College of Engineering
Department of Civil and Environmental Engineering

Complex Groundwater Model Development for the Chicot Aquifer System in Southwest Louisiana

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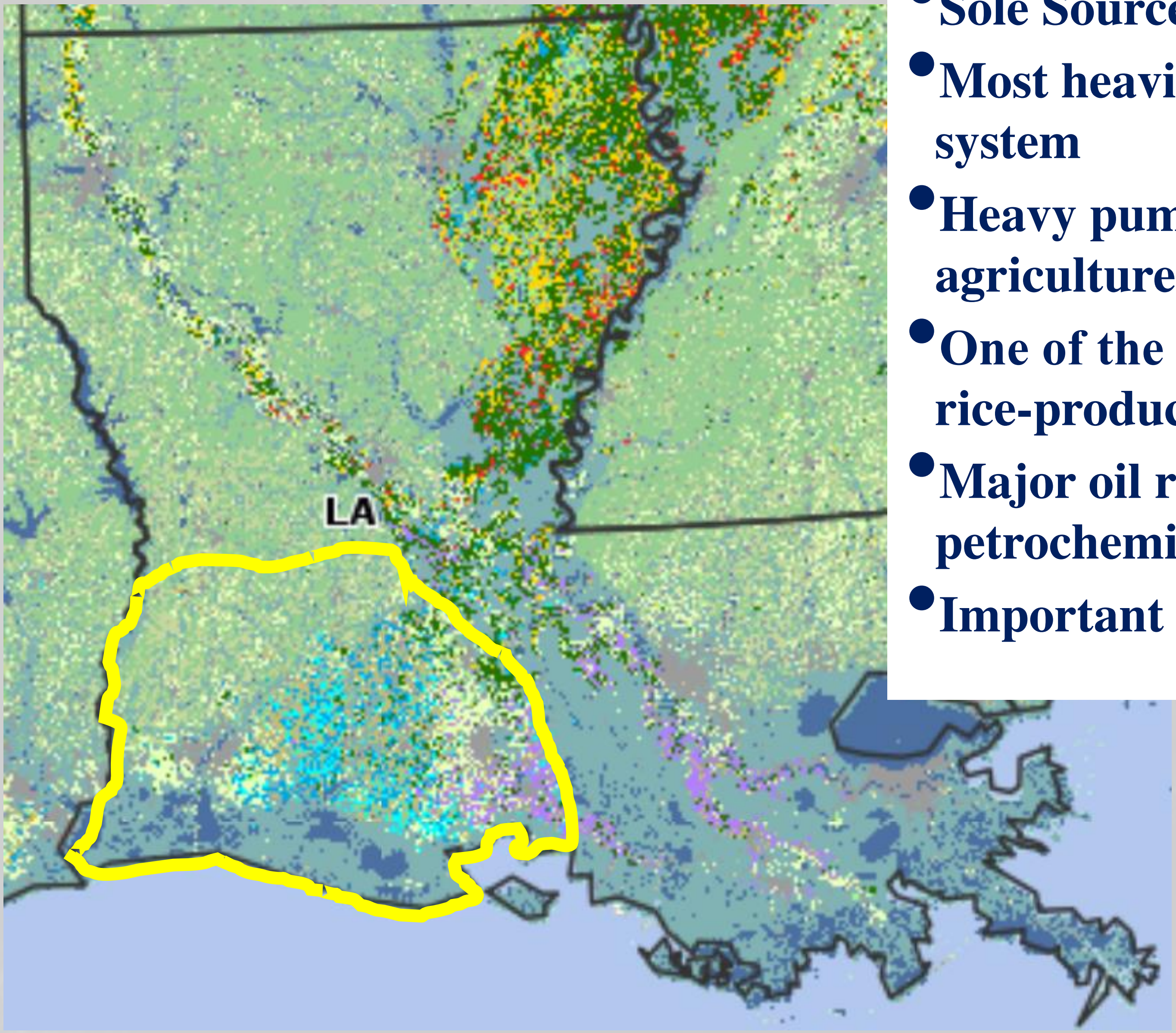
LOVE PURPLE LIVE GOLD

Outline

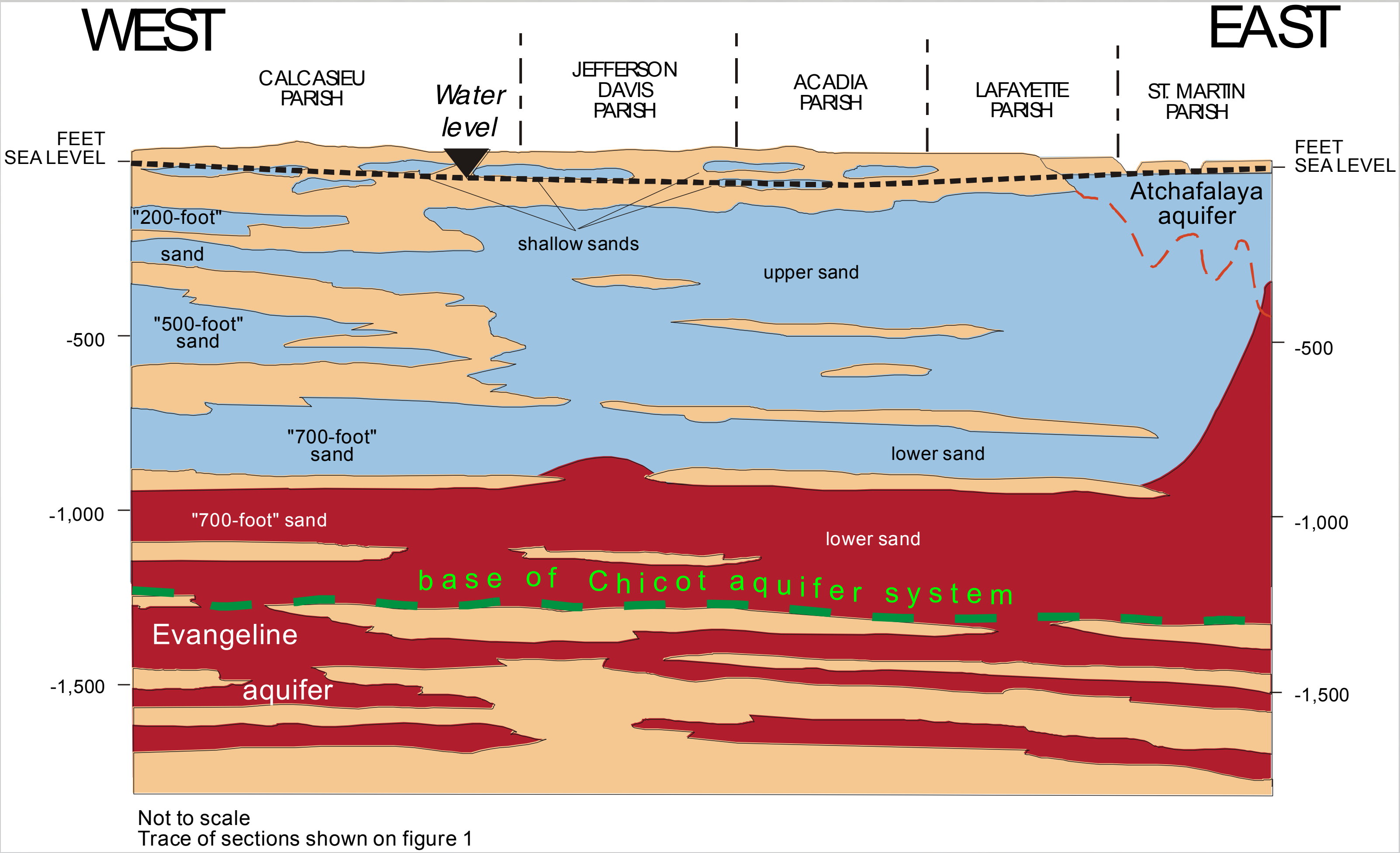
- Chicot aquifer system
- Problems/concerns
- Groundwater model development
- Water budget and energy consumption analyses
- Conclusion

Chicot Aquifer System

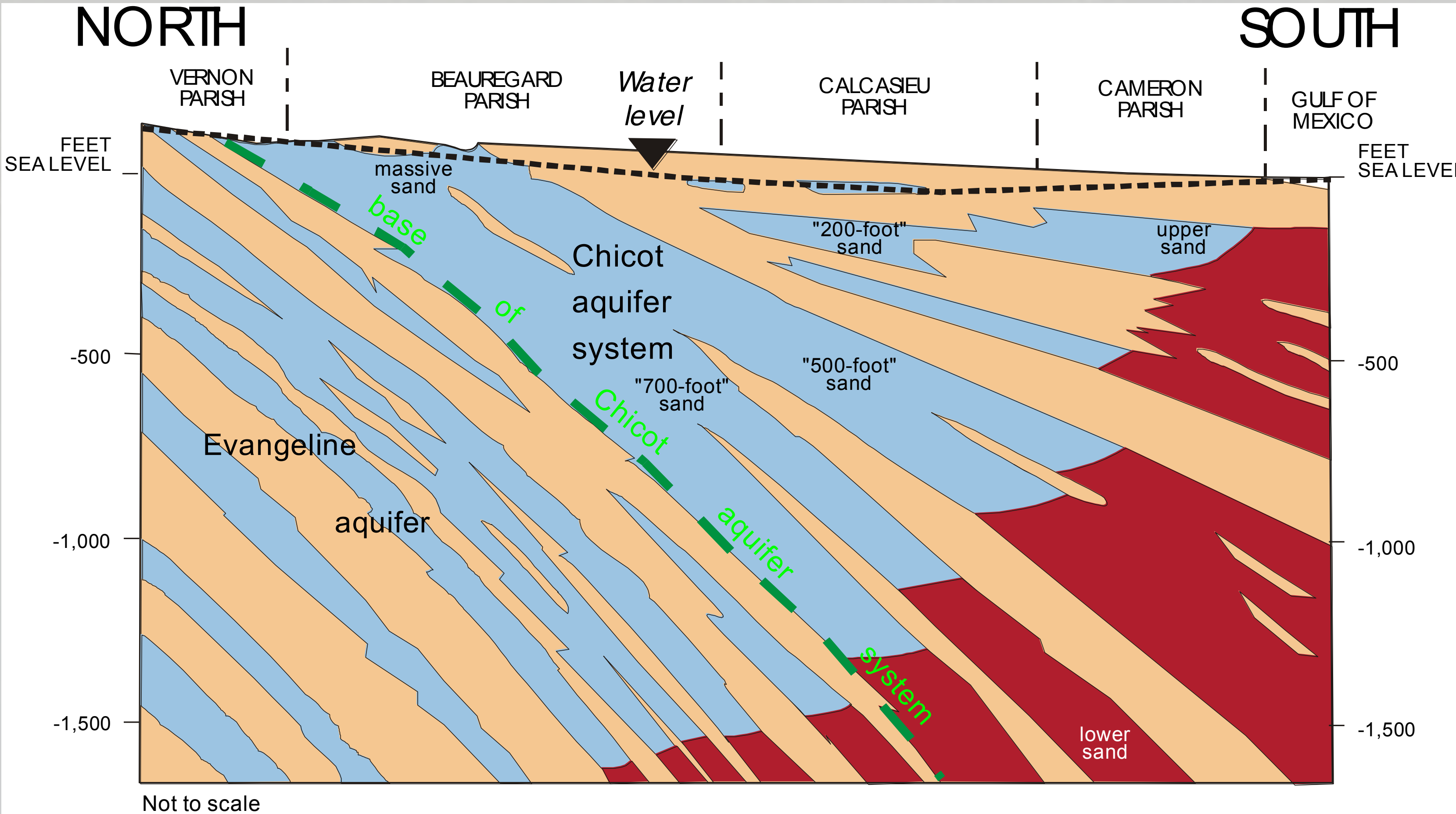


- Sole Source Aquifer (SSA)
- Most heavily pumped aquifer system
- Heavy pumping for agriculture (650 mgd, 2010)
- One of the nation’s top three rice-producing states
- Major oil refinery and petrochemical plants
- Important economic values

USGS Hydrogeological Framework

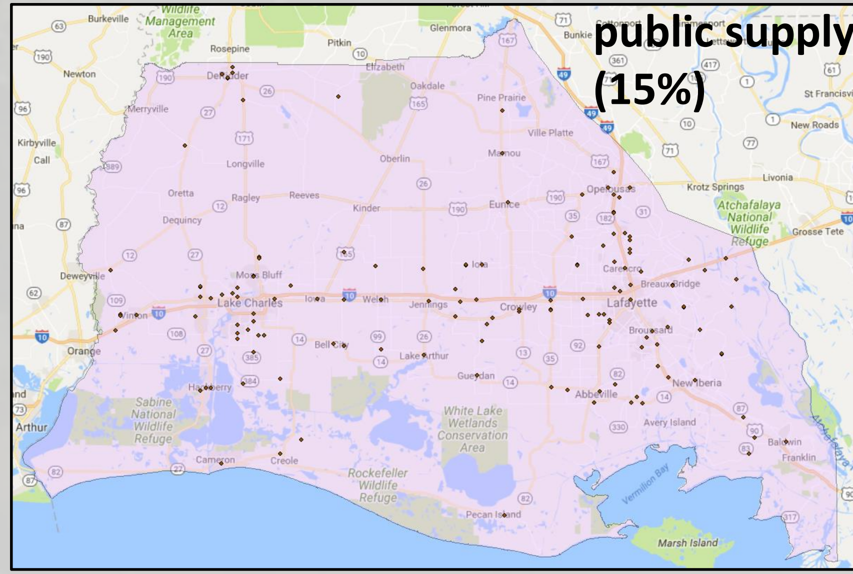


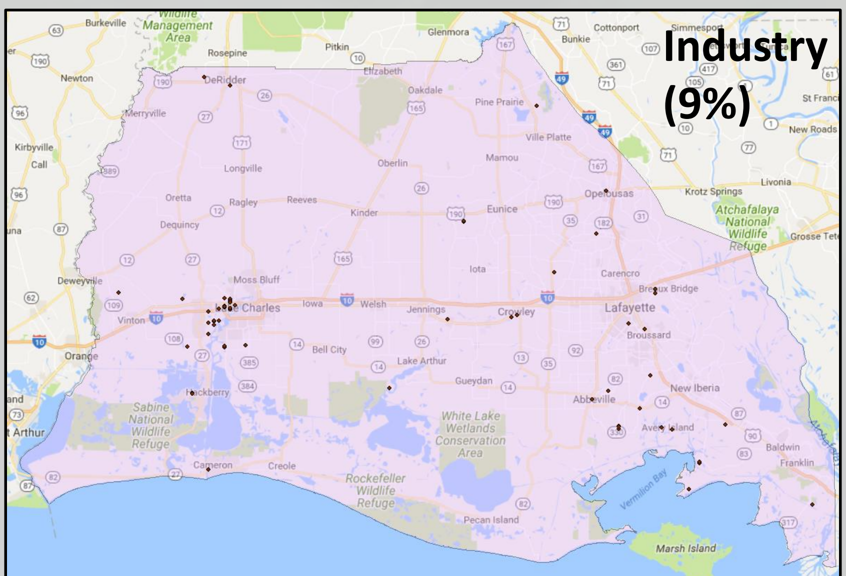
USGS Hydrogeological Framework

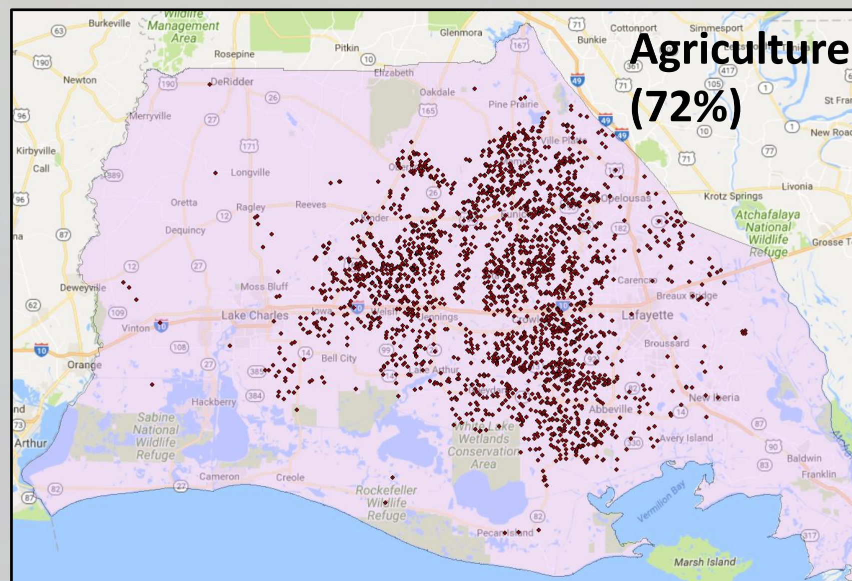


Groundwater Withdrawals (650 mgd, 2010)

Withdrawals, in million gallons per day (Mgal/d)	
Public supply	96.55
Industry	57.86
Power generation	14.74
Rural domestic	11.84
Livestock	1.20
Rice Irrigation	341.90
General irrigation	10.55
Aquaculture	113.89
Total	648.54

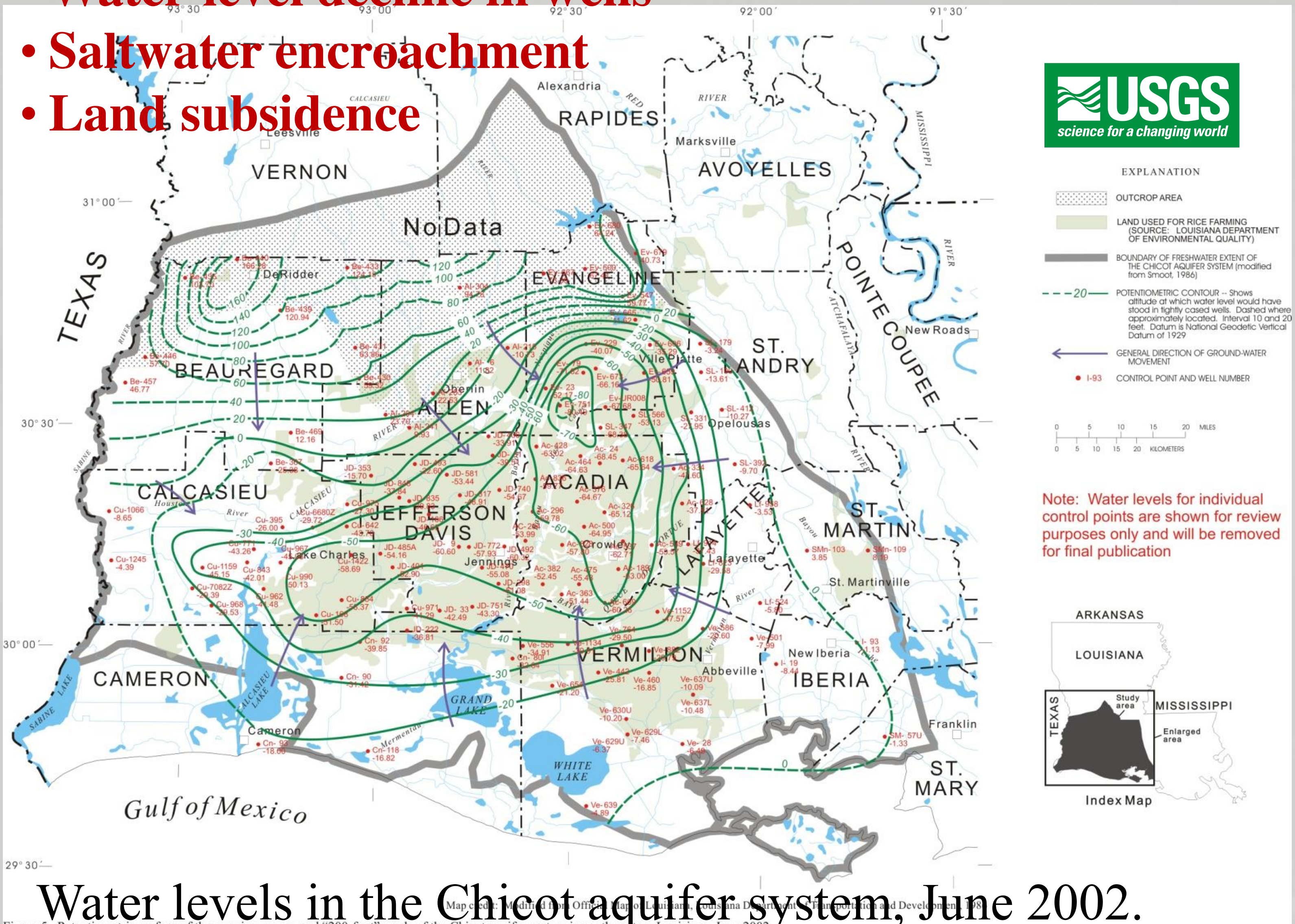






Problems/Concerns

- **Water-level decline in wells**
- **Saltwater encroachment**
- **Land subsidence**



Water levels in the Chicot aquifer system, June 2002.

Goal and Approach

Goal: Ensure the Chicot aquifer system to be sustainable for economical development

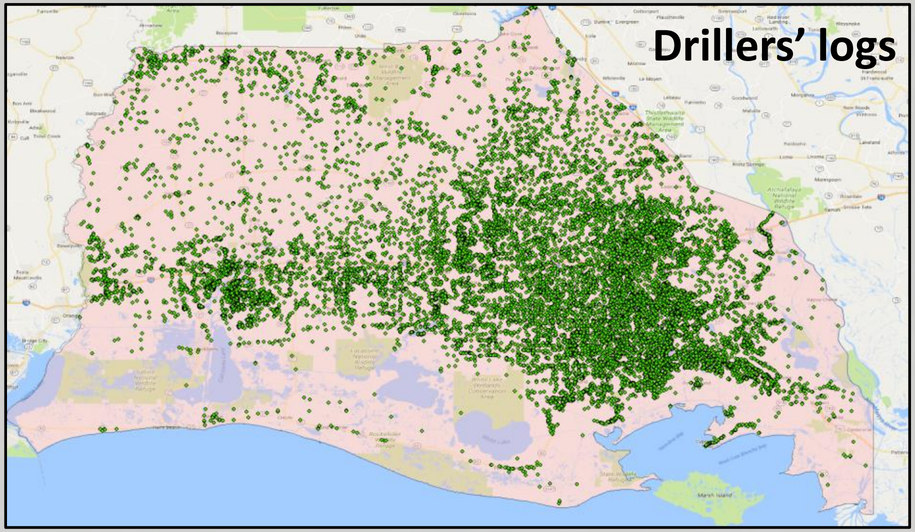
Approach:

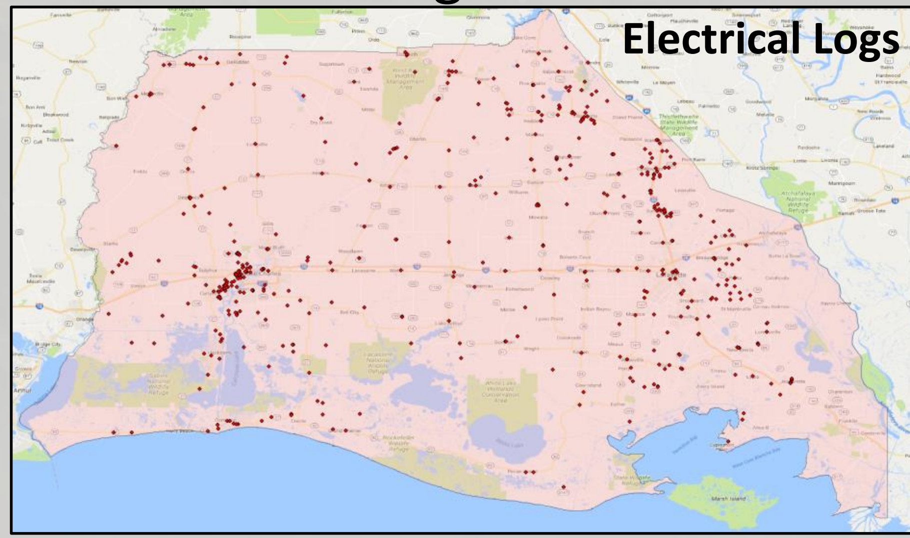
(1) Develop a groundwater model as a management tool

(2) Apply the groundwater model for groundwater management

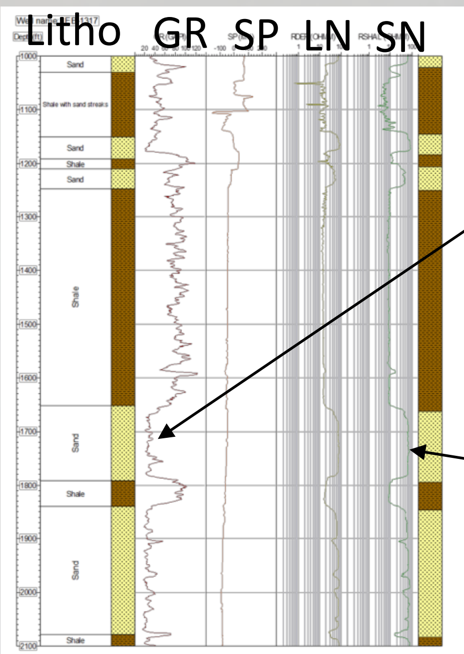
Geological Information

Over 29,000 D-Log and over 800 E-logs





Sand	Clay	Undetermined
Sand: Coarse sand Medium sand Fine sand Silty sand Shaly sand Clayey sand Sand with clay streaks Sand with clay breaks Sand with shall fragment Sand and gravel Gravel GW, GP, GM, GC SW, SP, SM, SC	**Clay:** Clay Shale Silty clay Clayey silt Clay with sand streaks Shale with sand breaks ML, MH, CL, CH	Clay and sand Shale and sand Streaks of sand and shale, Poor sand and streaks of shale Sand and hard sandy shale



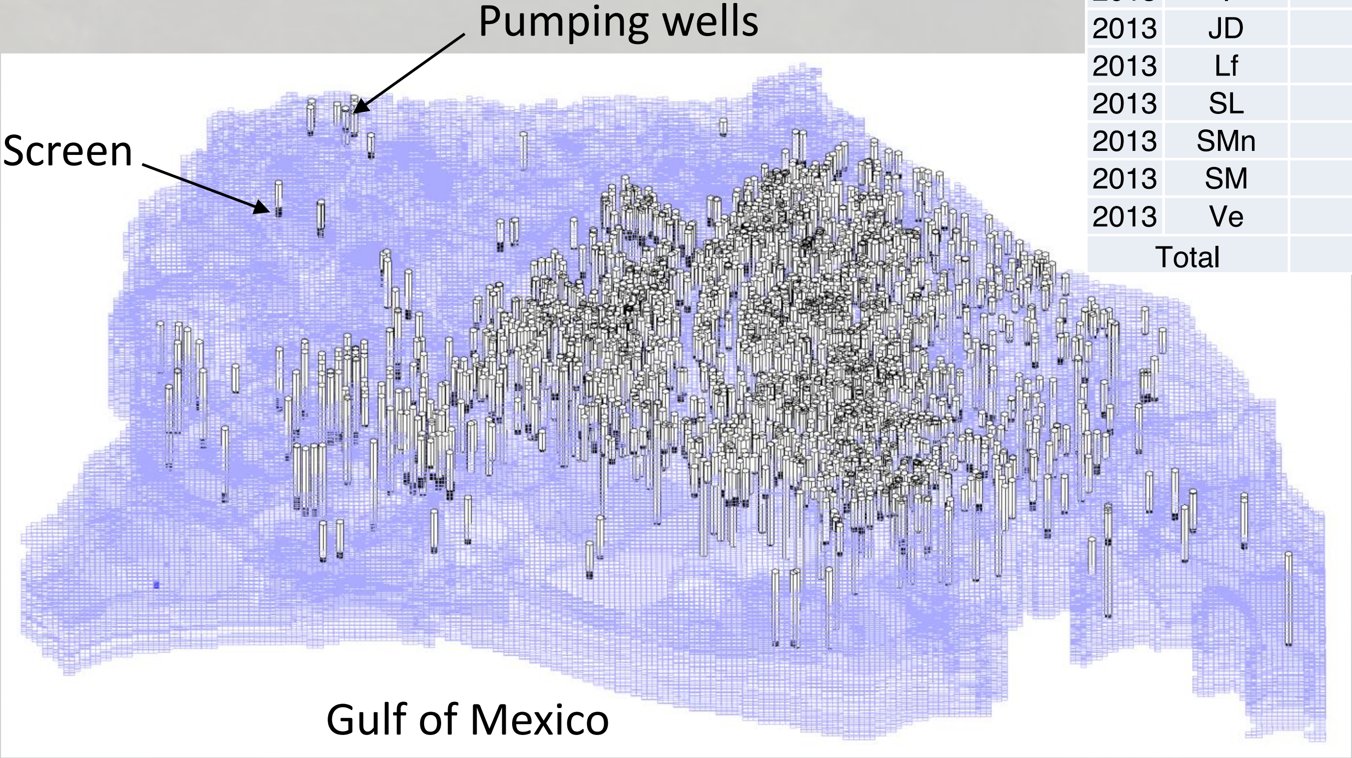
Sand picks:

- (GR) Low gamma ray
- (SP) Deviation from shale baseline
- (SN) High electrical resistivity

Pumping Wells

Over 2300 pumping wells (public supply, industry, agriculture, etc.)

Year	PARISH	LSU AgCenter (MGD)	USGS (MGD)
2013	Ac	447.57	107.98
2013	Al	61.46	21.82
2013	Be	2.20	2.46
2013	Cu	32.02	15.95
2013	Cn	3.18	3.36
2013	Ev	232.94	67.91
2013	I	0.13	0.43
2013	JD	274.84	115.90
2013	Lf	18.76	5.56
2013	SL	264.31	42.69
2013	SMn	22.45	0.37
2013	SM	0.00	0.04
2013	Ve	207.84	7.89
Total		1567.70	392.36



From well logs to a hydrostratigraphy model and to a MODFLOW grid

Hydrogeol J
DOI 10.1007/s10040-016-1532-6

PAPER

Modeling complex aquifer systems: a case study in Baton Rouge, Louisiana (USA)

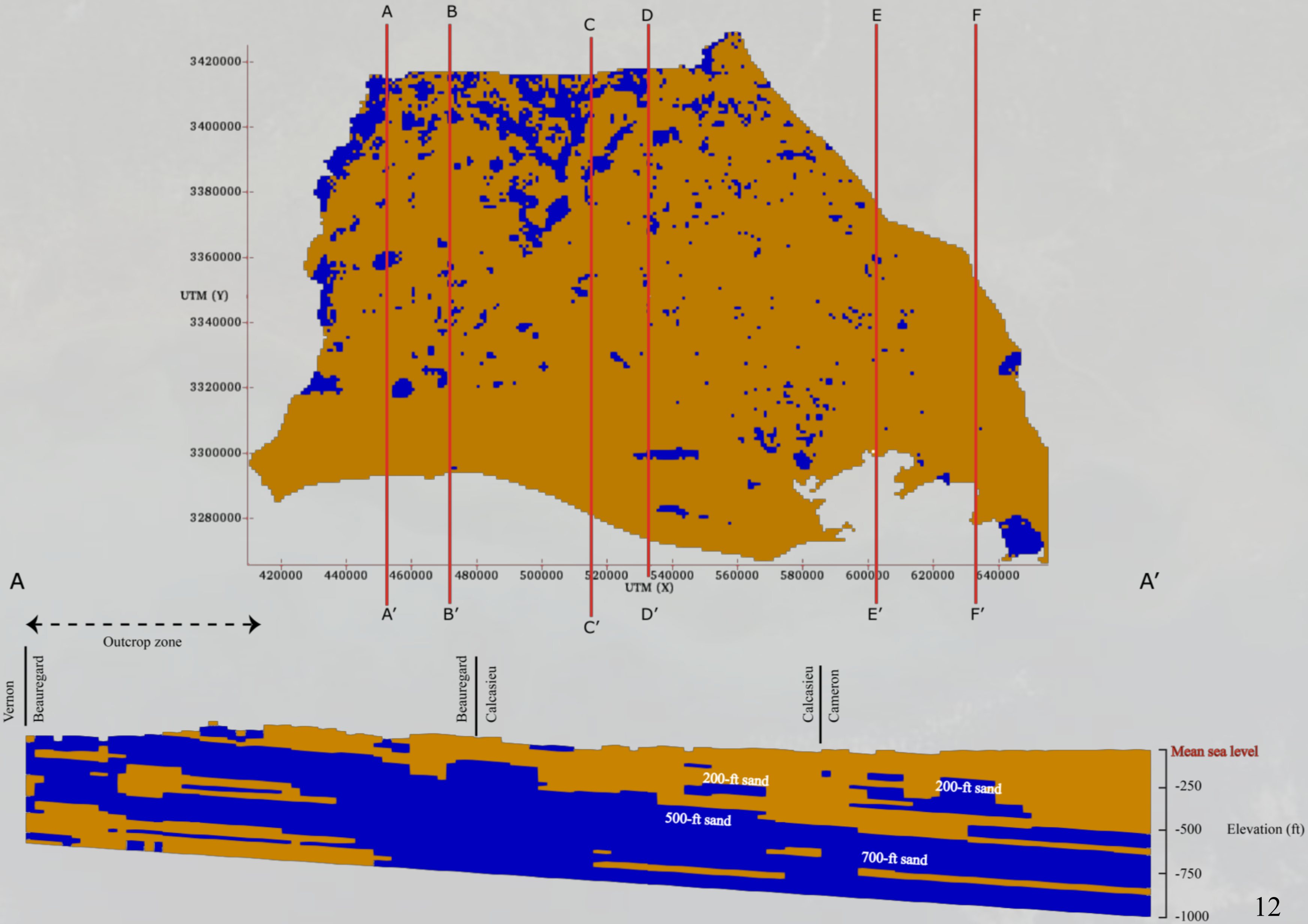
Hai V. Pham[1] · Frank T.-C. Tsai[2]

Received: 4 May 2016 / Accepted: 29 December 2016

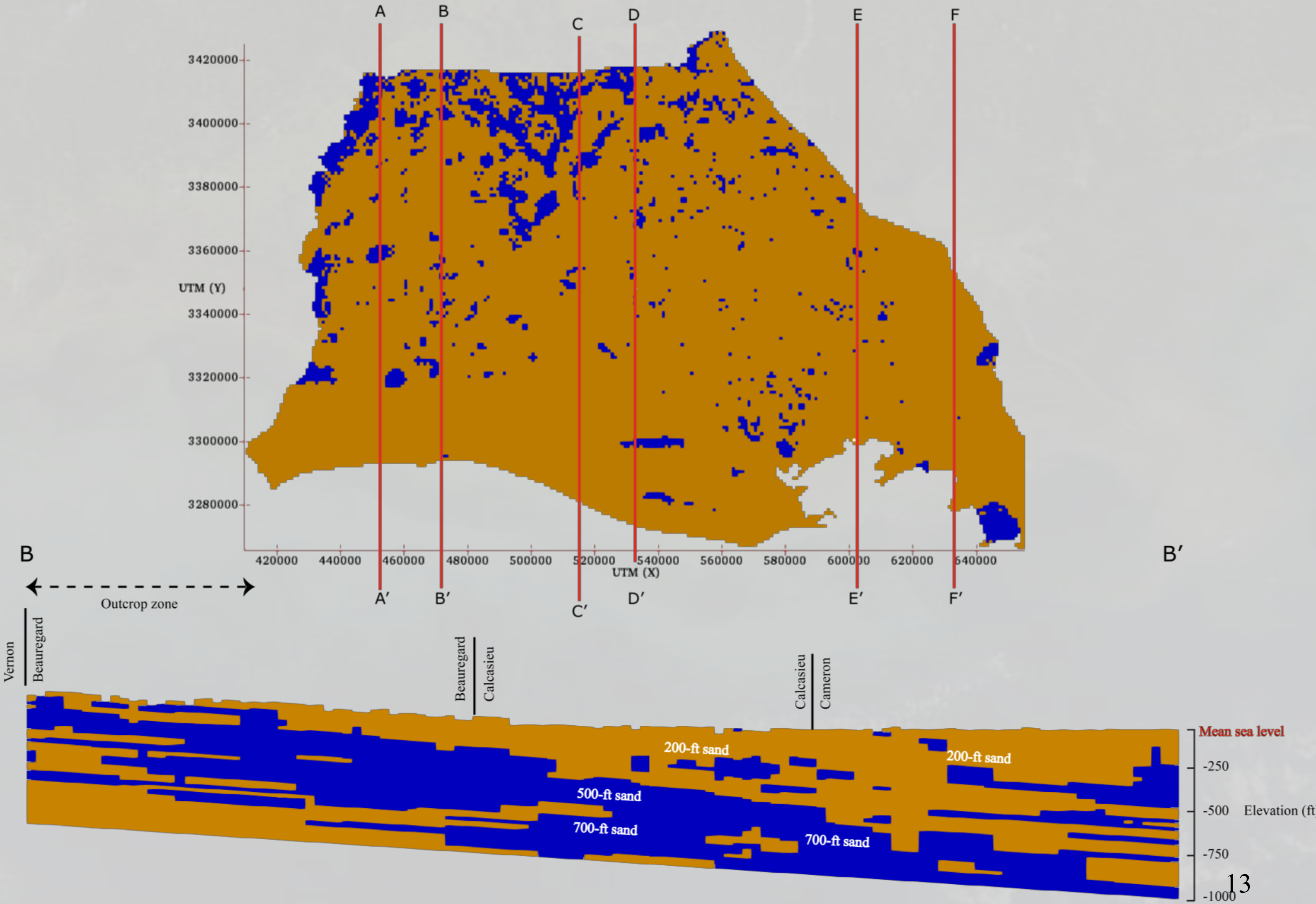
Abstract This study targets two challenges in groundwater model development: grid generation and model calibration for aquifer systems that are fluvial in origin. Realistic hydrostratigraphy can be developed using a large quantity of well log data to capture the complexity of an aquifer system. However, generating valid groundwater model grids to be consistent with the complex hydrostratigraphy is non-trivial.

indicates hydraulic conductivity for Miocene sands is higher than that for Pliocene to Holocene sands and indicates the Baton Rouge fault and the Denham Springs-Scotlandville fault to be low-permeability leaky aquifers. The modeling result shows significantly low groundwater level in the "2,000-foot" sand due to heavy pumping, indicating potential groundwater upward flow from the "2,400-foot" sand.

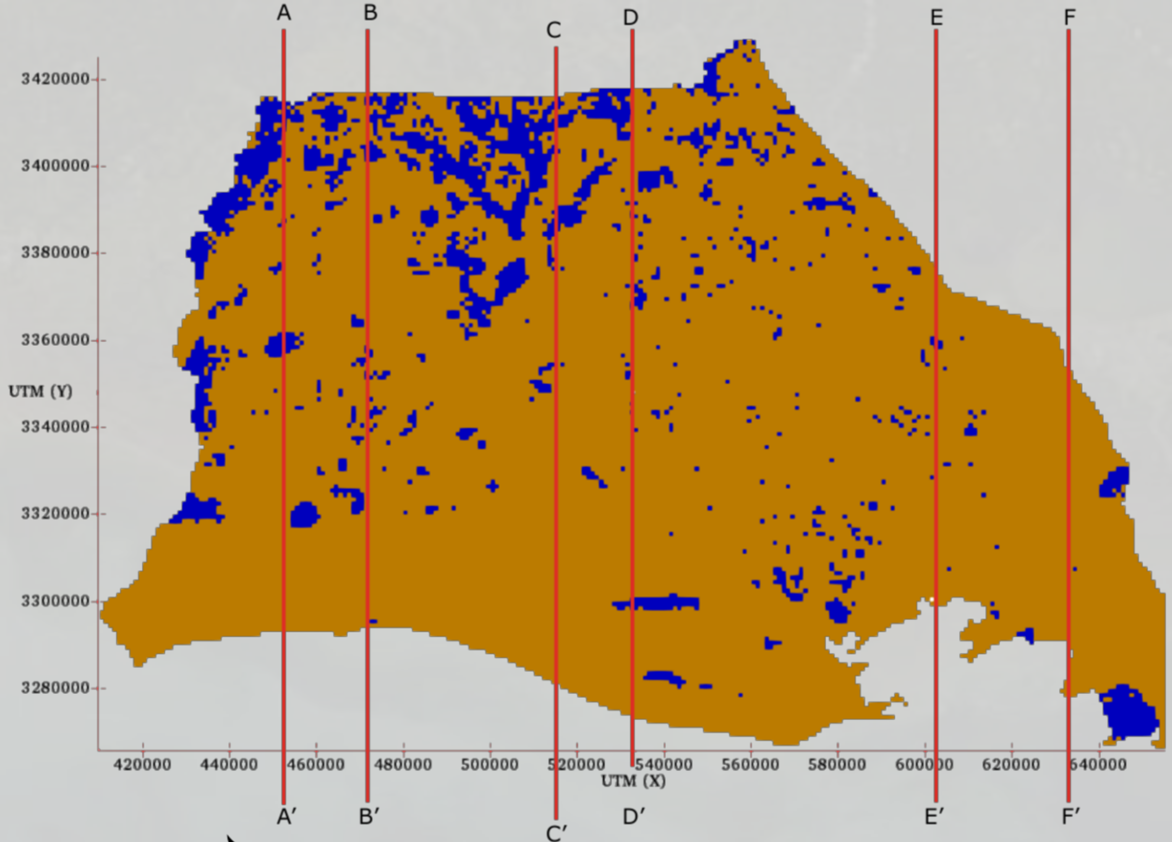
Hydrogeological Framework

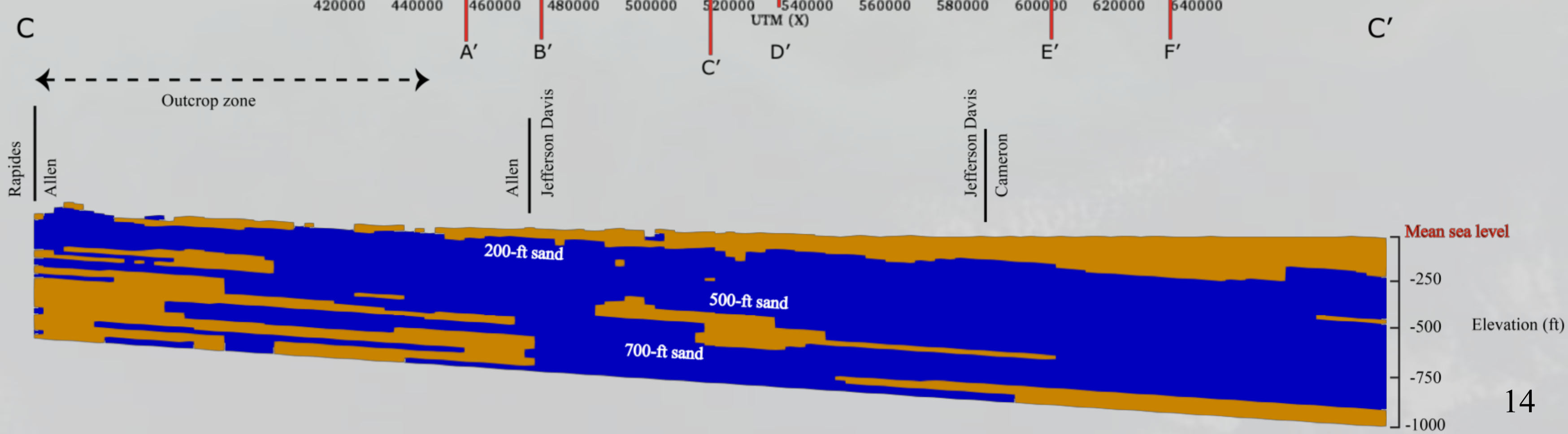


Hydrogeological Framework



Hydrogeological Framework





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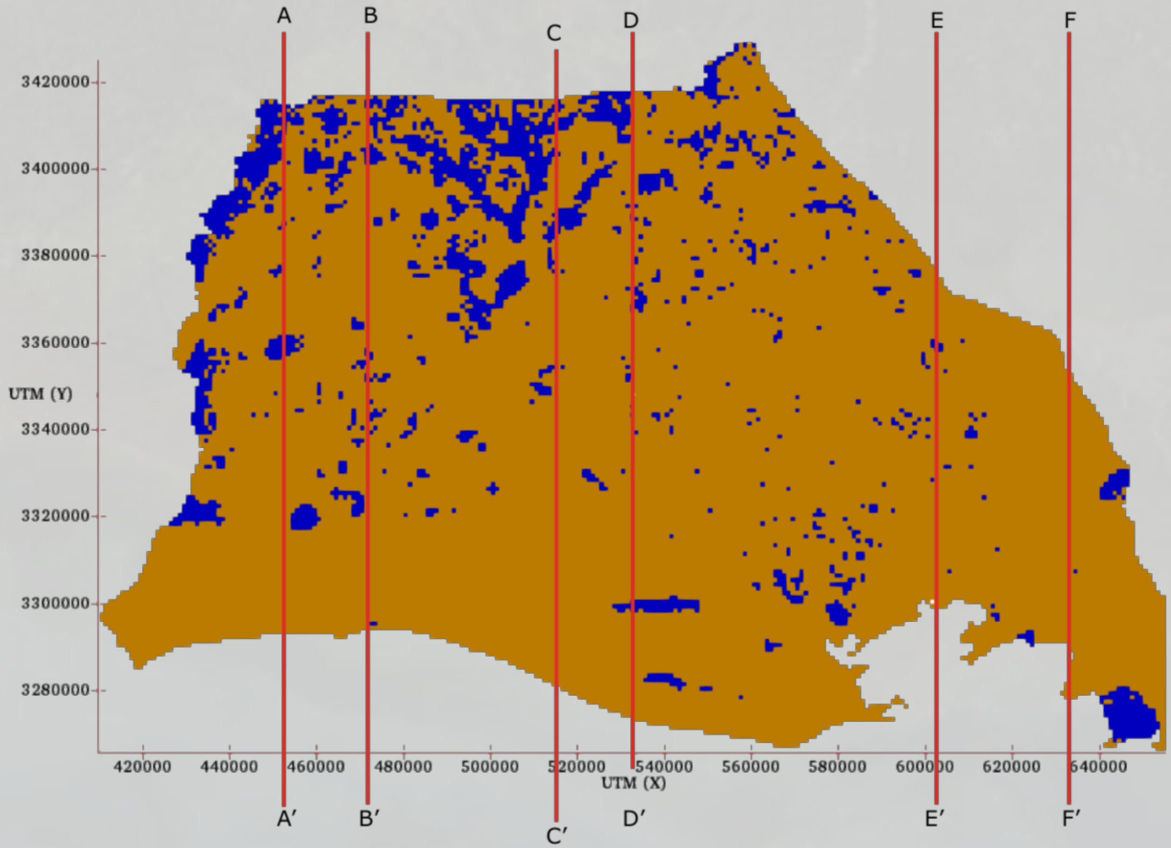
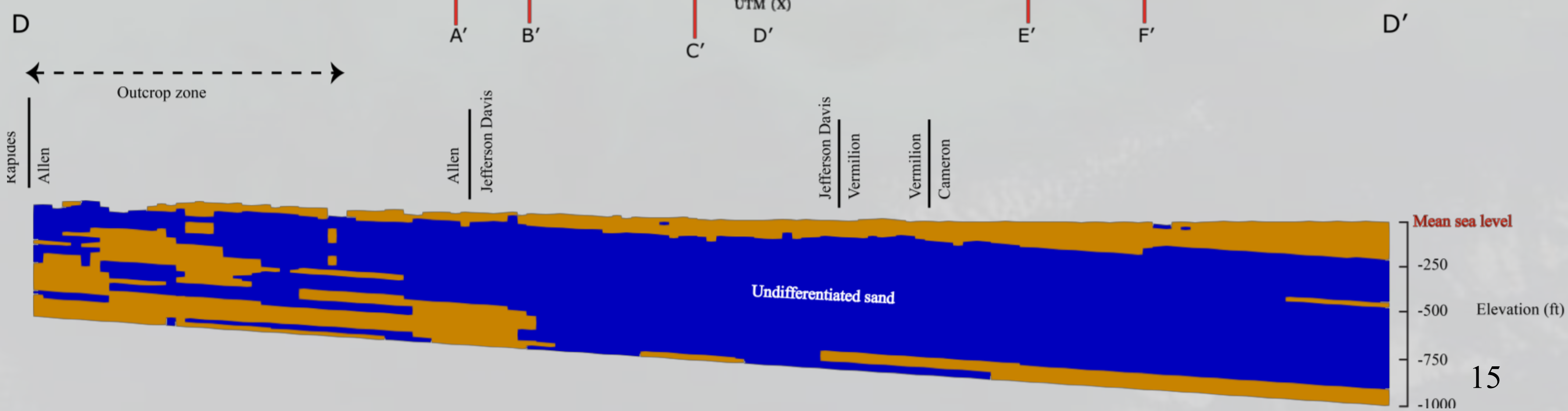
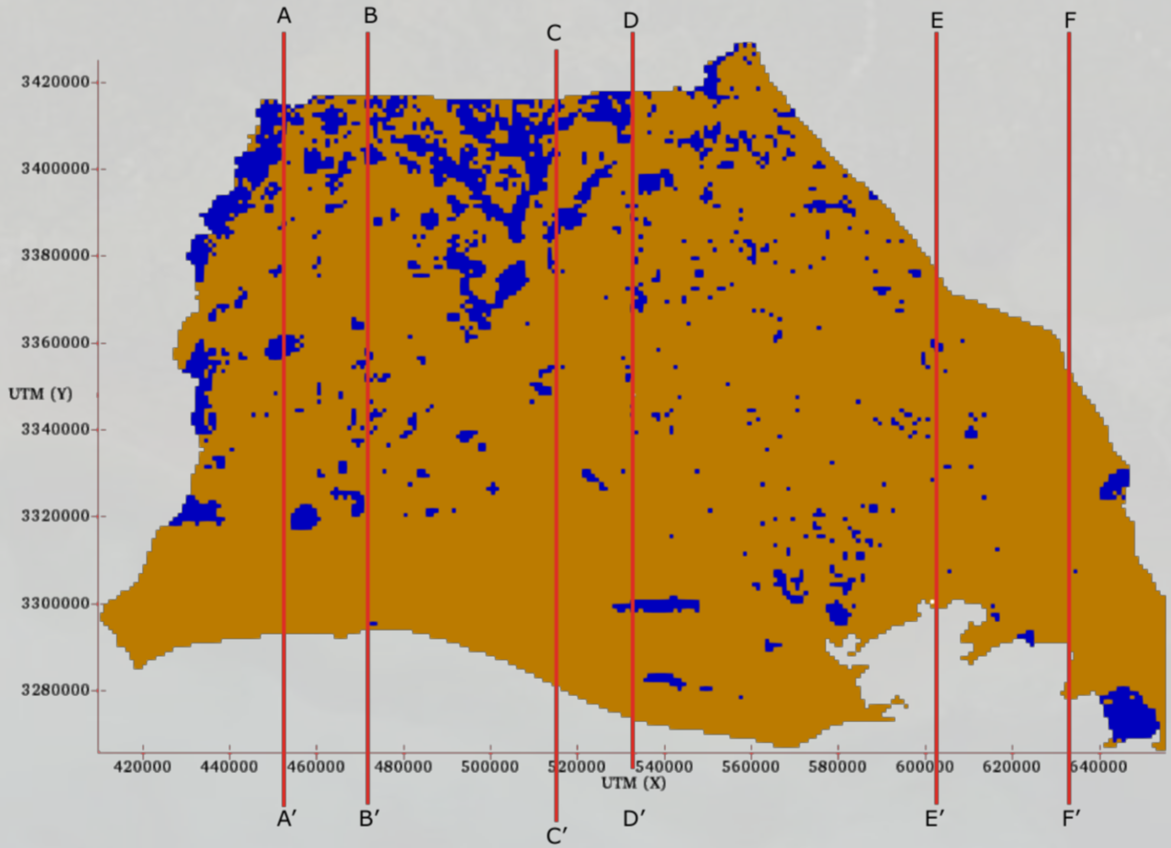
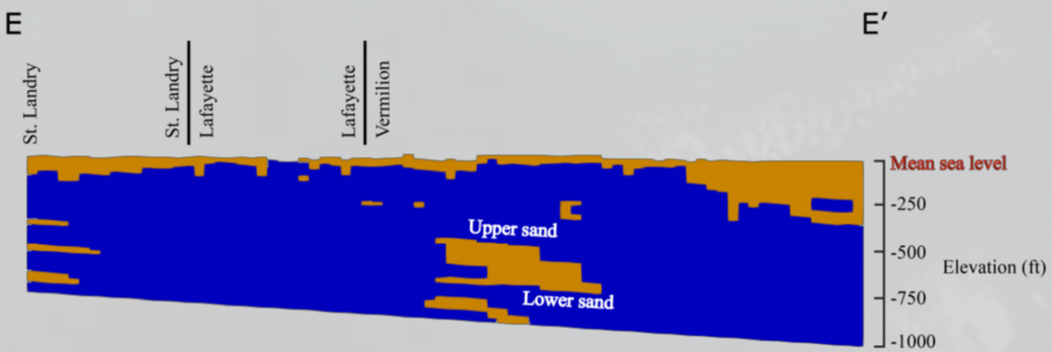


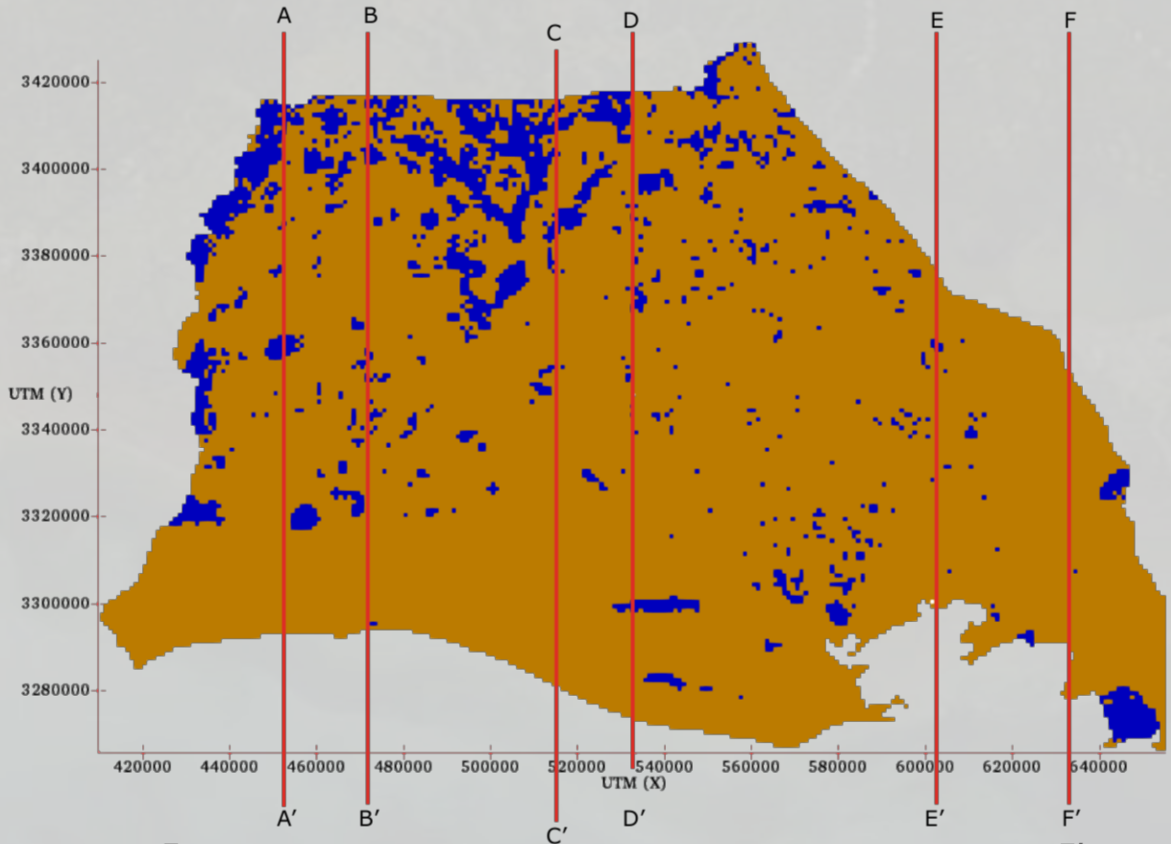


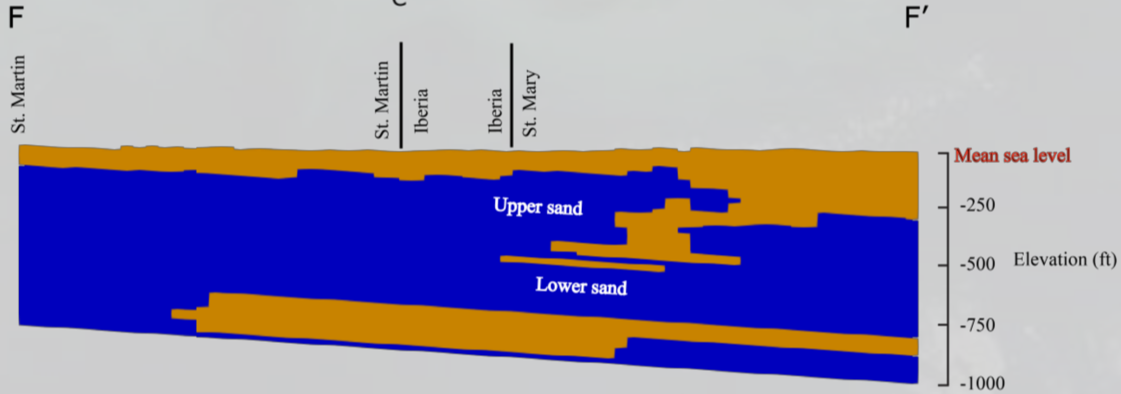
Hydrogeological Framework



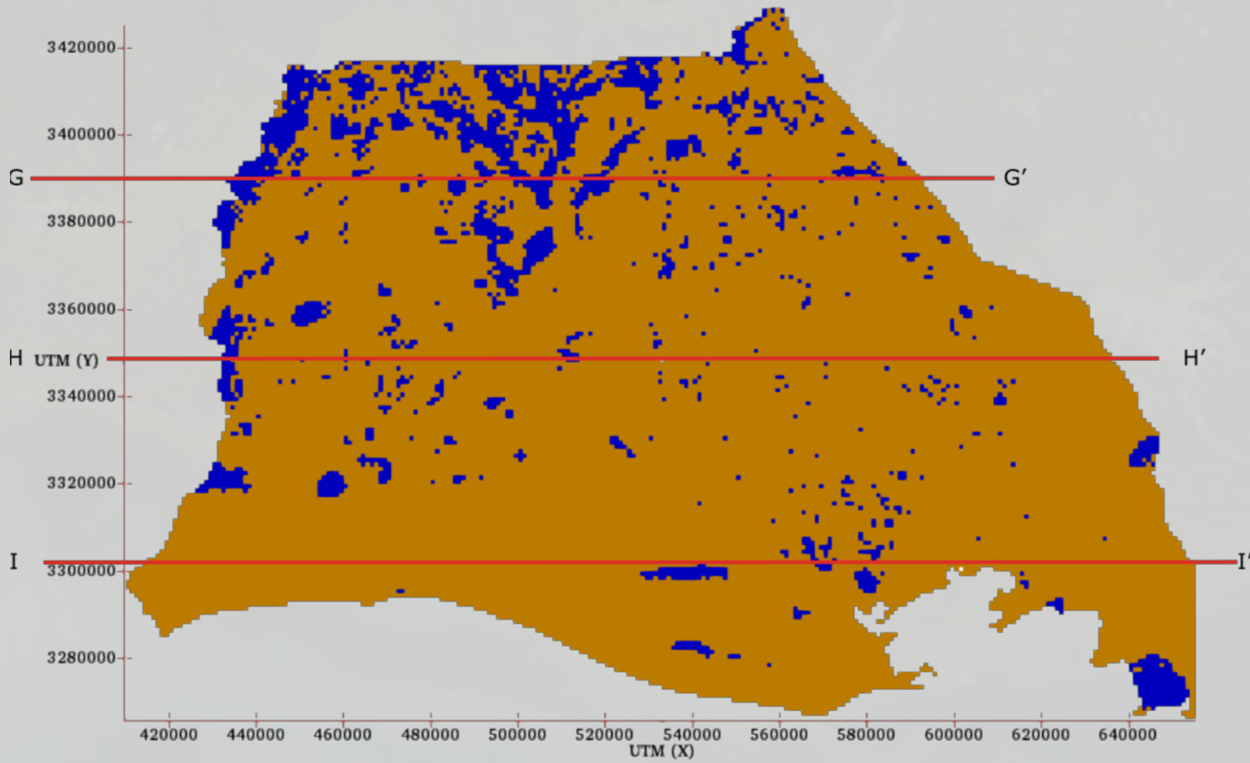


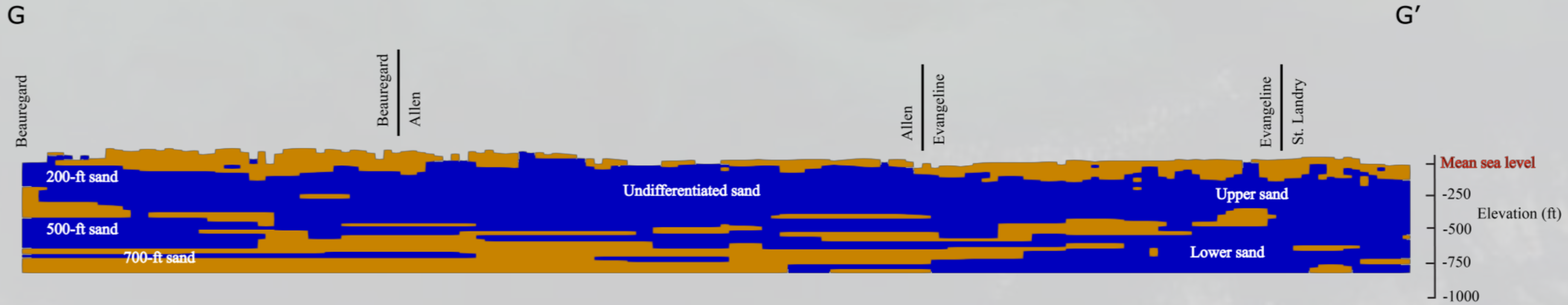
Hydrogeological Framework





Hydrogeological Framework





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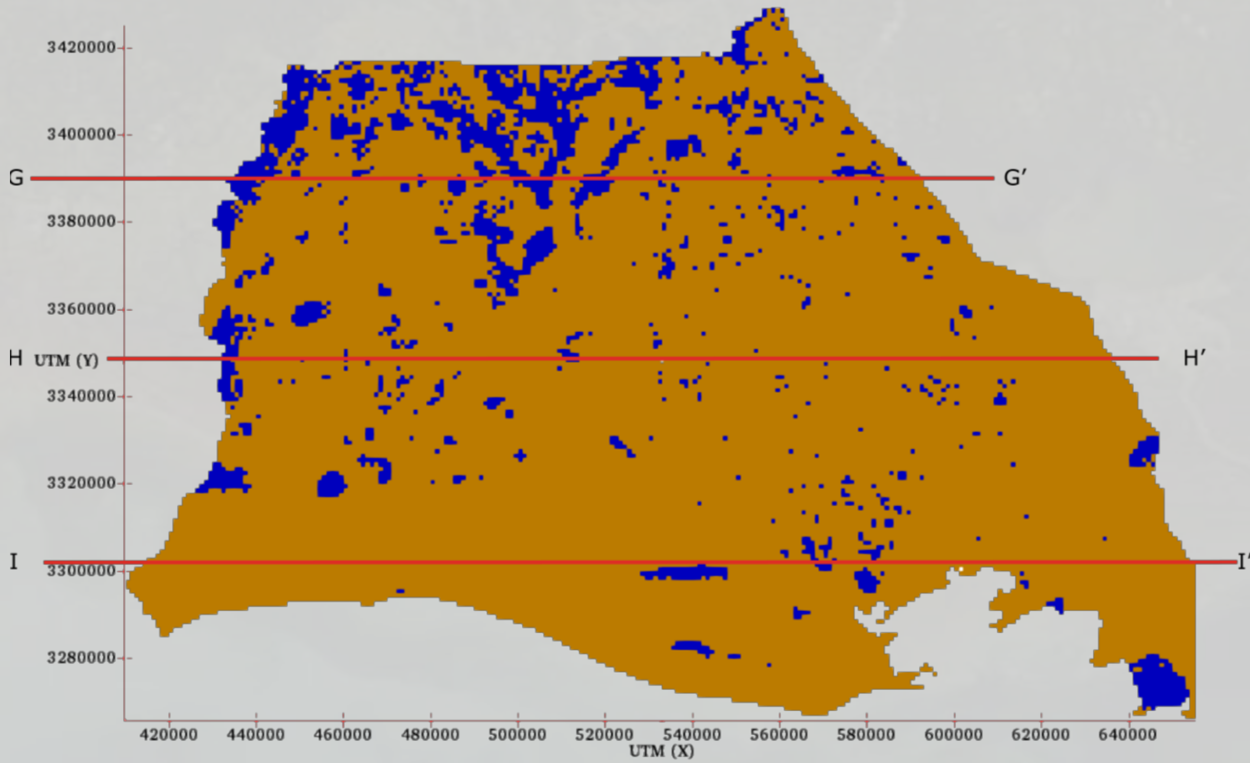

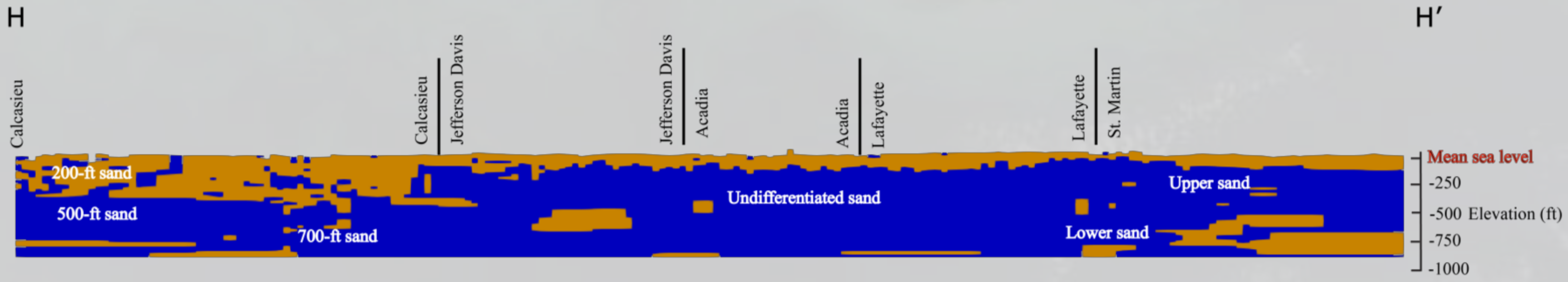

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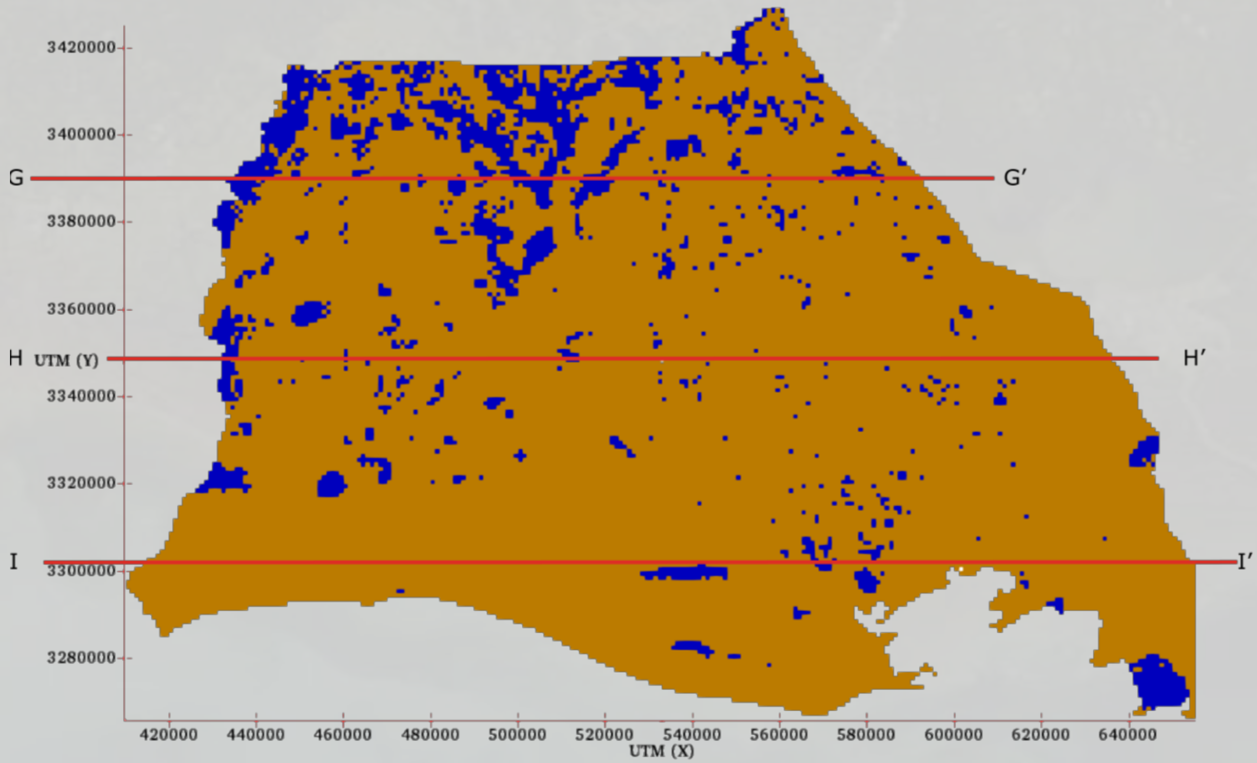
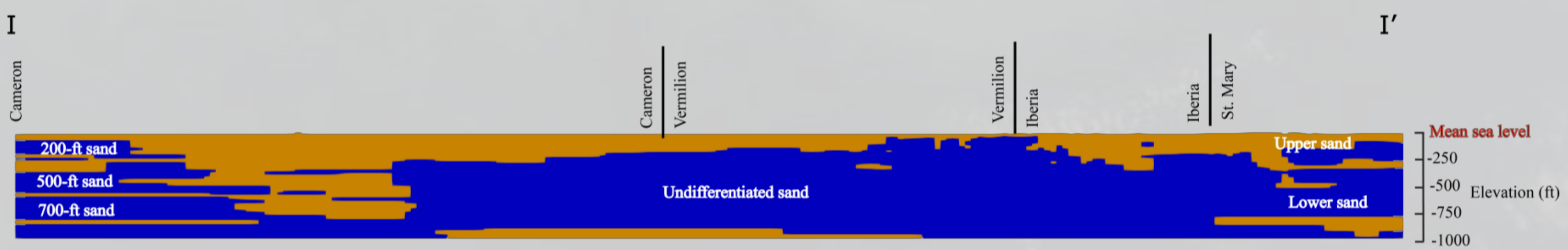
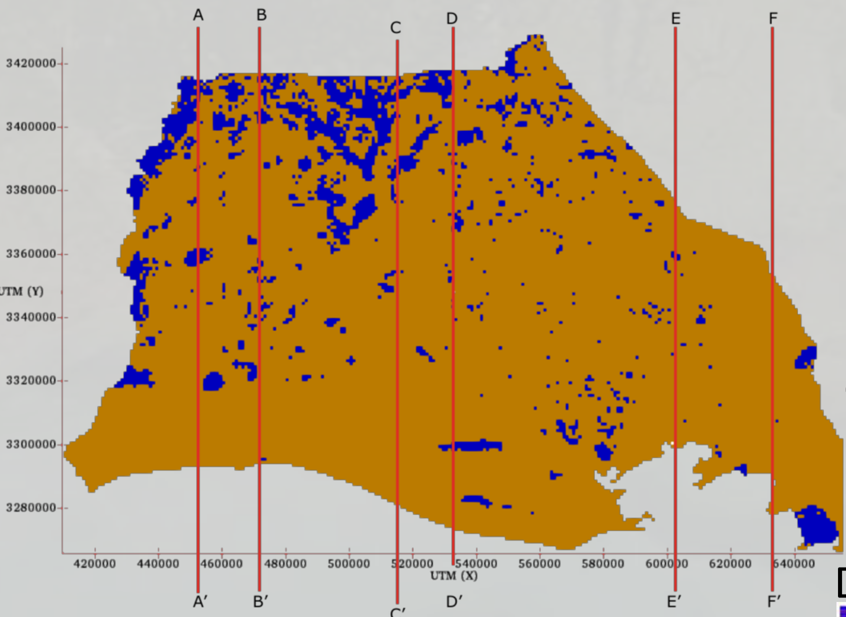
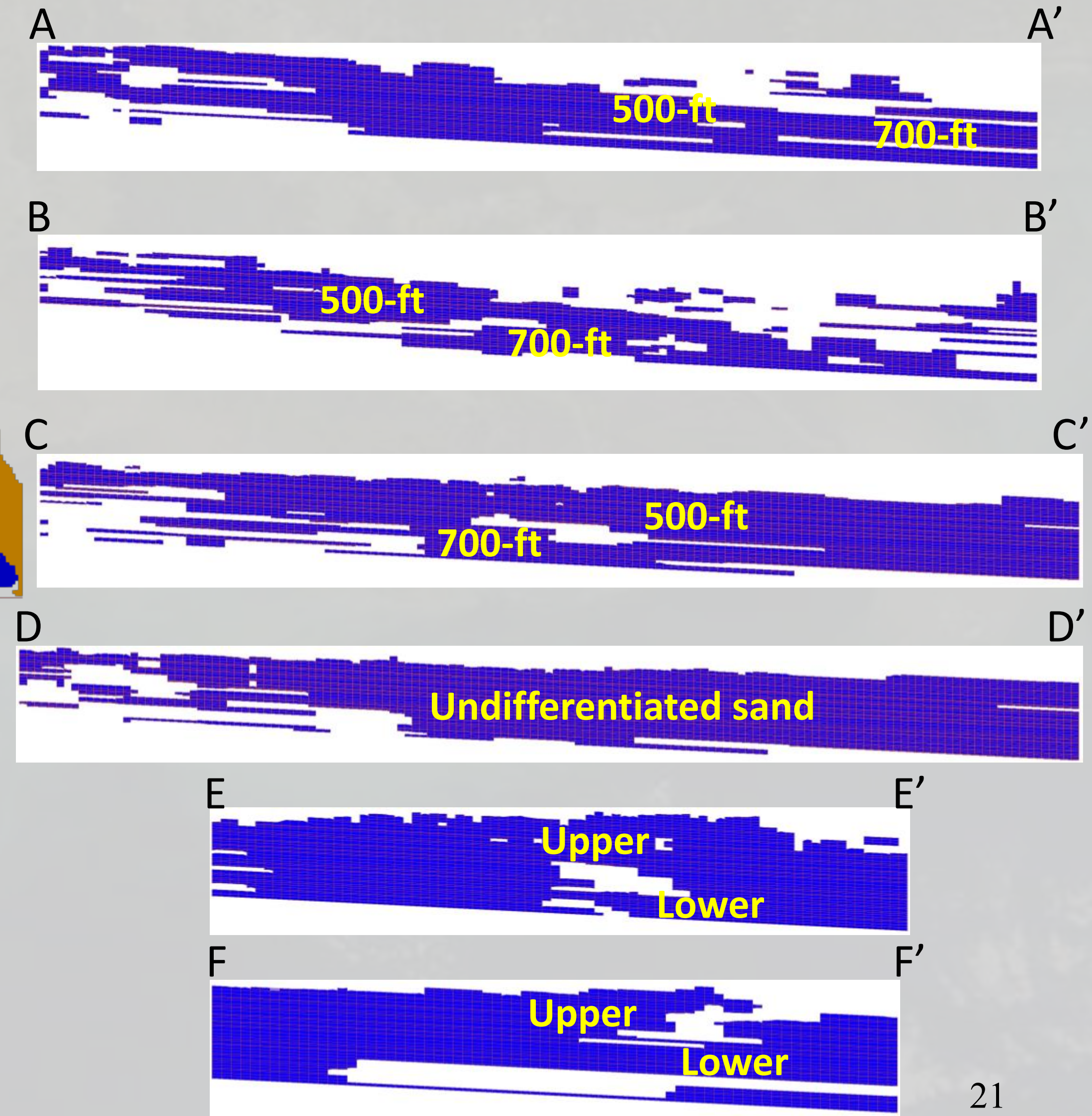




MODFLOW-2005 Grid





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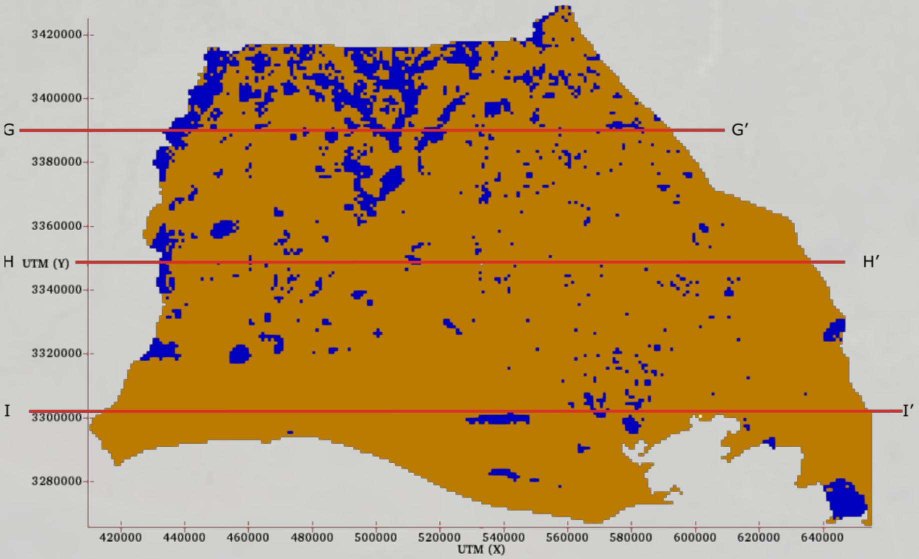
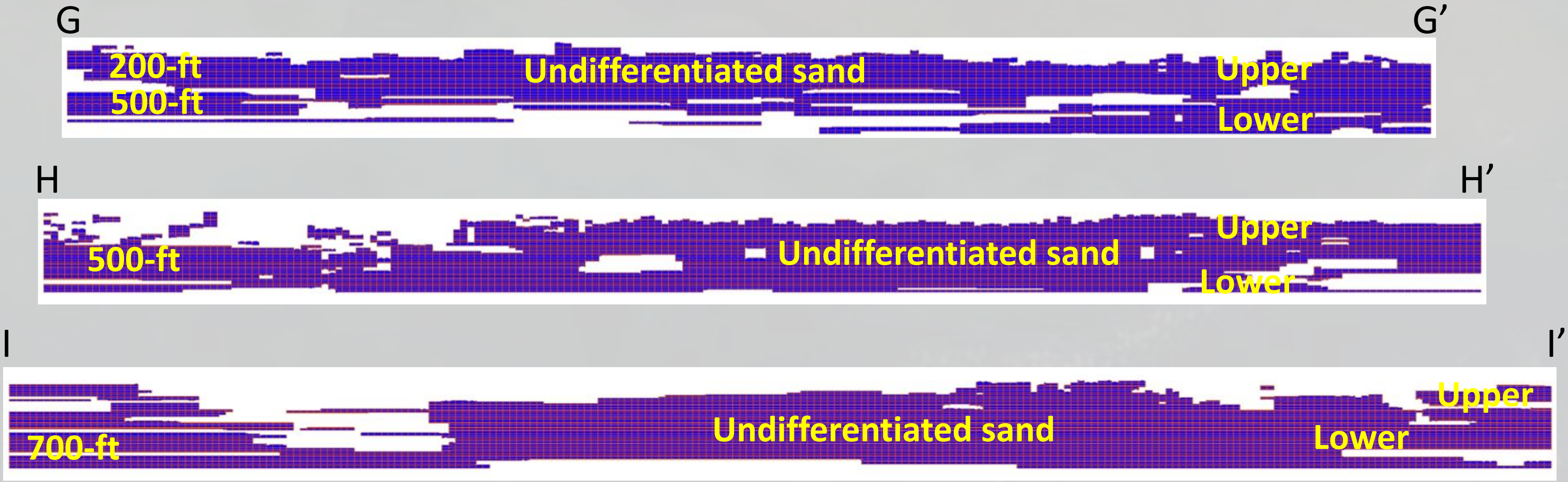
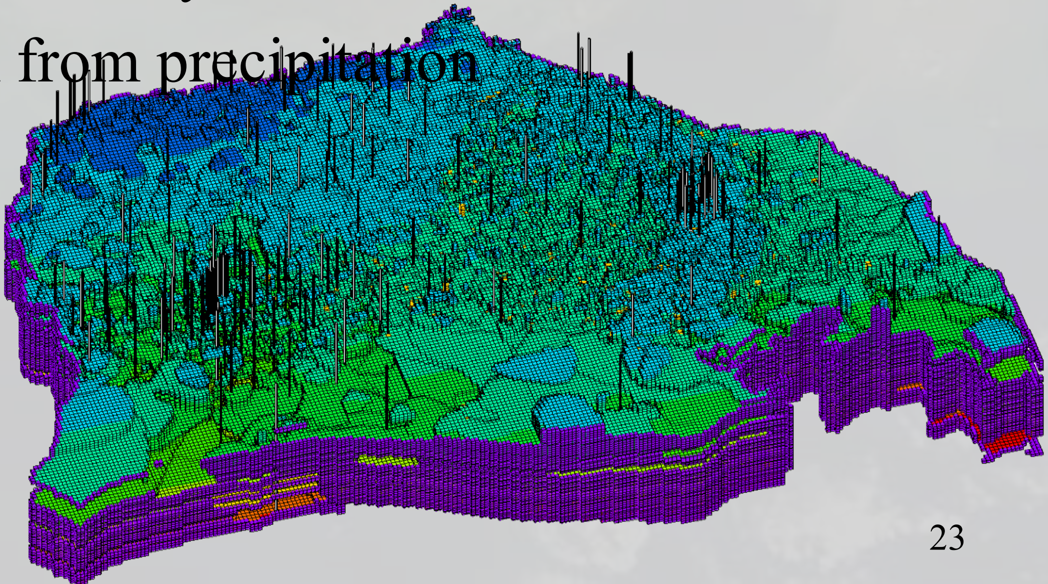




Building a MODFLOW Groundwater Model

- 165 rows, 247 columns, 56 layers
- Cell size: 1 km by 1 km
- The simulation time: 1/1/2004 to 12/1/2014
- Time step length: 1 month
- Number of stress periods: 132
- Initial head condition for 1/1/2004
- Time-varied constant-head boundary head condition
- Surficial recharge: a fraction from precipitation
- Fault: HFB package



Model Calibration

Parallel Inverse Modeling and Uncertainty Quantification for Computationally Demanding Groundwater-Flow Models Using Covariance Matrix Adaptation

Ahmed S. Elshall[1]; Hai V. Pham[2]; Frank T.-C. Tsai, M.ASCE[3]; Le Yan[4]; and Ming Ye, A.M.ASCE[5]

Abstract: This study investigates the performance of the covariance matrix adaptation-evolution strategy (CMA-ES), a stochastic optimization method, in solving groundwater inverse problems. The objectives of the study are to evaluate the computational efficiency of the parallel CMA-ES and to investigate the use of the empirically estimated covariance matrix in quantifying model prediction uncertainty due to parameter estimation uncertainty. First, the parallel scaling with increasing number of processors up to a certain limit is discussed for synthetic and real-world groundwater inverse problems. Second, through the use of the empirically estimated covariance matrix of parameters from the CMA-ES, the study adopts the Monte Carlo simulation technique to quantify model prediction uncertainty. The study shows that the parallel CMA-ES is an efficient and powerful method for solving the groundwater inverse problem for computationally demanding groundwater flow models and for deriving covariances of estimated parameters for uncertainty analysis. **DOI: 10.1061/(ASCE)HE.1943-5584.0001126.** *© 2014 American Society of Civil Engineers.*

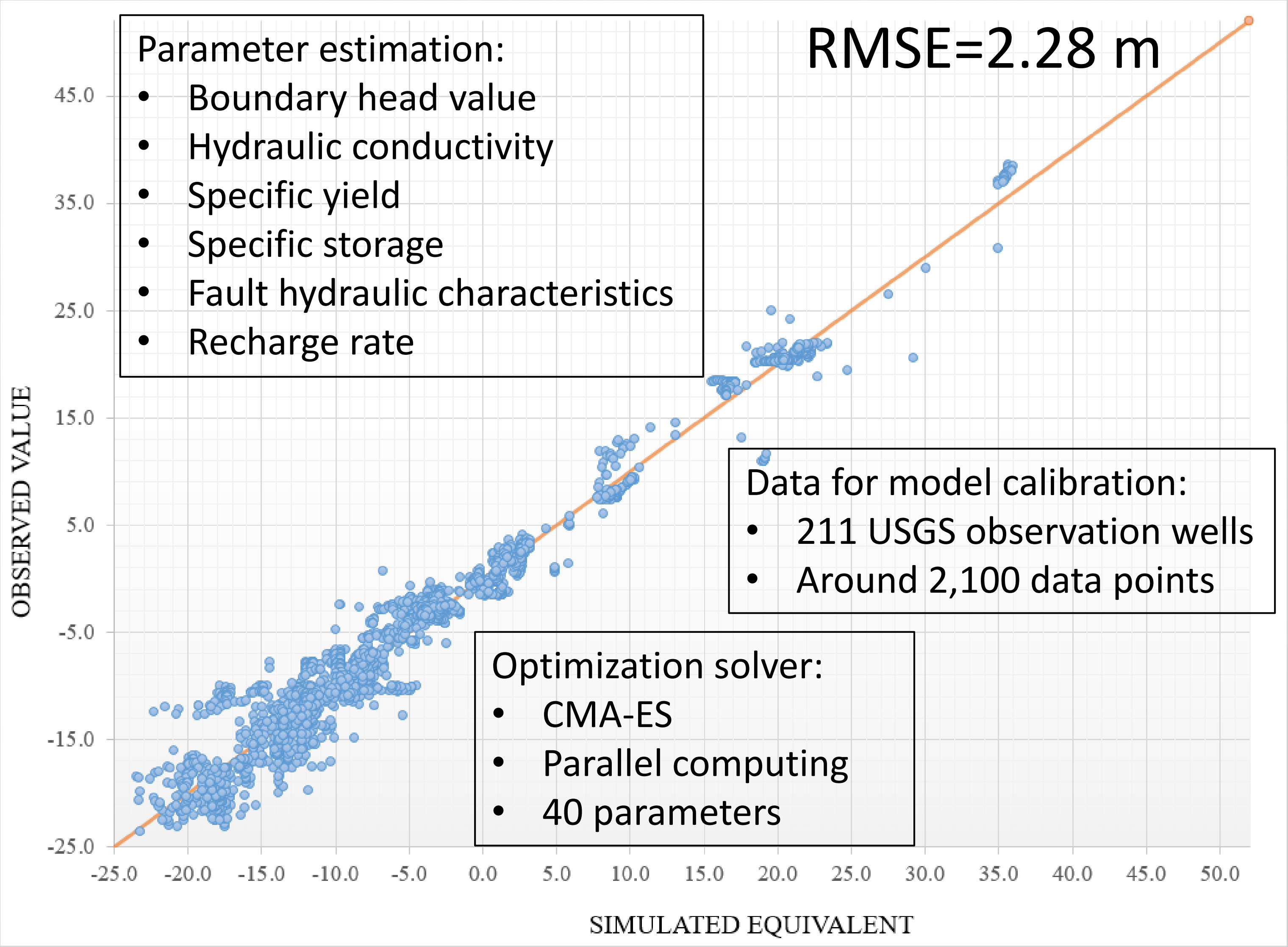
Author keywords: Groundwater; Inverse modeling; Stochastic optimization; Covariance matrix; Evolution strategy; Uncertainty quantification; Parallel computing.

Introduction

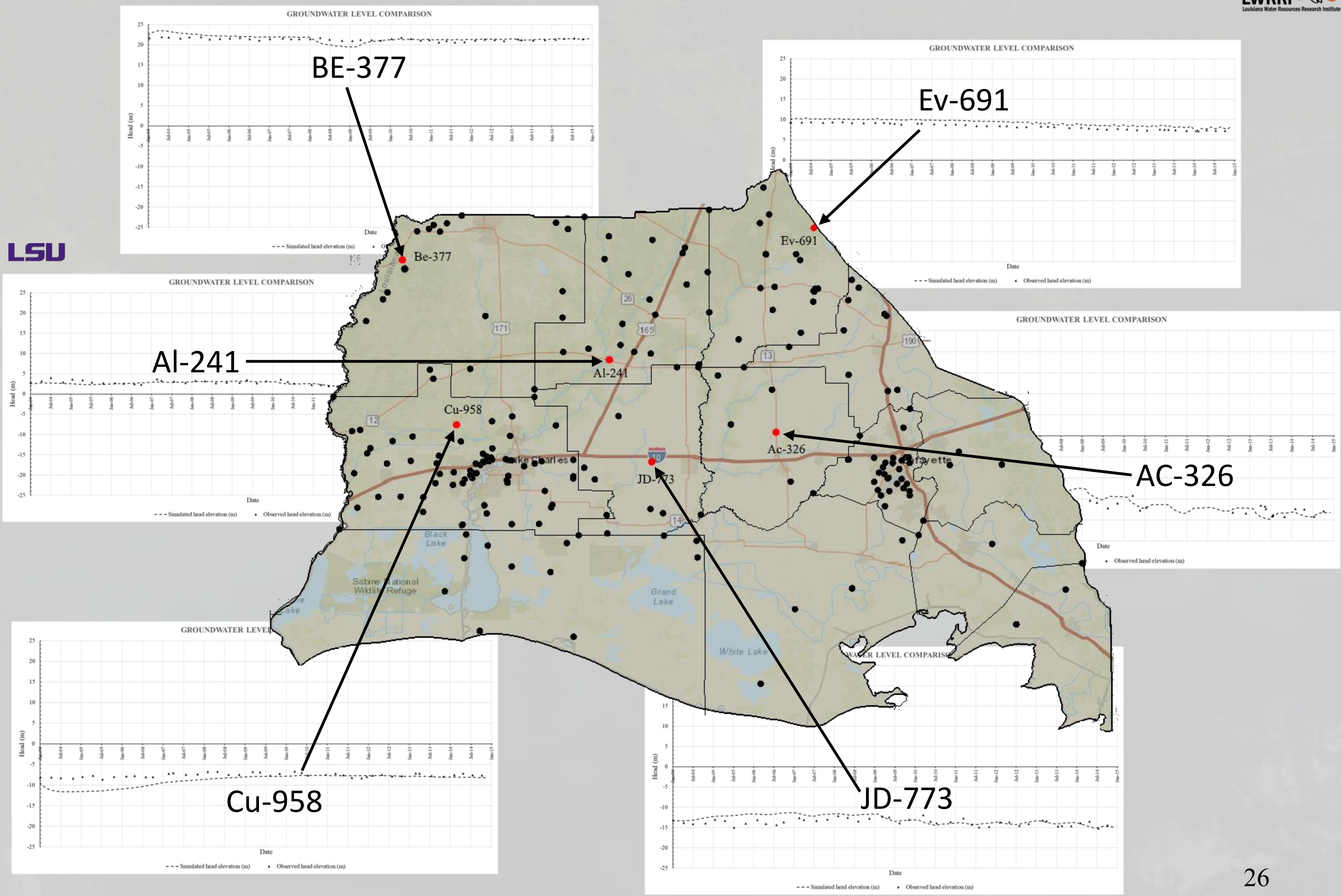
The use of optimization algorithms for solving the inverse problem in subsurface hydrology is a common practice. The classes of optimization algorithms include local derivative algorithms, global heuristic algorithms, hybrid global-heuristic local-derivative algorithms, and global-local heuristic algorithms. While the local derivative algorithms are computationally efficient and can handle

Karpouzos et al. 2001; Solomatine et al. 1999; Bastani et al. 2010) and particle swarm optimization (Scheerlinck et al. 2009; Jiang et al. 2010; Krauße and Cullmann 2012) to avoid entrapment at local minima. This class of algorithms might experience poor local convergence properties. Thus, a third class of algorithms for solving the inverse problem in subsurface modeling is to use the hybrid global-heuristic local-derivative algorithms (Tsai et al. 2003a, b; Blasone et al. 2007; Matott and Rabideau 2008; Zhang et al.

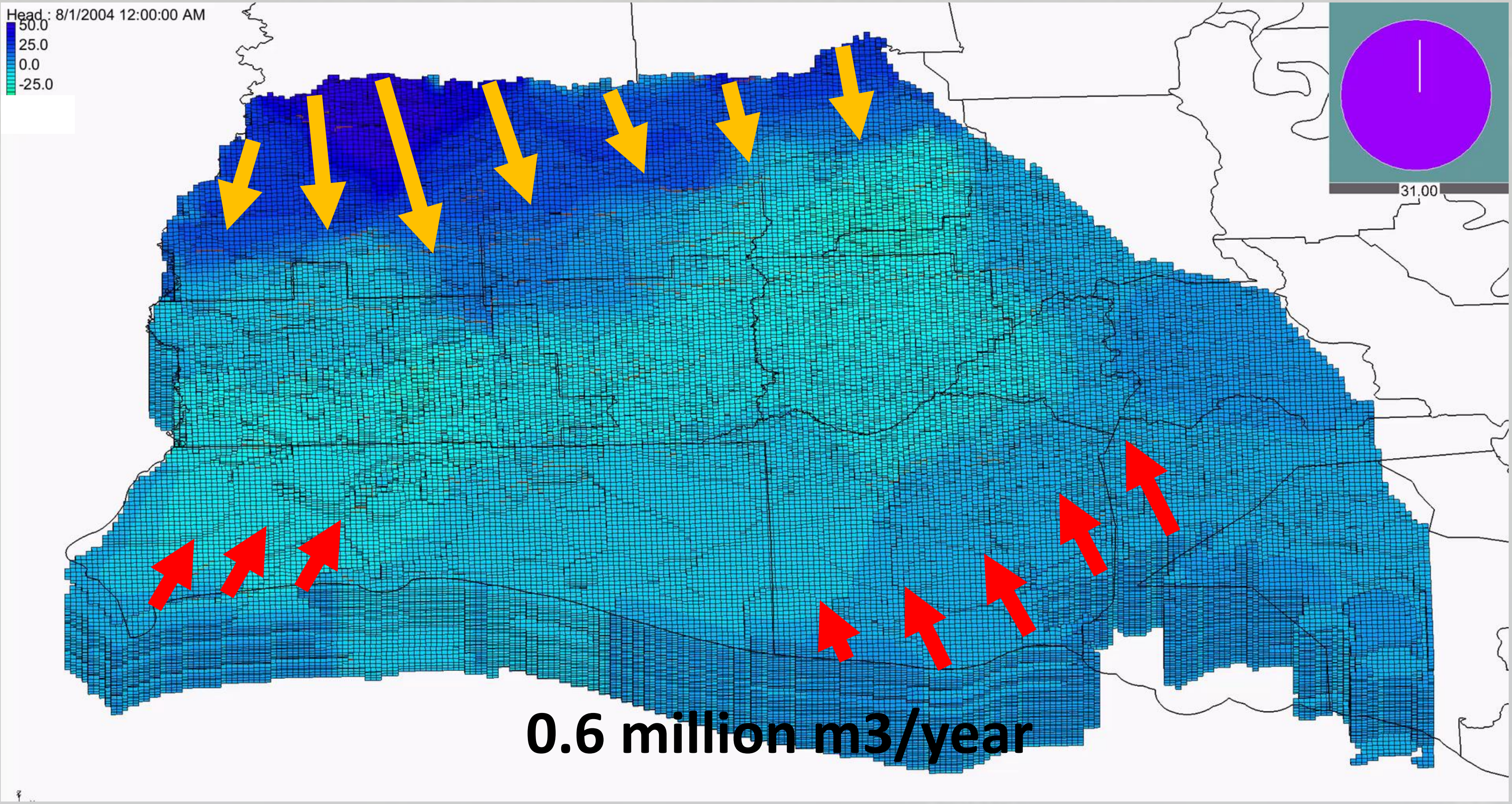
Calibration Result



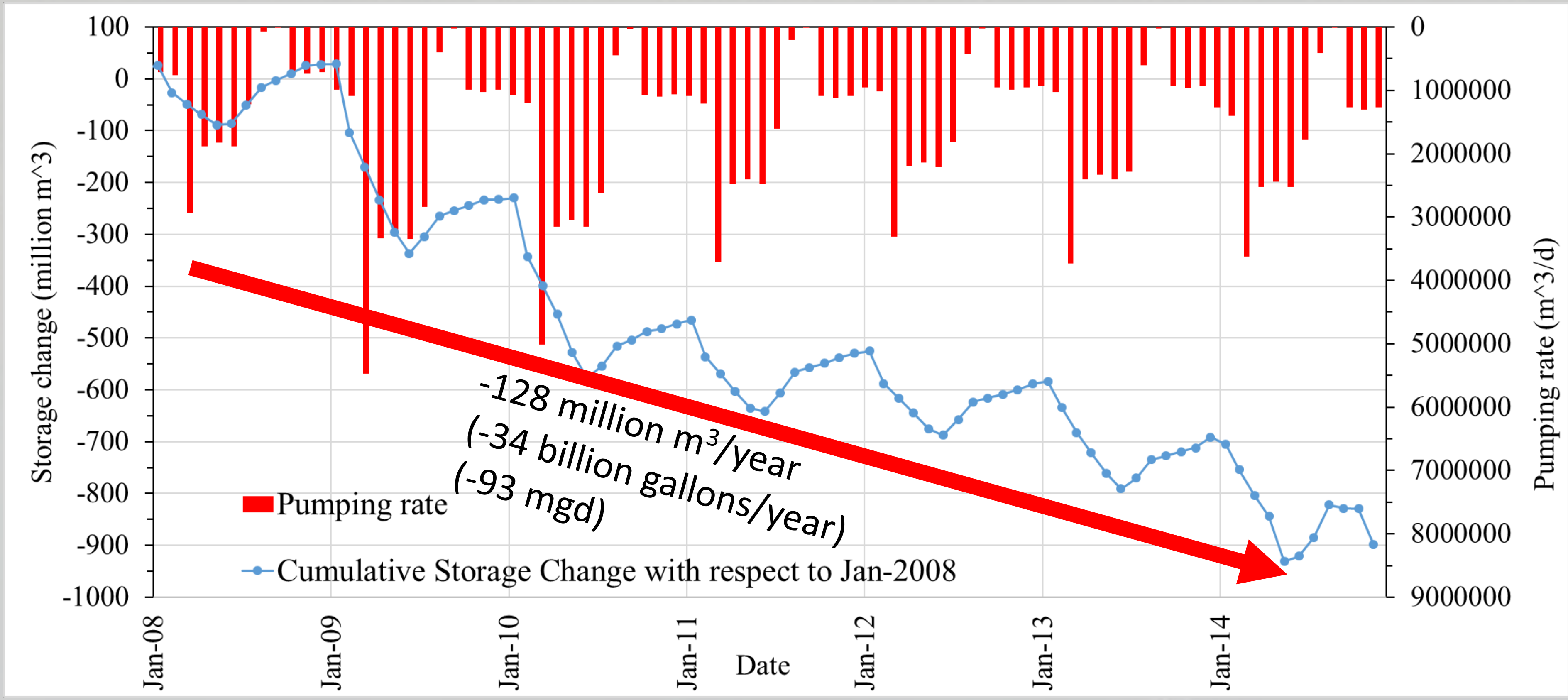
Calibration Result



Groundwater Flow Simulation



Water Budget Analysis



No pumping for 22 days per year would stop storage decline.

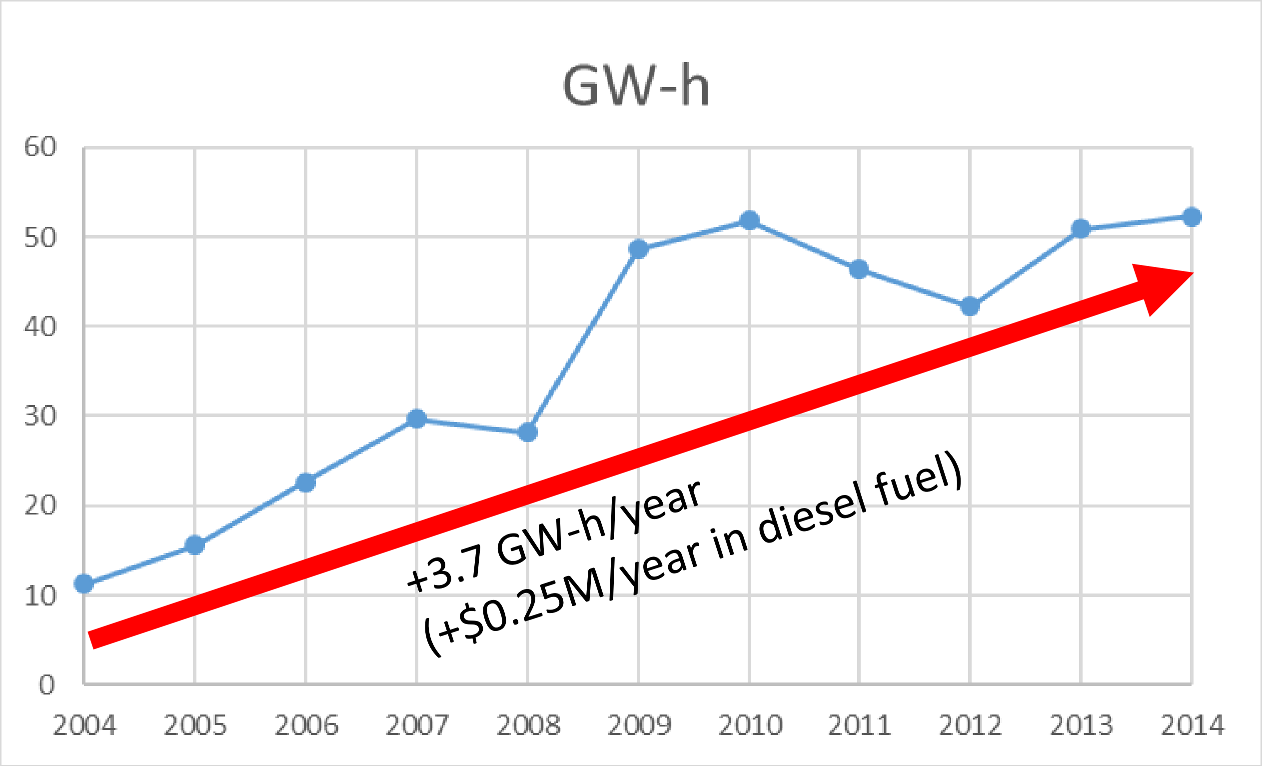
No pumping for 44 days per year would get to 2008 storage in 7 years.

Pumping Energy Consumption

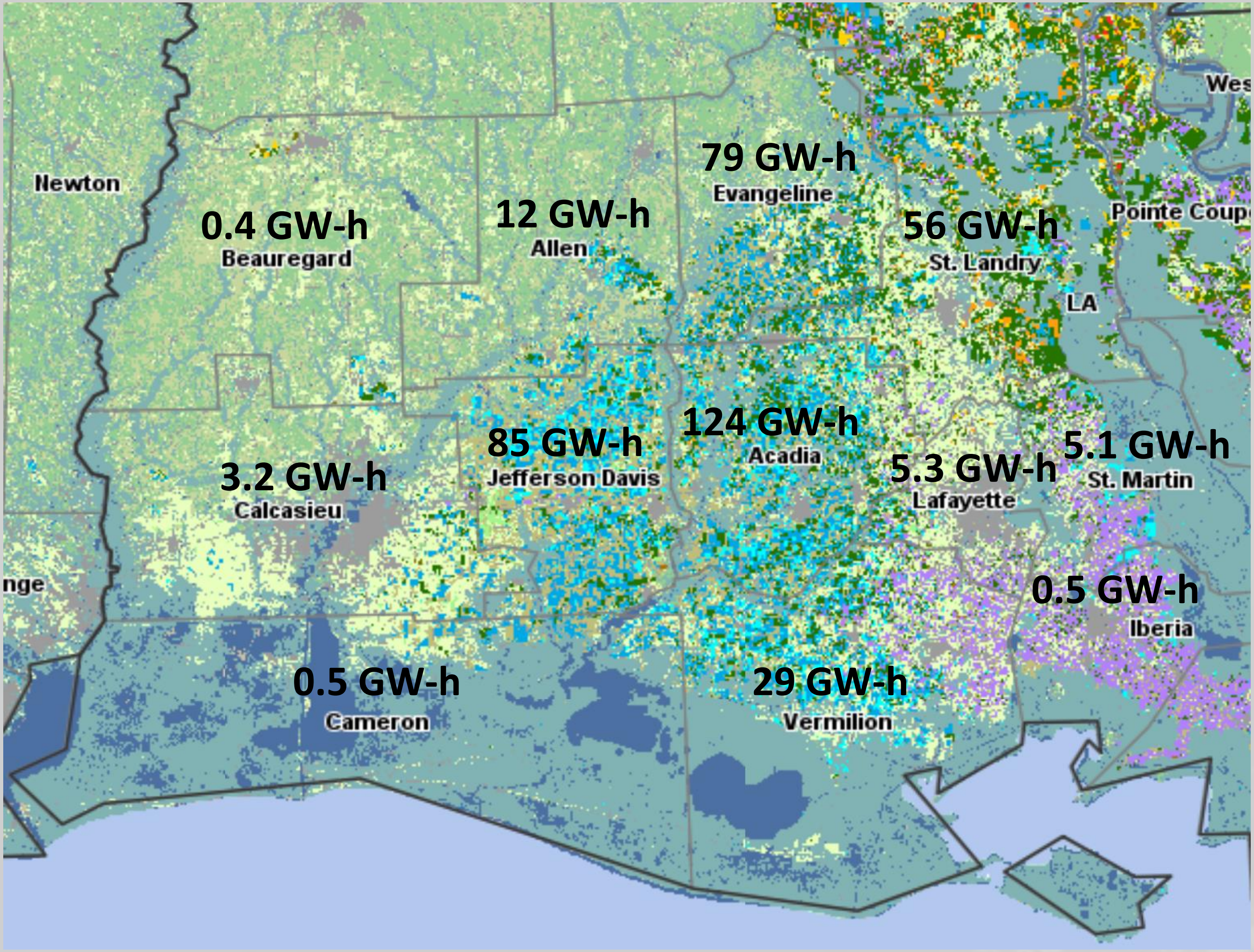
❖ Energy consumption is calculated for different years based on:

$$E = \frac{\gamma Q \Delta h}{\eta}$$

γ: water specific weight
Q: pumping rate
Δh : head lift
η : efficiency (70%)



Pumping Energy Consumption (2004-2014)



Conclusion

- The hydrogeological framework for the Chicot aquifer system is actually more complex than previously published studies.
- The previously developed hydrostratigraphic modeling technique successfully constructed a high-fidelity MODFLOW model to study the Chicot aquifer system.
- Chicot aquifer system is depleting 34 billion gallons of groundwater per year.
- Groundwater level decline along the coastal line creates a favorable condition for saltwater encroachment.
- Pumping energy increases 3.7 giga-watts-hour (GW-h) per year due to continuing water level decline in pumping wells. This is equivalent to a $0.25M energy bill increase per year in using diesel fuel.
- No pumping for at least 44 days every year would restore groundwater storage to 2008 condition within 7 years.

Acknowledgments

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- Louisiana Sea Grant College Program

- U.S. Geological Survey
- Louisiana Department of Natural Resources
- Louisiana Geological Survey