Water Budget Evaluation for a Proposed Reservation for Lake Hancock and Lower Saddle Creek in Polk County, Florida

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Environmental Flows and Assessments Section
Natural Systems and Restoration Bureau
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Southwest Florida Water Management District

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EXECUTIVE SUMMARY

The District has completed the Lake Hancock Lake Level Modification and Ecosystem Restoration Project as part of the Southern Water Use Caution Area (SWUCA) Recovery Strategy (SWFWMD 2006 and 2013) for meeting minimum flows established for the Upper Peace River (UPR) and improving water quality within the Peace River to protect the Charlotte Harbor Estuary.

To support minimum flow recovery in the UPR, a reservation rule is needed to reserve water stored in Lake Hancock at and below a water surface elevation of 100 feet above the National Geodetic Vertical Datum of 1929 (ft-NGVD) and released from Lake Hancock to Lower Saddle Creek for UPR recovery. This reservation, referred to in this document as the Lake Hancock Reservation or LHR, will protect water in the lake and that released to the creek for minimum flow recovery purposes from use by permit applicants.

Reservations are adopted for the protection of fish and wildlife, for example by supporting minimum flow recovery, or for protection of the public health and safety. With regard to reservations, the Florida Statutes and Water Resource Implementation Rule stipulate that all presently existing legal water users should be protected as long as their use is not contrary to the public interest.

To evaluate effects of raising the operating level of Lake Hancock, and in support of the adoption of a LHR rule, the District developed a water budget model to estimate Lake Hancock water levels and outflows through the P-11 control structure in Lower Saddle Creek near the lake outlet, flow rates at the U.S. Geological Survey (USGS) Peace River at Bartow (No. 02294650), Fort Meade (No. 02294898), Zolfo Springs (No. 02295637) and Arcadia (No. 02296750) streamflow gaging stations. The model also incorporated estimated sink losses from the river between the Bartow and Fort Meade stations. The LHR analysis included assessment of the number of days minimum flow thresholds of 17 cfs, 27 cfs and 45 cfs would be achieved and number of years that 95% exceedance flows associated with the minimum flows can potentially be recovered in the UPR at the Bartow, Fort Meade, and Zolfo Springs stations, respectively. In addition, potential effects of raising the operating level of Lake Hancock on adopted minimum levels for the lake, established minimum flows for the Middle and Lower Peace River, permitted surface water withdrawals from the Lower Peace River by the Peace River Manasota Regional Water Supply Authority (PRMRWSA) and flows to the Charlotte Harbor Estuary were assessed.

Hydrologic data from Lake Hancock and Peace River at Bartow, Fort Meade, Zolfo Springs and Arcadia, as well as flows measured at the USGS Horse Creek near Arcadia, FL (No. 02297310) and Joshua Creek at Nocatee, FL (No. 02297100) streamflow gaging stations for a 38-year period from January 01, 1975 to December 31, 2012 were used in the water budget model. Model scenarios were developed to compare effects associated with the change in the operating level of the lake from 98.5 ft-NGVD to 100 ft-NGVD.

The simulations indicate that the LHR causes no change in the long-term average flow quantity through the P-11 structure; however, the temporal distribution of the outflow is altered as a result of the seasonal storage of water in Lake Hancock for subsequent release to promote minimum flow recovery in the UPR. This storage and release of water associated with the LHR supports recovery of minimum flows in the UPR and continued achievement of minimum levels in the lake. The LHR will also not adversely affect minimum flows established for the Middle and Lower Peace River or flows to the Charlotte Harbor Estuary, and is protective of existing permitted withdrawals by the PRMRWSA from the Peace River.

These findings and field-observations associated with recent operation of the P-11 structure support the District's planned reservation of water stored in Lake Hancock at and below a water surface elevation of 100.0 ft-NGVD[1] and released from the lake to Lower Saddle Creek when flow thresholds of 17 cfs, 27 cfs and 45 cfs at the Bartow, Fort Meade and Zolfo Springs gage sites are not met.

Stakeholder review and an independent, scientific peer review of the analyses described in this report and in a previous version were completed in 2019 and 2020. Public outreach and stakeholder review (see Appendix E to this report) were initiated in September 2019 and included the hosting of a public workshop on the proposed reservation for Lake Hancock and Lower Saddle Creek on January 8, 2020. Independent, scientific peer review by a two-member panel was voluntarily facilitated by the District in two phases during November and December 2019 (see Appendices F and G). The first phase included the panel's development of an initial peer review report that included recommendations for changes to the documentation and analyses described in the District's original, draft reservation report. For the second phase of the review, District staff documented staff responses to the initial peer review report, completed additional technical analyses and updated the draft reservation report in response to the panel's initial recommendations, and prepared a memorandum addressing a then outstanding review-panel concern. Based on consideration of this information, the panel completed the second phase of their review through development of a final peer review report in which they indicated that all their concerns were addressed by the District.

Subsequent to consideration of any additional stakeholder input and any necessary revisions based on that information, this report will be presented to the District Governing Board for approval, along with a request to initiate rulemaking for the reservation of water stored in Lake Hancock and released to Lower Saddle Creek for recovery of minimum flows in the Upper Peace River.

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[1] The District has recently converted from use of the National Geodetic Vertical Datum of 1929 (ft-NGVD) to use of the North American Vertical Datum of 1988 (ft-NAVD) for measuring and reporting vertical elevations. While the ft-NGVD datum is used for most elevation values included within this report, in some circumstances elevation data that was collected or reported relative to mean sea level or relative to the ft-NAVD datum was converted to elevations relative to the ft-NGVD datum. As necessary, these elevations were, or may be converted to elevations relative to ft-NAVD in accordance with the District's internal operating procedure for minimum flows and levels data collection, summarization, reporting and rule development (Leeper 2016).

1. PURPOSE AND BACKGROUND

1.1 PURPOSE: LAKE HANCOCK RESERVATION

The Florida Statutes and Water Resource Implementation Rule provide a legal framework for establishing and implementing reservations. A reservation is a rule that sets aside a defined quantity of water from consumptive use (i.e., from being included in a permitted withdrawal). Section 373.223(4), Florida Statutes and Rules 62-40.410(3) and 62-40.474, Florida Administrative Code (F.A.C.) (see Appendix A) authorize the state water management district Governing Boards or Department of Environmental Protection to reserve water from use by permit applicants as in its judgment may be required for the protection of fish and wildlife, or the public health and safety.

Rule 62-40.474, F.A.C., which provides specific guidelines concerning reservations, indicates that reservations may be used to aid in a recovery or prevention strategy for a water resource with an established minimum flow or level. The rule also requires that reservations, shall to the extent practical, clearly describe the location, quantity, timing and distribution of the reserved water. Both the Florida Statutes and the Water Resource Implementation Rule dictate that reservations are subject to periodic review and revision with respect to changed conditions, with the rule specifying that reservations are subject to review at least every five years. The statutes and the rule stipulate that all presently existing legal uses of water shall be protected so long as such use is not contrary to the public interest.

The District has prospectively adopted a reservation rule for recovery and protection of minimum flows and minimum water levels (MFLs) established for the SWUCA. Rule 40D-2.302(2), F.A.C. (see Appendix A) within the District's Consumptive Use of Water rules indicates reservations for this purpose will be adopted on a case-by-case basis to address water that is developed through water resource development projects designed to achieve and maintain MFLs. The adoption of a reservation of water stored in Lake Hancock and released to Lower Saddle Creek (hereafter referred to as the Lake Hancock Reservation or LHR) for recovery of minimum flows in the UPR that are not being met is currently prioritized for adoption into Rule 40D-2.302(2), F.A.C. in 2020.

The objectives of this investigation are to document analyses supporting adoption of the LHR, based on development and use of a daily water budget model. The model was developed to project current (i.e., post P-11 structure replacement at the Lake Hancock outlet) hydrologic conditions from historical (i.e., pre P-11 structure replacement) conditions such that long-term hydrologic data records prior to the completion of the project could be used for various evaluations on the Peace River. The results from these evaluations were used to assess effects of the LHR on outflows from Lake Hancock, recovery of minimum flows in the UPR, minimum water levels in Lake Hancock, minimum flows established for the Middle Peace River (MPR) and Lower Peace River (LPR), permitted water withdrawals from the LPR by the PRMRWSA, and flows to the Charlotte Harbor Estuary.

1.2 Background: Peace River Minimum Flows and Minimum Flow Recovery

Sections 373.042 and 373.0421 of the Florida Statutes (see Appendix B) require the Department of Environmental Protection or the Governing Board of each state water management district to establish and implement minimum flows for surface watercourses within the state. A minimum flow is the limit at which further withdrawals would be significantly harmful to the water resources or ecology of the area. If the existing flow is below an applicable minimum flow, the statutes require adoption and implementation of a recovery strategy to achieve recovery to the established minimum flow as soon as practicable.

The District has adopted minimum flows that are applicable to the entire Peace River (see Appendix C). These rules are used in planning and permitting activities to protect the river from its headwaters in Polk County, through Hardee, Desoto, and Charlotte Countries, to the river's terminus in the Charlotte Harbor Estuary (Figure 1). Major sub-basins of the watershed include Lake Hancock, Peace Creek, Peace River above Bartow, Peace River above Zolfo Springs, Peace River above Arcadia, Lower Peace River, Payne Creek, Charlie Creek, Horse Creek, Joshua Creek and Shell Creek.

For purposes of minimum flows establishment and implementation, the Peace River is divided into three river segments: the UPR, from the river's origin at the confluence of Lower Saddle Creek and the Peace Creek Canal in central Polk County, to Zolfo Springs in central Hardee County; the MPR, from Zolfo Springs to Arcadia in central DeSoto County; and the LPR, from Arcadia to Charlotte Harbor in Charlotte County.

Minimum flows have been established for the 37.9-mile long UPR (Rule 40D-8.041(7), F.A.C.) at three USGS streamflow gaging stations (Figure 1). The most upstream site, the Peace River at State Road 60 at Bartow, FL gage (No. 02294650) is located just downstream of the confluence of Lower Saddle Creek, which drains Lake Hancock and its watershed, and the Peace Creek Canal, which drains the Peace Creek watershed. The Peace River at Fort Meade, FL gage (No. 02294898), in south-central Polk County, is about 13.3 miles downstream from the Bartow gage. The Peace River at US 17 at Zolfo Springs, FL gage (No. 02295637) in Hardee County, is about 23.4 miles downstream of the Fort Meade gage. Bowlegs Creek and Payne Creek are two major tributaries flowing into the UPR between Fort Meade and Zolfo Springs.

Prior to the 1950s, the UPR was a gaining stream channel from Bartow to Fort Meade. Since that time, it has become a losing stream channel due to alterations associated with phosphate mining, changes in land use, and groundwater withdrawals. Streamflow is lost to the underlying groundwater system predominantly through karst features such as fractures, crevasses and sinkholes (Figure 2) as reported by Lewelling, et al. (1998), USGS (2004) and Metz and Lewelling (2009).

Minimum flows for the UPR were developed in 2002 as minimum low flows based on fish passage and wetted perimeter criteria (SWFWMD 2002). The minimum flows were approved by the District Governing Board in 2006 and adopted as Rule 40D-8.041(7), F.A.C., that became effective in 2007. However, minimum flows associated with medium and high flow ranges were not determined for the UPR at the time the minimum low flows were developed, due to limitations regarding confounding effects of withdrawals and structural alterations on the hydrologic regime of the river.

The adopted minimum flows for the UPR are defined as 95% annual exceedance flow rates of 17, 27 and 45 cubic feet per second (cfs), respectively, at the Bartow, Fort Meade and Zolfo Springs gage sites. The 95% annual exceedance for each minimum flow occurs when flows at the respective site exceed the corresponding flow rate at least 347 days (or 348 days for leap-years) during a calendar year. As specified in the compliance portion of the UPR minimum flows rule, each “Minimum Low Flow is achieved when the measured flow rate is at or above the Minimum Low Flow for three consecutive years. Once the Minimum Low Flow has been achieved for three consecutive years, the Minimum Low Flow is not met when the measured flow rate is below the Minimum Low Flow for two out of ten years commencing the year after achievement. If the two years below the minimum flow occur anytime before the ten-year period is complete, the upper Peace River is deemed below its Minimum Low Flow and the three consecutive years above the Minimum Low Flow is again required for compliance. Once the ten-year period is complete, the period will roll forward one year each year.”

At the time of their adoption, the District determined the UPR minimum flows were not being met. Recent investigations of flows for a 44-year period from 1975 to 2018 indicate that the adopted UPR minimum flows were met 12 years at Bartow, 5 years at Fort Meade, and 31 years at Zolfo Springs. The SWUCA Recovery Strategy (Rule 40D-80.0.074, F.A.C., SWFWMD 2006 and 2013) was developed in March 2006 for all or part of eight counties in the southern portion of the District. One of its goals is to restore the UPR minimum flows by 2025 through the implementation of recovery projects. One of these projects is the Lake Hancock Lake Level Modification and Ecosystem Restoration Project, which consists of two initiatives: the Lake Hancock Lake Level Modification Project and the Lake Hancock Outfall Treatment Project. In combination, these initiatives are critical for recovering minimum flows in the UPR, improving water quality in the Peace River, and protecting the Charlotte Harbor Estuary.

The goal of the Lake Hancock Lake Level Modification Project is to store additional water in Lake Hancock to meet minimum flow requirements in the UPR by raising the control elevation of the lake outflow structure (P-11) on Lower Saddle Creek from 98.5 to 100 ft-NGVD.

The additional water storage is achieved by capturing inflows to Lake Hancock during the wet season and releasing flows to the UPR through Lower Saddle Creek during the dry season, when flow conditions at the Bartow, Fort Meade and Zolfo Springs gages are below minimum flow thresholds.

Construction of a new P-11 structure for the Lake Hancock Lake Level Modification Project was completed in 2013. Following an approximate one-year period in which inflows were stored in the lake, operation of the P-11 structure to help achieve minimum flows in the UPR started in late 2015.

With the new P-11 control structure, an additional 1.5 ft of water storage can be captured and stored when Lake Hancock is at its full capacity. When lake stage exceeds 100 ft-NGVD, overflow occurs because the crest of the P-11 structure weir gates is at 100 ft-NGVD. When lake stage falls below 97.6 ft-NGVD no flow releases are made regardless of downstream flow needs due to the established minimum lake level for Lake Hancock (Rule 40D-8.624(12), F.A.C.), which was adopted and became effective in November 2016 (Leeper and Ellison 2017). The water storage between 97.6 and 100 ft-NGVD represents a maximum volume (approximately 4.359 billion gallons or 13,377 acre-feet) at a given time that can be achieved through the operation of the new, i.e., currently existing P-11 structure.

The Lake Hancock Outfall Treatment Project involved construction of treatment wetlands to improve water quality discharged from the lake. The project was completed in 2014. An outfall structure associated with the treatment wetlands provides an additional route for release of water from Lake Hancock to Lower Saddle Creek.

Other minimum flows and considerations relevant to the LHR analyses included minimum flows for the MPR that were adopted into District rules (specifically Rule 40D-8.041(5), F.A.C.) and became effective in 2006 (SWFWMD 2005), and minimum flows for the LPR (SWFWMD 2010) that were adopted by rule (specifically Rule 40D-8.041(8), F.A.C.) and became effective in 2010 (see Appendix C).

The water use permit (Individual Permit No. 2001420.010) issued to the PRMRWSA by the District in February 2019 for withdrawals from the LPR was also integral to this LHR analysis, because the Florida Statutes and Water Resource Implementation Rule require that all presently existing legal uses of water shall be protected so long as such use is not contrary to the public interest.

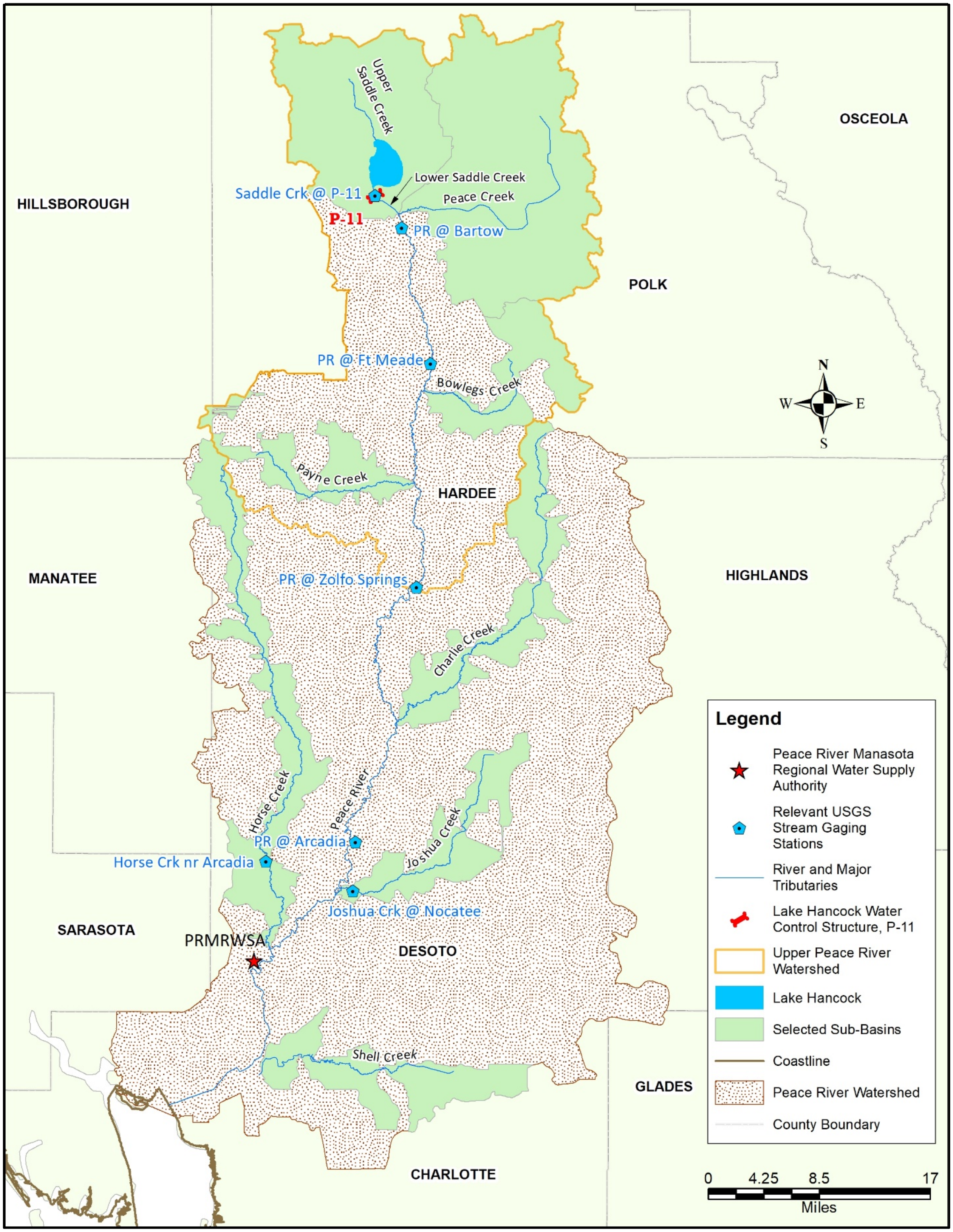
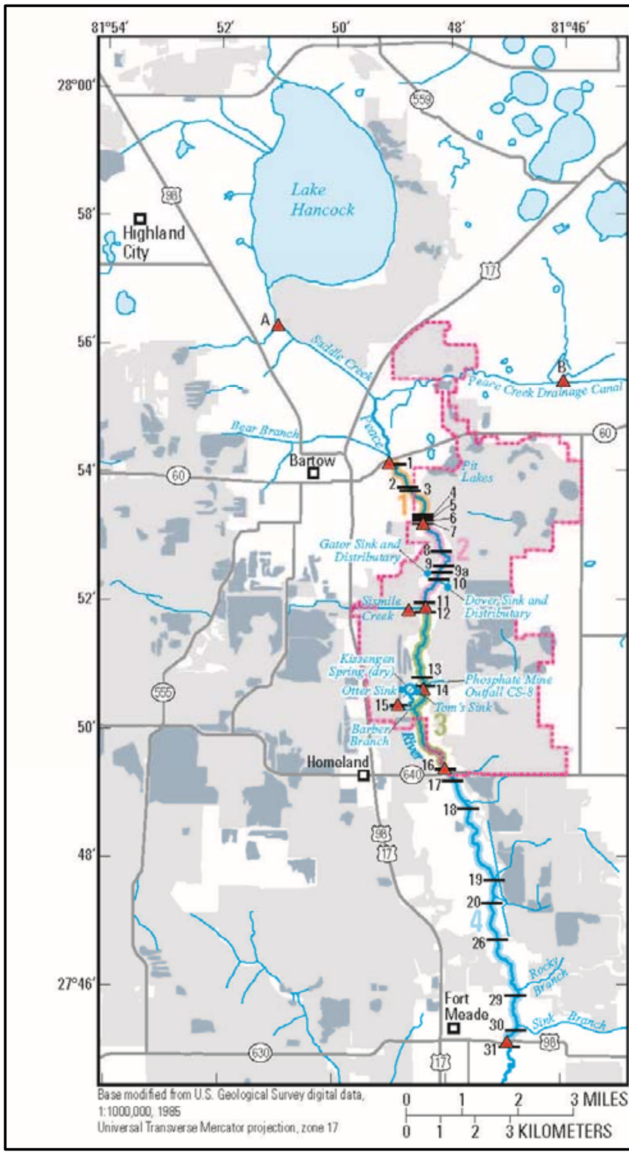


Figure 1. Lake Hancock, Peace River and Peace River watershed



Site number	River mile	Location
A		Saddle Creek at Structure P-11 (gaging station)
B		Peace Creek Drainage Canal (gaging station)
1	0	Peace River at Bartow (gaging station)
2[1]	0.8	Above Wabash Complex
3	0.9	Below Wabash Complex
4	1.3	Upper dragline crossing; Cook's Ripple
5	1.6	Above Ledges; Fricano Fracture
6	1.7	Below Ledges
7	1.8	Peace River near Bartow (gaging station)
8	1.9	Below diffuse zone and Midway
9	2.1	Below Elephant Graveyard
9a	2.6	Below Crevasses
10	2.8	Dover Sink and Dover Sink Distributary
11	3.7	Peace River at Clear Springs (gaging station)
12	3.8	Sixmile Creek (gaging station)
13	4.9	Above Kissengen Spring
14	5.2	Phosphate Mine Outfall CS-8 (gaging station)
15	5.7	Barber Branch (gaging station)
16	7.2	Peace River near Homeland (gaging station)
17	7.3	Department of Environmental Protection ditch
18	7.8	Below Juvenile Detention Center
19	9.5	Mobil Outfall 3W Cut
20	9.9	Camp Meeting Branch
26	10.8	Below Mobil bridge
29	11.9	Rocky Branch
30	12.6	Sink Branch
31	13.0	Peace River at Fort Meade (gaging station)

[1] Site 2 used as alternate discharge measurement section for site 1 during low-flow conditions

Figure 2. Karst features and sink locations between Bartow and Fort Meade (figure reproduced from Metz and Lewelling, 2009)

2. LAKE HANCOCK RESERVATION ANALYSIS

A daily water budget model was conceptualized for the LHR analysis, as described in Section 2.1. Requirements for the water budget model, including relevant hydrologic data, regression and information are summarized in Section 2.2. The water budget model was developed as an Excel spreadsheet, incorporating necessary adjustments, as discussed in Section 2.3. In addition, relevant data and model files for the water budget model and model scenario applications are included in Appendix D.

Using the spreadsheet model, available lake water storage, lake stage, P-11 outflows and change in outflows are projected from the historical condition for the simulation scenarios described in Section 2.3.1. The projected data reflect selected hydrologic conditions that would be expected to have occurred as a result of various operation protocols of the current P-11 structure.

2.1 DAILY WATER BUDGET MODEL

Lake Hancock is the Largest freshwater lake in the Peace River watershed and the fourth largest in Polk County. The lake is approximately 4,500 acres in size with an average depth of less than 5 ft (Patton 1980, Harper et al. 1999) and a maximum depth of 16 ft (SWFWMD 2019) that was expected to be increased after the P-11 structure replacement. Potential inflows to the lake include surface runoff from the Lake Hancock watershed, stream flows from primary tributaries, including Banana Creek, Upper Saddle Creek, Lake Lena Run, direct rainfall on the lake and groundwater baseflow. Potential outflows from the lake include evapotranspiration (ET) from the open water surface of the lake, groundwater seepage and recharge, and discharge through the P-11 control structure into Lower Saddle Creek, which in conjunction with the Peace Creek Canal, forms the UPR. Figure 3 illustrates the water budget components of Lake Hancock.

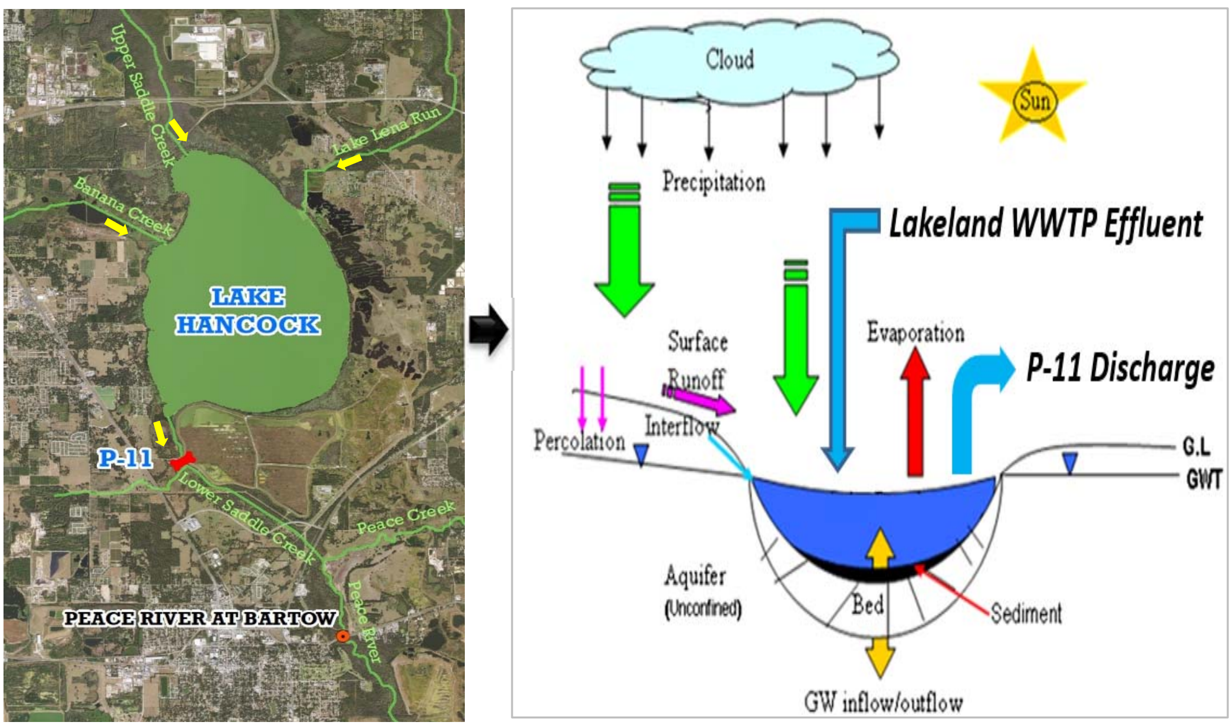


Figure 3. Schematic diagram of Lake Hancock water budget components

As discussed further in Section 2.2.2, the analysis period for the LHR analysis was defined as the period prior to the replacement of the previous P-11 control structure. However, through development and use of a water budget model, these available historical hydrologic data could be used to assess impacts of the LHR on current conditions in Lake Hancock and throughout the Peace River.

Assuming Lake Hancock can be considered as a level pool, a water budget for Lake Hancock can be simply expressed as shown below in Equation 1, where ΔS is the change in lake water storage, which can be defined using a lake stage versus volume relationship as discussed in Section 2.2.7, I represents total inflow and O corresponds to total outflow.

$$\Delta S = I - O \qquad \text{(Equation 1)}$$

The total outflow term, O, can be further defined as individual losses to evaporation (O_{ET}), groundwater (O_{GW}), and for the historical (again, pre P-11 structure modification) record, discharge through control structure P-11 ($O_{p\text{-}11,\ historical}$) as indicted in Equation 2 below. Historical discharge ($O_{p\text{-}11,\ historical}$) was recorded at a former USGS gage (see Section 2.2.4).

$$\Delta S_{historical} = I - (O_{ET} + O_{GW} + O_{p\text{-}11,\ historical}) \qquad \text{(Equation 2)}$$

Merging the total inflow term with O_{ET} and O_{GW} in Equation 2, a new term named effective inflow, I_E (i.e., $I - O_{ET} - O_{GW}$), can be defined as a lumped quantity representing total inflow minus outflow terms, excepting the historical discharge, $O_{p\text{-}11,\ historical}$. Development of the effective inflow term obviates the need for historical evapotranspiration and groundwater loss data that are not available.

Rearranging Equation 2 to Equation 3, yields the effective inflow that can be estimated using historical data, i.e., change in lake storage and discharge through the P-11 control structure.

$$I_E = \Delta S_{historical} + O_{p\text{-}11,\ historical} \qquad \text{(Equation 3)}$$

Determination of the effective inflow, I_E, into the lake is necessary to project hydrologic conditions under the operation of the current P-11 structure. Underlying the development and use of the effective inflow for this purpose is the assumption that effective inflow would be the same regardless of differences between the configuration and operation protocols of the current and previous P-11 structures. This assumption is considered appropriate for the purpose of the LHR analysis.

Higher water levels in Lake Hancock associated with the lake level modification project were predicted to inundate about 300 acres that was previously dominated by uplands (BCI 2006c). These inundated uplands have become part of the lake, resulting in an increase in ET, equivalent to about 1 inch per year in the newly inundated area, accounting for approximately 0.6% of the lake inflow (BCI 2006b). This reduction in inflow due to increased ET is considered negligible.

According to Darcy's Law, the deep aquifer recharge in the area of Lake Hancock is a function of hydraulic conductivity, head gradient (i.e., difference of potentiometric surface elevation of the Upper Floridan aquifer and lake level over the distance of measurement points) and recharge area. BCI (2006b) notes that lake level modification that was planned, and which has now occurred, would result in about a 10% increase in head gradient and about a 7% increase in recharge area, cumulatively resulting in up to a 17.7% increase in deep recharge from the lake, This translates to about a 4.4 inches loss from the lake to aquifer, which is equivalent to about 2.8% of lake inflow.

The increased ET and aquifer recharge sum to 3.4% of lake inflow, which is less than the generally accepted accuracy of 5% for USGS daily flow data. It is, therefore, reasonable to conclude potential errors in the ET and groundwater terms consolidated in the effective inflow due to elevated lake stages would be negligible and can be ignored. The water budget for the lake under the existing, i.e., current conditions can therefore be written as

$$\Delta S_{existing} = I_E - O_{p\text{-}11,\ existing} \qquad \text{(Equation 4)}$$

Once the discharge, $O_{p\text{-}11,\ existing}$, via the existing P-11 structure, is estimated (see Sections 2.2.5 and 2.2.6). The change in lake storage, $\Delta S_{existing}$, under the existing structure condition can be estimated using Equation 4. Subsequently, the lake stage under the existing condition can be estimated using a stage versus volume relationship (see Equation 7 in Section 2.2.7). With this approach, the lake stage under the existing condition is simulated for the analysis period. Then, the change in outflow, i.e., the difference between historical and existing discharge is calculated.

A daily time step was adopted in the water budget model to be consistent with the hydrologic data frequency used for developing the minimum lake levels for Lake Hancock, and minimum flows for each segment of the Peace River.

2.2 DATA, REGRESSION AND INFORMATION

Details related to data acquisition and processing, regression development and use, and other information in support of, relevant to and used in the daily water budget model and the LHR analysis are summarized in this section.

2.2.1 P-11 Control Structure

The original P-11 control structure at the outlet of Lake Hancock was a concrete and timber pile weir located approximately 0.7 miles downstream from the lake on Lower Saddle Creek (SWFWMD 1999 and 2003). This original structure was replaced with a concrete spillway and a steel sheet pile weir by the Peace River Valley Water Conservation and Drainage District in 1963 for regulating discharges into the Peace River for flood control purposes. The spillway/weir structure had two metal 7 ft high by 20 ft wide radial gates with an invert of 91.7 ft-NGVD and an overflow elevation of 98.7 ft-NGVD (SWFWMD 1999 and 2003; BCI 2006a; see Figure 4).

Figure 4. Downstream side of the former P-11 control structure showing two metal radial gates and the concrete-capped, sheet-pile wall

The District operated the spillway/weir P-11 according to an operation schedule and lake management levels that were adopted in September 1980 to provide guidance for management of seasonal lake level fluctuations. A maximum desirable level of 98.5 ft-NGVD, which was not adopted by rule, was also used as a guide to manage the lake to provide optimum aesthetic and recreational benefits, based on the then existing development on the shoreline and floodplain (BCI 2006a). When a flood was imminent or when the lake level approached or exceeded the maximum desirable level, water was released from the lake through structure P-11. As the lake continued to rise, structure P-11 would be overtopped at the elevation 98.7 ft-NGVD, surface water would begin to flow around the structure, and downstream conditions in Lower Saddle Creek would control discharge from the lake.

In 2003, the District began evaluating the feasibility of replacing the spillway/weir structure and raising the lake level, with the goal of storing additional water to help achieve minimum flow requirements for the UPR. BCI (2005) completed a preliminary evaluation of the potential benefits and impacts associated with raising Lake Hancock's operating levels from 98.5 ft-NGVD to 99.5 or 100.0 or 100.5 ft-NGVD. The normal operating level of 100 ft-NGVD was proposed because it was the approximate historical level of the lake before the area was mined for phosphate and the channelization (lowering) of the natural lake outlet (SWFWMD 2010), and based on minimizing impacts to surrounding infrastructure and facilities.

In 2004, the District Governing Board authorized staff to proceed with the preliminary design and draft environmental resource permit application for the Lake Hancock Lake Level Modification Project. In January 2006, the Board authorized staff to submit a Conceptual Environmental Resource Permit (CERP) application (BCI 2006a) upon reaching agreement with Polk County. The CERP application was submitted to the Florida Department of Environmental Protection on August 30, 2006 and a permit was issued to the District on June 14, 2007 (BCI 2006a). In September 2007, the District Governing Board approved implementation of the Lake Hancock Lake Level Modification Project, including the final design, permitting, and construction. Replacement of the then existing P-11 structure with a new structure began in November 2011 and was completed in April 2013 (SWFWMD 2019).

The new, i.e., currently existing P-11 structure (Figure 5) is located on Lower Saddle Creek, approximately 220 ft downstream of the former structure. It is designed to discharge up to 2,800 cfs for regulating water levels in Lake Hancock for water storage, recharge and recreation. However, the maximum discharge rate for the structure is limited by the channel capacity of Lower Saddle Creek and backwater effects at the creek's confluence with the Peace Creek Canal, where the UPR originates. The structure consists of an earthen embankment, a concrete spillway, and a three-bay concrete structure with sheet pile driven to hard lime rock (SWFWMD 2014). The central and easternmost structure bays include 20 ft wide by 10 ft tall roller (i.e., lift) gates with an invert elevation of 92.0 ft-NGVD. The third bay includes two 10-ft wide by 4 ft tall weir (i.e., drop) gates with an invert elevation at 96.0 ft-NGVD.

The two weir gates in the westernmost structure bay (Figure 5) were designed primarily for release of relatively small volumes of water at precise flow rates during the dry season to meet the UPR minimum flows and for routine operations. The two roller gates in the other two structure bays were designed primarily for moving large volumes of water during the wet season for flood protection purposes, when large flow releases are needed to lower lake levels. Because flows through the roller gates are released from the bottom of the bays and have the potential to erode the downstream stilling basin, the two large roller gates are infrequently operated during low and medium flow conditions.

Operation of the structure gates can be performed remotely through the District's Supervisory Control and Data Acquisition (SCADA) system or manually at the Programmable Logic Controller (PLC) in the on-site control building. A Verizon communication line is installed to the PLC to interface with the District's Sever for monitoring gated structure conditions and remote operation from the District's Brooksville office.

Figure 5. Downstream side of the Lake Hancock's P-11 control structure showing two weir gates in the westernmost bay on the left (one is partially open and the other is closed) and roller gates in the other two bays

Since late 2015, the P-11 structure has been operated to help achieve minimum flows in the UPR during the dry season, prevent floods during the wet season and replenish water storage. Current operational protocols for structure P-11 (SWFWMD 2014), developed based on a preliminary evaluation (BCI 2006b) conducted prior to the modification of P-11, include several considerations, as summarized below.

- *A low operating level of 97.5 ft-NGVD, below which no releases are to be made regardless of downstream conditions.*
- *The maximum desirable level of 100 ft-NGVD, above which releases shall be made with any combination of gates to lower the lake without causing increased downstream flooding.*
- *A typical lake-level fluctuation range between 97.5 to 100 ft-NGVD, which corresponds with water stored and released for meeting UPR minimum flow requirements.*
- *An inflow capture rate of 100% when the lake is below the low operating level.*

- *An inflow capture rate of 60% when the lake is between the low operating level and the maximum desirable level. Forty percent of the inflows are released under these conditions through P-11 and/or the wetland treatment system. Adjustments to outflows during high inflow conditions shall be made if deemed necessary. Inflows shall be captured when flows at the downstream USGS gaging stations on the Peace River exceed their established minimum flow rates, i.e. 17 cfs at Bartow, 27 cfs at Fort Meade, and 45 cfs at Zolfo Springs.*

The protocol provides general guidelines for routine operation of structure P-11. During the wet season, minimum flows established for the UPR at Bartow, Fort Meade and Zolfo Springs are likely being met and inflows to Lake Hancock may warrant discharge from P-11 to maintain lake levels around 100 ft-NGVD. During hurricane season, preemptive releases may occur in anticipation of large storm events to create flood attenuation storage. After storms, flows through P-11 are slowly released to avoid downstream flooding. At the end of wet season, lake levels are maintained around 100 ft-NGVD to ensure adequate storage for dry season minimum flow releases.

In day-to-day operations, flows in the Peace River at Bartow, Fort Meade and Zolfo Springs are monitored on a quasi-real-time basis (i.e., at 15-minute intervals) based on provisional data published by the USGS. Incoming flows from the primary tributaries to Lake Hancock are monitored on a daily basis and weather forecasts are monitored in real-time and on a weekly basis. These data are used to make predictions regarding flow trends in the UPR and support structure operation decisions. For releases necessary to meet minimum flows in the UPR, water travel-times are also considered. For example, it takes about six hours for released flows at the P-11 structure to reach the Bartow gage. When the need for a supplemental flow quantity to meet the minimum flow threshold (i.e., 17 cfs) at Bartow is predicted, such a release should be made six hours in advance of the predicted need.

To support structure operation decisions and schedule development, District staff has recently developed status reporting and predictive tools to assist with lake storage and river flow projections. As an example, Figure 6 demonstrates the effect of P-11 operation on meeting the minimum flow threshold of 27 cfs at Fort Meade for a typical dry period from April 23, 2016 to May 10, 2016. As illustrated in the figure, the flows for the five days (labeled in red) during the selected period, which could have fallen below 27 cfs at Fort Meade, met the minimum flow threshold through the operation of the P-11 structure.

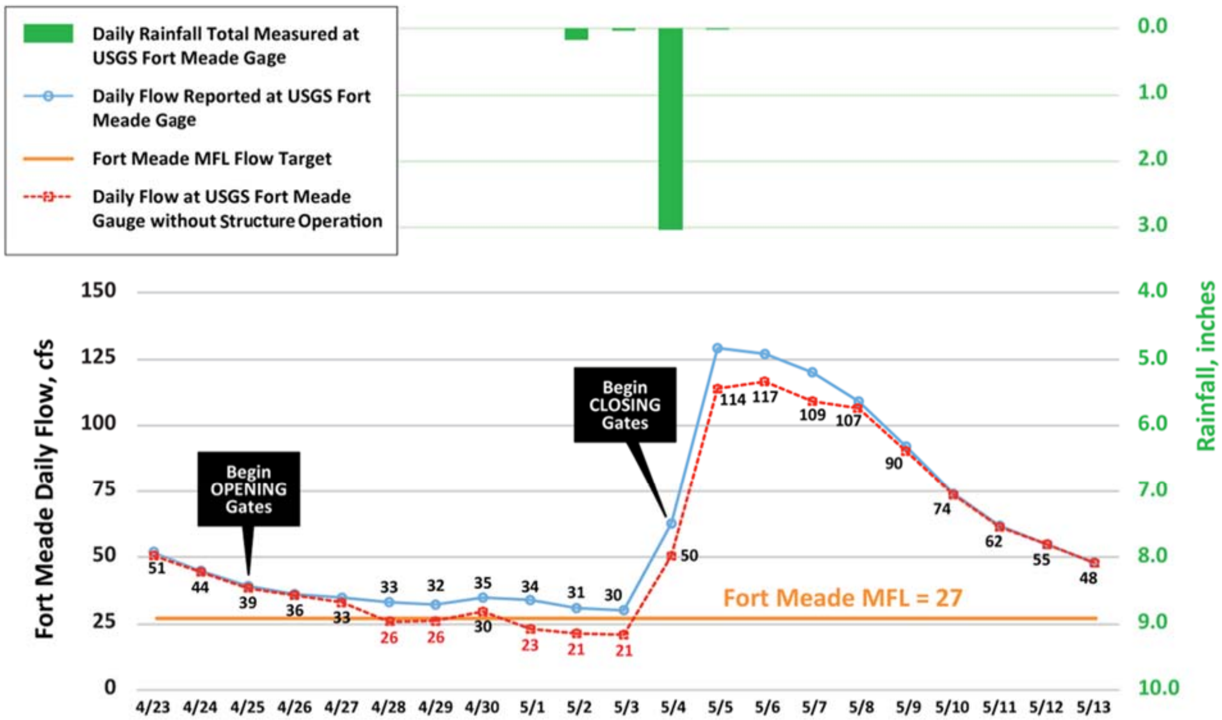


Figure 6. Example of the effect of structure P-11 operation on meeting the minimum flow in the UPR at Fort Meade for a selected period from April 23, 2016 to May 10, 2016

Recent status assessments indicate that 95% annual exceedance flows in the UPR at Bartow, Fort Meade and Zolfo Springs were, respectively, greater than the 17 cfs, 27 cfs and 45 cfs thresholds associated with the minimum flows established for the sites. This was not the case at any of the sites during 2017. For this recent period from 2016 through 2018, minimum flows compliance was achieved at only the Zolfo Springs gage, based on the flow threshold for the site having been met for three consecutive years, from 2014 through 2016.

The District continues to assess operational protocols for structure P-11 in terms of efficiency in achieving UPR MFLs recovery and other relevant factors. For example, as noted above, the low operating level of the lake, below which no releases will be made through the P-11 structure regardless of the downstream conditions, has been identified at 97.5 ft-NGVD. This low operating level was developed prior to the adoption of the minimum lake level of 97.6 ft-NGVD for Lake Hancock in November 2016. Based on this adopted minimum level, an elevation of 97.6 ft-NGVD was used as the lower limit below which no releases would be allowed for the LHR analyses described in this report. Results from the analyses, along with continued monitoring of structure operations, water levels in Lake Hancock and flow conditions in the UPR are expected to be useful for future operation protocol refinements.

2.2.2 Analysis Period

After a thorough review of relevant hydrologic records for Lake Hancock and the Peace River, a 38-year period from January 1, 1975 through December 31, 2012 was selected for the LHR analysis period. In addition, a six-month period from June 1, 1974 through December 31, 1974 was used for model warmup.

The start date for the model warmup and analysis periods was based on availability of critical flow records. Among the three UPR gage sites where minimum flows are established, the Peace River at Fort Meade gage has the shortest continuous period of record. The continuous record for this site begins on June 1, 1974.

Additional considerations for selection of the analysis period were associated with the replacement of and availability of discharge data for the previous P-11 control structure. As described in Section 2.2.1, construction of the new P-11 structure was completed in April 2013 and demolition of the old structure occurred in May 2013. A former USGS gaging station, Saddle Creek at Structure P-11 near Bartow FL (No. 02294491), was located about 65 ft downstream of the former P-11 structure, and was used for recording continuous flow records from December 1, 1963 through October 7, 2014, and gage height records from October 1, 1973 through October 7, 2014. The USGS gage was discontinued after construction of the new P-11 structure and a replacement gage has not been established. Records from the site for the period from January 1, 2013 to October 7, 2014 were not included in the analysis period due to concerns related to the construction of P-11, and demolition and removal of the former P-11 structure. The end-date of December 31, 2012 used for the LHR analyses was therefore selected to minimize construction-related data uncertainties.

2.2.3 Lake Hancock Surface Water Elevation

Water levels in Lake Hancock have been monitored by the USGS and the District on a regular basis since August 1959. Lake Hancock's maximum level of record (101.88 ft-NGVD) occurred on September 16, 1960 after Hurricane Donna passed through the area. The lowest level record (93.98 ft-NGVD) occurred on May 23, 1968 as a result of a sinkhole that opened near the center of the Lake. Lake Hancock levels ranged between 94.95 ft-NGVD to 101.45 ft-NGVD with a mean of 97.8 ft-NGVD for the LHR analysis period.

For this investigation, daily lake stages from three surface water sites (District Site IDs: 24532, 24760 and 24759 as shown in Figure 7) in Lake Hancock were retrieved to produce a single composite dataset for the period from June 1, 1974 to December 31, 2012 because none of these sites has a continuous record for the entire analysis period. Site 24760, a former USGS site located on the western shore of the lake, has the most historical stage records. However, that site was discontinued after September 24, 2002. Site 24759, at the southern end of the lake near the P-11 control structure, was selected as the primary site because it has the most data values available in the analysis period.

Missing data for this site were infilled using linear interpolation, regression, or field measurements available for the other two sites.

Figure 7. Locations of Lake Hancock stage data collection sites and primary tributaries for surface water inflows to Lake Hancock

Using the composite stage dataset, a lake stage duration curve was prepared for Lake Hancock for the period from January 1975 through December 2012 (Figure 8). As observed, the 50% exceedance lake level is about 97.97 ft-NGVD, which is approximately 0.4 ft higher than the adopted Minimum Lake Level of 97.6 ft-NGVD that is a required 50% exceedance elevation. Factors that could be associated with the differing exceedance values include use of a much longer period of record for stage data (i.e.,1966 through 2014 per Leeper and Ellison, 2017) for the Lake Hancock minimum level analysis and differing techniques used for infilling data gaps in the historical lake stage records.

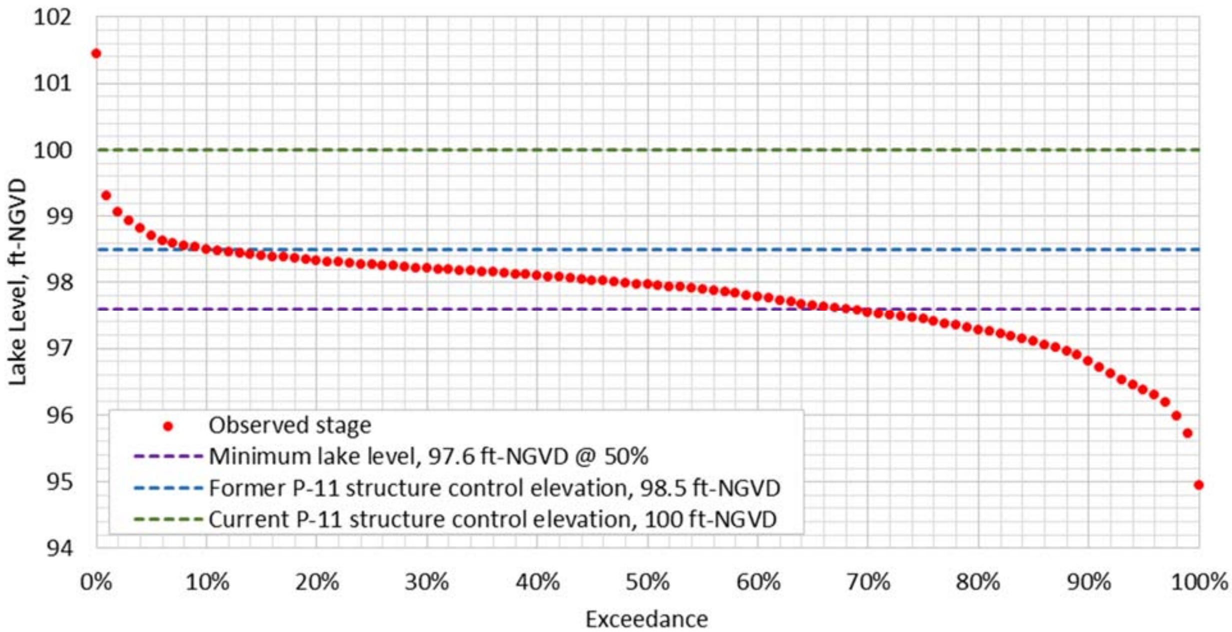


Figure 8. Lake Hancock stage duration curve for the period from January 1975 through December 2012

2.2.4 Relevant USGS Streamflow and Established Minimum Flows

Daily average flows at seven USGS gaging stations (Table 1; see Figure 1) were retrieved from the USGS National Water Information System through June 2019 for this study. The site at Saddle Creek at Structure P-11 near Bartow recorded historical flow associated with the former P-11 structure and this site was discontinued in 2014 as discussed in Section 2.2.2. The remaining six sites are all associated with minimum flows that have been established for different segments of the Peace River.

As discussed in Section 1.2, the UPR minimum flows include minimum low flow thresholds that have been established for the Peace River at Bartow, Fort Meade and Zolfo Springs gages and are applicable upstream of these sites. Minimum flows for the MPR have been established at the Peace River at Arcadia gage for the full hydrologic regime, i.e., for low, medium and high flow ranges or seasons, and are applicable from the Arcadia gage upstream to the Zolfo Springs gage. Minimum flows for the LPR, which extends downstream of the Peace River at Arcadia gage, have also been established for the full hydrologic regime of the river, and were developed and are implemented based on the combined flows at the Peace River at Arcadia gage and flows from two tributaries measured at the USGS Horse Creek near Arcadia, FL and Joshua Creek at Nocatee, FL gages. The combined flow at the Peace River at Arcadia, Horse Creek and Joshua Creek gages is also used for permitted withdrawals from the LPR by the PRMRWSA.

Based on the data available from the relevant USGS gaging stations, a 38-year continuous flow records from 1975 to 2012 was developed for the analyses used in this study.

Table 1. Relevant USGS gaging stations on Lower Saddle Creek and the Peace River and associations with the Upper, Middle and Lower Peace River minimum flows

<table>
<tr><th>USGS Site Name</th><th colspan="3">Gaged River Reach/Creek and Associations with Peace River Minimum Flows</th></tr>
<tr><td>02294491 Saddle Creek at Structure P-11 near Bartow FL</td><td colspan="3">Lower Saddle Creek</td></tr>
<tr><td>02294650 Peace River at Bartow FL</td><td rowspan="3">UPR Minimum Flows</td><td></td><td></td></tr>
<tr><td>02294898 Peace River at Fort Meade FL</td><td></td><td></td></tr>
<tr><td>02295637 Peace River at Zolfo Springs FL</td><td rowspan="2">MPR Minimum Flows</td><td></td></tr>
<tr><td>02296750 Peace River at Arcadia FL</td><td></td><td rowspan="3">LPR Minimum Flows</td></tr>
<tr><td>02297310 Horse Creek near Arcadia FL</td><td></td><td></td></tr>
<tr><td>02297100 Joshua Creek at Nocatee FL</td><td></td><td></td></tr>
</table>

2.2.5 P-11 Structure Discharge Rating Curve

Rating curves for predicting discharge from the P-11 control structure as a function of Lake Hancock stage recorded upstream of the structure were developed using historical flow records from the discontinued USGS gaging station Saddle Creek at Structure P-11 Near Bartow FL collected prior to July 2, 2013. The rating curves (Figure 9, Table 2) were developed to be used as a basis for comparing lake stage alternations and resulting flows.

An original piecewise linear regression (shown using blue triangle symbols in Figure 9), comprised of a three-part function representing varying relationships between flows and three ranges of lake stage, was developed in 2013 (Harry Downing, personal communication) using data collected prior to replacement of the current P-11 structure. This regression was developed to represent generated flood releases during the period when P-11 was not operated for minimum flow recovery in the UPR. The first part of this regression is simply a curve fit through the stage and discharge data from 98.5 ft-NGVD to an inflection in the relationship that occurs at 98.7 ft-NGVD, the elevation associated with the top of the former P-11 structure. The second part of the regression reflects the linear relationship between lake stage and P-11 flows that occurs for high flows at stages greater than 98.7 ft-NGVD but less than 101.2 ft-NGVD. The last part reflects the relationship for very high discharges that occur in association with lake stages greater than 101.2 ft-NGVD.

As illustrated in Figure 9, varying stage conditions often exist for a given flow rate due to backwater effects and other hydrodynamic factors such as sediment and debris loads. In addition, District operation of the structure depended on both lake stage and perceived inflow rates and influenced the flow-stage relationship. For example, during the wet season when lake levels were high, the structure was typically opened to discharge at greater rates in response to heavy downpours versus light rainfall conditions. An underlying assumption for the original regression is that average daily outfall at the P-11 structure can be estimated using average daily lake stage, with consideration that Lake Hancock is a large lake and change in lake stage in a given day is expected to be small.

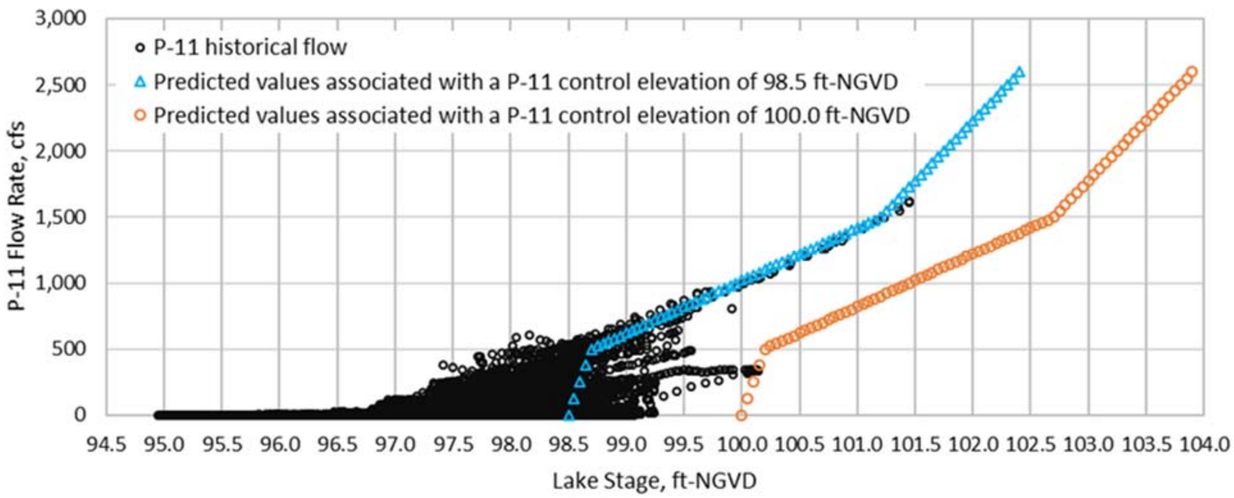


Figure 9. Recroded and regressed P-11 control structure flow versus Lake Hancock stage

Table 2. Summary of piecewise regression equations for estimation of P-11 control structure flows (Q in cfs) using Lake Hancock stage (S in ft-NGVD) *

Lake Stage	P-11 Flow Equations Associated with a P-11 Control Elevation of 98.5 Ft-NGVD	Lake Stage	P-11 Flow Equations Associated with a P-11 Control Elevation of 100.0 Ft-NGVD
S ≤ 98.7	Q = 2500*S - 246250	S ≤ 100.2	Q = 2500*S - 250000
98.7 < S ≤ 101.2	Q = 400*S - 38980	100.2 < S ≤ 102.7	Q = 400*S - 39580
101.2 < S ≤ 102.4	Q = 913.29*S - 90925	102.7 < S ≤ 103.9	Q = 913.29*S - 92295

** Equations fitted using lake stages and corresponding predicted flows provided by Harry Downing (July 2, 2013)*

Based on the original regression, a second rating curve (shown using golden circle symbols in Figure 9) was developed by simply shifting lake stage values used in the original regression by 1.5 ft, to account for the 1.5-ft difference between structure control elevation of 98.5 and 100 ft-NGVD with anticipation that downstream releases beyond the control elevation would be similar to the previous operation of the structure and not to cause increased downstream flooding. The 100 ft-NGVD elevation was selected for the second regression to support analyses based on the 100 ft-NGVD control elevation associated with the current P-11 structure.

It should be emphasized that improvement of UPR flow conditions to support minimum flow achievement is an important driver for operation of the current P-11 structure. Structure operation when lake stages between 97.6 ft and 100 ft may therefore be expected during the dry season to assist in meeting projected downstream flow needs. Operation under such conditions is determined by a combination of downstream flow demand and allowable lake storage that can be released through weir gates as discussed in Section 2.2.6.

2.2.6 P-11 Structure Weir Equation

There are two sets of gates, as described in Section 2.2.1, for the new, i.e., existing P-11 structure. One set, consisting of two weir gates in the westernmost of the three structure bays, is designed primarily for routine use, for example for the purpose of UPR minimum flows recovery. The other set, comprised of the roller gates in the other two structure bays, is designed primarily for flood protection purposes, when large flow releases are needed to lower lake levels. Because the two large roller gates are rarely used, releases for minimum flows were typically determined based on routine use of the two weir gates.

A sharp-crested weir equation (Equation 5) similar to the 1883 Francis' standard contracted rectangular weir equation, provided by Trihedral, Inc. (email communication on July 24, 2014), was applied in this investigation to estimate the weir flow through the weir gates or the gate heights for desired flow releases to meet downstream flow requirements.

$$Q = C*(L - 0.2*H) * H^{3/2} \qquad \text{(Equation 5)}$$

where Q is the discharge in ft^3/s, C is the weir coefficient with a constant value of 3.36, L the length or width of weir in feet and H is the hydraulic head on the weir in feet, which is the difference between the lake stage and current gate top elevation.

2.2.7 Lake Surface Area and Volume versus Lake Stage

As part of the Lake Hancock Lake Level Modification Project, Light Detection and Ranging Data (LiDAR) data were collected by EarthData International, LLC (2005) and surveyed spot elevation data were collected from inundated lake areas with a survey grade fathometer and digital global positioning system equipment (Pickett & Associates 2004), both datasets were combined to create a digital elevation model (DEM).

A 2-ft interval contour map with additional contour lines at 97.6 and 98.5 ft-NGVD was prepared using the DEM for the lake and its adjacent lakeshore area with surface elevations ranging from 92 to 120 ft-NGVD (Figure 10). Basin slopes are relatively steep along the western shore of the lake and more gradual along the northern and eastern shores. A 5-ft deep trough lies about 500 to 1,500 ft from the western shore, which is probably the submerged stream channel of Saddle Creek (Hammett et al. 1981). At the lake stage of 97.6 ft-NGVD associated with the adopted Minimum Lake Level and indicated by the black contour line in Figure 10, the lake covers a surface area about 4,508 acres (Figure 11). At the lake stage of 98.5 ft-NGVD, the lake surface expands mostly in the northwest and southeast directions and increases by about 10.6% or 478 acres (Figure 11). When the lake level rises to 100 ft-NGVD, the water surface area would increase significantly by about 47.5% or 2,142 acres relative to the surface area associated with the Minimum Lake Level (Figures 10 and 11). These areal increases occur mostly in the northwestern shore along the Banana Creek, Upper Saddle Creek and along the eastern lakeshore (Figure 10).

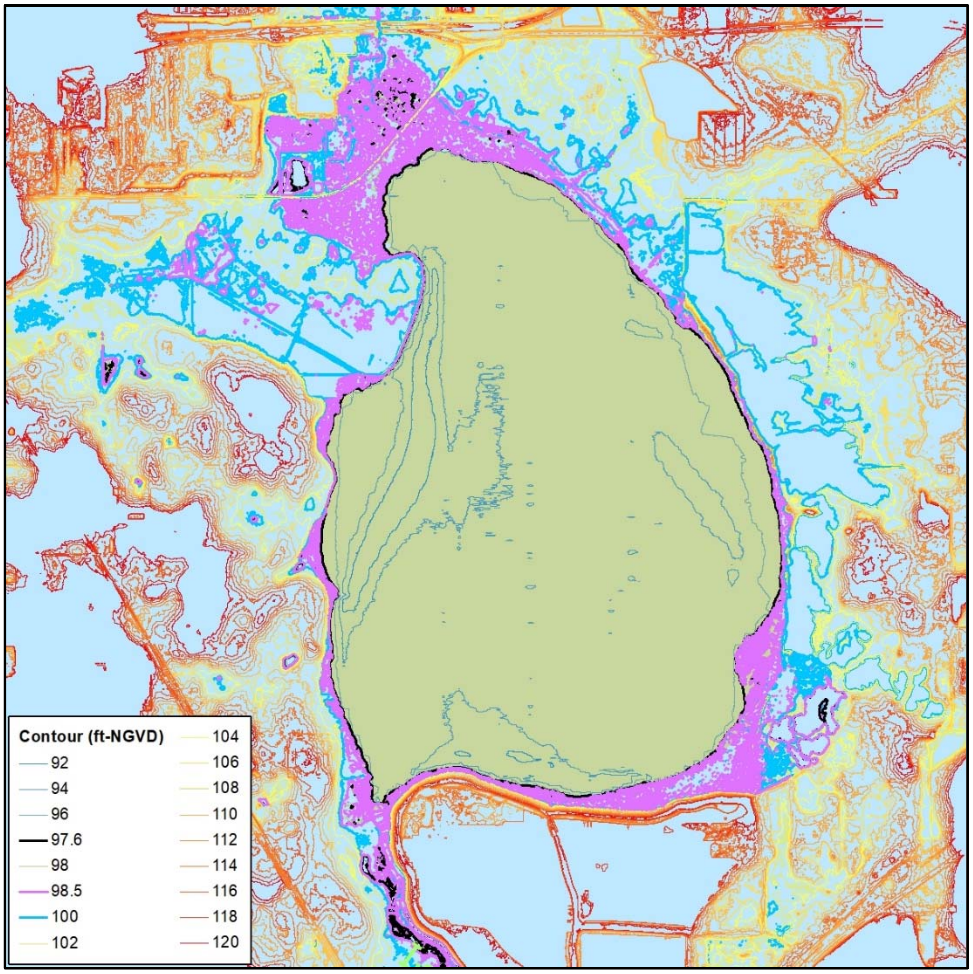


Figure 10. Contour map of lake bathymetry for Lake Hancock

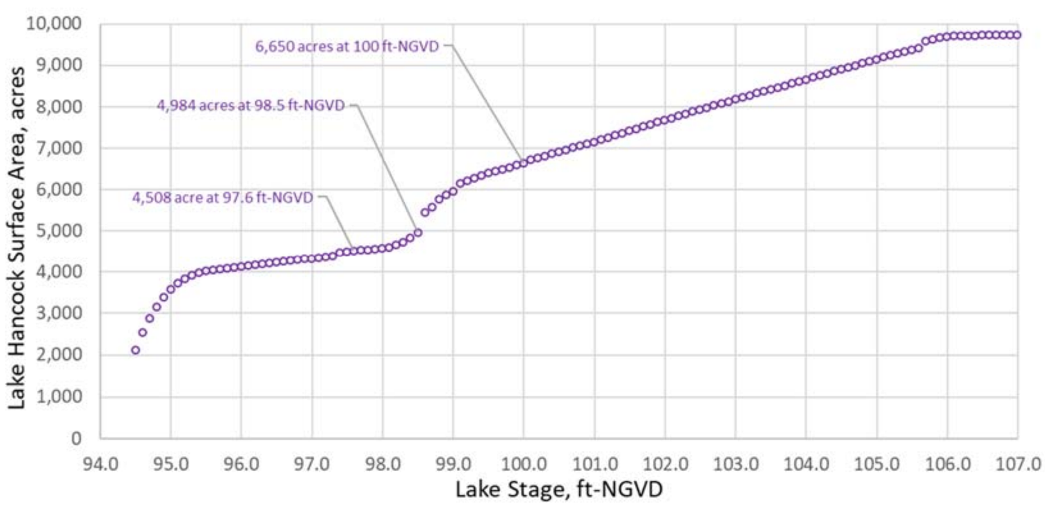


Figure 11. Lake Hancock water surface area versus lake stage

The increased shoreline and water surface areas resulted from lake level modification will alter the hydrologic regime of Lake Hancock and its fringe wetlands. BCI (2006a, c) assessed wetland function under pre- and post-lake level modification conditions in support of the District's application for a CERP to modify the lake levels and concluded that the water regime resulted from the lake level modification will enhance wetland function by providing high water level pulses and greater water level fluctuation that will seasonally interconnect various aquatic and wetland habitats to benefit a wide variety of wetland dependent wildlife.

To estimate lake water storage for a given lake surface water elevation, a relationship between lake volume and stage is required. Such a relationship was established for Lake Hancock using the DEM derived from LiDAR and bathymetry to calculate cumulative lake water volumes (cubic feet) corresponding to lake surface water elevations ranging from 94.5 to 107 ft-NGVD (see Figure 12) with the ArcHydro tool in ArcGIS, then using a quadratic regression equation to provide a strong fit between lake volume and lake surface water elevation with a coefficient of determination (R-squared) value close to 1. Based on the regression, lake volume, V, can be estimated using Equation 6 for any given lake stage, S, within the range from 94.5 to 107 ft-NGVD:

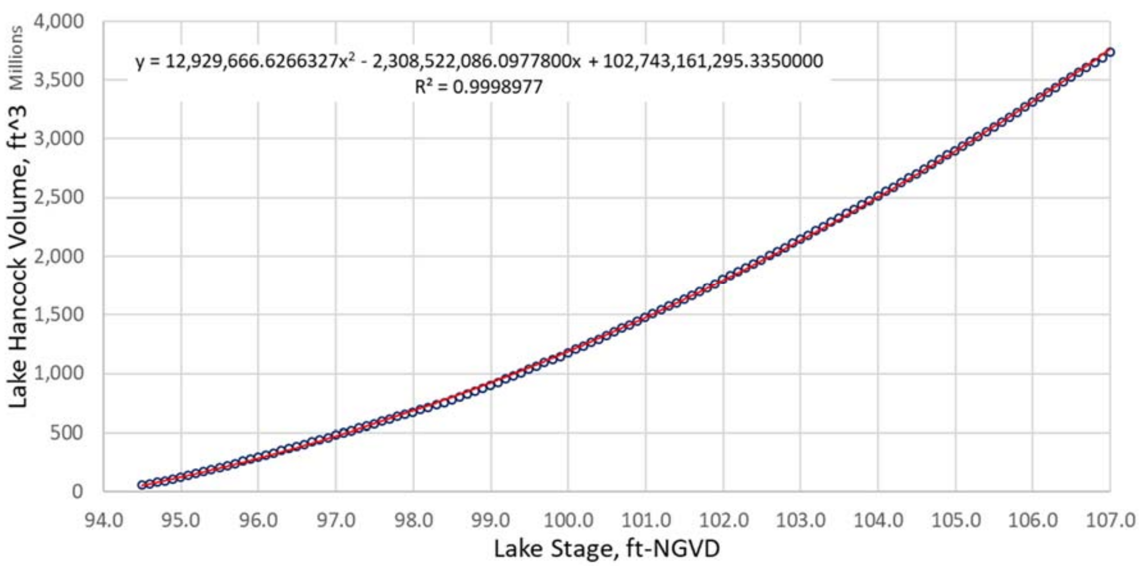


Figure 12. Lake Hancock volume versus surface water elevation

$$V = a*S^2 + b*S + c \qquad \text{(Equation 6)}$$

where a, b and c are regression coefficients,

a = 12,929,666.6266327

b = - 2,308,522,086.09778, and

c = 102,743,161,295.335

The change in lake storage can thus be estimated between two lake stages. By solving the quadratic Equation 6, lake stage can be estimated for a given lake volume using Equation 7:

$$S = (-b + (b^2 - 4a*(c - V))^{1/2})/(2*a) \qquad \text{(Equation 7)}$$

2.2.8 City of Lakeland Wastewater Treatment Effluent

Lake Hancock had been heavily impacted by human activities, including domestic and industrial wastewater treatment plant discharges (Harper et al. 1999). Several point-source discharges previously contributed a significant portion of the inflows to the lake. One significant source that has been discontinued is effluent from the City of Lakeland Wastewater Treatment Plant. Others, including two citrus processing plants and a distillery in Auburndale previously discharged effluent into Lake Lena Run (Harper et al. 1999), which is one of major tributaries of the lake, as discussed in Section 2.1.

From 1926 through April 1987, the City of Lakeland Wastewater Treatment Plant discharged effluent through Stahl Canal to Banana Lake, which drains through Banana Creek to Lake Hancock (see Figure 7) (Harper et al. 1999). The average discharge rate from January 1975 to April 1987 was nearly 10 cfs, accounting for about 20% of the average Lake Hancock outflow of about 52 cfs prior to April 1987.

Because this treated-wastewater effluent historically delivered to Lake Hancock represented a significant point source of flow, it was removed from the lake inflow records to better assess effects of the LHR on minimum flow recovery and Peace River flows and withdrawals under current conditions that do not include delivery of the effluent to the lake. Reported monthly averaged discharges from the City of Lakeland Wastewater Treatment Plant were removed on daily basis in the water budget model during the period of effluent discharge.

However, limited by data availability, no adjustments for inflow changes from Lake Lena Run that may have occurred as a result in changes in effluent discharges from the citrus plants and distillery in Auburndale were made for the water budget model.

2.2.9 Sink Loss

Based on the additional 90-square mile drainage area that contributes flow to the Peace River between Bartow and Fort Meade, flows greater than those historically reported at the Fort Meade gage site may reasonably be expected. However, streamflow losses occur between these two locations (see Figure 2), predominantly through karst features found in the low-water channel and the floodplain (Lewelling, et al. 1998, USGS 2004, Metz and Lewelling 2009).

Basso (2004) concludes the 1% exceedance of streamflow loss between Bartow and Fort Meade is 25 cfs, based on evaluation of flow data from 1975 through 2003. BCI (2006b) evaluated flow difference between Bartow and Fort Meade for flows of less than 30 cfs at Fort Meade and concludes that 25 cfs is a reasonable estimate of typical sink losses for that portion of the UPR under relatively low-flow conditions. The USGS (2004) reports measured stream losses did not exceed 30 cfs during the dry seasons of late spring 2002 and 2003. Metz and Lewelling (2009) report the largest measured flow loss for all karst features between Bartow and Fort Meade during a five-year period (water years 2002 through 2007) was about 50 cfs on June 28, 2002.

A scatter plot of flow differences between Bartow and Fort Meade versus flows less than 30-cfs at Fort Meade for the analysis period used in this current investigation of LHR impacts shows most of the differences are 25 cfs or less (Figure 13). Streamflow loss for the UPR can be expected to affect minimum flow recovery in the river segment and should be considered in the water budget to provide an accurate estimate of anticipated augmentation quantities necessary to overcome losses between Bartow and Fort Meade. Accordingly, based on observed and reported information, a 25-cfs flow rate was identified as a reasonable estimate of daily maximum sink loss in the Peace River between the Bartow and Fort Meade USGS gages.

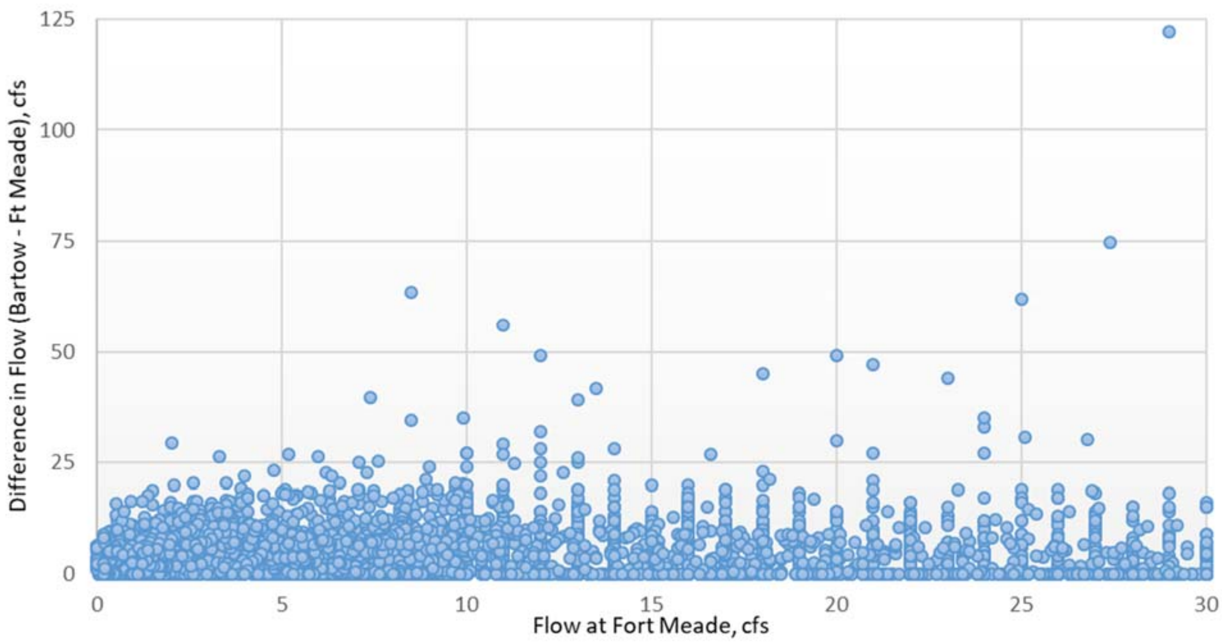


Figure 13. Flow difference between Fort Meade and Bartow versus flow less than 30-cfs at Fort Meade for the 1975 through 2012 period used for this study; note negative differences are not shown

2.2.10 Peace Creek Canal Flow

The Peace Creek watershed, located in northeastern Polk County (see Figure 1), is part of the headwaters of the Peace River and encompasses a drainage area of about 234 square miles. Drainage from the Peace Creek watershed through the Peace Creek Canal provides significant surface water flows to the UPR at the downstream watershed boundary, i.e., at the confluence of the Peace Creek Canal with Lower Saddle Creek.

The most downstream gaging station on the Peace Creek Canal is the USGS 02294161 Peace Creek near Bartow FL gage, located approximately 1.7 miles upstream from the confluence of the Peace Creek Canal and Lower Saddle Creek. Comparing data for this gage with others provides some insight on the respective contribution of the gaged watersheds to flows in the Peace River. Based in part on its relatively larger drainage area, the Peace Creek watershed contributes approximately 43% of the surface water flow to the UPR measured at Bartow, while the Saddle Creek watershed, based on flows gaged near the outlet of Lake Hancock, contributes approximately 35% of the flows in the UPR. This information highlights how changes in flows in either the Peace Creek Canal or Saddle Creek could potentially impact flows in the Peace River. For the current LHR investigation, it was assumed that hydrologic conditions in the Peace Creek Canal would be similar to those that occurred during the analysis period.

Table 3. Summary of drainage area and average flow rate for the selected USGS gage locations on Lower Saddle Creek, Peace Creek Canal and the Peace River for the period from 1975 through 2012*

USGS Site Name	Drainage Area ($mile^2$)	Average Flow (cfs)
02294491 Saddle Creek at Structure P-11 near Bartow FL	135	58
02294161 Peace Creek near Bartow FL	205	71
02294650 Peace River at SR 60 at Bartow FL	390	163

** Drainage area is extracted from the corresponding USGS site information; the period of record for Site 02294161, Peace Creek near Bartow, FL, is only available from July 8, 2005.*

2.3 Water Budget Model Development and Routing

Microsoft® Excel was used as a modeling environment to perform the water budget analysis. For a period from June 1, 1974 through December 31, 2012, historical, daily lake stages and discharges through the P-11 structure, and stream flows at downstream USGS gaging stations on the Peace River at Bartow, Fort Meade, Zolfo Springs and Arcadia were acquired and compiled into one spreadsheet. Data for the first half-year, from June 1, 1974 through December 31, 1974, were used primarily for model warm-up.

Selected progressive model scenarios developed in this investigation and relevant data and model setup are generally discussed in Section 2.3.1, followed by a detailed discussion of individual model setup or adjustment in Sections 2.3.2 through 2.3.6. Section 2.3.7 provides a description of a complete modeling process in a sequential manner.

2.3.1 Model Scenarios

Using the water budget model described in Section 2.1, four progressive model scenarios were selected and analyzed to gain insight on the effects of LHR under different operation schedules and with consideration of minimum flows recovery needs and sink loss. The four scenarios (with abbreviated scenario names in parentheses) used for presentation and discussion of model results were:

1) Historical Baseline (**Baseline**), for which the operation schedule involved holding the P-11 control structure at 98.5 ft-NGVD. Releases occurred only when the lake level exceeded this elevation. This scenario was created to represent the structure condition prior to the P-11 structure replacement, as discussed in Section 2.3.2, for comparison with three post P-11 structure modification scenarios.

2) Existing Control Level (**ECL**), for which the operation schedule involved holding the P-11 control structure at 100 ft-NGVD. Releases occurred only when lake levels exceeded this elevation.

3) ECL with operation for meeting MFLs in the UPR (**ECL+MFLs**), for which the operation schedule involved releasing flow through P-11 when UPR minimum flows recovery was needed. If no downstream minimum flows were needed, the P-11 structure was held at 100 ft-NGVD and overflows would occur over the top of weirs when lake levels exceeded 100-ft NGVD.

4) ECL with operation for meeting MFLs and overcoming sink loss in the UPR (**ECL+MFLs+SL**), for which the operation schedule involved releasing flow through P-11 when downstream flow augmentation was needed for minimum flows recovery and to compensate for sink loss between Bartow and Fort Meade. If no downstream flows were needed, the P-11 structure was held at 100 ft-NGVD and overflows occurred when lake level exceeded 100-ft NGVD.

The ECL+MFLs+SL scenario is considered representative of the District's current understanding of hydrologic conditions in the UPR and operational protocols for the P-11 structure. The scenario is, therefore, particularly useful for supporting development of the LHR. The other three scenarios are useful for assessing or comparing conditions associated with lake releases and downstream hydrologic responses under historical and alternative operational protocols.

For the Baseline scenario, historical data, including lake stages, discharges through P-11 and wastewater treatment effluent discharge were required to calculate the effective inflows with removal of the effluent discharge (or adjusted effective inflow). This information was subsequently used to estimate the P-11 outflow and change in outflow for the Baseline scenario as detailed in Section 2.3.2.

Once the Baseline scenario was developed, the effective inflows needed to be recalculated to reflect the P-11 discharge in the Baseline scenario and be used as the net inflows for the other three scenarios (i.e., for the ECL, ECL+MFLs and ECL+MFLs+SL scenarios). Differences among the four scenarios are related to the effective inflow, rating curve and flow adjustments.

The P-11 discharge rating curve associated with the control elevation of 98.5 ft-NGVD was used for the Baseline scenario and the curve associated with the control elevation of

100 ft-NGVD was used for the other three scenarios. The use of rating curves is essential for estimating flow from the lake under high flow conditions, when lake stages exceed the normal operating level or crest of weir gates (i.e., 98.5 or 100 ft-NGVD).

However, for the two scenarios associated with MFLs and or sink loss, when lake stages fall below 100 ft-NGVD while still above the Minimum Lake Level of 97.6 ft-NGVD, flow releases were determined by assessing downstream flow needs and lake storage availability. The storage availability, expressed as a flow rate, was calculated using weir equation as a function of hydraulic head as discussed in Section 2.2.6. More specifically, the flow release was determined as the minimum of the downstream demand and lake storage availability.

2.3.2 Adjustments for Historical Baseline Condition

Initial hydrologic data adjustments included subtraction of the City of Lakeland Wastewater Treatment Plant daily discharges from the lake's effective inflow. This was achieved by first calculating the lake's effective inflow as a sum of the change in lake storage and the historical P-11 discharge, then subtracting the wastewater discharge. The resultant time series was considered the adjusted effective inflow to the lake.

Although the former P-11 structure had a crest elevation of 98.7 ft-NGVD and a normal operating level of 98.5 ft-NGVD, recorded flow releases occurred at various lake levels indicate the operating level was not always consistently adhered to. Considering that minimum flows and levels were adopted for the UPR and Lake Hancock in 2007 and 2017, respectively, and that the minimum levels adopted for the lake replaced formerly adopted lake guidance levels, it is reasonable to infer during most of the analysis period used for this LHR investigation the former P-11 structure was not operated to assist in meeting minimum flows established for the UPR.

Creating a historical Baseline condition associated with the former P-11 structure was, however, considered necessary for the LHR analyses. For this effort, the 98.5 ft-NGVD normal pool elevation developed to support adoption of minimum levels for Lake Hancock, was identified as a desired elevation to be maintained before the former P-11 structure was replaced. Assuming no flow was released when lake stage was below 98.5 ft-NGVD and releases only occurred when lake stage was above 98.5 ft-NGVD, a historical Baseline condition was established, with flow releases estimated using the rating curve associated with the 98.5 ft-NGVD control elevation presented in Figure 9 and Table 2 and discussed within Section 2.2.5. In addition, the lake storage for the current day could be calculated based on the lake storage for the previous day, the effective inflow and outflow for the current day, and the lake stage could be subsequently estimated using the relationship discussed in Section 2.2.7. The resultant historical Baseline condition did not incorporate releases for UPR minimum flow recovery and was primarily developed to represent conditions prior to the P-11 structure replacement.

2.3.3 Adjustments for the Minimum Lake Level

The adopted minimum lake level for Lake Hancock is 97.6 ft-NGVD (Leeper and Ellison, 2017). Flow releases through P-11 were terminated when the lake stage dropped to this elevation or below, regardless of the downstream flow augmentation needs. However, hydrologic processes, such as evapotranspiration and groundwater seepage from the lake could cause lake levels to fall below the adopted minimum level elevation. These conditions are considered acceptable and representative of the lake's natural hydrologic cycle.

2.3.4 Adjustments for the Daily Minimum Flow Requirement

During dry season, daily P-11 flow releases were primarily driven by the largest flow deficit among the three UPR minimum flows sites (if not considering sink loss, as discussed in Section 2.3.5), i.e., the USGS gage sites at Bartow, Fort Meade and Zolfo Springs. The flow deficit was determined for each site as the difference between the established minimum low flow threshold and the adjusted observed daily average flow at the gage. If the deficit was less than zero, meaning the flow at the gage was greater than the minimum low flow threshold, no release was necessary for meeting the minimum flow at the site. If the deficits for all three UPR minimum flows sites were zero, then no flow release at P-11 was necessary. Otherwise, the largest of the three deficits, limited by lake storage, determined how much flow release should be made at P-11 to support minimum flow recovery.

If lake stage exceeded the P-11 structure control level, overflow would occur and was estimated using the rating curves described in Section 2.2.5. This situation typically occurred during the wet season when the lake was full and was not associated with minimum flow releases. Curve selection for outflow estimation was based on the P-11 control elevation appropriate for the simulation. Modeling associated with the Baseline condition included use of the piece-wise regression (i.e., rating curve) associated with a control elevation of 98.5 ft-NGVD. Model simulations involving conditions associated with the current P-11 structure involved use of the regression associated with a control elevation of 100.0 ft-NGVD.

2.3.5 Adjustments for Sink Loss between Bartow and Fort Meade

Sink losses were evaluated with assumption that up to 25 cfs will be lost to the karst features between Bartow and Fort Meade, which are used to determine how much of the sink loss deficit must be made up by the P-11 flow releases to assure downstream flow conditions. The sink loss deficit ($Q_{deficit}$) was estimated based on the adjusted flow at Bartow (B_{adj}) as indicated below.

$$Q_{deficit} = 0 \quad \text{if } B_{adj} \geq 25$$
$$Q_{deficit} = 25 - B_{adj} \quad \text{if } B_{adj} < 25$$

(Equation 8; Bartow flow-specific equations)

If the adjusted flow at Bartow was 25 cfs or greater, flow in the river was considered adequate to meet the minimum low flow threshold of 17 cfs at Bartow and the sink loss between Bartow and Fort Meade. The flow release from Lake Hancock to overcome sink loss would then be zero. However, if the adjusted flow at Bartow was less than 25 cfs, then the release from the lake to address the sink loss deficit would be the difference between 25 cfs and the adjusted flow at Bartow. As an extreme example, at an adjusted flow of 0 cfs at Fort Meade, 52 cfs would need to be released from Lake Hancock to account for the 27 cfs flow threshold requirement at Fort Meade plus a 25-cfs sink loss deficit.

2.3.6 Adjutsments for Operation Schedule

Change in P-11 structure outflows to Lower Saddle Creek can affect flows at downstream locations on the Peace River, given that the river originates at the confluence of Lower Saddle Creek and the Peace Creek Canal. The difference between the observed P-11 discharge (O_{obs}) and projected (O_{prj}) was used to adjust the downstream flows in the river:

$$\Delta O = O_{obs} - O_{prj} \quad \text{(Equation 9)}$$

where O_{obs} is historical P-11 discharge and O_{prj} is estimated using the rating curve associated with the 98.5 ft-NGVD control elevation for the Baseline scenario. The projected P-11 flow for the Baseline scenario is then used as O_{obs} for the other scenarios associated with the existing structure (i.e., ECL, ECL+MFLs and ECL+MFLs+SL). O_{prj} for these scenarios is estimated using the rating curve associated with the 100.0 ft-NGVD control elevation when lake stage exceeds 100 ft or, depending on model scenario under consideration, release driven by downstream flow needs and lake storage availability.

Flows at the downstream USGS Bartow (B), Fort Meade (F), Zolfo Springs (Z) and Arcadia (A) gages were then decreased by ΔO but limited to a value greater than or equal to zero. For example, if ΔO = 20 cfs and B = 15 cfs, then B_{adj} = 15 - 20 = -5 cfs, which would be set to zero. The underlying assumption for such adjustment is that the decrease or increase in flows through the structure P-11 results in a corresponding change in flows at the downstream gages on the same day although the reality of time-lag effects exists for the flow changes.

In addition, if the adjusted upstream gage flow becomes zero, the flow amount at the upstream gage should be deducted from the adjacent downstream gage to assure mass balance. For example, if ΔO = 20 cfs, B = 15 cfs, F = 25 cfs, then B_{adj} = -5 cfs, which would be set to zero and F_{adj} = 25 - 15 = 10 cfs. The adjusted flow at the Bartow, Fort Meade, Zolfo Springs, and Arcadia gages (B_{adj}, F_{adj}, Z_{adj} and A_{adj}, respectively) can be expressed with the following equations:

$$B_{adj} = B - \Delta O \quad \text{if } B > \Delta O \quad \text{(Equation 10; site-specific gage equation sets)}$$
$$B_{adj} = 0 \quad \text{if } B \le \Delta O$$

$$F_{adj} = F - \Delta O \quad \text{if } F > \Delta O \text{ and } B > \Delta O$$

$F_{adj} = F - B$ if $F > \Delta O$ and $B \leq \Delta O$
$F_{adj} = 0$ if $F \leq \Delta O$ or $F_{adj} < 0$

$Z_{adj} = Z - \Delta O$ if $Z > \Delta O$ and $F > \Delta O$
$Z_{adj} = Z - F$ if $Z > \Delta O$ and $F \leq \Delta O$
$Z_{adj} = 0$ if $Z \leq \Delta O$ or $Z_{adj} < 0$

$A_{adj} = A - \Delta O$ if $A > \Delta O$ and $Z > \Delta O$
$A_{adj} = A - Z$ if $A > \Delta O$ and $Z \leq \Delta O$
$A_{adj} = 0$ if $A \leq \Delta O$ or $A_{adj} < 0$

2.3.7 Lake Hancock Water Budget Routing

The adjusted effective inflows and releases from Lake Hancock through the P-11 structure were analyzed with respect to the LHR, i.e., the retaining of inflows for storage and subsequent release to support minimum flow recovery in the UPR at Bartow, Fort Meade and Zolfo Springs. Adjustments discussed in Sections 2.3.2 through 2.3.6 were applied to daily hydrologic records and releases from the lake were determined based on rating curves or the identified maximum demand (i.e., downstream flow recovery need) and lake level conditions, e.g., water level relative to the adopted minimum lake level.

The water budget was assessed on a daily basis, i.e., using a daily time-step, and the resultant condition served as the starting condition for subsequent day in the simulation period. This routing continued until the end of analysis period. Projected flow time-series for the Peace River at the Bartow, Fort Meade, Zolfo Springs and Arcadia gages were produced and used for analyses discussed in Section 3.

Water budget calculations specific to Lake Hancock were initiated with the modified historical baseline series, the potential releases associated with downstream minimum flow recovery needed for the UPR (see Section 2.2.4) and sink loss requirements (see Section 2.2.5). Three water level regimes considered for the Lake Hancock system during the water budget processing were:

- Lake levels were below 97.6 ft-NGVD, and all inflows to the lake were retained regardless of the downstream river condition;
- Lake levels were between the operating levels of 97.6 ft-NGVD and 100 ft-NGVD, and P-11 releases were determined based on whether storage or UPR minimum flow releases were required; and
- Lake levels exceeded the operating level of 100 ft-NGVD, and P-11 releases were determined using the rating curve. Generally, this was considered a flood condition.

3. SIMULATIONS, RESULTS AND DISCUSSION

3.1 LAKE HANCOCK OUTFLOW

The LHR is the water temporarily stored in Lake Hancock and subsequently released to Lower Saddle Creek to support MFLs recovery in the UPR. Through operation of the P-11 control structure at the outlet of the lake, all or a portion of the daily effective inflow could be captured and stored in the lake. On a daily basis, the LHR is determined by multiple factors, including inflows to Lake Hancock, current lake storage, outflows from the lake, as well as downstream recovery needs.

Using the water budget model, effects of the LHR on the long-term outflow at P-11 to Lower Saddle Creek, and ultimately the Peace River could be quantified. As summarized in Table 4, the long-term average effective inflow to Lake Hancock (excluding the effluent from the City of Lakeland Wastewater Facility between 1975 to April 1987) and outflow from the lake for the assessment period from 1975 through 2012 are about 55 cfs.

For all assessed scenarios, more than half of the effective inflow was captured and temporally stored in the lake. On a day-by-day basis, the capture rate (i.e., the temporarily stored quantity relative to the effective inflow) varied from 0% (no capture) to 100% (full capture). As expected, average capture rates and the quantities temporarily stored in the lake were highest for the scenarios involving storage and release to support UPR minimum flow recovery, i.e., for the ECL+MFLs and ECL+MFLs+SL scenarios. The long-term average lake outflow via the P-11 structure is about the same as effective inflow (Table 4), indicating all effective inflows were eventually released downstream.

Table 4. Summary of effective inflow, quantity temporarily stored in Lake Hancock, the average capture rate and the outflow from the lake at the P-11 structure simulated for four scenarios for the period from 1975 through 2012

Scenario	*Effective Inflow (cfs)*	*Temporarily Stored (cfs)*	*Average Capture Rate (%)*	*Outflow (cfs)*
Baseline	54.94	33.35	60.7	54.92
ECL		30.90	56.2	54.93
ECL+MFLs		33.55	61.1	54.93
ECL+MFLs+SL		34.87	63.5	54.94

The concept of “Building Blocks” has been used for development of minimum flows for many river systems within the District (Kelly et al. 2005). The Building Blocks essentially correspond with seasonal, or flow-based portions of the flow regime, in which Blocks 1, 2 and 3, respectively, represent low, medium and high flow seasons or conditions. These seasonal blocks provided a basis for assessing outflows from the lake that may be expected under the scenarios assessed for the LHR analysis.

As indicated in Table 4 and shown graphically in Figure 14, no differences in the long-term average outflow at the P-11 structure relative to the Baseline scenario with the 98.5 ft-NGVD control elevation were identified for the scenarios associated with the existing

100 ft-NGVD structure control elevation (ECL, ECL+MFLs, ECL+MFLs+SL). However, the P-11 outflow increased in Blocks 1 and 2 (the low and medium-flow seasonal blocks), especially for the ECL+MFLs and ECL+MFLs+SL scenarios associated with UPR minimum flow recovery (Figure 14). During Block 1, P-11 outflows increased 45% and 64%, respectively for the two recovery-based scenarios. Outflow increases were more moderate during Block 2, medium flow season, with 9% and 12% increases simulated for the ECFL+MFLs and ECL+MFLs+SL scenarios, respectively. As expected, these scenarios were also associated with decreased outflow via the P-11 structure during Block 3, the high flow period when temporary storage would be increased to support subsequent release during the drier seasons or blocks.

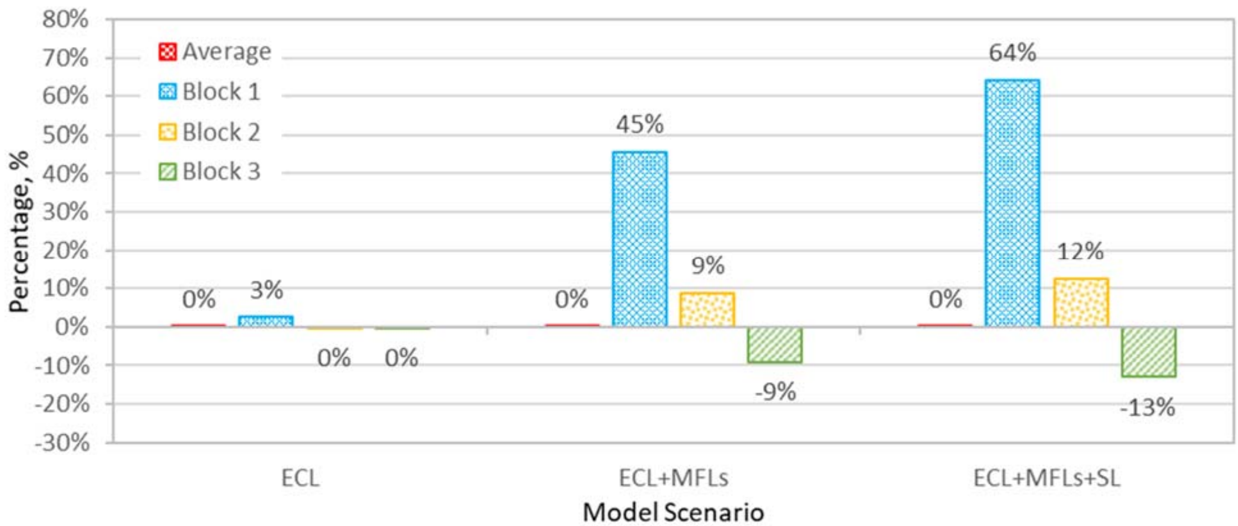


Figure 14. Changes in the average outflow and average outflow by seasonal block (Blocks 1, 2 and 3) through the Lake Hancock P-11 control structure for three modeled scenarios relative to the flows simulated for the Baseline scenario for the period 1975 through 2012

3.2 Flow Adjustments for Removal of Historical Wastewater Effluent and Structure Operation

Because of the removal of historical effluents from the City of Lakeland Wastewater Treatment Facility, and P-11 structure operations for the LHR in support of minimum flow recovery of the UPR, the projected outflows through P-11 are respectively reduced overall, and on a temporal basis relative to the historical flow condition. The reduction in P-11 outflows between the historical and projected conditions affects the downstream river flows as well. This means downstream historical flows should be adjusted for the purpose of mass balance to reflect the effect of the LHR and the removal of the City of Lakeland Wastewater Treatment Facility effluent. An assumption was made that the necessary flow adjustments would be made on the same day regardless of the downstream gage location on the Peace River. For example, a 5-cfs flow reduction at the P-11 structure would be applied from Bartow to Arcadia on the same day. By doing this, projected time series of flow records from historical could be obtained.

The required daily flow adjustment amounts varied for the simulation period. To gain some insight on the scale of the necessary adjustments on a long-term basis, the average flow adjustments for the USGS Peace River at Bartow, Fort Meade, Zolfo Springs and Arcadia gage sites, which are associated with adopted minimum flows for the river, were calculated for the assessment period (Table 5). The average flow adjustments for the Baseline, ECL and ECL+MFLs scenarios did not differ much at each respective gage site. However, the adjustments required for the Fort Meade, Zolfo Springs and Arcadia Gages were notably greater for the ECL+MFLs+SL scenario, which incorporated the effect of sink loss, because the three gages are located downstream of the major sink loss area between Bartow and Fort Meade.

Table 5. Average flow adjustments at the USGS gage site on the Peace River due to removal of the City of Lakeland Wastewater Treatment Facility effluent and structure operation simulated for four scenarios for the period from 1975 through 2012

Scenario	*Bartow (cfs)*	*Fort Meade(cfs)*	*Zolfo Springs (cfs)*	*Arcadia (cfs)*
Baseline	-2.99	-2.68	-2.72	-3.02
ECL	-2.98	-2.64	-2.69	-3.01
ECL+MFLs	-2.95	-2.60	-2.66	-3.00
ECL+MFLs+SL	-2.94	-5.12	-5.17	-5.58

The average quantity of historical wastewater effluent discharge is about 10 cfs over the period of data records as discussed in Section 2.2.8, which is equivalent to about 3.22 cfs over the 38-year analysis period. Flows at Bartow and Fort Meade historically benefited, i.e., were increased, more than those at further downstream sites because the effluent discharge is less than the sink loss between Bartow and Fort Meade. As indicated in Table 5, the flow adjustments vary by gage location on the Peace River, despite the same value of change in P-11 outflow being applied to each gage site on any given day. This variation is that on some days the projected change in P-11 outflow could be greater than downstream historical flow due to the timing lags and other factors. For example, if historically Bartow flow is 15 cfs and the projected outflow change at P-11 is 20 cfs, then a zero flow would be assigned to Bartow in the process of adjustment instead of -5 cfs. Subsequently, the 15 cfs at Bartow would be fully deducted from the adjacent downstream site at Fort Meade. This adjustment would also be propagated to each downstream site. The smaller absolute flow adjustment values listed in Table 5 may indicate more frequent occurrence of this situation than the relatively larger values for the associated site.

The removal of historical wastewater effluent caused an overall reduction in downstream historical flow as seen in Table 5, and this effect was much greater than the flow reductions associated with structure operations. Nevertheless, the flow adjustments for the historical wastewater effluent discharge described here were necessary for projection of current and future flow conditions in the Peace River and should also be made for similar analyses for the Peace River system that incorporate historical flow data. These types of flow adjustments are not, however, necessary for use of flow records measured after construction of the current P-11 structure was completed.

3.3 Lake Hancock Minimum Levels

Minimum levels were adopted into District rules for Lake Hancock and became effective in November 2016, replacing guidance levels previously adopted for the lake (Leeper and Ellison 2017). The adopted minimum levels include a Minimum Lake Level of 97.6 ft-NGVD and a High Minimum Lake Level of 98.8 ft-NGVD that must, respectively, be equaled or exceeded fifty and ten percent of the time on a long-term basis. The minimum levels were developed using current District methods for establishing minimum levels for Category 2 Lakes, which are lakes contiguous with at least 0.5 acres of cypress-dominated wetlands where structural alterations have substantially affected water levels. The minimum levels were based on lake level conditions that existed prior to the replacement of the previous P-11 control structure with the current structure.

To assess the effect of the various modeled scenarios on the status of the minimum levels adopted for Lake Hancock, historical and projected lake stage duration curves (Figure 15) were prepared for comparison against regulatory levels, and tenth and fiftieth exceedance percentiles were calculated for projected lake stages for comparison with the adopted minimum levels (Table 6). The comparisons indicate the scenarios associated with use of the existing, modified P-11 control structure (i.e., the ECL, ECL+MFLs and ECL+MFLs+SL scenarios) should support achievement of the adopted minimum lake levels. For example, the lake level at 50% exceedance for all scenarios are at least 0.7 ft greater than the adopted Minimum Lake Level of 97.6 ft-NGVD.

Table 6. Comparison of Lake Hancock minimum levels and lake stage exceedance percentiles simulated for four model scenarios

Adopted Minimum Levels[a]	Adopted Elevation	Exceedance Percentile[b]	Water Surface Elevations for Model Scenarios			
			Baseline	*ECL*	*ECL+MFLs*	*ECL+MFLs+SL*
High Minimum Lake Level	98.8	10%	98.6	100.1	100.1	100.1
Minimum Lake Level	97.6	50%	98.3	99.8	99.7	99.6

[a] All levels and water surface elevations are in ft-NGVD. [b] Lake stage exceedance percentiles are required on a long-term basis for the adopted minimum levels and are associated with elevations listed for the model scenarios.

Figure 16 illustrates projected lake water levels for the Baseline scenario associated with the 98.5 ft-NGVD control elevation associated with the previous P-11 structure and water levels projected for the ECL+MFLs+SL scenario that correspond to operation of the current P-11 structure with a control elevation of 100.0 ft-NGVD to support UPR recovery while accounting for sink loss deficits. Improved likelihood of achieving the minimum levels adopted for Lake Hancock under the ECL+MFLs+SL scenario is evident in the elevated hydrograph for the scenario (Figure 16).

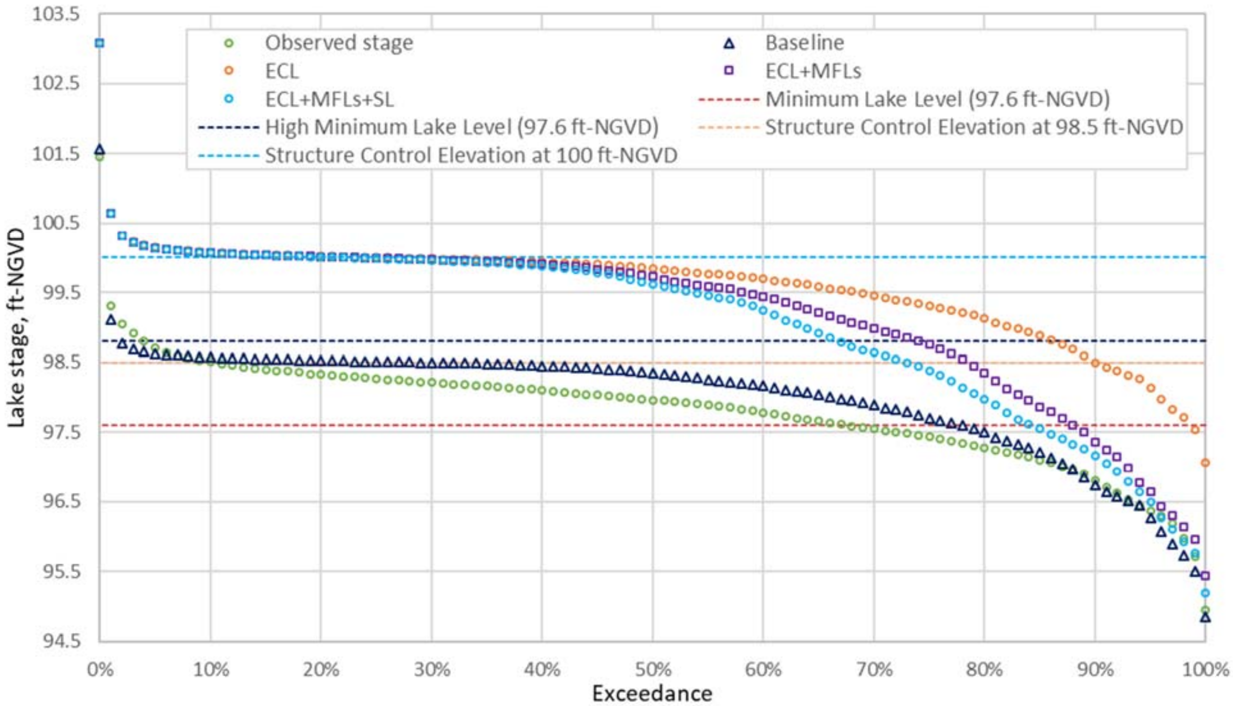


Figure 15. Lake Hancock stage duration curves associated with structure P-11 operating scearios and adopted lake minimum levels

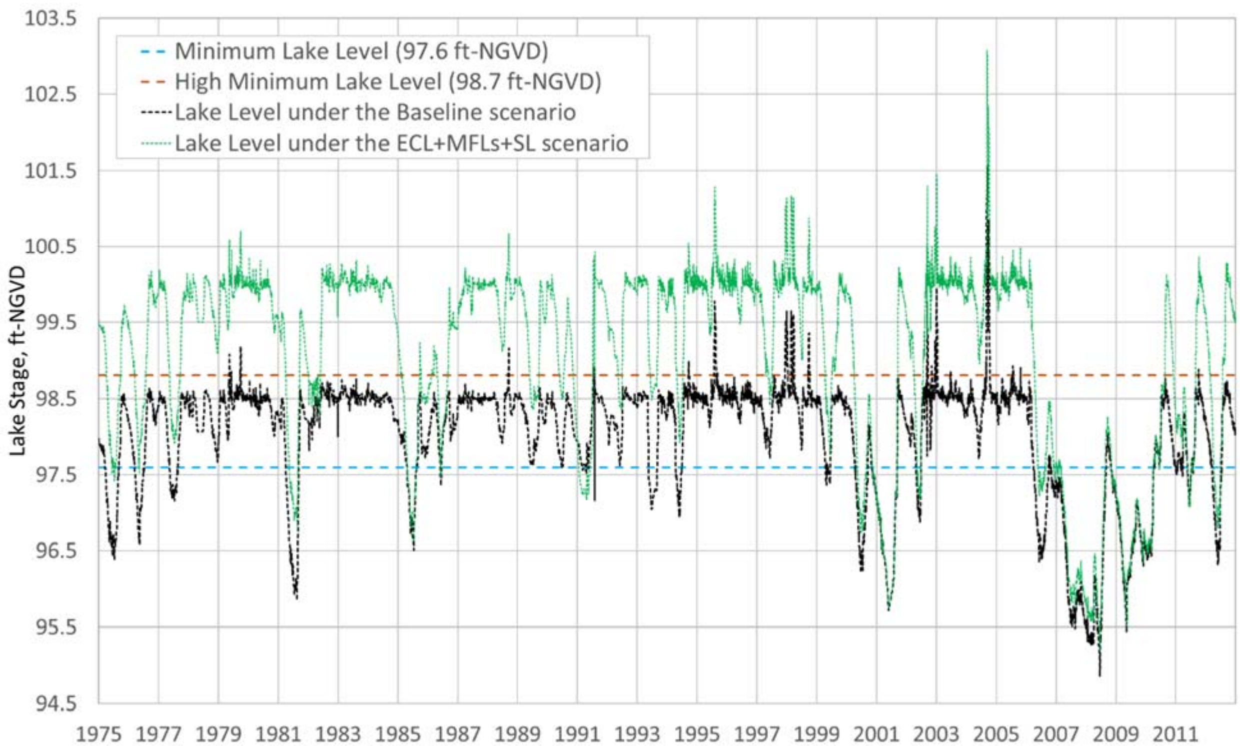


Figure 16. Adopted minimum levels for Lake Hancock and simulated water levels for the Baseline and ECL+MFLs+SL scenarios for the period from 1975 through 2012

3.4 Minimum Flow Recovery in the Upper Peace River

The major purpose of LHR is to restore the adopted minimum flows in the UPR. Although only minimum low flows have been established for the UPR, it is anticipated that minimum flows associated with medium and high flow ranges will be developed for the UPR as part of the reevaluation of the UPR minimum flows that is currently scheduled for 2025.

The established UPR minimum low flows were based on the lowest acceptable flow under the lowest anticipated flow conditions to maintain water surface elevations necessary for maintaining a 0.6-ft fish passage depth or the lowest wetted perimeter inflection point in each of the three UPR segments. A 95% annual exceedance occurs when the flow is greater than the minimum low flows at least 95% of the days of a calendar year.

Based on the compliance requirement for the UPR (Rule 40D-D.041(7)(d), F.A.C.; Appendix C), the minimum flows established at the Bartow, Fort Meade and Zolfo Springs gage sites are each achieved when the 95% annual exceedance flow is at or above the respective, rule-specified minimum flow rate for three consecutive years. Once the minimum flow at a site has been achieved for three consecutive years, the minimum flow is not met when the 95% annual exceedance flow rate is below the minimum flow rate for two out of ten years commencing the year after achievement. If the two years below the minimum flow occur any time before the ten-year period is complete, the UPR is deemed below its minimum flows and the three consecutive years above the minimum flow rates is again required for compliance. Once the ten-year period is complete, the period will roll forward one year each year.

Investigation of historical flow records at Bartow, Fort Meade and Zolfo Springs indicated that the minimum flows were not met in the UPR for many years during the 1975 through 2012 period assessed for the LHR analyses. Compliance at the Fort Meade site was the poorest; minimum flows established for the site were only met for 3 years in the 38-year assessment period. Minimum flows at Bartow and Zolfo Springs were, respectively, met 9 and 27 years (Table 7).

The number of days the flow threshold associated with the UPR minimum flows were met (MFLs Flow Days Met) and the number of years the 95% exceedance flows associated with the UPR minimum flows were met (MFLs Flow Years Met) were compared among the model scenarios and historical conditions at the Bartow, Fort Meade and Zolfo Springs gage sites. In contrast with historical conditions, i.e., unadjusted, measured flows at the gage sites, the MFLs Flow Days Met were reduced for the Baseline and ECL scenarios, primarily as a result of removal of the effluent discharges from the City of Lakeland Wastewater Treatment Facility. Differences in the MFLs Flow Days Met for the Baseline and ECL scenarios were minor and the number of MFLs Flow Years Met for the three UPR gage sites did not differ between the two scenarios. These results indicate the increase in the P-11 control elevation alone does not improve recovery of the UPR minimum flows.

However, increases in the MFLs Flow Days Met and MFLs Flow Year Met for the three UPR gage sites substantially increased for scenarios associated with P-11 structure operations that would be associated with the LHR and recovery of minimum flows in the UPR. For example, at the Fort Meade gage, the number of MFLs Flow Days Met increased by 21% and the number of MFLs Flow Years met increased by 25 years for the ECL+MFLs scenario relative to the Baseline scenario. A reduction in the number of MFLs Flow Days Met for the minimum flow recovery scenario associated with overcoming sink loss between Bartow and Fort Meade (i.e., Scenario ECL+MFLs+SL) relative to the minimum flow recovery scenario that does not account for sink loss (ECL+MFLs), indicated that flows released at P-11 for the ECL+MFLs+SL scenario were not sufficient to overcome sink losses during the analysis period.

The finding that the flows associated with all the modeled scenarios included in the LHR analysis were not sufficient for full recovery of the minimum flows in the UPR was expected. The Lake Hancock Lake Level Modification Project, which provides the primary basis for the conceptualization of the scenarios included in this LHR analysis was designed and constructed to promote compliance with the UPR minimum flows approximately 89% of the time (SWFWMD 2013).

The District anticipates continuing to apply an adaptive management approach for achieving minimum flow recovery in the UPR. Decisions regarding whether additional projects or water sources may be needed to fully meet minimum flow requirements in the UPR will be based on continued monitoring and evaluation of P-11 operations including releases for river recovery, reevaluation of the existing UPR minimum flows, and trends in hydrologic conditions.

Table 7. Comparison of minimum flows status in the Upper Peace River for historical (measured) and four modeled scenarios for the 38-year (13,880-day) simulation period from 1975 through 2012

Historical Condition or Flow Scenario	**Number (and Percent) of MFLs Flow Days Met**[a]			**Number of MFLs Flow Years Met**[b]		
	Bartow	Fort Meade	Zolfo Springs	Bartow	Fort Meade	Zolfo Springs
Historical	10,816 (78%)	9,741 (70%)	12,833 (92%)	9	3	27
Baseline	10,536 (76%)	9,458 (68%)	12,814 (92%)	6	3	27
ECL	10,529 (76%)	9,437 (68%)	12,813 (92%)	6	3	27
ECL + MFLs	12,851 (93%)	12,663 (91%)	13,282 (96%)	29	28	32
ECL + MFLs + SL	12,521 (90%)	12,068 (87%)	13,116 (94%)	26	21	28

[a] *MFLs Flow Days Met are the days the flow threshold associated with the respective UPR minimum flows at Bartow, Fort Meade and Zolfo Springs were equaled or exceeded.*

[b] *MFLs Flow Years Met are the years the 95% exceedance flow threshold associated with the respective UPR minimum flows at Bartow, Fort Meade and Zolfo Springs were equaled or exceeded.*

3.5 Impacts to Minimum Flows in the Middle and Lower Peace River

Minimum flows for the MPR were developed and are assessed based on flow at the USGS Peace River at Arcadia gage. This gage is also associated with the minimum flows for the LPR, which are based on the combined flows at the Peace River at Arcadia, Horse Creek near Arcadia and Joshua Creek at Nocatee gages. Tributary flow from Horse Creek and Joshua Creek are not affected by the LHR, so evaluation of the impacts on flows at the Arcadia gage are sufficient for assessing potential impacts of the LHR on minimum flows for both the MPR and LPR.

As shown in Figure 17, differences in long-term average flows at Arcadia relative to the Baseline scenario ranged from 0 to less than 0.5% for the modeled scenarios associated with the existing 100 ft-NGVD structure control elevation (ECL, ECL+MFLs, ECL+MFLs+SL). Minor flow increases of less than 2% in the low and medium flow seasons (i.e., Blocks 1 and 2) and decreases of less than 1% in high flow season (Block 3) were simulated for the scenarios. When compared to the allowable, block-specific flow reductions associated with the adopted MPR (8 to 18%) and LPR (16 to 38%) minimum flows (see Appendix C), these small flow differences at the Arcadia gage indicate the LHR is not expected to adversely impact the status of minimum flows established for the MPR and LPR.

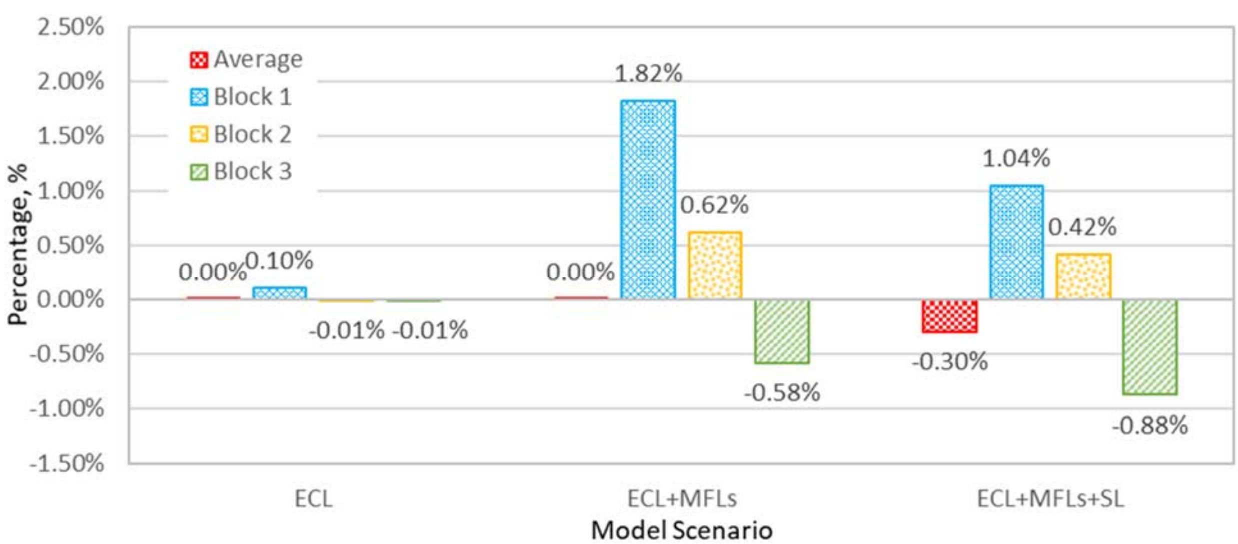


Figure 17. Changes in the average Peace River flows at the Arcadia gage and average flows by seasonal block (Blocks 1, 2 and 3) for three modeled scenarios relative to the flows simulated for the Baseline scenario for the period 1975 through 2012

3.6 Impacts to Existing Water Users

The PRMRWSA is currently the primary existing legal water user on the Peace River. Individual Water Use Permit No. 20010420.010, issued to the PRMRWSA by the District on February 26, 2019, authorizes a daily maximum withdrawal of 258 million gallons per day (MGD) and an annual average withdrawal of 80 MGD. The permit also includes conditions that limit seasonal, block-specific diversions (i.e., withdrawals) from the river (Table 8). These withdrawal restrictions are similar to the allowable, seasonal flow reductions identified in the minimum flows rule adopted for the LPR (see Appendix C). However, the permitted diversions when the combined Peace River at Arcadia, Horse Creek near Arcadia and Joshua Creek at Nocatee flows exceed 625 cfs during Blocks 2 and 3 are, respectively, 1% and 10% less than the withdrawal limits included in the LPR minimum flows rule.

Differences in the combined Peace River at Arcadia, Horse Creek and Joshua Creek flows for the scenarios associated with the 100 ft-NGVD control elevation were assessed, relative to the Baseline scenario on a long-term average and block-specific basis (Figure 18). Differences in the long-term average combined flow were minimal, ranging from 0% to less than 0.5% for the ECL, ECL+MFLs and ECL+MFLs+SL scenarios. As was the case for the Arcadia flows alone (see Figure 17), slight flow increases in Blocks 1 and 2 and decreases in Block 3 were noted (Figure 18). These minor flow changes indicated minimal impact of the LHR on the combined flows in the LPR, i.e., the combined flows in the Peace River at Arcadia, Horse Creek and Joshua Creek.

Table 8. PRMRWSA surface water diversion limits from the Peace River included in Individual Water Use Permit No. 20 010420.010 issued to the PRMRWSA for combined flows in the Peace River at Arcadia, Joshua Creek and Horse Creek

Period	Effective Dates	Where Flow on Previous Day Equals	Allowed Withdrawals
Block 1	April 20 through June 25	≤130 cfs	0 cfs
		>130 cfs	16% of the previous day's flow*
Block 2	October 28 through April 19	≤130 cfs	0 cfs
		>130 cfs and < 625 cfs	16% of the previous day's flow*
		≥ 625 cfs	28% of the previous day's flow*
Block 3	June 26 through October 27	≤130 cfs	0 cfs
		>130 cfs and < 625 cfs	16% of the previous day's flow*
		≥ 625 cfs	28% of the previous day's flow*

Not to exceed the difference between the combined previous day's flows at the Horse Creek near Arcadia, Joshua Creek at Nocatee and Peace River at Arcadia and 130 cfs. Also, withdrawals are capped at a maximum of 258 million gallons per day subject to Special Condition 17 within the water use permit.

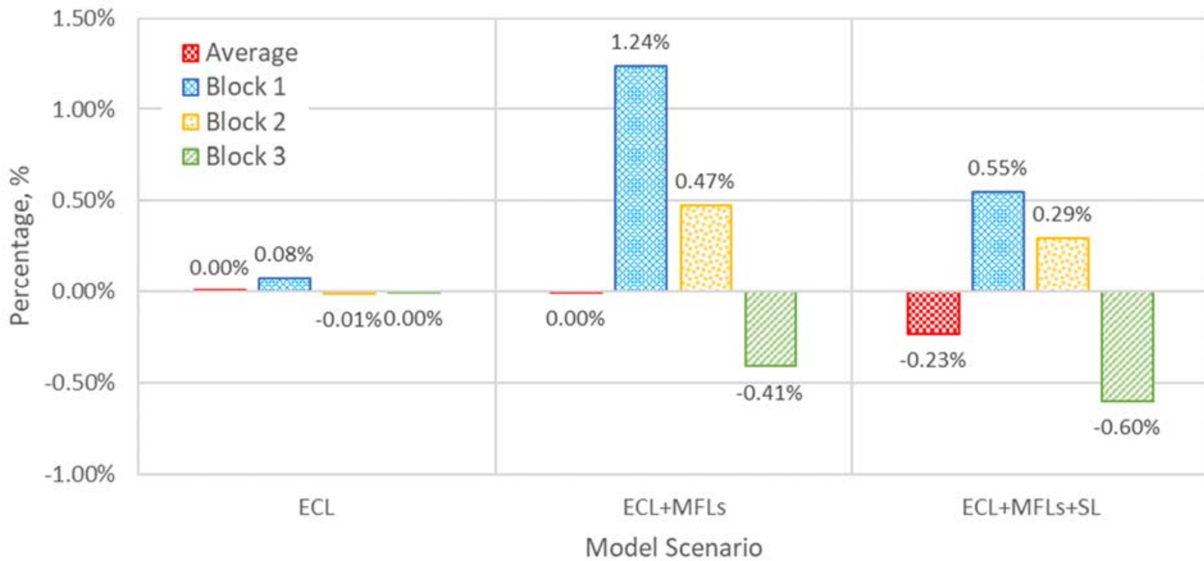


Figure 18. Changes in the combined daily flow in the Peace River at Arcadia, Horse Creek near Arcadia and Joshua Creek at Nocatee for three modeled scenarios relative to the flows simulated for the Baseline scenario for the period 1975 through 2012

Responses similar to those simulated for the combined flows in the LPR were observed for potential changes in water withdrawals from the Peace River by the PRMRWSA (Figure 19). On an annual basis when comparing the scenarios with the LHR with baseline, the LHR does not cause any impacts on the PRMRWSA water withdrawals.

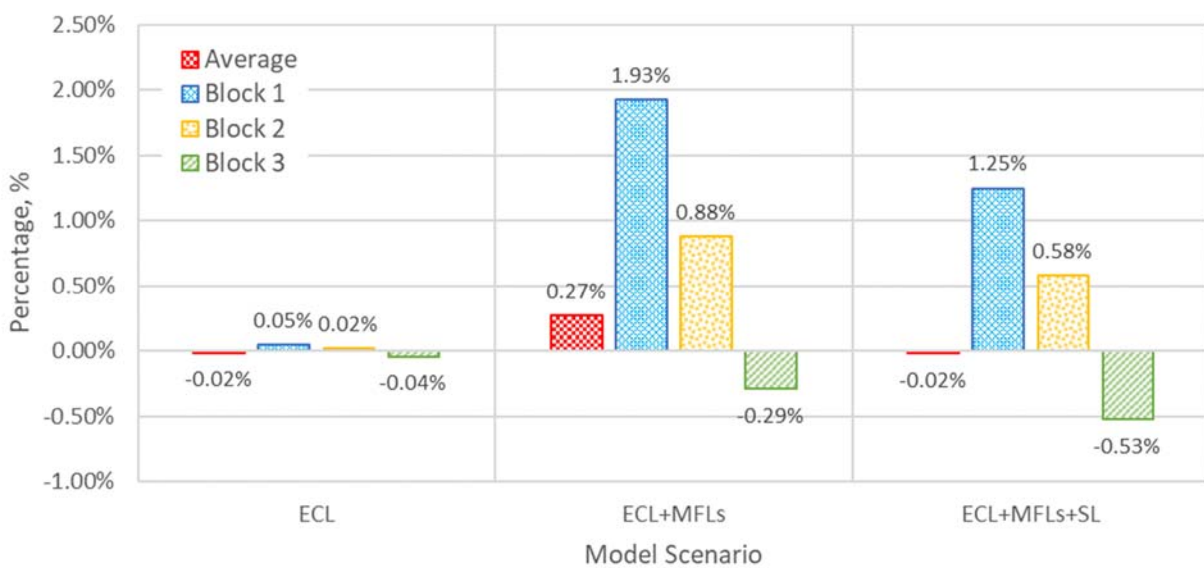


Figure 19. Changes in potential PRMRWSA surface water withdrawals for three modeled scenarios relative to the flows simulated for the Baseline scenario for the period 1975 through 2012

As an additional note, the historical average flow through P-11 for the assessed period is about 58 cfs, accounting for 6.7% of the historical average flow at Arcadia (i.e., 857 cfs), and 5% of the combined Peace River at Arcadia, Horse Creek near Arcadia and Joshua Creek at Nocatee (i.e., 1,138 cfs). After the flow adjustments based on the scenario projections, the flow contribution from Lake Hancock through the P-11 control structure is slightly reduced (Table 9), indicating Lake Hancock only accounts for a very small portion of the streamflow at the LPR.

Table 9. Average flow from Lake Hancock through P-11, at the Peace River at Arcadia, and for the combined flows at the Horse Creek near Arcadia, Joshua Creek at Nocatee and Peace River at Arcadia

Scenario	Outflow Through the P-11 Control Structure (cfs)	Flow at the Peace River at Arcadia (cfs)*	Combined Flows at the Horse Creek near Arcadia, Joshua Creek at Nocatee and Peace River at Arcadia (cfs)*
Historical	58	857 (6.7%)	1,138 (5.1%)
Baseline	55	854 (6.4%)	1,135 (4.8%)
ECL	55	854 (6.4%)	1,135 (4.8%)
ECL+MFLs	55	854 (6.4%)	1,135 (4.8%)
ECL+MFLs+SL	55	851 (6.5%)	1,131 (4.9%)

** The percentage in the parentheses indicates the contribution of the outflow through the P-11 control structure.*

3.7 Impacts to the Charlotte Harbor Estuary

The Charlotte Harbor Estuary, the second largest bay in Florida, is a threatened ecosystem because of rapid increases in regional population growth and associated development. Given these stresses, maintaining freshwater flows to the Estuary is important for protecting the health of this ecosystem. The Peace River is a major contributor of freshwater inflow to the Estuary and flows from the river are protected through implementation of the LPR minimum flows and compliance with conditions included in the water use permit issued to the PRMRWSA by the District.

Potential impacts to the Charlotte Harbor Estuary due to changes in Peace River flows were evaluated based on the expected flows past the PRMRWSA withdrawal intake, following any permitted diversions from the river (Figure 20). Differences in the long-term average flows to the Estuary relative to the Baseline scenario were minimal, ranging from 0% for the ECL scenario to less than 0.5% decreases for the ECL+MFLs and ECL+MFLs+SL scenarios. Slight increases in Block 1 and 2 flows and decreases in Block 3 flows of approximately 1% or less were noted for the three scenarios associated with the 100 ft-NGVD control elevation for the P-11 structure. These minor flow changes are not anticipated to lead to a violation of the LRP minimum flows and are expected to support maintenance of ecosystem health in the Charlotte Harbor Estuary.

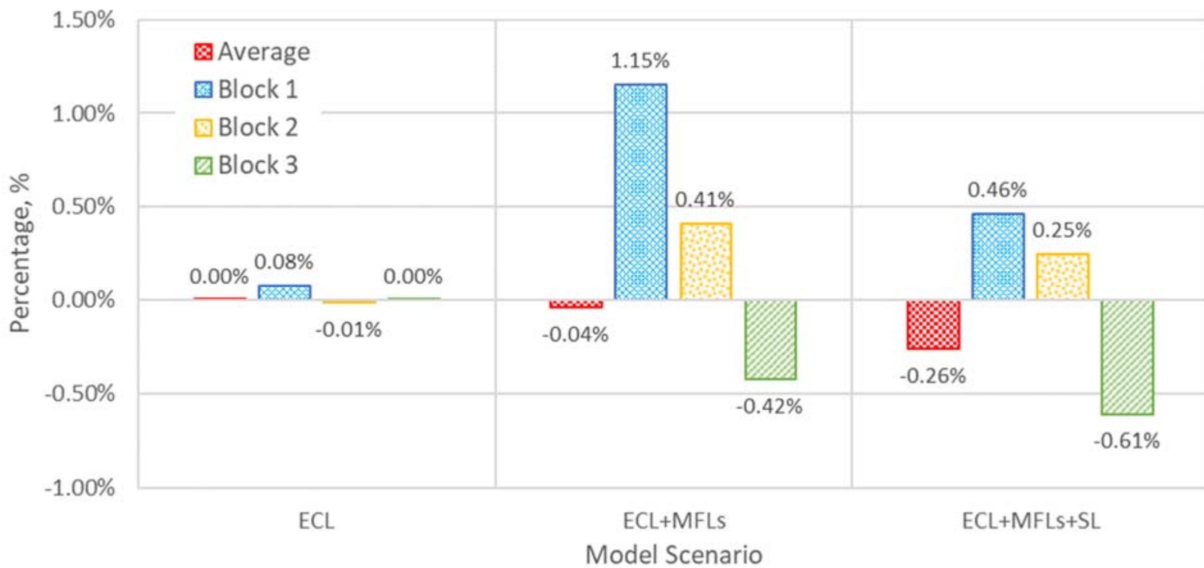


Figure 20. Change in the Peace River flows to the Charlotte Harbor Estuary for three modeled scenarios relative to the flows simulated for the Baseline scenario for the period 1975 through 2012

4. SUMMARY AND CONCLUSIONS

The District has prospectively adopted a reservation rule for recovery and protection of minimum flows and minimum water levels established for the SWUCA. The District's Consumptive Use of Water rules indicate reservations for this purpose will be adopted on a case-by-case basis to address water that is developed through water resource development projects designed to achieve and maintain minimum flows and levels. A reservation of water stored in Lake Hancock and released to Lower Saddle Creek (i.e., the LHR) for recovery of minimum flows in the UPR that are not being met is currently prioritized for adoption by rule in 2020.

To support adoption of the LHR rule, a spreadsheet-based water budget model was developed and used to project current (i.e., post P-11 structure replacement at the Lake Hancock outlet) hydrologic conditions in Lake Hancock and the Peace River from historical (i.e., pre P-11 structure replacement) conditions. Results from these simulations, i.e., from this LHR analysis were used to assess potential effects of the LHR on outflows from Lake Hancock, recovery of minimum flows in the UPR, minimum levels in Lake Hancock, minimum flows established for the MPR and LPR, permitted water withdrawals from the LPR by PRMRWSA, and flows to the Charlotte Harbor Estuary. Results from these assessments provide a basis for characterizing conditions that can be expected with P-11 structure operations associated with the LHR that is intended to support recovery of minimum flows in the UPR.

Three scenarios associated with operation of the current P-11 structure with a control elevation of 100 ft-NGVD were assessed relative to a Baseline scenario that represented operation of the P-11 structure at the control elevation of 98.5 ft-NGVD associated with the previous structure. The three scenarios associated with the current structure control elevation were designed to investigate conditions involving: 1) no lake storage or releases for UPR minimum flow recovery (Scenario ECL); 2) storage of water in lake for subsequent release to support UPR minimum flow recovery when the lake level exceeded the Minimum Lake Level of 97.6 ft-NGVD established for Lake Hancock (Scenario ECL+MFLs); and 3) storage of water in lake for subsequent release to support UPR minimum flow recovery when the lake level exceeded the Minimum Lake Level of 97.6 ft-NGVD established for Lake Hancock, while attempting to compensate for a sink loss of 25 cfs based on reported loss values for the Peace River between Bartow and Fort Meade (Scenario ECL+MFLs+SL). This last scenario was considered to most closely represent current hydrologic conditions in the UPR.

A 38-year analysis period, from 1975 through 2012 was selected based on consideration of available historical flow data and replacement of the previous P-11 control structure with the current P-11 structure in 2013 through 2014. Because of the replacement of the P-11 structure, structure operations intended to support minimum flow recovery in the UPR, the LHR to be adopted to support these efforts, and the elimination of a historical discharge of wastewater effluent that was ultimately delivered to the Peace River through Lake Hancock, it was necessary to adjust historical hydrologic data for the analysis. These adjustments were determined to be necessary throughout the Peace River, with the average quantity of reduction ranging from 2.6 to 5.6 cfs, for the various scenarios and sites included in the analysis. Comparable flow adjustments are considered necessary for other, similar hydrologic investigations that rely on the use of historic flow data collected in the Peace River.

Results from the scenario simulations indicated the long-term average outflow of 55 cfs from Lake Hancock at the P-11 structure did not differ from the effective inflow to the lake, regardless of structure control elevation or simulated structure operations. However, operation of the structure to temporarily store water in Lake Hancock, with the intent of helping achieve minimum flows in the UPR, changed the temporal distribution of outflow at the P-11. This was not unexpected as the structure operation for UPR recovery includes capturing inflows during the wet season for release during the dry season.

During the low-flow Block 1, P-11 outflows increased 45% and 64%, respectively for the two scenarios associated with UPR minimum flow recovery (ECL+MFLs) and minimum flow recovery with compensation for sink losses (ECL+MFLs+SL). Outflow increases were more moderate during Block 2, with 9% and 12% increases simulated for the ECL+MFLs and ECL+MFLs+SL scenarios, respectively. As expected, these scenarios were also associated with decreased outflow via the P-11 structure during Block 3, the high flow period when temporary storage would be increased to support subsequent release during the drier seasons or blocks.

Although the magnitude of outflows at structure P-11 is typically small relative to the long-term average downstream flows at the Peace River at Bartow, Fort Meade, Zolfo Springs and Arcadia gages, the P-11 outflow serves an important role in restoring low flows in the

UPR. Increases in the number of days the flow thresholds associated with the UPR minimum flows were achieved (i.e., MFLs Flow Days Met) and the number of years the 95% exceedance flows associated with the minimum flows for the three UPR gage sites were met (i.e., MFLs Flow Years Met) substantially increased for scenarios associated with P-11 structure operations associated with the LHR and recovery of minimum flows in the UPR. For example, at the Fort Meade gage, the number of MFLs Flow Days Met increased by 21% and the number of MFLs Flow Years Met increased by 25 years for the ECL+MFLs scenario relative to the Baseline scenario. Improvement in the number of days the threshold associated with the minimum flow at Zolfo Springs was achieved and the number of years the minimum flow was met were less than those simulated for the Fort Meade and Bartow minimum flow sites. Minimum flows are, however, more frequently met at the Zolfo Springs gage than at the two upstream gages.

The LHR analysis also indicated that sink loss between Bartow and Fort Meade has a strong impact on minimum flow recovery at Fort Meade. Accounting for an anticipated sink loss of up to 25 cfs reduced the number of days the flow threshold for the Fort Meade would be achieved by 4% and reduced the number of years the minimum flows would be met by 7 years for the 38-year simulation period. Effects of accounting for sink loss were relatively less at the Bartow and Zolfo Springs gages.

The finding that the flow releases associated with all the modeled scenarios included in the LHR analysis were not sufficient for full recovery of minimum flows in the UPR was not unexpected. The Lake Hancock Lake Level Modification Project, which provides the primary basis for the conceptualization of the scenarios included in this LHR analysis was designed to recover the UPR minimum flows approximately 89% of the time (SWFWMD 2013). The District anticipates continuing to use an adaptive management approach to improve minimum flows status in the UPR. Decisions regarding whether additional projects or water sources may be needed to fully meet minimum flow requirements in the UPR will be based on continued monitoring and evaluation of P-11 operations including releases for river recovery, reevaluation of the existing UPR minimum flows, and trends in hydrologic conditions.

Assessed effects on minimum levels for Lake Hancock, minimum flows established for the MPR and LPR, and flows to the Charlotte Harbor Estuary were also positive or minimal. Operation of structure P-11 for minimum flow recovery in the UPR will increase water levels in Lake Hancock relative to historical conditions and support compliance with minimum levels established for the lake. The structure operations associated with the LHR will not negatively affect compliance with minimum flows established for the MPR or LPR and will similarly not significantly affect flows to the Charlotte Harbor Estuary.

Analysis of withdrawal information based on the current water use permit issued to the PRMRWSA indicated that P-11 structure operation in accordance with the LHR and for UPR minimum flows recovery would not negatively impact permitted withdrawals from the Peace River. Withdrawals in the low and medium flow seasons could potentially be slightly enhanced and withdrawals during the high flow season could slightly be decreased by <1%.

In summary, the findings of this LHR analysis support the conclusion that the current and planned operation of the P-11 structure for UPR minimum flow recovery and the planned adoption of a reservation for the water stored in Lake Hancock at and below 100.0 ft-NGVD and released from Lake Hancock to Lower Saddle Creek when flow thresholds of 17 cfs, 27 cfs and 45 cfs at the Bartow, Fort Meade and Zolfo Springs gage sites are not met will support recovery of minimum flows in the UPR and continued achievement of minimum levels in Lake Hancock. The LHR also will not adversely affect minimum flows established for the MPR and LPR, flows to the Charlotte Harbor Estuary, and is protective of existing, permitted withdrawals from the Peace River.

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