ESTIMATING THE NORMAL SEASONAL HIGH GROUNDWATER TABLE: A MIX OF ART & SCIENCE

by

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Introduction

Perhaps the most important soil feature affecting site engineering in Florida is the water table and particularly its range of fluctuation from season to season. The prediction of the seasonal high water table is a subtle combination of many sciences--including soil science, shallow aquifer groundwater mechanics, geohydrology, hydrometeorology, geotechnical engineering, and bryology--which remain a mystery to the uninitiated non-soil engineer.

This article briefly describes the methods employed and factors considered by scientists and engineers in estimating the depth below land surface to the seasonal high groundwater table. Although this article focuses more on the Orlando (Florida) area, the methodology described herein is general and can be applied to other areas.

A seasonal high water table (SHWT) is the shallowest depth to free water that stands in an unlined borehole or where the soil moisture tension is zero for a significant period (more than a few weeks) (Watts and Hurt, 1991). According to Rule 40C-42, Florida Administrative Code, the seasonal high groundwater table (SHWT) elevation means the highest level of the saturated zone in the soil in a year with *normal* rainfall. Groundwater professionals are routinely called upon by site grading and drainage engineers and other professionals to predict these groundwater elevations, typically to within an accuracy of ±6 inches. Errors in these estimates can result in detrimental environmental, economic, and functional impacts, such as the hydrologic failure of created wetlands, septic tank drainfields, stormwater management ponds, effluent reuse land application systems, road base distress due to saturated conditions, etc.

The SHWT is a critical input parameter as it affects, among other things,

- site grading plans (fill quantities & associated cost, construction dewatering requirements, the need for roadway and lot underdrains, etc.),

- the design of numerous elements of the stormwater management system (pond control levels, choice of conveyance systems, potential wetland drawdown impacts, etc.),

- the selection of the base elevation of septic tank drainfields,

- effluent reuse application rates, and

- the hydroperiod of created wetlands.

Site-specific Data Collection

Although the published sources of information (such as the Soil Conservation Service publications) generally provide reliable preliminary guidance on the depth to the water table at a site, there is no substitute for a site-specific investigation for design level studies. The starting point is the measurement of the stabilized groundwater level in a newly opened borehole, or piezometer at a selected location and time. A stabilized reading, in this sense, means that the water level in the newly created borehole or well has equalized with the water table level in the aquifer. A minimum of 24 hours is usually allowed before taking a reading, although sandy soils require less time than silty or clayey soils to achieve equilibrium levels.

The density of measurement points (i.e., the number of borings or piezometers) considered reasonable for characterization of the three-dimensional water table surface within a site is not addressed in this article. Engineering judgement and experience plays a key role in deciding how many borings/piezometers should be used to investigate a particular site.

The date of the water table measurement is very important and must be recorded since the groundwater table fluctuates throughout the year in response to seasonal rainfall. In addition, the soil profile in the test hole or boring should be described, noting soil texture (i.e., sand, silty sand, "hardpan", clayey sand, etc.), color (including mottling and staining, more formally known as redoximorphic features), and, if available, Standard Penetration Test boring "N" values variations which may manifest memory of the seasonal fluctuation. On sites with considerable relief over short distances, it is also recommended that vertical control at the boring/well locations be surveyed to avoid approximation errors in converting the water table level to an elevation datum from a depth below land surface reading.

Evaluation of Data

Adjustments are made to the instantaneous measurement of the groundwater depth to arrive at an estimate of the normal seasonal high water level. The key factors to be considered in selecting the position of the seasonal high water table relative to the measured level are listed below:

1. Antecedent rainfall

2. Soil map unit descriptions published by the United States Department of Agriculture (USDA) Soil Conservation Service (SCS)

3. Examination of the soil profile, including color variations (redoximorphic features), SPT "N" values, depth to "hardpan" or other impermeable horizons (such as clayey fine sands and clays), etc.

4. Consistency of water levels with adjacent surface water bodies and knowledge of typical hydraulic gradients (water table slopes).

5. Vegetative indicators

6. Effects of existing and future development

7. Hydrogeologic setting including potentiometric surface of Floridan aquifer and degree of connection between the water table aquifer and the Floridan aquifer.

8. Mathematical Correlation With Soil Morphological Features

Each of these eight (8) factors are elaborated upon in the remainder of this article.

Factor #1: Adjustment for Antecedent Rainfall

General

Consider the following components of the water budget of a regular prism of soil on Figure 1 extending from the ground surface to a few feet below the seasonal low water table:

a. Natural Inflows
   i) Precipitation (less runoff) entering the top face of the prism
   ii) Lateral flow entering the side walls of the prism from the upgradient direction
   iii) Vetical flow upward from the bottom face of the prism (in areas where an underlying aquifer discharges to the uppermost water table aquifer)

b. Natural Outflows
   i) Evapotranspiration losses from the top face of the prism
   ii) Lateral flow exiting the downgradient side walls of the prism
   ii) Vertical flow downward from the uppermost aquifer to an underlying aquifer which is more often the case and is an important component in medium to high recharge areas.

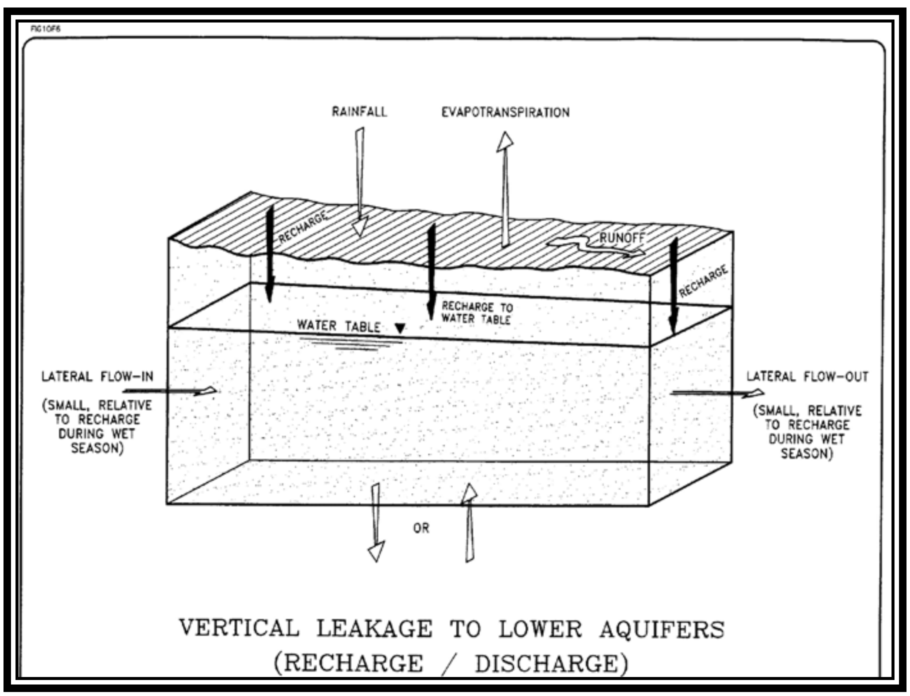

Figure 1. Water Budget Components

It is first important to appreciate that, under natural conditions, the rate of lateral groundwater movement in the uppermost water table aquifer in Central Florida is no more than 300 to 400 feet per year and usually much less. Therefore, a water particle entering the water table aquifer at one end of a site may take several years before it exits the downgradient boundary of the site or discharges into a surface water body within the site. The reaction of the water table within a wet season, spanning typically about 4 months (June through September), is therefore not controlled significantly by lateral groundwater inflows and outflows to the prism or by conditions which exist greater than a lateral distance of 300 to 400 feet.

In addition, vertical flow (recharge) from the surficial aquifer to the underlying Floridan aquifer is only significant in high recharge areas (10 to 20 inches per year). In general, the degree of connection between the surficial and Floridan aquifers is relatively low and vertical recharge is small (less than 5 inches per year). In other areas such as the high recharge sand ridges and areas around well-connected sinkhole depressions or paleosinks (hydrogeologic anomalies), other factors come into play in setting the SHWT. These factors are discussed later in the section on hydrogeology.

Rainfall recharging the uppermost aquifer is equal to rainfall minus runoff. Runoff from undeveloped land, as a fraction of total annual rainfall, is usually less than 20%. Hughes (1978) published the map "Runoff From Hydrologic Units in Florida" and it shows that the anuual runoff is in the range 5 to 15 inches per year as compared to an annual average rainfall of 53 inches for the state of Florida.

Based on the above, we therefore see that the vertical fluctuation of the water table in a typical soil profile is controlled primarily by rainfall recharge (i.e., rainfall minus runoff) and evapotranspiration. Table 1 summarizes average monthly precipitation at the NOAA Sanford (Seminole County) station together with estimates of monthly evapotranspiration (ET) for pasture (Jones et al., 1984). As noted on this table, rainfall recharge to the surficial aquifer is approximately 8 inches during the wet season months (June through September) for a moderately drained soil. Therefore, if we consider purely vertical movement of the water table due to rainfall recharge, this would translate into a 3 to 4 feet rise in the water table during the wet season, which is the range of fluctuation typically observed in wells on the flatwoods.

As an example of the correlation between rainfall and water table levels in a poorly drained soil and a very poorly drained soil, Figure 2 shows the water table depths and corresponding rainfall amounts recorded for the period July 1977 to October 1986 (Hyde and Ford, 1989). This is the longest continuous seasonal high water table investigation in the state of Florida. The observation well for the poorly drained soil is located in an improved pasture while the other well is in an undeveloped area with pine trees and saw palmettos in Polk County in south-central Florida. Neither of these sites were influenced by artificial drainage. Water table readings were measured approximately every two weeks and the rain gauges were situated within 100 feet of each well.

The data in Table 1 and Figure 2 indicates that the "dry" months generally run from October to May. The "wet" months, with almost double the total rainfall of the "dry" months, span from June to September. We would therefore expect that seasonal high water tables will occur around the end of September in years with a typical rainfall distribution. By the same reasoning, seasonally low water levels usually occur in the month of May.

In orange groves or range land with deep water tables and mostly bare sandy soil, the evapotranspiration and the runoff may be much less than on the pine flatwoods. As a result the rainfall recharge to the uppermost aquifer during the rainy season may be as high as 16 inches with the water table fluctuation range as much as 6 feet.

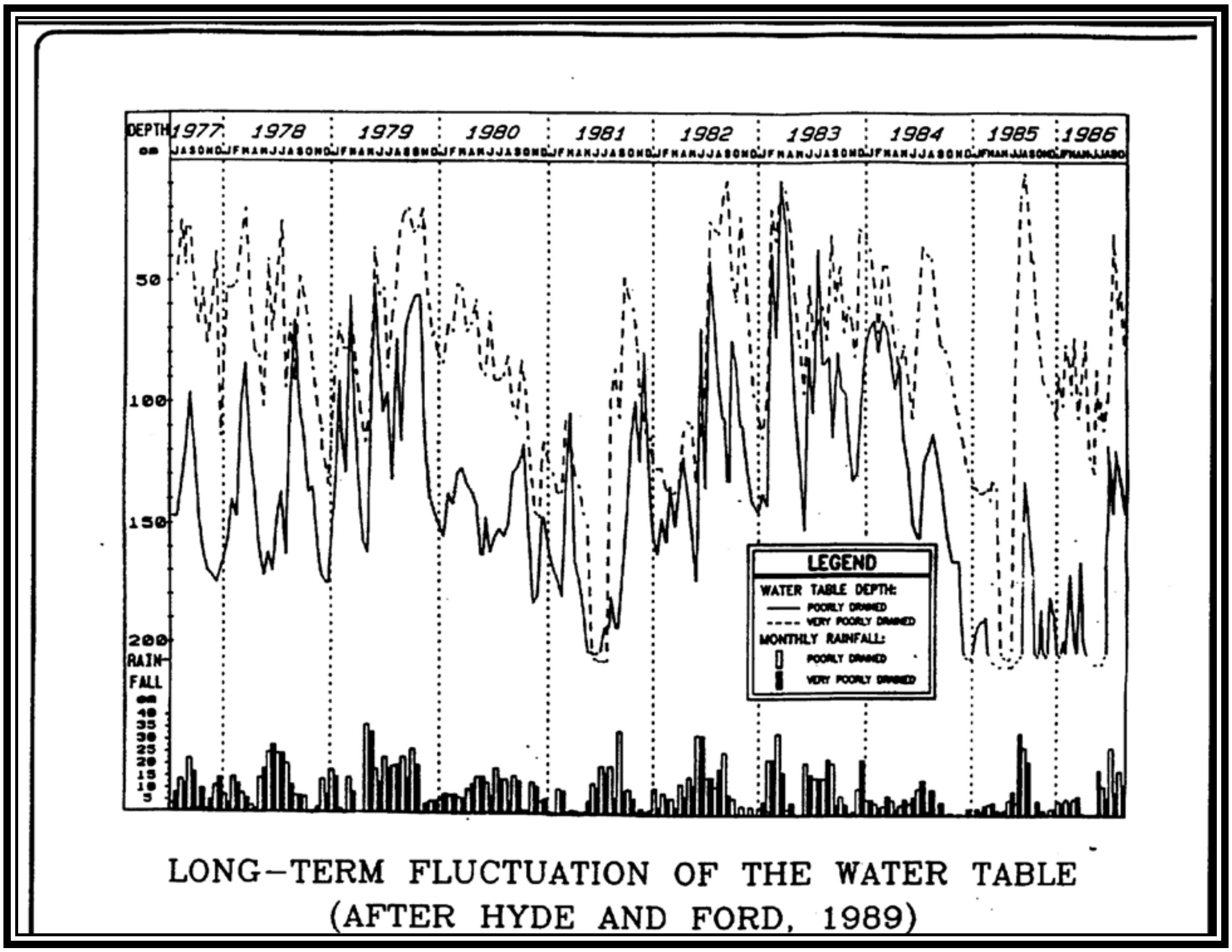

Figure 2. Recorded Long-Term Water Table Fluctuation

TABLE 1: RAINFALL RECHARGE TO UPPERMOST AQUIFER, CENTRAL FLORIDA VICINITY				
Month	Sanford Rainfall (in)	Runoff (in)	Pasture E.T. (in)	Rainfall - Runoff - Pasture E.T. (in)
January	2.40	0.01	1.76	0.63
February	3.57	0.03	2.29	1.25
March	3.49	0.05	3.16	0.28
April	2.47	0.00	4.12	-1.65
May	3.52	0.00	5.60	-2.08
June	6.41	0.06	4.71	1.64
July	7.12	0.02	4.96	2.14
August	7.02	0.59	4.80	1.63
September	7.19	0.66	3.91	2.62
October	4.35	0.26	3.21	0.88
November	2.19	0.00	2.19	0.00
December	2.10	0.00	1.61	0.49
Annual Totals.......	51.83	1.68	42.32	7.83
Wet Season (June-September) Rainfall Recharge Totals...				8.03

NOTES:
1. Monthly Evapotranspiration data from Jones et al., 1984
2. Rainfall for NOAA, Sanford station (1950-1980) (selected typical months)
3. Runoff computed assuming CN of 62 with discrete storm events

Adjustment For Rainfall

Short term deficits or surpluses in rainfall must be considered when evaluating a contemporaneous reading of the water table relative to its normal seasonal high level. For example, a water table measurement in Orlando at the end of September 1992 should take into account the magnitude and distribution of rainfall over say the preceding six months at the Orlando International Airport as compared to normal rainfall amounts:

Month	1992 Rainfall	Normal Rainfall
April	9.10 in	2.19 in
May	1.19 in	3.96 in
June	8.68 in	7.39 in
July	2.60 in	7.78 in
August	8.03 in	6.32 in
September	7.12 in	5.62 in

Rainfall records are usually available in the local daily newspaper (such as the "Local & State" section of the *Orlando Sentinel*) or water management district data bases. However, rainfall in Florida can be localized and an attempt should be made to obtain records closer to the site such as a rain gauge at a nearby golf course, wastewater treatment plant, or other instrumented site.

Where the water table is 20 feet or more below the land surface, rain filters slowly through the overlying sand and the response of the water table to heavy rainfall or drought usually lags about a month (Lichtler et al., 1968). The water table fluctuations in such areas reflect long periods of excessive and deficient rainfall. On the other hand, in the 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 (Lichtler et al., 1968).

Therefore, apart from the general yearly trends in groundwater fluctuation, heavy continuous rainfall in the days or weeks preceding a measurement should be considered in adjusting the contemporaneous water table reading. This may be difficult unless local site-specific rainfall information is available. Heavy antecedent rainfall or a recent rainfall deficit can distort the water table measurement relative to the SHWT.

Factor #2: SCS (NRCS) Published Data

The Soil Conservation Service (SCS) of the United States Department of Agriculture has mapped the shallow soil and groundwater table conditions in many areas and has published this information in the form of books and maps. "Shallow" here means less than 80 inches.

The SCS has published estimates of the seasonal high groundwater table for the various soil map units based on regional data collection. While the SCS procedure for determining SHWT is being updated (Vepraskas 1992), it has been based solely on morphology; i.e., identifying mottles and low chroma colors in a soil horizon which form by processes related to saturation and reduction of iron. These processes may be actively occuring during the year or have occured in the horizon at some time in the past. Soil mottling patterns can also be relicts of past moisture regimes (see, for example, the studies of Franzmeier et al., 1983). Other problems related to using morphology to determine saturation and reduction were discussed by Moorman and van de Wetering (1985).

Additional discussion on the methodology used by the SCS can be found in their publications such as the most recent Polk County Soil Survey (Ford et al., 1990). Although these SCS maps are on a scale of 1:20000 and are not a substitute for on-site investigations, experience indicates that the SCS estimates of SHWT are reliable in areas where recent development or long-term hydrogeologic changes have not influenced the shallow groundwater flow regime. The SCS data should always be reviewed as part of the water table evaluation. In areas where the natural soil has been graded or where there have been drainage improvements, the published data should be interpreted judiciously.

Factor #3: Examination of Soil Profile

Color Variation

The color variation in the soil horizon is a key indicator of historic seasonal water table movement. Soil scientists interpret gray colors and mottling in soils as indicators of reducing environments typically resulting from a fluctuating water table. Mottling in soil are irregular spots of different color that vary in number and size. Mottling generally indicates poor aeration and impeded drainage. The occurence of gray and red mottling is considered an indicator of periodic saturation.

In Florida's loamy (i.e., silty) and clayey soils, for example, soil scientists tend to look for low chroma (i.e., grayish) matrix or mottles as indicators of SHWT. Gray mottles are usually deficient in iron because compounds of iron have been removed through groundwater fluctuations. In sandy Florida soils, on the other hand, high chroma (i.e., reddish or orangish) mottles are seen by soil scientists to be better indicators of SHWT.

As the water table moves seasonally between the low and the high levels, it effectively washes this zone removing traces of organic stains and coatings resulting in a lighter color. On the other hand, the soil zone beneath the low groundwater table is always saturated and is subject to an accumulation of material components removed from the zone above and the slower horizontal component of flow.

Soil colors are examined in a freshly dug pit and this method of estimating SHWT applies only to those areas lacking hydrologic modification (such as ditching and dikes). All determinations should be made on moist soil. The following instructions are listed by Watts and Hurt (1991) and the Soil Conservation Service (1992) to determine depth to SHWT:

A. Soils with a hydric soil indicator.

1. Soils with the following hydric soil indicators have a SHWT at or above the surface:

- Indicator #1: Muck - peat, muck, and mucky peat are soil materials. Peat, muck, and mucky peat have at least 12 to 18% organic carbon. The percentage requirement is dependent upon the clay content of the soil; the higher the clay content, the higher the organic carbon requirement. A root or leaf mat is a non-soil layer that is slightly decomposed to undecomposed roots and leaves that covers and can be easily be removed from the soil surface. The presence of a root mat is not indicative of hydric soils or upland soils, but probably indicates the vegetation produces a large amount of biomass. Hydric soil indicators are made below the leaf or root mat.

- Indicator #2: Sulfidic odor - the sulfidic odor indicates that the soil is reduced and therefore saturated much of the year. In some sandy hydric soils, the presence or absence of sulfidic odor could be related to to tidal stage; present at high tide and absent at low tide.

- Indicator #3: Muck texture - "mucky" is a USDA texture modifier for mineral soils. Organic content is at least 5 to 10%. The percentage requirement is dependent upon the clay content of the soil. An example is mucky fine sand which has at least 5% organic carbon but not more than 12% organic carbon.

- Indicator #7: Gley colors - gley color are not synonmous with gray colors. Gley colors are those found on the gley page of the Munsell soil color charts.

2. "Sandy" soils with the following hydric soil indicators have a SHWT within 6 inches of the surface.

- Indicator #4: Dark surface - the organic matter content of this indicator is slightly less than required for "mucky". Seventy percent of the soil material is covered or coated with organic matter. A hand lens is an excellent aid in making this decision. Many soils have a ratio of about 50% soil particles which are covered or coated with organic matter and 50% uncoated or uncovered soil particles, giving the soil a salt and pepper appearance. This 50/50 ratio is not a hydric indicator.

- Indicator #5: Organic accretions - *not complete*.....

B. "Sandy" soils without a hydric soil indicator that have a matrix chroma of 2 or less.

1. In soils where the upper boundary of the polychromatic matrix is masked with surface or subsoil organic staining, the following surface layer colors are used:

   Black surface layer = a SHWT of 9±3 inches
   Very dark gray surface layer = a SHWT of 12±3 inches

C. "Sandy" soils without a hydric soil indicator.

1. The depth to the SHWT is the depth to the polychromatic matrix.

D. Soils without a hydric soil indicator that have a pale brown to brownish yellow and/or yellowish brown (chroma 3 or more) E and/or C horizons.

1. In "sandy" soil, the depth to the SHWT is the depth to common distinct or prominent red to strong brown mottles (hue of 10YR or redder, value of 5 or more, and chroma of 6 or more). These yellowish or reddish mottles are the result of alternating oxidizing and reducing conditions of iron caused by a fluctuating water table. Several auger holes are usually required because of the variability in the location of these mottles. Do not use the iron-segregated mottles that are in and along old root channels.

2. Some similar soils do not have iron-segregated mottles within the E horizon, but have an argillic (clayey) horizon. In these soils, the depth to the SHWT is where white to gray mottles (value of 5 or more, and chroma of 2 or less) occur on ped surfaces within the argillic horizon.

3. Similar soils in south Florida lack iron-segregated mottles. In these soils, the depth to the SHWT is the upper boundary of the polychromatic matrix.

Variation of Density (SPT "N" Values or CPT)

The Standard Penetration Test (ASTM D1586) "N" value profile also sometimes provides 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 SHWT is sometimes discerned by a marked increase in "N" value or Dutch cone point resistance with depth from the ground surface.

Presence of Intermittent Restrictive Layers

Layers restrictive to water movement may occur intermittently or continuously with respect to depth and/or areal extent. A relatively impermeable, discontinuous layer occuring at shallow depth (such as a hardpan) can create a localized perched water table above the shallow groundwater table. Perched groundwater is groundwater in a saturated zone which is separated from the main body of groundwater by unsaturated soil. Even if the water table is not encountered above the restrictive layer, temporary perching of the water table above this layer should be anticipated during periods of excess rainfall, unless the layer is removed or modified. Perched conditions may last for a few days.

Factor #4: Backcomputation from Knowledge of Typical Gradients

The shallow groundwater table surface is generally parallel to the natural ground surface in relatively flat areas. Therefore, unless the soil types vary significantly, the SHWT across a relatively flat site should be at a uniform depth below the ground surface over the site. Also, where seasonal high water levels of an adjacent lake, wetland or sinkhole basin are known (such as in Orange and Seminole Counties), it is possible to back calculate the seasonal high GWT at a nearby point based on knowledge of typical water table gradients (Figure 3). For example, Seminole and Orange Counties maintain records of lake levels which can be referenced for seasonal high levels on sites adjacent to lakes. The water table generally slopes upward and away from the lake's surface.

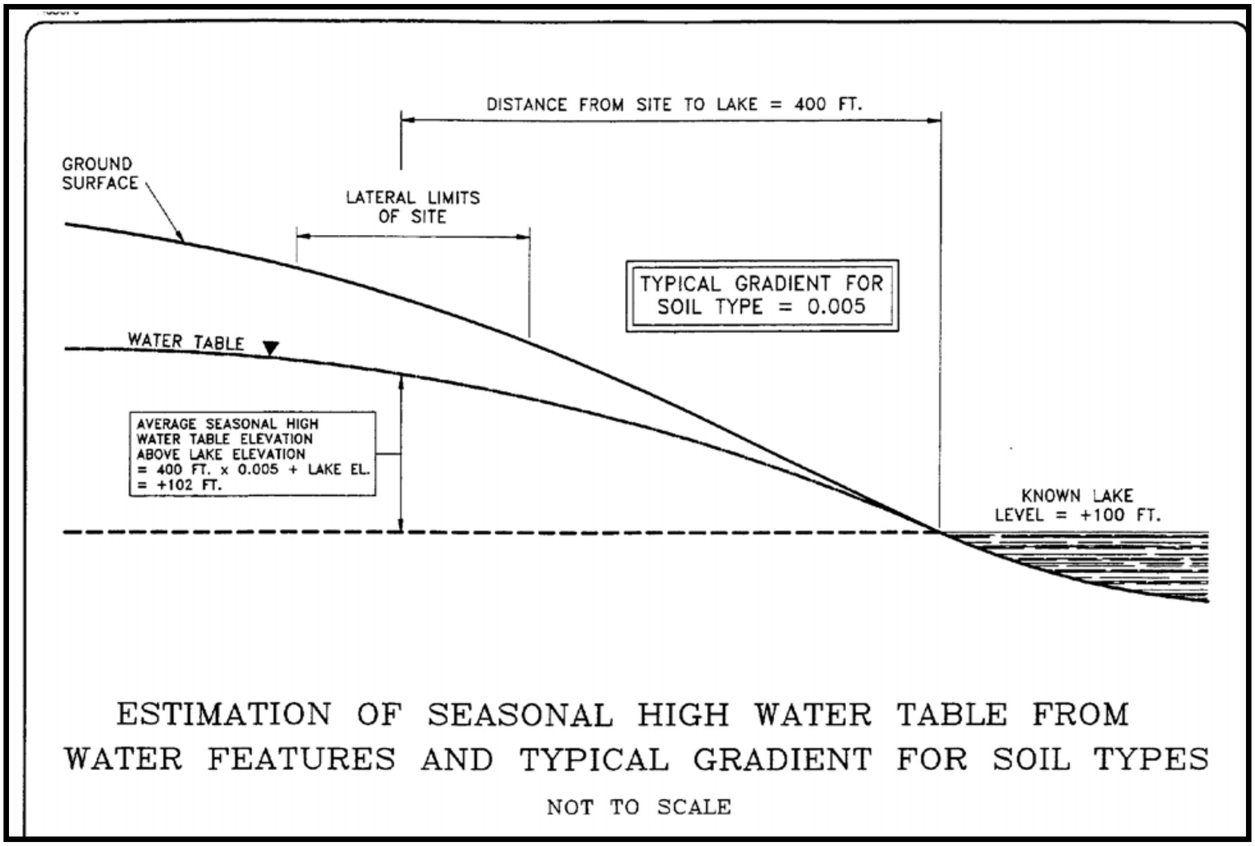

Figure 3. Water Table Gradient

Factor #5: Vegetative Indicators

Inspection of the natural vegetative cover on an undisturbed site gives a good 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.

It has been observed and well established that many forms of plant life are distinctly related to the amount, position, and duration of water over the surface of soils. Plants preferring and tolerating water around their bases, but most of the time remaining emerged above the water level, are known as hydrophytes or wetland plants. Some trees, such as many cypress, gum, maple, ash, bay, wax myrtle, and buttonwood, live with water permanently around their bases. Trees that can withstand water for a short period of time include sweet gum, magnolia, some oaks (such as laurel oak), some hickories, slash pine, and saw palmetto (Figure 4).

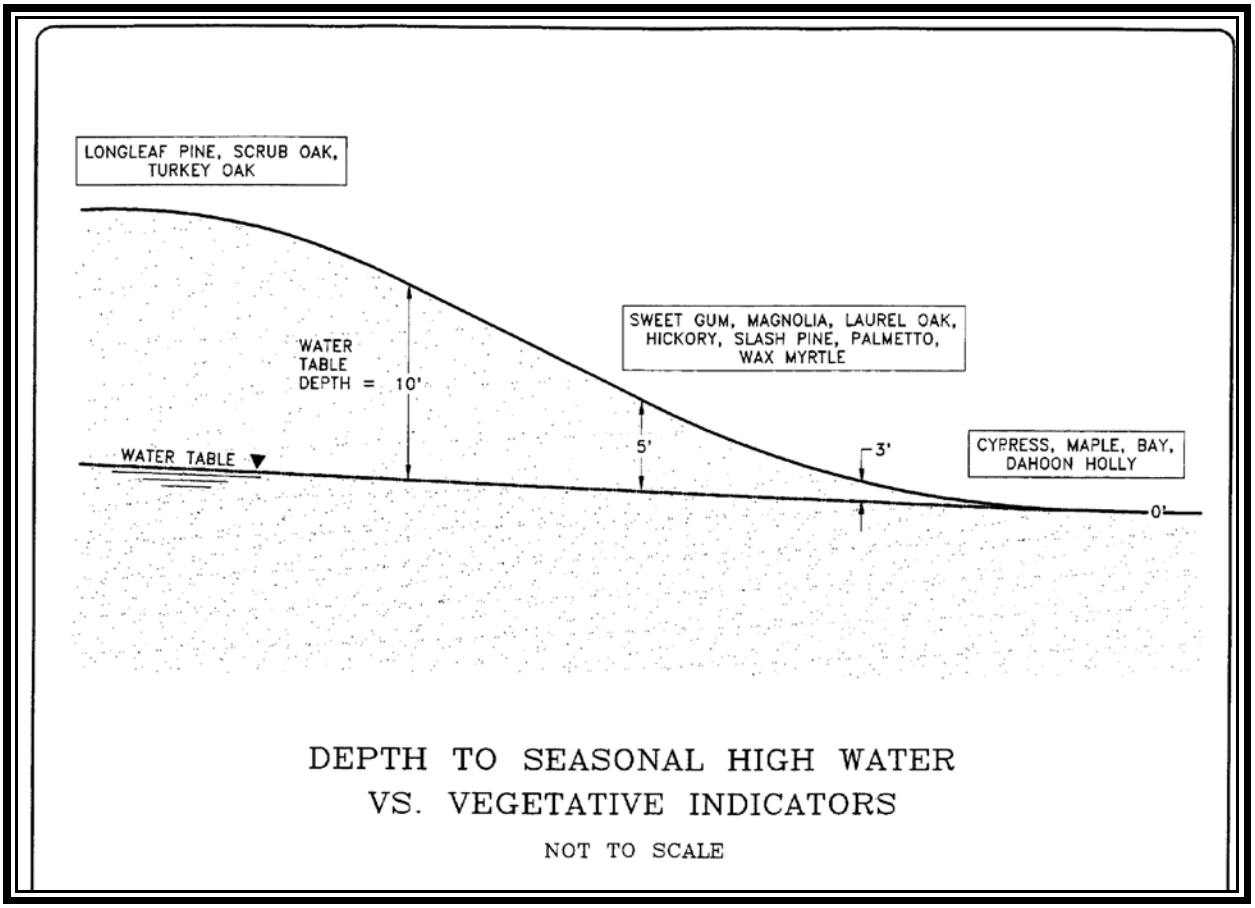

Figure 4. Vegetative Indicators

A great variety of trees are among the upland plants that seldom tolerate water around their bases for long periods of time. Those that grow under the driest conditions are known as xerophytes and include live oak and longleaf pine.

Review of old aerials of orange groves on sandy uplands usually shows up any areas of vegetative stress or variations which could indicate possible suppression of the water table due to buried paleosink features or other localized areas where there is higher than average vertical leakage from the surficial aquifer to the Floridan aquifer (Figure 5). Typically, orange trees do not grow where the wet season water table rises to within 36 inches of the ground surface.

The existence of a lichen line is well known to biologists who study wetlands where flooding is a normal occurrence. Typical lichens cannot survive prolonged submergence during flooding and as a result their lower limit of growth forms a so-called lichen line (Hale, 1984). This line rings the tree trunks, where below it there are no lichens and above it are it are dense whitish gray colonies of lichens. It is interpreted as a natural measure of high water that is sharply defined and easily observed in the field. Lichen line surveys are especially useful in providing a conservative estimate of the seasonal high pool elevation in wetlands, where groundwater discharges to surface water. Hale's (1984) study indicated that lichen lines represent high water marks which have not been exceeded in the preceding 10 to 15 years. High water levels within wetlands in Central Florida are usually 1 to 2 feet above the ground surface.

Factor #6: Impact of Development

Numerous developmental factors influence the post-development seasonal high groundwater table, including:

A) IMPROVED SURFACE DRAINAGE

i) Modification of land cover, such as directly connected impervious areas, alteration of slope of land, cutting and filling, etc.

B) IMPROVED SUBSURFACE DRAINAGE

i) man-made lakes, canal, ditches with control levels below the predevelopment SHWT.

ii) subsurface drains to lower water table levels beneath road subgrades, lots, or low wet areas.

C) INCREASED RECHARGE

i) spray irrigation of golf course

ii) percolation ponds

iii) septic tanks

iv) excessive residential lawn irrigation

v) uncapped flowing artesian wells

Buildings, paved areas, and other directly connected impervious surfaces prevent direct infiltration of rain into the aquifer and increase runoff. This rainwater falling on the impervious surfaces is directed to stormwater management ponds where it locally recharges the aquifer or discharge offsite through an outfall. If the postdevelopment offsite discharge of stormwater exceeds the predevelopment magnitude on an annual basis, there is a net deficiency of onsite rainfall recharge. Unless this recharge loss is made up with excess landscape irrigation water, recharge from septic tank drainfields or effluent reuse, the water table may drop in the long term within the developed site. The magnitude of the decrease in the water table level depends on a number of factors including the soil stratigraphy (especially the presence of shallow restrictive layers), the distribution of the impervious area and retention ponds within the site, the locations of subsurface drains, the control levels of stormwater management ponds, irrigation rates, etc. (Figure 5). Temporary effects such as adjacent construction dewatering must also be considered.

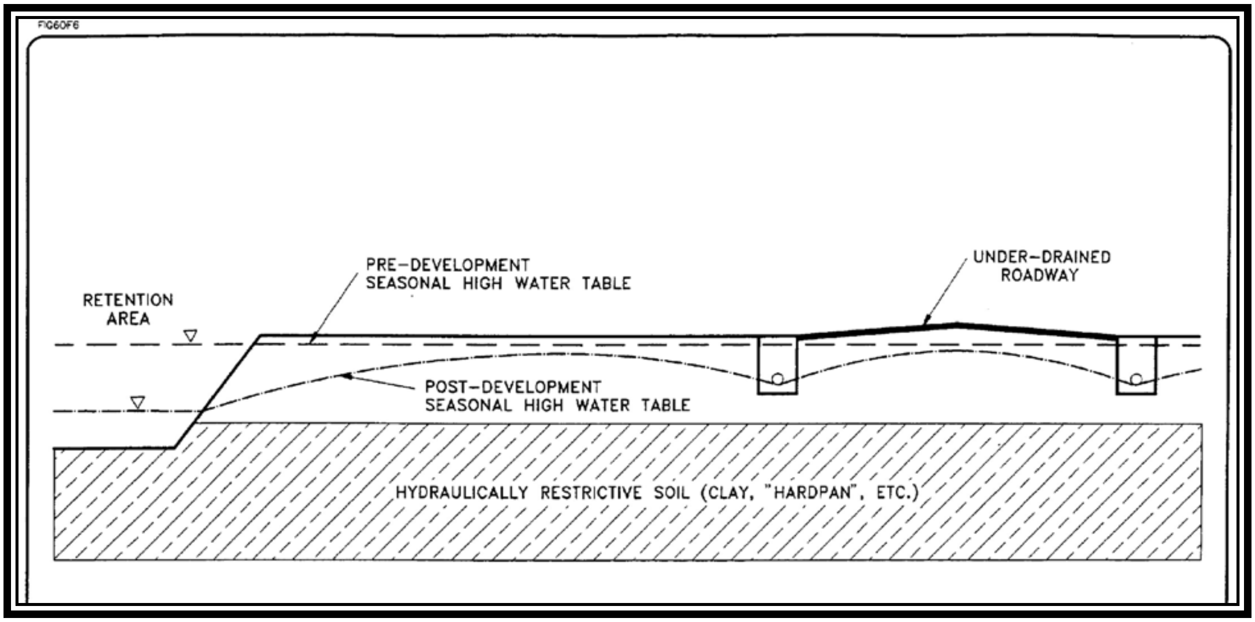

Figure 5. Postdevelopment Impacts

On more complicated sites, the postdevelopment water table level is best analyzed with a groundwater flow model (such as MODFLOW) or a flow net analysis by an experienced engineer. However, careful attention must be paid to the phasing of the construction during modeling since large developments take several years for buildout. Typically, a 1 to 2 foot drop in the water table is expected on developed sites with a high percentage of impervious area which do not have artificial recharge.

Underdrains and ditches drawdown the water table down within a zone of influence that primarily depends on the soil permeability and the head differential between the control/invert elevation and the level of the ambient groundwater table. Wang and Overman (1981) describe the effect of ditching on the water table in south Florida, while Segal et al. (1986) describe field observations of the effect of ditching on pine flatwoods north of Gainesville, Florida.

Factor #7: Hydrogeologic Setting

Knowledge of the hydrogeology of a site is important in assessing the relationship of the movement of the water table as it is affected by the degree of hydraulic connection between the water table aquifer and other underlying aquifers such as the Floridan limestone aquifer. The potentiometric surface of an aquifer represents the height above a datum plane at which the water level stands in tightly cased wells that penetrate the aquifer. The potentiometric surface of the Floridan aquifer may be above, below, or essentially equal to the altitude of the surficial water table. In some settings where there is good inter-aquifer connection, the altitude of the water table may be strongly influenced by the magnitude and fluctuation of the potentiometric level of an underlying aquifer that is recharged from offsite sources. In such instances, the fluctuation of the water table may reflect rainfall from a distant recharge area instead of onsite rainfall.

In areas of high recharge (10 to 20 inches per year) or high vertical leakance, such as some locations on the Lake Wales Ridge, the water level in the surficial aquifer may be the same or only slightly above the potentiometric surface of the Floridan aquifer. In such settings, the fluctuation of the potentiometric surface will control the water table more so than the hydrology of the surficial aquifer. The dry season (May) and wet season (September) potentiometric surface maps published by the water management districts in conjunction with the United States Geological Survey (USGS) should be consulted as the on-site water table may be controlled more by regional responses in the transmissive Floridan aquifer than by the net onsite recharge to the surficial aquifer. In addition, in such situations, the water table contours may bears little or no resemblance to the land surface topography, but strongly reflect the gradient in the Floridan aquifer.

In areas where the water table is below the potentiometric level of the Floridan aquifer and the potentiometric level of the underlying confined aquifer may in fact be above land surface, such as east of the St. Johns River in Brevard County, the possibility of upwelling must be addressed especially if excavations (such as deep utility mains) are planned. Such deep cuts can breach shallow hydraulically restrictive (clayey) layers which confine the artesian pressure and may lead to uncontrollable flows which render conventional dewatering almost impossible. To investigate the possibility of upwelling, it is advisable to place a piezometer cluster which comprises a series of piezometers in one location, each with their open sections screened at different depth intervals. The measured water levels will allow an estimate of upward (or downward) vertical gradients and will indicate which hydrologic units account for the majority of the pressure loss.

Sand-filled paleosinks (i.e., buried ancient sand-filled sinkholes) can create areas of localized effective inter-aquifer hydraulic connection which may result in a localized depression of the water table without obvious surficial manifestations (except maybe for vegetative differences) of internal drainage. Review of old aerial photographs can show locations within an orange grove, based on color variations, which might be stressed (see Figure 6). If knowledge of such anomalies are important to site development (such as in landfills), a network of piezometers or surface geophysical measurements (such as GPR) should be made to develop a refined groundwater contour map.

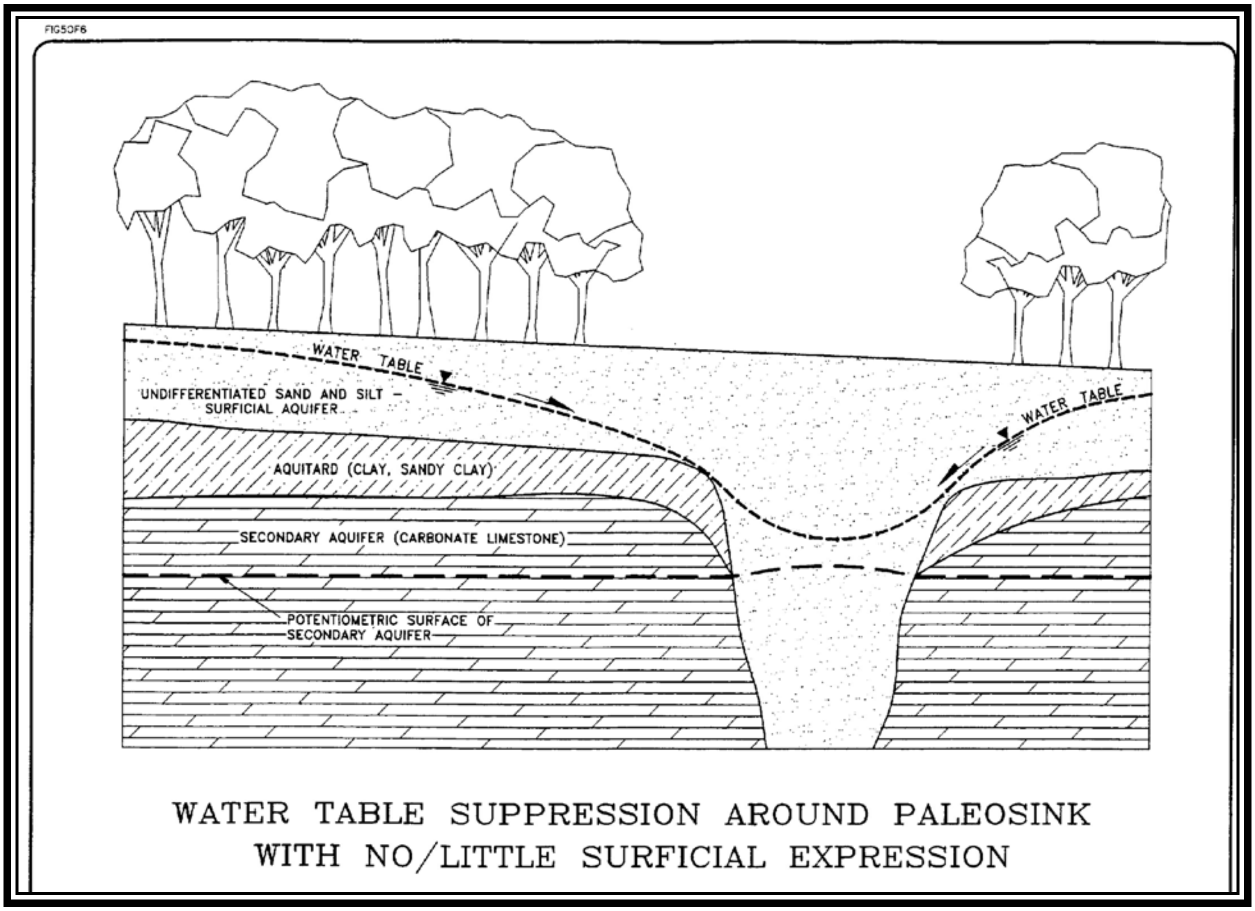

Figure 6. Paleosink Impacts

Published hydrogeologic data usually suffices for this level of study. Relevant published reports can be located at the Florida Geological Survey, United States Geological Survey, water management districts, state universities, local government agencies, private consultants, etc. Depending on the potential impact to the development and/or environment, it may be necessary to acquire site-specific data.

Factor #8: Correlation with Soil Morphological Features

Soil morphology refers to that process which involves the formation of the soil horizon or soil horizon differentiation. The differentiation of horizons in soils is the result of accumulation of organic matter, leaching of carbonates, reduction and transfer of iron, or accumulation of silicate clay materials. A recently completed study by Brown et al. (1989) correlates the wet season water table to the following soil morphological properties:

- 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.

- 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.

- 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 the observations in Florida is as follows:

$$XWT = -61 + 0.4 X_1 - 2.1 X_2 + 2.6 X_3$$

(Residual Sum of Squares, $R^2 = .81$)
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)

This equation is a useful check on the seasonal high water table assessed using the other adjustment factors.

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