Development and Maintenance of a Computer Model to Simulate Groundwater Flow and Saltwater Encroachment in the Baton Rouge Sands, Louisiana

SUMMARY

Ten aquifers beneath the Baton Rouge area, Louisiana, are used for freshwater supplies and are variably impacted by water-level declines and/or saltwater encroachment. Long-term water-level declines have occurred in most of these aquifers and saltwater encroachment has been detected in six aquifers north of the Baton Rouge fault in East Baton Rouge Parish. The encroachment is in response to groundwater withdrawals, primarily for public supply and industrial uses, in Baton Rouge. Additional information is needed for water planners and managers in the Baton Rouge area to make decisions on future management of groundwater resources in the area. Computer models of the aquifers can be used to assess the impacts of past, current, and future pumping on water levels, groundwater flow directions, and saltwater movement in these aquifers.

During 2007-12, The U.S. Geological Survey, in cooperation with the Capital Area Ground Water Conservation Commission, the Louisiana Department of Transportation and Development, and the East Baton Rouge City-Parish Government, developed a computer model to simulate groundwater flow in the '1,500-foot" and "2,000-foot" sands and saltwater encroachment in the "2,000-foot" sand. Although the model focused on the '1,500-foot" and "2,000-foot" sands and was primarily calibrated to simulate the hydrology of those sands, the model incorporated all 10 of the Baton Rouge sands so that it could be modified at a later date to simulate flow and encroachment in all of the aquifers.

The USGS proposes to update, modify, and calibrate the model to accurately simulate groundwater conditions in all 10 Baton Rouge sands. The model would provide a tool for water planners and managers to assess the impacts of pumpage changes on all of the aquifers, evaluate possible management alternatives, and to make decisions about future development of groundwater resources in the area.

INTRODUCTION

Groundwater withdrawals in southeastern Louisiana have caused saltwater to encroach into freshwater aquifers. The most heavily pumped area includes the City of Baton Rouge and surrounding areas. The ten aquifers that underlie the Baton Rouge area, which includes East and West Baton Rouge Parishes, Pointe Coupee Parish, and East and West Feliciana Parishes, supplied about 173 Mgal/d (million gallons per day) in 2010 (B.P. Sargent, U.S. Geological Survey, written commun., 2011). Withdrawals in East Baton Rouge Parish accounted for about 153 Mgal/d.

Groundwater investigations in the 1960's delineated a freshwater-saltwater interface located near the Baton Rouge fault. Generally, aquifers in the Baton Rouge area contain freshwater north of the fault and saltwater south of the fault. Chloride concentrations are generally less than 10 milligrams per liter in these aquifers north of the fault. Most saltwater north of the fault, with the exception of the "2,800-ft" sand, has been induced across the fault by withdrawals in the Baton Rouge area.

Saltwater encroachment into freshwater areas north of the fault has been monitored in several aquifers using a network of observation wells. Saltwater was initially detected as early as the 1940's in the "600-ft" sand; by the 1990's saltwater had been detected in six aquifers north of the fault including the "600-ft," "1,000-ft," "1,200-ft," "1,500-ft," "2,000-ft," "2,400-ft," and "2,800-ft" sands. In some aquifers, production wells have been impacted.

PROBLEM

Additional information is needed for water planners and managers in the Baton Rouge area to make decisions on future management of groundwater resources in the area. Groundwater flow and solute transport models are needed for the Baton Rouge sands to simulate the effects of past, current, and a variety of possible future pumping scenarios and provide a tool to evaluate possible management alternatives. A unified model that simulates conditions for all of the aquifers will facilitate analysis of the effects of pumping changes within a particular aquifer on water levels in other aquifers in the area.

OBJECTIVE

The objective of the proposed work is to develop and periodically update a groundwater flow and solute transport model of all 10 Baton Rouge sands that can be used to assess changes in pumping and evaluate possible groundwater management alternatives.

RELEVANCE AND BENEFITS

Use of a single model to simulate groundwater flow and saltwater encroachment in multiple aquifers will improve our understanding of how the aquifers work as a system. Because the aquifers are interconnected, changes in pumping in one aquifer often affects water levels within overlying and underlying aquifers. Use of a single model will improve our ability to assess these effects and manage groundwater resources. In addition, development of the proposed model will improve the understanding of:

1) current and future groundwater flow in the area.
2) the effects of each pumping center on the generalized flow (potentiometric surfaces).
3) the direction and movement of saltwater in the aquifers.
4) hydrogeologic structure of aquifers near the Baton Rouge fault in East and West Baton Rouge Parishes.

The finished model would provide a tool to evaluate:

1) the effectiveness of possible management options.
2) impacts of alternative pumping scenarios.
3) possible locations for saltwater monitor wells.
4) possible locations for scavenger or barrier wells.
5) saltwater discharge rates from scavenger wells.

APPROACH

The groundwater flow and solute transport model developed during 2007-12 will be enhanced, updated, and modified to enable assessment of the effects of pumping changes in all 10 Baton Rouge sands. The model was primarily calibrated to simulate flow in the "1500-ft" and "2,000-ft" sands and saltwater encroachment in the "2,000-ft" sand.

Model update

The groundwater flow and solute transport model developed during 2007-12 utilized well-construction data, pumpage, water-level, and chloride-concentration data from 1940 through 2007. The model will be updated to include data collected and compiled since 2007. The State well-registration database and CAGWCC records will be reviewed to identify new wells within the model domain. Well-construction data will be incorporated into the model as appropriate. Data on groundwater withdrawals since 2007 will be compiled from USGS and CAGWCC records and will be incorprated into the model simulation. Water-level and chloride concentration data collected since 2007 during routine monitoring also will be utilized first to test the predictive capability of the currently-calibrated model, and subsequently to provide additional data for an updated model calibration, if necessary.

Model modification and calibration

The model developed during 2007-12 emphasized accurate simulation of water levels in the "1,500-ft" and "2,000-ft" sands. To simplify development and calibration of the model, some sands were grouped into a single hydrogeologic unit. The model will be modified and calibrated for groundwater flow and, when needed, solute transport in additional sands in order of priorities established in consultation with the CAGWCC. A tentative list of concerns and priorities is shown in table 1.

Existing model layers that represent more than one aquifer will be split into two or more layers to represent individual aquifers. Where saltwater encroachment is an issue, mulitple layers will probably be used to more accurately resepresent the stratigraphic variability of a sand and the stratification of saltwater within the sand. For instance, 10 model layers are currently used to simulate groundwater flow and salt transport within the "2,000-ft" sand in the original model. The location and thickness of interbedded sand, silt, and clay layers within an aquifer will be determined from electric log data and used to define the thickness of layers within a sand.

Groundwater flow and saltwater encroachment will be calibrated for each sand as needed in orders of priorities determined in consultation with the CAGWCC. USGS modelling software, MODFLOW-2005 (Harbaugh, 2005), MT3DMS (Zheng and Wang, 1999),and SEAWAT

(Langevin and others, 2005), will continue to be used to simulate flow and saltwater encroachment.

Table 1. Baton Rouge aquifer concerns ranked and prioritized by water use, water-level trends, and chloride trends at network wells.

	Withdrawals, in million gallons per day			Priority/concern rating				
Sand	Total	Public supply	Industrial and power generation	Use	Water-level	Salt-water	Overall	Comments
400-ft	7.22	2.58	4.37	2	1	1	1	Several dual-screened wells in the 400-ft and 600-ft sands
600-ft	10.69	3.37	7.29	3	3	5	4	Large saltwater plume downtown
800-ft	5.37	4.79	0.58	2	2	2	2	Saltwater detected north of fault downtown
1000-ft	9.96	9.19	0.74	2	5	4	4	Saltwater along fault downtown and in southeast BR
1200-ft	21.55	12.05	9.40	4	5	3	4	Saltwater at public supply well near fault
1500-ft	25.49	17.34	7.36	4	5	5	5	Large plume affecting several public supply wells
1700-ft	11.36	4.89	6.03	2	5	1	3	Water-level declines likely caused by pumpage from 1500-ft sand
2000-ft	25.41	8.23	17.18	4	2	5	4	Large plume affecting public supply wells
2400-ft	21.66	16.33	5.24	4	4	3	4	Saltwater along fault downtown and in southeast BR
2800-ft	35.09	14.42	20.60	5	4	4	4	Saltwater affecting southernmost public supply wells in north BR

Use rankings (1, 0-5 Mgal/d; 2, 5-10 Mgal/d; 3, 10-20 Mgal/d; 4, 20-30 Mgal/d; 5, 30-40 Mgal/d)

Water-level rankings (1, rising water levels; 2, stable water levels; 3, stable with some declines; 4, slowing declines; 5, mostly declining)

Saltwater rankings (1, no encroachment; 2, saltwater present; 3, chloride rising; 4, production wells impacted; 5, large plume)

The version of the model developed during 2007-2012 utilizes a specified-head boundary condition in the model layer representing the “400-ft”, “600-ft”, and “800-ft” sands. This configuration does not allow simulation of the effects of future pumping from those sands, nor the possible effects of other environmental stresses, such as drought. The updated model will simulate water levels and possibly chloride concentrations within these sands by representing each of them with one or more finite-difference model layers. For the uppermost model layer, the change in water table elevation through time under unconfined conditions may be simulated by specifying transient (time varying) aerial recharge and evapotranspiration. Although simulation of transient changes in water table elevations has been difficult in the past because of a "wet/dry problem" with the model code, which can cause numerical instability, this model may utilize a new version of MODFLOW-NWT (Niswonger and others, 2011), that employs a Newton-Raphson-based formulation of the groundwater-flow equation and effectively eliminates this "wet/dry problem".

If the accurate simulation of particular sands requires a particular numerical technique (such as Newton-Raphson for an unconfined aquifer) or finer discretization than is present in the current version of the model, this may be accomplished by numically coupling a "child model" of the sand of interest with the current, or "parent model" using a local grid refinement technique (Mehl and Hill, 2012).

The model will be calibrated using historic water-level and chloride concentration data with the parameter-estimation programs PEST (Doherty, 2004) or UCODE-2005 (Poeter and others, 2005), both of which optimize the model calibration using non-linear regression. The calculation of observation and model-parameter sensitivities is an integral part of these regression methods, and these can be evaluated to help determine influential observations and controlling hydraulic properties. The formal parameter-estimation techniques also enable subsequent evaluation of predictive uncertainty (Doherty and others, 2010), and the potential worth of additional data in reducing model predictive uncertainty (Dausman and others, 2010). Such uncertainty analyses can be useful in designing effective mitigation strategies.

The particle-tracking code MODPATH (Pollock, 1994), which is compatible with MODFLOW, may also be used to initially delineate probable zones of contribution of water and salt to production wells, and estimate solute migration times due to advective transport.

If saltwater concentrations and resulting groundwater-density contrasts are sufficiently high to affect groundwater flow, the SEAWAT (Langevin and others, 2005) code could be used to simulate variable-density groundwater flow and the transport of the solute (saltwater). SEAWAT integrates MODFLOW with the solute-transport code MT3DMS (Zheng and Wang, 1999); most model input and output files are identical to their parent-code counterparts.

WORK SCHEDULE

Oct. 2012 – March 2013 Update pumpage, water-level, and chloride concentration data for all sands in the model. Perform additional calibration as needed. Run selected hypothetical scenarios.

April 2013 – Sept. 2013 Refine model to simulate saltwater encroachment in the "1,500-ft" sand. Run selected hypothetical scenarios. Begin documentation of results of model refinement and simulation of saltwater encroachment in the "1,500-ft" sand for publication in a technical report.

Oct. 2013 – Sept. 2014 Complete report on simulation of saltwater encroachment in the "1,500-ft" sand. Update pumpage, water-level, and chloride concentration data for all sands in the model. Refine model to simulate flow and saltwater encroachment in the "2,800-ft" sand (or other sand according to priorities). Run selected hypothetical scenarios. Begin documentation of results of model refinement and simulation of saltwater encroachment in the "2,800-ft" sand for publication in a technical report.

Oct. 2014 – Sept. 2015 Complete report on simulation of saltwater encroachment in the "2,800-ft" sand. Update pumpage, water-level, and chloride concentration data for all sands in the model. Refine model to simulate flow and saltwater encroachment in the "1,200-ft" sand (or other sand according to priorities). Run selected hypothetical scenarios. Begin documentation of results of model refinement and simulation of saltwater encroachment in the "1,200-ft" sand for publication in a technical report.

Oct. 2015 – Sept. 2016 Complete report on simulation of saltwater encroachment in the "1,200-ft" sand. Update pumpage, water-level, and chloride concentration data for all sands in the model. Refine model to simulate flow and saltwater encroachment in the "600-ft" sand (or other sand according to priorities). Run selected hypothetical scenarios. Begin documentation of results of model refinement and simulation of saltwater encroachment in the "600-ft" sand for publication in a technical report.

Oct. 2016 – Sept. 2017 Complete report on simulation of saltwater encroachment in the "600-ft" sand. Update pumpage, water-level, and chloride concentration data for all sands in the model. Refine model to simulate flow and saltwater encroachment in the "2,400-ft" sand (or other sand according to priorities). Run selected hypothetical scenarios. Begin documentation of results of model refinement and simulation of saltwater encroachment in the "2,400-ft" sand for publication in a technical report.

Oct. 2017 – Sept. 2018 Complete report on simulation of saltwater encroachment in the "2,400-ft" sand. Update pumpage, water-level, and chloride concentration data for all sands in the model. Refine model to simulate flow and saltwater encroachment in the "1,000-ft" sand (or other sand according to priorities). Run selected hypothetical scenarios. Begin documentation of results of model refinement and simulation of saltwater encroachment in the "1,000-ft" sand for publication in a technical report.

Oct. 2018 – Sept. 2019 Complete report on simulation of saltwter encroachment in the "1,000-ft" sand. Update pumpage, water-level, and chloride concentration data for all sands in the model. Refine model to simulate flow in the "1,700-ft" sand (or other sand according to priorities). Run selected hypothetical scenarios. Begin documentation of results of model refinement and simulation of saltwater encroachment in the "1,700-ft" sand for publication in a technical report.

Oct. 2019 – Sept. 2020 Complete report on simulation of saltwater encroachment in the "1,700-ft" sand. Update pumpage, water-level, and chloride concentration data for all sands in the model. Refine model to simulate flow in the "800-ft" sand (or other sand according to priorities). Run selected hypothetical scenarios. Begin documentation of results of model refinement and simulation of saltwater encroachment in the "800-ft" sand for publication in a technical report.

Oct. 2020 – Sept. 2021 Complete report on simulation of saltwater encroachment in the "800-ft" sand. Update pumpage, water-level, and chloride concentration data for all sands in the model. Refine model to simulate flow in the "400-ft" sand (or other sand according to priorities). Run selected hypothetical scenarios. Begin documentation of results of model refinement and simulation of saltwater encroachment in the "400-ft" sand for publication in a technical report.

Oct. 2021 – Sept. 2022 Complete report on simulation of saltwater encroachment in the "400-ft" sand.

PRODUCTS

Details of model refinement, calibration, and sensitivity analysis, as well as results or simulations, will be documented in USGS Scientific Investigations Reports or LaDOTD Water Resources Technical Reports. Upon completion of each major model refinement, copies of the model files will be given to the CAGWCC and also stored in the USGS Baton Rouge office groundwater model archives, where they will be available to the public.

PROPOSED FUNDING

Estimated total funding needed for the work over a 10-year period is $1,952,900. Estimated annual costs are shown below.

		FUNDING			
Fiscal Year	Total Cost	CAGWCC	LaDOTD	USGS	EBR-DPW
Oct. 2012 – Sept. 2013	$188,600	$85,000	$42,500	$31,100	$30,000
Oct. 2013 – Sept. 2014	$192,500	$86,700	$43,400	$31,800	$30,600
Oct. 2014 – Sept. 2015	$196,300	$88,400	$44,200	$32,500	$31,200
Oct. 2015 – Sept. 2016	$200,200	$90,200	$45,100	$33,100	$31,800
Oct. 2016 – Sept. 2017	$204,100	$92,000	$46,000	$33,600	$32,500
Oct. 2017 – Sept. 2018	$208,000	$93,800	$46,800	$34,400	$33,000
Oct. 2018 – Sept. 2019	$212,800	$95,700	$47,900	$35,400	$33,800
Oct. 2019 – Sept. 2020	$216,700	$97,700	$48,800	$35,700	$34,500
Oct. 2020 – Sept. 2021	$220,600	$99,600	$49,600	$36,300	$35,100
Oct. 2021 – Sept. 2022	$113,100	$50,800	$25,500	$18,800	$18,000
Total Cost	$1,952,900	$879,900	$439,800	$322,700	$310,500

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