Simulation of groundwater flow in the Southern Hills regional aquifer system, and movement of saltwater in the 2,000-foot sand of the Baton Rouge area, Louisiana.

Charles E. Heywood[1], John K. Lovelace[2]
[1]*U.S. Geological Survey, cheywood@usgs.gov, Ridgway, CO, USA*
[2]*U.S. Geological Survey, jlovelac@usgs.gov, Baton Rouge, LA, USA*

ABSTRACT

Groundwater withdrawals since the 1940s have lowered water levels, altered groundwater-flow directions, and caused saltwater to intrude within some freshwater-containing sands of the fluvial-deltaic Southern Hills regional aquifer system beneath Baton Rouge, Louisiana. Groundwater investigations in the 1960's identified a freshwater-saltwater interface located at the Baton Rouge fault, where abrupt changes in water levels also occur. Generally, aquifers south of the fault contain saltwater and aquifers north of the fault contain freshwater, although by 2005 saltwater intrusion had been detected in seven of the ten sand aquifers north of the fault. The aquifers underlie East and West Baton Rouge Parishes, Pointe Coupee Parish, and East and West Feliciana Parishes, and provided about 184 million gallons per day (Mgal/d) for public supply and industrial use in 2012. Groundwater withdrawals from one aquifer about 2,000-feet deep (locally termed the “2,000-foot” sand) in East Baton Rouge Parish totaled 28.5 Mgal/d during 2012, and have caused water-level drawdown up to 356 feet and induced saltwater movement across the fault. This saltwater threatens industrial wells located about 3 miles north of the fault that accounted for 68 percent of the withdrawals from the “2,000-foot” sand in East Baton Rouge Parish in 2012. A variable-density groundwater model was developed using SEAWAT to evaluate saltwater remediation scenarios, including reductions in the groundwater withdrawals and installation of “scavenger” wells to withdraw and divert saltwater. Scenarios that incorporate a scavenger well simulate more effective saltwater-plume remediation than scenarios that reduce groundwater withdrawals.

INTRODUCTION

Fresh groundwater from the Southern Hills regional aquifer system is used for public and industrial supply in southeastern Louisiana. Ten sand aquifers are named for their depth of occurrence in the Baton Rouge area, which includes East and West Baton Rouge Parishes, Pointe Coupee Parish, and East and West Feliciana Parishes (fig. 1). These aquifers provided about 184 million gallons per day (Mgal/d) for public supply and industrial use in 2012. Fresh groundwater in most of these aquifers is generally soft, sodium bicarbonate water with a dissolved-solids concentration of less than about 200 milligrams per liter (mg/L) (Meyer and Turcan, 1955) that requires little treatment (Stuart and others, 1994). Groundwater withdrawals in the Baton Rouge area since the 1940s have lowered water levels and altered groundwater-flow directions in most of the 10 underlying freshwater-bearing aquifers, and caused saltwater to intrude north of the Baton Rouge fault. By 2005, saltwater intrusion had been detected in seven aquifers, including the “1,200-foot” sand and “2,000-foot” sand in East Baton Rouge Parish (Lovelace, 2007). Groundwater withdrawals from the “2,000-foot” sand, (28.5 Mgal/d during 2012) have caused water-level drawdown up to 356 feet and induced saltwater movement north of the fault. This saltwater threatens industrial wells located about 3 miles north of the fault that accounted for about 68 percent of the withdrawals from the 2,000-ft sand in East Baton Rouge Parish in 2012.

Water planners and managers need a tool to assess possible remediation strategies to control further saltwater intrusion in the Baton Rouge area. The U.S. Geological Survey, in cooperation with the Capital Area Ground Water Conservation Commission, Louisiana Department of Transportation and Development, and the City of Baton Rouge and Parish of East Baton Rouge, developed a groundwater-flow and saltwater-transport model of the Southern Hills regional aquifer system (Heywood and others, 2014) to evaluate the effects of remediation strategies on saltwater intrusion.

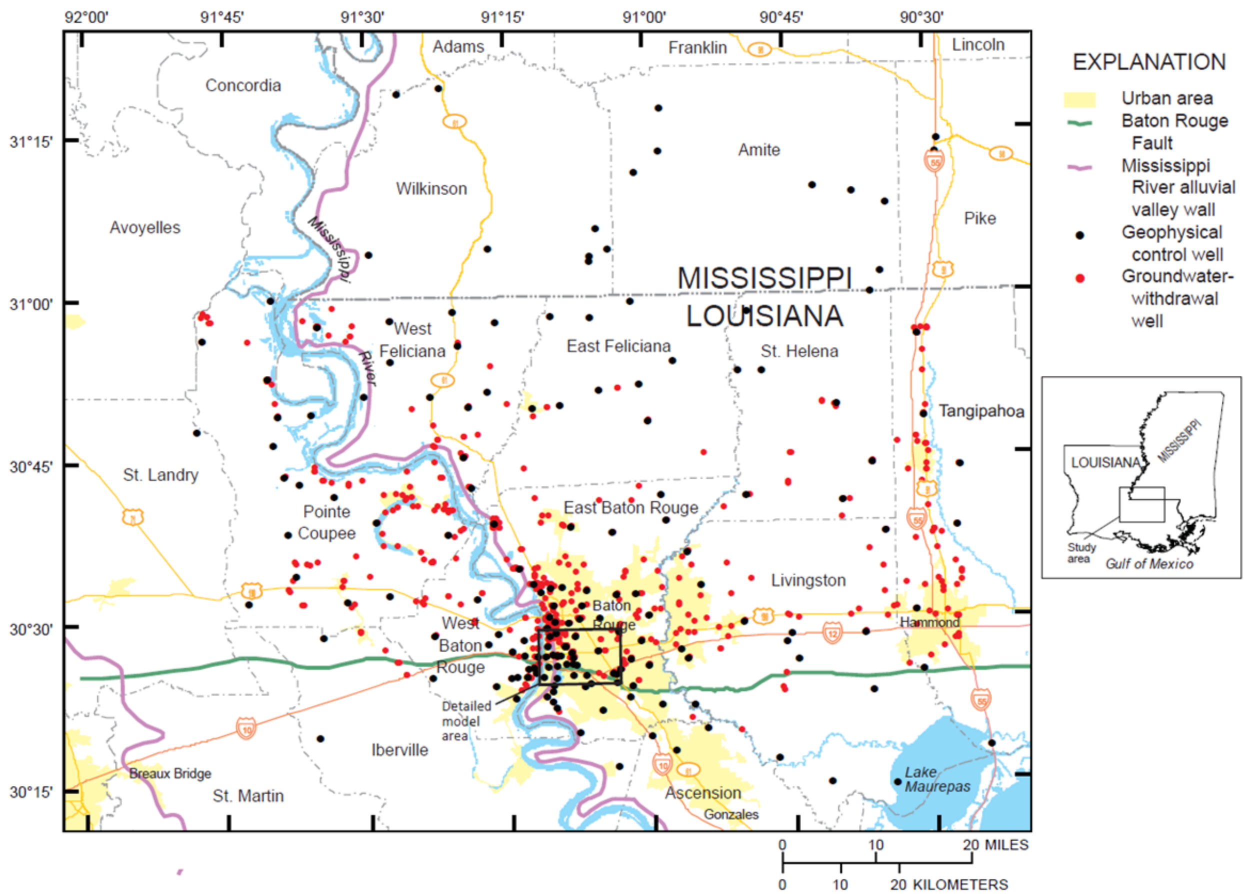

Figure 1. Map of the study area, showing location of the Baton Rouge Fault, geophysical-control and groundwater-withdrawal wells in southeastern Louisiana and southwestern Mississippi.

GROUNDWATER FLOW AND TRANSPORT MODEL

The flow and transport model of the Southern Hills regional aquifer system simulates the effects of groundwater withdrawals on groundwater flow in the aquifer system and the movement of saltwater northward from the Baton Rouge Fault in the “2,000-foot” sand in East Baton Rouge Parish. Density differences between areas with contrasting saltwater concentrations affect groundwater flow between those areas, so the variable-density SEAWAT code that couples the groundwater flow and solute-transport equations (Langevin and others, 2003), was used to simulate groundwater flow and chloride transport. A 3-dimensional hydrogeologic framework was constructed using geophysical data from locations shown in figure 1 to define the extents and thicknesses of the aquifers and confining units in the study area, which also encompasses the groundwater flow model domain. The model contains 24 layers that represent the entire sequence of sands and clays from land surface to the base of the “2,800-foot” sand (fig. 2). The top layer represents the Mississippi River alluvial aquifer, shallow sands, upland terrace aquifer, and the “400-foot” sand, “600-foot” sand, and “800-foot” sand. The “2,000-foot” sand is represented by 10 layers (layers 11-20). The finite-difference grid incorporates increasing cell spacing toward the model boundaries so that the entire 6,529 square mile study area is contained within 95 rows and 120 columns of finite-difference cells. The hydrogeologic framework geometry was defined independently from finite-difference discretization, which facilitated simulation of flow between hydrogeologic units where they are juxtaposed at the Baton Rouge Fault. Additional resistance to flow across the Baton Rouge Fault was simulated with horizontal flow barriers. Following an initial steady-state stress period that simulated predevelopment conditions prior to 1940, 73 annual transient stress periods simulated the period 1940 through 2012. The period 2013 through 2014 was simulated with 2012 withdrawal rates. Three additional stress periods were then used to simulate five scenarios to predict the effects of remediation strategies from 2015 through 2112. Transient water levels within the top model layer were specified by interpolation between levels observed during 1944, 1980, 1984, 1990, 1998, 1999, and 2004. Underflow to and from areas south of the simulated aquifer system was represented through a specified-head boundary along the southernmost row of the deepest model layer that was estimated during model calibration. The remaining lateral and lower boundaries of the flow domain were simulated as no-flow boundaries. Average daily withdrawal rates were specified for 636 wells for each annual stress period from 1940 through 2012.

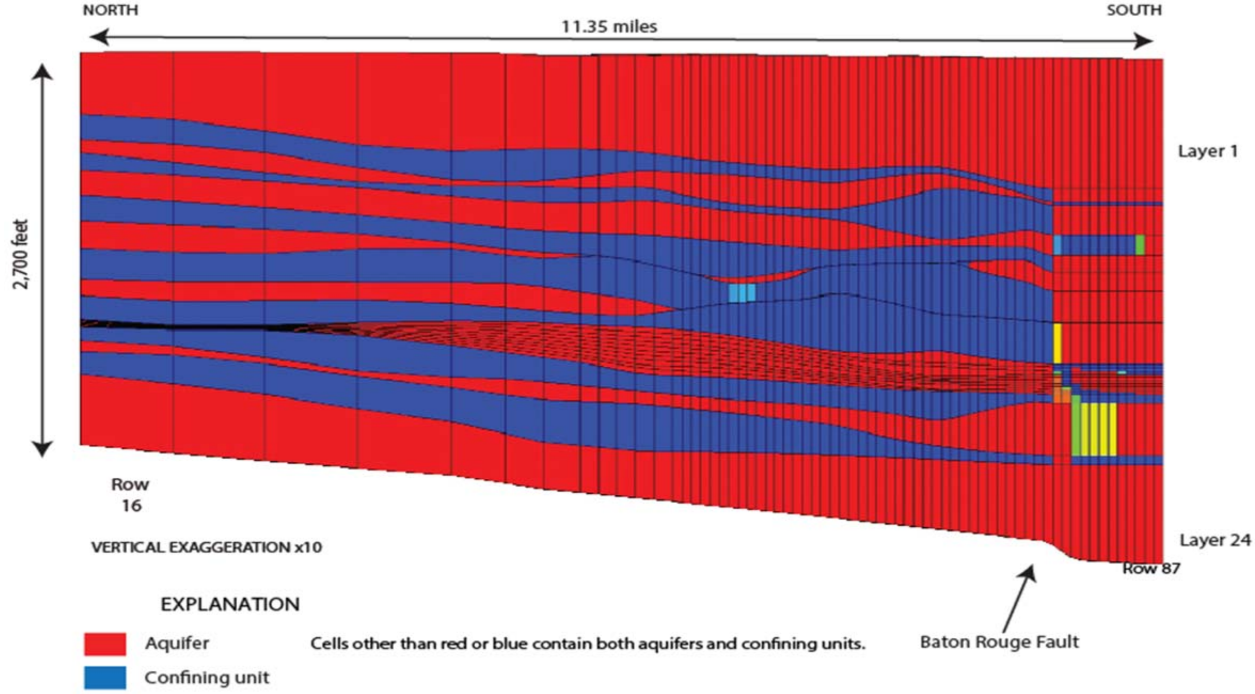

Figure 2. North-South vertical section along column 24 from row 16 to row 87 showing aquifer and confining layers.

The groundwater-flow model was calibrated to 3,895 water levels measured between 1940 and 2011 with the parameter-estimation code PEST (Doherty, 2004). One thousand sixteen additional water levels were used to evaluate the accuracy of the specified-head boundaries in the top model layer. The estimated values of 212 parameters representing hydraulic conductivity and specific storage were all within the range considered reasonable. Under predevelopment conditions, the simulated steady-state water budget indicates that about 67.5 Mgal/d of water entered and exited the groundwater-flow model domain (table 1). Net simulated infiltration of 3.35 Mgal/d from the top specified-head model layer into the underlying model layer is balanced by net outflow through the constant-head boundary along the southernmost row of the deepest model layer (layer 24). By the end of the transient historical simulation (December 31, 2012), substantial net groundwater withdrawals (171 Mgal/d during 2012) had caused water-level declines and increased net infiltration from layer 1 to 92.9 Mgal/d.

Budget component		Steady-state (Mgal/d)	Transient (Mgal/d)
In	Specified-head layer 1	65.56	108.45
	South row of layer 24	1.90	64.74
	Storage	0	13.66
	Multi-node wells	0	0.79
Out	Specified-head layer 1	62.21	15.52
	South row of layer 24	5.25	0
	Storage	0	0.02
	Multi-node wells	0	172.10

Table 1. Steady-state and transient flow rates.

Solute transport was simulated within a 60-row by 90-column portion of the model domain in the Baton Rouge area that is composed of 500-ft by 500-ft finite-difference cells (“detailed model area” on figure 1). Grid cells south of the Baton Rouge Fault are constant-concentration boundaries (fig. 3), while cells north of the fault are variable-concentration cells for which a concentration was calculated for each transport time step. The initial chloride concentration within grid cells on the south side of the Baton Rouge Fault (layers 10 through 20) increase linearly with depth from 0 to the maximum concentration of 10,000 milligrams per liter (mg/L) that was estimated during model calibration. These model layers are laterally connected to the 10 layers that simulate the “2,000-foot” sand north of the fault. Other areas within the solute transport domain had initial concentrations of 0 mg/L. By 2012, simulated chloride concentrations immediately north of the fault are as high as 5,120 mg/L and rapidly decline to the north between wells EB-781 and EB-807B (fig. 3).

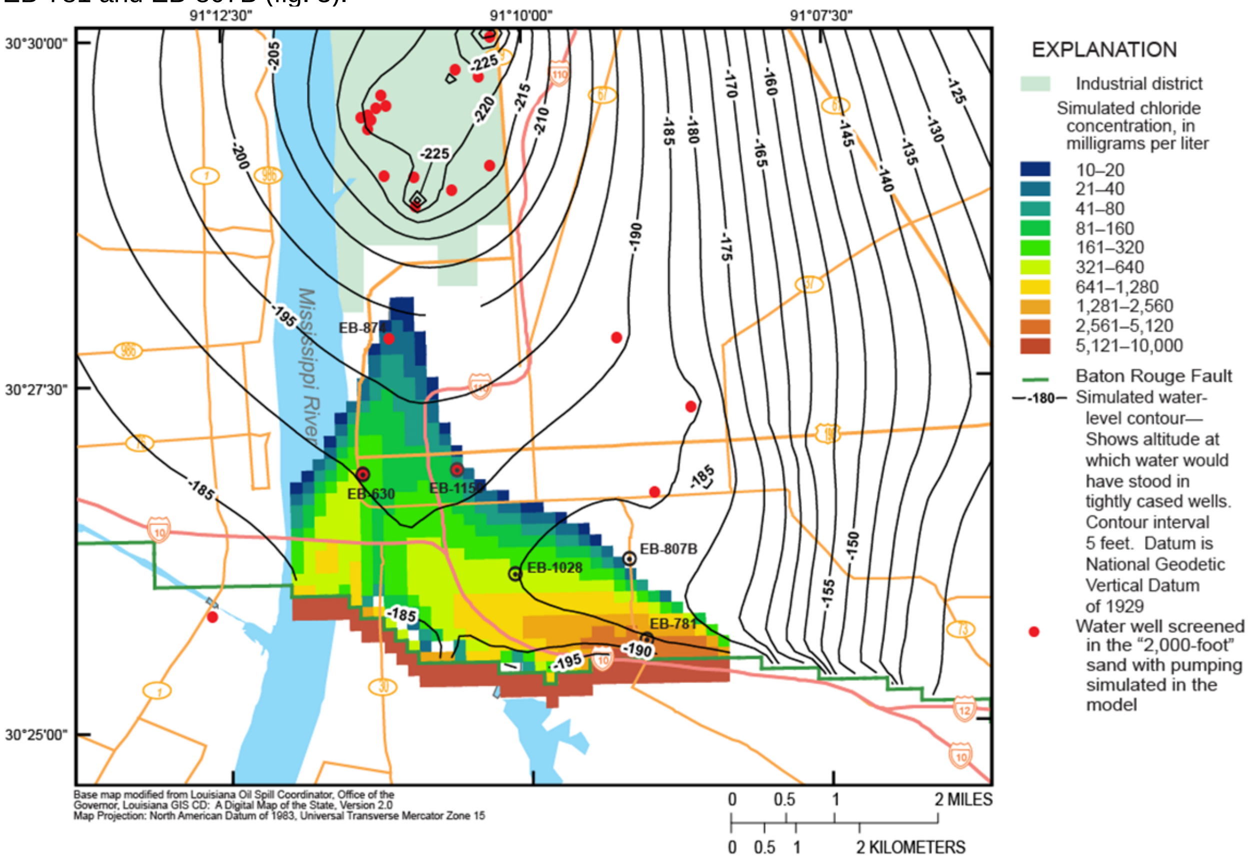

Figure 3. Simulated 2012 water levels and chloride concentrations at the base of the "2,000-foot" sand of the Baton Rouge area in the detailed model area in southeastern Louisiana.

SIMULATED MANAGEMENT SCENARIOS

Five scenarios simulated the effects of various remediation strategies in the “2,000-foot” sand from 2012 through 2112. Scenario 1 provides a “status quo” benchmark for comparison to four other scenarios by continuing 2012 withdrawal rates for 100 years. Scenario 2 simulates a 0.70 Mgal/d decrease in withdrawals from the “2,000-foot” sand, whereas scenario 3 simulates a ten-fold reduction, (7.34 Mgal/day). Scenario 4 simulates the same reduction as scenario 2, but includes 1.25 Mgal/d withdrawals from a “scavenger well” that pumps saltwater from the base of the “2,000-foot” sand and fresh water from the top of that aquifer. Scenario 5 simulates the larger reductions in scenario 3 with the 1.25 Mgal/d scavenger-well withdrawals at the same location as in scenario 4. Modifications to withdrawal rates at selected existing and hypothetical public supply and industrial wells were simulated to begin in 2015, whereas withdrawals from the hypothetical scavenger well were simulated to begin in 2017. The simulated effects of all scenarios are summarized by plots of the rate of net salt mass (NaCl) accumulation in the aquifer through time (fig. 4). The rate of salt accumulation decreases for all scenarios, including scenario 1, because salt transport decreases with the decreasing simulated hydraulic gradient across the fault as hydraulic equilibrium is approached. The rate curves could be used to evaluate the effectiveness of the different remediation scenarios. By this metric, scenario 2 is least effective in reducing salt accumulation, whereas the scavenger-well scenarios (4 and 5) are most effective in lowering the rate of salt-mass accumulation. The scavenger-well scenarios also result in the smallest median chloride concentrations within saline areas north of the fault. These results suggest that installation of scavenger wells are more effective in controlling saltwater intrusion than reductions to industrial and public-supply withdrawals.

Ongoing improvements to the model include simulation of transport in other aquifers including the “1,200-foot”, “2,400-foot”, and “2,800-foot” sands. Results of these simulations will further assist the local groundwater management authorities in their evaluation of their saltwater intrusion remediation options.

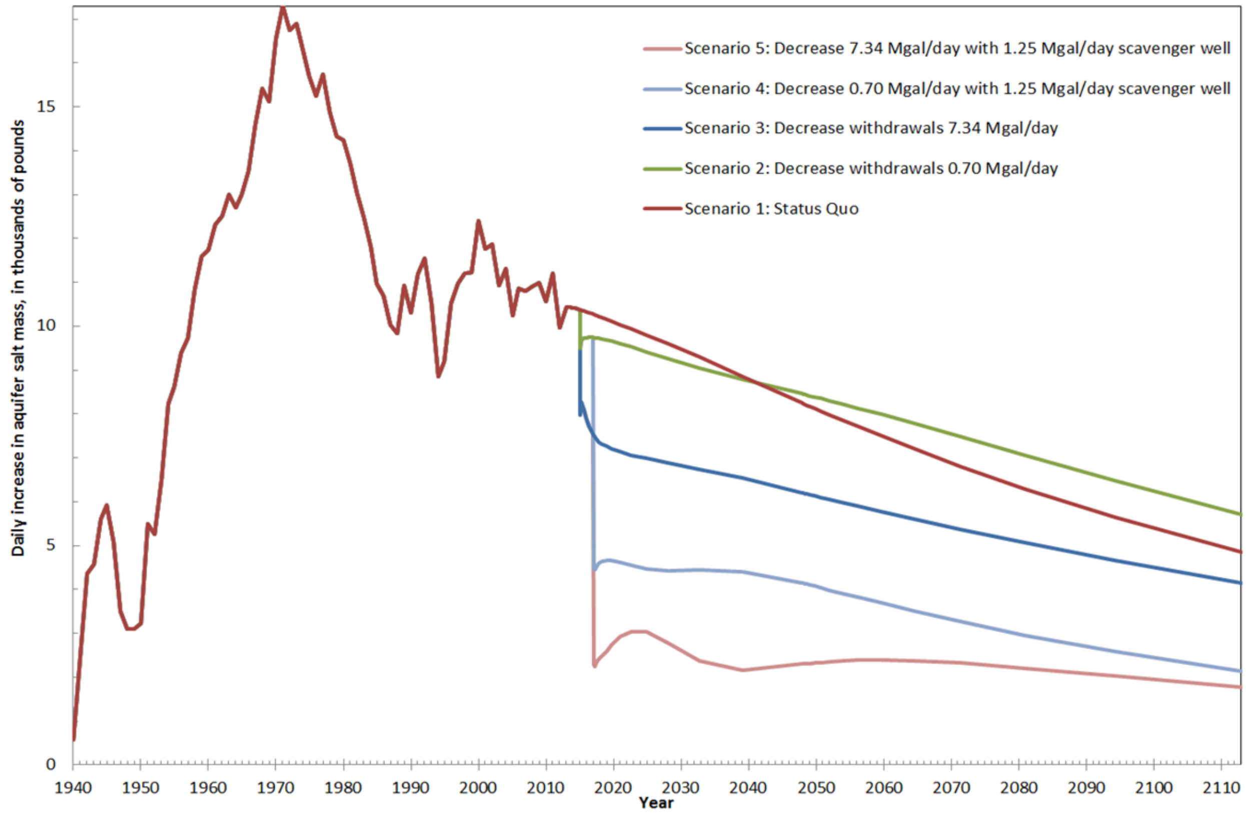

Figure 4. Simulated changes in salt mass in the "2,000-foot" sand of the Baton Rouge area north of the Baton Rouge Fault, 1940-2012, and predicted changes in salt mass during 5 hypothetical pumping scenarios, 2013-2112.

REFERENCES

Doherty, John, 2004, PEST—Model-independent parameter estimation, user manual (5th ed.): Corinda, Australia, Watermark Numerical Computing, 336 p.

Heywood, C.E., Griffith, J.M., and Lovelace, J.K., 2014, Simulation of groundwater flow in the “1,500-foot” sand and “2,000-foot” sand, with scenarios to mitigate saltwater migration in the “2,000-foot” sand of the Baton Rouge area, Louisiana (ver. 1.1, April 2014): U.S. Geological Survey Scientific Investigations Report 2013-5227, 63 p., http://dx.doi.org/10.3133/sir20135227

Langevin, C.D., Shoemaker, W.B., and Guo, Weixing, 2003, MODFLOW-2000, the U.S. Geological Survey modular ground-water model—Documentation of the SEAWAT-2000 version with the variable-density flow process (VDF) and the integrated MT3DMS transport process (IMT): U.S. Geological Survey Open-File Report 03–426, 43 p.

Lovelace, J.K., 2007, Chloride concentrations in ground water in East and West Baton Rouge Parishes, Louisiana, 2004–05: U.S. Geological Survey Scientific Investigations Report 2007–5069, 27 p.

Meyer, R.R., and Turcan, A.N., Jr., 1955, Geology and ground-water resources of the Baton Rouge area, Louisiana: U.S. Geological Survey Water-Supply Paper 1296, 138 p.

Stuart, C.G., Knochenmus, Darwin, and McGee, B.D., 1994, Guide to Louisiana’s ground-water resources: U.S. Geological Survey Water-Resources Investigations Report 94–4085, 55 p.