CARACTERIZACIÓN DEL BALANCE HÍDRICO Y LA RECARGA POR RETORNO DE RIEGO EN UN VALLE AGRÍCOLA DE UNA REGIÓN SEMIÁRIDA DE LOS ESTADOS UNIDOS DE AMÉRICA

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RESUMEN. En zonas áridas, una fuente importante de suministro de agua proviene de acuíferos poco profundos. En valles agrícolas de Nuevo México, el uso de sistemas de regadío tradicionales contribuye a la recarga de los acuíferos poco profundos. El objetivo de este estudio fue caracterizar las interacciones hídricas que ocurren en uno de dichos valles. Se utilizaron datos de campo (2003-2010) para caracterizar la interacción entre la zona no saturada y el acuífero. Se utilizaron diferentes variables climáticas, flujos de río y acequia, y niveles de riego para calcular el balance hídrico a escalas de parcela y de valle. Los niveles piezométricos se usaron para caracterizar las fluctuaciones del manto freático y para estimar la recarga al acuífero. Cálculos del balance hídrico a escala de valle mostraron que un 33% (12% percolación de acequia y 21% percolación del riego) del total de agua distribuida en este valle agrícola contribuye a la recarga potencial del acuífero. Los niveles piezométricos obtenidos de múltiples pozos en el valle mostraron un patrón estacional en respuesta a la percolación de acequia y riego. Se observó un incremento en el nivel piezométrico de hasta 0.8 m, en un plazo de 3 a 5 semanas después del inicio de la temporada de riego en 2008, el cual después de un almacenamiento temporal, disminuyó gradualmente hacia el final de la temporada de riego. La influencia del incremento temporal de los niveles piezométricos fue observada no solo en pozos localizados en áreas de riego, sino también en pozos localizados fuera del área de riego. Los resultados de este estudio contribuyen al mejor entendimiento de las interacciones hídricas de la zona no saturada con el acuífero poco profundo en un valle agrícola semiárido del suroeste de los Estados Unidos.

ABSTRACT. In arid areas, an important source of water supply comes from shallow aquifers. In agricultural valleys of northern New Mexico, the use of traditional irrigation systems contributes to the recharge of the shallow aquifer. The objective of this study was to characterize the hydrological interactions occurring in an agricultural valley of New Mexico. Field data (2003-2010) were used to characterize the hydrological interactions between the unsaturated zone and the shallow aquifer. Different climate variables, river and acequia flows, and irrigation levels were used to calculate the water budget at the field and valley scale. Piezometric levels were used for characterizing the water table fluctuations and for estimating aquifer recharge rates. Water balance calculations at the valley scale showed that 33% (12% acequia seepage and 21% deep percolation from irrigation) of the total water distributed in this agricultural valley contribute to potential aquifer recharge. Piezometric levels obtained from multiple wells in the valley showed a seasonal pattern in response to acequia and irrigation percolation. A piezometric level rise of up to 0.8 m was observed in 3 to 5 weeks after the onset of the irrigation season in 2008, which after temporary storage, receded gradually towards the end of the irrigation season. The influence of piezometric-level temporary rise was observed in wells located in irrigation areas, but also in wells located outside of the irrigated areas. Results from this study contribute towards a better understanding of the hydrological interactions of the unsaturated zone and the shallow aquifer in a semi-arid agricultural valley in the southwestern United States.

1.- Introduction

An important amount of groundwater supply in arid and semi-arid regions comes from shallow aquifers. A significant volume of these shallow aquifers' replenishment may come from percolation in irrigated landscapes. For instance, Schmidt and Sherman (1987) stated that a significant amount of groundwater recharge beneath large irrigated areas in California comes from irrigation percolation. Also, Willis and Black (1996) concluded that shallow water table formations in the Macquarie Valley in Australia were associated with excessive rates of deep percolation from irrigated croplands. In addition to deep percolation from irrigation, seepage from irrigation canals can contribute significantly to aquifer recharge. Different studies show combined percolation from field and canal seepage contributions to groundwater, as percentage of total canal flow, ranging from 14-49% (Fernald et al. 2010) to 34-43% (Singh et al. 2006). The importance of canal seepage in recharging the aquifer has been documented by several authors. For instance, Meijer et al. (2006) showed that annual groundwater recharge in irrigated areas of Sri-Lanka will be reduced by 50% after concrete lining of irrigation canals. Also, Knapp et al. (2003) indicated that canal-lining may have a negative impact on the water table of a representative region in California. Aquifer recharge from irrigation inputs is more prominent in fluvial valleys overlying shallow aquifers where highly permeable soils allow rapid water infiltration and aquifer replenishment. This is particularly true in fluvial agricultural valleys of northern New Mexico, where highly permeable soils and irrigation applied in excess combine to enable a rapid recharge of the shallow aquifer (Fernald et al. 2010; Ochoa et al. 2009).

2.- Study area

The area of interest for this research encompasses a region in the Española valley, in northern New Mexico, approximately 10 km along the Rio Grande and up to 2 km to the east of the river. For the purposes of this paper, this 20 km^2 area of interest is described as the Alcalde valley.The Alcalde valley is split by the main canal into dry land, where most of the housing development is located, and irrigated land (Fig. 1).

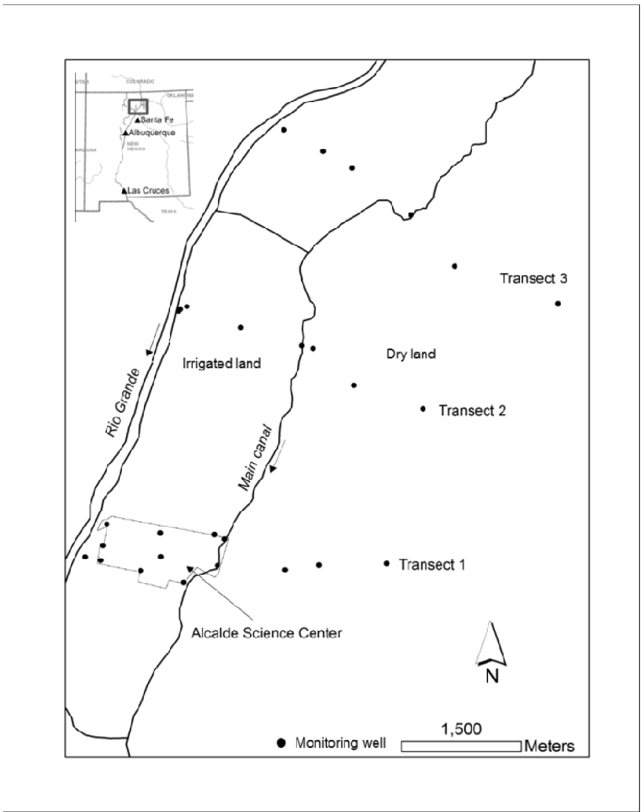

Fig.1. Map of the study area illustrating monitoring well locations.

The irrigated land portion of the valley comprises an agriculture corridor that is delimited by the Rio Grande on the west side and by the Alcalde-main irrigation canal on the east side. The 9-km length Alcalde main canal is primarily an earthen structure with small sections of rock and/or cement lining.This study was primarily based at the New Mexico State University Sustainable Agriculture Science Center (Alcalde Science Center) in Alcalde, NM. The Alcalde Science Center is located in the agriculture corridor between the Alcalde main irrigation canal and the Rio Grande. The Science Center has 24 ha of irrigated land for research on various forage, fruit, vegetable, and alternative high-value crops using primarily border or furrow irrigation, by far the most common practice in the valley and region. The study site is located at an elevation of 1733 m. Average annual precipitation in the study area is 251 mm, of which 40% occurs during the summer season. For the period of record 1953 to 2006, the average monthly temperature was 10.6°C, with the lowest average monthly temperature of -0.81°C during the month of January and the highest average monthly temperature of 22.37°C during the month of July (WRCC, 2006). The study area overlies a shallow unconfined aquifer with depth to water table generally ranging from 1.5 m to 10 m in the irrigated portion of the valley and from10 m to 30 m in the dryland portion, depending on proximity to the river and measured at the lowest level prior to onset of the irrigation season. Regional groundwater flow is mostly influenced by the Rio Grande.

3.- Methods

A field measurement approach was used to characterize the water balance of the irrigated portion (6.3 km^2) of the Alcalde valley. Field data were used to account for all water diverted from the river into the main irrigation canal and distributed throughout the irrigated corridor of the valley. A water balance equation was formulated as follows:

Canal inflow − canal seepage – flow control diversion
− canal outflow = crop evapotranspiration
+ crop field runoff + deep percolation (1)

Canal discharge (canal inflow, flow control diversion, and canal outflow) were calculated based on canal stage data collected at different locations along the Alcalde main canal. Three stage-measuring stations were installed and instrumented with pressure transducers at the canal near inflow, mid-section, and outflow locations. Canal stage-discharge rating curves were developed for each station using detailed flow measurement data collected for this purpose. Canal seepage was obtained using an inflow-outflow test that was conduceted at the end of the irrigation season in 2005, with no diversions and with no flow control other than the river inflow variations. Climate data was collected from an on-site weather station (Fernald et al. 2010). Total precipitation per month was multiplied by the total area of the irrigated corridor and was added to canal inflow. The amount of water diverted for irrigation purposes was obtained by subtracting canal seepage, flow control diversion, and canal outflow from total canal inflow (canal inflow plus precipitation). This amount of water was assumed to be used for crop-irrigation purposes and it was subdivided into crop evapotranspiration (ET), crop field runoff, and deep percolation. Crop ET was calculated using climate data from the weather station on-site. Deep percolation and crop field runoff were obtained from various irrigation experiments conducted on alfalfa-grass, oat-wheatgrass, and apple crops at the Alcalde Science Center (Ochoa, 2011 and Ochoa et al. 2011).

For estimating aquifer recharge at the valley scale, we used the water table fluctuation method, using an equation after Risser et al. (2005):

$$Re = \Delta h * Sy \qquad (2)$$

where, Re = Aquifer recharge (mm), Δh = Change in water level (mm), and Sy = Specific yield or drainable porosity of the unconfined aquifer. This method was used for calculating aquifer recharge using piezometric level data collected from multiple wells in the Alcalde valley. A total of 25 wells were used for monitoring water level fluctuations in the 20-km^2 Alcalde valley. We installed 15 non-pumping monitoring wells in the irrigated portion of the valley and we used 10 wells from collaborators in the dry land portion. All wells were equipped with stand-alone water level loggers programmed for hourly data collection. Daily-averaged groundwater level data collected from 20 monitoring wells were integrated for estimating seasonal aquifer recharge at the valley scale for years 2007 through 2009. Only data from non-pumping or minimal-use wells were used for estimating recharge. An average specific yield of 0.28 was obtained based on Sy values for unconsolidated alluvial deposits (medium to coarse sand and medium gravel) observed in the water table fluctuation zone of six pits excavated during a previous water transport experiment at the Alcalde Science Center (Ochoa et al., 2009). Similar Sy value of 0.28 was assumed the entire Alcalde valley. In addition, we used piezometric level data to characterize temporal and spatial distribution of water table fluctuations throughout the valley.

4.- Results

4.1. -Water budget

During a period of record of three years (2005 to 2007), the amount of water that was diverted from the Rio Grande into the Alcalde main canal averaged 3,275,823 m^3 month^{-1}. Total precipitation (25.3 mm month^{-1}) was added to the canal diversion inflow to account for the total amount of water available in the irrigated portion of the valley. On average, surface return flow (flow control diversions, crop field runoff, and canal outflow) represented 59.3% of the total inflow (canal inflow plus precipitation). Deep percolation and canal seepage were considered groundwater return flow and together accounted for 33.3% of total canal inflow. Crop evapotranspiration averaged 7.4% and ranged from 1 to 15% (Table 1). It is noteworthy to mention that the different components of the water budget varied widely depending on factors such as crop, amount of water applied, soil type, and depth to water table.

4.2.-Shallow aquifer recharge

Piezometric level data collected at 20 wells during years 2007 through 2009 were used for estimating monthly changes in water table and shallow aquifer recharge at the Alcalde valley scale. Monthly aquifer recharge ranged from 6 mm in January of 2007 to 155 mm in May of 2008. The year 2008 showed the highest total aquifer recharge value of 784 mm and the year 2007 showed the lowest total aquifer recharge value of 669 mm. The winter months showed the least aquifer recharge values in all three years. The highest aquifer recharge values were observed during the month of May in all three years, with change in water level values ranging from 405 mm (2007) to 554 mm (2008).

Table 1. Three-year (2005-2007) averaged water budget of the Alcalde main irrigation canal.

Component	Amount from canal diversion + total precipitation (%)	Range (%)
Flow control diversion	9.5	0 to 14
Crop field runoff	8.9	0 to 19
Canal outflow	40.9	28 to 67
Canal seepage	12.1	5 to 17
Deep percolation	21.2	9 to 32
Crop evapotranspiration	7.4	1 to 15
Total	100.0	

4.3.-Water table fluctuations

Piezometric level data collected in wells located at different distance from the Alcalde-main irrigation canal were used to characterize the spatial and temporal variability of water table fluctuations at the valley scale. Fig. 2 shows daily-averaged water table fluctuations along well-transect 1 (see Fig. 1) during years 2007 through 2009. Monthly rainfall, canal elevation, and river stage fluctuations are also shown. For all three years evaluated, a seasonal water table rise and decline pattern was observed in all wells along this transect. In general, the water table started rising 8-12 days after the onset of irrigation, reached peak around mid-irrigation season, then declined steadily towards the end of irrigation, until it reached base flow conditions. Time of water table response varied across well locations, the well located near the river generally responded first, then the near-canal and irrigated land wells, followed by the dryland location well. Sharp water table rises and declines were observed in all but the dryland location well (Fig.2).

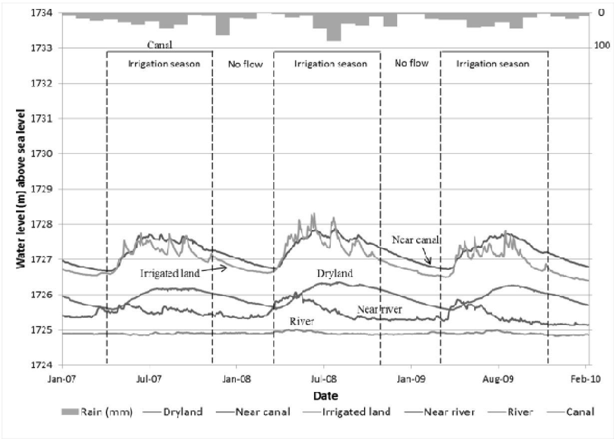

Fig. 2. Water table fluctuations in one transect of wells.

5.- Conclusions

Study results indicate that large flows are rapidly being exchanged between the river, the irrigation system, and the local aquifer. We found that water table fluctuations respond seasonally to canal seepage and irrigation percolation. Also we found relatively high amounts of total aquifer recharge, which remained relatively constant every year. We attribute these high amounts of aquifer recharge to three different factors, high rates of surface irrigation, highly permeable alluvium soils, and a relatively shallow water table. The combination of all these factors allowed the rapid transport of irrigation water from the soil surface, through the vadose zone, and into the unconfined aquifer. If current irrigation practices were to change towards more water-saving type of irrigation systems there is a good likelihood that the benefits of high aquifer recharge would be reduced. Study results add to the understanding of the mechanisms of shallow aquifer recharge and the interactions between surface water and groundwater in a floodplain agricultural valley of northern New Mexico. Further research that incorporates river - aquifer interactions into a modeling approach will enable characterization of surface water and groundwater interactions over larger spatial scales.

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