3-26-2007

Using Frequency Analysis to Determine Wetland Hydroperiod

Lisa D. Foster
University of South Florida

Using Frequency Analysis to Determine Wetland Hydroperiod

by

Lisa D. Foster

A thesis submitted in partial fulfillment
of the requirements for the degree of
Master of Science in Engineering Science
Department of Civil and Environmental Engineering
College of Engineering
University of South Florida

Major Professor: Mark A. Ross, Ph.D.
Mahmoud Nachabe, Ph.D.
Kenneth Trout, Ph.D.
G. Ladde, Ph.D.

Date of Approval:
March 26, 2007

Keywords: hydrology, time series, frequency analysis, spectral analysis, power spectrum density

Table of Contents

List of Tables

List of Figures

Using Frequency Analysis to Determine Wetland Hydroperiod

Lisa D. Foster

ABSTRACT

Wetlands are nominally characterized by, vegetation, presence of saturated soils and/or period and depth of standing water (inundation). Wetland hydroperiod, traditionally defined by the period or duration of inundation, is considered to control the ecological function and resultant plant community. This study seeks to redefine "hydroperiod" to incorporate both surface and subsurface water-level fluctuations, to identify predominant hydroperiod of different wetland types, and to find the range of the water-level fluctuations during the predominant hydroperiod durations. The motivation being that wetland ecological condition is controlled not just by the period of inundation but also by the proximity and depth to water-table and period of water-level fluctuation. To accomplish this, a frequency distribution analysis of water-table and stage levels in wetlands is performed. The conclusions of this study suggest a need to rethink current definitions and methodologies in determining hydroperiod. Redefining wetland hydroperiod taking into consideration depth to water-table, namely water-level periods and depths below ground surface, may also aid in the understanding of how fluctuations in water-levels in a wetland affect plant ecology.

Chapter One: Introduction

1.1 Introduction

Wetlands are a significant factor in the health and existence of other natural resources of the state, such as inland lakes, groundwater, wildlife, and designated Florida Outstanding Waters. Florida's wetland statute recognizes many benefits provided by wetlands including: flood and storm control by the storage capacity of wetlands; wildlife habitat by providing breeding, nesting, and feeding grounds and cover for many forms of wildlife and waterfowl; protection of subsurface water resources and recharging groundwater supplies; pollution treatment; and erosion control by serving as sedimentation areas and filtering basins. Wetlands are also beneficial to recreation and tourism in Florida, thus improving the economy.

Wetlands occur where surface water collects and/or groundwater interacts with land, inundating the area for extended periods of time (Tiner, 1996). The Clean Water Act defines the term 'wetlands' as "those areas that are inundated or saturated by surface or groundwater at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, bogs, and similar areas." For an area to be considered a wetland under this definition, that area must contain: water at or near the surface for a period of time (wetland hydrology), wetland plants (hydrophytic vegetation), and periodically anaerobic soils caused by prolonged inundation (hydric soils) (Dennison and Berry, 1993; Tiner, 1996). The hydrological regime of each wetland differs in frequency and magnitude of high water, duration, timing, and temporal sequences of high and low water (Zedler, 2001).

1.2 Background Information

1.2.1 Wetland Hydrology

Many studies have shown that wetlands reduce flooding, augment low flows, and/or recharge groundwater. Conversely, there are also many examples showing that wetlands increase flooding, reduce low flows, and/or act as a barrier to recharge (Bullock and Acreman, 2003). Differences in hydroperiod, fire frequency, accumulation of organic matter, and source of water can explain the range of structural and functional diversity of Florida wetlands. Florida's combination of high fire frequency, low topography, high surficial groundwater-tables, and seepage to/from deep groundwater aquifers has produced an unusually diverse array of wetlands (Ewel, 1990).

In the past, vegetation was used exclusively in the identification of wetlands and their boundaries. More current approaches, however, take into account vegetation, soil, and hydrologic characteristics for the identification and delineation of wetlands (Tiner, 1991). To assist in the identification of wetlands in the United States, the Soil Conservation Service developed a list of hydric soils and the U.S. Fish and Wildlife Service prepared a list of wetland plants (Tiner, 1996). In addition, the National Wetlands Inventory, conducted under the direction of the U.S. Fish and Wildlife Service, devised a hierarchical wetland classification system based on hydrologic, geomorphologic, chemical, and biological characteristics (Ewel, 1990). There is, however, "no single, correct, indisputable, ecologically sound definition for wetlands, primarily because of the diversity of wetlands and because the demarcation between dry and wet environments lies along a continuum" (Cowardin et al., 1979).

1.2.2 Water Budget

Wetlands exert a strong influence on the hydrologic cycle, however, the relationship between wetland type and the specific hydrologic functions they perform is complex (Bullock and Acreman, 2003). Hydrology remains a component of wetland ecosystems that has not been extensively investigated, though the importance of hydrologic conditions to the structure and function of wetlands has long been recognized (Shaffer et al., 2000). Wetland vegetation and function depend upon the frequency, duration, and depth of the water, whether it be surface or groundwater (Marble, 1992). "Hydrology leads to a unique vegetation composition but can limit or enhance species richness" (Mitsch and Gosselink, 2000). Hydrology, therefore, plays a critical role in the functional ability and health of a wetland.

"The major components of a wetland's water budget are precipitation, evapotranspiration, and overbank flooding in riparian wetlands; surface flows, groundwater fluxes, and tides in coastal wetlands" (Mitsch and Gosselink, 2000). Rainfall is the ultimate source of fresh water in central Florida. Most of the precipitation is, however, recycled back to the atmosphere by evapotranspiration (Clemens et al., 1984). Some precipitation is also retained by the overlying canopy, too. This is referred to as interception. This water is not "lost" in relation to the water budget, however, as it may reduce transpiration losses (Mitsch and Gosselink, 2000). When sufficient precipitation does overcome losses to evapotranspiration and hydrostatic capillary retention in the unsaturated zone, the remaining water can percolate to the water-table, and recharge the aquifer system. When the infiltration capacity of the soil is exceeded by precipitation rates or the ground becomes saturated, excess water becomes surface runoff (O'Reilly, 2004). Hydraulic inflows and outflows, such as precipitation, surface runoff, and groundwater inputs, together with wetland storage characteristics, control water depth, flow patterns, stage, duration, and frequency of flooding in wetlands (Mitsch and Gosselink, 2000). Mitsch and Gosselink (2000) expressed the general balance between water storage and inflows and outflows as:

$$\frac{\Delta V}{\Delta t} = P_n + S_i + G_i - ET - S_o - G_o \pm T$$

where V = volume of water storage in wetlands

$\Delta V/\Delta t$ = change in volume of water storage in wetland per unit time

P_n = net precipitation (precipitation-interception)

S_i = surface inflows, including flooding streams

G_i = groundwater inflows

ET = evapotranspiration

S_o = surface outflows

G_o = groundwater outflows

T = tidal inflow (+) or outflow (-)

Mitsch and Gosselink (2000) sugested that the average water depth at any time could be described as:

$$\overline{d} = \frac{V}{A}$$

where A = wetland surface area.

Although these are the major components of a wetland water budget, the terms vary in importance according to the type of wetland (Mitsch and Gosselink, 2000.) The hydroperiod of a wetland ultimately results from the time variability of all of these components of the water budget. Relatively small changes in the water cycle over extended time periods can drastically effect the hydrperiod and this can in turn change the biotic and abiotic stability of a wetland (Dennison and Berry, 1993)

1.2.3 Hydroperiod

The ecological characteristics of a wetland are controlled by the presence and duration of saturated soils or standing water for part of the year (Ewel, 1990), known as the hydroperiod. The hydroperiod is the result of the balance between inflows and outflows of water, wetland storage, and the subsurface soil, geology, and groundwater conditions (Mitsch and Gosselink, 2000). Hydroperiod refers to frequency, duration, and depth of the water within the wetland. The periodicity of inundation, permanent, seasonal, or intermittent, is the ecological and functional control for many wetlands. For those wetlands sustained by seepage, subsurface waterlogging or watertable rise, however, it is the periodicity of water-table fluctuations with respect to the root zone that maintains the wetland (Semeniuk and Semeniuk, 1997). Hence, the water budget and the storage capacity of the wetland (above and below ground) ultimately define the hydroperiod. Because the storage capacity of the wetland plays a critical role in defining hydroperiod, fluctuations in the depth to water-table must be taken into consideration.

It is still not known exactly how fluctuations in the hydroperiod of a wetland affect plant and animal communities (Zedler, 2001). Hydroperiod affects soil aeration, which in turn influences the ability of plants to survive and reproduce. During prolonged inundation, oxygen in the root zone is depleted and concentrations of soluble iron, manganese, and even hydrogen sulfide increase, thereby creating stressful conditions on roots (Ewel, 1990). Only a small portion of the thousands of species of vascular plants on Earth have adapted to survive in waterlogged soils (Mitsch and Gosselink, 2000). Wetlands, therefore, are inhabited by only a particular subset of plant species. Wetlands with longer hydroperiods may, consequently, contain fewer species and serve unique functions. Species richness is also dependent on fire frequency and depth of organic matter accumulation, because these factors create variations in water depth, residence time, and quality in wetlands with similar hydroperiod (Ewel, 1990).

Water-levels in most wetlands fluctuate seasonally, daily or semi-daily, or unpredictably. Wetland hydroperiods that vary greatest between high and low water-levels are often caused by flooding "pulses", which occur seasonally or periodically (Junk et al., 1989). Pulsing hydroperiod and flowing conditions enhance primary productivity and other ecosystem functions, which are frequently depressed by stagnant conditions (Mitsch and Gosselink, 2000).

De Steven and Toner (2004) found that while wetland vegetation integrates the influence of many ecological factors, wetland hydrologic regime was most strongly correlated with vegetation type. Statistical methods of classification have been increasingly used in the characterization of plant communities including wetland plant communities. Traditionally, however, the classification of wetlands follows simple schemes, which are based on a combination of characteristics, such as geomorphism, hydroperiod, location, physiognomy, species dominance, salinity, or topography (Pinder and Rosso, 1998). Although used for characterization of plant communities, use of statistical methods for the analysis of wetland hydroperiod have not gained popularity.

Water-level variability in wetlands is important to biological and hydrological function. It is, therefore, of keen interest to quantify the time scale and magnitude of the water-level fluctuations in order to fully understand hydroperiod. Because the variability is also periodic and recurring, it lends itself to a time series investigation in the frequency domain. This study attempts to quantify hydroperiod using spectral analysis of observed water-level data from various wetlands in West-Central Florida.

1.3 Objective of Study

Wetlands exhibit episodic (storm events), seasonal, and yearly patterns of fluctuation in surface and subsurface water (Dennison and Berry, 1993). West-Central Florida wetlands are influenced by a shallow and rapidly fluctuating water-table and regular high intensity rainfall events, yet depth to the water-table is not typically included as a parameter in the definition of hydroperiod. There is little information regarding the influence of the depth to the water-table in the classification of wetlands. Because wetland ecological condition is controlled not just by the period of inundation, but also by the proximity and depth to the water-table (controlling the dry periods), there is a need to thoroughly define hydroperiod incorporating the depth to water-table. Mitsch and Gosselink (2000) observed a wet and dry season for Big Cypress Swamp near the Florida Everglades, however, to date an attempt to quantify hydroperiod as a whole has not been done. This study seeks to analyze wetland hydroperiod using Fourier Transformation and Time Series analysis considering the frequency domain of observed water-levels, both above and below the land surface, in order to quantify and more accurately define hydroperiod.

Spectral analysis of the individual water-level time series data can provide an invaluable insight into the temporal and periodic behavior of hydrological processes (Hegge and Masselink, 1996). For this reason, spectral analysis will be used in an attempt to identify dominant frequencies (spectral peaks) in observed water-level time series. The dominant frequencies are representative of the significant components of the hydroperiod through the entire range of water-level fluctuations. Hence, spectral analysis provides a powerful tool to evaluate hydroperiod. By incorporating the perspective of water-table depth, and therefore the complete range of wetland water-level fluctuations, this approach should more fully quantify hydroperiod.

Specific objectives of this study were to: (1) redefine and quantify wetland "hydroperiod", incorporating both surface and subsurface water-level fluctuations using standard frequency analysis (2) identify predominant hydroperiods of different wetlands, (3) find the range of the water-level fluctuations associated with predominant hydroperiods, (4)investigate whether hydroperiod can be associated to a given type of wetland, and (5) very simply investigate whether the effects of pumping can be observed in the resultant hydroperiod of a wetland.

Chapter Two: Methodology

2.1 Study Area

The study area chosen is contained within a typical coastal plain environment incorporating parts of Pasco, Pinellas, Hillsborough, Polk, Lake, and Sumpter counties, which are located in the Southwest Florida Water Management District (SWFWMD) domain in West-Central Florida (Figure 1). The District is approximately 10,400 square miles encompassing 16 counties with a population of 3.1 million people. The climate of West central Florida is classified as humid subtropical. A strong climatic cycle of a cool, dry season and a warm, rainy season exists, however, spatial and temporal changes in daily temperature ranges can exceed the average annual ranges (Chen and Gerber 1990). The mean annual temperature is 73°F. The long-term average annual precipitation of the region is 52 inches per year, but precipitation shows substantial spatial and temporal variability (Clayback, 2006; Scott, 2006). On average, the driest months of record are November and April, with the wettest being July and August (NOAA, 2006). The mean annual open-water evaporation rate for the region is 50-52 inches per year (Clayback, 2006; Ruskauff et al., 2003).

Florida's unique geologic history has produced a sculptured topography. Several distinct physiographic features have been identified in this region. These features reflect interactions between the geology and both the surface- and ground-water systems over geologic time. Paleoshorelines that separate several marine plains or terraces, recognized by Cooke (1945) and MacNeil (1950), generally correspond to the physiographic boundaries (Schmidt, 1997; Lewelling, 1998).

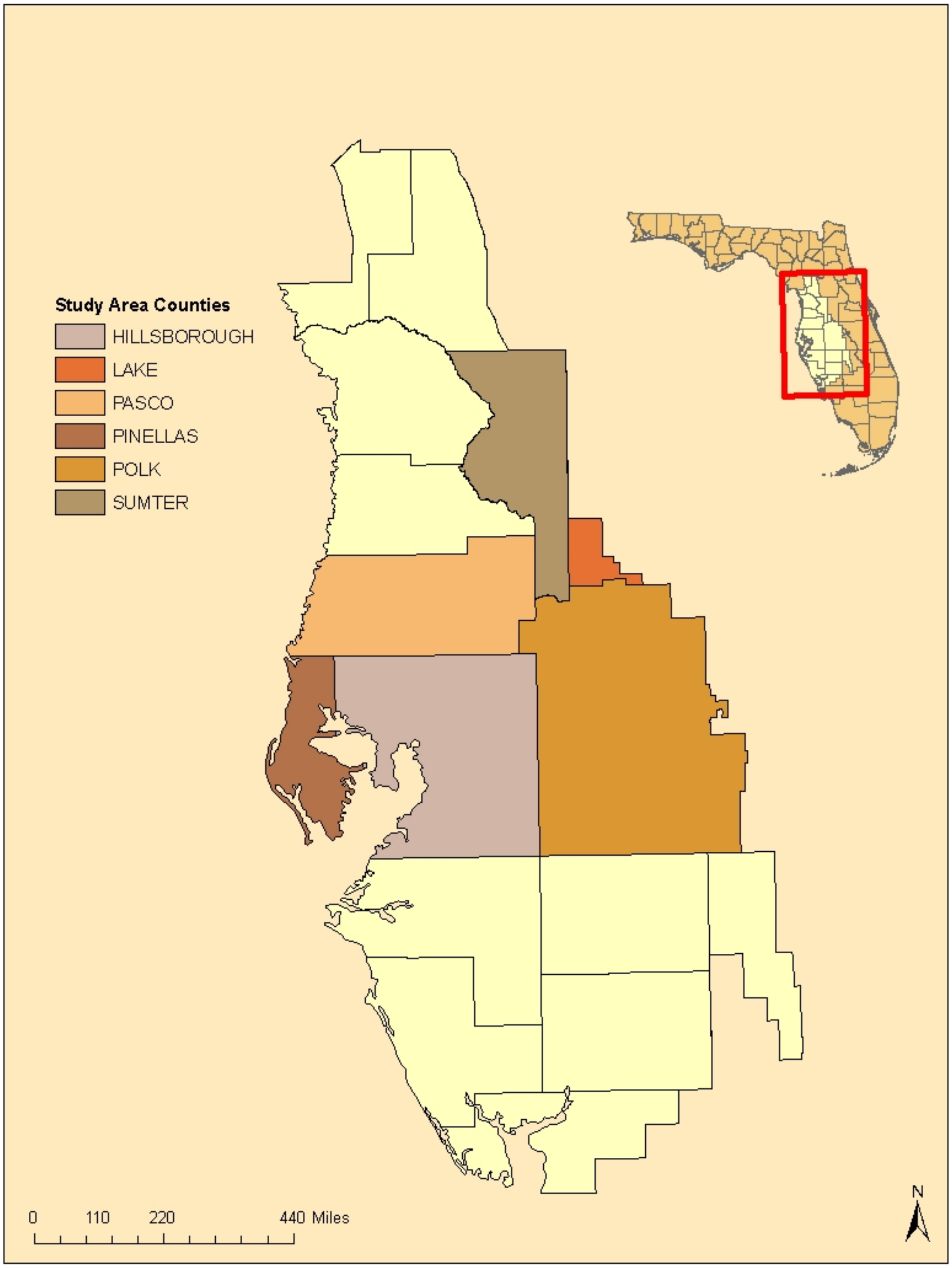


Figure 1: SWFWMD Domain: West-Central Florida Study Area Counties

The primary physiographic features within the study area counties are (1) the Northern and Southern Gulf Coastal Lowlands, (2) the Western and Central Valleys, (3) the Marion, Polk, and Lake Uplands, (4) the Brooksville, Lakeland, Winter Haven, and Lake Wales Ridges, and (5) the Tsala-Apopka and Osceola Plains (White, 1970; SWFWMD, 2000). A map of the physiography within the counties of interest, adapted from White (1970), is shown in Figure 2. The physiographic regions of particular interest in this study include (1) the Gulf Coastal Lowlands, (2) the Western Valley, and (3) both the Polk and Lake Uplands.

The Gulf Coastal Lowlands province consists of scarps and marine terraces of aeolian sands. The terraces range from near sea level to 100 ft NGVD. The Gulf Coastal Lowlands lie to the west of the Brooksville Ridge. Included is the area of the Big Cypress Swamp, as well as the extensive lowland lakes region in northwest Hillsborough County and south-central Pasco County. Soils are uniform fine sand, with little organic material and the landscape contains extensive flatwood pine, oak, and saw palmetto (SWFWMD, 1996; SWFWMD, 2000; Armstrong et al., 2003).

The Western Valley physiographic region lies to the south of the Brooksville Ridge and to the east of the Gulf Coastal Lowlands. It runs along the eastern borders of Pasco and Hernando Counties and up through the middle of Sumter County. The area is an erosional basin with sluggish surface-water drainage and many karst features. The region contains Karst limestone, which is overlaid with a thin layer of sand and clay. Springs and sinkholes are common. Elevations range from 10 to 140 feet, with poorly drained swamps and marshes in the lower elevations and pine flatwoods in the higher elevations (SWFWMD, 1996; SWFWMD, 2000; Armstrong, 2003).

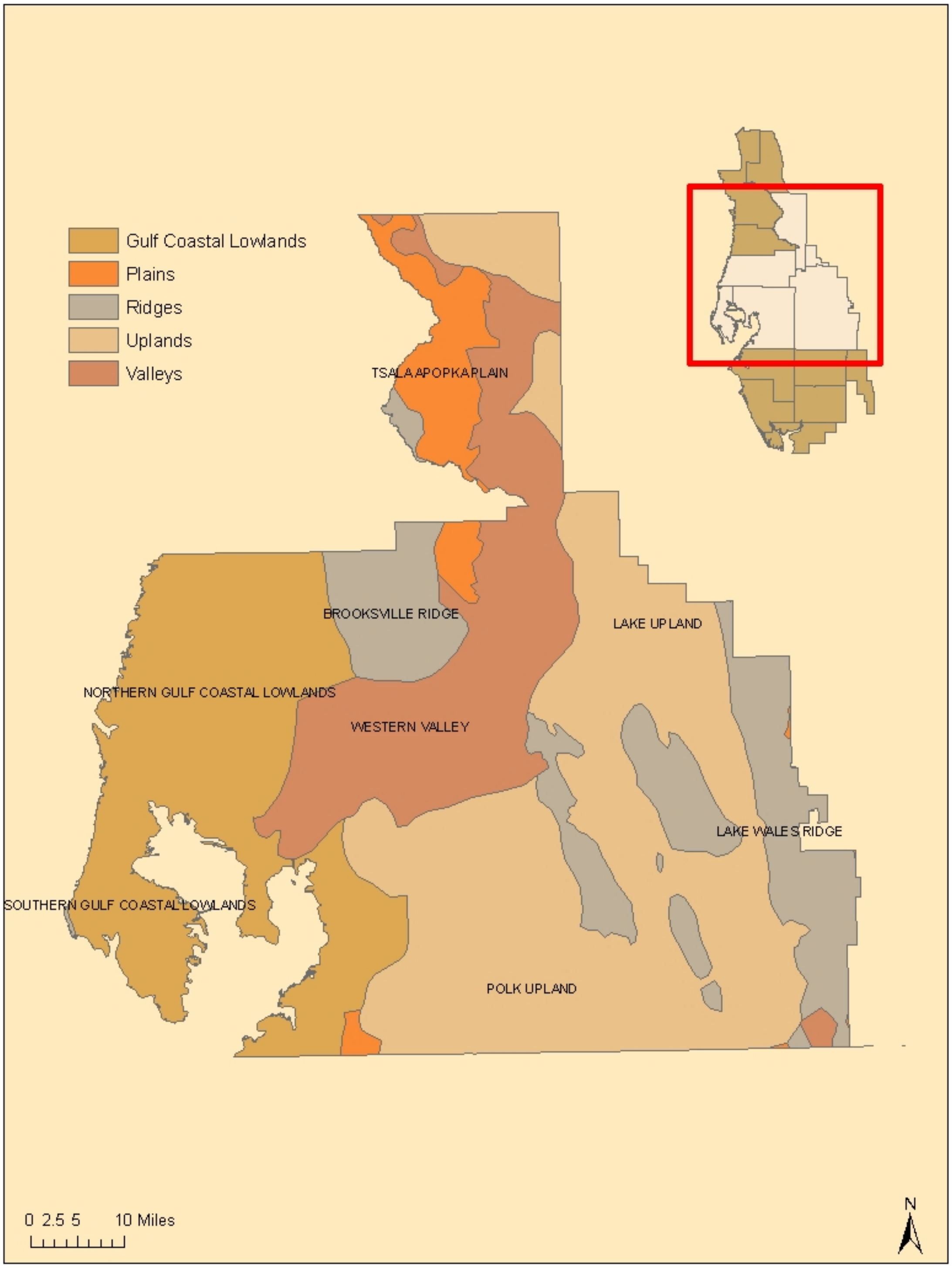


Figure 2: Physiographic Regions of West-Central Florida (Modified from White, 1970)

Moderate water-table depths and land-surface elevations and relief are characteristic of the upland physiographic regions. They contain numerous shallow lakes and closed-basin lakes, which can become connected during high water. Surface water can sometimes take many weeks to drain following extended periods of heavy rainfall due to the poor drainage (Knowles et al., 2002). The upland physiographic regions of interest are the Polk and Lake Uplands.

White (1970) classified the region of central or mid-peninsular Florida as the Polk Uplands and the Lake Wales Ridge physiographic regions. The Polk Uplands region lies to the east of the coastal lowlands in Hillsborough County and to the west of the Lake Wales Ridge in Polk County. The area extends north through Eastern Hillsborough and Western Polk Counties to the Western Valley and the Lake Upland, respectively. Land surface elevations are typically between 100 and 130 feet above sea level, The Polk Upland is characterized by flatwoods, wetlands, and lakes that occupy a poorly drained plateau, underlain by deeply weathered sand and clayey sand (Lewelling, 1998; Brooks, 1981; White, 1970). Brooks (1981) described the region as an extensive erosional basin filled with phosphatic and clayey sands.

The Lake Upland area extends northward from the Polk Upland in Polk County to Central Lake County where it meets the Central Valley region. The region contains gently rolling hills with elevations ranging from 50 to 200 ft. above sea level (White, 1970; Knochenmus and Hughes, 1976).

2.2 Data Collection

Water-level data used in this study were obtained from thirty-four wells in the four described physiographic regions. Eleven of the observation wells are located in the Gulf Coastal Lowlands, two are in the Polk Upland, one well is in the Lake Upland,

and the remaining 20 are located in the Western Valley (Figure 3). Table 1 lists all of the observation wells by ID number and their respective physiographic regions.

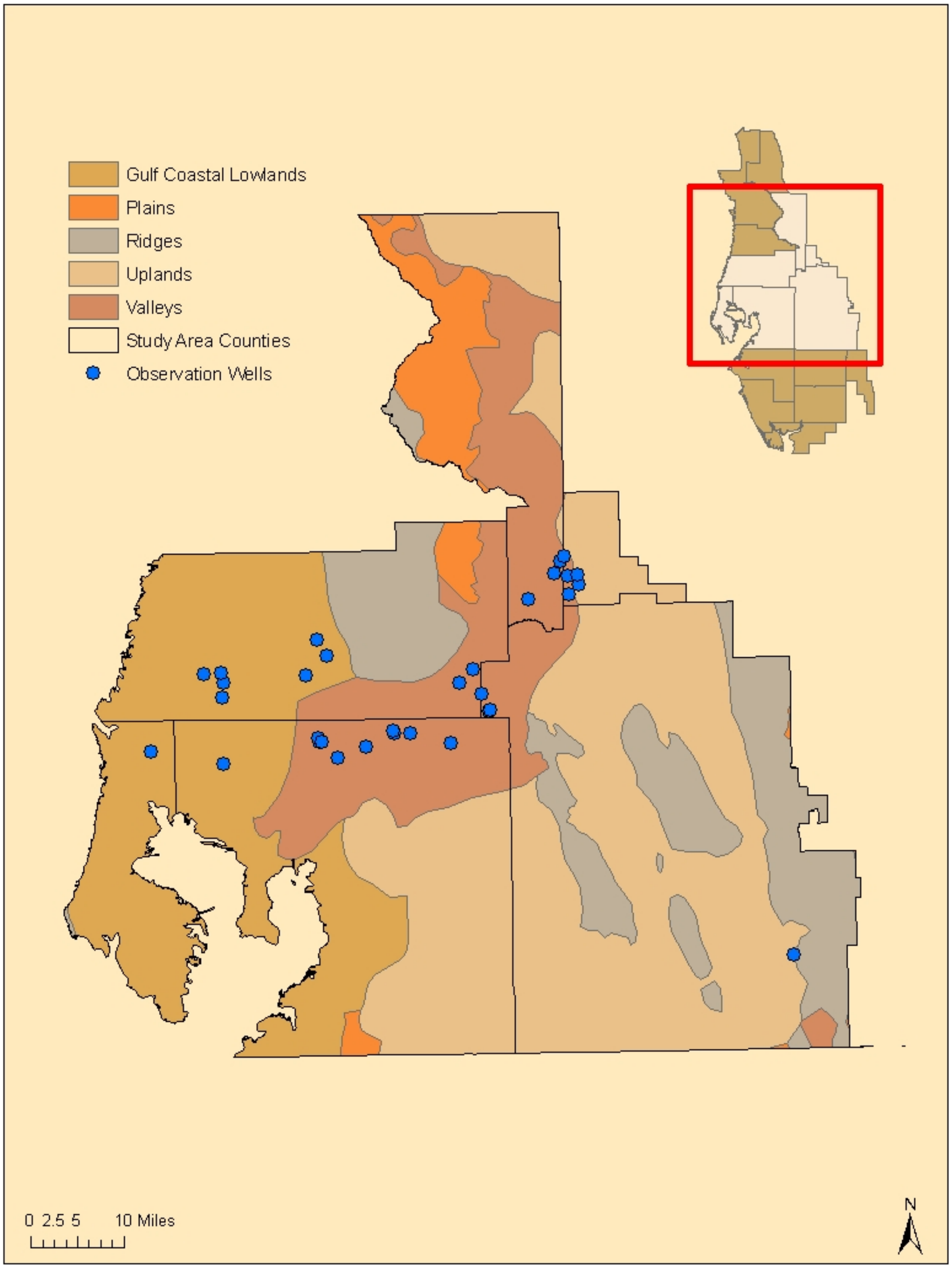


Figure 3: Location of Observation Wells

Table 1: Observation Wells and Physiographic Regions

Observation Well ID	Physiographic Region
598	Gulf Coastal Lowlands
1918	Gulf Coastal Lowlands
1929	Gulf Coastal Lowlands
1932	Gulf Coastal Lowlands
1935	Gulf Coastal Lowlands
1938	Gulf Coastal Lowlands
1944	Gulf Coastal Lowlands
1946	Gulf Coastal Lowlands
2159	Gulf Coastal Lowlands
10958	Gulf Coastal Lowlands
10965	Gulf Coastal Lowlands
1989	Lake Upland
1990	Lake Upland
10896	Polk Upland
1021	Western Valley
1954	Western Valley
1959	Western Valley
1960	Western Valley
1961	Western Valley
1966	Western Valley
1969	Western Valley
1977	Western Valley
1978	Western Valley
1980	Western Valley
1981	Western Valley
1987	Western Valley
1988	Western Valley
1991	Western Valley
1992	Western Valley
1995	Western Valley
2060	Western Valley
2062	Western Valley
2064	Western Valley
2066	Western Valley

The Florida Land Use, Cover and Forms Classification System (FLUCCS) was used to further distinguish the observations wells by location within a specific wetland type (Figure 4). The FLUCCS is a standardized numeric code developed by the Florida Department of Transportation for the classification of land use and plant communities (Florida Department of Transportation, 1999). The wetlands of interest in this study include: (1) Cypress, (2) Hardwood, (3) Marsh, (4) Wet Prairie, and (5) Stream and Lake Swamps (Figure 4). Table 2 lists each observation well, the respective code and corresponding wetland type.

Table 2: Observation Wells with Corresponding FLUCCS and Wetland Type

Well ID	FLUCCS	Wetland Type
598	615	Stream and Lake Swamps; Bottomland (Bot)
1021	615	Stream and Lake Swamps; Bottomland (Bot)
1969	615	Stream and Lake Swamps; Bottomland (Bot)
1918	621	Cypress Isolated (Cyp)
1929	621	Cypress Isolated (Cyp)
1932	621	Cypress Isolated (Cyp)
1935	621	Cypress Isolated (Cyp)
1938	621	Cypress Isolated (Cyp)
1961	621	Cypress Isolated (Cyp)
1978	621	Cypress Isolated (Cyp)
1987	621	Cypress Isolated (Cyp)
1988	621	Cypress Isolated (Cyp)
1989	621	Cypress Isolated (Cyp)
1990	621	Cypress Isolated (Cyp)
1991	621	Cypress Isolated (Cyp)
1992	621	Cypress Isolated (Cyp)
2064	621	Cypress Isolated (Cyp)
2159	621	Cypress Isolated (Cyp)
10958	621	Cypress Isolated (Cyp)
10965	621	Cypress Isolated (Cyp)
1944	621	Cypress Lake fringe (Cyp)
1946	630	Wetland Forest Mixed (Mix)
2062	630	Wetland Forest Mixed (Mix)
1980	630	Wetland Forest Mixed (Mix)
1995	630	Wetland Forest Mixed (Mix)
1954	641	Marsh Isolated (Msh)
1959	641	Marsh Isolated (Msh)
1960	641	Marsh Isolated (Msh)
1966	641	Marsh Isolated (Msh)
2060	641	Marsh Isolated (Msh)
2066	641	Marsh Isolated (Msh)
1977	643	Wet Prairie (WP)
1981	643	Wet Prairie (WP)
10896	643	Wet Prairie (WP)

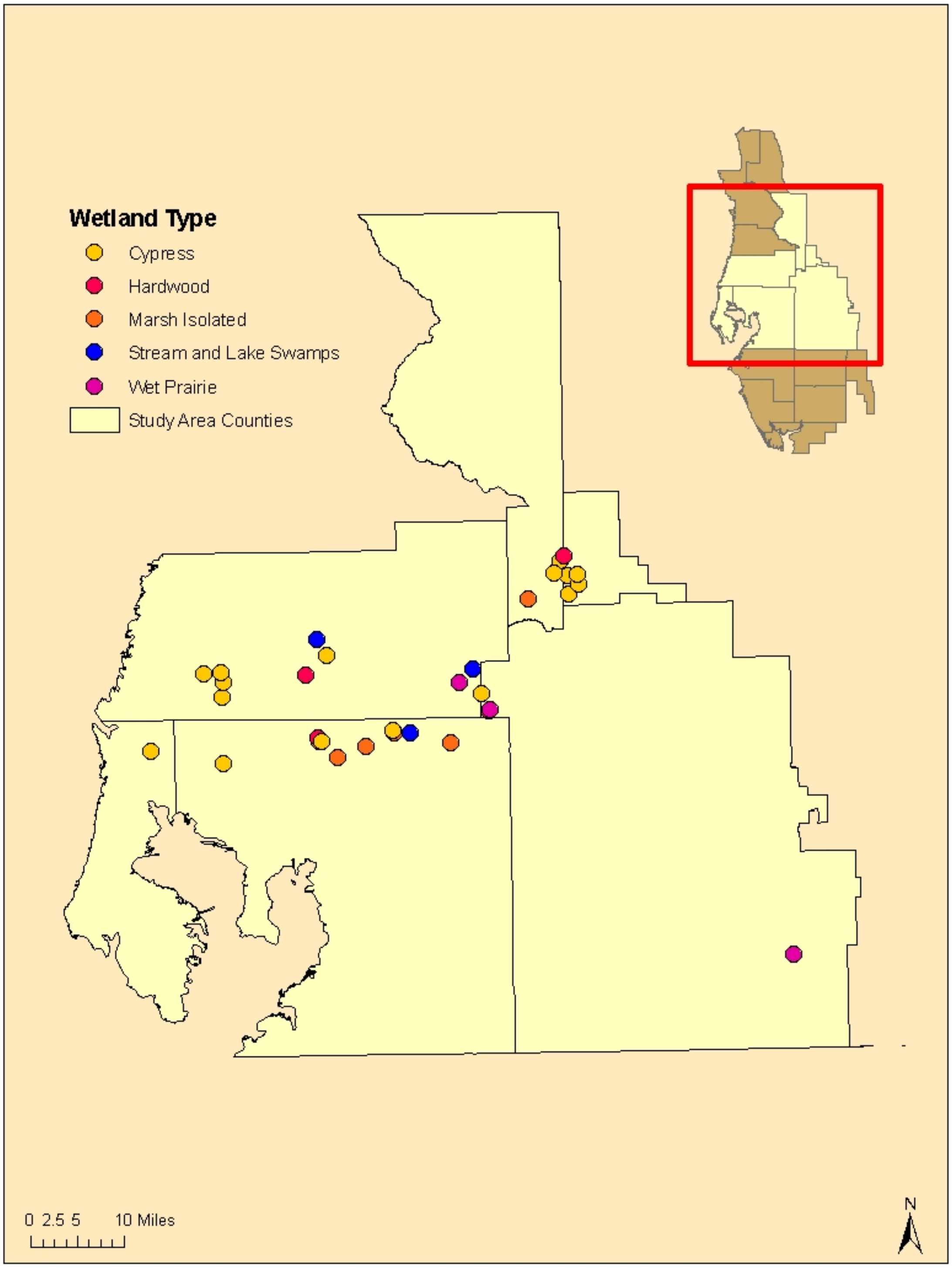


Figure 4: Observation Wells by Wetland Type

Three of the observation wells used in this study are classified as FLUCCS 615, stream and lake swamps. This community is often referred to as bottomland or stream hardwoods. Bottomland usually occurs on flooded soils along stream channels and in low spots within river, creek, and lake floodplains or overflow areas. This category has a wide variety of predominantly hardwood species, of which some of the more common components include red maple, river birch, water oak, sweetgum, willows, tupelos, water hickory, bays, and water ash and buttonbush. Associated species include cypress, slash pine, loblolly pine and spruce pine. The dominant trees in bottomlands, however, are usually buttressed hydrophytic trees such as cypress and tupelo. The understory and ground cover are generally very sparse (FNAI, 1990; FDOT, 1999). Periods of inundation in stream and lake swamps are typically very short, except in floodplain depressions containing clay and organic matter, which retain water for more extended periods (Ewel, 1990).

Eighteen of the thirty-four wells were located in FLUCCS code 621, cypress. Cypress, a conifer, is the most common wetland tree in Florida. Cypress swamps occur in a variety of physiographic areas ranging from isolated basins to broad, flat floodplains. Cypress trees are usually the dominant species in swamps with fluctuating water-levels. Tolerances to varying water-levels, anaerobic sediments, and nutrient conditions allow for wide distribution through much of the southeastern and south-central portions of the U.S. Cypress swamps typically experience a recognized seasonally fluctuating water regime, however, intermittent droughts, resulting in dry swamp conditions, can last for several months. Seasonal or periodic drydowns are important, though, as cypress seeds require nonflooded soil to germinate. Taller trees tend to occur toward the center of these swamps due to a longer period of inundation (Ewel, 1990; Dennison and Berry, 1993).

The cypress community is composed of either pure or predominant pond cypress or bald cypress. In the case of pond cypress, common associates are swamp tupelo, slash pine and black titi. Common associates of bald cypress include water tupelo, swamp cottonwood, red maple, American elm, pumpkin ash, Carolina ash, overcup oak and water hickory. On drier sites, bald cypress may also be associated with laurel oak, water oak, sweetgum and sweetbay. It remains unresolved, however, whether the two varieties of cypress are taxonomically different (Dennison and Berry, 1993; FDOT, 1999).

Four of the wells are classified as FLUCCS code 630, wetland mixed forest. This category includes mixed wetlands forest communities in which neither hardwoods nor conifers achieve a 66 percent dominance of the crown canopy composition (FDOT, 1999). Examples of hardwoods that are common in mixed forest wetlands are Black Gum, Water Tupelo, Oaks, Willows, and Melaleuca. Confers may include cypress, pines, and cedars (Ewel, 1990; FDOT, 1999).

Six of the observation wells are FLUCCS 641, fresh water marsh wetlands. Fresh water marshes, found in both palustrine (isolated) and floodplain environments, are comprised of relatively uniform herbaceous, usually emergent, plants. The communities included in the fresh water marsh category are characterized by having one or more of the following predominant species: Sawgrass Cattail, Arrowhead, Maidencane, Buttonbush, Cordgrass, Giant Cutgrass, Switchgrass, Bulrush, Needlerush, Common Reed, and Arrowroot. Marsh vegetation is well adapted to water-level fluctuations. Annual species, for example, sprout during dry periods and are succeeded by perennials during periods of inundation (FDOT, 1999; Dennison, 1993).

Water in inland fresh water marshes comes from rainwater, surface runoff, and groundwater. Palustrine marshes may not become inundated seasonally or may seldom become inundated in dry years. Surface water may not, therefore, be present at all times. "The permanence of flooding, hydroperiod, and hydropattern decisively affects the character of the palustrine marsh ecosystem" (Dennison, 1993). Floodplain marshes, on the other hand, are hydraulically connected to rivers and, therefore, hydroperiod also depends on their elevation relative to the river.

Three wells were located in wet prairies, FLUCCS code 643. A wet prairie is characterized as a treeless plain with a sparse to dense ground cover composed predominately of grassy vegetation on hydric soils. Both shallow and deep-water areas of wet prairies are typically dominated by grasses and sedges. Wet Prairies are distinguished from marshes by having less water, usually less than a foot at the deepest point, and shorter herbage. These communities are predominated by one or more of the following species: Sawgrass, Maidencane, Cordgrasses, Spike Rushes, Beach Rushes, St. Johns Wort, Spiderlily, Swamplily, Yellow-eyed Grass, Whitetop Sedge. (FNAI, 1990; FDOT, 1999; Southwest Florida Water Management District and Tampa Bay Water, 2005).

Data collection for the study consisted of two elements, water-level elevation time series and spatial geographic data. All of the data was acquired from SWFWMD and are available at www.swfwmd.state.fl.us. Water-level elevations were recorded in feet above National Geodetic Vertical Datum 1927 (NGVD). The land surface elevation, also in feet above NGVD, was then subtracted from the water elevation data to obtain water-levels with respect to land surface. A Geographic Information System (GIS) was used to evaluate spatial geographic data files. Shapefiles for land-use classification, location of observation wells, physiographic classification, and wellfields were used. Orthophotographic aerials were used to verify observation well placement within wetlands and site conditions (Figure 5).

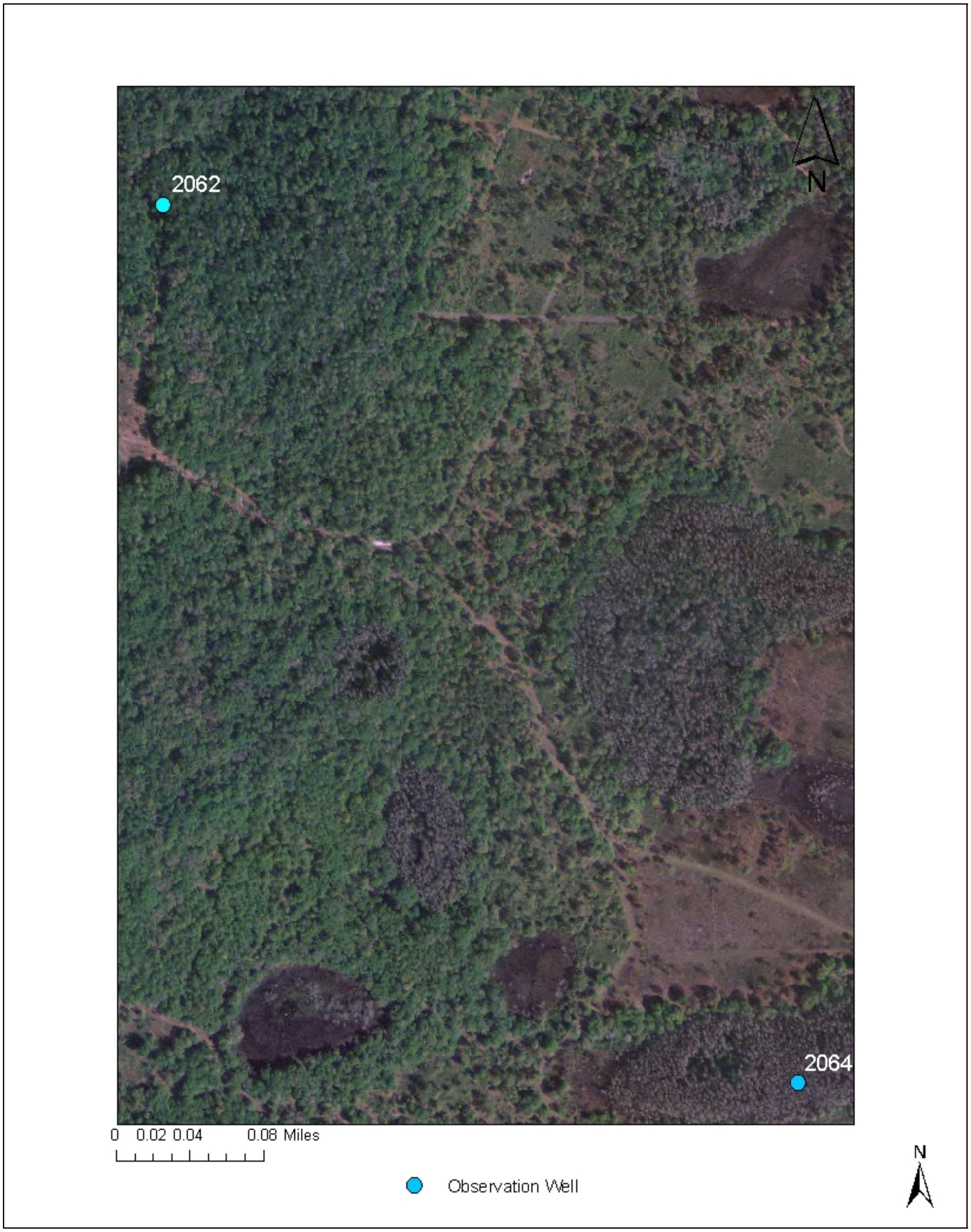


Figure 5: Orthophotographic Aerials of Wetland Observation Wells 2062 and 2064, Respectively Located in Mixed Forest and Cypress Wetlands

The SWFWMD-maintained wells chosen for this analysis met several study criteria. Each observation well was (1) a surficial aquifer well and (2) located entirely within a wetland. In addition, each wetland well time series had to (1) be derived from a continuous recording device, which provided daily (or more frequent) water-level measurements; (2) include a minimum of two consecutive years of records between January 2000 and November 2006, and (3) had no more than 40 consecutive days of missing data. Wells and associated time series that did not meet these criteria were omitted from this study.

The observation wells selected were then classified by (1) physiographic region, (2) the type of wetland at well location, and (3) location within a wellfield. Physiographic regions were identified from the shapefile of physiographic regions as defined in The Geomorphology of the Florida Peninsula by W. A. White, Florida Geological Survey Bulletin 51, 1970. The wetland classification was established based on the most recent (2004) land-use classification shapefile. The 2004 land use/cover features are categorized according to the Florida Land Use and Cover Classification System (FLUCCS). Using the wellfield shapefile, Figure 6 was created to show the location of the wells relative to wellfields in the study area. Observation wells were classified as wellfield wells if they were located entirely within or on the wellfield boundary. Table 3 lists all of the observation wells by ID number and their respective wellfield, if present. A compilation of the wells used in this study with their respective attributes is shown in Table 4.

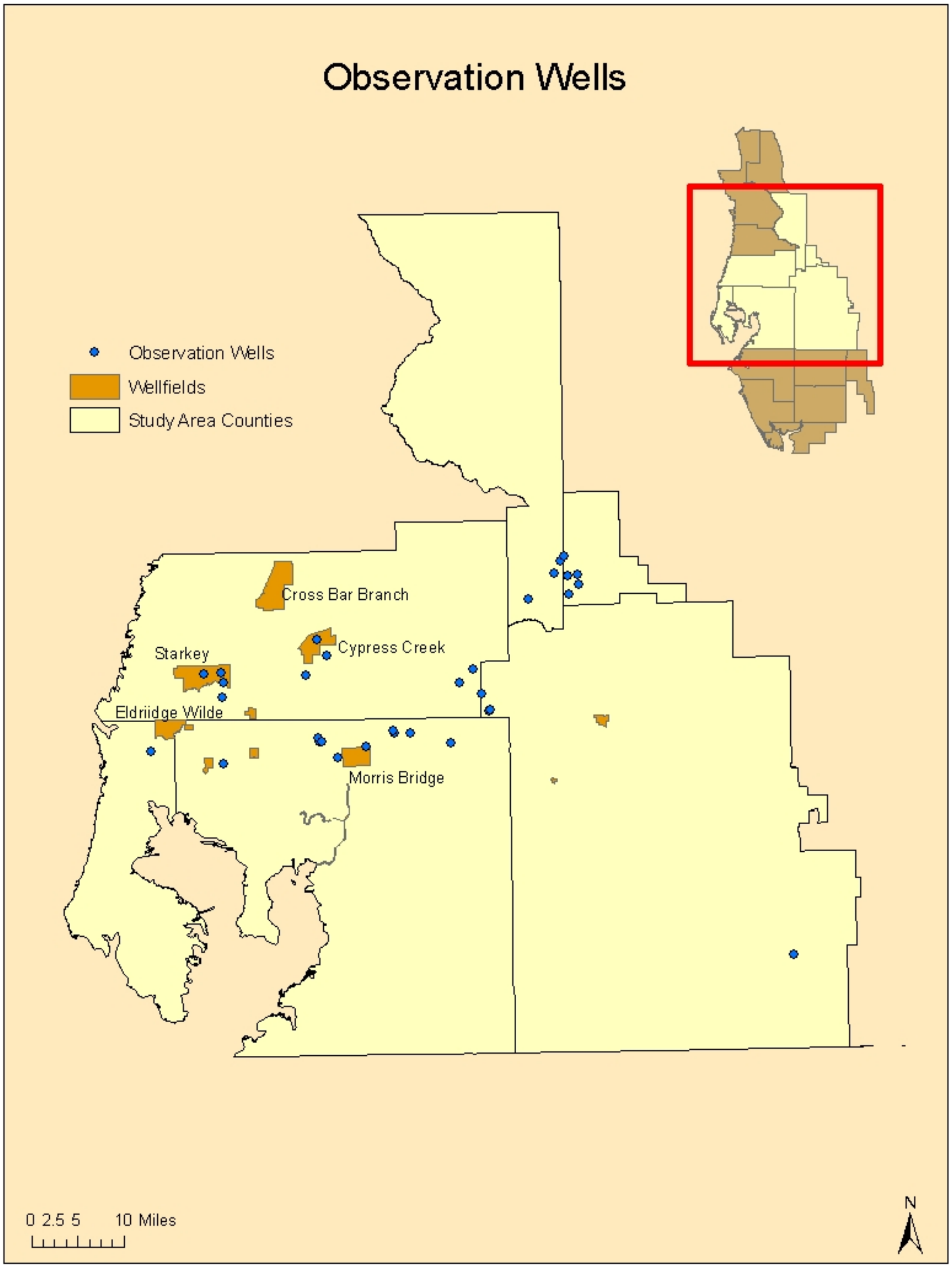


Figure 6: Observation Wells and Wellfields

Table 3: Observation Wells and Respective Wellfields

Well ID	Wellfield
598	Cypress Creek
1021	None
1918	None
1929	None
1932	None
1935	Starkey
1938	Starkey
1944	None
1946	None
1954	None
1959	None
1960	None
1961	None
1966	None
1969	None
1977	None
1978	None
1980	None
1981	None
1987	None
1988	None
1989	None
1990	None
1991	None
1992	None
1995	None
2060	None
2062	None
2064	None
2066	None
2159	None
10896	None
10958	Starkey
10965	Starkey

Table 4: Wetland Observation Well Attributes

Well ID	Wetland Name	Period of Record	Records	Physiographic Region	FLUCCS	Wetland Type	Wellfield
598	CCWF TMR-3 Shallow	1/28/03-10/23/06	1358	Gulf Coastal Lowlands	615	Bot	Cypress Creek
1021	Hills State Park Pkng	1/6/04-10/21/06	1019	Western Valley	615	Bot	None
1918	Pine Ridge	10/10/02-11/7/06	1489	Gulf Coastal Lowlands	621	Cyp	None
1929	J.B. Starkey #1	10/24/02-11/7/06	1475	Gulf Coastal Lowlands	621	Cyp	None
1932	STWF "FF"	10/22/03-11/7/06	1112	Gulf Coastal Lowlands	621	Cyp	None
1935	STWF Eastern #1	10/8/02-11/7/06	1491	Gulf Coastal Lowlands	621	Cyp	Starkey
1938	STWF Central	10/8/02-11/7/06	1491	Gulf Coastal Lowlands	621	Cyp	Starkey
1944	Lake Armistead	10/26/03-10/18/06	1079	Gulf Coastal Lowlands	621	Cyp	None
1946	Mertz Riverine	3/14/02-11/8/06	1700	Gulf Coastal Lowlands	630	Mix	None
1954	MBWF Trout Creek Marsh	10/18/02-10/19/06	1462	Western Valley	641	Msh	None
1959	MBWF East Cypress Marsh	9/13/02-10/19/06	1497	Western Valley	641	Msh	None
1960	New River Marsh	10/16/01-11/2/06	1843	Western Valley	641	Msh	None
1961	New River Cypress	10/16/01-11/1/06	1842	Western Valley	621	Cyp	None
1966	Green Swamp Marsh	11/24/03-10/9/06	1050	Western Valley	641	Msh	None
1969	UHFDA Riverine #1	3/1/02-11/1/06	1706	Western Valley	615	Bot	None
1977	UHFDA Wet Prairie	5/22/02-10/18/06	1610	Western Valley	643	WPr	None
1978	Alston Cypress #2	8/14/02-10/24/06	1532	Western Valley	621	Cyp	None

Table 4: (Continued)

Well ID	Wetland Name	Period of Record	Records	Physiographic Region	FLUCCS	Wetland Type	Wellfield
1980	Alston Bay	11/21/02-10/25/06	1434	Western Valley	630	Mix	None
1981	Alston Wet Prairie	3/8/02-10/25/06	1692	Western Valley	643	WPr	None
1987	Green Swamp #1	10/11/03-10/9/06	1094	Western Valley	621	Cyp	None
1988	Green Swamp #2	5/6/03-10/9/06	1252	Western Valley	621	Cyp	None
1989	Green Swamp #3	5/9/03-10/10/06	1250	Lake Upland	621	Cyp	None
1990	Green Swamp #4	8/14/03-10/9/06	1152	Lake Upland	621	Cyp	None
1991	Green Swamp #5	12/19/03-10/9/06	1026	Western Valley	621	Cyp	None
1992	Green Swamp #6	5/9/03-8/4/06	1085	Western Valley	621	Cyp	None
1995	Green Swamp Bay	12/19/03-10/10/06	1026	Western Valley	630	Mix	None
2060	Cypress Cr. ELAPP marsh	6/18/02-10/19/06	1584	Western Valley	641	Msh	None
2062	Cypress Cr. ELAPP riverine	6/18/02-10/19/06	1584	Western Valley	630	Mix	None
2064	Cypress Cr. ELAPP Cypress	6/14/02-10/19/06	1588	Western Valley	621	Cyp	None
2066	Blackwater Cr. ELAPP marsh 2	4/4/03-11/6/06	1312	Western Valley	641	Msh	None
2159	Pheasant Run	4/11/03-11/13/06	1311	Gulf Coastal Lowlands	621	Cyp	None
10896	ROMP 55 Surf	1/1/01-10/22/06	2120	Polk Upland	643	WPr	None
10958	STWF 2A East Surf	8/24/01-11/6/06	1900	Gulf Coastal Lowlands	621	Cyp	Starkey
10965	STWF 3A Central Surf	1/1/01-11/7/06	2136	Gulf Coastal Lowlands	621	Cyp	Starkey

2.3 Methodology

Various methods, such as the semi-variogram (Davis, 1986), harmonic analysis (Godin, 1972), higher order non-Fourier techniques (Kay and Marple, 1981), and spectral analysis (Bendat and Piersol, 1986) can be used to examine frequency components of a time series. Unlike other methods, spectral analysis does not strictly require a stationary time series (Hegge and Masselink, 1996). Hence, spectral analysis can be successfully applied to natural time series, such as hydrologic time series data to derive attributes of periodicity.

Spectral analysis is widely used to analyze the frequency constituents of time series by numerous scientists from various disciplines (Chatfield, 2004). It has been applied, for example, in investigations of annual temperature variations (Craddock, 1956), ocean waves (Kinsman, 1984), and oscillatory currents (Hardisty, 1993). Spectral analysis can be highly beneficial, as it allows for fine-scale resolution of the range of frequency components. It can be used to de-convolute multiple processes to derive the relative importance of each. The analysis can be further extended to analyze linear and non-linear relationships between different observed time series. Traditional spectral analysis is, in essence, an adaptation of Fourier analysis. The Fourier transform is efficient in the computational sense, robust, and produces reliable results for an array of time series. This method, therefore, is one of the most popular for the analysis of frequency components in a time series exhibiting periodicity (Hegge and Masselink, 1996; Chatfield, 2004), and is ubiquitous in the analysis of wave theory.

2.3.1 Discrete Fourier Transform

Typically, hydrometeorological observations are not made continuously through time. Observation taken only at specific times, usually equally spaced, results in a discrete time series. The Fourier transform of a discrete time series $x(n)$ with a finite length N , sampled at a uniform sampling frequency $f(s)$, can be expressed as:

$$X(k) = \sum_{n=0}^{N-1} x(n) e^{-2\pi i k n / N} \qquad k = 0,1,..., N-1 \tag{1}$$

where $X(k)$ is the discrete Fourier series. Substituting Euler's formula into Equation 1 results in:

$$X(k) = \sum_{n=0}^{N-1} x(n) \left(\cos \frac{2\pi k n}{N} - i \sin \frac{2\pi k n}{N} \right) \qquad k = 0,1,..., N-1 \tag{2}$$

where $X(k)$ is composed of a real cosine part and an imaginary sine element. The discrete Fourier series is of the same length (N) as the original time series $x(n)$. Redefining Equation 2 in terms of the Fourier cosine $a(k)$ and sine $b(k)$ coefficients yields:

$$X(k) = a(k) - i\, b(k) \qquad k = 0,1,..., N-1 \tag{3}$$

where

$$a(k) = \sum_{n=0}^{N-1} x(n) \cos \frac{2\pi k n}{N} \tag{4}$$

$$b(k) = \sum_{n=0}^{N-1} x(n) \sin \frac{2\pi k n}{N} \tag{5}$$

The length of the series (N) and the sampling frequency $f(s)$ is used to determine the k^{th} Fourier coefficient:

$$f_k = k\ f_s / N \tag{6}$$

The Fourier transform enables a time series to be represented by a series of cosines and sines whose frequencies are multiples of f_s/N, which is the frequency resolution, also referred to as binwidth.

$X(0)$ will be zero if the data is detrended prior to calculating the discrete Fourier transform. The next element in the discrete Fourier series $X(1)$ is the lowest frequency that can be determined from the time series using Fourier techniques. This frequency is referred to as the fundamental frequency f_f. The highest frequency yielding meaningful information from a data set is called the Nyquist frequency (f_c), which is a real number located in the center of the discrete Fourier series $X(N/2)$. All Fourier coefficients beyond the Nyquist frequency are complex conjugates of the first half of the series. These complex conjugates represent negative frequencies, which have no physical meaning and, therefore, do not provide additional information (Hegge and Masselink, 1996; Chatfield, 2004). The Nyquist frequency can be determined directly from the sampling frequency:

$$f_c = f_s / N \tag{7}$$

Unfortunately, aliasing (i.e. the inclusion of the variance of oscillations with frequencies higher than the Nyquist frequency) occurs as a result of excluding complex conjugates from the discrete Fourier series. To minimize the effects of aliasing, a sufficiently small sampling frequency should be used to ensure oscillations greater than half the sampling frequency are reduced. Alternatively, the series can be filtered to eliminate high-frequency components (Hegge and Masselink, 1996; Chatfield, 2004).

2.3.2 The Periodogram

A periodogram is a plot of the intensity (i.e. wave energy of a water-level fluctuation) or a multiple of the intensity against frequency for the wave components of a periodic function represented by a Fourier series (Kendall and Ord, 1990). After calculating the Fourier coefficients, the periodogram can be computed:

$$P(k) = \frac{a(k)^2 + b(k)^2}{f_s N} \qquad k = 0, \frac{N}{2} \tag{8}$$

$$P(k) = \frac{2\left(a(k)^2 + b(k)^2\right)}{f_s N} \qquad k = 1, \ldots, \frac{N}{2} - 1 \tag{9}$$

This is the first step in the determination of the auto-spectrum, which provides a representation of the amount of variance of the time series as a function of frequency. Because the Fourier coefficients beyond the Nyquist frequency are complex conjugates, they are not included in the calculation of the periodogram. Instead, the first half of the Fourier coefficients, with the exception of $P(0)$ and $P(N/2)$, are doubled for compensation. $P(k)$ is also referred to as variance-spectral density, power-spectral density, and energy-spectral density (Hegge and Masselink, 1996).

2.3.2.1 Spectral Leakage

Most of the hydrometeorological time series data are of finite length. Distortion of the calculated spectral density function caused by the discontinuities at the two endpoints is referred to as spectral leakage. Spectral leakage causes small amounts of spectral energy to leak into adjacent frequencies, thereby skewing the spectral estimates of respective frequencies.

In order to minimize leakage, one of the most popular methods is the Hann taper method (Hegge and Masselink, 1996; Chatfield, 2004). The application of Hann taper involves multiplying the original time series by the taper $w(n)$:

$$w(n) = 0.5\left(1 - \cos\frac{2\pi n}{N-1}\right) \qquad n = 1,2,\ldots,N \tag{9}$$

Applying a taper prior to calculating the periodogram has been shown to greatly improve the distinction of the power spectral density peaks.

2.3.2.2 Spectral Estimates

The periodogram obtained from the observed time series is a manifestation of the original time series. It may, therefore, change if a time series encompassing a different period of record is used, especially if either record is not fully representative of the full reoccurring periodicity. To improve the reliability (i.e. reduction in variance) of the spectral estimates, different statistical methods can be used. For this particular study, the segment averaging method, proposed by Welch (1967), was used.

The Welch method involves dividing the time series into several small segments with an underlying assumption that the adjacent segments are statistically independent. A periodogram is calculated for each of the segments. The resultant periodograms are then averaged over respective frequency bins to obtain more accurate estimates of the power spectral densities. The confidence interval level is directly proportional the number of segments used. To obtain a near maximum reduction of variance, a fifty percent overlap between adjacent segments is recommended (Welch, 1967; Hegge and Masselink, 1996)

2.3.3 Application of the Method

The MATLAB function, “psd”, estimates the power spectral density of a signal using the modified Welch periodogram technique. MATLAB applies the specified anti-leakage window to successive detrended sections of the time series. Using the specified window size, a fast Fourier transform, FFT, of each section is then computed. The function calculates a periodogram by obtaining the square of the magnitude of each transform to form the power spectral density estimation of the time series.

Specifically, a Welch spectrum object with an FFT length equal to the length of the time series was defined in MATLAB. The time series was then detrended by removing the series mean. A Hann taper window of length equal to the number of records was then applied in order to minimize spectral leakage. The ‘psd’ function was then called using the spectrum object defined above and the detrended time series to generate a power spectral density graph. The process was repeated for all the 37 wetland observation wells. A 95% confidence interval on the spectral estimates was defined by MATLAB.

Chapter Three: Results and Discussion

3.1 Overview

A simple plot of the time series allowed for visual identification of trends and illustrated obvious periodicity in the series. Figure 7 is a plot of the observed water-level time series between 2/1/03 and 10/15/06 for four wells, representative of different wetland characteristics, which exist in the wetlands analyzed in this study. Observation wells 1969, 10896, 1980, and 1929 are respectively located in a western valley bottomland, an upland wet prairie, a western valley mixed forest wetland, and a gulf coastal lowlands cypress wetland. Graphs of observed water-level for all of the observation well time series from 1/1/2001 through 12/31/2007 can be found in Appendix A.

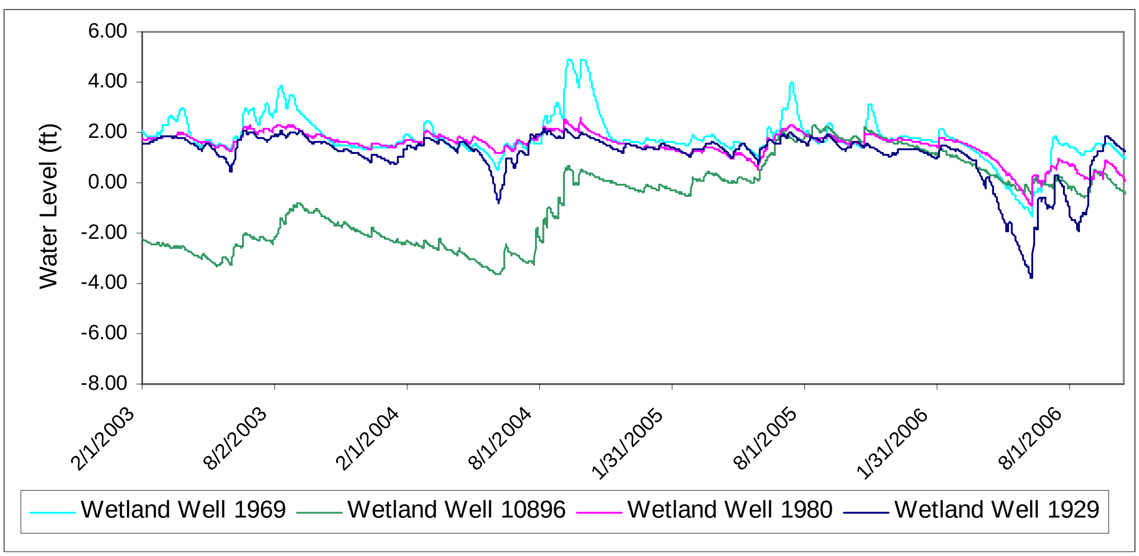
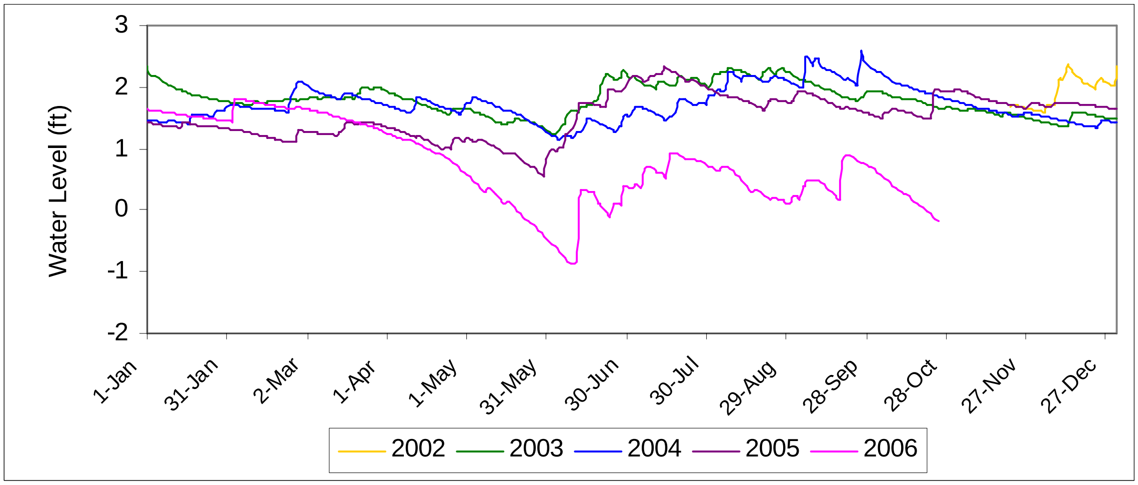


Figure 7: Observed Water-Level Time Series for Four Wetlands: Bottomland (1969), Wet Prairie (10896), Mixed (1980), and Cypress (1929)

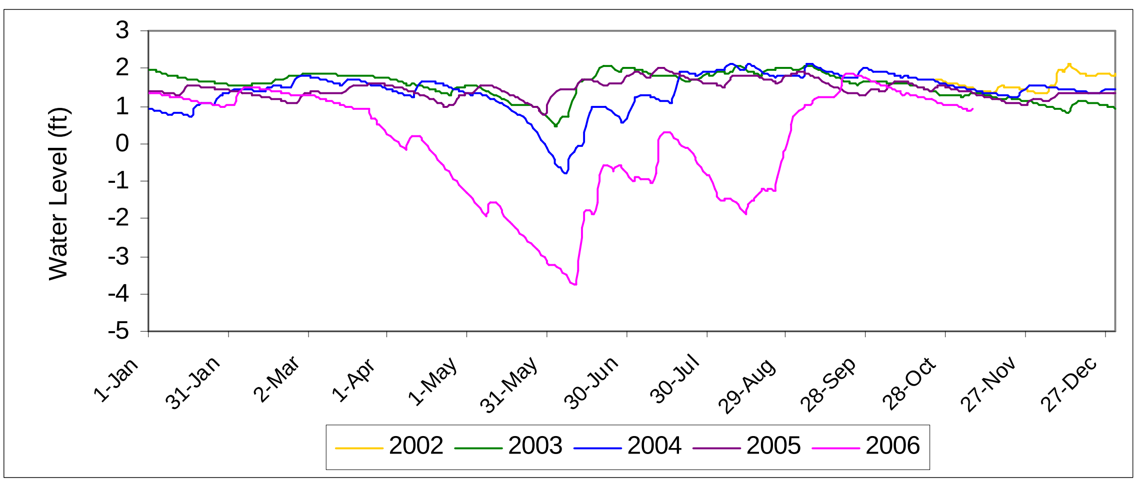
From inspection of the hydrographs, it can be observed that one or more predominant seasonal fluctuations are identifiable. In addition, smaller event-driven fluctuations are ubiquitous; however, the event fluctuations occur at a lower magnitude and inconsistent duration (period). Although these wells are located in different physiographic regions as well as distinct types of wetlands, it can be seen that the timing of the minimum and maximum water-levels in the wetlands is consistent. They do, however, differ in relative water depths, as well as in the overall range of the water-level fluctuations.

The observed water-level data in a mixed (1980) and cypress (1989) wetland are superimposed from January 1st through December 31st over all years of record in Figure 8 (a) and (b). Both wetlands exhibit similar seasonal behavior, not only to each other, but also from year to year. In addition, it is evident that there are two distinct inter-annual periods of water-level fluctuation. From the observations, there appears to be a winter/spring cycle, which generally occurs from December through May, and a summer/fall cycle that takes place from June through November each year. It is also observed that the range of water-level fluctuation varies both between wetlands and from year to year. Although the magnitude of the water-level varies, its pattern remains consistant. Changes from year to year are expected, too, as hydroperiod “varies statistically according to climate and antecedent conditions” (Mitsch and Gosselink, 2000). The annual graphs of observed water-level for all of the observation well time series from 1/1/2001 through 12/31/2007 can be found in Appendix B.

Both the temporal cycles and the magnitude and duration of water-level fluctuations during these inter-annual cycles appear to be of obvious importance when describing wetland hydroperiod. Spectral analysis is useful in determining the overall temporal characteristics of periodicity and thus, hydroperiod. What is also derived from spectral analysis and is very important for deterministic modeling comparisons, is the relative importance and magnitude of storm event periodicity versus seasonal fluctuations. The range of water-level fluctuations and accumulated durations, on the other hand, can be quantified with probability density histograms.



(a)



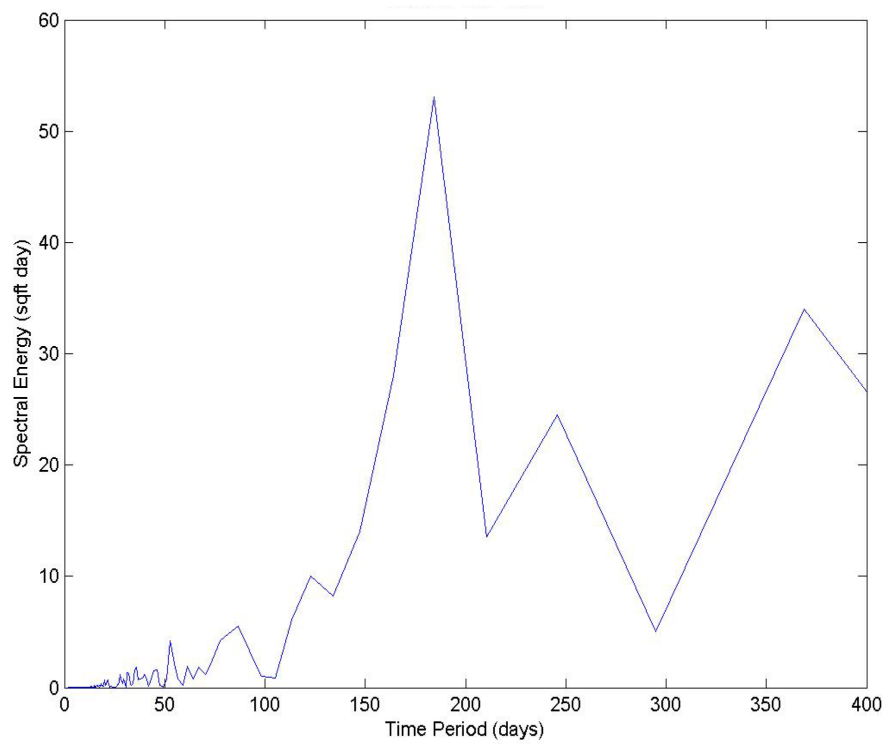
(b)

Figure 8: Annual Water-Level Observations for (a) Mixed (1980) and (b) Cypress (1929) Wetlands

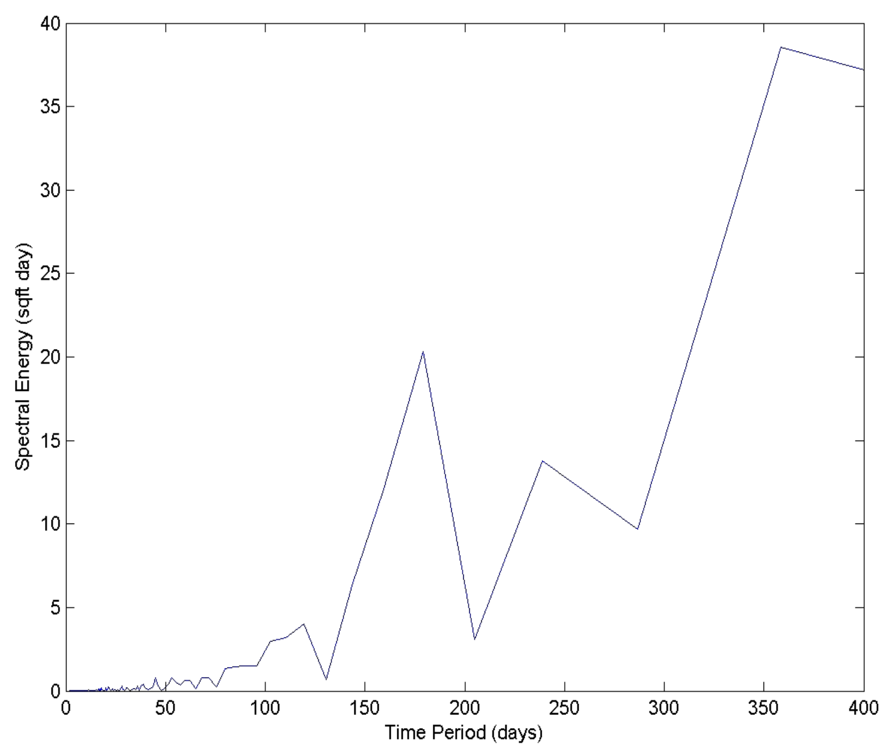
3.2 Temporal Characteristics of Hydroperiod

To further investigate the distinct inter-annual periodicity of water-level fluctuation observed in the time series plots, spectral estimates were plotted. Frequency was converted to period (days) prior to plotting. Distinct peaks can be clearly observed upon inspection of the plotted spectral analysis graphs (e.i. Figure 9 for cypress (1929) and mixed (1980) wetland wells). Results for all other wells are shown in Appendix C. The spectral peaks indicate presence of dominant waveforms representative of the temporal component of hydroperiod and encompass the entire range of water-level fluctuations. A pattern of generally decreasing energy with decreasing time period can also be seen. This behavior is typical of natural systems (Hegge and Masselink 1996). It can also be seen from the spectral analysis plots, that for time periods of less than 20 days, spectral energy effectively becomes zero. This justifies that the sampling frequency of 1 day was sufficiently high to minimize the effects of aliasing (Hegge and Masselink 1996). More importantly, it quantifies the obvious observation that storm event water-level fluctuations are much less intense than the dominant summer/fall and winter/spring water-level fluctuation.

The spectral density function for mixed (1980) and cypress (1929) wetlands are plotted in Figure 9. These wells are representative of the diverse collection of observation wells. From Figure 8, it is observed that the mixed (1980) wetland exhibited a primary peak period of about 365 days, while the cypress (1929) wetland had a primary peak of 180 days. It is noted, however, that the secondary inter-annual peak is approximately 180 days for the mixed (1980) wetland. Also, both display a tertiary peak near 240 days. The annual spectral peak was expected, as there is a strong annual periodicity in rainfall pattern in West-Central Florida. The semi-annual periodicity was, however, more significant than the annual cycle in approximately half of the wetlands.



(a)



(b)

Figure 9: Spectra of the Water-Level Record for Well Numbers (a) 1980, Located in a Mixed Forest Wetland and (b) 1929, Located in a Cypress Wetland

The inter-annual peaks are of particular interest in this study. All of the water-level records analyzed, regardless of contributing wetland attributes, contained either a primary or secondary inter-annual peak in the vicinity of 180 days (Table 5). All wetlands displaying an annual primary peak consistently had a secondary peak of approximately 180 days. Tertiary peaks varied between individual wetlands. Of special note was the relative insignificance of short-period (storm events) water-level fluctuations in the spectral energy.

All wetlands, regardless of type, physiographic region, or wellfield effects, exhibit predominant hydroperiod cycles of an approximately 180 day (semi-annual) seasonality (Table 6). A winter/spring cycle, occurring from December through May, followed by a summer/fall cycle that takes place from June through November, is prevelant in the data each year. The hydroperiod cycle for a wetland, therefore, incorporates the entire range of water-level fluctuations, including both surface and subsurface water-levels. The magnitude and range of surface and subsurface water-levels of different wetlands do, however, vary within the predominant inter-annual hydroperiod cycles.

Table 5: Power Spectral Density Peak Periods for all Observation Wells

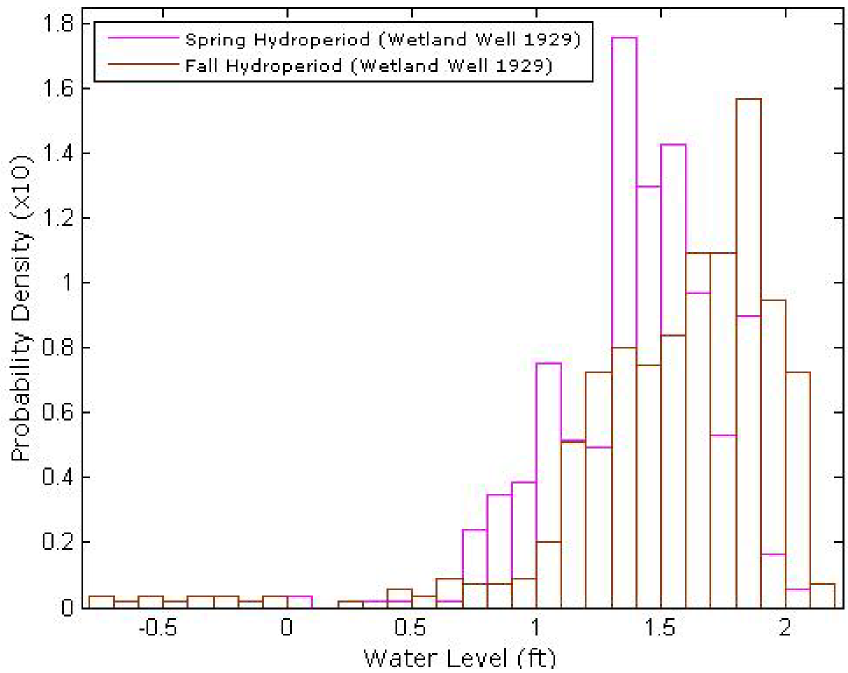
Well ID	Wetland Type	Primary Peak Period (days)	Secondary Peak Period (days)	Tertiary Peak Period (days)
598	Bot	272	170	102
1021	Bot	340	170	142
1969	Bot	213	341	99
1918	Cyp	186	248	123
1929	Cyp	184	369	83
1932	Cyp	371	185	246
1935	Cyp	186	373	111
1938	Cyp	373	186	108
1944	Cyp	360	180	123
1961	Cyp	184	368	96
1978	Cyp	383	170	94
1987	Cyp	365	182	83
1988	Cyp	179	104	153
1989	Cyp	179	89	121
1990	Cyp	384	165	239
1991	Cyp	171	114	54
1992	Cyp	362	181	93
2064	Cyp	318	176	95
2159	Cyp	187	119	82
10958	Cyp	190	119	60
10965	Cyp	356	178	151
1946	Mix	189	340	118
1980	Mix	359	179	124
1995	Mix	171	103	122
2062	Mix	176	122	123
1954	Msh	365	183	122
1959	Msh	374	187	83
1960	Msh	369	184	125
1966	Msh	350	175	93
2060	Msh	317	226	115
2066	Msh	164	109	176
1977	WPr	179	230	122
1981	WPr	188	60	115
10896	WPr	353	193	230

Table 6: Power Spectral Density Semi-Annual Peak Periods for all Observation Wells

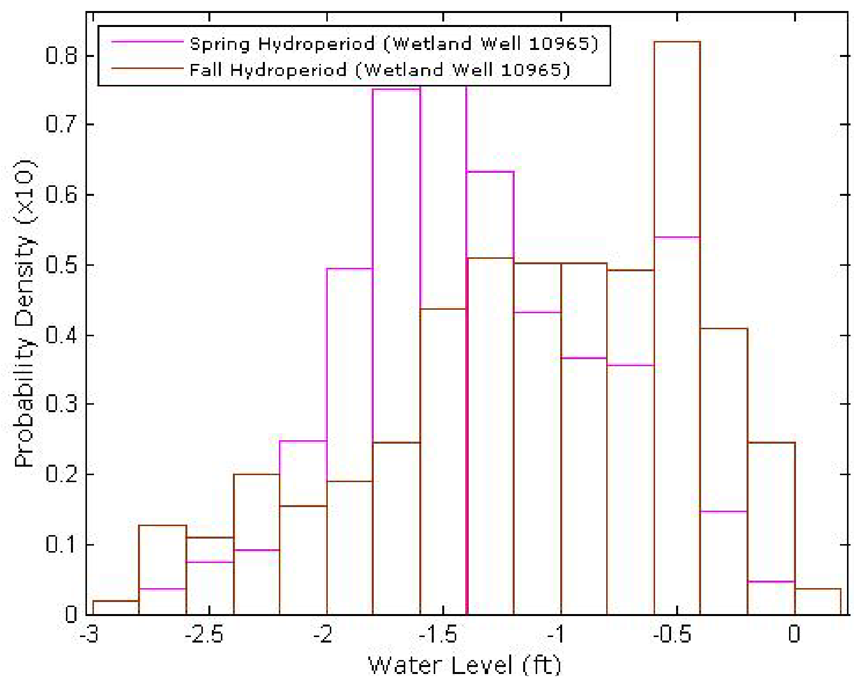
Well	Wetland Type	Primary Inter-annual Period (days)
1021	Bot	170
1969	Bot	213
598	Bot	170
Avg	Bot	184
Std dev	Bot	25
1918	Cyp	186
1929	Cyp	184
1932	Cyp	185
1944	Cyp	180
1961	Cyp	184
1978	Cyp	170
1987	Cyp	182
1988	Cyp	179
1989	Cyp	179
1990	Cyp	165
1991	Cyp	171
1992	Cyp	181
2064	Cyp	176
2159	Cyp	187
1935	Cyp	186
1938	Cyp	186
10958	Cyp	190
10965	Cyp	178
Avg	Cyp	181
Std dev	Cyp	7
1946	Mix	189
1980	Mix	179
1995	Mix	171
2062	Mix	176
Avg	Mix	179
Std dev	Mix	8
1954	Msh	183
1959	Msh	187
1960	Msh	184
1966	Msh	175
2060	Msh	226
2066	Msh	164
Avg	Msh	187
Std dev	Msh	21
1977	WPr	187
1981	WPr	188
10896	WPr	193
Avg	WPr	189
Std dev	WPr	3
Avg	All	182
Std dev	All	12

3.3 Hydroperiod Water-Level Fluctuations

The water-level fluctuations during the predominant 180 day semi-annual periods are of great importance in defining hydroperiod. Figure 9 contains histograms of three characteristically different wetlands, which display the probabilities that the water-level lies in specific ranges during the winter/spring and summer/fall hydroperiods over a three year period. It can be observed from the histograms that, the probability density distribution for the summer/fall is skewed to the right of the winter/spring distribution. This indicates that, regardless of wetland characteristics, higher water-levels exist in wetlands during the summer/fall hydroperiod. This is expected as, the summer/fall hydroperiod is the semi-annual period during which the peak of the rainy season in West-Central Florida falls. In addition, it is roughly in phase with the peak of the available solar radiation and extreme ET demand. Duration, maximum depth, and range between the winter/spring and summer/fall hydroperiods, on the other hand, appear to vary.

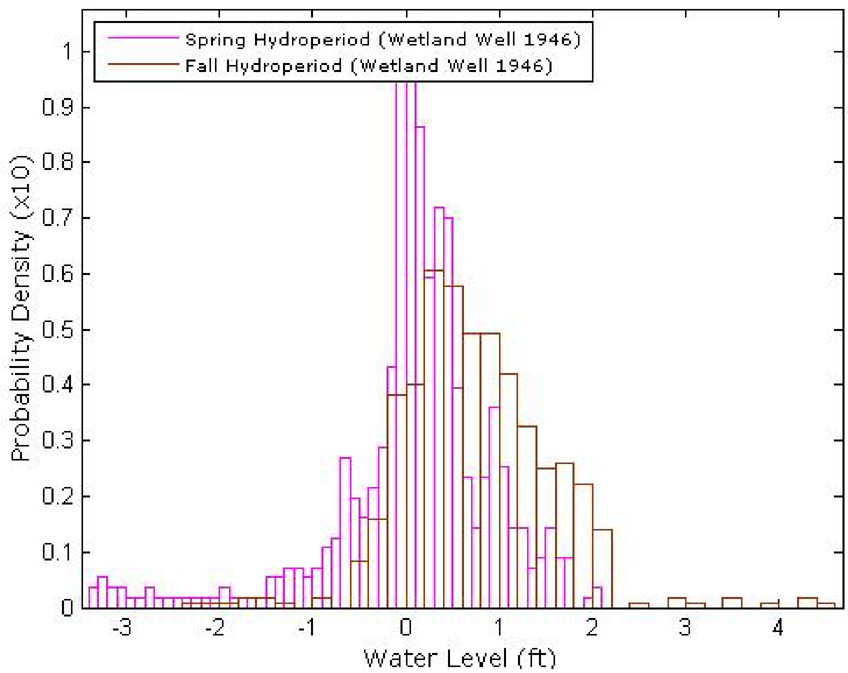


(a)



(b)

Figure 10: Probability Densities of the Winter/Spring and Summer/Fall Hydroperiod Phases of (a) Non-Wellfield Cypress (1929), (b) Wellfield Cypress (10965), and (c) Non-Wellfield Wet Prairie (1946) Wetlands



(c)

Figure 10: (Continued)

To understand water-table fluctuations with respect to different types of wetlands, wellfield stresses, and physiographic regions, probability distribution histograms of the complete raw well data were plotted. Wetlands of the same type show similarities in water-level ranges and probability distribution (Figures 9-11). Regardless of physiographic region (Figure 9), the overall water-level distribution for non-wellfield cypress wetlands (Figure 10) is skewed towards the positive end and the water-level varies from approximately -4 to +2 feet, relative to land surface. Figure 11 is a compilation of all non-wellfield cypress wetland water-level probability densities, which exhibit similar distributions and water-level ranges, regardless of physiographic region. Due to minimal available data for other wetland types, similarities within other types of wetlands are less apparent. The water-level in wet prairie wetlands (Figure 13), for example, ranges from about -6 to +3 feet, however, has a somewhat inconsistent distribution. The cypress and wet prairie wetlands display differences in water-level range, durations, and probability density distributions, thus attesting to hydrologic differences between different types of wetlands. Although semi-annual hydroperiod durations exists in different types of wetland, it cannot be expected that different wetlands will also have similarities in water-level fluctuation magnitudes or ranges.

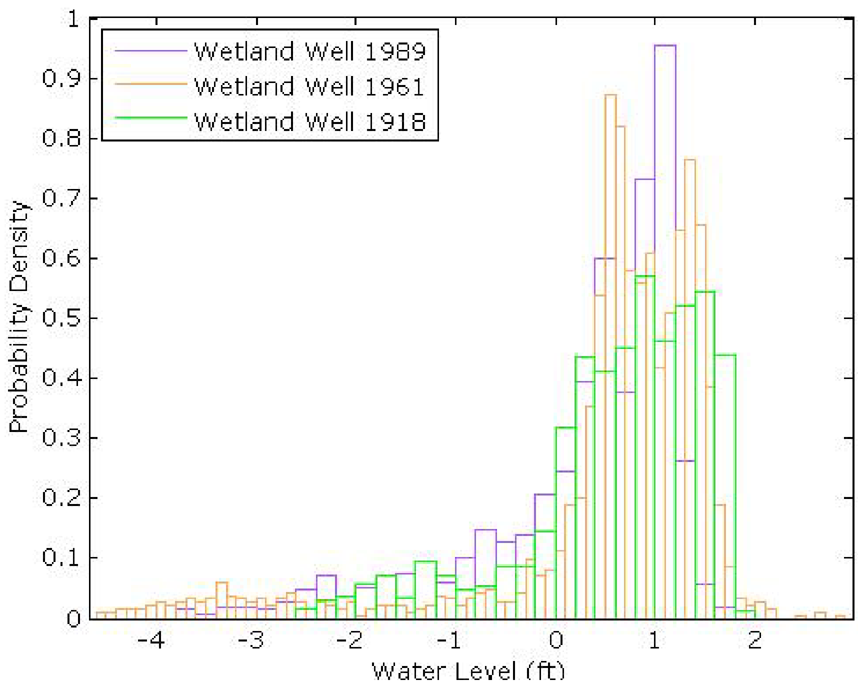


Figure 11: Probability Densities of Water-Levels for Non-Wellfield Cypress Wetland Wells 1989, 1961, and 1918, Which are Respectively Located in the Lake Upland, Western Valley, and Gulf Coastal Lowlands

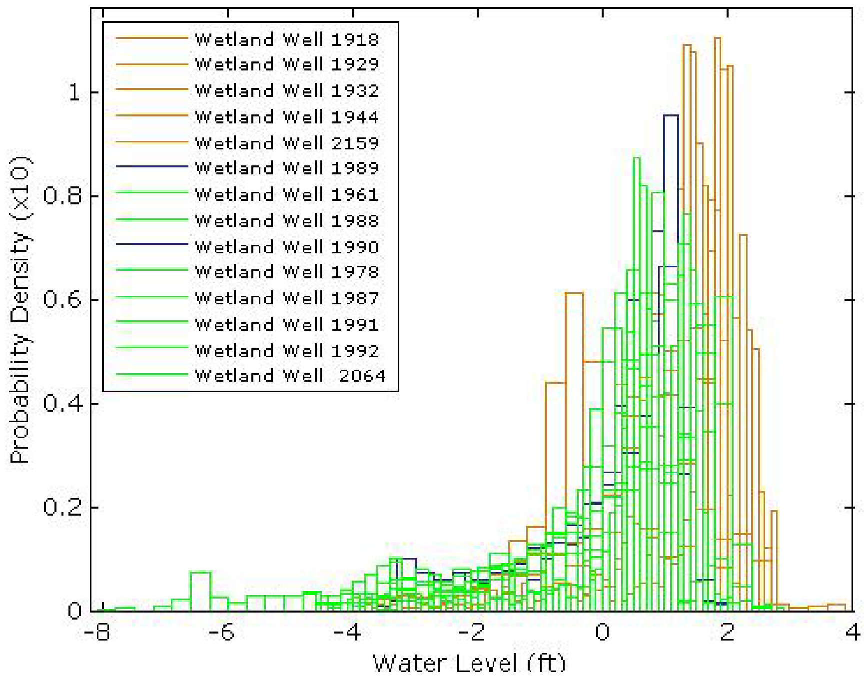


Figure 12: Probability Densities of Water-Levels for Non-Wellfield Cypress Wetland Observation Wells Located in all Physiographic Regions

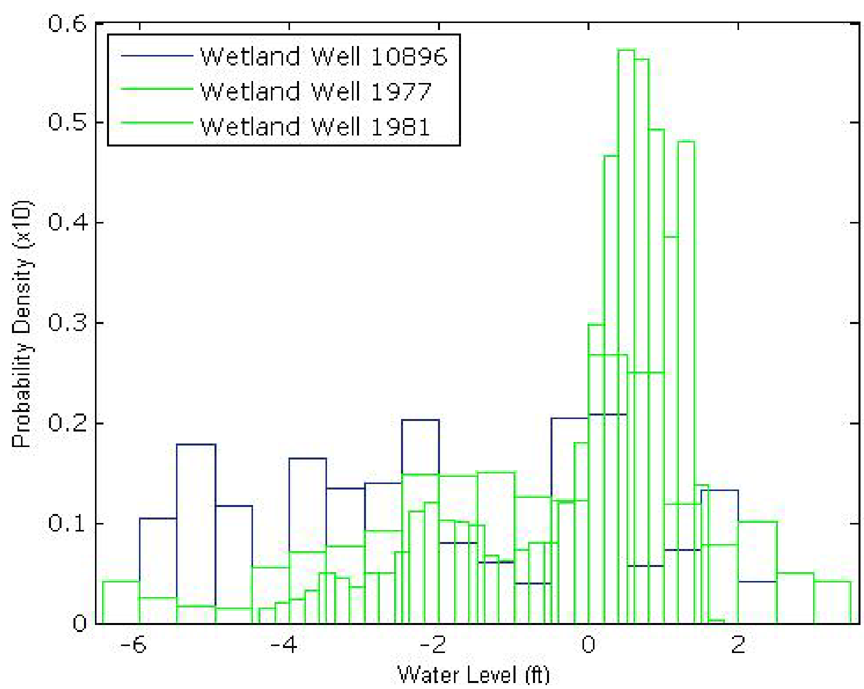


Figure 13: Probability Densities of Water-Levels for Non-Wellfield Wet Prairie Wetland Observation Wells Located in all Physiographic Regions

From the figures, analogous water-level behavior is found to exist between like wetland types, regardless of physiographic region. Because hydroperiod influences the type of vegetation present in a wetland, it is logical that individual wetlands of the same classification will exhibit similar hydrological behavior. Figure 14 illustrates differing water-level ranges and probability distributions for two different types of wetlands, which are both in the same physiographic region. This difference was characteristic of all wetland type comparisons. This corroborates the popular contention that changes in hydrological behavior of a wetland control the resultant plant communities.

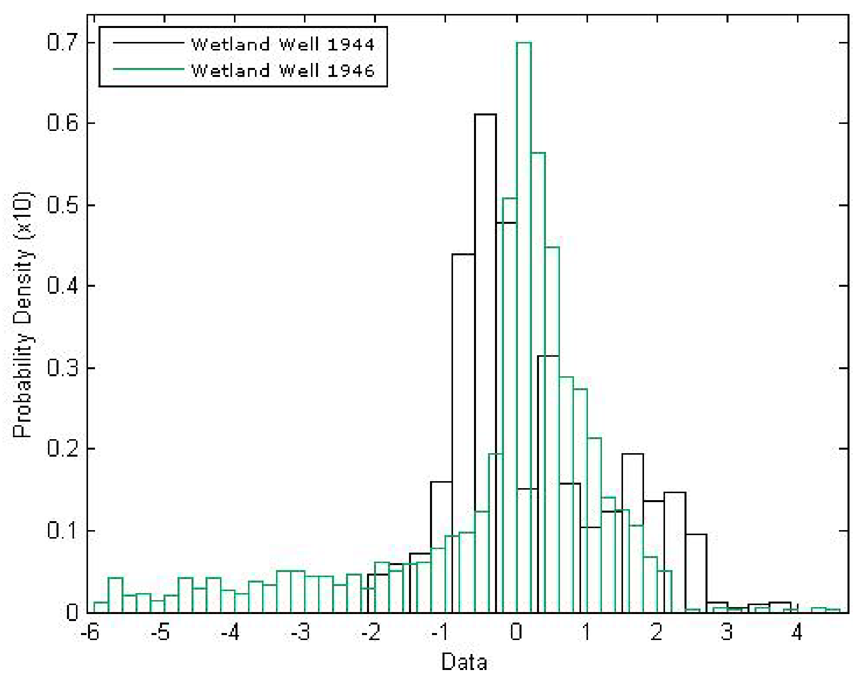


Figure 14: Probability Densities of Water-Levels for Cypress (1944) and Mixed (1946) Wetlands

It is also important to understand the effect of wellfield stresses, if any, on water-level fluctuations. Upon analysis of the water-level probability distributions for wells located within a wellfield, it was found that the water-level was skewed towards the negative side, regardless of wetland type (Figure 15). Although both wetland types exhibit predominantly negative water-levels, the overall water-level ranges and durations differ between the wetlands. The wellfield bottomland (598) wetland water-level ranged from -10 to +2 feet, while the wellfield cypress (10965) ranged from -8 to 0 feet.

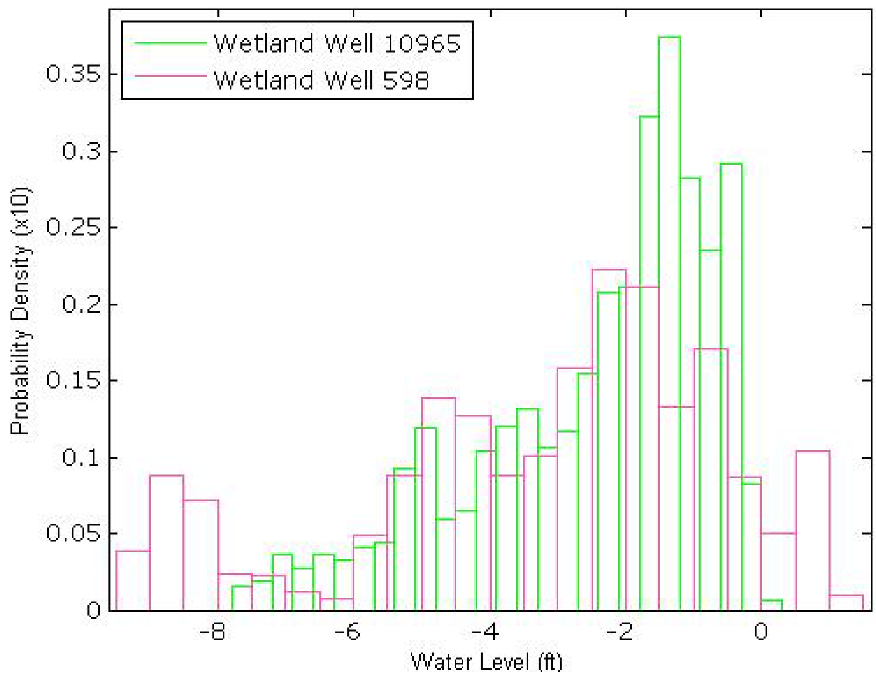


Figure 15: Probability Densities of Water-Levels for Wellfield Cypress (10965) and Wellfield Bottomland (598) Wetlands

Wellfield cypress (10958) and non-wellfield (1944) wetlands are directly compared in Figure 16. The figure clearly demonstrates the effects of pumping on the magnitude of water-levels occurring within inter-annual hydroperiod cycles of a wetland. The water-level probability distribution for the well located within a wellfield, is clearly skewed towards the negative side, while the non-wellfield water-level probability distribution is skewed toward the positive side. The wellfield wetland water-level is at approximately -3 feet most of the time, never reaching land surface, though the water-level fluctuates from -11 to -2 feet. The non-wellfield wetland water-level, on the other hand, fluctuates from -2 (the maximum wellfield wetland water-level) to +4 feet. It can be seen from the histogram that the water-level is predominantly around land surface for the non-wellfield wetland. Limited wellfield observation points were available for this study. Therefore, conclusions of overall decreased water-level and increased water-level fluctuation can not be fully made. Table 7 contains average water-level magnitudes and ranges for all of the wetlands analyzed in this study over all years of available data. Annual water-level magnitudes, ranges and statistics for all of the wetlands are tabulated in Appendix D.

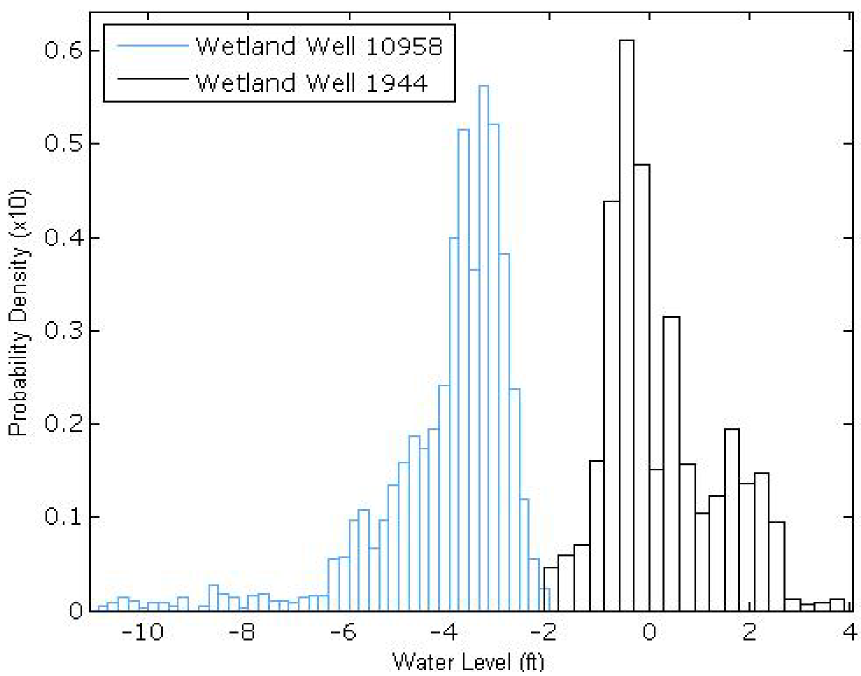


Figure 16: Probability Densities of Water-Levels for Gulf Coastal Lowlands, Cypress Wetland Observation Wells 10958, Located in a Wellfield, and 1944, Not Located in a Wellfield

Table 7: Average Wetland Water-Level Magnitudes and Ranges

Well	Wetland Type		Well Water-Level (ft) Low	High	Mean	Std dev
1918	Cyp	minimum	-2.54	-0.66	-1.44	0.79
		maximum	1.70	1.80	1.73	0.05
		range	2.36	4.34	3.17	0.84
1929	Cyp	minimum	-3.77	0.77	-0.83	2.08
		maximum	2.02	2.14	2.07	0.06
		range	1.25	5.79	2.90	2.06
1932	Cyp	minimum	-3.50	-1.58	-2.33	1.03
		maximum	1.64	2.10	1.83	0.24
		range	3.34	5.14	4.16	0.91
1944	Cyp	minimum	-2.06	-0.72	-1.20	0.75
		maximum	2.13	3.72	2.82	0.81
		range	2.94	4.68	4.02	0.94
1961	Cyp	minimum	-4.56	0.29	-2.05	2.16
		maximum	1.35	2.88	1.94	0.58
		range	1.47	5.91	3.99	1.95
1978	Cyp	minimum	-4.65	-0.10	-2.20	2.34
		maximum	-1.96	2.38	1.02	2.00
		range	1.89	5.59	3.21	1.63
1987	Cyp	minimum	-4.22	-0.30	-2.87	1.75
		maximum	0.63	1.34	1.04	0.30
		range	1.46	4.91	3.91	1.65
1988	Cyp	minimum	-4.38	-0.55	-2.67	1.67
		maximum	0.09	2.42	1.67	1.07
		range	2.69	5.57	4.35	1.20
1989	Cyp	minimum	-3.66	-1.87	-2.68	0.74
		maximum	0.63	1.98	1.47	0.59
		range	3.42	4.71	4.15	0.54
1990	Cyp	minimum	-2.94	-1.76	-2.35	0.83
		maximum	1.72	1.91	1.82	0.13
		range	3.67	4.66	4.17	0.70
1991	Cyp	minimum	-0.83	2.62	0.90	2.44
		maximum	2.37	2.58	2.48	0.15
		range	-0.25	3.41	1.58	2.59
1992	Cyp	minimum	-3.21	-1.36	-2.22	0.93
		maximum	1.55	1.72	1.61	0.09
		range	2.93	4.76	3.83	0.92
2064	Cyp	minimum	-7.77	-3.09	-5.35	1.96
		maximum	-0.60	1.45	0.82	0.81
		range	4.12	6.38	6.17	1.75
2159	Cyp	minimum	1.01	1.39	1.21	0.19
		maximum	2.44	2.70	2.59	0.13
		range	1.20	1.62	1.38	0.22

Table 7: (Continued)

Well	Wetland Type		Well Water-Level (ft) Low	High	Mean	Std dev
1935	Cyp WF	minimum	-5.32	-2.16	-3.32	1.38
		maximum	0.72	0.87	0.79	0.08
		range	3.03	6.04	4.10	1.33
1938	Cyp WF	minimum	-2.58	1.72	0.13	1.87
		maximum	1.42	3.51	2.72	1.00
		range	1.71	4.00	2.60	1.08
10958	Cyp WF	minimum	-10.69	-5.13	-7.33	2.32
		maximum	-2.57	-2.11	-2.33	0.18
		range	3.02	6.46	5.00	2.27
10965	Cyp WF	minimum	-7.78	-1.85	-4.77	2.55
		maximum	-1.46	0.12	-0.56	0.59
		range	1.83	4.65	4.21	2.17
1946	Mix	minimum	-5.81	-1.33	-3.33	1.98
		maximum	-0.46	4.27	1.65	1.74
		range	2.48	7.61	4.98	2.00
1980	Mix	minimum	-0.84	1.19	0.30	1.04
		maximum	0.88	2.60	1.91	0.91
		range	1.41	1.72	1.61	0.18
1995	Mix	minimum	-0.84	0.29	-0.28	0.57
		maximum	0.03	1.84	1.12	0.96
		range	0.87	1.79	1.40	0.48
2062	Mix	minimum	-4.53	0.12	-1.71	2.02
		maximum	1.58	4.07	3.11	0.95
		range	2.80	7.02	4.83	1.78
1021	Bot	minimum	-9.63	-8.37	-8.87	0.67
		maximum	-5.90	0.89	-2.32	3.41
		range	3.73	9.51	6.55	2.89
1969	Bot	minimum	-1.33	1.40	0.23	1.11
		maximum	1.78	4.85	3.70	1.16
		range	2.90	4.32	3.47	0.68
598	Bot WF	minimum	-5.76	-4.24	-4.89	0.78
		maximum	0.60	1.39	0.91	0.42
		range	4.99	6.36	5.80	0.72
1954	Msh	minimum	-6.64	0.12	-3.87	2.85
		maximum	0.12	3.28	2.29	1.46
		range	2.88	7.63	6.16	2.22
1959	Msh	minimum	-4.95	-0.96	-3.37	2.12
		maximum	1.35	1.90	1.71	0.31
		range	2.84	6.30	5.08	1.94
1960	Msh	minimum	-3.40	0.88	-0.97	2.15
		maximum	2.33	3.14	2.60	0.34
		range	1.45	5.56	3.57	2.11

Table 7: (Continued)

Well	Wetland Type		Well Water-Level (ft)			
			Low	High	Mean	Std dev
1960	Msh	minimum	-3.40	0.88	-0.97	2.15
		maximum	2.33	3.14	2.60	0.34
		range	1.45	5.56	3.57	2.11
1966	Msh	minimum	-2.54	-1.19	-2.05	0.75
		maximum	0.83	1.70	1.36	0.47
		range	2.74	4.24	3.41	0.76
2060	Msh	minimum	-3.29	0.45	-1.36	1.63
		maximum	1.11	2.21	1.87	0.44
		range	1.61	4.44	3.23	1.41
2066	Msh	minimum	-3.75	0.43	-1.56	2.11
		maximum	1.59	3.40	2.51	0.75
		range	2.21	5.37	4.06	1.56
1977	WPr	minimum	-6.39	-2.93	-4.56	1.68
		maximum	0.05	3.44	1.50	1.38
		range	4.57	7.06	6.06	1.09
1981	WPr	minimum	-4.33	-2.19	-3.08	0.90
		maximum	0.58	1.74	1.33	0.44
		range	3.68	4.91	4.41	0.57
10896	WPr	minimum	-5.74	-0.52	-3.75	2.15
		maximum	-3.15	2.27	-0.83	2.32
		range	2.39	4.15	2.92	0.70

3.4 Comparison of Findings

Mitsch and Gosselink (2000) recognized that wetland hydroperiod defines the rise and fall of surface and subsurface water-level in a wetland and suggested that it helps characterize each type of wetland. Mitsch and Gosselink (2000) also observed both a wet and dry season, year to year fluctuations, and pulsing water-levels, however, to date, an attempt to quantify hydroperiod as a whole has not been done. Table 8 contains the qualitative hydroperiod definitions as presented by Mitsch and Gossekink. From this study, it is seen that all wetlands exhibit a semi-annual hydroperiod and different types of wetlands exhibit varying water-level magnitudes, durations and ranges. The quantitative results of hydroperiod durations and water-level magnitudes and ranges for all wetland types are in Table 9.

Table 8: Qualitative Hydroperiod Definitions as Defined by Mitsch and Gosselink, 2000

Definition	Description
Permanently Flooded	flooded throughout the year in all years
Intermittently exposed	flooded throughout the year except in years od extreme drought
Semi-permanently Flooded	flooded in the growing season in most years
Seasonally Flooded	flooded for extended periods during the growing season, but usually no surface water by end of growing season
Saturated	substrate is saturated for extended periods in the growing season, but standing water is rarely present
Temporarily Flooded	flooded for brief periods in growing season, but water-table is otherwise well below land surface
Intermittently Flooded	surface is usually exposed with surface water present for vaiable periods without detectable seasonal pattern

Source: Mitsch and Gosselink, 2000

Table 9: Hydroperiod Durations and Water-Level Magnitudes and Ranges for All Wetland Types

	Cypress	Cypress WF	Mixed	Bottomland	Marsh	Wet Prairie
Avg Hydroperiod Duration (days)	179	185	179	184	187	189
Std Dev Hydroperiod duration (days)	7	5	8	25	21	3
Avg Minimum Water-Level (ft)	-1.9	-3.8	-1.3	-4.3	-2.2	-3.8
Std Dev Minimum Water-Level (ft)	1.6	3.1	1.6	6.4	1.2	0.7
Avg Maximum Water-Level (ft)	1.8	0.2	1.9	0.7	2.1	0.7
Std Dev Maximum Water-Level (ft)	0.6	2.1	1.1	4.3	0.5	1.3
Avg Water-Level Range (ft)	1.3	4.0	3.2	5.0	4.3	4.5
Std Dev Water-Level Range (Ft)	0.7	1.0	2.0	2.2	1.1	1.6

*Wetland well 598 was omitted from this table, as it was the only wellfield bottomland wetland

Also not yet quantified is the duration of inundation, which has been used traditionally to traditionally defined wetland hydroperiod. Ewel (1990) suggested hydroperiod durations, defined as period of inundation, for several types of swamps (Figure 17) as a comparison of species richness. It is not clear how the duration estimates were derived, though. Inundation depths were also not noted.

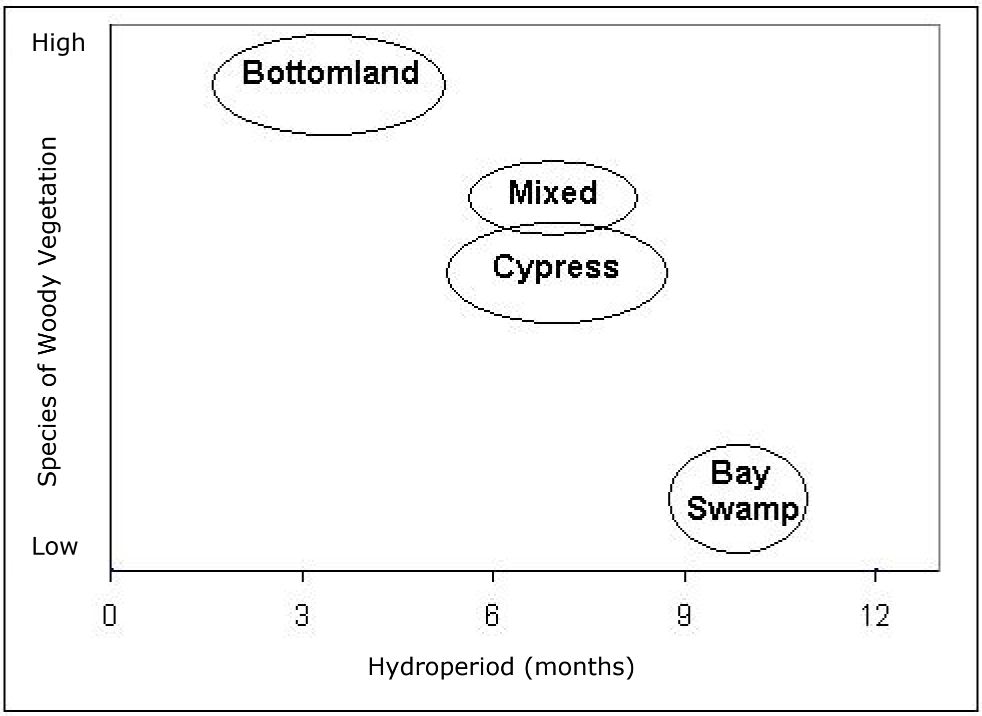


Figure 17: Proposed Relationships Between Species Richness of Woody Vegetation in Swamps Relative to the Hydroperiod (Source: After Ewel, 1990)

Figure 18 shows the average duration and depth of inundation from 2004 through 2006 for all wetland types. It can be seen from the figure that there is variability in both average depth as well as duration of inundation within similar wetland types. Due to variability in the location of wells within the wetlands and limited data collection sites, the depth and duration of inundation needs to be further investigated. It can, however, be said that on average, the water-level fluctuation above land surface during periods of inundation ranges from 0 to +2 feet. The figure clearly shows that neither period nor average depth of inundation appears to be an obvious characteristic of the various wetland types.

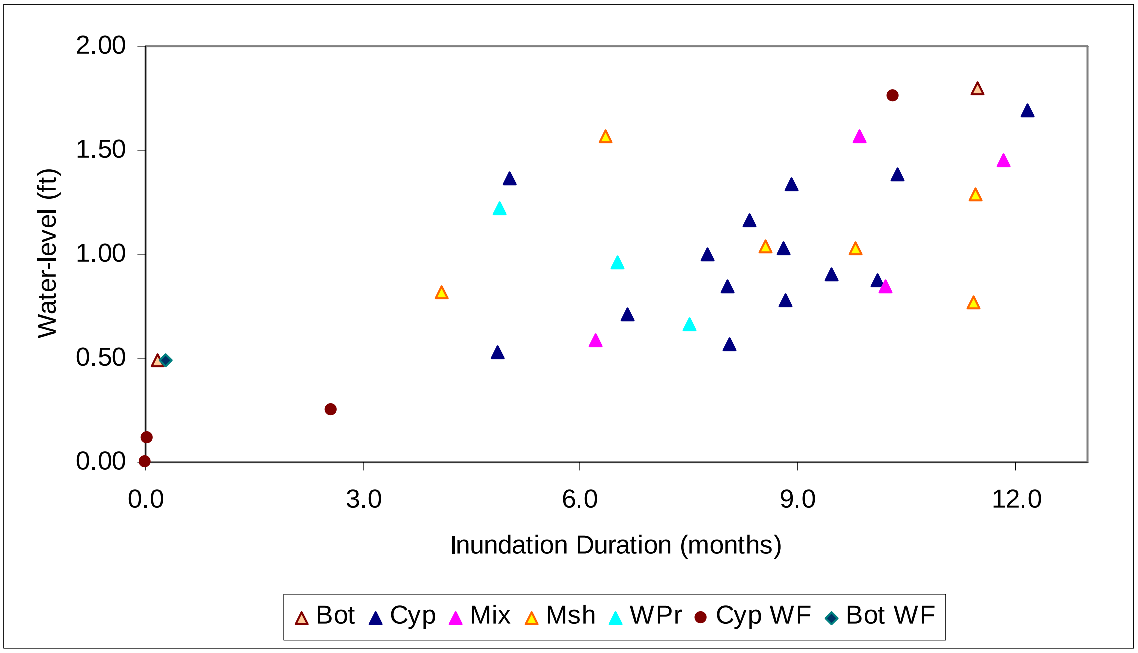


Figure 18: Average Duration and Depth of Inundation from 2004 through 2006 for All Wetland Types

Chapter Four: Conclusions

Since ecological characteristics of a wetland are controlled by wetland hydroperiod, the periodicity of both inundation and water-table fluctuations should be used in defining hydroperiod and in investigating ecological function. Spectral analysis of wetland water-level time series was used to successfully identify dominant frequencies, which are representative of the hydroperiod and encompass the entire range of water-level fluctuations. Spectral estimates of water-level time series from 34 wetland observation wells indicate a distinct semi-annual peak periodicity, found to be significant with a 95% confidence interval. Also, all of the wetlands analyzed, regardless of type, physiographic region, or wellfield effects, exhibit cyclic behavior of two dominant, 180-day hydroperiods each year. A winter/spring cycle, occurring from December through May, and a summer/fall cycle that takes place from June through November occur each year. A strong annual cycle is also exhibited in many of the wetlands, possibly occurring from the combination of the two semi-annual cycles. The hydroperiod cycle for West-Central Florida wetlands incorporates the entire range of water-level fluctuations, including both surface and subsurface water-levels. This cyclic behavior is of great importance in wetland sustainability, as dry to moist, but not saturated conditions are usually required for germination and seedling growth. The relative importance of the winter/spring cycle as compared to the summer/fall cycle is uncertain, though.

It appears, from the spectral analysis, that the hydroperiods of West-Central Florida wetlands are dominated by long term hydrologic processes and not by storm-event responses. No wetland investigated had a significant event periodicity. This doesn't mean that a particular hurricane won't change water-levels appreciably; however, for the years investigated, event periodicity was not exhibited in the spectral analysis. Flooding (elevated water-levels) associated with major tropical events is likely resultant from the relative coincidence of these storms during the summer/fall hydroperiod peak. These hydrologic events are less important from a wave (spectral) energy standpoint and perhaps less important to the overall health of a wetland.

The magnitude and range of surface and subsurface water-levels are not consistent between the 180 day winter/spring and summer/fall inter-annual hydroperiod cycles for individual wetlands. Wetlands generally exhibit higher and lower water-levels during the summer/fall hydroperiod, but similar storm response. Although the magnitude and range differ, the water-level probability distributions (shape) for the two 180 day semi-annual periods are similar.

Analogous water-level behavior does exist between like wetland types, regardless of physiographic region. This is intuitive, as it is generally believed that hydroperiod influences the type of vegetation present in a wetland. Therefore, for a given wetland type, physiographic region does not appear to affect wetland hydroperiod. Very interestingly and contrary to qualitative definitions, the period and depth of inundation in a wetland appears not to be a good index of wetland type, as seen in the seemingly random behavior shown in Figure 18. More data is, however, needed to fully conclude this tenuous, but significant observation. The water-level behavior, including probability distribution and magnitude and range of water-level fluctuation, both between different types of wetlands and from year to year, however, vary considerably. Comparison of the results from this study to the qualitative hydroperiod definitions suggest these types of relationships are oversimplistic and unreliable.

From the findings, wellfield stress (water-level pumping) can also affect wetland hydroperiod. Wetlands located in wellfields showed considerably lower water-levels than those wetlands not located in wellfields. Wellfield wetlands also exhibited a greater range of water-level fluctuation as a group. Water-level fluctuations in cypress wetlands outside of wellfields exhibited typical fluctuation from about -2 to +2 ft, with an average range of 1.3 feet, with a positively skewed (above land surface) water-level probability distribution. Cypress wetlands located in wellfields, however, displayed water-level fluctuations from approximately -4 to +.2 ft, with average ranges of 4 feet. In addition, the water-level probability distribution for wellfield wetlands is negatively skewed. Further analysis of a greater number of wetlands is required to draw more conclusive observations.

One last finding, resulting from this analysis, concerns wetland water-level measurements. Because the important water-level periodicity appears to be seasonal, observations recorded at intervals of several times a month appear to be relatively useful at further elucidating wetland hydroperiod characteristics for different wetland types. Less frequent monitoring, however, is probably not useful for this purpose or, in general, monitoring the health of a wetland. Also, any frequency less than daily will not expose the full extreme of water-level fluctuation, which may also be important for particular plant communities.

References

Armstrong, B., C. Doreen, A.Collazos, and J.L. Mallams. 2003. Doline and AQuifer Characteristics within Hernando, Pasco, and Northern Hillsborough Counties Tampa. Karst Studies in West Central Florida. Karst Research Group, USF: 39-51.

Battle, J. M. and S. W. Golladay. 2001. Hydroperiod Influence on Breakdown of Leaf Litter in Cypress-gum Wetlands. The American Midland Naturalist 146: 128-145.

Bendat, J. S. and Piersol, A. G. 1986. Random Data: Analysis and Measurement Procedures. 2/e, Wiley, Chichester, 566 pp.

Bourgeau-Chavez, L. L., K. B. Smith, S.B.Brunzell, E.S.Kasischke, E.A.Romanowicz, and C.J.Richardson. 1995. Remote Monitoring of Regional Inundation Patterns and Hydroperiod in the Greater Everglades Using Synthetic Aperture Radar. Wetlands 25(1): 176-191.

Brooks, H.K. 1981. Guide to the Physiographic Regions of Florida. Institute of Food and Agricultural Services, University of Florida. Gainesville, FL.

Brooks, R. T. 2005. A Review of Basin Morphology and Pool Hydrology of Isolated Ponded Wetlands: Implications for Seasonal Forest Pools of the Northeastern United States. Wetlands Ecology and Management 13: 335–348.

Bullock, A. and M. Acreman. 2003. The Role of Wetlands in the Hydrological Cycle. Hydrology and Earth System Sciences 7(3): 358-389.

Chatfield, C. 2004. The Analysis of Time Series: An Introduction. CRC Press. Boca Raton,FL.

Chen, E. and J. F. Gerber.1990. Climate. *In* R. L. Myers and J. J. Ewel (*eds.*). Ecosystems of Florida. University of Central Florida Press Orlando, FL: 11-34.

Clayback, K.B. 2006. Investigation of Normalized Streamflow in West Central Florida and Extrapolation to Ungaged Coastal Fringe Tributaries. Masters Thesis University of South Florida, Tampa, Fl.

Clemens, L. A., D. Spangler,and D.J.Patton. 1984. The Hydrologic Cycle. *In* E. A. Fernald and D. J. Patton (*eds.*). Water Resources Atlas of Florida. Institute of Science and Public Affairs, Tallahassee,FL.

Cooke, C.W. 1945. Geology of Florida. Florida Geological Survey Bulletin 29, 339 p.

Cowardin, L. M., V. Carter, F.C.Golet, and E.T.LaRoe. 1979. Classification of wetlands and deepwater habitats of the United States, U. S. Department of the Interior, Fish and Wildlife Service, 131 pp.

Craddock, J. M. 1956. The Representation of the Annual Temperature Variation Over Central and Northern Europe by a Two-Term Harmonic Form. Quarterly Journal of the Royal Meteorological Society, 82: 275-288.

Davis, J. C. 1986. Statistics and Data Analysis in Geology. John Wiley, New York, 646 pp.

Dennison, M. S. and J. F. Berry.1993. Wetlands - Guide to Science, Law, and Technology. Noyes Publications. Park Ridge, FL.

Ewel, K. 1990. Swamps. *In* R. L. Myers and J. J. Ewel (*eds.*).Ecosystems of Florida. University of Central Florida Press, Orlando: 281-323.

FDOT.1999. Florida Land Use, Cover and Forms Classification System. State of Florida Department of Transportation: 1-93.

FNAI.1990. Guide to the Natural Communities of Florida. Florida Natural Areas Inventory and Florida Department of Natural Resources: 1-120.

Godin, G. 1972. The Analysis of Tides. Liverpool University Press, 264 pp.

Haag, K. H., T. M. Lee, and D.C.Herndon. 2005. Bathymetry and Vegetation in Isolated Marsh and Cypress Wetlands in the Northern Tampa Bay Area, 2000-2004. Scientific Investigations Report 2005-5109: 1-49.

Hardisty, J. 1993. Time Series Analysis Using Spectral Techniques: Oscillatory Currents. Earth Surface Processes and Landforms, 18,855-862.

Hegge, B. J. and G. Masselink. 1996. Spectral Analysis of Geomorphic Time Series: Auto-Spectrum. Earth Surface Processes and Landforms 21: 1021-1040.

Junk, W. J., P. B. Bayley, and R.E.Sparks. 1989. The Flood Pulse Concept in River-Floodplain Systems. Journal Of Canadian Fisheries And Aquatic Sciences 106(Special Issue): 11-127.

Kay, S. M. and Marple, S. L. 1981.Spectrum analysis-A modem perspective. Proceedings of the IEEE, 69: 1380-1419.

Kinsman, B. 1984. Wind Waves: Their Generation and Propagation on the Ocean Surface. Dover Publications, New York, 676 pp.

Knochenmus, D.D., and Hughes, G.H. 1976. Hydrology of Lake County, Florida. U.S. Geological Survey Water Resources Investigation, 76-72, 100 pp.

Knowles, L. J., A. M. O'Reilly,and J.C.Adamski. 2002. Hydrogeology and Simulated Effects of Ground-Water Withdrawals from the Floridan Aquifer System in Lake County and in the Ocala National Forest and Vicinity, North-Central Florida. Water-Resources Investigations Report Tallahassee, Fl, U.S. Geological Survey.

Lewelling, B. R., A. B. Tihansky, and J.L.Kindinger. 1998. Assessment of the Hydraulic Connection between Groundwater and the Peace River, West-Central Florida. Water-Resources Investigations Report 97-4211, U.S. Geological Survey Tallahassee, FL.

MacNeil, F.S. 1950. Pleistocene shorelines in Florida and Georgia. U.S. Geological Survey Professional Paper, 221-F: 95-107.

Mann, C. J. and R. G. Wetzel. 2000. Hydrology of an Impounded Lotic Wetland—Subsurface Hydrology. Wetlands 20(1): 33–47.

Marble, A. D. 1992. A Guide to Wetland Functional Design, CRC Press LLC., Boca Raton, FL.

Mitsch, W. J. and J. G. Gosselink .2000. Wetlands. John Wiley and Sons, Inc. New York, NY.

O'Reilly, A. M. 2004. A Method for Simulating Transient Ground-Water Recharge in Deep Water-Table Settings in Central Florida by Using a Simple Water-Balance/Transfer-Function Model. Scientific Investigations Report 2004-5195. Reston, Virginia. U.S. Department of the Interior and U.S. Geological Survey: 49.

Pinder, L. and S. Rosso.1998. Classification and ordination of plant formations in the Pantanal of Brazil. Plant Ecology 136: 151–165.

Ruskauff, G., Aly, A., Ewing, J., Jobes, T., Donigan, A., Tara, P., Trout, K., Ross, M., 2003. The Integrated Northern Tampa Bay Hydrologic Model (INTB). Volume 3, Tampa Bay Water, Tampa, Fl.

Semeniuk, V. and C. A. Semeniuk. 1997. A Geomorphic Approach to Global Classification for Natural Inland Wetlands and Rationalization of the System Used By the Ramsar Convention – A Discussion. Wetlands Ecology and Management 5: 145-158.

Schmidt, W. 1997. Geomorphology and Physiography of Florida. *In* Jones, D.S. and Randazzo, A.F.(eds.). The Geology of Florida. University Press of Florida: Gainesville, pp. 1-12.

Scott. M.H. 2006. Precipitation Variability of Streamflow Fraction in West-Central Florida. Masters Thesis, University of South Florida, Tampa, Fl.

Shaffer, P. W., C. A. Cole, M.E.Kentula, and R.P.Brooks. 2000. Effects of Measurement Frequency on Water-Level Summary Statistics. Wetlands 20(1): 148–161.

Southwest Florida Water Management District. 1996. Northern Tampa Bay Water Resource Assessment Project. Volume 1, Surface water/Groundwater Interrelationships.

Southwest Florida Water Management District. 2000. Hillsborough River Watershed Management Plan.

Southwest Florida Water Management District and Tampa Bay Water. 2005. Wetland Assessment Procedure (WAP) Instruction Manual for Isolated Wetlands.

Tiner, R. W. 1991. The Concept of a Hydrophyte for Wetland Identification. BioScience 41(4): 236-247.

Tiner, R. W. 1996. Technical Aspects of Wetlands: Wetland Definitions and Classifications in the United States. U. S. Geological Survey Water-Supply Paper, Report: W 2425, Reston, VA.

Welch, P. D. 1967. The Use of Fast-Fourier Transform for the Estimation of Power Spectra: A Short Method Based on Time Averaging over Short, Modified Periodograms. IEEE Transactions of The Audio And Electroacoustics, AU-L5: 70-13.

White, W.A.1970. The Geomorphology of the Florida Peninsula. Florida Bureau of Geology Bulletin No. 51, 164 pp.

Zedler, J. B. 2001. Handbook for Restoring Tidal Wetlands. CRC Press, Boca Raton,FL.

Appendices

Appendix A: Time Series Figures

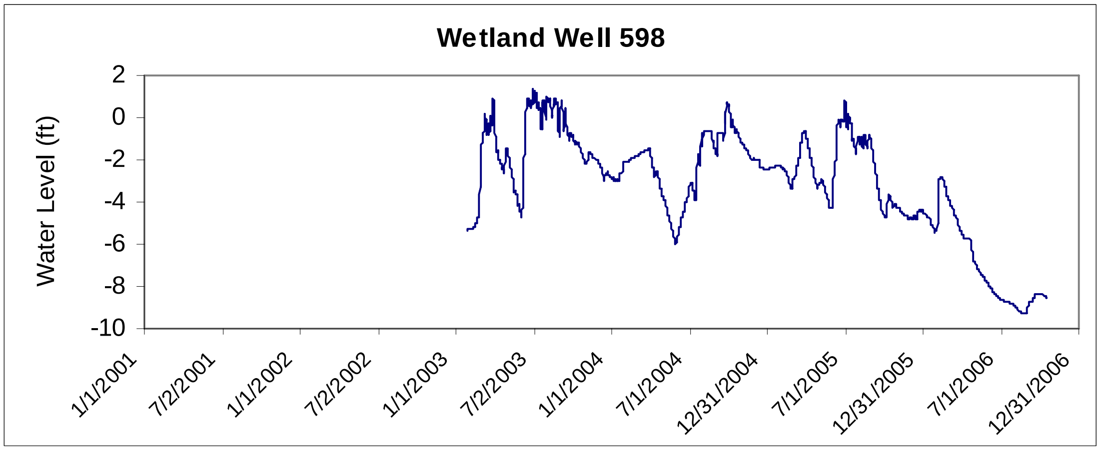


Figure 19: Observed Water-Level Time Series for Wetland Well 598

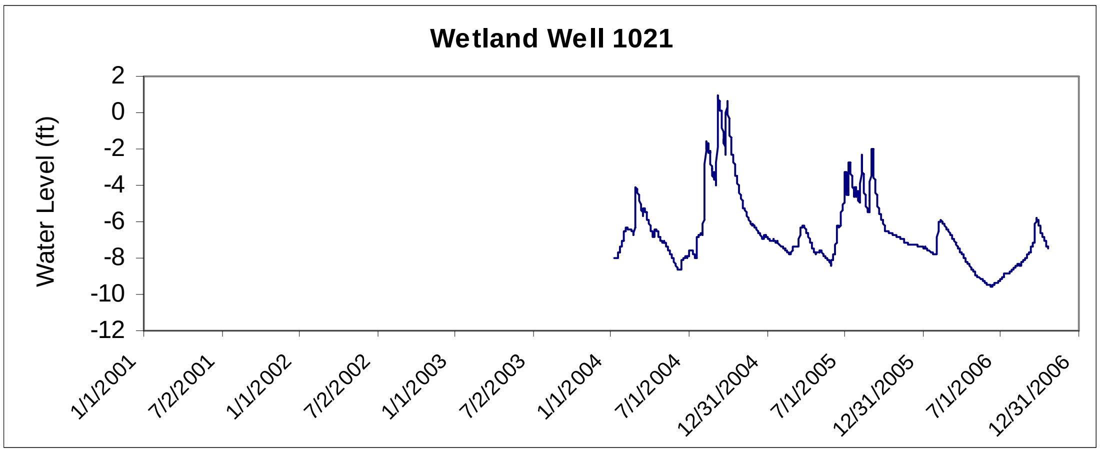


Figure 20: Observed Water-Level Time Series for Wetland Well 1021

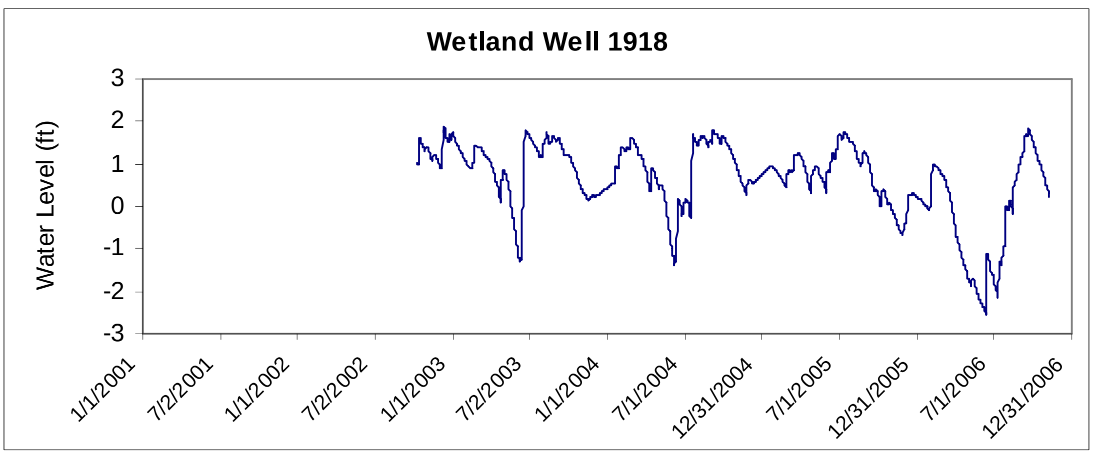


Figure 21: Observed Water-Level Time Series for Wetland Well 1918

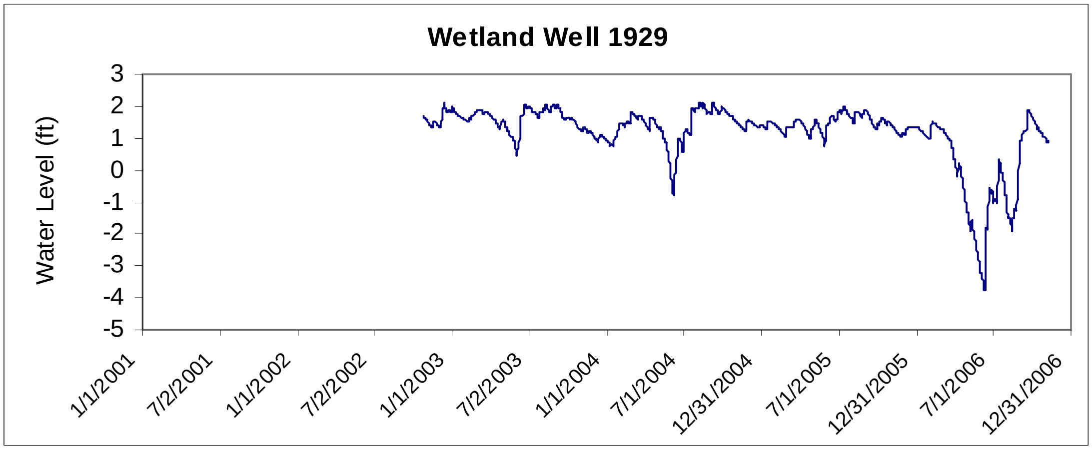


Figure 22: Observed Water-Level Time Series for Wetland Well 1929

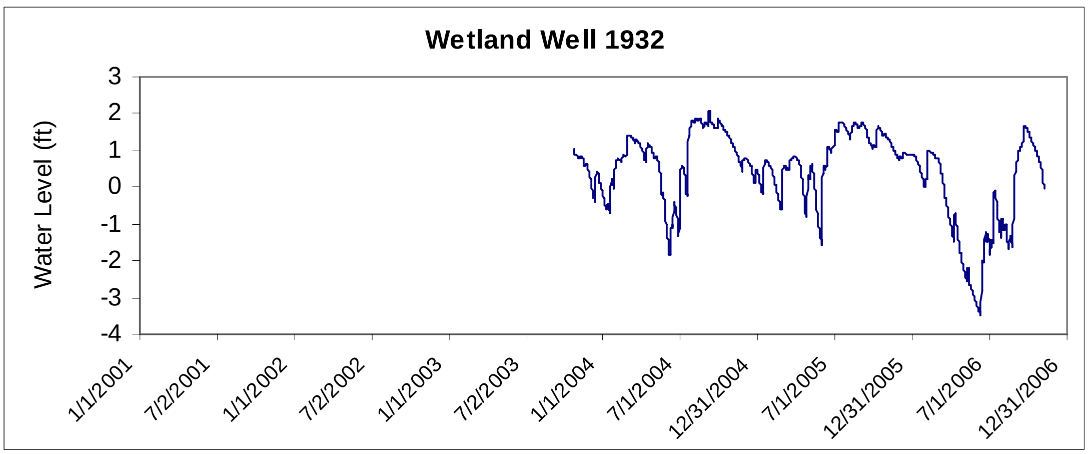


Figure 23: Observed Water-Level Time Series for Wetland Well 1932

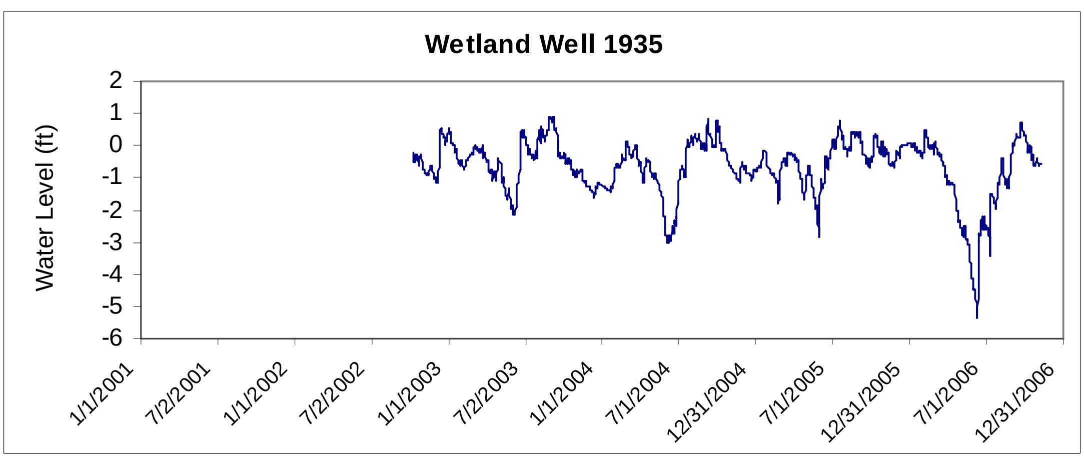


Figure 24: Observed Water-Level Time Series for Wetland Well 1935

Appendix A: (Continued)

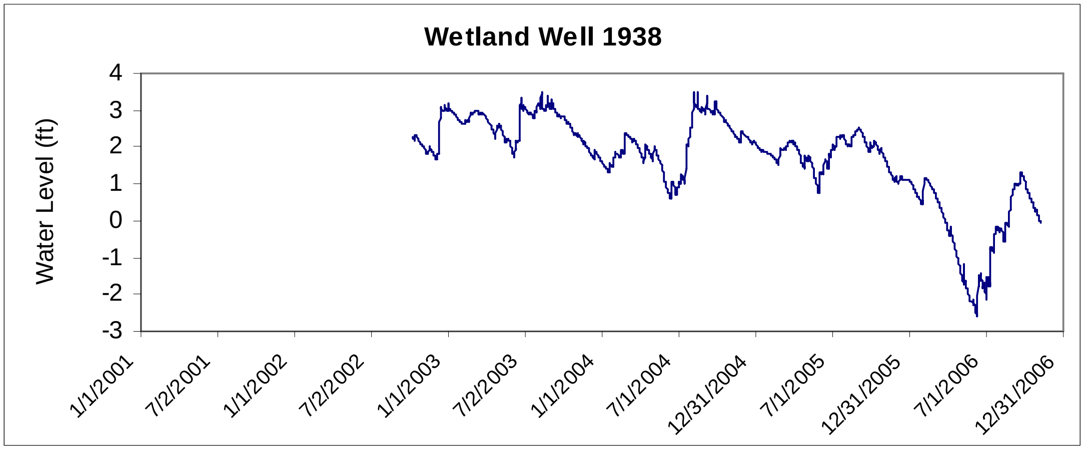


Figure 25: Observed Water-Level Time Series for Wetland Well 1938

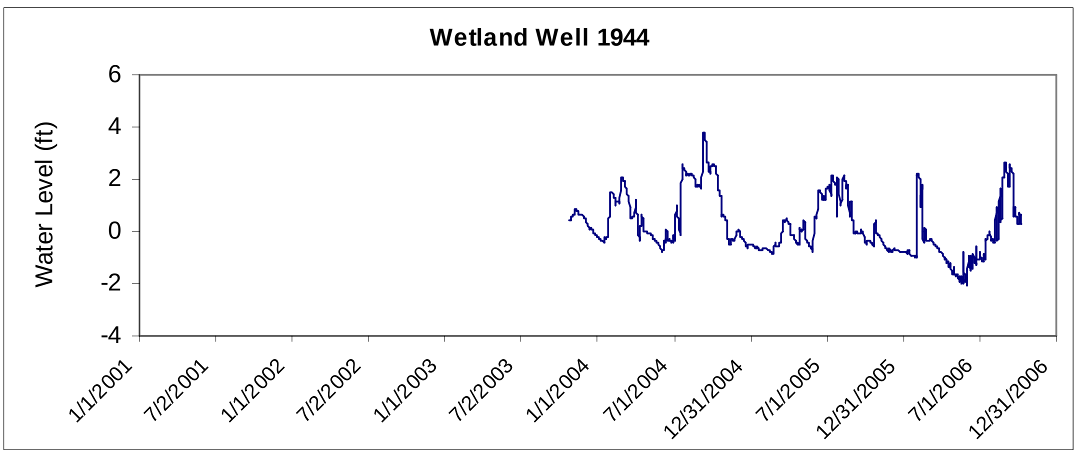


Figure 26: Observed Water-Level Time Series for Wetland Well 1944

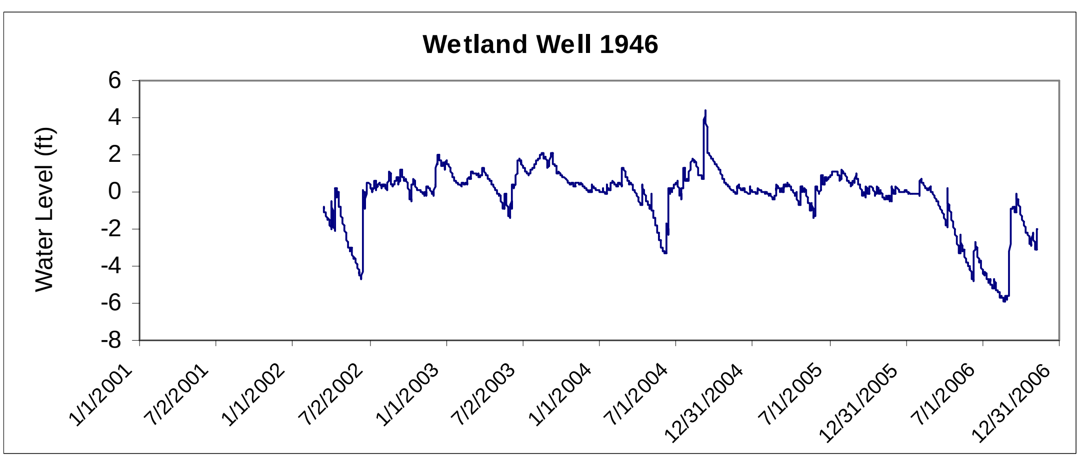


Figure 27: Observed Water-Level Time Series for Wetland Well 1946

Appendix A: (Continued)

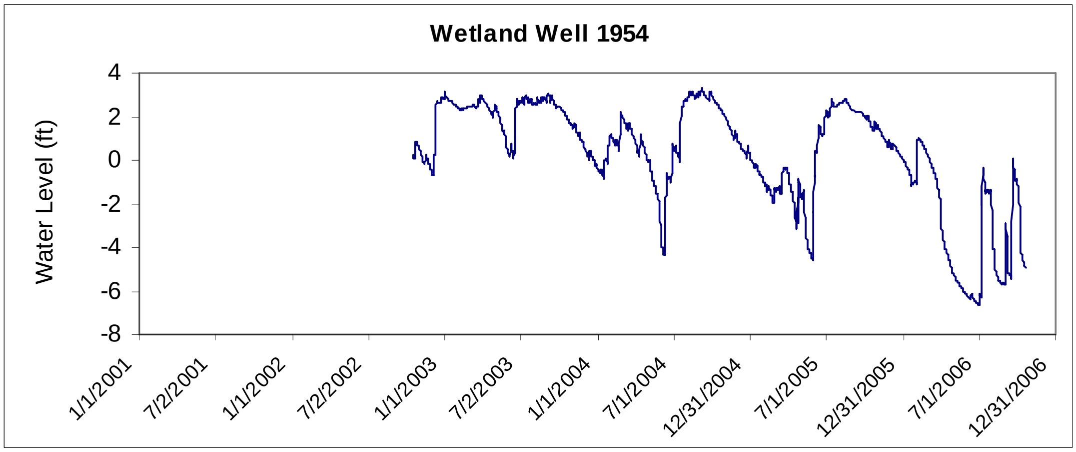


Figure 28: Observed Water-Level Time Series for Wetland Well 1954

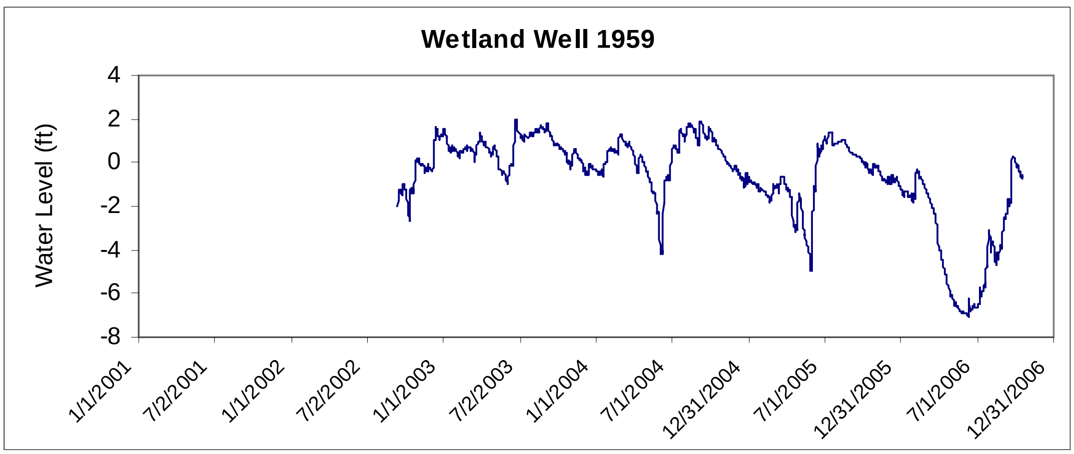


Figure 29: Observed Water-Level Time Series for Wetland Well 1959

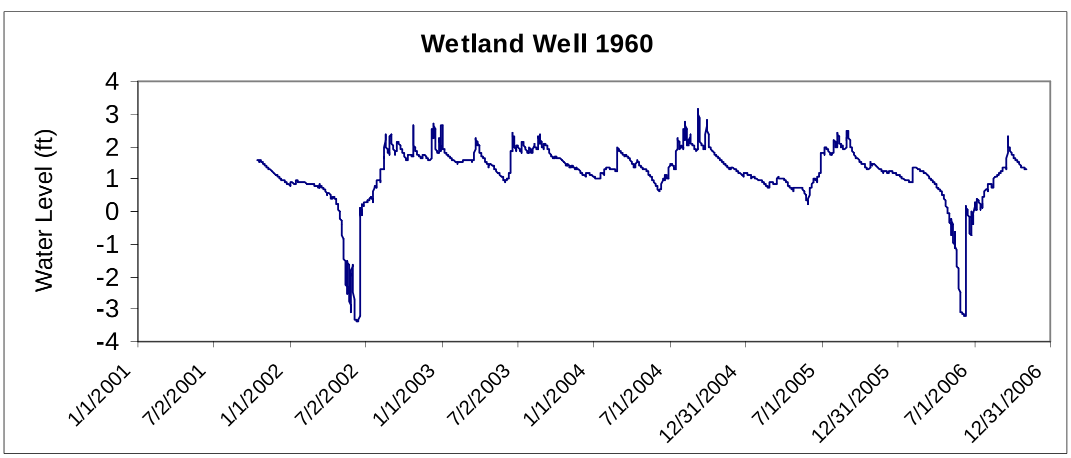


Figure 30: Observed Water-Level Time Series for Wetland Well 1960

Appendix A: (Continued)

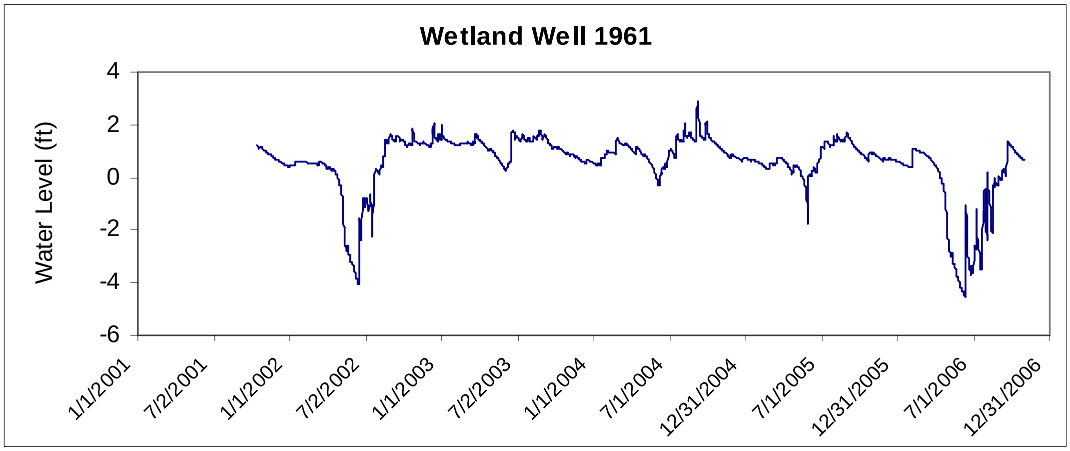


Figure 31: Observed Water-Level Time Series for Wetland Well 1961

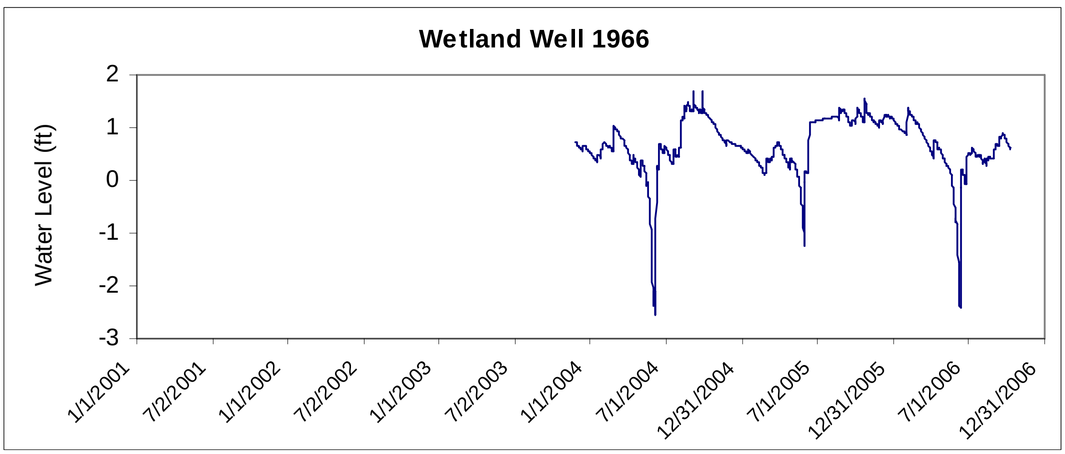


Figure 32: Observed Water-Level Time Series for Wetland Well 1966

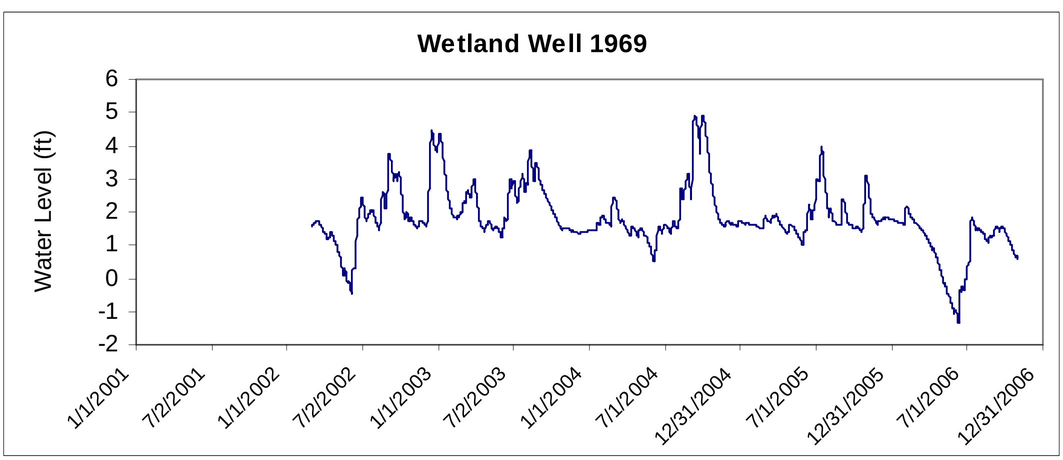


Figure 33: Observed Water-Level Time Series for Wetland Well 1969

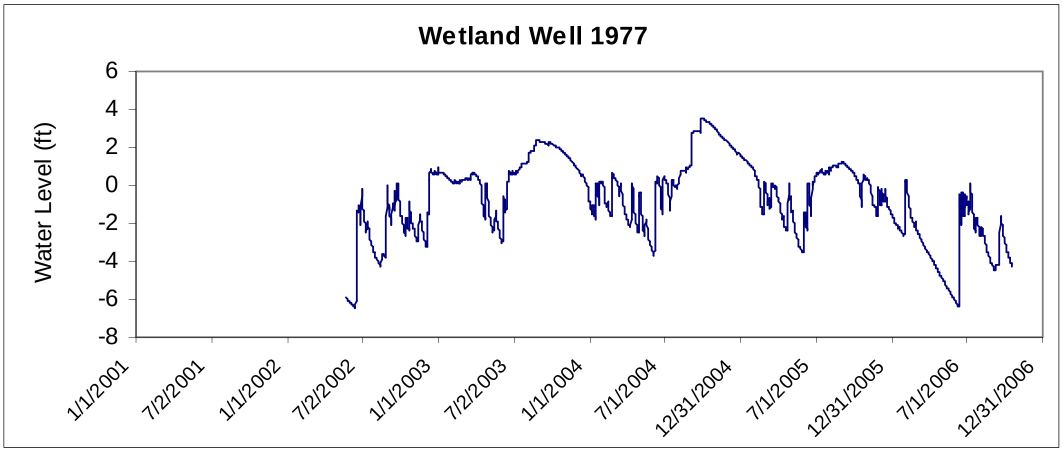


Figure 34: Observed Water-Level Time Series for Wetland Well 1977

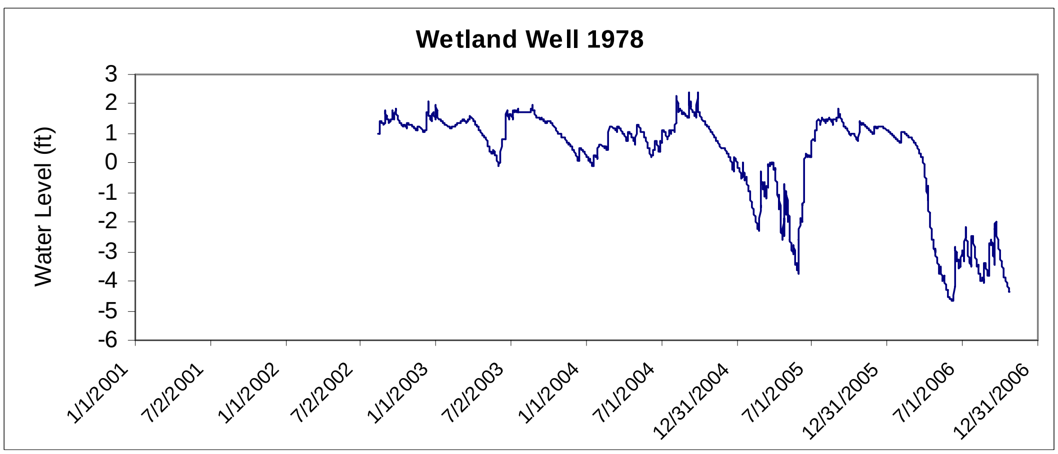


Figure 35: Observed Water-Level Time Series for Wetland Well 1978

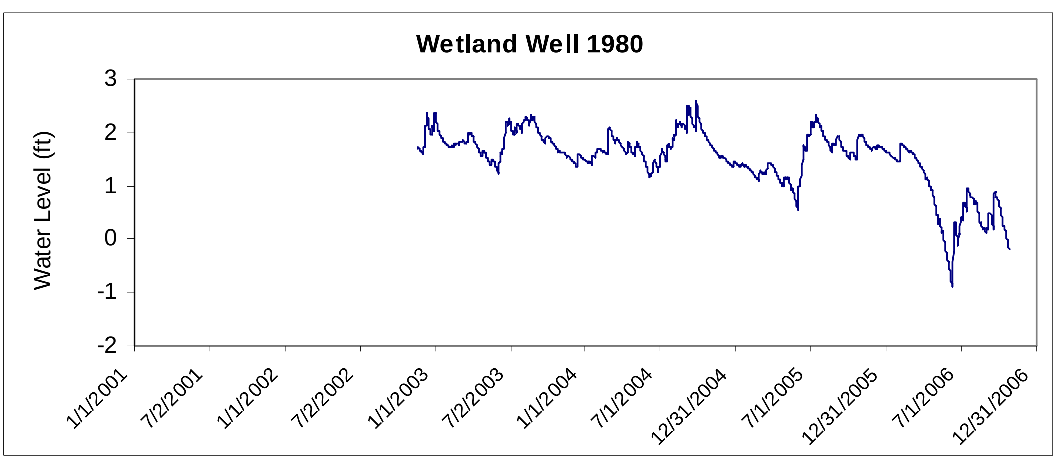


Figure 36: Observed Water-Level Time Series for Wetland Well1980

Appendix A: (Continued)

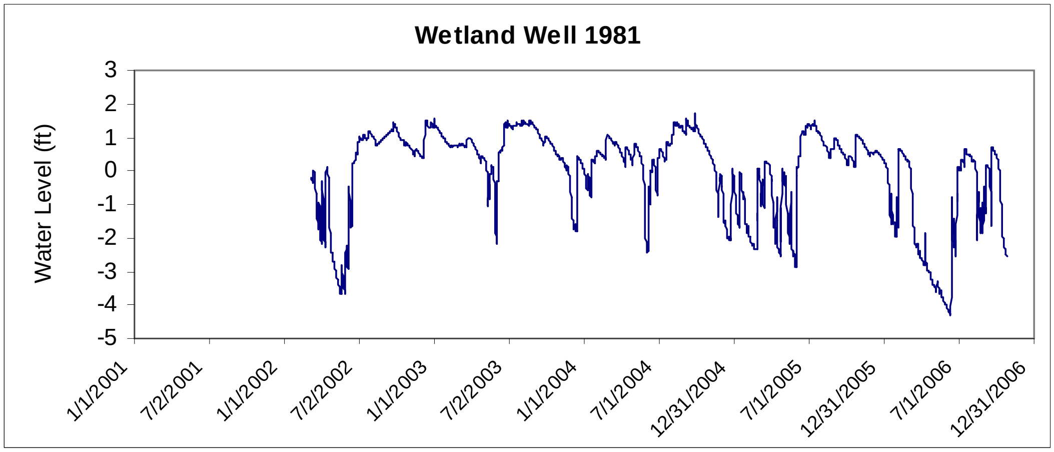


Figure 37: Observed Water-Level Time Series for Wetland Well 1981

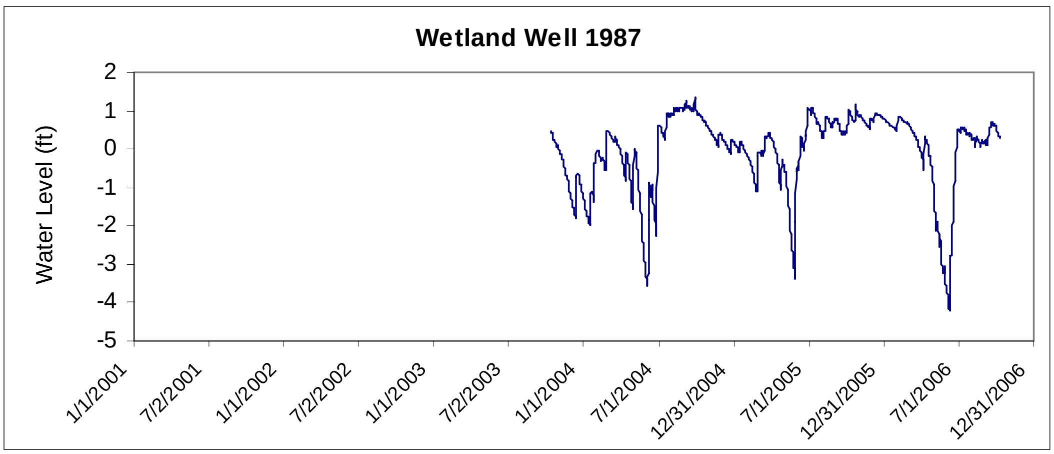


Figure 38: Observed Water-Level Time Series for Wetland Well 1987

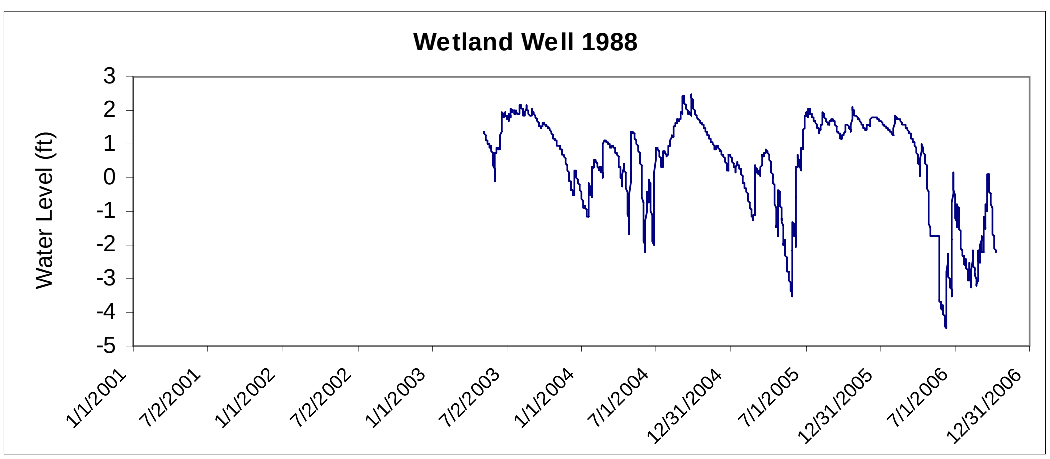


Figure 39: Observed Water-Level Time Series for Wetland Well 1988

Appendix A: (Continued)

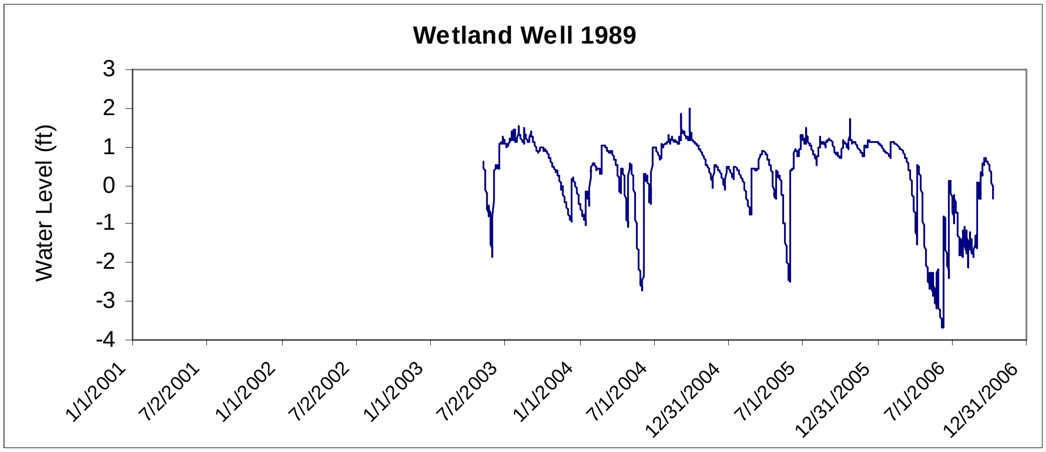


Figure 40: Observed Water-Level Time Series for Wetland Well 1989

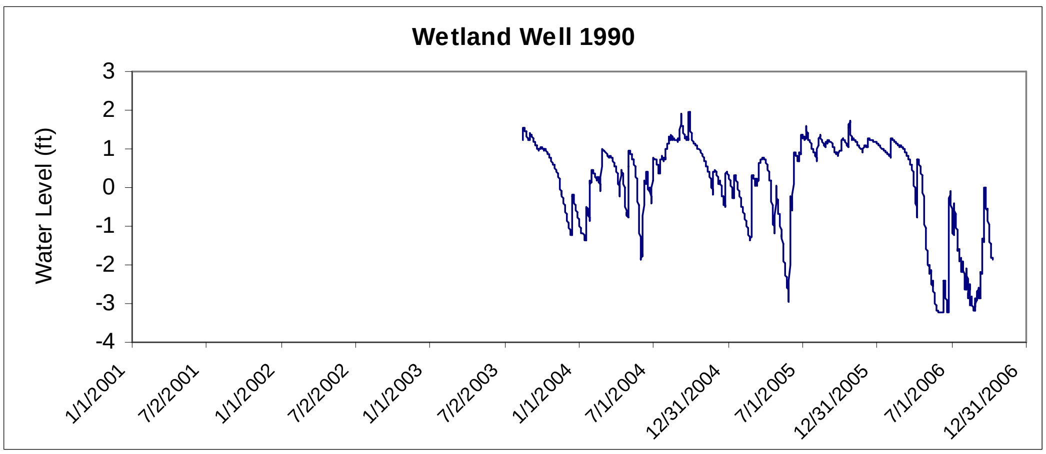


Figure 41: Observed Water-Level Time Series for Wetland Well 1990

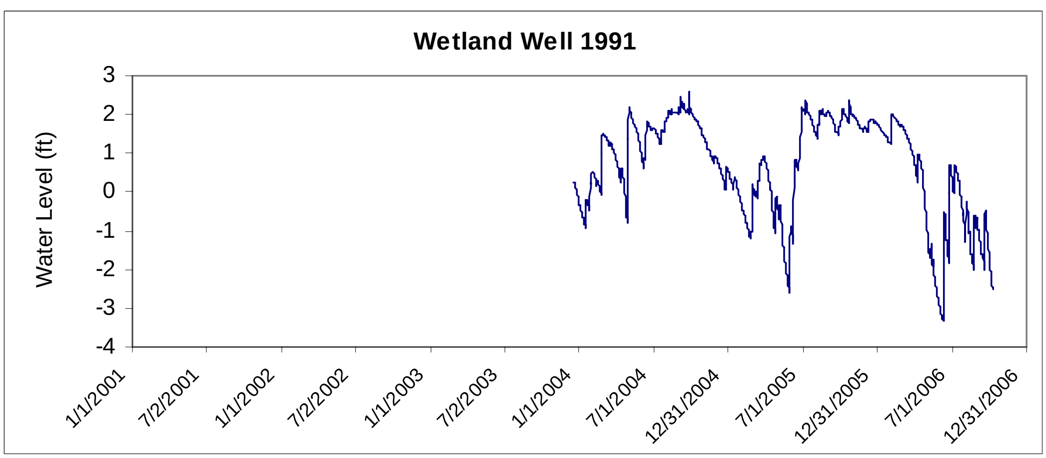


Figure 42: Observed Water-Level Time Series for Wetland Well 1991

Appendix A: (Continued)

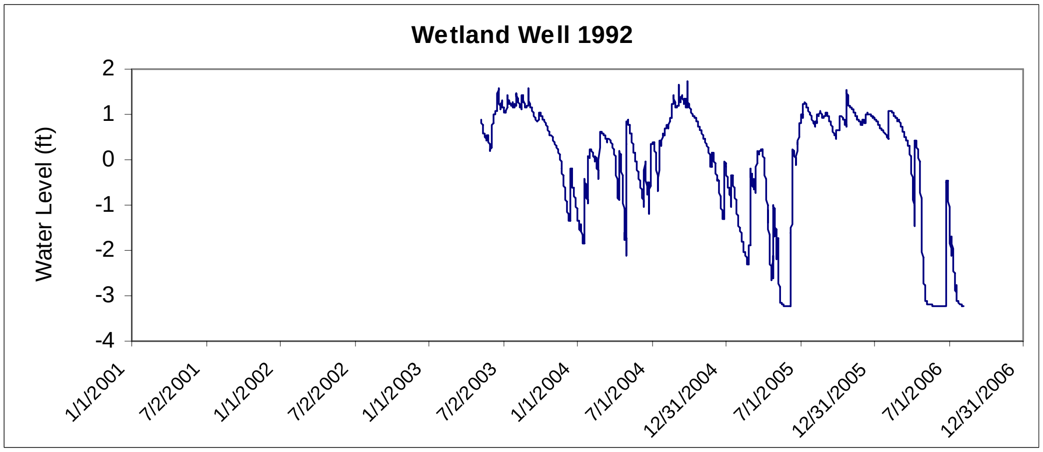


Figure 43: Observed Water-Level Time Series for Wetland Well 1992

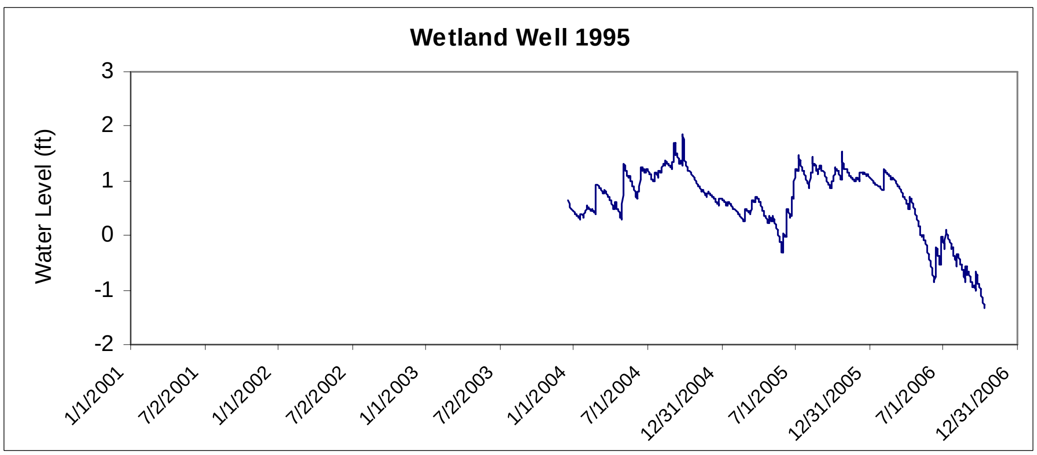


Figure 44: Observed Water-Level Time Series for Wetland Well 1995

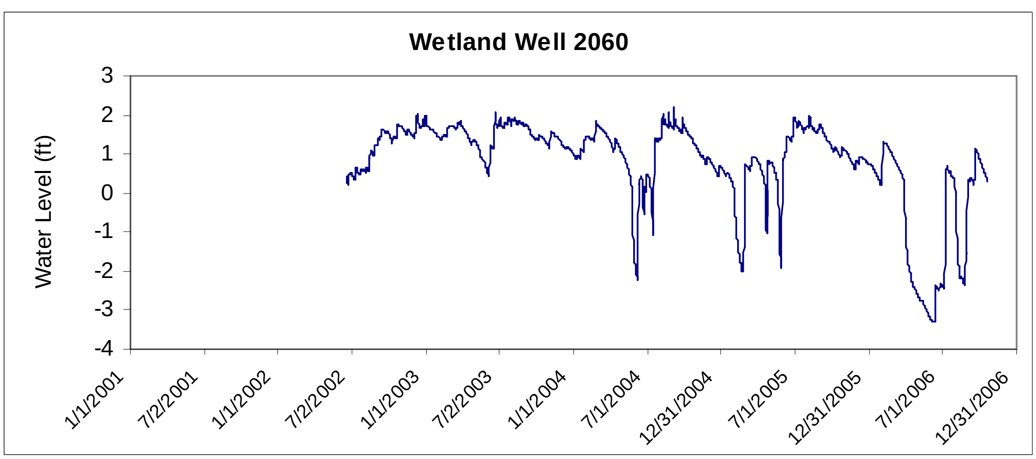


Figure 45: Observed Water-Level Time Series for Wetland Well 2060

Appendix A: (Continued)

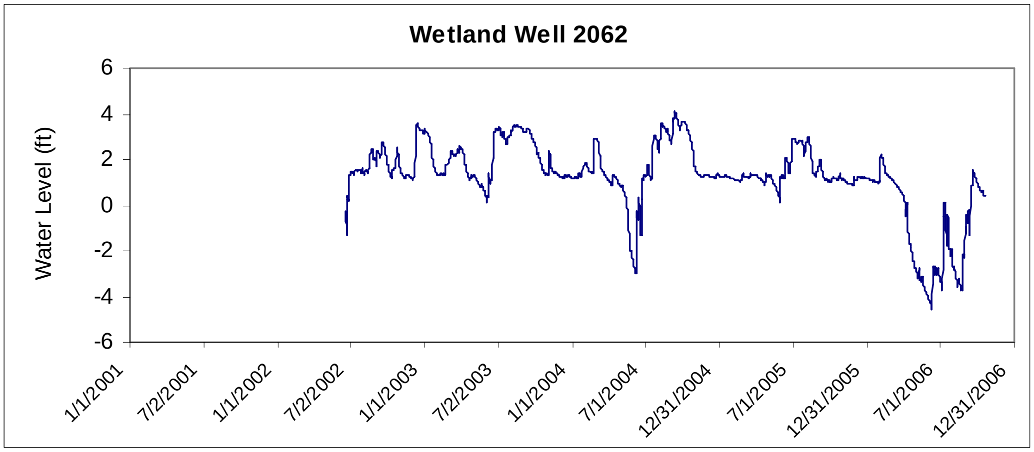


Figure 46: Observed Water-Level Time Series for Wetland Well 2062

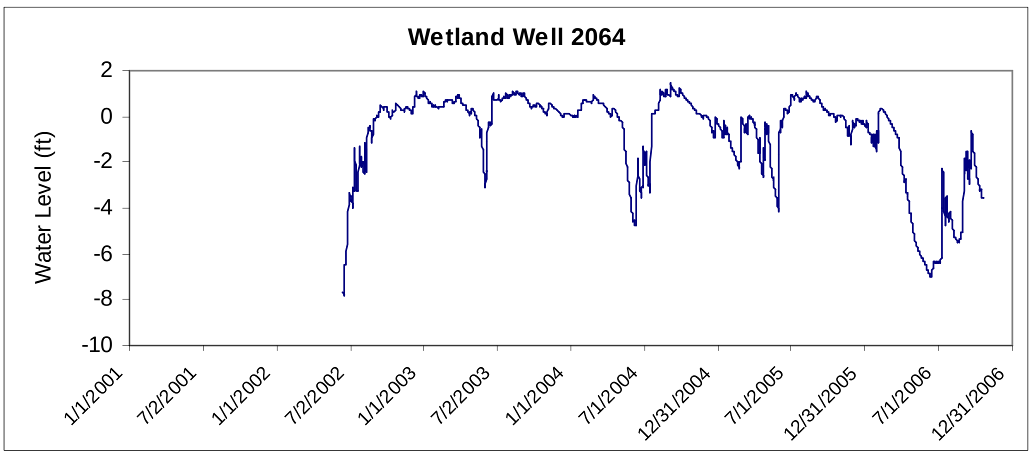


Figure 47: Observed Water-Level Time Series for Wetland Well 2064

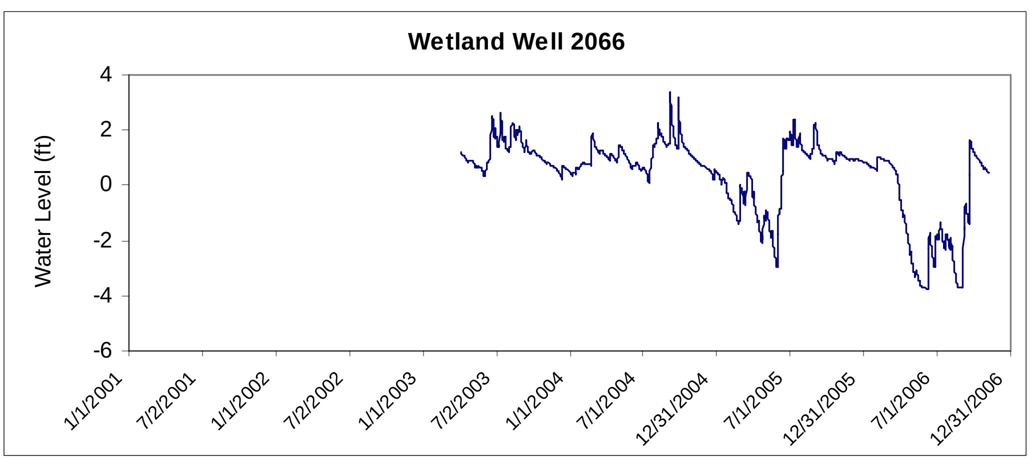


Figure 48: Observed Water-Level Time Series for Wetland Well 2066

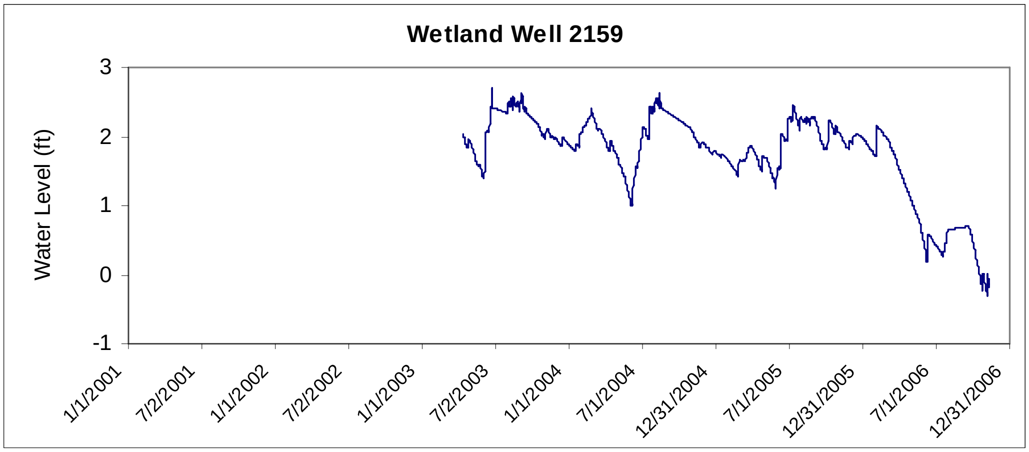


Figure 49: Observed Water-Level Time Series for Wetland Well 2159

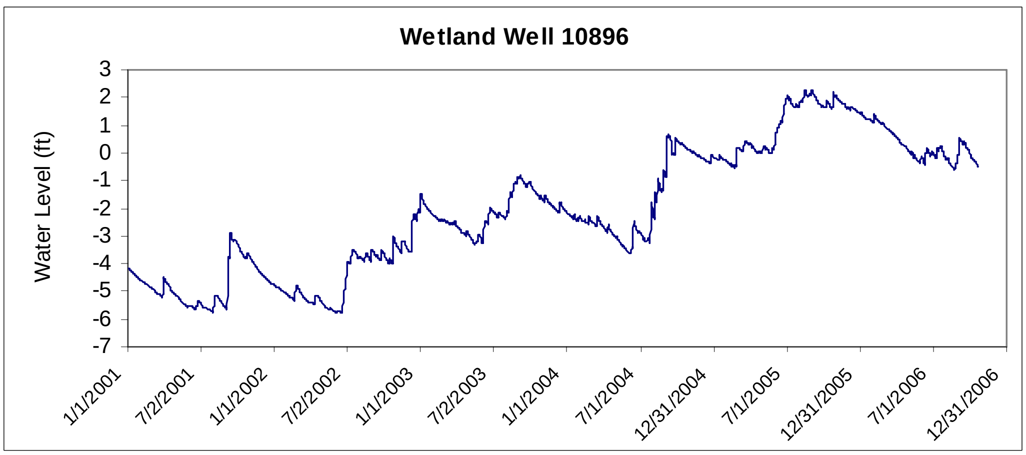


Figure 50: Observed Water-Level Time Series for Wetland Well 10896

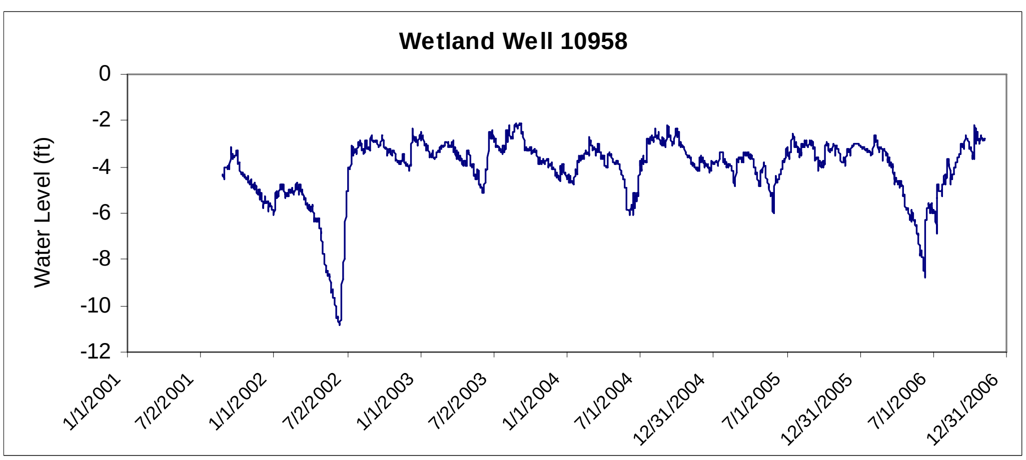


Figure 51: Observed Water-Level Time Series for Wetland Well 10958

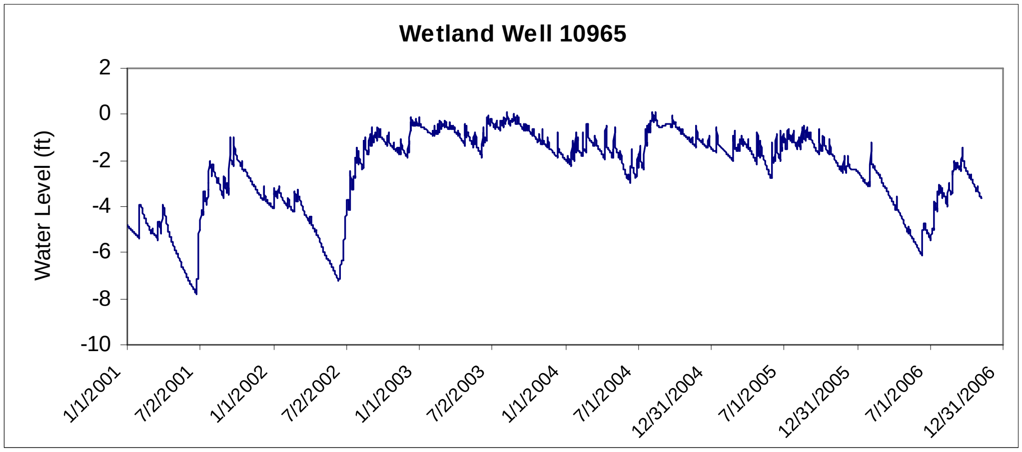


Figure 52: Observed Water-Level Time Series for Wetland Well 10965

Appendix B: Annual Observed Water-Level Time Series

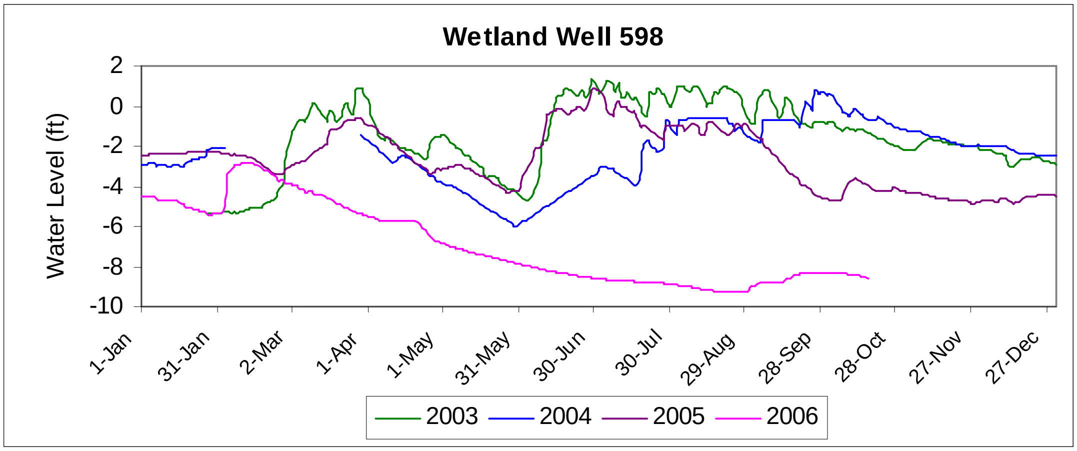


Figure 53: Annual Observed Water-Level Time Series for Wetland Well 598

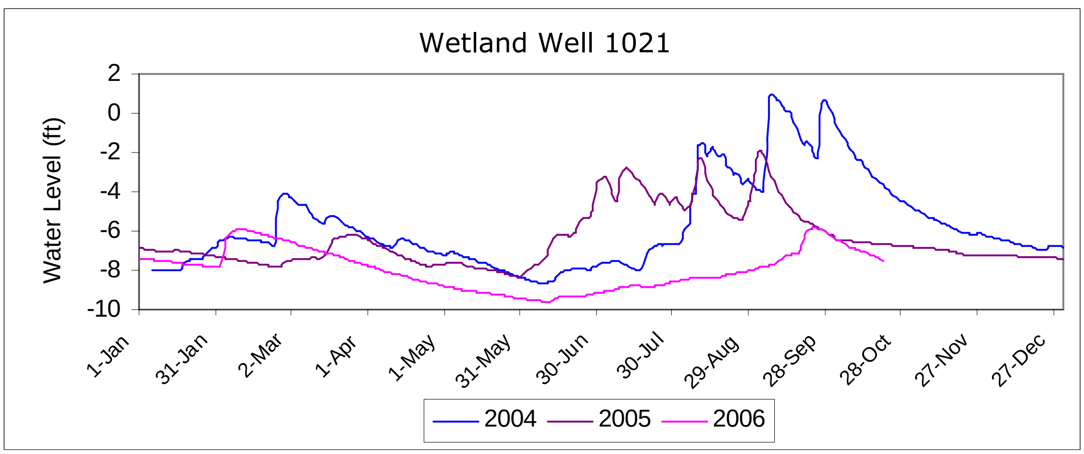


Figure 54: Annual Observed Water-Level Time Series for Wetland Well 1021

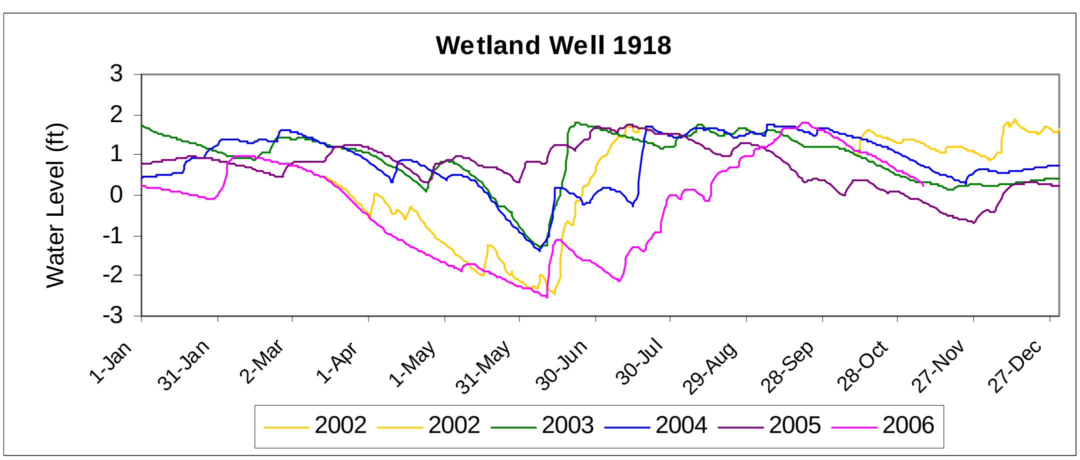


Figure 55: Annual Observed Water-Level Time Series for Wetland Well 1918

Appendix B: (Continued)

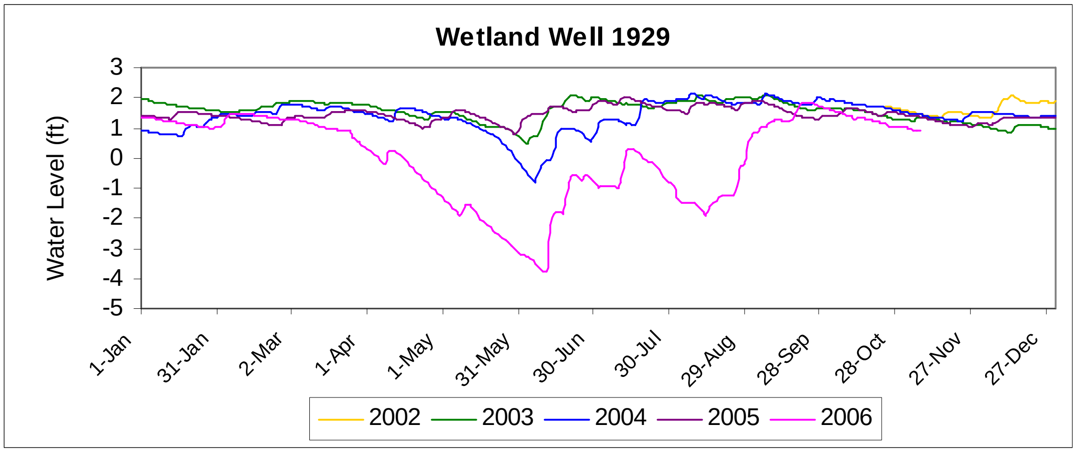


Figure 56: Annual Observed Water-Level Time Series for Wetland Well 1929

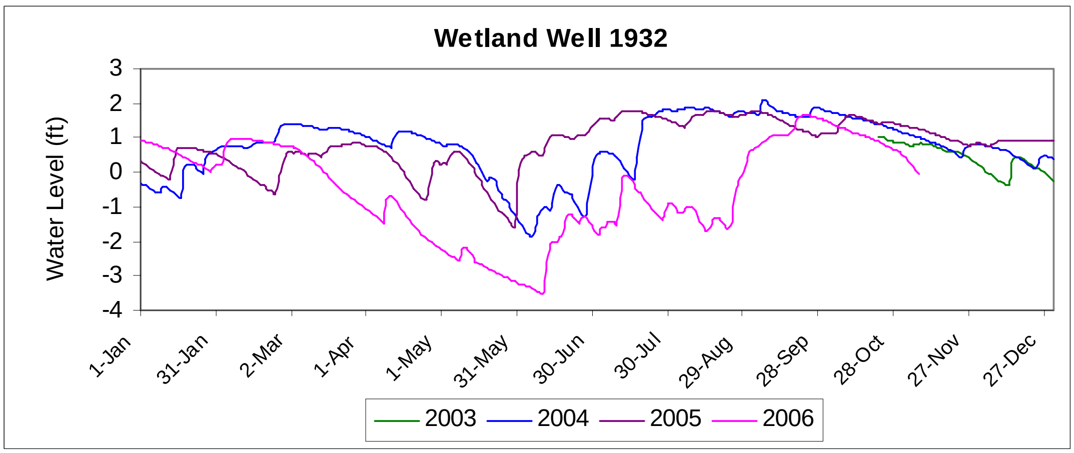


Figure 57: Annual Observed Water-Level Time Series for Wetland Well 1932

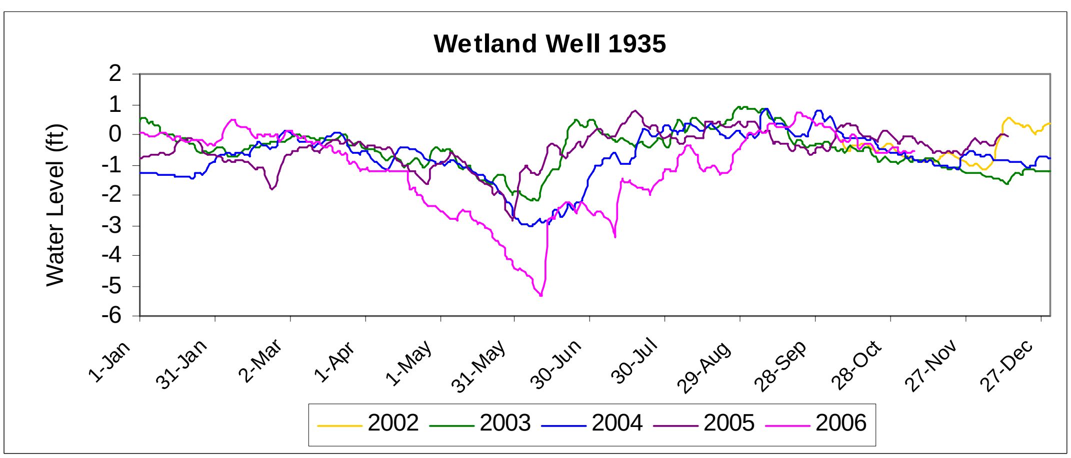


Figure 58: Annual Observed Water-Level Time Series for Wetland Well 1935

Appendix B: (Continued)

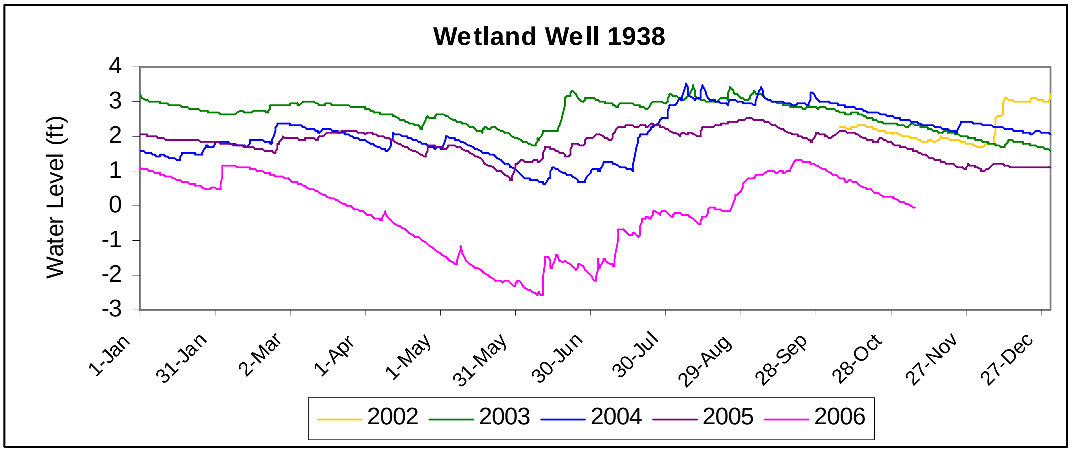


Figure 59: Annual Observed Water-Level Time Series for Wetland Well 1938

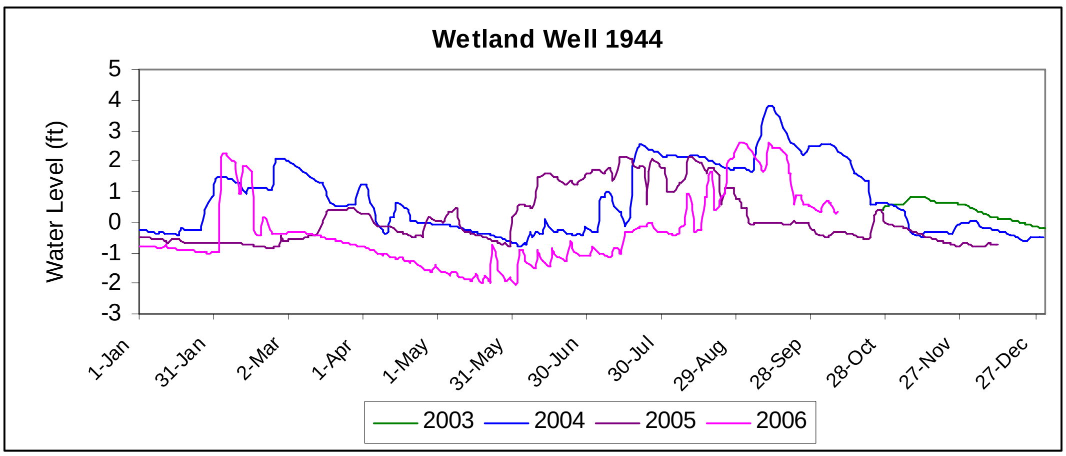


Figure 60: Annual Observed Water-Level Time Series for Wetland Well 1944

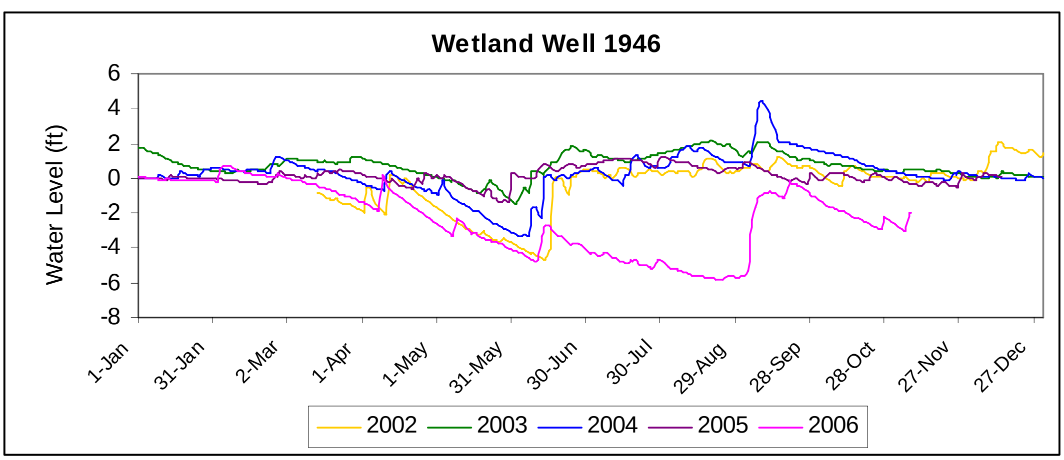


Figure 61: Annual Observed Water-Level Time Series for Wetland Well 1946

Appendix B: (Continued)

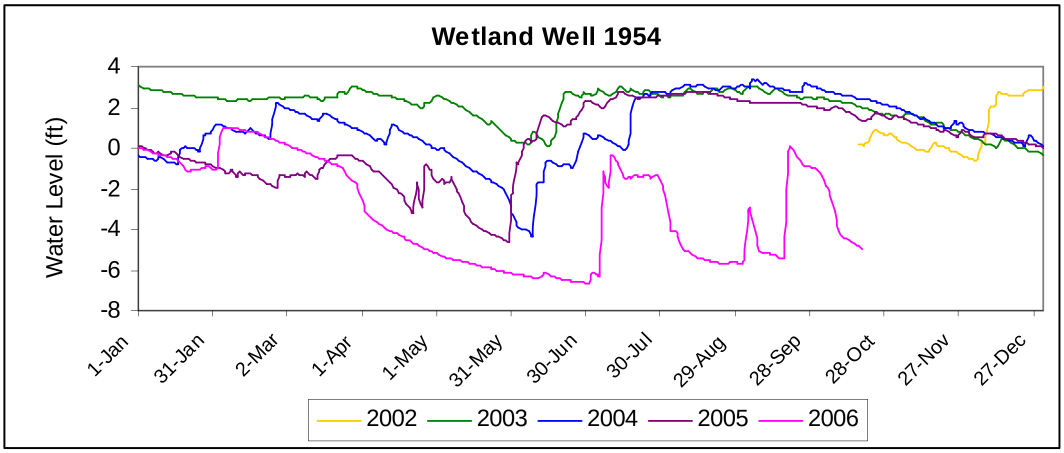


Figure 62: Annual Observed Water-Level Time Series for Wetland Well 1954

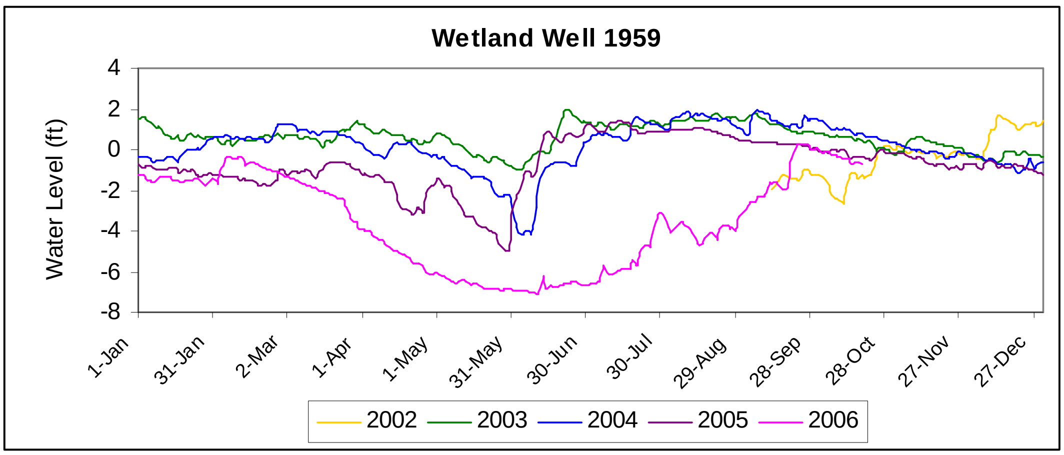


Figure 63: Annual Observed Water-Level Time Series for Wetland Well 1959

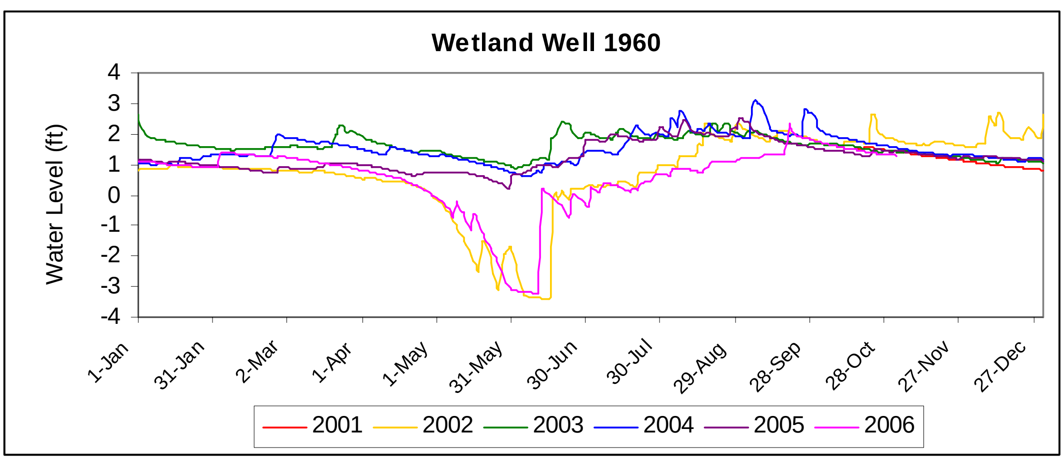


Figure 64: Annual Observed Water-Level Time Series for Wetland Well 1960

Appendix B: (Continued)

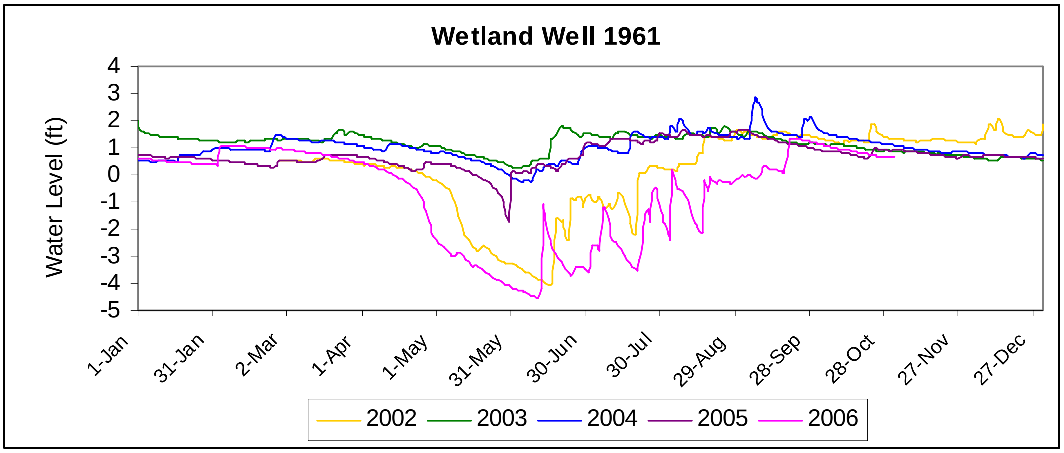


Figure 65: Annual Observed Water-Level Time Series for Wetland Well 1961

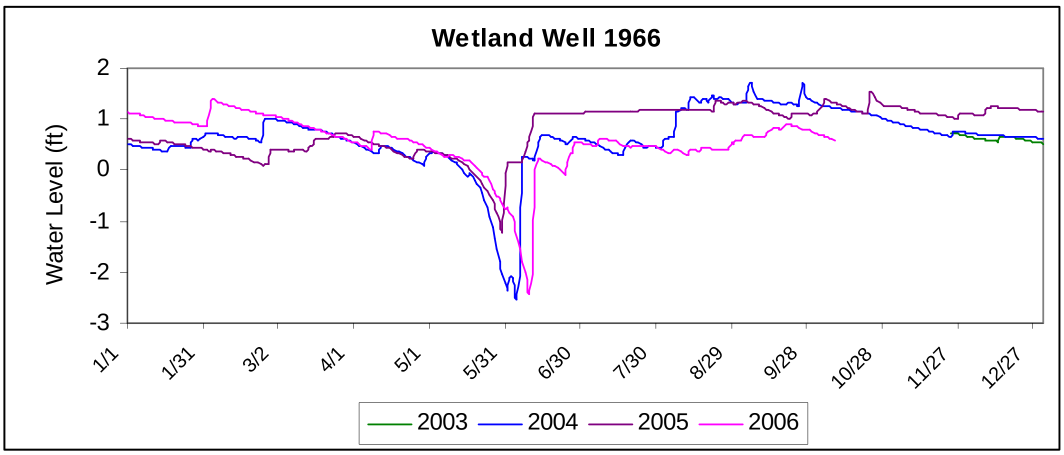


Figure 66: Annual Observed Water-Level Time Series for Wetland Well 1966

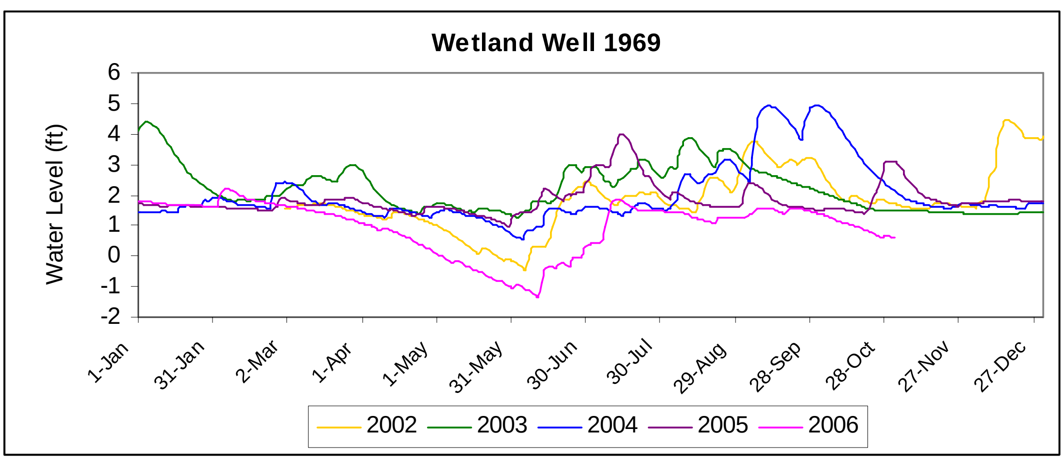


Figure 67: Annual Observed Water-Level Time Series for Wetland Well 1969

Appendix B: (Continued)

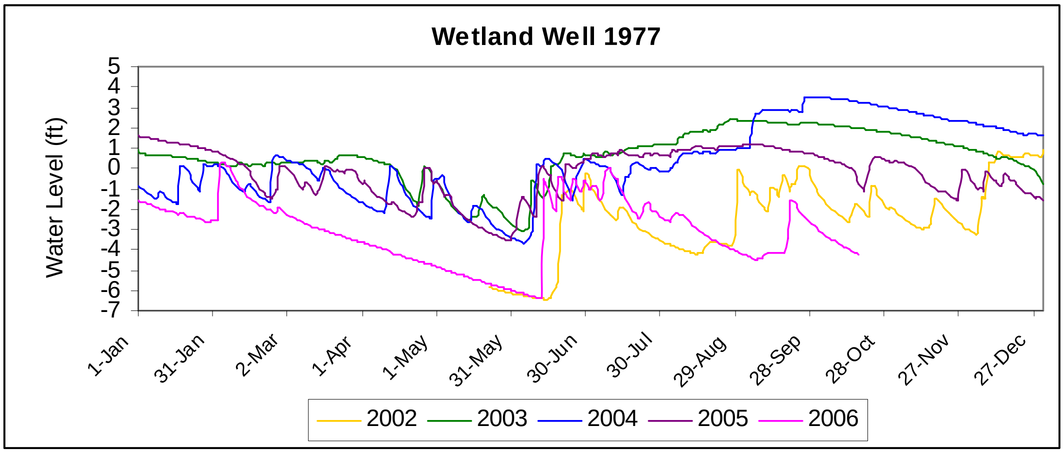


Figure 68: Annual Observed Water-Level Time Series for Wetland Well 1977

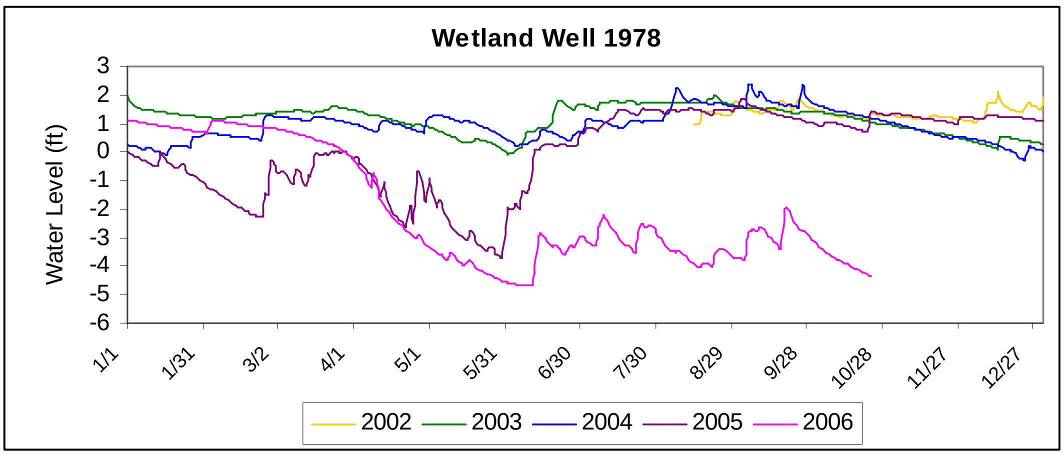


Figure 69: Annual Observed Water-Level Time Series for Wetland Well 1978

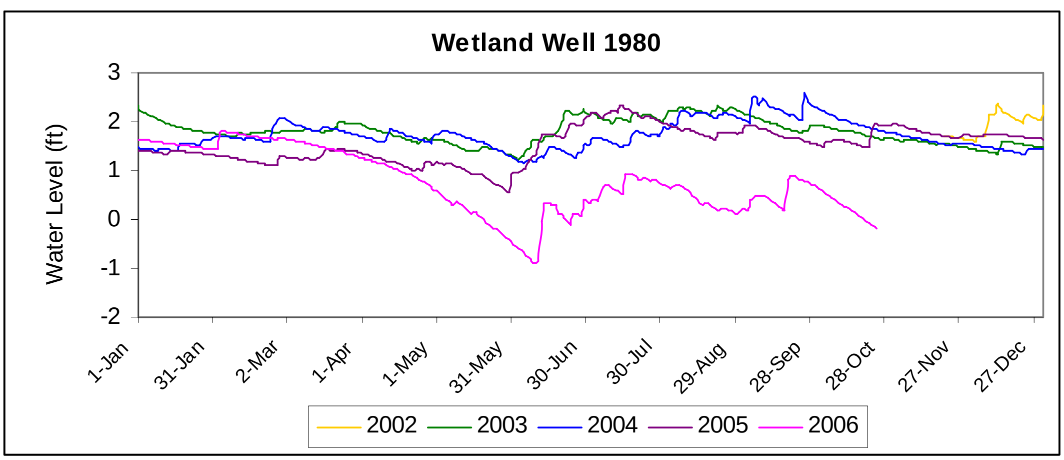


Figure 70: Annual Observed Water-Level Time Series for Wetland Well 1980

Appendix B: (Continued)

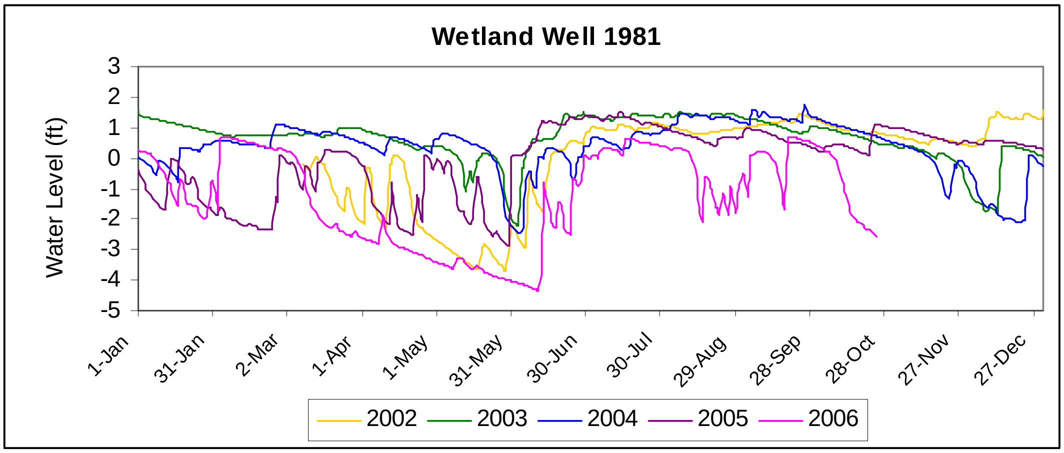


Figure 71: Annual Observed Water-Level Time Series for Wetland Well 1981

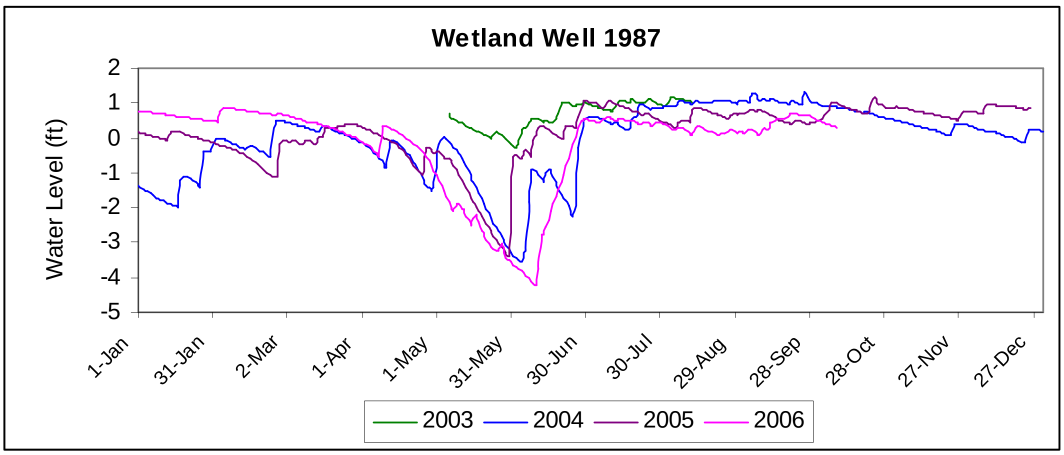


Figure 72: Annual Observed Water-Level Time Series for Wetland Well 1987

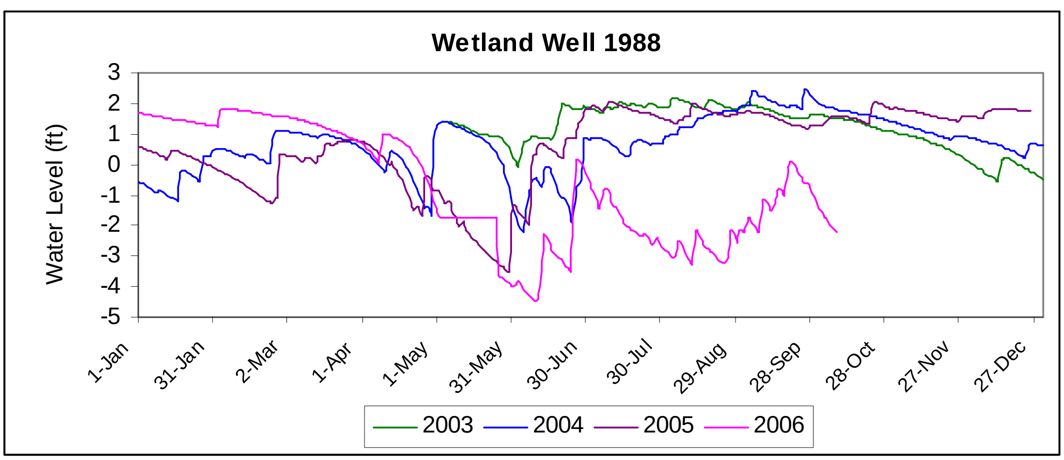


Figure 73: Annual Observed Water-Level Time Series for Wetland Well 1988

Appendix B: (Continued)

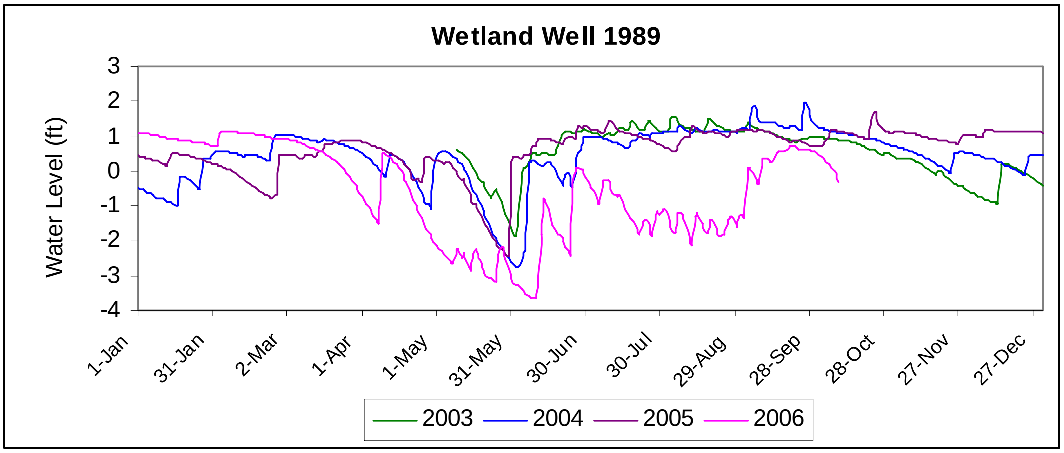


Figure 74: Annual Observed Water-Level Time Series for Wetland Well 1989

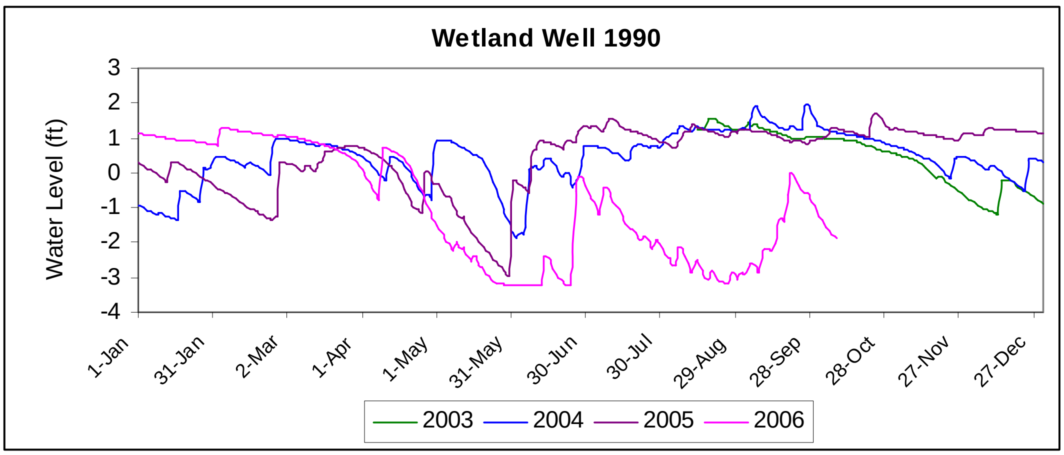


Figure 75: Annual Observed Water-Level Time Series for Wetland Well 1990

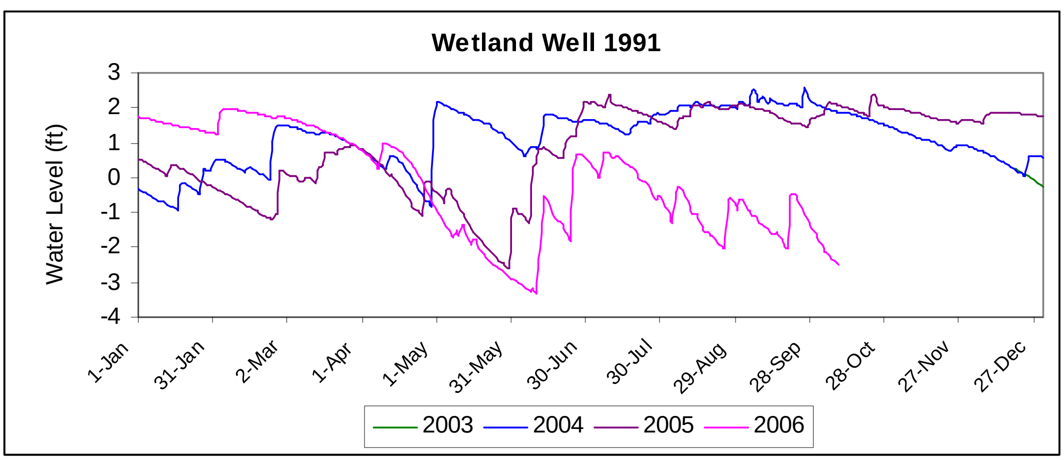


Figure 76: Annual Observed Water-Level Time Series for Wetland Well 1991

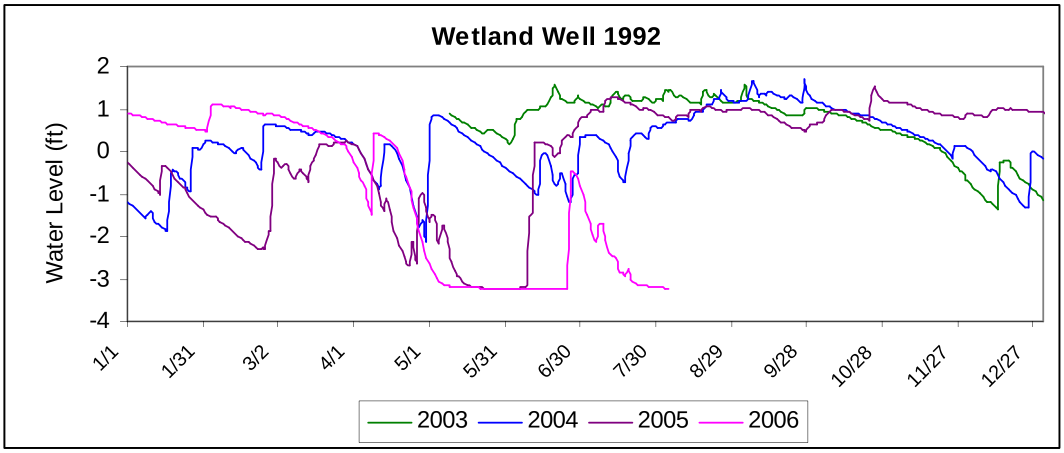


Figure 77: Annual Observed Water-Level Time Series for Wetland Well 1992

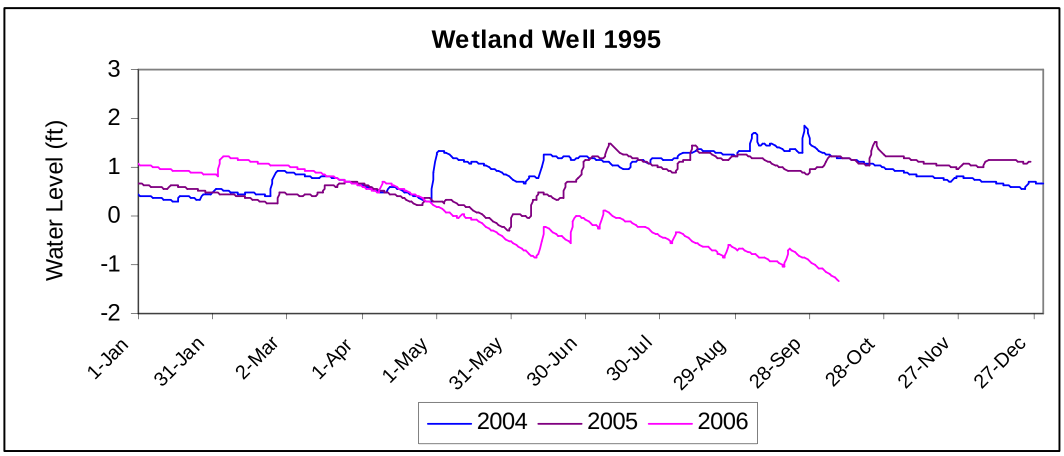


Figure 78: Annual Observed Water-Level Time Series for Wetland Well 1995

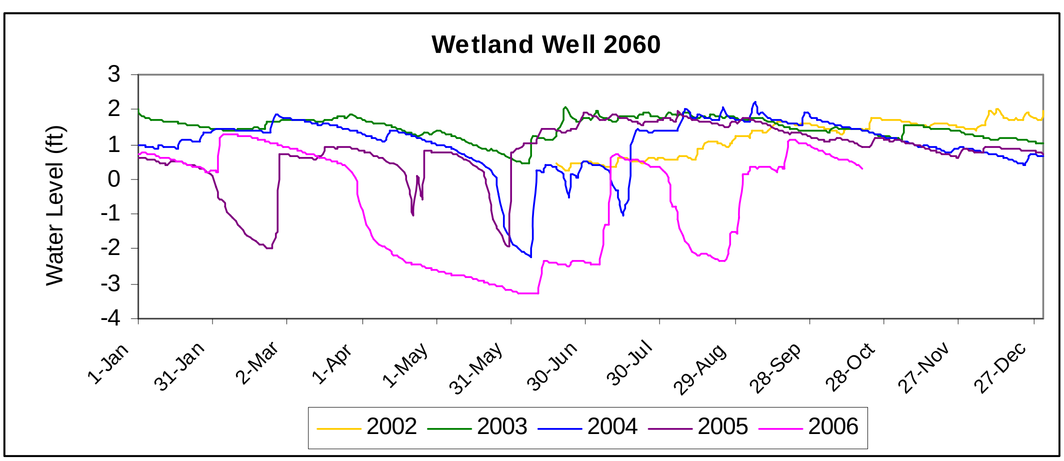


Figure 79: Annual Observed Water-Level Time Series for Wetland Well 2060

Appendix B: (Continued)

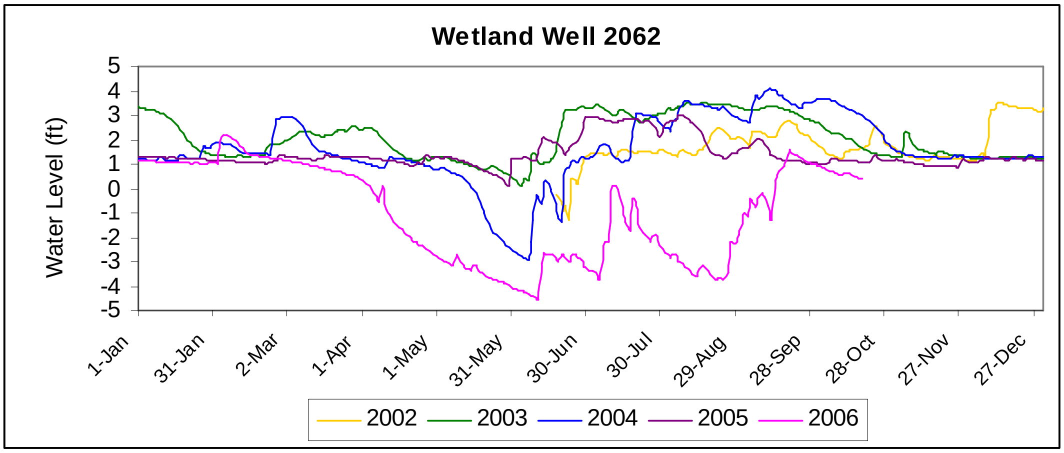


Figure 80: Annual Observed Water-Level Time Series for Wetland Well 2062

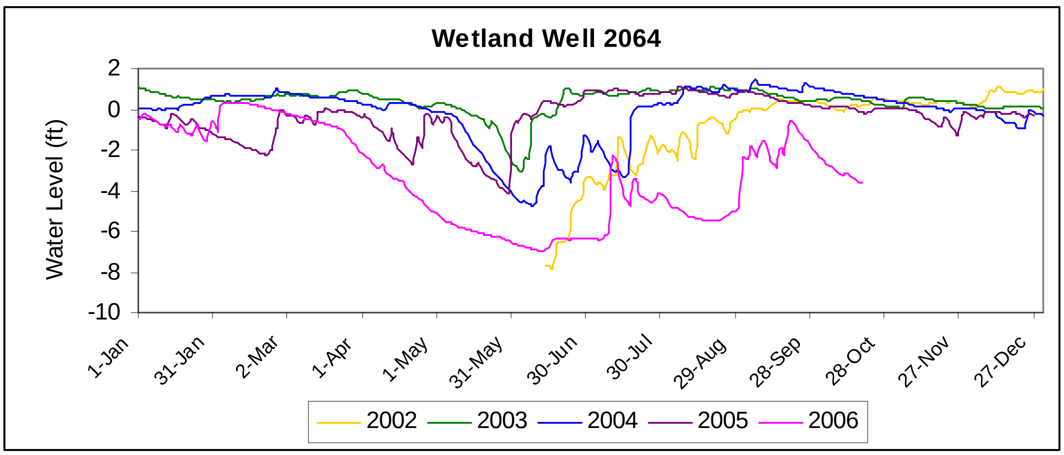


Figure 81: Annual Observed Water-Level Time Series for Wetland Well 2064

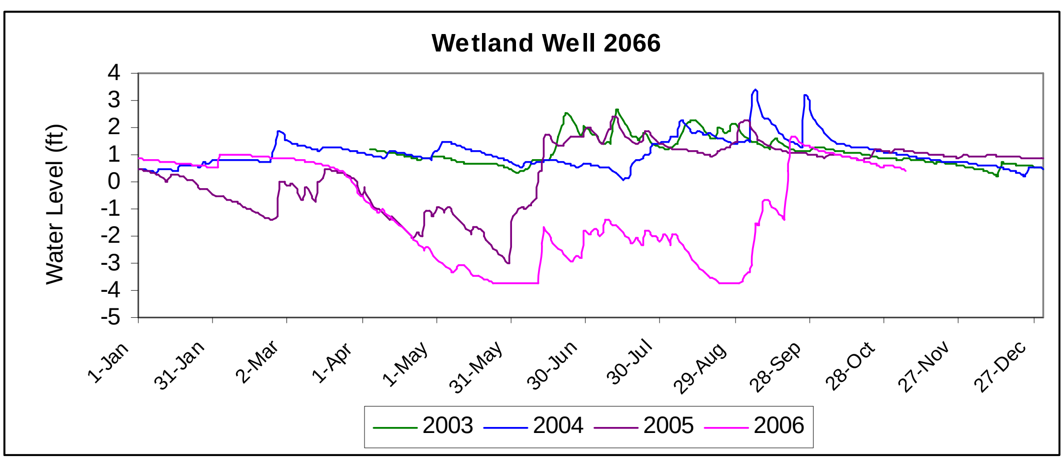


Figure 82: Annual Observed Water-Level Time Series for Wetland Well 2066

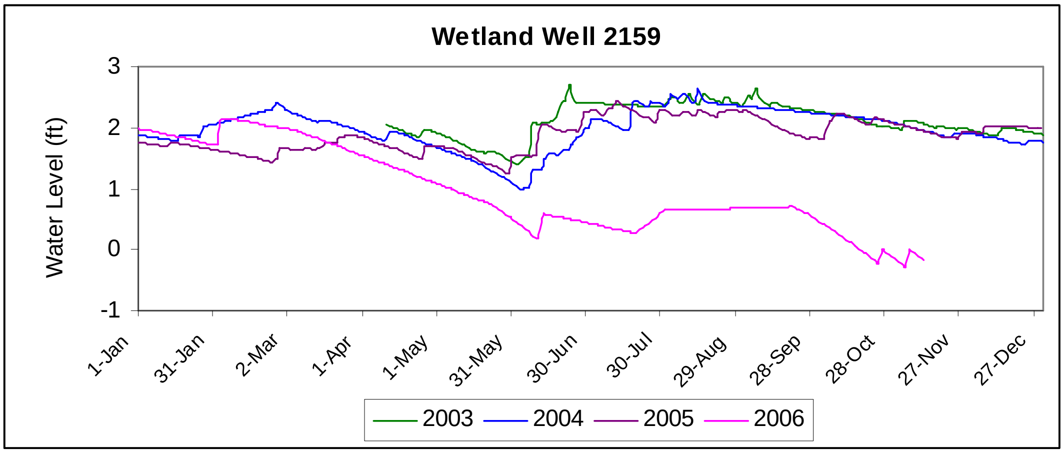


Figure 83: Annual Observed Water-Level Time Series for Wetland Well 2159

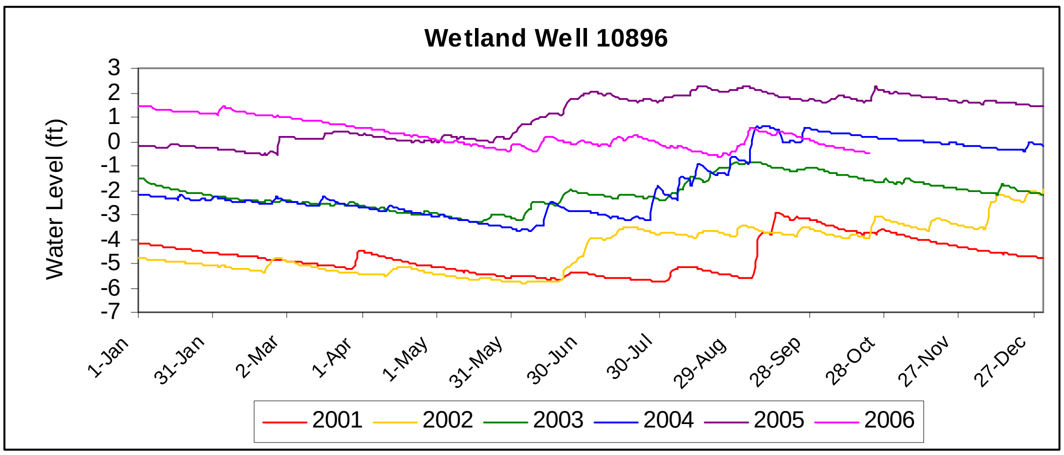


Figure 84: Annual Observed Water-Level Time Series for Wetland Well 10896

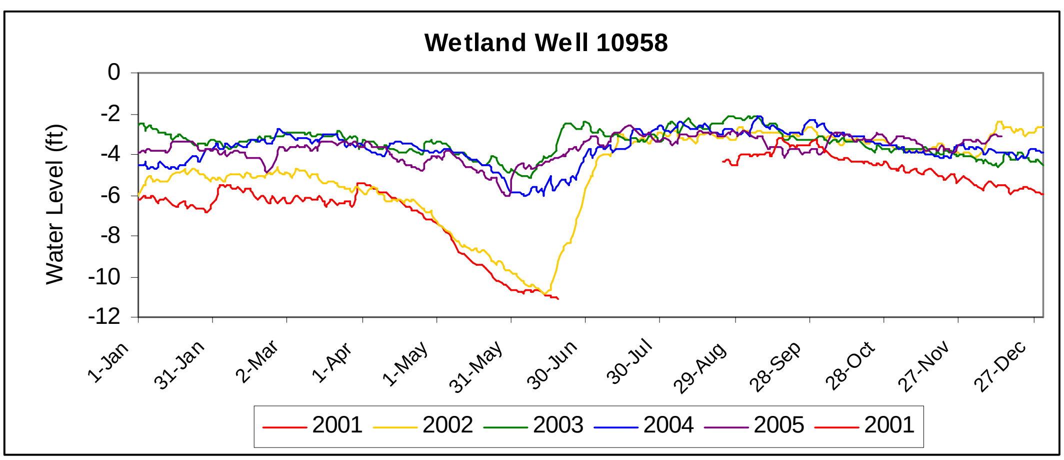


Figure 85: Annual Observed Water-Level Time Series for Wetland Well 10958

Appendix B: (Continued)

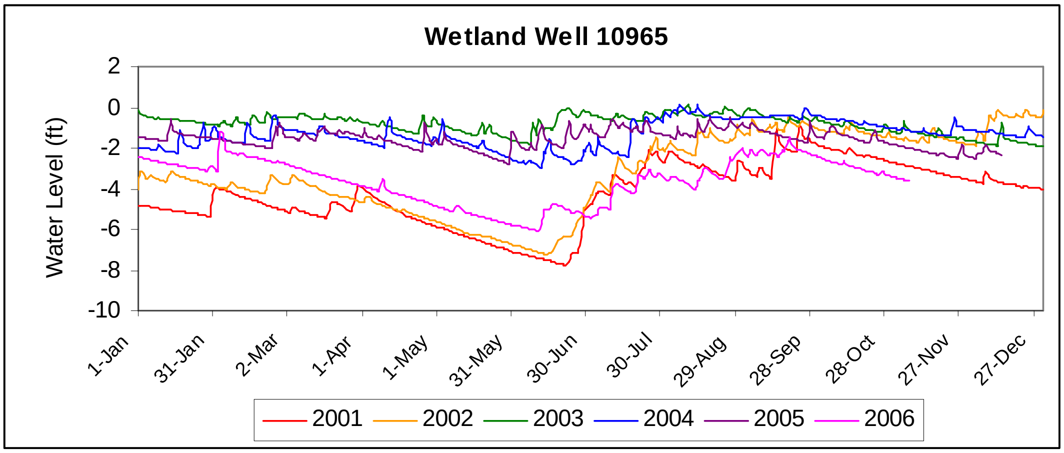


Figure 86: Annual Observed Water-Level Time Series for Wetland Well 10965

Appendix C: Spectral Analysis Figures

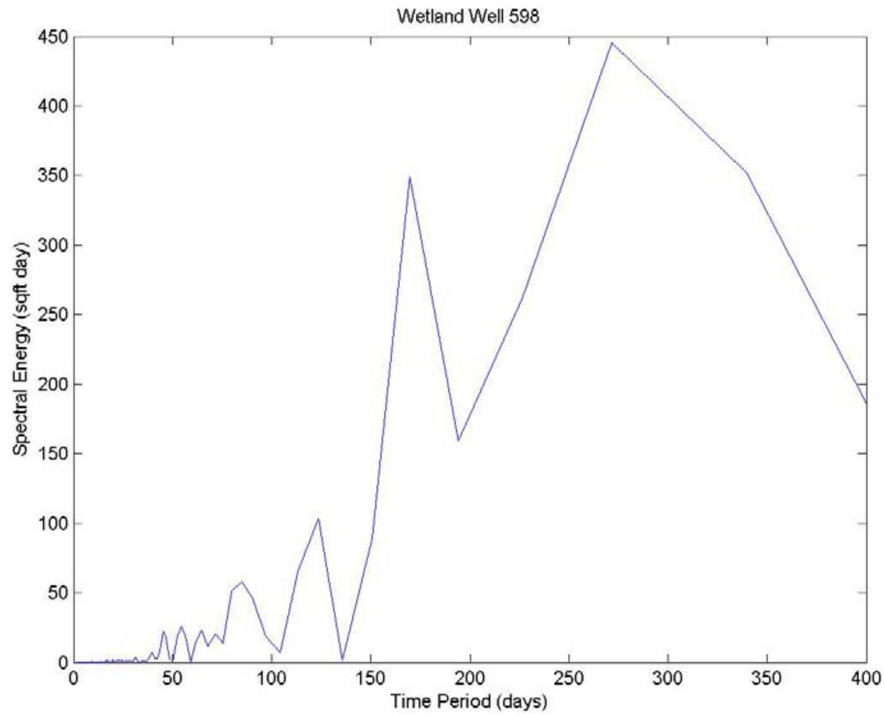


Figure 87: Spectral Analysis of Wetland Well 598 Water-Level Time Series

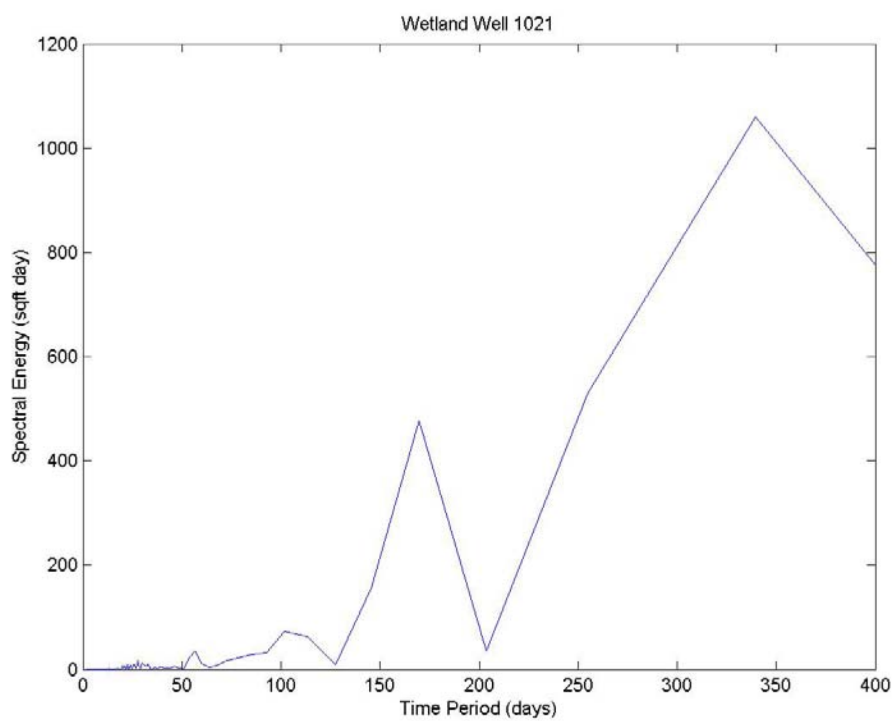


Figure 88: Spectral Analysis of Wetland Well 1021 Water-Level Time Series

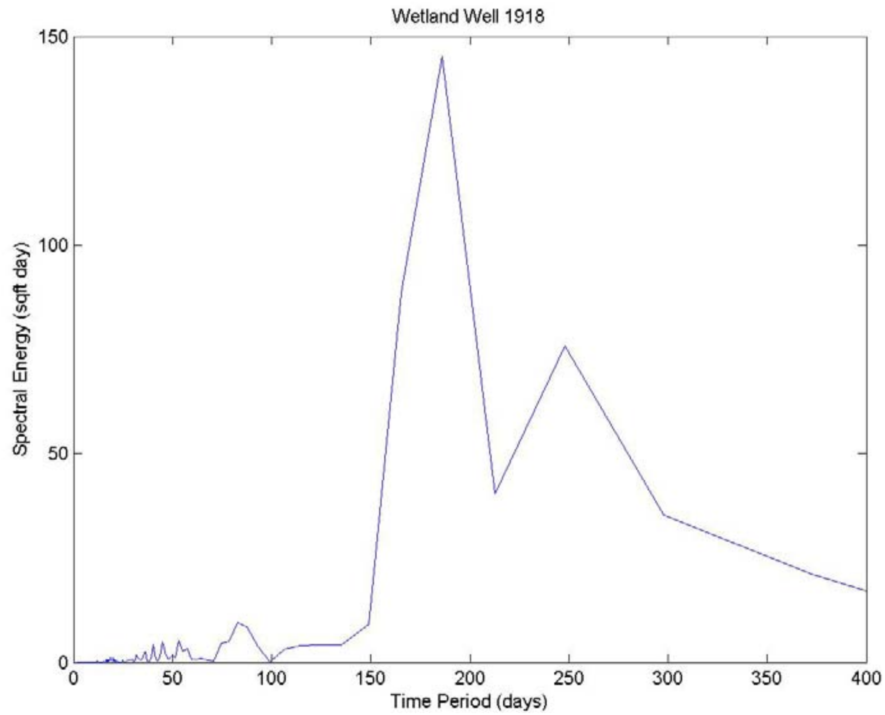


Figure 89: Spectral Analysis of Wetland Well 1918 Water-Level Time Series

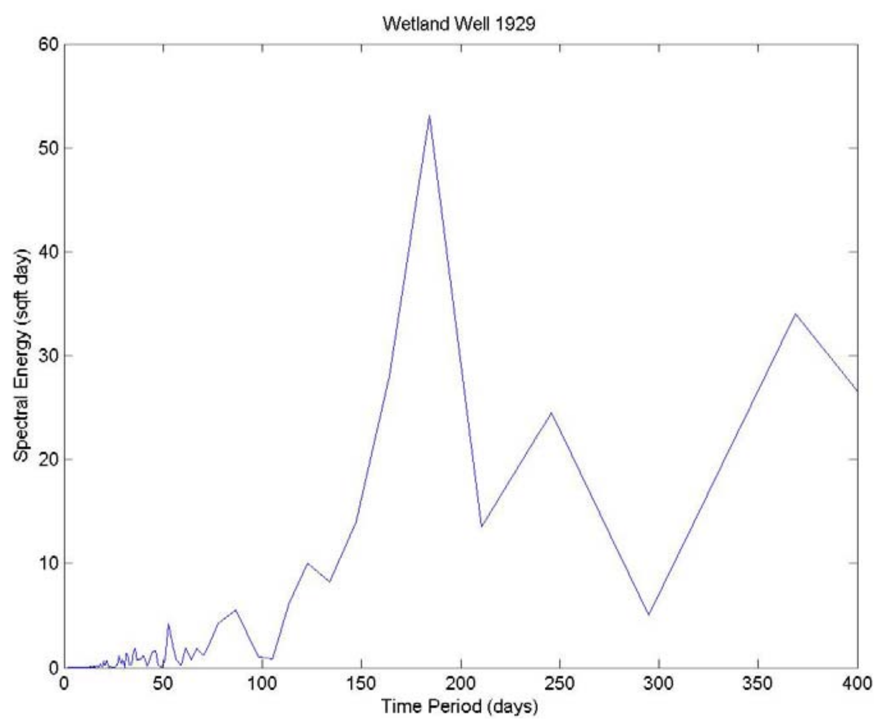


Figure 90: Spectral Analysis of Wetland Well 1929 Water-Level Time Series

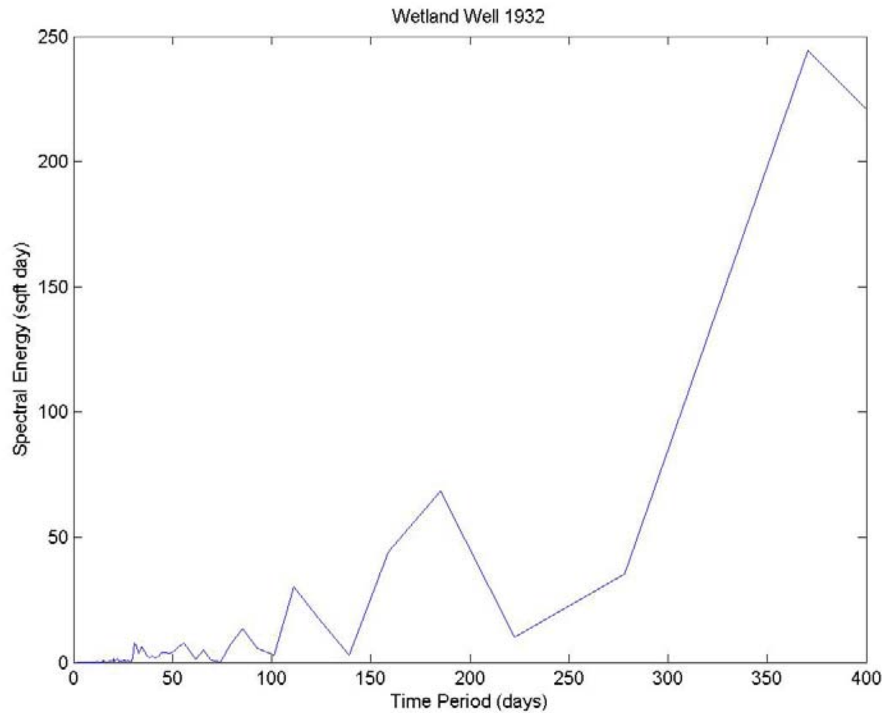


Figure 91: Spectral Analysis of Wetland Well 1932 Water-Level Time Series

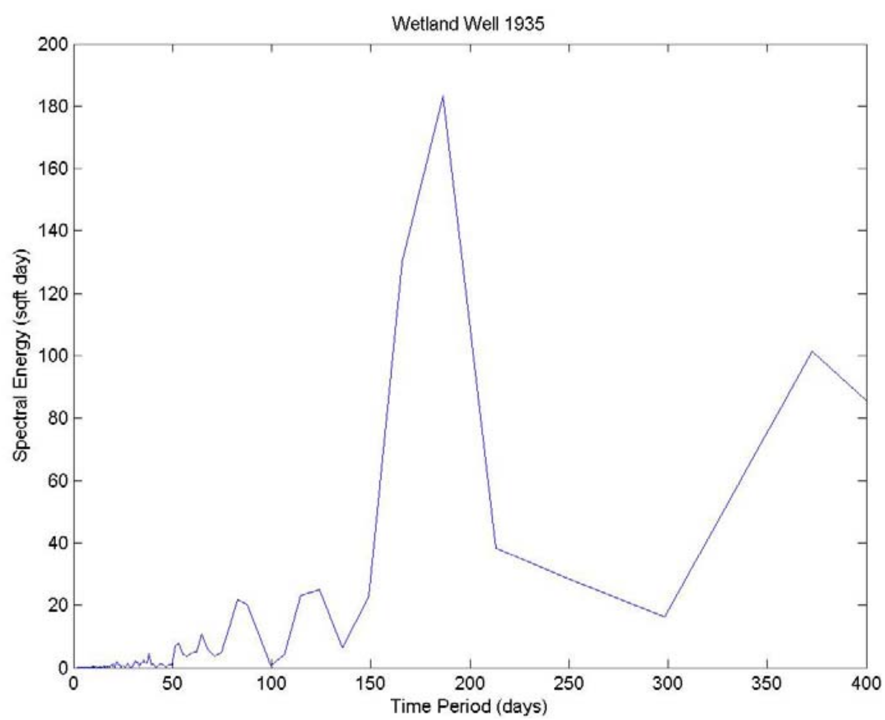


Figure 92: Spectral Analysis of Wetland Well 1935 Water-Level Time Series

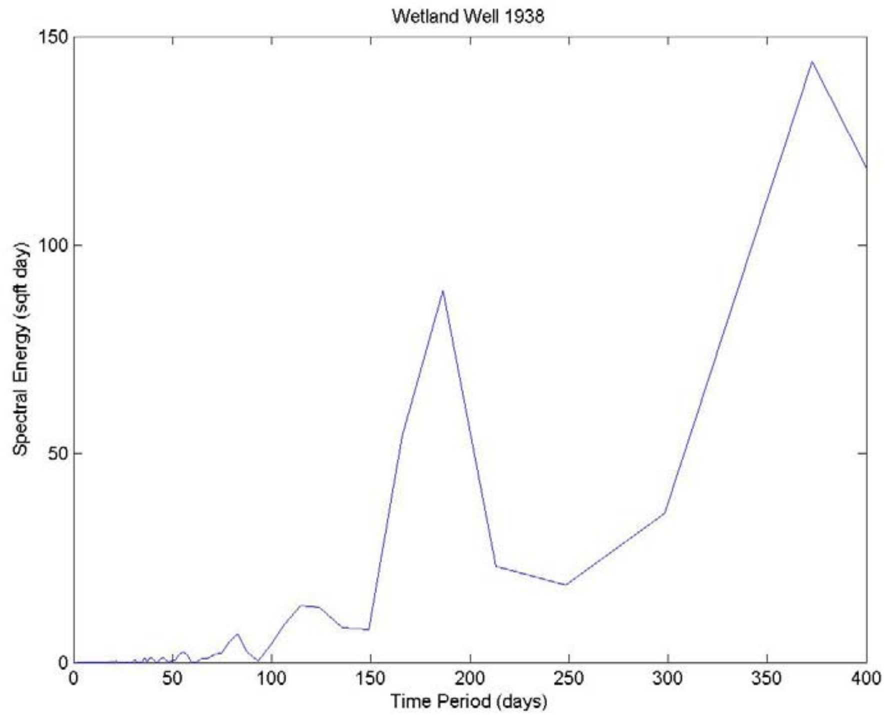


Figure 93: Spectral Analysis of Wetland Well 1938 Water-Level Time Series

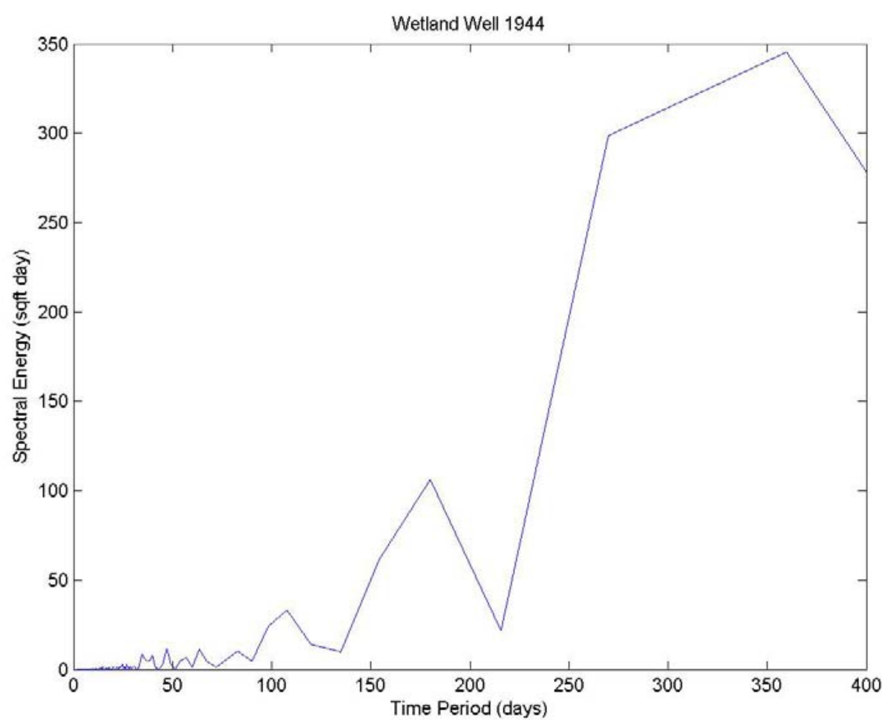


Figure 94: Spectral Analysis of Wetland Well 1944 Water-Level Time Series

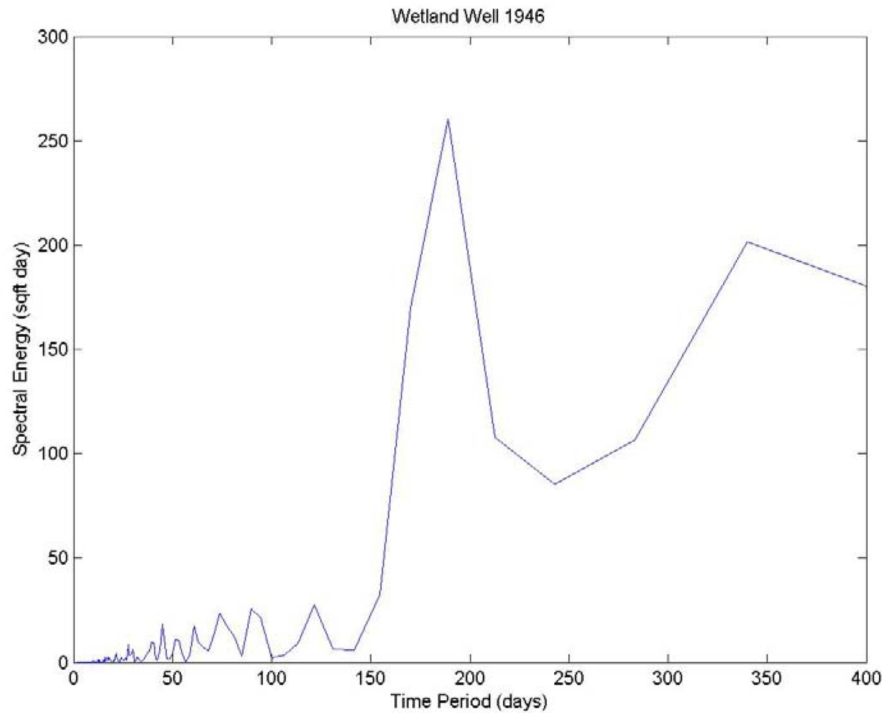


Figure 95: Spectral Analysis of Wetland Well 1946 Water-Level Time Series

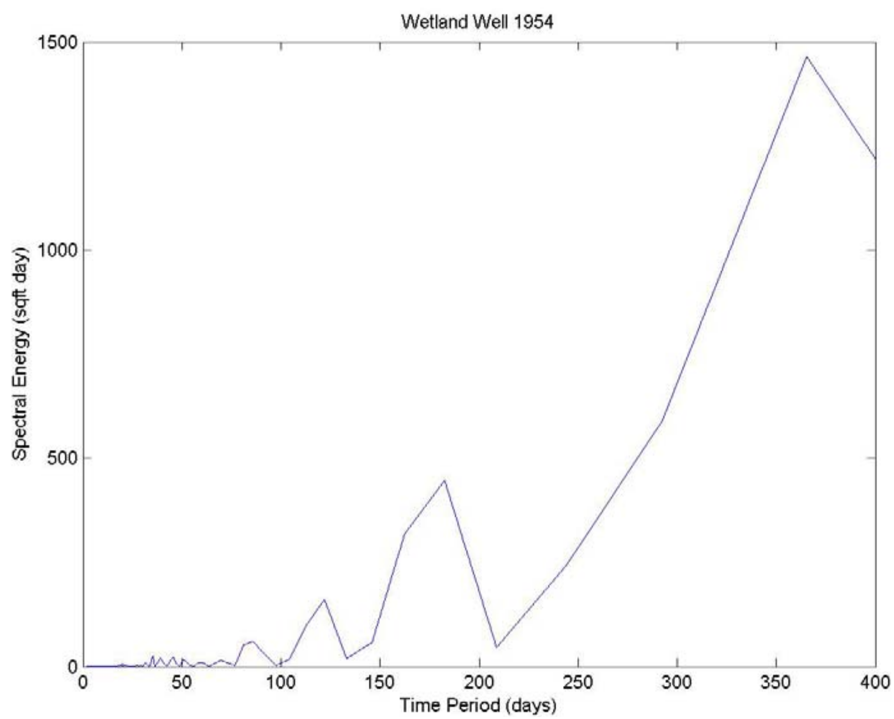


Figure 96: Spectral Analysis of Wetland Well 1954 Water-Level Time Series

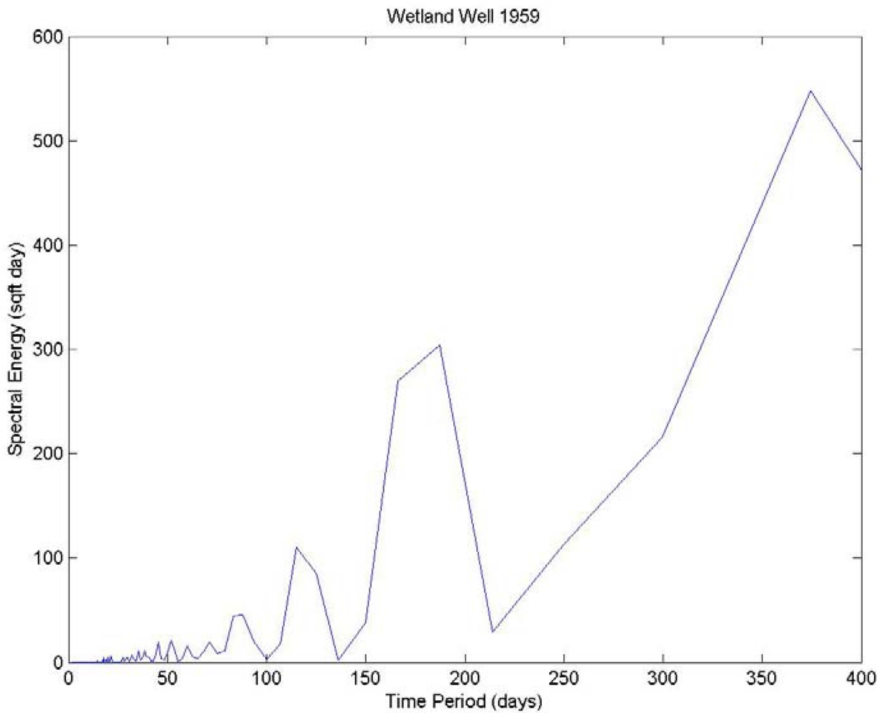


Figure 97: Spectral Analysis of Wetland Well 1959 Water-Level Time Series

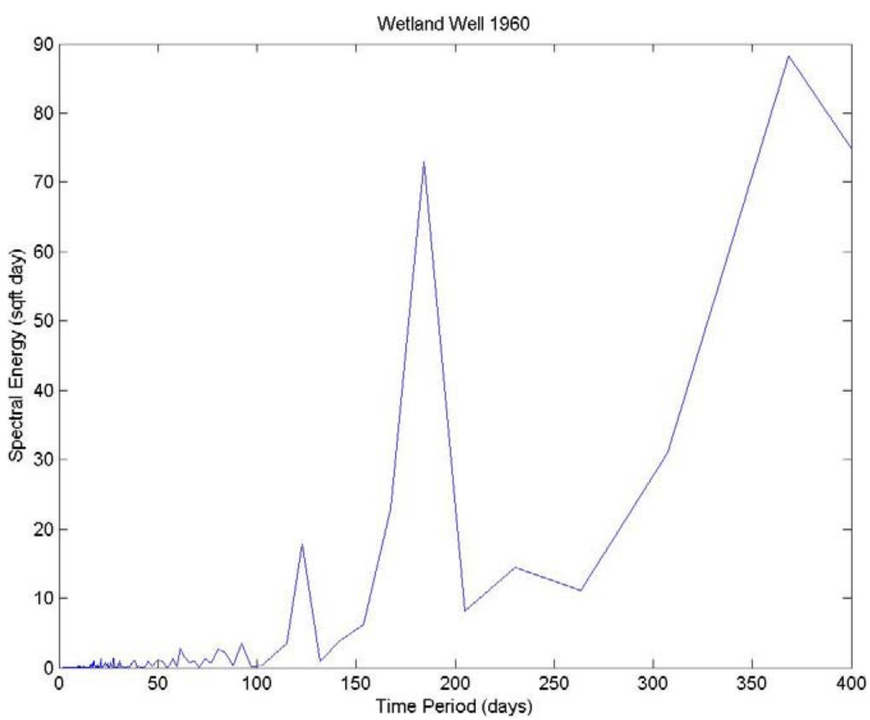


Figure 98: Spectral Analysis of Wetland Well 1960 Water-Level Time Series

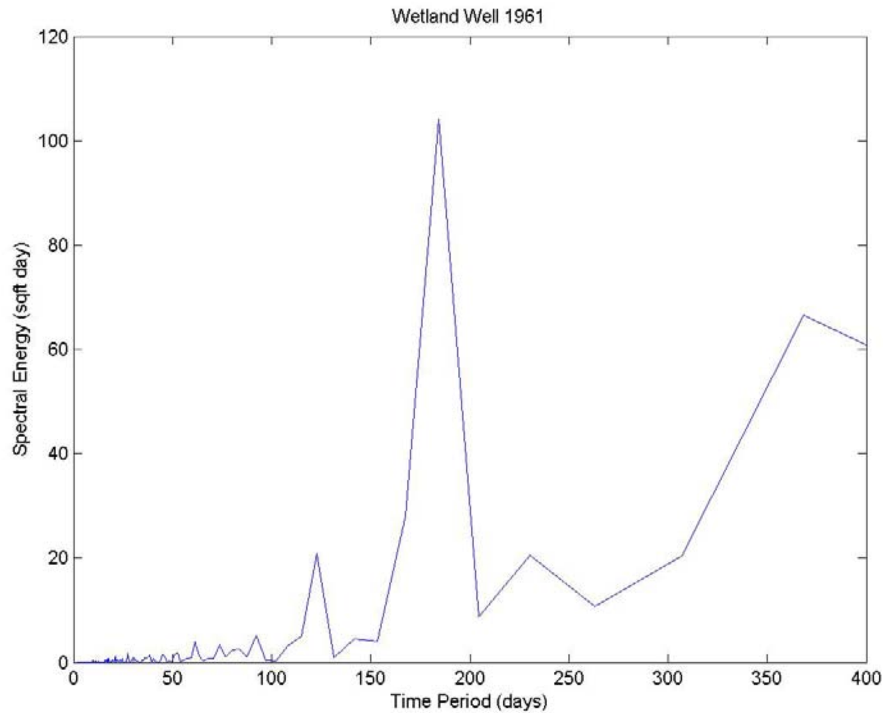


Figure 99: Spectral Analysis of Wetland Well 1961 Water-Level Time Series

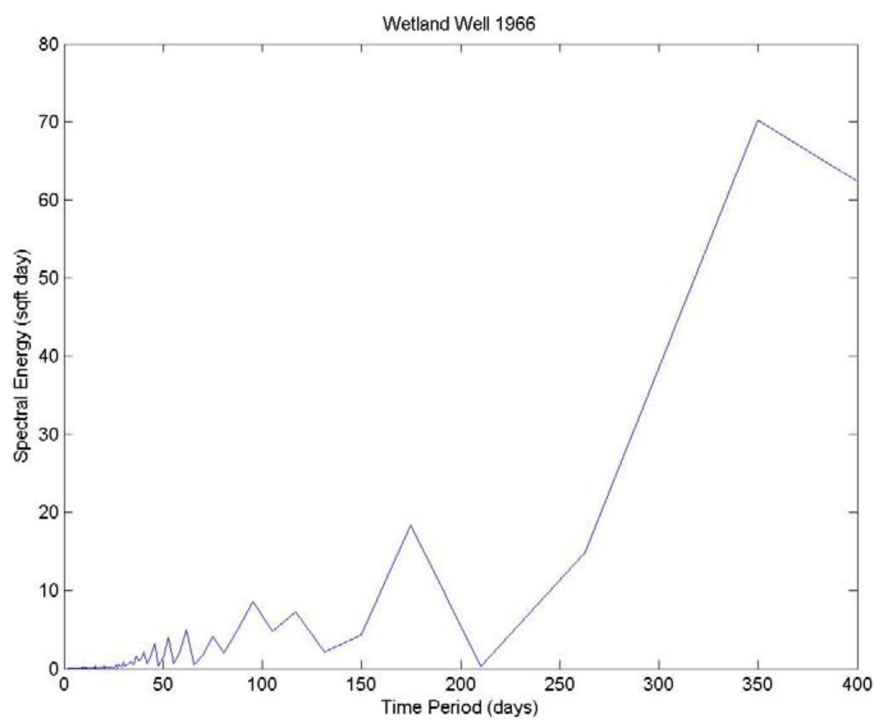


Figure 100: Spectral Analysis of Wetland Well 1966 Water-Level Time Series

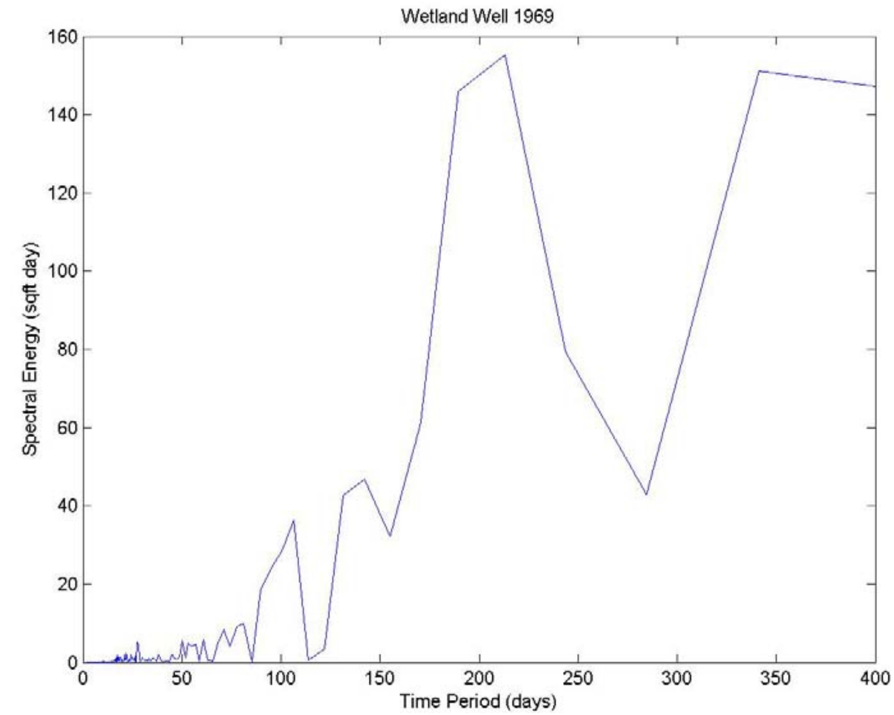


Figure 101: Spectral Analysis of Wetland Well 1969 Water-Level Time Series

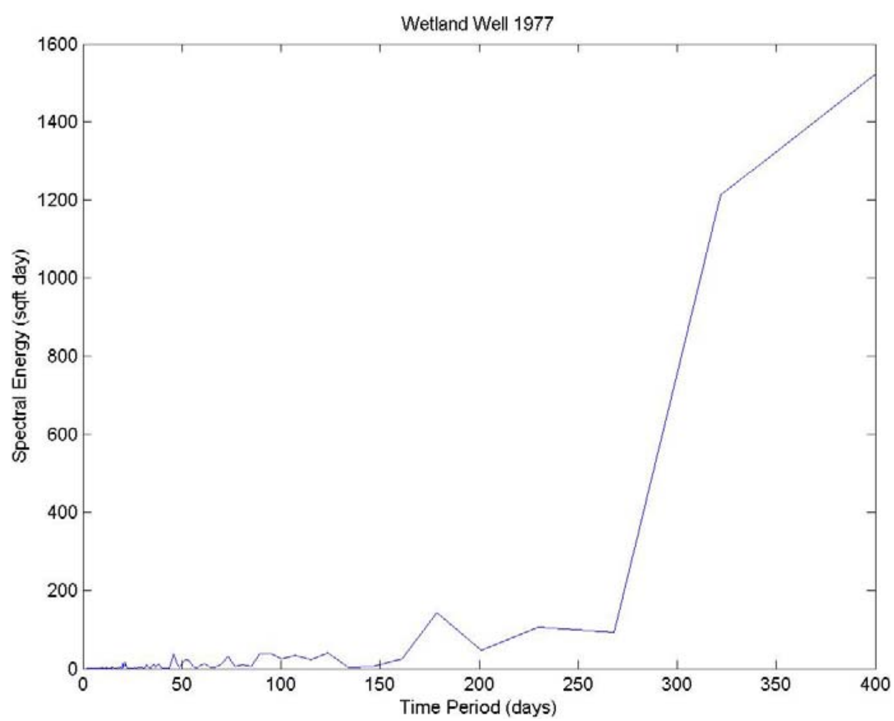


Figure 102: Spectral Analysis of Wetland Well 1977 Water-Level Time Series

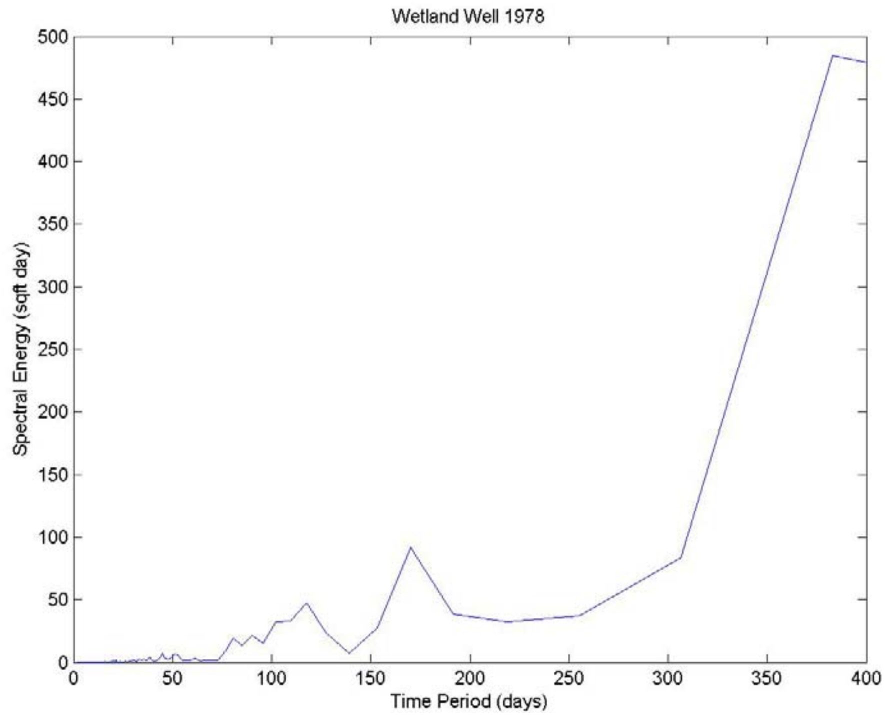


Figure 103: Spectral Analysis of Wetland Well 1978 Water-Level Time Series

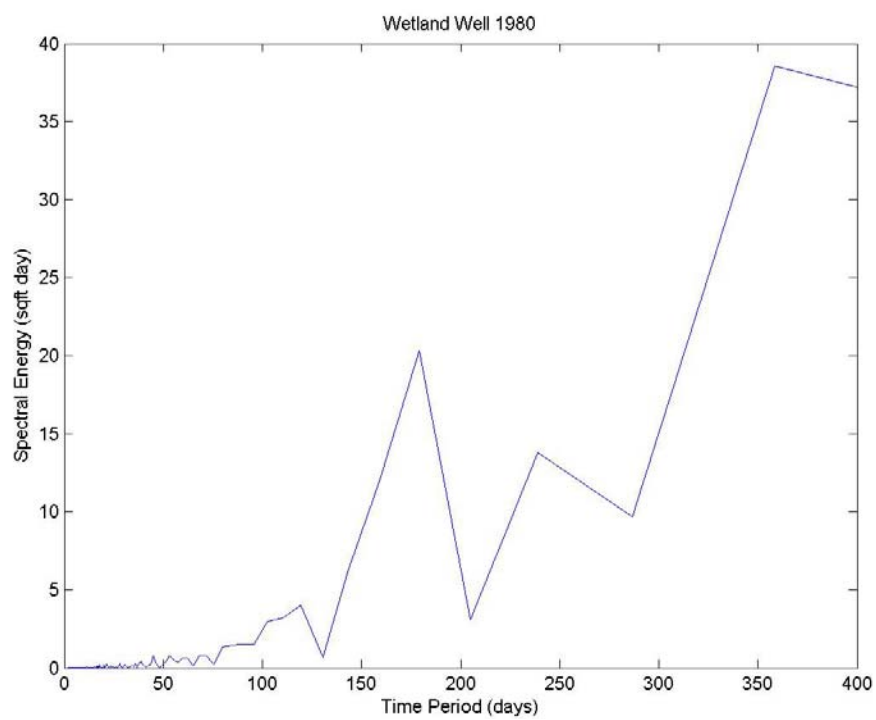


Figure 104: Spectral Analysis of Wetland Well 1980 Water-Level Time Series

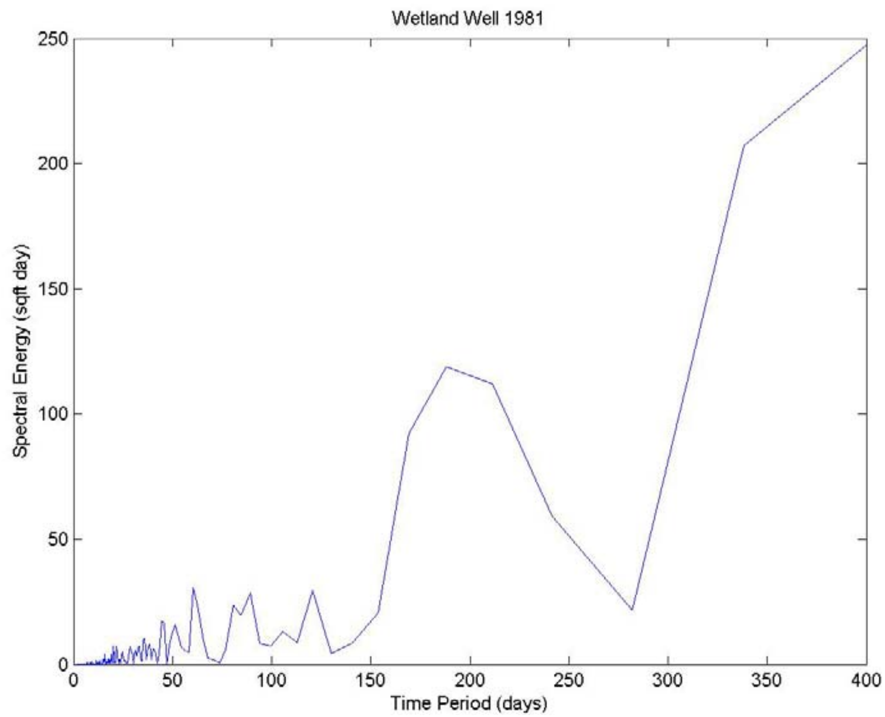


Figure 105: Spectral Analysis of Wetland Well 1981 Water-Level Time Series

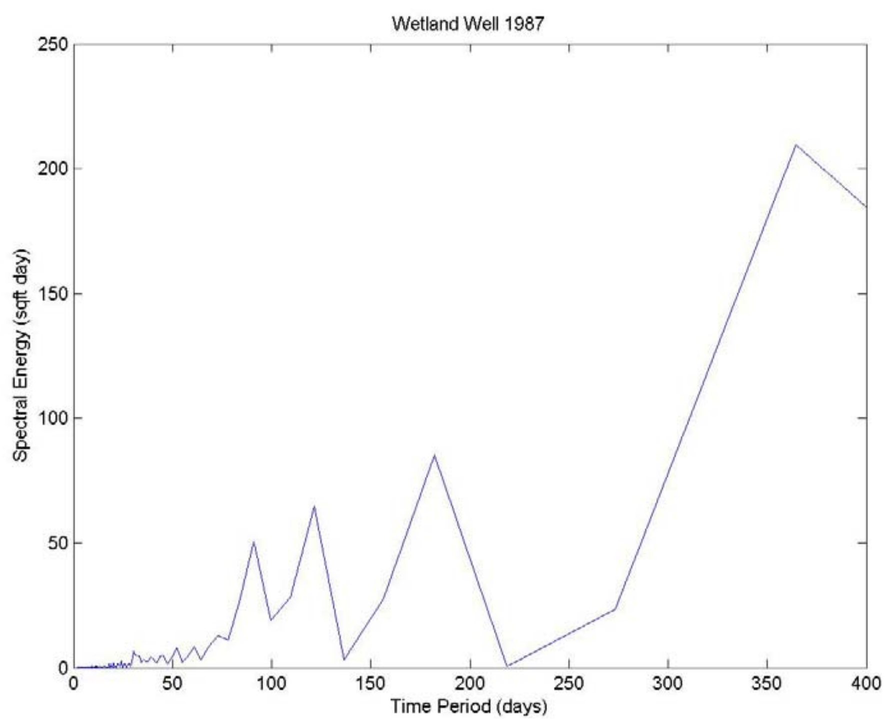


Figure 106: Spectral Analysis of Wetland Well 1987 Water-Level Time Series

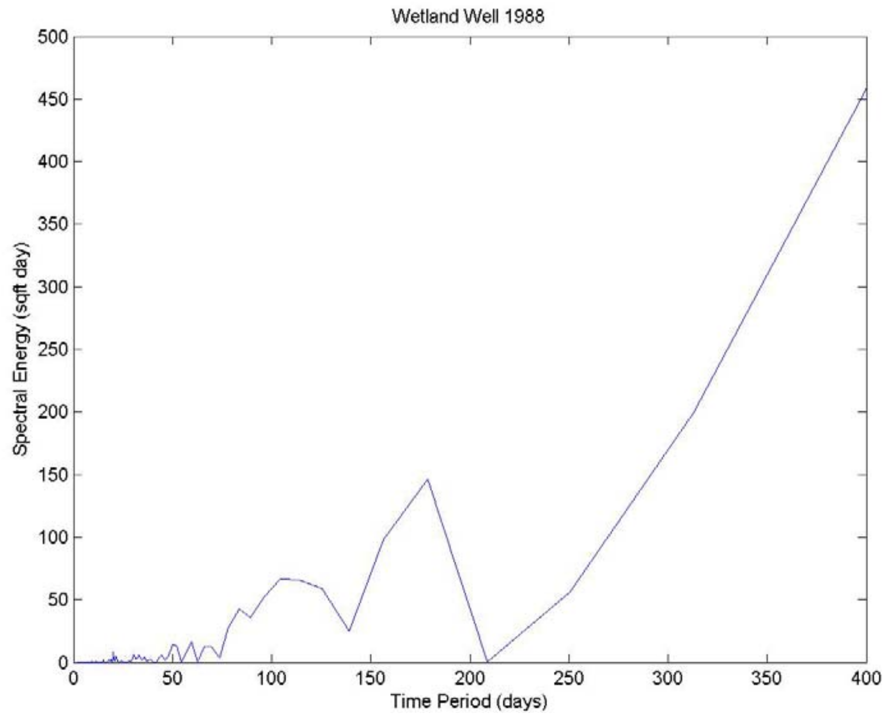


Figure 107: Spectral Analysis of Wetland Well 1988 Water-Level Time Series

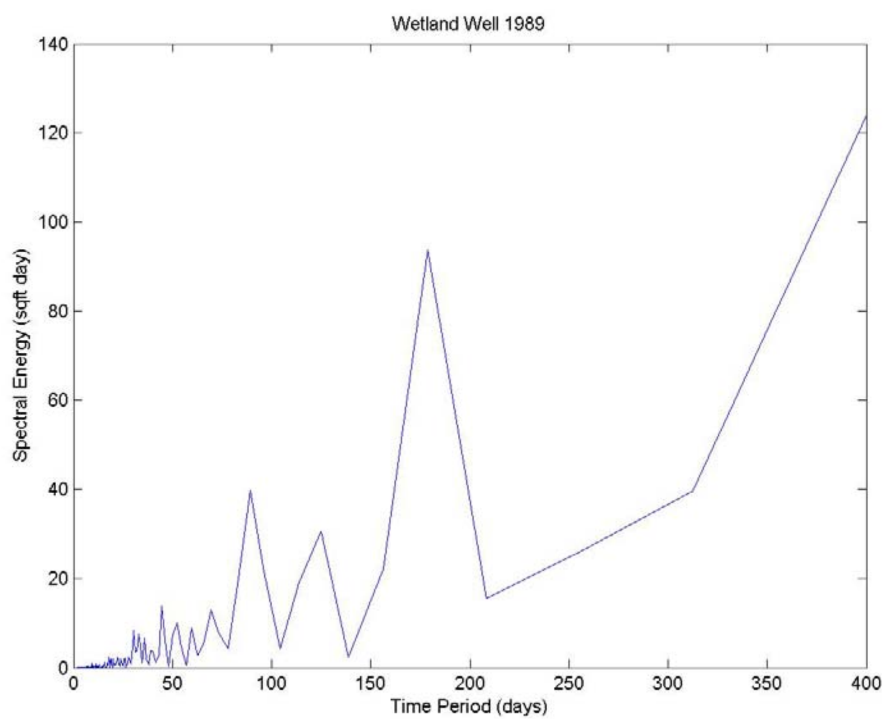


Figure 108: Spectral Analysis of Wetland Well 1989 Water-Level Time Series

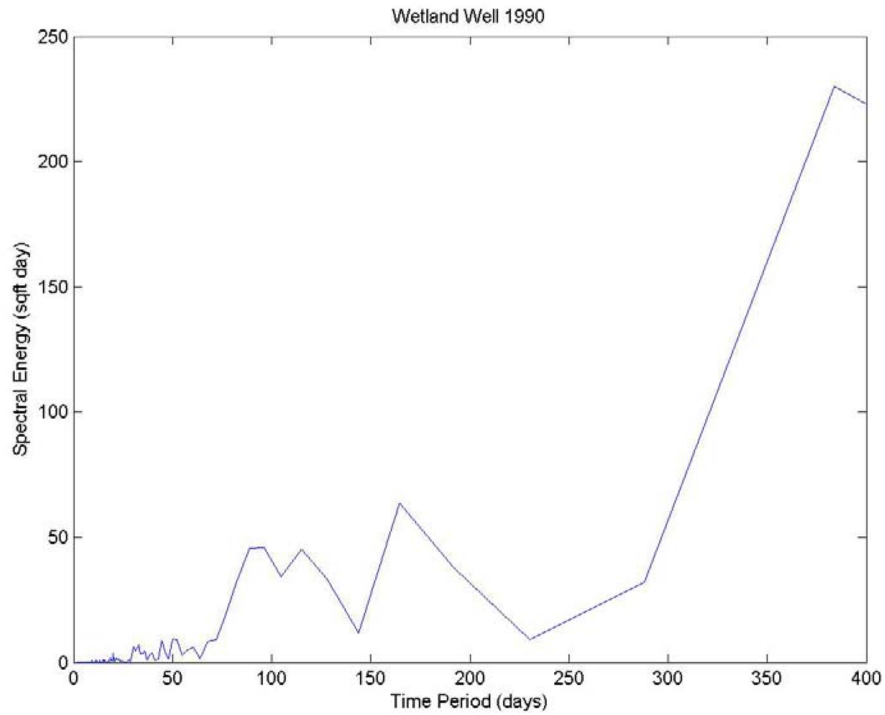


Figure 109: Spectral Analysis of Wetland Well 1990 Water-Level Time Series

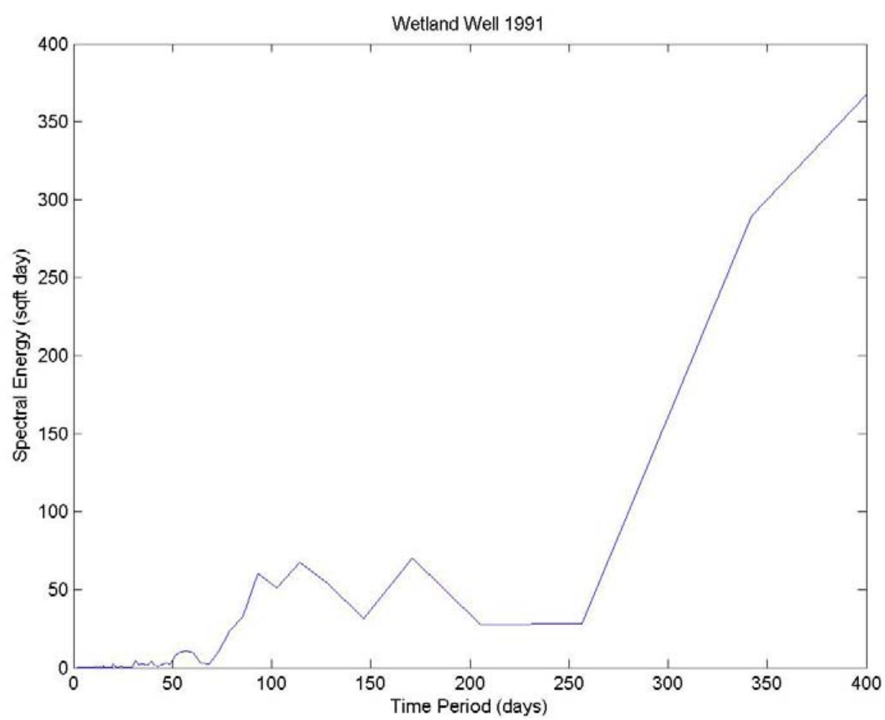


Figure 110: Spectral Analysis of Wetland Well 1991 Water-Level Time Series

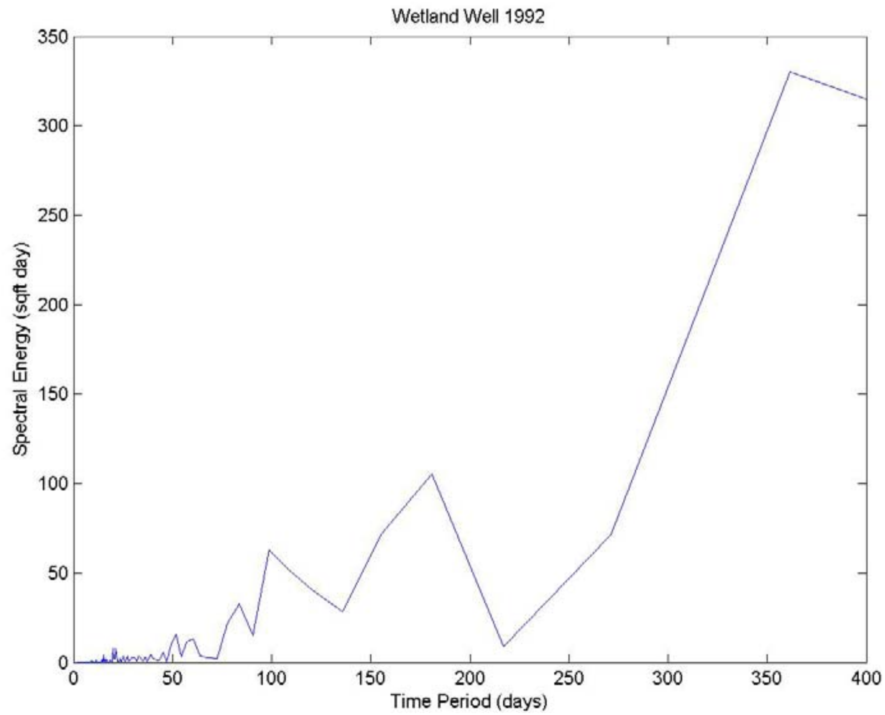


Figure 111: Spectral Analysis of Wetland Well 1992 Water-Level Time Series

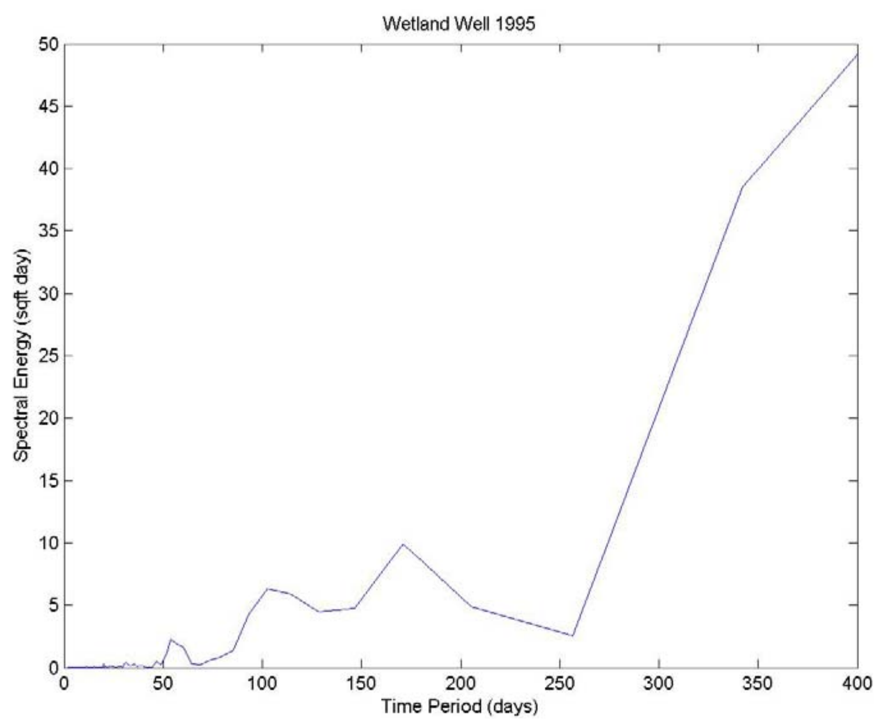


Figure 112: Spectral Analysis of Wetland Well 1995 Water-Level Time Series

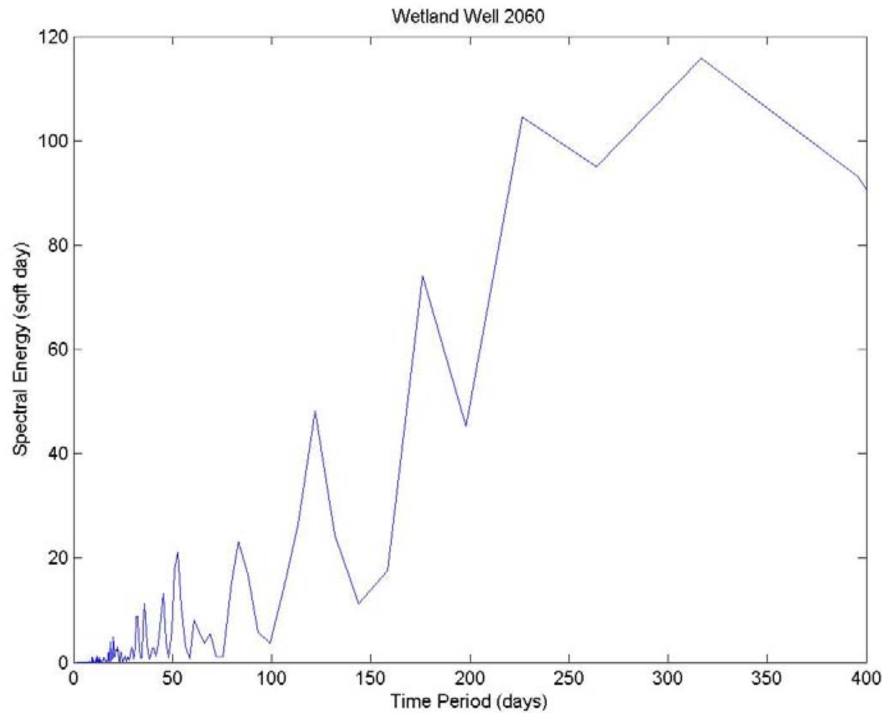


Figure 113: Spectral Analysis of Wetland Well 2060 Water-Level Time Series

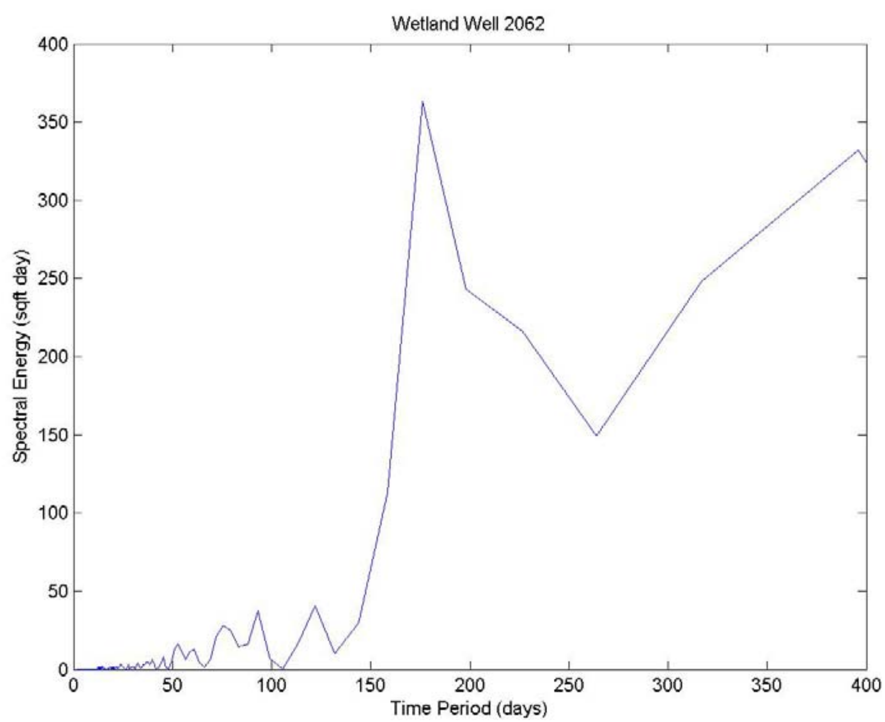


Figure 114: Spectral Analysis of Wetland Well 2062 Water-Level Time Series

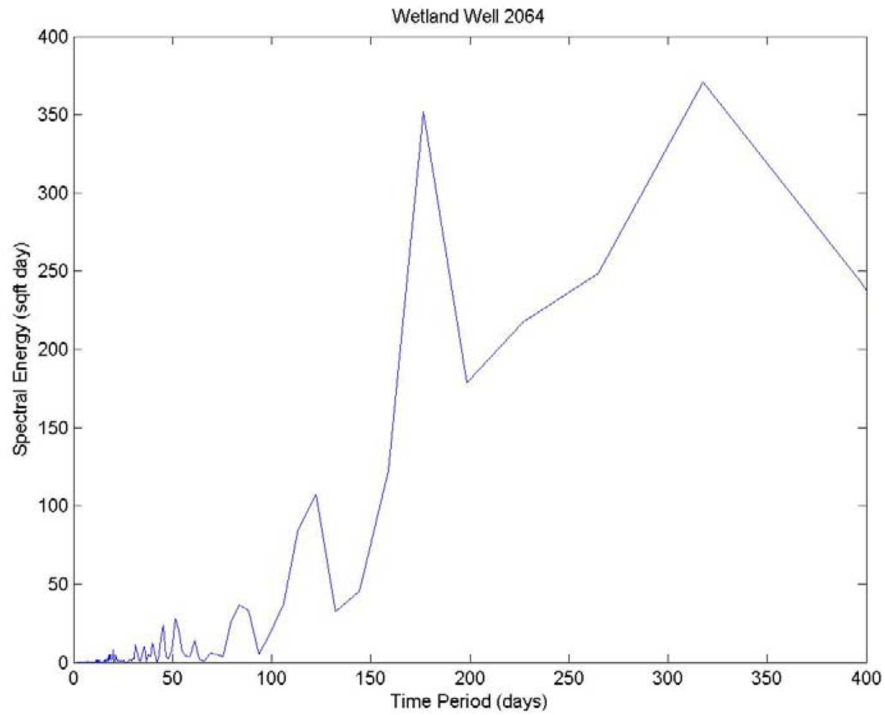


Figure 115: Spectral Analysis of Wetland Well 2064 Water-Level Time Series

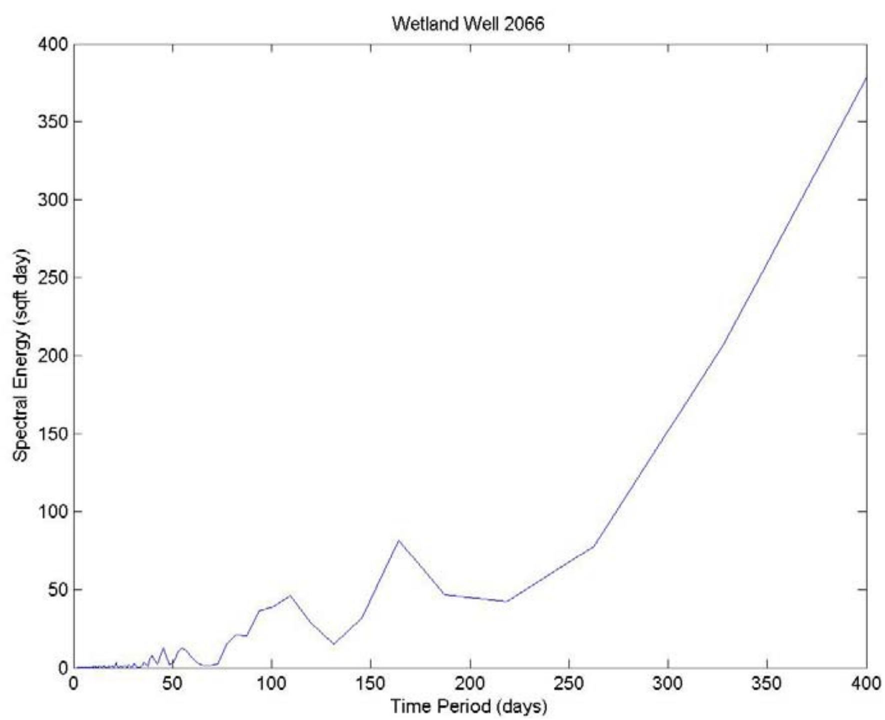


Figure 116: Spectral Analysis of Wetland Well 2066 Water-Level Time Series

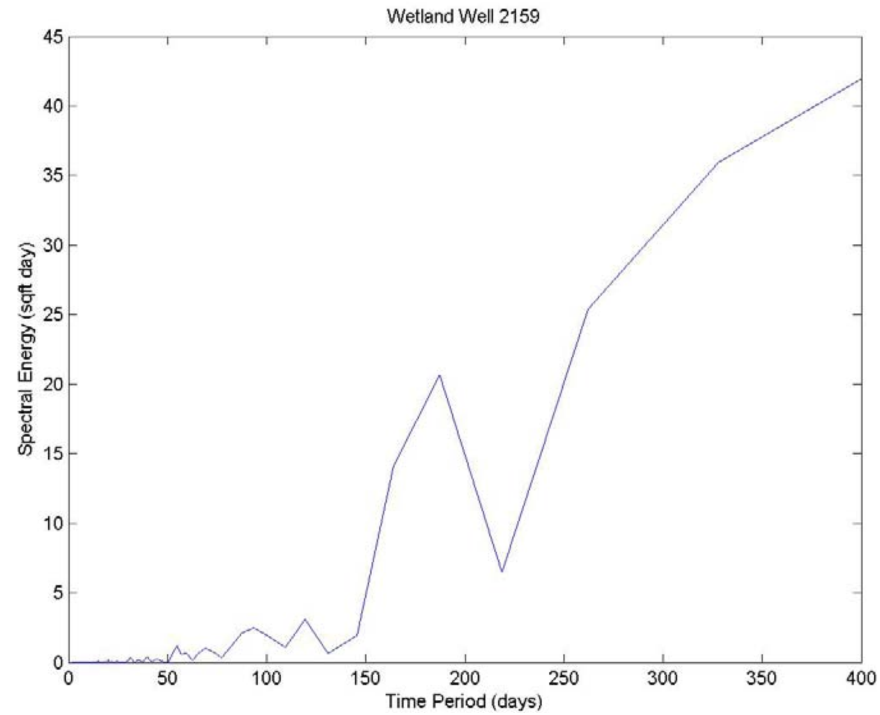


Figure 117: Spectral Analysis of Wetland Well 2159 Water-Level Time Series

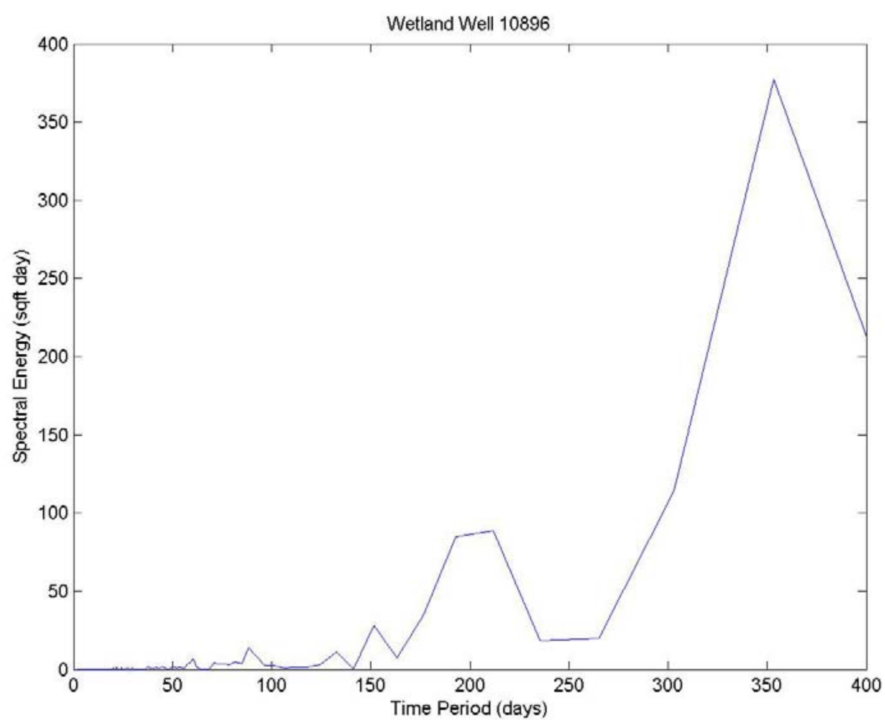


Figure 118: Spectral Analysis of Wetland Well 10896 Water-Level Time Series

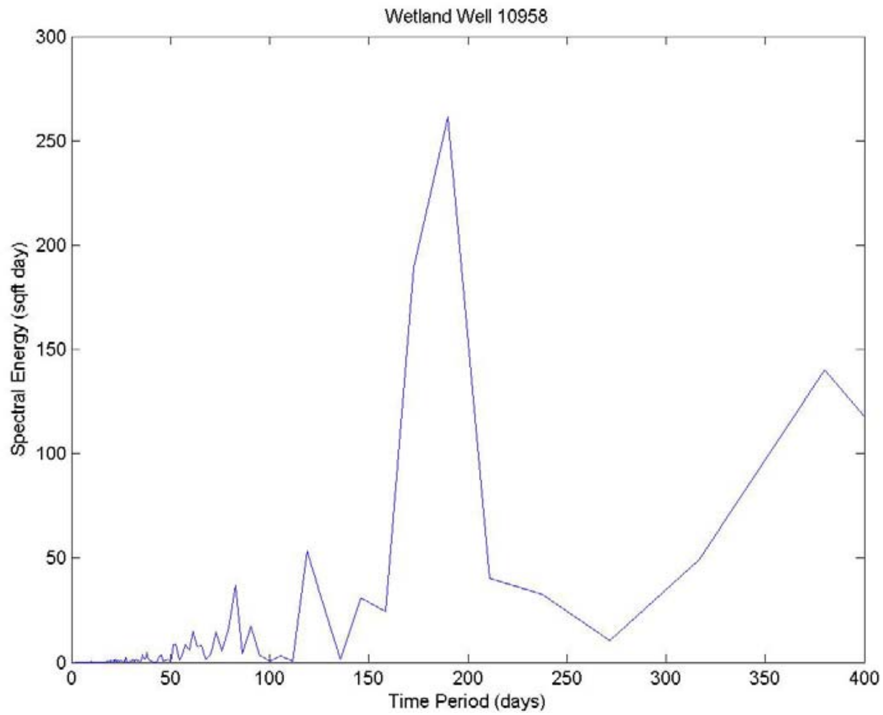


Figure 119: Spectral Analysis of Wetland Well 10958 Water-Level Time Series

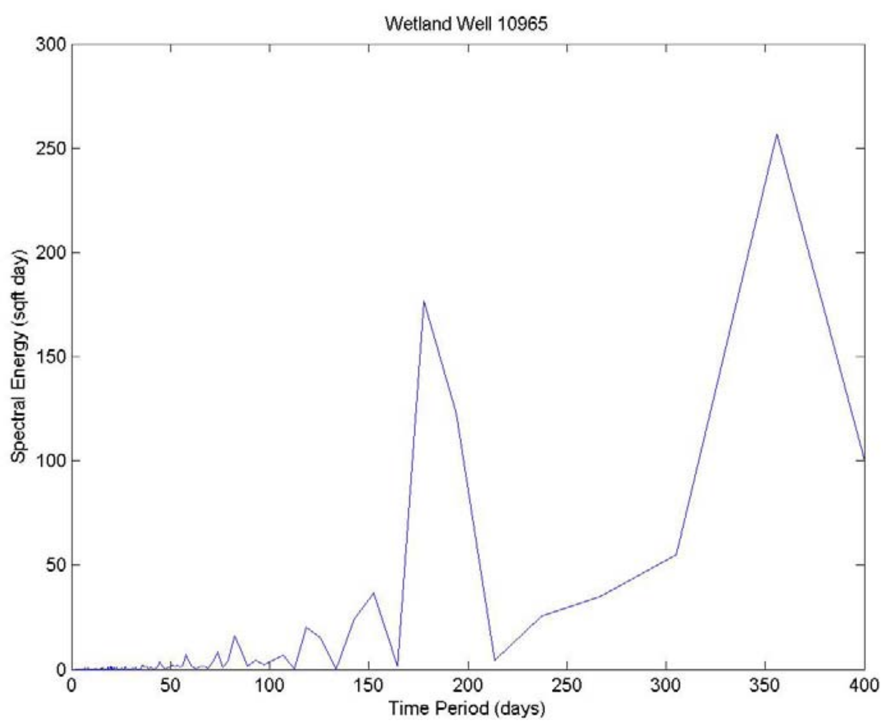


Figure 120: Spectral Analysis of Wetland Well 10965 Water-Level Time Series

Table 10: Annual Wetland Water-Level Magnitudes and Ranges

Well	Wetland Type	Water-level Characteristic	Well Water-Level (ft)									
			2001	2002	2003	2004	2005	2006	Low	High	Mean	Std dev
1918	Cyp	minimum			-1.25	-1.3	-0.66	-2.54	-2.54	-0.66	-1.44	0.79
		maximum			1.72	1.7	1.7	1.8	1.70	1.80	1.73	0.05
		range			2.97	3	2.36	4.34	2.36	4.34	3.17	0.84
1929	Cyp	minimum			0.48	-0.8	0.77	-3.77	-3.77	0.77	-0.83	2.08
		maximum			2.08	2.14	2.02	2.02	2.02	2.14	2.07	0.06
		range			1.6	2.94	1.25	5.79	1.25	5.79	2.90	2.06
1932	Cyp	minimum				-1.9	-1.58	-3.5	-3.50	-1.58	-2.33	1.03
		maximum				2.1	1.76	1.64	1.64	2.10	1.83	0.24
		range				4	3.34	5.14	3.34	5.14	4.16	0.91
1944	Cyp	minimum				-0.72	-0.81	-2.06	-2.06	-0.72	-1.20	0.75
		maximum				3.72	2.13	2.62	2.13	3.72	2.82	0.81
		range				4.44	2.94	4.68	2.94	4.68	4.02	0.94
1961	Cyp	minimum		-3.98	0.29	-0.29	-1.69	-4.56	-4.56	0.29	-2.05	2.16
		maximum		2.04	1.76	2.88	1.68	1.35	1.35	2.88	1.94	0.58
		range		6.02	1.47	3.17	3.37	5.91	1.47	5.91	3.99	1.95
1978	Cyp	minimum			-0.1	-0.29	-3.74	-4.65	-4.65	-0.10	-2.20	2.34
		maximum			1.79	2.38	1.85	-1.96	-1.96	2.38	1.02	2.00
		range			1.89	2.67	5.59	2.69	1.89	5.59	3.21	1.63
1987	Cyp	minimum			-0.3	-3.57	-3.38	-4.22	-4.22	-0.30	-2.87	1.75
		maximum			1.16	1.34	1.03	0.63	0.63	1.34	1.04	0.30
		range			1.46	4.91	4.41	4.85	1.46	4.91	3.91	1.65
1988	Cyp	minimum			-0.55	-2.23	-3.53	-4.38	-4.38	-0.55	-2.67	1.67
		maximum			2.14	2.42	2.04	0.09	0.09	2.42	1.67	1.07
		range			2.69	4.65	5.57	4.47	2.69	5.57	4.35	1.20

Table 10: (Continued)

Well	Wetland Type	Water-level Characteristic	Well Water-Level (ft)									
			2001	2002	2003	2004	2005	2006	Low	High	Mean	Std dev
1989	Cyp	minimum			-1.87	-2.73	-2.47	-3.66	-3.66	-1.87	-2.68	0.74
		maximum			1.55	1.98	1.72	0.63	0.63	1.98	1.47	0.59
		range			3.42	4.71	4.19	4.29	3.42	4.71	4.15	0.54
1990	Cyp	minimum				-1.76	-2.94		-2.94	-1.76	-2.35	0.83
		maximum				1.91	1.72		1.72	1.91	1.82	0.13
		range				3.67	4.66		3.67	4.66	4.17	0.70
1991	Cyp	minimum				-0.83	2.62		-0.83	2.62	0.90	2.44
		maximum				2.58	2.37		2.37	2.58	2.48	0.15
		range				3.41	-0.25		-0.25	3.41	1.58	2.59
1992	Cyp	minimum			-1.36	-2.08	-3.21		-3.21	-1.36	-2.22	0.93
		maximum			1.57	1.72	1.55		1.55	1.72	1.61	0.09
		range			2.93	3.8	4.76		2.93	4.76	3.83	0.92
2064	Cyp	minimum		-7.77	-3.09	-4.76	-4.15	-6.98	-7.77	-3.09	-5.35	1.96
		maximum		1.08	1.03	1.45	1.13	-0.6	-0.60	1.45	0.82	0.81
		range		8.85	4.12	6.21	5.28	6.38	4.12	6.38	6.17	1.75
2159	Cyp	minimum			1.39	1.01	1.24		1.01	1.39	1.21	0.19
		maximum			2.7	2.63	2.44		2.44	2.70	2.59	0.13
		range			1.31	1.62	1.2		1.20	1.62	1.38	0.22
All Avg	Cyp	minimum		-5.875	-0.636	-1.5893	-1.6807	-4.032	-3.36	-0.49	-1.86	1.41
		maximum		1.56	1.75	2.21071	1.79571	0.822	1.12	2.22	1.78	0.50
		range		7.435	2.386	3.8	3.47643	4.854	2.32	4.82	3.64	1.28

Table 10: (Continued)

Well	Wetland Type	Water-level Characteristic	Well Water-Level (ft)									
			2001	2002	2003	2004	2005	2006	Low	High	Mean	Std dev
1935	Cyp WF	minimum			-2.16	-2.96	-2.82	-5.32	-5.32	-2.16	-3.32	1.38
		maximum			0.87	0.84	0.72	0.72	0.72	0.87	0.79	0.08
		range			3.03	3.8	3.54	6.04	3.03	6.04	4.10	1.33
1938	Cyp WF	minimum			1.72	0.62	0.74	-2.58	-2.58	1.72	0.13	1.87
		maximum			3.5	3.51	2.45	1.42	1.42	3.51	2.72	1.00
		range			1.78	2.89	1.71	4	1.71	4.00	2.60	1.08
10958	Cyp WF	minimum		-10.69	-5.13	-6.06	-6.02	-8.77	-10.69	-5.13	-7.33	2.32
		maximum		-2.42	-2.11	-2.24	-2.57	-2.31	-2.57	-2.11	-2.33	0.18
		range		8.27	3.02	3.82	3.45	6.46	3.02	6.46	5.00	2.27
10965	Cyp WF	minimum	-7.78	-7.17	-1.85	-2.94	-2.78	-6.11	-7.78	-1.85	-4.77	2.55
		maximum	-0.97	-0.53	-0.02	0.12	-0.51	-1.46	-1.46	0.12	-0.56	0.59
		range	6.81	6.64	1.83	3.06	2.27	4.65	1.83	4.65	4.21	2.17
All Avg	Cyp WF	minimum	-7.78	-8.93	-1.855	-2.835	-2.72	-5.695	-6.59	-1.86	-3.82	2.03
		maximum	-0.97	-1.475	0.56	0.5575	0.0225	-0.4075	-0.47	0.60	0.15	0.46
		range	6.81	7.455	2.415	3.3925	2.7425	5.2875	2.40	5.29	3.98	1.71
1946	Mix	minimum		-4.73	-1.44	-3.34	-1.33	-5.81	-5.81	-1.33	-3.33	1.98
		maximum		1.15	2.15	4.27	1.15	-0.46	-0.46	4.27	1.65	1.74
		range		5.88	3.59	7.61	2.48	5.35	2.48	7.61	4.98	2.00
1980	Mix	minimum				1.19	0.55	-0.84	-0.84	1.19	0.30	1.04
		maximum				2.6	2.26	0.88	0.88	2.60	1.91	0.91
		range				1.41	1.71	1.72	1.41	1.72	1.61	0.18

Table 10: (Continued)

Well	Wetland Type	Water-level Characteristic	Well Water-Level (ft)									
			2001	2002	2003	2004	2005	2006	Low	High	Mean	Std dev
1995	Mix	minimum				0.29	-0.3	-0.84	-0.84	0.29	-0.28	0.57
		maximum				1.84	1.49	0.03	0.03	1.84	1.12	0.96
		range				1.55	1.79	0.87	0.87	1.79	1.40	0.48
2062	Mix	minimum		-1.31	0.12	-2.95	0.1	-4.53	-4.53	0.12	-1.71	2.02
		maximum		3.53	3.48	4.07	2.9	1.58	1.58	4.07	3.11	0.95
		range		4.84	3.36	7.02	2.8	6.11	2.80	7.02	4.83	1.78
All Avg	Mix	minimum		-3.02	-0.66	-1.2025	-0.245	-3.005	-3.01	0.07	-1.26	1.40
		maximum		2.34	2.815	3.195	1.95	0.5075	0.51	3.20	1.95	1.14
		range		5.36	3.475	4.3975	2.195	3.5125	1.89	4.54	3.21	1.11
1021	Bot	minimum				-8.62	-8.37	-9.63	-9.63	-8.37	-8.87	0.67
		maximum				0.89	-1.95	-5.9	-5.90	0.89	-2.32	3.41
		range				9.51	6.42	3.73	3.73	9.51	6.55	2.89
1969	Bot	minimum		-0.44	1.4	0.53	0.99	-1.33	-1.33	1.40	0.23	1.11
		maximum		3.65	4.3	4.85	3.93	1.78	1.78	4.85	3.70	1.16
		range		4.09	2.9	4.32	2.94	3.11	2.90	4.32	3.47	0.68
All Avg	Bot	minimum		-0.44	1.4	-4.045	-3.69	-5.48	-5.48	-3.485	-4.3217	0.88802
		maximum		3.65	4.3	2.87	0.99	-2.06	-2.06	2.87	0.691	2.2873
		range		4.09	2.9	6.915	4.68	3.42	3.315	6.915	5.01267	1.78548
598	Bot WF	minimum			-4.66	-5.76	-4.24		-5.76	-4.24	-4.89	0.78
		maximum			1.39	0.6	0.75		0.60	1.39	0.91	0.42
		range			6.05	6.36	4.99		4.99	6.36	5.80	0.72

Table 10: (Continued)

Well	Wetland Type	Water-level Characteristic	Well Water-Level (ft)									
			2001	2002	2003	2004	2005	2006	Low	High	Mean	Std dev
1954	Msh	minimum			0.12	-4.35	-4.6	-6.64	-6.64	0.12	-3.87	2.85
		maximum			3	3.28	2.77	0.12	0.12	3.28	2.29	1.46
		range			2.88	7.63	7.37	6.76	2.88	7.63	6.16	2.22
1959	Msh	minimum			-0.96	-4.19	-4.95		-4.95	-0.96	-3.37	2.12
		maximum			1.88	1.9	1.35		1.35	1.90	1.71	0.31
		range			2.84	6.09	6.3		2.84	6.30	5.08	1.94
1960	Msh	minimum		-3.4	0.88	0.68	0.22	-3.23	-3.40	0.88	-0.97	2.15
		maximum		2.71	2.33	3.14	2.49	2.33	2.33	3.14	2.60	0.34
		range		6.11	1.45	2.46	2.27	5.56	1.45	5.56	3.57	2.11
1966	Msh	minimum				-2.54	-1.19	-2.43	-2.54	-1.19	-2.05	0.75
		maximum				1.7	1.55	0.83	0.83	1.70	1.36	0.47
		range				4.24	2.74	3.26	2.74	4.24	3.41	0.76
2060	Msh	minimum		0.23	0.45	-2.23	-1.98	-3.29	-3.29	0.45	-1.36	1.63
		maximum		2.03	2.06	2.21	1.93	1.11	1.11	2.21	1.87	0.44
		range		1.8	1.61	4.44	3.91	4.4	1.61	4.44	3.23	1.41
2066	Msh	minimum			0.43	0.07	-2.97	-3.75	-3.75	0.43	-1.56	2.11
		maximum			2.64	3.4	2.4	1.59	1.59	3.40	2.51	0.75
		range			2.21	3.33	5.37	5.34	2.21	5.37	4.06	1.56
All Avg	Msh	minimum		-1.59	0.18	-2.09	-2.58	-3.87	-4.10	-0.05	-2.20	1.94
		maximum		2.37	2.38	2.61	2.08	1.20	1.22	2.61	2.06	0.63
		range		3.96	2.20	4.70	4.66	5.06	2.29	5.59	4.25	1.67

Table 10: (Continued)

Well	Wetland Type	Water-level Characteristic	Well Water-Level (ft)									
			2001	2002	2003	2004	2005	2006	Low	High	Mean	Std dev
1977	WPr	minimum		-6.39	-2.93	-3.62	-3.49	-6.38	-6.39	-2.93	-4.56	1.68
		maximum		0.58	2.36	3.44	1.08	0.05	0.05	3.44	1.50	1.38
		range		6.97	5.29	7.06	4.57	6.43	4.57	7.06	6.06	1.09
1981	WPr	minimum		-3.67	-2.19	-2.38	-2.85	-4.33	-4.33	-2.19	-3.08	0.90
		maximum		1.38	1.49	1.74	1.45	0.58	0.58	1.74	1.33	0.44
		range		5.05	3.68	4.12	4.3	4.91	3.68	4.91	4.41	0.57
10896	WPr	minimum	-5.68	-5.74	-3.22	-3.6	-0.52		-5.74	-0.52	-3.75	2.15
		maximum	-3	-3.15	-0.83	0.55	2.27		-3.15	2.27	-0.83	2.32
		range	2.68	2.59	2.39	4.15	2.79		2.39	4.15	2.92	0.70
All Avg	WPr	minimum	-5.68	-5.27	-2.78	-3.20	-2.29	-5.36	-5.49	-1.88	-3.80	1.58
		maximum	-3.00	-0.40	1.01	1.91	1.60	0.32	-0.84	2.48	0.67	1.38
		range	2.68	4.87	3.79	5.11	3.89	5.67	3.55	5.37	4.47	0.79

*Annual Water-Level Minimum, Maximum, and Range for the Summer/Fall Semi-Annual Hydroperiod Cycle for all Wetlands