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# SUMMARY OF RESULTS
# WETLAND AUGMENTATION
# DEMONSTRATION PROGRAM

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CH2MHILL

St. Johns River Water Management District
Palatka, Florida

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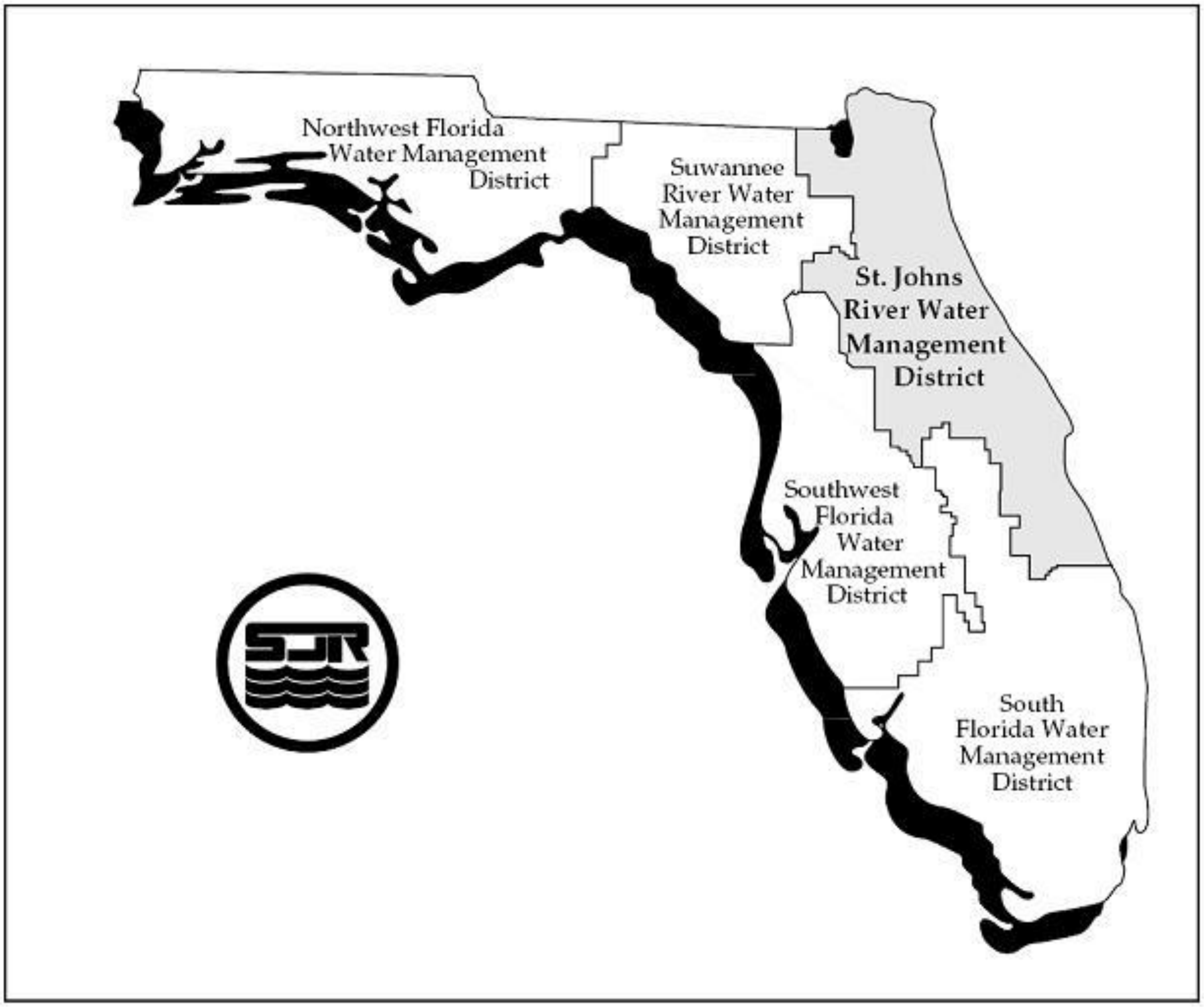
(Originally prepared September 2008)




The St. Johns River Water Management District (SJRWMD) was created by the Florida Legislature in 1972 to be one of five water management districts in Florida. It includes all or part of 18 counties in northeast Florida. The mission of SJRWMD is to ensure the sustainable use and protection of water resources for the benefit of the people of the District and the state of Florida. SJRWMD accomplishes its mission through regulation; applied research; assistance to federal, state, and local governments; operation and maintenance of water control works; and land acquisition and management.

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# EXECUTIVE SUMMARY

The Wetland Augmentation Demonstration Program reported on in this document is one of the St. Johns River Water Management District's (SJRWMD) water resource development projects identified in the 2000 and 2005 District Water Supply Plans. Unacceptable impacts to wetlands and other natural systems may be avoided or mitigated to acceptable levels by applying certain management strategies that have not been previously considered. Two management strategies were evaluated for this study:

- Active hydration of two wetlands by metered application of groundwater directly into the wetland
- Passive hydration of two wetlands by construction of a control weir designed to raise the control elevation in the wetland's outfall ditch and retain water within the wetland

The purpose of this demonstration program was to study the effectiveness of these two strategies at minimizing and avoiding ecological impacts from groundwater drawdown. A tabular summary of the results of implementing these strategies at four sites within the SJRWMD is presented in Table ES1, which is include at the end of the Executive Summary.

Active hydration provided a very flexible and manageable strategy that was less dependent on environmental conditions, such as rainfall and changes in the surrounding watershed, than was passive hydration. For the active hydration projects, the improved hydrologic conditions were evident within the first year of application. The passive hydration approach, while being less expensive to construct and maintain, was dependent on rainfall-driven water inputs and, therefore, was a less reliable impact avoidance strategy over the short term. Although manipulation of the weir elevation could control surface water elevation, the water source and, therefore, the overall success was solely dependent on rainfall. Where possible, implementing control weirs in conjunction with active hydration would provide greater management flexibility and a faster hydrologic response.

Frequent monitoring of plant communities within demonstration sites did not provide a clear indicator of the hydration success during the short baseline and the 5-year operational study periods. Data from plant communities were variable, usually inconclusive, and indicated that plant responses to changes in water levels likely were slower than the frequency at which they were observed except for when the plant communities were inundated by surface

water for extended periods. Less frequent monitoring of plant communities would be recommended to detect slow-to-respond shifts.

Amphibian communities, in contrast to plant communities, responded quickly to increased surface water availability from rainfall, hydration, or both. The use of groundwater at active hydration sites did not adversely affect amphibian communities. Amphibian abundance and diversity at both the active and passive hydration sites showed a positive correlation with changes in seasonal and annual rainfall.

Operation and maintenance of the water delivery system, monitoring equipment, and data reporting would be cost effective and could be implemented by utilities. Comparison of active hydration unit costs to wetland mitigation alternatives indicate that impact avoidance, using this strategy, would be more cost effective than purchasing wetland credits to offset impacts from surface water drawdown. Additionally, the augmentation strategies evaluated in this study may also be considered interim solutions to impact avoidance when other solution methodologies are forthcoming, or are being evaluated.

At a present worth cost of $26,556 per acre for active hydration compared to $82 per acre for passive hydration, passive hydration initially provides a more economical means to avoid impacts. However, passive hydration strategies are dependent on external factors for success whereas target water elevations can be achieved faster and more reliably using active hydration, potentially reaching an acceptable measure of success within the first year. Both strategies are more economically advantageous than using mitigation bank credits to offset impacts because mitigation bank credits cost an average of $56,000 per credit, based on current year (2009) rates. Approximately three credits are needed to offset 1 acre of impacted forested wetland, which would total $168,000 for mitigation of a 1-acre wetland.

A decision flowchart (Figure ES1) is provided at the end of the Executive Summary. The chart illustrates the factors that should be considered when selecting impact avoidance strategies. As depicted in the flowchart, a minimal amount of ecological data is needed to develop the target hydrograph for a wetland and the optimal augmentation schedule (quantity and timing). The target hydrograph provides a useful standard for measuring success in maintaining a viable ecological condition in the wetland. Ecological information specific to the site includes:

- Description of the type of wetland and mapping of total wetland area
- Soil condition assessment
- Establishment of historical hydrologic indicators by an environmental scientist
- Surveying of elevations in wetlands, upland edge, and hydrologic indicators
- Development of water budget and determination of groundwater hydration rates if applicable
- A review of historical rainfall data to determine augmentation cycle
- Establishment of success criteria goals (water levels, long-term vegetation metrics, or other applicable measure of success)

These data are used to develop a starting augmentation schedule (quantity and timing), through which the ecological condition of the wetland can be maintained, or improved, such that the augmentation avoids or reduces unacceptable harm to wetlands per SJRWMD permit conditions.

When wet-season water levels are maintained in the wetland within 1 foot of the target hydrograph, impacts can be avoided. Regular monitoring of the water levels will serve as a first indicator of the point at which augmentation amounts should be adjusted, that is, increased or decreased. In the situation of using a control weir to increase the wetland's hydroperiod, the water levels should be compared to the target hydrograph during normal, or above average rainfall years. A longer evaluation period (several years) may be necessary to measure the success of this passive (rainfall-dependent) augmentation strategy.

The hydration strategies provide feasible alternatives for avoiding or reducing impacts from groundwater drawdown effects in wetlands.

Table ES1. Comparison summary of results, St. Johns River Water Management District Wetland Augmentation Demonstration Program

| Augmentation Type | Location | Baseline Assessment | Hydration Options | Hydration Strategy Selection Criteria | Field Implementation | Monitoring Effort/ Effectiveness | Cost Considerations | Outcome and Benefits |
|---|---|---|---|---|---|---|---|---|
| ***Purpose or Goal*** | | ***Document existing pre-hydration conditions for comparison to post-hydration and success criteria*** | ***Is water readily available? Or an existing outfall ditch?*** | ***A method to determine the proper amount of hydration or the weir height*** | ***Level of effort to initiate the hydration strategy*** | ***Which monitoring parameters were the most effective and which were the least effective?*** | ***Compare present worth cost of strategy versus mitigation bank purchase*** | ***Which parameters were most reliable? Were hydrologic targets met? How certain is the success of the impact avoidance strategy?*** |
| Active Hydration | Tillman Ridge Study Site | • 5-acre isolated forested wetland, with deep organic soils, historical wetland surface waters averaged 1-2 feet deep<br>• Impacted from water level drawdown, soil subsidence evident, trees falling over<br>• Nearly absent shrub and herbaceous layers<br>• Few amphibians present | Close proximity to an existing abandoned production well<br><br>No existing outfall ditches or canals | Water applied to mimic the long-term average seasonal rainfall for amount and seasonal pattern: applied more water during wet season and less in dry season to maintain normal wetland hydroperiod. Simple 24-hour on/off schedule for ease of operation, per monthly schedule.<br><br>Observed water level response in first year, adjust hydration schedule, and amount accordingly in subsequent years. | Minimal construction effort to install new pump and distribution pipe from well<br><br>Environmental Resource Permitting avoided by terminating pipe at wetland edge | Water level - recorders easy to install, need to be regularly maintained, and good short- and long-term reliable measurement of hydration success<br><br>Vegetation - labor intensive and a poor short-term indicator of hydration success<br><br>Amphibian - labor intensive but a good short-term indicator of presence of surface water | Present worth cost of approx. $22,912 per acre, compared to wetland mitigation bank cost of $168,000 per forested acre. | Historical hydrology target was met quickly (in first year)<br><br>Amphibian populations responded quickly (in first year) to presence of surface water<br><br>Vegetation did not provide evidence of ecological benefits |
| Active Hydration | Port Orange Study Site | • 6.5-acre forested wetland, sandy soils, shallow surface water depth ~6 inches<br>• No evidence of wetland affected by water level drawdown<br>• Wetland burned by wildfire prior to study<br>• Dense herbaceous layer<br>• Amphibians moderately abundant | Close proximity to existing production well<br><br>No significant existing outfall ditches or canals.<br><br>Minor connection to roadway ditch at higher surface water elevations which reduced hydration effectiveness | Water applied to mimic the long-term average seasonal rainfall, but at Port Orange only applied half the annual rainfall amount because the wetland is shallow and water level reached the surface quickly: applied water during wet season and none in dry season to maintain normal wetland hydroperiod.<br><br>Observe water level response in first year, adjust hydration schedule, and amount accordingly in subsequent years. | Minimal construction effort to install diverter valve on existing pump and distribution pipe from well<br><br>Environmental Resource Permitting avoided by terminating pipe and diffuser at wetland edge. Diffuser used to promote sheet flow across the wetland. | Water level - recorders easy to install, need to be regularly maintained, and good short- and long-term reliable measurement of hydration success<br><br>Vegetation - labor intensive and a poor short-term indicator of hydration success<br><br>Amphibian - labor intensive but a good short-term indicator of presence of surface water | Present worth cost of approx. $26,556 per acre, compared to wetland mitigation bank cost of $168,000 per forested acre. | The median stage of the water level exceedence curve was within1-foot of the estimated historical average water depth after 5 years of hydration<br><br>Hydration most effective when coupled with rainfall<br><br>Amphibians populations increased in both the test and control wetlands when surface water was present<br><br>Herbaceous vegetation exhibited rapid seasonal and inter-annual changes in relation to the presence or absence of surface water. Target indicator species also followed the same general trend. |
| Passive Hydration | Bennett Swamp Study Site | • 1,490-acre forested wetland, connected to Tiger Bay Swamp and Tomoka River, historical normal pool averaged 1 to 2 feet deep<br>• Impacted from water level drawdown, soil subsidence evident, estimated 1 foot of water level drawdown below historical conditions<br>• Moderately diverse vegetation layers<br>• Amphibians moderately abundant | Significant outflows through Thayer Canal and through a box culvert under US Highway 92 | Weir installed within Thayer Canal set at height to approximate historical hydrologic conditions. Historical water elevations estimated by evaluating vegetative and soil indicators and comparing those to SJRWMD historical hydraulic modeling.<br><br>Weir elevation also set to avoid flooding of surrounding pine plantations. | Moderate construction effort to install weir within Thayer Canal<br><br>Environmental Resource Permitting necessary due to alterations of surface water. No wetland impact mitigation required. | Water level - recorders easy to install, need to be regularly maintained, and good short- and long-term somewhat reliable measurement of hydration success. Vandalism an issue. More recorders installed due to size of Bennett Swamp<br><br>Vegetation - labor intensive and a poor short-term indicator of hydration success. Multiple monitoring transects necessary due to size of Bennett Swamp<br><br>Amphibian - labor intensive but a good short-term indicator of presence of surface water | Present worth cost of approx. $82 per acre, compared to wetland mitigation bank cost of $168,000 per forested acre. | Decreased rainfall inputs, which began during operational year 3, led to droughty conditions by the end of the study period<br><br>Water levels were below the historical target hydrograph during both the baseline and hydration periods<br><br>Amphibians populations increased in wet years and decreased in drought years<br><br>Vegetation did not indicate positive or negative benefits to the ecology of the swamp |
| Passive Hydration | Titusville Study Site | • 100-acre scrub-shrub wetland, within an urban upland landscape, historical normal pool averaged 1 to 2 feet deep<br>• Modeling predicted potential impact from wellfield drawdown, no signs of impact during baseline period<br>• Low vegetation diversity<br>• Few amphibians species present | Close proximity to newly installed production wells<br><br>Outflow from existing drainage ditch | Weir installed within outflow ditch to retain significant quantities of surface water from rainfall.<br><br>Height of weir set at 2-feet above ditch invert elevation to prolong wetland hydroperiod and avoid potential wellfield drawdown.<br><br>Weir elevation also set to avoid flooding of surrounding residential neighborhood. | Minimal construction effort to install weir within outflow ditch<br><br>Environmental Resource Permitting necessary due to alterations of surface water. No wetland impact mitigation required. | Water level - recorders easy to install, need to be regularly maintained, and good short- and long-term reliable measurement of hydration success. City of Titusville's CUP requirements for wetland water levels directly measurable using recorders<br><br>Vegetation - labor intensive and a poor short-term indicator of hydration success<br><br>Amphibian - labor intensive but a moderate short-term indicator of presence of surface water | Present worth cost of approx. $766 per acre, compared to wetland mitigation bank cost of $80,000 per herbaceous acre. | Rainfall and water levels greater during operational period compared to baseline<br><br>Water levels approximated the historical hydrograph during baseline and exceeded targets during operational period<br><br>Water levels remained above the City of Titusville's CUP special condition seasonal elevations during the operational period<br><br>Amphibian population changes tracked rainfall inputs<br><br>Vegetation data did not indicate an improved ecological response from increased water levels |

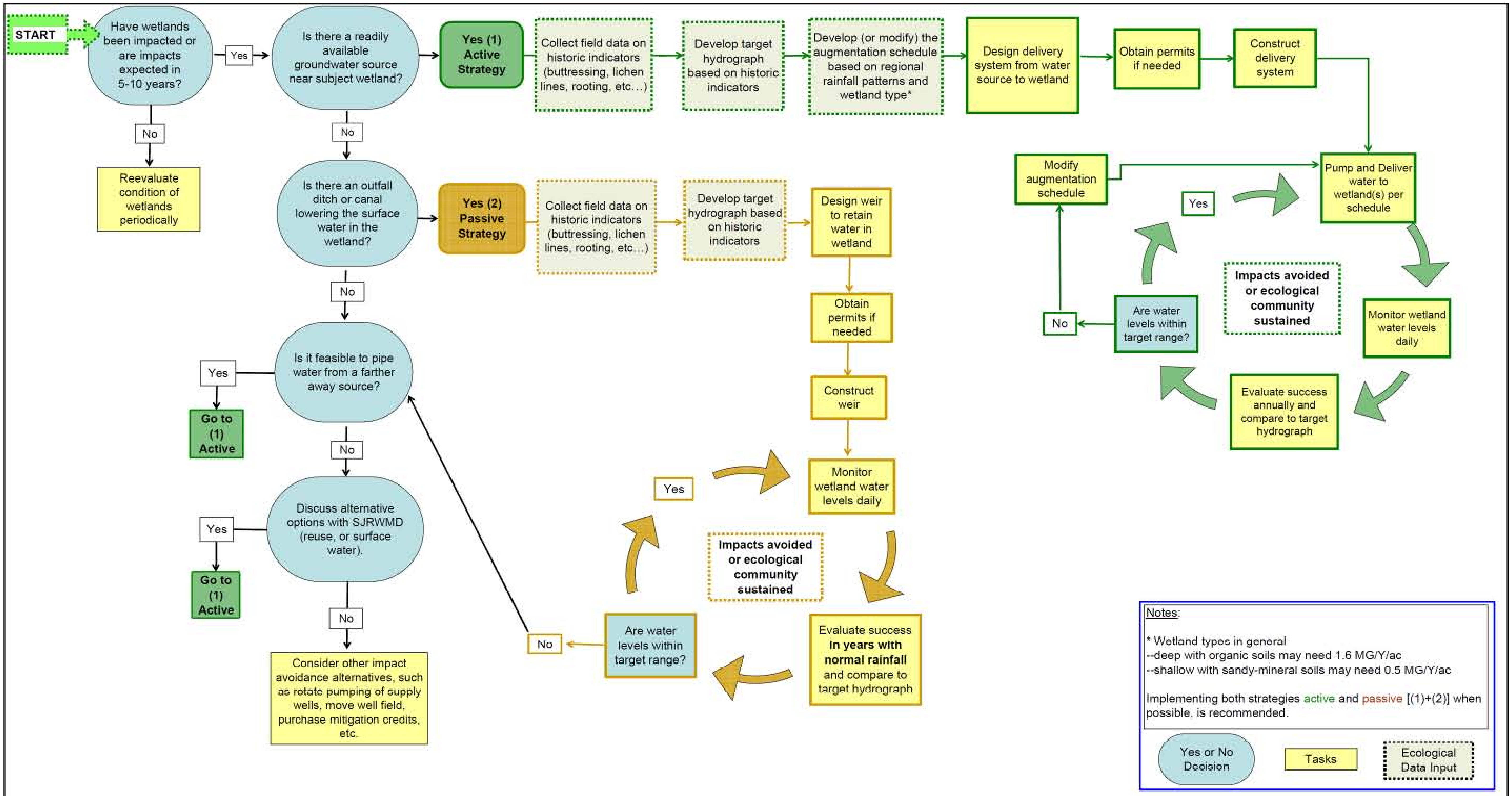


Figure ES1. Wetland augmentation strategy decision flowchart, St. Johns River Water Management District Wetland Augmentation Demonstration Program

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# ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| CPI | Coastal Plains Institute, Inc. |
| CUP | consumptive use permit |
| d/qtr/yr | days/quarter/year |
| ERP | environmental resource permit |
| gpd | gallons per day |
| Hp | horsepower |
| in. | inch(es) |
| MG | million gallons |
| mg/L | milligrams per liter |
| MOU | Memorandum of Understanding |
| N/A | not applicable |
| $NH_3$ | ammonia |
| NAVD88 | North American Vertical Datum of 1988 |
| NDMC | National Drought Mitigation Center |
| NGVD29 | National Geodetic Vertical Datum of 1929 |
| O&M | operations and maintenance |
| pH | potential of hydrogen (a measurement of acidity) |
| PVC | polyvinyl chloride |
| SAS | surficial aquifer system |
| SJRWMD | St. Johns River Water Management District |
| SWFWMD | Southwest Florida Water Management District |
| TDS | total dissolved solids |
| TSS | total suspended solids |
| USDA | U.S. Department of Agriculture |
| WTP | water treatment plant |

# INTRODUCTION

The St. Johns River Water Management District (SJRWMD) retained CH2M HILL to perform the Wetland Augmentation Demonstration Program to consider alternative strategies to reduce potential impacts to wetlands from water supply projects. This program is a water resource development project identified in SJRWMD's 2000 and 2005 District Water Supply Plans. Hydrologic impacts from groundwater drawdowns may cause unacceptable impacts to wetlands and other surface water systems. Mitigation requirements to offset these impacts can be very costly. Alternative approaches to avoid or mitigate these hydrologic impacts to acceptable levels can be implemented by applying certain management strategies, previously not considered. Two management strategies were evaluated for this study:

- Active hydration of two wetlands by metered application of groundwater directly into the wetland

- Passive hydration of two wetlands by construction of a control weir to raise the control elevation in the wetland's outfall ditch and retain water within the wetland

The following provides a summary of this demonstration program to determine the effectiveness of these two strategies in minimizing and avoiding ecological impacts from groundwater drawdown.

## BACKGROUND

Municipal water supply within the majority of the SJRWMD is provided by high-quality, reliable, and inexpensive groundwater. However, increasing demands on groundwater resources affect the hydrology of existing wetland and aquatic ecosystems in some locations, resulting in environmental changes considered as "unacceptable impacts" under current regulatory policy.

Changes in local hydrology were implemented under this study by effectively increasing one or more components of the wetland's hydrologic regime (frequency, duration, and depth of water storage) through hydration of the surficial aquifer system (SAS). This was attempted at four sites using one of two methodologies: direct application of pumped groundwater to the wetland, or by controlling the surface water. Each study consisted of collecting at least 1 year or more of existing conditions data, called the baseline period, followed by 5 years of additional data collection defining the operation period, once the hydration strategy was implemented.

For detailed descriptions of the sites, including project background, data collection methods, and study results, the reader is referred to the fifth annual hydration/ operational reports for Demonstration Project:

- No. 1 Tillman Ridge Wellfield, St. Johns County, Florida (CH2M HILL 2006)
- No. 2 Bennett Swamp Control Weir, Volusia County, Florida (CH2M HILL 2008)
- No. 3 City of Port Orange Wellfield, Volusia County (CH2M HILL 2007a)
- No. 4 City of Titusville Wellfield at Parkland Wetland (CH2M HILL 2007b)

## REPORT ORGANIZATION

This report discusses the results of these investigations, first at the two sites employing active hydration (Tillman Ridge and Port Orange), then at the two sites employing passive hydration (Bennett Swamp and Parkland Wetland). See Figure 1 for the four study locations. A summary of the expected costs of these projects is included to provide insight into the cost effectiveness of these approaches. Observations about these demonstration projects are in the Summary of Findings section of the report. Appendixes A and B are discussed throughout this summary report and, thus, are published as part of this report. Appendixes C through F provide the detailed site-specific information used to develop this summary report and are published under separate cover.

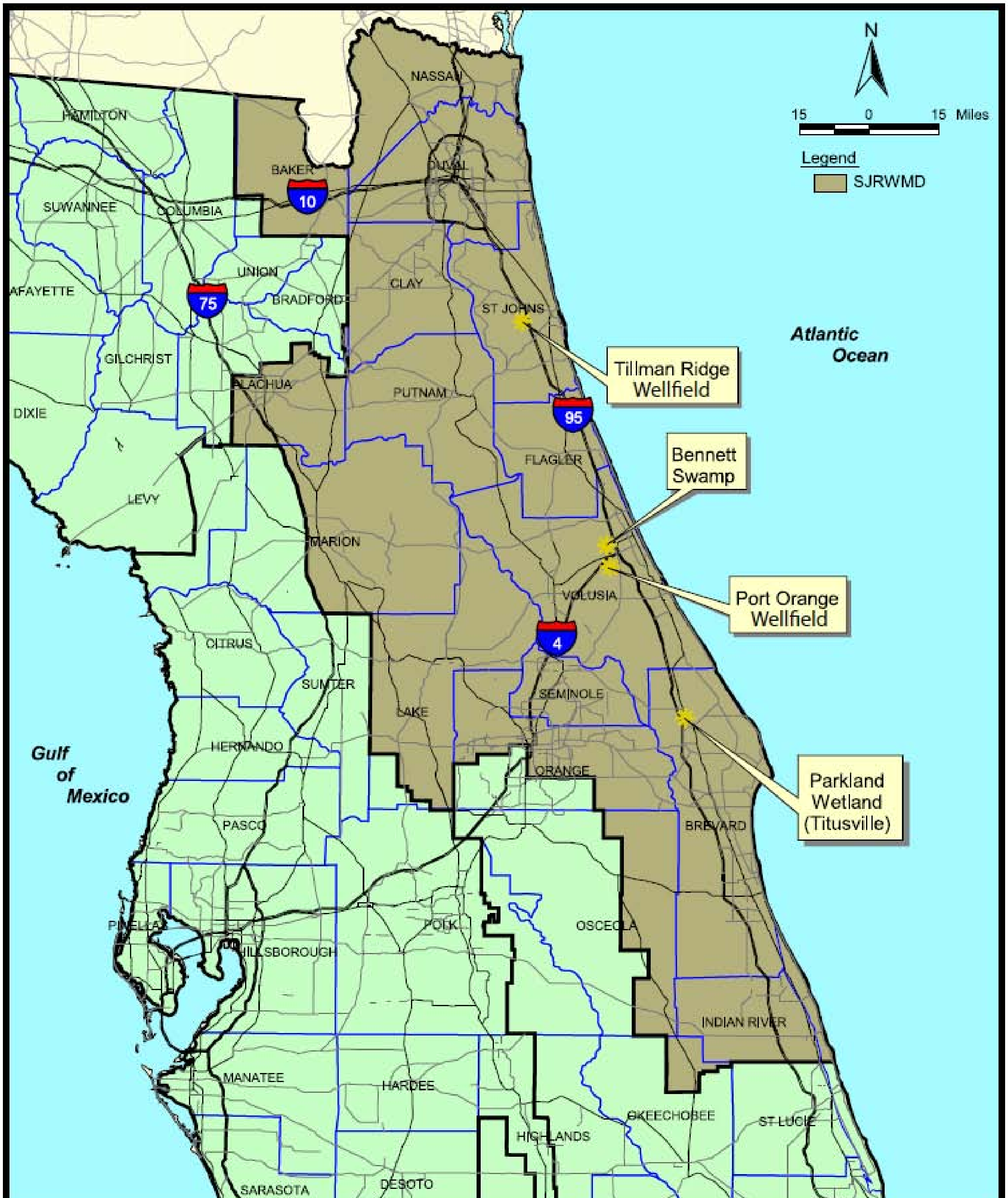


Figure 1. Study sites location map

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# ACTIVE HYDRATION AT TWO DEMONSTRATION SITES

Groundwater withdrawals have the potential for affecting the SAS by inducing greater recharge to the underlying aquifer zones, which in turn can reduce the depth, duration, and frequency of inundation in wetlands, resulting in wetland impacts over time. Two demonstration sites were selected to evaluate the effects, costs, and benefits of applying groundwater to wetlands that have been, or have the potential to be, ecologically impacted by local or regional groundwater drawdown:

- Tillman Ridge Wellfield (Demonstration Project No. 1) in St. Johns County, Florida

- City of Port Orange Wellfield (Demonstration Project No. 3) in Volusia County, Florida

## TILLMAN RIDGE WELLFIELD SITE

### Site Description

The wetland used for Demonstration Project No. 1 is an isolated 5-acre forested wetland in a north Florida flatwoods landscape (Figure 2) with little topographic relief from neighboring uplands (Figure 3). The wetland is located in the Tillman Ridge Wellfield, which supplies potable water to the St. Augustine area. The SJRWMD had previously analyzed the groundwater conditions in the wellfield, and the potential excessive drawdown of the SAS at the site had been recognized for some years. The wetland, and others nearby, showed evidence of surficial aquifer reduction including fallen trees, exposed roots, oxidized soils, and invasion by upland plants.

The site was selected because of the willing participation of the St. Johns County Utility Department, evidence of altered hydrologic conditions, proximity of the wetland to an existing well no longer used by the utility, the isolated and small size of the wetland, and the representative nature of the plant community when compared to other wetlands in the wellfield.

### Hydration Method

Groundwater from a semi-confined surficial aquifer (Toth 1994) was pumped from an existing offline well at an average rate of approximately 109,000 gallons per day (gpd). Approximately ¾ inch of water across the 5-acre wetland was delivered in a 24-hour period. Approximately 8 million gallons (MG) per year were delivered to the wetland.

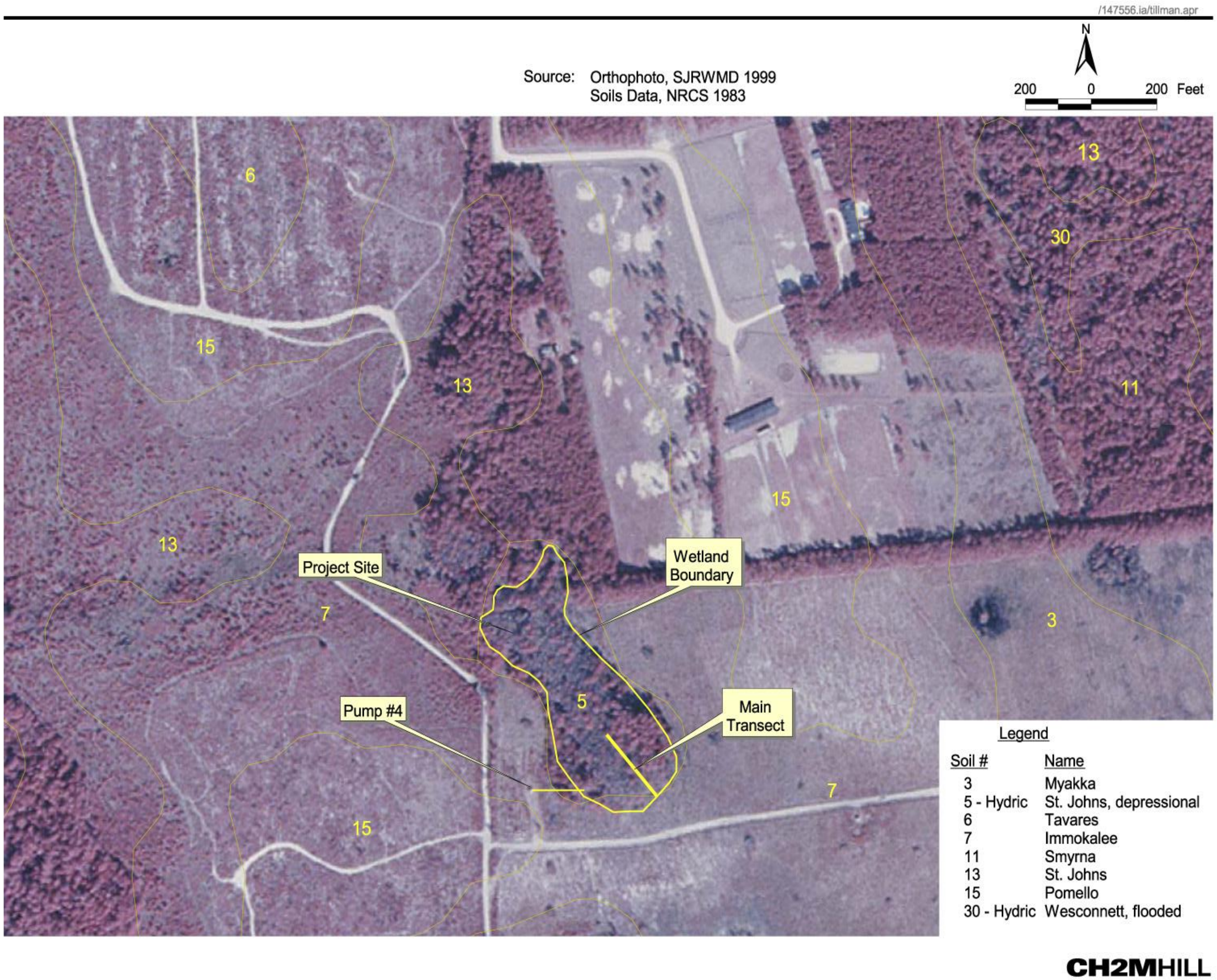


Figure 2. Tillman Ridge project location map, St. Johns County

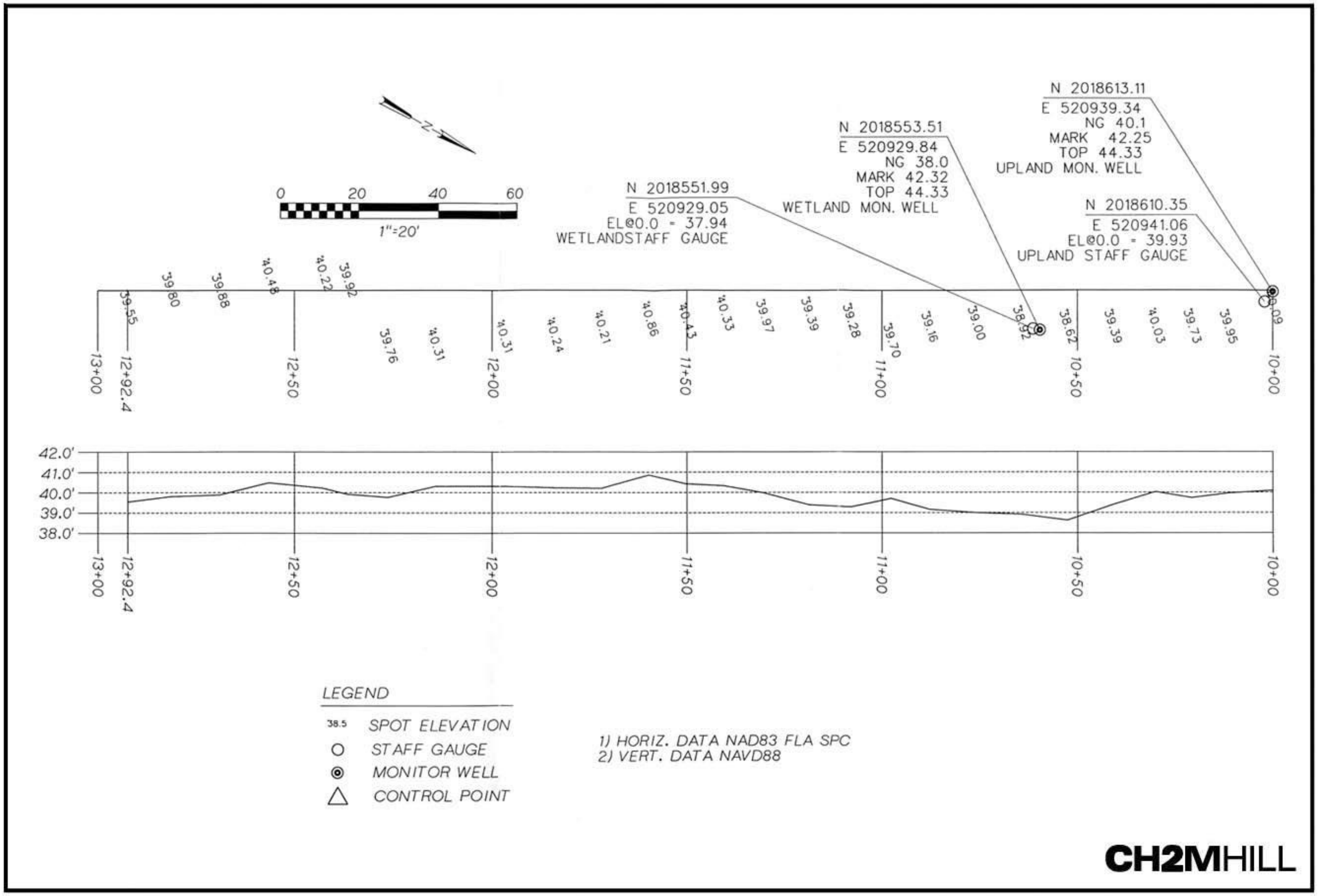


Figure 3. Tillman Ridge transect topographic survey

According to the hydration schedule provided by CH2M HILL, wellfield operators turned on the pump at 10:00 A.M. and 1 to 4 days later turned off the pump at 10:00 A.M. The intent of the pumping schedule was to deliver irrigation water volumes equal to the long-term average annual rainfall for the region and at rates that approximated the natural wet and dry seasons. Because of the significantly low water levels in the wetland during the baseline period, an initial hydration amount equal to average annual rainfall was scheduled.

### Study Period

Hydrologic conditions and ecological communities were monitored at the Tillman Ridge wetland from April 2000 through June 2006. The baseline period of the study began in April 2000, and concluded with the installation of the water delivery pipe from the adjacent groundwater well to the wetland edge on July 8, 2001. From that date, groundwater was delivered to the wetland on a seasonal schedule for 5 years until June 30, 2006, when the study was concluded.

The water level data set collected from the Tillman Ridge Demonstration Project was relatively complete throughout the study period. Unlike two of the other study sites, water level recorders functioned consistently and were not vandalized or destroyed because the site was located on private land with no public access.

## RESULTS

### Effect of Rainfall on Water Levels

Rainfall data was obtained from the Tillman Ridge Water Treatment Plant. Annual baseline period rainfall was 38.4 inches (July 2000 to June 2001), which was well below the long-term average for this area (48 to 50 inches) (see Table 1). Annual rainfall during each of the 5 years of hydration exceeded annual rainfall during the baseline period. Rainfall during the entire hydration period (5 years) averaged 48.7 inches annually, which is more typical of the region.

During rainfall periods when no active hydration occurred, water levels in the wetland piezometer decreased an average of 0.01 foot per day. This seems counter-intuitive until the probable influence of the wellfield drawdown of groundwater is considered. Annual input amounts (rainfall and hydration) and the average change in water level over the 5-acre wetland are presented in Table 1. The greatest monthly rainfall total (14.34 inches), mainly attributed to four storms that produced significant rainfall amounts, was reported for September 2004. Significant rainfall occurred each wet season (June through October) during each year of the study period. Monthly rainfall totals for the entire study are provided in Appendix A, Figure A1.

Table 1. Summary of hydrologic parameters at the Tillman Ridge wetland, April 2000 – June 2006

| Period (365 days) | Inputs | | | Water Level | | |
|---|---|---|---|---|---|---|
| | Rainfall (inches) | Hydration | | Mean (feet)* | Difference (feet) Between Baseline and Hydration Mean | Exceedence Above Wetland Surface* |
| | | Depth (inches) | Volume (MG) | | | |
| Baseline | 38.4 | 0 | 0 | 33.10 | N/A | 0% |
| Hydration Year 1 | 45.3 | 64.8 | 8.77 | 38.03 | 4.93 | 59% |
| Hydration Year 2 | 52.5 | 52.7 | 7.12 | 39.90 | 6.80 | 87% |
| Hydration Year 3 | 47.9 | 64.1 | 8.68 | 37.49 | 4.39 | 45% |
| Hydration Year 4 | 52.6 | 60.6 | 7.88 | 38.42 | 5.32 | 68% |
| Hydration Year 5 | 45.3 | 56.5 | 7.14 | 39.66 | 6.56 | 71% |
| **Average** (Hydration all years) | **48.7** | **59.7** | **7.92** | **38.8** | **5.7** | **71%** |

Note:

*Mean and Exceedence calculations are cumulative and include data from each previous hydration year
Ground surface elevation at the wetland piezometer is 38.0 feet
Elevations are in NAVD88, North American Vertical Datum of 1988
MG = million gallons
N/A = not applicable

### Effect of Hydration on Water Levels

During the 5-year study, active hydration provided an amount of water that was slightly more than and additional to the long-term average rainfall (Table 1). Therefore, the total water received by the wetland was more than double the natural amount it would have received from rainfall alone. For example, during hydration Year 1, the wetland received the equivalent of approximately 110 inches of rainfall (45.3 inches of rainfall and 64.8 inches of supplemental hydration).

The direct effect of water added to the wetland was detectable at the wetland piezometer. Daily wetland and upland water level elevations for the entire study are provided in Appendix A, Figure A2. During active hydration periods when no rainfall occurred, water levels in the wetland piezometer increased an average of 0.03 foot per day. When no active hydration and no rainfall occurred, daily water levels fell during both the baseline period

(-0.09 foot) and during all five hydration years (-0.13, -0.18, -0.06, -0.06, and -0.11 foot, respectively).

Fifty percent of the annual hydration amount of groundwater was supplied to the wetland during 4 months of the wet season (June through September) to mimic historical average monthly rainfall amounts for the region. During these months, on the days when only hydration occurred (no rainfall), the average increase in daily water levels was 0.07 foot.

**Effect of Rainfall plus Hydration on Water Levels**

Cumulative inputs from rainfall and active hydration had a greater effect on water levels during the hydration period than did rainfall alone during the baseline period (Appendix A, Figure A3). The double mass plot for cumulative rainfall and hydration inputs versus cumulative water levels during the hydration period was steeper and had a slope of 18.64 (r-squared 0.99), while the double mass line for the baseline period had a slope of 5.78 (r-squared 0.84). Compared to the baseline period, the increase in slope indicates that a greater increase in water levels was achieved per unit of increase of water inputs during the hydration period. The difference between levels of increase is attributed to the addition of hydration water from the nearby well.

Approximately the same hydration amounts and schedule were followed each year of the 60-month hydration period, thus the cumulative stage exceedence curve reflects the combination of the continuous hydration with a return to normal rainfall over the longer period. The full hydrologic recovery benefit occurred during the first hydration year and was then maintained over the following 4 years. Variables that likely influenced the water level exceedence above wetland ground surface, but investigation of which were outside of scope of this study, include improved conditioning of the soil and wellfield drawdown of ground water levels. Regardless, the effects of active hydration were very quickly realized at the Tillman Ridge site.

**Target Hydrograph and Stage Exceedence Curve**

Daily water levels were 5 feet below the soil surface at the wetland piezometer (38.0 feet National Geodetic Vertical Datum of 1929 [NGVD29]) during the entire baseline period (15 months) and averaged 33.1 feet (Table 1). As stated previously, the rainfall during the baseline period was well below the long-term average annual rainfall.

The effects of active hydration are shown in the stage exceedence curve (Appendix A, Figure A4). Throughout the hydration period, water levels fluctuated above and below the ground surface as anticipated and were almost 1 foot above the surface at the wetland piezometer, an average of 71% of the time. The stage exceedence curve for the hydration period was greater than the baseline-period stage- exceedence curve at all elevations. The stage- exceedence curve for the hydration period nearly approximated the target hydrograph (Appendix A, Figure A4), which was developed by analyzing biological indicators of long-term water level conditions (soils and vegetation) on site. Data from the organic soil profile and biological indicators of water elevation were used to estimate the target hydrograph. Pine (*Pinus* sp.), saw palmetto (*Serenoa repens*), fetterbush (*Lyonia lucida),* and lichen indicators were used to develop the lower percent exceedence end of the target hydrograph. Measurement of the indicators provided estimates of long-term or previous hydrologic regimes and provided hydration targets.

Water levels were above the wetland surface frequently throughout each season during the hydration period. Minimum levels criterion for maintaining organic wetland soils equate to water levels being within 0.25 foot of the muck surface on average and within 1.67 feet of the muck surface during the dry season (SWFWMD 1999). At the Tillman Ridge wetland, these elevations corresponded to 39.33 feet (minimum average water elevation) and 37.91 feet (minimum frequent low water elevation) and exceedence values of 50.0% and 71.9%, respectively; thus, this criterion was met and exceeded during the hydration years. Water levels fell beneath the wetland surface briefly during the dry season. The hydration regime returned conditions for the deposition of new organic material, which will maintain an organic soil horizon and will directly benefit the wetland by stopping the oxidative loss of the soil.

**Effect of Hydration on Water Quality**

Water quality parameters were within expected values for a north Florida cypress (*Taxodium* sp.) dome system in a flatwoods landscape (CH2M HILL 2006). Values for pH (a measurement of acidity, conductivity, total suspended solids (TSS), and nutrients were low. Ammonia ($NH_3$) was the only elevated water quality parameter measured at the Tillman Ridge wetland during March 2006 (Year 5). That these parameter values were a result of active hydration with groundwater is unlikely, as no active hydration occurred for 11 days prior to the collection of the water quality sample. Pumped groundwater is delivered to the wetland edge and allowed to trickle through the leaf litter and soils before reaching the deeper parts of the wetland where the samples were collected. Measured water quality parameters showed no evidence of being influenced by groundwater additions to the wetland during the study.

**Effect of Hydration on Vegetative Communities**

Vegetative strata (herbaceous, shrub, and trees) at the Tillman Ridge site were sparse with some strata showing impacts from soil subsidence at the time of the baseline study period. The herbaceous (non-woody) vegetation layer within the sampling plots had low coverage (14.0% cover), and plants able to tolerate a wide range of wetland and upland conditions were well established. Charts showing the trends in vegetative community composition for all sites are presented in Appendix B. The shrub stratum was also sparse and contained few plant species. Trees were dominated by pond cypress (*Taxodium ascendens*) and swamp tupelo (*Nyssa sylvatica var. biflora*), which are species found almost exclusively in wetlands. The broader ranging slash pine (*Pinus elliottii*) was also a dominant species of the canopy. The roots of many mature trees were exposed as a result of soil subsidence, a result of wetland soils drying out from groundwater drawdown. Numerous trees within the wetland had fallen over from the loss of support from the soil.

During the hydration study period, percent cover of herbaceous species in the sampling plots declined compared to the baseline period. In general, herbaceous vegetation cover decreased as water levels increased.

Soil subsidence within the study wetland effectively lowered the wetland soil surface. When water was pumped into the wetland to the target historical levels, deeper pools of water were created, averaging 1.85 feet deep in some areas. Many herbaceous plants that germinated during the spring were flooded by these deeper surface waters and did not survive. Herbaceous vegetation was observed germinating on hummocks that were not submerged. Percent cover was greatest near the upland edge of the monitoring transect for all species. The greatest percent plant cover was observed during the spring events prior to the rise of water levels from hydration and rainfall.

The return of water levels to their historical stage would likely continue to submerge large areas of vegetation and therefore limit the establishment of the herbaceous vegetation layer until the wetland soils regain their historical elevations. Re-establishment of wetland soils is slow and is beyond the timeframe of this study. Therefore, in this situation, vegetation is not as good a measure of success due to plant communities' slow response. Target water elevations provided an immediate measure of predicted success.

A subset of plant species was selected for tracking throughout the study. These site-specific “target” species were identified during the initial site visit to the wetland. The use of target indicator herbaceous species did not provide much information about the trends in the ecological status of the wetland plant community because of the sparse herbaceous cover. Percent cover of target species did not track changes in water levels other than an overall decrease with increasing water levels.

Shrub and sapling percent cover was low during the study period. Cover of shrub and sapling species was consistently greatest near the wetland end of the monitoring transect. Percent cover of shrub and sapling species did not track changes in water levels. Recruitment of sapling species was low throughout the study period.

The dominance of tree species was measured using total basal area, the sum of the cross-sectional areas of the tree trunks. Total basal area increased in the tree plot from the baseline through the end of the hydration period. However, tree density, measured as the number of individuals in the same plot, decreased. Although the tree plot lost some individuals during the study period as trees fell over due to soil subsidence, the remaining trees grew larger in diameter and increased the total basal area. Also observed was loss of sapling and subcanopy-sized trees of the species swamp bay (*Persea palustris*) from the suspected Laurel Wilt Disease, an exotic fungus spreading through the southeastern U.S. (Personal Communication 2008a, USDA 2008).The total basal area within the tree plot showed both gains and losses during the monitoring period since the baseline event. The larger trees forming the canopy stratum were denser and had a greater basal area than did the smaller trees forming the subcanopy stratum throughout the study.

**Effect of Hydration on Amphibians**

A total of 21 individual amphibians, grouped into seven species, were captured during a 4-month baseline period from June to September 2000. The seven species of amphibian observed were typical of pine flatwoods in northeast Florida (Franz and Means 2001). Eastern narrowmouth toad (*Gastrophryne carolinensis*) and pine woods treefrog (*Hyla femoralis*) dominated the captures with eight and five specimens, respectively.

Contrasted with 230 captures and eight species per year (averaged over 4 years) during the hydration period, amphibian species diversity (richness and particularly abundance) was significantly higher than during baseline. In addition, Coastal Plains Institute, Inc. (CPI) noted that amphibian species diversity and abundance was higher at the demonstration wetland than it was in their control wetlands (Means 2006). CPI scientists postulated that the increases were possibly a result of active wetland hydration, but that the data were inconclusive for two reasons: (1) a lack of sufficient baseline amphibian data, and (2) the possibility that increased overall rainfall in the hydration period may have caused elevated species diversity at the study and control wetlands. One other conclusion reached by CPI particular to the Tillman Ridge study, was that active hydration appeared to have no detrimental effects to the amphibian fauna of the demonstration wetland.

**Summary of Hydration Effects at the Tillman Ridge Wetland**

- Hydration of the wetland was detectable using shallow piezometers.
- Water levels increased in the wetland 5.7 feet during the hydration period compared to the baseline period. The baseline period had approximately 10 inches less average annual rainfall than the hydration period.
- The stage exceedence of water elevations in the wetland closely approximated the target historical stage exceedence throughout every year of active wetland hydration.
- The timing and quantity of water applied to the wetland was sufficient to raise water levels to target historical levels at this wetland site when coupled with rainfall. The hydrologic recovery benefit of hydration took place during the first hydration year and then was maintained over the duration of the study period.
- The hydration regime returned conditions for the maintenance of an organic soil horizon, which will directly benefit the wetland by stopping the oxidative loss of the soil and will restore conditions for deposition of new organic material.
- The use of shallow piezometers to record daily water levels and comparison of water levels to an established historic target hydrograph provided a rapid measure of hydration success.
- The application of groundwater did not significantly alter wetland water-quality parameters and did not specifically raise the pH of surface waters.
- Vegetative strata showed signs of ecological impact from drawdown, particularly causing soil oxidation prior to the inception of this study.

- Increasing the water levels in areas with oxidative soil loss created deep standing water, which inundated most herbaceous vegetation and prevented the recruitment of shrubs and saplings. Such an occurrence is an expected outcome of the dynamic changes the wetland undergoes in response to hydrologic regime restoration.

- No clear directional trends in the structure or species composition of vegetative strata emerged in response to increased water levels, within the 5-year limit of the study. Therefore, monitoring vegetation changes over time does not provide a rapid indicator of success although it would ultimately be considered an important criterion of restoration success.

- Amphibian abundance, species richness, and diversity were higher during the hydration period when compared to the baseline period. Amphibian reproductive success was greater in the demonstration wetland compared to a control wetland during the hydration period. Amphibian populations benefited from the improved hydrologic regime whether due to hydration or increased rainfall.

- Active hydration with groundwater appeared to have no detrimental effect on amphibian populations.

## PORT ORANGE WELLFIELD SITE

### Site Description

The wetland used for Demonstration Project No. 3, was a 6.5-acre cypress-strand wetland (Figure 4) with little topographic relief from neighboring pine flatwood uplands (Figure 5). The wetland was located in the Port Orange Wellfield, which supplies potable water to the City of Port Orange. The adjacent land uses were primarily managed pinelands, consisting of both natural pine flatwoods and areas of planted pine. The demonstration wetland was connected to a system of other wetlands within the wellfield by a roadside ditch and culvert adjacent to the study wetland.

The site was selected because of the willing participation of the City of Port Orange Utilities Department; the shallow nature of the wetland system, which was expected to reflect changes quickly in the water-table elevation; land ownership was not an issue; and water could be piped to the wetland from a nearby production well.

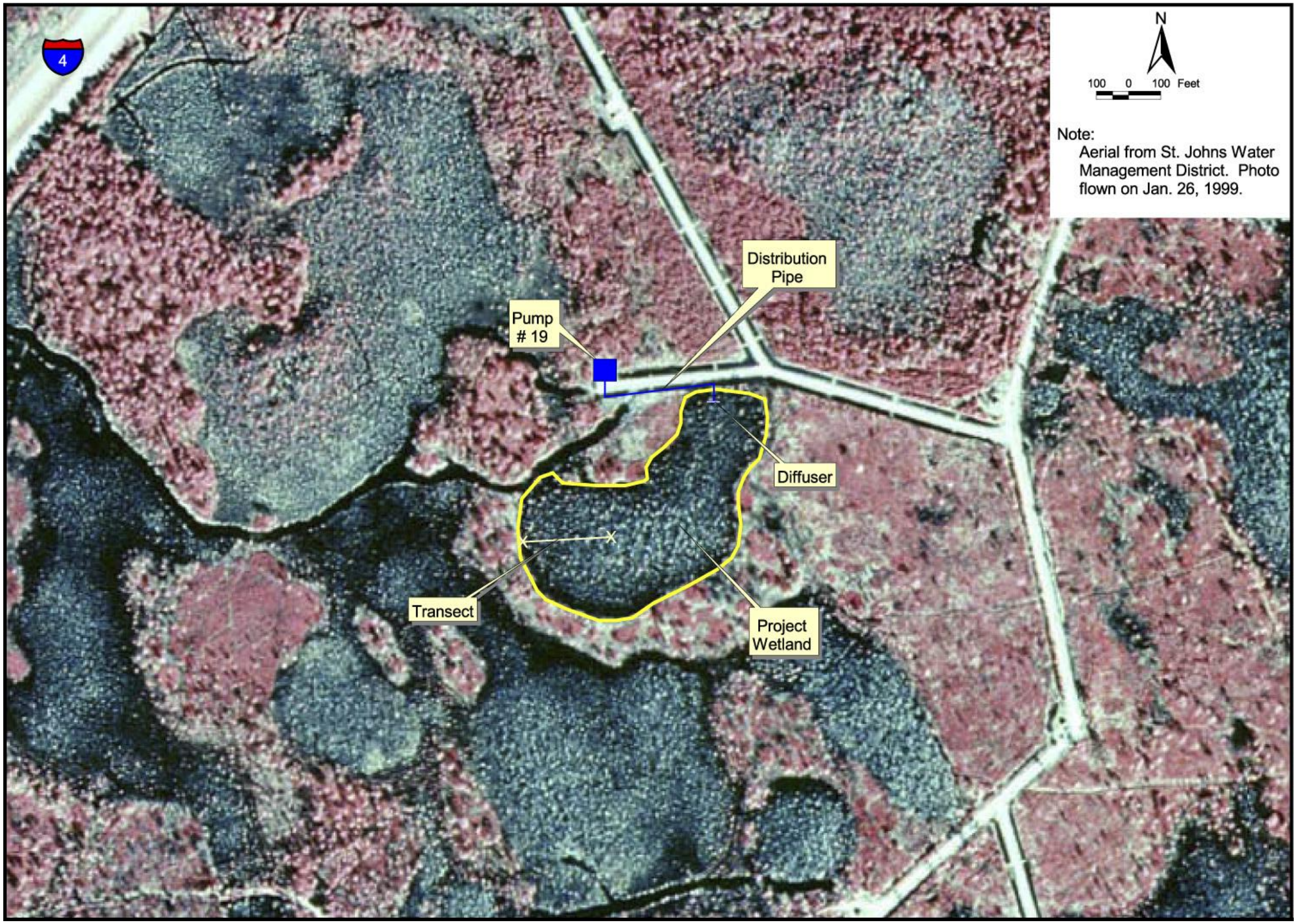


Figure 4. Port Orange project location map, Volusia County

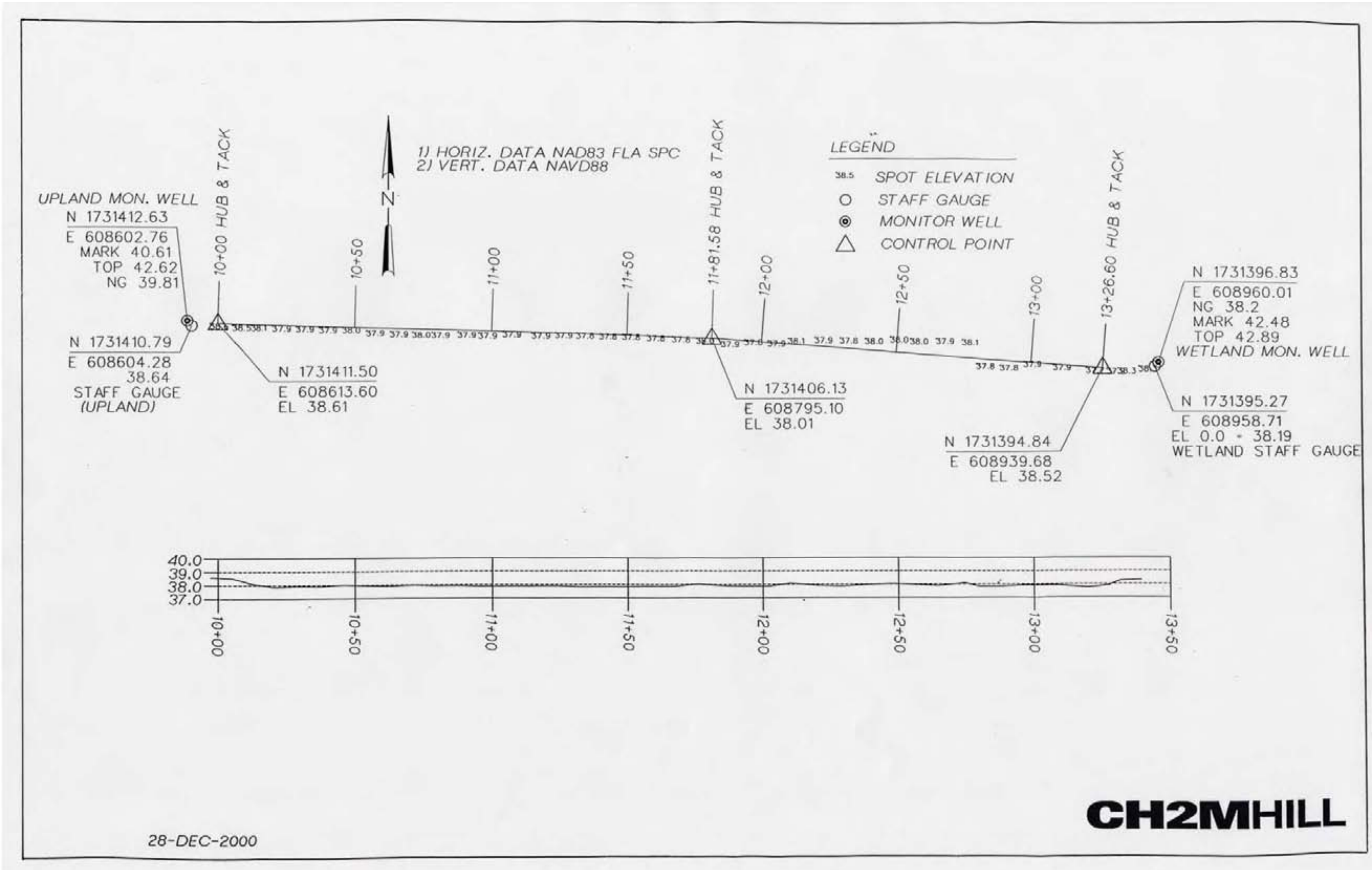


Figure 5. Port Orange transect topographic survey

### Hydration Method

Groundwater, presumably from the Upper Floridan aquifer, was pumped from an existing, online well (well 19) at an average rate of approximately 360,000 gpd. Approximately 2 inches of water across the 6.5-acre wetland was generally delivered in a 24-hour period. Approximately 4 MG per year was delivered to the wetland. According to the hydration schedule, wellfield operators turned on the pump on at 10:00 A.M. and turned off the pump at 10:00 A.M. 1 day later. Depending on the season and the wetland's specific condition, adaptive management was implemented to adjust the number of irrigation periods per month. Hydration water application was based on the monthly average rainfall patterns of seasonal rainfall inputs. Active hydration was conducted in the wet season, with no active hydration during the dry season. Because water levels were near the surface during the baseline period and the wetland pool shallow, the initial hydration amount scheduled was less than half the average annual rainfall.

### Study Period

Hydrologic conditions and ecological communities were monitored at the Port Orange wetland from February 2000 through April 2007. The baseline period of the study began in February 2000 and concluded with the installation of the water delivery pipe from the adjacent groundwater well to the wetland edge at the end of April 2002.

Beginning May 2002, groundwater was delivered to the wetland on a seasonal schedule for 5 years until April 2007 when the study was concluded. The water level data set collected from the Port Orange Demonstration Project was relatively complete throughout the study period. Water level recorders functioned consistently and were not vandalized or destroyed.

## RESULTS

### Effect of Rainfall on Water Levels

The Garnsey Water Treatment Plant (WTP) staff in the City of Port Orange provided local rainfall data. Average annual baseline period rainfall was 48 inches, which was similar to the long-term average for this area (48 to 50 inches). Annual rainfall during the 5-year hydration period exceeded the baseline period annual rainfall except during the fifth year of hydration (Table 2).

Table 2. Summary of hydrologic parameters at the Port Orange wetland, February 2000 – April 2007

| Period (365 days) | Inputs | | | Water Level | | |
|---|---|---|---|---|---|---|
| | Rainfall (inches) | Hydration Depth (inches) | Hydration Volume (MG) | Mean (feet)* | Difference (feet)* Between Baseline and Hydration Mean | Exceedence Above Wetland Surface* |
| Baseline | 48.0 | 0 | 0 | 36.69 | N/A | 42% |
| Hydration Year 1 | 67.7 | 8.5 | 1.5 | 38.51 | 1.82 | 90% |
| Hydration Year 2 | 51.1 | 24..4 | 4.3 | 38.06 | 1.37 | 71% |
| Hydration Year 3 | 69.2 | 14.0 | 2.5 | 38.12 | 1.43 | 71% |
| Hydration Year 4 | 59.6 | 25.0 | 4.4 | 38.55 | 1.86 | 76% |
| Hydration Year 5 | 41.5 | 21.7 | 3.8 | 37.48 | 0.79 | 63% |
| **Average** (Hydration all years) | **58.0** | **18.7** | **3.3** | **37.48** | **0.79** | **63%** |

Note:

*Mean and Exceedence calculations are cumulative and include data from each previous hydration year
Ground surface elevation at the wetland piezometer is 38.2 feet
Elevations are in NAVD88, North American Vertical Datum of 1988
N/A = not applicable

Rainfall during the entire hydration period averaged 58 inches annually, above the long-term average of the region. Year 3 of active hydration reported the greatest annual rainfall (69 inches), mainly from Hurricane Frances, which produced significant rainfall amounts in September 2004. Drought conditions prevailed during Year 5 beginning late March 2006 through the end of the hydration period. Monthly rainfall totals that fell within the Port Orange wetland watershed are presented for the entire study in Appendix A, Figure A5.

The effect of rainfall on water level elevations within the Port Orange wetland was detectable at the wetland piezometer. Daily water level elevations rose an average of 0.03 foot (baseline and hydration periods) during days when only rainfall (no active hydration) inputs to the wetland were recorded.

### Effect of Hydration on Water Levels

Hydration amounts reported as inches of application over the 6.5-acre wetland for the hydration period are presented in Table 2. During the 5-year study, active hydration provided approximately 32% of the long-term average rainfall inputs. The initial hydration schedule called for water to be applied during specific months to mimic the dry/ wet seasons. The amount of hydration water initially scheduled was 24 inches per year, which was approximately half the annual rainfall. The full, planned hydration amount was not delivered by the utility operators during the first hydration year because of heavy rainfall. The shallow system responded quickly to above normal rainfall, which filled the wetland to its maximum control point above which surface water began to overflow into an adjacent ditch. During the first year, a method for skipping a scheduled hydration event when the wetland was at maximum water level was proposed and agreed to by utility operators; however, in subsequent years this method was followed inconsistently by the utility operators. The hydration schedule was modified after the fourth hydration year to deliver water across more months. This modified hydration schedule was implemented to attempt to lengthen the wetland's hydroperiod to observe whether the change would affect amphibian populations. However, low rainfall conditions during the fifth hydration year resulted in water levels below the ground surface from March 2006 through the end of the project (April 2007). CPI also noted that hydroperiods at both the study wetland and several adjacent control wetlands were similar throughout the operational period.

Daily water levels during the baseline period averaged 36.69 feet North American Vertical Datum of 1988 (NAVD88) (refer to Table 2 and see Appendix A, Figure A6). During the hydration period, water levels averaged 37.48 feet, which is 0.79 foot greater than the baseline period. The maximum control elevation in the wetland was determined to be 38.40 feet NAVD88, only 0.20 foot above the ground surface at the wetland piezometer. Above this elevation, surface water began to spill into the adjacent ditch and flowed into other wetlands through a system of ditches and culverts. Water elevations exceeded 38.40 feet, 50% of the time during the hydration period. Water elevations above 38.40 feet NAVD88 were more likely the result of rainfall events since a significantly larger acreage of wetlands was filling above this control point. The volume of water needed to fill these larger wetland acreages likely was beyond the capacity of localized active hydration alone.

Increases in water levels at the wetland piezometer were not observed on days when only active hydration took place and when no rainfall occurred. On these days during the hydration period, water levels in the wetland piezometer decreased an average of 0.03 foot per day, which is in excess of evapotranspiration alone, indicating that water was moving from the wetland to the SAS. Water levels also decreased in the same piezometer an average of 0.03 foot when neither hydration nor rainfall occurred.

### Effect of Rainfall plus Hydration on Water Levels

Cumulative inputs from rainfall and active hydration had a slightly greater effect on water levels during the hydration period than rainfall alone did during the baseline period (Appendix A, Figure A7). The trend of cumulative rainfall and hydration inputs versus cumulative water levels during the hydration period was slightly steeper and had a slope of 10.44 (r-squared 0.99) while the baseline trend had a slope of 8.80 (r-squared 0.95).

During days when both rainfall and active hydration occurred, water levels in the wetland piezometer rose an average of 0.09 foot per day. Increases in average daily water levels when both rainfall and active hydration occurred were observed in 4 out of the 5 hydration years. When rainfall inputs were at their lowest, during hydration Year 5, the combined rainfall and active hydration inputs were ineffective at increasing average daily water levels (-0.07 foot per day). Water levels were lower during the drier fifth year of hydration than in the previous year, while hydration inputs were similar (Table 2) indicating that rainfall inputs had a dominant role with respect to changing water levels.

### Target Hydrograph and Stage Exceedence Curve

Daily water levels were above the soil surface at the wetland piezometer 42% of the time during the baseline period (Table 2). During the hydration period, water levels averaged 0.78 foot greater than the baseline period and were above the surface at the wetland piezometer 62% of the time. Maximum and minimum water levels recorded during the baseline and hydration periods were similar. During the hydration period, water levels typically fell beneath the ground surface in late winter, spring, and early summer, providing an extended but typical seasonal hydroperiod. Water levels were below the wetland ground surface the entire fifth hydration year.

The median stage value for the hydration period exceedence curve was within 1 foot of the estimated average normal pool (39.4 feet NAVD88) (Appendix A, Figure A8), close to the target hydration elevations. The normal pool in the Port Orange wetland was estimated from historical hydrologic indicators onsite including: the lower limit of moss collars, the lower inflection point of cypress buttress swelling, the saw palmetto edge, and the ground elevation of the outermost (landward) cypress trees. The literature indicates that water levels within 1.0 foot of the normal pool (seasonal high water level) are necessary to avoid wetland impacts and that unacceptable harm can occur when median stage values are more than 1.9 feet below the normal pool (Southwest Florida Water Management District [SWFWMD]

1999). The median stage value for the baseline-period exceedence curve was 36.8 feet NAVD88, 2.6 feet below the normal pool. Increased inputs from rainfall and active hydration moved the median stage value at the Port Orange wetland to within the target range during the hydration period. The greatest increase in water elevation from the baseline period to hydration period occurred between the 60% and 70% exceedence, when water levels were near or at the soil surface at the wetland piezometer.

**Effect of Hydration on Water Quality**

Active hydration had no clear or long-term measurable effect on water quality in the wetland. Water quality samples were collected once during the baseline period and six times during the hydration period when surface water was present. Water quality parameters were similar during the baseline and hydration periods and were typical of a central Florida still-water cypress swamp. Values for pH, conductivity, TSS, metals, and nutrients were typically low.

On occasion, several parameters were elevated, which is more indicative of groundwater (high pH and high alkalinity). However, active hydration occurred in conjunction with or prior to only one water quality sampling event (October 21, 2003) when alkalinity values were elevated (80 milligrams per liter [mg/L]) above median values (6.0 mg/L). Elevated alkalinity values were recorded again from surface water samples collected during October 20, 2004, when active hydration was suspended due to the heavy rainfall from Hurricane Jeanne.

**Effect of Hydration on Vegetative Communities**

As was found for the Tillman Ridge Demonstration project, vegetation did not prove to be a reliable indicator of water level changes over this 5-year hydration period. The Port Orange wetland was characterized by a herbaceous (non-woody) layer dominated by wetland grasses and sedges, a nearly absent shrub layer, and a canopy of mostly pond cypress, a wetland species. Plants species found almost exclusively in wetlands dominated all strata during the baseline period while species typical of uplands constituted very low percent cover. The herbaceous layer was moderately dense because of the relatively open canopy and shallow surface water and was the most diverse of any of the demonstration sites, with 82 species recorded during the study. A ground fire passed through the wetland in 1998 prior to the inception of the study, and fire scars were still clearly evident on the trunks of the canopy trees. Most canopy trees survived the fire; however many woody seedlings, small saplings, and many shrubs were killed.

The percent cover of herbaceous species generally increased from the beginning of the study until it peaked during summer 2003, after the first year of hydration. Percent cover then decreased rapidly and continued to decrease through the end of the study. Changes in percent cover of herbaceous species during the hydration period did not follow changes in water levels and did not differ from the baseline period. Some shifts in the dominance of herbaceous species were observed, but the relative contribution of wetland plants and upland plants did not change.

A subset of plant species was selected for tracking throughout the study. These site-specific "target" species were identified during the initial site visit to the wetland. The percent cover of target indicator species at the Port Orange wetland reflected general trends in total herbaceous percent cover (Appendix B). The percent cover of the target species showed a general increasing trend from the beginning of the study until it peaked in summer 2003 after the first year of hydration. Percent cover of target species then showed a decreasing trend through summer 2006. Notably, target species were nearly absent from the Port Orange wetland after water levels were above the wetland surface for nearly 6 consecutive months. Target species were consistently dominated by species typically found in wetlands, specifically maidencane (*Panicum hemitomon*). The species wiregrass (*Aristida stricta*), a common flatwoods species, showed a general decrease in percent cover as water levels increased. Wiregrass percent cover increased slightly at the end of the study once water levels receded.

Shrub cover at the Port Orange wetland was consistently low (less than 2.5%) during the entire study period. The basal area of tree species, measured as the sum of the cross-sectional areas of the tree trunks, did not appreciably increase in the tree plot from the beginning of the study until the end. The presence of tree saplings was noticeably absent from the tree plot during the study period. As noted, the fire in 1998 killed many of the woody seedlings, tree saplings, and shrubs that were present at that time.

**Effect of Hydration on Amphibians**

Amphibian species observed were typical of shallow Florida wetlands in pine flatwoods (Franz and Means 2001). No appreciable change was detected in the amphibian assemblage at Port Orange that could be attributed to the hydration amounts. The return to a normal rainfall was most likely the strongest factor in observing an increase in amphibian abundance from baseline period (average 106 individual frogs) through the first 3 years of hydration (237, 140, 199, respectively). After the third year, the total number captured fell to 51, due to the prolonged flooding (from previous hurricanes) through the spring breeding cycle; in the last year, the total number captured fell to three individuals as a result of persistent dry conditions throughout the last 2 years of the study.

During the baseline period of the study, oak toad (*Bufo quercicus*), squirrel treefrog (*Hyla squirella*), Florida cricket frog (*Acris gryllus*), southern leopard frog (*Rana sphenocephala*), eastern narrowmouth toad, and pine woods treefrog dominated the captures. Similarly, during hydration years, Florida cricket frog, southern leopard frog, eastern narrowmouth toad, and pine woods treefrog dominated the captures. The species richness did not notably change until the last year of hydration, in which it dropped to two from an average of nine in previous hydration years. Means (2007) noted that no breeding among the amphibian species occurred during the consecutive 2 years of drought (2006 and 2007).

In general, an increased depth, duration, and frequency of seasonal inundation in the study and control wetlands had a positive effect on the amphibian community, whether the source of water was rainfall, runoff, or hydration. Active hydration with groundwater appeared to have no detrimental effects on the amphibian fauna.

**Summary of Results from the Port Orange Wetland**

- Due to a typical flatwoods hydrology in which flow gradients between the uplands and wetland change seasonally, the active hydration inputs to the wetland were not always detectable using shallow piezometers.

- Water levels increased in the wetland 0.78 foot during the hydration period compared to the baseline period improving wetland inundation frequency by 20%.

- The median stage values for water elevations in the wetland were within 1-foot of the average normal pool (39.4 feet NAVD88) estimated by historical hydrologic indicators after 5 years of active wetland hydration, an elevation necessary to avoid impacts to the wetland from potential drawdown.

- Active hydration water alone was insufficient to increase water levels in the wetland at the application rates. Rainfall was the dominant input that contributed to increases in water levels at the Port Orange wetland.

Average daily water levels rose the greatest when active hydration took place in conjunction with rainfall.

- The application of groundwater did not significantly alter wetland water-quality parameters and did not specifically raise the pH of surface waters to a point that affected amphibian populations.

- Vegetative strata exhibited different responses to increased water levels. The subcanopy, sapling, and shrub layers likely are still recovering from the fire in 1998. The herbaceous stratum exhibited rapid seasonal and inter-annual changes in cover and species composition in relation to depth, duration, frequency, and seasonality of both inundation and drought. Target indicator species also followed the same general trend.

- At the Port Orange site, amphibian response was inconclusive of direct effects of active hydration on breeding success or species abundance. In general, an increased depth, duration, and frequency of seasonal inundation in study wetland and control wetlands had a positive effect on the amphibian community, whether the source of water was rainfall, runoff, or hydration. Active hydration with groundwater appeared to have no detrimental effects on the amphibian fauna.

# PASSIVE HYDRATION AT TWO DEMONSTRATION SITES

Two demonstration sites were selected to evaluate the effects, costs, and benefits of increasing the hydroperiod of wetlands that have the potential to be ecologically impacted from groundwater drawdown:

- Bennett Swamp Control Weir (Demonstration Project No. 2) in Volusia County, Florida

- City of Titusville Wellfield (Demonstration Project No. 4) in Brevard County, Florida

The study sites were designed as passive hydration through raising the wetland water levels and the duration of inundation by installing water control outfalls from the wetlands. As such, no active hydration with groundwater addition was proposed. Instead, weirs were constructed within wetland outlet drainage features to retain greater volumes of surface water for longer durations by raising the outlet elevation without increasing flooding during major storms.

## BENNETT SWAMP SITE

### Site Description

The wetland used for Demonstration Project No. 2, was Bennett Swamp, a 2,200-acre swamp in the Tomoka River Basin in Volusia County, Florida (Figure 6). The majority of the swamp is forested, cypress-mixed hardwood wetland with some pine flatwoods and uplands with little topographic relief (Figure 7). Water exits the swamp primarily through Thayer Canal (to the east) and secondarily through a box culvert under U.S. Highway 92 (to the south). Tiger Bay Swamp drains into Bennett Swamp from the west. The City of Daytona Beach wellfield is located near the study area.

The demonstration site was selected because of the willing participation of Volusia County and the Florida Division of Forestry, evidence of altered hydrologic conditions, modeling of historical SAS declines, proximity of the wetland to the City of Daytona Wellfield, and the ease in which a control weir could be located in Thayer Canal.

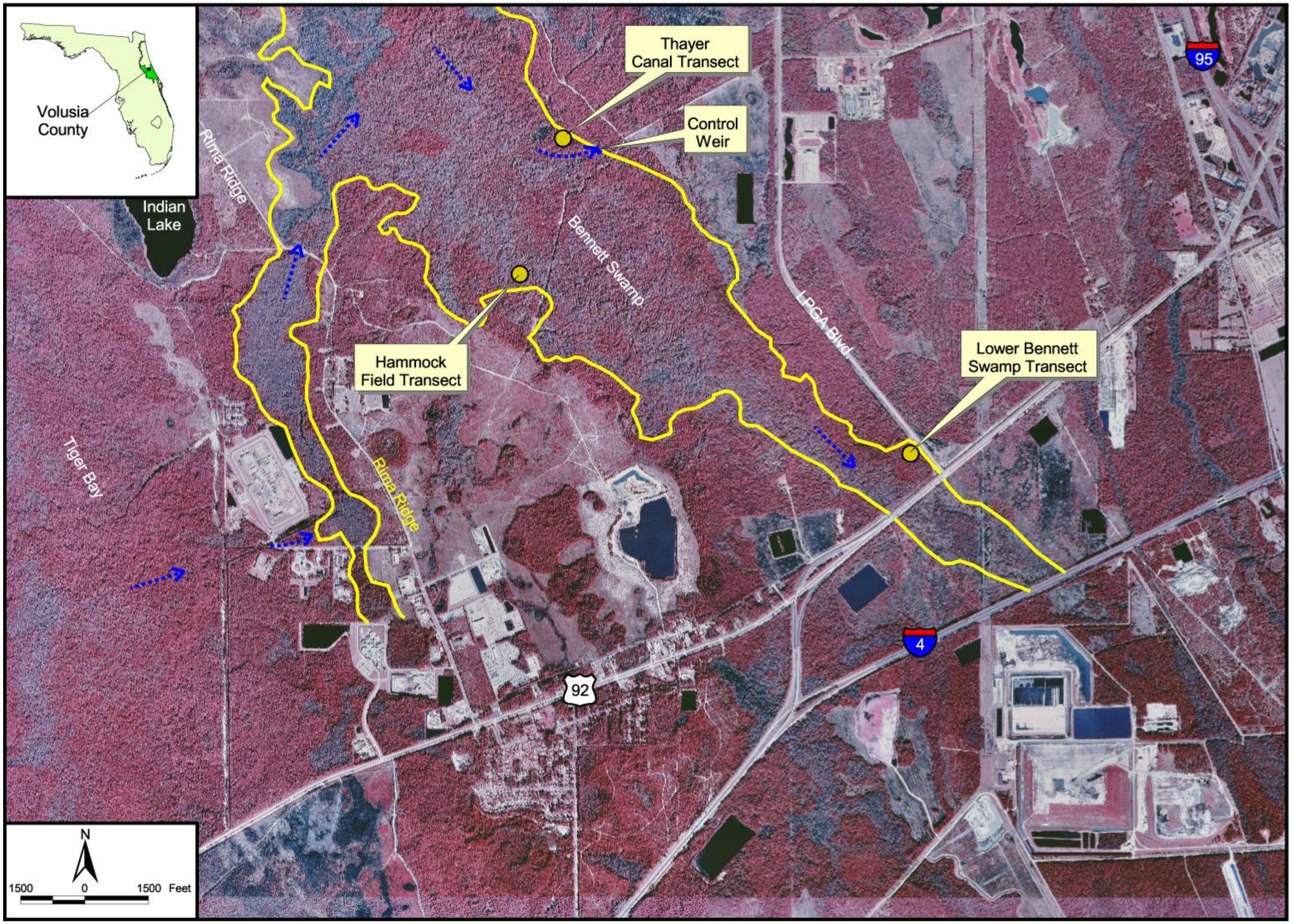


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Figure 6. Bennett Swamp project location map, Volusia County

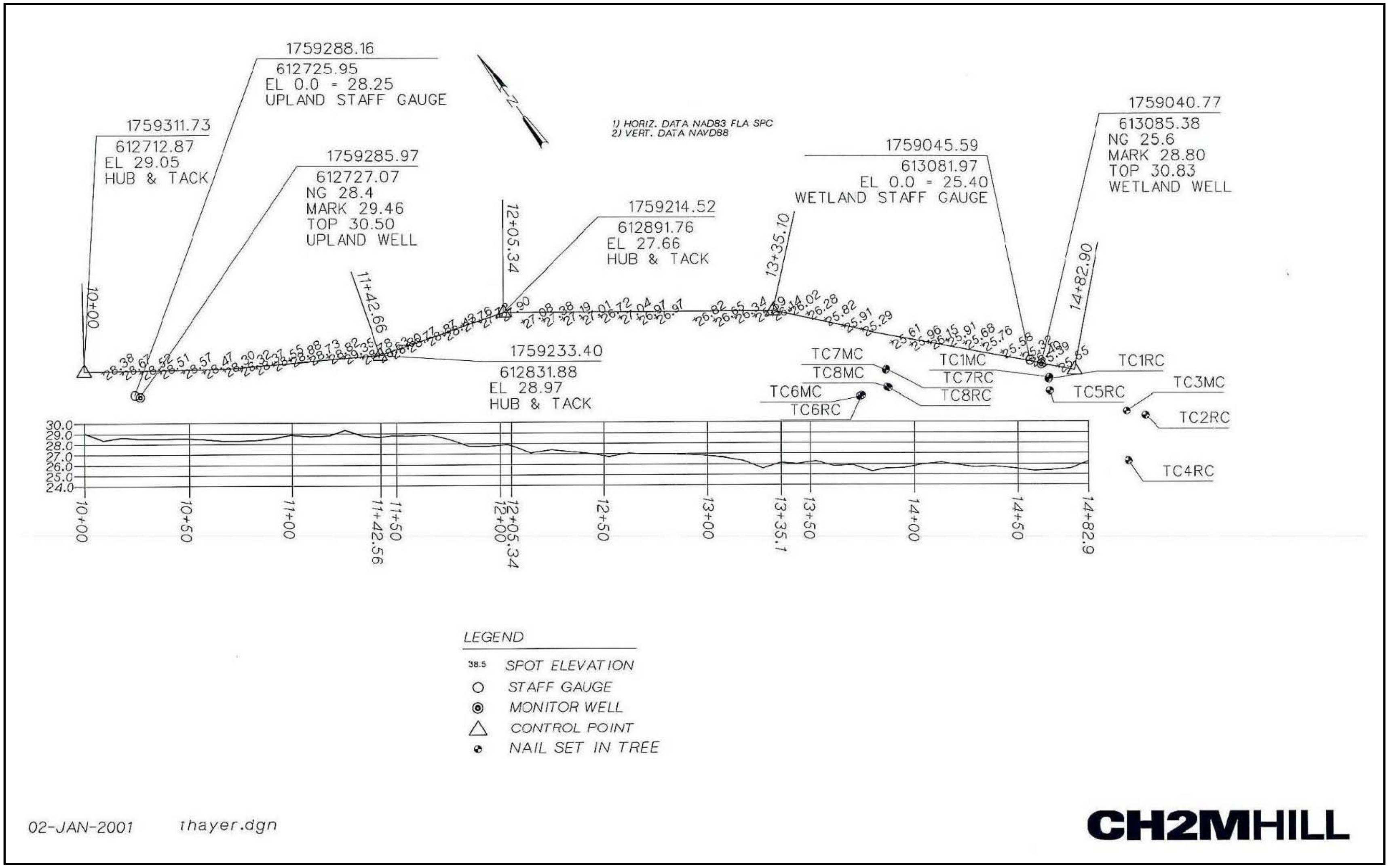


Figure 7. Bennett Swamp, Thayer Canal transect topographic survey

### Hydration Method – Controlling Surface Water Outfall

A control weir was constructed on the east outfall canal, Thayer Canal. The Thayer Canal Control Weir was positioned approximately 400 meters east of the Thayer Canal monitoring transect. Three monitoring transects, designated as Thayer Canal, Hammock Field, and Lower Bennett Swamp, were established within Bennett Swamp and generally located in the east, west, and south part of the swamp. A description of the control weir is provided below in subsection *Weir Design*.

### Study Period

Hydrologic conditions and ecological communities were monitored at Bennett Swamp from February 2000 through April 2008. The baseline period of the study began in February 2000 and concluded with the construction of the weir on January 15, 2004. The operational period began after weir construction and continued until April 2008, approximately 4.5 years. The fifth operational year was shortened to allow inclusion of the results in this report.

This summary of Bennett Swamp focuses mainly on the results from the Thayer Canal monitoring transect because (1) the transect is nearest to the weir, where changes in water levels and responses to ecological communities were most likely to be observed, and (2) the water level data set from this transect was reasonably complete. However, data from the other two monitoring transects were included to provide additional insight to the results. Equipment malfunctions, storm damage, access delays, and vandalism caused gaps in the data at all three transects.

### Target Hydrograph

Field measurements of vegetative and soil indicators of hydrology were compared to modeled stage-duration curves for recent and historical conditions and were summarized in the *Technical Memorandum Hydrologic Goals in Bennett Swamp – Rehydration Water Level Targets Using Biological Indicators* (CH2M HILL 2002).

Hydrologic indicators collected from the site were distributed among the three monitoring transects, and the resulting target hydrograph represented the main part of Bennett Swamp (see Appendix A, Figure A9). Results from these analyses indicated that historical impacts from surface water alterations and from SAS declines due to groundwater withdrawals had reduced water levels by 1.75 to 2.00 feet relative to pre-disturbance conditions. In Bennett

Swamp, a 1-foot increase in the stage-exceedence was recommended as an initial rehydration target. The increase would bring the hydrology toward the historical condition without affecting adjacent land uses, such as managed pine plantations, at the edge of the swamp.

### Weir Design

The objective of the weir was to retain naturally occurring surface water within the system for a longer duration by raising the outlet elevation without increasing flooding potential to adjacent land uses from major storm events. The system is considered passive because it is rainfall-dependent and does not provide hydration water through a pump and delivery pipe system. The lengthened hydroperiod would be used to offset potential drawdown of the SAS by nearby supply wells.

The control elevation of the weir was set at 26.4 feet NAVD88 (27.5 feet NGVD29), 2 feet above the invert elevation of Thayer Canal at that location, and was designed to increase the wetland average seasonal high using adjustable 6-inch boards up to 2 feet above the canal's invert and wetland outflow elevation. The control elevation of the weir corresponded to historical hydrologic indicators identified within the swamp and to historical hydraulic modeling conducted by the SJRWMD (CH2M HILL 2002). The weir will be maintained and operated by Volusia County for a period of 30 years (from the date of operational startup) per the Memorandum of Understanding (MOU) between the SJRWMD, Florida Department of Forestry, and Volusia Country (SJRWMD 2004).

## RESULTS

### Effect of Rainfall on Water Levels

Rainfall data were obtained from the National Weather Service from the Tiger Bay State Forest station for the sampling period. Average annual baseline period rainfall was 56 inches (February 2000 to September 2003), above the annual average rainfall for the area (48 to 50 inches) (see Table 3). Maximum annual rainfall was recorded during operational Period 1 (59.9 inches) because of the 2004 hurricane season. Annual rainfall during operational Periods 2 and 4 was similar to the long-term annual average for the region, and operational Period 3 was below the long-term annual average. Annual rainfall was already below the long-term average (22.2 inches) at the end of the shortened operational Period 5 (only 7 months).

Deviations from monthly rainfall totals collected during the project period were compared to two long-term (1971 – 2000) local data sets. Monthly departure values from normal values were summed and the cumulative departure from normal precipitation was calculated to develop trends in precipitation. For the first 16 months (February 2000 through May 2001) for the baseline period, rainfall at the Tiger Bay State Forest station was below the long-term average. Throughout the rest of the baseline period and first two operational years, monthly rainfall totals exceeded the long-term average monthly totals. Monthly rainfall totals were below the long-term average monthly totals from the third operational period (September 2005) through the end of the study. Rainfall across Florida in 2006 was the third lowest in 112 years (*Tampa Tribune* 2007). Drought conditions began in late March 2006 and progressed across the state. By November 2006, half of the state was experiencing moderate drought (National Drought Mitigation Center [NDMC] 2007), and by May 2007, which was the end of the fourth hydration year, half the state was undergoing severe drought and most of the other half was in moderate drought. Monthly rainfall totals recorded for Bennett Swamp for the entire study are presented in Appendix A, Figure A10.

Table 3. Summary of hydrologic parameters at Bennett Swamp – Thayer Canal transect, February 2000 – April 2008

| Period (365 days) | Rainfall (inches) | Water Level | | |
|---|---|---|---|---|
| | | **Mean (feet)*** | **Difference (feet)* Between Baseline and Operation Mean** | **Exceedence Above Wetland Surface*** |
| Baseline | 56 | 26.11 | N/A | 76% |
| Hydration Year 1 | 59.9 | 26.29 | 0.18 | 98% |
| Hydration Year 2 | 49.9 | 27.24 | 1.13 | 99% |
| Hydration Year 3 | 34.4 | 26.78 | 0.67 | 90% |
| Hydration Year 4 | 47.7 | 26.72*** | 0.61*** | 73%*** |
| Hydration Year 5** | 18.2 | 26.72*** | 0.61*** | 73%*** |

Note:

*Mean and Exceedence calculations are cumulative and include data from each previous operational year
**Shortened year, 7 months of data
***Portion of period of record out of range of water level recorder. 4th and 5th year out-of-range values differ from previous years because new well was dug after original well was vandalized. The new well had shallower bottom elevation.
Ground surface at the wetland piezometer is 25.6 feet
Elevations are in NAVD88, North American Vertical Datum of 1988
N/A = not applicable

**Effect of the Weir on Water Levels**

The collection of water level data from six piezometer locations among the three Bennett Swamp transects was problematic. The Thayer Canal transect in particular experienced several occurrences of vandalism in which water level recorders were damaged, stolen, or destroyed. The available data set from the Thayer Canal transect was sufficient to produce basic water level statistics for the study period (Appendix A, Figure A11). The Hammock Field transect experienced several occurrences of water level recorder failure and destruction from falling trees. As a result, the available data set from the Hammock Field transect was the most incomplete, and no water level statistics were calculated (Appendix A, Figure A12). The Lower Bennett Swamp transect provided the most complete water level data set at Bennett Swamp (Appendix A, Figure A13). However, this transect was the furthest from the weir and in proximity to another wetland outfall near the U.S. Highway 92 roadway.

Low rainfall conditions began in September 2005, which resulted in moderate drought by March 2006. Consequently, water levels in Bennett Swamp fell below the bottom of the wetland piezometers at all three transects by September 2007 and remained so through the end of the study period. Low water elevations further reduced the amount of the available water level data affecting water level statistics. No water elevations below 21.31 feet NAVD88 were available to be included in water level statistics from the Thayer Canal transect. Results reported from the baseline period, operational period 4, and operational period 5 are likely elevated above actual means, medians, minimums, and stage exceedence values (Table 3).

At the Thayer Canal transect, daily water levels averaged 26.11 feet NAVD88 and were above the soil surface at the wetland piezometer (25.6 feet) 76% of the baseline period (Table 3). During the operational period, water levels averaged 26.72 feet NAVD88 (0.61 foot greater than baseline) and were above the surface at the wetland piezometer 73% of the time. Greater peaks in daily water levels drove up the mean for the operational period. However, water levels remained at these higher elevations for short periods of time during the operational period as indicated by the stage exceedence curves. Average water levels were greatest during the second operational period (27.24 feet), corresponding to increased rainfall inputs from the 2004 hurricane season.

Both baseline and operational period exceedence curves at the Thayer Canal transect were above the wetland ground surface and the 26.4-foot NAVD88 (27.5-foot NGVD29) target modeled historical level at the 50% exceedence; however, both periods were below the historical soil-estimated curve

(27.2 feet NAVD88 [28.3 feet NGVD29]) at the 50% exceedence level (Appendix A, Figure A14). Water levels during the baseline period were above the target modeled historical level by 0.20 foot and below the historical soil-estimated level by approximately 0.60 foot. The operational period was, at 26.7 feet NAVD88 at the 50% exceedence, 0.30 foot greater than the target modeled historical level and below the historical soil-estimated level by approximately 0.50 foot. Exceedence values were similar between the baseline and operational periods at the weir elevation (26.4 feet NAVD88)

The average change in daily water levels within the effective weir height (between 24.4 to 26.4 feet NAVD88) differed slightly between the baseline and operational periods at the Thayer Canal transect. During the baseline period on days when no rainfall was recorded, average daily water levels fell 0.01 foot within the effective weir height. During the operational period, under the same conditions and at the same elevations, average daily water levels did not change (0.00 feet).

Data collected from the Lower Bennett Swamp transect shows a reduced hydroperiod after the construction of the weir which contrasts with the Thayer Canal results for daily water elevations during the study period. Average daily water levels in Lower Bennett Swamp during the baseline period were 25.28 feet NAVD88 and exceeded the ground surface at the wetland piezometer 84% of the time (Appendix A, Figures A13 and A15). During the operational period, water levels averaged 24.18 feet NAVD88, 1.1 feet lower than the baseline period. Water levels exceeded the ground surface at the wetland recorder 53% of the time during the operational period. Both baseline and operational period exceedence curves were below the 26.4-foot NAVD88 target (modeled historical level) and the soil-estimated historical curve (227.2 feet NAVD88) at the 50% exceedence level. Based on the target hydrograph, the stage at the wetland piezometer should have been exceeded 88% of the time once historical conditions were restored.

**Effect on Water Quality**

Water quality parameter values from the three monitoring transects within Bennett Swamp were similar to one another. Surface water samples that were collected exhibited water quality typical of central Florida forested, black water swamps (low pH, conductivity, nutrients, total dissolved solids [TDS], and high color). Water quality values were also similar between baseline and operational periods.

**Effect on Vegetative Communities**

Vegetation data were recorded from the three monitoring transects within Bennett Swamp. Overall, plant diversity within the swamp was moderate, with 56 species observed during the study period. Data for herbaceous, shrub, canopy, and subcanopy vegetation layers were similar among each of the monitoring transects.

Both the Thayer Canal and the Hammock Field transects exhibited signs of soil subsidence from water level drawdown and soil compaction from heavy logging equipment used prior to inception of the study. The soil surface in these areas was lower in elevation than they would have been in an undisturbed condition, creating deep pockets of surface water that inundated the herbaceous vegetation layer, similar to conditions at the Tillman Ridge site.

During the baseline period, herbaceous species cover among transects ranged, on average, from 10 to 20% within the sampling plots. Percent cover of herbaceous species peaked near the end of the baseline period and was consistently highest near the upland end of the monitoring transects. Herbaceous species were dominated by plant species usually found in wetlands. No upland herbaceous species were recorded at the monitoring transects during the baseline period.

During the operational period, percent cover of herbaceous species in the sampling plots decreased significantly compared to the baseline period. The plants that were recorded were primarily wetland species. Groundcover was sparse when surface water levels were high, which occurred as a result of the active 2004 hurricane season. Groundcover rebounded somewhat once water levels began to recede at the Thayer Canal and Hammock Field transects, but did not return to the average percent cover recorded during the baseline period. Percent cover within the sampling plots at the Lower Bennett Swamp transect remained low and did not increase during the operational period.

Several plant species that tolerate a wide variety of wet or dry soil conditions, including dog fennel (*Eupatorium capillifolium*) and blackberry (*Rubus argutus*), were recorded at the Thayer Canal transect once water levels fell beneath the wetland surface. No strictly upland species were observed in the sampling plots during the operational period. Percent cover was greatest near the upland edge of the monitoring transects through most of the operational period. However, once water levels began to fall in spring 2006, groundcover began to increase in plots near the deeper end of the transects, predominantly by Japanese climbing fern (*Lygodium japonicum*), which is an invasive exotic pest plant.

Target species percent cover was low during the baseline period and peaked near the end in 2002. The exception was at the Thayer Canal transect, where target species percent cover peaked during the operational period. Target species percent cover during the operational period decreased from peak values during the spring 2002 baseline monitoring event at both the Hammock Field and Lower Bennett Swamp transects, but showed no consistent trend at the Thayer Canal transect. Percent cover of all target species was low during the operational period, averaging below 10%. Dominant target species during the operational period included species usually found in wetlands, which have short periods of standing water. No upland target species were recorded.

Percent cover of shrubs was moderate (25 to 50%) during the baseline period. Shrubs were dominated by plants that are usually, but not exclusively, found in wetlands. Shrub percent cover generally decreased after periods of elevated surface water during both the baseline and operational periods at the Thayer Canal and Hammock Field transects. Percent cover of shrubs at the Lower Bennett Swamp transect increased slightly during the operational period compared to the baseline period.

The canopy and subcanopy layers were dominated by the wetland species loblolly bay (*Gordonia lasianthus*), swamp tupelo, and sweetbay (*Magnolia virginiana*). The larger canopy trees contributed a greater percentage of the total basal area than the smaller subcanopy trees combined, but the subcanopy trees were more numerous. Canopy trees increased in both basal area and density at the Thayer Canal and Hammock Field tree plots, while the total basal area and number of individuals of the subcanopy-sized trees decreased. The Lower Bennett Swamp tree plot was heavily impacted by a tree fall that occurred during the 2004 hurricane season, which made tracking changes problematic. Nearly one fifth of the trees within that tree plot were overturned during October 2004. Trees from the heavily damaged section of the tree plot at the Lower Bennett Swamp transect were subsequently removed from the database.

**Effect on Amphibians**

Amphibian species diversity (the total number of different species) observed during the baseline period was typical of Florida swamps. During the 2-year baseline period, nine amphibian species and 609 individuals were captured in Bennett Swamp.

Ninety percent (or 551 out of 609) of the abundance (total number of individuals captured) was comprised of five species. The captures included 211 southern toads (*Bufo terrestris*), 95 eastern narrowmouth toads, 84 greenhouse frogs (*Eleutherodactylus planirostris*) (an exotic species), 78 pine woods treefrogs, and 83 southern leopard frogs. The remainder was made up of Florida cricket frogs, oak toads, squirrel treefrogs, and little grass frogs (*Pseudacris ocularis*).

Based on data from the operational period, amphibian species diversity (richness and particularly abundance) increased and decreased in response to rainfall, when rainfall was sufficient enough to form surface water in the swamp. In the first two operational years, 275 individuals across 12 amphibian species were observed. These included the same species as in the baseline period plus three new species: an exotic species, Cuban treefrog (*Osteopilus septentrionalis*); bronze frog (*Rana clamitans*); and pig frog (*Rana gryllio*). The remaining years of the study were drought ridden, and amphibian richness and abundance declined steadily. In the third operational year (2006), richness and abundance were 7 and 80, respectively; and in the fourth operational year (2007), the numbers fell to 6 and 21, respectively.

CPI scientists postulated that the data are inconclusive regarding the extent to which amphibian species diversity and abundance may have been affected by installation of the weir. CPI noted that environmental variables—such as weather (hurricanes of 2004-2005 and intense drought of 2006-2008), along with population boom and bust cycles—fluctuated during the study period, but that short-term fluctuations are not always congruent to long-term trends.

**Summary of Results from the Bennett Swamp Study**

- Average annual rainfall was greater during the baseline period than during the operational period. Decreased rainfall inputs, which began during operational Year 3, led to droughty conditions by the end of the study period, which complicated the interpretation of results.

- Measurable water levels increased in the wetland 0.61 foot at the Thayer Canal transect, located near the control structure, during the operational period compared to the baseline period.

- The stage exceedence of water elevations in the wetland was above the historical (target) hydrograph during both the baseline period and the operational period at the 50% exceedence level. The period of record for the operational period, however, included an extended period of low to very low rainfall, resulting in water elevations below the wetland piezometer. The frequency distribution of water levels was likely closer to or actually below the target rehydration curve.

- Surface water levels fell more slowly within the effective height of the weir during the operational period compared to the baseline period at the Thayer Canal transect. This indicates that the weir is having the desired effect of retaining surface waters for longer periods with slower attenuation.

- Vandalism and destruction of water level recorders from falling trees created gaps in the available water level data set.

- Offsetting of wellfield drawdown likely would not have occurred during the operational period because of low rainfall inputs to Bennett Swamp.

- Water quality data did not significantly differ from water quality data for similar types of wetlands.

- Herbaceous vegetation data moderately tracked changes in water levels but did not indicate positive or negative benefits to the ecology of the swamp.

- Amphibian species richness and diversity increased in wet years and decreased in drought years. Installation of the weir did not appear to have any detrimental effects on amphibian populations or reproduction success.

## TITUSVILLE'S PARKLAND WETLAND

### Site Description

The wetland used for Demonstration Project No. 4, was a 100-acre scrub-shrub wetland in proximity to the City of Titusville's Area II Wellfield, in Brevard County, Florida (Figure 8). The wetland, known as the Parkland Wetland, is an integral part of the Bay Meadows–Parkland Ditch drainage basin, which provides important water management functions including attenuation of peak flood flows, wetland habitat, and surficial aquifer recharge. Uplands surrounding the wetland are almost fully developed as urban/ residential community. The wetland has little surrounding buffer and uplands transition rapidly into the wetland (Figure 9). The Parkland Wetland fills with surface water from the surrounding uplands until outflow occurs at the Crescent Street ditch, which then flows into the Parkland Street ditch.


Figure 8. Titusville Parkland Wetland project location map, Brevard County

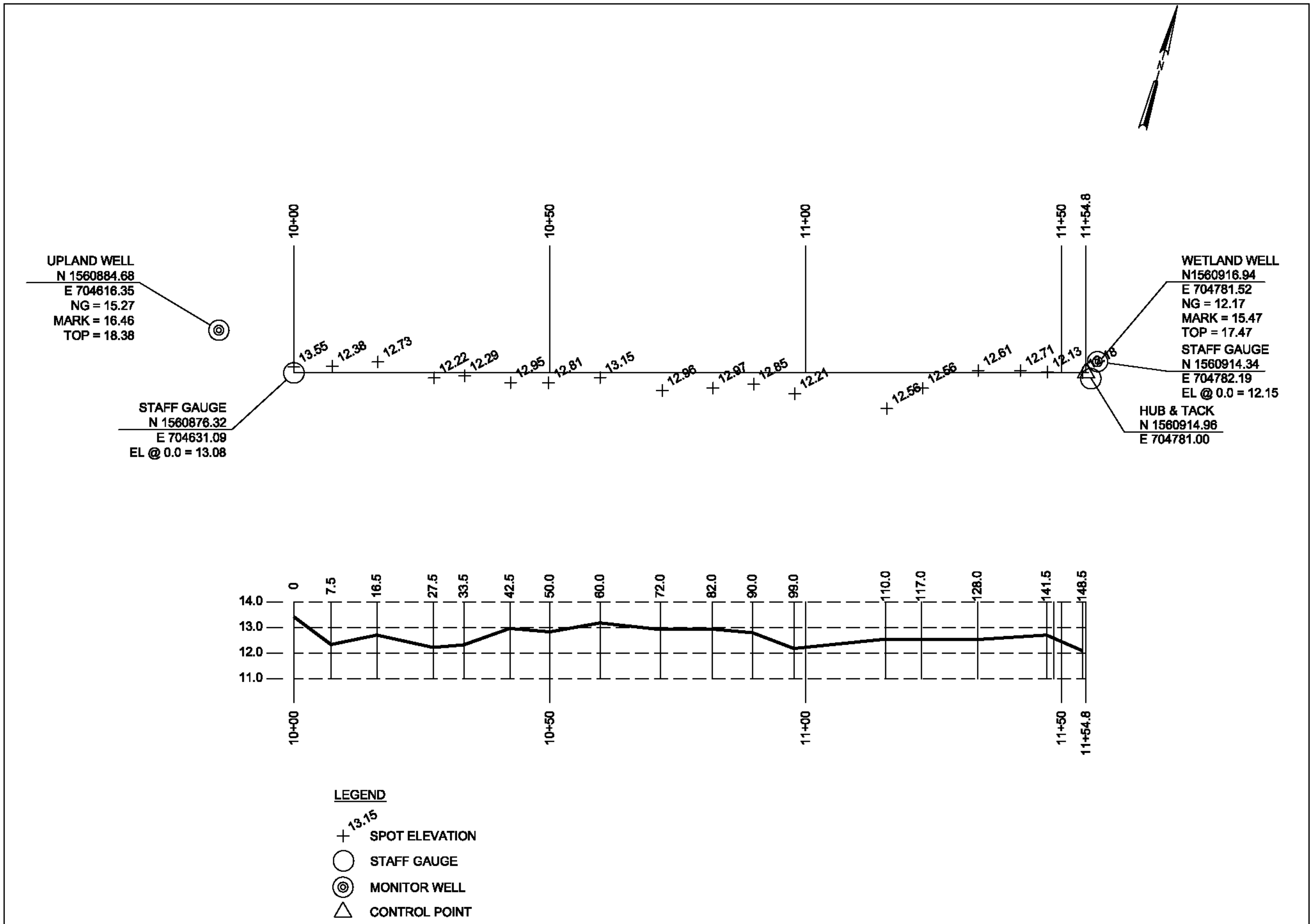


Figure 9. **Transect profile at Titusville Parkland Wetland (elevations in NGVD 29)**

CH2MHILL

The site was selected because the City of Titusville was concerned that drawdown in excess of 10 feet could occur in the surficial aquifer due to the absence of a solid confining layer in the area (City of Titusville 1996). The anticipated effects of withdrawals from the City of Titusville's Area II Wellfield might include induced drawdown in the Parkland Wetland. The city's Water Resources Department proposed this outfall control project in September 1996 as an impact avoidance strategy (City of Titusville 1996), thus the city's Utilities Department was a willing participant in the study. The control weir was easily located in the city-maintained drainage ditch.

**Hydration Method – Controlling Surface Water Outfall**

A control weir was constructed on the Parkland Street ditch, an outfall ditch located on the north side of the Parkland Wetland. A description of the control weir is provided below in subsection *Weir Design*.

**Study Period**

Hydrologic conditions and ecological communities were monitored at the Parkland Wetland from August 1999 through April 2007. The baseline period of the study extended from August 1999 until the installation of the weir in the outflow ditch in April 2002. From that date, the operational period of the study continued for 5 years until April 2007 when the study was concluded.

**Weir Design**

Rainfall and drainage from the surrounding uplands to the Parkland Wetland would fill the wetland until an elevation of 13.89 feet NGVD29 was reached at an outflow ditch on the north side of the wetland. A new control elevation of 15.89 feet NGVD29 was set by CH2M HILL hydrologists to increase the hydroperiod of the Parkland Wetland without increasing the potential for flooding of the surrounding uplands. Restoration of a more historically representative hydroperiod would offset potential drawdown of the surficial aquifer.

An adjustable weir was built in April 2002 by the City of Titusville to allow flexibility in operation and to accommodate a lower control elevation, in the event that experience would indicate that the maximum control elevation could not be sustained or was unnecessary. The weir was also designed so that floodwaters from high rainfall events would overtop the weir and water levels would be controlled by downstream flow constrictions. During April 2006, a new weir was installed due to repeated vandalism. The control height "as built" was raised to an elevation of 16.00 feet NGVD29.

## RESULTS

### Effect of Rainfall on Water Levels

The City of Titusville Water Resources Department staff provided rainfall data from the nearby Mourning Dove and Blue Heron WTPs. Average annual baseline period rainfall was 51 inches, which was consistent with the long-term annual average for the area (48 to 50 inches) (see Table 4). Annual rainfall during four of the five operational years exceeded annual rainfall during the baseline period. October 2005 (Year 4) reported the greatest rainfall monthly total (15.3 inches), from Hurricane Wilma. Monthly rainfall totals for the entire study are presented in Appendix A, Figure A16.

Table 4. Summary of hydrologic parameters at the City of Titusville's Parkland Wetland, August 1999 – April 2007

| Period (365 days) | Rainfall (inches) | Water Level | | |
|---|---|---|---|---|
| | | Mean (feet)* | Difference (feet)* between Baseline and Operation mean | Exceedence Above Wetland Surface* |
| Baseline | 51.0 | 13.23 | N/A | 68% |
| Hydration Year 1 | 58.7 | 15.04 | 1.81 | 98% |
| Hydration Year 2 | 48.9 | 14.73 | 1.50 | 99% |
| Hydration Year 3 | 67.2 | 14.80 | 1.57 | 99% |
| Hydration Year 4 | 57.6 | 15.18 | 1.95 | 99% |
| Hydration Year 5 | 57.1 | 14.78 | 1.55 | 99% |
| **Average** (Hydration all years) | **58.0** | **14.78** | **1.55** | **99%** |

Note:

*Mean and Exceedence calculations are cumulative and include data from each previous operational year
Ground surface at the wetland piezometer is 12.25 feet
Elevations are in NGVD29, National Geodetic Vertical Datum of 1929
N/A = not applicable

### Effect of the Weir on Water Levels

Installation of the weir in April 2002 blocked the primary low water outflow of the Parkland Wetland without changing the flood conditions. During the operational period, the surface water was held at higher elevations and for longer periods than during the baseline period.

Average baseline and operational periods daily water elevations differed by a mean value of 1.55 feet (Table 4). Daily water levels during the baseline period averaged 13.23 feet NGVD29 and were above the ground surface at the wetland piezometer 71% of the time. During the operational period, daily water levels averaged 14.78 feet and were above the ground surface at the wetland piezometer 99% of the time. Changes in water levels occurred more gradually and fluctuated less during the operational period. Daily wetland and upland water level elevations for the entire study are presented in Appendix A, Figure A17.

The baseline-period stage exceedence curve closely resembled the estimated historical exceedence curve produced from available hydrologic indicators onsite (Appendix A, Figure A18). Holding back surface water in the wetland pushed the stage exceedence curve above that of the historical curve during the operational period, providing a potential to avoid drawdown. However, water levels exceeded the ground surface at the wetland piezometer greater than 99% of the time during all five operational years (Table 4). This high frequency of inundation is indicative of a wet pool where drawdown to the ground surface is infrequent. The increased standing water had the potential to alter wetland ecological functions by inundating some herbaceous species and enabling others.

The City of Titusville's consumptive use permit (CUP) also requires monitoring of water levels within the Parkland Wetland. The City's CUP prescribed seasonal water level elevations below which, pumping of nearby wells is suspended to avoid drawdown of the Parkland Wetland. At no time during this study was pumping suspended due to water levels falling below these elevations as reported by the City of Titusville. The wet season (June through October) minimum pumping elevation (13.5 feet NGVD29) was exceeded 99% of the time during the operational period. The dry season (November through May) minimum pumping elevation (11.5 feet) was exceeded 100% of the time during the operational period. However, a post-study update indicated that water levels in the Parkland Wetland fell below the CUP limit on June 1, 2008, and continued to drop due to the regional drought. Pumping will not resume until rainfall replenishes the wetland up to the elevation of 13.5 feet.

**Effect on Water Quality**

Water quality parameters were within expected values for surface water systems in Brevard County and adjacent areas in central Florida. The Parkland Wetland exhibits water quality typical of Class III Surface Waters and a wetland receiving runoff from an urban area.

For most parameters, the baseline and operational periods water quality results were similar. Dissolved oxygen, chloride, turbidity, and TSS were low. For several parameters, the baseline period values, including pH, color, and sulfate, were higher than those measured during the operational period. Nutrients, metals, conductivity, and TDS levels were moderate for a wetland located within residential development. The operational period did not significantly affect water quality parameters compared to the baseline period.

**Effect on Vegetative Communities**

Vegetation within the Titusville Parkland Wetland study site was dominated by wetland species during the baseline period. Overall species diversity was low and plant percent cover was dominated by only a few species. The herbaceous vegetation covered the wetland in response to available sunlight and depth of surface water. Areas with an open tree canopy exhibited a denser cover by herbaceous plants. Cattail, a wetland species, dominated herbaceous plots near the deeper end of the monitoring transect. Species typically found in upland environments were observed only near the upland edge of the monitoring transects. When standing water was present, the majority of emergent ground cover became submerged and floating aquatic plants dominated. During the baseline period, the shrub stratum, low in percent cover and diversity, was dominated by Carolina willow (*Salix caroliniana*), a wetland species. Carolina willow was also the only tree species present (canopy and subcanopy) during the entire sampling period.

During the operational period, the greatest percent cover of herbaceous vegetation varied between emergent and floating aquatic species. When water levels increased, emergent vegetation was submerged and was then quickly replaced by floating aquatic species making comparisons of herbaceous percent cover difficult. Throughout the operational period, floating aquatic species such as duckweed (*Lemna* sp.) and water fern (*Salvinia minima*) covered the water surface. Cattail, which dominated only the deepest herbaceous plots during the baseline period, steadily increased in percent cover throughout the operational period, creating dense stands that excluded other herbaceous species.

The percent cover of wetland herbaceous species, emergent and floating aquatic species combined, peaked in operational Year 4 from spring 2005 through fall 2006, with 80 to 100% cover. As water levels receded in response to drought conditions, emergent herbaceous species began to replace floating aquatic species, particularly near the upland end of the monitoring transects. This replacement began with low percent cover, as emergent species were slower to establish than floating aquatic species. By the end of the operational period, the herbaceous percent cover had risen to 24% and was dominated by emergent species. The percent cover of upland plants within the wetland study plots showed a decreasing trend during the operational period until they were no longer present in fall 2003. Beyond that time, upland plant species had only occasional minor occurrences through the end of the operational period. The long periods of increased surface waters during the study period prevented upland plant species from germinating, and the seed bank for these plants was slow to be reestablished once water levels receded.

In the Parkland Wetland, the use of target indicator species generally supported data collected from other herbaceous species within the study plots. The percent cover of the target species was greatest at the beginning of the baseline period. The target species declined until they were nearly absent during Years 3 and 4 of the operational period, they then re-established and increased in cover near the end of the study as water levels receded. Target species were dominated by cattail, a wetland species, throughout the study.

Shrub cover declined from the baseline period to nearly absent (5% or less) through spring 2006, they then increased to 20% by the end of the operational period. Shrub cover was consistently dominated by wetland species. The total basal area of Carolina willow, measured as the sum of the cross-sectional areas of the trees within the study plot, increased from the baseline through the end of the operational period. The basal area of subcanopy-sized trees was greater than the basal area of the canopy stratum throughout the study.

The change in dominance from emergent to floating aquatic vegetation and the decrease in shrub cover both reflected the general increase in water depth and the lengthened hydroperiod at the Parkland Wetland.

**Effect on Amphibians**

Amphibian monitoring was limited to four times a year using a variety of methods including dip netting, frog call surveys, and incidental captures. Typical trapping methods (drift fence array with screen funnel traps, coverboards, and polyvinyl chloride [PVC] pipes) were not possible to maintain because of repeated vandalism. The Parkland Wetland is adjacent to Astronaut High School and is surrounded by residential development.

Because of the limited quantitative data, definitive statements are not possible. However, based on the survey results during this study, species richness likely increased with increased rainfall and decreased with decreased rainfall. Increased hydroperiod may have helped as a secondary factor, perhaps boosting amphibian activity and reproduction. The increased hydroperiod did not appear to be a detriment to amphibian populations.

Five amphibian species were observed during the baseline period. Species richness increased to nine, eight, and eight, respectively, in the first 3 years of operation (through 2005); then in 2006 the total number of species observed (six) dropped off to near baseline levels (Means 2006). This reduction probably resulted from persistent dry conditions during important spring and early summer breeding months for resident amphibians. The same species were observed in the baseline period as in the operational period, with the addition in the operational period of greenhouse frog, southern toad, Cuban treefrog, pig frog, and Florida cricket frog.

**Summary of Results at the Parkland Wetland in Titusville**

- Annual rainfall during the operational period was greater than the long-term annual average for the region and was greater than annual rainfall during the baseline period.
- Water levels increased in the wetland 1.55 feet during the operational period compared to the baseline period indicating the weir had a positive effect on retaining water levels in the wetland.
- The stage exceedence of water elevations in the wetland was near the historical hydrograph during the baseline period and exceeded the historical hydrograph during the operational period.
- A greater volume of water was retained in the Parkland Wetland for a longer period during the operational period without increasing flooding.
- Water levels remained above the City of Titusville's CUP special condition seasonal elevations during the operational period.
- Water quality data were consistent with those of wetland and surface waters within urban/ suburban areas.
- Vegetation data did not indicate an improved ecological response from increased water levels.
- Amphibian species richness increased with increased rainfall and decreased with decreased rainfall. The increased hydroperiod may have helped as a secondary factor in boosting amphibian activity and reproduction. The increased hydroperiod did not appear to be a detriment to amphibian populations.

# COSTS AND EFFECTIVENESS AS A MANAGEMENT TOOL

Assessing the environmental impacts of water table declines due to aquifer withdrawals on a regional scale can be difficult and is associated with a high degree of uncertainty. However, developing water supplies without regard for impacts to wetland and aquatic systems and then mitigating after impacts have occurred can be a very costly approach. Strategies to augment wetland hydrology can be very effective in avoiding impacts as described in these four wetlands studies performed for the SJRWMD.

## LONG-TERM SAVINGS

Methods used in this study, as well as other impact-avoidance strategies, may offer a more cost-effective alternative to traditional mitigation practices. Traditional mitigation typically involves purchase of land, design, and permitting of wetland mitigation, construction, and implementation, including a significant lag time in establishing success metrics and ability to claim credit for mitigation.

Additionally, the augmentation strategies evaluated in this study may also be considered interim solutions between other impact avoidance or augmentation methods. Unlike the permanent approach of purchasing mitigation credits, augmentation can serve as a temporary solution in impact avoidance while other solutions are being evaluated; such as pumping rotation among the supply wells, relocation of the wellfield, transition to an alternative water supply source, or waiting for mitigation credits to become available.

The cost benefit of recognizing the potential for wetlands to be adversely affected by water table decline and proactively implementing an avoidance strategy is demonstrated in Table 5 on a per acre basis for augmentation compared to post-impact mitigation at each study site. At present (in 2009 dollars), the average cost of purchasing credits at a mitigation bank (Personal Communications 2009) to offset 1 acre of impacted forested wetland (at a 3:1 replacement ratio) is roughly $168,000, and $80,000 for herbaceous wetland (at a 2:1 ratio), compared to $22,912 per acre for augmentation at Tillman Ridge. If current mitigation practices were used for the Tillman Ridge 5-acre study wetland, the cost would be a one-time fee of approximately $840,000. In comparison, the active hydration strategy implemented at Tillman Ridge had a present worth cost estimated to be roughly $114,560 for the 5-acre wetland.

Using the forested Tillman Ridge study wetland as an example from which to extrapolate cost estimates and applicability to other wetlands systems being considered for active impact-avoidance hydration, the long-term savings realized can be significant, depending on site-specific conditions.

Table 5. Summary of estimated cost per acre for augmentation compared to per acre costs of mitigation

| Study Site | Affected Area (acres) | Augmentation Water Source | Delivery System Elements Needed | Capital Cost | O&M Present Worth Cost | Unit Augmentation Present Worth Cost ($/ac) | Unit Mitigation Cost* ($/ac) |
|---|---|---|---|---|---|---|---|
| **No. 1 Tillman Ridge** | 5 | Groundwater pumped from an abandoned supply well | Pipe 175 ft, pump 3-Hp, valves, gauge, meter | $57,157 | $57,403 | $22,912 | $168,000 |
| **No. 3 City of Port Orange** | 6.5 | Groundwater pumped from an existing supply well | Pipe 360 ft, diffuser 40 ft, valves, gauge, meter | $117,334 | $55,277 | $26,556 | $168,000 |
| **No. 2 Bennett Swamp** | 1490 | N/A (control weir – passive system) | 35 ft W, 2 ft H aluminum stop log control weir in Thayer Canal (outfall) | $77,775 | $45, 061 | $82 | $168,000 |
| **No. 4 City of Titusville** | 100 | N/A (control weir – passive system) | 15 ft W, 2 ft H wooden stop log control weir in Parkland Ditch (outfall) | $31,525 | $45,061 | $766 | $80,000 |

Note:
*Based on average cost per credit: habitat types forested ($56,000) and herbaceous ($40,000) at mitigation banks in the region. Cost was estimated using an average cost (July 2009 price quotes) at the Colbert-Cameron Mitigation Bank, the East Central Florida Regional Mitigation Bank South, the TM-Econ Mitigation Bank, and the Mary A. Ranch Mitigation Bank. Assuming a ratio of "credits needed per impacted acres" at 3 to 1 (forested) and 2 to 1 (herbaceous).
Hp = Horsepower
O&M = operations and maintenance
Present Worth Cost basis of 7.5%, 30 Years (see Table 6 for details)

## Practical Application on a Wellfield-wide Basis

Unit costs and life-cycle costs for infrastructure such as pumps, pipes, simple and adjustable control weirs; design, construction, permitting, monitoring equipment, and estimates of minimal operation, maintenance, and monitoring labor costs; as well as assumptions are presented in Table 6. Examples of order of magnitude cost are presented that might be useful in planning for augmentation on an individual wetland basis or for use in wider applications, such as a wellfield. Site-specific conditions will dictate the specific equipment that would yield cost-effective results. Beyond a simple one pump/ one wetland approach, options could include additional piping to allow one pump to serve several wetlands. Similarly, a simple weir in an outfall ditch that might otherwise serve a limited area could be combined with a pump and pipe system providing active hydration at other locations.

Design costs also included a portion for ecological data input, such as collecting historical hydrologic indicator elevations in the field and establishing the target hydrograph and success metrics. Permitting costs were included in the cost estimate, although an environmental resource permit (ERP) was not needed for the active hydration projects because the delivery pipe did not enter the wetland, but stopped at the wetland's edge. An ERP was needed for construction of the weir in a surface water canal; however, no wetland mitigation was required for construction of the weir.

Table 6 provides a present worth cost estimate using actual and estimated costs of implementing an impact avoidance method at the four study sites for using active hydration and passive outfall control methods. Total capital costs were estimated by CH2M HILL. Present worth costs, an estimate of the present-day equivalent financial value of a future cash flow, or future investment dollars, were estimated using a rate of 7.5% over 30 years.

**Monitoring Startup and Operations and Maintenance**

One-time monitoring setup costs and annual operation and maintenance cost estimates are presented in Table 7. Based on this study, water level was the most cost-effective parameter to monitor. A simple continuous recording unit was attached to the top of a PVC piezometer, which was installed with a hand auger to a depth of 6 to 10 feet below ground surface. This depth captures the productive root zone. Monitoring water levels far below the root zone will not provide additional useful information in terms of assessing the ecological viability of the wetland. The units were programmed to record daily water levels in the deep part of the wetland. Unless remote sensing equipment is used, labor is required to download the data from the recording units (and change batteries) on a quarterly basis, at a minimum to reduce the potential for loss of data.

For the purposes of this cost estimate, the service-life of the pumps was presumed to be 10 years, and the recording units averaged 5 years. Unforeseen pump damage, such as a lightning strike at Tillman Ridge, would add to the maintenance costs. Nominal repairs, such as replacing boards of a wooden weir, can be expected. No maintenance would be expected for at least 30 years with a more permanent adjustable weir, as that used at Bennett Swamp.

Table 6. Present worth cost estimate per acre augmented at the Impact Avoidance Demonstration Projects

| Cost Element[1] | Study Site No. 1 Tillman Ridge Wellfield Wetland (St. Johns Co.) Active Hydration | Study Site No. 3 City of Port Orange Wellfield Wetland (Volusia Co.) Active Hydration | Study Site No. 2 Bennett Swamp (Volusia Co. Rima Ridge Wellfield) Passive Hydration | Study Site No. 4 City of Titusville Wellfield Parkland Wetland (Brevard Co.) Passive Hydration |
|---|---|---|---|---|
| **Total Capital Costs** DI Pipe (6-in; 290 ft) | - | $23,600 | - | - |
| PVC Pipe (3-in; 70 ft) | $1,500 | - | - | - |
| PVC Pipe (6-in; 50 ft), (8-in; 20 ft) | - | $3,400 | - | - |
| Diffuser Pipe (4-in; 40 ft) | - | $1,800 | - | - |
| Steel Pipe (2-in; 100 ft), (3-in; 5 ft) | $4,800 | - | - | - |
| Pump Station | $20,000 | $30,000 | - | - |
| Control Weir | - | - | $37,500 | $12,500 |
| Subtotal Construction Costs | $26,300 | $58,800 | $37,500 | $12,500 |
| Design and Permitting 25% | $6,575 | $14,700 | $9,375 | $3,125 |
| Conflict Resolution at 10% | $2,732 | $6,034 | $3,750 | $1,250 |
| Contingencies and Non Construction Costs at 50% | $13,150 | $29,400 | $18,750 | $6,250 |
| Monitoring Setup cost[2] | $8,400 | $8,400 | $8,400 | $8,400 |
| **Total Capital Costs** | **$57,157** | **$117,334** | **$77,775** | **$31,525** |
| **Annual Operations & Maintenance** | | | | |
| Annual O&M Costs[3] | $4,560 | $4,560 | $3,815 | $3,815 |
| Annual Energy - pumping costs | $300 | $120 | $0 | $0 |
| Present Worth of Annual O&M (7.5%, 30 Years) | $53,860 | $53,860 | $45,061 | $45,061 |
| Present Worth Annual Energy - pumping costs (7.5%, 30 yrs) | $3,543 | $1,417 | $0 | $0 |
| **Total Present Worth Annual O&M** | **$57,403** | **$55,277** | **$45,061** | **$45,061** |
| **Total Present Worth** | **$114,560** | **$172,611** | **$122,836** | **$76,586** |
| No. of Acres | 5 | 6.5 | 1490 | 100 |
| **Total Present Worth per Acre** | **$22,912** | **$26,556** | **$82** | **$766** |

Table 6—*Continued*

Note:

[1]Order of magnitude cost estimate - is a combination of actual and estimated cost based on the specifics of the study wetlands and on anticipated common situations of wellfields. Such as ready access to nearby wells and existing pump houses, either online, offline, or abandoned. Pumps were specifically sized for the augmentation study

Study Site No. 1 – A 3-Hp pump was used for calculating the pump station cost. Specifications were adapted from the Tillman Ridge 5th Annual Hydration memorandum (CH2M HILL 2006)

Study Site No. 3 – A 5-Hp pump and pipe specifications were adapted from the City of Port Orange Wellfield 5th Annual Hydration report (CH2M HILL 2007a) and were used in calculating the pump station cost

Study Site No. 2 – Adjustable height aluminum weir with 6-in. stop logs, total weir height 2 ft, weir width 35 ft

Study Site No. 4 – Adjustable height wooden weir with 12-in. stop logs, total weir height 2 ft, weir width 15 ft

Environmental resource permit applications (ERP) to construct the weirs in the outfall canal and ditch were prepared by each utility.
ERP was avoided at the active hydration sites by terminating the delivery pipe at the wetland edge

Permit preparation/engineering design labor, at 25% of total capital costs, was estimated by CH2M HILL.
Contractor's Markups - Overhead 10%, Profit 5%, Insurance 5%, Contingency 20%

[2]Monitoring equipment and installation costs are based on quotes from Infinity, Inc., for water level recorders (in 2009 dollars) plus labor estimates from CH2M HILL (see Table 7 for details).

[3]Annual operations and maintenance (O&M) costs are based on estimates from CH2M HILL (see Table 7 for details)

Table 7. Monitoring startup and annual operations, maintenance, and monitoring costs estimate

| Monitoring Startup (one time cost) | | | | | |
|---|---|---|---|---|---|
| **Description** | **Quantity** | **Unit** | **Unit Cost** | **Total Cost** | **Comments/Assumptions** |
| Equipment for water level monitoring | 2 | each | $1,000 | $2,000 | Continuous recording unit on top of PVC piezometer set 6-10 feet below ground surface |
| Installation and Startup | 128 | labor hours | $50 | $6,400 | Includes 3-man survey crew and 1 ecologist. |
| Total Monitoring Startup Cost | | | | $8,400 | Per wetland monitored |
| **Annual Operations & Maintenance and Monitoring Costs** | | | | | |
| **Description** | **Quantity** | **Unit** | **Unit Cost** | **Annual Cost[1]** | **Comments/Assumptions** |
| Annualized replacement of pump and valve | 1 | each | $4,000 | $745.00 | Pump needs replacement every 10 years (not applicable to control weir projects) |
| Annualized replacement of water level recorders | 2 | each | $1,000 | $727.50 | Recorders need replacement every 5 years |
| Taking water Level readings | 1.5 d/qtr/yr 1 person | per hour per person | $25 | $2,058.60 | Wellfield technician from utility would record reading |
| Annual Report - if required by agency | 3 days/year 1 person | per hour per person | $25 | $1029.30 | Wellfield technician from utility would prepare report |
| Total Annualized O&M Cost | | | | $4,560.40 | |

Note:
[1]Annual Costs include 4% construction inflation rate and 3% interest earnings rate.
Monitoring equipment and installation costs are based on quotes from Infinity, Inc., for water level recorders (in 2009 dollars) plus labor estimates from CH2M HILL
O&M labor costs for wellfield technician utility is estimated to be $25 per hour, working 8 hours per day; plus annual labor inflation rate of 4%
d/qtr/yr = days/quarter/year
O&M = operations and maintenance
PVC = polyvinyl chloride

In accordance with this study, public access to the wetlands should be considered in the maintenance costs. Two of the four sites were moderately accessible to the public, although not open to the public: Titusville Parkland Wetland – set amid a residential area with a high school across the street; and Bennett Swamp – unfenced and adjacent to a growing residential area near Daytona. Security should be considered in protecting equipment and structures as vandalism occurred at both of these sites and would be a potential add-on cost.

Operating pilot projects for up to 5 years yield actual capital costs for planning, permitting and design, construction, monitoring, and operation and maintenance.

**Monitoring of Success Criteria**

Monitoring water levels (previously discussed) as a success metric will allow the wellfield operator to assess the option of implementing a pump rotation and/ or allow flexibility in timing of the water delivery. Wetlands are quite adaptable to the natural fluctuations in the regional rainfall patterns; therefore, adaptive management of a scheduled pumping plan is expected.

As illustrated in the flowchart (Figure ES-1), the decisions and various factors that should be considered when selecting one of these impact avoidance strategies include a minimal amount of ecological data needed to develop a target hydrograph, which provides a useful standard for measuring success in maintaining a viable ecological condition in the wetland. Site-specific ecological data are used to develop a starting augmentation schedule (quantity and timing), through which a viable ecological condition of the wetland can be maintained

When wet-season water levels are maintained in the wetland within 1 foot of the target hydrograph, impacts can be avoided. Regular monitoring of the water levels will serve as a first indicator of the point at which augmentation amounts should be adjusted, that is, increased or decreased. In the situation of using a control weir to increase the wetland’s hydroperiod, the water levels should be compared to the target hydrograph during average, or above average, rainfall years. A longer evaluation period (several years) may be necessary to measure the success of this passive (rainfall-dependent) augmentation strategy. If weather patterns become increasingly more irregular, the passive strategy will also become less reliable when used alone. However, when used in conjunction with active augmentation, the effectiveness of the combined strategies would be substantial.

**Water Quantity, Efficiency and Timing of Water Delivery**

Site-specific wetland conditions (habitat type, size, soil condition, hydroperiod) will factor into the determination of quantity and timing of water delivery. For example, the Tillman Ridge study site, an isolated, forested wetland with a relatively deep hydroperiod (historically) and thick mucky soils showed dramatic improvement in surface water levels when 8 MG per year were delivered to the wetland. However the Port Orange study site, a wetland with more complex hydrologic connections, a shallow hydroperiod, sandy-mineral soils, and normal water table condition showed no additional benefit after receiving an average of 3.3 MG per year.

During this study, one goal was to set a realistic and simple operation schedule so that managing the effort could be achieved without significant additional cost to the wellfield operators. The 24-hour pumping increment was simple to implement and document and was not overly burdensome to the wellfield operators. For ease of operation, hydration occurred in 24-hour increments each month. The number of irrigation periods per month varied depending on the season and the wetland's specific condition. Tillman Ridge wetland received more water in a year's time than did the wetland at Port Orange; and three times the volume of water was delivered in August than in January to Tillman Ridge wetland.

The rates of application varied with the pump size; at Tillman Ridge, a small amount of water, approximately ¾ inch was applied in a 24-hour irrigation period; and at Port Orange, water was applied at a rate of 2 inches per 24-hour period, in general. For example, the augmentation schedule conducted in 2003 at the Tillman Ridge wetland (see Table 8) represents a typical annual schedule. Included in the table are the monthly application amounts and total annual gallons (8 million) and inches (58) applied to the 5-acre wetland.

Table 8. Typical annual augmentation schedule and monthly summary at Tillman Ridge 5-acre study wetland

| Date Pump On 10 A.M. | Date Pump Off 10 A.M. | START Flow Value Reading | STOP Flow Value Reading | Total Gallons | Number of Days | GPD | GPM | Application Depth (inches)* | Total Gallons /month | Monthly Application Depth (inches)* | Month |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1/13/2003 | 1/17/2003 | 128,529 | 132,840 | 431,100 | 4 | 107,775 | 75 | 3.2 | 431,100 | 3.2 | Jan-03 |
| 2/10/2003 | 2/13/2003 | 132,840 | 136,198 | 335,800 | 3 | 111,933 | 78 | 2.5 | | | |
| 2/24/2003 | 2/27/2003 | 136,198 | 139,561 | 336,300 | 3 | 112,100 | 78 | 2.5 | 672,100 | 5.0 | Feb-03 |
| 3/3/2003 | 3/6/2003 | 139,561 | 142,910 | 334,900 | 3 | 111,633 | 78 | 2.5 | | | |
| 3/17/2003 | 3/19/2003 | 142,910 | 145,162 | 225,200 | 2 | 112,600 | 78 | 1.7 | 560,100 | 4.1 | Mar-03 |
| 4/14/2003 | 4/18/2003 | 145,162 | 149,666 | 450,400 | 4 | 112,600 | 78 | 3.3 | 450,400 | 3.3 | Apr-03 |
| 5/5/2003 | 5/8/2003 | 149,666 | 153,056 | 339,000 | 3 | 113,000 | 78 | 2.5 | | | |
| 5/19/2003 | 5/21/2003 | 153,056 | 154,206 | 115,000 | 2 | 57,500 | 40 | 0.8 | 454,000 | 3.3 | May-03 |
| 6/23/2003 | 6/27/2003 | 154,206 | 158,975 | 476,900 | 4 | 119,225 | 83 | 3.5 | 476,900 | 3.5 | Jun-03 |
| 7/8/2003 | 7/12/2003 | 158,975 | 162,863 | 388,800 | 4 | 97,200 | 68 | 2.86 | | | |
| 7/15/2003 | 7/19/2003 | 162,863 | 166,913 | 405,000 | 4 | 101,250 | 70 | 3.0 | | | |
| 7/22/2003 | 7/23/2003 | 166,913 | 167,920 | 100,700 | 1 | 100,700 | 70 | 0.7 | 894,500 | 6.6 | Jul-03 |
| 8/5/2003 | 8/8/2003 | 167,920 | 172,270 | 435,000 | 3 | 145,000 | 101 | 3.2 | | | |
| 8/12/2003 | 8/15/2003 | 172,270 | 176,878 | 460,800 | 3 | 153,600 | 107 | 3.4 | | | |
| 8/19/2003 | 8/23/2003 | 176,878 | 181,578 | 470,000 | 4 | 117,500 | 82 | 3.5 | 1,365,800 | 10.1 | Aug-03 |
| 9/9/2003 | 9/13/2003 | 181,578 | 186,228 | 465,000 | 4 | 116,250 | 81 | 3.4 | | | |
| 9/16/2003 | 9/20/2003 | 186,228 | 191,326 | 509,800 | 4 | 127,450 | 89 | 3.8 | | | |
| 9/23/2003 | 9/25/2003 | 191,326 | 193,198 | 187,200 | 2 | 93,600 | 65 | 1.4 | 1,162,000 | 8.6 | Sep-03 |
| 10/7/2003 | 10/10/2003 | 193,198 | 195,719 | 252,100 | 3 | 84,033 | 58 | 1.9 | | | |
| 10/21/2003 | 10/23/2003 | 195,719 | 197,619 | 190,000 | 2 | 95,000 | 66 | 1.4 | 442,100 | 3.3 | Oct-03 |
| 11/4/2003 | 11/8/2003 | 197,619 | 202,369 | 475,000 | 4 | 118,750 | 82 | 3.5 | 475,000 | 3.5 | Nov-03 |
| 12/9/2003 | 12/13/2003 | 202,369 | 207,751 | 538,200 | 4 | 134,550 | 93 | 4.0 | 538,200 | 4.0 | Dec-03 |
| | | | Total | Gallons /Year | Days | Average GPD | Average GPM | Inches* | Gallons /Year | Inches /Year* | |
| | | | | **7,922,20** | **70** | **113,174** | **77** | **58.4** | **7,922,200** | **58.4** | |

Note:
GPD = gallons per day
GPM = gallons per minute
*Based on a 5-acre wetland

# SUMMARY OF FINDINGS

The existing hydrologic and ecological condition of a wetland contributes to the success of hydration strategies and should be evaluated during the preliminary investigation of any potential site. For example, existing outfalls, culverts, ditches, pop-offs, and improved surface water connections to other systems will alter a wetland's hydrology and could diminish the potential benefits of active hydration. Alterations such as these need to be considered when selecting a hydration method, or combination of methods, to enhance the success of reaching target historical hydrological conditions. The amount of runoff from contributing drainage areas should be evaluated and long-term water balances estimated to help set target water control levels appropriate for the wetland, as well as the surrounding land uses. Existing conditions of ecological communities should also be identified prior to implementing a hydration strategy. Wetlands exhibiting effects of long-term impacts, such as soil subsidence, invasive exotic plants, fire, logging, and watershed urbanization, will be slow to demonstrate improved ecological benefits. These conditions should be thoroughly assessed, and a baseline condition documented, in order to evaluate accurately the success of the hydration strategy implemented.

The strategy flowchart (Figure ES-1) provided previously in this report is an example of the step-wise evaluations and decisions that a utility might consider when selecting a site-specific strategy for impact avoidance. As depicted in the flowchart, minimal ecological data are needed to develop the target hydrograph upon which the augmentation schedule is based.

A target hydrograph, based on historical wetland hydrologic indicators, was a necessary and effective tool for evaluating whether hydration rates or weir heights were successful. Active and passive hydration strategies were able to meet or exceed target hydration goals at three of the four demonstration sites (Tillman Ridge, Port Orange, and Titusville). Only at Bennett Swamp did water levels not meet the target hydrograph. At Bennett Swamp, the operational period included an extended period of low to very low rainfall, and for nearly half the study, the weir had no effect in raising water levels or prolonging hydroperiods. Once a more typical rainfall pattern returns, the frequency distribution of water levels likely will more closely align with the target hydrograph.

Active hydration provided a very flexible and manageable strategy that was less dependent on environmental conditions (rainfall) and changes in the surrounding watershed compared to passive hydration. For the active hydration projects, the improved hydrologic conditions were evident in the first year; and these changes were easily monitored with simple water level recording equipment. Active hydration schedules can be adjusted in response to changes in monthly or annual rainfall. Hydration rates could be calibrated to each site's target performance goal.

Under the active hydration strategy described here, operation and maintenance of the water delivery system, monitoring equipment, and data reporting would be cost effective and could be implemented by utilities. Comparison of active hydration unit costs to wetland mitigation alternatives indicate that impact avoidance using this strategy would be more cost effective than purchasing wetland credits to offset impacts from surface water drawdown. Depending on the site-specific conditions, the cost savings from avoiding impacts through active augmentation might be 85% lower than the current practice of purchasing credits from a mitigation bank (see Table 5).

Passive hydration sites, while being less expensive to construct and maintain, cannot provide control of rainfall-driven water inputs when rainfall is low or absent and thus proved to be a less reliable impact avoidance strategy over the short term. The target performance of wetlands using passive hydration was also detectable with simple water level monitoring equipment. While management of water levels through a control weir may be appropriate at some sites, one must recognize that the process may take longer to demonstrate that target hydrograph goals are met when compared with the relatively short amount of time needed to achieve results using active hydration. At the passive hydration demonstration sites, target hydration goals were either exceeded (Titusville Parkland Wetland) for most of the study period in response to above average seasonal rainfall, or were closely approximated (Bennett Swamp). When Bennett Swamp received average or above average rainfall, water levels were measurable by the transect recorders; this also occurred during the baseline period (prior to weir installation), however during periods of extended drought water levels fell beneath the bottom of the piezometers and were not measurable.

Water levels in the Titusville Parkland Wetland fluctuated greatly in response to rainfall during the baseline (prior to weir construction) and operational periods of the study. Periods of heavy seasonal rainfall produced deep, long-standing surface water in the Parkland Wetland, which limited the germination and establishment of most herbaceous plants and shrubs and provided favorable conditions for floating aquatic species. Installation of the control weir in the outfall ditch resulted in surface water being stored for longer periods compared to the baseline period and without increasing flooding of the surrounding urbanized watershed. Slightly greater than average seasonal rainfall amounts during the operational period increased the stage exceedence at every elevation compared to the baseline period and pushed exceedence values above the historical hydrograph, which kept the wetland water levels above the CUP pumping-limit threshold for the supply wells near the wetland. It will be important to manage water levels in association with corresponding rainfall to avoid over-extending hydroperiods, which could result in potential adverse responses in the wetland (i.e. changes to vegetative communities, impacts to amphibians from predatory fishes).

During periods of below average rainfall, water levels fell below the surface at both passive hydration demonstration sites, at which point the weirs had no effect. When rainfall at these passive sites was low, or none, for a prolonged period, managing water levels to near-target elevations proved to be difficult. Nevertheless, without blocking these man-made outfall conveyances, the effectiveness of any hydration strategy likely would be reduced. Where possible, the inclusion of control weirs in conjunction with active hydration would provide greater management flexibility and a faster hydrologic response.

Frequent monitoring of plant communities within demonstration sites did not provide a measurable indicator of the hydration success during the short baseline and 5-year study periods. Data from plant communities were variable and indicated that plant response to changes in water levels were likely slower than the frequency at which they were observed, except when inundated by surface water. Less frequent monitoring of plant communities over an increased duration is recommended to detect slow-to-respond shifts.

Amphibian communities, in contrast to plant communities, responded quickly to increased surface water availability from rainfall, hydration, or both. At the Tillman Ridge demonstration site, amphibian abundance and diversity were greater than nearby control wetlands within the same wellfield. At Port Orange, changes in amphibian abundance and diversity responded to changes in rainfall and did not differ between the demonstration site and the control wetlands. Results from the Port Orange site reinforced observations that rainfall, more so than hydration, was the dominant water input. Amphibian populations also were observed to decline at Port Orange after long periods of surface water availability, particularly after the 2004 hurricane season. Too much and too little rainfall reduced amphibian abundance and diversity at Port Orange.

Amphibian abundance and diversity at the passive hydration sites (Bennett Swamp and Titusville) tracked changes in seasonal and annual rainfall. During periods of increased rainfall, amphibian populations increased. When rainfall inputs decreased, amphibian populations declined once surface water fell below the wetland surfaces. Because of the seasonal and annual fluctuation in rainfall, the results of passive hydration alone may not be enough to avoid potential impacts to amphibian communities.

The use of groundwater at active hydration sites did not adversely affect amphibian communities. Water quality samples collected when surface water was available were more characteristic of Florida swamps (low pH, high color, low alkalinity) than of typical groundwater (elevated pH and alkalinity). Only minor and temporary deviations in surface water quality were observed at Tillman Ridge and Port Orange, and none that could be attributed to groundwater additions. The placement of the water delivery system at the wetland edge (active hydration sites) had a two-fold benefit: First, by buffering the potential affect of groundwater quality by allowing supply water to contact wetland soils before mixing with surface waters and second, by avoiding pipeline and structures in the wetland, thus reducing the cost and issues associated with permitting.

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# Appendix A
# Hydrologic Study Results

# Graphs of Hydrology Results at Tillman Ridge Wellfield Wetland

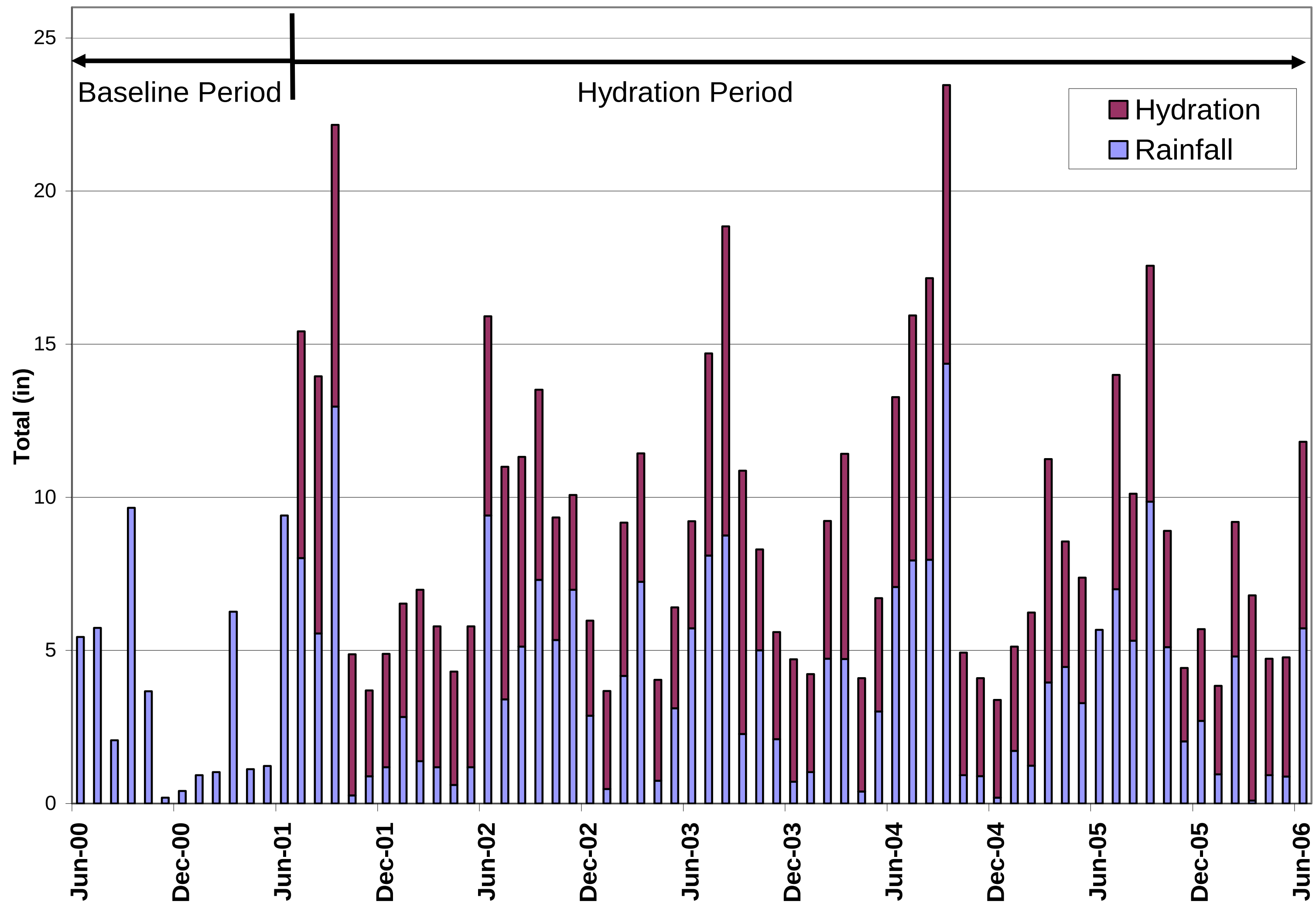


Figure A1. Tillman Ridge wellfield wetland. Rainfall and hydration water input: June 2000 to June 2006

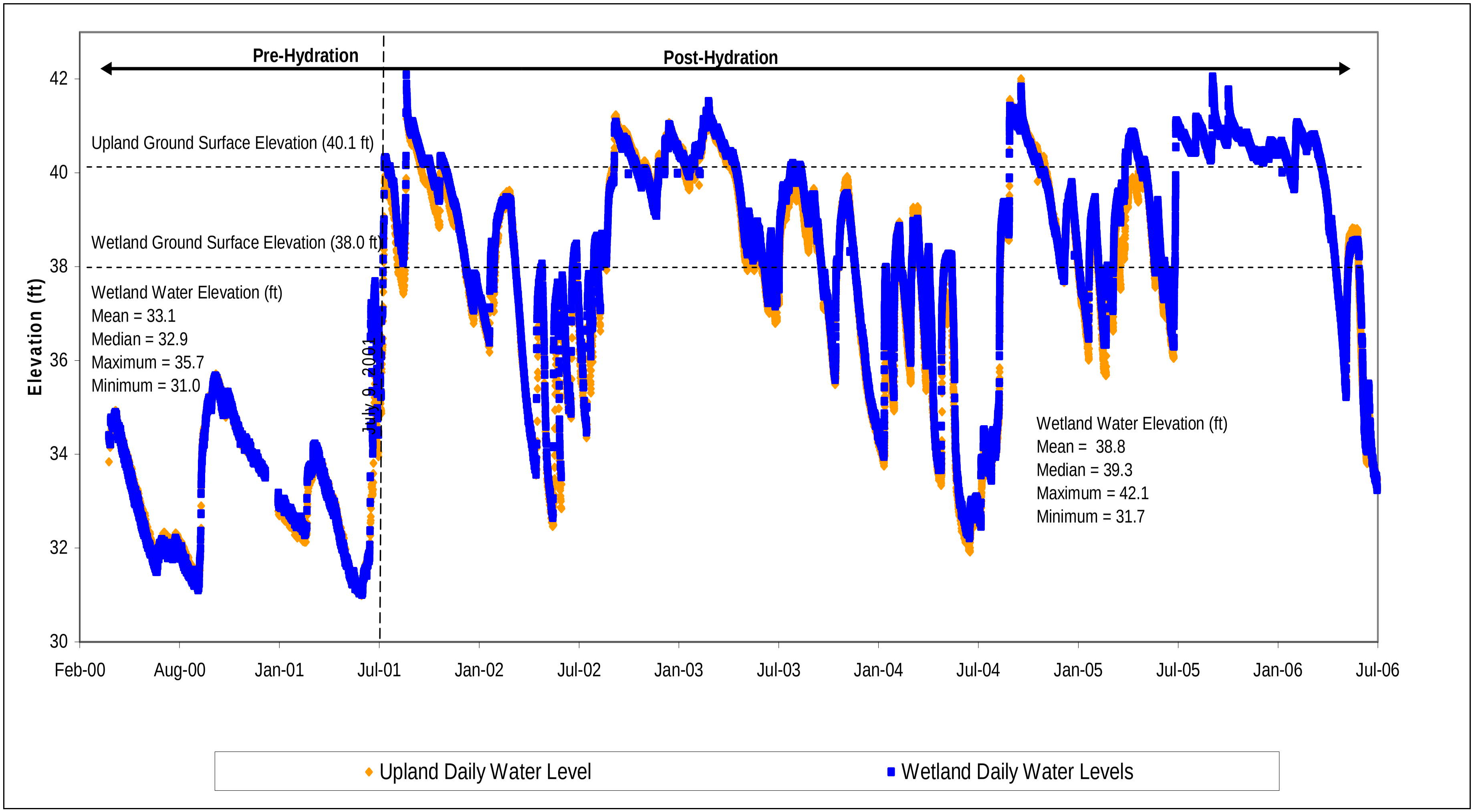


Figure A2. Tillman Ridge wellfield wetland. Upland and wetland water level elevations (NAVD88): March 2000 to June 2006

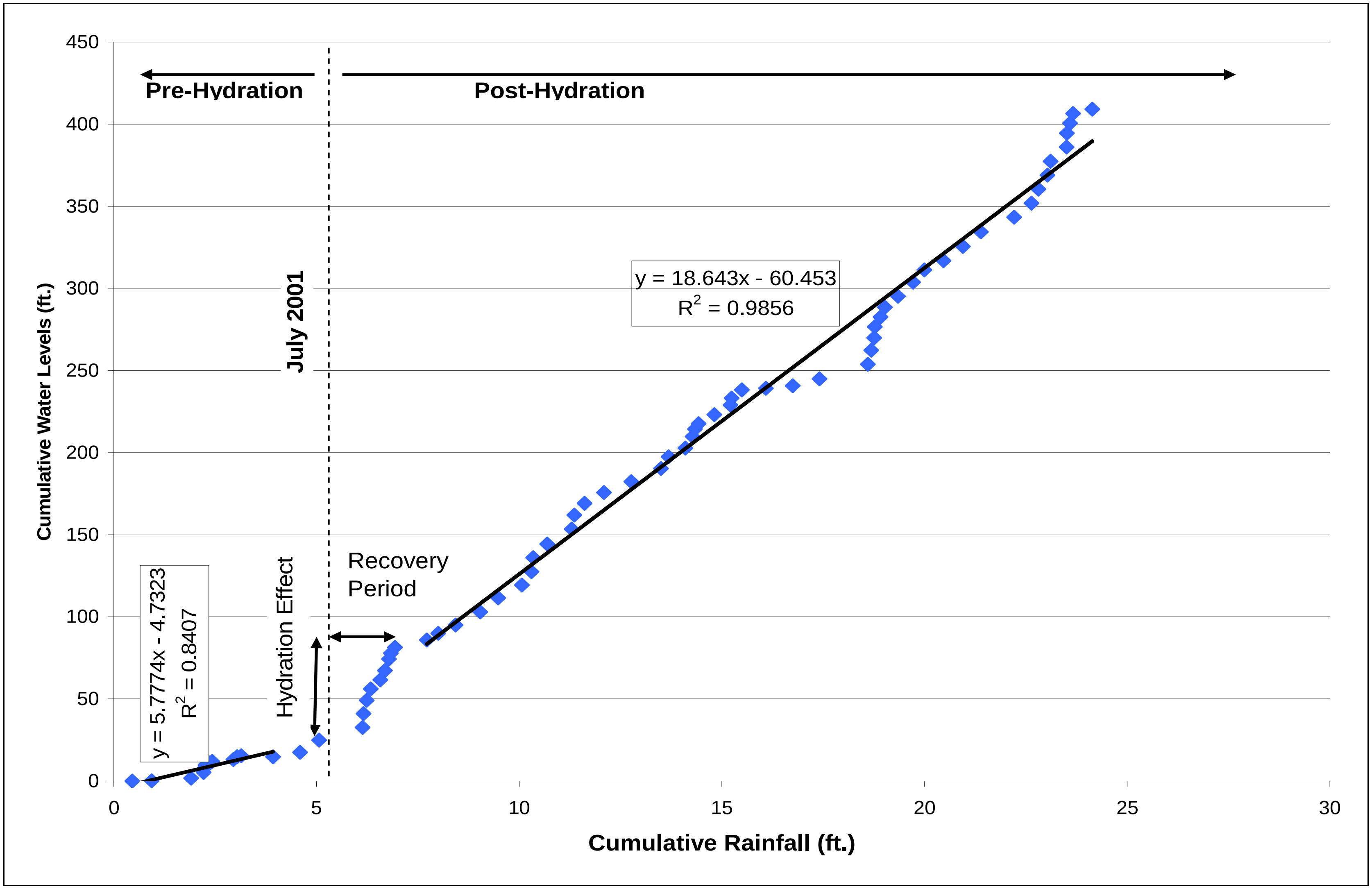


Figure A3. Tillman Ridge wellfield wetland. Cumulative water levels versus cumulative rainfall

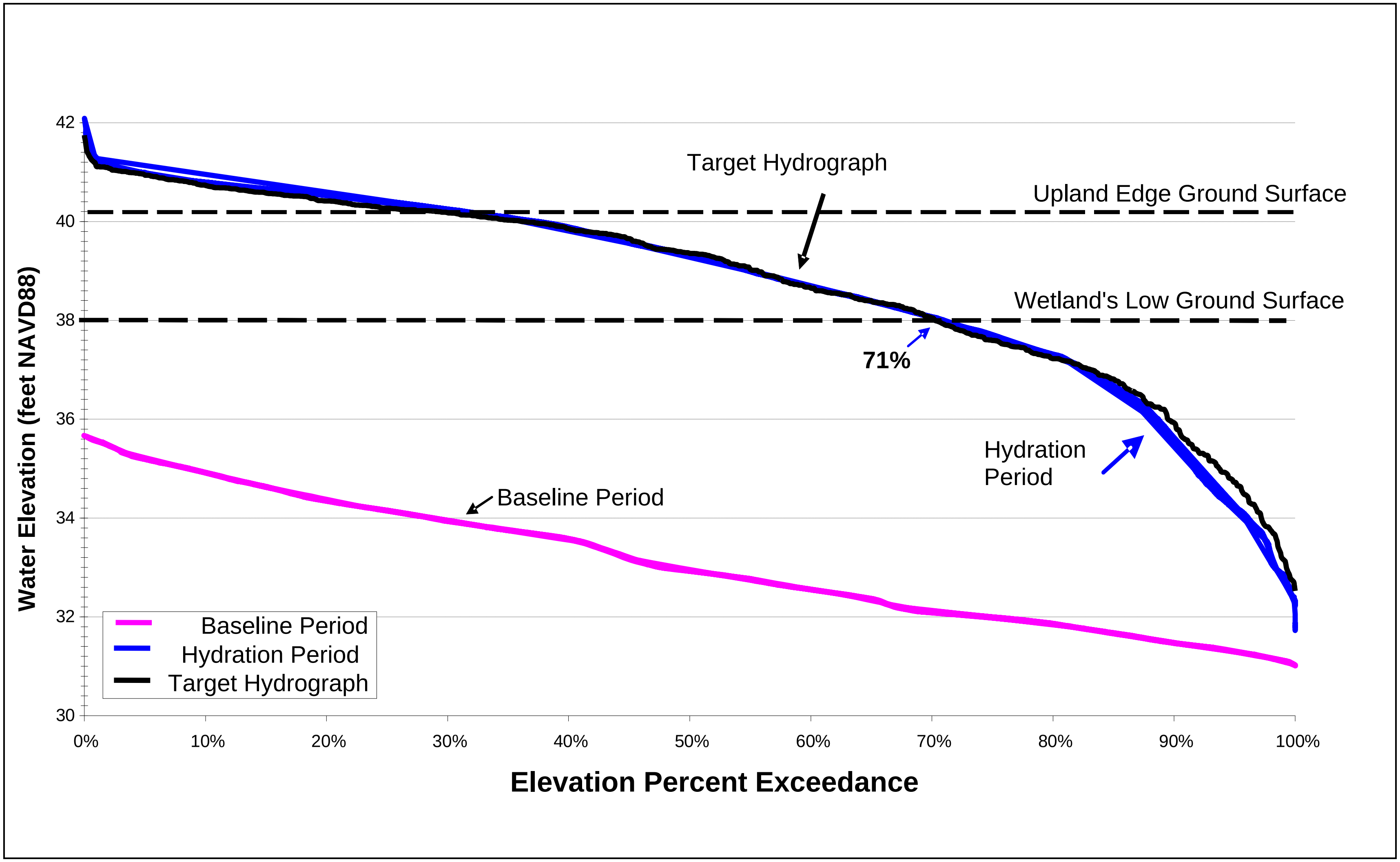


Figure A4. Tillman Ridge wellfield wetland. Pre-hydration and post-hydration stage exceedance curves

TARGET HYDROGRAPH WAS DEVELOPED BY ANALYZING BIOLOGICAL INDICATORS OF LONG-TERM WATER LEVEL CONDITION (SOILS AND VEGETATION) ON SITE.

# Appendix A - *Continued*

# Graphs of Hydrology Results at City of Port Orange Wellfield Wetland

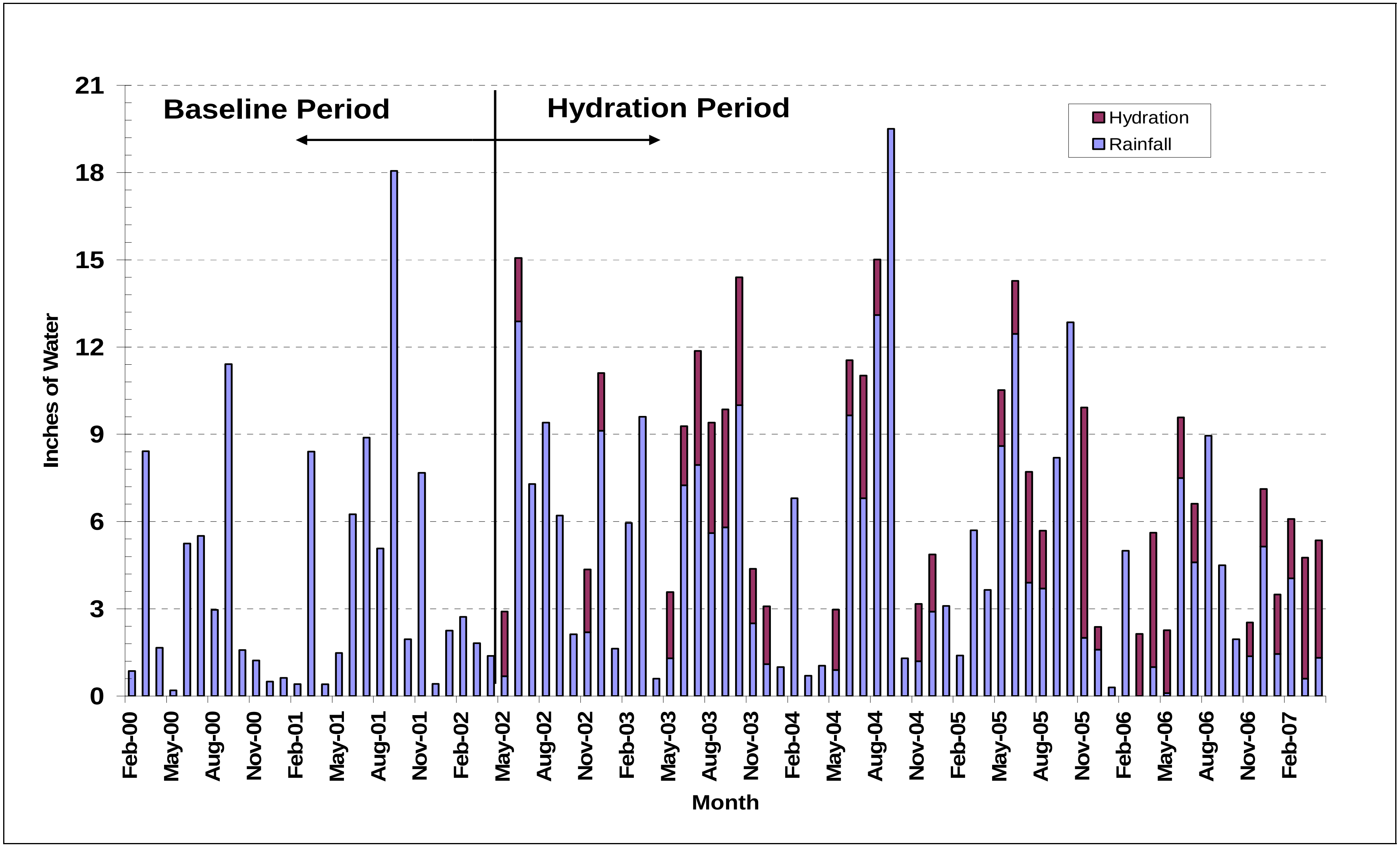


Figure A5. Port Orange wellfield wetland. Rainfall and hydration input: February 2000 to April 2007

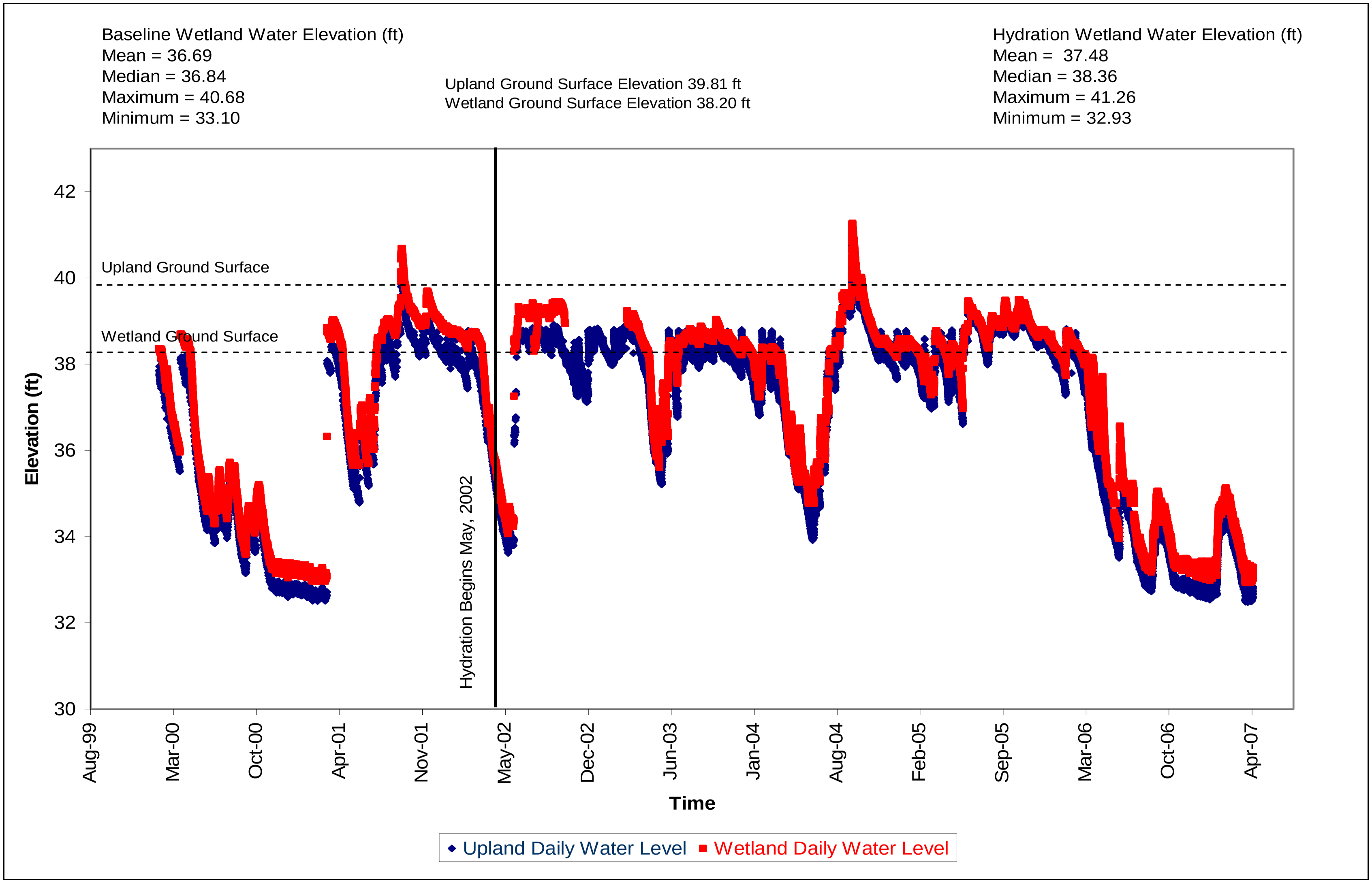


Figure A6. Port Orange wellfield wetland. Daily water elevations (NAVD88): February 2000 to April 2007

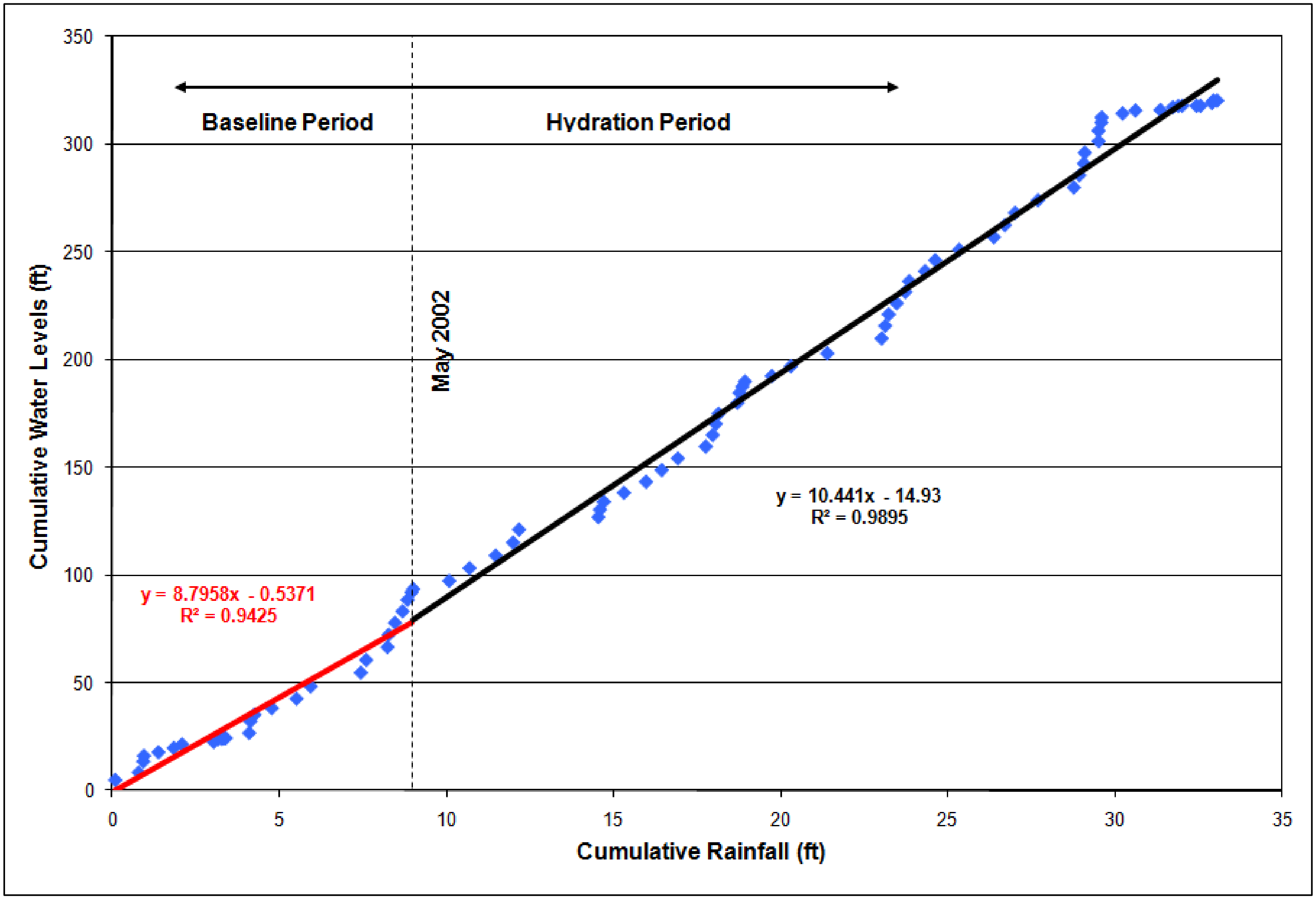


Figure A7. Port Orange wellfield wetland. Cumulative water level versus cumulative rainfall: February 2000 to April 2007

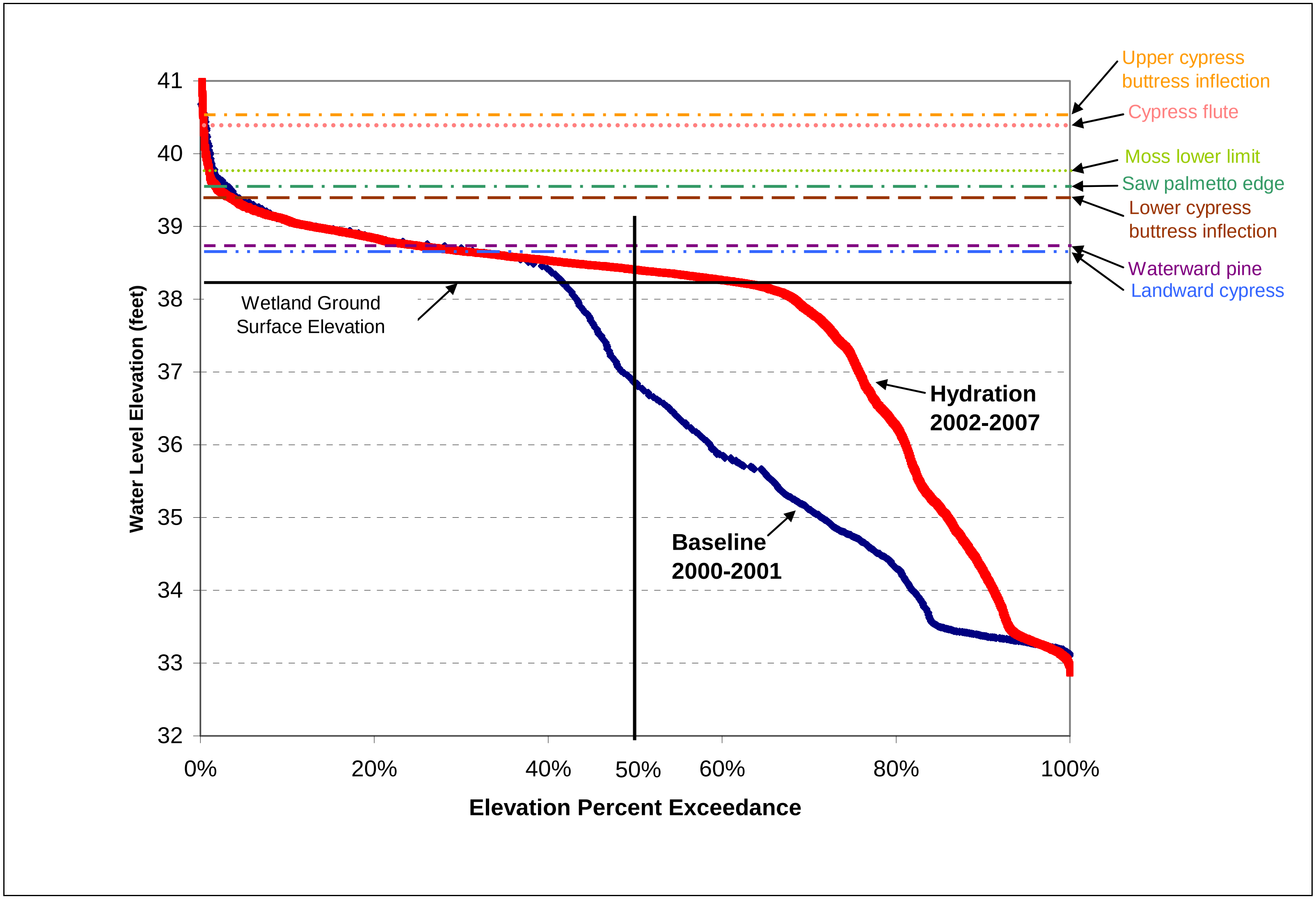


Figure A8. Port Orange wellfield wetland. Pre-hydration and post-hydration stage exceedance curves and hydrologic indicator stage elevation percentile rank (elevation in NAVD88)

Target hydrograph between 38.4 and 39.4 feet at 50% exceedence stage based on available historic hydrologic indicators (CH2M HILL 2007a).

# Appendix A - *Continued*

## Graphs of Hydrology Results at Bennett Swamp

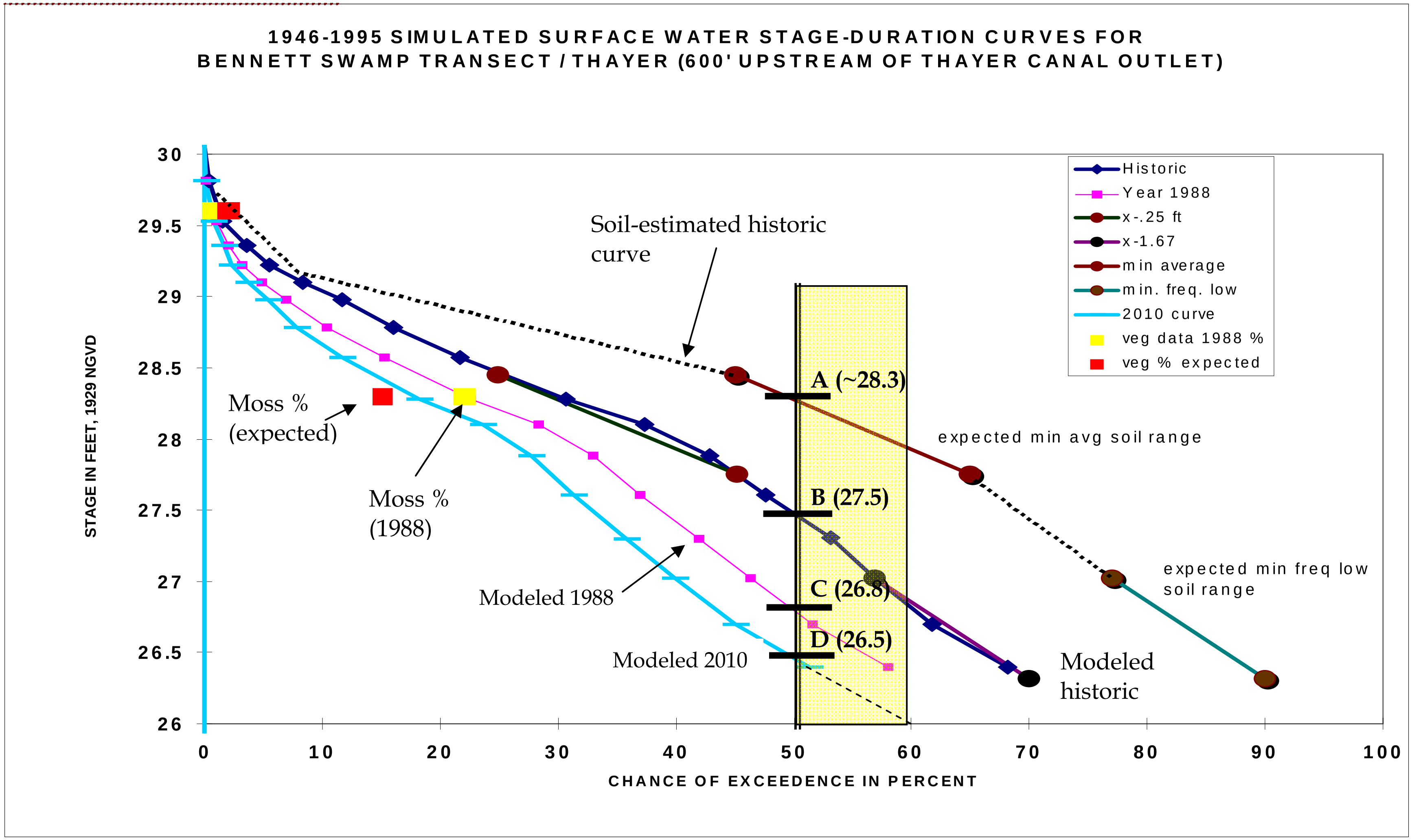


Figure A9. Stage-exceedance diagram with an approximation of the historical condition, Bennett Swamp

Estimation of possible elevation changes between about 15 and 60 percent stage-exceedance values in Bennett Swamp. Yellow-shaded zone shows the minimum average elevation zone for each curve (estimated from soil, historical, 1988, and 2010). Dotted lines on the curves are projected, not calculated, ranges of a curve.

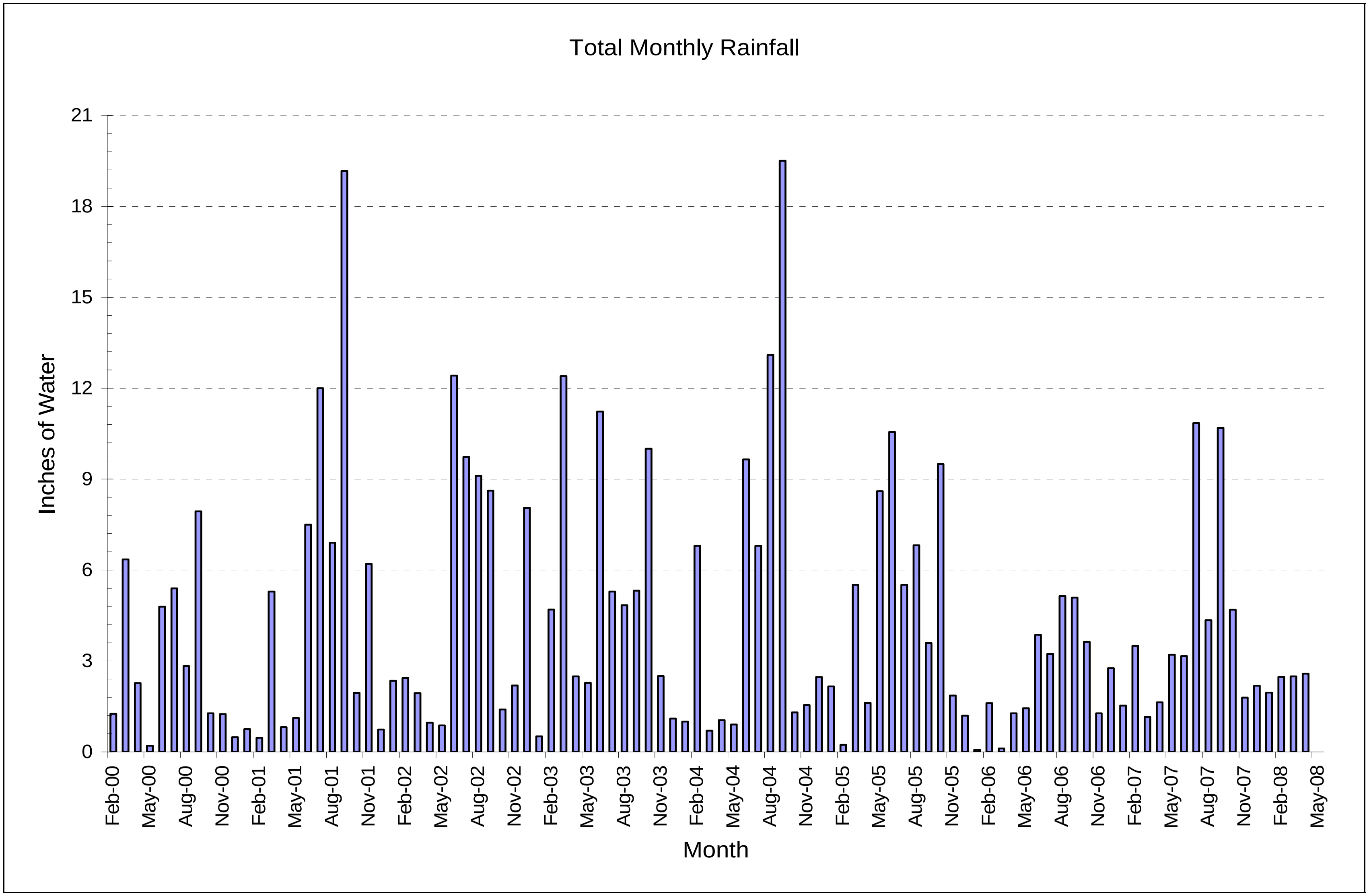


Figure A10. Bennett Swamp. Rainfall inputs from February 2000 to April 2008

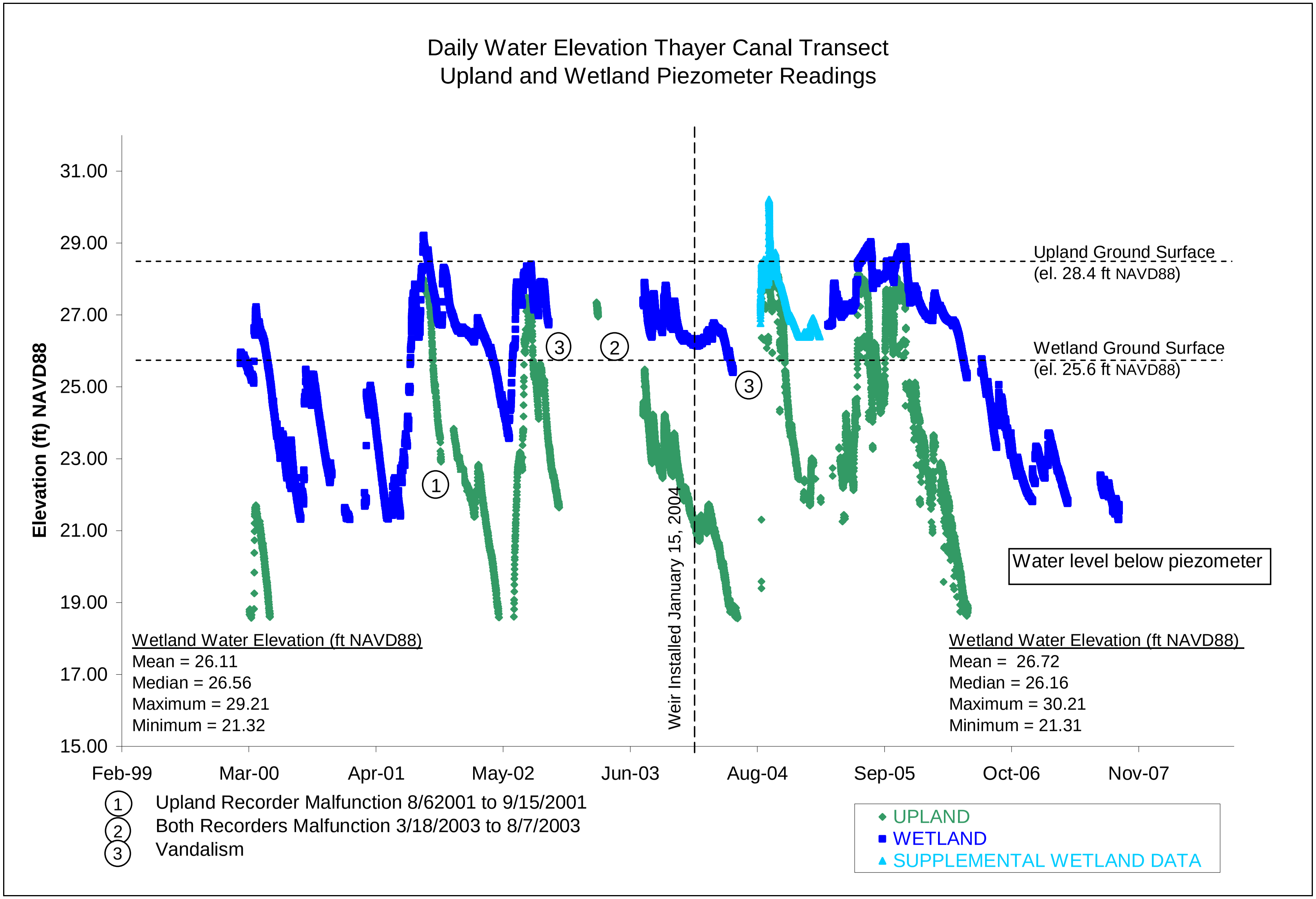


Figure A11. Bennett Swamp. Upland and wetland water-level elevations at Thayer Canal transect: February 2000 to April 2008

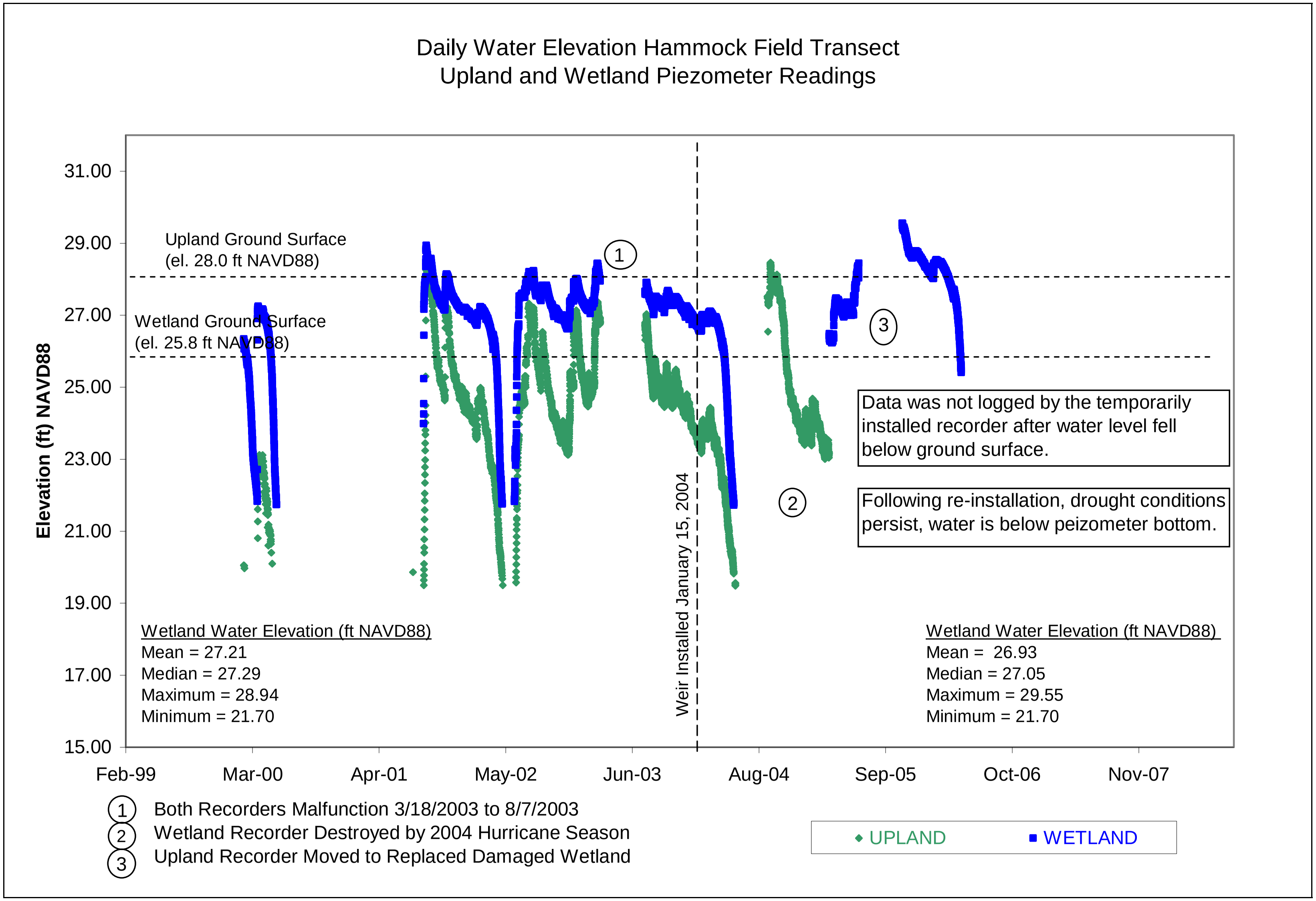


Figure A12. Bennett Swamp. Upland and wetland water-level elevations at Hammock Field transect: February 2000 to April 2008

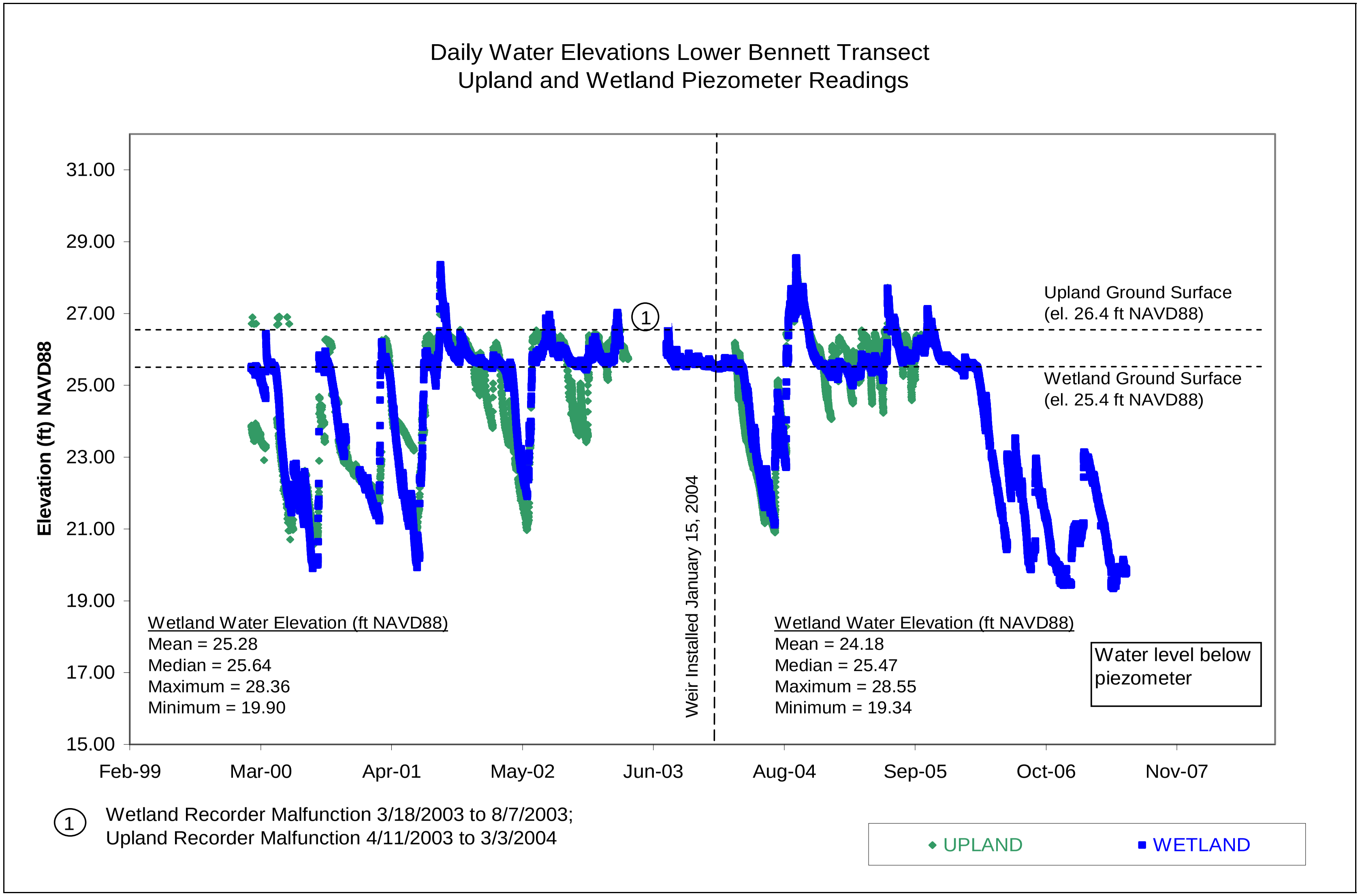


Figure A13. Bennett Swamp. Upland and wetland water-level elevations at Lower Bennett Swamp transect: February 2000 to April 2008

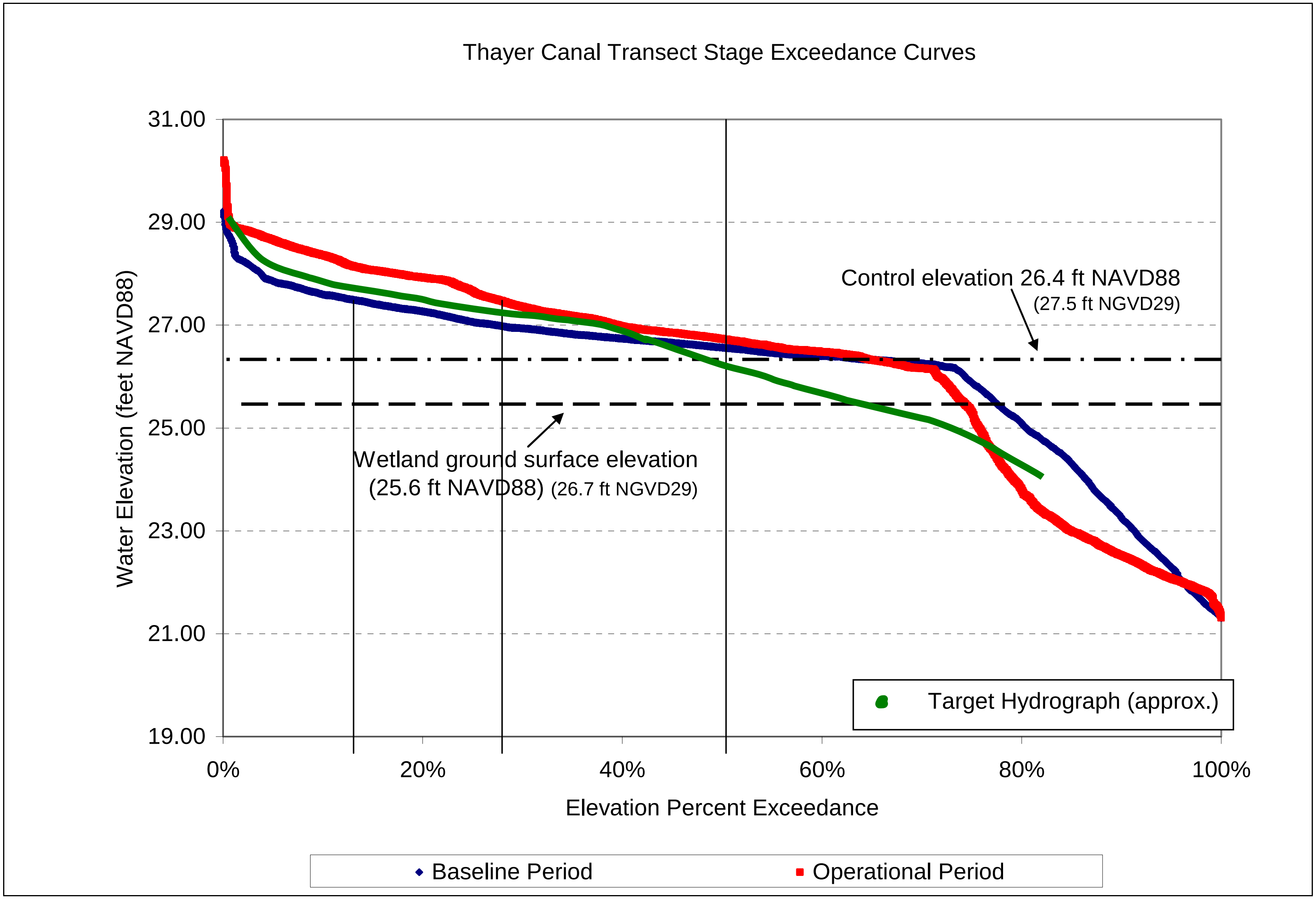


Figure A14. Bennett Swamp. Baseline and Operational period stage-exceedance curves at Thayer Canal transect: February 2000 to April 2008

Target hydrograph line (green) is an estimation of the line shown in Figure A9 for the Modeled Historic exceedance curve.

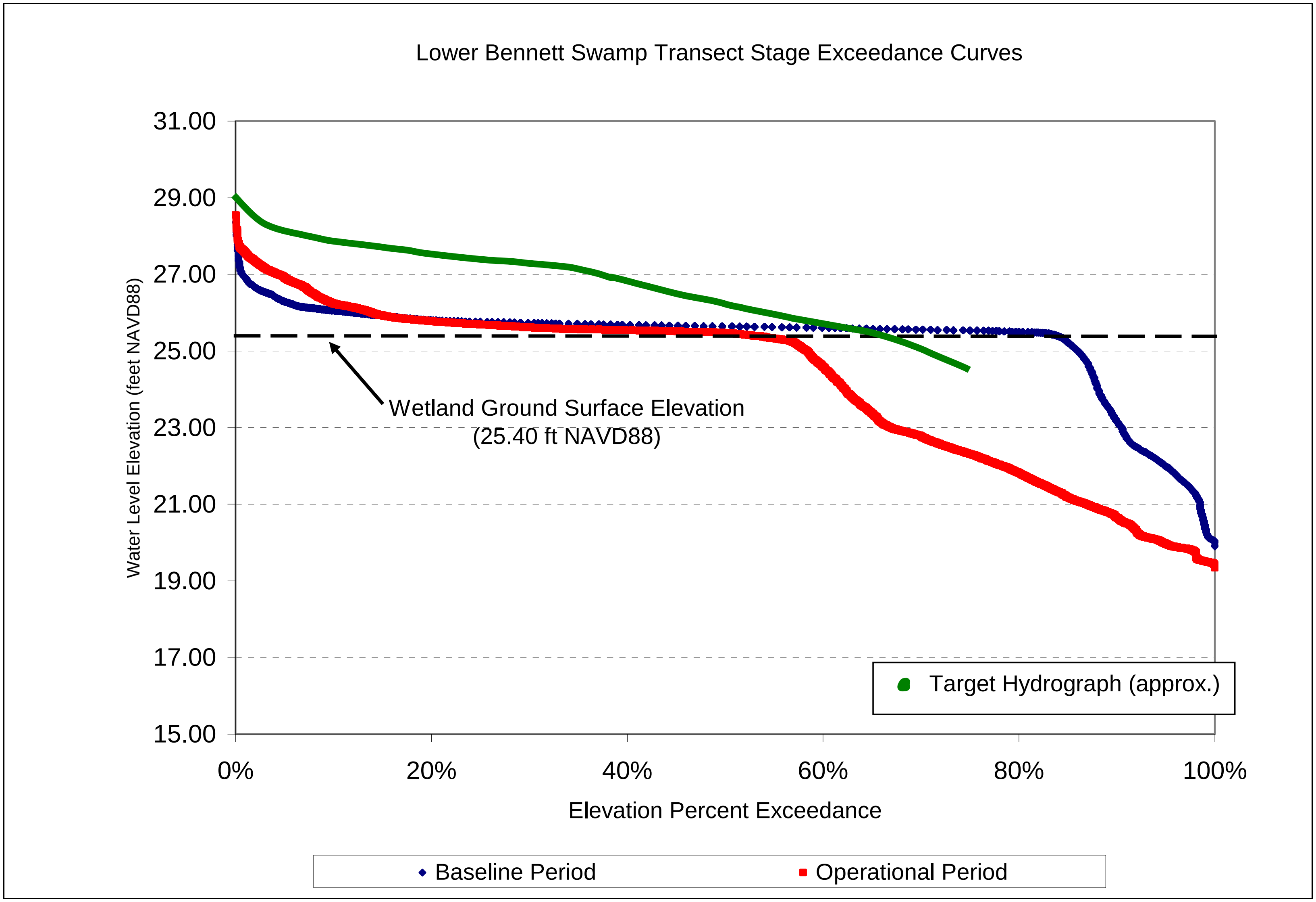


Figure A15. Bennett Swamp. Baseline and operational period stage-exceedance curves at Lower Bennett Swamp transect: February 2000 to April 2008

Target hydrograph line (green) is an estimation of the line shown in Figure A9 for the Modeled Historic exceedance curve.

# Appendix A - *Continued*

# Graphs of Hydrology Results at Parkland Wetland at Titusville

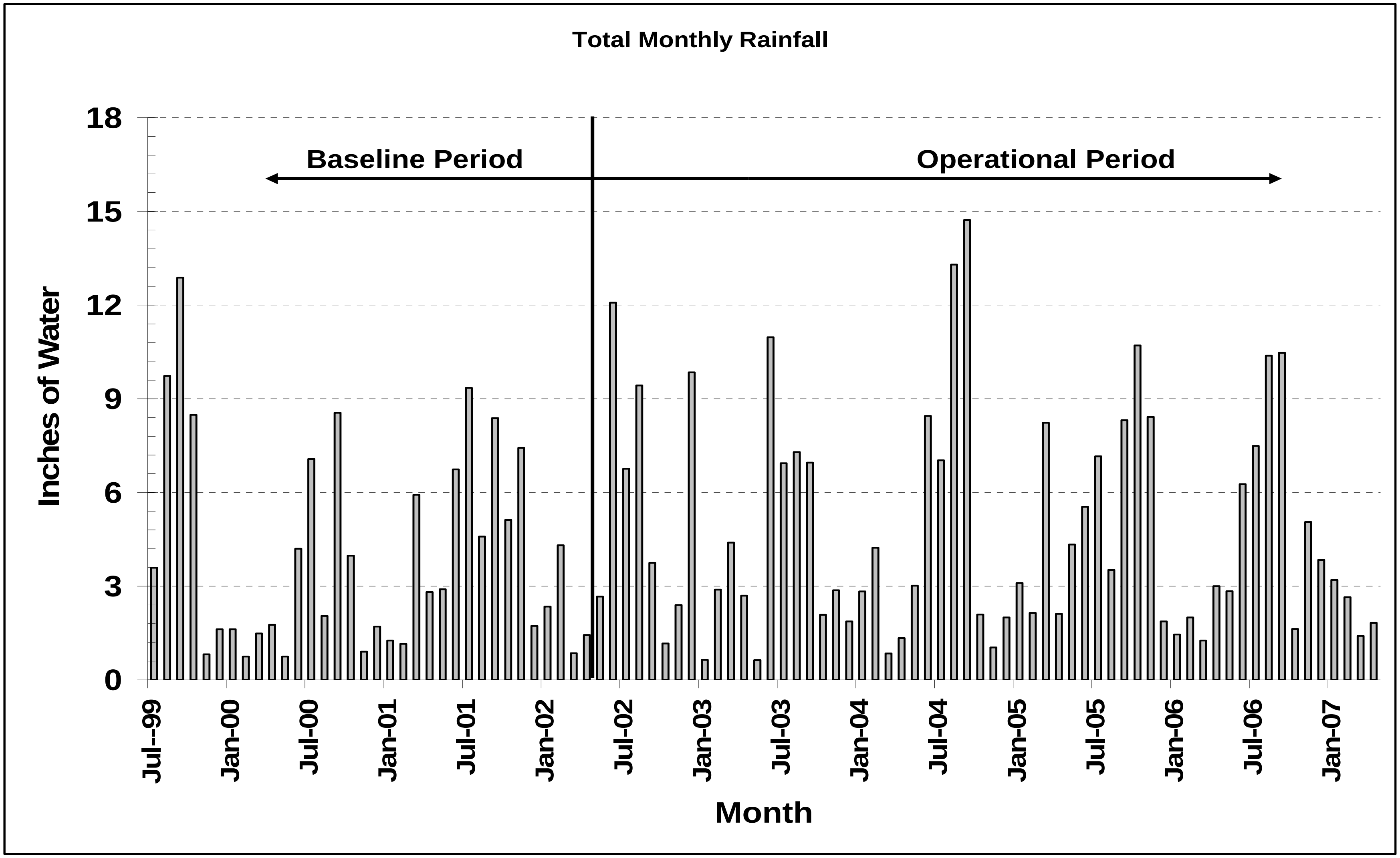


Figure A16. Titusville Parkland Wetland. Rainfall inputs from August 1999 to April 2007

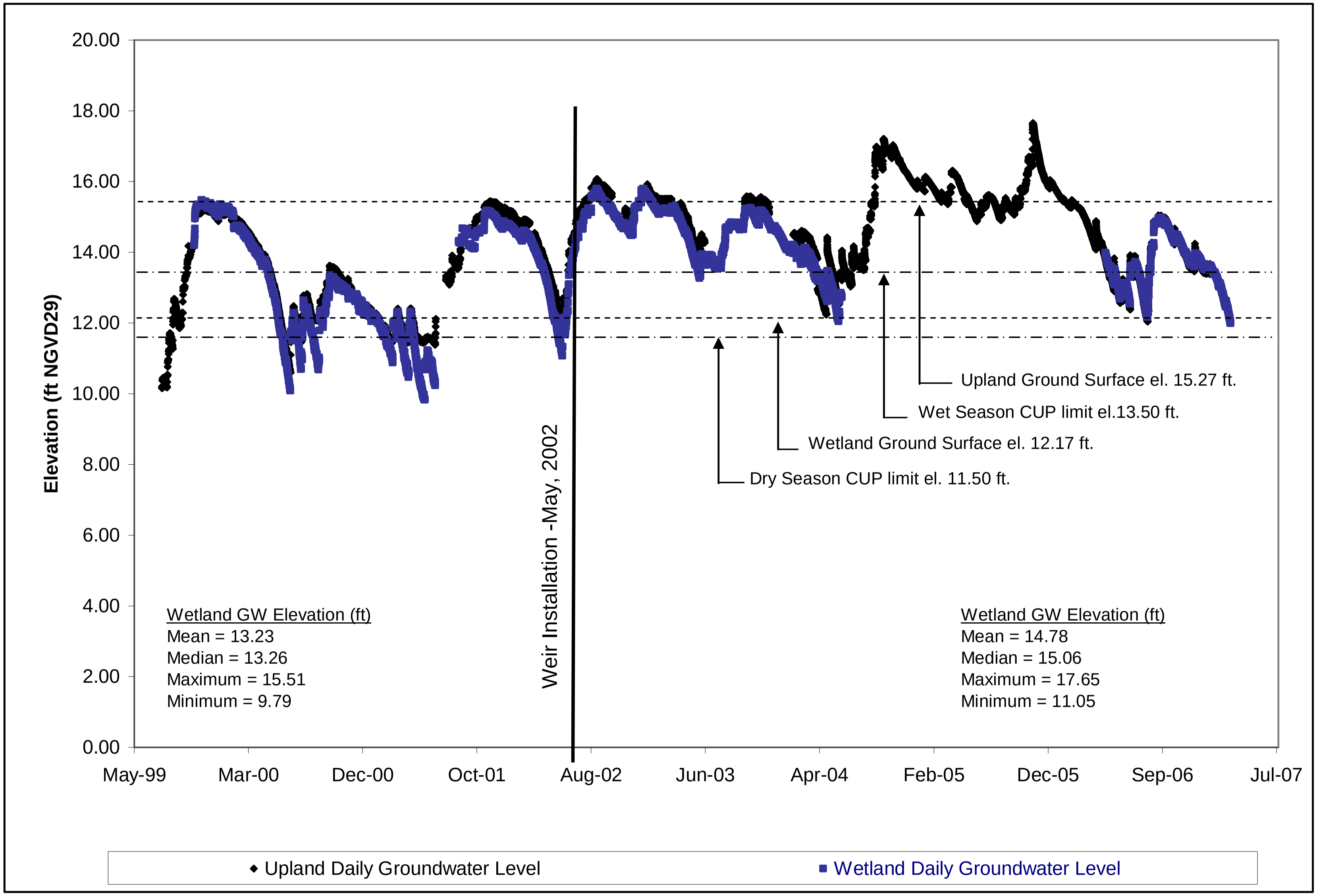


Figure A17. Titusville Parkland Wetland. Upland and wetland water level elevations: August 1999 to March 2007

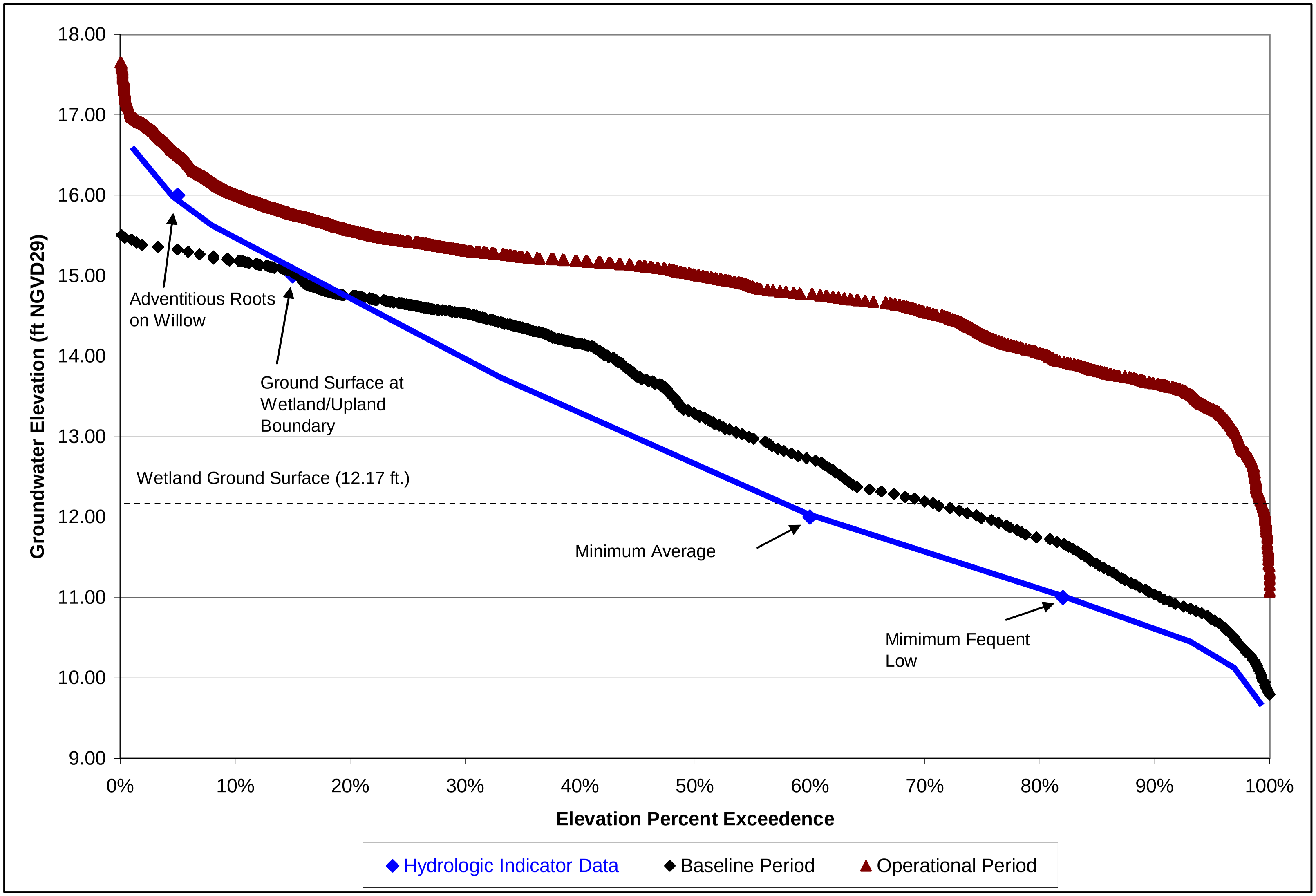


Figure A18. Titusville Parkland Wetland. Baseline and operational period stage-exceedance curves: August 1999 to April 2007

# Appendix B
# Vegetation Monitoring Results

# Charts of Vegetation Results at Tillman Ridge Wellfield Wetland

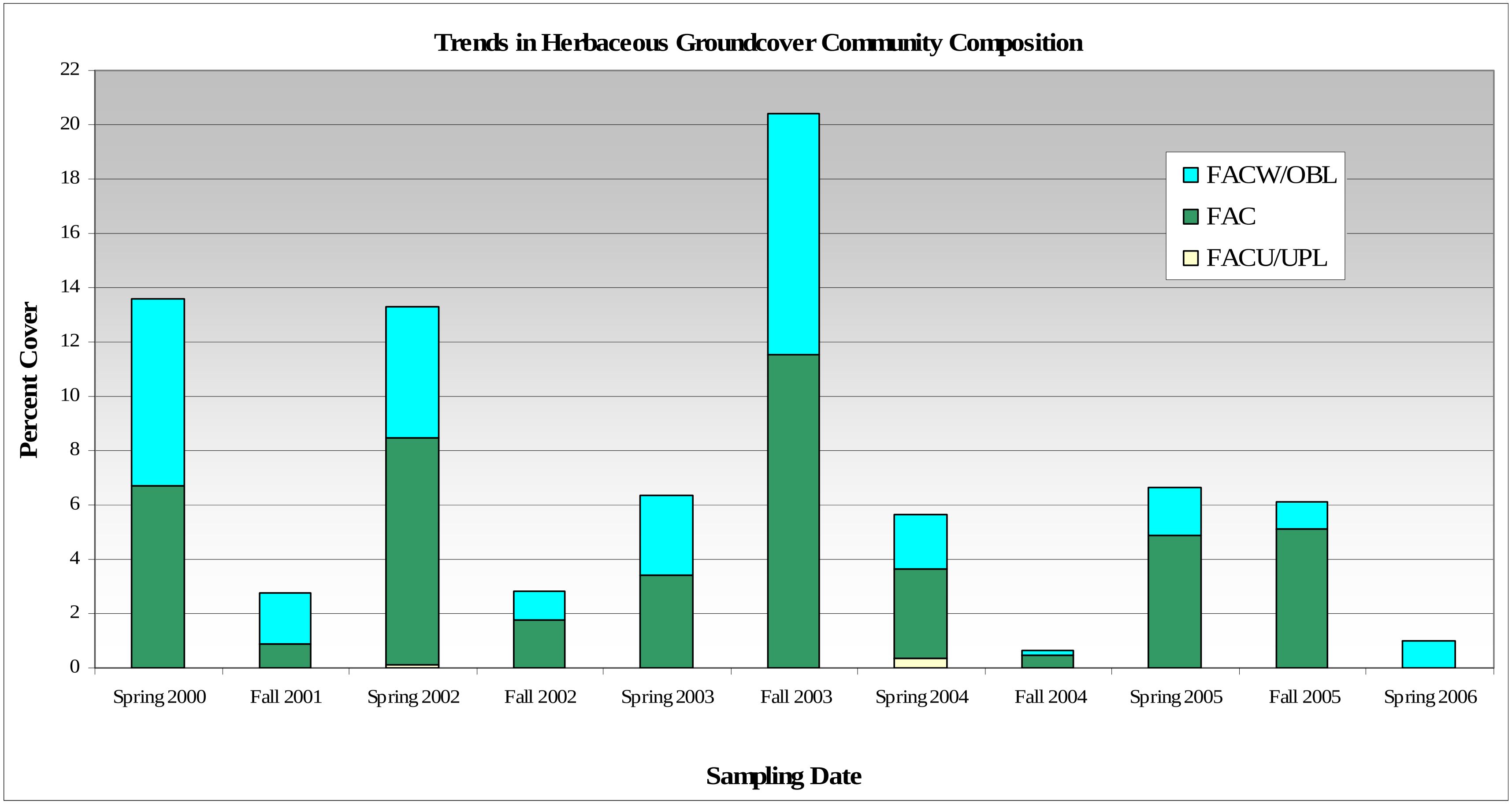


Figure B1. Trends in herbaceous groundcover in meter-square plots by wetland indicator status at the Tillman Ridge wellfield wetland

Wetland indicator status: UPL = plant almost always occurs in uplands; FACU = Plant usually occurs in uplands 67 to 99 percent of the time; FAC = plant equally likely to occur in wetlands 34 to 66 percent of the time; FACW = Plant usually occurs in wetlands 67 to 99 percent of the time; OBL = plant almost always occurs in wetlands.

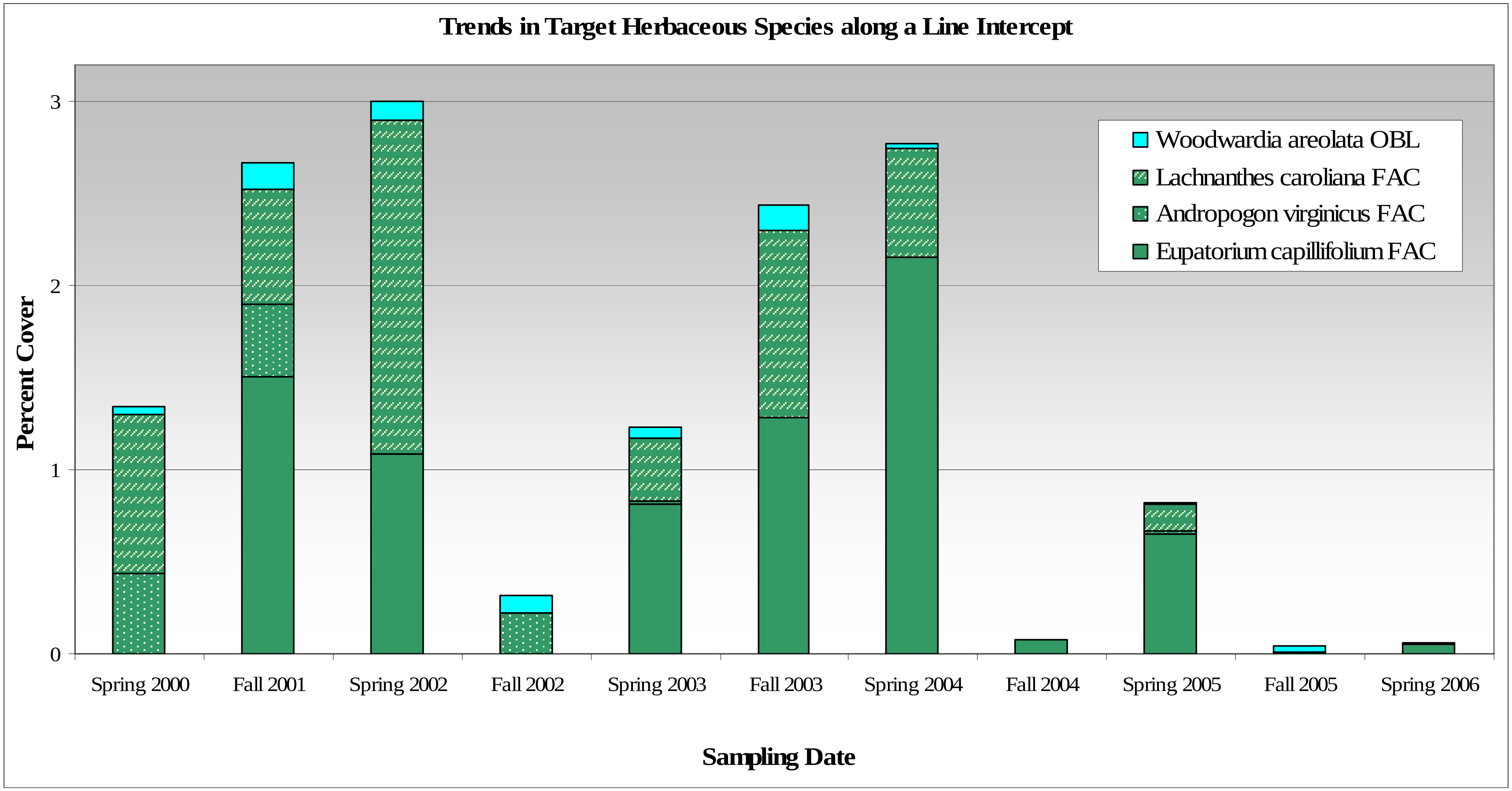


Figure B2. Trends in target herbaceous species along line intercept by species at the Tillman Ridge wellfield wetland

Wetland indicator status: FAC = plant equally likely to occur in wetlands 34 to 66 percent of the time; OBL = plant almost always occurs in wetlands.

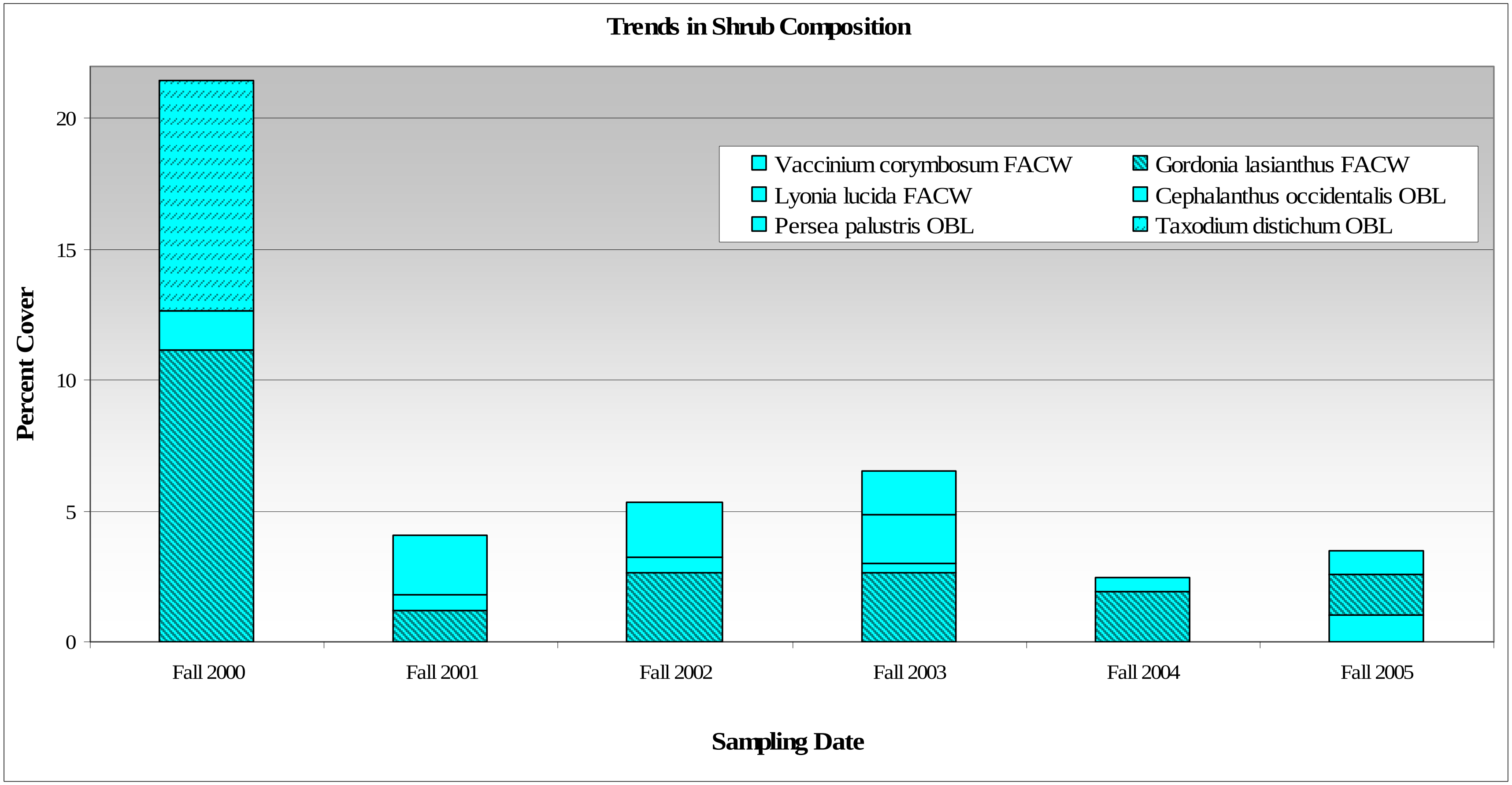


Figure B3. Trends in shrub species along belt transect by species at the Tillman Ridge wellfield wetland

Wetland indicator status: FAC = plant equally likely to occur in wetlands 34 to 66 percent of the time; FACW = Plant usually occurs in wetlands 67 to 99 percent of the time; OBL = plant almost always occurs in wetlands.

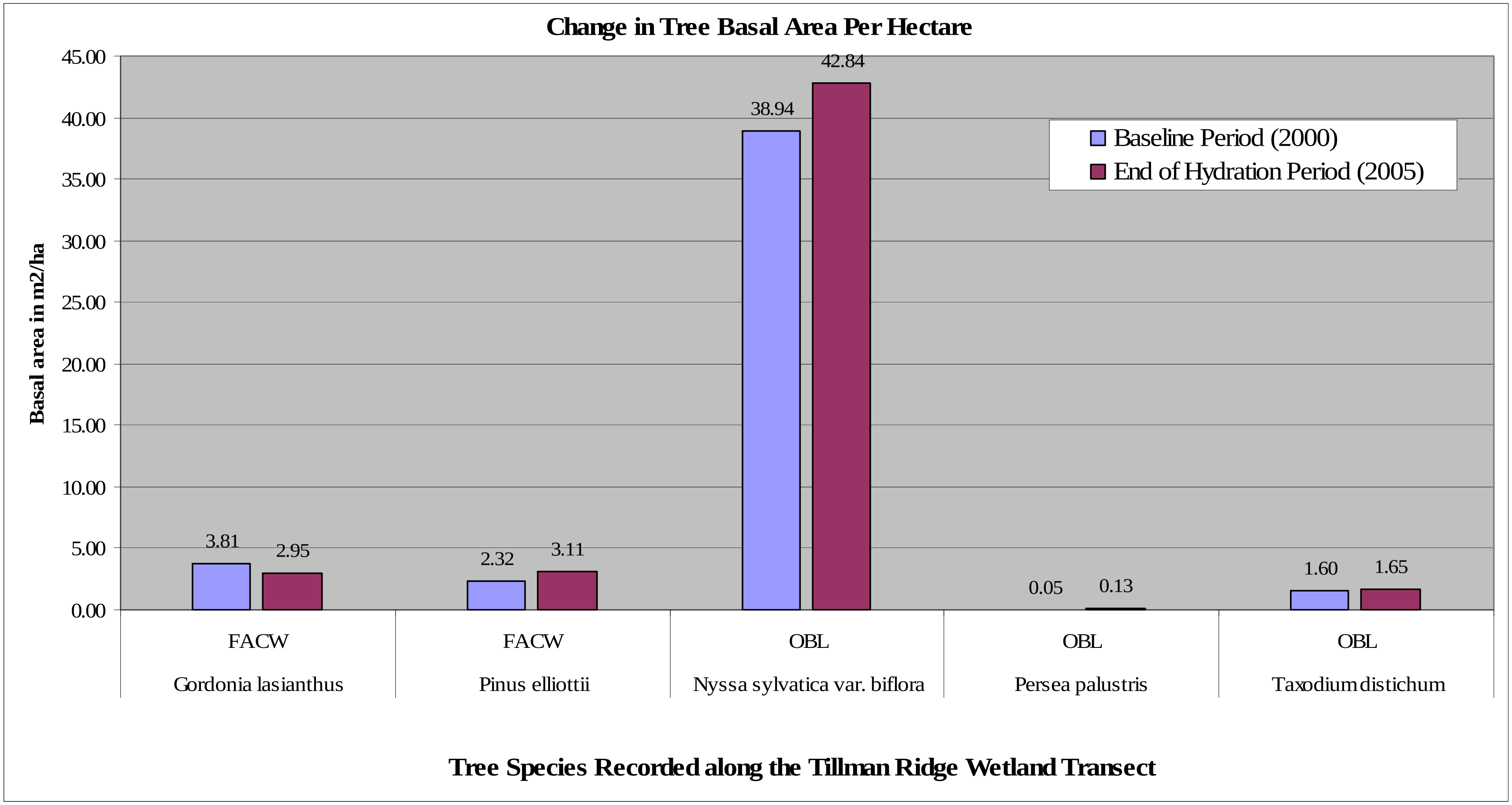


Figure B4. Comparison of total basal area of tree species from baseline period (2000) to last operational year (2005) at the Tillman Ridge wellfield wetland

Wetland indicator status: FACW = Plant usually occurs in wetlands 67 to 99 percent of the time; OBL = plant almost always occurs in wetlands.

# Appendix B - *Continued*

# Charts of Vegetation Results at City of Port Orange Wellfield Wetland

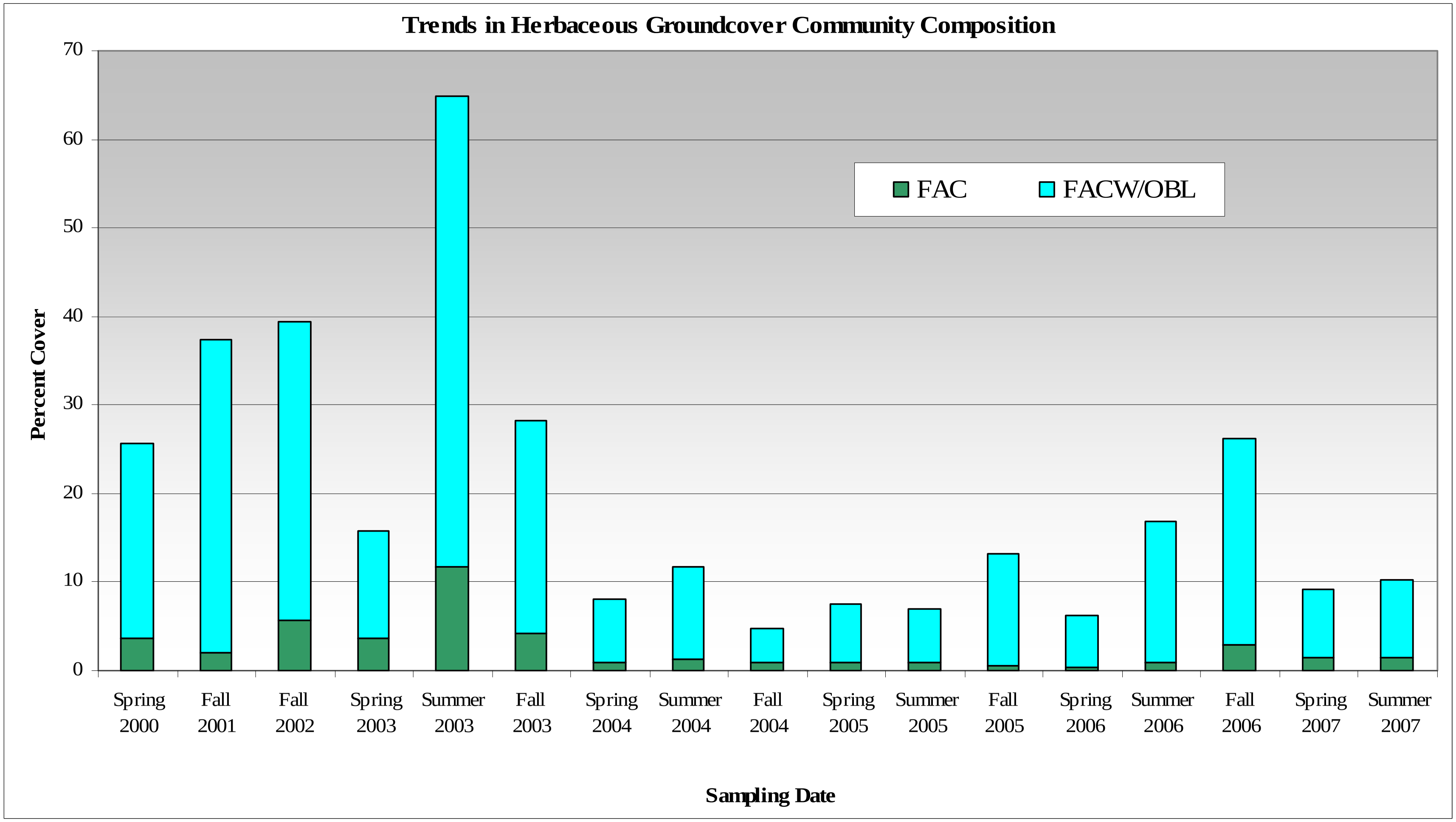


Figure B5. Trends in herbaceous groundcover in meter-square plots by wetland indicator status at the Port Orange wellfield wetland

Wetland indicator status: FAC = plant equally likely to occur in wetlands 34 to 66 percent of the time; FACW = Plant usually occurs in wetlands 67 to 99 percent of the time; OBL = plant almost always occurs in wetlands.

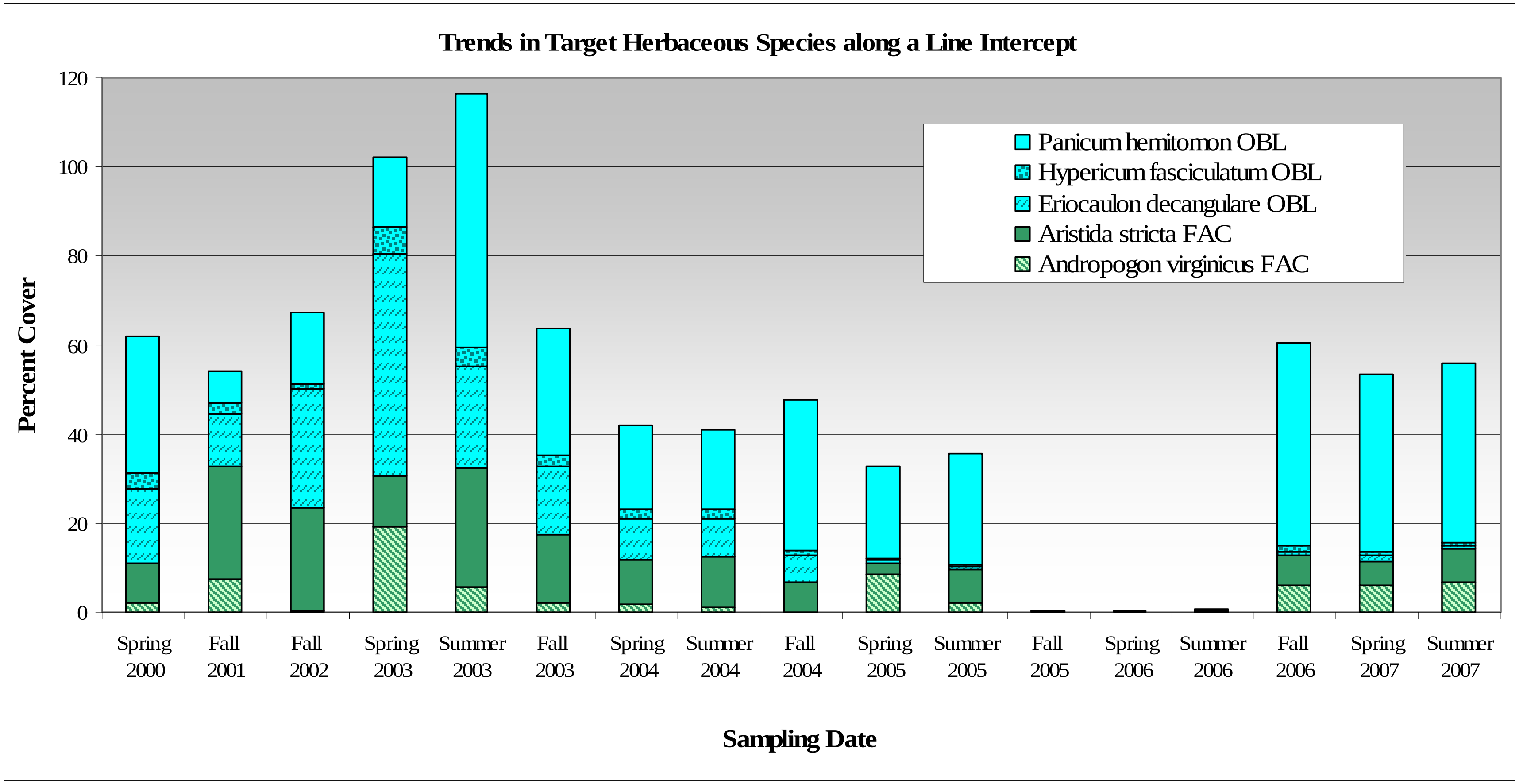


Figure B6. Trends in target herbaceous species along line intercept by species at the Port Orange wellfield wetland

Wetland indicator status: FAC = plant equally likely to occur in wetlands 34 to 66 percent of the time; OBL = plant almost always occurs in wetlands.

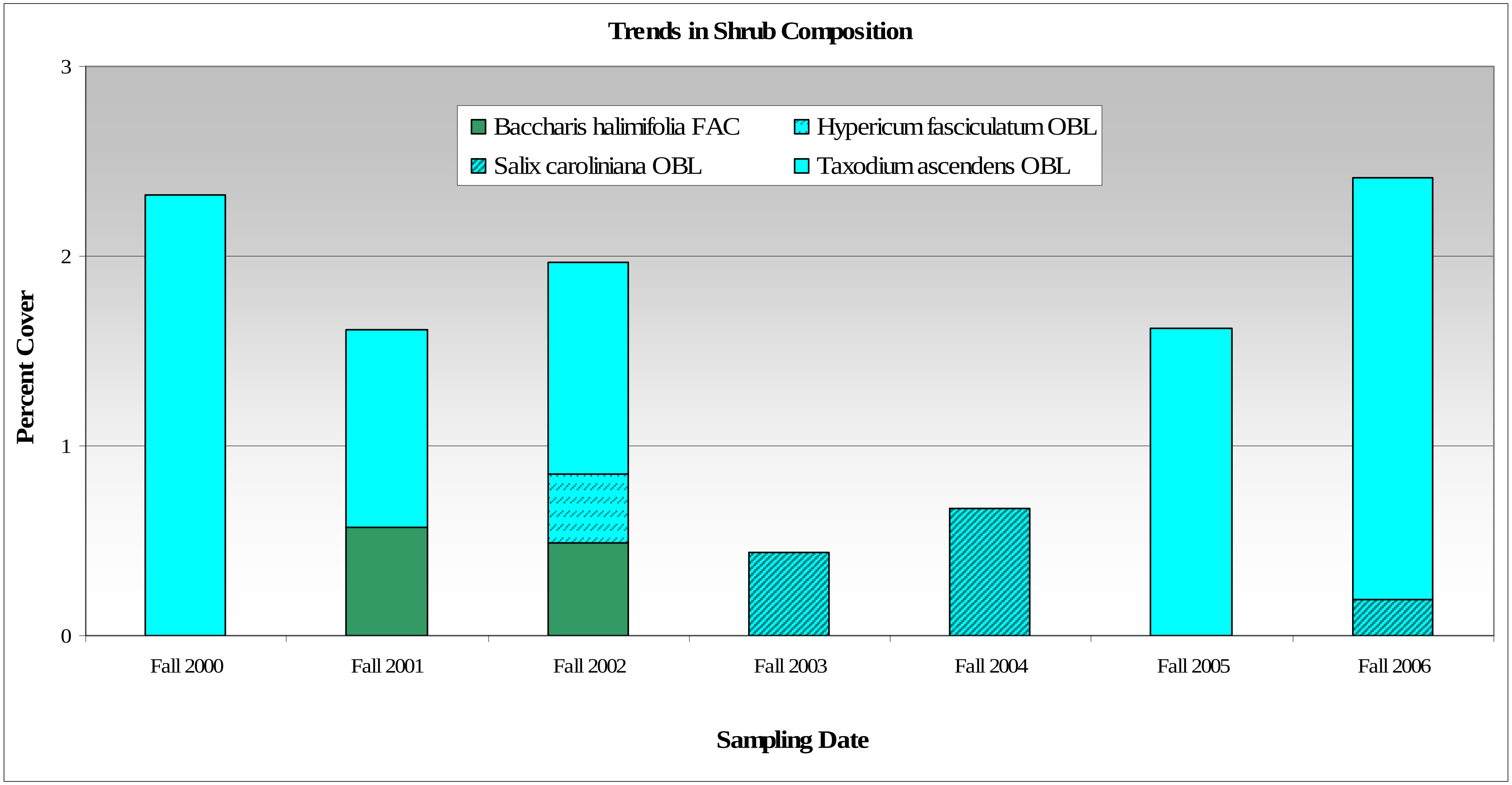


Figure B7. Trends in shrub species along belt transect by species at the Port Orange wellfield wetland

Wetland indicator status: FAC = plant equally likely to occur in wetlands 34 to 66 percent of the time; OBL = plant almost always occurs in wetlands.

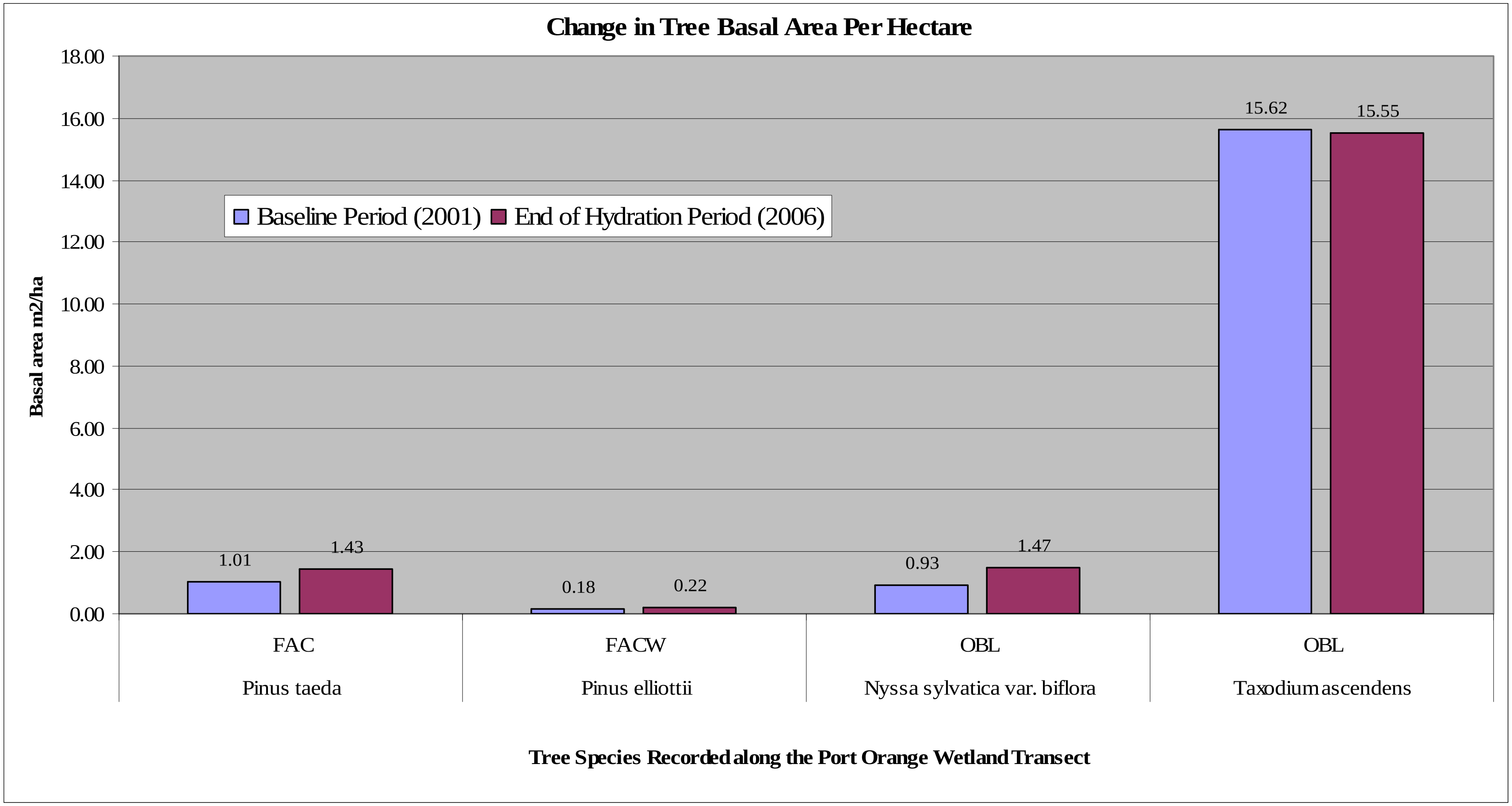


Figure B8. Comparison of total basal area of tree species from baseline period (2001) to last operational year (2006) at the Port Orange wellfield wetland

Wetland indicator status: FAC = plant equally likely to occur in wetlands 34 to 66 percent of the time; FACW = Plant usually occurs in wetlands 67 to 99 percent of the time; OBL = plant almost always occurs in wetlands.

# Appendix B - *Continued*

# Charts of Vegetation Results at Bennett Swamp's Thayer Canal Transect

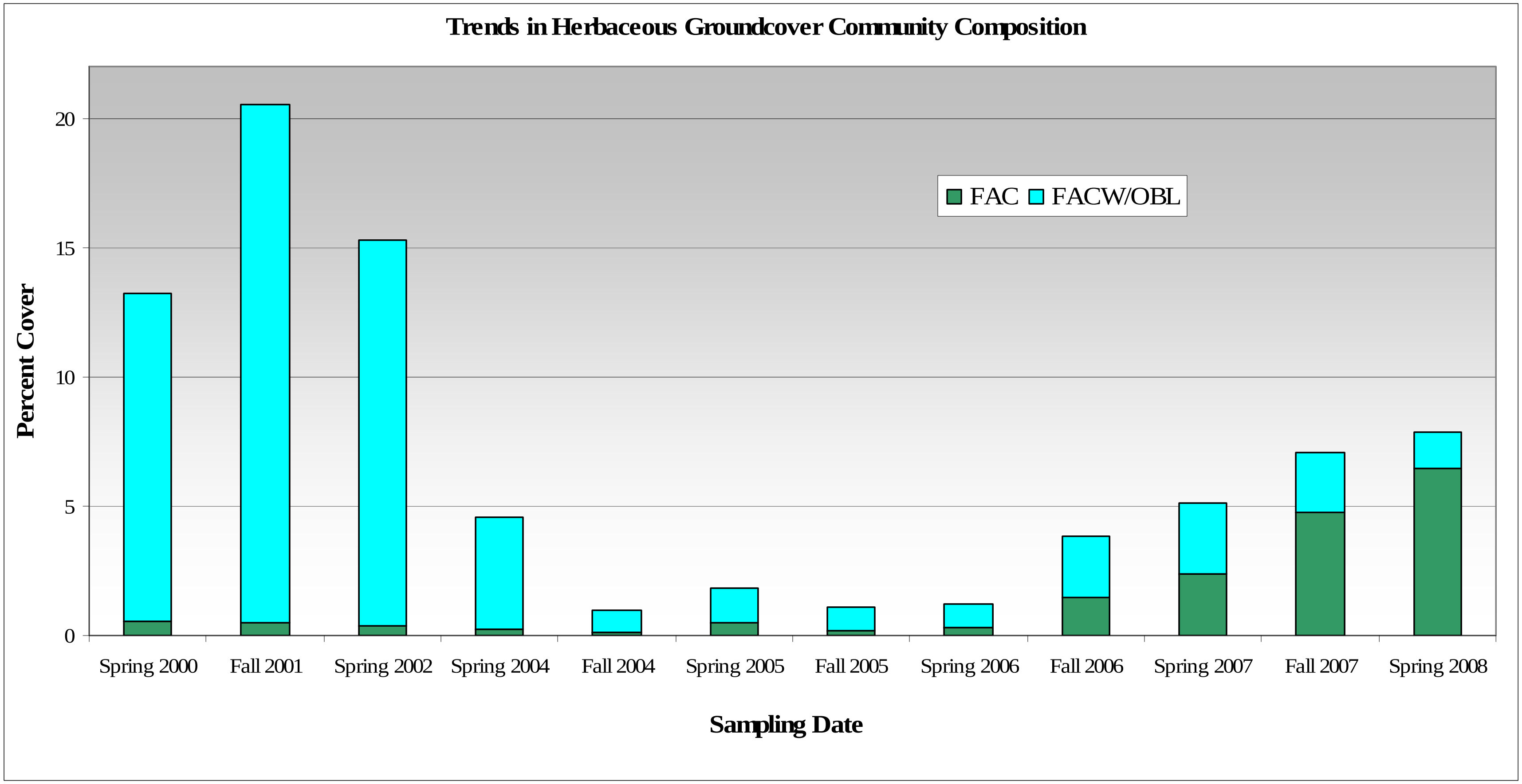


Figure B9. Trends in herbaceous groundcover in meter-square plots by wetland indicator status along the Thayer Canal transect in Bennett Swamp

Wetland indicator status: FAC = plant equally likely to occur in wetlands 34 to 66 percent of the time; FACW = Plant usually occurs in wetlands 67 to 99 percent of the time; OBL = plant almost always occurs in wetlands.

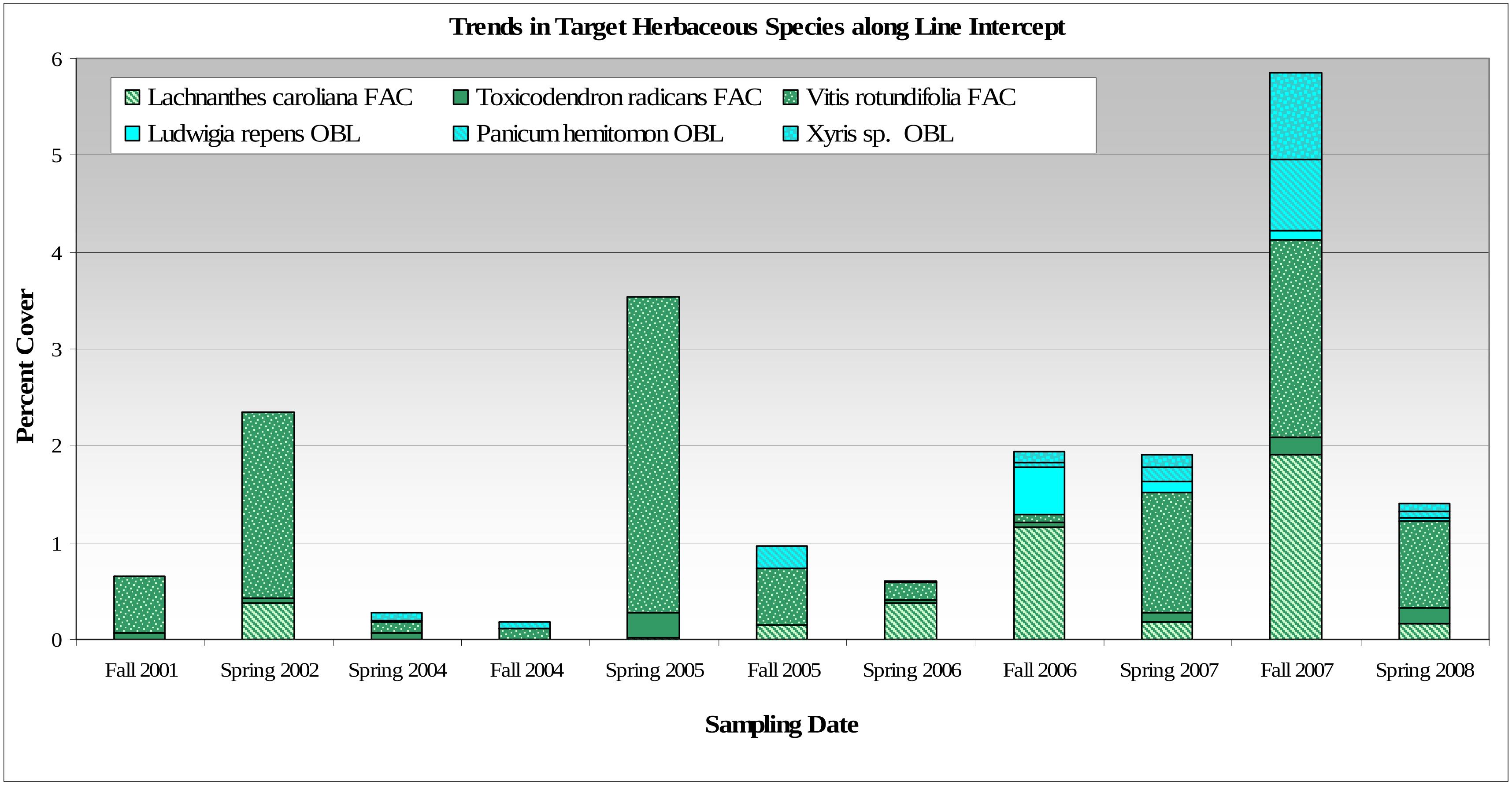


Figure B10. Trends in target herbaceous species along line intercept by species at the Thayer Canal transect in Bennett Swamp

Wetland indicator status: FAC = plant equally likely to occur in wetlands 34 to 66 percent of the time; OBL = plant almost always occurs in wetlands.

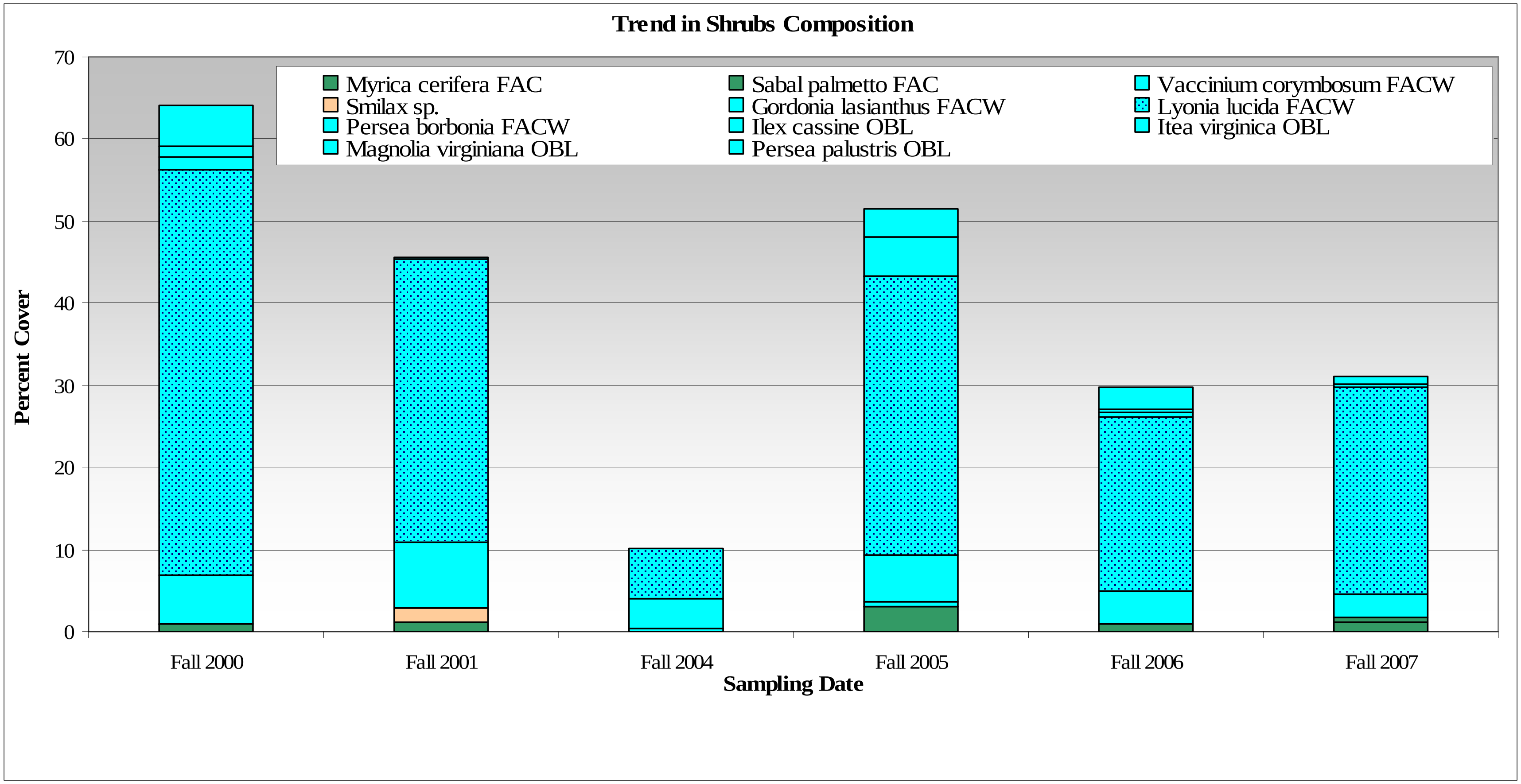


Figure B11. Trends in shrub species along belt transect by species at the Thayer Canal transect in Bennett Swamp

Wetland indicator status: FAC = plant equally likely to occur in wetlands 34 to 66 percent of the time; FACW = Plant usually occurs in wetlands 67 to 99 percent of the time; and tends to be more (+)/less (-) towards upland.

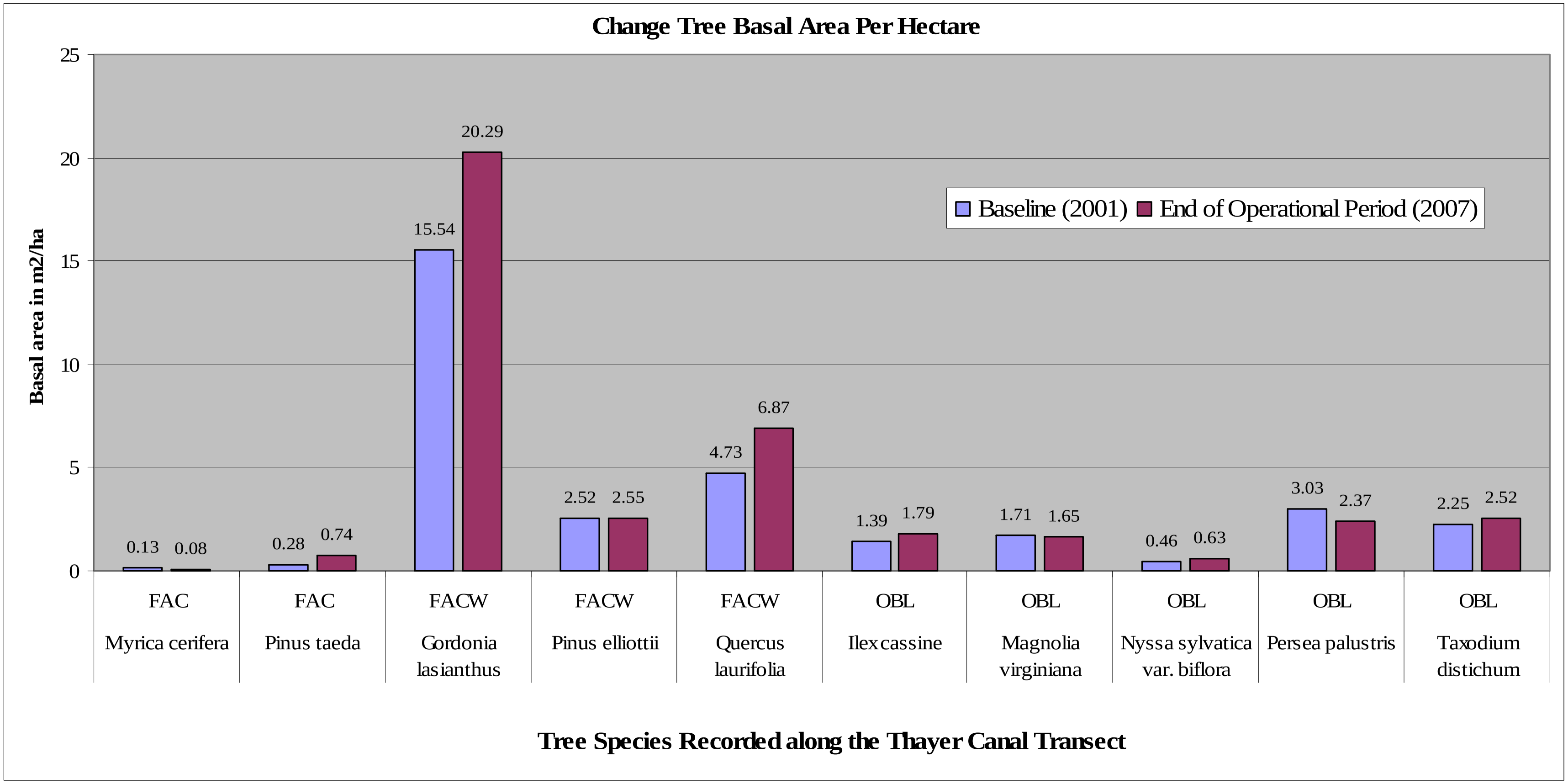


Figure B12. Comparison of total basal area of trees from baseline period (2001) to last operational year (2007) at the Thayer Canal transect in Bennett Swamp

Wetland indicator status: FAC = plant equally likely to occur in wetlands 34 to 66 percent of the time; FACW = Plant usually occurs in wetlands 67 to 99 percent of the time; OBL = plant almost always occurs in wetlands.

# Appendix B - *Continued*

# Charts of Vegetation Results at Bennett Swamp’s Hammock Field Transect

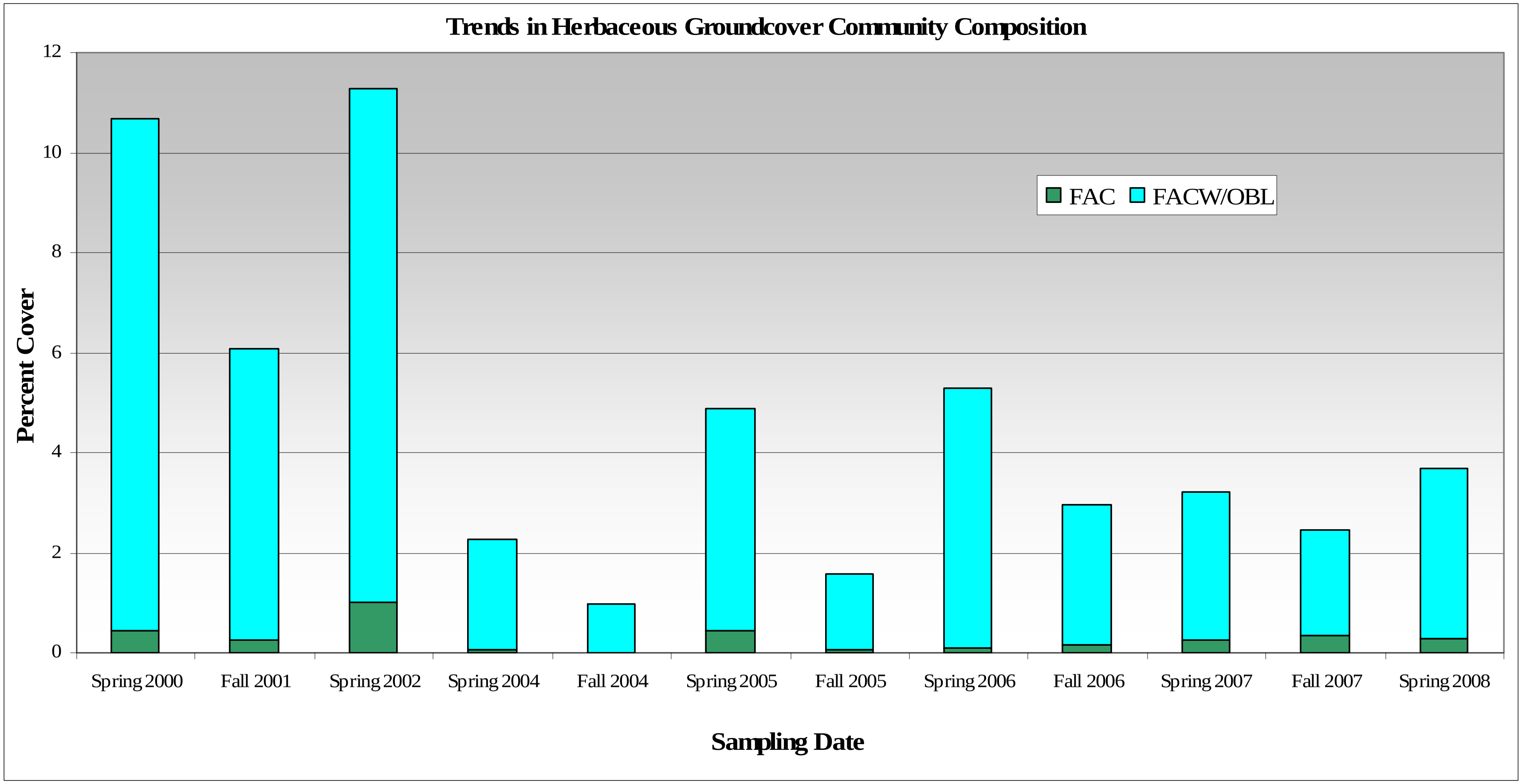


Figure B13. Trends in herbaceous groundcover in meter-square plots by wetland indicator status along the Hammock Field transect in Bennett Swamp

Wetland indicator status: FAC = plant equally likely to occur in wetlands 34 to 66 percent of the time; FACW = Plant usually occurs in wetlands 67 to 99 percent of the time; OBL = plant almost always occurs in wetlands

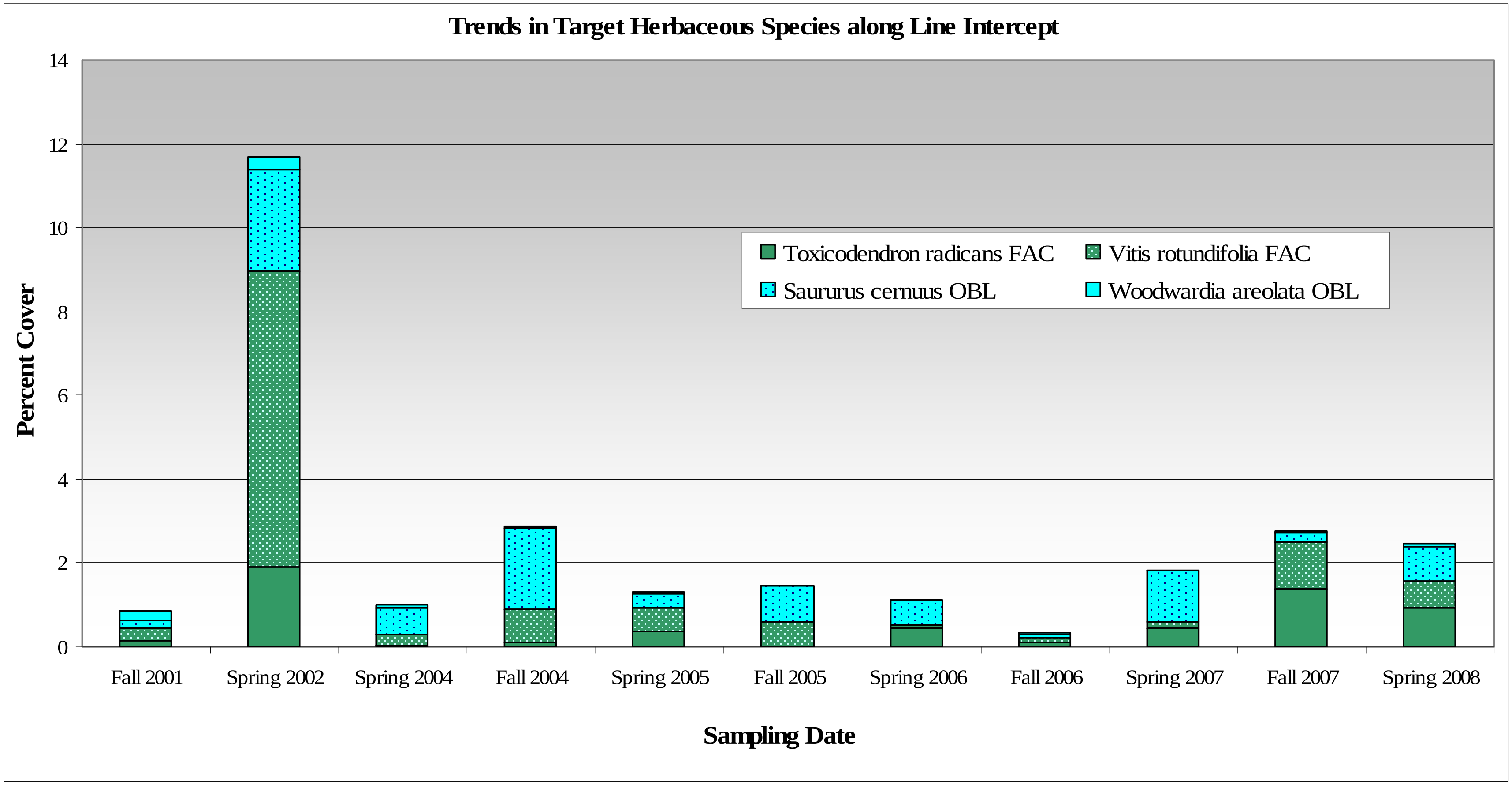


Figure B14. Trends in target herbaceous species along line intercept by species at the Hammock Field transect in Bennett Swamp

Wetland indicator status: FAC = plant equally likely to occur in wetlands 34 to 66 percent of the time; OBL = plant almost always occurs in wetlands.

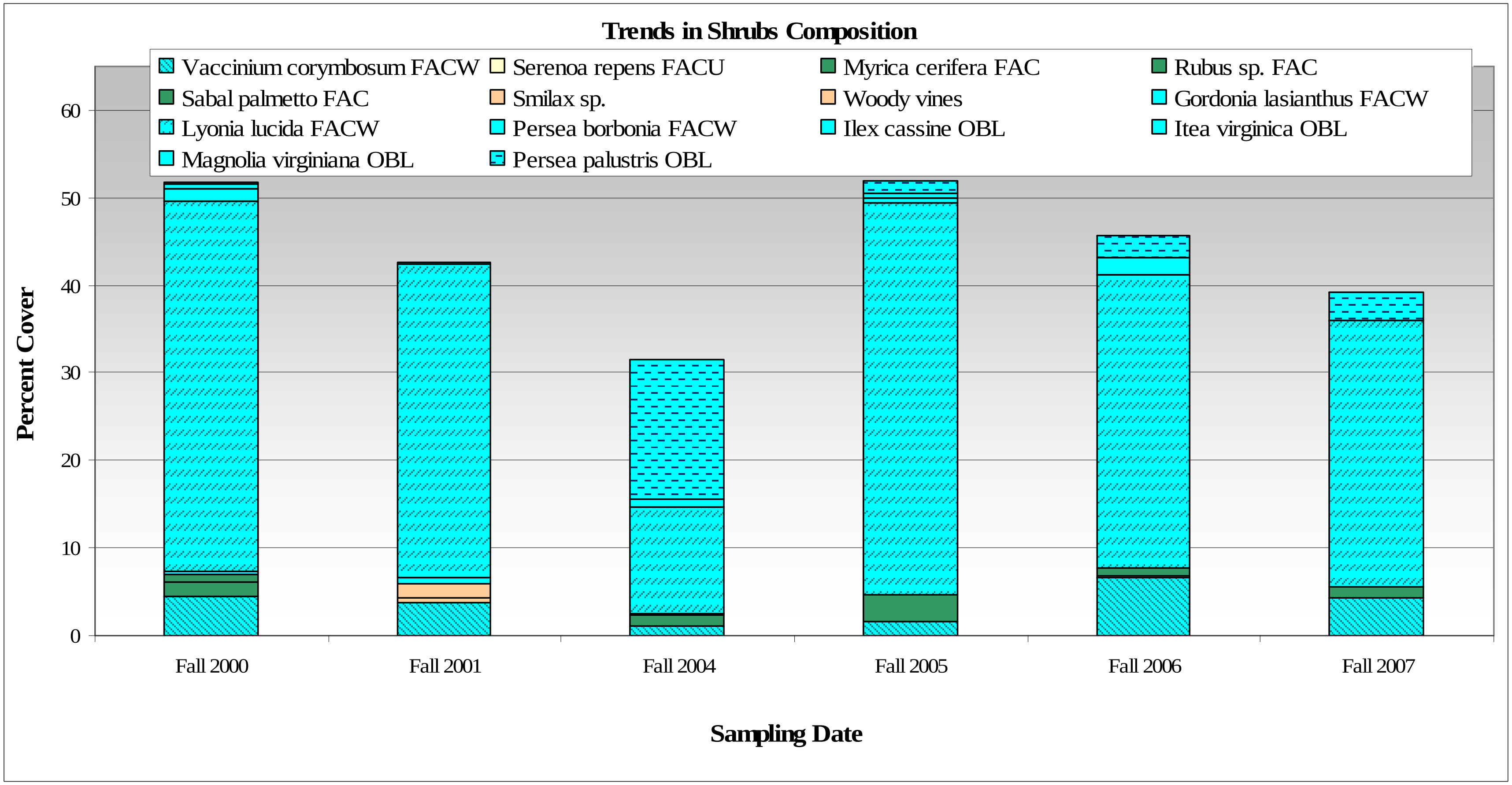


Figure B15. Trends in shrub species along belt transect by species at the Hammock Field transect in Bennett Swamp

Wetland indicator status: FACU = Plant usually occurs in uplands 67 to 99 percent of the time; FAC = plant equally likely to occur in wetlands 34 to 66 percent of the time; FACW = Plant usually occurs in wetlands 67 to 99 percent of the time; OBL = plant almost always occurs in wetlands.

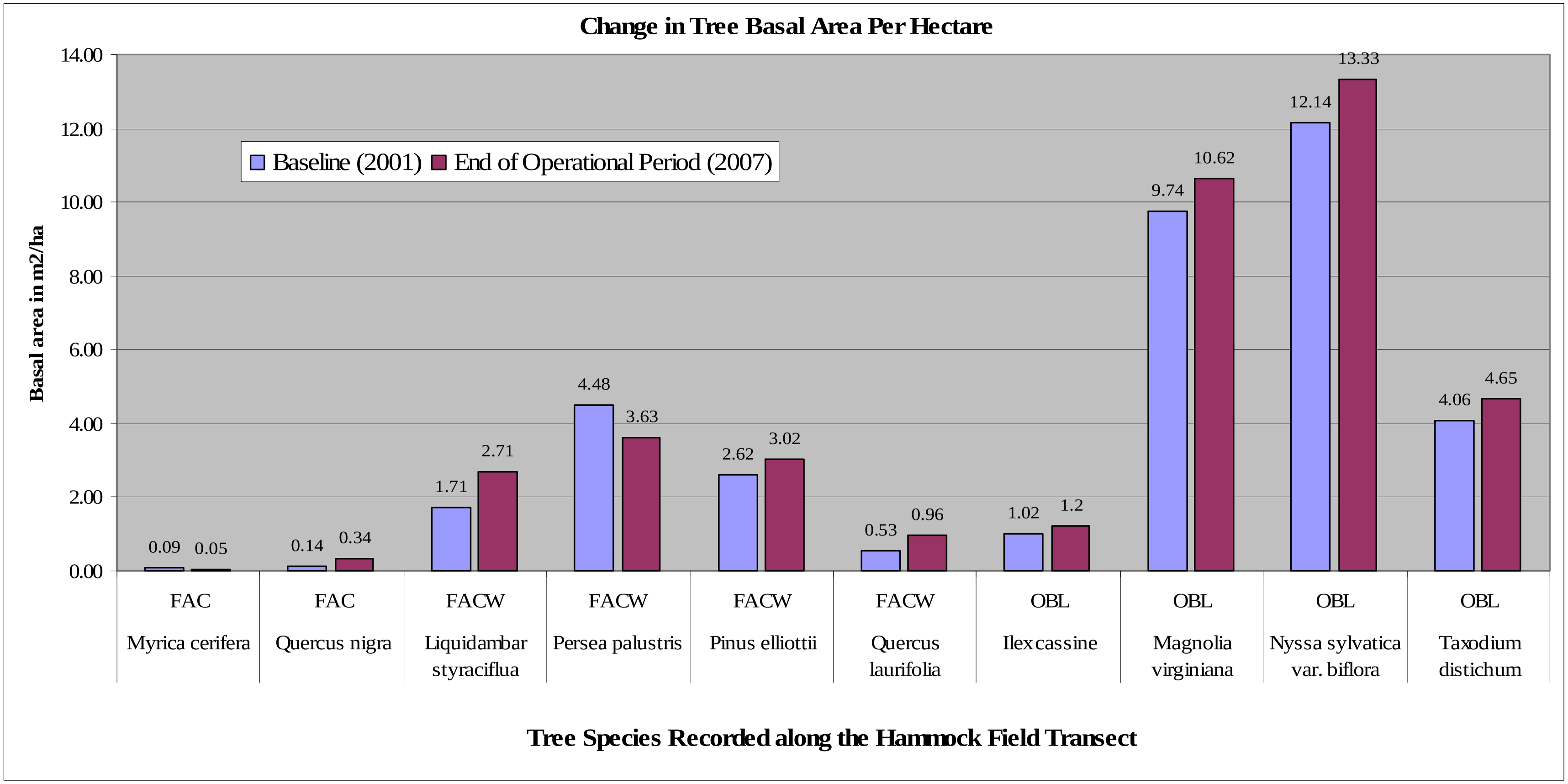


Figure B16. Comparison of total basal area of trees from baseline period (2001) to last operational year (2007) at the Hammock Field transect in Bennett Swamp

Wetland indicator status: FAC = plant equally likely to occur in wetlands 34 to 66 percent of the time; FACW = Plant usually occurs in wetlands 67 to 99 percent of the time; OBL = plant almost always occurs in wetlands.

# Appendix B - *Continued*

# Charts of Vegetation Results at Bennett Swamp's Lower Bennett Swamp Transect

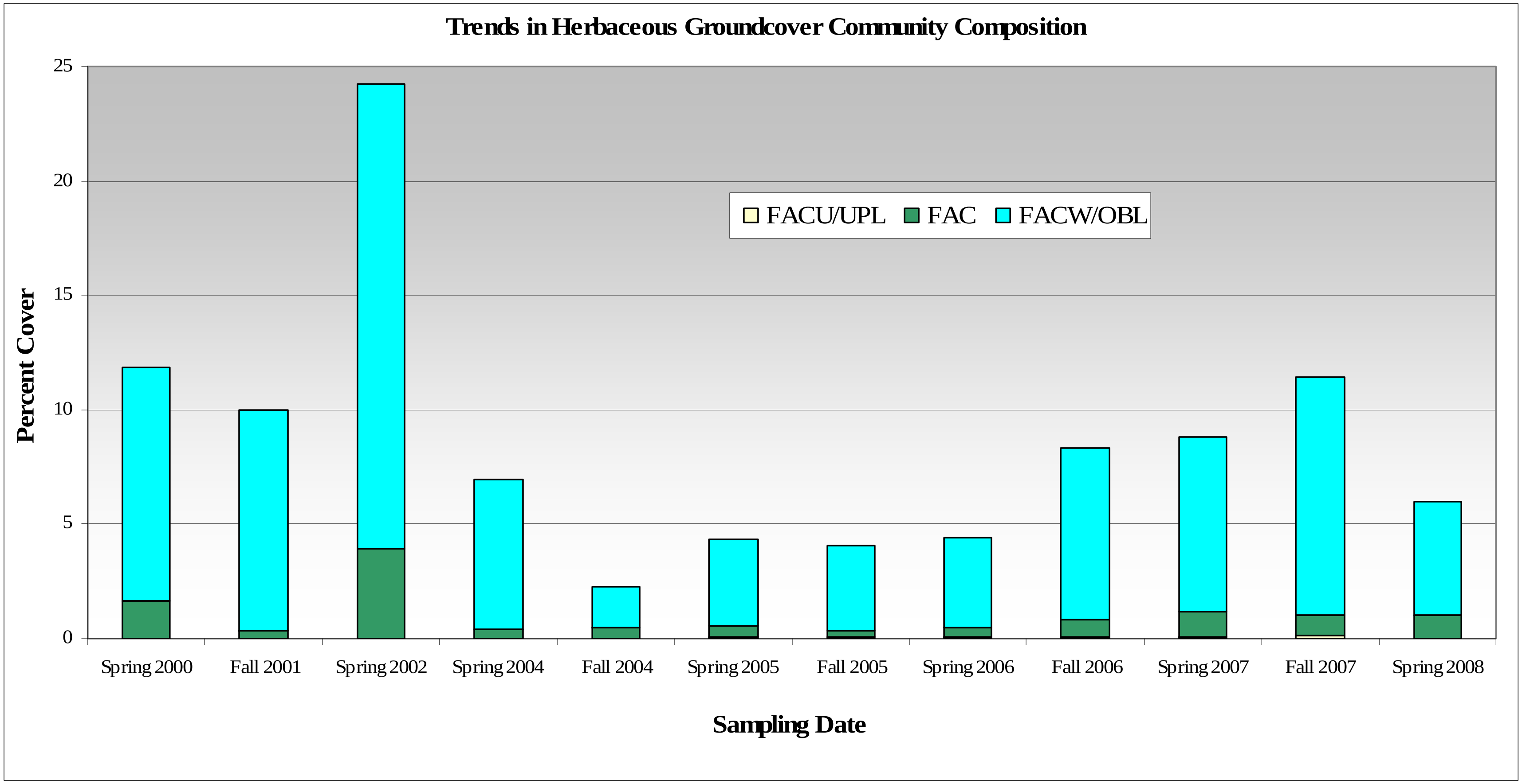


Figure B17. Trends in herbaceous groundcover in meter-square plots by wetland indicator status along the Lower Bennett Swamp transect in Bennett Swamp

Wetland indicator status: UPL = plant almost always occurs in uplands; FACU = Plant usually occurs in uplands 67 to 99 percent of the time; FAC = plant equally likely to occur in wetlands 34 to 66 percent of the time; FACW = Plant usually occurs in wetlands 67 to 99 percent of the time; OBL = plant almost always occurs in wetlands.

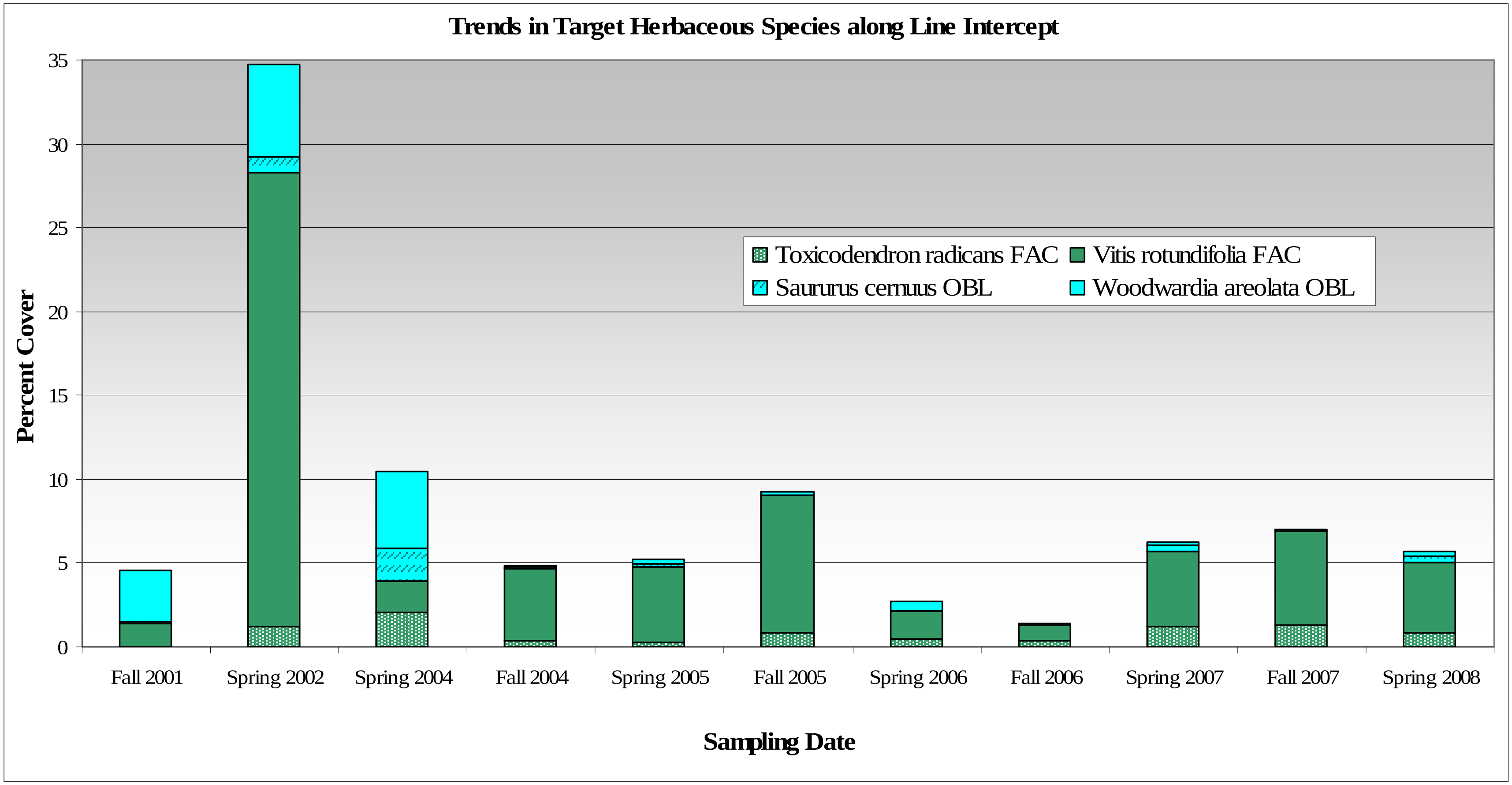


Figure B18. Trends in target herbaceous species along line intercept by species at the Lower Bennett Swamp transect in Bennett Swamp

Wetland indicator status: FAC = plant equally likely to occur in wetlands 34 to 66 percent of the time; OBL = plant almost always occurs in wetlands.

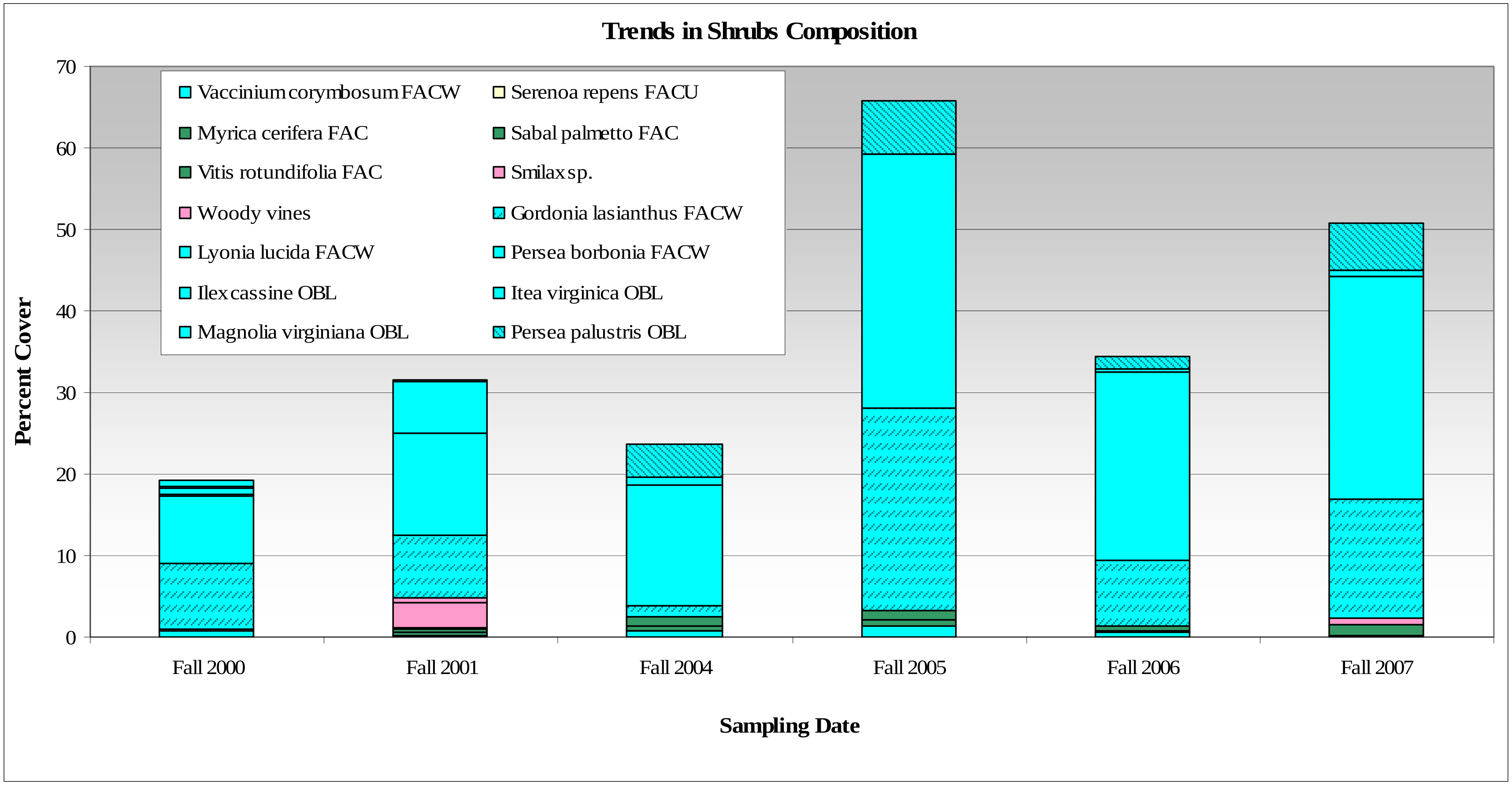


Figure B19. Trends in shrub species along belt transect by species at the Lower Bennett Swamp transect in Bennett Swamp

Wetland indicator status: FACU = Plant usually occurs in uplands 67 to 99 percent of the time; FAC = plant equally likely to occur in wetlands 34 to 66 percent of the time; FACW = Plant usually occurs in wetlands 67 to 99 percent of the time; OBL = plant almost always occurs in wetlands.

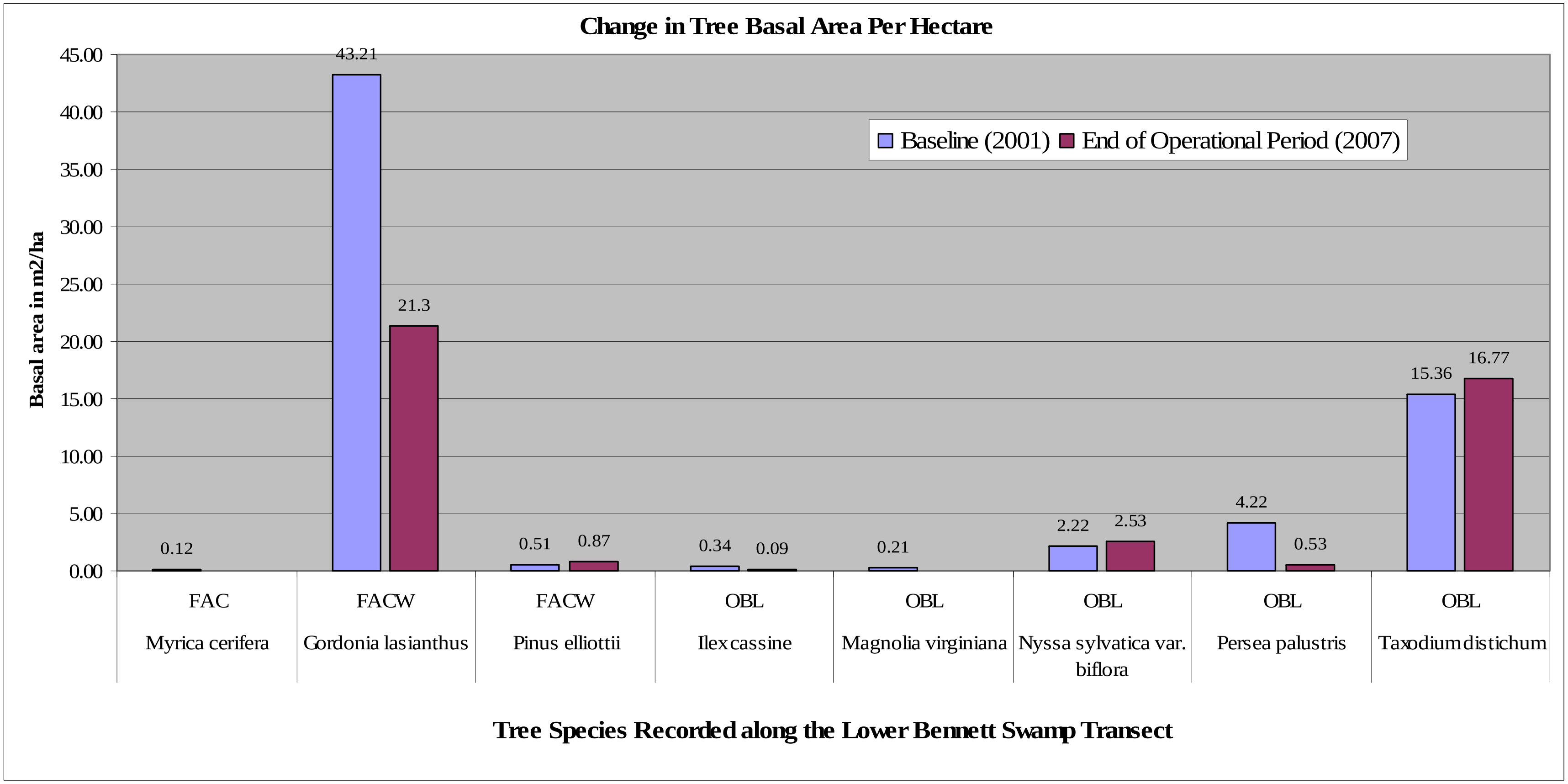


Figure B20. Comparison of total basal area of trees from baseline period (2001) to last operational year (2007) at the Lower Bennett Swamp transect in Bennett Swamp

Wetland indicator status: FAC = plant equally likely to occur in wetlands 34 to 66 percent of the time; FACW = Plant usually occurs in wetlands 67 to 99 percent of the time; OBL = plant almost always occurs in wetlands. Loss of Gordonia was mainly due to storm damage.

# Appendix B - *Continued*

# Charts of Vegetation Results at City of Titusville's Parkland Wetland

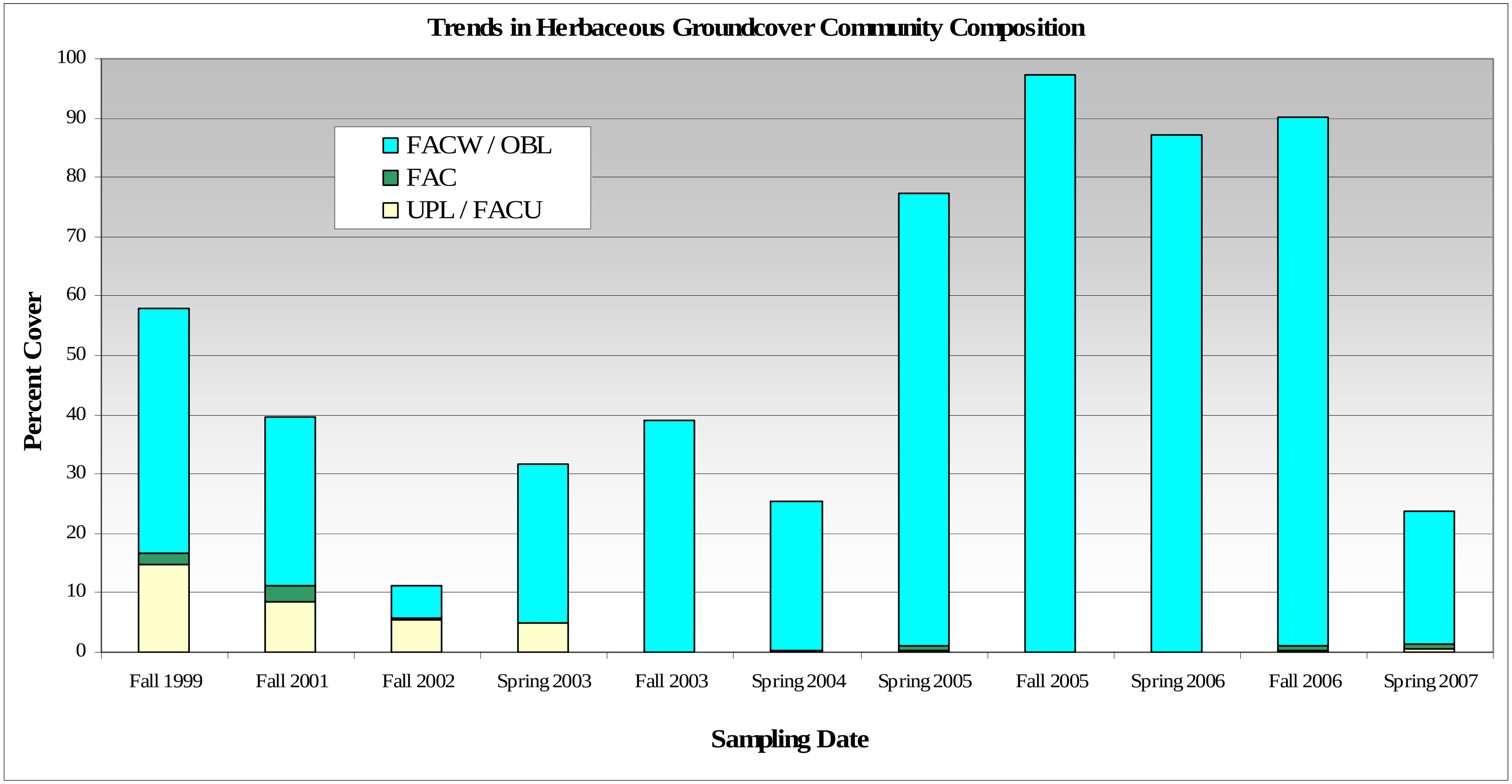


Figure B21. Trends in herbaceous groundcover in meter-square plots by wetland indicator status at the Parkland Wetland, Titusville, Florida

Wetland indicator status: UPL = plant almost always occurs in uplands; FACU = Plant usually occurs in uplands 67 to 99 percent of the time;
FAC = plant equally likely to occur in wetlands 34 to 66 percent of the time; FACW = Plant usually occurs in wetlands 67 to 99 percent of the time; OBL = plant almost always occurs in wetlands and.

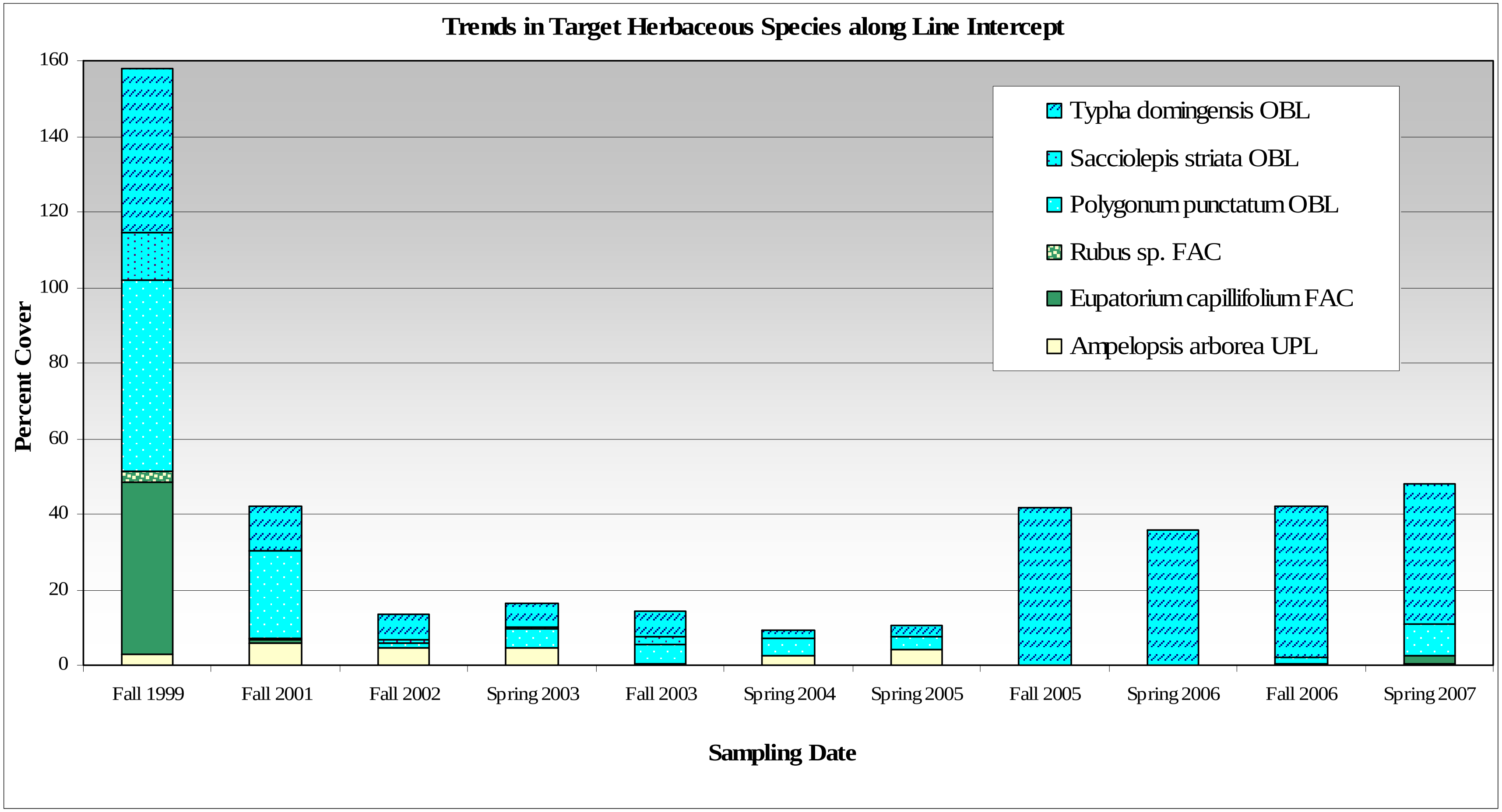


Figure B22. Trends in target herbaceous species along line intercept by wetland indicator status at the Parkland Wetland, Titusville, Florida

Wetland indicator status: UPL = plant almost always occurs in uplands; FAC = plant equally likely to occur in wetlands 34 to 66 percent of the time; OBL = plant almost always occurs in wetlands.

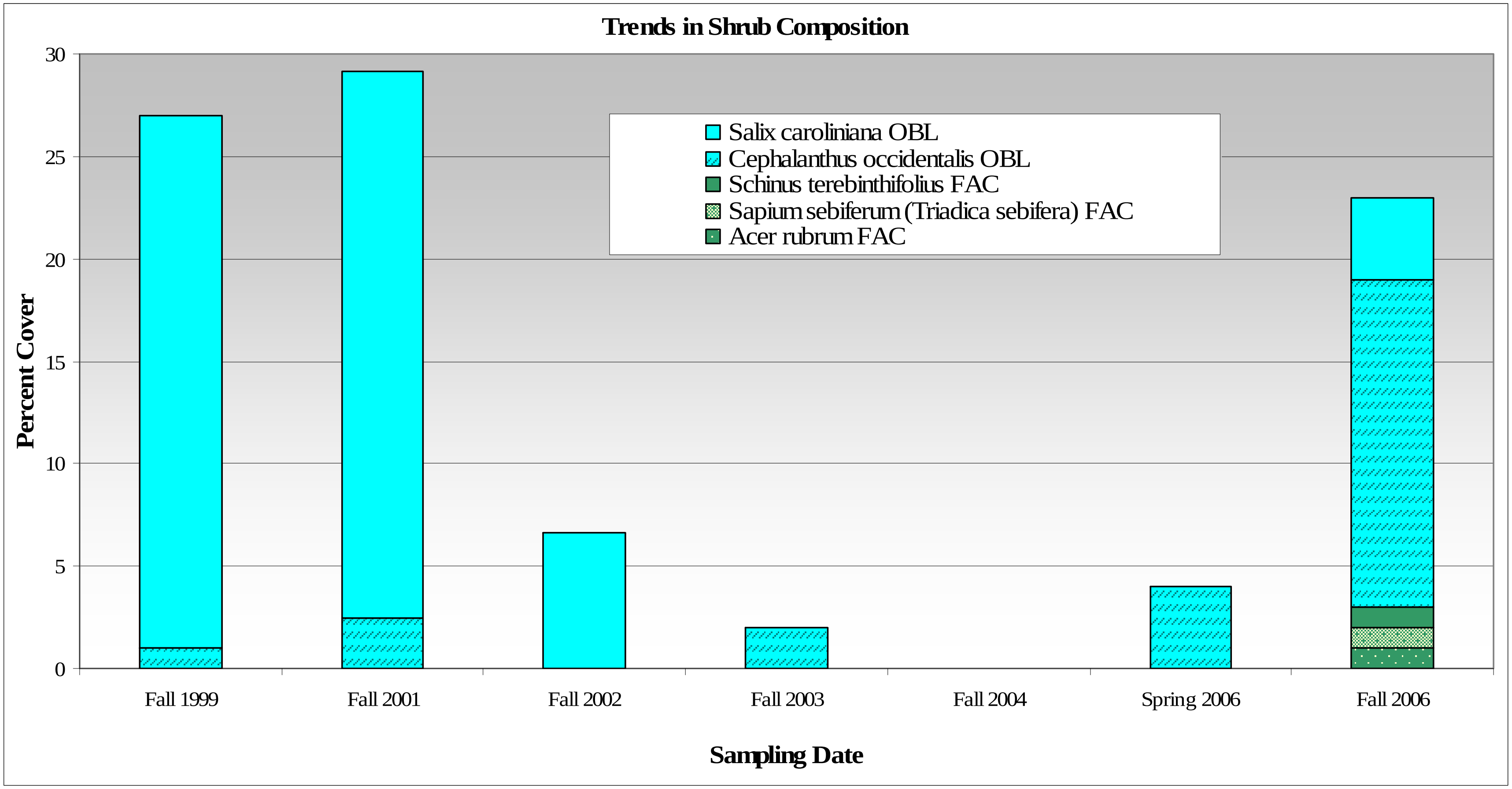


Figure B23. Trends in shrub species along belt transect by species at the Parkland Wetland, Titusville, Florida

Wetland indicator status: FAC = plant equally likely to occur in wetlands 34 to 66 percent of the time; OBL = plant almost always occurs in wetlands.

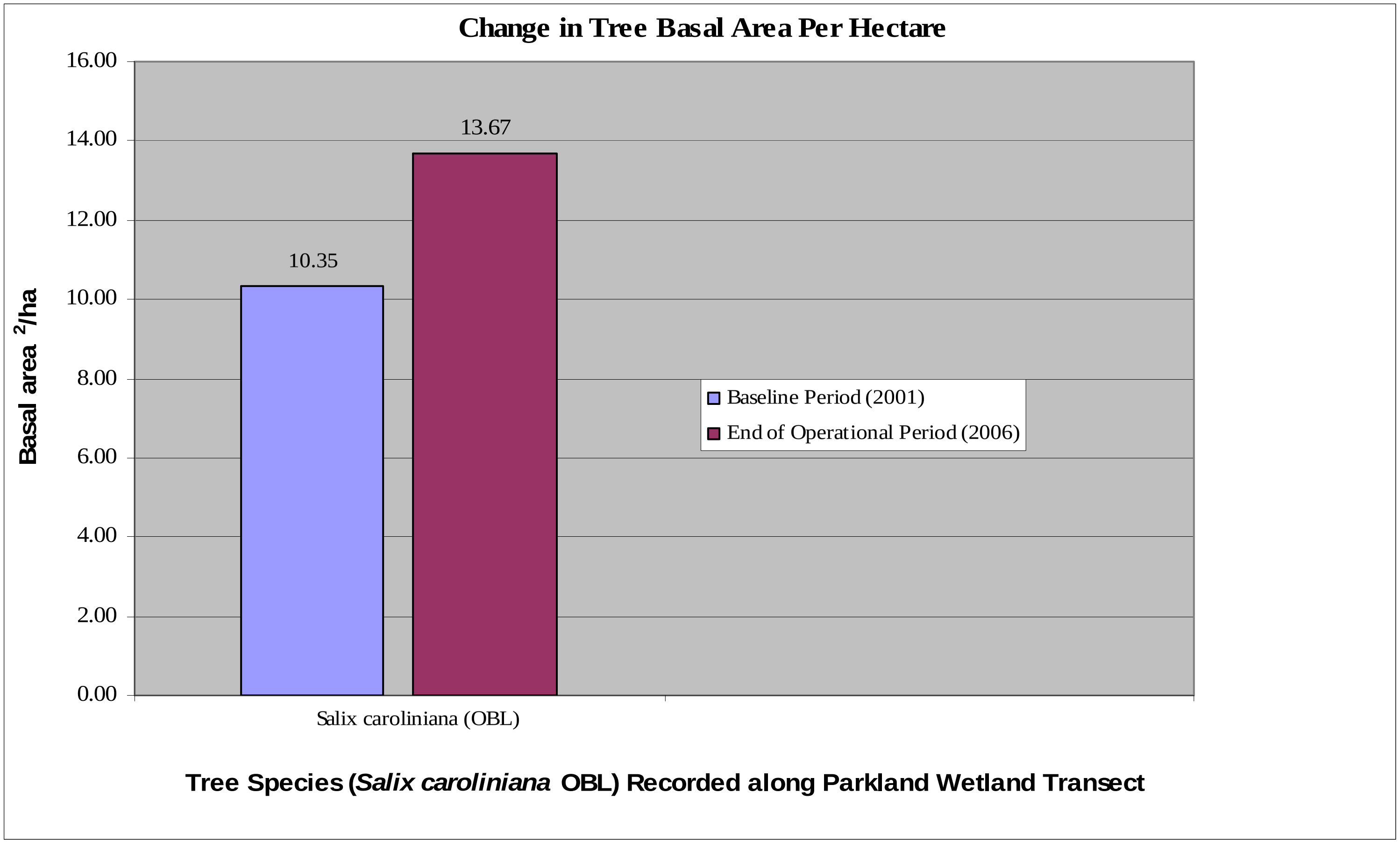


Figure B24. Comparison of total basal area of tree species from baseline period (2001) to last operational year (2006) at the Parkland Wetland, Titusville, Florida

Wetland indicator status: OBL = plant almost always occurs in wetlands.