Session 29

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Groundwater Table Prediction for Tidal and Inland Conditions

Topic Description

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, long term maintenance of retention ponds are 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. The focus of this project is to understand, document and validate the methods used to determine seasonal high groundwater table elevations. The principal objective of this work is to provide FDOT with tools for determining SHGWT elevations that can be coalesced into a statewide standard operating procedure.

Speaker Biography

Areas of interest: Groundwater and surface water hydrology; computer modeling of groundwater and surface water flow along with contaminant fate and transport; contaminant site characterization and remediation.

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

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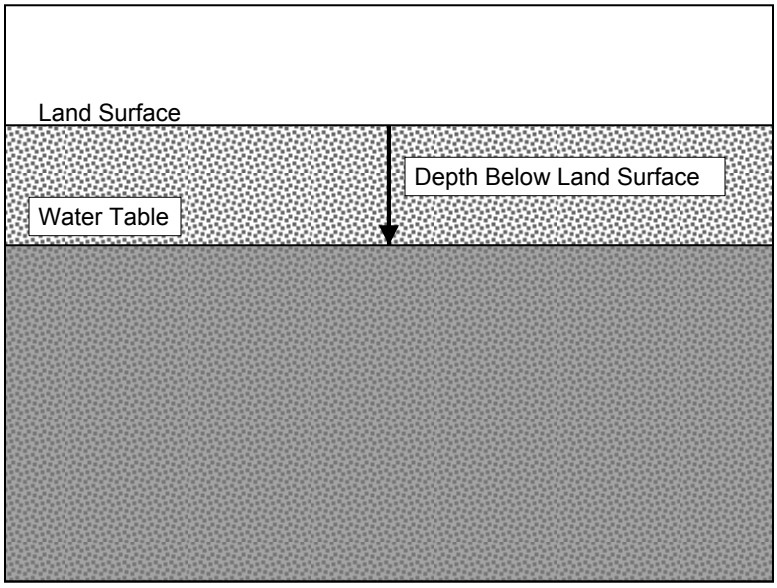
Outline

- **Introduction**
- **Objectives**
- **Literature Review**
- **Tidal Influences**
  - **Field monitoring**
  - **Theory**
  - **Data analysis**
- **Inland Conditions**
  - **Concept**
  - **Data collection and analysis**
  - **Results to date**
- **Summary and Conclusions**

Project Objectives

- **Provide a consistent definition for the seasonal high groundwater table (SHGWT) that**
- **Is applicable for roadway and drainage design**
- **Can be coalesced into a statewide standard operating procedure**
- **Provides specific guidelines targeting regional and local factors**



Literature Review

- **Reviewed the current definitions and methods that are typically applied to estimate the SHGWT**
- **Several factors affect water table elevations**

Factors affecting water table

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**

Literature Review

- **Various methods for estimating water table elevations**

Methods for estimating water table elevations

1. **Historical water table elevations**
2. **NRCS hydric soil characterization**
3. **NRCS soil maps**
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**

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

Agency definitions relating to water table and seasonal high water table elevations.

Literature Review Conclusions

- **One indicator will not provide a reliable estimate for SHGWT levels under all conditions**
- **A more practical concept would be to establish a set of guidelines for estimating SHGWT elevations while taking into account site-specific conditions.**
- **The intent of this project is to encourage a dialogue towards developing a statewide standard operating procedure.**

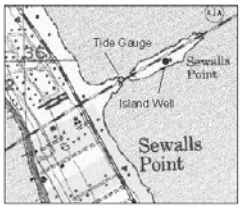
Tidal Influences

Tidal Influences

Field Monitoring

- **Two sites were instrumented**
- **Investigate the influence of tides and waves on the water table**
- **Sites differ based upon the**
  - **coastal setting**
  - **predominant type of oscillations influencing the water table**

Stuart, FL
(Earnest Lyons Bridge)



Coastal setting:

- Small island
- Indian River

Monitoring:

- Tide
- Water table
- Rain

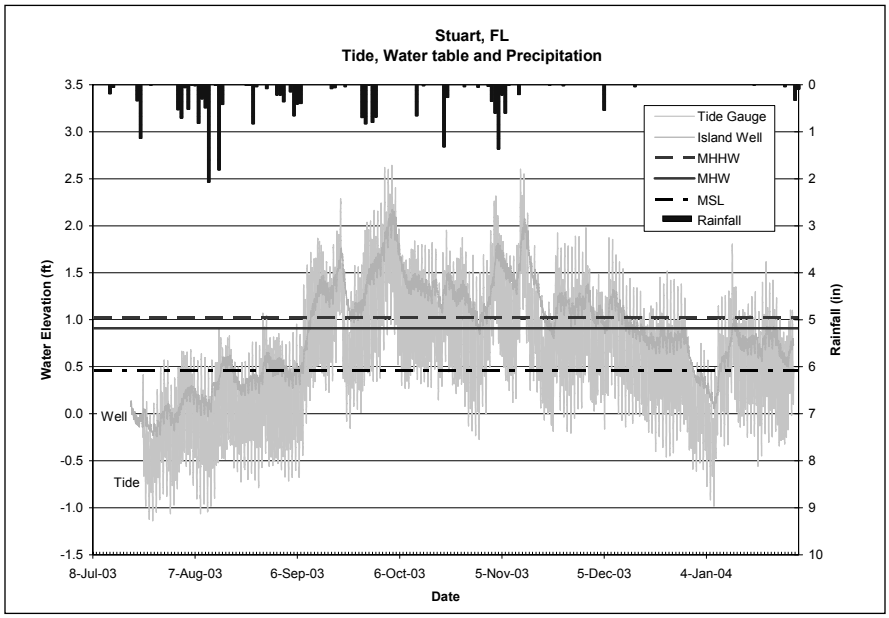
Stuart, FL
(Earnest Lyons Bridge)

Predominant oscillations:

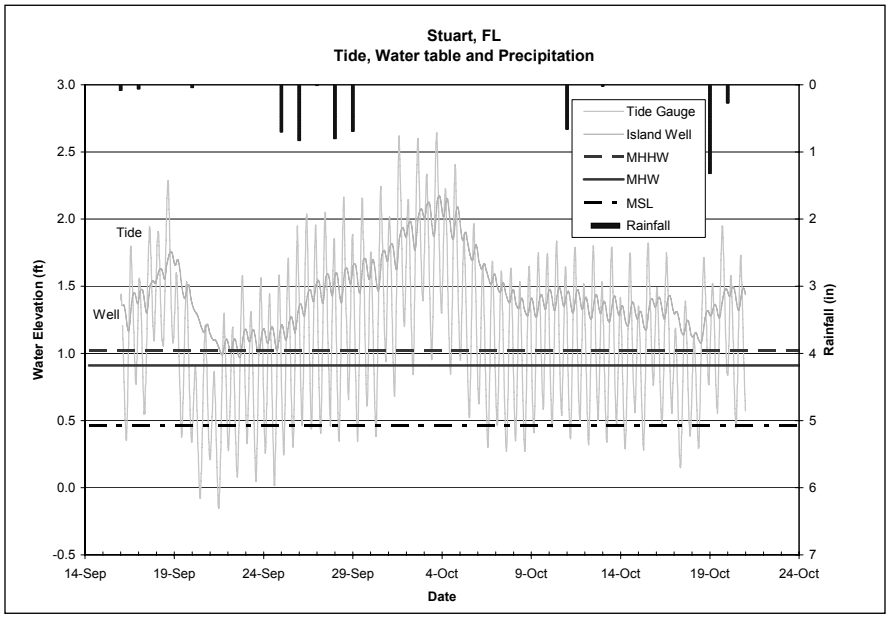
- Daily tidal fluctuations
- Monthly tidal fluctuations

Observations:

- Mean high tide and mean high water table are closely related
- Average lag is approximately 4.5 hours



Transition from seasonal low to seasonal high water levels at Stuart, FL (July - September 2003). MSL Referenced to NGVD-29 and based upon Tidal Epoch 1983-2001.



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

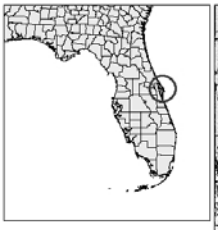
CCAFS, FL
(Launch Complex 15)

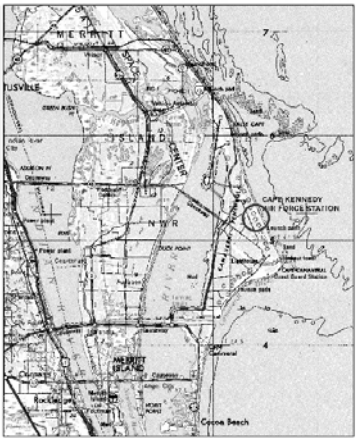
Coastal setting:

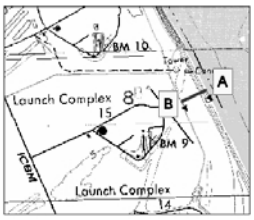
- Active beach face
- Atlantic coast

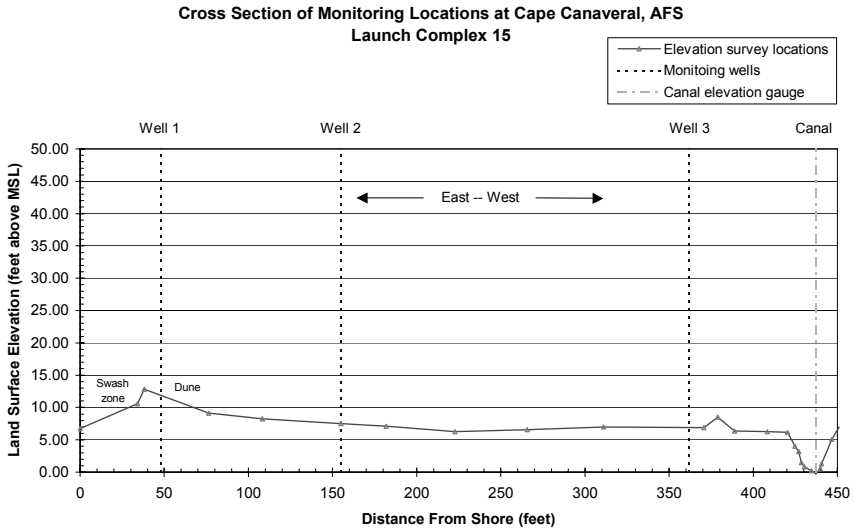
Monitoring:

- 4 monitoring wells
- Canal gage
- Precipitation









Note: Vertical scale is exaggerated.

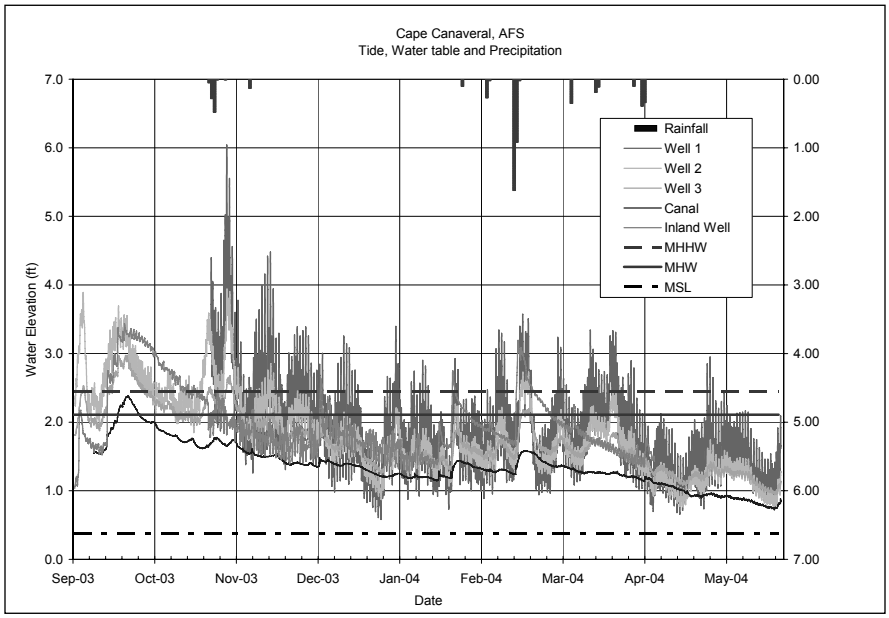
CCAFS
(Launch Complex 15)

Predominant oscillations:

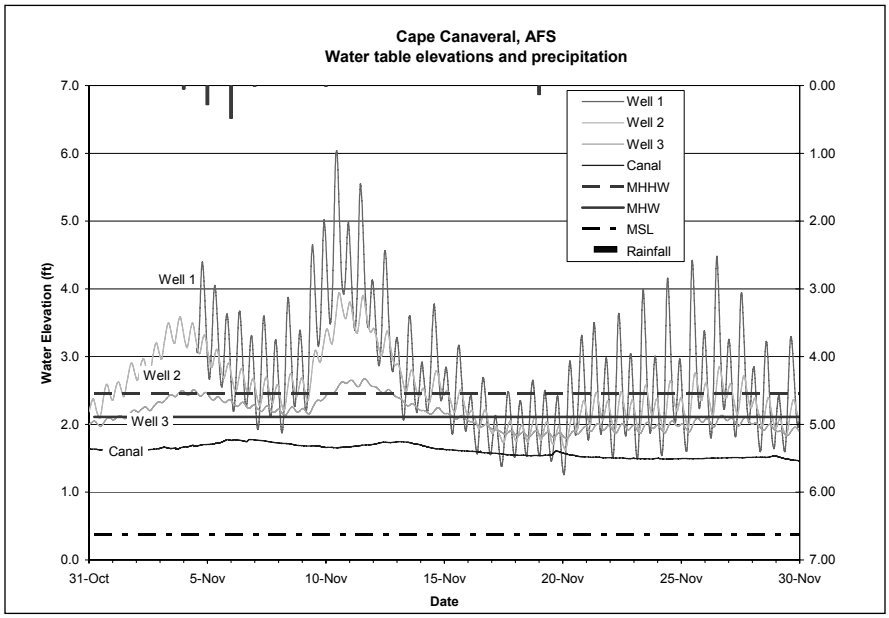
- Significant wave activity
- Daily tidal fluctuations
- Monthly tidal fluctuations

Observations:

- Tidal influences observed 360 feet inland



Recorded water levels at Cape Canaveral AFS (September 2003 to May 2004). MSL referenced to NGVD-29 and based upon Tidal Epoch 1983-2001.

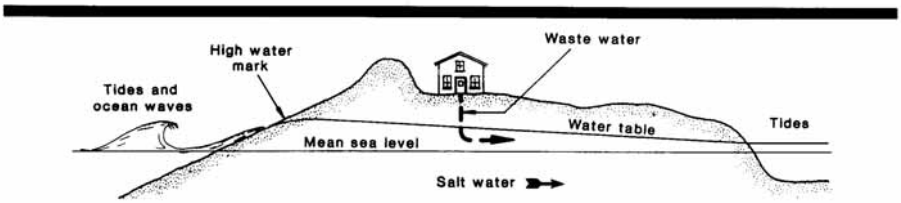


Recorded seasonal high water levels at Cape Canaveral AFS (November 2003). MSL referenced to NGVD-29 and based upon Tidal Epoch 1983-2001.

CCAFS
(Launch Complex 15)

Observations:

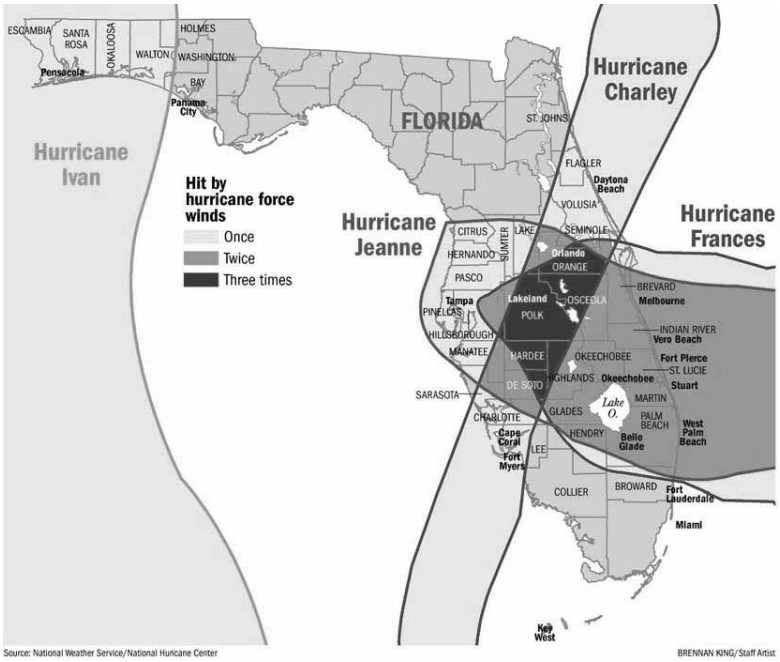
- Water table over-height or super-elevation
  - sloping beach face
  - wave activity
  - tidal variation



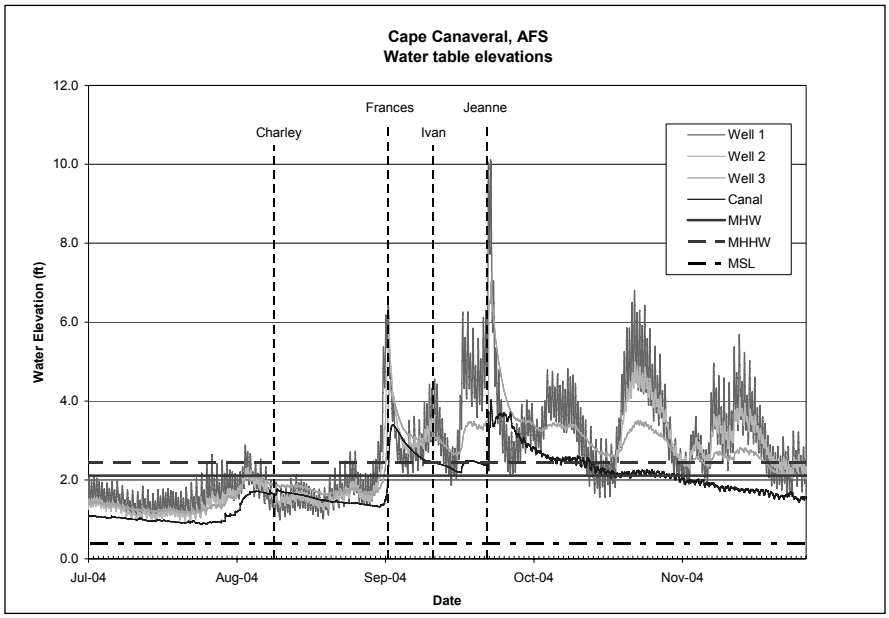
(Adapted from Nielsen, 1999)

The water table under coastal barriers may be highest near the ocean because of the action of waves and tides.

Consequently there is a net flow of groundwater towards the continent.



2004 Hurricane season.



Recorded extreme (hurricane) high water levels at Cape Canaveral AFS (May 2004 to April 2005). MSL referenced to NGVD-29 and based upon Tidal Epoch 1983-2001.

Tidal Influences

Theory

- **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.**

Tidal Influences

Darcy's equation

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

Q **= flowrate [L^3/T]**
K **= hydraulic conductivity [L/T]**
A **= cross-sectional area [L^2]**
dh/dL **= hydraulic gradient**

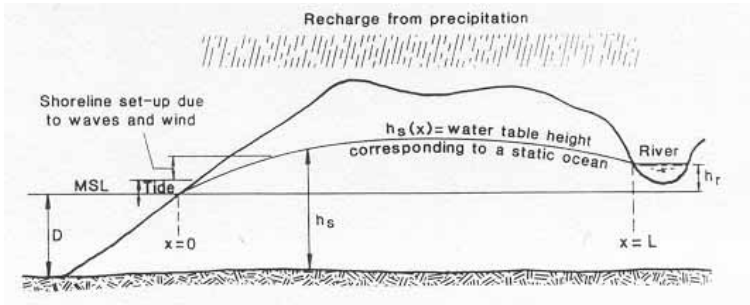
Tidal Influences

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

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*.

$$n = S_y + S_r$$



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

Tidal Influences

Estimating water table elevation based upon tidal influences (no waves).

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

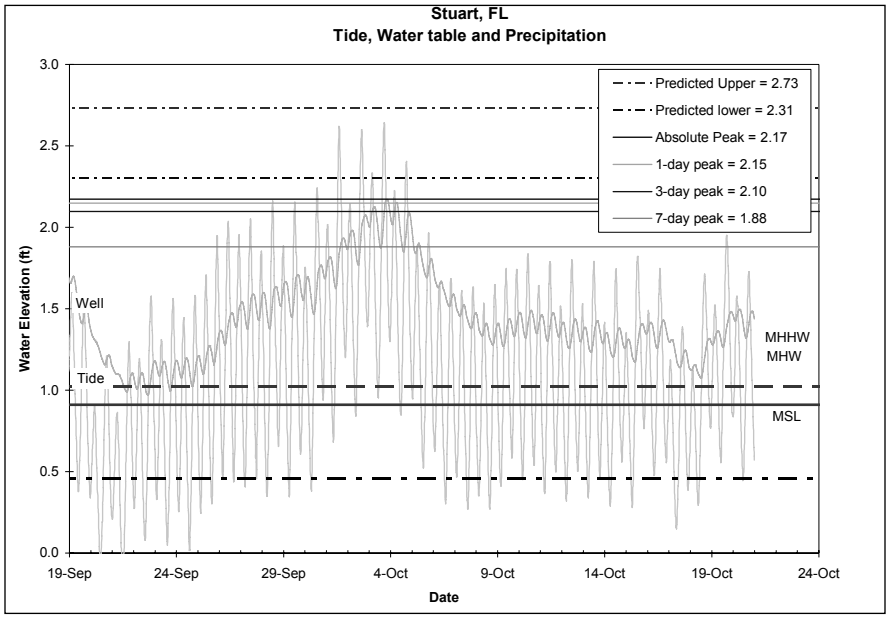
***h_s* = water table height as a function of a static ocean level**

***D* = depth below MSL of an impermeable layer**

***h_r* = water table height at a distance x = L**

***i* = a steady recharge rate**

***K* = hydraulic conductivity**



Predicted and estimated SHGWT elevations for Stuart Site (October, 2003).

Tidal Influences

The inland extent of tidal variations for an unconfined aquifer.

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

h_x = amplitude of tide-induced fluctuations at a distance x

h_o = tidal amplitude

S_y = specific yield

t_o = tidal period

T = transmissivity = Kb

b = aquifer thickness

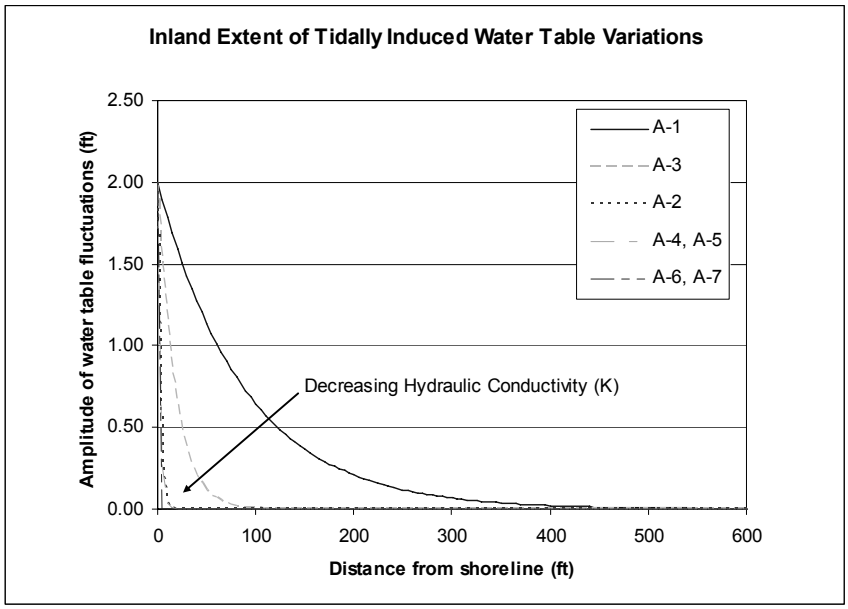
CLASSIFICATION OF HIGHWAY SUBGRADE MATERIALS
(With suggested subgroups)

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					

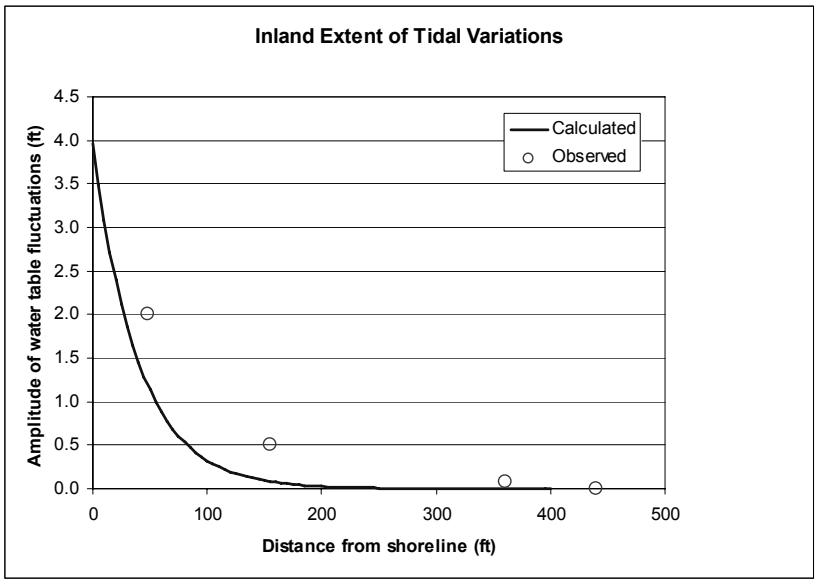
AASHTO soil classifications.

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

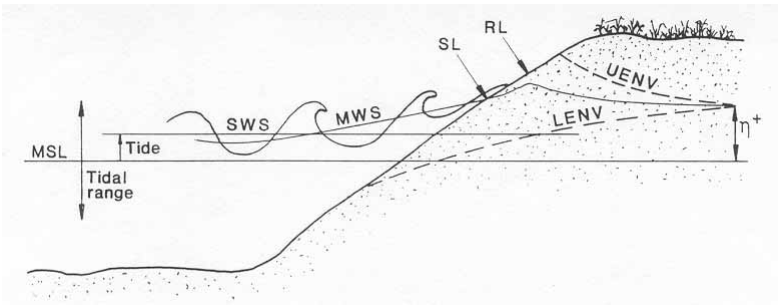
Typical values of hydraulic conductivity and specific yield generalized to AASHTO soil classifications (Sources: Batu, 1998, Dawson and Istok, 1991).



Inland extent of tidally induced water table variations as a function of AASHTO soil classification. Assuming a tidal amplitude of 2 ft and an aquifer depth of 25 ft.



Inland extent of tidally induced water table at CCAFS (November, 2003).



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

η^+ = average super elevation above mean sea level

Inland Conditions

Inland Conditions

Reference well database

Purpose:

- **Incorporate information that is currently available**
- **Provide a tool for considering water table conditions at similar sites based upon location and site-specific conditions**

Inland Conditions

Reference well database

- **Contains historical water level, precipitation, and soil characteristics all referenced by date and location**

Inland Conditions

Reference well database

- **User provides information that is typically obtained from initial site assessments:**
  - **Location (coordinates)**
  - **Observed water level**
  - **Time of year**
  - **Soil characteristics**
  - **Rainfall conditions**

Inland Conditions

Reference well database

- **Search results are ranked to indicate which reference wells are the most similar to the site of interest**
- **Distance may not always be the primary comparison (also considering soil type and rainfall conditions)**

Inland Conditions

Reference well database

- **Using the ranked search results water levels at the site of interest can be estimated**

Inland Conditions

Reference well database: BENEFITS

- **Tool for inferring water levels based upon long-term historical data**
- **Data already exists**
- **Can determine focus areas requiring additional information**
- **Incorporates multiple factors that influence water table elevations**

Inland Conditions

Reference well database: DISADVANTAGES

- **Coverage will be sparse or non-existent in many portions of the state**
- **Estimating mean water levels is a relatively straightforward task, but predicting extreme values (seasonal high) introduces greater uncertainty**

Summary

1. Literature Review

One indicator will not provide a reliable estimate for SHGWT levels under all conditions

Encourage dialogue towards developing a statewide standard operating procedure

Summary

2. Tidal influences

Analytical solutions exist which relate tidal levels to water table elevations.

For sites where water fluctuations are predominantly tidal these analytical solutions may provide reasonable estimates for SHGWT.

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.

Summary

3. Inland conditions

Preliminary results indicate that methodology is applicable to Florida soils.

Work is on going to supplement the initial database of reference wells