R	**18.4 (18.2-18.5)	18.7 (18.6-18.9)	3307 (3260-3360)	3342 (3250-3380)	22.4 (22.2-22.7)	22.4 (21.7-23.3)
MES_28R	**15.4 (15.3-15.6)	16.0 (15.7-16.3)	2795 (2760-2820)	2932 (2860-3020)	14.3 (13.5-15.4)	16.0 (15.2-17.6)
MES_52R	24.2 (23.7-24.3)	*23.3 (21.6-24.4)	2200 (2040-2290)	2380 (2220-2660)	6.2 (5.9-6.9)	5.8 (4.8-6.8)
MES_49R	23.9 (23.6-24.3)	*23.4 (23.1-23.7)	2134 (1807-2470)	2658 (1970-3700)	4.6 (4.0-4.8)	4.5 (3.8-5.4)
MES_38R	21.9 (21.4-22.3)	22.3 (22.1-22.6)	2157 (2070-2240)	2100 (2040-2210)	4.8 (4.7-5.0)	5.0 (4.7-5.1)
MES_31R	21.1 (20.8-21.5)	21.1 (20.9-21.3)	2670 (2420-2790)	2187 (2030-2440)	9.5 (9.4-9.6)	9.0 (8.6-9.5)
MES_53R	19.3 (18.7-20.4)	*18.6 (18.3-19.2)	2860 (2350-3210)	3143 (2810-3380)	11.8 (10.9-13.5)	11.6 (9.5-12.8)
RIVER	7.0 (6.1-7.7)	0.0	791 (424-935)	0.0	3.0 (1.1-7.7)	0.0

GWT indicates Groundwater table: The mean depths to GWT with * indicates the mean rise in GWT observed in a well during no river flow period was *significant* ($p \leq 0.10$): The mean depths to GWT with ** indicates the mean rise in GWT observed in a well during river flow is significant ($p \leq 0.10$).

When the river was flowing below the Mesilla dam area, the shallowest depth to groundwater table of 12.6 feet was measured in wells sited in Berino beyond 6500 feet from the river. The deepest water table in area during the period was near the Vado elementary School. This 27.1 feet depth was measured in a well that was located about 4900 feet from the river. Moreover, the average depth to groundwater table below the dam at Canutillo was 18.3 feet. When there was no-flow in the river, the shallowest depth to the groundwater table was 13.4 feet while the deepest was 24.4 feet and the area average of 18.9 feet (Table C). Again, the shallowest depths were measured in Berino and deepest near Canutillo about 6500 feet from the river.

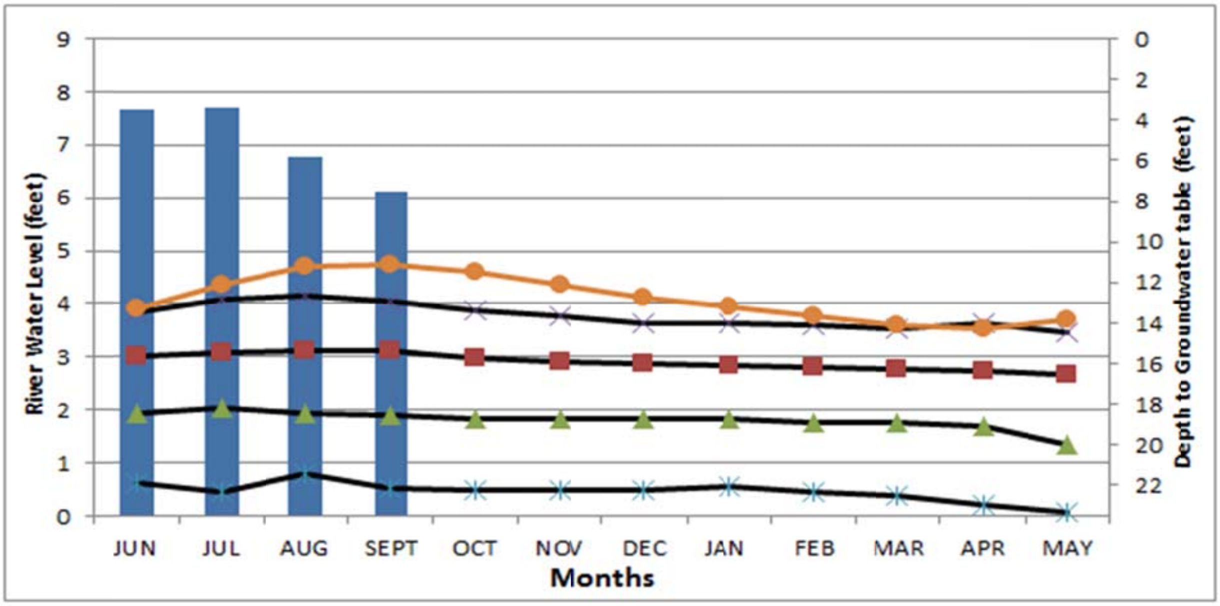

Fig.4: River water level during periods of river flow (June to September) and depth to groundwater table (June to May) of some wells in the areas below Mesilla dam to Canutillo, NM. The wells (fig.3) observed a decline in the depth to groundwater table on an average of about 1.3 feet from October to May when there was no river flow.

Lowest EC of 962µS/cm was determined near Canutillo in groundwater within 1600 feet from the river, when the river was flowing. A value as high as 5,000 µS/cm was measured in groundwater close to Berino, about 6500 feet away from the river with an average of 2,560 µS/cm in the areas below the Mesilla dam to Canutillo. Moreover, at times of no river flow, the lowest EC of 1,199µS/cm was recorded within 1600 feet from the river near Canutillo. The highest for the period was 5,070 µS/cm near Vado elementary School within 1000 feet from the river. The area average was 2,557µS/cm. Generally, the river water EC was lower compared to groundwater from all wells within the area (Table C).

The lowest SAR of 2.8 was determined for groundwater near Canutillo within 1600 feet from the river during periods of river flow. The maximum SAR of 22.7 was found in a groundwater well near Anthony about 6500 feet from the river. An average for the entire area was about 9.2. On the other hand, a minimum SAR of 2.7 was found in groundwater from Canutillo about 1600 feet from the river at periods when there was no-flow in the river. A maximum SAR was determined for groundwater in the area below the Mesilla dam was from Anthony, beyond 6500 feet from the river, which were 23.3 with season average of 8.8. In general, the maximum SAR found in the river water in the area was lower than groundwater from over 70% of the wells. Those with lower SAR than the river water were generally found within 4900 feet from the river.

Conclusions

Interestingly, all the study wells observed monthly changes in the measured parameters; including depth to groundwater table, EC and SAR. During periods of river flow in the Hatch-Rincon valley, wells in the region generally showed a short initial increase flowed by a decline in depth to groundwater table. An average of a foot decline during periods of river flow was observed and this was irrespective of the wells location from the river. However, the situation was different for one well within 1600 feet and another beyond 4900 feet from the river in south east of Hatch which observed a decline in depth to groundwater table at periods of no river flow.

It is believed that the initial increase in water depth was caused by the fact that surface water was being delivered to farms in the area at this time. During this period it is likely that little pumping was occurring from the wells in the area. This would allow for water to seep from the river into the shallow ground water. The result would be an increase in water level. However, the farms only received surface water for a short period of time and ounce the surface water delivery ended, pumping would resume. Pumping appears to have a quick impact on the ground water table in this area. Considering that the Hatch area has a limited aquifer, this is likely the cause.

The equation that was developed to model the increase in groundwater level in the Hatch-Rincon valley had a high R^2 value of 0.93. It is believed that the equation would track water level increases during river flow when there is limited pumping from the aquifer. However, this equation was developed from on season of data and further data needs to be collected to validate this equation.

During periods of river flow, EC values were measured in the areas south of Hatch about 1600 to 3200 feet from the river. Generally, the EC of the water when there was no river flow, were lower for most wells compared to river flow periods notwithstanding the well locations from the river. However, the contrast was seen in some of the wells within similar intervals from the river, which signifies that there may be other sources of salts and water within the area. Moreover, the case of the SAR was no different from the EC.

In the region from Leasburg through Las Cruces to Mesquite, the depth to groundwater table was generally shallow east of Las Cruces, with the greatest depth south of Las Cruces within 4900 to

6500 feet from the river, during periods of river flow. The depths to groundwater table in the area were generally deeper during periods of no-flow in the river compared to periods of river flow with a drop of 2 feet on average at no river flow periods. When water was flowing in the river, the wells closest to the river again had an initial increase in water level. This initial increase was modeled using the average increase in water level for the wells within 4900 feet of the river. The R^2 value of 0.9991 for the model equation was surprisingly high. Again, this equation needs to be validated with further data collection.

However the wells farthest away had varied responses in water depth. Some wells saw increases in water level while others had continual decreases in water level. Many factors seem to be causing these varied changes. These wells are a long distance from the river (over 6400 feet) and it would take longer for the river water to move through the aquifer to this area. It is believed that there is also ground water inflow to portions of this aquifer from the west.

Along this stretch of the study area, the highest EC of well water was observed west of Las Cruces about 6500 feet from the river at times of river flow which was above the highest EC measured at periods of no river flow in the area. The EC values obtained during periods of no river flow were generally lower than when the river was flowing. Moreover, on average, the SAR calculated during river flow periods were higher than those computed for no-flow periods.

The groundwater table depth in Berino was shallowest in the areas below the Mesilla dam to Canutillo for periods of river flow and no-flow. The deepest depth to groundwater table was found in areas close to Vado elementary school and Canutillo for periods of river flow and no-flow respectively. On average, the depth to groundwater table in the area declined about 1.3 feet when the river was not flowing. Moreover, some wells also saw the groundwater table decline when the river was flowing which serve as a proof of other source(s) of water to the area. During periods of river flow and no-flow, the lowest EC was observed in groundwater near Canutillo about 1600 feet from the river. Berino groundwater had the highest EC when the river was flowing, and an area close to Vado School had groundwater with the highest EC. This was about 3200 feet from the river during periods of no river flow. The maximum SAR was found in groundwater from Anthony and minimum from Canutillo about 6500 feet from the river for both periods of river flow and no-flow.

During this study 31 of the 58 observation wells saw an increase in EC. An additional 16 wells did not see a much of a change. As indicated earlier, many of the increases occurred while the river was flowing and recharging the ground water with lower EC river water. Why is there an increase in many of these wells? As one attempts to answer the question, the potential source of salts must be considered. One source could be from other ground water flows. There may be some increase in EC from this source. However, considering that many water users claim that the ground water quality was better 20 years ago and the ground water flows likely existed at that time as well, the salts likely came from somewhere else. The State of New Mexico has been experiencing an extended drought. Many of the farmers indicate that in the last few years, they have been meeting the crop water requirements using groundwater. In addition, in order to insure that crops receive sufficient water so that crop production is profitable, the water users tend to over irrigate. This means that excess water runs off the land or deep percolates into the soil. When this occurs salts are washed from the land into the surface waters and into the ground water. As this process is continued, there will be an accumulation of salts in the groundwater. However, the study does not have conclusive data that this is true. More data is required.

This study has produced some interesting data, but more data is needed to determine if there is a continued decline in groundwater levels in some areas and continued increases in EC in other areas. Sources of salts need to be identified so that steps can be taken to reduce the salts in the groundwater. In addition, river-groundwater interaction has been validated further, but additional study is needed to try to understand if this interaction can be manipulated in a desired manner.

References

Alley, W. M., Taylor, C. J., 2001. The value of Long-Term Groundwater Level Monitoring Groundwater, 39, 801

Aslan, A.S.T., Gundogdu, K.S., 2007. Mapping multi-year groundwater depth patterns from time-series analyses of seasonally lowest depth-to-groundwater maps in irrigation areas, *J. Environ. Stud. 16, (2),183.*

Cay, T., Uyan, M., 2009. Spatial and temporal groundwater level variation geostatistical modeling in the City of Konya, Turkey. Water Environment Research; Dec 2009; 81,12; ProQuest Environmental Science Collection, Pg. 2460.

Conover, C. S., 1954. Groundwater conditions in the Rincon and Mesilla Valleys and Adjacent Areas in New Mexico, U.S. Geological Survey Water-Supply Paper 1230.

Dinka, M.O., 2010. Analyzing the extents of Basaka Lake expansion and soil and water quality status of Matahara irrigation scheme, Awash Basin (Ethiopia). PhD Dissertation submitted to Boku University, Vienna, Austria.

Hecker, S., Harty, M.H., Christenson, G. E., 1998. Shallow ground water and related hazards in Utah. Utah Geological and Mineral Survey, Utah Department of Natural Resources Technical Publication 110. 606 Black Hawk Way. Salt ölake City, Utah.

Helmuth, J., Johnson, D., Karklins, S., and Lindorff, D., 1997. Status of groundwater quantity in Wisconsin. Wisconsin Department of Natural Resources, PUBL-DG-043-97.

Jinglong, F., Xinwen, X., Jaqiang, L., Jingfeng, Z., Shengyu, L., Haifeng, W., Jianguo, Z., and HongWei, Z., 2008. The temporal and spatial fluctuation of the groundwater level along the Tarim Desert Highway. *Chinese Sci. Bull. 53, 53, 2008.*

Lee, W.T., 1907. Water resources of the Rio Grande Valley in New Mexico and their development, U.S. Geological Survey Water-Supply Paper 188, 1907.

Maddock, T. III, and Wright Water Engineers, Inc., 1987. An investigation of the effects of proposed pumping in the Lower Rio Grande Declared Basin.

Nickerson E. L., Myers R. G., 1993. Geohydrology of the Mesilla Groundwater Basin, Dona Ana County, New Mexico, and El-Paso County, Texas. USGS Water Resources Investigations Report 92-4156.

Nickerson, E.L., 1994. Selected hydrologic data for the Mesilla ground-water basin, 1987, through 1992 water years, Dona Ana County, New Mexico and El Paso County, Texas,, U.S. Geological Survey, Draft.

Sharda, V. N., Kurothe, R. S., Sena, D. R., Panda, V. C., and Tiwari, S. P., 2006. Estimation of groundwater recharge from water storage structures in a semi-arid climate of India. *J. Hydrol., 329 (1-2), 224-234.*

Sharma H., Shukla, M. K., and Deb. S. K., 2013. Water conservation using partial root drying for drip irrigated Chile. USCID Conference, October 22-25, Denver, Colorado.

Sheng, Z., Michelsen, A., Liu, Y., Creel, B., McGuckin, T., and Lacewell, R., 2010, Statistical analysis of flow exchange and salt loading between the Rio Grande and underlying aquifers. In Proceedings of World Environmental and Water Resources Congress 2010: Challenges of Change, ASCE, Reston, Virginia, USA.

Slichter, C.S., 1905. Observations on the ground waters of the Rio Grande Valley. Water Supply and Irrigation Paper No. 141, 1905.

Weeden, C. A., Maddock, T., 1999. Simulation of groundwater flow in the Rincon Valley area and Mesilla basin, New Mexico and Texas

Wilson, C. A., White, R. R., Orr, B. R., and Roybal, G. G., 1981. Water resources of the Rincon and Mesilla Valleys and adjacent areas, New Mexico, New Mexico State Engineer, Technical Report 43, 1981.