Final Report

Seasonal Variability of Near Surface Soil Water and Groundwater Tables in Florida

Submitted to:

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yards	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	ml
gal	gallons	3.785	liters	l
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3

NOTE: Volumes greater than 1000 l shall be shown in m^3.

Symbol	When You Know	Multiply By	To Find	Symbol
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5(F-32)/9 or (F-32)/1.8	Celcius temperature	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	l
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
psi	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
ml	milliliters	0.034	fluid ounces	fl oz
l	liters	0.264	gallons	gal
m^3	cubic meters	35.71	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg	megagrams	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact)		
°C	Celcius temperature	1.8C + 32	Fahrenheit temperature	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	psi

* SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.

(Revised August 1992)

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16. Abstract

The principal objective of this project was to review standard procedures and methods for estimating seasonal high groundwater table (SHGWT) levels. With this purpose in mind, the initial scope of work for this project defined three major tasks that were to be performed: SHGWT literature review, SHGWT field monitoring, and analysis of water table levels and known boundary conditions. Where the term "known boundary" refers to cases in which there is one known boundary condition that predominantly affects the water table. Two known boundary conditions were considered in this study. The predominant focus of this work was to investigate SHGWT elevations affected by tidal boundaries. While a secondary focus was to consider SHGWT elevations affected by water levels in adjoining canals.

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Executive Summary

The water table and its range of fluctuation are required design factors for most projects that involve altering the landscape. In order to estimate the affect of a proposed alteration on surface water quality and quantity, it is necessary to determine the current or predevelopment water table conditions. Most regulations stipulate that no significant change can be imposed to these conditions. Typically, it is the maximum or high water level that is a required design criterion. Several terms have been adopted regarding the maximum high water level, with one of the most common terms being seasonal high groundwater table (SHGWT).

The Seasonal High Groundwater Table (SHGWT) is a critical measure for design projects requiring surface water permits including roadway design and detention or retention pond design. In addition to constructability issues, the long-term maintenance of retention ponds is impacted by these cited levels. In regions characterized by poorly drained soils and high seasonal water tables, the functional designs are highly sensitive to the SHGWT. In Florida, the Department of Environmental Protection and five Water Management Districts are responsible for issuing surface water permits. At the present time, there are differences among the definitions and methods documented by the Water Management Districts for estimating the seasonal high groundwater table. These differences can potentially result in significantly different design standards at nearly coincident locations.

The principal objective of this project was to review standard procedures and methods for estimating SHGWT levels. With this purpose in mind, the initial scope of work for this project defined three major tasks that were to be performed: SHGWT literature review, SHGWT field monitoring, and analysis of water table levels and known boundary conditions. Where the term "known boundary" refers to cases in which there is one known boundary condition that predominantly affects the water table. Two known boundary conditions were considered in this study. The predominant focus of this work was to investigate SHGWT elevations affected by tidal boundaries. While a secondary focus was to consider SHGWT elevations affected by water levels in adjoining canals.

The literature review was performed to consider existing methods and procedures for estimating seasonal high groundwater table elevations. Included in the review is a summary of existing regulatory definitions and methodologies maintained by state permitting agencies.

Two field sites were instrumented for this project in order to investigate the influence of tides and waves on the water table. The two sites differ based upon their coastal setting and the predominant types of oscillations influencing the water table. The Stuart, FL site was established in order to observe the effects of tidal influences with minimal wave activity. The Cape Canaveral Air Force Station (CCAFS) site was established in order to observe the effects of both tidal and wave activities while considering the distance over which these influences typically occur.

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Introduction

The water table and its range of fluctuation are required design factors for most projects that involve altering the landscape, including development within uplands and wetlands, installation of septic systems, dredging and filling activities, roadway construction, and agricultural alterations that impede or divert the flow of surface waters. In order to estimate the affect of a proposed alteration on surface water quality and quantity, it is necessary to determine the current or predevelopment water table conditions, and most regulations stipulate that no significant change can be imposed to these conditions. The regulations vary depending upon the type of project, but the primary requirement is that some estimate for predevelopment water table conditions must be determined. The water table fluctuates over time due to contributions from various factors. In most cases it is the maximum or high water level that is a required design criteria. Several terms have been adopted regarding the maximum high water level, with the most common terms being seasonal high groundwater table (SHGWT), seasonal high water level (SHWL), and seasonal high saturation (SHS). Each of these terms will be discussed in more detail, but for the purpose of discussion the term SHGWT will be used as the general term regarding maximum groundwater levels.

The water table represents a relatively simple concept: the level at which water exists below ground surface. However, accurately measuring and more importantly, predicting water table elevations is a complex process controlled by numerous factors and involving several areas of study including but not limited to soil science, geotechnical engineering, and hydrogeology. As each area of study has progressed with investigation of water table processes they have developed terminology and methods in parallel without direct reference to one another. It follows that as these varying methods have been adopted by different regulatory agencies differing definitions and methodology have been put into practice. The intent of this project was to review standard procedures and methods for estimating SHGWT levels.

With this purpose in mind, the initial scope of work for this project defined three major tasks that were to be performed: SHGWT literature review, SHGWT field monitoring, and analysis of water table levels and known boundary conditions.

Work has been completed on all three tasks as discussed in the following sections. Following the initial literature review and based upon input from FDOT it was decided to focus the research effort for this phase of work on situations in which there is one predominant factor controlling water table elevations. Such situations are referred to as "known boundary" conditions as there is one known boundary condition that predominantly affects the water table. Two known boundary conditions were considered in this study. The predominant focus of this work was to investigate SHGWT elevations affected by tidal boundaries. While a secondary focus was to consider SHGWT elevations affected by water levels in adjoining canals.

Review of Literature and Current Practices

A literature review was performed in order to consider the typical terminology and methodologies used to estimate water table elevations. With this purpose in mind, the next section provides a general discussion of the factors that affect the water table and its range of fluctuations. Then, the existing regulatory definitions and methodologies maintained by state permitting agencies are reviewed. After which, typical methods for estimating water table elevations are discussed.

Factors that affect the water table

In simplest terms, the water table is the upper surface of groundwater. It is assumed that below the water table all soil material is saturated with water. This is a simple definition that does not truly indicate the numerous components that affect the water table and contribute to its range of fluctuation. Factors that play a role in the water table and its fluctuation are listed below; several of the factors listed are interrelated.

1. Soil composition
2. Rainfall
3. Adjacent surface water levels
4. Tidal influences
5. Topography
6. Degree of connection between underlying aquifers
7. Perched water table conditions
8. Irrigation
9. Seasonal trends

Soil composition. Soil composition is a principle factor that influences how the water table is established at a given site. Water is retained within a soil matrix due to capillary forces maintained within the soil pores. The capillary forces are directly related to soil composition and structure. For instance, under similar hydrologic conditions, soils with higher clay content and finer grain sizes will typically maintain a higher water table when compared to soils composed of coarser sand or gravel. The combination of soil composition and water content in turn play a roll in the chemical and biological processes that occur within the soil matrix. These chemical and biological processes are critical to wetland and estuary systems, the treatment capabilities of soils for stormwater and septic systems, and are the basis for the NRCS hydric soil classification system, which is discussed later in this report.

Soils and their properties are considered by many areas of study, with two of the primary fields being soil science and geotechnical engineering. Typically, soil science is focused on the study of soil composition, chemistry and biology as they relate to soil quality, erosion and sediment control, and wetland issues. While geotechnical engineering is usually concerned with the structural properties of a soil at a larger scale, such as load bearing capacity and stability as related to construction of roadways, structures and earthquake design. These definitions are broad generalizations of soil science and geotechnical engineering, but they provide some insight as to how the two fields have worked in parallel while developing different terminology and methodology. The purpose of this review is not to compare these methods, but to point out that these differences in methodology have contributed to inconsistencies that exist in current permitting procedures.

Rainfall. Rainfall is the primary source of natural recharge to the water table. Not all rainfall reaches the water table as some is lost to overland runoff and evapotranspiration. The rainfall that reaches the water table does not do so immediately—it must infiltrate through the land surface and percolate downward—resulting in a lag between rainfall events and the corresponding water table response. For instance, where the water table is 20 feet or more below the land surface, rain filters slowly through the overlying soil and the response of the water table to heavy rainfall or drought usually lags about a month (Lichtler et al., 1968). The water table in such areas does not tend to fluctuate frequently, but the magnitude of fluctuation is typically greater than that in shallower water table conditions. On the other hand, in pine flatwoods where the water table is within 3 to 4 feet of the ground surface, the water table reacts quickly to local showers and with prolonged rainfall quickly rises to the land surface. During drought, the water table quickly declines to a few feet below the land surface, but once the water table is 3 to 4 feet below land surface, further decline is slow because evapotranspiration declines (Seereram, 1993 and Lichtler et al., 1968).

There are definite seasonal trends in rainfall, and it follows that these trends are apparent in water table elevations. In Florida, rainfall is usually greater in the late spring and summer months and less in the fall and winter months. Accordingly, water table elevations are generally higher during and for a period of time after the rainy season (June through October) and lower during the dry season (November through May) (Durden, 1997 and Rao et al., 1990).

Adjacent surface water levels. The water table is strongly related to adjacent surface water levels both natural (lakes and ponds) and manmade (canals, drainage ditches, retention/detention structures). When changes are made to the landscape that alter surface water conditions, corresponding changes are imposed on the surrounding water table elevations. Likewise, when stresses are applied that affect water table elevations, such as pumping, surface water levels respond accordingly. The relationship between the groundwater table and surface water elevation decreases with distance, but under conditions where the surface water body is expansive or there exists a significant canal network, surface water levels can be a dominant factor affecting water table elevations over a large area.

Tidal influences. In coastal regions tidal influences should be considered when investigating water table elevations. As with other surface water boundaries, the affect of tidal influences decreases with distance from the shoreline (Turner et al., 1997). The inland range of water level fluctuations depends on the shape of the shore or beach face, and the types of waves and tidal action observed. Wind waves, surf beats, and tides can be observed up to a few hundred feet inland while the affect of wave height changes over several days extends further (Nielsen, 1999). Turner et al. (1997) recorded tidal influences extending inland approximately 100 m (328 ft). Both Turner et al. (1997) and Nielsen (1999) also address the issue of water table super-elevation brought about by the combination of tidal and wave action. Under such conditions the net flow of groundwater can be reversed so that flow moves inland instead of the typically assumed seaward direction.

Topography. There are recognizable trends that relate topography to water table elevation. The water table usually forms a subdued image of the land surface. When the landscape gently undulates, the surface of the water table also undulates, but more gently. In Florida, the water table is typically near land surface in topographically low lying areas, wetlands, or near surface water bodies, and at greater depths in the upland, sandy ridges where there are minimal surface water features (Boniol et al., 1993). These trends between land surface and the water table are often used to estimate water table elevations at a regional scale.

Hydrogeological connection to underlying aquifers. The degree of connection and pressure differential between the water table aquifer and underlying confined aquifers can result in recharge from or discharge to the confined aquifer. For instance, in northeast Florida the water table aquifer is underlain by the confined Floridan Aquifer. In a confined aquifer the potentiometric surface is used to indicate how high water will rise in wells that penetrate the aquifer. In some locations the elevation of the Floridan potentiometric surface is higher than the elevation of the water table, causing water to flow upward from the Floridan aquifer into the water table aquifer. In areas where the elevation of the Floridan aquifer potentiometric surface is higher than land surface, springs and free-flowing artesian wells may occur. In some areas of northeast Florida, recharge from the Upper Floridan to the water table aquifer is significant, as shown by Boniol et al., (1993). Under such conditions, water table elevations may be predominantly controlled by the degree of connection between aquifers rather than recharge from land surface.

Perched water table conditions. At some sites conditions exist where layers or lenses of less permeable clays or rock exist within a more permeable soil matrix. Such conditions can lead to a perched water table, where the water table above the less permeable layer is trapped and retained at a higher elevation than the surrounding water table. In some cases perched conditions may only occur after an intense rainfall event, and after a short period of time the water table will stabilize. Care must be taken to recognize perched conditions when they exist, because they may differ considerably from the surrounding water table conditions.

Irrigation. Rainfall was discussed previously as the primary source of natural recharge to the water table. In many locations, such as agricultural areas and golf courses, irrigation is the major source of recharge to the water table. Irrigation is often classified based upon its purpose: agricultural, recreational, domestic, or wastewater treatment. Irrigation represents another seasonal component to water table fluctuations; however irrigation quantities are typically inversely proportional to the seasonal patterns of rainfall (SJRWMD, 1995).

Seasonal trends. Although, not truly a controlling factor, seasonal trends are definitely noticeable in water table fluctuations. Many of the above mentioned factors have some form of seasonal trend (rainfall, irrigation, and tidal). However, identifying specific seasonal trends can be difficult at times as they are not all directly proportional and they may not correspond chronologically. It is the presence of these trends that predicated definitions for high groundwater levels in terms of "seasonal" high values (seasonal high groundwater table, seasonal high saturation, and seasonal high water level). However, these terms do not always refer to the same season. Some definitions refer to rainfall trends, others refer to the growing season, and some do not specify.

State regulations regarding water table elevations in Florida

In the state of Florida there are five water management districts (WMDs), each of which is tasked with regulating water resources within their specified boundaries. Nearly all alterations to the landscape, including uplands, wetlands and other surface waters are regulated by the environmental resource permit (ERP) program. The ERP program is implemented jointly by the Department of Environmental Protection (DEP) and the water management districts. Operating agreements between the DEP and the water management districts specify which agency will process a given application.

The intent of the ERP program is to divide the permitting responsibilities among regional agencies in an attempt to streamline the permitting process. However, as with any task that considers numerous applications among multiple agencies, maintaining consistency is a challenge. Although each of the water management districts must follow the same codes and statutes, they are regulated based upon district interpretation. The regulations are then applied base upon to the consent of the individual permit reviewers. This process allows for a wider range of flexibility, but in turn can lead to different interpretations between agencies. For large scale projects, which often require consecutive permits within the jurisdiction of multiple water management districts, this can lead to redundant permit applications that yield different permit requirements. These differences can potentially result in dissimilar design standards at nearly coincident locations within adjacent water management districts.

As discussed previously, design criteria are established to meet specific project goals (floodwater management and water quality maintenance). If design requirements differ between water management districts, questions then arise as to whether this is due to differing district interpretation or whether different criteria may be used to achieve the same goal. If the latter is the case, then the question becomes which criteria is most effective.

The agency definitions relating to seasonal high groundwater elevations are summarized in Table 1. It should be noted that although the definitions may differ, all agencies either directly or indirectly reference the NRCS hydric soil method for estimating seasonal high groundwater elevations. Detailed discussion of state regulations regarding water table elevations in Florida is provided in Appendix A.

Table 1: Agency definitions relating to water table and seasonal high water table elevations.

Agency	Term	Definiton	Reference to NRCS
St. Johns River Water Management District (SJRWMD)	Seasonal High Ground Water Table Elevation (SHGWT)	The highest level of the saturated zone in the soil in a year with normal rainfall.	NRCS
South Florida Water Management District (SFWMD)	Seasonal High Water Table (SHWT)	The highest average depth of saturation during the wet season.	NRCS
Southwest Florida Water Management District (SWFWMD)	Seasonal high water level (SHWL)	The elevation to which the ground or surface water can be expected to rise due to a normal wet season.	NRCS
Suwannee River Water Management District (SRWMD)	No term	Discretion of permit reviewer. Reviewers have attended SWFWMD/NRCS SHGWT workshop.	NRCS
Northwest Florida Water Management District (NWFWMD)	No term	Permiting authority is DEP.	
USDA, Natural Resources Conservation Service (NRCS)	Seasonal High Saturation (SHS)	Observed water table in an unlined augered hole at the wettest time of the year during periods of normal precipitation.	NRCS
Department of Environmental Protection (DEP)	Seasonal High Water	The elevation to which the ground or surface water can be expected to rise due to a normal wet season.	NRCS
United States Army Corp of Engineers (USACE)	Active water table	A condition in which the zone of soil saturation fluctuates, resulting in periodic anaerobic soil conditions. Soils with an active water table often contain bright mottles and matrix chromas of 2 or less.	NRCS
Department of Health (DOH)	Wet Season Water Table Elevation	That period of time each year in which the ground water table elevation can normally be expected to be at its highest elevation at the upper surface of the ground water or where the underlying soil is completely saturated.	NRCS

Methods for estimating water table elevations and extremes

There are several methods that can be used to estimate water table levels and their range of fluctuation. These methods are based upon one or more of the previously discussed factors that affect the water table. Often times these methods are used in conjunction with one another in order to provide a more reliable estimate of water table elevations. Methods for estimating water table elevations include the following:

1. Historical water table elevations
2. NRCS hydric soil characterization
3. NRCS soil map data
4. Tidal influences
5. Vegetative indicators
6. Geotechnical engineering penetration methods
7. Correlation with soil morphological features
8. Correlation to observed historical elevations
9. Linear regression to land surface elevation
10. Numerical simulation

Historical water table elevations. The most direct method for estimating the SHGWT is through measurement of water levels over an extended period of time. This approach is often considered too costly and time consuming to be practical because a significant period of record is usually needed in order to accurately reflect representative conditions. The period of record necessary to accurately represent normal conditions at a site is often stated to be 10 years (SFWMD, 2000); although, based upon site conditions this value may decrease or increase accordingly. Care must also be taken to assure that the well or borehole used for measurement purposes accurately represents the water table conditions within the surrounding aquifer. For instance, at sites with fractured rock formations or high clay content, conditions may exist where only large conduits or fissures fill with water after a recharge event, while the soil matrix remains unsaturated.

NRCS hydric soil classification. As outlined in Table 1, almost all of the ERP documentation provided by the DEP and the water management districts include direct or indirect reference to the hydric soil characterization methods developed by the United States Department of Agriculture (USDA), Natural Resources Conservation Service (NRCS). This methodology is based upon soil indicators that are created due to chemical and biological changes in the soil resulting from the presence of water. The NRCS methodology is presented in Field Indicators of Hydric Soils in the United States, Guide for Identifying and Delineating Hydric Soils, Version 5.0, 2002 (USDA, NRCS, 2002). In this document, hydric soils are defined as *soils that formed under conditions of saturation, flooding, or ponding long enough during the growing season to develop anaerobic conditions in the upper part of the soil*. The development of hydric soils is summarized in the same document as:

> Nearly all hydric soils exhibit characteristic morphologies that result from repeated periods of saturation or inundation, or both, for more than a few days. Saturation or inundation when combined with microbial activity in the soil causes a depletion of oxygen. This anaerobiosis promotes

biogeochemical processes, such as the accumulation of organic matter and the reduction, translocation, and/or accumulation of iron and other reducible elements. These processes result in characteristic morphologies that persist in the soil during both wet and dry periods, making them particularly useful for identifying hydric soils.

Hydric soil indicators are formed predominantly by the accumulation or loss of iron, manganese, sulfur, or carbon compounds.

(USDA, NRCS, 2002)

The document provides a procedure for examining soil horizons for visual evidence that may indicate hydric soil conditions. Numerous studies have been performed to correlate the seasonal high water table to the presence of hydric soils. However, determining SHGWT by soil indicators alone can be inaccurate as the NRCS document is careful to point out: *the list of indicators are considered to be dynamic; changes and additions are anticipated annually* (USDA, NRCS, 2002). Cautions are also included regarding soil morphologies that are difficult to interpret, soils that are artificially drained, or soils that indicate relict conditions; such conditions can make it difficult to accurately ascertain water table conditions at a site.

NRCS soil map data. Most of the counties in the state of Florida have had soil surveys performed and the soil classification data are compiled in county soil survey maps. These maps are available in both hard copy and electronic format. These data are typically incorporated into a geographical information system (GIS) and used for various soils-based analyses, including estimates for the expected range of SHGWT. The primary limitation of these maps and the corresponding data is the scale at which the information was compiled. These surveys were performed at the county level; as such numerous inclusions of soil types with differing properties are often not represented at this scale (Hurt et al., 2002). Considering these limitations, the soil survey maps provide preliminary information for soil characteristics, but should not be used in lieu of onsite inspection of soil and groundwater conditions.

Tidal influences. In coastal areas, the water table can be strongly influenced by tidal conditions. The effect of tidal influence typically decreases with distance from the coastline. The relative distance for the tidal influences to be minimized is related to soil type and the corresponding soil properties such as permeability and hydraulic conductivity. At some locations, with specific soil conditions, the tidal elevations may be the predominant factor controlling water table fluctuations. As such, the tidal elevation may provide a reasonable estimate for water table elevations (within a specified distance of tidal influence).

Vegetative indicators. Vegetation is often the most readily observed parameter that can indicate water table elevations. Inspection of the natural vegetative cover on an undisturbed site can provide a general indication of the depth to the water table as certain plant species thrive under wet conditions and only certain species survive where the water table is deep (Seereeram, 1993). However, sole reliance on vegetation can be misleading. Many plant species can grow successfully in both wetlands and nonwetlands, and hydrophytic vegetation and hydric soils may persist for decades following alteration of hydrology (USACE, 1987). It is best to use vegetation as preliminary indicator, prior to more extensive investigation.

Geotechnical engineering penetration methods. Although not widely used in this capacity, the standard penetration test (SPT) N value profile can at times provide an indication of the water table fluctuation since repeated changes in effective stress due to drying out followed by inundation leads to compaction of the soil in the zone of fluctuation. The SHGWT is sometimes discerned by a marked increase in N value or Dutch cone point resistance with depth from the ground surface (Seereeram, 1993).

Correlation with soil morphological features. Seereeram (1993) summarized a study performed by Brown et al. (1989) that correlates the wet season water table to the following soil morphological properties:

1. Depth to low chroma (grayish) mottles (i.e., chroma 2 or less). Mottling in soil are irregular spots of different colors that vary in number and size. Mottling generally indicates poor aeration and impeded drainage.
2. The thickness of the E horizon. The E horizon is the mineral horizon in which the main feature is the loss of silicate clay, iron, aluminum, or some combination of these.
3. The depth to the B horizon. The B horizon is the mineral horizon below an O, A, or E horizon. An O horizon is an organic layer of fresh and decaying plant residue at the surface of a mineral soil while an A horizon is the mineral horizon at or near the surface in which an accumulation of humified organic matter is mixed with mineral material.

The equation fitted by Brown et al. (1989) to observations in Florida is as follows:

$$XWT = -61 + 0.4\ X_1 - 2.1\ X_2 + 2.6\ X_3 \quad (1)$$

where

XWT = mean of three highest monthly water table depths observed (cm)
X_1 = depth to mottles of chroma 2 or less (cm)
X_2 = thickness of the E horizon (cm)
X_3 = depth to the B horizon (cm)

Correlation to historical water table elevations. This method utilizes historical water level elevation, without requiring long-term observations at the site of interest. The method was developed by the USGS using water table information from the state Massachusetts. The USGS method (Frimpter, 1981) utilizes historical data that has been collected from observation wells throughout the state since the 1930's. The method is used to estimate the seasonal high groundwater elevation at a proposed construction site based on current groundwater levels at the test site and the ratio of the present water level to the historic water level range in a network observation well located in the same geologic strata as the proposed construction site. The high groundwater elevation can be estimated using the following relationship (Frimpter, 1981):

$$S_h = S_c - [S_r \text{ X } (OW_c) - Ow_{max})/OW_r] \quad (2)$$

where

S_h = estimate depth to the high groundwater elevation at the proposed building lot
S_c = measured depth to the current groundwater elevation at the site
S_r = expected range in water levels at the site. This value is based on the combined records of all observation wells for that parent material and landform.
O_{wr} = historical upper limit of the annual range for the selected observation well
O_{wc} = measured depth to the present groundwater elevation in the selected observation well
O_{wmax} = maximum groundwater elevation on record for the selected observation well

Linear regression to land surface elevation. At the regional scale, typically for numerical modeling purposes, a commonly used method for generating water table elevations for an unconfined aquifer is to perform a linear regression between measured water levels and land surface elevation. Several regression algorithms have been applied to estimate water table elevations and varying approaches are presented by Boniol, 1993; Durden, 1997; Sepulveda, 2002; and Williams and Williamson, 1989. Regression methods can incorporate levels of adjacent surface water bodies including tidal elevations, and usually provide reliable results in low lying areas with minimal land surface variability. However, this method is not as reliable in upland areas of low recharge or high hydraulic conductivity. In such areas, land surface elevation and water levels are not strongly correlated.

Numerical simulation (groundwater flow models). Simulation results from groundwater flow models such as MODFLOW and DRAINMOD are commonly accepted methods for estimating groundwater elevations. Numerical models are powerful tools that allow for the consideration of numerous processes and parameters such as surface recharge, evapotranspiration, and the degree of connection between aquifers. The limitation of such methods however, is the amount of information that is necessary to properly calibrate a model to a site of interest. If a model is not properly calibrated, simulation results can be extremely inaccurate.

For each of the methods mentioned in the previous discussion a certain level of professional experience is necessary to interpret the results and make a reasonable statement of the expected seasonal high groundwater table elevations. Considering the availability of so many varying methods and the fact that each method is based upon different contributing factors, it is not surprising that different methods can provide estimates for the SHGWT that vary significantly. It stands to reason that developing a consistent procedure that incorporates multiple indicators would enhance the technical accuracy, consistency, and reliability of SHGWT estimation.

Methods and Procedures

Field monitoring

Two field sites were instrumented for this project in order to investigate the influence of tides and waves on the water table. The two sites differ based upon their coastal setting and the predominant types of oscillations influencing the water table. The Stuart, FL site was established in order to observe the effects of tidal influences with minimal wave activity. The Cape Canaveral Air Force Station (CCAFS) site was established in order to observe the effects of both tidal and wave activities while considering the distance over which these influences typically occur. Both sites are discussed below.

Stuart, FL (Earnest Lyons Bridge). The first site instrumented for this project was located in Stuart, Florida on the western approach to the Earnest Lyons Bridge. The site is located on a small island near the western shore of the Indian River (Figure 1). The data from this site were used to investigate tidal influences on the SHGWT. The site consisted of a small island where a shallow well, tidal gage and rain gage were installed. The well and tidal gage were each instrumented with a pressure transducer and data logger. Water elevations at both the well and tide gage were collected starting on March 25, 2003. The rain gage was installed and started recording on April 24, 2003. The tidal elevation, water table elevation, and precipitation were monitored using a 15-minute sampling interval. Base upon borehole percolation test results, the estimated hydraulic conductivity for the Stuart site was K = 80.2 ft/day and the site is composed predominantly of an extremely permeable A-3 soil. Due to roadway and bridge construction data collection at this site was concluded in July 2004.

The primary water oscillations observed at this site were daily and monthly tidal fluctuations. There was typically minimal wave activity at the site. The observed water levels for the period July 2003 to January 2004 are shown in Figure 2. Also included in the figure are the mean sea level (MSL), mean high water (MHW), and Mean Higher High Water (MHHW). Figure 2 shows the transition from low water conditions to high water conditions, with the seasonal high (peak annual value) being observed in September 2003. The seasonal high values observed in September 2003 are shown in Figure 3. Both the daily and monthly tidal influences are apparent in the shallow well. The average tidal amplitude was 1.68 ft while the average well water level amplitude was 0.23 ft. The well water level lagged the tidal activity by an average of 4.5 hours. A salinity profile of the island well is shown in Figure 4, which indicates a general trend of increasing salinity with depth. This is to be expected for conditions in which a fresh water lens exists over salt water and Figure 4 shows the transition from freshwater to higher salinity water below. The salinity profile was used to estimate the appropriate water density for conversion of pressure transducer readings to water table elevations.

For the conditions of this site, the water table rarely exceeds the tidal levels (Figure 2). Cases where the water table does exceed tidal levels were typically during times of dropping water levels (receding periods of the hydrograph). During the period of record, water table elevations were not observed to exceed tidal levels during peak conditions. The observed relationship between water table and tidal elevations during typical peak conditions suggest that for sites with similar conditions the water table will be at or below daily peak tidal elevations.

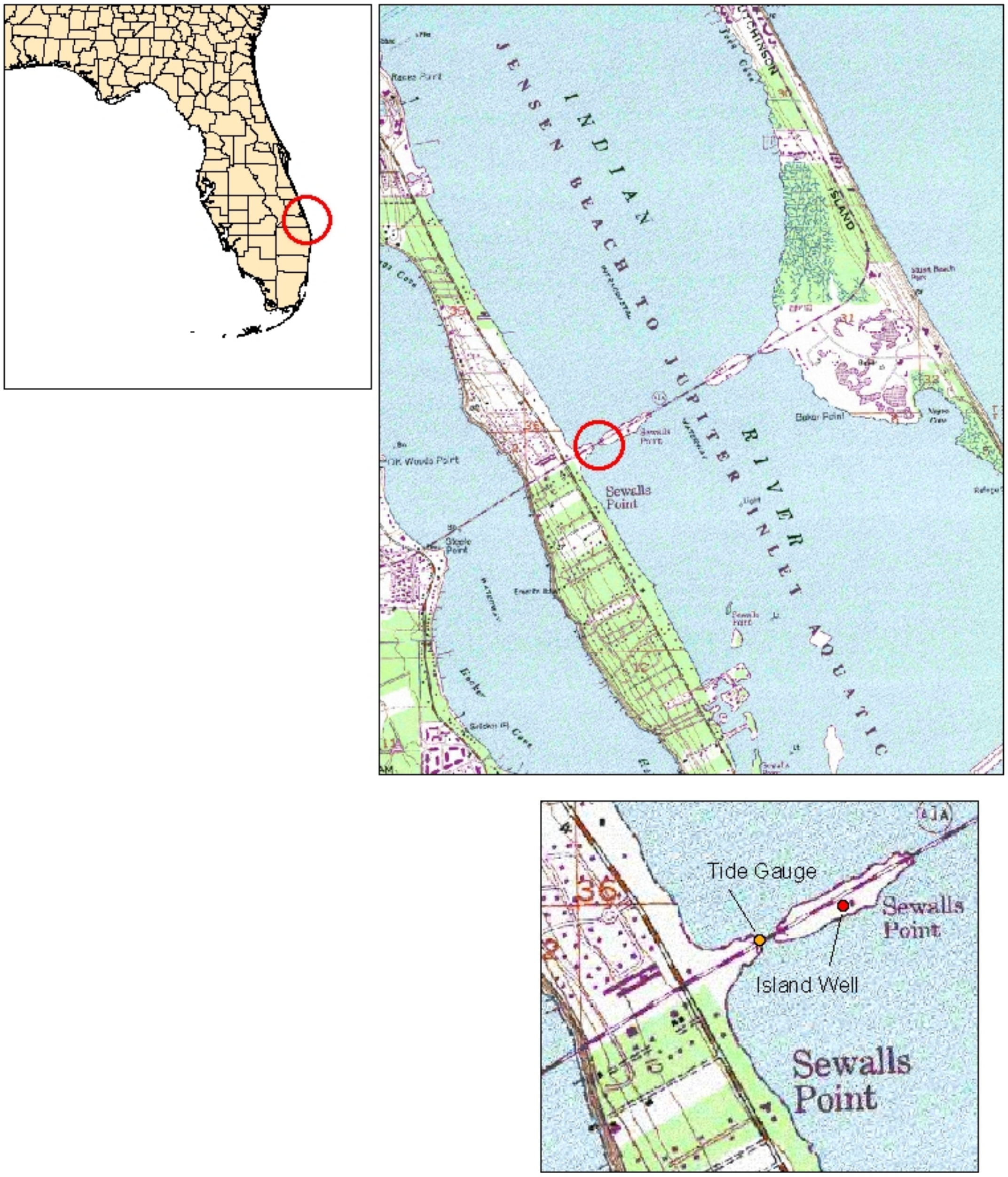


Figure 1: Stuart, FL site map. (Earnest Lyons Bridge -- West Island) Tide gauge and island well locations.

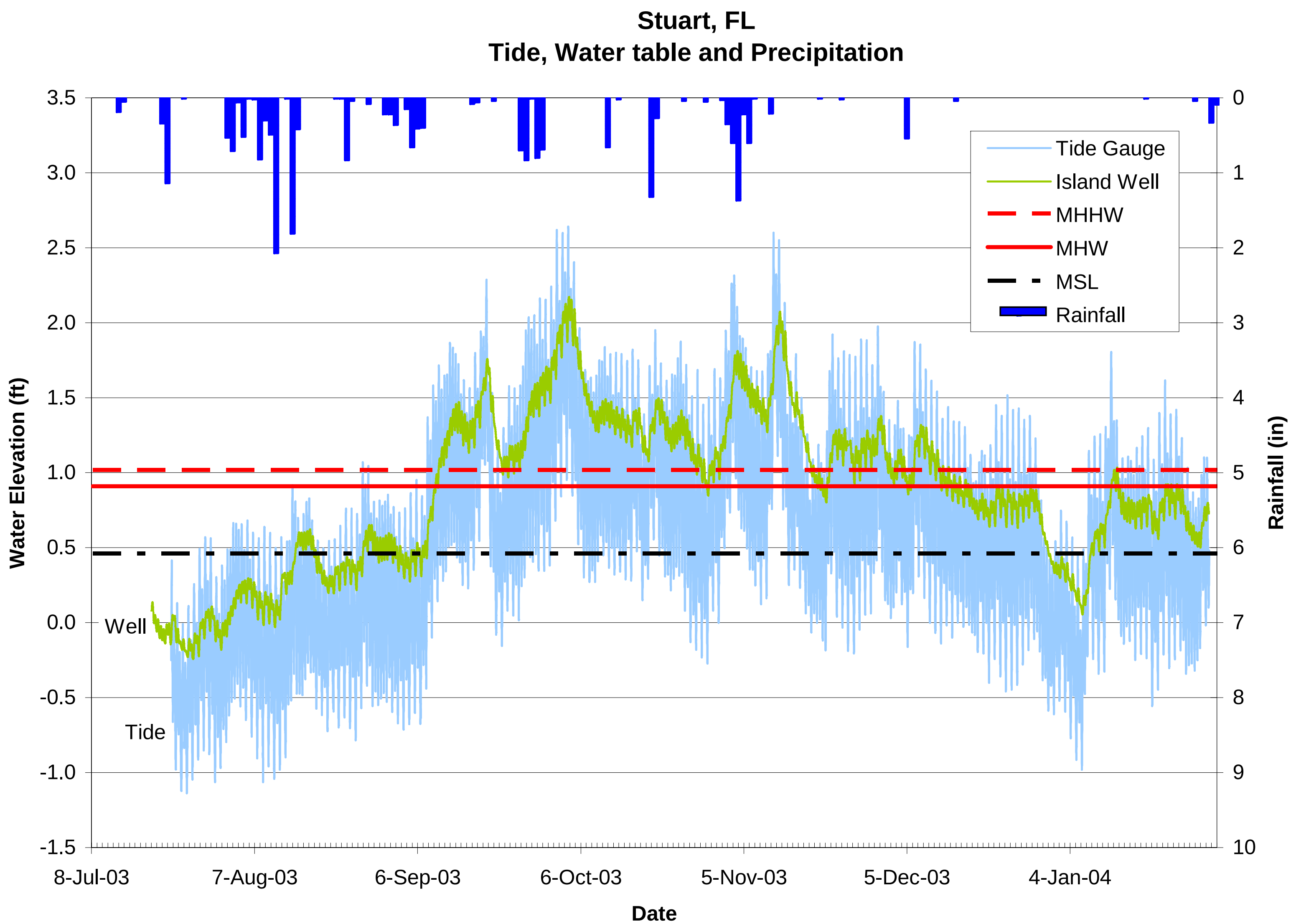


Figure 2: Transition from seasonal low to seasonal high water levels at Stuart, FL (July - September 2003). MSL, MHW, and MHHW are referenced to NGVD-29 and are based upon Tidal Epoch 1983-2001.

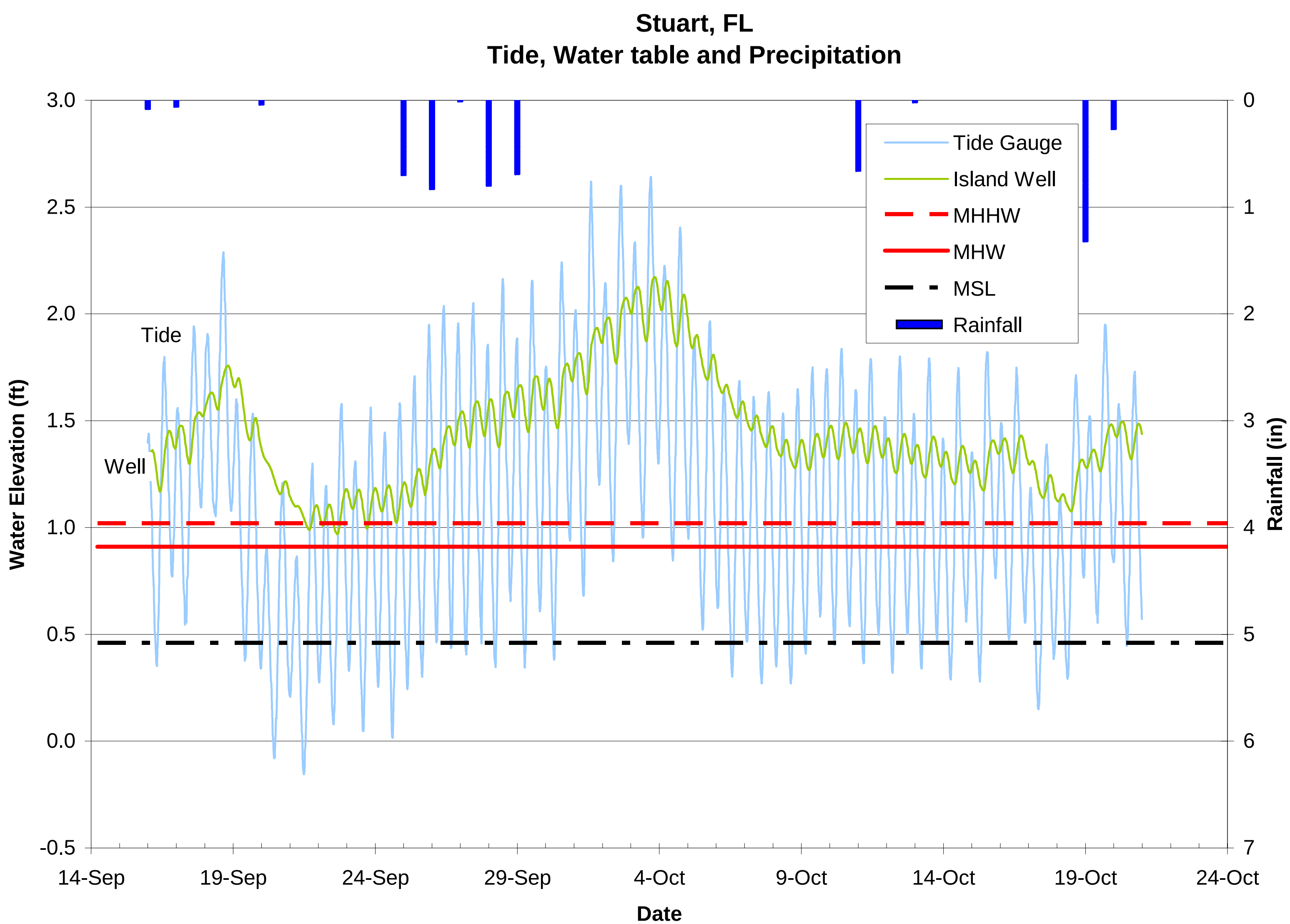


Figure 3: Recorded seasonal high water levels at Stuart, FL (September 2003). MSL, MHW, and MHHW are referenced to NGVD-29 and are based upon Tidal Epoch 1983-2001.

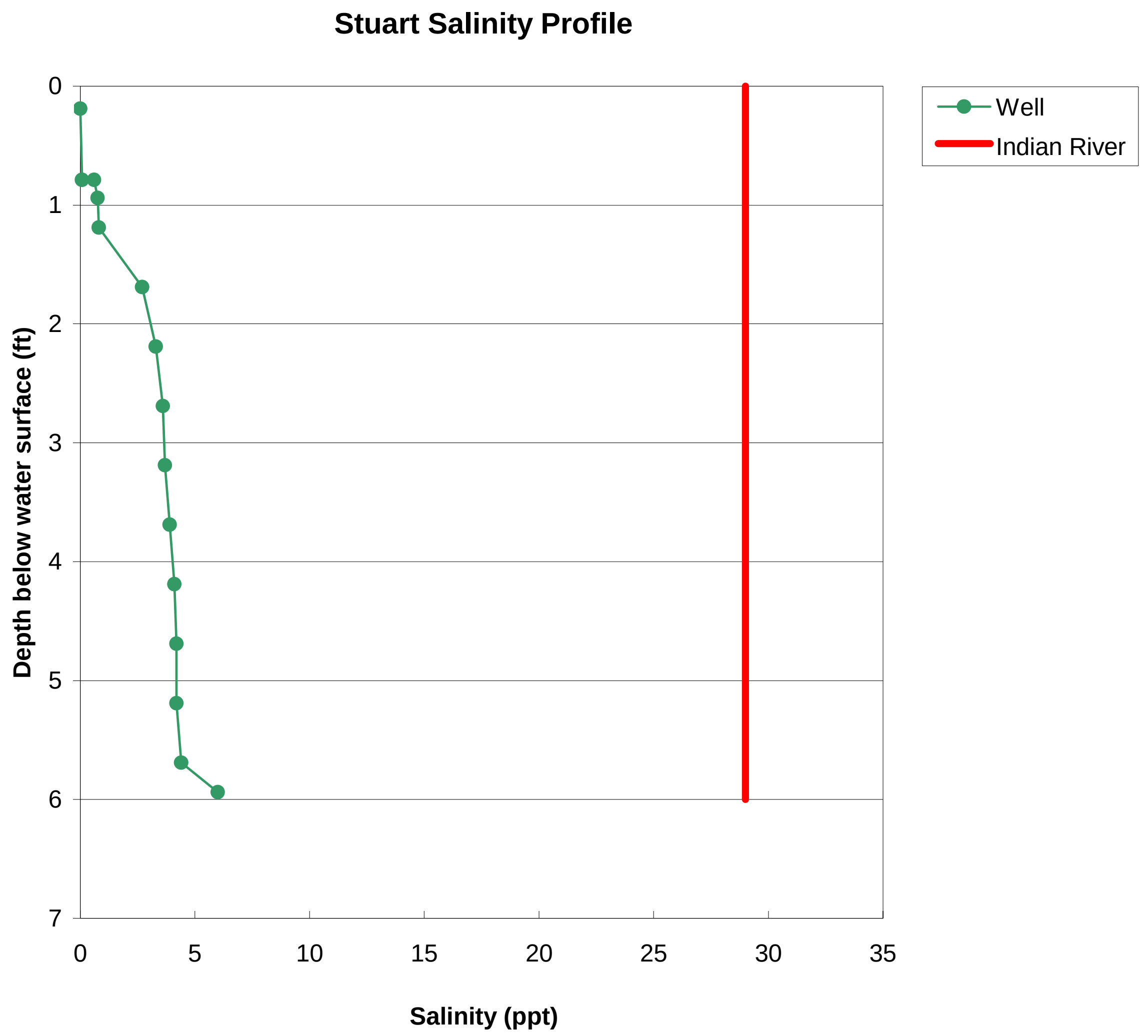


Figure 4: Salinity profiles for island well and Indian River (Stuart, FL).

Cape Canaveral Air Force Station (AFS), Launch Complex 15. The Cape Canaveral AFS site is located on an active beach face along the Atlantic coast (Figure 5). At this site water levels are being monitored at 4 locations along a transect consisting of 3 wells and a canal gage. The transect extends from just inland of the swash zone to a canal located 430 feet inland (Figure 6). Precipitation is also being monitored at this site. Observations are being recorded using a 15-minute sampling interval and have been recorded from September 2003 to the present. The site is composed predominantly of very permeable A-3 soils with similar soil properties to the Stuart site. Specific capacity (slug) tests were preformed to estimate the surficial aquifer hydraulic conductivity. However, the soil was so permeable and the water levels in the wells recovered so quickly that an exact estimate for the hydraulic conductivity could not be determined. Based upon recorded values for adjoining sites, it is estimated that the hydraulic conductivity is within the range of 40 to 60 ft/day. Salinity profiles for each of the wells are shown in Figure 7, which indicate a general trend of increasing salinity with depth. This is to be expected for conditions in which a fresh water lens exists over salt water and, Figure 7 shows the transition from freshwater to higher salinity water below. It should be noted that the profile for Well 3 shows less variation with depth. This profile is the second of two profiles recorded within a one hour timeframe. The profile was repeated due to instrument malfunction during the first run. However, it is believed that the first profile induced mixing in the well resulting in the more uniform salinity distribution shown for Well 3. The salinity profiles were used to estimate the appropriate water density for conversion of pressure transducer readings to water table elevations.

The water oscillations at this site consist of significant wave activity along with daily and monthly tidal fluctuations (Figure 8). The seasonal high values observed for November 2003 are shown in Figure 9 and as an interpolated water table in figure 10. Data recorded to date indicate that prior to the storms of 2004, the effects of tidal and wave activity were noticeable at distances up to 360 ft from shore, with the magnitude of water table fluctuations decreasing as the distance from shore increased (Figures 9 and 10). Extreme high water conditions were observed at this site during the hurricanes of 2004 as shown in Figure 11. The date of landfall for each storm is indicated in Figure 11. Not all of the storms passed directly over CCAFS, however the effect of each storm can be seen in the recorded water levels at the site. Following storms Charley, Frances, and Jeanne portions of the site were submerged, and the beach face along with the site topography between the canal and dunes were altered. Inspection of Figure 11 shows that the level of connection between tidal variations and canal water levels increased following the storms. This is apparent due to the increased variability in canal water levels when compared to Figures 8 and 9.

The primary difference between the CCAFS site and the Stuart site is the presence of considerable wave activity which contributes to water table over-height or super-elevation conditions. Water table over-height conditions are clearly present in figures 8, 9, and 11. For discussion purposes, the water table over-height conditions for the November seasonal high (Figure 9) are most evident, as the water level is greater at the dune and decreases when moving inland from Well 1 to the canal. Such conditions are induced by the combination of a sloping beach face, wave activity, and tidal variation, which act to elevate the water table and induce a net flow of groundwater inland as shown in Figure 12 (Turner, et al. 1997 and Nielsen 1999). The water table over-height conditions subside for a short period from November 17 to November 20. The water table over-height conditions are again evident following November 20 but they are not as significant.

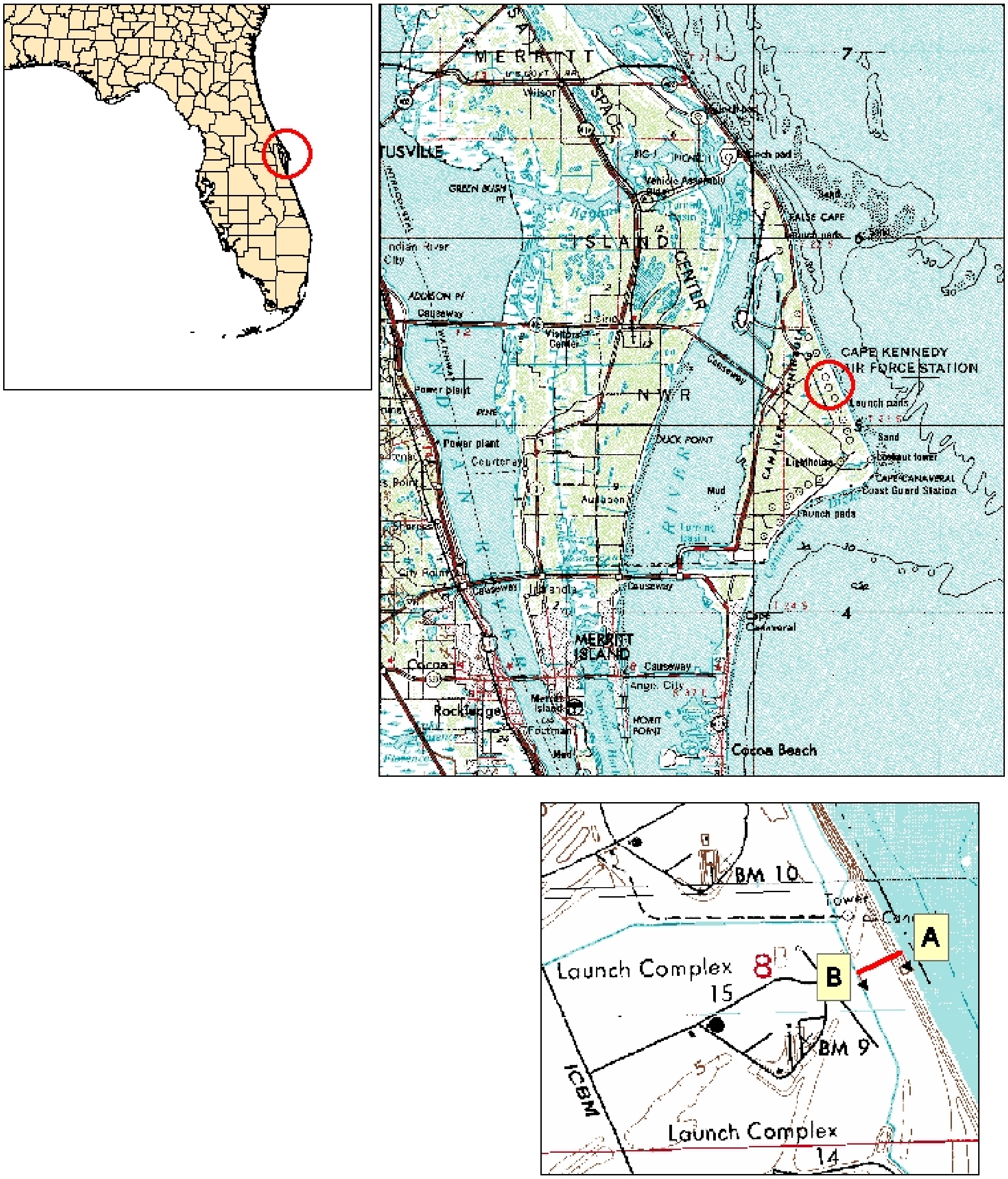


Figure 5: Cape Canaveral AFS site map (Launch Complex 15). Maps show site location and well orientation along transect A – B.

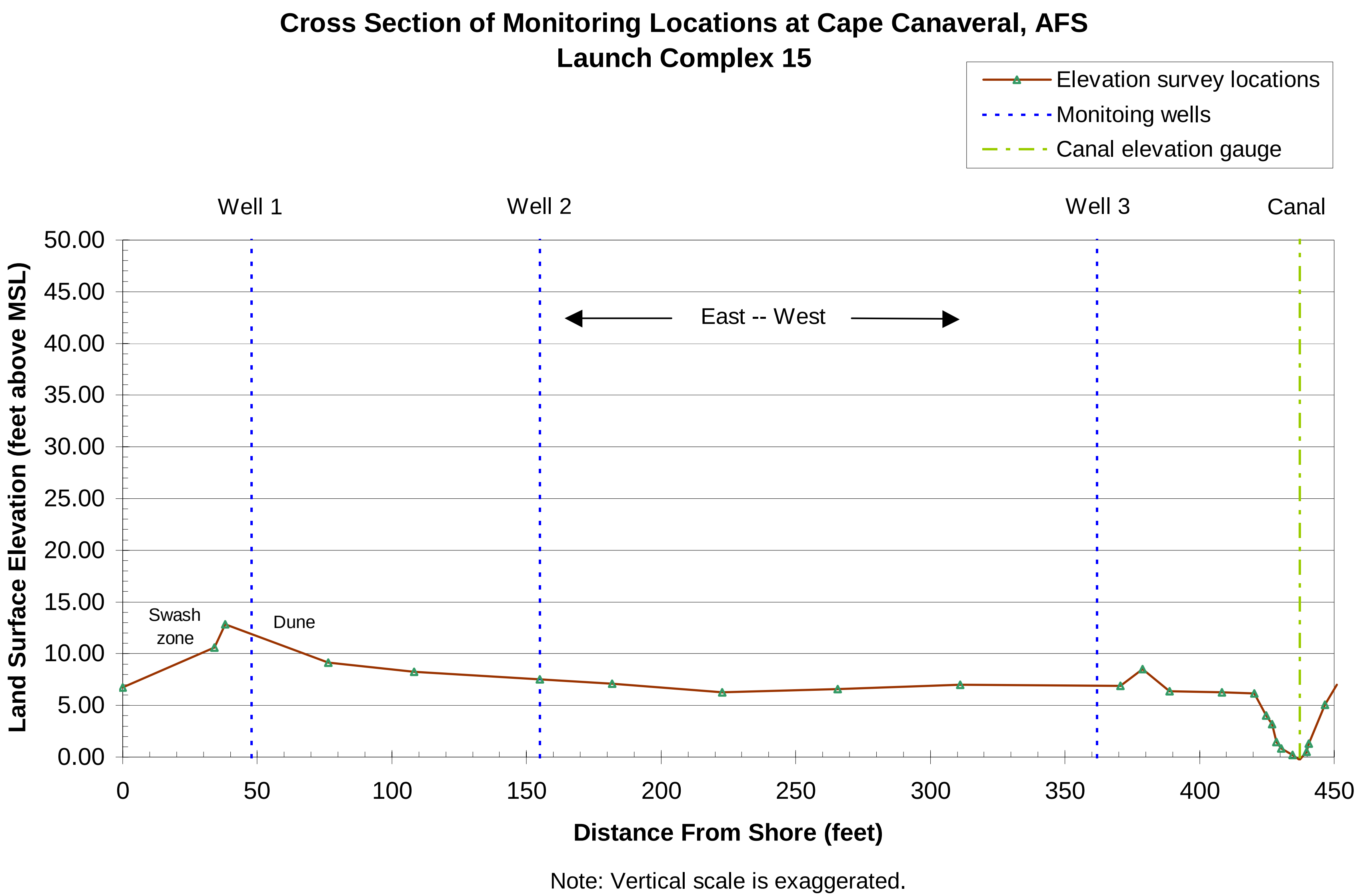


Figure 6: Monitoring well transect looking southeast (looking down shore).

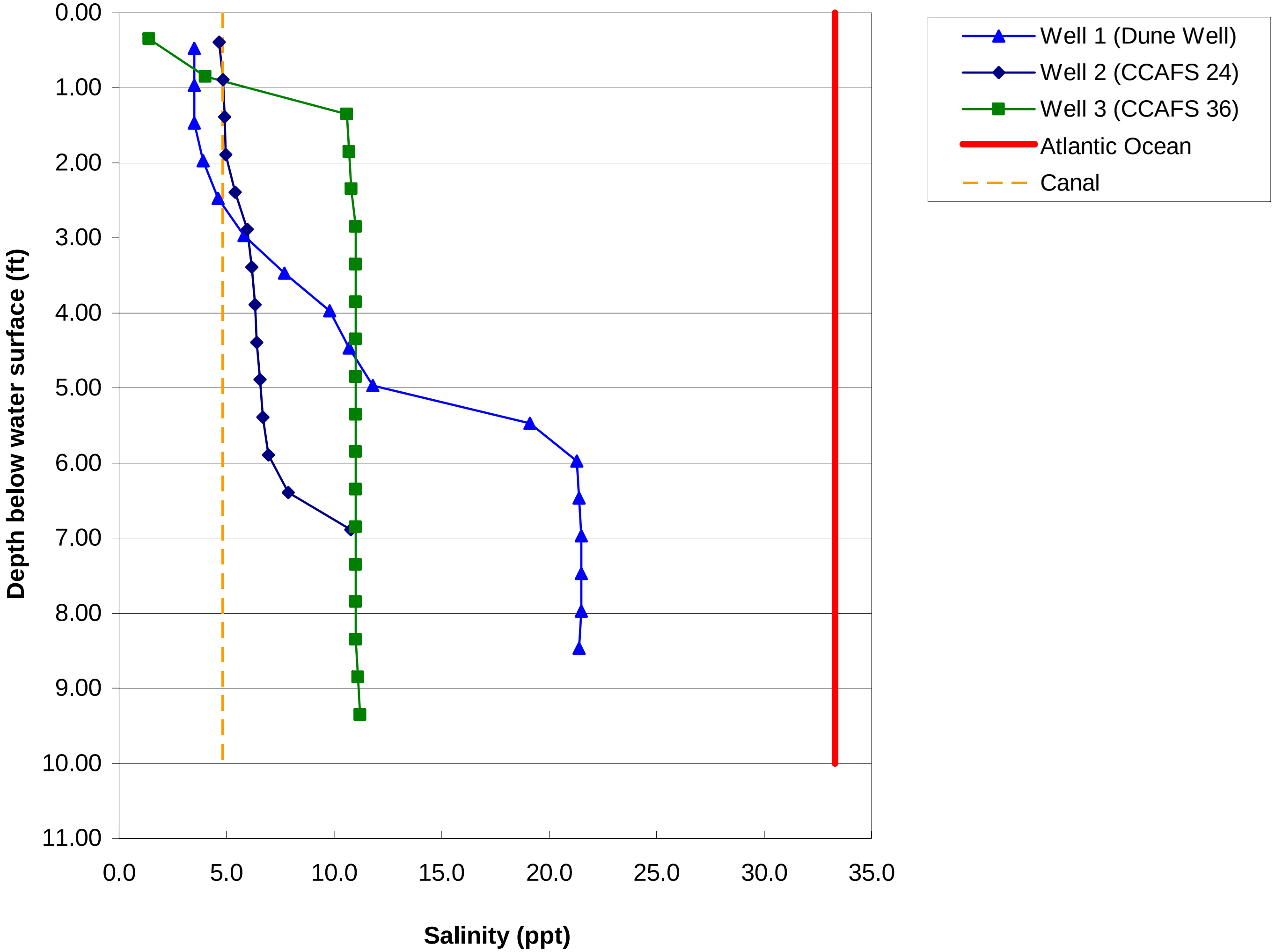


Figure 7: Salinity profiles for wells, canal, and Atlantic Ocean (Cape Canaveral AFS).

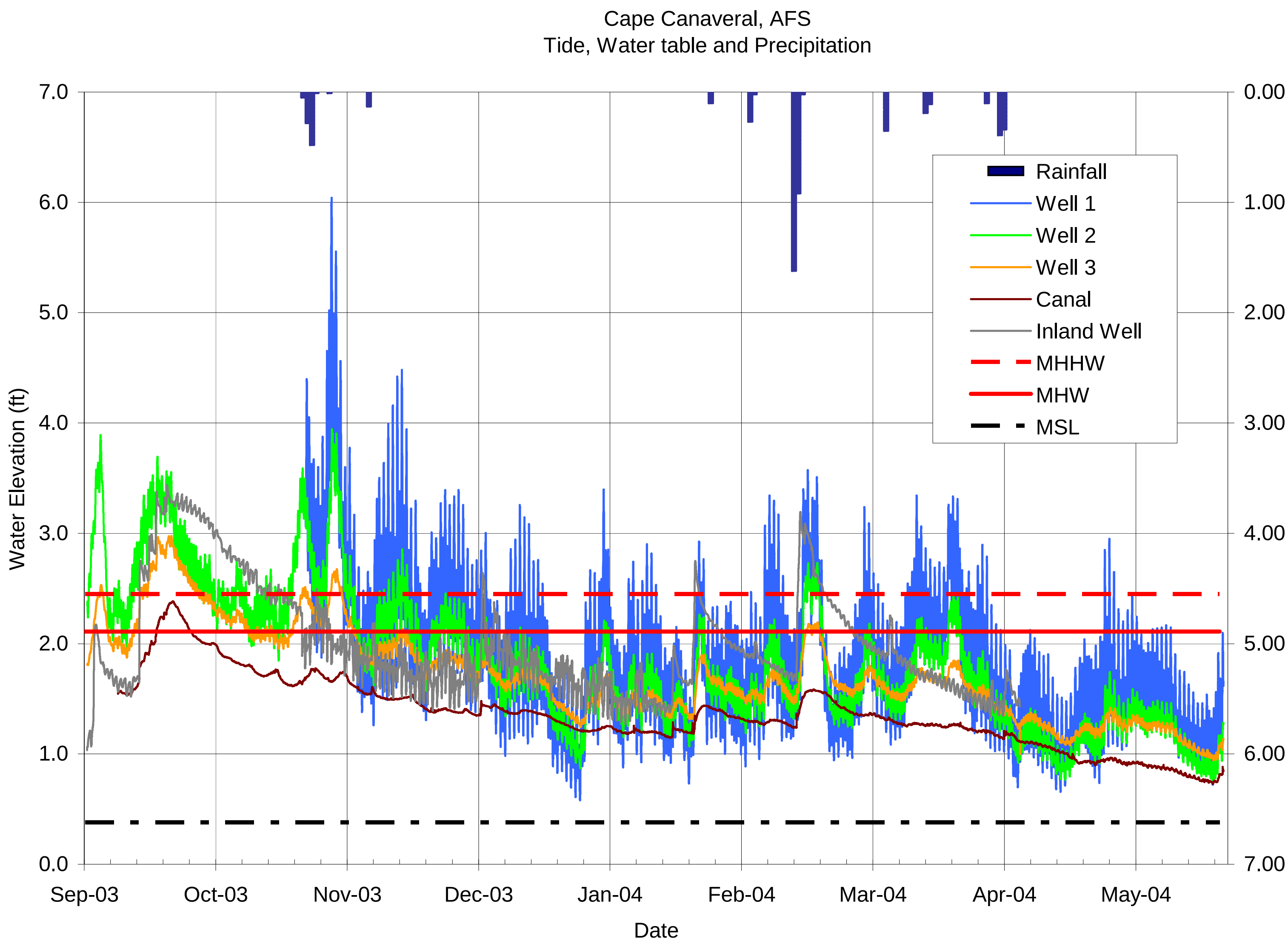


Figure 8: Recorded water levels at Cape Canaveral AFS (September 2003 to May 2004). MSL, MHW, and MHHW are referenced to NGVD-29 and are based upon Tidal Epoch 1983-2001.

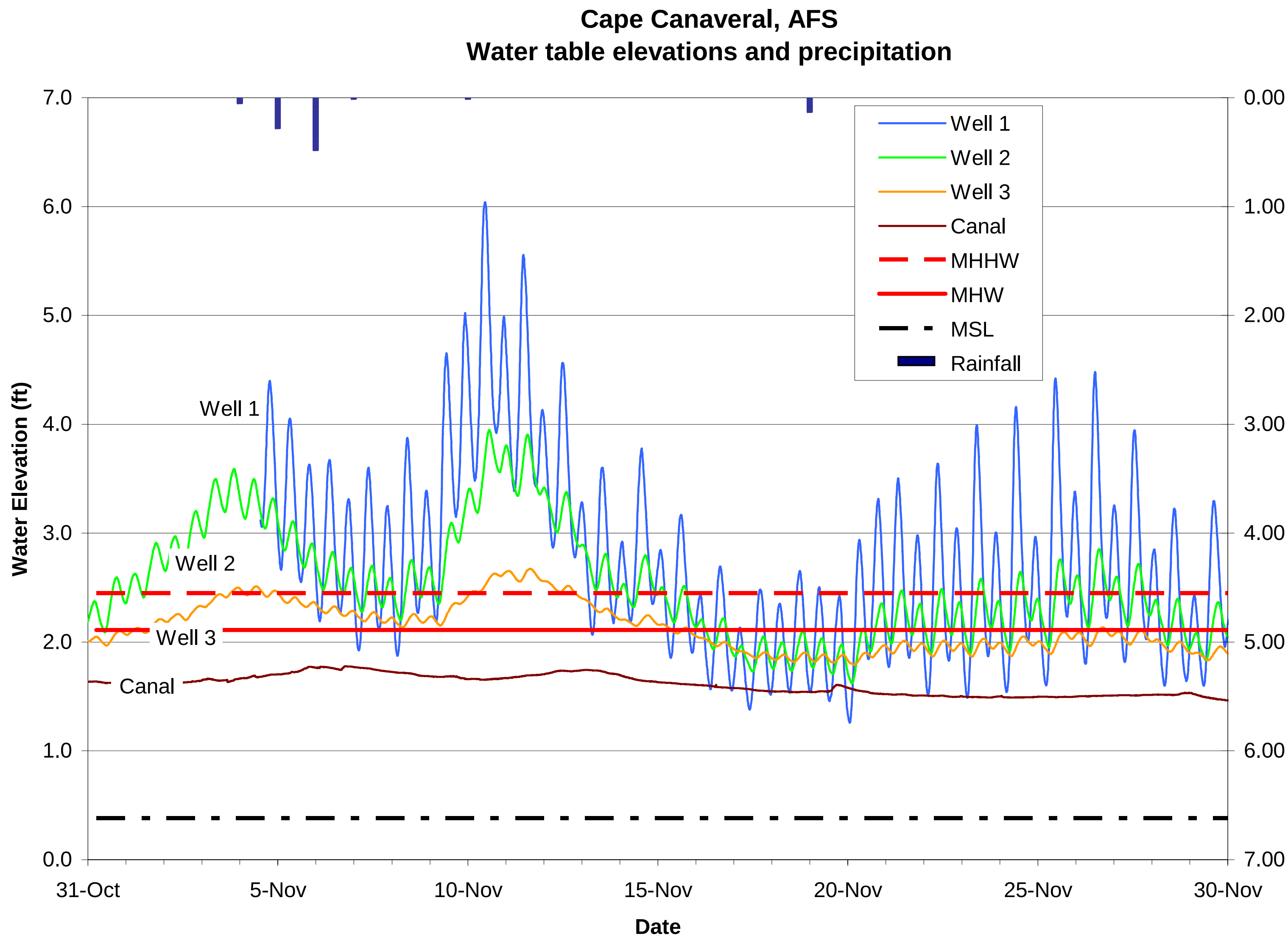


Figure 9: Recorded seasonal high water levels at Cape Canaveral AFS (November 2003). MSL, MHW, and MHHW are referenced to NGVD-29 and are based upon Tidal Epoch 1983-2001.

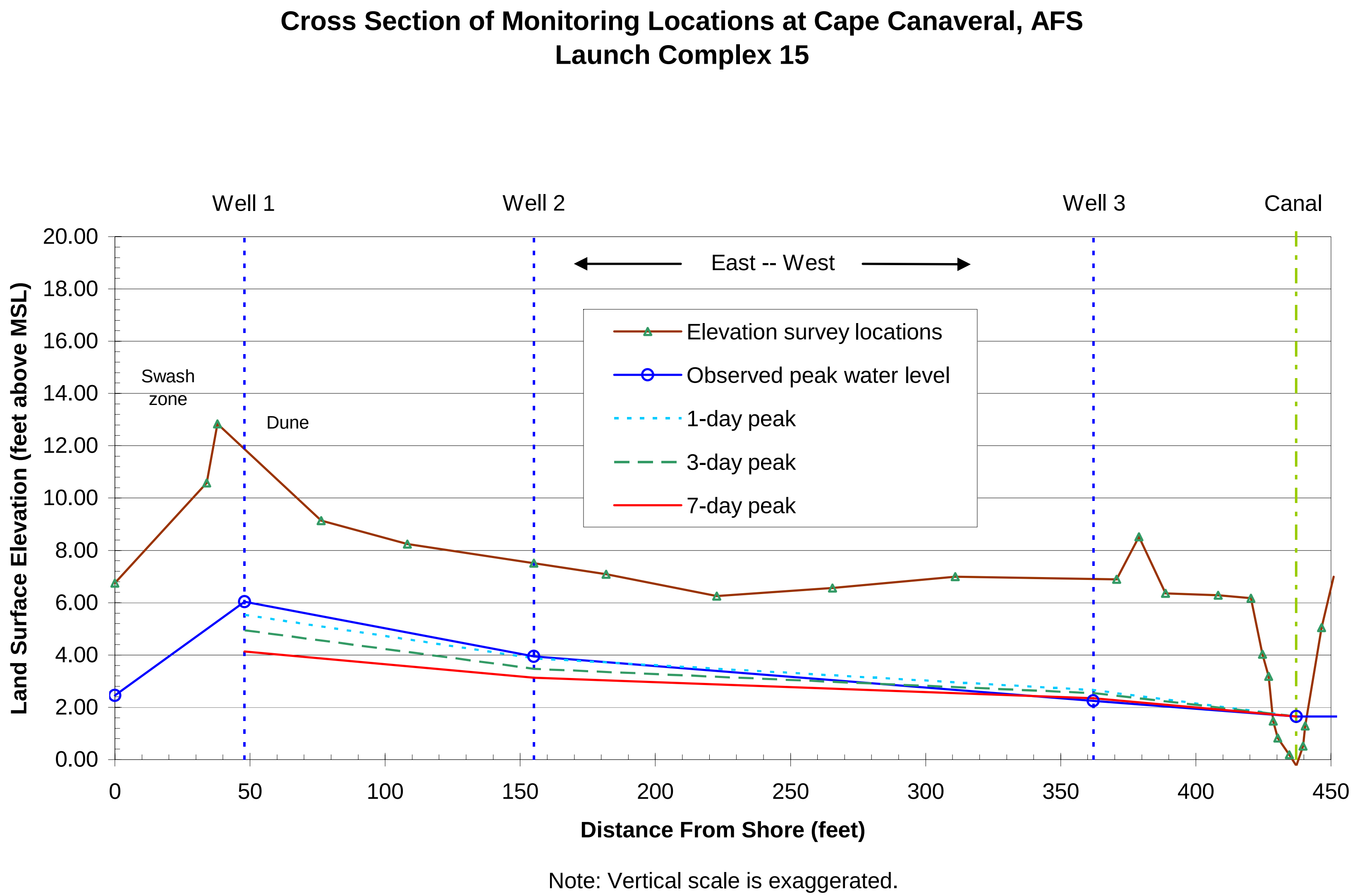


Figure 10: Transect showing observed seasonal high water levels at Cape Canaveral AFS (November 2003)

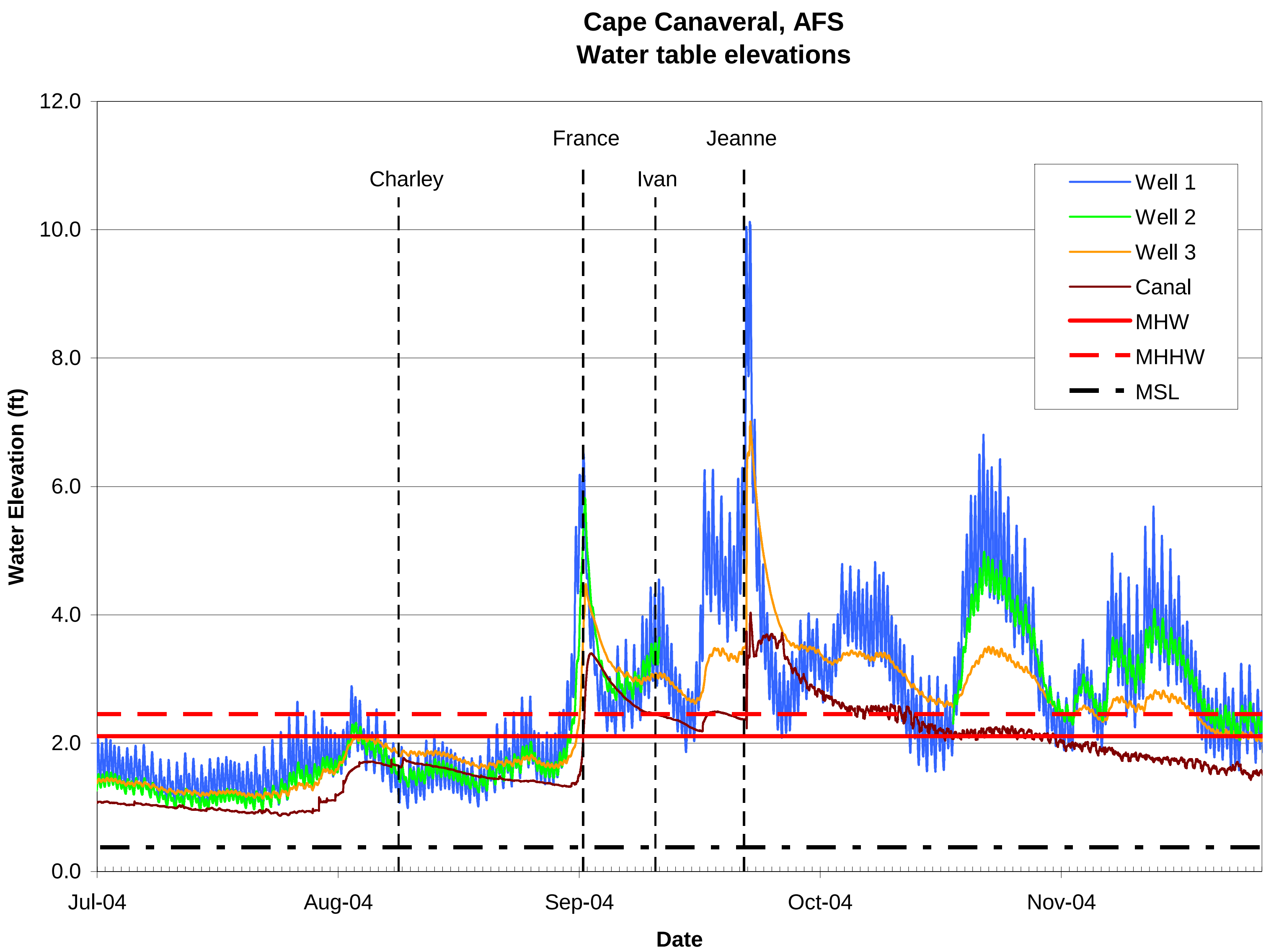


Figure 11: Recorded extreme high water levels at Cape Canaveral AFS (May 2004 to April 2005). MSL, MHW, and MHHW are referenced to NGVD-29 and are based upon Tidal Epoch 1983-2001.

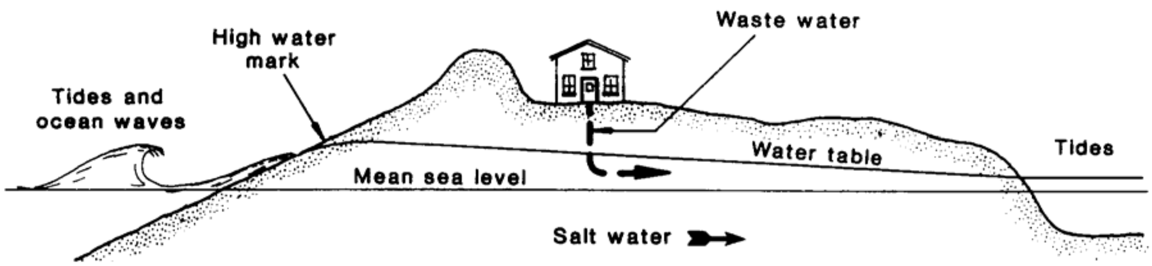


Figure 12: Combined effect of tides and ocean waves on water table elevations. The water table under coastal barriers will be highest near the ocean because of the action of waves and tides. Consequently there is a net flow of groundwater towards the continent and the fresh water lens tends to be very thin (From Nielsen, 1999)

Analysis of water table levels and known boundary conditions

The purpose of this task is to consider the relationship between water table elevations and known boundary conditions. Where the term "known boundary" refers to cases in which there is one known boundary condition that predominantly affects the water table. Two known boundary conditions were considered in this study. The predominant focus of this work was to investigate SHGWT elevations affected by tidal boundaries. While a secondary focus was to consider SHGWT elevations affected by water levels in adjoining canals.

Tidal Influences

When discussing water levels and flow in porous media one of the most common terms used is hydraulic conductivity, K, which is a measure of the ease with which a fluid flows through a saturated porous media. It should be noted that hydraulic conductivity is a property of both the fluid and the porous media. The hydraulic conductivity is determined as the constant of proportionality from Darcy's Equation which describes flow through a porous media.

$$Q = -KA\frac{dh}{dL} \tag{3}$$

Where Q (L^3/T) is the volumetric flowrate of fluid through cross-sectional area A (L^2) induced by the gradient dh/dL (L/L = dimensionless ratio) (Batu, 1998). Often times the term permeability is used interchangeably with hydraulic conductivity, but for the sake of consistency the term hydraulic conductivity will be used throughout this report. By default the term hydraulic conductivity will be used to refer to horizontal hydraulic conductivity and it should be noted that vertical hydraulic conductivities may be one to three orders of magnitude less than the horizontal hydraulic conductivity depending on the geology of the site (Batu, 1998). Typical values for hydraulic conductivities based upon the type of porous material are summarized in Table 3.

When considering water levels in an unconfined aquifer, the storage capacity of the aquifer is represented as the specific yield, S_y. The specific yield is a measure of the water yielded by gravity drainage when the water table of an unconfined aquifer declines (Batu, 1998). The amount of water retained by the aquifer is the specific retention, S_r, and the sum of the two is equal to the aquifer porosity, n.

$$n = S_y + S_r \tag{4}$$

It should be noted that hydraulic conductivity is a property of the porous media and the fluid, while the specific yield is a property of the aquifer. As such, the specific yield is typically less variable than the hydraulic conductivity (Dawson and Istok, 1991). Typical values for specific yield based upon porous material are presented in Table 3.

Both the hydraulic conductivity and specific yield are necessary in order to consider water table fluctuations affected by known boundary conditions such as tidal influences.

For a site in which the primary source of water table variation is tidal influences (no waves) an analytical solution exists to describe the water table height h_s as a function of a static ocean level assumed to be mean sea level (MSL) (Figure 13).

$$h_s = \sqrt{D^2 + \frac{h_r^2 + \frac{iL^2}{K} - D^2}{L} x - \frac{i}{K} x^2} \tag{5}$$

Where D is the depth below MSL of an impermeable layer, h_r is the water table height at a distance x = L, i is a steady recharge rate, and K is the hydraulic conductivity (Nielsen, 1999). Equation 5 can be used to predict the expected range for the peak groundwater level at the Stuart, FL site. The range is estimated based upon expected values for the aquifer thickness (D), hydraulic conductivity (K), and rainfall (i), and MSL. The equation predicted range (2.31 to 2.73 ft) is compared to the observed peak water level in figure 14, which indicates that the observed peak water level for the year 2003 fell within the equation predicted range. Figure 14 also includes multiple estimates for the seasonal high (peak) groundwater elevation. The absolute peak, 1-day, 3-day, and 7-day peaks are shown. These different values are included to address the question, "Over what time period should the SHGWT be defined?" It can be seen that as the period of observation increases, the estimated peak value decreases. Also, it should be noted that the absolute peak can only be observed if detailed monitoring is undertaken.

The inland extent of tidal variations for an unconfined aquifer can be estimated using the analytical solution below (Turner et al., 1997).

$$h_x = h_o e^{-x\sqrt{\frac{\pi S_y}{t_o T}}} \tag{6}$$

where h_x is the amplitude of tide-induced fluctuations at a distance x, h_o is the tidal amplitude, S_y is the specific yield, t_o is the tidal period, and T is the transmissivity, which is the product of hydraulic conductivity (K) and aquifer thickness (b). Application of equation 6 with representative values for each of the AASHTO soil classifications was used to produce figure 15 (assuming a tidal amplitude of 2 ft and aquifer depth of 25 ft). It can be seen that the inland extent of tidal variations decreases with decreasing hydraulic conductivity. The inland extent of tidal variations for the representative values and assumed conditions are summarized in Table 4. Equation 6 can be used to predict the inland extent of tidal variations at the CCAFS site as shown in figure 16. It is apparent that the results from equation 6 under-estimate the amplitude of water table fluctuations and the inland extent of their effect.

What should be noted is that up to this point in the discussion, only tidal variations have been considered. The combined effects of waves and tidal activity are not as easily predicted. For tidally influenced sites, an estimate may be made for the distance of influence and possible relationships for water table heights can be based upon equation 5. However, for sites with significant wave activity the problem is much more complex due to water table over height conditions where the shape of beach is a primary factor controlling over-height.

Combined Tidal and Wave Influences

The combined effects of tidal variation and wave activity will typically increase the inland extent of water table fluctuations and may lead to the presence of water table over-height conditions as mentioned previously. Figure 17 provides a schematic of wave induced variations on the water table. The long-term average level of the ocean is represented as mean sea level (MSL) while the still water surface (SWS) is the sea surface that would exist in the absence of wind and waves. Short term averaging of the water level is used to estimate the mean water surface (MWS), which intersects the beach at the shoreline (SL) and becomes the water table (Nielsen, 1999). Due to the affect of wave activity the water table oscillates within an envelope with upper and lower limits (UENV and LENV). The mounded water table tapers off in the inland direction and can be represented as an average super elevation η^+ above mean sea level (Nielsen, 1999). In order to accurately predict η^+ one must consider the shape of the beach face contributing to over-height, wave generated over-height, and wind setup over-height. Each of these factors are variable and site-specific. As such, site specific observations are necessary in order to estimate over height conditions.

Canal influenced water table elevations

Many of the canals within the state of Florida are affected by tidal variations. As such, the water table within the adjoining aquifer can be affected by tidal variations. A schematic showing the typical relationship between canal and water table levels is shown in Figure 18. The inland extent of tidal variations from a canal into an adjoining aquifer can be estimated as discussed for coastal conditions using equation 6 along with representative values for hydraulic conductivity and specific yield. As such, Figure 15 and Table 4 provide general estimates for the inland extent of water table fluctuations induced by tidal variations in an adjoining canal (assuming an aquifer depth of 25 ft) as summarized to AASHTO soil classifications.

Similarly, water table elevations may be estimated using equation 5 along with recorded canal levels, provided that estimates for water levels (h_r) at an inland location ($x = L$) are available for reference. Because equation 5 is based upon static water levels for the bounding water body (ocean or canal) it can be applied for cases of tidally influenced canal levels or for annual average canal levels with no tidal activity.

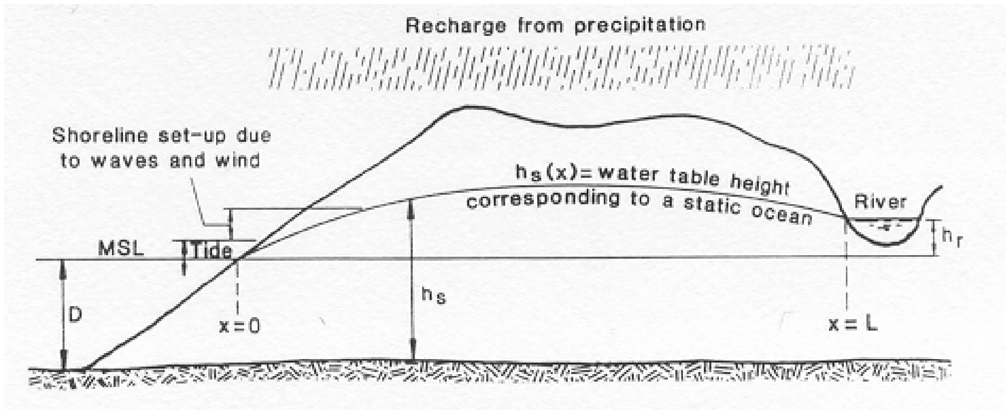


Figure 13. Estimated water table height corresponding to a static ocean (no waves) (From Nielsen, 1999).

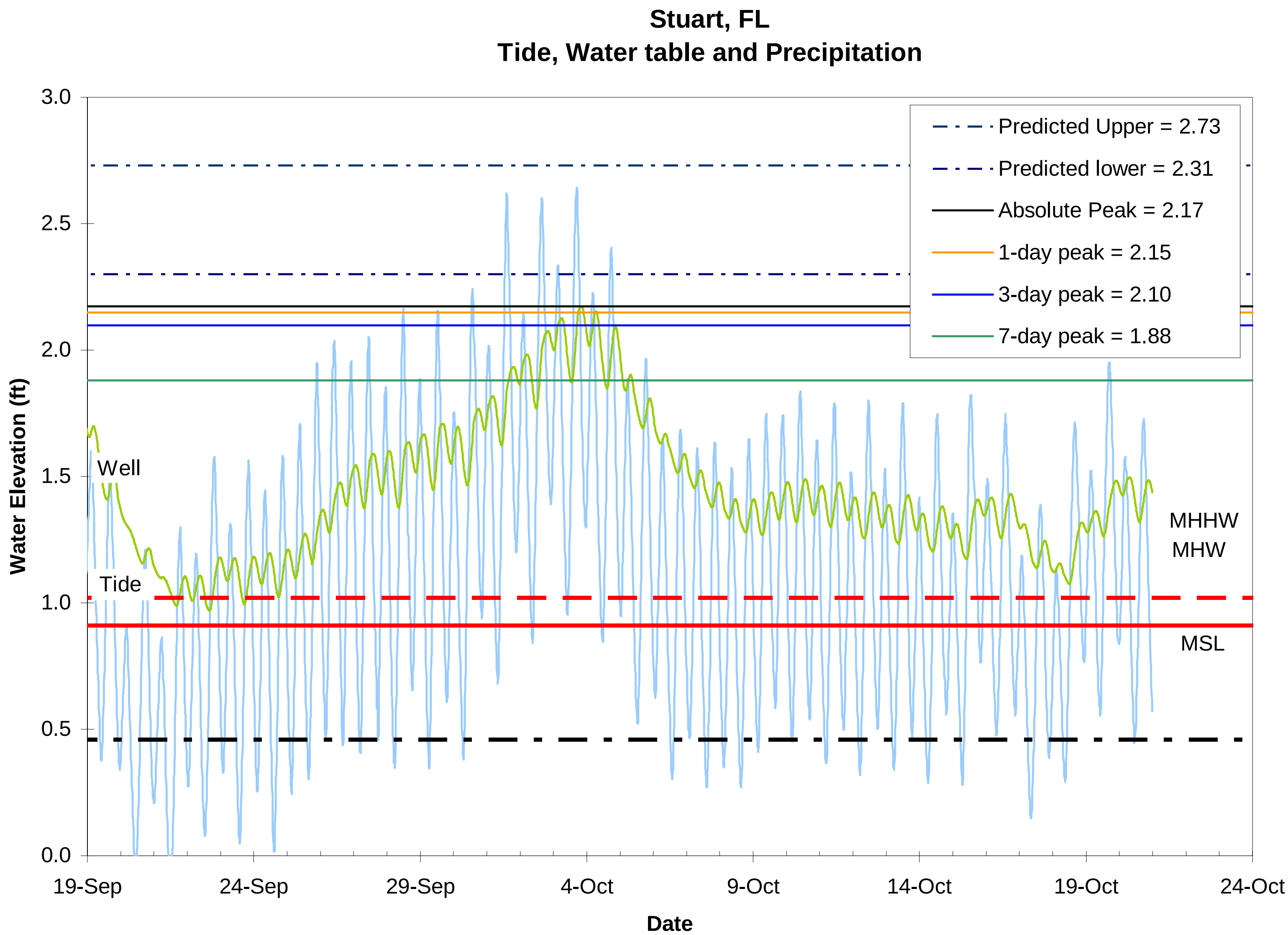


Figure 14: Comparison of predicted and observed peak water levels for Stuart, FL (September 2003).

Table 2. AASHTO soil classifications.

CLASSIFICATION OF HIGHWAY SUBGRADE MATERIALS (With suggested subgroups)											
General Classification	Granular Materials (35% or less passing No. 200)							Silt-Clay Materials (More than 35% passing #200)			
Group Classification	A-1		A-3	A-2				A-4	A-5	A-6	A-7
	A-1-a	A-1-b		A-2-4	A-2-5	A-2-6	A-2-7				A-7-5 A-7-6
Sieve Analysis, Percent Passing:											
No. 10	0-50										
No. 40	0-30	0-50	51-100								
No. 200	0-15	0-25	0-10	0-35	0-35	0-35	0-35	36-100	36-100	36-100	36-100
Characteristics of fraction passing # 40:											
Liquid Limit				0-40	41+	0-40	41+	0-40	41+	0-40	41+
Plasticity Index	0-6		N.P.	0-10	0-10	11+	11+	0-10	0-10	11+	11+
Group Index	0		0	0		0-4		0-8	0-12	0-16	0-20
Usual Types of Significicant Constituent Materials	Stone Fragments, Gravel and Sand		Fine Sand	Silty or Clayey Gravel and Sand				Silty Soils		Clayey Soils	
General Rating as Subgrade	Excellent to Good					Fair to Poor					

Table 3. Typical values of hydraulic conductivity and specific yield generalized to AASHTO soil classifications.

Material	AASHTO Classification	Hydraulic Conductivity (cm/s)			Specific Yield (%)		
		Maximum	Minimum	Average	Maximum	Minimum	Average
Gravel	A-1	3.12E+00	03.00E-02	4.03E-01	13	25	21
Coarse Sand	A-1	6.61E-01	9.00E-05	5.20E-02	18	43	30
Medium Sand	A-1	5.67E-02	9.00E-05	1.65E-02	16	46	32
Fine Sand	A-3	1.89E-02	2.00E-05	2.28E-03	1	46	33
Silt	A-4, A-5	7.09E-04	9.00E-09	2.83E-05	1	39	20
Silty/Clayey Sand	A-2-4	1.00E-03	1.00E-08	1.00E-05	3	12	7
Clay	A-6, A-7	4.70E-07	1.00E-09	9.00E-08	1	18	6

Source: Batu, 1998, Dawson and Istok, 1991

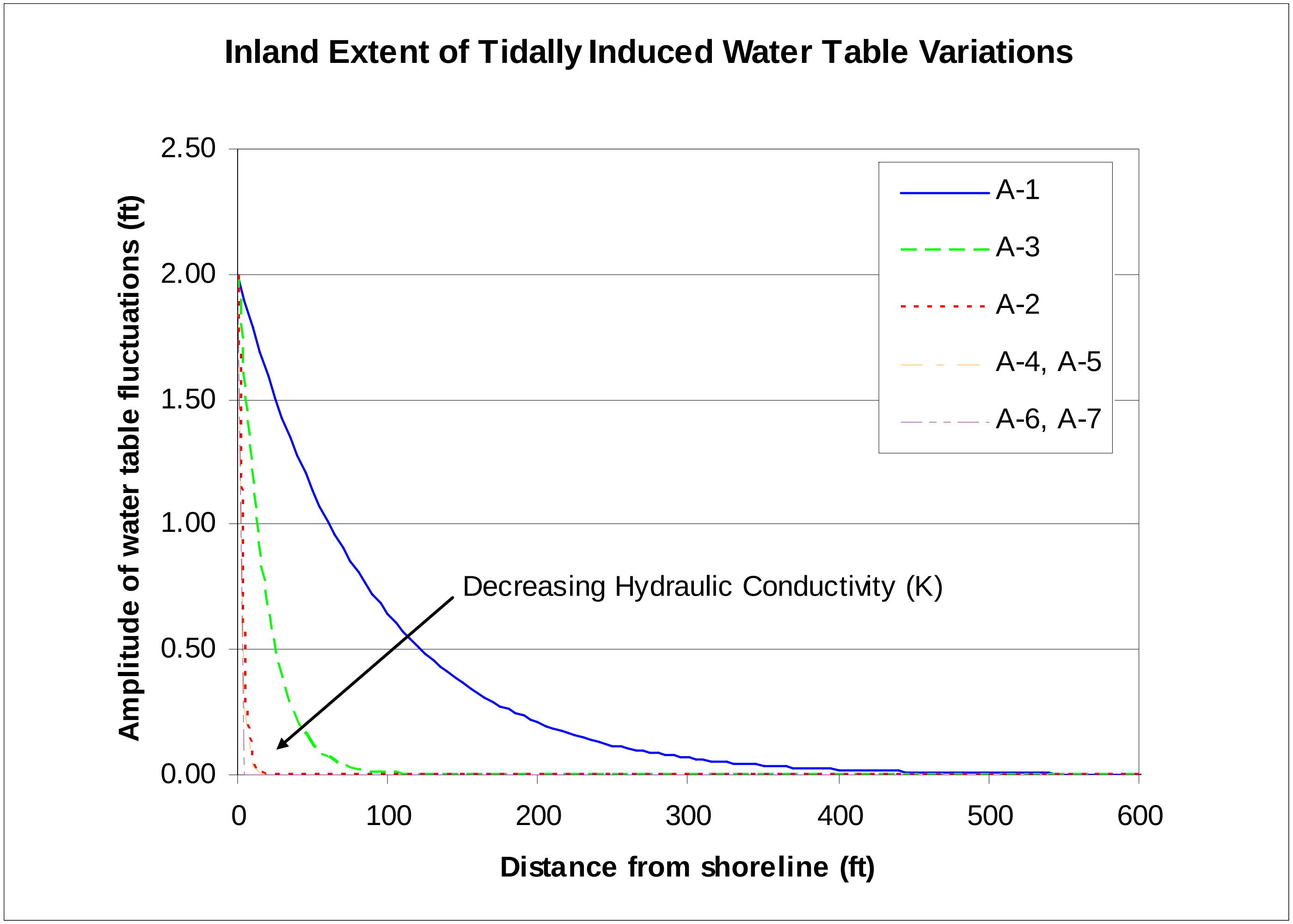


Figure 15. General estimates for the inland extent of tidally induced water table variations as a function of AASHTO soil classification. Assuming tidal amplitude of 2 ft and an aquifer depth of 25 ft.

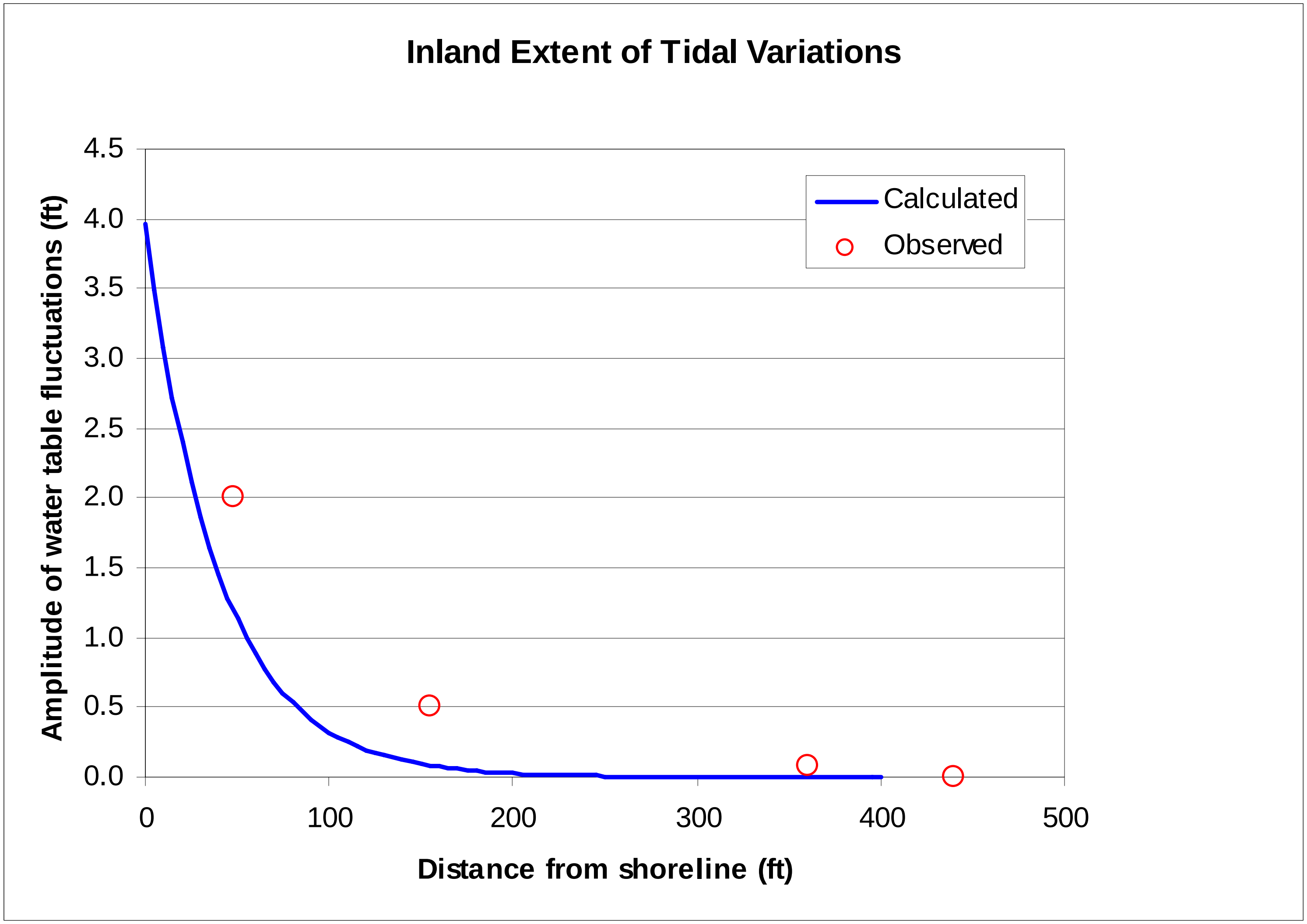
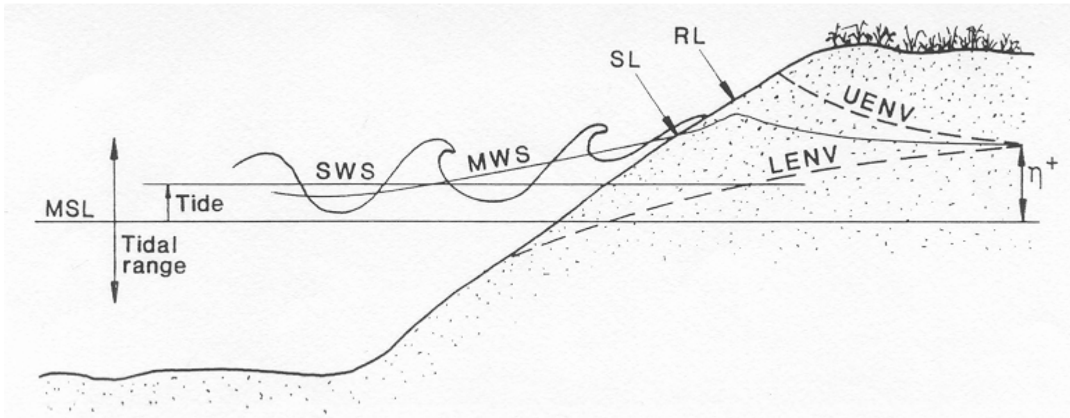


Figure 16. Comparison of calculated and observed inland extent of tidally induced water table at CCAFS (November, 2003).

Table 4. Inland extent of tidally induced water table variations generalized for AASHTO soil classifications (Assuming depth to base of aquifer of 25 ft).

AASHTO Classification	Inland Extent (ft)	
	Lower Bound	Upper Bound
A-1	400	--
A-3	70	400
A-2	10	70
A-4, A-5	5	10
A-6, A-7	0	5



MSL – mean sea level
SWS – still water surface
MWS – mean water surface
SL – shoreline
RL – runup line
UENV – upper envelope
LENV – lower envelope
η^+ - average super elevation above mean sea level

Figure 17. Schematic of wave induced variations in the water table (From Nielsen, 1999).

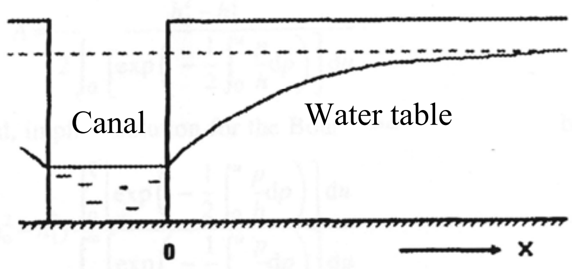


Figure 18: Water table elevation with respect to canal water levels.

Summary and Conclusions

This project was composed of three major tasks: a SHGWT literature review, SHGWT field monitoring, and analysis of water table data and relationships.

Literature review

A literature review was performed to consider existing methods and procedures for estimating seasonal high groundwater table elevations. A summary of the literature review with recommendations is provided below

- Based upon the numerous factors that affect the water table, it is evident that one indicator will not provide a reliable estimate for seasonal high water table levels under all conditions.
- <u>Recommendation:</u> Establish a set of guidelines for estimating seasonal high water table elevations while taking into account site-specific conditions.
- There are considerable differences among the definitions and methods presented by each regulating agency for determining SHGWT.
- <u>Recommendation:</u> Encourage a dialogue towards developing a statewide standard operating procedure for estimating SHGWT elevations.

Field Monitoring

Two field sites were instrumented for this project in order to investigate the influence of tides and waves on the water table. The two sites differ based upon their coastal setting and the predominant types of oscillations influencing the water table. The Stuart, FL site was established in order to observe the effects of tidal influences with minimal to no wave activity. The Cape Canaveral Air Force Station (CCAFS) site was established in order to observe the effects of both tidal and wave activities while considering the distance over which these influences typically occur. Observations for both sites with recommendations are summarized below.

Stuart, FL (Earnest Lyons Bridge)

- Coastal setting: Located on small island near western shore of the Indian River.
- At this site open water tidal elevation, water table elevation, and precipitation were monitored using a 15-minute sampling interval from March 2003 – July 2004.
- The primary water oscillations observed at this site are daily and monthly tidal fluctuations (minimal wave activity).
- The analytical solution presented (equation 5) provided reasonable estimates for the observed peak water levels.
- <u>Recommendations:</u> The observed relationship between water table and tidal elevations during typical peak conditions suggest that for sites with similar characteristics the water table will not typically exceed daily peak tidal elevations.

Cape Canaveral AFS, Launch Complex 15

- Coastal setting: Located on active beach face along the Atlantic coast.

- At this site water levels are being monitored at 4 locations along a transect consisting of 3 wells and a canal gage. The transect extends from just inland of the swash zone to a canal located 430 feet inland. Precipitation is also being monitored at this site. Observations are being recorded using a 15-minute sampling interval, and have been recorded since September 2003
- The water oscillations at this site consist of significant wave activity along with daily and monthly tidal fluctuations.
- Data recorded to date indicate that the effects of tidal and wave activity are noticeable at a distance of 360 ft from shore, with the magnitude of water table fluctuations decreasing as the distance from shore increases.
- Water table over-height or super-elevation conditions are observed at this site. Such conditions are induced by the combination of a sloping beach face, wave activity, and tidal variation, which act to elevate the water table and induce a net flow of groundwater inland.
- Recommendations: For sites with similar conditions to Cape Canaveral AFS (considerable wave activity with a sloping beach face) water table over-height conditions will most likely be present. As such, site specific observations are necessary in order to consider water table over height conditions.

Analysis of water table levels and known boundary conditions

Tidal influences

Analytical solutions exist which relate tidal levels to water table elevations. For sites where water fluctuations are predominantly tidal (minimal wave activity) these analytical solutions can be used to estimate the inland extent of tidal variations based upon historic tidal information (MSL, MHW, MHHW).

For sites at which there is significant wave activity and sloping beach faces, estimating the induced variation in the water table is a far more complex problem due to water table over-height or super-elevation conditions. In order to accurately estimate the magnitude of over-height multiple contributing factors must be considered: the shape of the beach face contributing to over-height, wave generated over-height, and wind setup over-height. Each of these factors are variable and site-specific. As such, site specific observations are necessary in order to consider water table over height conditions.

Recommendations: For sites with conditions similar to the Stuart, FL site (minimal wave activity) historic tidal information along with the methods discussed in this report can be applied to estimate the inland extent of tidal variations in the water table at a site of interest. However, for sites similar to the Cape Canaveral, AFS site (considerable wave activity with a sloping beach face) the presence of water table over height conditions make estimating water table elevations more difficult. Site specific observations would be required in order to evaluate water table over height conditions.

Canal influenced water table elevations

The analytical solutions relating tidal levels to water table elevations can also be used to estimate water table elevations adjoining canals based upon historic records for canal water levels. These estimates can be applied for tidally active canals or non-tidal canals, provided that estimates for water levels at an inland location are available for reference.

Appendix A

State regulations regarding water table elevations in Florida

In the state of Florida there are five water management districts (WMDs), each of which is tasked with regulating water resources within their specified boundaries. Nearly all alterations to the landscape, including uplands, wetlands and other surface waters are regulated by the environmental resource permit (ERP) program. The ERP program is implemented jointly by the Department of Environmental Protection (DEP) and the water management districts. Operating agreements between the DEP and the water management districts specify which agency will process a given application.

St. Johns River Water Management District (SJRWMD)

Definition. The St. Johns River Water Management District provides an Applicant's Handbook (SJRWMD, 2002), which defines the seasonal high groundwater table (SHGWT) as *the highest level of the saturated zone in the soil in a year with normal rainfall*. In the same document, mention is also made of the average wet season water table (WSWT), but no definition is provided. Both the seasonal high and wet season water table elevations are mentioned in the permit application forms, and no clarification is provided as to whether or not they refer to the same quantity.

Methodology. The documentation provided by SJRWMD regarding environmental resource permits includes Chapter 40C-42 F.A.C (SJRWMD, 2003), the Applicant's Handbook (SJRWMD, 2002), and the Joint Application for Environmental Resource Permits, Form 40C-4.900(1). Each of these documents lists the same definition for SHGWT that is referenced above. However, throughout the documents, the terms seasonal high water table and wet season water table appear to be used interchangeably. The definitions for these terms are not clarified.

Specific methods for determining the SHGWT are not presented in any of the documents. Mention is made in two cases (Applicants Handbook sections 14.10 and 20.8) of estimating the normal on-site ground water table elevation as the average of the seasonal high and seasonal low ground water table elevations, but how the seasonal high and seasonal low should be determined is not mentioned. In section 26.4.2 of the Applicant's Handbook (SJRWMD, 2003) the following discussion is provided regarding the SHGWT:

> ***Estimated Normal Seasonal High Ground Water Table***
> *In estimating the normal seasonal high ground water table (SHGWT), the contemporaneous measurements of the water table are adjusted upward or downward taking into consideration numerous factors, including: antecedent rainfall, redoximorphic features (i.e., soil mottling), stratigraphy (including presence of hydraulically restrictive layers), vegetative indicators, effects of development, and hydrogeologic setting. The application of these adjustments requires considerable experience.*

This statement does not provide specific information in regards to determining the SHGWT, but instead emphasizes the complexity of doing so. However, the mention of redoximorphic features and several references to USDA, NRCS hydrologic soil groups indicates that the NRCS soils classification system is most likely acceptable if considered properly.

South Florida Water Management District (SFWMD)

Definition. The South Florida Water Management District (SFWMD) has compiled information regarding environmental resource permits into one document, which is entitled the Environmental Resource Permit Information Manual, Volume IV (SFWMD, 2000). This document includes relevant Florida Administrative Codes along with sections containing the Joint Application for Environmental Resource Permits, Basis of Review for Environmental Resource Permits, and Design Aids. Within the Manual SFWMD defines two different terms regarding maximum water table elevations: the SHWT and the WSWT. The seasonal high water table (SHWT) is defined in the Design Aids section as *the highest average depth of soil saturation during the wet season in a normal year*. While the WSWT is listed on the Application Supplement form as *the average annual wet season water table… normally used to set the project control elevation*. These two definitions are used interchangeably throughout the SFWMD environmental resource permit documents including the Basis of Review and Joint Application.

Methodology. SFWMD lists possible methods for estimating both the SHWT and the WSWT. The SHWT is discussed in the Design Aids portion of the Manual. The section entitled Determination of the Seasonal High Water Table provides a summary of the hydric soil characterization methodology developed by the Natural Resource conservation Service (NRCS). The section closes with a general 4-step procedure for performing a site evaluation of SHWT. Within in the discussion of methodology, it is stated that preliminary SHWT information can be obtained from the NRCS county soil survey maps. The possible limitations of such information due to the scale of the soil maps is mentioned, and it is stressed that onsite evaluation should be performed. Physical measurement of the water table is mentioned as the most direct method for determining the SHWT. However, it is described as often being too costly and time-consuming to be practical, as typically *10 to 12 years of data are needed to reflect representative conditions* (SFWMD, 2000). For this reason, the preferred method for estimating SHWT is based upon observation of hydric soil indicators as outlined by the Natural Resource conservation Service (NRCS).

The WSWT is also discussed in the ERP Application Supplement portion of the Manual. The supplement is meant to provide general guidelines for ERP application and provides a Quick Reference Checklist. On page 7 of the checklist the WSWT is defined and the appropriate methods for determining WSWT levels are listed as *surrounding projects, monitoring data, USGS well data, wet season borings, wet season water table contour map, adjacent canal control elevation, wetland indicator elevation, other* *(clarify)*. This provides a much broader range of possible methods when compared to the Design Aids discussion of SHWT.

Southwest Florida Water Management District (SWFWMD)

Definition. The South West Florida Water Management District (SWFWMD) provides an ERP Manual (SWFWMD, 2003), which includes relevant Florida Administrative Codes along with sections containing the Joint Application for Environmental Resource Permits, Basis of Review for Environmental Resource Permits, and Design Aids. In the Basis of Review section the seasonal high water level (SHWL) is defined as *the elevation to which the ground or surface water can be expected to rise due to a normal wet season*. Within the Manual the terms seasonal high water table (SHWT) and seasonal high groundwater table (SHGWT) are also used but never defined. The terms SHWL, SHWT, and SHGWT are used interchangeably throughout the Manual.

Methodology. SWFWMD requires a pre-application meeting for environmental resource permits and provides a pre-application guideline that has a section listing typical information that should be considered when determining the SHWL or SHGWT. This section lists both SHWL and SHGWT and clearly communicates that the two terms are considered interchangeable. The topics listed for determining SHWL include site topography, soil surveys, soil borings, and ground penetrating radar. The methods are not detailed in the document, but the implied intent is that they will be discussed in the pre-application meeting. Also, the SWFWMD and NRCS host an annual SHGWT workshop, which covers the reasons for estimating the SHGWT, the complexity involved due to the numerous factors that affect the SHGWT, and provides an overview of the hydric soil characterization methodology developed by the Natural Resource conservation Service (NRCS).

Suwannee River Water Management District (SRWMD)

Definition. The Suwannee River Water Management District (SRWMD) provides an ERP Applicant’s Handbook. Within this document mention is made of the terms seasonal high groundwater table (SHGWT), and wet season high water table (SHWT) but definitions are not provided for either term. Communications with permit reviewers confirmed that the District does not have a definition on record. The definition and application of methodology is typically left to the discretion of the permit reviewer.

Methodology. SRWMD does not provided documentation regarding possible methods for determining the SHGWT or SHWT. However, the permit reviewers typically attend the SWFWMD/NRCS seasonal high groundwater table workshop.

Northwest Florida Water Management District (NWFWMD)

The Northwest Florida Water Management District does not implement Florida's Environmental Resource Permit (ERP) program. Section 373.4145, Florida Statutes, exempts the District from the implementation of this program due to its limited financial resources. The Florida Department of Environmental Protection (DEP) is responsible for all non-agricultural wetland related permits. As such, the NWFWMD does not have a definition or methodology regarding seasonal water table elevations on record.

Florida Department of Environmental Protection (DEP)

Definition. As discussed previously, the ERP process in most of peninsular Florida is overseen by the appropriate water management districts as defined by the operating agreements established between the DEP and the water management districts. Within the territory of the NWFWMD a wetland resource permit program is implemented solely by the Department of Environmental Protection. Within the Environmental Resource Permitting (ERP) and Sovereign Submerged Lands (SSL) Rules, Chapter 62-340 the term seasonal high water (SHWL) is defined as *the elevation to which the ground and surface water can be expected to rise due to a normal wet season*. No reference is made to methods for determining the SHWL.

Rule amendments are currently being drafted regarding ERP practices within the geographical territory of the NWFWMD. The Draft Rule Amendments of the Environmental Resource Permitting (ERP), Wetland Resource Permitting and Submerged Lands Program provide for an Applicant's Handbook similar to those provided by the other water management districts. In this document the seasonal high groundwater table (SHGWT) is defined as *the highest level of the saturated zone in the soil in a year with normal rainfall*.

Methodology. No reference is made to methods for determining the SHGWT.

Along with the DEP and the water management districts, the Florida Department of Health and the United States Army Corps of Engineers also have definitions on record regarding seasonal water table elevations or similar terms.

Department of Health

Definition. The Florida Department of Health (DOH) is responsible for regulating construction of onsite sewage treatment and disposal systems. One of the critical design criteria for such projects is the clearance distance between the base of the treatment system and the wet season high water table. As such, the DOH has the following definitions in rule (Chapter 64E-6, Florida Administrative Code (FAC)):

> *Water table elevation - the upper surface of the groundwater or that level below which the soil or underlying rock material is wholly saturated with water. Water table elevation is measured from the soil surface downward to the upper level of saturated soil or up to the free water level.*
>
> *Wettest season - that period of time each year in which the ground water table elevation can normally be expected to be at its highest elevation.*

Methodology. The general methodology for estimating the wet season water table is outlined in the Florida Administrative Code (Chapter 64E-6, FAC):

The following information shall be used in determining the wet season water table elevation:

(a) U.S. Department of Agriculture Soil Conservation Service soils maps and soil interpretation records.
(b) Evaluation of soil color and the presence or absence of mottling.
(c) Evaluation of impermeable or semi-permeable soil layers.
(d) Evaluation of onsite vegetation.
(e) An onsite evaluation of the property which has used the above referenced sources of information and which has considered the season of the year when the evaluation was performed, historic weather patterns, and recent rainfall events.

U.S. Army Corps of Engineers

Definition. In the U.S. Army Corps of Engineers (USACE) Wetland Delineation Manual, the active water table is defined as *a condition in which the zone of soil saturation fluctuates, resulting in periodic anaerobic soil conditions. Soils with an active water table often contain bright mottles and matrix chromas of 2 or less* (USACE, 1987).

Methodology. In order to estimate active water table conditions, the USACE, Wetland Delineation Manual (USACE, 1987) provides a summary of the USDS, NRCS hydric soil classification methodology.

Review of the various regulating agency definitions and methods indicates the range of information that applicants and reviewers must process for projects involving water table design criteria. In some cases multiple definitions exist within a single agency and guidelines for evaluating water table elevations are not always provided. Some of the typical methods for evaluating water table elevations are discussed in the following section.

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Appendix B

Electronic Appendix (field monitoring data provided on CD)