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Long-term geochemical evaluation of the coastal Chicot aquifer system, Louisiana, USA

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SUMMARY

Groundwater is increasingly being overdrafted in the Gulf and Atlantic Coastal regions of the United States. Geochemical data associated with groundwater in these aquifers can provide important information on changes in salinity, recharge, and reaction pathways that can be used to improve water management strategies. Here we evaluated long-term geochemical changes associated with the 23,000 km^2 Chicot aquifer system in Louisiana, USA. The Chicot aquifer is currently being overdrafted by about 1,320,000 m^3 per day. We compiled selected bulk geochemical data from samples collected from 20 wells in the Chicot aquifer from 1993 to 2015. Oxygen and hydrogen isotope measurements were additionally completed for the 2014 samples. We identified three zones of groundwater with distinctive geochemical character; (1) A groundwater recharge zone in the northern part of the study area with low pH, low salinity, and low temperature relative to other groundwater samples, (2) a groundwater recharge zone in the southeastern part of the study area with low temperature, high alkalinity, and higher Ca and Mg concentrations compared to the other groundwater samples, and (3) groundwater in the southwestern part of the aquifer system with high salinity, high temperature, and a ~1:1 Na/Cl ratio. The geochemistry of these regions has been relatively stable over the last ~20 years. However, in the drought year of 2011, the estimated extent of zones with elevated salinity increased substantially. Geochemical evidence suggests that there was increased infiltration of deeper, more salt-rich waters into the shallower Chicot aquifer.

1. Introduction

Groundwater is increasingly being overdrafted in the Gulf and Atlantic Coastal regions of the U.S., including states such as Louisiana, Alabama, Georgia, Florida, and South Carolina (e.g., Konikow, 2013; Liu et al., 2008; Hook et al., 2000). A recent investigation of decadal trends in water budget changes using satellite data from the Gravity Recovery and Climate Experiment (GRACE) highlights severe groundwater depletion in these coastal aquifer systems (Famiglietti and Rodell, 2013). In some areas the overuse of groundwater has led to increased saltwater intrusion near the coast and diminished base flow in streams further landward (e.g., Garza and Krause, 1996; Heywood and Griffith, 2013). Collection of water geochemical data is essential in these regions because it can be used for tracking salt water intrusion, delineating changes in recharge zones, identifying areas of groundwater surface water interaction, and identifying water–rock interaction pathways. The difficulty in applying this tool, however, is that the water chemistry of most aquifer systems in the region has not been effectively monitored over decadal or longer time periods. One exception is the Chicot aquifer system in Southwest Louisiana. Chemical data have been collected regularly from approximately 20 wells in the Chicot aquifer for well over a decade. The Chicot is the most used aquifer in the state of Louisiana and is being overdrafted by an estimated 1,320,000 m^3 per day (350 million gallons per day; Sargent, 2011).

In this study, we compile available bulk geochemical data, including pH, temperature (T), salinity, sodium (Na), calcium (Ca), magnesium (Mg), chloride (Cl), and alkalinity, to evaluate changes in the Chicot aquifer that have occurred from 1993 to 2015. These data are combined with new oxygen (O) and hydrogen (H) isotope measurements to identify zones of saltwater intrusion, recharge, and water–rock interaction. This geochemical evaluation provides insights into how the Chicot aquifer may evolve in response to continued (and possibly accelerated) pressures from drought and the demand for groundwater.

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2. Chicot aquifer

The Chicot aquifer, covering an area of 23,000 km^2, is the most-used source of fresh groundwater in Louisiana, accounting for 41% of all groundwater withdrawals (Sargent, 2011; Fig. 1). The Chicot is comprised of a series of unconsolidated sands, gravels, silts and clays of Holocene through Pliocene-age that were generated by the ancestral Mississippi River to the east and the smaller Sabine and Calcasieu Rivers to the west (Prakken, 2003; Tollett et al., 2003; Lovelace et al., 2004; Fig. 1). Two >60 m thick sand units called the upper and lower Chicot aquifers comprise the primary aquifer units to the east. In the western part of the study area these units grade into a series of thinner sand units interbedded by impermeable zones of clay and silt (Nyman et al., 1990). In the western region the subunits are informally referred to as the 200ft (61 m), 500ft (152 m), and 700ft (213 m) sand units based on their approximate depths below ground surface (bgs). The sand units of the Chicot aquifer subcrop beneath soils to the north of the study region and dip steeply beneath semipermeable clays and silts to the south and southeast (Fig. 1). The clay/silt units that cap the aquifer sands range from 12 m to over 60 m in thickness (Sargent, 2004). Hence, the Chicot behaves as an unconfined aquifer system where it subcrops to the north and a confined aquifer system to the south. The Chicot aquifer study area is bounded on the west by the Sabine River and to the east by the Atchafalaya River and its alluvial floodplain (Fig. 1). The geologic extent of the Chicot aquifer extends westward, well outside of the hydrologic zone that defines the aquifer system in southwestern Louisiana, and is an important aquifer for the city of Houston, Texas. Recharge to the Chicot aquifer in Louisiana is thought to be limited to rainfall in the north, upward movement from underlying aquifers, and downward infiltration associated with the Atchafalaya boundary river to the east (e.g., Nyman et al., 1990; Sargent, 2004).

Demand for water from the Chicot aquifer is dominated (~70%) by agricultural users, primarily for the irrigation of rice (LDNR, 2012; Sargent, 2011). The cities of Lake Charles and Lafayette are the largest public supply users of groundwater in the region (Fig. 1). Prior to the development of the aquifer in the early 1900s, water flowed from north to south and had a high enough pressure head that wells near the coast were artesian (Nyman et al., 1990). Nyman et al. (1990) estimates that the Chicot aquifer has lost about 0.3 m of potentiometric surface per year since 1900. Currently, the drawdown of the potentiometric surface from pumping due to rice irrigation and industrial needs, largely in Jefferson Davis, Acadia, and Calcasieu Parishes (Fig. 1), has caused groundwater to flow from all directions toward these agricultural and industrial centers. Recent estimates of the water supply gap suggest that the Chicot aquifer is being over-drafted by about 1,320,000 m^3 per day and projections suggest that over-drafts will increase by an additional 460,000 m^3 per day by 2030 (LDNR, 2012).

Previous geochemical investigations of groundwater in the Chicot aquifer have primarily been limited to "snapshots" of the quality of water collected during investigations of domestic wells (e.g., Prakken, 2003; Tollett et al., 2003). These investigations have shown that water in the Chicot is generally of high quality with few contaminants of concern. For example, in a study of 173 domestic wells, Prakken (2003) found that sulfate, fluoride, and nitrate concentrations for all the sampled wells were below US EPA drinking water standards. Tollett et al. (2003) analyzed about 30 wells within the present study area and also found that nutrients (e.g., ammonia, nitrate, and phosphorous) did not exceed US EPA drinking water standards. Some areas of elevated iron, manganese, and chloride concentrations were, however, identified in both investigations. Other studies have reported solely on chloride and/or specific conductivity measurements, demonstrating that

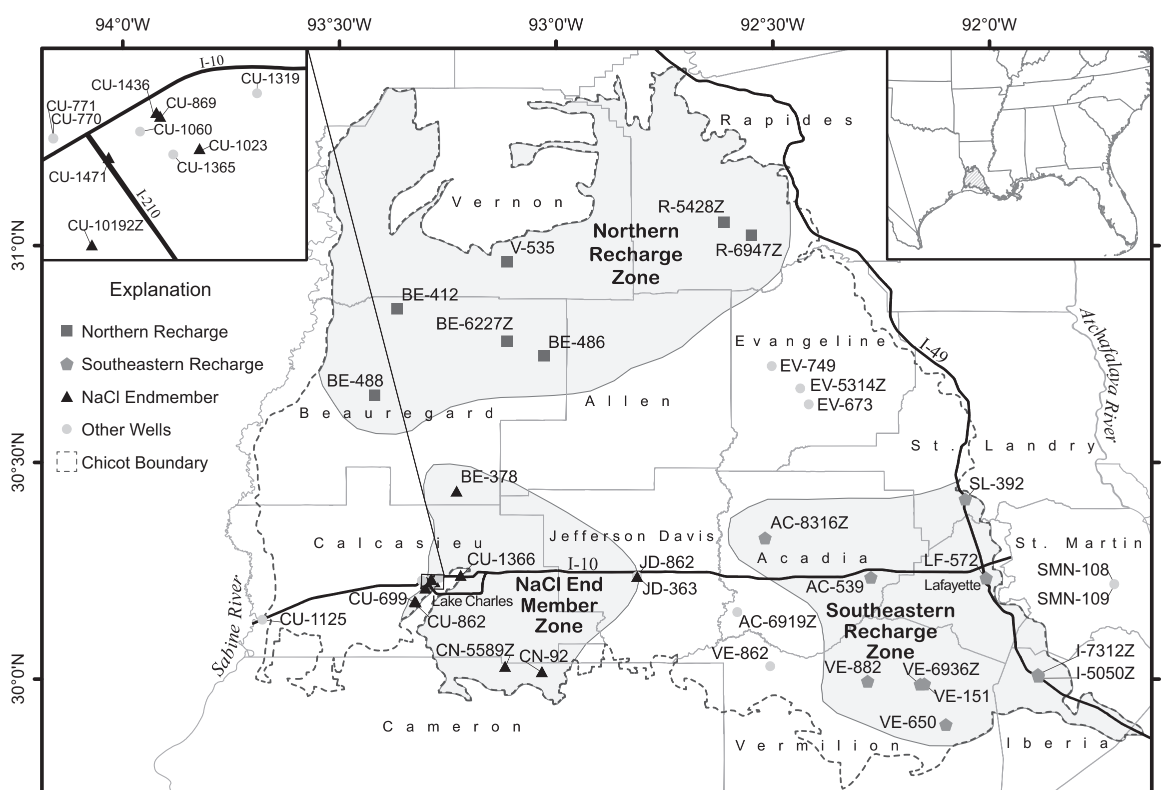

Fig. 1. Location map showing the Chicot aquifer study area and the locations of sampled wells. The shaded regions represent the zones identified in the text that exhibit different groundwater chemistries.