Validation of the Cypress Offset and Mesic Wetland Offset for Development of Minimum Wetland and Lake Levels (DRAFT)

May 4, 2022

Southwest Florida Water Management District

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Cover: Eldridge Wilde 11 (NW-44) Cypress Dome, Hillsborough County, FL (C. Cameron)

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Executive Summary

This report revisits the Cypress Offset and Mesic Wetland Offset currently used by the Southwest Florida Water Management District to develop minimum levels for certain lakes and wetlands. These offsets determine when a mesic wetland is likely to experience significant harm based on withdrawal-driven changes in water levels and are among several criteria the District evaluates during the development of minimum levels.

The Cypress Offset finds that significant harm is likely to occur at a cypress dome when the long-term median water level (P50) falls more than 1.8 feet below the “normal pool” elevation, a field-derived high-water reference level. The Mesic Wetland Offset, which was derived from the Cypress Offset, finds that significant harm is likely to occur at a mesic wetland when the P50 is lowered by more than 0.8 feet relative to Historic conditions (i.e., no measurable impacts due to withdrawals). “Mesic” refers to waterbodies located in landscapes dominated by mesic soils, typically within a flatwoods shallow water table semi-confined hydrogeologic setting.

The values of the Cypress Offset and Mesic Wetland Offset, and their ability to detect significant harm in mesic wetlands, were validated as robust and reasonable through literature review and analyses of updated and expanded datasets. This process included reexamining data used in the original development of the Cypress Offset, assessing work conducted as part of the Northern Tampa Bay Recovery assessment, considering findings from the Central Florida Water Initiative, and evaluating the hydrologic behavior of unimpacted cypress domes.

Given that the Cypress Offset and Mesic Wetland Offset result in identical minimum levels at the average mesic waterbody with no structural alterations, the advantages of each were considered to develop updated recommendations for application of the offsets. The Mesic Wetland Offset offers the advantages of better accounting for structural alterations (often present at lakes) and removing the need to identify normal pool (often absent at lakes). The Cypress Offset offers the advantage that it does not incorporate a simplification made by the Mesic Wetland Offset regarding average Historic behavior. Therefore, in developing minimum levels, rather than assessing both offsets for the same waterbody, the Mesic Wetland Offset should be assessed for mesic lakes, while the Cypress Offset should be assessed for mesic cypress domes.

Finally, literature review and evaluation of water level data indicate differing hydrology and water level behavior between mesic and xeric waterbodies. Specifically, compared to mesic waterbodies, xeric waterbodies experience much larger water level fluctuations, and available information suggests that their median water levels can change substantially more before they exhibit stress. This underscores the need for development of a Xeric Wetland Offset for xeric lakes and wetlands.

Definitions

Control point – The elevation of the highest stable point along the outlet profile of a surface water conveyance system (whether natural or anthropogenic) that principally controls water level fluctuations.

Cypress Offset – Refers to the standard originally developed in SWFWMD (1999b), which found that significant harm occurs at cypress wetlands when the P50 elevation is lowered more than 1.8 feet below the normal pool elevation. See Rule 40D-8.623(1)(a), Florida Administrative Code (F.A.C.).

Historic (H) – A long-term period when there are no measurable impacts due to withdrawals and structural alterations are similar to current conditions. Historic percentiles can be measured from observed data for waterbodies with Historic data; where such data do not exist (due to a short period of record or due to impacts occurring throughout the period of record), Historic percentiles can be estimated using numerical modelling, statistical techniques, or other methods. Historic percentiles reflect rainfall conditions during the long-term period used to develop the Historic percentiles. Historic percentiles estimated for a waterbody for one long-term period may not be identical to Historic percentiles estimated for the same waterbody during a different long-term time period, even though both sets of percentiles are considered Historic as they have no measurable impacts due to withdrawals. For example, all else being equal, Historic percentiles developed using a long-term dryer-than-average period would be lower than Historic percentiles developed using a long-term wetter-than-average period. Therefore, contextualizing rainfall is important when comparing sets of percentiles within and between waterbodies. See Rule 40D-8.021(3), F.A.C.

Mesic – In the context of this report and its west-central Florida study area, “mesic” waterbodies are geographically isolated freshwater lentic systems (e.g., lakes and wetlands) located in landscapes dominated by mesic soils, typically associated with flatwoods ecosystems, shallow water-table conditions, and semi-confinement of the upper Floridan aquifer (Hancock and Basso, 1996; GPI, 2016; Cameron et al., 2020). Water levels at mesic waterbodies are frequently dominated by an annual or semi-annual cyclicity (e.g., Foster, 2007) and display, on average, a total range of less than 6 feet, with healthy sites rarely exceeding 10 feet, where maximum elevations are typically controlled by surface outflows (see text; GPI, 2016). Mesic soils contrast with xeric and hydric soils by having “moderate” moisture content, typically with a hydric rating between 3.5 and 43.5% (CFWI-EMT, 2013; GPI, 2016, 2021b). Minimum levels work completed for lakes and wetlands in SWFWMD (1999a, 1999b) and Hancock (2007) largely focused on mesic waterbodies. All work in this report references mesic waterbodies, unless otherwise noted.

Minimum level – The level of groundwater in an aquifer and the level of surface water at which further withdrawals would be significantly harmful to the water resources or ecology of the area, which "shall be calculated…using the best information available." The minimum level must be developed with consideration of the effects and constraints that watershed changes and structural alterations have placed on the hydrology of an affected watershed, surface water, or aquifer. As used in this paper, the minimum level is discussed with respect to the P50 for lakes and wetlands, unless otherwise noted. See Sections 373.042 and 373.0421, Florida Statutes (F.S.). See also Rules 40D-8.021(7), 40D-8.623(3), 40D-8.624(3) and 40D-8.624(4), F.A.C.

Normal pool (NP) elevation – A water level datum originally identified for use in wetland stormwater treatment systems (SWFWMD, 1988) and subsequently used by the District for the establishment of minimum lake and wetland levels. The NP elevation is determined based on consideration and use of reasonable scientific judgement of Hydrologic Indicators of sustained inundation (see Rules 40D-8.623(1)(b) and 62-340.500, F.A.C.) and is most frequently identified by the inflection point (angular change) on the buttress of cypress trees (*Taxodium ascendens* or *T. distichum*). Other biologic indicators, namely the elevations of *Lyonia lucida* root crown bases and the lower limits of epiphytic bryophytes (moss collars) on cypress trunks, have been shown to closely match cypress-derived NP elevations. The NP elevation typically corresponds to the highest 1 to 10% of water levels (SWFWMD, 1999b; Carr et al., 2006; Cameron et al., 2020). Due to the use of persistent indicators to determine the NP elevation, the association of NP with high-water levels that are less influenced by withdrawals (see Basso et al., 2020), and consideration of NP-P50 differences at unimpacted versus impacted sites (see text; SWFWMD, 1999b), NP is believed to be minimally influenced by withdrawals at most cypress domes. Some reports refer to NP as "Historic Normal Pool" (HNP), and the two terms are generally synonymous. See also 40D-8.623(1)(b), F.A.C.

Percentile (Px) – A water level or stage exceedance percentile based on a long-term period. Specific percentiles can be abbreviated as Px, where x is a number between 0 (maximum water level) and 100 (minimum water level). The P10 represents the water level equaled or exceeded 10% of the time. The P50 represents the water level equaled or exceeded 50% of the time. When a percentile is denoted as Historic (HPx), that percentile is associated with current structural alterations but the total absence of withdrawals. See Rule 40D-8.021, F.A.C.

Significant harm – The limit or water level at which further withdrawals would be significantly harmful to the water resources or ecology of the area. See Section 373.042(1)(b), F.S.

Structural alteration – Anthropogenic alteration of an inlet or outlet of a lake or wetland that affects water levels (Rule 40D-8.021(11), F.A.C.). Section 373.0421(1), F.S., requires that changes and structural alterations to watersheds, surface waters, and aquifers and the effects such changes or alterations have had, and the constraints such changes or alterations have placed, on the hydrology of an affected watershed, surface water, or aquifer must be considered when establishing minimum flows and minimum water levels.

Wetland Offset (Mesic Option) – Refers to the standard originally developed in Hancock (2007), which found that significant harm occurred at cypress wetlands when the P50 elevation was lowered more than 0.8 feet below the Historic P50 elevation.

Introduction and Previous Work

Previous Work on the Cypress Offset

Original Development and Application

In a seminal paper, the Southwest Florida Water Management District (SWFWMD 1999b) determined that cypress domes in the Northern Tampa Bay (NTB) area exhibit significant harm when the 50th percentile elevation (P50) is greater than 1.8 feet below the normal pool (NP) elevation. This difference in elevations between the NP and the 50th percentile associated with significant harm became known as the "Cypress Offset." To derive this number, SWFWMD (1999b) assessed 36 cypress wetlands, divided into a sample of 21 "not significantly changed" wetlands and a sample of 15 "significantly" and "severely" changed wetlands (Figure 1). These wetlands were selected based on water level data availability, site accessibility (for ecological assessments), lack of structural alterations, and size (at least 0.5 acre in area). Each wetland's change designation resulted from expert assessments of wetland condition, i.e., wetland health, as indicated by the shrub stratum, stage of vegetative succession (changes in vegetative zonation), prevalence of "weedy" (opportunistic, invasive) species, and degree of soil subsidence; these four parameters were selected from among nine measured health parameters based on their stronger quantitative correlations to hydrology and to minimize redundancies.

Assuming normality for each sample's distributions of NP-P50 differences based on 1989-1995 water level data (Figure 2), SWFWMD (1999b) found that intersection of the cumulative frequency distribution of one classification (the probability of non-exceedance assuming a normal distribution) and the inverse cumulative frequency distribution (the probability of exceedance assuming a normal distribution) of the other represents the classification threshold that minimizes both false positives and negatives (type I and II errors). The probability where the curves intersect equals the misclassification error. This identification of misclassification error based on crossing points of probability distributions is known as the "crossing point" method. Using this method, SWFWMD (1999b) found that the Cypress Offset was associated with a misclassification error of 5%. The Cypress Offset was subjected to independent, scientific peer review (Bedient et al., 1999) and has been used to establish minimum levels for numerous cypress domes in the District (SWFWMD, 1999b; Campbell et al., 2020).

The District extended use of the Cypress Offset to the determination of significant harm and establishment of minimum levels for lakes associated with cypress-dominated wetlands of 0.5 acre or more in size (SWFWMD, 1999a). This approach, which was also peer reviewed (Bedient et al. 1999), was based on the potential for significant changes to occur at a lake and its associated wetlands due to the lowering of water levels as a result of withdrawals.

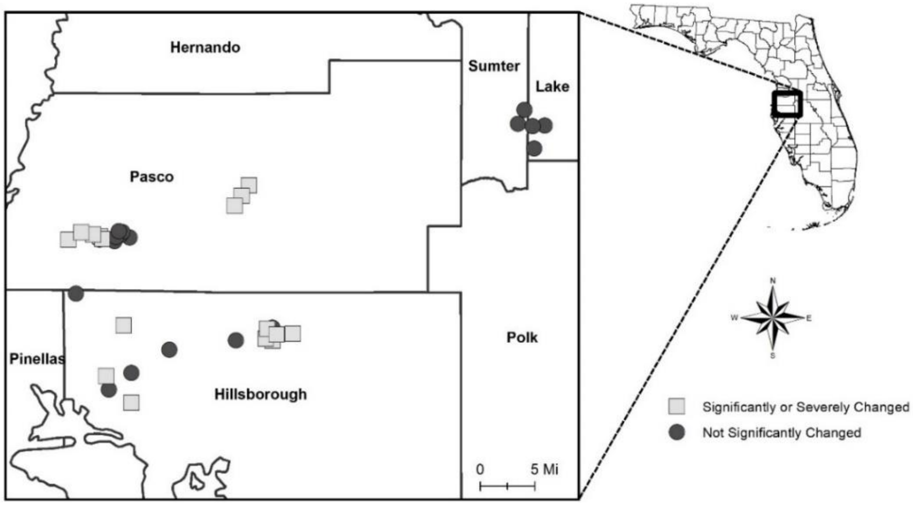

Figure 1. Locations of 36 cypress wetlands used in SWFWMD (1999b) to develop the Cypress Offset.

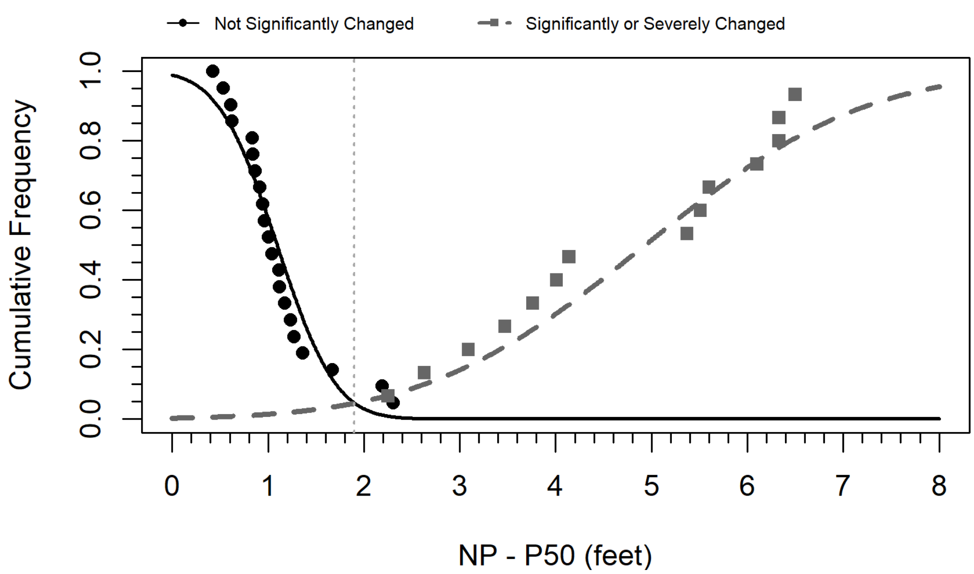

Figure 2. Cumulative frequency function curves used in SWFWMD (1999b) to derive the Cypress Offset. The curve for the “Not Significantly Changed” group is exceedance probability and represents the proportion of sites with NP-P50 differences greater than the x-axis value. The curve for the “Significantly or Severely Changed” group shows the non-exceedance probability and represents the proportion of sites with NP-P50 differences less than the x-axis value. The crossing point method identifies misclassification error as the y-axis value or probability where the probability frequency distributions intersect. The threshold associated with that error is the x-axis value or the NP-P50 difference in feet. Here, that crossing point is at 1.8 ft and the misclassification error is 0.05 or 5%.

Post-Cutback Follow-up Study

In a follow-up study to SWFWMD (1999b), HSW (2012) employed the crossing point method and a similar approach to health designations (although more parameters were included) for 33 cypress domes in the NTB area using data from 2003-2010 to identify an NP-P50 difference threshold that could be used to discriminate between differing wetland groups. Their investigation used a different sample of wetlands than did SWFWMD (1999b), with 7 wetlands in common between the studies. Importantly, the time period used in the study overlapped with large reductions in groundwater withdrawals at regional wellfields (Figure 3) associated with the phased implementation of a recovery strategy for the NTB area (Basso et al., 2020). Cutback-related improvements in hydrologic conditions during this period resulted in limited ability to differentiate between those wetlands that were "changed" (comparable to SWFWMD's [1999b] "significantly changed" group) versus "unchanged" (comparable to SWFWMD's [1999b] "not significantly changed" group). Therefore, 28 changed and unchanged wetlands ("composite") were classified into a single group for comparison against just 5 "severely changed" wetlands; this contrasted with SWFWMD's (1999b) derivation of the Cypress Offset, which compared unchanged wetlands against changed wetlands. Thus, NP-P50 difference threshold of 2.5 feet identified by HSW (2012) for distinction between the two wetland groups is associated with a notably different definition for significant harm than used in SWFWMD (1999b) and is complicated by hydrologic conditions in flux due to wellfield withdrawal cutbacks.

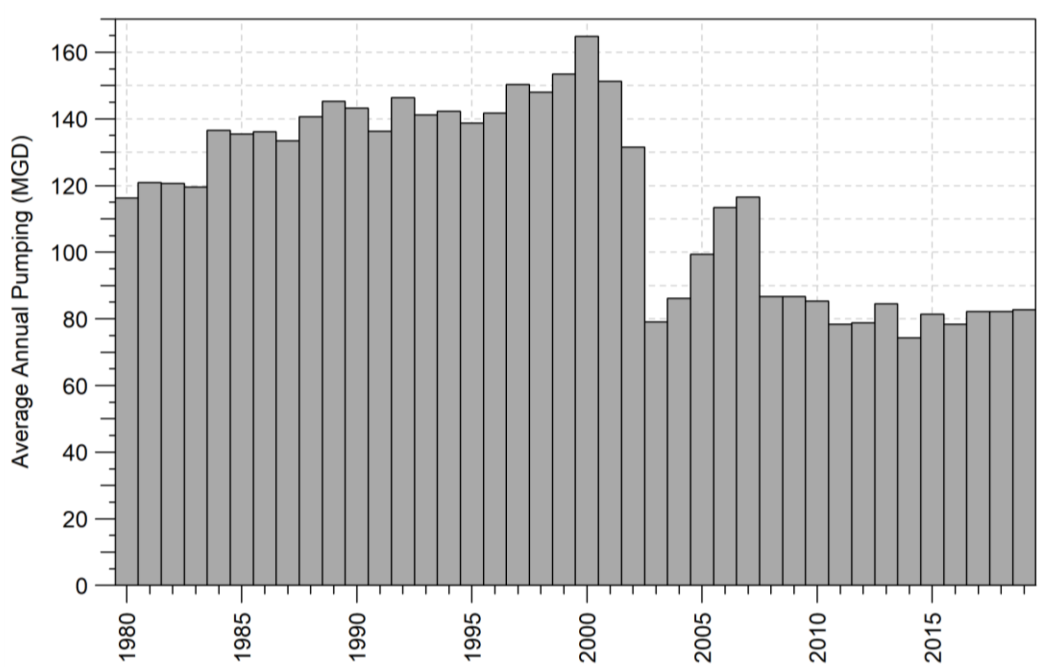

Figure 3. Average annual withdrawals from 1980-2019 at Tampa Bay Water's Consolidated Water Use Permit wellfields in the Northern Tampa Bay area.

Central Florida Water Initiative Plains Wetlands

The Central Florida Water Initiative (CFWI) is a collaborative approach to water management in a region where the boundaries of the South Florida Water Management District, St. Johns River Water Management District and Southwest Florida Water Management District abut and where water withdrawals in one district may impact water resources and water users throughout the area (CFWI, 2020).

In support of the CFWI, the CFWI Environmental Measures Team used a wetland edge elevation (WE) as a high water level indicator based on assessment of water level records, aerial photography, observed hydrologic indicator and soils (CFWI-EMT, 2013, 2020). Using data from 2006-2011 for sites in Lake, Orange, Osceola, Pasco, Polk, and Seminole counties, 10 “unstressed” plains wetlands had an average WE-P50 of 1.26 feet (range: 0.68 to 1.95 feet), while 8 “stressed” wetlands had an average WE-P50 of 3.91 feet (range -1.29 to -6.69 feet) (Bays et al., 2013). Plains wetlands can include cypress domes, marshes, wet prairies, and other types of mesic wetlands located within a flatwoods landscape.

Applying the SWFWMD (1999b) crossing point method to compare stressed and unstressed plains wetlands, a WE-P50 difference of 1.8 feet is identified as the threshold separating unstressed and stressed plains wetlands (MacIntyre, 2018). The relationship of WE to NP for plains wetlands is not currently known, the hydrogeology of the CFWI area differs from that of the NTB area, and the plains wetlands include wetlands other than cypress domes. However, the CFWI WE-P50 difference threshold closely matches the NTB NP-P50 difference threshold (both 1.8 feet), and the unstressed average WE-P50 difference (1.3 feet) approximates the average unstressed NP-P50 difference (about 1.0 feet; see section on “Hydrologic Behavior of Unimpacted Cypress Domes”). Therefore, qualitatively, the WE and NP appear to represent a similar high-water level.

Northern Tampa Bay Recovery Assessment

A comprehensive review of lake and wetland recovery in the NTB area following regional wellfield cutbacks provided an opportunity to assess the efficacy of the Cypress Offset in practice. Of 35 wetlands with minimum levels developed using the Cypress Offset, an initial screening based solely on water level data determined that four wetlands fell below their minimum levels, suggesting ongoing impacts to those wetlands (Basso et al., 2020). The 35 wetlands had recently undergone extensive review to confirm the accuracy and appropriateness of the site-specific NP elevations (Campbell et al., 2020), suggesting little potential for data issues to explain the failure to achieve minimum levels at the four wetlands. However, using a weight-of-evidence assessment that incorporated additional data, such as vegetative data and groundwater level data, Basso et al. (2020) determined that environmental conditions at three of those four wetlands were acceptable. These findings suggested that use of the Cypress Offset may have resulted in overly strict minimum levels at these sites. However, further investigation by Basso et al. (2020) determined that the time periods used to select water level data for the initial screening did not fully account for hydrological changes that occurred after wellfield cutbacks. Using a more appropriate time period (2010-2019), minimum levels at all but one of the wetlands were achieved. Therefore, one out of 35 wetlands was significantly harmed according to the Cypress Offset, and review of other data on wetland health confirmed this assessment. Additionally, when status was reviewed using data from 2010-2020, all 35 wetlands met their minimum level. Accordingly, it was concluded that the Cypress Offset resulted in minimum levels that appropriately identified thresholds for wetland health with respect to significant harm, when the appropriate assessment period is used.

<u>Previous Work on the Mesic Offset</u>

Original Work on Cypress Domes

Following SWFWMD (1999a) and SWFWMD (1999b), which applied the Cypress Offset to cypress domes and lakes for which NP could be assessed, the District later extended its wetlands protection approach for minimum levels development to include lakes for which NP could not be assessed due to lack of appropriate indicators.

Noting that the Cypress Offset delineated significant harm as occurring when the NP-P50 difference exceeds 1.8 feet and finding that the average unimpacted cypress dome had a natural NP-HP50 difference of 1.0 feet, Hancock (2007) determined that the HP50 could thus change by 0.8 feet before significant harm occurred at the average cypress dome, and by extension, lake-fringing wetland. The metric for significant harm of 0.8 feet below the HP50 was called the “Wetland Offset” (further annotated here as the “Mesic Wetland Offset”) and is used to protect lake-fringing wetland habitats where a reliable NP elevation is not available. At the time of writing, the Mesic Wetland Offset has been used to determine minimum levels for more lakes in the District than any other standard or criterion.

As part of an expert panel convened to review standards used in lake minimum levels development, Hull (2019) found that the Mesic Wetland Offset filled a need to protect lake-fringing wetlands and recommended implementing the offset as a standard for minimum levels development. Rains (2019) similarly found that the Mesic Wetland Offset was “justified” and recommended its codification.

More Recent Work on Mesic Wetlands

Nilsson et al. (2013) found no significant differences comparing median water level behaviors for cypress domes, marshes, cypress marshes, wet prairies, and hardwood swamps. However, the empirical density functions were significantly different between the groups. Overall, Nilsson et al. (2013) postulated that "wetlands within a region, i.e., west-central Florida, exhibit similar hydraulic behavior." This suggests that, while originally developed using data for cypress domes, the Mesic Wetland Offset is reasonable to apply to other types of mesic waterbodies in west-central Florida. Applicability of the Cypress and Mesic Wetland Offsets to mesic marshes in the NTB area was confirmed in work by TBW (2018) and Hancock (2020).

Validation of the Cypress and Mesic Wetland Offsets

Revisiting the Original Crossing Point Approach

Given more recent data and updates to historical data included in SWFWMD (1999b), we sought to determine if the Cypress Offset NP-P50 difference threshold of 1.8 feet identified in that original study is still an appropriate threshold for distinguishing between changed and unchanged wetlands. As will be discussed, relative to the NP-P50 differences reported in SWFWMD (1999b), the updated datasets have resulted in revised NP-P50 differences for the original 36 wetlands for the 1989-1995 period. Additionally, as highlighted by the HSW (2012) work, changes to pumping and rainfall have confounded extensions of the period of record beyond the original 1989-1995 analysis period.

Namely, in the NTB area, significant rebounds in groundwater and wetland water levels occurred following large reductions in groundwater withdrawals at regional wellfields that were initiated in the early- to mid-2000s (Figure 3; Basso et al., 2020). Accordingly, compared to SWFWMD (1999b), considerably fewer wetlands with significantly changed hydrological conditions occur in the area today, a phenomenon already evident by the time of the HSW (2012) study, for which only a small number of changed wetlands could be identified. The hydrologic recovery has also contributed to changes in wetland health. Additionally, due to extensive land development in the NTB area, stressed wetland health can result from non-hydrologic confounding factors, making some wetlands inappropriate for use in development of a threshold meant to relate hydrology to health. Finally, most wetlands lack health score data appropriate for direct use in classification techniques. While many wetlands in the District have Wetland Health Assessment (WHA) or Wetland Assessment Procedure (WAP) data (SWFWMD and TBW, 2005), transforming these into binary designations appropriate for classification methods requires extensive data review and processing (e.g., Bartholomew et al., 2020; GPI, 2020) that is beyond the scope of our current effort. Finally, as noted in SWFWMD (1999b), most wetlands lack of survey and water level data, in particular the subsurface water level data essential to characterize cypress dome hydrology. Therefore, updating the work of SWFWMD (1999b) using additional wetlands would require extensive time and cost, with wellfield cutbacks limiting the potential sample size of significantly and severely changed wetlands, while extending the analysis period subjects the classification of changed and unchanged wetlands to complicating factors associated with changes in pumping and rainfall. Therefore, the sample identified in SWFWMD (1999b) remains the best available information.

As regional wellfield cutbacks did not begin until 2003 and were not fully implemented until 2012 (Figure 3), health classifications provided in SWFWMD (1999b), which are based on assessments conducted in 1997, may be representative of wetland conditions through at least 2003, and, due to lag between cutbacks and hydrologic and ecologic responses, possibly several years longer. However, given changing withdrawal and rainfall conditions, the applicability of the SWFWMD (1999b) health classifications beyond 1997 is not known and will be discussed later. For 32 of the 36 wetlands assessed in SWFWMD (1999b), monitoring continues into the present, with monitoring discontinued after 2004 for the remaining four. Therefore, staff gage and well data through 2004 for four wetlands and through 2019 for 32 wetlands were obtained from water level databases maintained by the District and Tampa Bay Water.

In some instances, water level data obtained from the modern databases appear incongruent with data in SWFWMD (1999b), when comparing data from the overlapping time period (1989-1995) available in both datasets. These discrepancies can result from datum corrections following more accurate survey benchmarks that are retroactively applied to data, loss of historical data records, and occurrences or corrections of errors in the modern database. Additionally, changes in monitoring stations can result in differences between older data and newer data within the modern database. For example, after 2000, hand-dug wells at many wetlands (evidenced in early hydrographs by upwards migration of water level minima as debris filled the well) were replaced with professionally installed wells, so older subsurface readings at some wetlands may not be directly comparable to recent subsurface readings. Hydrographs for the wetlands are shown in Appendix A.

As a further complication, additional fieldwork and assessments performed by the District and Tampa Bay Water have determined that, for some wetlands, NP elevations reported in SWFMWD (1999b) could either be improved based on more recent, accurate survey data or are potentially inappropriate for inclusion in the sample due to the wetlands being considered “connected” wetlands (which often lack reliable NP indicators), or due to having other issues (Table 1). For the following analyses, the most updated NP elevations were used, but for consistency with SWFWMD (1999b) and to avoid reducing the sample of changed wetlands to a very low number, i.e., from 15 down to 8, all wetlands were retained.

Table 1 shows a comparison of the NP-P50 for the overlapping period of 1989-1995 from modern records versus that provided in SWFWMD (1999b), which provides a measure of the difference between water level and NP data used in SWFWMD (1999b) versus the current work.

Despite these limitations, the crossing point method was applied to the extended and modernized dataset to provide an updated review of the Cypress Offset as originally developed in SWFWMD (1999b) (Table 2). Eight time periods of at least five years were assessed to capture varied rainfall conditions. Time periods were limited to ending in 2004 due to wellfield cutbacks and the discontinuation of data collection at four sites. For each evaluated period, the Shapiro-Wilk test was performed to assess normality of NP-P50

Table 1. Wetlands used to develop the Cypress Offset in SWFWMD (1999b). Period-of-record water level data through 2019 was downloaded from modern databases for these wetlands; however, this data and NP elevation data do not appear to exactly match data used in SWFWMD (1999b), as indicated by comparing the NP values and 1989-1995 NP-P50 differences reported in SWFWMD (1999b) against the NP and 1989-1995 NP-P50 differences based on data accessed from modern databases.

Wetland Name(s)	Health Rating[†]	SWFWMD (1999b) NP (feet NGVD29)[%]	Modern Database NP (feet NGVD29) ^	SWFWMD (1999b) 1989-1995 NP-P50 (feet)[%]	Modern Database 1989-1995 NP-P50 (feet)^
Morris Bridge X-4 (MBR-89) (NW-115)	B	42.4	42.2	0.4	1.2
WC342718*[#]	B	54.8	N/A	0.5	1.1
Starkey N	B	46.9	47.0	0.6	0.6
Green Swamp 1	B	100.5	100.6	0.6	0.5
Starkey M (S-69)	B	44.8	44.9	0.8	0.8
MBWF X-5 (MBR-60) (NW-125)[§]	B	34.8	N/A	0.8	0.1
STWF DD (S-68)	B	43.9	43.9	0.9	1.0
Green Swamp 6	B	97.7	98.1	0.9	0.9
Green Swamp 3	B	102.7	103.2	0.9	0.9
NW072818 (NW-61)*[#]	B	34.2	N/A	1.0	0.6
Starkey S-97*	B	44.2	44.2	1.0	1.0
Starkey S-75	B	47.2	47.2	1.0	1.2
Starkey Eastern (S-73) (SE Rec)	B	46.4	46.4	1.1	1.1
Starkey S-70*[§]	B	44.7	N/A	1.1	1.0
MBR-96*[‡¶]	B	35.4	N/A	1.2	0.8
Green Swamp 4	B	102.7	103.2	1.2	1.1
NWH142817*[¶]	B	15.7	N/A	1.3	2.2
Green Swamp 2	B	100.5	100.6	1.4	1.3
Green Swamp 5	B	98.9	98.8	1.7	1.7
WC302818*[‡#]	B	21.1	N/A	2.2	2.9
COS NC242717*[‡#]	G	51.0	N/A	2.3	3.0
Eldridge-Wilde 11 (NW-44)	B	38.5	38.2	2.3	2.3
Starkey S-94*[‡¶]	G	39.7	N/A	2.6	1.7
WC102817*[¶]	G	23.6	N/A	3.1	3.2
STWF S-10 and STWF CC*	G	29.2	29.5	3.5	3.6
Starkey Central	G	45.1	45.1	3.8	3.8
Morris Bridge Clay Gully Cypress (MBR-88)	G	41.6	41.4	4.0	2.7
MBWF X-2 (MB3C)[#]	G	35.1	35.1	4.1	0.7
Cypress Creek W-11	R	69.4	69.6	5.4	5.1
Cypress Creek W-17	G	64.9	64.6	5.5	4.4
STWF U (S-30)[#]	R	31.9	N/A	5.6	1.9
MBR-91 (W-160)*	G	36.3	35.2	6.1	6.8
Cypress Creek W-41[#]	R	74.9	N/A	6.3	5.9
MBR-30*[#]	R	34.1	N/A	6.3	5.6
Morris Bridge Entry Dome (MBR-35)	G	35.5	35.6	6.5	5.4
Starkey Western (Windowmaker) (S-44)*	R	35.3	36.9	8.9	9.2

*Data from Tampa Bay Water. [†]B = unchanged; G = significantly changed; R = severely changed. [%]From SWFWMD (1999b). ^Values from modern databases; if current NP not available, uses NP from SWFWMD (1999b). [‡]Data discontinued after 2004 but before 2019. [§]Potential connected wetland. [¶]Survey issues. [#]Unreliable NP indicators or other issues.

difference distributions for the changed and unchanged wetland samples. In numerous instances, the distributions were non-normal, so an empirical distribution (with data points linearly interpolated) was also assessed. The empirical distributions generally provided threshold values similar to the normal distributions, as the normal distributions typically performed well in characterizing the curves near the region of overlap, despite performing poorly at the distribution extremes. Figures of the tested distributions are shown in the Appendix B, and the results are summarized in Table 2.

For the evaluated time periods, NP-50 difference thresholds ranged between 1.3 and 2.1 feet. Notably, analyzing the 1989-1995 period with modernized data as described above, the threshold of 1.8 feet matches SWFWMD (1999b), but the misclassification rate is 16%, much higher than the 5% reported in SWFWMD (1999b) (Table 2). Misclassification rates for other time periods ranged from 15 to 24%. Due to the small sample sizes for changed (n = 15) and unchanged (n = 21) wetlands, misclassification of even one additional wetland can substantially change the misclassification rate.

Table 2. Threshold value using crossing point classification method to distinguish between changed (n = 15) and unchanged (n = 21) cypress wetlands using different time periods and the modern dataset.

Time Period	Normal Distribution NP-P50 Difference Threshold (feet)	Normal Distribution Misclassification Rate	Empirical Distribution NP-P50 Difference Threshold (feet)	Empirical Distribution Misclassification Rate	Average Annual Rainfall (in)‡
1989-1995	1.8	0.16	1.8	0.16	47.5
1989-2000	1.9	0.18	1.9	0.15	47.8
1995-2000*	1.8	0.24	1.9	0.19	49.6
1989-2002	1.9	0.17	2.0	0.14	48.8
1989-2004*†	1.7	0.21	1.6	0.17	50.1
1995-2002*	1.9	0.21	2.1	0.16	50.9
1995-2004*†	1.5	0.24	1.5	0.17	52.6
2000-2004*	1.6	0.23	1.3	0.23	51.9

*Changed wetlands exhibited non-normal distribution at alpha = 0.05. †Unchanged wetlands exhibited non-normal distribution at alpha = 0.05. ‡Using rainfall data for "Central" region from https://www.swfwmd.state.fl.us/resources/data-maps/rainfall-summary-data-region; average annual rainfall from 1915-2020 is 52.5 in.

Over time, since the end of the 1989-1995 period originally analyzed in SWFWMD (1999b), wellfield pumping has been reduced (Figure 3) and rainfall has increased (Table 2). Concurrently, misclassification has increased as the area of overlap between probability density functions of changed and unchanged wetlands has increased. This is consistent with the explanation that the "changed" wetlands are recovering (noted in Basso et al., 2020), P50 values are increasing toward NP elevations, correspondingly causing the NP-P50 threshold value to decrease. Therefore, the reduced NP-P50 difference thresholds associated with inclusion of post-1995 data are not likely data artifacts, but rather, reflect increasing water levels and potential recovery of the wetlands originally classified as “changed”.

Average annual rainfall is linearly related to the NP-P50 difference threshold ($R^2 = 0.59$ for the normal distributions; $R^2 = 0.36$ for the empirical distributions), with each additional inch of average annual rainfall associated with a decrease of about 0.1 feet in the threshold value. This suggests that higher rainfall somewhat offsets withdrawal-related impacts at changed wetlands. However, the higher rainfall periods also potentially coincide here with cutbacks that began phasing in during the early 2000s, which complicates this interpretation. The NP-P50 difference of unchanged wetlands could be influenced by changing rainfall conditions, as well. To better understand how rainfall could influence results, the relationship between rainfall and the NP-P50 differences for changed and unchanged wetlands was explored.

As noted in the definitions section, at unimpacted waterbodies, the P50 equals the HP50[1], and the HP50 reflects the climate conditions of the time period used for assessment. Considering the periods assessed in Table 2, the mean NP-P50 difference for unchanged wetlands varied between 1.0 and 1.3 feet (which is consistent with findings from several studies for unimpacted cypress domes, as discussed in the next section), compared to changed wetlands varying between 2.8 and 4.3 feet (Figure 4). The correlation between average annual rainfall and the mean NP-50 difference for each period is significant for both unchanged wetlands ($R^2 = 0.51$; $p = 0.05$) and changed wetlands ($R^2 = 0.84$; $p < 0.01$). Specifically, as rainfall increases, the mean NP-P50 differences for both unchanged and changed wetlands decrease; that is, the P50 moves closer to NP, an intuitive response. However, based on least-squares regression slopes, the response is five times greater for changed wetlands than at unchanged wetlands (Figure 4). Thus, while the NP-P50 differences for changed and unchanged wetlands move in the same direction in response to rainfall variations, the effect is much smaller at unchanged wetlands, where the NP-P50 difference is much more stable. Thus, the average NP-P50 difference for unchanged wetlands appears to be relatively insensitive to rainfall conditions, provided that a sufficiently long period (i.e., several years) is sampled. This provides support for the interpretation that the smaller thresholds found in Table 2 are influenced by higher rainfall conditions leading to decreased NP-P50 differences for changed wetlands, which suggests SWFWMD (1999)’s health classifications may not be appropriate to extend beyond 1995.

[1] Recall that the “H” prefix denotes a Historic percentile, where Historic indicates water levels with current structures but the total absence of withdrawals. At an unimpacted waterbody, HPx can be taken as the Px for all percentiles. At an impacted waterbody, generally, the elevation associated with HPx is higher than the elevation associated with Px.

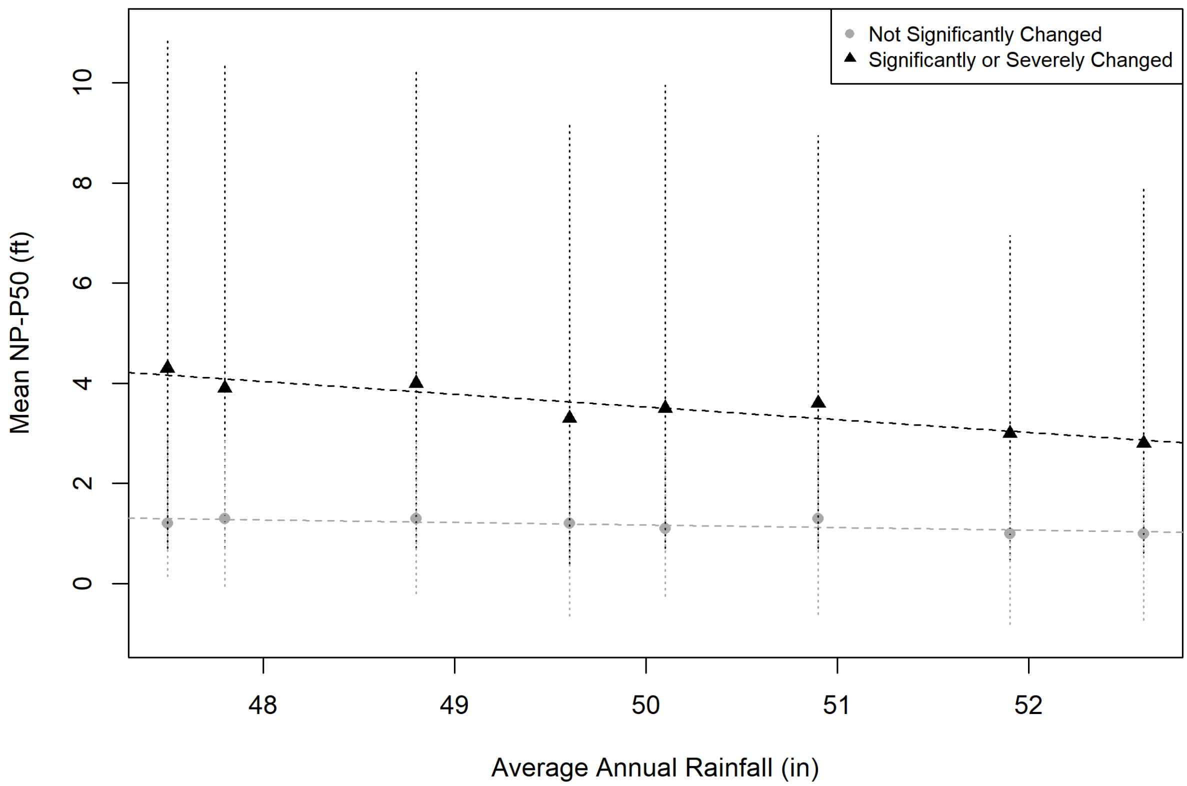

Figure 4. Relationship between the average NP-P50 difference and average annual rainfall for changed and unchanged wetlands. Points show the mean, vertical lines show the range, and diagonal lines show the least-squares regression for each group.

As an additional comparison, using the 1989-1995 period with modern water level and NP data, but excluding connected wetlands, wetlands with survey or other issues, and wetlands lacking a reliable NP elevation (Table 1), both changed (n = 8) and unchanged (n = 14) wetlands exhibited normal distributions (based on Shapiro-Wilks tests at an alpha of 0.05), and the crossing point classification method results in an NP-P50 difference threshold of 1.7 feet and total misclassification rate of 8%. Both of these values are similar to those reported in the District's (SWFWMD 1999b) original analysis.

In summary, a reassessment of the 1989-1995 dataset with modernized elevations following datum corrections, improved accuracy, and error corrections including updated NP elevations, reaffirmed the Cypress Offset at 1.8 feet (Table 2). However, this offset is now associated with a 16% error rate, contrasted with the 5% error rate originally reported in SWFWMD (1999b). Other time periods result in differing threshold values from 1.3 to 2.1 feet, but many of these analyses are confounded by changes to pumping and rainfall such that the classification of wetlands done in 1997 may not apply beyond the original assessment period. Due to limited availability of significantly and severely changed wetlands following wellfield cutbacks, this dataset represents the best available information for development of the Cypress Offset. As a result, we conclude that the

Cypress Offset value of 1.8 feet continues to be a reasonable threshold for distinction between changed and unchanged wetlands and operates as a reasonable threshold for significant harm in mesic cypress domes.

Hydrologic Behavior of Unimpacted Cypress Domes

There are several approaches for identifying a NP-50 difference threshold between unchanged and changed wetlands. One approach involves application of classification techniques such as the crossing point method to NP-P50 differences for samples of changed and unchanged wetlands. An alternative is to simply analyze a sample of unchanged wetlands and use the means, maxima, or other univariate metrics of the NP-P50 to identify a threshold value, given that for unimpacted waterbodies the P50 equals the HP50.

Several studies, including some introduced in a previous section, have characterized unchanged wetlands using differing sample sizes, wetlands, and time periods (Table 3). Using data from the 41 hydrologically unimpacted NTB cypress domes (Figure 5) used in Cameron et al. (2020), extended from 2003-2019, the average NP-P50 difference was 1.0 feet (range: 0.4 to 1.9 feet; the NP-P50 differences are normally distributed based on a Shapiro-Wilk test an alpha of 0.05). This value matches that reported by Hancock (2007), who identified an average NP-P50 difference of 1.0 feet (range: 0.5 to 1.3 feet) based on nine cypress domes with observed (1979-2005, except one beginning in 1984) and modeled (1946-2005) data. Similarly, SWFWMD (1999b), used 1989-1995 data reported an average NP-P50 difference of 1.1 feet (range: 0.4 to 2.3 feet) for 21 unchanged cypress wetlands. Using the current work's extended dataset for SWFWMD (1999b) but excluding wetlands with NP issues (Table 1), 14 unchanged cypress wetlands with data from 1989-2019 had an average NP-P50 difference of 1.0 feet (range: 0.6 to 1.8 feet). For 10 unstressed plains wetlands in the CFWI, Bays et al. (2013) found an average WE-P50 of 1.3 feet (range: 0.7 to 2.0 feet) using data from 2006-2011; however, the relationship of WE to NP has not been rigorously quantified for mesic waterbodies, much of the CFWI area differs hydrologically from the NTB area, and the hydrologic and ecological similarity of NTB cypress domes and CFWI plains wetlands is not currently well characterized. Thus, mean, maximum, and minimum statistics for the NP-P50 difference in unimpacted NTB cypress wetlands are remarkably consistent, even when evaluating different samples and time periods (and thus differing rainfall conditions; for example, 1989-1995 represented an unusually dry period while 2003-2019 represented more average conditions; Table 3; Basso et al., 2020). Irrespective of wetlands sampled and time periods chosen, the average NP-P50 difference is approximately 1.0 feet and the maximum NP-P50 difference is approximately 2.0 feet (Table 3).

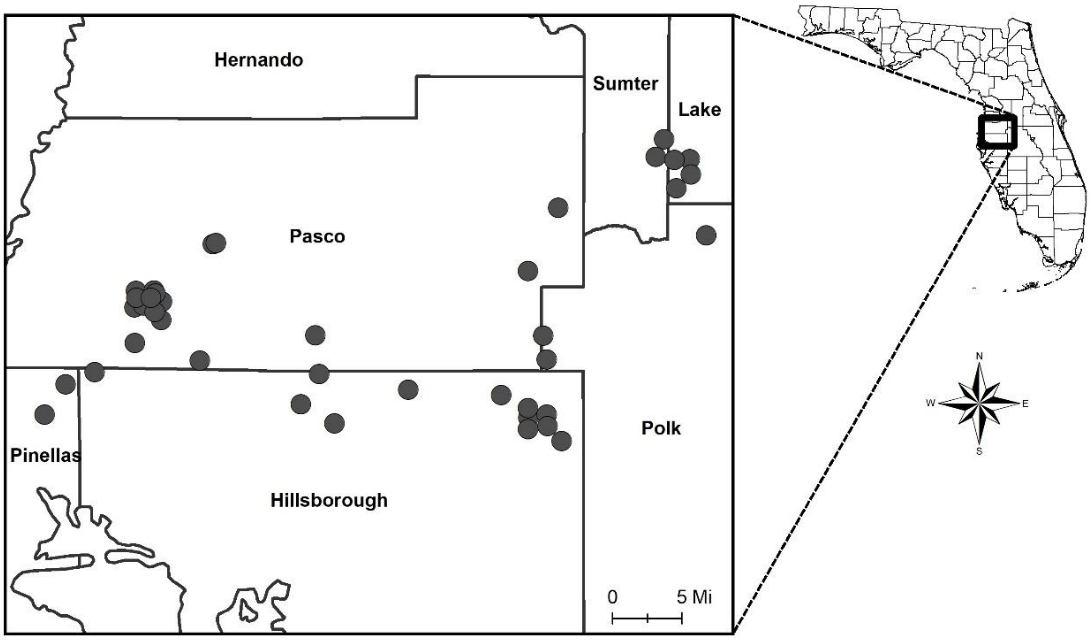

Figure 5. Locations of 41 unimpacted cypress domes.

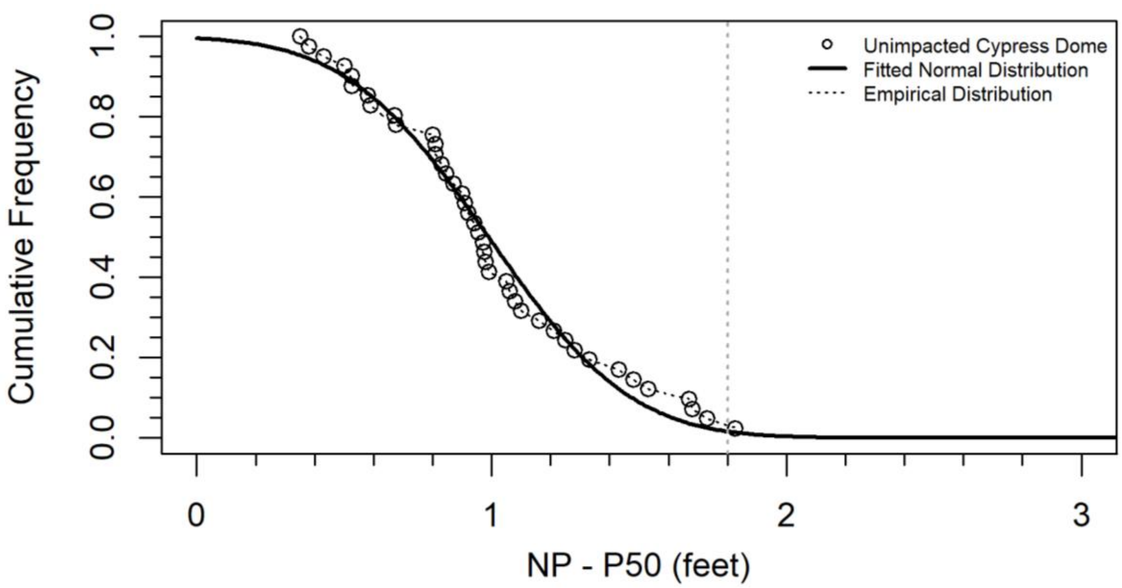

Figure 6. Cumulative frequency distribution of NP-P50 differences for 41 unimpacted cypress domes using 2003-2019 water level data. The vertical line indicates the Cypress Offset threshold of 1.8 feet. The domes were not impacted by withdrawals during the assessed period, so P50 = HP50.

While various classification methods derive thresholds using different mathematical approaches, based on the NP-P50 difference maxima for the samples in Table 3, a threshold value of about 2 feet essentially demarcates the greatest expected NP-P50 difference at an unchanged cypress dome in the NTB area. Accordingly, any cypress dome with an NP-P50 difference larger than about 2 feet can be considered as very likely to be changed. Using Cameron et al. (2020)'s sample of 41 unimpacted cypress domes with 2003-2019 data, both the fitted normal and empirical distributions estimate that only 2% of cypress domes would have NP-HP50 differences greater than the 1.8 feet identified by the Cypress Offset (Figure 6). On the other hand, while changed cypress domes could have NP-P50 differences of less than 1.8 feet, based on the 5 to 16% misclassification rate reported in SWFWMD (1999b) and Table 2, this is a relatively infrequent occurrence. This provides additional support that the Cypress Offset value of 1.8 feet continues to be a reasonable threshold for distinction between changed and unchanged wetlands.

Table 3. Minimum, mean, and maximum NP-P50 differences (feet) for unchanged or unstressed wetlands, and average annual rainfall. Withdrawal impacts were minimal or not detected during the assessed periods, so NP-P50 differences approximate NP-HP50 differences.

	SWFWMD (1999b)*	Updated SWFWMD (1999b)†	Hancock (2007)‡	Bays et al. (2013)§	Updated Cameron et al. (2020)¶
N	21	14	9	10	41
Time Period	1989-1995	1989-2019	1946-2005	2006-2011	2003-2019
Minimum	0.4	0.6 (0.6)	0.5	0.7	0.4
Mean	1.1	1.0 (1.2)	1.0	1.3	1.0
Maximum	2.3	1.8 (2.0)	1.3	2.0	1.9
Rainfall (in)#	47.5	51.5 (47.5)	53.5	46.6	52.4

*Based on values as reported in the original study. †Using data from modern databases and excluding wetlands later identified to have NP issues. Parenthetical values show 1989-1995. ‡Includes modeled water level data. §Uses WE (instead of NP) for plains wetlands (which includes wetlands other than cypress domes) in the CFWI area. ¶Includes data updated through 2019 (record for original study ended in 2018). #Using rainfall data for "Central" region from https://www.swfwmd.state.fl.us/resources/data-maps/rainfall-summary-data-region; average annual rainfall from 1915-2020 is 52.5 in.

Conclusion Regarding the Cypress Offset

Based on a reassessment of SWFWMD (1999b) and consideration of NP-P50 difference distributions for unimpacted cypress domes, we conclude that the Cypress Offset value of 1.8 feet continues to be a reasonable threshold for distinction between changed and unchanged wetlands and can reasonably be used as a significant harm threshold in mesic cypress domes. Its use for identifying significantly harmed wetlands was confirmed during a recent comprehensive recovery assessment effort for the NTB area (Basso et al., 2020). Regional wellfield cutbacks have resulted in the availability of few significantly harmed wetlands to use in classification methods, which complicates efforts to expand upon the SWFWMD (1999b) dataset either with additional wetlands or with substantially more years of data. Accordingly, the Cypress Offset remains the best available information for use at cypress domes and other mesic wetlands within the District. Therefore, we recommend that the Cypress Offset continue to be used to develop minimum levels for wetlands that have reliable NP (or equivalent) and are positioned in hydrogeologic settings similar to and demonstrate hydrologic behavior similar to that of the cypress wetlands from which the offset was derived.

Validation of the Mesic Wetland Offset

By validating the NP-P50 difference of 1.8 feet as delineating significant harm at cypress domes and the average NP-HP50 difference of 1.0 feet for an unimpacted cypress dome, Hancock's (2007) Mesic Wetland Offset, which subtracts these values to determine that significant harm occurs at the average cypress dome when the HP50-P50 difference exceeds 0.8 feet, is also validated.

Application of Offsets to Northern Tampa Bay Lakes

As described in SWFWMD (1999a), the District assumed the Cypress Offset could be used for the establishment of minimum levels for lakes with cypress-fringing wetlands. The underlying assumption was that the NP-HP50 fluctuation and the percentile of the NP for an unimpacted, unstructured cypress dome was representative of those for an unimpacted, unstructured lake. To further explore this assumption, we compared NP-HP50 fluctuations for cypress domes and NTB lakes.

Cypress Offset for Northern Tampa Bay Lakes

A normal pool (NP) elevation cannot be established at many lakes, due to a lack of appropriate hydrologic indicators. For these lakes, the Cypress Offset may be used by translating NP elevations from wetlands to percentiles. However, even at lakes with a reliable NP elevation, the NP-HP50 difference may vary from that observed for cypress domes. This could occur for at least two reasons. First, the natural hydrologic behavior of the typical NTB lake could differ from that of the typical NTB cypress dome. Second, structural alterations are considerably more common at NTB lakes than cypress domes (e.g., Campbell et al., 2020), and these alterations typically reduce high lake water levels, creating a new hydrologic regime such that NP values associated with pre-structural water levels no longer reflect the hydrologic behavior possible at the lake, even in the absence of withdrawals.

Percentile of NP at Lakes and Comparison to Reference Lake Water Regime Statistics

Using a set of 22 reference lakes in the NTB area, SWFWMD (1999a) found that the average and median HP10-HP50 difference was 1.0 feet (range: 0.4 to 2.5 feet). This value was included as part of the NTB “Reference Lake Water Regime”, which was used for characterizing water level fluctuations expected in the absence of withdrawal impacts and for minimum levels development. Accordingly, if the NP of a typical lake represents a percentile higher than the HP10, then the typical NTB lake with HP10-HP50 difference of 1.0 feet (as found in SWFWMD, 1999a) would be expected to have an NP-HP50 difference greater than 1.0 feet, where 1.0 feet is the NP-HP50 difference of the typical cypress dome (Table 3).

Based on data from Cameron et al. (2020), the average NP elevation for unimpacted cypress domes in the NTB area corresponds to the P03, although the percentile varied by wetland. As these wetlands are unimpacted, we can consider the P03 to be identical to the HP03. Normal pool percentiles calculated from modelled Historic water levels for 16 NTB lake systems for which NP and modelled long-term Historic water level data are available (Figure 7), yielded a median NP associated with the HP05 (range: HP01 to HP27). Additionally, the median NP-HP50 difference for the lakes was 1.9 feet (range: 0.8 to 5.7 feet). Documentation for the individual lakes and their Historic models are available in Carr et al. (2014), Carr et al. (2018a, 2018b, 2018c), Kolasa and Patterson (2015), Uranowski et al. (2015), Leeper and Ellison (2016), Carr and Hancock (2017a, 2017b), Swindasz et al. (2017a, 2017b), Hurst et al. (2018, 2019), and Campbell and Hancock (2017).

In the NTB area, record-high regional groundwater levels in the post-2008 period (most 12-year median water levels were the highest in 40 to 60 years from long-term UFA monitor wells in the lakes region) and slightly above-average rainfall occurred in the 2010-2019 time period (Basso et al., 2020), which means that the effects of groundwater withdrawals on most NTB lakes is believed to be relatively low during this time period. Even after the mandatory cutback of nearly 50 percent in groundwater use during this period, overall groundwater withdrawals were still substantial (Figure 3), and there is undoubtably some small change on most lake stages from withdrawals. However, that presumed impact doesn't rise to the level of significant harm as minimum levels on all 71 lakes in the NTB region were met using 2010-2019 stage data.

Analyses involving 2010-2019 data for NTB lakes do, however, provide supporting evidence for Historic modelled water level data. For example, Basso et al. (2020) found no significant difference between pre-cutback and post-cutback P10s for a sample of 51 NTB lakes. This was interpreted as P10 and higher water levels for NTB lakes being (relative to lower water levels) less sensitive to withdrawals and more controlled by structures and high or sustained rainfall events. This suggests that analyses of P10 and higher water levels using 2010-2019 data, in aggregate, may approximate Historic conditions for these lakes. With these limitations in mind, using empirical 2010-2019 data for the 16 lake systems (Figure 7), the median NP is approximately the HP03 (range: HP00 to HP19), and the median NP-HP50 difference is 1.2 feet (range: 0.5 to 4.2 feet).

Both the modelled Historic water level data and the empirical 2010-2019 water level data for the 16 lake systems provided similar estimates for the percentile of the NP (HP05 and HP03, respectively). That the percentile estimated from the Historic data is lower than that estimated from the empirical data could be explained by manifestation of withdrawal impacts in the empirical data, differing time periods between the empirical and Historic datasets, and possibly overprediction of extreme water levels in the modelled Historic data. While not identical, the two percentile estimates are, however, very similar (HP03 to HP05) and comparable to the estimate for cypress domes (HP03).

As noted above, Reference Lake Water Regime Statistics predict that the HP10-HP50 difference at a typical reference NTB lake is 1.0 feet. The average NP-HP50 difference of the typical unimpacted cypress dome is about 1.0 feet (Table 3), and the NP is approximately the HP03 (Cameron et al., 2020). Using Historic and empirical datasets for 16 lake systems, the percentile of the NP at lakes is estimated as falling between the HP03 and HP05, which by comparison to the Reference Lake Water Regime, suggests that NP-HP50 difference at typical NTB lakes exceeds 1.0 feet and therefore exceeds the average cypress dome NP-HP50 difference. Additionally, assessment of NP-P50 differences calculated from the empirical and Historic datasets suggest that the NP-HP50 difference at lakes is between 1.2 and 1.9 feet, respectively, and in either case is larger than the NP-HP50 difference of 1.0 feet typical at unimpacted cypress domes.

In summary, comparison of data against Reference Lake Water Regime statistics suggests that NP-HP50 differences at NTB lakes are greater than those at area cypress wetlands. However, data for the assessed lakes include variable effects of water control structures, withdrawal impacts, and in some cases, augmentation to increase water levels.

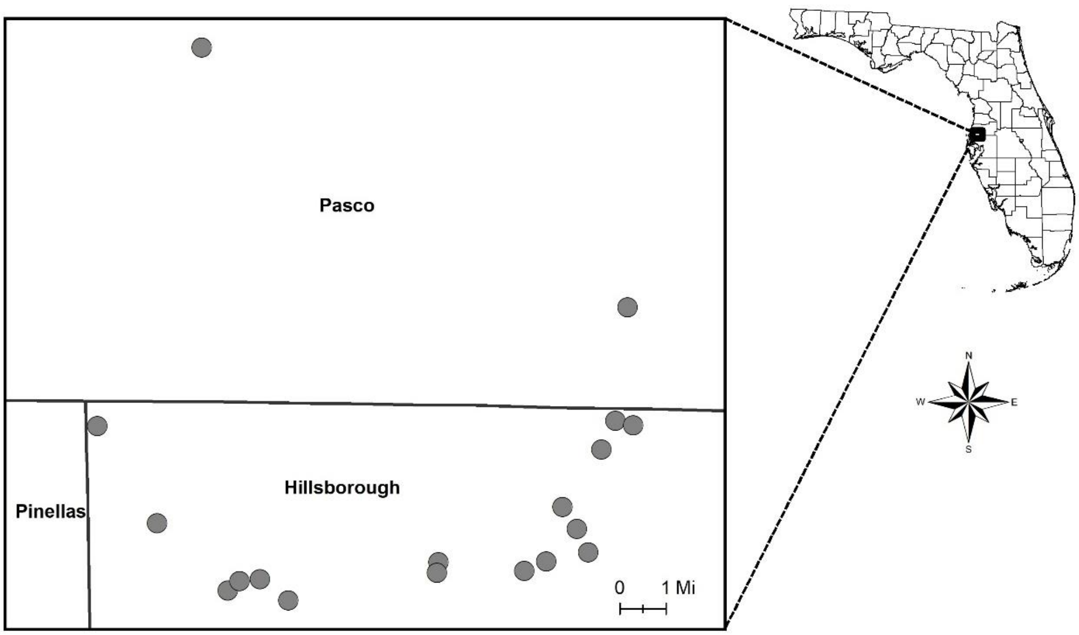

Figure 7. Locations of 16 lake systems in the NTB area used to calculate historic percentiles for the NP elevation.

Approximate Empirical NP-HP50 Differences of Lakes versus Cypress Domes

To further assess the possibility that lakes in the NTB area exhibit a greater NP-HP50 difference than do cypress domes, inter-percentile water level statistics were calculated using 2010-2019 data for a sample of 51 NTB lakes with minimum levels (Figure 8; Table 4). The 2010-2019 period was assessed for reasons described in the previous section, again noting that the lakes may have varying degrees of impacts, although these are believed to be small at most lakes, especially at water levels at or above the P10 (Basso et al., 2020).

As noted in the previous section of this report, the NP at NTB lakes was estimated to occur between the P03 and P05 and corresponds with the P03 for NTB cypress domes.

Based on the similarity of these percentiles, the P03 was used to approximate NP at both lakes and wetlands and facilitate comparisons between the two water body types.

Table 4 shows inter-percentile statistics for the lakes and those for the unimpacted cypress domes evaluated by Cameron et al. (2020). Comparing the P03-P50 difference for 51 NTB lakes against the sample of 41 unimpacted cypress domes, indicates that on average, lakes exhibit a larger P03-P50 difference. Using a Kolmogorov-Smirnov test, the P03-P50 difference distributions were significantly different ($p < 0.01$), but the P10-P50

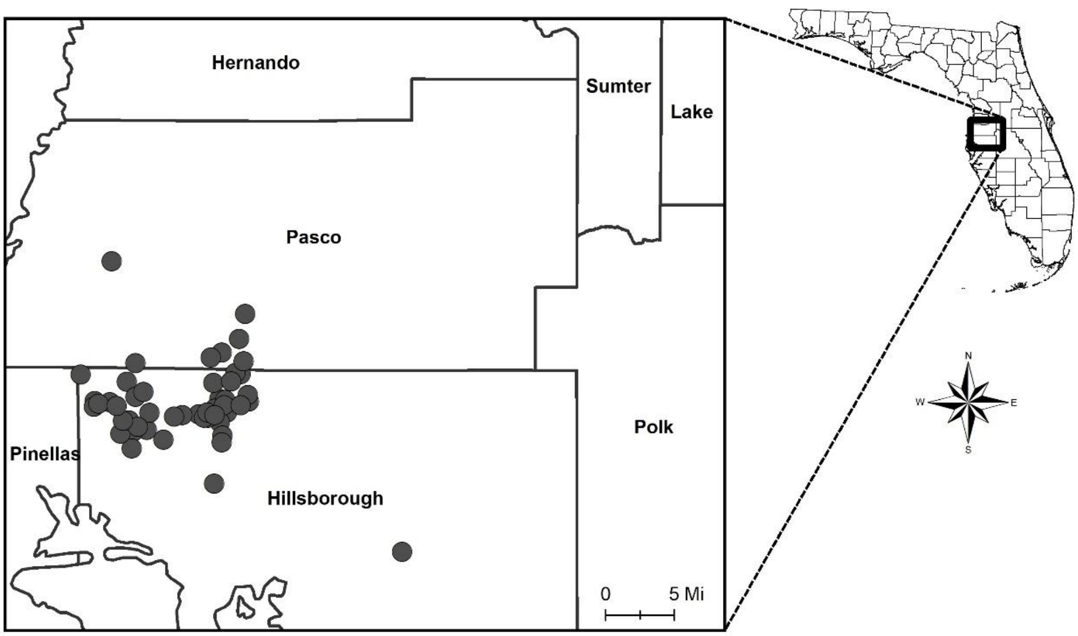

Figure 8. Locations of 51 lakes in the NTB area used for comparison of inter-percentile stage values with those determined for 41 cypress wetlands shown in Figure 4.

Table 4. Average (and range of) inter-percentile differences for lakes versus cypress domes in the NTB area. The P03 is used to approximate NP elevation. The cypress domes had no or minimal withdrawal-related impacts during the assessed period, so $Px \approx HPx$. The lakes may have varying degrees of impacts, although these are believed to be minimal-to-moderate at most lakes, especially at water levels at or above the P10 (Basso et al., 2020).

	NTB Lakes*	Cypress Domes†
N	51	41
Time Period	2010-2019	2010-2019
P03-P50 Difference (feet)	1.2 (0.3 – 4.7)	0.8 (0.5 – 1.4)
P10-P50 Difference (feet)	0.8 (0.2 – 3.6)	0.7 (0.3 – 1.2)
Range (feet)	4.6 (2.5 – 11.7)	5.5 (3.2 – 9.0)

Percentile values were based on aggregated monthly means. *Percentile values incorporate variable effects of structures, withdrawal impacts, and augmentation. †Water level records used for percentile values included subsurface measurements.

differences were not ($p = 0.19$). Additionally, average P05-P50 differences of lakes (1.1 feet; not shown in Table 4) are larger than average P03-P50 differences of cypress domes (0.8 feet), and the lake P05-P50 difference distribution is significantly different from the cypress dome P03-P50 difference distribution ($p < 0.01$). However, these lake data include variable effects of structures, augmentation to increase water levels at some lakes, and variable withdrawal impacts.

NP-HP50 Differences when Controlling for Structures

For a more direct comparison of NP-HP50 ranges for cypress domes versus lakes, an evaluation that includes NP-HP50 values for lakes for which the HP50 is minimally affected by structures was needed. Although most lakes in the District and especially the NTB area have been structurally altered, where the control point of the structure (i.e., the elevation associated with the structure that principally controls water levels) is above the HP50, it may be assumed that the HP50 is minimally influenced by the structure. Considering a lake with a perfectly efficient structure, all water level elevations above the structure control point in a stage record would be replaced with the control point elevation; while the mean water level would clearly change, the median water level would change much less so, if at all. As structure efficiency is almost always less than 100%, the effect of a structure on the HP50 is assumed to be negligible where the control point exceeds the HP50.

Information for a sample of 12 lake systems in the NTB area with structure control points above the HP50 is presented in Table 5. These HP50 values were developed using modeling tools that remove the impacts of withdrawals while retaining structural effects; previously, the HP50 was frequently calculated using Reference Lake Water Regime statistics based on differences between stage percentiles for reference lakes, which is believed to have resulted in less accurate estimates compared to lake-specific modeling tools, so those older estimates are not included here. The modelled HP50 incorporates approximately seven decades of modelled Historic water levels. As an additional point of comparison, the P50 based on 2010-2019, for reasons discussed in previous sections, is provided. Documentation for control point, field-derived NP, and HP50 elevations shown in Table 5 are available in Carr et al. (2014), Carr et al. (2018a, 2018b, 2018c), Kolasa and Patterson (2015), Uranowski et al. (2015), Carr and Hancock (2017a), Swindasz et al. (2017a, 2017b), Hurst et al. (2019), Campbell and Hancock (2017), and Campbell and Cameron (2020).

As shown in Table 5, for NTB lakes with HP50 elevations believed to be minimally affected by structures, the average NP-HP50 difference is 2.4 feet (range: 1.2 to 5.7 feet), as compared to an average NP-HP50 difference of 1.0 feet at cypress domes (Cameron et al. 2020; see also Table 3). Thus, even in the absence of withdrawals and structural effects on the HP50, many lakes in the NTB area exhibit a larger NP-HP50 range than cypress wetlands. For such lakes, use of the Cypress Offset could potentially result in inappropriately high minimum levels; in many lakes the HP-HP50 difference exceeds the Cypress Offset of 1.8 feet.

Table 5. Structure control point, field-derived NP, modelled and empirical HP50 elevations and differences between NP elevation and HP50 and P50 values for 12 lake systems in the NTB area where the control point is above the HP50. For the 2010-2019 empirical period, the lakes may have varying degrees of impacts, although these are believed to be minimal-to-moderate at most lakes, especially at water levels at or above the P10 (Basso et al., 2020).

Lake Name	Control Point (feet NGVD29)	Field-derived NP (feet NGVD29)	Modelled HP50* (feet NGVD29)	NP-HP50* (feet)	Empirical 2010-2019 P50† (feet NGVD)	Empirical 2010-2019 NP-P50† (feet)
Brant	57.4	58.9	56.7	2.2	57.8	1.1
Dan	32.3	32.7	31.0	1.7	31.1	1.6
Dosson + Sunshine	52.9	54.7	52.8	1.9	53.4	1.3
Halfmoon	42.8	44.6	42.4	2.2	42.9	1.7
Hobbs	65.4	67.0	64.0	3.0	64.7	2.3
Horse	46.9	50.4	44.7	5.7	46.2	4.2
Juanita	41.2	43.5	40.3	3.2	41.2	2.3
Kell	65.3	66.0	64.8	1.2	65.5	0.5
Little Moon + Rainbow	38.6	40.0	38.4	1.6	39.0	1.0
Merrywater	57.2	57.8	56.0	1.8	57.3	0.5
Moon‡	39.8	40.0	38.3	1.7	39.4	0.6
Sapphire	63.5	63.8	61.8	2.0	62.7	1.1
Average	-	-	-	2.4	-	2.0§

*Includes approximately seven decades of modelled water levels. † Data aggregated to monthly means. ‡ Located in Pasco County. § Includes only lakes where the control point elevation was above the 2010-2019 P50.

Mesic Wetland Offset for Northern Tampa Bay Lakes

The NP-HP50 difference (or its approximate equivalent, the HP03-HP50 difference) appears greater for NTB lakes than for cypress domes, such that a minimum lake level calculated using the Cypress Offset could result in an inappropriately high expectation for a lake's P50 relative to its NP elevation. The NP-HP50 difference of the typical NTB lake was shown to be larger than that of the typical cypress dome using several lines of evidence, including Reference Lake Water Regime statistics, approximate NP-HP50 differences using empirical lake and cypress dome data for the same time period, modelled NP-HP50 differences when controlling for structures, and approximate NP-HP50 differences using empirical data controlling for structures.

NP-HP50 differences could vary between the typical NTB lake and cypress dome for at least two reasons. First, the natural hydrologic behavior of the typical NTB lake could differ from that of the typical NTB cypress dome. Second, structural alterations are considerably more common at NTB lakes than cypress domes (e.g., Campbell et al., 2020), creating a new hydrologic regime such that NP values associated with pre-structural water levels no longer reflect the hydrologic behavior possible at the lake, even in the absence of withdrawals.

By comparison, the Mesic Wetland Offset is applied relative to the HP50 for a lake, which reflects the lake's unique hydrology inclusive of structural alterations. Importantly, this report has validated the Cypress Offset of 1.8 feet and the average NP-HP50 difference of 1.0 feet for an unimpacted cypress dome. This finding also supports Hancock's (2007) original identification of the Mesic Wetland Offset, which indicates that significant harm occurs at a cypress dome when the HP50-P50 difference exceeds 0.8 feet.

When applied to lakes, both the Cypress and Wetland Offsets aim to protect lake-fringing wetlands. Additionally, given that the NP-HP50 difference for lakes exceeds that of cypress domes, the offsets, derived from cypress domes, are conservative for lakes. However, compared to the NP-based Cypress Offset, the HP50-based Wetland Offset offers several advantages for lakes. First, the Wetland Offset can be applied to all lakes irrespective of the presence of NP indicators, with consideration given to the hydrogeologic setting. Second, the Wetland Offset reduces the need to assume that a lake's NP-HP50 difference is similar to that of reference cypress domes. As previously discussed, even after controlling for structures, the NP-HP50 difference is often larger at lakes than at cypress domes, in some cases exceeding the Cypress Offset. In these latter cases, a minimum level defined by the Cypress Offset would be unlikely to be met, irrespective of withdrawal-related effects. Third, use of the Wetland Offset better integrates effects of structural alterations on the hydrologic regime through use of Historic percentiles that account for existing structures. However, the Wetland Offset retains the assumption that a significant harm threshold derived from wetlands is applicable to lakes. As this assumption is shared with the Cypress Offset in application to lakes, and the Wetland Offset offers several advantages over the Cypress Offset for lakes, we conclude that the Mesic Wetland Offset and not the Cypress Offset should be used for lakes.

Although the Mesic Wetland Offset offers several advantages specific for lakes, the Cypress Offset remains preferable for cypress domes, as cypress domes typically have reliable NP and less frequently have significant structural alterations, and the Cypress Offset does not incorporate the Mesic Wetland Offset's simplification regarding average NP-HP50 behavior.

Xeric Lakes and Wetlands: Need for Xeric Wetland Offset

The Cypress Offset was developed for mesic NTB area cypress wetlands and later applied (either directly or, through the Mesic Wetland Offset, indirectly) to lakes throughout the District, including numerous lakes outside of the NTB area. As discussed in the previous section, NP-HP50 differences in lakes appears to be larger in lakes than in wetlands in the NTB area. Beyond this, however, consideration must also be given to how the NP-HP50 difference (which defines the Mesic Wetland Offset) could differ in hydrogeologic settings that vary from NTB.

Specifically, evidence has accumulated that lakes and wetlands located within landscapes dominated by xeric soils tend to have larger water level fluctuations than wetlands and lakes embedded in landscapes dominated by mesic soils (BHI & SDII, 2000; Epting et al., 2008; FNAI, 2010; EMT, 2013; GPI, 2016, 2020, 2022; Nowicki, 2019). Note that generally, characteristics associated with xeric soils in the District include a deep water-table setting, low hydric rating, well-drained drainage classes, and ecological classifications of sand pine scrub or longleaf pine–turkey oak hills (GPI, 2016, 2021b). Therefore, understanding differences between the hydrologic behavior of xeric waterbodies, which dominate portions of the northern and southern District (GPI 2021a, 2021b), and the hydrologic behavior of mesic waterbodies, which dominate the NTB area (Hancock & Basso, 1996; Cameron et al., 2020; GPI 2021a, 2021b), is essential to understanding the types of lakes and wetlands for which the Cypress and Mesic Wetland Offsets are most appropriate.

Sandhill Lakes in the Northern District

The northern District is generally characterized by a deep water-table (greater than 10 ft), unconfined hydrogeology that differs from the semi-confined, shallow water-table hydrogeologic setting of the NTB area (Basso, 2019; Nowicki, 2019). As described in Nowicki (2019) and Nowicki et al. (2021), sandhill lakes in this area occur in depressions in deep sandy (xeric) uplands and have a close hydraulic connection with a large regional aquifer, such that groundwater exchange with the lake comprises the largest component of the lake water budget; this contrasts with other lakes, where groundwater levels indirectly influence water levels by driving hydraulic head differences that control vertical lake leakage. Water levels at many sandhill lakes fluctuate substantially and over cycles of years to decades, in contrast to the smaller ranges and shorter cycles observed at lakes in the NTB area.

To investigate differences between xeric lakes and mesic cypress domes, a sample of 15 northern District xeric sandhill lakes with minimum levels was selected for review (Figure 9). The lakes either lack structures or have structures positioned at high elevations relative to typical (and in many cases even high) water levels, so structural impacts on water level ranges can be assumed to be comparatively small. Additionally, based on review of groundwater model results, groundwater withdrawal data, lake and upper Floridan aquifer water level data, lake-specific reports, hydrogeologic setting, and expert opinion, these lakes are no more than minimally impacted by withdrawals throughout the period of record, so period-of-record percentiles can be used to estimate Historic percentiles. Finally, lakes were considered only if they had a reported NP value. All of these lakes were classified in GPI (2021a) as xeric based on soils analysis. Documentation for control point and field-derived NP values shown in Table 6 are available in Munson (2004), Leeper (2004a, 2004b, 2004c, 2004d), Leeper et al. (2004a, 2004b), SWFWMD (2005, 2006, 2008a, 2008b), Carr et al. (2013a, 2013b), Kolasa et al. (2018), and Hurst et al. (2020).

As seen in Table 7 using period-of-record data through 2019, the average P10-P50 difference for northern District sandhill lakes was 3.5 feet (range: 1.0 to 7.0 feet), almost four times the average P10-P50 difference of about 1.0 feet for NTB reference lakes (SWFWMD, 1999a) and more than four times the average 0.8 feet P10-P50 difference identified for 51 NTB lakes in this study using 2010-2019 data (see Table 4).

The NP at sandhill lakes is typically determined using elevations at the base of saw palmetto and, sometimes, live oak. These indicators are also commonly used for high water line, safe upland line or wetland boundary or edge determinations (Bishop, 1967; Duever et al., 1987; FDEP, 1995; CFWI-EMT, 2013, 2020) and in support of minimum level determinations in other water management districts (e.g., ECT, 2021; Sutherland et al., 2021). The NP derived at 12 of the 15 lakes we assessed were based on these two indicators, while the NP for a single lake relied on citrus trees, and two were based on cypress trees. Although the NP elevations at sandhill lakes may not be directly comparable to NP elevations for NTB lakes, which are typically derived from cypress trees or equivalent indicators (Carr et al., 2006; Cameron et al., 2020), the sandhill lake NP values do correspond with a high-water level and are illustrative of the wide water level fluctuations that occur in sandhill lakes.

At 13 of the 15 sample lakes, inundation of the NP occurred less frequently than the P01 and in many instances water levels did not reach the NP elevation during the period of record. Two of the lakes had a cypress-based NP and exhibited NP percentiles that differed markedly from those for the other lakes.

Haag (2005) notes that saw palmetto only survive a “few weeks” in water, while Carr et al. (2006) reported saw palmetto at elevations that allow no more than an average of approximately 2 months of water. Saw palmetto grow slowly, taking decades to mature and to migrate horizontally (Abrahamson, 1995; Carr et al., 2006; Abrahamson et al., 2009; Abrahamson, 2016). Rare extended high-water events may therefore kill palmetto

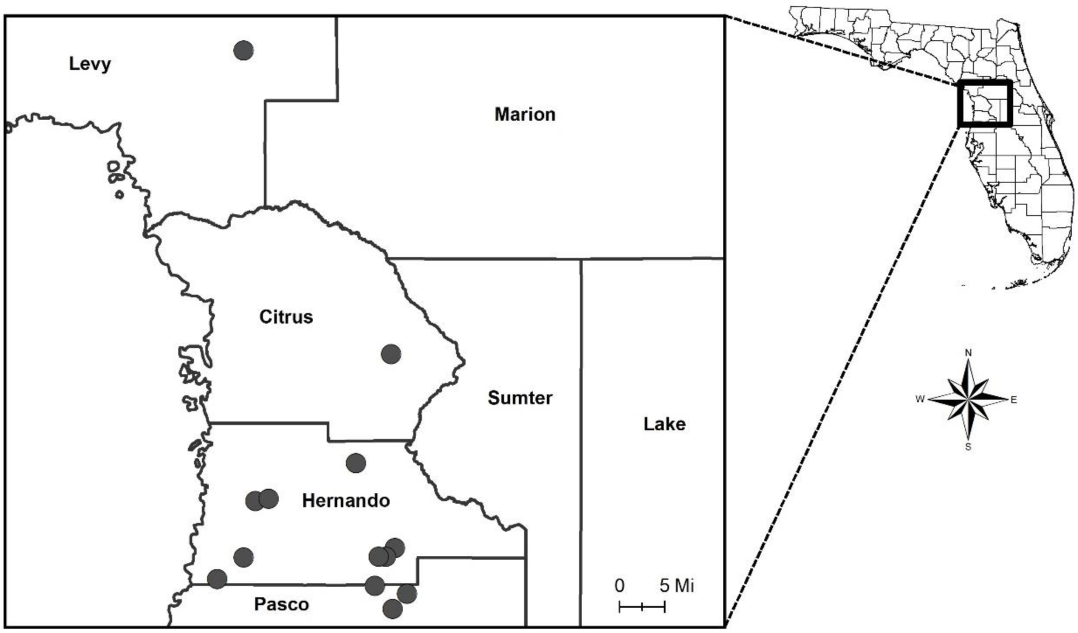

Figure 9. Locations of 15 sandhill lakes in the northern District.

Table 6. Summary statistics for select sandhill lakes with minimum levels in the northern District. The waterbodies have no or minimal impacts during the assessed period, so P*x* ≈ HP*x*.

Lake	Period of Record Start	Control Point (feet NGVD29)	Maximum Water Level (feet NGVD29)	POR P50 (feet NGVD29)	Field-derived NP (feet NGVD29)	NP Percentile	Range (feet)	P03-P50 (feet)	P10-P50 (feet)
Buddy/Pasadena	1984	N/A	92.3	88.3	93.5	<P1	13.3	6.0	5.2
Clear*	1965	127.1	126.9	125.9	126.9	P19*	6.3	1.6	1.3
Fort Cooper	2001	N/A	30.2	27.4	34.0	<P1	10.3	3.9	3.1
Hancock	1978	N/A	101.5	100.2	104.0	N/A	18.9	5.2	2.4
Hunters	1965	19.2	18.8	16.8	23.0	<P1	8.8	3.0	2.4
Iola	1965	153.5	140.7	140.5	154.6	<P1	19.6	6.7	5.0
Jessamine	1978	N/A	131.5	129.1	150.0	<P1	22.5	8.8	7.0
Lindsey*	1965	72.5	66.0	65.5	68.0	P11*	10.3	3.5	2.7
Marion	1992	N/A	55.3	48.8	57.1	<P1	12.9	5.9	4.5
Mountain	1984	N/A	101.7	100	110.0	<P1	10.6	3.5	2.8
Neff	1965	N/A	99.7	94.6	110.0	<P1	27.9	8.4	7.0
Spring	1965	181.0	181.2	180.5	185.0	<P1	8.5	1.3	1.0
Tooke	1999	24	17.9	15.5	21.5	<P1	8.3	3.3	2.2
Whitehurst	1999	N/A	20.3	16.6	23.9	<P1	11.7	5.0	4.1
Weekiwachee Prairie	1942	23.3	20.8	18.9	24.6	<P1	12.4	4.4	3.3
Average	-	-	-	-	-	<P1	13.3	4.5	3.5

Water level data aggregated to monthly means. * NP derived from cypress trees and excluded from the average; the NP for all other lakes used the bases of saw palmetto, live oak trees, or (in one instance) citrus trees.

shrubs, with subsequent encroachment to lower elevations within a basin occurring over multiple decades. The CFWI-EMT (2013) and Nowicki (2019) describe this possibility for sandhill lakes and wetlands, noting that within these basins, vegetation is dynamic in response to extreme low-water and high-water events. Thus, considering the differences between NP and observed water level maxima at the lakes, the lakes' true water level ranges are likely greater than the observed water level data indicate.

Relative to sandhill lakes, NTB cypress domes also typically exhibit a smaller range of above-ground water-level fluctuations, with maximum dome depths typically ranging between 0.9 and 4.5 feet and averaging about 1.9 feet (Cameron et al., 2020). During times of high water, many cypress domes experience surface outflows through natural saddles (e.g., Campbell et al., 2020), which limits their possible above-ground water level fluctuations. By comparison, the smallest water level range for the 15 sandhill lakes we assessed was 6.3 feet. As most of these lakes never achieved water levels associated with either NP or surface outflows in their periods of record, the water level range likely underestimates the maximum depth for most of the lakes.

The hydrologic range of the cypress dome is dominated by the annual cyclicity and, under average rainfall conditions, can exhibit nearly the full range of above-ground fluctuation (from near-drying to near-full inundation) within a single year (Foster, 2007; Cameron et al., 2020). Conversely, the hydrology of sandhill lakes is dominated by longer, decadal cyclicities (Nowicki, 2019). Even accounting for subsurface hydrologic behavior, healthy cypress domes experience a much smaller range of fluctuation relative to sandhill lakes. These differences persist after controlling for period-of-record differences between sandhill lake and cypress dome data; considering the 2003-2019 time period, the average sandhill lake experienced about twice the water level fluctuation of the average cypress dome (Table 7).

Table 7. Average (and range of) inter-percentile differences for sandhill lakes in the northern District versus cypress domes in the NTB area. The waterbodies had no or minimal withdrawal-related impacts during the assessed period, so P*x* ≈ HP*x*.

	Sandhill Lakes	Cypress Domes*
N	15	41
Time Period	2003-2019	2003-2019
P03-P50 Difference (feet)	4.2 (1.1 – 7.4)	0.9 (0.5 – 1.7)
P10-P50 Difference (feet)	3.2 (0.8 – 5.9)	0.8 (0.4 – 1.5)
Range (feet)	12.1 (5.7 – 23.8)	6.1 (3.2 – 9.9)

Water level data aggregated to monthly means. * Includes subsurface water levels.

This comparison focused on sandhill lakes located in the northern District, without examining xeric lakes in the well-drained, deep-water setting of the southern District. However, varying degrees of withdrawal-related impacts have occurred at many southern

District lakes during their periods-of-record for available water level data, which would affect the magnitude of fluctuations in their water levels and complicate analyses of their hydropatterns.

Rather than attempting to complete these analyses and contrast the findings with the water level fluctuations presented in this report for NTB mesic sites, we note that our primary purpose for assessment of northern District sandhill lakes was to provide additional support for differences between mesic and xeric water level behavior, demonstrating the need for a Xeric Wetland Offset specific to xeric sites that reflects their unique hydrologic behavior and potential differing stress responses. This supports Rains' (2019) finding that sandhill lakes may require a different Wetland Offset than the one developed for mesic waterbodies.

Xeric Wetland Offset

GPI (2022a, 2022b, 2022c) assessed relationships between stress designations and water level behavior for xeric lakes and wetlands in the NTB area and southern District. Specifically, GPI (2022b) evaluated data for 90 xeric sites from the NTB area, while GPI (2022a) evaluated data for 28 ridge sites from the CFWI area. P50-based offsets for these two samples were developed using the crossing point method for empirical distributions of HP50-P50 differences for stressed and unstressed xeric sites.

Many factors differed between the two studies: spatial locations, sample sizes, xeric determination methods, field assessors, water level data collectors, time periods (with some overlap), and data aggregation approaches. However, despite these differences, both studies found that, using a conservative (i.e., environmentally protective) method to estimate the HP50, the P50 at a xeric site can be up to 2.2 feet lower than the HP50 before it is likely to be stressed as a result of water level reductions.

Through analysis of the combined NTB and CFWI area datasets, GPI (2022c) found additional support for the threshold of 2.2 feet. This threshold value is nearly triple that of the Mesic Wetland Offset, suggesting that, compared to mesic waterbodies, xeric waterbodies can experience much greater changes to their median water levels before they experience significant harm.

Key Findings

1. The existing values for the Cypress Offset (NP-P50 difference of 1.8 feet) and its derived Mesic Wetland Offset (HP50-P50 difference of 0.8 feet) are reasonable to delineate significant harm for mesic wetlands.
    - The Cypress Offset is relatively stable based on an updated analysis that incorporated different time periods.
    - The Cypress Offset has been functionally replicated by CFWI data and analyses.
    - Using different sites and time periods, NP-P50 difference distributions for unchanged cypress domes consistently demonstrate a maximum approximately equal to the Cypress Offset, which therefore represents the greatest difference that can likely be expected at unchanged cypress domes.
    - The utility of the Cypress Offset for identifying significantly harmed wetlands was confirmed during a recent comprehensive recovery assessment effort for the NTB area.
    - Using different sites and time periods, NP-P50 difference distributions for unchanged cypress domes consistently demonstrate an average of about 1.0 feet, indicating the Mesic Wetland Offset, which was derived by subtracting this value from the Cypress Offset, is reasonable.
2. The Cypress Offset offers the advantage that it does not incorporate a simplification made by the Mesic Wetland Offset regarding average Historic behavior. The Mesic Wetland Offset offers the advantages of better accounting for structural alterations (often present at lakes) and removing the need to identify NP (often absent at lakes).
3. Lakes in the NTB area tend to show larger NP-HP50 differences compared to cypress domes.
4. Available data and literature suggest that, compared to mesic lakes and wetlands in the NTB area, xeric lakes and wetlands show substantially larger water level fluctuations and can experience greater changes to their water levels before they become stressed.

Recommendations

1. Retain existing values for the Cypress Offset (NP-P50 difference of 1.8 feet) and its derived Mesic Wetland Offset (HP50-P50 difference of 0.8 feet).
2. Assessing both the Cypress Offset and Wetland Offset for the same waterbody is redundant and therefore unnecessary.
3. When developing minimum levels for wetlands:
    a) For wetlands that have reliable NP (or equivalent) and that demonstrate hydrologic behavior similar to that of the cypress wetlands from which the offset was derived, use the Cypress Offset.
    b) For wetlands lacking reliable NP but which demonstrate hydrologic behavior similar to that of the cypress domes from which the offset derived, use the Mesic Wetland Offset.
4. When developing minimum levels for lakes:
    a) For lakes which demonstrate hydrologic behavior similar to or are positioned in hydrogeologic settings similar to that of the cypress wetlands from which the offset derived, use the Mesic Wetland Offset.
5. A Xeric Wetland Offset should be developed for application to xeric lakes and wetlands.

Acknowledgements

Numerous scientists have made significant contributions to the body of knowledge underlying the development of wetland health–based standards for lake and wetland minimum levels, with special mention made for (in alphabetical order) Donna Campbell, David Carr, Shirley Denton, Tricia Dooris, Don Ellison, Scott Emery, Patty Fesmire, Richard Gant, Michael Hancock, Lisa Henningsen, Clark Hull, Mark Hurst, Doug Keesecker, Marty Kelly, Manny Lopez, Adam Munson, Ted Rochow, Don Richters, Dan Schmutz, Richard Schultz, Chris Shea, Christina Uranowski, and Diane Willis.

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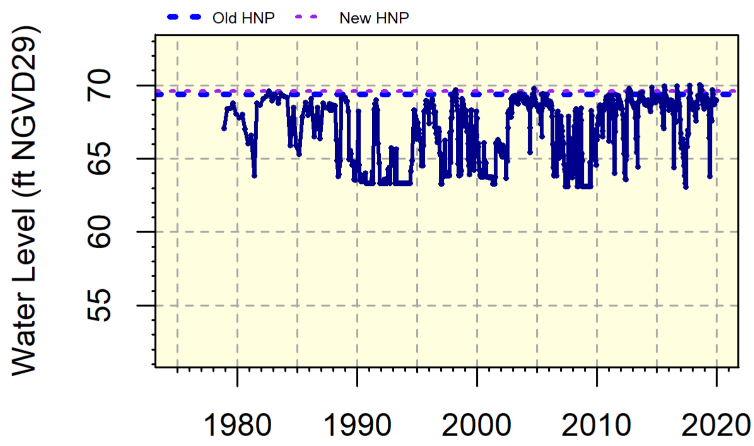
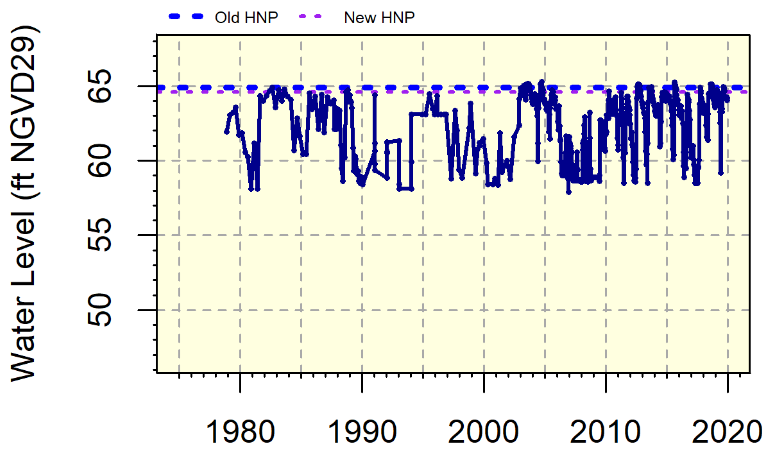
Appendix A: Hydrographs

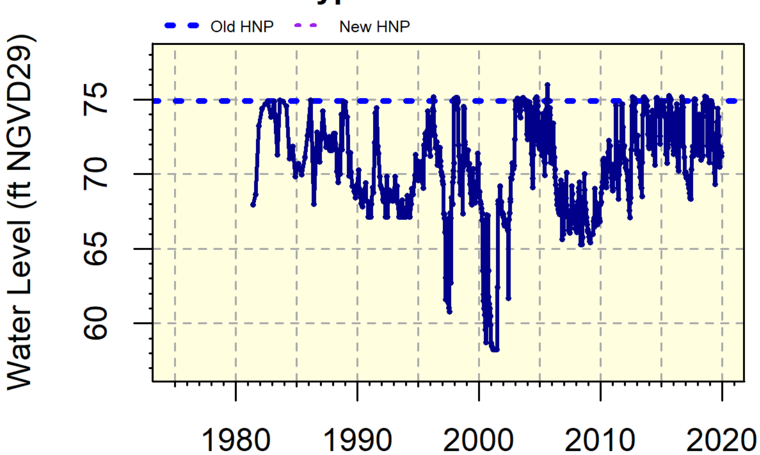
Cypress Creek W-11



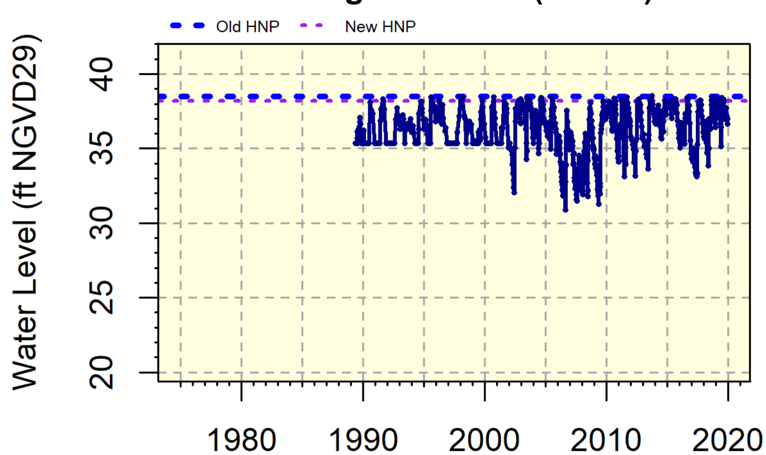
Cypress Creek W-17



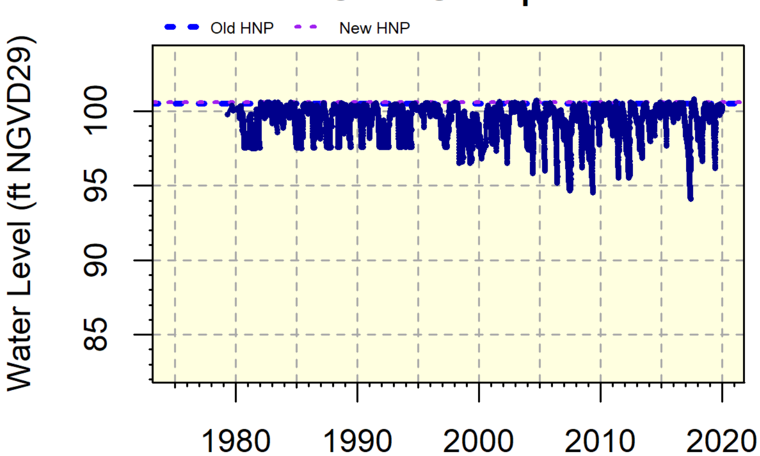
Cypress Creek W-41



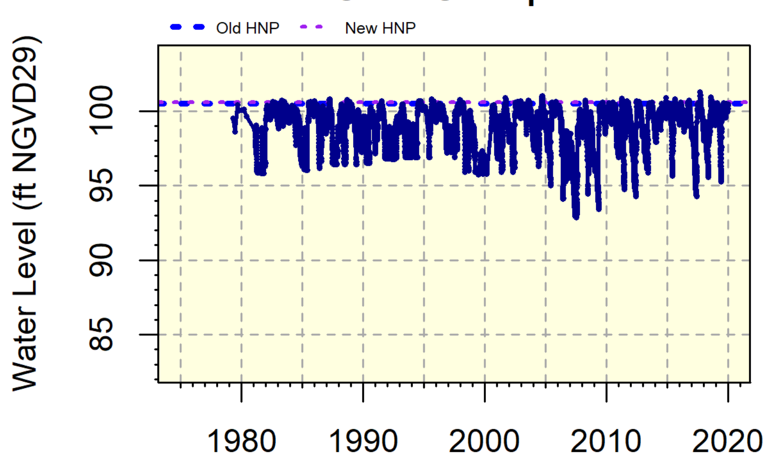
Eldridge-Wilde 11 (NW-44)

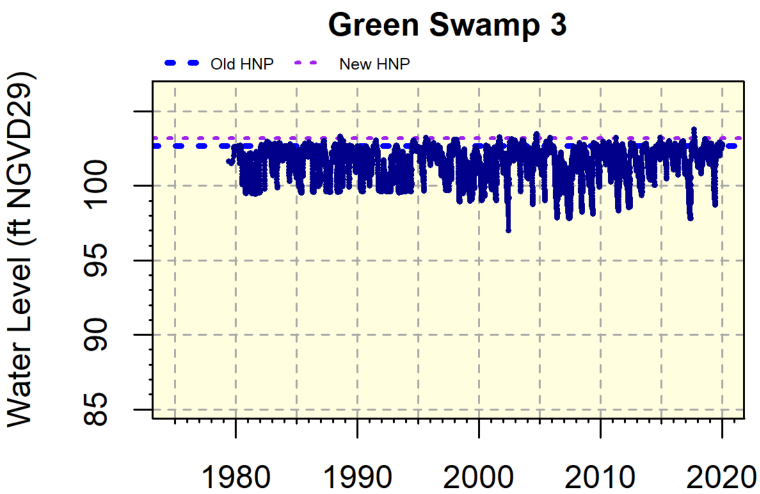


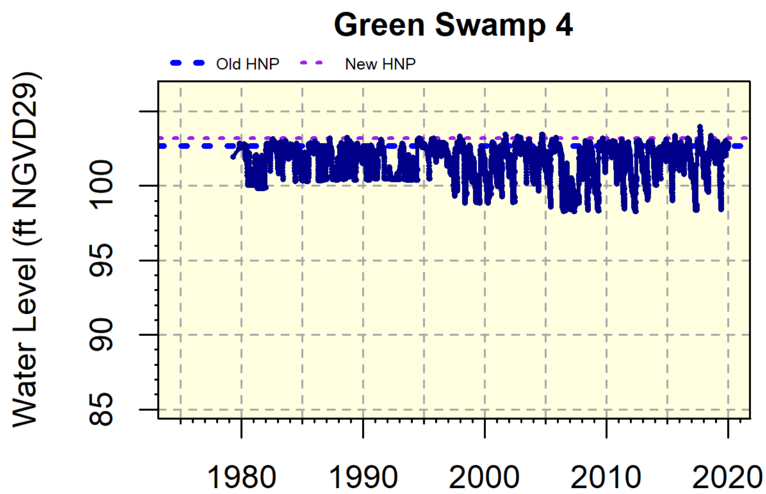
Green Swamp 1

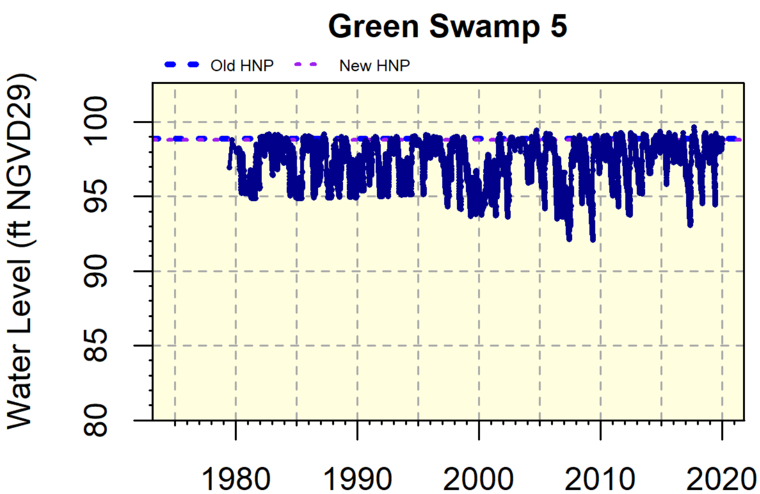


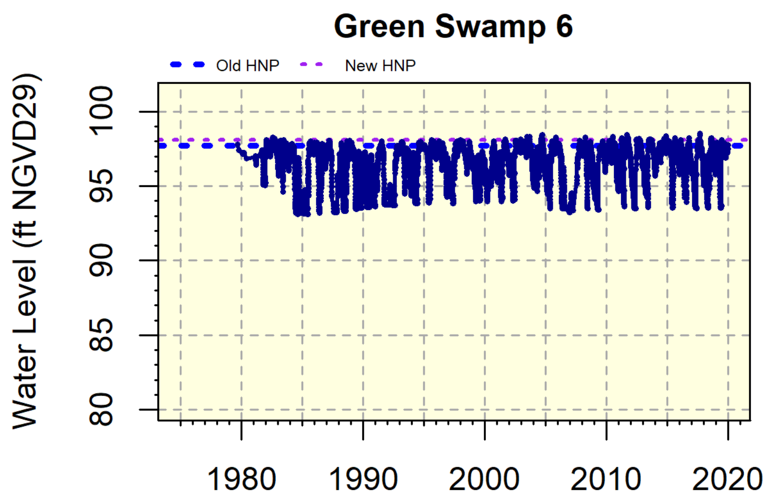
Green Swamp 2

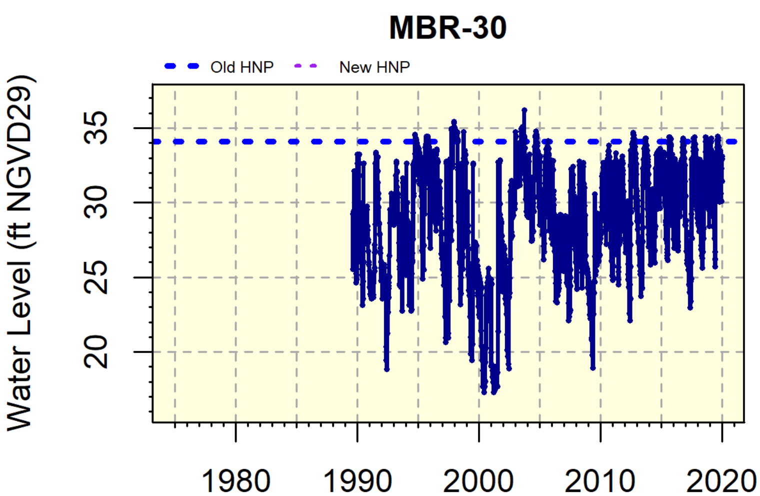


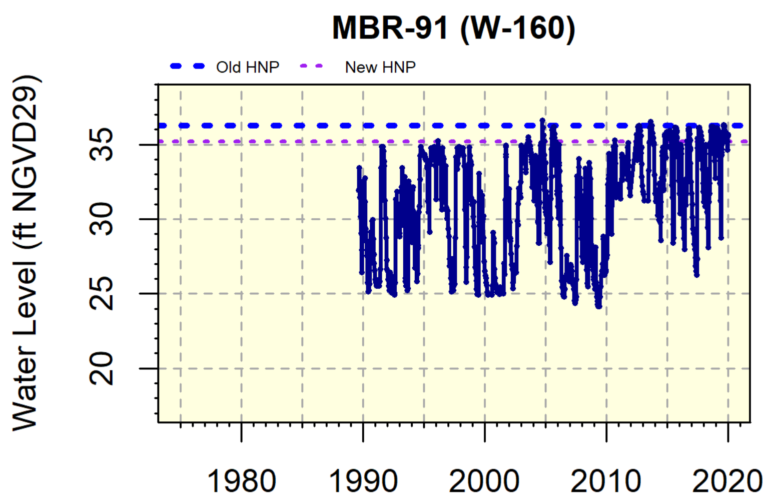

Green Swamp 3
Old HNP
New HNP
Water Level (ft NGVD29)
85
90
95
100
1980
1990
2000
2010
2020

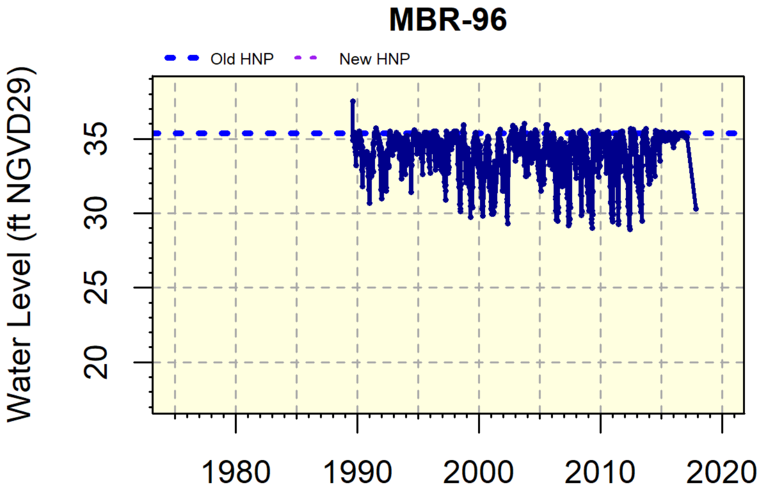

Green Swamp 4
Old HNP
New HNP
Water Level (ft NGVD29)
85
90
95
100
1980
1990
2000
2010
2020

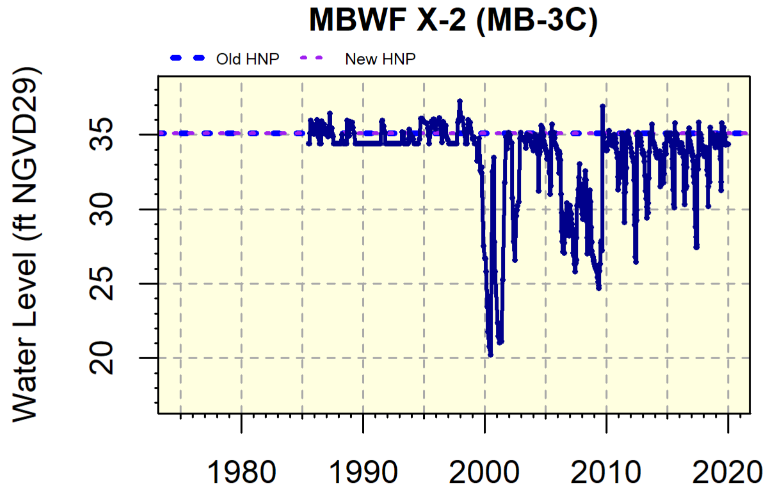

Green Swamp 5
Old HNP
New HNP
Water Level (ft NGVD29)
80
85
90
95
100
1980
1990
2000
2010
2020

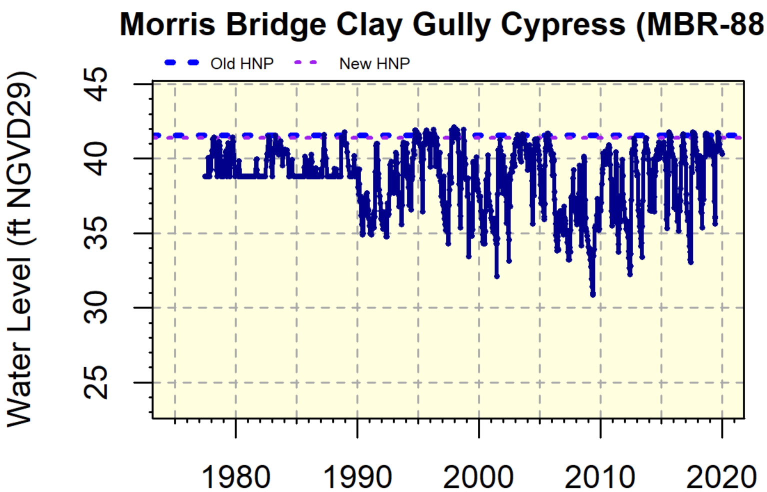

Green Swamp 6
Old HNP
New HNP
Water Level (ft NGVD29)
80
85
90
95
100
1980
1990
2000
2010
2020

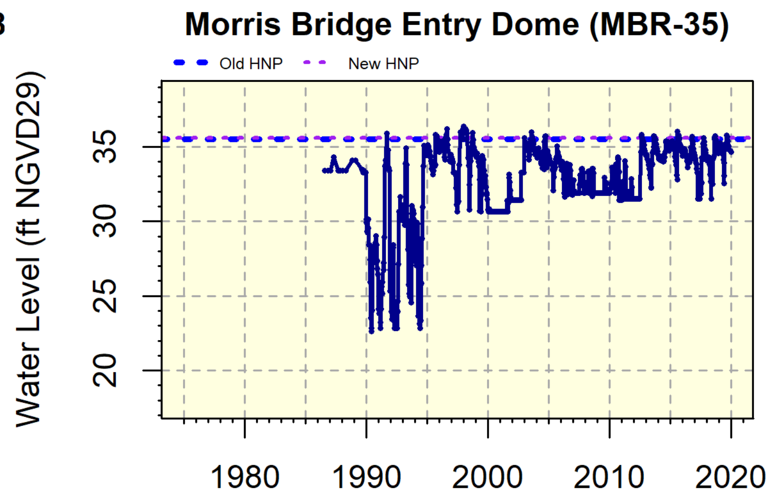

MBR-30
Old HNP
New HNP
Water Level (ft NGVD29)
20
25
30
35
1980
1990
2000
2010
2020

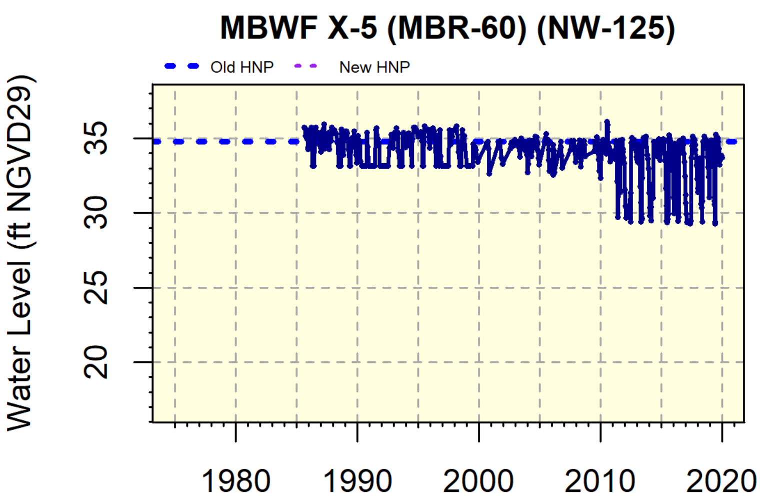

MBR-91 (W-160)
Old HNP
New HNP
Water Level (ft NGVD29)
20
25
30
35
1980
1990
2000
2010
2020

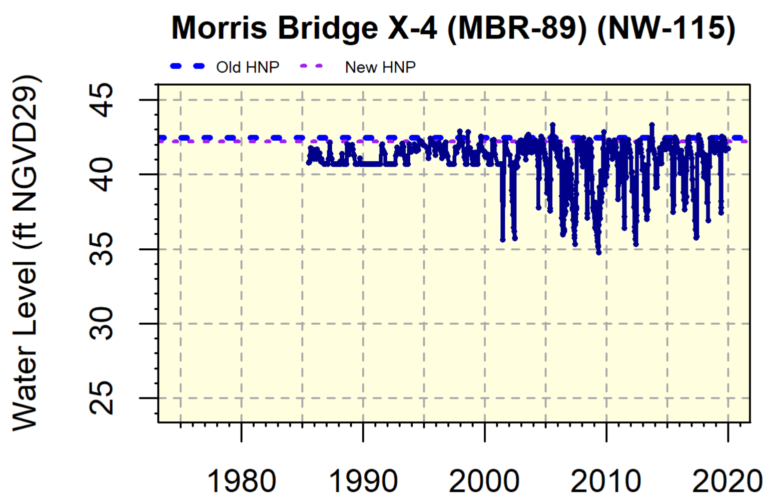

MBR-96
Old HNP
New HNP
Water Level (ft NGVD29)
20 25 30 35
1980 1990 2000 2010 2020

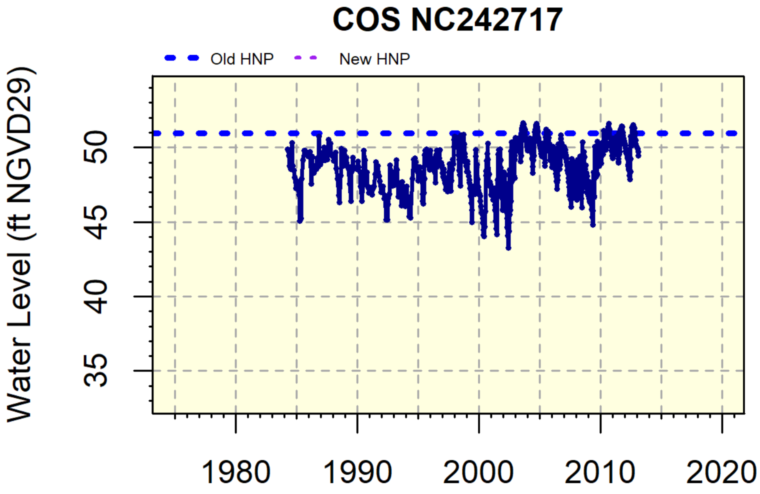

MBWF X-2 (MB-3C)
Old HNP
New HNP
Water Level (ft NGVD29)
20 25 30 35
1980 1990 2000 2010 2020

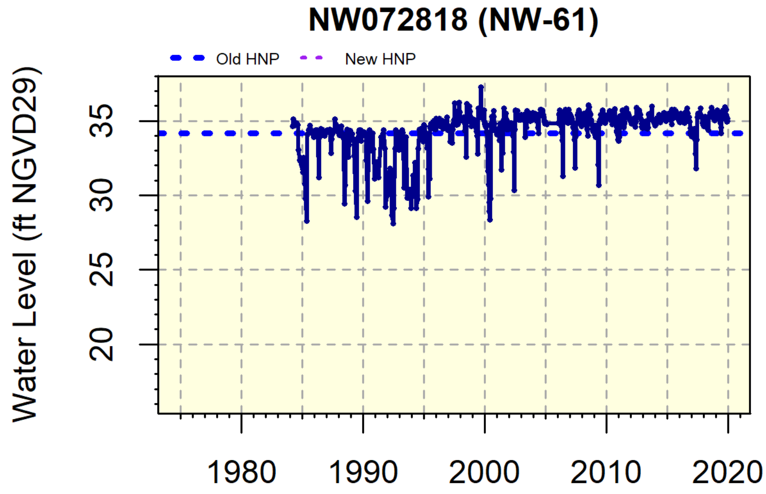

Morris Bridge Clay Gully Cypress (MBR-88
Old HNP
New HNP
Water Level (ft NGVD29)
25 30 35 40 45
1980 1990 2000 2010 2020

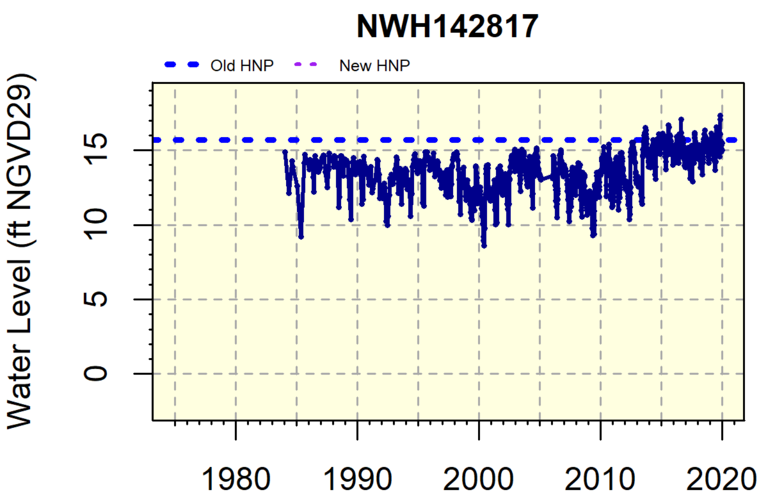

Morris Bridge Entry Dome (MBR-35)
Old HNP
New HNP
Water Level (ft NGVD29)
20 25 30 35
1980 1990 2000 2010 2020

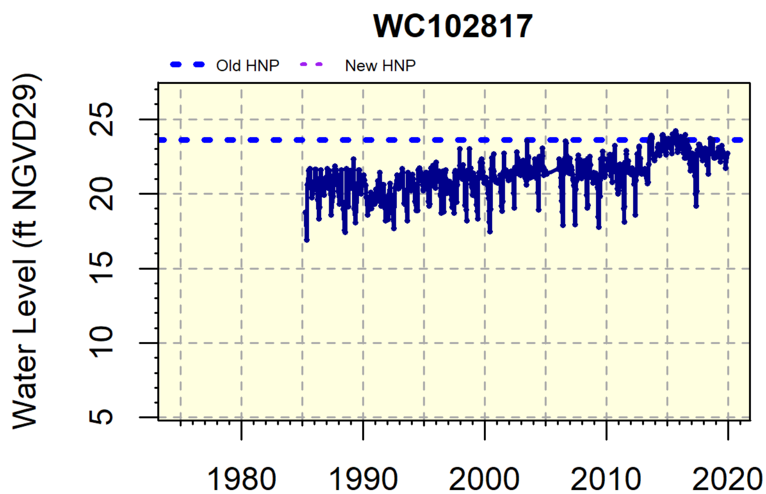

MBWF X-5 (MBR-60) (NW-125)
Old HNP
New HNP
Water Level (ft NGVD29)
20 25 30 35
1980 1990 2000 2010 2020

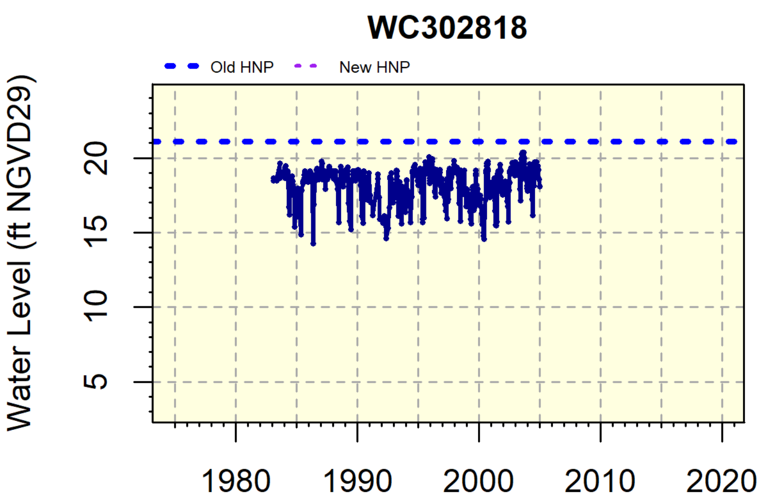

Morris Bridge X-4 (MBR-89) (NW-115)
Old HNP
New HNP
Water Level (ft NGVD29)
25 30 35 40 45
1980 1990 2000 2010 2020

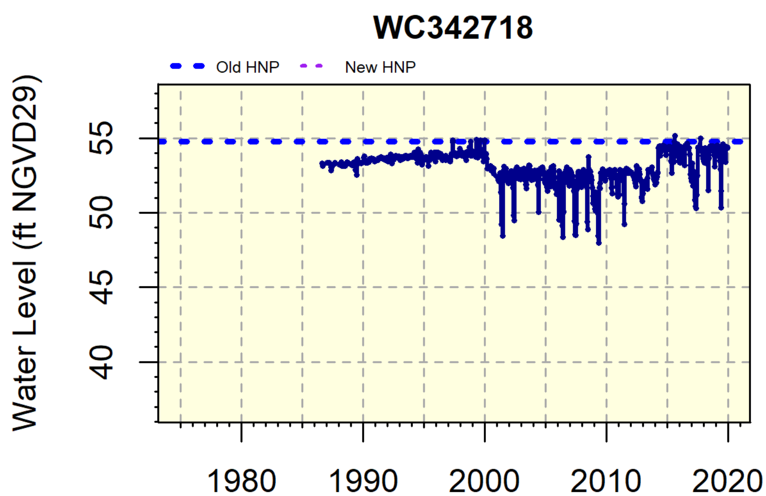

COS NC242717
Old HNP
New HNP
Water Level (ft NGVD29)
35 40 45 50
1980 1990 2000 2010 2020

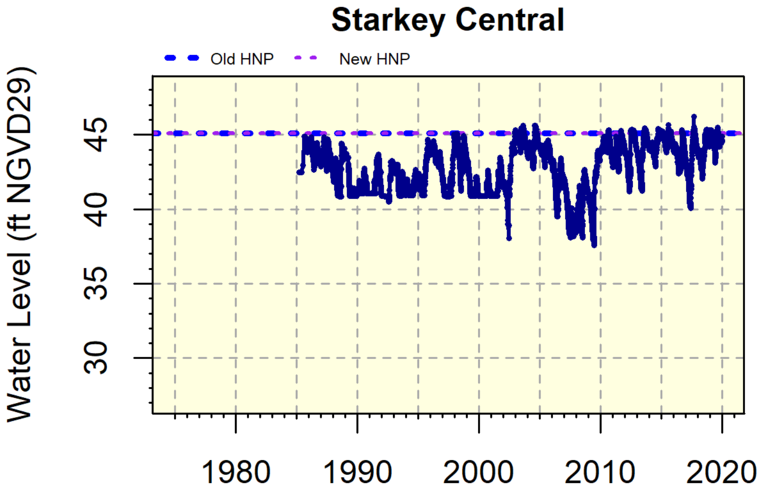

NW072818 (NW-61)
Old HNP
New HNP
Water Level (ft NGVD29)
20 25 30 35
1980 1990 2000 2010 2020

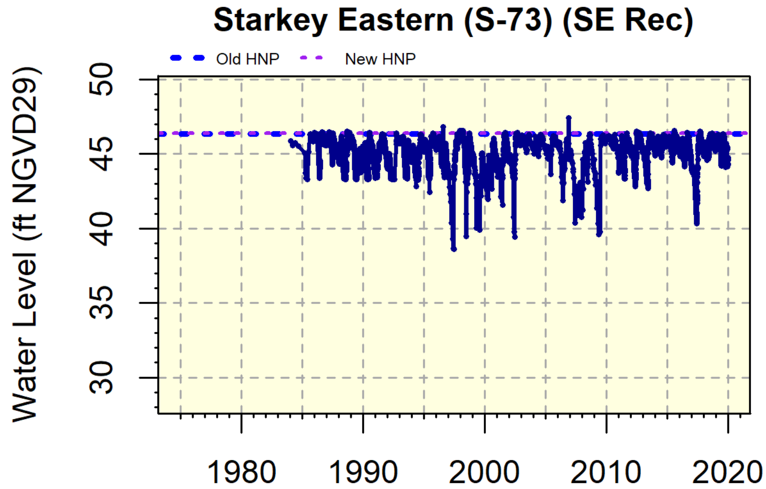

NWH142817
Old HNP
New HNP
Water Level (ft NGVD29)
0 5 10 15
1980 1990 2000 2010 2020

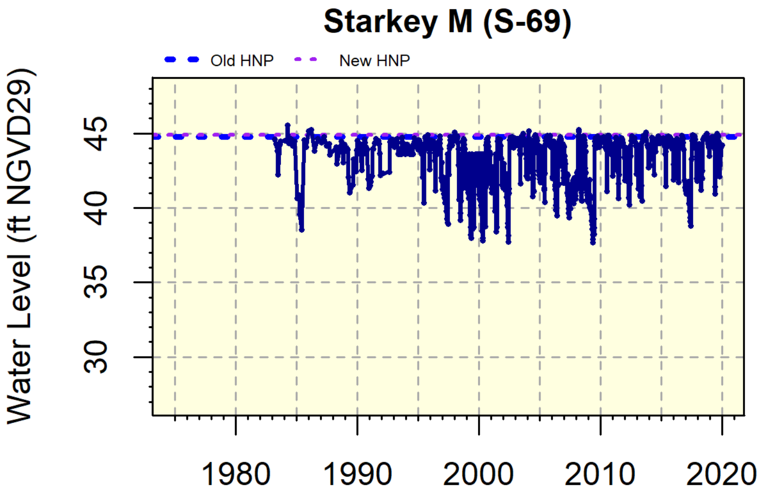

WC102817
Old HNP
New HNP
Water Level (ft NGVD29)
5 10 15 20 25
1980 1990 2000 2010 2020

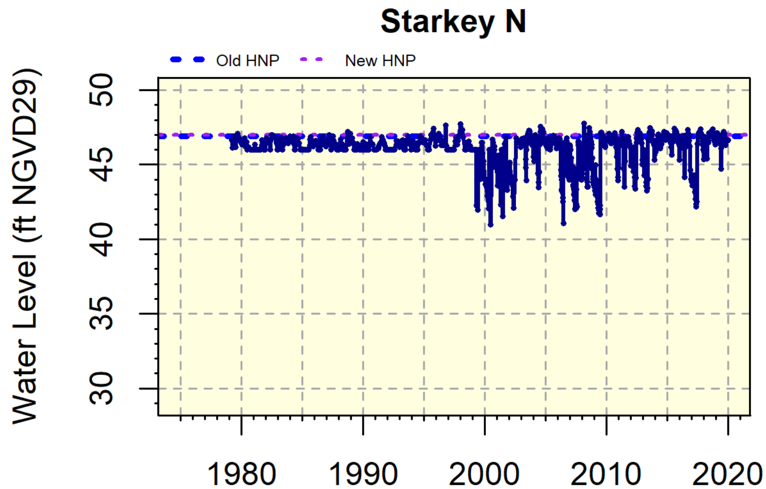

WC302818
Old HNP
New HNP
Water Level (ft NGVD29)
5 10 15 20
1980 1990 2000 2010 2020

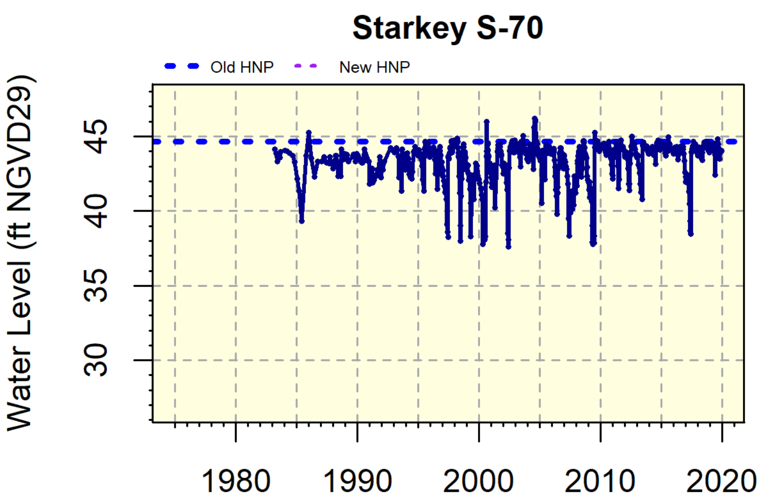

WC342718
Old HNP
New HNP
Water Level (ft NGVD29)
40 45 50 55
1980 1990 2000 2010 2020

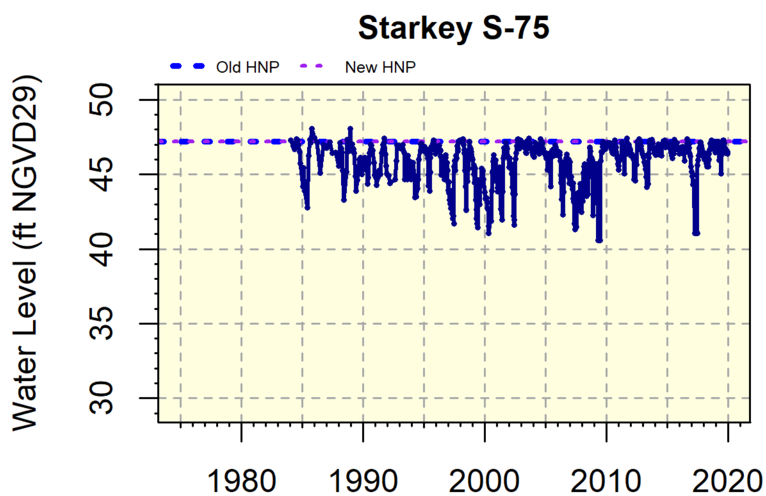

Starkey Central
Old HNP
New HNP
Water Level (ft NGVD29)
30
35
40
45
1980
1990
2000
2010
2020

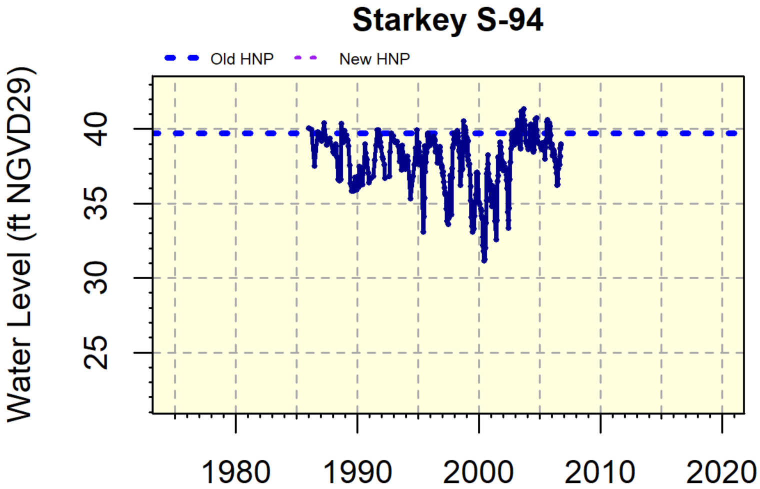

Starkey Eastern (S-73) (SE Rec)
Old HNP
New HNP
Water Level (ft NGVD29)
30
35
40
45
50
1980
1990
2000
2010
2020

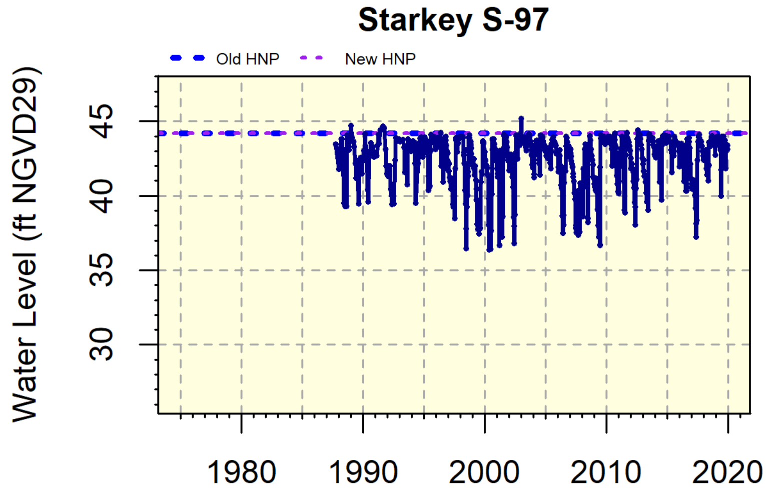

Starkey M (S-69)
Old HNP
New HNP
Water Level (ft NGVD29)
30
35
40
45
1980
1990
2000
2010
2020

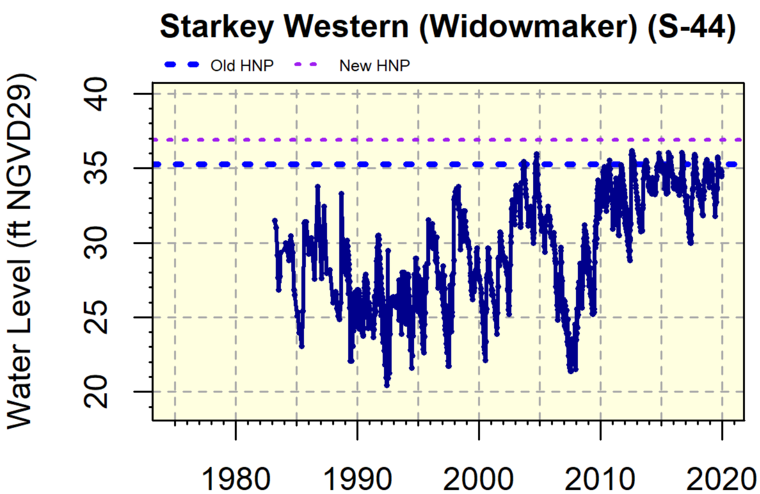

Starkey N
Old HNP
New HNP
Water Level (ft NGVD29)
30
35
40
45
50
1980
1990
2000
2010
2020

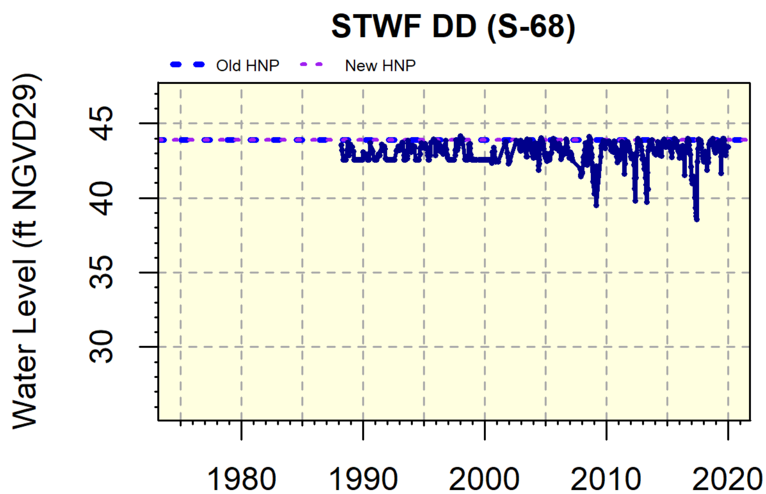

Starkey S-70
Old HNP
New HNP
Water Level (ft NGVD29)
30
35
40
45
1980
1990
2000
2010
2020

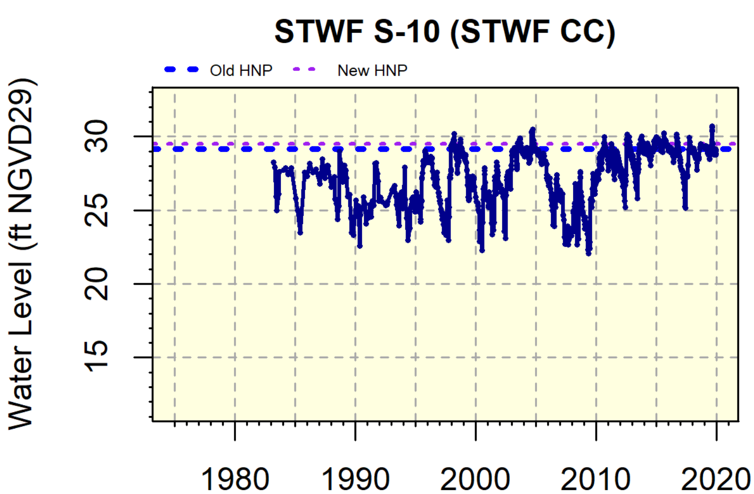

Starkey S-75
Old HNP
New HNP
Water Level (ft NGVD29)
30
35
40
45
50
1980
1990
2000
2010
2020

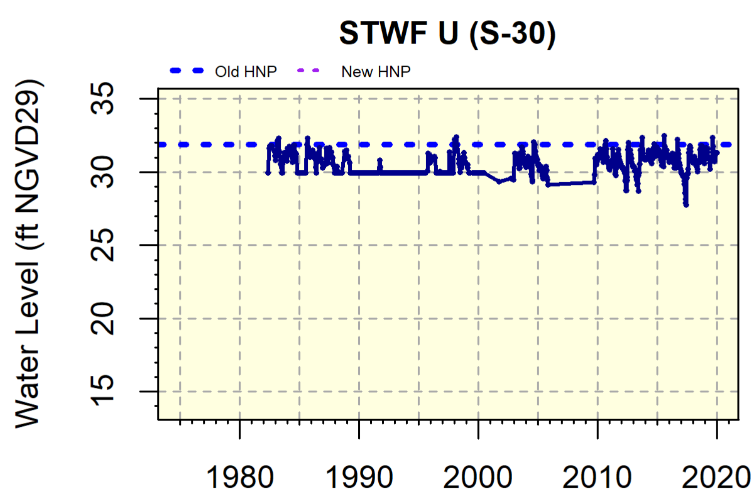

Starkey S-94
Old HNP
New HNP
Water Level (ft NGVD29)
25
30
35
40
1980
1990
2000
2010
2020


Starkey S-97
Old HNP
New HNP
Water Level (ft NGVD29)
30
35
40
45
1980
1990
2000
2010
2020

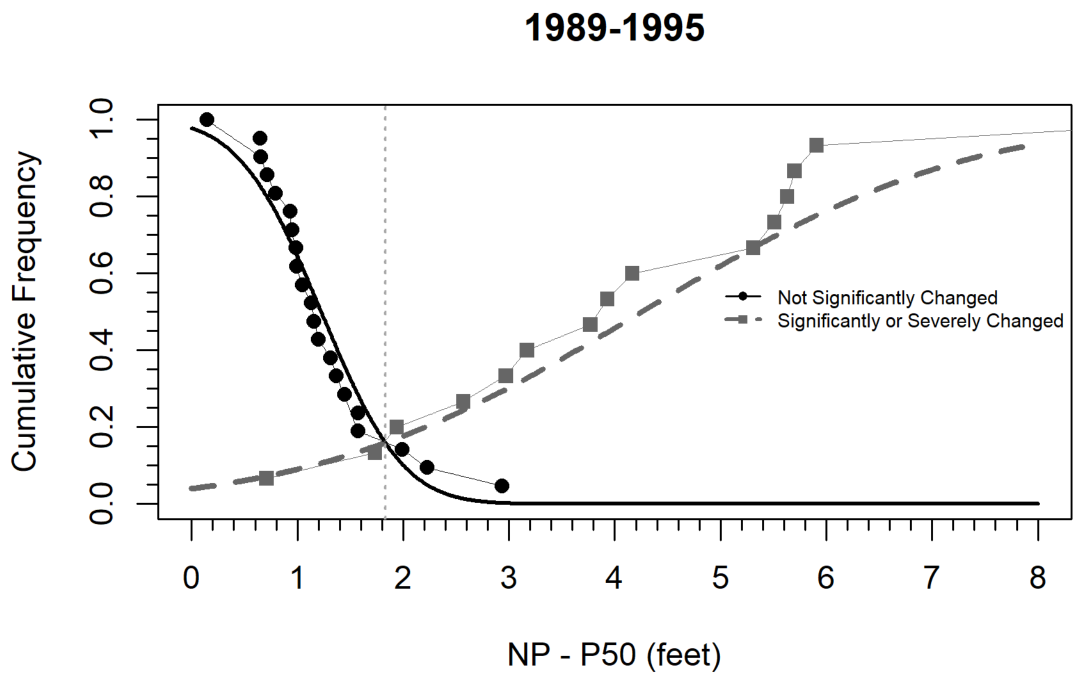

Starkey Western (Widowmaker) (S-44)
Old HNP
New HNP
Water Level (ft NGVD29)
20
25
30
35
40
1980
1990
2000
2010
2020

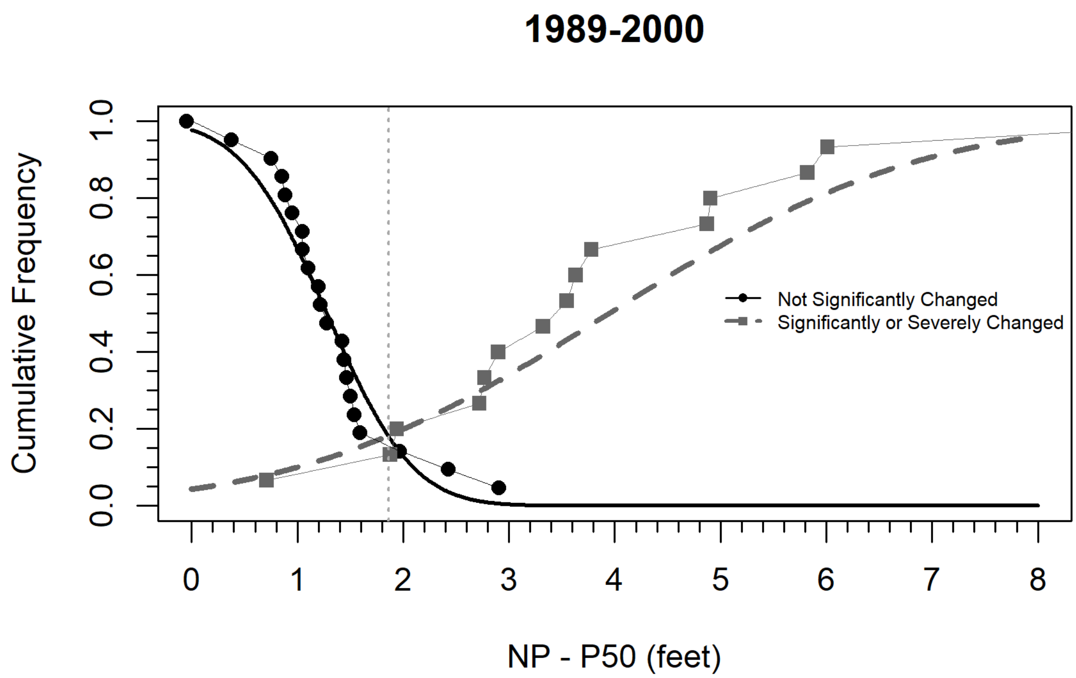

STWF DD (S-68)
Old HNP
New HNP
Water Level (ft NGVD29)
30
35
40
45
1980
1990
2000
2010
2020


STWF S-10 (STWF CC)
Old HNP
New HNP
Water Level (ft NGVD29)
15
20
25
30
1980
1990
2000
2010
2020

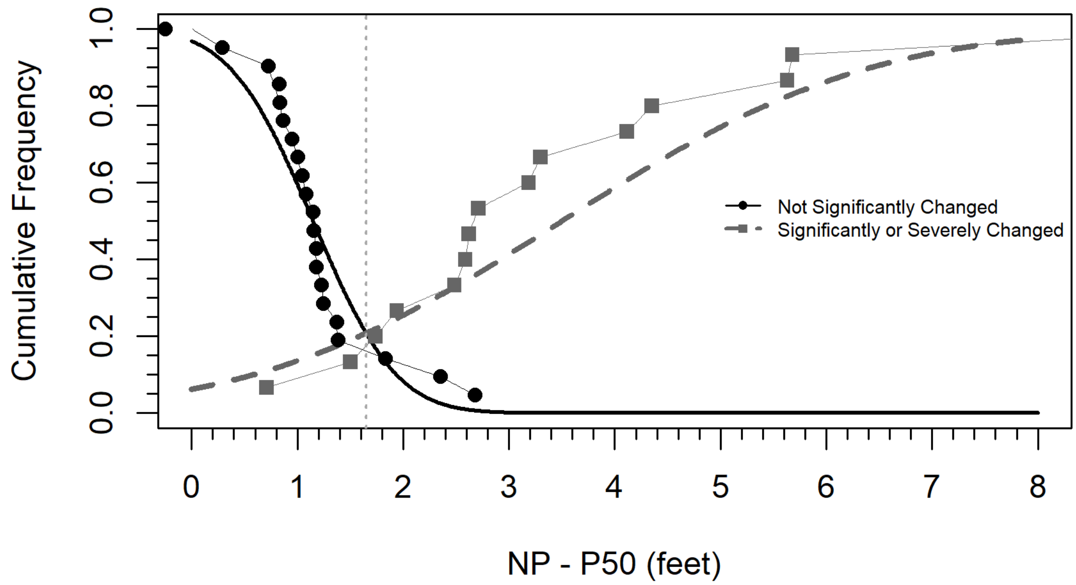

STWF U (S-30)
Old HNP
New HNP
Water Level (ft NGVD29)
15
20
25
30
35
1980
1990
2000
2010
2020

Appendix B: Crossing Point Figures

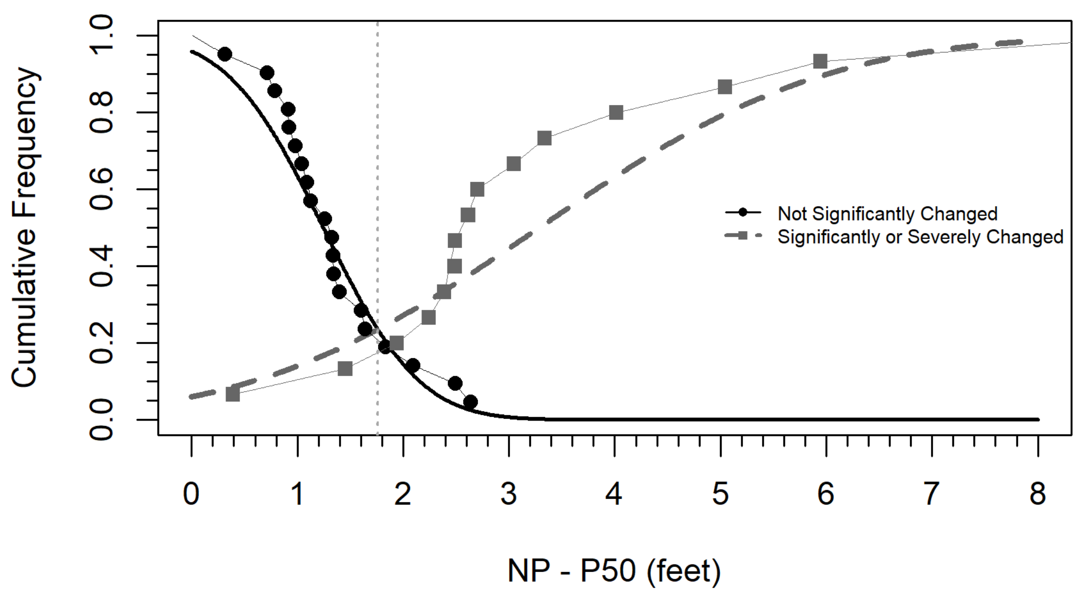


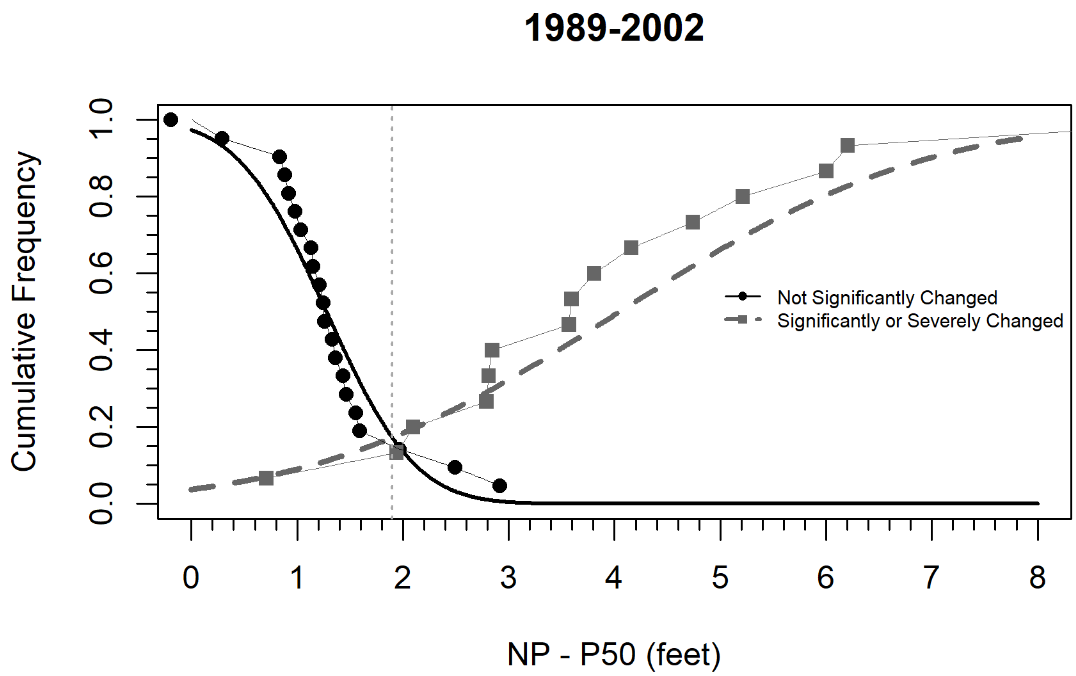


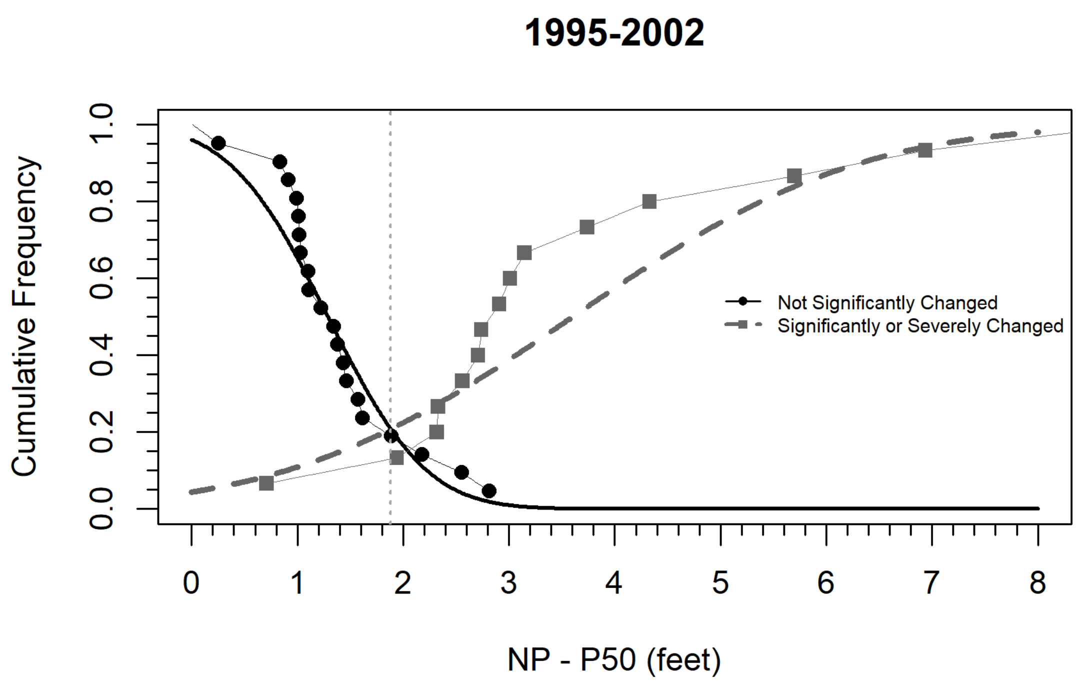
1989-2004

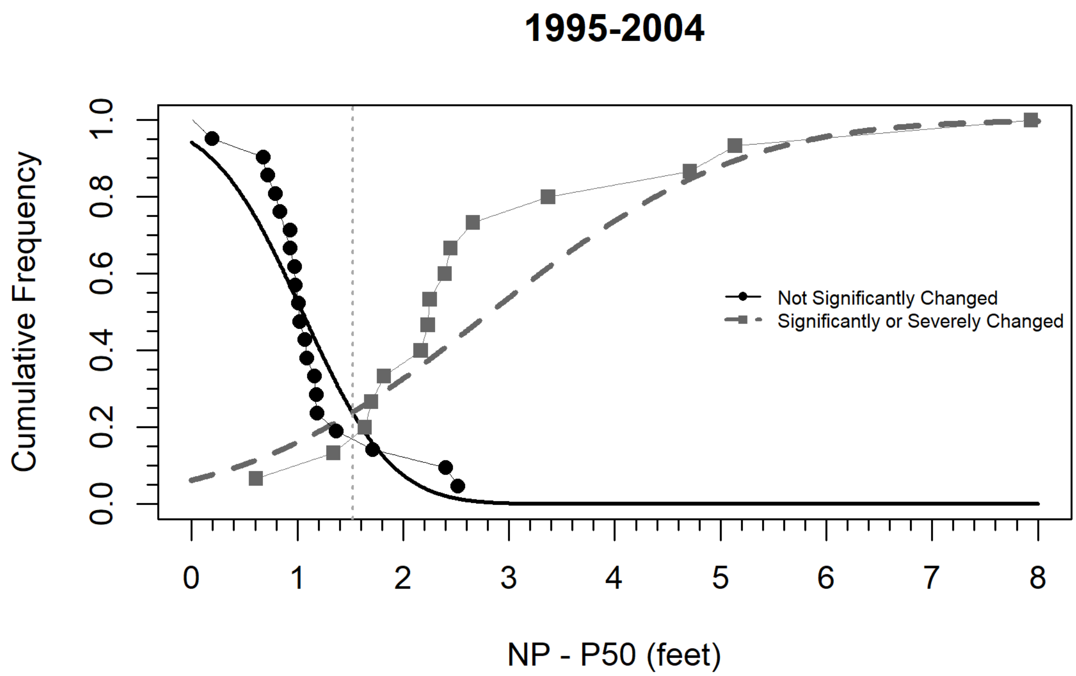


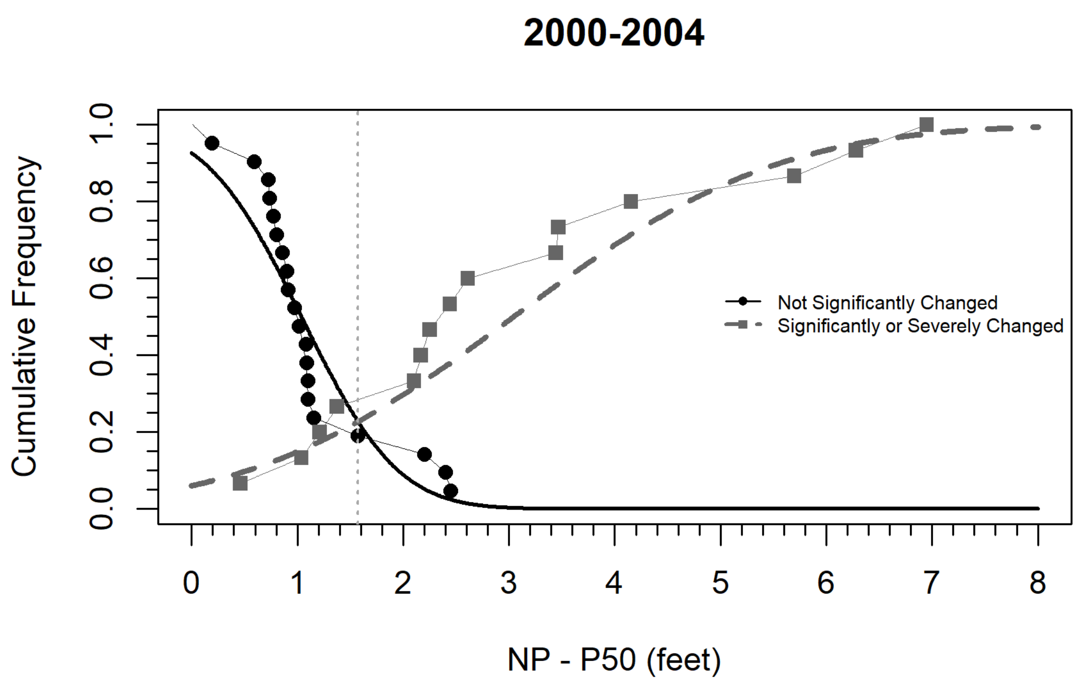
1995-2000




1989-2002
Cumulative Frequency
0.0
0.2
0.4
0.6
0.8
1.0
0
1
2
3
4
5
6
7
8
NP - P50 (feet)
Not Significantly Changed
Significantly or Severely Changed


1995-2002
Cumulative Frequency
0.0
0.2
0.4
0.6
0.8
1.0
0
1
2
3
4
5
6
7
8
NP - P50 (feet)
Not Significantly Changed
Significantly or Severely Changed


1995-2004
Cumulative Frequency
0.0
0.2
0.4
0.6
0.8
1.0
0
1
2
3
4
5
6
7
8
NP - P50 (feet)
Not Significantly Changed
Significantly or Severely Changed


2000-2004
Cumulative Frequency
0.0
0.2
0.4
0.6
0.8
1.0
0
1
2
3
4
5
6
7
8
NP - P50 (feet)
Not Significantly Changed
Significantly or Severely Changed