Final Report

Methods to Predict Seasonal High Water Table (SHGWT)

Submitted To:

The Florida Department of Transportation
Research Center,
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The opinions, findings, and conclusions expressed in this publication are those of the author.

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16. Abstract: The research study was sectioned into 5 separate tasks. Task 1 included defining the seasonal high ground water table (SHGWT); describing methods and techniques used to determine SHGWTs; identify problems associated with estimating SHGWT conditions; summarizing results from interviewing state agencies and engineering consultants for determining how SHGWTs are determined; and, providing a preliminary data set for developing a technical procedure manual for applying various SHGWT predictive methods.

Task 2 characterized pilot test site locations by describing procedures for establishing ten (10) physical and four (4) hypothetical tests sites using future road construction corridor projects. The procedures section described multiple sets of methods in order to evaluate method consistencies between test site methods, topographical, and hydrogeological conditions.

Task 3 was divided into three tasks- Task 3A, 3B, and 3C. Task 3A provided a summary of field and analytical methods used to evaluate baseline SHGWT conditions during setup of both physical and hypothetical test sites. A preliminary evaluation of methods used to predict SHGWT conditions at each test site was included. Task 3B involved collection of water level data from test well and surface water locations along with hydrologic station data to evaluate various equation methods for estimating SHGWT conditions. Task 3B covered a two year long term monitoring program involving the collection of water level data and applying model equations to both ground water and surface water observation sites, and nearby hydrologic stations for evaluating SHGWT predictive methods. Quarterly status reports were prepared summarized field collected data and equation evaluation methods. Task 3C addressed the issue of applying the NRCS water table ranges for specified soil types throughout the seven (7) FDOT districts by compiling ground water and rainfall data from available water management district records. The data was evaluated for statistical probabilities for applying NRCS water table ranges for predicting ground water levels by direct comparison with actual ground water level data.

Task 4. Report of Recommendations summarized the most successful methods for predicting seasonal high ground water elevations through application of both qualitative and quantitative methods for each FDOT District based on data collected over the three year study.

Task 5. The Draft and Final Report summarized the research study tasks as described above.

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Groundwater prediction; water table estimation;	Three year research study applied towards identifying issues and methods, developing, implementing, and collecting ground water measurement data associated with predicting seasonal high ground water conditions through application of combined qualitative and quantitative methods.

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Section 5.0. Recommendations

Executive Summary

The Florida Department of Transportation (FDOT) contracted with Mr. William Szary, CPG, PG, EurGeol (Contract No. BDX86) to conduct a research study addressing various techniques for determining seasonal high water table (SHWT) predictions within and across the seven (7) district boundaries within the State of Florida. This final report summarizes the research, pilot test site development and implementation, data collection and prediction evaluation, and the development of method guidelines for Department implementation. The terms seasonal high water table (SHWT) and seasonal high ground water table (SHGWT) are used interchangeably throughout the report text.

1.1. ***Section 1.0. Research Summary***. The purpose of the research study task was to define the seasonal high water table, to research the State of Florida Water Management Districts (WMDs), FDOT Districts and engineering consultants related methods used to determine SHWT conditions; to identify various methods, techniques, inconsistencies and problems associated with estimating SHWT conditions; and, to evaluate sources of historical data available within the public domain considered appropriate for evaluating SHWT conditions.

Differences on how SHWTs are defined exist among the different FDOT Districts and WMDs based on the different types of landscapes and hydrogeological settings present within each district. These discrepancies created a certain level of confusion as to how to approach the determination, techniques, and methods for estimating SHWT conditions by the seven (7) FDOT Districts. Therefore, a set of procedural recommendations were developed to help guide the design engineer through the process of applying methods and techniques for determining SHWT conditions within the seven (7) FDOT Districts. These recommendations are presented in **Section 5.0**.

The seasonal high water table is the depth at which the “normal” water table rises in response to recharge occurring through the unsaturated zone, entering the saturated zone during the wet season. A seasonal high water table condition appears when the water table becomes elevated above the “normal” elevation range and is maintained for a duration exceeding a specified length of time. The United States Department of Agriculture Natural Resource Conservation Service (USDA NRCS) definition: “*a seasonal high saturation is the highest level to a zone of saturation in the soil that occurs in most years. A seasonal high saturation normally persists for several weeks, normally occurring during the time of year when the most rain falls (June through September in Florida)”.*

The USDA NRCS uses a 30 day criteria to judge SHWT for ranges present in the soil surveys. The Florida Department of Health (FDOH) provided the most comprehensive definition “*the highest depth to a zone of saturation. The SHWT normally persists at its depth for several weeks or more, and normally occurs during the time of year when the most rainfall occurs”*.

A *perched water table* is defined by water standing above an unsaturated zone. Perched water tables are separated from a lower one by a dry zone (*NRCS Technical Soil Service Handbook Part 617*). Perched conditions occur when a more permeable layer occurs above a less permeable layer, preventing infiltration from seeping into the lower soil profile below the less permeable layer. *Hanging water tables* occur when a slow permeable soil layer overlies a rapid permeable soil layer. Water infiltrating through the profile seeps through the slower permeable layer into a layer of greater permeability. A saturated zone “hangs” below the slowly permeable zone. An *apparent water* table develops as a thick zone of free water in the soil indicated by the level at which water stands in an uncased borehole after adequate time is allowed for adjustment (stabilization of water level) in the surrounding soil.

Methods for Determining SHWTs. In the FDOT Drainage Manual, Section 2.5, FDOT states most Districts accept NRCS soil survey data for pond site evaluation. For areas where poor soils are present, the manual states site specific studies may be more appropriate. Methods for determining SHWT conditions include the use of NRCS soil surveys, project specific soil investigations, and field observations. Field observations include vegetative indicators, observation wells, etc. for estimating the SHWT.

Review of water management district’s Environmental Resource Permit (ERP) applicant’s handbooks provided treatment design specifications including example design equations used to calculate infiltration through unsaturated and saturated equations for submitting designs of storm water management systems for permit approval. Many of these methods and examples were adopted from the FDOT Drainage Manual and from consultant studies completed under contract to specific water management districts.

Quantitative Methods. Quantitative methods require data collection and/or calculation by equations to produce an estimate on determining SHWT conditions based on field data collected at specific sites, or based on a review of historical data published by the USGS and WMDs.

A discussion of the methods and equations are provided in greater detail in this section. Example calculations for the methods described in *Section 1.3* were provided in the Task 1 report dated June 9, 2014, Appendix D (see references).

Problems with Recognizing SHWT Conditions. Fill placed on top of native soil may produce mottling in the fill or just below the contact interface with native soil, unrelated to true redox features. Fill compaction may simulate the action of an artificially induced hanging water table at the interface between the dense compacted layer and the underlying looser native soil layer.

Soil drainage may produce problems with infiltrating rain fall and percolation from drainage basins. In Florida, there are six recognized drainage classes of soils categorized by NRCS. Each soil drainage class is characterized by SHWT conditions with varying depths. A summary of the soil classes is provided in Section 1.0 of the report.

Spodic Soil Conditions are special soils which are recognized by the presence of an ashy gray “A” horizon and an iron rich organic “B” horizon. The spodic horizon is usually recognized by a dark brown silty sand layer sometimes hardened by accumulating iron leached downward from the upper “A” horizon. SHWT depths occur 10 inches or less even though the depths to the spodic horizons occur below the estimated SHWT depth. SHWT depths are typically encountered at about 10 inches below grade in the gray soil horizon. The spodic horizon by itself does not represent a SHWT condition nor do high chroma colors represent a SHWT condition. Spodic zones represent fluctuating water table conditions (Hammond, 2013a).

Iron cemented nodules and concretions develop by localized deposition of iron resulting from precipitation of dissolved iron from solutions moving through the profile. Iron migration does not necessarily reflect vertical rise and fall of the water table, although vertical movement may contribute towards nodule and concretionary development (AGI, 1976). Iron segregated mottles appearing along root channels are not indicative of SHWT conditions. Misinterpretation of SHWT conditions may result from applying this observation as an interpretive indicator. Iron cemented soils are rare in Florida.

The St. Johns River Water Management District (SJRWMD) identified the Indian River Lagoon Basin as a problematic region where percolation was limited due to poorly drained soils consisting of clays and clayey sands.

Alachua and Marion Counties were cited to be the most difficult region to estimate SHWT conditions due to the presence of karst. Alachua and Suwannee Counties do not have a water table but has an intermediate and Floridan aquifer exposure. Marion County has a water table present in the eastern half and an intermediate or Floridan aquifer exposure in the western half of the county.

Developmental impacts which improve surface drainage including modification of land cover, connection of impervious surfaces, alteration of natural land slopes, cutting and filling, etc. prevent direct rain infiltration and recharge to the water table by increasing the runoff component. Man-made lakes, canals, ditches with control elevation structures below the predevelopment SHWT lowers water levels beneath road subgrades, lots, or low wet areas. Seasonal rainfall into surface water features influences ground water recharging and discharging phenomenon.

A survey questionnaire was provided to each FDOT District geotechnical engineers and water management districts for identifying various methods, techniques, supporting data, and problems associated with estimating SHWT conditions throughout the state. The purpose of the questionnaire was to maintain consistent responses from each of the contacted agencies. Some FDOT Districts forwarded the questionnaire to engineering consultants for response which were tabulated as an FDOT response. Engineering consultants were contacted from each district with no response to the survey. District 3 did not participate in the survey. The response from the Northwest Florida Water Management District (NWFWMD) was relied on for evaluating conditions within the district. The responses were summarized *in the Task 1 Definitions, Methods, and Techniques Report dated June 9, 2014.* The results are summarized below.

District Method Consistencies. Hydrologic data provided by WMDs and NRCS soils data appear to be the most commonly used methods obtained from public domain sources for estimating SHWTs. Redox features appeared to be the next most common method used in all Districts (except for District 5) for estimating SHWT conditions. Correlation to historical high water levels and vegetative/soil indicators were the third highest ranked method used to determine SHWTs.

District Method Inconsistencies. None of the FDOT Districts indicated use of back computational methods for determining SHWT; Districts 2 and 5 identified the use of the correlation method to historical high water levels as a method for determining SHWTs; Districts 1, 4 and 6 utilized vegetative and soil indicators as a SHWT technique; District 2 indicated use of the FDOT Storm Water Drainage

Manual as a method for determining SHWTs for storm water treatment design. Soil drainage was not selected as a problem issue for determining SHWTs; hydrogeologic setting was not indicated as a condition of concern; and, select Districts identified various landscape types as a problem for determining SHWTs. District 2 stated SHWT determinations were provided by the FDOT District to the drainage section and to engineering consultants upon specific request for a determination.

Problems, Symptoms, & Causes: Soil Problems. The presence of silts, clays, and hardpan appeared to be the most common limitation for developing proper SHWT estimations. District 1, District 2, District 5, NWFWMD, and SWFWMD indicated soil type was the most significant limitation for estimating accurate SHWT conditions. Soil drainage was indicated by District 5, NWFWMD, SWFWMD, and SJRWMD as a problematic issue.

Extremely low permeable aquifers and perched/hanging water table conditions appeared to be the greatest problem for determining accurate SHWT conditions for all Districts. SFWMD stated problems occurred where ground water was historically drained or where conveyance was limited. Soil classification, soil permeability were cited by District 1 and District 7, responsible for slow drained soils. SJRWMD mentioned Alachua and Marion Counties. District 4 mentioned West Palm Beach County including all counties along the Atlantic Coast SR A1A due to tidal impacts. District 5 mentioned Flagler, Volusia, Seminole, Orange, Osceola, Brevard, and Lake Counties citing poor drainage as the dominant issue.

Landscape type: Districts 1 and 7 indicated Sand Dune Hills and shallow depressions were symptoms in which difficulties occurred while estimating SHWTs; Coastal Plains were identified by District 4 specifically referring to tidal influences affecting accurate SHWT estimations along SR A1A.

NWFWMD, SWFWMD, and SFWMD indicated Flatwoods were an issue where SHWT estimates were difficult to predict due to spodic soil horizons and/or perched-hanging water table conditions occurring within 1 foot below grade. District 2, District 5, NWFWMD, SRWMD, and SJRWMD indicated karst was a symptomatic problem in estimating SHWT conditions. Karst issues were identified by District 2 in Suwannee, Taylor, Dixie, Alachua, Levy, and Lafayette Counties. SRWMD identified karstic areas as being the most problematic condition for estimating SHWT conditions. Suwannee River and Gulf Coastal Lowlands and portions of the interior peninsular region are exposed to these conditions.

The region is exposed to confined aquifer potentiometric surfaces including both upward recharge into the water table and downward discharge from the water table into the confined aquifer. Lower aquifer contributions to the water table (upward flow) and downward flow from the water table into the lower aquifer contribute towards SHWT fluctuations.

Hydrogeologic aquifer type: Unconfined aquifers with restrictive layers were mentioned by all WMDs, confined aquifers with potentiometric surfaces (SWFMWD, SRWMD), and perched and/or hanging water tables (Districts 1,2,5,6,7, NWFWMD, SWFWMD, SRWMD, and SJRWMD) were mentioned for improper estimation of SHWT conditions. District 2 mentioned Alachua, Taylor, Dixie, and Lafayette Counties were problematic with karst. Highly permeable aquifers were cited by NWFWMD, SWFWMD, and SRWMD. Slowly permeable aquifers were cited by District 1, 2, 5, 4, and 6, and by all WMDs as problematic symptoms. Karst was also mentioned by District 5 as an issue for specific types of storm water systems.

Special Problematic Symptoms. SWFWMD stated urbanized settings where significant changes to land use and drainage occurred; construction methods included sedimentation, compaction, and fill replacement of native soils. District 5 and SWFWMD cited underestimation and/or overestimation of SHWT conditions as a symptomatic problem. Pinellas, Hillsborough, and Sarasota Counties were mentioned by SWFWMD as being particularly troublesome with respect to urbanized conditions resulting in land use and drainage alterations.

District 5 listed several projects which presented underestimation of SHWT resulting in flooding or poor estimation during road and storm water system construction. Seminole County, SR 434, US 17/92 Saxon Blvd recharge pond, SR 551 Goldenrod Road under-drain failure, and Naranja Road retention pond flooding were mentioned. District 7 mentioned US 301 as a problem road due to replacement of native soils by fill material interfering with proper estimation of SHWT conditions.

District 1 mentioned specific road projects with malfunctioning storm water management systems due to fines being introduced into basins: I 75 Jones Loop Road; SR 70; US 98; SR 60 Lake Wales. **Table 1.5** (**Section 1.0**) provides a summary of FDOT Problem Conditions.

FDOT Districts indicated geotechnical consultants relied on SPTs for use in identifying SHWTs for Districts 2, 4, 5, and 6; District 7 indicated soil moisture determination as a method for evaluating infiltration; District 2 indicated use of infiltrometers, percolation, and hydraulic conductivity measurements collected in the field as methods for determining SHWTs.

All Districts indicated soil classification and soil profiles as a technique for determining SHWTs; all Districts utilized WMD and USGS hydrologic data and the NRCS soil survey data for determining SHWTs. Districts 4 and 6 indicated use of the Florida Geological Survey well log database as a method for determining SHWTs.

Field Pilot Testing Site Research. A future project list was released by FDOT in April 2014. The April 2014 list was used to select targeted project corridors in an attempt to address problems identified in the survey questionnaire. Responses from FDOT and the WMDs were reviewed to identify problems associated with soil properties (soil type, drainage, permeability), hydrogeologic aquifer conditions resulting in adverse impacts with respect to storm water drainage including unconfined aquifers with restrictive layers, confined aquifers with potentiometric surfaces, perched and/or hanging water table conditions, and extremely slow permeable soil conditions.

Selection Criteria. Physical test sites located in urban settings were avoided due to lack of sufficient work area along FDOT right of ways and the exposure of residential and commercial business to potential disruptions associated with operating a drill rig in densely populated areas. Pilot test sites were selected to provide reasonable access along the right of way or adjacent to right of ways on public owned property based on the most recent aerial photographs available for review (2013), and the presence of public agency hydrologic stations and surface water feature availability.

Hypothetical test sites were established for District 1 (DeSoto County), District 4 (Broward and Palm Beach Counties), District 6 (Miami-Dade County) due to the presence of public agency hydrologic station data.

Hypothetical stations were selected along proposed construction corridor routes for prediction evaluation. Potential pilot test corridors were extracted from a PDE study road project corridor master list.

1.2. ***Section 2.0. Technical Procedures Summary***. Pilot test site setup procedures were developed for the purpose of collecting baseline data required to estimate SHWT conditions; and, to present various quantitative and qualitative methods applied through the collection of data obtained from each pilot test location. Each of the fourteen (14) pilot test sites were subjected to multiple sets of field methods in order to evaluate method consistency between test sites under varying topographical and hydrogeological conditions.
Theoretical and practical methods were used to calibrate and validate methods for determining SHWT conditions between each District and between each pilot test site for determining which methods provided the most effective results.

Proposed test site profiles provided general geologic information obtained from FGS county geologic maps; FGS lithologic database for obtaining thickness of unconfined, confined, and Floridan aquifers for well sites located closest to the pilot test site; a preliminary review of water table depths based on topographic map interpretation; summarizing NRCS soil profile and other soil characteristics such as evidence of perched or hanging WT conditions; aquifer property conditions based on water management district (WMD) potentiometric surface maps; and, completing preliminary interpretation on gradients occurring between the water table and confined aquifer systems (upward or downward flow). *Hydrologic* stations were identified by ID number, station type, data source, and location description and by STR. *Pilot Test Site Procedure*s summarized field methods applied during baseline establishment of each test site location. Collected data included observation well detail, soil boring, and geotechnical testing methods were previously reported in *Task 2, Technical Procedures Manual* dated August 11, 2014, revised October 31, 2014. Data used to characterize each proposed test site was contained in the cited report document.

"Hypothetical" test sites were defined by sites where methods to predict SHWT conditions were based strictly on public record acquisition through the USGS and WMD hydrologic databases. Hypothetical sites utilized hydrologic data collected from public agency sources during determination of SHWT conditions in accordance with the methods listed in **Appendix B,** Task 1 report.

Physical Observation Points. During setup of physical test sites, additional observation points for evaluating surface water features were established at the time each pilot test site was setup for baseline data collection.

Observation points were established for the purpose of repeating measurement observations during the data collection and prediction evaluation program. Stations were also marked on aerial photographs for identification (see *Baseline Supporting Documentation*). Inspection and collection of baseline data during well construction activities included conducting hand held penetrometer testing, completing hand auger borings, performing percolation testing, conducting pump drawdown and recovery testing on installed observation wells, and obtaining vertical elevations for each physical test site. A simple rain gage was placed at each physical test site.

1.3. *Section 2.2. Pilot Test Site Setup Summary*. The objective of the pilot test study was to establish hypothetical and physical observation stations for collecting ground water, surface water, and hydrologic station data for evaluating qualitative methods, and for input into quantitative equation methods for estimating SHWT conditions. Each physical pilot test site was characterized by a uniform set of geotechnical and hydrogeologic field methods for obtaining field data necessary for estimating SHWTs through various methods described in Sections 1.0 and 2.0. Ten physical and four hypothetical test sites were setup to evaluate a variety of circumstances identified in the problems described in Section 1.0. DeSoto County, Palm Beach County, Broward County, and Miami-Dade pilot test sites were categorized as hypothetical sites.

Physical sites were established by constructing observation wells at various depths for collecting ground water measurements. Measurement data was applied to both qualitative and quantitative methods for predicting ground water elevations. Hydrologic station and surface water observation measurement data were included in the evaluation process. Geotechnical, hydrogeological, and soils data were collected from each physical pilot test site for obtaining baseline data prior to the initial start of the data collection and prediction evaluation program. Suwannee and Alachua Counties relied on geotechnical methods due to the depth of the limestone aquifer and absence of surface water features and public agency managed hydrologic stations. Details of test site setup procedures and collected baseline data were reported in *Task 3A, Pilot Test Site Field Study Baseline Report* dated December 4, 2014. *Baseline Supporting Documentation* was appended to the report.

A summary is provided below.

Field Methods Summary: Geotechnical Methods. Standard penetration testing (SPTs) provided soil log information including color, texture, and degree of saturation for each soil profile. Blow count density and pocket soil penetrometer testing reflected similar density variations with slight deviations ranging between 1 and 2 feet between the two methods. A pocket penetrometer was used to cover the entire soil profile and to speed up the descriptive process in lieu of static cone penetrometer probe testing. SPT values were recorded for 0.5 ft interval counts for use in estimating density variations which provided a more accurate aquifer level fluctuation estimate.

Soil Color Descriptions. The use of the Munsell chart was cumbersome, resulting in minor delays while processing soil core samples extracted from the SPT process. The obvious indicator for recognizing SHWT conditions were the gray soil horizons. Soil colors other than gray hues may be used to distinguish between textural variations between percent sand (light colors), silt (dark browns), and clay (variable colors).

Soil Horizon Designation. Assignment of specific horizons to each test site profile was difficult based on the types of soils encountered during the pilot test site setup. Proper designation of soil horizons was required for the application of the soil morphological method for estimating SHWT conditions. This method could not be pursued due to soil horizon identification difficulties.

Redox Features. Limited soil profiles observed during pilot test site setup exhibited distinguishable redox features for recognizing SHWT depths. Soil matrices appeared uniformly consistent in color.

Redox features were difficult to distinguish in sandy soils. The Lake County site was the exception. Subtle redox features appeared in the sandy profile with very slight changes in color. Without close observation, the features would've been easily missed. At the Alachua, Pasco, and Suwannee sites, clay zones had very pronounced relict mottling left over from when clays were originally deposited. Based on the lack of observed evidence, redox features were not considered to be a reliable indicator for estimating SHWT conditions due to the inconsistent nature of recognizing these features. Recognition of subtle contemporary redox features required technical expertise in soil science.

Hydraulic Conductivity Analyses. Percolation and aquifer testing occasionally produced reasonable results, some extreme results, and some lower than expected results. Percolation tests were used for application of the Hantush method for estimating storm water basin sizing. Where percolation values were extremely high, NRCS Ksat values were substituted in the analyses. Where results occurred within NRCS Ksat range of values, the testing data were used as input into water balance and flow net analyses equations. Potentiometric surface maps were used to estimate initial confined aquifer elevations. Where observation measurements were available from either hydrologic ground water station data or from pilot test site baseline elevation data, elevation changes were determined from measurement differences between shallow and deep wells.

Flow Net Analyses. Flow nets were constructed graphically for estimating upward and downward flow between aquifer depths. Horizontal hydraulic conductivity values obtained from aquifer tests were used for equation input. Where values were unreasonable high, NRCS Ksat values were substituted by converting vertical hydraulic conductivity estimates into horizontal hydraulic conductivity estimates by the formula Kv = 0.3Kh (Fetter, 1988). Gains were attributed to rainfall recharge exceeding estimated runoff and evaporation conditions. Losses occurred when runoff and evaporation exceeded rainfall recharge. Evaporation was held constant for all test site locations. Rainfall was input based on data collected from the State Climatology Center web site for locations closest to each test site. Runoff values were estimated from the Florida Geological Survey runoff estimation map provided in *Appendix C of the Task 1A report.*

Baseline Prediction Issues. During baseline and the 1^{st} quarter of 2015 method application, unexpected issues surfaced when applying various method equations due to misunderstanding of equation functions, required input, and physical test site issues resulting in unusually high errors occurring between predicted and measured ground water elevations. The baseline results presented in the Task 3A report **Appendix B** for November 2014 and 1^{st} quarter 2015 are considered invalid due to use of improper land elevations obtained from old topographic map contour data. This issue produced problems with determining whether or not ground water and surface water measurements represented the same aquifer system. For example, in Bay County both observation well and surface water elevations were thought to be at a much lower land surface elevation.

Incorrect land elevations placed the ground water interface at a much lower elevation than the lake producing the impression that the lake and ground water systems were positioned in two different aquifers.

A review of Google Earth satellite image land elevations for both sites placed the lake and ground water within the same aquifer which changed prediction results from unacceptable to acceptable errors. Other test sites experienced similar issues which were corrected when discovered.

Single sets of assumed hydraulic gradient values were applied to 1st quarter 2015 monthly data producing unacceptable predictions which strayed well above actual measurement values. A new hydraulic gradient condition was calculated for all measurements observed between surface and ground water conditions for subsequent quarters. This correction resulted in production of acceptable prediction errors when compared with measurement data.

During the first quarter of 2015, unacceptable prediction errors occurred when both simplified and back computational methods were applied without considering the direction of gradient slope between surface and ground water stations. During the 2nd quarter of 2015, corrected application of hydraulic gradient methods produced acceptable results between predicted and measured ground water elevations.

A summary of data collection and prediction modeling efforts completed during the 2015 – 2016 data collection period is summarized below. Details are provided in **Section 3.0** of this report document.

1.4. ***Section 3.0. Data Collection & Prediction Evaluation Summary*.** The long term monitoring program involved collection of field water levels from observation and hydrologic station data for evaluating normal and seasonal high water table conditions at each of the fourteen (14) pilot test sites on a monthly schedule covering the period between January 2015 and October 2016. The objective was to address issues and problems associated with predicting “acceptable” results within a 0.5 foot error from test site measurements.

Throughout 2015, each test site was evaluated for understanding how each equation functioned, what conditions produced small and large errors, and to attempt to resolve problematic issues for improving predicted results.

Some test sites had unique problems due to the following issues which affected application of some equations:

1) Clayey soil types exhibiting temporary perched and hanging water table conditions; 2) lack of public agency hydrologic data sources; 3) lack of surface water features to adequately test methods; 4) changes in topographic elevations occurring between hydrologic data sources and road corridor stations; 5) suspect public hydrologic station data errors showing surface water elevations at the same height as ground water hydrologic data. Attempts were made to correct for special conditions during the data collection and prediction analyses period during the measurement collection period.

Qualitative evaluation methods relied on direct comparisons between test site measurement data and baseline field data collected at the time of pilot test site setup for soil indicators and geotechnical methods. Published seasonal water table ranges offered by NRCS were used to evaluate water table measurement data through direct comparisons.

Cursory observation for the quantitative set of methods suggests there was not a single method other than the hydraulic gradient methods (simplified and back computational) reliable enough to cover multiple landscape and district boundary conditions. Several test sites produced results which have no means for confirming or verifying whether or not predictions achieved acceptable criteria.

NRCS Water Table Evaluation.

Four out of fourteen test sites (DeSoto, Liberty, Lake, and Palm Beach County) met the NRCS water table range criteria for the third quarter (2015) water level measurements by technically meeting the >6.5 foot depth criteria. The summer seasonal high ground water table depths occurred within or greater than the NRCS range for DeSoto County. This method appeared to be applicable when rainfall amounts resulted in a rise of the ground water table surface to its seasonally high maximum elevation. Total rainfall between January and November 2015 occurred below typical annual rainfall totals for Florida assumed to be 50+ inches per year. The Task 3B 8th Quarter Status Report **Appendix C** presented hydrographs for each pilot test site showing peaks and declines in rainfall vs. ground water depths. A more detailed study was completed to evaluate this method based on statistical probabilities, presented in **Section 4.0**.

Soil Profile Indicators

Gray soils are indicators of the top of the seasonal high ground water table depth (Vepraskas, M., ___). Eight out of the ten test site profiles had gray color indicators suggesting the seasonal high ground water table may be estimated by soil profile during 2015. Based on comparisons between observed gray soil profiles and seasonal high ground water measurement data, sandy type soils appeared to be more closely matched to ground water table indicators than clayey soils although some deviations occurred for sandy soil types.

Verifying Predicted Results Where No Measurement Controls Exist

For situations where hydrologic ground water stations were used to establish hydraulic gradients for predicting ground elevations at hypothetical subject sites, and where no control ground water elevations existed along the road construction corridors, there were no acceptable means for verifying predicted ground water elevation results. An attempt was made to use NRCS soil type water table ranges as an alternative means for establishing some mechanism for control which did not produce acceptable results. The DeSoto County CR 769 hypothetical site and the Palm Beach US 1 hypothetical site were two examples where this condition was tested. Recommended procedures for resolving this issue include placing a temporary well point into the ground water table for the exclusive purpose of estimating a temporary hydraulic gradient condition. This option was not applied during this study but may be considered by FDOT during the FDOT field implementation portion of this study.

Comparisons were made between ground water vs. surface water fluctuations to determine whether or not surface water fluctuation measurements could be used to predict ground water fluctuations by projection back inland from surface water features using any equation method. This method of estimating ground water elevations has the potential to produce significant errors for all equation methods (except the hydraulic gradient method) specifically under conditions where rivers or creeks have low staging heights.

1.5. *Section 4.0. NRCS Statistical Probability Study*

The probability of achieving a direct match with NRCS water table range estimates for Districts 1, 2, 4, and 5 appears to be less than 30%. For the urban setting represented by District 6, greater than 64% probability appears to be likely for achieving acceptable predictions using the NRCS method.

Caution should be exercised when applying published NRCS data for predicting water table ranges. NRCS water table ranges may represent pre-urbanization and thus may not reflect true water table conditions.

Acceptable probability results appear to be near 50% for District 7. Applying the NRCS method for use in direct correlation with predicting seasonal high ground water measurements is low, except for the urban setting in District 6. Caution should be exercised when attempting to assume the NRCS range intervals are accurate. Field investigative methods are recommended as a means for validating NRCS estimates. For example, qualitative methods such as gray soil indicators, SPT density counts, and the hydraulic gradient method would be appropriate for verification purposes.

When the NRCS method is used to predict conservative seasonal high ground water table condition, probability increases to greater than 45% for District 1, and greater than 77% for the remaining districts (Districts 2, 4, 5, 6, and 7). Application of the NRCS method appears to be more successful in predicting conservative seasonal high ground water conditions where seasonal high ground water measurements occur below the lower NRCS water table range interval value.

Temporary water table conditions are expected to be encountered less than 15% for all districts due to fill placement in urban settings. About one third of the sites had a probability of producing temporary water tables due to the presence of clay. For Districts 1, 5, and 7, the probabilities of temporary water table conditions occurring below 15%, 5%, and 3%, respectively.

Some NRCS range estimates may represent temporary water table conditions as opposed to misinterpreting temporary conditions as “normal” seasonal high ground water conditions. Geotechnical soil borings would be the best method to make this determination in cases where temporary water table conditions are present or interpreted.

1.6. ***Section 5.0. Recommendations Summary***. A set of recommendations were developed for implementing various qualitative and quantitative methods for predicting seasonal high ground water during the data collection and prediction analysis period covering 2015 and 2016.

Some methods appeared to be more effective than others, although there did not appear to be a uniform method for district wide or statewide application with the exception of the hydraulic gradient methods. Recommendations presented in this report addressed all methods which produced effective results. An effective result was defined by the NRCS for recognition of seasonal high water in Florida. Acceptable results were defined by less than or equal to 0.5 foot difference between predicted errors and measured observations. Test sites within each District had to have met the accepted criteria for a single month during the two year data collection cycle, consistent with the NRCS definition of a seasonal high water table. Special considerations were given to test site properties including landscape type, soil type, temporary, and/or normal water table conditions. The NRCS method study (Task 3C) revealed statistical probabilities for achieving defined prediction categories related to landscape classifications applied by the NRCS soil survey descriptions. A summary of the NRCS method result presented by landscape type for each district is provided below, and is intended for use as a guideline and not as a replacement for site specific investigation. A set of maps were compiled from different public agency data sources, and from data compiled during the NRCS study (Task 3C). These maps were presented in the NRCS Study Report Appendix C, dated November 25, 2016.

Districts 1. Flatwoods and urbanized settings were evaluated by both qualitative and quantitative prediction methods. Variation in soil type ranged from fine sands to silty sands influenced by drainage conditions. Soil drainage was considered very slow to moderate in the upper 4 feet of the soil profile. District 1 was subjected to river and canal artificial drainage influences on ground water. The following predictive methods appeared to be most effective for this District: hydraulic gradient method, Correlation method, seasonal high surface water to SHGWT prediction method was effective for this District (except DeSoto County).

The NRCS Study revealed a statistical probability for the District 1 region based on evaluation of 26 sites, and 14 sites. Within District 1, a 7% probability of achieving acceptable criteria, 45% probability of achieving a conservative result, and a 15% of encountering temporary water table conditions was predicted.

Districts 2. Marine terrace and flatwood settings were represented by District 2. Sands and clays were the dominant soil types observed. Very slow to moderate drainage was observed in the upper 4 feet of the soil profile.

The following methods for predicting SHWTs appeared to be most common to the District in order of significance: Gray soil indicators; geotechnical SPTs. Prediction methods could not be applied for the Suwannee test site due to lack of surface or ground water source data. Hydraulic gradient methods were most suited for clayey soil and distant hydrologic station applications.

The NRCS Study revealed a statistical probability for the region based on evaluation of 49 sites in District 2. Within District 2, a 18% probability of achieving acceptable criteria, 94% probability of achieving a conservative result, and a 2% chance of encountering temporary water table conditions.

District 3. Flatwoods were represented by this District. Sand and sandy clays were the most common soil types observed with moderate drainage properties. The following methods for predicting SHWTs appeared to be most common to the District in order of significance: NRCS comparisons (technical match), geotechnical SPTs, and hydraulic gradient methods. Technical matching was defined by ground water measurements exceeding the NRCS defined range of greater than 6.5 feet below grade. All measurements collected from ground water stations met the criteria. Seasonal high surface water to SHGWT comparison method was effective for the District. The NRCS study could not produce probabilities based on statistical data due to lack of public agency wells penetrating the upper 10 feet of soil profile. Maps presented in Task 3C, Appendix C were based on similar soil, aquifer, and probability data compiled from similar landscapes noted in District 2.

District 4. Flatwoods and urbanized settings were evaluated by both qualitative and quantitative prediction methods. Variation in soil type ranged from fine sands to silty sands influenced by drainage conditions. Soil drainage was considered very slow to moderate in the upper 4 feet of the soil profile. District 1 was subjected to river and canal artificial drainage influences on ground water. District 4 was artificially drained by canals. The following predictive methods appeared to be most effective for both Districts: Gray soil indicators (Martin County), hydraulic gradient method, and Laplace method.

The NRCS Study revealed a statistical probability for the District region based on evaluation of 14 sites within District 4.

Within District 4, a 29% probability of achieving acceptable criteria, 100% probability of achieving a conservative result, and a 7% probability of encountering temporary water table conditions was predicted.

District 5. Flatwoods and Sand Hills were represented by this District. Sands and limestone with slow to rapid drainage were represented by influences to ground water from regional lakes, river, and storm water ponds. The following methods for predicting SHWTs appeared to be most common in order of significance: geotechnical SPTs, hydraulic gradient methods, tidal method (Brevard only).

The NRCS Study revealed a statistical probability for the region based on evaluation of 39 sites in District 5. Within District 5, a 18% probability of achieving acceptable criteria, 80% probability of achieving a conservative result, and a 5% of encountering temporary water table conditions was determined.

District 6. Flatwoods and urban settings were represented by both Districts. Organic silt and limestone (District 6) dominated district urban settings. Moderate to rapid drainage was represented by artificially drained canal systems for the District. The following methods for predicting SHWTs appeared to be most common in order of significance: hydraulic gradient method, NRCS comparison, Laplace method, tidal method, and CT DEP Method.

The NRCS Study revealed a statistical probability for the region based on evaluation of 11 sites in District 6. Within District 6, a 64% probability of achieving acceptable criteria, 82% probability of achieving a conservative result, and an absence of encountering temporary water table conditions.

Districts 7. Marine terrace and flatwood settings were represented by District 7. Sands and clays were the dominant soil types observed. Very slow to moderate drainage was observed in the upper 4 feet of the soil profile. The following methods for predicting SHWTs appeared to be most common in order of significance: Geotechnical SPTs; and, rainfall vs. depth to water graphical method. Hydraulic gradient methods were most suited for District 7 clayey soil and distant hydrologic station applications.

The NRCS Study revealed a statistical probability for the region based on evaluation of 31 sites in District 7. Within District 7, a 48% probability of achieving acceptable criteria, 77% probability of achieving a conservative result, and a 3% probability of encountering temporary water table conditions was predicted.

Based on the two year field data collection period and accompanying prediction method analyses, a set of qualitative and quantitative methods were identified as providing acceptable predictions of seasonal high ground water conditions for individual districts. Statewide application of methods was indeterminate, with the exception of the NRCS method. The qualitative methods were based on practical field application associated with geotechnical soil boring investigations and recording of SPT blow counts and soil colors for comparison with NRCS water table range intervals. These methods were identified as gray or white soil indicators, geotechnical SPT density values, and the NRCS method for comparing ground water measurements to estimated water table range intervals. One hydrographic method produced limited acceptable results for seasonal high ground water predictions but did not exhibit strong confidence in application due to the requirement of accumulating large data sets for generating the graph.

Quantitative methods were strongly associated with theoretical applications for predicting seasonal high ground water conditions. These methods relied on equations and ground water measurement data to achieve prediction results. Acceptable results were consistently achieved by the hydraulic gradient method which appeared to be appropriate for statewide and district regional application. The Laplace Equation appeared limited to district applications, and the Dupuit Tidal Effect method was limited to coastal regions up to 300 feet distance from the shoreline.

Collection of field data from methods already employed by FDOT as part of the preliminary design PD&E road construction study process are already in place for applying both qualitative and quantitative methods described in this report. The geotechnical SPT borings are the most common site investigative method that could provide a transition into applying predictive methods for present and future road construction activities. Geotechnical soil log data should incorporate at a minimum: density values recorded for every 0.5 foot interval; soil color changes for each soil horizon encountered including gray and white colors; unsaturated and saturated soil zones encountered for the entire boring length.

Field collected data would satisfy the requirements for most of the qualitative prediction methods. Placement of temporary well points strategically placed along proposed construction corridors and at storm water basin locations would help data collection efforts for predicting seasonal high ground water conditions using quantitative equation methods.

1.7. ***Study Summary & Conclusions***. Qualitative method limitations included gray soil indicators which were absent from District 3 sandy soil (SP, SW) profiles. Palm Beach, Broward, and Miami hypothetical sites did not have gray soil profiles identified in the NRCS soil descriptions obtained from the Web Soil Survey.

Evaluation of the NRCS water table method could not be completed for the Broward hypothetical test site. Broward County was limited to evaluating surface water elevations due to the absence of ground water measurement data. An assumption was made that ground water elevations were directly controlled and influenced by canal systems.

Geotechnical evaluations could not be completed for the Highlands and Martin County test sites due to shallow water table conditions at the time of test site setup. No geotechnical data was available for the Palm Beach, Broward, and Miami hypothetical test sites.

All quantitative methods were omitted from District 2, Suwannee County due to the absence of surface water features and hydrologic station reference measurement data. The Alachua County test site had the same situation with the exception of the hydraulic gradient methods which were applied seasonally when ground water measurements were available from the shallow observation well. Results for Alachua County represented temporary water table conditions, and not true ground water conditions.

The Depth to Ground Water Correction Method was uniquely applied to DeSoto County due to land surface elevation discrepancies between the hydrologic stations and CR 769 corridor. The Correlation Method was selectively applied to Districts 3, 4, 5 (Sumter County), and 7 (Pasco County) test sites. The Laplace Method was selectively applied to Districts 1, 3, 4 (Palm Beach), 5 (Brevard), and 6. The Dupuit Tidal Method (one dimensional model) was applied to District 5 (Brevard) and District 6 (Miami) test sites.

The CT DEP Method was omitted from District 2 due to lack of hydrologic reference measurement data, and District 6 Broward County due to surface water canal measurement stations.

District SHWT Specific Issues. The research phase of the study identified several problematic conditions identified by FDOT and Water Management District for predicting SHWT conditions. Fill material, soil drainage, soil type, and soil conditions, landscape types, development impacts to temporary water tables, slowly permeable aquifers, and tidal impacts were identified.

Each District was grouped together which exhibited similar characteristics based on identified problems associated with predicting seasonal high ground water table conditions. A summary is provided below.

Districts 1. Slowly permeable soils, landscape type, restrictive soils, surface drainage features (lakes, canals, rivers) impacted Desoto and Highlands Counties. Based on hydrograph analyses, soil permeability and soil saturation appear to play significant roles in controlling ground water response lag periods. Saturated soils, particularly silty sands (SM) during periods of heavy and persistent rainfall periods, contributed to sustaining rising ground water levels. When soils dried out, ground water levels dropped when soil capacity diminished. Landscape type played a role when measurement data represented higher land elevations compared to subject site elevations. Corrective methods were required to bring consistency to predicted results from known measurement sources. Canals and lakes exerted influences on ground water hydraulic gradient directions often reversing at times when surface water elevations occurred higher than ground water elevations, and vice versa.

Districts 2. Soil drainage, soil type, restrictive soil horizons, slowly permeable soils, and temporary water table conditions were interconnected and interrelated to clayey type soils (SC, CH, CL) represented by Alachua and Suwannee Counties. Qualitative methods were the most useful method to employ for evaluating clay absorption and infiltration. Gray soil indicators, geotechnical SPTs, and hydrographs played the most effective role in estimating seasonal high ground water table conditions. Within clayey soils, perched and/or hanging water table conditions were observed.

A standard hydrograph was used to observe temporary water table dissipation over time with results produced for estimating the infiltration rate based on observed measurements occurring within the clay zone. Clay stiffness played a significant role in delaying vertical infiltration. Quantitative methods were ineffective due to lack of public agency surface water and/or ground water station data availability. The storm water basin in Alachua County was evaluated by extremely limited quantitative methods due to perching of surface water on top of clayey soils during the summer wet season. The limestone aquifer was too deep in Suwannee County to arrive at reasonable conclusions other than flow net analyses suggesting downward flow was the dominant force in controlling aquifer elevations. Alachua County limestone was consistently observed in dry condition during the baseline SPT procedure.

District 3. Surface water drainage consisting of lakes and creeks exerted influences on ground water gradients similar to those described for District 1.

Districts 4. Artificial drainage canals and urbanized setting appeared to be the most problematic for Palm Beach, and Broward Counties. Under these conditions, application of public agency surface water canal hydrologic station data and ground water station data appeared most appropriate for predicting ground water elevations along proposed corridor routes. Where ground water station measurement data was unavailable, temporary well points are recommended for substitution for establishing temporary hydraulic gradient conditions.

District 5. Surface drainage (lakes, rivers, canals, storm water ponds), and landscape type were the two most important conditions encountered. Regional lakes exerted control over ground water elevations more so than rainfall, particularly in sand soil profiles (SW, SP). Saturated soils tended to contribute to subtle ground water increases but more profoundly in lake surface water elevation increases. Rivers also tended to control ground water fluctuations more profoundly than rainfall.

District 6. Artificial drainage canals and urbanized setting appeared to be the most problematic for Miami-Dade County. Under these conditions, application of public agency surface water canal hydrologic station data and ground water station data appeared most appropriate for predicting ground water elevations along proposed corridor routes.

Where ground water station measurement data was unavailable, temporary well points are recommended for substitution for establishing temporary hydraulic gradient conditions.

District 7. Soil drainage, soil type, restrictive soil horizons, slowly permeable soils, and temporary water table conditions were interconnected and interrelated to clayey type soils (SC, CH, CL) represented by Alachua and Suwannee Counties. Qualitative methods were the most useful method to employ for evaluating clay absorption and infiltration. Gray soil indicators, geotechnical SPTs, and hydrographs played the most effective role in estimating seasonal high ground water table conditions. Within clayey soils, perched and/or hanging water table conditions were observed.

1.8. ***Appendix A. Case Study Summary***. District 5 experienced a seasonal high ground water issue during March 2015 when SR 415 in Seminole County underwent recent construction. Premature pavement cracking occurred at several locations between Stations 460+00 and 488+00. Pumping of the limestone road based material occurred into the cracked pavement from hydraulic pressure exerted beneath the road base material by high ground water levels. After 3 months of traffic use, wheel path cracks were filled with road base material due to high ground water levels. To correct the situation, limestone road base material was removed and replaced by an asphalt base (base group 15). An under drain was installed beneath the roadway to lower the ground water elevation.

Based on the information provided during early 2015, the project corridor station 486+00 was used to evaluate equation methods for predicting ground water elevations using the creek located approximately 0.5 mile due east of the targeted site, and using the storm water pond located approximately 0.83 miles south of the targeted station. A surface to ground water hydraulic gradient was estimated at 0.0045 ft/ft between the river and road station. A smaller gradient was approximated between the storm water basin and corridor station, 0.0025 ft/ft.

The back computational method between the river and station provided results which fit the NRCS water table range at Station 486+00 but produced a large error for the storm water pond.

The large error was probably related to an assumption that the pond surface water elevation was equal to the topographic contour shown on the provided map, or the storm water basin surface water was perched on top of a slowly permeable soil unit. The simplified method was not applicable because the evaluation relied on surface projections up-gradient inland from the creek towards the west and from the storm water basin towards the north.

In April 2016, a re-evaluation of the hydraulic gradient method was applied due to the discovery of a SJRWMD maintained hydrologic ground water station in the slough area north of the impacted corridor. In March 2015, the slough ground water elevation was recorded at 4.31 feet. Using the FDOT measured ground water elevation at station 486+00 of 13.9 feet msl, a more accurate hydraulic gradient was estimated at a distance of 2640 feet or 0.00363 ft/ft ground water slope. Projecting back to the impacted corridor at station 486+00 from the slough, the predicted ground water elevation beneath the roadway surface would be 0.00363ft/ft x 2640 ft or a rise in ground water elevation of 9.56 ft + 4.31= 13.89 ft msl producing an error of 0.01 feet from the FDOT measurement.

Section 1.0. Definitions, Methods, and Techniques

1.1. Introduction

Section 1.0 of this report highlights the findings of Task 1: defining the SHWT; describing the methods and techniques used to determine SHWT conditions; identifying problematic conditions associated with estimating SHWT conditions; providing interview results compiled from various state agencies and engineering consultants for determining how SHWT conditions are determined; and, providing a preliminary set of data for development of a technical procedures manual to apply field methods for estimating SHWT conditions.

Differences on how SHWTs are defined exist among the different FDOT Districts and WMDs based on the different landscape and hydrogeological settings present within each district. These discrepancies create a certain level of confusion as to how to approach the determination, techniques, and methods for estimating SHWT conditions by the seven (7) FDOT Districts. Therefore, a set of protocols need to be developed to help guide the design engineer through the process of unifying methods and techniques for determining SHWT conditions within the seven (7) FDOT Districts.

1.2. Defining the Water Table

The seasonal high water table is the depth at which the “normal” water table rises in response to recharge occurring through the unsaturated zone when infiltration enters the saturated zone during the wet season. A seasonal high water table condition appears when the water table rises above the “normal” elevation range and is maintained for a duration exceeding a specified length of time, typically 30 days or longer according to NRCS.

A *water table* is defined by saturation throughout the entire profile. A *perched water table* is defined by water standing above an unsaturated zone. In places, an upper or perched water table is separated from a lower one by a dry zone (*NRCS Technical Soil Service Handbook Part 617*). An *apparent water table* develops as a thick zone of free water in the soil indicated by the level at which water stands in an uncased borehole after adequate time is allowed for adjustment, or stabilization of water level, in the surrounding soil.

The **US Environmental Protection Agency (USEPA) Center for Environmental Research Information**, *Ground Water Handbook* (Office of Research and Development, 1989) defined the water table by water occurring under the surface of the ground in two zones: an upper unsaturated zone and a deeper saturated zone. The boundary between the two zones is the water table.

The **Florida Department of Health** defined the water table as the depth to saturated soil material including “the depth at which the water table can be measured at any time”. A single measurement is not useful for making land use interpretations.

The **American Geological Institute** *Dictionary of Geological Terms (AGI, 1976)* defined the water table as the upper surface of a zone of saturation except where the upper surface is formed by an impermeable body. Special water table conditions occur within the soil profile which may be encountered during a specific site investigation. These water table conditions may be erroneously interpreted as the seasonal high water table if the field observation is not performed in an accurate manner.

1.3. Defining the Seasonal High Water Table

a. Federal and State Agency Definitions

The **US Department of Agriculture Natural Resource Conservation Service (USDA NRCS)** defined a seasonal high saturation *“as the highest level to a zone of saturation in the soil that occurs in most years. A seasonal high saturation normally persists for several weeks, normally occurring during the time of year when the most rain falls (June through September in Florida)”.* Water tables that are seasonally high for less than 30 days are not presented in the Soil and Water features table within the soil surveys. The USDA NRCS uses a 30 day criteria to judge SHWT for ranges present in the soil surveys.

The **Florida Department of Health Bureau of Environmental Health (FDOH)** adopted the definition of a seasonal high water table (SHWT) defined by the US Department of Agriculture Natural Resources Conservation Service (USDA NRCS) for the purpose of determining SHWT depths for commercial and residential designing and permitting of onsite sewage disposal drain fields. FDOH defined the SHWT “*as the highest depth to a zone of saturation. The SHWT normally persists at its depth for several weeks or more normally occurring during the time of year when the most rainfall occurs”*.

The **Florida Department of Environmental Protection (FDEP)** Wetland Permitting Rule, Chapter 62-340.200 defined the SHWT by the elevation to which the ground and surface water can be expected to rise due to a normal wet season.

The **Northwest Florida Water Management District (NWFWMD)** Environmental Resource Permit Applicant’s Handbook Volume II (2013) defers definition of the SHWT to the NRCS definition.

The **South Florida Water Management District (SFWMD)** ERP Applicant's Handbook, Volume II (2013) does not formally define what a SHWT condition is but references the term "wet season water table elevation on several occasions throughout the manual text.

The **St. Johns River Water Management District (SJRWMD)** Applicant's Handbook: *Regulation of Storm Water Management Systems, Chapter 40C-42, FAC (2010)* defines the SHWT elevation as the highest level of the saturated zone in the soil in a year with normal rainfall, consistent with the NRCS definition.

The **Suwannee River Water Management District (SRWMD)** ERP Applicant's Handbook, Volume II (2012), *Design Requirements for Storm Water Treatment and Management Systems* does not define SHWT conditions.

The **Southwest Florida Water Management District (SWFWMD)** ERP Applicant's Handbook, Volume II design requirements for storm water treatment and management systems water quality and water quantity manual (2013) does not provide methods or techniques for how a SHWT condition is defined.

b. Engineering Study Definitions

Research conducted for various water management districts by engineering consultants targeted specific methods related to storm water infiltration and management system functions. Publications indirectly addressed specific subject matter related to SHWT conditions.

Gregory and others (1999) published research addressing the estimation of soil storage capacity for storm water modeling applications for SWFWMD. The research presented methods for determining soil storage capacity which described the relationship between water content to soil void space. The derived equations contained within the publication rely on extracted data contained within the NRCS county soil survey tables. The equations rely on water table data contained within the soil surveys.

Jammal & Associates (1991, 1993) discussed field testing methods for characterizing hydrogeological properties of soil profiles related to the determination of designing storm water retention basins in a study completed for the SJRWMD for the Indian River Lagoon Basin. The report describes the application of SPT borings and hand auger borings for observing unsaturated soil profiles including laboratory permeameter testing, and field testing methods for obtaining hydraulic conductivity data. The report also summarizes applicability of analyzing ground water flow through various computer programming methods, listing MODRET as the most popular modeling program used within the SJRWMD. The report states MODRET is numerically unstable in some situations. SHWT determinations are addressed by some methods without elaborating on the techniques used to make these determinations.

Some of the methods identified included antecedent rainfall, redoximorphic features (soil mottling), stratigraphy (determining restrictive layers), vegetative indicators, developmental effects, and hydrogeologic setting. Most of the same statements contained within the Jammal report were incorporated into many of the water management district ERP handbooks. Descriptions of various soil types and depths to water tables within the WMD were included in the Jammal & Associates report. The report relied on SHWT data contained within published county soil surveys.

1.4. Methods for Determining SHWT Conditions

Review of the water management district's ERP applicant's handbooks provided treatment design specifications including example design equations used to calculate infiltration through application of both unsaturated and saturated equations for the purpose of submitting designs for storm water management system permit approval. Many of these methods and examples were adopted from the FDOT Drainage Handbook and from consultant studies completed under contract to specific water management districts. A detail of various publication content were included in the full report titled *Definitions, Methods, and Techniques* submitted to FDOT Research Center dated June 9, 2014. A brief summary follows:

Florida Department of Transportation (FDOT). The Drainage Handbook-Storm water Management Facility (2004) refers to the NRCS Soil Surveys for estimating the SHWT as a means for preliminary identification of alternative drainage solutions for soil and ground water conditions explicitly stating the NRCS is to be used as a tool and guide for qualitatively eliminating areas indicative of hydraulic issues associated with problematic soil drainage characteristics (Section 2.1.1). FDOT states most Districts accept NRCS soil survey data for pond site evaluation. For areas where poor soils are present, the manual states site specific studies may be more appropriate.

Southwest Florida Water Management District (SWFWMD). The handbook states the SHWT must be determined by on site investigation but does not specify methodology. The manual states soil reports published by the NRCS are cited as acceptable documentation along with supporting field soil boring data.

Northwest Florida Water Management District (NWFWMD). The NWFWMD applicant's handbook references use of generally accepted geotechnical and soil science principles for determining SHWT conditions. Reference is made to the USDA NRCS October 27, 1997 "*Depth to seasonal high saturation and seasonal inundation*" technical memorandum for principles and methods used for determining SHWT conditions.

Suwannee River Water Management District (SRWMD). The SRWMD handbook references determination of the SHWT condition through the statement “generally accepted and well documented methods for determining SHWT conditions”. The handbook does not offer specific methods for making this determination.

St. Johns River Water Management District (SJRWMD). The SJRWMD handbook references the statement “any generally accepted and well documented methods may be used to reflect drainage practices, SHWT elevation, and any underlying soil characteristics which would limit or prevent percolation of storm water into the soil column”.

South Florida Water Management District (SFWMD). The SFWMD handbook references “soil zone storage estimates are completed using generally accepted engineering and scientific principles which reflect drainage practices, average wet seasonal water table elevation, antecedent moisture, and any underlying soil characteristics that would limit or prevent percolation of storm water through the entire soil column”.

1.5. Techniques Used to Determine SHWT Conditions

Seereeram (1993) published a research paper on estimating the normal seasonal high ground water table for Orange County. The methods and techniques may be subdivided into two categories: *quantitative* and *qualitative* methods.

1.5.1. Quantitative Methods. Quantitative methods require data collection and/or calculation by equations to produce an estimate on determining SHWT conditions based on field data collected at specific sites. A brief review of the methods and equations are summarized as follows:

a. *Water Balance Equation*. This method falls within the antecedent rainfall technique for determining natural inflows and outflows impacting the water table.

   Natural inflow accounts for the amount of precipitation entering the ground surface applying the rainfall less runoff component; lateral inflow entering from the side and from the up-gradient position; and vertical flow upward from a lower confined aquifer into the water table under special circumstances. Natural outflows consider evapotranspiration losses from the ground surface; lateral flow exiting in the down gradient direction of the water table; and, vertical flow downward from the water table into the lower aquifer in recharge areas.

b. *Back Computational Method.* Where seasonal high water levels of an adjacent lake, pond, wetland, or sinkhole basin are known, or can be determined by field observation, it may be possible to back calculate the SHWT at a nearby point based on knowledge of typical soil type gradients. Lake or wetland level, and/or stream gaging records may be used as a reference for determining seasonal high ground water levels for sites located near surface water features. The water table generally slopes upwards, landward, and away from these features. This method also relies strongly on the ability to accurately determine the soil type gradient between the surface water feature and intended project site location.

c. *Correlation to Historical Water Level Elevations.* The USGS (1994) completed a study on Rhode Island for estimating SHWT conditions at sites where there was a single water level reading available and there were several reference (index) wells available with historical water level data covering the current year for which the subject site reading was completed. The method was applicable to subject sites located within a distance of 10 miles from the index well. The selection of the index well was based on wells completed in similar lithologic material as the subject site. Where subject sites were located greater than 10 miles from the index well, topographic setting and depth to water were the principle guides for applying the technique. Where topographic settings were unique for subject and index well sites, depth to water was the principle guide for applying the technique. The USGS equation was broken down into separate equations used to estimate the high, median, and low SHWT depths.

   Limitations included pumping stresses resulting in drawdown and recovery of water levels which affected measured water levels at a site; tidal water bodies causing diurnal changes in water levels at a site. Changes in weather and climate patterns affect ground water fluctuations as well as changes in drainage patterns (channeling into culverts), or from landscaping which alters drainage and runoff patterns.
   Underlying clays or other low permeable material may result in perched ground water table conditions which cannot be accounted for in estimating water levels.
   Perched water table conditions may appear in clays, silty soils, or sandy soils containing zones of silt or clay layers which may interfere with ground water flow patterns.

The following criteria must be considered when applying this technique: 1) well depths must occur between 5 and 94 feet bls; 2) wells are completed in an unconfined aquifer; 3) wells are measured on a quarterly basis; 4) water level fluctuations must occur within 10 feet of the land surface; and, 5) the majority of water level measurements occur below grade (no ponding or flooding). Assumptions for applying this method are based on a) water levels will always fluctuate the same in the future as they have historically; b) water levels will fluctuate seasonally; c) ground water fluctuations depend on similar site geologic properties between the reference site and the site of interest; d) water levels are affected by precipitation and climate.

Where errors are calculated for ranges which fall outside the correlative values, estimated water levels may result from dissimilar soil types between the site of interest and the reference well, or may be related to excessive distances between the subject site and index well site. During this study, fluctuation ranges which were closely matched between referenced and measured observations produced low prediction errors. When referenced fluctuation ranges were much greater than measured fluctuation ranges, large prediction errors occurred.

d. *Flow Net Analyses.* Flow nets may be used for two dimensional problems (vertical section or horizontal plan) in uniform, isotropic medium where flow boundaries are known. Two of the boundaries established must be boundaries of the flow region. Boundaries may be ground water divides or surface water bodies (streams, lakes, ponds, etc.). Streamlines are drawn which represent flow lines through the soil medium. Equipotential lines are lines drawn which represent equal head through the vertical profile. The intersection of flow lines and equipotential lines must produce a rectangular area as closely as possible. This condition may require numerous attempts at constructing the flow net to arrive at equal rectangular regions throughout the area of interest. Where inflows occur from lower confining aquifer units, a flow net may be used to estimate the discharge rate into the unconfined aquifer for predicting interference related to determining accurate SHWT conditions.
Where discharges occur from the unconfined aquifer into the confined aquifer, downward losses from the water table may also be estimated using flow net analyses.

e. *Laplace Equation*. Laplace (Fetter, 1988, pg. 134) derived an equation used to determine water levels from any subject site location with an unknown water level measurement using known observation network station points (observation wells, surface water features, etc.) positioned on either side of the subject site. The elevations of both known network stations must be known along with the distance between the stations. The stations should be located within the same drainage basin or must form boundary conditions for the subject site to be accurately estimated.

f. *Dupuit – Ghyben - Herzberg Equation.* The equation was intended for application towards estimating *confined aquifers* positioned near tidal bodies, subjected to short term fluctuations in head due to tidal cycles (Fetter, 1988). The amplitude of fluctuation in hydraulic head (height of the tidal wave) is greatest at the coast and diminishes further inland. There is a lag time that occurs from the time the tide changes to the time a linear wave propagates inland depending on the distance and formation materials the wave migrates through.

   For an *unconfined aquifer,* estimation of tidal amplitude (or wave height) moving through the water table from the coastline, hydraulic conductivity is substituted for the transmissivity term. Hydraulic conductivity (Kh) may be estimated by flow net analyses, by obtaining ranges from the NRCS soil survey, determined in the field by pump or slug testing on observation wells near the coastline, or by application of the formula K=T/b, where b is the known thickness of the unconfined aquifer. Aquifer thicknesses may be estimated by using lithologic logs available through the Florida Geological Survey Lithologic Database. Tidal charts may be acquired from the Florida US Harbors web site (FL.USharbors.com) or from NOAA. The method may also apply towards project sites positioned near rivers and channeled systems exposed to tidal fluxes where historical stage data are available.

1.5.2. *Qualitative Methods.* Qualitative methods are collected in the field by physical observation. Correlation with quantitative methods may be necessary to calibrate, validate, and confirm application of both method approaches used for determining SHWT conditions.

Methods include collecting depth to water levels from observation wells at each pilot test site on a routine basis; logging soil boring profiles using soil horizon descriptions, recording soil color, soil texture, relative moisture content, and relative density properties; recording SPT "N" values for describing soil relative densities for determining depth to restrictive layers or estimating ground water fluctuation ranges.

a. *USDA NRCS Soil Surveys.* Soil survey publications provide SHWT estimates based strictly on soil morphological features (mottles, gray soil color, and low chroma colors related to saturation and reduction of iron). Mottling may be relict features from past moisture conditions depending on how the feature is preserved in the profile (relict or contemporary mottles).

   Soil surveys are accurate for areas not subjected to alteration impacts from developments which remain in a natural condition and are not useful as a substitute for site specific investigations (Seereeram, 1993). An evaluation of site specific and NRCS soils survey water table estimates were completed during the pilot test site setup.

   County soil survey maps provided soil classification data including estimated ranges of water table conditions expected for various soil types. The application of these maps is limited to the scale at which the maps were prepared. Soil variability is not accurately represented at the local level by these maps but do provide a means for preliminary evaluation of soil properties and characteristics. Soil surveys should not be substituted for site specific investigations (Newman, 2006).

b. *Gray Soil Indicators.* Gray colors in soils indicate reduced conditions associated with a fluctuating water table. This is the most obvious feature that can be easily applied by recording the most basic soil profile from SPTs. These are the most obvious indicator of seasonal high water table conditions.

c. *Geotechnical SPT "N" value profiling.* Standard Penetration Test borings (SPT) provide data on density variations where blow counts (n values) are recorded from a soil profile. "N" values may, on occasion, provide an indication of the water table fluctuation due to repeated changes in effective stress resulting from the drying out and rewetting of the soil profile. Cyclic wetting and drying of the soil profile leads to compaction within the zone of fluctuation.

Very often, soil profile indicators may not be recognized by the blow count value due to the weight of the hammer and rods being driven into the ground. Raw blow count data representing every 0.5 foot interval will most likely provide the most reliable data on determining where the fluctuating ground water table is positioned coupled with the aid of another technique (e.g. NRCS, temporary ground water measurement, and gray soil indicators).

d. *Static Cone Penetrometer Density Readings.* A spring loaded probe is continuously pushed into the soil profile yielding readings which indicate variable compaction densities within a specified distance of the ground surface. Rods are usually 2 feet in length with a dial pressure indicator gage providing readings in the 0 to 200 psi range for loose to moderately compacted soils; 200 to 300 psi range for moderately to densely compacted soils; and, 300 and greater range for densely to very densely compacted soil horizons. Use of this method may be more appropriate for water tables that are between 5 and 10 feet deep (FDOT, 2004). Readings obtained from this method may substitute or compliment SPT "N" values. An alternative method is to apply a hand held density penetrometer, checking the soil core extracted from the SPT boring every 0.5 foot to gauge the density variability of the soil profile. This may provide a quicker method for obtaining density variability over the entire length of the boring leading up to the saturated portion of the soil core.

The application of vegetative indicators of seasonal high water levels is considered well beyond the scope of this study, and beyond the practicality of staff conducting geotechnical investigations.

e. W*ater level measurements.* Water levels observed from surface water bodies, including high water lines observed on trees in wetlands, cypress knees, tree trunks, vegetative pattern distributions may provide seasonal high water occurrences. Lakes, ponds, and structural features (control structures, bridge pilings, etc.) may provide indicators useful in determining surface SHWLs. Indicators marking seasonal high water lines may be masked by flood water marks. The elevation relative to mean sea level must be determined in order to be able to project back inland to ground water.

Water levels from existing surface water gaging stations and ground water monitoring networks may be used to evaluate historical and current trends in water table fluctuations on a daily, weekly, or monthly basis. Water management districts (WMDs) and the USGS maintain networks and data collection sites throughout Florida for evaluating relevant historical data.

f. *Topographic Settings.* The water table forms a subdued image of the land surface. When the landscape gently undulates, the water table parallels the landscape, but within a more subdued pattern than the land surface. In low lying areas, the water table is typically near the land surface exposed within wetlands, floodplains, and surface water bodies. The water table lies at greater depths beneath upland sand ridges where minimal surface water features exist. Trends below the land surface and water table are often used to estimate water table elevations at a regional scale (Newman, 2006).

g. *Hydrogeologic Settings*. Recharge or discharge to the confined aquifer from the water table may occur as a result of pressure differences between the aquifers controlled by the confined aquifer's clay layer thickness and by the potentiometric surface. In northeast and central Florida, the water table is underlain by an intermediate aquifer or by the Floridan Aquifer. The Floridan Aquifer flows upward or downward under confined pressure changes.

When wells penetrate a portion of the aquifer which is under pressure, the surface of the aquifer will rise above the water table elevation indicating confined water flows upwards into the water table from below.

Recharge occurs by interconnection between the water table and confined aquifer in conjunction with recharge from the land surface by precipitation (Newman, 2006).

Near coastal regions and along river channels, the confined aquifer discharges upwards into the water table aquifer providing contributions to the water table in addition to precipitation recharge.

Sand filled paleo-sinks can create areas of localized effective inter-aquifer connection which may result in a depression of the water table without obvious surface manifestations. Aerial photographic and potentiometric surface map review can help identify these situations.

1.6. Problems with Determining SHWT Conditions

1.6.1. Problems with Recognizing SHGWT Conditions. Fill, placed on top of native soil may produce black mottling just below the contact interface with native soil. Fill compaction may simulate an artificially induced hanging water table at the interface between the dense compacted layer and the underlying looser native soil layer. Infiltrating water will tend to leach out minerals from the interface zone between the fill and native soil layer thereby producing an unusual black color.

When this condition is encountered, this blackened zone is not a true indicator of SHWT conditions but is an indicator of an artificially induced “hanging” water table condition.

Soil Drainage Issues. In Florida, there are six drainage classes of soils recognized. Each soil drainage class is characterized by SHWT conditions with varying depths. Slowly drained soils occur within restricted layers consisting of silts, clays, and spodic horizons. Infiltrating water will “hang up” on top of the restricted layer creating mottling conditions at the interface zone. These conditions would most likely be exhibited in the set of poorly drained soils up to 2.5 feet below grade.

Spodic Soil Conditions. The spodic horizon is recognized by a dark brown silty sand layer sometimes hardened by accumulating iron leached downward from the upper A horizon. The upper A horizon is the layer of soil occurring below the organic root layer. There are 80 spodic soil types present in Florida. The most common types are the Ona, Smyrna, Myakka, Immokolee, and Pottsburg soil types. SHWT depths occur 10 inches or less within these soil types even though the depths to the spodic horizons occur below the estimated SHWT depth. The spodic horizon does not represent a SHWT condition but does represent a fluctuating water table condition (Hammond, 2013a).

Iron cemented nodules and concretions exhibit sharp boundaries within soil matrices. These features are not true redox features. Nodules and concretions develop by localized deposition of iron resulting from precipitation of dissolved iron from solutions moving through the profile. Iron migration does not necessarily reflect vertical rise and fall of the water table although vertical movement may contribute towards nodule and concretionary development (American Geological Institute, 1976).

Landscape types. SRWMD identified karst areas as being the most problematic condition for estimating SHWT conditions. Karst features are exposed along the Suwannee River, beneath the Gulf Coastal Lowlands, and portions of the interior peninsular region. The region is exposed to confined aquifer potentiometric surfaces including both recharge and discharge conditions. Aquifer contributions to the water table at the outflow boundaries and recharge areas within the interiors of the confined aquifer contribute towards gains and losses to the SHWT.

Within the SJRWMD, the Indian River Lagoon Basin is cited as a problematic region where percolation is limited due to poorly drained soils due to clays and clayey sands. The District also identified Alachua and Marion Counties as the most difficult region to estimate SHWTs due to the presence of karst.

Developmental Impacts. Man-made lakes, canals, ditches with control elevation structures below the predevelopment SHWT lowers water levels beneath road subgrades, lots, or low wet areas. Water levels decrease from localized redistribution of runoff collected in storm water management systems. A water table drop of 1 to 2 feet can be expected on developed sites with a high percentage of impervious surfaces which do not have artificial recharge as a mechanism to replace natural rainfall recharge.

1.7. Survey Questionnaire Results

The purpose of the questionnaire was to maintain consistent responses from each of the contacted agencies (FDOT, FDEP, and WMDs). In addition, FDOT districts were requested to provide three engineering consultant firms per district for the purpose of providing the same survey questionnaire for evaluation by engineering consultants.

FDOT districts were also requested to identify specific past and future project sites which presented unique SHWT conditions or problems. Some FDOT Districts forwarded the questionnaire onto engineering consultants for response which were tabulated as an FDOT response in the summary table. FDEP NPDES contacts were eliminated from the survey due to reorganization of personnel within each District office limiting the ability of contacting the proper staff with sufficient technical knowledge to respond to the survey questions with respect to storm water management and soils related issues. Responses are briefly summarized as follows:

1.7.1. FDOT District Responses.

No responses were received from FDOT District 3. Lack of participation by the District was not vital to determining issues and problems for the District. Responses from the NWFWMD provided adequate substitution. FDOT Districts 4 and 6 referred the survey to geotechnical engineering consultants for response which were received. Limited responses were received from engineering consulting firms from Districts 2, 3, 5, and 7). Due to a lack of response from external engineering consultants, no other surveys were provided to other consultants within the various districts.

1.7.2. Survey Response Consistencies and Inconsistencies.

Consistencies. Redox features appeared to be the common method applied in all Districts (except District 5) for estimating SHWT conditions. Correlation to historical high water levels and vegetative/soil indicators were the next most common methods used to determine SHWTs. Hydrologic data provided by WMDs and NRCS soil data appear to be the most commonly used methods obtained from public domain sources for estimating SHWTs.

Inconsistencies. None of the FDOT Districts indicated use of back computational methods for determining SHWT at an arbitrary distance from a known surface water body elevation. Districts 1, 4, and 6 identified the use of the correlation method to historical high water levels. Districts 1, 2, 5, and 6 indicated vegetative and soil indicators as a SHWT technique. District 2 indicated use of the FDOT Storm Water Drainage Manual as a method for determining SHWTs for storm water treatment design. Soil drainage (except District 5) was not selected as a problem issue for determining SHWTs; hydrogeologic setting was not indicated by FDOT but was indicated as a problem by WMDs. Select FDOT and WMD districts stated landscape type as a problem for determining SHWTs.

1.7.3. FDOT District Problems, Symptoms, & Causes

Soil Problems. Generally, soil type was indicated as a problematic symptom for determining accurate SHWTs. The presence of silts, clays and hardpan appeared to be a limitation in developing proper SHWT estimations. Districts 1, 2, 5, NWFWMD, and SWFWMD indicated soil type as a limitation. Soil drainage was indicated by District 5, NWFWMD, SWFWMD, and SJRWMD as a problematic issue.

Extremely low permeable aquifers and perched/hanging water table conditions appeared to be the greatest problem for determining accurate SHWT conditions. SFWMD stated problems occur where ground water has been historically drained or where conveyance was limited. Soil classification, soil permeability was problematic for District 1 and District 7. Districts 5 and 7 suggested underestimation of SHWT was a problem for proper storm water system functioning.

Landscape type. Districts 1 and 7 indicated Sand Dune Hills and shallow depressions as a symptom in which difficulties were identified;. Coastal Plains were identified by District 4, specifically referring to tidal influences causing interference in determining accurate SHWT estimations along SR A1A. NWFWMD and SWFWMD indicated Flatwoods were difficult to predict most likely due to spodic soil horizons and/or perched-hanging water table conditions. District 2, District 5, NWFWMD, SRWMD, and SJRWMD indicated karst as a symptomatic problem in estimating SHWT conditions. SFWMD stated flatwoods were problematic where SHWT ranges vary between 0.5 and 1 foot. Karst issues were identified by District 2 occurring in Suwannee, Taylor, Dixie, Alachua, Levy, and Lafayette Counties. District 5 identified Flagler, Volusia, Seminole, Orange, Osceola, Brevard, and Lake Counties concerning karst and poor soil drainage problems. SJRWMD mentioned similar issues were associated with Alachua and Marion Counties. District 4 mentioned West Palm Beach County as being a problem area for estimating SHWT conditions, and all counties along the Atlantic Coast SR A1A due to tidal impacts.

Hydrogeologic aquifer type: Unconfined aquifers with restrictive layers present (WMDs), confined aquifers with potentiometric surfaces (SWFMWD, SRWMD), and perched and/or hanging water tables (Districts 1,2,5,6,7, NWFWMD, SWFWMD, SRWMD, and SJRWMD) were mentioned as problems encountered for proper estimation of SHWT conditions. District 1 mentioned Alachua, Taylor, Dixie, and Lafayette Counties were problematic with karst. Highly permeable aquifers were cited by NWFWMD, SWFWMD, and SRWMD. Slowly permeable aquifers were cited by District 1, 2, 4, 5, and 6, by all WMDs as a problematic symptom.

Special Problematic Symptoms. SWFWMD stated urbanized settings were problematic where significant changes to land use and drainage occurred. Issues related to construction included sedimentation, compaction, and fill replacement of native soils. District 5 and SWFWMD cited underestimation and/or overestimation of SHWT conditions as a symptomatic problem. Pinellas, Hillsborough, and Sarasota Counties were mentioned by SWFWMD as being particularly troublesome due to urbanized developmental impacts. District 1 mentioned specific road projects as having problems with malfunctioning storm water management systems due to fine sediments being introduced into basins: I 75 Jones Loop Road; SR 70; US 98; SR 60 Lake Wales. District 7 mentioned US 301 as a problem road due to replacement of native soils by fill material interfering with proper estimation of SHWT conditions.

1.7.4. Common Geotechnical Methods

Geotechnical consultants relied on SPTs for use in identifying SHWTs for Districts 2, 4, 5, and 6. District 7 indicated soil moisture determination as a method for evaluating infiltration. District 2 indicated field methods including infiltrometer, percolation, and hydraulic conductivity measurements were collected in the field as part of the overall design phase of road construction projects. All Districts indicated soil classification and soil profiles were used as a technique for determining SHWTs. All Districts utilized WMD and USGS hydrologic data, and use of the NRCS soil survey data for determining SHWTs. Districts 4 and 6 indicated use of the Florida Geological Survey well log database as a method for determining SHWTs. The database provided lithologic log and thickness data but did not offer estimates on SHWT conditions. Estimates are usually interpreted from soil color, redox features, or restrictive layers (silts, clays, limestone).

Section 2.0. Technical Procedures

2.1. Introduction

The objective of the technical manual was to characterize each pilot test site location proposed in Section 1.0, D*efinitions, Methods and Techniques for Determining SHWT Conditions*; and, to present the various quantitative and qualitative methods applied through the collection of field data obtained from each pilot test location. Each of the fourteen (14) pilot test sites were subjected to multiple sets of field methods in order to evaluate method consistencies between test sites under varying topographical and hydrogeological conditions.

2.2. Site Profile Selection Procedure

The procedure for developing each test site profile began with a review of most recent aerial photographs (2013) for FDOT Right Of Way (ROW) corridor access along selected roadway corridors listed on the Department's future road construction program funding list. The most desirable locations were selected at major road intersections where there was typically more room within the ROW than along straightened roadway segments. Soil profile data review, identification of WMD hydrologic stations, hydrogeologic and geologic data for evaluating aquifer conditions concluded test site selection process.

2.3. Pilot Test Site Profiles

Each pilot test site profile was organized with an *Objective* and *General Description* section providing basic information and methods used for selecting each test site; listing contact information through public records search; providing general site property information on ownership (when appropriate); and providing site surface elevation and STR location. Details for each test site were provided in the Task 2 report titled *Technical Procedures Manual* dated August 11, 2014, Revised October 31, 2014.

The *Hydrogeologic Setting* section of the profile provided general geologic information obtained from the Florida Geological Survey (FGS) county geologic map; the FGS Lithology Log Database was reviewed for obtaining thickness information for unconfined, confined, and Floridan aquifers for well sites located closest to the pilot test site; a preliminary review of water table depth based on topographic map interpretation; summarization of NRCS SCS soil profile and other soil characteristics such as evidence of perched or hanging WT conditions; conditions based on WMD potentiometric surface maps; and completing preliminary interpretation on the vertical hydraulic gradients occurring between the water table and confined aquifer system (upward or downward flow).

The *Hydrologic Station* section identified the availability of public agency data sources and station locations. Where stations were present, the station was identified by ID number, station type, data source, and location description.

The *Pilot Test Site Procedure* section summarized proposed field methods implemented during baseline set up of each test site. Information included observation well detail, soil boring, and various testing methods implemented during field setup. Two types of pilot tests were established. “Hypothetical” test sites were defined by sites where methods to predict SHWT conditions were based strictly on public record acquisition through the USGS and WMD hydrologic databases. “Physical” test sites were defined by the establishment of observation wells and surface water measuring locations. Measurements were targeted for collection on a monthly basis. General descriptions are provided below:

District 1. *DeSoto County CR 769 between Charlotte County Line and the Peace River*

Objective: To estimate SHWT conditions along a road construction corridor using estimation methods developed by hydrologic data acquired from public agency sources. Several hydrologic stations were available for surface water, surficial aquifer, and precipitation data.

General Description. The CR 769 ROW was setup as a hypothetical pilot test corridor study. Arbitrary locations where SHWT methods were applied by sectioning off the corridor into sub-drainage basins formed by the creek and artificial drainage structures intersecting the route.

Highlands County SR 70 from Jefferson Ave to SR 29.

Objective: To estimate SHWT conditions within a ROW through the use of several combined surface and ground water hydrologic stations positioned within close proximity to the SR 70 ROW corridor. A single shallow observation well was established at the entrance to Lake Annie for the purpose of confirming, calibrating, and validating various model equation estimation techniques. A rain gage was established at the site.

General Description: This test site was proposed for collection of observation data based on the installation of a shallow well and on measurements collected from multiple hydrologic stations scattered around Lake Annie, west of US 27 in the Lake Placid Florida area (Lake Wales Ridge). The pilot test site was proposed to be located within the SR 70 ROW at the entrance to the Archbold Biological Station.

District 2. *Suwannee County CR 252 & CR 349 intersection*.

Objective: To establish a test site in an upland setting with no water table aquifer present, with no surface water features and no hydrologic stations. The purpose was to rely on specific geotechnical field methods. A shallow and deep observation well cluster was intended to evaluate vertical flow between shallow and deep zones, and to developing comparisons for evaluating SPT, NRCS, and other qualitative methods for predicting SHWT conditions in clays. A rain gage was established at the site.

General Description: The proposed location was positioned at the northeast corner of CR 252 & CR 349, set back along the tree line. No surface water features were identified at the time of pilot test site research and setup.

Alachua County SR 26 FDOT Storm Water Basin, W. Newberry Road

Objective: To establish a test site in an upland setting with no water table aquifer present, with no surface water hydrologic stations near the test site. The purpose of the test site was to rely on specific geotechnical methods used to evaluate soil profile characteristics. Qualitative methods were relied upon for evaluating and confirming SHGWT observations including SPT borings, hand auger borings, soil profile descriptions, SHWT soil indicators, and NRCS soils data. The observation well was used as a control for determining whether storm water ponds can be used as a source method for determining SHWT conditions at various times during significant rainfall events. A rain gage was established at the site.

General Description. This test site was located on the south side of SR 26 opposite the Dudley Farms State Park entrance driveway, east of Newberry, Alachua County.

District 3. *Bay County SR 77 from Bay County line to CR 279.*

Objective: To establish a test site for evaluating SHWT estimation techniques from nearby surface water features easily accessed; to evaluate upward confined aquifer flow into the water table system for determining impacts towards estimating accurate SHWTs; to evaluate geotechnical methods for describing soil profiles; and to evaluate NRCS soils data. Hydrologic data sources were absent.

The shallow observation well was used as a control to determine whether or not surface water lakes could be accurately projected back to the ROW test site. A rain gage was established at the site.

General Description. The site was located within the FDOT ROW at the southwest corner of SR 77 and SR 20. The site lies north of Tank Pond and west of River Lake. A well cluster was established for this location.

Liberty County SR 20 from SR 12 to CR 1641.

Objective: To estimate SHWT conditions from creeks positioned adjacent to the ROW corridor using hydraulic gradient computational methods. Geotechnical methods were applied towards collecting and describing soil profiles. Creek surface water elevations were used to estimate SHWT conditions at the test site using quantitative methods. The pilot test site consisted of establishing an observation well, surface water creek observation point, and rain gage for the purpose of obtaining water levels as a control data source for determining accuracy for applying estimation techniques

General Description. The site was located within the FDOT ROW along SR 20 at the northeast corner of the CR 1641 intersection. The site was surrounded by uplands. West of the site, Telogia Creek was located approximately 4.5 miles. To the north, Big Creek was located approximately 0.25 mile at the CR 1641 culvert. A single well was placed at this location.

District 4. *Martin County SR 708 from SR 76 to CR 711.*

Objective: To estimate SHWT conditions at a test site with a shallow soil profile, no hydrologic stations, and with the presence of storm water drainage features located alongside the ROW. A shallow observation well was established as a control data source for determining SHWT estimation accuracies. The Okeechobee Waterway was located approximately 200 feet to the west. The storm water culvert basin was used for calculating SHWTs at the test site well. Geotechnical methods were not applied due to shallow water table conditions at the time of test site setup.

General Description. The site was located within the FDOT ROW at the center of the triangle located at the junction of SR 76 and CR 708. The site was surrounded by agricultural uplands to the east. Artificial drainage canals and storm water ditches occurred adjacent to the road.

West of the site, the Okeechobee Waterway was channelized approximately 200 feet from the proposed site. Storm water ditches were present along SR 708 near the intersection which was not targeted for surface water observation due to the absence of reliable water line indicators. The ground elevation was approximately 23 feet msl. A single well was installed at this location.

Palm Beach County US 1 from Northlake Blvd to east of SR 710.

Objective: To evaluate a project corridor using limited hydrologic station data located on a tidally influenced canal system. The corridor study was represented by variable topographic and soil conditions. Methods for estimating SHWTs were focused on model equations except for flow net analyses. No geotechnical or soil field methods were applied to the corridor study. Several hydrologic surface and ground water stations were utilized to estimate SHWT variations at several selected test site locations along the corridor. The area was heavily urbanized, densely developed with limited right of way access for completing a field type study of the proposed corridor.

General Description. The site was established as a hypothetical corridor type study. Select locations were evaluated along the proposed corridor alignment for the purpose of evaluating two canal hydrologic stations and one ground water hydrologic station for estimating SHWT conditions.

District 5. *Brevard County SR 514 from Babcock Road to US 1.*

Objective: To estimate SHWT conditions at the SR 514-Marie Street ROW using storm water basins located approximately 0.3 miles to the southeast of the proposed test site location, and a storm water pond located 0.7 miles west of the Marie Street observation well. A single observation well was established at the intersection of SR 514 and Marie Street as a control for projecting surface water elevations back to the ROW. No hydrologic stations were present in the area. In addition, the Indian River intra-coastal waterway was located at the SR 514 and US 1 intersection 0.5 mile east. Tidal influences were evaluated for impacts to the water table aquifer up to 300 feet inland from the coastline. Monthly tidal charts were reviewed from the US Harbors web site for estimating fluctuating impacts to the SHWT from the Micco Florida tidal station. The observation well served as a control data source. Geotechnical methods were applied along with an evaluation of soil color and NRCS data.

General Description. The site was located within the FDOT ROW on the southeast corner of SR 514 and Marie Street. The site was in an upland, suburban setting. A single well was installed at this location.

Lake County SR 19 from CR 46 to CR 561.

Objective: The pilot test site was used to evaluate downward confined flow losses to the water table as a method for determining interferences for estimating SHWT conditions. The test site also relied on surface water back computational methods for projecting lake water levels back to the test site. The hydrologic station located at the boat ramp, west side of SR 19, was used to evaluate the same method for estimating SHWT at the ROW. All estimation methods were applied to the site with the exception of tidal evaluation.

General Description. The site was located on FDOT owned property (Parcel ID 1320251200000001BO, address 6151 SR 19, Tavares FL) at the northeast quadrant of SR 19 and Lake Harris. The site was in an upland setting near Lake Harris. A clustered set of observation wells were located at the test site.

Sumter County - SR 44W @ Withlacoochie River, Rutland FL.

Objectives: The test site evaluated hydrogeologic impacts to the water table from the Withlacoochie River. USGS river hydrologic data was used in conjunction with an observation station to estimate normal and seasonal high stage elevations for projecting SHWT conditions to the ROW. All estimation methods were applied to the test site with the exception of tidal influences. SHWT evaluations relied on hydrologic station data and on observation station data. Observation wells were used as a control for estimating SHWT accuracies.

General Description. The site was located on FDOT owned property at the southeast corner of SR 44W and the Withlacoochie River. The site was set within a floodplain type setting located in Rutland Park, an open area parking lot facility with boat ramp access.
A clustered set of observation wells were located at this test site at the northwest corner of the property.

District 6. *Broward County - SR 25 Okeechobee Blvd from SR 997 to SR 826.*

Objective: The corridor study applied surface water canal hydrologic station data acquired from SFWMD for evaluating selected test sites along a ROW corridor length. Estimates of SHWT conditions were projected back to the ROW from each station using canal measurement data as the control mechanism for determining whether or not the estimation techniques were effective. Each selected test location was positioned in direct line with the established hydrologic station positions. Four model equation methods were evaluated: back computation, correlation with high water level elevations, Hantush spreadsheet model (using NRCS soils data for input), and the Laplace Equation. No geotechnical methods were applied.

General Description. Broward County presented unique difficulties based on an urbanized setting and on the presence of the Everglades positioned along the western urban boundary. The Everglades were seasonally flooded, characterized by organic soils, shallow limestone and wet season inundation. SHWT conditions were evaluated based on equation modeling as opposed to conducting physical field measurement methods. The hypothetical study covered the entire proposed project corridor for evaluating consistency and variability along the intended road construction route.

Miami-Dade - US 1 from SW152nd Street to I-95.

Objective: The objective was similar to the Broward County corridor study using various equation methods to estimate SHWTs along the corridor ROW. The ROW was segmented into three sub-basins separated by canals intersecting with US 1. Flow net analyses, all geotechnical methods, and surface water feature observations were excluded. Tidal affects were evaluated for the section of US 1 positioned near the coastline (orange segment). Ground water hydrologic stations were used to provide control for the applied estimation methods.

General Description. Based on the urbanized setting, a hypothetical pilot test site corridor study was evaluated for the length of the proposed road construction project. For the section of US 1 near Bayshore Drive (orange line), an evaluation of tidal flux influences was included.

District 7. *Pasco County-SR 56 from Meadow Point Blvd to US 301.*

Objective: The pilot test site evaluated SHWT estimation techniques using a remote hydrologic station ground water well maintained by SWFWMD and an observation well for evaluating hydraulic gradient methods. The observation well was used as a control data source.

All methods except for flow net analyses and tidal fluctuation methods were applied to the test site. A storm water pond was incorporated into the test site for evaluating the presence of perched water table conditions due to the presence of shallow clays.

General Description. The site was located on FDOT owned ROW, northeast corner of SR 56 and Meadow Point Blvd. The site was set in an upland setting approximately 75 ft above msl. A single observation well was located at the intersection.

2.4. SHWT Estimation Methods Summary

Each pilot test site was subjected to a set of methods used to predict SHWT conditions within each project site. The procedures for applying each method are summarized below:

Specific field parameters were required for input into equations evaluating SHWT conditions for each pilot test site. Field parameters were collected from each site pilot test site.

Water Balance Method. Applied to all pilot test sites where site specific rainfall data, evapotranspiration estimates, saturated hydraulic conductivity estimates, upward and downward flow from confined aquifers, and runoff estimates were balanced against each other for determining water table contributions. The method provided information on the potential gains or losses to the modeled location or region.

Runoff estimates were estimated from the map produced by Hughes, 1978 (refer to *Task 1 Definitions, Methods, and Techniques Report*, *Appendix C, Page C-23*) for areas which are sparsely developed or remain in a natural condition.

Hydraulic conductivity estimation represented the most significant input parameter into the water balance and flow net analyses equations. Site specific estimates were obtained from drawdown-recovery testing from test site observation wells, or from publications produced by the NRCS or WMD for each specified location.

For single observation well pilot test sites, transmissivity estimates for confined aquifer influences were estimated with knowledge of the thickness of the confining layer (b) and the hydraulic conductivity estimate (K) using the following equation: T= Kb. For clustered observation well sites, transmissivity estimates were determined from drawdown-recovery test data for the deep well. Hydraulic conductivity estimates were obtained from shallow observation wells. For hypothetical sites, public agency sources were researched for obtaining the required data.

Back Computational Method. This method relied on estimating SHWT conditions from known surface water and ground water elevations. Surface water elevations were back calculated to the ROW for estimating SHWT conditions. Normal and seasonal high surface water measurements were used to project back to the ROW for estimating SHWTs. Observation well measurement data confirmed and verified the equation method's estimate. Wetlands, storm water ponds, and other surface water features were applied to various test sites where measurement data was collected by observation, or hydrologic station data provided routine measurement data.

Soil Slope or Gradient Determination. The most difficult part of applying the back computational equation was determining an accurate soil slope which was different than the topographic or ground water slope. The best way to measure soil slope was to complete a hand auger in the upland position where the project site was located, then move down to the lake level and complete a second hand auger boring while looking for similar recognizable soil horizons that could be measured by elevation survey. An attempt was made to accomplish this task during the test site setup implementation. An accurate slope could not be recognized by soil profile observation. In the absence of recognizing similar soil horizons, the least accurate alternative method was to apply the NRCS slope which represented landform slope, not soil slope. The percentage value was converted into a decimal (e.g. 2% = 0.02/distance). The distance between the subject site and lake was divided into the slope value for an estimated soil slope value, based on the assumption that the soil slope occurred parallel with the topographic slope, sloping towards the lake from the upland position.

Correlation of Historical Water Level Ratio Method. The application of this method relied on the presence of several reference hydrologic stations within close proximity to the project site. The stations and Project Site "A" ratio was established by dividing the subject site by the reference site multiplied by the referenced site measurement value and then added to the subject site value to obtain an estimated SHWT value.

Flow Net Analyses. This method relied on an accurate estimation of hydraulic conductivity and transmissivity value. Ranges provided in the NRCS soil survey identified as Ksat varied too widely to produce reliable results. Hydraulic conductivity estimates were obtained from each project site from drawdown-recovery testing of the observation well for input into the model equation. Test data replaced Ksat values during this study where values were reasonable. A one dimensional approach towards estimating downward and upward flow was used for estimating confined aquifer impacts.

Hantush Analytical Model. This model was intended to estimate mounding heights beneath rectangular basins. Input parameters required an accurate estimation of vertical hydraulic conductivity (Kv) through the unsaturated zone, accurate input of saturated horizontal hydraulic conductivity (Kh) values, input of fillable porosity, duration of infiltration, and basin dimensions. The process of estimating basin recharge mounding conditions was the same as estimating regional watershed mounding of the water table for establishing SHWT conditions. Cased hole percolation testing of the upper 4 ft was completed at each pilot test location by hand auger boring methods.

Saturated hydraulic conductivity data (Kh) was determined by drawdown-recovery testing of the observation well. Fillable porosity was estimated by NRCS soils data. Duration of infiltration corresponded to the length of time recharge occurred near the pilot test site based on collected rainfall measurements recorded every 30 days from the site gage.

Laplace Equation. This method did not require the presence of a physical observation station located at a project site. Instead, the equation relied on a project site positioned between two known hydrologic stations (surface water or ground water). For this study, the method was applied using known measurement data collected from observation stations and hydrologic stations. Distances between the subject site and known station, and the total distance between the two known stations produced a ratio which was entered into the equation along with known head elevations. The SHWT estimate was compared against observation well control data.

NRCS Soil Survey Data Evaluation. Key parameters for evaluating soil survey data included comparing field soil logs with the profile provided by the county soil survey. Soil types did not match exactly but appeared close enough to place the log into the proper NRCS soil type, with some distinctions occurring between depth to soil horizons, and soil textural classification. This method required experience with soil identification practices and recognition of SHWT indicators. Gray soils appeared to be the most obvious and easily identifiable SHWT indicator that could be documented by field geotechnical personnel (i.e. drillers).

Geotechnical SPT "n" Values or blow counts. SPT borings were effective for collection of continuous undisturbed soil samples for describing soil profiles and horizons. SPT methods were useful for identifying restrictive hard pan layers, dense clay, and limestone units. SPT blow counts were recorded for every 0.5 foot interval. In sandy soils (SW, SP), blow counts occasionally represented fluctuating ground water levels. In silty (SM) and clayey (SC, CH, CL) soils, the usefulness in making this determination was less effective.

Static Cone Penetrometer. A pocket penetrometer probe provided the required sensitivity for evaluating changes in density within soft sands, suggesting water table fluctuations were present. The depth of probing was unlimited when applied to the SPT soil core samples brought to the surface for inspection. Correlation to SPT blow count data was, on occasion, accurate. The most common issue between comparing SPT density values with the pocket penetrometer was a deviation of density values by an interval or two between SPT and pocket penetrometer density values.

Water Level Measurements. Ground water and surface water elevations provided evidence of seasonal high water conditions when sufficient data spanned both wet and dry season cycles over a time period long enough to represent fluctuating water table conditions. Placement of observation wells and establishment of station points where repeat observations were collected over the long term appeared to be critical requirements for obtaining valid data sets needed to estimate SHWT's. Each observation well was monitored for water levels on a monthly basis over a two year period. Observation well data was used as a control towards evaluating equation modeling methods, including evaluation of NRCS soil survey water level range estimates. All test sites with observation wells along with hydrologic station data were evaluated using appropriate methods.

Hydrologic Station Data Evaluation. Historical data collected from stations managed and operated by the USGS and Water Management Districts were effective tools in estimating water table fluctuations and ranges occurring over normal, high, and low rainfall periods. The application of current data was most effective when data acquired coincided with the time period in which the project site observations were collected. Comparison between the acquired data and observation data provided a more accurate prediction of SHWT conditions. Hydrologic data was acquired from public agency records where stations were located near pilot test sites and corridors. All test sites with observation wells and hydrologic station data were evaluated using both qualitative and quantitative methods.

Surface Water Feature Observations. Surface water features accounted for normal, seasonal high and flood level water lines appearing on structures such as storm water culverts and control structures, and other manmade structures exposed to high water line staining. Repeated staining resulting from flooding may mask the true height of seasonal high water lines, which may be difficult to identify. Measurement data were used as a substitute for projecting surface water seasonal highs back inland for predicting ground water elevations.

Dupuit-Ghyben-Herzberg Equation. The one dimensional tidal wave height model was applied through unconfined aquifer conditions inland from the coastline. The equation was modified for unconfined conditions by substituting transmissivity and storativity (confined aquifer properties) with hydraulic conductivity and specific yield (unconfined aquifer properties) values. Key input data was obtained from tidal charts for the coastal regions where the subject sites were located. The distance from the coastline to the project site must be within 300 feet for the estimate to produce a reliable theoretical result. The method may be applied to distances beyond 300 feet with significant reductions in effective predictability. Two pilot test sites were subjected to evaluation for tidal effects on the water table aquifer: Brevard County test site at the US 1/SR 514 intersection; and the Miami hypothetical site at the junction of US 1 and I95.

Section 3.0. Data Collection & Prediction Analysis – 2015 & 2016

3.1. Introduction

Ten (10) physical pilot test sites were established by installing observation wells o monitor ground water elevations as a control mechanism for estimating SHGWT's using various qualitative and quantitative methods described in Section 2.0. Some sites included both hydrologic and/or observation stations for projecting SHGWT estimates back to the right of way using model equations. Geotechnical, hydrogeological, and soils data were collected from each physical pilot test site for obtaining baseline data prior to the initial start of the long term monitoring program in January 2015. Rainfall data was collected from TheWeatherCollector.com, SFWMD, and from the State Climatology Center at FSU. Data was acquired from the nearest meteorological station to the test site location. Rainfall was used as input into water balance equations for each of the pilot test sites.

Significant errors occurred at the time of pilot test setup concerning land surface elevations which translated into surface and ground water measurement errors due to old topographic map availability at the time of pilot test setup. During the baseline set up evaluation, and the first quarter of 2015, very large prediction errors occurred when measurements were evaluated with respect to erroneous land elevations. The error was corrected by reviewing Google Earth satellite imagery for each pilot test location for more accurate land elevations for each observation station. Land elevations were corrected and retrofitted for the first quarter prediction results but were not retrofitted back to the baseline data.

Estimates from several of the quantitative equations were incorrect since the initial data collected from some of the test sites were used and due to lack of familiarity of how these equations functioned. During the first quarter data collection period, many of the equation functioning issues were resolved while processing measurement data from each test site. Most errors generated during the 1st quarter data collection period were corrected during the 2nd quarter data collection period. Summaries provided in this section were extracted from the Task 3A report titled *Pilot Test Field Study Baseline Report*. Field logs and baseline test data were previously documented in the Baseline Documentation Appendix of the report, dated December 4, 2014.

3.2. Pilot Test Site Setup Procedure

Four (4) hypothetical test sites represented corridor type studies relying exclusively on hydrologic station data collected by water management districts and by the US Geological Survey. Baseline data for each hypothetical site was obtained from public agency sources which were extremely limited for describing physical conditions associated with these sites.

Each physical pilot test site was set up using a uniform procedure for collecting geotechnical, soil, and hydrogeologic information. An SPT boring was completed at each observation well location for obtaining soil samples of the profile extending down to the total depth of the observation well. Shallow water tables at some test site locations prevented the use of an SPT to identify the previous water table horizon.

Soil logs were recorded with respect to soil texture, soil matrix, mottling (redox features), stripping, and depleted indicator colors using a standardized soil color chart, relative observed density, and percentage of visible organic content. Blow counts were also recorded to identify water table conditions (apparent, normal, perched, and hanging) characteristics (see Task 3A, *Pilot Test Filed Study Baseline Report Supporting Documentation* dated December 4, 2014 for the completed field log data).

Each SPT boring was converted into an observation monitoring well for the purpose of collecting static water level measurements. Pump testing was completed for each well to estimate the horizontal hydraulic conductivity values for the surficial and confined aquifer depths. Aquifer hydraulic conductivities were estimated using the model program AQTESOLVE. Well construction logs and aquifer testing logs were recorded during the procedure.

Cased hole percolation testing was completed within the upper 4 feet of the soil profile. A 2 inch diameter by 4 foot length of solid PVC pipe was set in the open, hand augered borehole. The casing was filled with water and allowed to percolate into the base of the boring. A water level meter was used to measure the water level drop for estimating vertical hydraulic conductivity in the unsaturated zone above the ground water interface. Percolation test results were compared with the NRCS Ksat range of values representing vertical hydraulic conductivity estimates. Vertical estimates were converted into horizontal hydraulic conductivity estimates using the equation $K_v = 0.3K_h$ (Fetter, 1988). NRCS defines Ksat as the vertical hydraulic conductivity occurring within the most restrictive layer within the upper saturated zone.

Observation well top of casings were measured by standard tape measure. Land elevations were obtained by reviewing Google Earth satellite imagery. A rain gauge was set up next to each observation well anchored to the concrete pad by a 4 foot PVC riser. The rain gauge was mounted into the top of an open PVC pipe. Where surface water features were present within reasonable distances from the observation well site, a surface observation station was established for obtaining normal and seasonal high elevations based on horizontal surveying methods using a targeting laser. For pilot test sites where hydrologic station data existed, data was acquired for the purpose of collecting an initial surface water and/or ground water elevation for input into the quantitative methods during estimation of SHGWTs

During the progress of setting up pilot test sites in central and south Florida, significant rainfall affected the normal ground water levels for the following pilot test sites: Pasco (1 inch), Highlands (0.25 inch), Martin (0.10 inch), and Brevard (1.0 inch) Counties. Observation wells were constructed according to visual observation of ground water conditions for establishing total well depth and well screen length at each site during the field setup procedure. Estimates of rainfall totals were obtained from the NOAA weather map published on the internet for November 20, 2014.

Baseline test site results were presented in the Task 3A report entitled Pilot Test Study Baseline Report, dated December 4, 2014, Appendix B. As stated previously, prediction analyses for many of the quantitative methods contained errors due to improper elevations. Subsequent reports corrected these errors which improved the prediction results for evaluation and analyses. The results are summarized in the following sections.

3.3. District Summaries

Ten of the fourteen pilot test sites were established along FDOT future road project corridors scheduled for improvement or reconstruction during the 2017 Fiscal Year. Each one of the observation wells was used for control measurements for predicting ground water elevations and to provide quality control for application of public agency hydrologic station data. Where measurement data along hypothetical corridors were unavailable to compare predicted results against measurement data, prediction errors could not be established. One method to resolve this issue would be to place temporary well points along corridors for establishing an additional measurement data set for predicting ground water elevations when this type of situation emerges during the future implementation program initiated by FDOT.

District 1.

The *DeSoto County* site relied on public agency data sources from ground water wells operated by a water supply authority with the exception of ground water measurement data collected by this study along the road corridor.

The absence of public agency hydrologic station data near the CR 769 right of way introduced a level of uncertainty into the prediction results when attempting to evaluate the acceptance criteria. To address this issue, a modification was implemented to accommodate hydraulic gradient conditions occurring at a higher land surface elevation for projecting ground water predictions to a lower land surface elevation. This adaptation focused on evaluating depth to ground water measurement data as a means for transforming higher ground water elevations to lower ground water elevations. This adaptation did not resolve the issue of lack of measurement data along the hypothetical roadway corridor. Application of temporary well points placed along the corridor would help resolve prediction error evaluation issues.

The Peace River gaging stations produced another set of problems which could not be resolved. The river was tidally influenced with reported surface water elevations occurring a few feet above mean sea level. Applying equation methods with low river elevations produced extremely low predicted elevations which were considered unreliable at the road corridor hypothetical stations.

Qualitative Methods Summary: **Soil Indicators**. Driller's logs were used to evaluate the soil profile conditions with respect to gray soil profile indicators. Upper soil profile gray indicators were present at two distinct but separate horizons: at grade and 5 feet below grade. Clayey or loamy sands occurred below the upper sandy horizon causing periods of flooding at the surface during heavy rainfall and storm events. Clayey to loamy soil conditions helped explain why flooding occurred around the reservoir. A second gray soil horizon was noted on several driller logs between 10 and 15 feet below grade. Soil indicators appeared to be the most reliable predictor method over the entire data collection period when measurement data was compared against soil types at the reservoir ground water station GW 4.

The gray soil depth interval occurred within the NRCS range interval, suggesting NRCS relied on this indicator for developing the seasonal high ground water table range.

Hydrograph Method. A direct correlation existed between rainfall and the rise/fall response of the ground water table during periods when soils were in relatively dry condition.

When soils became saturated due to consistent rainfall, a continuous rise in ground water lagged behind rainfall by a period of approximately 30 days, although a direct response was observed to correlate between rainfall and ground water. When rainfall receded, saturated soils appeared to continue to contribute to ground water.

During the waning seasonal wet period months (September and October), ground water depths appeared to stabilize to the levels prior to receding. This method appeared to be useful for establishing when the seasonal high ground water conditions were expected to occur.

Geotechnical Methods Evaluation. Driller's logs from hydrologic station well installation were completed by a cable tool drill rig so did not include SPT data. An evaluation of SPT density values relative to estimating seasonal high ground water depths could not be assessed for this test site.

NRCS Seasonal High Water Table Range Evaluation. Seasonal high ground water table ranges estimated for DeSoto County soil profiles occurring along CR 769 between 0.5 to 1.5 feet below grade. Soil indicators (gray color) were present between 0 and 5 feet below grade, determined from hydrologic station GW 4 at the reservoir. During the data collection period, measured ground water depths met the NRCS range criteria with flooding occurring at the surface during the month of August 2015. Appendix B provides a comparison between NRCS water table range data converted to ground water elevations with predicted results. Section 4.0 will address NRCS water table range evaluation in greater detail.

Depth to Ground Water Correction Method. To evaluate this method, the predicted ground water elevation results for the hypothetical stations A, B, and C obtained from the simplified hydraulic gradient method were input into the measurement column in Appendix B and compared with the method's predictions. This allowed errors to be generated for evaluating method success. Large errors occurred above and below the hydraulic gradient predictions throughout the entire data collection period. Because both measurement values and predicted results contained uncertainties, this method was not considered reliable enough to be effective.

A second option for evaluating this method was to apply the NRCS water table ranges for the soil types located along the CR 769 corridor and comparing these with the prediction results generated from each hypothetical station. Throughout the data collection period, seasonal measurements occurred below the lower NRCS range value with one exception.

Generally, application of this method would produce a conservative prediction for seasonal high ground water conditions. There is the likelihood that during the peak rainy season, a significant increase in ground water elevation could be expected to occur.

Rainfall Evaluation. During the summer months, rainfall occurred above average during July and August 2015, and during August and September 2016. Prediction results at hypothetical stations A and B were not influenced by the above normal rainfall during 2015 (consistently below the lower NRCS range value) but reached the acceptable criteria for Stations A and B during 2016 but not Station C.

Quantitative Methods Summary: Due to the lack of measurement data positioned along the CR 769 corridor, comparisons between measurement results obtained from remotely positioned monitoring wells at the Griffin Reservoir could not be accomplished with predicted results generated at the CR 769 corridor. Method results were inconclusive for this test site.

Highlands County had an abundant source of both surface and ground water data collected by public agency sources which were used in conjunction with observation ground water and surface water measurements. On occasion, public agency data appeared suspect due to similar measurements reported between ground water and surface water wetland features for a few months during the 2^{nd} quarter data collection period. By September 2015, hydrologic data appeared to represent proper measurement data. This issue affected the ability of some methods to properly predict ground water elevations for a limited time. Other than the aforementioned issue, no major issues were observed when applying quantitative predictive methods.

Qualitative Methods Summary. ***Soil Indicators***. Gray soils were logged between 0 and 6 ft below grade corresponding to seasonal high ground water table depths observed during peak summer rainfall for the entire data collection period. The gray soil depth interval occurred within the NRCS range, suggesting NRCS relied on this indicator for developing the seasonal high ground water table range. This method appeared to be acceptable for predicting seasonal high ground water conditions.

NRCS Water Table Range Evaluation. NRCS water table ranges matched ground water measurements for the entire data collection period. This method produced acceptable results for predicting seasonal ground water elevations.

Hydrograph Method. Rainfall peaked during several cyclical periods. During the first half of both 2015 and 2016, when rainfall peaked, ground water receded.

Ground water appeared to be influenced by the Lake Annie Canal, located 100 feet due east of the observation well as opposed to rainfall. When the canal was at its lowest elevation, ground water discharged into the surface water when soils were in a drier condition.

During the second half of both years, peak rainfall continued its cyclical trend with ground water increases influenced by saturated soil conditions and rising surface water conditions in the canal.

The canal appeared to be recharging ground water in addition to saturated soils contributing to ground water throughout the summer months. When rainfall receded during the latter part of both 2015 and 2016, soils dried out and the canal surface water receded, allowing ground water to discharge back into the surface water.

Geotechnical Methods Evaluation. Geotechnical SPT density data were inconclusive for this site. The increase in density values began at the 9 foot interval, representing an increase in compaction due to the presence of minor amounts of silt and clay soil matrices. The method did not compare with ground water measured at the test site observation at the time of test site setup.

Rainfall Evaluation. During the entire data collection period summer month cycle, rainfall occurred below average. Proper evaluation could not be completed because ground water elevations also occurred below the NRCS range interval.

Quantitative Methods Summary. **Hydraulic gradient** methods produced consistently acceptable prediction results compared to measurement data during the data collection period. Prior to April 2015, land surface elevation adjustments and hydraulic gradient determination errors produced unacceptable results. These issues were corrected subsequent to first quarter analyses.

The **Correlation Method** produced results ranging from acceptable to those above the seasonal measured ground water elevations. Application of this method produced a probability factor of 50-50 for overestimation of seasonal ground water conditions.

The **Laplace Equation** tended to produce estimates occurring below measurement values when surface water features were input into the equation for estimating ground water. When higher ground water measurements were input when compared to the observation well measurements, prediction results occurred higher than measurement values. This method was considered to be unreliable for a prediction method application.

CT DEP Method. This method produced an unreliable probability of 50-50 where prediction estimates occurred below and above acceptable criteria throughout the data collection period.

District 2.

Two sites were evaluated for perched or hanging water table conditions occurring in clayey soils overlying limestone (Alachua and Suwannee Counties). Under these conditions, qualitative methods appeared to be most effective in predicting seasonal high ground water conditions.

Alachua County. Due to the presence of a storm water basin, the ability to apply predictive equation methods was not considered to be successful as previously thought. The storm water basin surface appeared to be set on top of clay which tended to pond up surface water in the basin. The observation well indicated there was an unsaturated zone occurring between the pond basin surface and the true ground water elevation, suggesting perched water table conditions were represented by the storm water basin surface water.

Qualitative Methods. **Soil Indicators**. Gray clays were logged between 2.5 and 14 ft below grade. Measured temporary ground water elevations consistently occurred below the soil indicator interval throughout the data collection period. This method would tend to provide a conservative predication method for determining seasonal high ground water conditions.

The observed gray soil interval range spanned the NRCS water table range suggesting gray soils may not have been the source for NRCS water table range estimation unless another indicator was applied such as soil mottling features.

Hydrograph Method. Rainfall peaked in two cycles at this site: during January and again in July and August 2015. The gap in ground water depths between February and June represent ground water depths dropping below the well screen. Due to the presence of clays, there was a lag in response between peak rainfall and peak ground water depths of approximately 30 days.

The lag occurred from slow infiltration of rainfall through the unsaturated clay zone creating a temporary “hanging” water table condition when infiltrating ground water contacted more dense clay zones. During 2016, a single seasonal rainfall cycle peak occurred during the month of June. There did not appear to be a delay in ground water response during 2016.

The rise and fall of ground water was used to estimate dissipation of ground water infiltrating through clays. When rainfall exceeded 4 inches, perched ground water conditions appeared in the observation well. This observation appeared to hold true for the entire data collection period.

Geotechnical Methods Evaluation. Density contrasts in the clay zone possibly represented vertical movement of ground water at times when perched water table conditions dissipated from the surface downward. There were small pockets of higher density variations representing slight clay compaction from vertically moving ground water under the influence of clay expansion and contraction during saturation and desiccation.

Below 24 feet, there was a significant density drop off extending into limestone at a depth of 42 feet below grade. Between 12 and 14 feet, density consistencies suggest the ground water interface occurred within the interval based on comparisons with observed measurement data. Measured ground water elevations occurred consistently below the lower SPT density range, suggesting this method would produce a conservative prediction of seasonal high ground water conditions.

However, due to the presence of clay controlling density variations, application of this method by itself would be considered unreliable. Application of a second confirmation method should be used to validate SPT density interpretations.

NRCS Water Table Range Evaluation. Measured ground water elevations occurred consistently below the lower NRCS water table range interval. Application of this method would produce a conservative approach towards predicting seasonal high ground water table conditions. Additional evaluation of this method is presented in Section 4.0 covering several other counties within the district region.

Rainfall Evaluation. Measured rainfall at the test site was consistently below average during the summer month cycle covering the data collection period. Ground water measurements also occurred below the lower NRCS range of values which prevented an evaluation from being completed. Section 4.0 addresses this issue through consideration of additional sites.

Quantitative Methods Summary. Equation methods were applied between the storm water basin and the observation well when ground water was present in the well and in the basin, simultaneously. Prediction results were inconclusive based on the presence of an unsaturated zone appearing between the ponded surface water in the basin and the depth to ground water observed in the wells.

A consistently steep hydraulic gradient between the two features was an indicator that the two systems were not positioned within the same aquifer. Steep hydraulic gradients occurring between surface water and ground water may be used as an indication that the two features are not connected. Steep gradients are defined by occurrences on the order of greater than 0.001 ft/ft. For example, a gradient value of 0.01 ft/ft would represent indications of separate aquifers. The exception to this observation would be supported or refuted by a review of soil logs indicating where the depth to saturated zone occurs and by a review of measurement data for both surface and ground water elevations. Prediction results for this method were inconclusive.

Suwannee County. Due to a lack of surface water features, qualitative methods were used to evaluate clay behavior and temporary ground water conditions in lieu of applying equation methods. The rainfall vs. ground water hydrograph demonstrated clay response was directly correlated to rainfall influenced ground water increases throughout the data collection period. A minimum of 3.5 inches of rainfall was required to produce temporary ground water conditions.

Qualitative Methods Summary. **Soil Indicators**. Gray clays were logged between 8 and 10 feet below grade. Seasonal high ground water measurements were recorded consistently below observed soil indicator intervals suggesting this method would be appropriate for use in predicting conservative seasonal high ground water conditions.

Hydrograph Method. The hydrograph method was used to predict dissipation rate of movement through the clay zone. In the Suwannee County case, clays occurred at grade, suggesting slow permeable conditions existed throughout the entire soil profile. The presence of a lower ground water elevation observed by measurements collected from the deep observation well indicated an unsaturated zone existed between the depth of the shallow and deep well. The limestone aquifer was actively over pumped by agricultural irrigation in the area, evidenced by the aquifer occurring tens of feet below the shallow observation well measurements through measurements collected from the deep observation well. During the 2015 data collection period, three cycles of peak rainfall occurred throughout the year. During 2016, two peak rainfall cycles were observed. Reaction between rainfall and ground water response indicated no significant delays occurred for ground water elevation increases. This method appears appropriate for use in estimating long term infiltration rates in clay.

Geotechnical Methods Evaluation. Clays occurred at the surface to 6 feet below grade resulting in gradual ground water infiltration at or just below the surface. Below 6 feet, clays were mixed with limestone resulting in temporary water table conditions.

Hanging water table conditions most likely formed where ground water seepage from the surface clay contacted the more porous clayey limestone. The higher SPT value range represented stiff clay and hard limestone. High SPT blow counts masked indications of vertically infiltrating ground water movements. Ground water measurements occurred consistently below the lower range of SPT densities. If this method were applied in predicting seasonal high ground water conditions, the result would produce an acceptable conservative prediction.

NRCS Water Table Range Evaluation. NRCS estimated the water table range between 0 and 1 foot below grade suggesting NRCS was using a temporary water table condition occurring on top of the shallow clay horizon. Gray clays were observed at a lower interval than the NRCS range, suggesting NRCS may have been using another soil indicator (mottling?) to predict seasonal ground water conditions. An expanded evaluation is presented in Section 4.0.

Rainfall vs. Depth to Water Method. This method produced consistently invalid results due to the presence of temporary water table conditions which did not correlate with ground water rises.

Rainfall Evaluation. Throughout the summer month season, rainfall was consistently below averages during the data collection period.

Quantitative Methods Summary. Equation methods could not be applied to this test site due to the absence of surface water features within close proximity to the observation well location. Prediction results could not be established.

District 3.

Bay County test site relied on predicting ground water elevations using ground water and lake surface water measurements collected by observation combined with remote surface water creek measurements collected by public agency sources.

The USGS discontinued data collection of the ground water hydrologic station located at Deaden Lakes Cemetery 4.2 miles from the test site location on October 1, 2015. Ground water data for this station was no longer available for evaluation. No other issues were noted during the data collection period.

Qualitative Methods Summary. **Soil Indicators**. The soil profile had several indicators of relict ground water fluctuations but no gray soil horizon to confirm seasonal high ground water depths.

A thin white sand zone occurred between 26 and 28 feet below grade, possibly suggesting seasonal ground water conditions occurring at a historically higher elevation. Ground water depths were consistently observed at lower depths suggesting the soil indicator may be used to predict a conservative seasonal high ground water condition.

NRCS Comparison Method. NRCS established seasonal ground water depths greater than 6.5 feet which resulted in a “technical” match occurring between the NRCS depth and measured ground water elevations. A technical match was defined by measurements consistently occurring below the 6.5 foot depth. Actual ground water depths occurred approximately 35 feet below grade. This method was attempted for expansion as part of Task 3C. Public agency data was unavailable for review. A more complete discussion is presented in Section 4.0.

Hydrograph Method. The observation well was surrounded by large lake systems, the closest occurring to the south (Tank Pond-less than 0.25 miles), Crystal Lake, and River Lake (0.25 miles east). Rainfall peaked during two cycles during January and April 2015, receding throughout the wet season cycle up until ground water depths rose in again in August 2015. Sands were very porous suggesting soils percolated downward through the sands rapidly. However, the sudden decline in ground water depth during October is unexplained because rainfall continued to be consistent throughout this month. Discharging into lakes may help explain ground water declines.

A single rainfall peak appeared during the month of August 2016, declining during the subsequent months. Ground water depths peaked in April reaching static conditions from May through July with declines occurring in August during 2016.

Geotechnical Methods Evaluation. A review of the geotechnical standard penetration test (SPT) blow count data with the range of ground water measurement data revealed an increase in density occurring at the interval between 25.5 and 26 feet below grade, extending vertically through the ground water interface to a depth below the interface at 32 feet below grade. At 32 feet below grade, sandy soils were saturated enough to reveal lower densities between 32 and 32.5 feet based on a drop in SPT density values. The soil profile was predominantly fine sand with a 2 foot layer of sandy clay loam occurring between 20 and 22 feet deep. During 2015, ground water measurements occurred consistently below the lower interval. During 2016, ground water measurements consistently fell within the interval range of soil densities.

This method appeared to be effective for predicting seasonal high ground water conditions. Due to the variability in results, this method would be recommended for use where a second method of observation was applied to confirm density observations.

Rainfall Evaluation. Summer month rainfall was consistently below average rainfall.

Water Balance. Gains and losses were estimated during the summer rainy season as a result of variable rainfall occurring at the test site. Nearby lakes appeared to be more influential on controlling ground water elevations than rainfall.

Surface Water Fluctuation Method. Comparisons between River Lake and ground water measurements during the data collection period produced consistently high seasonal ground water measurements. Lake levels occurred much lower than the ground water suggesting the use of high water lines would not be an acceptable method for predicting seasonal high ground water conditions unless another method were applied where predictions are required at some arbitrary distance from the surface water feature. For example, the hydraulic gradient method applied to lake elevations would produce a closer approximation of ground water elevations at some distance from the lake.

Quantitative Methods Summary. **Hydraulic gradient** methods produced acceptable results for the entire data collection period. Application of this method using either ground water or surface water measurement data sources would produce acceptable seasonal high ground water prediction results.

The **Correlation Method** produced unacceptable prediction results occurring above measurement data due to wide ranging fluctuations occurring between surface water features and lower fluctuation ranges occurring in the ground water environment throughout the data collection period. Application of this method would produce consistent overestimation of seasonal high ground water conditions.

The **Laplace Equation** produced unacceptable prediction results when compared with measurement data. Predicted results occurred consistently above seasonal ground water measurements. Application of this method would produce consistent overestimation of seasonal high ground water conditions.

CT DEP Method. This method was applied during the 2016 data collection period. Seasonal high ground water predictions were consistently above ground water measurements. Based on the large errors produced by this method, it is not recommended for implementation.

Liberty County test site utilized ground water and surface water creek measurements collected from combined observation site and public agency sources.

Qualitative Methods Summary. **Soil Indicators**. Gray soils were absent. As a result, this method could not be evaluated.

Hydrograph Method. Rainfall peaked during three cycles throughout 2015: January, April, and August. Ground water depths corresponded directly to rainfall during the first quarter of 2015 but declined during the second quarter, remaining stable during the second half of 2015 up until September and October as rainfall and ground water receded. Big Creek, coupled with saturated sandy soils, appeared to maintain ground water at consistent depths below grade. During 2016, rainfall peaked in January and July. Ground water increases lagged behind rainfall by 30 days when saturated permeable sands contributed to the ground water interface.

Geotechnical Methods Evaluation. Fine sands occurred between the ground surface and total depth of the soil boring. At 11 feet below grade, an increase in SPT density was observed which corresponded to the ground water table interface. At 13 feet below grade, density increases at the water table interface matched the observed ground water depth measured at the time of observation well installation. Between 14 and 16 feet, reduced densities appeared to be attributed to lower density saturated fine sands. Higher densities were recorded to depths greater than16 feet below grade indicative of sand compaction. Measurements indicated ground water fluctuation occurred over a relatively narrow interval.

The entire profile was fine sand between the surface and 16 feet below grade. Seasonal high ground water measurements occurred consistently below the lower density stratum throughout 2015 but occurred within this stratum during seasonal months in 2016. This method would be appropriate for use in predicting seasonal high ground water conditions in deep sandy profiles. It is recommended that a second method should be applied to confirm density data interpretations.

NRCS Comparison Method. NRCS established seasonal ground water depths greater than 6.5 feet which resulted in a “technical” match occurring between the NRCS depth and measured ground water elevations. A technical match was defined by measurements consistently occurring below the 6.5 foot depth. Actual ground water depths occurred approximately 9 and 12 feet below grade. During the Task 3C data collection period, neither NWFWMD nor the USGS had wells penetrating depths shallow enough to correlate with the NRCS range estimate. Predictions had to be extrapolated from aquifer and environmental soil maps, and from knowledge of conditions associated with North Florida obtained from ground water data sources representing similar conditions. The issue will be discussed in detail in Section 4.0.

Rainfall Evaluation. September 2015 rainfall exceeded the average rainfall for the month but occurred below average rainfall for the remaining 2015 summer months and throughout the entire 2016 data collection period.

Higher than average rainfall during September 2015 did not have an effect on ground water measurements when compared to the NRCS water table range of values.

Water Balance. During the 2015 data collection period, losses were estimated for the entire cycle. Gains were estimated for the 2016 period covering August through October.

Surface Water Fluctuation Method. Ground water measurements were consistently higher than Big Creek surface water elevations positioned 1410 feet from the observation well station. Application of high surface water elevations for estimating ground water at some arbitrary distance is not recommended based on direct comparisons between surface and ground water. Application of the hydraulic gradient method is suggested when applying high surface water marks in predicting ground water elevations at a relatively long distance from the surface water source. In the case of Liberty County, surface water measurement data was successfully applied up to 4.5 miles from the ground water monitoring well.

Quantitative Methods Summary. **Hydraulic gradient** methods provided consistently acceptable prediction results compared to measurement data. This method would be an appropriate method for predicting seasonal high ground water conditions.

The **Correlation Method** produced prediction results above the measured seasonal high ground water elevations with deviations falling within acceptable ranges. This method appears to produce an overestimation of seasonal high ground water conditions with occasional acceptable matching of criteria. Caution should be exercised when applying this method.

Laplace Equation predictions produced unacceptable results compared to measurement data. Seasonal predictions occurred consistently below measured ground water conditions. This method does not appear to be appropriate for estimating seasonal high ground water conditions.

CT DEP Method. Prediction results were consistently above and outside of acceptable criteria when compared with measured ground water elevations. Application of this method produced consistently overestimated ground water predictions. This method is not recommended for use.

District 4.

The *Broward County* test site relied on surface water canal gaging stations operated by SFWMD and USGS. No ground water hydrologic station data was available for the test site. This presented problems when applying some equation methods for predicting ground water elevations along the Okeechobee Blvd corridor. Ground water measurement data was not available to confirm predicted results. Error deviations could not be established for comparing predictions against measured data. Predicted data was considered unreliable for the hypothetical corridor.

Qualitative Methods Summary. **Soil Indicators***. S*oil log data was unavailable for review to compare with surface water seasonal high surface water canal measurements.

Hydrograph Method. A surface water hydrograph was compiled for hydrologic station S32 along the Snake Creek and Miami Canal system. The seasonal high rainfall period during 2015 occurred in September, while in 2016, the peak rainfall occurred in August. Delays in canal water level responses appeared to be attributed to ground water recharge as opposed to direct rainfall because of the delayed response in surface water elevation following peak rainfall events.

Rainfall vs. DTW Method. This method was applied during the 2016 data collection period due to late development of the procedure. One valid prediction was obtained during the seasonal month of August 2016 where an acceptable prediction result was achieved. This method may not be appropriate for ground water use since it was applied to canal surface water.

Geotechnical Methods Evaluation. No geotechnical evaluations were completed for Broward County due to the lack of SPT data availability along the corridor.

NRCS Water Table Range Evaluation. Ground water stations were absent for this test site. An evaluation of soil profile properties could not be completed for this test site corridor. A more thorough evaluation was completed from USGS well measurement data scattered throughout Broward County, presented in Section 4.0.

Rainfall Evaluation. Rainfall was consistently below average monthly values for the entire data collection period.

Water Balance. Seasonal months typically produced gains to surface water conditions. Rainfall was typically below average monthly totals.

Quantitative Methods Summary. The **Surface Water Hydraulic Gradient Method** relies on the same principles for determining ground water hydraulic gradients as the Simplified and Back Computational Method approaches. The majority of predictions were below surface water measurements with an occasional exception occurring above measurement values. Some stations modeled fell within acceptable criteria. The prediction occurring between S32 and Hypothetical Station B met acceptable criteria due to the short distance and extremely low gradient between the two stations. The seasonal prediction between the USGS station and hypothetical stations A, B, and C produced acceptable results within criteria. Not enough ground water data was available for extrapolating this method to ground water. A second method to verify surface water prediction results to ground water would be recommended in order to extrapolate canal system predictions to ground water.

The **Laplace Equation** produced consistent seasonal predictions for surface water with occasional exceptions above measured values. Not enough ground water data was available for extrapolating this method to ground water. A second method to verify surface water prediction results to ground water would be recommended in order to extrapolate canal system predictions to ground water.

The *Martin County* test site relied on a storm water culvert collection basin and ground water observation measurements for evaluation of various equation methods with no significant obstacles. Both hydraulic gradient methods produced acceptable results between prediction and measured values.

Qualitative Methods Summary. **Soil Indicators**. Gray soils were present between 2 and 4 feet below grade. Ground water measurements occurred consistently below the lower observed range. This method would be appropriate for predicting conservative seasonal high ground water conditions. The gray soil range occurred below the NRCS seasonal water table range suggesting NRCS may have used other methods to obtain at the reported seasonal high interval. Gray soil appears to be an appropriate method for predicting conservative seasonal high ground water conditions.

Hydrograph Method. During 2015, peak rainfall occurred in September. During 2016, peak rainfall occurred in August. Ground water rise and fall cycles were directly correlated with rainfall peaks and declines due to the shallow ground water table.

Geotechnical Methods Evaluation. Due to the shallow ground water depth observed at the time of test site setup, SPT data was not collected. An evaluation could not be completed for this site.

NRCS Water Table Range Evaluation*.* The NRCS estimated water table ranged between 0 and 1 foot below grade. Ground water measurements occurred consistently below the NRCS range. NRCS seasonal water table range appears to an acceptable method for predicting conservative seasonal high ground water conditions.

Rainfall vs. DTW Method. During the month of August 2016, a predicted ground water elevation was slightly below the acceptable criteria by 0.03 feet. The method was considered to be acceptable for achieving predicted ground water elevations by rainfall. This method tends to underestimate seasonal high ground water conditions when applied. A second method should be used to confirm this method's results.

Rainfall Evaluation. Measured rainfall occurred below average monthly rainfall throughout the entire data collection period.

Water Balance. Mixed gains and losses were estimated for the 2015 data collection period. Gains were estimated for July and September. Losses were estimated for the entire 2016 period.

Quantitative Methods Summary. **Hydraulic gradient** methods produced acceptable prediction results following a change in procedure in April 2015. Adjustments made to ground surface elevations and methods for establishing hydraulic gradients reduced errors to within acceptable criteria. Changes in methods included determining the correct ground water flow direction, and applying the correct method. For example, the back computational method was applied when ground water flow occurred from low to high elevation. The Simplified Method was applied when the direction occurred from high to low elevation. This method would be acceptable for predicting seasonally high ground water conditions.

The **Correlation Method** produced prediction results within acceptable criteria during 2015 with a several exceptions above ground water measurements. During 2016, this method was consistently above and greater than acceptable criteria. This method is not considered to be reliable for predicting seasonal high ground water conditions based on 2016 ground water measurements. Application of this method would produce predictions which would periodically overestimate seasonal high ground water conditions.

Surface Water Fluctuation Method. When the culvert basin was compared to ground water measurements for predicting seasonal high ground water conditions, acceptable results were achieved during 2015. During 2016, most of the seasonal months also achieved acceptable criteria with an exception occurring above the criteria for a single month.

This method would be appropriate for predicting seasonal high ground water conditions with the possibility of occasional overestimation of ground water conditions during the summer months.

CT DEP Method. This method produced unacceptable predictions occurring above ground water measurements during 2016. Method application would produce an overestimation of seasonal high ground water conditions. This method is not recommended for application.

Palm Beach County had to be relocated due to the absence of hydrologic station data along the proposed Northlake Blvd extension from Congress Avenue to US 1. In addition, a water treatment plant was withdrawing surficial aquifer ground water from production wells located near one of the hypothetical corridor stations which rendered static predictions invalid. The corridor was relocated to US 1 between Northlake Blvd and Okeechobee Blvd. The hydrologic ground water well operated by SFWMD located in Riviera Beach provided ground water elevation for evaluating predictive methods along the corridor.

Qualitative Methods Summary. **Soil Indicators**. The hypothetical site could not be evaluated due to a lack of soil logging data along the US 1 project corridor.

Hydrograph Method. Peak rainfall occurred during September 2015, and in August 2016. The delay in rising ground water during peak rainfall events appeared to be related to saturated soil drainage from soil storage capacity.

Geotechnical Methods Evaluation. This test site was setup as a hypothetical site with no geotechnical field data being collected other than the hydrologic station data posted by SFWMD. Evaluation could not be completed.

NRCS Water Table Range Evaluation. Ground water measurements were consistently below the NRCS lower range throughout the entire data collection period. Application of this method would produce a conservative seasonal high ground water condition. An expansion of this method is presented in Section 4.0.

Rainfall Evaluation. Measured rainfall was consistently below average monthly rainfall throughout the entire data collection period for the summer months.

Quantitative Methods Summary. **Hydraulic gradient** method errors between predicted and measured ground water results could not be determined properly due to a lack of corridor specific ground water measurements for the simplified method.

However, to compensate for the lack of measurement data availability, the back computational method was applied to verify hypothetical station predictions met hydrologic station measurements accurately. Very low prediction errors for the back computational method from each hypothetical station back to the canal stations achieved acceptable criteria. The hydraulic gradient methods are considered to provide acceptable predictions for seasonal high ground water conditions.

Predictions were projected back to the US 1 corridor from PB 632 or the error evaluation. Establishment of a temporary well point along the corridor would help to provide a confirmation method for comparing predictions with measured data. Predicted errors occurred below acceptable criteria for most stations except for Station B from PB 632. Application of this method using a uniform hydraulic gradient between the canal stations and PB 632 produced results below acceptable criteria, resulting in an underestimation of seasonal high ground water conditions.

Correlation Method. Mixed results occurred in obtaining seasonal high ground water predictions. Errors occurred within and above measurements which would produce an overestimation of seasonal high ground water elevations with some results falling within acceptable criteria. This method appeared to be inconsistent with the majority of results occurring above the acceptable criteria.

Laplace Method. Prediction results occurred predominantly above acceptable criteria. Application of this method would generally produce an overestimation of seasonal high ground water conditions with some exceptions occurring below acceptable criteria. This method is not recommended for a prediction method.

CT DEP Method. This method produced a split between occurring within acceptable criteria and exceeding acceptable criteria in estimating seasonal high ground water conditions. Application of this method would require a second method for confirmation of results if used to predict ground water conditions.

District 5.

Brevard County relied on two storm water ponds and one observation test well site for evaluating prediction methods with no significant issues. Hydraulic gradient reversals were noted between surface and ground water stations. When reversals occurred, both simplified and back computational methods were substituted for each other to accommodate gradient changes.

Qualitative Methods Summary. **Soil Indicators***.* Gray soils were observed from the surface to 0.5 foot below grade. Ground water measurements were consistently below the gray soil indicator throughout the data collection period, suggesting application of this method would result in a conservative prediction of seasonal high ground water conditions. Gray soils appeared at shallower depths than the NRCS water table range. Another indicator appears to have been used to derive the NRCS intervals.

Hydrograph Method. Rainfall peaked during three cycles in 2015: April, July, and September. Ground water depths peaked directly in response. The presence of silty loams occurring beneath 0.5 foot of gray sand appeared to retain percolating rainfall near the ground surface. Slow infiltration appeared to contribute directly to the ground water before soils dried out. Rainfall peaked in January, May, June, and September 2016 with direct increases in the ground water elevation.

Geotechnical Methods Evaluation*.* Ground water measurements were consistently within the density range interpreted from SPT blow count data throughout the entire data collection period. The method appeared to produce acceptable seasonal predictions of ground water conditions.

NRCS Water Table Range Evaluation. The NRCS water table range was estimated between 0.5 and 1.5 feet below grade. Ground water measurements were consistently below the NRCS lower range value. Application of this method would produce a conservative seasonal high ground water condition.

Rainfall vs. DTW Graphical Method. This method was applied to the 2016 data collection period. Two months occurred during the seasonal high ground water period which produced errors occurring above ground water measurements but within acceptable criteria. The remaining months produced invalid results due to lack of correlation between rainfall increases coupled with ground water table rises. When valid, this method appeared to be reliable for predicting seasonal high ground water conditions but should not be relied upon alone for generating consistent valid application data sets.

Rainfall Evaluation. Seasonal rainfall measurements occurred consistently below average monthly rainfall.

Water Balance. During 2015, the month of September was estimated to show a gain to the water table. The remaining seasonal balance estimates suggest losses occurred to the water table. A 50-50 split between gains and losses was estimated for the seasonal months during 2016.

Quantitative Methods Summary. **Hydraulic gradient** methods produced consistently acceptable results. Each method was substituted for the other depending on the direction of the hydraulic gradient. This method would be appropriate for use in predicting seasonal high ground water table conditions.

The **Laplace Equation** produced seasonal high ground water predictions below actual measured values with the exception of a single occasion occurring above ground water measurements during August of 2016. All prediction errors exceeded the acceptable criteria and would tend to produce an underestimation of seasonal high ground water conditions.

The original **Dupuit Ghyben Tidal Method** published in FDOT Study BC354 RFPWO79 was applied to determine effects to the water table along the coastline. Results could not be generated beyond the coastline in the inland direction. This equation was substituted by a scaled down one dimensional flow version which produced prediction effects up to 300 feet away from the coastline.

This equation produced an increasing predicted ground water lens occurring further inland than directly along the coastline. Theoretically, the water table lens thickens inland from the coastline. A method to determine prediction errors from this application was attempted at the observation well that was 2640 feet away from the coastline for the 2016 data collection period. The seasonal results were split between occurring above and below the ground water measurements. Three out of four predictions produced unacceptable results with a single acceptable result occurring during the month of September.

Surface Water Fluctuation Method. Two sources were evaluated to determine whether or not surface water ponds could be used to predict seasonal high ground water conditions. The pond at Malabar Park seasonal high surface water was compared with ground water measurements collected at the test site well. The seasonal high surface water measurements were consistently higher than ground water measurements occurring above the acceptable criteria. A second source was evaluated between the Gladder Road storm water management pond and an observation point located closer to the test site well. Seasonal high surface water conditions occurred within acceptable criteria, but above ground water measurements. During the summer month period for both 2015 and 2016, one exception occurring below the accepted criteria occurred for this location. The more distant pond at the park was considered to be an unreliable prediction source which would produce an overestimated ground water condition.

The Gladder Road pond was considered to be a more reliable prediction source for estimating seasonal high ground water conditions. The Gladder Road pond covered a much larger area than the park pond.

CT DEP Method. Seasonal high ground water conditions were predicted above acceptable criteria with a single occasion that met acceptable criteria. Application of this method would produce an overestimation of seasonal high ground water conditions.

Lake County relied on a single lake hydrologic station operated by SJRWMD and a shallow observation well location for testing various prediction methods with no significant issues. The hydraulic gradient methods produced acceptable results between predicted results and measured data. Data collection and prediction evaluation ended in January 2016 due to test site destruction by land clearing contractors. The following discussion refers to the data collection period occurring throughout 2015.

Qualitative Methods Summary. **Soil Indicators***.* Gray soils were absent from the soil profile. White fine sand was present at the same zone as faint contemporary mottles between 18 and 30 feet below grade. White soils are also considered to be depleted indicators of seasonal high ground water conditions. Ground water measurements occurred within the indicator zone consistently throughout the seasonal high period in 2015. This method is considered an acceptable method to predict seasonal high ground water conditions.

Hydrograph Method. Lake Harris dramatically influenced ground water depths more than rainfall. Lake Harris was prone to responding to rainfall more rapidly than ground water, maintaining surface water elevations during periods of low rainfall. The ground water hydrograph appeared to reflect discharging into the lake in response to rainfall as opposed to direct correlation with rainfall peaks. A delay in recharge by rainfall was noted, but ground water response to rainfall did not appear to correlate with rainfall peaks very well.

Geotechnical Methods Evaluation. A slight increase in SPT density occurred between 9.5 feet to 18 feet within the range of ground water fluctuations measured from the shallow well. Around 18 feet, density changes represented compaction due to burial as opposed to compaction due to ground water fluctuations based on soil log data. This depth correlated with the upper white soil interface. Ground water measurements consistently occurred below predictions, producing unacceptable predictions. Application of this method would produce a conservative prediction of seasonal ground water conditions. It is recommended this method be supported by a second method for confirmation purposes.

NRCS Water Table Range Evaluation. The NRCS water table ranges technically matched ground water measurements consistently throughout 2015 due to the estimated range occurring greater than 6.5 feet below grade. A more thorough evaluation for Lake County in provided in Section 4.0.

Rainfall Evaluation. Measured rainfall occurred consistently below the average monthly rainfall during the seasonal monthly cycle.

Water Balance. Water balance estimation was completed for the 2015 data collection period only. Losses were estimated for the first three summer months with a gain estimated for September.

Quantitative Method Summary. **Hydraulic gradient** and **Correlation Methods** produced acceptable prediction results compared to the measured data. The Correlation Method functioned well due to low fluctuation ranges for both surface and ground water systems, which were attributed to the large surface area of Lake Harris. The lake appeared to be the controlling factor on the ground water elevation, discharge-recharge boundary conditions, and on hydraulic gradient flow direction. Both methods appeared to be acceptable for predicting seasonal high ground water conditions under situations where large surface water lakes control ground water levels.

Surface Water Fluctuation Method. Ground water elevations were consistently below surface water elevations. Large lakes in the vicinity appear to control ground water more significantly than rainfall infiltration. Application of seasonal high water lines would tend to produce a conservative prediction of seasonal high ground water conditions where these regional influences occur.

Flow Net Analyses. Losses to the ground water occurred due to the drawdown influence of regional surface water on the adjacent ground water.

The *Sumter County* site relied on a single river gaging station, a canal observation station, and test well site for predicting ground water elevations. The testing procedure used a surface water gradient method to predict the river gaging height at the boat canal during the 1st and 2nd quarters of 2015 without much success.

The surface water gradient was subsequently replaced by direct gradient estimation between the gaging station and observation well. Hydrologic conditions varied between river and ground water discharging and recharging in both directions. In addition, changes in aquifer interactions were observed with both upward and downward flow between the upper clay horizon and limestone aquifer.

Qualitative Methods Summary. **Soil Indicators***.* Gray soils were logged between the ground surface and 3 feet below grade. Ground water was consistently measured below the gray soil indicator zone throughout the entire data collection period. Application of this method would produce a conservative prediction of seasonal high ground water conditions.

Hydrograph Method. Rainfall peaks correlated with rising ground water during the first half of 2015. A delay in ground water response appeared during the second half of 2015. The 2016 data collection period began with a corresponding ground water response to winter month rainfall peaks but declined during the spring and summer months even though rainfall peaked in May and August. Ground water elevations declined along with river stages. Ground water rebound occurred during increased river stages following peak rainfall events.

Geotechnical Methods Evaluation. Increased density values represented stiff clay between 6 and 10 feet. Increasing SPT values represented clayey limestone at 10 feet below grade. Ground water measurements occurred consistently below the lower SPT density range but were within acceptable criteria throughout the entire data collection period. Applying this method for predicting seasonal high ground water conditions would result in a conservative seasonal high ground water condition. A second method is recommended to confirm interpretations.

NRCS Water Table Range Evaluation*.* The estimated NRCS range was estimated between 0.5 and 1.5 feet below grade. Ground water measurements were consistently below this range, and below the acceptable criteria. Application of this method would result in a conservative prediction of seasonal ground water conditions.

Rainfall vs. DTW Graphical Method. This method produced unacceptable results based on inconsistencies between rainfall increases and ground water rising during the 2016 data collection period. The method is considered unreliable.

Quantitative Method Summary. The **Surface Water Gradient Method** did not produce acceptable results for the first two quarters of 2015. The procedure was modified to apply the gage height at the river directly to the observation well using a hydraulic gradient estimate for ground water to surface water.

This change improved prediction results within acceptable errors. Hydraulic gradient reversals were also noted between surface water and ground water conditions. Reversals were addressed by substituting both simplified and back computational methods to accommodate gradient changes. **Hydraulic gradient** methods produced acceptable prediction results compared to the measured data.

The **Correlation Method** produced unacceptable results due to large river and canal fluctuation patterns and low ground water fluctuation patterns. Predictions occurred above acceptable criteria and greater than ground water measurements for the river gage to observation well scenario. Application of this method would produce overestimation of seasonal high ground water conditions.

Water Balance. Losses to the upper clay zone occurred during February and March 2015, and up until May 2016. The remaining months of 2015 and 2016 had negligible gains occurring to the ground water.

Flow Net Analyses. Throughout the data collection period, consistent upward flow was estimated from the limestone to the upper clay zone at the observation well site with the exception of September 2016 which exhibited downward flow. Upward flow contributed to increases in the estimated water table of up to 0.4 foot which was accounted for by ground water measurements at the shallow observation well.

Surface Water Fluctuation Method. Seasonal high surface water elevations at the canal occurred consistently higher than the observed ground water at the observation well. Application of this method would produce an overestimation of seasonal high ground water when the canal high water level is relied upon for estimating ground water (i.e. ground water was measured consistently below surface water elevations).

CT DEP Method. Application of this method produced consistent seasonal ground water estimates occurring above the acceptable criteria. This method would result in the overestimation of predicted seasonal high ground water conditions. This method is not recommended for use as a predictive method.

District 6.

The *Miami Dade* test site relied on two ground water hydrologic stations to predict ground water elevations along the US 1 corridor. During the first and second quarter of 2015, the canal stations were assumed to be surface water gages.

Upon review of the SFWMD hydrologic database, the canal station was described as a ground water station located at the canal location. Therefore, first two quarters of 2015 are in error but the 3rd & 4th quarter 2015 and the entire 2016 results are correct.

Qualitative Methods Summary. **Soil Indicators***.* No soil log data was available for review to compare with surface water seasonal high measurements.

Hydrograph Method. The hypothetical site represented an urbanized setting where storm water runoff was directed into canals with low ground water infiltration properties. Peak rainfall occurred in September 2015, and during July and August in 2016. Canal recharge to the ground water appeared to play a more significant role in controlling seasonal high ground water conditions than peak rainfall events.

Geotechnical Methods Evaluation. No geotechnical evaluations were completed for District 6 based on a lack of SPT data availability along the corridors.

NRCS Water Table Range Evaluation. Ground water measurements from the USGS G580A well occurred consistently within the NRCS range of seasonal high ground water depths. Application of this method appears to be reliable for predicting seasonal high ground water conditions.

Rainfall vs. DTW Method. This method was applied during August 2016 for predicting seasonal high ground water conditions. The predicted result occurred above the acceptable criteria, producing an overestimation of seasonal high ground water conditions. Due to the inconsistency of this method and the large number of invalid correlations between rainfall increases and ground water rises, this application appears to be unsuitable for predicting seasonal high ground water conditions.

Rainfall Evaluation. During 2015, the month of September produced measured rainfall above the average monthly rainfall. During 2016, rainfall occurred below the average monthly values during the seasonal high period.

Water Balance. Gains to the water table were estimated throughout the entire data collection period during the seasonal high months.

Quantitative Methods Summary. **Hydraulic gradient** methods provided mixed results due to the reliance on a single determination of hydraulic gradient conditions occurring between two known hydrologic ground water stations. A uniform hydraulic gradient was applied to all hypothetical stations which produced increasingly unacceptable results for the stations positioned at greater distances away from the source measurement. During 2015, the simplified method consistently produced prediction errors within but below measured values with a few exceptions exceeding the acceptable criteria at specific hypothetical stations (A & B). During 2016, prediction errors improved within the acceptable criteria but below measured results with two exceptions occurring below the acceptable criteria at Stations A and B.

The back computational method produced predictions within and outside of acceptable criteria during 2015. During 2016, results occurred within the acceptable criteria. This method does not appear to be reliable enough to generate acceptable seasonal high ground water conditions when a uniform hydraulic gradient is applied. The presence of a hydraulic barrier at C2SW2 may have created conditions that were not accounted for in the analysis until the ground water boundary condition was overcome. Placement of a temporary well along the corridor would improve prediction results by allowing more precise hydraulic gradient determinations for predicting ground water conditions along the corridor route.

The **Laplace Equation** produced acceptable results due to distance ratios less than 0.7. Consistently low errors were generated throughout the data collection period. This method appeared to be appropriate for use in predicting seasonal high ground water conditions.

The one dimensional version of the **Dupuit Ghyben Tidal Effect Method** was applied to predict tidal effects up to 300 feet away from the coastline. Results between 10 and 300 feet consistently produced low estimates for ground water increases inland from the coastline.

CT DEP Method. Mixed results were generated with this method. During 2016, June and August errors occurred within the acceptable criteria while July results predicted seasonal high ground water conditions above the acceptable criteria, and September errors occurred below the acceptable criteria. This method produced unreliable results and is not recommended for predictive application.

District 7.

Pasco County test site had consistently dry wetlands present adjacent to the test well site during both dry and extremely seasonal wet periods. No equation method could be applied using surface water features for the entire data collection period. The nearest hydrologic station was located in Wesley Chapel approximately 4.6 miles northwest of the test site, operated by SWFWMD.

Prediction methods relied on ground water measurement data alone. A combination of factors including dry wetland conditions, subdivision storm water basins containing ponded surface waters, and the monitored depths of ground water in the test well indicated perched water table conditions were present similar to those described for Alachua and Suwannee Counties. Clays were relatively permeable, so there was a quick response between rainfall infiltration and the corresponding ground water elevation increases.

Qualitative Methods Summary. **Soil Indicators***.* Gray soils were logged between 2 and 4 feet below grade resting on top of the clays. Seasonal high ground water measurements occurred consistently below the observed lower range. Application of this method would produce a conservative prediction of seasonal high ground water conditions.

Hydrograph Methods. Due to the presence of clay, although relatively permeable due to the presence of coarse limestone fragments, a lag occurred between peak rainfall and ground water response. Peak rainfall during 2015 occurred in July, August, and September. During 2016, July and August were the peak rainfall months. A 30 day lag in ground water response occurred due to slow infiltration capacity attributed to clay.

Geotechnical Methods Evaluation. The soil log consisted of 4 feet of fine sand overlying stiff dense sandy clay between 4 and 18 feet. A combined perched/hanging ground water table may be present between the upper sand and clay interface. Ground water measurements were consistently within the range of higher densities throughout the entire data collection period. This method appeared to be reliable for producing seasonal high ground water conditions. It is recommended that a second method be applied for substantiating SPT density interpretations related to seasonal high ground water predictions.

NRCS Water Table Range Evaluation. NRCS estimated water table ranges between 1.5 and 3.5 feet below grade. Measured ground water elevation occurred consistently below the lower NRCS range throughout the entire data collection period. Application of this method would produce a conservative prediction for seasonal high ground water conditions.

Rainfall vs. DTW Graphical Method*.* This method was applied for the 2016 data collection period only. One event produced valid results which occurred within the acceptable criteria. This method was not reliable enough to predict seasonal high ground water conditions.

Rainfall Evaluation. Measured seasonal rainfall occurred below average monthly rainfall throughout the entire summer data collection period.

Quantitative Methods Summary. Both **hydraulic gradient** methods produced acceptable results after adjustments to procedures were applied after April 2015 between the shallow SWFWMD well in Wesley Chapel and the observation test well site. Hydraulic gradient methods produced acceptable predictions of seasonal high ground water conditions using remote hydrologic ground water station data.

The **Correlation Method** produced estimates within the acceptable criteria during 2015 with two events exceeding the criteria during seasonal months. During 2016, this method produced consistent errors exceeding acceptable criteria, which were above the observed ground water measurements. Application of this method would produce an overestimation of seasonal high ground water conditions.

Flow Net Analyses. During 2015, consistent down ward flow between the upper clay and limestone occurred at the Wesley Chapel hydrologic station site. The downward gradient was extrapolated to the test site, which was approximately 4.5 miles to the southeast of the hydrologic station. During the summer season in 2016, the same condition was estimated. Measurements collected at the test site compared well with these conditions.

CT DEP Method. This method was applied during 2016. During the summer season, three out of four predictions occurred above the acceptable criteria. Application of this method would produce an overestimation of seasonal high ground water conditions.

3.4. Summary

Based on the two year field data collection period and accompanying prediction method analyses, a set of qualitative and quantitative methods were identified as providing acceptable predictions of seasonal high ground water conditions for individual districts.

Statewide application of qualitative methods would produce inconsistent results, with the exception of the NRCS method. The qualitative methods were based on practical field application associated with geotechnical soil boring investigations and recording of SPT blow counts and soil colors for comparison with NRCS range of water table. These methods were identified as gray or white soil indicators, geotechnical SPT density values, and the NRCS method for comparing ground water measurements to estimated water table range intervals. The rainfall vs. depth to ground water hydrographic method produced limited acceptable results but not practicable for statewide implementation due to the requirement of accumulating large data sets for predictions.

Quantitative methods are strongly associated with theoretical applications for predicting seasonal high ground water conditions. These methods rely on equations and ground water measurement data to obtain predictions. Acceptable results were consistently achieved by the hydraulic gradient method which appears to be appropriate for statewide and district regional implementation.

The Laplace Equation appears limited to district applications, and the Dupuit Tidal Effect method is limited to coastal regions up to 300 feet distance from the shoreline.

A set of recommendations is presented in Section 5.0 to address future data collection methods and procedures. On a preliminary basis, FDOT already has procedures in place for collection of preliminary geotechnical data as part of the planning, design, and environmental study program. Geotechnical soil borings can be used to accumulate sufficient data to utilize many of the qualitative methods and for input into many of the quantitative methods that were used for this research project.

Section 4.0. NRCS Statistical Probability Study

4.1. Introduction

Based on continuing interest in applying NRCS water table estimates as a method for predicting seasonal high ground water tables throughout the state, and in consideration of the FDOT and the five water management districts specifying use of NRCS soil survey data for designing storm water management systems, this study was proposed to address several recurring issues. Task 3B evaluated the NRCS water table estimated ranges based on 2 test sites per district, assuming the evaluation could be extrapolated regionally or statewide. Extrapolation appeared to be very difficult based on the limited acceptable criteria occurring between NRCS ranges and ground water measurements. A single FDOT District displayed acceptable criteria based on a technical match where NRCS range occurred greater than 6.5 feet below grade. This result was considered to be poor criteria for extrapolating a District wide evaluation. The remaining Districts had ground water measurements occurring below the NRCS ranges. Application of the NRCS estimates would result in a conservative approach towards predicting ground water conditions. A more detailed expansion of the comparison study was proposed, accepted, and implemented to properly evaluate the NRCS range of ground water estimates by applying a larger statistically valid population data set.

This section attempts to answer the following questions with respect to applying the NRCS water table range of estimates:

1. Can the NRCS upper limit be used with hydraulic gradient methods to predict seasonal high ground water elevations? Preliminary considerations suggest there would be no variation in determining the rise and fall of the predicted ground water results. Applying the high or low range value would produce a persistent high or low result. Estimated hydraulic gradients would have to rely on a second ground water measurement point, either an existing public agency or a project specific installed measurement point. For example, the second ground water measurement point would have to be derived from a temporary well point or nearby public agency hydrologic station.

   For example, assuming a hypothetical Site A had a land surface elevation of 100.0 feet msl. The upper NRCS limit of 0.5 feet below grade would suggest an estimated seasonal high ground water elevation of 99.5 feet msl. Without a second measurement point, a hydraulic gradient would be difficult to estimate. In lieu of a second well point measurement, a second point B with an NRCS estimated water table at 1.5 feet below grade can be used as an arbitrary land surface elevation at 89 feet msl. The predicted seasonal high ground water would be estimated at 87.5 feet.

The second point is 1000 feet from point A. The gradient would be estimated at (99.5-87.5)/1000 ft or 0.012 ft/ft. This is a steep gradient for the water table. At point C, we know the distance to the target is 800 feet from point B in the down gradient direction x 0.012 ft/ft. The drop in ground water would be 87.5-9.6 feet or 77.9 ft msl, which would be very steep. A measurement point may produce a smaller gradient that is more reflective of true ground water table conditions. The NRCS gradient, by itself, suggests the possibility of temporary water table conditions and/or a very steep landscape.

2. Can the NRCS water table estimates be applied statewide or on a regional scale? Based on the long term data collection period, a conclusion was difficult to draw during the data collection period based on limited matching data. The expanded evaluation was conducted to provide answers.

3. Based on "normal" annual rainfall occurring 50 inches or greater, would the NRCS estimates be considered reliable for SHGWT predictions? Due to the wide variability of rainfall occurring throughout the state, some regions were considered to occur closer to normal rainfall totals. During the data collection period, many sites occurred below "normal" annual rainfall. An attempt to determine "normal" rainfall totals for each month were obtained from decade averages obtained from USClimatedata.com web site for specific cities and towns closest to well site locations. Averaged monthly rainfall totals were incorporated into Task 3C NRCS Statistical Probability Report, Appendix A (revised December 12, 2016) for comparisons with measured monthly rainfall totals.

4.2. Study Methods

Each of the water management district web-based data portals were canvassed for ground water wells representing the surficial aquifer zone within each county. A list of current surficial aquifer wells was generated along with rainfall stations positioned either at the well site or within close proximity to the well site location (*Task 3C, NRCS Statistical Probability Study Report, Appendix A*). In some instances, a review of posted ground water hydrographs had to be completed to differentiate surficial from intermediate and Upper Floridan aquifer wells. Well sites with rainfall stations were considered to be of highest quality for inclusion in this NRCS evaluation study. Many well sites did not have rainfall stations which were conveniently positioned near the well site.

The original proposal suggested the study should be limited to those counties within each FDOT District based on results obtained from the research questionnaire provided by FDOT and WMD responses obtained during Task 1.

The study was expanded to include as many wells within as many counties covering each district, selected on a randomized basis. **Table 4.0** (Page 96) summarizes the counties, and number of sites selected for this study.

Study Exceptions. Within FDOT District 3, Bay and Liberty County test sites previously reported during Task 3B were excluded from this study due to NRCS water table estimates occurring greater than 6.5 feet below grade. All sites meeting the 6.5 foot depth criteria were excluded from the study. Furthermore, no well sites were documented by NWFWMD or USGS for the upper aquifers. This caused NRCS water table range evaluations to be extrapolated based on data collected mostly from District 2. Within District 5, the Lake County pilot test site was excluded for the same reason. The NRCS estimate placed measured ground water depths at a technical match with NRCS, which tended to skew results produced by comparisons between defined NRCS ranges and measured data.

Monroe County was excluded due to lack of published soils data for the USGS wells identified in the Everglades region. Intermediate aquifer measurement data was available from the USGS or SRWMD for Alachua and Clay Counties but were excluded due to the depth of ground water conditions exceeding the NRCS soil descriptive data of 6.5 feet below grade.

Occasionally, well sites were positioned near or at soil type boundaries representing two different soil types. When this situation was encountered, the estimated water table range accounted for the highest and lowest seasonal ground water range limit by combining different soil type.

During the period occurring between August 31 and September 3, 2016, some locations experienced higher than average rainfall due to Tropical Storm Hermine for the west coast, and Hurricane Matthew for the east coast (late September). Table 1 provides a summary for the months of August and September 2016 along the coastal counties impacted by both storm events for each district with the corresponding rainfall data correlated to the ground water elevation data. Within District 2, interior counties were impacted by Hermine moving across the state from the Gulf to the Atlantic Ocean. A direct correlation between heavy rainfall events and elevated ground water responses occurred with the NRCS ranges were limited to individual sites. Extrapolation to a district wide or statewide basis would not be recommended.

Table 4.0. District Rainfall Measurement vs. Ground Water Response Summary

District	County	Rainfall measurement	Ground water Response
1	Desoto	> Average rainfall	>NRCS upper limit
	Manatee	< average rainfall	= NRCS limits
2	Taylor	➢ Average rainfall	<NRCS lower limit
	Gilchrist	< Average rainfall	<NRCS lower limit
	Lafayette	< average rainfall	< NRCS lower limit
	Columbia	< average rainfall	= NRCS limits
	Dixie	< average rainfall	= NRCS limits
	Baker	➢ Average rainfall	➢ NRCS upper limit
	Bradford	< average rainfall	< NRCS lower limit
	Levy	< average rainfall	< NRCS lower limit
	Nassau	< average rainfall	< NRCS lower limit
4	Martin	< average rainfall	< NRCS lower limit
	Palm Beach	< average rainfall	<NRCS lower limit
5	Sumter	< average rainfall	<NRCS lower limit
	Flagler	< average rainfall	< NRCS lower limit
	Brevard	< average rainfall	<NRCS lower limit
	Volusia	<average rainfall	< NRCS lower limit
6	Miami	< average rainfall	< NRCS lower limit
7	Citrus	>average rainfall	< or = NRCS limit
	Hillsborough	➢ Average rainfall	➢ NRCS limit
	Pasco	< average rainfall	< NRCS lower limit
	Pinellas	< average rainfall	➢ NRCS upper limit

4.3. Data Collection Procedures

1) Hydrologic stations were randomly selected from public agency data sources. Preference was given to ground water stations within each FDOT District (minimum of 5 stations per district set in different counties, but more where abundant ground water station data existed). Each of the water management districts and the USGS were canvassed to identify and select wells positioned in the surficial (water table) aquifer. Intermediate and Florida aquifer wells were ignored due to the lower elevations typically accompanying deeper aquifer conditions. NRCS soils data is restricted to the upper 6.5 feet.

2) The NRCS web site was used as the source for obtaining the water table data for each hydrologic station location. Land surface elevations for each well site location was obtained from WMD, USGS descriptive data, or Google Earth for each well site location.

3) Rainfall and ground water measurement data covering the same time period as the research study between January 2015 and October 2016. The NRCS definition of seasonal high ground water coincided with the summer months that occurred between June and September.

4) Direct ground water measurements were compared against NRCS estimates for establishing acceptable, above, and below seasonal high ground water error criteria. Rainfall stations were used to establish “normal” patterns that occurred on a monthly basis during the summer season to determine whether or not rainfall exerted a role in influencing the NRCS water table intervals. The ultimate goal of this study was to establish whether or not the NRCS water table estimates could be implemented statewide or regionally.

NRCS Definition of a Seasonal High Ground Water Table. The NRCS defines seasonal high saturation *“as the highest level to a zone of saturation in the soil that occurs in most years. A seasonal high saturation normally persists for several weeks, normally occurring during the time of year when the most rain falls (June through September in Florida)”.* Water tables that are seasonally high for less than 30 days are not indicated in the Soil and Water features table within the soil surveys. The USDA NRCS uses a 30 day criteria to judge SHWT for ranges present in the soil surveys. For any well site meeting the NRCS definition during any month of the two year data collection period, the site was categorized as matching the acceptable criteria between NRCS and measured data.

Restricted layers were present in some soil profiles suggesting temporary water table conditions may be present due to the presence the following soil classes: fine sandy loam, loamy sand, or sand clay loam In the upper 6.5 feet of the soil profile. Loamy textures are defined by the presence of sand, silt, and clay mixtures in varying percentages.

4.4. NRCS Water Table Range Evaluation.

Sites exhibiting restricted soil types suggest NRCS water table ranges represented temporary conditions (perched or hanging water tables). Occasionally, NRCS applied other indicators to arrive at an estimated range (e.g. gray or white soil horizons, or soil mottling features).

Temporary water tables were identified in this study by the presence of restrictive soil types and ground water measurements occurring above the upper NRCS estimated range.

The Landscape Classification summary provided in **Table 4.1** applied the following definitions to each category: accepted is defined by ground water measurements falling within the estimated NRCS upper and lower range of values; above is defined by ground water measurements occurring greater than the upper NRCS range limit; and below is defined by ground water measurements occurring less than the lower NRCS range limit.

A total of 170 ground water measurement sites representing ground water wells within the surficial aquifer zone were evaluated for comparisons with the NRCS seasonal water table ranges statewide (except District 3). Each site was characterized by the presence or absence of restrictive soil types including loams, silts, and clays which would tend to form slowly percolating zones within the upper 6.5 feet of the soil profile. Slow drainage zones would also tend to form temporary water table conditions.

In addition, landscape classifications contained within the NRCS soil profile descriptions were also included in the Task 3C report, Appendix A ground water measurement tables. The more common types of landscapes included North and South Florida Flatlands, sand hills, sands in depressions, sandy loams and clays, and urban landscapes. Landscape classification may yield indicators of restrictive soil types along with soil profile descriptions. Where the term “no data” was entered into the table, the site could not be located on the hydrologic station district map for the month of September 2016.

Test sites were selected randomly from each county within each district. Wells set within the intermediate and upper Floridan aquifer were systematically excluded based on ground water measurements occurring below the NRCS water table range of depth.

Table 4.1. Ground Water Measurement Site Tabulation

District	County	No of Well Sites	No. with Restrictive Soils	Accepted	Above	Below
1	Charlotte	1	0	1	0	0
	Collier	3	3	0	0	3
	DeSoto	1	0	1	0	0
	Hardee	8	2	1	7	0
	Highlands	2	0	1	0	1
	Lee	4	1	0	0	4
	Manatee	2	0	0	2	0
	Polk	3	1	0	2	1
	Sarasota	2	2	0	1	1
	Totals	**26**	**9**	**4**	**12**	**10**
District	Alachua	1	1	0	0	1
2	Baker	1	0	1	0	0
	Bradford	2	1	1	0	1
	Clay	3	1	0	0	3
	Columbia	1	0	0	0	1
	Dixie	3	2	2	0	1
	Duval	5	2	1	0	4
	Gilchrist	1	0	0	0	1
	Lafayette	3	1	0	0	3
	Levy	3	1	0	0	3
	Madison	1	0	0	0	1
	Nassau	7	1	2	0	5
	Putnam	7	1	1	0	6
	St. Johns	7	3	2	0	5
	Suwannee	1	1	0	0	1
	Taylor	2	0	0	0	2
	Union	1	0	0	0	1
	Totals	**49**	**15**	**10**	**0**	**39**
District 3	no	ground	water	data		
District	Broward	6	3	1	0	5
4	Martin	3	0	2	0	1
	Palm Beach	2	0	0	0	2
	St. Lucie	1	1	1	0	0
	Indian River	2	0	0	0	2
	Totals	**14**	**4**	**4**	**0**	**10**
District	Brevard	3	2	1	0	2
5	Flagler	9	3	0	2	6
	Lake	7	2	1	3	3

District	County	No of Well Sites	No. with Restrictive Soils	Accepted	Above	Below
	Seminole	1	0	0	0	1
	Sumter	8	5	0	3	6
	Volusia	8	4	3	0	5
	Osceola	3	**0**	1	**0**	**2**
	Totals	**39**	**16**	**6**	**8**	**25**
District	Miami Dade	11	9	9	0	2
6	**Totals**	**11**	**9**	**9**	**0**	**2**
District	Citrus	3	0	1	1	1
7	Hernando	4	0	2	0	2
	Hillsborough	8	0	4	1	3
	Pasco	10	3	5	1	4
	Pinellas	6	0	3	2	1
	Totals	**31**	**3**	**15**	**5**	**11**
Project Totals		**170**	**56**	**48**	**25**	**97**

4.5. Landscape Classification Effects

Landscape classifications were obtained from NRCS soil profile descriptions provided for each well site location. In the event the user is interested in determining landscape type for seasonal high ground water evaluation purposes, the NRCS soil profile data sheet is the primary reference source for this information. **Table 4.1** presents a summary of landscape type by district represented by well site locations. The designation 8/3R is defined as a total of 8 sites met the category listed in the column heading with 3 sites out of the total representing restrictive soil types for the specified landscape type.

Table 4.2. Landscape Type Classification Tabulation

District	Landscape Type	No of Well Sites	Accepted	Above	Below
1	S. FL Flatwoods	16	1	11/3R	4/3R
	Sand Pine Scrub	2	1	1	0
	Sloughs	1	0	1/1R	0
	Longleaf Pine hills	1	0	0	1
	Urban settings	2	0	1	1
	Sands on Rises	1	0	0	1/1R
	Sands/loams in depressions	3	0	0	3/1R
	Totals	**26**	**2**	**14/4R**	**10/5R**

District	Landscape Type	No of Well Sites	Accepted	Above	Below
District	N FL Flatwoods	10	2/1R	1	7/1R
2	S FL Flatwoods	2	0	0	2
	Longleaf Pine Hills	2	0	0	2
	Upland hardwoods	1	0	0	1
	Sands on flatlands	11	2/1R	0	9/2R
	Sands on rises	8	2	1	5/3R
	Sandy hills	1	0	0	1
	Sands in depressions	2	0	0	2/1R
	Sand and loams on flatlands	5	1/1R	0	4/3R
	Sand Pine Scrub	1	0	0	1
	Sands & loams in depressions	2	1/1R	0	1/1R
	Sands & organics in depressions	1	0	0	1
	Loams & clays on flatlands	1	0	0	1
	Organics in depressions	1	0	1/1R	0
	Salt marsh tidal	1	1	0	0
	Totals	**49**	**9**	**3/1R**	**37/11R**
District 3	no	Ground water	data		
District					
4	S FL Flatwoods	7	3/1R	0	4/1R
	Sand pine scrub	1	1	0	0
	Sands on flatlands	1	0	0	1
	Sands & loams on flatlands	1	0	0	1
	Loams and clays on flatlands	1	0	0	1/1R
	Urban settings	3	0	0	3/1R
	Totals	**14**	**4/1R**	**0**	**10/3R**
District	S FL Flatwoods	24	6/2R	5/2R	13/3R
5	Sands on ridges	1	0	0	1
	Upland hardwood hammocks	3	0	0	3/2R
District	**Landscape Type**	**No of Well Sites**	**Accepted**	**Above**	**Below**
	Sands on flatlands	2	0	1	1
	Urban settings	2	0	1	1/1R
	Sands & loams in depressions	1	0	1	0
	Sand pine scrub	1	0	0	1
	Salt marsh	1	0	0	1/1R
	Sands & loams on flatlands	2	1	0	1/1R
	Organics in depressions	1	0	0	1/1R
	Sands in depressions	1	0	0	1/1R
	Totals	**39**	**7/2R**	**8/2R**	**24/10R**

District	Landscape Type	No of Well Sites	Accepted	Above	Below
District	Urban	7	4/3R	1/1R	2/2R
6	Loams & clays on flatlands	1	1/1R	0	0
	Sands & loams on ridges	3	2/2R	1/1R	0
	Totals	**11**	**7**	**2**	**2/2R**
District	North FL Flatwoods	1	1	0	0
7	S. FL Flatwoods	15	8/1R	2	5/1R
	Sands on flatlands	4	2/1R	1/1R	1
	Longleaf Pine Hills	1	0	0	1
	Sands on terraces	2	0	1	1
	Urban settings	6	4	2	0
	Sand pine scrub	1	0	1	0
	Sand & loams on flatlands	1	0	0	1/1R
	Totals	**31**	**15**	**7/1R**	**9/2R**
Project Totals		**170**	**44**	**34/8R**	**92/33R**

4.6. NRCS Method Statistical Evaluation

The following tables present probabilities for achieving prediction categories by District and landscape type. Based on the research interview questionnaire results provided by FDOT and water management districts (Task 1), the most problematic issues were focused on the North and South Florida Flatwoods, urbanized settings, and landscape depressions. Landscape depression types were assumed to represent karst type conditions filled in by collapsed soil layers. Sand hills were also identified as a problem landscape type.

Application of the NRCS method would be most likely effective for predicting conservative seasonal high ground water conditions for most landscape types within each of the districts. The results produced by this study are intended for general guidelines only and are based solely on statistical probabilities.

District 1. District-wide application of the NRCS water table method produced a 7% acceptable prediction when compared to the measured ground water tables, which represented the seasonal high ground water conditions during the summer months occurring between June and September. The probability of producing an overestimation of the seasonal high ground water conditions was estimated at 54%; 38% for an underestimation of the seasonal high ground water conditions.

When combining the acceptable and underestimation categories, the likelihood of obtaining a conservative prediction for seasonal high ground water conditions increases to 45%. It is estimated that 15% of the seasonal ground water sites will exhibit temporary water table conditions.

Table 4.3. District 1 NRCS Probability Evaluation Table 2015-2016

Landscape Classification	Acceptable Prediction	Overestimated Prediction	Underestimated Prediction	Conservative Prediction	Temporary WT Prediction
District 1 Region	**7%**	**54%**	**38%**	**45%**	**15%**
So Florida Flatwoods	6%	68%	25%	31%	19%
Longleaf Pine Hills (1)	0	0	100%	100%	0
Urban	0	50%	50%	50%	0
Sand pine scrub	50%	50%	0	0	0
sands on rises (1)	0	0%	100%	100%	100%
sands & loams in depressions	0	0	0%	100&%	100%
Sloughs (1)	0	100%	0	0	100%

(1) insufficient data to properly evaluate. Probability based on a single site.

For the **South Florida Flatwoods** landscape, a 6% acceptable prediction was estimated; a 68% overestimation prediction; a 25% underestimated prediction; and, a 31% conservative prediction with 19% resulting in temporary water table conditions. **Urbanized settings** resulted in no acceptable predictions; 50% over estimation and 50% underestimation, with a 50% conservative prediction result. Temporary water table conditions did not appear to exist for this landscape type.

The third category, **sands and loams in depressions** produced 100% underestimated predictions with a 100% probability of producing a conservative prediction using the NRCS method.

South Florida Flatwoods appear to be the most problematic landscape type for predicting seasonal high ground water conditions as described by water management districts within the District 1 region.

There appears to be a 31% probability of achieving a conservative prediction using the NRCS method. There is a 68% chance of overestimating the seasonal high ground water using this method and a 19% chance that temporary water table conditions will be present.

Urban settings also appear to present difficulties with a 50% chance of producing a conservative prediction and a 50% chance of overestimating the seasonal high ground water condition by applying this method. Sands on rises could not be evaluated due to the lack of ground water sites within this landscape.

District 2. District-wide results produced an 18% acceptable prediction; a 6% overestimation; and, a 76% underestimation of the seasonal high ground water condition; corresponding to 94% conservative predictions. Approximately 2% of the sites supported evidence of temporary water table conditions. North and South Florida Flatwoods were evaluated for this District.

Table 4.4. District 2 NRCS Probability Evaluation Table 2015-2016

Landscpe Class'n	Acceptable Prediction	Overestimated Prediction	Underestimated Prediction	Conservative Predictioo	Temporary WT Prediction
District 2	18%	6%	76%	94%	2%
So Florida Flatwoods	0	0	100%	100%	0
North Florida Flatwoods	20%	10%	70%	90%	10%
Longleaf Pine Hills	0	0	100%	100%	0
upland hardwood hammocks (1)	0	0	100%	100%	0
Sand pine scrub (1)	0	0	100%	100%	0
sands on rises	25%	13%	63%	88%	0
sands on flatlands	18%	0	82%	100%	9%
sands/loams on flatlands	20%	0	80%	100%	20%
loams & clays on flatlands (1)	0	0	100%	100%	0
sandy hills (1)	0	0	100%	100%	0
sands in depressions	0	0	100%	100%	50%
sands/organics in depressions (1)	0	0	100%	100%	0
sands & loams in depressions	50%	0	50%	100%	50%
organics in depressions (1)	0	100%	0	0	100%
salt marsh (1)	100%	0	0	100%	0

North Florida Flatwoods had a 20% acceptable prediction probability; a 10% overestimation prediction; a 70% underestimation prediction; and, a 90% conservative prediction with 10% supporting temporary water table conditions.

South Florida Flatwoods did not produce acceptable results.

Approximately 100% of sites produced underestimated prediction results which translated into 100% of conservative predictions when the NRCS method is applied. Temporary water table conditions were absent. **Sands on rises** produced 25% acceptable predictions; 13% overestimated predictions; 63% underestimated conditions; and, 88% conservative predictions. Temporary water table conditions were absent.

Sands and loams in depressions resulted in probabilities of 50% acceptable predictions; 50% underestimated predictions; and, 100% conservative predictions with 50% supporting conditions for a temporary water table.

District 3. Public agency ground water measurement sites established in the upper soil zone represented by NRCS soil data were absent from the district.

An assessment could not be established based on measured data. Extrapolation of NRCS results obtained from District 2 were used to produce a district-wide probability map along with other sources. Section 4.7 presents a discussion.

District 4. Throughout the district, there was a 29% acceptable prediction probability; 71% underestimation prediction; and, a 100% conservative prediction with 7% of sites supporting temporary water table conditions.

Table 4.5. District 4 NRCS Probability Evaluation Table 2015-2016

Landscpe Class'n	Acceptable Prediction	Overestimated Prediction	Underestimated Prediction	Conservative Prediction	Temporary WT Prediction
District 4	**29%**	**0**	**71%**	**100%**	**7%**
So Florida Flatwoods	43%	0	57%	100%	14%
Urban	0	0%	100%	100%	33%
Sand pine scrub (1)	100%	0	0	100%	0
sands on flatlands (1)	0	0	100%	100%	0
sands/loams on flatlands (1)	0	0	100%	100%	0
loams & clays on flatlands (1)	0	0	100%	100%	100%

South Florida Flatwoods resulted in a 43% acceptable prediction result; underestimated predictions were absent; and, a 100% conservative predictions when applying the NRCS method. Approximately 14% of sties supported temporary water table conditions. **Urban settings** provided no acceptable results; overestimated predictions were absent; 100% underestimated predictions; and, 100% conservative prediction results. Temporary water table conditions were represented by 33% of sites. There were not enough sites represented by the remaining landscape types to evaluate properly.

District 5. Throughout the District, 18% of sites met the acceptable prediction category; 21% of sites fell within the overstated prediction category; 62% met the underestimated prediction category; and, 80% occurred within the conservative prediction category. Approximately 5% of sites met the temporary water table condition category.

Table 4.6. District 5 NRCS Probability Evaluation Table 2015-2016

Landscpe Class'n	Acceptable Prediction	Overestimated Prediction	Underestimated Prediction	Conservative Prediction	Temporary WT Prediction
District 5	**18%**	**21%**	**62%**	**80%**	**5%**
So Florida Flatwoods	25%	21%	54%	79%	8%
upland hardwood hammocks	0	0	100%	100%	0
Urban	0	50%	50%	50%	0
Sand pine scrub (1)	0	0	100%	100%	0%
sands on flatlands	0	50%	50%	50%	0
sands/loams on flatlands	50%	0%	50%	100%	50%
Sands on ridges (1)	0	0	100%	100%	0
sands in depressions (1)	0	0	100%	100%	100%
sands & loams in depressions (1)	0	100%	0	0	100%
organics in depressions (1)	0	0	100%	100%	0
salt marsh (1)	0	0	100%	100%	100%

South Florida Flatwoods resulted in a 25% probability of acceptable predictions; 21% occurred within the overestimation prediction category; 54% occurred within the underestimated predictions; and, 79% occurred within the conservative prediction categories. Temporary water table conditions made up 8% of sites. **Urban settings** had no acceptable predictions; 50% had overestimated predictions; 50% had underestimated predictions; and, 50% had conservative predictions. The remaining landscape types did not have sufficient numbers of sites to adequately assess probabilities.

District 6. District-wide, 64% of sites met the acceptable prediction category; 18% occurred in the overestimated prediction category; 18% had underestimated predictions; and, 82% had conservative predictions with no sites that supported temporary water table conditions.

Table 4.7 District 6 NRCS Probability Evaluation Table 2015-2016

Landscape Classification	Acceptable Prediction	Overestimated Prediction	Underestimated Prediction	Conservative Prediction	Temporary WT Prediction
District 6	**64%**	**18%**	**18%**	**82%**	**0%**
Urban	57%	14%	29%	86%	43%
sands & loams on ridges	66%	33%	0%	66%	66%
loams/clays on flatlands (1)	100%	0	0	0	100%

Urban settings produced a 57% probability of acceptable prediction results; 14% probability of overestimating seasonal high ground water conditions; 29% of underestimating seasonal high conditions; and, an 86% of estimating conservative predictions. Temporary water table conditions accounted for 43% of sites evaluated.

Sands and loams on ridges resulted in 66% of sites had acceptable predictions; 33% had overestimated predictions; no were underestimated; and, 66% of the sites had conservative predictions. Temporary water table conditions accounted for 66% of the sites.

District 7. Throughout the district, 48% of results had acceptable predictions; 23% occurred within the overestimated prediction category; 29% had underestimated predictions; and, 77% had conservative predictions. Temporary water table conditions were supported by 3% of the sites.

Table 4.8. District 7 NRCS Probability Evaluation Table 2015-2016

Landscape Classification	Acceptable Prediction	Overestimated Prediction	Underestimated Prediction	Conservative Prediction	Temporary WT Prediction
District 7	**48%**	**23%**	**29%**	**77%**	**3%**
So Florida Flatwoods	53%	13%	33%	86%	7%
North Florida Flatwoods (1)	100%	100%	0	0	0
Longleaf Pine Hills (1)	0	0	100%	100%	0
Urban	67%	33%	0	0	0
Sand pine scrub (1)	0	100%	0	0	0
sands on flatlands	50%	25%	25%	75%	25%
sands/loams on flatlands (1)	0	0	100%	100%	0
sands on terraces	0	50%	50%	50%	0

North Florida Flatwoods could not be properly evaluated due to the presence of a single ground water site representing this landscape type. **South Florida Flatwoods** had an acceptable prediction rate of 53%; 13% of the sites were overestimated; 33% were underestimated; and, 86% had conservative predictions. Temporary water table conditions were represented by 3% of the sites. **Urban settings** resulted in 67% of the sites meeting acceptable predictions; 33% being overestimated; no sites were underestimation which would correspond to 100% of the sites producing conservative predictions. Temporary water table conditions were absent.

Sands on flatlands presented a 50% acceptable prediction; 25% overestimated prediction; 25% underestimated prediction; and, 75% conservative prediction. Temporary water table conditions accounted for 25% of the sites. **Sands on terraces** represented no acceptable predictions; 50% overestimation; 50% underestimation; and 50% conservative predictions. Temporary water table conditions were absent.

4.7. NRCS Evaluation Analysis and Guide Maps.

A series of questions occurred recurrently throughout the data collection review process following submittal of quarterly status reports. These questions are presented below with responses based on the study's results.

Can the NRCS upper limit be used with hydraulic gradient methods to predict seasonal high ground water elevations? Yes.

Under circumstances where the NRCS range meets the acceptable criteria or occurs below the published soil range, the hydraulic gradient method may be applied using the NRCS limits to establish a conservative seasonal high ground water table conditions. The application of this method would require the user to establish an estimated hydraulic gradient representing the seasonal high ground water condition for the target site. Land surface elevation must be known to confirm seasonal high ground water measurements do not occur above grade. This situation was a problem which emerged during the data collection of ground water measurement data for some sites selected for this study. Elevation discrepancies were resolved by either satellite imagery obtained through Google Earth or by confirming surveyed elevation data reported by the public agency source.

For example, if a specific soil type had a depth to ground water range occurring between 0.5 to 1.5 feet below grade, and two selected locations show land surface elevations of 101 ft msl and 95 ft msl, the hydraulic gradient method could be applied. The upper NRCS range would place Site A at a SHWT elevation of 100.5 ft msl. At Site B, ground water elevation would occur at an elevation of 94.5 ft msl. Knowing the distance between the two sites (e.g. 1000 ft), an estimated ground water gradient could be established (100.5 -94.5)/1000 = 0.006ft/ft. If the target point was positioned down gradient from Site B at 360 ft, then the predicted SHWT would be 2.16 feet lower than Site B, or 92.34 ft msl. The same method may be applied for a fixed ground water measurement replacing the Site B data point.

In the event the upper NRCS range value was the sole source of seasonal ground water prediction under circumstances where ground water measurement data either met the acceptable or underestimated prediction criteria (i.e. occurred below the lower NRCS range limit), a conservative prediction of seasonal high ground water condition would be generated. The problem with applying this technique falls on the accuracy in estimating the hydraulic gradients using a second known location source to determine a proper gradient.

The source may appear in the form of qualitative sources (upper gray or white depleted soil zones), SPT density values substantiated by a confirmation data source, temporary piezometers, or public agency seasonal ground water measurement data. These sources may or may not produce a sufficient gradient representing the true ground water slope, unless there was a second source of ground water measurement to validate the use of qualitative sources for making the gradient determination.

Can the NRCS water table estimates be applied statewide or on a regional scale? Yes.

A set of maps were developed which may help to identify areas where the NRCS range method would produce acceptable and/or conservative prediction methods, and where overestimation and /or temporary ground water conditions may occur.

Maps were compiled based on three data sources: ground water probability data compiled from the *Task 3C NRCS Statistical Probability Report*, Appendix B tables; the Florida Aquifer Vulnerability Assessment (FAVA) environmental geology map showing sand, clay, and limestone exposures covering the state; and, the Florida aquifer map published by the Florida Geological Survey.

The following set of maps should be used as guidelines for evaluating the NRCS method for predicting seasonal high ground water tables. The maps are based on statistical probabilities (Section 4.6) established from 170 known measurement sites scattered statewide throughout the seven FDOT districts. Where probabilities exist for the presence of temporary water table conditions, normal ground water depths will typically occur at a deeper interval separated from a perched or hanging water table condition by an unsaturated zone.

District 1. District 1 is estimated to have a 45% probability of generating acceptable and/or conservative seasonal high ground water conditions when applying the NRCS method. A 55% probability exists for generating overestimated seasonal high ground water conditions with temporary water tables present.

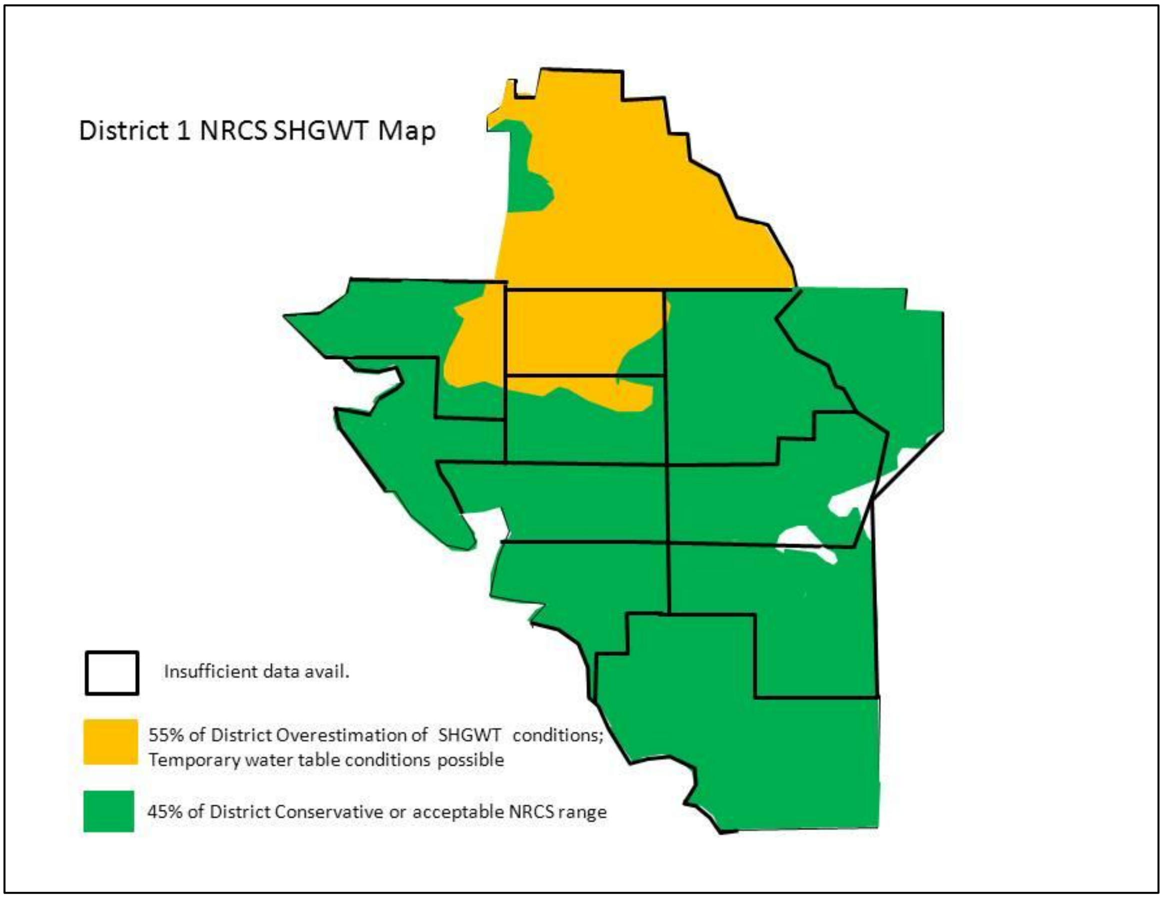

Figure 1. District 1 NRCS probability map showing most of Polk and Hardee County with conditions suitable for temporary water table conditions, or achieving overestimated ground water conditions due to restrictive soil types. The remaining region suggests a high probability of achieving acceptable to conservative seasonal high ground water conditions when applying the NRCS water table ranges as a method.

District 2. The District is estimated to generate a 94% probability of acceptable and/or conservative predictions of seasonal high ground water conditions. Approximately 6% of seasonal high ground water conditions are anticipated to generate an overestimated prediction accompanied by temporary water table conditions.

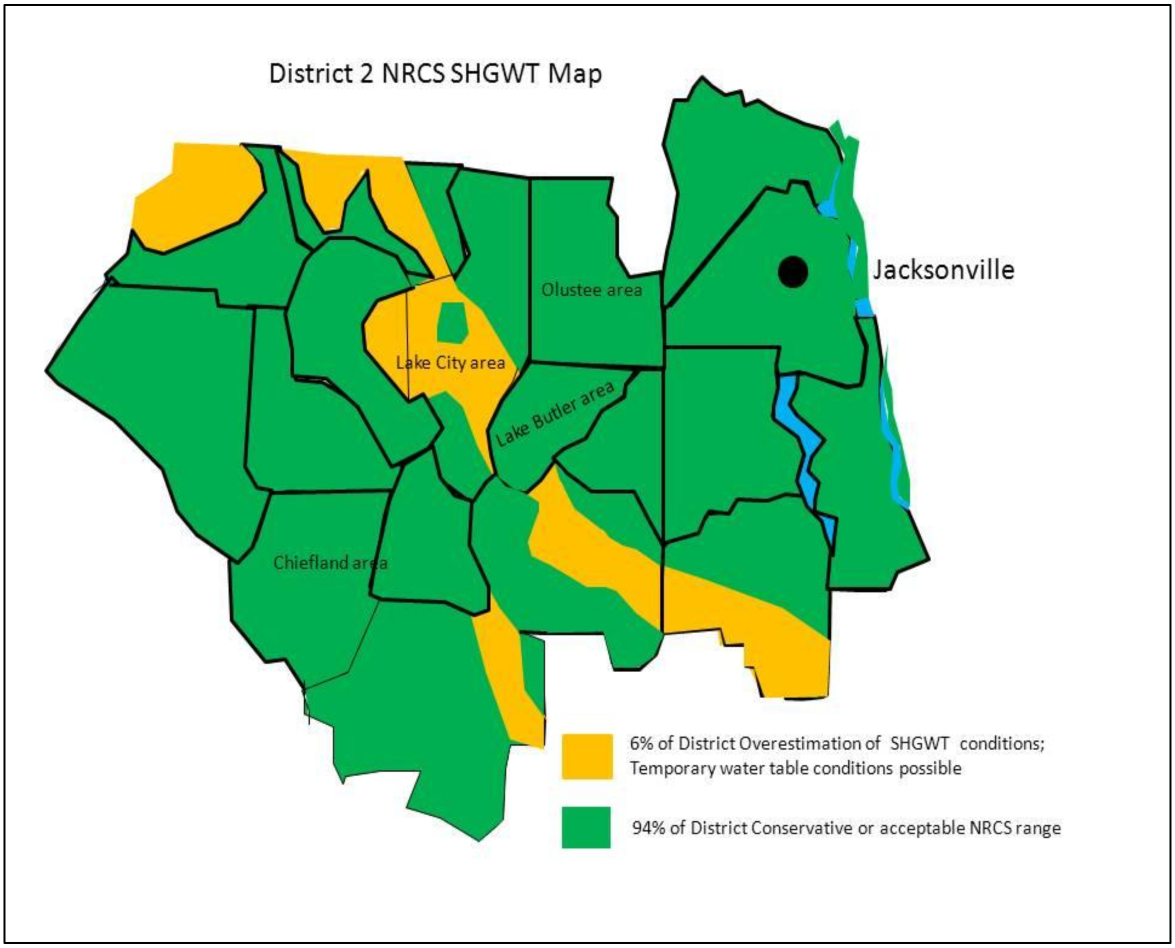

Figure 2. Probabilities of encountering temporary water table conditions are restricted to areas located within northwestern Madison County, Hamilton, central Lake, central Putnam, and southern Flagler are likely to be present beneath ridges supported by clays. Although the map indicates a high percent probability of NRCS acceptable to conservative predictions, for the counties surrounding the orange areas, thick clays a high probability exists shallow clays will continue to produce temporary water table conditions. Coastal counties are more likely to exhibit water table conditions than counties occupying inland areas.

District 3. The map presented from District 3 was compiled from similar conditions present within District 2 due to the absence of shallow ground water well data availability. Public agency data was available for the intermediate clay and Upper Floridan aquifer zones, which is too deep for evaluating shallow NRCS soil profile data. The northern part of the District is supported by sandy clays and clays which tend to create overestimated prediction results due to temporary water table conditions. The coastal plain region is mostly underlain by permeable sands which tend to promote water table development which either produces acceptable or conservative predictions of seasonal high ground water conditions when the NRCS method is applied.

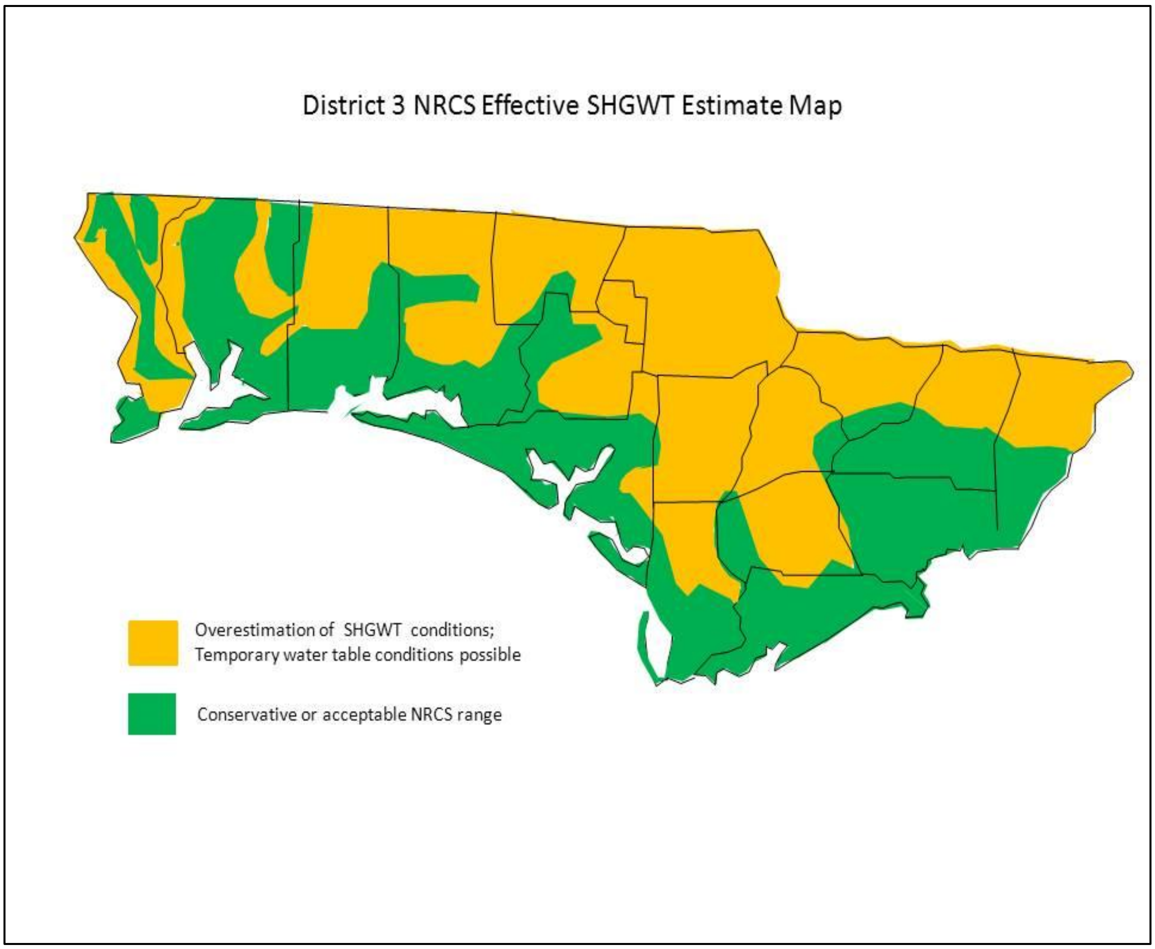

Figure 3. The northern hilly parts of the district have a high probability of producing overestimated seasonal high ground water conditions and temporary water table conditions. Floodplains, intervening valleys, and coastal plains tend to have higher probabilities for meeting acceptable or conservative seasonal high ground water conditions using the NRCS estimates.

District 4. Within the urbanized portions of the District, there is a 100% probability of generating acceptable and/or conservative seasonal high ground water conditions. The western part of the District is underlain by thick deposits of peat which tend to create overestimated predictions for seasonal high ground water due to the presence of temporary water table conditions. A percentage could not be established based on a lack of ground water measurement data for these special conditions.

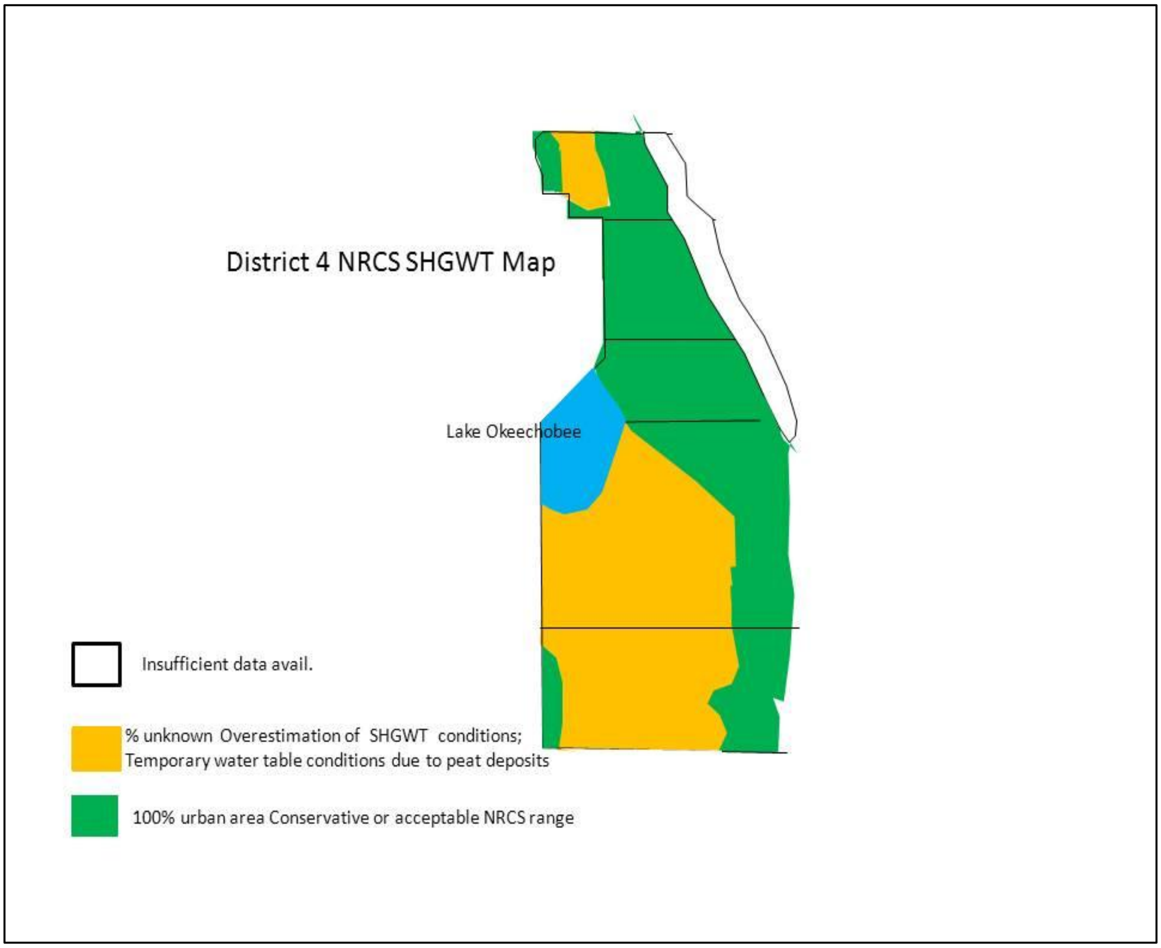

Figure 4. Western Palm Beach and Broward Counties have a higher probability of achieving temporary water table conditions due to high organic soil types. The western part of Indian River County was considered to have a high probability of temporary and overestimated ground water conditions. The urbanized portions of the district occupying the eastern parts were considered to have the higher probability of acceptable and conservative predictions when the NRCS method is applied.

District 5. The District 5 region was estimated to generate approximately 80% acceptable to conservative prediction results for seasonal high ground water conditions with a 20% probability of overestimating seasonal high ground water conditions with temporary water tables present.

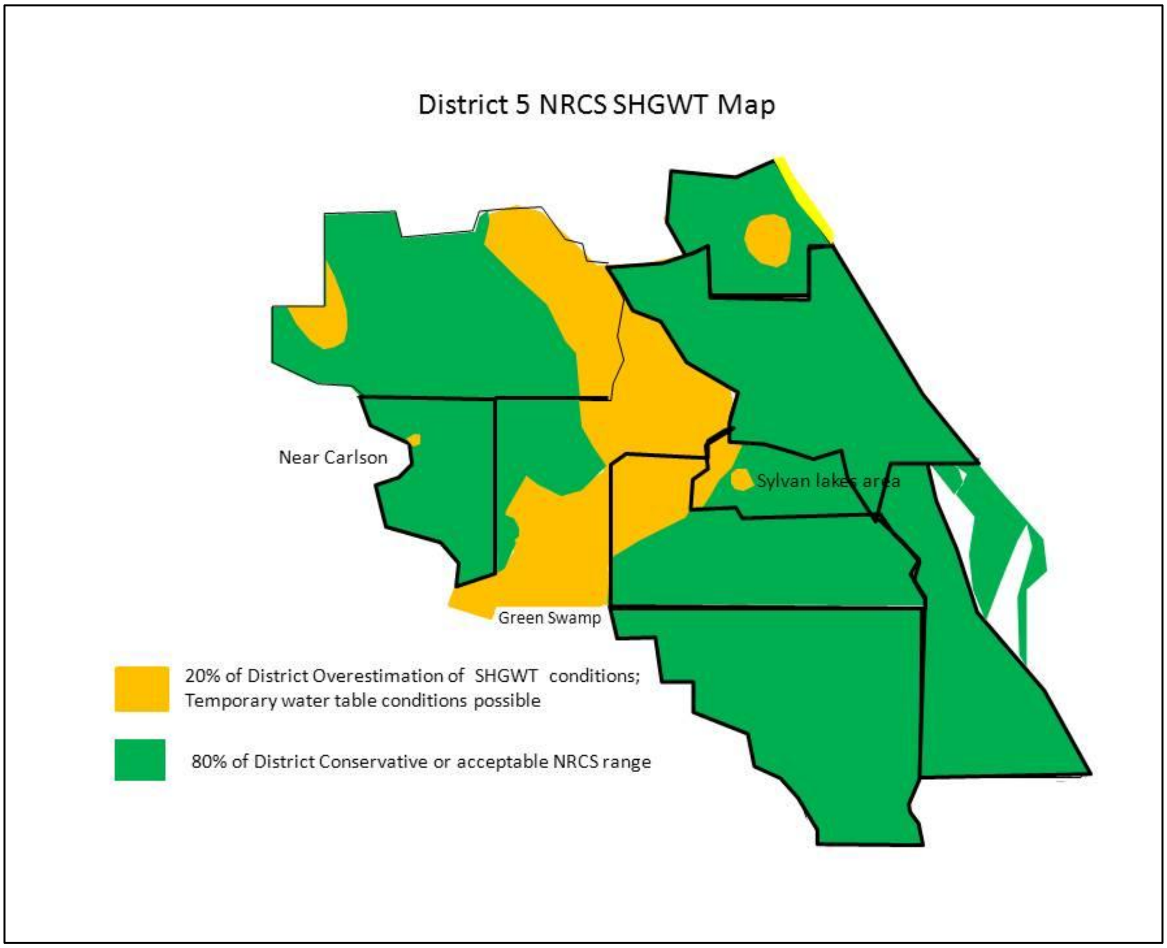

Figure 5. Hilly regions within eastern Marion, northeastern and southern Lake, and northwestern Orange Counties are areas where temporary water table and overestimated seasonal ground water conditions are likely to appear. The remaining low lying areas have a high probability of acceptable and conservative prediction results when the NRCS method is applied by comparing with ground water measurements.

District 6. Within the urbanized settings of the district, there is an 82% probability of the estimate for achieving acceptable and/or conservative seasonal high ground water predictions through application of the NRCS method. An 18% probability exists for generating overestimated seasonal high conditions with temporary water table conditions being present.

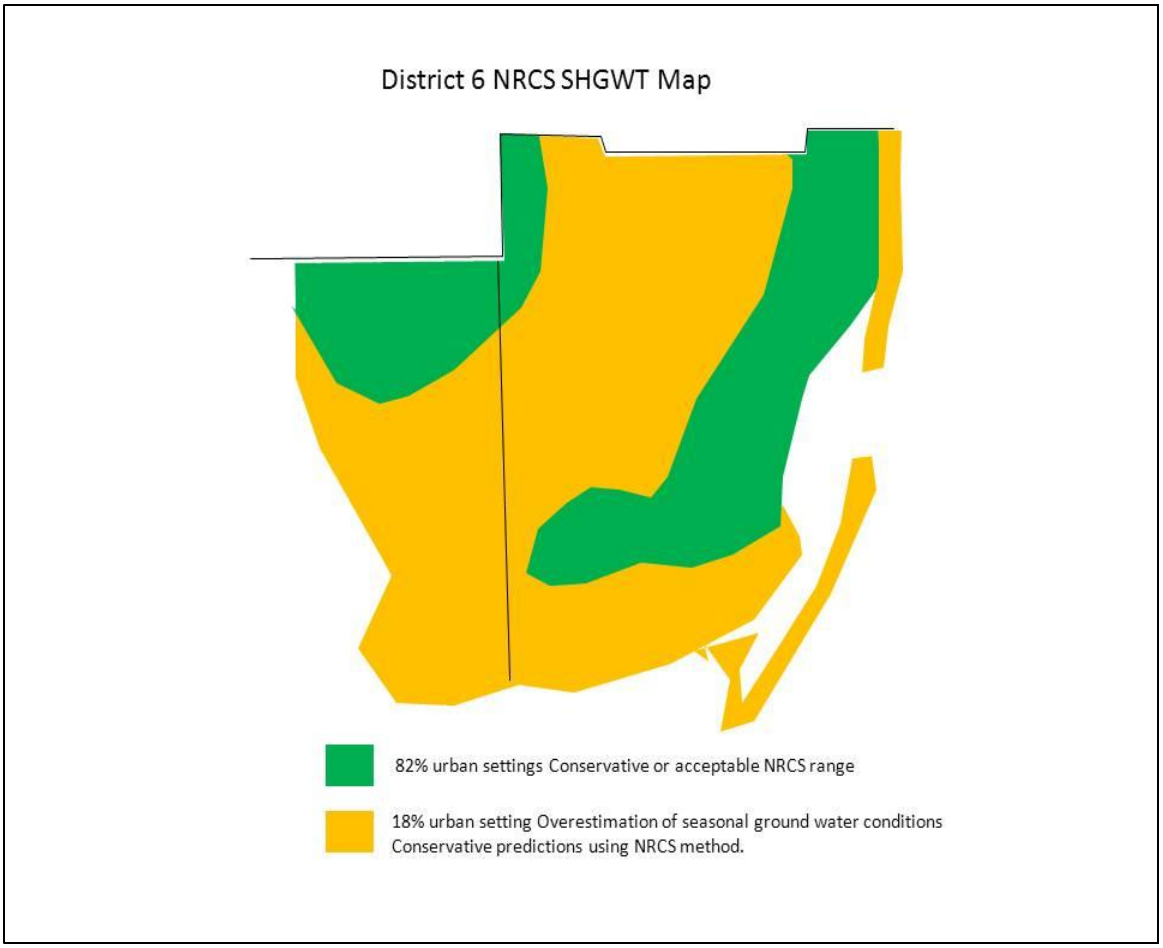

Figure 6. The urbanized areas of Miami Dade County and northeastern Monroe Counties exhibit the highest probabilities of encountering acceptable to conservative seasonal high ground water predictions. The remaining areas appear to be subjected to overestimated seasonal high ground water and temporary ground water conditions when the NRCS method is compared with ground water measurements.

District 7. District-wide, a 77% probability exists for acceptable to conservative results of seasonal high ground water conditions through application of the NRCS method. A 23% probability exists for producing overestimated seasonal high ground water conditions with temporary water table conditions being present.

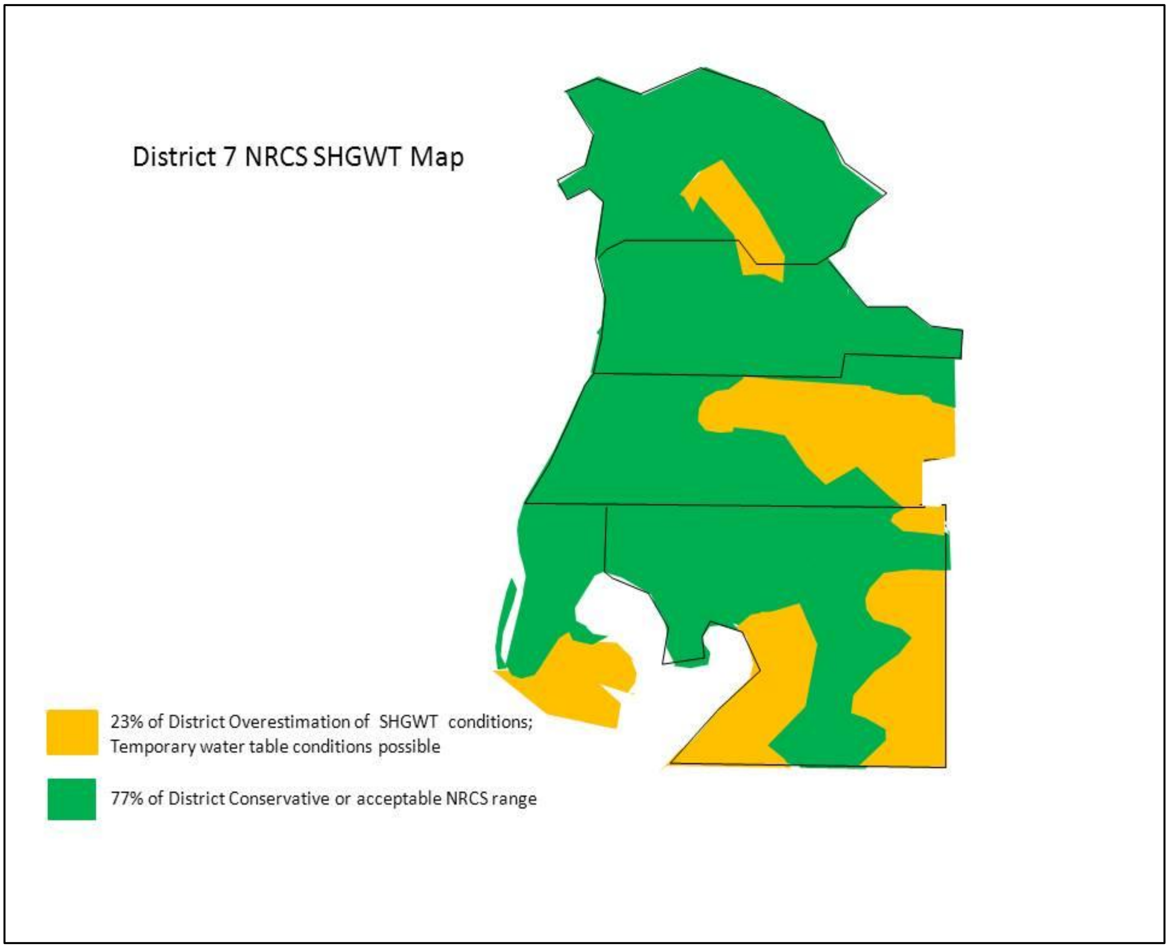

Figure 7. Hilly areas along the Brooksville Ridge in south central Citrus and north central Hernando Counties, and eastern Pasco County are likely to produce temporary water table and overestimated ground water conditions. Eastern Hillsborough is underlain by Bone Valley clays which limit vertical infiltration, resulting in temporary water conditions. Southern Hillsborough and southern Pinellas Counties are characterized by silts and clays deposited from the former Tampa Bay estuaries, likely to result in temporary or overestimated seasonal high ground water conditions.

Based on "normal" annual rainfall occurring 50 inches or greater, would the NRCS estimates be considered reliable for NRCS SHGWT applications?

An attempt was made to clarify and further define "normal" rainfall during this study. Each district was evaluated for both ground water measurements and rainfall stations where data existed close to each other.

The intent was to establish whether or not rainfall had a direct correlation to ground water elevation especially during seasonal periods. To establish "normal" rainfall conditions, averaged rainfall data from the nearest city was collected during the period between 1998 and 2010 by NOAA (usclimatedata.com), and the National Weather Service (weathercollectordb.com). The results of this analysis are presented in Section 4.8.

4.8. Seasonal Rainfall and Ground Water Response.

Both the rainfall station measurement data and average rainfall data were compared monthly during the seasonal monthly collection period (2015 and 2016) to evaluate matching, above, and below rainfall trends. The objective was to review rainfall patterns covering the seasonal months for correlation with seasonal ground water influences. In **Table 4.2**, rainfall stations were compared with ground water measurements for several counties within the districts to identify "normal" rainfall and ground water interactions when compared with the NRCS water table ranges. These descriptive categories are defined in the same manner as described previously.

Five counties were evaluated for **District 1**. There appeared to be a correlation between "normal" and above average rainfall and NRCS predictions meeting or greater than the acceptance criteria (i.e. Conservative).

Thirteen counties were evaluated for **District 2**. The majority of county sites which exhibited above average rainfall had corresponding ground water measurements occurring below the lower NRCS water table range value. Four county sites had mixed categories between above and below the average rainfall where ground water measurements either occurred above or within the acceptable NRCS intervals.

District 3 could not be evaluated due to lack of shallow ground water measurement sites.

Two counties were evaluated for **District 4**. Both Martin and Palm Beach Counties had rainfall measurements occurring below average with corresponding ground water measurements occurring below the lower value of the NRCS range.

Four counties were evaluated for **District 5** with mixed results. Brevard, Flagler, and Volusia Counties had both above and below rainfall measurements compared with average rainfall with ground water measurements occurring below the lower value of the NRCS range. Sumter County had above average rainfall with corresponding below NRCS ground water predictions. Volusia County had a split result where seasonal rainfall occurred above average rainfall with acceptable to above measured ground water results exceeding the upper value of the NRCS range.

Table 4.9. Seasonal Rainfall and Ground Water Response Table

District	Rainfall	Ground Water
1		
DeSoto	Above average	Acceptable
Highlands	Below average	Below
Hardee	Above average	Above
Polk	Above	Above/Acceptable
Manatee	Equal/Above average	Acceptable/Above
2		
Alachua	Below	Below
Baker	Above	Above
Bradford	Above	Below
Columbia	Above/below	Above/acceptable
Dixie	Above/below	Below/acceptable
Gilchrist	above	Below
Lafayette	above	Below
Levy	above	Below
Madison	above	Below
Nassau	above	Below/acceptable
Putnam	above	Below
Suwannee	below	Below
Taylor	Below/above	below
3		
	Not evaluated	
4		
Martin	below	Below
Palm Beach	below	below
5		
Brevard	Below/above	Below
Flagler	Above/below	Below
Sumter	above	Below
Volusia	Above/below	Below/acceptable to above
6		
Miami Dade	below	below
7		

Citrus	above	Below
Hillsborough	above	Above/below
Pasco	below	Below
Pinellas	above	above

One site was available for rainfall evaluation within **District 6**. Measured rainfall occurred below average seasonal rainfall with a corresponding ground water measurement occurring below the lower NRCS range.

Four sites were available for rainfall evaluation within **District 7**. There appears to be a correlation between monthly seasonal rainfall occurring above average rainfall and ground water measurements occurring above the upper NRCS value.

4.9. Conclusions and Recommendations

Table 4.10. NRCS Method Probability for Achieving Predicted SHGWTs.

District	Acceptable Prediction	Conservative Prediction	Temporary WT Predictions
1	7%	45%	15%
2	18%	94%	2%
3	not	Evaluated	
4	29%	100%	7%
5	18%	80%	5%
6	64%	82%	0
7	48%	77%	3%

The probability of achieving a direct match with NRCS water table range estimates for Districts 1, 2, 4, and 5 appears to be less than 30%. For the urban setting represented by District 6, greater than 64% probability appears to be likely for achieving acceptable predictions using the NRCS method. Acceptable probability results appear to be near 50% for District 7. Applying the NRCS method for use in direct correlation with predicting seasonal high ground water measurements is low, except for the urban setting in District 6. Caution should be exercised when attempting to assume the NRCS range intervals are accurate. Field investigative methods are recommended as a means for validating NRCS estimates. For example, qualitative methods such as gray soil indicators, SPT density counts, and the hydraulic gradient method would be appropriate for verification purposes.

When the NRCS method is used to predict conservative seasonal high ground water table condition, probability increases to greater than 45% for District 1, and greater than 77% for the remaining districts.

The highest probabilities occurred for Districts 2, 4, 5, 6, and 7. Application of the NRCS method appears to be more successful in predicting conservative seasonal high ground water conditions where seasonal high ground water measurements occur below the lower NRCS water table range of values.

Temporary water table conditions are expected to be encountered less than 15% for all districts due to fill placement in urban settings. About one third of the sites had a probability of producing temporary water tables due to the presence of clay. For Districts 1, 5, and 7, the probabilities of encountering temporary water table conditions are expected to occur less than 15%, 5%, and 3%, respectively.

Some NRCS range of estimates may represent temporary water table conditions as opposed to misinterpreting temporary conditions as “normal” seasonal high ground water conditions. Geotechnical soil borings would be the best method to make this determination in cases where temporary water table conditions are present.

Section 5.0. Recommendations and Implementation Guidelines

5.1. Recommended Prediction Methods

Several prediction methods were identified from this study to produce acceptable predictions for estimating seasonal high ground water conditions. Methods included both qualitative and quantitative approaches which were specific to FDOT District regions based on the two year data collection period. Qualitative methods included gray and white soil indicators, geotechnical SPTs, Rainfall vs. DTW graphical, and the NRCS Methods. Quantitative methods included the Hydraulic Gradient Methods and Laplace Method.

Table 5.0. Test Site Methods Summary Evaluation 2015-2016

Test Site	*Gray Soils*	*Geotechnicial SPTs*	*Rainfall vs. DTW*	*Hydraulic Gradient*	*DTW Corrective*	*Correlation Method*	*Laplace Method*	*Dupuit Tidal*	*CT DEP DTW*	*Sfc Wtr Fluct'n*
District 1										
DeSoto	acceptable	not eval.	not eval.	undeter.	above/below	not eval.	undeter.	not appl.	not eval.	not eval.
Highland	acceptable	not eval.	acceptable	acceptable	not appl.	acceptable	above/below	not appl.	above/below	above/below
										canal only
District 2										
Alachua	below	below	invalid appl.	not eval.	not appl.	above	not eval.	not appl.	not eval.	not eval.
Suwannee	acceptable	below	invalid appl.	not eval.	not appl.	not eval.	not eval.	not appl.	not eval.	not eval.
District 3										
Bay	absent	acceptable	invalid appl.	acceptable	not appl.	above	above	not appl.	above	above
Liberty	absent	acceptable	acceptable	acceptable	not appl.	above	below	not appl.	above/below	above
District 4										
Martin	below	not eval.	below	acceptable	not appl.	acceptable	not eval.	not appl.	above	acceptable
Palm Bch	not eval.	not eval.	not eval.	acceptable	not appl.	above	above/below	not appl.	above/below	not eval.
District 5										
Brevard	below	acceptable	acceptable	acceptable	not appl.	not eval.	bove & belo	eval.	above	above/below
Lake	acceptable	below	not eval.	acceptable	not appl.	above	not eval.	not appl.	not eval.	below
Sumter	below	below	invalid appl.	acceptable	not appl.	above	not eval.	not appl.	above	below
District 6										
Broward	not eval.	not eval.	acceptable	acceptable	not appl.	not eval.	acceptable	not appl.	not eval.	not eval.
Miami	not eval.	not eval.	above	acceptable	not appl.	not eval.	acceptable	eval.	not eval.	not eval.
District 7										
Pasco	below	acceptable	acceptable	acceptable	not appl.	above	not eval.	not appl.	above	not eval.

Table 5.0 provides a prediction evaluation summary for reference purposes of the successful prediction methods evaluated for both qualitative and quantitative categories. Categories are defined as:

1) A*cceptable* criteria are those which produced predictions equal to measured seasonal high ground water elevations. The acceptable category was reserved for conditions where both pilot test sites within each district met the NRCS definition. Where one test site met the acceptable criteria, and the second site did not, this constituted a 50% success rate. For example, the gray soil indicators for District 2 occurred below acceptance criteria for Alachua County but met the acceptance criteria for Suwannee County.

2) *Conservative (below)* is defined by method results which produced predictions below measured ground water. Application of the method would produce a prediction result occurring above measured values resulting in a conservative prediction of seasonal high ground water conditions where the true ground water was positioned below the predictor. Successful applications for applying the NRCS method were based on probabilities exceeding 75% for producing acceptable predictions within each district region.

3) Unconservative (above) is defined by method results which produced predictions above measure ground water. Application of the method would produce a prediction result occurring above measured values resulting in an overestimated prediction of seasonal high ground water conditions where the true ground water was positioned above the predictor.

Table 5.1. Recommended Prediction Methods Summary

Districts	***Recommended Qualitative Methods***	***Comments***
1, 2, 5, 7	Gray soil indicators	D 1 acceptable; D2&5 acceptable to conservative; D7 conservative
3,5,7	Geotechnical SPTs	D3 acceptable; D5 acceptable to conservative; D7 conservative.
7	Rainfall vs. DTW	D7 acceptable
2, 4, 5, 6, 7	NRCS Method	D6 64% probability of acceptable results; D5,6,7 landscape type dependent;
	Recommended Quantitative Methods	
1,3,4,5,6,7 (2)	Hydraulic Gradient	Acceptable for all districts including district 1(1)
4	Laplace Equation	Acceptable for surface water predictions
5, 6	Dupuit Tidal Effect	Acceptable for distances up to 300 feet from coastline

(1) Although there were site specific conditions which limited method application for DeSoto County, given the addition of ground water measurement points, the hydraulic gradient method would have resulted in acceptable predictions.

(2) D2 was not evaluated due to lack of surface and/or ground water hydrologic data to derive hydraulic gradient estimates.

5.2. Predictive Methods Discussion

Gray soil indicators produced acceptable prediction results for Districts 1, 2, and 5. Districts 2 and 5 were mixed between acceptable and underestimated results, which were assigned to an overall conservative prediction. District 7 fell within the conservative category. This method is recommended as the easiest method for estimating predicted seasonal high ground water due to the obvious nature of recognizing and logging soil profiles while performing geotechnical SPT borings. Coupled with soil logging techniques, *geotechnical SPT densities* were the next most obvious method for estimating fluctuating seasonal high ground water conditions. District 3 produced acceptable results; while Districts 5 and 7 produced conservative results due to lower than expected seasonal high ground water measurement conditions. This method is recommended for use in combination with a second method for confirming interpretations from SPT density data. Although, for proper interpretation, the SPT blow counts need to be analyzed for each 6 inch interval and not solely by the resulting N values.

The *Rainfall vs. DTW graphical method* produced acceptable results for District 7 only. Based on the limited number of test sites available for evaluation, this method is not recommended for application due to the unreliability of matching increasing rainfall months with corresponding rises in ground water elevation. Several sites had delayed responses in ground water increases which masked the ability to correlate ground water increases with monthly rainfall event increases.

The *NRCS Method* appeared to be effective for specific types of landscape classifications although the application of this method appeared to produce conservative predictions for Districts 2, 4, 5, 6, and 7. This method is recommended for producing conservative predictions with probabilities greater than 77% based on results reported in Section 4.6. District 1 had the lowest probability for producing conservative predictions by the NRCS method (45%). A second method should be applied to confirm NRCS soil predictions such as the gray soil indicators. Occasionally, soil indictors will not meet the NRCS range interval which suggests the NRCS relied on another method for establishing the range (for example, temporary water table conditions, soil classification, soil mottling, etc.).

The *hydraulic gradient method* appeared to be the most reliable method for predicting seasonal high ground water conditions. All districts met the acceptable criteria with the exception of District 2 due to the presence of dense clayey soils which produced temporary water table conditions. District 1 was the exception due to the inability of applying the method to DeSoto County based on the absence of measured ground water data along the CR 769 corridor. With proper ground water measurement stations, this method would be considered to have a high probability of succeeding. This method is recommended for all districts where at least two ground/surface water stations were present. It is recommended at least two SPT borings be used during preliminary site investigation to monitor the water levels for at least 24 hours.

The *Laplace Method* produced acceptable results for District 4 Broward County where surface water canal stations were evaluated. This method is recommended for predicting surface water canal features, and also for determining surface to ground water predictive interactions. This method is not recommended for applying to ground water situations where large ground water fluctuations occur.

The *Dupuit Tidal Effect* method produced values which appeared reasonable for representing fresh water lens increases occurring on top of a salt water interface within 300 feet from the coastline. The method appears valid where ground water measurements are available to confirm equation model results.

5.3. Predictive Method Guidelines

5.3.1. Gray Soil Indicator Implementation

The presence of gray soils appeared in some soil profiles which were indicators of seasonal high ground water table conditions. Gray soils appeared in both sandy and clayey recorded profiles. Occasionally, within sandy hill landscapes, gray soils may be absent from the soil profile. White sands may appear at some depth below grade. White colors are indicative of depleted soil horizons associated with fluctuating ground water conditions.

5.3.2. Soil Indicator Applications.

1) Gray soils are site specific criteria intended to estimate SHGWT conditions. Soil color may be applied in conjunction with other methods such as SPT density values, estimated water table depths from soil borings, and NRCS soil survey water table ranges to evaluate and interpret field observations. At some locations, particularly in urbanized settings, gray soils may represent historical seasonal high ground water levels prior to development and changes in hydrologic conditions (rainfall, and ground water depths). Temporary water tables may also be represented by soil color.

2) Sandy soils (SP, SW) appear to be most favorable soils where gray soils are likely to be encountered, and would most accurately reflect seasonal high ground water conditions.

3) Clayey soils may exhibit gray soil horizons which may represent temporary perched or hanging water table conditions. SPT soil boring data may reveal the presence of temporary water table conditions where an upper and lower saturated zone is separated by an unsaturated zone.

5.3.3. Implementing Geotechnical SPT Methods

Evaluation of geotechnical methods requires interpretation of subtle SPT density changes most commonly associated with sandy profiles, usually on the order of 1 or 2 blow count differences. Clayey profiles will produce more abrupt density changes due to density variations occurring with depth, considered unreliable for assessing ground water fluctuations. Recording soil color, and the observed ground water depths will help identify the density change representing fluctuating ground water conditions. Temporary well point measurements will also support density change interpretations related to ground water conditions. A period of at least 24 hours should be allowed for the ground water interface to recover from disturbances resulting from SPT boring installations.

In less permeable soils (silts, and clays), longer stabilization periods may be required. Sandy soils appear to be more susceptible to SPT density variations than silts and clays. This method does not appear to be effective unless ground water depths are measured at the time of performing the SPT blow counts. Based on the SPT data collected during the data collection period, sandy soils produced density changes of 1 to 5 blow counts (per 6 inch interval) at the seasonal high interface. There is no fixed number of blow counts that can define a seasonal high condition. Interpretive experience coupled with other field observation methods would provide the best support for applying this method.

Installation of temporary well points at select SPT locations would help provide a snapshot of ground water elevations representing the time at which the ground water is measured. Collection of short term data may help support applying other quantitative predictive methods such as the hydraulic gradient methods. Raw density counts for each 6 inch interval should be preserved, not averaged into a single N value for any specified interval. Averaging would tend to mask subtle variations in density associated with seasonal ground water fluctuations. When recording SPT values, the full set of blow counts should remain intact on the soil log instead of averaging the values to interpret density.

The 0.5 ft interval counts can be used to estimate density variations which may be used to interpret aquifer level fluctuations within a 0.5 ft difference.

Soil logs prepared from SPT samples should contain a minimum amount of information in order to be useful in establishing existing seasonal high and normal water table conditions: color, texture, and degree of saturation are the most important descriptions that should be included in any soil profile. Degree of saturation should include all zones separated by unsaturated conditions for identifying temporary water table conditions. Soil penetrometer testing was conducted during this study, and appeared to reflect similar density variations when compared to SPT data with slight deviations ranging between 1 and 2 feet in depth. A pocket penetrometer may help speed up the descriptive process as opposed to static cone penetrometer probe testing. Pocket penetrometers may be used to evaluate continuous soil split spoon samples measured at 1 foot intervals over the entire length of the soil core.

Geotechnical soil boring locations should be surveyed for land surface elevation for establishing depth to the saturated zone elevation. The data can then be used as input into the various equation methods for predicting ground water table conditions by projection to the right of way, and at proposed storm water basin locations by hydraulic gradient methods.

5.3.4. Geotechnical Method Application

1) Sandy soils appear to be the most useful soil type for applying density variations for determining fluctuating ground water conditions. Gray soils correlated to density changes, usually recognized by subtle increases noted by each 0.5 foot interval is the most useful data to record. The tendency is to combine the entire 2 foot interval to obtain a single SPT value for characterizing soils by the UCS classification system. By combining the SPT values, the ability to mark the density change related to ground water fluctuations is lost.

2) Clays (CH, CL) are not suitable for applying density variations due to constant increases and decreases as a result of clay stiffness variations within the profile. Where gray clays are present, density changes may indicate ground water fluctuations related to temporary water table conditions (perched or hanging water tables).

3) SPT density values should be applied in conjunction with other indicators such as soil color measured and recorded ground water depths from SPT borings, NRCS soil survey water table ranges, temporary well point measurements, and/or hydrologic ground water station measurement data located within close proximity to the target site.

Hydrologic data may be obtained from Water Management District, and the USGS Water Data web sites.

5.3.5. Rainfall vs. DTW Implementation

This method is based on correlations occurring between increasing monthly rainfall totals for specific months and rising ground water depths. A nomograph was generated through semi log plot of rainfall changes versus differences in ground water depth to predict the rise in ground water depth. The plot may consist of a single year of rainfall and ground water measurement data to generate the graph. Multiple observation well data were used to generate the graph applied during this study. The graph was presented in the 5th Quarter Status Report, 2016, Page 10.

5.3.6. Rainfall vs. DTW Graphical Application

1) Development of the graph requires a set of rainfall data and depth to ground water measurements. Both data sets must correlate with increases in rainfall and a corresponding rise in ground water. Where more than one hydrologic measurement station is available, the data may be plotted together.

2) Hydrologic station data should be located within the same drainage basin and rainfall data should reflect conditions correlated to measured ground water depths. The plot places rainfall increases on the vertical axis and ground water rises on the horizontal axis.

3) In the case of this study, thirteen (13) pilot test site's data were plotted on the graph to generate linear trends. Three linear trends were developed representing low, medium, and high rainfall amounts. An invalid application of this method would happen when there is an absence of correlated rainfall and ground water increases.

4) Based on the graph, a horizontal line is drawn from the rainfall axis until it intersects the center line on the graph. Center line represents the average plot (best fit through the dataset). Trace the intersected point down to the depth of ground water rise and record that value.

5) Take the ground water depth or elevation value representing the low, medium, or high graph value and add the predicted depth to ground water rise to the previous month measurement to obtain a predicted ground water elevation.

For example, in November 2015, ground water elevation was 56.42 feet above mean sea level. The January 2016 ground water elevation was 57.75 feet mean sea level. A 1.2 foot increase in ground water was predicted to occur from an increase in rainfall from the preceding month. Adding the 1.2 foot DTW prediction to 56.42 produces a predicted ground water elevation of 57.62 ft mean sea level. The predicted value is 0.13 foot lower than the January measured value, indicating the result is within acceptable criteria of 0.5 feet above or below the measured value.

5.3.7. *NRCS Method Implementation*.

Comparing the NRCS SHGWT range of estimates with physical field data such as gray soil indicators, SPT density logs, and actual water table measurements is recommended to verify the NRCS estimates.

1) The probability of successfully applying the NRCS method focuses on several preliminary steps prior to committing towards applying the method for predicting seasonal high ground water conditions:

    a) Identify the landscape type from the NRCS soil description page for soil types occurring along the subject roadway corridor. Very often, several soil types will be present. The NRCS water table range may be combined to cover the highest and lowest depths where the NRCS estimates cover a wide range of soil types. Where the NRCS has not classified the landscape type, the location is typically classified as an urbanized setting due to removal and replacement of native soils.

    b) With knowledge of the water table range, and landscape type, refer to the tables contained in **Section 4.6** of this report to determine the probability of achieving an acceptable or conservative prediction. The tables are sectioned by District, and specific landscape type with percentage probabilities of encountering acceptable, overestimation, underestimation, and conservative prediction results. Temporary water table probabilities are also defined.

    c) **Section 4.7** (this report) contains a set of FDOT District maps representing areas most likely to produce acceptable and conservative results using the NRCS method. These maps were generated based on the probability tables contained in Section 4.6 along with guidance provided by the Florida Geological Survey environmental geology map and surficial aquifer maps contained within the Florida Aquifer Vulnerability Study (Arthur, J. and others, 2005).

These maps are not intended for site specific ground water determinations but as a guiding reference for the likelihood of encountering acceptable and/or conservative seasonal high ground water conditions when applying the NRCS method.

d) Where probabilities are less than 45% for generating acceptable and/or conservative predictions, a second method should be employed to verify NRCS range estimates. These methods may be qualitative in nature including soil indicator colors from soil logs (gray or white colors), or geotechnical SPT boring density logs depicting the original 0.5 foot density intervals. A change in density value may reflect seasonal ground water fluctuations. The change may be subtle in sandy type soils with increasing density values associated with restrictive soil types (silts, sandy clays, clays, and loams).

e) When applying the NRCS method, the estimated water table interval established by the NRCS should be converted to elevation feet for comparison with land surface elevations, and surveyed elevations along the project corridor route. This will allow an easier comparison to other qualitative methods and quantitative methods for consistent interpretation.

5.3.8. Hydraulic Gradient Implementation

Prediction methods require accurate land survey elevations in order to determine whether or not ground water and surface water measurements represent the same aquifer system. This determination is of paramount importance towards proper application of the hydraulic gradient method for predicting seasonal high ground water conditions. A new hydraulic gradient condition must be determined for all measurements observed between surface and ground water conditions.

Proper determination of the direction of gradient slope between surface and ground water stations, or between two ground water stations will establish which method is appropriate for use (back computational or simplified gradient method).

Hydraulic gradients may be determined from a combination of surface water features and ground water elevations obtained by temporary well points, geotechnical, and other site specific methods (gray soils, or NRCS ranges). The more accurate the hydraulic conductivity estimated value is, the more accurate the equation result becomes.

Observation Stations. Surface water features including lakes, rivers, canals, and storm water basins which retain surface water year round are acceptable sources of data where the feature is connected to the ground water system. Elevations of surface water levels are required to project back to a road project corridor using one of the hydraulic gradient methods. The more accurate the hydraulic gradient, the more accurate the predicted result will occur. Surface and ground water units must be positioned within the same hydrogeological unit.

Hydrologic Data Acquisition. Hydrologic station data collected by the USGS, the five Water Management Districts, and regional water supply authorities are effective sources of measurement data. The hydrologic data may be projected back from the station location to a road project corridor using hydraulic gradient principles described in the previous paragraph. Distances between the known station and right of way, and between the two known elevations representing either surface to ground water or ground water to groundwater elevations must be known.

Topographic Influences. Prediction equations provided the best results when surface land elevations were accurately known. Use of topographic maps do not account for land elevation changes due to fill placement and other land modifications altering topographic contour shapes and elevations, particularly in urbanized settings.

When applying both simplified and back computational methods, the estimated hydraulic gradient accounts for different types of landscapes (steep and moderate hills, and flatlands). Caution should be exercised when applying hydraulic gradients. Similar drainage basin and landscape configuration should be accounted for as well as similarity in hydrogeologic positioning of both surface and ground water features. New hydraulic gradients must be calculated for each and every measurement collected in the field. Where a set of seasonal gradients exist, averaging will produce an average seasonal high ground water prediction result which may or may not represent actual measurement conditions.

The **Simplified Method** and **Back Computational Method** use the same principle to arrive at a predicted ground water elevation. A hydraulic gradient must be established between two known hydrologic data sources. The source measurement data may represent open surface water features: lakes, storm water ponds, creeks, rivers, wetlands, etc., or ground water hydrologic stations or installed observation wells.

The method may be applied to any landscape configuration (flatland, hilly, gently to moderately sloping, etc.) as long as a new hydraulic gradient is established between two known measurement points, and the gradient represents connected surface to ground water conditions.

Using the gradient value, direction of ground water flow, distance, and with one unknown measurement point, a ground water prediction can be accurately made using the established hydraulic gradient bearing in mind that the gradient may change value and/or direction with exposure to changing surface and/or ground water elevations.

The Simplified Method is applied when the hydraulic gradient occurs from a high elevation to a low elevation. The Back Computational Method is applied when the hydraulic gradient is from a low elevation to a high elevation. Both techniques provide the most accurate ground water prediction result regardless of distance or type of surface water feature used as a source of measurement (lake, pond, storm water basin, creek, non-tidally influenced river).

Both measurement features must be positioned within the same hydrogeologic (aquifer) unit. Where land elevations differ between the established hydraulic gradient and the targeted site modifications may be applied to correct for land surface elevation differences. A corrective procedure for changes in land elevation between the source measurement data and target site was described in the 3rd Quarter Status Report dated October 5, 2016.

When considerations are given towards the use of surface water features combined with ground water measurements, the User must be aware that the two sources of data represent the same aquifer unit. This may be determined by:

a) Reviewing the hydraulic gradient value determined from measurements collected from each surface to ground water measurement. If the hydraulic gradient is steep, chances are the surface water is not connected to the ground water.

b) The presence of stiff, dense clay at the surface may be an indicator of apparent perched or hanging water table conditions and may not represent true ground water conditions.

c) Where surface water and ground water measurements are within reasonable vertical distances of each other, the surface water may be connected to the ground water. SPT soil logs and temporary well screens may be used to make this determination.

Temporary water tables are separated from true normal ground water by an unsaturated zone occurring between them.

d) Hydraulic gradient predictions will produce high errors when the target site distance is greater than the distance used to calculate the gradient between two known stations. For example, if the gradient distance between measured stations is 7600 feet and the target site is 10,000 feet away, a large error will likely occur.

When collecting measurement data from the Water Management District, and/or USGS web-based data sources, reporting of river stage gages may be in feet above NGVD which does not necessarily reflect elevation feet above mean sea level. The user may distinguish between these two units by the value reported. Where the value appears unreasonably lower than typical land surface elevations, the value reported is probably in feet above NGVD (known as stream gaging height).

Direct ground water measurements are the best means for determining hydraulic gradients. The use of SPT boring data with a temporary well point monitored within 24 hours of original disturbance may be used to establish hydraulic gradients, representing the conditions at the time in which the two measurements were obtained. When hydrologic conditions change (i.e. change in ground water elevation), hydraulic gradients change correspondingly. Gradients may reverse, requiring a new gradient determination and substitution of either back or simplified method depending on the ground water slope direction.

Hydraulic gradients may be estimated graphically for predicting ground water elevations where vertical and horizontal scales provide detailed elevations and distances between the measurement station points.

5.3.9. Laplace Equation Implementation

The ***Laplace Method*** equation applies to any location where an unknown ground water elevation is positioned between two known ground water or surface water stations with measured elevations. The equation is influenced by the ratio of the distances between two known measurement stations and the subject site. The ratio is established by determining the distances between station 1 input measurement and the subject site divided by the total distance between the two known measurement stations. Results with a distance ratio close to 0.5 produced an averaged predicted elevation positioned between the two known station elevations.

A ratio closer to 1.0 produces a predicted result closer to the higher elevation input into the equation, and a ratio less than 0.5 produces a predicted elevation closer to the lower of the two known measurement values input into the equation. Caution must be exercised when applying this method. When the known surface or ground water elevations are higher than the targeted or subject site elevation, the result will produce a large error. Known measurement input data must be near the unknown ground water elevation, or must occur at an elevation positioned between the known site ground water elevations.

The elevation heads of both the known network stations must be known along with the distance between the stations. The stations should be located within the same drainage basin, or must form boundary conditions for the subject site to be accurately estimated. Stations must be positioned on opposite sides of the targeted site to produce the most accurate predictions. For example, if a subject site were positioned between two lakes, rivers, creeks, wetlands, sinkholes, or well sites, and the elevation of the normal water levels and the seasonal high water levels were known either by physical measurement survey or by historical monitoring data, the subject site ground water may be calculated using the available data.

5.3.10. Laplace Equation Application

The Laplace method may be used for any location positioned within the same drainage basin, bounded by a surface water feature or observation well positioned on opposite sides where the subject site is located between the known stations. For example, if a site of interest is positioned between two lakes, or is bounded by a river or stream on either side, the equation may be applied for estimating ground water levels.

1) Two stations should be positioned on opposite sides of the target site. Surface or ground water elevation measurements may be obtained by setting a temporary well point, by soil boring data, NRCS range elevation, or other means for the targeted site. Surface or ground water measurement data must be available for the known measurement sites. Distances between all stations must be known. A distance ratio is part of the equation input as a decimal.

2) All measurements should represent the same hydrologic conditions under which measurements were collected from the known station points. In other words, where measurements from the one known station represents Day 1, the measurement from station 2 must also represent the same conditions present on Day 1, not Day 20.

5.3.11. Laplace Preliminary Application Considerations

There are some basic steps the user can follow to evaluate whether or not the Laplace Equation would be an appropriate and effective method to apply for obtaining seasonal high ground water predictions.

1) The higher value, irrespective of whether it is surface or ground water, needs to be assigned to Station 1. The lower value needs to be assigned to Station 2 for prediction errors to occur below acceptable criteria of 0.5 feet. There will be an occasional deviation from this norm under conditions where surface water elevations rise above the surrounding ground water. For example, during the summer rainy months, surface water lakes and ponds will fill up at a much faster rate than ground water increases due to direct exposure to rainfall.

2) To verify and confirm whether or not the Laplace Equation produces an acceptable result, one of the hydraulic gradient methods may be used to generate a predicted measurement at the unknown location provided there are two water level measurements available and a known distance between them. Follow the procedures detailed under the hydraulic gradient guidelines.

3) Preliminary calculation of the distance ratio may reveal how the equation behaves with respect to producing an acceptable prediction error. The distance between Station A and the target site divided by the total distance between the two known measurement sites will result in a ratio used in the equation. For ratios occurring above 0.75, the equation will tend to produce high errors. Where the ratios are less than 0.75, the equation has a higher probability of generating errors within acceptable criteria.

4) In the rare event where both Station A and B are equal in elevation, the result generated will occur above the input elevations. Unacceptable results will occur under this condition.

5.3.12. Dupuit Tidal Effect Method

5.3.12.1. *Dupuit Tidal Effect Implementation*.

The one dimensional model successfully produced results up to 300 feet from the coastline. Although the equation will produce results beyond 300 feet, this distance is considered to represent the limit of tidal wave propagation through unconfined aquifers inland from the coast.

Increases in predicted ground water rise may occur at greater distances from the coastline which is reasonable given the fact that the water table lens is typically thicker inland than at the coastline. Application of the equation beyond 300 feet will begin to produce increasingly larger errors. The equation was presented in the 4th Quarter Summary Report dated December 5, 2015. Two important factors are tied to the equation:

1) The hydraulic conductivities (Kh values) values input into the equation represent aquifer conditions determined at a known measurement well site and do not necessarily represent conditions occurring at the coastline where ground water is expected to discharge.

2) The equation relies on factoring a product occurring between the estimated aquifer discharge rate at the coastline multiplied by the distance between the coastline and target location. As the distance increases, the aquifer discharge-distance numerator becomes larger while the denominator remains uniform.

The result produces an increasing rise in ground water depth when the distance increases away from the coastline. The predicted rise results appear reasonable, numerically for those results produced during the data collection period of the study.

3) The discharge of the aquifer at the coastline determined by the estimated hydraulic conductivity multiplied by the hydraulic gradient. Hydraulic gradient is determined by the difference in ground water elevation between a measurement point and the coastline using either mean sea level (0) or the high/low tide value. During this study, the high tide value was applied from tidal station data operated by NOAA.

4) The distance between the targeted site and coastline where the targeted site is less than or equal to 300 feet from the coastline. Tidal wave propagation through an aquifer is limited to 300 feet distance from the coastline (see discussion below).

5) The ratio of fresh water to salt water density value is a constant value = 40.

6) Hydraulic conductivity may be estimated by percolation test, infiltrometer test, or published data sources representing aquifer properties associated with the soil unit under consideration. The NRCS soil drainage ranges may be appropriate when converted to ft/day from inches per hour.

Caution should be exercised when using NRCS data because the percolation drainage values may be too small to adequately represent aquifer characteristics.

5.4. Field Implementation Recommendations

Primary consideration should be given to project sites which are subject to PD&E studies for road construction projects, including development of sites targeted for storm water management systems. The geotechnical methods employed during this procedure produces field data required to evaluate prediction methods presented in this report. Soil borings also provide site specific data generated for nearly every corridor study actively under investigation, specifically related to the qualitative methods recommended in this study.

The remaining quantitative methods may be implemented as part of a desktop study for the hydraulic gradient, Laplace Method, and Dupuit tidal effect methods. The ground water measurement data provided in Appendix A of the Task 3C NRCS Study Report (November 11, 2016) represents most of the shallow wells identified within each District county representing the surficial aquifer. Each well was identified using latitude and longitude coordinates, and approximate land surface elevation.

5.4.1. Geotechnical Soil Logs and the SPT Method.

Accurate soil logs should be recorded by the driller, or field personnel, noting depth interval for blow counts every 6 inches using 1.5 to 2 foot split spoon samplers, soil color, general texture, and saturated soil conditions. Training is minimal based on driller logs reviewed during this study. Basic soil color should note gray and/or white soils in particular. Texture (sand, silt, clay, and sandy clay) classification should be noted for potential temporary water table conditions. Soil conditions should be recorded where continuous saturation occurs, and where saturated soil zones are separated by unsaturated zones. This data is pertinent for establishing temporary water table conditions. Gray soils will typically occur within the upper portion of the soil profile. Where gray soils are absent, white soil colors may appear in deeper parts of the profile.

SPT blow count data requires additional knowledge of the soil and/or hydrogeological conditions encountered at a targeted site. Density blow counts should be recorded for every 0.5 foot per spoon, kept in raw data form, not combined into a single value. Combining would tend to minimize changes reflected in fluctuating ground water changes.

SPT density interpretations should be accompanied by a secondary method for confirming blow counts interpreted as fluctuating water table zones. This method is most effective for sandy type soils. Clay type soils with classification SC, CL, CH should be avoided because clay densities vary with depth. Gray colors would help make seasonal conditions more obvious.

5.4.2. Rainfall vs. Depth to Water Graphical Method

Implementation of this method would require preparation of a semi-log graph representing differences in rainfall values covering monthly trends plotted along the vertical axis and rising ground water differences plotted along the horizontal axis. A large set of data is required to generate linear trends representing low, average, and high values for ground water increases. The difficult part of the method relies on at least one source of known ground water measurement which is used as the baseline value for adding the extrapolated ground water increase obtained from the graph. The predicted ground water elevation requires an index measurement value obtained from a second ground water monitoring point at the targeted site for confirming the accuracy the extrapolated value. If an index value is not available, this method would not be appropriate for implementation. The index value may be represented by another qualitative method (soil, SPT, NRCS source). This method appeared to produce acceptable results for District 7. It is not recommended for the other six district applications.

The graph may be generated from the set of ground water measurements provided in the Task 3C, Appendix A tables. Ground water measurement and rainfall data represent each of the seven FDOT districts by county. A composite graph may be generated from each District where a sufficient number of sites are presented which statistically represent increasing monthly rainfall and increasing ground water elevations. Graph preparation may be prepared by District or statewide. Graph preparation procedures were described in the 5th Quarter Status Report on Page 10.

Application of his method may be used along with other qualitative methods representing seasonal high ground water conditions along project sites. For example, gray soil indicators, SPT blow counts representing fluctuating ground water table conditions, and the NRCS comparative method would be good methods for the predicted rise in ground water to compare against. For example, in the District 7 NRCS table in Appendix A, the rainfall gage at Inverness indicates an increase in rainfall between May and June 2015 of 7.87 inches.

Using the graph generated from the pilot test site study, a low, average, and high value for ground water increase was predicted to occur at 0.4 feet, 1.2 feet, and 3.0 feet respectively. Adding these values to the May 2015 ground water elevation of 37.43 feet mean sea level, predicted ground water elevations are expected to range between 37.83 for the low prediction, 38.63 for the average prediction, and 40.43 feet for the high prediction value. The measured ground water elevation for June 2015 was 37.61, matching the low predicted value of 37.83, a slightly higher conservative predicted ground water elevation.

5.5. FDOT Pilot Projects Recommendations

Specific qualitative and quantitative methods are applicable for predicting ground water conditions (Table 5.0, Section 5.1, this report). Qualitative methods are more appropriately applied in the field, focusing on generating quality soil logs through SPT boring methods during the preliminary phases of PD&E roadway project studies. The NRCS method would be applied following review of soil logs looking for gray and white soil indicators for comparison with NRCS water table range of values. Quantitative methods are more appropriately applied in the office. Hydraulic gradient and the Laplace methods may be applied through the use of public agency ground water station data supplemented by surface/ground water hydrologic station data. Water management districts are good data sources for retrieving current and historical elevations. Where public agency data is either unavailable or positioned too remote for reasonable evaluation, temporary well points may substitute.

The following recommendations are based on deficiencies identified during the data collection and predicted method analyses period, summarized in Table 5.0, Section 5.1 of this report (*Prediction Method Evaluation Table*). The four hypothetical test sites studied during the data collection period created a set of uniform problems which should be addressed by FDOT to resolve outstanding issues related to the prediction methods previously identified.

This section is dedicated towards addressing those districts where unacceptable criteria occurred. For the districts that were split between acceptable and below acceptable criteria, these would be suitable for applications in producing conservative predictions of seasonal high ground water conditions. No further evaluation is discussed for conservative predictions. Under conditions where splits occurred between acceptable and above acceptable criteria, evaluation should be considered. Future pilot testing should focus on the districts discussed in this section for further evaluation.

Physical conditions under consideration involved predominantly flat landscapes, presence of a shallow ground water table, sandy soil profiles with occasional clayey type soils, and nearby surface water features assumed to influence ground water conditions. These conditions continue to hold true for implementing future pilot test projects. Where hills are present, sand profiles tend to be thick, supported by underlying clays within the profile at depth. Ground water measurements occur well below the limits of NRCS soil profile descriptions, and NRCS water table range estimates.

It is the opinion of the researcher that the identified prediction methods can be easily evaluated from the office using collected data obtained from engineering consultants' PD&E studies, and from obtaining public agency data from water management districts and from the USGS. When acquiring public agency data, evaluation must utilize wells set within the upper surficial aquifer zone. Many of the surficial aquifer data compiled during Task 3C, NRCS Study represented the majority of surficial aquifer wells located within each of the FDOT districts (by county) and may be referenced for additional pilot test site consideration.

5.5.1. Qualitative Method Field Study Recommendations

Gray soil indicators could not be properly evaluated for **Districts 3, 4, and 6**. Indicators were absent in District 3. Evaluations for District 4 (Palm Beach and Broward) and 6 were due to lack of soil descriptive data. These districts should be considered for future pilot test evaluation. **District 3** has no surficial aquifer wells maintained by NWFWMD, nor the USGS. This creates a problem in resolving use of gray soil indicators as a technique for predicting seasonal high ground water conditions. **Districts 4 and 6** represent mostly urbanized settings which may produce difficulties in observing gray soils due to fill placement.

Geotechnical methods could not be evaluated for **Districts 1, 4, and 6**. **District 1** ground water elevations were too shallow for Highlands County. DeSoto County did not have SPT soils data available for review and evaluation. SPT testing began after the water table was encountered in Highlands County. **Districts 4 and 6** were studied by public agency hydrologic station data. Therefore, SPT density data were not available for review and evaluation. All three districts would be good candidates for expanding a pilot testing program.

The Rainfall vs. DTW Graphical Method achieved a 50% success rate for each district and was not considered reliable enough for implementation. However, the method could be further evaluated in the office by plotting the data sets into separate graphs from the ground water and rainfall data contained in the Task 3C, *NRCS Statistical Probability Study Report*, Appendix A for each district. All seven districts would benefit from an expanded evaluation. Some districts may have enough ground water data to provide a linear plot for graphical predictive evaluation. The objective is to observe increasing monthly rainfall trends associated with monthly increasing ground water elevations. The difficulty arises when there is a significant delay in ground water recharge due to thick sandy profiles.

District Recommendations. **District 1** is a good candidate for expanded field study in DeSoto and Highlands Counties. DeSoto County continued to demonstrate unresolved issues for establishing reliable project corridor predictions due to lack of ground water measurement data positioned along the CR 769 corridor. Additional studies may take two approaches: PD&E geotechnical soil boring data evaluation for soil color indicators and collection of SPT density data; or, direct field studies implemented by FDOT. At least three or four locations along the corridor may be selected, including additional borings for storm water management system locations for obtaining soil descriptive and geotechnical SPT logs. NRCS soil descriptive data should accompany the locations where borings are installed.

Gray soil indicators should be compared with NRCS water table ranges for verification of predicted methods by NRCS water table range estimates representing specific soil types encountered along the corridor route. SPT densities may be evaluated with respect to soil indicators. Soil borings may be converted into temporary well points for obtaining ground water measurement data. Placement of additional borings and temporary well points along the route would clear up the issues encountered during application of the hydraulic gradient methods. Hydraulic gradients could be estimated along the corridor route instead of being extrapolated from remote public agency sources. The same procedure would apply towards SR 70 in Highlands County. Water table conditions are present throughout the entire corridor between DeSoto and Okeechobee County lines.

A review of the **District 3 (Section 4.7, Figure 3)** guide map suggests there are limited areas where NRCS water table range probabilities are considered effective for predicting seasonal high ground water conditions (green).

Orange areas should be avoided entirely due to the higher probabilities of encountering ground water conditions occurring above the NRCS water table ranges, and the likelihood of encountering temporary water table conditions.

Additional field studies are recommended for this district due to lack of available public agency hydrologic data. An expanded pilot testing program should focus on flatlands where sandy profiles are less than 50 feet thick. Review of NRCS soil descriptions will help guide locations by landscape type. Landscape types should consider North Florida Flatwoods, sand pine scrub, sands on flatlands, sands and loams on flatlands, sands and clays on flatlands, sandy hills, sands in depressions, sands and organics in depressions, and sands and loams in depressions.

Candidate landscapes typically produced high probabilities for achieving conservative predictions based on ground water levels occurring below NRCS water table range values. To achieve a statistically valid population, at least two sites per landscape type would be satisfactory. Geotechnical methods would be an acceptable approach towards collecting field data with adequately described soil profiles, or hand augers (posthole diggers) in the upper 7 to 10 feet would suffice. In the event geotechnical methods are employed, temporary well points may be placed in soil boring holes which penetrate saturated soils. It is projected that up to 10% of North Florida Flatwood landscapes will exhibit temporary water table conditions where loams and clays are encountered at shallow depths. Deep ground water conditions are expected to be common. Field, aerial photographic and topographic map review of select targeted sites may help make a determination of ground water depths by comparing surface water lake feature elevations. The number of test sites would be subjected to the length of the project corridor and location of storm water management system locations. For example, within a five mile project corridor, several temporary well point stations could be established covering locations where storm water basins are targeted, and several points occurring within a half to one mile distance in the center section of the corridor would help project seasonal high predictions to the outer ends of the project corridor.

Within **Districts 4, and 6**, collection of soil profile data may be completed in the field by hand auger or posthole digger should FDOT wish to pursue physical testing. An alternative field procedure is already in place for obtaining geotechnical soil boring information through the preliminary design PD&E work for roadway corridor improvements. For implementation by the PD&E study route, the number of pilot test sites would be restricted to the number of ongoing studies.

Both geotechnical SPT and soil boring logs would be available for review upon completion of the preliminary corridor study.

Locations to focus on include storm water management system sites, and along proposed road construction corridors. A review of the NRCS soils descriptive data would provide the information necessary for comparing soil log data for evaluating NRCS water table ranges. In the event FDOT chooses to implement an expanded pilot testing study, it is recommended at least two soil borings be completed along the proposed corridor and at sites selected for proposed storm water management systems. Temporary well points may be placed in each boring for collection of water table measurements.

NRCS soils data are available through the web based or published soil surveys for obtaining water table range estimates. Due to the urbanized nature of **Districts 4 and 6**, gray soils may not be encountered due to fill placement on top of limestone. The eastern parts of the district appear to have a higher probability of achieving acceptable to conservative seasonal high ground water conditions.

5.5.2. *Quantitative Method Field Study Recommendations*.

The Task 4 *Report of Recommendations*, Appendix D provides marked aerial photographs setting up example typical pilot test projects that would cover the acceptable prediction methods discussed in this report. A typical project corridor would consist of at least one known hydrologic ground water station operated by either a water management district, or by a permanent well placed somewhere for referencing. A set of SPT borings should be placed at arbitrary intervals along the corridor with at least one location converted to a temporary well point for collecting ground water measurement data. More details were provided in the Task 4, *Report of Recommendations Report*, Appendix D figure descriptions.

The hydraulic gradient method appeared to be the most successful method employed during this study. **Districts 1 and 2** presented problems for applying this method. DeSoto County issues were discussed in the previous section. District 2 presented a different set of conditions associated with temporary water tables and the presence of thick clayey soil profiles. **District 1** could be easily resolved with placement of temporary well points along the proposed roadway corridor. This would alleviate the uncertainty associated with projecting gradients to the corridor from remote public agency sources. District 2 could not rely on hydraulic gradients due to lack of surface water features within Suwannee County.

The storm water management basin in Alachua County could not be assessed due to ponding of surface water occurring on top of clays. Gradients were much too steep to represent connected surface to ground water conditions. The District 2 NRCS probability map (Section 4.7) suggests water table conditions associated with the NRCS probability evaluation covers the majority of the district region including Suwannee and Alachua Counties. NRCS most likely interpreted temporary water table conditions as representing the water table range estimates provided in the soil descriptions.

District 2 is a good candidate for evaluating hydraulic gradient conditions. The Task 3C report, Appendix A measurement data representing surficial aquifer conditions could be expanded into test site evaluation. Each ground water station within the identified counties may be modeled for gradient conditions occurring between ground water stations. The issue becomes whether or not the stations are located within close proximity to proposed road construction corridors. If not, during the geotechnical portion of the PD&E study, temporary well points may be installed at various distances along the proposed corridor for use in generating hydraulic gradient conditions between the temporary well points themselves, and between hydrologic ground water stations at remote locations.

The Laplace Method performed well for **District 6** but under performed for the six remaining districts. District 6 was set in an urbanized setting with artificial drainage structures influencing ground water elevations. Ground water was also influenced by tidal effects which limited fluctuations between hydrologic stations. In addition, distance ratios between stations occurred less than 0.75 which helped keep prediction values within the range provided by input station measurements.

For the remaining districts, the method may be re-evaluated by an expanded study in an office setting using the measurements provided in *Task 3C, NRCS Statistical Probability Study, Appendix A* for each of the remaining districts. Application criteria focused on the presence of an unknown targeted location occurring between two known measurement sites. Where proposed road construction projects are located, temporary well points may supplement the data compiled in Task 3C, Appendix A for representation of project specific predictions. The conditions of having an unknown station positioned between two known stations must be met. Where proposed road construction corridors are positioned between two established measurement points, the target prediction would occur at the road project site. The measurements collected from the temporary well point may be used to validate the procedures.

Although this research study utilized both surface and ground water station data to evaluate the equation, issues associated with mixed surface and ground water elevations appeared to limit the effectiveness of the results. To eliminate this issue, ground water stations should be positioned within similar topographic settings. Surface water features such as lakes, ponds, and wetlands should be avoided.

The Dupuit Ghyben Tidal Effect Method was applied to two test sites located in **District 5** (Brevard County), and **District 6** (Miami-Dade County). Performance appeared acceptable based on the small elevation increases occurring within 300 feet of the coastline. This method is recommended for expansion of test site evaluation for coastal counties covering all districts. Task 3C, Appendix A contains shallow well measurement data from public agency wells which may be used to validate equation calculations targeting the locations where these well sites are positioned at the coastline. The landscape category salt marsh would satisfy measurement data representing coastal situations.

This method may be evaluated from an office setting but may include field establishment of temporary well points at various locations to validate equation results. Two coastal wells were identified at Fernandina Beach in Nassau County (**District 2**), and in Flagler County (**District 4**) in Task 3C, Appendix A. Both sites may be used for confirmation sources for equation results. Missing data such as hydraulic conductivity, distance between the target location and coastline, hydraulic head difference, and distance inland from coastline (0 to 300 feet) are required for equation input parameters. Unconfined aquifer thickness was assumed to be 50 feet but may vary by region. Hydraulic head difference would be determined by ground water elevation at the well and high tide value.

In addition, at least two to three locations should be selected for consideration within the coastal counties associated with Districts 1, 3, 4, 6, and 7. Temporary well points should be established within 300 feet of the coastline for collection of ground water measurement data used to confirm rise in ground water elevations determined by the equation. Please note that the increase in ground water elevation determined by the equation should be added to the high tidal value to arrive at a final ground water elevation. The temporary well point should be the validating source of confirmation for the predicted result.

5.6. *Summary*

Based on the two year field data collection period and accompanying prediction method analyses, a set of qualitative and quantitative methods were identified as providing acceptable predictions of seasonal high ground water conditions for individual districts. Statewide application of a single quantitative method was indeterminate, with the exception of the NRCS method. The qualitative methods were based on practical field application associated with geotechnical soil boring investigations and recording of SPT blow counts and soil colors for comparison with NRCS water table range intervals. These methods were identified as gray or white soil indicators, geotechnical SPT density values, and the NRCS method for comparing ground water measurements to estimated water table range intervals. One hydrographic method produced limited acceptable results for seasonal high ground water predictions but did not exhibit strong confidence in application due to the requirement of accumulating large data sets for generating the graph.

Quantitative methods were strongly associated with theoretical applications for predicting seasonal high ground water conditions. These methods relied on equations and ground water measurement data to achieve prediction results. Acceptable results were consistently achieved by the hydraulic gradient method which appeared to be appropriate for statewide and district regional application. The Laplace Equation appeared limited to district applications, and the Dupuit Tidal Effect method was limited to coastal regions up to 300 feet distance from the shoreline.

Collection of field data from methods already employed by FDOT as part of the preliminary design PD&E road construction study process are already in place for applying both qualitative and quantitative methods described in this report. The geotechnical SPT borings are the most common site investigative method that could provide a transition into applying predictive methods for present and future road construction activities. Geotechnical soil log data should incorporate at a minimum: blow counts recorded for every 0.5 foot interval; soil color changes for each soil horizon encountered including gray and white colors; unsaturated and saturated soil zones encountered for the entire boring length. Field collected data would satisfy the requirements for most of the qualitative prediction methods. Placement of temporary well points strategically placed along proposed construction corridors and at storm water basin locations would help data collection efforts for predicting seasonal high ground water conditions using quantitative equation methods.

Appendix A

Section VI. Seasonal High Ground Water Case Study
SR 415 Widening Project, Seminole County (SR 46 in Volusia County)
Financial Project No. 407355-1-52-01

Problem Description. District 5 experienced a seasonal high ground water issue during March 2015 when SR 415 in Seminole County underwent recent construction. Premature pavement cracking occurred at several locations between Stations 460+00 and 488+00. Pumping of the limestone road based material was pushed up into roadway cracks from hydraulic pressure exerted beneath the road base material by high ground water levels. After 3 months of traffic use, wheel path cracks were filled with road base material due to high ground water levels.

FDOT Remedy: Limestone road base material was removed and replaced by an asphalt base (base group 15). An under drain was installed beneath the roadway to lower the ground water elevation.

Figure A.1. Ground water pumping of limestone road base material occurring between Stations 484+30 and 487+90.

Station	Offset	Water Table depth below back of sidewalk (feet)	Approximate Water Table Elevation* (feet)
483+00	Left	2.14	+14.4
484+00	Left	1.49	+14.8
485+00	Left	1.41	+14.5
486+00	Left	1.51	+13.9
487+00	Left	1.32	+13.7
488+00	Left	1.59	+13.4

Table A.1. Ground water levels and elevations collected from sidewalk area along SR 415 during FDOT construction inspection on March 6, 2015.

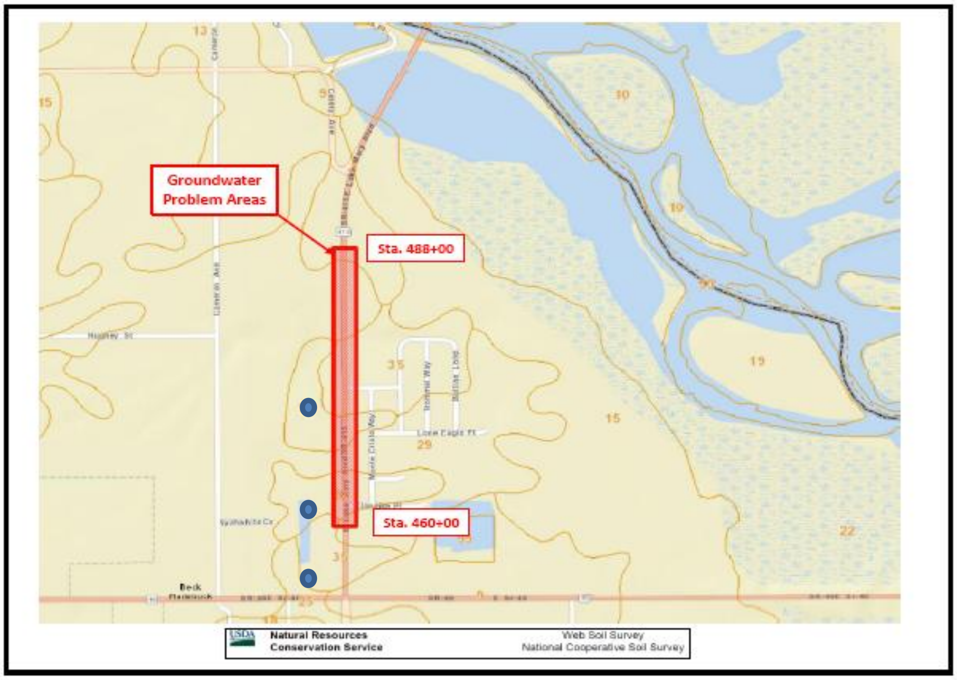

Figure A.2. Street map showing construction zone impacted by ground water issue. Soil type contours are delineated along impacted corridor. Soil Types: 10 – Basinger, Samsula, Hoonton fine sand (WT 0 feet bls); 29 – St. Johns-EauGallie fine sand (0.5 to 1.5 feet bls); 35 – Wabasso fine sand (WT 0.5 to 1.5 feet bls).

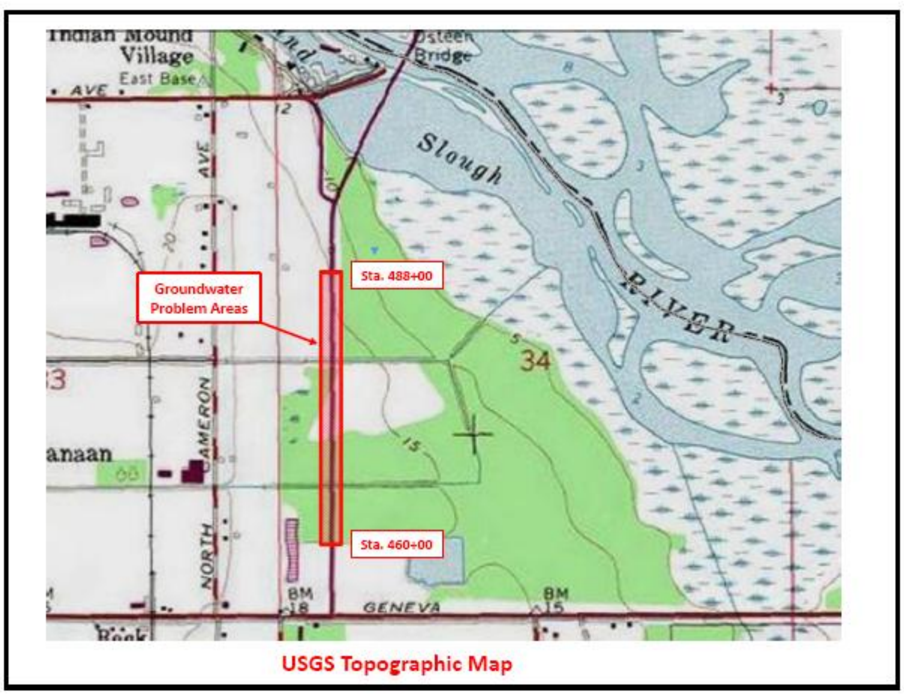

Figure A.3. USGS topographic map showing impacted construction zone with river and landscape elevations.

Figure A.4. Aerial photograph showing impacted construction zone.

Based on the information provided during early 2015, the project corridor station 486+00 was used to evaluate equation methods for predicting ground water elevations using the creek located approximately 0.5 mile due east of the targeted site and the storm water pond located approximately 0.83 miles south of the targeted station (**Table A.1**). A surface to ground water hydraulic gradient was estimated at 0.0045 ft/ft between the river and road station. A smaller gradient was approximated between the storm water basin and corridor station, 0.0025 ft/ft.

The back computational method between the river and station provided results which fit the NRCS water table range at Station 486+00. A large error occurred for the storm water pond. The large error was probably related to an assumption that the pond surface water elevation was equal to the topographic contour shown on the provided map or the storm water basin surface water was perched on top of a slowly permeable soil unit.

The simplified method was not applicable because the evaluation relied on surface projections back inland from the creek towards the west and from the storm water basin towards the north (lower to higher elevation).

Table A.1. Method Analyses Summary Completed in March 2015

Station	Station GW Elevation	Back Computational Method	Simplified Method	Correlation Method	Laplace Equation
486+00 & slough	13.9 ft msl	13.88 ft msl	Not applicable	Not enough data range for accurate result determination	11.91 ft msl
486+00 & storm water basin	15 ft msl	26.39 ft msl	4.05 ft msl	Same as above	14.31

The correlation method could not be accurately applied because there was not a sufficient fluctuation range of ground or surface water data covering a period of time for equation input.

The Laplace equation produced a lower than expected result using a river elevation of 2 ft msl and the storm water pond surface water elevation of 15 ft msl. As a means for confirming the accuracy of the predicted result for the back computational method, the simplified hydraulic gradient method was applied to the estimated ground water elevation of 13.88 ft msl for reverse projection back to the creek. The result achieved an estimated creek elevation of 2.81 ft msl, an error of 0.81 ft from the topographic river elevation of 2 ft msl. An accurate creek elevation would provide a more reliable input value into the back computational equation for projecting ground water back to the target station. Hydrologic data collected by SJRWMD for the ground water station located within the slough may also provide a more accurate measurement for input into the back computational method.

To determine SHGWT conditions using the back computational method assuming an accurate hydraulic gradient could be established, two approaches may produce effective results: 1) collection of hydrologic measurement data from the SJRWMD ground water well station 10291655 positioned in the slough north of the impacted construction zone for the seasonal wet period occurring between July and October 2015, or- 2) physical elevation survey of the seasonal high water line offered by the slough surface water feature may be applied as an approximate seasonal high surface to ground water condition.
Applying the back computational method to the seasonal high water line would produce a fairly accurate ground water elevation up gradient at SR 415. Prediction errors would probably be low.

In April 2016, a re-evaluation of the hydraulic gradient method was applied due to the presence of SJRWMD maintained hydrologic ground water station in the slough area north of the impacted corridor. In March 2015, the slough ground water elevation was recorded at 4.31 feet. Using the FDOT measured ground water elevation at station 486+00 of 13.9 feet msl, a more accurate hydraulic gradient was estimated at a distance of 2640 feet or 0.00363 ft/ft ground water slope. Project back to the impacted corridor at station 486+00 from the slough, the predicted ground water elevation beneath the roadway surface was 0.00363ft/ft x 2640 ft or a rise in ground water elevation of 9.56 ft + 4.31= 13.89 ft msl producing an error of 0.01 feet from the FDOT measurement (**Table A.2**).

Table A.2. Method Analyses Summary Completed in March 2016

Station	**Station GW Elevation**	**Back Computational Method**	**Simplified Method**	**Laplace Equation**
486+00 & slough	13.9 ft msl	13.89 ft msl	Not applicable	13.9 ft msl

The Laplace Method produced a low error due to the extremely low distance ratio applied by the equation (0.00098).

FDOT Conclusions

Conclusions:

- Based on USGS Topographic Map, the Natural Ground Elevation in vicinity of problem areas is about +15’ to +17’
- NRCS/USDA Soil Types in problem area:
  - EauGallie & Immokalle fine sands (SHGWL 6” – 18”)*
  - St. Johns & EauGallie fine sands (SHGWL 6” – 18”)
  - Wabasso fine sand (SHGWL 6” – 18”)
  - Basinger, Samsula & Hontoon soils, depressional (SHGWL 0”)
  - Myakka & EauGallie fine sands (SHGWL 6” – 18”)
- Based on USGS Natural Ground Elevation and NRCS/USDA SHGWL estimates: the SHGWL would be between about Elevation +13.5’ to +15.5’ (average +14.5’)
- Measured groundwater levels between Sta. 483+00 and Sta. 488+00 ranged between Elevation +14.8’ to +13.4’ (average +14.1’)
- Measured groundwater levels compared well with the NRCS/USDA SHGWL predictions

* Seasonal High Groundwater Level (SHGWL)

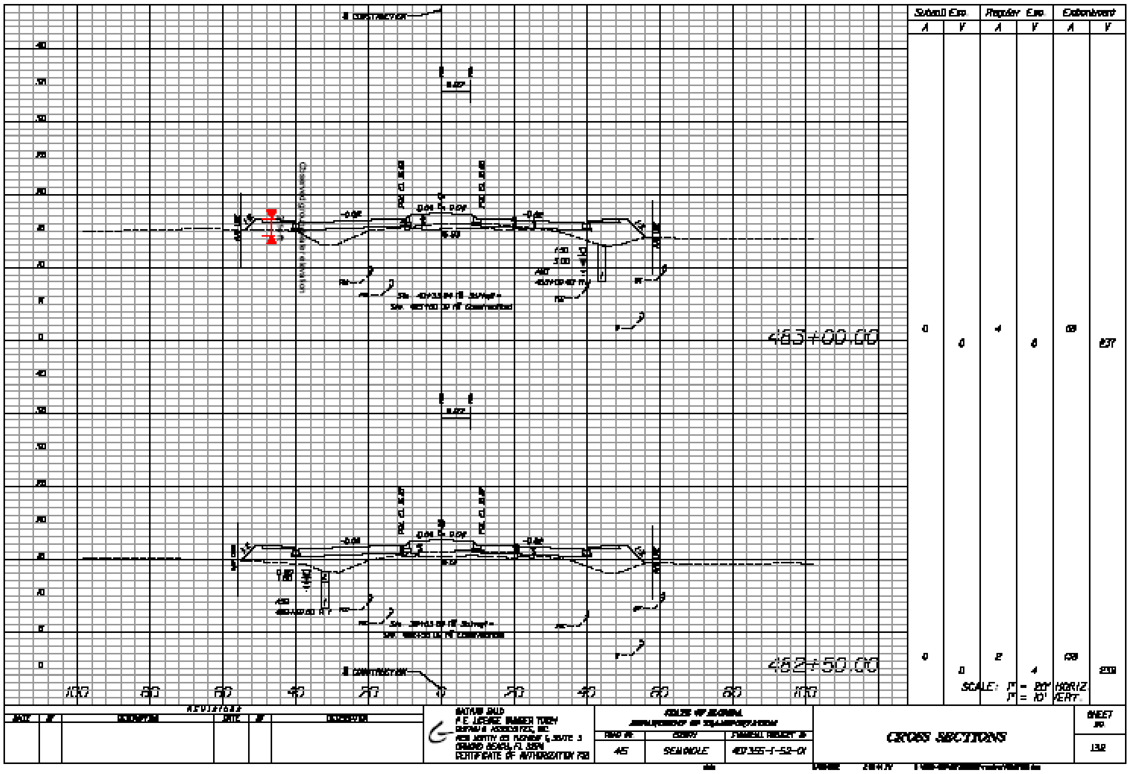

Figure A.5. Station 483+00 cross section showing the location where FDOT collected ground water measurements (top section-red). Measurement was 2.14 feet below sidewalk grade.

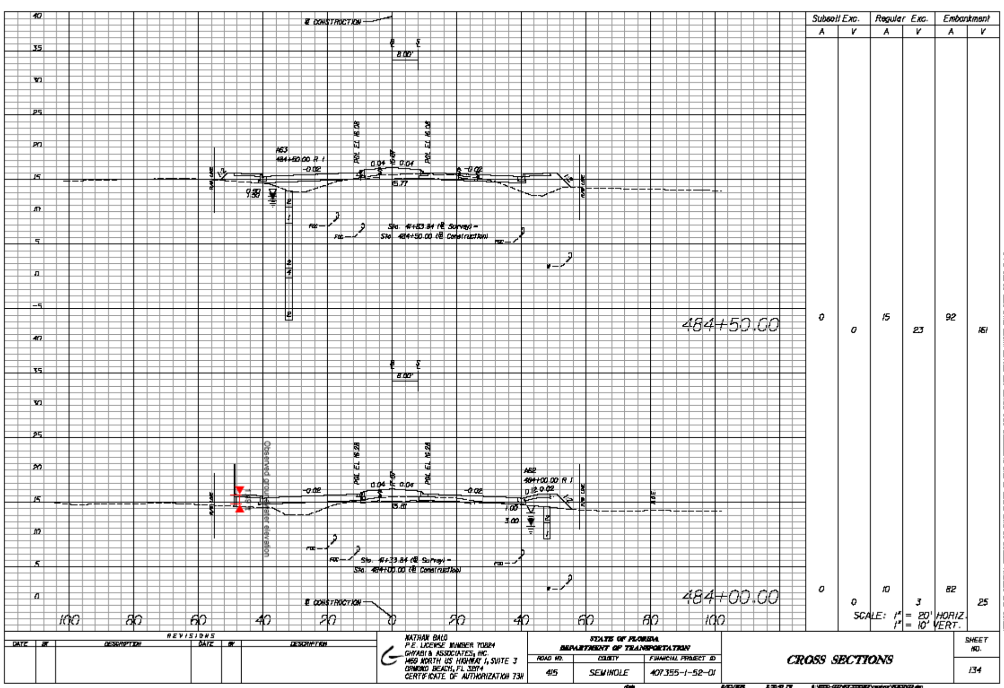

***Figure A.6**. Cross section at Station 484+00 showing ground water measurement location from sidewalk grade at 1.49 feet below grade.*

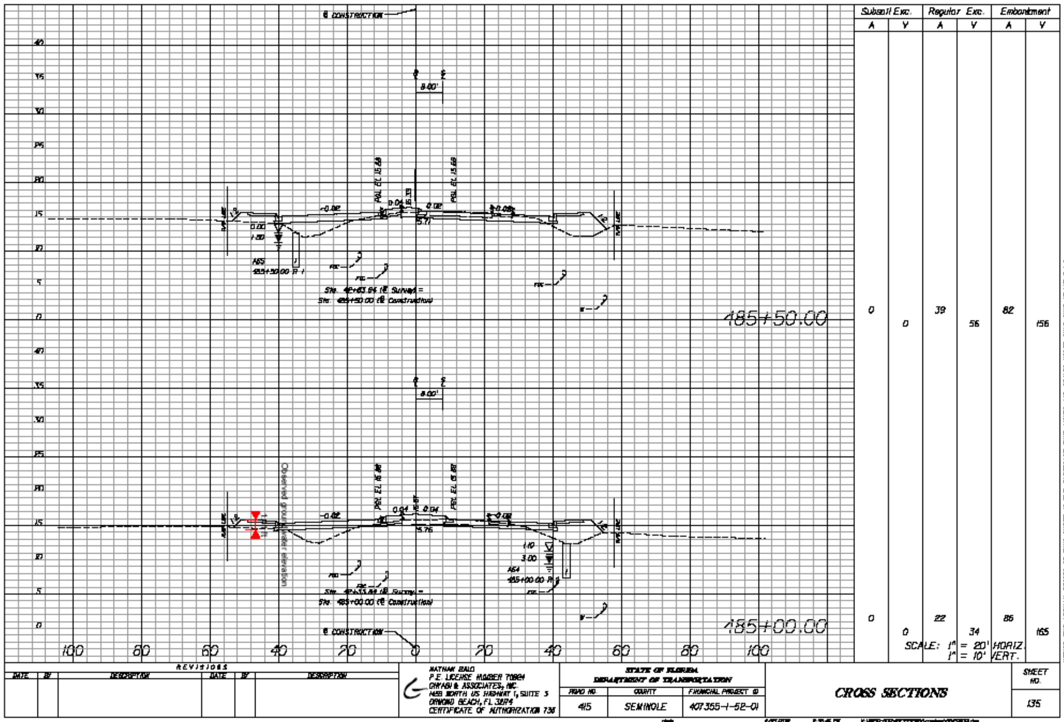

Figure A.7. Station 485+00 cross section showing ground water measurement collected from sidewalk grade at a depth of 1.41 feet below grade.

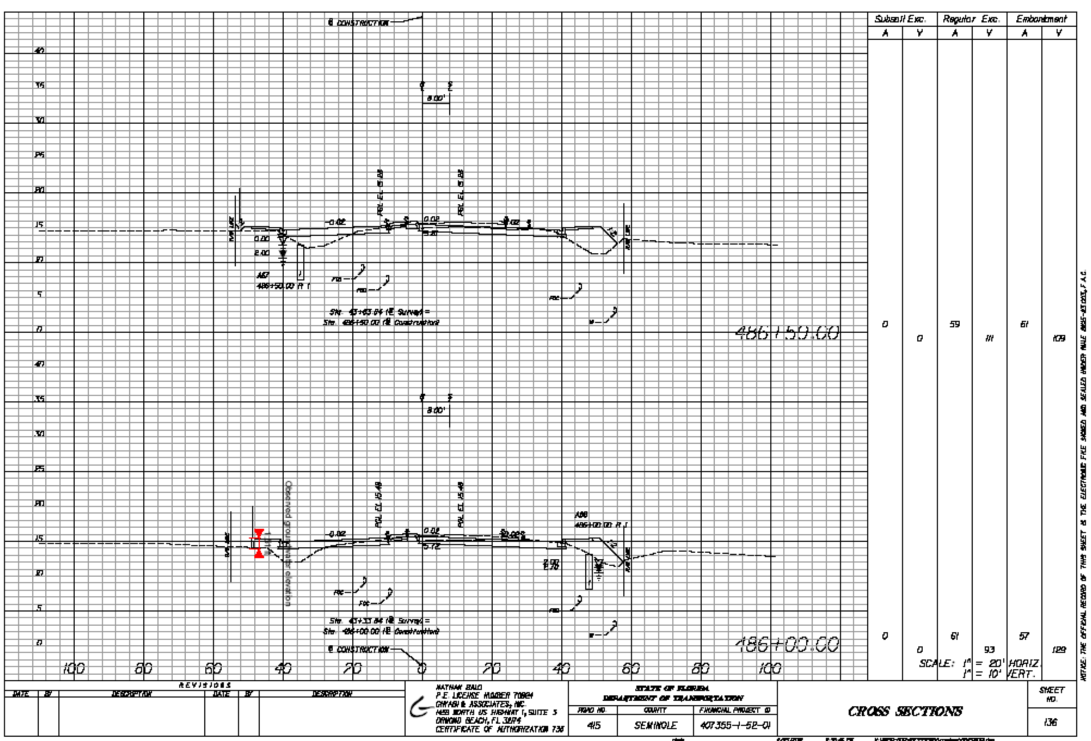

Figure A.8. Station 486+00 cross section showing ground water measurement collected from sidewalk grade at a depth of 1.51 feet below grade.

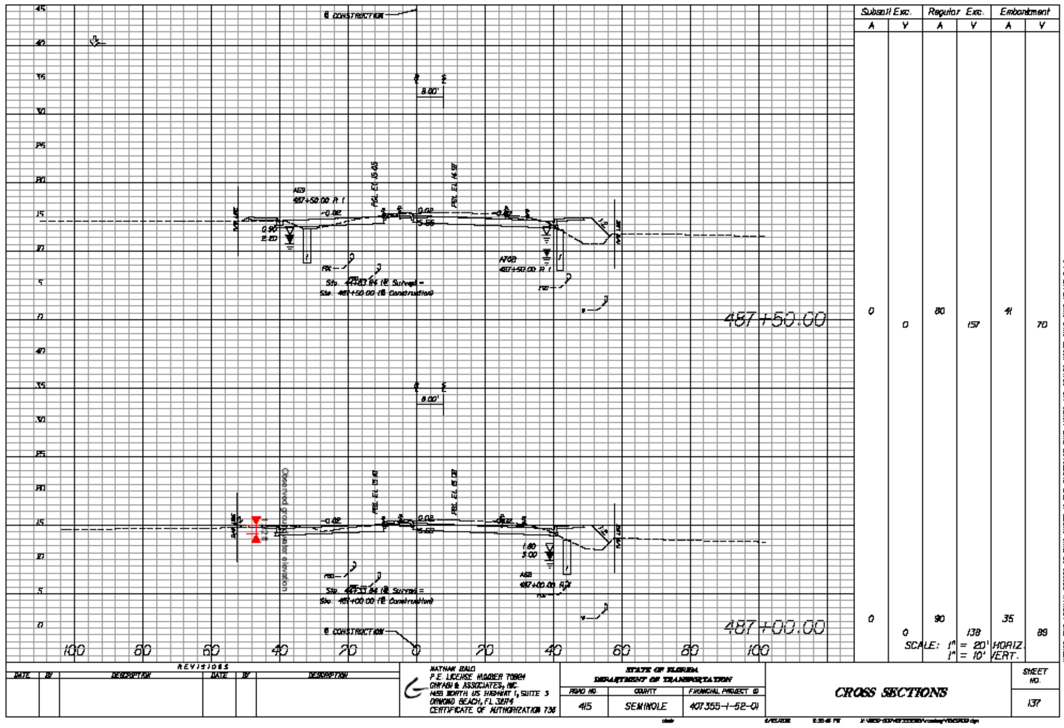

Figure A.9 Station 487+00 cross section showing ground water measurement collected from sidewalk grade at a depth of 1.32 feet below grade.

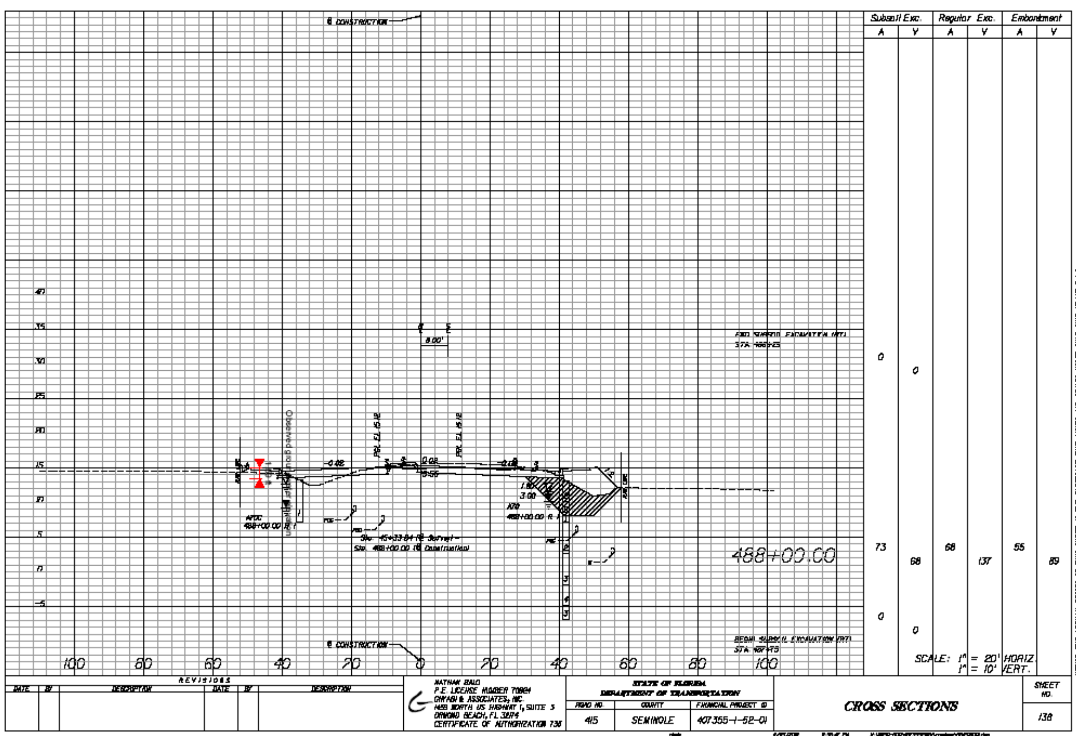

Figure A.10. Station 489+00 cross section showing ground water measurement collected from sidewalk grade at a depth of 1.59 feet below grade.

Appendix B. Hydraulic Gradient Pilot Test Site Example

Since the hydraulic gradient method appears to be suitable for predicting ground water elevations statewide. Perched and/or hanging water tables would present problems when attempting to apply this method. Identification of temporary water table conditions would require another method for recognizing the presence this condition. For example, geotechnical soil boring logs with soil textures may be one source, and review of NRCS soil profiles may provide a second source for identifying temporary water table conditions.

An example is presented to demonstrate the setup and implementation of applying the gradient method to the Appendix A case study. Using the aerial photograph from Appendix A, the blue marker represents the temporary ground water well point placed at Station 486+00 with measured ground water elevation at 13.9 feet above msl. The green marker represents a surface water hydrologic station maintained by SJRWMD at the CR 415 overpass at the slough. Surface water elevation was measured at 4.61 feet above msl. The red circle marker represents an arbitrary point where ground water prediction is required. The distance between the surface water and ground water measurement points is 2640 ft. The mid-point is 1320 ft from each hydrologic measuring point. Taking the difference in ground water elevation minus the surface water elevation (13.9 ft=4.51 ft), the result is 9.29 ft of elevation change. The distance of 2640 feet is used to determine the gradient by dividing it with the change in elevation of 9.29 ft: 9.29 ft/2640 ft = 0.00351 ft/ft slope. Since the gradient is sloped from Station 486+00 to the floodplain, the gradient is falling to the north. Therefore, the slope 0.00351 x the distance 1320 ft = fall of 4.65 ft. Therefore, the ground water elevation is 13.9 ft-4.65 ft= 9.25 ft above mean sea level, and the predicted ground water elevation is shown as the open circle marker in the figure. A temporary well point placed at this location would provide a confirmation measurement.

In the event ground water prediction was required south of the ground water measurement point, the slope could be used to predict ground water at an arbitrary distance. For example, if a point 1,000 ft south were considered, the rise in ground water would be equivalent to 3.51 ft, which would be added to the known measurement of 13.9 ft msl, resulting in an elevation of 17.41 ft msl.

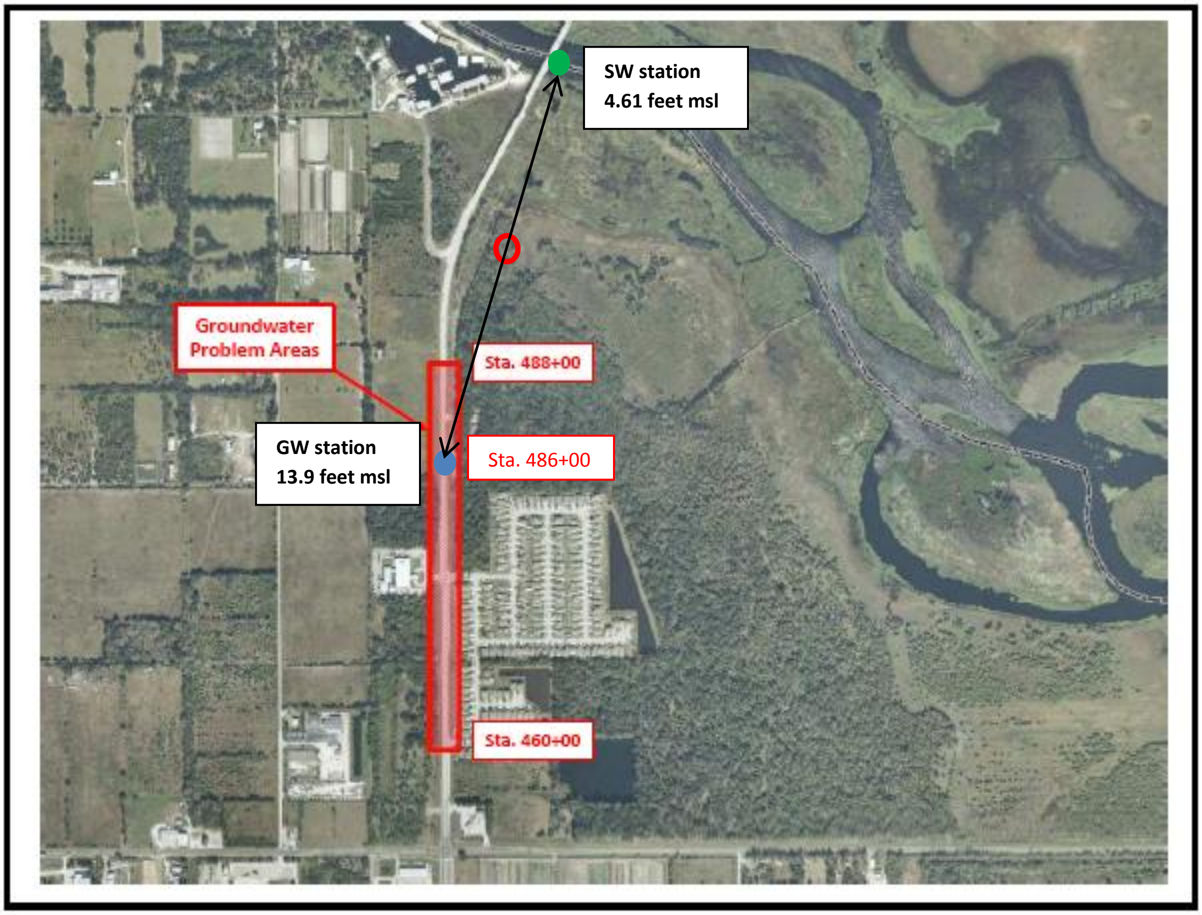

Figure B.1. Aerial photograph of the SR 415 corridor presented in Appendix A. Station 486+00 represents the location of a temporary well point used to measure ground water elevation (blue marker). The green marker represents a surface water hydrologic station used to estimate a hydraulic gradient for predicting ground water elevation at the red circle marker.

To predict a ground water elevation at Station 460+00, the distance between Station 486+00 and 460+00 must be determined. Assuming the gradient increases between 486+00 and 460+00, the hydraulic gradient from the previous example, 0.00351 ft/ft, is used to determine the predicted ground water elevation. The distance is multiplied by the gradient to arrive at a rise in ground water. The calculated rise is added to the known ground water measurement at 486+00 to arrive at a new predicted ground water elevation.

Predicting the SHGWT beyond the known measured stations to an unknown location can be accurately completed. For example, a hypothetical storm water management basin is proposed to be located approximately 2.5 miles (13,200 ft) south of the construction zone. Assuming there are no hills and the landscape is flat for the entire distance, within the same drainage basin, the established hydraulic gradient from the construction zone can be applied to arrive at a prediction.

Taking the example hydraulic gradient estimated above, 0.00351 ft/ft, we know the ground water slope is rising towards the south from station 460+00. First, we must calculate the ground water elevation at Station 460+00 using the known estimated hydraulic gradient value of 0.000351 ft/ft. The distance from Station 486+00 to 460+00 is approximately 1650 ft. the rise in ground water is expected to be 1650 ft x 0.000351 ft/ft resulting in 0.58 ft. The measured ground water elevation at 486+00 was 13.9 ft above msl added to the rise in ground water 0.58 ft results in a predicted ground water elevation of 14.48 ft above msl. Projecting to the proposed storm water management basin south of the construction zone, an estimated rise in ground water must be calculated using the known hydraulic gradient value of 0.000351 ft/ft and a distance of 13,200 ft. The resulting rise is estimated to be 4.63 ft. Applying the predicted ground water elevation at 460+00 of 14.48 ft added to the 4.63 ft rise, a predicted ground water elevation at the storm water basin site would be 19.11 ft above msl. Depth to ground water from the ground surface may be determined from knowledge of the topographic land surface at the proposed storm water basin location.

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