Influence of surface-water recharge on the potential for agricultural nutrient and pesticide transport to the Mississippi River alluvial aquifer, Northwestern Mississippi

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In December 2006, the Agricultural Chemical Transport (ACT) topical team of the U.S Geological Survey National Water Quality Assessment (NAWQA) Program began a study in northwestern Mississippi to evaluate the influence of surface-water recharge on the occurrence of agriculturally related nutrients and pesticides in the Mississippi River alluvial aquifer. A series of nine piezometers was installed along a transect across the Bogue Phalia, a stream located near Leland, Miss., Washington County. Water levels were monitored continuously in nine piezometers and in one monitoring well approximately 1 mile north of the site. Local ground-water flow direction was determined using bi-annual water-level data collected by the Yazoo-Mississippi-Delta Joint Water Management District (YMD) in selected irrigation wells screened in the alluvial aquifer. Routine and event-driven water-quality samples were collected from 2006-2007 and were evaluated for major ions, nutrients, organic carbon, and physical parameters. In addition, water samples were analyzed for two commonly used pesticides in the area, atrazine and glyphosate.

Regionally, flow in the alluvial aquifer tends to be toward the axis of the Mississippi Embayment, which is the Mississippi River. Local ground-water flow patterns were evaluated to determine potential movement of nutrients and pesticides from streams to the alluvial aquifer. Historically, water-quality results indicate that nutrients are present in ground water. Although pesticides have occasionally been detected in ground-water samples, their detections indicate that there is potential for anthropogenic contamination of the alluvial aquifer. Data collected as part of this study will be used to quantify surface-water recharge to the alluvial aquifer as a transport mechanism for nutrient and pesticide movement into the ground-water system.

Key Words: Water Quality, Ground Water, Agriculture, Hydrology

Introduction

In 2006, the Mississippi Embayment (MISE) Study Unit of the National Water Quality Assessment (NAWQA) Program began data-collection activities in the Bogue Phalia Basin, northwestern Mississippi, as part of the U.S. Geological Survey's (USGS) Agricultural Chemical Transport (ACT) Study (http://in.water.usgs.gov/NAWQA_ACT/index.shtml). The Bogue Phalia Basin (fig. 1), one of seven watersheds currently being studied to determine the mechanisms and extent to which natural and agricultural factors influence chemical transport and water quality, is one of the most agriculturally productive (cotton, rice and soybeans) areas in the Nation. Data collection and analysis in each ACT study basin are designed similarly and a multi-scale approach is used to evaluate water and chemical transport. An integral part of the multi-scale approach is a network of shallow wells, in-stream piezometers, and surface-water gages that are used to monitor water levels, streamflow, and water quality.

The data-collection network for Bogue Phalia was designed to describe ground- and surface-water interaction and its effects on water quality. A series of shallow ground-water wells and in-stream piezometers were installed along a transect that crosses the Bogue Phalia (fig. 1). Continuous and synoptic water levels were recorded in each well beginning May 2006. An existing USGS real-time surface-water monitoring station is located less than a mile downstream from the transect and provides continuous measurements of gage height, discharge, and precipitation. Surface- and ground-water samples were collected quarterly beginning in late spring 2006 and after significant storm events in June and July 2007 and February 2008 following standard sampling

protocols described by Koterba and others (1995) and the USGS National Field Manual (USGS, variously dated). Samples were analyzed for field parameters, major ions, sulfide, and nutrients. Additionally, surface-water-quality samples are collected at the Bogue Phalia weekly to bi-weekly as part of the NAWQA Status and Trends Assessment program (http://water.usgs.gov/nawqa/studies/regional_assessments.html).

The ACT study in the Bogue Phalia basin was designed to: (1) describe ground- and surface-water interaction in the Bogue Phalia basin; (2) determine whether surface water could be contaminating the shallow ground-water system; (3) determine the extent to which applications of pesticides and nutrients for agricultural production are affecting surface- and ground-water quality; and (4) use information developed as a result of this study to help further understand processes in similar environmental settings.

Ground-Water/Surface-Water Interaction

The Mississippi River alluvial aquifer is recharged from the west by the Mississippi River, from underlying aquifers and from the bluff hills to the east. But the largest contributor to recharge, larger than all the other sources combined, is infiltrated precipitation, which accounts for only 2.6 inches of recharge annually (Arthur, 2001). Understanding how, when, and if surface water recharges the Mississippi River alluvial aquifer is an important component to developing an understanding of how surface water may be affecting the water quality of the alluvial aquifer.

Ground-Water Flow Patterns

Regional ground-water flow patterns in the alluvial aquifer are typically from east to west toward the Mississippi River (Arthur, 2001); during the study period local ground-water flow in the alluvial aquifer was toward the Yazoo River, generally west to east except in areas near the Mississippi River where flow remains east to west (fig. 2). All nine piezometers along the flowpath had ground-water levels fluctuate in response to precipitation; whether these increases are the result of infiltrated precipitation or contributions from surface-water recharge into the aquifer is not well understood. Piezometers installed in the streambed of the Bogue Phalia indicate surface water recharges the shallow ground-water system when stage rises above about 10 feet (Bryson, 2006); this was a value calculated during the summer of 2005 and may change seasonally with fluctuating water levels.

In-stream piezometers showed varying responses to rising stage in the Bogue Phalia due to rainfall, most likely a result of discontinuous silt and clay layers that affect the rate of water flow between surface and ground water. Piezometers installed in the left, center, and right channels tend to have more interaction with the surface water than the other piezometers as indicated by hydrographs of water-surface altitude (fig. 3). The left, center, and right channel piezometers' ground-water levels have similar timing and magnitude of response to rainfall events as the Bogue Phalia stage, even during low-flow periods when the magnitude of stage fluctuations in the Bogue Phalia are relatively small (fig. 3).

Water Quality

Water-quality data are being examined to determine the interaction between surface and ground water in the study area. Non-parametric multidimensional statistics (MDS) were used to evaluate the potential surface- and ground-water interactions along the Bogue Phalia transect. Although most typically used in ecological applications, MDS significance testing of group distinctions (among other characteristics) is fully applicable to water-quality studies (Dan Calhoun, U.S. Geological Survey Georgia Water Science Center, oral communication, 2008). Samples were grouped into four categories: ground water, surface water, wells in the hyporheic zone (in-stream piezometers), and alluvial aquifer wells. Specific conductance, total dissolved solids, and nutrient concentrations were the constituents used in initial comparisons between groupings. Unlike traditional quantitative plots, the axes of an MDS plot only function to indicate the similarity among groups and are otherwise meaningless (Chan et al, 2005); therefore, for the purposes of this paper, the axes are not included in figure 4.

Preliminary analysis of water chemistry data, September 2005 through December 2007, using MDS plots, indicate that while most of the samples from individual groups plot together, on several occasions samples from aerial recharge well 1 (AR1) plot more similarly with samples from the Bogue Phalia (fig. 4). Future analysis will focus on determining the factors that allow well AR1 to behave chemically more like surface than ground water. Analysis will include examining different constituent combinations and how these combinations may affect the distribution of water types in the MDS plots. Additionally by varying constituent combinations, MDS analysis will help identify which particular constituents contribute most in determining similarity of water types.

Initial specific conductance (SC) data (fig. 5) indicate interaction to some degree between all wells and surface water. SC in the Bogue Phalia gradually rises during low-flow conditions from ground-water input, but then declines rapidly during run off events when rain water forms a large component of flow. During some run off events, the SC is lowered in some of the piezometers, presumably due to dilution of the ground water with surface water (fig. 5). This relation seems to be more pronounced in well AR1, located on the east side of the Bogue Phalia, than the other piezometers, and under certain conditions the SC changes similarly with the stage of the Bogie Phalia. Previous hypotheses about the direction of ground water movement in the Bogue Phalia basin assumed ground water flowed east to west, toward the Mississippi River. It appears here that, at the small scale, ground-water flow direction is west to east and is more highly dependent upon soils and local gradients and less influenced by regional flow.

Discussion

The change in the Bogue Phalia from a gaining to a losing stream has been determined using temperature data collected during Hurricanes Katrina and Rita (Bryson, 2006). Under normal conditions, the Bogue Phalia is a gaining stream, but after large storm events (when the gage height rises greater than about 10 feet) the alluvial aquifer is recharged by the stream, and so the potential exists for the quality of water in the alluvial aquifer to be affected by the introduction of surface water that may be carrying anthropogenic compounds. Water-quality data indicate that the water sampled from in-stream piezometers and shallow alluvial wells appears to be, at times, a mixture of surface and ground water. After storm events, water in well AR1 appears to be chemically similar to water in the Bogue Phalia; whereas water sampled in the other wells and piezometers seems to be less affected by high flows on the Bogue Phalia, probably due to the flow direction of localized ground water. Continued data collection at the site will allow further development of this hypothesis. Additionally, refining the model used in MDS analysis will aid in defining which constituents are important for determining the extent of surface and ground water interaction during periods of high or low flow.

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Figure 1. Location of Mississippi Embayment Study Unit, Bogue Phalia Basin, and Agricultural Chemical Transport Study flowpath.

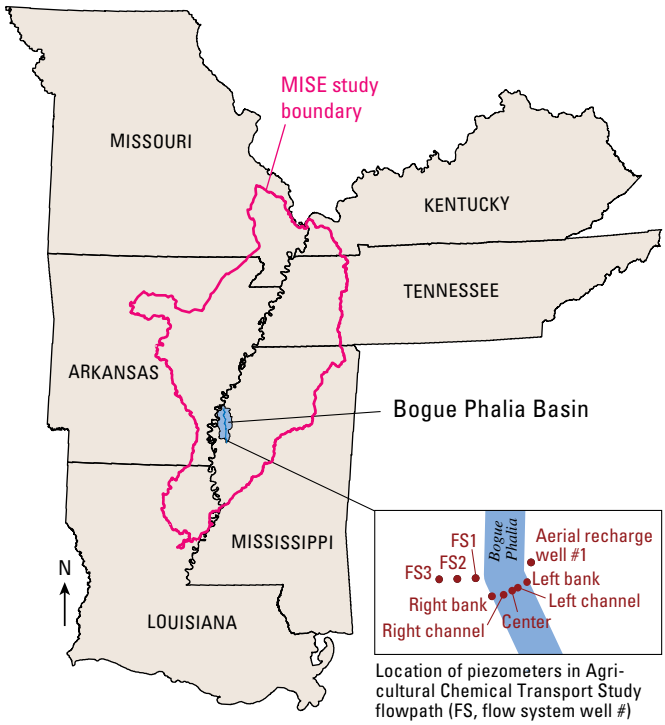
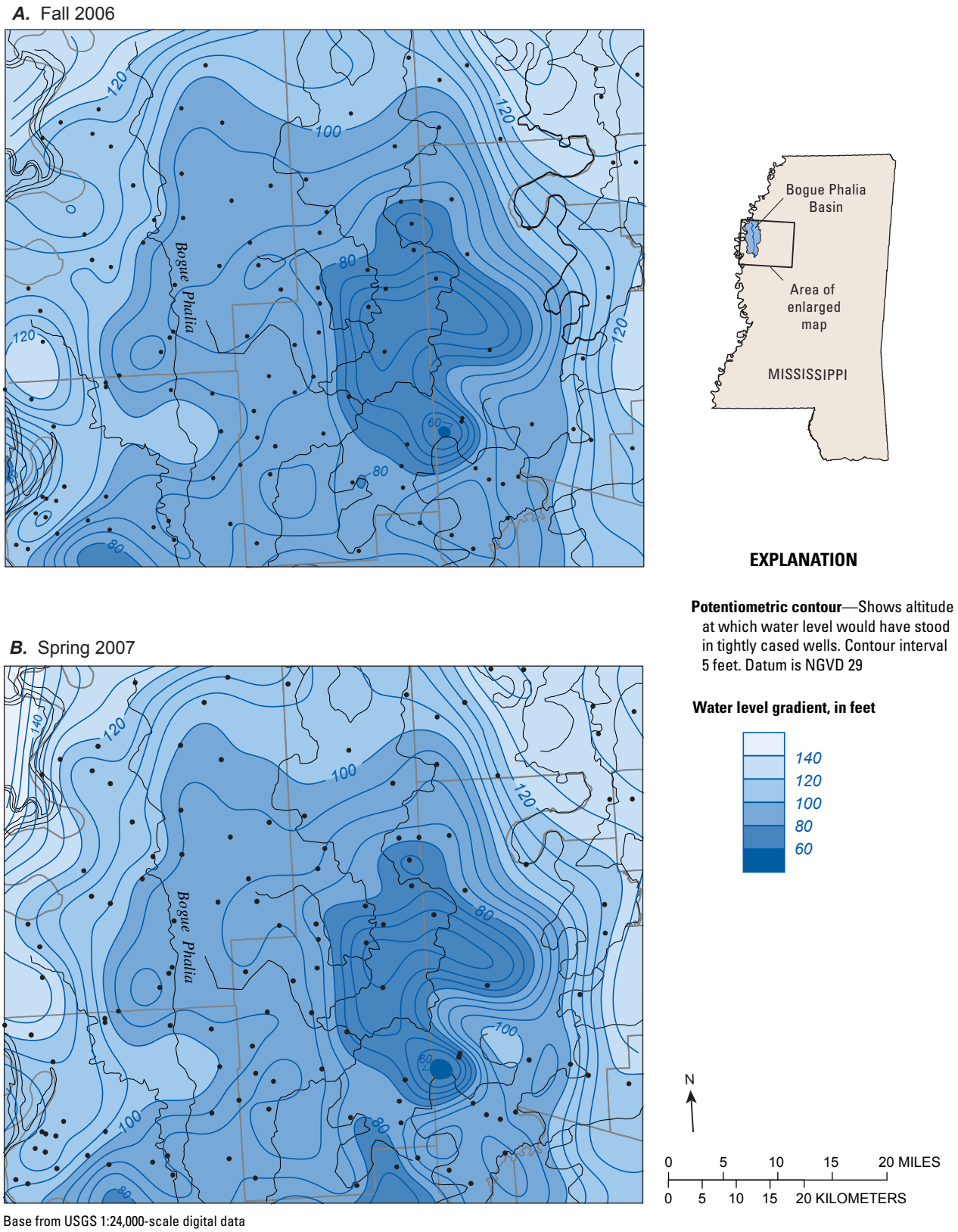


Figure 2. Potentiometric surface contours of the alluvial aquifer, fall 2006 and spring 2007 (Data from YMD, 2007).



Base from USGS 1:24,000-scale digital data

Figure 3. Water-surface altitudes for the Bogue Phalia and flowpath wells, (A) October-November 2006 and (B) April-May 2008.

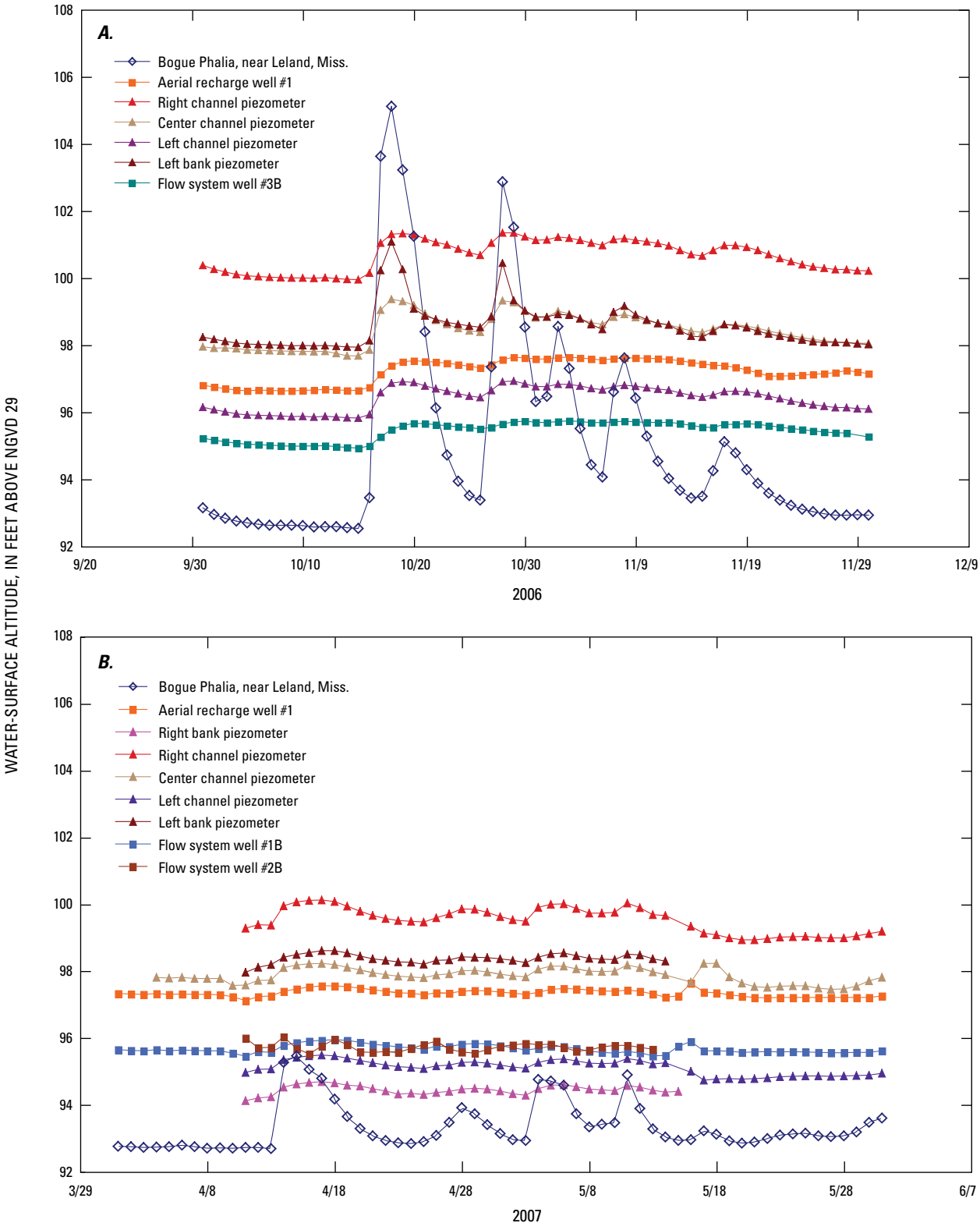


Figure 4. Comparison of water types along the Bogue Phalia transect using non-parametric multidimensional statistical plots of water-quality data.

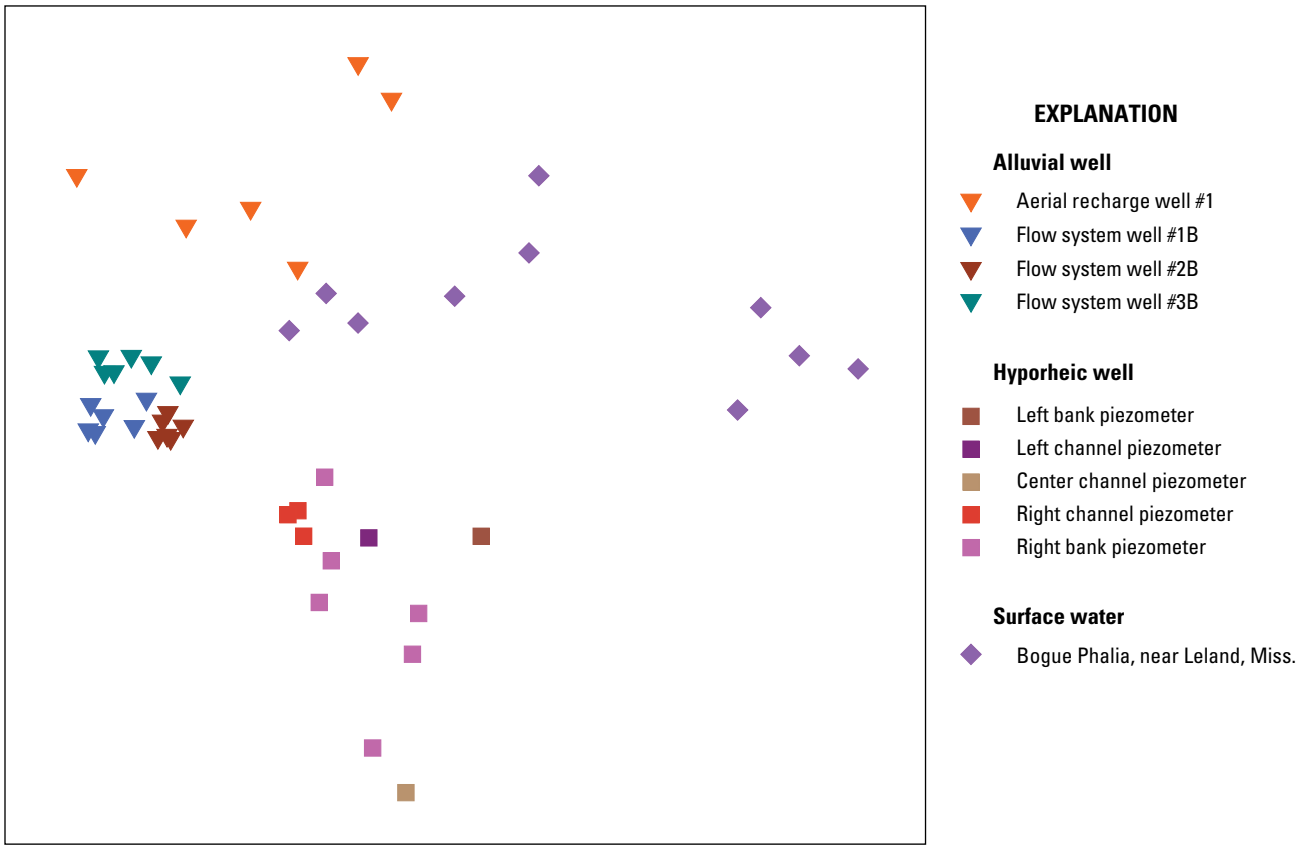


Figure 5. Specific conductance values measured at the Bogue Phalia, in-stream piezometers, flow system wells, and areal recharge well during quarterly sampling and storm events, 2006–2008.