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Improved Methodologies for Modeling Storage and Water Level Behavior in Wetlands

by

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of the requirements for the degree of
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ABSTRACT

Wetlands are important elements of watersheds that influence water storage, surface water runoff, groundwater recharge/discharge processes, and evapotranspiration. To understand the cumulative effect wetlands have on a watershed, one must have a good understanding of the water-level fluctuations and the storage characteristics associated with multiple wetlands across a region. An improved analytical method is presented to describe the storage characteristics of wetlands in the absence of detailed hydrologic and bathymetric data. Also, a probabilistic approach based on frequency analysis is developed to provide insight into surface and groundwater interactions associated with isolated wetlands. The results of the work include: 1) a power-function model based on a single fitting parameter and two physically based parameters was developed and used to represent the storage of singular or multiple wetlands and lakes with acceptable error, 2) a novel hydrologic characterization applied to 56 wetlands in west-central Florida provided new information about wetland hydroperiods which indicated standing water was present in the wetlands 62% of the time and these wetlands were groundwater recharge zones 59% of the time over the seven year study, 3) the smallest extreme value probability distribution function was identified as the best-fit model to represent the water levels of five wetland categories in west-central Florida, 4) representative probability models were developed and used to predict the water levels of specific wetland categories, averaging less than 10% error between the predicted and recorded water levels, and 5) last, based on this probability analysis, the various wetland categories were shown to exhibit similar means, extremes and ranges in water-level behavior but unique slopes in frequency distributions, a here to for new finding. These results suggest that wetland types may best be differentiated by the regular variability in water levels, not by the mean and/or extreme water levels. The methods and analytical techniques presented in this dissertation can be used to help understand and quantify wetland hydrology in different climatological or anthropogenic stress conditions. Also, the methods explored in this study can be used to develop more accurate and representative hydrologic simulation models.

CHAPTER 1

INTRODUCTION

Wetlands are defined as "…those areas that are inundated or saturated by surface or groundwater at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions…" [33CFR328.3(b)] (U.S. Environmental Protection Agency 2009). Wetlands play an important role in the hydrology of watersheds impacting water storage, surface water runoff, groundwater recharge/discharge processes, and evapotranspiration (Bullock and Acreman 2003). These influences are difficult to quantify or model in many settings, especially in shallow water-table environments typified by west-central Florida.

In order to understand the individual or cumulative effect wetlands have on a watershed or region, water level records associated with multiple wetlands across a region or within a specific wetland category must be studied. The hydrologic characterization of wetlands requires the use of long-term data records to describe the interaction of different surface and groundwater influences. Monitoring the pooled water fluctuations as well as water-table fluctuations in and around wetlands is critical in evaluating surface and groundwater interactions.

An application of the hydrologic characterization of wetlands is the development of accurate hydrologic models that can be used to predict watershed responses. In particular, the variability associated with wetland water level fluctuations needs to be understood and quantified. A good representation of wetland storage behavior is essential to ensure the respective hydrologic model functions reliably (Winter 1999). Without reasonable hydraulic and storage information, hydrologic models may not represent or predict the water balance in the hydrologic system accurately, and may produce inaccurate estimates of stream flows, groundwater recharge/discharge, evapotranspiration, flood plain delineation, and/or wetland sustainability. To avoid this shortcoming, water resource engineers and hydrologists need to better define: 1) the surface and subsurface water level characteristics associated with wetlands, 2) the movement of water into and out of wetlands, and 3) the surface and subsurface water storage of wetlands in a hydrologic study area.

Defining these characteristics for any finite hydrologic study area could be a daunting task. For example, approximately 20% of the land surface in the Southwest Florida Water Management District (SWFWMD), which encompasses 25,900 km^2 (10,000 square miles) of west-central Florida, and 29% of Florida overall are occupied by wetlands (Lee et al. 2009; Southwest Florida Water Management District 2007). This presents a significant problem for large simulation models. Detailed bathymetric profiles, used to estimate wetland storage behavior, as well as abundant, long-term and accurate water-level records typically do not exist for most wetlands. Furthermore, traditional methods used to describe wetland water-level fluctuations, such as the statistical mean, median and ranges, provide limited insights into the hydrologic characteristics of a wetland or particular wetland types.

This dissertation presents an analysis of long-term water-elevation data and improved methods designed to help describe wetland water-level fluctuations. Further, the work provides a better means to define the above ground storage characteristics as well as the surface and groundwater interactions associated with wetlands. An analytical method is developed to describe the storage characteristics of wetlands in the absence of detailed hydrologic and bathymetric data. Also, a probabilistic approach (frequency analysis) is used to provide insights into surface and groundwater interactions associated with isolated wetlands. The scopes of the specific chapters are outlined below.

In Chapter Two an analytical model is developed and evaluated that can be used to predict the storage behavior of multiple wetlands and lakes when detailed bathymetric data is limited or unavailable. General models were developed based on detailed bathymetry of wetlands and lakes located in west-central Florida, North Dakota and Canada.

A new method employing frequencies is introduced in Chapter Three to characterize the surface water and groundwater levels associated with 56 various isolated wetlands located in west-central Florida. The hydrologic characterization of these wetlands utilizes a unique long-term data set comprised of paired wetland and upland monitoring-well water elevations. The data describe the duration of different water-level elevations in the wetland when it is flooded, and the duration of different water-table elevations below the wetland when they are dry. Empirical (frequency) distributions were used to identify key probability indices corresponding to the period of wetland inundation, as well as median and extreme water levels. These distributions were then used to compare the hydrologic characteristics of different wetland categories. Additionally, the distributions were used to help identify impacted wetlands located throughout the region.

In Chapter Four water-elevation records for wetlands were paired with groundwater elevation records at upland wells to evaluate the interactive relationships and recharge/discharge characteristics between the isolated wetlands and surrounding uplands. Long-term wetland and upland monitoring well data were compared as well as specific data relating to the peak dry season (e.g., March-May) and wet season (e.g., July-September) to note differences in behavior.

Best-fit probability density functions (probability models) were developed in Chapter Five to represent the water levels associated with five distinct wetland categories, and five groups of wetlands in west-central Florida. The model development data sets were comprised of water levels representing all of the individual wetlands within a specific category or group. The combined data sets were developed using water-elevation data normalized to the respective wetland dry bed elevation. The probability models can be used to differentiate the water-level characteristics associated with different wetland categories and groups, and can be used as a calibration tool for hydrologic modeling applications.

The methodologies defined in this work will provide insight into the hydrologic characteristics of various wetland types, and enhance the modeling capability of wetland storage where available data is scare or does not exist. The storage model in conjunction with the frequency analyses and probability models will improve the accuracy of wetland representation in hydrologic models and aid hydrologists in predicting surface water runoff, river stage and discharge, and groundwater fluctuations. Further, this work will help evaluate the overall hydrologic impact on wetlands subjected to anthropogenic and natural climatological stresses. Last, the methodologies set forth in this dissertation can be applied to wetlands in other regions around the United States and the world to help understand their behavior and function in different geologic settings.

CHAPTER 2

A GENERAL MODEL TO REPRESENT MULTIPLE WETLAND STAGE-STORAGE BEHAVIOR

2.1. Introduction

Quantifying the relationship between stage and storage volume for wetlands and lakes is important for developing accurate hydrologic models for environments containing significant wetland or lake features. Hydrologic simulation models such as the Hydrological Simulation Program–FORTRAN (HSPF) (Bicknell et al. 2001) require specification of stage-storage behavior of wetlands and lakes in the model domain. Wetland area-depth (A-h) and volume-depth (V-h) relationships pertaining to the standing (pooled) water portion of the wetland basin are typically determined from detailed bathymetric maps or simple geometric models usually specific to each depression (Hayashi and van der Kamp 2000). Extensive and costly surveying is the most reliable method to determine accurate bathymetric profiles. However, detailed surveying is often impractical for larger hydrologic model domains comprised of hundreds to thousands of wetlands (Lee et al. 2009; Southwest Florida Water Management District 2007). Yet, a reasonable representation of wetland storage behavior is necessary for hydrologic models to function reliably and possess adequate predictive capabilities. Unfortunately, estimating the storage characteristics of each wetland in such a study area, especially when faced with a lack of survey data, can present a significant problem.

Analytical models have been utilized in hydrologic studies to predict wetland storage behavior for many years (Singh and Woolhiser 2002). However, most of the time the respective models and/or model parameters were developed to predict the behavior of the individual wetlands contained in a particular study. For instance, O'Connor (1989) developed power-function models to simulate the variations of dissolved solids in lakes and reservoirs, where separate model parameters were developed for each lake and reservoir. Shjeflo (1968) used a prismoidal formula to verify that wetland volumes developed from specific topographic maps were accurate, and Wise et al., (2000) developed a stage-volume relationship for an isolated marsh wetland. Furthermore, Hayashi and van der Kamp (2000) used a power function model utilizing a scaling constant and a dimensionless slope profile to represent the area-depth relations of individual shallow wetlands. The power-function model parameters were used to define the size and geometry of specific depressions. Later Brooks and Hayashi (2002) modified Hayashi and van der Kamp's equation to estimate the maximum volumes of the individual wetlands. Although these models proved effective for their respective purposes, they were not intended to be used in a generalized manner, i.e. to model the storage behavior of multiple wetlands in a study domain.

Two primary objectives were established to address these issues. The first was to develop an analytical technique that utilizes a simple power-function model to represent the stage-storage relationships of individual wetlands and lakes (i.e. specific power-function model). The technique makes use of a single dimensionless fitting or "shape" parameter that can be used to define a specific wetland stage-storage relationship.

Further, the technique requires limited field data such as the maximum or reference pool area (based on vegetative cover) obtained from aerial photographs or from polygon coverages in Geographic Information System (GIS) databases, such as the National Wetlands Inventory (U.S. Fish and Wildlife Service 2007b), and the associated maximum pool depth corresponding to that area.

The second was to use the power-function model to predict the storage behavior of multiple wetlands and lakes in a hydrologic study area when detailed bathymetric data is limited or unavailable. The goals of this objective were to: 1) develop generalized shape parameters (i.e. general stage-storage models) for specific wetland categories, lakes, and wetland groups, 2) investigate the error of the predicted stage-storage relationships using the general shape parameters, 3) test the general shape parameter against an independent validation data set comprised of 21 lakes in west-central Florida, and 4) to aid hydrologic modelers potentially using the stage-storage model by quantify the sensitivity and uncertainty of the shape parameter and the sensitivity of the reference pool depth.

2.2. Theory and Methodology

2.2.1. *V-h* Power-Function Wetland Model

Wetland and lake stage-storage relationships can be described via a simple power function relating the wetland pool volume (V) to the wetland pool depth (h) using a single dimensionless "shape" parameter (m) (Nilsson et al. 2008). Parabolic equations serve as a starting geometric model for these depressions. From this model, it can be shown that a power function representing the conical rotation of any profile (i.e. convex, planar or concave) with the origin at the deepest point in the wetland can be expressed as:

$$V_{Vh}(h) = \left(\frac{A_o h_o}{m}\right)\left(\frac{h}{h_o}\right)^m \tag{2.1}$$

where V_{Vh} [L^3] is the wetland or lake volume corresponding to the respective pool depth, h [L], A_o [L^2] is the maximum coverage area when the wetland pool is full, h_o [L] is the maximum wetland pool depth, and m is the dimensionless fitting or shape parameter describing the wetland *V-h* geometric relationship. The *V-h* power-function model [Eq. (2.1)] will be referred to as the *V-h* Model hence forth. The wetland *V-h* relationship is robust, describing a wide range of geometries, depending on the value of the m parameter, however the primary assumption for this method is that wetlands are circular in shape. For instance, $m = \infty$ in Eq. (2.1) produces a vertical line at the maximum pool depth, representing cylindrical storage, $m = 1$ produces a planar curve, and $0 < m < 1$ and $1 < m < \infty$ produce convex and concave volume-stage curves respectively.

2.2.2. Model Development Data Set

Specific *V-h* Models were developed for 42 individual wetlands and lakes. The specific shape parameters presented in Table 2.1 were derived from the specific *V-h* Models using detailed bathymetric survey data for five cypress wetlands, five marsh wetlands and 17 lakes located in west-central Florida (Haag et al. 2005; Nilsson et al. 2008), as well as five pothole wetlands located in St. Denis National Wildlife Area in Saskatchewan, Canada (Hayashi and van der Kamp 2000), and 10 prairie pothole wetlands located in

North Dakota (Shjeflo 1968). The west-central Florida wetlands and lakes were formed by solution weathering of the karst terrain and in some instances deep karst collapse, while the pothole wetlands located in the northern United States and Canada were formed by glacial scouring. Additionally, Table 2.1 contains the maximum pool areas (A_o), pool depths (h_o), pool volumes (V_o) and the individual wetland storage shape parameters (m), and associated summary statistics for all wetlands in the data set.

Table 2.1. Wetland site characteristics and *V-h* Model performance.

		Characteristics				Model Evaluation					
Wetland	Category	A_o	h_o	V_o	k	Upper 80% V_o		100% V_o		V_{ARE}	V_{RE}
		(x10^3 m^2)	(m)	(x10^3 m^3)		m	$RMSE_{Rel}$*(%)	m	$RMSE_{Rel}$*(%)	(%)	(%)
West-Central Florida											
W05	Cypress	35.5	0.6	5.7	23	4.2	2.9	4.3	2.8	7.7	2.8
W19	Cypress	8.4	0.8	2.8	28	2.5	0.6	2.5	0.6	1.1	0.2
S63	Cypress	5.1	0.4	0.9	16	2.7	4.8	2.7	4.6	10.2	4.1
S68	Cypress	23.4	0.5	5.6	17	2.0	1.7	2.0	1.7	1.4	-0.4
GSC	Cypress	6.8	0.5	1.0	18	3.5	1.2	3.5	1.2	4.2	-2.4
W03	Marsh	29.9	1.5	17.2	35	2.7	6.2	2.8	5.8	7.1	-0.5
W29	Marsh	26.4	0.9	11.6	29	2.0	1.9	2.0	1.8	2.2	0.2
HRSP	Marsh	9.0	0.7	1.8	24	3.3	1.5	3.3	1.5	4.3	-2.4
DP	Marsh	21.0	2.4	20.5	41	2.5	1.6	2.5	1.6	2.7	-1.2
GSM	Marsh	6.6	0.3	1.2	12	1.8	1.9	1.8	1.8	1.6	-0.1
Big Fish	Lake	4,330	7.3	19,300	13	1.8	6.6	1.8	6.4	15.6	8.3
Bonnie	Lake	133	4.6	253	17	2.3	3.3	2.3	3.3	10.0	-6.8
Calm	Lake	610	10.0	2,200	12	2.8	2.0	2.8	1.9	3.8	0.5
Clear	Lake	698	8.8	3,900	11	1.6	1.7	1.6	1.7	2.9	1.1
Garden	Lake	72	8.4	177	11	3.4	1.0	3.4	1.0	1.8	-0.5
Green	Lake	423	5.6	440	11	5.1	6.8	5.1	6.8	22.8	-13.1
Jackson	Lake	13,300	9.8	77,100	12	1.7	2.5	1.7	2.5	4.6	1.1
Letta	Lake	2,210	6.7	9,880	11	1.5	2.0	1.5	1.9	2.4	1.1
Middle	Lake	1,110	5.8	3,440	11	1.9	1.3	1.9	1.3	2.8	1.6
Mound	Lake	444	9.7	1,650	12	2.6	1.2	2.6	1.2	1.5	-0.2
Mountain	Lake	272	5.1	632	10	2.2	2.2	2.2	2.2	6.3	3.0
Neff	Lake	1,310	7.8	3,230	10	3.1	0.4	3.1	0.4	2.8	-1.1
Placid	Lake	14,700	18.0	106,000	13	2.6	2.1	2.6	2.1	4.8	2.1
Pretty	Lake	420	8.0	1,950	10	1.7	1.9	1.7	1.9	2.2	-1.0
Reinheimer	Lake	158	3.6	187	12	2.9	2.2	2.9	2.1	8.1	-3.2
Round	Lake	57	8.1	143	10	3.2	1.3	3.2	1.3	3.3	-2.4
Spring	Lake	259	15.5	1,830	12	2.2	1.3	2.2	1.3	1.3	0.1

Table 2.1. (Continued).

		Characteristics						Model Evaluation			
Wetland	Category	A_o (x10^3 m^2)	h_o (m)	V_o (x10^3 m^3)	k	Upper 80% V_o		100% V_o		V_{ARE} (%)	V_{RE} (%)
						m	$RMSE_{Rel}$*(%)	m	$RMSE_{Rel}$*(%)		
St. Denis NWA											
S92	Pothole	3.2	1.2	1.7	12	2.2	1.8	2.2	1.8	5.2	-3.4
S104	Pothole	1.2	0.7	0.4	7	2.0	1.0	2.0	1.0	2.7	-1.7
S109	Pothole	4.1	1.2	2.1	12	2.3	1.2	2.3	1.2	3.0	-1.3
S120	Pothole	3.2	1.1	1.9	11	1.8	0.8	1.8	0.8	2.2	-1.4
S125s	Pothole	3.9	1.0	2.0	10	2.0	0.4	2.0	0.4	0.4	0.2
North Dakota											
1	Pothole	81	2.6	143	11	1.5	0.6	1.5	0.6	1.7	-1.1
2	Pothole	174	3.3	403	14	1.4	1.0	1.4	1.0	1.3	0.3
3	Pothole	352	4.3	850	14	1.8	1.3	1.8	1.3	3.6	-1.8
4	Pothole	138	3.0	300	13	1.4	0.5	1.4	0.5	0.8	0.2
C-1	Pothole	198	1.9	278	10	1.4	0.9	1.4	0.9	1.3	0.1
5	Pothole	105	2.3	178	11	1.4	0.4	1.4	0.4	0.4	-0.2
5A	Pothole	13	1.4	10	11	1.8	0.7	1.8	0.7	0.6	-0.2
6	Pothole	38	1.5	43	12	1.3	0.8	1.3	0.8	1.4	0.2
7	Pothole	105	1.5	101	11	1.5	0.8	1.6	0.8	2.4	1.5
8	Pothole	121	1.1	91	10	1.5	1.4	1.5	1.3	2.8	1.2
Summary Statistics	Mean	1,000	4.3	5,590	15	2.3	1.8	2.3	1.8	4.0	-0.4
	StD	3,040	4.2	20,000	7	0.8	1.6	0.8	1.5	4.3	3.1
	Min	1.21	0.3	0.41	7	1.3	0.4	1.3	0.4	0.4	-13.1
	Max	14,700	18.0	106,000	41	5.1	6.8	5.1	6.8	22.8	8.3

*$RMSE_{Rel}$ = $RMSE_{V\text{-}h}$ normalized by the maximum wetland volume (V_o).

k represents the total number of pool stages.

The methodology and specific details used to obtain the wetland bathymetry as well as the data quality for the pothole wetlands in Saskatchewan, Canada and the prairie pothole wetland located in North Dakota are outlined in the respective studies listed above. The cypress and marsh wetland bathymetry data, stage-storage data and classification were provided by the United States Geological Survey (USGS) (Haag et al. 2005). Haag et al. (2005) provides a complete description of the bathymetry data quality used in the study. The extent of each wetland was determined using biological indicators and the respective wetland perimeter elevations. The lake bathymetry data were provided as TINs by Mr. Doug Leeper, Senior Environmental Scientist, Resource Conservation and Development Department, Southwest Florida Water Management District (SWFWMD) (personal communication, January 19, 2006). According to Mr. Leeper, the lake bathymetry data were collected using standard survey equipment (rod/level) or a Global Positioning System (GPS)/Sonar system. The water depths or sediment elevations were measured relative to water level gauges, which are routinely surveyed to check accuracy against known benchmarks within the lake basins. Additional elevation data for the basins were obtained from SWFWMD aerial photographs in conjunction with 0.3048 meter (1.0 foot) contour maps. The elevation data from the maps were digitized using ArcMap. The field data and digital elevation data were combined to create TINs using ArcMap. Furthermore, the horizontal tolerance of the surveyed bathymetry data is reported to be ± 0.5 meters (1 to 2 feet). The vertical tolerance of the surveyed data is reportedly within 0.061 meters (0.2 feet) to 0.183 meters (0.6 feet). The vertical tolerance of the digital elevation data is within 0.152 meters (0.5 feet). Stage-storage relationships were later developed from the TINs using ArcMap 3D Analyst, Area and Volume Statistics tool.

Constant interval depths were calculated by dividing the total number of wetland stages (k) into the maximum pool depth (Table 2.1) to define the lake stage depths. At each stage, starting at h_o, the corresponding planar area and pool volume were calculated using the statistics tool creating the stage-storage profile for the respective lake wetland. The developed stage-storage relationships were then incorporated into this study.

2.2.3. *V-h* Model Shape Parameter Development

The dimensionless wetland fitting or shape parameter (m) was calculated using a spreadsheet solver (Microsoft Excel Solver) for every wetland in the study. The solver tool was used to minimize the root-mean-squared error (RMSE) between the GIS-derived, observed or reported volumes (V_{GIS}) and the *V-h* Model generated volumes (V_{Vh}) by adjusting the respective wetland shape parameter m [Eq. (2.1)]. The RMSE for the *V-h* relationship is:

$$RMSE_{Vh} = \sqrt{\frac{1}{k}\sum_{i=1}^{k}\left[(V_{GIS})_i - (V_{Vh})_i\right]^2} \tag{2.2}$$

where $RMSE_{Vh}$ [L^3] is the RMSE calculated for the *V-h* Model, i is the wetland or lake pool stage, k is the total number of pool stages, $(V_{GIS})_i$ [L^3] is the wetland or lake volume at stage i as reported in the original articles, and $(V_{Vh})_i$ [L^3] is the pool volume produced from the *V-h* Model [Eq. (2.1)] at stage i. For the remainder of the chapter, the RMSE will be reported as a percent of the respective wetland maximum volume (V_o) to keep the

RMSE comparable with the wide range of wetland and lake volumes:

$RMSE_{\mathrm{Re}l} = (RMSE_{Vh}/V_o)*100\%$.

Specific wetland shape parameters were developed using two stage-storage data sets: (1) the upper 80% of the maximum wetland volume (80% V_o), determined by the closest stage data point, and (2) the complete wetland stage-storage data set (100% V_o). The purpose was to evaluate the specific wetland shape parameters developed from the different input data sets. The respective shape parameters were used to reproduce wetland volumes at each stage for all 25 wetlands and 17 lakes discussed in this chapter.

2.3. Methods

2.3.1. Model Evaluation Techniques

The RMSE analysis [(Eq. (2.2)] in conjunction with an absolute volumetric error (V_{ARE}) analysis was used to evaluate the predicted wetland storage generated from the *V-h* Model and general shape parameters. The error analyses provide an indication of how well the *V-h* Model storage prediction matches the actual wetland storage. It was hypothesized that the *V-h* Model should perform best on circular bowl shaped wetlands and lakes. However, wetlands and lakes are not generally circular in shape. Even so, these analyses give an overall indication of the fit of the model to the stage-storage characteristics of the wetlands, indirectly taking into account the deviation of the wetland shape from a circular bowl. Although the wetlands and lakes used in this study exhibited a wide variety of shapes, elongated lakes such as oxbows were not included and may need further investigation.

The absolute volumetric error (V_{ARE}) is defined as:

$$V_{ARE} = \frac{1}{k}\sum_{i=1}^{k}\left[ABS\left(\frac{(V_{Vh})_i - (V_{GIS})_i}{(V_{GIS})_i}\right)\right]*100\% \quad \text{for } k \geq 20\%V_o \tag{2.3}$$

where *ABS* is the absolute value, and all other parameters are defined in Eq. (2.2). The volumetric error was developed from a range of volumes comprised of the upper 80% V_o, determined by the closest stage data point. The upper 80% V_o was used to calculate the relative volumetric error because the micro-topography of the bottom of the wetlands is difficult to know with confidence, particularly when data sets are used from different studies. Further, the relative volumetric error (V_{RE}) for each wetland was calculated to determine if the *V-h* Model under or over predicted the actual reported wetland volume. This was accomplished by removing the absolute value term in Eq. (2.3).

2.3.2. General Shape Parameter Development

General shape parameters were developed from the specific wetland and lake shape parameters based on the complete wetland stage-storage data set (100% V_o) listed in Table 2.1. The general shape parameters were calculated by combining the specific parameters associated with the various categories using three averaging methods: mean, median and volume-weighted. The volume-weighted average (m_V) was calculated as:

$$\left(m_V\right)_t = \frac{\sum_{j=1}^{n}\left[m_j \times \left(V_o\right)_j\right]}{\sum_{j=1}^{n}\left(V_o\right)_j} \tag{2.4}$$

where m_V is the volume-weighted average shape parameter value for wetland category t, j is a wetland in wetland category t, m_j is the dimensionless shape parameter for wetland j, $(V_o)_j$ [L^3] is the maximum volume for wetland j, and n is the number of wetlands in the wetland category. These statistical methods were chosen to determine which was the most robust for this application.

General shape parameters were developed for each of the four wetland categories and lakes (Table 2.1), and for three different category groupings outlined in Table 2.2. The first group (Case I) consists of the cypress wetlands, marsh wetlands and lakes representing the west-central Florida region, the second group (Case II) consists of all 25 wetlands, and the third group (Case III) is comprised of all 25 wetlands and 17 lakes identified in Table 2.1. The groups were chosen to represent west-central Florida regional data, only wetland data, and all wetland and lake data respectively.

2.4. Specific *V-h* Model Parameters

Table 2.1 contains the results of the iterative solver showing the calculated shape parameter for each wetland based on the respective bathymetry data set (Upper 80% V_o and 100% V_o). The results illustrate that there are no significant differences in the shape parameters generated from the two different stage-storage data sets. The average relative error between the shape parameters produced from each stage-storage data set is only 0.5%. This confirms that minimizing the RMSE between the GIS volumes and *V-h* Model volumes generate consistent shape parameters for the stage-storage data sets based on either the upper 80% V_o or the entire data set (100% V_o). The nature of the RMSE analysis weights the larger volumes (upper 80% V_o) more than the smaller wetland volumes (bottom 20% V_o). Since there are minimal differences between the data set shape parameters, the remainder of this study will utilize the shape parameters based on 100% V_o.

Furthermore, this analysis shows that the wetland shape factors can be equally developed from the upper 80% V_o potentially eliminating the need to perform expensive and labor intensive detailed bathymetric surveys of the bottom 20% of the wetland. Estimates of the lowest wetland volumes are subject to survey errors and/or noise. These errors are due to small topography variations (micro-topography) in the bottoms of the wetlands.

The respective *V-h* power-function shape parameter values for each wetland in the study are listed in Table 2.1. The average shape parameter values and corresponding coefficients of variation (CV) for the five wetland categories are: cypress (3.0, 30%), marsh (2.5, 25%), St. Denis NWA (2.1, 9%), pothole (1.5, 11%), and lake (2.5, 35%). The coefficient of variation was calculated for each category from the respective shape parameter mean and standard deviation associated with each category listed in Table 2.1. The average shape parameter and CV for all wetlands in the study are 2.3 and 36% respectively. Solving for the shape parameter by minimizing the RMSE between the

GIS-derived or reported volumes and corresponding *V-h* Model volumes ensured the best overall specific shape parameter and corresponding wetland stage-storage relationship was found.

Additionally, the model statistics (Table 2.1 – Model Evaluation) indicate the normalized RMSE ($RMSE_{Rel}$), and the absolute relative volumetric error (V_{ARE}) associated with each wetland stage-storage prediction are very close. These analyses were performed to evaluate the goodness-of-fit of the *V-h* Model volumes with the respective GIS-derived wetland volumes. The average $RMSE_{Rel}$ and V_{ARE} developed by the *V-h* Model for each wetland category are: cypress (2.2%, 5%), marsh (2.5%, 4%), St. Denis NWA (1.1%, 3%), pothole (1.5, 1%), and lake (2.4%, 6%). The average $RMSE_{Rel}$ and V_{ARE} for the complete wetland data set are only 1.8% and 4%. Furthermore, the relative volumetric error analysis (V_{RE}) showed little bias in over or under prediction of the respective wetland volumes. The *V-h* Model over predicted the wetland storage for 48% of the wetlands and under predicted storage for 52% of the wetlands. Based on these small errors the *V-h* Model appears robust and adaptive, and was found to be accurate for particular shape parameters with relatively small variability.

2.5. *V-h* Model Parameter Sensitivity Analysis

A sensitivity analysis was performed on the respective wetland *V-h* Model shape parameter (m) and on the maximum pool depth estimate (h_o) to better understand the relationships these variables have on the *V-h* Model performance. This analysis provides a quantitative measure of how sensitive the *V-h* Model storage predictions are to the shape-parameter value-estimate, and how the model results are affected by errors in the maximum pool depth. This is important because the shape parameter will need to be estimated when survey data are unavailable, and the maximum pool depth may be determined in a variety of ways (i.e. surveyed or estimated) with varying associated errors.

The sensitivity analysis was conducted by adjusting the best-fit shape parameter and the maximum pool depth listed in Table 2.2 by ± 10% and ± 20%. Each parameter was adjusted separately to isolate the effect on the *V-h* Model prediction. The resultant wetland stage-storage relationships were then compared to the specific *V-h* Model best-fit results. The absolute value of the positive and negative parameter changes were averaged to get a relative sensitivity, and evaluated using the corresponding V_{ARE} for each wetland. Table 2.2 contains the average V_{ARE} generated from the shape parameter (m) and maximum pool depth (h_o) estimates for each wetland in the development data set. Adjusting the shape parameters (m) by ± 10% and ± 20% increased the average V_{ARE} for the data set from 4% (specific m) to 17.5% and 35.7% respectively. Likewise the average V_{ARE} increased from 4% (specific m) to 12.8% and 25.8% when the depth parameter (h_o) was adjusted by ± 10% and ± 20% respectively. This indicates that the model predicted volumes are more sensitive to the shape parameter (power coefficient) than the maximum depth parameter (linear coefficient); however, as can be seen in Table 2.2, the results indicate strong sensitivity to both values.

Table 2.2. *V-h* Model shape parameter and maximum pool depth estimate sensitivity analysis.

				Sensitivity (V_{ARE})			
Wetland	Category	h_o (m)	m	m (%)		h_o (%)	
				± 10%	± 20%	± 10%	± 20%
West-Central Florida							
W05	Cypress	0.6	4.3	17.9	37.3	31.4	70.1
W19	Cypress	0.8	2.5	17.7	36.9	14.8	30.9
S63	Cypress	0.4	2.7	19.3	37.7	19.4	35.9
S68	Cypress	0.5	2.0	16.6	34.6	9.9	20.3
GSC	Cypress	0.5	3.5	18.1	37.7	22.6	48.8
W03	Marsh	1.5	2.8	16.7	34.5	18.1	37.5
W29	Marsh	0.9	2.0	17.0	35.3	9.7	20.1
HRSP	Marsh	0.7	3.3	17.2	35.8	21.8	46.8
DP	Marsh	2.4	2.5	15.8	32.8	14.5	30.2
GSM	Marsh	0.3	1.8	16.6	34.4	8.3	16.9
Big Fish	Lake	7.3	1.8	22.8	39.0	17.4	24.2
Bonnie	Lake	4.6	2.3	17.2	36.0	15.3	25.4
Calm	Lake	10.0	2.8	16.6	34.4	16.6	34.8
Clear	Lake	8.8	1.6	16.6	34.4	7.2	13.2
Garden	Lake	8.4	3.4	16.2	33.8	21.2	45.3
Green	Lake	5.6	5.1	25.4	33.5	35.1	67.1
Jackson	Lake	9.8	1.7	16.4	34.0	8.8	16.0
Letta	Lake	6.7	1.5	17.7	36.9	6.5	12.2
Middle	Lake	5.8	1.9	17.3	36.0	9.4	19.3
Mound	Lake	9.7	2.6	16.6	34.6	14.9	31.2
Mountain	Lake	5.1	2.2	18.7	39.1	14.2	25.4
Neff	Lake	7.8	3.1	17.8	37.1	19.3	41.0
Placid	Lake	18.0	2.6	17.5	36.4	15.4	32.2
Pretty	Lake	8.0	1.7	16.6	34.6	7.5	15.3
Reinheimer	Lake	3.6	2.9	16.7	34.8	17.1	35.9
Round	Lake	8.1	3.2	16.2	33.7	18.6	39.5
Spring	Lake	15.5	2.2	16.7	34.8	11.9	24.5

Table 2.2. (Continued).

Wetland	Category	h_o (m)	m	Sensitivity (V_{ARE})			
				m (%)		h_o (%)	
				± 10%	± 20%	± 10%	± 20%
St. Denis NWA							
S92	Pothole	1.2	2.2	17.7	36.9	11.7	23.5
S104	Pothole	0.7	2.0	17.5	36.6	10.2	21.0
S109	Pothole	1.2	2.3	16.9	35.2	12.3	25.5
S120	Pothole	1.1	1.8	17.7	36.9	8.2	16.9
S125s	Pothole	1.0	2.0	18.2	38.0	9.8	20.2
North Dakota							
1	Pothole	2.6	1.5	17.4	36.2	5.6	10.9
2	Pothole	3.3	1.4	16.7	34.8	5.0	10.0
3	Pothole	4.3	1.8	18.1	37.9	8.4	16.2
4	Pothole	3.0	1.4	17.4	36.2	4.6	9.3
C-1	Pothole	1.9	1.4	16.4	34.2	4.9	9.8
5	Pothole	2.3	1.4	16.5	34.3	4.7	9.5
5A	Pothole	1.4	1.8	16.6	34.4	8.5	17.4
6	Pothole	1.5	1.3	16.8	35.1	4.0	8.2
7	Pothole	1.5	1.6	18.7	39.0	6.3	12.7
8	Pothole	1.1	1.5	16.1	33.4	6.8	12.4
Summary Statistics	Mean	4.3	2.3	17.5	35.7	12.8	25.8
	StD	4.2	0.8	1.7	1.6	7.0	14.8
	Min	0.3	1.3	15.8	32.8	4.0	8.2
	Max	18.0	5.1	25.4	39.1	35.1	70.1

2.6. Results and Discussion

2.6.1. General Shape Parameter Analyses

The application of this work is to use a single generalized wetland shape parameter in conjunction with *V-h* Model [Eq. (2.1)] to represent the stage-storage behavior of multiple wetlands and lakes. Table 2.3 lists the generalized shape parameters that were calculated using the three statistical averages (mean, median and m_V) for the four individual wetland categories, the lake category, and for the three wetland groups: Case I – cypress wetlands, marsh wetlands and lakes located in west-central Florida, Case II – cypress, marsh, St. Denis pothole and North Dakota pothole wetlands, and Case III – all wetlands and lakes identified in Table 2.1. Additionally, the *V-h* Model performance results produced using the general shape parameters and the wetland category specific shape parameters (specific *m*) are presented in Table 2.3. The results are listed as summary statistics of the $RMSE_{Rel}$ and V_{ARE} for each wetland category or group. The stage-storage model [Eq. (2.1)] will be referred to as a *general V-h* Model when general shape parameters are incorporated and as a *specific V-h* Model when wetland or lake specific shape parameters are incorporated.

Table 2.3. Generalized shape parameter evaluation.

Case	Data Set	General *m*		$RMSE_{Rel}$* (%)				V_{ARE} (%)				V_{OP}
		m	Statistic	Ave	StD	Min	Max	Ave	StD	Min	Max	(%)
	Cypress	**Specific *m***		**2.2**	**1.6**	**0.6**	**4.6**	**4.9**	**4.0**	**1.1**	**10.2**	**60**
		3.0	mean	15.8	14.2	0.6	36.8	52.9	54.9	1.3	139.5	40
		2.7	median	14.3	10.4	4.6	29.8	45.8	41.7	10.3	113.4	60
		3.0	m_V	15.8	14.2	0.6	36.8	52.9	54.9	1.3	139.5	40
	Marsh	**Specific *m***		**2.5**	**1.9**	**1.5**	**5.8**	**3.6**	**2.2**	**1.6**	**7.1**	**20**
		2.5	mean	12.8	7.2	2.0	19.9	31.6	20.9	3.7	57.4	40
		2.5	median									
		2.5	m_V									
	Lake	**Specific *m***		**2.4**	**1.7**	**0.8**	**6.5**	**5.7**	**5.7**	**1.3**	**22.8**	**53**
		2.5	mean	16.6	13.9	2.3	62.3	42.0	38.1	4.7	173.7	47
		2.3	median	18.0	16.4	3.1	74.0	47.0	47.1	6.7	211.0	47
		2.2	m_V	19.1	18.2	1.3	80.8	50.4	53.3	1.2	232.6	65
	St. Denis Pothole	**Specific *m***		**1.0**	**0.5**	**0.4**	**1.8**	**2.7**	**1.7**	**0.4**	**5.2**	**20**
		2.1	mean	5.2	2.9	2.3	9.8	12.1	7.8	5.3	24.9	40
		2.0	median	5.2	3.6	1.2	9.5	11.8	9.0	2.3	22.4	60
		2.1	m_V	5.2	2.9	2.3	9.8	12.1	7.8	5.3	24.9	40
	N. Dakota Pothole	**Specific *m***		**0.8**	**0.3**	**0.4**	**1.3**	**1.6**	**1.0**	**0.4**	**3.6**	**60**
		1.5	mean	5.9	3.9	1.7	14.1	15.4	10.5	3.9	35.7	40
		1.4	median	6.1	6.4	1.1	20.0	16.4	18.3	2.1	50.9	60
		1.5	m_V	5.9	3.9	1.7	14.1	15.4	10.5	3.9	35.7	40
I	C,M,L^{+}	**Specific *m***		**2.4**	**1.6**	**0.6**	**6.5**	**5.2**	**4.9**	**1.1**	**22.8**	**48**
		2.6	mean	15.4	11.7	1.2	57.2	40.2	34.7	1.8	157.5	44
		2.5	median	15.8	12.6	0.6	62.3	42.1	38.3	1.3	173.7	48
		2.2	m_V	19.2	16.6	1.3	80.8	53.6	53.5	1.2	232.6	67
II	C,M,St.D, N.D^{+}	**Specific *m***		**1.5**	**1.3**	**0.4**	**5.8**	**2.9**	**2.4**	**0.4**	**10.2**	**44**
		2.1	mean	17.0	12.6	2.3	55.6	46.6	44.6	5.3	208.2	36
		2.0	median	17.2	14.6	1.2	61.7	47.7	51.4	2.3	230.1	40
		1.6	m_V	25.3	25.0	2.1	94.9	72.2	84.9	4.1	347.2	68
III	**All**	**Specific *m***		**1.8**	**1.5**	**0.4**	**6.5**	**4.0**	**4.3**	**0.4**	**22.8**	**48**
		2.3	mean	17.5	12.9	1.4	74.0	46.4	39.5	3.4	211.0	36
		2.2	median	17.8	14.3	1.3	80.8	47.8	44.8	1.25	232.6	45
		2.0	m_V	19.5	18.1	1.2	96.7	53.8	57.9	2.3	283.3	50

$^{+}$ C, M, St.D, N.D, L = Cypress, Marsh, St. Denis NWA and North Dakota wetlands, and Lakes.

* $RMSE_{Rel}$ = $RMSE_{V\text{-}h}$ normalized by the maximum wetland volume (V_o).

#.# = Optimal general shape parameter (*m*).

The general *V-h* Model results were obtained by predicting the wetland stage-storage relationships for each wetland in a category or group using the general shape parameter developed from each of the three averages. Likewise, the specific *V-h* Model results (Table 2.3 – Specific *m*) were obtained using the specific wetland shape parameters listed in Table 2.1 (100% V_o). These parameters were used to predict the stage-storage relationships of the individual wetlands and lakes in each category and group. Summary statistics were then calculated for the respective general *V-h* Model predictions and the specific *V-h* Model predictions for all wetlands in the particular category or group. The general *V-h* Model performance was evaluated by comparing the respective $RMSE_{Rel}$ and V_{ARE} results (Table 2.3) to that of the specific *V-h* Model $RMSE_{Rel}$ and V_{ARE} results (Table 2.3 – Specific *m*). The optimal general shape parameter for each wetland category and group was determined by identifying the general *V-h* Model with the least deviation from the specific *V-h* Model $RMSE_{Rel}$ and V_{ARE} results.

2.6.1.1. Individual Wetland Categories

The general shape parameters developed from the three statistical measures (mean, median and m_V) had little variation within the individual wetland categories. The largest range of shape parameter values for the individual wetland categories was 0.3 found in the cypress and lake wetland categories (Table 2.3). The cypress general shape parameter ranged from 2.7 (median) to 3.0 (mean and m_V), and the lake general shape parameter ranged from 2.2 (m_V) to 2.5 (mean). The range of parameter values for the St. Denis and North Dakota pothole wetlands was only 0.1, and there was no variation in the general parameters calculated for the marsh wetlands (m = 2.5). Overall, the general parameter values calculated for the individual wetland categories ranged from 1.4 (North Dakota pothole) to 3.0 (cypress). In order to gain some perspective of the errors associated with this shape parameter range, the $RMSE_{Rel}$ and V_{ARE} were calculated for all the wetlands in this study (Case III). The average $RMSE_{Rel}$ and V_{ARE} associated with each general shape parameter are: 42.2% and 120.4% (m = 1.4) and 19.9% and 48.4% (m = 3.0).

Another analysis was performed to determine the number of wetlands needed to develop an effective general shape parameter for use in the *V-h* Model. For this exercise, the lake and pothole wetland categories (St. Denis and North Dakota) were chosen because they had the most entries, 17 lakes and 15 pothole wetlands (Table 2.1). The number of entries used to calculate the general shape parameter was incrementally increased from two to the maximum number of entries in each data set. The order of the lakes and pothole wetlands were randomly chosen before the calculations were performed. This procedure was repeated several times for each data set. The mean shape parameter for the lakes became constant, $m \approx 2.5$, when the data set was comprised of five to 10 lakes. Also, the mean shape parameter for the pothole wetlands became constant, $m \approx 1.7$, when the data set was comprised of five to 10 wetlands. The specific number of entries required to stabilize the shape parameter varied based on the order of selection. If the first entries had a shape parameter near the mean, fewer entries were needed; conversely if the first entries had a shape parameter far from the mean, more were needed to reach a stable value. This analysis suggests that a minimum of five to 10 wetlands might be needed to develop a general shape parameter(s) that can be used to describe the stage-storage characteristics of multiple wetlands and lakes.

2.6.1.2. Wetland Groups

The generalized shape parameters for the Case I, Case II and Case III wetland groups are listed in Table 2.3. The Case I general shape parameters ranged from 2.2 (m_V) to 2.6 (mean), the Case II shape parameters ranged from 1.6 (m_V) to 2.1 (mean), and the Case III shape parameters ranged from 2.0 (m_V) to 2.3 (mean). The largest general shape parameter range was 0.5 found in Case II, which was comprised of all wetlands except lakes. However, the Case III scenario, consisting of all 42 wetland and lakes, had a reduced range of general shape parameters (0.3).

2.6.2. General *V-h* Model Performance

2.6.2.1. Individual Wetland Categories

The $RMSE_{Rel}$ and V_{ARE} analysis results generated from the general *V-h* Model predictions and the specific *V-h* Model predictions are presented in Table 2.3. The optimal general shape parameters found for each wetland category are highlighted in grey. The optimal general shape parameters that produced the smallest $RMSE_{Rel}$ and V_{ARE} difference from the specific *V-h* Model results for each wetland category were: cypress (2.7), marsh (2.5), lake (2.5), St. Denis pothole (2.0), and North Dakota pothole (1.5). The mean statistic produced the best stage-storage results for the marsh, lake and pothole wetland categories; while the median statistic produced the best storage results for the cypress and St. Denis pothole wetland categories. The respective average $RMSE_{Rel}$ and V_{ARE}

associated with each identified optimal shape parameter, hence the optimal *V-h* Models, were: cypress (14.3% and 45.8%), marsh (12.8% and 31.6%), lake (16.6% and 42.0%), St. Denis pothole (5.2% and 11.8%), and North Dakota pothole (5.9% and 15.4%). Comparatively, the average $RMSE_{Rel}$ and V_{ARE} baseline (Table 2.3 – Specific *m*) values generated from the specific shape parameters were: cypress (2.2% and 4.9%), marsh (2.5% and 3.6%), lake (2.4% and 5.7%), St. Denis pothole (1.0% and 2.7%), and North Dakota pothole (0.8% and 1.6%).

The optimal shape parameters for the cypress wetlands, marsh wetlands and lakes of west-central Florida are very similar, $m \approx 2.5$. It is interesting to note that the lake storage behavior is similar to the cypress and marsh behavior, although the lakes are much deeper and larger than the cypress and marsh wetlands and exhibit a larger diversity in depth and storage (Table 2.1). Further, the St. Denis pothole and North Dakota pothole wetlands differ from the west-central Florida wetlands. The optimal shape parameter for the St. Denis pothole and North Dakota pothole wetlands were m = 2.0 and m = 1.5 respectively. Because the shape parameter describes the stage-storage relationship of a wetland, it is reasonable to expect different shape parameters for wetlands that are formed by different mechanisms. Hence, on average the St. Denis and North Dakota pothole wetlands appear to have steeper storage profiles than the west-central Florida wetlands and lakes. The cypress wetlands appear to have the shallowest stage-storage profile of all the wetlands in this study. This is to be expected since cypress wetlands need to be somewhat shallow for the cypress seeds to germinate, and to support cypress knob root structures (Mitsch and Ewel 1979).

Overall, the general shape parameters calculated for the individual wetland categories did a reasonable job predicting the individual wetland stage-storage behavior. The optimal *V-h* Models developed for the St. Denis pothole wetlands (m = 2.0) and North Dakota pothole wetlands (m = 1.5) produced the best results for the individual wetland categories. The respective average $RMSE_{Rel}$ and V_{ARE} for both categories were: 5.2% and 11.8% (St. Denis), and 5.9% and 15.4% (North Dakota) (Table 2.3). This is due, in part, to the small shape parameter distribution in each wetland category (Table 2.1). The shape parameter variance expressed as the coefficient of variation (CV) for the St. Denis and North Dakota pothole wetland categories are: 9% and 11%, respectively. The small parameter variance could be attributed to the similar wetland topography in the respective category. The cypress wetland, marsh wetland and lake optimal *V-h* Model storage predictions were not as good. The average $RMSE_{Rel}$ and V_{ARE} for each category were: 14.3% and 45.8% (cypress), 12.8% and 31.6% (marsh), and 16.6% and 42.0% (lakes) (Table 2.3). Again, this is due in part to the shape parameter variability associated with each category. The variability (CV) in the individual wetland shape parameters was: 30% (cypress), 25% (marsh), and 35% (lake).

2.6.2.2. Wetland Groups

Table 2.3 also lists the $RMSE_{Rel}$ and V_{ARE} general *V-h* Model analysis results for each wetland group (Cases I, II, III). Again, the $RMSE_{Rel}$ and V_{ARE} were calculated from the respective general shape parameters and compared to the specific *V-h* Model results for each wetland group. The optimal general shape parameters found for each wetland group are highlighted in grey. The optimal general shape parameters that produced the smallest

$RMSE_{Rel}$ and V_{ARE} were: 2.6 (Case I), 2.1 (Case II), and 2.3 (Case III). The average $RMSE_{Rel}$ and V_{ARE} produced from the optimal *V-h* Model for each case were: 15.4% and 40.2% (Case I), 17.0% and 46.6% (Case II), and 17.5% and 46.4% (Case III). Comparatively, the average $RMSE_{Rel}$ and V_{ARE} produced from the specific *V-h* Models (Specific *m*) were: 2.4% and 5.2% (Case I), 1.5% and 2.9% (Case II), and 1.8% and 4.0% (Case III) (Table 2.3). Again, the elevated errors can be attributed to the diverse nature of the wetlands incorporated in each group. The variability (CV) in the individual wetland shape parameters for each group was: 32% (Case I), 35% (Case II) and 36% (Case III).

Figure 2.1 contains a series of panels showing representative volume reproductions for the west-central Florida wetlands, St. Denis pothole wetlands, North Dakota pothole wetlands, and lakes analyzed in this study. The graphs compare the reported volumes (Actual), and the *V-h* power-function model stage-storage reproductions based on the specific wetland shape parameter found in Table 2.1 (100% V_o), and on the Case III (all wetlands and lakes) optimal generalized shape parameter, $m = 2.3$. Figure 2.1 illustrates the goodness-of-fit of the general *V-h* Model predictions (Case III) and the specific *V-h* Model storage predictions to the actual wetland volumes. Overall the general *V-h* Model predicted the individual wetland storage behavior rather well. The largest deviation from the actual storage occurred with the cypress wetland (W05). According to Haag et al. (2005) this cypress wetland has a large surface area (35,500 square meters) but an intermediate maximum depth of 0.6 meters. The relatively shallow depth was due in part to a thick layer of organics and flocculent sediment that accumulated on the floor of the wetland. The organic rich material may have filled in the deeper parts of the wetland basin, impacting the shape factor.

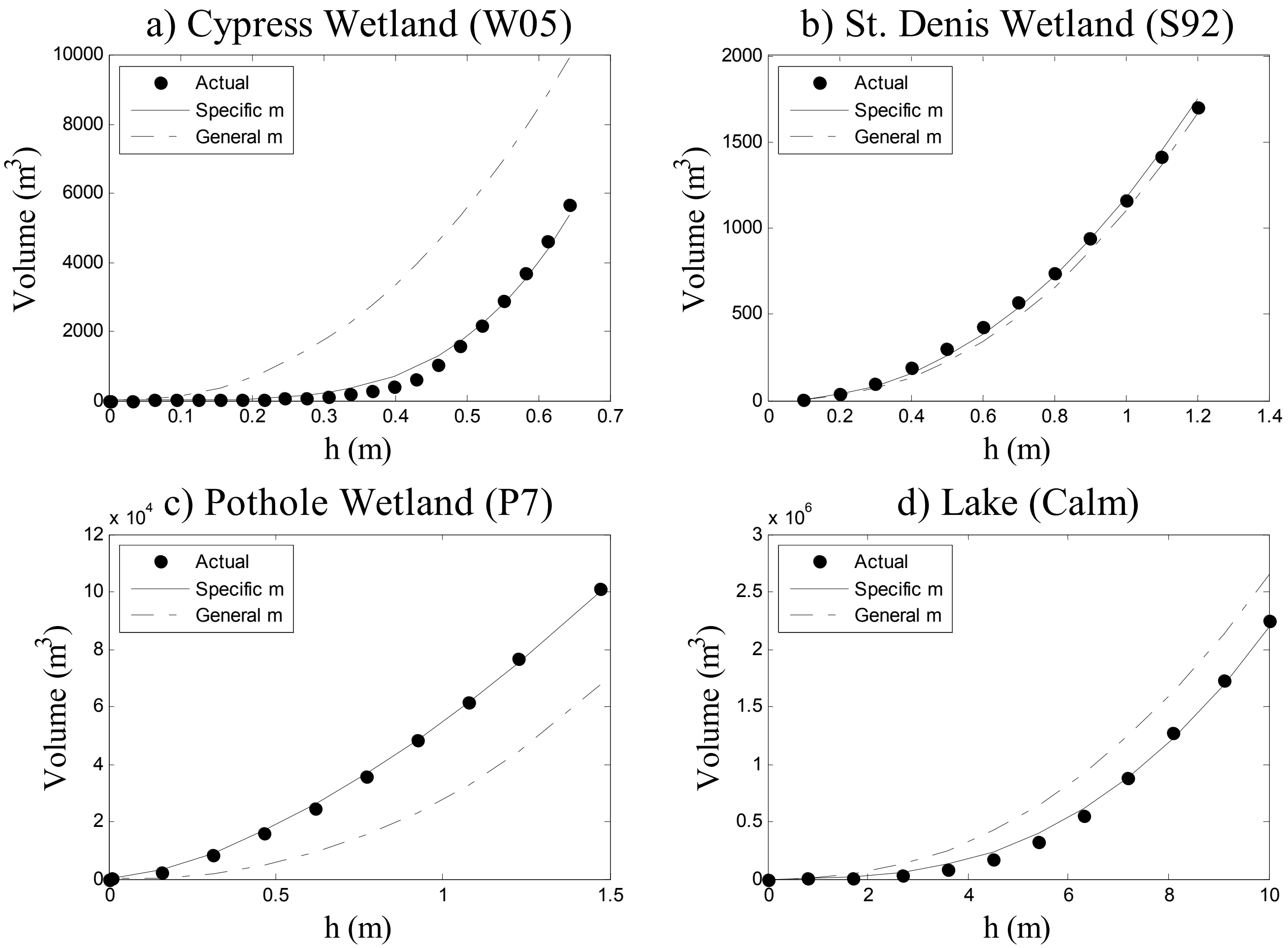

Figure 2.1 Representative model prediction comparisons for a) West-central Florida wetlands, b) St. Denis NWA wetlands, c) Pothole wetlands, and d) Lakes.

2.6.2.3. Volume Over Prediction (V_{OP}) Analysis

An analysis identifying the number of wetlands in which the general *V-h* Models over predicted the wetland storage (V_{OP}) in each category and group is shown in Table 2.3. The V_{OP} is defined as the ratio of the number of wetlands the *V-h* Model over predicted the storage to the total number of wetlands in each category expressed as a percent (Table 2.3 – V_{OP}). The V_{OP} for the specific *V-h* Model predictions and the optimal general *V-h* Model predictions for each wetland category were: cypress (60% vs. 60%), marsh (20% vs. 40%), lake (53% vs. 47%), St. Denis pothole (20% vs. 60%), and North Dakota pothole (60% vs. 40%). Additionally, the V_{OP} for the specific *V-h* Model predictions and the optimal general *V-h* Model predictions for the wetland groups were: Case I (48% vs. 44%), Case II (44% vs. 36%), and Case III (48% vs. 36%). On average, both the specific and optimal general *V-h* Models showed little bias in over or under prediction of the respective wetland volumes.

2.7. Validation Data Set Analysis

An application of the *V-h* Model and method is presented here. The model was used to predict the storage behavior of an independent data set comprised of 21 lakes in west-central Florida (Table 2.4). Based on the method, two parameters for each lake must be estimated or calculated. First the maximum pool depth (h_o) must be determined. This can be accomplished via a survey or estimation. Second the shape parameter (m) describing the stage-storage characteristics of the lake must be determined. The shape parameters can be calculated using the procedure outlined in Nilsson et al. (2008) if survey data is available, or from the parameters developed and presented in this study

(Tables 2.1 and 2.3). Once the maximum pool depth and shape parameter for each lake are determined they can be incorporated into the *V-h* Model [Eq. (2.1)] to calculate the respective lake stage-storage characteristics.

Table 2.4. Lake validation data set for general shape parameter evaluation.

Wetland	Category	Characteristics			k	General V-h Model Evaluation (%)									
						$m = 2.3$					$m = 2.5$				
		A_o X10^3 m^2	h_o m	V_o x10^3 m^3		$RMSE_{Rel}$*	V_{ARE}	V_{RE}	h_{ARE}	h_{RE}	$RMSE_{Rel}$*	V_{ARE}	V_{RE}	h_{ARE}	h_{RE}
Armistead	Lake	145	7.9	302	14	37.3	112.8	94.0	27.1	-22.6	29.2	88.1	73.4	21.7	-18.0
Brant	Lake	256	5.5	571	10	6.9	21.4	21.4	7.5	-7.5	3.6	8.0	5.2	2.8	-1.7
Carlton	Lake	332	3.0	488	6	7.1	19.4	-19.4	10.0	10.0	11.6	31.1	-31.1	16.8	16.8
Chapman 2	Lake	52	1.8	46	4	7.6	26.6	-26.6	16.5	16.5	12.1	37.4	-37.4	24.3	24.3
Chapman	Lake	165	5.5	345	10	10.5	37.5	37.5	12.2	-12.2	5.0	19.1	19.1	6.4	-6.4
Commiston	Lake	63.8	7.3	173	13	12.4	39.6	39.6	12.8	-12.8	6.9	21.5	21.5	7.1	-7.1
Deer	Lake	142	9.8	479	17	18.6	63.9	63.9	17.9	-17.9	12.6	43.3	43.3	12.4	-12.4
Elaine	Lake	9.41	2.1	13.5	8	23.6	50.8	-42.4	38.2	31.9	26.8	57.5	-47.9	43.9	36.5
Elizabeth	Lake	77.0	7.3	251	13	1.7	2.7	-1.5	1.2	0.7	5.9	14.9	-14.9	6.7	6.7
Fleur	Lake	12.1	5.5	15.4	10	46.5	136.2	113.5	30.8	-25.7	37.4	105.3	87.7	24.8	-20.6
George	Lake	109	7.3	350	13	1.4	4.0	-3.5	1.8	1.6	6.3	16.9	-14.8	7.8	6.8
Glass	Lake	85.2	6.7	146	12	39.9	142.8	142.8	30.3	-30.3	31.5	112.2	112.2	24.7	-24.7
Grace	Lake	65.1	6.1	185	11	4.8	12.5	-10.7	6.0	5.2	9.4	24.1	-20.7	11.9	10.2
Joseph	Lake	198	6.7	371	12	35.7	112.3	89.9	26.5	-21.2	28.0	88.4	70.7	21.3	-17.0
Little Deer	Lake	40.1	6.1	83.4	11	15.6	43.3	36.1	14.3	-11.9	9.3	25.4	21.2	8.6	-7.2
Lutz	Lake	26.9	5.5	53.3	10	13.0	42.7	42.7	13.6	-13.6	7.1	23.6	23.6	7.7	-7.7
Mead	Lake	59.9	2.4	62.1	5	4.0	11.1	-7.3	5.6	3.7	7.7	21.5	-16.1	11.1	8.3
Platt	Lake	256	4.3	427	8	8.0	22.2	17.8	8.0	-6.4	3.4	6.3	5.1	2.3	-1.8
Rocket	Lake	13.2	4.3	21.8	8	12.0	55.8	55.8	14.6	-14.6	7.3	34.2	34.2	8.9	-8.9
Starvation	Lake	66.3	2.4	69.9	9	1.7	6.8	6.6	2.6	-2.5	4.5	8.2	-8.2	3.6	3.6
Wastena	Lake	74.9	7.3	218	13	8.5	26.3	26.3	8.8	-8.8	4.4	10.4	9.9	3.4	-3.2
Summary Statistics	Mean	107	5.5	222	10	**15.1**	**47.2**	**32.2**	**14.6**	**-6.6**	**12.9**	**38.0**	**16.0**	**13.2**	**-1.1**
	StD	91.6	2.2	181	3	13.9	43.9	49.3	10.6	15.2	10.7	33.0	43.6	10.3	15.5
	Min	9.41	1.8	13.5	4	1.4	2.7	-42.4	1.2	-30.3	3.4	6.3	-47.9	2.3	-24.7
	Max	332	9.8	571	17	46.5	142.8	142.8	38.2	31.9	37.4	112.2	112.2	43.9	36.5

* $RMSE_{Rel}$ = $RMSE_{V\text{-}h}$ normalized by the maximum wetland volume (V_o).
k represents the total number of pool stages or pool volume increments.

In this application, general shape parameters presented in Table 2.3 were used to predict the storage behavior of the 21 lakes in west-central Florida. The maximum pool depths were obtained from surveys. The validation data set (Table 2.4) was used to evaluate the general *V-h* Model predictive capabilities on a unique lake group.

Two measures were chosen to evaluate the model: (1) storage prediction (V) and (2) stage prediction (h). The storage predictions were performed and evaluated using the techniques outlined in the Theory and Methodology section of the manuscript. Two general shape parameters, $m = 2.3$ and $m = 2.5$, were incorporated into the *V-h* Model [Eq. (2.1)] and used to develop the storage characteristics of each lake. The first was the optimal shape parameter for the 42 wetlands and lakes in the development data set (Table 2.3 – Case III), and the second was the optimal shape parameter for the west-central Florida lake category (Table 2.3 – Lake). The lake general parameter was chosen to see if the optimal parameter specific to the lake category performed better than the overall general parameter developed from the entire data set.

The stage prediction was added to the evaluation because hydrologic models such as HSPF require a defined relationship between stage, storage and discharge. This technique could be used to populate a table relating stage to storage volumes. The stage predictions were performed by rearranging Eq. (2.1), solving for the stage (h) given a specific volume (V):

$$h(V) = (h_o)\left[\frac{V}{\left(\frac{A_o h_o}{m}\right)}\right]^{\left(1/m\right)} \tag{2.5}$$

Again the general shape parameters, $m = 2.3$ and $m = 2.5$, were used in the analysis. Once the stage profile corresponding to given volumes was obtained, the absolute relative stage error (h_{ARE}) was calculated and used to evaluate the model performance. The h_{ARE} was calculated by replacing the volume parameter (V) in Eq. (2.3) with a stage parameter (h):

$$h_{ARE} = \frac{1}{k}\sum_{i=1}^{k}\left[ABS\left(\frac{(h_{Vh})_i - (h_{GIS})_i}{(h_{GIS})_i}\right)\right]*100\% \quad \text{for } k \geq 20\% V_o \tag{2.6}$$

where ABS is the absolute value, i is the lake pool volume increment, k is the total number of pool volume increments, $(h_{GIS})_i$ [L] is the known lake GIS-derived stage at lake volume i, and $(h_{Vh})_i$ [L] is the lake stage produced from the rearranged *V-h* Model [Eq. (2.5)] at lake volume i. Furthermore, the relative stage error (h_{RE}) for each lake was calculated to determine if the *V-h* Model under or over predicted the actual reported lake stage, which was accomplished by removing the absolute value term in Eq. (2.6).

2.7.1. Validation Data Set

The 21 lake validation data set was developed out of 100 lakes found on the Hillsborough County *Watershed Atlas* (Florida Center for Community Design and Research 2007). The lakes were grouped into three size categories based on maximum volumes and seven lakes were randomly selected from each size category for the validation data set. The lake bathymetry data were collected using a SONAR depth finder along with a Global Positioning System (DGPS). Triangulated Irregular Networks (TINs) were created from the digital survey data using ArcMap (Environmental Systems Research Institute Inc. (ESRI) 2007), which were subsequently used to create 0.6096 meter (2.0 foot) contour maps. The contour maps were downloaded from the Hillsborough County *Watershed Atlas* web site and converted to raster images, cell size of 0.061 meters (0.2 feet). Stage-storage relationships were developed from the raster images using the ArcMap 3D Analyst, Area and Volume Statistics tool. Constant interval depths were calculated by dividing the total number of lake stage values (k) into the maximum pool depth (Table 2.4) to define the lake stage depths. At each stage, starting at h_o, the corresponding open water surface area and pool volume were calculated using the GIS 3D Analyst tool. The developed stage-storage relationships were then used as the reference values for error analyses. Table 2.4 identifies the lakes in the validation data set and contains the maximum pool areas (A_o), pool depths (h_o) and pool volumes (V_o) for each lake. The summary statistics of A_o, h_o and V_o for the validation data set are listed at the bottom of Table 2.4.

2.7.2. General *V-h* Model Performance with Validation Data

2.7.2.1. Storage Predictions (*V*)

The average $RMSE_{Rel}$ and V_{ARE} corresponding to the storage predictions for the general shape parameter $m = 2.3$ were: 15.1% and 47.2% respectively (Table 2.4). The V_{ARE} ranged from 2.7% to 142.8% with a standard deviation of 44%. The average $RMSE_{Rel}$ and V_{ARE} corresponding to the storage predictions for the general shape parameter $m = 2.5$ were: 12.9% and 38.0% respectively (Table 2.4). The V_{ARE} ranged from 6.3% to 112.2% with a standard deviation of 33%. Additionally, the general *V-h* Model over predicted (positive V_{RE}) 67% of the lake volumes with $m = 2.3$, and 62% of the lake volumes with $m = 2.5$ (Table 2.4 – V_{RE}).

2.7.2.2. Stage Predictions (*h*)

The average absolute relative stage error (h_{ARE}) corresponding to the stage predictions for $m = 2.3$ was 14.6% (Table 2.4). The h_{ARE} ranged from 1.2% to 38.2% with a standard deviation of 10.6%. The average h_{ARE} corresponding to the general shape parameter storage predictions for $m = 2.5$ was 13.2%. The h_{ARE} ranged from 2.3% to 43.9% with a standard deviation of 10.3%. Additionally, the general *V-h* Model over predicted (positive h_{RE}) 33% of the lake stages with $m = 2.3$, and 38% of the lake stages with $m = 2.5$ (Table 2.4 – h_{RE}). In general, the error in predicting stages was much lower than that for the predicted volumes.

2.7.3. Discussion of the Validation Application

The use of a general shape parameter and the *V-h* Model to predict the storage characteristics of an independent lake data set was very promising even though some relatively high errors were observed for specific lakes. The average V_{ARE} produced by the optimal lake general parameter (m = 2.5) and the Case III optimal general parameter (m = 2.3) might seem large to some; however, this error may be acceptable since hydrologic modelers often do not have any wetland storage data to incorporate into a model, and consequently, no useful way to estimate the error introduced from a set of wetland assumptions. Models are often made of areas where significant lakes, reservoirs and wetlands are present with inadequate stage-storage survey information. Given this consideration, the average stage error h_{ARE} produced by these shape parameters might be very reasonable. Modelers do need to be aware of the large variation in the V_{ARE} and h_{ARE} when utilizing this technique. The variability expressed as the coefficient of variation (CV) in the V_{ARE} was 93% (m = 2.3) and 87% (m = 2.5). The variability (CV) in the h_{ARE} was slightly lower with 73% (m = 2.3) and 78% (m = 2.5) (Table 2.4).

Last, the results for lake storage produced by the general lake parameter (m = 2.5) had slightly less variation and an overall lower average V_{ARE} and h_{ARE} than the results produced by the more general Case III parameter, m = 2.3 (Table 2.4). This is an indication that specific wetland category or lake general shape parameters can be developed that will predict, within an improved and possibly acceptable error level, the storage characteristics of wetlands and lakes that have not been surveyed.

2.8. Conclusions

The goal of this chapter was to provide water resource engineers and hydrologists the analytical tools needed to estimate wetland and lake water storage where data does not exist. An analytical technique utilizing a power-function model that is based on a single fitting parameter and two physically-derived parameters was developed to describe wetland and lake storage in the absence of detailed bathymetry for use in hydrologic modeling studies. The model utilizes two readily obtainable physical characteristics: the maximum or representative wetland or lake planar area A_o, and the corresponding maximum pool depth h_o. Best-fit dimensionless shape parameters describing wetland and lake stage-storage relationships were developed using an iterative procedure for known bathymetry data sets. There was little difference between the specific shape parameters generated from the data sets based on the higher end subset, 80% of the maximum pool (V_o), and the complete data set, 100% V_o. Hence, the V-h power-function model (V-h Model) could be based on the bulk of the storage data, i.e. the upper 80% V_o, potentially eliminating the expensive and labor intensive effort required to precisely survey the intricate and perhaps inaccessible wetland or lake bottom. Furthermore, this approach produced the optimal shape parameter (minimum RMSE) for each wetland which accurately described the individual stage-storage relationships with an average absolute relative volumetric error less than 5.0% for all wetlands in this study.

The application of the aforementioned V-h power-function model was to predict the storage behavior of multiple wetlands and lakes in the absence of detailed survey data. General shape parameters describing wetland and lake stage-storage relationships were developed and evaluated for four wetland categories, 17 lakes, and three different category groupings. The general shape parameters were incorporated in to the *V-h* Model and used to predict individual wetland and lake storage characteristics. Furthermore, the predictive capabilities of two general *V-h* Models were evaluated on an independent validation data set consisting of 21 lakes. Last, the study provided insight into the magnitude of error associated with this shape parameter and method.

Overall the general *V-h* Models predicted the individual wetland and lake storage behavior well. The average relative volumetric predictive errors ranged from 11.8% (St. Denis pothole wetlands) to 46.4% for the category group comprised of all 42 wetlands and lakes in the study. These results were substantiated by the validation data set stage-storage predictions. The average relative volumetric error and average relative stage error produced by the general *V-h* Models on the lake validation data set were 43% and 14% respectively. It should be noted there was high variability in all of the prediction results. These errors may be acceptable for estimating storage volumes considering hydrologic study areas might be comprised of many wetlands and lakes for which no storage data or representative parametric models are available. One of the benefits of this method is that errors associated with the storage model have been quantified. Hydrologic modelers can utilize these errors as they evaluate their confidence in the model results. In lieu of an analytical method, many hydrologic modelers are forced to quantify wetland storage with a guess.

The predictive capability of the general *V-h* models, i.e. general shape parameters, was affected by the diversity of the wetland or lake topography associated with an individual wetland category, lake category, or category group. The differences in the wetland or lake topography were due to diverse mechanisms of formation. In general, it appears that five to 10 wetlands are necessary to produce a useful general shape parameter.

This work demonstrates that a single wetland shape parameter could be used to represent the storage of multiple wetlands and/or lakes with acceptable and quantifiable error in field, theoretical and modeling studies. A specific example is the stage-volume relationship needed for an HSPF f-table as the errors associated with stage estimates are low. Additionally, the *V-h* power-function model shape parameter(s) could be used by modelers as a calibration factor in hydrologic models; as opposed to individually adjusting rating relationship terms thereby easing calibration difficulty and reducing over parameterization.

There are many other types of wetlands such as bogs, mangrove swamps, estuarine and tidal wetlands, arctic wetland areas, playa lakes, vernal pools, and riparian areas, to name a few that were not covered in this study. Shape factors could be developed for each of these wetland types and used to develop storage models. The expansion of the data set to include any of these wetlands would help in the development of specific shape parameters that could be used to define the stage-storage relationship for a particular wetland category.

2.9. Acknowledgements

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CHAPTER 3

HYDROLOGIC CHARACTERIZATION OF 56 WEST-CENTRAL FLORIDA ISOLATED WETLANDS USING A PROBABILISTIC METHOD

3.1. Introduction

The hydrologic characterization of wetlands requires the use of long-term data records and the characterization of climatic variability to describe the duration of different water-level elevations in the wetland when it is flooded, and the duration of different water-table elevations below the wetland when they are dry. Long-term data records are important because short-term records (months – year) might not adequately represent the hydrologic trends of the wetland, nor adequately explain the variability in the wetland surface and subsurface water-level fluctuations. This variability is attributed to the inherent randomness in the driving variables, i.e. climatic variability (precipitation and evapotranspiration), the hydrologic system (topographic, aquifer, and soil characteristics) (Bras and Rodríguez-Iturbe 1993; Maidment 1993), and anthropogenic stresses such as groundwater pumping and surface water augmentation associated with the wetland. Further, short-term records may be indicative of a purely transient response to the short-term climatic variability.

Monitoring the pooled (surface) water as well as the subsurface water-table fluctuations associated with wetlands is critical in understanding and evaluating the hydrologic response of the wetland. High variability in the surface and subsurface water level fluctuations are indicative and possibly responsible for the distinct differences exhibited by different wetland types in shallow water-table environments, such as Florida. In west-central Florida, the water-table is typically within a few of meters of land surface for a good portion of the year creating a situation where this shallow water-table environment can influence surface water bodies such as rivers, lakes and wetlands. Additionally, almost all of the wetlands in Florida spend part of the year with no standing surface water (dry bed) due to the seasonal precipitation patterns, and in some cases due to anthropogenic influences such as groundwater pumping (Dahl 2005). Even when there is no standing water in the wetlands, existing phreatophyte plant communities continue to draw water from the proximal groundwater system supporting evapotranspiration.

Water levels in and around wetlands control the plant species present in wetlands, and may be crucial in determining the speciation of the different wetland types (Hammersmark et al. 2009). The distribution of plant species associated with wetlands are assumed to be a function of environmental gradients, such as groundwater levels (Rains et al. 2004). Rains et al. (2004) simulated the mean depth to groundwater for several plant communities: grassland (-1.06 m), riverine forest (-0.77 m), sedge meadow (-0.48 m), willow forest (-0.27 m), and emergent marsh (0.07 m above the ground surface). The study provides examples that diverse plant communities can be associated with small differences in groundwater depths.

Wetland stage and groundwater levels have been collected over time in numerous wetlands for various studies, e.g. Bradley (2002), Hayashi et al (1998), Johnson et al (2004), and Wise et al. (2000). However, these studies and others mainly focused on a single or particular type of wetland behavior. Generally, the emphasis was to provide a detailed description of the water-level fluctuations and surface-water storage for a particular wetland, and did not attempt to generalize these descriptions across a broad range of wetland types or categories. Lee et al. (2009) conducted an extensive four-year study comparing the hydrology, water quality and ecology of 10 isolated wetlands in west-central Florida. They recognized the importance of studying multiple wetlands to compare and contrast the hydrologic character. This study, in effect, builds on Lee et al. by utilizing a unique and extensive set of water elevations in 56 various isolated wetlands located in west-central Florida. The seven year study utilized water elevation data associated with paired wetland and upland monitoring wells associated with each wetland.

The hydrologic analysis and understanding of long-term wetland water levels requires reducing the data into specific patterns. According to Nestler and Long (1997) hydrologic patterns can be used to understand nearly all significant wetland processes. Various statistical techniques can be used to reduce wetland water level data into patterns for analysis. For instance, simple indices and summary variables such as the statistical mean, median and ranges, describe measures of central tendency and dispersion, however they provide a low resolution description summary of complex hydrological patterns (Nestler and Long 1997). Advanced statistics and probabilistic methods can provide a more robust means for analyzing the complex hydrological patterns associated with wetlands.

Empirical distribution functions representing frequencies of occurrence are one of the advanced statistical techniques used to analyze hydrologic data (Maidment 1993). The distributions portray ordered or ranked sample data as relative frequencies. In short, the empirical distribution function is a graphical display that provides information about how data values are distributed in relation to other values (Maidment 1993). For example, frequencies and probabilities of occurrences over time of sample data can be used to determine the probability of a response being less than a certain value, greater than a certain value, or between two values (Hogg and Ledolter 1987; Weisstein 2009a). Furthermore, empirical distribution functions are used in hydrology to: 1) compare two or more data distributions, 2) compare data to a theoretical distribution such as the normal distribution, and 3) calculate the frequencies of exceedance (Maidment 1993).

The objective of this chapter is to characterize wetland surface and subsurface water-levels based on the probability of inundation and the frequency distribution of the depth to the water-table. Specifically, empirical distribution functions (EDFs) were developed using water elevations associated with 56 various isolated wetlands in west-central Florida. The water elevations were recorded over a seven year period from January 2001 through December 2007. The empirical distribution functions were used to identify representative wetland non-exceedance probability percentiles for the direct hydrologic comparisons of various wetland types, to identify the period of wetland inundation, and to identify the percent of time that high water marks in wetlands were experienced or exceeded. Further, the empirical distribution functions were used to compare the different wetland categories for unique hydrologic characteristics or responses, and possibly to identify individual wetlands that may be under adverse hydrologic stresses.

3.2. Description of Study Area

The wetlands used in this study are located in west-central Florida within the boundaries of the South West Florida Water Management District (SWFWMD) and spread across parts of six counties (Figure 3.1). The climate of the study area is humid and subtropical. The regional geology is comprised of a mantled karst terrain which is characterized by numerous sinkholes brought about by the dissolution of the underlying limestone (Lee et al. 2009). The wetlands are located within three physiographic regions: Northern Gulf Coastal Lowlands (NGCL), Lake Upland (LU) and Western Valley (WV) outlined in Table 3.1. These regions are characterized by a relatively high water-table and are underlain by the Upper Floridan aquifer (Haag et al. 2005; Lee et al. 2009).

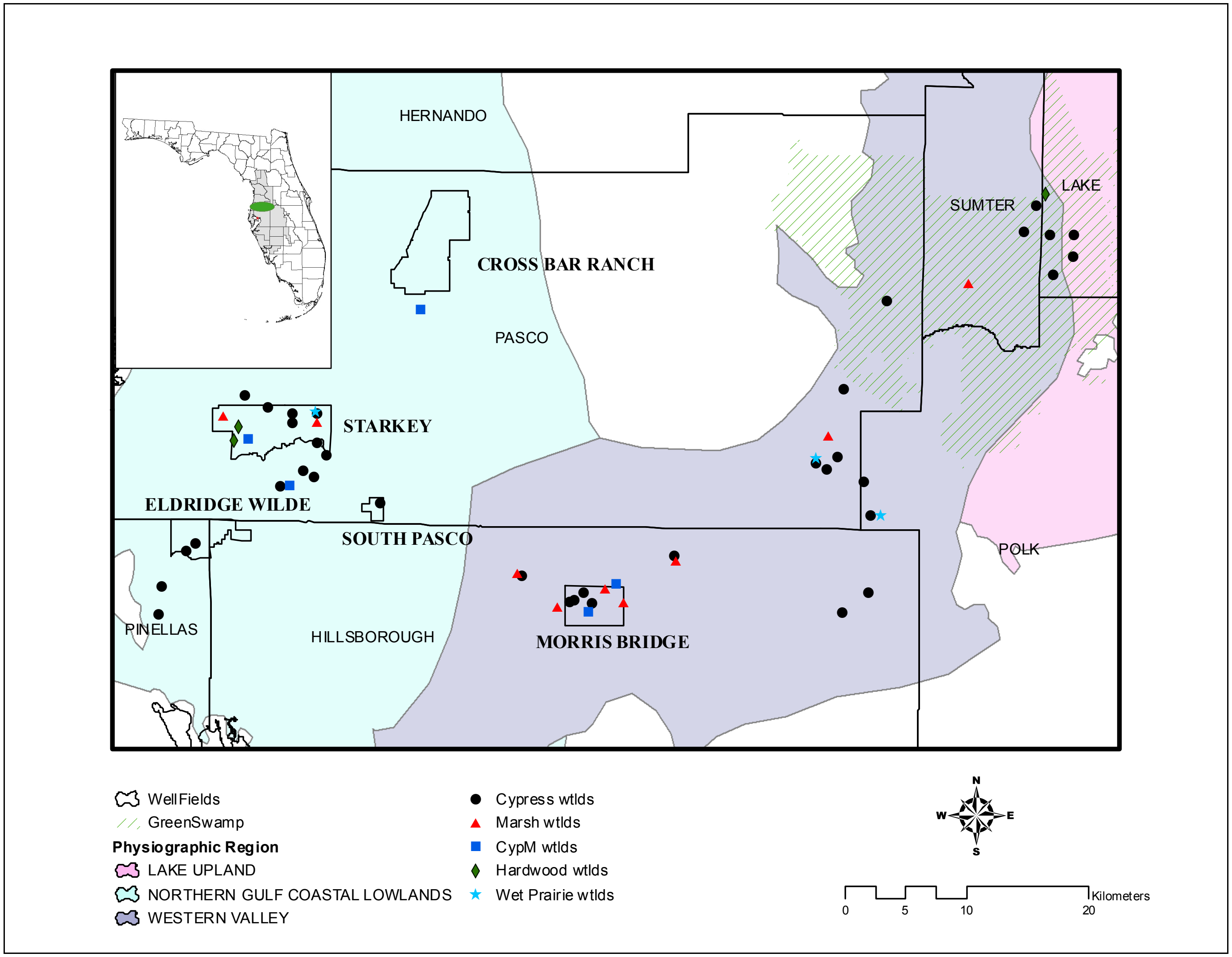


Figure 3.1 Study wetland locations in the northern Tampa Bay region of west-central Florida.

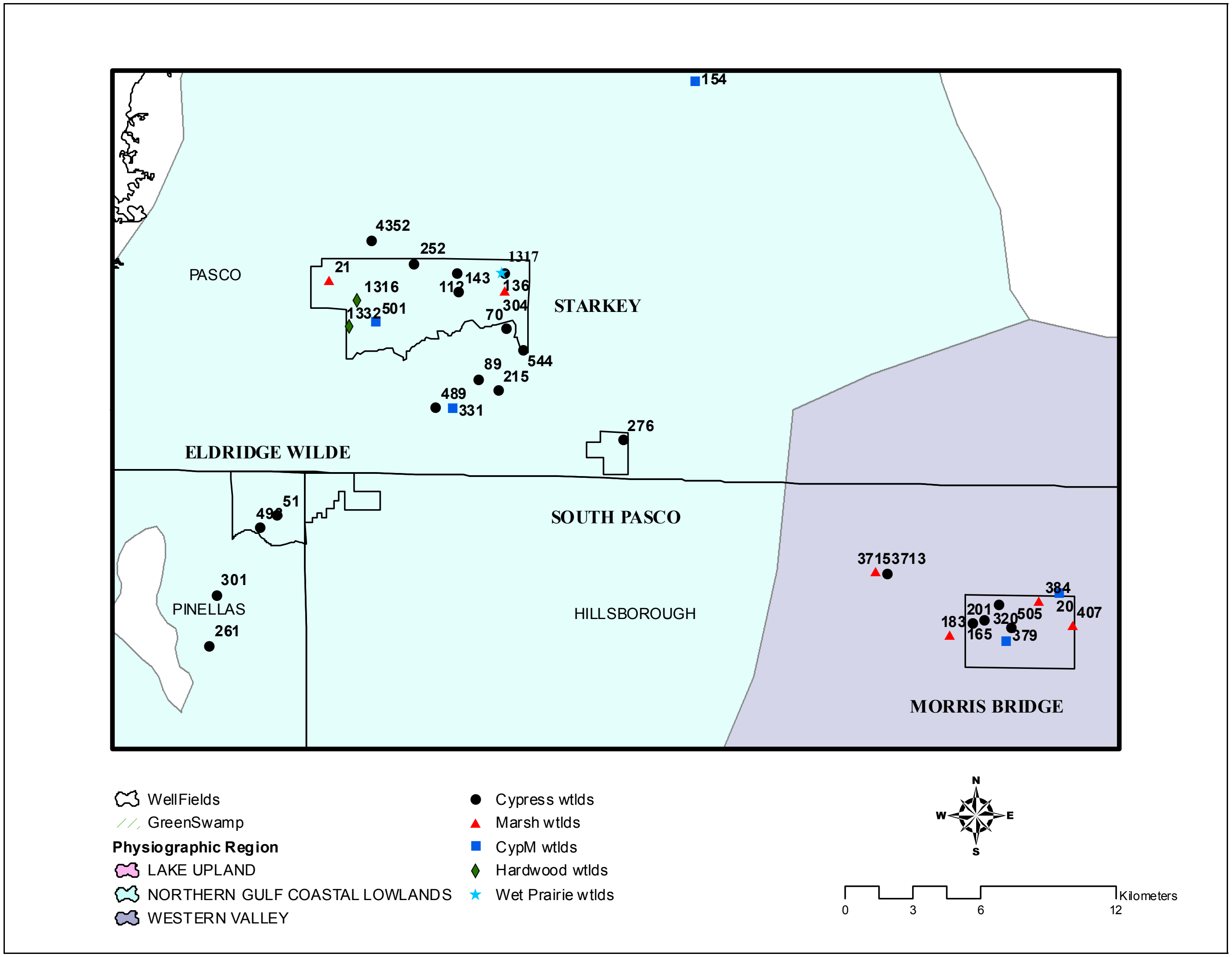


Figure 3.1 (Continued).

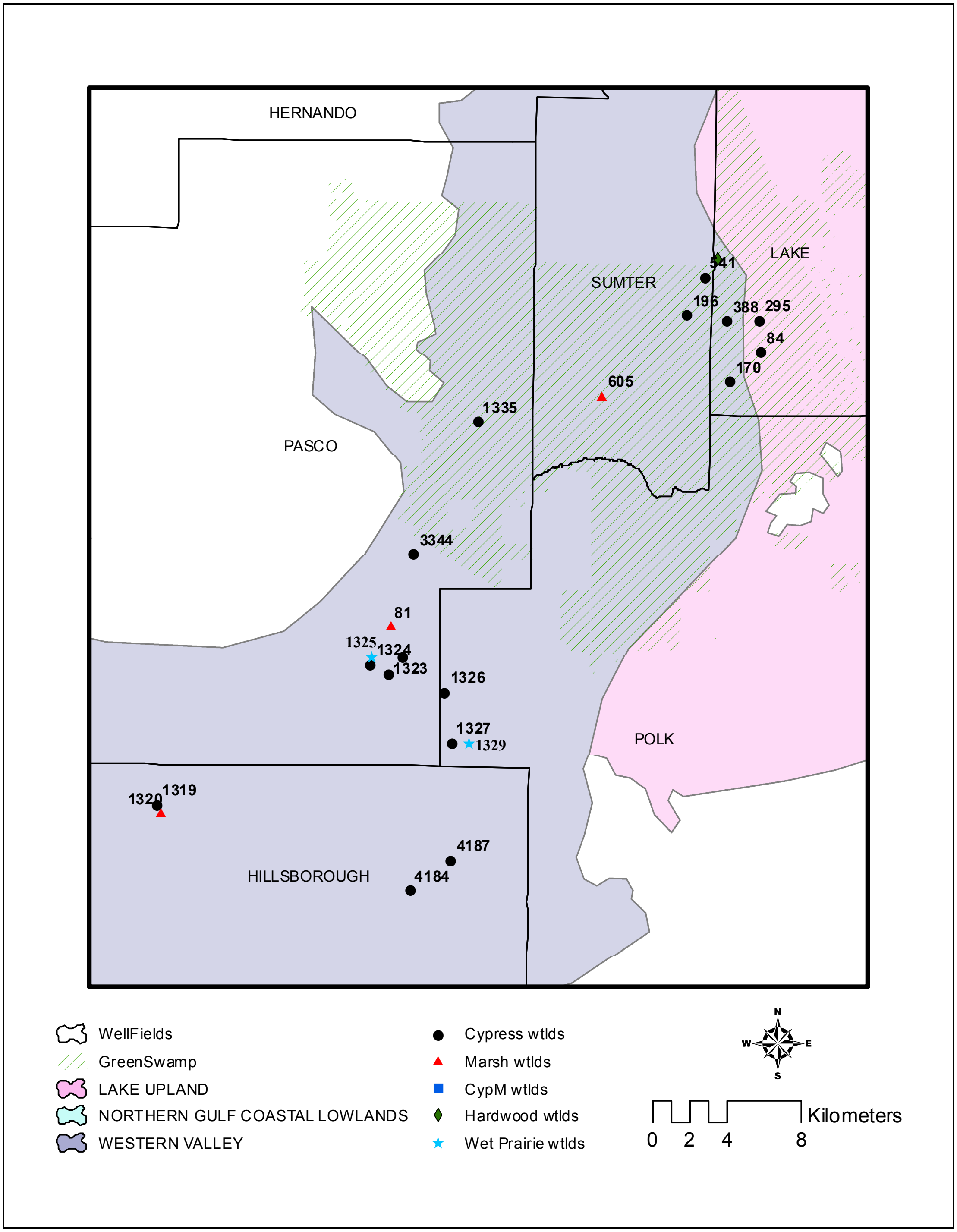


Figure 3.1 (Continued).

Table 3.1. Wetland identification and physical characteristics.

Wetland	Wetland Physical Characteristics					Location	Physiographic
ID	DB (m)	NP (m)	A ($x10^3$ m^2)	P ($x10^2$m)	Type		Region
20	12.4	13.1	59.7	14.8	CM	MB	WV
21	8.0	9.4	392.9	31.2	M	S	NGCL
51	7.9	8.8	6.9	3.1	C	EW	NGCL
70	13.4	14.1	31.1	8.7	C	S	NGCL
81	22.0	24.4	25.1	7.4	M	UHFDA	WV
84	30.9	31.3	4.6	2.5	C	GS	LU
89	13.6	13.9	188.9	38.8	C	S	NGCL
112	11.9	12.7	18.2	6.1	C	S	NGCL
136	13.9	14.3	143.5	18.3	C	S	NGCL
143	12.3	12.9	80.6	18.4	C	S	NGCL
154	21.9	23.3	52.3	9.5	CM	CBR	NGCL
165	11.7	12.2	34.0	9.4	C	MB	WV
170	30.3	30.6	7.8	3.3	C	GS	WV
183	10.0	10.9	9.5	3.8	M	MB	WV
196	29.4	29.9	4.0	2.4	C	GS	WV
201	11.0	11.6	34.9	7.9	C	MB	WV
215	13.5	14.3	32.1	7.0	C	S	NGCL
252	10.9	11.6	8.6	3.4	C	S	NGCL
261	3.5	4.6	12.0	4.1	C		NGCL
276	17.0	18.1	7.3	3.2	C	SP	NGCL
295	30.9	31.4	10.4	3.9	C	GS	LU
301	4.0	4.5	3.3	2.1	C	EW	NGCL
304	13.5	14.3	1.1	1.5	M	S	NGCL
320	12.4	12.9	25.3	6.0	C	MB	WV
331	12.3	13.7	15.5	4.6	CM	S	NGCL
379	9.8	10.5	28.2	6.4	CM	MB	WV
384	12.3	12.9	13.3	4.2	M	MB	WV
388	30.0	30.6	3.0	2.0	C	GS	WV

DB = Dry-bed elevation
NP = Normal Pool elevation

Wetland Identification

C = Cypress wetland
CM = Cypress-Marsh wetland
H = Hardwood wetland
M = Marsh wetland
WP = Wet Prairie wetland

Physiographic Region

LU = Lake Upland
NGCL =. Northern Gulf Coastal Lowland
WV = Western Valley

GS = Green Swamp Wildlife Management Area
UHFDA = Upper Hillsborough Flood Detention Area

Well Field Identification

CB = Cypress Bridge
CBR = Cross Bar Ranch
EW = Eldridge Wild
MB = Morris Bridge
S = Starkey
SP = South Pasco

Table 3.1. (Continued).

Wetland	Wetland Physical Characteristics					Location	Physiographic
ID	DB (m)	NP (m)	A ($x10^3$ m^2)	P ($x10^2$m)	Type		Region
407	10.5	11.2	4.5	2.5	M	MB	WV
489	11.7	13.2	34.8	9.4	C	S	NGCL
493	6.7	7.3	21.0	5.5	C	EW	NGCL
501	8.8	11.3	44.4	7.9	CM	S	NGCL
505	10.1	10.7	25.4	7.1	C	MB	WV
541	29.4	30.1	7.1	3.2	C	GS	WV
544	14.2	14.8	42.9	11.1	C	S	NGCL
605	28.2	28.6	8.3	3.4	M	GS	WV
1316	9.0	10.0	237.9	27.7	H	S	NGCL
1317	14.1	14.5	2.9	2.7	WP	S	NGCL
1319	14.1	14.6	23.4	6.8	C	CB	WV
1320	12.9	13.5	9.9	3.8	M	CB	WV
1322	23.5	24.1	6.9	3.0	C	UHFDA	WV
1323	21.9	23.0	35.2	8.2	C	UHFDA	WV
1324	23.2	23.7	35.9	8.4	C	UHFDA	WV
1325	23.3	24.2	89.0	17.4	WP	UHFDA	WV
1326	27.4	28.0	25.4	8.5	C	UHFDA	WV
1327	29.2	29.6	23.5	7.5	C	UHFDA	WV
1329	30.5	31.0	12.1	5.1	WP	UHFDA	WV
1332	8.9	9.8	159.3	22.9	H	S	NGCL
1335	26.6	27.0	32.5	11.1	C	GS	WV
1337	30.3	30.9	272.6	23.4	H	GS	WV
3344	23.7	24.2	354.0	50.4	C	UHFDA	WV
3713	12.4	12.8	29.4	7.7	C		WV
3715	11.6	12.1	9.8	3.8	M		WV
4184	29.3	29.6	30.3	6.5	C		WV
4187	29.3	29.8	38.5	7.3	C		WV
4352	8.9	9.4	23.7	6.4	C	S	NGCL

DB = Dry-bed elevation
NP = Normal Pool elevation
<u>Wetland Identification</u>
C = Cypress wetland
CM = Cypress-Marsh wetland
H = Hardwood wetland
M = Marsh wetland
WP = Wet Prairie wetland
<u>Physiographic Region</u>
LU = Lake Upland
NGCL =. Northern Gulf Coastal Lowland
WV = Western Valley

GS = Green Swamp Wildlife Management Area
UHFDA = Upper Hillsborough Flood Detention Area
<u>Well Field Identification</u>
CB = Cypress Bridge
CBR = Cross Bar Ranch
EW = Eldridge Wild
MB = Morris Bridge
S = Starkey
SP = South Pasco

3.2.1. Precipitation Patterns

Precipitation patterns and climate variability are important factors that influence the hydrologic conditions of wetlands. Overall, the annual precipitation in west-central Florida is approximately 132 cm (52 in) per year based on 110 years of record (Lee et al. 2009), with approximately 60% falling during the months of June – September (Southeast Regional Climate Center 2010). Because precipitation in the region varies strongly both temporally and spatially, it should be measured at multiple locations around a study area to get a true indication of the precipitation and hydrologic response for the area. Annual precipitation records from two weather stations, 1) Tampa International Airport (T.I.A.) located to the south side of the study area and 2) Hillsborough River State Park (HRSP) located central to the study area, are presented in Figure 3.2. The mean annual precipitation during the seven year study period was 127.2 cm (50 in) at the Tampa International Airport, and 137.4 cm (54 in) at the HRSP (National Oceanic and Atmospheric Administration 2009). Typically the airport receives less rain than other areas of the region. The long-term (119 year) mean annual precipitation recorded at the airport is 113.4 cm (45 in), compared to 139.0 cm (55 in), the 64 year mean annual precipitation recorded at the HRSP site.

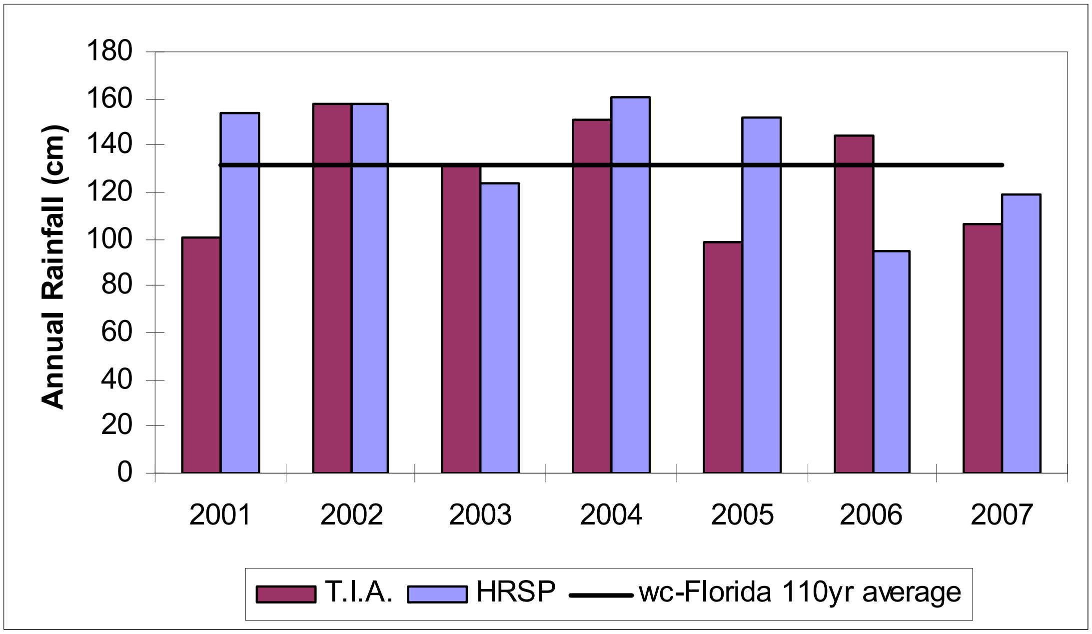


Figure 3.2 Annual regional rainfall measured at the Tampa International Airport (T.I.A.) and at the Hillsborough River State Park (HRSP).

3.2.2. Wetland Classifications

The wetlands studied are comprised of 36 cypress (C), 5 cypress-marsh (CM), 3 hardwood (H), 9 marsh (M), and 3 wet prairie (WP) as classified by SWFWMD (Table 3.1). Nine wetlands are located in the Green Swamp Wildlife Management Area (GS), which encompasses 194 km^2 (75 square miles) of the region (Figure 3.1). The associated surface water levels in the Green Swamp are considered largely unaffected by human activities, and there has been little development of the groundwater resource in the region (Haag et al. 2005). Additionally, 33 wetlands are located within the extents or in the immediate vicinity of six public water-supply well fields in the northern Tampa Bay region: Cypress Bridge (CB) not shown, Cross Bar Ranch (CBR), Eldridge Wilde (EW), Morris Bridge (MB), South Pasco (SP) and Starkey (S) (Figure 3.1). The rest of the wetlands are located throughout Hillsborough, Pasco, Pinellas, and Polk counties. It is believed that these wetlands represent the range of hydrologic conditions across west-central Florida.

Wetland planar area (A) and perimeter (P) values corresponding to the wetland extents and spatial coverage were calculated from the Geographic Information System (GIS) Land Use 1999 and National Wetland Inventory (NWI) shapefile records (Table 3.1) (Southwest Florida Water Management District 2007; U.S. Fish and Wildlife Service 2007a). The shapefiles contain approximations of the wetland extents based on aerial photos (Figure 3.3). These files were used to calculate the wetland areas and perimeters because physical measurements for the 56 wetland areas and perimeters were unavailable. The isolated wetlands range in size (spatial coverage) from 1,100 km^2 to 392,900 km^2 with an average wetland area and perimeter of 51,700 km^2 and 9,300 km respectively (Table 3.1). In general, the hardwood wetlands have the largest spatial coverage (223,300 km^2), while the wet prairie wetlands have the smallest spatial coverage (34,700 km^2).

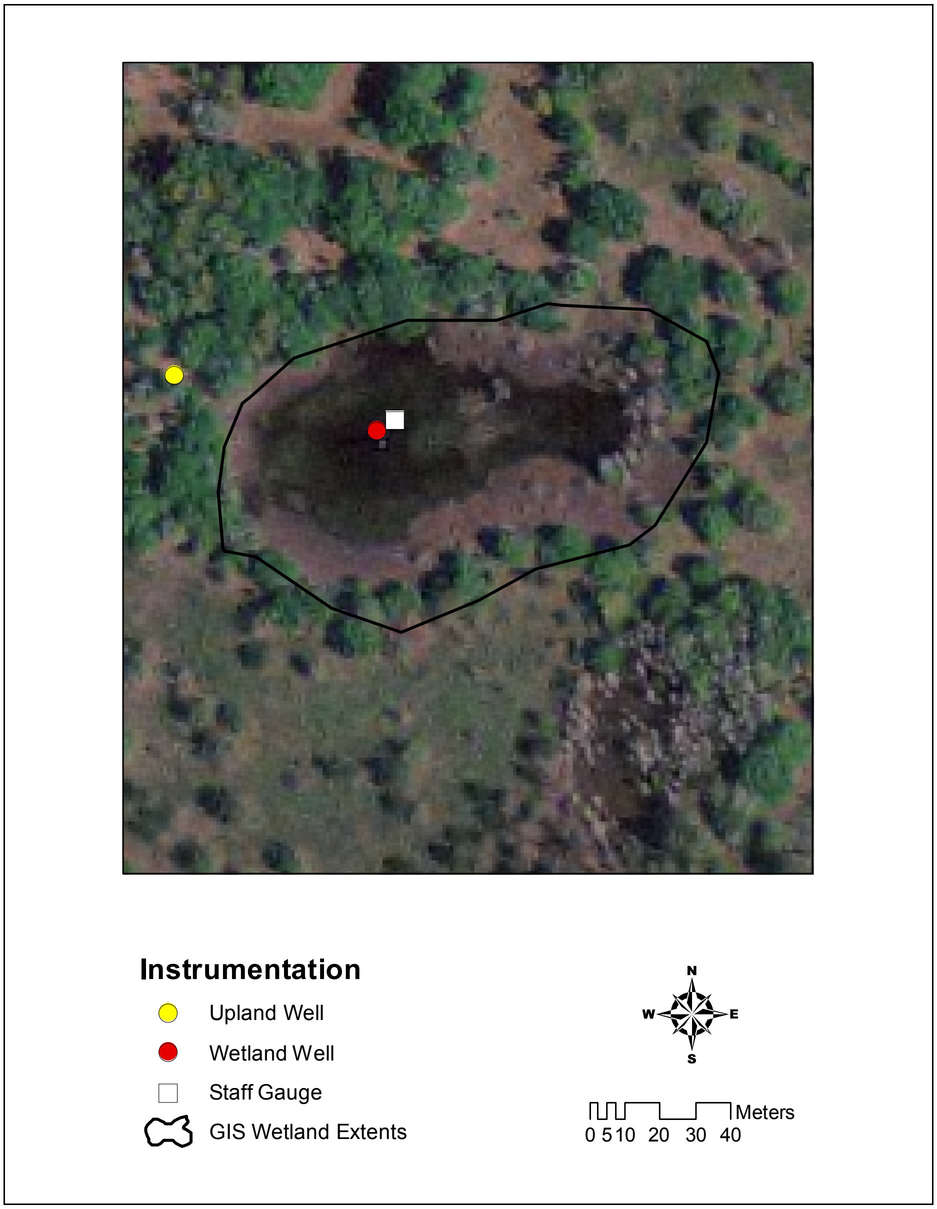


Figure 3.3 Example of SWFWMD well and staff gauge locations for a typical wetland.

Additionally, wetland dry bed (DB) and normal pool (NP) elevations have been previously identified by SWFWMD staff (Table 3.1). According to Mike Hancock, Senior Professional Engineer, Resource Projects Department, Southwest Florida Water Management District , the wetland dry bed elevation was identified as the dry reading mark on the staff gauge and assumed to be the representative low point in the wetland (personal communication, February 4, 2010). This datum was subject to the ability of the staff gauge installation crew to get to the deepest point in the wetland as well as a visual inspection of the wetland, so some variability exists. Also wetland bottom elevations are not consistent throughout the wetland extents (Haag et al. 2005; Nilsson et al. 2008). Therefore, the dry-bed elevation may not be representative for larger wetlands. The wetland normal pool elevation corresponds to physical and vegetative markers, i.e. inflection points on the buttresses of cypress trees, stain marks, moss collars, and the elevation of root crowns, that identify a high water mark for the respective wetland (Carr and Rochow 2004; Haag et al. 2005). The normal pool elevation is typically a more consistent measure across the entire wetland than the dry-bed elevation.

The mean dry bed and normal pool elevations based on the National Geodetic Vertical Datum of 1929 (NGVD) for all wetlands and each wetland category are: 17.1 m and 17.9 m (all), 18.1 m and 18.7 m (cypress), 14.3m and 15.3 (marsh), 13.0m and 14.4m (cypress-marsh), 16.1 m and 16.9 m (hardwood), and 22.7 m and 23.2 m (wet prairie) (Table 3.1). The wetland dry-bed elevations range from 3.5 m NGVD (NGCL region) to 30.9 m NGVD (LU region). The wetland maximum depth estimate, calculated as the difference between the normal pool elevation and dry-bed elevation, range from 0.4 m to 2.5 m with an average depth of 0.8 m. On average, the cypress and wet prairie wetlands are the shallowest at 0.6 m and the cypress-marsh wetlands are the deepest at 1.4 m.

3.2.3. Wetland Hydrogeologic Setting

The study wetlands are underlain by three hydrogeological units: the surficial aquifer system, intermediate confining unit, and Upper Floridan aquifer. Figure 3.4 shows a typical wetland in relation to the hydrogeologic units. The surficial unit borders the land surface and primarily consists of unconsolidated sand and clayey sand deposits a few meters to 10's of meters thick (Lee et al. 2009). The intermediate confining unit is rich in clay and generally impedes the flow of water from the surficial aquifer to the Upper Floridan aquifer (Lee and Swancar 1997). The deepest of the units is the Upper Floridan aquifer. The unit is the primary source of local water supplies in the study area, and is confined or semi-confined depending on the integrity of the intermediate confining unit. The Upper Floridan unit is 100's to 1000's of meters thick depending on location, comprised of limestone and dolomites, and is highly transmissive due to large fractures.

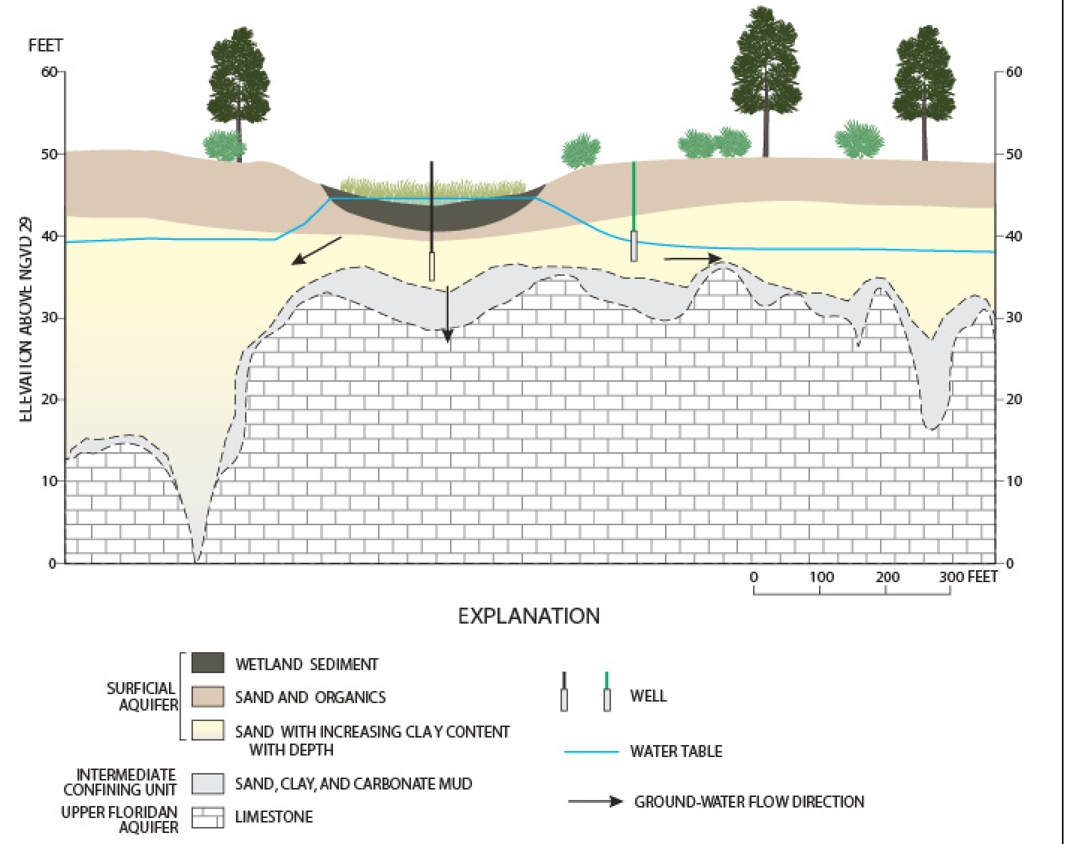


Figure 3.4 Generalized hydrogeologic section and vertical head distribution (modified from Lee et al., 2009).

3.3. Wetland and Upland Water Elevation Data

Surface water and groundwater elevations associated with each of the 56 isolated wetlands were monitored and recorded by SWFWMD over a period of seven years, January 1, 2001 thru December 31, 2007. This period was chosen due to data availability, and to ensure representative hydrologic and meteorologic conditions were covered. Two monitoring wells associated with each wetland were used to record the groundwater levels in the surficial aquifer system (Figure 3.3). One monitoring well is located within the wetland close to the staff gauge, hence forth referred to as the *wetland well*, and the other is located in the nearby upland area/vegetation surrounding the wetland, hence forth referred to as the *upland well*. The wetland well data represent standing water levels measured inside the wetland when the wetland was flooded, and groundwater levels below the wetland during dry periods. The standing water elevations were verified and are generally very consistent with the corresponding staff gauge (Figure 3.3) water elevations for each wetland to ensure accurate surface water representation (Appendix A). The upland well data represent groundwater levels adjacent to the wetlands.

Physical properties of the 56 paired wetland wells and upland wells are listed in Table 3.2. The wells range in diameter (Dia) from 5.1 cm (2.0 in) to 15.2 cm (6.0 in), and range in total depth from 1.1 m (3.5 ft) to 10.2 m (33.5 ft) below the respective ground elevation listed in Table 3.4. Further, the linear distance (Ld) between each paired wetland well and upland well is listed. The linear distances were calculated using the respective well GIS latitude and longitude coordinates. The mean separation distance between the paired wells is 56 m, ranging from 8 m to 149 m.

Table 3.2. Monitoring well identification and physical properties.

	Wetland Wells				**Upland Wells**				
Wetland ID	Well ID	Dia (cm)	Depth (m)		Well ID	Dia (cm)	Depth (m)		Ld (m)
			Total	Casing			Total	Casing	
20	1959	15	4.3	0.6	1792	5	4.6	1.5	23
21	1943	5	3.8	0.8	17542	5	6.2	3.2	149
51	1924	5	6.1	1.5	1923	5	4.3	1.2	79
70	1932	15	9.1	1.5	1741	5	4.0	0.9	29
81	1971	5	2.6	1.1	1818	5	3.8	0.8	98
84	1989	15	1.4	0.3	17400	5	5.8	2.7	49
89	1985	5	4.1	1.1	1928	5	5.2	0.9	94
112	1937	5	8.7	2.6	1718	5	4.6	0.9	35
136	1933	5	8.8	1.2	1724	5	3.0	0.6	49
143	1936	5	10.2	1.1	1719	5	4.6	0.9	63
154	1948	5	5.5	0.9	1947	5	4.6	1.5	64
165	1953	5	8.5	0.9	17456	5	5.8	2.7	78
170	1987	15	3.0	1.5	17398	5	3.0	0.5	57
183	1954	15	4.6	1.5	17485	5	5.7	2.7	59
196	1992	15	1.2	0.3	17403	5	2.7	0.3	46
201	1952	5	3.7	0.6	17457	5	5.7	2.7	59
215	1929	15	4.7	1.7	1930	5	3.0	0.9	57
252	1939	5	4.0	1.2	1736	5	3.0	0.6	78
261	2076	5	3.0	0.6	2077	5	4.0	0.9	67
276	1984	5	6.7	0.6	2120	5	6.7	1.1	35
295	1990	15	1.2	0.3	17401	5	2.9	0.5	74
301	1918	15	8.5	2.4	1745	5	3.0	0.9	31
304	17427	5	3.8	2.9	17478	5	5.2	2.1	73
320	1958	5	4.3	1.2	1791	5	7.6	1.5	77
331	2157	5	4.0	0.6	2158	5	5.2	0.6	38
379	1951	5	5.8	1.2	17458	5	5.6	2.5	84
384	1793	5	3.0	1.2	17461	5	3.9	0.8	37
388	1988	15	2.4	0.6	17399	5	2.8	0.4	53

Table 3.2. (Continued).

	Wetland Wells				**Upland Wells**				
Wetland ID	Well ID	Dia (cm)	Depth (m)		Well ID	Dia (cm)	Depth (m)		Ld (m)
			Total	Casing			Total	Casing	
407	1790	5	6.1	1.5	17460	5	3.3	0.8	59
489	1927	5	5.8	1.2	1926	5	7.6	0.9	58
493	17487	5	2.4	1.5	1925	5	11.0	1.2	54
501	1941	5	7.5	1.4	17488	5	5.8	2.8	24
505	1950	5	5.2	0.6	17459	5	5.7	2.6	62
541	1991	15	4.6	0.9	17402	5	4.2	1.2	51
544	1931	5	5.6	1.1	1744	5	4.0	0.9	31
605	1966	15	1.8	0.3	17397	5	2.8	0.4	58
1316	1942	5	7.0	0.9	1743	5	4.6	1.5	36
1317	1934	5	6.1	1.5	1717	5	4.6	0.6	31
1319	1961	15	2.4	0.5	1786	5	4.6	1.5	43
1320	1960	15	1.2	0.3	1785	5	6.1	1.5	39
1322	1974	5	2.6	0.5	1804	5	2.1	0.6	43
1323	1975	5	1.5	0.3	1802	5	2.1	0.6	103
1324	1976	5	6.1	1.5	1811	5	7.6	1.5	41
1325	1977	15	2.1	0.6	1803	5	3.0	0.6	67
1326	1978	15	1.5	0.6	1800	5	4.6	0.9	8
1327	1979	5	4.9	0.3	1799	5	2.1	0.6	42
1329	1981	15	3.0	0.6	1808	5	2.1	0.6	83
1332	1940	5	5.9	0.6	1742	5	4.6	1.5	27
1335	1965	5	1.5	0.6	1739	5	1.5	0.3	82
1337	1995	15	1.8	0.3	1851	5	3.0	0.9	75
3344	1972	5	2.1	0.6	1973	5	2.3	0.8	25
3713	2064	15	4.1	0.8	2063	5	3.5	0.5	83
3715	2060	15	1.1	0.3	2059	5	2.9	0.6	79
4184	2260	5	1.5	0.5	2259	5	1.5	0.5	29
4187	2251	5	1.1	0.3	2250	5	1.5	0.3	58
4352	2253	5	3.0	0.3	2252	5	3.7	0.6	25

The wetland water levels and upland groundwater levels were measured continuously using electronic water-level recorders and/or periodically with a graduated tape. Over the course of the study, between 52 and 2,153 water level measurements were collected at each wetland well, and between 52 and 137 groundwater level measurements were collected at each upland well (Table 3.3). A couple of factors influenced the number of water-level records available at each monitoring well: 1) the start of the data collection and 2) the frequency at which the data was collected. The wetland water level data collection began in 2001 for all but four of the wells, which were installed in 2002 and 2003. The wetland water-level data were collected continuously (daily), semi-monthly or on a monthly basis. The upland groundwater data collection began in 2001 for all but five of the wells, which were installed in 2002 and 2003. The upland water-level data were collected on a semi-monthly or monthly basis.

The water-elevation data recorded at each wetland well and upland well corresponding to the 56 wetlands are summarized in Table 3.4. In addition, the ground elevation (GE) associated with each well is listed. The ground elevation was determined from a land survey adjacent to the well. The wetland well ground elevations range from 3.5 m to 30.9 m NGVD, and the upland well ground elevations range from 4.8 m to 31.6 m NGVD.

Table 3.3. Wetland well and upland well data collection schedule.

	Wetland Wells				**Upland Wells**			
Wetland ID	Well ID	Data Collection			Well ID	Data Collection		
		Start	Frequency	Records		Start	Frequency	Records
20	1959	2001	continuous	1837	1792	2001	monthly	137
21	1943	2001	monthly	122	17542	2001	monthly	131
51	1924	2001	monthly	66	1923	2001	monthly	64
70	1932	2001	continuous	1464	1741	2001	monthly	83
81	1971	2001	monthly	71	1818	2001	monthly	84
84	1989	2001	continuous	1421	17400	2001	monthly	74
89	1985	2001	monthly	125	1928	2001	monthly	125
112	1937	2001	monthly	125	1718	2001	monthly	132
136	1933	2001	monthly	125	1724	2001	monthly	130
143	1936	2001	monthly	122	1719	2001	monthly	130
154	1948	2001	monthly	67	1947	2001	monthly	71
165	1953	2001	monthly	128	17456	2001	monthly	134
170	1987	2001	continuous	1354	17398	2001	monthly	75
183	1954	2001	continuous	1757	17485	2001	monthly	136
196	1992	2001	continuous	1385	17403	2001	monthly	75
201	1952	2001	monthly	128	17457	2001	monthly	134
215	1929	2001	continuous	1811	1930	2001	monthly	128
252	1939	2001	monthly	123	1736	2001	monthly	132
261	2076	2001	monthly	62	2077	2001	monthly	65
276	1984	2001	monthly	67	2120	2002	monthly	61
295	1990	2001	continuous	1326	17401	2001	monthly	73
301	1918	2001	continuous	1849	1745	2001	monthly	73
304	17427	2001	monthly	131	17478	2001	monthly	133
320	1958	2001	monthly	126	1791	2001	monthly	132
331	2157	2002	monthly	115	2158	2002	monthly	116
379	1951	2001	monthly	126	17458	2001	monthly	134
384	1793	2001	monthly	135	17461	2001	monthly	135
388	1988	2001	continuous	1424	17399	2001	monthly	73

Table 3.3. (Continued).

	Wetland Wells				**Upland Wells**			
Wetland ID	Well ID	Data Collection			Well ID	Data Collection		
		Start	Frequency	Records		Start	Frequency	Records
407	1790	2001	monthly	134	17460	2001	monthly	135
489	1927	2001	monthly	124	1926	2001	monthly	125
493	17487	2001	monthly	72	1925	2001	monthly	65
501	1941	2001	monthly	124	17488	2001	monthly	132
505	1950	2001	monthly	128	17459	2001	monthly	135
541	1991	2001	continuous	1205	17402	2001	monthly	75
544	1931	2001	monthly	126	1744	2001	monthly	130
605	1966	2001	continuous	1197	17397	2001	monthly	74
1316	1942	2001	monthly	125	1743	2001	monthly	130
1317	1934	2001	monthly	125	1717	2001	monthly	133
1319	1961	2001	continuous	2153	1786	2001	monthly	82
1320	1960	2001	continuous	2140	1785	2001	monthly	81
1322	1974	2001	monthly	77	1804	2001	monthly	82
1323	1975	2001	monthly	79	1802	2001	monthly	79
1324	1976	2001	monthly	79	1811	2001	monthly	82
1325	1977	2001	continuous	1965	1803	2001	monthly	81
1326	1978	2001	continuous	1688	1800	2001	monthly	76
1327	1979	2001	monthly	71	1799	2001	monthly	76
1329	1981	2001	continuous	1826	1808	2001	monthly	76
1332	1940	2001	monthly	124	1742	2001	monthly	130
1335	1965	2001	monthly	77	1739	2001	monthly	77
1337	1995	2001	continuous	1207	1851	2001	monthly	74
3344	1972	2001	monthly	78	1973	2001	monthly	79
3713	2064	2001	continuous	1964	2063	2001	monthly	70
3715	2060	2001	continuous	1967	2059	2001	monthly	70
4184	2260	2003	bi-monthly	56	2259	2003	bi-monthly	55
4187	2251	2003	bi-monthly	55	2250	2003	bi-monthly	56
4352	2253	2003	bi-monthly	52	2252	2003	bi-monthly	52

Table 3.4. Wetland and upland water elevation summary statistics (NGVD 29).

	Wetland Water Elevations							**Upland Water Elevations**						
Wetland	Well	GE	Water Level Statistics (m)					Well	GE	Water Level Statistics (m)				
ID	ID	(m)	Mean	StD	Median	Min	Max	ID	(m)	Mean	StD	Median	Min	Max
20	1959	12.5	12.2	0.7	12.3	9.8	13.1	1792	13.1	11.7	1.0	11.9	9.0	13.2
21	1943	8.0	8.3	0.7	8.4	6.9	9.8	17542	10.1	8.1	0.8	8.0	6.6	9.7
51	1924	7.9	7.7	0.7	7.8	6.4	8.9	1923	8.7	7.7	0.8	7.8	5.2	8.9
70	1932	13.5	13.5	0.5	13.7	12.2	14.2	1741	14.4	13.5	0.5	13.6	12.2	14.3
81	1971	22.1	22.8	0.8	23.0	20.8	23.9	1818	24.4	23.4	0.6	23.5	21.8	24.4
84	1989	30.9	31.0	0.3	31.1	29.6	31.5	17400	31.6	30.9	0.4	31.0	29.9	31.5
89	1985	13.5	13.5	0.5	13.7	11.9	14.0	1928	14.2	13.4	0.5	13.6	12.2	14.1
112	1937	12.3	12.3	0.4	12.5	11.2	12.9	1718	12.9	12.4	0.4	12.5	11.0	12.9
136	1933	14.0	13.8	0.4	14.0	12.7	14.5	1724	14.5	13.8	0.5	13.9	12.5	14.5
143	1936	12.4	12.3	0.5	12.4	10.9	13.2	1719	13.0	12.2	0.6	12.4	10.7	13.1
154	1948	21.9	22.2	0.7	22.5	20.3	23.0	1947	23.3	22.3	0.7	22.6	20.4	23.2
165	1953	11.7	11.6	0.5	11.8	10.0	12.2	17456	12.4	11.6	0.5	11.6	10.1	12.4
170	1987	30.3	30.3	0.3	30.4	28.8	30.7	17398	30.8	30.1	0.3	30.2	29.1	30.8
183	1954	10.1	9.9	0.9	10.1	7.5	11.1	17485	11.4	9.3	1.0	9.4	7.4	11.3
196	1992	29.5	29.3	0.5	29.5	28.3	30.0	17403	30.1	29.2	0.6	29.4	27.6	30.0
201	1952	11.1	11.0	0.7	11.4	8.9	11.7	17457	12.0	10.6	1.0	10.9	8.7	12.0
215	1929	13.6	13.8	0.4	14.0	12.2	14.2	1930	14.5	13.9	0.4	14.0	12.6	14.5
252	1939	10.9	10.7	0.7	10.8	9.1	11.6	1736	11.8	10.7	0.7	10.8	9.0	11.7
261	2076	3.5	4.3	0.2	4.3	3.5	4.6	2077	4.9	4.3	0.2	4.4	3.6	4.7
276	1984	17.1	17.0	0.9	17.3	14.8	18.1	2120	17.9	17.2	0.8	17.3	15.5	18.1
295	1990	30.9	30.9	0.4	31.0	29.7	31.5	17401	31.6	30.8	0.4	30.9	29.6	31.5
301	1918	4.0	4.1	0.3	4.2	3.1	4.6	1745	4.8	4.1	0.3	4.2	3.3	4.6
304	17427	13.7	13.4	0.6	13.4	11.9	14.6	17478	15.1	13.5	0.6	13.5	12.1	14.8
320	1958	12.5	12.4	0.6	12.6	10.8	13.0	1791	13.0	12.0	0.6	12.0	10.5	13.0
331	2157	12.8	13.3	0.3	13.4	11.9	13.6	2158	13.7	13.2	0.4	13.3	12.0	13.7
379	1951	9.8	9.2	1.1	9.7	5.9	10.6	17458	10.3	9.2	0.9	9.3	6.0	10.6
384	1793	12.3	12.0	0.7	12.1	10.3	12.9	17461	13.1	11.7	0.7	11.8	9.9	13.1
388	1988	30.0	30.1	0.5	30.2	28.3	30.8	17399	30.8	30.1	0.4	30.1	28.8	30.8

Table 3.4. (Continued).

	Wetland Water Elevations							**Upland Water Elevations**						
Wetland ID	Well ID	GE (m)	Water Level statistics (m)					Well ID	GE (m)	Water Level statistics (m)				
			Mean	StD	Median	Min	Max			Mean	StD	Median	Min	Max
407	1790	10.5	10.3	0.7	10.6	8.4	11.4	17460	11.5	10.1	0.8	10.1	8.4	11.4
489	1927	11.8	12.4	0.5	12.6	10.8	13.0	1926	13.3	12.5	0.5	12.8	11.0	13.2
493	17487	6.7	6.8	0.6	7.0	5.3	7.6	1925	7.3	6.9	0.5	7.0	5.8	7.5
501	1941	8.9	9.7	0.9	9.9	7.8	11.3	17488	11.7	9.9	1.0	10.0	7.9	11.6
505	1950	10.1	9.8	0.9	10.2	7.7	11.6	17459	11.1	9.3	1.2	9.6	6.4	11.0
541	1991	29.5	29.6	0.5	29.7	28.2	30.3	17402	30.2	29.5	0.5	29.6	28.2	30.1
544	1931	14.2	14.3	0.5	14.5	12.8	14.8	1744	14.8	14.2	0.4	14.3	13.0	14.9
605	1966	28.1	28.3	0.2	28.3	26.9	28.7	17397	28.8	28.0	0.5	28.0	26.6	28.8
1316	1942	9.2	9.0	0.6	9.1	7.7	10.0	1743	10.4	9.1	0.6	9.1	7.7	10.2
1317	1934	14.1	13.5	0.6	13.5	12.1	14.6	1717	14.6	13.5	0.6	13.5	12.1	14.6
1319	1961	14.1	14.2	0.4	14.3	11.6	14.9	1786	14.8	12.9	0.5	13.0	11.5	14.2
1320	1960	12.9	13.2	0.3	13.3	11.8	13.8	1785	13.6	12.4	0.7	12.4	10.7	13.6
1322	1974	23.6	22.8	0.7	22.8	21.0	24.0	1804	24.2	22.6	0.6	22.6	21.6	24.0
1323	1975	21.1	21.5	0.6	21.4	20.5	22.9	1802	23.1	22.1	0.5	22.1	21.0	23.1
1324	1976	23.2	22.2	1.3	22.2	18.3	24.2	1811	23.7	21.7	1.6	21.9	18.2	23.7
1325	1977	23.4	22.9	0.8	23.0	21.3	24.5	1803	24.6	22.8	0.8	22.7	21.6	24.4
1326	1978	27.4	27.4	0.6	27.7	26.0	28.1	1800	28.0	26.8	1.0	27.2	24.3	28.0
1327	1979	29.2	28.9	0.6	29.2	27.5	29.5	1799	29.7	28.6	0.7	28.7	27.5	29.6
1329	1981	30.5	30.5	0.4	30.6	29.0	31.1	1808	31.0	30.1	0.5	30.1	28.9	31.0
1332	1940	8.9	9.1	0.7	9.2	7.5	9.9	1742	10.2	9.1	0.7	9.3	7.5	10.1
1335	1965	26.6	26.4	0.5	26.6	25.1	27.0	1739	26.9	26.4	0.5	26.6	24.9	27.0
1337	1995	30.3	30.4	0.3	30.5	29.0	30.9	1851	31.2	30.3	0.6	30.5	28.5	31.2
3344	1972	23.7	23.6	0.7	23.9	21.7	24.5	1973	24.3	23.6	0.7	23.8	21.8	24.5
3713	2064	12.4	12.0	0.7	12.3	10.0	12.8	2063	13.1	12.2	0.5	12.1	11.1	13.1
3715	2060	11.6	11.8	0.4	11.9	10.6	12.3	2059	12.1	11.2	0.7	11.2	9.5	12.1
4184	2260	29.2	29.3	0.4	29.4	27.8	29.6	2259	29.7	29.1	0.4	29.1	28.2	29.6
4187	2251	29.3	29.5	0.4	29.6	28.5	29.9	2250	29.9	29.1	0.5	29.1	28.0	29.9
4352	2253	9.2	9.1	0.1	9.1	8.5	9.3	2252	9.8	9.0	0.2	9.1	8.4	9.4

3.4. Methods

3.4.1. Hydrologic Evaluation

3.4.1.1. Empirical Distribution (Frequency) Development

Empirical distribution functions (EDFs) were developed from the wetland water elevation and upland groundwater elevation data sets summarized in Table 3.4. The functions represent the discrete frequency distribution of surface and groundwater elevations within the wetland extents, and the frequency distribution of groundwater elevations in the adjacent/surrounding upland. The resulting irregular distributions were compared between the different study wetlands and wetland categories.

The empirical distribution function is a discrete step function that is an unbiased estimator of the cumulative or probability distribution function (Chow et al. 1988). The empirical distribution function is defined as:

$$F_s(p_x) = \sum_{m=1}^{x} f_s(p_m) \tag{3.1}$$

where $F_s(p_x)$ is the sum of the values of the relative frequencies $f_s(p_m)$ up to a given observation x, m is the rank of the observation, and the subscript s denotes the function is calculated from sample data (Chow et al. 1988; Maidment 1993).

Relative frequencies (probabilities) were computed based on ordered or ranked data (Maidment 1993; Weisstein 2009c). The general expression for computing relative frequencies is:

$$p_m = \frac{m - a}{N - 2a + 1} \tag{3.2a}$$

$$p_m = \frac{m}{(N + 1)} \tag{3.2b}$$

where p_m is the relative frequency, i.e. the probability of a value being less than the m^{th} smallest observation in the data set, m is the rank of the observation, N is the sample size, and a is a constant associated with a probability model, e.g. for a uniform distribution, $a = 0$. For this application a uniform distribution is assumed, therefore the relative frequencies were calculated using Eq. (3.2b).

The procedure used to develop empirical distributions to represent the wetland and upland water elevations associated with an individual wetland or category is: 1) sort the water elevations from the smallest value to the largest value, 2) assign a rank (*m*) to each water elevation, and 3) calculate the relative frequency (probability of exceedance) associated with each water elevation using Eq. (3.2b). The cumulative probability for any water elevation is the sum of all relative frequencies up to the respective value.

The empirical distributions developed in this chapter are presented as percentiles (Altman and Bland 1994). In general, the percentile of a distribution represents the fraction of data that are less than or equal to a specific observation or value (StatSoft Inc. 2010). For instance, the 50th percentile indicates 50% of the data is equal to or less than the corresponding value. In this work, the percentiles represent the cumulative probabilities, i.e. frequencies of occurrence, and the amount of time the wetland or upland recorded water elevations were at or below a specific elevation.

In order to glean insight into representative wetland water elevation and upland groundwater elevation characteristics associated with the 56 wetlands, representative percentiles needed to be identified. Three percentiles were chosen due to the skewed (non-normal) nature of the wetland and upland water elevation histograms (Appendix B). Altman and Bland (1994) recommend using the median (50th percentile) and two outer percentiles to summarize skewed distributions. Therefore, the 10th, 50th, and 90th percentiles, hereafter referred to as target percentiles, were chosen to represent the respective frequency distributions. The 10th percentile represents low water elevations, the 50th percentile represents median water elevations, and the 90th percentile represents high water elevations.

3.4.1.2. Relative Water Level Development

The individual wetland and upland well water-elevation data were normalized so as to provide a means of comparing one data set to another. Relative water levels (RWLs) were developed with respect to two datums: 1) the ground elevation at each well (*GE*), and 2) the associated wetland dry-bed elevation (*DB*). The normalized data are presented as centimeters above or below the respective datum. The datums were chosen to provide different perspectives on the water-elevation distributions. Further, the datums provide a means to evaluate the overall trend of the wetland and upland water-elevation distributions, and evaluate the variability in the water levels associated with all the wetlands at the 10th, 50th, and 90th percentiles.

3.4.1.3. Frequency of Water Levels at Dry Bed (*DB*) and Normal Pool (*NP*)

Additionally, the empirical distribution functions were used to identify the cumulative probability (percentile) corresponding to the wetland dry-bed elevation, *F*(*DB*), and the wetland normal-pool elevation, *F*(*NP*). The percentiles were used to identify the duration of time standing water was present within the wetlands, and the amount of time water was above the normal pool vegetative markers over the seven year study. Monthly data, based on a single measurement or the average of all water elevations recorded during the respective month, were used in this analysis. Monthly values were used to eliminate any bias brought about by combining data sets comprised of daily water elevations and monthly elevations. Further, the use of monthly data did not influence the results because data sets comprised of monthly data are not statistically different from data sets comprised of daily data (Appendix C).

3.4.2. Wetland Category and Group Comparisons – Kolmogorov-Smirnov Tests

The two-sample Kolmogorov-Smirnov test (KS-test) was used to compare the wetland categories and various groups of wetlands. The KS-test is a form of minimum distance estimation used to compare empirical distribution functions to determine if two datasets are statistically similar (Massey 1951; StatSoft Inc. 2010). The KS-test makes no assumption about the data distribution, i.e. it is a non-parametric and distribution free test. The test was used due to the non-parametric nature of the water-elevation data (Appendix B). The KS-test statistic (*D* statistic) quantifies the maximum distance expressed as a probability between the empirical distribution functions of two samples. The null hypothesis for the test is that the two data sets are from the same continuous distribution. The result of $h = 1$ is returned if the test rejects the null hypothesis at the 5% significance level, otherwise the result of $h = 0$ is returned indicating a failure to reject the null hypothesis.

3.4.2.1. Wetland Category Comparisons

Empirical distribution functions representing the various wetland categories (Table 3.1) were developed and evaluated to determine if the observed water levels associated with each wetland category are significantly different. As indicated previously, monthly data records were used in this analysis to eliminate potential bias brought about by various data collection frequencies. The distributions were developed by combining individual wetland water elevation data, normalized by subtracting the individual wetland dry bed elevation, within the specific wetland category. For example, the wetland relative water levels associated with each of the 36 cypress wetlands were combined into one aggregate or representative data set. Using the procedure outlined in Section 3.4.1.1, relative frequencies were then calculated for each of the water levels in the data set, and a characteristic empirical distribution was developed for the cypress category. Archetypal empirical distributions were developed for each of the five wetland categories. Each wetland category distribution was compared to every other wetland category distribution using the KS-test to determine if the respective hydrologic data were statistically similar.

3.4.2.2. Wetland Group Comparisons

Four wetland groups were identified based on regional location and the associated hydrogeology. The first group is comprised of the nine wetlands located in the Green Swamp, the second and third groups are comprised of wetlands located in the Morris Bridge (9 ea.) and the Starkey (17 ea.) well fields, and the fourth group is comprised of nine wetlands in the UHFDA area located south-southeast of the Green Swamp (Figure 3.1). Individual wetlands within a particular group are identified in Table 3.1. The wetland groups were compared to determine if the observed water levels are statistically different. As before, empirical distribution functions were developed by aggregating the wetland relative water levels within the specific wetland group. Each aggregated wetland group distribution was compared to every other wetland group distribution using the KS-test. Monthly data were also used for this comparison.

3.5. Results

3.5.1. Wetland Hydrologic Evaluation (Frequency Analysis)

3.5.1.1. Well Ground Elevation Datum (*GE*)

The empirical distribution functions shown in Figure 3.5 depict the relative water levels, based on the respective ground elevations at the well (*GE*), associated with all 56 wetland wells (Chart A) and upland wells (Chart B). The charts provide a direct comparison of the wetland and upland relative water levels, and illustrate the variability in the water levels at each cumulative probability (percentile). Further, the charts show no distinct patterns that could be used to identify the various wetland types.

The overlaid water-level distributions presented in Charts A and B are a bit hard to decipher; therefore, mean-relative-water-level plots representing the wetland water levels (Chart C) and upland groundwater levels (Chart D) were developed from the 56 individual wetland and upland water-level distributions. The charts show the mean relative water level ± one standard deviation at each percentile, and show the variability of the water levels over the empirical distribution range.

Wetland water levels and upland groundwater levels corresponding to the 10th, 50th, and 90th target percentiles on Figure 3.5 are summarized in Table 3.5 to provide additional insights into the wetland hydrologic characteristics. On average, the wetland water levels were 90.8 cm below the ground elevation at the wetland well for the 10th percentile, and 13.0 cm and 57.5 cm above the ground elevation at the wetland well for the 50th and 90th percentiles respectively (Table 3.5 – Regional Wetlands). In general, the upland groundwater levels were below the ground elevation at the well for each target percentile: 196.5 cm (10th percentile), 94.3 cm (50th percentile) and 28.6 cm (90th percentile) (Table 3.5 – Regional Wetlands).

The variability, indicated by the standard deviation (StD), of the wetland water levels and upland groundwater levels was generally highest at the 10th percentile (57.6 cm and 80.7 cm respectively), and lowest at the 90th percentile (35.6 cm and 24.6 cm respectively). This can be seen on Figure 3.5, Charts C and D, as well. Also, Charts A and B on Figure 3.5 show the wetland and upland water levels associated with the various wetlands crisscross at the target percentiles, which is substantiated in Table 3.5. For instance, water levels at the 50th percentile for the cypress wetlands ranged from 103.6 cm below the well ground elevation (min) to 81.4 cm above the well ground elevation (max), and for the marsh wetlands ranged from 28.7 cm below the well ground elevation (min) to 89.3 cm above the well ground elevation (max).

The interdecile range is the difference between the 10th and 90th percentiles, and is a measure of dispersion of the values in the data set. The range is the width about the median that includes 80% of the cases or water-level data. The mean range of wetland water levels between the 10th and 90th percentiles is 148.3cm, and the mean range of upland groundwater levels is 167.9 cm (Table 3.5). Thus, the upland wells show greater fluctuations than the wetland wells. The cypress-marsh wetlands have the largest range of wetland water levels and upland groundwater levels between the 10th and 90th percentiles, 198.2 cm and 215.0 cm respectively. While, the cypress wetlands have the smallest range of wetland and upland water levels, 138.6 cm and 151.7 cm respectively.

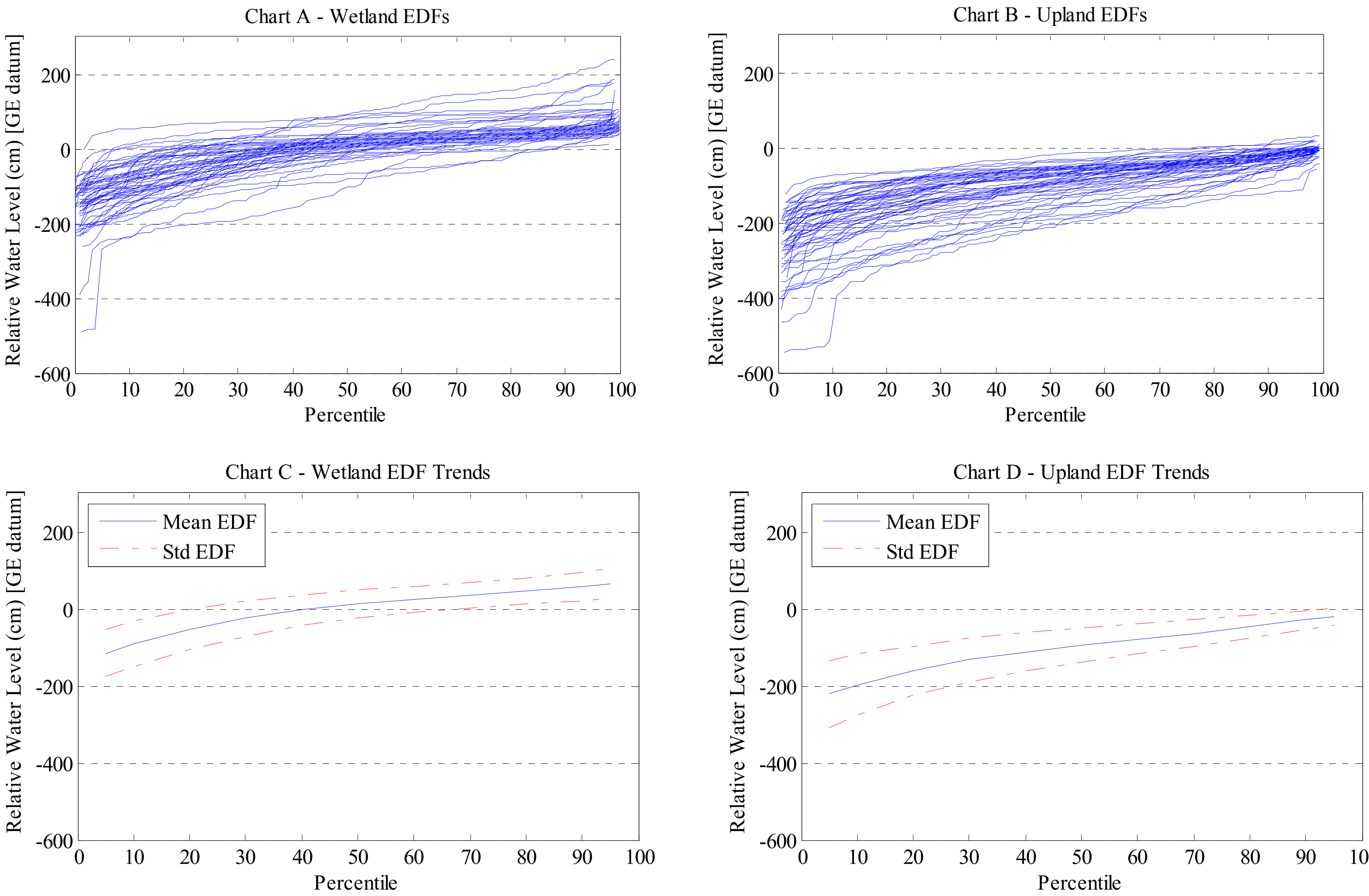


Figure 3.5 Empirical distribution function charts representing wetland and upland water levels adjusted to the ground elevation at the well (*GE*).

Table 3.5. Wetland and upland empirical distribution summary statistics adjusted to the ground elevation at the wetland well (*GE*).

	Relative Water Levels (cm)					
	Wetland			Upland		
Statistic	10th	50th	90th	10th	50th	90th
	Regional Wetlands					
Mean	-90.8	13.0	57.5	-196.5	-94.3	-28.6
StD	57.6	35.9	35.6	80.7	45.5	24.6
Median	-87.0	14.3	49.1	-174.2	-81.4	-23.6
Min	-239.0	-103.6	5.5	-514.2	-211.8	-118.9
Max	54.9	92.4	192.9	-73.2	-20.7	13.4
Range	293.8	196.0	187.5	441.0	191.1	132.3
	Cypress Wetlands					
Mean	-88.0	11.7	50.6	-176.9	-79.7	-25.2
StD	52.4	32.2	28.1	81.3	37.9	22.2
Median	-86.7	14.3	46.5	-157.4	-71.2	-22.3
Min	-239.0	-103.6	5.5	-514.2	-181.7	-118.9
Max	54.9	81.4	149.7	-73.2	-20.7	10.1
Range	293.8	185.0	144.2	441.0	160.9	128.9
	Marsh Wetlands					
Mean	-78.8	21.1	73.5	-241.8	-135.3	-43.5
StD	63.4	36.8	39.9	62.9	48.6	32.1
Median	-66.4	18.3	59.4	-247.8	-135.3	-41.5
Min	-176.8	-28.7	37.5	-340.2	-211.8	-99.7
Max	6.1	89.3	154.2	-153.0	-76.2	-5.8
Range	182.9	118.0	116.7	187.1	135.6	93.9
	Cypress-Marsh Wetlands					
Mean	-105.3	36.3	92.9	-230.2	-98.7	-15.2
StD	94.6	51.0	60.7	103.2	51.2	25.7
Median	-86.9	60.4	81.4	-197.8	-93.6	-9.8
Min	-235.0	-19.2	36.9	-356.3	-170.7	-57.0
Max	14.0	92.4	192.9	-94.2	-37.5	13.4
Range	249.0	111.6	156.1	262.1	133.2	70.4
	Hardwood Wetlands					
Mean	-93.5	10.4	59.2	-219.0	-100.0	-36.7
StD	41.2	23.4	27.4	34.3	24.0	20.6
Median	-108.2	18.9	50.6	-236.2	-94.8	-33.8
Min	-125.3	-16.2	37.2	-241.4	-126.2	-58.5
Max	-46.9	28.3	89.9	-179.5	-78.9	-17.7
Range	78.3	44.5	52.7	61.9	47.2	40.8
	Wet Prairie Wetlands					
Mean	-134.1	-30.9	31.2	-217.4	-133.1	-39.7
StD	58.8	39.1	18.3	70.3	52.3	15.0
Median	-140.8	-37.2	38.4	-192.3	-113.7	-42.7
Min	-189.3	-66.4	10.4	-296.9	-192.3	-53.0
Max	-72.2	11.0	44.8	-163.1	-93.3	-23.5
Range	117.0	77.4	34.4	133.8	99.1	29.6

3.5.1.2. Wetland Dry-Bed Datum (*DB*)

The empirical distribution function plots shown in Figure 3.6 depict the relative water levels, based on the associated wetland dry-bed elevation (*DB*), for all 56 wetland wells (Chart A) and upland wells (Chart B). The charts provide a direct comparison of the wetland and upland water levels, and illustrate the variability in the water levels at each percentile. As before, the charts show no obvious distinct patterns that could be used to differentiate the various wetland categories.

The overlaid water-level distributions presented in Charts A and B are a bit hard to decipher; therefore, mean-relative-water-level plots representing the wetland water levels (Chart C) and upland groundwater levels (Chart D) were developed from the 56 individual wetland and upland water-level distributions. The charts show the mean water level ± one standard deviation at each percentile, and show the variability of the water levels.

The relative water levels at the 10th, 50th, and 90th percentiles corresponding to the distributions presented in Figure 3.6 are summarized to provide additional insights into the wetland and upland hydrologic differences and interactions (Table 3.6). On average, the water levels in the wetlands were 85.2 cm below the dry bed elevation at the 10th percentile, and 18.7 cm and 63.1 cm above the dry bed elevation at the 50th and 90th percentiles respectively (Table 3.6 – Regional Wetlands). The mean upland water levels were 102.7 cm and 0.5 cm below the wetland dry bed elevation at the 10th and 50th percentiles respectively, and 65.1 cm above the dry bed elevation at the 90th percentile

(Table 3.6 – Regional Wetlands). Further, in general, the water levels in the uplands were deeper than the associated wetland water levels at the 10th and 50th percentiles; while the water levels in the wetlands were deeper than the associated upland water levels at the 90th percentile.

The variability, expressed as the standard deviation (StD), of the wetland water levels and upland groundwater levels was on average largest at the 10th percentile, 58.2 cm and 80.2 cm respectively, and smallest at the 90th percentile, 37.1 cm and 45.8 cm respectively (Figure 3.6 – Charts C and D). Also, Charts A and B on Figure 3.6 show the wetland and upland relative water levels associated with the various wetlands crisscross at the three target percentiles, which is substantiated in Table 3.6. For instance, relative water levels at the 50th percentile for the cypress wetlands ranged from 103.3 cm below the wetland dry bed elevation (min) to 82.0 cm above the wetland dry bed elevation (max), and for the marsh wetlands the 50th percentile water levels ranged from 19.2 cm below the well wetland dry bed elevation (min) to 100.0 cm above the wetland dry bed elevation (max).

In general, the interdecile range of the regional wetland water levels is 148.3 cm, and the upland groundwater level range is 167.9 cm (Table 3.6). The cypress-marsh wetlands exhibit the largest range between the 10th and 90th percentiles for both the wetland and upland wells (198.2 cm and 215.0 cm respectively), while the cypress wetlands have the smallest range between the 10th and 90th percentiles (138.6 cm and 151.7 cm respectively).

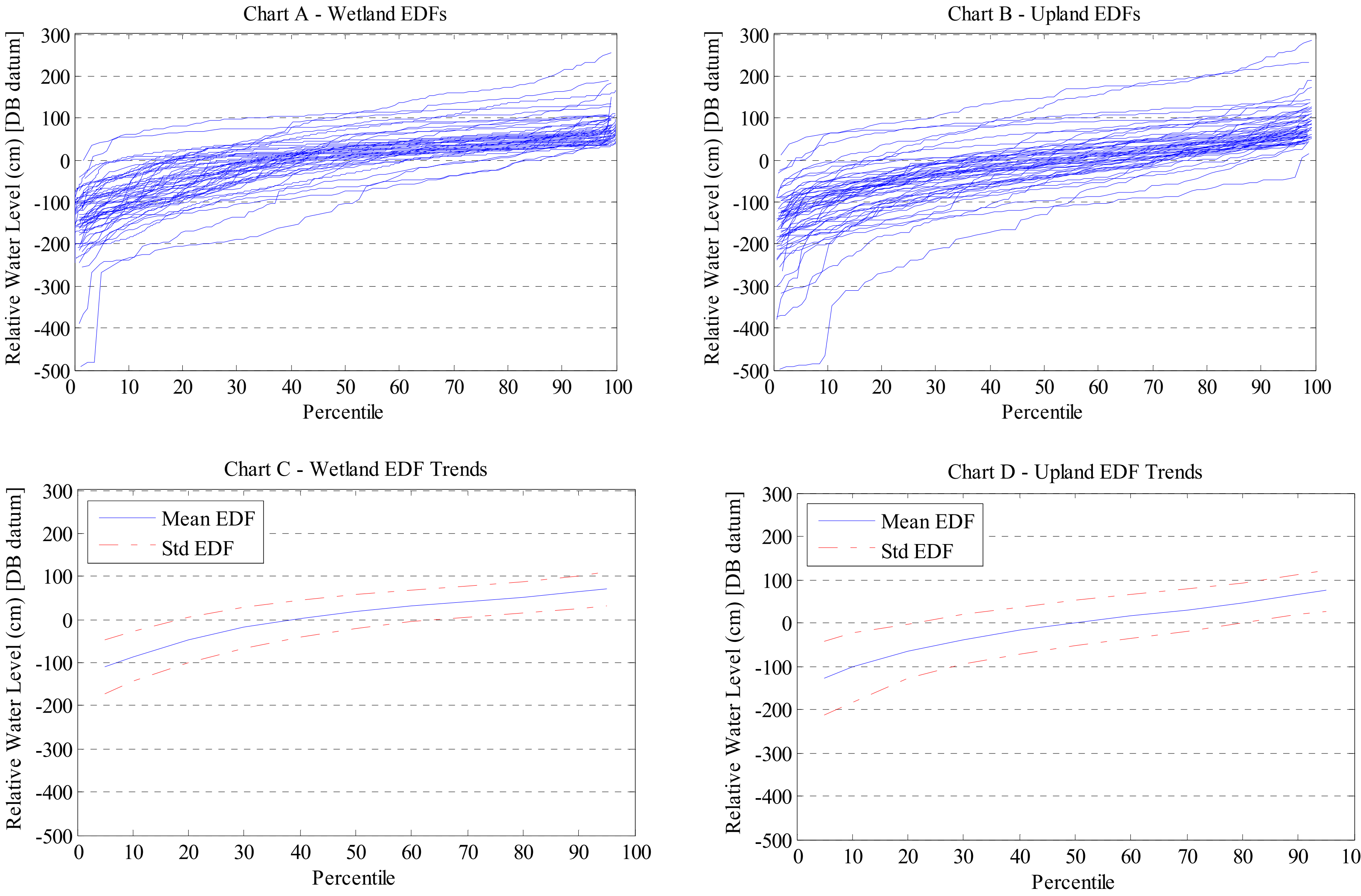


Figure 3.6 Empirical distribution function charts representing the wetland and upland water levels adjusted to the wetland dry-bed elevation (*DB*).

Table 3.6. Wetland and upland empirical distribution summary statistics adjusted to the wetland dry-bed elevation (*DB*).

	Relative Water Levels (cm)					
	Wetland			Upland		
Statistic	10th	50th	90th	10th	50th	90th
	Regional Wetlands					
Mean	-85.2	18.7	63.1	-102.7	-0.5	65.1
StD	58.2	39.6	37.1	80.2	52.1	45.8
Median	-87.0	20.0	55.9	-96.0	-1.8	55.2
Min	-238.7	-103.3	13.4	-466.6	-128.9	-48.8
Max	60.4	110.9	207.9	64.6	146.9	236.8
Range	299.0	214.3	194.5	531.3	275.8	285.6
	Cypress Wetlands					
Mean	-86.2	13.5	52.5	-100.4	-3.2	51.3
StD	53.8	34.8	22.8	87.5	46.8	30.5
Median	-87.0	18.3	49.8	-84.7	0.8	50.3
Min	-238.7	-103.3	14.3	-466.6	-128.9	-48.8
Max	55.5	82.0	118.6	64.6	102.1	134.7
Range	294.1	185.3	104.2	531.3	231.0	183.5
	Marsh Wetlands					
Mean	-67.8	32.1	84.5	-111.0	-4.5	87.3
StD	52.6	39.0	47.1	74.2	60.4	59.1
Median	-68.0	36.0	61.6	-139.9	-14.6	55.5
Min	-135.9	-19.2	34.7	-174.7	-53.0	40.8
Max	7.6	100.0	164.9	64.3	146.9	217.3
Range	143.6	119.2	130.1	239.0	199.9	176.5
	Cypress-Marsh Wetlands					
Mean	-83.3	58.3	114.9	-85.7	45.8	129.3
StD	105.0	53.4	57.8	91.3	71.4	64.9
Median	-71.9	60.4	98.1	-63.7	65.8	124.4
Min	-232.3	-14.0	57.9	-200.3	-40.8	66.1
Max	60.4	110.9	207.9	40.5	123.1	236.8
Range	292.6	125.0	150.0	240.8	164.0	170.7
	Hardwood Wetlands					
Mean	-82.8	21.0	69.9	-95.8	23.3	86.6
StD	36.4	12.5	24.9	13.7	12.3	10.1
Median	-102.1	25.0	73.8	-96.0	18.6	81.7
Min	-105.5	7.0	43.3	-109.4	14.0	79.9
Max	-40.8	31.1	92.7	-82.0	37.2	98.1
Range	64.6	24.1	49.4	27.4	23.2	18.3
	Wet Prairie Wetlands					
Mean	-131.5	-28.2	33.8	-140.8	-56.5	36.9
StD	57.6	38.1	18.2	30.4	13.4	31.7
Median	-137.8	-33.5	39.6	-139.3	-60.7	28.3
Min	-185.6	-63.4	13.4	-171.9	-67.4	10.4
Max	-71.0	12.2	48.5	-111.3	-41.5	71.9
Range	114.6	75.6	35.1	60.7	25.9	61.6

3.5.1.3. Dry Bed (*DB*) and Normal Pool (*NP*) Relative Frequency Identification

The empirical distribution functions shown in Figure 3.6 were used to identify the relative frequency (percentile) corresponding to the dry-bed elevation *F*(*DB*) and normal pool elevation *F*(*NP*) associated with the study wetlands. Overall, the wetland dry-bed elevations correspond to a relative frequency of 0.39, ranging from 0.02 to 0.86 (Table 3.7 – Regional Wetlands). This indicates 39% of the recorded water elevations were equal to or less than the wetland dry-bed elevation. The wet prairie wetlands exhibited the highest dry bed relative frequency (0.70), while the cypress-marsh wetlands had the lowest dry bed relative frequency (0.35). Additionally, on average, the wetland normal-pool elevations corresponded to a relative frequency of 0.96, indicating 96% of the recorded wetland water elevations are equal to or less than the normal-pool elevation. This value is consistent for all wetland categories, ranging from 0.95 (Hardwood) to 0.99 (Cypress-Marsh).

Table 3.7. Dry bed (*DB*) and normal pool (*NP*) probability.

	Regional Wetlands			Cypress			Marsh		
Statistic	*F*(*DB*)	*F*(*NP*)	h_o (cm)	*F*(*DB*)	*F*(*NP*)	h_o (cm)	*F*(*DB*)	*F*(*NP*)	h_o (cm)
Mean	**0.39**	**0.96**	**74.4**	**0.38**	**0.96**	**61.8**	**0.38**	**0.96**	**94.6**
StD	0.20	0.04	43.2	0.18	0.04	25.5	0.20	0.04	59.8
Median	0.39	0.98	59.6	0.37	0.97	55.3	0.31	0.97	72.8
Min	0.02	0.76	36.0	0.02	0.76	36.0	0.13	0.86	46.9
Max	0.86	0.99	250.2	0.86	0.99	148.7	0.65	0.99	235.0
Range	0.84	0.22	214.3	0.84	0.22	112.8	0.53	0.13	188.1
	Cypress-Marsh			Hardwood			Wet Prairie		
	F(*DB*)	*F*(*NP*)	h_o (cm)	*F*(*DB*)	*F*(*NP*)	h_o (cm)	*F*(*DB*)	*F*(*NP*)	h_o (cm)
Mean	**0.35**	**0.99**	**131.4**	**0.36**	**0.95**	**87.4**	**0.70**	**0.97**	**56.1**
StD	0.26	0.00	74.4	0.12	0.05	20.5	0.19	0.02	25.7
Median	0.35	0.99	134.1	0.41	0.99	93.0	0.75	0.98	45.7
Min	0.05	0.98	62.2	0.23	0.89	64.6	0.49	0.95	37.2
Max	0.64	0.99	250.2	0.45	0.99	104.5	0.85	0.99	85.3
Range	0.59	0.00	188.1	0.22	0.09	39.9	0.36	0.04	48.2

Last, the maximum wetland pool depth (h_o) estimate is shown on Table 3.7. The pool depth approximation was included to show depth of the wetland categories that correspond to the normal pool and dry bed elevation differences. Overall, the regional wetlands are 74.4 cm deep. The wet prairie wetlands are the shallowest (56.1 cm), and the cypress-marsh wetlands are the deepest (131.4 cm).

3.5.2. Wetland Category Water-Level Data Comparisons – Kolmogorov-Smirnov Tests

3.5.2.1. Wetland Category Comparisons

The two-sample Kolmogorov-Smirnov tests were performed on the wetland category empirical distribution functions illustrated on Figure 3.7. Summary statistics of the abridged relative water-level data used to populate the respective wetland categories are listed in Table 3.8. All of the wetland category comparisons failed the respective KS-test, $h = 1$ (Table 3.9). The table results are presented in a matrix format in which each wetland category (first column) is compared to every other wetland category (top row). The maximum vertical deviation between the respective category distribution curves (Dstat) vary between 0.10 (Cypress vs. Hardwood) and 0.36 (Hardwood vs. Wet Prairie) for the wetland water levels. These results indicate there are statistical differences, albeit unobvious, between the representative probability distributions.

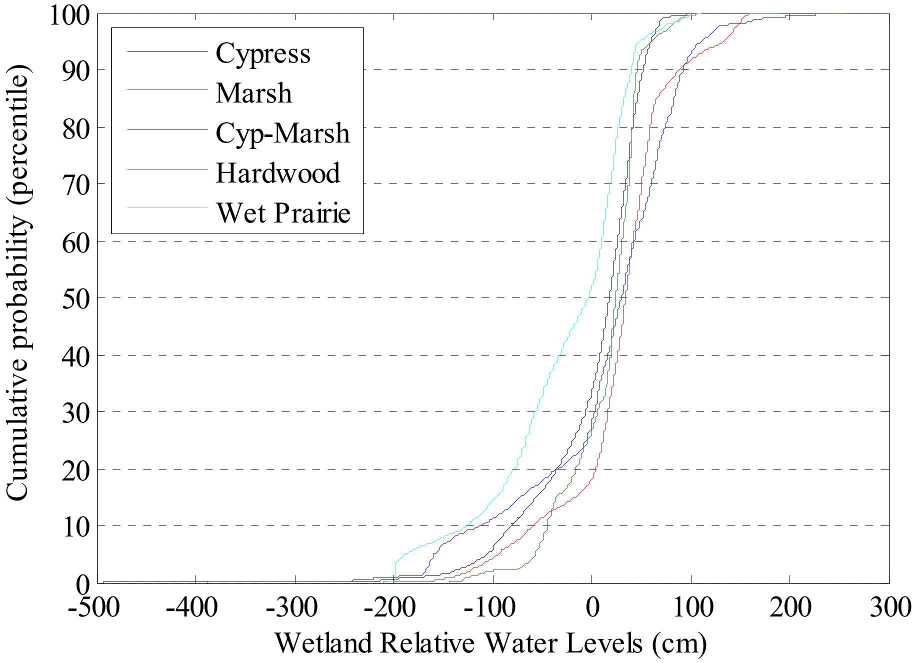


Figure 3.7 Wetland category empirical distribution functions, relative water levels based on the dry bed datum (*DB*).

Table 3.8. Wetland category monthly water level description.

	Relative Water Level Summary Statistics (cm)				
	Cypress	Marsh	Cypress-Marsh	Hardwood	Wet Prairie
Wetlands	36	9	5	3	3
Records	2,525	663	353	216	224
Mean	-5.4	11.1	22.4	10.0	-46.3
StD	68.5	69.5	98.1	57.3	69.1
Median	15.2	23.3	46.0	22.7	-39.9
Min	-491.9	-209.4	-388.6	-138.4	-205.7
Max	208.5	156.4	132.3	104.9	103.3

Table 3.9. Wetland category water-level distribution comparisons, Kolmogorov-Smirnov test results.

Category	**Cypress**			**Marsh**			**Cypress-Marsh**			**Hardwood**		
	h	*p*	*D*stat	*h*	*p*	*D*stat	*h*	*p*	*D*stat	*h*	*p*	*D*stat
Cypress	0											
Marsh	**1**	0.00	14%	0								
Cypres-Marsh	**1**	0.00	36%	**1**	0.00	24%	0					
Hardwood	**1**	0.03	10%	**1**	0.04	11%	**1**	0.00	27%	0		
Wet Prairie	**1**	0.00	32%	**1**	0.00	35%	**1**	0.00	47%	**1**	0.00	36%

3.5.2.2. Regional Wetland Groups

KS-tests were performed on the aggregate empirical distribution functions illustrated on Figure 3.8. Summary statistics of the relative water level data used to populate the respective wetland groups are listed in Table 3.10. Each of the wetland group comparisons failed the respective KS-test, $h = 1$ (Table 3.11). As before, the table results are presented in a matrix format in which each wetland group (first column) is compared to every other wetland group (top row). The maximum vertical deviation between the respective group distribution curves (*D*stat) vary between 0.15 (Green Swamp vs. Morris Bridge) and 0.26 (Green Swamp vs. Starkey) for the wetland water levels.

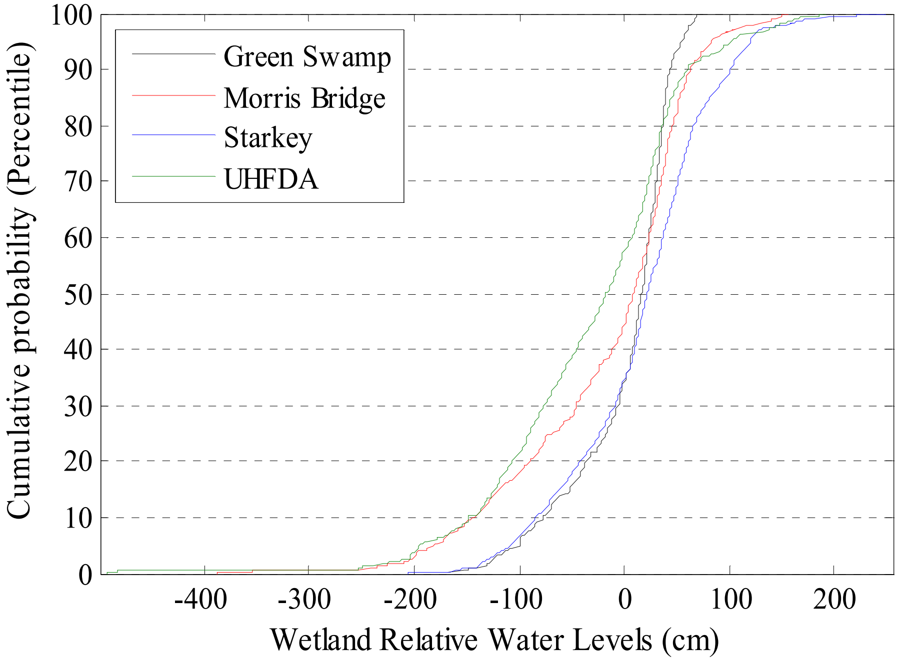


Figure 3.8 Regional wetland group empirical distribution functions, relative water levels based on the dry bed datum (*DB*).

Table 3.10. Regional wetland group monthly data description.

	Relative Water Level Summary Statistics (cm)			
	Green Swamp	Morris Bridge	Starkey	UHFDA
Wetlands	9	9	17	9
Records	604	692	1,199	669
Mean	0.8	-16.9	16.4	-31.0
StD	48.0	84.5	69.0	90.7
Median	17.2	8.5	22.3	-17.4
Min	-169.5	-388.6	-205.7	-491.9
Max	73.7	156.6	248.1	190.8

Table 3.11. Regional wetland group water-level distribution comparisons, Kolmogorov-Smirnov test results.

Regional Group	**Green Swamp**			**Morris Bridge**			**Starkey**		
	h	*p*	*D*stat	*h*	*p*	*D*stat	*h*	*p*	*D*stat
Green Swamp	0								
Morris Bridge	**1**	0.00	0.14	0					
Starkey	**1**	0.00	0.26	**1**	0.00	0.14			
UHFDA	**1**	0.00	0.25	**1**	0.00	0.14	**1**	0.00	0.24

3.6. Discussion

3.6.1. Wetland Hydrologic Evaluation (Frequency Analysis)

The empirical distributions representing the wetland and upland relative water levels, based on the ground elevation (*GE*) at the well and the bed elevation of the wetland (*DB*), did not provide a clear means of distinguishing the different wetland types (Figures 3.5 and 3.6). The distributions representing the respective wetland water levels (Figures 3.5 and 3.6 – Chart A) and upland groundwater levels (Figures 3.5 and 3.6 – Chart B) cross at almost every percentile. Based on the distribution overlap and the reported standard deviations in Tables 3.5 and 3.6, it is apparent there was high variability in both the surface and sub-surface water levels between the 56 study wetlands at each of the target percentiles (10th, 50th, and 90th). Overall, the highest variability was observed at deep groundwater levels (10th percentile), and the lowest variability was observed at high water levels within the wetland extents and in the surrounding uplands (90th percentile). This was generally the case for each wetland category as well.

The increased variability at the deep groundwater levels (10th percentile) can, in part, be attributed to the depth of the water table. In general, the range of recorded water levels across these wetlands increases as the depth to the water table increases. The point is illustrated in Figure 3.9, which presents a linear regression between the depth to the water table and the range of recorded upland water levels associated with each wetland. The water-table depth was approximated using the deep groundwater levels corresponding to the 10th percentile. The deep upland groundwater levels are summarized in Table 3.5. The upland groundwater level ranges for each wetland were calculated from the summary statistics presented in Table 3.4. All upland water levels were normalized by the ground elevation at the upland well.

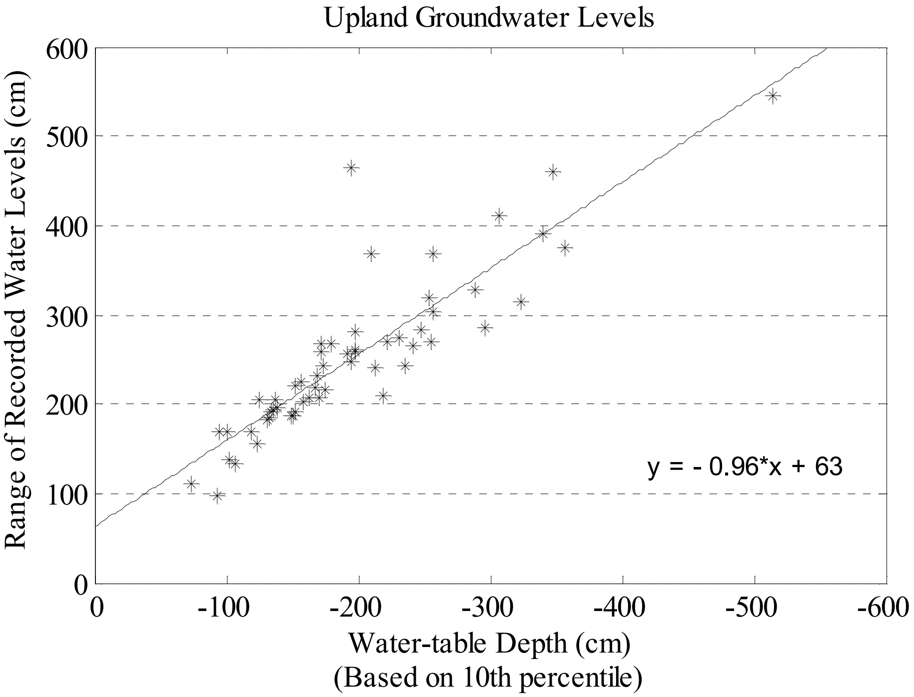


Figure 3.9 Comparison of water-table depth and upland water level range.

Local water-table depths associated with the wetlands in northern Tampa Bay region can be influenced by several factors or combinations of factors. One is the location of the wetland in the region. For instance, wetlands located in the flat coastal areas on the western side of the region (Figure 3.1) will have local water tables that remain shallow much of the year. Other, wetlands located away from the coast in higher slope areas with more conductive soil types enable higher water-table variability in the groundwater levels throughout the year or during dry years. Yet other wetlands are located in areas such as the Green Swamp where the water-table remains near the land surface due to the hydrogeologic characteristics of the area. In this area, there is an Upper Floridan aquifer groundwater mound that hinders the downward movement of water, as well as high clay content in the soils providing surficial aquifer confinement which stabilize the water table (Spechler and Kroening 2007). Further, confining layers can be present throughout the region preventing water-table levels from dropping. In places where the confining layer is thin or has been breached groundwater levels can drop considerably. Last, the depth of the water-table can be influenced by anthropogenic stresses such as groundwater pumping, which could lower local groundwater levels, and surface water augmentation which could raise and/or stabilize local groundwater levels.

Conversely, water levels at the 90th percentile within the wetland extents and in the uplands generally had the lowest variability (Tables 3.5 and 3.6). The reduced water-level variability within the wetlands is due to the bowl shape near the wetland extents (Haag et al. 2005; Nilsson et al. 2008). The upper bowl near the maximum pool depths tends to fans out, with gradual or low-gradient topography. Hence, for a given water-level change the incremental volume increase is at its maximum. Therefore, large volume changes are required to see significant changes in the surface water level. Finally, at the maximum pool depth many wetlands exceed a discharge invert limiting the water levels. As a result, the surface-water levels of the various wetlands are more consistent at the 90th percentile than at the 50th percentile (median water levels) and the 10th percentile (deep groundwater levels). Consequently the variability in the recorded water levels between the wetlands is lower.

The lower variability in the shallow upland groundwater levels (90th percentile) can be attributed to the local topography. As the depth to the water-table decreases, the groundwater becomes an expression of the local topography of the land surface, which is a physical boundary. Also, water levels above ground are associated with rapid surface water overland flow. As a result, high groundwater levels in the upland wells become consistent from one wetland to another; hence, the variability of the upland groundwater levels decreases at shallow water-table depths.

3.6.2. Frequency of Water Levels at Dry Bed (*DB*) and Normal Pool (*NP*)

Two important datums associated with wetlands, the dry bed elevation (*DB*) and the normal pool elevation (*NP*) were identified on the respective wetland water-level empirical distribution functions. Based on these elevations, there was at least some standing water in all study wetlands on average 61% of the time over the study duration (Table 3.7 – Regional Wetlands). A comparison of the cypress and marsh categories, which have the largest number of representative wetlands, revealed some standing water was present in each category 62% of the time, indicating no difference in this variable for two very different vegetative types.

The normal pool elevation is identified by stain markers, mosses and unique plant species that are typically found at the wetland extents. In order for these indicators and plant species to exist, they can only be inundated by water a small percentage of time. This analysis verified that the normal pool elevations supplied by SWFWMD were, in general, exceeded only 4% of the time for the 56 study wetlands (Table 3.7). This result was approximately the same for all of the wetland categories (Table 3.7). Overall, this finding was consistent with the District's goal of using vegetation that is intolerant of flooding as an indication of the normal pool elevations.

3.6.2.1. Analytical Model Application

Several analytical models used to predict wetland storage require the maximum pool depth as an input parameter (Hayashi and van der Kamp 2000; Nilsson et al. 2008; O'Connor 1989). The maximum pool depth can be obtained via survey or estimate. Surveys are the most accurate measure of the depth. However, depending on the number of wetlands within a study area surveys may be impractical and cost prohibitive. Estimating the wetland pool depth is much less costly and may be practical for large study areas, albeit estimation may introduce error into a hydrologic modeling analysis.

The difference in elevation between the wetland normal pool and the dry bed is a good approximation of the wetland maximum pool depth. The maximum pool depth estimates (h_o) for each wetland category are listed in Table 3.7. These pool depths can be used in analytical models to represent the various wetland categories. Additionally, summary statistics are provided to enable water resource engineers and hydrologists to account for errors that may be introduced from the normal variability in the pool depth estimate.

Further, the dry bed and normal pool probability results can be used as a calibration tool for the models. For instance, based on the probability data, on average the water levels within the cypress wetlands should be below the normal pool elevation 96% of the time, and the wetlands should generally be dry 38% of the time. Therefore, some standing water should be present within these indices 58% of the time for the cypress wetlands in order for a model performance to be statistically similar.

3.6.3. Combined Wetland Water-Level Data Comparisons

The visual comparison of the individual wetland frequency distributions did not show hydraulic differences between the various wetland categories. However, combining the water-level data of each wetland within a category revealed that all five wetland categories have statistically unique water-level characteristics (Table 3.9). Based on this finding, the water-level variability associated with individual wetland categories could be represented by distinct probability density functions. These functions could be incorporated into hydrologic models to represent wetland water-level fluctuations or used to test the model validity.

Similarly, comparisons of four regional wetland groups indicated the water-level variability related to each group are statistically different (Table 3.11). This implies the water-level behavior of these wetland groups are strongly influenced by the local hydrogeology, climatology and anthropogenic stresses.

3.7. Application: Impacted Wetland Identification

A simple technique of identifying wetlands that may be influenced by anthropogenic activities or natural stresses is presented here. For instance, the water levels within and around a wetland may be lowered due to groundwater pumping, or the water levels could be augmented from the inadvertent or intentional addition of water to the wetland and surrounding upland. Individual wetland and/or upland water-level distributions are compared to the trend distributions (Charts C and D) in Figure 3.6 by visual and numerical inspection. The inspection is used to identify two hydrologic conditions: 1) raised water levels and 2) lowered water levels. Raised water levels are evident by frequency distributions that lie above the trend standard deviation, and lowered water levels are evident by frequency distributions that lie below the trend standard deviation. Also, frequency distributions indicative of outside influences or stresses may deviate from the trend distribution in the form of a vertical line or horizontal line. A vertical distribution curve would indicate high water-level fluctuations or variability, while a flat or horizontal curve would indicate low or minimal water-level fluctuations. For example, wetlands that are augmented or in the Green Swamp (natural hydrogeologic conditions) may exhibiting minimal water-level fluctuations.

Wetlands that exhibit stressed water-level behavior have all or part of the respective frequency distribution (0th percentile to the 100th percentile) lie outside the standard deviation range (outliers), or deviate from the general distribution trend. Depending on the number outliers and the magnitude of the departure from the standard deviation limit, or trend in the case of vertical and horizontal curves, an investigation can be conducted to determine the hydrologic state of the wetland.

Two examples of this technique are demonstrated in Figure 3.10. The Figure shows the respective wetland water-level distribution curves for cypress-marsh wetland 331 (Chart A) and cypress wetland 1322 (Chart B) overlaid on the wetland water-level distribution trend curves, Figure 3.6 – Chart C. The distribution curve for wetland 331 is above the trend standard deviation, suggesting the wetland may be under the influence of elevated groundwater levels or surface-water runoff, or augmented. The distribution curve for wetland 1322 is below the trend standard deviation, suggesting the water levels associated with the wetland have been lowered possibly by reduced surface water flows to the wetland.

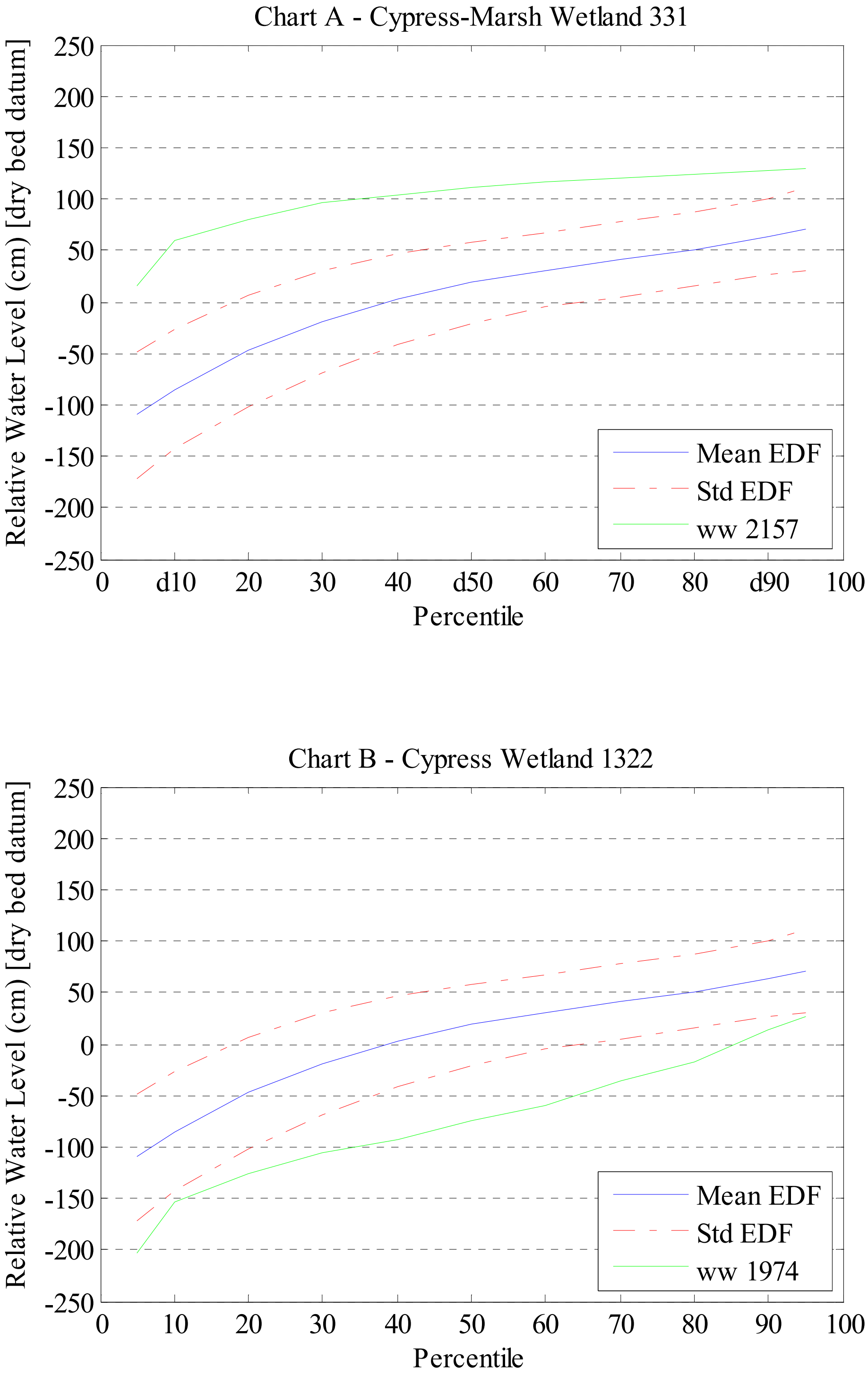


Figure 3.10 Individual wetland outlier distribution functions.

Investigations into the hydrologic state of both wetlands were conducted since both of these wetlands have distribution curves that lie outside the standard deviation range of the trend at all percentiles. Wetland 331 is located in the immediate vicinity of a waste water treatment facility containing two sludge lagoons and a spray field (Appendix D). The waste water treatment discharge practices appear to have artificially raised the local water table and/or surface flows to the wetland, hence increasing the frequency of elevated wetland water levels. Conversely, historic observations of wetland 1322 indicate the wetland experiences greatly depressed water levels (Appendix D). The reason of the depressed water level is unknown at this time. Further hydrologic investigations need to be conducted to determine the cause. Additionally, Appendix D contains the investigation summaries performed by the District for all 56 study wetlands listed in Table 3.1.

This analysis was conducted on all 56 wetlands presented in Table 3.1. The respective wetland water-level empirical distributions were compared to the trend distributions (Figure 3.6 – Chart C). The empirical distributions were evaluated at the 10th, 50th and 90th percentiles to identify water-level outliers and potential hydrologic stresses. Twenty wetlands, including the two discussed previously, were identified as having low or high outliers (beyond the standard deviation range) (Table 3.12). The wetland locations are shown on Figure 3.11. Each of the respective wetland water-level distributions has an outlier at one or more of the target percentiles, noted by a (▲) or (▼) in the representative column in Table 3.12. The blue (▲) markers indicate the respective wetland water level was to the high side of the trend standard deviation range, and the red

(▼) markers indicate the wetland water level was to the low side of the deviation range. Thirteen wetlands exhibited distribution outliers at the 10th percentile (7 low, 6 high), 12 at the 50th percentile (5 low, 7 high), and 10 at the 90th percentile (3 low, 7 high) (Table 3.13). To put this in perspective, 23% (13 of 56) of the wetlands studied have water-level outliers at the 10th percentile, 21% at the 50th percentile, and 18% at the 90th percentile.

Table 3.12. Wetland percentiles exceeding one standard deviation (outliers).

Wetland UID	Well ID	Outliers per Target Percentile			Type	Location
		10th	50th	90th		
21	1943			▲	M	S
81	1971		▲	▲	M	
154	1948		▲		CM	CB
183	1954		▲	▲	M	MB
261	2076	▲	▲	▲	C	
276	1984	▼			C	SP
331	2157	▲	▲	▲	CM	S
379	1951	▼			CM	MB
489	1927	▲	▲	▲	C	S
501	1941		▲	▲	CM	S
505	1950	▼			C	MB
605	1966	▲			M	
1317	1934		▼	▼	WP	S
1320	1960	▲			M	CB
1322	1974	▼	▼	▼	C	UHFDA
1323	1975		▼		C	UHFDA
1324	1976	▼	▼		C	UHFDA
1325	1977	▼	▼		WP	UHFDA
3713	2064	▼		▼	C	
4352	2253	▲			C	S

▲ = High Frequency Distribution outliers
▼ = Low Frequency Distribution outliers

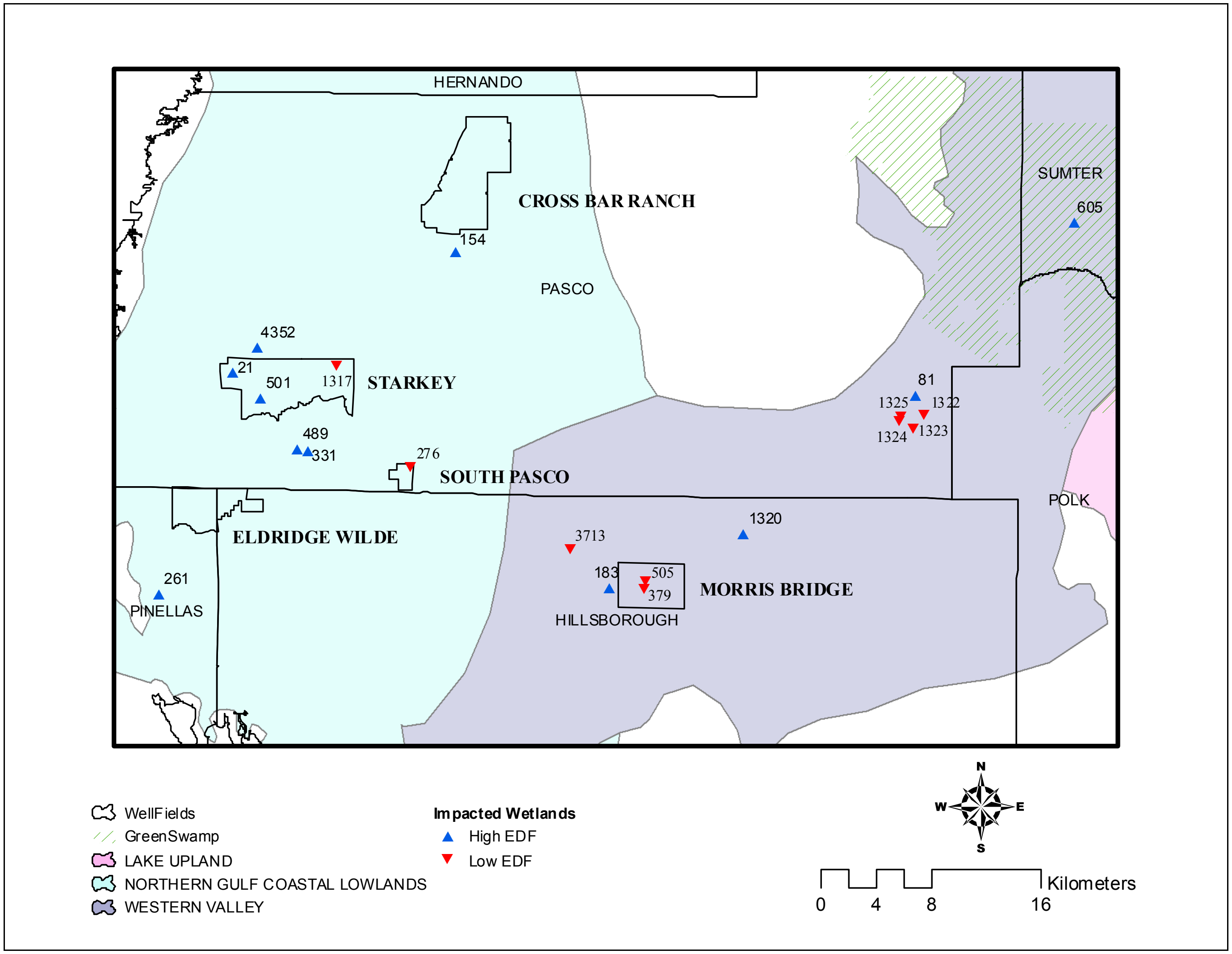


Figure 3.11 Wetlands with empirical distribution outliers (± 1 StD from mean).

The wetlands that exhibit stressed water-level behavior are located throughout the region, from coastal areas to the Green Swamp (Figure 3.11). Reasons for the respective elevated or depressed water levels for given wetlands are difficult to determine from their region location, because wetlands with high water levels (blue (▲) markers) as well as wetlands with low water levels (red (▼) markers) are located in the vicinity of one another. Further complicating matters, several wetlands within and around the Starkey well field have elevated water levels. Contrary to this, it would be expected that wetlands located on well fields or possibly in the vicinity of well fields would have lower water levels due to pumping stresses. This suggests that the local hydrolgeologic properties, such as soil composition and the presence or integrity of the intermediate confining unit, associated with the various wetlands could be the dominate factor affecting the water levels of these wetlands. Therefore, detailed hydrogeologic surveys need to be performed in order to determine the exact reason these wetlands exhibit the water level behavior.

This analysis demonstrates that empirical (frequency) distribution functions can be used to identify potentially impacted wetlands where traditional temporal water-level plots may not. Also, based on this analysis, approximately 80% of the wetland water-level data are within the empirical trend standard deviation range (Figure 3.6 – Chart C). This could be another indication that the 56 west-central Florida wetlands exhibit similar hydraulic behavior.

3.8. Conclusions

The purpose of this chapter was to characterize wetland water-levels based on the probability of inundation and the frequency distribution of the depth to the water table. Empirical distribution functions were developed from historic wetland water elevation records and upland groundwater elevation records associated with 56 different isolated wetlands in west-central Florida. The empirical distribution functions provide a means to analyze the water-level data using frequencies and probabilities of occurrence of water levels over time. Further, the distributions were used to compare the hydraulic characteristics of five wetland categories and four regional wetland groups, and to identify wetlands that are potentially under adverse hydrologic stresses.

In general, standing water was present in these wetlands 61% of the time over the seven year study. Also, the water levels in the wetlands exceeded the normal pool vegetative markers only 4% of the time. These levels represent critical indicators for the hydrologic condition or state of the wetland, and may serve as useful parameters to calibrate or test hydrologic models. Also, an estimate of the maximum pool depth can be obtained using the dry bed and normal pool elevations. This depth can be incorporated in the storage model presented in Chapter Two to develop wetland stage-storage characteristics.

Surprisingly, individual wetland categories could not be identified simply by viewing the representative empirical distribution functions associated with each wetland type. The variability in water levels between the regional wetlands and wetland types was significant. Consequently, individual wetland categories could not be identified via simple inspection of the respective water-level distributions. Additionally, there was higher variability in the groundwater levels beneath the wetlands than in the surface-water levels within the wetlands. The high variability in the groundwater levels is most likely a reflection of varying water-table depth across the west-central Florida region. The depth of the water table can be affected by pumping stresses, surface water augmentation or local hydrogeology. The reduced variability at high water levels within the wetlands is attributed to the natural shape of the wetlands. The pooled water fluctuations are small due to large changes in volume near the wetland extents.

Frequency distributions can be used as a comparison tool to identify similarities and differences between representative data sets and to identify a typical hydrologic behavior. Statistical tests performed on frequency distributions representing the combined water levels of the various wetlands within a wetland category showed significant differences in the water-level behavior for the specific wetland categories. Further, wetlands were identified that might be adversely influenced by anthropogenic activities or natural stresses. This was accomplished by simply comparing the respective wetland empirical distribution functions to the general trend distribution curve developed in this chapter to determine the number and magnitude of water-level measurements that fall outside the trend standard deviation range. Hence, probability distributions can be used in hydrologic modeling to test the water-level behavior, trends, or stresses to individual wetlands and wetland categories.

3.9. Acknowledgments

I would like to graciously acknowledge the contributions of Michael C. Hancock, Senior Professional Engineer, Resource Projects Department, Southwest Florida Water Management District, who provided the wetland database used in this dissertation. He provided valuable advice and insights throughout the development of this dissertation.

CHAPTER 4

THE EXTENT AND PREVALENCE OF GROUNDWATER RECHARGE/DISCHARGE CONDITIONS IN WEST-CENTRAL FLORIDA ISOLATED WETLANDS

4.1. Introduction

Closed-basin wetlands are perhaps the most numerous and prominent freshwater systems in west-central Florida (Dahl 2006; Lee et al. 2009). These wetlands are hydrologically connected to the shallow surficial aquifer (Haag et al. 2005), and in many instances hydrologically connected to the deeper Floridan aquifer where the confining layer is breached or thin due to subaerial erosion or subterranean karst collapse (Lee et al. 2009). Groundwater levels in and around these wetlands in both the surficial and Floridan aquifers are typically within a few meters of the land surface for much of the year. Therefore, these wetlands provide a direct interface between surface water and groundwater during much of the year.

In west-central Florida, precipitation is approximately 140 centimeters per year, with approximately 60% of the precipitation falling during the four-month period of June-September (Southeast Regional Climate Center 2010). The mean evapotranspiration (ET) for the region is approximately 100 centimeters per year (Bidlake et al. 1996), and is generally considered higher in wetlands than uplands (Hill and Neary 2007). Because of this, it is often assumed that wetlands serve as drains that lower the local water-table thereby creating local water-table depressions (Whigham and Jordan 2003). However, empirical data generally supporting this assumption are largely lacking.

There are sound hydrogeologic reasons that may indicate wetlands are groundwater recharge features on average or at least some of the time. Evapotranspiration in these wetlands is temporally variable by season, with wetland evapotranspiration strongly declining in the dry season due to a reduced availability of water and a lowering of the water-table. Also, winter time senescence of the leaves of the typical dominant or co-dominant tree, Bald Cypress (*Taxodium distichum*), results in reduced evapotranspiration. Furthermore, the specific yield (Sy), defined as the volume of water a water-table aquifer releases from or takes into storage per unit aquifer area per unit change in water-table elevation (Freeze and Cherry 1979), is much higher in the surface-water systems of these wetlands, when water is present, than in the groundwater systems of the surrounding uplands. In surface-water systems, such as these wetlands, specific yield typically is assumed to be 1.0 (Hill and Neary 2007; Mitsch and Gosselink 2000), while in groundwater systems, such as the uplands adjacent to these wetlands, specific yield is on the order of 10^{-1} (Johnson 1967). Therefore, surface-water drawdown in the wetlands will be lower than groundwater drawdown in the uplands. Other possible explanations are: 1) the leakage through the wetlands may be slower than the leakage in the intermediate confining unit of the surrounding uplands, and 2) the wetland can be located at a topographic low point in the watershed, above the water table, that can collect runoff from the surrounding upland areas and recharge the local groundwater system.

The objective of this chapter is to characterize the groundwater recharge potential or trends of 56 various isolated wetlands in west-central Florida by comparing wetland water levels to surrounding upland water levels. It is hoped that this empirical data analysis will provide new insight into the groundwater recharge or discharge characteristics of these wetlands that has largely been lacking to date. Long-term, paired wetland-upland monitoring well data as well as peak dry season (e.g., March-May) and wet season (e.g., July-September) data were used to determine the water-level relationships and recharge characteristics between these wetlands and surrounding uplands.

4.2. Methods

4.2.1. Head Differences between Paired Wetland and Upland Water Levels

The water elevation data for the wetland wells and upland wells presented in Chapter 3.2.3 were used to evaluate the groundwater recharge between the 56 various isolated wetlands and surrounding uplands. To ensure representative analysis, only paired wetland and upland water elevation records measured on the same date over the seven year study were used in this analysis. The groundwater recharge conditions were evaluated by calculating the difference in hydraulic head between the wetland water elevations and upland groundwater elevations for the matched data records. This net hydraulic head was used to determine the potential flow of the surficial aquifer, either into the wetland (groundwater sink) or out of the wetland (groundwater source).

Additionally, paired wetland and upland water elevation data, measured on the same date, from the peak dry season (March – May) and the peak wet season (July – September) were used to understand the seasonal recharge characteristics of these wetlands. Typically the lowest measured water-table elevations occur during or near the end of the dry season, and the highest water-table elevations are measured during or near the end of the wet season. The two seasons represent the extreme water-table elevations, which help shed light on the surficial aquifer recharge conditions of these wetlands under these hydrologic conditions.

Empirical distribution functions (EDFs) defined in Chapter 3.2.4 were used to provide additional insights into the groundwater recharge characteristics of these wetlands at low, median and high water levels. Paired wetland and upland water elevations, measured on the same date, were used to develop representative wetland and upland frequency distributions. The net hydraulic head associated with each distribution frequency or percentile was calculated by subtracting the upland water elevation from the wetland water elevation at the particular relative frequency, i.e. the 10th percentile. The hydraulic head differences were then evaluated at the three target percentiles: 10th - representing low water elevations, 50th - representing median water elevations, and 90th - representing high water elevations.

4.2.2. Seasonal Group Water Level Analyses

This analysis focused solely on the wetland and upland water elevation data recorded in the peak dry season (March – May) and the peak wet season (July – September). Monthly data, based on a single measurement or the mean of all water elevations recorded during the respective month, were used in this analysis. Monthly values were used to eliminate any bias brought about by combining data sets comprised of daily water elevations and monthly elevations. Further, the use of monthly data did not influence the results because data sets comprised of monthly data are not statistically different from data sets comprised of daily data (Appendix C).

Seasonal analyses were conducted by grouping the dry season and wet season wetland water elevations and the upland groundwater elevations. Relative water levels (RWL) were developed to provide a means to combine the respective wetland and upland well data into four seasonal groups: 1) dry season wetland water levels (WW_{DS}), 2) dry season upland groundwater levels (UW_{DS}), 3) wet season wetland water levels (WW_{WS}), and 4) wet season upland groundwater levels (UW_{WS}). The relative water levels were developed by normalizing the recorded water elevation data with respect to the associated wetland dry bed (DB) elevation (Table 3.1). The normalized data is presented as centimeters above or below the wetland dry-bed datum.

Further, empirical distribution functions were developed from the combined wetland and upland water levels associated with the four seasonal groups to provide additional insights into the groundwater recharge/discharge at low, median and high water levels. The frequency distributions were evaluated at the 10th, 50th, and 90th target percentiles.

A battery of Wilcoxon rank sum tests were performed on the paired wetland well and upland well seasonal water level data to test whether sample combinations are drawn from the same population (Dallal 2007). The Wilcoxon test is the nonparametric alternative to the student *t* test. This test was implemented due to the non-normal distribution of the wetland and upland water level data (Appendix B). The Wilcoxon rank sum test is used to evaluate two distributions to determine if the data sets are independent samples from identical continuous distributions with equal medians (null hypothesis), against the alternative that they do not have equal medians. The Wilcoxon test returns the result of $h = 1$ which indicates a rejection of the null hypothesis at the 5% significance level, and $h = 0$ which indicates a failure to reject the null hypothesis at the 5% significance level. Simply, a test result of $h = 0$ indicates the distributions are statistically similar and can be considered representative of one another.

The Wilcoxon rank sum test was used to compare four combinations of the seasonal relative water-level data. The first test evaluated wetland water levels recorded during the dry season and wet season respectively. The test was used to determine if the recorded wetland water levels in the dry season were statistically different than those recorded during the wet season. Likewise the second test evaluated the seasonal upland groundwater levels to determine if the groundwater levels recorded during dry season were statistically different than those recorded during the wet season. The third test focused solely on the wet season water levels. The test was setup to determine if the wetland water levels were significantly different from the adjacent water-table elevations, recorded at the upland wells, during the wet season. Last, the fourth test focused solely on the dry season water levels. The test was setup to determine if the wetland water levels were significantly different from the adjacent water-table elevations during the dry season.

4.3. Results

4.3.1. Head Difference between Wetland and Upland Water Levels (Surficial Aquifer)

4.3.1.1. Standard Statistical Analyses

The hydraulic head comparison showed wetland water elevations were generally 9.2 cm higher than the paired upland surficial groundwater elevations over the seven year study (Table 4.1 – All). The head differences range from -177.7 cm to 227.7 cm. Also, based on this data set, 36 wetlands had positive head differences, and 20 wetlands had negative head differences.

Table 4.1. Wetland-upland head difference.

Statistic	Separation Distance (m)	Head Difference (cm)		
		All	Dry season	Wet season
Data Count		5178	1237	1255
Mean	**56**	**9.2**	**12.8**	**0.3**
StD	25	37.1	39.3	34.7
Median	57	3.7	5.5	-1.5
Min	8	-177.7	-139.6	-177.7
Max	149	227.7	215.2	189.6
Range	142	405.4	354.8	367.3

Additionally, on average the wetland water elevations were 12.8 cm higher than the surrounding upland surficial groundwater elevations during the dry season (March – May) (Table 4.1 – Dry Season). The difference in the hydraulic heads ranged from -39.2 cm to 215.2 cm. During the wet season (July – September), the wetland water elevations were nearly the same as the surrounding upland surficial groundwater elevations (Table 4.1 – Wet Season). On average the wetland water levels were the only 0.3 cm higher than the surficial levels ranging from -177.7 cm to 189.6 cm

4.3.1.2. Frequency Analyses

Empirical distribution functions were developed to further investigate the wetland recharge characteristics at low, median and high water elevations. In general the water levels within the wetland extents were higher than the upland groundwater levels at the 10th and 50th percentiles, 8.8 cm and 16.3 cm respectively (Table 4.2 – All Records). However, the groundwater levels in the upland were 2.2 cm higher than the wetland water levels at the 90th percentile. Furthermore, the analysis revealed that 18 of the wetlands had positive head differences at all three of the target percentiles, and nine of the wetlands had negative head differences at all of the target percentiles.

Table 4.2. Wetland surficial aquifer head difference at particular frequency indices.

Statistic	All Records (cm)			Dry Season (cm)			Wet Season (cm)		
	10th	50th	90th	10th	50th	90th	10th	50th	90th
Mean	**8.8**	**16.3**	**-2.2**	**10.4**	**18.5**	**5.9**	**1.5**	**2.7**	**-8.5**
StD	43.3	31.1	18.1	52.6	36.7	26.0	47.0	26.6	18.9
Median	1.5	9.6	-1.7	-0.9	13.0	3.8	-5.5	2.0	-7.9
Min	-103.0	-65.8	-59.1	-102.1	-57.9	-56.1	-139.3	-77.4	-46.0
Max	166.4	132.9	94.2	210.0	157.0	130.8	164.6	95.7	91.1
Range	269.4	198.7	153.3	312.1	214.9	186.8	303.9	173.1	137.2

The empirical distribution functions representing the wet season and dry season wetland water elevation and upland groundwater elevation head differences showed slightly different trends (Table 4.2 – Dry Season). On average, the dry season water levels were higher in the wetlands than the upland groundwater levels at each target percentile as indicated by the positive head differences: 10th (10.4 cm), 50th (18.5 cm) and 90th (5.9 cm). Additionally, the analysis revealed that 19 of the wetlands had positive head differences at all of the target percentiles, while 10 of the wetlands had negative head differences at the target percentiles.

Unlike the dry season distributions, the wet season distributions showed the wetland water elevations were slightly higher than the upland groundwater elevations at the 10th and 50th percentiles, 1.5 cm and 2.7 cm respectively (Table 4.2 – Wet Season). However, the upland groundwater levels were on average 8.5 cm higher than the wetland water levels at the 90th percentile. In addition, eight of the wetlands had positive head differences at all of the target percentiles, whereas 21 of the wetlands had negative head differences at all target percentiles.

4.3.2. Seasonal Group Water-level Conditions

4.3.2.1. Standard Statistical Analyses

The four seasonal wetland and upland relative water level groups: 1) dry season wetland water levels (WW_{DS}), 2) dry season upland groundwater levels (UW_{DS}), 3) wet season wetland water levels (WW_{WS}), and 4) wet season upland groundwater levels (UW_{WS}) are represented by the box-and-whisker plots shown on Figure 4.1. The wetland water levels were generally higher than the upland surficial groundwater levels in each season (Figure 4.1 and Table 4.3). The average water levels within the wetland extents were 21.1 cm below the wetland bottom, and the average surficial groundwater levels in the adjacent uplands were 37.8 cm below the wetland bottom during the dry season. Conversely, during the wet season the mean water levels within the wetlands were 13.0 cm above the wetland bottom, and the mean surficial groundwater levels in the upland were 14.4 cm above the wetland bottom. Also, both the wetland and upland surficial water levels were regularly below the wetland dry bed elevation in the dry season, and above the dry bed elevation in the wet season.

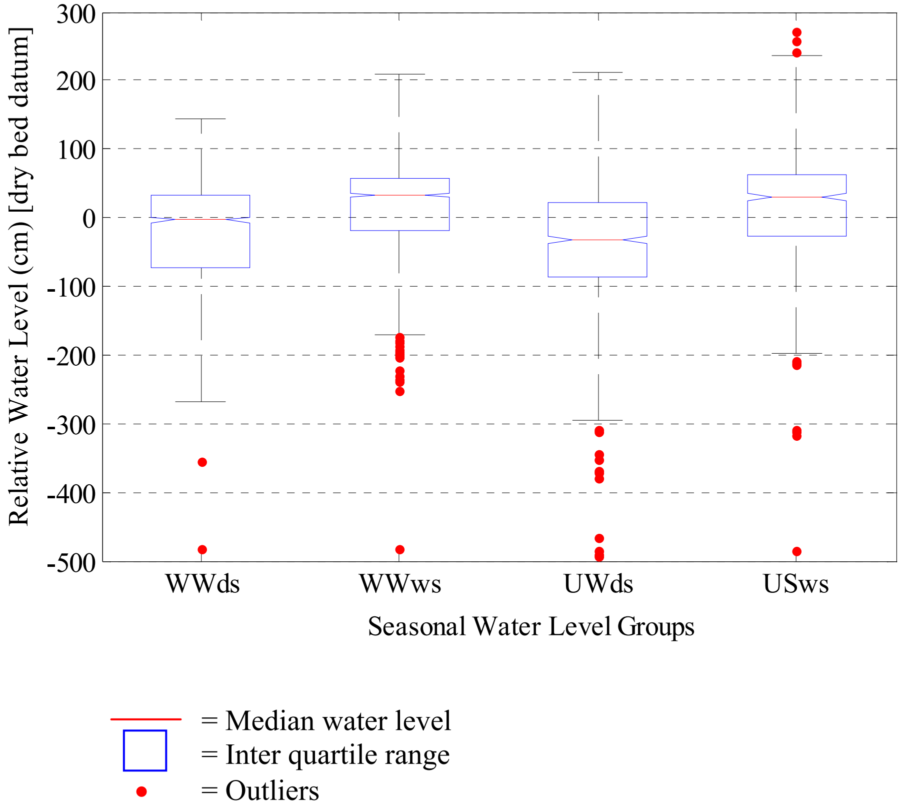


Figure 4.1 Seasonal wetland and upland surficial aquifer water levels.

Table 4.3. Seasonal wetland and upland surficial water levels.

Statistic	Dry Season Water Levels (cm)		Wet Season Water Levels (cm)	
	Wetland	Upland	Wetland	Upland
Data Count	961	1075	946	965
Mean	**-21.1**	**-37.8**	**13.0**	**14.4**
StD	76.6	89.4	72.2	82.3
Median	-3.7	-32.0	32.9	30.5
Min	-482.8	-493.2	-482.2	-484.0
Max	143.6	211.8	208.5	272.2
Range	626.4	705.0	690.7	756.2

4.3.2.2. Frequency Analyses

Empirical distribution functions were developed from the seasonal groupings of the wetland water levels and upland groundwater levels associated with the 56 wetlands. In general, the water levels at the upland surficial well were lower than the corresponding water levels at the wetland well during the dry season (Table 4.4 – Dry Season). This observation was true for all three of the distribution target percentiles. For instance, at the 50th percentile the mean water levels inside the wetland were 6.3 cm below the wetland dry bed, and the mean surficial groundwater levels in the nearby upland were 33.5 cm below the wetland dry bed. The wet season results were different. In general, the water levels at the upland surficial well were lower than the subsequent wetland well water levels at the 10th percentile (Table 4.4 – Wet Season). Conversely, on average the wetland water levels were lower than the upland groundwater levels at the 50th and 90th percentiles. For instance, the mean groundwater levels in the adjacent uplands were 10.2 cm higher than the corresponding wetland water levels at the 90th percentile.

Table 4.4. Seasonal wetland and upland surficial water levels at particular frequency indices.

Statistic	Dry Season			Wet Season		
	Wetland Water Levels (cm)			Wetland Water Levels (cm)		
	10th	50th	90th	10th	50th	90th
Mean	-107.8	-6.3	49.5	-70.6	32.2	67.9
StD	62.4	47.2	32.7	65.8	43.3	28.7
Median	-103.2	-2.6	40.8	-84.1	31.4	60.8
Min	-268.5	-107.9	-12.5	-238.7	-136.9	29.6
Max	59.7	102.7	139.0	89.3	124.1	154.8
Range	328.3	210.6	151.5	328.0	260.9	125.3
	Upland Groundwater Levels (cm)			Upland Groundwater Levels (cm)		
	10th	50th	90th	10th	50th	90th
Mean	-125.8	-33.5	47.2	-81.5	34.7	78.1
StD	92.6	61.9	47.7	74.7	49.3	47.5
Median	-104.4	-36.9	39.0	-77.9	32.2	65.7
Min	-490.1	-175.9	-71.6	-310.6	-139.0	-44.5
Max	37.8	101.5	204.5	124.4	187.8	257.6
Range	527.9	277.4	276.1	434.9	326.7	302.1

4.3.2.3. Wilcoxon Rank Sum Tests

The Wilcoxon rank sum test results comparing the four seasonal water level groups presented in Figure 4.1 identified Test 3, the comparison of the wet season wetland water levels and the adjacent upland groundwater levels, as the only scenario that failed to reject (Table 4.5). In this instance the null hypothesis indicated failure to reject $h = 0$, which suggests the two samples come from identical continuous distributions with equal medians. Furthermore, a strong result is evident based on the high p-value, 0.9.

Table 4.5. Wilcoxon rank sum test results.

Trial	Condition	*h*	*p*
1	WW_{DS} vs. WW_{WS}	1	0.0
2	UW_{DS} vs. UW_{WS}	1	0.0
3	**WW_{WS} vs. UW_{WS}**	**0**	**0.9**
4	WW_{DS} vs. UW_{DS}	1	0.0

WW_{DS} = Dry season wetland water levels
WW_{WS} = Wet season wetland water levels
UW_{DS} = Dry season upland groundwater levels
UW_{WS} = Wet season upland groundwater levels

4.4. Discussion

4.4.1. Head Differences between Paired Wetland and Upland Water Levels

4.4.1.1. Complete Data Set

The water levels within the wetlands, whether as standing water above the wetland bottom or as a groundwater levels below it, were generally higher than the adjacent upland water-table. Under natural conditions, water flows from high head conditions to low head conditions. Therefore, this head difference allowed water to flow out of the wetland into the surrounding upland recharging the local surficial groundwater system. A negative head difference would have indicated water was flowing from the local groundwater system into the wetlands, hence lowering the local water-table. These wetlands were most often recharge features replenishing the local surficial groundwater system over the seven year study.

Moreover, frequency analyses added additional insights into the recharge/discharge characteristics of these wetlands by evaluating the hydraulic head differences at low (10th percentile), median (50th percentile) and high (90th percentile) wetland and upland water elevations. The frequency analysis revealed the local groundwater system was usually recharged by the study wetlands at the low and median water elevations (Table 4.2 – All Records). Conversely, at high water elevations (90th percentile) water was generally flowing from the upland either as surface runoff or local groundwater flow during wet conditions replenishing wetland water levels. Additionally, the frequency analysis revealed that the study wetlands were groundwater recharge zones 59% of the time over the seven years.

4.4.1.2. Seasonal Data Sets

The seasonal data sets were used to characterize the recharge/discharge characteristics of the study wetlands during the dry season (March – May) and the wet season (July – September). The head difference between the wetland water elevations and upland surficial groundwater elevations indicated these wetlands were generally groundwater recharge zones in the both the dry season and in the wet season. Albeit the net head difference in the wet season was very small, 0.3 cm (Table 4.1). These results were based on the mean water levels in each season, which may provide limited insight into the recharge characteristics of these wetlands.

For this reason, frequency analyses were used to further characterize the seasonal recharge/discharge conditions associated with the study wetlands. In general, the study wetlands were groundwater recharge zones at all three target percentiles, representing low, median and high water levels, in the dry season (Table 4.2 – Dry Season). Further, the wetlands were groundwater recharge zones, on average, 61% of the time during the dry season. This result could be an indication that groundwater mounds form beneath these wetlands during the dry season. The mounds may be caused by slower leakage through the soils beneath the wetlands than in the intermediate confining unit of the surrounding uplands. Also, these wetlands may be local recharge points in the landscape because they are located in, or in effect are, low points in the local topography that are above the water table.

The frequency analysis of the wet season hydraulic head differences indicated the study wetlands were generally surficial groundwater recharge features at the low (10th percentile) and median (50th percentile) water elevations, though the average head differences were very small, 1.5 cm and 1.2 cm respectively (Table 4.2 – Wet Season). Conversely, the head difference at the high water levels (90th percentile) indicated the movement of water during these wet periods was into the wetland and out of the local groundwater system. This could be an indication that the local water table becomes an expression of the local topography during the wet season. As discussed previously, the local topography generally increases in elevation outside of the wetland extents; therefore as the water table approaches the land surface the head difference between the wetland and upland water levels would decrease or reverse creating a possible scenario in which groundwater can flow into the respective wetland. Overall, the study wetlands were groundwater recharge features 47% of the time during the wet season.

4.4.1.3. Consistent Recharge Feature Spatial Locations

Each statistical analysis revealed that a certain number of wetlands were consistent groundwater recharge features or discharge features over the seven year study period. The particular number and wetlands varied depending on the analysis conducted (Section 4.3.2). The number of wetlands that were consistent recharge or discharge features varied due in part to the type of analysis conducted. The frequency analyses are more robust than basis statistical analyses, as a result, provide a more detailed look into the recharge/discharge characteristics of the study wetlands. Further, the available data does not explain why certain features were consistent recharge or discharge features. There were mixed wetland types for both conditions and there was no geographical significance that could provide a reasonable explanation for these observations. The distinction between these wetlands could be in the way they were formed, i.e. karst collapse and/or small topographical depression, or simply due to the hydraulic variations in these complex natural systems. Also, the location of the upland well relative to the wetland could affect the results.

4.4.1.4. Recharge Wetland Versus Flow-through Wetland

The recharge characteristics of a wetland might be misinterpreted since the head difference between the wetland water elevations and the adjacent upland groundwater elevations was determined using a single paired wetland well and a single upland well (Rosenberry and Winter 1997). The head differences might indicate the wetland was a recharge feature when in fact the wetland was a flow through feature (Lee et al. 2009). Figure 3.2 shows the concept of a groundwater recharge wetland (A) and a groundwater flow through wetland (B). The problem can occur when an upland well is located on the predominant outflow side of a wetland, for instance along a regional water-table gradient toward a river. In this instance the head difference between the wetland water elevations and the upland groundwater elevations could indicate the wetland is a recharge feature where in actuality it is a flow through feature. Further, the paired well system might not provide sufficient evidence to determine discharge conditions either. A study using a single upland well may indicate the local groundwater was flowing into a wetland, where in actuality the wetland was in a flow through condition. Ideally, two upland monitoring wells would need to be installed, on opposite sides of the wetland along the regional water-table gradient, in order to determine with certainty the recharge/discharge condition of the wetland.

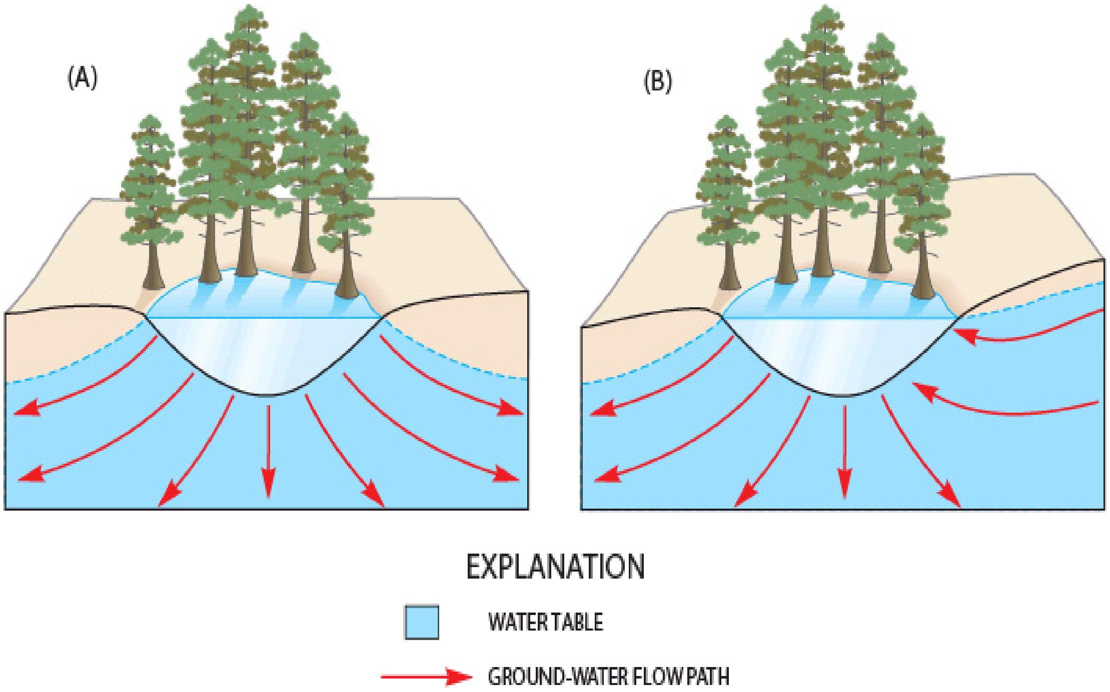


Figure 4.2 Conceptualized interactions of wetlands with (A) groundwater recharge and (B) groundwater flow through (modified from Lee et al., 2009).

4.4.2. Seasonal Group Water Levels

4.4.2.1. Recharge Characteristics

Wetland and upland water levels were grouped into comprehensive dry season and wet season data sets to substantiate the head analysis results, and to gain a more complete understanding of the wetland recharge behavior at extreme water-table elevations. The initial analyses showed the wetland water levels were generally higher than the associated upland surficial groundwater levels during the dry season (Table 4.3 – Dry Season), which coincides with the head results in Table 4.1. Even though the mean water levels within the wetlands and in the surrounding uplands were below the dry bed elevation of the wetlands, the results suggest these wetlands were groundwater recharge features during the dry season. During the wet season, typically the upland water levels were slightly higher (1.4 cm) than the associated wetland water levels implying the wetlands were groundwater sinks (Table 4.3 – Wet Season).

Furthermore, the frequency analysis revealed the study wetlands were overall groundwater recharge features at all three target percentiles during the dry season, as evident by the wetland water levels being higher than the upland surficial groundwater levels, e.g. -6.3 cm versus -33.5 cm at the 50th percentile (Table 4.4 – Dry Season). This is consistent with the head analyses presented in Table 4.1. During the wet season the study wetlands were in general groundwater recharge features at the 10th percentile, and groundwater discharge features at the 90th percentile which corresponds to the head analysis (Table 4.4 – Wet Season). However, at the 50th percentile (median water levels) the wetlands were groundwater depressions instead of recharge zones.

4.4.2.2. Wilcoxon Rank Sum Tests

The comparison of the wet season wetland water levels and upland surficial groundwater levels, using the Wilcoxon rank sum test, indicates the respective wetland water levels and upland surficial groundwater levels are statistically similar (Table 4.5 – Trial 3). The result suggests the surface-water levels in the wetlands are associated with the depth of the surrounding water table, and implies that these wetlands become surface-water expressions of the local groundwater system as the water table approaches the land surface. Hence, as the water table rises during the wet season, the water levels in the wetland and upland become similar as shown by similar mean and median water levels in Tables 4.3 and 4.4.

The opposite test scenario comparing the dry season wetland water levels and upland groundwater levels failed the rank sum test (Table 4.5 – Trial 4). The result indicates the wetland water levels and upland groundwater levels recorded in the dry season are statistically dissimilar. This test result indicates the wetland water levels and upland groundwater levels uncouple during the dry season as the local water-table drops.

4.5. Conclusions

The objective of this chapter was to characterize the groundwater recharge potential between isolated wetlands in west-central Florida and surrounding uplands, and to provide an empirical data analysis addressing the assumption that wetlands are local water-table depressions. Standard statistical analyses showed these wetlands were generally groundwater recharge zones over the seven year study. Additionally, seasonal analyses, utilizing water elevation data from the peak dry season (March – May) and the peak wet season (July – September), indicated these wetlands were overall groundwater recharge zones during both seasons.

Further, frequency analyses employing empirical distribution functions shed additional light into the recharge characteristics of the study wetlands. On the whole, these wetlands were groundwater recharge features at least 59% of the time, over the seven year study. The seasonal analyses indicated the wetlands were groundwater recharge zones 61% of the time during the dry season and 47% of the time during the wet season.

Last, Wilcoxon rank sum tests showed the wet season wetland water levels and upland groundwater levels were statistically similar, which suggests that the wetland water levels are governed by the depth of the water-table. Also, this may indicate that the land surface of the wetland perimeters is the controlling/limiting elevation in the wetland and surrounding water table, and that runoff may be occurring under these conditions. Further, this indicates these wetlands are surface-water expressions of the local groundwater system during the wet season. Conversely, the rank sum tests showed dry season wetland water levels and the associated upland groundwater levels were statistically independent of each other, indicating the wetland water levels and upland groundwater levels disassociate during the dry season as the local water-table drops.

Overall, the study showed these wetlands tend to be groundwater recharge zones in the dry season and surface-water expressions of local groundwater levels in the wet season. Also, the study revealed that these wetlands were largely groundwater recharge zones over the seven year period. Hydrologic modelers should be aware of these findings to ensure regional models accurately represent water-table fluctuations.

CHAPTER 5

PROBABILITY DENSITY FUNCTION REPRESENTATIONS OF WEST-CENTRAL FLORIDA ISOLATED WETLAND WATER LEVELS

5.1. Introduction

Probability distribution functions or probability models can be developed that represent wetland water-level fluctuations. These models can be used to approximate the water levels of similar wetland types without having to install and monitor wetland wells and staff gauges. This could save time and money in data collection, and/or provide hydrologic modelers with a reasonable means to approximate ungaged wetland water-level fluctuations. Also, the use of probability models to represent the water-level fluctuations of wetlands will enable engineers and hydrologists to make objective comparisons between individual wetlands, wetland types, assign probability to a particular event, and test hypotheses.

A probability density function $f_X(x)$ “describes the relative likelihood that a continuous random variable X takes on different values”, and a cumulative distribution function $F_X(x_1)$ defines the probability P that random variable X is less than or equal to a real number x_1 (Hogg and Ledolter 1987; Maidment 1993):

$$P[X \le x_1] = F_X(x_1) = \int_{-\infty}^{x_1} f_X(x)\,dx \tag{5.1}$$

These functions are known as continuous distributions because specific function parameters can be defined to describe the function or curve over an explicit range of data. The parameters can be arbitrarily defined based on experience and/or calculated by fitting a probability distribution to a set of data.

The parameters enable quantiles and expectations, e.g. wetland water elevations, to be calculated with the fitted probability model (Maidment 1993). Further, fitting a probability distribution to a set of hydrologic data enables a large amount of probabilistic information to be efficiently summarized in the function and its associated parameters (Chow et al. 1988; Maidment 1993). This also provides a smooth and compact representation of the data.

The objective of this chapter is to develop best-fit probability density functions that accurately represent the water levels associated with the west-central Florida isolated wetlands presented in Chapter Three. Explicitly, probability models were developed from the aggregate recorded water levels for each wetland category and all 56 wetlands in the northern Tampa Bay region. These models can be used to represent water levels of various wetland types in the absence of recorded hydrologic data. This is useful in hydrologic studies with large numbers of wetlands and limited water-level data. Further, smallest extreme value models representing the hydrologic characteristics of five wetland categories, and four wetland groups were compared to identify any distinguishable differences or similarities. Last, an application was presented demonstrating the use of the probability models to assign/predict wetland water levels based on antecedent moisture conditions, or projected moisture conditions that could be used in extended period hydrologic model simulations.

5.2. Water-Level Data

Wetland water-elevation data presented in Chapter 3.2.3 were used to develop empirical distribution functions representing the five wetland categories as well as a west-central Florida regional group comprised of all 56 study wetlands. Monthly data, based on a single measurement or the mean of all water elevations recorded during the respective month (Chapter 3.4.1.3), were normalized with respect to the wetland dry-bed datum and combined into the respective wetland category and regional group (Table 5.1). Relative water level statistics, presented as centimeter above or below the dry bed datum, as well as the number of monthly water-level records are listed for each wetland category and the regional group in Table 5.1. The cypress wetland category is comprised of 36 wetlands and contains the most water-level records, 2,525. The hardwood wetland category is comprised of three wetlands and contains the least water-level records, 216.

Table 5.1. Wetland category monthly data description.

	Relative Water Level Summary Statistics (cm)					
	Region	Cypress	Marsh	Cypress-Marsh	Hardwood	Wet Prairie
Wetlands	56	36	9	5	3	3
Records	3,980	2,525	663	353	216	224
Mean	-0.8	-5.4	11.1	22.4	10.0	-46.3
StD	74.3	68.5	69.5	98.1	57.3	69.1
Median	16.8	15.2	23.3	46.0	22.7	-39.9
Min	-491.9	-491.9	-209.4	-388.6	-138.4	-205.7
Max	248.1	208.5	156.4	132.3	104.9	103.3

5.2.1. Best-Fit Probability Distribution Identification

The Anderson-Darling test (Stephens 1974) was used to identify the best-fit cumulative distribution function type for the five wetland categories and for all the wetlands in the study (regional group). The Anderson-Darling test provides a means to evaluate different cumulative distribution functions to determine the best-fit for the respective data. Generally, the smaller the test statistic the better the distribution represents the data.

The test was applied to each of the aggregate wetland category data sets as well as the regional group data set listed in Table 5.1. The Smallest Extreme Value (SEV) distribution was identified by the Anderson-Darling test, based on the smallest test statistic, as the best-fit distribution for all of the wetland categories except the marsh wetlands (Table 5.2). The Logistic distribution was identified as the best-fit distribution for the marsh wetlands. However, a comparison of the two distributions showed negligible gains in using the logistic distribution over the small extreme value distribution when predicting the marsh water levels. Therefore, the smallest extreme value distribution will be used to represent the marsh water levels as well.

Table 5.2. Comparison of alternative probability distributions, Anderson-Darling test.

	Anderson-Darling Test Statistic					
Distribution Type	Region	Cypress	Marsh	Cypress-Marsh	Hardwood	Wet Prairie
Smallest Extreme Value	**39.5**	**22.6**	7.4	**1.2**	**0.7**	**0.8**
Logistic	54.9	62.5	**3.3**	4.0	2.4	2.1
Normal	75.1	80.6	5.3	6.3	3.3	2.1
Gamma (3-Parameter)	79.2	83.8	5.9	6.7	3.7	2.3
Laplace	80.7	83.4	4.4	4.6	3.9	3.0
Largest Extreme Value	<no fit>	<no fit>	23.0	19.5	9.5	6.1
Exponential	Weak Distribution Fit					
Gamma						
Loglogistic						
Lognormal						
Pareto						
Uniform						
Weibull						

Note: Bold numbers represent best-fit distributions.

5.2.2. Wetland Category Empirical Distributions

Empirical distribution functions were developed from the respective wetland category and regional wetland group data sets (summarized in Table 5.1) using the procedure outlined in Chapter 3.4.1.1. Eleven target percentiles {0.05, 0.10:0.10:0.90, 0.95} were selected to represent the empirical distributions in this chapter. The 11 target percentiles were chosen to provide a detailed representation of the distributions developed from the water-level data sets. The associated relative water levels for the five wetland categories and the regional wetland group are summarized in Table 5.3. Additionally, the mean interdecile range ($IntD_{EDF}$) is listed for each wetland category. The cypress-marsh wetlands have the largest interdecile range (201.8cm) and the cypress wetlands have the smallest interdecile range (144.3 cm).

Table 5.3. Wetland category empirical distribution function statistics per percentile.

	Wetland Category Relative Water Levels per Percentile (cm)											
	Region				Cypress Wetlands				Marsh Wetlands			
Percentile	Mean	StD	Min	Max	Mean	StD	Min	Max	Mean	StD	Min	Max
95th	69.4	38.9	25.4	224.6	56.7	22.9	25.4	120.4	95.0	49.9	37.5	184.4
90th	62.8	37.3	14.3	209.7	52.1	23.1	14.3	119.5	84.1	46.5	36.0	164.9
80th	50.7	35.5	-18.3	170.1	42.6	24.5	-18.3	108.5	67.5	44.0	24.4	147.2
70th	41.3	36.2	-38.4	158.5	34.6	25.9	-38.4	104.9	56.0	41.9	10.8	135.0
60th	29.4	36.9	-59.4	125.4	24.3	29.5	-59.4	97.5	41.4	38.8	-7.0	110.3
50th	16.5	40.0	-107.9	112.8	13.2	35.4	-107.9	82.0	26.9	38.0	-28.7	100.0
40th	-0.7	44.6	-159.7	103.3	-2.2	41.9	-159.7	77.7	10.2	41.7	-41.1	89.3
30th	-22.1	51.0	-192.6	101.3	-23.1	48.1	-192.6	74.4	-12.1	37.7	-68.0	29.7
20th	-50.9	55.2	-204.8	86.1	-53.0	51.9	-204.8	67.7	-39.4	46.7	-101.5	18.7
10th	-91.6	58.2	-238.7	59.7	-92.2	52.6	-238.7	55.5	-77.2	57.0	-165.2	-9.1
5th	-117.3	61.3	-268.5	42.7	-119.2	58.5	-267.6	42.7	-97.8	63.9	-197.2	-16.4
$IntD_{EDF}$	154.4				144.3				161.3			

	Cypress-Marsh Wetlands				Hardwood Wetlands				Wet Prairie Wetlands			
Percentile	Mean	StD	Min	Max	Mean	StD	Min	Max	Mean	StD	Min	Max
95th	121.8	62.3	65.5	224.6	76.9	29.2	44.8	102.0	49.7	19.8	36.0	72.4
90th	114.6	58.8	62.5	209.7	71.7	27.6	42.1	96.8	32.4	15.1	15.8	45.4
80th	97.7	50.9	40.2	170.1	58.6	20.5	39.6	80.4	10.9	21.0	-12.3	28.5
70th	85.9	54.0	27.3	158.5	50.4	19.6	37.7	73.0	-6.2	26.6	-31.4	21.6
60th	69.2	53.8	2.4	125.4	37.8	16.5	25.8	56.5	-20.1	34.2	-52.3	15.8
50th	52.8	58.3	-26.7	112.8	17.7	11.2	4.9	25.6	-36.0	34.6	-60.8	3.5
40th	19.8	69.7	-79.6	103.3	4.7	15.1	-7.3	21.6	-55.2	31.5	-75.4	-18.9
30th	-3.8	89.6	-140.2	101.3	-10.0	24.0	-24.7	17.7	-82.0	41.8	-116.7	-35.5
20th	-33.3	95.1	-171.3	86.1	-33.8	21.6	-47.4	-8.8	-106.9	52.7	-149.4	-48.0
10th	-87.2	106.9	-234.8	59.7	-85.6	35.1	-109.4	-45.3	-140.3	53.4	-193.3	-86.5
5th	-128.1	97.7	-268.5	-4.6	-97.4	35.9	-118.7	-56.0	-155.2	44.3	-198.5	-110.0
$IntD_{EDF}$	201.8				157.4				172.6			

5.3. Methods

5.3.1. Smallest Extreme Value Distribution

The smallest extreme value distribution, identified as the best-fit distribution to represent the wetland water levels by the Anderson-Darling test (Section 5.2.2), is a form of the extreme value type I distribution, aka the Gumbel distribution (NIST/SEMATECH *e-Handbook of Statistical Methods* 2010). The distribution is based on the minimum extreme value. The smallest extreme value density function *f(x)* and cumulative distribution function *F(x)* are defined as:

$$f(x \mid \mu,\sigma) = \frac{1}{\sigma}\exp\left[\frac{x-\mu}{\sigma} - \exp\left(\frac{x-\mu}{\sigma}\right)\right] \tag{5.2}$$

$$F(x \mid \mu,\sigma) = 1 - \exp\left[-\exp\left(\frac{x-\mu}{\sigma}\right)\right] \tag{5.3}$$

where μ [L] is the location parameter and σ [L] is the scale parameter ($\sigma > 0$), and x is a real number, in this instance x [L] is the wetland surface and sub-surface water level observation (Weisstein 2010a). The location parameter is an indication of the central location of the given distributions, and the scale parameter is an indication of the spread of the water level data around the location parameter. The smallest extreme value distribution density function is typically identified by a long tail and is skewed to the left (Figure 5.1). The distribution is not bounded, i.e. defined on the entire real axis $x \in (-\infty;\infty)$, therefore, can be used to represent the wetland relative water levels.

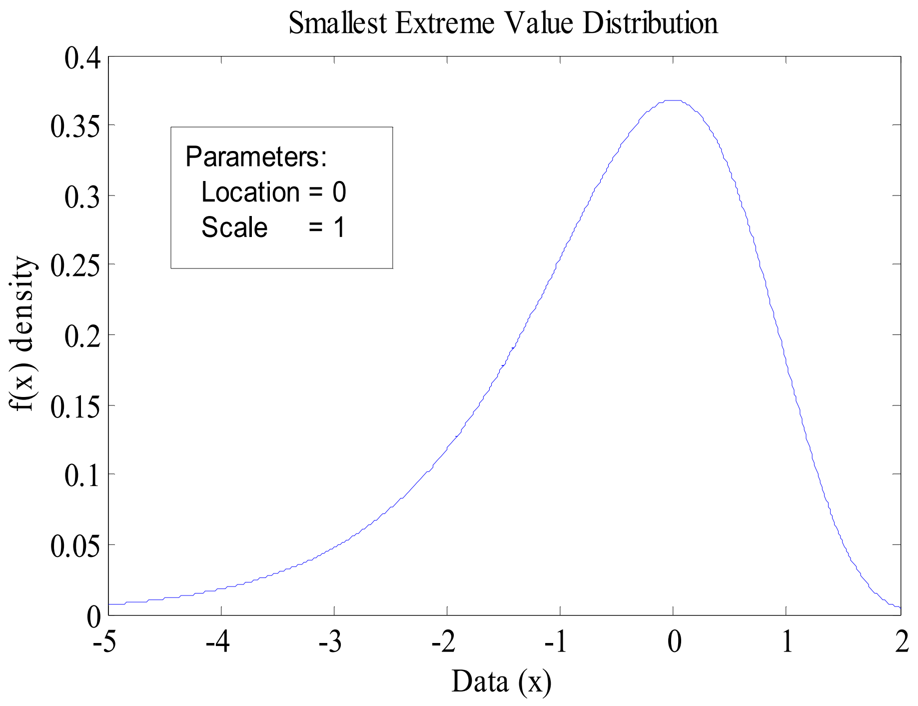


Figure 5.1 Smallest extreme value distribution, general case.

The final variant of the smallest extreme value distribution of interest is the inverse cumulative distribution function:

$$F^{-1}(p \mid \mu, \sigma) = \mu + \sigma \ln[-\ln(1-p)] \tag{5.4}$$

where $F^{-1}(p)$ is a unique relative water level x [L] (quantile) that is coupled with cumulative probability p or $F(x)$ from Eq. (5.3) (NIST/SEMATECH *e-Handbook of Statistical Methods* 2010). The inverse cumulative distribution function was used to predict relative water levels at the target percentiles for comparison to the associated mean recorded relative water levels presented in Table 5.3.

5.3.2. Smallest Extreme Value Parameter Identification

Representative smallest extreme value distribution location (μ) and scale (σ) parameters were calculated for each of the five wetland categories and the regional group (Table 5.1) using the maximum likelihood method (Chow et al. 1988; Maidment 1993; Weisstein 2010b). The method returns the best-fit estimates of the smallest extreme value distribution parameters for each data set. The smallest extreme value distribution parameters are predicated on the relative water levels within a respective wetland category. As a result, a specific distribution function, hence forth referred to as the *SEV* model, was developed for each of the wetland categories and regional group. Additionally, Kolmogorov-Smirnov tests (Massey 1951; Weisstein 2009b), outlined in Chapter 3.4.2, were performed between the *SEV* model distributions and the corresponding empirical distribution functions (Table 5.1) for each category to verify the *SEV* model robustness.

5.3.3. *SEV* Model Evaluation

5.3.3.1. Wetland Category Analyses

The *SEV* models were evaluated by comparing the predicted relative water levels to the mean relative water levels for each wetland category (Table 5.3) to determine how well the smallest extreme value distribution represented the category as a whole. The *SEV* models were evaluated using a root-mean-squared-error (RMSE) analysis and an absolute water level error analysis. The root-mean-squared-error analysis is:

$$RMSE_{CAT} = \frac{RMSE}{IntD_{EDF}} = \frac{\sqrt{\frac{1}{k}\sum_{p=1}^{k}\left[(x_{SEV})_p - (\bar{x}_{EDF})_p\right]^2}}{IntD_{EDF}} \times 100\% \qquad (5.5)$$

$$p = \{0.05, 0.10{:}0.10{:}0.90, 0.95\}$$

where $RMSE_{CAT}$ is the normalized RMSE, $IntD_{EDF}$ [L] is the interdecile range of the mean relative water level distribution for a specific wetland category (Table 5.3), p is a target percentile, k is the total number of percentiles used to evaluate the distributions, x_{SEV} [L] is the *SEV* model predicted relative water level (quantile) at percentile p, and $\bar{x}_{EDF}$ [L] is the recorded mean relative water level at percentile p. The absolute water level error (AE_{CAT}) for the category comparison is:

$$AE_{CAT} = \frac{1}{k}\sum_{p=1}^{k}\left[ABS\left(\frac{(x_{SEV})_p - (\bar{x}_{EDF})_p}{IntD_{EDF}}\right)\right] * 100\%; \qquad (5.6)$$

$$p = \{0.05, 0.10{:}0.10{:}0.90, 0.95\}$$

where *ABS* is the absolute value.

Further , a relative water level error (RE_P) analysis was conducted to determine if the *SEV* models under or over predicted the respective mean recorded relative water levels at each of the target percentiles. The relative water level error was calculated as:

$$RE_P = \left(\frac{(x_{SEV})_p - (\overline{x}_{EDF})_p}{(R_{EDF})_p} \right) * 100\% \; ; \qquad (5.7)$$

$$p = \{0.05, 0.10{:}0.10{:}0.90, 0.95\}$$

where R_{EDF} [L] is the range of relative water levels at each target percentile (Table 5.3).

5.3.3.2. Individual Wetland Comparisons

To this point the *SEV* model comparison analyses have focused on the mean relative water levels of each wetland category. The final analysis technique compares the *SEV* model distributions to the individual wetland distributions in each category in order to gain understanding into the predictive capabilities of the *SEV* model on an individual wetland basis. The analysis was conducted using a root-mean-squared-error analysis defined by:

$$RMSE_P = \sqrt{\frac{1}{n} \sum_{w=1}^{n} \left[(x_{SEV}) - (x_{EDF})_w \right]_p^2} \; ; \qquad (5.8)$$

$$p = \{0.05, 0.10{:}0.10{:}0.90, 0.95\}$$

where $RMSE_P$ [L] is the root-mean-squared-error at target percentile *p*, *w* is the individual wetland identifier, *n* is the total number of wetlands in the category, x_{SEV} [L] is the *SEV* model predicted relative water level (quantile) at percentile *p*, and x_{EDF} [L] is the recorded relative water level for wetland *w* at target percentile *p*.

5.4. Results and Discussion

5.4.1. Smallest Extreme Value Parameter Identification

Specific smallest extreme value distribution function parameters were developed for each wetland category and the west-central Florida regional wetland grouping (Region). The maximum likelihood estimates for the wetland category location parameter (μ) and scale parameter (σ) [Eq. (5.2)] are presented in Table 5.4. The location parameters range from -13.4 cm for the wet prairie wetlands to 73.9 cm for the cypress-marsh wetlands. The scale parameters range from 46.0 cm for the hardwood wetlands to 83.9 cm for the cypress-marsh wetlands. In addition, the variation in the shape and scale parameters, represented by the standard deviation (StD), is listed in Table 5.4. The standard deviation was calculated from individual wetland distribution parameters (i.e. 36 location parameters for the cypress category) for the respective wetland category and the regional group. The standard deviation for the location parameters range from 11.0 cm (Hardwood wetlands) to 60.0 cm (Cypress-Marsh wetlands), and the standard deviation for the scale parameters range from 17.3 cm (Cypress wetlands) to 26.5 cm (Cypress-Marsh wetlands).

Table 5.4. SEV distribution function parameters and distribution fit test results.

	Location (cm)		Scale (cm)		Kolmogorov-Smirnov test		
Category	μ	StD	σ	StD	*h*	*p*	*Dstat*
Region	33.3	35.6	65.2	19.3	0	0.58	0.09
Cypress	24.5	27.1	51.2	17.3	0	0.37	0.09
Marsh	48.8	38.1	67.5	20.9	0	0.34	0.10
Cypress-Marsh	73.9	60.0	83.9	26.5	0	0.94	0.06
Hardwood	36.6	11.0	46.0	17.4	0	0.97	0.06
Wet Prairie	-13.4	22.5	58.4	20.2	0	1.00	0.05

The best-fit *SEV* models for the regional wetland group as well as the five wetlands categories are shown in Figures 5.2, 5.3 and 5.4. The best-fit smallest extreme value density functions [Eq. (5.2)], defined by the specific location and scale parameters, for the respective categories are overlaid on the water-level histograms (Charts A, C, E, G, I and K). Note the skewed nature of the empirical histograms and the best-fit density functions. This lends credence to the use of the smallest extreme value probability density function to represent the wetland water-level data (Section 5.3.1).

Another observation is the noticeable under prediction of the water levels at the distribution mode, e.g. Figure 5.2 – Chart A. This deviation may be misleading due to the histogram bin sizes. Bin sizes can be set several different ways, each affecting the amount of data represented in the bin, which will distribute the data in the histogram accordingly. Also, by definition both the histogram bin densities and the area under the density function curve have to add up to one. Therefore, the density function is a more consistent representation of the water-level data.

In addition, the best-fit cumulative distribution functions [Eq. (5.3)] are overlaid on the respective empirical distribution functions for the regional wetlands (Chart B) and the five wetland categories (Charts D, F, H, J and L) on Figures 5.2, 5.3 and 5.4. By inspection it is apparent the best-fit *SEV* models match the regional group and cypress category empirical distributions, the two categories with the largest populations (Table 5.1). Similar results were observed for the other wetland categories, with the largest apparent deviation observed for the marsh wetlands. Further, all of the *SEV* model distributions passed the Kolmogorov-Smirnov tests, $h = 0$ (Table 5.4). This verifies the *SEV* model shape and scale parameters effectively reproduce the water levels for each wetland category.

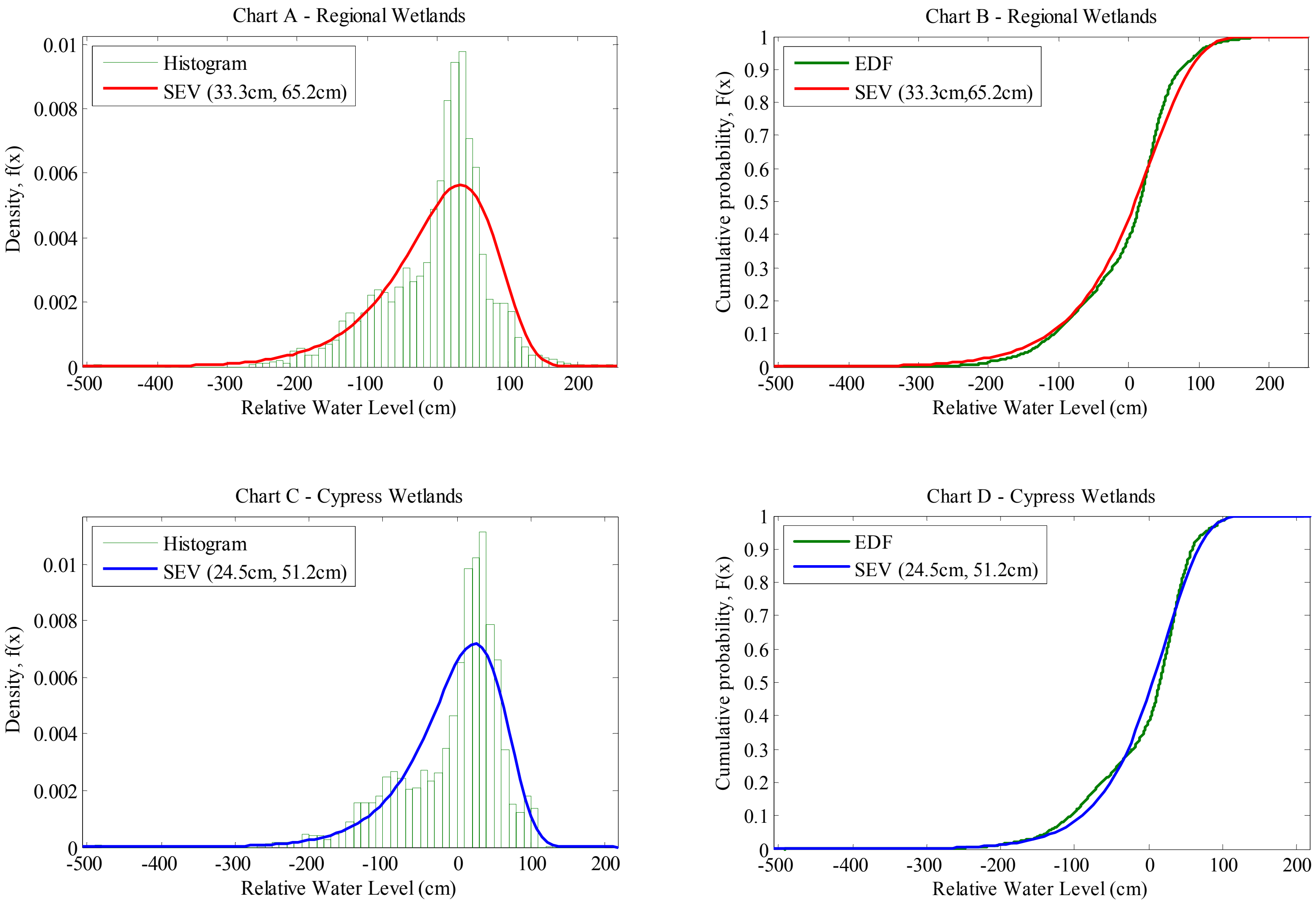


Figure 5.2 *SEV* Model best-fit distributions, regional group and cypress wetlands.

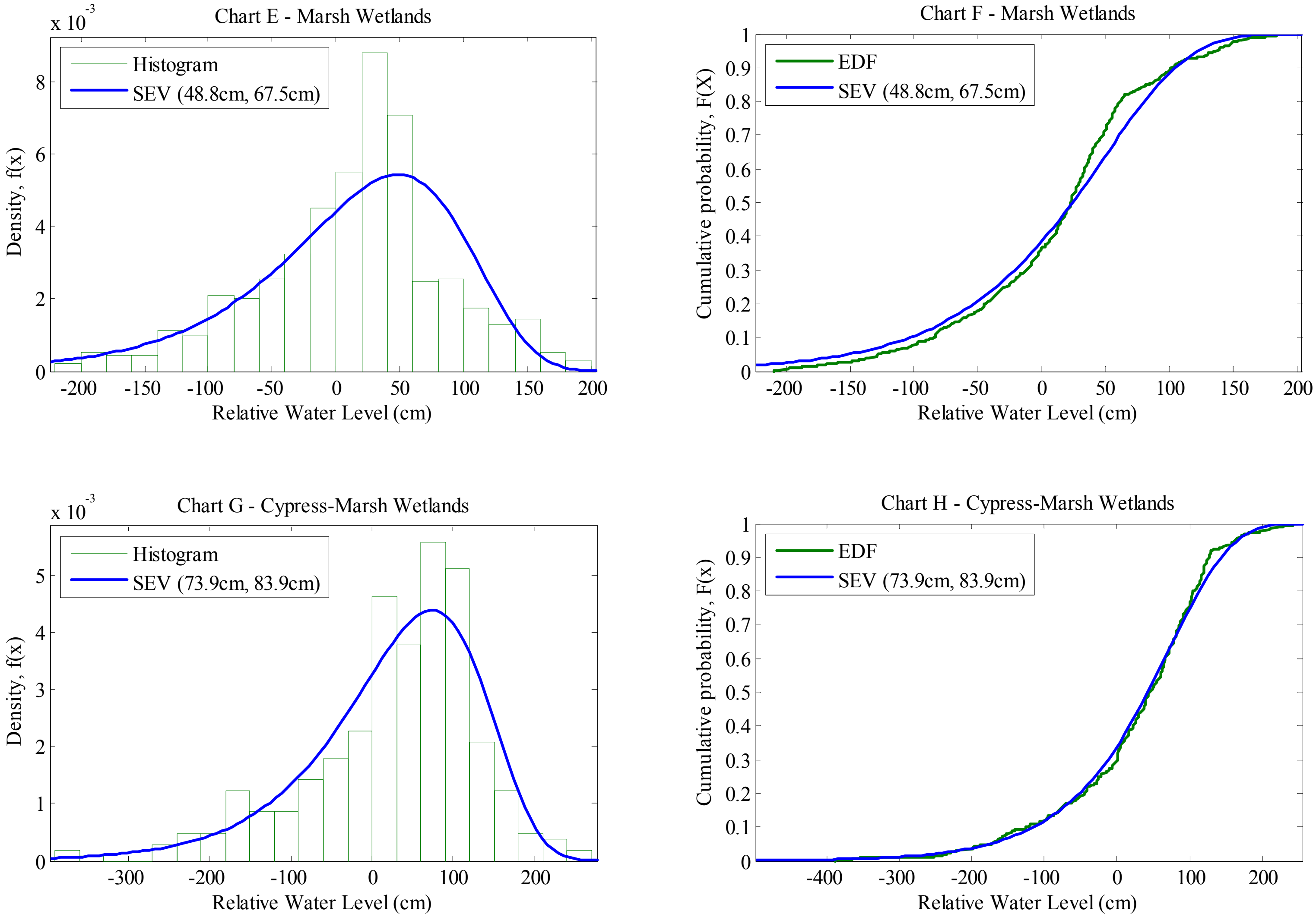


Figure 5.3 *SEV* Model best-fit distributions, marsh and cypress-marsh wetlands.

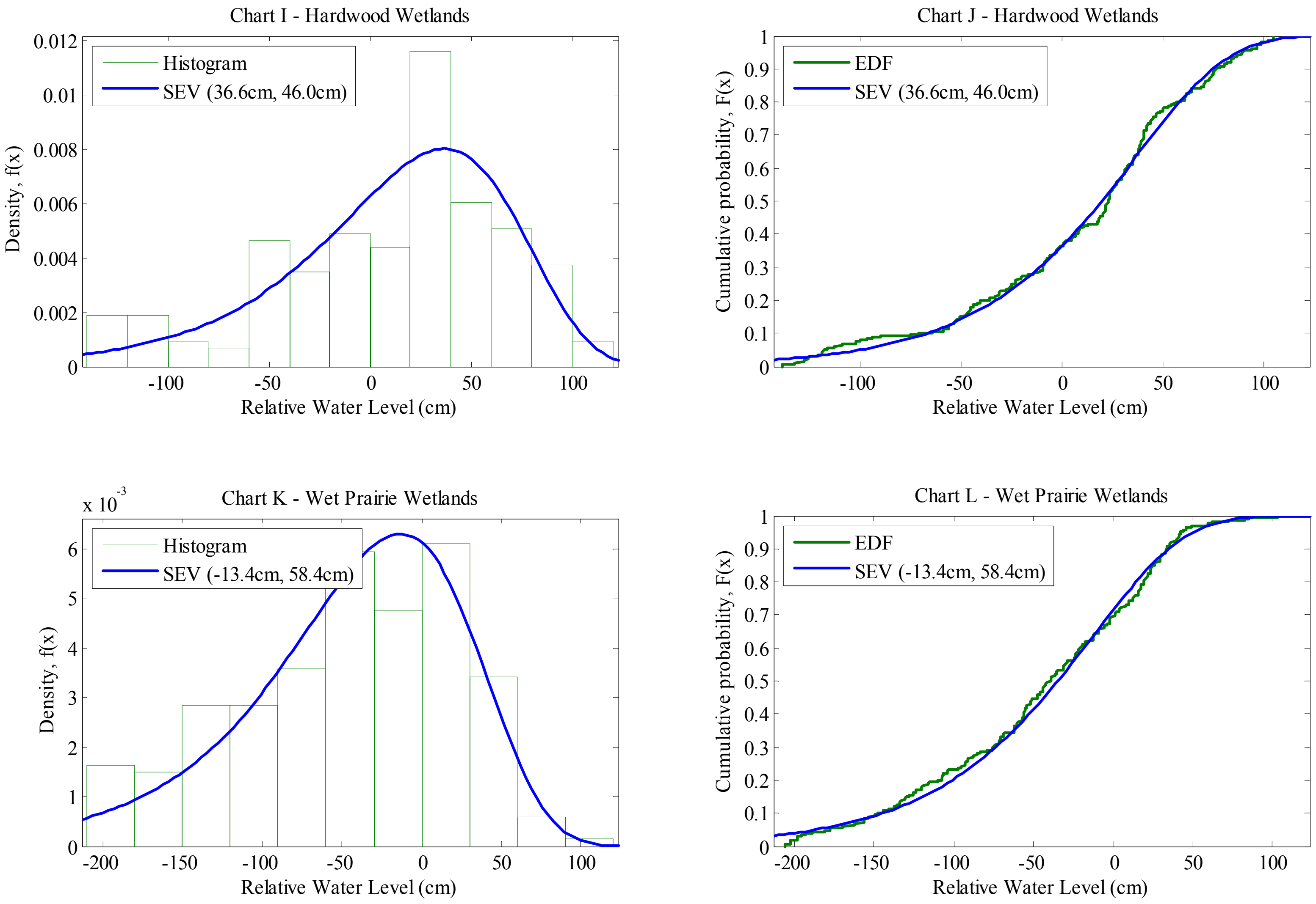


Figure 5.4 *SEV* Model best-fit distributions, hardwood and wet prairie wetlands.

5.4.2. Smallest Extreme Value (*SEV*) Distribution Models

5.4.2.1. *SEV* Model Water Level Predictions

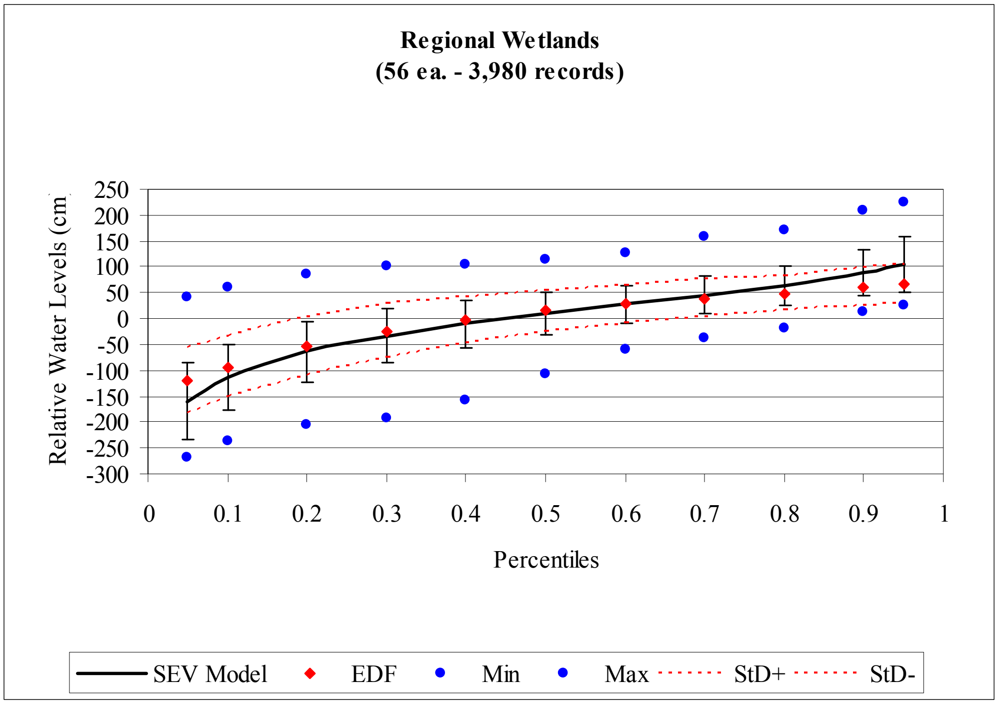
Water levels were calculated for each wetland category using the smallest extreme value inverse cumulative distribution function [Eq. (5.4)] and the respective location and shape parameters listed in Table 5.4. The water levels were calculated at the 11 target percentiles. The predicted water levels (SEV) for each wetland category are listed next to the recorded or actual relative water levels (Mean) at 11 target percentiles (Table 5.5). For example, the predicted water levels for the cypress wetlands range from 127.5 cm below the wetland dry bed elevation at the 5th percentile to 80.7 cm above the wetland dry bed elevation at the 95th percentile. The corresponding recorded water levels are: -119.2 cm (5th) and 56.7 cm (95th) respectively.

Table 5.5. *SEV* Model predicted water levels and category evaluation.

	Region (cm)			Cypress (cm)			Marsh (cm)		
Percentile	Mean	**SEV**	RE_P	Mean	**SEV**	RE_P	Mean	**SEV**	RE_P
95th	69.4	**104.9**	17.8%	56.7	**80.7**	25.3%	95.0	**122.9**	19.0%
90th	62.8	**87.7**	12.7%	52.1	**67.2**	14.4%	84.1	**105.2**	16.3%
80th	50.7	**64.4**	7.3%	42.6	**48.9**	5.0%	67.5	**81.0**	11.0%
70th	41.3	**45.4**	2.1%	34.6	**34.0**	-0.4%	56.0	**61.4**	4.4%
60th	29.4	**27.6**	-1.0%	24.3	**20.1**	-2.7%	41.4	**42.9**	1.3%
50th	16.5	**9.4**	-3.2%	13.2	**5.8**	-3.9%	26.9	**24.1**	-2.2%
40th	-0.7	**-10.5**	-3.7%	-2.2	**-9.8**	-3.2%	10.2	**3.5**	-5.1%
30th	-22.1	**-33.9**	-4.0%	-23.1	**-28.2**	-1.9%	-12.1	**-20.8**	-8.9%
20th	-50.9	**-64.5**	-4.7%	-53.0	**-52.2**	0.3%	-39.4	**-52.5**	-10.8%
10th	-91.6	**-113.4**	-7.3%	-92.2	**-90.6**	0.5%	-77.2	**-103.1**	-16.6%
5th	-117.3	**-160.3**	-13.8%	-119.2	**-127.5**	-2.7%	-97.8	**-151.7**	-29.8%
$RMSE_{CAT}$	13.6%			6.9%			13.6%		
AE_{CAT}	7.1%			5.5%			11.4%		

	Cypress-Marsh (cm)			Hardwood (cm)			Wet Prairie (cm)		
Percentile	Mean	**SEV**	RE_P	Mean	**SEV**	RE_P	Mean	**SEV**	RE_P
95th	121.8	**165.9**	27.8%	76.9	**87.0**	17.7%	49.7	**50.7**	2.8%
90th	114.6	**143.9**	19.9%	71.7	**74.9**	5.8%	32.4	**35.3**	10.0%
80th	97.7	**113.8**	12.4%	58.6	**58.4**	-0.3%	10.9	**14.4**	8.6%
70th	85.9	**89.4**	2.7%	50.4	**45.1**	-15.1%	-6.2	**-2.6**	6.9%
60th	69.2	**66.5**	-2.2%	37.8	**32.5**	-16.9%	-20.1	**-18.5**	2.4%
50th	52.8	**43.1**	-6.9%	17.7	**19.7**	9.9%	-36.0	**-34.8**	1.8%
40th	19.8	**17.5**	-1.3%	4.7	**5.7**	3.5%	-55.2	**-52.6**	4.5%
30th	-3.8	**-12.7**	-3.7%	-10.0	**-10.8**	-2.0%	-82.0	**-73.6**	10.3%
20th	-33.3	**-52.0**	-7.3%	-33.8	**-32.4**	3.7%	-106.9	**-101.0**	5.8%
10th	-87.2	**-115.0**	-9.4%	-85.6	**-66.8**	29.3%	-140.3	**-144.8**	-4.3%
5th	-128.1	**-175.4**	-17.9%	-97.4	**-99.9**	-4.0%	-155.2	**-186.9**	-35.8%
$RMSE_{CAT}$	12.2%			4.4%			6.0%		
AE_{CAT}	10.1%			9.8%			8.5%		

The predicted water levels (*SEV* model) and the corresponding mean recorded water levels for each wetland category are presented on inverse quantile plots on Figure 5.3. Figure 5.3 is comprised of six charts each representing a wetland category. The *SEV* models are portrayed as a solid line because it is a continuous distribution, and the mean recorded water levels, empirical data, are represented as single points at each target probability level. Additionally, each chart shows one positive and one negative standard deviation about the mean recorded water levels, as well as the minimum and maximum water levels corresponding to the target probability. The last object on each chart is the *SEV* model error bars. The bars represent the model errors associated with individual wetland water level predictions at each target percentile.



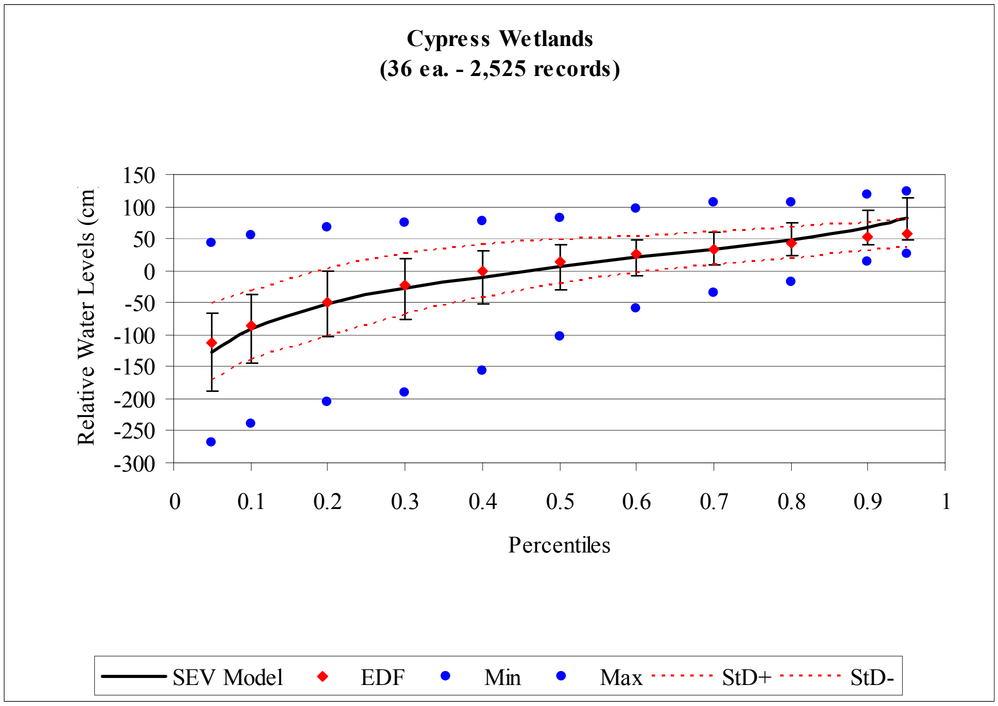
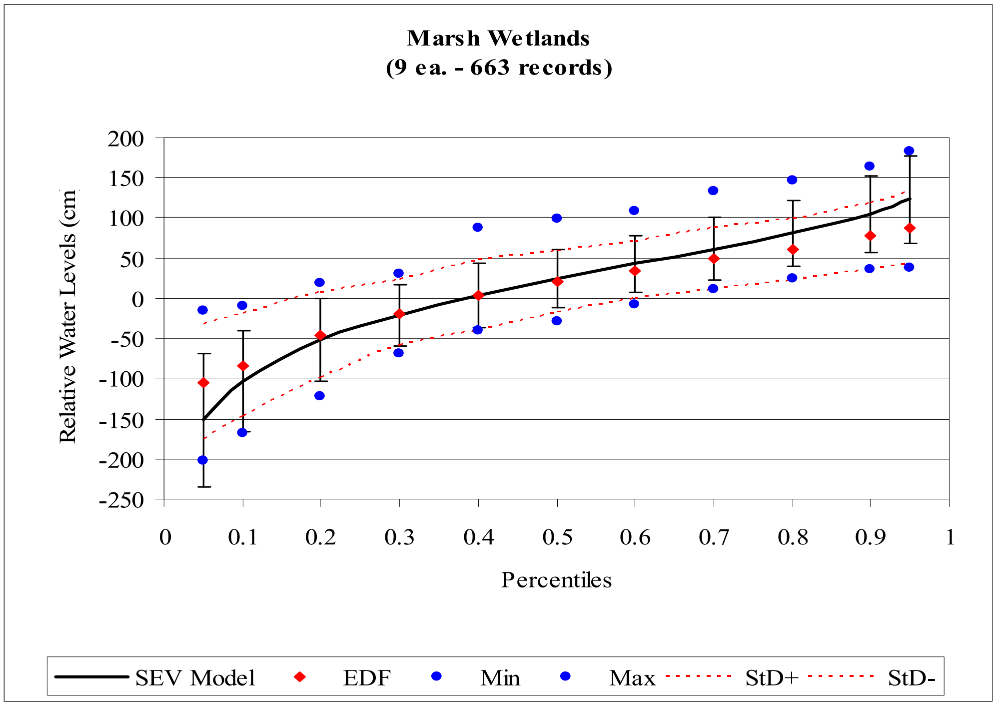


Figure 5.5 *SEV* Model predicted water levels and recorded water levels for the regional and cypress wetlands.



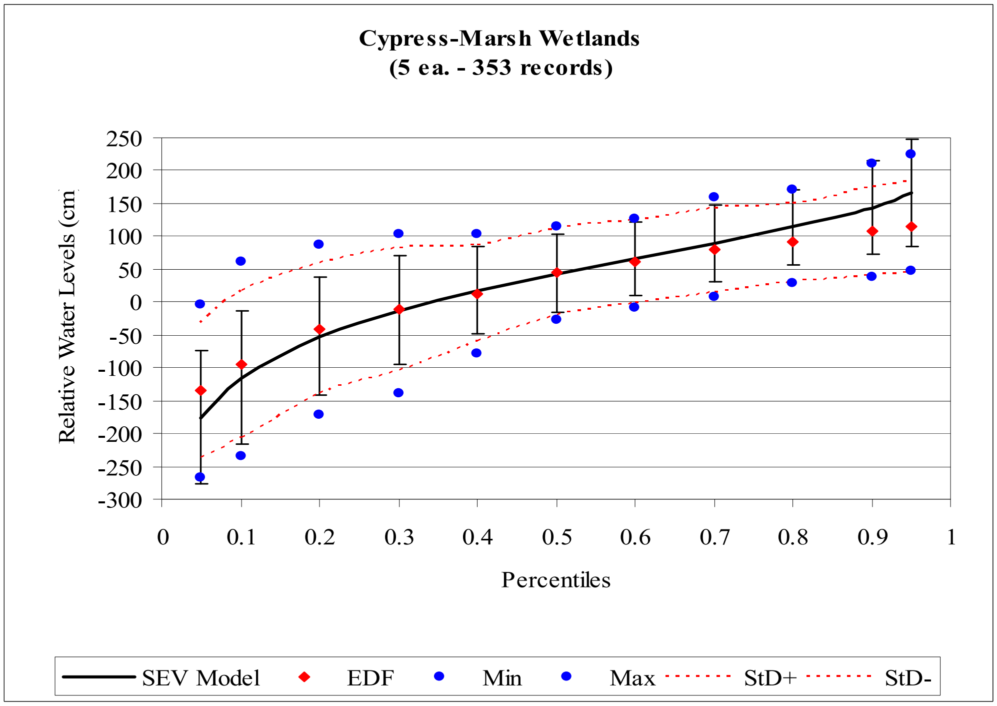
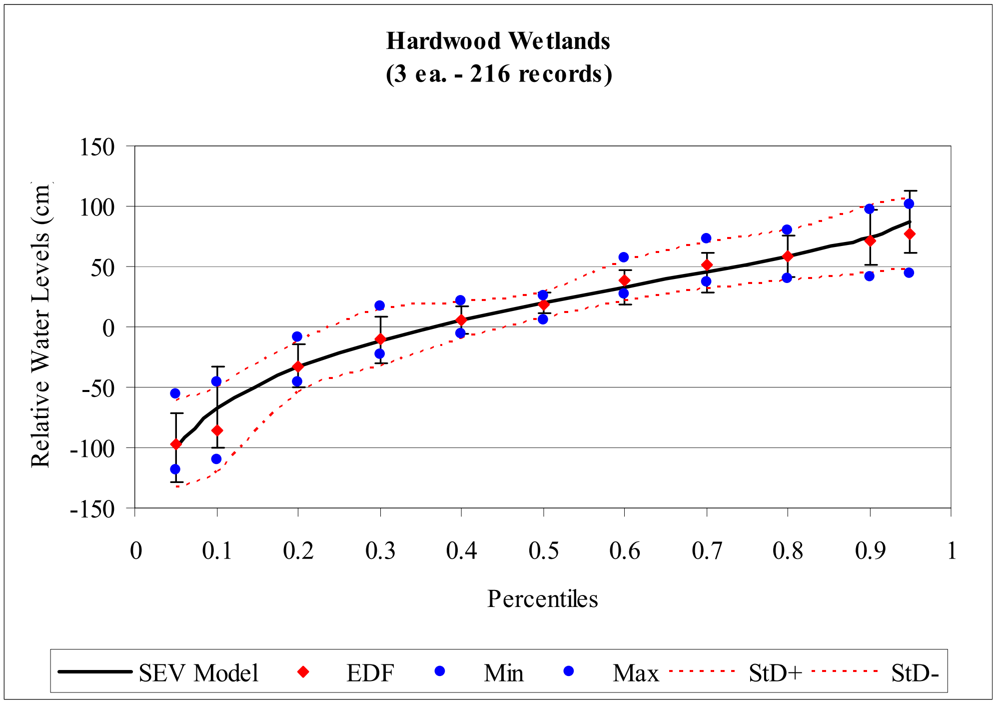


Figure 5.6 *SEV* Model predicted water levels and recorded water levels for the marsh and cypress-marsh wetlands.



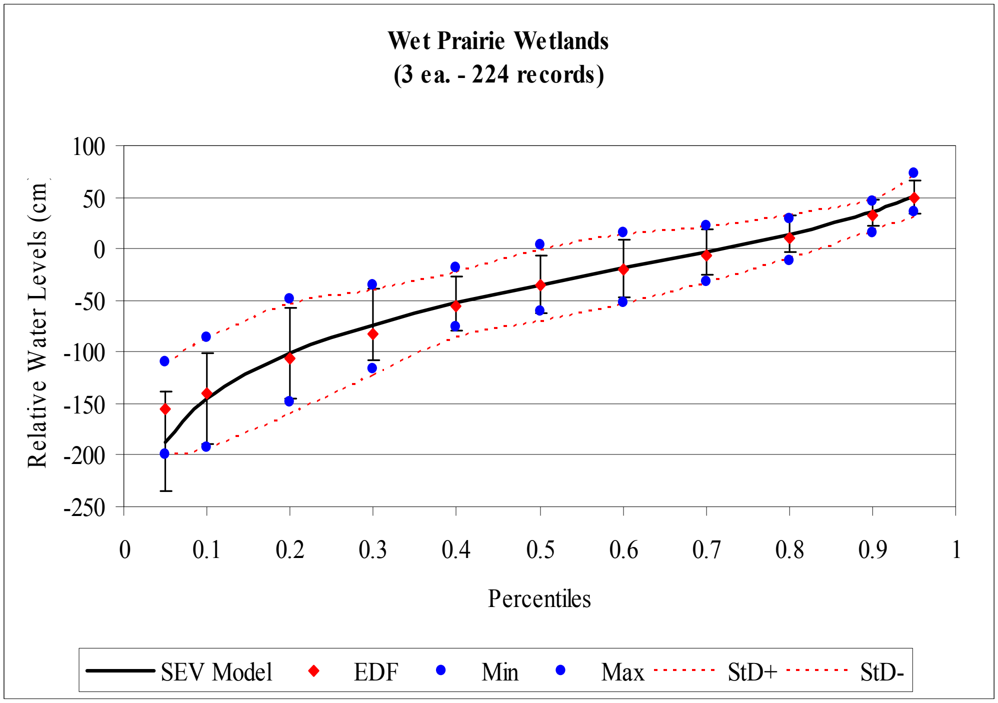


Figure 5.7 *SEV* Model predicted water levels and recorded water levels for the hardwood and wet prairie wetlands.

5.4.2.2. *SEV* Model Evaluation

5.4.2.2.1. Wetland Category Evaluation

The smallest extreme value distribution functions were first evaluated by comparing the predicted water levels [Eq. (5.4)] to the mean recorded water levels for each wetland category. The root-mean-squared-errors for the category analyses [Eq. (5.6)] range from 4.4% for the hardwood wetlands to 13.6% for the regional and marsh wetlands (Table 5.5 $-RMSE_{CAT}$). Further, the absolute water level error [Eq. (5.7)] ranges from 5.5% for the cypress wetlands to 11.4% for the marsh wetlands (Table 5.5 $-AE_{CAT}$).

Additionally, water level error analyses [Eq. (5.7)] compared the predicted water levels to the mean recorded water levels at each target percentile (Table 5.6 $-RE_{P}$). Overall, for all the wetland categories, the analyses show the *SEV* model under predicted the mean water levels at the 5th thru the 60th percentiles (i.e. produced lower water levels) and over predicted the mean water levels at the 70th thru 95th percentiles (i.e. predicted higher water levels).

5.4.2.2.2. Individual Wetland Comparisons

The final analyses investigated the capability of the respective *SEV* model to predict the recorded water levels for each individual wetland within a category. The root-mean-squared-error ($RMSE_P$) [Eq. (5.8)] for the regional wetland group range from 36.1 cm at the 70th percentile to 74.4 cm at the 5th percentile (Table 5.6). Further, the RMSE associated with each percentile are illustrated on the respective wetland category chart as error bars about the respective *SEV* model continuous distribution (Figures 5.5 thru 5.7).

The length of each error bar is twice the $RMSE_P$ value listed in Table 5.6 centered about the *SEV* model predicted water level.

Table 5.6. *SEV* model prediction RMSE per percentile ($RMSE_P$).

	$RMSE_P$ (cm)					
Percentile	Region	Cypress	Marsh	Cypress-Marsh	Hardwood	Wet Prairie
95th	52.4	33.0	54.7	71.1	25.9	16.2
90th	44.5	27.3	48.6	60.2	22.8	12.7
80th	37.8	25.0	43.6	48.2	16.8	17.5
70th	36.1	25.6	39.9	48.4	16.9	22.0
60th	36.6	29.4	36.6	48.2	14.4	27.9
50th	40.3	35.7	36.0	53.1	9.4	28.2
40th	45.3	42.0	39.9	62.4	12.4	25.8
30th	51.9	47.7	36.6	80.6	19.6	35.2
20th	56.4	51.2	45.9	87.1	17.7	43.4
10th	61.6	51.9	59.7	99.6	34.3	43.8
5th	74.4	58.3	80.8	99.4	29.4	48.1

5.4.2.3. Discussion – *SEV* Model Performance

The *SEV* models reproduced the mean water levels for each wetland category and the regional group adequately when considering the overall error and visual fit. The predicted water levels for each category are within the recorded empirical distribution deviation range at each of the target percentiles (Figures 5.5 thru 5.7). However, upon closer inspection, the *SEV* models do not predict the water levels at the distribution tails as good. This is confirmed by the relative error (RE_P) and root-mean-squared-error ($RMSE_P$) calculated at each target percentile (Tables 5.5 and 5.6 respectively). In general, the *SEV* models under predicted the low water levels (5th percentile) and over predicted the high water levels (95th percentile). The reduced predictive capabilities of the *SEV* models at the tails might be due to the limited amount of data recorded at the extreme water elevations. Also, the best-fit distributions are fitted to the bulk of the water-level data, which is centered on the location parameter values for the representative *SEV* model away from the tails. Furthermore, the largest prediction errors were generally observed at the 5th and 10th percentiles. This could be attributed to the high variability in the deep wetland water levels discussed in Chapter Three.

The *SEV* models can be applied to specific wetland types where representative water level data is not available. Further, the distributions can be used as a calibration tool to indicate whether a hydrologic model is portraying the respective wetland or wetland category water levels adequately. For example, an extended period simulation model should produce cypress wetland water levels that form a probability distribution curve similar to the one on Figure 5.5 – Cypress Wetlands.

5.4.3. *SEV* Models – Probability Plots

Statistical comparisons of the five wetland categories and four regional groups of wetlands located in different areas throughout the region were presented in Chapter 3.5.2. A battery of Kolmogorov-Smirnov tests discussed in Chapter 3.4.2 indicated observed water levels for the same period were unique. It was conjectured that *SEV* models could be developed to verify and further explore their uniqueness. *SEV* models representing the various wetland categories and wetland groups were plotted on smallest extreme value probability scale (Figures 5.8 and 5.9). Probability plots are used to portray distributions in a linear manner ($y = mx + b$) so that one can easily interpolate, extrapolate, or compare the data in a simpler manner (Chow et al. 1988). This is accomplished by rearranging the inverse smallest extreme value distribution function [Eq. (5.4)] into a linearized form:

$$\ln\left[-\ln(1-p)\right]=\frac{1}{\sigma}x-\frac{\mu}{\sigma} \tag{5.9}$$

where x is the relative water level (quantile) [L] and $\ln\left[-\ln(1-p)\right]$ is the corresponding scaled cumulative probability, $F(x)$ in Eq. (5.3).

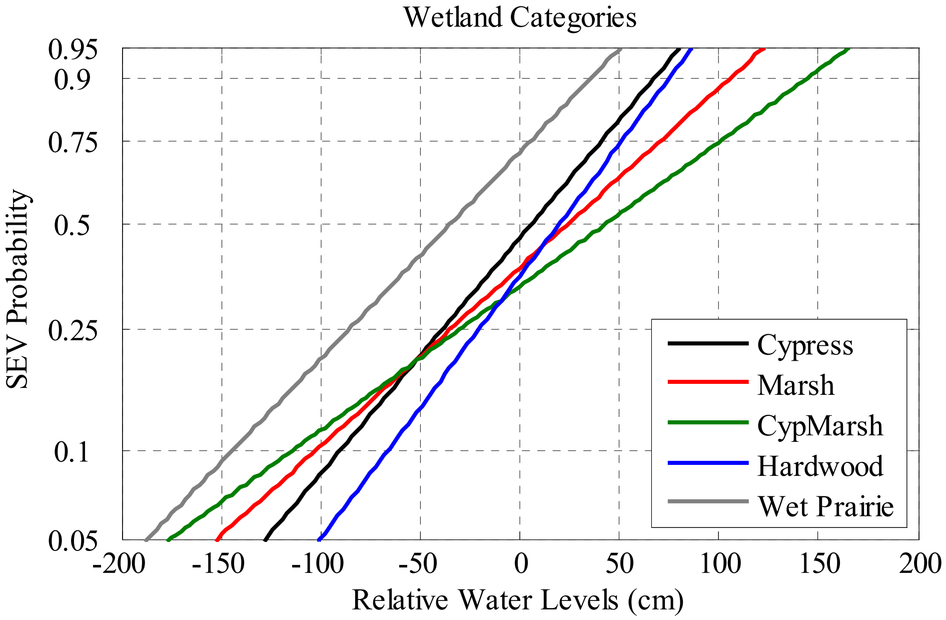


Figure 5.8 *SEV* Model probability plots for all wetland categories.

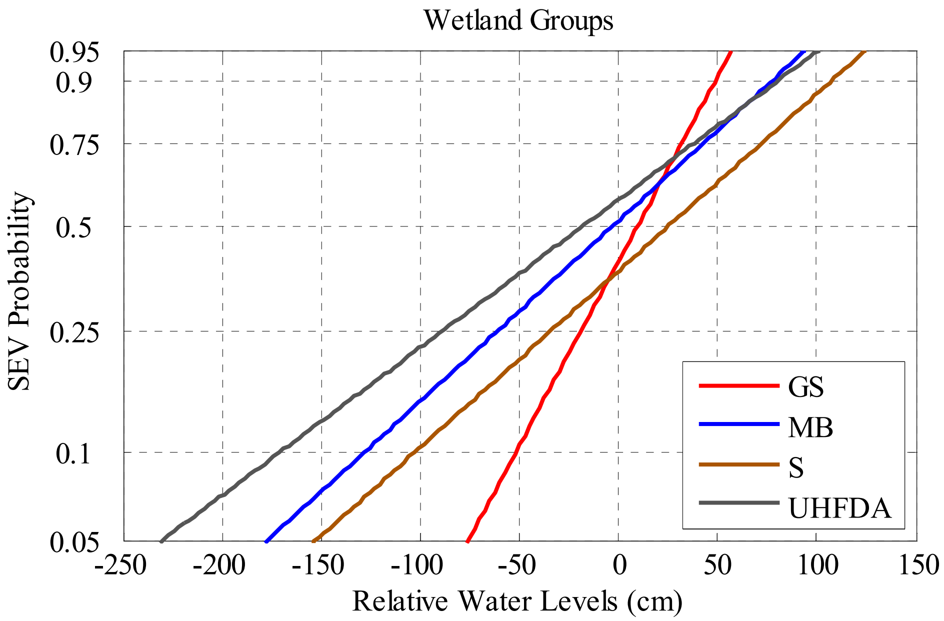


Figure 5.9 *SEV* Model probability plots for the wetland groups.

Based on the observation of the linearized probability plots, each distribution exhibits similar means, extremes and ranges in water-level behavior, however, has a unique slope. The slopes of the fitted distributions are defined by σ^{-1} [L^{-1}]. The slopes of the wetland categories ranged from 0.0119 cm^{-1} (cypress-marsh) to 0.0217 cm^{-1} (hardwood), and the slopes of the wetland groups ranged from range from 0.014 cm^{-1} (UHFDA) to 0.026 cm^{-1} (Green Swamp). The use of scaled probabilities to display the *SEV* model distributions clearly shows there are hydrologic differences between the individual wetland categories and the respective wetland groups.

Further, the variability in water levels associated with each wetland category or regional group is related to the slope of the respective probability curve (Figures 5.8 and 5.9). For instance, the steeper the *SEV* model curve (higher slope) the lower the variability in water levels. Conversely, high variability in water levels corresponds to a lower slope or a flat curve.

As an example, the hardwood wetlands have the highest slope (steepest curve) of the five wetland categories, suggesting low water-level variability. This is confirmed on the *SEV* model comparison chart (Figure 5.7 – hardwood wetlands). As seen on the chart and from the corresponding data in Table 5.3, the hardwood wetland category generally has the tightest standard deviation, and minimum and maximum water-level range at each of the percentiles. Also, the *SEV* model errors are generally small for this category (Table 5.6). This could be indicative of a more consistent water-table depth, which makes ecological sense since hardwood species generally have a lower tolerance to extreme water-level variability (Mitsch and Ewel 1979). Furthermore, the reduced variability in the water levels could be due to the limited water-level data available for the hardwood category.

5.4.4. Theoretical Application

The smallest extreme value probability models can be used in conjunction with current or projected meteorological data to determine representative water levels for wetlands. For example, extended period hydrologic simulations need to account for changing climate conditions, precipitation patterns in particular. The changing precipitation patterns will affect the antecedent moisture conditions within a region or hydrologic study area. The moisture conditions can be above or below long-term averages, and at varying departures from the norm, i.e. 20% below or 40% above normal conditions.

The normal moisture conditions and departures can be transferred to the smallest extreme value inverse cumulative distribution functions [Eq. (5.4)] to predict a representative water level for a particular wetland, wetland category or group of wetlands within a hydrologic study area. For instance, moisture conditions projected to be 50% above normal, will equate to the 75th percentile for the *SEV* Model (50% above the median percentile). Incorporating this percentile into the specific inverse cumulative distribution functions will yield representative wetland water levels. Further, the predicted water levels can be adjusted using the *SEV* model error bars or any of the other boundary parameters on the respective chart on Figures 5.5, 5.6 and 5.7. The adjustments can be made based on modeling experience and knowledge of the hydrogeology.

5.5. Conclusions

The smallest extreme value (*SEV*) probability distribution was identified as the best-fit model to represent the water levels of five wetland categories and a region group comprised of 56 wetlands located in the northern Tampa Bay region. *SEV* models were developed to represent water levels of various wetland types in the absence of recorded hydrologic data or where an analytical representation is desired. The probability models were shown to adequately represent the relative water levels associated with the wetland categories as well the regional wetland group. The predicted water levels were usually close to the mean recorded water levels for a given category, generally falling within one standard deviation of the mean recorded water levels. On average, the discrepancy between the predicted water levels and the recorded water levels was less than 10%, shown by a root-mean-squared-error analysis. Further observations showed the *SEV* models under predicted the wetland water levels at the low probability levels and over predicted the water levels at the high probability levels.

In addition, smallest extreme value density functions representing the five wetland categories as well as four groups of wetlands spread across the region were linearized and compared on special probability axes. The slopes of the linear distributions indicated differences between the individual wetland categories, and between the wetland groups. This result suggests there are distinct hydrologic differences between the various wetland categories and wetland groups in west-central Florida. Further, this indicates wetlands subjected to similar hydrologic stresses behave similarly.

Overall, the smallest extreme value probability models can be used to represent water levels of various wetland types in the absence of recorded hydrologic data. With the information in this chapter water resource engineers and hydrologists can develop representative water-level characteristics of wetlands with quantifiable errors. This is useful in developing accurate hydrologic models to be used in hydrologic studies with large numbers of wetlands and limited water level data.

CHAPTER 6

SUMMARY AND CONCLUSIONS

Hydrologic data including water-level observations, stage/storage, and surface/groundwater interactions do not generally exist for the vast majority of wetlands within west-central Florida let alone other less studied regions throughout the United States and the world. Therefore, this dissertation presents several improved analytical and empirical methods designed to provide a better means to quantify the above ground storage of wetlands, and characterize the water level fluctuations as well as the surface and groundwater interactions associated with wetlands. First, an analytical method was developed to describe the storage characteristics of wetlands and lakes in the absence of detailed hydrologic and bathymetric data. Second, an empirical probabilistic approach was developed to characterize the water levels associated with isolated wetlands, and to provide insights into surface and groundwater interactions within and adjacent to the wetlands. Third, analytical probability models were developed to represent the water levels of wetlands in the absence of detailed hydrologic data. The end product is to improve the accuracy of hydrologic model predicted water levels and fluctuations within wetlands, and associated surface and groundwater exchange between the wetland and local surficial aquifer system.

In Chapter Two wetland and lake stage-storage relationships were defined using a power-function model that is based on a single fitting parameter and two physically-based parameters: the reference wetland or lake planar area (e.g. a GIS data coverage), and the corresponding maximum pool depth. General models were developed based on detailed bathymetry of wetlands and lakes located in west-central Florida, North Dakota and Canada, representing different geologic settings. These models were then used to predict the storage behavior of multiple wetland and lake combinations. To determine the strength of the general model in the absence of detailed survey data, the model was applied to an independent validation data set comprised of 21 lakes in west-central Florida.

This work demonstrated that a single wetland shape parameter can be used to represent the storage of a single or multiple wetlands and/or lakes with acceptable and quantifiable error in field, theoretical and modeling studies. Additionally, the power-function model shape parameter(s) could be used as a calibration tool in hydrologic models, as opposed to individually adjusting rating relationship terms thereby easing calibration difficulty and reducing over parameterization.

Chapter Three focused on the hydrologic characterization of 56 various isolated wetlands in west-central Florida. Empirical distribution functions or frequency distributions were developed from historical paired wetland and upland water elevation records collected over seven years. The empirical distributions provided a means to analyze the water-level data using frequencies and probabilities of occurrence of water levels over time.

Further, the distributions were used to compare the water-level fluctuations of five wetland categories (cypress, marsh, cypress-marsh, hardwood and wet prairie), and to identify potentially impacted wetlands.

In general, at least some standing water was present in these wetlands 62% of the time over the seven year study. Also, the water levels in the wetlands exceeded the normal pool vegetative markers only 4% of the time. These crucial parameters can be used as a calibration tool to ensure hydrologic models accurately represent water levels in wetlands, as well as means to determine indicative behavior for normal or impaired wetland hydroperiods.

Variability in water levels between the wetlands in the west-central Florida region was significant. Consequently, individual wetland categories could not be identified via simple inspection of the respective water-level distributions. Additionally, there was higher variability in the groundwater levels beneath the wetlands than in the surface-water levels within the wetlands. The high variability in the groundwater levels is most likely a reflection of varying water-table depth across the west-central Florida region. The depth of the water table can be affected by pumping stresses, surface water augmentation or local hydrogeology. Water level variability within the wetlands near the wetland extents (maximum pool depth) was lower due in part to the natural shape of the wetlands. The incremental rise or fall of the wetland surface water levels will be small in comparison to the increase or decrease of the wetland pool volume near the wetland extents effectively stabilizing the surface water levels within the wetlands.

Frequency distributions can be used as a comparison tool to identify similarities and differences between representative data sets, and to identify atypical hydrologic behavior in wetlands. Statistical tests performed on frequency distributions representing the combined water levels within a wetland category showed significant differences in the water-level behavior for the specific wetland categories. Further, wetlands that may be adversely influenced by anthropogenic activities or natural stresses were identified using a simple technique comparing a respective wetland empirical distribution to a general trend distribution curve developed in this work. These are examples that show probability distributions can be used in hydrologic modeling to test the water-level behavior, trends, or stresses to individual wetlands and wetland categories.

Chapter Four provided insight into the groundwater recharge/discharge characteristics between 56 isolated wetlands and surrounding uplands. The analysis was performed to test the assumption that wetlands are local water-table depressions. The results indicated these wetlands were groundwater recharge zones 59% of the time over the seven year study. This was based on the head difference between the paired wetland and upland well water elevations.

Additional seasonal analyses, utilizing water elevation data from the peak dry season (March – May) and the peak wet season (July – September), indicated these wetlands were groundwater recharge zones 61% of the time during the dry season and 47% of the time during the wet season. Further, statistical tests comparing the seasonal wetland water levels and upland groundwater levels indicated these wetlands are surface-water expressions of the local groundwater system during the wet season, and indicated the wetland and upland water levels disassociate during the dry season as the local water table drops. Hydrologic modelers should be aware of these findings to ensure regional models accurately represent water-table fluctuations.

The aim of Chapter Five was to identify specific probability models that can be used to represent the surface and subsurface water-level behavior of various wetland types. The application of these probability models would be to predict wetland range of water-level fluctuations especially during different seasonal conditions, in the absence of recorded hydrologic data. Furthermore, the models were used to discern hydrologic differences between the various wetland categories and four groups of wetlands located in different hydrogeologic settings.

The smallest extreme value probability distribution was identified as the best-fit model to represent the water levels associated with the five wetland categories as well as a regional group comprised of all 56 wetlands. Specific distributions, predicated on respective location and scale parameters, were used to predict the water levels associated with each wetland category. Overall, the discrepancy between the predicted water levels and the recorded water levels was less than 10%. Additional observations showed the smallest extreme value models under predicted the wetland water levels at the low probability levels, and over predicted the relative water levels at the high probability levels.

In addition, smallest extreme value probability models representing the five wetland categories as well as four groups of wetlands spread across the region were linearized on probability scale. Based on the probability models, the various wetland categories exhibited similar means, extremes and ranges in water-level behavior, but unique slopes in frequency distributions. The slopes of the linear distributions indicated distinct hydrologic differences between the individual wetland categories, as well as between the wetland groups. The result suggests there are different hydrologic properties associated with the various wetland categories in west-central Florida, and indicate wetlands subjected to similar hydrologic stresses or conditions behave similarly.

Water resource engineers and hydrologists can utilize the representative wetland and/or wetland category characteristics presented in this work to develop comprehensive and more accurate hydrologic models. The accuracy of hydrologic models is predicated on sound and complete input parameters such as the surface and sub-surface water storage associated with wetlands, which are often estimated due to the lack of detailed bathymetry and water-level data. However, now these parameters can be estimated with quantifiable error using the methods and analytical techniques presented in this dissertation.

The storage model in conjunction with the frequency analysis and probability models will improve the accuracy of wetland representation in hydrologic models. The methods and techniques can be utilized to define wetland water-level and storage characteristics derived from various anthropogenic and climatic stresses. Further, they will aid engineers and hydrologists in predicting surface water runoff, river stage and discharge, and groundwater fluctuations.

Overall, wetland water-level fluctuations were characterized and coupled with improved analytical methods geared toward modeling the storage and water-level behavior in wetlands. The techniques and methodologies presented in this dissertation are not solely for the purposes of understanding the hydrology, and especially the surface/groundwater interactions of west-central Florida wetlands. These techniques can be applied to other areas to help understand the hydrology of these wetlands in various geologic and climatic settings.

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APPENDICES

Appendix A: Staff Gauge and Wetland Well Data Correlations

Spearman rank correlation coefficient tests (Dallal 2007) were performed comparing the wetland well data set to the associated staff gauge data sets for each wetland in this study to determine if the respective data sets are statistically similar. The data sets used for this analysis were developed from paired water level measurements that were matched based on the data collection date. Fifty-four paired wells were used in this analysis because two of the staff gauges did not have recorded data. The wetland well and staff gauge time series correlations were performed to validate the use of the wetland well data set to characterize the wetland pooled water levels in stead of using the staff gauge data sets. The Spearman rank correlation tests the hypothesis that there is no correlation ($p = 1$) against the alternative there is a nonzero correlation at the 5% confidence interval. The Spearman rank correlation was used for this analysis due to non-parametric nature of the well and staff gauge data sets.

The average Spearman's rho (correlation coefficient) for the 54 wetland well and staff gauge comparisons was 0.90, and the corresponding *p*-value for each wetland pair was 0.0. Based on the results of the Spearman rank correlation tests the wetland well data sets were strongly related to the corresponding staff gauge data sets. The analysis showed the general trend behavior between the staff gauge and wetland well was statistically similar, thus allowing the use of the wetland well to characterize the pooled wetland hydrologic behavior. Also, based on the strong correlation, the staff gauge data was used to fill in the associated wetland well data gaps.

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Appendix B: Wetland Well and Upland Well Data Normality Check

A Lilliefors test (Conover 1980) was performed on the wetland and upland well data sets to determine if the data were normally distributed. The Lilliefors test is a two-sided goodness-of-fit test suitable when a fully-specified null distribution is unknown and the respective parameters must be estimated. The well water level distribution type was evaluated to ensure the proper statistical models and methods were used in the analyses, i.e parametric or non-parametric (Dallal 2007; StatSoft Inc. 2010). The null hypothesis being that the sample comes from a distribution in the normal family, against the alternative that it does not come from a normal distribution. The test returns the logical value $h = 1$ if it rejects the null hypothesis at the 5% significance level, and $h = 0$ if it cannot.

Five of the wetland well data sets passed the Lilliefors normality test, null hypothesis $h = 0$, and 51 wetland well data sets failed the test $h = 1$. Two of the well data sets that passed the test had very small *p*-values (0.17 and 0.07 respectively) suggesting the test results were very weak, and three of the wetland well data sets had moderate *p*-values of 0.50 indicating the test results were good. Additionally, the Lilliefors test rejected the null hypothesis for 37 of the upland well data sets. Ten of the well data sets returned a logical value $h = 0$ with very small *p*-values, average of 0.12. Nine of the upland well data sets passed the null hypothesis $h = 0$ with moderate *p*-values, average of 0.47.

The Lilliefors normality test showed that the majority of the wetland and upland well data sets did not pass the normality tests. Furthermore, sample probability density functions for the paired wetland and upland wells associated with wetland 20 clearly showed that the data distributions were skewed to the low end of the water levels (Figure B.1). This could be due to the relatively short time period the data set comprises, or due to the topography of the wetlands. For instance, wetlands typically fan out at the upper pool depths covering more area (Brooks and Hayashi 2002; Hagg et al. 2005; Nilsson et al. 2008). Thus little increases in water depth can equate to large increases in pooled surface area. This would tend to shift the mean of the mass distributions to the higher water levels. Since the majority of the data sets failed the Lilliefors normality test, the statistical analyses performed in this study were designed to handle non-parametric or distribution-free data.

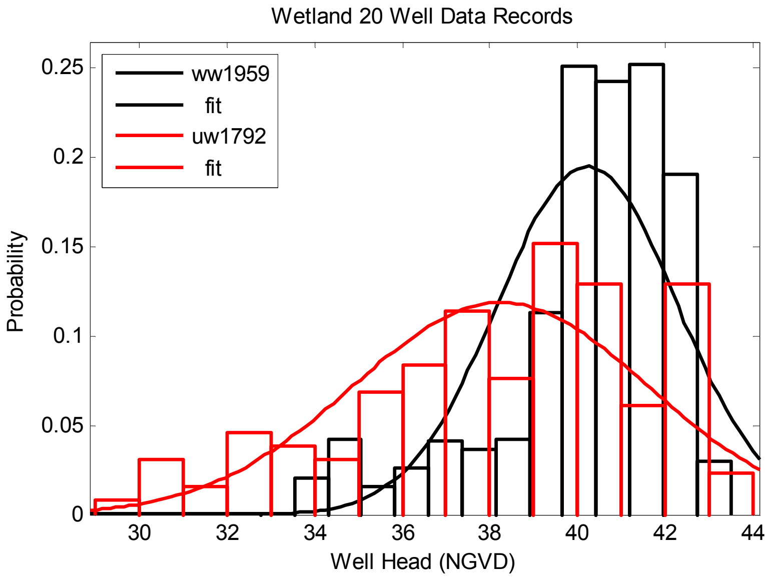

Figure B.1 Typical wetland and upland well probability density functions.

References:

Brooks, R. T., and Hayashi, M. (2002). "Depth-Area-Volume and Hydroperiod Relationships of Ephemeral (Vernal) Forest Pools in Southern New England " *Wetlands*, 22(2), 247-255.

Conover, W. J. (1980). *Practical Nonparametric Statistics*, Wiley, NJ.

Dallal, G. E. (2007). "Nonparametric Statistics." http://www.jerrydallal.com/LHSP/npar.htm (Jun. 2008).

Haag, K. H., Lee, T. M., and Herndon, D. C. (2005). "Bathymetry and Vegetation in Isolated Marsh and Cypress Wetlands in the Northern Tampa Bay Area, 2000-2004." U.S. Geological Survey Scientific Investigations Report 2005-5109, 49.

Nilsson, K. A., Ross, M. A., and Trout, K. E. (2008). "Analytic method to derive wetland stage-storage relationships using GIS areas." *Journal of Hydrologic Engineering*, 13(4), 278-282.

StatSoft Inc. (2010). "Electronic Statistics Textbook." Tulsa, OK: StatSoft. WEB: http://www.statsoft.com/textbook/stathome.html (Dec. 2009).

Appendix C: Monthly Versus Daily Data Comparison

Two-sample Kolmogorov-Smirnov tests (KS-test) were performed to determine if wetland well monthly water level records are statistically different from the corresponding daily water level records. The KS-test is a form of minimum distance estimation used to compare the empirical distribution functions of two samples, and tries to determine if two datasets differ significantly (Massey 1951; StatSoft Inc. 2010). The KS-test makes no assumption about the data distribution, i.e. it is a non-parametric and distribution free test. The test was used due to the non-parametric nature of the water elevation data sets (Appendix B). The Kolmogorov-Smirnov statistic quantifies a distance between the empirical distribution functions of two samples. The null hypothesis is that the two data sets are from the same continuous distribution; else they are from different continuous distributions. The result of $h = 1$ is returned if the test rejects the null hypothesis at the 5% significance level, otherwise the result of $h = 0$ is returned indicating a failure to reject the null hypothesis.

The KS-test comparing wetland well daily distributions of values and representative monthly distributions of values was used to determine if monthly well records are statistically similar to daily well records. The null hypothesis for this test is that the daily data set and the monthly data set were drawn from the same continuous distribution. Two sets of KS-tests were performed comparing the following data sets: 1) daily well values versus the well record value recorded on the 15th of each month and 2) daily well values versus monthly average values. The tests were limited to 19 wetland wells due to limited daily recorded well levels.

The Kolmogorov-Smirnov test results comparing: 1) daily well values versus monthly average values and 2) daily well values versus the well record value on recorded on the 15th of each month are shown in Table C.1. Based on the two-sample tests, the null hypothesis could not be rejected for either test scenario. Therefore, both the water level distributions comprised of monthly average values and the single day value were drawn from the same distribution as the daily wetland well samples for all of the 19 wetland wells. The test results for each of the 38 individual tests had $h = 0$ and $p = 1.0$.

The analysis indicates that monthly well record time series are statistically indistinguishable from the daily well record time series. This finding is supported by (Foster et al. 2008) in which the authors compared frequency distributions based on daily and monthly data. These results indicate that hydrologic studies could be designed based on monthly data records instead of daily data records, which could eliminate the use of costly continuous data recorders or the need to manually record well water levels on a daily basis.

References:

Foster, L. D., Shah, N., Ross, M., Ladde, G. S., and Wang, P. (2008). "Using frequency analysis to determine wetland hydroperiod." *Neural, Parallel Sci. Comput.*, 16(1), 17-34.

Massey, F. J., Jr. (1951). "The Kolmogorov-Smirnov Test for Goodness of Fit." *Journal of the American Statistical Association*, 46(253), 68-78.

StatSoft Inc. (2010). "Electronic Statistics Textbook." Tulsa, OK: StatSoft. WEB: http://www.statsoft.com/textbook/stathome.html (Dec. 2009).

Appendix C: (Continued)

Table C.1. Wetland well daily versus monthly data distribution comparisons.

				15th of the Month						**Monthly Average**					
Wtld ID	WW **ID**	Data Count		Kolmogorov-Smirnov test				Wilcoxon Rank-Sum		Kolmogorov-Smirnov test				Wilcoxon Rank-Sum	
		Daily	Monthly	*h*	*p*	*D*stat	*p* valid	*h*	*p*	*h*	*p*	*D*stat	*p* valid	*h*	*p*
20	1959	1819	61	0.000	0.994	0.054	59	0.000	0.891	0.000	0.999	0.047	59	0.000	0.907
70	1932	1440	47	0.000	0.965	0.072	46	0.000	0.907	0.000	0.997	0.058	47	0.000	0.964
84	1989	1399	46	0.000	0.922	0.081	45	0.000	0.801	0.000	0.871	0.087	45	0.000	0.625
170	1987	1329	43	0.000	0.964	0.076	42	0.000	0.782	0.000	0.979	0.069	44	0.000	0.749
183	1954	1741	57	0.000	1.000	0.046	55	0.000	0.959	0.000	0.944	0.068	58	0.000	0.947
196	1992	1362	45	0.000	0.991	0.065	44	0.000	0.837	0.000	0.966	0.072	45	0.000	0.961
215	1929	1797	58	0.000	0.995	0.055	56	0.000	0.856	0.000	0.979	0.061	59	0.000	0.872
295	1990	1302	43	0.000	0.879	0.089	42	0.000	0.670	0.000	0.990	0.066	43	0.000	0.882
388	1988	1402	46	0.000	0.985	0.067	45	0.000	0.836	0.000	0.980	0.068	45	0.000	0.803
541	1991	1175	38	0.000	0.947	0.084	37	0.000	0.755	0.000	0.788	0.103	39	0.000	0.759
605	1966	1178	38	0.000	0.960	0.082	37	0.000	0.734	0.000	0.911	0.087	40	0.000	0.833
1319	1961	2144	69	0.000	0.980	0.057	67	0.000	0.876	0.000	0.994	0.049	71	0.000	0.844
1320	1960	2131	69	0.000	0.998	0.047	67	0.000	0.771	0.000	0.988	0.053	71	0.000	0.991
1325	1977	1950	64	0.000	0.930	0.068	62	0.000	0.815	0.000	0.658	0.090	64	0.000	0.831
1326	1978	1670	55	0.000	0.999	0.049	53	0.000	0.996	0.000	1.000	0.047	55	0.000	0.997
1329	1981	1813	59	0.000	0.875	0.077	57	0.000	0.795	0.000	0.694	0.090	60	0.000	0.761
1337	1995	1175	38	0.000	1.000	0.057	37	0.000	0.783	0.000	0.981	0.073	39	0.000	0.792
3713	2064	1956	65	0.000	0.996	0.051	63	0.000	0.910	0.000	0.955	0.064	63	0.000	0.731
3715	2060	1959	65	0.000	0.991	0.054	63	0.000	0.904	0.000	0.853	0.075	63	0.000	0.696

Appendix D: SWFWMD White Papers on Wetland Histories

Uid 20 Morris Bridge East Cypress Marsh

The Morris Bridge East Cypress Marsh was one of several wetlands selected by the District for monitoring in the 1970s. Hydrologic monitoring began in 1977. On or about this time a stilling well recorder was installed. In 2000 a shallow upland well was added and in 2001 a 6-inch shallow wetland well. Hydrologic information is part of the District's Hydrologic Data Base (HDB).

Along with other Morris Bridge wetlands selected for monitoring in the 1970s, plots and transects were installed at approximately the time of staff gage installation. Biological monitoring was conducted at least yearly from the 1970s through the 1990s. From 2000-2006 East Cypress Marsh was monitored using the Wetland Assessment Procedure (WAP).

The 1983 Review report indicates that plant species characteristic of more upland areas invaded wetland monitoring plots in the early 1980s. These included broomsedge bluestem (Andropogon virginicus), dogfennel (Eupatorium capillifolium) and slender flattop goldenrod (Solidago microcephala). Sustained ground-water production during this time was thought to be a contributor to reduced wetland hydroperiod and invasion by upland species. Improved wetland conditions in recent years might be attributed to a sizable reduction in overall wellfield pumping along with more normal rainfall. Wetland conditions in the East Cypress Marsh are changed somewhat from those seen in the 1970s although the cypress canopy remains in good condition.

References:

Lopez, M. 1980. Hydrobiological monitoring of Morris Bridge Wellfield, Hillsborough County, Florida: 1978-1979 update. SWFWMD Environmental Section Technical Report 1980-1. 68 pp.

Lopez, M. 1983. Hydrobiological Monitoring of Morris Bridge Well Field, Hillsborough County, Florida. A Review: 1977-1982. Environmental Section Technical Report 1983-5. 96 pp.

Mumme, R.L. 1978. Hydrobiological monitoring of Morris Bridge Wellfield, Hillsborough County, Florida. SWFWMD Environmental Section Technical Report 1978-3. 42 pp.

Rochow, T.F. 1998. The effects of water table level changes on fresh-water marsh and cypress wetlands. SWFWMD Environmental Section Technical Report 1998-1. 64 pp.

Appendix D: (Continued)

Uid 21 STWF "B" (Grass Prairie)

STWF "B" marsh is located in the western part of the Starkey Wellfield just east of the large pasture south of the entrance road to the Park. The large marshy wetland is usually called Grass Prairie. Marsh "B" may historically have been a large grassy lake since there is considerable elevational decline from the palmetto fringe to the marsh center. In 1975 a staff gauge, transect and two meter-square vegetation plots were installed in the marsh. Transect and meter-square monitoring of vegetation was conducted from 1975 to 2001. After 2001, vegetational monitoring information comes from the WAP (Wetland Assessment Procedure).

A surficial upland monitoring well was added by SWFWMD in 1999 and a surficial wetland monitoring well next to the staff in 2001. Hydrological information from SWFWMD's installations is part of the WMDB. Another SWFWMD staff and wetland shallow well (STWF "G") is located on the eastern side of the Grass Prairie marsh. Water fluctuations at "B" and "G" are very similar and suggest that water is part of one system rather two separate pools. Tampa Bay Water monitors Grass Prairie with a site called S-24 near the northern end of the wetland system.

Surface waters at the Marsh "B" site have nearly always been low relative to control marshes during 30 years of SWFWMD monitoring. It has been assumed that groundwater production from four wells in the western part of the wellfield starting prior to 1975 has been a major influence in the relatively low waters levels. In some years water levels have only risen slightly at the staff gauge and have been well below the level of saw palmettos at the edge of the marsh.

In 1975 pickerelweed (Pontederia cordata) was quite abundant in the staff gauge area but over the years pickerelweed has either disappeared or been much less abundant. Fennel (Eupatorium spp.) and bluestem (Andropogon spp.) have often occupied the area near the staff. Spadeleaf (Centella asiatica), bluestem and fennel have often been abundant in the marsh fringe area over the years. Vegetational trends are depicted in graphs that accompany the history.

The accompanying file of photos taken at Grass Prairie "B" shows the vegetational trends noted. The photos also add evidence to observations that the stand of red maples (Acer rubrum) in the central area of the Grass Prairie marsh has expanded and has mostly blocked the view across the marsh. The area of red maples is part of a floating mat occupying an extensive area of the marsh.

Due to the invasion of fennel, bluestem and other shallow-water plants, the health of Grass Prairie "B" has been poor in below rainfall years although recovery occurs in above-normal rainfall years. In addition to the effects of rainfall, wetland conditions in the marsh are likely affected by the level of water production from wells in the western Starkey area.

Appendix D: (Continued)

STWF Marsh "B" was last visited for vegetational observations in July, 2006. The most noteworthy new occurrence was a large conspicuous soil slump feature about 50 feet north of the staff. The soil slump area was estimated to have dimensions of 30 x 200 feet and to be 1-2 feet deep. The slumped area was photographed and the photograph added to the photo-file that accompanies the history. The most likely cause of the soil slump feature is a history of depressed surface water levels in the marsh.

References:

Southwest Florida Water Management District. 1976. Biological assessment of the Jay B. Starkey Wilderness Park. SWFWMD Environmental Section Technical Report 1976-4. 135 pp.

Rochow, T.F. 1982. Biological assessment of the Jay B. Starkey Wilderness Park --- 1982 update. SWFWMD Environmental Section Technical Report 1982-9. 58 pp.

Rochow, T.F. 1983. 1983 Photographic survey of the Jay B. Starkey Wilderness Park. SWFWMD Environmental Section Technical Memorandum 4-27-83.

Rochow, T.F. 1984. 1984 Photographic survey of the Jay B. Starkey Wilderness Park. SWFWMD Environmental Section Technical Memorandum 4-27-84.

Rochow, T.F. 1985. Biological assessment of the Jay B. Starkey Wilderness Park --- 1985 update. SWFWMD Environmental Section Technical Report 1985-4. 105 pp.

Rochow, T.F. 1998. The effects of water table level changes on fresh-water marsh and cypress wetlands. SWFWMD Environmental Section Technical Report 1998-1. 64 pp.

Uid 51 EWWF #5

History of the EWWF #5 cypress dome located in the western part of the Eldridge-Wilde Wellfield extends back to the early 1980s. The EWWF #5 dome was visited many times during the period from 1982 to 1994 partly to collect environmental information for SWFWMD's consumptive use evidentiaries (CUP 202673). During this time the dome was called the TR-PMD #5 dome. A considerable number of leaning and fallen cypress trees were noted as well as visible fire burn scars on trees. More light than normal appeared to penetrate through the cypress canopy leading to considerable grasses and sedges in the understory. The dome appeared drier than normal when observed on site visitations. Observations through the 1990s showed at times dense fennel (Eupatorium spp.) along with considerable amounts of blackberries (Rubus spp.).

In 1989 a staff gauge was established in EWWF #5 and in 2001 wetland and upland surficial wells were added. The hydrologic information is part of the WMDB.

Observations of Dome #5 continued and increased as part of the Northern Tampa Bay Water Resources Assessment Project (1996). More than forty site visitations occurred between 1989 and 1999. The dome continued to have an impacted appearance during this time. Only on rare occasions was standing water noted. Abundant fennel (Eupatorium spp.) was commonly noted as well as some blackberry (Rubus spp.).

From 2000 through 2006, the dome was assessed using the WAP (Wetland Assessment Procedure). Over the entire period of observation the health of the dome has generally been poor although a considerable number of cypress trees are still standing.

General surveillance of aerial photography over the wellfield starting before wellfield pumpage leads to the conclusion that impacts to the EWWF #5 dome started not too long following the initiation of pumping at the wellfield in 1956.

References:

Rochow, T.F. 1988. Eldridge-Wilde Well Field (CUP 202673) environmental evaluation. Southwest Florida Water Management District memorandum. August 24, 1988.

Rochow, T.F. 1998. The effects of water table level changes on fresh-water marsh and cypress wetlands. SWFWMD Environmental Section Technical Report 1998-1. 64 pp.

Rochow, T.F. 1998. Investigation of historic aerial photography in and around the Eldridge-Wilde Wellfield. SWFWMD Memorandum. August 31, 1998.

Rochow, T.F. and P. Rhinesmith. 1991. Comparative analysis of biological conditions in five cypress dome wetlands at the Starkey and Eldridge-Wilde well fields in southwest Florida. SWFWMD Environmental Section Technical Report 1991-1. 67 pp.

Southwest Florida Water Management District. 1982a. Evidentiary evaluation, CUP No. 202673, Eldridge-Wilde Wellfield, Renewal. February 24, 1982.

Southwest Florida Water Management District. 1982b. Historic impact on wetlands within the Eldridge-Wilde Wellfield, Work Order Number 238. April 13, 1982. Memorandum by Rock G. Taber.

Southwest Florida Water Management District. 1989. Staff Report. Consumptive Use Permit Application No. 202673.02, Eldridge-Wilde Wellfield, May 25, 1989.

Southwest Florida Water Management District. 1996. Northern Tampa Bay Water Resources Assessment Project. Volume one. Surface-Water/Ground-Water Interrelationships. Resource Evaluation Section, SWFWMD

Uid 70 STWF "FF"

The STWF "FF" dome lies in S. 12, T. 26, R. 17 south of the Starkey Wellfield and the Anclote River and west of the Suncoast Parkway. The wetland is surrounded mostly by flatwoods. The dome lies approximately one mile from the easternmost Starkey production well.

A staff was installed in the dome in 1988 as part of the Northern Tampa Bay Water Resources Assessment Project (SWFWMD, 1996). During the 1990s a stilling well with recorder was added. A shallow upland well was installed in 2000 and a six-inch wetland well next to the staff in 2001. Hydrologic data is part of the Water Management Data Base.

Quantitative meter-square monitoring has not been conducted in the "FF" dome but numerous observations with written notes as well as photographs have been taken. The photographs are in the photographic file which accompanies the history. Approximately forty site visitations with notes were recorded from 1989-1999.

On site visitations the dome has often been well hydrated although notes reveal water levels were sometimes lower-than-expected when compared to control cypress dome wetlands. At times scattered fennel (Eupatorium spp.) has been observed. The ecologic conditions in the dome are regarded as good although it is possible that some surface water depression has occurred at times.

Since 2000, environmental conditions have been monitored with the WAP.

Reference:

Northern Tampa Bay Water Resources Assessment Project. 1996. Volume One. Surface-Water/Ground-Water Interrelationships. Resource Evaluation Section, Southwest Florida Water Management District. March 1996

Appendix D: (Continued)

Uid 81 UHFDA North Marsh

The North Marsh is located in SWFWMD's Upper Hillsborough Flood Detention Area close to the north fence line (S. 8, T. 26, R. 22). The North Marsh is composed of a large central marsh surrounded by a narrow fringe of cypress trees. The marsh was first observed in the late 1970s and the earliest photographs in the photo-file accompanying the history date from this time.

A staff was installed in 1982. A shallow upland well was installed in 2000 and a shallow wetland well in 2001. The current staff in the marsh lies in a deep gator-like depression. In the years since 1982 a manufactured housing park was built just north of the marsh on private land. Runoff from the park and/or package treatment plant at times augments marsh waters. The marsh is very large however, so water augmenting the marsh is likely not great.

The District has not monitored the North Marsh with quantitative monitoring installations but has relied on the photographic record and observations for knowledge of ecologic conditions. Starting in 2000 the North Marsh was monitored using the Wetland Assessment Procedure (WAP).

At times the marsh-like area of North Marsh has had considerable amounts of duckpotato (Sagittaria lancifolia), pickerelweed (Pontederia cordata), spatterdock (Nuphar lutea), maidencane (Panicum hemitomon) and smartweed (Polygonum hydropiperoides). At other times dog fennel (Eupatorium capillifolium) has been abundant. Observations over a long time period have shown that peak water levels seldom enter the cypress fringe therefore allowing wax myrtle and slash pines to invade along the ground. In addition to generally depressed water levels, dry cycles appear to be more severe in the North Marsh than in control wetlands. Whether this apparent abnormality in the hydrologic behavior of the marsh is valid need further analysis.

The UHFDA North Marsh has not been mentioned in any District publications and therefore no references are given. Hydrologic measurements are part of the District's Hydrologic Data Base.

Appendix D: (Continued)

Uid 84 Green Swamp Dome #3

Green Swamp Dome #3 along with five other Green Swamp domes was selected for monitoring in 1979 (S. 20, T. 24, R. 24). A staff gauge was installed and hydrologic monitoring began in May 1979. A stilling well was installed not too long after staff reading began. The depth of the stilling well is not available and a somewhat sketchy historical record indicates that the stilling well may have been deepened one or more times over the lengthy period of observation. A two-inch upland surficial well was installed in 1999 and a six-inch wetland surficial well in 2001 . Instrumentation on the stilling well was moved to the wetland surficial well after it was drilled.

Three meter-square vegetational plots (A-C) were installed in vegetational zones from the center of dome (A) to the edge (C). The graphical plots are in a file accompanying the history. The plots were initially sampled for percent plant species coverage in May, 1981 and November, 1981 --- at a later date sampling was changed to once per year in May-June. Yearly quantitative vegetational sampling continued until June, 2002. A report on 1979-1982 monitoring was completed in 1984. Many photographs were taken over the years of the exterior and interior of the dome. Some of the photos are shown in the photo-file which accompanies the history.

Hydrologic conditions over the years in the dome have been close to what is normally reported in the literature for isolated cypress domes. Dome #3 at the present time is in good condition.

Reference:

Rochow, T.F. and M. Lopez. 1984. Hydrobiological monitoring of cypress domes in the Green Swamp area of Lake and Sumter counties, Florida 1979-1982. Environmental Section Technical Report 1984-1. Southwest Florida Water Management District. 79 pp.

Appendix D: (Continued)

Uid 89 J.B. Starkey #2

The J.B. Starkey #2 cypress dome (S. 23, T. 26, R. 17) was selected for monitoring in 1989 and a staff gauge placed in the dome at this time. A 2-inch shallow wetland well and a 2-inch shallow upland well were added in 2001. The water level record is part of the District's Hydrologic Data Base (HDB).

J.B. Starkey dome #2 has predominantly been a hydrologic monitoring site with ecologic monitoring of secondary importance until WAP monitoring was begun in 2000. However, nearly forty site visitations with observations of conditions were made and notes taken during the 1990s. Hydrology of the dome and vegetation appeared close to control domes in the District's monitoring network.

From 2000 to 2006 the dome was monitored with the WAP. WAP monitoring scores appear to indicate that the dome continues to be in good condition. Photographs of conditions in the dome are included in the photo-file that accompanies this history.

Appendix D: (Continued)

Uid 112 STWF "BB"

The Starkey "BB" cypress dome (S. 2, T. 26, R. 17) was selected for monitoring in 1985 and a staff gauge installed at the time. A shallow upland well was drilled in 2000 and a shallow wetland well next to the staff in 2001.

No quantitative monitoring has been conducted in the STWF "BB" dome but a descriptive transect was installed in the dome in 1985 with detailed descriptions at intervals along the transect. Notes indicate the dome was in good health with considerable amounts of chain fern (Woodwardia virginica), lesser pipewort (Eriocaulon compressum), and giant pipewort (Eriocaulon decangulare) in the understory. Fetterbush (Lyonia lucida) was noted as common through the dome. The cypress canopy was healthy.

Many observations of STWF "BB" were made in the period from 1985 to 2005. Healthy canopy, shrub, and understory conditions were noted during this time. Observations showed the dome to be reasonably well hydrated without the appearance of depressed surface water levels shown by other domes in the central part of the wellfield.

Starting in 2000 the "BB" dome was assessed with the Wetland Assessment Procedure (WAP). WAP scores indicate the cypress stand is in good condition.

Appendix D: (Continued)

Uid 136 STWF "EE"

The Starkey "EE" cypress dome (S. 1, T. 26, R. 17) in the eastern area of the wellfield was selected for monitoring in 1988 and a staff gauge installed at this time. A shallow upland well was drilled in 2000 and a shallow wetland well next to the staff in 2001.

No plot monitoring has been conducted in the STWF "EE" dome but a descriptive transect was installed in the dome in 1988 with detailed descriptions made at intervals along the transect. Notes indicate the dome was in good health with a good sandweed (Hypericum fasciculatum) fringe and considerable amounts of lesser pipewort (Eriocaulon compressum) in the outer cypress fringe area. Fetterbush (Lyonia lucida) was noted to be common through the dome. The cypress canopy was healthy.

Many observations of STWF "EE" were made in the period from 1988 to 2005. Healthy canopy, shrub, and understory conditions were noted during this time. The dome is about 4000 feet from the easternmost Starkey water production well. At this distance signs of water table drawdown are not very apparent and hydrology of the dome is close to that expected under natural conditions.

Starting in 2000 the "EE" dome was assessed with the Wetland Assessment Procedure (WAP). WAP scores indicate that vegetational conditions in the dome are quite good.

Appendix D: (Continued)

Uid 143 STWF "T"

The Starkey "T" dome (S. 2, T. 26, R. 17) located just west of the Cross Cypress slough in the central part of the wellfield was selected for monitoring in 1983. A staff gauge was placed in the dome in 1983 along with a shallow upland well in 2000 and a shallow wetland well in 2001. The hydrologic record is part of the District's Hydrologic Data Base (HDB).

Vegetational conditions in the dome were monitored from 1983 to 2003 with inner and outer meter-square plots. The inner plot is close to the staff and there is little rooted vegetation in the plot due to deep water during the summer rainy season. Floating eastern purple bladderwort (Utricularia purpurea) has typically been abundant during wet years in the monitoring plot.

During the first ten years of monitoring, lesser pipeworts (Eriocaulon compressum) were common in the outer meter-square plot. In 1993 the plant covered 70% of the plot. Since 1993 lesser pipeworts have been considerably less abundant in the outer meter-square area. Following 2000, lesser pipeworts essentially disappeared from the monitoring area although a few could be found nearby. Horned rush (Rhynchospora corniculata) appears to have replaced lesser pipeworts in the area. Dome "T" was last observed in June, 2006.

When Dome "T" was initially observed in the early 1980s the dome was called "Polygala Head" due to the abundance of yellow milkworts (Polygala cymosa). From recent observations the plant appears to have a much-reduced presence in the dome possible for the same reasons as lesser pipeworts.

Since 2000 the Wetland Assessment (WAP) has been used to monitor vegetation in the dome. Observations have shown that in recent years wax myrtle has moved a considerable distance into the edge of the dome on the ground. This could be due to somewhat depressed surface-water levels in recent years. When the dome was last observed in 2006 wax myrtle was noted to be stressed/dead perhaps indicating improved water levels.

The overall health of the dome is good with a full cypress canopy and no leaning or fallen trees. A photo-file accompanies the history showing some of the conditions in the dome.

References:

Rochow, T.F. 1984. 1984 Photographic survey of the Jay B. Starkey Wilderness Park. SWFWMD Environmental Section Technical Memorandum 4-27-84.

Rochow, T.F. 1985. Biological assessment of the Jay B. Starkey Wilderness Park --- 1985 update. SWFWMD Environmental Section Technical Report 1985-4. 105 pp.

Rochow, T.F. 1998. The effects of water table level changes on fresh-water marsh and cypress wetlands. SWFWMD Environmental Section Technical Report 1998-1. 64 pp.

Appendix D: (Continued)

Uid 154 Pasco Trails

Wetland monitoring at the Pasco Trails Cypress Marsh (S. 11, T. 25, R. 18) was initiated in 1984 with the installation of a staff gauge. The wetland is about one mile south of the Cross Bar Wellfield and three miles northwest of the Cypress Creek Wellfield. The wetland has an extensive marsh in the area of the staff and dense cypress at the wetland edge. Entrance to the site on private property is by license agreement. In 2001 a shallow wetland well was installed next to the staff and a shallow upland well in the uplands at the edge of the wetland.

Unlike a number of the District's wellfield monitoring sites, no sampling plots were installed at the Pasco Trails Cypress Marsh. Monitoring was accomplished in the 1980s and 1990s by yearly examination of a descriptive transect, photography, and written observations. During this time records show more than forty visits to the wetland for staff reading and observation of environmental conditions. Photographs are included in the photo-file which accompanies the history.

During the 1980s a dense growth of pickerelweed (Pontederia cordata) and bulltongue arrowhead (Sagittaria lancifolia) existed in the marsh area near the staff. At more moderate depths in the marsh several species were common including spikerush (Eleocharis spp.), horned beaksedge (Rhynchospora corniculata), white water lily (Nymphaea odorata), and floating hearts (Nymphoides aquatica). Lesser pipeworts (Eriocaulon compressum) were common in the cypress fringe area.

During the 1990s water levels in the cypress marsh were observed to be much lower than in control wetlands some distance from wellfield pumping. At this time maidencane (Panicum hemitomon) and fennel (Eupatorium spp.) were frequently noted in the central marsh area. In response to depressed water levels, blue maidencane (Amphicarpum muhlenbergianum) in the 1990s became abundant in the cypress fringe.

In recent years water levels in the Pasco Trails Cypress Marsh appear to have improved. Wetland vegetation in the central marsh area has improved but the appearance of the wetland has changed from what was originally seen in the 1980s. A small area of soil slumping and fissuring exists not far from the staff.

From 2000-2006 the Cypress Marsh has been monitored with the Wetland Assessment Procedure (WAP).

Appendix D: (Continued)

Uid 165 Morris Bridge X-6 Dome

The Morris Bridge X-6 Dome was added to monitoring program at the Morris Bridge Wellfield in 1985 with the installation of a staff gage. The monitoring program began in the 1970s but the need was seen in the 1980s to expand geographic coverage of the program and hence several other wetlands were added in the 1980s. A shallow upland well was installed for hydrologic monitoring in 1999 and a shallow wetland well next to the staff in 2001. Hydrologic information is part of the District's Hydrologic Data Base (HDB).

Unlike wetlands selected for monitoring in the 1970s, the X-6 dome was not monitored quantitatively using plots and transects. It has also not been mentioned in several comprehensive technical reports on Morris Bridge monitoring since the last such monitoring report on the wellfield was in 1983. Biological information on the dome has relied on photography, observations, and repeat site visitations from 1985 to 2005. Photographs of wetland conditions are included in the photo-file which accompanies the history. Since 2000 the Wetland Assessment Procedure (WAP) has been used at the wetland to assess environmental conditions.

Relatively high pumpage rates at Morris Bridge in the early 1980s may have caused a drying of the X-6 dome in the mid to late 1980s (Rochow, 1998). In recent years hydrologic and biologic conditions have been quite good on site visitations.

References:

Lopez, M. 1983. Hydrobiological Monitoring of Morris Bridge Well Field, Hillsborough County, Florida. A Review: 1977-1982. Environmental Section Technical Report 1983-5. 96 pp.

Rochow, T.F. 1998. The effects of water table level changes on fresh-water marsh and cypress wetlands. SWFWMD Environmental Section Technical Report 1998-1. 64 pp.

Uid 170 Green Swamp Dome #1

Green Swamp Dome #1 along with five other Green Swamp domes was selected for monitoring in 1979 (S. 30, T. 24, R. 24). A staff gauge was installed and hydrologic monitoring began in May 1979. A stilling well was installed not too long after staff reading began. The depth of the stilling well is not available and a somewhat sketchy historical record indicates that the stilling well may have been deepened one or more times over the lengthy period of observation. A two-inch upland surficial well was installed in 1999 and a six-inch wetland surficial well in 2001. Instrumentation on the stilling well was moved to the wetland surficial well after it was drilled.

Four meter-square vegetational plots (A-D) were installed in vegetational zones from the center of dome (A) to the edge (D). The graphical plots are in a file accompanying the history. The plots were initially sampled for percent plant species coverage in May, 1981 and October, 1981 --- at a later date sampling was changed to once per year in May-June. Yearly quantitative vegetational sampling continued until June, 2002. A report on 1979-1982 monitoring was completed in 1984. Many photographs were taken over the years of the exterior and interior of the dome. Some of the photos are shown in the photo-file which accompanies the history.

Dome #1 was severely burned in November, 1980 by a fire through the entire dome. Even though a number of cypress were lost from the canopy, by spring1981 surviving cypress were beginning to resprout. Over the next several years, the effects of the fire gradually disappeared with the vigorous resprouting of the cypress and understory shrubs. Dome #1 at the present time appears much as it did prior to the fire. Hydrologic conditions over the years in the dome have been close to what is normally reported in the literature for isolated cypress domes. There have been considerable fluctuations in understory plant composition over the years in Dome #1. Much of the fluctuation is attributed to the opening of the dome to light after the fire and then the gradual shading of the understory as shrubs and the dense cypress overstory was restored.

Reference:

Rochow, T.F. and M. Lopez. 1984. Hydrobiological monitoring of cypress domes in the Green Swamp area of Lake and Sumter counties, Florida 1979-1982. Environmental Section Technical Report 1984-1. Southwest Florida Water Management District. 79 pp.

Appendix D: (Continued)

Uid 183 Morris Bridge Trout Creek Marsh

Morris Bridge Trout Creek Marsh was one of several wetlands selected by the District for monitoring in the 1970s. Hydrologic monitoring began in 1977. On or about this time a stilling well recorder was installed. In 1999 a shallow upland well was added and in 2001 a 6-inch shallow wetland well. Hydrologic information is part of the District's Hydrologic Data Base (HDB).

Along with other Morris Bridge wetlands selected for monitoring in the 1970s, plots and transects were installed at approximately the time of staff gage installation. Biological monitoring was conducted at least yearly from the 1970s through the 1990s. From 2000-2006 Trout Creek Marsh was monitored using the Wetland Assessment Procedure (WAP).

Trout Creek Marsh is somewhat more distant from the center of the wellfield than other monitored Morris Bridge wetlands and was observed to experience more moderate wellfield impacts when 17.2 mgd (yearly average) was pumped from the wellfield in 1982. The 1983 review report indicates a reduction of sandweed (Hypericum fasciculatum) and branched hedgehyssop (Gratiola ramosa). Dogfennel (Eupatorium capillifolium) became prominent for a time in the early 1980s. Continued observations of Trout Creek Marsh as wellfield production was reduced indicate improvement in hydrologic and biologic conditions in the marsh although vegetation differs somewhat from than of the 1970s.

Appendix D: (Continued)

References:

Hancock, M.C., T. Rochow and J. Hood. 2005. Review of original wetland assessment procedure (WAP – March 2000) and test results of a proposed revision to the WAP, May 2004. Southwest Florida Water Management District, Brooksville, FL 121 pp.

Hancock, M.C., T. Rochow, and J. Hood. 2005. Test results of a proposed revision to the Wetland Assessment Procedure (WAP), October 2004 and Development of the Final WAP Methodology Adopted in April 2005. Southwest Florida Water Management District, Brooksville, FL 147 pp.

Lopez, M. 1980. Hydrobiological monitoring of Morris Bridge Wellfield, Hillsborough County, Florida: 1978-1979 update. SWFWMD Environmental Section Technical Report 1980-1. 68 pp.

Lopez, M. 1983. Hydrobiological Monitoring of Morris Bridge Well Field, Hillsborough County, Florida. A Review: 1977-1982. Environmental Section Technical Report 1983-5. 96 pp.

Mumme, R.L. 1978. Hydrobiological monitoring of Morris Bridge Wellfield, Hillsborough County, Florida. SWFWMD Environmental Section Technical Report 1978-3. 42 pp.

Rochow, T.F. 1998. The effects of water table level changes on fresh-water marsh and cypress wetlands. SWFWMD Environmental Section Technical Report 1998-1. 64 pp.

Appendix D: (Continued)

Uid 196 Green Swamp Dome #6

Green Swamp Dome #6 along with six other Green Swamp domes was selected for monitoring in 1979 (S. 13, T. 24, R. 23). A staff gauge was installed and hydrologic monitoring began in May 1979. A stilling well was installed not too long after staff reading began. The depth of the stilling well is not available and a somewhat sketchy historical record indicates that the stilling well may have been deepened one or more times over the lengthy period of observation. A two-inch upland surficial well was installed in 1999 and a six-inch wetland surficial well in 2001 . Instrumentation on the stilling well was moved to the wetland surficial well after it was drilled.

Four meter-square vegetational plots (A-D) were installed in vegetational zones from the center of dome (A) to the edge (D). The graphical plots are in a file accompanying the history. The plots were initially sampled for percent plant species coverage in May, 1981 and October, 1981 --- at a later date sampling was changed to once per year in May-October. Yearly quantitative vegetational sampling continued until June, 2002. A report on 1979-1982 monitoring was completed in 1984. Many photographs were taken over the years of the exterior and interior of the dome. Some of the photos are shown in the photo-file which accompanies this history.

Hydrologic conditions over the years in the dome have been close to what is normally reported in the literature for isolated cypress domes. Dome #6 has remained in good condition over the entire period of monitoring.

References:

Berryman & Henigar, Inc. 2005. Vertical distribution of vegetation species relative to normal pool elevations in ten isolated wetlands in the Northern Tampa Bay area. Prepared for Tampa Bay Water, Clearwater FL

Rochow, T.F. and M. Lopez. 1984. Hydrobiological monitoring of cypress domes in the Green Swamp area of Lake and Sumter counties, Florida 1979-1982. Environmental Section Technical Report 1984-1. Southwest Florida Water Management District. 79 pp.

Uid 201 Morris Bridge West Cypress

Morris Bridge West Cypress was one of several wetlands at the Morris Bridge Wellfield selected by the District for monitoring in the 1970s. A staff gage was installed in 1977. A shallow upland well was installed in 1999 and a shallow wetland well in 2001. The hydrologic record is part of the District's Hydrologic Data Base (HDB).

Along with other Morris Bridge wetlands selected for monitoring in the 1970s, plots and transects were installed at approximately the time of staff gage installation. Biological monitoring was conducted at least yearly from the 1970s through the 1990s. From 2000-2006 Clay Gully Cypress was monitored using the Wetland Assessment Procedure (WAP).

The 1983 review report notes 17.2 mgd (yearly average) for 1982 was pumped from Morris Bridge. Although several other cypress and marsh systems in the wellfield showed adverse hydrologic and biologic impacts at this time, wetland vegetation at West Cypress remained healthy. Unlike some of the other wetland systems, lesser pipewort continued to be abundant in the wet meadow zone near the edge of the dome (Lopez, 1983). Observations up though 2005 have indicated a healthy cypress canopy and understory in the wetland.

References:

Hancock, M.C., T. Rochow, and J. Hood. 2005. Test results of a proposed revision to the Wetland Assessment Procedure (WAP), October 2004 and Development of the Final WAP Methodology Adopted in April 2005. Southwest Florida Water Management District, Brooksville, FL 147 pp.

Lopez, M. 1980. Hydrobiological monitoring of Morris Bridge Wellfield, Hillsborough County, Florida: 1978-1979 update. SWFWMD Environmental Section Technical Report 1980-1. 68 pp.

Lopez, M. 1983. Hydrobiological Monitoring of Morris Bridge Well Field, Hillsborough County, Florida. A Review: 1977-1982. Environmental Section Technical Report 1983-5. 96 pp.

Mumme, R.L. 1978. Hydrobiological monitoring of Morris Bridge Wellfield, Hillsborough County, Florida. SWFWMD Environmental Section Technical Report 1978-3. 42 pp.

Rochow, T.F. 1998. The effects of water table level changes on fresh-water marsh and cypress wetlands. SWFWMD Environmental Section Technical Report 1998-1. 64 pp.

Appendix D: (Continued)

Uid 215 J.B. Starkey #1

The J.B. Starkey #1 cypress dome (S. 24, T. 26, R. 17) was selected for monitoring in 1989. A 6-inch stilling well with a water level recorder was installed in the dome at or shortly after this time. A 6-inch shallow wetland well and a 2-inch shallow upland well were added in 2001. The water level record is part of the District's Hydrologic Data Base (HDB).

J.B. Starkey dome #1 has predominantly been a hydrologic monitoring site with ecologic monitoring of secondary importance. Observations of conditions were made periodically and notes taken during the 1990s. Generally the dome was in good ecological and hydrologic condition during this time. It is worth noting that a reason for selecting the dome as part of the District's monitoring program was that loblolly bay (Gordonia lasianthus) existed at the edge of the dome. Therefore the wetland was different from others in the District's wetland monitoring network and provided diversity in wetlands being monitored.

From 2000-2006 J.B. Starkey #1 was monitored systematically using WAP methodology. The very central part of the dome near the recorder is open to light --- pickerelweed (Pontederia cordata) and bladderwort (Utricularia spp.) are often seen in this area. The dome understory is hummocky with ferns on the hummocks but little noteworthy ground-cover vegetation. The transition of the dome to the uplands is narrow with inkberry (Ilex glabra) and fetterbush (Lyonia lucida). Muscadine (Vitis rotundifolia) has been noted in the trees at the very edge of the dome. Photographs of the wetland are in the photo-file which accompanies this history.

Appendix D: (Continued)

Uid 252 STWF "C" History

STWF "C" dome located near the Power Lines in the western portion of the Starkey Wellfield was equipped with a staff gauge, transect, and two meter-square vegetation monitoring plots in 1975. In 1975 there was no wellfield/pipeline road and water production was 2-3 miles away in the far western part of the wellfield. Transect and meter-square monitoring of vegetation was conducted from 1975 to 2001. After 2001, vegetational monitoring information comes from the WAP with occasional monitoring of the meter-square quadrats. Hydrological information from 1975 to present is part of the District's WMDB. Surficial upland and wetland monitoring wells were installed in 2000-2001. Further information on hydrologic installations is found in the EXCEL file in the uid 252 STWF "C" History.

Vegetational conditions were relatively stable in the dome from 1975 into the mid 1980s. From the mid to late 1980s up to the present time there have been notable understory changes. Juncus repens, originally common in the inner-meter square near the staff gauge, disappeared from the area after the initial ten years of monitoring. In its place chain fern (Woodwardia virginica) has become quite common. This is evident from the inner meter-square figure in the History file.

In the outer meter-square near the cypress fringe, Eriocaulon compressum (lesser pipewort) virtually disappeared by the late 1980s and Blechnum serrulatum (swamp fern) along with some Woodwardia virginica greatly increased in abundance. Historic photographs in the photo-file along with the outer meter-square figure confirm these vegetational changes. The changes occurred within a few years after water production wells were drilled and water production began in the central area of the wellfield in the 1980s. The dominance of ferns and absence of lesser pipewort continued to be evident when the meter square was visited in June, 2006.

Photographic information and observations show that Pinus elliottii (slash pine) has increased in abundance in the outer cypress fringe area. Observations during the 1990s indicate Amphicarpum muhlenbergianum (blue maidencane) invaded the edge of the dome. STWF "C" was last visited in June, 2006.

Appendix D: (Continued)

References:

Southwest Florida Water Management District. 1976. Biological assessment of the Jay B. Starkey Wilderness Park. SWFWMD Environmental Section Technical Report 1976-4. 135 pp.

Rochow, T.F. 1982. Biological assessment of the Jay B. Starkey Wilderness Park --- 1982 update. SWFWMD Environmental Section Technical Report 1982-9. 58 pp.

Rochow, T.F. 1983. 1983 Photographic survey of the Jay B. Starkey Wilderness Park. SWFWMD Environmental Section Technical Memorandum 4-27-83.

Rochow, T.F. 1984. 1984 Photographic survey of the Jay B. Starkey Wilderness Park. SWFWMD Environmental Section Technical Memorandum 4-27-84.

Rochow, T.F. 1985. Biological assessment of the Jay B. Starkey Wilderness Park --- 1985 update. SWFWMD Environmental Section Technical Report 1985-4. 105 pp.

Rochow, T.F. 1998. The effects of water table level changes on fresh-water marsh and cypress wetlands. SWFWMD Environmental Section Technical Report 1998-1. 64 pp.

Uid 261 Lansbrook East History:

The Lansbrook East dome is located north of Village Center Drive and east of East Lake Tarpon Road (S. 27, T. 27, R. 16) in Pinellas County. A staff gauge was installed in the wetland in 1989. Shallow wetland and upland wells were added in 2001. Water level data is part of the District's WMDB. When the dome was first observed in 1981 the surrounding land was undeveloped. In recent years a shopping center parking lot and roads to residential area have surrounded the dome on all sides.

Quantitative monitoring installations do not exist in the Lansbrook East dome but starting in the early 1980s observations and photographs were taken on a number of site visitations as part East Lake Tarpon Wellfield study, the NTB Water Resources Assessment Project (1996) and subsequent studies. During site visitations in the late 1980s into the 1990s the dome sometimes appeared drier than normal. However, as development occurred in the 1990s, runoff from a parking lot, detention pond, and roadways appears to have augmented water levels in the dome.

The cypress canopy at Lansbrook East since 1980 has been healthy. A few Chinese tallowtrees (Sapium sebiferum) have been observed in the dome but since the dome is large these invaders are not conspicuous. Due to deep water during the rainy season there is little understory vegetation in the interior of the dome.

Starting in 2000, monitoring of the Lansbrook East dome has taken place using the Wetland Assessment Procedure (WAP).

Reference:

Northern Tampa Bay Water Resources Assessment Project. 1996. Volume One. Surface-Water/Ground-Water Interrelationships. Resource Evaluation Section, Southwest Florida Water Management District. March 1996

Uid 276 SPSP-6 (NW-50)

The SPSP-6 cypress is located in the eastern part of the St. Petersburg-South Pasco Wellfield. Historiically, the dome has likely been connected to the large interior cypress stand at times of high water. Monitoring of SPSP-6 began in the early 1970s. Plot sampling of the dome was undertaken along a transect in the wetland from the early 1970s until the early 1980s. The transect was called TR-6. Five SWFWMD reports documented the initial five years of monitoring. Although a temporary staff was placed in the wetland, hydrologic data was not put in a permanent database. The final 1982 report in the Conclusions section mentioned impacts to isolated wetlands in the wellfield (Bradbury and Courser, 1982). In general these were described as: "… blow-downs of trees, late leaf-out of cypress, invasion of weedy terrestrial plants into formerly wetland areas, reduction and loss of wetland understory plants, increased susceptibility to fire damage, expansion of drier fringe communities, and reduction of the aquatic communities." It is assumed that some of these impacts were observed at SPSP-6.

In 1989 SWFWMD installed a staff gauge in the wetland as part of the Northern Tampa Bay Water Resources Assessment Project (1996). A wetland surficial well was installed next to the staff in 2001 and an upland surficial well in 2002. Data collected from the staff and wells are in the WMDB.

Forty site visitations were made to SPSP-6 as part of the NTB project from 1989-1999. Surface water in SPSP-6 was absent much of the time and water levels were judged to be much lower-than-expected when compared to those in domes far removed from wellfield pumpage. Fennel (Eupatorium spp.) at times was abundant. Soil subsidence of 6 inches or more was noted at cypress bases. Many leaning and fallen cypress were observed as well as burn marks on cypress. During the NTB project the dome was called NW-50.

During the period from 2000-2006 SPSP-6 was assessed using the WAP (Wetland Assessment Procedure). The dome continues to show a considerable levels of impacts.

Appendix D: (Continued)

References:

Putnam, S.A. and R.J. Moresi. 1974. Annual report of the St. Petersburg-South Pasco Wellfield study. SWFWMD Environmental Section Technical Report 1974-2.

Putnam, S.A. and R.J. Moresi. 1975. Second annual report of the St. Petersburg-South Pasco Wellfield study. SWFWMD Environmental Section Technical Report 1975-1.

Courser, W.D. and P.A. Hernandez. 1977. Third annual report of the St. Petersburg-South Pasco Wellfield study. SWFWMD Environmental Section Technical Report 1977-1.

Bradbury, K.R. and W.D. Courser. 1977. Fourth annual report of the St. Petersburg-South Pasco Wellfield study. SWFWMD Environmental Section Technical Report 1977-4.

Bradbury, K.R. and W.D. Courser. 1982. Fifth annual report of the St. Petersburg-South Pasco Wellfield study. SWFWMD Environmental Section Technical Report 1982-6.

Rochow, T.F. 1998. The effects of water table level changes on fresh-water marsh and cypress wetlands. SWFWMD Environmental Section Technical Report 1998-1. 64 pp.

Southwest Florida Water Management District. 1996. Northern Tampa Bay Water Resources Assessment Project. Volume one. Surface-Water/Ground-Water Interrelationships. Resource Evaluation Section, SWFWMD

Appendix D: (Continued)

Uid 295 Green Swamp Dome #4

Green Swamp Dome #4 along with five other Green Swamp domes was selected for monitoring in 1979 (S. 17, T. 24, R. 24). A staff gauge was installed and hydrologic monitoring began in May 1979. A stilling well was installed not too long after staff reading began. The depth of the stilling well is not available and a somewhat sketchy historical record indicates that the stilling well may have been deepened one or more times over the lengthy period of observation. A two-inch upland surficial well was installed in 1999 and a six-inch wetland surficial well in 2001 . Instrumentation on the stilling well was moved to the wetland surficial well after it was drilled.

Three meter-square vegetational plots (A-C) were installed in vegetational zones from the center of dome (A) to the edge (C). The graphical plots are in a file accompanying the history. The plots were initially sampled for percent plant species coverage in May, 1981 and November, 1981 --- at a later date sampling was changed to once per year in May-June. Yearly quantitative vegetational sampling continued until June, 2002. A report on 1979-1982 monitoring was completed in 1984. Many photographs were taken over the years of the exterior and interior of the dome. Some of the photos are shown in the photo-file which accompanies the history.

Hydrologic conditions over the years in the dome have been close to what is normally reported in the literature for isolated cypress domes. Dome #4, although burned severely in the November 1980 Green Swamp fire, has recovered and at the present time is in good condition.

Reference:

Rochow, T.F. and M. Lopez. 1984. Hydrobiological monitoring of cypress domes in the Green Swamp area of Lake and Sumter counties, Florida 1979-1982. Environmental Section Technical Report 1984-1. Southwest Florida Water Management District. 79 pp.

Uid 301 Pine Ridge Cypress Dome history:

The Pine Ridge Cypress Dome is located east of East Lake Tarpon Road (S. 22, T. 27 , R. 16) in Pinellas County. A staff gauge was installed in the wetland in 1989 with a stilling well recorder shortly thereafter. The recorder was vandalized during the 1990s with water level instrumentation being restored at a later date. A shallow upland well was installed in 2000 and a wetland well in 2001. Water level data is part of the District's WMDB. The dome is located on District Lower Brooker Creek land and is surrounded by flatwoods with considerable woody growth.

Quantitative monitoring installations do not exist in the Pine Ridge dome but photographs and observations have been taken on a number of site visitations as part of the NTB Water Resources Assessment Project (1996) and subsequent studies. During site visitations over the years water levels have appeared close to normal based on observations of control domes.

The cypress canopy and understory of the Pine Ridge Dome since first observed in 1988 have appeared healthy.

Since 2000, monitoring of the Pine Ridge dome has been conducted using the Wetland Assessment Procedure (WAP).

Reference:

Northern Tampa Bay Water Resources Assessment Project. 1996. Volume One. Surface-Water/Ground-Water Interrelationships. Resource Evaluation Section, Southwest Florida Water Management District. March 1996

Appendix D: (Continued)

Uid 304 STWF Marsh "Y"

Marsh "Y" (S. 1, T. 26, R. 17), in the eastern portion of the Starkey Wellfield, was selected as part of the District's wetland monitoring program in 1982 and a staff gauge placed in the marsh. Marsh "Y" is less than 0.25 acre but was chosen for monitoring since there are few marshes in the eastern part of the wellfield. The marsh lies a few hundred feet east of the most easterly of the production wells in the wellfield. STWF "Y" is distinctly sink-like in appearance and likely formed in a manner similar to other small sinks after a collapse in the underlying karst geology. Shallow wetland and upland wells were added in 1999.

Marsh "Y" was monitored yearly from 1983 to 2002 with descriptive observations along a transect from the saw palmetto edge to the staff as well as inner and outer meter-square plots. Originally present on the inner meter-square near the staff were creeping rush (Juncus repens), grassy arrowhead (Sagittaria graminea) and maidencane (Panicum hemitomon). Sampled on the outer meter-square during the initial years of monitoring were species such as southern beaksedge (Rhynchospora microcarpa), spikerush (Eleocharis sp.), southern umbrellasedge (Fuirena scirpoidea), sandweed (Hypericum fasciculatum), and broomsedge (Andropogon virginicus). Photographs in the photo-file and observations along the transect indicate a distinct fringe of healthy sandweed in the early 1980s. The sandweed fringe, which gives the marsh a stratified appearance, is typical of marshes with normal hydrology --- Marsh "Y" had 11-12 months of standing water at the staff in 1983 and 1984 (Rochow, 1985).

Marsh "Y" began a drying trend in the mid to late 1980s that has lasted through the present time. Water production beginning in 1989 from the easternmost Starkey production well probably contributed to this drying. Dry marsh conditions led to an increase in maidencane, broomsedge, and fennel in the marsh. Sandweed moved from the marsh edge to the central marsh area and decreased in abundance. In the 1990s fire from the flatwoods burned through the marsh and further altered vegetational conditions.

From 2000-2004, Marsh "Y" was monitored with the Wetland Assessment Procedure (WAP). The Marsh was removed from the list for WAP monitoring in 2005 due to its small size. Based on a long record of monitoring, Marsh "Y" is considered a severely impacted wetland.

References:

Rochow, T.F. 1985. Biological assessment of the Jay B. Starkey Wilderness Park --- 1985 update. SWFWMD Environmental Section Technical Report 1985-4. 105 pp.

Rochow, T.F. 1998. The effects of water table level changes on fresh-water marsh and cypress wetlands. SWFWMD Environmental Section Technical Report 1998-1. 64 pp.

Appendix D: (Continued)

Uid 320 Morris Bridge X-4 Dome

The Morris Bridge X-4 Dome was added to monitoring program at the wellfield in 1985 with the installation of a staff gage. The monitoring program at Morris Bridge began in the 1970s but the need was seen in the 1980s to expand geographic coverage of the program and hence several other wetlands were added in the 1980s. A shallow upland well was added for hydrologic monitoring in 2000 and a shallow wetland well next to the staff in 2001. Hydrologic information is part of the District's Hydrologic Data Base (HDB). In recent years, with Chapter 40D-8, F.A.C. the X-4 dome has become one of four domes at Morris Bridge that are especially important for assessing water level conditions over time.

Unlike wetlands selected for monitoring in the 1970s, the X-4 dome was not monitored quantitatively using plots and transects. It has also not been mentioned in several comprehensive technical reports on Morris Bridge monitoring since the last such monitoring report on the wellfield in 1983. Biological information on the dome has relied on photography, observations, and repeat site visitations from 1985 to 2005. Photographs of wetland conditions are included in the photo-file which accompanies the history. Since 2000 the Wetland Assessment Procedure (WAP) has been used at the wetland to assess environmental conditions.

The photographs in the photo-file show quite clearly that the cypress canopy of X-4 was considerably stressed in the mid 1980s when the staff gage was installed. Relatively high pumpage rates at Morris Bridge in the 1980s are believed to be the cause of this canopy stress (Rochow, 1998). The cypress canopy has appeared somewhat better in recent years although evidence of stress is still evident.

References:

Hancock, M.C., T. Rochow and J. Hood. 2005. Review of original wetland assessment procedure (WAP – March 2000) and test results of a proposed revision to the WAP, May 2004. Southwest Florida Water Management District, Brooksville, FL 121 pp.

Hancock, M.C., T. Rochow, and J. Hood. 2005. Test results of a proposed revision to the Wetland Assessment Procedure (WAP), October 2004 and Development of the Final WAP Methodology Adopted in April 2005. Southwest Florida Water Management District, Brooksville, FL 147 pp.

Lopez, M. 1983. Hydrobiological Monitoring of Morris Bridge Well Field, Hillsborough County, Florida. A Review: 1977-1982. Environmental Section Technical Report 1983-5. 96 pp.

Rochow, T.F. 1998. The effects of water table level changes on fresh-water marsh and cypress wetlands. SWFWMD Environmental Section Technical Report 1998-1. 64 pp.

Uid 331 J.B. Starkey #4

The J.B. Starkey #4 cypress marsh (S. 27, T. 26, R. 17) was selected for monitoring in 1989 and a staff gauge placed in the wetland at this time. A 2-inch shallow wetland well and a 2-inch shallow upland well were added in 2002. The water level record is part of the District's Hydrologic Data Base (HDB).

At the time the wetland was selected the area surrounding was improved pasture. Not long after selection land use changed with the construction of a Pasco County waste-water treatment plant. Treated waste-water from a nearby spray field may at times enter the cypress marsh.

The J.B. Starkey #4 cypress marsh has predominantly been a hydrologic monitoring site with ecologic monitoring of secondary importance until WAP monitoring began in 2000. However, observations of conditions were made periodically and notes taken during the 1990s. Generally the cypress marsh was in good ecological and hydrologic condition during this time. From 2000 to 2006 the wetland was monitored with the WAP. Photographs of conditions in the cypress-marsh are included in the photo-file that accompanies the history. The J.B. Starkey #4 wetland has not specifically been mentioned in any District report.

In March, 2007 Pasco County was observed excavating and pumping from a large pit close to the Starkey #4 wetland (see photos in the photo-file). According to communication with workers, the operation was being undertaken to lower the water table so that the nearby spray field would absorb water more efficiently. The operation is believed to have the potential to lower water levels in the cypress marsh wetland.

Uid 379 Morris Bridge South Cypress Marsh

The Morris Bridge South Cypress Marsh was one of several wetlands selected by the District for monitoring in the 1970s. A staff gage was installed in 1977. A shallow upland well was added in 1999 and a shallow wetland well in 2001. Hydrologic information is part of the District's Hydrologic Data Base (HDB). The South Cypress Marsh has also been monitored for many years by Biological Research Associates (BRA) in support of permit application for the wellfield. BRA's name for this wetland is MBR-29. Therefore, hydrologic and biologic information is available from different sources for this dome.

Along with other Morris Bridge wetlands selected for monitoring in the 1970s, plots and transects were installed at approximately the time of staff gage installation. Biological monitoring was conducted at least yearly from the 1970s through the 1990s. From 2000-2006 Clay Gully Cypress was monitored using the Wetland Assessment Procedure (WAP).

The 1983 review report notes 17.2 mgd (yearly average) for 1982 was pumped from Morris Bridge. At this time a reduction in hydroperiod was noted at the South Cypress Marsh leading to invasion by weedy, terrestrial plant species and disappearance of obligate aquatic and semi-aquatic plants. Certain of these changes are apparent in the photo-file that accompanies the history --- especially noteworthy are photographs showing severe canopy stress. With a cut-back in pumpage in the 1990s water levels and wetland health improved (Rochow, 1998). However, the stressed canopy is still very evident.

Appendix D: (Continued)

References:

Hancock, M.C., T. Rochow, and J. Hood. 2005. Test results of a proposed revision to the Wetland Assessment Procedure (WAP), October 2004 and Development of the Final WAP Methodology Adopted in April 2005. Southwest Florida Water Management District, Brooksville, FL 147 pp.

Lopez, M. 1980. Hydrobiological monitoring of Morris Bridge Wellfield, Hillsborough County, Florida: 1978-1979 update. SWFWMD Environmental Section Technical Report 1980-1. 68 pp.

Lopez, M. 1983. Hydrobiological Monitoring of Morris Bridge Well Field, Hillsborough County, Florida. A Review: 1977-1982. Environmental Section Technical Report 1983-5. 96 pp.

Mumme, R.L. 1978. Hydrobiological monitoring of Morris Bridge Wellfield, Hillsborough County, Florida. SWFWMD Environmental Section Technical Report 1978-3. 42 pp.

Rochow, T.F. 1998. The effects of water table level changes on fresh-water marsh and cypress wetlands. SWFWMD Environmental Section Technical Report 1998-1. 64 pp.

Appendix D: (Continued)

Uid 384 Morris Bridge Well Marsh

Morris Bridge Well Marsh was one of several wetlands selected by the District for monitoring in the 1970s. A staff gage was installed in 1977. Shallow upland and wetland wells were added in 2000. Hydrologic information is part of the District's Hydrologic Data Base (HDB). Well Marsh has also been monitored for many years by Biological Research Associates (BRA) in support of permit application for the wellfield. BRA's name for this wetland is MBR-42. Therefore, hydrologic and biologic information is available from two sources for this wetland.

Along with other Morris Bridge wetlands selected for monitoring in the 1970s, plots and transects were installed at approximately the time of staff gage installation. Biological monitoring was conducted at least yearly from the 1970s through the 1990s. From 2000-2006 Well Marsh was monitored using the Wetland Assessment Procedure (WAP).

The 1983 review report notes 17.2 mgd (yearly average) for 1982 was pumped from Morris Bridge. Vegetational trends through 1989 (as a result of reduced hydroperiods) ranged from the gradual invasion and increase in cover by upland/terrestrial plants and facultative wetland plants to the gradual and permanent loss of obligate aquatic and semi-aquatic plants which are dependent on regular, sustained seasonal inundation (Rochow, 1998). The 1983 Review report notes that lesser pipewort (Eriocaulon compressum) disappeared from the marsh edge in the early 1980s. In more interior areas of the marsh, floating hearts (Nymphoides aquatica) was reduced in abundance and pickerelweed (Pontederia cordata) disappeared. Maidencane (Panicum hemitomon) increased considerably in interior marsh areas. Dogfennel (Eupatorium capillifolium) was a prominent invader of the marsh during the early 1980s. The photo-file accompanying the history shows some of the trends described. Sustained ground-water production, coupled with several years of below normal rainfall conditions, were believed to be prime factors affecting wetland surface water levels.

For the period 1986-1989 (and through 1993), coincident with nearly a 40 percent reduction in overall average annual wellfield pumpage, wetland monitoring information suggested a stabilization of earlier vegetation trends. Principally, "dry wetland" vegetation trends did not continue to progress successionally to even more terrestrial (upland) conditions (Rochow, 1998).

In the mid 1990s (i.e. 1993-1997), low wellfield pumpage rates accompanied favorable rainfall conditions. During this time Well Marsh showed a trend toward improved wetland health compared with baseline 1977 conditions (Rochow, 1998). Observations through 2006 suggest a continuation of improved wetland health at Well Marsh although vegetational conditions still are not like they were in the 1970s.

Appendix D: (Continued)

References:

Hancock, M.C., T. Rochow and J. Hood. 2005. Review of original wetland assessment procedure (WAP – March 2000) and test results of a proposed revision to the WAP, May 2004. Southwest Florida Water Management District, Brooksville, FL 121 pp.

Hancock, M.C., T. Rochow, and J. Hood. 2005. Test results of a proposed revision to the Wetland Assessment Procedure (WAP), October 2004 and Development of the Final WAP Methodology Adopted in April 2005. Southwest Florida Water Management District, Brooksville, FL 147 pp.

Lopez, M. 1980. Hydrobiological monitoring of Morris Bridge Wellfield, Hillsborough County, Florida: 1978-1979 update. SWFWMD Environmental Section Technical Report 1980-1. 68 pp.

Lopez, M. 1983. Hydrobiological Monitoring of Morris Bridge Well Field, Hillsborough County, Florida. A Review: 1977-1982. Environmental Section Technical Report 1983-5. 96 pp.

Mumme, R.L. 1978. Hydrobiological monitoring of Morris Bridge Wellfield, Hillsborough County, Florida. SWFWMD Environmental Section Technical Report 1978-3. 42 pp.

Rochow, T.F. 1998. The effects of water table level changes on fresh-water marsh and cypress wetlands. SWFWMD Environmental Section Technical Report 1998-1. 64 pp.

Appendix D: (Continued)

Uid 388 Green Swamp Dome #2

Green Swamp Dome #2 along with five other Green Swamp domes was selected for monitoring in 1979 (S. 18, T. 24, R. 24). A staff gauge was installed and hydrologic monitoring began in May 1979. A stilling well was installed not too long after staff reading began. The depth of the stilling well is not available and a somewhat sketchy historical record indicates that the stilling well may have been deepened one or more times over the lengthy period of observation. A two-inch upland surficial well was installed in 1999 and a six-inch wetland surficial well in 2001. Instrumentation on the stilling well was moved to the wetland surficial well after it was drilled.

In 1981, three meter-square vegetational plots (A-C) were installed in vegetational zones from the center of dome (A) to the edge (C). The graphical plots are in a file accompanying the history. The plots were initially sampled for percent plant species coverage in May, 1981 and November, 1981 --- at a later date sampling was changed to once per year in May-June. Yearly quantitative vegetational sampling continued until June, 2002. A report on 1979-1982 monitoring was completed in 1984. Many photographs were taken over the years of the exterior and interior of the dome. Some of the photos are shown in the photo-file that accompanies this history.

Hydrologic conditions over the years in the dome have been close to what is normally reported in the literature for isolated cypress domes. Dome #2 at the present time is in good condition.

References:

Berryman & Henigar, Inc. 2005. Vertical distribution of vegetation species relative to normal pool elevations in ten isolated wetlands in the Northern Tampa Bay area. Prepared for Tampa Bay Water, Clearwater FL

Rochow, T.F. and M. Lopez. 1984. Hydrobiological monitoring of cypress domes in the Green Swamp area of Lake and Sumter counties, Florida 1979-1982. Environmental Section Technical Report 1984-1. Southwest Florida Water Management District. 79 pp.

Appendix D: (Continued)

Uid 407 Morris Bridge X-3 Marsh

The Morris Bridge X-3 Marsh was added to monitoring program at the wellfield in 1985 with the installation of a staff gage. The monitoring program at Morris Bridge began in the 1970s but the need was seen in the 1980s to expand geographic coverage of the program and hence several other wetlands were added in the 1980s. A shallow upland well was installed for hydrologic monitoring in 1999 and a shallow wetland well next to the staff in 2000. Hydrologic information is part of the District's Hydrologic Data Base (HDB).

Unlike wetlands selected for monitoring in the 1970s, the X-3 marsh was not monitored quantitatively using plots and transects. It has also not been mentioned in several comprehensive technical reports on Morris Bridge monitoring since the last such monitoring report on the wellfield in 1983. Biological information on the dome has relied on photography, observations, and repeat site visitations from 1985 to 2005. Photographs of wetland conditions are included in the photo-file that accompanies the history. Since 2000 the Wetland Assessment Procedure (WAP) has been used at the wetland to assess environmental conditions.

Relatively high pumpage rates at Morris Bridge in the early 1980s likely caused a drying of the marsh in the mid to late 1980s (Rochow, 1998). In more recent years water levels appeared to have improved.

References:

Hancock, M.C., T. Rochow and J. Hood. 2005. Review of original wetland assessment procedure (WAP – March 2000) and test results of a proposed revision to the WAP, May 2004. Southwest Florida Water Management District, Brooksville, FL 121 pp.

Lopez, M. 1983. Hydrobiological Monitoring of Morris Bridge Well Field, Hillsborough County, Florida. A Review: 1977-1982. Environmental Section Technical Report 1983-5. 96 pp.

Rochow, T.F. 1998. The effects of water table level changes on fresh-water marsh and cypress wetlands. SWFWMD Environmental Section Technical Report 1998-1. 64 pp.

Appendix D: (Continued)

Uid 489 J.B. Starkey #3

The J.B. Starkey #3 cypress dome (S. 27 T. 26, R. 17) was selected for monitoring in 1989 and a staff gauge placed in the dome at this time. A 2-inch shallow wetland well and a 2-inch shallow upland well were added in 2001.
The #3 dome is surrounded by improved pasture that is heavily fertilized at times. Water levels are part of the District's Hydrologic Data Base (HDB).

J.B. Starkey dome #3 has predominantly been a hydrologic monitoring site with ecologic monitoring of secondary importance until WAP monitoring began in 2000. Nevertheless, observations of conditions were made periodically and notes taken during the 1990s.

Within a short time after the monitoring site was selected it became apparent that environmental conditions were deteriorating rapidly in the dome. This is evident from the photographs taken during the 1990s displayed in the photo-file accompanying the history. A large number of leaning cypress are shown in the photographs. Soil subsidence of 1-2 feet exposing cypress roots can be seen. Inspection of conditions around the dome did not reveal reasons for the deterioration in ecology of the dome.

From 2000 to 2006 the J.B. Starkey #3 dome was monitored with the WAP. Extensive leaning of cypress and subsidence of soil around the bases of cypress continued to be noted during this time. Based on these impacts the dome is regarded as being in poor condition.

Uid 493 EWWF #1

History of the EWWF #1 cypress dome located just south of the wellfield road and east of the water treatment plant at the Eldridge-Wilde Wellfield extends back to the 1970s (Courser 1972, 1973). In these reports the dome was called the "0" Cypress Head. Notes provided indicate that the muck was partially oxidized, there were scattered ferns, and some alligator weed.

The EWWF #1 dome was visited a number of times during the period from 1982 to 1994 partly to collect environmental information that was provided for SWFWMD's consumptive use evidentiaries (CUP 202673). The dome was called TR-PMD #1 during this period of field evaluation. Soil subsidence up to ½ ft was noted with some cypress root exposure. The dome was observed to be drier than expected at visitation times. The possibility that the dome may at times receive water from augmented pasture areas was noted. More fallen cypress than normal were observed.

A staff gauge was installed in the wetland in 1989. Wetland and upland shallow wells were installed in 1999 and 2001 respectively. The hydrological records are part of the WMDB.

Three extensive examinations of aerial photographic sequences over Eldridge-Wilde wetlands have been performed (SWFWMD, 1982b; Rochow and Rhinesmith, 1991; and Rochow, 1998). The examinations covered years prior to wellfield production as well as following wellfield production. Examinations generally showed that over the wellfield impacts were readily evident in the form of leaning and falling cypress trees within approximately 15 years following the initiation of wellfield production in 1956.

Observations of EWWF #1 were continued and increased as part of the Northern Tampa Bay Water Resources Assessment Project (1996). Notes show the dome was visited and conditions observed on forty visitations from 1989 to 1999. Soil subsidence and treefall were noted a number of times during these site visitations.

From 2000 to 2006 conditions at EWWF #1 were monitored once or twice yearly using WAP (Wetland Assessment Procedure) methodology.   Greater than expected treefall and considerable soil oxidation were observed in the dome although the canopy overall was in relatively good condition compared to other Eldridge-Wilde cypress domes. Cattle trampling of the understory was noted.

References:

Courser, W.D. 1972. Investigations of the effect of Pinellas County Eldridge-Wilde Wellfield's aquifer cone of depression on cypress head water levels and associated vegetation. Southwest Florida Water Management District memorandum. July 14, 1972.

Courser, W.D. 1973. Investigations of the effect of Pinellas County Eldridge-Wilde Wellfield's aquifer cone of depression on cypress pond water levels and associated vegetation --- 1973. Southwest Florida Water Management District memorandum. October 10, 1973.

Rochow, T.F. 1988. Eldridge-Wilde Well Field (CUP 202673) environmental evaluation. Southwest Florida Water Management District memorandum. August 24, 1988.

Rochow, T.F. 1998. The effects of water table level changes on fresh-water marsh and cypress wetlands. SWFWMD Environmental Section Technical Report 1998-1. 64 pp.

Rochow, T.F. 1998. Investigation of historic aerial photography in and around the Eldridge-Wilde Wellfield. SWFWMD Memorandum. August 31, 1998.

Rochow, T.F. and P. Rhinesmith. 1991. Comparative analysis of biological conditions in five cypress dome wetlands at the Starkey and Eldridge-Wilde well fields in southwest Florida. SWFWMD Environmental Section Technical Report 1991-1. 67 pp.

Southwest Florida Water Management District. 1982a. Evidentiary evaluation, CUP No. 202673, Eldridge-Wilde Wellfield, Renewal. February 24, 1982.

Southwest Florida Water Management District. 1982b. Historic impact on wetlands within the Eldridge-Wilde Wellfield, Work Order Number 238. April 13, 1982. Memorandum by Rock G. Taber.

Southwest Florida Water Management District. 1989. Staff Report. Consumptive Use Permit Application No. 202673.02, Eldridge-Wilde Wellfield, May 25, 1989.

Southwest Florida Water Management District. 1996. Northern Tampa Bay Water Resources Assessment Project. Volume one. Surface-Water/Ground-Water Interrelationships. Resource Evaluation Section, SWFWMD

Appendix D: (Continued)

Uid 501 STWF South Central

The Starkey South Central cypress marsh (S. 8, T. 26, R. 17) near the power lines in the central part of the Starkey Wellfield was first observed and notes recorded in 1984. A staff gauge was installed in 1986 and a recording gauge by 1987. A shallow upland well was added in 1999 and a shallow wetland well in 2001. The recording gauge was removed at a later time and water levels currently come from the staff. Tampa Bay Water consultants monitor another part of the wetland as S-85.

Observations and photographs in the mid-1980s show giant and lesser pipeworts in wet meadow edge. Water levels in the wetland appeared normal compared to similar control wetlands outside the wellfield. By the late 1980s water levels appeared abnormally low in the wetland. Soil fissures were evident and young cypress were becoming established at the edge of the central open-water area. Signs of water level depression began to become evident at approximately the time water production was beginning in the central wellfield area and area along the power lines.

Photographs in the photo-file and observations show that within about ten years of initial observation leaning and fallen cypress were evident along with considerable soil subsidence and cypress root exposure. Sand pine and wax myrtle invasion into edge cypress were noted and photographed. Fennel (Eupatorium spp.) and bluestem (Andropogon spp.) were at times much more abundant in the wetland than expected. At least twenty visits to the wetland were made during this time to observe vegetational conditions.

Starting in 2000, the Starkey South Cypress Marsh was monitored with the Wetland Assessment Procedure (WAP). General observations show that health of this cypress marsh has continued to be poor.

Starting in 2005, the Starkey South Cypress Marsh was monitored with a WAP transect at Tampa Bay Water's S-85 site. WAP field data sheets, spreadsheets, and photographs should be consulted for environmental conditions at this wetland.

Reference:

Rochow, T.F. 1998. The effects of water table level changes on fresh-water marsh and cypress wetlands. SWFWMD Environmental Section Technical Report 1998-1. 64 pp.

Appendix D: (Continued)

Uid 505 Morris Bridge X-2 Dome

The Morris Bridge X-2 Dome was added to monitoring program at the wellfield in 1985 with the installation of a staff gage. The monitoring program at Morris Bridge began in the 1970s but the need was seen in the 1980s to expand geographic coverage of the program and hence several other wetlands were added in the 1980s. A shallow upland well was installed for hydrologic monitoring in 1999 and a shallow wetland well next to the staff in 2001. Hydrologic information is part of the District's Hydrologic Data Base (HDB). The X-2 dome is also monitored by Biological Research Associates (BRA) as MBR-14 for Tampa Bay Water and therefore there are two sources of biological and hydrologic information for this dome.

Unlike wetlands selected for monitoring in the 1970s, the X-2 dome was not monitored quantitatively using plots and transects. It has also not been mentioned in several comprehensive technical reports on Morris Bridge monitoring since the last such monitoring report on the wellfield in 1983. Biological information on the dome has relied on photography, observations, and repeat site visitations from 1985 to 2000. Photographs of wetland conditions are included in the photo-file that accompanies this history. Since 2000 the Wetland Assessment Procedure (WAP) has been used at the wetland to assess environmental conditions.

Relatively high pumpage rates at Morris Bridge in the early 1980s likely caused a drying of this dome in the mid to late 1980s (Rochow, 1998). The dome supported understory weeds such as fennel (Eupatorium spp.) during this time. There also appears to be some excess treefall in the dome. In recent years water levels in the dome appear to have improved.

References:

Lopez, M. 1983. Hydrobiological Monitoring of Morris Bridge Well Field, Hillsborough County, Florida. A Review: 1977-1982. Environmental Section Technical Report 1983-5. 96 pp.

Rochow, T.F. 1998. The effects of water table level changes on fresh-water marsh and cypress wetlands. SWFWMD Environmental Section Technical Report 1998-1. 64 pp.

Appendix D: (Continued)

Uid 541 Green Swamp Dome #5

Green Swamp Dome #5 along with five other Green Swamp domes was selected for monitoring in 1979 (S. 12, T. 24, R. 23). A staff gauge was installed and hydrologic monitoring began in May 1979. A stilling well was installed not too long after staff reading began. The depth of the stilling well is not available and a somewhat sketchy historical record indicates that the stilling well may have been deepened one or more times over the lengthy period of observation. A two-inch upland surficial well was installed in 1999 and a six-inch wetland surficial well in 2001. Instrumentation on the stilling well was moved to the wetland surficial well after it was drilled.

Five meter-square vegetational plots (A-E) were installed in vegetational zones from the center of dome (A) to the edge (E). The graphical plots are in a file accompanying the history. The plots were initially sampled for percent plant species coverage in May, 1981 and October, 1981 --- at a later date sampling was changed to once per year in May-June. Yearly quantitative vegetational sampling continued until June, 2002. A report on 1979-1982 monitoring was completed in 1984. Many photographs were taken over the years of the exterior and interior of the dome. Some of the photos are shown in the photo-file that accompanies the history.

Starting in 2000 Green Swamp Dome #5 was assessed each year with the Wetland Assessment Procedure (WAP). In 2000 the USGS began a study of the bathymetry and vegetation in Northern Tampa Bay marsh and cypress wetlands. Dome #5 was one of the wetlands studied intensively (Haag et al., 2005). Monitoring plots were set up at various elevations in the dome. Vegetational monitoring and bathymetry are reported in the publication.

Based on all evidence, hydrologic conditions over the years in the dome have been close to what is normally reported in the literature for isolated cypress domes. Dome #5 has remained in good condition over the period of monitoring.

References:

Haag, K.H., Lee T.M., and Herndon, D.C. 2005. Bathymetry and vegetation in isolated marsh and cypress wetlands in the Northern Tampa Bay Area, 2000-2004. U.S. Geological Survey Scientific Investigations Report 2005-5109. 49 pp.

Rochow, T.F. and M. Lopez. 1984. Hydrobiological monitoring of cypress domes in the Green Swamp area of Lake and Sumter counties, Florida 1979-1982. Environmental Section Technical Report 1984-1. Southwest Florida Water Management District. 79 pp.

Appendix D: (Continued)

Uid 544 STWF "GG"

The STWF "GG" dome lies in S. 13, T. 26, R. 17 south of the Starkey Wellfield and the Anclote River and just west of the Suncoast Parkway. The wetland at various times has been surrounded by a combination of overgrown flatwoods and pasture. In recent years the Suncoast Corridor parkway was built to the east of the dome. The dome lies about 1.5 miles from the easternmost Starkey production well.

A staff was installed in the dome in 1989 as part of the Northern Tampa Bay Water Resources Assessment Project (SWFWMD, 1996). A shallow upland well was installed in 2000 and a wetland well next to the staff in 2001. Hydrologic data are part of the Water Management Data Base.

Quantitative meter-square monitoring has never been conducted in the "GG" dome but numerous observations with written notes as well as photographs have been taken. The photographs are in the photographic file that accompanies the history. Nearly forty site visitations with notes were recorded from 1989-1999.

On site visitations the dome has often been reasonable well hydrated although notes reveal that water levels were often lower-than-expected when compared to control cypress dome wetlands. Pickerelweed has generally occurred near the staff although at times fennel (Eupatorium spp.) has been observed. The ecologic conditions in the dome are regarded as good although it is possible that some surface water depression has occurred at times. Lower-than-expected water levels sometimes lead to weediness in the dome.

Since 2000, environmental conditions have been monitored with the WAP.

Reference:

Northern Tampa Bay Water Resources Assessment Project. 1996. Volume One. Surface-Water/Ground-Water Interrelationships. Resource Evaluation Section, Southwest Florida Water Management District. March 1996

Uid 605 Green Swamp Marsh

The Green Swamp Marsh is the only marsh the District currently monitors in the Green Swamp (S. 33, T. 24, R. 23). A 6-inch stilling well with recorder was installed in 1994. In 1999 a 2-inch upland suficial well was drilled --- in 2001 a 6-inch wetland surficial was added. Instrumentation was moved to the wetland well after it was drilled.

In 1995, six meter-square monitoring plots were installed at 30 meter intervals from the wetland edge to the deep-water center of the marsh with the "0" plot closest to the wetland edge. The plots were first sampled for species cover in May, 1995 and then yearly through 2002. The last meter-square sampling was performed in July, 2006. Graphical results of vegetational monitoring are in the wetland history file. Photographs taken during ten years of monitoring are in the photo-file accompanying the history. Since year 2000, the Green Swamp Marsh has been monitored with the Wetland Assessment Procedure (WAP).

The Green Swamp Marsh has remained in good condition during the period of monitoring. However, from an examination of the vegetational plot data and photo record it is evident that there is more maidencane than pickerelweed across the marsh center than in earlier years. Slash pines from saplings to moderately large trees occur through the WAP's Outer Deep Zone. An apparent borrow area is 100-200 feet from the marsh but is thought to have minimal effects on the hydrology of the marsh.

Recently the USGS studied bathymetry and vegetation in the Green Swamp Marsh as part of a study on the effects of augmentation on cypress and marsh wetlands in the Northern Tampa Bay area (Haag et al., 2005). Berryman & Henigar has studied the vertical distribution of vegetation species in the marsh.

References:

Berryman & Henigar, Inc. 2005. Vertical distribution of vegetation species relative to normal pool elevations in ten isolated wetlands in the Northern Tampa Bay area. Prepared for Tampa Bay Water, Clearwater FL

Haag, K.H., Lee T.M., and Herndon, D.C. 2005. Bathymetry and vegetation in isolated marsh and cypress wetlands in the Northern Tampa Bay Area, 2000-2004. U.S. Geological Survey Scientific Investigations Report 2005-5109. 49 pp.

Uid 1316 Starkey Bay History

SWFWMD's Starkey Bay monitoring station (S. 8, T. 26, R. 17) was started in 2000 with the installation of a staff gauge in the wetland. In 2000 a shallow upland well was installed and a year later a shallow wetland well next to the staff.

Starkey Bay was known to SWFWMD's environmental monitoring program for many years prior to setting up the monitoring station in the wetland. During the 1970s and 1980s, as monitoring was initiated in the central and eastern parts of the wellfield, the bay wetland was observed from the "Old Dade City Road", a sandy road that runs east-west across the wellfield. On occasion the wetland was entered with some difficulty due to a dense growth of bays. During the early years the wetland was judged too dense to locate a staff in the deep interior and therefore only occasional observations were made of the wetland up until 2000 when inclusion of a wider diversity of wetland types became an objective of SWFWMD's monitoring program.

Starkey Bay is a large wetland extending from S. 8, T. 26, R. 17 into S. 5, T. 26, R. 17. The southern part of the wetland where the SWFWMD staff is located in the 1970s supported a dense healthy stand of bay (Gordonia lasianthus). It was believed that water levels in the wetland were supported by seepage from the surrounding sand pine uplands. Observations in the 1980s indicate that fire impacted much of the wetland possibly due to dry conditions the wetland experienced. WAP monitoring was conducted in the area of the SWFWMD staff from 2000-2004. Photos in the photo-file and field data indicate an impacted wetland. Many bays had fallen, opening up the formerly dense canopy, and muscadine grape was expanding in treefall area. Six inches of soil slump was noted.

In 2005 WAP monitoring was moved from SWFWMD's staff location to the S-90 station of Tampa Bay Water in S. 5, T. 26, R. 17. The Starkey Bay wetland in this location can best be described as a cypress marsh. Signs of impacts are also evident from 2005-2007 WAP monitoring at this location. Photos taken at the S-90 station appear in the S-90 photo-file.

In the initial years of monitoring the bay wetland was assigned a uid of 1331 on WAP field sheets. In recent years the wetland was reassigned to uid 1316 on field sheets.

1317 Starkey Wet Prairie

Starkey Wet Prairie is a small shallow wetland prairie in the northeastern part of the Starkey Wellfield (S. 1, T. 26, R. 17). The site was chosen for monitoring in 2000 and a staff gauge installed. An upland shallow well was drilled in 2000 and a wetland shallow well next to the staff in 2001.

The Wetland Assessment Procedure (WAP) has been used since Fall 2000 to monitor wetland conditions. Photographs appear in the photo-file accompanying the history.

Over the period of monitoring the wet prairie has appeared drier than normal. Broomsedge (Andropogon virginicus) and blue maidencane (Amphicarpum muhlenbergianum) have continually been present in more interior wetland areas than expected. Sandweed (Hypericum fasciculatum) also seems to have encroached into the interior wetland area possibly due to dry conditions.

Overall, the wet prairie does not appear as healthy as similar wetlands in non-wellfield areas.

Appendix D: (Continued)

Uid 1319 New River Cypress

New River Cypress lies several miles north of the Morris Bridge Wellfield and east of Morris Bridge Road (S. 12, T. 27, R. 20). A staff and shallow upland well were installed in the wetland in 2000 --- a 6-inch shallow wetland well was added in 2001. The shallow wetland well is equipped with a recorder.

Ecologic conditions at the wetland have been monitored for the last several years using WAP methodology. A photographic record accompanies the history. The interior of the dome according to the 2006 WAP is sparsely vegetated with mostly chain fern. Ferns are often typical of heavily shaded domes. Sour paspalum (Paspalum conjugatum), common carpetgrass (Axonopus fissifolius), witchgrass (Dichanthelium sp.), and St. Andrew's-Cross (Hypericum hypericoides) were noted in the Transitional Zone at the edge of the dome. Fetterbush (Lyonia lucida) and wax myrtle (Myrica cerifera) are common within the dome with some shrubs encroaching on the ground in the Transitional Zone. Buttonbush (Cephalanthus occidentalis) grows underneath the cypress canopy in the interior of the dome. The cypress canopy is healthy. The overall appearance of the New River Cypress dome has not changed since monitoring was initiated.

New River Cypress during the period of observation has been in good health. The cypress dome is well hydrated and water levels appear similar to other domes at some distance from groundwater pumping and development.

Reference:

Berryman & Henigar, Inc. 2005. Vertical distribution of vegetation species relative to normal pool elevations in ten isolated wetlands in the Northern Tampa Bay area. Prepared for Tampa Bay Water, Clearwater FL

Appendix D: (Continued)

Uid 1322 UHFDA Cypress #3

UHFDA Cypress #3 dome was added to SWFWMD's wetland monitoring network in 2000 with the installation of a staff gauge. The cypress dome is located in the Upper Hillsborough Flood Detention Area (S. 17, T. 26, R. 22). A surficial upland well was added in 2000 and a surficial wetland well near the staff in 2001. Hydrologic information is part of the District's Water Management Data Base (WMDB).

Ecological information about the wetland has been collected for the past several years with the Wetland Assessment Procedure (WAP). The most noteworthy ecologic observation about dome #3 is falling cypress which is clearly evident in photographs in the photo-file accompanying the history. Most cypress treefall occurred during the several years that the dome has been monitored. Compared to control cypress domes observations indicate that dome #3 experiences greatly depressed water levels.

Appendix D: (Continued)

Uid 1323 UHFDA Cypress #2

The UHFDA Cypress #2 wetland (S. 17, T. 26, R. 22) was added to SWFWMD's wetland with the installation of a staff gauge in 2000. A shallow upland well was added in 2000 and a shallow wetland well next to the staff in 2001. The hydrologic record is part of the District's Water Management Base (WMDB).

Ecological information over the past several years has been collected with the Wetland Assessment Procedure (WAP) and is not described in detail here. Cypress #2 has appeared abnormally dry whenever the dome has been visited in the last several years. At least one-half foot of soil subsidence is evident at the base of cypress causing root exposure in places. Considerable shrub and herbaceous understory invasion is evident. The wetland is close to a large borrow area to the south which may be causing water levels to be depressed in the wetland. WAPs should be consulted for more details on vegetational conditions.

Appendix D: (Continued)

Uid 1324 UHFDA Cypress #1

The UHFDA Cypress #1 wetland (S. 18, T. 26, R. 22) was added to SWFWMD's wetland monitoring network in 2000 with the installation of a staff gauge. A surficial upland monitoring well was added in 2000 and a shallow wetland well next to the staff in 2001. The hydrologic record is part of the District's Water Management Base (WMDB).

Ecological information over the past several years has been collected with the Wetland Assessment Procedure (WAP) and is not described in detail here. Cypress #1 has appeared abnormally dry whenever the dome has been visited in the last several years. The canopy is stressed with dying cypress. WAPs should be consulted for further information on vegetational conditions.

Appendix D: (Continued)

Uid 1325 UHFDA Wet Prairie

Ecologic monitoring of the Upper Hillsborough Wet Prairie (S. 18, T. 26, R. 22) began with the installation of a staff gauge in 2000. A 2-inch upland surficial well was added in 2000 and a 6-inch wetland surficial well in 2001. The wetland well has a water level recorder. Water levels are part of the District's Water Management Data Base (WMDB). Although considered a wet prairie based on GIS mapping the wetland system is sufficiently deep to likely have been a marsh in the past.

Ecologic information about the wet prairie comes from the Wetland Assessment Procedure (WAP). The photographic record that accompanies this history shows that at times the wet prairie has had dense dog fennel (Eupatorium capillifolium) in the central area near the recorder. Many slash pines (Pinus elliottii) have encroached into the wet prairie edge. Observations of water levels in the prairie indicate that surface waters are considerably lower than expected compared to control marsh-like wetlands.

Appendix D: (Continued)

Uid 1326 Alston Cypress #2

The Alston Cypress #2 dome lies on District-owned Alston lands (S. 22, T. 26, R. 22). A staff gauge and shallow upland well were installed in the wetland in 2000 --- a shallow wetland well was added next to the staff in 2001. The shallow wetland well is equipped with a recorder. The water level record is part of the District's Water Management Data Base.

Ecologic conditions in the dome during the past several years have been monitored with the WAP (Wetland Assessment Procedure). A photographic record accompanies this history. It is evident from the photos that fireweed (Erectites hieraciifolius) and dog fennel (Eupatorium capillifolium) have been common at times in the dome. Water levels at times have appeared lower than expected.

Appendix D: (Continued)

Uid 1327 Alston Cypress #1

The Alston Cypress #1 dome lies on District-owned Alston lands (S. 34, T. 26, R. 22). A staff gauge and shallow upland well were installed in the wetland in 2000 --- a shallow wetland well was added next to the staff in 2001. The water level record is part of the District's Water Management Data Base.

Ecologic conditions in the dome during the past several years have been monitored with the WAP (Wetland Assessment Procedure). A photographic record accompanies this history. It is evident from the photos that fireweed (Erectites hieraciifolius) and dog fennel (Eupatorium capillifolium) have been common at times in the dome. Excess dead and dying cypress have been noted in the canopy and water levels have appeared lower than normal. Causes for low water levels in the dome are not known but a borrow area exists within a few hundred feet of the dome.

Uid 1329 Alston Wet Prairie

The Alston Wet Prairie lies on District-owned Alston lands (S. 34, T. 26, R. 22). A staff gauge and shallow upland well were installed in the wetland in 2000 --- a shallow wetland well was added next to the staff in 2001. The shallow wetland well is equipped with a recorder. The water level record is part of the District's Water Management Data Base.

Ecologic conditions in Alston Wet Prairie during the past several years have been monitored with the WAP (Wetland Assessment Procedure). A photographic record accompanies this history.

1332 STWF Wetland Coniferous Forest

Monitoring of the Wetland Coniferous Forest (S.17, T. 26S, R. 17) in the western part of the Starkey Wellfield along the power lines was begun in 2000. The wetland was selected since it had a good representation of bay (Gordonia lasiathus) which was not found in most other wetlands monitored by SWFWMD. The wetland therefore was regarded as a worthwhile addition to SWFWMD's wetland monitoring network. A shallow upland well was added in 2000 and a shallow wetland well next to the staff in 2001. Hydrological records are part of SWFWMDs Hydrologic Data Base.

Biological data was collected with the Wetland Assessment Method (WAP) from 2000-2005. Up through 2004 the data was collected along a transect from the edge of the wetland to SWFWMD's staff. In Spring 2005 monitoring was moved to a nearby wetland monitoring station (S-112) in the same wetland being used for data collection by Tampa Bay Water's consultant.

In the years from 2000-2004 SWFWMD noticed considerable treefall and soil subsidence along the transect near the SWFWMD staff. WAP field sheets, spreadsheets, and photographs should be consulted for environmental conditions in this wetland.

Appendix D: (Continued)

Uid 1335 Green Swamp West Cypress

The Green Swamp West Cypress dome was added to SWFWMD's wetland monitoring network in 2000 with the installation of a staff gauge (S. 2, T. 25, R. 22). A shallow upland well was added in 2000 along with a shallow wetland well in 2001.

The West Cypress dome is typical of others in the Green Swamp but differs in the wide wet meadow that is part of the wetland assessment area. From 2000-2005 the West Cypress dome was monitored using WAP methodology. A brief photo-file accompanies the history. The Green Swamp West Cypress dome is regarded as generally healthy although the 2005 WAP indicates that ground-cover plants such as Centella asiatica, Eleocharis baldwinii, and Eupatorium capillifolium have moved into the deep zone in small numbers. Similarly a few shrubs and small trees such as wax myrtle and slash pine were detected in 2005 in the deep zone. Visual hydrologic indications during relatively few site visitations seem to indicate that the hydrology of the West Cypress dome is typical of other Green Swamp domes. However, the hydrology needs further investigation considering some invasion of shallow-water species along the dome edge.

Reference:

Berryman & Henigar, Inc. 2005. Vertical distribution of vegetation species relative to normal pool elevations in ten isolated wetlands in the Northern Tampa Bay area. Prepared for Tampa Bay Water, Clearwater FL

Uid 1337 Green Swamp Bay

A staff gauge was placed in the Green Swamp Bay (S. 6, T. 24, R. 24) in 2000 along with a shallow upland well. A shallow wetland well with a recorder was added in 2001. A considerable amount of Loblolly Bay (Gordonia lasianthus) occurs at the edge of the bay stand. Water level data are part of the District's Hydrologic Data Base.

Monitoring of the Green Swamp Bay during the past several years has taken place using the WAP. Pine invasion at the edge of the bay stand as well as soil slumping between trees are conspicuous. Water levels apparently have not been reaching historic levels in the bay stand --- soil slumping between trees may be one explanation for depressed water levels at the edge of the bay. Further comments on the Green Swamp Bay can be found on the field assessment sheets.

Uid 1344 UHFDA Cypress #4

UHFDA Cypress #4 dome was added to SWFWMD's wetland monitoring network in 2001 with the installation of a staff gauge. The cypress dome in located in the Upper Hillsborough area (S. 28, T. 25, R. 22) between Berry Road (35A) and U.S. 98. A surficial wetland well was added near the staff in 2001 and a surficial upland well also in 2001. Hydrologic information is part of the District's Water Management Data Base (WMDB).

Ecological information about the wetland has been collected for the past several years with the Wetland Assessment Procedure (WAP). The reader is referred to the WAPs for this information.

Uid 3713 Cypress Creek ELAPP Cypress

The Cypress Creek ELAPP Cypress was added to the District's wetland monitoring network in 2002 with the installation of a staff gauge (S. 15, T. 27, R. 19). The wetland is on Hillsborough County ELAPP land --- the District has a license agreement with the County to allow access to the wetland. Shallow wetland and upland wells were added to the wetland in 2001. The wetland well is 6-inches in diameter and has a recorder.

Cypress Creek ELAPP Cypress has been monitored with the Wetland Assessment Procedure (WAP) methodology for the past several years. The wetland is typical of other cypress domes in the Northern Tampa Bay (NTB) area. The deep area is occupied by moderate amounts of Walter's Sedge (Carex striata) and maidencane (Panicum hemitomon). The dome fringe has Walter's Sedge, maidencane, taperleaf waterhoarhound (Lycopus rubellus), Virginia buttonweed (Diodia virginiana), and falsefennel (Eupatorium leptophyllum). The 2005 WAP reports that slightly greater than expected amounts of buttonweed, falsefennel, waterhoarhound and rosy camphorweed (Pluchea rosea) were found in the deep wetland zone. Such findings are not uncommon in naturally occurring wetlands in the NTB area.

An indication of vegetational conditions in the cypress dome is seen in the photo-file. Cypress conditions during the period of monitoring are regarded as healthy.

Appendix D: (Continued)

Uid 3715 Cypress Creek ELAPP Marsh

The Cypress Creek ELAPP Marsh was added to the District's wetland monitoring network in 2002 with the installation of a staff gauge (S. 15, T. 27, R. 19). The wetland is on Hillsborough County ELAPP land --- the District has a license agreement with the County to allow access to the wetland. Shallow wetland and upland wells were added to the wetland in 2001. The wetland well is 6-inches in diameter and has a recorder.

Cypress Creek ELAPP Marsh has been monitored with the Wetland Assessment Procedure (WAP) methodology for the past several years. The wetland is typical of other marshes in the Northern Tampa Bay area. The deep area is occupied by maidencane (Panicum hemitomon), pickerelweed (Pontederia cordata), swamp smartweed (Polygonun hydropiperoides) and minor amounts of sawgrass (Cladium jamaicense). Blue maidencane (Amphicarpum muhlenbergianum) and moderate amounts of falsefennel (Eupatorium leptophyllum), broomsedge (Andropogon virginicus), and sugarcane plumegrass (Saccharum giganteum) are found toward the marsh fringe. An indication of vegetational conditions in the marsh can be seen in the photo-file. Marsh conditions during the period of monitoring have been healthy.

Appendix D: (Continued)

Uid 4184 Cone Ranch (CR-3) Cypress

The Cone Ranch (CR-3) Cypress wetland (S. 28, T.27, R. 22) was selected as a Minimum Level Wetland by District Governing Board action in 1998 (Chapter 40D-8, F.A.C.). As with other MFL wetlands, a Minimum Level in feet NGVD was specified for the wetland. The CR-3 wetland as with other MFL wetlands at Cone Ranch was part of Tampa Bay Water's wetland monitoring network on the Ranch and hence historical information exists on water levels and environmental conditions in the wetland.

The District upgraded water level installations at CR-3 in 2003 with the installation of a District staff and surficial wetland and upland wells. Wetland Assessment Procedure (WAP) evaluations have been conducted at the wetland for the past several years. Photographs of the wetland are included in the photo-file that accompanies the historical description. WAP assessment notes indicate pasture at the edge of the dome as well as cattle and hog signs within the dome. The cypress canopy is in good condition. Soils in the dome are mucky.

Appendix D: (Continued)

Uid 4187 Cone Ranch (CR-6) Cypress

The Cone Ranch (CR-6) cypress wetland (S. 22, T.27, R. 22) was selected as a Minimum Level Wetland by District Governing Board action in 1998 (Chapter 40D-8, F.A.C.). As with other MFL wetlands, a Minimum Level in feet NGVD was specified for the wetland. The CR-6 wetland as with other MFL wetlands at Cone Ranch was part of Tampa Bay Water's wetland monitoring network on the Ranch and hence historical information exists on water levels and environmental conditions in the wetland.

The District upgraded water level installations at CR-6 in 2003 with the installation of a District staff and surficial upland and wetland wells. Wetland Assessment Procedure (WAP) evaluations have been conducted at the wetland for the past several years. Photographs of the wetland are included in the photo-file that accompanies the historical description.

Recent WAP assessments have noted bahia grass (Paspalum notatum) at the edge of the dome and some dog fennel (Eupatorium capillifolium) in the Deep Zone. Cattle trampling has been extensive at the dome edge. Observations have shown some excess cypress canopy stress along with noticeable dead and leaning cypress in the dome.

ABOUT THE AUTHOR

Kenneth Allan Nilsson received a Bachelor's Degree in Civil Engineering from the University of Cincinnati in 2002 and a Master's of Science in Environmental Engineering from the University of Cincinnati in 2004. He entered the Ph.D. program at the University of South Florida in the fall of 2004. While at the University of South Florida he became very involved with the Florida Section of the American Water Works Association, an international society dedicated to the improvement of drinking water quality and supply.