Final Report

Summary of the Available Literature on Nutrient Concentrations and Hydrology for Florida Isolated Wetlands

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Florida Department of Environmental Protection, Tallahassee, Florida

Submitted by:

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EXECUTIVE SUMMARY

This report summarizes a database of environmental parameters for isolated wetlands in Florida with specific focus on nitrogen and phosphorus in the wetland water column and soils. This database, the Florida Isolated Wetland Nutrient Database (FIWND) was assembled through a comprehensive review of literature and available data sources, with a particular focus on gathering all existing nitrogen and phosphorus water quality data for reference isolated wetlands that have minimal impact from human disturbance, hereafter called non-impacted wetlands. Data were also collected for impacted isolated wetlands, thereby providing a record of wetland water and soil quality across the landscape (where recorded) and a basis for comparison with reference wetlands.

The data indicate that water column nitrogen and phosphorus both show considerable natural variation in non-impacted Florida wetlands. Total Kjeldahl Nitrogen (TKN) values for non-impacted isolated wetlands ranged from a low of 0.002 mg N/L to a high of 6.0 mg N/L while total phosphorus (TP) values ranged from a low of 0.002 mg P/L to 0.64 mg P/L. Impacted wetlands generally showed much more variation in water column nutrient parameters, with a TKN range from 0.450 mg N/L to 31.0 mg N/L and a TP range from 0.0035 mg P/L to 17.0 mg P/L. Note that TKN values are reported, as opposed to total nitrogen (TN), due to the low sample size of non-impacted (n = 3) and impacted (n = 21) TN data.

Using the 75^{th} percentile (or third quartile) of nutrient concentrations as an indicator of background nutrient concentrations during the wet season, isolated non-impacted wetlands water column TKN concentrations were below 2.000 mg N/L for forested depressional wetlands, 2.200 mg N/L for emergent depressional wetlands, and 1.608 mg N/L for emergent basin wetlands. Water column nitrate-nitrogen (NO_3-N) and ammonia-nitrogen (NH_3-N) 75^{th} percentile values were much lower. Background TP concentrations were below 0.085 mg P/L for forested depressional wetlands, 0.041 mg P/L for emergent depressional wetlands, and 0.047 mg P/L for emergent basin wetlands.

While the data show small differences in the range of soil nitrogen values between non-impacted and impacted wetlands, a strong difference is found for phosphorus levels in non-impacted and impacted wetlands. Background soil TN concentrations, based on the 75^{th} percentile of non-impacted wetlands, were 13.50 mg N/g soil for forested depressional wetlands, 12.35 mg N/g soil for emergent depressional wetlands, and 30.35 mg N/g soil for emergent basin wetlands. The 75^{th} percentile soil TP concentrations were 0.408 mg P/g soil for forested depressional wetlands, 0.260 mg P/g soil for emergent depressional wetlands, and 0.205 mg P/g soil for emergent basin wetlands.

We have proposed a methodology for calculating runoff for isolated depressional and basin wetlands for individual rainfall events. The methodology uses the US Department of Agriculture Soil Conservation Service (now Natural Resources Conservation Service) runoff equation with modified curve numbers (CNs) developed specifically for isolated wetlands. During the dry season, we propose that runoff will only occur if the rainfall event is greater than the difference between the wetland water level and the mean wet-season water level. Nutrient concentration for runoff can then be calculated based on the FIWND values collected for this study. We propose that 75^{th} percentile nutrient concentrations are used for dry season calculations, reflecting higher nutrient concentrations in lower water conditions. Further, the lower 25^{th} percentile nutrient concentrations should be used to calculate loading during the wet season, to reflect the more dilute nutrient conditions in times of higher wetland water levels and therefore dilution of nutrient concentrations.

Interpretive caution toward these results is warranted because much of the literature data were collected during relatively short-term research studies focused on a small number of specific sites. As well, reporting conventions across studies are quite idiosyncratic. A systematic approach for sampling water quality of Florida's isolated wetlands is necessary for a robust, regionally specific understanding of the natural condition of these systems and the role they play in maintaining water quality across the natural and developed landscape matrix.

INTRODUCTION

Wetlands are defined by the presence of hydric soils, hydrophytic vegetation, and characteristic hydrology that provides saturation or inundation for a sufficient part of the growing season to support hydric soils and hydrophytic vegetation. For the purposes of this review we refer to the US Fish and Wildlife Service standard classification scheme for wetlands and deepwater habitats (Cowardin et al. 1979). Our focus was on isolated palustrine forested and emergent wetlands. Data were further divided into smaller depressional wetlands and larger basin wetlands. In this review, the term *isolated* specifically refers to wetlands that generally lack a significant surface water connection, though may connect to other wetlands or water bodies in times of above average water levels, and are therefore considered to have surficial hydrologic isolation. Further, the wetlands are considered geographically isolated owing to the surrounding land cover being upland habitat (after Tiner 2003). Additional data for wetlands outside of Florida or for other palustrine wetland types (e.g. strands, sloughs) were collected and entered in the database when included in relevant data sets or otherwise available, but are not presented here.

A further focus of this review was on reference standard wetlands. That is, wetlands that represent ecological integrity, the highest ecological condition, and that were generally free from obvious and apparent anthropogenic influence. Hereafter, these reference standard wetlands are described as *non-impacted*, to facilitate standard terminology throughout this document. Additional data were collected for *impacted* wetlands, described as those influenced by anthropogenic activities in the surrounding landscape (e.g. row crops, pasture, dairy farms, residential development, highways). While the scope of work called for a specific review of *non-impacted*, the inclusion of data from *impacted* wetlands provides a broader understanding of the current state of wetland water and soil quality across the Florida landscape.

Extent of Florida Freshwater Wetlands

Wetlands once occurred on approximately 8.2 million ha throughout the state of Florida. Today considerably less of the landscape is occupied by wetlands, with an estimate from 1996 of 4.6 million ha of wetlands in Florida (Dahl 2005). Of these wetlands, approximately 90% are freshwater wetlands (4.1 million ha) with 2.3 million ha of freshwater forested wetlands, 1.1 million ha of freshwater emergent wetlands, 725,000 ha of freshwater shrub wetlands, and 98,000 ha of freshwater ponds (Dahl 2005).

The US Fish and Wildlife Status and Trends report (Dahl 2005) does not specifically address hydrologically isolated wetlands. The four broad types of freshwater wetlands include forested wetlands (e.g. wet pine flatwoods, mixed hardwoods, river swamps, cypress domes, and hydric hammocks), emergent wetlands (e.g. marsh, swale, slough, wet prairie, wet savanna, reed swamps, glades), shrub wetlands (e.g. titi swamps, scrub cypress, dwarf cypress), and natural and manmade freshwater ponds (Dahl 2005). The mean surface area of freshwater wetlands ranged from 7 ha for forested wetlands, 4 ha for emergent wetlands, 3 ha for shrub wetlands, to 0.7 ha for freshwater ponds (Dahl 2005).

Further, these wetland types are not equally abundant throughout Florida (Table 1). Lane (2000) presented four Florida wetland regions derived from a spatial hydrological model: panhandle, north, central, and south (Figure 1). In the panhandle region, Lane (2000) identified 90.1% of the freshwater wetlands as forested with the remaining 10% divided between shrub (6.8%) and emergent (3.2%) wetlands. In contrast, in the south region, 21.9% of the freshwater wetlands were forested, with 17.3% shrub and 60.8% emergent shrub wetlands. In an earlier study, the Florida Department of Community Affairs (1988) estimated that the ratio of forested to emergent wetlands in the Florida panhandle was 10:1; whereas the ratio was 3:1 and 1:5 in central and south Florida, respectively (as cited by Dahl 2005).

Table 1. Spatial distribution of palustrine wetland types in Florida (Lane 2000)

	Wetland Region			
Vegetation	**Panhandle**	**North**	**Central**	**South**
Forested	90.1%	78.2%	49.8%	21.9%
Emergent	3.2%	13.3%	41.4%	60.8%
Shrub	6.8%	8.6%	8.7%	17.3%

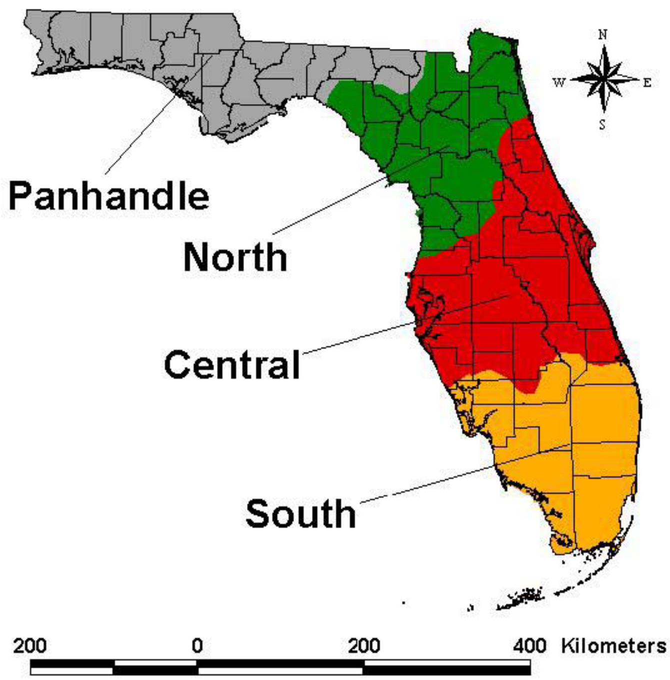


Figure 1. Florida wetland regions (Lane 2000)

Description of Florida Freshwater Wetlands

Distinct differences occur among Florida wetland types, though an overlap in flora and fauna occurs. This review focused on geographically isolated depressional and basin, forested and emergent wetlands. These geographically isolated wetlands belong to what Tiner (2003) calls Coastal Plain ponds, cypress domes, gum ponds, or pocosin wetlands.

Wetland Vegetation

Forested wetlands include those wetlands characterized by woody species that are at least 6 m tall or taller (Dahl 2005). Emergent wetlands, commonly called marshes, host rooted herbaceous hydrophytes, with the exclusion of wetlands dominated by mosses and lichens (Dahl 2005). The biomass turnover rate of emergent wetlands is typically an order of magnitude higher than forested wetlands (Hopkinson 1992).

Wetlands Hydrogeomorphology

For the purposes of this review we have broadly grouped the data as depressional or basin wetlands. Depressional wetlands often occur in relatively small watersheds and their water budget is dependent on precipitation (Brinson 1993), making them hydrologically isolated from surface water connectivity. While not strictly hydrologically isolated wetlands, basin wetlands in this review were characterized as larger wetland systems often with a seasonal or semi-permanent surface hydrologic connection to other wetlands or aquatic bodies, either as inflow or outflow. Because basin wetlands can be nearly "completely surrounded by uplands," which Tiner (2003) uses to define isolated wetlands, basin wetlands qualify as geographically isolated wetlands for the purposes of this review. Brinson and Lee (1989) described basin wetlands as having low hydrologic energy, long hydroperiods, low nutrient availability, low to moderate temperature, low to high fire frequency, and low herbivory.

Purpose of Study

This review was conducted in response to a request for a literature review to summarize and synthesize available scientific information regarding background nutrient concentrations and hydrology for Florida isolated wetlands. This review synthesizes information in order to define background conditions for *non-impacted* wetlands (i.e. natural, minimally impaired, reference standard wetlands) and *impacted* wetlands (i.e. wetlands surrounded by human land use activities) for the proposed Statewide Stormwater Treatment Rule. The available literature, including published, peer reviewed documents and gray literature reports, has been used to document nutrient concentrations, particularly nitrogen and phosphorus, and to summarize the existing information on wetland hydrology (i.e. depth, duration, flood frequency).

Wetland hydrology is generally considered the single most influential determinant of wetland condition (e.g. Duever et al. 1986; Mitsch and Gosselink 2007). Long term monitoring records of wetland hydrology are generally absent from wetland studies and what data are available generally span five growing seasons or less and are thus considerably dependent on short term weather conditions as opposed to long term climactic averages. An acceptable integration of wetland hydrology reflecting long term climatic averages is difficult to predict; however, understanding wetland hydrology is critical to developing realistic estimates of stormwater loading from wetlands.

As guidance for public policy, the wetland literature review presents what is known about nutrient concentrations and hydrology, the information gaps that inject substantial uncertainty, and suggested research to address these gaps.

METHODS

The primary objective of this scope was to develop a synthetic database on concentrations of water column nitrogen and phosphorus in isolated wetlands in order to provide usable scientific information as input to the development of the Statewide Stormwater Treatment Rule for Florida. To accomplish this objective, the project team reviewed available scientific literature on wetland nutrient concentrations, focusing on nitrogen and phosphorus, and hydrology. To reflect differences between wetland types and the spatial differences in ecological drivers across Florida, the review considered differences by wetland vegetation (e.g., forested, emergent), wetland hydrogeomorphology (e.g., depressional, basin), and wetland region (e.g., panhandle, north, central, south). A secondary objective of this scope was the development of a stormwater loading model that can be used to predict the nutrient load in runoff from isolated wetlands.

Data Search

Several sources of literature were consulted including the published, peer-reviewed literature; gray literature from academic and institutional literature, consulting reports, and city, county, state, and federal agencies; and unpublished data sets.

Published, Peer-Reviewed Literature

A comprehensive search of the UF library system was conducted using relevant key word searches: ammonia, basin, cypress, depressional, emergent, Florida, forested, hydrology, hydroperiod, isolated, nitrate, nitrite, nitrogen, nutrients, phosphate, phosphorus, and/or wetland. The search included nine ecological databases: Academic Search Premier, AGRICOLA (CSA), Biological and Agricultural Index Plus, BIOSIS Previews, CAB Abstracts, Ecology Abstracts, OmniFile Full Text Mega, Science Citation Index, and Wildlife & Ecology Studies Worldwide.

Academic Search Premier, as the largest academic multi-disciplinary database, includes nearly 4,700 publications, with more than 3,600 from peer-reviewed journals. AGRICOLA (CSA) is a bibliographic database including listings for journal articles, monographs, proceedings, theses, patents, translations, audiovisual materials, computer software, and technical reports pertaining to all aspects of agriculture. Biological and Agricultural Index Plus includes resources in biology and agriculture, with some content from peer-reviewed journals. BIOSIS Previews provides the largest collection of biological sciences records world-wide from over 6000 book chapters, book reviews, journals, meetings, review articles, software, and U.S. patents. CAB Abstracts presents international research and development materials in the fields of agriculture, animal health, forestry, human health, human nutrition, and management and conservation of natural resources. Ecology Abstracts provides a search in current ecology research. Wilson OmniFile Full Text, Mega Edition provides resources from six of Wilson's full-text databases as a single multi-disciplinary database. Science Citation Index Expanded provides a search in 5,900 major journals across 150 scientific disciplines and includes all cited references captured from indexed articles. Wildlife & Ecology Studies Worldwide includes over 650,000 bibliographic records and is the largest index for materials on wild mammals, birds, reptiles, and amphibians.

Gray Literature

A search for gray literature data sources included the University of Florida's Howard T. Odum Center for Wetlands library, which includes student theses and dissertations, internal project reports, and reports from agencies including the Florida Department of Environmental Protection, National Park Service, Water Management Districts (i.e., South Florida Water Management District, Southwest Florida Water Management District, and St. Johns River Water Management District), and some additional agency or consulting firm reports for individual projects. As a part of the search process, agency websites were searched for appropriate reports and materials (e.g., Sarasota County Water Atlas http://www.sarasota.wateratlas.usf.edu/Default.aspx, South Florida Water Management District http://www.sfwmd.gov/), Southwest Florida Water Management District http://www.swfwmd.state.fl.us/, St. Johns River Water Management District http://sjr.state.fl.us/publications.html, United States Geological Survey http://www.usgs.gov/pubprod/).

Unpublished Data

Many different avenues were explored for gathering unpublished wetland data including face-to-face meetings, phone calls, and email communication. The following individuals provided data, either as unpublished data sets or as published reports or journal articles: Mark Clark, University of Florida Department of Soil and Water Science, USEPA coastal plain database and Kissimmee soil phosphorus data; Katherine Ewel, University of Florida, unpublished reports; Boyd Gunsalus, South Florida Water Management District (SFWMD), repeat water measures for wetlands in south Florida; Joe Hand, Florida Department of Environmental Protection (FDEP), water quality data for eight wetlands; Steve Kintner, Director of Volusia County Environmental Management Division, provided USGS study, Knowles (2005); Ray Miller, Don Medellen, and Mike Lopushinsky, SFWMD, Jonathan Dickenson State Park hydrology data; Kim O'Dell, Orlando Diaz, and Benita Whelan, SFWMD, Okeechobee (research report); Todd Osbourne, University of Florida, Okeechobee basin, pasture study; Ted Rochow, SWFWMD (Green Swamp hydrology); Brian Gentry, Palm Beach County.

The following individuals, agencies, or organizations were contacted but did not have applicable data for this review: Patrick Bohlen, Buck Island Ranch; Tom DeBusk, consultant with DB Environmental; Mike Duever, SFWMD; Bob Epting, Sonny Hall, and Marc Minno, SJRWMD; Larry Kohrnack, University of Florida; Mike Owen, Fakahatchee Strand State Preserve; Pete Wallace; Karen Bickford, TMDL Director, Lee County Natural Resources; Julie Bortles, Environmental Program Supervisor, Orange County Environmental Protection Division; Aisa Ceric, Palmer Kinser, Vicki Toge, SJRWMD; Charlie Hunsicker, Director, Manatee County Natural Resources Department; Bob Knight, Wetland Solutions, Inc.; Robert Kollinger, Polk County Natural Resources and Drainage; Gordon A. Leslie, Hillsborough County, Environmental Protection Commission; Gary Maidhof, Citrus County; Randy Mathews, Coordinator, Osceola County Environmental Lands Conservation Program; Brian McMahon, EWR, Inc.; Caprecid Oliver, St. Lucie County Environmental Resources Department; John Ryan, Environmental Supervisor, Sarasota County Water Resources; Kirk Stage, Water and Air Resources, Inc.; St. Marks and St. Vincent National Wildlife Refuge; Walter Wood, Lake

County Environmental Utilities. Additional sources that led to duplicate data or data not relevant to this review included HGM Depressional Guidebook reference sites by the US Army Corps of Engineers; Disney Wilderness Preserve; Minimum Flows and Levels work; TMDL work; Tampa Bay Water well fields; and Withlacoochee State Forest.

Nutrient and Hydrology Database

As this is a review of available data and not a project with systematic data collection, entry points took variable formats. The Florida Isolated Wetland Nutrient Database (FIWND) developed in Microsoft Access was designed so that each row represented a data entry point. This may include data from an individual wetland from a single sampling event or the mean, standard deviation, standard error, or range for a given wetland or group of wetlands. Each row was assigned a unique, non-repeating, automatically assigned Contact ID number in the first column. In total there were 138 columns in the data base, though no data entry point (row) had data for every column. In addition to the unique Contact ID column there were 20 study description columns, 4 data source or citation columns, 49 water quality columns, 24 water or nutrient budget columns, and 40 soil quality columns.

Study description columns included: Wetland Name, One or More (e.g., ranges, mean, single wetland), Reference Wetland, Wetland Vegetation, Wetland Type, Sample Size, Area, Nearby City/Town, State, Region, County, Water Management District, Surrounding Land Use, Land Use Detail, Study Time Frame, Sample Frequency, Characteristic Hydrology, Hydroperiod, Hydrologic Alteration, and Characteristic Vegetation.

Columns specific to the data source and citation included: Data Source (e.g., author, year), Data Certainty, Applicability, and Other Comments.

Water quality columns included: Color, Dissolved Oxygen, pH, Temperature, Conductivity, Turbidity, Nitrate-Nitrogen (NO_3), Nitrite-Nitrogen (NO_2), Ammonia-Nitrogen (NH_3), Organic Nitrogen, Total Kjeldahl Nitrogen (TKN), Total Nitrogen (TN), Ortho-P, Soluble Reactive Phosphorus, Organic Phosphorus, Total Dissolved Phosphorus, Total Phosphorus (TP), Oxidation Reduction Potential, Secchi Depth, BOD, Suspended Solids, Dissolved Solids, Chloride, Flouride, Sulfate, Hydrogen Sulfide, Alkalinity, Hardness, Magnesium, Calcium, Potassium, Sodium, Iron, Manganese, Chlorophyll a, Silicon, Inorganic Carbon, Organic Carbon, Bicarbonate, Caffeine, Fecal Coliform, Total Coliform, *Enterococci*, Oil and Grease, Copper, Zinc, Cadmium, Lead, and Mercury.

Columns specific to water and/or nutrient budgets included: Rainfall, Transpiration, Evaporation, Total Water Loss, Inflow TN, Surface Runoff TN, Bulk Precipitation TN, Nitrogen Fixation, Infiltration TN, Denitrification, Surface Outflow TN, Sediment Deposition TN, Cypress Uptake TN, Above Ground Biomass TN, Below Ground Storage TN, Inflow TP, Surface Runoff TP, Bulk Precipitation TP, Infiltration TP, Surface Overflow TP, Sediment Deposition TP, Cypress Uptake TP, Above Ground Biomass TP, and Below Ground Storage TP.

Soil physical and chemical columns included: Core Depth, Temperature, pH, Redox Potential, %Moisture, Bulk Density, Organic Matter, %Organic Matter, %Loss on Ignition, Soluble

Reactive Phosphorus, Total Phosphorus (TP), Nitrate-Nitrogen (NO_3), Nitrite-Nitrogen (NO_2), Ammonia-Nitrogen (NH_3), Total Kjeldahl Nitrogen (TKN), Total Nitrogen (TN), Total Carbon, Carbon/Nitrogen Ratio, Nitrogen/Phosphorus Ratio, Carbon/Phosphorus Ratio, Microbial Biomass Carbon, Microbial Biomass Nitrogen, Nitrogen Mineralization Rate, Annual Nitrogen Mineralization, Denitrification Rate, Annual Denitrification, Calcium, Magnesium, Potassium, Calcium/Potassium Ratio, Calcium/Magnesium Ratio, Milliequivalent of Cations, Iron, Aluminum, Sodium, Hydrogen, Cation Exchange Capacity, Cadmium, Copper, Manganese, Lead, and Zinc.

Nutrient Data Summary and Synthesis

Due to the inherently variable nature of review data, advanced statistical analyses were inappropriate. Summary tables were constructed to specifically address ranges in nutrient concentration in the water column and soils of reference and impact, forested and emergent, depressional and basin wetlands. A graphical presentation of water column NO_3, NH_3, TKN, and TP and soil TN and TP was developed using box plots in Minitab v.15 (©2007 Minitab, Inc.). Wetland categories having three or fewer data entries were omitted from graphical representations.

Wetland Hydrology Summary and Synthesis

In an attempt to summarize available data on frequency and depth of flooding, figures showing temporal water level variations for Florida wetlands were compiled. Hydrographs were interpreted to provide a general overview of minimum and maximum flooding depth, an estimation of flooding duration, and an overview of months with standing water.

Methodology for Estimating Nutrient Loading from Wetlands

To fulfill the second objective of this project, we developed a method to predict nutrient loading, specifically nitrogen and phosphorus, to downstream systems in runoff from isolated wetlands. The method assumes that nutrient loading is from wetland surface runoff and that no contributions from groundwater seepage from the wetland to receiving water bodies are considered. Further, the method differentiates between two seasons, a wet season (growing season, June - October) and dry season (dormant season; November - May) and the corresponding antecedent soil moisture conditions. The method is based on a Soil Conservation Service (SCS) curve number (CN) (USDA 1985) and accounts for differences in background concentrations of water column phosphorus and nitrogen in two broad hydrogeomorphic classes (depressional and basin wetlands) and two vegetation types (forested and emergent). Wetland types not included in this project are those with direct permanent hydrologic exchanges with downstream water bodies (e.g. lake border swamps, riparian and floodplain wetlands). The assumption is that these latter types of wetlands are intimately connected to the receiving water bodies, and therefore their water quality is the same as the neighboring water body.

RESULTS

A complete list of the published peer-reviewed and gray literature references used to build the Florida Isolated Wetland Nutrient Database (FIWND) and compilation of hydrographs is presented in Appendix A. Dates of sample collection for entries in the database for nutrient concentrations range from 1973-2008.

Non-Impacted Wetlands

The FIWND database contained 372 entries for non-impacted wetlands in Florida. These entries break down into the following categories for isolated wetlands: 1) 142 depressional forested wetlands (~38%); 2) 3 basin forested wetlands (<1%); 3) 75 depressional emergent wetlands (~20%); 4) 20 basin emergent wetlands (~5%); and 5) 32 entries for non-impacted wetlands in which there was no identifying vegetation and/or geomorphic description available (~9%). The database also contains 3 entries for non-impacted strand wetlands (<1%) and 97 entries for non-impacted floodplain wetlands (~26%). An additional 304 entries are for non-impacted wetlands in southeastern states outside of Florida and 15 entries are for non-impacted wetlands in the state of Indiana. Because historical data on non-impacted wetlands generally are in short supply, non-isolated wetlands in Florida and isolated wetlands outside of Florida were included in the database as a matter of course when located during the literature review process, though the search for these additional wetland types was in no way exhaustive.

There was location information at the level of Florida regions (i.e. panhandle, north, central, and south) for 186 isolated non-impacted wetlands in the database. Of these, 25 (~13%) were in the panhandle, 64 were in north Florida (~34%), 41 were in central Florida (~22%), and 56 were in south Florida (~30%). Some additional entries were originally categorized at the coarser scale of USEPA regions and do not contain sufficient auxiliary information for categorization by Florida region.

Depressional Forested Wetlands

A relatively large number of data points were found for the parameters of water column NO_3, NH_3, TKN, and TP concentrations in non-impacted depressional forested wetlands (Tables 2 & 3). With the exception of TN, which only has two entries, all dissolved nitrogen parameters showed a lower bound that approached the common analytical detection limit (~0.002 mg N/L) (Figures 2 & 3). The range for TKN showed a relatively normal distribution up to an upper range of 5.6 mg N/L, while the upper values for both NO_3 (1.9 mg N/L) and NH_3 (1.7 mg N/L) were far outliers associated with one datum entry (Figure 2). Most values for TP were below 0.05 mg/L, although there were several outliers up to an upper value of 0.64 mg P/L (Figure 3). Direct interaction with highly phosphatic clays of the Hawthorne layer likely explained the very high phosphorus values found in some non-impacted forested depressional wetlands.

Soil nutrient ranges in reference forested depressional wetlands were shown in Tables 4 & 5 and graphically presented in Figure 4. Soil nitrogen concentrations ranged from 1.68 mg N/g to 14.45 mg N/g as measured by TKN and 2.2 mg N/g to 17.7 mg N/g of TN. Soil phosphorus concentrations showed greater variability, which also was almost certainly a function of some wetland soils having direct interaction with phosphate rich Hawthorne clays. The range of SRP (0.0022 mg P/g – 4.296 mg P/g) spanned across three orders of magnitude and TP values spanned approximately two orders of magnitude (0.02 mg P/g – 1.51 mg P/g).

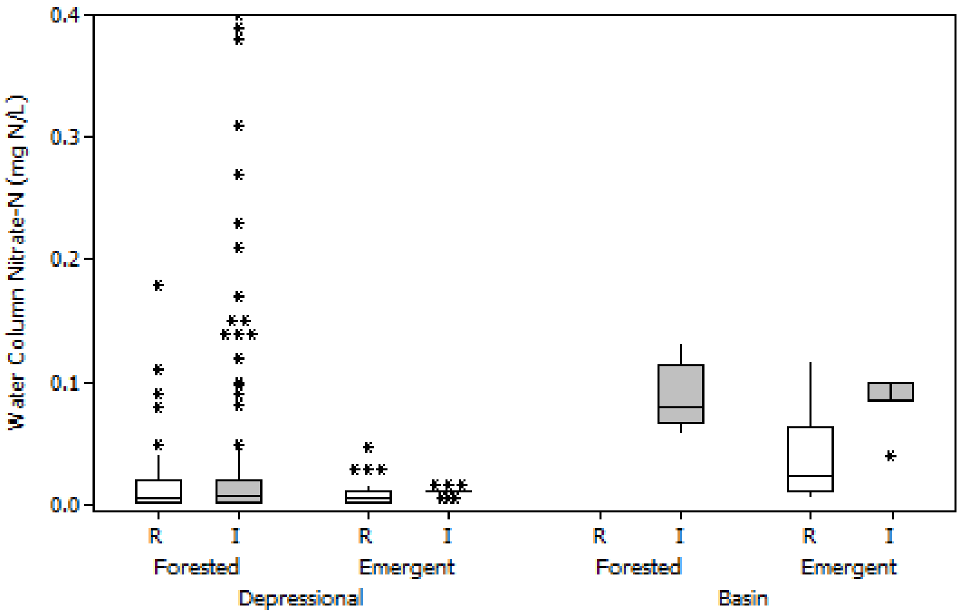
Table 2. Ranges of water column dissolved nitrogen parameters

	NO_3-N (mg N/L)	NH_3-N (mg N/L)	TKN (mg N/L)	TN (mg N/L)
Non-Impacted Wetlands				
Depressional forested	0.002 – 1.9 (79 entries)	0.002 – 1.7 (66 entries)	0.002 – 5.6 (82 entries)	1.6 – 1.67 (2 entries)
Basin forested	0.004 – 0.09 (3 entries)	0.01 – 0.095 (3 entries)	0.62 – 0.98 (3 entries)	0.94 (1 entry)
Depressional emergent	0.002 – 0.047 (49 entries)	0.005 – 2.6 (29 entries)	0.41 – 6.0 (49 entries)	N.A. (0 entries)
Basin emergent	0.007 – 0.117 (9 entries)	0.06 – 1.2 (9 entries)	0.92 – 1.77 (4 entries)	N.A. (0 entries)
Impact Wetlands				
Depressional forested	0.002 – 0.63 (124 entries)	0.002 – 12.6 (125 entries)	0.45 – 31.0 (126 entries)	1.2 – 17.1 (9 entries)
Basin forested	0.06 – 0.13 (6 entries)	0.01 – 0.03 (6 entries)	0.62 – 1.3 (7 entries)	0.1 – 1.33 (7 entries)
Depressional emergent	0.004 – 0.016 (17 entries)	0.136 (1 entry)	1.45 – 14.36 (16 entries)	N.A. (0 entries)
Basin emergent	0.04 – 0.1 (6 entries)	0.02 – 0.51 (6 entries)	0.57 – 3.9 (6 entries)	0.57 – 1.50 (5 entries)

Table 3. Ranges of water column phosphorus parameters

	Ortho-P (mg P/L)	SRP (mg P/L)	Organic P (mg P/L)	TP (mg P/L)
Non-Impacted Wetlands				
Depressional forested	0.0008 – 0.48 (7 entries)	Non-detect (1 entry)	0.02 – 0.12 (2 entries)	0.002 – 0.64 (82 entries)
Basin forested	0.003 – 0.006 (2 entries)	N.A. (0 entries)	0.01 (1 entry)	0.009 – 0.01 (3 entries)
Depressional emergent	N.A. (0 entries)	N.A. (0 entries)	N.A. (0 entries)	0.0069 – 0.12 (49 entries)
Basin emergent	0.002 – 0.035 (8 entries)	N.A. (0 entries)	N.A. (0 entries)	0.007 – 0.08 (5 entries)
Impact Wetlands				
Depressional forested	0.05 – 10.46 (19 entries)	0.03 – 0.05 (2 entries)	0.18 – 2.10 (7 entries)	0.0049 – 17.0 (150 entries)
Basin forested	N.A. (0 entries)	N.A. (0 entries)	0.003 – 0.01 (6 entries)	0.01 – 0.05 (7 entries)
Depressional emergent	N.A. (0 entries)	0.016 – 1.96 (3 entries)	N.A. (0 entries)	0.0035 – 7.98 (117 entries)
Basin emergent	0.25 (5 entries)	0.09 (1 entry)	N.A. (0 entries)	0.029 – 0.57 (7 entries)

(a)



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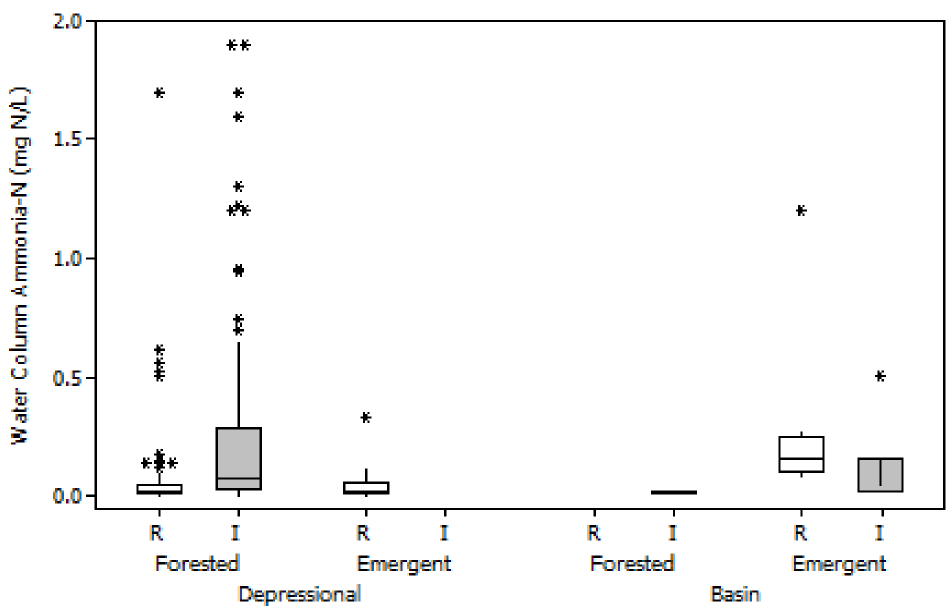
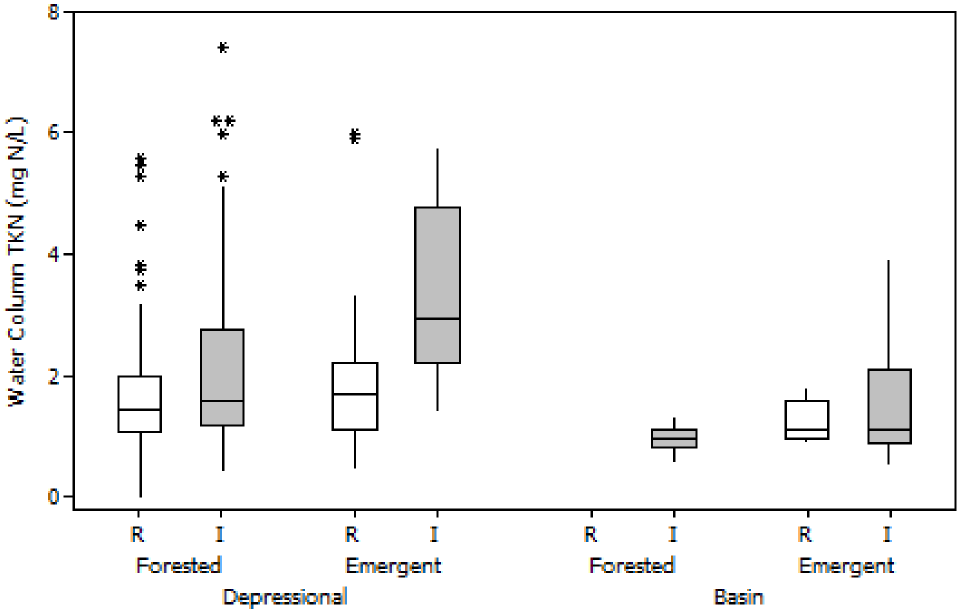


Figure 2. Water column nutrient concentrations: a) nitrate-nitrogen (NO_3-N) and b) ammonia-nitrogen (NH_3-N) for R (non-impacted or reference, no fill) or I (impacted, gray fill); forested and emergent; depressional and basin wetlands. Boxes represent the first through third quartiles; horizontal interior line represents the median; vertical whiskers represent data range; asterisks represent outliers. Extreme outliers are not shown due to scaling constraints.

(a)



(b)

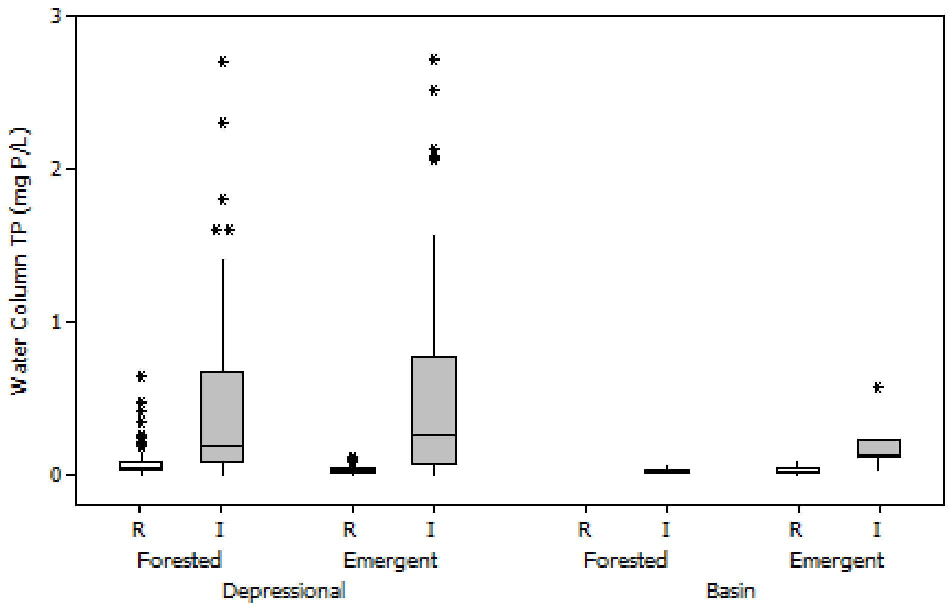


Figure 3. Water column nutrient concentrations: a) Total Kjeldahl Nitrogen (TKN), and b) total phosphorus (TP) for R (non-impacted or reference, no fill) or I (impacted, gray fill); forested and emergent; depressional and basin wetlands. Boxes represent the first through third quartiles; horizontal interior line represents the median; vertical whiskers represent data range; asterisks represent outliers. Extreme outliers are not shown due to scaling constraints.

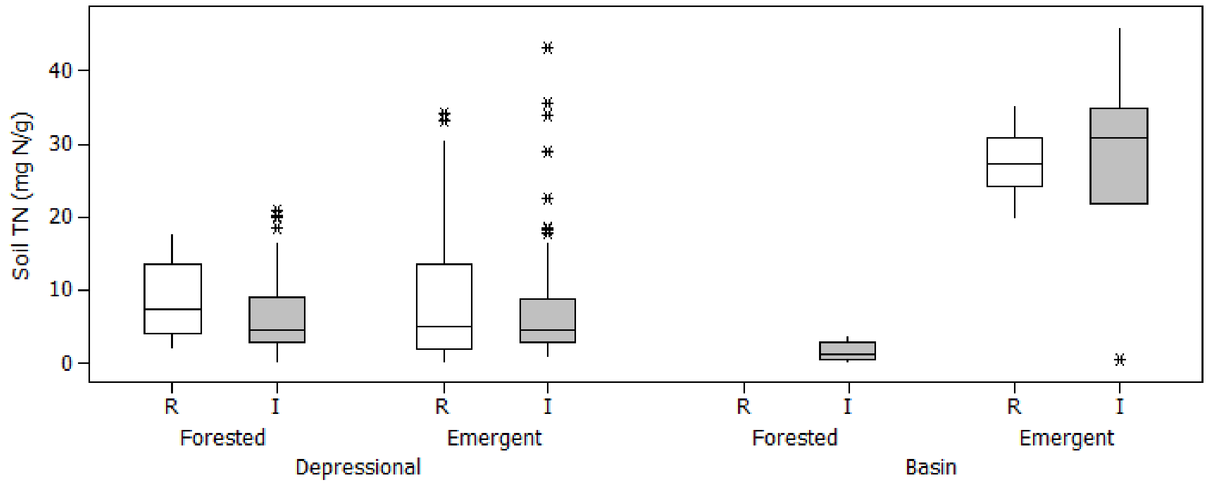
Table 4. Ranges for soil nitrogen parameters

	NO_3-N (mg N/g soil)	NH_3-N (mg N/g soil)	TKN (mg N/g soil)	TN (mg N/g soil)
Non-Impacted Wetlands				
Depressional forested	N.A. (0 entries)	N.A. (0 entries)	1.68 – 14.45 (37 entries)	2.2 – 17.7 (25 entries)
Basin forested	N.A. (0 entries)	N.A. (0 entries)	N.A. (0 entries)	N.A. (0 entries)
Depressional emergent	N.A. (0 entries)	N.A. (0 entries)	N.A. (0 entries)	0.002 – 34.2 (44 entries)
Basin emergent	0.00026 – 0.190 (4 entries)	0.0253 – 0.15 (12 entries)	N.A. (0 entries)	20 – 35.1 (12 entries)
Impact Wetlands				
Depressional forested	N.A. (0 entries)	N.A. (0 entries)	0.51 – 16.63 (83 entries)	1.2 – 21.0 (50 entries)
Basin forested	N.A. (0 entries)	N.A. (0 entries)	N.A. (0 entries)	0.36 – 3.54 (8 entries)
Depressional emergent	N.A. (0 entries)	N.A. (0 entries)	N.A. (0 entries)	1.1 – 43.3 (49 entries)
Basin emergent	N.A. (0 entries)	0.0963 (1 entry)	N.A. (0 entries)	0.619 – 46 (12 entries)

Table 5. Ranges for soil phosphorus parameters

	SRP (mg P/g soil)	Total P (mg P/g soil)
Non-Impacted Wetlands		
Depressional forested	0.0022 – 4.296 (29 entries)	0.02 – 1.51 (67 entries)
Basin forested	N.A. (0 entries)	N.A. (0 entries)
Depressional emergent	0.00072 – 0.033 (14 entries)	0.00468 – 1.01 (50 entries)
Basin emergent	0.00045 – 0.023 (12 entries)	0.048 – 0.270 (12 entries)
Impact Wetlands		
Depressional forested	0.00137 – 1.497 (18 entries)	0.0439 – 7.53 (163 entries)
Basin forested	N.A. (0 entries)	0.01463 – 0.225 (8 entries)
Depressional emergent	0.1217 – 3.54 (18 entries)	0.00187 – 4.32 (423 entries)
Basin emergent	0.0001 – 0.0235 (28 entries)	0.046 – 2.67 (43 entries)

(a)



(b)

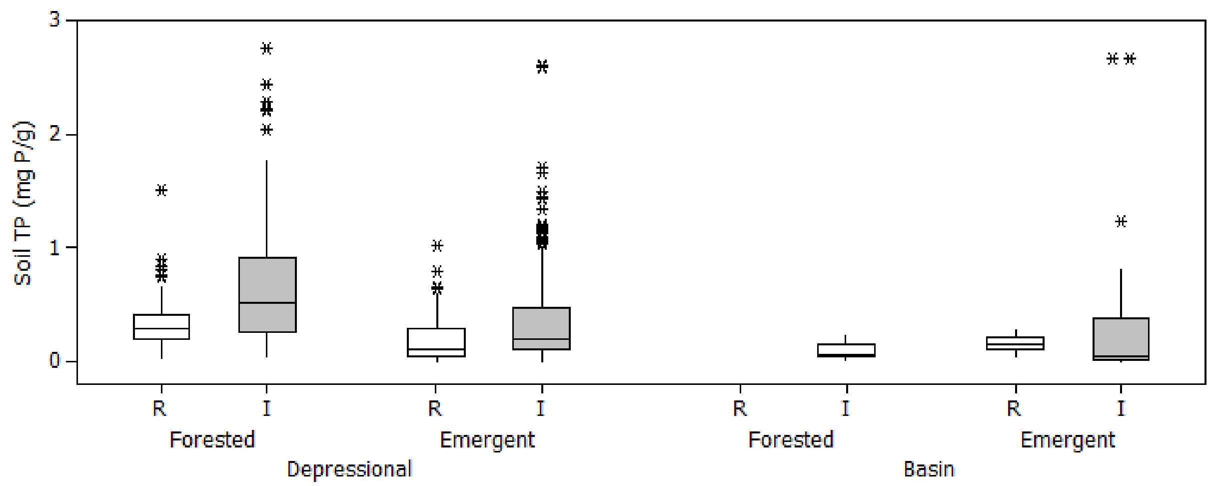


Figure 4. Soil nutrient concentrations: a) total nitrogen (TN) and b) total phosphorus (TP) for R (non-impacted or reference, no fill) or I (impact, gray fill); forested and emergent; depressional and basin wetlands. Boxes represent the first through third quartiles; horizontal interior line represents the median; vertical whickers represent data range; asterisks represent outliers. Extreme outliers are not shown due to scaling constraints.

Basin Forested Wetlands

Limited water quality data were located for non-impacted basin forested wetlands. Nitrate values ranged from 0.004 mg N/L to 0.09 mg N/L, ammonia ranged from 0.01 mg N/L to 0.095 mg N/L, and TKN ranged from 0.62 mg N/L to 0.98 mg N/L in three entries (Table 2). Ortho-P ranged from 0.003 – 0.006 mg P/L in two samples, and TP ranged from 0.009 – 0.01 mg P/L in three entries (Table 3). No soil N or P data were located for non-impacted basin forested wetlands (Tables 4 & 5; Figure 4).

Depressional Emergent Wetlands

A fair number of data points were found for the parameters of water column NO_3-N, NH_3-N, TKN (Table 2), and TP (Table 3) concentrations in non-impacted depressional emergent wetlands. NO_3-N values ranged from a lower bound near the common detection limit (0.002 mg N/L) to an upper bound of 0.047 mg N/L; NH_3-N data values showed a considerably wider range from a low of 0.005 mg N/L to an outlier value of 2.6 mg N/L (Table 2; Figure 2). TKN varied across an order of magnitude, from a low of 0.41 mg N/L to a high of 6.0 mg N/L in non-impacted depressional emergent wetlands (Table 2; Figure 3). Water column TP varied across two orders of magnitude, from a low of 0.0069 mg P/L to a high of 0.12 mg P/L (Table 3; Figure 3).

Soil nitrogen values in non-impacted depressional emergent wetlands showed considerable variation, with TN having an extreme lower end of 0.002 mg N/g and a high value of 34.2 mg N/g (Table 4; Figure 4). Soil phosphorus also varied considerably, with a low TP value of 0.00468 mg P/g to a high of 1.01 mg P/g (Table 5; Figure 4). While variability in both water column and soil phosphorus was likely a function of some wetlands having interaction with phosphate-rich Hawthorne clays, the source of variability in nitrogen among non-impacted depressional emergent wetlands was somewhat less clear.

Basin Emergent Wetlands

Few data points for water column nitrogen and phosphorus were found for non-impacted basin emergent wetlands (Tables 2 & 3). Ranges for both NO_3-N (0.007 – 0.117 mg N/L) and NH_3-N (0.06 -1.2 mg N/L) spanned across one and a half orders of magnitude in nine data entries, while TKN showed a much narrower range (0.92 mg N/L – 1.77 mg N/L) in four data entries (Table 2; Figures 2 & 3). Ranges for Ortho-P (0.002 mg P/L – 0.035 mg P/L) and TP (0.007 mg P/L – 0.08 mg P/L) both spanned across approximately one order of magnitude among eight data entries (Table 3; Figure 3).

Soil NO_3-N values showed a high level of variation in four entries, from a low of 0.00026 mg N/g to 0.190 mg N/g (Table 4). Soil NH_3-N ranged across an order of magnitude from 0.0253 mg N/g to 0.15 mg N/g in 12 entries, while soil TN showed a narrow range from 20 mg N/g to 35.1 g N/g for the same 12 entries (Table 4; Figure 4). Soil SRP ranged from 0.00045 mg P/g to 0.023 mg P/g, while soil TP ranged from 0.048 mg P/g to 0.270 mg P/g (Table 5; Figure 4).

Impacted Wetlands

The FIWND database contained 918 entries for wetlands in Florida that have some degree of impact by human land use disturbance. These entries break down into the following categories for isolated wetlands: 1) 291 depressional forested wetlands (~32%); 2) 7 forested basin wetlands (<1%); 3) 455 depressional emergent wetlands (~49%); 4) 48 basin emergent wetlands (~5%); and 5) 35 entries in which there was no identifying vegetation and/or geomorphic description available (~4%). The database also contained 34 entries for impacted strand wetlands (~4%) and 48 entries for impacted floodplain wetlands (~5%). An additional 229 entries are for impacted isolated wetlands in southeastern states outside of Florida and 60 entries are for impacted wetlands in the state of Indiana.

There was location information at the level of Florida regions for 701 isolated wetlands with human impact in the database. Of these, 44 (~6%) were in the panhandle, 64 were in north Florida (~14%), 562 were in central Florida (~76%), and 31 were in south Florida (~4%). Remaining entries were originally categorized at the coarser scale of USEPA regions and do not contain sufficient auxiliary information for categorization by Florida region.

Depressional Forested Wetlands

A relatively large number of data points were found for the parameters of water column NO_3-N, NH_3-N, TKN, and TP concentrations in impacted depressional forested wetlands (Tables 2 & 3). Similar to non-impacted systems, dissolved nitrogen and NH_3-N parameters showed a lower bound in impacted depressional forested wetlands at the common analytical detection limit of 0.002 mg N/L. In contrast to non-impacted systems, the lower TKN bound of 0.45 mg N/L was much higher than the common analytical detection limit, and the box plot in Figure 3 shows the somewhat higher 75th percentile range for TKN in impacted forested depressional wetlands. Interestingly, the highest value for NO_3-N (0.63 mg N/L) in impacted depressional forested wetlands is considerably lower than the high outlier value of 1.9 mg N/L found in the non-impacted depressional forested wetland data, and the 75th percentile (third quartile) ranges for NO_3-N in non-impacted and impacted systems were relatively similar (Figure 2). In contrast, the upper bound of 12.6 mg N/L for NH_3-N found in impacted depressional forested wetland systems was considerably higher than the 1.7 mg N/L shown in non-impacted depressional forested wetland systems (Figure 2), as is the upper bound of 31.0 mg N/L for TKN (5.6 mg N/L in non-impacted) (Figure 3). These upper NH_3-N and TKN nitrogen values represented severe nitrogen contamination in these isolated wetlands, and the extent of such contamination throughout the database was apparent in the 75th percentile ranges (Figure 2).

The lower TP bound of 0.0049 mg P/L in impacted systems was somewhat higher than the lower TP bound of 0.002 mg P/L found in non-impacted systems. Extremely high ortho-P values of 10.46 mg P/L and TP values of 17.0 mg P/L (Table 5) likely represented severe phosphorus contamination of wetlands associated with agricultural operations. The much higher 75th percentile (third quartile) range of TP in impacted depressional forested wetlands was clear (Figure 3).

Tables 4 & 5 shows soil nutrient ranges in impacted forested depressional wetlands. Soil nitrogen concentrations ranged from 0.51 mg N/g to 16.63 mg N/g as measured by TKN and 1.2 mg N/g to 21.0 mg N/g of TN, neither of which differ dramatically from the ranges found in non-impacted systems (Table 4; Figure 4). Like with non-impacted wetland systems, impacted wetland systems soil phosphorus concentrations showed greater variability. The range of soil SRP (0.00137 mg P/g – 1.497 mg P/g) spanned across three orders of magnitude, although, interestingly, the high soil SRP value was considerably lower than the high value of 4.296 mg P/g found in non-impacted systems (Table 5). TP values spanned well over two orders of magnitude (0.0439 mg P/g – 7.53 mg P/g), with the high value several times larger than the highest value (1.51 mg P/g) found in non-impacted systems. While soil phosphorus levels in impacted forested depressional systems also may have considerable natural variation due to interaction with phosphatic clays, the much higher 75th percentile (third quartile) range for soil TP in impacted systems is suggestive of anthropogenic enrichment.

Basin Forested Wetlands

Limited amounts of water quality data were identified for impacted basin forested wetlands. Nitrate values ranged from 0.06 mg N/L to 0.13 mg N/L and ammonia ranged from 0.01 mg N/L to 0.03 mg N/L for six entries. TKN ranged from 0.62 mg N/L to 1.3 mg N/L across seven entries (Table 2). Organic P ranged from 0.003 – 0.01 mg P/L in six entries, and TP ranged from 0.01 – 0.05 mg P/L in seven entries (Table 3).

Limited amounts of soil TN and TP data were collected for impacted basin forested wetlands (Tables 4 & 5). TN values ranged from 0.36 mg N/g to 3.54 mg N/g, while TP ranged from 0.01463 mg P/g to 0.225 mg P/g. Due to the limited amount of water quality and soil nutrient data for non-impacted and impacted basin forested wetlands it is premature to make detailed comparisons of the findings at this time.

Depressional Emergent Wetlands

Database entries for impacted depressional emergent wetlands showed a clear phosphorus bias. While there were large numbers of data points for water column TP (117 entries; Table 3) and soil TP (423 entries; Table 5), there were a little less than 20 entries for both water nitrate and water TKN (Table 2) and a little under 50 entries for soil TN (Table 4).

Nitrate values ranged from a lower bound of 0.004 mg N/L to an upper bound of 0.016 mg N/L. Interestingly, the higher bound for nitrate at impacted sites was somewhat lower than the 0.047 mg N/L found at non-impacted sites, although the small number of data points makes this result difficult to interpret. TKN varied across an order of magnitude in impacted depressional emergent wetlands, from a low of 1.45 mg N/L to 14.36 mg N/L. This range was considerably higher than the TKN range of 0.41 mg N/L to 6.0 mg N/L found in non-impacted systems, and the higher values showed up clearly in the 75th percentile (third quartile) range (Figure 2). TP varied across three and a half orders of magnitude in impacted depressional emergent wetlands, from a low of 0.046 mg P/L to a high of 7.98 mg P/L. The much higher 75th percentile (third quartile) range for impacted sites showed up clearly in the box plot in Figure 3. The high end of this range almost certainly was a function of extreme anthropogenic enrichment.

Soil nitrogen values in non-impacted depressional emergent wetlands showed quite a bit of variation, with TN having an extreme lower end of 1.1 mg N/g and a high value of 43.3 mg N/g. However, the high end of the TN range was not markedly higher than the high value of 34.2 mg N/g found in reference systems, and box plots were not dramatically different for soil TN in non-impacted and impacted sites (Figure 4). Soil phosphorus also varied considerably, with SRP ranging from 0.00137 mg P/g to 1.497 mg P/g and TP ranging from a low value of 0.00187 mg P/g to a high of 4.32 mg P/g. While some natural variability through Hawthorne interaction was certainly possible, the high ends of soil P values were most likely a function of anthropogenic enrichment from land use in the watershed. The 75th percentile (third quartile) box plot range for soil TP was marginally higher in impacted sites (Figure 4).

Basin Emergent Wetlands

Limited water column nitrogen and phosphorus data were located for impacted basin emergent wetlands (Tables 2 & 3). Ranges were 0.04 mg N/L to 0.1 mg N/L for NO_3-N, 0.02 mg N/L to 0.51 mg N/L for NH_3-N, 0.57 mg N/L to 3.9 mg N/L for TKN, and 0.57 mg N/L to 1.5 mg N/L for TN. The range for TP in impacted basin emergent wetlands was 0.029 mg P/L to 0.57 mg P/L. Interpretation of box plot ranges was somewhat tenuous, however, due to the small number of data points (Figures 2 & 3).

Soil TN in impacted basin emergent wetlands ranged greatly from an outlier low of 0.619 mg N/g to 46 g N/g across 12 entries (Table 4). Twelve entries for soil SRP showed a range from 0.1217 mg P/g to 3.54 mg P/g. Soil TP showed a considerable range of values from 0.00187 mg P/g to 2.67 mg P/g (Table 5). Much of soil P sampling in impacted basin emergent wetlands was performed for the express purpose of better understanding P transport in enriched areas, and thus it is fairly safe to conclude that the high end of the P soil ranges in these systems was a direct function of anthropogenic activities (Figure 4).

Non-Impacted Wetlands Quartiles and Nutrient Concentrations

Partitioning the non-impacted wetlands data into quartiles allowed a better focus on the reference standard condition in the Florida landscape (Figure 5). The Florida Department of Environmental Protection (FDEP) has used such an approach when determining thresholds for metric scoring for bioassessment work on lakes and streams (e.g. Barbour et al. 1996) as have other states (e.g. Royer et al. 2001). In some instances, values below the 75th percentile (3rd quartile) have been considered representative of the reference standard condition (for values that increase with human disturbances or impacts). Actual quartile values were presented in Table 6.

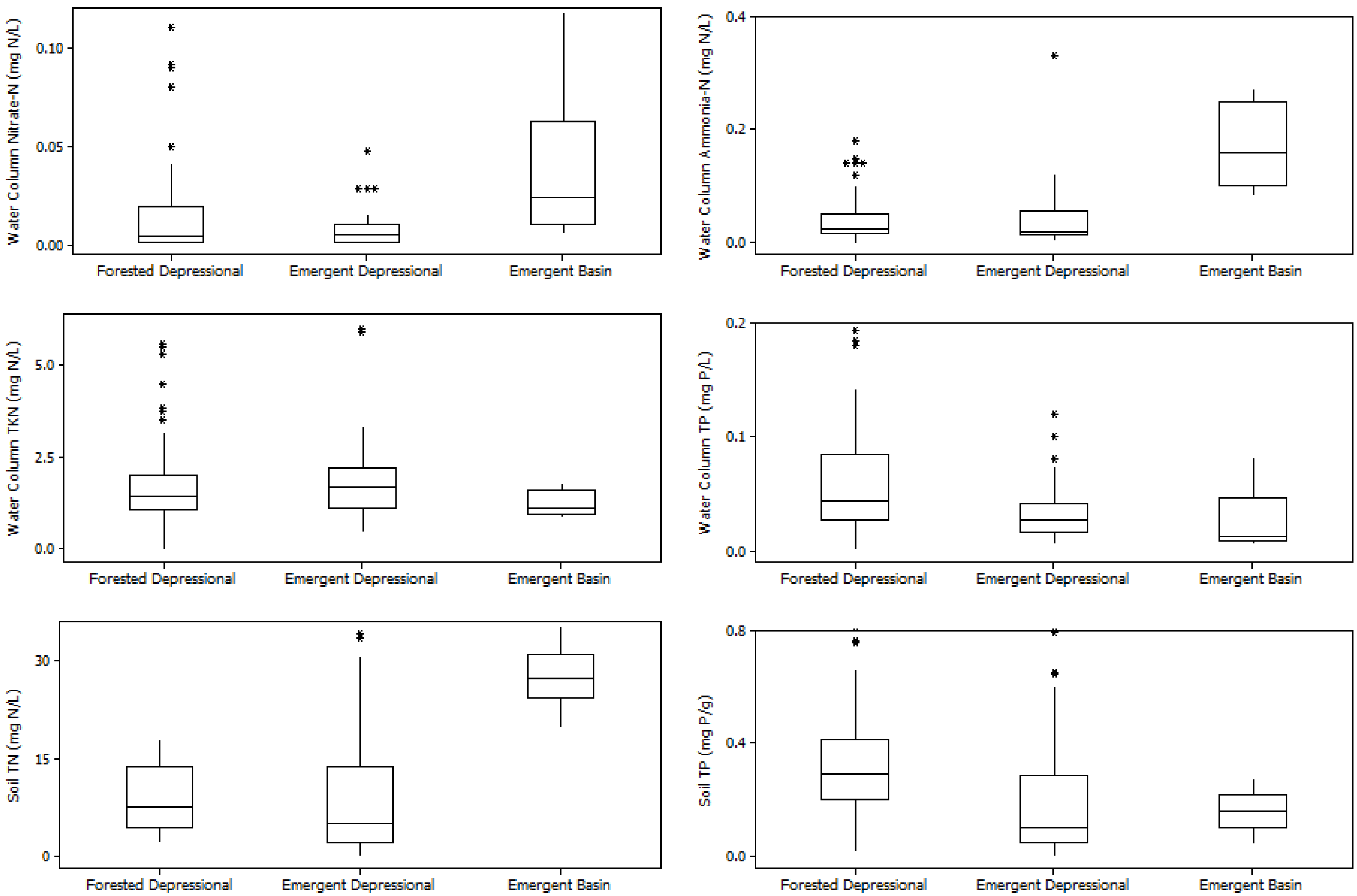


Figure 5. Non-impacted wetland nutrient concentrations: a) water column nitrate-N, b) water column ammonia-N, c) water column TKN, d) water column TP, e) soil TN, and f) soil TP for forested depressional, emergent depressional, and emergent basin wetlands. Boxes represent the first through third quartiles; horizontal interior line represents median; vertical whickers represent data range; asterisks represent outliers. Extreme outliers were not shown.

Table 6. Non-impacted wetland water column and soil nutrient data

	Forested Depressional	Emergent Depressional	Emergent Basin
Water Column			
Nitrate-N (mg N/L)			
25th Percentile	0.002	0.002	0.011
Median	0.005	0.006	0.024
75th Percentile	0.020	0.010	0.038
Ammonia-N (mg N/L)			
25th Percentile	0.018	0.016	0.111
Median	0.024	0.020	0.160
75th Percentile	0.050	0.033	0.230
TKN (mg N/L)			
25th Percentile	1.085	1.123	0.960
Median	1.450	1.694	1.100
75th Percentile	2.000	2.200	1.608
TP (mg P/L)			
25th Percentile	0.027	0.016	0.009
Median	0.044	0.026	0.012
75th Percentile	0.085	0.041	0.047
Soil			
TN (mg N/g)			
25th Percentile	4.300	2.200	25.525
Median	7.400	4.950	27.350
75th Percentile	13.500	12.350	30.350
TP (mg P/g)			
25th Percentile	0.205	0.048	0.100
Median	0.290	0.098	0.158
75th Percentile	0.408	0.260	0.205

Hydro-Graphs

Twenty-four figures taken from published reports or peer-reviewed documents were collected showing temporal water level variations for Florida wetlands (Appendix B). Some figures provided data for more than one wetland, and these were summarized for non-impacted and impacted wetlands (Tables 7 & 8). These hydrographs were interpreted to provide a general overview of minimum and maximum flooding depth, an estimation of flooding duration, and an overview of months with standing water. Note that interpretation was solely based on visual determinations from published figures, as raw data were typically unavailable.

Hydrographs were interpreted for 21 non-impacted wetlands and 20 impacted wetland systems, though some individual wetlands may be included in more than one row in Tables 7 & 8. For example, the non-impacted depressional forested wetland labeled Austin Cary was listed three times in Table 7 for three separate studies representing the same physical wetland. Similarly, the impacted wetland Sewage or Sewage Dome was listed in two separate rows in Table 8, representing data collected at the same physical wetland for two overlapping time periods, from January 1976 to January 1977 (Brown 1981) and from July 1974 to December 1977 (Dierberg and Brezonik 1983).

In total, 21 hydrographs for non-impacted Florida wetlands were interpreted, including hydrographs for 11 depressional forested wetlands, four depressional emergent wetlands, one mixed vegetation wetland, and five wetlands described as seasonally connected, larger wetland systems. Non-impacted depressional forested wetlands had a range in maximum flooding depth from 0.45-2.2 m with a range of length of flooding duration spanning 155-365 days/year (Table 7). Non-impacted depressional emergent wetlands had a higher range of maximum flooding depth from 0.5-3.3 m with flooding duration ranging from 305-365 days/year.

Twenty hydrographs for impacted Florida wetlands were interpreted, including 10 depressional forested wetlands, three larger connected forested wetlands, six depressional emergent wetlands, and a single basin emergent wetland. Impacted depressional forested wetlands had a lower range in maximum flooding depth from 0.25-1.10 m and a longer range of flooding duration from 263-365 days/year (Table 8). Three of the north region non-impacted wetlands and four of the north region impacted wetlands had standing water each month during the period of record. The impacted depressional emergent wetlands had a lower maximum flooding height of 0.13-0.45 m and fewer days flooded from 56-228 days/year. A single hydrograph was available for one impacted emergent basin wetland, which had standing water 365 day/year.

Table 7. Interpretation of hydrographs for non-impacted Florida wetlands. All values are approximations based on visual interpretation of published figures.

Type	Region	Wetland Name	Min Depth (m)	Max Depth (m)	Flooding Duration (days)	Data Start Date	Data End Date	J	F	M	A	M	J	J	A	S	O	N	D	Data Source
Depressional Forested	Central	Forested	0.00	0.80	316	Jan-1981	Dec-03	x	x	x	x				x	x	x	x	x	Bardi et al. 2005
	Central	G1	0.00	0.80	345	May-89	Apr-99	x	x	x	x	x	x	x	x	x			x	Carr et al. 2006
	North	Large Dome	0.20	0.63	365	Jan-76	Jan-77	x	x	x	x	x	x	x	x	x	x	x	x	Brown 1981
	North	Control	0.00	0.59	350	Jan-94	May-96	x	x	x	x			x		x	x	x	x	Casey and Ewel 1998
	North	Austin Cary	0.00	0.75	350	Jan-74	Jun-79	x	x	x	x	x				x	x		x	Dierberg 1980
	North	Austin Cary	0.00	0.75	340	Jan-74	Jun-79	x	x	x	x	x				x	x	x	x	Dierberg and Brezonik 1983
	North	Large	1.00	2.20	365	Mar-82	Mar-83	x	x	x	x	x	x	x	x	x	x	x	x	Ewel 1990
	North	Medium	0.80	1.25	365	Mar-82	Mar-83	x	x	x	x	x	x	x	x	x	x	x	x	Ewel 1990
	North	Small	0.00	1.00	350	Mar-82	Mar-83		x	x	x		x	x	x	x	x	x	x	Ewel 1990
	North	Austin Cary	0.00	0.50	155	Mar-74	Dec-74	x	x	x			x	x	x	x			x	Mitsch 1984
	North	C Wetland	0.00	0.45	295	Jan-92	Dec-96	x									x	x	x	Sun et al. 2000
Depressional Emergent	Central	Herbaceous	0.00	0.50	320	Jan-94	Dec-03	x	x	x	x				x	x	x	x	x	Bardi et al. 2005
	Central	Lyonia Large	Unk	3.30	365	Sep-01	Jun-03	-	-	-	-	-	-	-	-	-	-	-	-	Knowles et al. 2005
	Central	Lyonia Small	Unk	1.80	305	Sep-01	Jun-03	-	-	-	-	-	-	-	-	-	-	-	-	Knowles et al. 2005
	North	Study Wetland	0.00	0.50	Unk	May-99	Nov-99	-	-	-	-	-	x	x	x	x	x	x	-	Wise et al. 2000
Mixed	Central	Sarasota Wetlands	Unk	Unk	Unk	Apr-85	Sep-86	-	-	-	-	-	-	-	-	-	-	-	-	CH2MHILL 1987
Seasonally Connected	South	Hydric Pine Flatwoods	0.00	0.20	47	Unk	Unk								x					Duever et al. 1986
	South	Cypress Swamp	0.00	1.00	226	Unk	Unk	x	x						x	x	x	x	x	Duever et al. 1986
	South	Marsh	0.00	0.50	153	Unk	Unk	x							x	x	x	x	x	Duever et al. 1986
	North	Hopkins Prairie	0.00	0.70	Unk	Jan-81	Dec-91	-	-	-	-	-	-	-	-	-	-	-	-	Clough 1992
	North	Hopkins Prairie	0.00	0.27	61	Mar-90	Feb-91			x	x	x								Clough 1992

(x) signifies standing water was reported; ( ) empty space signifies no standing water was reported (-) signifies no data were available.

Table 8. Interpretation of hydrographs for impacted Florida wetlands. All values are approximations based on visual interpretation of published figures.

Type	Region	Wetland Name	Min Depth (m)	Max Depth (m)	Flooding Duration (days)	Data Start Date	Data End Date	J	F	M	A	M	J	J	A	S	O	N	D	Data Source
Depressional Forested	North	Small Dome1	0.00	0.60	263	Jan-76	Jan-77	x	x				x	x		x	x	x	x	Brown 1981
	North	Small Dome2	0.00	0.52	287	Jan-76	Jan-77	x	x	x	x		x	x						Brown 1981
	North	Sewage Dome	0.65	0.73	365	Jan-76	Jan-77	x	x	x	x	x	x	x	x	x	x	x	x	Brown 1981
	North	Bermed Dome	0.00	0.25	358	Jan-76	Jan-77	x	x	x	x		x	x	x	x	x		x	Brown 1981
	North	Pasture	0.00	0.25	359	Jan-76	Jan-77	x	x	x			x			x	x	x	x	Brown 1981
	North	Sewage	0.35	1.10	365	Jul-74	Dec-77	x	x	x	x	x	x	x	x	x	x	x	x	Dierberg and Brezonik 1983
	North	Swamp Harvest	0.00	0.85	358	Jan-94	May-96	x	x	x	x	x		x	x	x	x	x	x	Casey and Ewel 1998
	North	Swamp+ Upland	0.00	0.60	350	Jan-94	May-96	x	x	x	x			x	x	x	x	x	x	Casey and Ewel 1998
	North	W Wetland	0.00	0.65	301	Jan-92	Dec-96	x	x	x	x	x	x	x	x	x	x	x	x	Sun et al. 2000
	North	ALL Wetland	0.00	0.50	331	Jan-92	Dec-96	x	x	x	x	x	x	x	x	x	x	x	x	Sun et al. 2000
Connected Forested	North	K	0.00	2.30	319	Jan-93	Dec-96	x	x	x	x						x	x	x	Riekerk and Korhnak 2000
	North	N	0.00	1.20	319	Jan-93	Dec-96	x	x	x	x						x	x	x	Riekerk and Korhnak 2000
	North	C	0.00	1.60	293	Jan-93	Dec-96	x	x	x	x							x	x	Riekerk and Korhnak 2000
Depressional Emergent	Central	Improved	0.00	0.45	228	Mar-01	Mar-02	x	x						x	x	x	x	x	Bohlen and Gathumbi 2007
	Central	Semi-Native	0.00	0.30	154	Mar-01	Mar-02								x	x	x	x		Bohlen and Gathumbi 2007
	Central	Improved	0.00	0.45	225	Sep-00	Apr-03							x		x	x	x	x	Gathumbi et al. 2005
	Central	Seminative	0.00	0.35	180	Sep-00	Apr-03							x		x	x			Gathumbi et al. 2005
	Central	Improved	0.00	0.33	76	Jul-00	Jul-01									x	x	x		Steinman et al. 2003
	Central	Semi-Improved	0.00	0.13	56	Jul-00	Jul-01									x	x			Steinman et al. 2003
Basin Emergent	Central	Boggy Marsh	Unk	Unk	365	Sep-01	Jun-03	-	-	-	-	-	-	-	-	-	-	-	-	Knowles et al. 2005

(x) signifies standing water was reported; ( ) empty space signifies no standing water was reported (-) signifies no data were available.

Methodology for Estimating Nutrient Loadings from Wetlands

Since it is unclear how nutrient loads are to be calculated for predevelopment and post-development loading analysis within the new Statewide Stormwater Treatment Rule, this methodology is designed to be used for individual rainfall events. With some relatively broad assumptions and the use of a Microsoft Excel® spread sheet model (Appendix C), daily rainfall data can be used to determine annual discharge volumes. The methodology uses the USDA SCS (1972) runoff equation:

$$Q = (P-0.2S)^2 / (P + 0.8S) \qquad \text{(Eq. 1)}$$

and:

$$S = (1000/CN) - 10 \qquad \text{(Eq. 2)}$$

where:

Q = amount of runoff (inches),
P = precipitation (inches),
S = maximum potential retention (inches), and
CN = Curve Number (integer between 0 and 100).

Data Input

<u>Land Cover by Wetland Type</u>

Florida land use and land cover have been classified through the Florida Land Use, Cover and Forms Classification System (FLUCCS) developed by the Florida Department of Transportation (FDOT 1999). For this project, wetlands were included with assigned FLUCCS codes 610 Wetland Hardwood Forests, 620 Wetland Coniferous Forests, 630 Wetland Forested Mixed, and 641 Freshwater Marshes (Table 9).

Table 9. Isolated wetland FLUCCS codes (FDOT 1999)

Wetlands Classification	FLUCCS Codes
Depressional forested	610, 620, 630
Basin forested	610, 620, 630
Depressional emergent	641
Basin emergent	641

Suspected differences in background concentrations of nitrogen and phosphorus in Florida wetlands necessitated classifying wetlands based on a simplified hydrogeomorphic classification system (i.e. depressional or basin), dominant vegetation type (i.e. forested or emergent) and further separated as non-impacted and impacted wetlands. Wetlands that were equal to or less than approximately 2.5 hectare in size, often occurring in relatively small watersheds, were classified as *depressional wetlands*. The water budget of depressional wetland has been described as being dependent primarily on precipitation (Brinson 1993), making them hydrologically isolated from surface water connectivity. *Basin wetlands* were described as larger in size, characterized with a larger contributing watershed, and having a seasonal or semi-permanent surface hydrologic connection to other wetlands or aquatic bodies. *Non-impacted wetlands* were those in primarily natural setting, surrounded by natural lands and having no obvious hydrologic alterations. *Impacted wetlands* were those wetlands having at least 25% of their adjacent land area in agricultural or urban uses. Impacted wetlands were further divided into those that were in landscapes with lowered water tables (i.e. dryer than normal) and those that were receiving higher than normal runoff inputs (i.e. wetter than normal). Determination of these hydrologic conditions required a degree of best scientific judgment, but we believe that it was necessary to take into consideration the hydrologic alterations that occur in impacted wetlands. In some cases, wetlands are drained that will require more rainfall to induce runoff, while in other cases, where wetlands are receiving higher than normal runoff from adjacent lands, smaller rainfall events are required to induce runoff.

Determination of Hydrologic Soil Groups

The Natural Resources Conservations Service's Soil Survey Geographic Data Base (SSURGO) classifies wetland soils based on hydrologic soil groups (HSG) (USDA SCS 1972; USDA NRCS 2009). With soil groups running a gradient from *Group A* soils, with more than 90% sand or gravel, having low runoff potential when thoroughly wet to *Group D* soils, with less than 50% sand, having high runoff potential when thoroughly wet (NRCS 2009).

The average Curve Numbers (CN) for wetlands hydrologic soil groups were taken from a recent study on pollution load reduction goals for the Newnans Lake watershed in north central Florida (Di et al. 2009) (Table 10). The CNs for wetlands and other land uses were developed based on average antecedent moisture conditions (AMC) II (Di et al. 2009). AMC II CNs reflect average conditions.

Table 10. Wetland Curve Numbers (CN) for soil hydrologic groups (Di et al. 2009)

	Hydrologic Soil Group			
	A	**B**	**C**	**D**
AMC II Wetland CNs	49	65	72	80

Antecedent Moisture Conditions (AMC)

Because of the variable hydrologic conditions in isolated wetlands driven by the large influence of precipitation events and the natural inter-annual variability in wetland water levels, CNs must be adjusted based on antecedent moisture conditions (AMC), a short-term adjustment factor for the preceding 5-days rainfall, and seasonal adjustments, a longer-term adjustment factor reflecting the dry or wet season water levels. AMC II CNs for wetlands are given above in Table 10; however, NRCS (2009) recognizes three AMC classes: AMC I (drier than average condition), AMC II (average condition), and AMC III (wetter than average condition) using rainfall event and season.

Table 11 lists average dry and wet season water levels in non-impacted and impacted depressional and basin wetlands in Florida. These water levels are derived from the Wetland Hydrology Model simulation results (Appendix C). Using these data, reasonable water level ranges for isolated wetlands in the dry and wet season under AMC adjustment factors I-III are determined based on the rainfall quantity (over a 5-day period) required to cause outflow from the wetland during dry and wet seasons (Table 12). The variability in dry and wet season water levels, antecedent weather conditions, and hydrologic soil unit influence the wetland adjusted CNs (Table 13). The average depths of water in each of the wetland types given in Table 11 were derived based on the simulation model given in Appendix C. Dry and wet initial conditions were set for each simulation and then average water levels were calculated for wet and dry seasons using an average rainfall year for north central Florida. To determine the rainfall necessary to cause runoff during wet and dry seasons and thus AMC adjustment factors in Table 12, again the model was used. In this case, rainfall events were increased during a period of 5 days until runoff occurred in the dry and wet season. The values were rounded to the nearest half inch. Rainfall amounts less than this value were equivalent to the AMC I events. AMC III events were determined in much the same way except the event sizes were increased until nearly all rainfall became runoff within the first 24 ours following the event. Rainfall events larger than this number were considered AMC III events and those between AMC I and AMC III were considered AMC II events. The adjustment factors in Table 13 are estimates based on best scientific judgment.

Table 11. Dry and wet season water levels (inches) in isolated wetlands

Wetland Type	Water Level - Dry Season	Water Level - Wet Season
Non-Impacted		
Depressional	6	20
Basin	10	24
Impacted		
Depressional	7	22
Basin	14	27

Table 12. Isolated wetland water level ranges by AMC adjustment factors for dry and wet seasons

	Dry Season (inches)	Wet Season (inches)
Non-Impacted Depressional Wetlands		
AMC I	Less than 5	Less than 0.5
AMC II	5.0 to 10.0	0.5 to 1.0
AMC III	Over 10.0	Over 1.0
Non-Impacted Basin Wetlands		
AMC I	Less than 1.5	Less than 0.1
AMC II	1.5 to 2.5	0.1 to 0.5
AMC III	Over 2.5	Over 0.5
Impacted Depressional Wetlands (Dryer than normal)		
AMC I	Less than 7	Less than 1.0
AMC II	7.0 – 12.0	1.0- 1.5
AMC III	Over 12	Over 1.5
Impacted Basin Wetlands (Dryer than normal)		
AMC I	Less than 3.0	Less than1.5
AMC II	3.0 to 5.0	1.5 – 2.5
AMC III	Over 5.0	Over 2.5
Impacted Depressional Wetlands (Wetter than normal)		
AMC I	Less than 3	- None -
AMC II	3.0 to 5.0	Less than 0.5
AMC III	Over 5.0	Over 0.5
Impacted Basin Wetlands (Wetter than normal)		
AMC I	Less than 1.0	- None -
AMC II	1.0 -2.0	Less than 0.1
AMC III	Over 2.0	Over 0.1

Table 13. Adjusted wetland Curve Numbers (CNs)

Hydrologic Soil Group	AMC I CN	AMC II CN	AMC III CN
A	32	49	60
B	45	65	75
C	52	72	81
D	63	80	88

Calculation of Discharge Volumes

Using equations 1 and 2 above, the runoff volume for a rainfall event can be calculated using the adjusted wetland CNs (Table 13). During the dry season, we propose that runoff will only occur if the rainfall event is greater than the difference between the wetland water level and the mean wet-season water level for depressional and basin wetlands (Table 11). For example, for a non-impacted depressional wetlands with a current dry season water level of 8 inches and a mean wet season water level of 20 inches (Table 11), a dry-season rainfall event of greater than 12 inches would be required to produce run-off from the given wetland.

Then, using data for event mean concentrations (Table 14), runoff volumes of TKN and TP can be calculated when the wetland surface area is known. Values for event mean concentrations reflect background nutrient concentrations for isolated wetlands as determined from the FIWND database developed for this project. We propose that 75th percentile nutrient concentrations are used for dry season calculations, reflecting higher nutrient concentrations in lower water conditions. Further, the lower 25th percentile nutrient concentrations should be used to calculate loading during the wet season, to reflect the more dilute nutrient conditions in times of higher wetland water levels. Note that nitrogen nutrient concentrations are available for TKN, as opposed to TN. TKN values should be lower than TN values for wetlands, as TKN measurement does not account for nitrate (NO_3-N) or nitrite (NO_2-N) in the water column. At this time, a sufficient quantity of water column TN values was not available for estimating nutrient loading from Florida isolated wetlands.

Table 14. Isolated wetland nutrient concentrations

Wetland Type →	**Forested Depressional**	**Forested Basin**	**Emergent Depressional**	**Emergent Basin**
Non-Impacted				
TKN (mg N/L)				
Sample Size (n)	82	3	49	4
25th Percentile	1.085	0.620	1.123	0.960
Median	1.450	0.920	1.694	1.100
75th Percentile	2.000	0.980	2.200	1.608
TP (mg P/L)				
Sample Size (n)	82	3	49	5
25th Percentile	0.027	0.009	0.016	0.009
Median	0.044	0.010	0.026	0.012
75th Percentile	0.085	0.010	0.041	0.047
Impacted				
TKN (mg N/L)				
Sample Size (n)	126	7	16	6
25th Percentile	1.177	0.820	2.233	0.893
Median	1.600	0.980	2.956	1.100
75th Percentile	2.770	1.120	4.789	2.100
TP (mg P/L)				
Sample Size (n)	150	7	117	7
25th Percentile	0.080	0.010	0.073	0.120
Median	0.186	0.010	0.250	0.130
75th Percentile	0.669	0.030	0.769	0.230

Sample Calculation for Estimating Wetland Loading

As a sample calculation, a non-impacted depressional emergent wetland has a surface area of 1 acre, soils classified within hydrologic soils *Group D,* and normal antecedent moisture conditions (AMC II) during the wet season. If a rainfall event produced 3 inches of rain, what is the estimated nutrient loading from the wetland runoff?

First, defining the variables, we see:

Q = amount of runoff (inches) = $(P - 0.2S)^2 / (P + 0.8S) = (3 - (0.2*2.5))^2 / (3 + (0.8*2.5)) =$ 1.25 inches

P = amount of precipitation (inches) = 3 inches

CN (AMC II, Hydrologic soil *Group D*) = 80

S = maximum potential retention (inches) = (1000/CN) – 10 = (1000/80) – 10 = 2.5 inches

Unit conversions: 1 acre = 43,560 ft^2

1 cubic meter = 35.315 cubic foot = 1000 liter

Applying the calculated amount of runoff of 1.25 inches of water over a surface area of 1 ac, the volume of the wetland runoff is 128,486 liters. Using the 25th percentile values for TKN (1.085 mg N/L) and TP (0.027 mg P/L) concentrations (Table 14), the estimated load to the downstream environment from the wetland runoff is 139.41 g N and 3.47 g P. Note that if the same 3 inch rainfall event occurred in the dry season, runoff would not occur from this wetland unless the current water level (at the time of calculation) in the wetland was within 3 inches or higher of the mean wet season water level of 20 inches for non-impacted depressional wetlands.

DISCUSSION AND RECOMMENDATIONS

Because wetlands are not normally thought of as contributing nutrient loads in stormwater runoff and as a consequence they are often left out of calculations or included as sinks for stormwaters and nutrients, some explanation of this relatively complex approach to calculating runoff from wetlands is in order. We consider several things in this discussion: types of wetlands that can generate runoff, the assumptions necessary to generate runoff, and the effects of altered hydroperiod and depths of inundation on runoff generation.

It is important to note that we have not included all types of wetlands in this review and especially in the modeling methodology. Wetlands that are directly connected to water bodies and that share surface waters, such as lake fringe and riverine floodplain swamps, are receiving bodies, and therefore should not be considered contributors of stormwater or associated nutrients to the adjacent open water. By eliminating lake fringe and riverine floodplain swamps from this evaluation of stormwater contributions, we are left identifying the contributions from isolated depressional and basin wetlands that are common throughout the low topographic relief areas of the Florida landscape. We turn next to the assumptions necessary to include these wetlands as generators of stormwater runoff and nutrients to receiving water bodies.

Isolated depressional and basin wetlands are typically considered nutrient sinks (e.g. Howard-Williams 1985), since they are most frequently found in low areas of the landscape. When there is surface runoff from upland areas, it usually finds its way to these wetlands, thus driving their seasonally dynamic hydrology. Only after these wetlands reach their maximum storage capacity does water runoff (from these wetlands) towards lower elevations. Thus, any methodology used to predict stormwater runoff from isolated wetlands must take into account the storage function of these wetlands. During the dry season much larger rainfall events are necessary before there is wetland runoff, and in contrast, during the wet season much smaller events will generate wetland runoff. Our methodology recognizes these facts and adjusts curve numbers (CNs) to take into consideration these different hydrologic realities.

Not all wetlands are untouched by human activities. That is to say, the hydrologic characteristics of landscapes can be altered by such things as groundwater pumping or ditching that results in dryer than normal conditions in a particular wetland. By the same token, hydrologic alteration to surrounding uplands that increases runoff or impounds water can cause wetter than normal situations. In either case, the potential for runoff from a wetland is altered. In the first case, dryer than normal conditions mean lower than normal water levels in the wetland and larger rainfall events in both the dry and wet season to produce wetland runoff. In the second case the opposite is true. We have taken these potential conditions into consideration in this methodology and have made allowances for their incorporation.

In all, we have addressed the main controlling factors that affect wetland stormwater runoff with this methodology. It recognizes four different types of wetlands, in altered and unaltered landscapes, and the different potential for runoff generation between Florida's wet and dry seasons.

In comparison to a recent study addressing pollutant loads in the hypereutrophic Newnan's Lake watershed in north central Florida, Di et al. (2009) estimated mean nutrient loading from wetlands and aquatic bodies of 1.680 mg/L TN and 0.173 mg/L TP from 1995-1998. Nutrient concentrations for isolated wetlands throughout Florida in this project were similar for the 75th percentile of non-impacted wetlands at 0.980-2.200 mg/L TKN (though note the different nitrogen form and range for multiple wetland types) and lower for the 75th percentile of non-impacted wetlands at 0.010-0.085 mg/L TP, and similar for the 75th percentile of impacted wetlands at 1.120-4.789 mg/L TKN and 0.030-0.769 mg/L TP.

Data Uncertainty

One of the key findings of this project is that there has been very little systematic collection of water quality data for isolated wetlands in Florida. Much of the literature data were collected during relatively short-term research studies focused on a small number of specific sites. This site bias makes it quite uncertain as to whether the nutrient ranges reported accurately reflect the distribution found in isolated wetlands throughout the state. Amplifying this uncertainty is the fact that there is wide divergence in reporting conventions and sampling regimes among different studies and wetland sites. For example, a number of studies only report the mean values and standard deviations from a series of sampling events over time, while others have raw data available. A similar problem is that several wetland sites have more than 50 data points sampled over several years, while others only have data for one discrete sampling date. Such idiosyncrasies make it inherently difficult to make robust and confident generalizations from the given data. Differences in field collection and laboratory analytic methods among studies are a final source of uncertainty that should also be noted. However, such data quality concerns likely are minor, as most data come from highly reliable sources such as government reports, peer reviewed literature, and doctoral dissertations.

Future Research

While the comprehensive cataloguing of archival nutrient data from isolated wetlands is a step forward in understanding the natural condition of these systems and evaluating their nutrient treatment capacity, it is also quite clear that a more systematic sampling effort would greatly benefit ongoing efforts to develop a Statewide Stormwater Treatment Rule and otherwise protect water quality.

One possible approach for reaching a broad range of isolated wetland systems across the state would be to add a water chemistry sampling component to some percentage of wetlands that will be evaluated through the US Environmental Protection Agency's National Wetland Condition Assessment (NWCA) program scheduled to begin in 2011. The NWCA is developing a probabilistic method for site selection, and it stands to reason that a random sub-selection of these could be used for collection of water chemistry as a complement to the other site condition assessments that will be performed. The NWCA is currently debating what parameters will be included in sample design, and it is the understanding of the authors that to date it is likely soil chemical and physical measures will be collected but water measures will not.

Another approach for acquiring more data for the isolated wetlands database would be to include regular water chemistry sampling at wetlands in well-fields that are already being monitored for hydrologic impacts from groundwater draw-downs. Because both the NWCA and well-field monitoring programs are existing programs, start up costs to add water quality sampling as a regular monitoring component should be minimal.

A final thought for future research priorities is that isolated wetlands in the panhandle region are very under-studied in comparison to other regions of the state. Given the low population density and large natural areas in much of the panhandle, the region seems ideal for targeted sampling of reference isolated wetland types, particularly as development pressure increases. Additional research of wetlands in the panhandle region would also have the benefit of making it clearer as to how these systems are similar to, and in what ways they differ from, peninsular wetland types. Such information will be invaluable for adaptive watershed management as development pressure continues to increase in the panhandle region over the next decades.

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Appendix B - Collected Hydrographs for Florida Wetlands

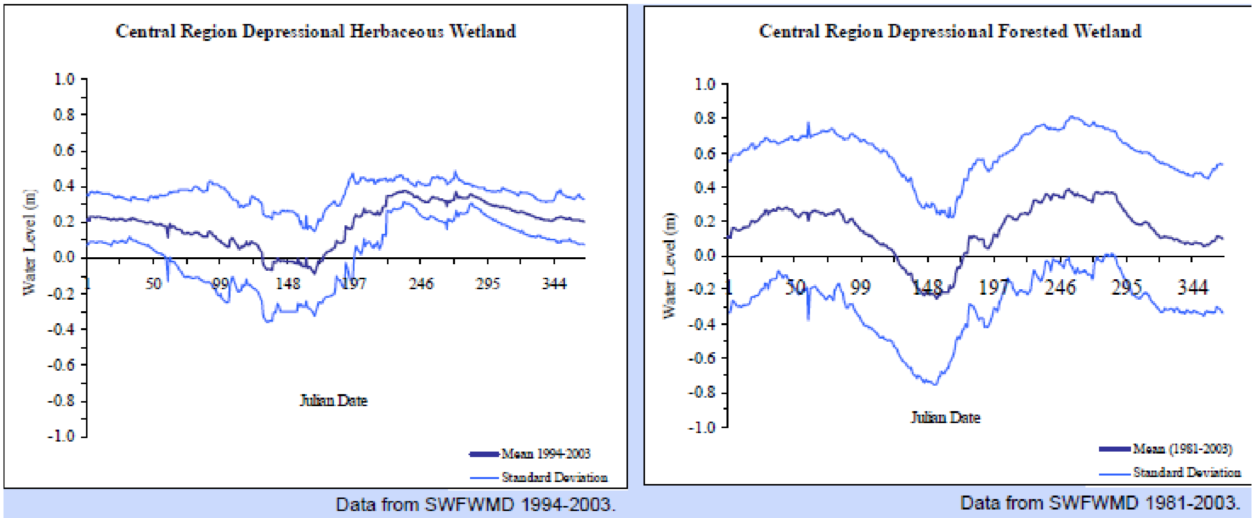

Figure B-1. Figure from Bardi et al. (2005), data compiled from the Southwest Florida Water Management District (SWFWMD) from 1994-2003 for a reference standard central Florida depressional herbaceous wetland (left) and 1981-2003 for a reference standard central Florida depressional forested wetland (right).

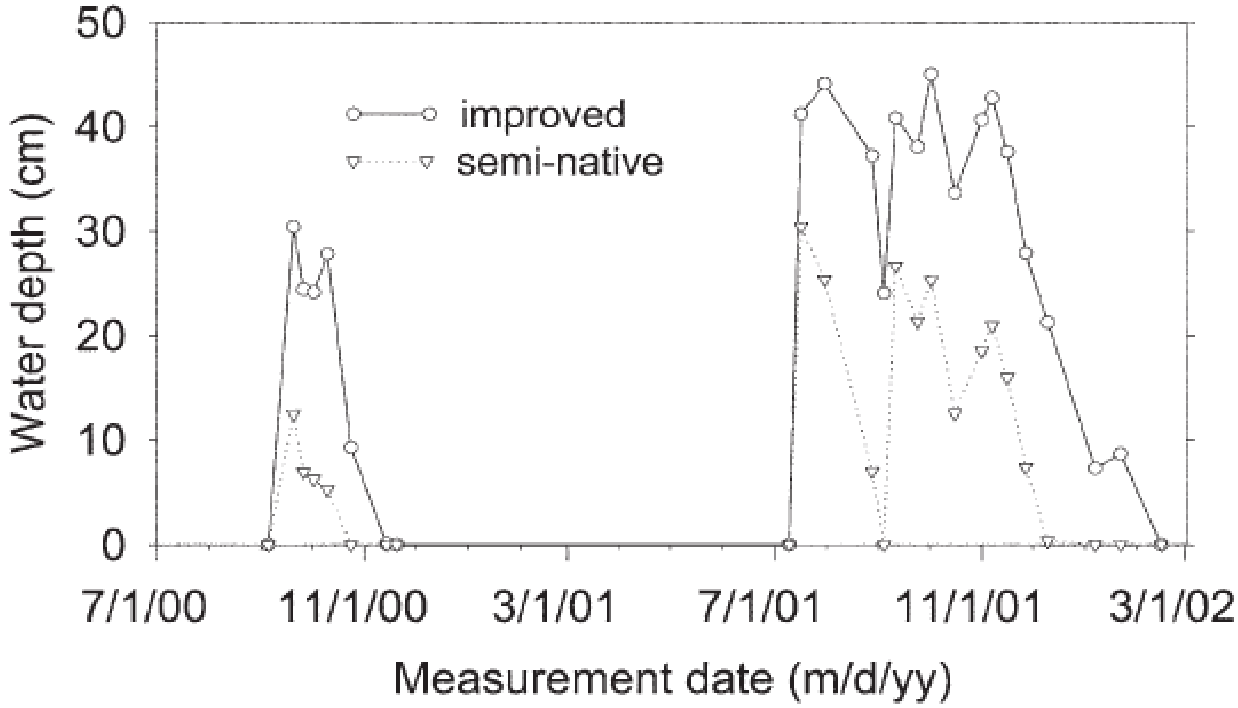

Figure B-2. Figure 1 from Bohlen and Gathumbi (2007). Original caption reads: “Average water depth and hydroperiod in wetlands in improved (solid line) and semi-native (dotted line) pastures from July 2000 through March 2002.”

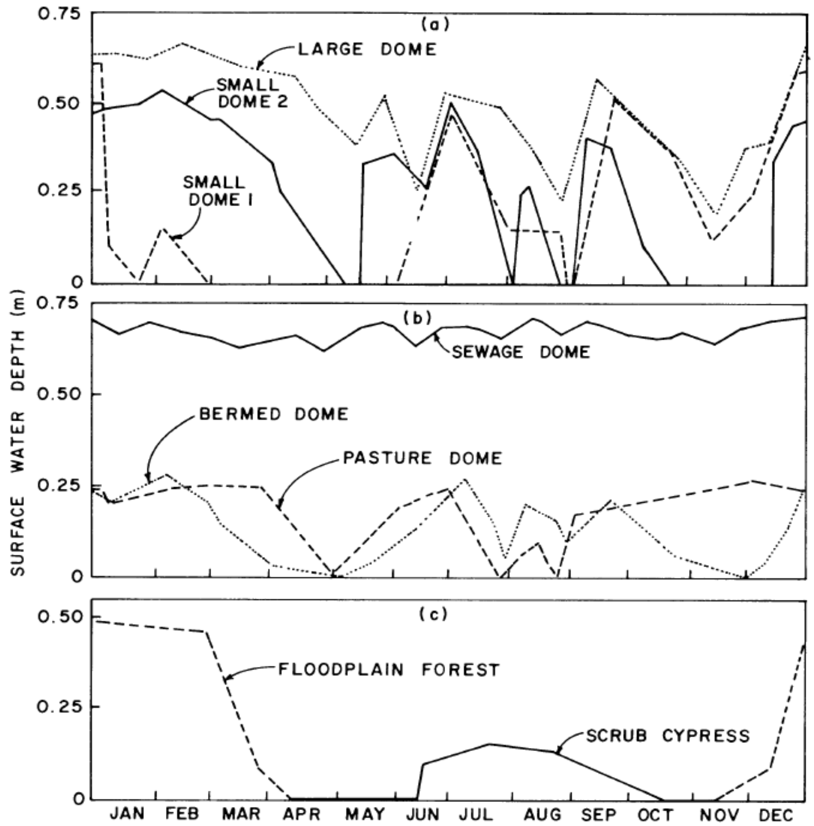

Figure B-3. Figure 2 from Brown (1981). The Large Dome in (a) is considered a reference standard depressional forested wetland. Small Dome 1 and Small Dome 2 in (a) and Sewage Dome, Bermed Dome, and Pasture Dome in (b) are impacted depressional forested wetlands. Original caption reads: "The annual fluctuation of surface water levels. Records are from December 1976 to December 1977 for the scrub cypress forest (Flohrscutz 1978) and from January 1976 to January 1977 for the other sites. Data for Sewage Dome and Large Dome were obtained from K. Heimburg (*personal communication*)."

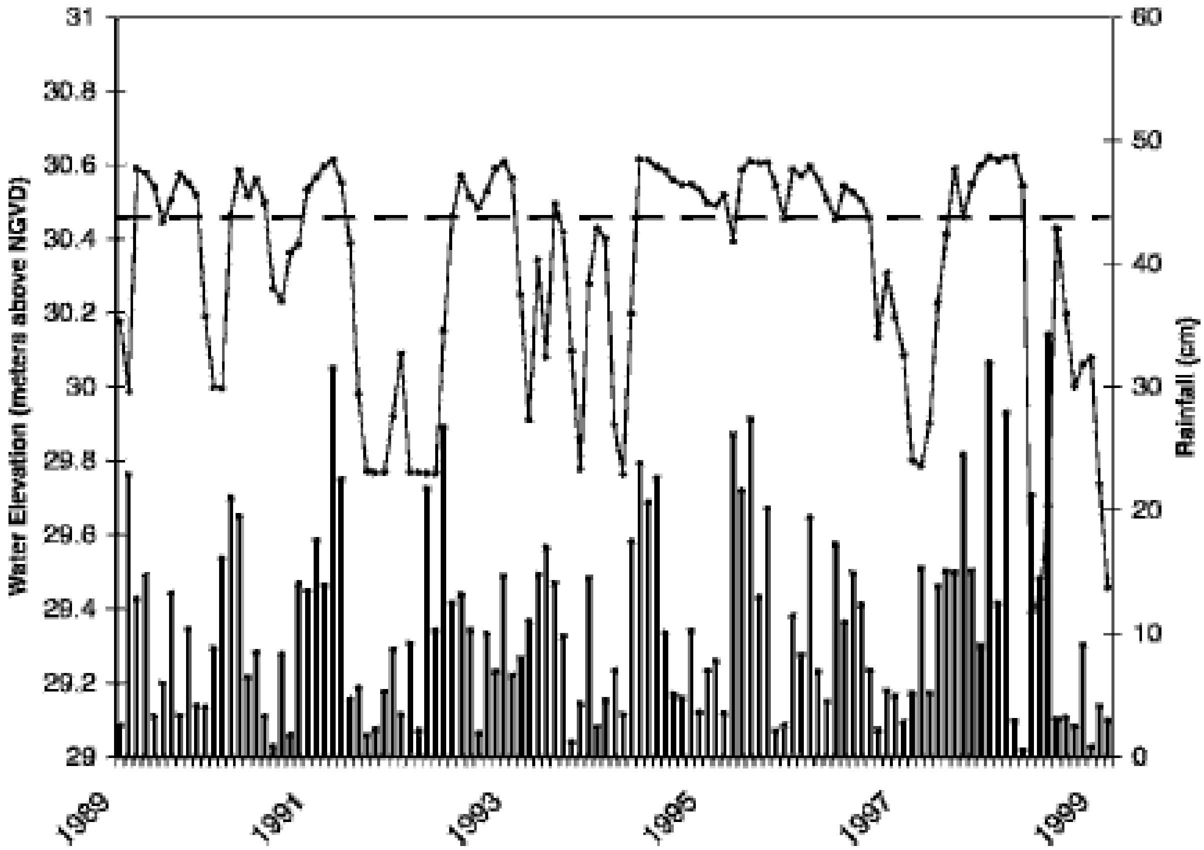

Figure B-4. Figure 2 from Carr et al. (2006). Original caption reads: "Water surface elevation (points and solid line) for median water surface elevation (dashed line) for cypress dome G1 in Lake County, Florida from May 1989 through April 1999. Mean monthly rainfall totals (bars) for 55 stations in Pasco County, Florida are also shown."

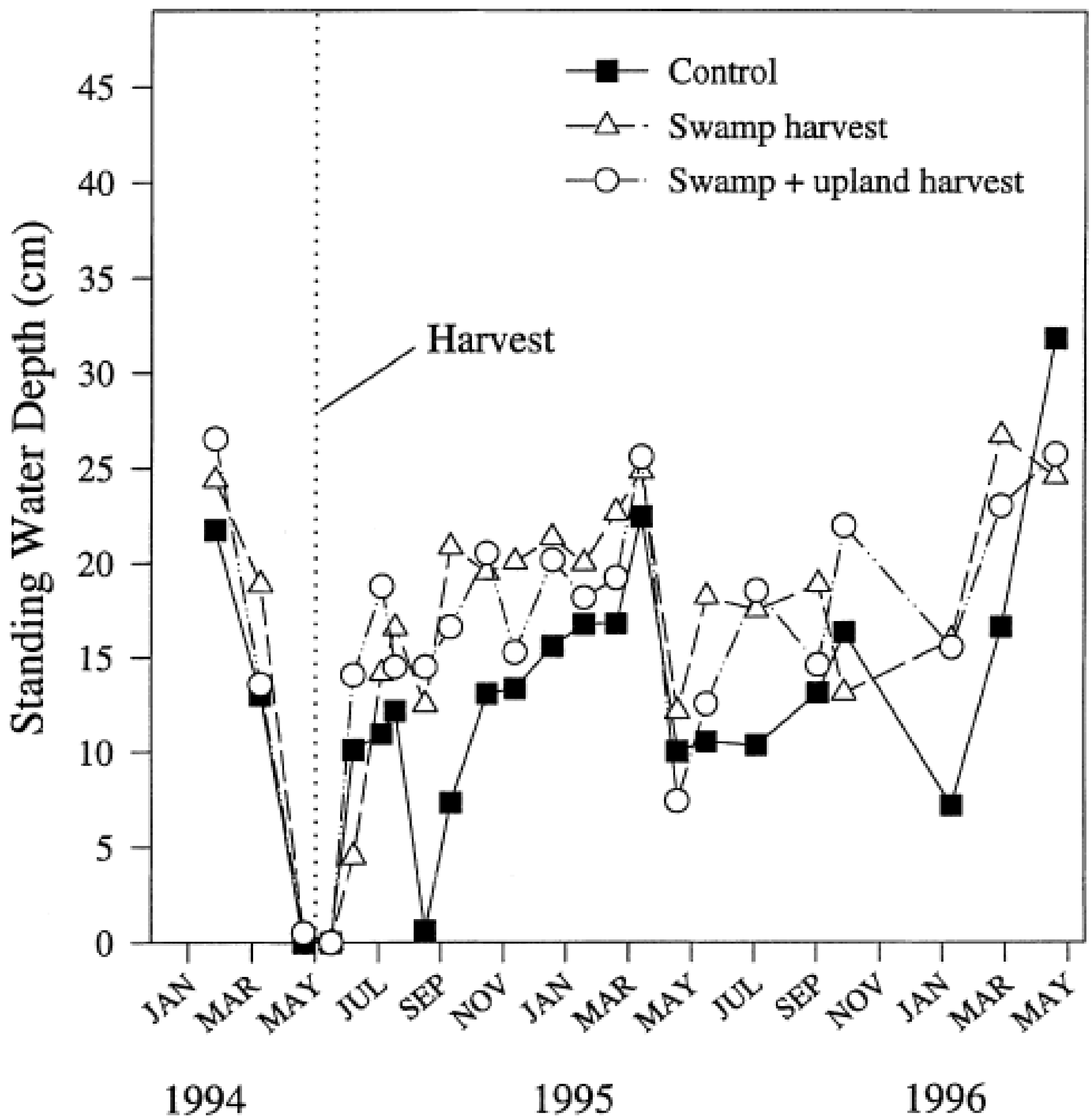

Figure B-5. Figure 3 from Casey and Ewel (1998). Original caption reads: "Monthly mean standing water depth in three groups of cypress swamps. Before April 1994, none of the nine swamps had been harvested. After May 1994, the nine swamps were divided into three treatments: control, swamp harvest, and swamp+upland harvest with three swamps per treatment."

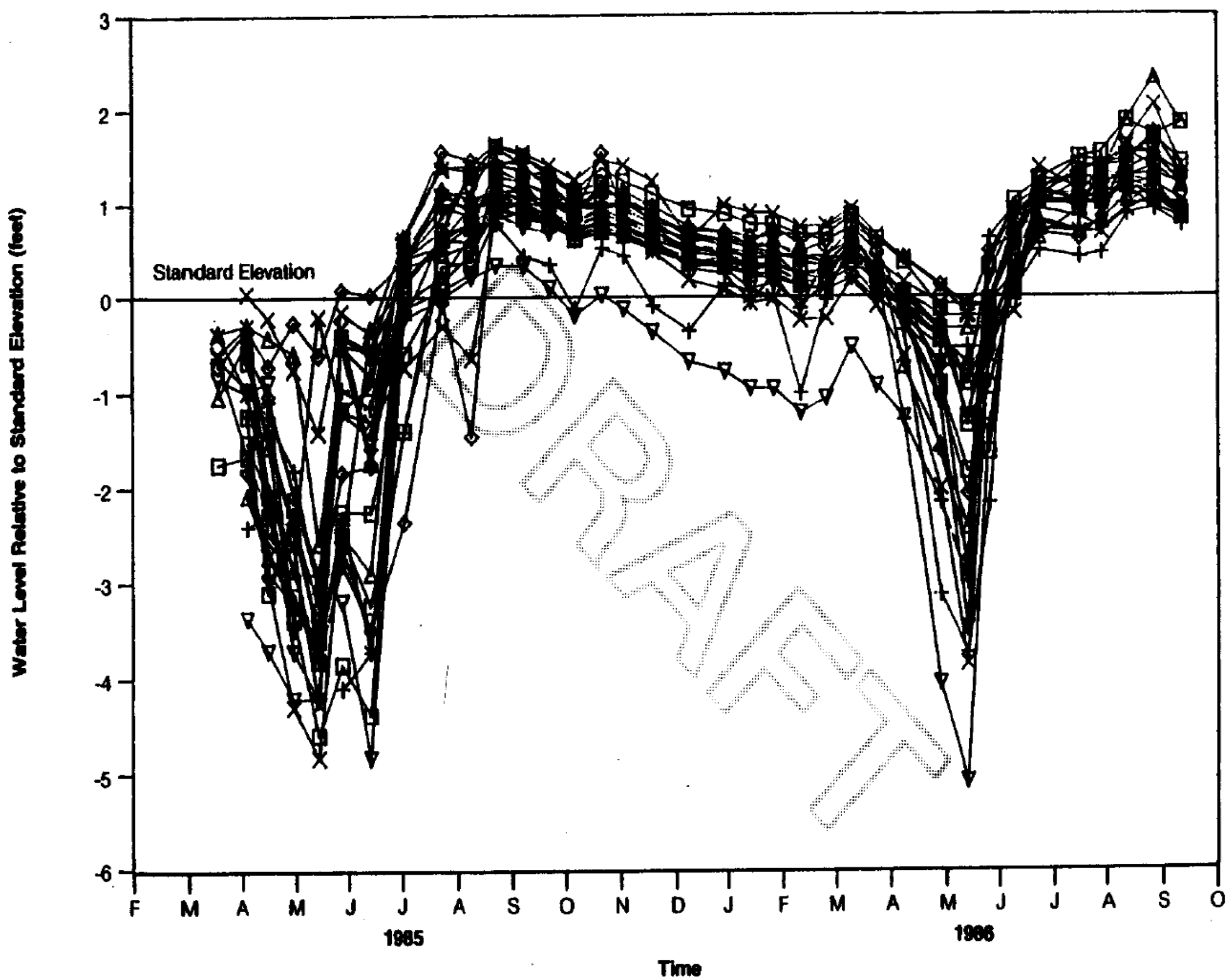

Figure B-6. Figure 3-1 from CH2MHILL (1987). 'Standard Elevation' line represents the elevation 0.33 m (1 ft) below the upland elevation; it does not represent the soil surface. Original caption reads: "Hydrograph of 23 unditched study wetlands."

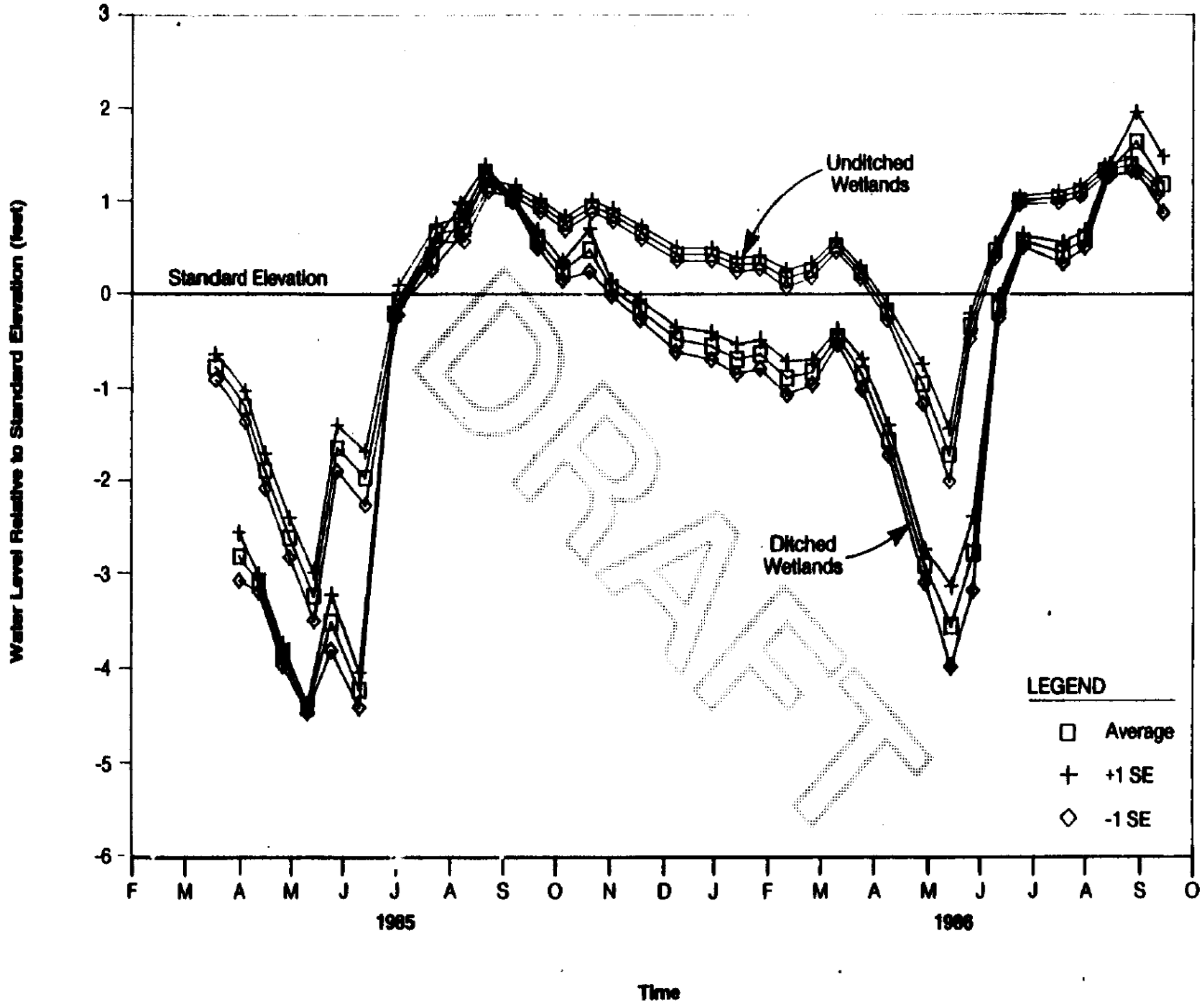

Figure B-7. Figure 3-2 from CH2MHILL (1987). 'Standard Elevation' line represents the elevation 0.33 m (1 ft) below the upland elevation; it does not represent the soil surface. Original caption reads: "Average hydrograph of ditched versus unditched study wetlands."

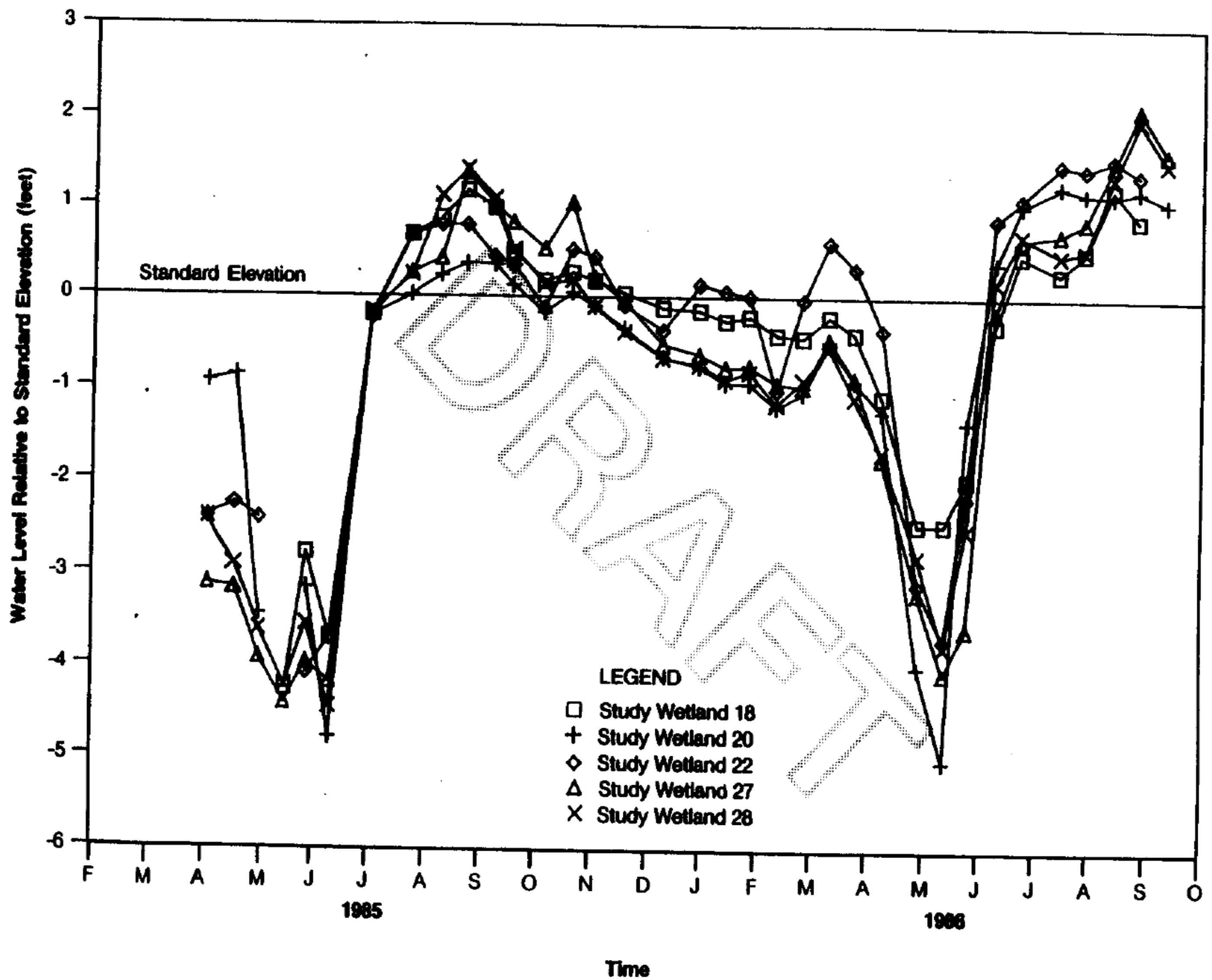

Figure B-8. Figure 3-3 from CH2MHILL (1987). 'Standard Elevation' line represents the elevation 0.33 m (1 ft) below the upland elevation; it does not represent the soil surface. Original caption reads: "Hydrograph of hydrologically altered study wetlands."

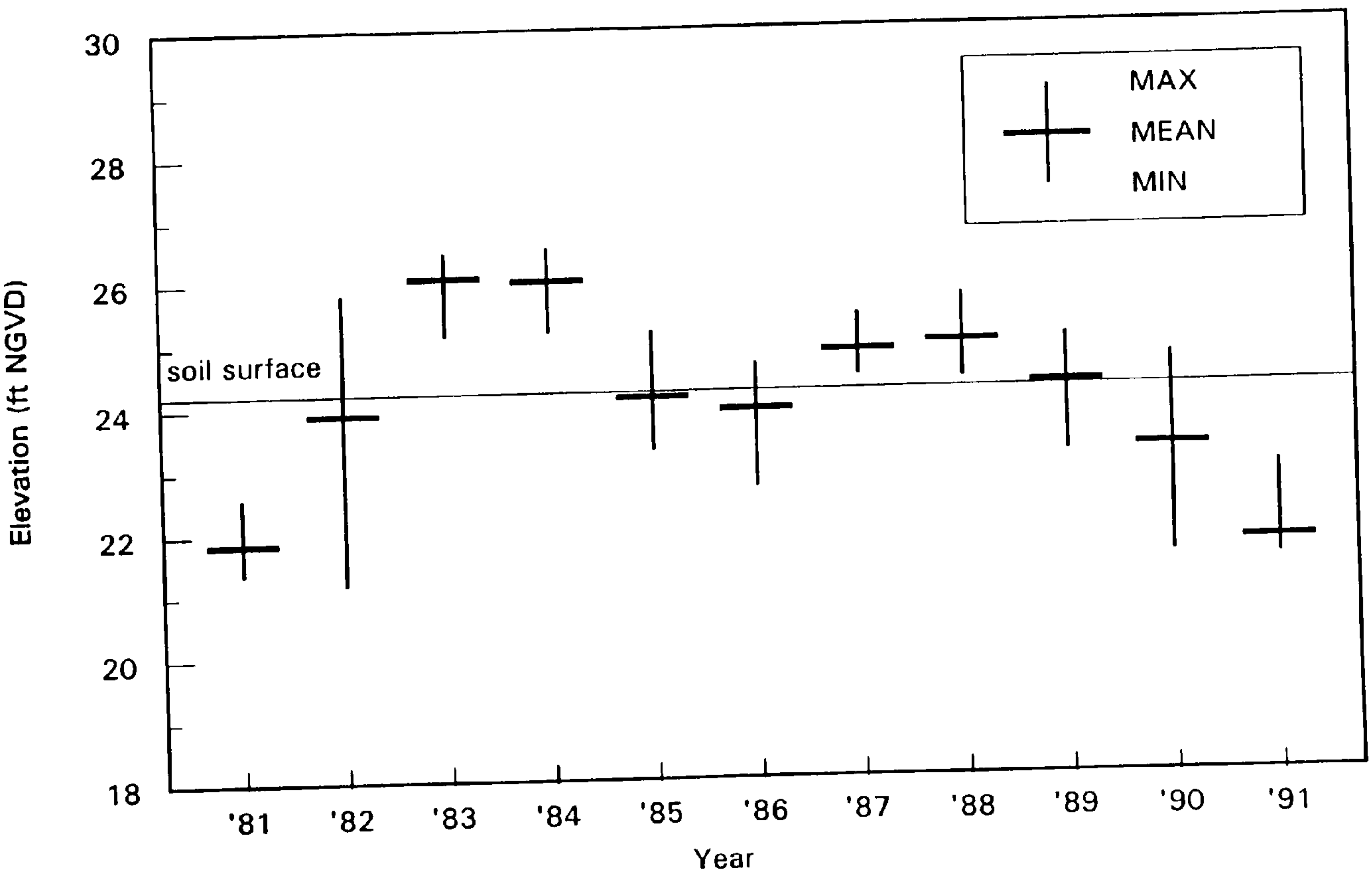

Figure B-9. Figure 3-2 from Clough (1992). Data represent yearly fluctuations for a wet prairie. Original caption reads: “Mean, maximum, and minimum annual stage at Hopkins Prairie from 1981 to 1991 (data from St. Johns River Water Management District).”

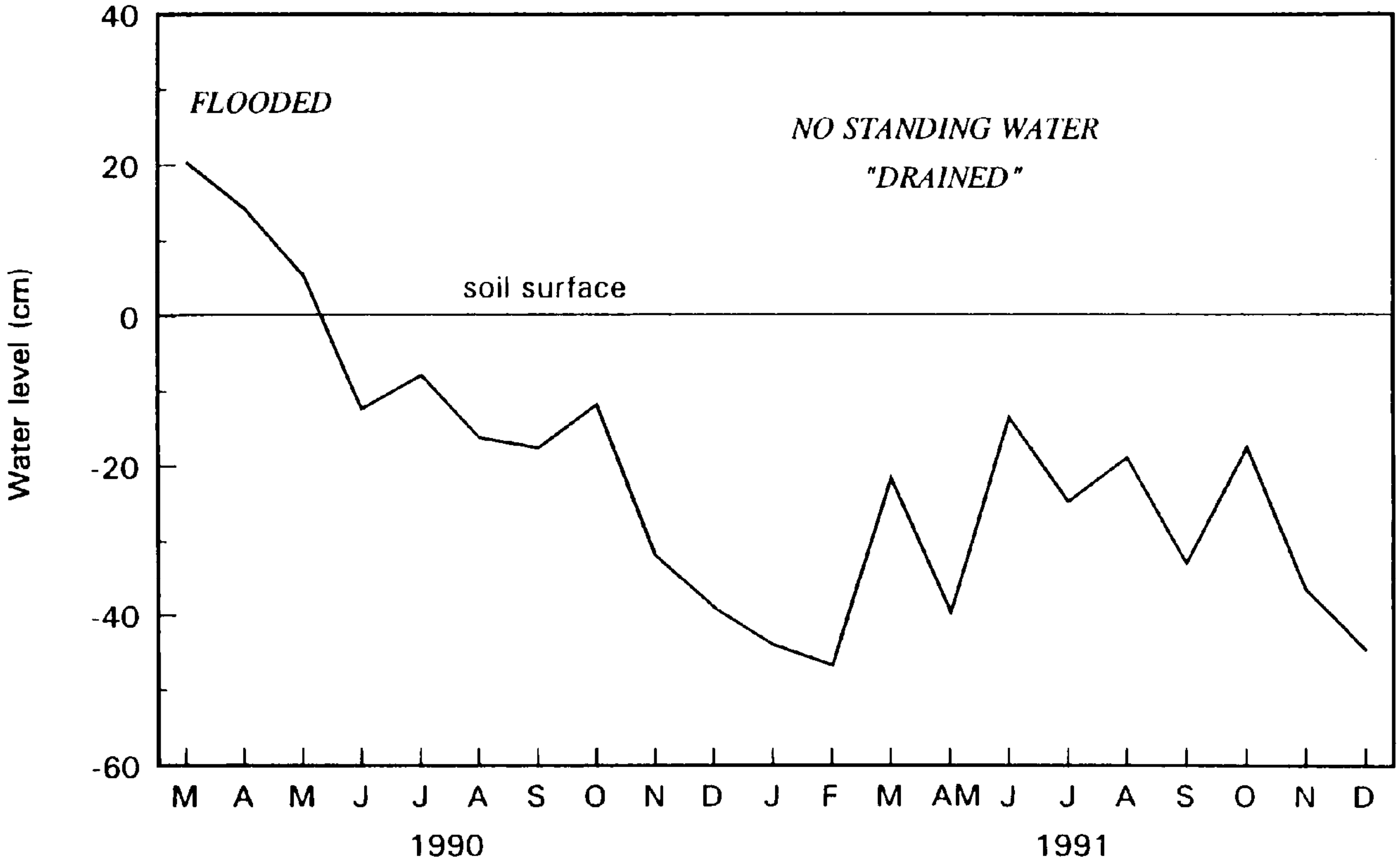

Figure B-10. Figure 3-3 from Clough (1992). Data represent yearly fluctuations for a wet prairie. Original caption reads: “Mean, monthly water level at Hopkins Prairie from March 1990 to December 1991.”

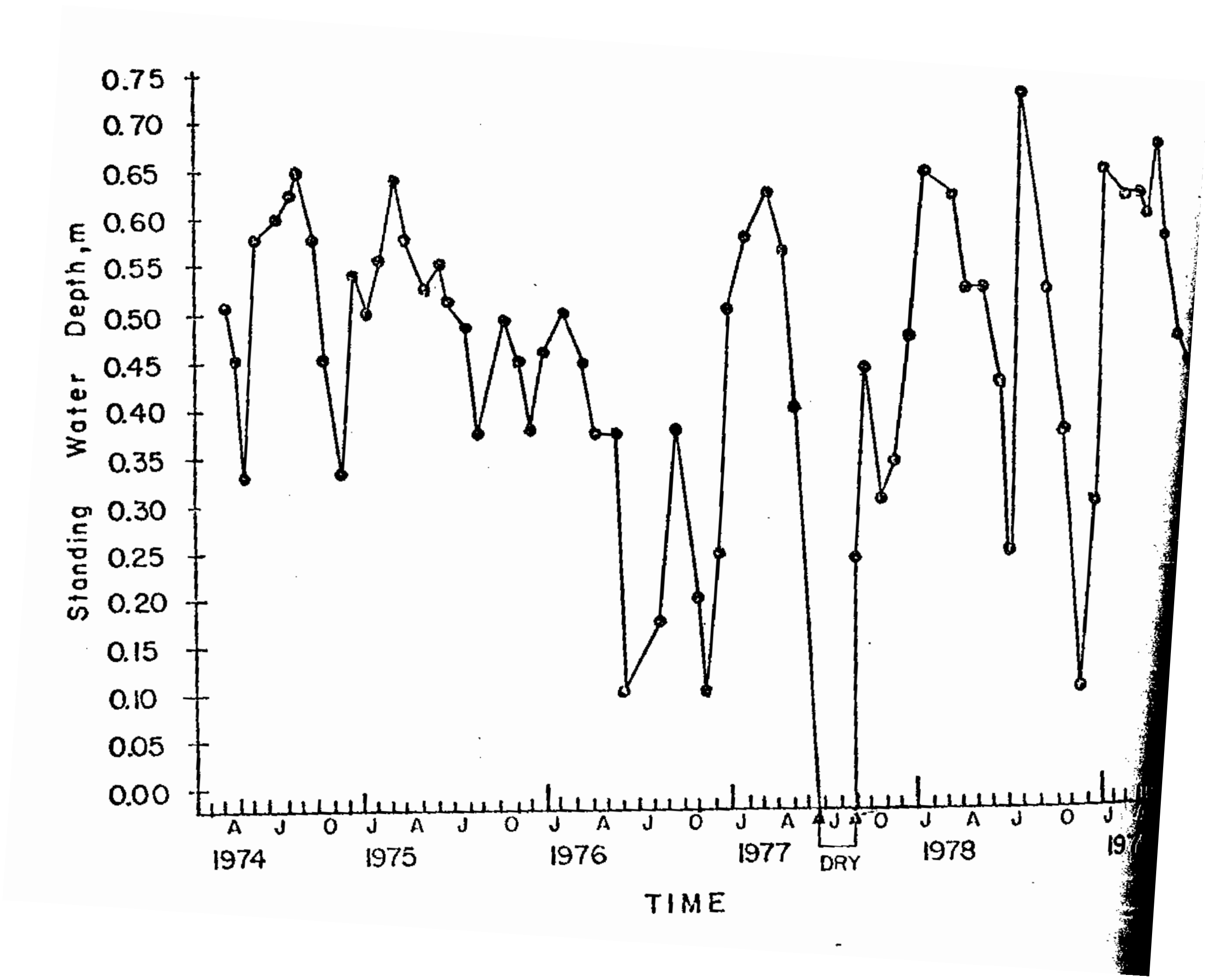

Figure B-11. Figure 4-2 from Dierberg (1980). Original caption reads: "Monthly variations in the depth of standing water at the center of Austin Cary cypress dome."

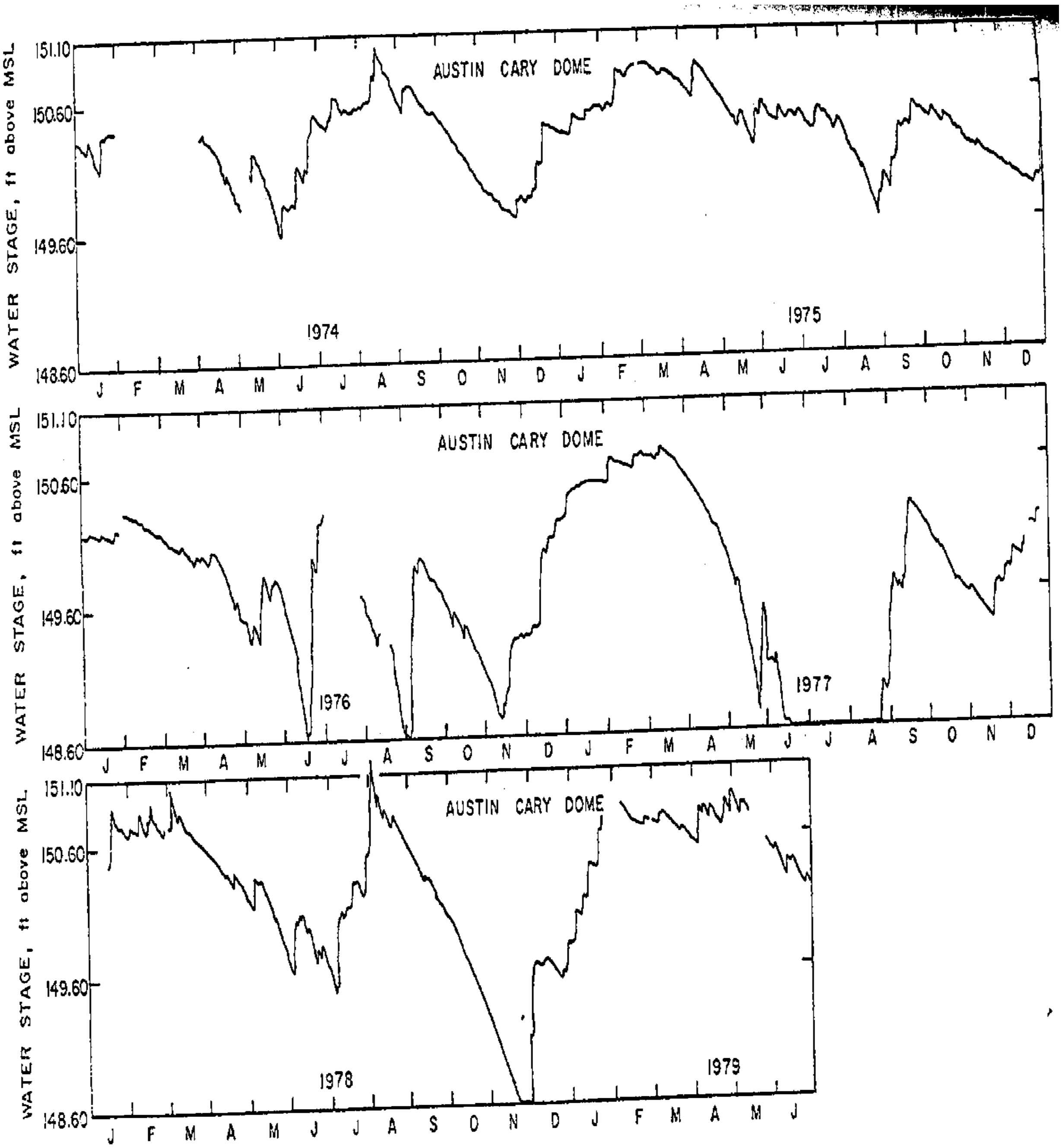

Figure B-12. Figure 7-6 from Dierberg (1980). Original caption reads: "Water level fluctuations in the surface waters of the center of Austin Cary natural dome from 1974 to 1979."

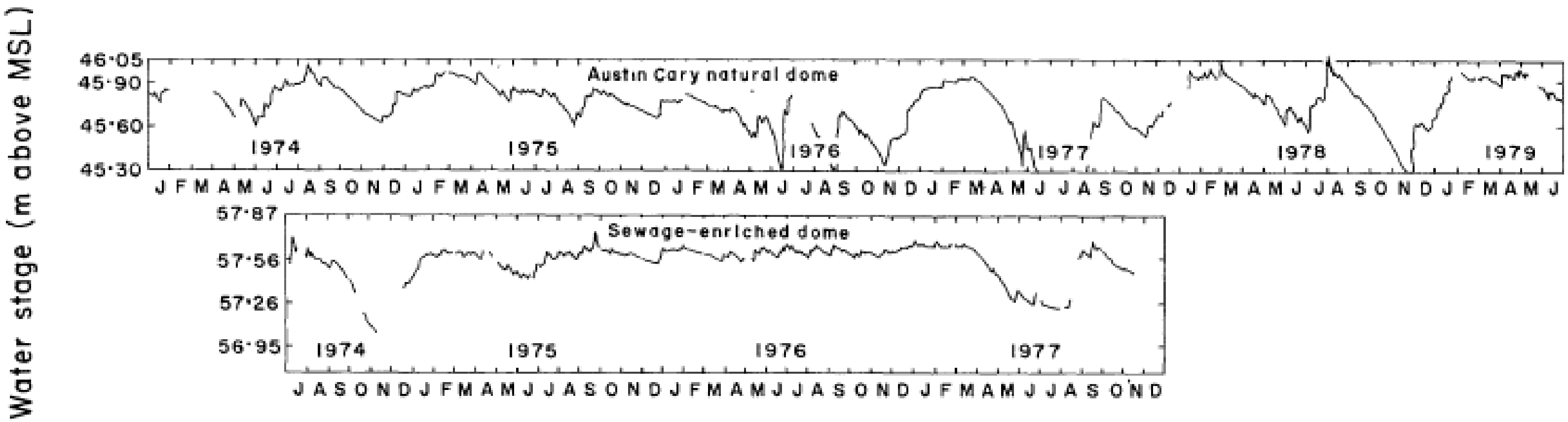

Figure B-13. Figure 1 from Dierberg and Brezonik (1983). Austin Cary natural dome (top) is a reference standard wetland; Sewage-enriched dome (bottom) is an impacted wetland. Original caption reads: “Water level fluctuations in the surface water at the centres of Austin Cary natural (1974-1979) and sewage-enriched (1974-1977) domes. Data collected by K. Heimburg.”

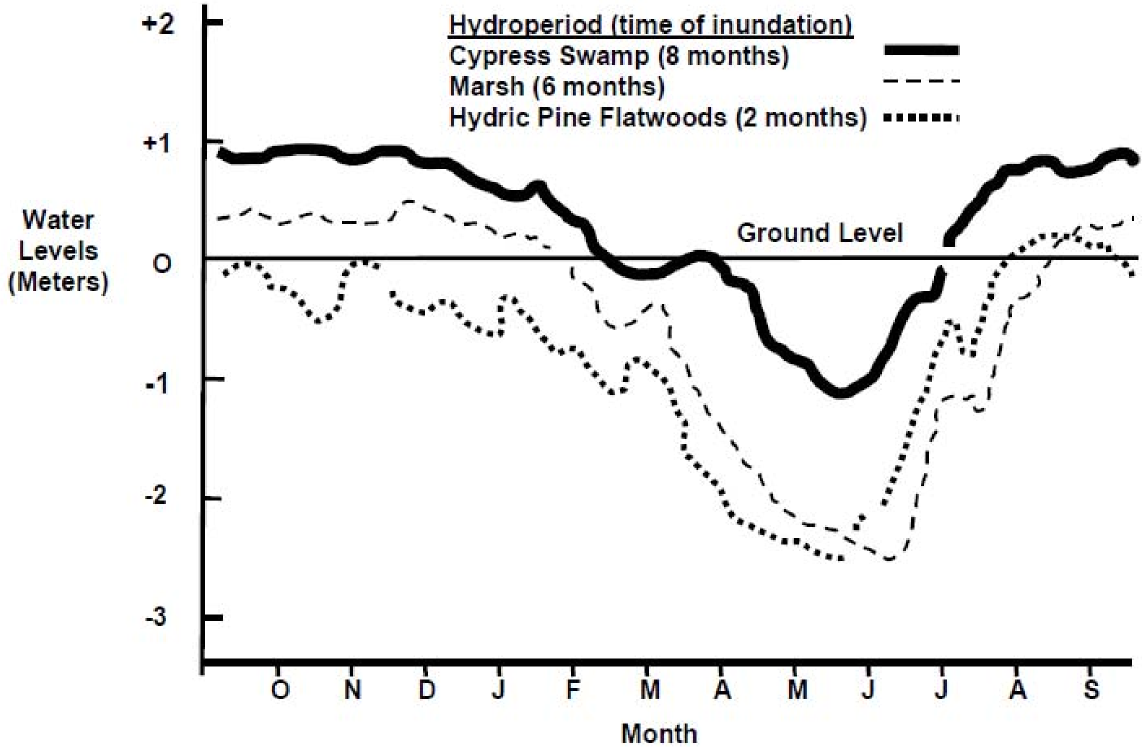

Figure B-14. Figure 7-6 from LWCWSP, summarized from Duever et al. (1986). Original caption reads: "Hydrographs and hydroperiod ranges for three different south Florida vegetation types (Duever et al., 1986)."

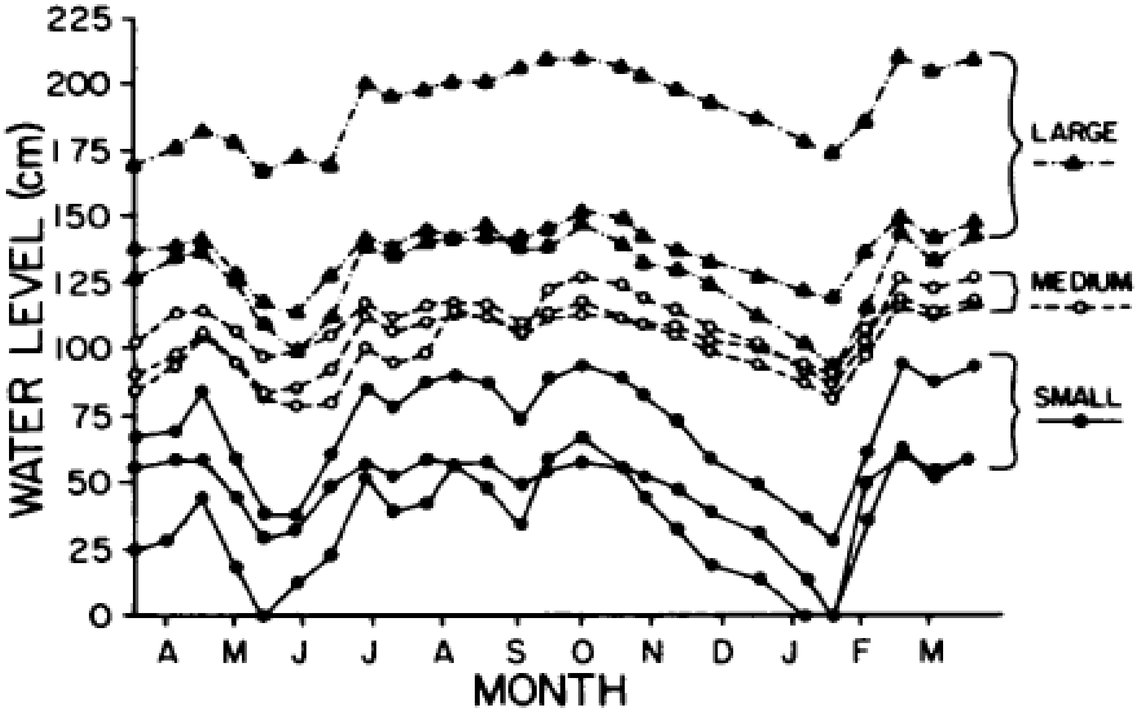

Figure B-15. Figure 5 from Ewel (1990). Original Caption reads: "Typical hydrographs recorded in the centers of nine swamps in central Florida (Ewel and Wickenheiser 1988). Water levels and depths of water above ground in each basin. Small swamps are less than 1 ha, medium swamps are 1-2 ha, and large swamps are more than 5 ha." Taken from Ewel and Wickenheiser (1988), caption: "Biweekly changes in water level (March 1982-March 1983) in the nine study sites."

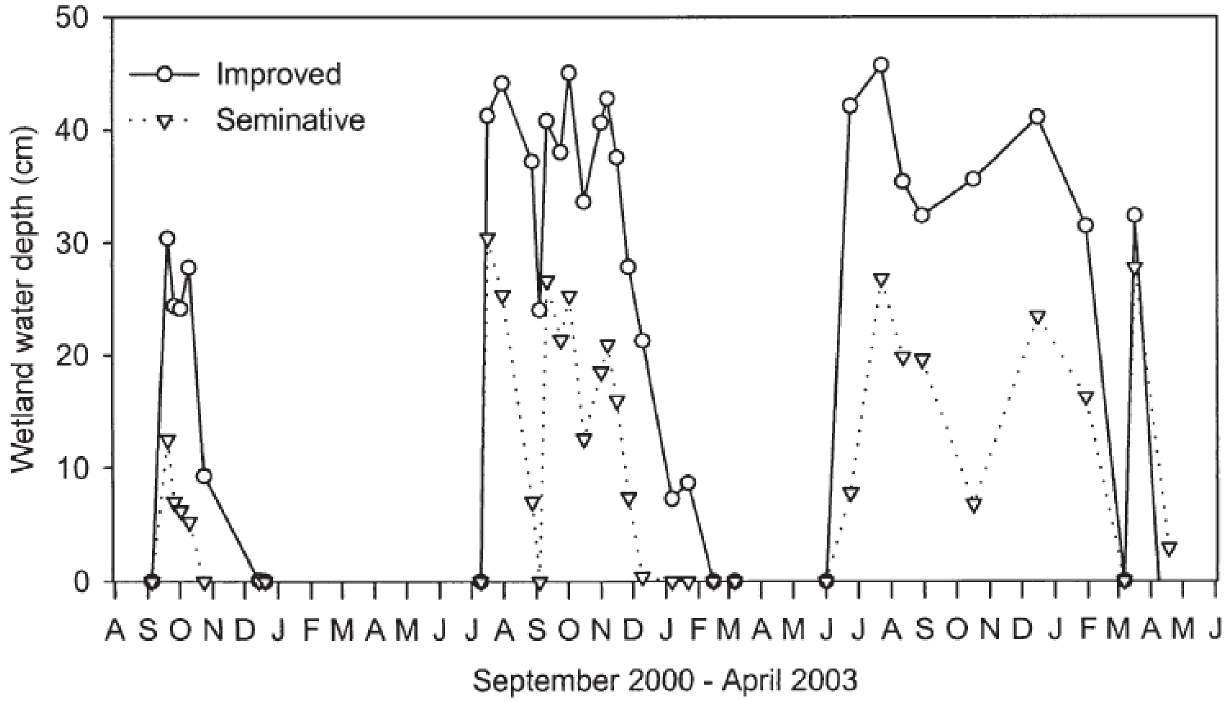

Figure B-16. Figure 1 from Gathumbi et al. (2005). Original caption reads: “Mean monthly water depth measured in improved pasture and seminative pasture wetlands (September 2000 to May 2003) illustrating the seasonal fluctuation of both water depth and hydroperiod in these wetland systems (modified from Steinman et al. 2003).”

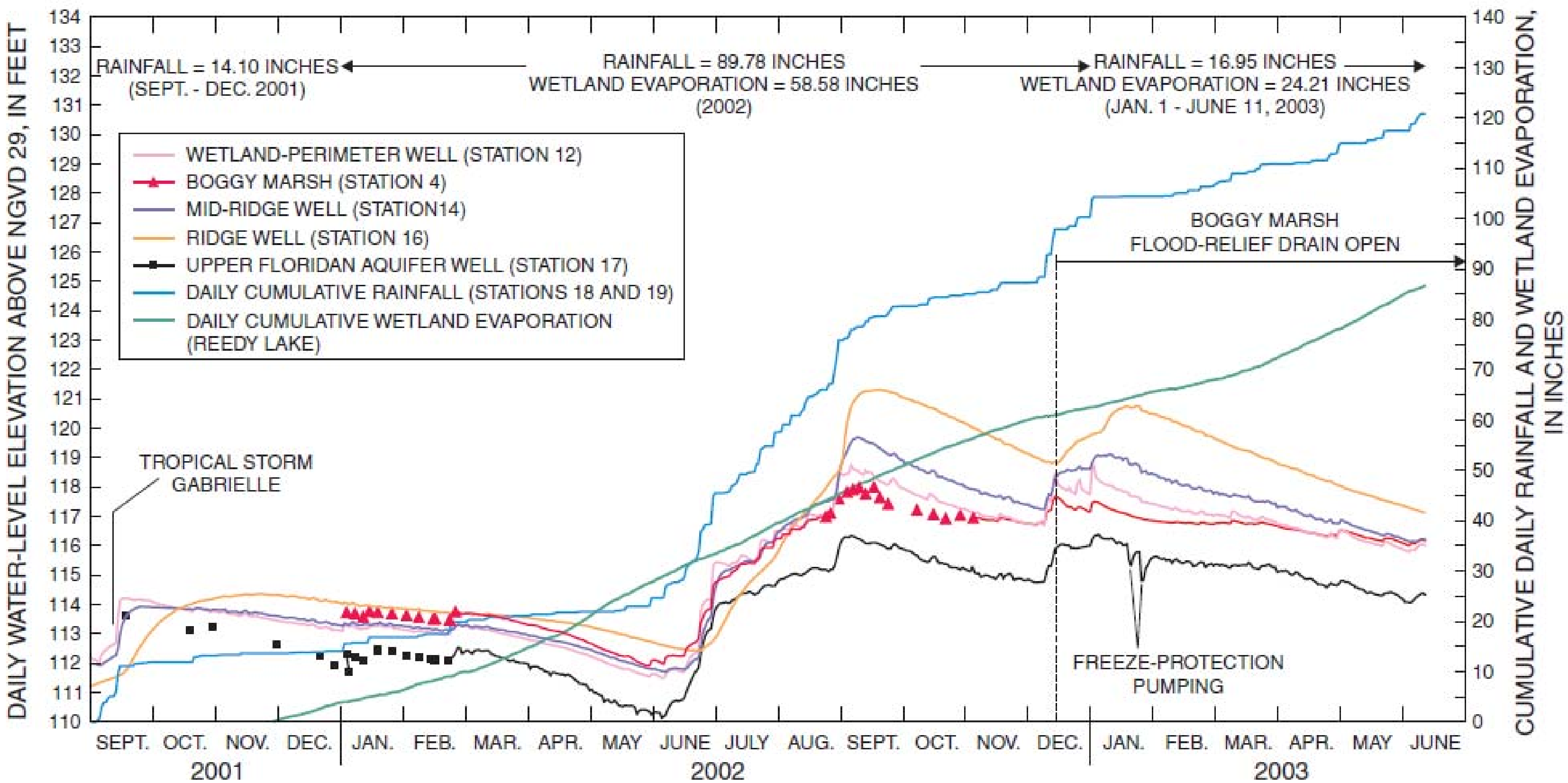

Figure B-17. Figure 19 from Knowles et al. (2005). Original caption reads: “Daily water levels, cumulative rainfall, and cumulative wetland evaporation for the Boggy Marsh site, Hilochee Wildlife Management Area (station numbers refer to figure 5 and table 1).”

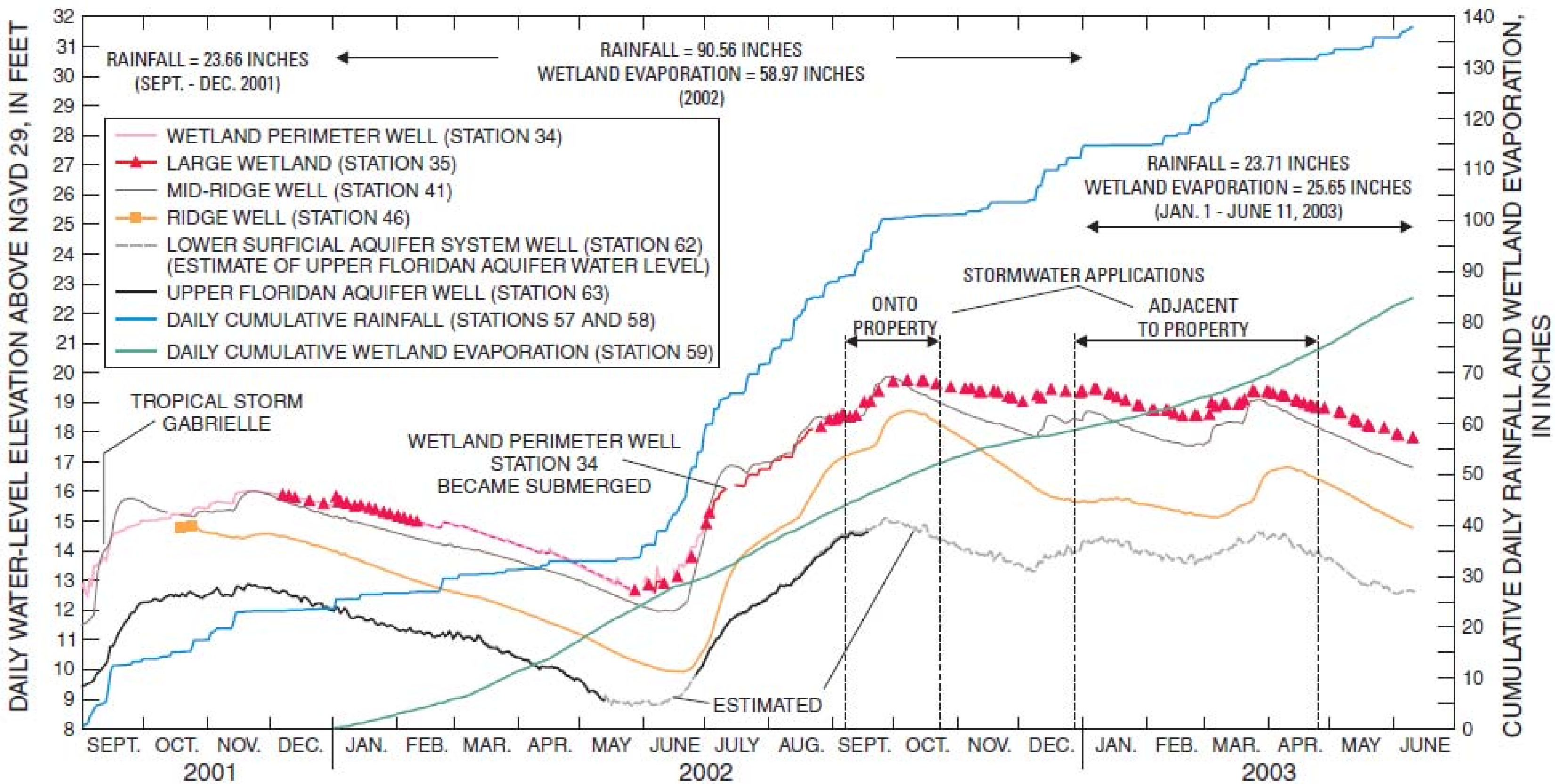

Figure B-18. Figure 20 from Knowles et al. (2005). Original caption reads: “Daily water levels, cumulative rainfall, and cumulative wetland evaporation for the large wetland, Lyonia Preserve (station numbers refer to figure 6 and table 1).”

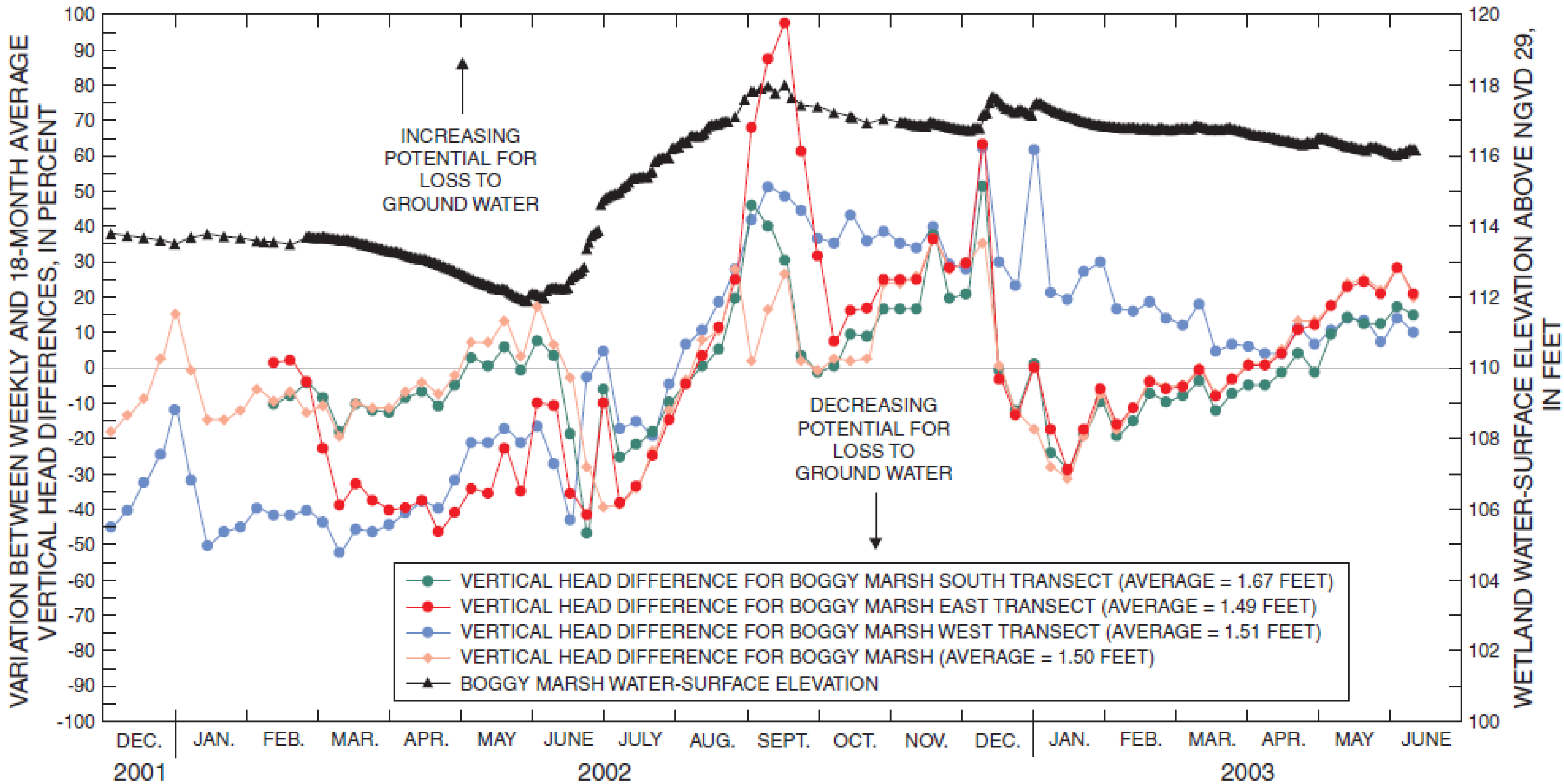

Figure B-19. Figure 32 from Knowles et al. (2005). Original caption reads: "Potential for exchange (vertical) between ground water and Boggy Marsh, Hilochee Wildlife Management Area."

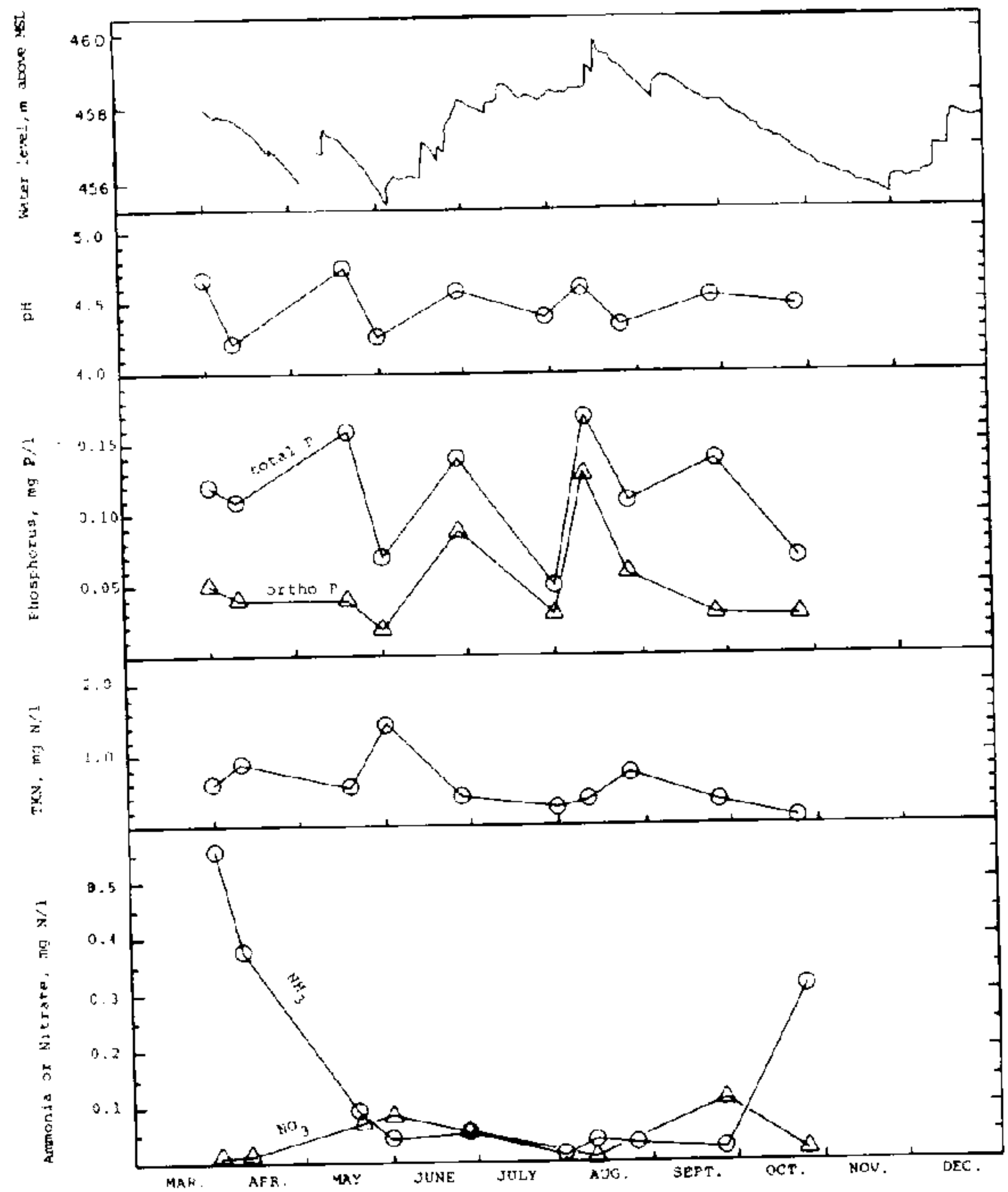

Figure B-20. Figure 3.1 from Mitsch (1984). Original caption reads: “Annual pattern of water level, pH, phosphorus, and nitrogen in the Austin Cary cypress dome pond.”

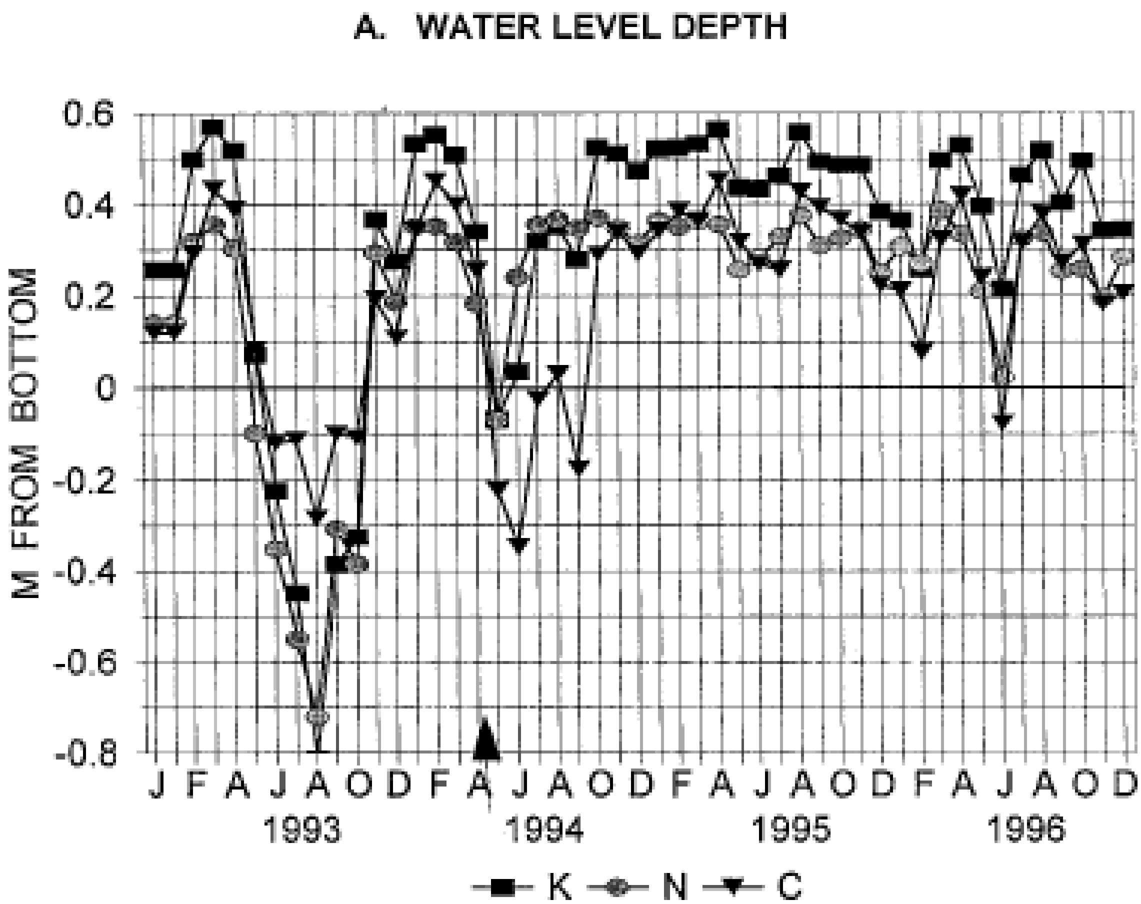

Figure B-21. Figure 6A from Riekerk and Korhnak (2000). Original caption reads: "A) Monthly wetland water-level depths." Three wetlands are depicted: K, N, and C.

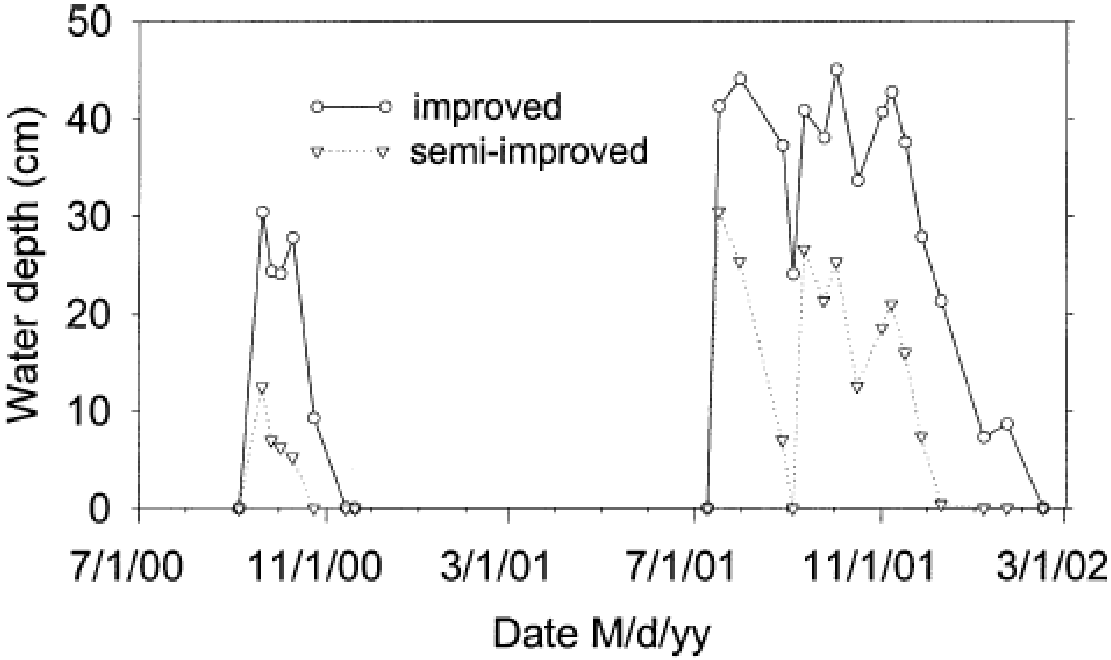

Figure B-22. Figure 1 from Steinman et al. (2003). Original caption reads: "Mean water depth in wetlands from improved and semi-native pastures revealing the seasonal nature of these systems. Data presented in this paper correspond only to the July through October 2001 period."

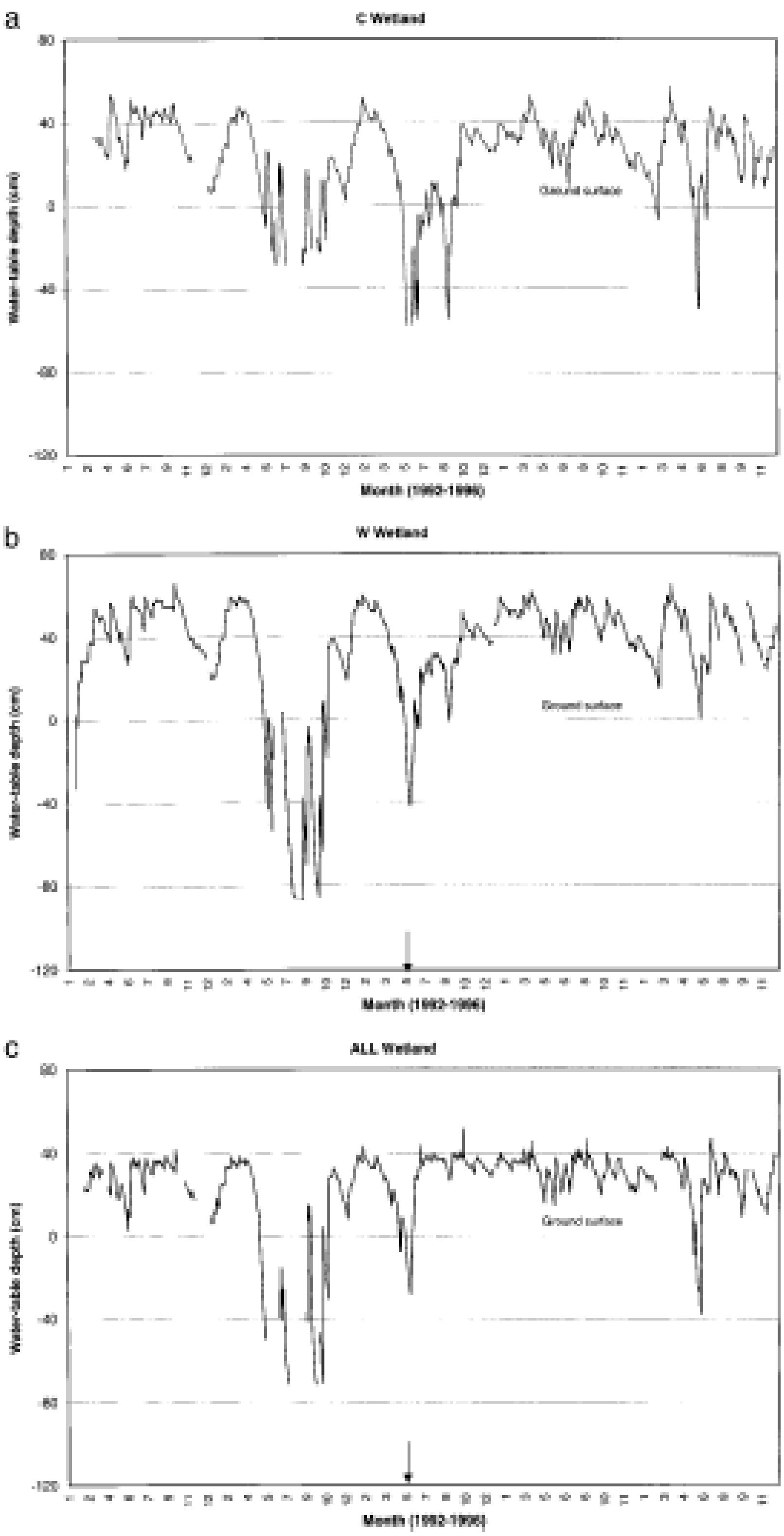

Figure B-23. Figure 1 from Sun et al. (2000). Original caption reads: "Daily water-level dynamics in three cypress wetlands during 1992-1996; the arrow indicates harvesting treatment completed."

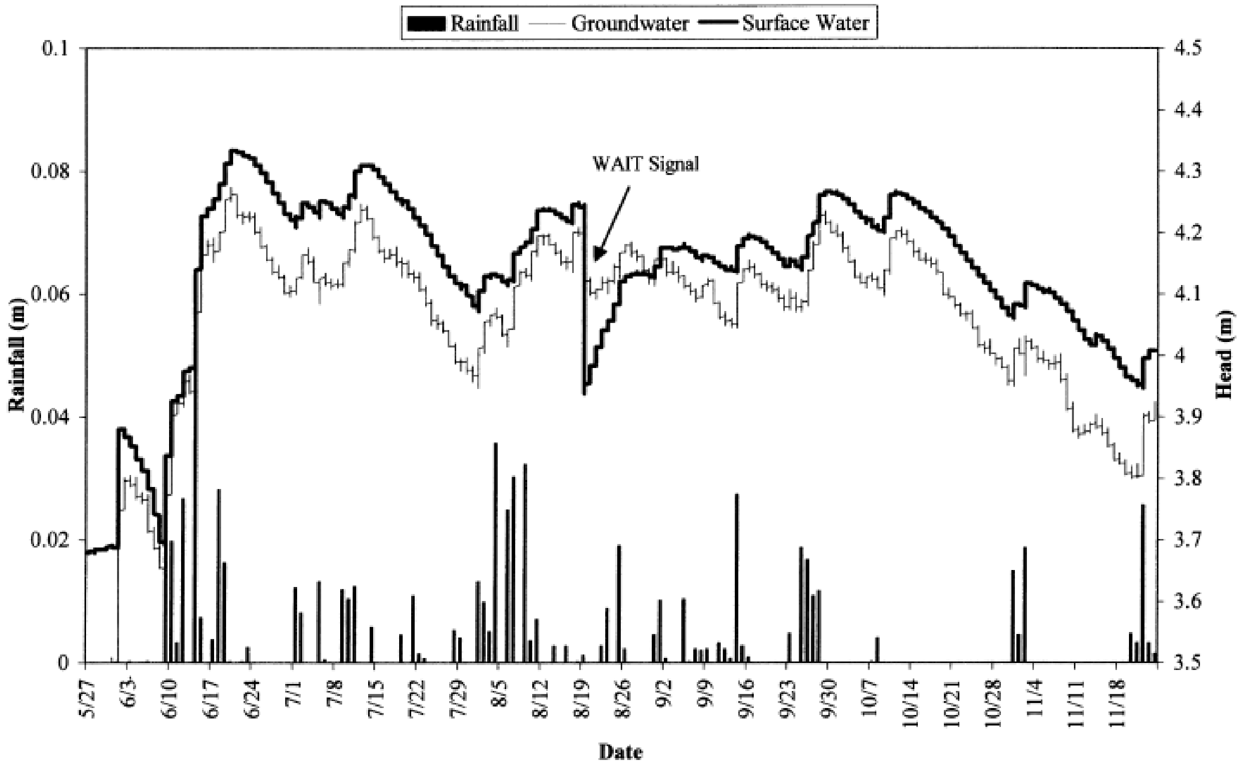

Figure B-24. Figure 3 from Wise et al. (2000). Original caption reads: "Long-term monitoring data including study period."

Appendix C – Wetland Hydrology Model

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DESCRIPTION of the MODEL

Given in Figure C-1 is a systems diagram of the wetland hydrology model. For a complete description of the symbols and resulting mathematics see Odum (1983). The systems diagram is a method of writing differential equations since each symbol is rigorously defined with explicit mathematical meaning. Differential equations are written directly from the diagram and programmed as difference equations in EXCEL.

Storages of water include surface water, soil water (as the interstitial waters in organic soils of the wetland), and groundwater. Inputs to surface water include rainfall ($J_{2.1}$), runoff from surrounding lands (called runin [$J_{2.2}$]), and "exchange" with soil water ($J_{4.1}$). Surface outflow from the wetland ($J_{4.2}$) occurs when surface water elevation exceeds the elevation of the wetland's outer edge. Evapotranspiration (J_3) includes evaporation from surface water ($J_{3.2}$) and transpiration ($J_{3.1}$). Ground water exchange with soil water ($J_{5.1}$) is driven by ground water elevation, which results from exchange with ground waters outside the system boundary ($J_{5.2}$). Numbered pathways in the diagram refer to corresponding line items in Table 1.

The water balance equations for each water storage are as follows:

$$\text{Surface water} = J_{2.1} + J_{2.2} - J_{3.2} - J_{4.1} - J_{4.2} \quad (1)$$

$$\text{Soil water} = J_{4.1} - J_{3.1} - J_{5.1} \quad (2)$$

$$\text{Ground water} = +/- J_{5.1} \quad (3)$$

Rainfall is programmed as daily events from any climate data set. Runoff from surrounding lands depends on slope and conditions of the watershed, and is programmed by adjusting rate coefficients. Water level within the wetland is controlled by inflows of rain and surface run-in , and outflows of transpiration (exchange with soil water), evaporation, and surface outflow. Since vegetation is rooted in soils, and transpired water is "extracted" from the soil (not the water column) a storage of soil water is included in the model. The amount of soil water is controlled by input from surface water and outflows via transpiration and seepage. Infiltration to surficial aquifer (ground water) is calculated as follows:

$$I_{gw} = K*A*dH/dL \quad (4)$$

where

K = 0.25
A = Area of wetland
dL = 50 meters

Evapotranspiration is calculated using a Hargreaves model as follows:

$$ET = 0.0135(T_S + 17.78)R_S \frac{a}{(585.5 - 0.55T_S)} \qquad (5)$$

where:

ET = Evapotranspiration (mm/day)

T_S = Mean Temperature (C °)

R_S = incident solar radiation (MJ/m^2/day or Langleys/m^2/day)

A = coefficient (a = 10 when Rs is expressed as Lengleys/day, or a = 238.8 when Rs is expressed as MJ/m2/day.

Surface outflow from the wetland occurs through a rectangular weir set at 0.5 meters above the wetland bottom. The following equation is used to calculate the discharge when water level is greater than 0.5 meters. ($Q=1.21\ LH^{1.5}$)

where:

Q = discharge in m^3/day

L = the length of weir in meters

H = head on the weir in meters

Table C-1 lists each of the pathways and storages within the wetland and the initial or programmed values for each. From these data rate coefficients for each pathway in the model were calculated.

Output from the model is displayed on the computer screen during each simulation run. The output shows a yearly hydrograph and also a maximum water level plotted against a section view through the wetland and adjacent upland.

Sensitivity analysis, calibration, and validation of the model was done using data from previously studied wetland systems (see Odum and Ewel, 1974, 1975, 1976, 1978, 1980, 1986; Heimburg and Wang, 1976 and Heimburg, 1986) and data collected from field measurements at the Lake County site.

Sensitivity analysis was conducted by evaluating the effect on model output of varying input parameters and flow pathway coefficients. Results obtained when parameters were increased and decreased by as much as 100% from programmed values were compared with expected model behavior (ie if an increase in a parameter should cause an increase in a flow or storage, the resulting behavior was compared with the expected result).

The model was calibrated against a data set for a cypress wetland in north central Florida (Heimberg and Wang, 1976). Total flows into and out of the simulated wetland were compared to measured parameters in the cypress wetland. Predicted water levels that were generated by the model were compared to measured water levels. In the absence of long term water level data for the Lake County site, the elevations of lichen lines and cypress knees were used as indicators of depth of inundation (Brown and Doherty, 2000).

Rate coefficients and input parameters were adjusted based on results of the sensitivity analysis during calibration until a good fit between measured values for the cypress wetland and the simulation model was obtained. Of primary concern was the total flows into and out of the surface wetland (rainfall, runin, ET, and seepage). The goal of calibration was to obtain simulation results for total flows within 5% of the measured values.

Simulation Runs

Water levels in the wetland were simulated for the base condition using actual precipitation for an average rainfall year. The base condition was 0% impervious surface, 1% watershed slope, four to one watershed to wetland ratio (4 hectares of watershed to 1 hectare of wetland), watershed soil hydrologic group "C", wetland water depth of 0.53 meters (1.75 feet), and an average rainfall year.

The model was then simulated for varying conditions and rainfall events to evaluate the area of upland immediately adjacent to the wetland that would be inundated. First different storm events were simulated during the rainy season by introducing a five, 10, 25, 50, and 100 year storm event on the 190th day of the year. Second, the percent impervious surface was increased in 10% increments to 50% to simulate development of the watershed.

Table C-1. Flows for Wetlands Model

Flow number	Name	Description	Footnote
J_1	Sunlight	Programmed daily from averages	1.
$J_{2.1}$	Rain	Programmed daily from precipitation data	2.
$J_{2.2}$	Surface runin	Function of surrounding upland watershed	3.
J_3	Evapotranspiration	Sum of evaporation and transpiration	4.
$J_{3.1}$	Transpiration by vegetation	Function of sunlight and and net production of veg.	5.
$J_{3.2}$	Evaporation from surface water	Function of sunlight and area of wetland	6.
$J_{4.1}$	Surface/soil	Programmed based on ET,	7.

	water interchange	and seepage	
$J_{4.2}$	Surface water outflow	Calculated output	8.
$J_{5.1}$	Seepage	Function of soil trasnmissivity and head of surface water	9.
$J_{5.2}$	Groundwater Exchange	Programmed	10.

Footnotes to Table 1.

1. **J_1 – Sunlight**. Average monthly solar radiation at Gainesville, Florida (Dohrenwend, 1978), based on a 20-year record from 1955 to 1975. Daily solar radiation calculated by fitting a sine function to average monthly radiation as follows:

Jan.	-	8480	langleys
Feb.	-	9945	"
Mar.	-	13703	"
Apr.	-	16307	"
May	-	17404	"
Jun.	-	15553	"
Jul.	-	14999	"
Aug.	-	15619	"
Sep.	-	13305	"
Oct.	-	12061	"
Nov.	-	10009	"
Dec.	-	8765	"

2. **$J_{2.1}$ – Rainfall**. Rainfall directly on wetland area. Programmed daily from NOAA data.

3. **$J_{2.2}$ – Runin**. Daily runin from surrounding watershed. Calculated from rainfall (NOAA data), soil moisture conditions (programmed minimum event for runoff), percent imperviousness, area of contributing watershed, and slope of watershed.

4. **J3 – Evapotranspiration**. Sum of Transpiration and Evaporation. Used measured evapotranspiration values (Heimberg and Wang, 1976) for calibration as follows:

Jan.	7mm
Feb.	12mm
Mar.	22mm

Apr.	141mm
May	143mm
Jun.	119mm
Jul.	105mm
Aug.	119mm
Sep.	80mm
Oct.	94mm
Nov.	32mm
Dec.	13mm
Total	887mm

5. **$J_{3.1}$ – Transpiration**. Transpiration of wetland calculated as average water use per increment of net production normalized to fit a growth curve for the growing season based on solar insolation. Water use was taken as 1775 g H_2O/g carbohydrate, average GPP is between 5.6 and 7.9 gC/m^2 day $^{-1}$ (depending on wetland type), and 30 g H_2O per 12 g Carbon fixed (Brown, 1978).

6. **$J_{3.2}$ – Evaporation**. Evaporation determined as difference between measured values of evapotranspiration (Heimberg and Wang, 1976) and calculated transpiration during the growing season. Evaporation during the dormant season is and equal to daily measured ET.

7. **$J_{4.1}$ - Surface / soil water interchange.** Calculated rate. When there is surface water in the wetland, interchange equals sum of transpiration, and seepage. When there is no surface water the rate is equal to transpiration

8. **$J_{4.2}$ – Surface outflow.** Surface water outflow from wetland is programmed to occur when water levels are greater than elevation of wetland edge. If there is no positive outfall, water levels increase in surrounding upland landscape.

9. **$J_{5.1}$ – Seepage.** Rate is a function of the height of water in wetland and height of groundwater outside the wetland. Rate equation was simplified from an empirically derived equation (Heimberg and Wang, 1976)

10. **$J_{5.2}$ – Groundwater exchange.** Programmed rate constant based on transmissivity. Generally the flow is considered groundwater recharge (ie waterflow is away from the wetland). Wetland can be programmed to be experience groundwater discharge if surrounding groundwater elevation is higher than water levels in the wetland.

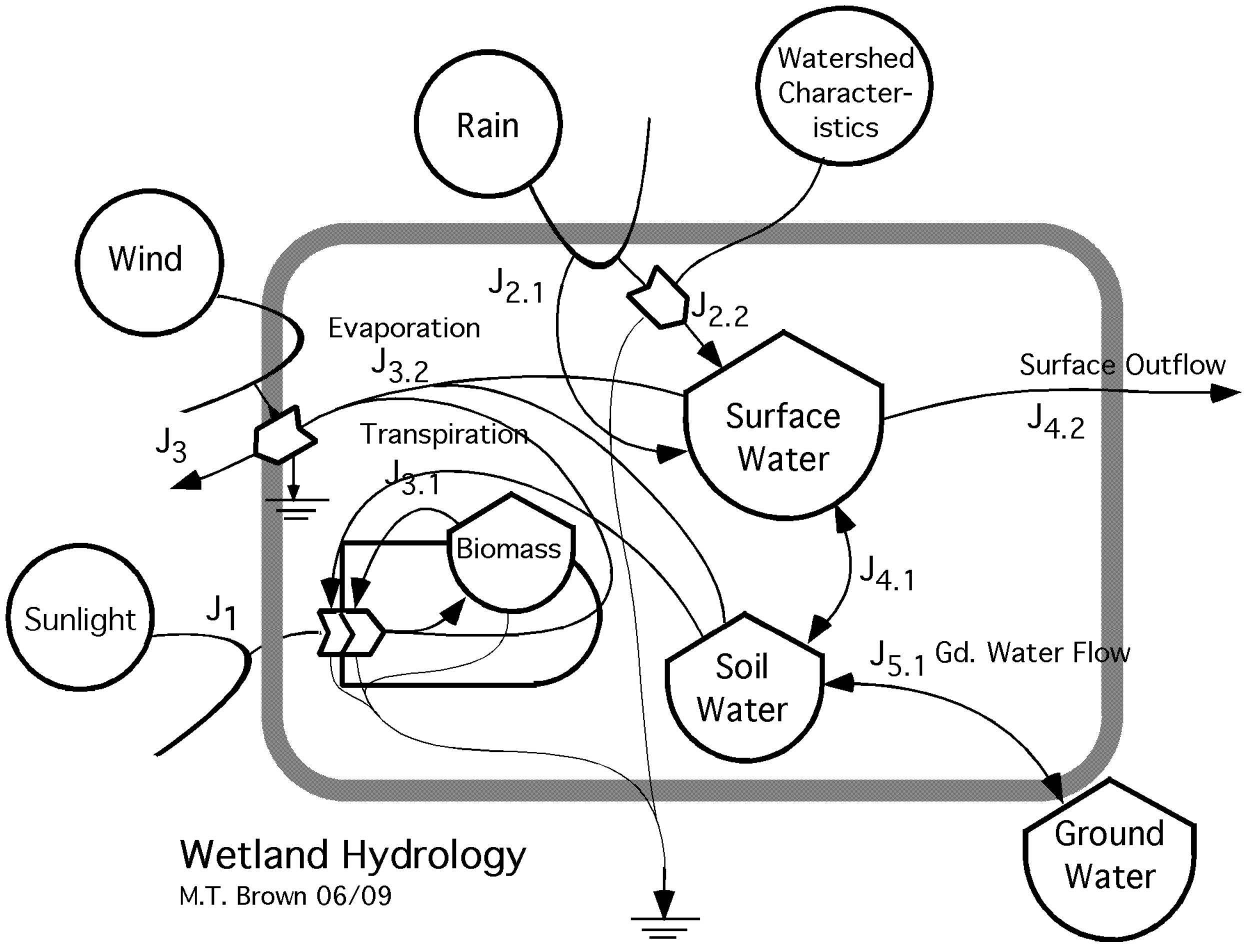

Figure C-1. Wetland Hydrology Model.

Appendix C Literature Cited

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