Report for 2003KS33B: A Field Assessment of a Method for Estimation of Ground-Water Consumption By Phreatophytes

- Conference Proceedings:
  - Butler, J.J., Jr., Some interesting aspects of groundwater flow in interconnected stream-aquifer systems: A report from Americans Heartland, an invited presentation to the Center for Applied Geoscience (ZAG) at the Eberhard-Karls-University of Tübingen, Germany, July 2, 2003.
  - Billinger, M., and J.J. Butler, Jr., Phreatophyte study in Solomon and Middle Arkansas River Basins, invited presentation at 2003 Annual Fall Conference of the Division of Water Resources of the Kansas Department of Agriculture, October 15, 2003.

Report Follows

KWRI PROGRESS REPORT – YEAR ONE

Project Title: A Field Assessment of a Method for Estimation of Groundwater Consumption by Phreatophytes – Year One

Start Date: March 1, 2003

End Date: February 28, 2004

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Research Category: Statewide Competitive Grant

Descriptors: phreatophytes, ground water, evapotranspiration, water balance

PROBLEM AND RESEARCH OBJECTIVES

Low streamflows are an increasing problem in Kansas and other areas of the U.S. As a result, smaller amounts of water are available for diversions to water supplies and wetlands, for inflows to reservoirs, for capture by wells in nearby aquifers, for sustaining aquatic wildlife, and for recreation. Stream-aquifer interactions play an important role in the generation and maintenance of low streamflows. Ground-water development in regional aquifers that discharge water to stream corridors and in alluvial aquifers immediately adjacent to streams is often a major factor responsible for low-flow periods. Consumption of ground water by phreatophytes in riparian zones could also be an important factor contributing to periods of reduced streamflow. Reliable estimates of the magnitude of this consumption, however, have not yet been obtained.

In this project, we will develop a method for estimation of the amount of ground water consumed by phreatophytes. This method will be evaluated at a field site of the Kansas Geological Survey at which a great deal of previous work has been performed. The previous work, in conjunction with the additional work to be done as part of this project, will enable the methodology development and assessment to be carried out under highly controlled conditions. The end product of this research will be a technique of demonstrated effectiveness for both identifying and quantifying phreatophyte activity. Although the technique will be developed at a site with a mix of phreatophytes common in central Kansas, the approach will be equally viable in areas with different mixes of phreatophytes. The major objectives for this research project are to 1) develop a new method for quantifying the consumption of ground water by phreatophytes in hydrologic conditions common to central and western Kansas, 2) evaluate this method at a well-controlled field site, and 3) quantify ground-water consumption by phreatophytes along a portion of the middle reach of the Arkansas River in Kansas. An auxiliary objective of this work is to gather a detailed data set on the major fluxes in stream-aquifer systems that can serve as the basis for research proposals on the quantitative assessment of stream-aquifer interactions in settings common to the Great Plains.

The five specific objectives for year one were as follows:

1. Establish and characterize the Larned Control Volume (LCV);

2. Commence monitoring of subsurface fluxes for water and salinity balances in the LCV;
3. Commence monitoring of phreatophyte activity;
4. Relate water-table fluctuations to phreatophyte activity during periods of negligible flux from the vadose zone;
5. Perform uncertainty analyses of water and salinity balances within the LCV.

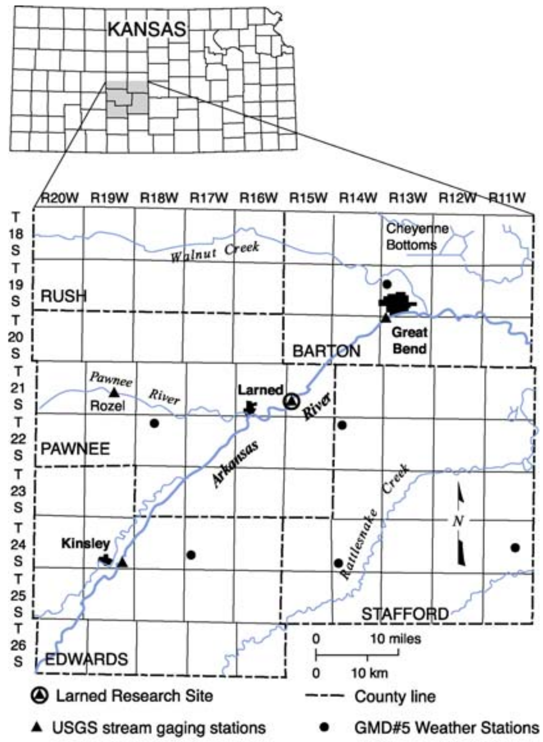


Figure 1

METHODOLOGY

The ultimate objective of this project is to develop a practical approach for quantifying phreatophyte consumption of ground water. This is being done at the Larned Research Site, a field area of the Kansas Geological Survey that is located adjacent to the USGS stream-gaging station on the Arkansas River near Larned in central Kansas (Larned Research Site – Figure 1). Since the late spring of 2001, KGS personnel have done extensive work on stream-aquifer interactions at the Larned site. This previous work enables the tasks of this project to be performed in a controlled field setting.

The methods development that is the focus of this work is being done using the control volume concept. A control volume is essentially a very large lysimeter. Water and salinity fluxes into/out of this volume are determined so that the relationship between phreatophyte activity and water-level fluctuations can be assessed (Figure 2). In the first phase of this project, the Larned Control Volume (LCV) was established in the riparian zone just west of the Arkansas River channel. Wells and vadose-zone monitoring equipment were installed within and adjacent to the LCV in May 2003. Direct-push electrical conductivity logging was used for detailed lithologic characterization at all sites prior to well installation.

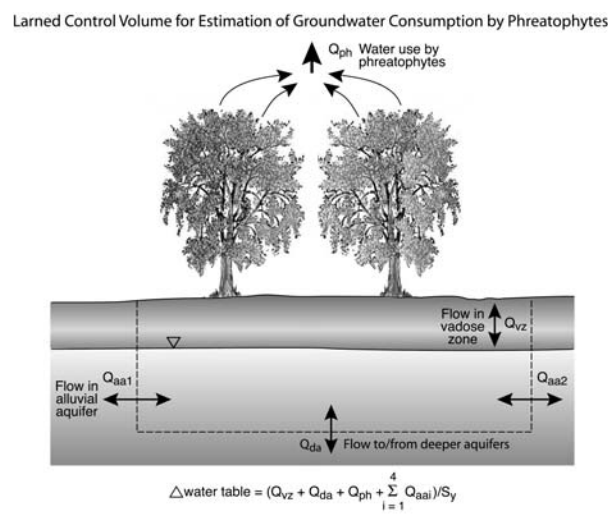


Figure 2

All wells in the LCV were equipped with integrated pressure transducer/datalogger units (In-Situ MiniTroll) that were programmed to take pressure-head readings every 15 minutes. Since the wells in the LCV could be overtopped during periods of high flow, absolute pressure transducers were used instead of the gauge-pressure sensors utilized in most hydrogeologic studies. The absolute-pressure sensors measure the pressure exerted both by the height of the overlying column of water in the well and by the atmosphere. The atmospheric pressure component is removed using data from a barometer at the site. Given the importance of the barometric pressure correction, a backup barometer was added to the monitoring network in September of 2003. Figure 3 displays records from an absolute-pressure sensor in the riparian zone prior to and after the barometric pressure correction. Manual measurements of water levels in the monitoring wells were taken on a monthly interval in order to assess the performance of the pressure sensors and, if necessary, to adjust the calibration parameters.

Vadose-zone monitoring equipment (tensiometers and neutron access tubes) was installed in the LCV in May 2003. Tensiometer readings were recorded every two to three weeks with a Tensimeter (Soil Measurement Systems). Measurements in the neutron access tubes were recorded at the same time with a neutron probe (Model 503 DR Hydroprobe Moisture Depth Gauge; Campbell Pacific Nuclear) using a count duration of 16 s and depth increments of 0.152 m. Standard counts were recorded in the field both prior to and after access tube measurements. The mean standard count for the duration of the study was used to convert each measured count to a count ratio (CR). The soil volumetric water content ($m^3\ m^{-3}$), θ, corresponding to each measured count ratio was calculated with the calibration equation $\theta = 0.2992 \times CR - 0.01839$, which was based on laboratory calibrations and an adjustment for PVC pipe.

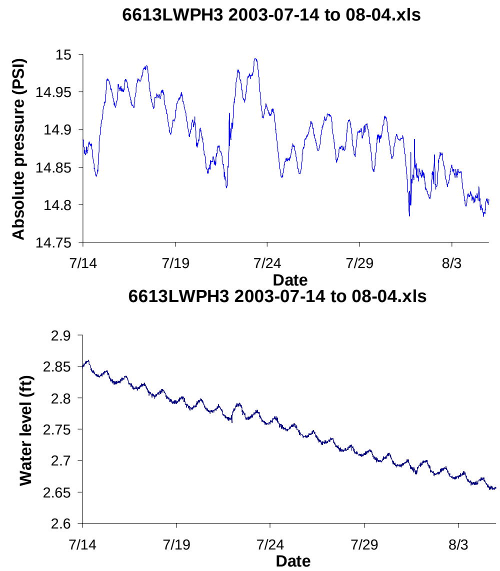


Figure 3

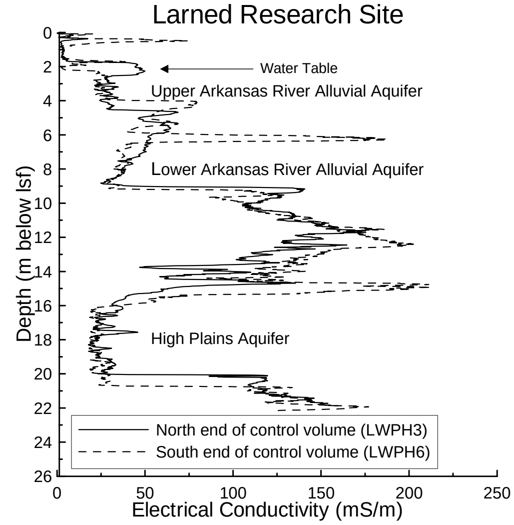
Ground-water samples were collected from all wells in the LCV and analyzed for specific conductance and major and minor constituents. A conductivity and temperature sensor with data logger (In-Situ MP Troll 9000) was installed in a well at the center of the LCV. In addition, a conductivity and temperature probe with a surface readout (YSI Model 30/50) was obtained to allow measurement of vertical profiles of these parameters in the LCV wells. Profiles have been measured in the LCV wells during 5 different months from September 2003 to February 2004.

Transpiration on the leaf scale was measured using a portable photosynthesis system (Li-Cor Li-6400). This machine consists of an infrared gas analyzer (IRGA) that measures the concentration of CO_2 and H_2O in the system air flow. There are two separate IRGA readings, one for the incoming air and one for the air in the sample chamber. A leaf is placed in the sample chamber and sealed inside. The system has its own light source and can control the concentrations of CO_2 and H_2O with the use of soda lime and Drierite, chemicals that scrub the air of CO_2 and H_2O, respectively. For all the measurements taken during this study, the concentration of CO_2 in the sample chamber was 370 PPM. Leaves from cottonwood and mulberry trees were measured under two different light levels and were maintained under conditions approximating ambient during the measurement. The light levels were 1500 μmol photons $m^{-2}\ s^{-1}$, which is typical of clear sky light in mid-morning and mid-afternoon during the summer in Kansas, and 300 μmol photons $m^{-2}\ s^{-1}$, which is typical for mostly cloudy conditions during the summer. Measurements were taken once a month from June through September 2003. Data were gathered from 7:30 AM to 4:00 PM. Leaves both near the ground and high in the canopy were measured using a cherry picker unit. Data for all of the leaves are in the form of the amount of H_2O transpired per m^2 of leaf area per second at the given light level, temperature and vapor pressure deficit. To extrapolate to the entire canopy, the m^2 leaf tissue per m^2 of ground was estimated using a leaf area index (LAI) sensor. LAI was measured on Aug. 12, 2003 between 2 PM and 4 PM. Five random points were selected within the riparian zone and LAI was measured at waist height in the four cardinal directions at each of the points. The process was repeated so that eight measurements were taken at each of the five points.

Transpiration on the tree scale was measured using sapflow sensors (Thermal Logic Model SF18). A sapflow sensor consists of two needles encased in an epoxy head. One needle has an embedded heating element, while the other has three embedded thermocouples. The installation procedure consists of removing a section of bark from the tree, emplacing the needles in the xylem, and covering the exposed xylem and probe with aluminum foil. The heater is turned on for eight seconds every 30 minutes and the temperature at three depths in the xylem above the heater is measured using the thermocouples. Three sensors are equally spaced around the circumference of the tree and remain in the tree for a period of four days. A programmable datalogger (Campbell Scientific 23X) is used to control sensor operation. The velocity of the water flow in the xylem is determined from the time it takes the heat pulse to move past the thermocouples. The volumetric rate of water movement in the trunk is determined from the thickness of the xylem and the velocity measurements. Sapflow measurements were taken every two to three weeks from June to September 2003.

A weather station (Hobo Weather Station logger and sensors, Onset Computer Corp.) was installed within 1600 m of the LCV in June of 2003 and then moved to within 800 m of the LCV in September. The weather station is equipped with sensors to measure temperature, precipitation, solar radiation, wind speed and direction, and relative humidity. Data are averaged (temperature, solar radiation, wind speed and direction, and relative humidity) or summed (precipitation) and logged at a 15-minute interval. Potential evapotranspiration is calculated from the meteorologic data using the Penman-Monteith equation.

Figure 4
Electrical Conductivity Logs
Larned Research Site



PRINCIPAL FINDINGS AND SIGNIFICANCE

The principal findings and their significance will be discussed in the context of the five objectives of the project:

Objective 1: Establish and characterize the Larned Control Volume (LCV) - five wells, four neutron-access tubes and 24 tensiometers were installed within and adjacent to the LCV. Direct-push electrical conductivity logging was used for detailed lithologic characterization at all well sites. As shown in Figure 4, three aquifer units can be identified in the shallow subsurface within the LCV. The thickness of the sandy silt zone separating the upper and lower portions of the Arkansas River Alluvial Aquifer varies across the site, so the degree of interconnection between these units also varies. The clay and silt zone separating the Arkansas River alluvial aquifer and the High Plains aquifer is consistent across the LCV. Three of the wells were screened in the upper zone of the Arkansas River alluvial aquifer (A), one in the lower zone of that aquifer (B), and one in the High Plains aquifer (C). Figure 5 provides an aerial view of the diamond-shaped LCV to the west of the river channel, and the nearby well network. Note that an additional well in the upper zone of the alluvial aquifer was installed in a pasture to the east of the riparian zone in year one to provide background information.

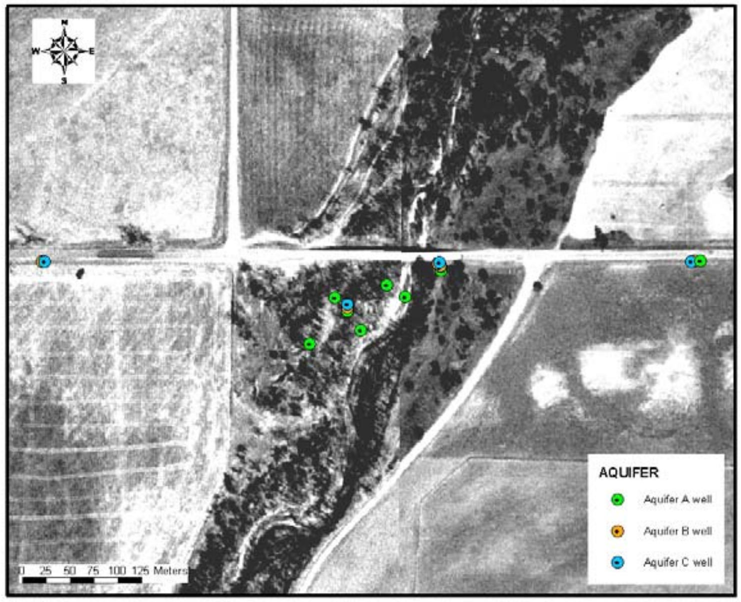


Figure 5

Objective 2: Commence monitoring of subsurface fluxes for water and salinity balances in the LCV – pressure-head measurements were obtained in all wells in the LCV and adjacent areas at 15-minute intervals beginning in the spring of 2003. These measurements clearly show that prominent diurnal fluctuations in the water table are only observed in the growing season (Figure 6) and are limited to the riparian zone (Figure 7). Gradients will be calculated from the pressure-head measurements after the vertical and horizontal locations of the wells are surveyed to a high degree of accuracy early in year two. Six tensiometers and a single neutron access tube were installed in each of four vadose-zone instrument nests in May 2003. Within each instrument nest, two tensiometers were installed at each of three depths: 0.91, 1.22, and 1.52 m. The neutron access tube was installed to a depth of 2.29 m. Figure 8 displays the water content profiles obtained over the field season from one of the nests. These profiles indicate that very little water moved from the land surface to the water table during the

Figure 6
Water Table Fluctuations
Across Growing Season

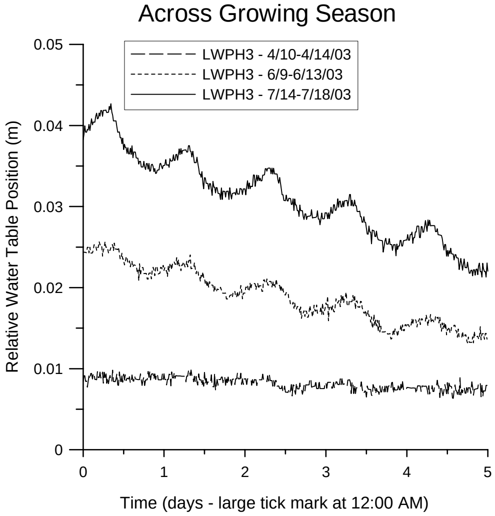
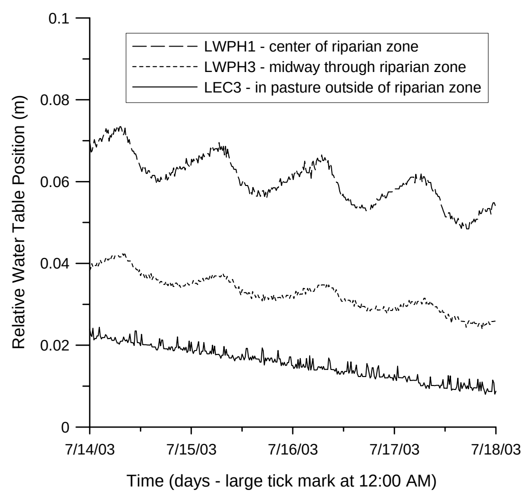


Figure 7
Water Table Fluctuations
Across Riparian Zone



monitoring period. Ground-water samples and conductivity profiles have been acquired from all wells in the LCV. These water-quality data have been useful for characterizing chemical heterogeneities in the LCV. Initial chemistry data indicate that water quality varies substantially in space and time within the LCV in response to differences in phreatophyte water consumption and recharge from precipitation and high river flow. The data collected to date suggest that phreatophyte water consumption in one summer season could be responsible for a doubling of the total-dissolved solids (TDS) concentration at one of the LCV well locations. This level of variation means that the salinity change will be valuable as an estimate of water consumption. The conductance profiles showed that the TDS concentration of the water changed with depth in some wells. Low-flow sampling at two different depths within the screened interval of the upper alluvial aquifer well at the center of the LCV also produced water with different TDS content based on chemical analysis. The spatial and temporal changes observed in conductance from well to well, and with depth in a single well, demonstrate the importance of detailed measurements at each well. Recording of specific conductance profiles is the most efficient way to obtain such detailed measurements. The specific conductance is very well correlated with the TDS concentration obtained from the sum of major dissolved constituents based on the analyses of the LCV ground waters. The sampling and conductance profile results were used to modify the procedure for salinity balance measurements for the remainder of the project.

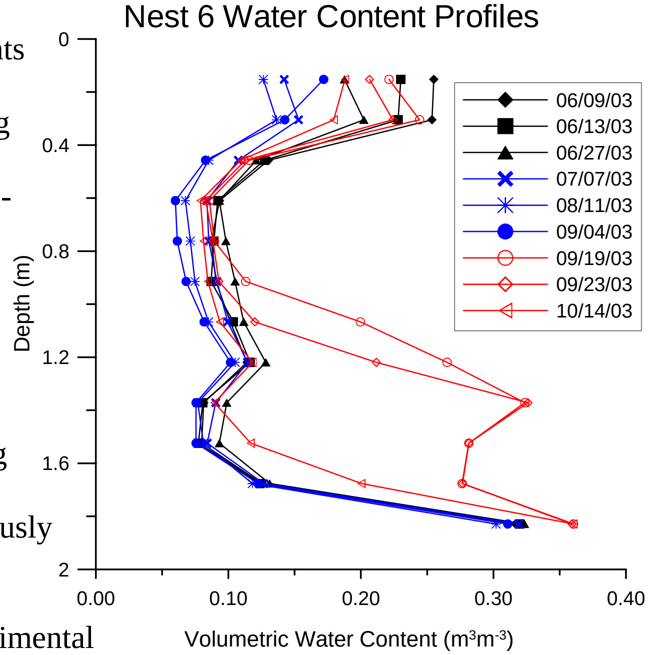


Figure 8
Nest 6 Water Content Profiles

Objective 3: Commence monitoring of phreatophyte activity – phreatophyte activity was monitored at the leaf- and tree-scale using a portable photosynthesis system and sapflow sensors, respectively. The analysis of the transpiration data is ongoing and will be completed in year two;

Objective 4: Relate water-table fluctuations to phreatophyte activity during periods of negligible flux from the vadose zone – a theoretical assessment of a previously developed method for estimating phreatophyte activity from water-table fluctuations has been completed. An experimental assessment of this method will be performed in year two after the high-accuracy well survey has been completed. The method will be modified for conditions at the Larned Research Site after completion of the experimental assessment;

Objective 5: Perform uncertainty analyses of water and salinity balances within the LCV – preliminary chemical data indicate that the spatial and temporal variability in chemistry at the different locations in the LCV is greater than expected. The results are being used to design an approach for more detailed monitoring of changes in the LCV wells. Another uncertainty in the salinity balance approach is the determination (based on the water chemistry) that a significant percentage of constituents dissolved in the water at the water table could be precipitated in the unsaturated zone during water consumption and slow decline in water levels. This objective will be addressed further in year two after the high-accuracy well survey has been completed.

PRESENTATIONS

Butler, J.J., Jr., Some interesting aspects of groundwater flow in interconnected stream-aquifer systems: A report from American's Heartland, an invited presentation to the Center for Applied Geoscience (ZAG) at the Eberhard-Karls-University of Tübingen, Germany, July 2, 2003.

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INFORMATION TRANSFER

Two presentations concerning project methodology and the initial phase of the data collection were presented at the University of Tübingen in Germany and at the Annual Fall Meeting of the Division of Water Resources in Topeka. Two abstracts were prepared in year one for presentations early in year two (Water and the Future of Kansas Conference - March 2004, American Geophysical Union Spring Meeting - May 2004). One manuscript on the theoretical assessment of a previously developed method for estimating groundwater consumption by phreatophytes from water-table fluctuations was completed. This paper was submitted to a scientific journal early in year two.

STUDENT SUPPORT

One KSU graduate student and one KSU undergraduate were partially supported from this grant during the summer of 2003. These students contributed to the aspects of the project involving vadose-zone monitoring equipment, the sapflow sensors, and the weather station. Travel, research supplies, and cherry-picker rental were provided for a KU graduate student to perform the leaf-scale transpiration monitoring.