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Hydrology of Isolated Wetlands of South Florida: Results of 1997-98 Monitoring and Data Analysis and Guidance for Developing Wetland Drawdown Criteria

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South Florida Water Management District
Water Supply Planning and Regulation

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EXECUTIVE SUMMARY

This report is a product of an ongoing research effort by the South Florida Water Management District to provide a scientific basis for developing wetland protection criteria for water use permitting. The report documents and interprets hydrologic and environmental monitoring conducted during 1997 and 1998 at twenty isolated wetland study sites located in Martin, St. Lucie, Lee, Osceola, and Polk Counties within the District. These study sites are located near large public water supply wellfields and in relatively unimpacted reference areas. Comparison of hydrologic regimes and ecological conditions at wellfield and reference sites provides insight into the nature of impacts produced by moderate levels of water table drawdown.

For the purposes of this study, three categories of wetlands are defined, based on hydrologic regime, soils, landscape position, and ecosystem dependence on the water table position. Type 1 wetlands include lake and pond communities with permanent hydroperiods and relatively deep water supporting mostly aquatic plants and animals. Type 2 wetlands such as depression marshes and cypress domes are typically situated in sandy depressions with deposits of organic soils forming the wetland substrate; these wetlands typically dry out for at least short periods during the dry season. Type 3 wetlands such as wet prairies and hydric flatwoods have short hydroperiods with shallow depths of inundation and are situated on mineral soils; flora and fauna are adapted to frequent and unpredictable drying of surface water.

Analysis of hydrologic and environmental data indicates that isolated wetlands are surface expressions of the water table, and wetland surface water levels are essentially the same as groundwater heads in the sandy upper portion of the Surficial Aquifer. Wetting of Type 2 and 3 wetlands in the rainy season occurs only when the water table reaches the ground surface and is influenced by vertical groundwater discharge to the wetland substrate and lateral redistribution of the water table in response to rainfall. The timing of wetting affects the duration of inundation (hydroperiod) and is strongly influenced by the position of the water table at the end of the dry season. Drying of wetlands in the spring is governed by the rate of decline of the surficial aquifer water table and is more strongly influenced by external controls than by site-specific features. The presence of

hardpan or other potential confining layers in the landscape appears to have little effect on drying rates or retention of water in the dry season. Wetlands that are lowest in the landscape are typically the last to dry out; these sites often function as important dry-season refugia for aquatic organisms.

Different wetland types may be more vulnerable to the effects of water table drawdown in different seasons. Water table position at the end of the dry season and median wet-season surface water stage are considered the most important hydrologic indicators of wetland ecological functions. Type 1 wetlands are most vulnerable to reductions in water table position during the dry season. These wetlands naturally contain standing water throughout the dry season, and a minimum water table elevation is required to maintain aquatic refugia for fish, invertebrates, reptiles, and a variety of other animals which use these sites when Type 2 and 3 wetlands are dry. Large amounts of water storage and adequate water depths make Type 1 wetlands less vulnerable to adverse effects of drawdown during the wet season. Type 2 wetlands may be equally vulnerable to drawdown impacts in both the wet and dry seasons. In Type 2 wetlands, the dry-season water table typically stays near the ground surface and in contact with organic soil layers, keeping surface soils saturated most of the time. Many organisms inhabiting Type 2 wetlands rely on saturated soils to survive the lack of standing water in the dry season. Sufficient surface water levels are needed in the wet season to ensure normal levels of primary and secondary production, but relatively smaller amounts of surface water storage makes them more vulnerable than Type 1 wetlands to drawdown during the wet season. Type 3 wetland communities are typically adapted to short hydroperiods and seasonal drying of surface water. The dry season water table naturally falls below the root zone of the dominant plants and, with few exceptions, the dominant fauna are not highly dependent on the water table position during the dry season. Notable exceptions to this include crayfish and some benthic invertebrates that burrow during the dry season in response to changes in the soil moisture gradient. Additional research on these organisms may eventually suggest a biological limit on the dry-season water table position for Type 3 wetlands. In the absence of such a limit, constraints on the water table position at the end of the dry season are needed to ensure that the hydroperiod is not substantially reduced due to delayed wetting in early summer. Type 3 wetlands are considered most vulnerable to adverse impacts during the wet season because reductions in the naturally short hydroperiods and shallow water depths of these wetlands can seriously reduce biological production.

Performance standards that reflect these differences in wet and dry season vulnerability to drawdown are recommended for each of the three wetland types. It is also recommended that numerical criteria developed from the performance standards maintain a level of protection no less than that afforded by the "one-foot" guideline presently used in the District's water use permitting process. Recommendations are given for additional research to help validate and refine performance standards for normal and 1-in-10 drought conditions.

1. Introduction

1.1 Project Background

This report documents interim results of monitoring studies conducted by staff of the South Florida Water Management District (District or SFWMD) to support development of wetland protection criteria for regulating consumptive use of groundwater. This project began as an outgrowth of the water supply planning process in response to concerns over potential impacts to wetlands caused by groundwater withdrawal and the adequacy of drawdown criteria used in water use permitting to protect wetlands from adverse harm.

The existing guideline for wetland drawdown used in permitting specifies that: *No more than one-foot of well-induced drawdown is allowed in the surficial aquifer at the edge of the nearest wetland at the end of a hypothetical period of 90 days with no recharge with pumping at maximum allocated rates.* Drawdown less than one foot under such conditions is presumed to cause no significant harm to affected wetlands, except for some special cases where unique wetland types are involved. This guideline has been successfully applied in the regulatory process since the mid-1980's without legal challenge or demonstrated evidence of impacts to wetlands near major permitted water uses. However, successful legal challenges to similar criteria used by other water management districts in Florida during the 1990's have underscored the fact that a strong scientific basis for such criteria is lacking and that objective data on wetland hydrology and ecology are needed to make sound permitting decisions.

In response to these concerns, the District convened a panel of wetland scientists in late 1994 to review existing drawdown criteria in light of best available information from the scientific literature and the results of limited hydrologic modeling. The panel concluded that there was insufficient information to determine whether the existing level of wetland protection was either allowing adverse impacts or was unnecessarily strict. They recommended that the present level of protection be maintained and that the District initiate research needed to provide scientific guidance for making future decisions regarding drawdown criteria (SFWMD, 1995). These recommendations were echoed in water supply planning documents prepared for the Lower West Coast region in 1994 (SFWMD, 1994) and the Upper East Coast in 1998 (SFWMD, 1998).

The District's Water Resource Evaluation Department was charged with developing a research program focusing on hydrobiological monitoring of typical isolated wetland sites (SFWMD, 1995, Mortellaro *et al*, 1996). A research plan was developed for the project in 1995 based on the recommendations of the expert panel, and study sites were selected during 1995 and 1996 as part of a District-wide survey of impacts. The survey concluded that groundwater drawdown impacts to wetlands were not as severe as those experienced in other parts of Florida and are less extensive than other forms of development impacts. Twenty sites in four study areas were established and instrumented in early 1997, and hydrologic data collection began during the 1997 dry season. This report documents and interprets hydrologic observations from these twenty sites during 1997 and 1998.

In May 1998, seventeen additional sites were established in the Lower West Coast region in Lee and Collier Counties. These sites comprise wetlands in two large agricultural projects, additional reference sites, and two new hydric flatwoods sites added to the existing Flint Pen Strand study area. Details of the hydrology of these new sites are not included in this report, but will be included in the next annual hydrology report projected for completion in early 2000.

1.2 Purpose of Report

The intent of this report is to communicate what has been learned to date about the hydrology of isolated wetlands monitored as part of the research described above and of their vulnerability to adverse environmental impacts caused by groundwater withdrawals. To this end, the remainder of the report documents hydrologic settings and background conditions at the twenty original wetland study sites and interprets hydrologic data collected at those sites from April 1997 to the end of December 1998. Additional data from January-May 1999 is also presented due to the significance of drought conditions that developed across the District during that time; however this data is not analyzed in detail. Interpretation of the hydrologic data is used to classify common isolated wetland types according to hydrologic regime and sensitivity to drawdown impacts. Guidance is provided for developing wetland protection criteria that are consistent with observed data and based on best available information.

2. Setting and Background

2.1 Isolated Wetlands

The term **isolated wetland,** as used by the water management districts and the Florida Department of Environmental Protection, refers to any wetland with no direct surface water connection to a lake, stream, estuary, or marine waters. For the purposes of this report, "isolated wetlands" includes naturally occurring freshwater wetlands in three common settings:

(1) **Perennially isolated wetlands** – depressional wetlands completely surrounded by uplands and naturally isolated in closed basins such as may occur on sand ridges, dunes, and some pine flatwoods;
(2) **Seasonally isolated wetlands** – depressional wetlands that are naturally connected to other surface water features by an intermittent water course (e.g, wet prairies, hydric flatwoods, or small streams) flowing only during the peak of the wet season;
(3) **Fragmented wetlands** -- wetlands that have become artificially isolated from other surface water features by landscape fragmentation caused by urban and agricultural development.

Isolated wetlands are commonly small, often circular, depressions within scrub or pine flatwoods. They are typically distinguished from larger regional wetlands and riverine systems such as rivers, strands, and sloughs by size and flow characteristics. Isolated wetlands may range in size from small wetland fragments of 0.25 acre or less to larger depressions in the neighborhood of 50 acres, with 0.5 acre the minimum threshold size for legal protection. In a recent survey of large contiguous tracts of natural land in the Southwest Florida Water Management District, 68% of isolated wetlands were between 0.5 and 5.0 acres and 90% were less than 10 acres in area (Hart and Newman, 1995). Wetlands chosen for our study are representative of isolated wetlands in south and central Florida, ranging from 0.5 to 8 acres, with an average size of 3.7 acres for twenty study sites. Because of their size and shape and the lack of surface connections to other water bodies, the hydrology of isolated wetlands is often assumed to be dominated by spatially-lumped, vertical processes such as rainfall, evapotranspiration, and groundwater flux, thereby greatly simplifying hydrologic modeling and analysis (Konyha *et al*, 1995).

Isolated wetlands provide wildlife habitat and other beneficial ecological functions similar to larger, regional wetland systems. However, because of their isolation, small size and variable hydrology, isolated wetlands often support a very different species assemblage than more permanent water bodies and may provide important ecological functions that larger wetlands do not (Moler and Franz, 1987). Regular drying and isolation from other water bodies selects for plants and animals that are capable of surviving periods with reduced or no standing water and tends to exclude many of the larger aquatic predators. This relatively predator-free environment serves as an important nursery that is critical to the survival of juvenile and larval forms of many species of reptiles, amphibians, and invertebrates. Many invertebrate and small vertebrate species adapted to isolated wetlands exhibit high rates of growth and productivity that enable them to exploit relatively short periods of optimal aquatic conditions. Isolated wetlands thus function both as locations of concentrated aquatic food resources and as sources of population dispersal for important prey species. Isolated wetlands may also serve as sanctuaries for immature wading birds and alligators and as refugia for waterfowl, sandhill cranes, and migratory birds by providing appropriate food and cover in an environment that excludes larger predators and competitors. Isolated wetlands interspersed within a pine flatwoods or scrub landscape are important sources of drinking water and aquatic food resources for a variety of upland fauna, particularly in the dry season when such wetlands may be the only sources of water in an otherwise xeric environment.

Historically, most small depressional wetlands in south Florida were part of a larger matrix of flatwoods and other wetland types that were hydrologically connected during at least part of the summer and fall wet season. Most of the wetlands monitored for this project in the Flint Pen Strand and Jonathan Dickinson State Park study areas are situated within a relatively unimpacted matrix of wet flatwoods and prairies that becomes completely connected during much of the wet season. Isolation of individual depressional wetlands at these sites occurs only during winter through late spring.

At many locations in south Florida, the flatwoods and prairie matrix has been drained and fragmented by road construction, agricultural and urban development, and surface water management, truly isolating the depressional wetlands contained within the landscape (Geonex, 1996). Depressional wetlands in fragmented landscapes are represented in this study by sites in portions of the Flint Pen Strand and Savannas study areas and by the new sites established during 1998 in lower west coast agricultural settings. In these areas, physical alteration of the wetlands themselves has been insignificant. However, the loss of seasonal sheetflow connections and isolation caused by changes in the surrounding landscape may have altered the wet season hydrologic regime in some locations. In cases where sheetflow connections are lost completely, wetlands may become more vulnerable to impacts from groundwater drawdown than they had been when the surrounding flatwoods matrix was still intact.

Similar small depressional wetlands in many parts of central Florida were more likely to have been naturally isolated because of greater topographic relief and a corresponding greater proportion of uplands (scrub, sand hills, high pine, and scrubby flatwoods) surrounding the wetland depressions. Sites of this type are monitored in the Savannas study area in Martin County and the Disney Wilderness Preserve study area in Osceola and Polk Counties.

2.2 Isolated Wetland Community Types

The most common isolated wetland types in south and central Florida are designated by the Florida Natural Areas Inventory as depression marsh and dome swamp. Accordingly, most of our monitoring effort is focused on these two main community types. A **depression marsh** is defined as a small rounded depression in sand substrate with peat or muck accumulating toward the center. Most are at least seasonally isolated, seasonally inundated, and are characterized by grasses or broad-leaf emergents such as maidencane (*Panicum hemitomon*), fire flag (*Thalia geniculata*), and pickerelweed (*Pontedaria cordata*), distinct zones of which may occur in concentric rings according to hydrologic tolerance.

Dome swamps are similar small depressions in sand or limestone substrates, often with considerable peat or muck accumulation in the center. Most are seasonally isolated and inundated and dominated by cypress (*Taxodium* spp.), blackgum (*Nyssa aquatica*), or bays (*Gordonia, Persea, Magnolia* spp.), with the tallest trees often near the center. Understory vegetation consists of various ferns, wax myrtle (*Myrica cerifera*), dahoon (*Ilex cassine*) and other shrubs and vines. Many cypress dome swamps in the Lower West Coast region are "donut shaped" with cypress forming an outer ring and an open center dominated by fire flag or water lily. Dome swamps in our Walker Ranch study area are dominated by a mix of cypress, blackgum, and loblolly bay (*Gordonia lasianthus*); this community composition is typical of dome swamps in the northern part of the District. At present we do not monitor any "bay heads," a type of dome swamp dominated almost exclusively by bay species.

Wet flatwoods and **wet prairie** communities are also common in south Florida, but often there is some question as to whether such wetlands are truly isolated. Wet flatwoods and wet prairies are palustrine wetlands that commonly occur on flat, poorly drained sand substrates and have relatively short hydroperiods, compared with dome swamps and depression marshes. Wet flatwoods are characterized by slash pine (*Pinus elliottii*) and cabbage palm (*Sabal palmetto*) with an understory of mixed grasses and herbs. Wet prairies are similar to wet flatwoods, but are distinguished from the latter by the lack of slash pine and almost complete dominance by herbaceous species. In many places, both community types blend together (e.g. at FP9, where sparse pine occurs with an understory typical of wet prairies), making it difficult to make clear distinctions between the two in the field.

Dominant natural communities for each wetland site monitored for this project are summarized in Table D.1 (Appendix D). Many of the wetlands monitored for this project consist of several community types along a hydrologic gradient. For instance, many of the Flint Pen sites, although nominally characterized as dome swamps in Table D.1, actually consist of cypress dome swamps with small depression marshes or open ponds in the center and surrounded by wet prairie or wet flatwoods.

Other isolated wetland types in the region include hydric hammocks, marl prairies, baygalls, sinkholes and rockland depressions, and sandhill upland lakes. None of these types were considered sufficiently common to warrant including sites of these types in the original twenty sites. A hydric hammock site was added during 1998 at the Hogan Island Farms study area. A baygall wetland at Sea Branch State Preserve in Martin County was evaluated for inclusion in the network, but was not selected due to the rarity of this wetland type in south Florida. No sinkhole or rockland depression wetlands were included in the monitoring because most such wetlands in south Florida are confined to the rocklands and tree islands of southern Dade County and the Keys and have either been lost to farming and development or are protected in Everglades National Park and other well-buffered preserve areas. Sandhill upland lakes occur in higher elevation portions of the District, most notably in a few places along the Atlantic Ridge on the east coast, along the Lake Wales Ridge in the center of the state, and in portions of the upper Kissimmee basin in the extreme northern portion of the District. We have tentatively selected one sandhill lake site in Jonathan Dickinson State Park that will be added to the monitoring network in 1999. Water level data from a groundwater monitoring well at the site has been collected by the District since 1985.

2.3 Study Areas

Figure 2.1 shows the locations of the study areas discussed in this report plus new agricultural sites added to the program in 1998. An additional study area shown on the map is located in the vicinity of the Dade West Well Field (Miami-Dade Water and Sewer) is monitored by Miami-Dade Department of Environmental Resources Management; data analysis from this site is not included in this report. Study areas and sites were selected by project staff in 1996 based on the following criteria:

- Geographic (water supply planning) region/geologic setting (located in water use "hot spots"),
- Wetland type (geomorphic setting & plant community),
- Proximity to large groundwater withdrawal source from the water table aquifer (municipal water supply wellfields given preference over other use types for this phase),
- Ability to identify wetlands of similar type situated along a drawdown gradient,
- Ability to match potential impact sites with good quality reference sites,
- Minimal influences by other potential sources of impact such as roads, development, ditches, canals, etc., and expected to remain so over projected five-year duration of monitoring
- Ability to obtain long-term access agreements (public land given preference over private lands for this phase),
- Ease of access for monitoring.

Very few study areas in south Florida perfectly satisfied all of these criteria. In particular, it was difficult to locate sites that provided sufficient information on the effects of drawdown and could be studied over a period of five or more years without undergoing substantial change that were not also potentially influenced by other sources. This contrasts with similar studies conducted by Southwest Florida Water Management District in west central Florida where large municipal wellfields are located on large tracts of protected public land owned by the district and containing numerous isolated wetlands that could be monitored (Rochow, 1994). Nevertheless, the sites selected satisfy most of these criteria and represent the majority of common isolated wetland types and settings found in the District.

A brief description of each study area and the wetland sites monitored therein is presented in the remainder of this section. Additional details on the physical attributes of the sites are given in subsequent sections of this chapter. Details on the common biota (vascular plants, bryophytes, amphibians and reptiles, birds, fishes, and invertebrates) based on biological inventories of each site completed in 1996-1997 are documented in a separate report (Mortellaro, 1998).

2.3.1 Flint Pen Strand (Lee County). The Flint Pen Strand study area is located in south central Lee County in the vicinity of the Lee County Corkscrew Well Field. Source, capacity and allocation information for the well field is given in Table A.1 (Appendix A). The sites are located south of Corkscrew Road (CR-850) approximately four miles east of I-75 and eight miles inland from Estero Bay. Wetland sites monitored in the study area are shown in Fig. 2.2. Six wetland sites (FP3-FP8) located in Section 33

(T46S, R26E) have been monitored continuously since May 1997. Each of these sites is a cypress dome swamp surrounded by pine or hydric flatwoods in various states of disturbance and typically containing an open pond in the center, giving the wetland a "donut-shaped" appearance from the air. These center ponds often contain alligator holes and may be entirely open water or dominated by alligator flag (*Thalia geniculata*) or West Indian marsh grass (*Hymenachne amplexicaulis*). A seventh study site (FP2) was established in May 1997 in Section 27 (T46S, R26E) immediately adjacent to the Corkscrew Well Field. This site consists of a marsh with a cypress fringe on the south side. The marsh is dominated by alligator flag and West Indian marsh grass. The depressional basins of these seven wetlands range from five to approximately twelve acres in size. Two additional monitoring sites (FP9, FP10) were established in Section 33 in May 1998, with continuous data collection beginning December 1998. Both of these sites are located in hydric flatwoods and wet prairie settings. Detailed analysis of data from these two sites is not included in this report. A District weather station (FPWX) was installed for this project in September 1997 on the west boundary of Section 33 about 0.25 mi. south of the northwest section corner. Additional monitoring stations in the area include a 60-foot groundwater monitoring well (FP11) installed as part of this project near wetland FP4, shallow piezometers in the flatwoods around sites FP5, FP6 and FP7, USGS monitoring wells near Corkscrew Rd. and the southwest corner of Section 33, and numerous wetland and groundwater wells monitored by Lee County Utilities in and around the well field.

The Flint Pen Strand study area is located in the upper portion of the Imperial River/Estero Bay watershed on the western periphery of the main strand swamp that carries water south from the headwaters in the Imperial Marsh to the Imperial River near Bonita Springs. This watershed comprises the northwestern portion of the Corkscrew Regional Ecosystem Watershed (CREW). The study sites are situated in a matrix of wet flatwoods that comprises the majority of Section 33 and a large portion of Section 27. Much of this flatwoods area is inundated 6-12 inches in depth during the wet season. The ground surface across the property ranges from 16.5 to 18 feet (NGVD) and drops approximately one foot per mile from north to south. Sheet flow across Section 33 is roughly north to south with some evidence that peak stages from the same rainfall event reach the southernmost sites as much as 12 to 24 hours later than the northern sites. There is also evidence that during the transition from dry to wet conditions a significant amount of water enters the depressional cypress domes as sheet flow from the surrounding wet prairies and flatwoods. Site FP2 receives surface inflow from roadside swales along Corkscrew Rd. during very wet periods and discharges surface water via sheetflow to the south when the wetland stage is above 17.8 feet. Sites FP3 and FP4 previously may have received agricultural discharge when the section to the north was actively farmed.

The property containing the study sites is part of CREW and is owned by Lee County and the CREW Trust and managed by the District, except for site FP3 which is located on private land owned by the Youngquist Brothers. On the CREW lands, a successful melaleuca (*Melaleuca quinquefolia*) eradication program was begun in 1995 and has greatly reduced the density of melaleuca around the study sites in the intervening four years; substantial amounts of dead melaleuca snags and slash are still present around sites FP5, FP6, and FP7. The District has also successfully treated for Brazilian pepper (*Schinus terebinthifolius*) in selected areas of the property, notably around the fringes of site FP2. West Indian marsh grass has invaded several of the monitored wetland sites (and many nearby wetlands) over the course of the study. The marsh area of site FP2 was, during 1996 and 1997, almost completely dominated by West Indian marsh grass, which was apparently introduced as cattle forage. Half of this site was treated in early 1998 by Lee County as part of a demonstration project; the treated half of the marsh is now dominated by native alligator flag. Other study sites containing substantial amounts of West Indian marsh grass include FP3, FP5, and FP7. Small amounts of other exotic plants, including old world climbing fern (*Lygodium microphyllum*) and water lettuce (*Pistia stratiotes*) have been observed at several sites. Cattle were once grazed extensively in the area and are still seen regularly in low numbers. Wild hogs are common in the flatwoods and wetland edges. No wildfires or prescribed burns have been observed in the study area over the period of record.

During the period of record, numerous land use changes have occurred in the vicinity of the study sites, some with potential for substantially altering the landscape and hydrologic regimes of some of the study sites. Historically, construction of Corkscrew Rd. and the raised-grade well pads and access roads for the Corkscrew Well Field have changed surface flow patterns north of the study area (Geonex, 1996). The small vegetable farm operation in Section 28 (immediately north of Section 33) was converted to cattle grazing in 1997, followed by rock mining beginning in late 1997. This section is permitted for residential development as mining operations are gradually phased out over the next several years. Construction plans show wetland sites FP3 and FP4 connected to or receiving discharge from the project's surface water management system and site FP3 completely surrounded by roads and home lots. Clearing for roads and home sites began near sites FP3 and FP4 in early 1999. Lands immediately to the southwest of Section 33 are also slated for development.

The original portion of the Corkscrew Well Field was constructed in the early 1980's and became operational in 1981-82. This portion of the well field includes 18 surficial aquifer wells located near the intersection of Corkscrew Rd. and Alico Rd., with the nearest production well only a few hundred yards from wetland FP2. Additional wetlands inside the well field property are monitored by Lee County Utilities as a condition of their District water use permit. In 1998, an expansion to the well field was permitted, consisting of four additional surficial aquifer wells (and an equal number of sandstone wells) located on the western boundary of Sections 28 and 33. The wells were installed in late 1998, but to our knowledge, were not operated during the period of record. The two production well clusters on the Section 33 boundary are located nearest sites FP5 and FP10. A raised-grade access road for the new wells was constructed along the west boundary of Section 33 in the fall of 1998. Culverts were installed in several locations to maintain connections between wet prairies distributed on both sides of the property line.

2.3.2 Savannas State Preserve (Martin/St. Lucie Counties). The Savannas study area is located in northeastern Martin and southeastern St. Lucie Counties in the Savannas State Preserve near the town of Jensen Beach and northeast of the Martin County Utilities North County Well Field. Source, capacity and allocation information for the well field is given in Table A.1 (Appendix A). Four depression marsh wetlands and a weather station are monitored in this study area as shown in Fig. 2.3. Three marsh sites (SV4-6) surrounded by pine flatwoods and scrubby flatwoods are monitored in the southwestern portion of the preserve just north of Jensen Beach Blvd. (CR-732) in Sections 16 and 20-21 (T37S, R41E). The marsh sites include examples of circular depressions likely derived from buried solution features (SV4, SV5) and elongated depressions that are remnants of ancient dune fields oriented parallel to the coast line (SV6). These wetlands are approximately one mile west of the Indian River Lagoon, and shallow groundwater at the sites is often influenced by daily tidal fluctuations in the estuary. An additional depression marsh (SV1) is monitored in the portion of the preserve just north of Walton Rd. in St. Lucie County approximately four miles north of sites SV4-6. These sites range in size from 1 to 6 acres. The weather station (SVWX) is located at the preserve headquarters just west of Indian River Drive about one-half mile south of Walton Rd. Additional monitoring in the vicinity of the study area includes groundwater monitoring wells throughout the area monitored by Martin County Utilities (MCU), a rain gauge at the MCU treatment plant south of Jensen Beach Blvd., and wetland wells in several nearby development projects monitored by permit holders. Additional piezometers and a rain gauge at site SV5 are monitored by University of Florida researchers.

Topography of the study area ranges from 13 to 15 feet NGVD west of the deep sawgrass marsh and slough system that comprises the defining feature of the preserve. Historic drainage of the western flatwoods where our monitoring sites are located was poor, except in the vicinity of drainage ditches constructed to improve cattle forage area and, later, to facilitate urban development. In the vicinity of sites SV4-6, surface water drained to the south via Warner Canal until the mid-1990's when historic control elevations were re-established as part of a restoration project. Similarly, surface flows in the vicinity of site SV1 drain in an east-west direction due to influence from Hog Pen Ditch and smaller drainage ditches installed when the area was used for grazing. However, none of the monitored wetland sites have ever been drained or directly connected to any surface water management system. Surface water management systems in the vicinity, especially south of Jensen Beach Blvd., are observed to have low control elevations relative to the study sites in the preserve and may exert some controlling influence on wetland hydrology.

The preserve is owned by the State of Florida and managed by the Department of Environmental Protection, Division of Recreation and Parks. SV5 and SV6 are located on property (Spices Tract) that was purchased by the District and added to the preserve in the early 1990's. No prescribed burns have been conducted in the vicinity of the monitoring sites during the period of record; however, several wildfires have occurred in areas near SV4 and SV6 during the past two years. Few if any exotic plants have been found in the wetland sites; however, FDEP conducts periodic eradication of Brazilian pepper, melaleuca, and carrotwood (*Cupaniopsis anacardioides*) in the vicinity. Signs of wild hog are common on the edges of all sites monitored in this study area. In some sites (e.g., SV4) hogs have caused substantial disturbance during dry periods to certain plant zones in the wetland. These disturbed areas often raised in elevation and later become dominated by native red root (*Lachnanthes caroliniana*).

The landscape surrounding the preserve is highly fragmented and is rapidly developing. Completion of projects along Jensen Beach Blvd. to the south and west of the preserve will likely result in buildout conditions in the next few years. The MCU North County Well Field is located just southwest of the study sites in an area bounded by Jensen Beach Blvd., US 1 and the Pineapple Plantation development. The nearest surficial aquifer production wells are located approximately one-quarter mile from sites SV4 and SV5. During a previous drought in 1989-90, concern was raised over extremely dry conditions in wetlands in what is now the southwestern part of the Savannas Preserve, and a modeling study indicated that the well field was potentially influencing hydrology of wetlands in the vicinity of SV4-6 (Hopkins, 1991). As a result of this concern, operation of surficial aquifer wells was modified to decrease withdrawals from the northeastern portion of the well field nearest the preserve. Since 1989, the utility has shifted much of its production from the surficial aquifer to the deeper Floridan aquifer using reverse osmosis treatment techniques. However, periodic problems with the Floridan wells and the associated treatment train have resulted in periods of increased withdrawals from the surficial aquifer.

2.3.3 Jonathan Dickinson State Park (Martin County). Jonathan Dickinson State Park is located in southern Martin County west of the Atlantic Ridge and south of the town of Hobe Sound. Three wetland sites are monitored in the park as shown in Fig. 2.4. Two of these sites are depression marshes (JD6 and JD12) and one is a wet prairie with a small cypress dome swamp in the center (JD26). The sites are located in Sections 5 and 9 (T40S, R42E) within the portion of the 10,000-acre park designated as Wilderness Preserve. A sandhill upland lake site (JD29) may be added in 1999; although not shown in Fig. 2.4, JD29 is located near the Florida East Coast (FEC) railroad tracks on the western slope of the Atlantic Ridge in the east central portion of the park. The project weather station (JDWX) is located adjacent to the northern park boundary nearest wetland site JD12. Additional monitoring in the vicinity includes several USGS groundwater monitoring wells near JDWX and along the FEC tracks and a rain gauge monitored by FDEP biologists on the east side of the park near US1.

All monitored sites are situated within a broad expanse of flatwoods and wet prairie that comprise the drainage basin of Kitching Creek. Although plant communities tend to be similar throughout the basin, wetlands in the eastern portion of the basin (JD6, JD26) tend to be more elongated in shape and part of a reticulated system distributed throughout the flatwoods (Fig. 2.4). Wetlands in the western part of the basin (JD12) are typically more round or teardrop shaped and tend to be somewhat deeper and lower in the landscape. Most of the wetlands in both parts of the basin still retain some connections to seasonally wet prairies that ultimately drain in a southerly direction to the creek. However, at some wetlands these wet season connections are affected by fire ditches, shallow drainage ditches, and road construction within the park. A fire ditch on the southeast side of wetland JD26 likely bleeds off high stages in the wetland during portions of the wet season. Site JD6 was historically connected to similar wetlands to the east, but the connection was severed by the construction of the main park road.

The park is managed by FDEP Division of Recreation and Parks, including an active program for eradicating exotic plants. No problem exotics have been observed at any of the monitored wetland sites. However, several exotics, especially old world climbing fern and downy rose myrtle (*Rhodomyrtus tomentosa*), pose serious threats to wetlands and surrounding habitats in the park. Old world climbing fern in particular has spread to nearly 11% of the park (Pemberton and Ferriter, 1998), most of that in wetlands, and is present in wetlands near our monitoring sites. Wild hogs are fairly common in the park. Park staff have conducted prescribed burns in areas immediately adjacent to each of our monitored sites during the past two years.

Most of the park is fairly well buffered from development impacts, including wellfield drawdowns. South Martin Regional Utility (formerly Hobe Sound Water Co.) operates a small public water supply wellfield on the northeast side of park, but none of the monitoring sites are influenced by their drawdown. The portion of the property where our sites are located was previously used as cattle range prior to inclusion in the park; many of the shallow drainage ditches in the area were constructed during this period.

2.3.4 Disney Wilderness Preserve (Osceola/Polk Counties). The Disney Wilderness Preserve study area straddles the Osceola/Polk County line on the east side of Reedy Creek from Lake Russell and the Village of Poinciana in the north to Lake Hatchineha in the south. The Nature Conservancy (TNC) owns the property and manages and restores wetlands and other habitats on behalf of the Disney Development Corporation as part of a mitigation agreement for projected impacts to wetlands from future development activities. The entire property totals nearly 10,000 acres and is bounded by state-owned conservation land on the south, east, and north sides. As shown in Fig. 2.5, six wetland sites and a weather station are monitored in the preserve. Three depression marsh wetlands (WR6, WR8-9) are monitored in the north central part of the property and three cypress-tupelo dome swamps (WR11, WR15-16) are monitored in the southeast portion of the property known as the Graves Brothers tract. Sites WR6, WR8 and WR9 are located in Osceola County in Section 28 (T27S, R29E); sites WR11, WR15 and WR16 are located south of the Polk County line in Sections 2-3 (T28S, R29E). The weather station (WRWX) is located in the south of the property near Lake Hatchineha. Preserve staff monitor over 400 additional shallow groundwater wells on the property, four additional rain gauges, and stage gauges on Lake Russell and Reedy Creek (TNC, 1999).

The preserve is divided by a low sand ridge running the length of the property from north to south that separates the Reedy Creek basin to the east from the Lake Marian Creek basin to the west. Sites WR6, WR8 and WR9 are situated on this sand ridge and are surrounded by dry oak scrub and scrubby flatwoods. These three sites are truly isolated wetlands and are rarely if ever hydrologically connected with adjacent flatwoods or other wetlands. The dome swamp sites are situated in a low-lying plain between the sand ridge and Reedy Creek and are surrounded by longleaf pine flatwoods and dry prairie. During the wet season, runoff and sheet flow (when it occurs) is generally toward Reedy Creek. Canopy dominance of these sites ranges from all tupelo at WR11 to mixed cypress and tupelo at WR16 to all cypress at WR15. There is some evidence to suggest that the marsh sites and the dome swamp sites are in two distinctly different geologic settings.

The preserve staff maintain a very active fire management program over most of the property. Prescribed burns have been conducted in areas surrounding the wetland monitoring sites at several occasions during the period of record. No invasive exotic species have been observed in any of the monitoring sites, and the property as a whole has relatively few problems with exotics. Access to the monitoring sites is limited to all-terrain vehicles and other vehicles with low ground pressure tires.

Many isolated wetlands on the preserve were ditched during the period the property operated as a cattle ranch; many of these are presently being restored by TNC staff. However, none of the sites monitored for this project appear to have ever been ditched or drained. Site WR9 may receive inflow from an old fire ditch now used as an access trail through the flatwoods on the south side. However, no such flow has yet been observed. The only production wells in the vicinity are those in the Village of Poinciana, the nearest of which is located about two miles to the northwest of site WR9. The property is otherwise well buffered from development impacts.

2.4 Geology and Soils

2.4.1 Aquifer Description. Geology provides important context for studying hydrology and hydrologic impacts to wetlands. It defines the geomorphic setting for the wetland, provides clues to the wetland's genesis, and is the medium through which groundwater drawdown impacts are translated to the wetland.

The hydrogeologic system most relevant to this study is referred to as the **Surficial Aquifer System**, or "surficial aquifer" in short. The surficial aquifer provides the majority of the groundwater used for public water supply and agricultural irrigation in south Florida and is also the hydrologic and landscape setting for isolated wetlands and other aquatic natural resources. The surficial aquifer is relatively shallow, ranging from 50 to 200 feet thick depending on landscape position and location within south and central Florida. It is comprised primarily of unconsolidated sands, sometimes with substantial water-bearing limestone units, and often containing interfingered clays, silts, shell hash, and thin limestone layers. Table B.1 (Appendix B) summarizes the surficial aquifer system configuration, thickness, and dominant water production zones for the four main planning regions of the District. Figures B.1-B.3 (Appendix B) show the major known units of the surficial aquifer system in each planning region. Low-permeability clays of the Hawthorne formation separate the surficial aquifer system from the deeper Floridan Aquifer System; the top of the Hawthorne is commonly considered to be the bottom of the surficial aquifer. The surficial aquifer is considered an unconfined or semi-confined system with generally good hydrologic communication throughout its constituent layers. Recharge is primarily by rainfall occurring over broad sandy flatwoods, and the aquifer's proximity to the ground surface means that other surficial processes such as evapotranspiration, runoff and drainage can have a significant influence on groundwater hydrology. Water production in most areas of the District is typically from porous limestone units within the surficial aquifer system (see Table B.1) less than 150 feet below ground surface (Alvarez and Bacon, 1988), except in northern portions of the Kissimmee River basin where production is primarily from the Floridan Aquifer System.

This shallow aquifer system is considered a "mantled" or "covered" karst environment (Parker, 1992), in which a karst limestone layer is overlain by marine sands of recent origin. Irregular solution features in the limestone were blanketed by sand during periods of high sea levels, creating a surface landscape of low-relief, but one which still retains some memory of the topography of the underlying limestone. In south Florida, wetlands occur in the resulting shallow depressions and poorly drained flats in the surficial sands, and farther north lakes may occur where sinkholes penetrate from the surface to deeper aquifers (Shaw and Trost, 1984; Parker, 1992).

2.4.2 Geological Setting and Structural Features. As described above, the surficial aquifer is typically comprised of one or two dominant units that can be conceptualized as shown in Fig. 2.6. A sandy layer of marine origin typically begins at the ground surface or just below organic soil deposits and extends to about twenty feet below ground in most flatwoods areas and much deeper in some scrub and sandhill environments. In south Florida, isolated wetlands are typically situated within these sands, either within depressions or on flat sandy plains. Water production is most frequently from relatively thick porous limestone units typically underlying the sands.

Pumping from the unconfined surficial aquifer creates an area of depressed water tables that diminishes with distance from the source of withdrawal. This region of depressed water table elevations is often referred to as the "cone of depression," and the difference in elevations between the depressed water table created by pumping and the water table that would occur with no pumping is referred to as the "drawdown." The amount of drawdown at a given location depends on the distance from the source of pumping, the rate of pumping, and the transmissivity of the aquifer material. Severity of hydrologic impacts to wetlands situated within the cone of depression depends in part on the amount of drawdown, the landscape position of the wetland, and the presence and extent of low-permeability units that may lie between the production zone and the wetland depression.

The limestone production zone is often separated from the sandy upper zone of the aquifer by a thin transition zone of silts and fine particles (Hopkins, 1991). The characteristics of this transition zone, including its thickness and transmissivity can potentially determine whether the sandy zone is relatively isolated from the effects of pumping from the limestone production zone or whether there is good hydrologic communication between the two zones. At present, not much is known about the hydraulic characteristics of the transition zone (DHI, 1999). Well boring logs from many of our monitoring sites show evidence of this transition zone beginning at about 20 feet below ground surface.

Various kinds of low-permeability units are often interspersed throughout the sandy zone of the aquifer between the production zone and the wetlands. Some prominent units of this kind, include "hardpan" and "caprock," which are frequently presumed to result in a perched water table where they occur and are thought to buffer isolated wetlands from drawdown impacts. Caprock refers to dense, low-permeability limestone layers that may overlie the more permeable production limestone in parts of the lower west coast. No such units have been found beneath any of the monitored wetlands sites.

Hardpan is a term commonly used to describe any shallow (<10 ft depth) low-permeability soil unit that occurs over a wide area. In parts of Martin, St. Lucie and northern Palm Beach Counties, hardpan most commonly refers to a shallow spodic horizon that often occurs at depths of two to four feet in the flatwoods. These spodic soils are composed of dark brown or reddish brown cemented fine sand or silt and organic matter formed through the repeated seasonal movement of the water table through the soil. Most often, such layers are thin, spatially discontinuous, and are frequently shallow enough to be penetrated by plant roots. Investigations of the North County Well Field adjacent to our Savannas study area by Hopkins (1991) and JMM (1988) have confirmed the presence of hardpan in and around wetlands. However, data presented by JMM (1988) show that such layers are not present in all wetlands, are not present in all locations within wetlands where they do occur, and where present average only 4-5 inches in thickness. It should also be noted that all units typically identified as hardpan layers in this area have high sand contents. Hopkins (1991) concludes that the hardpan layers have "variable leakage characteristics and are spatially discontinuous" and that "they do not isolate the wetlands from the underlying aquifer."

Field investigations of our study sites at the Savannas and Jonathan Dickinson are consistent with many of the above observations and may shed some additional light on the distribution of hardpan units. Test holes augured to a depth of 72 inches in and around wetland sites in these areas suggest that spodic hardpan layers are often (but not always) found in flatwoods, short-hydroperiod wet prairies and other transitional wetlands (including edges of depressional wetlands). We have not found evidence of hardpan in the center of depressional wetlands. As a rough rule of thumb we have found that where there are significant deposits of organic soils (muck or peat) there is no hardpan layer and visa versa; this observation is also confirmed by the data presented by JMM (1988).

In the dry season, the hardpan layer is often found to be unsaturated, suggesting that these layers may play a role in transporting runoff as interflow and possibly into adjacent wetlands during the transition from dry to wet conditions (Hopkins, 1991). Seepage faces on the edges of some wetlands at Jonathan Dickinson and Savannas (identified by saturated soils on relatively steep slopes and the presence of sphagnum) may be evidence of interflow from surrounding flatwoods into the wetlands occurring over the top of hardpan layers.

Sandy clay loam lenses are present in the substrata of many common hydric soils, especially in northern Collier and southern Lee Counties. However, few of the boring logs (Appendix C) from our wetland monitoring well sites show evidence of substantial clay units. The primary exception to this is site FP2 in the Flint Pen Strand, which shows nearly eight feet of clay below about two feet of organic surface soils. Logs from the new Flint Pen Strand wet prairie sites (FP9, FP10) also show evidence of clays and silts, some with considerable organic matter, at less than ten feet depth. Cores taken from auger holes at site FP10 revealed a dark brown sandy loam layer, similar in appearance to hardpan units in Martin County, approximately 12 inches thick at a depth of two feet. The logs from a few other sites show thin zones of very fine sand with clay-sized particles at depths of less than ten feet; others have similar zones at about 20-ft depth, near the transition from the sand to the limestone unit of the surficial aquifer as noted above. Additional recent investigation at sites FP5, FP6, and FP7 found clay layers in the flatwoods and wetland edges at depths of 5 to 8 feet, but not in the depressional wetlands themselves.

Organic surface deposits occur in many depressional wetlands, especially those with relatively long hydroperiods. In most isolated wetlands, organic soils typically take the form of muck or highly organic sands, and occasionally peat. These soils are often assumed to have a retarding effect on wetland drying because of their perceived low hydraulic conductivity. However, few meaningful estimates of hydraulic conductivity are available for organic wetland soils under realistic field conditions (Walser, 1998). University of Florida researchers have recently estimated the "bulk resistance" of muck to water flow at site SV5 to be 10-15 times greater than typical depressional sands (Wise *et al*, 1999). However, when the water table is sufficiently lowered that a moderate downward gradient is present through the wetland substrate, it is unlikely that the presence of an organic soil has any appreciable effect on wetland drying rates or maintenance of surface water.

Most of the muck deposits at our wetland monitoring sites are insufficiently thick to significantly retard seepage or create perched conditions in the wetlands. Muck thickness measured or estimated for each site is given in Table D.1 (Appendix D). It is presumed that muck deposits that are thinner than the rooting depth of the dominant plants do not effectively function as confining layers because penetrating roots create preferential pathways for water flow. Rooting depths for herbaceous wetland plants are typically less than 18 in.; rooting depths for mature cypress may be 50-60 inches (personal observations and Duever, 1990). In Table D.1 it can be seen that only a few marsh sites have muck deposits greater than 18 inches in thickness and only two dome swamp sites have greater than 50 inches of muck.

2.4.3 Soils. Mapped soil units for each study wetland are summarized in Table D.1 (Appendix D). Note that the mapped unit for almost all sites is a depressional sand, regardless of any organic deposits that occur in the center of the depression. Hence, most are classified by Natural Resources Conservation Service (NRCS) according to landscape position as "sand depressions." Most often these organic soil deposits are smaller than the minimum mapping unit used by NRCS (2.5 acres) and are therefore considered "inclusions" in the sandy soils. The information in Table D.1 is supplemented by site-specific information from well borings or measurements of muck thickness (depth to sand). In some cases, the entire study wetland may be smaller than the NRCS minimum mapping unit and was consequently mapped the same as the surrounding flatwoods or mapped as an undifferentiated complex of soils. In such cases, descriptions in the appropriate county soil surveys (USDA, 1979, 1980, 1981, 1984, 1990) and on-site soil cores were used to determine the most likely soil type for the wetland.

2.5 Wetland Topography

The majority of the wetland study sites are shallow bowl-shaped depressions situated within flatwoods of very low topographic gradient. General descriptions of the topography of each study area were given in Section 2.3. Elevations of important topographic features and hydrologic indicators in each wetland depression are summarized in Table G.1 (Appendix G). These elevations were surveyed by project staff using vertical control established previously by District surveyors. Detailed elevation transect and plant community data were surveyed for selected sites in each study area. Transect information is not included in this report, but is incorporated into the stage-duration curves in Appendix H.

Figure 2.7 depicts hydrologically-important topographic elevations associated with depressional wetlands. The wetland bottom elevation is the elevation of the "floor" of the depression and is often the lowest ground elevation in the wetland. As such, it represents the lowest elevation to which the water table can decline and still remain in substantial contact with the wetland ground surface. At some wetlands, alligator holes may extend this potential for contact with the water table an additional two feet or more below the nominal bottom elevation, providing more permanent dry season refugia and deepwater habitat. Although alligator holes may be important in sustaining longer contact with the water table, their total area rarely exceeds more than a small fraction of the total surface area of the wetland depression. For logistical reasons, some of the monitoring stations were not located at the deepest point in the wetland, and consequently the ground elevation at the staff gauge (or equivalently, the bottom of the surface water stilling well) may be higher than the nominal wetland bottom elevation.

At the edge of the wetland depression, the margin elevation is defined here as the ground elevation at the upper "rim" of the depression where the topography flattens out and the plant community changes from predominantly wetland (cypress dome or marsh) to flatwoods. In practice this break in community type is often indistinct, with the communities changing gradually over a broad ecotone up to 100 feet wide, resulting in the need to survey several ground points around the outside edge of the wetland. The average of those elevations is taken as the margin elevation. The margin elevation typically corresponds closely to the average elevation of "normal pool" indicators (e.g., lower edges of moss collars on cypress trees) inside the wetland, suggesting that the wet season water level stabilizes at or near the margin in most years. At some sites, the margin elevation represents the point at which the wetland depression is no longer isolated and becomes connected with other wetlands via sheetflow through the flatwoods. The seasonal high water level (SHWL) shown in Fig. 2.7 and reported for some sites in Table G.1 is taken from the surveyed elevations of indicators such as the upper edges of moss collars or the lower edges of lichen colonies on cypress trees within the wetland. The SHWL is typically only 4 to 6 inches higher than the margin elevation and is likely determined by a drainage divide or similar topographic barrier to flow in the flatwoods. Duever (1990) observed that rate of water level rise in wetlands falls off quickly as natural barriers to flow are overtopped, leading to fairly constant year-to-year maximum water levels.

For the purposes of this report, the total relief (R) of the wetland depression is defined as the margin elevation minus the wetland bottom elevation and is a measure of the depth of the depressional bowl. The total relief is reported for each wetland site in Table G.1 and typically ranges from 1.5 to 3.5 feet. The cypress domes at Flint Pen Strand are situated in relatively deep depressions greater than 2.5 feet in total relief, while the depression marshes in the Savannas study area are the shallowest with total relief typically about 1.5 feet.

3. Methods

3.1 Monitoring Equipment and Setup

Figure 3.1 is a schematic of the monitoring equipment setup at each wetland study site. At each wetland, the monitoring station consists of a 20-ft groundwater monitoring well, an 8-inch diameter surface water stilling well, staff gauge, and platform to facilitate access and support the datalogger housing. This monitoring station is installed at a location considered representative of the main wetland depression, but not necessarily the deepest point of the wetland.

The groundwater wells were installed and sampled by a licensed well driller under supervision of a District geologist. Wells were completed to a nominal depth of 20 feet below ground surface, with actual completion depths ranging from 16 to 24 feet, the approximate depth of the upper sandy portion of the surficial aquifer in most of the study areas. In many cases, limestone or low permeability layers were encountered at or near the nominal depth; in such cases the well was completed to the depth of this layer. If no such layer was encountered prior to reaching 24 feet in depth, the bore hole was backfilled and the well was completed at 20-22 feet. Wells consist of 2-inch PVC casing installed using casing advancement techniques with the aid of a tripod rig hand-carried to the site to avoid disturbance. Wells were screened over the lower 2 feet and the annular space between the casing and the bore hole backfilled with clean silica sand over the screened interval, one foot of bentonite sealant above the sand, and cement grout to the ground surface. The well casing extends 5-7 feet above ground so that the casing rim remains 3-4 feet above seasonal high water. An 8-inch diameter outer casing protects the above-ground portion of the well casing from fire and other hazards; the annular space between the 2-inch and 8-inch casings is also filled with cement grout (EESI, 1997)

Additional groundwater wells were installed near wetlands in some study areas to depths of 60-80 feet to facilitate monitoring water levels in the lower portions of the aquifer in the vicinity of the production zone. These wells were installed and completed in a manner similar to the 20-ft wells described above, except that drilling was accomplished with a truck-mounted rig using mud rotary methods (EESI, 1999).

Water levels in the groundwater wells are sampled using a Design Analysis H3-10 vented pressure transducer with signal input to a Campbell Electronics CR-10 (or CR-10X) data logger housed in a weather-resistant steel box mounted on top of the outer well casing. The data loggers and other electronics are powered by a solar panel mounted on top of the housing in conjunction with an internal lithium battery. Surface water is measured in the stilling well using a float-type sensor with Handar encoder input to the CR-10. Surface water stage can also be checked using a manual staff gauge mounted adjacent to the monitoring platform. All stage elevations are referenced to the National Geodetic Vertical Datum of 1929 (NGVD), and sensors were surveyed in by District electronics support staff utilizing second-order benchmarks installed at each site by District survey crews in 1997. Groundwater and surface water levels are logged by the CR-10 continuously at 15-minute intervals.

Data is downloaded from the data loggers once a month by a field technician who also conducts routine maintenance and calibrates the sensors as needed. Field calibration of surface water compares sensor readings with readings on the Handar encoder, staff gauge, and depth-to-water readings taken with a portable well sounder. Groundwater sensor readings are also calibrated against well sounder readings. Sensor readings that are more than 0.03 ft. different from manual readings are re-calibrated electronically in the field; sensors more than 0.10 ft. out of tolerance or that do not hold a calibration are tagged for repair or replacement. Field maintenance includes cleaning solar panels, replacing batteries (when voltage falls below 11V for more than one month), cleaning the inside of the data logger housing (spiders and ants), and changing dessicant packs in the housing and in the transducer vent apparatus. Upon returning from the field, data is plotted and quality checked, typically within 24 hours of downloading, so that any symptoms of equipment malfunction can be quickly relayed to the Electronic Support and Data Acquisition staff. If necessary, repairs are typically made within one week of notification. Additional quality checking is done by Data Management Division staff when the data is entered into the District's DBHYDRO database.

One weather station was established in each study area. Weather station locations were selected which were representative of the study area, relatively well protected from possible vandalism, and which best satisfied standard District siting criteria for the different sensors. Instruments are mounted at various heights on a 10-meter tall tower, and sensor readings are logged continuously at 15-minute intervals by a CR-10 data logger (except for rainfall, which is logged at 5-minute intervals during an event and totaled on a daily basis). The solar panel and data logger housing for the weather stations are similar to those used at the wetland monitoring stations. Like the wetland stations, data from the weather stations is downloaded in the field monthly, and rainfall data is plotted and quality checked within 24 hours of downloading. Table E.1 (Appendix E) summarizes sensor specifications and hydrologic and weather parameters monitored at each station.

3.2 Equipment Problems

Electronic malfunctions caused data gaps at various times since the initiation of data recording in spring 1997. In the first six months following site initiation, there was a nearly 70% failure of the Design Analysis H3-10 pressure transducers used for monitoring groundwater stage. These failures were caused by defective chips in a specific lot of transducers manufactured prior to 1997. Resulting data loss ranged from several days up to two weeks at affected sites. Failures were detected either in the field during monthly downloading or during initial data screening. The defective sensors were replaced by District electronic support personnel.

The original electronic configuration of the sites used CR-10 dataloggers and SM-192 data storage modules. After upgrades in early 1998 to the CR-10X datalogger, data collection and recording problems were noted. Problems with compatibility between the CR-10X and the SM-192 caused duplicated blocks of previously collected data to be inserted at inappropriate intervals, which resulted in loss of data of up to 20 days at some sites. This situation was corrected by removing the SM-192 module, as the CR-10X datalogger is designed to function without an additional storage module.

Additional sporadic problems have been caused by lightning strikes at or near the recording sites. At weather stations, lightning strikes have caused failures of rain gauges and ultrasonic wind sensors. These problems were corrected by replacing the damaged component. Strikes at the wetland sites have on occasion caused power surges that resulted in resetting of stage reference values to zero, without loss of data. This problem was easily corrected by reprogramming the reference values in the field and by adding the appropriate constant to the data during processing.

4. Wetlands Classification System

A classification system for wetlands previously proposed by the SFWMD Regulation Department is introduced (and refined) here as a construct for organizing the results of hydrologic monitoring and analysis and recommendations for wetland protection criteria. The classification scheme, like other such systems in common usage, assumes that differences in wetland processes and functions are reflected as differences in hydrology, soils, and dominant plant communities. A wetland classification scheme based on geomorphic setting and plant community was developed by Bernáldez *et al* (1993) to assess adverse impacts caused by long-term groundwater extraction in the Douro River basin of Spain.

Three wetland categories, designated Types 1, 2, and 3, will be used here as shown below in Table 4.1. The three categories correspond well to three broad categories of hydrologic descriptors used in the U.S. Fish and Wildlife Service classification scheme (Cowardin *et al*, 1979) and the soil landscape position descriptors used by the Natural Resources Conservation Service (Zahina *et al*, 1999). Table 4.1 gives typical natural wetland communities from the Florida Natural Areas Inventory included in each of the three wetland types. As will be seen in subsequent chapters, the classification system is useful in delineating differences in hydrologic regime and important hydrologic parameters, including hydroperiod, timing of wetting and drying, wet season water depth, depth to dry season water table, ecosystem dependence on water table position and responses to drying.

Table 4.1 – Wetlands Classification System

Category	**Type 1**	**Type 2**	**Type 3**
Hydroperiod[1,2]	Permanent or usually inundated	Semi-permanent or seasonally inundated	Temporarily or occasionally inundated (short hydroperiod)
Typical Wet Season Water Depth	> 2 ft.	1.0-2.0 ft	< 1.0 ft
Community[2]	Lakes, sloughs, ponds (including centers of depressional wetlands)	Dome swamp, depression marsh	Wet prairie, wet flatwoods (including outer edges of depressional wetlands)
Soils	Peat or sand	Sand often with muck deposits	Sand, marl
Landscape Position[3]	Water	Sand Depression, Muck Depression	Slough (Flats) Soils, Flatwood Soils
FLUCCS Land Cover Codes[4]	500's, 644-645	611-617, 621, 630, 641, 646	311, 400's, 618, 622, 624, 625, 643, 653

[1] Based on U.S. Fish and Wildlife Service hydrologic modifier, Cowardin et al (1979)

[2] Based on Florida Natural Areas Inventory natural community types

[3] Based on Natural Resources Conservation Service natural soil landscape position (Zahina *et al*, 1999)

[4] Florida Land Use Cover and Forms Classification System (Florida Department of Transportation, 1999)

Type 1 wetlands include lakes, deep sloughs, and ponds that typically contain some standing water all year, including during drought. Some of these systems may not satisfy the definition of an isolated wetland and may be permanently connected to streams, canals, or other perennial bodies of water. These wetlands are characterized by deep water (often sustained by large amounts of water storage or connections to deeper portions of the aquifer), open water or floating-leaved aquatic habitat, and long hydroperiods (Schiffer, 1998). Relatively few such wetlands are found outside the Everglades in south Florida, but Type 1 sinkhole lakes are common in northern parts of the District. Some deep ponds and alligator holes in the center of depressional wetlands (e.g., cypress domes) may also be categorized as Type 1 wetlands.

Type 2 wetlands are probably the most common and easily recognizable isolated wetlands in south Florida, and comprise the majority of our monitoring sites. These are archetypal depressional wetlands such as dome swamps and depression marshes with seasonal hydrologic regimes and intermediate hydroperiods and water depths. Type 2 wetlands are typically situated in sand depressions, either with or without muck deposits. Seasonal strand swamps might also be considered Type 2 wetlands.

Type 3 wetlands are short hydroperiod wetlands on topographic flats or at the outer margins of depressions. Many have become isolated wetlands only as a result of landscape fragmentation, and substantial acreage of this wetland type has been lost to development and drainage (Mazzotti *et al*, 1993). Plant communities in Type 3 wetlands are characteristically adapted to seasonal dry spells or alternating periods of wet and dry.

In this study, individual wetland depressions are often seen to include all three wetland types at a single site (Fig. 4.1). Most of the study sites are predominantly Type 2 wetlands, with the majority of each wetland depression consisting of dome swamp or depression marsh communities. At many sites, a fringe of Type 3 wetland prairie is found at or above the margin elevation, and some sites are surrounded by extensive wet prairies or wet flatwoods. Deep ponds or alligator holes categorized as Type 1 wetlands are found at the centers of some sites, most notably those in the Flint Pen Strand study area.

The three categories described above include the most common wetland types comprising the vast majority of isolated wetlands within the boundaries of the District. Wetland cover categories from the Florida Land Use Cover and Forms Classification System (FLUCCS) were each assigned to one of the three wetland types discussed here (Table 4.1). In the Lower West Coast planning area, Type 1, 2, and 3 wetlands comprise approximately, 4%, 81%, and 15%, respectively, of total freshwater wetland acreage, based on 1995 land use/land cover information (SFWMD, 1999). Rare or geographically restricted wetlands (e.g., baygalls, rockland depressions) or wetlands not included in the scope of this report (e.g., hydric hammocks) may have hydrologic regimes and other characteristics that are different from those of the Type 1, 2, and 3 wetlands described above and therefore should not be placed in one of these categories for convenience.

5. Results

5.1 Rainfall

Seasonal Rainfall and Climate. The climatic conditions for the period of record covered in this report can only be characterized as unusual. The 1997-98 seasons were dominated by weather and rainfall patterns that were linked to the very strong El Niño and La Niña events during the same period. Strong El Niño events are correlated with above-average rainfall in south Florida from November to March, while La Niña events are typically correlated with a dry winter (SFWMD, Operations and Maintenance Department, 1999). The result of these patterns was a very wet winter from November 1997 through March 1998 producing high water conditions in the wetlands that closely resembled the wet season, followed by a very dry spring and early summer beginning in April 1998.

Comparison of observed seasonal rainfall totals for 1997-98 with SFWMD historical rainfall sources shows a near-reversal of typical annual rainfall distribution at most sites, with below-average wet season totals and above-average dry season totals (Table 5.1). Above average rainfall totals were observed at all sites for the 1997-98 dry season. Return periods of these above-average totals is estimated to be from 5 years (Disney Wilderness) to as much as 100 years (Flint Pen) (based on Scully, 1986). By contrast, all sites recorded below-average rainfall during the 1998 wet season, with return periods ranging from 2 to 25 years. Annual rainfall totals for 1998 were near normal for Savannas and Disney Wilderness Preserve and above average for the Flint Pen Strand and Jonathan Dickinson study areas. Duever (1990) found that average annual wetland water levels in south Florida were not significantly correlated with annual rainfall totals, but that average wet season and dry season water levels are strongly correlated with wet season and dry season rainfall, respectively.

In this report, the wet season is defined as the five-month period from June 1 to October 31 and the dry season is the seven-month period beginning November 1 and ending May 31, consistent with Scully (1986). Note that this wet season definition is one month out of synchronization with the Atlantic tropical storm/hurricane season which is officially considered to begin June 1 and end November 30. In 1998, a late season tropical storm (Mitch) moved across the southern part of the District in early November, and at most sites this event represents the majority of the rainfall recorded during that month. Although not considered as part of the 1998 wet season here, this event contributed significantly to the amount of water in the wetlands going into the 1998-99 dry season. As a result of heavy rainfall produced by Mitch, total rainfall for the 1998-99 dry season was near normal at three of four study areas, despite several months of extremely dry weather recorded from February to May 1999. Dry season rainfall at the Disney Wilderness Preserve was substantially below average, continuing a trend of below average rainfall that began in April 1998.

Table 5.1 – Wet and Dry Season Rainfall 1997-99

Study Area	**Flint Pen Strand**	**Savannas**	**Jonathan Dickinson**	**Disney Wilderness**
1997 Wet Season Rainfall (in)	N/D	25.34 * (- 6.76)	N/D	17.38 * (-12.12)
1997-98 Dry Season Rainfall	30.86 (+14.96) *100-yr high*	25.58 * (+ 7.48) *5-yr high*	30.60 * (+12.50) *10-yr high*	28.31 (+10.21) *10 to 25-yr high*
1998 Wet Season Rainfall	34.01 (- 2.79)	24.69 (- 7.41) *5 to 10-yr low*	22.93 (- 9.17) *10 to 25-yr low*	24.35 (- 5.15) *5-yr low*
1998 Annual Rainfall	**64.36 (+11.76)** *10-yr high*	**47.58 * (- 3.12)**	**57.78 (+ 7.08)** *5-yr high*	**45.43 (- 2.97)**
1998-99 Dry Season Rainfall	14.56 (-1.34)	17.54 (-0.56)	23.72 (+ 5.62)	12.46 (- 5.64)

Note: values in parentheses are amounts (inches) above (+) or below (-) long-term average seasonal totals reported by Scully, 1986.

N/D:	Insufficient data to estimate total seasonal rainfall
*	Some data missing, but sufficient to estimate seasonal totals and return periods

Daily Rainfall Patterns and Storm Events. Plots of daily rainfall recorded at the four project weather stations (FPWX, SVWX, JDWX, WRWX) for 1997-98 are presented in Appendix F. Also included in Appendix F are cumulative daily rainfall plots for each weather station and monthly rainfall totals (Table F.1) obtained from the DBHYDRO database.

No large regional rainfall events affected the District during the 1997 wet season, a period notable for the lack of tropical weather systems affecting south Florida. Nevertheless, each study area experienced one or more spells of wet weather with rains of 5-7 inches over several days, and adequate summer rainfall kept wetlands near seasonal high levels throughout the summer until October. El Niño winter rain events associated with cold fronts occurred regularly from November 1997 through March 1998. These rain events typically produced 1 to 4 inches of rain at the study sites over a 1 to 2 day period every 7-10 days or so throughout the winter. After March 1998, dry conditions prevailed through June or even July in some locations, delaying the normal start of the wet season.

Major regional rainfall events in 1998 occurred September 14-21 when a tropical wave produced as much as 10 inches of rain at some sites and November 4-5 when Tropical Storm Mitch moved across south Florida producing 6-8 inches in two days. Neither of these major rainfall events substantially affected the Disney Wilderness Preserve study area (less than 3.5 and 2.3 inches were recorded there during the September and November events, respectively), giving little relief from drier than average conditions that had prevailed there since at least April 1998.

Dry Periods. Because existing wetland drawdown stress criteria used in water use permitting and water supply planning are evaluated under simulated drought conditions (90-day No-Recharge period or 1-in-10 year low rainfall), verifying the hydrologic behavior of wetlands under real dry conditions is of utmost interest. Although the 1997-98 period of record was not especially dry overall, portions of each year were drier than average, and, as described above, the 1998 wet season rainfall approached 25-year low return period at one site.

Comparing observed rainfall totals at the study sites with the monthly average rainfall, one could identify one or more months at each study area during 1997-98 that were substantially drier than average (see Table F.1, Appendix F). These months tended to occur during the seasonal transitions early (June-July) and late (September-October) in the wet season. Jonathan Dickinson and Disney Wilderness Preserve experienced runs of three and four months at a time with below-average rainfall during the spring and summer of 1998. In 1998, peak cumulative rainfall deficits occurred in October for Savannas, Jonathan Dickinson, and Disney Wilderness Preserve sites. Not surprisingly, these dry months corresponded to periods of drying in the wetlands.

Substantially below-average rainfall was recorded at all sites during each month from February to May 1999, with cumulative deficits during this period ranging from 3 to 5 inches below normal. Although this total deficit is less than the average rainfall for some summer months, even small deficits in the spring can result in prolonged dry spells, causing stress to natural plant communities (Chen and Gerber, 1990). During this period, the number of recorded rain days (days with rain > 0.1 inch) averaged only 1-2 per month, and some of the study areas experienced dry spells approaching forty days in length. In April, the District declared water shortage conditions and implemented Phase 1 water use restrictions for parts of the lower west coast, including Lee County, and Martin and St. Lucie Counties were designated as "Areas of Concern." By mid-May, groundwater levels in key indicator wells in the lower west coast were at record low levels (SFWMD, Water Resources Evaluation Dept., 1999). Comprehensive analysis of data from this period has not yet been completed. However, minimum water table elevations observed in our wetland wells as of the publication date are reported in Section 5.4 and summarized in Table G.1 (Appendix G).

5.2 Wetland Hydropatterns

5.2.1 Water Level Plots. Water level plots for surface and groundwater for the period of record at each site are shown in Appendix G. The plots were constructed from daily average water level data taken from the DBHYDRO data base from spring 1997 through December 31, 1998. Water level recording began at different times from February through May 1997 depending on the date the instruments were installed in each study area. Missing data, typically caused by sensor or datalogger failure (see Section 3.2), are shown as gaps. Important topographic elevations, including SHWL, margin, wetland bottom, and ground elevation at the staff gauge are shown on the water level plots. Total annual variation of the water table ranged from 1.75 ft. (JD6, 1998) to 7.2 ft (FP2, 1997) with typical values for unimpacted sites of 2.5-3.0 ft. These figures give some idea of the range of annual water level variation to which the wetland ecosystem is adapted.

It can be seen in the plots that the surface water and groundwater track each other closely throughout the period of record. Pearson correlation coefficients between daily surface water and groundwater data at each site over the period of record are extremely high, ranging from 0.912 (FP6) to 0.990 (JD26). These values were computed with all data, including dry periods in which no surface water was recorded but groundwater continued to vary; removing these dry periods from the calculation would presumably increase the correlation. Analysis of the original water level data recorded by the data loggers at 15-minute intervals gave similarly high correlation coefficients for the period of record. Such high correlation at such fine time scales (daily, 15-minute) is indicative of a high degree of communication between surface water and groundwater as would be expected of a sandy wetland-aquifer system with only small amounts of water storage above the ground surface. However, selected one-month periods of 15-minute data at certain sites gave much lower correlation, especially in some transitional months (e.g., June) when surface water was relatively low and ET effects in the groundwater overshadowed surface water variation.

At some of the wetland sites, the plot of groundwater level is virtually indistinguishable from surface water (e.g., SV6), while in other sites separation is evident between surface and groundwater (e.g., SV1, WR8). When surface water in the wetland is consistently higher than the underlying groundwater head, the wetland is considered a groundwater **recharge** wetland (Mitsch and Gosselink, 1993, Winter, 1988) due to the potential for downward (or lateral) movement of water into the aquifer. Conversely, when groundwater heads are higher than wetland surface water levels, it is considered a **discharge** wetland, indicating the potential for groundwater movement into the wetland. Doss (1993) and other researchers have demonstrated that many wetlands fluctuate between recharge and discharge conditions in response to seasonal changes in rainfall, evapotranspiration, and water table position. Most of the wetlands monitored for this study consistently exhibit some potential for recharge, as evidenced by groundwater heads from a few inches to more than a foot less than surface water stages. These conditions are especially evident during drying periods.

Wetlands in which the surface water is consistently higher than the underlying groundwater are often assumed to be perched above an impermeable confining layer. Such separation indicates that a downward head gradient exists, likely the result of a low-permeability layer, but does not confirm that the wetland is truly perched. If the separation is large and groundwater fluctuations are independent of surface water fluctuations, then the possibility of a relatively impermeable confining layer might be inferred. However, when the groundwater closely tracks the surface water as is the case with our study sites, a high degree of connection between the wetland and groundwater is indicated, even when measured surface water is higher than the groundwater head. Despite substantial surface water-groundwater separation in the water level plots of sites WR8 and SV1, no distinctive confining layers can be identified from the well boring logs and standard penetration test (SPT) data from these sites (Appendix C). Additional study will likely be required at these sites to confirm whether confining layers are indeed present and, if so, what role they are playing in sustaining wetland hydrology and maintaining separation between surface and groundwater.

When surface water is consistently higher than groundwater, this is sometimes indicative of geologic conditions (e.g., high-permeability shell beds) or external features (e.g., pumping wells, lakes, canals) that accelerate the movement of groundwater away from the wetland faster than surface water can percolate down through the wetland substrate. Duever (1990) provided similar explanations for several cases of surface water-groundwater separation observed at the Corkscrew Swamp Sanctuary and observed that apparent cases of perched water tables most often reflected transient conditions.

In a few cases, groundwater heads are observed to be higher than surface water levels, indicating that groundwater discharge may be occurring. Such conditions are typically short-lived and usually occur after heavy rainfall during early summer when the water table is rising. Transient discharge conditions lasting from a few days to a few weeks are most evident in the data from the Flint Pen Strand wetlands.

Descriptions of wetland water level variation summarized by study area and site are given below.

5.2.2 Flint Pen Strand. The hydropatterns of the Flint Pen dome swamp sites during the period of record are characterized by prolonged inundation with extended periods of hydrologic connection between the sites, relatively short dry periods, and often dramatic water level changes at the start of the wet season. At the beginning of the wet season in June 1997, surface water at site FP5 (which is representative of all of the dome swamp sites here) rose 2.4 feet from ground surface to above the wetland margin in only 8 days. Similarly dramatic water level changes were observed in late November 1997 at the beginning of the El Niño rains, but rewetting at the beginning of the 1998 wet season was more gradual, occurring over a period of almost two months. The extent of hydrologic connection throughout the study area during the period of record can be inferred by the relatively high proportion of stage observations above the margin elevations of the depressional wetlands; e.g., 53% of all daily surface water observations at FP5 during 1997-98 were above the margin. Dome swamp sites exhibited remarkable consistency in peak water levels from wet period to wet period.

Surface water patterns at Flint Pen sites FP3-FP8 are remarkably similar, with few obvious differences evident in the water level plots from site to site. In Fig. 5.1, surface water elevations at the Flint Pen sites are standardized by subtracting the margin elevation of the wetland from each observation. This standardization technique is similar to the procedure used by Winchester *et al* (1987) and accounts for differences in ground elevation across the study area. The vertical axis of the graph is interpreted as the elevation of the wetland surface water relative to the elevation of the margin, where zero on the axis is the margin elevation, positive numbers are elevations above the margin and negative numbers are elevations below the margin. The standardized plots confirm the high similarity among the sites, especially during the wet season (and the wet dry season of 97-98), indicating that regional processes (groundwater and regional sheetflow patterns) dominate the wetland hydrology. Higher inter-site variability is evident during the 1998 dry season, suggesting that site-specific processes may significantly influence wetland hydrology when the water table is low. These observations are consistent with the findings of Winchester *et al* (1987), Duever (1990), and Crownover *et al* (1995) for wetlands in similar settings in southwest and north-central Florida.

In Fig. 5.1, the plot for site FP2 is the obvious exception to the observations noted above. This site, which is suspected of being impacted by groundwater drawdown from the adjacent well field, exhibits shorter hydroperiods, longer dry spells, and faster and more severe drying than the other sites at Flint Pen. Despite this, FP2 consistently reaches the wetland margin during the wet season. Total relief at FP2 is 2.6 feet compared to an average relief at FP3-FP8 of about 3.0 feet (Table G.1, Appendix G). Further discussion of possible impacts at this site and implications of those findings are discussed in Section 6.4.

Measured groundwater heads frequently are above surface water stages at the Flint Pen sites, indicating that potential for groundwater discharge into the wetland may exist at such times. Most of these instances occur immediately after heavy rainfall and are often accompanied by dramatic spikes in surface and groundwater. These water level spikes are short-lived, usually beginning to decline back to pre-rainfall levels within a day after the rain occurred. As water levels decline following the spikes, groundwater head converges with the wetland surface water stage until the next rain event. These observations suggest that the temporary head reversals are produced by mounding of groundwater following rainfall. Groundwater discharge conditions are dissipated as the groundwater mound quickly redistributes across the upper portions of the aquifer.

5.2.3 Disney Wilderness Preserve.

All six wetlands monitored in the Disney Wilderness Preserve exhibited similar patterns of water level variation due to generally common rainfall patterns across the study area. However, the most notable observations regarding these sites are the distinct differences in the hydropatterns of the three marsh sites (WR6, 8, 9) from those of the three dome swamp sites (WR11, 15, 16), especially during 1998. All marsh sites sustained some standing water through the period of record, with only short periods of complete drying, if any, since the end of the spring 1997 dry season. The marsh sites, especially WR8 and WR9, retained a considerable amount of water during 1998, particularly during and after the winter El Niño rains. Nevertheless, wet season water levels at these sites during 1997 and 1998 barely achieved typical wet season highs, most likely the result of persistent below-average rainfall during those seasons.

The large separation between surface water and groundwater seen at WR8 (average 1.7 ft. over the period of record) superficially suggests the possibility that subsurface confining layers may be playing a role in sustaining the hydrology of this site. However, no such layers have yet been detected, and high correlation (0.92) between daily surface water and groundwater at WR8 is indicative of strong hydrologic communication between the two. More detailed analysis of local topography, geology, and local groundwater flow patterns will be needed to gain further insight on the causes of the large separation at this site.

Compared to the marsh sites, dome swamps WR11, 15 and 16 have been very dry since the end of April 1998 with almost no standing water present even during the wet season. Surface and groundwater levels at these sites during the El Niño winter were consistent with "normal" wet season levels. However, following the cessation of El Niño rains, the water table dropped rapidly, and standing surface water disappeared by the first part of May 1998. The decline in surface and groundwater during March and April was much more rapid than declines experienced at the marsh sites during the same period. After April standing water was measured at WR15 and WR16 only for brief periods following rainfall when the water table temporarily rose to the ground surface. The dome swamp sites show much closer correspondence between surface water and groundwater than the marsh sites; indeed surface water and groundwater are essentially the same at the dome swamps during the period of record.

Comparison of rainfall from WRWX and several gauges maintained by the Nature Conservancy in different parts of the Preserve (including one adjacent to marsh site WR6) (TNC, 1999) suggest that there is no significant difference in the amount of rainfall measured in different locations over the periods of interest. This not only rules out spatial differences in rainfall as an explanation for the differences between marsh and dome swamp hydrology, but also validates the use of WRWX as being representative of rainfall at all of the monitored sites. Given the different landscape settings and patterns of surface water-groundwater separation between the marsh and dome swamp sites, it is possible that there may be a geological explanation for the different hydropatterns observed among the two groups of sites. Nevertheless, all sites (marshes and dome swamps) exhibited signs of considerably reduced wet season water levels and hydroperiods in 1998. The entire study area experienced more severe rainfall deficits than the other study areas monitored for this project, and the effects of the 1998 drought were probably more pronounced here than in southern parts of the District.

5.2.4 Savannas Preserve.

The Savannas sites exhibited considerable differences in the amount of time surface water levels were above the margin elevation. At site SV1 in St. Lucie Co., 76% of daily water level observations through the period of record were above the margin, and this site never dried completely to the wetland bottom. Consistent high separation between surface and groundwater of about 1.5 ft. is observed at SV1, but correlation between surface and groundwater is also very high at 0.95.

Two of the three Savannas sites near Jensen Beach showed subtle signs of drawdown impact. A poss' drawdown gradient exists in this area due to relatively low surface water control elevations in some of the residential communities immediately south of the preserve and at certain times due to pumping from Martin County Utilities (MCU) production wells located along Jensen Beach Blvd. Figure 2.3 shows the proximity of sites SV4, 5, and 6 to these possible sources of drawdown. Hydroperiods are shorter at sites SV4 and SV5 than at SV6 (and SV1), and drying rates at the former sites are among the highest of any of the twenty study sites monitored for this project. Surface water levels equaled or exceeded the wetland margin 27% and 33% of the period of record at SV4 and SV5, respectively. Neither site retained much water above the margin during the 1998 wet season. Both of these sites exhibit some separation between surface and groundwater, particularly during periods of drying. By contrast, 42% of the daily water levels at SV6 were above the wetland margin, and groundwater is essentially the same as surface water throughout the period of record.

No instances were observed in the daily data where groundwater head exceeded surface water head at these sites, except for a short period in August 1997 at site SV5 where surface water is seen to decline abruptly. This occurrence is the result of a Wetland-Aquifer Interaction Test (WAIT) conducted jointly by the District and researchers from the University of Florida-Gainesville. The WAIT involves pumping surface water from the wetland until the surface and groundwater heads are reversed and then studying the characteristics of surface water recovery. Details of the WAIT methodology and results are given in Walser (1998) and Wise *et al* (1999).

Figure 5.2 shows 15-minute surface and groundwater data from the SV5 monitoring station during the pumping and recovery periods. Pumping took place during the 9-hour period on August 19 when surface water was lowered approximately one foot from 13.94 ft. to 12.93 ft. As seen in the figure, the pumping reversed the vertical head difference from approximately 0.10 ft in the downward direction (i.e., surface water higher than groundwater) to approximately 0.60 ft in the upward direction (i.e., groundwater head higher than surface water). Groundwater head at 20-ft depth decreased approximately 0.25 ft. during the pumping period, indicating strong communication between surface and groundwater. Groundwater wells at shallower depths installed by UF researchers showed head drawdowns between 0.25 and 1.0 ft., depending on depth of the well (Walser, 1998). Recovery of surface water occurred over a period of approximately 10-14 days following cessation of pumping; pre-test head differences were re-established in about 14 days. Analysis of UF and SFWMD well data during the recovery period indicates that wetland surface water was replenished primarily by lateral groundwater flow as the water table redistributed in response to the new head gradient (Walser, 1998). During the recovery period, rainfall was negligible except for a thunderstorm producing 0.75 in. at SVWX that occurred on August 25. Diurnal oscillations seen in the groundwater plot in Fig. 5.2 are caused by tidal fluctuations in the nearby Indian River Lagoon.

5.2.5 Jonathan Dickinson State Park.

All three sites in the Jonathan Dickinson study area exhibit similar hydropatterns despite different soils and wetland communities. Between-site correlation of daily 1997-98 surface water levels is high, with correlation coefficients varying between 0.77 and 0.97 inversely with distance between sites (Table 5.2).

Table 5.2 Between-Site Surface Water Correlation

Sites	Correlation Coefficient	Distance (mi)
JD6-JD12	0.77	2.00
JD12-JD26	0.85	1.65
JD6-JD26	0.97	0.50

Standardized surface water levels for these sites are shown in Fig. 5.3. Standardization was performed in the same manner as Fig. 5.1 (see Section 5.2.2). Such high similarity of surface water levels over a large spatial area again indicates that the regional water table is strongly influencing the hydrology of these sites. The main differences between the standardized water levels occurs from June-September 1998, when the departure from the margin elevation was much greater at JD6 and JD26 than at JD12.

Dramatic swings in groundwater elevations are observed in the Jonathan Dickinson sites as a result of water table mounding and redistribution after rainfall. Relatively long hydroperiods and shallow water depths are recorded at all three sites, with longest hydroperiods observed at JD12. There is a moderate amount of separation between surface water and groundwater at all sites, but within-site correlation between surface water and groundwater is extremely high, ranging from 0.94 to 0.99.

5.2.6 Stage-Duration Curves. Stage-duration curves were prepared for the 1998 calendar year for sites with adequate topographic and plant community data (Appendix H). These curves were prepared from the same daily surface water data used to prepare the water level plots in Appendix G less any gaps resulting from missing data. Where ground elevations were available from transect data, approximate plant community zone boundaries are delineated on the graphs. Stage-duration information was computed by constructing a frequency histogram for each site of the number of days in the year in which the surface water stage fell within pre-defined 0.50 ft. or 0.25 ft stage intervals encompassing the entire range of variation. The resulting frequency histogram was then summed over its range to create a cumulative frequency histogram. The cumulative histogram was inverted and graphed to produce the stage-duration curves. Stage-duration curves were not prepared for the 1997 calendar year because less than one year of daily data was available for 1997, making interpretation of these curves and comparison with 1998 data very difficult.

Each point on the stage-duration curve represents the number of days during the year that the wetland surface water equaled or exceeded a given stage elevation. This information can be used to estimate the total length of time a location in the wetland (or a plant community zone) was inundated during the year. In most years (where the wet season is contained entirely within the calendar year) this duration would be equivalent to the **hydroperiod** of the plant community. However, the El Niño wet period that began in November 1997 and ended in March 1998 resulted in the 1998 calendar year containing two distinct "wet seasons," each separated from the other by a period of drying. Some definitions of hydroperiod assume the duration of inundation is continuous, which would not be the case for some of the durations indicated on the curves, particularly for plant communities located on higher ground near the wetland margin. Although interpretation of the 1998 curves is complicated by the El Niño event, the calendar year format is consistent with the normal wet-dry season dynamics and will facilitate comparison with stage-duration information in subsequent years.

Table 5.3 summarizes the total observed days of inundation for the delineated plant communities at each site taken from the stage-duration curves in Appendix H. The table compares the observed range of inundation in 1998 with more generic values reported for similar communities in SFWMD (1995). The reported values were compiled from the literature and are derived from studies of wetland plant communities in south Florida for which at least five years of hydroperiod data were available. Although at least part of the observed range of hydroperiods falls within the reported range for each community, most of the observed values are on the wet side of the reported values and many exceed the upper limit of the reported range. These communities are designated as "wet" in the table. The majority of the communities shown in the table are so designated, as would be expected for sites that experienced, in effect, two "wet seasons" during the 1998 calendar year. The exceptions to this include the two Flint Pen Strand sites, which were about normal relative to reported values, and site WR15 at the Disney Wilderness Preserve, which was abnormally dry during the 1998 summer wet season.

Table 5.3 - Duration of Inundation from 1998 Stage-Duration Curves

Site	Community or Zone	Observed Range of Inundation	Reported Range of Inundation*	Wet/Dry
JD12	Pine Flatwoods	0-110 days	0-75 days	Wet
	Hypericum	110-360 days	50-150 days (Wet Prairie)	Wet
	Panicum-Pontedaria	360+ days	210-280 days (Marsh)	Wet
JD26	Pine Flatwoods	0-120 days	0-75 days	Wet
	Hypericum	120-280 days	50-150 days (Wet Prairie)	Wet
	Dwarf Taxodium	280-350 days	120-365 days (Cypress Prairie)	Wet
	Taxodium	350-365 days	150-365 days (Cypress Dome)	Wet
SV4	Pine Flatwoods	0-115 days	0-75 days	Wet
	Hypericum-Amphicarpum	115-235 days	50-150 days (Wet Prairie)	Wet
	Lachnanthes-Cephalanthus	235-355+ days	45-275 days (Shallow Marsh)	Wet
SV5	Pine Flatwoods	0-155 days	0-75 days	Wet
	Hypericum-Xyris-Woodwardia	155-315 days	50-150 days (Wet Prairie)	Wet
	Panicum	315-365 days	210-280 days (Marsh)	Wet
FP2	Pine Flatwoods	0-50 days	0-75 days	Normal
	Schinus	50-220 days	0-180 days**	Normal
	Taxodium	220-235 days	150-365 days (Cypress Dome)	Normal
	Hymenachne-Thalia	235-365 days	210-280 days (Marsh)	Normal
FP6	Pine Flatwoods	0-30 days	0-75 days	Normal
	Hydric Flatwoods	30-265 days	N/A	N/A
	Taxodium	265-360 days	150-365 days (Cypress Dome)	Normal
	Open Pond	360-365 days	310-350 days (Open Pond)	Normal
WR6	Pine Flatwoods	0-40 days	0-75 days	Normal
	Hypericum-Amphicarpum	40-295 days	50-150 days (Wet Prairie)	Wet
	Panicum-Pontedaria	295-330+ days	210-280 days (Marsh)	Wet
WR15	Pine Flatwoods	0-60 days	0-75 days	Normal
	Taxodium-Woodwardia	60-130 days	150-365 days (Cypress Dome)	Dry
	Open Pond	130-365 days	310-350 days (Pond)	Dry

* Source: SFWMD (1995), Figure 4: Summary of Hydroperiod Ranges for Various Plant Communities within the Lower West Coast Planning Area

** Source: Shaw and Moore (1996)

5.3 Wet Season Hydrology

Relevant aspects of the observed wet season hydrology, including the timing and nature of summer rewetting, the relationship between wet season water levels and topography of the wetland depression, and typical hydroperiods and water depths, are summarized in this section. Table 5.5 provides a summary of the wet season hydrologic regime for each of the wetland types.

Rewetting. For wetlands that dry out seasonally, the timing and nature of summer re-wetting are important influences on ecological functions such as primary productivity, plant phenology, emergence and recruitment of aquatic invertebrates, dispersion of fish, and foraging potential for wading birds. The timing and rate of re-wetting depends on the amount and intensity of rainfall in early summer, the degree of connection between the wetland and other sources of surface water, and the depth to the water table at the end of the dry season. Of these factors, the water table depth is the most critical to the timing of re-wetting and is also the most readily influenced by groundwater drawdown.

Standing surface water can be sustained in a wetland only after the water table reaches the ground surface, or sufficiently near the ground surface that the soils above the water table are essentially saturated. When the water table at the end of the dry season is within a foot or so below the wetland bottom, re-wetting occurs very soon after summer rains begin, and rates of re-wetting can be quite rapid. When the water table depth is greater than a foot, a substantial portion of the rainfall that occurs early in the summer goes into replenishing available pore space in the uppermost part of the aquifer, and re-wetting may not occur until the mid- or late-June. When the dry-season water table is very low, due to groundwater pumping, surface drainage, or prolonged drought, re-wetting may be significantly delayed or may not occur at all. Minimum dry-season water table depths of 4 to 6 feet below the wetland bottom at site FP2 in the Flint Pen Strand consistently lead to delays of 2 to 4 weeks in re-wetting compared to other sites in the same study area. Changes in hydrology at FP2 caused by groundwater withdrawal from the adjacent Corkscrew Wellfield are discussed in detail in Section 6.4. At some sites in the Disney Wilderness Preserve, re-wetting did not occur at all during the 1998 wet season as a result of persistent low water table elevations and below-average rainfall caused by drought.

Timing of re-wetting for the study wetlands is summarized by wetland type in Table 5.4. Re-wetting of the Type 2 zone at each site is assumed to occur when surface water is sustained above the wetland bottom elevation. For the Type 3 zones, re-wetting is assumed when the wetland stage is sustained above the margin elevation. In most cases, re-wetting of Type 3 zones occurred 3-5 weeks after re-wetting of the adjacent Type 2 zones. Re-wetting at all sites occurred later and the length of time for stages to reach the margin elevation were much longer in 1998 than in 1997 due to below average wet season rainfall.

Table 5.4 – Timing of Re-wetting

Study Area	**1997**		**1998**	
	Type 2	**Type 3**	**Type 2**	**Type 3**
Flint Pen Strand[*]	Late June	Early July	Mid-July	Early August
Site FP2	*Late July*	*Mid-August*	*Early August*	*Mid-August*
Disney Wilderness	Mid-June	Early August	N/A[1]	N/A[2]
Savannas	Mid-June	Early July	Late July	Mid-September
Jonathan Dickinson	N/A[1]	Early June	N/A[1]	Mid-September

[*] Not including site FP2

[1] Zone did not dry out during the preceding dry season

[2] Zone remained dry throughout wet season

During the wetting period early in the rainy season, the response of the wetland surface water stage to rainfall is similar to the groundwater response and is typically much greater than the recorded rainfall depth. For example, during a one-inch rainfall event, the surface water level in the wetland and in the underlying groundwater may rise 5-7 inches. This response may be due in part to interflow (subsurface runoff) entering the wetland from surrounding upland areas. However, potential contributing areas for interflow are in most cases relatively small compared to the size of the wetland. In some cases, such as many of the Flint Pen Strand sites, sheetflow from surrounding wet prairies also contributes significantly to the water entering depressional wetlands during wet periods. Most importantly, such rainfall response in wetlands reflects the response of the groundwater, where because of porosity effects, large fluctuations in the water table elevation can result from relatively small amounts of rainfall. This suggests that the increase in the wetland surface water stage during a rain event is in large part due to the re-distribution of the water table in response to infiltrating rain water and is indicative of the control exerted by groundwater on wetland hydrology.

Wet Season Water Level Envelope. Based on analysis of the monitoring data, some general statements can be made about wet season water levels in depressional wetlands. Given sufficient rainfall, wet season water levels appear to fluctuate between the elevations defined by biological indicators of "normal pool" and seasonal high water level (SHWL). As noted in Section 2.5, the normal pool elevation itself closely corresponds to the wetland margin elevation. This wet season pattern is illustrated by site FP5 in Fig. 5.4, where it can be seen that the wet season "envelope" defined by the two elevations contains a large proportion of the water level observations during the three wet periods in 1997-98. At this site, 61% of the daily water level observations from June to October 1997 (97 wet season), 79% of observations from November 1997 to April 1998 (El Niño winter), and 58% of the observations from June to October 1998 (98 wet season) fell within the envelope.

Where known, the elevations of the wetland margin and of seasonal high water level indicators are shown on the water level plots in Appendix G. Most of the monitored sites reached their normal wet season water level envelope during the 1997-98 El Niño winter and for at least short periods during the 1997 and 1998 wet seasons. Water levels at many sites made only sporadic excursions above the margin elevation during the 1998 wet season due to the late onset of rains and below-average seasonal rainfall. Exceptions include sites SV4 and 5, where water levels did not attain the wetland margin at all during the 1997 wet season, and most of the sites at the Disney Wilderness Preserve, which failed to attain normal levels in the 1997 and/or the 1998 wet seasons (see Section 5.2.3 above). The Flint Pen sites exhibited normal wet season behavior in all three wet periods and were the most consistent from wet season to wet season.

Median daily wet season water levels were strongly related to wet-season rainfall and generally reflected the observations described above. Pooled wet-season median daily water levels for each site were computed as the median of all daily water level observations from the following three periods: June-October 1997 (1997 wet season), November 1997-April 1998 (El Niño wet period), and June-October 1998 (1998 wet season). These pooled median water levels are shown in Table G.3 (Appendix G) and compared with margin elevations for each site. The departure of the median from the margin is then expressed as a percentage of the total relief (R) of the wetland depression. At many of the sites, the median wet-season water level is very close to the margin elevation of the wetland, and at most of the sites the departure of the median from the margin is less than about 20% of the total wetland relief. Exceptions to this include the Disney Wilderness Preserve sites, for which the median wet season water levels ranged from 20-66% below the margin, and suspected impact sites FP2 and SV4, both of which had median water levels about 20% lower than the margin. Median wet-season water levels at the Disney Wilderness Preserve sites were strongly influenced by the extremely dry conditions during the 1998 wet season.

Wet Season Hydrologic Regime. Table 5.5 summarizes key information regarding the wet season hydrologic regime for the three wetland types. In the table, typical hydroperiod ranges were taken from SFWMD (1995) rather than our actual data due to the bias in estimated hydroperiods caused by the extra El Niño "wet season" during 1997-98.

Type 3: Type 3 wetlands are characterized by relatively short hydroperiods and shallow depths. Total water level variation is small, typically less than one foot, but water level reversals are frequent as the stage varies back and forth between the margin and seasonal high (see Fig. 5.4). Because of their shallow water depths, maintenance of characteristic hydroperiods may be highly sensitive to small changes in wet season water table position. Although Type 3 biological communities are adapted to frequent wetting and drying, they are also likely adapted to a fairly narrow range of water levels in the wet season and are therefore relatively intolerant of even modest changes in surface water elevations.

Type 2: Type 2 wetlands are characterized by a strongly seasonal hydrology, with relatively short periods of drying each year. Most water level variation occurs during the spring, when stages can decline from margin to bottom and back again in a few months time. Wet season water levels are frequently and consistently at or above the margin elevation and hydrologic connections are often established with surrounding Type 3 wetlands. Because of the moderate water depths in Type 2 wetlands, the hydroperiod may be equally influenced by the water table position at the end of the preceding dry season as by modest water level changes during the wet season itself.

Type 1: Type 1 wetlands are characterized by long (permanent) hydroperiods and seasonal variations in water levels that sustain stable aquatic conditions. During the wet season, connections are often maintained with adjacent Type 2 and 3 wetlands. Type 1 wetlands should be fairly well buffered against water level change due to large amount of storage and prolonged contact with water table (often they are the lowest points in the landscape) and are therefore the least sensitive to modest water level changes during the wet season.

Table 5.5 – Wet Season Hydrologic Regime

	Type 1	**Type 2**	**Type 3**
Wet Season Hydrology	Stable hydrology; deep water, large water storage volumes	Seasonal hydrology; rapid wet-dry transitions	Short hydroperiods; small changes in water levels, frequent reversals
Typical Wet Season Water Depths	> 2 ft	1.0-2.0 ft	< 1.0 ft
Typical Hydroperiod*	300+ days	150-300 days	30-150 days
Tolerance of Water Level Changes in Wet Season	High	Moderate	Low

* Source: SFWMD (1995)

5.4 Dry Season Hydrology

Relevant aspects of the dry season hydrology, including drying rates, observed minimum water table depths for different wetland types, and relationships between wetland biota and water table position, are summarized in this section. Table 5.6 provides a summary of the dry season hydrologic regime for each of the wetland types.

Drying Rates. Wetland water levels typically begin declining in October or November in response to decreased frequency and amount of rainfall associated with the beginning of the dry season. Type 3 wetlands may dry out completely early in the fall. Most Type 2 wetlands dry out completely by April or May, if not earlier, as the water table falls below the ground surface. Drying spells may also occur in the wet season during periods when no rainfall occurs for two to three weeks.

Wetland water levels usually decline rapidly when the stage is still above the margin elevation due to surface runoff away from the wetland depression and re-distribution of the water table mound caused by recent rainfall. A gentle exponential decline in water level is typically observed after the stage falls below the margin and water is confined to the wetland depression. During dry periods, diurnal evapotranspiration (ET) signals can be seen in the groundwater data until the water table falls well below the root zone of the dominant plants.

Inspection of water level plots in Appendix G suggests that drying rates are relatively constant for a given site regardless of when drying occurred. Drying rates of sites within the same study area are fairly similar to one another, except for sites such as FP2 which are likely impacted by groundwater pumping. Average drying rates for each site were estimated from daily water level data during rainless periods when the stage in the wetland was below the margin elevation. Drying rates ranged from about 5mm/day at site JD12 to 22mm/day at FP2, with typical values for unimpacted sites ranging from 5-8 mm/day. Monthly average ET rates for wetlands in south Florida range from about 1mm/day in winter to 5-6 mm/day during the peak of the summer (Dolan *et al*, 1984). Thus wetland drying rates are generally greater than typical ET rates, especially where groundwater is affected by drawdown from pumping (e.g., FP2) and surface drainage (e.g., SV4 and SV5 where drying rates are about 10.5 mm/day). There appears to be no relationship between estimated wetland drying rates and wetland topography or substrate type. Surface water drying rates are very similar to groundwater drying rates at the same site, with ratios of surface water to groundwater drying mostly greater than 0.60.

Taken together, the observations described above imply that drying rates in wetlands are influenced more strongly by external controls on groundwater (wellfields, surface water structures) than by internal controls within the wetland site (substrate, topography). Surface water drying appears to be strongly related to decline of the water table in the surficial aquifer, with ET accounting for 50-80% of the observed drying rate at unimpacted sites and as little as 10% of the drying at impacted sites.

Minimum Water Table Elevations. Table G.1 (Appendix G) gives minimum groundwater elevations measured at each of the sites during calendar years 1997and 1998; these elevations are used to estimate depth of the water table below ground for different wetland types shown in Table G.2. Values from the very dry first quarter of 1999 are also shown for comparison, but are not used in estimating below-ground water table depths for typical dry season conditions.

As shown previously in Fig. 4.1, at each depressional wetland site, communities above the margin elevation are considered Type 3 wetlands and those below the margin are considered Type 2. Alligator holes, where present, are considered Type 1 wetlands. Minimum dry-season water table depths for Types 3, 2, and 1 communities shown in Table G.2 are estimated by subtracting the minimum measured groundwater elevation from the wetland bottom elevation, margin elevation, and alligator hole bottom elevation, respectively. For Type 3 wetlands, this data was validated and supplemented with information from other sources, including:

- Limited observations during 1998 at new sites FP9 and FP10,
- Shallow piezometer data from wet flatwoods and prairies outside sites FP3, FP5, FP6, FP7, and SV5,
- Auger holes dug at monitored and unmonitored Type 3 sites in Martin Co.,
- Information from soil science literature.

Findings regarding depth of the water table below the wetland ground surface and dependence on water table position are summarized below in Table 5.6. Water table depths for each wetland type shown in Table 5.6 represent the natural range of variability for dry-season water table position as determined from our study sites and supplemental information from the literature.

Through the period of hydrologic monitoring, it has become obvious that certain wetlands are consistently wetter and sustain standing water during dry periods longer than the other sites in the same study area. In the dry season, these sites have high ecological value for wildlife in that they are often the only sources of standing water in the landscape to sustain habitat for aquatic fauna and drinking water for upland animals. Observed wildlife usage of these sites in the dry season is high relative to other wetlands and nearby upland habitat. Game trails and alligator drags are commonly seen leading to these wetlands.

Marsh sites WR9, JD6, JD12, and SV1 remained wet (i.e., standing water above the wetland bottom) throughout the 1997-98 period of record and were among the last of the sites to dry out during the spring of 1999. Consistent separation (up to 1.5 ft.) between surface and groundwater is evident in the water level plots of each of these sites (Appendix G), suggesting that some form of confining layer or aquiclude may be playing a role in maintaining surface water. However, no obvious confining units are evident in the well boring logs of these sites (Appendix C) nor are there any obvious lithologic patterns common only to these sites. Average surface water drying rates for these four sites are the lowest of all sites monitored and are approximately equal to typical ET rates. The ratios of surface water to groundwater drying rates at these sites (average 0.54) are among the lowest of all the sites, indicating that surface water declines about half as fast as groundwater during the same period. However, as discussed in Section 5.2.1, overall correlation between surface water and groundwater is extremely high, reflecting that groundwater and surface water track each other closely, despite the separation apparent in the water level plots. There is also good evidence to suggest that these sites stay wet longer simply because they are lower in the landscape than other wetlands and therefore maintain longer contact with the receding water table. Although complete topographic surveys of the wetlands and their vicinity have not been completed, the bottom elevations of each of the sites listed above appear to be lower than any other monitored wetland in the vicinity.

Cypress dome sites FP5, FP6, FP7, FP8 in Flint Pen Strand have dried out to the nominal bottom elevation each year of the study so far. However, deeper alligator holes at each of these sites have remained wet through the entire 1997-98 period of record and through the dry months of the first quarter of 1999. Flint Pen sites without alligator holes dried out each year. Alligator holes are created by female alligators (*Alligator mississippiensis*) in the process of scraping up and mounding earth and vegetation for nests and in the excavation of dens (Mazzotti and Brandt, 1994; Kushlan and Hunt, 1979). Some holes may be centuries old, maintained by generations of alligators through the years, and may be excavated deeper as the water level recedes during dry years (Lodge, 1994). Alligator holes at the Flint Pen sites are sufficiently deep that they penetrate the muck deposits present in each wetland and are in contact with the underlying sand. Buoyant sand and cool water temperatures encountered at the bottom of some of these holes suggests that they may be locations of groundwater discharge. A wide variety of aquatic organisms and wildlife make use of standing water in alligator holes during the dry season when surrounding wetlands are dry (Lodge, 1994; Kushlan and Hunt, 1979).

Table G.1 gives the bottom elevation of the alligator holes at these sites for comparison with minimum water table elevations in each year. Water levels in the alligator holes closely correspond with measured groundwater elevations at the site, which have not to date dropped below the bottom elevation of the holes. Minimum depths of standing water in alligator holes during the 1996-97 and 1997-98 dry seasons ranged from 0.9 ft to 3 ft; minimum standing water depths observed during the severe 1998-99 dry season ranged from near zero up to 1.8 ft. These water depths in the deep alligator holes give some indication of expected dry season conditions for Type 1 wetlands.

Dry Season Hydrologic Regime. Observations of the wetland study sites during the 1996-97 and 1997-98 dry seasons provide insight into the dry season hydrologic regime of each of the three wetland types and the ways in which wetland organisms have adapted or adjust to drying. A summary of dry season hydrology by wetland type is given in Table 5.6.

Type 1: Type 1 wetlands will typically contain standing water above the ground surface throughout a normal dry season and even during drought because the water table does not drop below the wetland bottom. Alligator holes within depressional wetlands and other Type 1 sites in the vicinity of the study wetlands did not dry out during the 1997-98 period of record. In each case, the bottom elevation of the wetland (or alligator hole) was from one to several feet below the minimum water table elevation measured for the wetland. In some Type 1 wetlands large amounts of water storage or sustained surface water inflows may buffer the effects of decreased rainfall and groundwater drawdown.

Wetland biota in Type 1 wetlands rely on the presence of standing water during the dry season. Many organisms in Type 1 wetlands are true aquatics, with few or limited adaptations for complete drying. These wetland types represent dry season refugia to which aquatic fauna retreat as water levels recede in the spring and from which they disperse in the summer when the rains return (Carlson and Duever, 1979).

Type 2: Type 2 wetlands typically dry out in the winter and spring of most years, during which time they contain little or no standing surface water. Some Type 2 wetlands situated lower in the landscape may remain wet through most of the dry season or may only partially dry out before the summer wet season begins. Type 2 wetlands in this study, even those that dried out, typically remained saturated at or near the ground surface, and, with the exception of impacted sites, the water table elevation during the 1997-98 period of record never dropped more than 1.5 feet below the wetland bottom. In most cases, the water table remained within one foot of the ground surface and well within the root zone of the dominant wetland plants. At sites with organic soils greater than 6 inches in thickness, the dry season water table remained in direct contact with the muck, keeping the soil well saturated through capillary action. This observation is consistent with hypotheses that as long as the water table is in contact with the muck layer, the entire soil profile stays saturated through capillary "wicking" (Duever, 1990). Given their high water retention capacity, organic soils are also highly effective at soaking up moisture from sporadic dry season rains. Davis (1946) observed that Florida peat can absorb 350-935 percent water by weight, but water flows through it relatively poorly.

Some important classes of wetland organisms, including amphibians, invertebrates, small fishes, and plants may rely, in the absence of surface water, on saturated soils to survive the dry season and possibly to complete important stages in their life cycles. Macroinvertebrates, fish, and some free-floating plants can often be found at or just below the wetland ground surface, surviving in saturated conditions during the dry season. During the dry season of 1996-97, thousands of small frogs were observed at the Flint Pen wetlands, thriving in saturated soils, with no standing water present.

Type 3: The minimum groundwater table at unimpacted Type 3 wetlands ranged from 1.5 to nearly 5.0 feet below ground surface, with an average depth of 3.0 ft below ground. These observations are consistent with dry season water table depths of 3-4 feet below ground reported for slough (wet flatwoods) soils in *the Hydric Soils of Florida Handbook* (Cooper *et al*, 1995). Water table depths in this range are well below the rooting depth of dominant herbaceous plants, even when the thickness of the capillary fringe above the water table (25-50 cm in medium to fine sand, Fetter, 1994) is considered. Samples of dominant St. Johns wort (*Hypericum fasciculatum*) and corkwood (*Stillingia aquatica*) taken from Type 3 wetlands in the Flint Pen Strand study area revealed that these plants are very shallow rooted and have root balls that are considerably larger in diameter than they are deep. For St. Johns wort, average root depth was 4.8 in. and average root ball diameter was 9.9 inches; for corkwood, average depth of roots was 7 in. and root ball diameter was 8.5 in. Observations of wind-thrown pines in wet flatwoods suggest that even relatively large trees have roots that are mostly within two feet of the ground surface. This information on root morphology combined with knowledge of the dry season water table depth in these wetlands suggests that such plants are adapted to a shallow water table in the wet season, but are not highly dependent on water table position in the dry season. Such plants appear to rely primarily on efficient capture of sporadic rainfall during the dry season. Many of the dominant plants in Type 3 wetlands have evolved small, narrow, scaly leaves that tend to reduce moisture loss from transpiration, an adaptation to seasonally dry conditions.

Most fauna in Type 3 wetlands appear to be adapted to regular seasonal drydown and employ a variety of strategies to avoid desiccation. Crayfish burrows are common in Type 3 wetlands in the dry season and often extend as much as 3 feet below ground seeking soil with higher moisture content and avoiding high temperatures at the surface (Hobbs, 1942). In some cases, crayfish burrows may reach the water table, thereby providing micro-refugia for other aquatic invertebrates and small fish. Crayfish and other organisms may enter temporary states of decreased metabolism or aestivation in the dry season, surviving in relatively higher moisture soils near the water table or underneath dried periphyton mats and plant debris.

Table 5.6 – Dry Season Hydrologic Regime

	Type 1	Type 2	Type 3
Dry Season Hydrology	Water table above ground surface; large water storage volumes	Water table contact with organic soils	Rainfall
Minimum Water Table in Dry Season	Above ground; some standing water present	0-1.5 ft below ground; soil saturated to near ground surface	1.5-5 ft below ground; dry at ground surface
Biota Dependence on Water Table Position	Yes	Yes	No (?)
Dry Season Adaptations and Survival Strategies	None	Dependent on saturated soils, burrowing in substrate	Mobility, aestivation, water retention
Tolerance of Complete Drydown	Low	Moderate	High

6. Discussion

6.1 Hydrologic Regime – Hypotheses and Evidence

Two competing hypotheses have traditionally been posed for the persistence of isolated wetlands in south Florida, both of which have important implications on the wetland hydrologic regime. Although numerous variations on similar themes have been proposed, the two main explanations for isolated wetlands hydrology are:

(1) Wetlands are sustained by a perched water table above a coherent confining unit, are isolated from the underlying groundwater and influenced mainly by direct rainfall and evapotranspiration;

(2) The wetland is a surface expression of the water table of the surficial aquifer and is highly connected to and influenced by the underlying groundwater

Previous research in south Florida has most often supported the second of these two hypotheses, concluding that wetlands occur where the water table intersects the ground surface. Duever (1990) observed that wetlands are rarely sustained by perched water tables and that wetland water levels nearly always coincide with the "regional" groundwater table. Similar conclusions are supported by the findings of research on Carolina bays, a type of isolated depressional wetland similar to those studied here that occurs on the coastal plain of North and South Carolina. Lide *et al* (1995) found that a continuous 1-4 meter thick clayey hardpan layer beneath a Carolina bay in South Carolina did not isolate the wetland from the underlying groundwater and that perched water table conditions were never observed. They concluded from the basis of five years of hydrologic monitoring at the site that the water ponded in the wetland is a surface expression of the groundwater table.

We have seen no evidence from our data that would lead us to a different conclusion here. We find that the isolated wetlands monitored for this project exhibit a high degree of communication with the sandy portion (and perhaps lower levels) of the surficial aquifer and are strongly influenced, both vertically and laterally, by groundwater response to rainfall. Evidence from our data supporting this assertion is discussed throughout the Results Section. The main points of evidence are summarized below:

- Extremely high correlation at small time scales between surface and groundwater at each site;
- Groundwater and surface water elevations are the same at many sites, and at sites where separation between surface and groundwater is observed, the difference between the two is usually on the order of only a few inches;
- High degree of similarity in hydropatterns is observed among all sites in a given study area, even those separated by large distances and regardless of differences in soil type or wetland plant community types;
- Sites that stay wet longest are those that are lowest in the landscape, and sites that dry out first are those that are situated at the highest ground elevations. Most sites dry out completely when the water table falls below the bottom of the wetland;
- Wet season rehydration of wetlands occurs only when the water table reaches the ground surface and is significantly delayed when the water table is drawn down by pumping or drought;
- Wetland response to rainfall is often of the same magnitude as the groundwater response and typically much greater than rainfall depth;
- The drying rate of wetland surface water is controlled by the rate of water table decline and is usually substantially greater than the typical summer ET rate;
- Results of a Wetland-Aquifer Interaction Test at one site provide direct evidence of substantial amounts of groundwater discharge into the wetland when typical groundwater and surface water heads are abruptly reversed.

Our investigation and those of others working in the same areas provide additional evidence against the notion that wetlands are sites of perched water tables. This evidence was discussed in Sections 2.4.2 and 5.2.1 and is summarized below:

- Lithologic and soil layers that are most often identified as possible confining units are not continuous in thickness or in their spatial distribution in and around wetlands, leading to highly variable leakage characteristics. For these reasons, Hopkins (1991) concluded that hardpan layers do not isolate wetlands from the underlying aquifer. These same layers are most often seen to be relatively thin and shallow, sometimes penetrated by roots, and have very high sand contents, suggesting that permeability may be relatively high.

- No evidence has been found to suggest the presence of an unsaturated zone beneath the wetlands during periods when they contain standing surface water. Similarly, Lide *et al* (1995) found that soils were completely saturated above, below, and within a thick clay "hardpan" layer underlying their study wetland during periods when standing water was observed.

- The kind of wetlands most often said to be perched (Type 3 wetlands) are actually observed to dry out the earliest, as would be expected given their position in the landscape. Deeper Type 2 depressional wetlands are rarely if ever found to be underlain by hardpan or similar confining layers, but usually contain standing water long after Type 3 wetlands have dried out. It is possible that Type 3 wetlands could become perched in cases where they are not directly connected to a Type 2 wetland. However, evidence of perched water tables occurring under anything but transient conditions remains elusive.

Although we find evidence of substantial geologic complexity at many sites and some evidence of possible confining layers at two sites (WR8, SV1), the effects of site-specific geologic features on the overriding hydrologic regime are considered minimal. It is possible that additional research and monitoring might reveal more distinct hydrologic patterns related to geomorphic setting, geology, or soils. However, it is not likely that such distinctions would appreciably alter our basic understanding of the relationship between isolated wetlands and the surficial aquifer. Our best available information indicates that wetlands are essentially "windows" on the surficial aquifer. Rate and timing of wetland drydown appears to be more strongly related to the position of the wetland depression in the landscape and its proximity to external controls on the water table elevation than on any observable site-specific characteristics. The fact that wetlands are expressions of the water table, however, does not necessarily imply that a specified amount of drawdown in the aquifer results in an equal amount of decline in the wetland water level. Effects of differing porosity, the presence of less permeable strata at various depths, and lateral re-distribution of the water table in response to perturbations means that drawdown in the wetland can be substantially less than the corresponding drawdown in the surficial aquifer.

6.2 Reference Hydrology

A generic picture of isolated wetlands hydrology emerges from the results in the previous section that can be used to define performance standards. All evidence thus far points to a high degree of connection between wetland surface water and groundwater levels in the sandy zone of the aquifer. The entire upper portion of the surficial aquifer, including wetlands, is rainfall driven, with rapid response to increases or decreases in rainfall amount and frequency. Shallow subsurface features such as hardpan and organic soils may affect the details of wetting and drying, but they do not appreciably alter the basic hydrologic regime or the vulnerability of the wetland to hydrologic changes caused by groundwater withdrawal. The following is a summary of the annual hydrologic regime for a depressional reference wetland.

- ➢ Beginning at the end of the dry season in May and early June, most sites are dry at the ground surface, except for deep alligator holes and other low portions of depressional wetlands (i.e., Type 1 wetlands) that are sufficiently low in the landscape to remain in contact with the dry season water table. In normal years the dry-season water table is rarely more than a foot below the ground at the bottom of the wetland depression, maintaining contact with organic soil horizons. However, because of the natural topographic relief of the depression, the water table may be as much as 4 to 5 feet below the ground surface in the transitional (Type 3) wetlands at the margin of the depression and the surrounding hydric flatwoods and wet prairies (Fig. 6.1a).

- As summer rains begin to increase in frequency and coverage, the water table in the sandy upper portion of the aquifer begins to rise. As the water table nears the ground surface, it may become momentarily confined by shallow soil layers of relatively low conductivity (hardpan, clays, organic deposits), and the groundwater head may temporarily rise above the surface water head, creating a vertical head gradient that facilitates groundwater discharge into the wetland. Inflow to the wetland depression may begin soon after the water table begins rising, through a combination of direct rainfall input, horizontal interflow from the surrounding sands, and groundwater discharge from below (Fig. 6.1b). However, sustained wetting typically occurs only when the water table reaches the ground surface and the wetland substrate becomes thoroughly saturated (Fig. 6.1c). Timing of rewetting (and hence the start of the seasonal hydroperiod) is highly correlated with the depth of the water table at the end of the dry season. Sites with lowered water tables exhibit delayed rewetting, as it takes longer for the available pore space in the desaturated zone to fill and the water table to rise to the ground surface. At some sites (e.g., Flint Pen Strand), spillover of surface water into wetland depressions from surrounding wet prairies and flatwoods represents another significant source of inflow to the wetlands. During the early part of the wet season, wetland water level response to rainfall is similar in magnitude to that of the underlying aquifer and usually much greater than the total rainfall depth, evidence that the wetland is hydrologically a surface expression of the water table.

- With additional rainfall during the wet season, wetland depressions continue to fill by a combination of the mechanisms discussed above. When the wetland water level reaches the margin elevation, surface water flow processes become more important as the wetland becomes connected to flowways or as excess surface water spills over into the flatwoods (Fig. 6.1d). Further water level rise above the margin elevation is difficult to sustain due to the much flatter topography beyond this point. At the height of the wet season, the water table is relatively flat, and water level rise in response to rainfall in both the aquifer and the wetland are typically equal to the total rainfall depth. If rains continue to fall regularly (as is characteristically true in the wet season) and the water table remains high, the water level in the wetland will typically fluctuate between the margin elevation and the seasonal high level. In the absence of severe drawdown impacts, the wet season envelope defined by these elevations remains remarkably constant from year to year (or from wet period to wet period within the same year).

- As rainfall decreases in late fall and dry spells become more prolonged, the water table begins falling, and so too does the wetland surface water. When no significant rainfall occurs for several weeks, the water table may begin to make excursions below the ground surface (Fig. 6.1e). In some sites, thick organic soils and/or low conductivity layers such as hardpans may slightly delay wetland drydown. However, these effects are rarely significant, and such layers are most effective in retaining water in the wetland when the water table remains close to the ground surface and the resulting vertical head gradient is small. Wetland drying rates are much greater than ET rates and appear to be largely controlled by the rate of water table decline, even at unimpacted sites. At impacted sites, drying rates can be an order of magnitude greater than typical summertime ET rates, and external controls on the water table (wellfield cone of depression, control elevations of surface water management systems) completely overshadow the delaying effects of any confining features that may be present.

- As the dry season progresses, the water table may continue to fall and some wetlands may dry out. In most years the water table remains in contact with organic soils in the depressional wetlands and rarely if ever falls below the bottom of alligator holes and certain other (Type 1) wetlands situated low in the landscape. Transitional (Type 3) wetlands such as occur in wet prairies, hydric flatwoods, and the edges of depressional systems typically dry out much earlier. The water table often drops well below the root zone of the dominant herbaceous species in those communities (Fig. 6.1f).

6.3 Drought Hydrology and Recovery

In south and central Florida, droughts of varying duration are not unusual in the long-term record and may develop quickly in response to regional weather patterns (Winsberg, 1990). Multi-year drought has occurred periodically throughout the southeastern United States during the last several hundred years, and even in normal years, rainfall may seasonally decrease below amounts necessary to sustain surface water in isolated wetlands. The hydrologic and ecological response of wetlands to drought is of interest for two reasons. First, the impacts of extended drought on isolated wetlands are similar in many respects to the expected impacts of long-term water table drawdown and may provide insight into how wetland functions are altered as a result of increased frequency and duration of drying. Second, drawdown limits presently used in water use permitting are applied under hypothetical drought scenarios (e.g., 90-days of no rainfall recharge, 1-in-10-year rainfall drought, etc.). Thus it is necessary to understand the background conditions that may occur in wetlands during natural drought, so that a clearer picture of any additional effects of groundwater drawdown may be obtained.

During drought years, the basic mechanisms described in the previous section still govern the hydrology of the wetlands. The wetland remains a surface expression of the groundwater table, but surface water cannot be sustained until the water table reaches the ground surface. Data collected during the short drought of spring 1999 indicates that by May or June water tables had declined as much as 1.0 to 1.8 feet lower than the minimum elevations observed during 1997 and 1998. All Type 2 and 3 wetlands dried out by late April or early May, and in some cases wetlands stayed dry for extended periods. Even when thunderstorms occurred during this period, the wetlands remained dry or nearly so as rain went mostly toward replenishing the pore space in the unsaturated zone. Evidence from sites FP2, WR15, and WR16 suggests that wetland hydration will not occur so long as the water table remains well below ground surface. Water table drawdown beneath FP2 delayed summer rewetting at the site by as much as four weeks during each of the past two years (see Section 6.4 below). The two WR sites have failed to rehydrate at all since May 1998, despite ample (if below average) rainfall during the 1998 wet season. The water table at these sites has consistently been below the wetland bottom elevation throughout this period. This is likely the result of cumulative rainfall deficits over the past two years. As reported in the previous section, Type 1 wetlands (alligator holes) in the Flint Pen Strand study area have remained wet through the period of record, including the spring 1999 drought period. Standing water depths in these wetlands at the peak of the spring 1999 drought ranged from a few inches to nearly two feet in the deepest hole.

Hydrologic simulation of wetlands in the Flint Pen Strand study area provides additional insight into the effect of drought on wetland hydrology. Simulation of one year of 1-in-10-year drought conditions, followed by multiple years of normal rainfall indicates that the minimum water table elevation occurs at the end of the drought year, when accumulated rainfall deficit is at a maximum. However, the greatest impacts to the wetland hydrology may occur during the following year because the low water table at the end of the previous year prevents or delays rewetting, resulting in shortened hydroperiods and wet season water levels. Recovery to normal hydroperiods and water levels may take one to two years following cessation of drought conditions, even when no additional drawdown is imposed on the water table (E. Hopkins, unpublished data, 1999).

The long period of reduced hydroperiods and water depths during the drought and subsequent recovery suggests that changes to the wetland biota are likely. Successional changes may occur in the wetland plant community as species adapted to transitional areas at the wetland margin (e.g., *Andropogon*, pine, melaleuca, dog fennel, sesbania) encroach further into the wetland depression. Decline of certain herbaceous wetland species in response to drought has been observed in isolated wetlands in parts of south and southwest Florida (Winchester *et al*, 1985). Many such changes are not permanent, and will often reverse themselves within a year or two after normal water levels are re-established. However, in the case of certain exotics such as melaleuca (*Melaleuca quinquenervia*) and West Indian marsh grass (*Hymenachne amplexicaulis*), which germinate under drydown conditions but thrive under normal wetland conditions, such changes may be irreversible in the absence of human intervention. Native tree species and woody shrubs may be slow to exhibit symptoms of drought stress due to their deeper, more extensive root systems, persistent structural features, and large amounts of stored moisture and energy reserves. However, many years may be required for the wetland to recover from severe drought impacts (e.g., severe fires occurring during drought conditions) resulting in loss of canopy species.

Less is known about response to and recovery from drought by wetland fauna. Many animals that inhabit Type 2 and 3 wetlands are adapted to seasonal drying, and these adaptations may allow them to survive extended drought periods as well. Common adaptive strategies for surviving drought include burrowing or aestivation in the wetland substrate, migration to terrestrial or aquatic refugia, alteration of metamorphosis or reproductive behavior, and ability to forage in or otherwise exploit dry wetlands. The survivable drought duration depends on a variety of factors, including rate and severity of drying, size and mobility of the organism and adaptive strategy employed. Animals that inhabit Type 1 wetlands may have few or no adaptations for surviving the complete loss of surface water, instead relying on the presence of standing surface water in situ through the end of the drought. Type 1 wetlands may be extremely important during droughts as refugia for resident aquatic animals as well as animals emigrating from dried out Type 2 and 3 wetlands in the vicinity.

6.4 Effects of Groundwater Withdrawals

Nature of Impacts. Potential environmental impacts to wetlands from severe groundwater drawdown are characterized by Mortellaro *et al* (1995), who documented case studies of drawdown impact in the scientific literature. Most of the cases reported in the literature are from Southwest Florida Water Management District (SWFWMD), where modeled drawdowns of as much as 5 feet were allowed in the aquifer underneath isolated wetlands in the vicinity of large public water supply well fields. Average groundwater withdrawals in seven well fields considered by Rochow (1994) ranged from 12 to 45 MGD, compared to 5.8 and 1.3 MGD, respectively, for the LCU Corkscrew and MCU North County Wellfields discussed in this report (Table 6.1). As shown in Fig. 6.2, when the water table is drawn down well below the ground surface (as occurred in the SWFWMD wellfields), seepage losses from the wetland may occur year around, resulting in severe impacts to wetland hydrology. In such cases, rainfall does little to ameliorate the effects of the lowered water table on wetland hydrology. Documented impacts in such wetlands include severely reduced hydroperiods and water levels, soil subsidence, excessive tree fall and loss of cypress canopy, conversion of wetland plant communities to transitional and upland species, more frequent and more severe fires, and loss of wetland-dependent wildlife (Mortellaro *et al*, 1995; Rochow, 1994). Loss of organic soils and conversion of wetland communities in turn led to loss of jurisdictional acreage from some wetlands. Impacts of this magnitude are dramatic and easily observed and may lead to irreversible or long-term changes in wetland form and function.

By contrast, in surveying nearly 100 wetlands near public water supply wellfields and agricultural projects in the SFWMD for inclusion in this study, District staff were unable to identify any with symptoms of impact as severe as those seen in SWFWMD. More modest drawdowns allowable under existing SFWMD permitting guidelines have apparently prevented serious drawdown impacts to most isolated wetlands. The effects of moderate drawdowns where the water table does not decline too far below ground may be transient in nature, becoming evident only in the dry season or during drought (Fig. 6.2). In the wet season the effects of minor drawdown may be easily "damped out" by rainfall. With sufficient rainfall, affected wetlands may attain normal wet season water levels, but possibly with shortened hydroperiods caused by delayed rewetting or more frequent drydown. Affected wetlands may not permanently lose acreage or exhibit loss of canopy. Biological changes may be reflected more in terms of trends or subtle shifts in plant and animal community structure or composition.

Table 6.1 – Comparison of Impacted Wetlands

	SWFWMD Wellfields (Rochow, 1994; Mortellaro *et al*, 1995)	**SFWMD Wellfields**
Maximum Drawdown	2-5 feet	0-2 feet
Withdrawal Rates	12-45 MGD	1.5-6 MGD
Impacts Observable	All year, all conditions	Dry season and drought
Symptoms of Impact	❖ Reduced hydroperiod and depths ❖ Soil oxidation ❖ Loss of canopy species ❖ Invasion by upland species ❖ Loss of wetland acreage	❖ Delayed wetting and reduced hydroperiod ❖ Invasion by transitional or facultative species ❖ Long-term or periodic shifts in plant and animal communities

Site FP2 Example. Of the twenty study sites covered in this report, site FP2 in the Flint Pen Strand study area exhibits the most distinctive patterns of hydrologic impact. A discussion of the altered hydrology observed at FP2 caused by groundwater pumping from the adjacent Lee County Utilities Corkscrew Well Field provides further insight on the nature of impacts likely from moderate amounts of drawdown. We believe the level of hydrologic impacts and resulting ecological change observed at this site are close to but do not exceed the threshold for "unacceptable harm" proposed for use in the St. John's River Water Management District (CH2M Hill, 1996).

Characteristics of site FP2 are summarized in Table D.1 (Appendix D). The wetland is predominantly a depression marsh (Type 2 wetland) historically dominated by broad-leaf emergent vegetation (e.g., *Thalia geniculata*) and grasses (e.g., *Panicum hemitomon*) with a broad fringe of cypress on the south edge of the depression. Analysis of historical aerial photos indicates that pine and cypress in and around the site were logged during the 1940's and have gradually returned over the ensuing decades; mature second-growth cypress dominates the fringe today. Exotic Brazilian pepper (*Schinus terebinthifolius*) now dominates much of the wetland margin, and native emergent vegetation has been largely replaced by exotic West Indian marsh grass (*Hymenachne amplexicaulis*). Cattle are regularly observed grazing in the wetland, especially when the depression is dry. Soils consist of about two feet of muck and organic sand at the ground surface underlain by an approximately eight-foot thick layer of silt and clay.

During the wet season, surface water closely tracks groundwater. When the stage in the wetland is greater than about 17.8 feet NGVD, water flows out of the wetland toward the south. Construction of the Corkscrew Road grade in the 1950's altered surface flows north of FP2, and some indications of drying are evident in aerial photos taken just after this period. At present, storm runoff from swales along Corkscrew Rd. now enters the wetland in pulses during wet periods, often carrying high concentrations of suspended solids. The extent to which these historic changes in surface water patterns altered the hydrology of FP2 is difficult to quantify, but any such effects would be expected to occur primarily during the wet season when the wetland is least sensitive to change.

The LCU Corkscrew Wellfield, which began operation in 1981, is located immediately adjacent to FP2, and the nearest production well cluster is only a few hundred feet from the eastern margin of the wetland. Observations during the past two years indicate that the hydrology of wetland FP2 is similar to that of other wetlands located inside the wellfield property and is affected by drawdown of the water table caused by pumping from the surficial aquifer. Monitoring well data from some wetland margin locations inside the main wellfield near Corkscrew Rd. indicate that the dry season water table may be depressed as much as 10 feet below land surface. However, wet season water table elevations appear near normal and are typically at or above land surface by mid-summer. Monthly water level patterns in wetlands along a drawdown gradient in the vicinity of the wellfield are depicted in Fig. 6.3.

Minimum dry season water table elevations FP2 have ranged from 3.7 to 6.0 feet below the wetland bottom, or 6.3 to 8.6 feet below the wetland margin (Table G.2, Appendix G). This corresponds to an estimated drawdown of 2 to 4 feet, based on comparison with nearby control sites. The dry season water table at the other Flint Pen sites more removed from the wellfield has remained within 1.3 feet of the wetland bottom (or 2.5-5.0 feet below the margin), even during 1999. Comparison of 1997-98 daily water levels at FP2 with those of site FP5 are shown in Fig. 6.4.

Fig. 5.1 is a more direct comparison of surface water hydrology at FP2 with the other FP sites. As can be seen in this figure, the depressed dry season water table consistently results in delayed rewetting of the wetland, which only occurs when the water table rises to the ground surface. Compared to the other Flint Pen sites, rewetting at FP2 is delayed by two to three weeks at the beginning of both the 1997 and 1998 wet seasons. Further, during dry periods, FP2 dries out much more rapidly and the water table drops much lower than at the other sites. The combined effect of these changes results in the typical hydroperiod being shortened by approximately six to eight weeks each wet season. Yet despite this decreased hydroperiod, the stage in the wetland consistently reached the wetland margin and seasonal high water level indicators during the height of the 1997 and 1998 wet seasons and during the El Niño winter of 1997-98. This hydrologic behavior is consistent with the severity and extent of impacts expected from moderate levels of groundwater drawdown.

The depressed dry season water table depths and shortened hydroperiods observed at FP2 might lead one to expect that the site will over time change from a Type 2 wetland community to a Type 3 community. Indeed, the minimum water table depths at the site fall within the range indicated for Type 3 wetlands in Table 5.6. The observed range of water depths during the wet season appears to be typical for Type 2 wetlands, with surface water consistently rising above the margin elevation during 1997 and 1998. However, the median wet-season surface water elevation (see Section 5.3 and Table G.3, Appendix G) is about 0.5 feet below the margin elevation, a departure from the margin equivalent to about 21% of the total relief of the wetland depression at FP2. Median wet-season water levels at the other Flint Pen sites are mostly equal to or slightly higher than the margin elevation.

Assuming an unimpacted hydroperiod of 225 days for Type 2 wetlands, a reduction of 40-60 days (6-8 weeks) of inundation results in an altered hydroperiod of 165-185 days, close to the threshold between Type 2 and Type 3 wetlands shown in Table 5.5. Hydroperiods consistently falling within this range over the long term might be expected to lead to deterioration or replacement of cypress and marsh plant communities (based on typical ranges for these communities reported in Table 5.3) and possible loss of organic soils. However, it should be noted that there is considerable year-to-year variability in the observed hydroperiods for wetland communities of south Florida, and in 1998 the cypress and marsh communities at FP2 each experienced more than 200 days of inundation (Appendix H).

A procedure developed for the St. Johns River Water Management District to evaluate the impacts of groundwater drawdown introduces the concept of "dehydration succession" whereby a decrease in hydroperiod causes a long-term shift to drier plant and animal communities along a hydrologic gradient. The methodology focuses on dominant plant communities and assemblages of amphibian (frog) species as indicators of ecological change (CH2M Hill, 1996). Applying this methodology to FP2, a decrease in hydroperiod from 225 days to 165 days presumably does not result in the loss of any amphibian species groups; cypress swamp and marsh communities would change to "shallow cypress" and "shallow marsh," respectively (Fig. 6.5). This level of change would not result in a change in the Florida Land Use, Cover and Classification System (FLUCCS) category for these communities, suggesting that such changes might be difficult to detect from large-scale aerial photography. The methodology classifies the severity of this ecological change on a scale from one to five (Table 6.2) as a "Category 2 change," described as:

> "Water table reductions create a hydrologic regime that will support species more characteristic of lower flood levels or shorter hydroperiods, or both. Some shift in the mix of dominant species in one or more vegetative strata are expected in the long-term; however, the wetland type remains the same. Also the amphibian assemblage is little changed" (CH2M Hill, 1996).

Table 6.2 – Categories of Ecological Change
(from CH2M Hill, 1996)

Category	Description
Category 1	No change in dominant plant/animal species
Category 2	Some dominant species change; wetland type remains the same
Category 3	Change in dominant species and wetland type
Category 4	Transitional to upland condition
Condition 5	No longer jurisdictional wetland; upland conditions prevail

The St. John's methodology also proposes the following definition for "unacceptable harm,"

> Unacceptable changes to flora and fauna will be indicated by replacement of the dominant species group such that another species or group of species becomes dominant or a significant increase in the on-site abundance or productivity of nuisance, exotic, or other uncharacteristic species occurs (CH2M Hill, 1996).

As depicted in Fig. 6.6, the threshold for unacceptable harm by this definition appears to occur between a category 2 and a category 3 ecological change. From the above discussion, the nature and severity of changes observed at FP2 would appear to fall just short of this threshold for unacceptable harm.

A more realistic assessment of ecological impacts that may result from altered hydrology must take into account changes in wet season water levels, frequency of surface water drydown, and secondary sources of disturbance, in addition to changes in minimum water table elevation and hydroperiod. Observations during 1995 and 1996 suggest that during the dry season, the wetland was dominated by weedy annual species that were then flooded out and replaced by native broad-leaved emergent vegetation typical of Type 2 wetlands during the wet season. However, frequent grazing by cattle during 1997 and 1998 likely led to the spread and total replacement of the marsh community by the exotic West Indian marsh grass (*Hymenachne amplexicaulis*), a common cattle forage species found in wet areas throughout the lower west coast. West Indian marsh grass is well adapted to the current conditions at FP2: it is spread by cattle, wildlife, and humans, produces prodigious quantities of seeds, germinates in wetlands under drydown conditions, and once established can thrive during prolonged periods of deep inundation. West Indian marsh grass continues to dominate most of the wetland depression today, except for an area of about 1.5 acres that was treated with herbicides by Lee County staff. The treated area has re-vegetated with alligator flag (*Thalia geniculata*), suggesting that this native species can also tolerate the altered hydrology of the site. Comparisons of the treated and untreated portions of the site indicate that the *Thalia*-dominated area supports more native frogs, insects, songbirds, and wading birds than the *Hymenachne*-dominated area. Feeding by most species of wading birds is hampered in dense *Hymenachne* even when sufficient water and prey organisms are present because the dense mat of stems and runners limits the effectiveness of typical foraging strategies. However, greater numbers of American bitterns (*Botaurus lentiginosus*) have been observed in the *Hymenachne*-dominated area, presumably because the grass provides the dense cover preferred by this species for foraging and refuge.

In summary, the depressed water table caused by groundwater withdrawal in the vicinity of wetland FP2 has likely resulted in some alteration of typical wetland plant and animal communities and degradation of wetland functions. Most of the hydrologic parameters under present conditions are indicative of a wetland that is transitional between Type 2 and Type 3 communities. Barring any further shortening of the hydroperiod, some Type 2 characteristics will likely remain intact. However, the present marginal hydrology leaves the wetland vulnerable to invasion by opportunistic exotic species, some of which will require human intervention to reverse adverse impacts on wetland functions.

7. Recommendations

7.1 Recommendations for Criteria Development

Existing Drawdown Guideline and Level of Protection. The existing permitting guideline allowing no more than one foot of drawdown under a wetland at the end of a hypothetical 90-day no recharge scenario (here referred to as the "one-foot guideline") is used as a first-cut filter for evaluating the potential impacts of groundwater withdrawals. Proposed withdrawal scenarios that do not satisfy the guideline are considered more likely to cause impacts to wetlands and are analyzed and evaluated in greater detail; proposals that satisfy the guideline are considered less likely to cause adverse impacts. The one-foot guideline, though lacking in strong scientific basis, is nevertheless considered protective of wetlands. The reasons for this are, first, that a one-foot drawdown in the aquifer would likely be expressed as a drawdown of less than one foot in the wetland due to porosity effects and lateral redistribution of the water table. Second, work by the Southwest Florida Water Management District found some empirical support for a one-foot drawdown as the threshold for adverse impacts to wetlands (Rochow, 1994). Third, the hypothetical drought conditions assuming 90 days of no recharge used in the guideline are considered highly conservative. Ninety consecutive days of no recharge-producing rainfall in south Florida is extremely rare – the longest periods with daily rainfall less than 0.1 inch recorded at Florida weather stations between 1951 and 1980 range from 50 to 55 days (Chen and Gerber, 1990).

An expert panel convened by the District in 1994 determined that there was insufficient information at the time to conclude that the existing level of protection for wetlands provided by the one-foot guideline was either allowing adverse impacts or was unnecessarily strict. The panel acknowledged that subtle adverse impacts may be occurring and are not being detected because of inadequate monitoring programs, but also noted that dramatic impacts would presumably have been observed and reported. The panel therefore recommended that a level of protection equivalent to that provided by the one-foot guideline be maintained until evidence becomes available that supports a change (SFWMD, 1995).

We have found no evidence in the SFWMD of drawdown impacts to wetlands as dramatic as those documented in the northern Tampa Bay region of the SWFWMD, where modeled drawdowns greater than one foot were permitted. It is likely that application of the one-foot guideline in our permitting has limited the severity and extent of groundwater drawdown and associated environmental impacts to wetlands. Consequently, *we recommend maintaining a level of protection no less than that afforded by the one-foot guideline*. Nevertheless, we have indeed found evidence that subtle impacts are occurring at some sites where modeled drawdown presumably satisfied the one-foot guideline (see Section 6.4 above). Observed impacts are likely transient in nature, are more evident in the dry season than in the wet season, and do not directly result in wholesale changes in the wetland flora and fauna. However, even subtle hydrologic impacts such as observed at site FP2 can lead to degradation of wetland functions. The fact that impacts are observable for modest levels of drawdown (the magnitude of which approaches the lower limits of accuracy of most groundwater modeling tools) also suggests that a distinct no-impact threshold drawdown may be difficult to define.

Proposed Modifications. Nearly two years of detailed hydrologic monitoring at twenty wetland sites in south and central Florida has provided a better understanding of the effects of groundwater drawdown on isolated wetland functions. The available information on wetland hydrology and the effects of groundwater drawdown is sufficient to warrant modification of the one-foot guideline and the present approach for regulating drawdown. Three important conceptual changes are recommended:

First, we recommend setting different drawdown criteria for different wetland community types and hydrologic regimes. The nature and extent of impacts can vary over large areas because of differences in geological setting, hydrologic regimes, plant communities and their inherent vulnerability to groundwater drawdown at different times of the year. Citing the need to consider differences in vulnerability to impacts among different wetland types and settings, an administrative law judge strongly criticized the SWFWMD for applying a single numerical drawdown limit similar to the one-foot guideline to all wetland types throughout the region[1]. Our interpretation of the data from wetlands in the SFWMD supports the concept of using different drawdown criteria for the three different wetland types introduced in this report based on inherent differences in hydrologic regime. This categorization represents the vast majority of wetland types in south and central Florida and reflects broad differences in wet and dry season hydrologic regimes and ecological tolerance of water table drawdown.

Second, we recommend the use of different criteria for the wet season and the dry season. Our study of isolated wetlands indicates that there are distinct seasonal differences in the dependence of wetland biota on the water table position and tolerance of drawdown which stem from adaptations of flora and fauna to natural hydrologic fluctuations. Although wet season criteria are needed to maintain the present level of protection and avoid extreme impacts, we believe that constraining dry season water table position is most critical to sustaining beneficial wetland functions over the long term.

Type 1 wetlands are most vulnerable to reductions in water table position during the dry season. These wetlands naturally contain standing water throughout the dry season, and a minimum water table elevation is required to maintain aquatic refugia for fish, invertebrates, reptiles, and a variety of other animals which use these sites when Type 2 and 3 wetlands are dry. Large amounts of water storage and adequate water depths make Type 1 wetlands less vulnerable to adverse effects of drawdown during the wet season. Type 2 wetlands may be equally vulnerable to drawdown impacts in both the wet and dry seasons. In Type 2 wetlands, the dry-season water table typically stays near the ground surface and in contact with organic soil layers, keeping surface soils saturated most of the time. Many organisms inhabiting Type 2 wetlands rely on saturated soils to survive the lack of standing water in the dry season. Sufficient surface water levels are needed in the wet season to ensure normal levels of primary and secondary production, but relatively smaller amounts of surface water storage makes them more vulnerable than Type 1 wetlands to drawdown during the wet season. Type 3 wetland communities are typically adapted to short hydroperiods and frequent drying of surface water. The dry season water table naturally falls below the root zone of the dominant plants and, with few exceptions, the dominant fauna are not highly dependent on the water table position during the dry season. Notable exceptions to this include crayfish and some benthic invertebrates that burrow during the dry season in response to changes in the soil moisture gradient. Additional research on these organisms may eventually suggest a biological limit on the dry-season water table position for Type 3 wetlands. In the absence of such a limit, constraints on the water table position at the end of the dry season are needed to ensure that the hydroperiod is not substantially reduced due to delayed wetting in early summer. Type 3 wetlands are considered most vulnerable to adverse impacts during the wet season because reductions in the naturally short hydroperiods and shallow water depths of these wetlands can seriously reduce biological production.

Third, we recommend setting criteria and evaluating drawdown such that wetland functions are protected for all hydrologic conditions up to and including a 1-in-10-year drought. Recent statutory guidance indicates that potential impacts of water withdrawals be evaluated under a 1-in-10-year drought condition to ensure an equivalent level of certainty for allocations (Burns, 1997). However, focusing evaluation of wetlands solely on drought conditions does not necessarily protect wetland functions during periods of normal or less extreme weather. The maximum expected drawdown in severe drought (no recharge) conditions may be little different from the drawdown expected during a normal dry season.

Approaches to Setting Criteria. The ultimate goal of this research is to provide scientific guidance for developing numerical criteria to protect wetlands from harmful impacts of groundwater drawdown. At this interim stage of progress, our ability to set definitive criteria applicable to 1-in-10-year drought conditions is limited by the relatively short (2 years) data set collected and analyzed so far. Nevertheless, this data set provides insight into the generic hydrologic behavior of isolated wetlands and how groundwater pumping alters the wetland hydrologic regime. This knowledge combined with the results of hydrologic simulation

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[1] Charlotte County; Pinellas County; Environmental Confederation of Southwest Florida, Inc.; DeSoto County; Hardee County; Polk County; GBS Groves, Inc.; and Citrus Grower Associates, Inc. v. Southwest Florida Water Management District and Intervenors, Florida Citrus Mutual and Manatee County, 19 F.A.L.R. 3280 (DOAH Final Order, March 27, 1997)

modeling and information from the scientific literature on the hydroecology of important wetland species and communities can be used to develop interim criteria based on best currently available information. These interim criteria can then be evaluated and refined as additional data are analyzed and new research results become available. Several alternative approaches for developing drawdown criteria based on hydrobiological data and modeling are described below.

Several approaches have been used previously by water managers to set hydrologic criteria for protecting aquatic and environmental resources. One type of approach relies on direct evidence linking harmful changes in wetland functions or ecological processes to specific levels of drawdown. Such an approach not only requires statistically robust hydrologic and ecological data sets encompassing a wide range of possible drawdown scenarios and wetland settings, but also necessitates a quantifiable definition of "harm." Obtaining statistically significant data that convincingly demonstrates a cause and effect relationship between drawdown and impacts requires either long periods (>5 years) of monitoring or controlled experiments whereby pumping and drawdown are manipulated within prescribed limits and resulting changes in ecological functions are carefully measured. However, even a controlled experiment may require several years of operation before meaningful data relating drawdown to ecological harm can be generated. At present, neither our hydrologic nor biological data sets are of sufficient length to apply this kind of cause-and-effect approach to setting drawdown criteria. Opportunities may exist in the future for implementing controlled drawdown experiments in cooperation with public water supply utilities. However, this approach will require close coordination and cooperation on the part of District regulatory and scientific staff, the utility operator, and the landowner of affected wetlands.

Another possible approach to setting criteria looks at patterns of impacts in many wetlands within the cone of depression of a withdrawal. Using hydrologic modeling to estimate drawdown contours over the cone of depression, threshold levels of drawdown can be identified at which impacts first become observable or significant. Using this approach on large public water supply wellfields, the Southwest Florida Water Management District found that most of the wetlands for which the modeled drawdown was greater than one foot exhibited clear signs of impact, while few, if any, wetlands with drawdown less than one foot were impacted (Rochow, 1994). Application of this approach is limited by the accuracy of the groundwater models used to compute drawdown, the need for groundwater data for calibrating such models, and the need for sufficient numbers of replicate wetlands within the cone of depression to provide statistical validity. Ideally, this approach is best suited to areas with a high density of similar-type wetlands, each subjected to a different magnitude of drawdown encompassing the full range of interest (i.e., from no drawdown to very high values of drawdown). Unfortunately, none of our present study sites offer ideal conditions for application of this approach. Constraints in site selection prevented our monitoring a sufficient number of sites over a sufficient range of drawdown values to ensure adequate statistical validity or to accurately determine threshold levels.

A third potential approach develops performance standards based on the expected hydrologic behavior of unimpacted wetlands. One such approach utilizes long-term hydrologic data sets to define a natural range of variability for ecologically-relevant hydrologic parameters. Criteria can be set such that departure of hydrologic parameters from the normal range of variability occurs with no greater frequency and magnitude than would have occurred naturally. This kind of approach has been used by SFWMD to set minimum water level values for wetlands in the Everglades Protection Area (Swift *et al*, 1998). In this case, the natural range of variability was determined using a Natural Systems Model to simulate historic (pre-development) water levels in the Everglades. Richter *et al* (1997) describes a similar method for setting flow targets in large rivers, whereby the normal range of variability of various hydrologic parameters is defined using the standard deviation of historic unimpacted flows. At present our hydrologic data records from reference wetlands are of insufficient length to confidently estimate the range of natural variability in this manner. However, the existing database, combined with inferences from previous published studies of wetland hydrology in south Florida and known hydrologic requirements of key wetland species and communities, can be used to develop hydrologic performance standards. Hydrologic modeling of the study wetlands under various drawdown scenarios would then be used to determine maximum allowable drawdown levels for which the performance standards are satisfied.

Performance Standards. Section 6.2 described a "reference hydrology" for isolated wetlands based on the annual hydrologic regime of unimpacted reference wetlands. This reference hydrology can be used to set hydrologic performance standards for use in permitting groundwater withdrawals. These **performance standards** are qualitative statements or constraints on wetland hydrology and water table position based on the findings of this study and inferences drawn from similar research that are indicative of unimpacted reference wetlands. Our recommendation is to relate performance standards to those parameters that are critical to sustaining beneficial wetland functions and most likely to be affected by groundwater drawdown. Based on our interpretation of the hydrologic data, the most important parameters to constrain are the minimum dry season water table position and the median wet season surface water stage. Rationale for setting wet and dry season performance standards for these parameters is discussed below and summarized in Table 7.1. Simulation modeling will be needed to refine this guidance in several areas and to develop specific numerical drawdown criteria.

- Dry season performance standards – *Dry season constraints on water table position are the most important in sustaining critical wetland functions.* The dry season is the period of the year most stressful to wetland biota and when irreversible successional changes are most likely to occur if stress becomes too severe. It is also the period when water demand is highest, drawdowns are at a maximum, and rainfall is least likely to buffer the adverse effects of drawdown. The dry season water table position also has a strong influence on the timing of re-wetting in the summer and hence can affect the length of the wetland hydroperiod. A relatively high dry-season water table can buffer the effects of below-average rainfall during the subsequent wet season. However, when the dry-season water table is substantially depressed, wet season hydrologic functions can be impaired due to delayed wetting and reduced hydroperiod. Based on this research, we believe that the hydroperiod will not be adversely affected as long as the dry-season water table position remains within the natural range of variability indicated in Table 5.6.

  - *Performance standards must address the dependence of wetland biota on the dry-season water table position and differences among the three wetland types.* Wetland community types 1 and 2 are most dependent on the dry-season water table position to sustain biological functions over the annual hydrologic cycle. Criteria for Type 1 wetlands should address their function as dry-season refugia and sources of dispersal for certain aquatic organisms.
  - *Performance standards must address the depth of the water table at the end of the dry season and its effect on the timing of wetland rehydration and length of hydroperiod.* The minimum allowable dry-season water table elevation to prevent harmful changes in the wet-season hydrology will need to be determined by simulation modeling. This constraint will be most critical for Type 2 and 3 wetlands. At FP2 (Type 2), dry-season water table depths 2-5 feet greater than typical depths observed at reference sites resulted in a reduction of 18-25% in the hydroperiod.

- Wet season performance standards -- *Wet season criteria are necessary to maintain the present level of protection and avoid extreme impacts on biological productivity.* Drawdown should be constrained to avoid substantial changes in hydroperiod or intolerable changes in wet-season water levels. Performance standards could be based on the duration the wetland stage is above the margin elevation or departure of the median wet-season stage from the margin elevation as described in Section 5.3. During the wet season, Type 3 wetlands are most sensitive to reductions in water level and hydroperiod because of the small water depths characteristic of these systems.

Hydrologic performance standards based on the above guidance are proposed below (Table 7.1). These performance standards should be considered tentative, to be refined as additional monitoring data is analyzed and interpreted; in some cases where considerable uncertainty still exists the performance standards could be treated as hypotheses to be tested through further research.

Table 7.1 – Summary of Recommended Performance Standards

1. Type 1 wetlands, Dry Season: Water table position should be limited so that a minimum standing water depth is maintained during a normal dry season to provide refuge for alligators and sustain aquatic conditions for fish and invertebrates. Surface water depth should not fall below the upper threshold for foraging by wading birds, or approximately 2 feet (Mahoney, 1997). The dry-season water table should at no time drop below the bottom of the wetland.

2. Type 1 wetlands, Wet Season: Due to the large volume/depth of water in Type 1 wetlands, drawdown impacts during the wet season are considered unlikely. Performance standard should be based on maintaining aquatic productivity through adequate surface water depth.

3. Type 2 wetlands, Dry Season: Drawdown should be limited so that the capillary fringe above the water table remains in contact with the ground surface of the wetland throughout a normal dry season. This standard will ensure that the wetland substrate remains saturated through the dry season.

4. Type 2 wetlands, Wet Season: Drawdown should be limited so that the median wet season surface water stage during a normal year stays within ± 10 % of the wetland margin elevation to ensure adequate biological productivity and hydrologic connectivity with adjacent flatwoods. Water levels should equal or exceed margin elevation continuously for a duration of 90 days at least once each wet season.

5. Type 3 wetlands, Dry Season: Minimum dry-season water table position should be limited in a normal year such that the subsequent hydroperiod is reduced no more than 20% due to delayed re-wetting.

6. Type 3 wetlands, Wet Season: Drawdown should be limited so that the wetland is inundated continuously for a period of at least 90 days during a normal wet season. This standard is intended to prevent frequent dryout caused by water level reversals in the wet season and will ensure adequate hydroperiod and mobility for characteristic Type 3 plants and animals.

These performance standards can be used in conjunction with hydrologic modeling to determine appropriate numerical drawdown limits for each wetland type and season. Numerical criteria should be selected which provide equal or greater levels of protection than the existing one-foot guideline and which satisfy the performance standards for normal rainfall conditions. Additional performance standards may be warranted to ensure that the hydrologic needs of certain listed wetland species are not compromised by the timing or magnitude of a proposed groundwater drawdown. Listed species in south Florida wetlands with special hydrologic needs include wood stork, sandhill crane, snail kite, gopher frog, alligator, little blue and tricolor herons, white ibis, and snowy egret.

7.2 Recommendations for Further Research and Monitoring

This project was conceived and implemented as a long-term research and monitoring effort with a targeted duration of five years of data collection. To date, we have collected approximately two years of detailed hydrologic data and analyzed and interpreted about eighteen months of this at the original twenty study sites. We have also collected approximately one year of monthly water level data at the agricultural study wetlands that were installed in 1998; instrumentation of these sites to allow collection of more detailed hydrologic data was completed in January 2000. Analysis of this data is expected to begin in early 2000.

This report provides interim guidance for criteria development based on a limited (and somewhat unusual) range of observed climate conditions. Continuation of this research and monitoring effort is important so that we can expand the range of observations for normal, wet, and dry climatic conditions in both the wet and dry seasons. Additional recommendations for further work needed to improve the quality of information, refine performance standards, and broaden the applicability of the results are outlined below:

General:

- *Continue hydrologic monitoring at all existing study wetlands (including agricultural sites) through fiscal year 2002.* Continued monitoring will ensure a minimum of five years of monitoring under a variety of climatic and hydrologic conditions, improving confidence in estimates of minimum water table depths, hydroperiods, and wet season water levels.

- *Continue hydrologic monitoring at the Lower West Coast agricultural sites.* Monitoring at agricultural sites will allow for comparison with wetlands affected by public water supply (PWS) wellfields and reference sites. The hydrologic regimes and vulnerability of wetlands in agricultural settings may be very different from wetlands discussed in this report that are influenced by PWS withdrawals because of differences in timing and frequency of water use and interactions between surface and groundwater. Monitoring at agricultural sites will enable us to determine whether different criteria should be applied to different categories of water use.

- *Continue effort to develop robust hydrologic models of the wetland study areas described in this report.* Several years of detailed surface and groundwater data from a variety of wetlands in each study area provide a robust data set for calibrating hydrologic models that can be used to simulate conditions (e.g., severe drought) not encountered in monitoring. Modeling should be used to determine numerical criteria that satisfy the performance standards described in Section 7.1. An integrated surface water-groundwater modeling effort focusing on the Flint Pen Strand study area was begun in early 1999 and is expected to be a critical component of the criteria development process for the Lower West Coast planning area. We recommend expanding this effort to include other study areas in different planning regions that may have characteristics different from those at Flint Pen.

Expand Monitoring Program:

- *Expand monitoring in existing study areas to include more Type 1 and Type 3 wetlands.* More observations are needed of Type 1 and 3 wetlands that are not presently well represented to validate and refine conclusions regarding these wetland communities. Most of the existing study sites are depressional wetlands that contain zones of Type 1, 2, and 3 communities. However, additional observations are needed of non-depressional Type 1 wetlands such as sloughs and riverine systems and Type 3 wetlands such as hydric flatwoods, hydric hammocks, and wet prairies. Additional biological investigation may be necessary to verify that sites identified as Type 1 wetlands are functioning as dry-season refugia for aquatic organisms.

- *Expand geographic representation of the District to include new sites in the Lower East Coast and upper Kissimmee basin planning areas.* New study sites may be warranted in west Miami-Dade Co. and Orange Co. in areas where new wellfields are being developed or where projected future water use is expected to pose a threat to wetland systems. These areas are under-represented in the present study.

Improve Observation and Measurement of Hydrologic Parameters at Existing Sites:

- *Additional production zone monitoring wells are needed at selected sites to investigate the important relationship between the groundwater production zone of the aquifer and sandy surficial zone that underlies most wetlands.*

- *Improved measurements are needed of soil moisture at various depths in the soil profile.* The recommended minimum water table elevations discussed in this report are based on best available information on the root zone depths, soil moisture content above the water table, and the dry-season ecology of key wetland organisms. Monitoring soil moisture continuously at various depths within and below the root zone would allow for greater refinement of root zone depth, height of the capillary fringe above the water table, distribution of soil moisture in the unsaturated zone, and utilization of soil water by wetland plants. This information is needed to validate and refine dry season drawdown criteria for Type 2 and 3 wetlands.

- *Conduct additional hydrogeologic investigation at sites SV1 and WR8 to determine if confining layers are present and, if so, if they are producing a perched water table in the wetlands.* Soil borings within the wetland depression at these sites could be used to identify the presence and thickness of possible confining layers and more thoroughly document sub-surface conditions. Additional piezometers would then need to be installed above and below suspected confining layers and in the wetland margin area to assess fluctuations in the water table relative to those of the wetland surface water.

Refine Basis for Performance Standards through Additional Hydrobiological Research:

- *Conduct research on the response of benthic invertebrates and crayfish to declining water table position.* Proposed dry-season performance standards for Type 2 and 3 wetlands in Section 7.1 are based on hydrologic observations only. Additional study of these important wetland organisms and the responses (e.g., burrowing) they make to falling water tables in the dry season is needed to determine if biological limits to water table position exist which would be more protective than those suggested by hydrologic observations alone.

Other:

- *Implement a controlled drawdown experiment at selected wetland sites in cooperation with a public water supply wellfield.* A controlled field experiment would be valuable in validating assumptions regarding the effects of drawdown on wetland hydrology and refining drawdown criteria to be used for different wetland types.

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APPENDICES

APPENDIX A

Table A.1 – Well Field Characteristics

Well Field (Project Study Area)	Lee County Utilities Corkscrew Well Field (Flint Pen Strand)	Martin County Utilities North County Well Field (Savannas)
Permit No.	36-00003-W	43-00102-W
Permit Duration	2/12/98 to 2/12/03	8/15/96 to 8/15/01
Type	Public water supply	Public water supply
Source	Water table (surficial) and Sandstone Aquifers	Surficial and Floridan Aquifers
No. Production Wells (Surficial)	18 existing plus 4 additional drilled in 1998 but not yet operated	10 existing plus 3 additional permitted
Production Zone Depth	40-150 feet	70-125 feet
Began Pumping	1981-82	1982-83 (Wells 1-8) 1988 (Wells 9-10)
Average Withdrawals 1997-98 (Surficial Only)	5.8 MGD	1.3 MGD
Capacity (Surficial Only)	15.12 MGD	5.18 MGD
Allocation (Surficial Only)	8.84 MGD	35.69 MGM (1.19 MGD)

APPENDIX B

Table B.1 - Surficial Aquifer Characteristics

Planning Region	Surficial Aquifer System Constituents	Thickness	Major Producing Zones
Kissimmee River Basin	Unconsolidated sands with interfingered clays, shells, sandstone, limestone, and gravel	50-200 ft. (thickness increases north to south) (50-100 ft. in Disney Wilderness Preserve vicinity)	SAS: none Other: Floridan Aquifer System
Lower West Coast	Unconsolidated sands and water-bearing limestone with interfingered shells, clays, silts, and thin limestone layers	25-125 ft. (50-100 ft. in Flint Pen Strand vicinity)	SAS: Water Table zone (0-40 ft depth), Tamiami zone (50-70 ft depth) Other: Sandstone Aquifer (within Hawthorne Formation)
Upper East Coast	Unconsolidated fine sand, shells, sandy limestone	90-200 ft. (120 ft. in Savannas, 160-180 ft. in vicinity of Jonathan Dickinson SP)	SAS: limestone layers (50-120 ft depth) Other: Floridan Aquifer System
Lower East Coast *	Biscayne Aquifer: Low-permeability oolitic limestone (Miami limestone) over porous water-bearing limestone (Ft. Thompson) Tamiami Formation: shelly sands, clays, silts, and limestone	130-250 ft. (vicinity of Dade West Well Field)	SAS: Ft. Thompson Formation in Biscayne Aquifer, Tamiami zone Other: none

* Source: Merrit (1996)

APPENDIX D
Table D.1 – Soils and Natural Communities

Site	Soil Unit [1]	Muck Thickness in Center (inches)	NRCS Soil Landscape Position	Dominant FNAI Natural Community
Flint Pen Strand				
FP2	Copeland sandy loam, depressional	24	Sand depression	Depression marsh (w/cypress fringe)
FP3	Felda fine sand, depressional	72	Sand depression	Dome swamp (cypress)
FP4	Felda fine sand, depressional	48	Sand depression	Dome swamp (cypress)
FP5	Felda fine sand, depressional	72	Sand depression	Dome swamp (cypress)
FP6	Felda fine sand, depressional	48	Sand depression	Dome swamp (cypress)
FP7	Felda fine sand, depressional	48	Sand depression	Dome swamp (cypress)
FP8	Copeland sandy loam, depressional	48	Sand depression	Dome swamp (cypress)
FP9*	Pineda fine sand	0	Slough (flats)	Wet flatwoods (disturbed)
FP10*	Pineda fine sand	0	Slough (flats)	Wet flatwoods/wet prairie
Savannas S.P.				
SV1	Waveland-Lawnwood Complex**	12	Sand depression	Depression marsh
SV4	Placid sand	12	Sand depression	Depression marsh
SV5	Mapped as Waveland sand (SV5 is likely an inclusion of Waveland sand, depressional or Placid Sand)	18	Flatwoods (mapped unit) Sand depression (inclusion)	Depression marsh
SV6	Mapped as Waveland sand (SV6 is likely an inclusion of St. Johns variant sand)	0	Flatwoods (mapped unit) Slough (flats) (inclusion)	Depression marsh? (sand cordgrass)
Jonathan Dickinson S.P.				
JD6	Waveland sand, depressional	6	Sand depression	Depression marsh or wet prairie (fragmented)
JD12	Riviera fine sand, depressional	6	Sand depression	Depression marsh
JD26	Basinger fine sand, depressional	2	Sand depression	Wet flatwoods and wet prairie with dome swamp in center

JD29	Inclusion in Paola and Pomello sands (sandhills) Inclusion is likely Waveland sand, depressional or Basinger fine sand, depressional	?	Sand depression	Sandhill upland lake (note: soil survey denotes this site as perennially wet pond)
Walker Ranch				
WR6	Basinger fine sand, depressional	12	Sand depression	Depression marsh
WR8	Basinger fine sand, depressional	6	Sand depression	Depression marsh
WR9	Basinger fine sand, depressional	24	Sand depression	Depression marsh
WR11	Placid and Myakka fine sands, depressional	42	Sand depression	Dome swamp (tupelo)
WR15	Placid and Myakka fine sands, depressional	36	Sand depression	Dome swamp (cypress)
WR16	Placid and Myakka fine sands, depressional	6	Sand depression	Dome swamp (cypress, tupelo)

* Site added 5/98

** Undifferentiated complex of Waveland sand, depressional and Lawnwood fine sand, depressional

[1] Note that most of the sites may actually be undifferentiated soil complexes or inclusions, given size of depression and/or muck deposit is typically at or less than NRCS minimum mapping unit; further soil investigation in the field may be necessary to further delineate.

APPENDIX E

Table E.1 – Sensor Specifications

Parameter	Device	Accuracy	Logging Frequency
Wetland Monitoring Stations			
Groundwater elevation	Design Analysis H3-10 Pressure transducer	±0.02 ft	15 minutes
Surface water elevation	Handar float & encoder	±0.02 ft	15 minutes
Weather Monitoring Stations			
Rainfall	Weathertronics or Leopold and Stevens tipping bucket gauge	±0.01 in	5 minutes during event (Recorded as daily totals)
Air temperature	Vaisala HMP35C temperature and humidity probe	±0.40 °C.	15 minutes
Relative humidity	Vaisala HMP35C temperature and humidity probe	±2% RH 0-90% ±3% RH 90-100%	15 minutes
Barometric pressure	Vaisala PTB101B pressure transducer	±0.375 mm Hg	15 minutes
Total solar radiation	LI-COR LI200SZ pyranometer	±0.075 kWm^{-2}	15 minutes
Net radiation	REBBS Q6 or Q7 net radiation probe	±0.075 kWm^{-2}	15 minutes
Photo-active radiation	LI-COR LI190SZ Quantum	±100 $\mu Es^{-1}m^{-2}$	15 minutes
Wind speed	Handar ultrasonic wind sensor	±1 MPH < 30 MPH ±3% > 30 MPH	15 minutes
Wind direction	Handar ultrsonic wind sensor	±3.6°	15 minutes

APPENDIX F
Table F.1 Monthly Rainfall Totals

Study Area	**Flint Pen Strand**	**Savannas**	**Jonathan Dickinson**	**Disney Wilderness Pres.**
April	ND	ND[2]	ND	3.38 P[4]
May	ND	0.69 P	ND	ND
June	ND	7.77 (+0.52)	ND	0.35 P
July	ND	3.16 (-3.34)	ND	9.27 (+2.02)
August	ND[1]	8.08 (+0.83)	ND[3]	3.57 (-2.93)
September	8.46 (+0.21)	5.07 (-2.68)	5.07 P	0.64 (-5.36)*
October	0.34 (-2.91)*	1.26 (-5.74)*	0.48 P (-6.77)*	3.55 (+0.55)
November	4.00 (+3.00)	6.21 (+3.21)	ND	2.78 (+0.78)
December	7.53 (+6.13)	1.84 P (-0.56)	0.73 (-1.77)	8.71 (+6.71)
1997 Total	20.33 P	34.08 P	6.28 P	32.25 P

Study Area	**Flint Pen Strand**	**Savannas**	**Jonathan Dickinson**	**Disney Wilderness Pres.**
January	2.61 (+0.51)	3.08 P (+0.78)	3.07 (+0.47)	3.61 (+1.36)
February	6.58 (+4.33)	3.47 P (+0.87)	6.92 (+4.32)	5.70 (+3.20)
March	4.72 (+2.22)	4.13 (+0.63)	6.53 (+3.28)	4.72 (+1.72)
April	0.88 (-1.12)	4.28 (+1.58)	5.50 (+2.50)	0.85 (-1.40)
May	4.54 (+0.54)	2.57 (-2.43)	1.57 (-3.68)	1.94 (-2.06)
June	6.19 (-2.81)	1.29 (-5.96)*	3.03 (-4.97)*	3.31 (-4.19)*
July	5.84 (-2.66)	8.06 (+1.56)	2.55 (-3.95)*	10.97 (+3.72)
August	11.16 (+2.66)	6.81 (+0.31)	5.39 (-1.86)	4.61 (-1.89)
September	8.48 (+0.23)	7.60 (-0.15)	10.76 (+2.51)	4.77 (-1.23)
October	2.34 (-0.91)	0.93 (-6.07)*	1.20 (-6.05)*	0.69 (-2.31)*
November	8.75 (+7.75)	4.21 (+1.21)	9.62 (+6.12)	3.74 (+1.74)
December	2.27 (+0.87)	2.16 (-0.24)	1.64 (-0.86)	0.52 (-1.48)
1998 Total	64.36	47.58 P	57.78	45.43

Note: Values in parentheses are amounts (inches) above (+) or below (-) long-term monthly average reported by Ali, *et al* (1999) and Macvicar (1981)

P	Partial record for period indicated
ND	No data for period indicated or weather station not installed
*	Approaches 1-in-10-year dry month for wet season (based on Ali, *et al*, 1999)

[1] Flint Pen Strand weather station installed September 3, 1997.

[2] Savannas weather station installed April 14, 1997.

[3] Jonathan Dickinson weather station installed September 12, 1997.

[4] Disney Wilderness Preserve weather station installed April 16, 1997.

APPENDIX G

Table G.1 – Topography and Water Elevations

Site (Acreage Below Margin)	**Wetland Topographic Elevations**	**Spring 1999 Drought**	**CY 1997**		**CY 1998**	
	B = Bottom **M** = Margin **R** = M-B **NP** = Normal Pool Indicator **SH** = Seasonal High Indicator	**Low**	**Low**	**High**	**Low**	**High**
FP2 (3.98)	B = 16.0’ Outlet* = 17.8’ M = 18.6 R = 2.6’ NP = 18.6’ SH: 18.9-19.2’	**GW**: 10.01’ 6/7/99	**GW**:11.73' 5/22/97	18.91' 10/27/97	**GW**:12.31' 7/10/98	18.65' 3/18/98 18.69' 9/21/98 19.35’ 11/4/98
FP3 (3.71)	B = 14.0’ M = 17.4’ R = 3.4’ NP = 17.5’ SH = 18.1’	**GW**: 12.66’ 6/8/99	**GW**: 14.18’ 5/11/97 & 6/12/97	17.68’ 9/30/97 17.53’ 12/17/97	**GW**: 14.24’ 5/26/98	17.63’ 2/19/98 17.63’ 9/17/98 17.72’ 11/7/98
FP4 (6.52)	B = 13.6’ M = 16.6’ R = 3.0’ NP = 17.3’ SH = 18.0’	**GW**: 12.63’ 6/7/99	**GW**: 13.82’ 6/12/97	17.25’ 9/29/97	**GW**: 13.80’ 5/25/98	17.38’ 2/20/98 17.40’ 9/20/98 17.68’ 11/7/98
FP5 (3.22)	B = 14.2’ AH = 12.2’ M = 17.0’ R = 2.8’ SH = 17.4’	**GW**: 12.95’ 6/8/99	**GW**:14.00' 6/12/97	17.46' 12/14/97	**GW**:13.79' 5/26/98	17.33' 1/17/98 17.42' 9/21/98 17.69’ 11/4/98
FP6 (2.61)	B = 14.1’ AH =11.0’ M = 16.7’ R = 2.6’ NP = 17.0’ SH = 17.5’	**GW**: 12.83’ 6/8/99	**GW**: 14.05' 5/11/97	17.33' 9/28/97	**GW**:13.60' [1] 5/26/98	17.21' 2/18/98 17.54’ 11/5/98
FP7 (5.36)	B = 13.6’ AH = 12.8’ M = 16.7’ R = 3.1’ NP = 16.6’ SH = 17.2’	**GW**: 12.87’ 5/10/99	**GW**: 13.95' 6/12/97	17.00' 12/15/97	**GW**:13.74' [1] 5/25/98	16.88' 3/19/98 16.94' 9/21/98 17.37’ 11/5/98

FP8 (7.14)	B = 14.3’ AH = 12.7’ M = 16.7’ R = 2.4’ NP = 16.8’ SH = 17.7’	**GW**: 12.40’ 6/8/99	**GW:** 13.61’ 6/12/97	17.13’ 7/30/97 17.17’ 9/27/97	**GW**: 13.65 5/25/98	17.35’ 2/20/98 17.35’ 9/20/98 17.63’ 11/7/98
FP9	B: 16.5’	**GW**: 12.87’ 6/7/99	N/A	N/A	N/A	N/A
FP10	B: 16.3’	**GW**: 12.05’ 5/9/99	N/A	N/A	N/A	N/A
WR6 (3.23)	B = 62.5’ M = 64.5’ R = 2.0’	**GW**: 60.35’ 5/6/99	**GW**: 61.80' 4/23/97	64.82' 8/10/97	**GW**: 61.80' 6/19/98	65.31' 3/18/98 64.83’ 9/19/98
WR8 (3.80)	B = 66.1’ M = 69.4’ R = 3.3’	**GW**: 63.17’ 5/6/99	**GW**: 64.59’ 4/13/97	70.16’ 12/28/97	**SW**: 66.61’ **GW**: 64.50’[2] 7/5/98	70.34’ 2/17/98 70.29’ 3/22/98
WR9 (6.83)	B = 64.8’ M = 68.3’ R = 3.5’	**GW**: 63.44’ 5/6/99	**SW**: 65.75’ **GW**: 64.96’[2] 5/30/97	68.76’ 12/28/97	**SW**: 66.16’ **GW**: 64.99’[2] 7/4/98	69.04’ 2/20/98 69.08’ 3/20/98
WR11 (4.27)	B = 66.0’ M = 67.4’ R = 1.4’ SH = 67.9’	**GW**: 62.71’ 6/2/99	**GW**: 65.10’ 4/22/97	67.93’ 12/14/97	**GW**: 64.49’ 7/4/98	67.97’ 2/20/98 67.96’ 3/19/98
WR15 (1.40)	B = 61.5’ M = 63.5’ R = 2.0’ NP = 63.5’ SH = 63.9’	**GW**: 58.24’ 6/2/99	**GW**:60.57' 4/23/97	63.73’ 8/8/97	**GW**:59.36' 7/5/98	63.98' 2/19/98
WR16 (2.81)	B = 64.3’ M = 66.3’ R = 2.0’ SH = 66.2	**GW**: 60.60’ 6/2/99	**GW**:63.05' 4/22/97	66.18' 8/7/97	**GW**:62.17' 7/5/98	66.32' 2/19/98
JD6 (4.93)	B = 6.8’ M = 9.5’ R = 2.7’	**GW**: 5.32’ 5/29/99	**SW**: 8.78’ **GW**: 7.55’[2] 4/11/97	9.86’ 8/10/97	**SW**: 7.68’ **GW**: 6.34’[2] 9/3/98	9.43’ 3/22/98 9.37’ 9/26/98 9.30’ 11/9/98
JD12 (4.35)	B = 10.7’ M = 13.0’ R = 2.3’	**GW**: 8.73’ 5/8/99	**SW**: 12.57' **GW**: 10.80’[2] 5/18/97	13.32' 8/8/97	**SW**: 11.92' **GW**: 9.80’[2] 8/2/98	13.17' 3/20/98 13.11’ 9/24/98 13.30’ 11/4/98
JD26	B = 8.7’ M = 9.9’ R = 1.2’ NP = 10.1’ SH = 10.6’	**GW**: 6.22’ 5/29/99	**SW**: 9.50' **GW**: 8.80’[2] 11/20/97	10.66' 8/9/97	**GW**: 7.45' 7/30/98	10.41' 3/20/98 10.38' 9/24/98 10.64 11/5/98
SV1 (3.36)	B = 14.7’ M = 16.4’ R = 1.7’ SH = 17.1’	**GW**: 12.01’ 4/27/99	**SW**: 15.58' **GW**: 13.75’[2] 5/27/97	17.17' 8/10/97	**SW**: 15.17' **GW**: 12.95’[2] 7/8/98	17.24' 2/16/98 17.20’ 9/20/98 17.10’ 11/5/98

SV4 (1.70)	B = 12.0' M = 13.5' R = 1.5'	**GW**: 8.11' 5/29/99	**GW**:9.86' 5/19/97	13.71' 6/20/97	**GW**:10.07' 8/5/98	14.43' 2/16/98 14.20' 9/25/98 14.30' 11/5/98
SV5 (0.74)	B = 12.4' M = 13.9' R = 1.5'	**GW**: 9.27' 5/30/99	**GW**:11.07' 5/28/97	14.21' 6/20/97	**GW**:11.62' 8/5/98	14.84' 3/21/98 14.70' 9/26/98 14.87' 11/5/98
SV6 (0.41)	B = 12.3' M = 13.6' R = 1.3'	**GW**: 10.59' 5/30/99	**GW**: 12.17' 5/28/97	14.04' 9/29/97	**GW**: 12.05' 8/3/98	14.16' 3/20/98 14.07' 9/20/98 14.36' 11/5/98

SW: lowest surface water reading
GW: lowest groundwater reading
2 surface water remained in main depressional basin of wetland the entire calendar year
* Elevation of surface flow outlet from FP2 to south

Table G.3 – Median Wet-Season Water Levels

SITE	Median Wet-Season Surface Water Elevation (ft NGVD)[1]	Departure from Margin Elevation (Margin – Median)[2]	Departure as Percentage of Total Wetland Relief (%)[3]
FP2	18.04	0.56	21.5
FP3	17.16	0.24	7.1
FP4	16.90	-0.30	-10.0
FP5	17.07	-0.07	-2.5
FP6	16.82	-0.12	-4.6
FP7	16.59	0.11	3.5
FP8	16.72	-0.02	-0.8
WR6	64.09	0.41	20.5
WR8	67.96	1.44	43.6
WR9	67.14	1.16	33.1
WR11	66.90	0.50	35.7
WR15	62.30	1.20	60.0
WR16	64.98	1.32	66.0
JD6	9.15	0.35	13.0
JD12	12.75	0.25	10.9
JD26	9.87	0.03	2.5
SV1	16.76	-0.36	-21.2
SV4	13.21	0.29	19.3
SV5	13.65	0.25	16.7
SV6	13.52	0.08	6.1

[1] Median daily surface water elevation from all observations during the following three wet periods: 6/1/97-10/31/97, 11/1/97-4/30/98, 6/1/98-10/31/98

[2] Margin elevation of each site given in Table G.1 (Appendix G)

[3] Total relief of each site given in Table G.1 (Appendix G)

APPENDIX H – Stage-Duration Curves

FIGURES

Fig. 2.6 Surficial Aquifer System

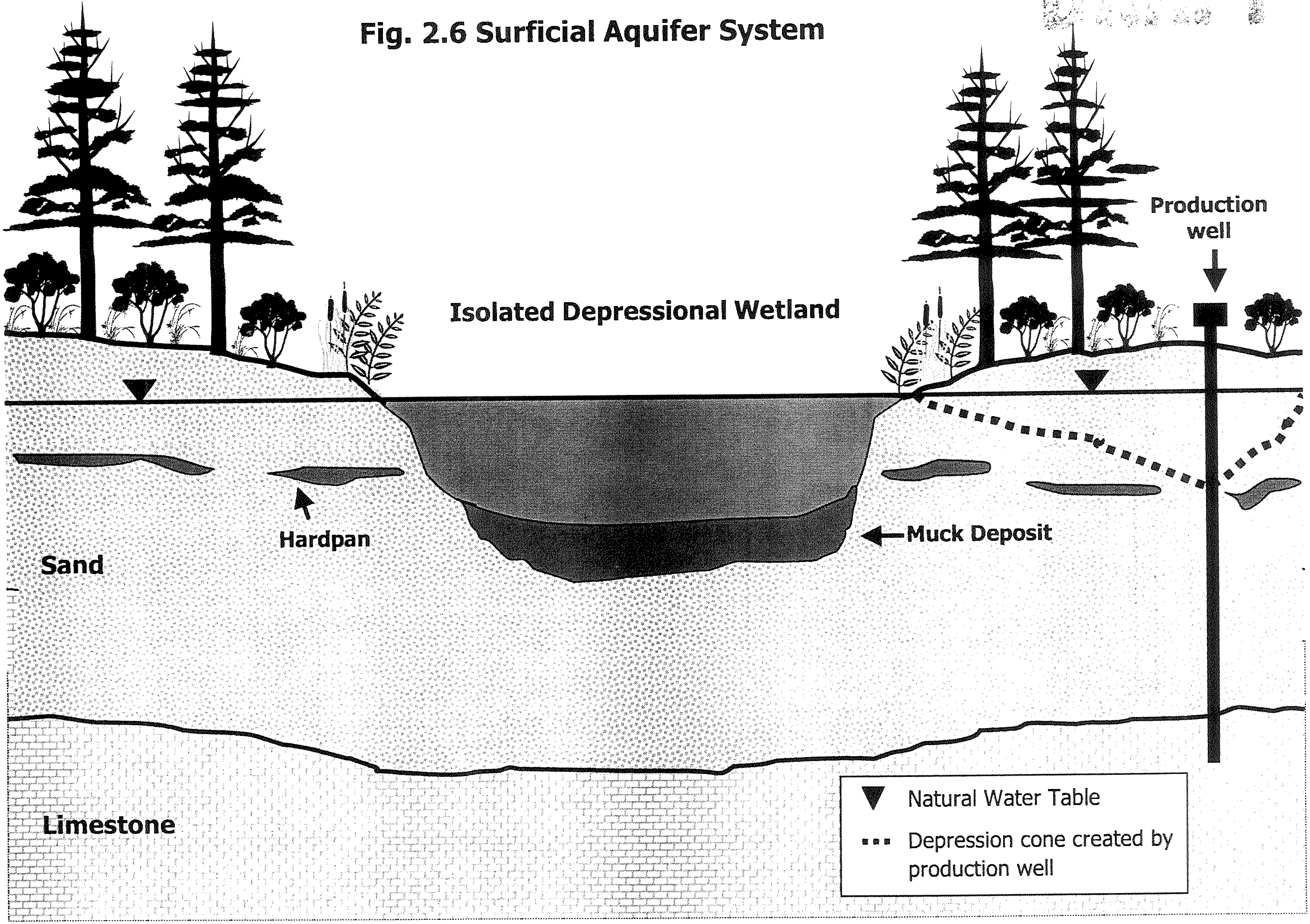


Fig. 2.7 Hydrologically Relevant Topographic Elevations

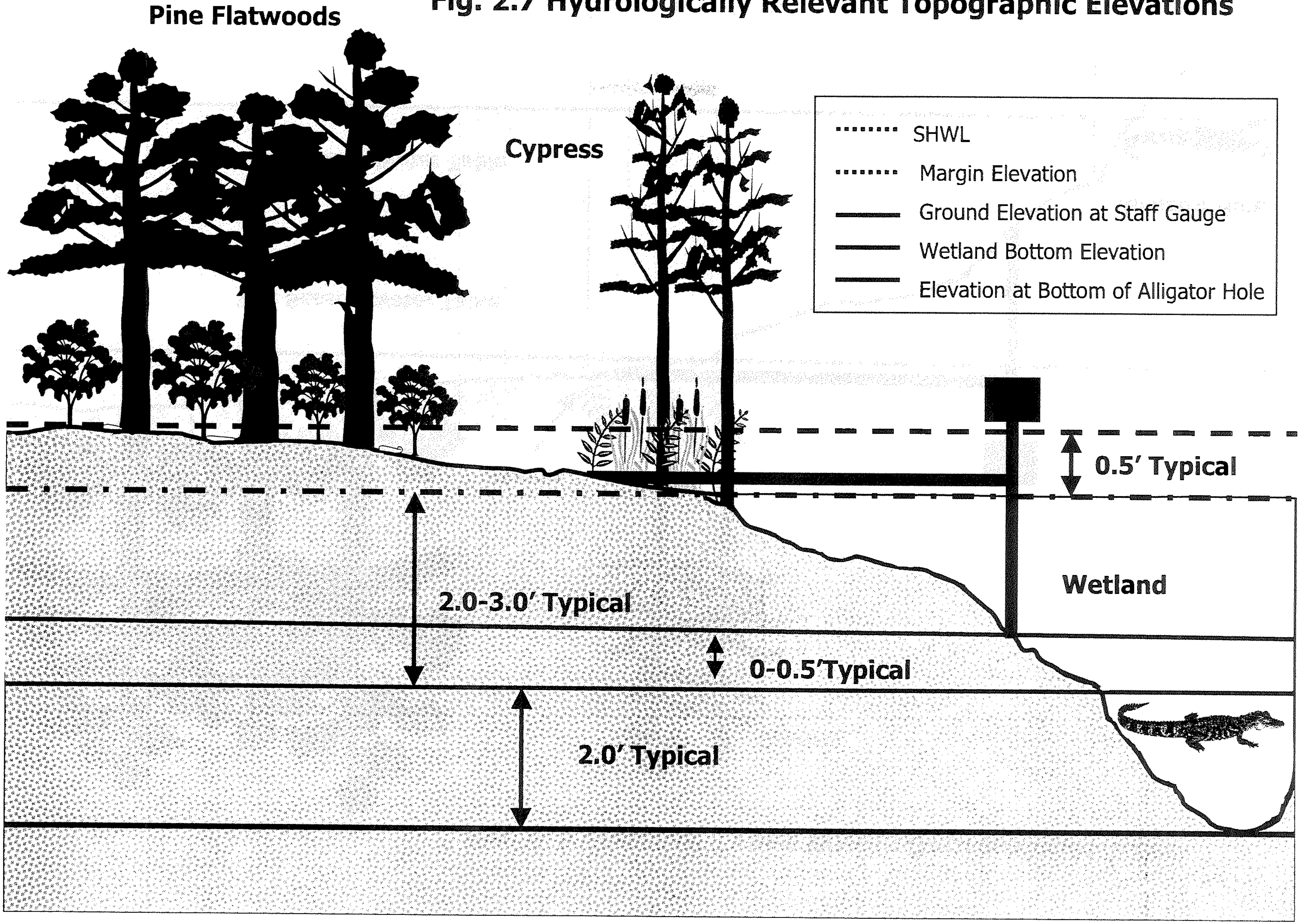


Fig. 4.1 Wetland Types Within Depressional Areas

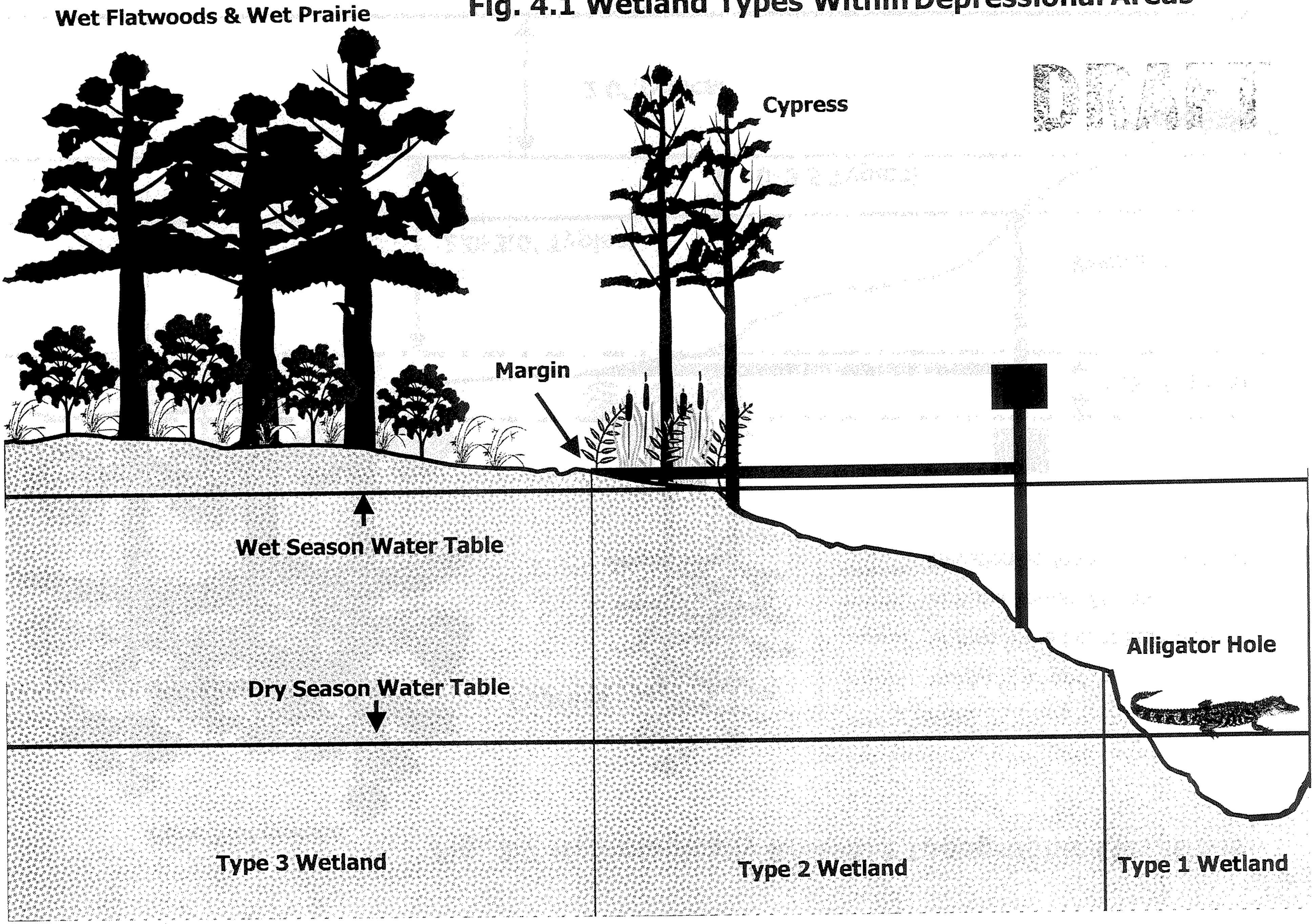


Fig. 5.2 Effects of WAIT test at SV5

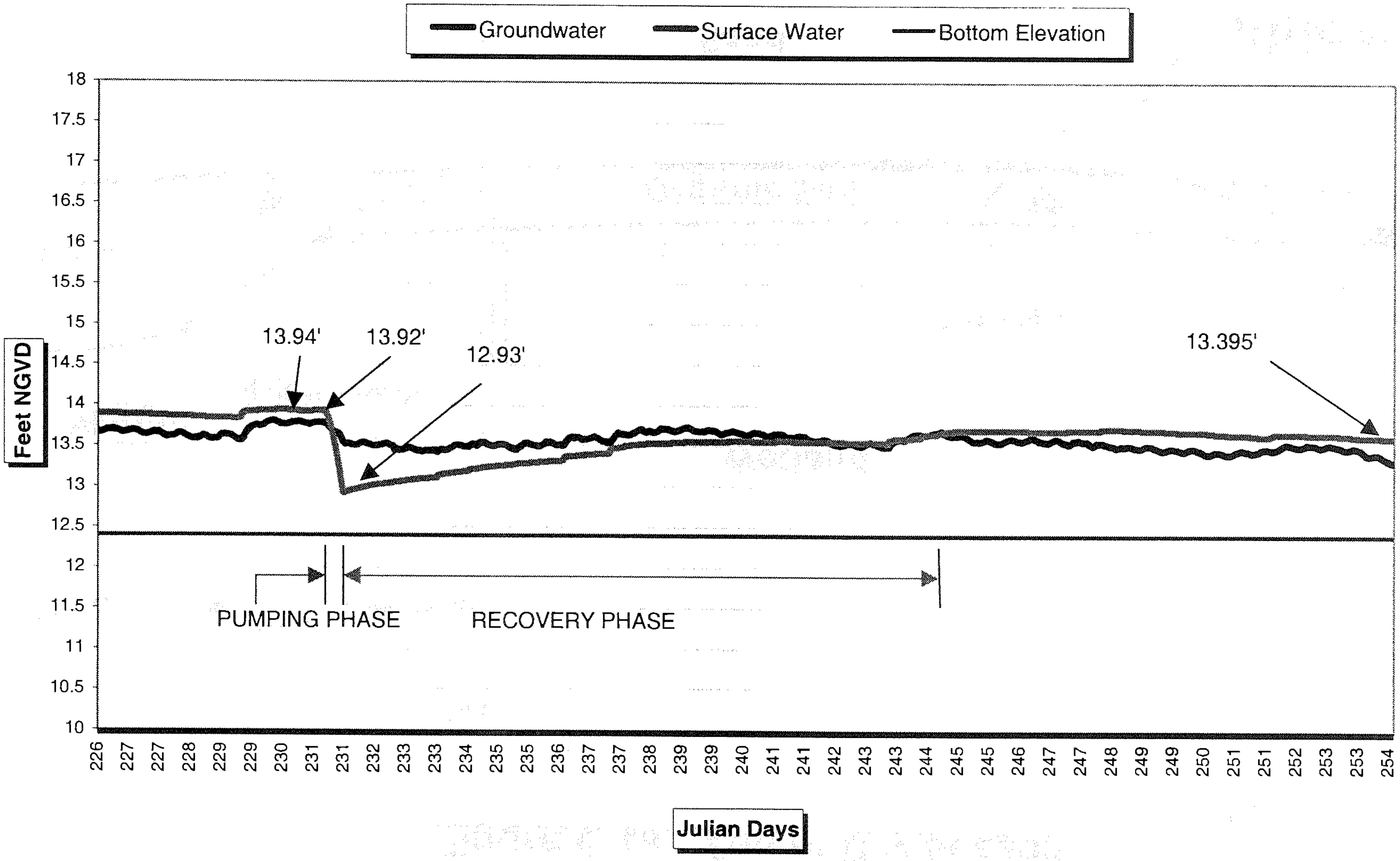


Figure 6.1a - End of Dry Season

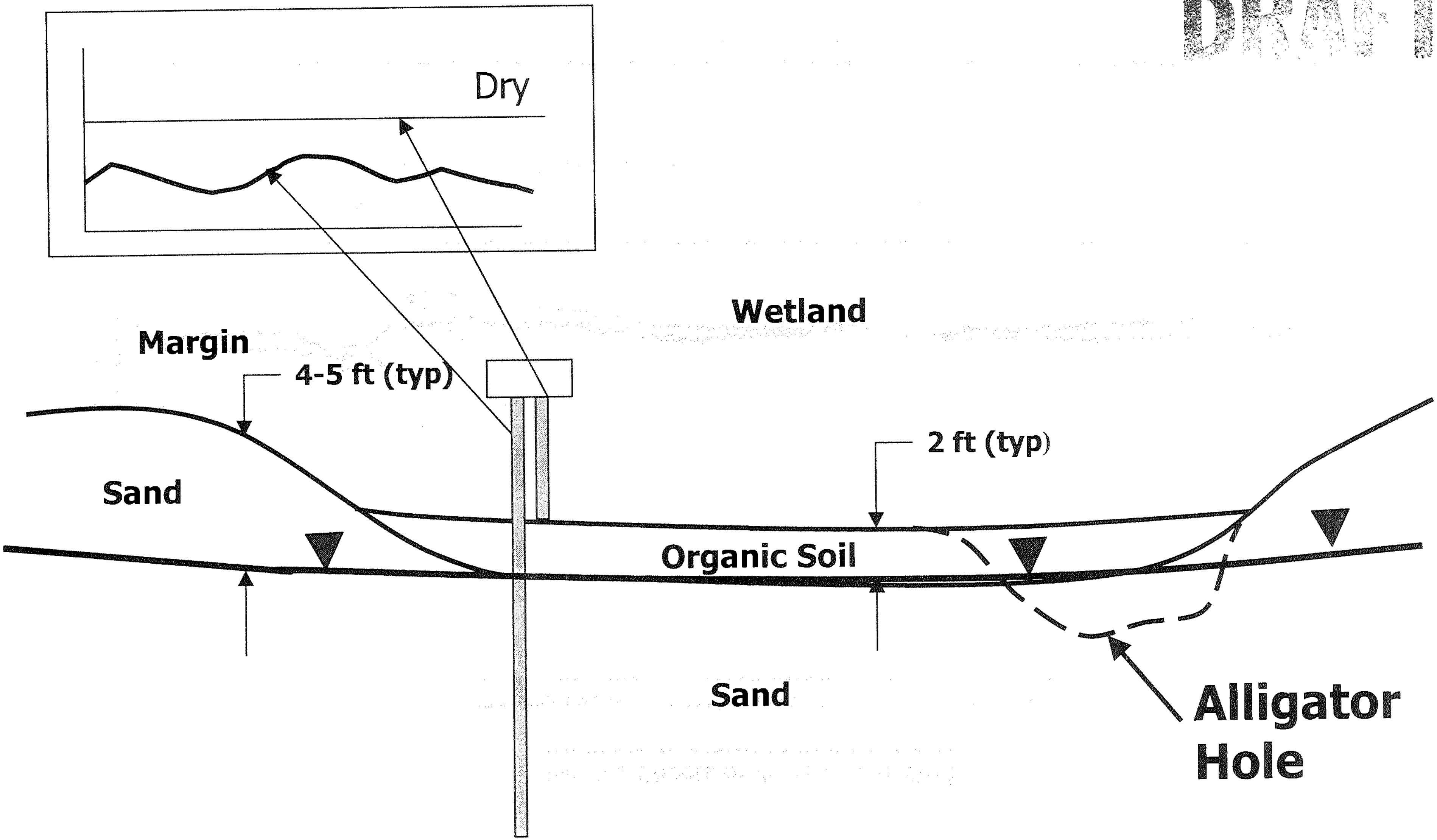


Figure 6.1b - Rewetting Period

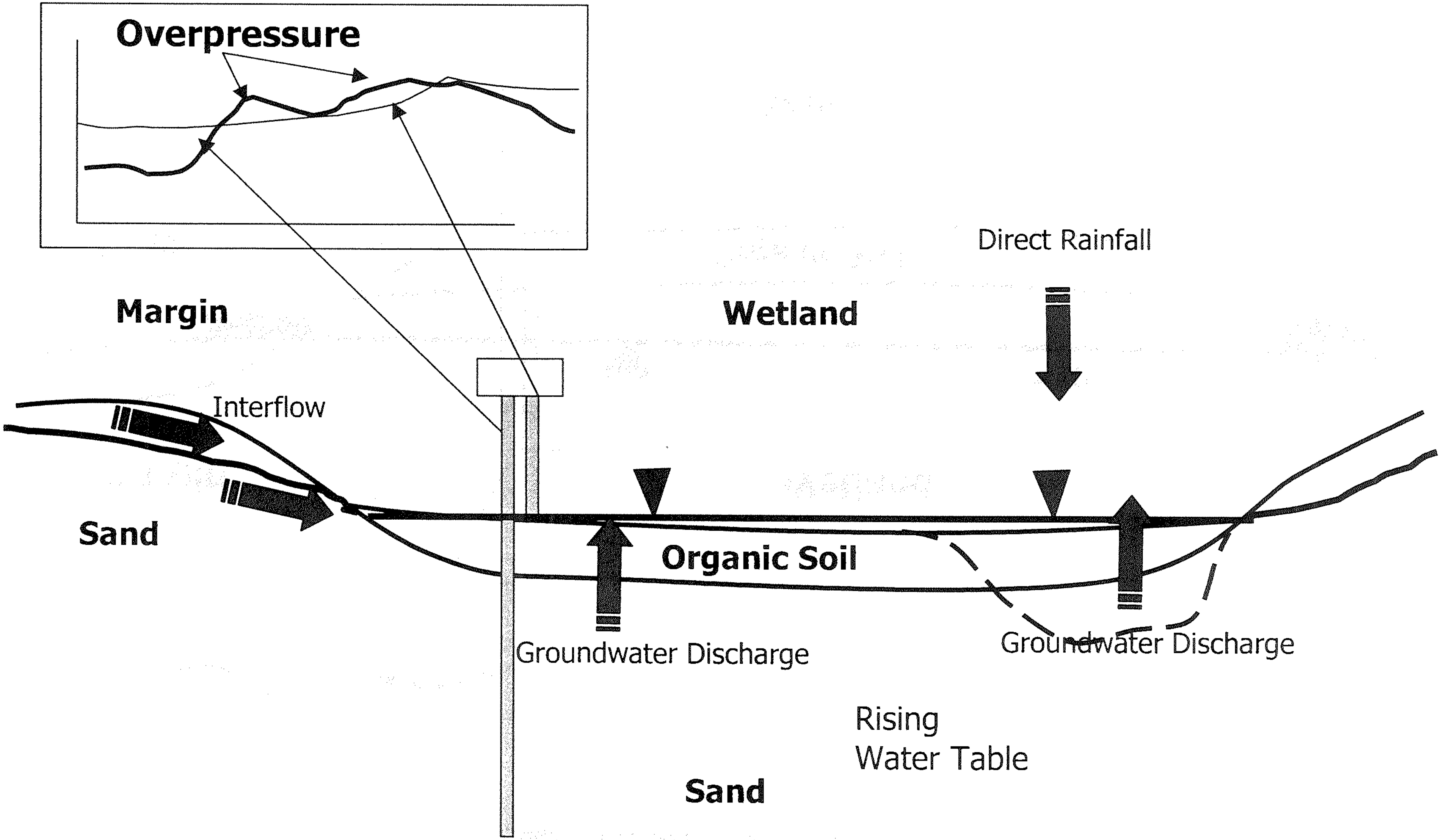


Figure 6.1c - Early Wet Season

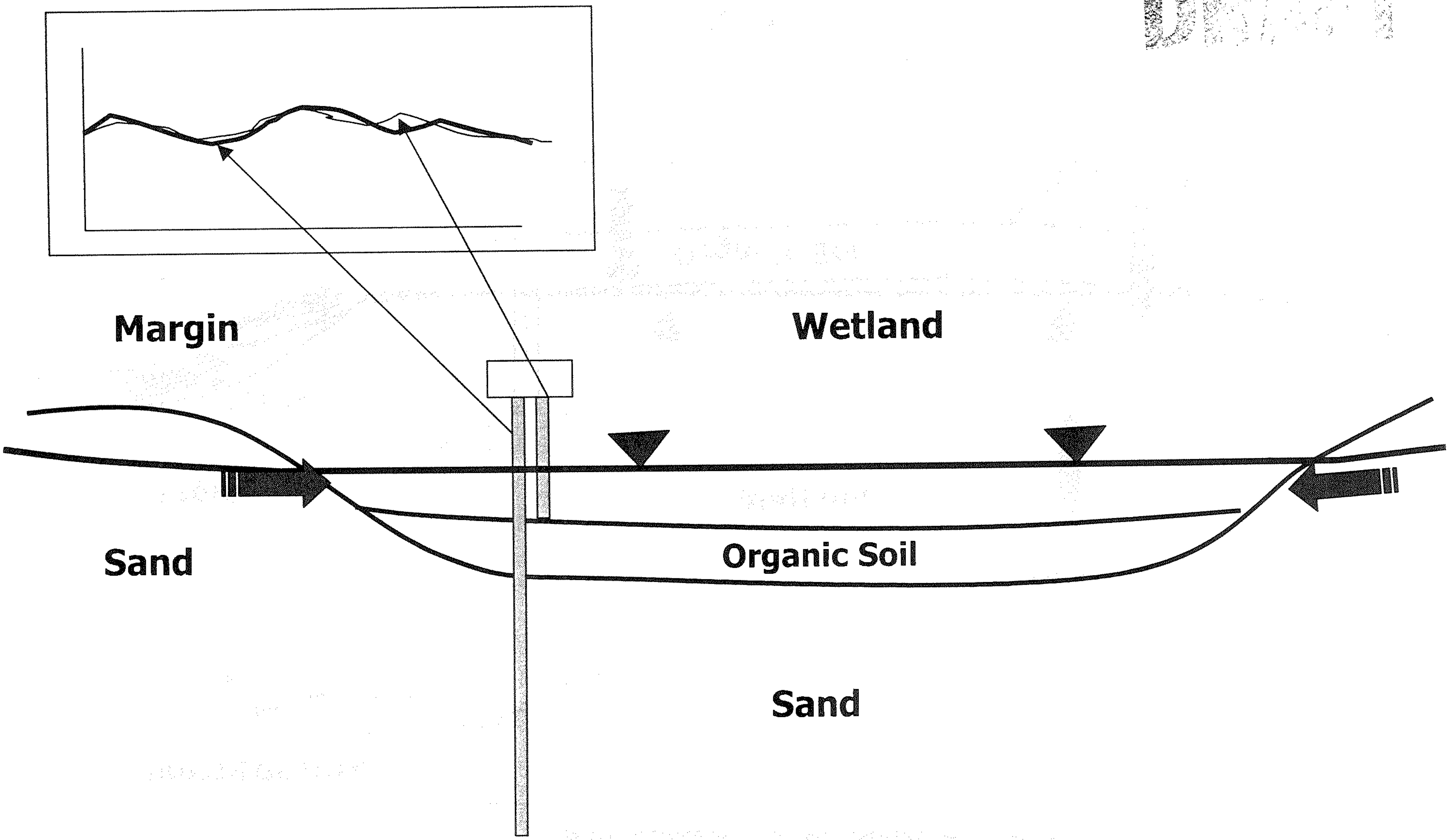


Figure 6.1d - Peak Wet Season

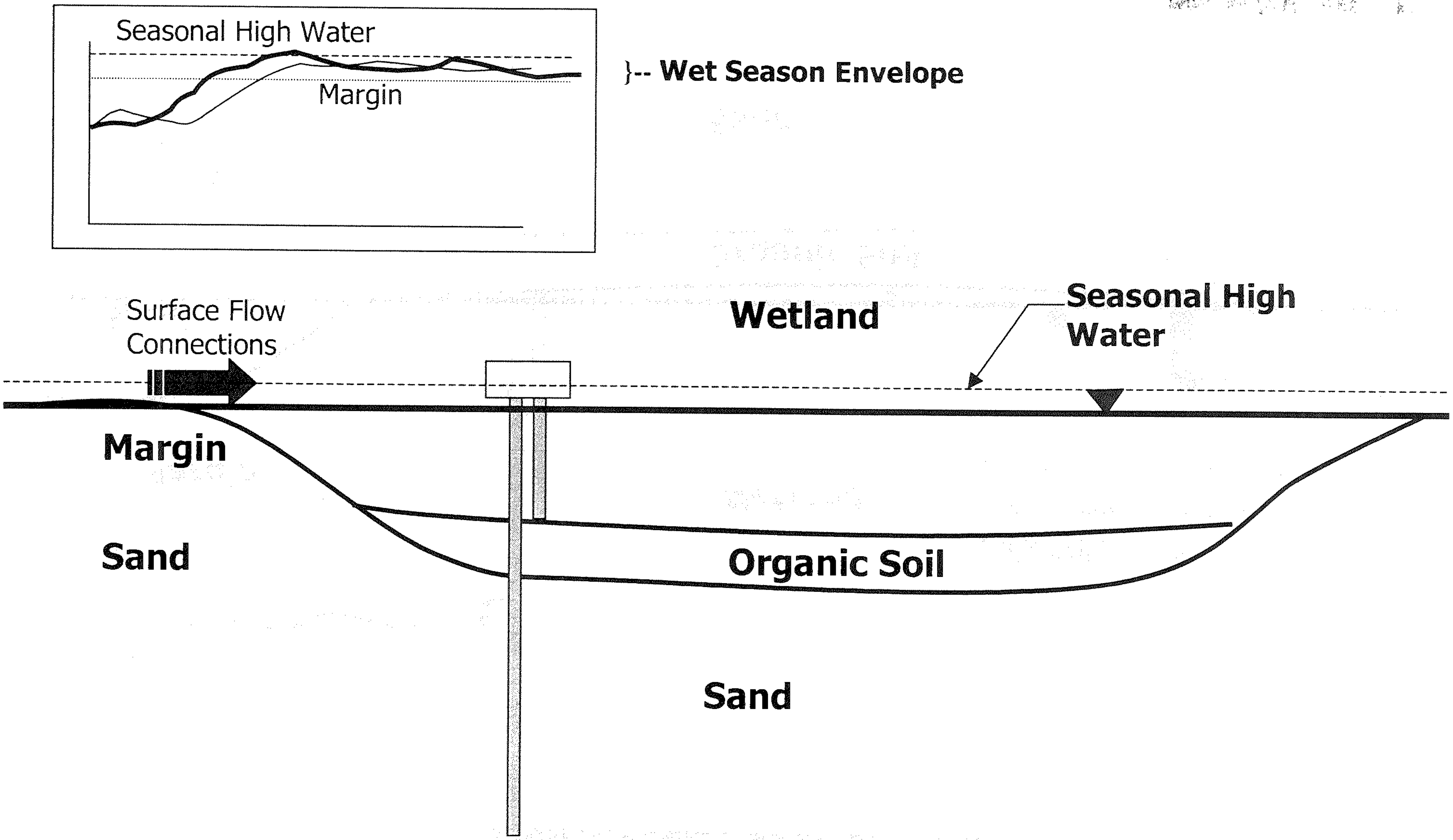


Figure 6.1e -- Drying Period

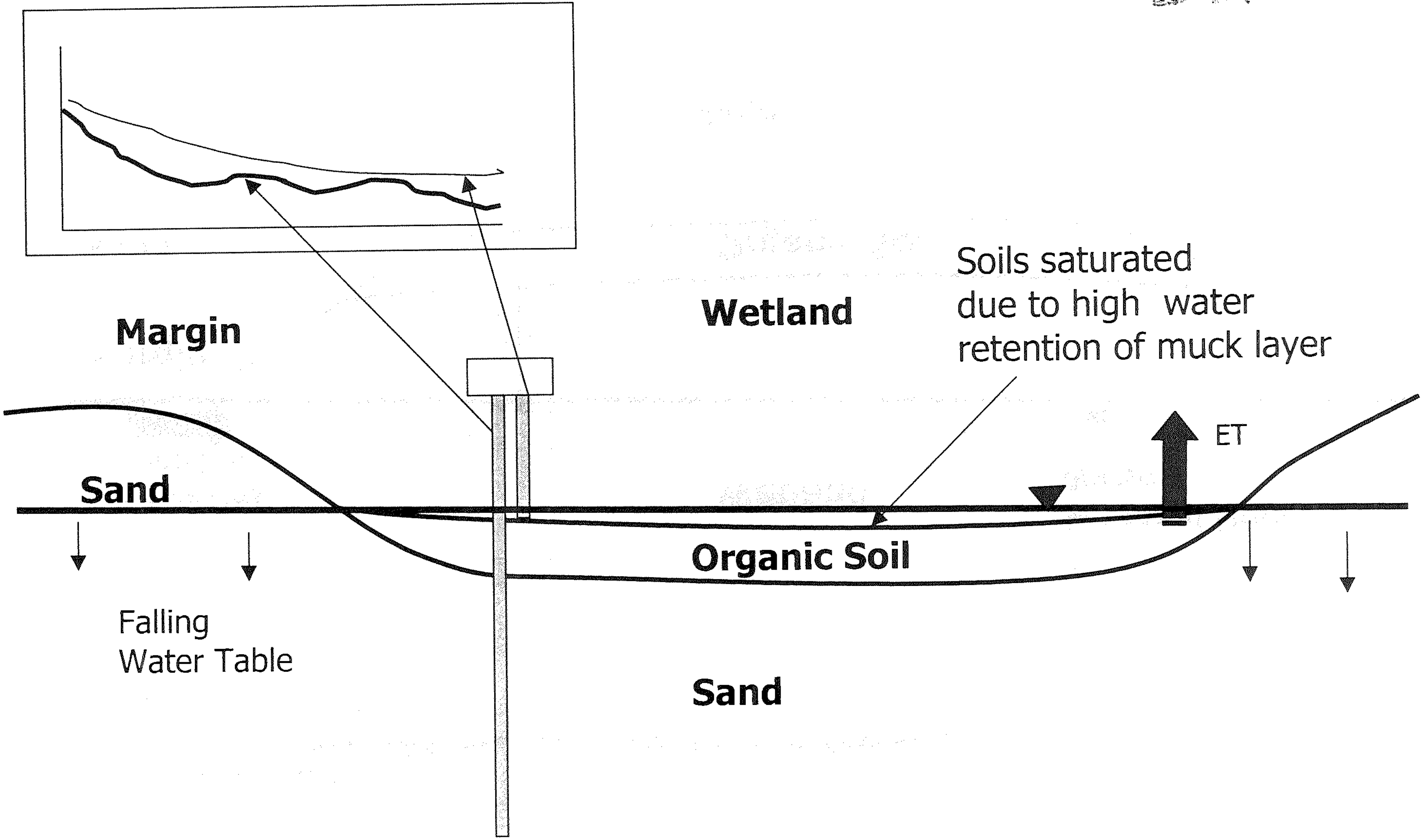
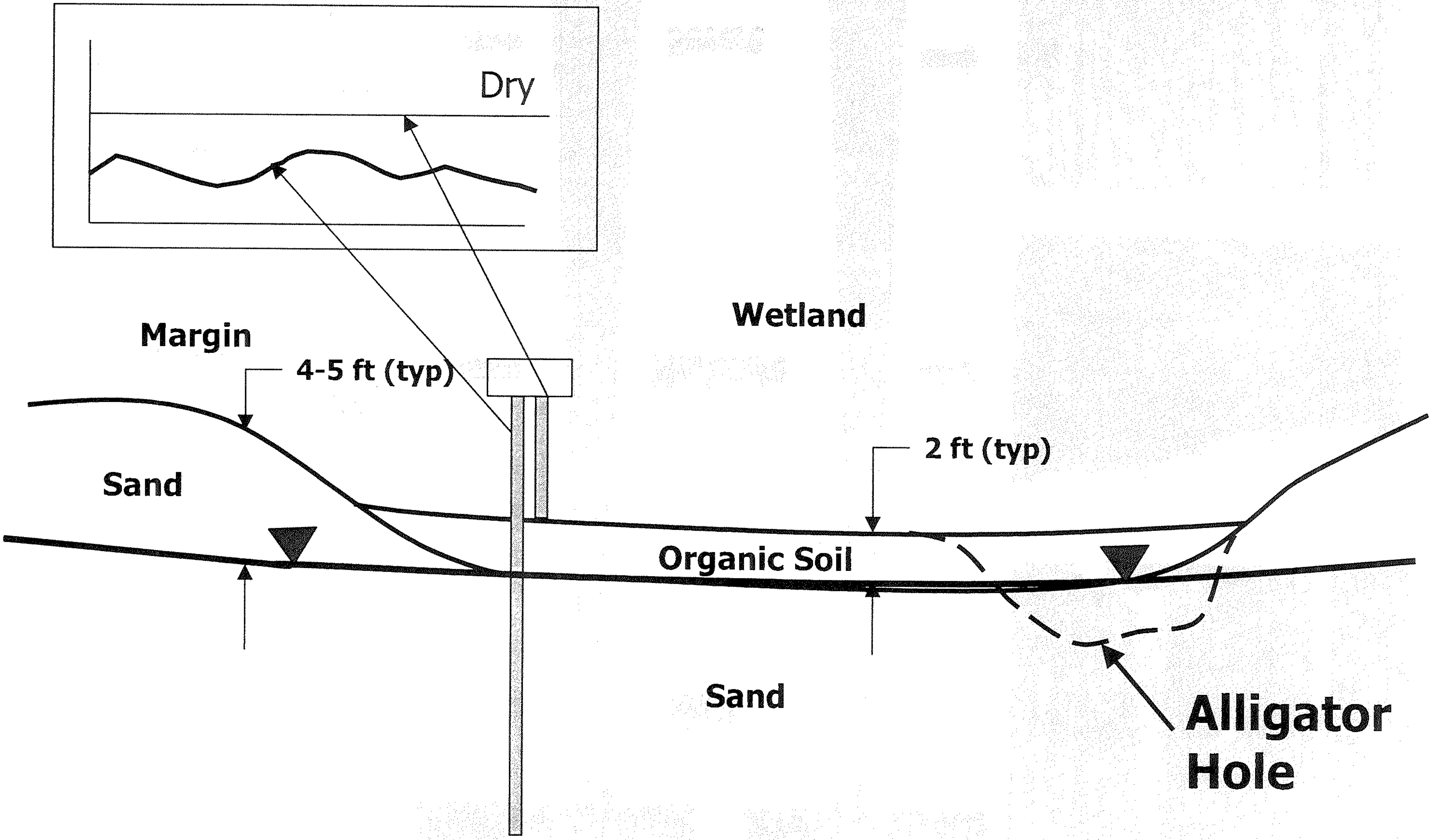


Figure 6.1f - End of Dry Season



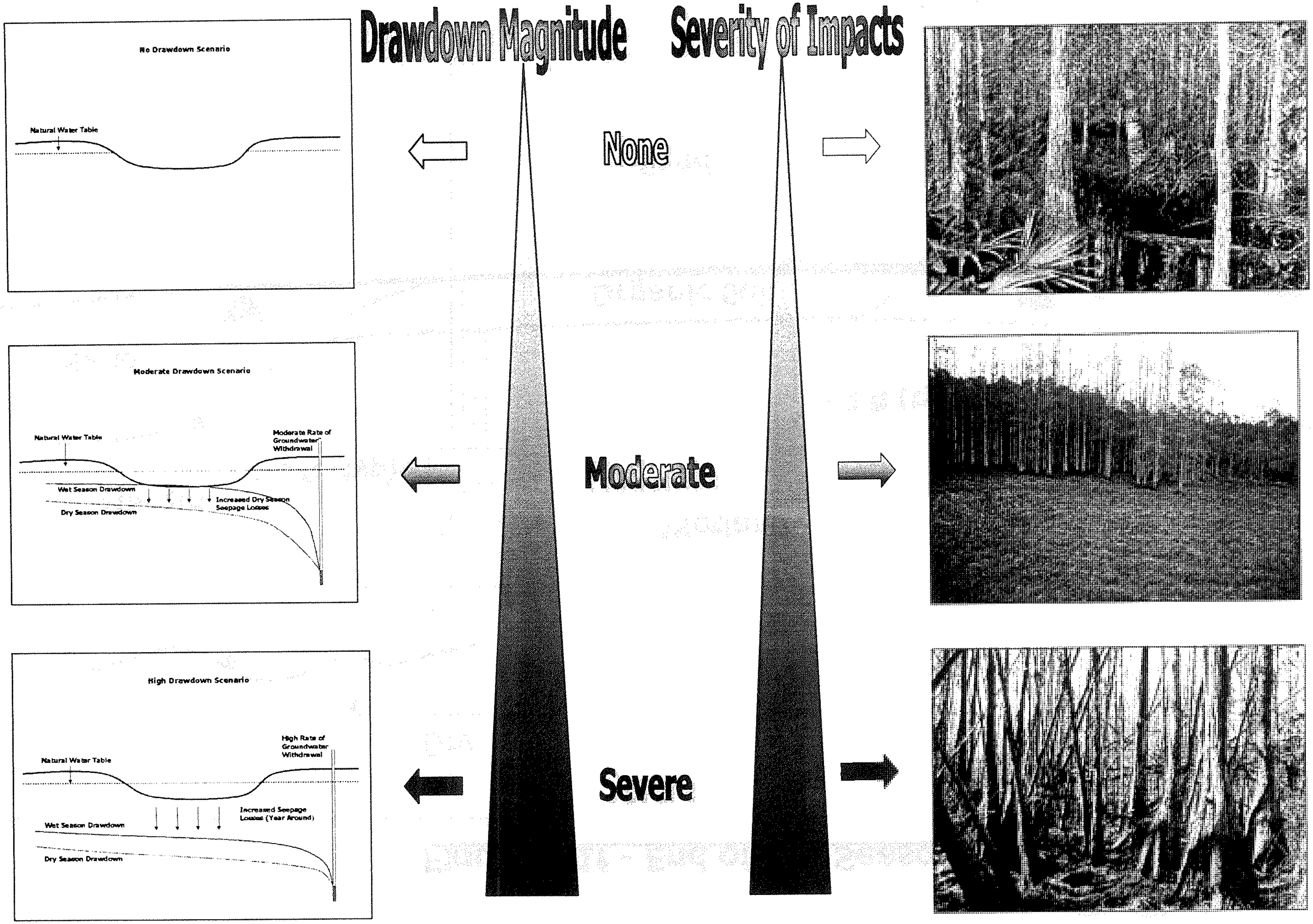
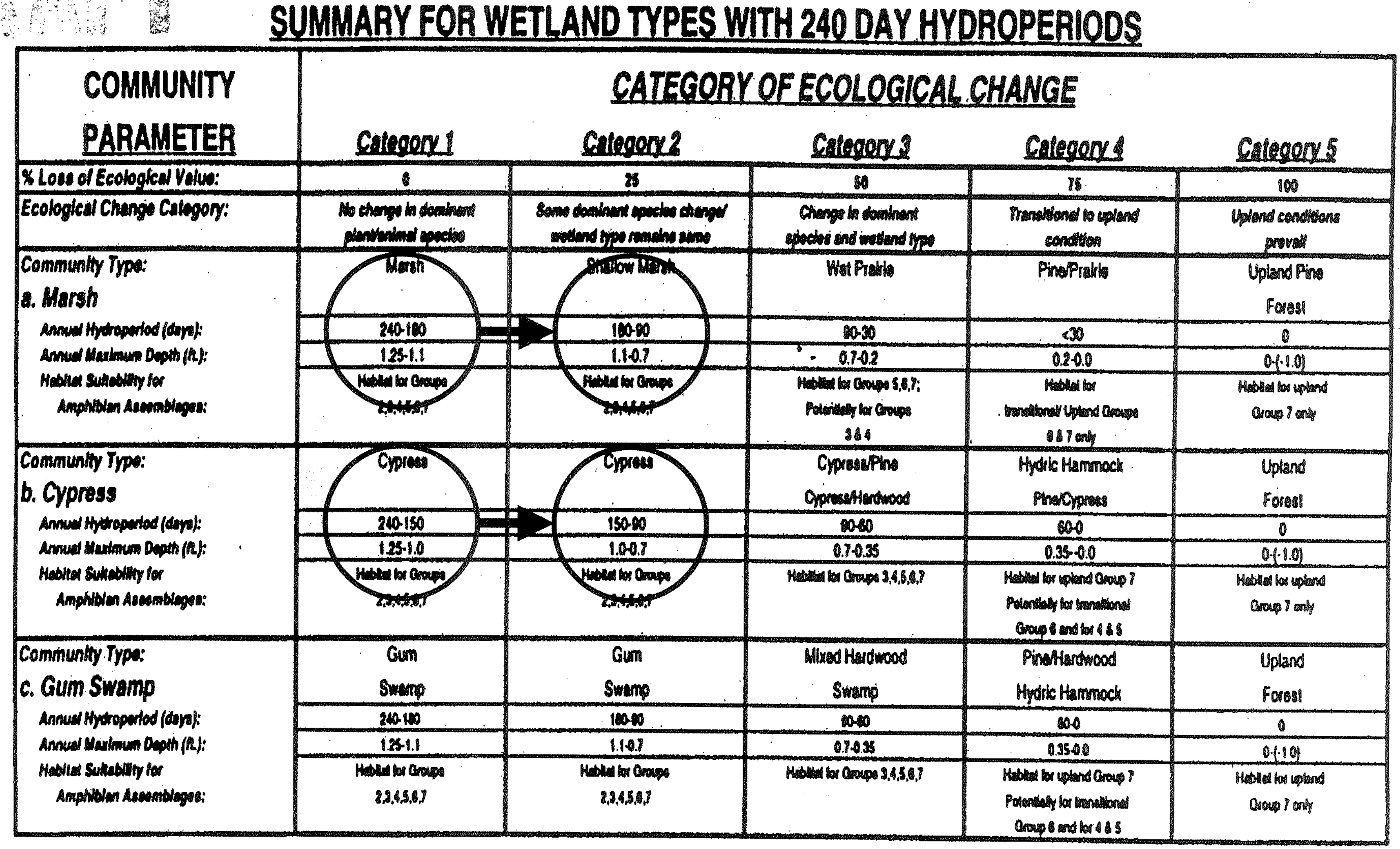


Figure 6.2 -- Severity of Impacts vs. Drawdown Magnitude

Figure 6.5 - Summary of Ecological Changes (Adapted from CH2M Hill, 1996)



SUMMARY FOR WETLAND TYPES WITH 240 DAY HYDROPERIODS

COMMUNITY PARAMETER	CATEGORY OF ECOLOGICAL CHANGE				
	Category 1	*Category 2*	*Category 3*	*Category 4*	*Category 5*
% Loss of Ecological Value:	0	25	50	75	100
Ecological Change Category:	*No change in dominant plant/animal species*	*Some dominant species change/ wetland type remains same*	*Change in dominant species and wetland type*	*Transitional to upland condition*	*Upland conditions prevail*
Community Type: ***a. Marsh***	Marsh	Shallow Marsh	Wet Prairie	Pine/Prairie	Upland Pine Forest
Annual Hydroperiod (days):	240-180	180-90	90-30	<30	0
Annual Maximum Depth (ft.):	1.25-1.1	1.1-0.7	0.7-0.2	0.2-0.0	0-(-1.0)
Habitat Suitability for Amphibian Assemblages:	Habitat for Groups 2,3,4,5,6,7	Habitat for Groups 2,3,4,5,6,7	Habitat for Groups 5,6,7; Potentially for Groups 3 & 4	Habitat for transitional/ Upland Groups 6 & 7 only	Habitat for upland Group 7 only
Community Type: ***b. Cypress***	Cypress	Cypress	Cypress/Pine Cypress/Hardwood	Hydric Hammock Pine/Cypress	Upland Forest
Annual Hydroperiod (days):	240-150	150-90	90-60	60-0	0
Annual Maximum Depth (ft.):	1.25-1.0	1.0-0.7	0.7-0.35	0.35-0.0	0-(-1.0)
Habitat Suitability for Amphibian Assemblages:	Habitat for Groups 2,3,4,5,6,7	Habitat for Groups 2,3,4,5,6,7	Habitat for Groups 3,4,5,6,7	Habitat for upland Group 7 Potentially for transitional Group 6 and for 4 & 5	Habitat for upland Group 7 only
Community Type: ***c. Gum Swamp***	Gum Swamp	Gum Swamp	Mixed Hardwood Swamp	Pine/Hardwood Hydric Hammock	Upland Forest
Annual Hydroperiod (days):	240-180	180-90	90-60	60-0	0
Annual Maximum Depth (ft.):	1.25-1.1	1.1-0.7	0.7-0.35	0.35-0.0	0-(-1.0)
Habitat Suitability for Amphibian Assemblages:	Habitat for Groups 2,3,4,5,6,7	Habitat for Groups 2,3,4,5,6,7	Habitat for Groups 3,4,5,6,7	Habitat for upland Group 7 Potentially for transitional Group 6 and for 4 & 5	Habitat for upland Group 7 only

Original hydroperiod: 150-240 days

Reduction of 40-60 days (6-8 weeks) ➤ *Category 2*

Altered hydroperiod: 90-200 days

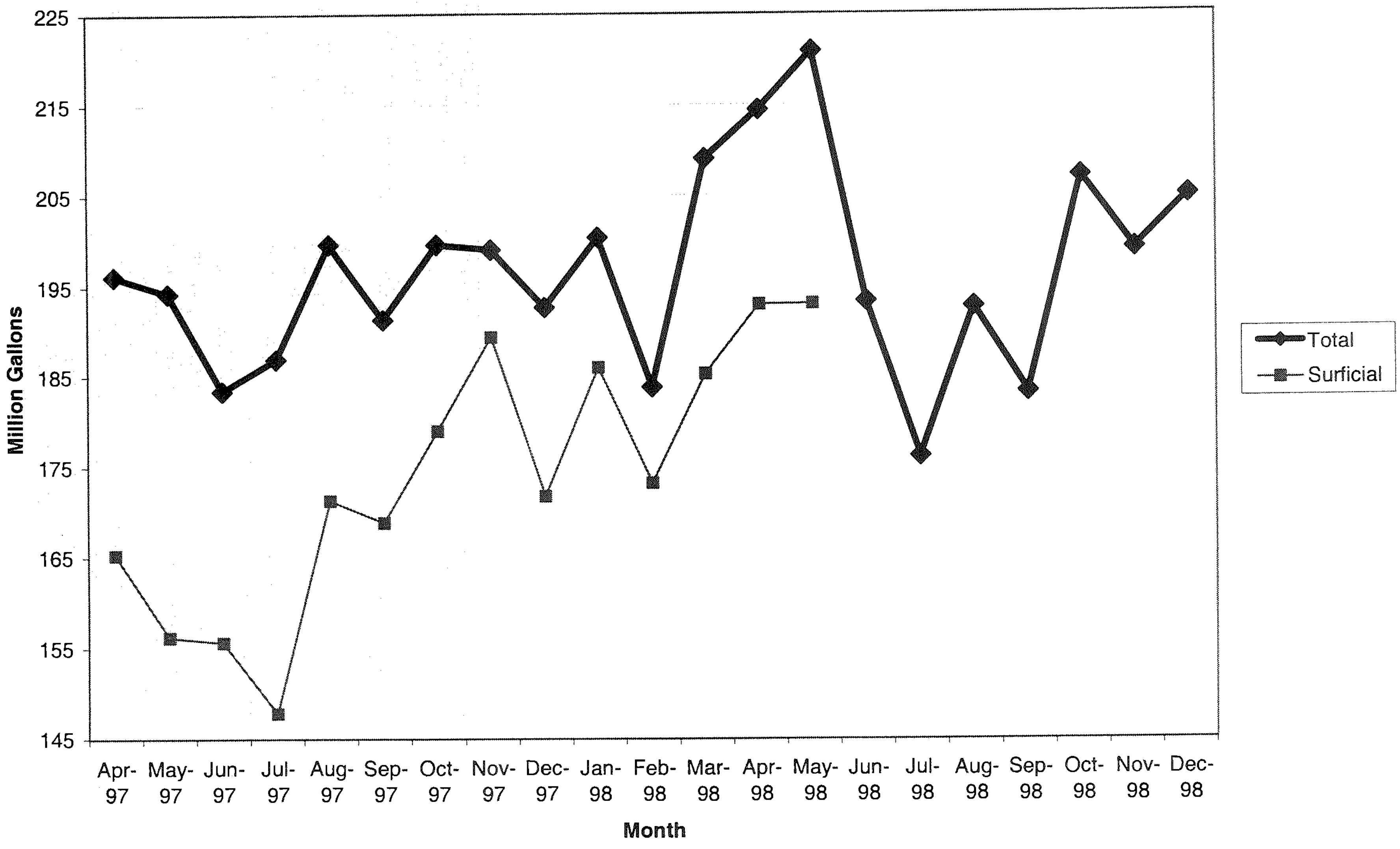
APPENDICES

APPENDIX A

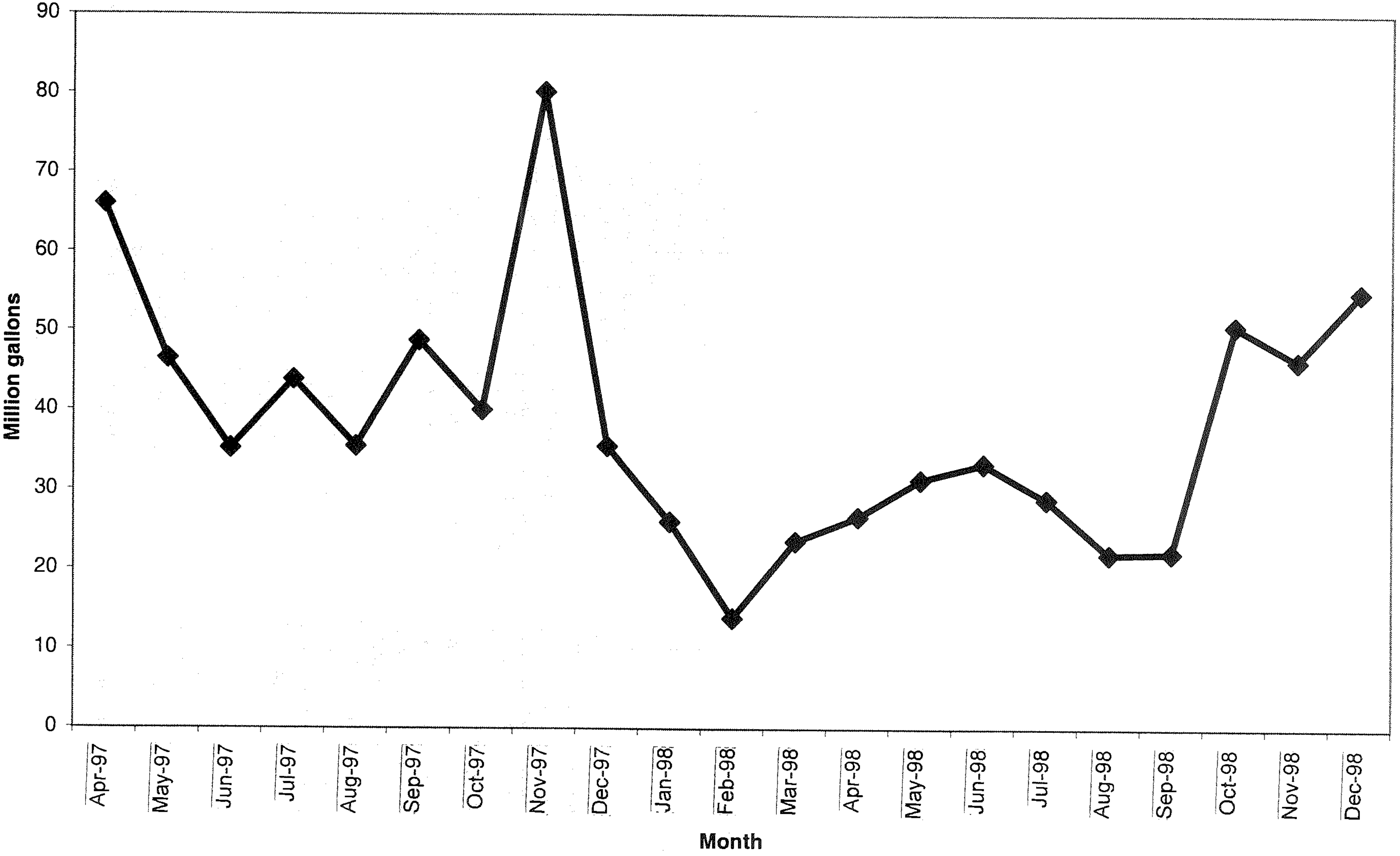
Table A.1 – Well Field Characteristics

Well Field (Project Study Area)	Lee County Utilities Corkscrew Well Field (Flint Pen Strand)	Martin County Utilities North County Well Field (Savannas)
Permit No.	36-00003-W	43-00102-W
Permit Duration	2/12/98 to 2/12/03	8/15/96 to 8/15/01
Type	Public water supply	Public water supply
Source	Water table (surficial) and Sandstone Aquifers	Surficial and Floridan Aquifers
No. Production Wells (Surficial)	18 existing plus 4 additional drilled in 1998 but not yet operated	10 existing plus 3 additional permitted
Production Zone Depth	40-150 feet	70-125 feet
Began Pumping	1981-82	1982-83 (Wells 1-8) 1988 (Wells 9-10)
Average Withdrawals 1997-98 (Surficial Only)	5.8 MGD	1.3 MGD
Capacity (Surficial Only)	15.12 MGD	5.18 MGD
Allocation (Surficial Only)	8.84 MGD	35.69 MGM (1.19 MGD)

LCU Corkscrew Well Field Pumping



MCU Jensen Beach Well Field Pumping (Surficial Aquifer)



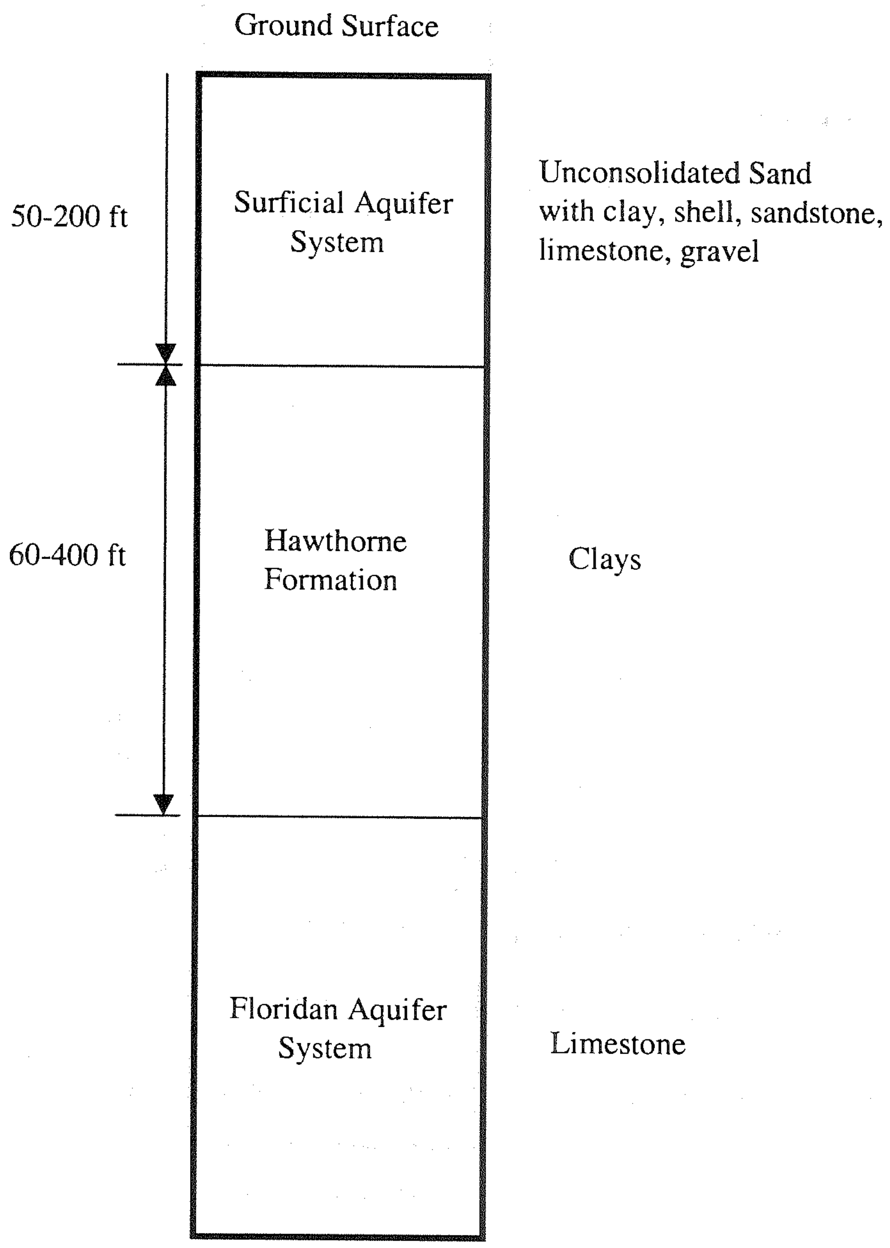
APPENDIX B

Table B.1 - Surficial Aquifer Characteristics

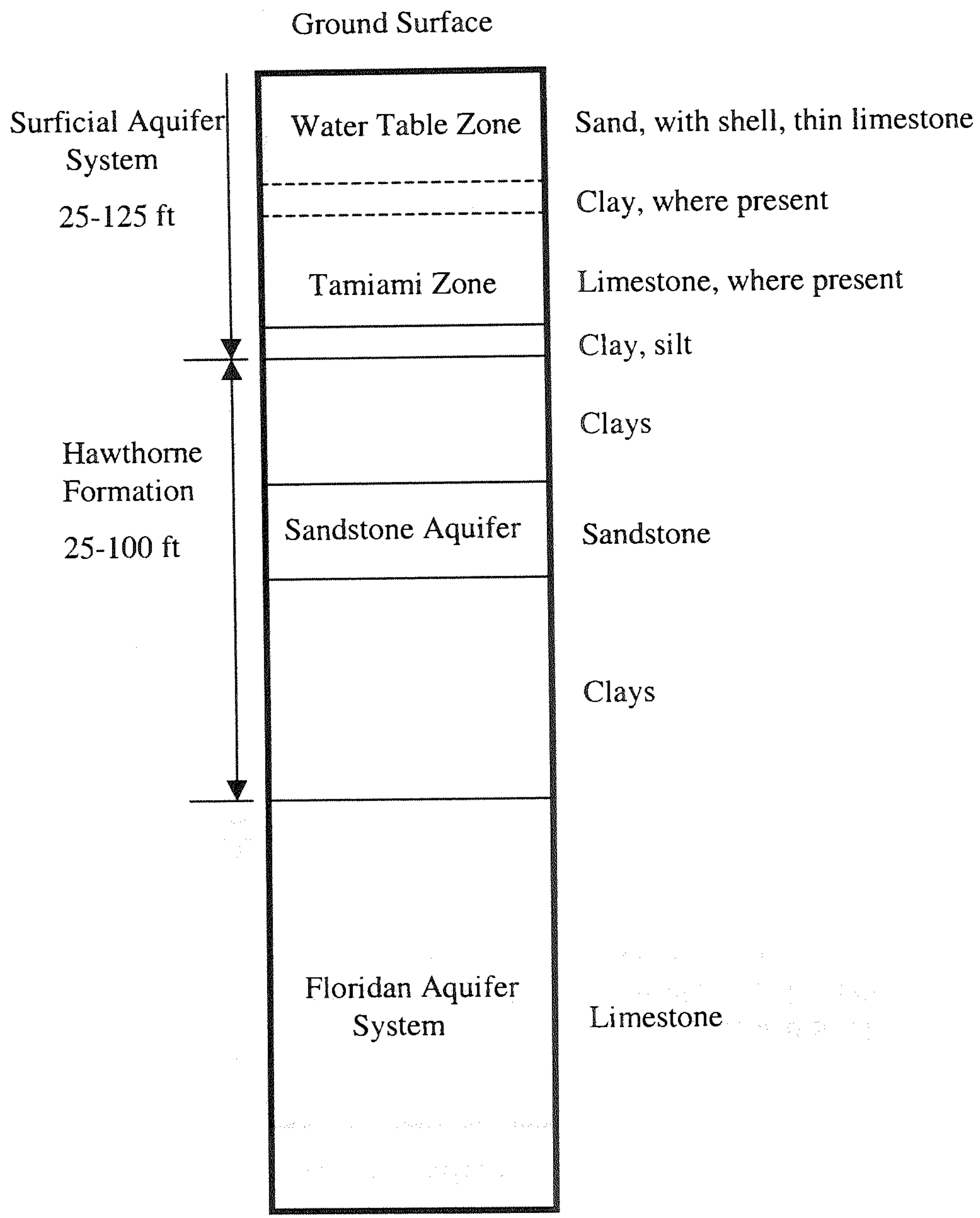
Planning Region	**Surficial Aquifer System Constituents**	**Thickness**	**Major Producing Zones**
Kissimmee River Basin	Unconsolidated sands with interfingered clays, shells, sandstone, limestone, and gravel	50-200 ft. (thickness increases north to south) (50-100 ft. in Disney Wilderness Preserve vicinity)	SAS: none Other: Floridan Aquifer System
Lower West Coast	Unconsolidated sands and water-bearing limestone with interfingered shells, clays, silts, and thin limestone layers	25-125 ft. (50-100 ft. in Flint Pen Strand vicinity)	SAS: Water Table zone (0-40 ft depth), Tamiami zone (50-70 ft depth) Other: Sandstone Aquifer (within Hawthorne Formation)
Upper East Coast	Unconsolidated fine sand, shells, sandy limestone	90-200 ft. (120 ft. in Savannas, 160-180 ft. in vicinity of Jonathan Dickinson SP)	SAS: limestone layers (50-120 ft depth) Other: Floridan Aquifer System
Lower East Coast *	Biscayne Aquifer: Low-permeability oolitic limestone (Miami limestone) over porous water-bearing limestone (Ft. Thompson) Tamiami Formation: shelly sands, clays, silts, and limestone	130-250 ft. (vicinity of Dade West Well Field)	SAS: Ft. Thompson Formation in Biscayne Aquifer, Tamiami zone Other: none

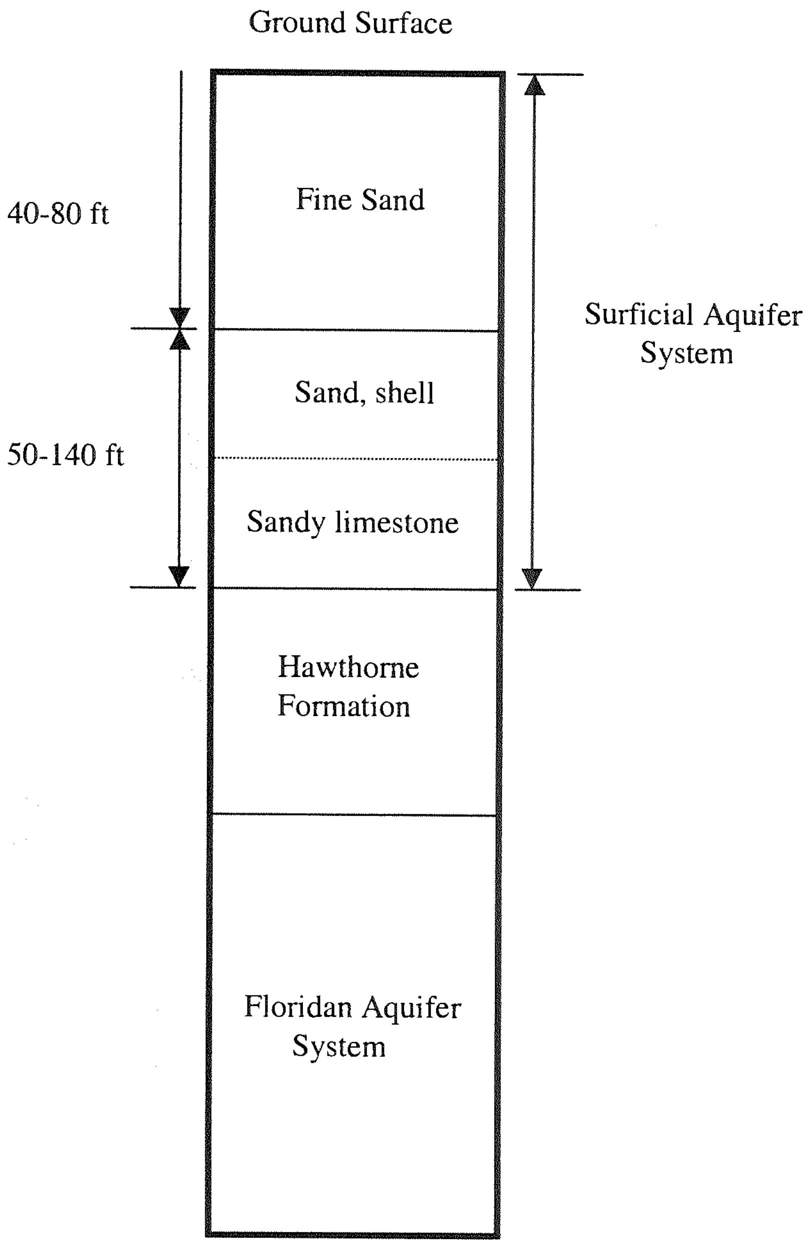
* Source: Merrit (1996)

Schematic Geology of Kissimmee River Basin Planning Region (based on Shaw and Trost, 1984)



Schematic Geology of Lower West Coast Planning Region (based on Wedderburn *et al*, 1982)





Schematic Geology of Upper East Coast Planning Region (based on Lukasiewicz and Smith, 1996)

DRAFT

APPENDIX C-WELL BORING LOGS

South Florida Water Management District
3301 Gun Club Road
West Palm Beach, Florida 33406
(561) 686-8800 / Fax 687-6442

Engineered Environmental Solutions, Inc.
1301 NW 4th Street
Boca Raton, Florida 33486
Ph/Fax: (561) 394-3969

DRAFT

BORING LOG

BORING/WELL NO. **SV1**

PROJECT NO./NAME **1033/Isolated Wetlands Shallow Drilling Program**	LOCATION **Savannas State Preserve, St. Lucie County, Florida**

DRILLING CONTRACTOR/DRILLER
Precision Drilling/Robert Miller

GEOLOGIST/OFFICE
Steve Krupa/South Florida Water Management District

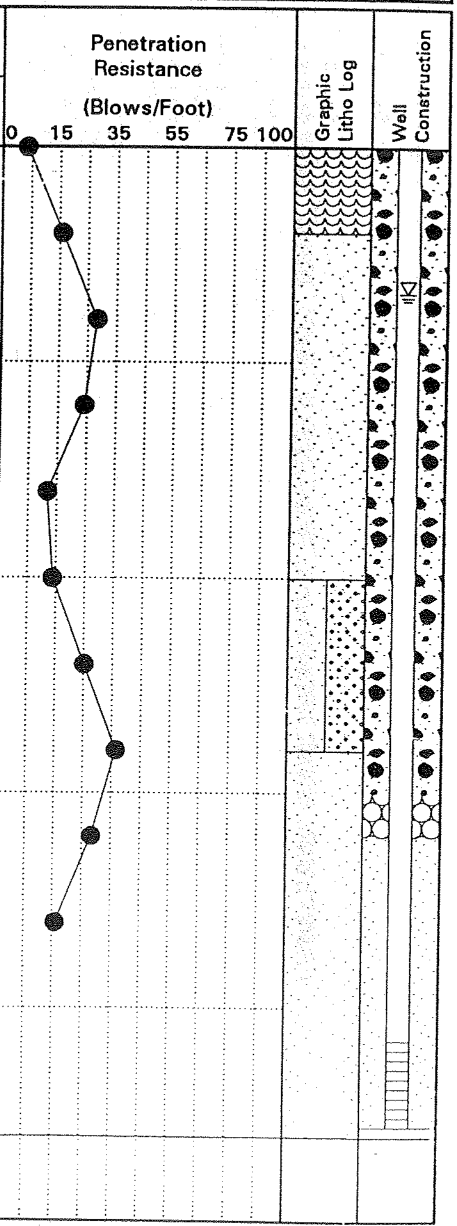
DRILLING EQUIPMENT/METHOD **Tripod/SPT**	SIZE/TYPE OF BIT **3'-5" dia. casing, driven and washed**	SAMPLING METHOD **Split Spoon**	START/FINISH DATE **1/23/97-1/24/97**

WELL INSTALLED? YES ☒ NO ☐	CASING MAT./DIA. **Sch.40 monoflex PVC/2"**	SCREEN: TYPE Slotted MAT. PVC LENGTH 2' DIA. 2" SLOT SIZE .010

ELEVATION OF: (FT. ABOVE M.S.L.)	GROUND SURFACE **15.2 est.**	TOP OF WELL CASING **2.25 ft**	TOP & BOTTOM SCREEN **20.75 ft/22.75 ft**	DATE **1/24/97**

REMARKS:

Depth (ft)	Sample Type & Recovery	Sample Number	Penetration Resistance Blows/6" N-Value	Unified Classification	LOG OF TEST BORING FIELD DESCRIPTION	Munsell Field Color
		S1	1 1 1 1 2	OL	7 in. organic material grading to 7 in. fine sand 2.0	1 2.5/N = 10 YR 6/2
		S2	6 6 8 8 14	SP	8 in. fine sand grading to 8 in. fine sand w/ heavy organic staining	10 YR 8/1 = 1 2.5/N
5		S3	12 14 12 9 26		Fine sand w/ staining	7.5 YR 3/1
		S4	8 13 9 9 22		5 in. fine sand w/ organic staining grading to 15 in. fine sand	7.5 YR 3/1 = 2.5 Y 6/3
		S5	4 5 5 6 10	SP-SW	5 in. medium to fine sand, 1.5 in. (1 2.5/N) fine sand grading to 9 in. (2.5 y 8/1) fine sand 10.0	2.5 Y 7/2 = 2.5 Y 8/1
10		S6	6 6 6 8 12		5 in. medium to fine sand grading to fine sand	2.5 Y 6/2 = 2.5 Y 8/1
		S7	12 11 12 18 23		14.0	2.5 Y 7/2
15		S8	18 18 16 14 34	SP	Fine sand	2.5 Y 8/1
		S9	8 8 18 23 26			2.5 Y 6/1
		S10	5 7 7 8 14			
20						
					23.0	



LA 9/11/97

EMP

- ▯ Fine Sand
- ⁘ Medium Sand
- ○ Bentonite Pellets
- ● Cement Grout
- ▭ Silt/Clay w/ shell
- ≋ Organic Material
- ▨ Clay
- ☒ Split Spoon
- ■ Percent Recovery
- ○ No Recovery

South Florida Water
Management District
3301 Gun Club Road
West Palm Beach, Florida 33406
(561) 686-8800 / Fax 687-6442

Engineered Environmental
Solutions, Inc.
1301 NW 4th Street
Boca Raton, Florida 33486
Ph/Fax: (561) 394-3969

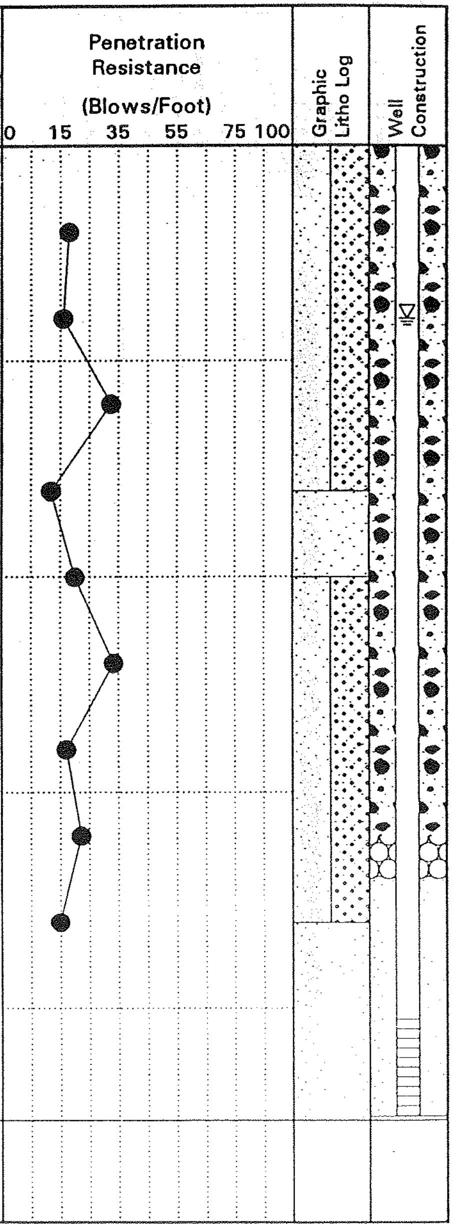
DRAFT

BORING LOG

BORING/WELL NO.	SV4
PROJECT NO./NAME	1033/Isolated Wetlands Shallow Drilling Program
LOCATION	Savannas State Preserve, St. Lucie County, Florida
DRILLING CONTRACTOR/DRILLER	Precision Drilling/Robert Miller
GEOLOGIST/OFFICE	Steve Krupa/South Florida Water Management District
DRILLING EQUIPMENT/METHOD	Tripod/SPT
SIZE/TYPE OF BIT	3'-5" dia. casing, driven and washed
SAMPLING METHOD	Split Spoon
START/FINISH DATE	1/20/97-1/20/97
WELL INSTALLED?	YES ☒ NO ☐
CASING MAT./DIA.	Sch.40 monoflex PVC/2"
SCREEN:	TYPE Slotted MAT. PVC LENGTH 2' DIA. 2" SLOT SIZE .010
ELEVATION OF: (FT. ABOVE M.S.L.) GROUND SURFACE	12.4 ft
TOP OF WELL CASING	2.55 ft
TOP & BOTTOM SCREEN	20.25 ft/22.50 ft
DATE	1/24/97
REMARKS:	

LOG OF TEST BORING

Depth (ft)	Sample Number	Penetration Resistance Blows/6" N-Value	Unified Classification	FIELD DESCRIPTION	Munsell Field Color
	S1	- - - 4	SP-SW	Medium to fine grained sand w/ heavy organic staining	1 2.5/N
	S2	9 8 8 8 16			1 2.5/N
5	S3	5 5 9 7 14	SW	4 in. medium sand grading to 15 in. fine sand	10 YR 8/1 = 10 R 4/2
	S4	7 18 12 12 30	SP-SW	Medium to fine sand 8.0	7.5 YR 6/2
10	S5	4 4 6 7 10		Fine sand 10.0	10 R 5/4
	S6	5 9 9 9 18		Medium to fine grained sand	2.5 YR 3/2
	S7	11 14 17 7 31			2.5 YR 4/3
15	S8	6 7 8 9 15			2.5 YR 3/2
	S9	6 7 13 24 20		18.0	2.5 YR 7/1
20	S10	9 7 6 4 13		8 in. fine sand grading to 12 in. of fine sand w/ organics	2.5 YR 3/2 = 1 2.5/N
				22.6	



ILA 9/11/97

EMI

Fine Sand	Medium Sand
Bentonite Pellets	Cement Grout
Silt/Clay w/ shell	Organic Material
Clay	Split Spoon
Percent Recovery	No Recovery

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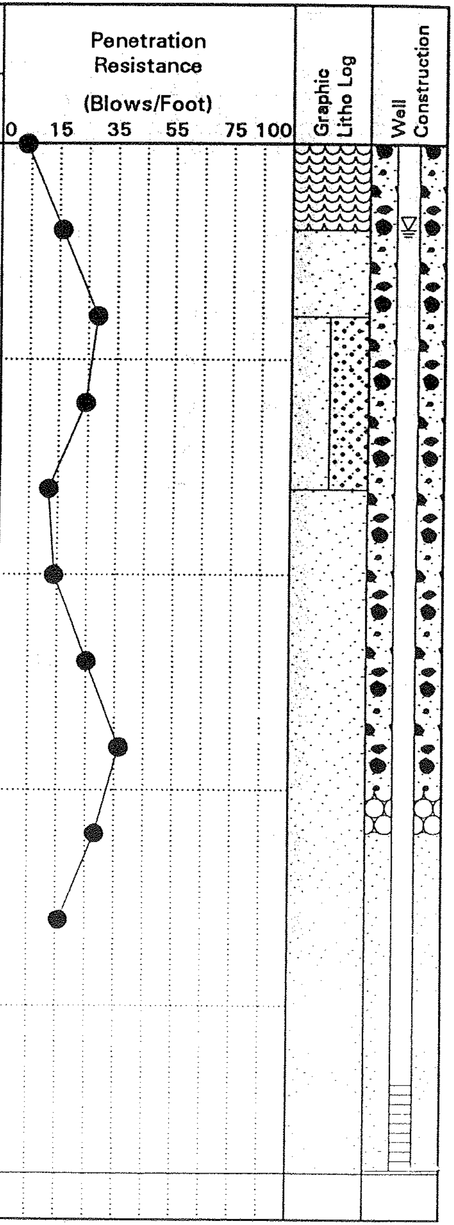
DRAFT

BORING LOG

BORING/WELL NO. SV5				
PROJECT NO./NAME 1033/Isolated Wetlands Shallow Drilling Program	LOCATION Savannas State Preserve, St. Lucie County, Florida			
DRILLING CONTRACTOR/DRILLER Precision Drilling/Robert Miller				
GEOLOGIST/OFFICE Steve Krupa/South Florida Water Management District				
DRILLING EQUIPMENT/METHOD Tripod/SPT	SIZE/TYPE OF BIT 3'-5" dia. casing, driven and washed	SAMPLING METHOD Split Spoon	START/FINISH DATE 1/23/97-1/23/97	
WELL INSTALLED? YES ☒ NO ☐	CASING MAT./DIA. Sch.40 monoflex PVC/2"	SCREEN: TYPE Slotted MAT. PVC LENGTH 2' DIA. 2" SLOT SIZE .010		
ELEVATION OF: (FT. ABOVE M.S.L.)	GROUND SURFACE 12.4	TOP OF WELL CASING 1.08 ft	TOP & BOTTOM SCREEN 21.82/23.82	DATE 1/24/97
REMARKS:				

Depth (ft)	Sample Number	Penetration Resistance Blows/6" N-Value	Unified Classification	LOG OF TEST BORING FIELD DESCRIPTION	Munsell Field Color
	S1	1/1/1/1 2	PT	Organic material top 4 in. grading to fine sand w/ heavy staining 2.0	1 2.5/N
	S2	6/6/8/8 14	SP	Fine sand heavily stained w/ organics grading toward a 5 YR 5/2 4.0	
5	S3	12/14/12/9 26	SW	Medium sand grading toward fine sand	7.5 YR 4/1
	S4	8/13/9/9 22		4 in. medium to fine sand grading to 15 in. fine sand 8.0	10 YR 4/1 = 10 YR 7/2
	S5	4/5/5/6 10	SP	4 in. (10 YR 8/1) fine sand grading toward marbled (10 YR 8/4) medium to fine sand grading to (10 YR 8/1) fine sand	10 YR 8/1 = 10 YR 8/4
10	S6	6/6/6/8 12		11 in. (10 YR 7/1) fine sand grading toward a marbled (10 YR 5/1) fine sand grading to 5 in. (10 YR 7/1) fine sand	10 YR 7/1 = 10 YR 5/1
	S7	12/11/12/18 23		17 in. (10 YR 6/2) fine sand grading to 10 YR 3/1 fine sand	10 YR 6/2 = 10 YR 3/1
15	S8	18/18/16/14 34		Fine sand	5 YR 4/3
	S9	8/8/18/23 26		13 in. fine sand grading to 10 in. 5 YR 2.5/1 fine sand	5 YR 4/3 = 5 YR 2.5/1
	S10	5/7/7/8 14		6 in. fine sand grading to 16 in. of 1 2.5/N fine sand	5 YR 4/3 = 1 2.5/N
20					
				23.9	



LA 9/11/97

EMP

▥ Fine Sand
⁘ Medium Sand
Bentonite Pellets
Cement Grout
Silt/Clay w/ shell
Organic Material
▨ Clay
☒ Split Spoon
■ Percent Recovery
☐ No Recovery

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DRAFT

BORING LOG

BORING/WELL NO. **SV6**

PROJECT NO./NAME **1033/Isolated Wetlands Shallow Drilling Program**

LOCATION **Savannas State Preserve, St. Lucie County, Florida**

DRILLING CONTRACTOR/DRILLER **Precision Drilling/Robert Miller**

GEOLOGIST/OFFICE **Steve Krupa/South Florida Water Management District**

DRILLING EQUIPMENT/METHOD **Tripod/SPT**

SIZE/TYPE OF BIT **3'-5"dia. casing, driven and washed**

SAMPLING METHOD **Split Spoon**

START/FINISH DATE **1/22/97-1/22/97**

WELL INSTALLED? YES ☒ NO ☐

CASING MAT./DIA. **Sch.40 monoflex PVC/2"**

SCREEN: TYPE **Slotted** MAT. **PVC** LENGTH **2'** DIA. **2"** SLOT SIZE **.010**

ELEVATION OF: (FT. ABOVE M.S.L.)

GROUND SURFACE **12.7**

TOP OF WELL CASING **4.45 ft**

TOP & BOTTOM SCREEN **21.35/23.35**

DATE **1/24/97**

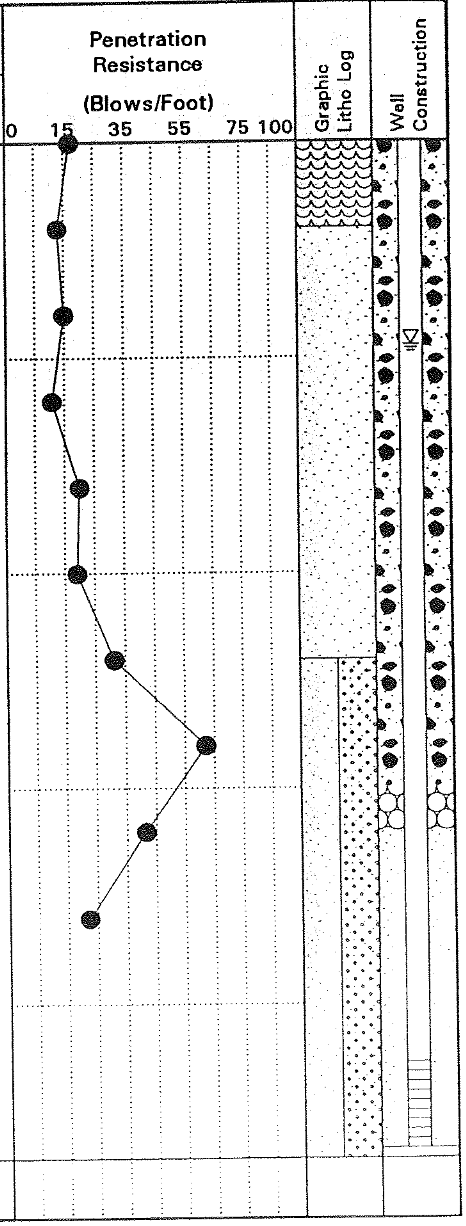
REMARKS:

LOG OF TEST BORING

Depth (ft)	Sample Type & Recovery	Sample Number	Penetration Resistance Blows/6" N-Value	Unified Classification	FIELD DESCRIPTION	Munsell Field Color
		S1	3 6 9 7 15	PT	2 in. organic material grading to 6 in. 7.5 YR 5/2 grading to 5 in. 7.5 YR 3/1 2.0	7.5 YR 3/1 = 7.5 YR 5/2
		S2	4 4 7 7 11	SP	Fine sand w/ heavy staining	1 2.5/N = 7.5 YR 2.5/1
5		S3	8 7 6 6 13			7.5 YR 2.5/1
		S4	5 9 0 9 9		Fine sand	7.5 YR 4/1
		S5	9 13 6 7 18			7.5 YR 3/1
10		S6	10 8 9 14 17		12.0	7.5 YR 5/3
		S7	15 15 14 14 29	SP-SW	11 in. medium to fine sand grading to 11 in. fine sand	7.5 YR 7/1 = 7.5 YR 5/3
15		S8	27 22 37 40 59		Medium to fine sand	
		S9	15 17 22 24 39			7.5 YR 7/1
		S10	10 13 7 7 20			
20						
					23.6	

LA 9/11/97

EMP



Fine Sand
Medium Sand
Bentonite Pellets
Cement Grout
Silt/Clay w/ shell
Organic Material
Clay
Split Spoon
Percent Recovery
No Recovery

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BORING/WELL NO. **JD6**

BORING LOG

PROJECT NO./NAME **1033/Isolated Wetlands Shallow Drilling Program**	LOCATION **Jonathan Dickinson State Park, Martin County, Florida**

DRILLING CONTRACTOR/DRILLER
Precision Drilling/Robert Miller

GEOLOGIST/OFFICE
Steve Krupa/South Florida Water Management District

DRILLING EQUIPMENT/METHOD **Tripod/SPT**	SIZE/TYPE OF BIT **3' - 5" dia.casing, driven and washed**	SAMPLING METHOD **Split Spoon**	START/FINISH DATE **1/2/97-1/15/97**

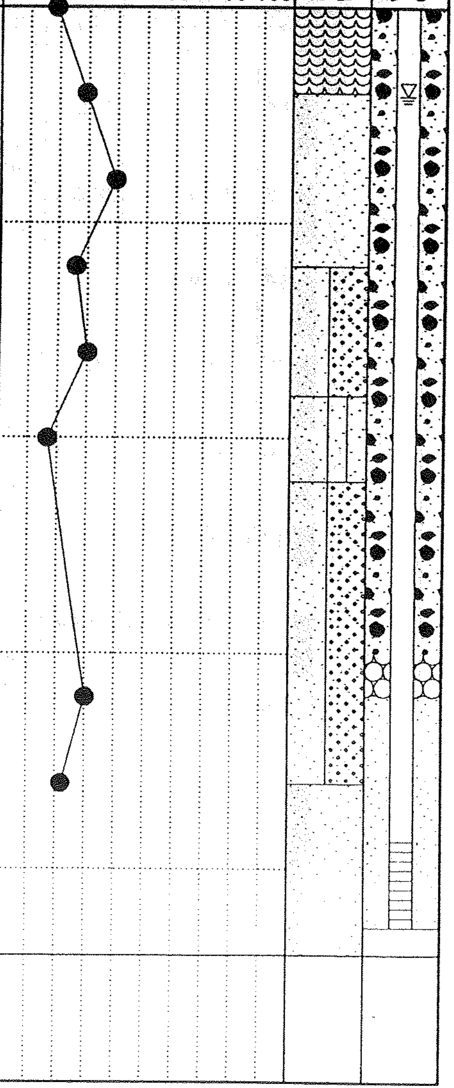
WELL INSTALLED? YES ☒ NO ☐
CASING MAT./DIA. **Sch.40 monoflex PVC/2"**
SCREEN: TYPE **Slotted** MAT. **PVC** LENGTH **2'** DIA. **2"** SLOT SIZE **.010**

ELEVATION OF: (FT. ABOVE M.S.L.)	GROUND SURFACE	TOP OF WELL CASING	TOP & BOTTOM SCREEN	DATE
		1.42 ft	**19.35 ft/21.35 ft**	**1/24/97**

REMARKS:

Depth (ft)	Sample Type & Recovery	Sample Number	Penetration Resistance Blows/6" N-Value	Unified Classification	LOG OF TEST BORING FIELD DESCRIPTION	Munsell Field Color
	☒	S1	6 6 6 6 12	PT	4 in. muck, 6 in. fine sand 2.0	1 2.5/N=7.5 YR 8/1
	☒	S2	14 10 12 16 22	SP	12 in. fine sand, 4 in. black fine sand	7.5 YR 6/3=1 2.5/N
5	☒	S3	10 16 16 10 32		12 in. fine sand 6.0	7.5 YR 6/1
	☒	S4	12 7 12 12 19	SP-SW		
	☒	S5	10 10 13 15 23		18 in. medium to fine sand w/ organics 9.0	1 2.5/N
10	☒	S6	4 5 5 7 10	SP-SM	12 in. fine sand, silty sand toward bottom of interval 11.0	10 YR 4/1
	○	S7			14 in. medium to fine sand No sample	7.5 YR 7/1
15	○	S8			No sample	
	☒	S9	15 14 9 6 23		16 in. medium to fine sand 18.0	
	☒	S10	4 5 10 15 15	SP	14 in. fine sand	10 YR 7/2
20					22.0	

Penetration Resistance (Blows/Foot) | Graphic Litho Log | Well Construction



EMP .ILA 9/10/97

- ▯ Fine Sand
- ⁙ Medium Sand
- ○ Bentonite Pellets
- ● Cement Grout
- ▭ Silt/Clay w/ shell
- ≈ Organic Material
- ▨ Clay
- ☒ Split Spoon
- ■ Percent Recovery
- ○ No Recovery

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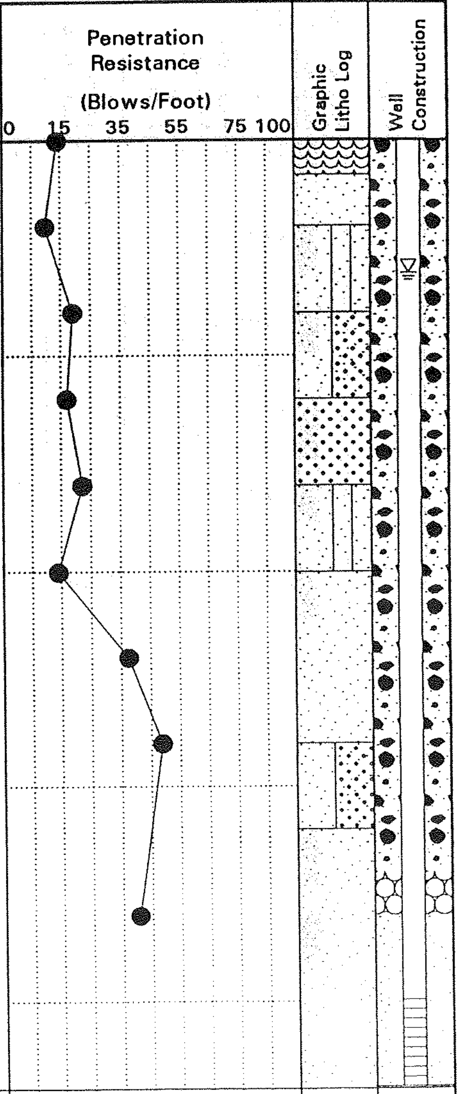
DRAFT

BORING LOG

BORING/WELL NO.	JD12
PROJECT NO./NAME	1033/Isolated Wetlands Shallow Drilling Program
LOCATION	Jonathan Dickinson State Park, Martin County, Florida
DRILLING CONTRACTOR/DRILLER	Precision Drilling/Robert Miller
GEOLOGIST/OFFICE	Steve Krupa/South Florida Water Management District
DRILLING EQUIPMENT/METHOD	Tripod/SPT
SIZE/TYPE OF BIT	3'-5"dia casing, driven and washed
SAMPLING METHOD	Split Spoon
START/FINISH DATE	1/17/97-1/17/97
WELL INSTALLED?	YES ☒ NO ☐
CASING MAT./DIA.	Sch.40 monoflex PVC/2"
SCREEN:	TYPE Slotted MAT. PVC LENGTH 2' DIA. 2" SLOT SIZE .010
ELEVATION OF: (FT. ABOVE M.S.L.) GROUND SURFACE	
TOP OF WELL CASING	3.25 ft
TOP & BOTTOM SCREEN	19.95 ft/21.95 ft
DATE	1/24/97
REMARKS:	

LOG OF TEST BORING

Depth (ft)	Sample Type & Recovery	Sample Number	Penetration Resistance Blows/6" N-Value	Unified Classification	FIELD DESCRIPTION		Munsell Field Color
	☒	S1	8 6 6 6 12	PT	3 in. organic material, 16 in. fine sand	0.8 2.0	1 2.5/N
	☒	S2	3 3 5 8 8	SM	4 in. fine sand, 12 in. fine sand w/silt size particles	4.0	10 YR 8/1 = 10 YR 3/1
5	☒	S3	6 10 7 8 17	SP-SW	Medium grading to fine sand	6.0	10 YR 6/1
	☒	S4	17 9 6 5 15		6 in. fine sand grading to 15 in. medium sand	8.0	10 YR 8/1 = 7.5 YR 7/1
	☒	S5	8 10 10 10 20	SM	6 in. fine sand grading to 14 in. fine sand w/ silt size particles	10.0	7.5 YR 8/1 = 5 YR 5/3
10	☒	S6	4 5 7 4 12	SP-SW	8 in. fine sand grading to 11 in. medium to fine sand		7.5 YR 8/1 = 2.5 YR 4/4
	☒	S7	13 18 17 24 35	SP	Fine sand	14.0	10 R 3/1
15	☒	S8	9 15 31 40 46	SP-SW	Medium to fine grained sand w/ heavy organic staining	16.0	1 2.5/N
	○	S9			No sample, washed casing too deep		
20	☒	S10	12 19 19 20 38	SP	Fine sand	22.0	1 2.5/N = 10 R 4/1



EMP LA 9/10/97

Fine Sand	Medium Sand	Bentonite Pellets	Cement Grout	Silt/Clay w/ shell
Organic Material	Clay	Split Spoon	Percent Recovery	No Recovery

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DRAFT

BORING LOG

BORING/WELL NO. **JD26**

PROJECT NO./NAME **1033/Isolated Wetlands Shallow Drilling Program**	LOCATION **Jonathan Dickinson State Park, Martin County, Florida**
DRILLING CONTRACTOR/DRILLER **Precision Drilling/Robert Miller**	
GEOLOGIST/OFFICE **Stev Krupa/South Florida Water Management District**	

DRILLING EQUIPMENT/METHOD **Tripod/SPT**	SIZE/TYPE OF BIT **3'-5"dia. casing, driven and washed**	SAMPLING METHOD **Split Spoon**	START/FINISH DATE **1/15/97-1/16/97**

WELL INSTALLED? YES ☒ NO ☐

CASING MAT./DIA. **Sch.40 monoflex PVC/2"**

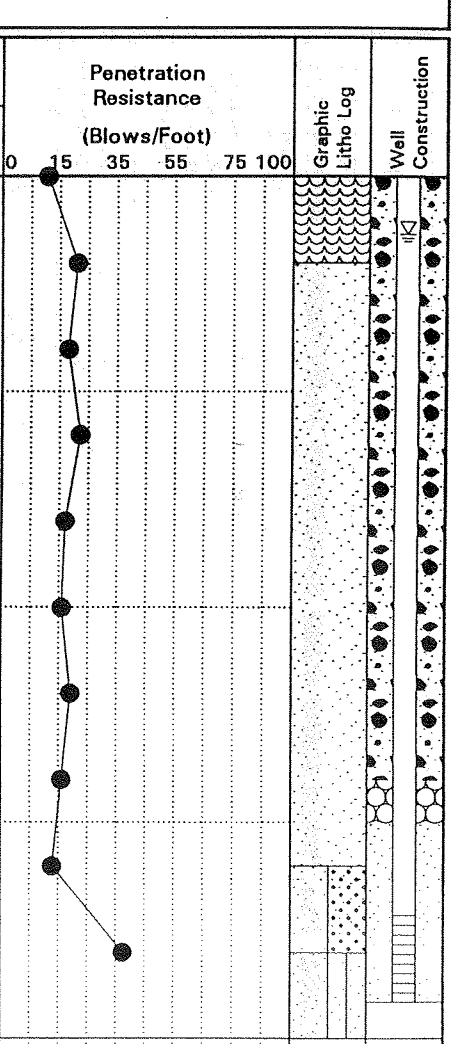
SCREEN: TYPE Slotted MAT. PVC LENGTH 2' DIA. 2" SLOT SIZE .010

ELEVATION OF: (FT. ABOVE M.S.L.)	GROUND SURFACE	TOP OF WELL CASING	TOP & BOTTOM SCREEN	DATE
	8.50 est.	3.16 ft	17.14 ft/19.14 ft	1/24/97

REMARKS:

LOG OF TEST BORING

Depth (ft)	Sample Type & Recovery	Sample Number	Penetration Resistance Blows/6" N-Value	Unified Classification	FIELD DESCRIPTION	Munsell Field Color
		S1	4 5 4 8 9	PT	Organics/fine sand and roots 2.0	1 2.5/N
		S2	8 11 8 10 19	SP	8 in. fine sand, 4 in. organics/sand	10 YR 5/2 = 1 2.5/1
5		S3	8 8 8 16 16		4 in. cypress stump, 6 in. fine sand	10 YR 4/3 = 10 YR 5/1
		S4	8 10 10 10 20			
		S5	7 8 7 8 15		12 in. black fine sand w/ organics	1 2.5/N
10		S6	7 7 7 7 14		Fine sand	10 YR 2/1 = 2.5 Y 7/1
		S7	8 10 7 6 17		2 in. fine sand, 11 in. medium to fine sand	10 YR 2/1 = 10 YR 4/3
15		S8	15 9 5 6 14		Fine sand 16.0	10 YR 3/1 10 YR 5/3
		S9	6 5 6 10 11	SW	Medium to fine grained sand 18.0	10 YR 7/1
		S10	6 20 15 22 35	SP-SM	Fine sand w/ silt size particles 20.0	
20						



EMP LA 9/10/97

- Fine Sand
- Medium Sand
- Bentonite Pellets
- Cement Grout
- Silt/Clay w/ shell
- Organic Material
- Clay
- Split Spoon
- Percent Recovery
- No Recovery

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DRAFT

BORING LOG

BORING/WELL NO. **WR6**

PROJECT NO./NAME **1033/Isolated Wetlands Shallow Drilling Program**

LOCATION **Nature Conservancy, Disney Preserve, Kissimmee, Florida**

DRILLING CONTRACTOR/DRILLER **Precision Drilling/Robert Miller**

GEOLOGIST/OFFICE **Steve Krupa/South Florida Water Management District**

DRILLING EQUIPMENT/METHOD **Tripod/SPT**

SIZE/TYPE OF BIT **3'- 5"dia. casing, driven and washed**

SAMPLING METHOD **Split Spoon**

START/FINISH DATE **1/28/97-1/28/97**

WELL INSTALLED? YES ☒ NO ☐

CASING MAT./DIA. **Sch.40 monoflex PVC/2"**

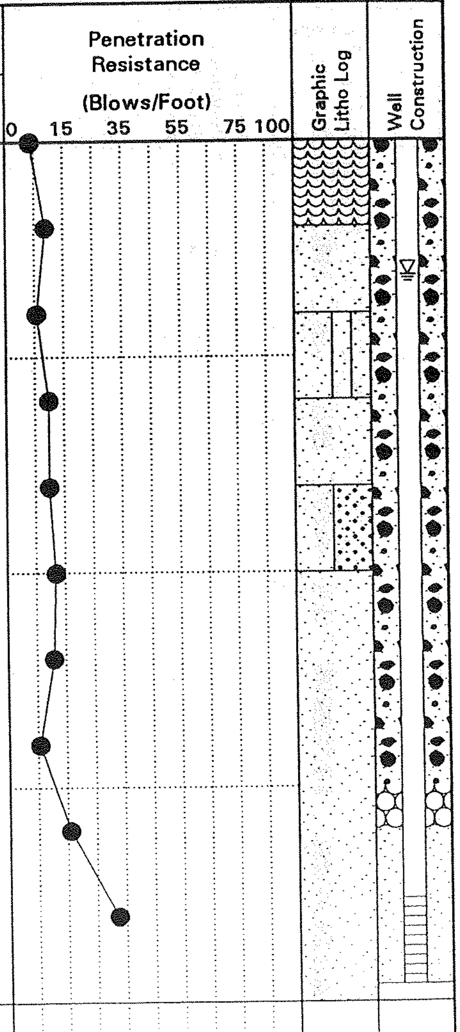
SCREEN: TYPE **Slotted** MAT. **PVC** LENGTH **2'** DIA. **2"** SLOT SIZE **.010**

ELEVATION OF: (FT. ABOVE M.S.L.) GROUND SURFACE **62.6** TOP OF WELL CASING **2.75 ft** TOP & BOTTOM SCREEN **17.60 ft/19.60 ft** DATE **2/2/97**

REMARKS:

LOG OF TEST BORING

Depth (ft)	Sample Type & Recovery	Sample Number	Penetration Resistance Blows/6" N-Value	Unified Classification	FIELD DESCRIPTION		Munsell Field Color
		S1	1 1 1 1 2	PT	Fibrous organic material	2.0	1 2.5/N
		S2	4 4 3 4 7	SP	Marbled 10 YR 8/1 (4 in) grading to fine sand 10 YR 3/1	4.0	10 YR 4/1
5		S3	2 2 2 2 4	SP-SM	4 in. fine sand grading to fine sand w/ clay size particles	6.0	10 YR 4/1 = 10 YR 6/1
		S4	4 4 4 4 8	SP	Fine sand	8.0	10 YR 5/2
		S5	4 4 4 3 8	SP-SW	Medium to fine sand	10.0	10 YR 7/2
10		S6	6 6 4 4 10		Fine sand grading to clay size sand		10 YR 8/1
		S7	5 5 4 3 9	SP	Fine sand		10 YR 8/1 = 10 YR 5/2
15		S8	2 2 2 3 4				10 YR 8/1
		S9	12 9 5 6 14		Fine Sand		
20		S10	12 12 18 18 30			20.0	10 YR 8/1 = 10 YR 5/2



EMP .LA 9/9/97

▯	Fine Sand
⁘	Medium Sand
○	Bentonite Pellets
●	Cement Grout
☰	Silt/Clay w/ shell
≋	Organic Material
▨	Clay
☒	Split Spoon
■	Percent Recovery
○	No Recovery

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DRAFT

BORING LOG

BORING/WELL NO. **WR8**

PROJECT NO./NAME **1033/Isolated Wetlands Shallow Drilling Program**	LOCATION **Nature Conservancy, Disney Preserve, Kissimmee, Florida**

DRILLING CONTRACTOR/DRILLER
Precision Drilling/Robert Miller

GEOLOGIST/OFFICE
Steve Krupa/South Florida Water Management District

DRILLING EQUIPMENT/METHOD **Tripod/SPT**	SIZE/TYPE OF BIT **3'- 5"dia. casing, driven and washed**	SAMPLING METHOD **Split Spoon**	START/FINISH DATE **1/27/97-1/27/97**

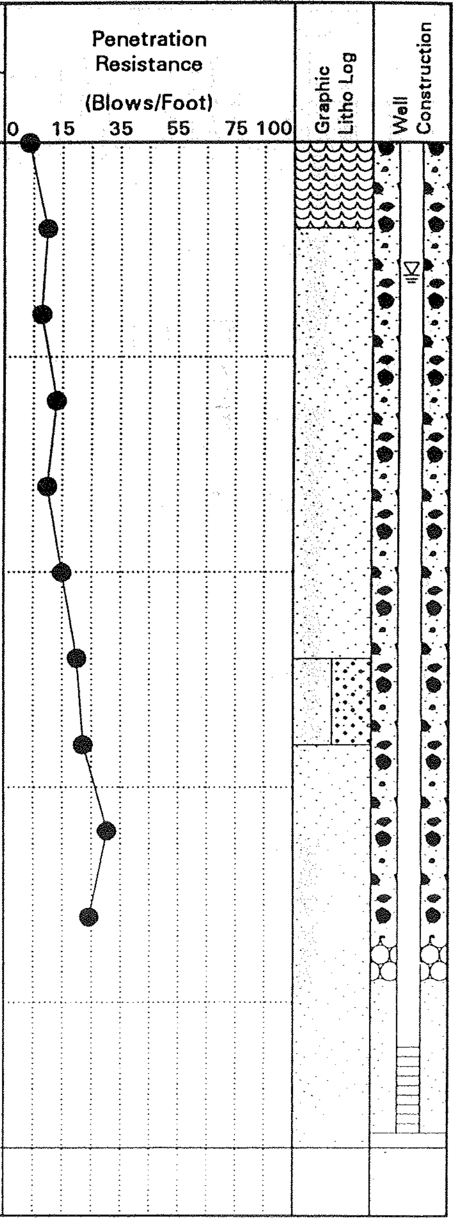
WELL INSTALLED? YES ☒ NO ☐	CASING MAT./DIA. **Sch.40 monoflex PVC/2"**	SCREEN: TYPE **Slotted** MAT. **PVC** LENGTH **2'** DIA. **2"** SLOT SIZE **.010**

ELEVATION OF: (FT. ABOVE M.S.L.)	GROUND SURFACE **66.24 ft**	TOP OF WELL CASING **2.08 ft**	TOP & BOTTOM SCREEN **21.04 ft/23.04 ft**	DATE **2/2/97**

REMARKS:

LOG OF TEST BORING

Depth (ft)	Sample Type & Recovery	Sample Number	Penetration Resistance Blows/6" N-Value	Unified Classification	FIELD DESCRIPTION	Munsell Field Color
	○	S1	1 1 1 1 2	PT	Organic material 2.0	1 2.5/N
	⊠	S2	3 4 4 4 8	SP	Fine sand w/ heavy organic staining	7.5 YR 3/1
5	⊠	S3	2 1 5 5 6		12 in. fine organic sand grading to 8 in. fine sand w/ marbled clean white sand	7.5 YR 3/1 = 10 YR 5/2
	⊠	S4	5 7 4 6 11		Fine Sand	10 YR 4/2
	⊠	S5	10 4 4 4 8	SP	Fine Sand	10 YR 7/2
10	⊠	S6	14 9 4 4 13		12.0	
	⊠	S7	15 12 6 6 18	SP-SW	6 in. medium to fine sand grading to fine sand 14.0	10 YR 8/1 = 10 YR 6/1
15	⊠	S8	21 10 10 15 20	SP	marbled fine sand	
	⊠	S9	18 14 14 13 28		Fine sand	10 YR 7/2
	⊠	S10	14 10 12 18 22			
20						
					23.4	



LA 9/9/97

EMF

▯	Fine Sand
⁙	Medium Sand
○	Bentonite Pellets
●	Cement Grout
≡	Silt/Clay w/ shell
≈	Organic Material
▨	Clay
⊠	Split Spoon
■	Percent Recovery
○	No Recovery

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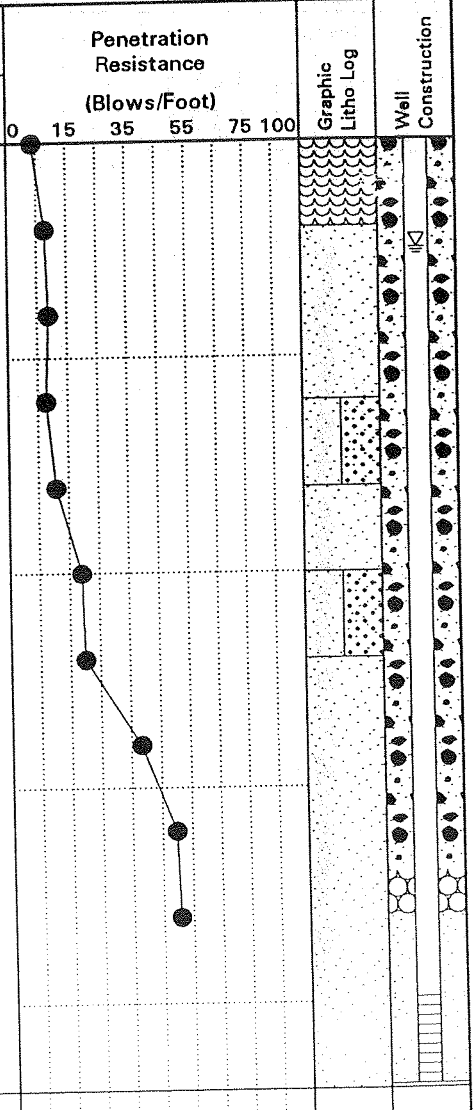
DRAFT

BORING LOG

BORING/WELL NO.	WR9
PROJECT NO./NAME	1033/Isolated Wetlands Shallow Drilling Program
LOCATION	Nature Conservancy, Disney Preserve, Kissimmee, Florida
DRILLING CONTRACTOR/DRILLER	Precision Drilling/Robert Miller
GEOLOGIST/OFFICE	Steve Krupa/South Florida Water Management District
DRILLING EQUIPMENT/METHOD	Tripod/SPT
SIZE/TYPE OF BIT	3'- 5"dia. casing, driven and washed
SAMPLING METHOD	Split Spoon
START/FINISH DATE	1/29/97-1/29/97
WELL INSTALLED?	YES ☒ NO ☐
CASING MAT./DIA.	Sch.40 monoflex PVC/2"
SCREEN:	TYPE Slotted MAT. PVC LENGTH 2' DIA. 2" SLOT SIZE .010
ELEVATION OF: (FT. ABOVE M.S.L.) GROUND SURFACE	65.71 ft
TOP OF WELL CASING	2.91 ft
TOP & BOTTOM SCREEN	19.90 ft/21.90 ft
DATE	2/2/97
REMARKS:	

Depth (ft)	Sample Type & Recovery	Sample Number	Penetration Resistance Blows/6" N-Value	Unified Classification	LOG OF TEST BORING FIELD DESCRIPTION	Munsell Field Color
	☒	S1	1 1 1 2 2	PT	Fibrous organic material 2.0	1 2.5/N
	☒	S2	3 3 3 4 6	SP	Fine sand	10 YR 7/2
5	☒	S3	3 4 3 4 7		6.0	10 YR 5/2
	☒	S4	3 3 3 3 6	SW	5 in. medium sand grading to fine sand 8.0	10 YR 8/1 = 10 YR 7/2
	☒	S5	5 5 4 6 9	SP	Fine sand 10.0	10 YR 7/2
10	☒	S6	12 10 7 6 17	SW	5 in. medium sand grading to fine sand with iron staining 12.0	10 YR 8/1 = 10 YR 6/4
	☒	S7	10 8 10 1 18		7 in. fine sand grading to 14 in. 10 YR 5/2	10 YR 8/1 = 10 YR 5/2
15	○	S8	13 13 23 24 36	SP	No sample	10 YR 5/2
	☒	S9	16 30 17 20 47		Fine sand grading toward 10 YR 4/1	10 YR 8/2
	☒	S10	20 20 28 29 48		Fine sand	10 YR 8/1
20					22.0	



Fine Sand
Medium Sand
Bentonite Pellets
Cement Grout
Silt/Clay w/ shell
Organic Material
Clay
Split Spoon
Percent Recovery
No Recovery

EMI FLA 9/10/97

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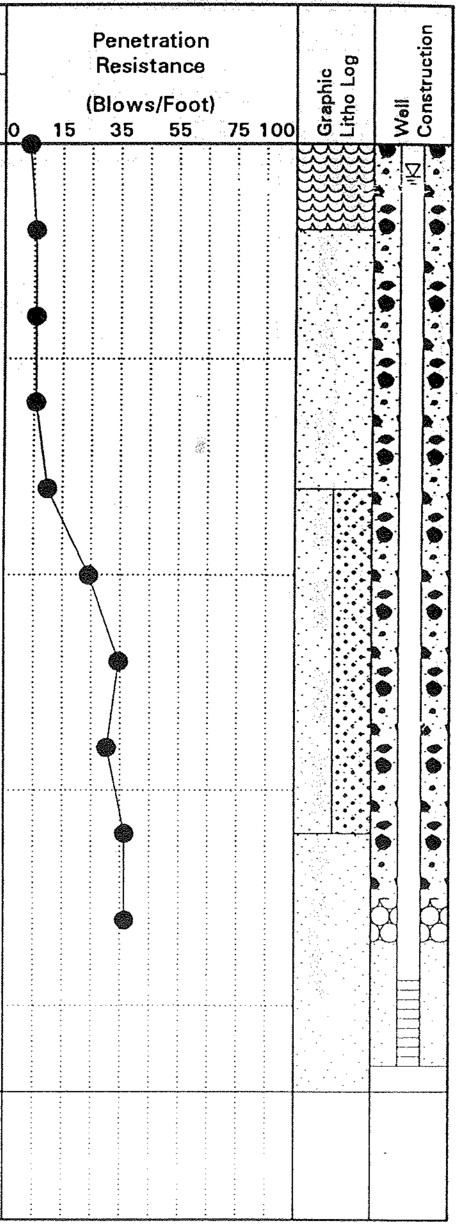
DRAFT

BORING LOG

BORING/WELL NO.	**WR11**
PROJECT NO./NAME	**1033/Isolated Wetlands Shallow Drilling Program**
LOCATION	**Nature Conservancy, Disney Preserve, Kissimmee, Florida**
DRILLING CONTRACTOR/DRILLER	**Precision Drilling/Robert Miller**
GEOLOGIST/OFFICE	**Steve Krupa/South Florida Water Management District**
DRILLING EQUIPMENT/METHOD	**Tripod/SPT**
SIZE/TYPE OF BIT	**3'- 5"dia. casing, driven and washed**
SAMPLING METHOD	**Split Spoon**
START/FINISH DATE	**1/30/97-1/30/97**
WELL INSTALLED?	YES ☒ NO ☐
CASING MAT./DIA.	**Sch.40 monoflex PVC/2"**
SCREEN:	TYPE Slotted MAT. PVC LENGTH 2' DIA. 2" SLOT SIZE .010
ELEVATION OF: (FT. ABOVE M.S.L.) GROUND SURFACE	
TOP OF WELL CASING	1.16 ft
TOP & BOTTOM SCREEN	19.39 ft/21.39 ft
DATE	2/2/97
REMARKS:	

Depth (ft)	Sample Number	Penetration Resistance Blows/6" N-Value	Unified Classification	LOG OF TEST BORING FIELD DESCRIPTION	Munsell Field Color
	S1	1 1 1 1 2	PT	Organic material 2.0	7.5 YR 2.5/1
	S2	3 2 2 2 4		5 in. organics grading to fine Sand	7.5 YR 2.5/1 = 7.5 YR 4/2
5	S3	2 2 2 2 4	SP	Fine sand w/ root bits	7.5 YR 6/2
	S4	2 2 2 2 4		Fine sand 8.0	10 YR 7/2
	S5	5 4 4 4 8	SP-SW		
10	S6	13 9 13 15 22		Medium to fine grained sand	
	S7	12 19 13 17 32	SW		10 YR 6/2
15	S8	11 10 18 18 28		16.0	
	S9	11 15 19 19 34	SP	Fine Sand	10 YR 6/3
	S10	8 13 21 21 34			10 YR 4/2
20				22.0	



LA 9/10/97
EMP

▯ Fine Sand	⁙ Medium Sand
Bentonite Pellets	● Cement Grout
Silt/Clay w/ shell	Organic Material
▨ Clay	☒ Split Spoon
■ Percent Recovery	○ No Recovery

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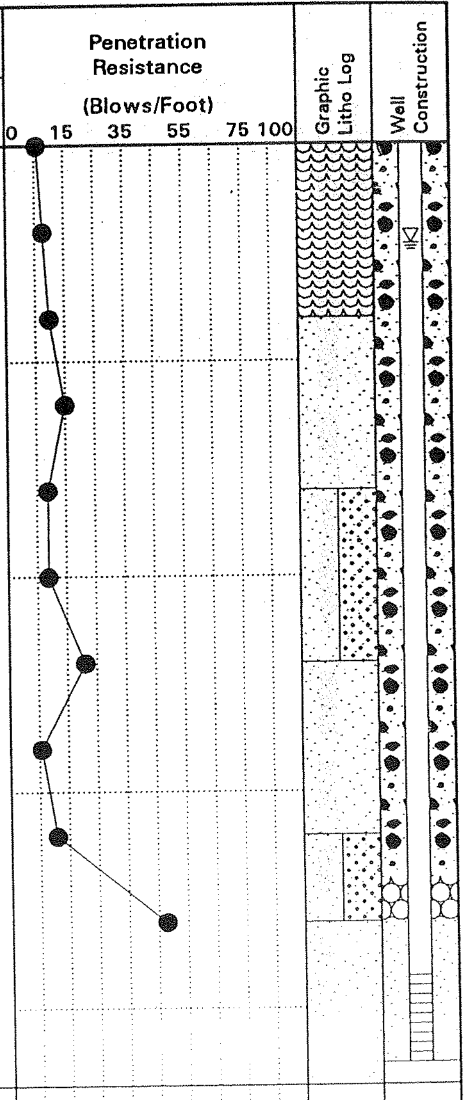
DRAFT

BORING LOG

BORING/WELL NO.	WR15
PROJECT NO./NAME	1033/Isolated Wetlands Shallow Drilling Program
LOCATION	Nature Conservancy, Disney Preserve, Kissimmee, Florida
DRILLING CONTRACTOR/DRILLER	Precision Drilling/Robert Miller
GEOLOGIST/OFFICE	Steve Krupa/South Florida Water Management District
DRILLING EQUIPMENT/METHOD	Tripod/SPT
SIZE/TYPE OF BIT	3' - 5"dia. casing, driven and washed
SAMPLING METHOD	Split Spoon
START/FINISH DATE	2/1/97-2/1/97
WELL INSTALLED?	YES ☒ NO ☐
CASING MAT./DIA.	Sch.40 monoflex PVC/2"
SCREEN:	TYPE Slotted MAT. PVC LENGTH 2' DIA. 2" SLOT SIZE .010
ELEVATION OF: (FT. ABOVE M.S.L.) GROUND SURFACE	
TOP OF WELL CASING	1.50 ft
TOP & BOTTOM SCREEN	19.27 ft/21.27 ft
DATE	2/2/97
REMARKS:	

LOG OF TEST BORING

Depth (ft)	Sample Number	Penetration Resistance Blows/6" N-Value	Unified Classification	FIELD DESCRIPTION	Munsell Field Color
	S1	4 2 2 1 4	PT-SP	Organic material w/ fine sand	1 2.5/N
	S2	4 3 3 2 6		4 in. organic material grading to fine sand 4.0	1 2.5/N=7.5 YR 3/2
5	S3	3 4 4 4 8	SP	Fine sand	7.5 YR 3/2
	S4	9 7 6 6 13		8.0	10 YR 5/2
	S5	6 4 3 4 7	SP-SW	Medium to fine grained sand	
10	S6	3 3 4 3 7		12.0	
	S7	9 11 8 6 19	SP	Fine sand	10 YR 6/2
15	S8	7 2 2 5 4		16.0	10 YR 5/2
	S9	4 4 5 10 9	SP-SW	Medium to fine grained sand 18.0	
20	S10	24 24 21 18 45	SP	Fine Sand 21.8	10 YR 6/2



EMP LA 9/10/97

Fine Sand
Medium Sand
Bentonite Pellets
Cement Grout
Silt/Clay w/ shell
Organic Material
Clay
Split Spoon
Percent Recovery
No Recovery

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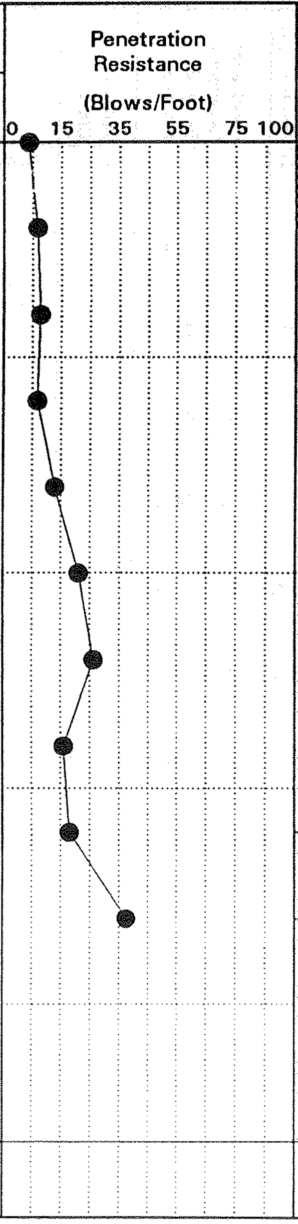
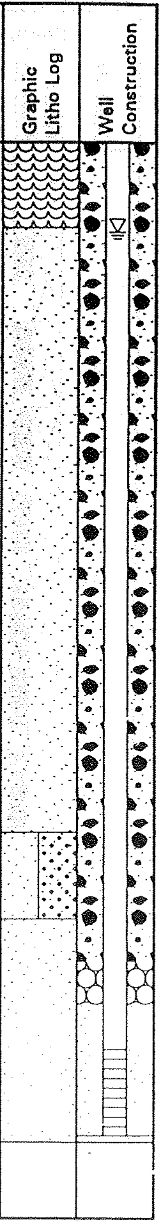
BORING LOG

BORING/WELL NO. **WR16**			
PROJECT NO./NAME **1033/Isolated Wetlands Shallow Drilling Program**	LOCATION **Nature Conservancy, Disney Preserve, Kissimmee, Florida**		
DRILLING CONTRACTOR/DRILLER **Precision Drilling/Robert Miller**			
GEOLOGIST/OFFICE **Steve Krupa/South Florida Water Management District**			
DRILLING EQUIPMENT/METHOD **Tripod/SPT**	SIZE/TYPE OF BIT **3'-5" dia. casing, driven and washed**	SAMPLING METHOD **Split Spoon**	START/FINISH DATE **1/31/97-1/31/97**
WELL INSTALLED? YES ☒ NO ☐	CASING MAT./DIA. **Sch.40 monoflex PVC/2"**	SCREEN: TYPE Slotted MAT. PVC LENGTH 2' DIA. 2" SLOT SIZE .010	
ELEVATION OF: (FT. ABOVE M.S.L.)	GROUND SURFACE **0.0**	TOP OF WELL CASING **1.75 ft**	TOP & BOTTOM SCREEN **21.05 ft/23.05 ft**
DATE **2/2/97**			
REMARKS:			

LOG OF TEST BORING

Depth (ft)	Sample Number	Penetration Resistance Blows/6" N-Value	Unified Classification	FIELD DESCRIPTION	Munsell Field Color
	S1	1 1 1 1 2	PT	Organic material w/ fine sand 2.0	1 2.5/N
	S2	1 2 3 4 5	SP	14 in. of fine sand grading to 10 YR 6/2	1 2.5/N=10 YR 6/2
5	S3	2 3 3 2 6		11 in. fine sand grading to 7.5 YR 3/1 fine sand	10 YR 6/2=7.5 YR 3/1
	S4	6 3 2 3 5		Fine sand	7.5 YR 3/1
	S5	4 4 7 14 11		Fine sand w/ heavy organic staining	7.5 YR /1
10	S6	8 11 8 10 19		13 in. fine sand grading to 7.5 YR /1	10 YR 3/2=7.5 YR 3/1
	S7	12 13 11 10 24		Fine sand	10 YR 6/2
15	S8	6 7 7 8 14		16.0	
	S9	7 9 7 11 16	SP-SW	Medium to fine Sand 18.0	10 YR 5/2
	S10	22 19 16 13 35		Fine sand	10 YR 6/2
20				23.2	





Fine Sand	Medium Sand
Bentonite Pellets	Cement Grout
Silt/Clay w/ shell	Organic Material
Clay	Split Spoon
Percent Recovery	No Recovery

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BORING LOG

BORING/WELL NO. FP2

PROJECT NO./NAME 1033/Isolated Wetlands Shallow Drilling Program

LOCATION Flint Pen Strand, Fort Myers, Florida

DRILLING CONTRACTOR/DRILLER Precision Drilling/Robert Miller

GEOLOGIST/OFFICE Steve Krupa/South Florida Water Management District

DRILLING EQUIPMENT/METHOD Tripod/SPT

SIZE/TYPE OF BIT 3'-5"dia. casing, driven and washed

SAMPLING METHOD Split Spoon

START/FINISH DATE 2/16/97-2/16/97

WELL INSTALLED? YES ☒ NO ☐

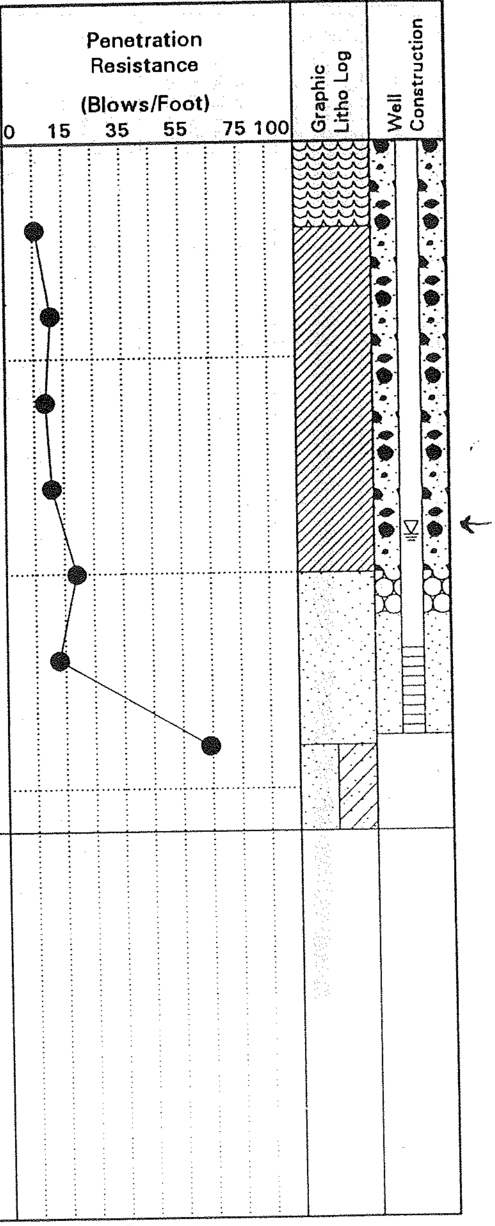
CASING MAT./DIA. Sch.40 monoflex PVC/2"

SCREEN: TYPE Slotted MAT. PVC LENGTH 2' DIA. 2" SLOT SIZE .010

ELEVATION OF: (FT. ABOVE M.S.L.) GROUND SURFACE 17.60 ft TOP OF WELL CASING 4.0 ft TOP & BOTTOM SCREEN 11.78 ft/13.78 ft DATE 2/17/97

REMARKS:

Depth (ft)	Sample: Type & Recovery	Sample: Number	Penetration Resistance Blows/6" N-Value	Unified Classification	LOG OF TEST BORING: FIELD DESCRIPTION	Munsell Field Color
	○	S1		PT	Organic Material 2.0	12.5/N
	☒	S2	2 2 2 3 4	CL	Clay w/ Iron Staining	10 YR 8/2
5	☒	S3	3 5 4 6 9			10 YR 6/2
	☒	S4	7 3 4 3 7			
	☒	S5	12 6 3 3 9		10.0	
10	☒	S6	9 8 9 15 17	SP	Fine sand w/ iron staining	10 YR 8/1
	☒	S7	12 6 5 25 11		Fine sand grading to clay size particles 14.0	
15	☒	S8	18 33 28 13 61	SP-SC	9 in. Fine Sand w/ shell fragments grading to clay size particles w/ sand 16.0	
		S9 S10				No sample



EMF FLA 9/9/97

▯	Fine Sand
⁘	Medium Sand
○	Bentonite Pellets
●	Cement Grout
▭	Silt/Clay w/ shell
≋	Organic Material
▨	Clay
☒	Split Spoon
■	Percent Recovery
○	No Recovery

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BORING LOG

BORING/WELL NO. **FP3**

PROJECT NO./NAME **1033/Isolated Wetlands Shallow Drilling Program**

LOCATION **Flint Pen Strand, Fort Myers, Florida**

DRILLING CONTRACTOR/DRILLER **Precision Drilling/Robert Miller**

GEOLOGIST/OFFICE **Steve Krupa/South Florida Water Management District**

DRILLING EQUIPMENT/METHOD **Tripod/SPT**

SIZE/TYPE OF BIT **3'-5" dia. casing Driven and Washed**

SAMPLING METHOD **Split Spoon**

START/FINISH DATE **2/11/97-2/11/97**

WELL INSTALLED? YES ☒ NO ☐

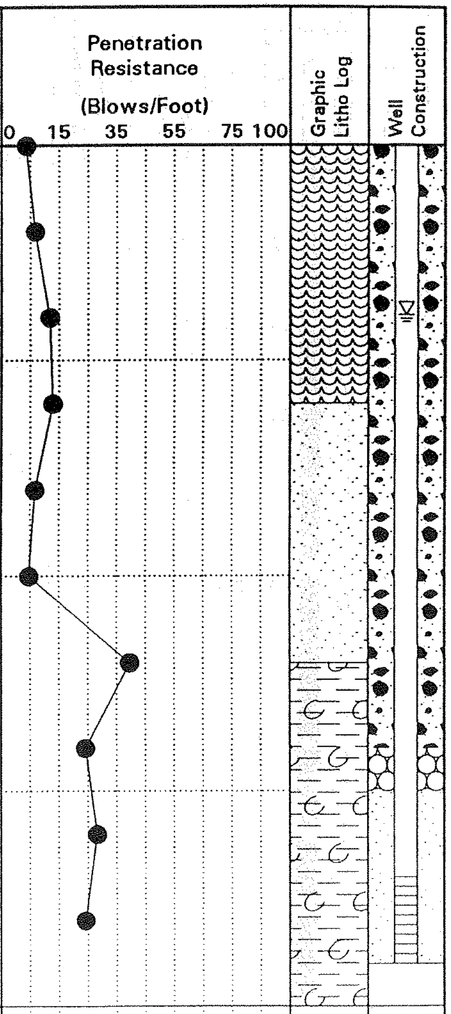
CASING MAT./DIA. **Sch.40 monoflex PVC/2"**

SCREEN: TYPE **Slotted** MAT. **PVC** LENGTH **2'** DIA. **2"** SLOT SIZE **.010**

ELEVATION OF: (FT. ABOVE M.S.L.) GROUND SURFACE **15.00 ft** TOP OF WELL CASING **3.46 ft** TOP & BOTTOM SCREEN **16.90 ft/18.90 ft** DATE **2/17/97**

REMARKS:

Depth (ft)	Sample Type & Recovery	Sample Number	Penetration Resistance Blows/6" N-Value	Unified Classification	LOG OF TEST BORING Field Description	Munsell Field Color
		S1	1 1 1 2 2	PT	Fibrous Organic Material	1 2.5/N
		S2	1 1 4 6 5			
5		S3	5 4 6 5 10		6.0	1 2.5/N=10YR 6/1
		S4	15 5 6 5 11	SP	6 inches 10 YR 3/1 grading to 13 inches fine sand (10 YR 7/2)	10 YR 3/1=10 YR 7/2
		S5	5 3 2 1 5		Marbled fine sand grading toward 11 inches fine sand (10 YR 6/3)	10 YR 4/1=10 YR 6/3
10		S6	2 2 1 4 3		13 inches fine sand with 10% shell fragments grading towards 60% shell fragments 12.0	10 YR 5/2=10 YR 8/1
		S7	1 10 27 29 37	SC	Fine sand w/ 50% shell fragments w/ clay size particles	10 YR 8/1
15		S8	8 14 8 6 22	SP	8 inches shell mash grading towards fine sand w/ 60% shell	
		S9	4 5 21 21 26		10 inches shell mash grading towards fine sand w/ 80% shell	
20		S10	6 12 10 12 22		Shell fragments 20.0	



▯ Fine Sand	⁙ Medium Sand
○ Bentonite Pellets	● Cement Grout
▤ Silt/Clay w/ shell	≋ Organic Material
▨ Clay	☒ Split Spoon
■ Percent Recovery	○ No Recovery

EMP FLA 9/9/97

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DRAFT

BORING/WELL NO. **FP4**

BORING LOG

PROJECT NO./NAME **1033/Isolated Wetlands Shallow Drilling Program**	LOCATION **Flint Pen Strand, Fort Myers, Florida**

DRILLING CONTRACTOR/DRILLER: **Precision Drilling/Robert Miller**

GEOLOGIST/OFFICE: **Steve Krupa/South Florida Water Management District**

DRILLING EQUIPMENT/METHOD	SIZE/TYPE OF BIT	SAMPLING METHOD	START/FINISH DATE
Tripod/SPT	**3'-5"dia. casing, driven and washed**	**Split Spoon**	**2/13/97-2/13/97**

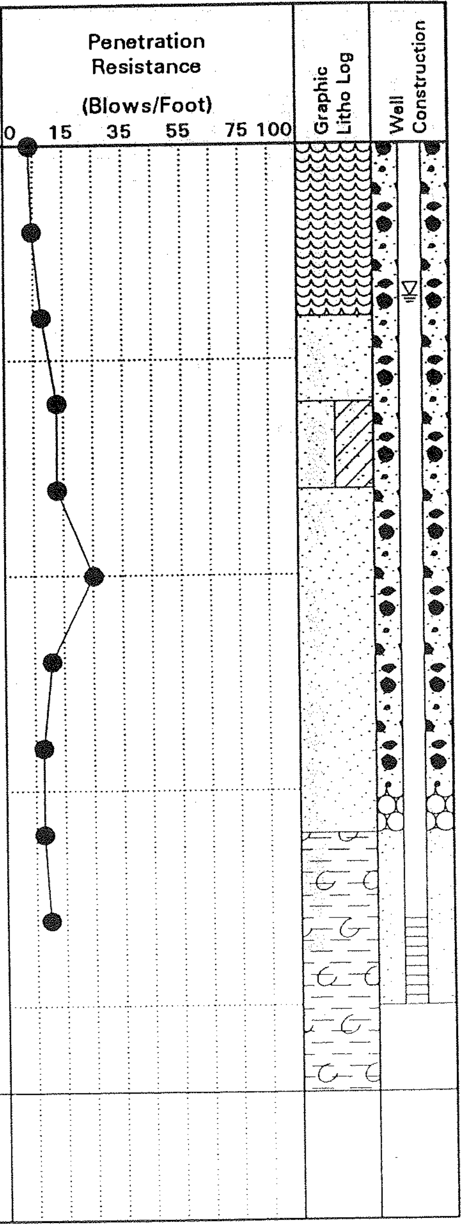
WELL INSTALLED?	CASING MAT./DIA.	SCREEN: TYPE	MAT.	LENGTH	DIA.	SLOT SIZE
YES ☒ NO ☐	**Sch.40 monoflex PVC/2"**	Slotted	PVC	2'	2"	.010

ELEVATION OF: (FT. ABOVE M.S.L.)	GROUND SURFACE	TOP OF WELL CASING	TOP & BOTTOM SCREEN	DATE
	15.25 ft	**2.55 ft**	**18.00 ft/20.00 ft**	**2/17/97**

REMARKS:

LOG OF TEST BORING

Depth (ft)	Sample Type & Recovery	Sample Number	Penetration Resistance Blows/6" N-Value	Unified Classification	Field Description	Munsell Field Color
	☒	S1	1 1 1 1 2	PT	Fibrous organic material	1 2.5/N
	☒	S2	1 1 2 5 3		Fibrous organic material w/ fine sand 4.0	
5	☒	S3	4 3 3 4 6	SP	Fine sand 6.0	1 2.5/N = 1 8/N
	☒	S4	7 6 5 7 11	SP-SC	Fine sand grading toward clay size particles 8.0	2.5 YR 7/1
	☒	S5	6 5 6 8 11		Fine sand w/ iron staining	10 YR 6/1
10	☒	S6	12 11 12 14 23	SP		
	☒	S7	10 5 4 3 9			
15	☒	S8	11 4 2 2 6		16.0	10 YR 6/3
	☒	S9	4 3 3 3 6	OHSH	Fine sand w/ shell fragments grading towards clay size particles	10 YR 6/1 = 10 YR 8/1
	☒	S10	5 5 3 3 8		Fine sand w/ shell mash w/ 50% shell fragments grading toward clay size particles	10 YR 8/1
20					22.0	



EMF TLA 9/9/97

- ▯ Fine Sand
- ⁙ Medium Sand
- ○ Bentonite Pellets
- ● Cement Grout
- ☰ Silt/Clay w/ shell
- ≋ Organic Material
- ▨ Clay
- ☒ Split Spoon
- ■ Percent Recovery
- ○ No Recovery

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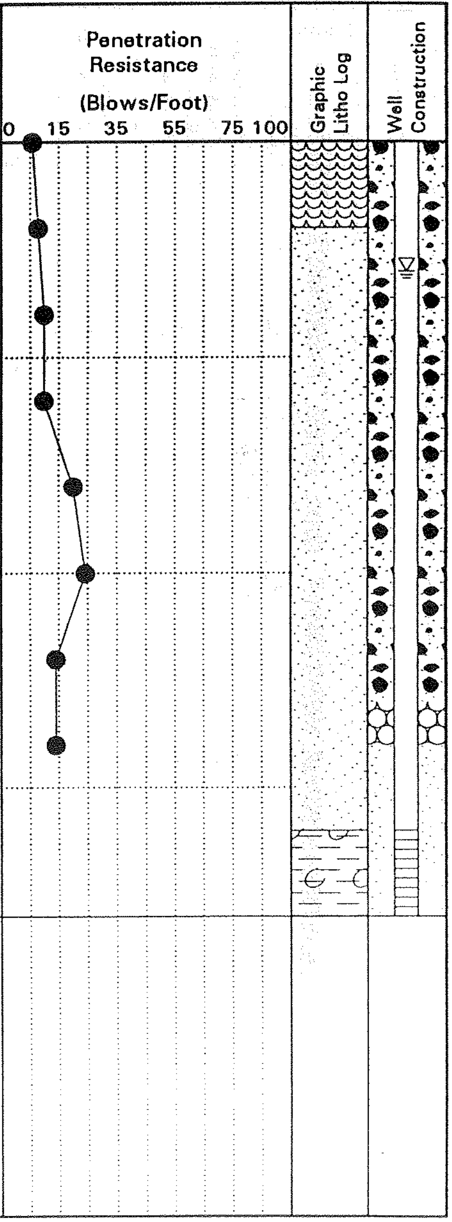
BORING LOG

BORING/WELL NO.	FP5
PROJECT NO./NAME	1033/Isolated Wetlands Shallow Drilling Program
LOCATION	Flint Pen Strand, Fort Myers, Florida
DRILLING CONTRACTOR/DRILLER	Precision Drilling/Robert Miller
GEOLOGIST/OFFICE	Steve Krupa/South Florida Water Management District
DRILLING EQUIPMENT/METHOD	Tripod/SPT
SIZE/TYPE OF BIT	3'-5" dia. casing, driven and washed
SAMPLING METHOD	Split Spoon
START/FINISH DATE	2/12/97-2/12/97
WELL INSTALLED?	YES ☒ NO ☐
CASING MAT./DIA.	Sch.40 monoflex PVC/2"
SCREEN:	TYPE Slotted MAT. PVC LENGTH 2' DIA. 2" SLOT SIZE .010
ELEVATION OF: (FT. ABOVE M.S.L.) GROUND SURFACE	14.80 ft
TOP OF WELL CASING	2.3 ft
TOP & BOTTOM SCREEN	16.00 ft/18.00 ft
DATE	2/17/97
REMARKS:	

LOG OF TEST BORING

Depth (ft)	Sample Type & Recovery	Sample Number	Penetration Resistance Blows/6" N-Value	Unified Classification	FIELD DESCRIPTION	Munsell Field Color
		S1	2 2 2 2 4	PT	Organic Material w/ fine sand 2.0	1 2.5/N
		S2	2 3 3 4 6		13 in. fine sand (1 2.5/N) grading to 7 in. (1 4/N)	1 2.5/N=1 4/N
5		S3	5 4 4 4 8	SP	Fine sand	10 YR 8/1
		S4	6 4 4 4 8			
		S5	9 9 9 9 18			10 YR 7/1
10		S6	12 11 10 10 22		Fine sand w/ iron staining	10 YR 8/1
		S7	21 8 4 8 12			
15		S8	13 6 6 4 12		16.0	
		S9	1 1	OLSH	6 in. fine sand w/ clay grading to fine sand w/ 50 % shell 18.0	1 6/N=2.5 YR 8/1
	○	S10			No sample	



- Fine Sand
- Medium Sand
- Bentonite Pellets
- Cement Grout
- Silt/Clay w/ shell
- Organic Material
- Clay
- Split Spoon
- Percent Recovery
- No Recovery

EMF TLA 9/9/97

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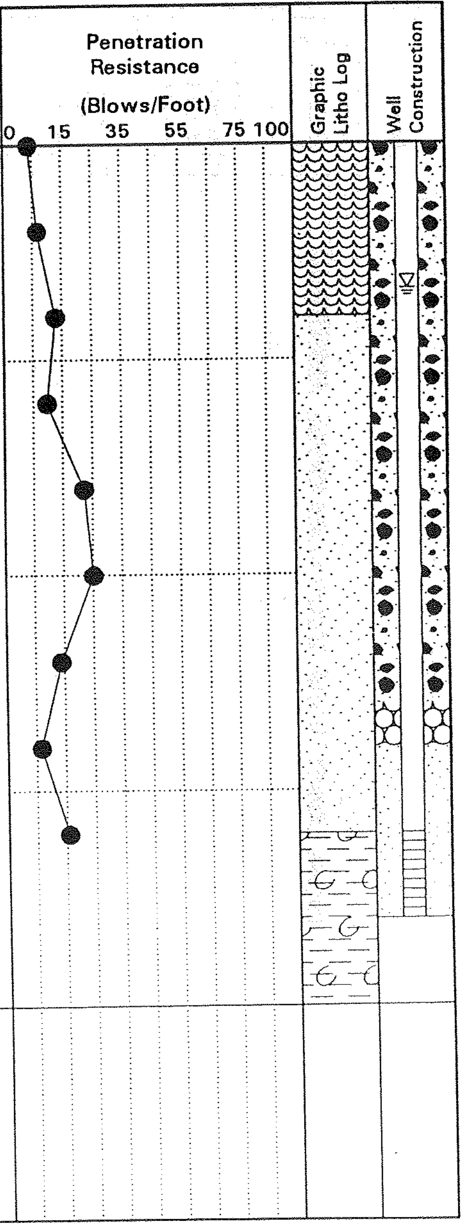
BORING LOG

BORING/WELL NO. **FP6**				
PROJECT NO./NAME **1033/Isolated Wetlands Shallow Drilling Program**	LOCATION **Flint Pen Strand, Fort Myers, Florida**			
DRILLING CONTRACTOR/DRILLER **Precision Drilling/Robert Miller**				
GEOLOGIST/OFFICE **Steve Krupa/South Florida Water Management District**				
DRILLING EQUIPMENT/METHOD **Tripod/SPT**	SIZE/TYPE OF BIT **3'-5" dia. casing, driven and washed**	SAMPLING METHOD **Split Spoon**	START/FINISH DATE **2/15/97-2/15/97**	
WELL INSTALLED? YES ☒ NO ☐	CASING MAT./DIA. **Sch.40 monoflex PVC/2"**	SCREEN: TYPE Slotted MAT. PVC LENGTH 2' DIA. 2" SLOT SIZE .010		
ELEVATION OF: (FT. ABOVE M.S.L.)	GROUND SURFACE **14.75 ft**	TOP OF WELL CASING **2.70 ft**	TOP & BOTTOM SCREEN **15.62 ft/17.62 ft**	DATE **2/17/97**
REMARKS:				

LOG OF TEST BORING

Depth (ft)	Sample Number	Penetration Resistance Blows/6" N-Value	Unified Classification	FIELD DESCRIPTION		Munsell Field Color
	S1	1 1 1 1 2	PT	Fibrous organic material		1 2.5/N
	S2	1 1 4 4 5		Fibrous organic w/ fine sand	4.0	
5	S3	11 7 4 4 11	SP	Fine sand		10 YR 4/1
	S4	8 4 4 5 8				10 YR 6/2
	S5	22 10 10 10 20		2 in. fine sand grading to 10 YR 7/1 w/ iron staining		10 YR 2/1 = 10 YR 7/1
10	S6	8 11 12 16 23		3 in. 10 YR 7/1 fine sand grading to 2 in. 10 YR 3/1 fine sand grading to 8/1 w/ iron staining		10 YR 7/1 = 10 YR 4/1
	S7	18 6 6 6 12		4 in. fine sand marbled w/ organic material grading to 15 in. fine sand		10 YR 7/1
15	S8	20 4 1 1 5		Fine sand w/ iron staining	16.0	
	S9	7 7 7 5 14	OLSH-	Fine sand w/ shell fragments grading to 8 in. of 1 8/N fine sand		1 8/N = 1 2.5/N
	S10	8 11	SC	Fine sand w/ 50 % shell grading to fine sand w/ clay size particles	20.0	1 8/N
20						



EMF ILA 9/9/97

▯	Fine Sand
⁖	Medium Sand
○	Bentonite Pellets
●	Cement Grout
⌇	Silt/Clay w/ shell
≋	Organic Material
▨	Clay
☒	Split Spoon
■	Percent Recovery
○	No Recovery

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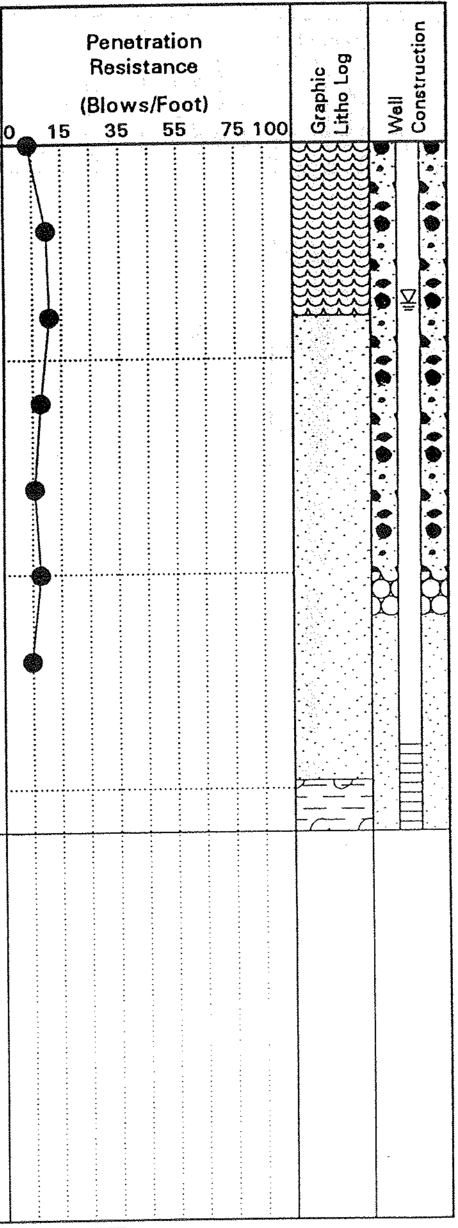
BORING LOG

BORING/WELL NO. **FP7**				
PROJECT NO./NAME **1033/Isolated Wetlands Shallow Drilling Program**	LOCATION **Flint Pen Strand, Fort Myers, Florida**			
DRILLING CONTRACTOR/DRILLER **Precision Drilling/Robert Miller**				
GEOLOGIST/OFFICE **Steve Krupa/South Florida Water Management District**				
DRILLING EQUIPMENT/METHOD **Tripod/SPT**	SIZE/TYPE OF BIT **3'-5" dia. casing, driven and washed**	SAMPLING METHOD **Split Spoon**	START/FINISH DATE **2/16/97-2/16/97**	
WELL INSTALLED? YES ☒ NO ☐	CASING MAT./DIA. **Sch.40 mononflex PVC/2"**	SCREEN: TYPE **Slotted** MAT. **PVC** LENGTH **2'** DIA. **2"** SLOT SIZE **.010**		
ELEVATION OF: (FT. ABOVE M.S.L.)	GROUND SURFACE **16.90 ft**	TOP OF WELL CASING **2.85 ft**	TOP & BOTTOM SCREEN **13.95 ft/15.95 ft**	DATE **2/17/97**
REMARKS:				

LOG OF TEST BORING

Depth (ft)	Sample Number	Penetration Resistance Blows/6" N-Value	Unified Classification	FIELD DESCRIPTION	Munsell Field Color
	S1	1 1 1 1 2	PT	Fibrous Organic Material	1 2.5/N
	S2	3 3 5 5 8		4.0	
5	S3	7 5 4 5 9	SP	18 in. fine sand (1 2.5/N) grading to 5 in. fine sand (10 YR 7/1)	1 2.5/N = 10 YR 7/1
	S4	3 3 3 3 6		Fine sand	10 YR 6/2
	S5	2 2 2 2 4		Marbled fine sand	10 YR 2/1 = 10 YR 6/1
10	S6	7 3 3 3 6		5 in. fine sand (10 YR 2/1) grading to 8 in. fine sand (10 YR 5/2)	10 YR 2/1 = 10 YR 5/2
	S7	3 2 1 1 3		7 in. fine sand (10 YR 4/1) grading to 10 in. 2.5 YR 6/3	10 YR 4/1 = 2.5 YR 6/3
15	S8	8		14.8 5 in. fine sand w/ 30% black specks grading to 9 in. fine sand w/ shell fragments 16.0	2.5 YR 7/1
	S9			No sample	
	S10			No sample	



EMF FLA 9/9/97

Fine Sand
Medium Sand
Bentonite Pellets
Cement Grout
Silt/Clay w/ shell
Organic Material
Clay
Split Spoon
■ Percent Recovery
○ No Recovery

South Florida Water
Management District
3301 Gun Club Road
West Palm Beach, Florida 33406
(561) 686-8800 / Fax 687-6442

Engineered Environmental
Solutions, Inc.
1301 NW 4th Street
Boca Raton, Florida 33486
Ph/Fax: (561) 394-3969

DRAFT

BORING LOG

BORING/WELL NO. **FP8**

PROJECT NO./NAME **1033/Isolated Wetlands Shallow Drilling Program**

LOCATION **Flint Pen Strand, Fort Myers, Florida**

DRILLING CONTRACTOR/DRILLER **Precision Drilling/Robert Miller**

GEOLOGIST/OFFICE **Steve Krupa/South Florida Water Management District**

DRILLING EQUIPMENT/METHOD **Tripod/SPT**

SIZE/TYPE OF BIT **3'-5"dia. casing, driven and washed**

SAMPLING METHOD **Split Spoon**

START/FINISH DATE **2/14/97-2/14/97**

WELL INSTALLED? YES ☒ NO ☐

CASING MAT./DIA. **Sch.40 monoflex PVC/2"**

SCREEN: TYPE **Slotted** MAT. **PVC** LENGTH **2'** DIA. **2"** SLOT SIZE **.010**

ELEVATION OF: (FT. ABOVE M.S.L.)

GROUND SURFACE **14.60 ft**

TOP OF WELL CASING **2.58 ft**

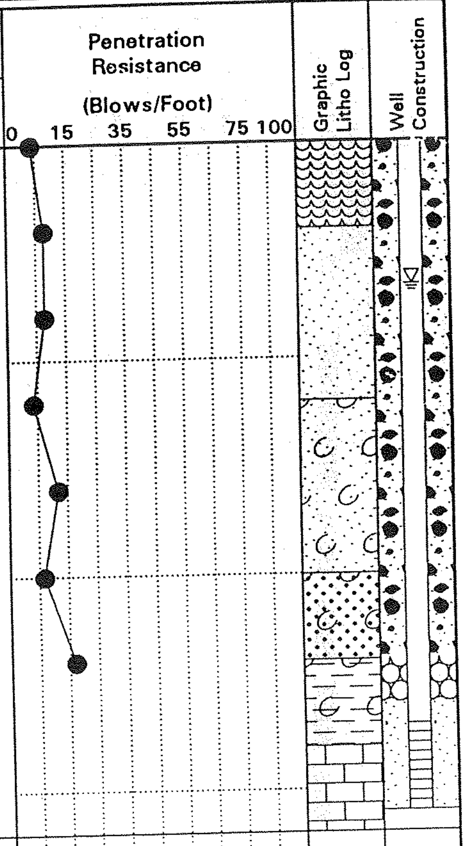
TOP & BOTTOM SCREEN **10.68 ft/12.68 ft**

DATE **2/17/97**

REMARKS:

LOG OF TEST BORING

Depth (ft)	Sample: Type & Recovery	Sample: Number	Penetration Resistance Blows/6" N-Value	Unified Classification	Field Description	Munsell Field Color
	☒	S1	1 1 1 1 2	PT	Organic Material 2.0	1 2.5/N
	☒	S2	2 3 3 2 6	SP	17 in. fine sand w/ organic staining grading to 6 in. fine sand (7.5 YR 5/1)	1 2.5/N=7.5 YR 5/1
5	☒	S3	2 3 3 2 6		6.0	
	☒	S4	4 1 1 1 2		5 in. fine sand (1 2.5/N) grading to fine sand grading to fine sand w/ 20% shell	1 2.5/N=10 YR 7/1
	☒	S5	5 5 5 6 10		14 in. fine sand w/ 20% shell fragments 10.0	
10	☒	S6	6 3 2 2 5	SP-SW	4 in. med/fine sand w/ shell grading to calcareous sand w/ 10% shell fragments 12.0	10 YR 6/1=10 YR 8/1
	☒	S7	3 5 10 +50 15	SP	10 in. 80% shell mash grading to fine sand w/ <10% shell fragments 14.0	10 YR 8/1
15	☒	S8			Limestone Fragments 16.0	10 YR 8/1
	○	S9			No sample	
	○	S10			No sample	



LA 9/9/97

EMF

▯	Fine Sand
⁙	Medium Sand
○	Bentonite Pellets
●	Cement Grout
▭	Silt/Clay w/ shell
≋	Organic Material
▨	Clay
☒	Split Spoon
■	Percent Recovery
○	No Recovery

APPENDIX D
Table D.1 – Soils and Natural Communities

Site	Soil Unit [1]	Muck Thickness in Center (inches)	NRCS Soil Landscape Position	Dominant FNAI Natural Community
Flint Pen Strand				
FP2	Copeland sandy loam, depressional	24	Sand depression	Depression marsh (w/cypress fringe)
FP3	Felda fine sand, depressional	72	Sand depression	Dome swamp (cypress)
FP4	Felda fine sand, depressional	48	Sand depression	Dome swamp (cypress)
FP5	Felda fine sand, depressional	72	Sand depression	Dome swamp (cypress)
FP6	Felda fine sand, depressional	48	Sand depression	Dome swamp (cypress)
FP7	Felda fine sand, depressional	48	Sand depression	Dome swamp (cypress)
FP8	Copeland sandy loam, depressional	48	Sand depression	Dome swamp (cypress)
FP9*	Pineda fine sand	0	Slough (flats)	Wet flatwoods (disturbed)
FP10*	Pineda fine sand	0	Slough (flats)	Wet flatwoods/wet prairie
Savannas S.P.				
SV1	Waveland-Lawnwood Complex**	12	Sand depression	Depression marsh
SV4	Placid sand	12	Sand depression	Depression marsh
SV5	Mapped as Waveland sand (SV5 is likely an inclusion of Waveland sand, depressional or Placid Sand)	18	Flatwoods (mapped unit) Sand depression (inclusion)	Depression marsh
SV6	Mapped as Waveland sand (SV6 is likely an inclusion of St. Johns variant sand)	0	Flatwoods (mapped unit) Slough (flats) (inclusion)	Depression marsh? (sand cordgrass)
Jonathan Dickinson S.P.				
JD6	Waveland sand, depressional	6	Sand depression	Depression marsh or wet prairie (fragmented)
JD12	Riviera fine sand, depressional	6	Sand depression	Depression marsh
JD26	Basinger fine sand, depressional	2	Sand depression	Wet flatwoods and wet prairie with dome swamp in center

JD29	Inclusion in Paola and Pomello sands (sandhills) Inclusion is likely Waveland sand, depressional or Basinger fine sand, depressional	?	Sand depression	Sandhill upland lake (note: soil survey denotes this site as perennially wet pond)
Walker Ranch				
WR6	Basinger fine sand, depressional	12	Sand depression	Depression marsh
WR8	Basinger fine sand, depressional	6	Sand depression	Depression marsh
WR9	Basinger fine sand, depressional	24	Sand depression	Depression marsh
WR11	Placid and Myakka fine sands, depressional	42	Sand depression	Dome swamp (tupelo)
WR15	Placid and Myakka fine sands, depressional	36	Sand depression	Dome swamp (cypress)
WR16	Placid and Myakka fine sands, depressional	6	Sand depression	Dome swamp (cypress, tupelo)

* Site added 5/98

** Undifferentiated complex of Waveland sand, depressional and Lawnwood fine sand, depressional

[1] Note that most of the sites may actually be undifferentiated soil complexes or inclusions, given size of depression and/or muck deposit is typically at or less than NRCS minimum mapping unit; further soil investigation in the field may be necessary to further delineate.

APPENDIX E

Table E.1 – Sensor Specifications

Parameter	Device	Accuracy	Logging Frequency
Wetland Monitoring Stations			
Groundwater elevation	Design Analysis H3-10 Pressure transducer	±0.02 ft	15 minutes
Surface water elevation	Handar float & encoder	±0.02 ft	15 minutes
Weather Monitoring Stations			
Rainfall	Weathertronics or Leopold and Stevens tipping bucket gauge	±0.01 in	5 minutes during event (Recorded as daily totals)
Air temperature	Vaisala HMP35C temperature and humidity probe	±0.40 °C.	15 minutes
Relative humidity	Vaisala HMP35C temperature and humidity probe	±2% RH 0-90% ±3% RH 90-100%	15 minutes
Barometric pressure	Vaisala PTB101B pressure transducer	±0.375 mm Hg	15 minutes
Total solar radiation	LI-COR LI200SZ pyranometer	±0.075 kWm^{-2}	15 minutes
Net radiation	REBBS Q6 or Q7 net radiation probe	±0.075 kWm^{-2}	15 minutes
Photo-active radiation	LI-COR LI190SZ Quantum	±100 $\mu Es^{-1}m^{-2}$	15 minutes
Wind speed	Handar ultrasonic wind sensor	±1 MPH < 30 MPH ±3% > 30 MPH	15 minutes
Wind direction	Handar ultrsonic wind sensor	±3.6°	15 minutes

APPENDIX F
Table F.1 Monthly Rainfall Totals

Study Area	Flint Pen Strand	Savannas	Jonathan Dickinson	Disney Wilderness Pres.
April	ND	ND[2]	ND	3.38 P[4]
May	ND	0.69 P	ND	ND
June	ND	7.77 (+0.52)	ND	0.35 P
July	ND	3.16 (-3.34)	ND	9.27 (+2.02)
August	ND[1]	8.08 (+0.83)	ND[3]	3.57 (-2.93)
September	8.46 (+0.21)	5.07 (-2.68)	5.07 P	0.64 (-5.36)*
October	0.34 (-2.91)*	1.26 (-5.74)*	0.48 P (-6.77)*	3.55 (+0.55)
November	4.00 (+3.00)	6.21 (+3.21)	ND	2.78 (+0.78)
December	7.53 (+6.13)	1.84 P (-0.56)	0.73 (-1.77)	8.71 (+6.71)
1997 Total	20.33 P	34.08 P	6.28 P	32.25 P

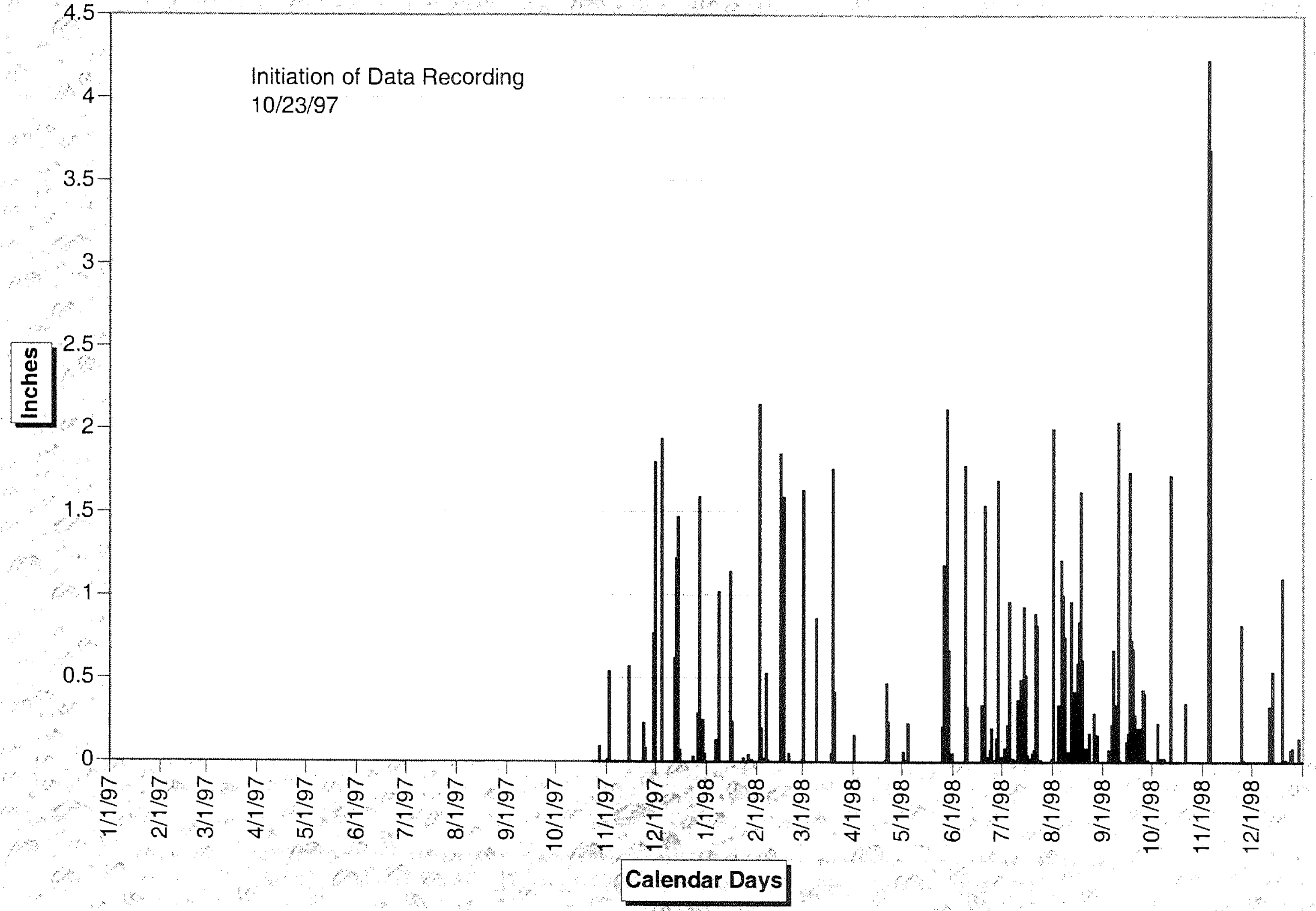
Study Area	Flint Pen Strand	Savannas	Jonathan Dickinson	Disney Wilderness Pres.
January	2.61 (+0.51)	3.08 P (+0.78)	3.07 (+0.47)	3.61 (+1.36)
February	6.58 (+4.33)	3.47 P (+0.87)	6.92 (+4.32)	5.70 (+3.20)
March	4.72 (+2.22)	4.13 (+0.63)	6.53 (+3.28)	4.72 (+1.72)
April	0.88 (-1.12)	4.28 (+1.58)	5.50 (+2.50)	0.85 (-1.40)
May	4.54 (+0.54)	2.57 (-2.43)	1.57 (-3.68)	1.94 (-2.06)
June	6.19 (-2.81)	1.29 (-5.96)*	3.03 (-4.97)*	3.31 (-4.19)*
July	5.84 (-2.66)	8.06 (+1.56)	2.55 (-3.95)*	10.97 (+3.72)
August	11.16 (+2.66)	6.81 (+0.31)	5.39 (-1.86)	4.61 (-1.89)
September	8.48 (+0.23)	7.60 (-0.15)	10.76 (+2.51)	4.77 (-1.23)
October	2.34 (-0.91)	0.93 (-6.07)*	1.20 (-6.05)*	0.69 (-2.31)*
November	8.75 (+7.75)	4.21 (+1.21)	9.62 (+6.12)	3.74 (+1.74)
December	2.27 (+0.87)	2.16 (-0.24)	1.64 (-0.86)	0.52 (-1.48)
1998 Total	64.36	47.58 P	57.78	45.43

Note: Values in parentheses are amounts (inches) above (+) or below (-) long-term monthly average reported by Ali, *et al* (1999) and Macvicar (1981)

P Partial record for period indicated
ND No data for period indicated or weather station not installed
* Approaches 1-in-10-year dry month for wet season (based on Ali, *et al*, 1999)

1 Flint Pen Strand weather station installed September 3, 1997.
2 Savannas weather station installed April 14, 1997.
3 Jonathan Dickinson weather station installed September 12, 1997.
4 Disney Wilderness Preserve weather station installed April 16, 1997.

FPWX Daily Rain Totals, January 1, 1997-December 31,1998



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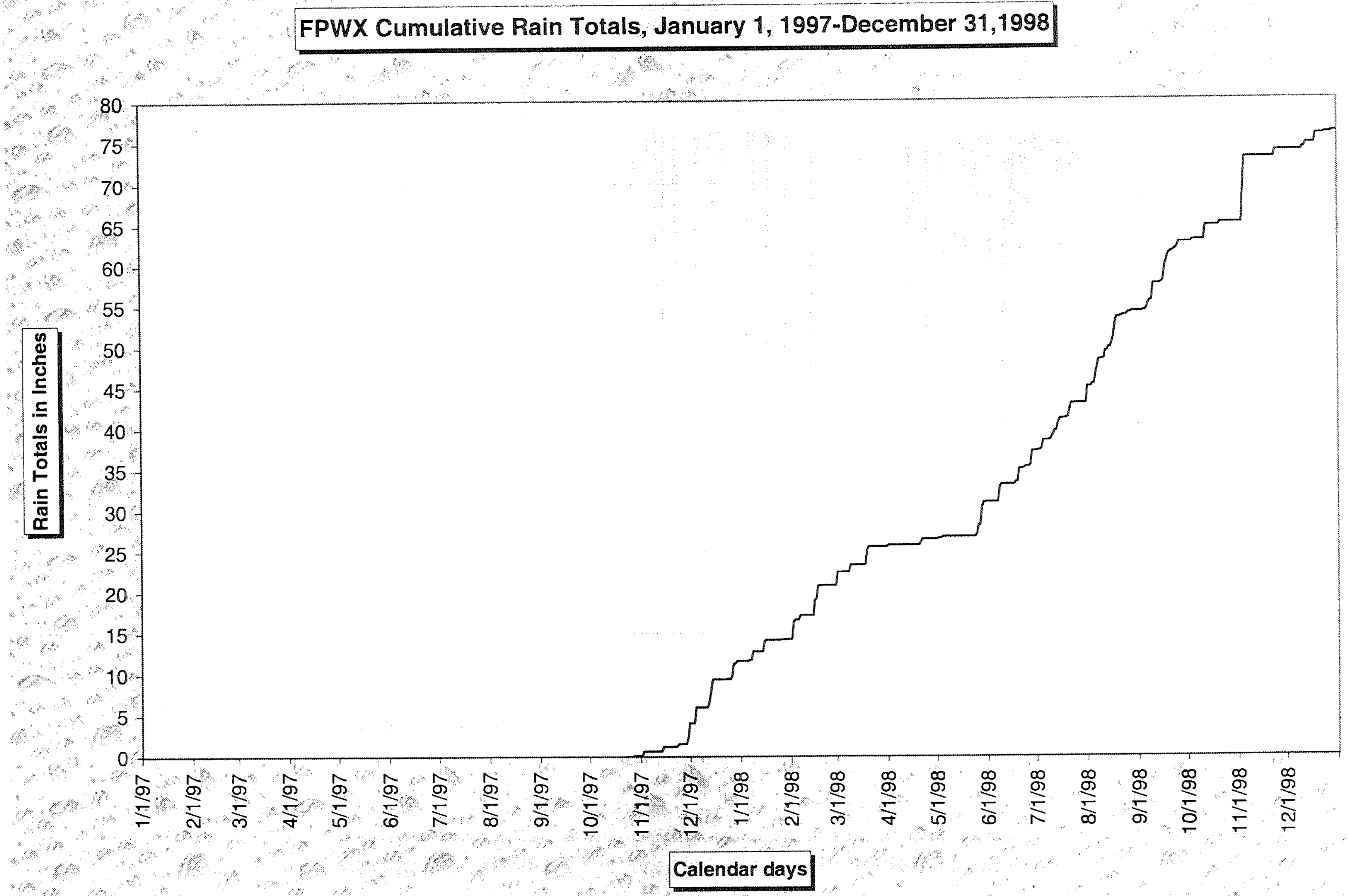
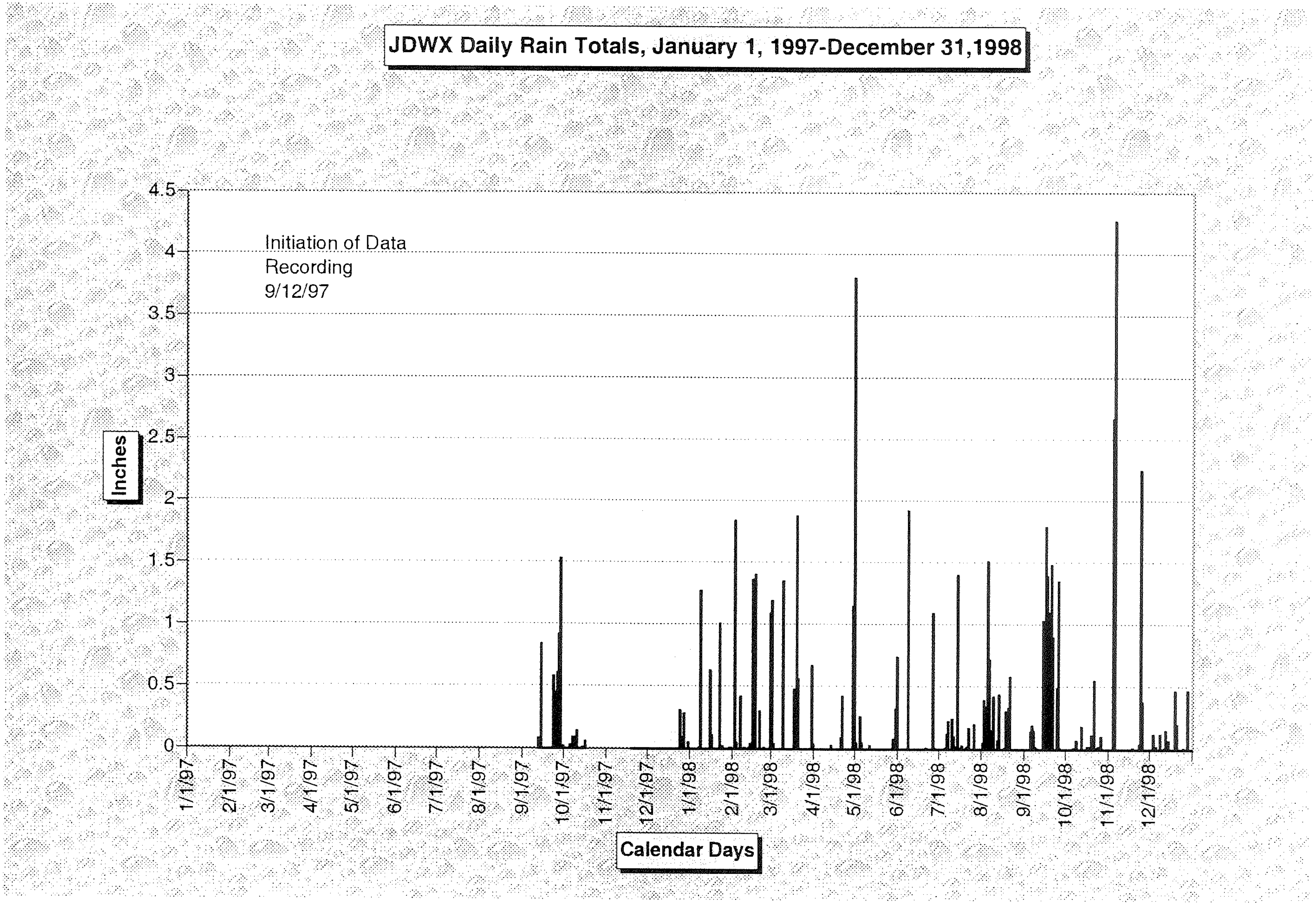
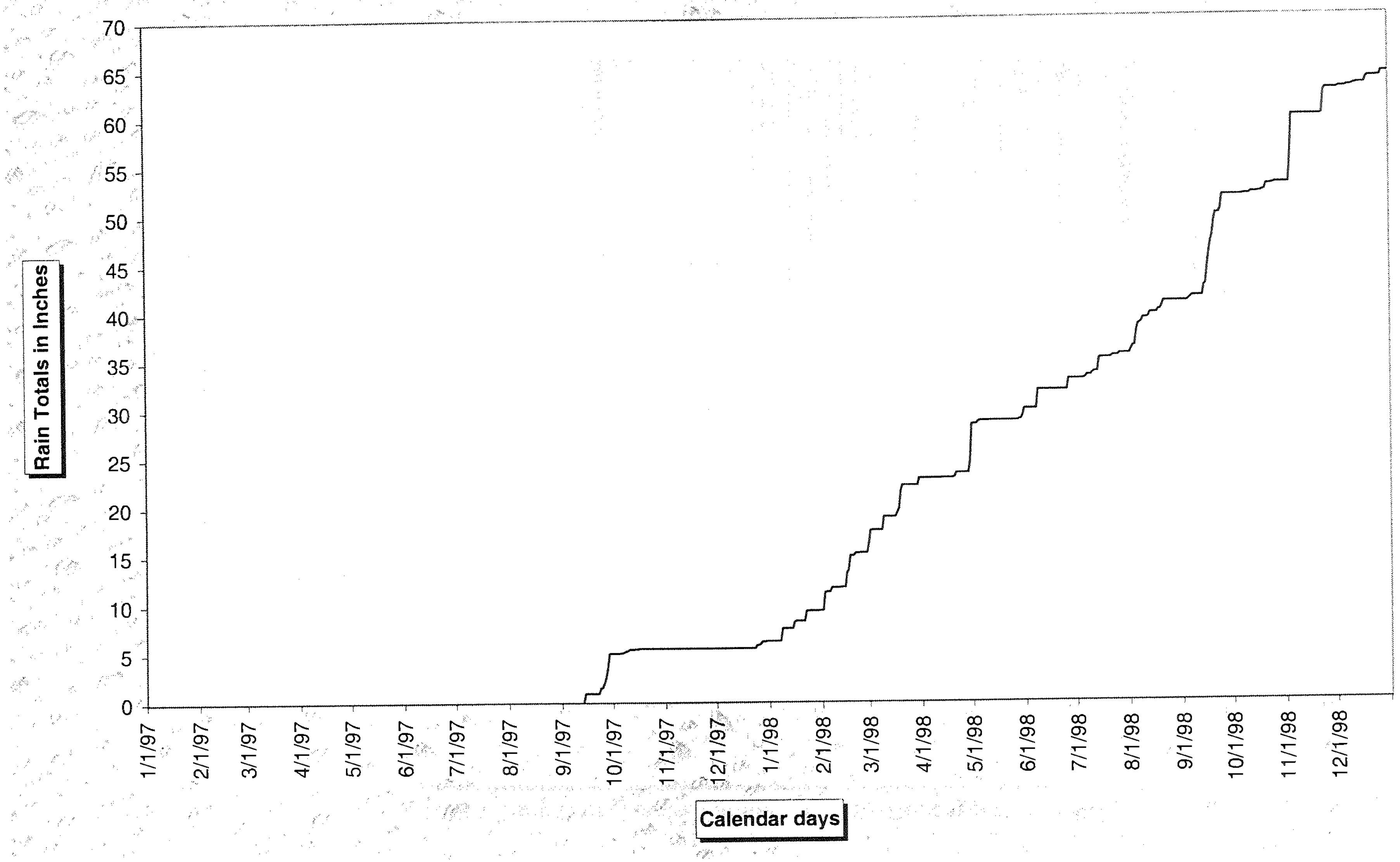


FPWX Cumulative Rain Totals, January 1, 1997-December 31,1998

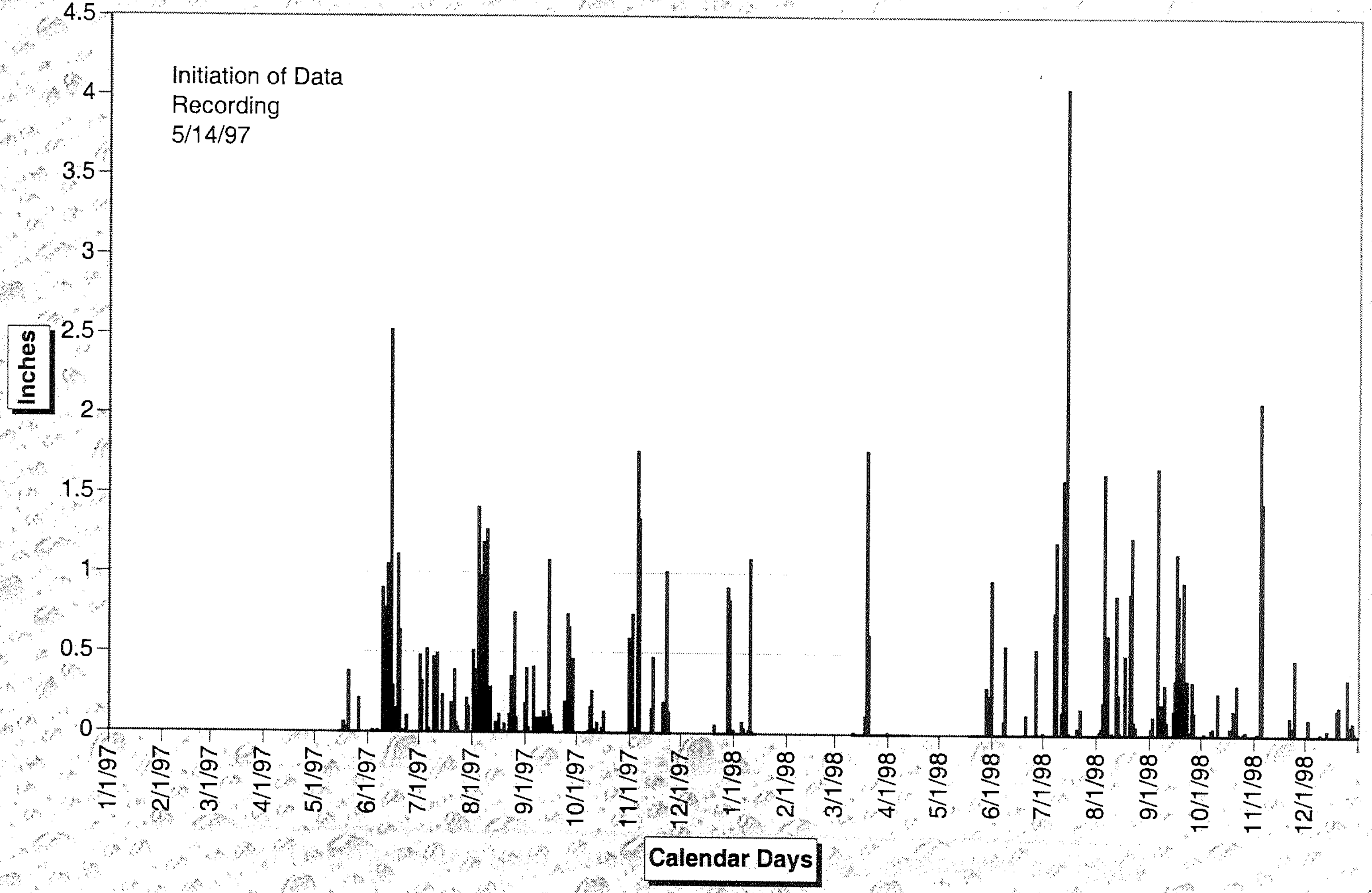


JDWX Daily Rain Totals, January 1, 1997-December 31,1998



JDWX Cumulative Rain Totals, January 1, 1997-December 31,1998

SVWX Daily Rain Totals, January 1, 1997-December 31,1998



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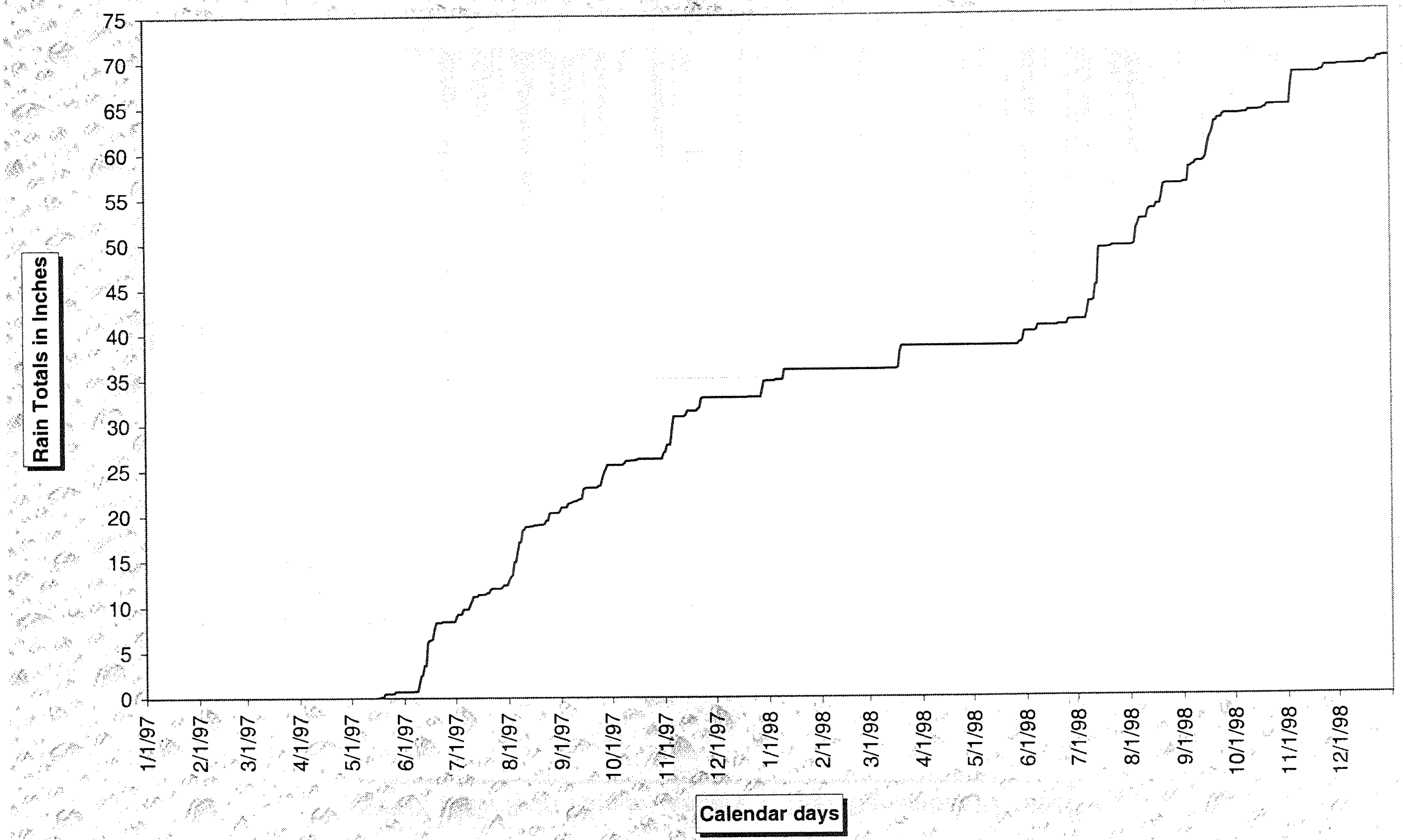
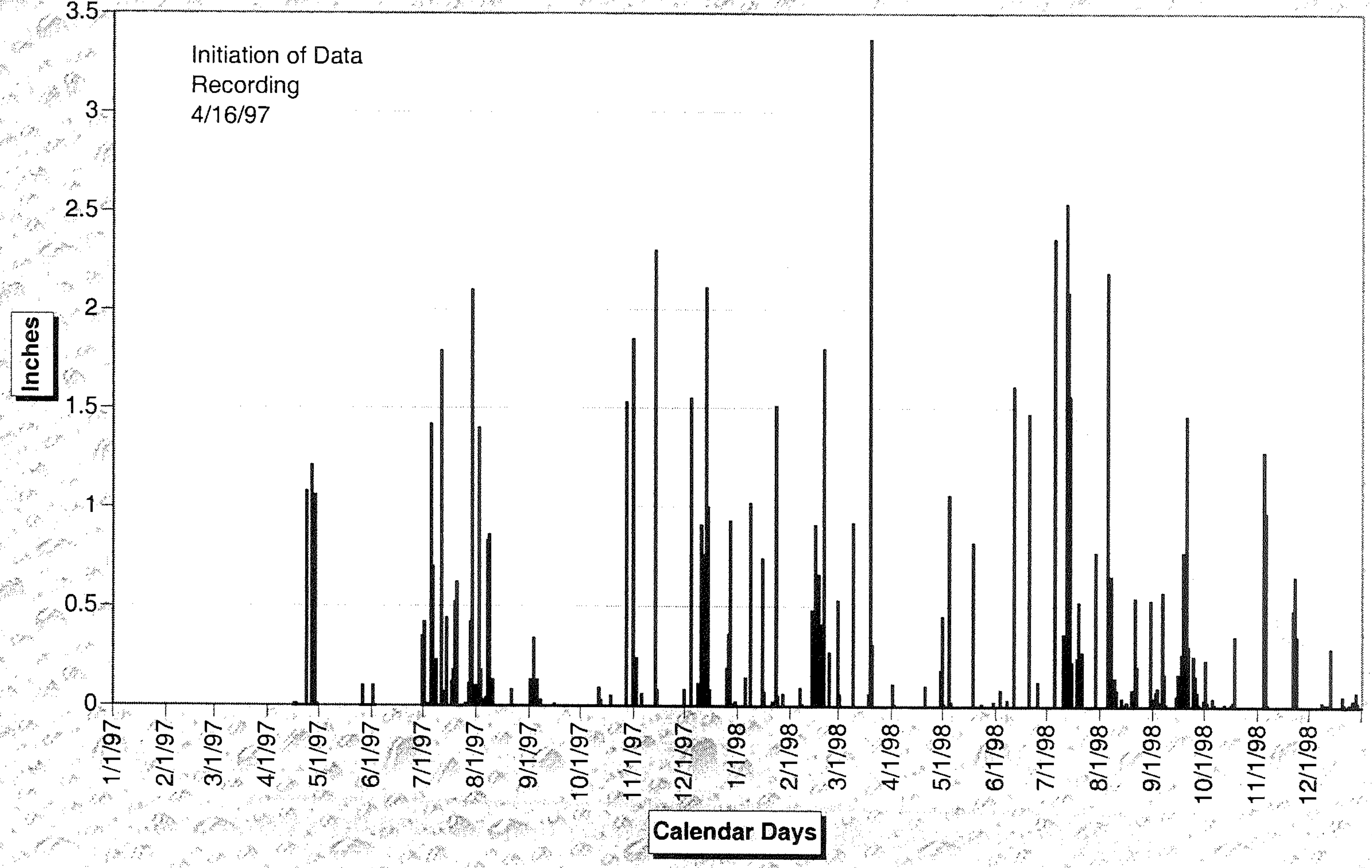
SVWX Cumulative Rain Totals, January 1, 1997-December 31,1998



WRWX Daily Rain Totals, January 1, 1997-December 31,1998



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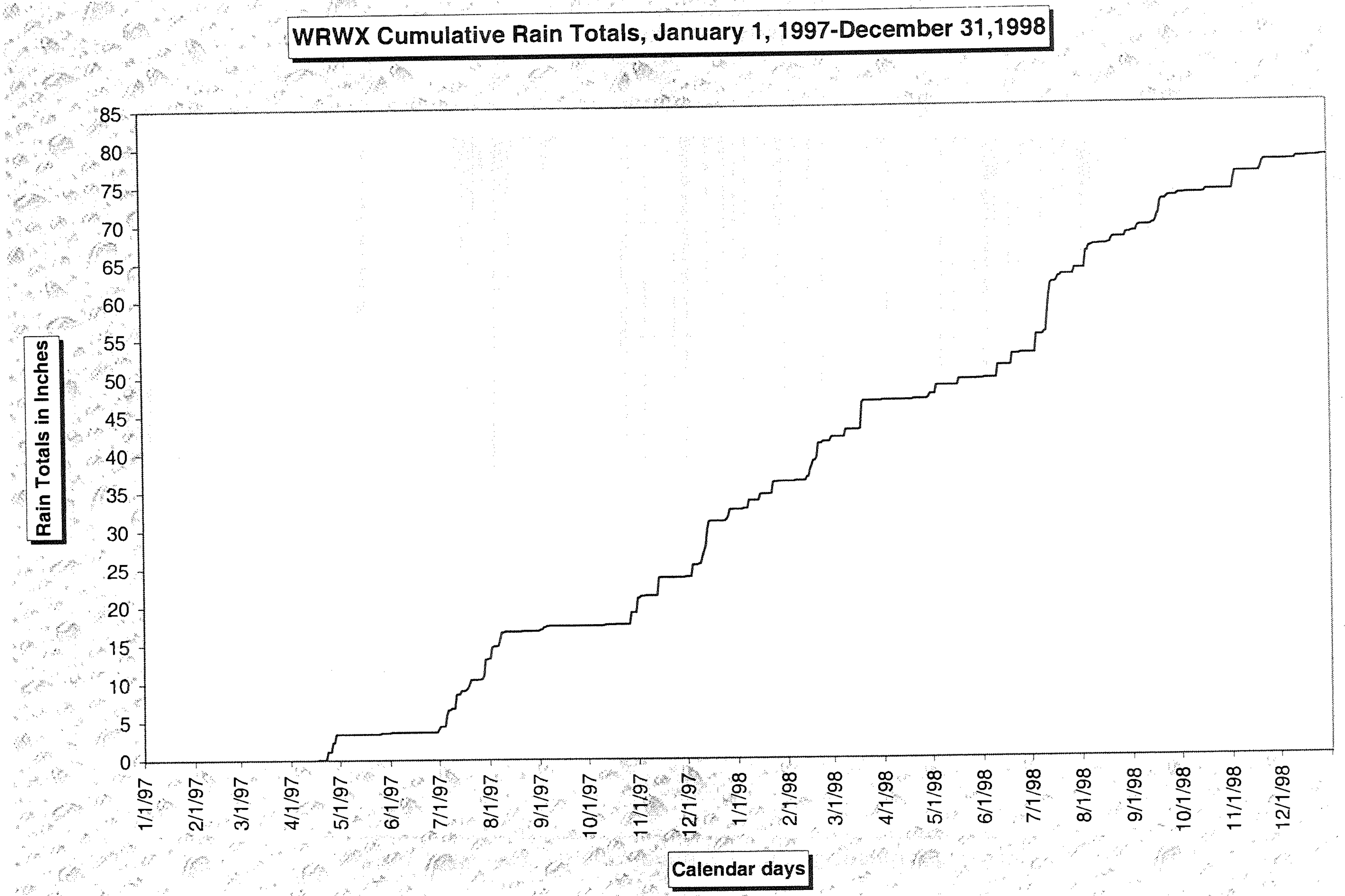
WRWX Cumulative Rain Totals, January 1, 1997-December 31,1998
Rain Totals in Inches
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
1/1/97
2/1/97
3/1/97
4/1/97
5/1/97
6/1/97
7/1/97
8/1/97
9/1/97
10/1/97
11/1/97
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4/1/98
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6/1/98
7/1/98
8/1/98
9/1/98
10/1/98
11/1/98
12/1/98
Calendar days

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APPENDIX G

Table G.1 – Topography and Water Elevations

Site (Acreage Below Margin)	Wetland Topographic Elevations	Spring 1999 Drought	CY 1997		CY 1998	
	B = Bottom **M** = Margin **R** = M-B **NP** = Normal Pool Indicator **SH** = Seasonal High Indicator	**Low**	**Low**	**High**	**Low**	**High**
FP2 (3.98)	B = 16.0’ Outlet* = 17.8’ M = 18.6 R = 2.6’ NP = 18.6’ SH: 18.9-19.2’	**GW**: 10.01’ 6/7/99	**GW**:11.73' 5/22/97	18.91' 10/27/97	**GW**:12.31' 7/10/98	18.65’ 3/18/98 18.69' 9/21/98 19.35’ 11/4/98
FP3 (3.71)	B = 14.0’ M = 17.4’ R = 3.4’ NP = 17.5’ SH = 18.1’	**GW**: 12.66’ 6/8/99	**GW**: 14.18’ 5/11/97 & 6/12/97	17.68’ 9/30/97 17.53’ 12/17/97	**GW**: 14.24’ 5/26/98	17.63’ 2/19/98 17.63’ 9/17/98 17.72’ 11/7/98
FP4 (6.52)	B = 13.6’ M = 16.6’ R = 3.0’ NP = 17.3’ SH = 18.0’	**GW**: 12.63’ 6/7/99	**GW**: 13.82’ 6/12/97	17.25’ 9/29/97	**GW**: 13.80’ 5/25/98	17.38’ 2/20/98 17.40’ 9/20/98 17.68’ 11/7/98
FP5 (3.22)	B = 14.2’ AH = 12.2’ M = 17.0’ R = 2.8’ SH = 17.4’	**GW**: 12.95’ 6/8/99	**GW**:14.00' 6/12/97	17.46' 12/14/97	**GW**:13.79' 5/26/98	17.33’ 1/17/98 17.42’ 9/21/98 17.69’ 11/4/98
FP6 (2.61)	B = 14.1’ AH =11.0’ M = 16.7’ R = 2.6’ NP = 17.0’ SH = 17.5’	**GW**: 12.83’ 6/8/99	**GW**: 14.05' 5/11/97	17.33' 9/28/97	**GW**:13.60'[1] 5/26/98	17.21' 2/18/98 17.54’ 11/5/98
FP7 (5.36)	B = 13.6’ AH = 12.8’ M = 16.7’ R = 3.1’ NP = 16.6’ SH = 17.2’	**GW**: 12.87’ 5/10/99	**GW**: 13.95' 6/12/97	17.00' 12/15/97	**GW**:13.74'[1] 5/25/98	16.88' 3/19/98 16.94' 9/21/98 17.37’ 11/5/98

FP8 (7.14)	B = 14.3’ AH = 12.7’ M = 16.7’ R = 2.4’ NP = 16.8’ SH = 17.7’	**GW**: 12.40’ 6/8/99	**GW**: 13.61’ 6/12/97	17.13’ 7/30/97 17.17’ 9/27/97	**GW**: 13.65 5/25/98	17.35’ 2/20/98 17.35’ 9/20/98 17.63’ 11/7/98
FP9	B: 16.5’	**GW**: 12.87’ 6/7/99	**N/A**	**N/A**	**N/A**	**N/A**
FP10	B: 16.3’	**GW**: 12.05’ 5/9/99	**N/A**	**N/A**	**N/A**	**N/A**
WR6 (3.23)	B = 62.5’ M = 64.5’ R = 2.0’	**GW**: 60.35’ 5/6/99	**GW**: 61.80' 4/23/97	64.82' 8/10/97	**GW**: 61.80' 6/19/98	65.31' 3/18/98 64.83’ 9/19/98
WR8 (3.80)	B = 66.1’ M = 69.4’ R = 3.3’	**GW**: 63.17’ 5/6/99	**GW**: 64.59’ 4/13/97	70.16’ 12/28/97	**SW**: 66.61’ **GW**: 64.50’[2] 7/5/98	70.34’ 2/17/98 70.29’ 3/22/98
WR9 (6.83)	B = 64.8’ M = 68.3’ R = 3.5’	**GW**: 63.44’ 5/6/99	**SW**: 65.75’ **GW**: 64.96’[2] 5/30/97	68.76’ 12/28/97	**SW**: 66.16’ **GW**: 64.99’[2] 7/4/98	69.04’ 2/20/98 69.08’ 3/20/98
WR11 (4.27)	B = 66.0’ M = 67.4’ R = 1.4’ SH = 67.9’	**GW**: 62.71’ 6/2/99	**GW**: 65.10’ 4/22/97	67.93’ 12/14/97	**GW**: 64.49’ 7/4/98	67.97’ 2/20/98 67.96’ 3/19/98
WR15 (1.40)	B = 61.5’ M = 63.5’ R = 2.0’ NP = 63.5’ SH = 63.9’	**GW**: 58.24’ 6/2/99	**GW**:60.57' 4/23/97	63.73’ 8/8/97	**GW**:59.36' 7/5/98	63.98' 2/19/98
WR16 (2.81)	B = 64.3’ M = 66.3’ R = 2.0’ SH = 66.2	**GW**: 60.60’ 6/2/99	**GW**:63.05' 4/22/97	66.18' 8/7/97	**GW**:62.17' 7/5/98	66.32' 2/19/98
JD6 (4.93)	B = 6.8’ M = 9.5’ R = 2.7’	**GW**: 5.32’ 5/29/99	**SW**: 8.78’ **GW**: 7.55’[2] 4/11/97	9.86’ 8/10/97	**SW**: 7.68’ **GW**: 6.34’[2] 9/3/98	9.43’ 3/22/98 9.37’ 9/26/98 9.30’ 11/9/98
JD12 (4.35)	B = 10.7’ M = 13.0’ R = 2.3’	**GW**: 8.73’ 5/8/99	**SW**: 12.57' **GW**: 10.80’[2] 5/18/97	13.32' 8/8/97	**SW**: 11.92' **GW**: 9.80’[2] 8/2/98	13.17' 3/20/98 13.11’ 9/24/98 13.30’ 11/4/98
JD26	B = 8.7’ M = 9.9’ R = 1.2’ NP = 10.1’ SH = 10.6’	**GW**: 6.22’ 5/29/99	**SW**: 9.50' **GW**: 8.80’[2] 11/20/97	10.66' 8/9/97	**GW**: 7.45' 7/30/98	10.41' 3/20/98 10.38' 9/24/98 10.64 11/5/98
SV1 (3.36)	B = 14.7’ M = 16.4’ R = 1.7’ SH = 17.1’	**GW**: 12.01’ 4/27/99	**SW**: 15.58' **GW**: 13.75’[2] 5/27/97	17.17' 8/10/97	**SW**: 15.17' **GW**: 12.95’[2] 7/8/98	17.24' 2/16/98 17.20’ 9/20/98 17.10’ 11/5/98

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SV4 (1.70)	B = 12.0’ M = 13.5’ R = 1.5’	**GW**: 8.11’ 5/29/99	**GW**:9.86' 5/19/97	13.71' 6/20/97	**GW**:10.07' 8/5/98	14.43' 2/16/98 14.20’ 9/25/98 14.30’ 11/5/98
SV5 (0.74)	B = 12.4’ M = 13.9’ R = 1.5’	**GW**: 9.27’ 5/30/99	**GW**:11.07' 5/28/97	14.21' 6/20/97	**GW**:11.62' 8/5/98	14.84' 3/21/98 14.70’ 9/26/98 14.87’ 11/5/98
SV6 (0.41)	B = 12.3’ M = 13.6’ R = 1.3’	**GW**: 10.59’ 5/30/99	**GW**: 12.17' 5/28/97	14.04' 9/29/97	**GW**: 12.05’ 8/3/98	14.16' 3/20/98 14.07’ 9/20/98 14.36’ 11/5/98

SW: lowest surface water reading

GW: lowest groundwater reading

2 surface water remained in main depressional basin of wetland the entire calendar year

[*] Elevation of surface flow outlet from FP2 to south

Table G.3 – Median Wet-Season Water Levels

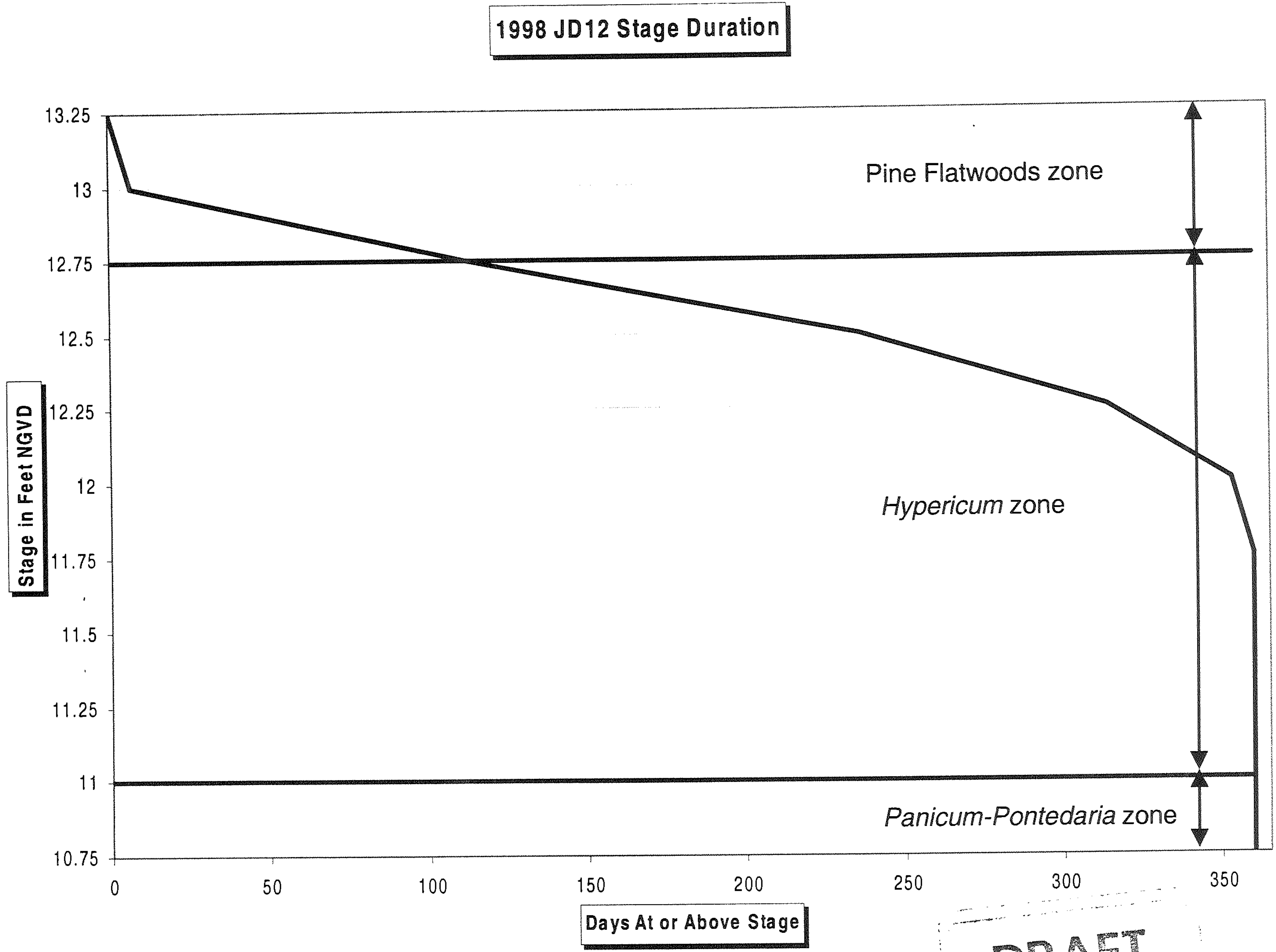
SITE	Median Wet-Season Surface Water Elevation (ft NGVD)[1]	Departure from Margin Elevation (Margin – Median)[2]	Departure as Percentage of Total Wetland Relief (%)[3]
FP2	18.04	0.56	21.5
FP3	17.16	0.24	7.1
FP4	16.90	-0.30	-10.0
FP5	17.07	-0.07	-2.5
FP6	16.82	-0.12	-4.6
FP7	16.59	0.11	3.5
FP8	16.72	-0.02	-0.8
WR6	64.09	0.41	20.5
WR8	67.96	1.44	43.6
WR9	67.14	1.16	33.1
WR11	66.90	0.50	35.7
WR15	62.30	1.20	60.0
WR16	64.98	1.32	66.0
JD6	9.15	0.35	13.0
JD12	12.75	0.25	10.9
JD26	9.87	0.03	2.5
SV1	16.76	-0.36	-21.2
SV4	13.21	0.29	19.3
SV5	13.65	0.25	16.7
SV6	13.52	0.08	6.1

[1] Median daily surface water elevation from all observations during the following three wet periods: 6/1/97-10/31/97, 11/1/97-4/30/98, 6/1/98-10/31/98

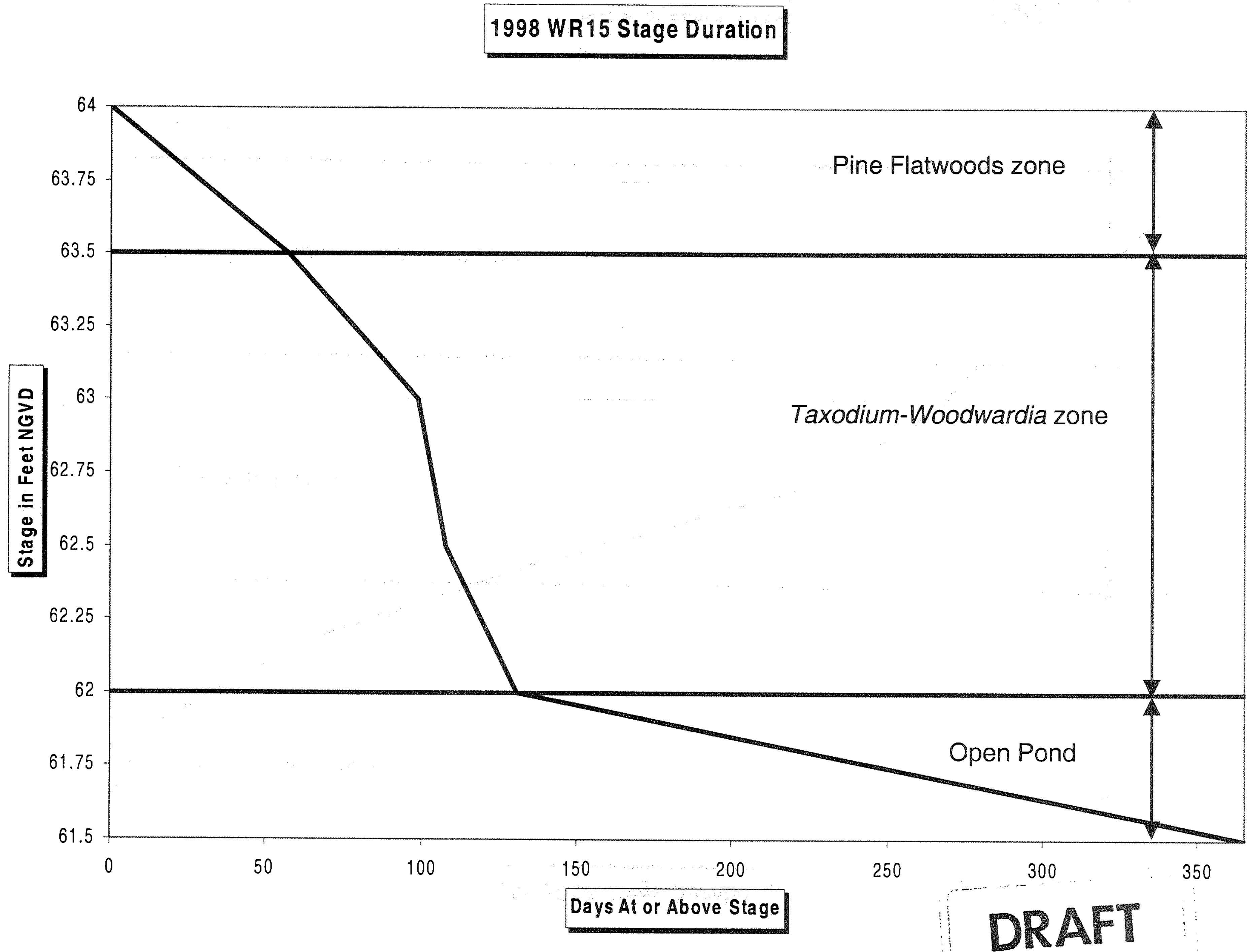
[2] Margin elevation of each site given in Table G.1 (Appendix G)

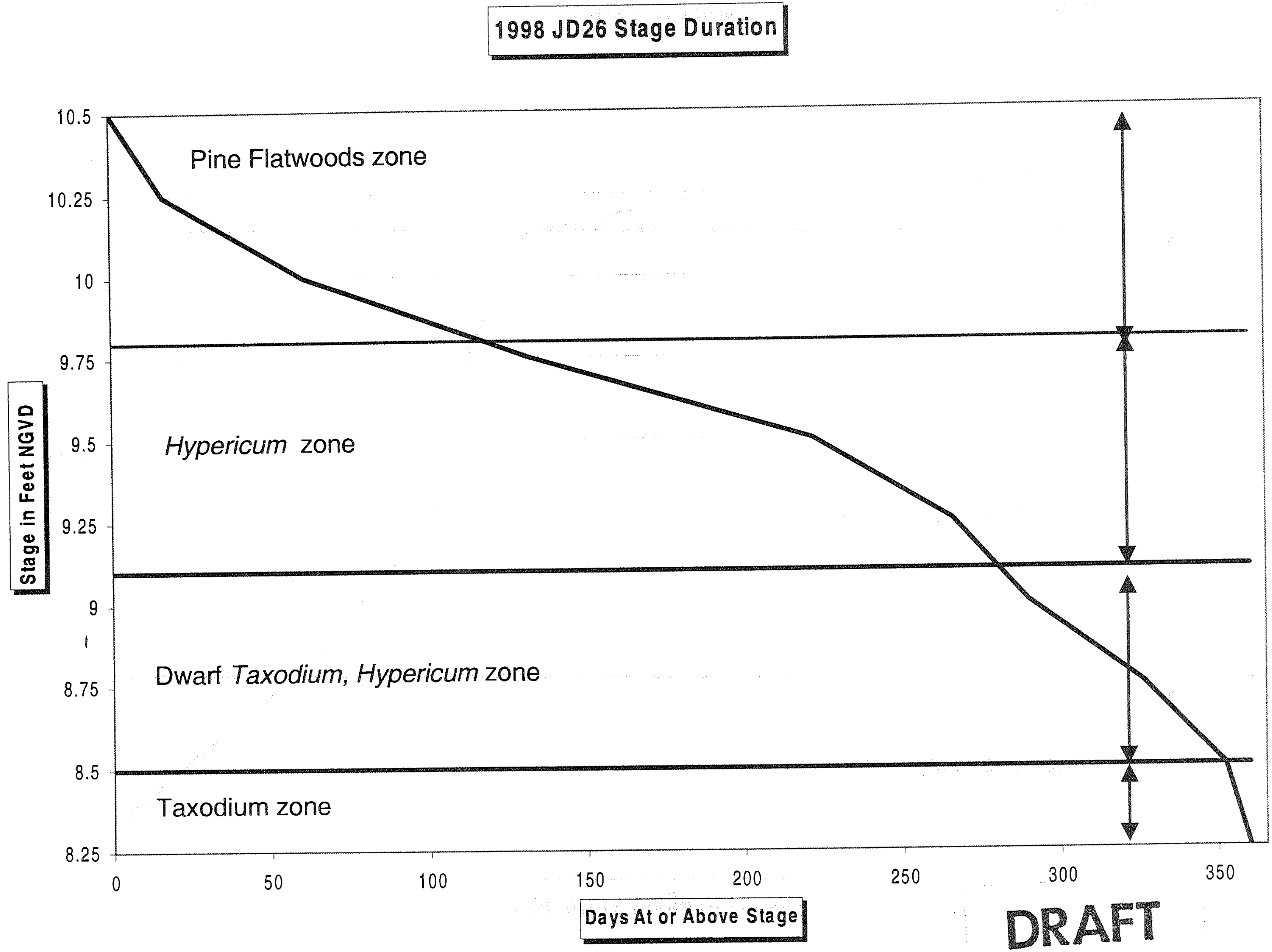
[3] Total relief of each site given in Table G.1 (Appendix G)

APPENDIX H – Stage-Duration Curves



1998 JD12 Stage Duration


1998 WR15 Stage Duration
Stage in Feet NGVD
64
63.75
63.5
63.25
63
62.75
62.5
62.25
62
61.75
61.5
0
50
100
150
200
250
300
350
Days At or Above Stage
Pine Flatwoods zone
Taxodium-Woodwardia zone
Open Pond


1998 JD26 Stage Duration
Stage in Feet NGVD
10.5
10.25
10
9.75
9.5
9.25
9
8.75
8.5
8.25
Pine Flatwoods zone
Hypericum zone
Dwarf *Taxodium, Hypericum* zone
Taxodium zone
0
50
100
150
200
250
300
350
Days At or Above Stage

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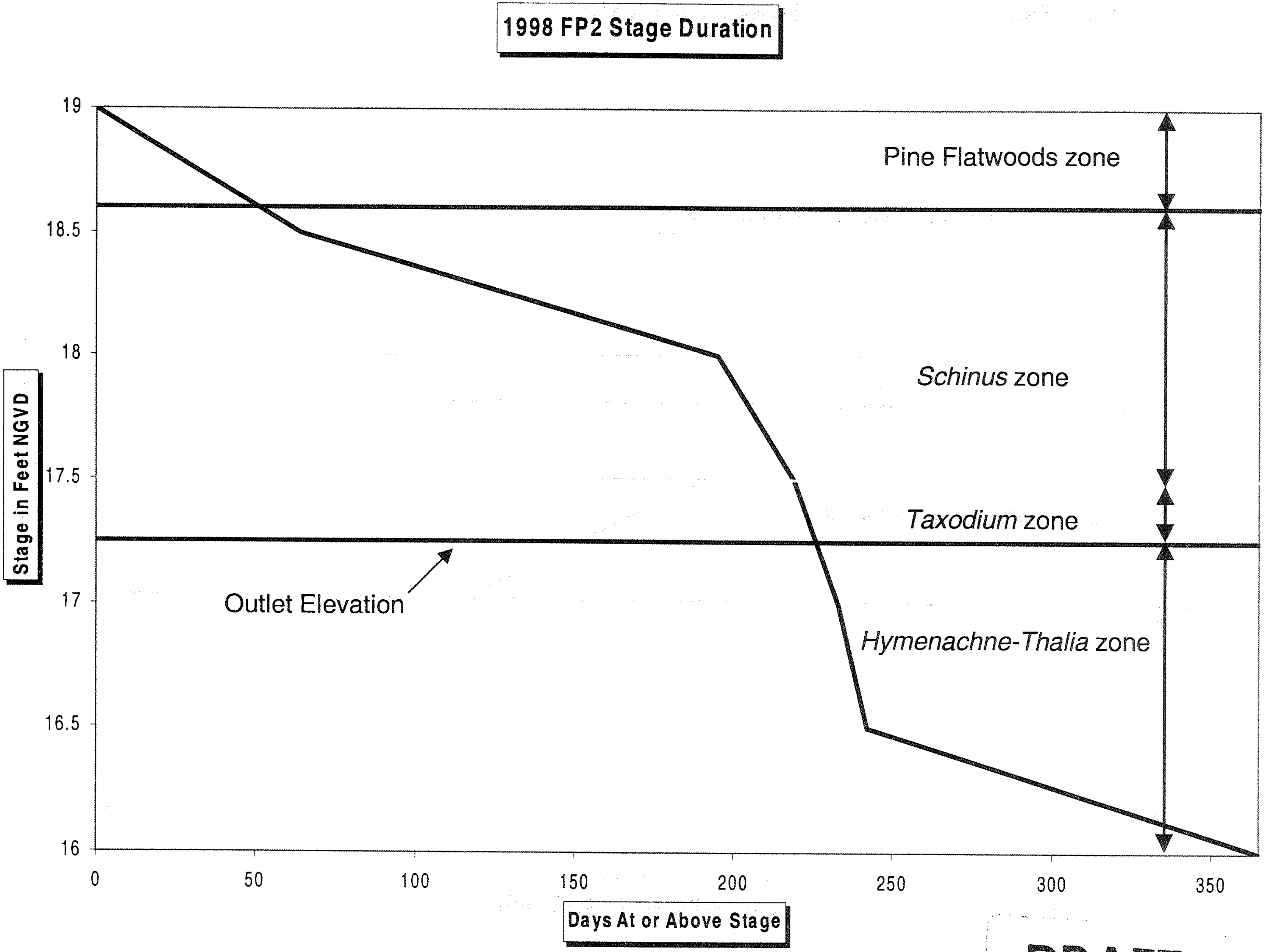
1998 FP2 Stage Duration
19
18.5
18
17.5
17
16.5
16
0
50
100
150
200
250
300
350
Stage in Feet NGVD
Days At or Above Stage
Pine Flatwoods zone
Schinus zone
Taxodium zone
Hymenachne-Thalia zone
Outlet Elevation

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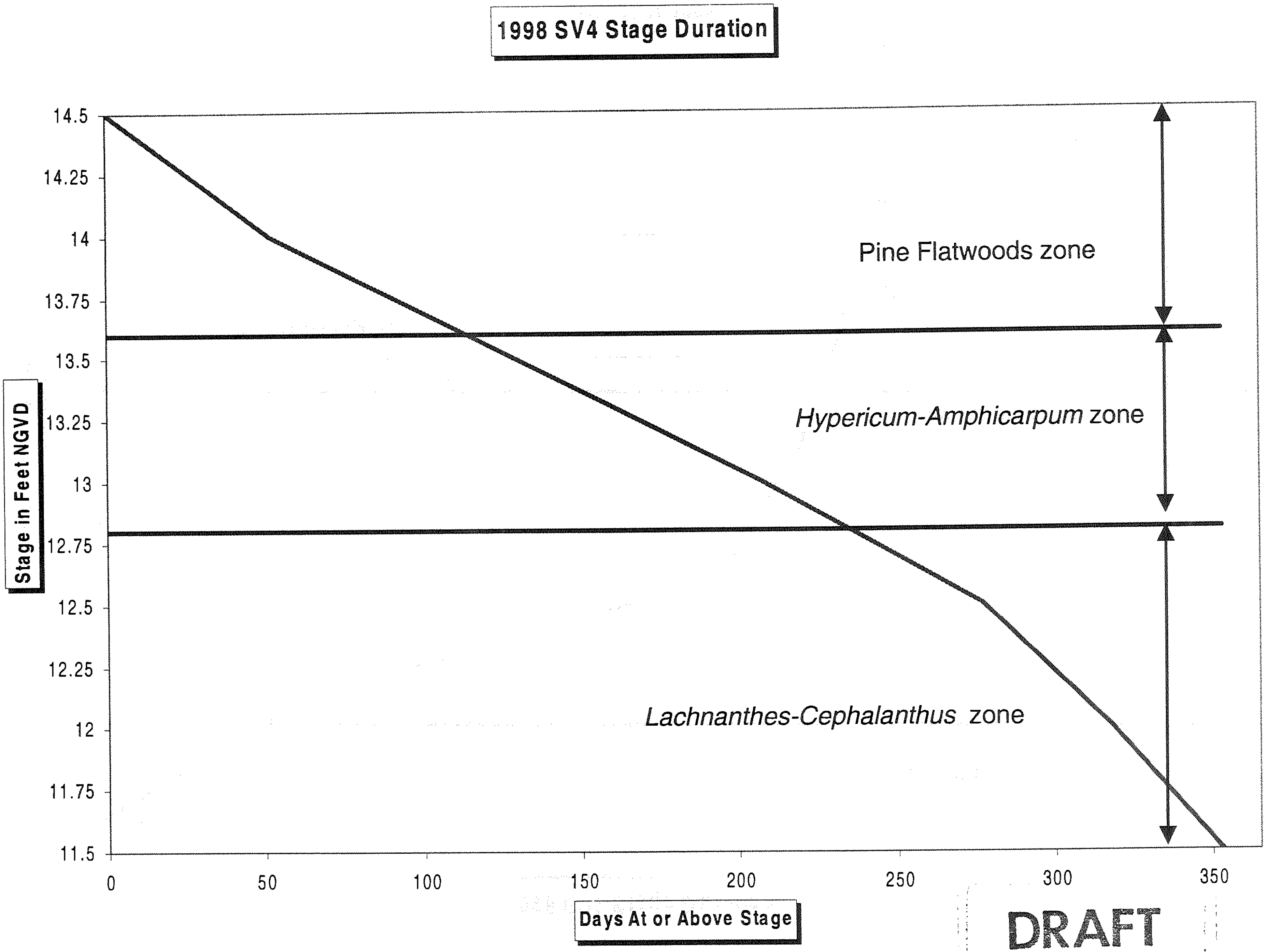
1998 SV4 Stage Duration
Stage in Feet NGVD
14.5
14.25
14
13.75
13.5
13.25
13
12.75
12.5
12.25
12
11.75
11.5
Days At or Above Stage
0
50
100
150
200
250
300
350
Pine Flatwoods zone
Hypericum-Amphicarpum zone
Lachnanthes-Cephalanthus zone

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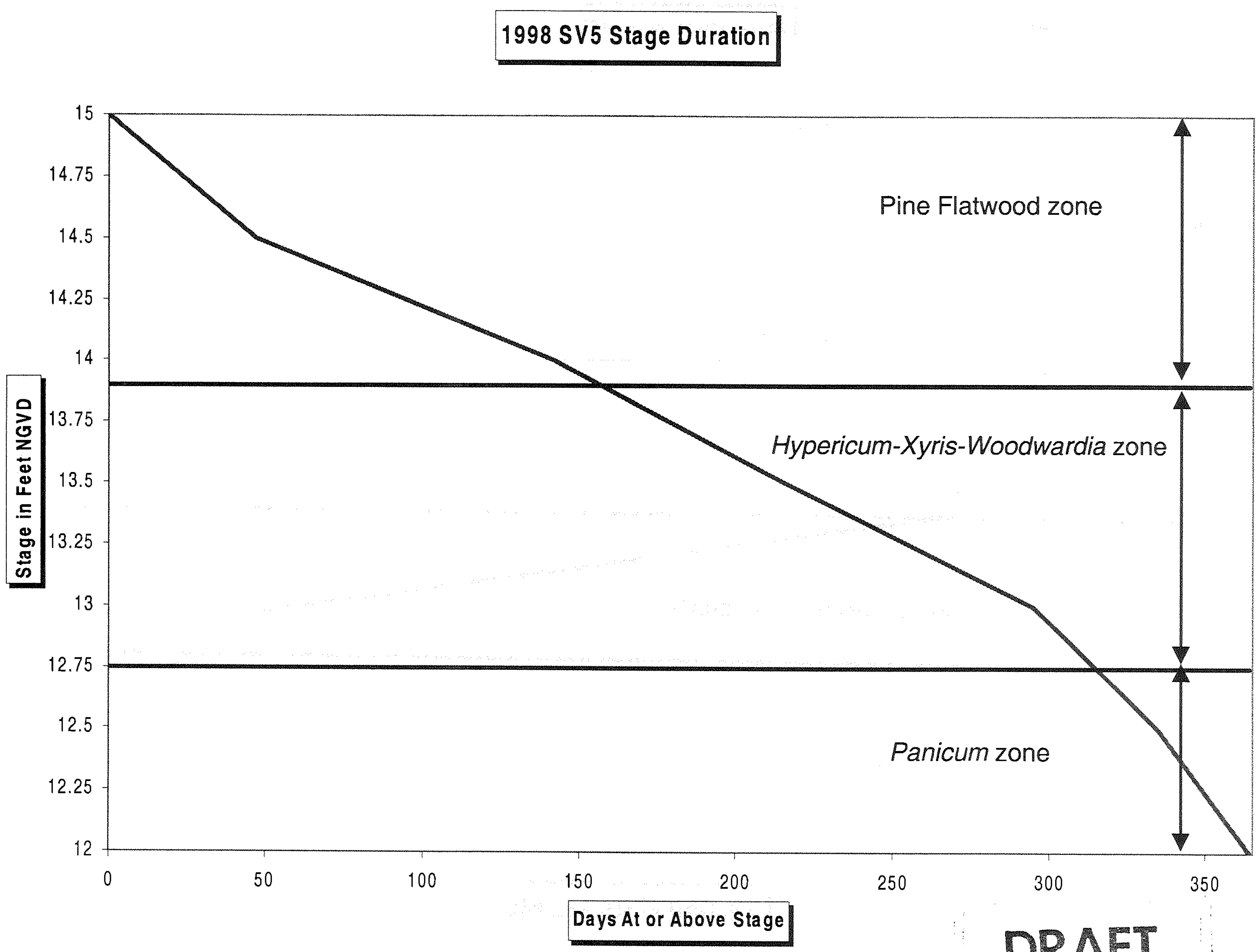
1998 SV5 Stage Duration
Stage in Feet NGVD
15
14.75
14.5
14.25
14
13.75
13.5
13.25
13
12.75
12.5
12.25
12
0
50
100
150
200
250
300
350
Days At or Above Stage
Pine Flatwood zone
Hypericum-Xyris-Woodwardia zone
Panicum zone

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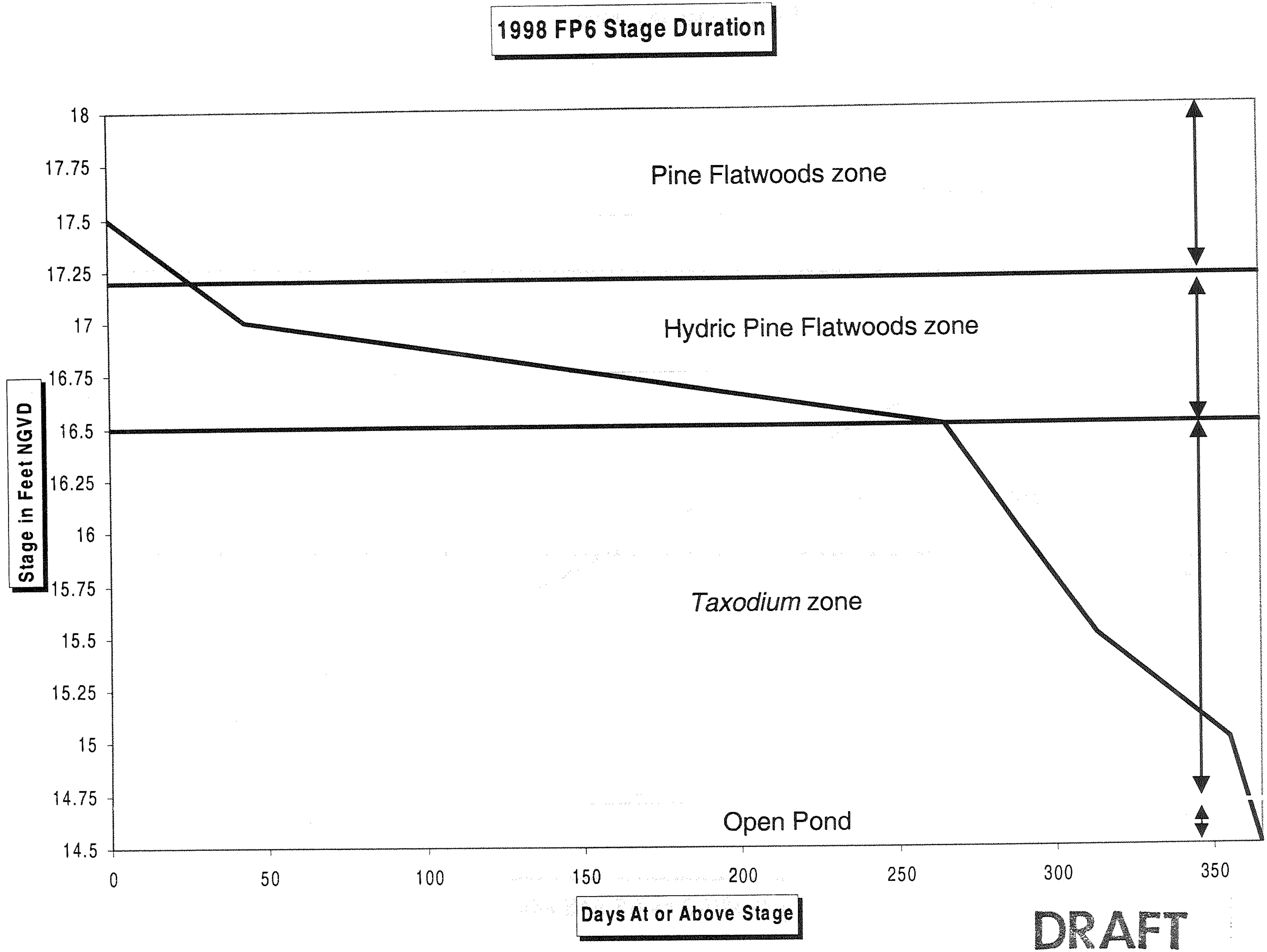
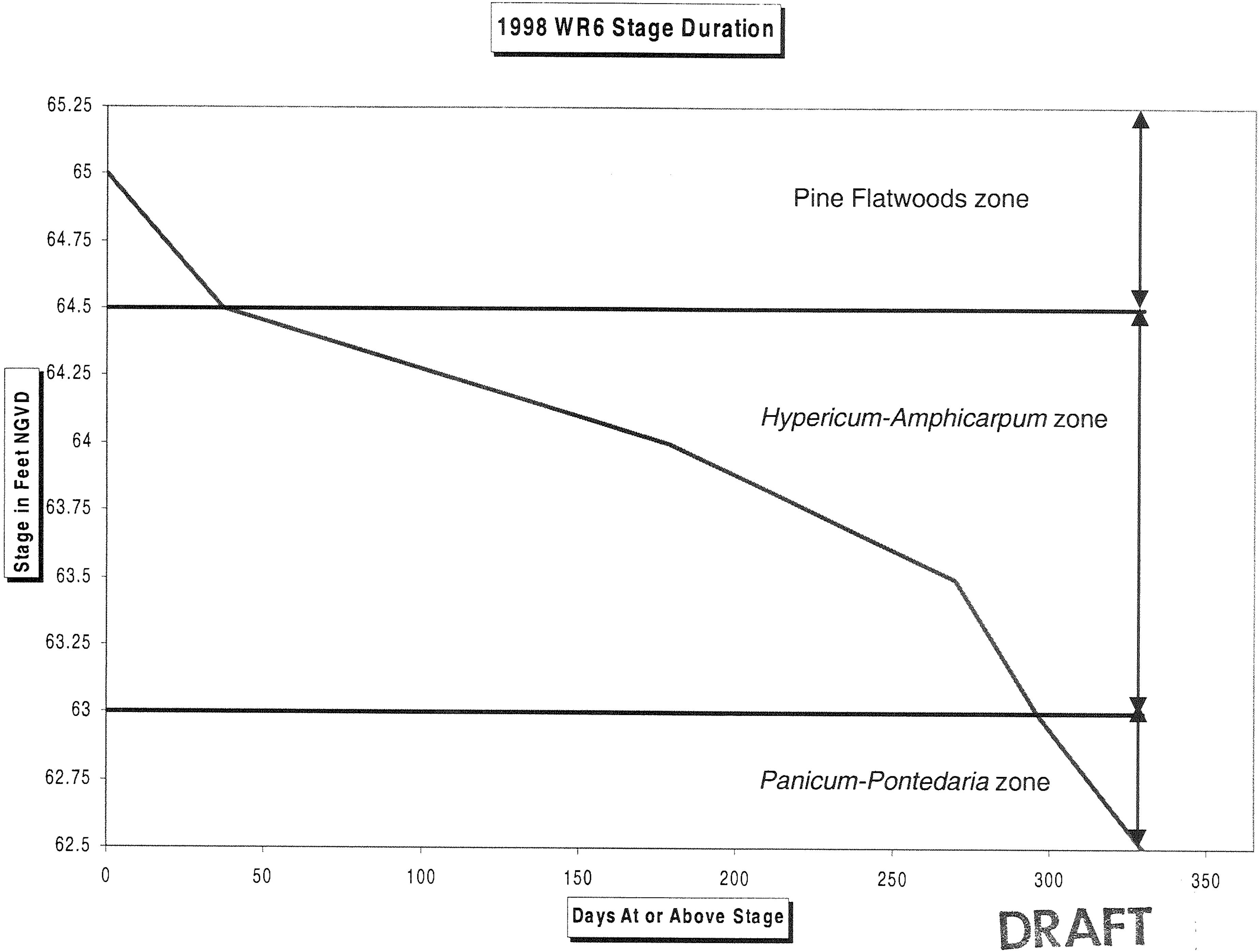
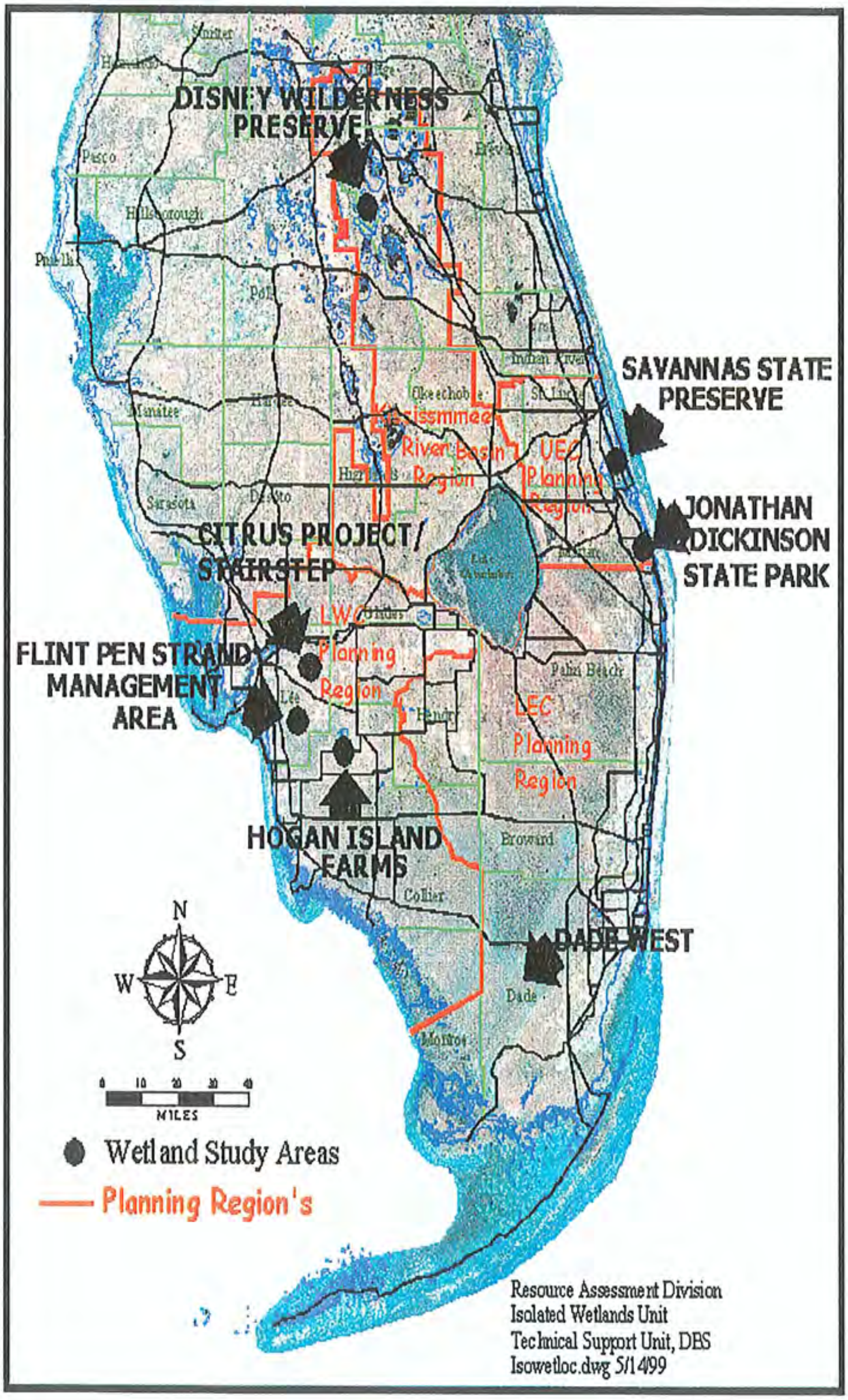

1998 FP6 Stage Duration
Stage in Feet NGVD
18
17.75
17.5
17.25
17
16.75
16.5
16.25
16
15.75
15.5
15.25
15
14.75
14.5
Pine Flatwoods zone
Hydric Pine Flatwoods zone
Taxodium zone
Open Pond
0
50
100
150
200
250
300
350
Days At or Above Stage



1998 WR6 Stage Duration

FIGURES

Fig 2.1 Wetlands Study Area Locations



Resource Assessment Division
Isolated Wetlands Unit
Technical Support Unit, DBS
Isowetloc.dwg 5/14/99

Fig. 2.2 Flint Pen Strand

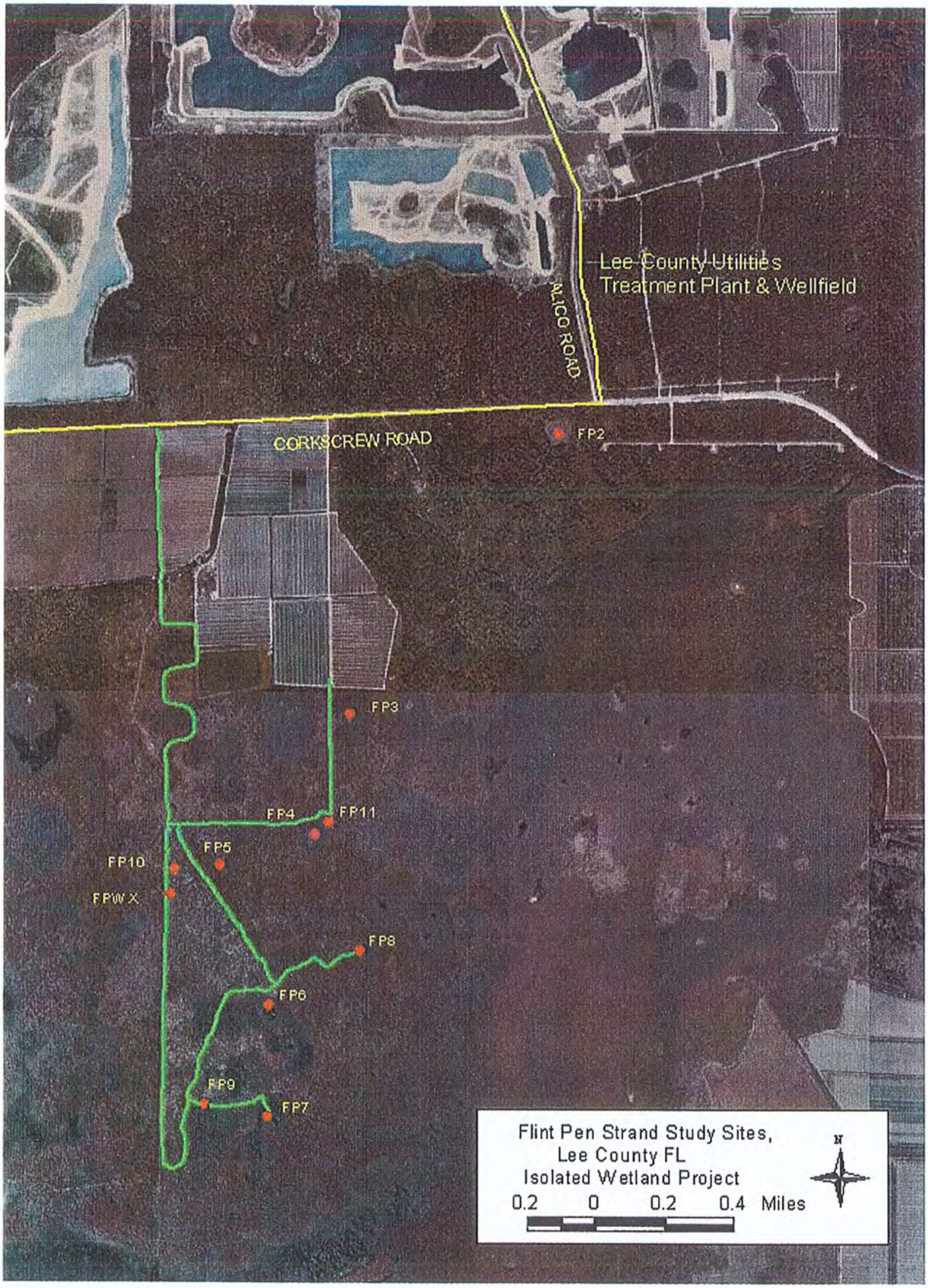


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Fig 2.3 Savannas State Reserve

Fig. 2.4 Jonathan Dickinson State Park

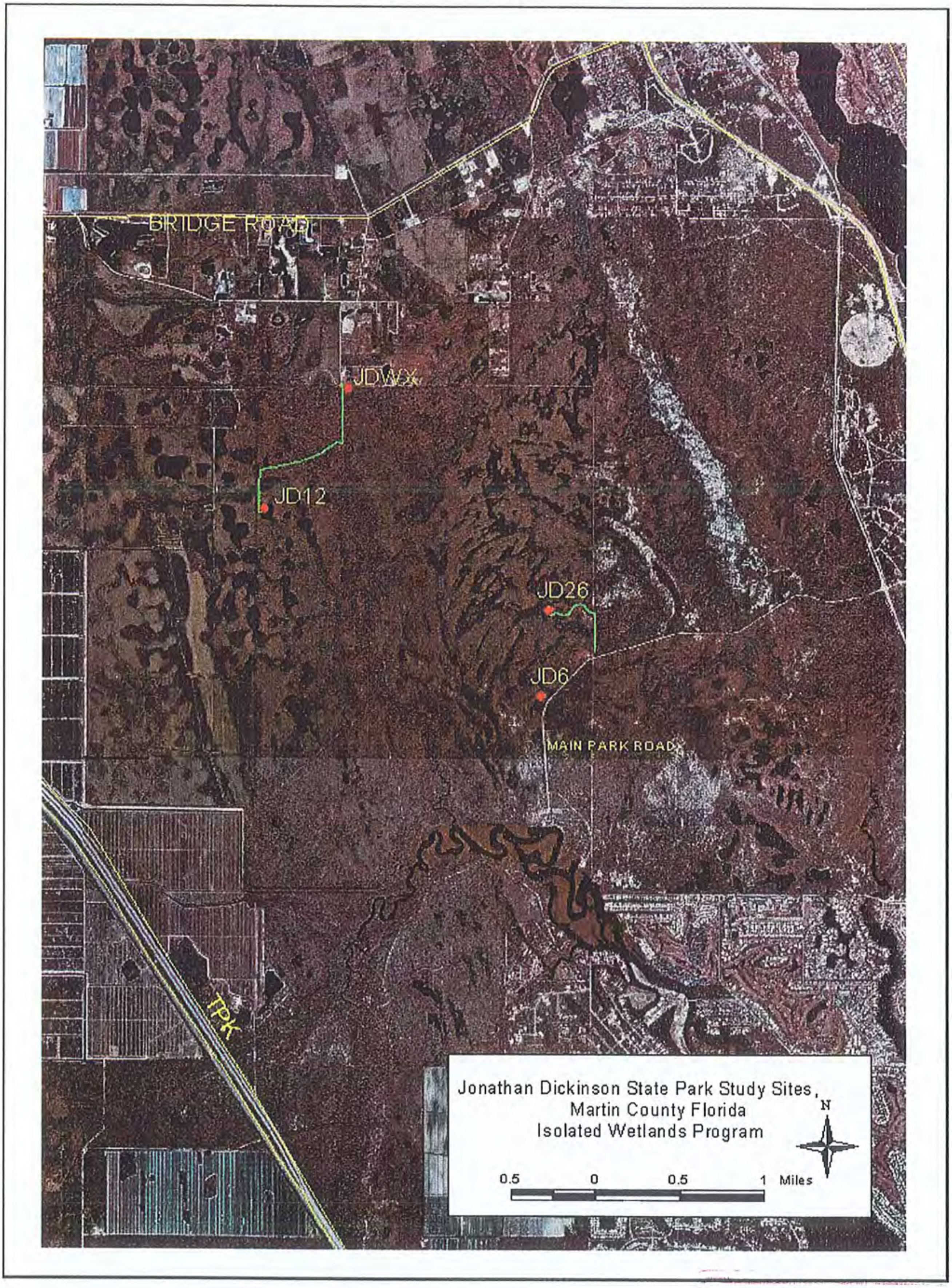
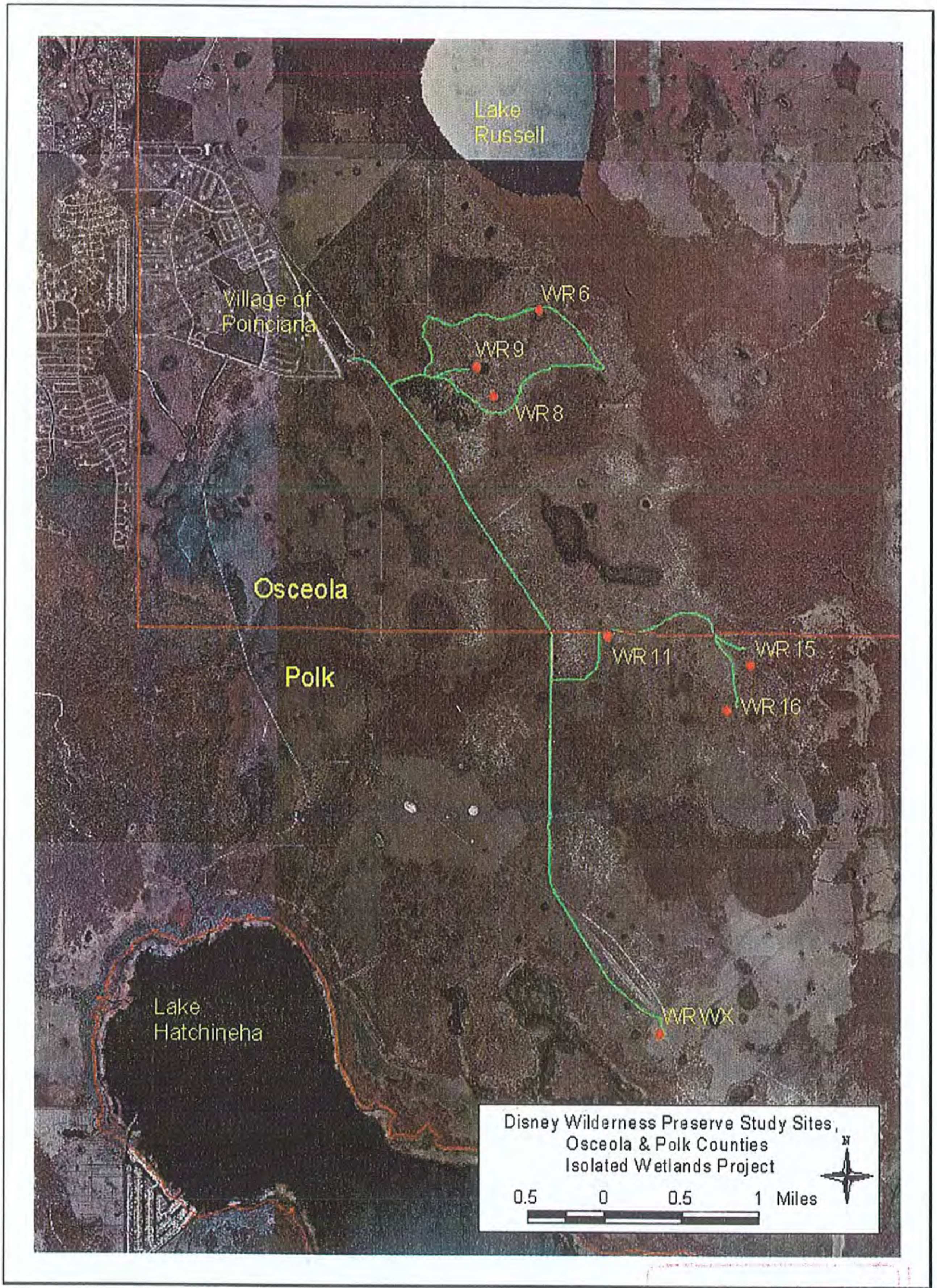


Fig 2.5 Disney Wilderness Preserve



DRAFT

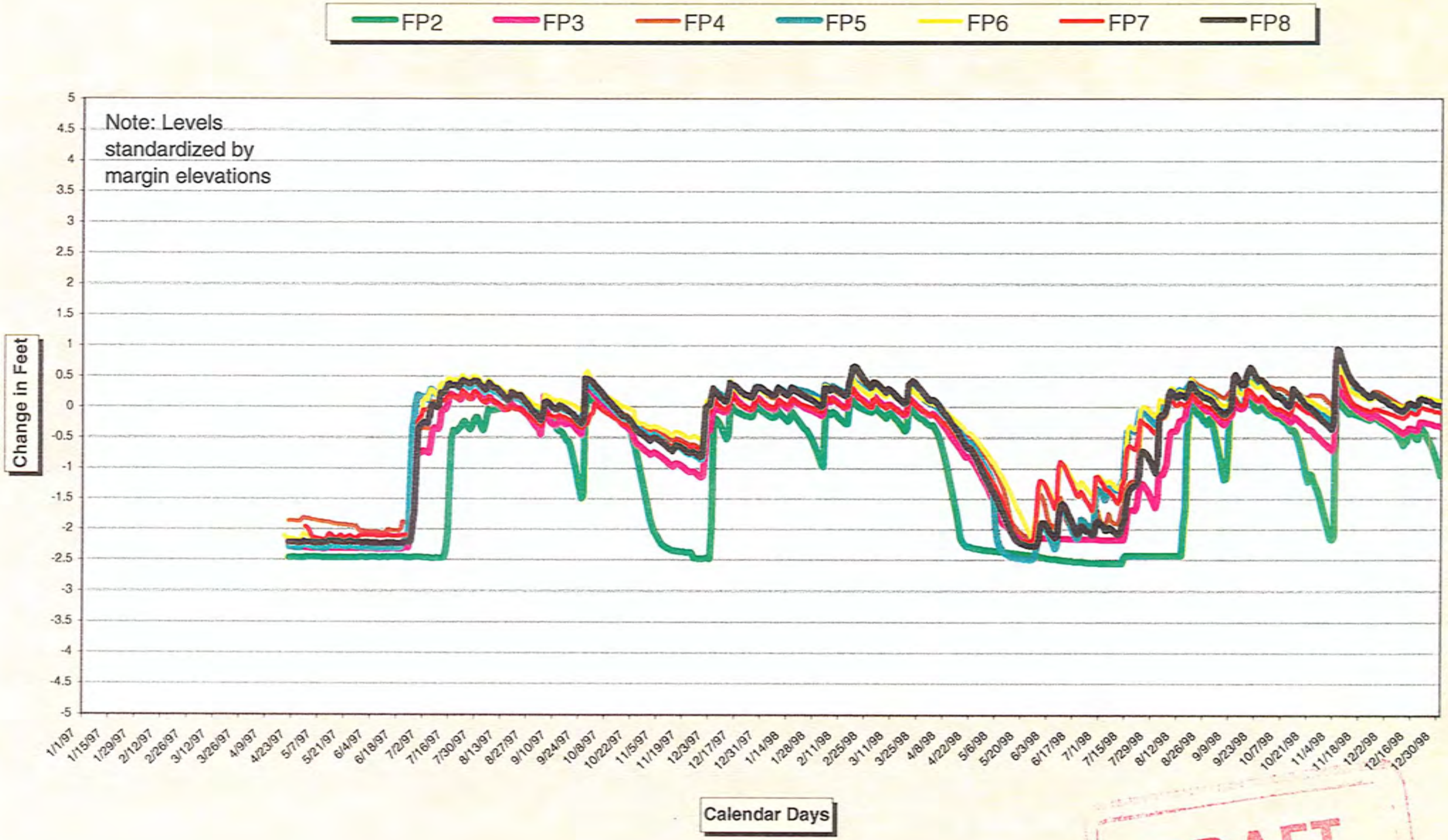


Fig. 5.1 Standardized Flint Pen Surface Water Levels January 1,1997-December 31, 1998

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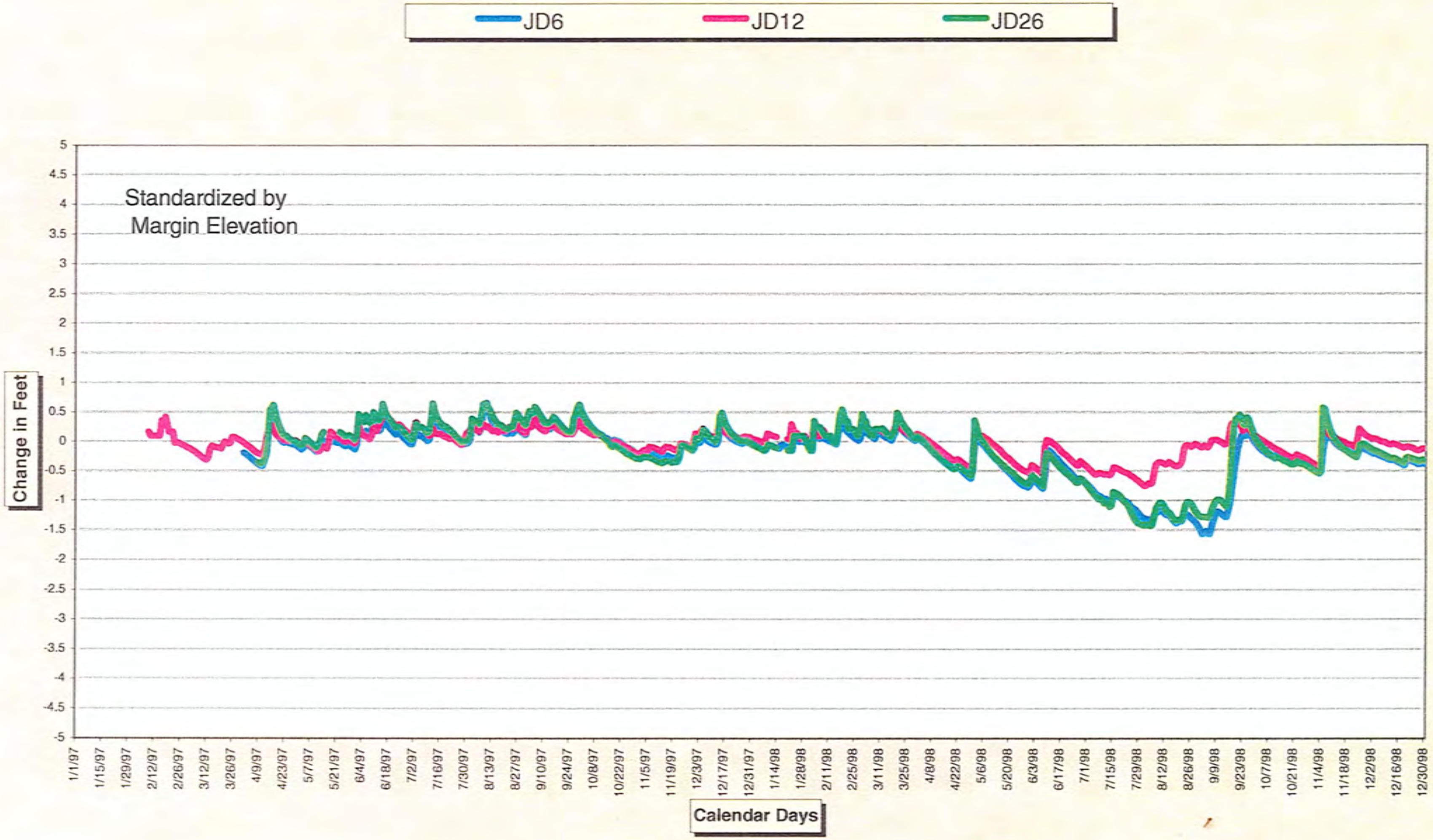
Fig. 5.3 Standardized JDSP Surface Water Levels January 1,1997-December 31, 1998



DRAFT

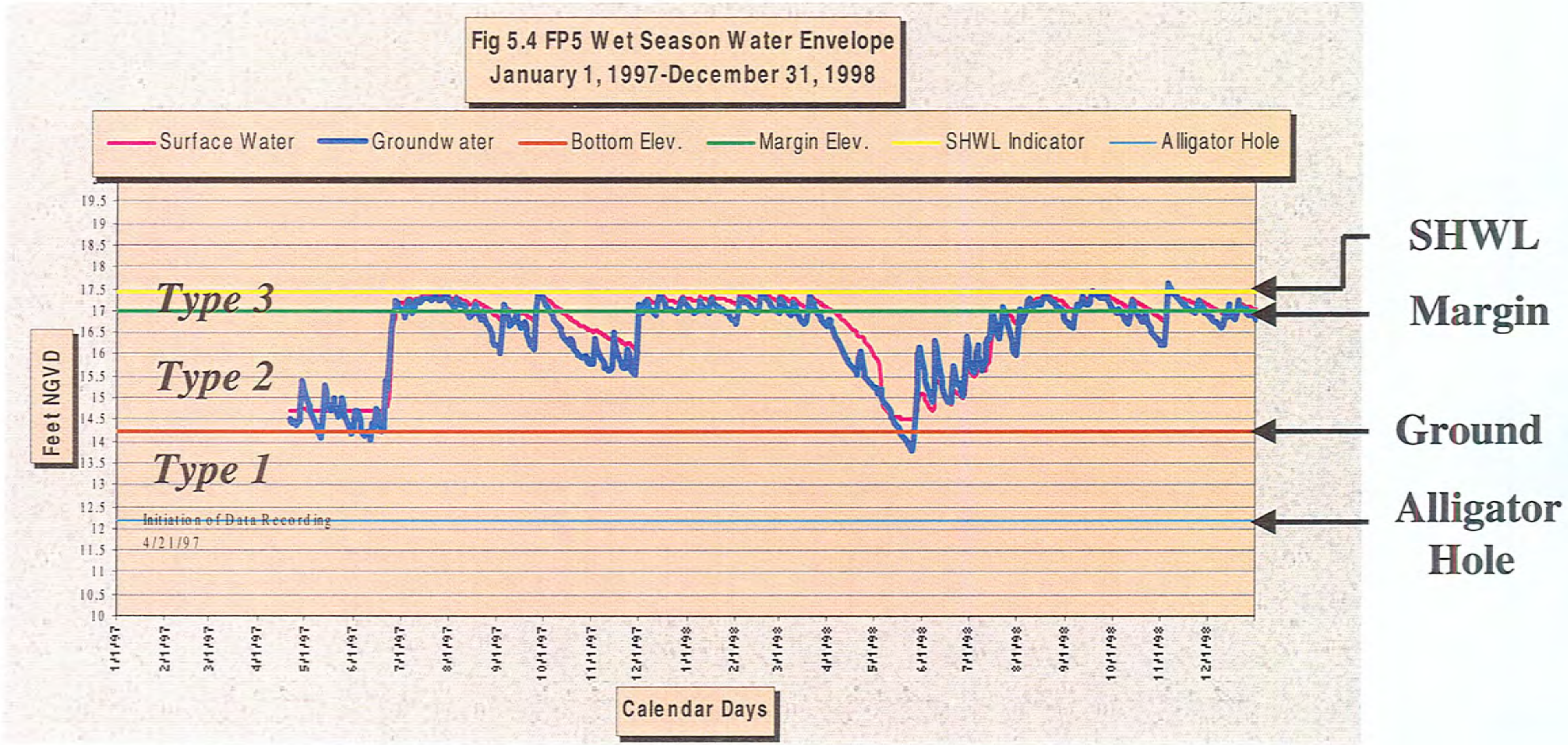
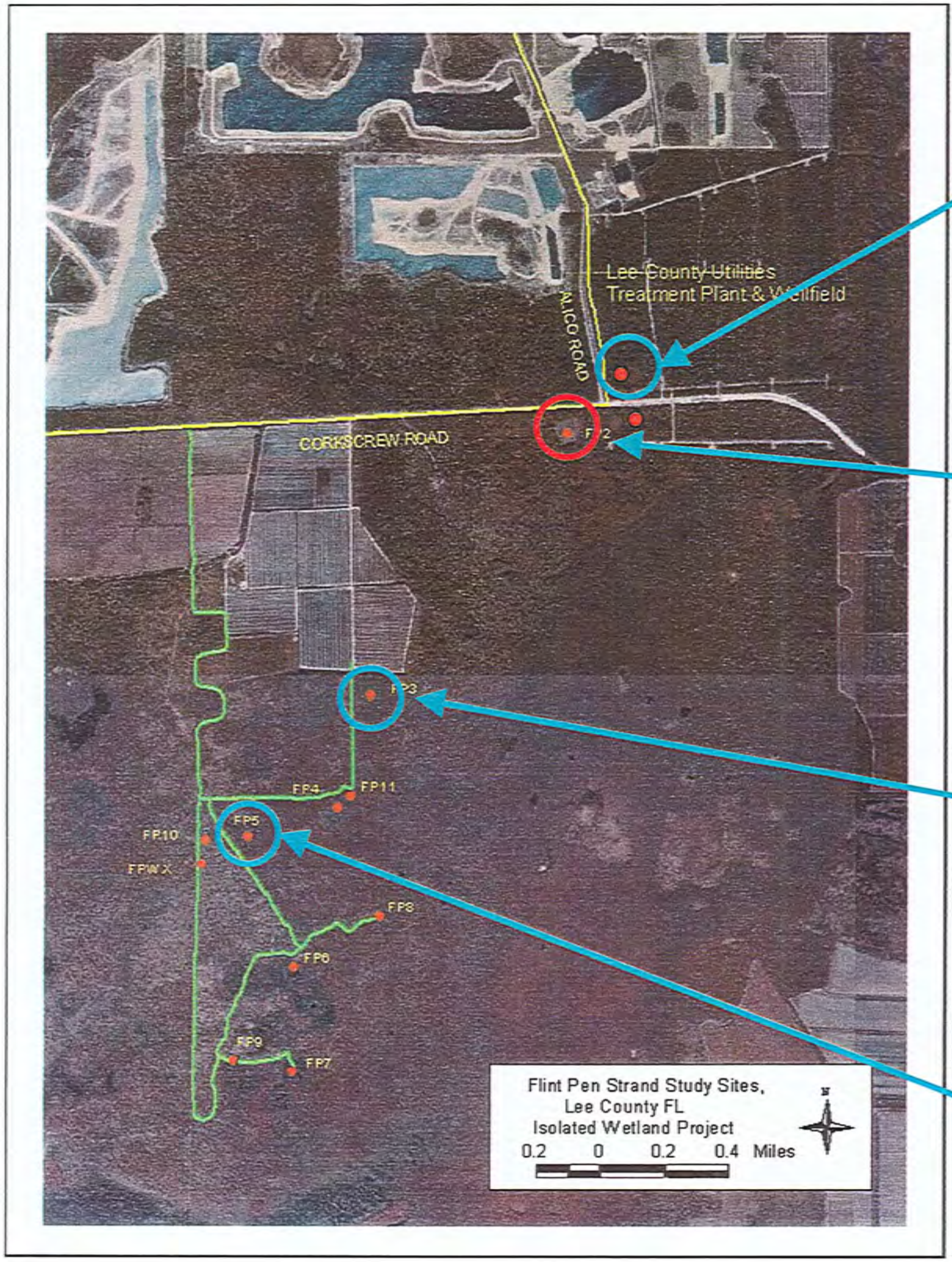
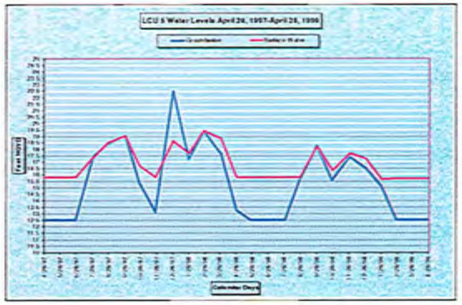


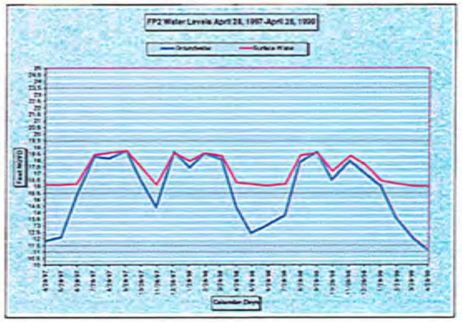
Fig 5.4 FP5 Wet Season Water Envelope
January 1, 1997-December 31, 1998

Figure 6.3 -- Wetland Water Level Patterns Along Drawdown Gradient

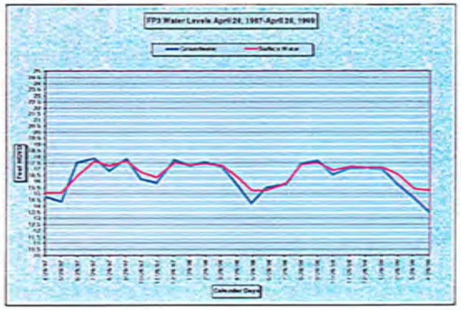




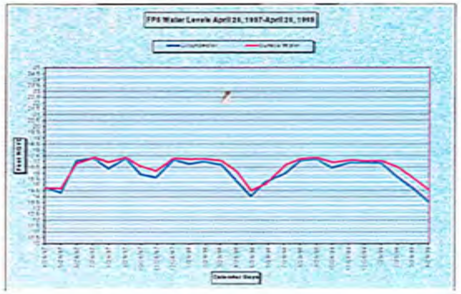
LCU5



FP2



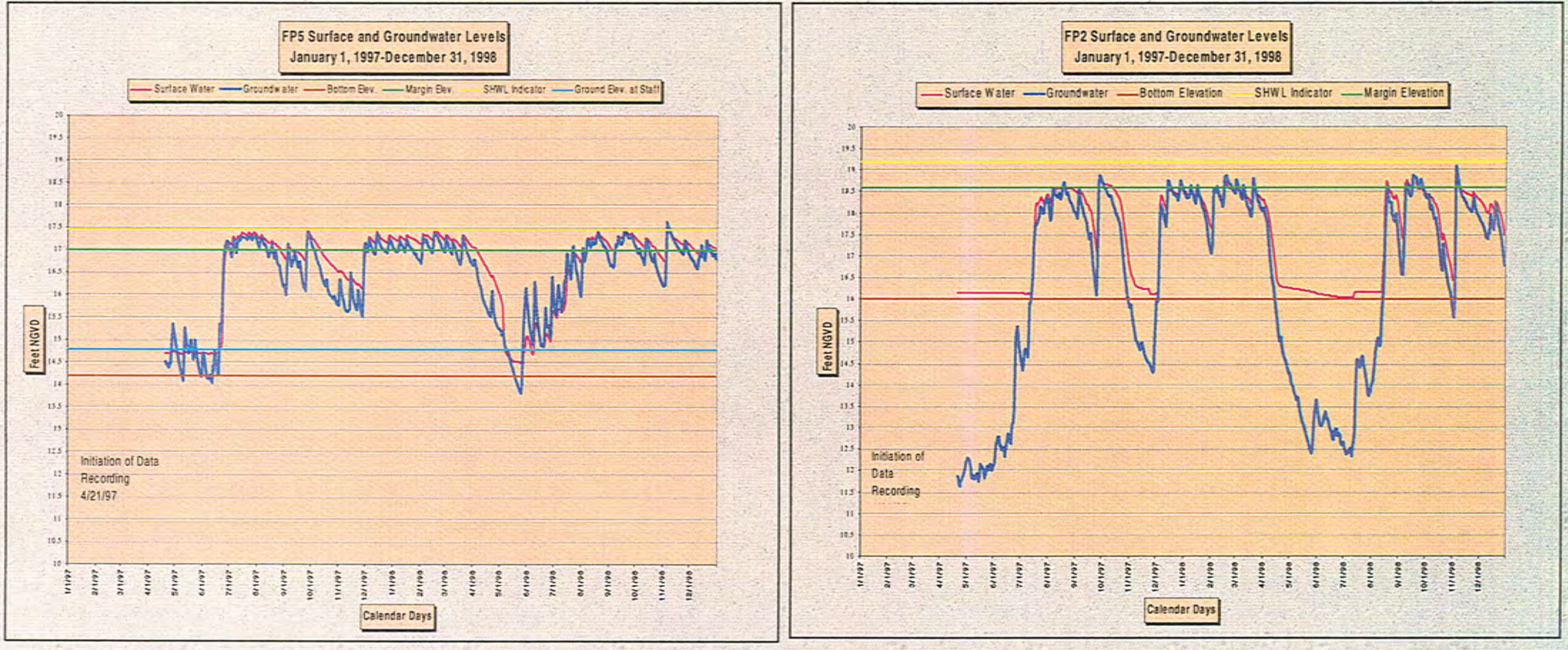
FP3



FP5

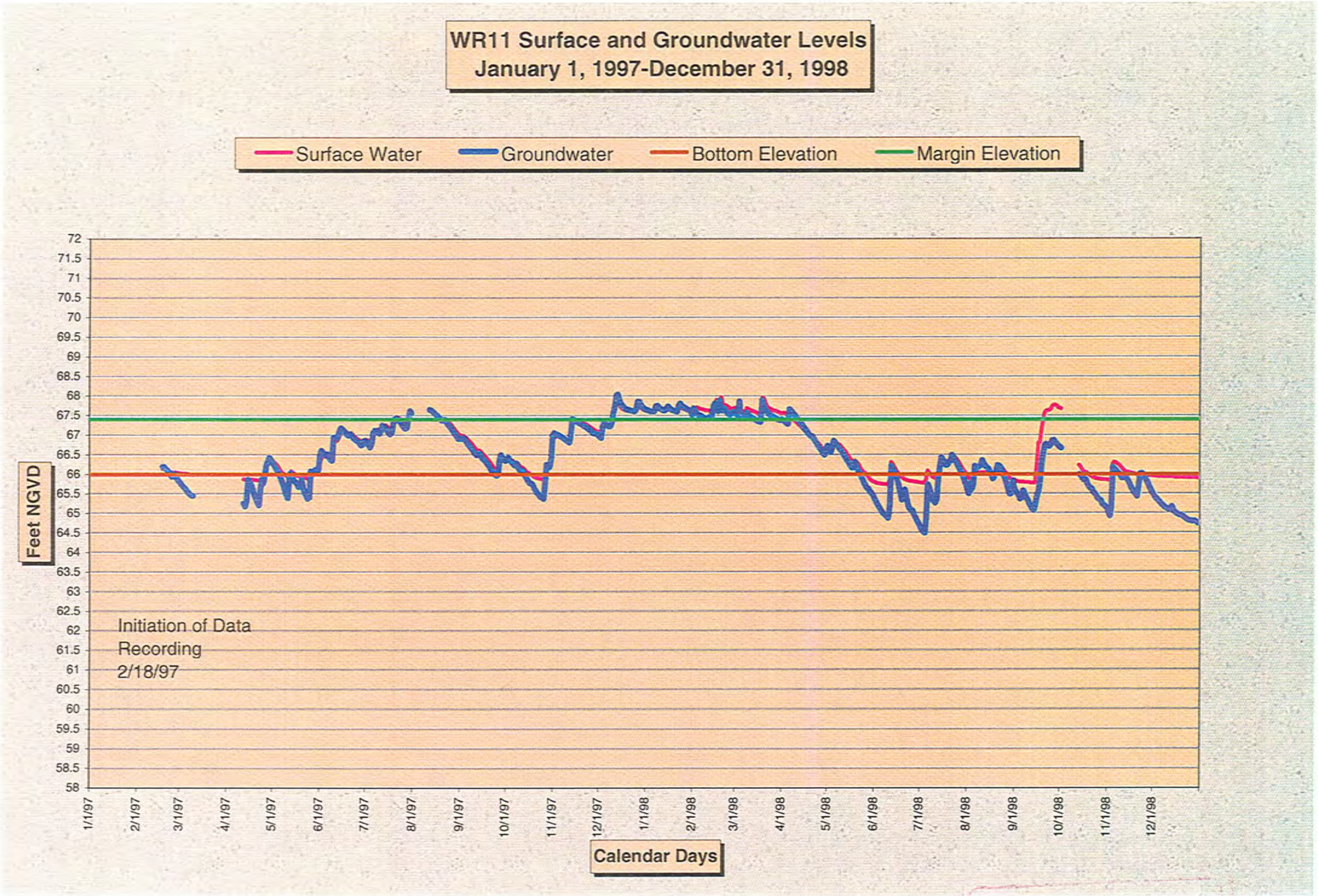
Fig. 6.4 Comparison Of Water Levels at FP2 & FP5

January 1, 1997-December 31, 1998



FP5 Surface and Groundwater Levels
January 1, 1997-December 31, 1998

FP2 Surface and Groundwater Levels
January 1, 1997-December 31, 1998



WR11 Surface and Groundwater Levels
January 1, 1997-December 31, 1998

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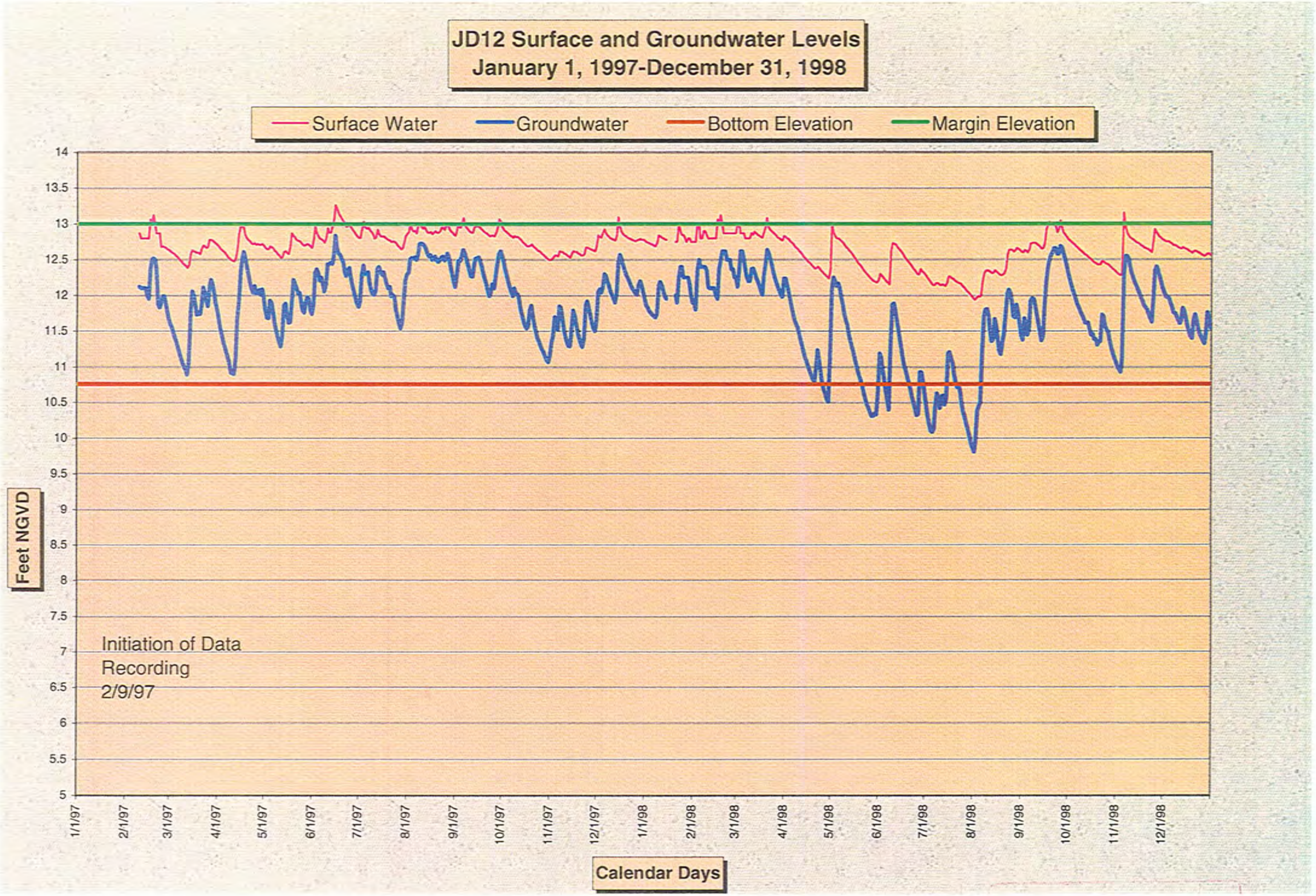
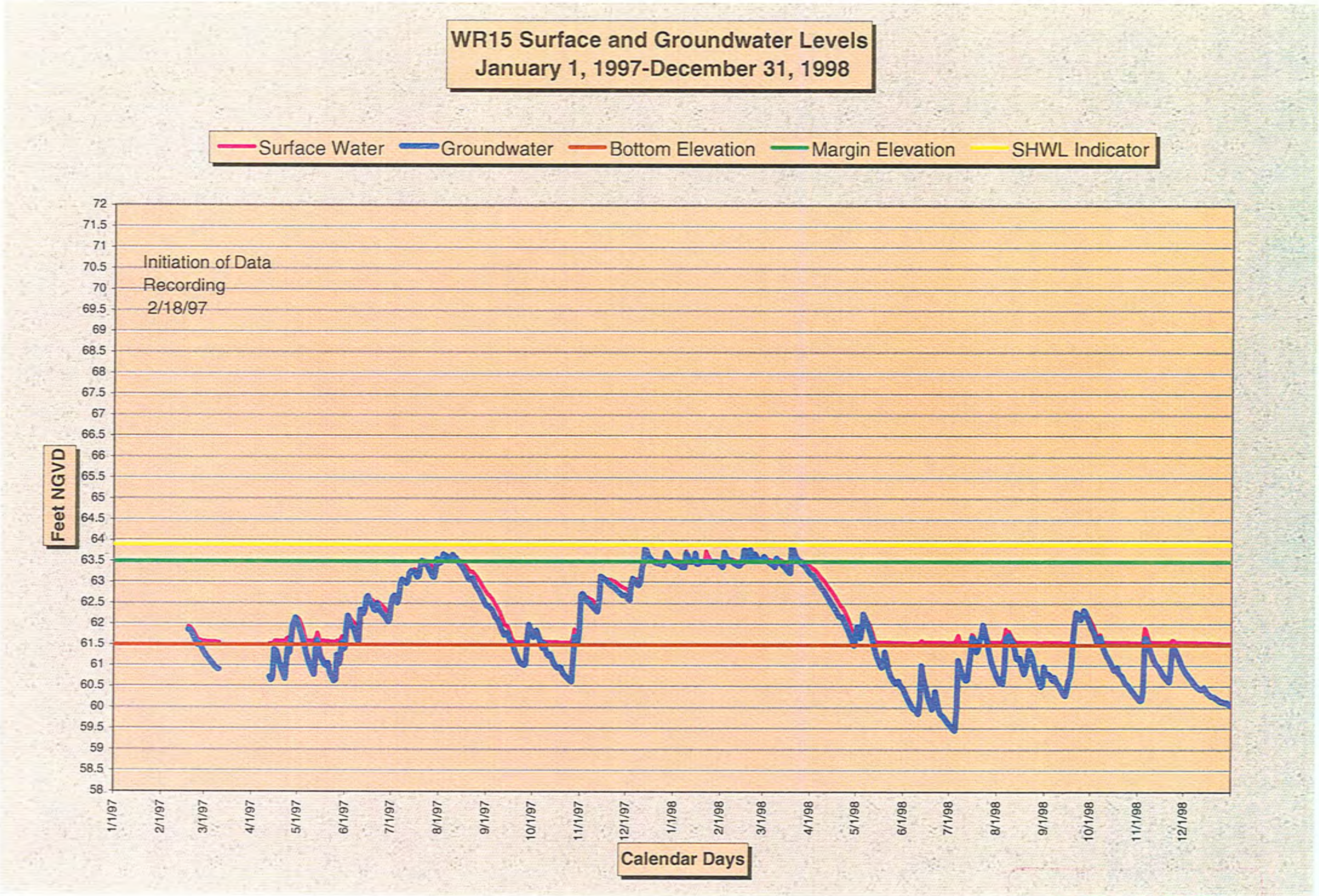

JD12 Surface and Groundwater Levels
January 1, 1997-December 31, 1998
Surface Water
Groundwater
Bottom Elevation
Margin Elevation
Feet NGVD
14
13.5
13
12.5
12
11.5
11
10.5
10
9.5
9
8.5
8
7.5
7
6.5
6
5.5
5
Initiation of Data
Recording
2/9/97
1/1/97
2/1/97
3/1/97
4/1/97
5/1/97
6/1/97
7/1/97
8/1/97
9/1/97
10/1/97
11/1/97
12/1/97
1/1/98
2/1/98
3/1/98
4/1/98
5/1/98
6/1/98
7/1/98
8/1/98
9/1/98
10/1/98
11/1/98
12/1/98
Calendar Days



WR15 Surface and Groundwater Levels
January 1, 1997-December 31, 1998

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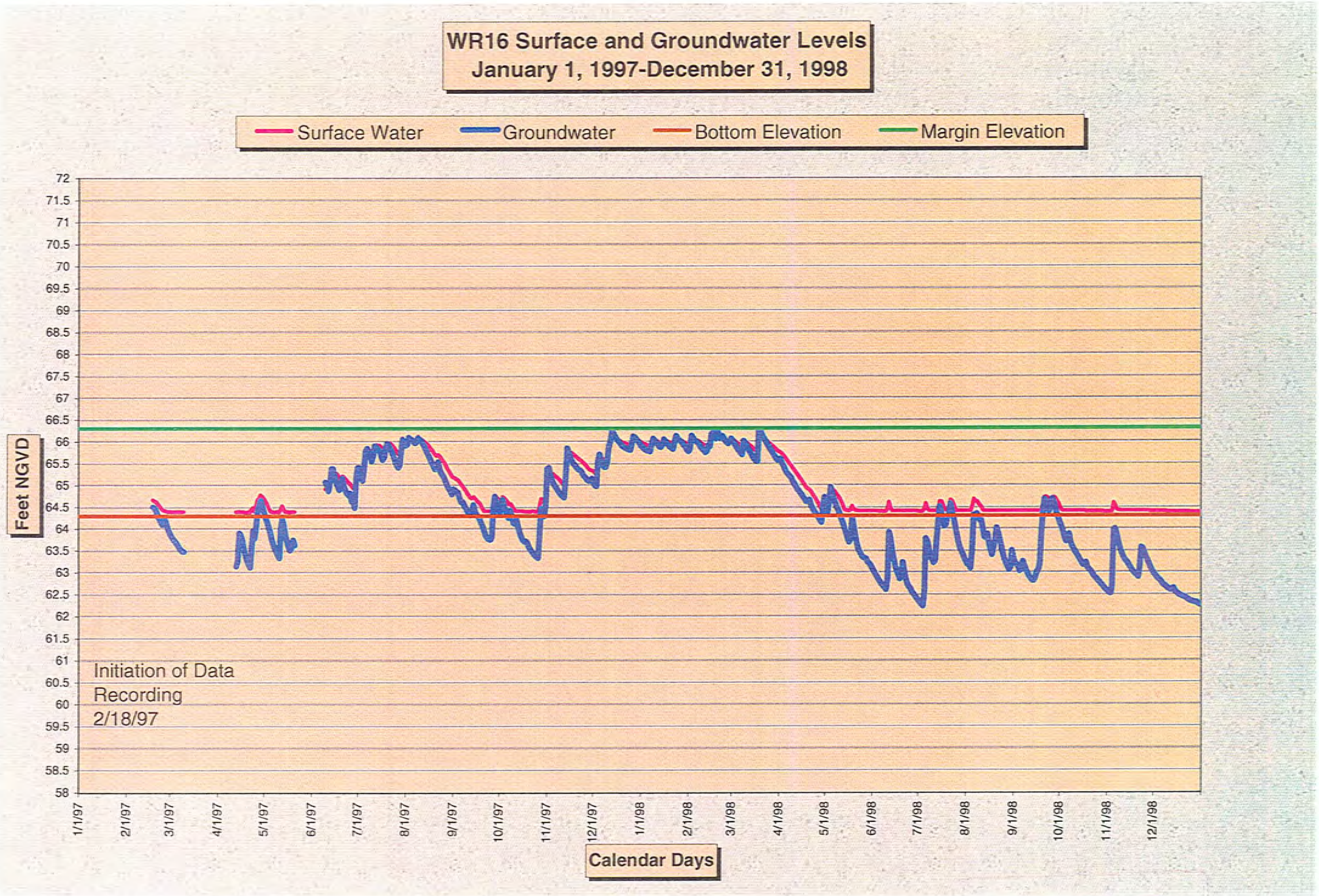
WR16 Surface and Groundwater Levels
January 1, 1997-December 31, 1998
Surface Water
Groundwater
Bottom Elevation
Margin Elevation
Feet NGVD
72
71.5
71
70.5
70
69.5
69
68.5
68
67.5
67
66.5
66
65.5
65
64.5
64
63.5
63
62.5
62
61.5
61
60.5
60
59.5
59
58.5
58
Initiation of Data
Recording
2/18/97
1/1/97
2/1/97
3/1/97
4/1/97
5/1/97
6/1/97
7/1/97
8/1/97
9/1/97
10/1/97
11/1/97
12/1/97
1/1/98
2/1/98
3/1/98
4/1/98
5/1/98
6/1/98
7/1/98
8/1/98
9/1/98
10/1/98
11/1/98
12/1/98
Calendar Days

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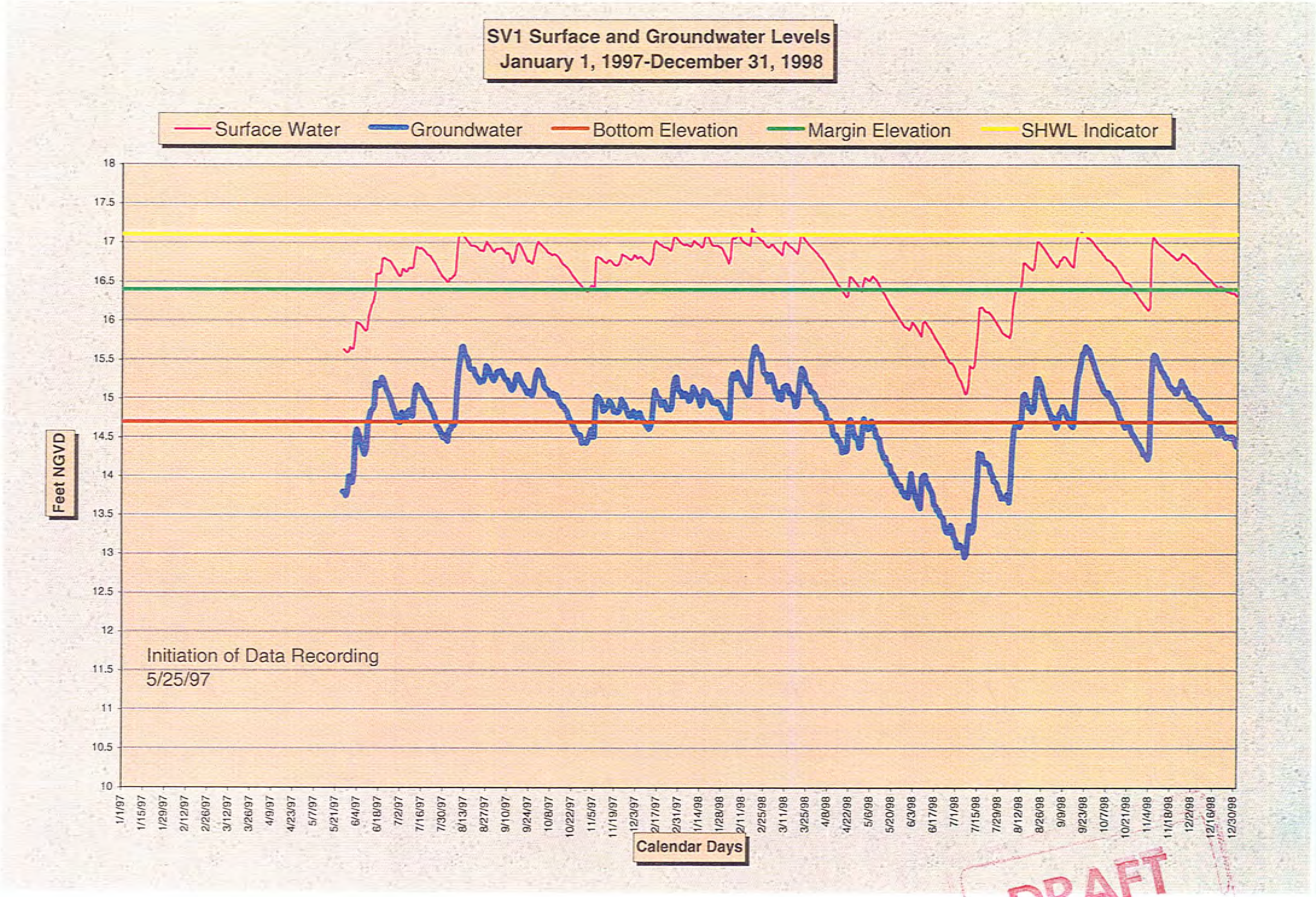

SV1 Surface and Groundwater Levels
January 1, 1997-December 31, 1998

Initiation of Data Recording
5/25/97

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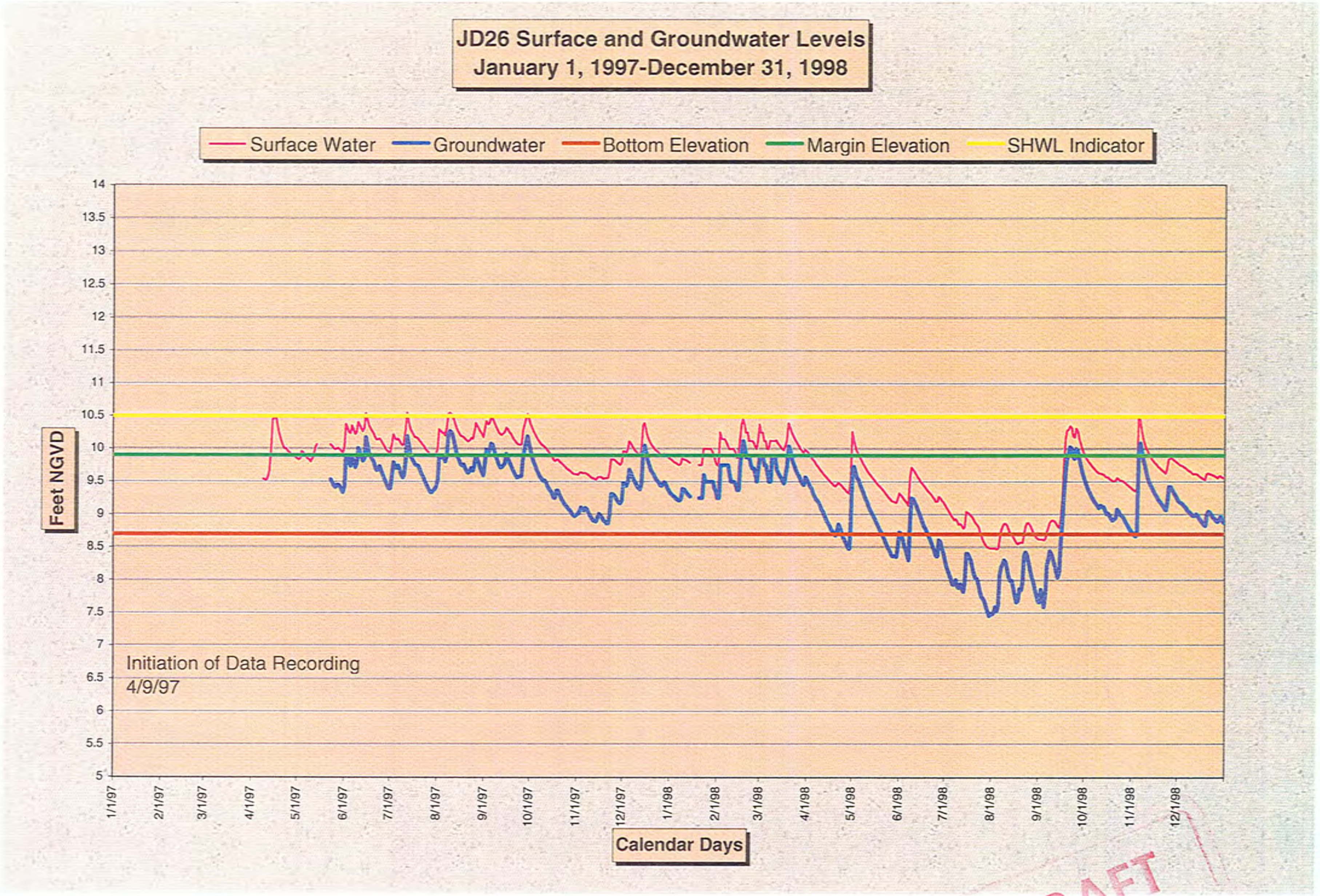
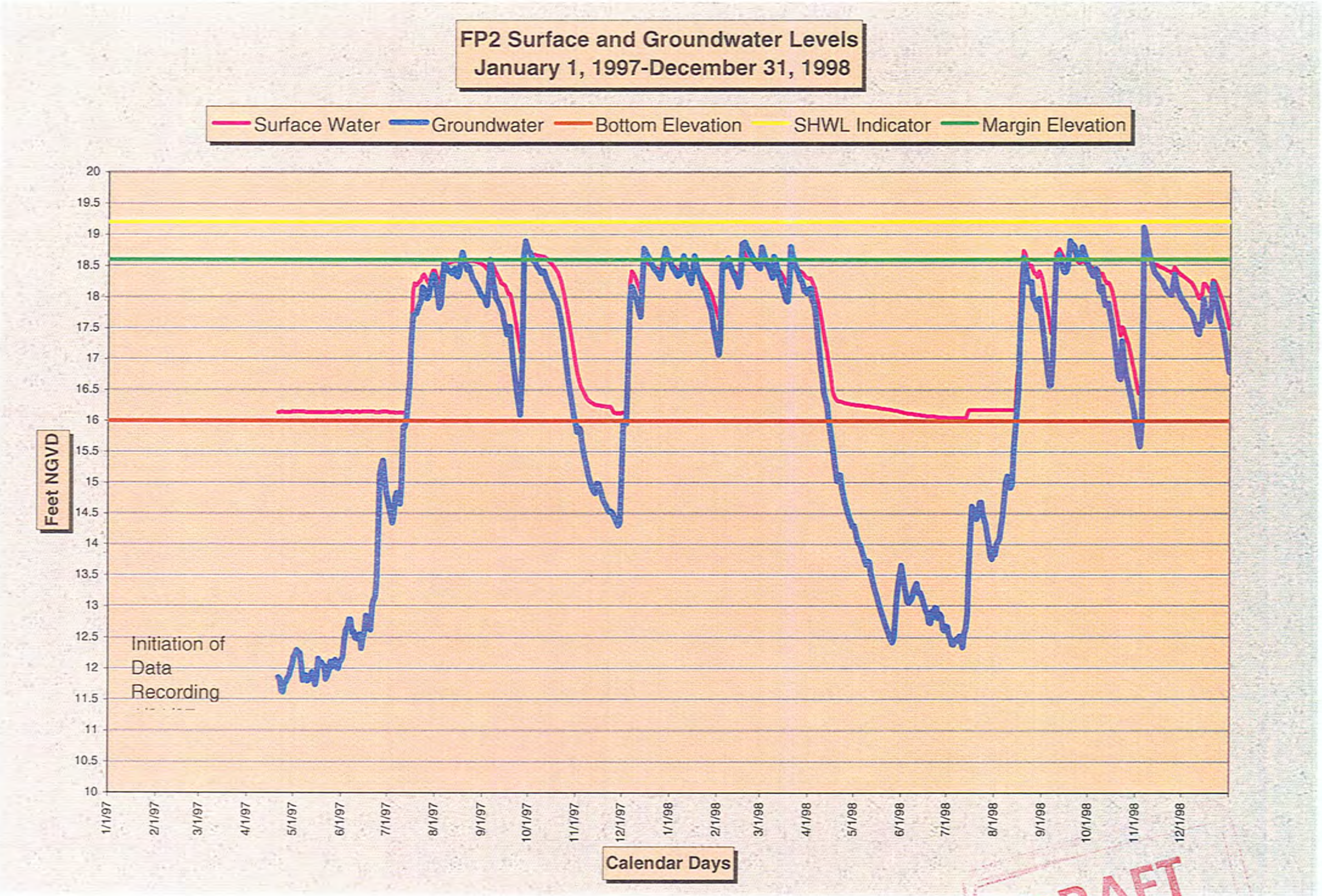

JD26 Surface and Groundwater Levels
January 1, 1997-December 31, 1998
Surface Water
Groundwater
Bottom Elevation
Margin Elevation
SHWL Indicator
Feet NGVD
14
13.5
13
12.5
12
11.5
11
10.5
10
9.5
9
8.5
8
7.5
7
6.5
6
5.5
5
Initiation of Data Recording
4/9/97
1/1/97
2/1/97
3/1/97
4/1/97
5/1/97
6/1/97
7/1/97
8/1/97
9/1/97
10/1/97
11/1/97
12/1/97
1/1/98
2/1/98
3/1/98
4/1/98
5/1/98
6/1/98
7/1/98
8/1/98
9/1/98
10/1/98
11/1/98
12/1/98
Calendar Days



FP2 Surface and Groundwater Levels
January 1, 1997-December 31, 1998

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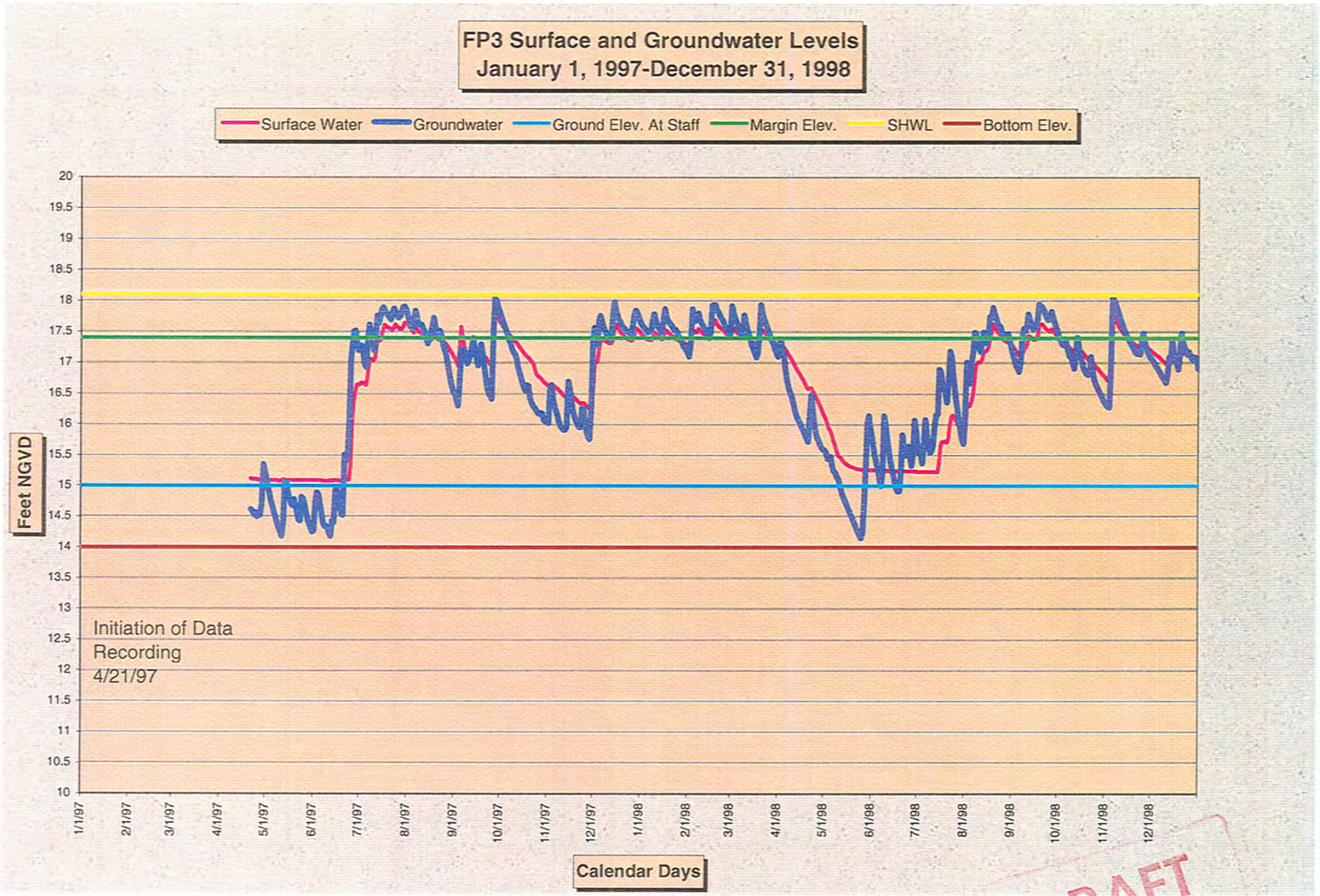
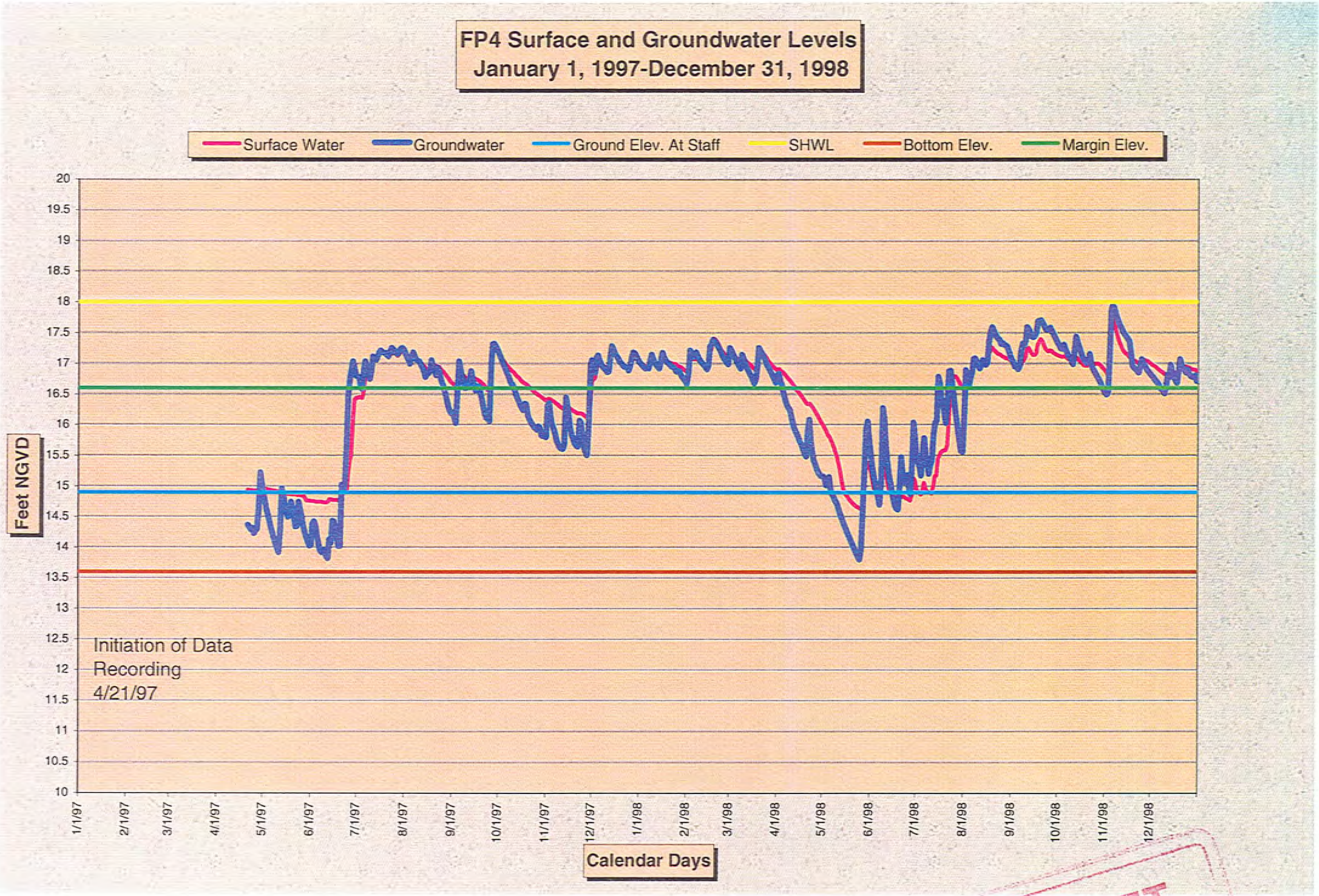
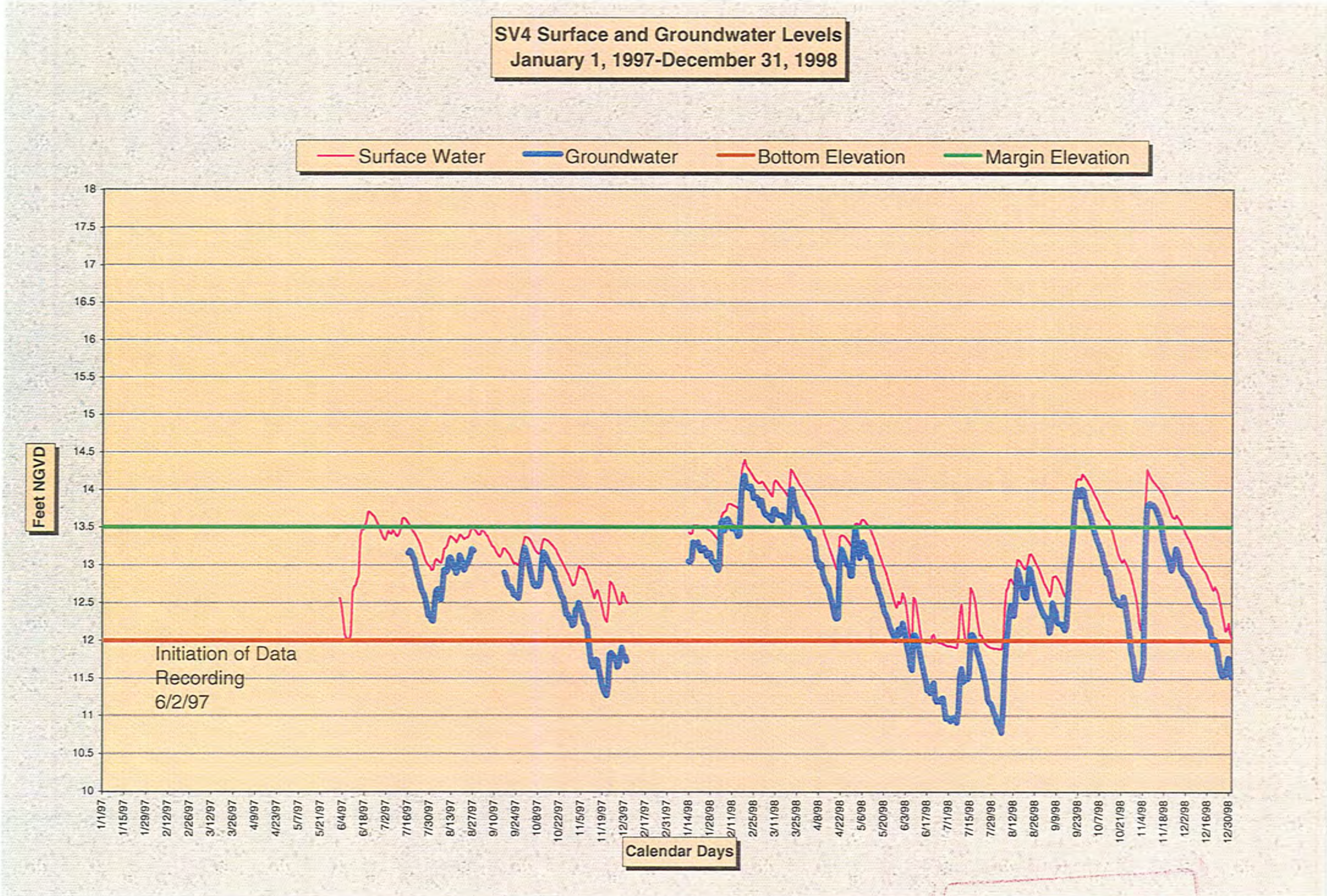

FP3 Surface and Groundwater Levels
January 1, 1997-December 31, 1998
Surface Water
Groundwater
Ground Elev. At Staff
Margin Elev.
SHWL
Bottom Elev.
Feet NGVD
20
19.5
19
18.5
18
17.5
17
16.5
16
15.5
15
14.5
14
13.5
13
12.5
12
11.5
11
10.5
10
Initiation of Data Recording 4/21/97
1/1/97
2/1/97
3/1/97
4/1/97
5/1/97
6/1/97
7/1/97
8/1/97
9/1/97
10/1/97
11/1/97
12/1/97
1/1/98
2/1/98
3/1/98
4/1/98
5/1/98
6/1/98
7/1/98
8/1/98
9/1/98
10/1/98
11/1/98
12/1/98
Calendar Days

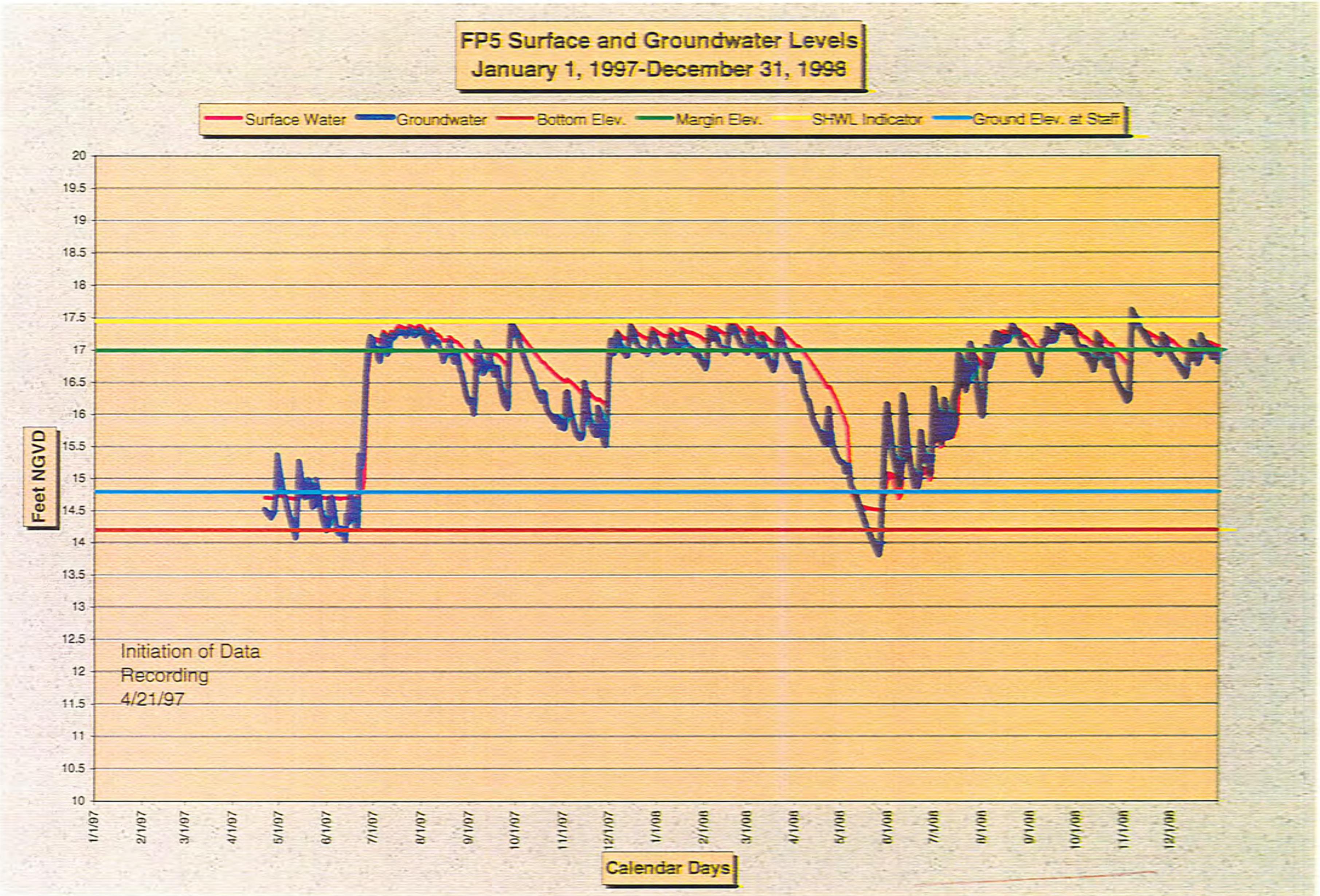
DRAFT


FP4 Surface and Groundwater Levels
January 1, 1997-December 31, 1998
Surface Water
Groundwater
Ground Elev. At Staff
SHWL
Bottom Elev.
Margin Elev.
Feet NGVD
20
19.5
19
18.5
18
17.5
17
16.5
16
15.5
15
14.5
14
13.5
13
12.5
12
11.5
11
10.5
10
1/1/97
2/1/97
3/1/97
4/1/97
5/1/97
6/1/97
7/1/97
8/1/97
9/1/97
10/1/97
11/1/97
12/1/97
1/1/98
2/1/98
3/1/98
4/1/98
5/1/98
6/1/98
7/1/98
8/1/98
9/1/98
10/1/98
11/1/98
12/1/98
Calendar Days
Initiation of Data
Recording
4/21/97

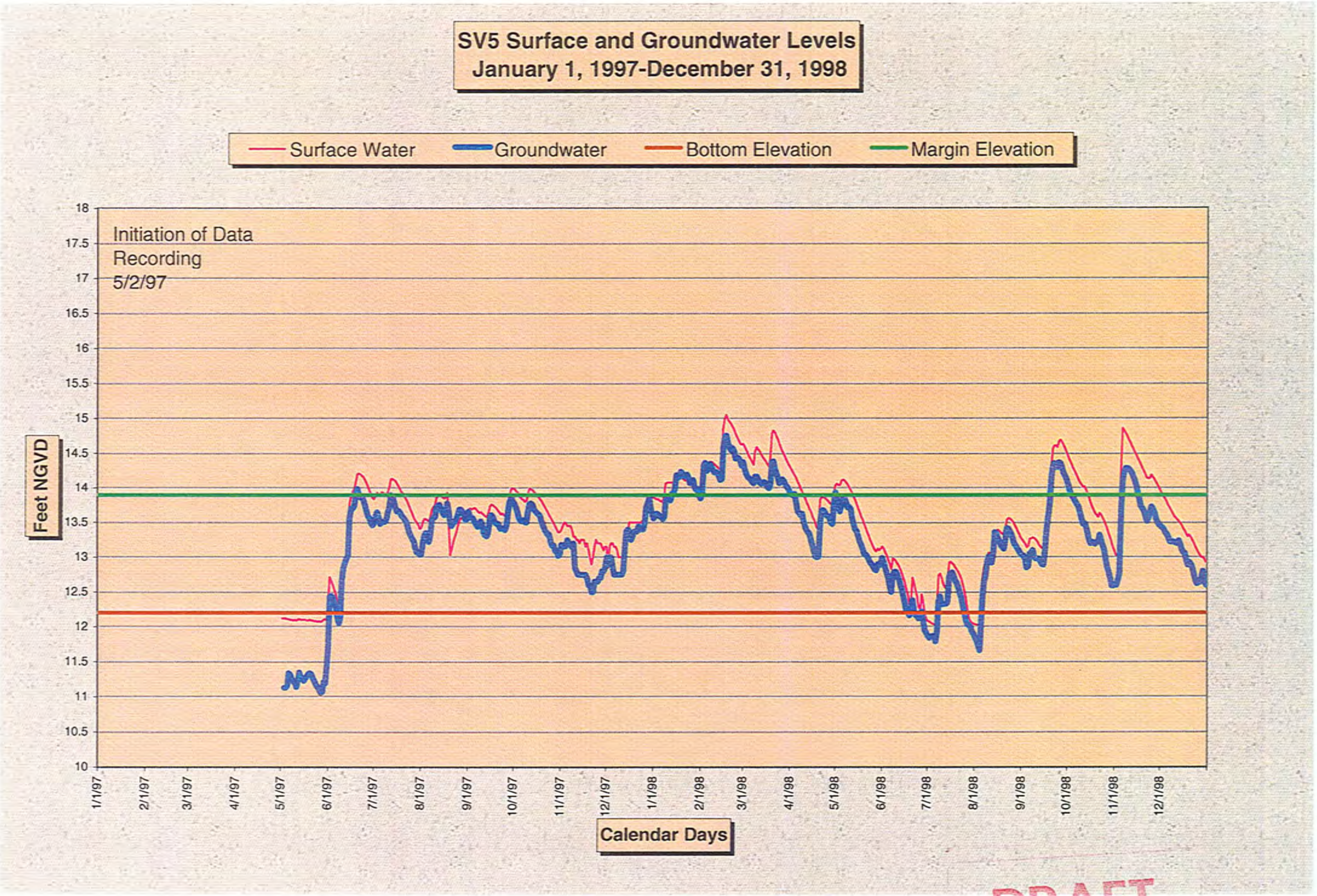
DRAFT


SV4 Surface and Groundwater Levels
January 1, 1997-December 31, 1998
Surface Water
Groundwater
Bottom Elevation
Margin Elevation
Feet NGVD
18
17.5
17
16.5
16
15.5
15
14.5
14
13.5
13
12.5
12
11.5
11
10.5
10
Initiation of Data Recording 6/2/97
1/1/97
1/15/97
1/29/97
2/12/97
2/26/97
3/12/97
3/26/97
4/9/97
4/23/97
5/7/97
5/21/97
6/4/97
6/18/97
7/2/97
7/16/97
7/30/97
8/13/97
8/27/97
9/10/97
9/24/97
10/8/97
10/22/97
11/5/97
11/19/97
12/3/97
2/17/97
2/31/97
1/14/98
1/28/98
2/11/98
2/25/98
3/11/98
3/25/98
4/8/98
4/22/98
5/6/98
5/20/98
6/3/98
6/17/98
7/1/98
7/15/98
7/29/98
8/12/98
8/26/98
9/9/98
9/23/98
10/7/98
10/21/98
11/4/98
11/18/98
12/2/98
12/16/98
12/30/98
Calendar Days

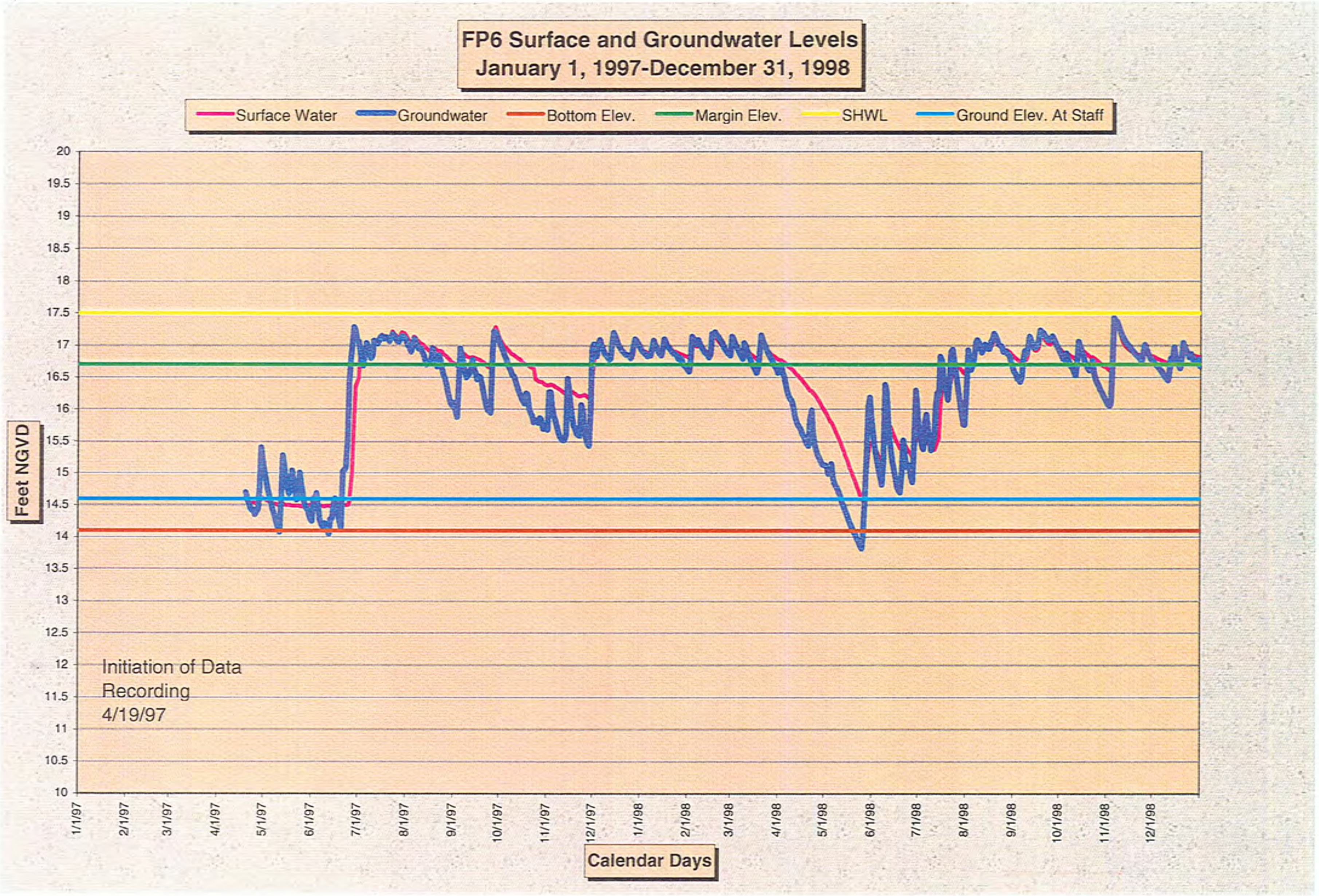
DRAFT


FP5 Surface and Groundwater Levels
January 1, 1997-December 31, 1998
Surface Water
Groundwater
Bottom Elev.
Margin Elev.
SHWL Indicator
Ground Elev. at Staff
20
19.5
19
18.5
18
17.5
17
16.5
16
15.5
15
14.5
14
13.5
13
12.5
12
11.5
11
10.5
10
Feet NGVD
Initiation of Data
Recording
4/21/97
1/1/97
2/1/97
3/1/97
4/1/97
5/1/97
6/1/97
7/1/97
8/1/97
9/1/97
10/1/97
11/1/97
12/1/97
1/1/98
2/1/98
3/1/98
4/1/98
5/1/98
6/1/98
7/1/98
8/1/98
9/1/98
10/1/98
11/1/98
12/1/98
Calendar Days

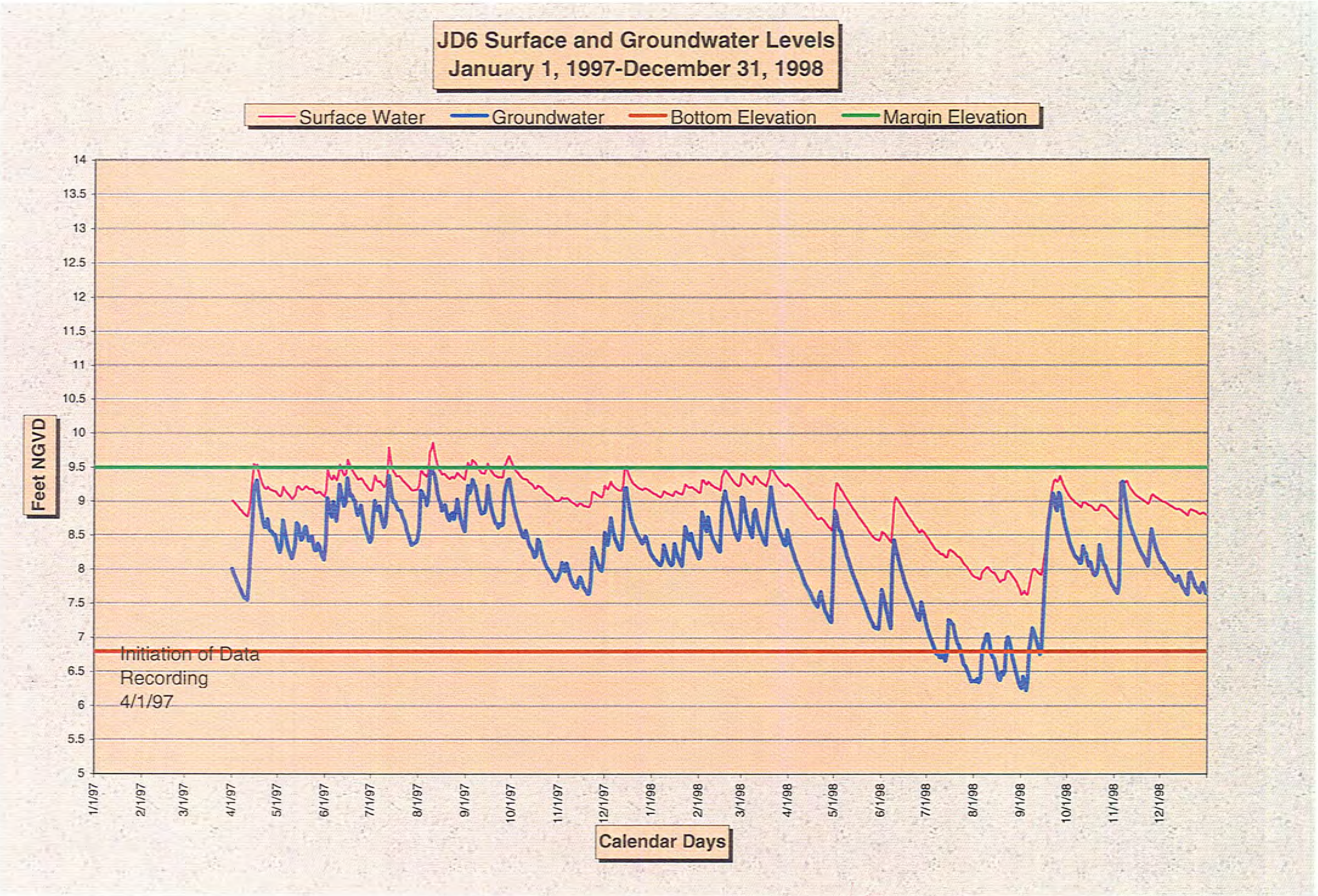
DRAFT


SV5 Surface and Groundwater Levels
January 1, 1997-December 31, 1998
Surface Water
Groundwater
Bottom Elevation
Margin Elevation
Initiation of Data Recording 5/2/97
Feet NGVD
18
17.5
17
16.5
16
15.5
15
14.5
14
13.5
13
12.5
12
11.5
11
10.5
10
1/1/97
2/1/97
3/1/97
4/1/97
5/1/97
6/1/97
7/1/97
8/1/97
9/1/97
10/1/97
11/1/97
12/1/97
1/1/98
2/1/98
3/1/98
4/1/98
5/1/98
6/1/98
7/1/98
8/1/98
9/1/98
10/1/98
11/1/98
12/1/98
Calendar Days

DRAFT

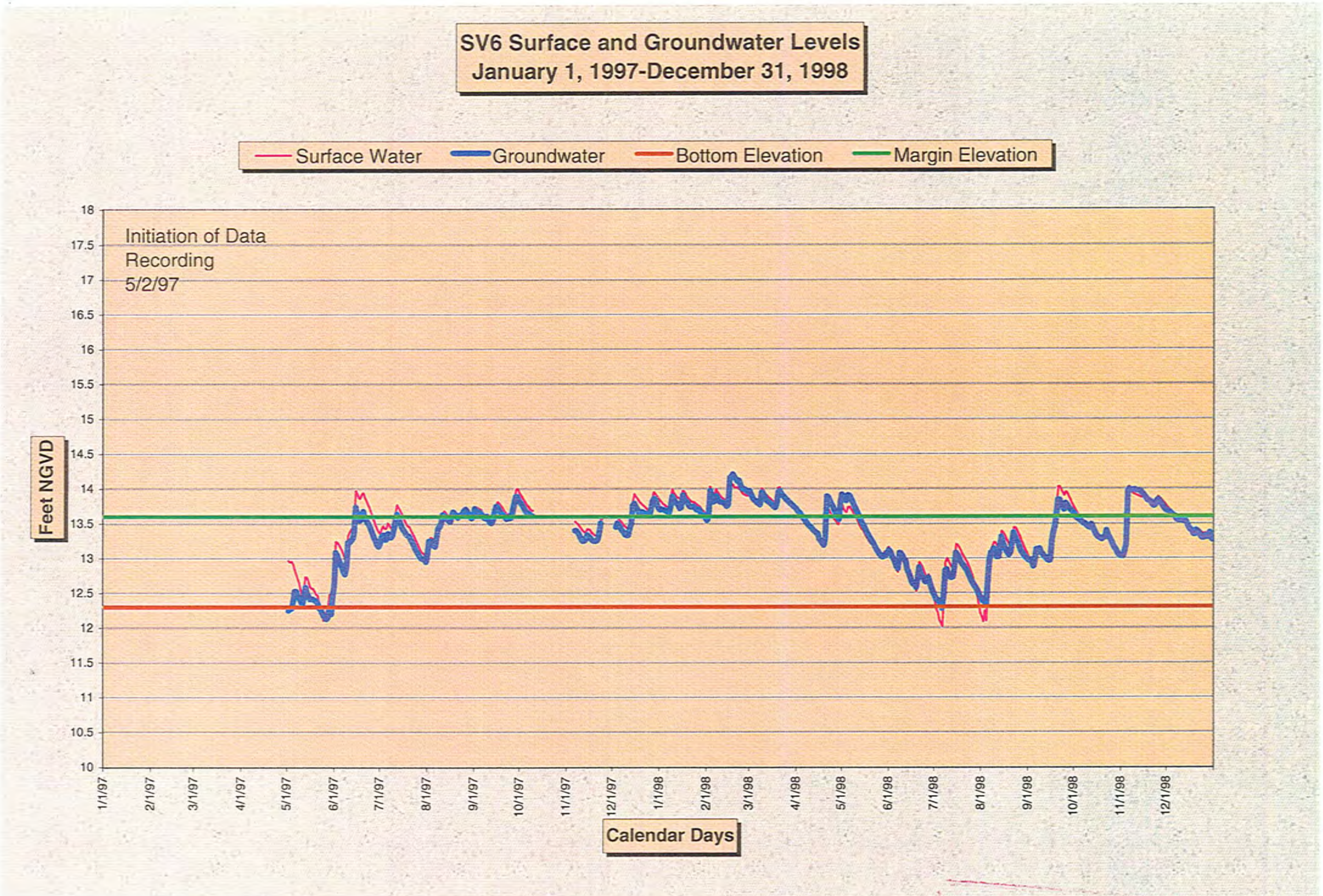

FP6 Surface and Groundwater Levels
January 1, 1997-December 31, 1998
Surface Water
Groundwater
Bottom Elev.
Margin Elev.
SHWL
Ground Elev. At Staff
Feet NGVD
20
19.5
19
18.5
18
17.5
17
16.5
16
15.5
15
14.5
14
13.5
13
12.5
12
11.5
11
10.5
10
Initiation of Data Recording 4/19/97
1/1/97
2/1/97
3/1/97
4/1/97
5/1/97
6/1/97
7/1/97
8/1/97
9/1/97
10/1/97
11/1/97
12/1/97
1/1/98
2/1/98
3/1/98
4/1/98
5/1/98
6/1/98
7/1/98
8/1/98
9/1/98
10/1/98
11/1/98
12/1/98
Calendar Days

DRAFT



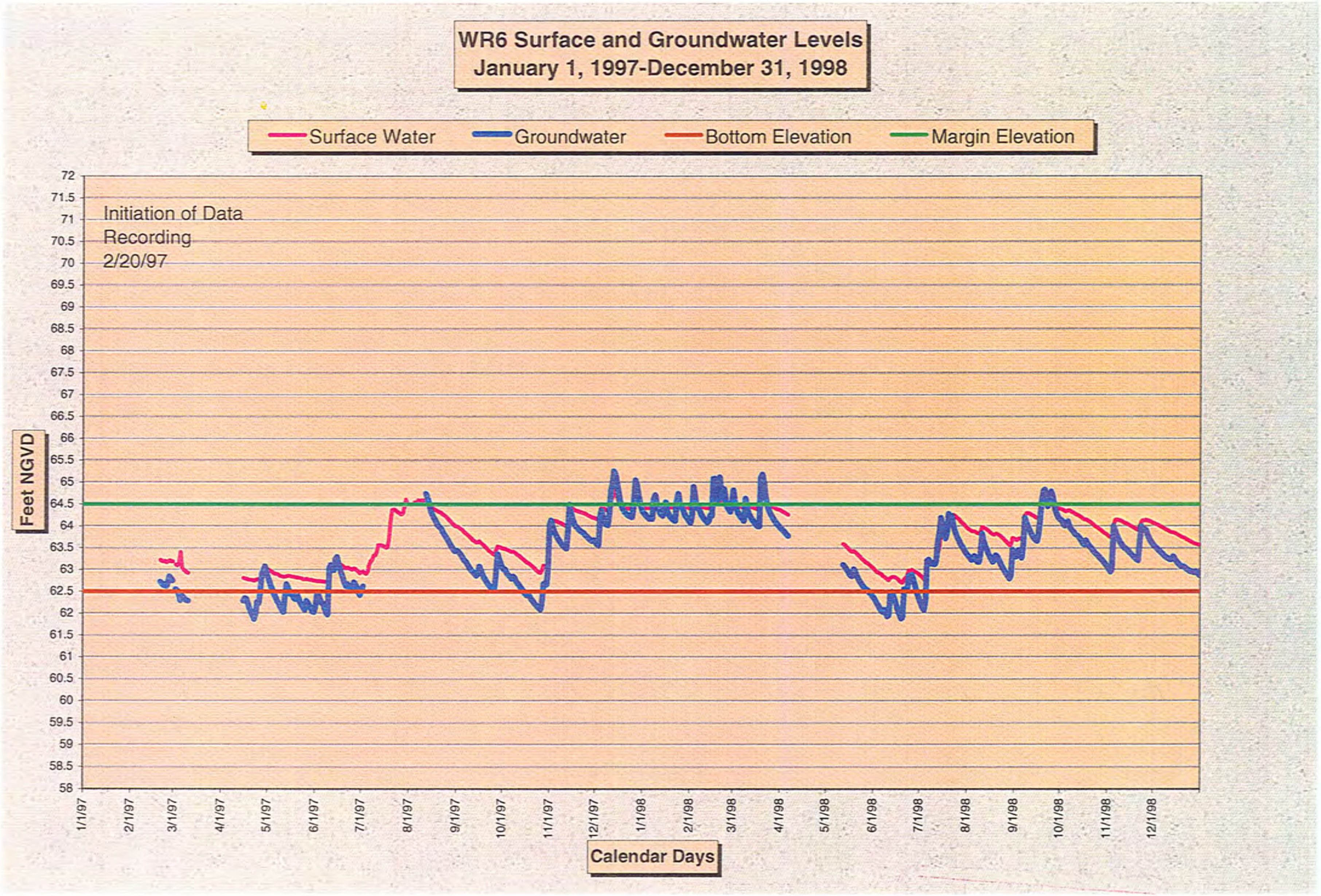
JD6 Surface and Groundwater Levels
January 1, 1997-December 31, 1998

DRAFT



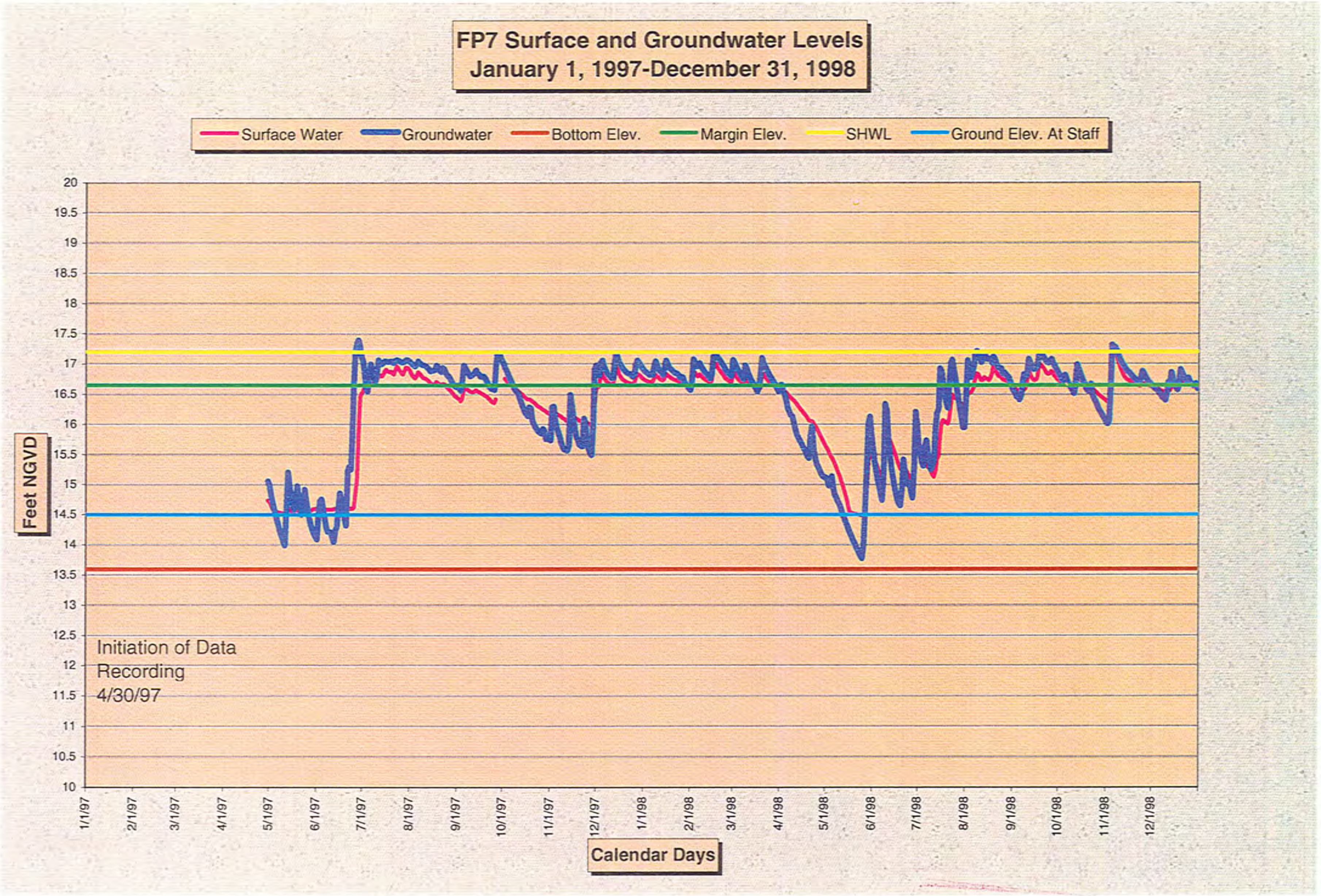
SV6 Surface and Groundwater Levels
January 1, 1997-December 31, 1998

DRAFT

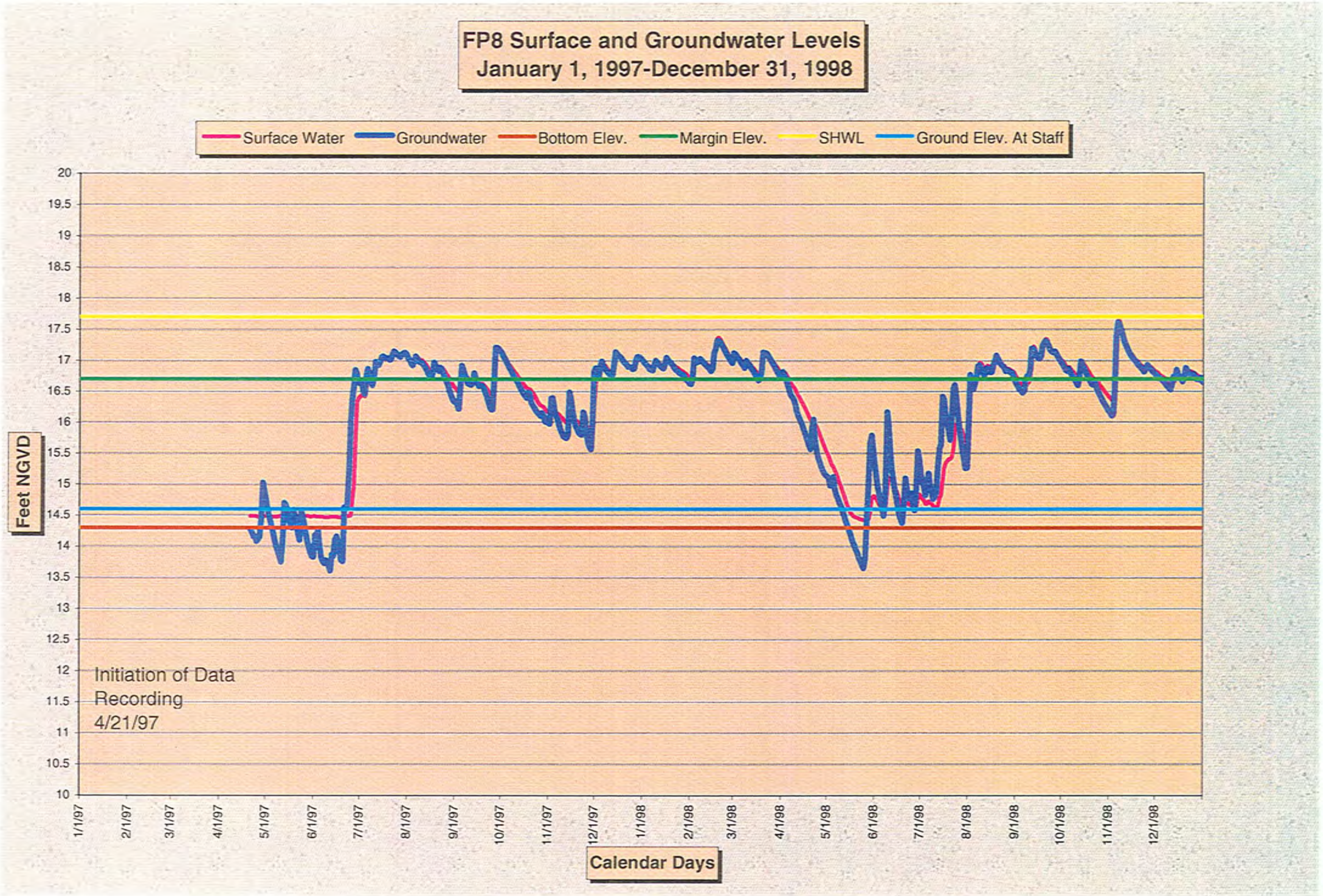


WR6 Surface and Groundwater Levels
January 1, 1997-December 31, 1998

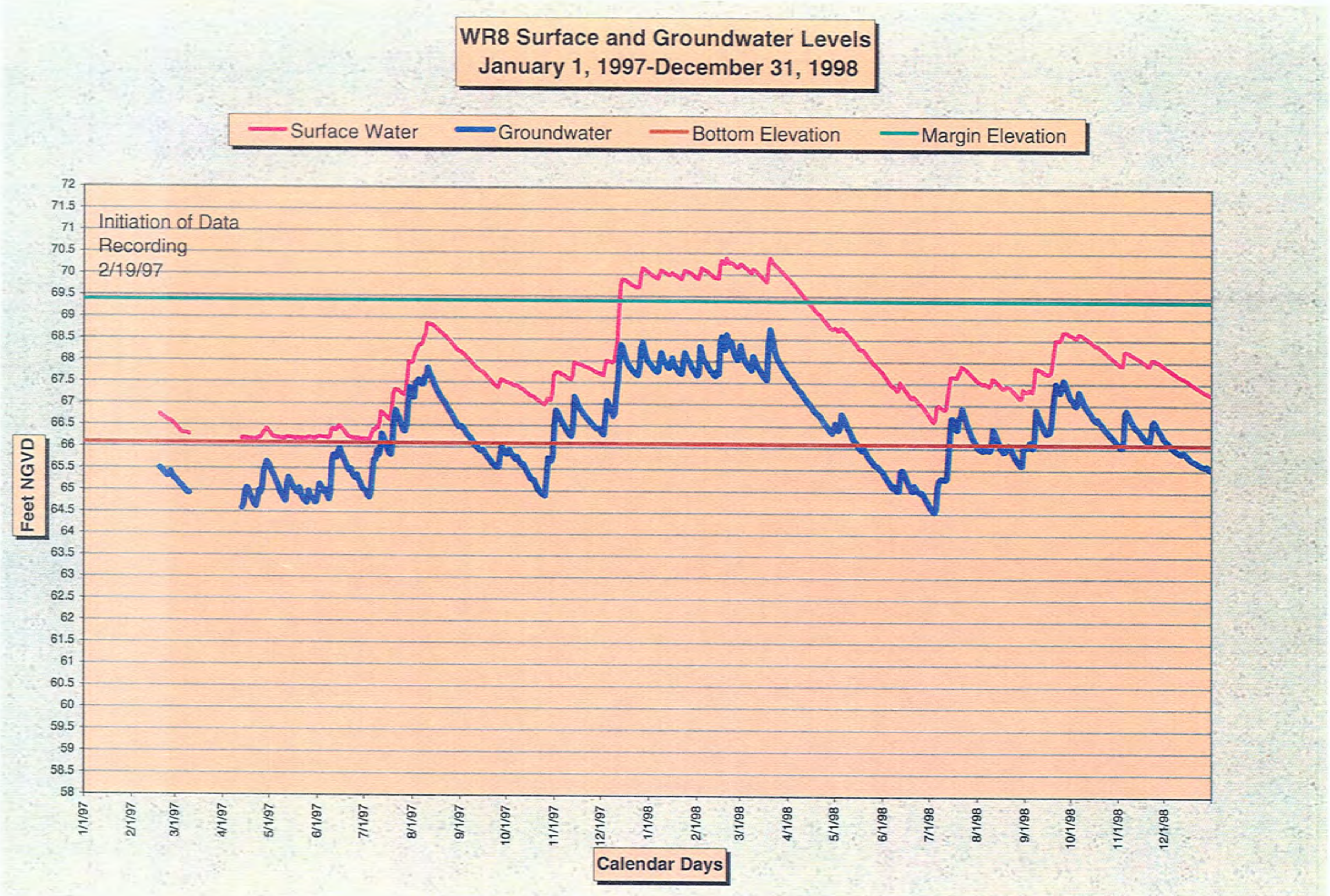
DRAFT



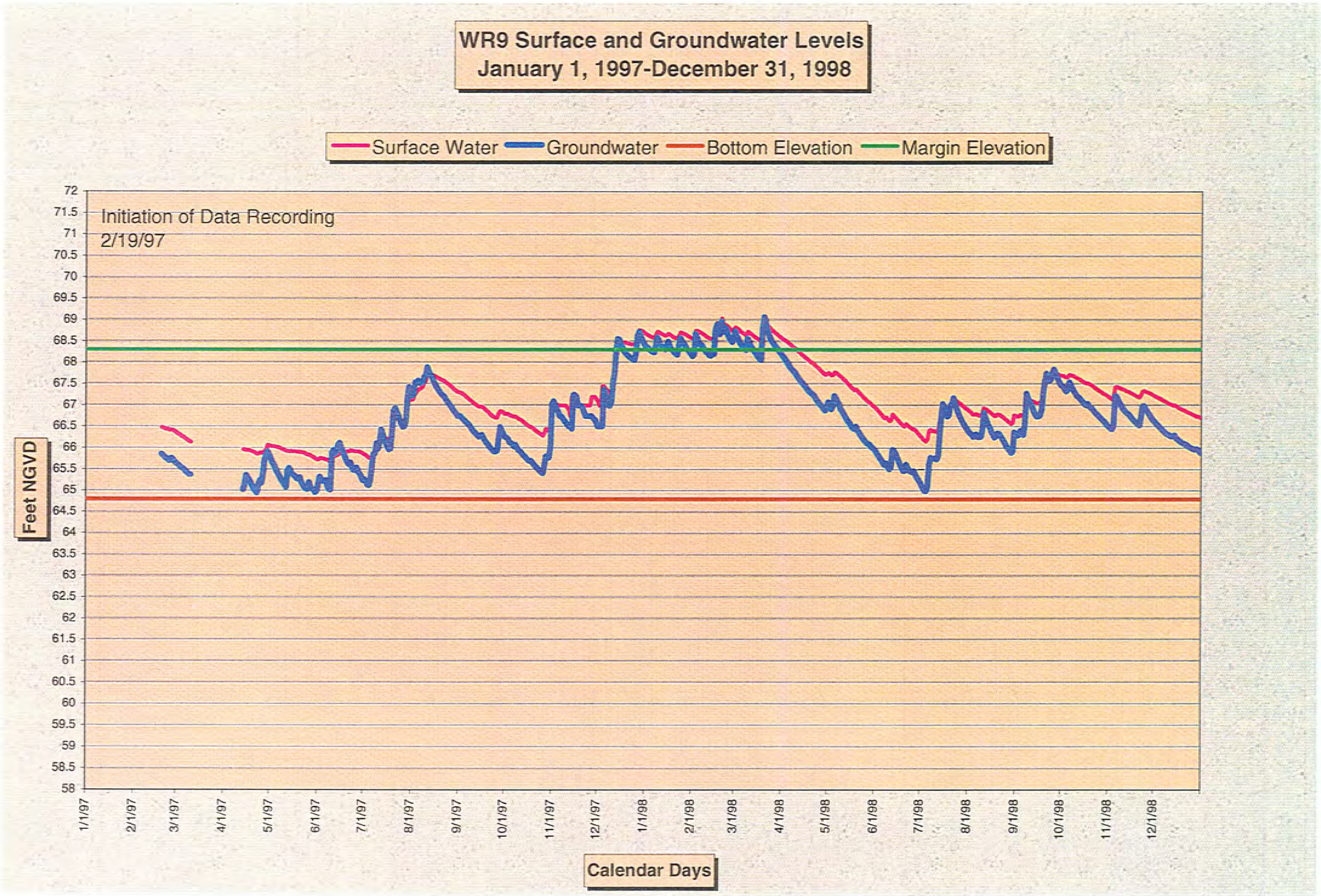
FP7 Surface and Groundwater Levels
January 1, 1997-December 31, 1998


FP8 Surface and Groundwater Levels
January 1, 1997-December 31, 1998
Surface Water
Groundwater
Bottom Elev.
Margin Elev.
SHWL
Ground Elev. At Staff
Feet NGVD
20
19.5
19
18.5
18
17.5
17
16.5
16
15.5
15
14.5
14
13.5
13
12.5
12
11.5
11
10.5
10
Initiation of Data
Recording
4/21/97
1/1/97
2/1/97
3/1/97
4/1/97
5/1/97
6/1/97
7/1/97
8/1/97
9/1/97
10/1/97
11/1/97
12/1/97
1/1/98
2/1/98
3/1/98
4/1/98
5/1/98
6/1/98
7/1/98
8/1/98
9/1/98
10/1/98
11/1/98
12/1/98
Calendar Days

DRAFT


WR8 Surface and Groundwater Levels
January 1, 1997-December 31, 1998

DRAFT


WR9 Surface and Groundwater Levels
January 1, 1997-December 31, 1998
Surface Water
Groundwater
Bottom Elevation
Margin Elevation
Initiation of Data Recording
2/19/97
Feet NGVD
72
71.5
71
70.5
70
69.5
69
68.5
68
67.5
67
66.5
66
65.5
65
64.5
64
63.5
63
62.5
62
61.5
61
60.5
60
59.5
59
58.5
58
1/1/97
2/1/97
3/1/97
4/1/97
5/1/97
6/1/97
7/1/97
8/1/97
9/1/97
10/1/97
11/1/97
12/1/97
1/1/98
2/1/98
3/1/98
4/1/98
5/1/98
6/1/98
7/1/98
8/1/98
9/1/98
10/1/98
11/1/98
12/1/98
Calendar Days