Toward developing more realistic groundwater models using big data

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Abstract

Rich geological data is the backbone of developing realistic groundwater models for groundwater resources management. However, constructing realistic groundwater models can be challenging due to inconsistency between different sources of geological, hydrogeological and geophysical data and difficulty in processing big data to characterize the subsurface environment. This study develops a framework to utilize a big geological dataset to create a groundwater model for the Chicot Aquifer in the southwestern Louisiana, which borders on the Gulf of Mexico at south. The Chicot Aquifer is the principal source of fresh water in southwest Louisiana, underlying an area of about 9,000 square miles. Agriculture is the largest groundwater consumer in this region and overpumping has caused significant groundwater head decline and saltwater intrusion from the Gulf and deep formations. A hydrostratigraphy model was constructed using around 29,000 electrical logs and drillers' logs as well as screen lengths of pumping wells through a natural neighbor interpolation method. These sources of information have different weights in terms of accuracy and trustworthy. A data prioritization procedure was developed to filter untrustworthy log information, eliminate redundant data, and establish consensus of various lithological information. The constructed hydrostratigraphy model shows 40% sand facies, which is consistent with the well log data. The hydrostratigraphy model confirms outcrop areas of the Chicot Aquifer in the north of the study region. The aquifer sand formation is thinning eastward to merge into Atchafalaya River alluvial aquifer and coalesces to the underlying Evangeline aquifer. A grid generator was used to convert the hydrostratigraphy model into a MODFLOW grid with 57 layers. A Chicot groundwater model was constructed using the available hydrologic and hydrogeological data for 2004-2015. Pumping rates for irrigation wells were estimated using the crop type and acreage data from the USDACropScape. Groundwater level data obtained from the USGS were used to determine the model boundary and initial conditions. Recharge rates were approximated based on surficial lithology and rainfall data. The Chicot aquifer model will be used to understand groundwater availability in southwest Louisiana.

Significance of Study

Chicot aquifer geographically spreads over southwest Louisiana and is formed by dipped sand formations. The aquifer is underlain by Evangeline aquifer of Pliocene and Miocene ages. A clay formation of Holocene age confines the aquifer at the top (Sargent et. al., 2004). A big portion of extracted water from this aquifer is allocated to the agriculture (68%), public supply (11%) and industry (9%) in southwest Louisiana. It is the most heavily pump aquifer in the state. The groundwater table drop, formation of cone of depression (Dan J. Tomaszewski, John K. Lovelace, 2002), and salt water intrusion from ocean are major concerns in this aquifer. Considering the fact that Louisiana is one of the nation's top three rice-producing states and southwest Louisiana is the major contributor to this portion, groundwater study of Chicot aquifer is of paramount importance.

Research Objective

In this study we develop a groundwater model through which the availability of groundwater and problems due to pumping are investigated in Chicot aquifer. To reach such a goal, the initial step is to build the geological model through the well log data available for this region. Then, different packages for groundwater model are prepared. Finally, a MODFLOW model is developed based on collected data and geological model. The model is run from 2004 to 2014 and the results are discussed. Fig. 1 demonstrates Chicot aquifer boundaries in southwest Louisiana. The boundaries for this study is built based on USGS, USEPA boundaries as well as considering hydrogeological aspects of the region.

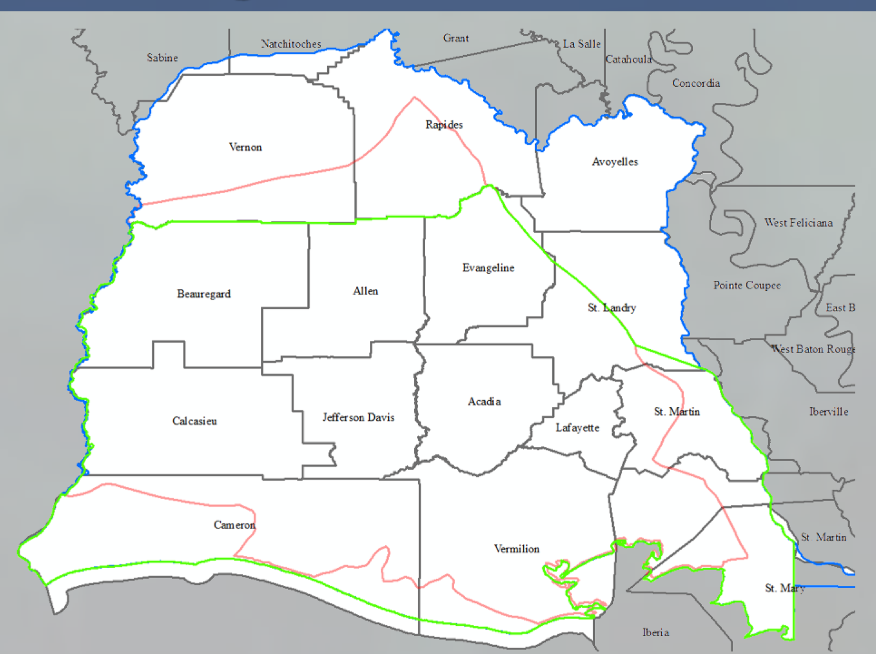

Fig 1: Different boundary delineations. Blue line: USEPA boundaries, red line: USGS, green Chicot boundary assumed in this study

Building Geological Model

More than 29000 well log data were used to build the geological model. There are three sources of data from where data are extracted to build the model: driller's logs, electrical logs, and screen information. In comparison to the other sources, electrical logs have a higher level of accuracy. Screens information prepared by USGS is the second important source of data. The less trustable data are the driller's logs where the stratigraphic information has been recorded by well owners. Hence, the data used for creating geological model need to be prioritized based on their source. In this study, the wells are clustered based on computational grid over the region and all the cells in a specific cell are combined to build a representative well for that cell. For a certain depth in the representative well, the stratigraphic data are extracted from electrical logs available in the related cell. If electrical log is not available for that depth , the screen data are used and if there is not neither electrical log nor screen information available, the driller's logs information is used.

More than 29000 log data including electrical logs, screens, and drillers' logs were used in this study. The overall portion of sand in the model is close to 0.4 which is consistent with portion of sand in input data. Fig. 2 demonstrates the results. Looking at the side plane view at the western part, almost three sand formations can be recognized. These formations separated by thin layers of clay are the "200-foot" "500-foot," and "700- foot" sands from top to bottom, respectively, named after their depth of occurrence in the Lake Charles area (Dale J. Nyman et al., 1990). Moving from west to east, these sand formations merge into two sand formations called "upper sand" and "lower sand". The plane view clearly shows the outcrop region at north with high portion of sand. The bottom plane view demonstrates a big connection. The large sections of sand at the bottom guarantees that the Chicot aquifer is not completely separate from the Evangeline aquifer.

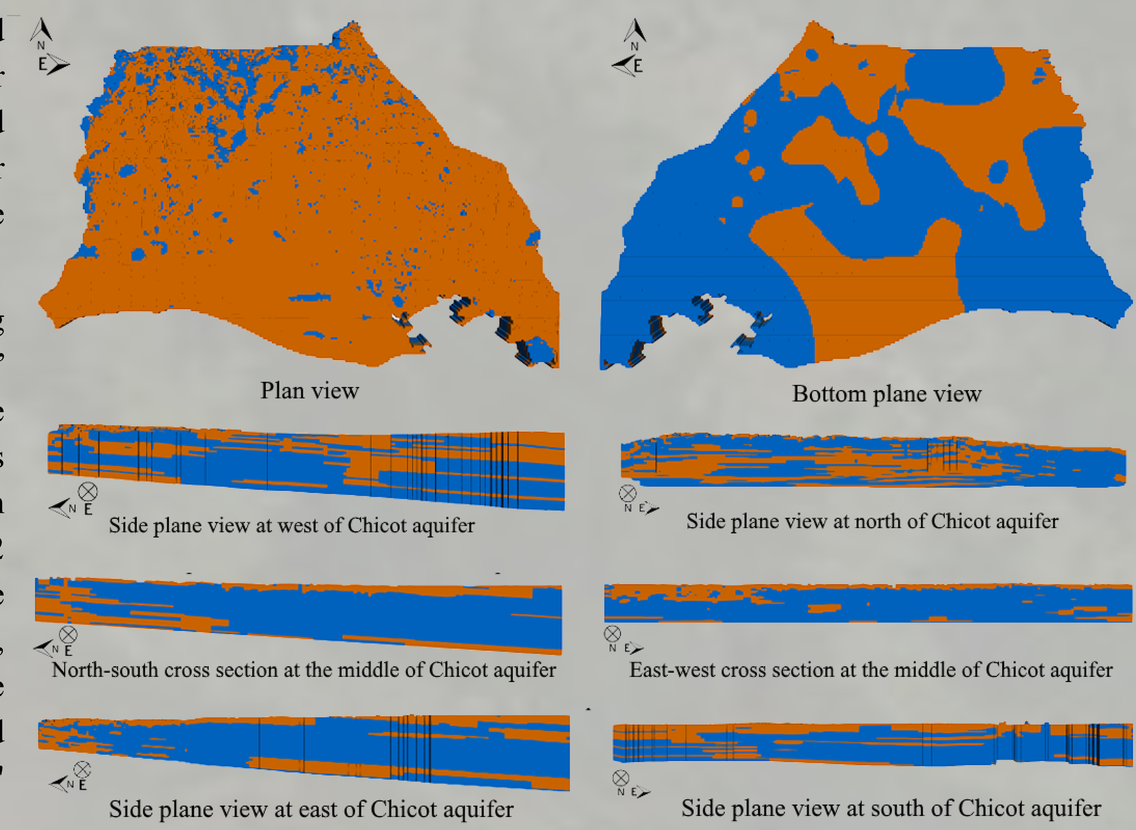

Fig. 2: Different views of geological model for Chicot aquifer. Blue color: sand, brown color: clay

Developing Groundwater Model

The geological model with 57 layers created in the previous step is used to create MODFLOW grid. The simulation period for Chicot aquifer is considered to start from begging of year 2004 to the end of year 2014. Around 43 observations were available for January 2004. The initial head for different cells were interpolated using Inverse Distance Weight (IDW) based on initial observations. These head values were the best ones compared to those obtained from Kriging method over the region. In the next step, the boundary conditions were assigned based on nearest observation well. In this approach, the gap in time series for different observation wells were filled with values obtained from linear interpolation and then a complete set of dataset for different observation locations were used to assign boundaries. The distances between each of the boundary cells and all the observation wells were calculated. Finally, the dataset for the nearest observation was used as boundary condition for the related cell.

Collecting data from USGS, 153 observation wells with approximately 1348 observed values were used to create observation package. The observation value for a single well with several observations at a specific stress period was calculated by averaging all those values. Fig. 3 illustrates the observation wells in Chicot aquifer. The current Chicot aquifer model includes around 2700 pumping wells. The pumping rates are estimated using the crop type and acreage data from the USDACropScape. The model was run with initial parameter values shown in table 1. Fig. 4 demonstrates the 27th layer of Chicot aquifer in June of 2010. Yellow dots are the pumping wells. The existence of cone of depression in agriculture area, central part of the aquifer, is obvious.

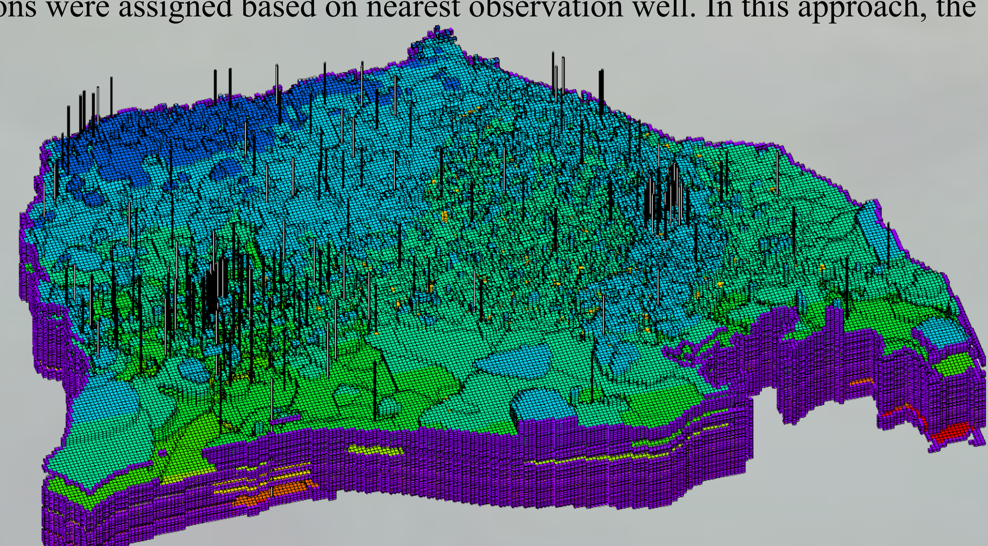

Fig 3: Observation wells in Chicot aquifer

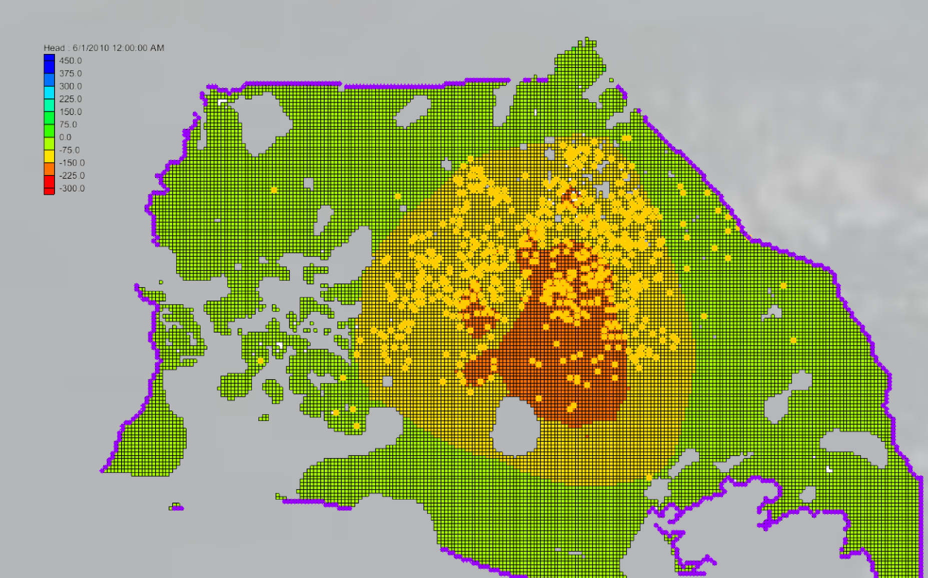

Fig 4: Cone of depression in the center of Chicot aquifer

Model Calibration

A genetic algorithm based optimization method was used to calibrate the model parameters. The algorithm was set up with 100 generations and population size of 5. The code was paralleled to run on Louisiana State University high performance computer center. Fig. 5 shows difference between the observation values and the simulated ones. Looking at graphs (a) and (c), the pattern for the observation and simulated values are almost the same. The maximum difference between heads reduces from a value of around 75 m to roughly 10 m for well JD-485A, the first well in Fig. 5. Comparing the scatter plots at Fig. 5, the values of head for the calibrated model became closer to the 45 degree line.

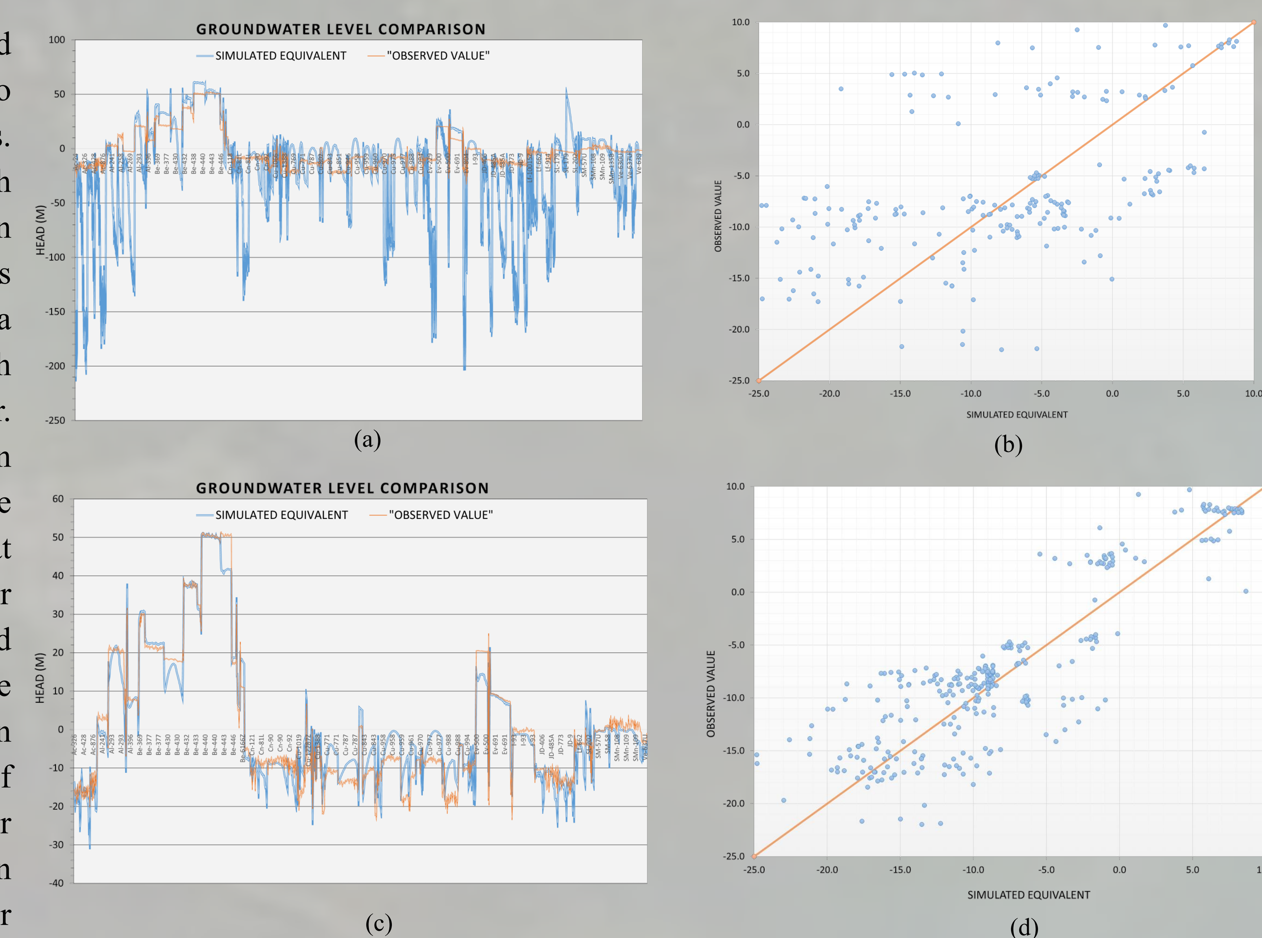

Fig. 5: Comparison of observed values with simulated ones for different wells. (a) and (b): initial model. (c) and (d): calibrated model

Values of initial and calibrated values for three parameters of hydraulic conductivity, specific yield and specific yield as well as the Root Squared Mean Error (RMSE) values can be found in table 1. RMSE value has dropped remarkably. It seems that the most sensitive parameter is hydraulic conductivity. This problem can be solved by defining different zones with different hydraulic conductivity for the aquifer system.

Table 1: Layer property parameter values

	k (m/d)	Specific yield	Specific storage	RMSE (m)
Initial model	200	0.3	0.0015	19.45
Calibrated model	297.64	0.26429	0.001	5.62

Conclusions

In this study a geological model was constructed for Chicot aquifer using well log data from different sources. Results show that there are three sand formations at the west of Chicot aquifer which gradually merge to thicker sand formations at east. The geological model also demonstrates a recognizable outcrop zone in north of the aquifer region. The big sand formation at the bottom of the aquifer verifies the connection between the Chicot and the underneath Evangeline aquifer. The geological model was used to develop the groundwater model for Chicot aquifer. The initial and boundary conditions were revised using different interpolation techniques and removing the dry cells. The initial results shows a cone of depression at the central part of the aquifer where the most of the pumping wells exist. A genetic algorithm optimization method was used to calibrate three parameters of hydraulic conductivity, specific storage, and specific yield. The simulated head values was improved as a result. However, further revisions are needed to be applied to the model in order to improve the Chicot groundwater model results.

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