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WATER-LEVEL CHANGES IN THE HIGH PLAINS AQUIFER OF KANSAS AND IMPLICATIONS FOR WATER USE

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INTRODUCTION

Large water-level declines have occurred in parts of the western portion of the High Plains aquifer in Kansas (commonly known as the Ogallala aquifer, henceforth HPA) as a result of substantial groundwater withdrawals. The Kansas Geological Survey (KGS) and the Kansas Department of Agriculture's Division of Water Resources measure water levels across the aquifer each winter to determine annual water-level changes. In addition, during the last several years, the KGS has recorded detailed water-level changes in monitoring wells in each of the three western groundwater management districts (GMDs) in Kansas as a part of the index well program. These changes are being examined to develop improved approaches for measuring and interpreting hydrologic responses at the local scale. Recently, the KGS has found high correlations between regional annual water-level declines and climatic indices (Whittemore et al., 2015). The correlation between regional annual water-level declines and reported pumping in northwest Kansas (Northwest Groundwater Management District No. 4 [GMD4]) is also high and indicates that practically feasible pumping reductions would temporarily stabilize water levels in the aquifer in that area.

LONG-TERM ANNUAL HYDROGRAPHS

Long-term annual hydrographs based on winter measurements of depth to water characterize some of the general differences in water-level changes in the three GMDs in the western Kansas HPA. The long-term records for three wells were chosen to represent each of these three GMDs (Figures 1 and 2). The hydrograph for the well in Thomas County (GMD 4 area) shows the smallest water-level decline of the three wells. After a period of very little decline from the start of the record to the mid-1960s, the decline rate has generally slowly increased. The current saturated thickness at the Thomas County well is approximately 110 ft. The water-level decline at the Scott County well in GMD1, where the aquifer was developed sooner than in the other two GMDs, began during the 1930s soon after the start of the record. The decline rate accelerated during the 1950s drought, and has then moderated to the present. The moderation of the decline probably reflects local pumping reductions due to a relatively small saturated thickness (currently about 50 ft), although delayed drainage from low-permeability units and return flow from irrigation could also be causing the slowing in the decline. The hydrograph for the Meade County well (GMD3) displays the greatest water-level decline. After a nearly stable water level from 1940 to the early 1950s, the decline rate has substantially increased, with a precipitous drop from 2002 onwards. However, the record is considerably more variable than for the other two wells, with brief periods of recovery followed by sizable declines. The saturated thickness is appreciably greater at the Meade County well (currently about 220 ft) as it is in general for GMD3 in comparison with the other two western GMDs. In addition to the influence of saturated thickness on recent decline rates, the increase in evapotranspiration from GMD4 south to GMD3 is a factor in the generally larger amount of pumping needed for irrigation of the same crop.

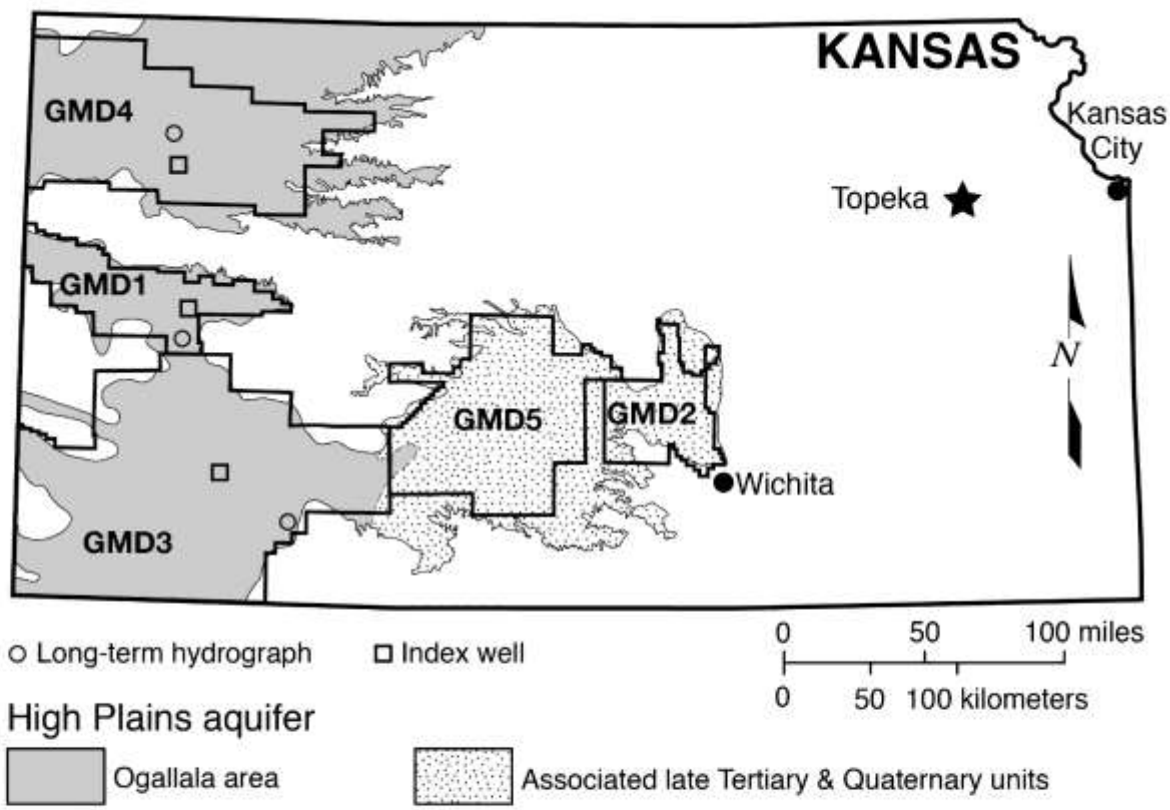

Figure 1. Location of wells with long-term hydrographs and index wells in the western part of the HPA. The boundaries of the five GMDs in Kansas are shown along with the extent of the HPA.

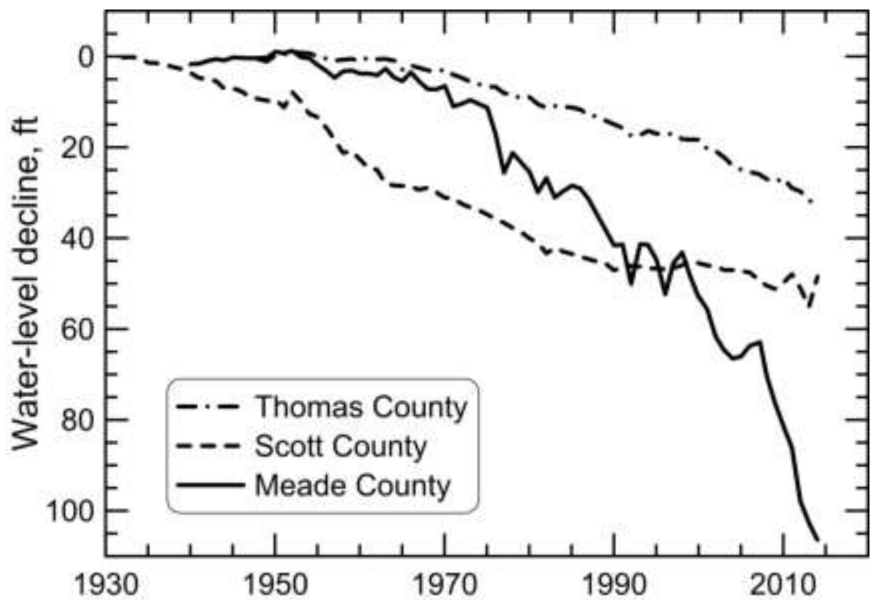

Figure 2. Long-term hydrographs of winter water levels for the western HPA in Kansas. The starting water level for each well has been adjusted to zero for comparison of the water-level declines.

INDEX WELL HYDROGRAPHS

The index well program was developed to assess detailed changes in water levels and the factors controlling them, with a major focus on evaluating the effectiveness of management strategies at the local scale (Butler et al., 2014). The program is supported with Kansas Water Plan funding through the Kansas Water Office. The first three index wells were installed in the three western GMDs, one each in Thomas, Scott, and Haskell counties (Figure 1). The screened interval for each of the wells is at the bottom of the HPA. The detailed hydrographs of these index wells display the water-level drawdown during the irrigation pumping season followed by recovery. The drawdown for wells where the aquifer is generally unconfined (Thomas County, Figure 3, and Scott County) is much smaller than for the well in Haskell County that is in a confined portion of the aquifer (Figure 4).

The level to which the groundwater recovers before pumping begins in the next irrigation season is usually lower than at the beginning of the previous irrigation season. The drop is generally related to the amount of pumping in the previous season. However, at the Thomas County well (Figure 3) the water level at the end of the recovery period in 2010 was appreciably above that of the recovery level in 2009. In addition, the level to which the water level rose at the end of recovery in 2011 was about the same as in 2009, although the irrigation season started three months earlier in 2011. These and related observations and the analysis of the water-level changes (described in Butler et al., 2013 and 2014) indicate that a source of inflow is present in Thomas County. This inflow decreases the amount of decline that would be expected from one year to the next or, in the case for 2010, results in an increase in the water level. The most probable source of inflow is a combination of delayed drainage from low permeability units, which were formerly saturated before the water-level decline, and recharge from past irrigation activity. In addition, variations in focused precipitation recharge from ephemeral stream drainages and playas could contribute to inflow.

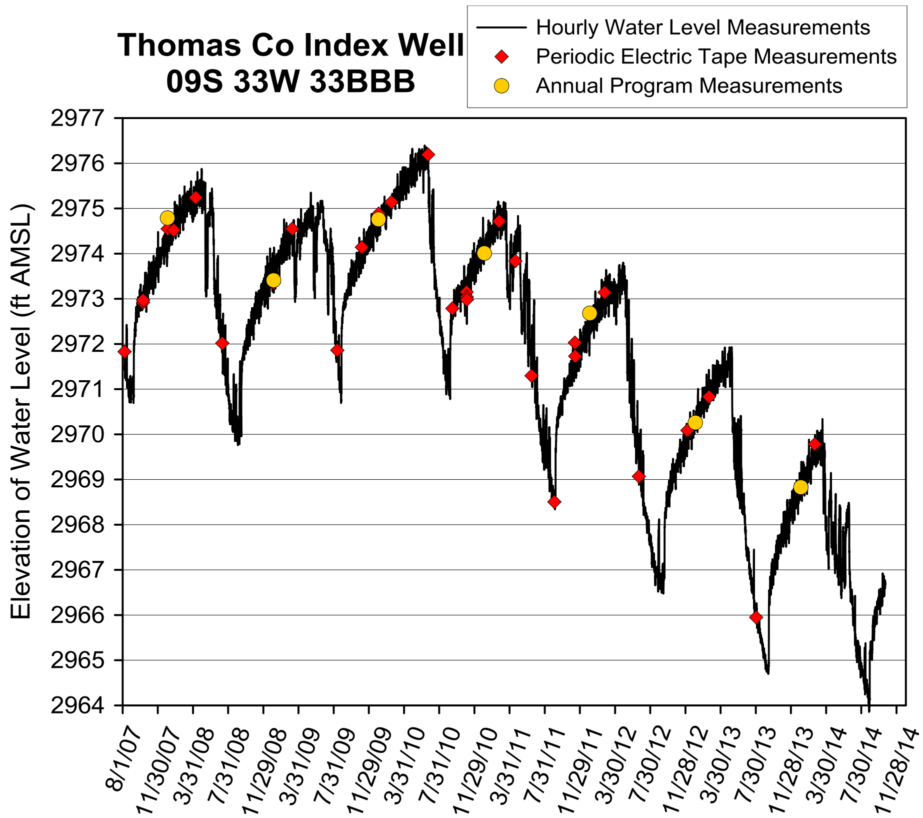

Figure 3. Thomas County index well hydrograph to 10/21/14. A water-level elevation of 2968 ft corresponds to a depth to water of 219.56 ft below land surface (lsf); the screened interval is 274–284 ft below lsf and extends to the bottom of the aquifer.

CORRELATION OF CLIMATIC INDICES WITH WATER-LEVEL CHANGES

The KGS has studied the association among water-level changes, climatic indices, and water use as a part of Kansas Water Plan studies and an NSF grant (Whittemore et al., 2014). The areas of each of the three western GMDs coincide well with the three western climatic divisions (GMD4 with Division 1, GMD1 with Division 4, and GMD3 with Division 7). The correlation of climatic indices, such as the Palmer Drought Severity Index, the Palmer Z index, and the Standardized Precipitation Index (SPI), with annual water-level changes are high for all the GMD regions. The coefficient of determination (R^2) values for the correlations of SPI with water-level change are greater than 0.7 for all of the western GMD areas (Figure 5). Figure 5a shows that the temporal variations in the annual water-level changes parallel the variations in the SPI. The regression lines for the correlations in Figure 5b have R^2 values that range up to 0.78 for GMD3. If the anomalous, circled point in Figure 5a for 1997 in GMD1 is removed, the R^2 increases from 0.72 to 0.81.

The correlations between water-level changes and SPI can be used to predict what the water-level change would be given a SPI representing future climatic conditions. For example, if the driest year of the 1950s drought (1956) were repeated, the predicted annual-water level declines would be -1.7 ft, -2.0 ft, and -4.5 ft for GMDs 4, 1, and 3, respectively. The regression lines also allow estimation of the annual water-level changes for average climatic conditions (SPI = 0), the declines would be -0.61 ft, -0.57, and -1.91 ft for GMDs 4, 1, and 3, respectively.

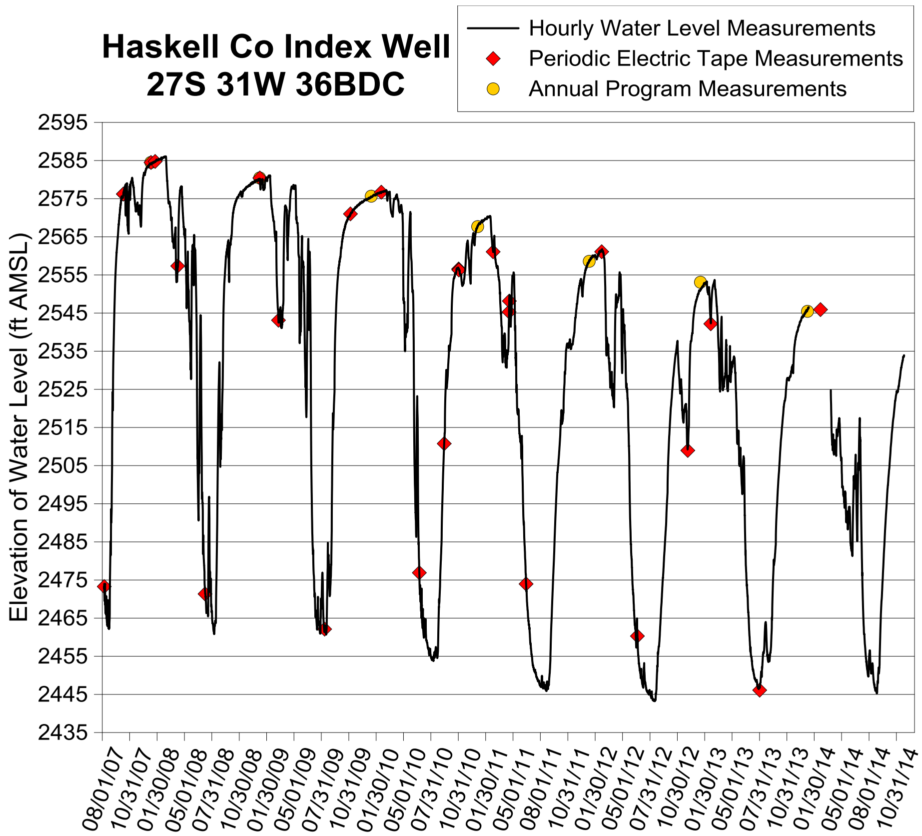

Figure 4. Haskell County index well hydrograph to 11/26/14 (break in continuous measurements from 1/12/14 to 3/26/14 due to sensor failure). A water-level elevation of 2445 ft corresponds to a depth to water of 392.85 ft below land surface (lsf); the screened interval is 420–433 ft below lsf and extends to 3 ft above the bottom of the aquifer.

Annual water-level changes that are near or slightly above zero (Figure 5) indicate that significant regional sources of inflow must be present to counteract the impact of pumping withdrawals. As indicated in the previous section, these are likely due to delayed drainage from the zone below which the water levels have dropped and from irrigation return flow and focused precipitation recharge.

CORRELATION OF WATER USE WITH WATER-LEVEL CHANGES

Variations in annual water-level change for the three western GMDs are generally the inverse of variations in annual reported water use (Figure 6a), as would be expected. The correlation of annual water-level change and annual water use for GMD4 is high; the R^2 is 0.72 (Figure 6b), which is nearly the same as for the correlation of water-level change and SPI for GMD4 (Figure 5b). No correlation exists between water-level change and water use for GMD1; the correlation for GMD3, although statistically significant at the $P = 0.05$ level, explains only 31% of the variation in the data. Linear trends exist in both the water-level change and water use data for GMD1 and in the water-level change values for GMD3. If these linear trends are removed, the R^2 values increase substantially such that the correlations are statistically significant at the $P = 0.01$ level, although the correlation still only explains around 50% of the variations. The most likely explanation for the much weaker correlations for GMDs 1 and 3 in comparison to GMD4 is greater uncertainty in the self-reported water-use data, for example, use of duration-of-pumping versus flow-rate meters and less accurate reporting. Changes in hydrostratigraphic conditions could be the cause of the downward trends in the water-level change for GMDs 1 and 3, whereas decreasing transmissivity is the likely explanation for the downward trend in water use in GMD1.

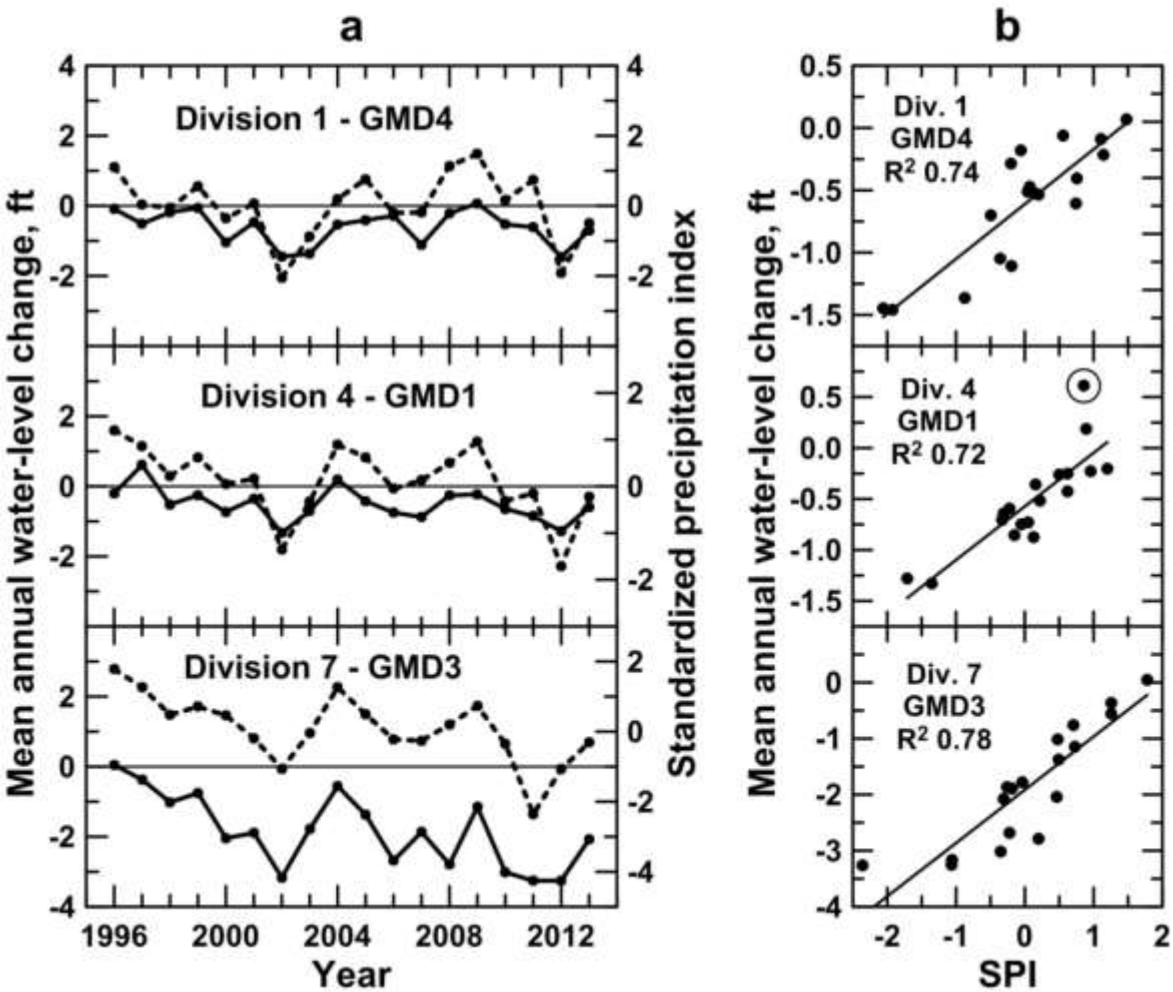

Figure 5. (a) Mean annual water-level changes (solid lines) in the HPA in the western Kansas GMD areas and SPI 9-month values (dashed lines) during 1996-2013. The y-axes ranges vary among the some of the plots to accentuate the relationship between fluctuations in water-level change and those in SPI. A value for a particular year represents the water-level difference between that year and the following year for a given well; the mean annual change is an unweighted arithmetic average of the values for all the wells. A SPI value of zero indicates average (historic norm) conditions, values <0 and >0 indicate dry and wet conditions, respectively. (b) Correlation plots for data displayed in (a). The point within the circle in (b) is the outlier referred to in the text.

The high correlation between water-level decline and water use for GMD4 can be used to estimate the reduction in pumping needed to stabilize water levels. This reduction would likely be only temporary if the inflow is from delayed drainage and irrigation return flow. A stabilized water level is represented in Figure 7 as a zero water-level change. The difference in pumping between the water use at the zero water-level change and the mean annual water use indicates that a 23.5% reduction in pumping could stabilize water levels for the short term (Figure 7). This percent reduction is close to the 20% target reduction for the first Local Enhanced Management Area (LEMA) in Sheridan County.

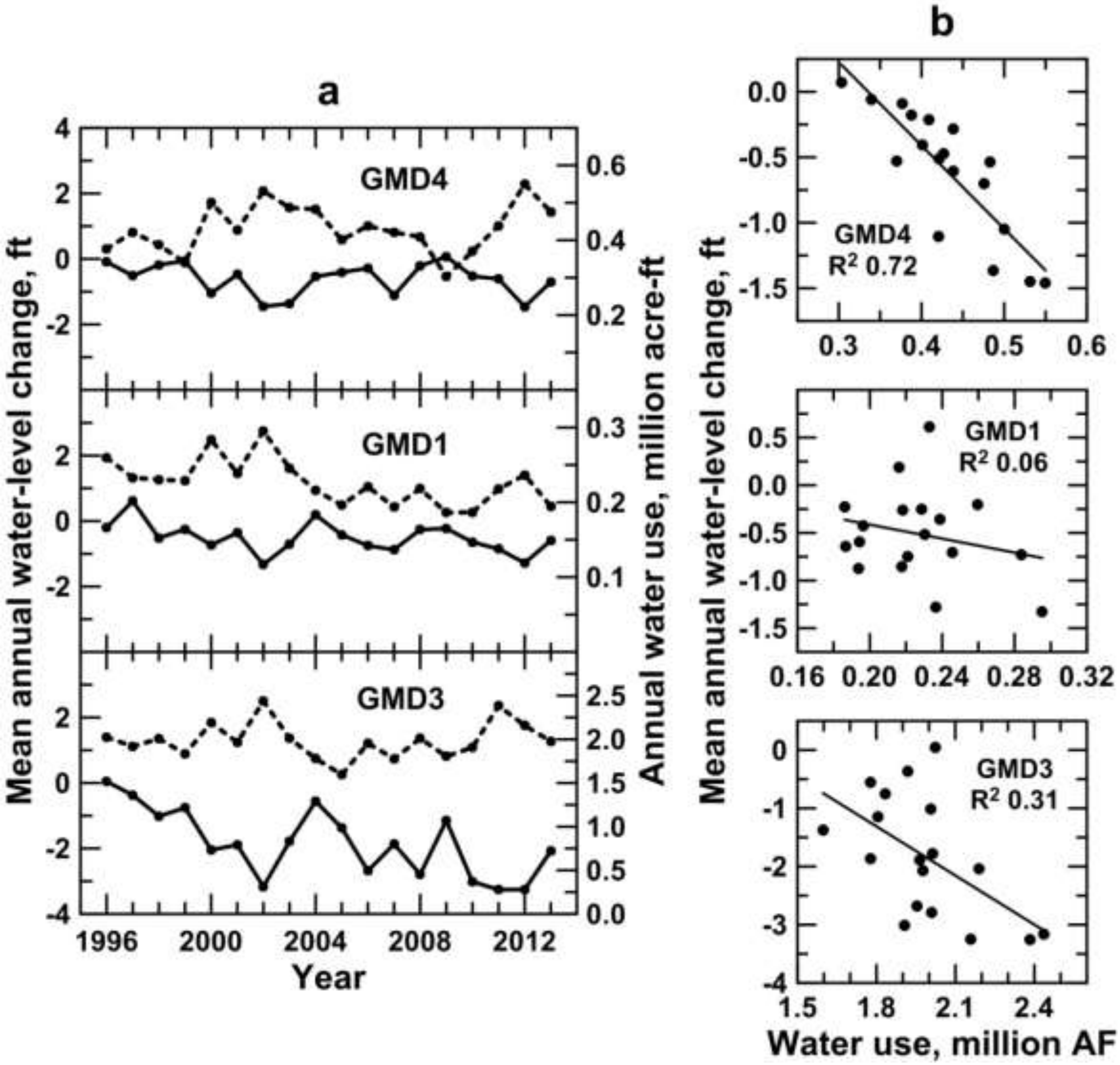

Figure 6. (a) Mean annual water-level changes (solid lines) and reported water use (dashed lines) for the HPA in the western Kansas GMD areas during 1996-2013. The axes ranges vary among plots to accentuate the relationship between fluctuations in water-level change and water use. The water-level data are the same as shown in Figure 5a. (b) Correlation plots for data displayed in (a).

CONCLUSIONS

Annual water-level changes in the HPA in western Kansas vary substantially depending on the amount of seasonal irrigation pumping, the hydrostratigraphy of the aquifer, and inflow to the water table (delayed drainage, irrigation return flow, and focused recharge such as in playas and ephemeral stream valleys). Seasonal variations in water levels are much greater in confined portions of the aquifer than in unconfined areas. Correlations between annual water-level changes and climatic indices are high for the three western GMD areas and reflect the importance of climate in driving irrigation pumping. The correlations allow predictions of water-level responses to future climatic conditions such as severe drought as well as estimation of the annual water-level decline for normal climate. The correlation between annual water-level change and water use is also high for northwest Kansas (GMD4) and provides a means for estimating the amount of pumping reduction needed to stabilize water levels, at least over the short term. The stabilization would probably be temporary due to the potential future reduction in inflows to the water table from smaller delayed drainage as water-level declines decrease and from irrigation return flow as pumping is reduced.

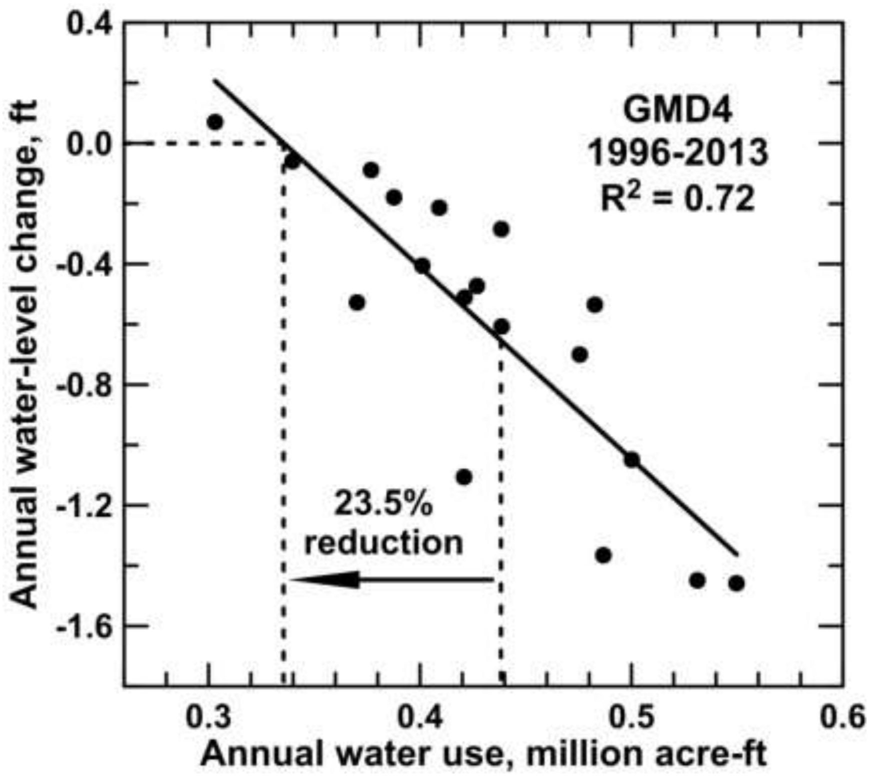

Figure 7. Mean annual water-level changes versus reported annual water use for the HPA in GMD4 during 1996-2013. The dashed lines indicate the water use at zero water-level change and the mean annual water use for the period.

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