Freshwater Lens Development on Padre Island, Texas

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ABSTRACT
Padre Island is one of the most extensive barrier islands in the world. With a length of ~100km and a width of ~3km the island morphology is the acme of a wave dominated barrier island in the microtidal Gulf of Mexico. This study presents preliminary results of a hydrogeophysical and sedimentological study being conducted in a 3km transect of the island to elucidate sedimentary processes and controls on the development of the freshwater lens. The freshwater lens was characterized by water table elevation measurements and resistivity soundings acquired with a magnetotelluric technique. The FW/SW interface is significantly shallower than the Ghyben-Herzberg-Dupuit equation would predict from the water table elevations. We suggest that this difference exists because of lithological variability within the sedimentary package on the island and because of the submarine discharge of water along the island margins.

INTRODUCTION
Padre Island, Texas is one of the most extensive barrier island systems in the world, which borders the microtidal Gulf of Mexico in south Texas. This barrier island is approximately 3km wide in most areas, and, as presently configured, constitutes approximately 100 km of length without any active tidal passes (Garrison and McCoy, 2007).

In addition, Padre Island is primarily encompassed within the Padre Island National Seashore unit of the National Park Service, and is thus essentially undeveloped. On the shoreward side of Padre Island is the Laguna Madre, which can occasionally experience hypersaline conditions. The uninterrupted length of Padre Island and the fact that this island is located in a relatively dry, sub-humid climate zone makes this island distinct from many islands on the U.S. East Coast where barrier islands are more intensively studied for stratigraphic and hydrogeologic models.

The purpose of this study is to develop an understanding of the stratigraphic and hydrogeologic dynamics within such a barrier island setting. We present here preliminary results from Padre Island where a cross-section of the island is being examined using shallow wells and geophysical techniques.

METHODS
The investigation of Padre Island is being conducted using a variety of methods to characterize the surface and subsurface. To begin, a differential GPS survey was conducted along a transect perpendicular to the Gulf Coast which encompassed approximately 3,100 meters (Figure 1). Reference points were marked at regular/semi-regular intervals to accommodate the collection of ground penetrating radar (GPR) surveys. In addition, 12 points were marked where coring to the water table could be accomplished. Vertical accuracy is in the range of 2-3 cm. The GPR data is being processed and will be discussed in later works.

The first data evaluated in this study is the elevation profile of the topography and the water table. At each water table measurement site, an 8 cm auger was used to penetrate up to a meter below the water table and then a drive point screen was inserted to refusal. The dominantly finesand subsurface allowed equilibration of the water level within several minutes. Then the water level was measured with respect to the surveyed point. The water table elevations are likely within 3-4 cm. The elevation of the ground surface was also measured. Elevations of the survey were reference to NAVD88. Data from a nearby Texas Coastal Ocean Observation Network observing station was used to correct the vertical datum to Mean Sea Level. The offset used here was derived from the Bob Hall Pier station which indicates a MSL 0.15m below NAVD88. All depth measurements here are referenced to this MSL estimate.

The geophysical data used in this study was acquired using a Stratagem™ EH4 magnetotelluric (MT) survey system. The data was acquired using a controlled source audio magnetotelluric mode (CSAMT) with 13 frequencies in the range of 0.8 kHz to 66 kHz. In brief, the impedance response of the subsurface represents deeper integrated depths for observations at lower frequencies.

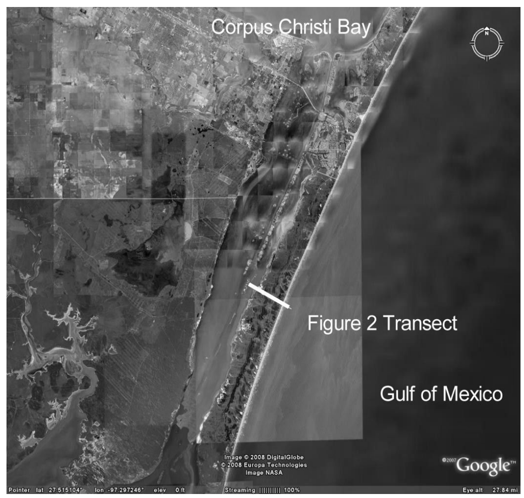

Figure 1. The Padre Island transect site on a Google Earth™ Image.

The data was then reduced to the impedance tensor measurements. In general, the data complies well with the geometric expectations of impedance isotropy, and 1-D behavior. However, the transverse electric data (Z_{xy}) appears to be somewhat noisy on some sites so the transverse magnetic (Z_{yx}) data is used for the presentation here. The Z_{yx} data was then used to generate curves of apparent resistivity (ρ_{app}) and phase (φ) versus frequency at each site (Simpson and Bahr, 2005).

All MT survey sites were then interpreted using a 1-D resistivity sounding model. This was accomplished by using a multiple-layer resistivity model based upon a Schmucker-Weidelt transfer function. This 1-D forward modeling approach uses a recursive algorithm to integrate the electromagnetic response of the subsurface from the deep subsurface to the surface response which is what the MT system actually measures (Simpson and Bahr, 2005). The profile of the resistivity curve was described as a polynomial which was optimized to minimize the predicted (ρ_{app}) and phase (φ) curves when compared with the MT data.

In addition to the above observations, the GPR survey is being complimented with coring along the transect. These data and results are not yet ready to present.

RESULTS

The preliminary results are presented in Figure 2 where the cross section of the island is shown along with the data and interpretations. The x-axis is the distance along the island with Laguna Madre on the Left and the Gulf of Mexico on the right, depth is displayed in meters from mean sea level. The surface of the island and the water table elevations at the 12 sites are shown on the top of the figure; both are extrapolated into the surrounding water body.

Figure 2 also shows an interpretation of the 18 MT resistivity soundings. All such soundings show a decrease in the resistivity with depth from values of over 100 Ωm at the top to values below 1 Ω−m at the bottom. The depth of investigation varies from less than 5 meters at the Laguna Madre side to up to 50 meters in the center of the island. The location of the FW/SW interface in the MT soundings was selected using either the 1 Ω−m layer or the inflection in the 1-5 Ω−m range depending on the structure of the data. The FW/SW interface is plotted as the thick blue line in Figure 2.

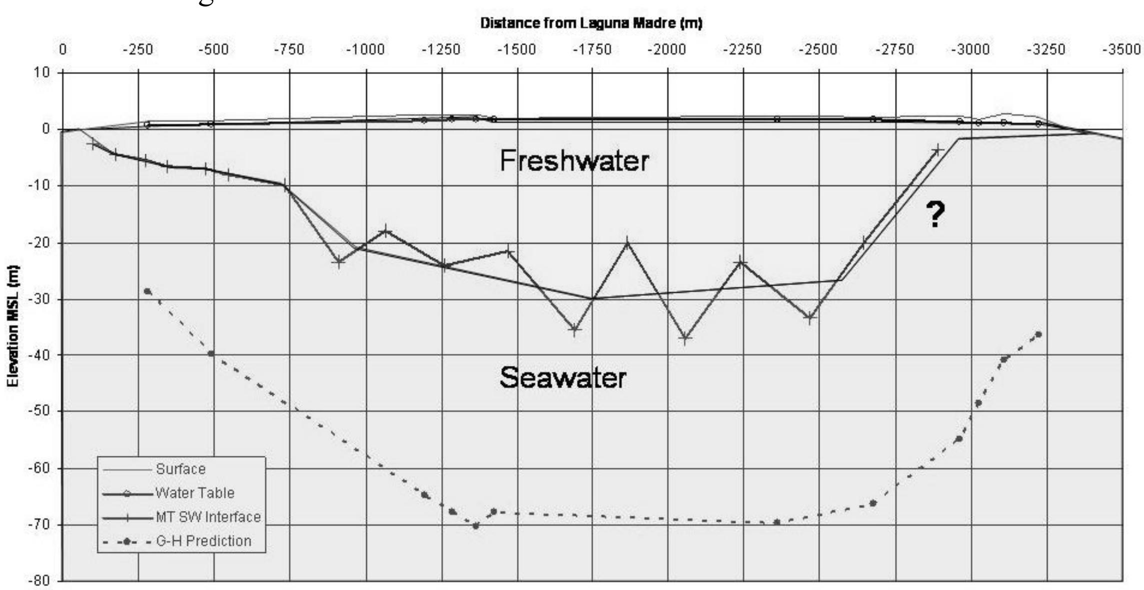

Figure 2. Padre Island Cross Section.

DISCUSSION AND CONCLUSIONS

Two pertinent observations can be made from the cross section presented in Figure 2. First, the depth of the FW/SW interface is much shallower than the Ghyben-Herzberg-Dupuit equation would suggest based upon the water table elevations; certainly, this static model of freshwater lens development is oversimplified (Urish and Ozbilgin, 1989). The freshwater lens system is most likely discharging along the shore face on both sides of the island (Fetter, 1972). In addition, the sandy material of the island is underlain by the somewhat clayey and heterolithic Beaumont formation at approximately 10 meters. This, and buried wetland soils likely effect the vertical hydraulic conductivity and may result in anomalous water table elevations (e.g., Anderson et al., 2000)

The second observation is that the depth of the FW/SW transition is variable in the center of the island where it is typically below 10 meters of depth. Although the interpretation in Figure 2 simplifies this variation, the variation may indeed be real. This variation in depth of the interface may indeed be real and related to variations in hydraulic conductivity in the Beaumont formation.

REFERENCES

Anderson, W.P. Jr., D.G. Evans, and S.W. Snyder. 2000. The effects of Holocene barrier –island evolution on water-table elevations, Hatteras Island, North Carolina, USA. Hydrogeology Journal. 8: 390-404.

Fetter C.W. 1972. Position of the saline water interface beneath oceanic islands. Water Resources Research. 8: 1307-1315.

Garrison, J.R., Jr., and B. McCoy. 2007. The Nueces Incised Valley revisited: A reinterpretation of the sedimentology and depositional sequence stratigraphy of preserved Pleistocene and Holocene valley-fill sediments: Gulf Coast Association of Geological Societies Transactions, 57, pp.

Simpson, F, and K. Bahr. 2005. Practical magnetotellurics: Cambridge University Press, Cambridge, U.K., 254 p.

Urish D.W., and Ozbilgin M.M. 1989. The coastal ground-water boundary. Ground Water. 27: 310-315.

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