Title: Assessment of the impact of hurricane Katrina's and Rita's storm surges on the Southern Hills Aquifer System in southern St. Tammany and Tangipahoa Parishes

PROBLEM AND RESEARCH OBJECTIVES

On August 29th and again on September 21st, 2005, the shoreline communities located on the north shore of Lake Pontchartrain, an estuarine lake connected to the Gulf of Mexico, were flooded by hurricane storm surges (Fig. 1). The surges displaced the saline water from the lake onto the surrounding coastal lowland. Many of structures lining the shoreline were damaged or destroyed by the surging waters. Of those, many of the residences and businesses obtained their drinking water from adjacent water wells drilled in shallow aquifers. The shallow aquifers (<500-feet deep) along the north shore of Lake Pontchartrain (Fig. 2) are predominantly used by older residential water wells. The shallow aquifer is identified by Griffin (2003) as being part of the Norco Aquifer (aka Upland Terrace Aquifer), which is hydraulically connected with the deeper Gonzales-New Orleans Aquifer, and Upper Ponchatoula Aquifer (Nyman and Fayard, 1978). Although few new wells have been completed in the Norco Aquifer, the other two deeper aquifers are regularly used for domestic water supply. In addition, a review of drillers' well logs from the Louisiana Department of Transportation and Development (DOTD) shows that the surficial clay protecting the shallow aquifer is thinnest/non-existent in the vicinity of Bayou Lacombe. The storm surge at Bayou Lacombe was observed to be ≤5 feet above ground, and extended ~2 miles inland. Near Slidell, the surge was >10 feet, and extended in excess of 3 miles inland.

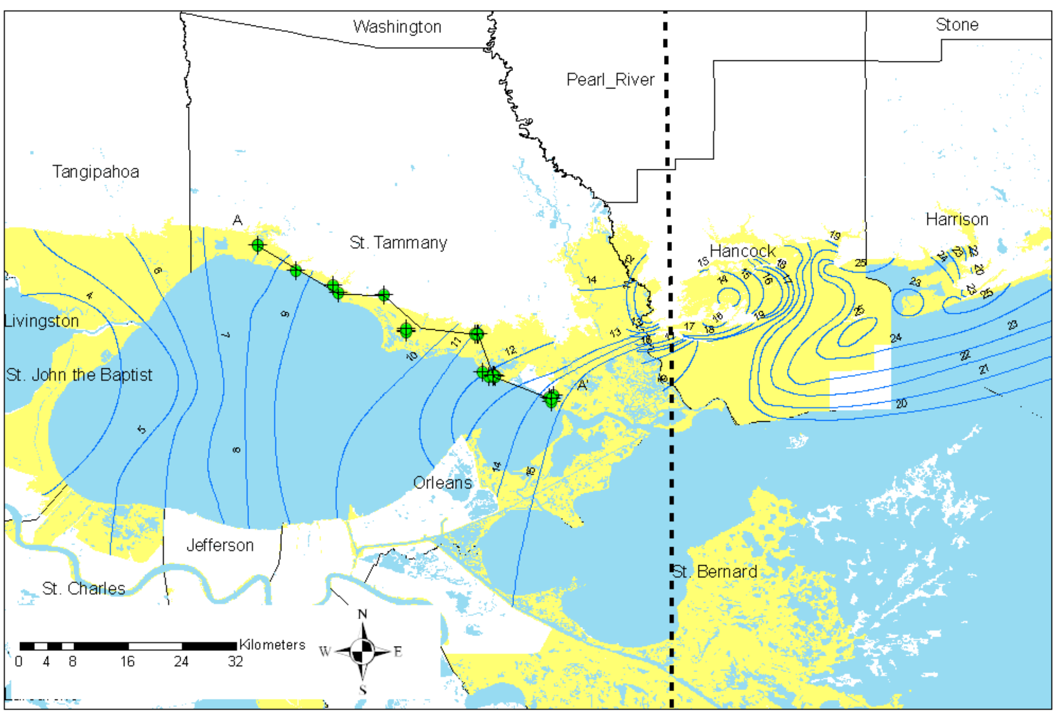

Figure 1: Extent of flooding (shaded in yellow with blue elevation contours) caused by the storm surge of Hurricane Katrina (data source: Federal Emergency Management Agency (FEMA)

2006; Anderson and Brakenridge 2005; and Carroll et al. 2005). The bold dashed line represents the path of Hurricane Katrina (modified from Van Biersel et al, 2007a)

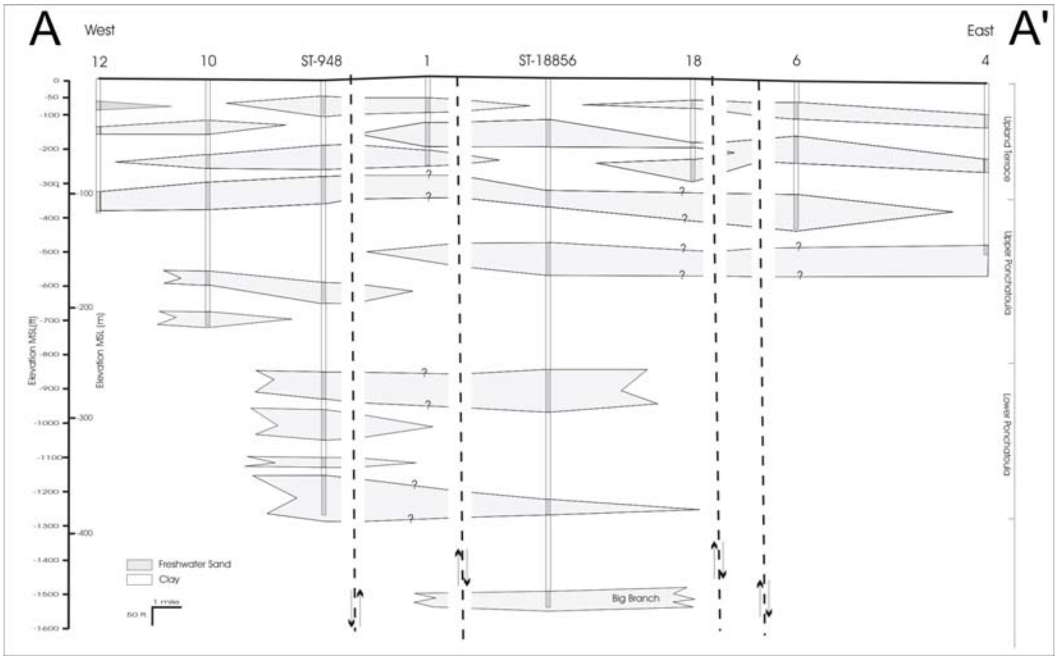

Figure 2: Geologic cross-section of the aquifers along the north shore of Lake Pontchartrain. The cross-section locator is located on Fig. 1 (modified from: Van Biersel et al, 2007b).

As the buildings were damaged or destroyed, so were the associated plumbing, pumps and well housings and casings. These wells became open conduits between the surging lake water of non-drinking water quality and the subsurface aquifer. Saline lake water and surface contaminants were introduced into the aquifer, impacting an important source of drinking water supply. The goal of this research is to assess the short- and long-term implications of hurricane Katrina's and Rita's storm surges on the shallow aquifer system along the north shore of Lake Pontchartrain.

Groundwater sampling and field observations conducted in September and October, 2005 by the PI and CoPIs, in collaboration with the Louisiana Dept. of Environmental Quality (DEQ) and the U.S. Geological Survey (USGS), have shown that surge water has entered the aquifer through water wells damaged during the storm (Van Biersel et al, 2006). Analyses of the groundwater show decreased Ca/Mg ratio from a pre-Katrina value of ~3.8 (average historical value for the Upper Ponchatoula aquifer in St. Tammany parish) to a post-Katrina value of ~1.3 (wells sampled). In addition, chloride concentrations increased from a pre-Katrina of ~8.4 mg/L (average historical value for the Upper Ponchatoula aquifer in St. Tammany parish) to a post-Katrina value up to 6,449 mg/L (wells sampled). The low Ca/Mg ratios and elevated chloride concentrations are indicative of saltwater intrusion. In addition, most wells were contaminated by coliform bacteria, including, in some cases, *Enterococcus* and *Escherichia coli (E Coli).*

Bacterial contamination is a greater risk to public health than the presence of elevated seawater constituents, such as chloride. Chloride does have a U.S. Environmental Protection Agency (EPA) National Secondary Drinking Water Standard (non-enforceable nuisance guidelines) of 250 mg/L. However, elevated chloride concentration can be detected by well owners relatively easily by taste. This does provide an early detection mechanism for identifying a change in water quality. The presence of waterborne bacteria can only be found by testing the water for specific microorganisms. In Louisiana, public water supply systems are regularly tested by the Louisiana Department of Health and Hospitals (DHH); however, private residence wells are not. It is the responsibility of the well owners to test his/her water supply routinely. However, after Katrina, 263 residences and/or businesses submitted water samples to the DHH for bacterial analysis. Fecal coliforms/*E Coli* was present in 2.3% of the samples, and total coliforms in 28.9% of the samples (DHH, 2006).

In addition, the lake water that stagnated for an extended period of time in the areas affected by the two storm surges, overtime, is percolating downward through the subsoil in the form of a saltwater-rich pulse. Overtime, this pulse is diluted with the addition of fresh rainwater to the substrate, and may reach the shallowest aquifer system (Fig. 2), resulting in additional degradation of the water supply for residential wells.

The primary scope of this project was to determine the extent, both aerially and vertically, of contamination in the aquifers affected by the storm surge along the north shore of Lake Pontchartrain in St. Tammany and Tangipahoa Parishes. This is done by sampling water wells, interviewing well owners, combining information gathered by several agencies after the storm, and performing geophysical surveys. Sixteen water wells were monitored for the duration of the study, to determine if bacterial contamination will be a recurring issue for the water wells affected by the storm. The objectives of this study were as follows: (1) to determine the aerial extent of aquifer contamination by lake water along the north shore of Lake Pontchartrain; (2) to determine the vertical extent of storm water migration in areas where the surficial clay is thin or absent; and (3) to determine whether there will be a recurrence of bacterial contamination in the water wells overtime.

METHODOLOGY

The researchers collected geohydrological data from Louisiana Geological Survey (LGS), USGS and DOTD, storm surge data from the Dartmouth University Flood Observatory, the University of Maryland global Land Cover Facility, the USGS and FEMA, geophysical soundings, and groundwater samples. In addition, DHH provided bacteriological data.

Geophysical soundings were collected, using the LGS's Super MiniRes Earth Resistivity (ER) meter. The ER method was selected in this case because it uses an electrical pulse to measure the resistance of the earth material(s) between electrode arrays. The method is neither intrusive nor destructive, and can be used repeatedly at the same location without requiring additional markings. The data was modeled to determine the geological make-up of the subsurface and salinity of the interstitial water. ER soundings were performed at the Fairview Riverside State Park and Fontainebleau State Park. No suitable location was found at Big Branch Marsh National Wildlife Refuge. ER was used in areas of the study where the shallow aquifer is within ~200 feet of the surface, and had been submerged during the storm surge. The selection of data collection sites for ER soundings was made based upon access availability, and the lack of human interferences (e.g. overhead or buried electrical wires, pipelines, cables, etc). The geophysical data was downloaded into a personal computer, and plotted in profiles to verify that a sufficient depth had been reached, and/or to determine if saltwater had been encountered. The analysis of the modeled ER data, in corroboration with groundwater samples and available geologic logs (driller's logs were available at the DOTD) had the advantage of providing data on both the geology of the aquifer and the salinity of the groundwater.

Groundwater samples were collected by the PIs after obtaining permission from the property owners. The water wells were purged for approximately 20 minutes prior to collection of an unpreserved 250-mL bottle for anions, and a field-filtered and HNO_3-preserved 250-mL bottle for cations. A 100-mL water sample was passed through a 0.45µ membrane filter. The filter was then be placed in a Petri dish with m-ColiBlue 24 broth media and placed in the portable incubator. The total coliform analysis (and *E Coli*) was quantified at LGS's lab. The water was field-tested using LGS's portable meters for specific conductance (e.g. salinity), temperature and pH. The sample bottles were stored and cooled to 4ºC in the field, and transferred to a refrigerator in the lab. The water samples were analyzed in the lab, using LGS's spectrophotometer for anions (Cl, B, F, SO_4, PO_3, CO_3 and NO_3). Furthermore, the water samples was tested using Prof. Gambrell of the LSU Dept. of Wetland Biochemistry's Varian (model MPX) Inductively Coupled Plasma – Optical Emission Spectrometer (ICP-OES) for cations of interest (e.g. Al, As, Bo, Ca, Cd, Cr, Cu, Fe, K, Mg, Mn, Na, Ni, P, Pb, Rb, Si, Sr, Zn).

PRINCIPAL FINDINGS AND SIGNIFICANCE

The groundwater sampling results indicate that water wells recovered to pre-Katrina status relatively quickly under normal use. Most wells were sampled after a water well contractor had rehabilitated the well (e.g. plumbing repair, pump repair/replacement, flushing and chlorination). Tests showed little or no significant changes, which cannot be explained by seasonal variation during the testing period. Of the 25 wells sampled (Table 1), only three wells (#4, #8 and #14) had results which included the impacted water in the casing, as indicated by changes in the specific conductance (SC) recorded in the field (Fig. 3).

Table 1: Summary of well construction information

Well #	Depth (m)	Screen Interval (m)	Aquifer Code	Casing Diam. (cm)	Pump Type	Vented (Y/N)	Surge Depth (m)	# of Smpls	Location	Comments
1	79	70-79	112UPTC	10	Sub.	yes	0	1	Mandeville	Not flooded
2	178	172-178	112PNCLU	5	Jet	no	1.5	1	Lacombe	
3			112PNCLU	5	Jet	no	1.5	15	Lacombe	
4	152	146-152	112PNCLU	10	Sub.	yes	4.0	20	Slidell	not rehabilitated
5	82	76-82	112UPTC	5	Jet	no	4.0	15	Slidell	
6	61		112UPTC	5	none	yes	3.0	15	Slidell	Flowing artesian
7	131	125-131	112PNCLU	10	Sub.	yes	3.0	14	Slidell	no longer vented
8	116	110-116	112UPTC	5	Jet	no	3.0	4	Slidell	
9	83	80-83	112UPTC	5	Jet	no	0.3	15	Slidell	
10				5	Jet	no	1.8	1	Madisonville	
11	122	116-122	112PNCLU	10	Sub.	no	1.5	1	Madisonville	
12	119	110-119	112PNCLU	15	Drive	yes	0.9	1	Madisonville	
13	119	113-119	112UPTC	5	Jet	no	3.4	15	Slidell	
14	140	134-140	112PNCLU	10	Sub.	yes	3.0	24	Slidell	no longer vented
15	162	155-162	112PNCLU	10	Sub.	yes	4.0	12	Slidell	
16	81		112UPTC	8	Jet	no	4.0	14	Slidell	
17	84	78-84	112UPTC	5	Jet	no	0.3	14	Slidell	
18	90	87-90	112UPTC	5	Jet	no	0.3	14	Slidell	has filter
19	184		112PNCLU	10	Sub.	yes	1.5	14	Lacombe	
20			112PNCLU	5	Jet	no	1.5	13	Lacombe	
21	91		112PNCLU	10	Sub.	no	1.8	14	Mandeville	

22	134	125-134	112PNCLU	10	Jet	yes	1.5	14	Mandeville	Flowing artesian
23	107		112UPTC	5	Jet	no	3.0	1	Slidell	
24			112UPTC	5	Jet	No	3.0	1	Slidell	
25	512		120ABIT	15	none	Yes	<0.3	2	Mandeville	Flowing artesian

Note: modified from Van Biersel et al, 2007a

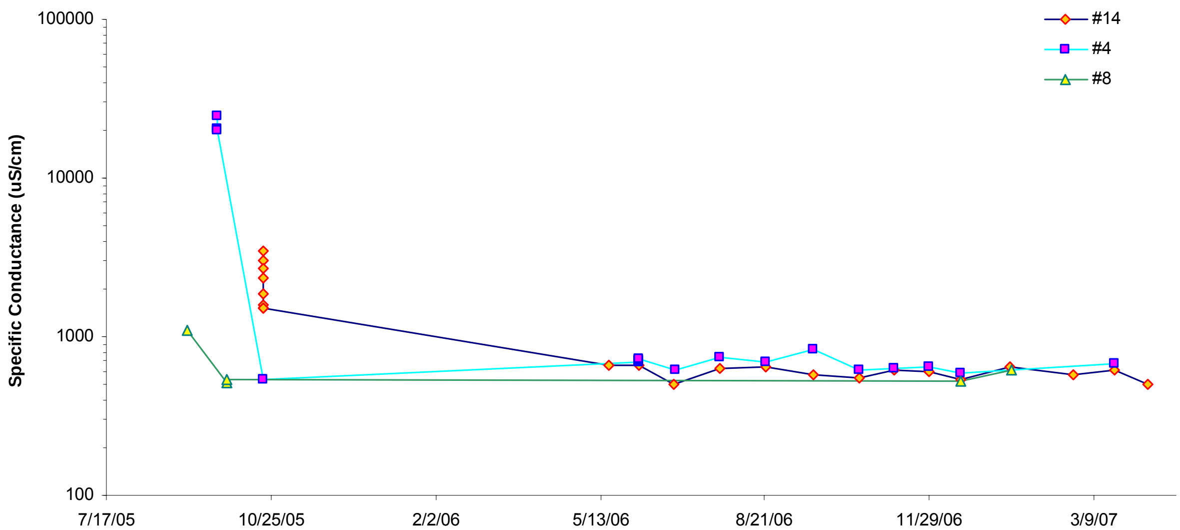

Figure 3: Specific conductance results for the three wells (#4, #8 and #14) whose impacted casing water was tested (modified from Van Biersel et al, 2007a)

Parameters indicative of seawater intrusion, including the calcium (Ca) – magnesium (Mg) ratio, as well as sodium (Na), chloride (Cl), silica (Si) and boron (Bo) concentrations, show the same trend overtime as the SC (Fig. 4). Statistical comparison of the results (Van Biersel et al, 2006; and Van Biersel et al, 2007b) indicated that samples collected after the storm surge exhibit a small to significant deviation from pre-hurricane values. This is particularly true for SC, Si, the Cl/Si ratio, and, to a lesser extent, of Ca.

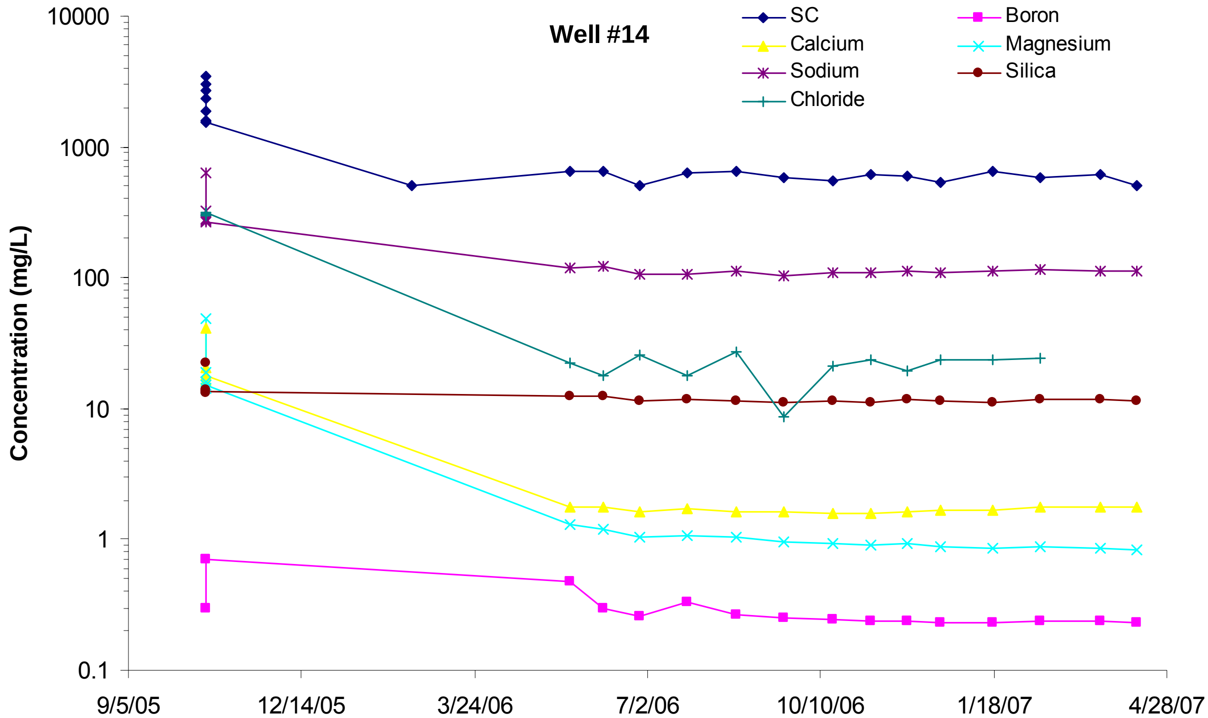

Figure 4: Cations measured in well #14 exhibiting substantial variation as a result of the storm surge

Bacterial testing of the groundwater samples (Fig. 5 and 6) indicates that most water wells remain free of total coliform and E coli bacteria after the rehabilitation of the well, with the exception of six wells. Three wells (#5, #20 and #21) had detectable concentration which could be related to likely field contamination from airborne particulates (e.g. dusty conditions caused by construction equipment) at the time of sampling. One well (#4) was not rehabilitated (e.g. chlorinated), and showed that total coliform was detected in 40% of the samples collected. Two wells (#7 and #15) had repeated total coliform bacteria detected in the samples; although both wells had been rehabilitated more than once. It should be noted that well #4, #7, #14 and #15 (Table 1) have a 10 cm (4”) inner diameter casing (e.g. riser) equipped with submersible pumps, and a vented well cap (wells #7 and #14 were modified after the storm to remove the vents).

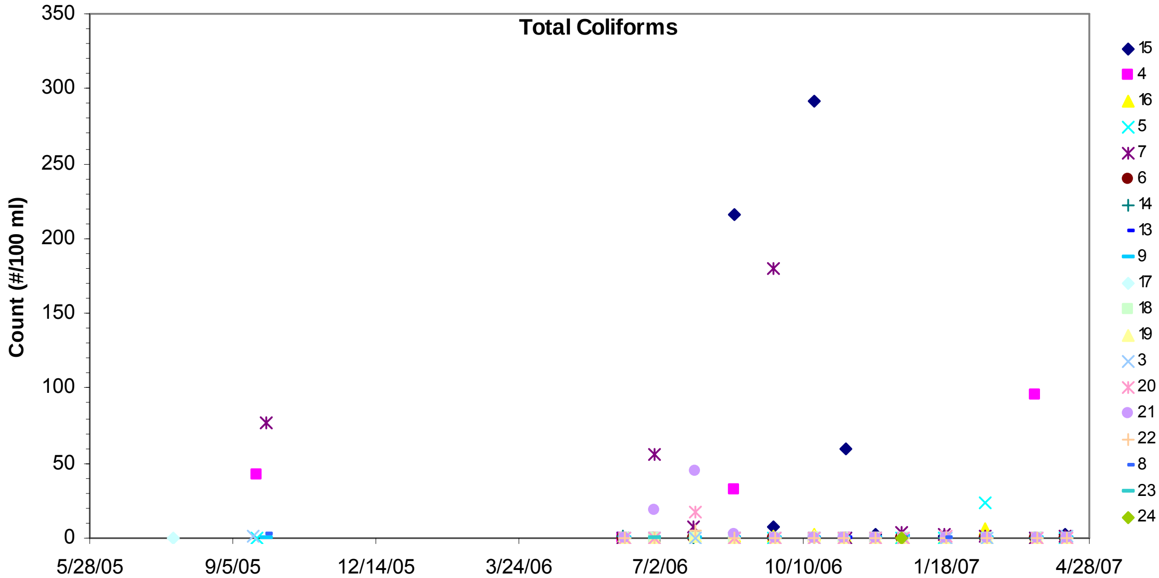

Figure 5: Result of total coliforms count. The 2005 data is the Most Probable Number (MPN) value; thereafter it is the Membrane Filter (MF) value.

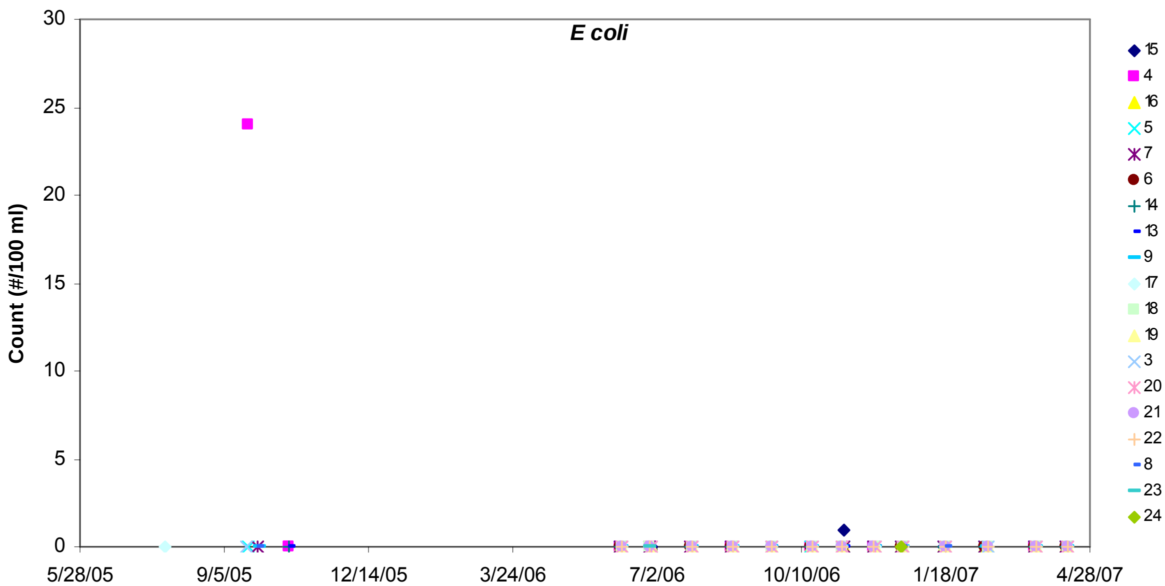

Figure 6: Result of E coli count. The 2005 data is the Most Probable Number (MPN) value; thereafter it is the Membrane Filter (MF) value.

The geophysical surveying included measuring the apparent resistivity of the geological material and interstitial fluid (e.g. groundwater) with depth [e.g. A-spacing (Fig. 7) represents approximately two times (2X) the measurement's depth]. Seven vertical profiles were collected at Fontainebleau State Park (Mandeville, LA), including three replicate profiles (total of 10 profiles), and three at Fairview Riverside State Park (Madisonville, LA). The profiles show an initial decrease in apparent resistivity (e.g. increased conductivity, potentially due to the presence of electrolytes such as chloride) followed generally by an increase in apparent resistivity. This indicates that an unsaturated zone is present. Profile FSP-1 (Fig. 7) exhibits a significant increase in apparent resistivity (with depth) which is related to the transition from a clay to a sand layer at depth (based on a nearby water well driller's log, there is a sand layer at a depth of 4 m, extending to a depth of 12 m). The results for the three sites (Fig. 7) with surveys repeated approximately seven months apart, suggest that apparent resistivity profiles exhibit decreasing conductivity (e.g. freshening of the interstitial fluid) with time. This occurred at two out of three locations where profiles were repeated. The presence of sand at FSP-1 may explain why resistivity values are fairly consistent over the survey time period. The pulse of saltwater may have already traveled downward beyond the maximum depth achieved (in this case ~25 m). The other two repeated profiles (FSP-6 and FSP-7) appear to have a finer-grained (more clay/silt) lithology, which may have delayed the movement of saltwater downward. This resulted in the larger difference between the profiles (blue diamonds versus magenta squares on Fig. 7).

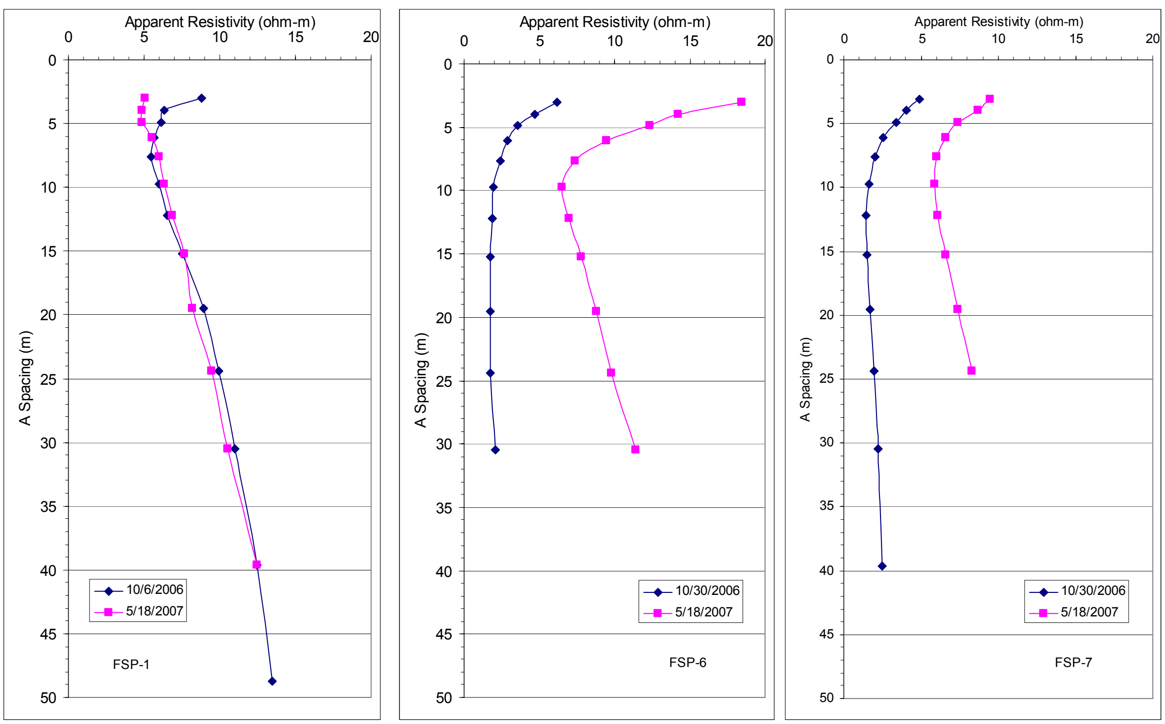

Figure 7: Apparent resistivity profiles repeated at Fontainebleau State Park

In conclusion, based on the results of this study, it can be stated that there appears to be no long term effect of the storm surge flooding on the aquifers screened by the wells tested. However, there appear to be some concerns regarding the wellhead protection of vented-well casings, and the need for these wells to be repeatedly treated to prevent residual bacterial contamination.

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