Structural Controls on Saltwater Intrusion in the Surficial Aquifer on St. Catherines Island, Georgia

James S. Reichard[1], R. Kelly Vance[1], Jacque L. Kelly[1], and Brian K. Meyer[2]

(1) Department of Geology and Geography, Georgia Southern University, Statesboro, GA 30460
(2) Department of Geosciences, Georgia State University, Atlanta, GA 30302

Abstract

St. Catherines Island is a composite barrier island located along the Georgia coast, consisting of a Pleistocene core surrounded by Holocene salt marsh and ridge and swale terrain. Hydraulic head and chemical data have been collected since 2011 from the surficial aquifer along an east-west transect of six monitoring wells, ranging in depth from 5-8 meters. In 2016, two additional transects were installed in the shallow aquifer, creating a network of 18 wells.

Chloride and total dissolved solids data from the original 6-wells have revealed periodic saltwater intrusion events into the surficial aquifer on the marsh-side of the traverse as opposed to the ocean side. Chemistry data from the additional wells installed in 2016 show that salinity is highly variable at two wells, S4 and M6. Analysis of tidal data show that pulses of saltwater intrusion are associated with unusually large, spring-tide events. Due to the localized nature of the intrusion events in the vicinity of wells S4 and M6, it was hypothesized that saline water is moving into the shallow aquifer system along preferred structural or stratigraphic pathways.

To investigate the shallow subsurface near wells S4 and M6, ground-penetrating radar and electrical resistivity profiles were conducted. These data are consistent with the presence of fractures and faults near wells S4 and M6 along with a pronounced sag structure located near well M6. It is hypothesized that prior to modern pumping withdrawals from the regional carbonate aquifer system, artesian water from the Upper Floridan aquifer flowed upwards along regional joint and fault trends. Solution caverns naturally developed along these trends over time, some of which collapsed, creating sag structures in the overlying units and artesian springs at the surface. Data from this study indicates that large tidal events periodically cause saline water to move laterally, and perhaps vertically, into the surficial aquifer along fault and solution collapse features at wells S4 and M6. This study concludes that the primary mechanism of saltwater intrusion is not necessarily by diffuse lateral flow of more saline water, but rather by the flow of more saline water along structural pathways.

Research Site and Hydrogeologic Setting

(Reichard et. al. 2014)

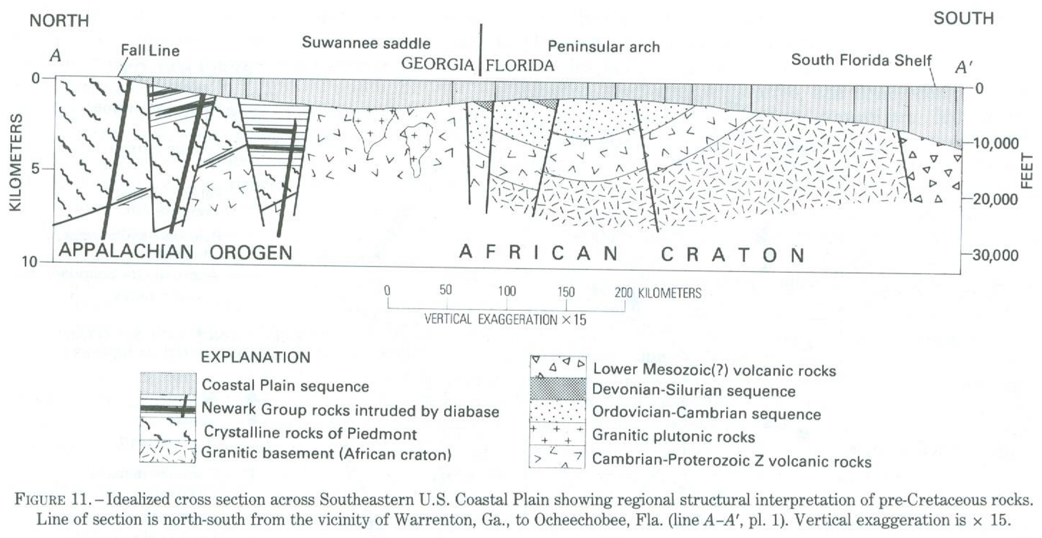
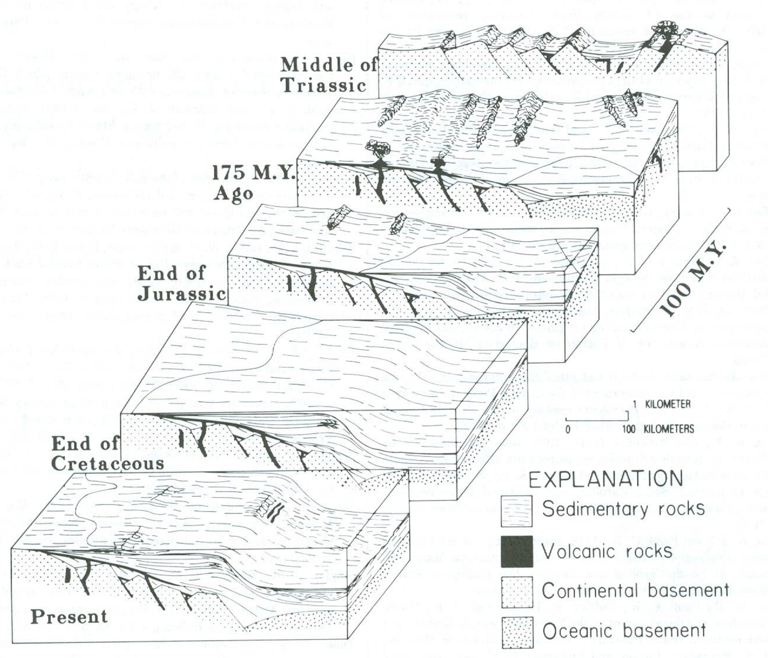


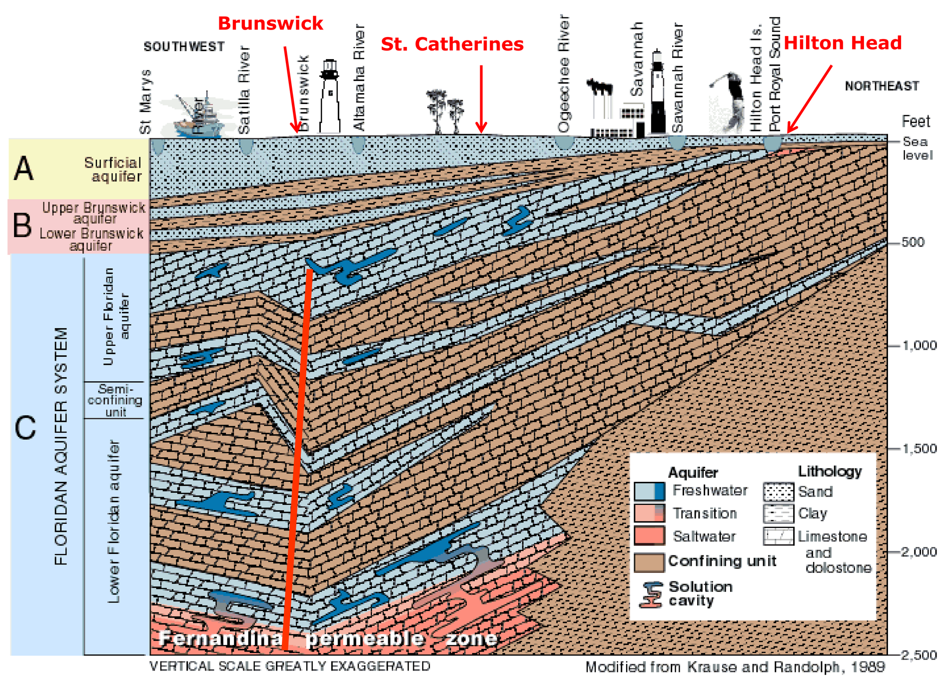
FIGURE 11.—Idealized cross section across Southeastern U.S. Coastal Plain showing regional structural interpretation of pre-Cretaceous rocks. Line of section is north-south from the vicinity of Warrenton, Ga., to Ocheechobee, Fla. (line A–A', pl. 1). Vertical exaggeration is × 15.

(Chowns and Williams, 1983)

St. Catherines Island (left) is located on the Atlantic Coastal Plain between the Savannah and Altamaha Rivers (40 miles south of Savannah). USGS studies in the late 70s and early 80s reveal that the coastal plain sequence (right) is draped over pre-Cretaceous basement rocks, which underwent extensive faulting during Mesozoic rifting and opening of the Atlantic Ocean.

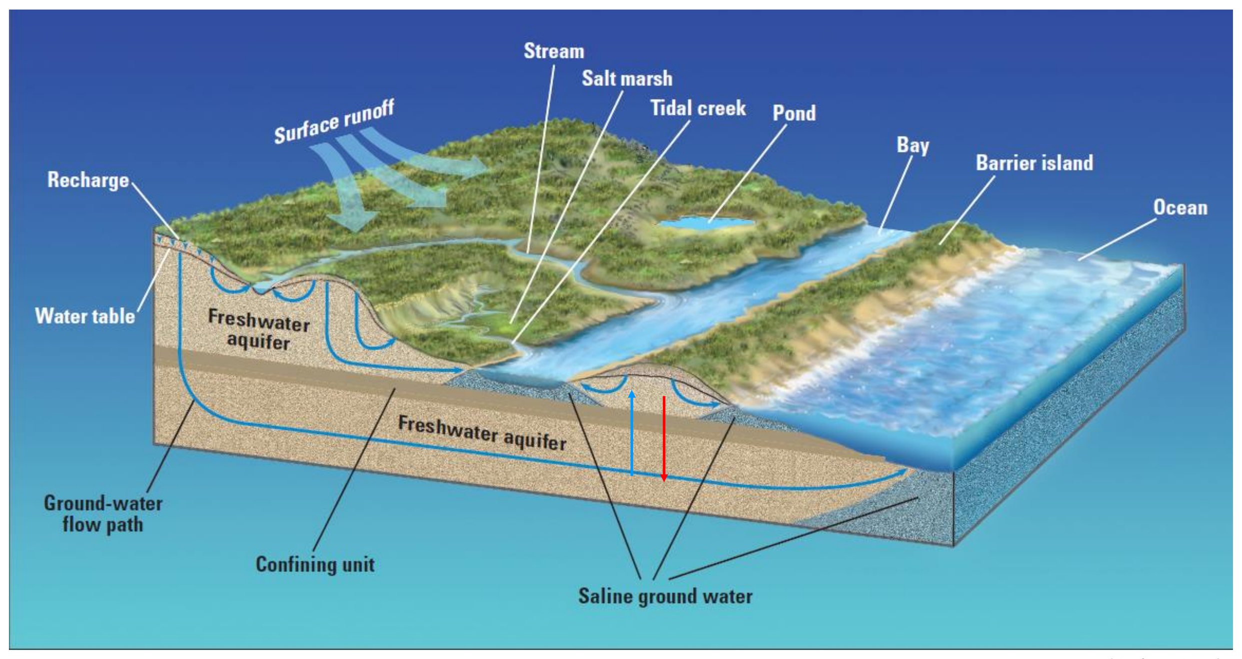


(Dillon, Klitgord, and Paull, 1983)



(USGS 2001)

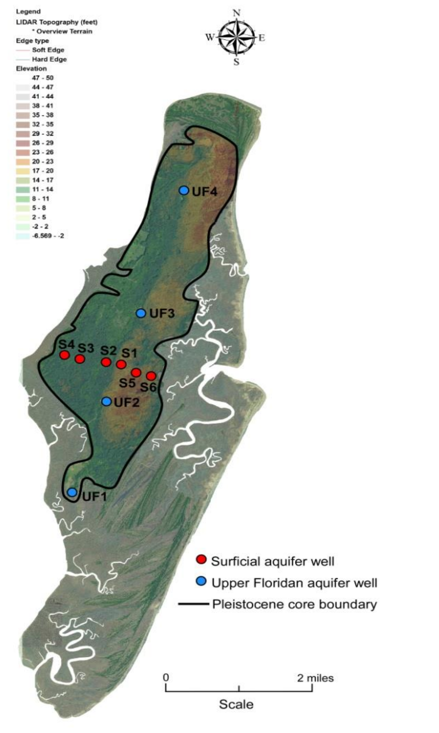
There's substantial evidence that some of these buried basement faults (left) have been re-activated at various times in the geologic past and have propagated upwards, creating permeable pathways for the vertical movement of groundwater within the coastal plain. A good example is beneath the city of Brunswick, Georgia (right), where a fault and/or solution conduit, at least 2,000 ft in length, has allowed hypersaline water to move up from depth, causing vertical saltwater intrusion in the Upper Floridan aquifer, which is part of major carbonate system that serves as the principle water supply for the region.



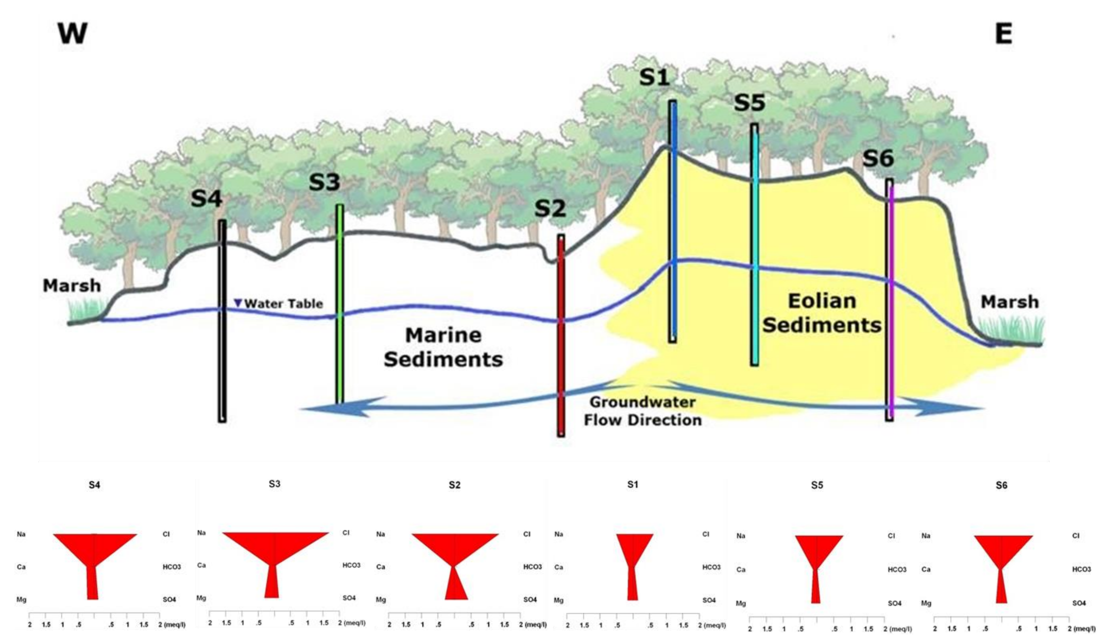
(Barlow, 2003)

The overall hydrogeologic setting at St. Catherines is that of a surficial aquifer on a barrier island, which consists of unconsolidated Pleistocene and Holocene sediments that overlay a regional artesian system composed of Eocene to Oligocene carbonate units. Historically, the vertical hydraulic gradient has been upwards (blue arrow), but due to modern pumping withdrawals, the gradient is now downwards (red arrow) within the study area.

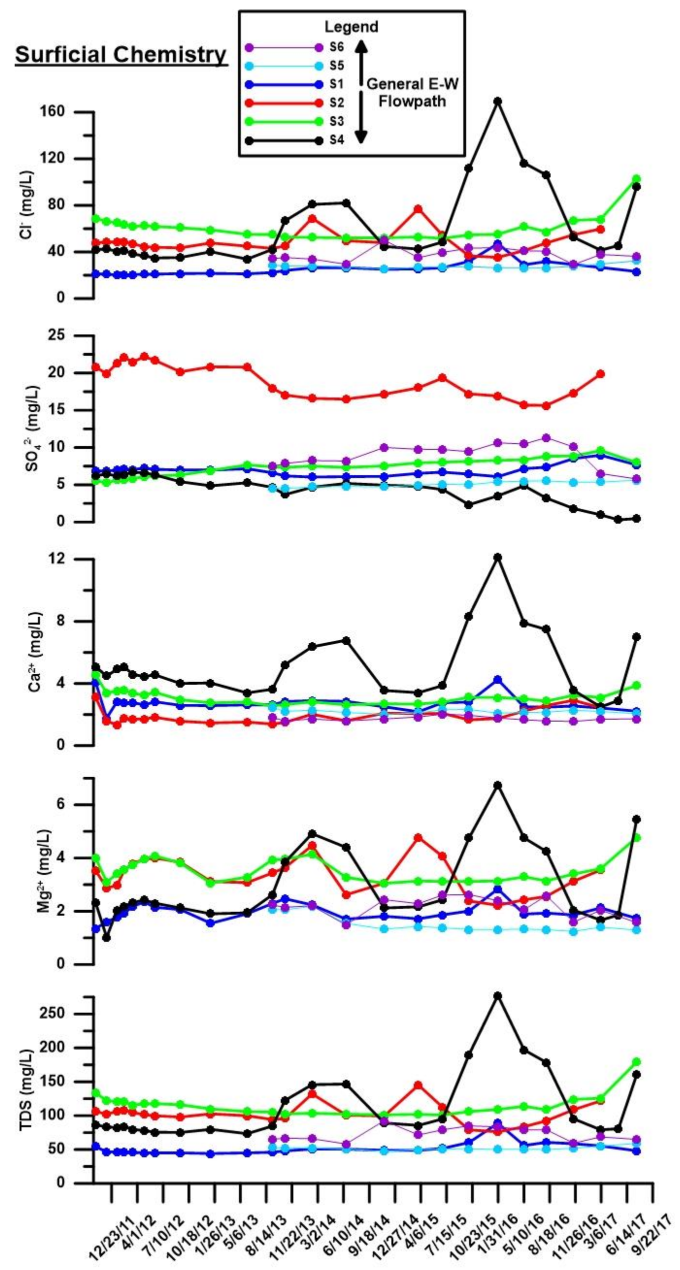
Initial Hydrogeologic Study on St. Catherines

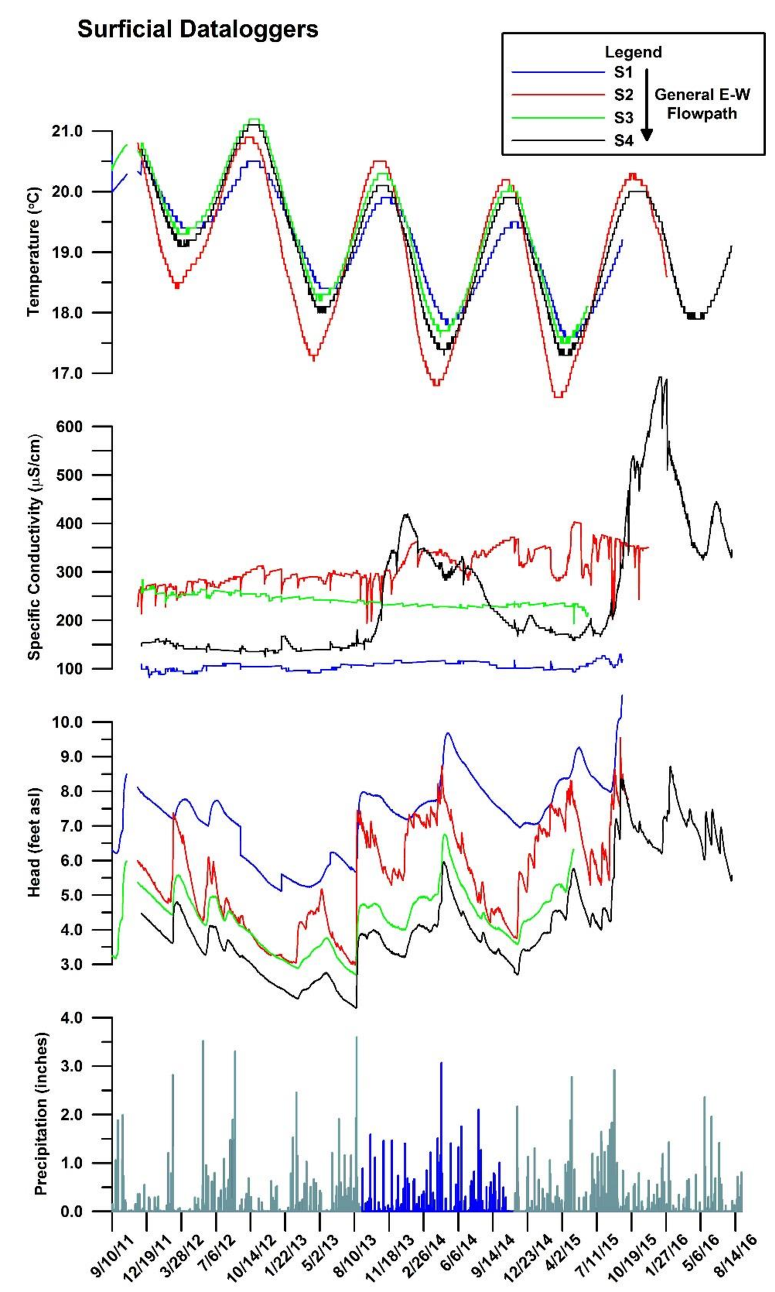


After Meyer et. al. 2009

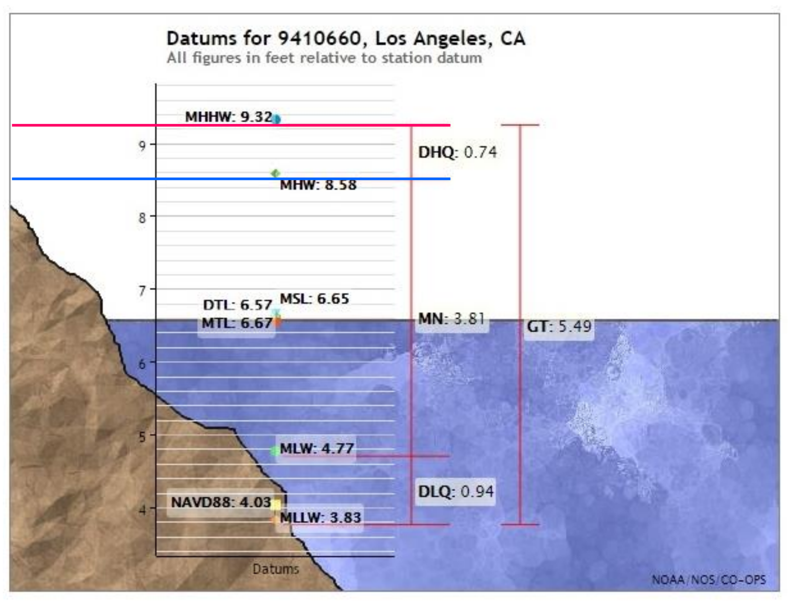


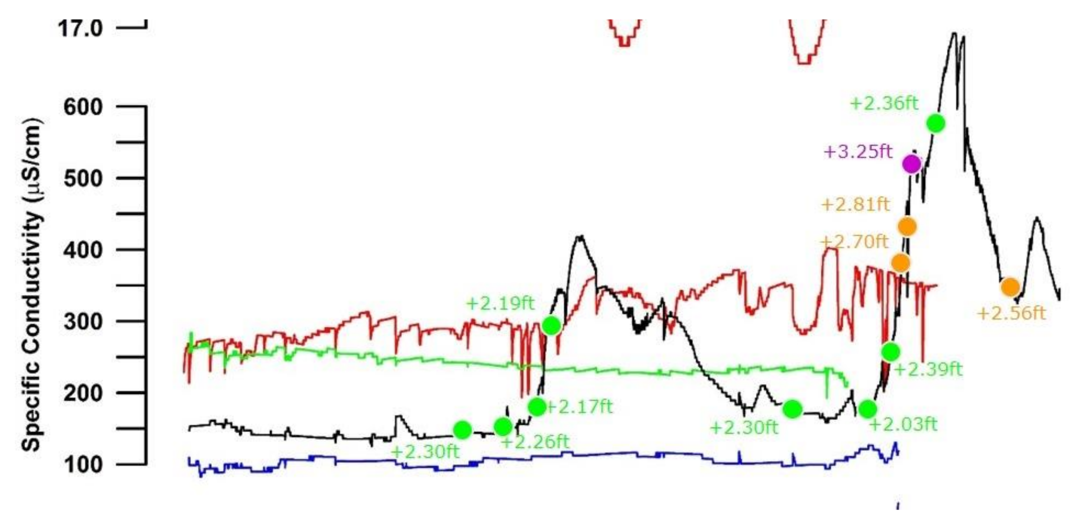
LIDAR map (left) of St. Catherines shows the Pleistocene core outlined in black along with two well transects; an E-W transect of 6 wells installed in the surficial aquifer and an existing N-S transect of 4 production wells in the Upper Floridan aquifer. Surficial wells 1-4 (right) were installed in 2011 and wells 5 and 6 were added in 2013 – wells range in depth from 15 to 22 ft. Data loggers (head, temp, conductivity) were placed in wells 1-4 and set to record every 12-hrs. Water samples were collected on a monthly basis for the first year, followed by quarterly sampling over the past five years. Water chemistry data (right) show that wells 2-4 in the topographic low part of the island have a strong Na-Cl type water with ion proportions similar to that of seawater. In contrast, wells 1 and 5 on the topographic high have lower proportions of Na-Cl and contain fewer total dissolved solids.





Plot on left shows select ion data from the surficial transect over the past six years. Of interest are the concentration spikes found in well 4, which is located on the lagoon side of the island (see above map). The salinity spikes in well 4 are well defined in the high resolution (12 hr) specific conductivity data shown in the right plot. It was hypothesized that the salinity spikes were induced by large tide events.





To test the tidal hypothesis, maximum high water levels (left - red line) greater than 2 ft above mean-high tide (left - blue line) were plotted on the conductivity curve (right) of surficial well 4. Tides between 2.0-2.5 ft above mean high tide are in green, 2.5-3.0 ft in orange, and above 3.0 ft in magenta. Since all the tidal events plotted here were astronomical (lunar) in nature, the data clearly represent pulses of saltwater being driven into the surficial aquifer during large astronomical tides. Moreover, since the salinity spikes are much more pronounced on the marsh-side of the island, one can infer that some type of preferred pathway exists near well 4.