UNUSUAL SEDIMENTATION OF A GALVESTON BAY WETLAND AT PINE GULLY, SEABROOK, TEXAS: IMPLICATIONS FOR BEACH RENOURISHMENT

A Thesis

by

WESLEY RICHARD CULVER

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

August 2007

Major Subject: Geology

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Approved by:

Chair of Committee,	Christopher Mathewson
Committee Members,	Jack Vitek
	Kevin McInnes
Head of Department,	John Spang

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ABSTRACT

Unusual Sedimentation of a Galveston Bay Wetland at Pine Gully, Seabrook, Texas: Implications for Beach Renourishment. (August 2007)

Wesley Richard Culver, B.S., Sul Ross State University

Chair of Advisory Committee: Dr. Christopher Mathewson

Excess sedimentation began affecting the wetland dynamics of Pine Gully in Seabrook, Texas during the first quarter of 2004. This sedimentation was sudden and became a serious problem for the dynamics of the Pine Gully wetland because the fine, well sorted, quartz rich sediments began plugging the main channel of the previously tidally dominated wetland. Progressive sedimentation has produced overbank deposits in the marine grasses, contributing to the death of wetland grasses by sediment chocking. The main purpose of this study is to determine the new source and mechanism of sedimentation in Pine Gully, document changes from sedimentation, and determine a solution to prevent future sedimentation.

Sedimentation in Pine Gully and coastal areas adjacent to Pine Gully has occurred in a region that has experienced subsidence and sea level rise. The sedimentation in Pine Gully is a direct result of new and sustained sediment at the mouth of Pine Gully. These new sediments are transported into Pine Gully by displacement waves from ships moving through the Houston Ship Channel. Beach renourishment at Wright Beach, located a half mile north of Pine Gully, occurred as Pine Gully experienced sedimentation. Construction of a breakwater at the mouth of Pine Gully and

subsequent removal of sediment in Pine Gully itself is ultimately the solution to revitalizing the wetland to its pre-sedimentation state. Replanting of native vegetation killed off by sedimentation is recommended and would hasten the recovery of the wetland.

Documenting the effects of this unique sedimentation in Pine Gully has implications for the future. Beach renourishment or coastal projects that may contribute excess sediment to the coastline should be concerned with unintended effects they may cause. Although an historically eroding shoreline exists, the effects of excess sedimentation can be severe. A coastal study should be done before sediment is added to the shoreline to identify any areas within the sphere of influence of the project. Ecosystems determined to be within the sphere of influence by a coastal study should implement preventative measures at those locations to avoid an ecological disaster similar to that in Pine Gully.

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Thanks also to my friends in the Department of Geology & Geophysics at Texas A&M University for making my time here a great experience. A special thanks to Anne Herrin for keeping me sane at lunch every Friday and to Kerri Vance, Fightin' Texas Aggie Class of '06, for introducing me to the Aggie Spirit.

I extend my thanks to my faculty mentors in Geology at Sul Ross University; Dr. James Whitford-Stark for jumpstarting my interests in Geology and to Dr. Kevin Urbanczyk for helping me become a trendsetter, and for providing the opportunity to keep him on his toes.

I also extend my gratitude to the Citizens, City Council and Staff in the City of Seabrook for being so helpful and hospitable for the duration of this study.

Finally, thanks to my family; especially my Mom, Dad and Granny for their support and patience in continuing my education.

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CHAPTER I

INTRODUCTION

Pine Gully is located on the western shore of Galveston Bay in Seabrook Texas (Figure 1). Much of the coastline along Galveston Bay is armored with waste concrete rip rap to protect the shore from erosion induced by subsidence and sea level rise. The climate in the area is humid to semi-humid with an average annual rainfall of 42 inches. The prevailing winds are onshore from the Gulf of Mexico at an average of 11 miles per hour (NOAA, internet resource). Pine Gully directly adjoins Galveston Bay and is influenced by the counter clockwise circulation pattern in the bay (Fisher et al., 1972). The drainage link to Galveston Bay for the City of Seabrook and for part of the Bayport Terminal adjacent to Seabrook, an area totaling approximately 2,100 acres is provided by the Pine Gully watershed (Spinks et al., 2005). Pine Gully runs roughly east to west perpendicular to Todville Road toward Galveston Bay. The portion of the Gully west of Todville Road is maintained by the Harris County Flood Control District. The portion east of Todville Road is maintained through natural flow and is primarily where the wetland exists. A small tributary adjoins Pine Gully from the North, East of Todville Road.

The surface geology of the area, shown in Figure 2, consists of the sand facies of the Beaumont Formation. This formation consists of barrier island and beach deposits of fine sand and silt size quartz rich sediments (Fisher, 1982).

This thesis follows the style of *Environmental and Engineering Geoscience.*

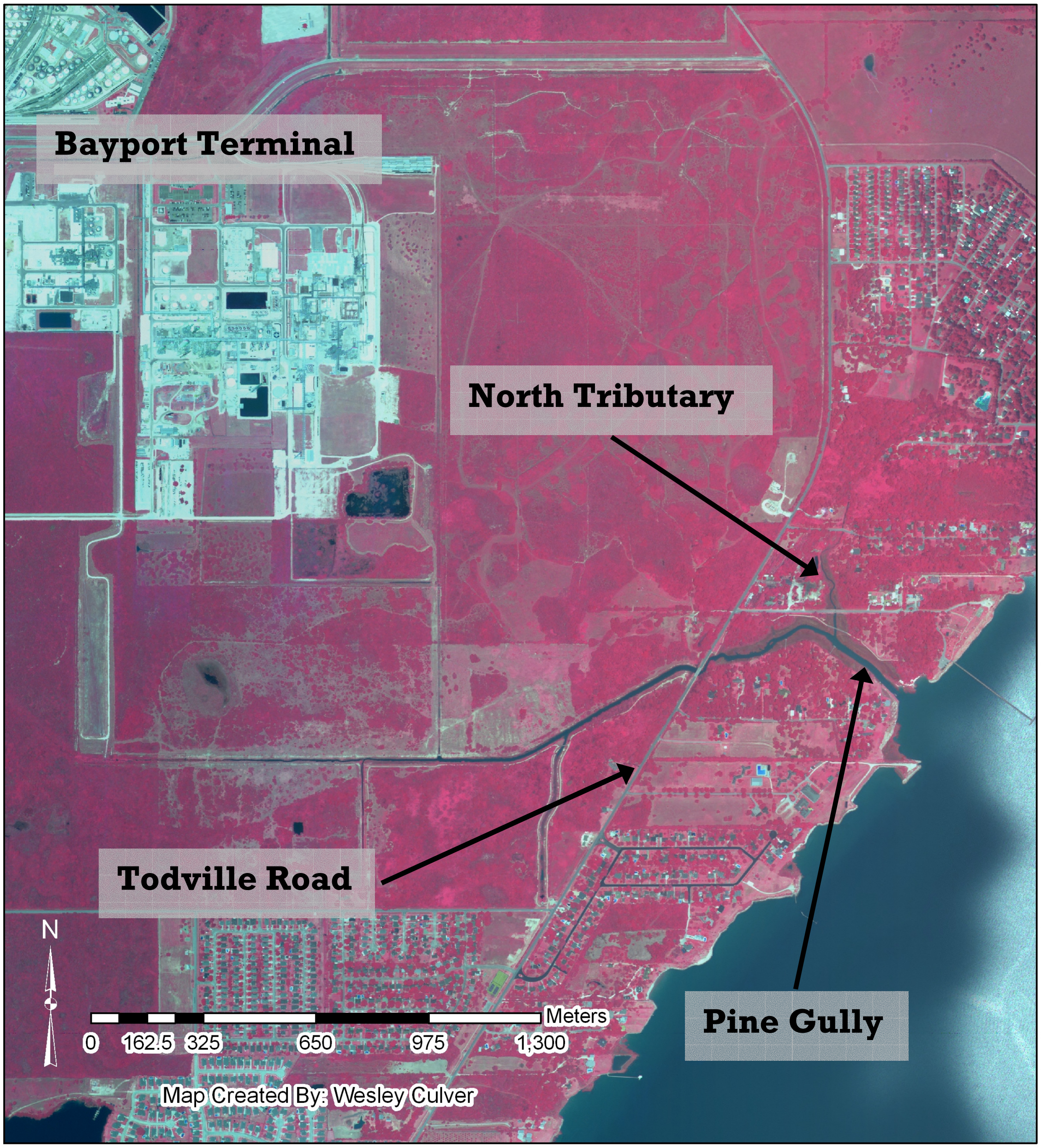

Figure 1. Surface areas around Pine Gully. 2004 NAIP downloaded from the TNRIS website.

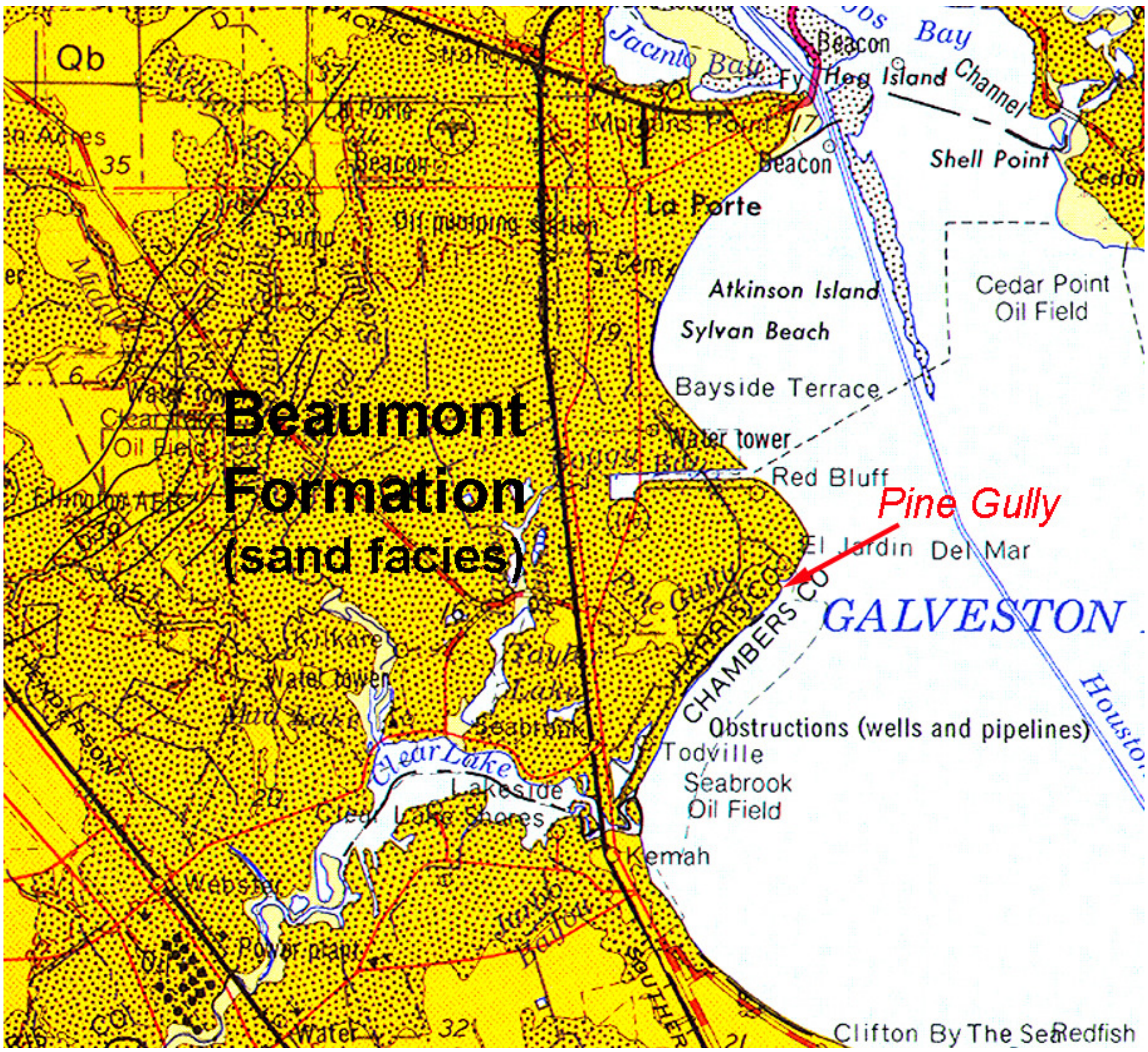

Figure 2. Geologic map of the area around Pine Gully. Pine Gully shown by the red arrow on the western shore of Galveston Bay. (Bureau of Economic Geology, Houston Sheet, 1982)

1.1. Problem in Pine Gully

Problems in Pine Gully were first observed by residents in August 2004 when a light dusting of sediment was observed in the wetland grasses after high tide (Figure 3). This phenomenon was a shock even to long-standing residents of the area because they had never seen such sediment deposition in the 25+ years of residency (Sally Antrobus, Personal Communication). After the first dusting of sediment in Pine Gully, the problem continued to get worse. Deposition in Pine Gully eventually produced a sand plug at the mouth of the Gully and caused the wetland to be cut off from Galveston Bay. This has been detrimental to the dynamics of the wetland because it is no longer possible to get nutrient and oxygen rich saltwater flushing from Galveston Bay into Pine Gully. Having the plug emplaced at the mouth of Pine Gully ceased the tidal dominance and created a fresh water lens to build behind what is now effectively a dam made of sand. The source of fresh water trickles in from the small drainage basin of Pine Gully and stagnates. Dominance of this stagnant freshwater for long durations puts undue stress on the once tidally dominated wetland grasses, such as *Spartina alterniflora*. After some time, these grasses succumb to the adverse conditions, slowly dying off in patches (Figure 4). Because the sand plug acts as a dam, the water level can be six inches to a foot higher than normal. These elevated water levels in Pine Gully have killed off hardwoods that lined the margins of the wetland, such as *Ilex vomitoria*, simply because they were submerged for prolonged periods of time (Figure 5). Long durations of freshwater inundation have made it possible for *Bacopa monnieri* and *Scirpus spp.* to out-compete the *Spartina alterniflora* (Feagin, In Press). Plant identification was done in the field with the help of Starr Lozada (personal communication).

Figure 3. First dusting of sediment observed in Pine Gully, February 2004 (Antrobus, personal communication).

Figure 4. Patches of *Spartina alterniflora* killed by stands of anoxic freshwater and sediment choking. Picture taken March 2007.

Figure 5. Hardwoods on the margins of Pine Gully killed by high stands of water. Picture taken May 2007.

Sedimentation in Pine Gully has also become a political problem. The residents that utilize this park for recreation and tourism have become increasingly frustrated with the ongoing problem, with no solution in sight. Sedimentation in Pine Gully has resulted in the loss of a once beautiful attraction to the local Pine Gully Park. Because not many similar wetlands like Pine Gully exist on Galveston Bay, this is a unique habitat for birds that are hard to find outside Pine Gully. For this reason, Pine Gully is listed on the Great Texas Coastal Birding Trail as a popular tourist attraction. Wetland destruction has transformed much of the wetland into a black algae soup in some places, or salt flats in others, not aesthetically pleasing for the residents or functional for bird watching tourists. Other groups of people utilized Pine Gully in its natural state, for example, kayaking was a popular attraction to Pine Gully before it was plugged with sand. Kayaks can not navigate the main channel of the wetland with the plug in place because the depth of water is not sufficient to float a kayak.

The degradation of Pine Gully is also detrimental to the ecology of Galveston Bay and the Gulf of Mexico. At least 50% of the fishery harvests are dependant upon estuarine environments such as Pine Gully. This number is probably much higher for the estuarine habitats in the Gulf of Mexico and other mid-latitude marine environments (Houde, 1993; Boeschi, et al., 1984). Even though Pine Gully is a small estuarine habitat it is being lost as a productive environment to Galveston Bay, one step in the wrong direction for the declining health of Galveston Bay wetlands. The decline of wetlands on Galveston Bay since 1955 is well documented in studies by Moulton et al. (1997).

In response to the problem recognized by the citizens of Seabrook, this study focuses on the problems in Pine Gully and potential solutions. Specific objectives of this thesis include:

1. A description of the historical formation of Pine Gully.
2. Documentation of sedimentation and the resulting environmental changes.
3. Determination of the source and processes of sedimentation found in Pine Gully.
4. A proposal for possible reconstruction and preservation efforts in Pine Gully.

CHAPTER II

HISTORICAL FORMATION OF PINE GULLY

The processes that have shaped Pine Gully are natural and anthropogenic and include: subsidence, sea level rise, wave attack, and shoreline armoring. The morphological changes in Pine Gully have been a direct result of these processes. Presently, these processes still affect Pine Gully to some degree.

2.1. Subsidence, Sea Level Rise and Wave Attack

The largest changes to Pine Gully over time are caused by subsidence from withdraw of groundwater. Figure 6 shows that the Pine Gully region has been subjected to as much as 5.5 feet of subsidence. Figure 6 also shows other areas have experienced up to ten feet of subsidence, also mainly from withdraw of groundwater. The rate of subsidence has not been steady over time (Figure 7); relatively recent groundwater pumping restrictions have slowed the rate of subsidence. From the oldest elevation data of 1906 up to 1976, the rates of subsidence progressively increased. Groundwater restrictions were put in place after 1976 to immediately alleviate the problem. Between 1906 and 1983, approximately 5 feet of subsidence was experienced in the areas around Pine Gully. Groundwater pumping restrictions have significantly slowed or stopped subsidence in the Pine Gully area. Some areas have even shown signs of rebound as a result of groundwater pumping restrictions. Subsidence in the Pine Gully area after 1983 has only been .5 feet (Kasmarek et al., 2002).

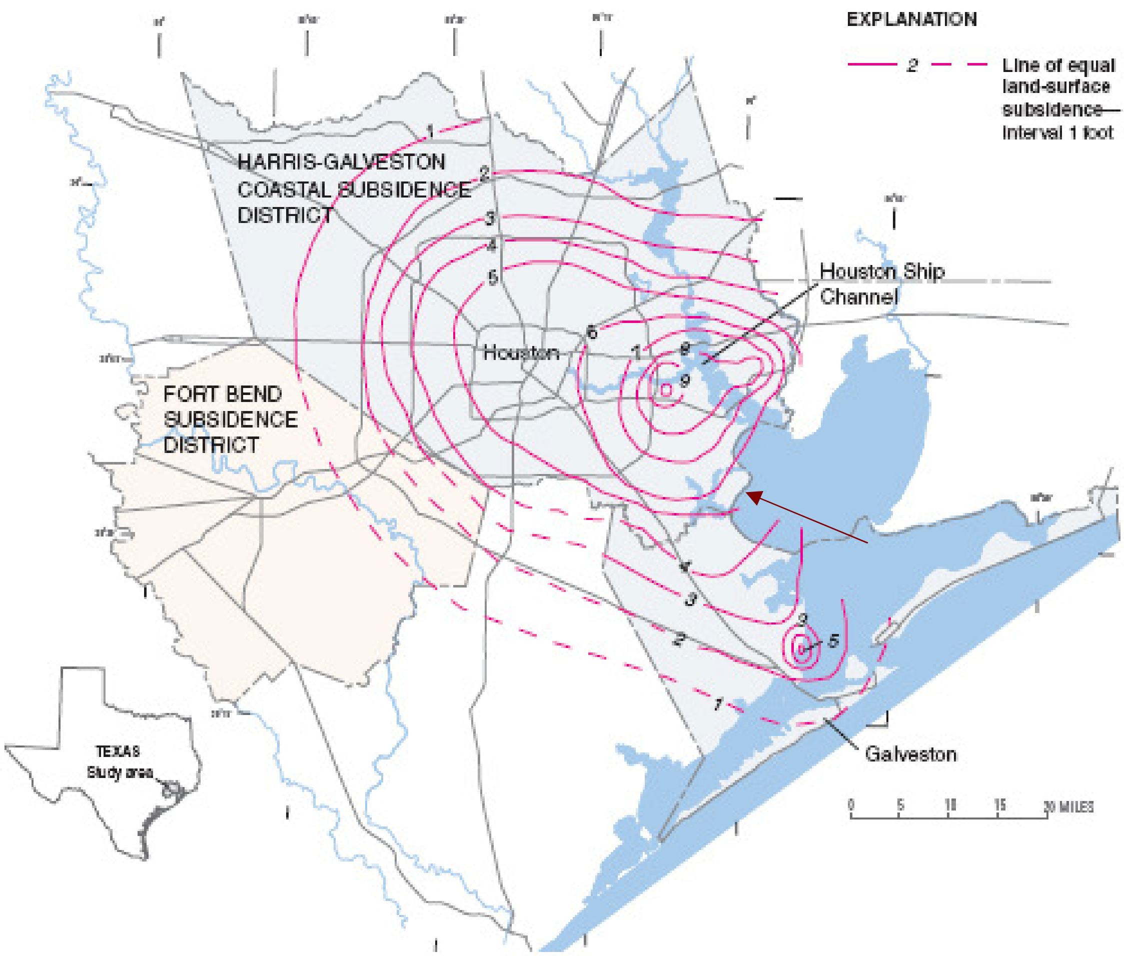

Figure 6. Cumulative subsidence from 1906 – 1995. Arrow shows approximate location of Pine Gully (USGS Fact Sheet, 2002).

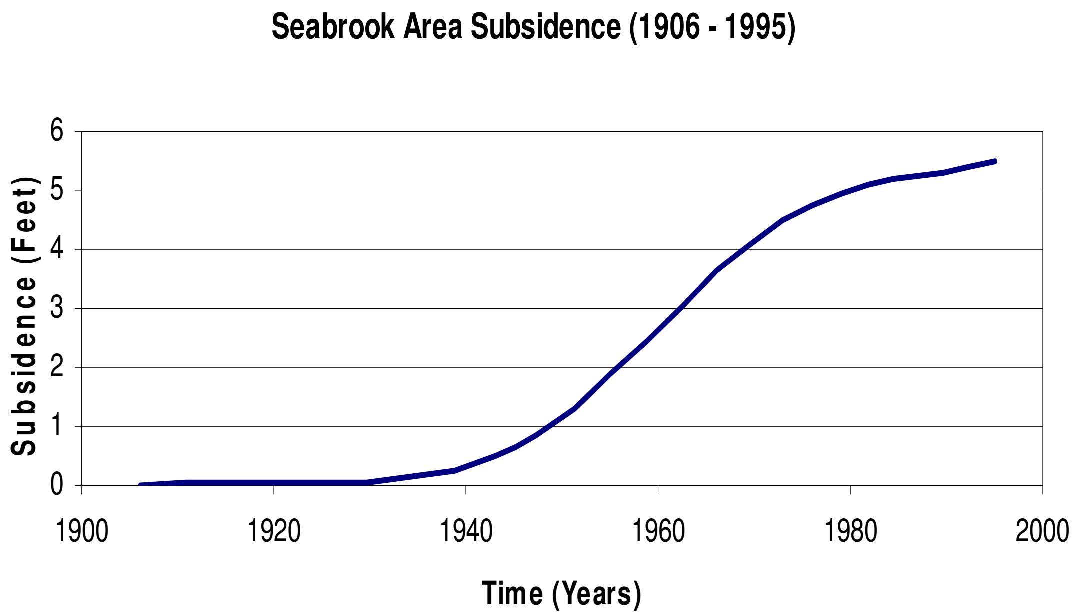

Figure 7. Rates of subsidence over time; notice the dramatic change in the rate of subsidence after 1976 when groundwater restrictions were put in place. Subsidence rates from (Kasmarek et al., 2002).

The effects of sea level rise and wave attack resemble that of subsidence. The net result of all three processes is shoreline retreat. Pine Gully has always experienced wave attack from normal wind waves but over time has experienced added wave energy from bore waves produced by ship navigation in Galveston Bay through the Houston Ship Channel. These bore waves have become larger as the channel has been improved to accommodate larger displacement ships. Sea level rise is also a contributor to the shoreline retreat in Pine Gully. Turner (1991) shows the water level in Galveston Bay and the Gulf of Mexico has risen gradually over the past decades, which is concurrent with studies that global sea level is rising. Wave attack and sea level rise are minor contributors to shoreline retreat at Pine Gully; subsidence has been the most significant factor.

2.2. Historical Retreat of Shoreline

Historical photographs from the Texas Natural Resource Information System (TNRIS) have been very useful to show the historical shoreline of Pine Gully. Pine Gully was a sinuous tidal stream with an irregular shape to the adjacent shoreline caused by the irregularities of the shoreline wetland vegetation. Since 1944, over 300 meters of shoreline erosion occured in the area around Pine Gully. The Pine Gully wetland is the last remnant of a much larger wetland ecosystem that has slowly been submerged and eroded away. The former wetland can be seen in the 1944 aerial photograph, Figure 8. The shoreline has been outlined in red for cross reference in other figures. The 1978 shoreline in Figure 9 is markedly different from the 1944 shoreline. The shoreline retreat of over 300 yards around Pine Gully occurred in 24 years. The erosion at Pine Gully after 1978 is much less severe because subsidence had been controlled, and the shoreline had been armored to protect the remaining shoreline, Figure 10. Digitized shorelines, Figure 11, are from aerial photos in: 1944, 1978, 1989 and 2004. All of these shorelines are plotted on the 2004 NAIP aerial photograph from the TNRIS website. The end of the fishing pier shown on the 2004 NAIP photo marks the 1944 shoreline. Only a small portion of the historic 1944 wetland still exists outside Pine Gully today. Figure 12 is a photo of the small portion of wetland that has survived the shoreline retreat with from the Camp Casa Mare Marina remains.

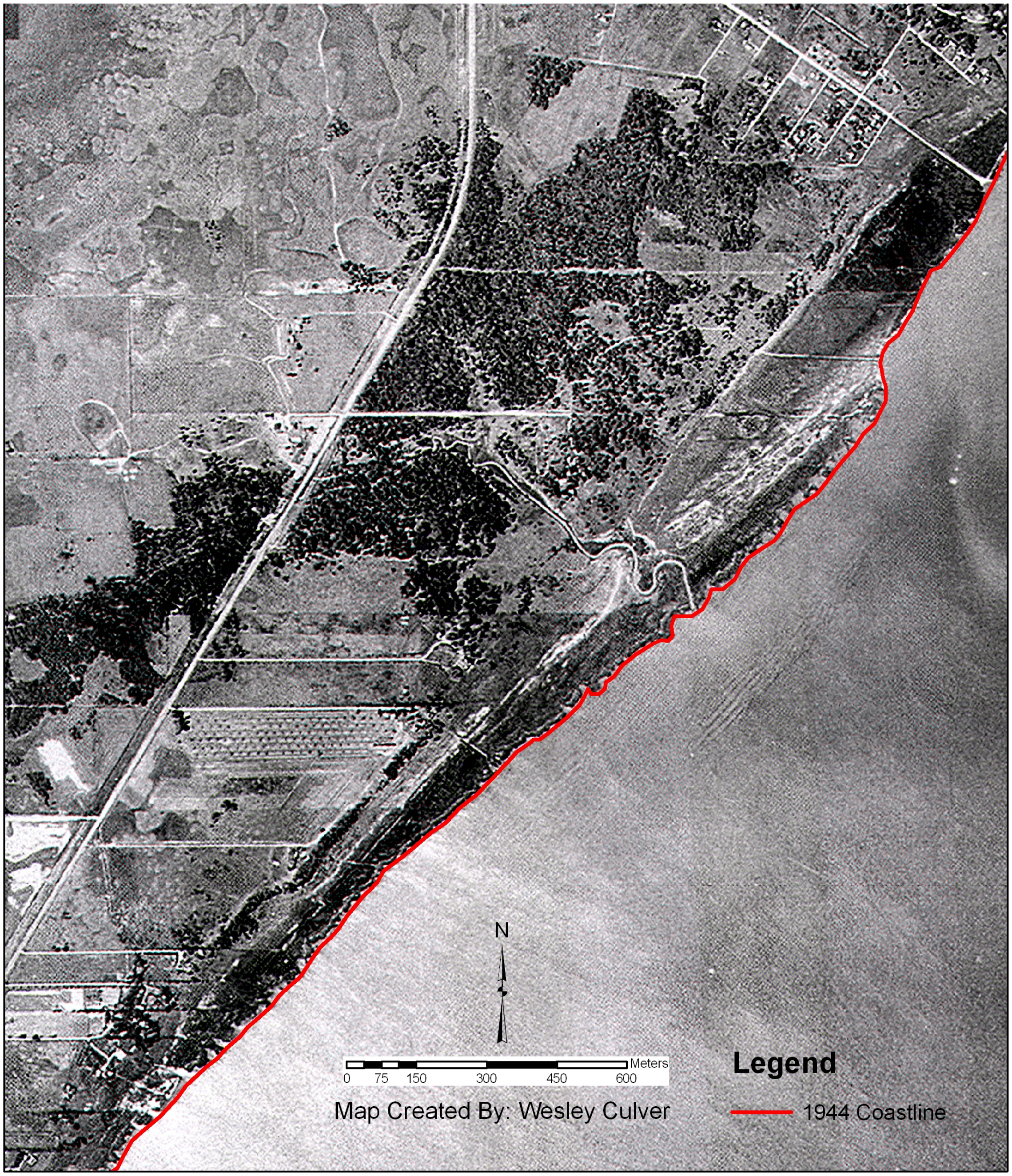

Figure 8. 1944 shoreline is outlined in red. Photo acquired from report by Spinks (2005).

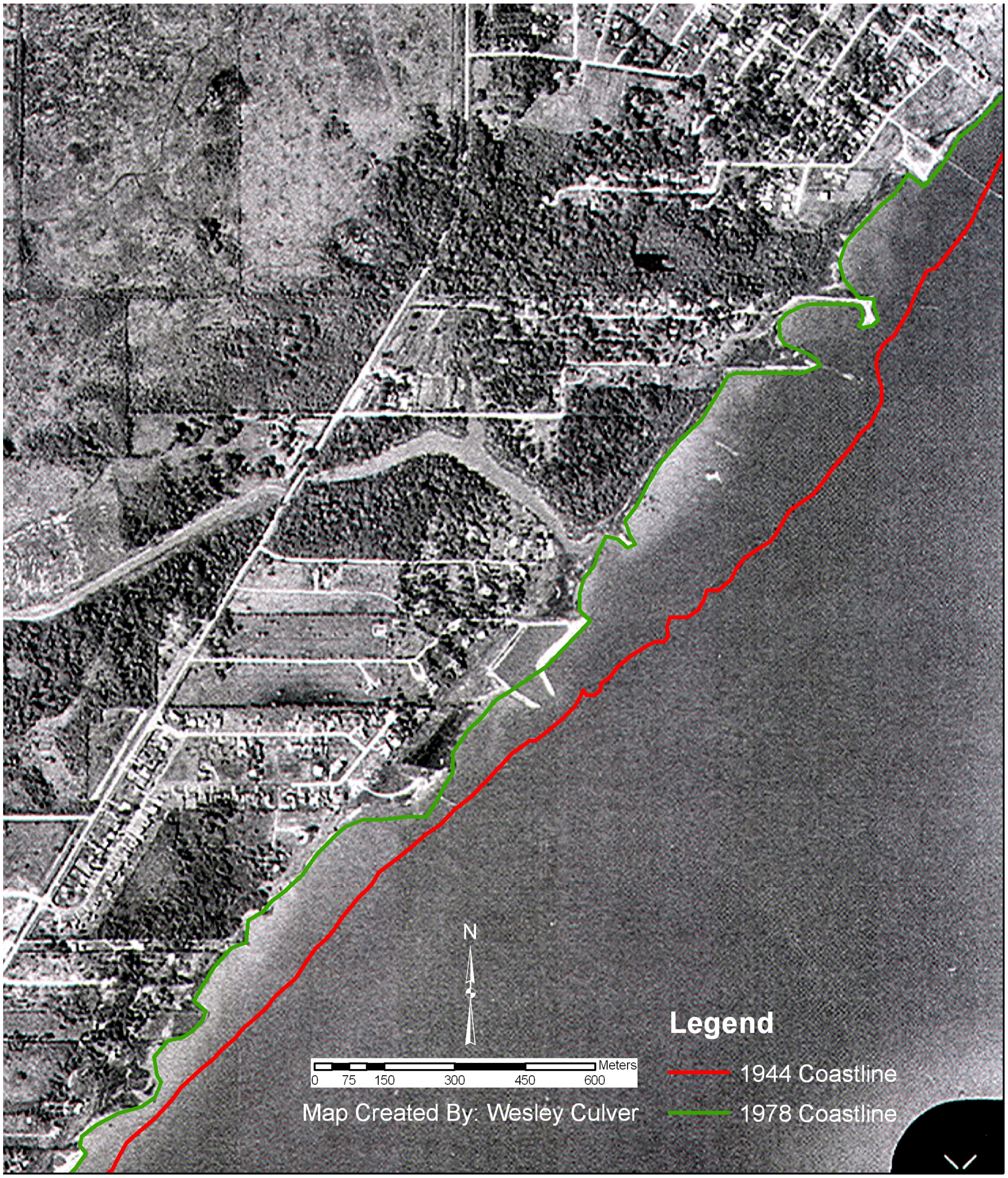

Figure 9. 1978 shoreline outlined in green with the 1944 shoreline superimposed in red. The erosion through the 24 year period has been over 300 meters. Photo from USDA historical photo archive.

Figure 10. Shoreline armoring with concrete rip rap. Picture taken at Pine Gully Pier, March 2005.

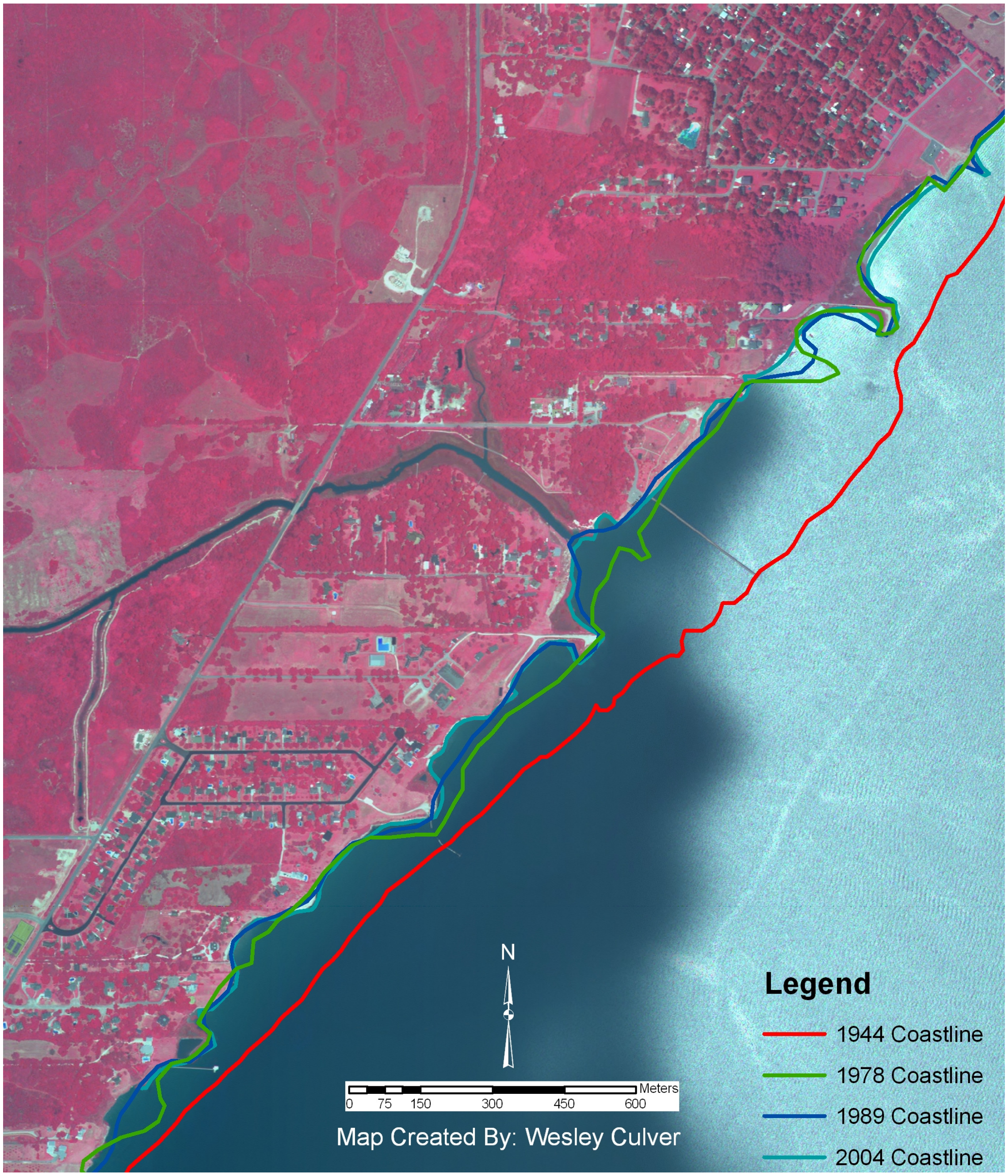

Figure 11. Four digitized shorelines showing how shoreline retreat has been virtually stopped with control of subsidence and the use of shoreline armoring. Data plotted on 2004 NAIP aerial photograph from TNRIS.

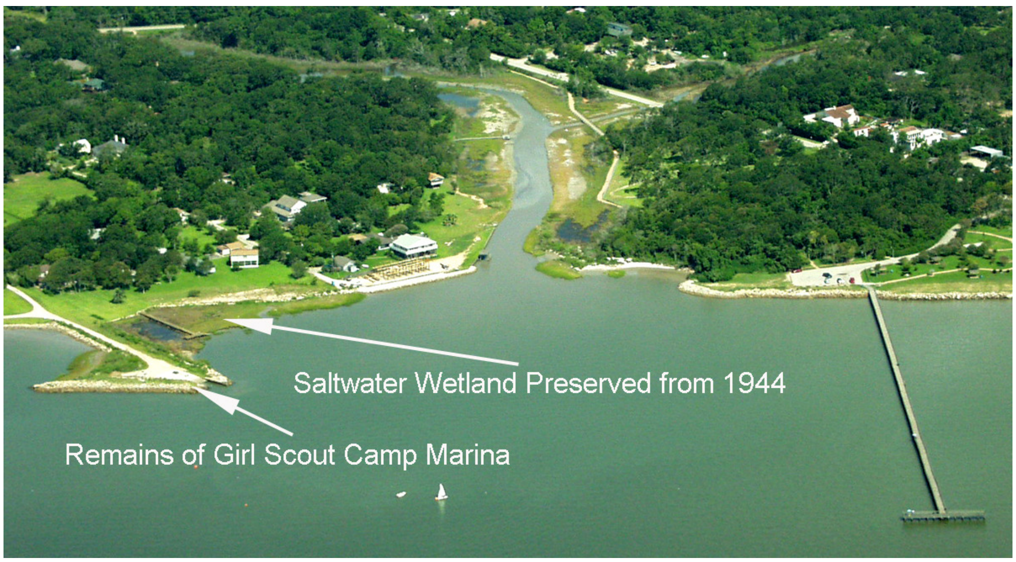

Figure 12. Aerial photo taken July 2006 showing remaining wetland preserved from 1944. Wetland has been protected with the remains of the Camp Casa Mare marina.

CHAPTER III

DOCUMENTATION OF SEDIMENTATION AND CHANGES

Many possible hypotheses exist about the processes affecting sedimentation in Pine Gully. Documenting the processes in Pine Gully is the key to finding the source of sediment and mechanism of transport into Pine Gully. Varying analyses form the basis for explaining the sedimentation processes effecting Pine Gully.

3.1. Core Sampling

New sediments being deposited in Pine Gully are a fine, quartz rich sand, typical of a coastal environment. Cores of these sands were taken to analyze the properties. To obtain the cores, 2 inch diameter clear polyurethane pipe, 2.5 feet long, was used. These core tubes were then pushed into the ground by hand until about 4 inches above the ground or until refusal. Before extracting the core tube from the sediment, the tube was filled to the top with water. Filling the tube with water enabled a suction to be created using the palm of my hand (Figure 13). Full recovery was achieved unless the core hit refusal. The core samples were then marked for future identification and a GPS point was taken to reference the location for each core. To package the cores, wet paper towels were stuffed in the space at the top of the tube to keep the samples moist. To seal the samples, small plastic bags were used that fit snugly over both ends of the tube and then sealed with tape.

Figure 13. Extraction of core sample by hand using water filled core tube. Photo taken August 2006.

Multiple samples were taken in the newly deposited sediments of Pine Gully. One of the core samples was able to capture the interface between the sand and original Pine Gully sediments (Figure 14). This core had stiff clay on the bottom, characteristic of the original Pine Gully sediments. This was the only core able to retrieve the original sediments because the core tube either encountered shells that were impossible to drive through, or the stiff clay portion was lost upon extraction of the core tube. An immediate observation about these newly deposited sandy sediments is that they have a black color to them 2 to 4 inches below the surface. This is characteristic for rapid

Figure 14. Original stiff Pine Gully clay sediments are shown in the lower portion of the core below the newly deposited sandy sediments. Core is identified as "Pine Gully, Core 9" in the location map.

sediment deposition where aerobic bacteria are not able to break down the organic matter in the sediments before they are buried and become anoxic. Once these organics are quickly buried in the sediments, all the oxygen is used up by aerobic bacteria and slow anaerobic processes take over organic break down. This anaerobic breakdown produced the strong smell of rotten eggs in the cores, hydrogen sulfide gas, a byproduct of these anoxic breakdown processes. Figure 15 is a location map for the cores shown in Figure 16. The cores in Figure 16 from Pine Gully do not include the original sediments from Pine Gully. Cores were collected at two different dates 15 August 2006 and 11 March 2007. The first sampling date included more cores because it was thought that a difference might occur in the sediments from the mouth of Pine Gully as opposed to those more inland. I concluded from the first cores that no change occurred in the sediments from the mouth of Pine Gully to those further inland so only one core was collected the second time. The three cores to the left in Figure 16 are from the first trip and exhibit the black color from rapid deposition. The core to the far right in Figure 16 is from the second sampling period and exhibits less black coloration. This is probably because the sediments had more time to be oxygenated by wave action and the organics had more time to be broken down at the later date. All of the cores in Figure 16 had a hydrogen sulfide smell to them upon extraction.

Evidence that shows the rapid deposition of sediment in Pine Gully is the presence of quick sand. Field work in the back portion of Pine Gully became hazardous because of the quick sand conditions. Because these sediments were deposited rapidly, they did not have the chance to compact as they would normally. This is especially true in the low energy environment at the back of Pine Gully where the sand is not worked by wave action. My advisor had an experience with the quick sand. In his attempts to free himself, he submerged his field camera which was lost to the Pine Gully quick sand.

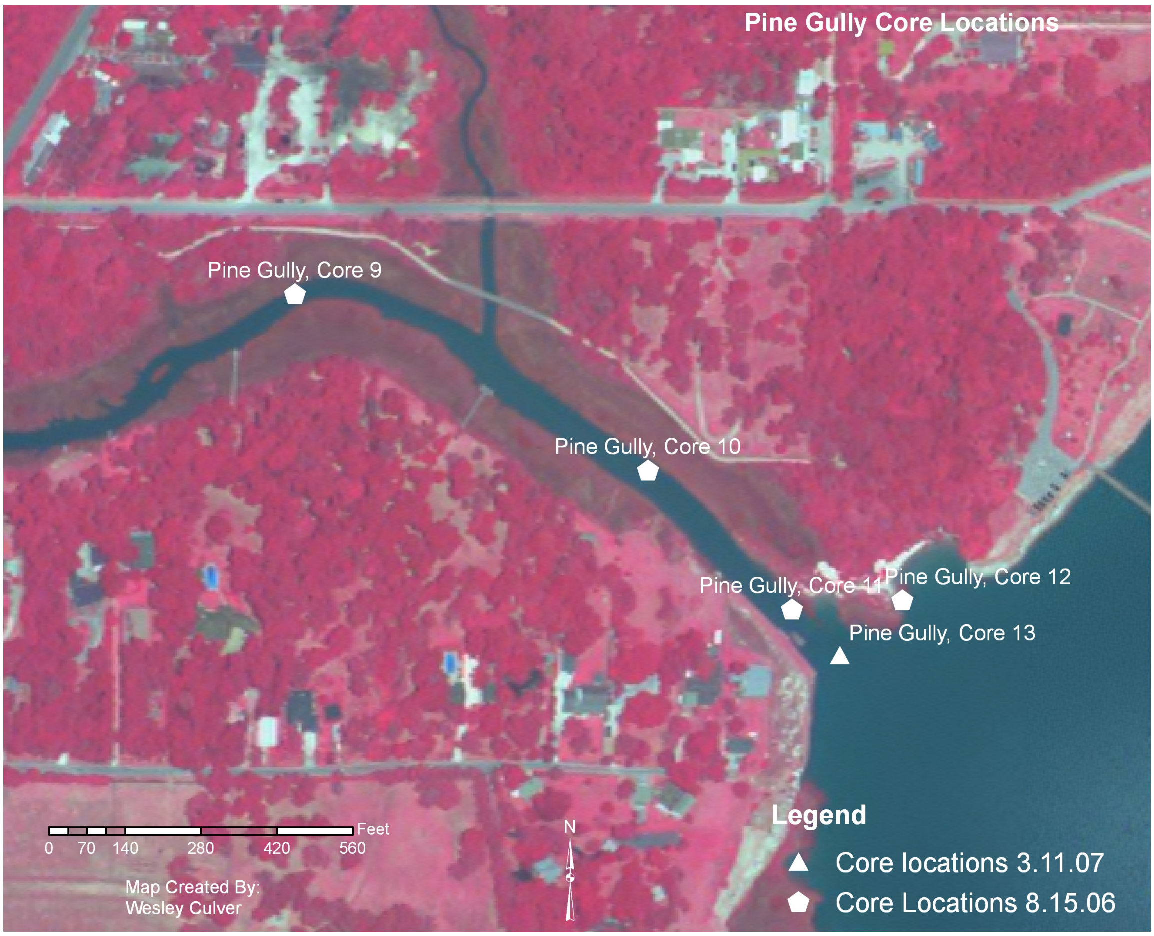

Figure 15. Location map for cores collected in Pine Gully on 15 August 2006 and 11 March 2007. Data plotted on the 2004 NAIP aerial photo from TNRIS.

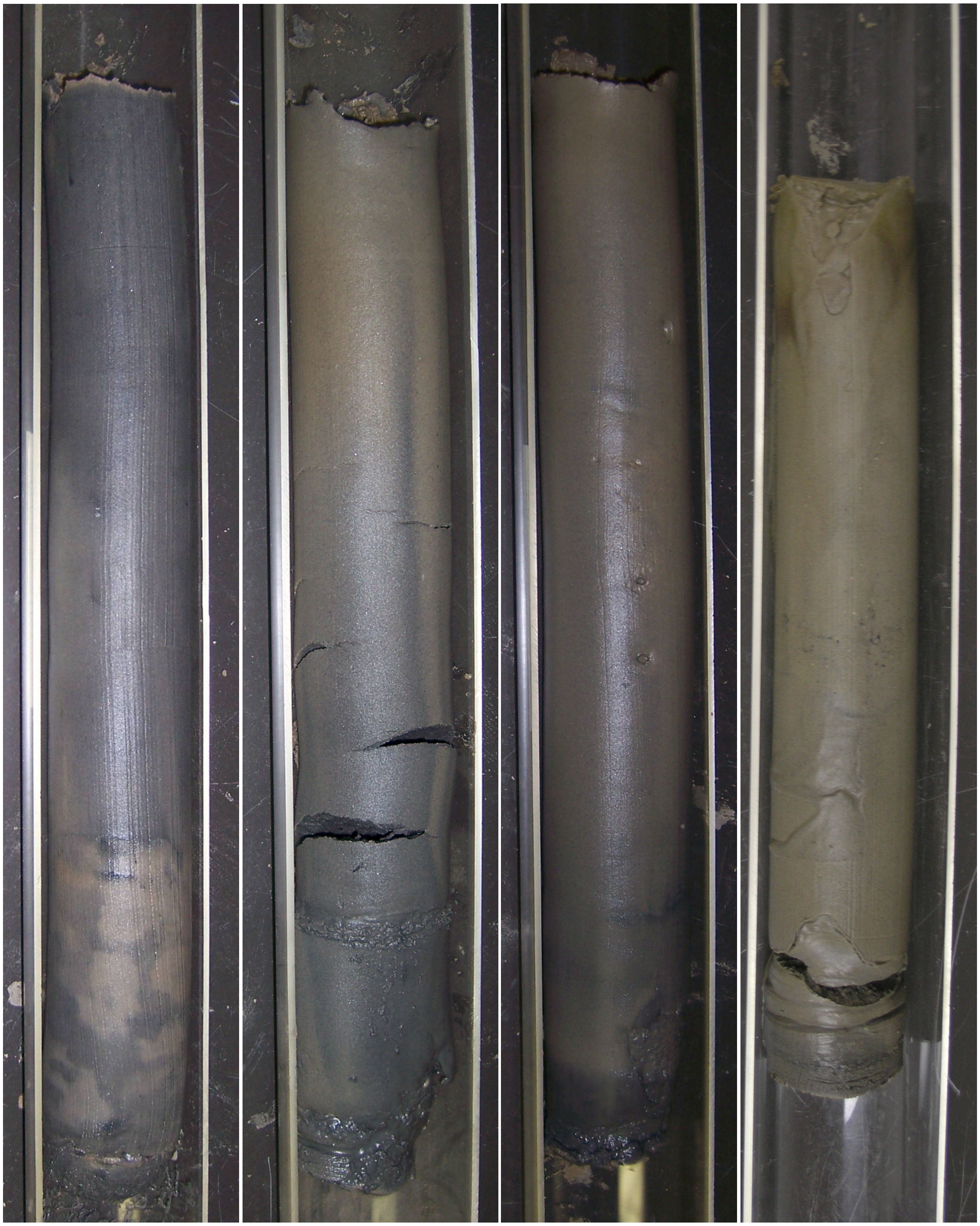

Figure 16. Pine Gully cores from two sampling dates. Notice the lack of any bedding or bioturbation of sediments. The cores are identified left to right on the location map as Pine Gully Core 10,11,12 and 13. Notice Core 13 is not as black as the previous cores.

3.2. Sand Sieve Analyses

To further analyze the sand in Pine Gully, sieve analyses were done in an attempt to correlate sand samples taken from the different locations. A selection of sieve sizes that captured the particle size distribution was chosen from a distribution of the following U.S. mesh size numbers: 50, 100, 120, 140, 170, 200 and 230. The number 230 sieve correlates with the boundary between sand and silt on the Wentworth Scale. Table 1 is a conversion chart for the sieve sizes used in the study. A Ro-Tap© model RX-30 was used for the sieving process.

Table 1. Sieve size conversion chart for U.S. mesh sieve sizes used.

Sieve Size Conversion Chart		
Size (Microns)	Size (in)	U.S. Sieve Mesh
297	0.0117	50
149	0.0059	100
125	0.0049	120
105	0.0041	140
88	0.0036	170
74	0.0029	200
62	0.0024	230
<62	<0.0024	<230

Determining the time to shake the sieves was done by testing the difference of weight in the catch pan in thirty second intervals. The preliminary shake time started at two minutes and incrementally increased at thirty second intervals. Once a shake time of four minutes was completed, the determination was made that a less than one percent change had occurred in weight since the 2.5 minute interval. Each subsequent sample was given 2.5 minutes to shake in the Ro-Tap© machine. Because the sands were visually homogenous, the decision was made to analyze one core from the 15 August 2006 sampling date and one core from the 11 March 2007 date. Each core was divided into three portions; top, middle and bottom, to capture any possible particle size changes over time. Figure 17 shows the particle size distribution for the 15 August 2006 core collection. Notice how the bottom portion of the core deviates from the middle and top portions of the core. When Figure 17 is compared with Figure 18, the sampling period of 11 March 2007, the particle sizes tend to be more concurrent with each other. This makes sense because in the time between collection of these cores, the sediments were re-worked by wave action and flood events in Pine Gully. This provided the energy to better sort these sediments.

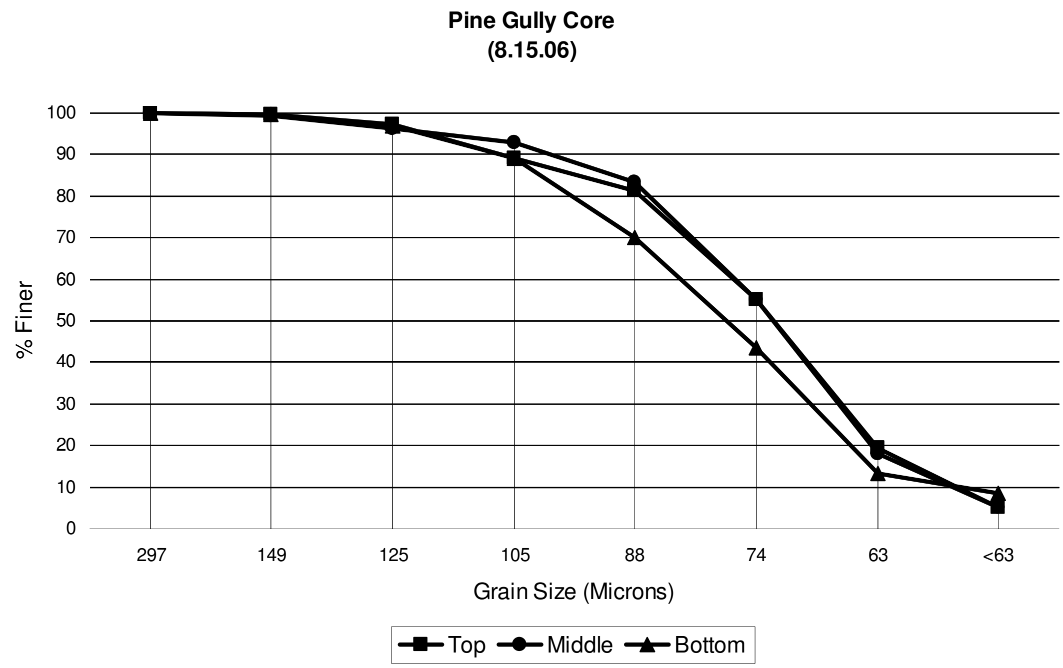

Figure 17. Percent finer curve for Pine Gully from the sampling date 15 August 2006. Notice the deviation of the bottom sediments from the middle and top sediments.

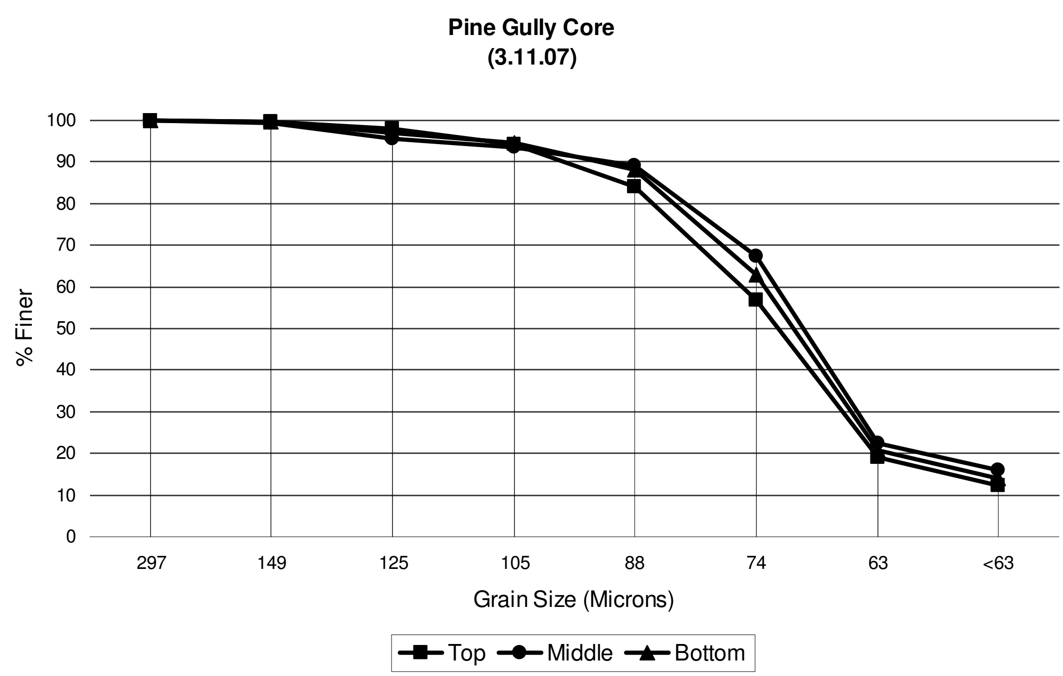

Figure 18. Percent finer curve for Pine Gully from the sampling date 11 March 2007. Notice the deviation of the bottom sediments from the middle and top sediments.

3.3. Coastal Survey and Processing

In an effort to look at the profile of the shoreline at Pine Gully and attempt to capture the addition of sediment, a beach survey was done at the mouth of Pine Gully. This would supply unmistakable evidence that shoreline accretion occurred at the mouth of Pine Gully. An unconventional method was used to collect the data because this method only required at most two people and was designed to be efficient. To collect the data, a Lasermark© LMH Series laser level system was used. The laser level was set atop a tripod so that line of site could be achieved for the whole survey in that location. The Universal Laser Detector included with the System was attached to a Measuremark© F/G Rod by CST/berger survey rod. The Universal Laser Detector would respond to the Lasermark unit when it was at the correct level. Once the survey rod was stabilized, the corresponding height of the rod was recorded along with the GPS position of the reading. The GPS unit used was a Garmin© GPSmap 76C, with a horizontal accuracy of plus or minus 15 feet. To be able to carry the data sheets and the GPS unit efficiently, a fitted plastic frame was purchased and hard-mounted on an extended clipboard. This system was user friendly and efficient, and many points were mapped in a short amount of time. This Pine Gully survey was tied to the northeastern most pile on the boat dock in the Pine Gully channel, Figure 19.

Figure 19. Picture of the boat dock used as the benchmark for the survey. Arrow labeled BM-1 shows the top of the pile used for the benchmark in this survey. Photo taken August 2006.

The first step in processing the survey data is to enter it into a Microsoft Excel spreadsheet. Elevations are referenced to a benchmark at each survey site so that subsequent surveys can be tied together. No USGS elevation markers are available in the vicinity of Pine Gully so easily identifiable structures, such as the boat dock in Figure 19, page 28, was chosen as a benchmark. After all the data has been adjusted to the benchmark elevation, the instrument height is subtracted from each value. Required data are then highlighted and re-saved in DBF IV format. The DBF IV formatted database is imported into ArcMap© by ESRI using the "add XY data" tool to visualize the data. Each of the surveys were added as their own shapefile so that each could be viewed independently. These layers were laid on top of a 2004 NAIP aerial photo from TNRIS. For these layers to be projected correctly, the datum of the GPS unit is required; in this case, the WGS 1984 datum, because it is a commonly used datum and default on the GPS unit. Without knowing the datum, your data may not match your base and vice versa.

The processed results of the beach profile can be seen plotted together on a 2004 NAIP aerial photograph from TNRIS in Figure 20. Notice the irregularity of the contours caused by periodic flooding in Pine Gully that scours the sand bar that has formed in the mouth of Pine Gully. The purpose of the coastal survey was to document the sediment building out from the shore, but the beach survey shows the sand did not change elevations at the times of the survey. If the coastal survey had been done earlier in the sedimentation of Pine Gully perhaps definite changes in sediment elevation would have been discovered. What this work does show is that the energy in Pine Gully reworks the sediment at the mouth. This is why the contours are shaped so irregular. This alludes to the idea that the sediments in Pine Gully have an intricate interaction with the coastal system in Galveston Bay. Contours from each of the coastal surveys are plotted separately in Appendix B.

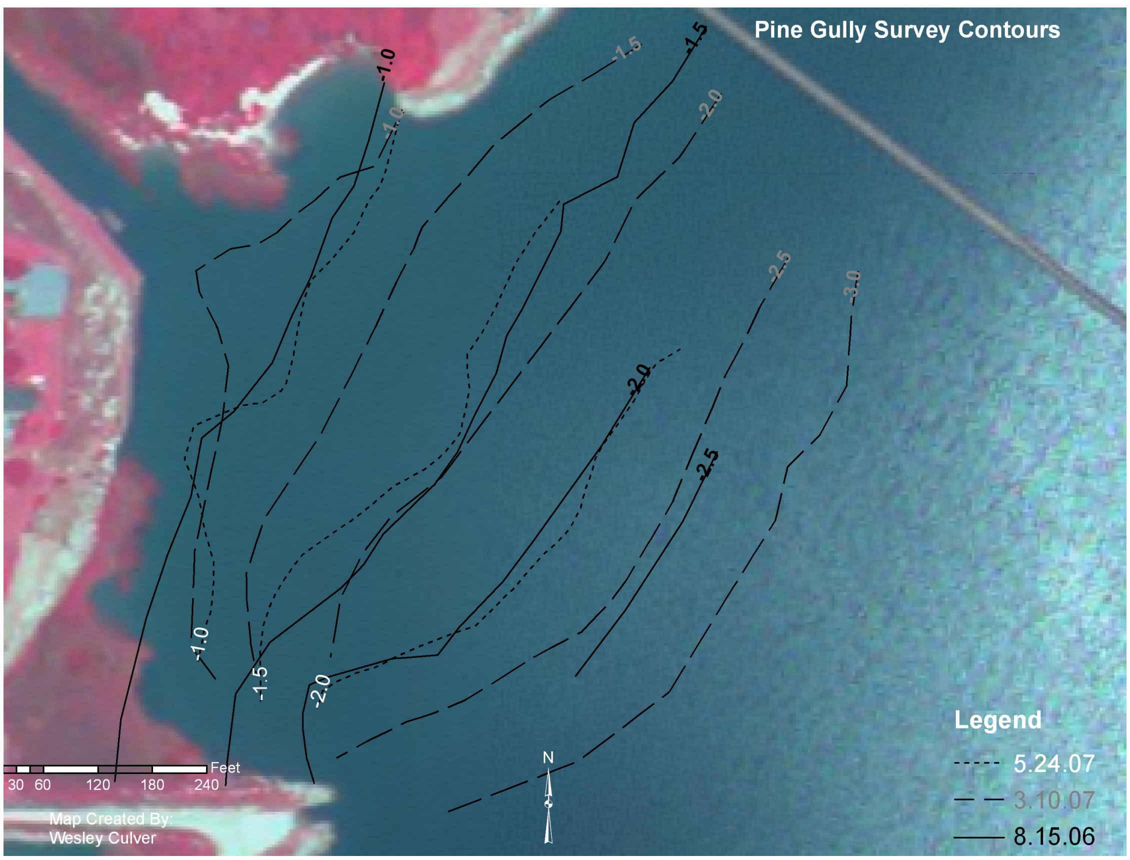

Figure 20. Pine Gully survey data plotted using contours in feet for each of the three coastal surveys. Data plotted on 2004 aerial photo from TNRIS.

3.4. Monitoring Salinity

A diagnostic to monitor the changes in the water in Pine Gully, caused by parts of the wetland being cut off from tidal flow, was to take salinity readings. The salinity instrument used was a Y S I Environmental salinity monitor, model EC 300. Calibration of the instrument was done using a 1,000 μs fluid. Operation of the unit was simple after calibration, the sensor is simply submerged and the unit displays a reading. Each recorded point was also given a GPS location. Readings were first taken beyond the mouth of Pine Gully to measure the salinity of the bay water. Then readings were taken periodically in the Pine Gully channel. At the time the salinity readings were taken, the channel of Pine Gully was almost completely blocked with sediment. Readings were also taken in the stagnating water that had pooled on the flanks of Pine Gully behind the levees, cut off from tidal flow. Not surprisingly, the salinity behind the sand dam in Pine Gully was much lower than the bay waters. Small amounts of runoff from the Pine Gully watershed had filled in behind the sand dam. This fresh water is less dense than salt water so it effectively floats on top of the saltwater and creates a freshwater lens at the surface. The low salinity and elevated water level behind the sand dam and in stagnating pools on the flanks of Pine Gully are negatively influencing the Pine Gully ecology. Salinity concentrations are plotted on a 2004 NAIP aerial photograph from TNRIS in Figure 21.

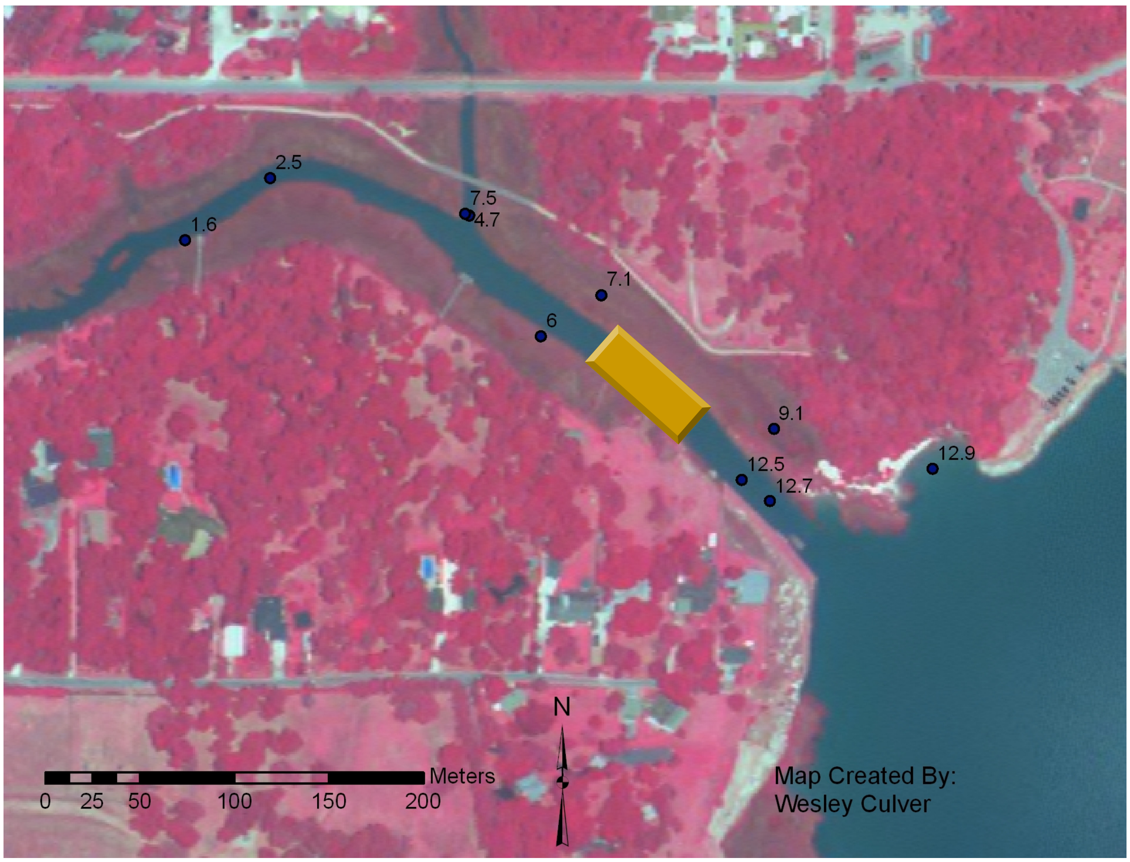

Figure 21. Salinity concentrations plotted on a 2004 NAIP aerial photo from TNRIS. Salinity concentrations plotted in parts per thousand. The box in the center of the photo shows the approximate location of the sand plug at the time these readings were taken. Data collected 15 August 2006.

3.5. Analysis of Wave Energy

Three types of waves affect Pine Gully on a regular basis: wind waves, oscillatory waves, and marine bore waves. To do a wave analysis to monitor various spikes in wave energy, the process that creates each wave has to be recognized. Wind waves are created by the prevailing winds that blow over Galveston Bay and on an ordinary day they do not have the reach to transport sand into Pine Gully. They have a short wavelength and are unable to reach the sediments at the mouth of Pine Gully. Therefore, they are considered background noise and unwanted in any wave collection data. Oscillatory waves affect Pine Gully on a daily basis and have been studied all over the world (Suursaar, et al., 2002; Fukumori, et al., 2006; Yu, 1996). These waves are influenced primarily by the wind, and interaction between Galveston Bay and the Gulf of Mexico. Numeric modeling of these oscillatory waves has been conducted with some success by (Suursaar et al., 2002) in other bay systems. These are very low energy waves with a long wavelength that also could not be a transport mechanism for sand into Pine Gully. The ship wave energy affecting Pine Gully, however, does have the reach to pick sand up off the mouth of Pine Gully and carry it deep into the wetland. A thesis by Allison (2005) has documented the same process in a study involving tidal creeks on the Texas Intracoastal Waterway. Figure 22 is a picture of one of these bore waves entering a side tributary well inside Pine Gully.

To monitor the wave energies in Pine Gully, pressure transducers were temporarily installed at the mouth of Pine Gully. Links of solid two inch PVC pipe were cut to 8 feet in length. For the deep water sample points (depth of water 2 to 4 feet),

Figure 22. Picture of a marine bore wave in the upper portions of Pine Gully seen by the turbulence caused by the small piers in the picture. Arrows direction and point out pictured bore wave location.

holes were drilled below the water line down to the bottom of the pipe. Having holes only below the water line helped to filter out the surface waves that are not of interest to the study. The pipes were placed in position and twisted into the sandy mouth of Pine Gully. A tamping device was carried in the field but never used because the loosely compacted sediments offered little resistance to emplacement. The shallow water stations were constructed the same way but used environmental well pipe slotted at .010 inches. This slotted pipe was used in shallow water because the water depths would become too low to use the other technique of holes only below water level.

Setting up the pressure transducers is relatively simple and uses the equipment included with the Levelogger© system. Software provided with the transducers is also somewhat easy to use. The basic functions are downloading the data and turning the transducers on and off. A variation on the pressure transducers provides a barometric reading that is concurrent with the readings of the pressure transducers. This provides a barometric pressure correction for data collected over time. This is the first unit to be deployed so that all data are correctable from the fluctuations in atmospheric pressure. The Barologger© model 3001 was used in this study. Once the barometric pressure device was in place, the Levelogger© Model 3001 pressure transducers were turned on by the Levelogger© software and are lowered into the pipes, suspended by fishing line and tied off to the prescribed fastener. These transducers were lowered to the sediment bottom and then pulled up, off the bottom, by two inches. Tape was then applied to the fishing line to secure it to the pipe. Orange caution tape was also tied off to each of the temporary gauge stations for precautionary measures. Results of the wave data captured all three types of waves. Figure 23 shows an excerpt of the wave data and is annotated to show the signature of the different types of waves.

Background noise in the data is caused by the wind waves. These wind waves do not affect the data because they are small events compared to the resonant and bore waves. The resonant waves are the somewhat regularly spaced waves that are continuous throughout the data. They have a long wavelength and low amplitude and therefore are not a mechanism moving sediment into Pine Gully. The energy of ship waves is evident in the data and in the field. These waves produce a rapid draw-down of water level followed by large continuous train of breaking waves. This train of breaking waves pick up sediment at the bar mouth of Pine Gully and transports it into the channel

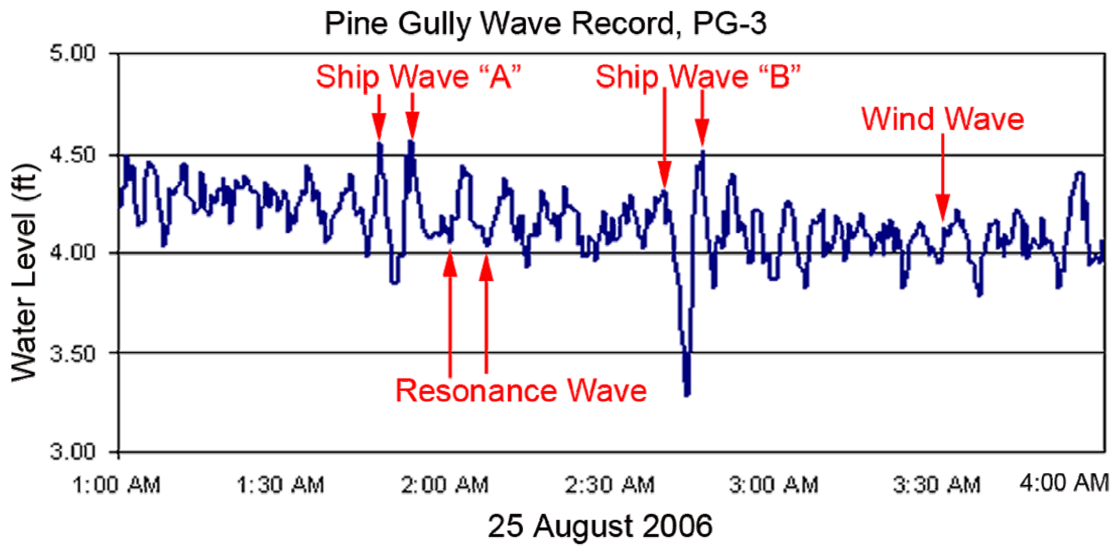

Figure 23. Wave record from station PG-3 located offshore Pine Gully that shows the common wave forms impacting the area.

of Pine Gully. Two common types of ship waves were captured in this data, one of them is ship wave type "A". These are generated by a conventional hull form with a bow and stern wave of approximately the same height separated by the hull wave which lowers sea level approximately the same amount as the bow and stern wave elevate sea level. The type "B" waves are characteristically asymmetric with a minimal non-detectable bow wave and a pronounced hull wave and stern wave. Type "B" waves are produced by ships with a bulbous bow; the bulb on these ships is designed to cancel out the bow wave energy at a certain speed and reduce resistance. Figure 24 shows effects of an incoming bore wave, while Figure 25 shows a train of bore waves refracting around the sediment at the mouth of Pine Gully. All wave station data are recorded in Appendix A.

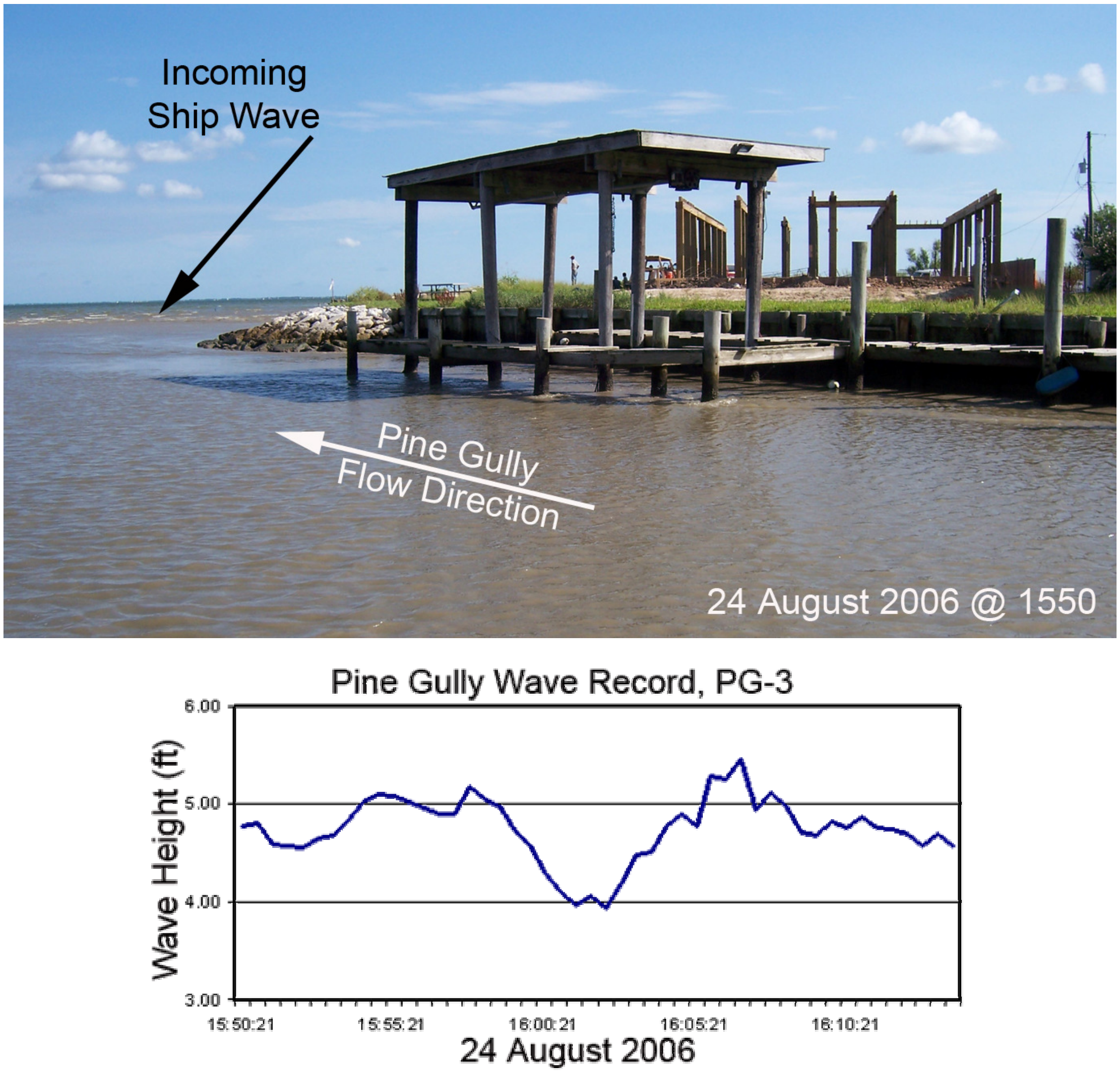

Figure 24. Photograph taken on 24 August at 1550 (3:50 PM) showing the impact of an incoming type “B wave” on the circulation in Pine Gully. Note that the arriving hull wave is visible just offshore while the current in Pine Gully is flowing toward the incoming wave. The standing wave against the right pile on the dock across Pine Gully demonstrates the significance of this outward flow. The graph below the photograph shows the wave record for the period of the photograph above. Note on the wave record that the water level dropped more than 1 foot in about 2 minutes and rose about 1.5 feet over the next 3 minutes.

Figure 25. White line shows incoming waves are parallel offshore, then as the wave train approaches the sand bar the waves "feel bottom" and refract around the sand bar. Every train of ship waves brings in more sand to Pine Gully in this way.

3.6. Use of Photography

Photography was a very useful tool to monitor Pine Gully throughout the study. A valuable lesson learned in this project was to really think about taking pictures not only of the problem areas, but other areas that are not yet a focus of your study. In this case, pictures of the unaffected areas in Pine Gully at the beginning of the study were useful to show the destruction of the wetland grasses as the sediment continued to change the dynamics of the system. Areas where the wetland grasses were affected most is behind the levees that had cut off tidal flow from Galveston Bay. Figure 26 is a set of photos that show Pine Gully as it progressively fills up with sediment. The left photo was taken 25 August 2006 and the right photo was taken 24 May 2007. The pictures were not taken from exactly the same location or at the same time of year, but you can see the change in vegetation cover and the transition to salt flat.

Figure 26. Left photo taken 25 August 2006, right photo taken 24 May 2007. Notice how much of the wetland grasses in similar areas of the photos have been lost and replaced by salt flat.

Tide levels, wind setup, and bay height are variable at Pine Gully. Photos can be useful to show from one visit to the next how the water level in the bay has changed. Figure 27 shows the relative difference in water level using the boat dock at the mouth of Pine Gully. The water levels were over one foot different from the two dates, shown by water levels on the boat dock.

One of the greatest drawbacks using photography in the field is that it is hard to get a similar picture of the same location at two different dates with the same lighting conditions. Having different perspectives and lighting conditions on the subject you are photographing can make pictures look very different from each other when they really are not. The pictures you take can also look very similar when they really are not. It is important not to be misled by photographs because of their dynamic nature.

Figure 27. Picture taken 10 March 2007 on left shows lower water level at mouth of Pine Gully than in the picture taken 24 May 2007 on right where the water level is over one foot higher.

Historical aerial photography was used to study the progressive changes in the geometry of Pine Gully and the shoreline changes caused by erosion and subsidence in the introduction of this study. These historical aerial photos were ordered from the TNRIS aerial photo archive. These photos are delivered as analog prints, so to digitize these prints they were scanned in as non-georeferenced photos. After the photos were scanned in, ArcMap© was utilized to georeference the pictures so that they would match. After the georeferencing process was complete, separate shapefiles were created showing the shoreline each year as it retreated inland. All of these shapefile layers were later plotted together to show the progressive shoreline erosion that has taken place over time. The finished product of this process is shown in Figure 11, page 16.

Aerial photos have helped to see the changes in Pine Gully over time at a much finer scale than any photos ordered from TNRIS or those ordered from the USDA. A set of aerial photos, Figure 28A through Figure 28D, shows how Pine Gully changes over time. The Clear Lake tide data from the NOAA website is included in these photos so that misconceptions are not made because the tide level in Galveston Bay is higher or lower from one aerial photo mission to another.

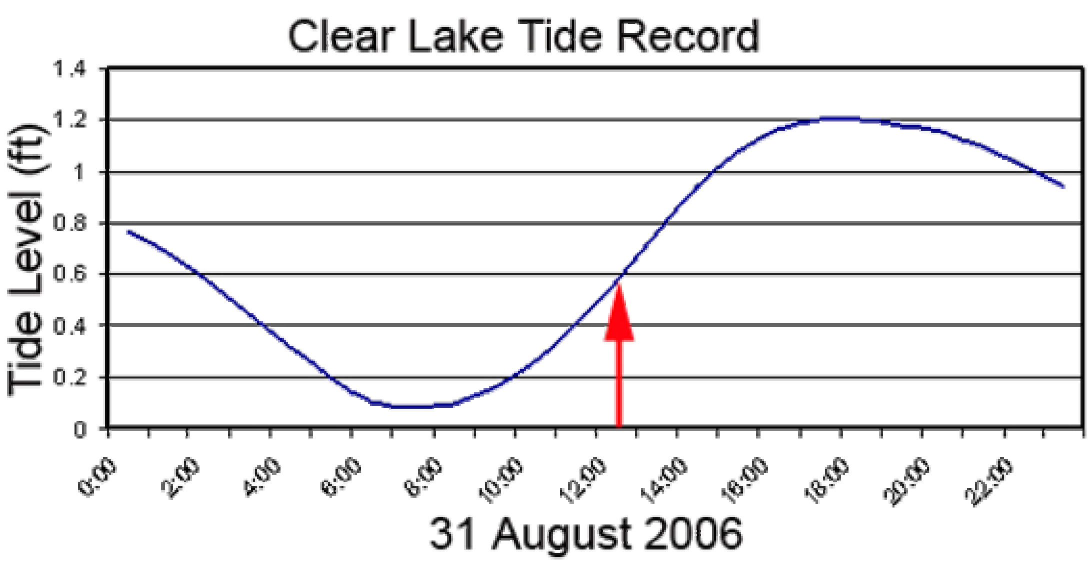

Figure 28A. Picture taken 31 August 2005 by Sally Antrobus. Note the rising tide at +0.6 feet. This marks the beginnings of sedimentation as the north tributary has been plugged and the main channel of Pine Gully has been plugged.

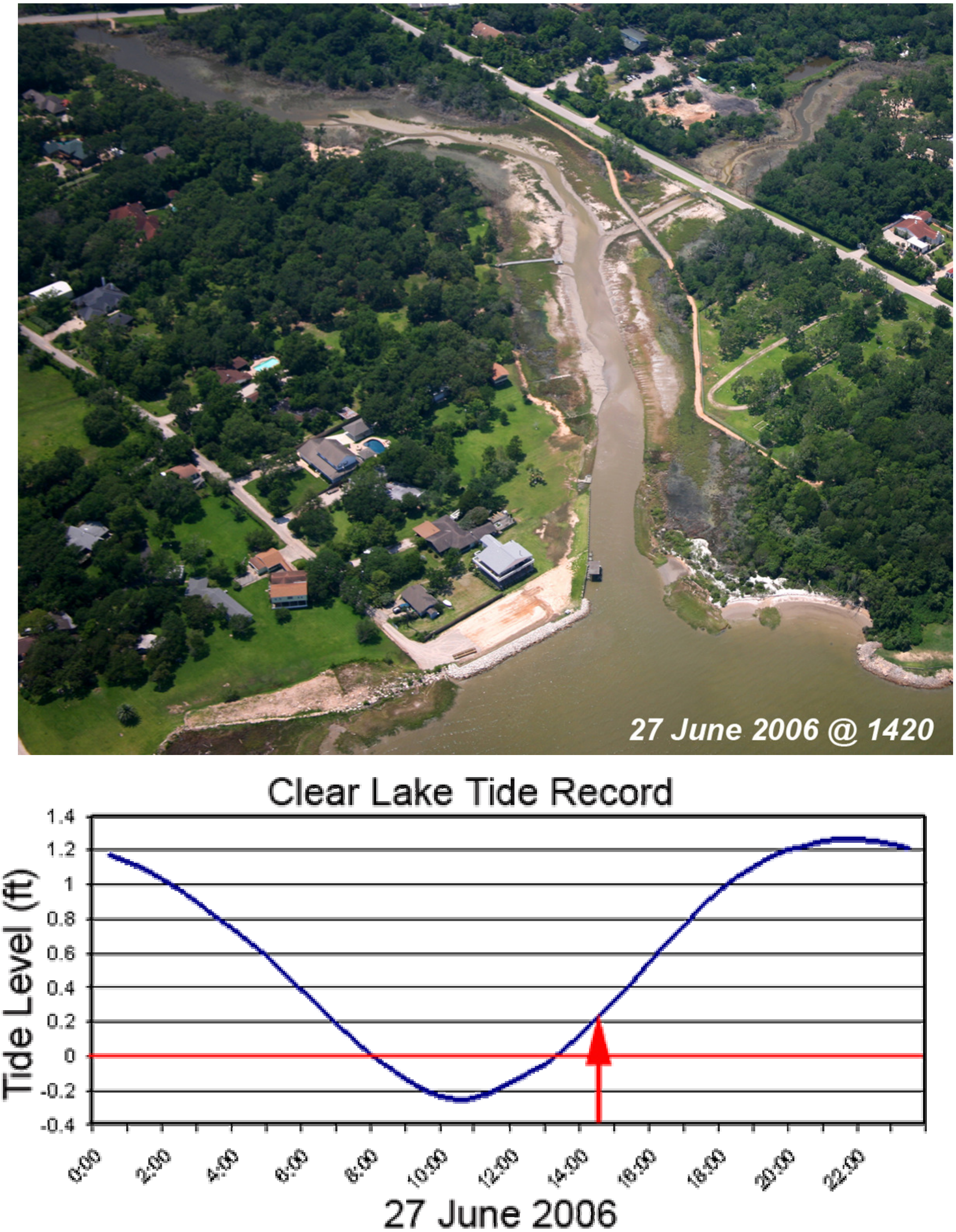

Figure 28B. Aerial view of Pine Gully sand plug on 27 June 2006 (tide level is rising currently +0.2). Note that the sand plug has advanced toward Galveston Bay and that the sand levees are clearly visible along both sides of Pine Gully.

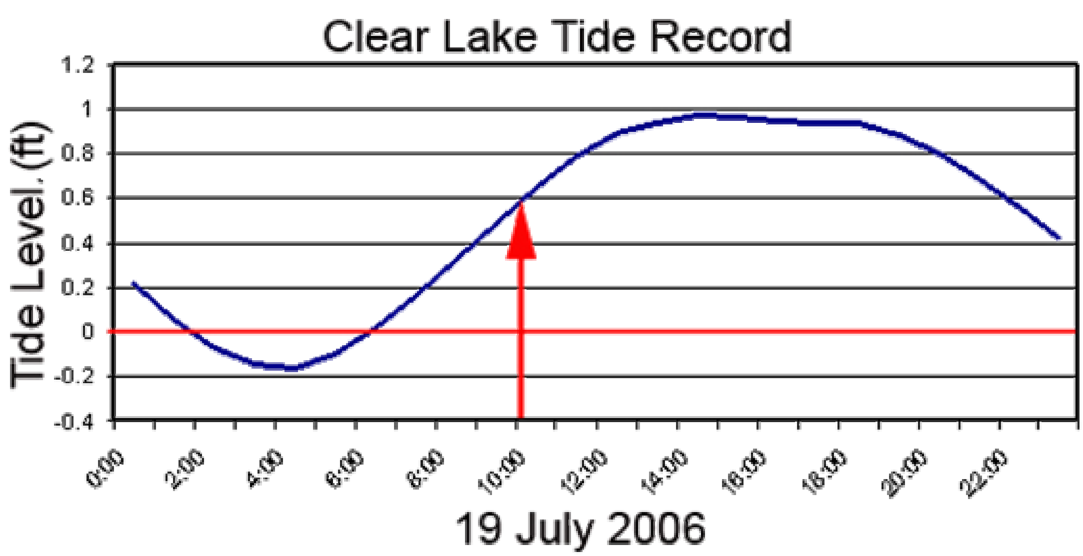

Figure 28C. Aerial View of Pine Gully on 19 June 2006 (tide is currently +0.6 feet). Note that the sand plug has advanced toward Galveston Bay in the 23 days since the previous photograph and that the sand levees are more developed.

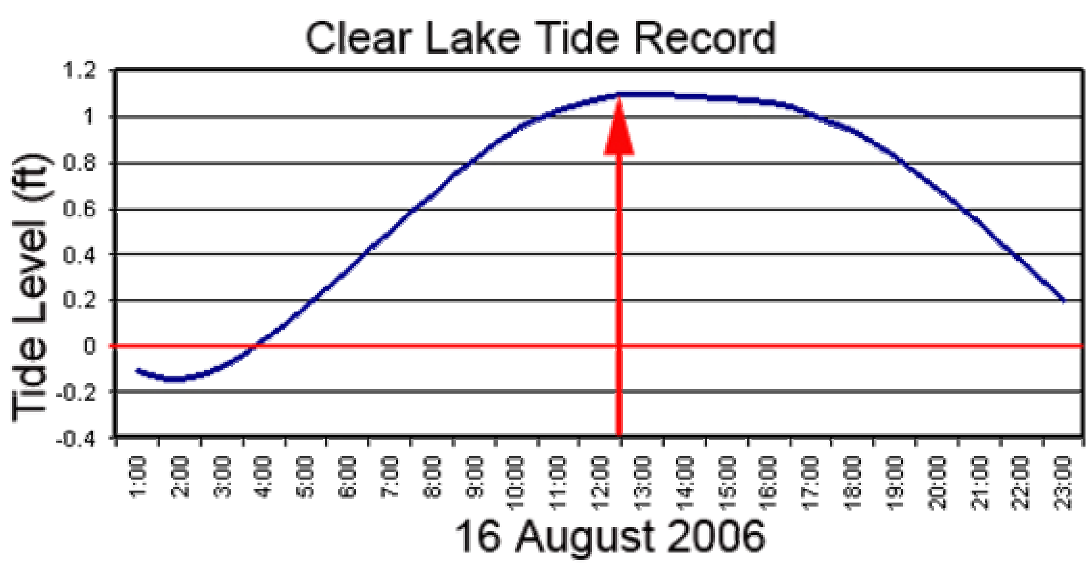

Figure 28D. Aerial view of Pine Gully on 16 August 2006 (the tide is currently at +1.1 ft). Note the ponded freshwater behind the sand plug and the extent of the plug. Sand levees are clearly visible above high tide along both banks of the Pine Gully channel.

Photography helped interpret the process of filling Pine Gully with sand. The marine bore waves carry excess sediment into Pine Gully and deposit sediment slowly over time, shown in Figure 29 as small laminations of sand. This eventually produces overbank deposits that spill out into the wetland. During a storm event, the Pine Gully channel is flushed out and levees are produced along the side of the channel. Figure 30 shows levee deposits in Pine Gully after the channel has been flushed out by a rain storm. After the flow in Pine Gully subsides, the bore waves are able to resume silting the channel. But this time the bore waves are forced to stay in the channel by the levee deposits remaining. This ultimately forces sediment further into Pine Gully each time this process begins again. Figure 31 is a schematic of this process.

Figure 29. Laminations of sand brought into Pine Gully by bore waves. Each of the laminations marks more sedimentation from a bore wave. Photo taken March 2007.

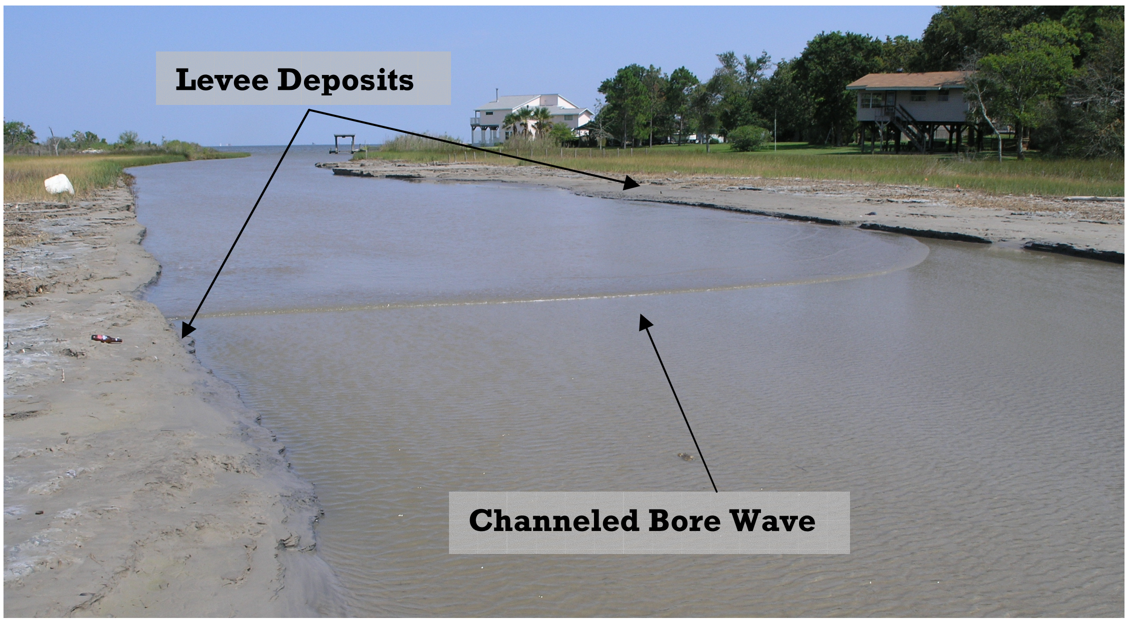

Figure 30. Photo of Pine Gully levees formed by scouring of the channel through the sand plug that formed previously. Notice the levee deposits keep the incoming bore wave channeled, pushing sediment further into Pine Gully. Photo taken March 2007.

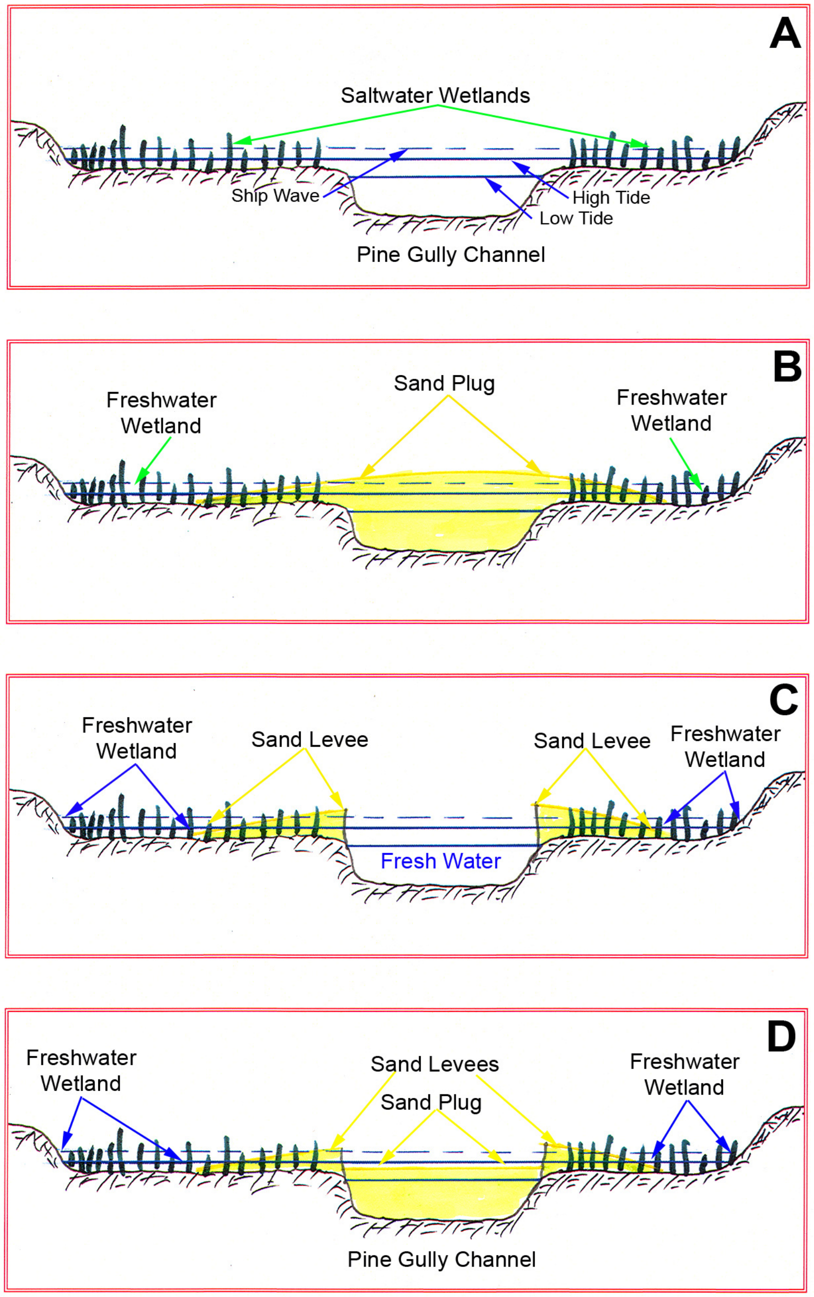

Figure 31. Schematic diagram showing the sedimentological processes in Pine Gully. A) natural conditions without a significant source of sand at the coast; B) development of the sand plug from landward transport of sand; C) sand plug flushed out of Pine Gully by rainstorm runoff; and D) reestablished sand plug at the original location at a lower elevation because the previously constructed sand levees confine the landward transport of sand within the modified Pine Gully channel.

CHAPTER IV

CAUSE AND SOURCE OF SEDIMENTATION IN PINE GULLY

Before this study began, other scientists and citizens had already made multiple hypotheses about what was happening in Pine Gully. The common factor in each of these hypotheses was whether or not a new source of sediment existed, or if the sedimentation in Pine Gully was a natural process and should be expected.

4.1. Proposed Hypotheses

One of the scientists that preceded my visit to Pine Gully and studied the processes was, Dr. Tom Ravens, Ocean Engineer, Texas A&M Galveston. Dr. Ravens hypothesized that climate was the driving force, where sedimentation was caused by the unusually dry year and not by a new source of sediment. With this unusually prolonged dry weather, Pine Gully does not have the energy to naturally flush all the sediment that was deposited by the marine bore waves. Given sufficient rainfall, Pine Gully would flush out the sediment that had built up in the channel and return it to the bay.

A different hypothesis is that Pine Gully has a "memory" of pre-subsidence conditions. This suggests that Pine Gully may be naturally rehabilitating itself to a pre-subsidence state. The level of the ground surface level is being raised with the natural sediments being deposited in the wetland, hence the land is returning to the upland habitat as it was in the past.

In a meeting at the Seabrook City Hall, Dr. Douglas J. Sherman, Head, Department of Geography, Texas A&M suggested that subsidence was a likely cause of the sedimentation in Pine Gully. In his hypothesis, he suggested that over time a shoaling process occurs as the land subsides. The same sediments originating from a landward source that had always deposited in Pine Gully are being deposited at the shore water interface. As the land subsides, this shoaling process progresses up the Gully and constructs a small delta of sediment that collectively form a freshwater floodplain that supports upland vegetation that existed historically in Pine Gully. The claims made by this hypothesis use extensive historical aerial photo data in an attempt to show what Dr. Sherman interprets as evidence of this shoaling process.

Addressing hypotheses for a new source of sediment include either a land source for the sediment or a bay source for the sediment. One of the first hypotheses noted by personal communication from residents of the area is that the sediment was derived from a land source. To the north of Pine Gully, a major construction project had recently broken ground and they naturally thought the drainage from that project was contributing excessive sediment to Pine Gully. For this to happen, it would require that Pine Gully experienced regular floods during this time, and land based sediment controls would have to be absent or not effective.

The only other new sediment source could be from Galveston Bay. In the first visit to Pine Gully, observations of the marine bore waves generated by ships in the Houston Ship Channel were evident. These waves appeared to have sufficient energy and reach to pick sand up off the shallow bar in the mouth of Pine Gully and bring the sand into the channel, where the energy decreases and the sand settles out of the water.

4.2. Pine Gully Is Returning to Historic Conditions

The hypothesis that Pine Gully is just naturally returning to its pre-subsidence state, or that nature has a "memory" of past conditions and will naturally gravitate back toward that condition, has little supporting evidence. The area where the Pine Gully wetland exists today used was upland in the past. This is evidenced by tree trunks preserved in the wetland (Figure 32). In the introduction of this paper, I showed that over 300 meters of shoreline erosion has taken place since 1944. To return Pine Gully to historical conditions, at least some shoreline must be re-established. With the sedimentation at Pine Gully no significant shoreline addition has occurred to make the "memory" hypothesis valid. Continued sea level rise will make the situation even worse in the future for Pine Gully as the land is submerged by the bay. Evidence against a "memory" of past conditions in Pine Gully because of shoreline erosion exacerbated by sea level rise and a permanently altered shoreline environment will never allow Pine Gully to naturally return to historic conditions without human intervention.

Figure 32. Dead hardwoods from an upland setting in what is now the Pine Gully wetland. Photo taken March 2007.

4.3. Shoaling in Pine Gully

Dr. Sherman's presentation about subsidence causing a shoaling process to form, progressing up Pine Gully over time, interpreted aerial photography in a misleading way. The evidence presented for this hypothesis was a series of historical aerial photographs that show light colored areas in Pine Gully. The aerial photos Dr. Sherman used in his presentation are presented in Figures 33 through Figure 37 and Figure 39. All six of these photos are from his presentation given at the City of Seabrook meeting.

Each of the photos, starting in 1982, has an area circled in yellow that highlights the proposed shoaling locations. In each subsequent year after 1982 and up to 1990, the shoaling location appears to move up-stream in Pine Gully. The misconception with this hypothesis is that the black and white aerial photographs used for this analysis are assumed to exhibit excess sediment, or shoaling, depositing in the light colored areas of the Gully. These light colored areas are really just bare ground, or areas without vegetation. These areas should not automatically be interpreted as areas with excess sedimentation. Dr. Sherman interpreted these light colored areas as excess sediment that was part of a progressive shoaling process migrating upstream in Pine Gully. The described shoaling process is actually not shoaling at all. Freshwater wetland grasses are dying off as a response to the land being submerged with saltwater after the effects of subsidence and continued sea level rise. The aerial photos show areas that resemble shoaling once the freshwater grasses have died; yet these areas are healed in subsequent photos as the saltwater vegetation moves into the bare area, replacing the freshwater grasses. Figure 38 is an aerial photo retrieved from the TerraServer operated by

Microsoft. These photos are provided to the TerraServer by the USGS. The date of this photo is January 2002. There is no evidence of any shoaling in this photo, but suddenly in Figure 39 there appears to be massive amounts of sedimentation in Pine Gully. Three yellow circles exist from the mouth of Pine Gully to just past the north fork of Pine Gully. If this is part of the same shoaling process described in the past aerial photographs, and that seems to disappear in the 2002 aerial photo, the shoaling process should not have gotten closer to the mouth of Pine Gully, but should have continued its progression inland.

Figure 33. 1982 aerial photograph of Pine Gully report given to the City of Seabrook by Dr. Sherman. Figure is pulled directly out of presentation.

Figure 34. 1984 aerial photograph of Pine Gully report given to the City of Seabrook by Dr. Sherman. Figure is pulled directly out of presentation.

Figure 35. 1986 aerial photograph of Pine Gully report given to the City of Seabrook by Dr. Sherman. Figure is pulled directly out of presentation.

Figure 36. 1989 aerial photograph of Pine Gully report given to the City of Seabrook by Dr. Sherman. Figure is pulled directly out of presentation.

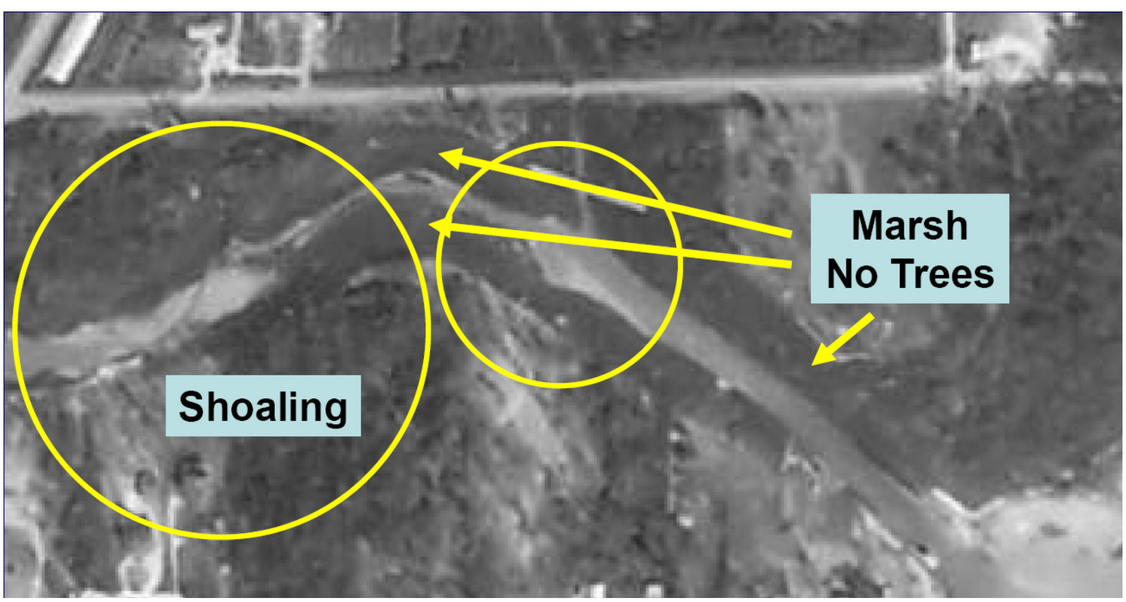

Figure 37. 1990 aerial photograph of Pine Gully report given to the City of Seabrook by Dr. Sherman. Figure is pulled directly out of presentation.

Figure 38. 2002 aerial photograph of Pine Gully collected from the TerraServer run by Microsoft. The photo was provided to the TerraServer by the USGS. Notice the lack of any sedimentation in this 2002 aerial photograph.

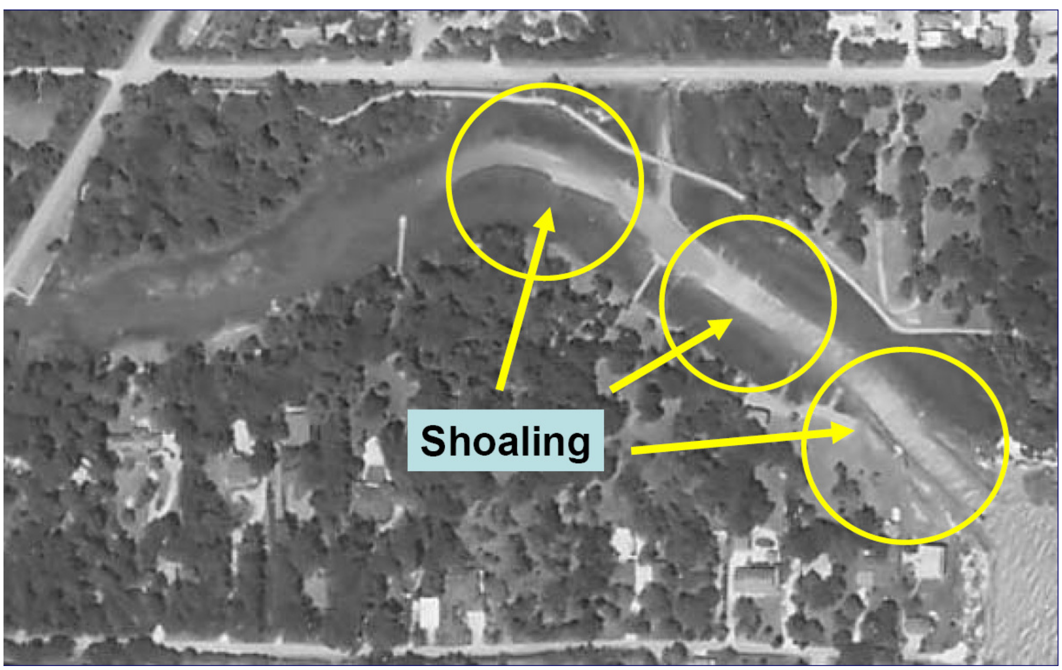

Figure 39. 2005 aerial photograph of Pine Gully report given to the City of Seabrook by Dr. Sherman. Figure is pulled directly out of presentation. Notice the areas marked as shoaling have moved back toward the mouth of Pine Gully.

Another issue with this hypothesis has to do with the amount of sediment being delivered into Pine Gully from its small watershed. Not enough sediment is available to produce a sediment plug so extensive and so quickly in a few months time. The shoaling process that Dr. Sherman described would have been a gradual one, taking decades to achieve.

In any fluvial system, sediments are moved primarily in storm events. Bringing this amount of sediment into Pine Gully would have been even more difficult because the time period in question has been relatively dry. To show dryness, rain data from the NOAA historical weather archive was used to create the rainfall differential shown in Figure 40. A rainfall differential is produced by subtracting each annual precipitation total from the average annual precipitation of all the years in question. Many other years experienced higher rainfall and would have had much more energy to move sediment but those years lacked sedimentation.

Dr. Sherman's hypothesis is not valid because the aerial photos were misinterpreted. The shoaling process is not supported with all the evidence. Pine Gully has a small drainage basin that could deliver only small amounts of sediment, and rainfall data does not support the quantity of energy required to move the massive amount of sediment that has filled up Pine Gully.

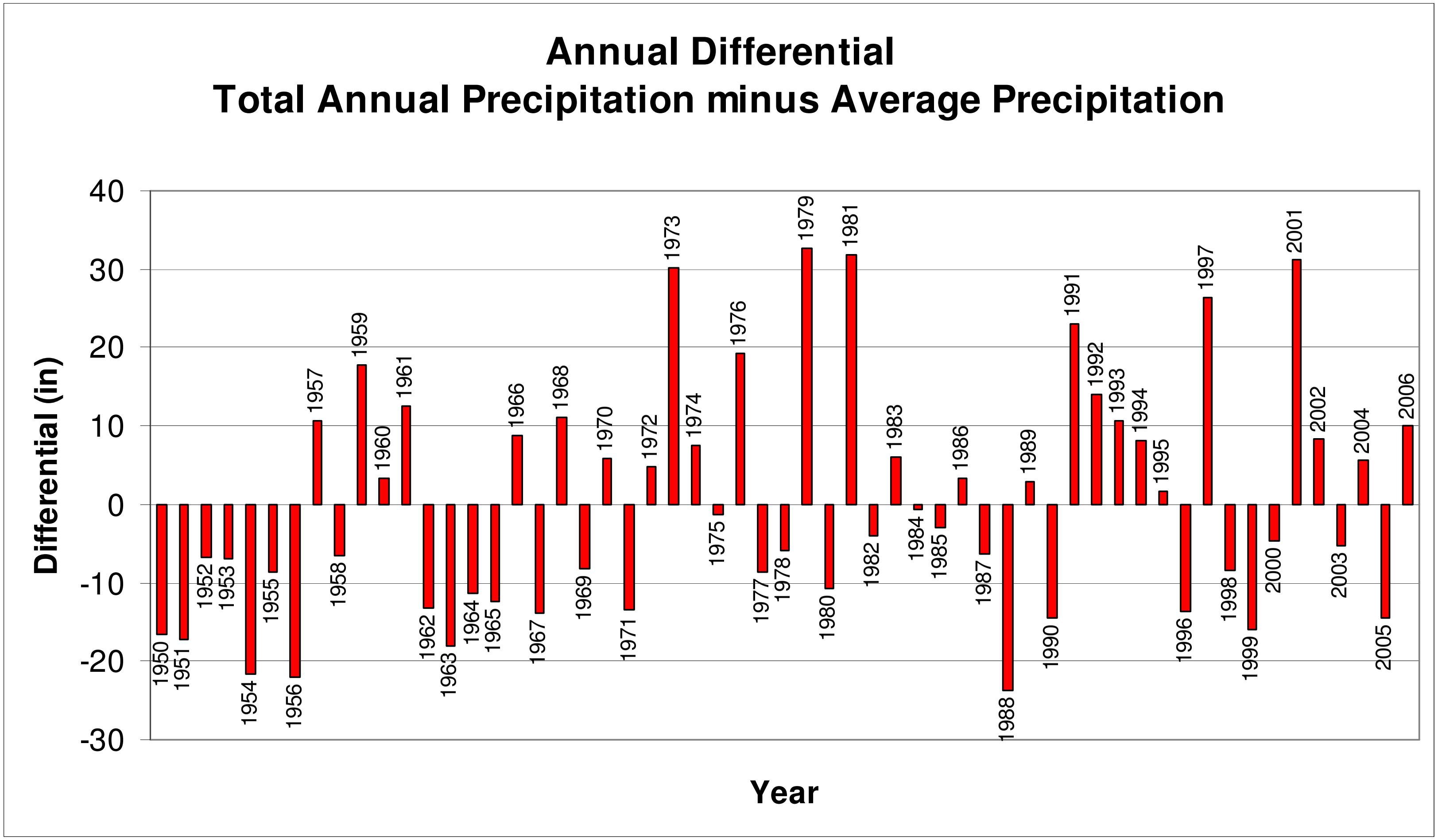

Figure 40. Annual precipitation differential measured from data obtained at Hobby Airport. Note 2005 was a relatively dry year.

4.4. New source of Landward Sediment

An hypothesis involving a new source of sediment being deposited in Pine Gully is attributed to a new landward source of sediment. This would require that all the sediment be brought into Pine Gully from intermittent storm events. The first evidence against a land source is that 2005 was a relatively dry year. Just as in Dr. Sherman's hypotheses, why would Pine Gully begin silting up in a year where less precipitation and, therefore, fewer storm events move sediment into Pine Gully than in other years? The answer is less sediment is available to move into Pine Gully than in years past when Pine Gully had not experienced sedimentation.

The reason a land source was suspected is because a large construction project started concurrently with the sedimentation in Pine Gully. A complaint was filed with the Texas Commission on Environmental Quality (TCEQ) by a concerned citizen and an investigation into the sedimentation allegations were conducted by a TCEQ investigator. The report generated by the investigation concluded that adequate sedimentation procedures were being conducted to control the movement of sediment (Johnson, 2006). The investigator also had the benefit of observing storm water flow and it was determined that this storm water was not carrying the sediments responsible for sedimentation in Pine Gully. This investigation was a visual appraisal of the construction project to make sure adequate sediment controls were in place. Expected sediment in the runoff from this project would have been very fine, in the clay range; considering the flat topography, on-site erosion control measures, and the distance storm waters would have to travel to get to Pine Gully. By the time sediments would reach

Pine Gully, the sand size particles, consistent with those in Pine Gully, would have deposited relatively close to the construction site.

The most convincing evidence against a land source is the direction that the sand plug built into Pine Gully. The original sand dam in Pine Gully formed close to the mouth. Over time, the location of the plug migrated inland and deposited more sand and overbank deposits in Pine Gully. If the sediment was from a land source it would have first deposited inland and then migrated to the mouth of Pine Gully. Figure 41 shows the most recent aerial photograph taken at Pine Gully on 11 March 2007. The sedimentation is restricted to the downstream portion of Pine Gully. Ripple marks are important sedimentary features found in Pine Gully and again confirm a bay source of sand and not a landward source. The direction of sand transport, seen in Figure 42, shows the ripple marks and the dominant direction of sand transport from the bay. As waves from ships wash into Pine Gully they carry sediment into the channel and produce the ripple marks in Figure 42. The wave then disperses into the wetland once it passes the levee structures formed on the banks of Pine Gully. If the sediments were coming from a land source, none of these features should be present. Because no significant source of sand is available from a landward source to Pine Gully, rainfall data is unsupportive and the sedimentary structures contradict a land source, a landward source of sediment can be rejected as a viable hypothesis.

Figure 41. Aerial photo of Pine Gully taken 11 March 2007 showing limit of inland sedimentation in Pine Gully.

Figure 42. Views of the sedimentary structures preserved on the sand plug in Pine Gully, confirming that the dominant direction of sand transport is from Galveston Bay. Photos taken August 2006.

4.5. Pine Gully Is Filling Naturally

Dr. Tom Ravens presented his findings to the City of Seabrook and other authorities on the issue. Dr. Ravens used climate data to show how Pine Gully had gone through an unusually dry year and this had caused it to be naturally plugged with sediment; given enough precipitation Pine Gully would flush out the excess sediment and return to its previous condition. Dr. Ravens proposed that the mechanism of transport into Pine Gully was from the bore waves bringing sediment in from Galveston Bay. Calculations by Dr. Ravens show how much sediment could be brought into the gully in one year with the incoming bore waves. Dr. Ravens calculated that 0.41 cubic meters would be transported into Pine Gully with each marine bore wave. The U.S. Army Corps of Engineers (2003) provides online data that specify around 10,000 ships pass Pine Gully per year. Knowing the sediment transported per wave and assuming at least one bore wave was produced by each ship, Dr. Ravens estimated around 4,100 cubic meters of sediment could be transported into Pine Gully per year. This rate of sediment transport by the bore waves would be sufficient to fill up Pine Gully within a few months if the total sediment accumulation of 2,300 cubic yards (1,758 cubic meters), calculated by Spinks and others (2005), is correct.

Evidence against Pine Gully naturally silting up because of the relatively dry year starts with the rainfall data. Using the rainfall data plotted in Figure 40 of page 59, Pine Gully should have naturally plugged up with sediment in at least ten other years if the process was linked to drought. Another problem with the drought hypothesis is that you must have sediment available for the marine bore waves to bring into Pine Gully.

Because the Texas Coast is a historically eroding shoreline, no excess sediment under natural conditions is available to marine bore waves; therefore, sediment could not naturally be carried into Pine Gully without a new sediment source.

4.6. Pine Gully Is Filling from a New Bay Source of Sand.

A land source of sediment in Pine Gully is not supported by the evidence. The direction of sedimentation illustrated in Figure 42 on page 63 shows an inland direction of sediment transport. Sediments being deposited in Pine Gully are also not consistent with sediments that would come from the Bayport Construction Project, and a TCEQ investigation cleared the Project from the allegations (Johnson, 2006). The remaining portion of the Pine Gully watershed that sits outside the Bayport Construction Project would not be able to deliver this massive amount of sediment in such a short timeframe. Beside the Bayport Construction, there is no other change in the Pine Gully watershed that could possibly release an unusual amount of sediment into Pine Gully.

Dr. Sherman's hypothesis requires natural sediments to build up in Pine Gully and create a freshwater floodplain, returning Pine Gully to historic conditions. The aerial photos used to show this process are not supportive of the hypothesis. The natural sediments required to fill Pine Gully from land would not dramatically affect Pine Gully in the short term as they have, especially in a relatively dry year.

A land source of sediment is not possible, so a bay source of sediment is implicated. Dr. Sherman hypothesized Pine Gully was filling from a natural source of sediment originating at the mouth of Pine Gully. This sediment would be delivered into Pine Gully by the marine bore waves and flushed out by periodic flood events. In a normal year Dr. Ravens hypothesized this would keep Pine Gully free of sediment, but in drought years this sediment would accumulate because the lack of flood events. The process of sedimentation observed today has not existed in the past, so previous drought years shown in Figure 40 on page 59 should have yielded sedimentation in Pine Gully. These drought years did not experience sedimentation, as witnessed by 25+ year residents. Marine bore waves also did not have sediment available at the mouth of Pine Gully prior to sedimentation. Evidence that there was no excess sediment at the mouth of Pine Gully in the past is shown by the historic shoreline retreat and shoreline armoring to prevent erosion.

The marine bore waves must have available sediment at the mouth of Pine Gully; this means a new source of sediment from Galveston Bay must exist. The mechanism bringing in this new sediment into Pine Gully is the marine bore waves described by Dr. Ravens. The marine bore waves can be seen from the aerial photo in Figure 25 on page 38 that show refraction around the sediment bar that has accumulated at the mouth of Pine Gully. According to calculations by Dr. Ravens, these marine bore waves have the ability to fill up Pine Gully to the estimated volume of sedimentation within three months. Ripple marks in Figure 42 on page 63 show the direction of sedimentation is from Galveston Bay. Sedimentation has progressed from the mouth of Pine Gully, inland. This progressive sequence of sedimentation is shown conceptually as a schematic drawing in Figure 31 on page 48 and is indicative of a bay source of sediment. Many of the hypotheses that have been presented are only supported by a select few pieces of data but are not supported by all the data. All the data provided by this study is supportive of a new source of sediment being delivered to the mouth of Pine Gully by the littoral drift system. This sediment is then transported into Pine Gully by the marine bore waves where it deposits.

CHAPTER V

SOURCE OF SEDIMENT TO PINE GULLY

The determination that a new source of sediment exists that had not been present in past years at Pine Gully required an extension of the study up and down coast from Pine Gully. Understanding where this new source of sediment originates is critical to finding a solution to the problems in Pine Gully. Without knowing where this new sediment comes from, a blind decision would have to be made as to an engineering solution to the problems in Pine Gully.

5.1. Locating a Sediment Source

Any new sediments being delivered to the mouth of Pine Gully must be delivered through the littoral drift system on Galveston Bay. To find which way to pursue further investigation into a sediment source, the direction of littoral drift in Galveston Bay must be understood. Figure 43 shows the direction of littoral drift from Fisher (1972). This data shows a counter clockwise circulation in Galveston Bay. Pine Gully is on the West side of Galveston Bay, so any new sediment source being delivered through the littoral drift system on Galveston Bay must be delivered from North of Pine Gully.

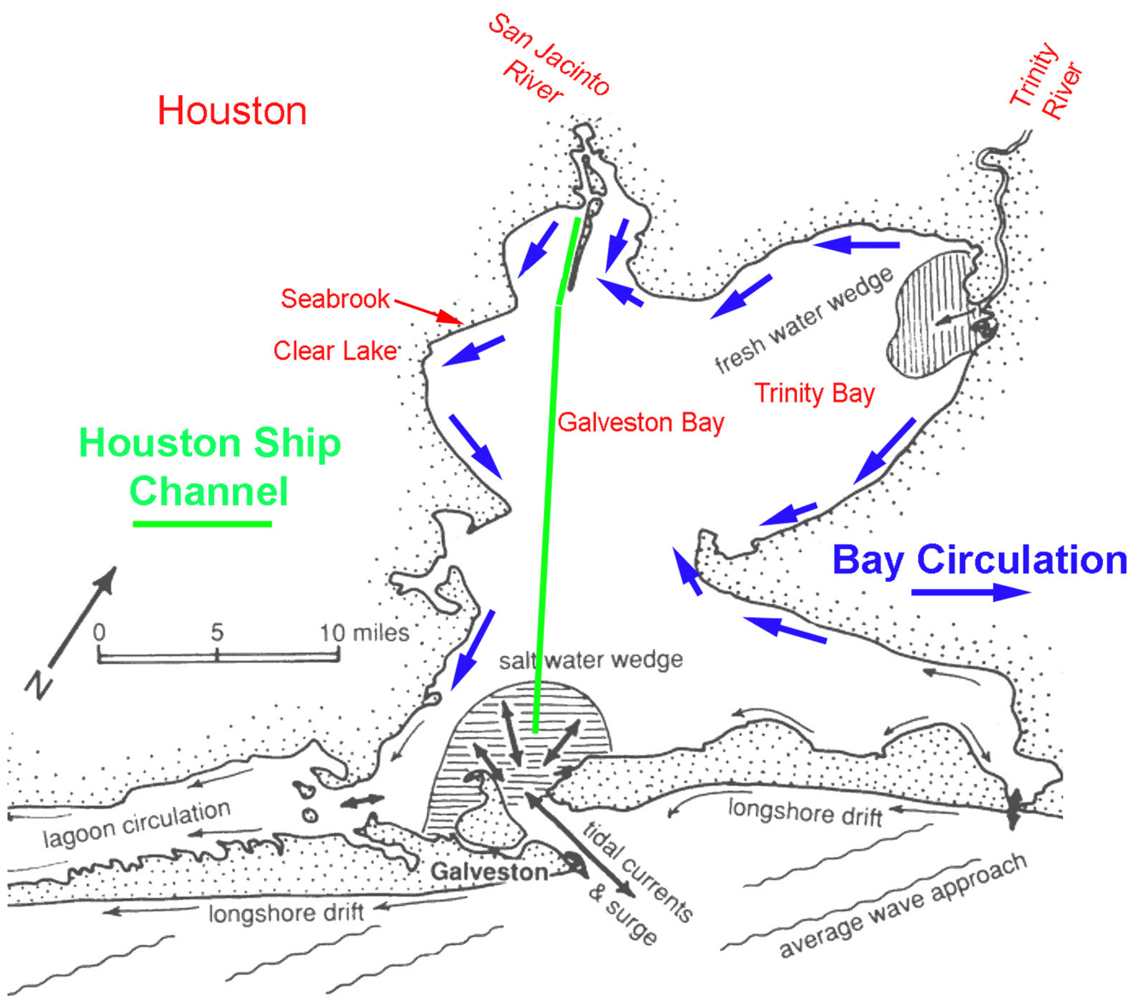

Figure 43. Direction of littoral drift on Galveston Bay from Fisher (1972).

5.2. Wright Beach Sediment Photographs and Cores

The search for a possible sediment source north of Pine Gully led to Wright Beach, a public beach maintained by the City of El Jardin. This site had experienced significant beach renourishment concurrent with the sedimentation problems in Pine Gully. Preliminary evidence of sedimentation was the presence of fresh sand deposition existing in the marine grasses on the back of the beach (Figure 44). This sediment appeared to be consistent with the sediment in Pine Gully. Residents confirmed suspicions that Wright Beach had undergone beach accretion.

Figure 44. Sedimentation in marine grasses on the back of Wright Beach. Picture taken 10 August 2006.

Cores were taken from Wright Beach on two different dates: 15 August 2006 and 11 March 2007. Figure 45 shows the cores from the first and second core collection and Figure 46 shows the location where these cores were extracted on Wright Beach. Examination of the cores shows a striking resemblance to the ones from Pine Gully. The cores taken on the first collection date do not exhibit any regular bedding features. The black color is randomly distributed throughout the core. This appearance probably occurs because the sediments at Wright Beach were just deposited at the site and did not have time to use up all the oxygen in the lower portions of the core. In the second sampling date, shown in the right most core of Figure 45, the aerobic bacteria had plenty of time to use up all the oxygen. This leaves room only for anaerobic bacteria to break down the organics in the rapidly deposited sediments, which may be why the March 2007 core has a darker color on the bottom than the August core.

5.3. Wright Beach Core Analysis

All three cores appeared to have similar sediment distributions compared to the sediment in Pine Gully upon visual appraisal. To confirm similarities in sediment between Wright Beach and Pine Gully, sieve analyses were conducted. As with the Pine Gully sieve analysis, only one core was analyzed from each sample date but three analyses were done on each core for the top, middle and bottom portions. Figure 47 shows the sieve results for core 2 from 15 August 2006 and Figure 48 shows the sieve analysis results of core 3 collected 11 May 2007.

Figure 45. Left two cores collected 15 August 2006, Right core collected 11 March 2007. Notice the color difference between the two core collection dates.

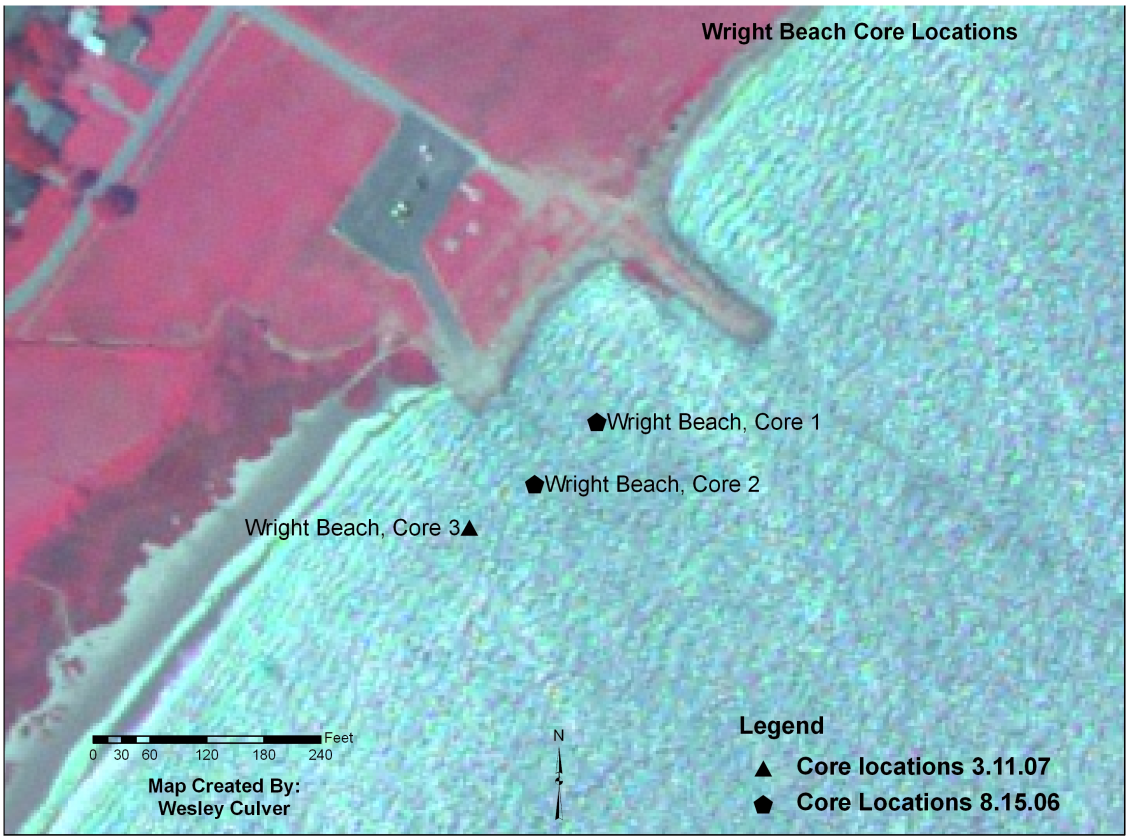

Figure 46. Core locations at Wright Beach for both sampling dates of 15 August 2006 and 11 March 2007. Data plotted on the 2004 NAIP aerial photo from TNRIS.

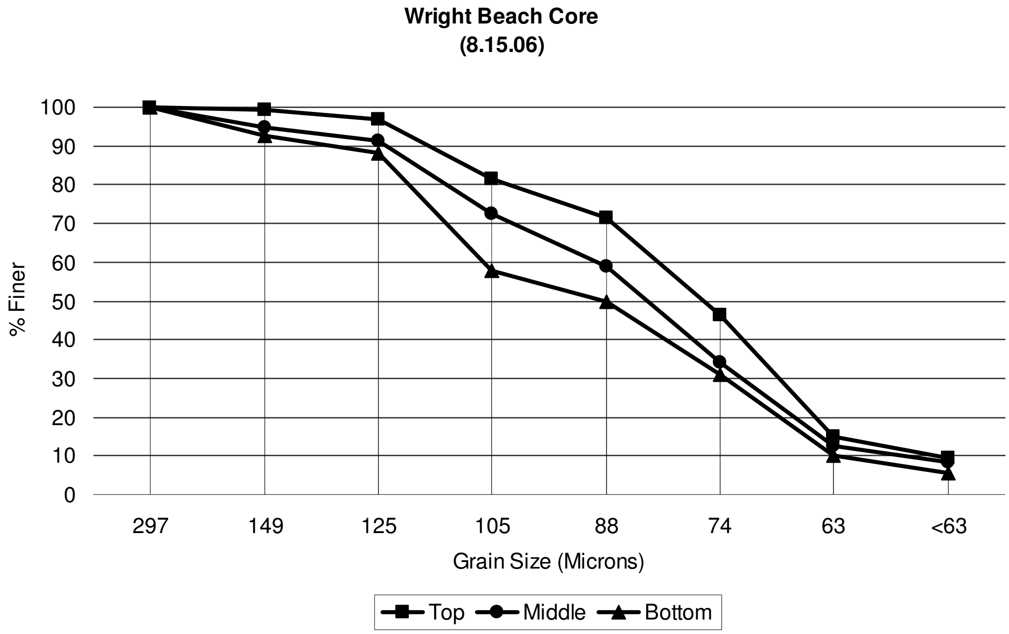

Figure 47. Sieve analysis from 15 August 2006, Wright Beach, Core 2. Notice the variability of the sediments from the bottom to the top of the core.

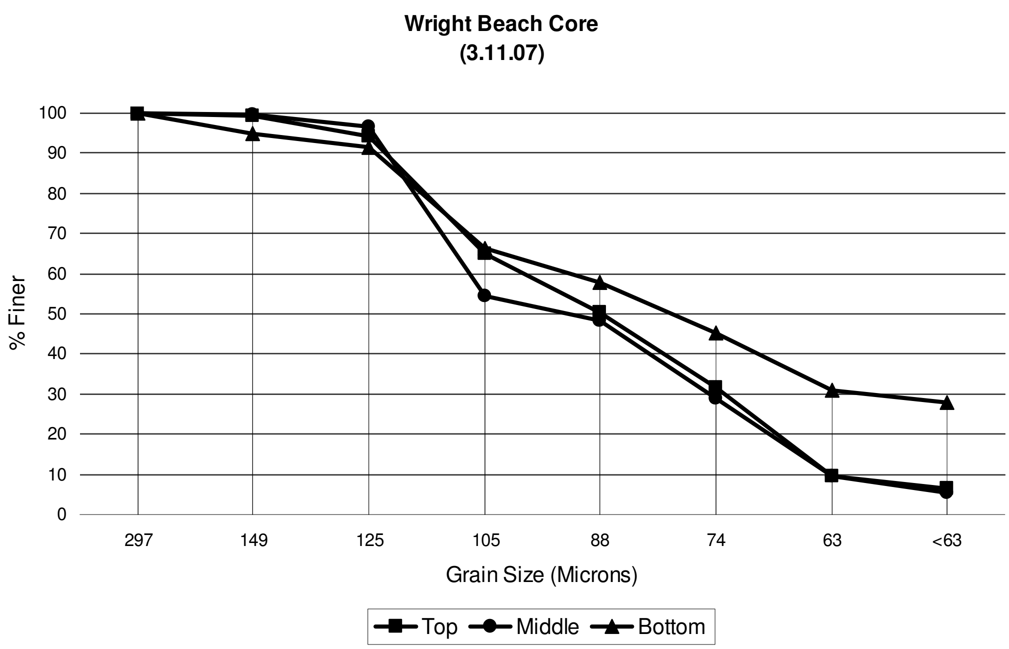

Figure 48. Sieve analysis from 11 March 2007, Wright Beach, Core 3. Notice how the top and middle sieve analyses match more closely than the bottom portion of the core.

Variability exists in the sediment distributions for the top middle and bottom portions of the cores for the 8 August 2007 core. This probably occurs because the sediments were newly deposited and did not have the time to be sorted by wave action. At the second collection date, 11 March 2007, the middle and top portions correlated with each other quite well. But then the bottom portion does not correlate well. This probably results because the sediments continued to be deposited at a rapid rate and the bottom portion of the core never received the amount of energy though wave action to sort the sediments.

The sieve analysis shows that the Pine Gully sediments are similar to the Wright Beach sediments. Wright Beach also experienced beach accretion at approximately the same time as the Pine Gully sedimentation. The fact that Wright Beach is up-drift from Pine Gully, and that the sediment sizes are similar, begins to indicate a bay source of sediment with no connection to a land source of sediment. This bay source of sediment would be delivered to Pine Gully by the longshore currents in Galveston Bay.

5.4. Coastal Survey at Wright Beach

To monitor the changes in sediment at Wright Beach, a beach survey was done with the same technique as in Pine Gully. Figure 49 shows the three separate coastal surveys conducted at Wright Beach plotted on the 2004 NAIP aerial photograph from TNRIS. The surveys appear nearly featureless because the high rate of deposition prevents anything such as an offshore sandbar to form. One feature that may be forming, as seen in the Wright Beach profile of the 24 May 2007 survey, is a winter beach. The wave action in the winter is much greater than the wave action in the summer. This means a winter beach will experience more erosional power which produces a steeper beach profile with a small bar just off shore (Mathewson, 1981). If this is truly a winter beach profile as shown in the last coastal survey, beach renourishment at Wright beach must have stopped because it no longer inhibits beach formations. Also, the coastal survey detected a stable beach environment; and indicated there was no loss or gain of sediment. Each of the survey contours are plotted separately in Appendix B.

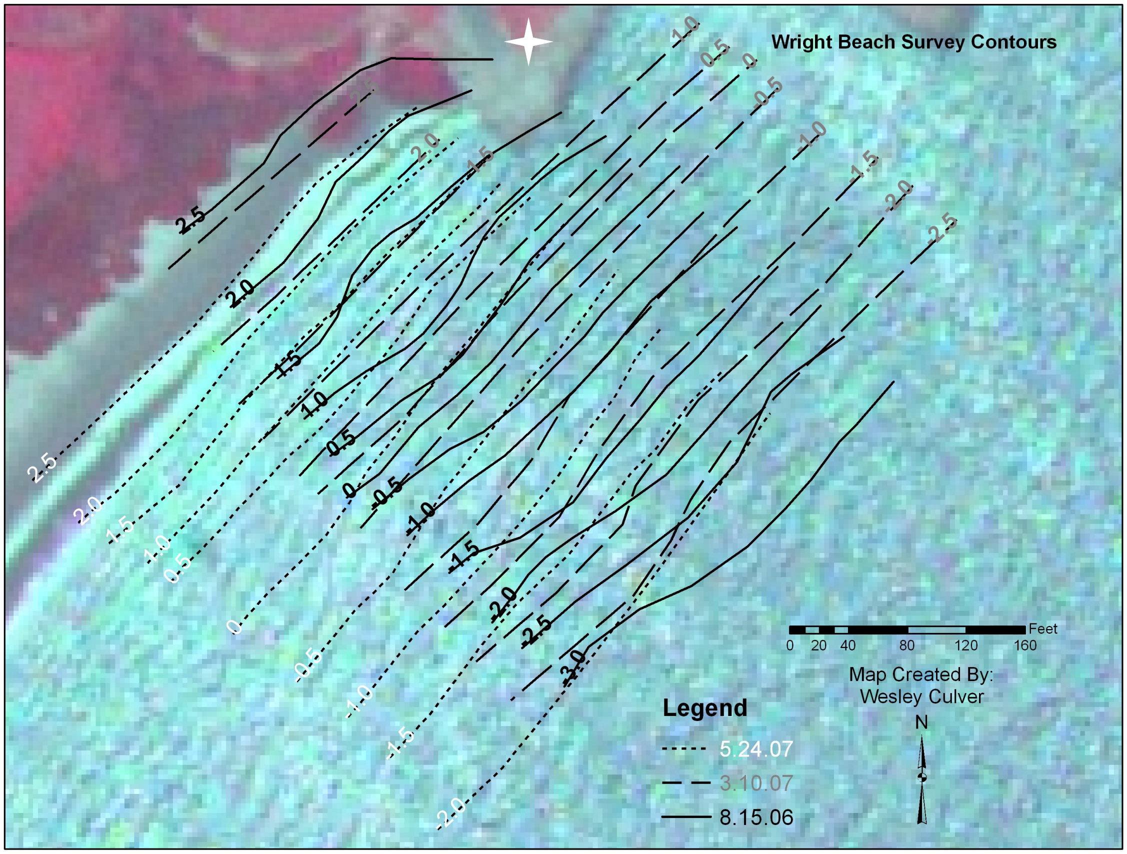

Figure 49. Survey contours from Wright Beach plotted on 2004 NAIP aerial photograph from TNRIS. The inset picture below is the bench mark used. Star represents location of benchmark.

5.5. Down-Drift Sedimentation

With the counterclockwise circulation of Galveston Bay, a considerable amount of sediment should exist south of Pine Gully. Sedimentation was found adjacent to Pine Gully in the marina of the Girl Scout Camp, Camp Casa Mare, and even further south at First Street Beach. During field work in August 2006, the Director of the camp confirmed that the sediments in the marina at Camp Casa Mare were new and sedimentation had never been an issue during his term at the camp. He also added the sedimentation was severe enough that launching of the small Sunfish© used by the girls at the camp had become difficult. The girls now have to carry these small boats out by hand to deeper water, a difficult task for the young girls that attend the camp. Figure 50 shows the sedimentation found building up in the Camp Casa Mare Girl Scout Camp Marina.

Sedimentation was also found at First Street Beach (Figure 51) during this study. Sediments at First Street Beach appeared to be consistent with the sediments found at Camp Casa Mare, Pine Gully and Wright Beach. Cores were taken at Camp Casa Mare and First Street Beach to compare with Pine Gully and confirm the sand is similar to that observed at Wright Beach. Figure 52 is a set of cores from Camp Casa Mare. The top of the two sediment cores collected 15 August 2006, is black. These sediments are mostly likely black on the top because of a pulse of sediment rapidly being deposited and not giving the organics in the upper portion of the sediment time to break down. The core collected on 11 March 2007 shows much less black color and suggests sedimentation may not be as severe as it was when the previous cores were taken.

Figure 50. Sediment building up at the Camp Casa Mare marina. Picture taken on 14 August 2006.

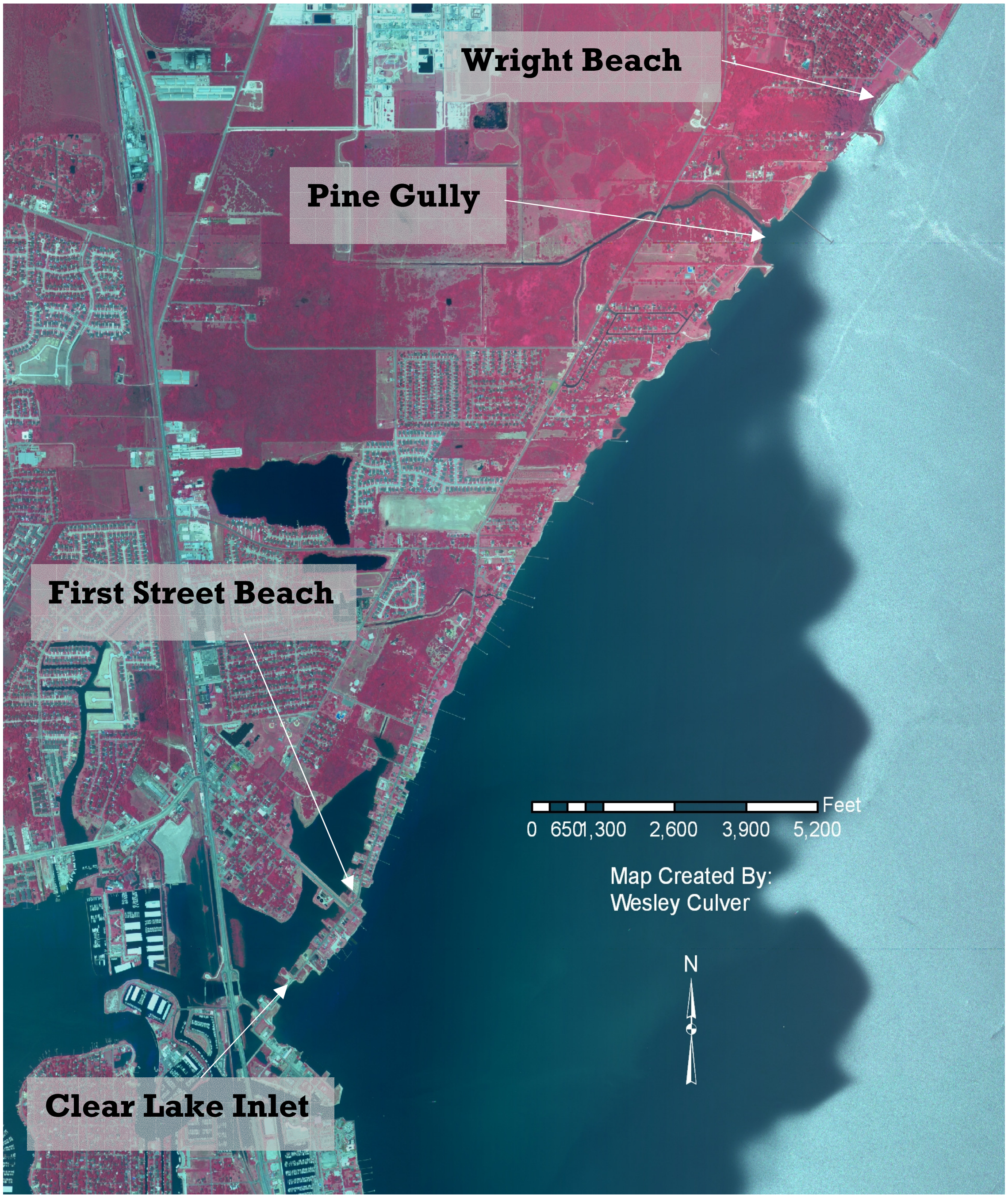

Figure 51. 2004 NAIP aerial photograph mosaic from TNRIS showing the locations of Wright Beach, Pine Gully, Camp Casa Mare, First Street Beach and Clear Lake Inlet.

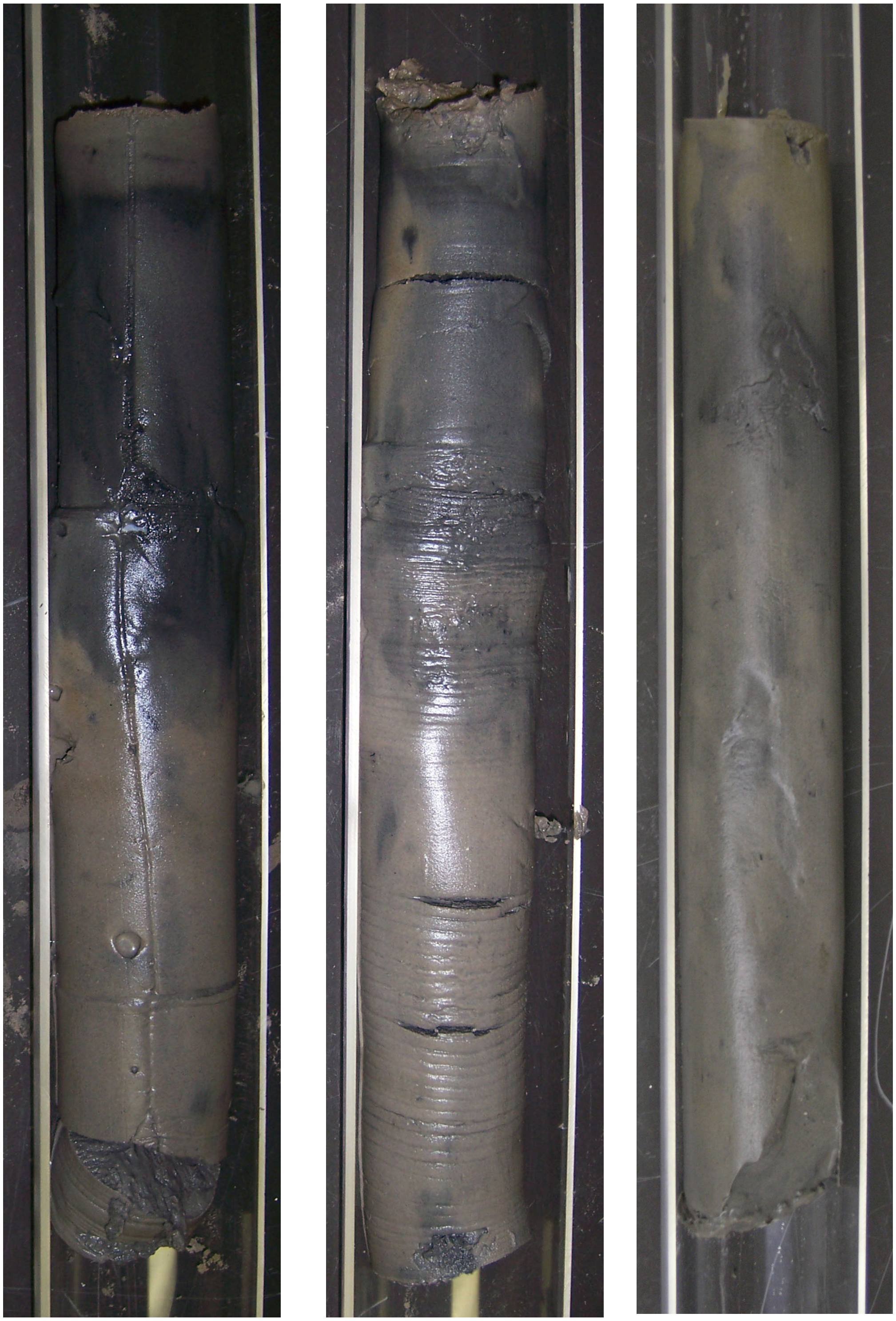

Figure 52. Cores collected from Camp Casa Mare. Left two cores collected on 15 August 2007. Right core collected 11 March 2007.Notice the difference in color between the cores taken on different collection dates.

Cores from First Street Beach were also compared to the cores from other locations. Figure 53 is a core from First Street Beach that contains the original sediments from First Street Beach on the bottom and the new sediments being deposited on the top. The original First Street Beach sediments are just crushed up shells and road fragments from Todville Road. This provides evidence the sediments from Wright Beach South to First Street Beach are similar. Figure 54 is the other three cores collected 15 August 2006 and 11 March 2007. Core collection locations are plotted in Figure 55 and Figure 56 for Camp Casa Mare and First Street Beach, respectively.

Figure 53. Core of Original First Street Beach sediments overlain by newly deposited sediments. Core collected on 15 August 2007.

Figure 54. Cores collected from First Street Beach. Two cores on left are from the collection date 15 August 2007. Again, notice the rich black color of the sediments from the first core collection as opposed to the color of the core on the right taken on 11 March 2007.

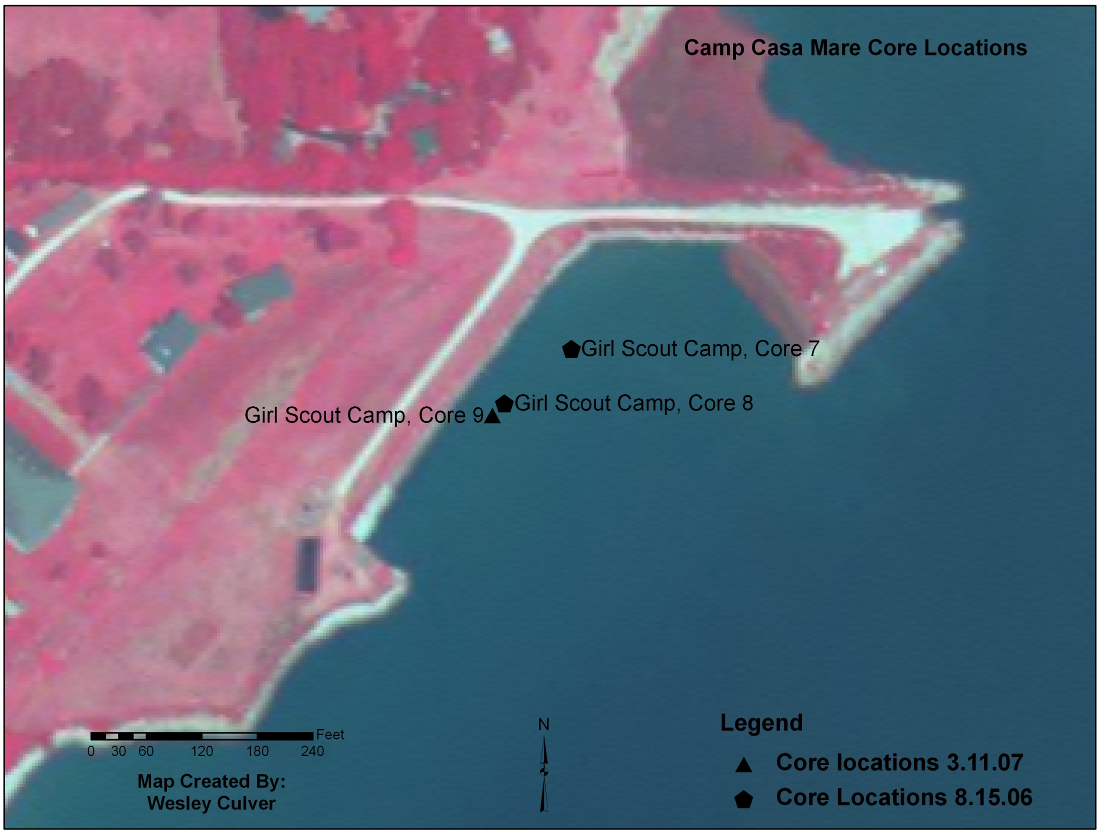

Figure 55. Core Locations for cores taken at Camp Casa Mare Girl Scout Camp on 15 August 2006 and 11 March 2007. Data plotted on a 2004 aerial photo from TNRIS.

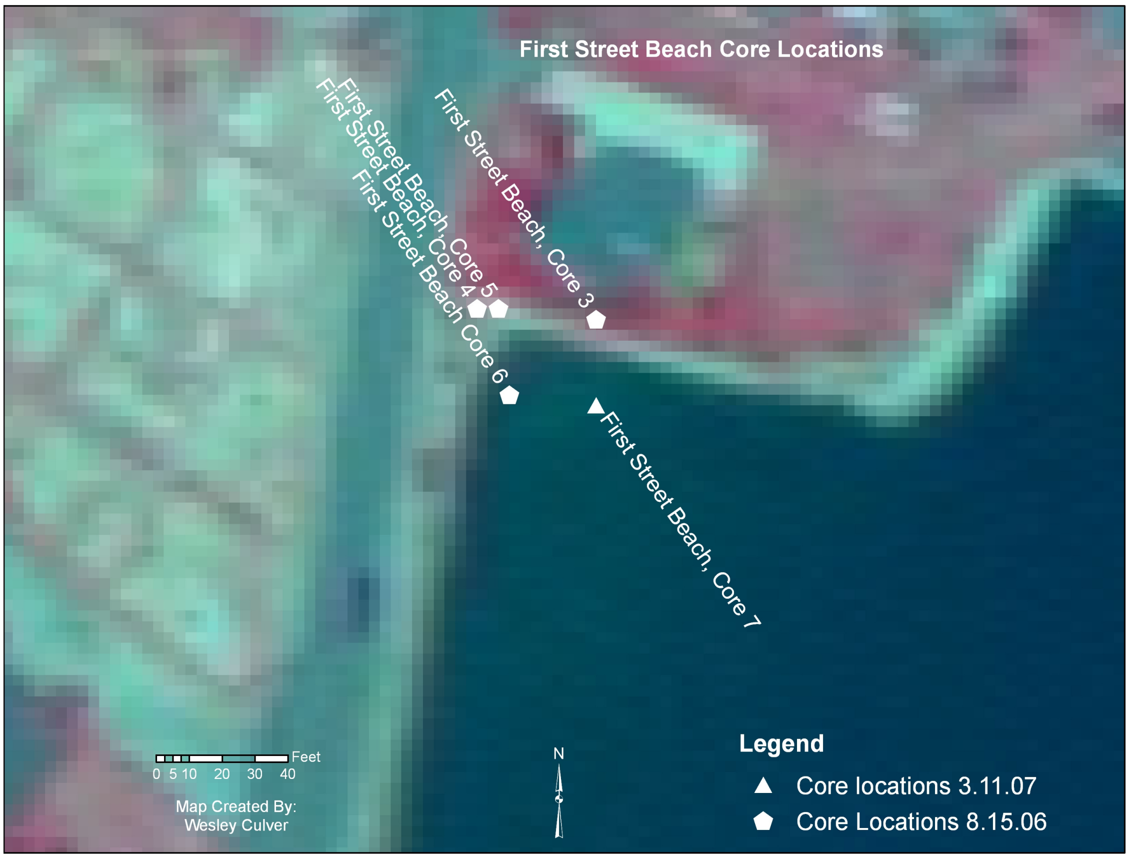

Figure 56. Core locations for First Street Beach Cores collected on 15 August 2006 and 11 March 2007. Data plotted on a 2004 aerial photo from TNRIS.

5.6. Camp Casa Mare and First Street Beach Sand Sieve Analysis

Camp Casa Mare, located just down drift and adjacent to Pine Gully, was in such close proximity I elected not to conduct a sand sieve analysis on the Camp Casa Mare Cores. Figure 57 shows the sieve analyses for the sediments collected on 15 August 2006 at First Street Beach. Only two sieve analyses were performed for this core because the amount of sediment was not sufficient to do three as with all the rest of the cores. The separation seen in the coarser grain sizes probably results from the original sediments that were present in the bottom of the core and not the top. All sieve analyses have a similar distribution of sizes. Figure 58 shows the sieve analysis for the sediments collected on 11 March 2007. Three sieve analyses were done on this sample because the sediment was deeper when the core was taken and full recovery was achieved. Some separation occurs in the grain size between the bottom versus the middle and top that is probably a function of some of the original sediments at the bottom of the core that skewed the data. The net result of these findings is that the sand at Wright Beach is similar.

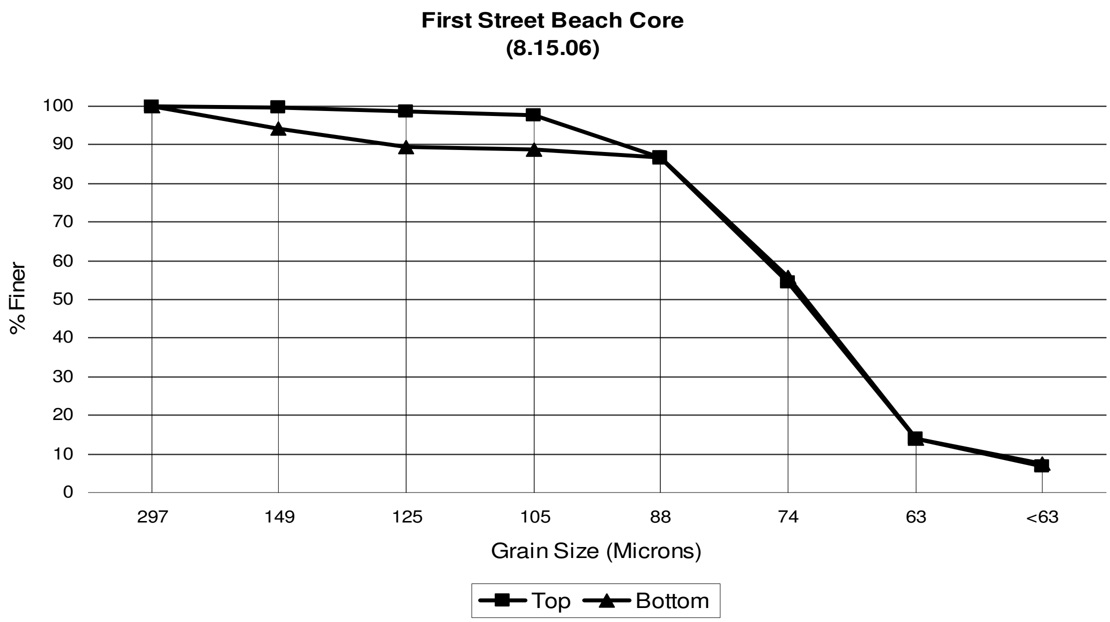

Figure 57. Sand Sieve Analyses results for First Street Beach Core 5 collected on 15 August 2006.

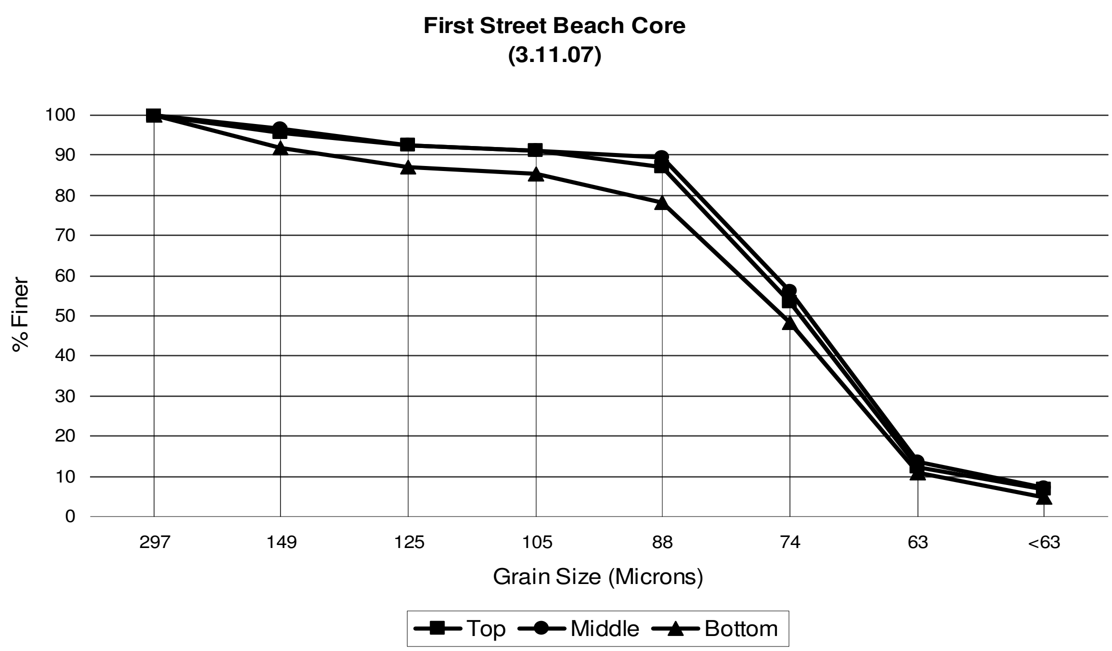

Figure 58. Sand Sieve Analysis results for First Street Beach Core 3 collected on 11 March 2007.

5.7. Coastal Survey for Camp Casa Mare and First Street Beach

To complete the study, coastal surveys were done at Camp Casa Mare and First Street Beach. The results of the Camp Casa Mare coastal survey are plotted on a 2004 NAIP aerial photo from TNRIS (Figure 59). The Camp Casa Mare coastal survey is tied into the Pine Gully survey using the western most bolt of the new pier. A picture of the location is included in Figure 59. The features found in this coastal survey show much of the same features found at Wright Beach. The sediments are very flat and lack the features a normal coastline would have, such as the offshore bar mentioned earlier. The 24 May 2007 Survey was not able to cover many survey lines because we were experiencing one to two feet of setup in the bay and the wave action was higher than it had been in any previous survey. This survey at Camp Casa Mare did not show any evidence for the formation of a winter beach as Wright Beach did, but similar to Wright Beach, the sediment seems to be at equilibrium.

The First Street Beach survey, Figure 60, is plotted on a 2004 NAIP aerial photo from TNRIS. The benchmark for this survey was the top of the fire hydrant at the corner of First Street and Todville Road. The 24 May 2007 survey was unable to complete many survey lines because a one to two foot setup occurred in the bay and serious wind waves increased in height all day since the coastal survey at Camp Casa Mare earlier in the day. First Street Beach appears to have the same winter profile as Wright Beach does, even though First Street Beach experienced significantly less sedimentation than Wright Beach. At the shoreline, the water depth is now actually deeper than it was in the previous two surveys. Just offshore the water depth gets shallower and continues that trend for the length of the third survey. This is the evidence First Street Beach may be responding to seasonal conditions and had formed what is considered a winter beach as observed at Wright Beach. The presence of seasonal structures suggests First Street Beach has also reached an equilibrium point of sedimentation as observed further up-drift at Wright Beach.

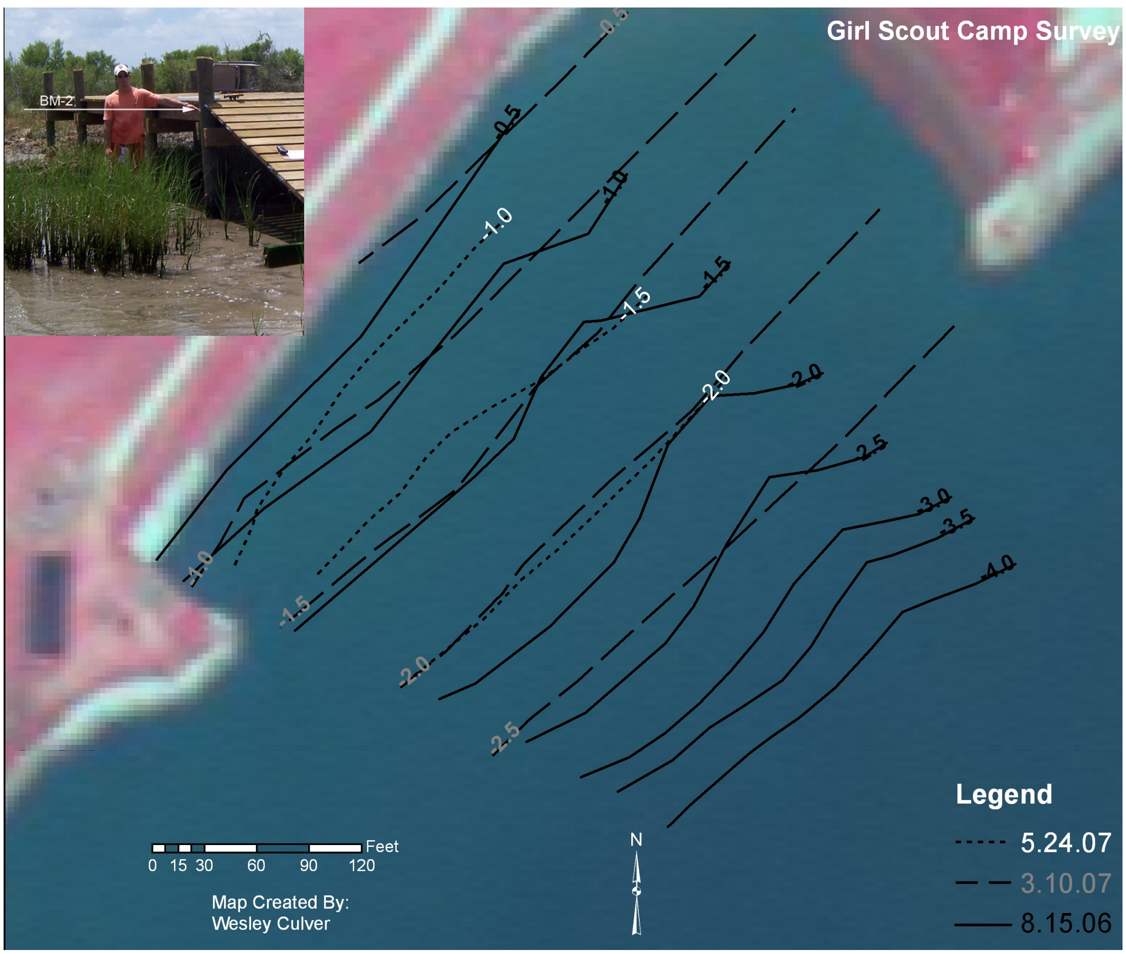

Figure 59. Survey contours at Camp Casa Mare Girl Scout Camp Marina for the three survey dates listed in the legend. Plotted on 2004 NAIP aerial photo from TNRIS. Inset picture points to bolt on pier that serves as the benchmark.

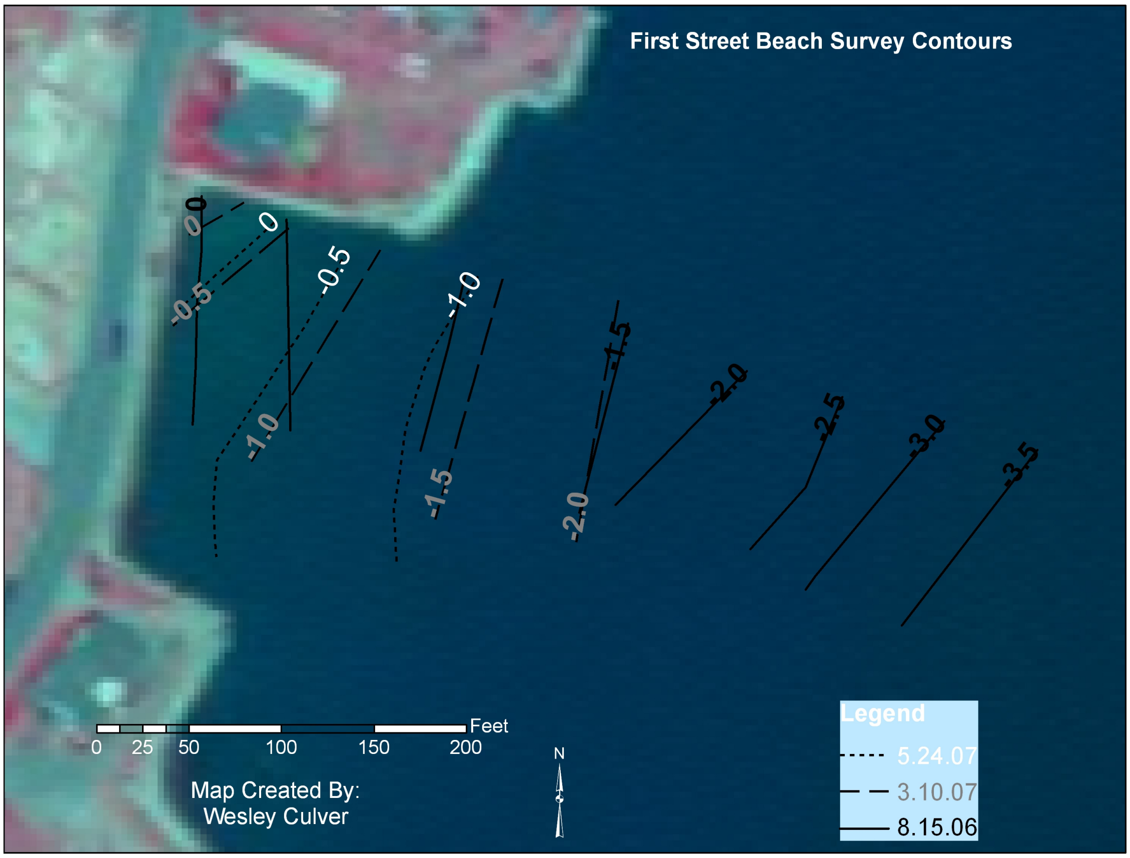

Figure 60. Survey contours at First Street Beach for the three survey dates listed in the legend. Plotted on 2004 NAIP aerial photo from TNRIS. Bench mark for the survey is just off the west part of the photo, which is the top of the fire hydrant at the corner of First Street and Todville Road.

5.8. New Sedimentation at Clear Lake Inlet

Sedimentation at Clear Lake Inlet was first observed on 11 March 2007. Sediments had already been observed as far south as First Street Beach and after that point there was no active search for sediment. One core sample of the sediment, shown in Figure 61, was collected for sand sieve analyses. A small amount of shell hash is visible at the bottom of the core. As with First Street Beach, these are the original sediments at Clear Lake Inlet. The sandy sediments above the shell hash represent new sediment that had been observed and are consistent with the sediments found at Wright Beach. Sand sieve analyses were done on this core but only one analysis was completed because insufficient sediment existed in the core to do an analysis similar to those done at the other locations. Figure 62 shows the results of the sieve analysis of the Clear Lake Inlet Core. The sand sieve analysis confirms that the sand sizes from Clear Lake Inlet are consistent with the other locations in this study located up-drift.

Figure 61. Clear Lake Inlet Core collected on 11 March 2007. Notice the original sediments consisting of shell hash on the bottom and new sandy sediments on top.

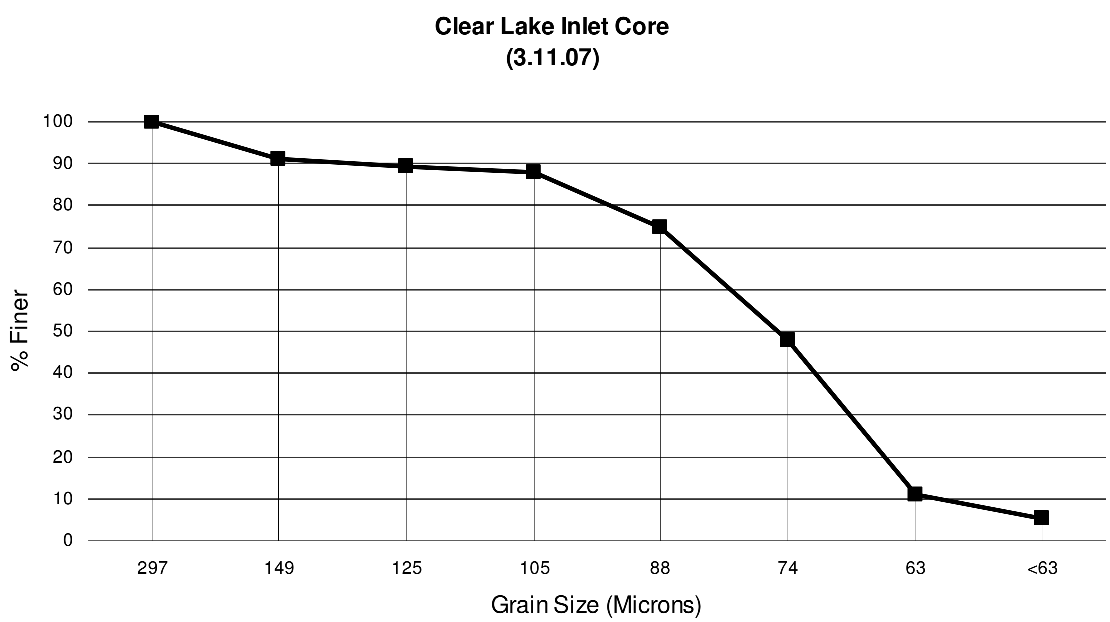

Figure 62. Sand sieve analysis results for Clear Lake Inlet core collected on 11 March 2007. Notice the size distribution is similar to the other study locations.

CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS

The enhanced beach growth at Wright Beach is related to the sedimentation in Pine Gully. This beach growth at Wright Beach has been beneficial for patrons of Wright Beach Park without any negative impacts to the existing ecology. As long as the ecology of the coastline is taken into account before sediment is introduced into a littoral drift system the renourishment may be totally beneficial. Because high rates of shoreline retreat have occurred along the Texas coast, caused by subsidence, sea level rise and wave attack, beach renourishment is more common in some places.

6.1. Repairing the Pine Gully Ecosystem

The most important gain in knowledge from this study is the effects coastal sedimentation can have and the sphere of influence it can encompass. Adding sediment to a coastline that has experienced only erosion for a significant amount of time can have adverse effects on the ecology of the coastline down drift. The sedimentation north of Pine Gully, evidenced at Wright Beach, is a perfect example of these unintended effects. The sediment that ended up in Pine Gully, similar to the sediment found at Wright Beach, adversely affected the Pine Gully ecosystem. The changes in sediment at Pine Gully will not be short lived. As sand is stabilized by invading plants that thrive in this new environment, the once tidally dominated marine wetland will become converted to a freshwater wetland and upland ecosystem.

A remedy to this issue requires mechanical removal of the sediments out of Pine Gully, restoration to the correct elevation for the marine wetland, and re-establishment of the wetland vegetation. Removing the sedimentation from Pine Gully is a delicate project because it would need to be done while protecting the parts of the wetland that are still viable. These small viable portions of the wetland will help to re-vegetate the areas where the sand is mechanically removed. More than one approach can be taken to re-establish the long term health and protection of Pine Gully. The approach taken depends upon other issues in the system that contribute to the movement of sediment.

If erosion of sand from Wright Beach will not happen again, the solution for Pine Gully would be more simple and inexpensive. Without excess sediment at the mouth of Pine Gully, sedimentation in the channel will not continue. Fixing Pine Gully in the event excess sedimentation ceases, only requires the removal of sediment from Pine Gully and restoration of the wetland ecosystem. The sand would need to be removed delicately so the grasses that have survived sedimentation can help to re-vegetate the newly excavated areas. The excavation will also need to return the base level for the sediments in the wetland to where they were before sedimentation. If the excavated level is too deep the grasses will not be able to reestablish themselves. A good way to help re-vegetate Pine Gully would be to use the existing plants that have evolved in the Pine Gully wetland. This redistribution would have to be supervised by a biologist so that the redistribution was done correctly and not at the detriment of Pine Gully.

The removal of sand and subsequent replanting is far less expensive than the cost of a structure built to discourage sedimentation in the Pine Gully wetland. The reason

Pine Gully would absolutely need a sediment barrier is if the sediment source up-drift from Pine Gully continues to supply excessive amounts of sediment to the mouth of Pine Gully. There are two possibilities in creating a sediment barrier. One of these possibilities is a long jetty that runs perpendicular to the shore, north of Pine Gully. This jetty would create a sediment trap, preventing any sediment from reaching the mouth of Pine Gully. The problem with building a jetty is that if you do not build the structure out far enough the sand will build up to a level behind the jetty where it can get around to the other side. Sediments making it to the mouth of Pine Gully would resume sedimentation and begin plugging up the wetland where the sediments had previously been removed. A jetty at Pine Gully may have to be built the length of the Pine Gully pier, 300 yards, where there is sufficiently deep water where wave action can not move sediment around the jetty. A jetty would work in this situation but it seems unreasonable because there is a pro-ecological and inexpensive alternative.

The pro-ecological, inexpensive alternative solution would be to build a breakwater at the mouth of Pine Gully. The key to discouraging sedimentation in Pine Gully is to stop the marine bore wave energy at the mouth of Pine Gully. If this marine bore wave energy is not able to deliver sediment into the channel, the sedimentation problem will be solved. The proposed breakwater would have a low profile with a restricted entrance. The low profile of the breakwater would only be high enough to deflect the effects of the normal tidal range. During storm tides, or unusually high tides, the breakwater would be overtopped. This would better mimic the natural dynamics of the Pine Gully wetland from the past before the breakwater was installed. A restricted entrance to the breakwater would be constructed in an echelon form so that only small amounts of marine bore wave energy would penetrate the breakwater. The breakwater entrance should be roughly the same width as the Pine Gully channel after the sediment is removed so that flood events do not back up behind the breakwater and cause residential flooding. A digitized version of this breakwater is shown in Figure 63.

A requirement to rehabilitate Pine Gully into the productive wetland it once was is to remove the sand levees that remain. With the aid of a breakwater, the sand removed from Pine Gully could be used beneficially and re-distributed out on the up-drift side of Pine Gully to encourage a larger semi-protected wetland outside the breakwater. Another option would be to re-distribute the sand in the north and south pockets at the mouth of Pine Gully that would be created by the breakwater. Either of these options would enhance Pine Gully, even from the days before sedimentation, by creating a larger tidally dominated saltwater wetland.

Subsidence is the main reason the Pine Gully wetlands are smaller than they were in the 1944 aerial photo. Because subsidence has ceased in this region, the time to execute a rebuilding project in Pine Gully is now. The increased wetland will be beneficial to the marine ecosystem, tourism, and aesthetics of Pine Gully Park. With the breakwater in place, erosion caused by sea level rise will be minimal because this breakwater will be able to impede wave erosion into the Pine Gully wetland. Pine Gully will recover after the removal of sand and re-vegetation efforts but will continue gradual erosion if the breakwater is not in place. The excess sand gained from Pine Gully would also have to be hauled off if a breakwater is not constructed, and would add to

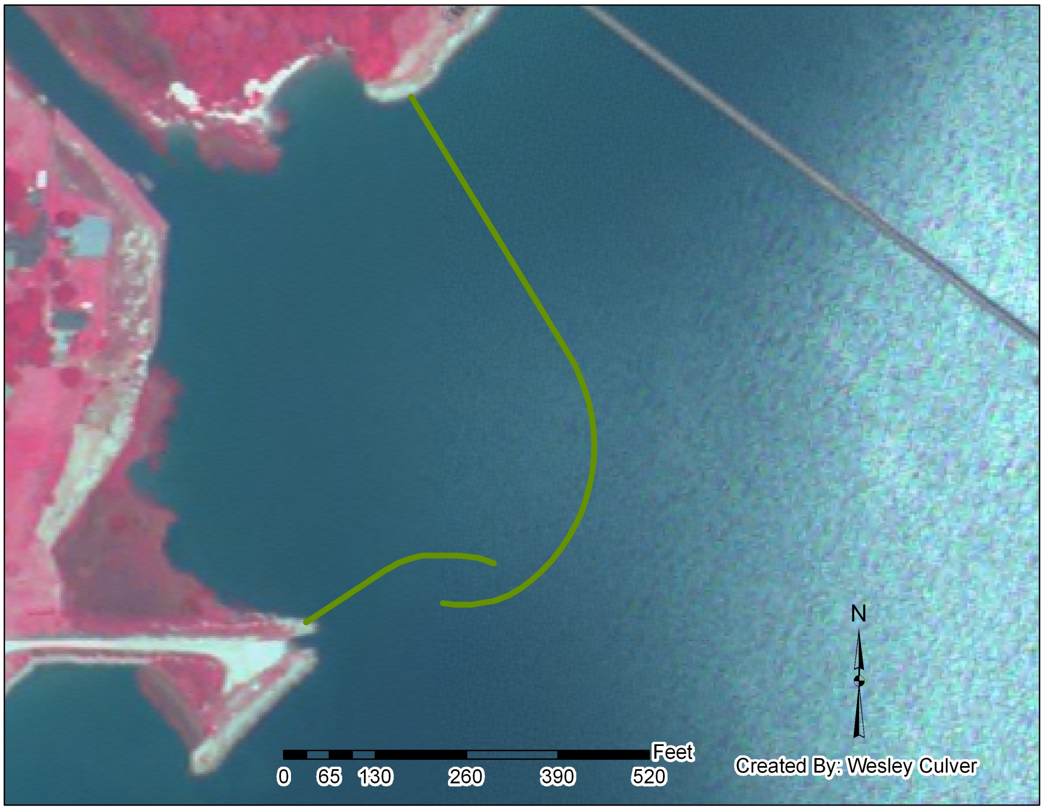

Figure 63. Proposed breakwater design for Pine Gully. Design plotted on the 2004 NAIP aerial photo from TNRIS.

expenditures. Without the breakwater, sand removed from Pine Gully and dumped at the mouth of Pine Gully would be washed into the channel and re-deposited. The smartest solution to the problems facing Pine Gully, now and in the future, would be to install the breakwater structure and invest in the environment.

With beach renourishment, and coastal projects in general common in Galveston Bay, it is inappropriate to say these projects should not be carried out because they may negatively affect ecologically sensitive areas. Coastal projects need to take into account the system that they are going to affect and then design around them. In the case of Pine

Gully, before sedimentation at Wright Beach, a breakwater should have been constructed to dissipate the marine bore wave energy before it brought sand into Pine Gully. By building the breakwater, it would have cut off the mechanism bringing sand into Pine Gully and this problem would never have occurred. The cost of a breakwater structure of this size would be quite considerable on top of an already expensive renourishment project. But the cost of these projects should include structures that would eliminate the harm to coastal areas like Pine Gully.

The cost of a preventative measure like this may be met with some distaste, but what really needs to be considered is the loss of valuable ecosystems for the short term cost benefit of not protecting them. Studies on wetland systems have concluded that they contribute to the health of marine systems like Galveston Bay, and larger marine systems like the Gulf of Mexico. The health of these systems is far more cost effective in the long term because they preserve the environment in which we live. This value is not only felt with increased marine fish populations and avian habitat, but with tourist attractions to unique locations like Pine Gully.

6.2. Sphere of Influence for Coastal Studies

The sphere of influence, or how far the sediment can affect ecosystems down-drift, should be considered when a study for beach renourishment or a coastal project is conducted. After completing this Pine Gully study, it is obvious that any project that contributes sediment to the littoral drift system should exercise preventative measures down drift. The question is, how far down-drift would you have to go to rule out unintended damage to other ecosystems? The question may be partially answered with this study by looking at the amount of distance from Wright Beach to Pine Gully, First Street Beach, and also to Clear Lake Inlet. The amount of sediment is evidence of sedimentation down drift of Wright Beach. In addition, a considerable amount of sediment was lost to deeper water between these locations. It would probably not be accurate to say a certain distance from a sediment source would automatically put a site of concern out of the zone of influence. Many factors, such as prevailing wind direction and the angle of the coastline to the resultant waves, determine what the zone of influence will be. Variables in a coastal study to find the sphere of influence must be conducted for each site independently.

6.3. Future Work

Future work could be conducted to monitor the breakwater design if one is installed at the mouth of Pine Gully. This long term project would assess the wetland before the breakwater was installed. In the future more influxes of sediment will probably occur along the coastline. Sediment should be monitored to learn if it impacts Pine Gully with the breakwater in place. As the breakwater reaches its design life and subsides below the water surface, responses to the increased energy by the wetland plants should be documented. This long term information could later become valuable for a beach renourishment project where it was determined the sand would effect a wetland system similar to Pine Gully. Possible improvements on the design and implementation of the project may be made to better serve the situation and possibly lower the cost and usefulness of breakwater construction.

Monitoring the movement of sand with coastal surveys on a scheduled basis for a long term period would also be helpful to see how new sediment affects the coast after it has been deposited. Continuing these coastal surveys would also be useful in monitoring any unexpected pulses of sand being carried down the coast. If the coastal surveys are done on a periodic basis, it would be easy to observe shoreline accretion as the sediment advances down-coast.

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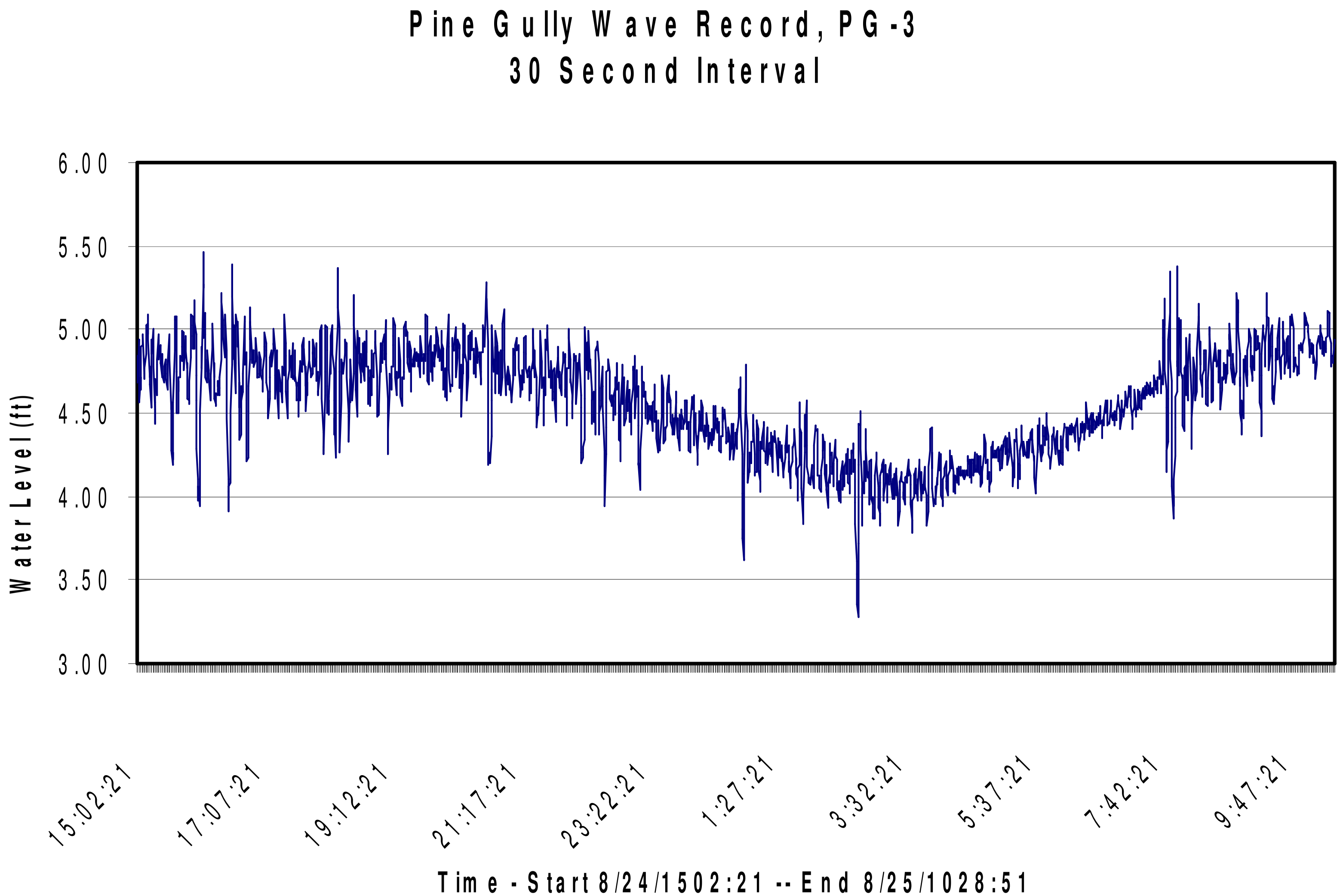
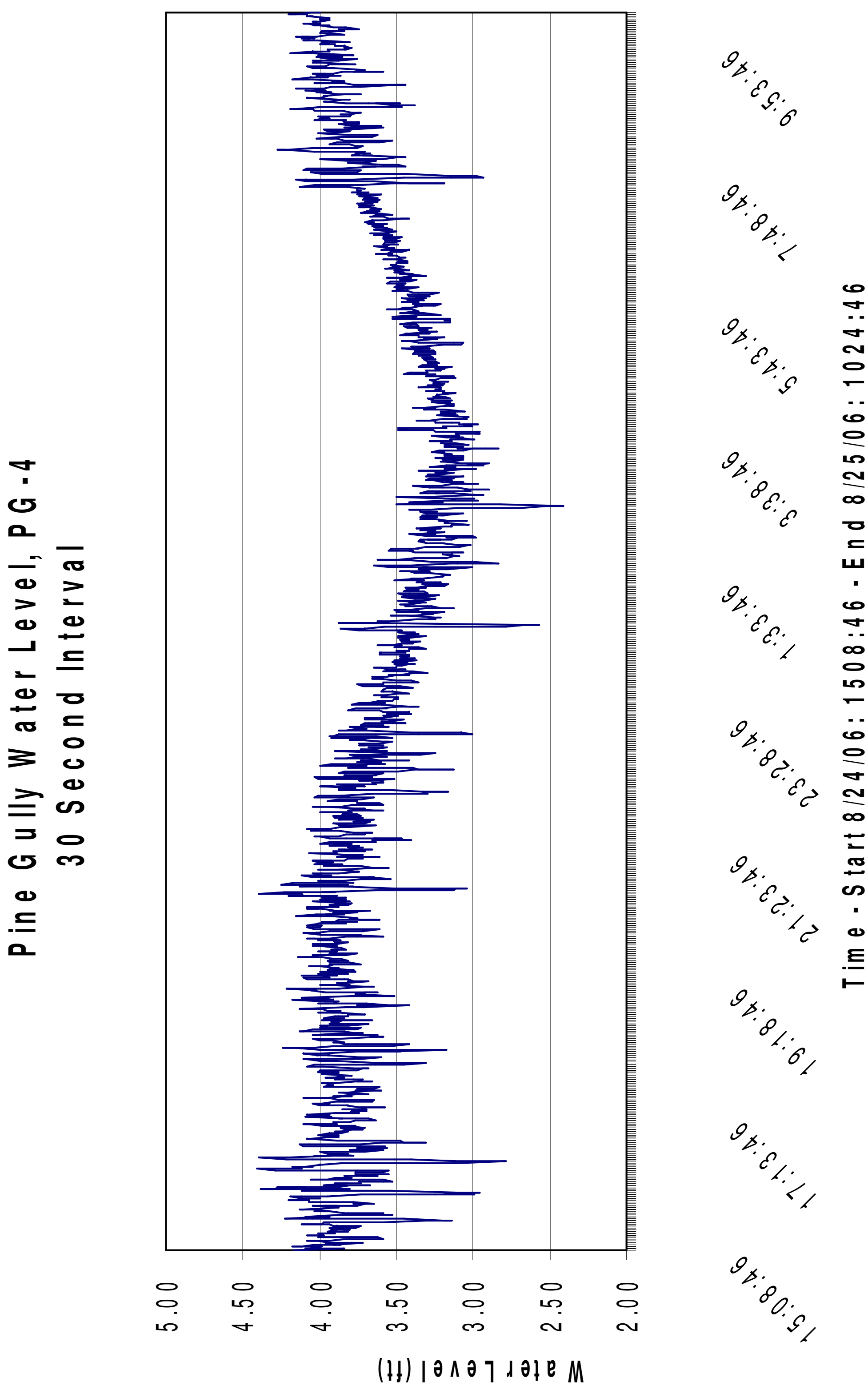
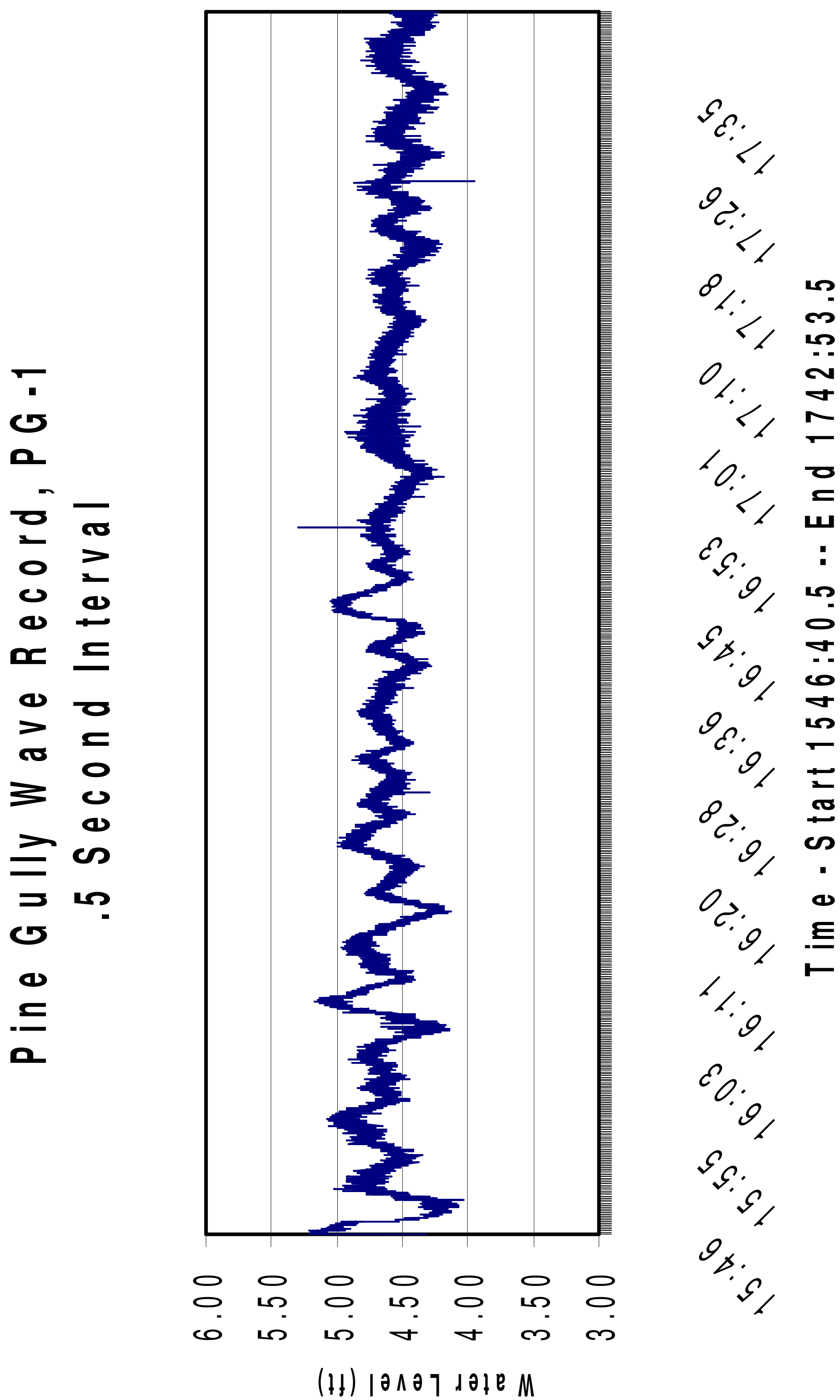
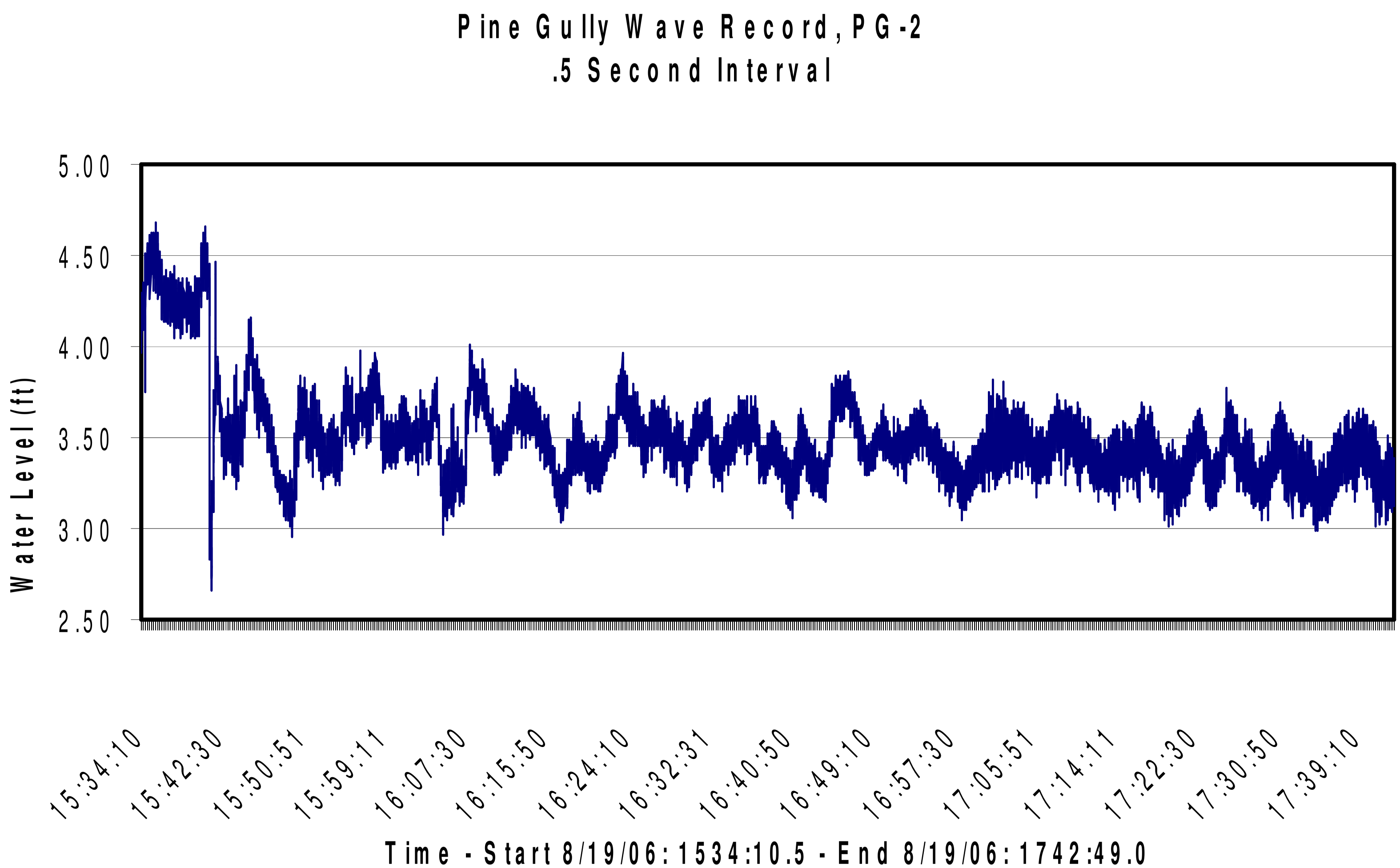
APPENDIX A

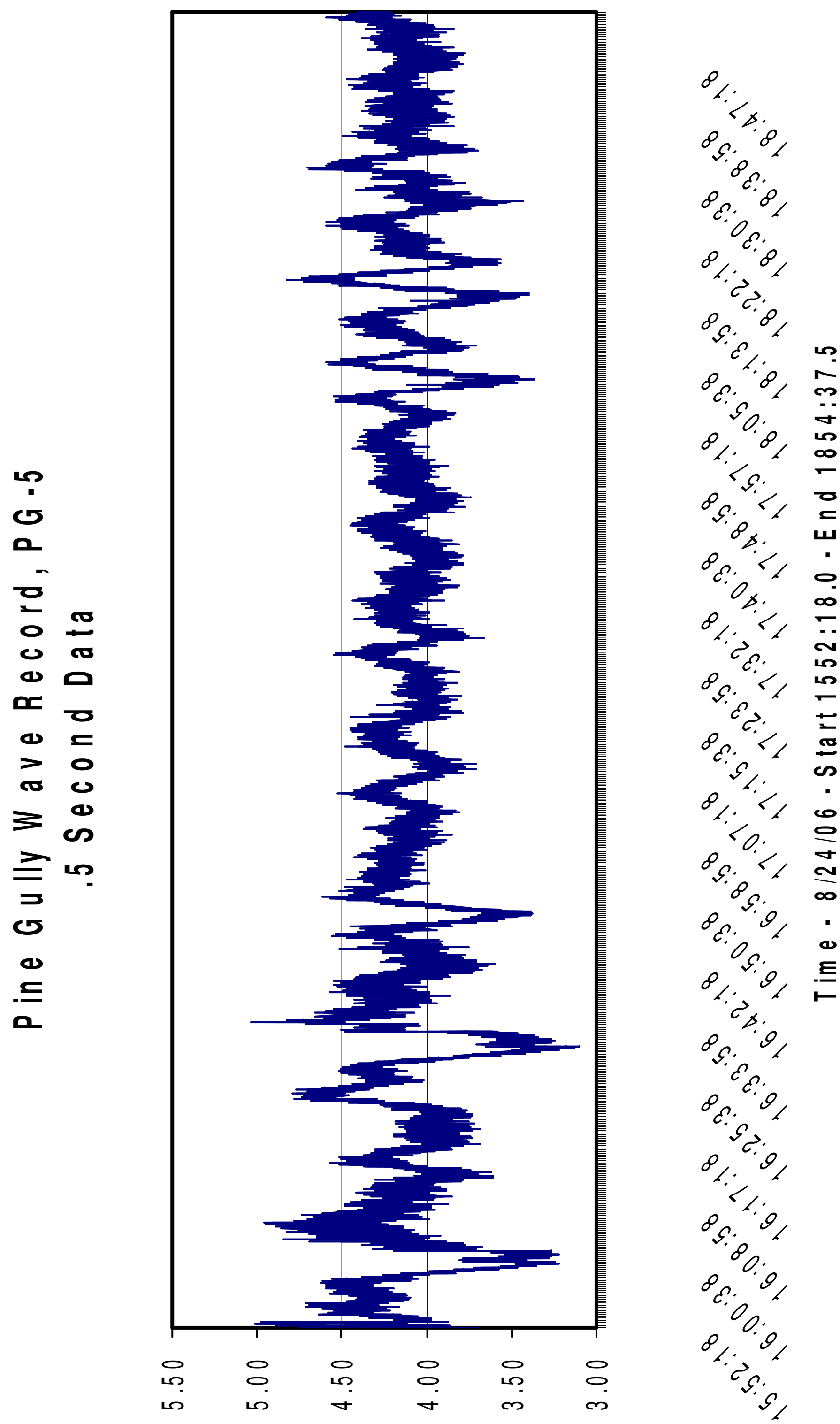
PINE GULLY WAVE DATA

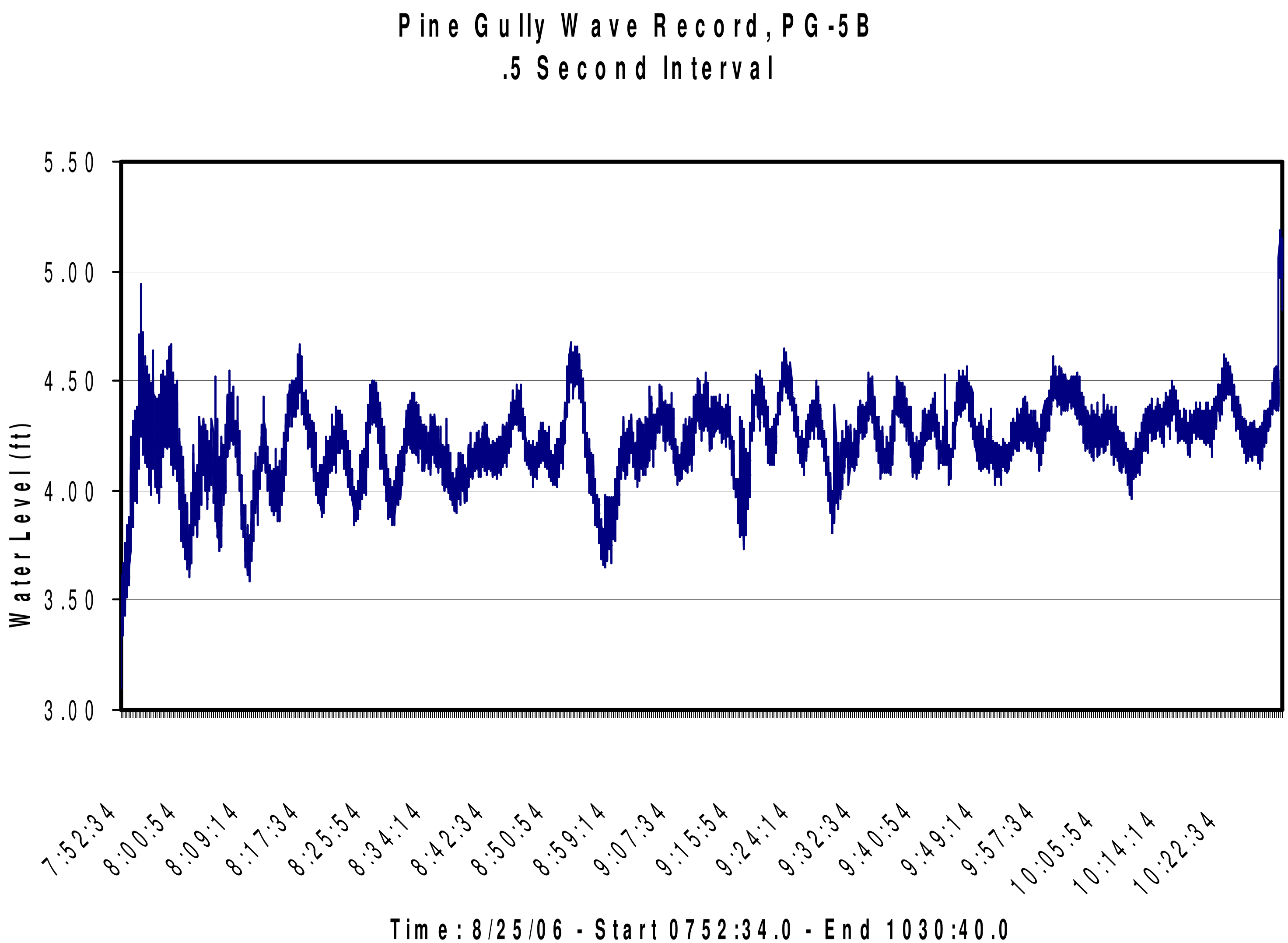

Pine Gully Wave Record, PG-3
30 Second Interval
6.00
5.50
5.00
4.50
4.00
3.50
3.00
Water Level (ft)
15:02:21
17:07:21
19:12:21
21:17:21
23:22:21
1:27:21
3:32:21
5:37:21
7:42:21
9:47:21
Time - Start 8/24/1502:21 -- End 8/25/1028:51

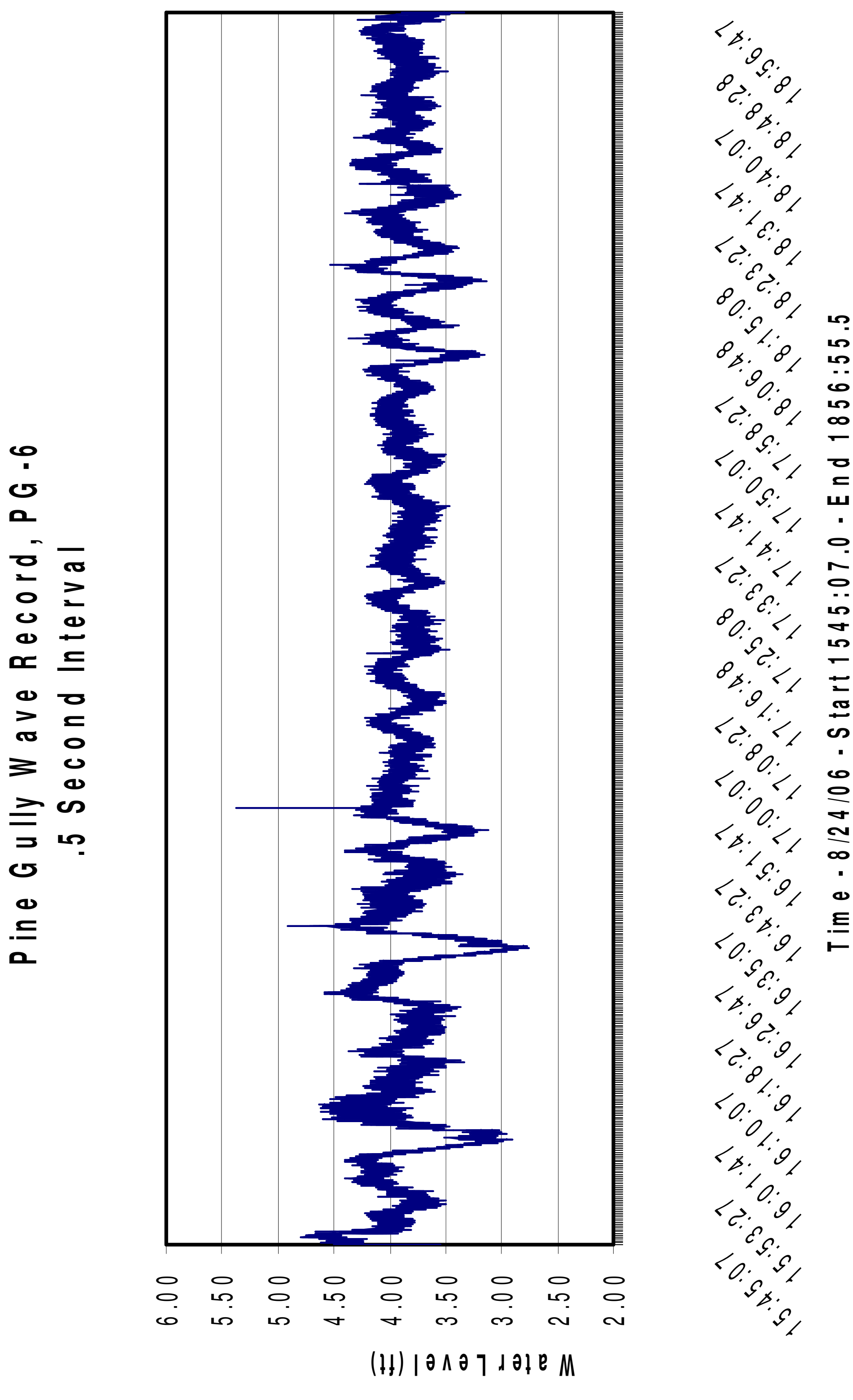

Pine Gully Water Level, PG-4
30 Second Interval
Water Level (ft)
5.00
4.50
4.00
3.50
3.00
2.50
2.00
15:08:46
17:13:46
19:18:46
21:23:46
23:28:46
1:33:46
3:38:46
5:43:46
7:48:46
9:53:46
Time - Start 8/24/06: 1508:46 - End 8/25/06: 1024:46

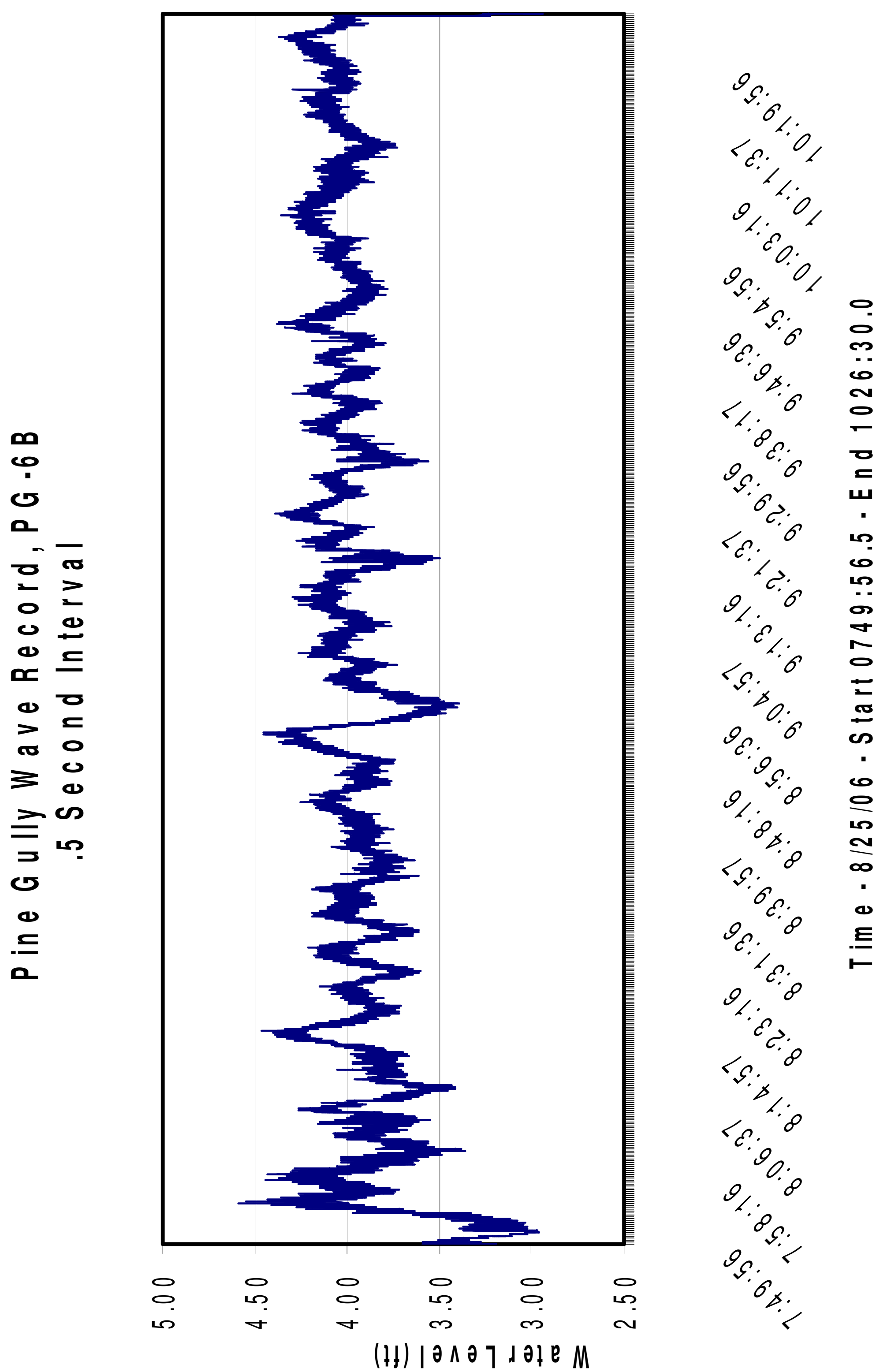

Pine Gully Wave Record, PG-1
.5 Second Interval
Water Level (ft)
6.00
5.50
5.00
4.50
4.00
3.50
3.00
15:46
15:55
16:03
16:11
16:20
16:28
16:36
16:45
16:53
17:01
17:10
17:18
17:26
17:35
Time - Start 1546:40.5 -- End 1742:53.5

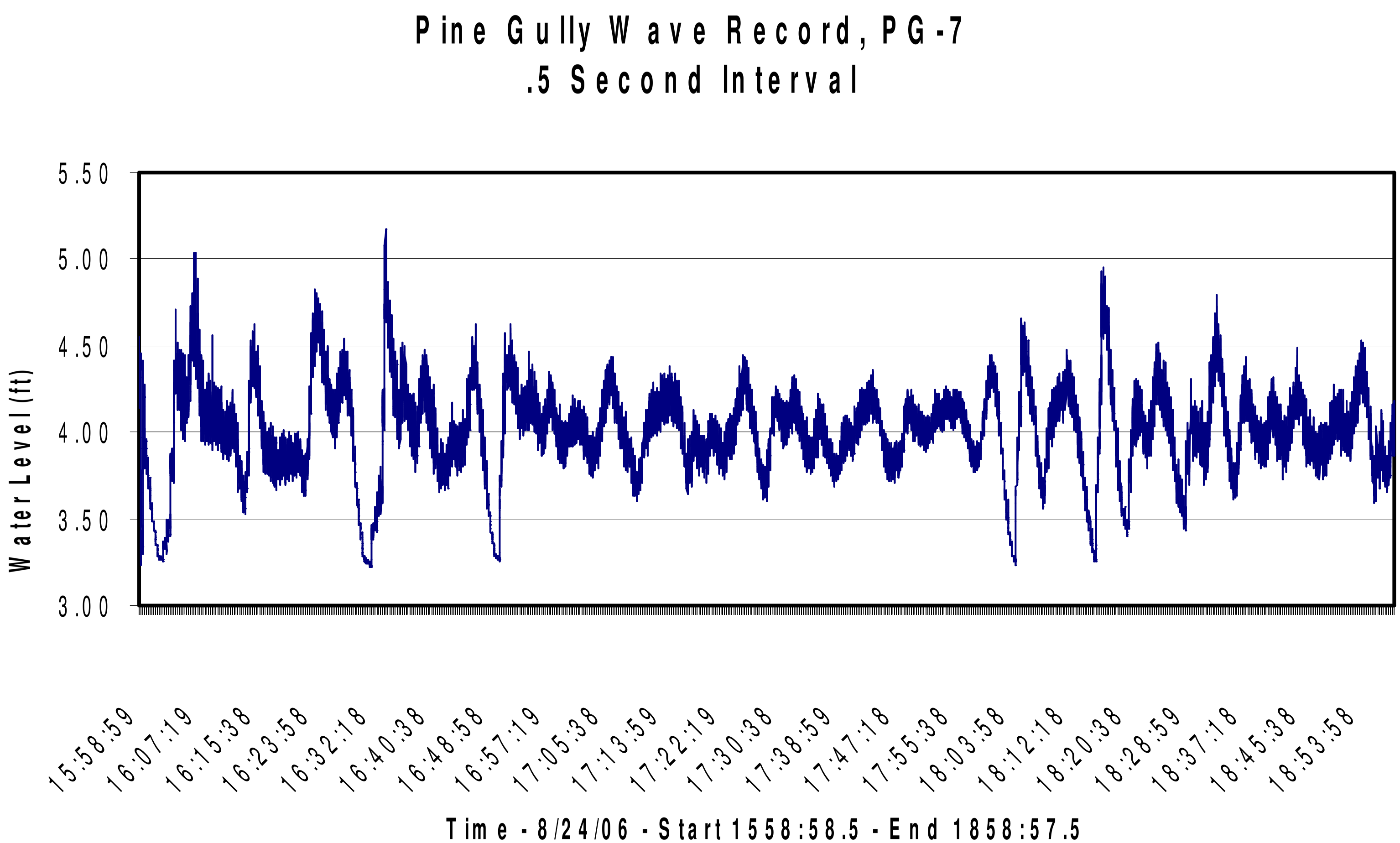

Pine Gully Wave Record, PG-2
.5 Second Interval
Water Level (ft)
5.00
4.50
4.00
3.50
3.00
2.50
15:34:10
15:42:30
15:50:51
15:59:11
16:07:30
16:15:50
16:24:10
16:32:31
16:40:50
16:49:10
16:57:30
17:05:51
17:14:11
17:22:30
17:30:50
17:39:10
Time - Start 8/19/06:1534:10.5 - End 8/19/06:1742:49.0


Pine Gully Wave Record, PG-5
.5 Second Data
Water Level (ft)
5.50
5.00
4.50
4.00
3.50
3.00
15:52:18
16:00:38
16:08:58
16:17:18
16:25:38
16:33:58
16:42:18
16:50:38
16:58:58
17:07:18
17:15:38
17:23:58
17:32:18
17:40:38
17:48:58
17:57:18
18:05:38
18:13:58
18:22:18
18:30:38
18:38:58
18:47:18
Time - 8/24/06 - Start 1552:18.0 - End 1854:37.5


Pine Gully Wave Record, PG-5B
.5 Second Interval
5.50
5.00
4.50
4.00
3.50
3.00
Water Level (ft)
7:52:34
8:00:54
8:09:14
8:17:34
8:25:54
8:34:14
8:42:34
8:50:54
8:59:14
9:07:34
9:15:54
9:24:14
9:32:34
9:40:54
9:49:14
9:57:34
10:05:54
10:14:14
10:22:34
Time: 8/25/06 - Start 0752:34.0 - End 1030:40.0


Pine Gully Wave Record, PG-6
.5 Second Interval
Water Level (ft)
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
15:45:07
15:53:27
16:01:47
16:10:07
16:18:27
16:26:47
16:35:07
16:43:27
16:51:47
17:00:07
17:08:27
17:16:48
17:25:08
17:33:27
17:41:47
17:50:07
17:58:27
18:06:48
18:15:08
18:23:27
18:31:47
18:40:07
18:48:28
18:56:47
Time - 8/24/06 - Start 1545:07.0 - End 1856:55.5

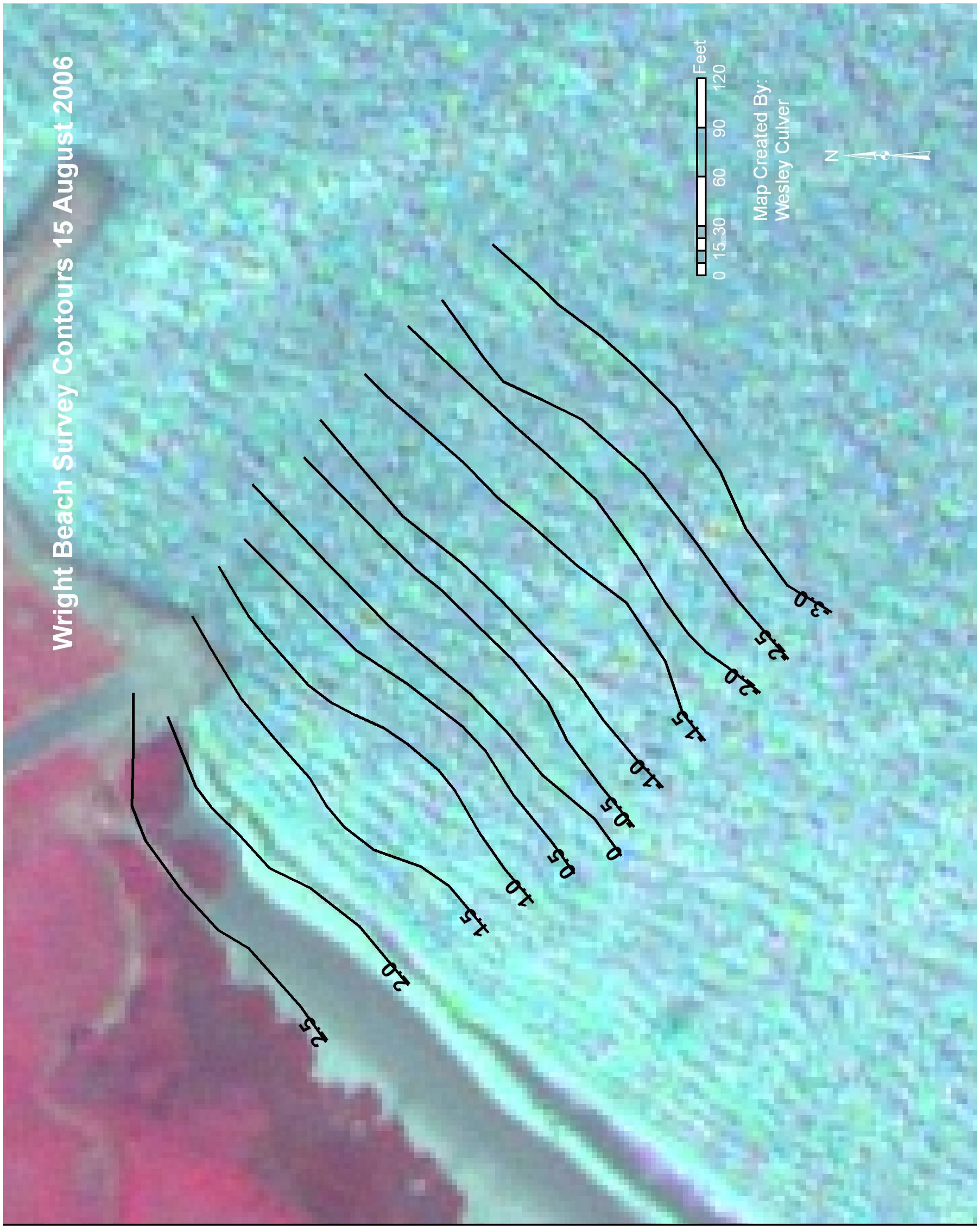

Pine Gully Wave Record, PG-6B
.5 Second Interval
Water Level (ft)
5.00
4.50
4.00
3.50
3.00
2.50
7:49:56
7:58:16
8:06:37
8:14:57
8:23:16
8:31:36
8:39:57
8:48:16
8:56:36
9:04:57
9:13:16
9:21:37
9:29:56
9:38:17
9:46:36
9:54:56
10:03:16
10:11:37
10:19:56
Time - 8/25/06 - Start 0749:56.5 - End 1026:30.0

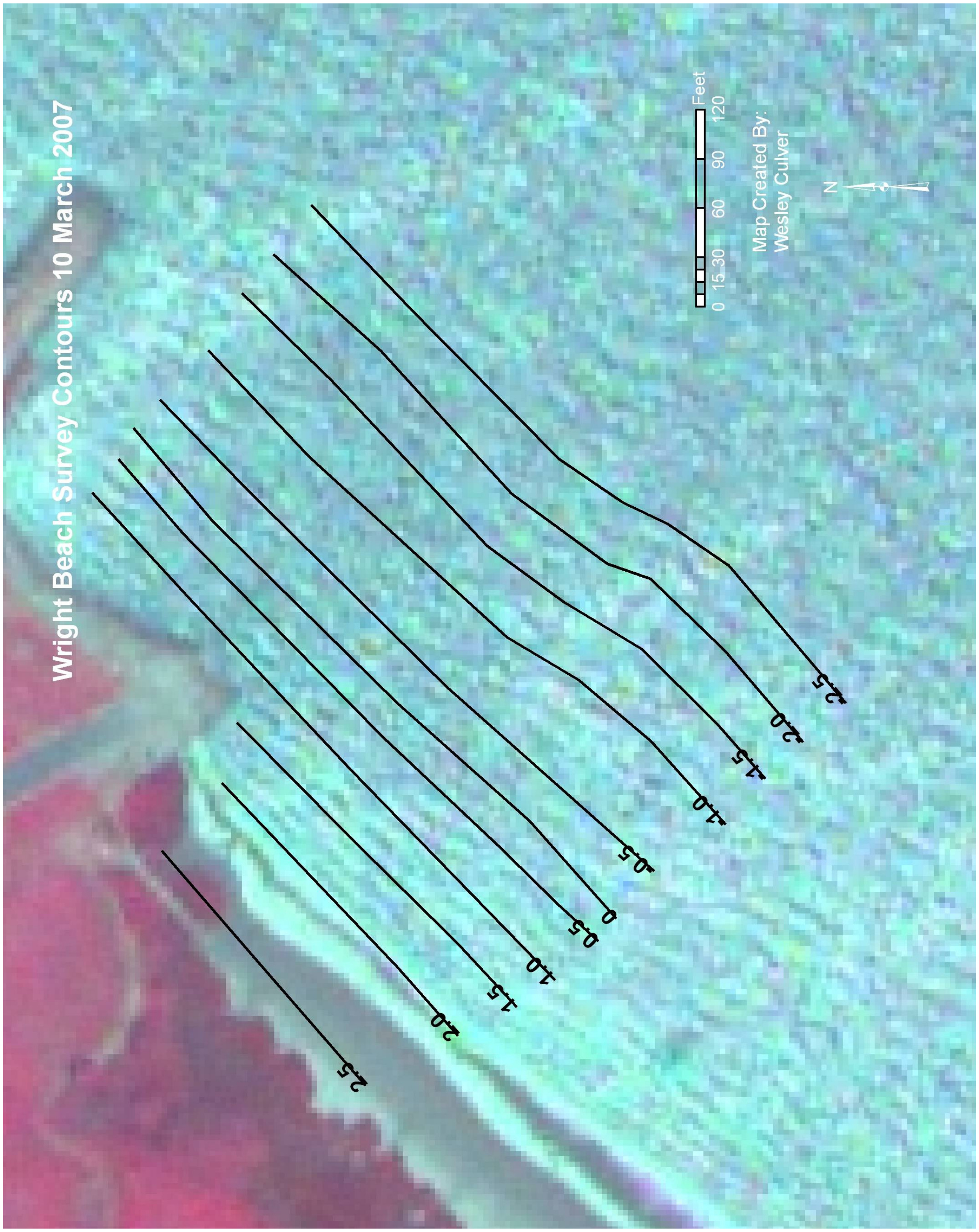


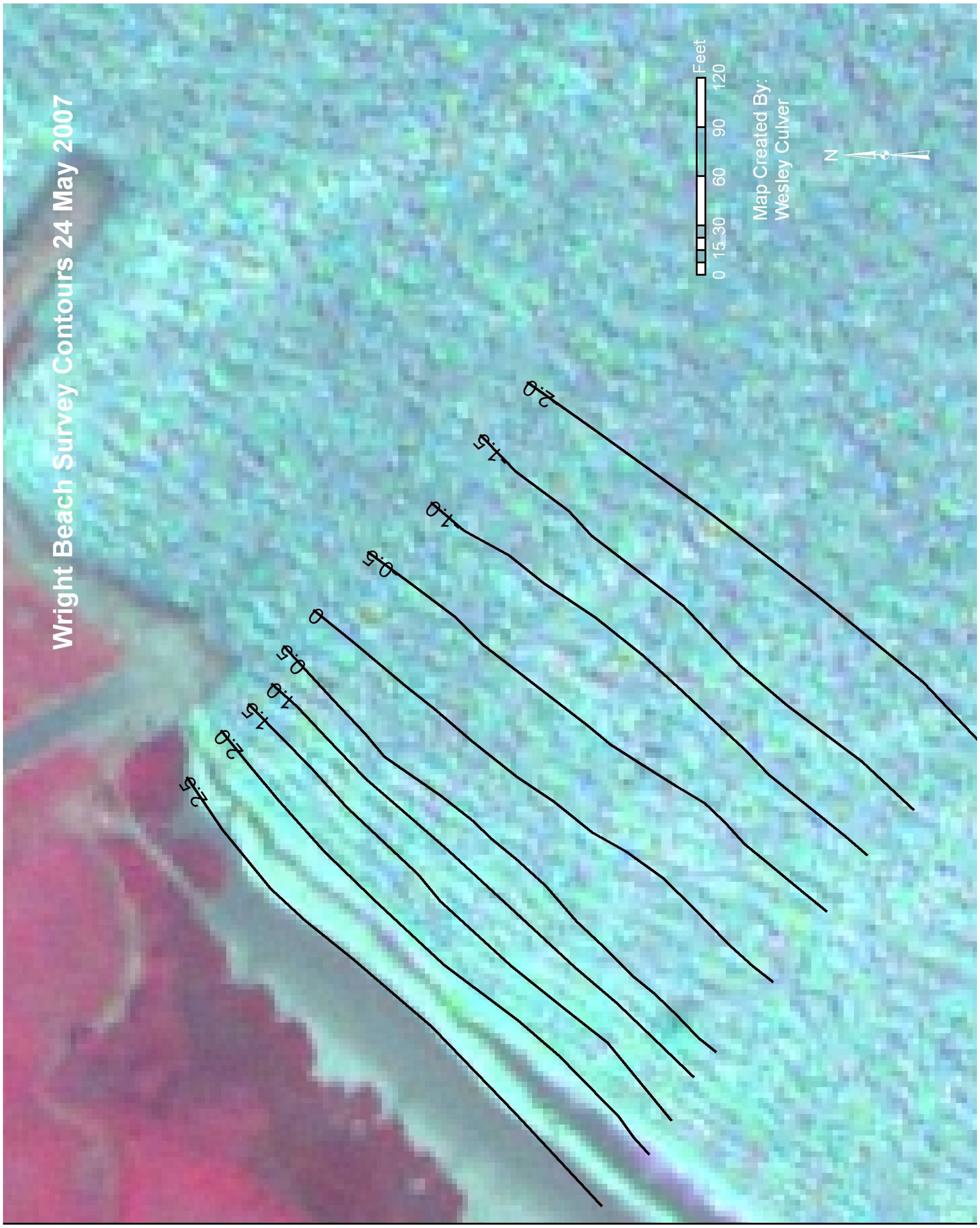
Pine Gully Wave Record, PG-7
.5 Second Interval
Water Level (ft)
5.50
5.00
4.50
4.00
3.50
3.00
15:58:59
16:07:19
16:15:38
16:23:58
16:32:18
16:40:38
16:48:58
16:57:19
17:05:38
17:13:59
17:22:19
17:30:38
17:38:59
17:47:18
17:55:38
18:03:58
18:12:18
18:20:38
18:28:59
18:37:18
18:45:38
18:53:58
Time - 8/24/06 - Start 1558:58.5 - End 1858:57.5

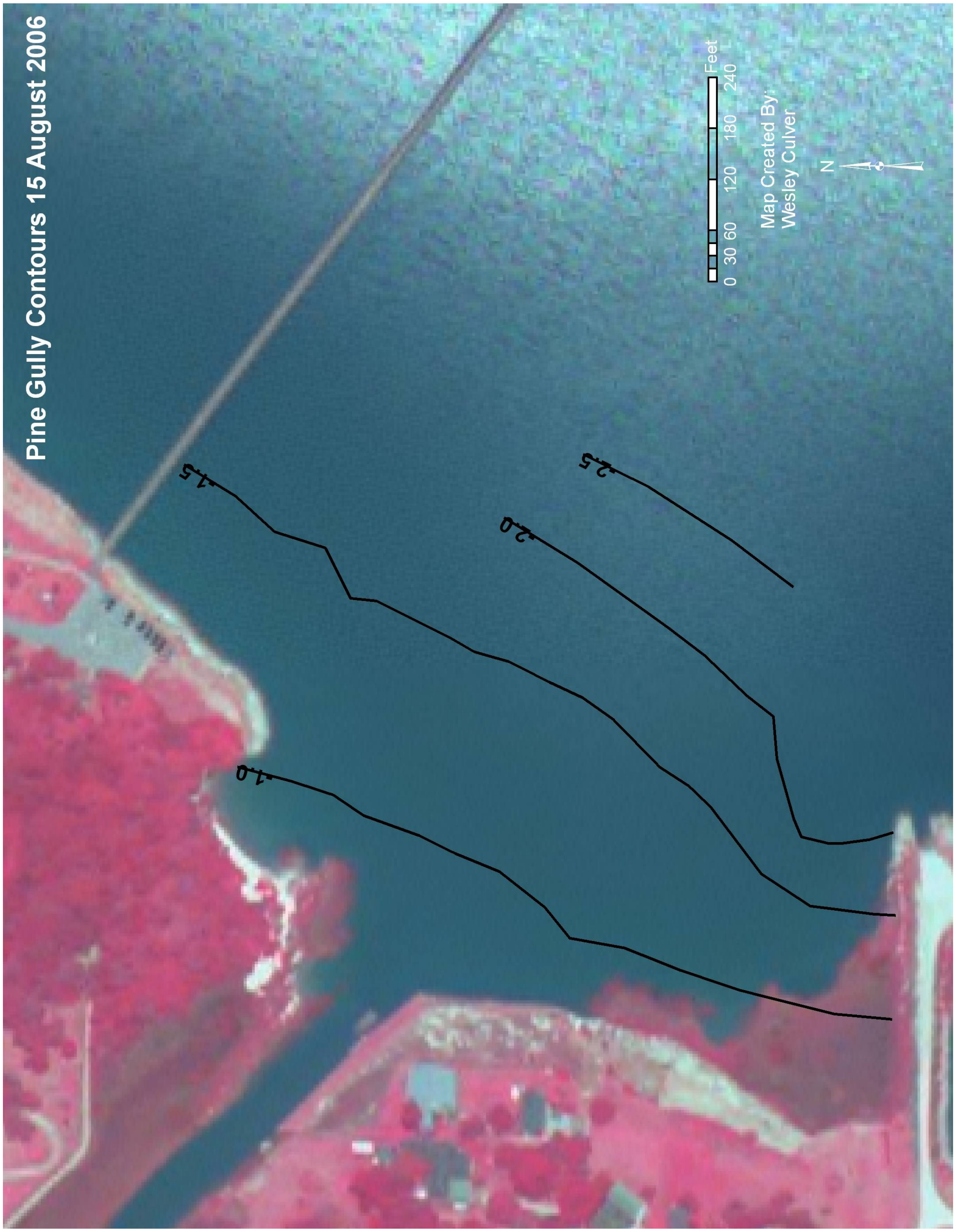
APPENDIX B

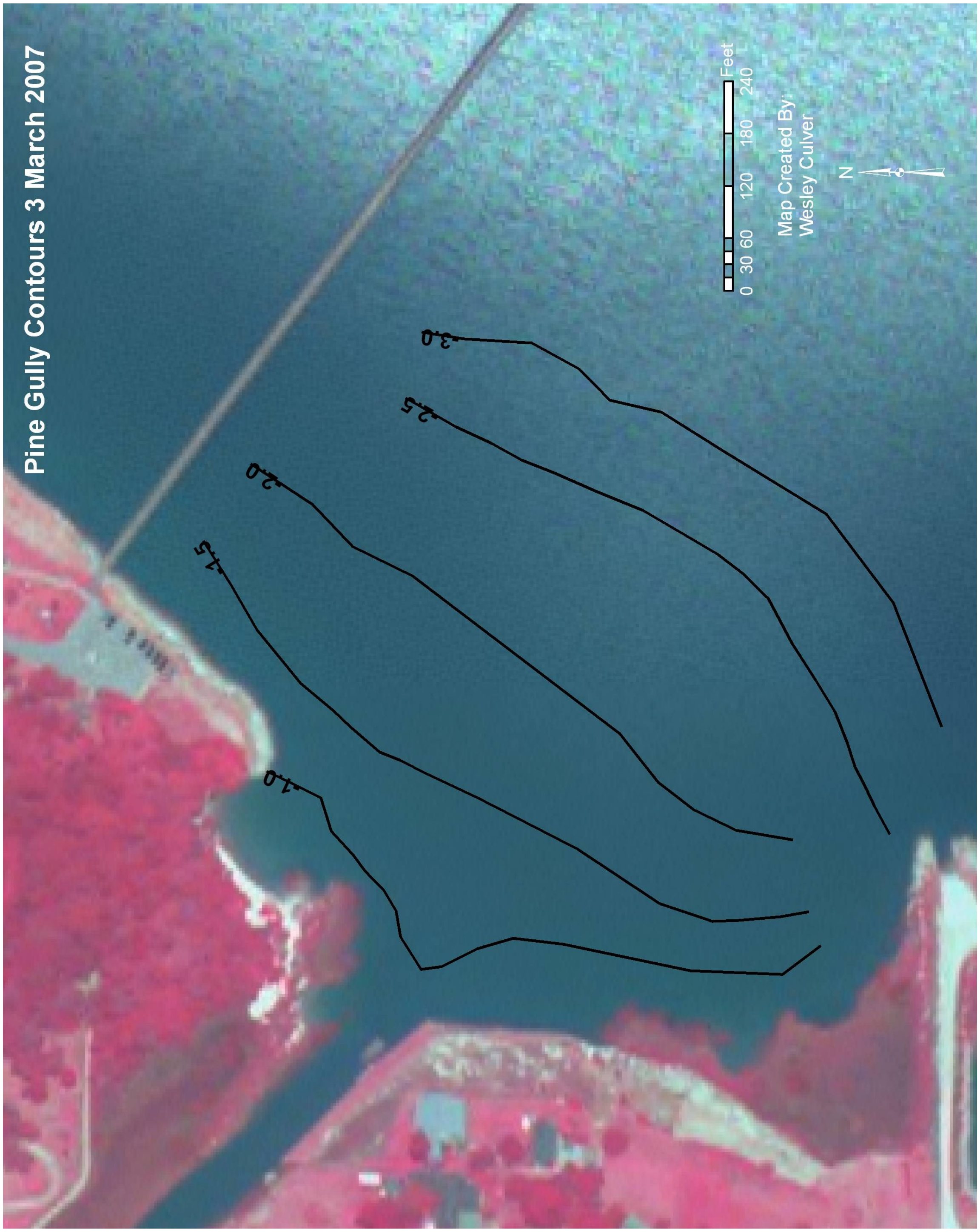
INDIVIDUAL COASTAL SURVEYS

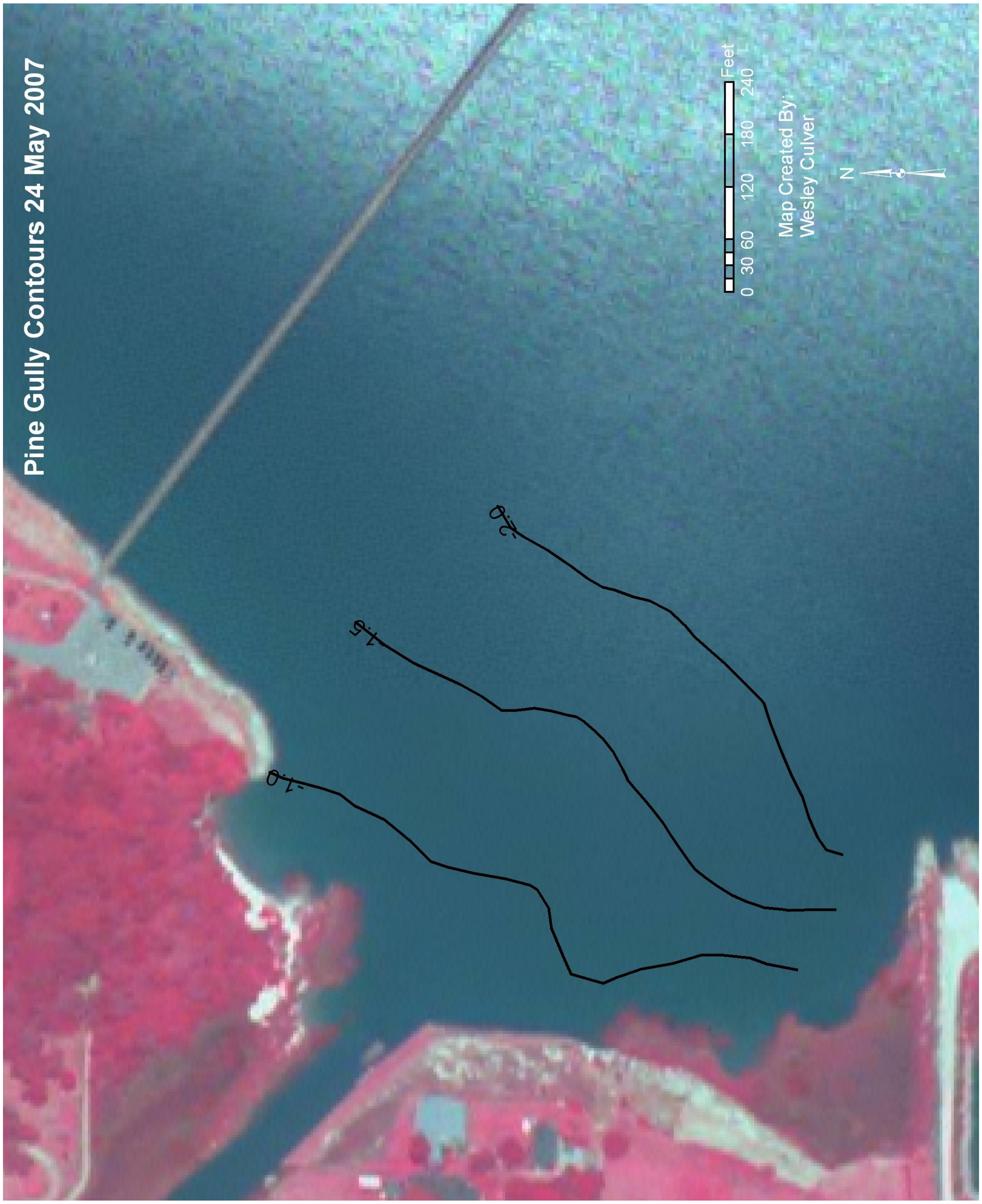

Wright Beach Survey Contours 15 August 2006
0 15 30 60 90 120
Feet
Map Created By:
Wesley Culver
N

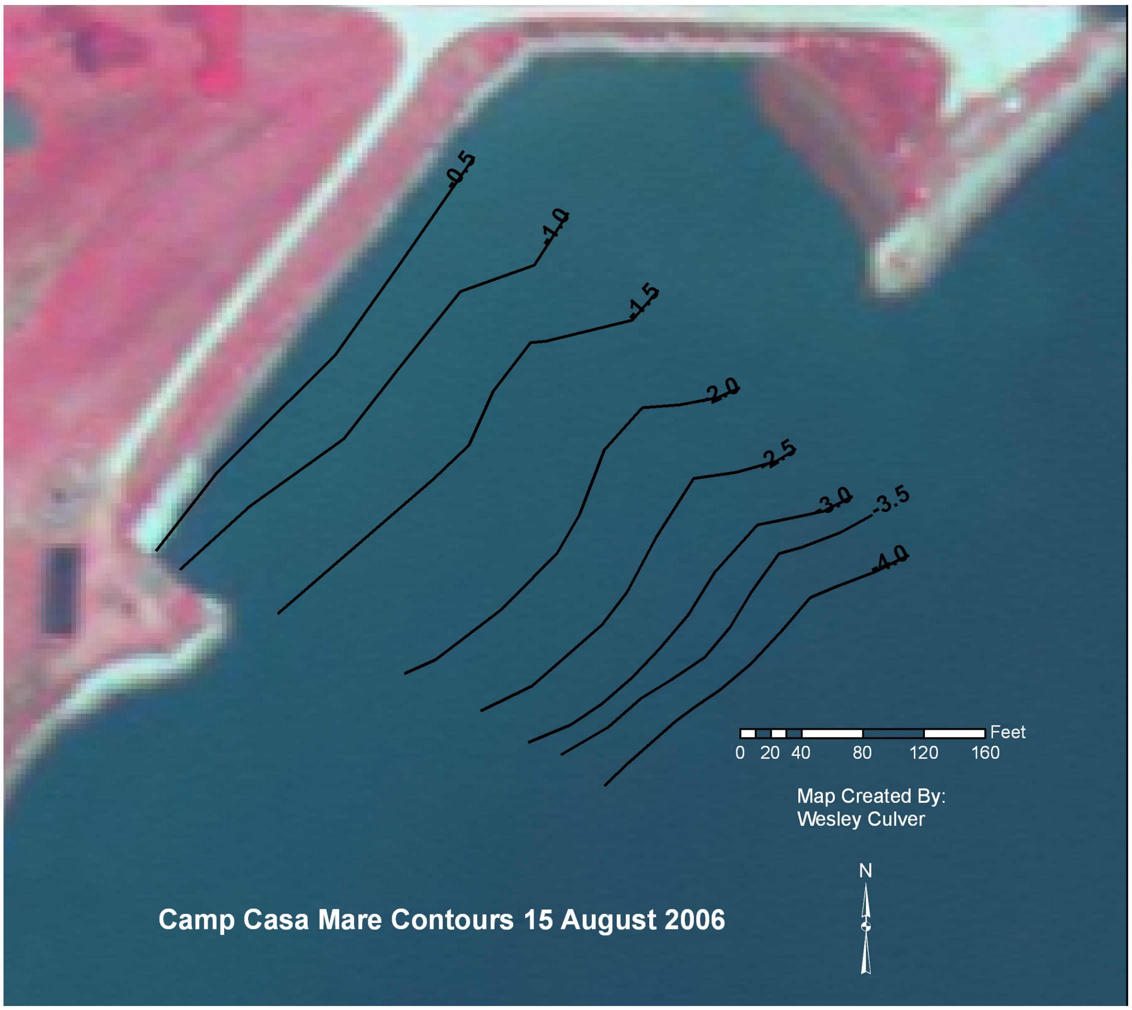

Wright Beach Survey Contours 10 March 2007
-2.5
-2.0
-1.5
-1.0
-0.5
0
0.5
1.0
1.5
2.0
2.5
0 15 30 60 90 120
Feet
Map Created By:
Wesley Culver
N

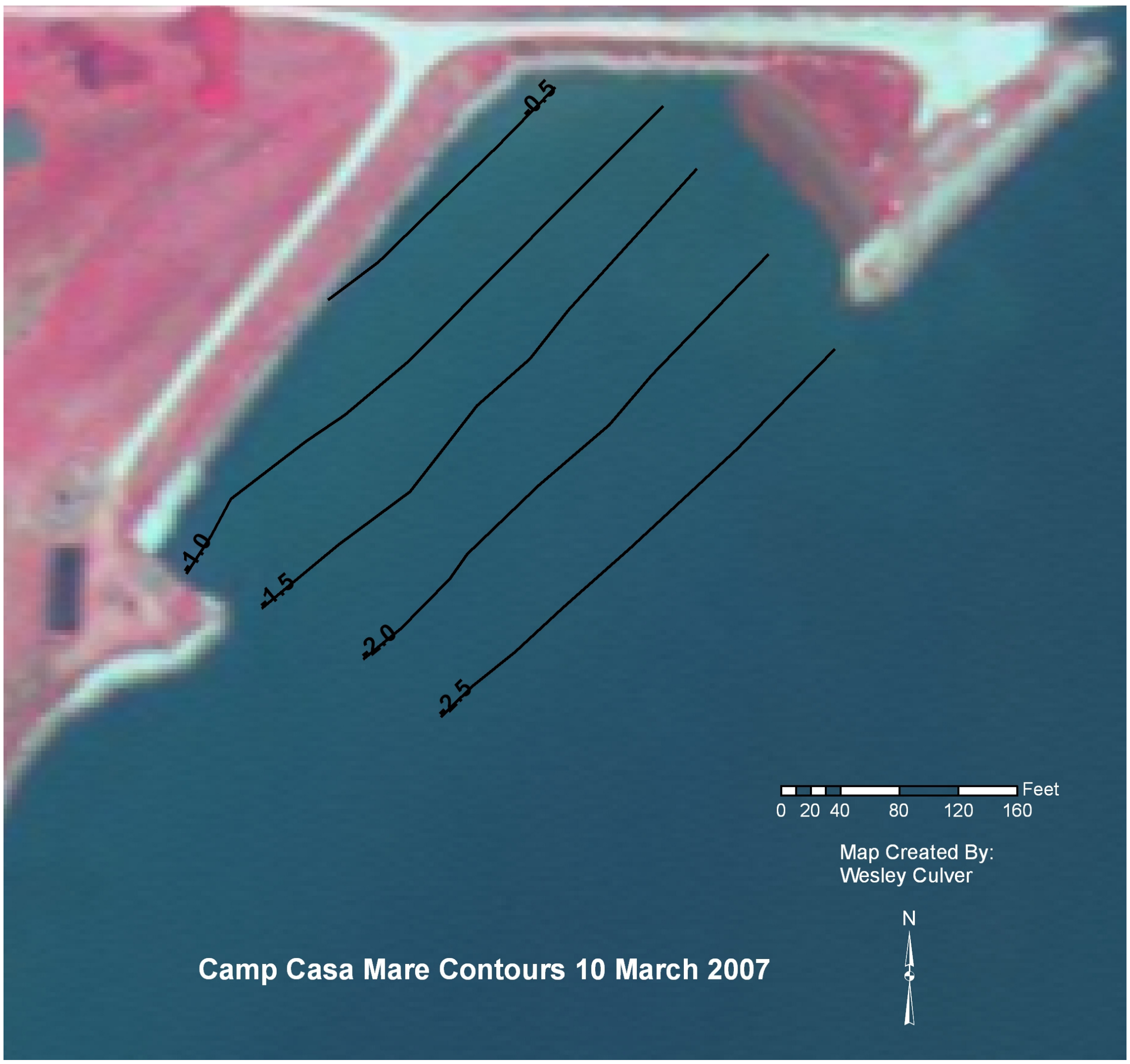

Wright Beach Survey Contours 24 May 2007
Feet
0 15 30 60 90 120
Map Created By:
Wesley Culver
N

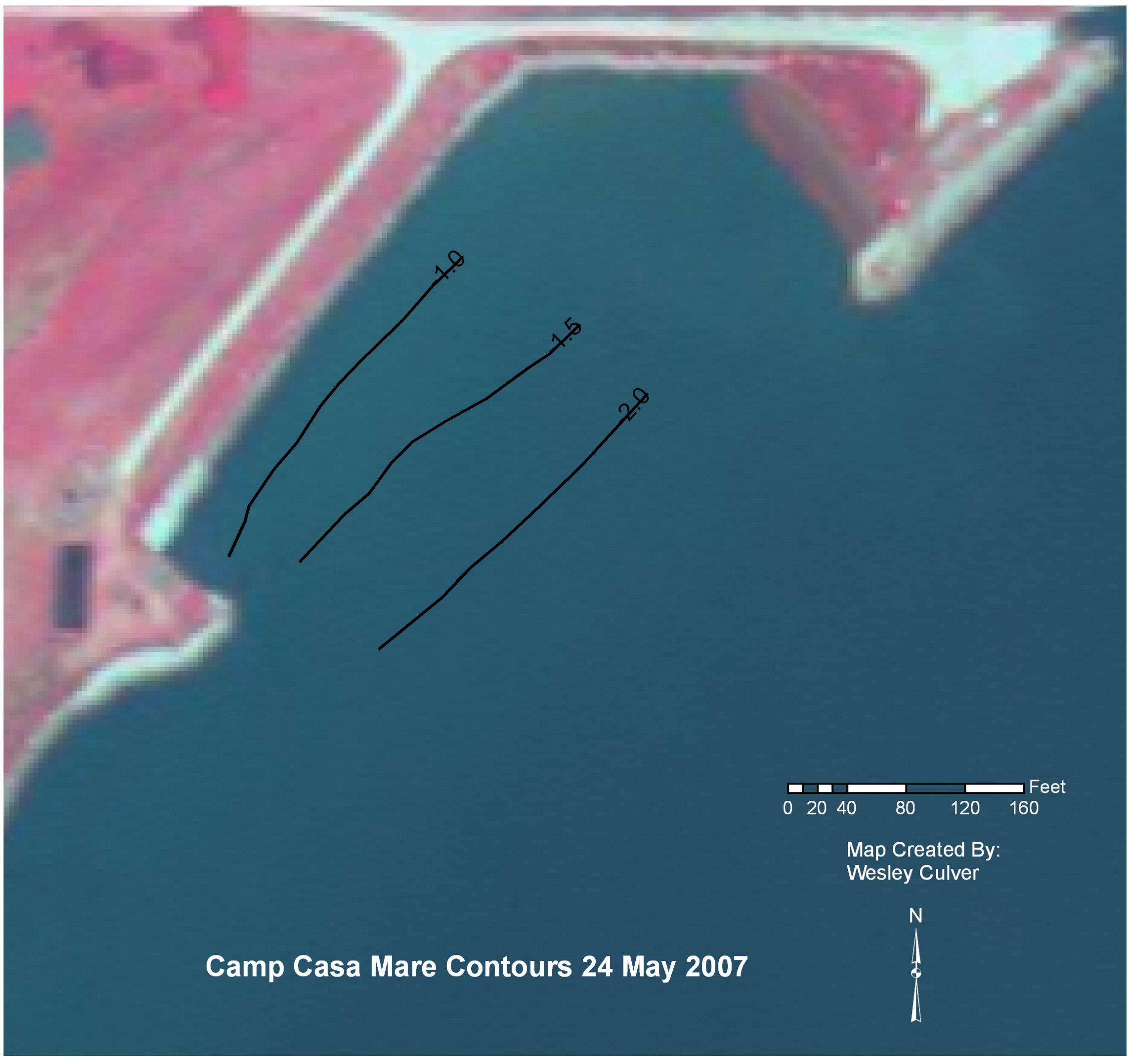

Pine Gully Contours 15 August 2006
Feet
0 30 60 120 180 240
Map Created By:
Wesley Culver
N
-1.0
-1.5
-2.0
-2.5

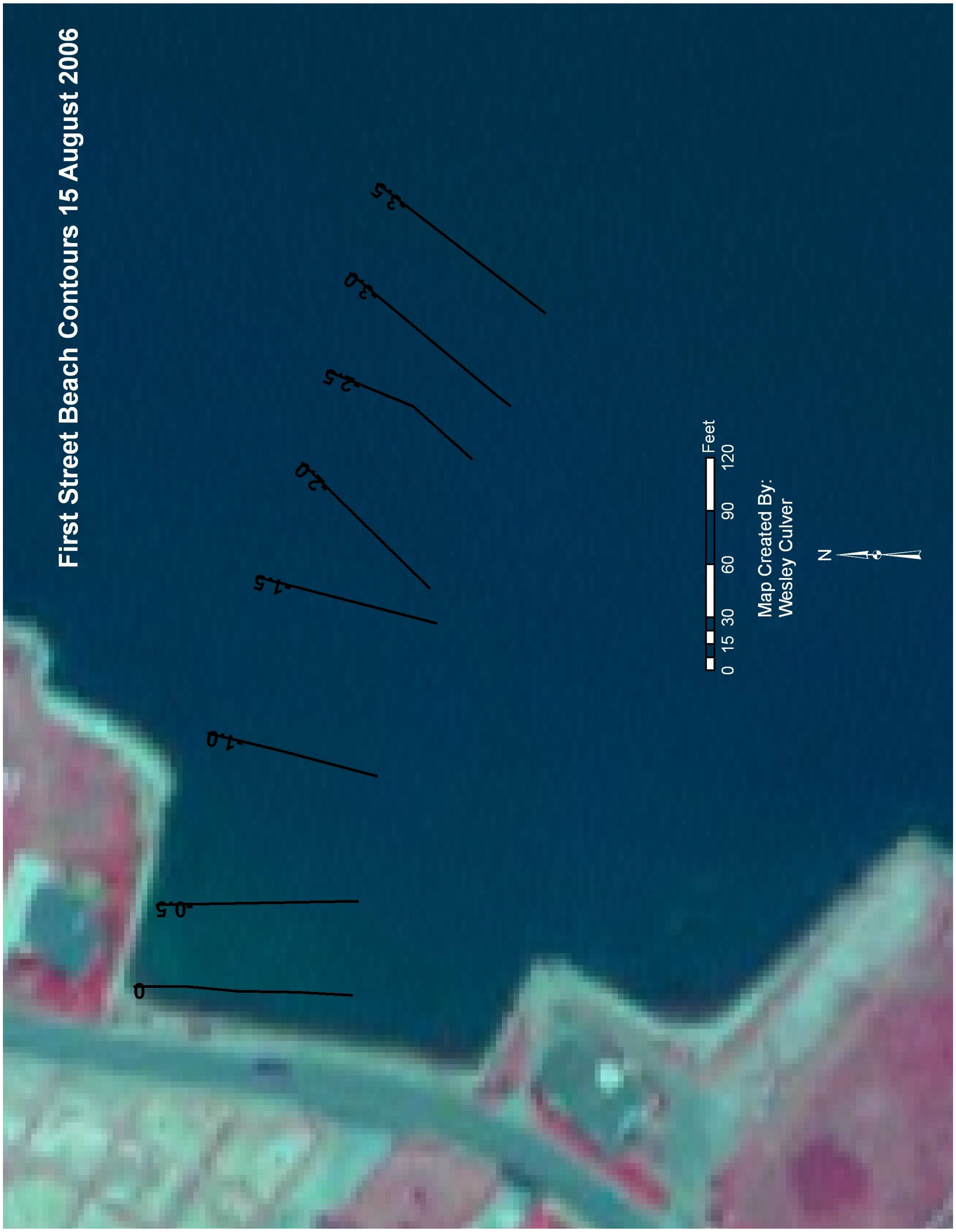

Pine Gully Contours 3 March 2007
-3.0
-2.5
-2.0
-1.5
-1.0
0 30 60 120 180 240
Feet
Map Created By:
Wesley Culver
N

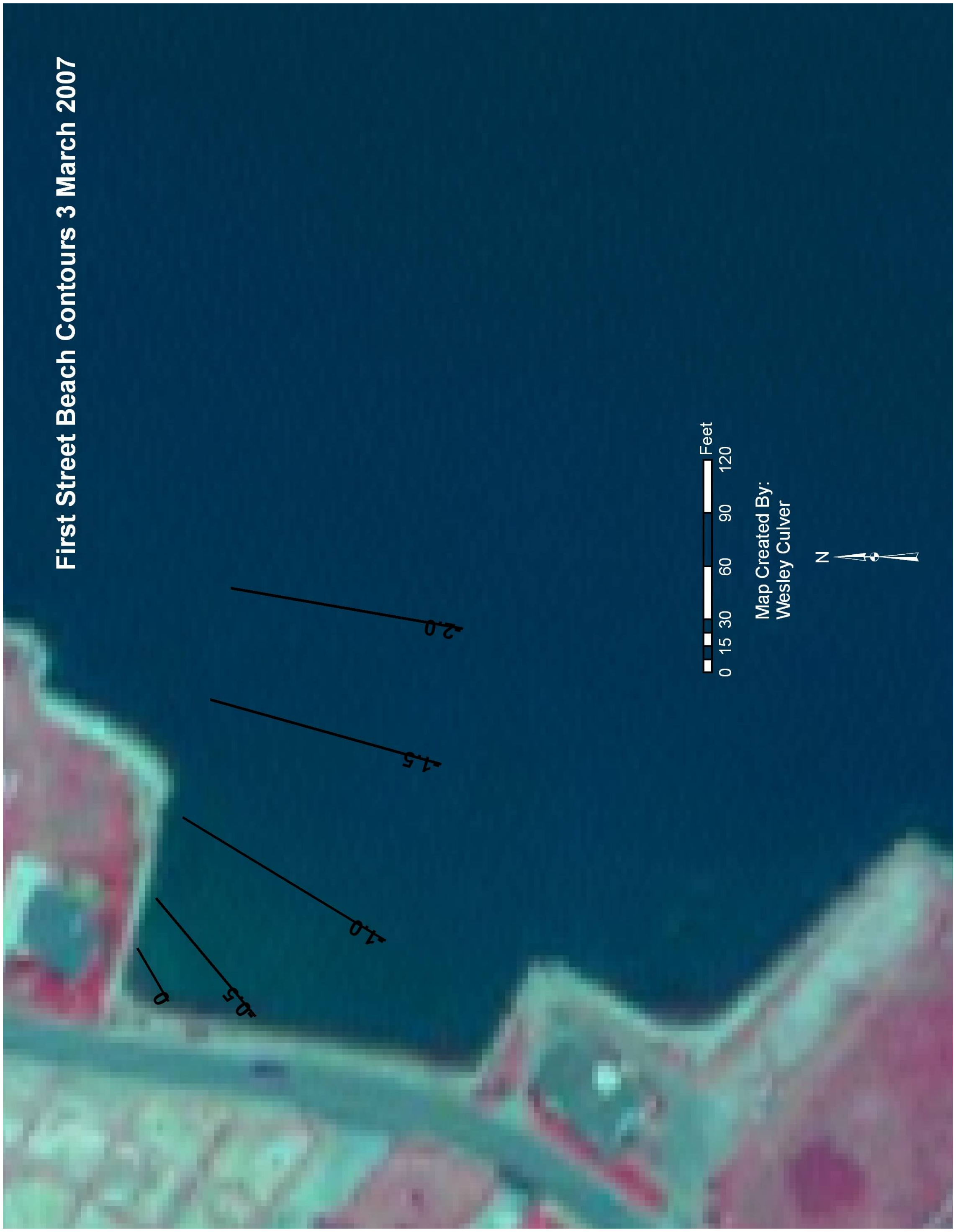

Pine Gully Contours 24 May 2007
0 30 60 120 180 240
Feet
Map Created By:
Wesley Culver
N
-2.0
-1.5
-1.0

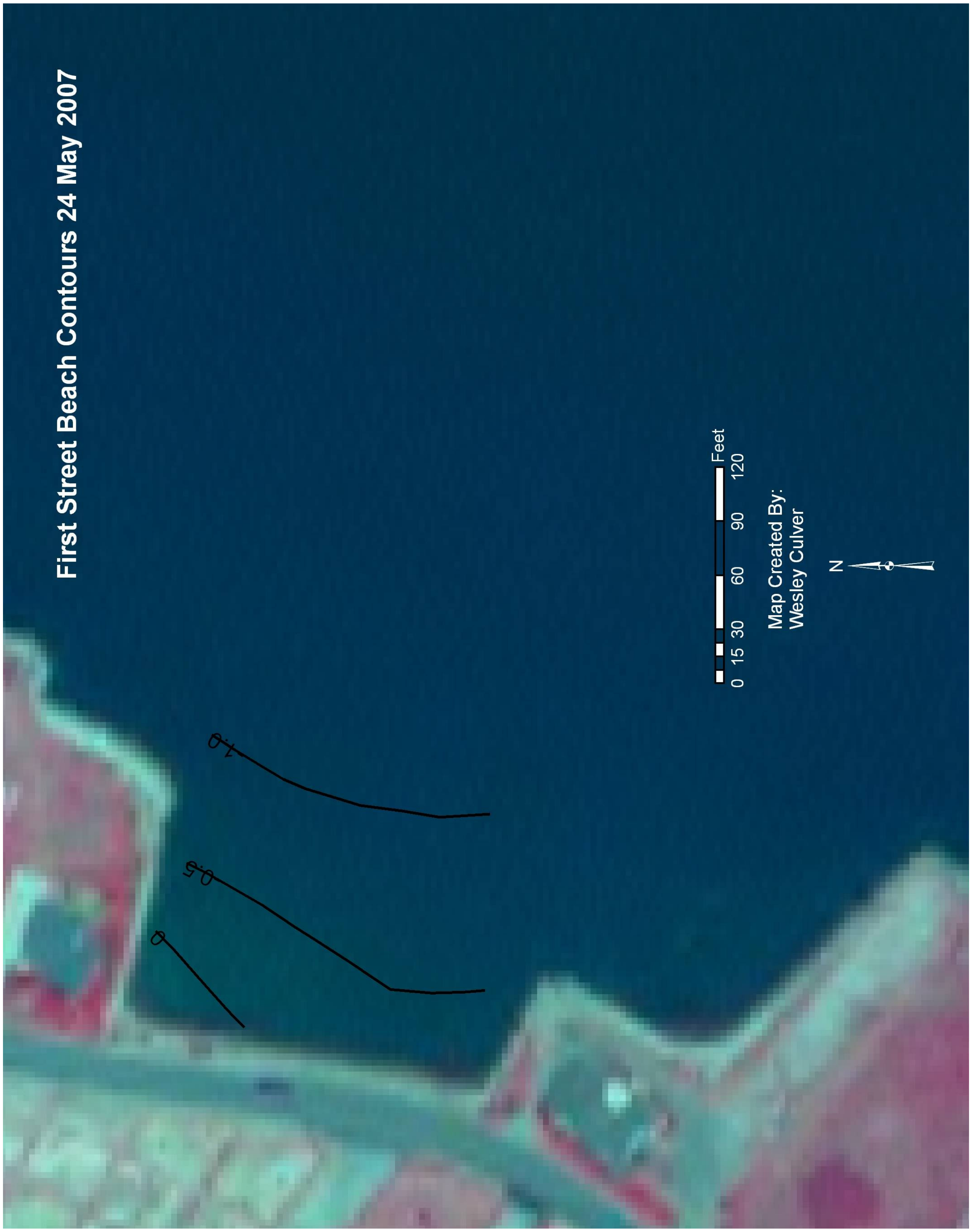

-0.5
-1.0
-1.5
-2.0
-2.5
-3.0
-3.5
-4.0
Feet
0 20 40 80 120 160
Map Created By:
Wesley Culver
N
Camp Casa Mare Contours 15 August 2006


-0.5
-1.0
-1.5
-2.0
-2.5
Feet
0 20 40 80 120 160
Map Created By:
Wesley Culver
N
Camp Casa Mare Contours 10 March 2007


1.0
1.5
2.0
Feet
0 20 40 80 120 160
Map Created By:
Wesley Culver
N
Camp Casa Mare Contours 24 May 2007


First Street Beach Contours 15 August 2006
0 15 30 60 90 120
Feet
Map Created By:
Wesley Culver
N


First Street Beach Contours 3 March 2007
-2.0
-1.5
-1.0
-0.5
0
0 15 30 60 90 120
Feet
Map Created By:
Wesley Culver
N


First Street Beach Contours 24 May 2007
1.0
0.5
0
0 15 30 60 90 120
Feet
Map Created By:
Wesley Culver
N

VITA

Name:	Wesley Richard Culver
Address:	The Department of Geology & Geophysics Texas A&M University College Station, TX 77843-3115
Email Address:	wcul229@AggieNetwork.com
Education:	B.S., Geology, Sul Ross State University, 2005 M.S., Geology, Texas A&M University, 2007