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## Isotopic composition of the Ogallala-High Plains aquifer and vadose zone

Randy L. Stotler<sup>a\*</sup>, Donald O. Whittemore<sup>b</sup>, Jon J. Smith<sup>b</sup>, Britney S. Katz<sup>a</sup>, Adam Yoerg<sup>a</sup>, James J. Butler, Jr.<sup>b</sup>, Greg A. Ludvigson<sup>b</sup>, Daniel R. Hirmas<sup>c</sup><sup>a</sup>Department of Geology, University of Kansas, 1475 Jayhawk Blvd., Lawrence, KS 66045, USA<sup>b</sup>Kansas Geological Survey, 1930 Constant Blvd., Lawrence, KS, 66046, USA<sup>c</sup>Department of Geography, University of Kansas, 1475 Jayhawk Blvd., Lawrence, KS 66045, USA

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### Abstract

The Ogallala-High Plains aquifer is an important resource for irrigated agriculture in a semi-arid region of the United States. Steep declines in groundwater levels are putting increasing strain on the viability of the aquifer for irrigation, necessitating improved estimates of recharge rates and sources to the aquifer. This study uses a combined approach to obtain high resolution geochemical and isotopic composition of the vadose zone and aquifer pore fluids to better understand recharge dynamics to the aquifer. Significant differences between the shallow, intermediate and deep vadose zone and shallow and deep aquifer indicate modern precipitation is not providing a significant source of recharge to the aquifer across a large area (diffuse recharge). Rather, recharge to the aquifer is a result of either focused recharge or long-term, delayed drainage from the portion of the vadose zone which was saturated before irrigation development.

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### 1. Introduction

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\* Corresponding author. Tel.: +1-785-864-6048.  
E-mail address: [rstotler@ku.edu](mailto:rstotler@ku.edu)

The Ogallala-High Plains aquifer is one of the largest aquifers in the world, and accounts for ~23% of all groundwater withdrawals in the United States<sup>1</sup>. This aquifer provides vital irrigation water across a vital agricultural region stretching across 45,000,000 hectares (5,500,000 hectares irrigated) in parts of seven states. The resource has been over-exploited, resulting in steep groundwater-level declines in excess of 45 m from pre-development and

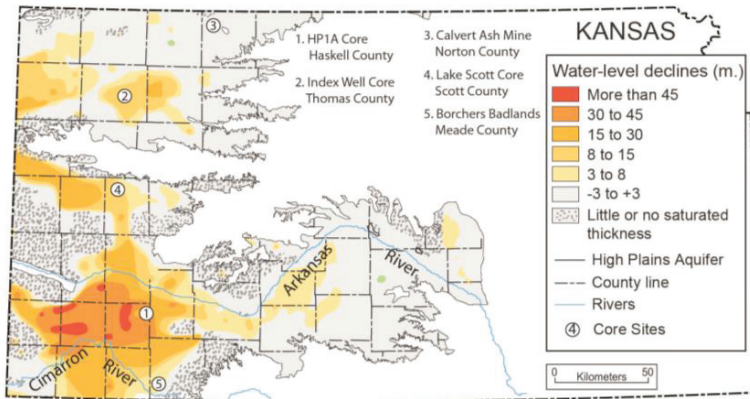


Figure 1: Map of core locations and water level declines from pre-development to 2009 (modified<sup>5</sup>).

depths to water on the order of 60-100 m in some areas. Large pumping induced declines have called into question the viability of the aquifer as a continuing source of water for irrigated agriculture<sup>2,3,4</sup>. As water levels decline, increased significance has been placed on understanding sources and rates of recharge to the aquifer. In some of the most heavily stressed portions of the aquifer, recent investigations have indicated at least some recharge is reaching the aquifer<sup>2,6</sup>. A closer investigation of one irrigated field indicated widespread irrigation return flow is not the likely source of this

recharge<sup>7</sup>.

The goal of this research is to better understand sources and ages of recharge across the High Plains aquifer. This work takes advantage of a recent drilling campaign that targeted the vadose zone to provide stratigraphic context to on-going hydrogeological investigations and both monitoring and irrigation wells. The core was collected at five sites (Figure 1) to depths of 10-30 m below ground surface. Some sites were located next to or beneath irrigated fields, while others were located beneath rangeland. Fluid samples from the saturated zone were available from monitoring and irrigation wells located near four of the five sites. This research takes advantage of new techniques for determining isotopic composition of vadose zone pore water.

## 2. Methods

Pore fluid was collected from both the vadose zone and saturated zone. Vadose zone core samples (5 cm diameter by 60 cm long) were collected in plastic tubes using an Acker soil max, wire-line split-spoon sampler advanced ahead of a hollow-stem auger (8.3 cm diameter) without introducing any drilling fluid. Subsamples for isotopic and geochemical analysis were collected directly from the drill-shoe in two Ziplok™ double-seal freezer bags, with all excess air pushed out, and stored in a cooler. Samples were weighed in the lab. At one site, saturated zone core samples were collected using a Sonic drill rig with an aqua-lock piston sampler. Pore fluids were gravity drained on site using a peristaltic pump to speed collection.

In the laboratory, vadose zone core subsamples were prepared and analyzed following the method of Wassenaar et al.<sup>8</sup> to determine isotopic composition. Briefly, the inner bag was inflated with air dried to less than 200 ppm water vapor. The capillary fluid was allowed to equilibrate with the dry air for two days. The sample was then direct-injected into a Picarro™ L2120-i Water Isotope Analyzer for a 5.5 minute measurement period. Measurements were averaged over the last 0.5 minute. Standards, prepared by placing water into the inner bag of the double Ziplock™ bag arrangement and then filling the bag with dry air, bracketed every three samples. Ten percent of the core samples were reanalyzed at time intervals of several days to several weeks to check stability of measurements. Assuming isotopic equilibrium between the liquid and vapor phases, the laboratory temperature at the time of the measurement was used to calculate isotopic values of the vadose zone pore fluid using equilibrium fractionation factors<sup>9</sup>. Dissolved ion contents were obtained from core samples by extracting fluid from core using a 1:1 saturated paste<sup>10,11</sup>. Core samples splits were oven dried to determine gravimetric water content.

Aquifer water was collected from monitoring wells and irrigation wells. Prior to sampling from monitoring wells, well water was purged until pH, eh, specific conductance, and temperature readings stabilized. Irrigation wells had been pumping for a minimum of one week (in most cases, two months) prior to sampling. Samples for cations, anions, stable isotopes ( $\delta^2\text{H}$ ,  $\delta^{18}\text{O}$ ),  $^3\text{H}$ , and  $^{14}\text{C}$  were collected in HDPE bottles and stored at  $4^\circ\text{C}$ . Cation and anion samples were filtered with  $0.45\ \mu\text{m}$ , and cation samples were preserved with nitric acid to a pH of 2. For both core and well fluid, anion concentrations were determined using an ion chromatograph and cation concentrations were determined on an inductively-coupled plasma optical emission spectrometer. Stable isotopic composition was determined on a Picarro™ L2120-i Water Isotope Analyzer. Tritium was analyzed at Isotope Tracer Technologies.  $^{14}\text{C}$  was analyzed at the University of Arizona AMS laboratory or Beta Analytics by accelerator mass spectrometry. Newly collected monitoring well data from Site 5 is compared with data collected in 2000<sup>12</sup>.

### 3. Results and Discussion

Nearly all the samples plot near the Global Meteoric Waterline (GMWL) (Figure 2), indicating a meteoric source for the water in the aquifer. Waters with isotopic signatures that fall near the GMWL have not been affected by evaporation. This suggests very little, if any, water within the HPA is irrigation return water, which would have an evaporative isotopic signature. Some core samples plot to the right-hand side of the GMWL, suggesting that they may have been affected by evaporation. These samples were not the shallowest of the saturated core samples. The isotopic signatures become lighter from south to north across the state (Figures 1 and 2). At site 1, water sampled from wells also exhibits a distinctly lighter isotopic signature compared with core pore water (Figure 3). The pore water was sampled above a thick clay layer, while the monitoring well is screened beneath the clay layer. Most irrigation wells are screened through the clay layer. Combined with monitoring well samples from discrete depths at site 5 (Figure 3), isotopic composition gets lighter with depth in the High Plains aquifer. These statewide and local trends are significant, and indicative of distinctly different sources of water within the HPA in Kansas.

Expected annual mean isotopic values for modern precipitation suggest  $\delta^{18}\text{O}$  should vary from  $-6.4 \pm 1.3\ ‰$  to  $-6.8 \pm 1.3\ ‰$  (VSMOW) from Site 5 to Site 2<sup>13,14</sup>. Thus, the range for modern precipitation is significantly smaller ( $0.4\ ‰$  vs.  $3.0\ ‰$  VSMOW) and heavier ( $-6.4\ ‰$  to  $-6.8\ ‰$  vs.  $-8.5\ ‰$  to  $-11.5\ ‰$ ) than observed in aquifer water.

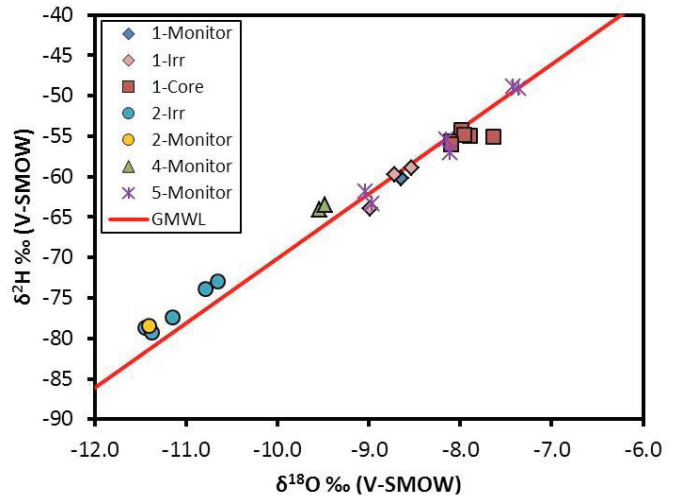


Figure 2: HPA  $\delta^2\text{H}$  vs.  $\delta^{18}\text{O}$  for waters sampled at sites 1, 2, 4, and 5, nearby irrigation wells, and pore water, relative to the Global Meteoric Waterline (GMWL).

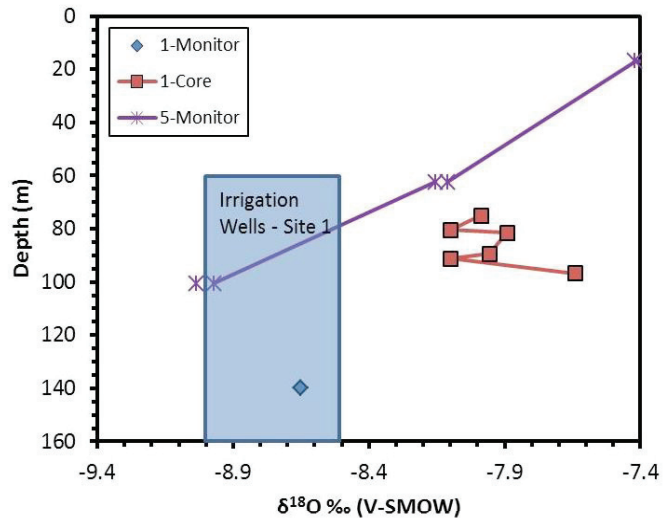


Figure 3: Depth vs.  $\delta^{18}\text{O}$  at Site 1 and pore water from Site 1, and from three discretely screened intervals near Site 5. The range of isotopic values for irrigation wells at Site 1, screened across the aquifer, is also displayed (blue box). Depth to water at Site 1 is approximately 60 m; at Site 5, 20 m.

The difference is greatest in waters sampled at Site 2. However, shallower vadose zone water was much closer to these modern precipitation values. This indicates that waters sampled from the aquifer either recharged during winter months only or under different climatic conditions than presently affect the region, but are not recharged with significant amounts of modern recharge, a conclusion confirmed by chloride mass balance (at present, only completed at Site 2), tritium and radiocarbon analysis.

The local trend observed at Sites 1 and 5 is also very informative. The isotopic signature of pore and aquifer water in upper part of the aquifer is significantly heavier than the water in the deeper confined aquifer. This suggests the water in the unconfined aquifer recharged under different climate conditions than the water in the deeper aquifer (warmer temperatures, or less intense precipitation events). It is also possible this lighter signature is a reflection of mixing with water from deeper aquifers.

#### 4. Summary

This study makes use of a combination of standard well water sampling and high resolution pore water sampling of core collected through the vadose zone and aquifer to better understand sources and rates of recharge to the High Plains aquifer. The distribution of anion and cation concentrations, and stable and radioactive isotope values, across western Kansas indicate widespread, diffuse modern recharge is not reaching the High Plains aquifer. In areas where the water table has declined since the 1960s due to groundwater mining, the geochemical signature of pore fluids in the 30 m thick drained portion of the vadose zone is identical to the aquifer water, and distinct from the shallow (0 – 10 m below ground surface) and intermediate (10 – 30 m below ground surface) vadose zone. As additional pore water, monitoring well and irrigation well samples are collected and analyzed across the High Plains aquifer, additional insights into recharge areas and flow path evolution will be possible.

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