Review and Recommendation Memo and Report Data Assessment for HEC-RAS Unsteady Flow Modeling of the Upper Peace River

Prepared for:

Southwest Florida Water Management District

2379 Broad Street
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Agreement No. 19CN0001933
TWA No. 20TW0002966

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December 2020

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Section 1 - Introduction

1.1 Background and Purpose

Barnes, Ferland and Associates, Inc. (BFA) received Task Work Assignment (TWA) No. 20TW0002966 in June of 2020 for the project titled: *Data Assessment for HEC-RAS Unsteady Flow Modeling of Upper Peace River (Project).* The HEC-RAS steady flow model was developed by the Southwest Florida Water Management District (SWFWMD or District) in support of previous minimum flow evaluation of the Upper Peace River (UPR). Model calibration and verification are anticipated to be included as part of the Minimum Flows and Levels (MFLs) reevaluation through conducting an unsteady flow analysis before running the HEC-RAS model for steady flow analysis for selected flow profiles that will be used for the UPR MFLs reevaluation.

Section 373.042, Florida Statutes, mandates Water Management Districts (WMDs) of Florida to establish MFLs for surface waters and aquifers in their jurisdictions. The definitions of MFLs are: *"The minimum flow for a given watercourse is the limit at which further withdrawals would be significantly harmful to the water resources or ecology of the area," and "The minimum water level is the level of groundwater in an aquifer and the level of surface water at which further withdrawals would be significantly harmful to the water resources or ecology of the area."* WMDs conduct detailed ecologic studies to formulate specific criteria in applying these rules for various locations of a chosen watershed. The Upper Peace River from Bartow gage to Zolfo Springs gage (Figures 1 and 2) is a watercourse for which the District established the minimum "low" flows in 2002 (SWFWMD 2002).

A computer program commonly used by WMDs both in establishing numerical values of MFLs and verifying compliance of the MFLs is the US Army Corps of Engineers' HEC (Hydrologic Engineering Center) RAS (River Analysis System). HEC-RAS is developed to analyze steady/gradually varied river flow conditions, and unsteady flow conditions (known as dynamic wave). HEC-RAS steady flow model develops water surface profiles for the specified flow values, giving depths of water for different locations (transects) for the river reach analyzed. For the past few decades WMDs used the HEC-RAS steady flow model for the MFLs studies, but recently HEC-RAS unsteady flow models are also being applied in these evaluations (e.g., Rainbow River by SWFWMD, 2017).

The District's resource management goals for the UPR MFLs are:

- Maintain minimum depths for fish passage and canoeing in the upper river;
- Maintain depths above inflection point in the wetted perimeter of the stream;
- Inundate woody habitats in the stream channel; and
- Meet the hydrologic requirements of floodplain biological communities.

HEC-RAS is helpful to develop the necessary stage and discharge data in a generalized fashion to evaluate the foregoing goals. As part of the UPR MFLs study, during late 2001 and early 2002 the District obtained and modified a USGS (US Geological Survey) HEC-RAS model, which, revised from a mid-1970s step-backwater flood profile model developed by USGS for the Peace River, included cross-sectional data collected at 183 sites on the river between Bartow and Arcadia (SWFWMD 2002). The USGS HEC-RAS model was developed on its Version 2.2, in which the UPR was divided into two segments: 1) from Bartow to Fort Meade and 2) from Fort Meade to Zolfo Springs. The District modified the USGS HEC-RAS model by adding more flow profiles, adding 18 cross sections surveyed by the District in 2001, and fine-tuning Manning's roughness coefficients. The output from this District's revised 2001/2002 HEC-RAS model and the field investigation at the 18 surveyed transects served as the basis for establishing the recommended MFLs that was completed in 2002.

Gore, Dahm, and Klimas (2002) peer reviewed the District's 2002 MFLs report (SWFWMD 2002) and expressed: "The District goals represent a reasonable subset of potential goals for an improved biotic community in the degraded upper basin. The rationale for choosing these goals is clearly presented and scientifically justified. The application of the HEC-RAS model to generate a wetted perimeter versus flow plot for each transect also is a justifiable scientific approach".

In 2011, Chen further modified the 2001/2002 HEC-RAS model to address the shortcomings discussed in the following Section 2 and incorporated data collected since the completion of the 2001/2002 model in support of the then scheduled 2012 UPR "middle" and "high" minimum flows evaluation. This data assessment does not include a review of that 2001/2002 HEC-RAS model, instead focuses on Chen's 2011 HEC-RAS model because it represents the latest model for the UPR and has not gone through peer review. The District anticipates that the results of this review will inform the next version of HEC-RAS model for the UPR MFLs reevaluation.

1.2 Scope of Work

The authorizing TWA and following report cover the six tasks listed below:

- Task 1 - Project Kick-off Meeting
- Task 2 - Review of Existing HEC-RAS Steady Flow Model
- Task 3 - Review of Existing Flow and Stage Data and Recommendations
- Task 4 - Review of Existing Topographic and Bathymetric Data and Recommendations
- Task 5 - Review of Structure Data and Recommendations
- Task 6 - Review and Recommendation Memo and Report and Conclusions

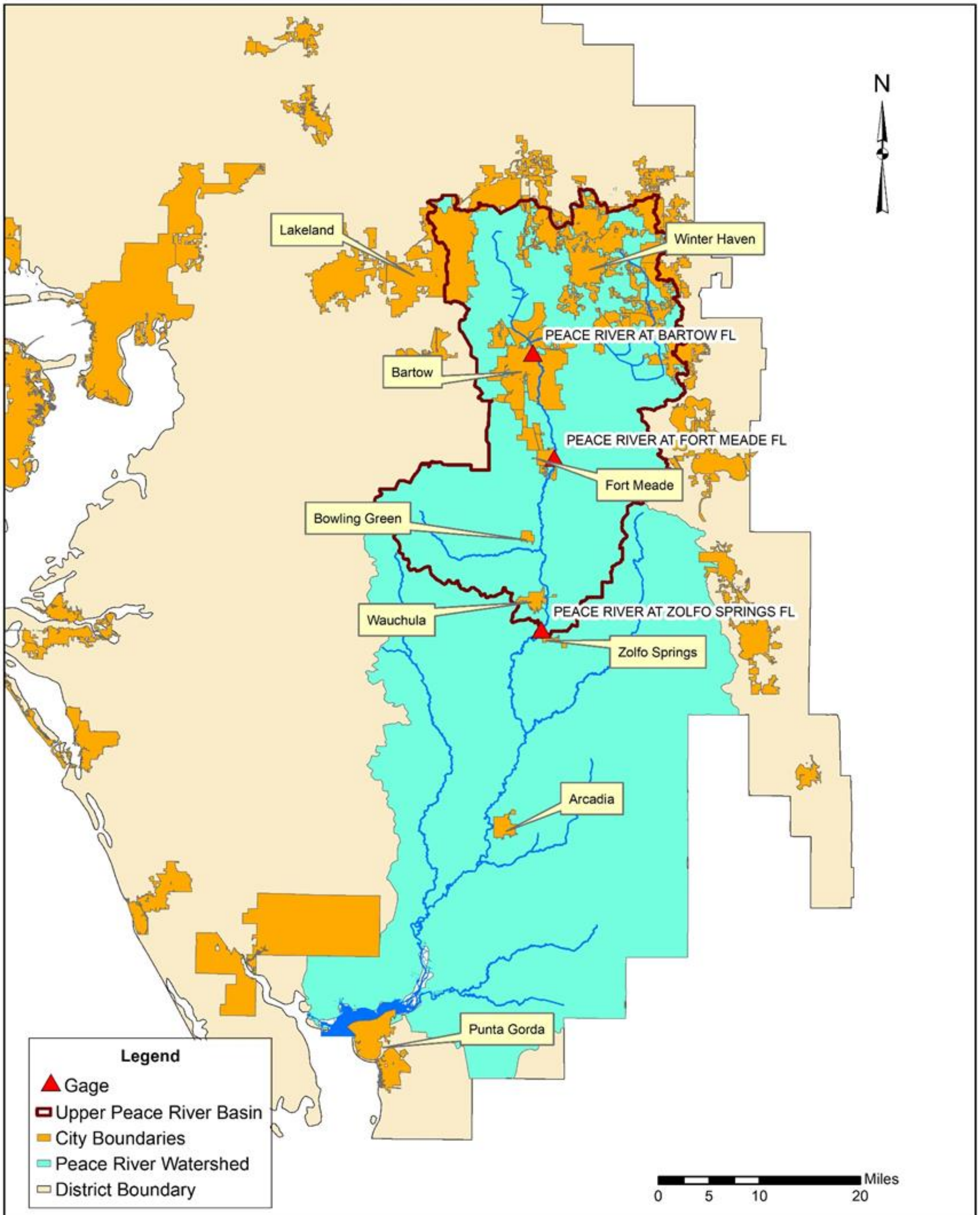
In Task 2, BFA first assessed the necessity of performing unsteady flow analysis in terms of model improvements based on reviewing the existing HEC-RAS steady flow model and summarized our conclusions in a technical memo (see Appendix). The findings and conclusions for the technical memo are provided in Section 2 of this report.

In Task 3, BFA obtained and reviewed relevant available existing *flow and stage data* that can be used for boundary conditions and model calibration targets between the USGS gages at Zolfo Springs (downstream) and Bartow (upstream). BFA also evaluated locations where additional or new flow and stage measurements could be collected if existing data are not adequate to conduct a HEC-RAS unsteady flow analysis of the UPR.

In Task 4, BFA obtained and reviewed relevant available *topographic and bathymetric data* that can be used for preparing geometric data inputs for the HEC-RAS model between the USGS gauges at Zolfo Springs and Bartow. BFA also evaluated locations where additional topographic and bathymetric data could be collected if existing data are not adequate to conduct a HEC-RAS unsteady flow analysis of the UPR. Recommendations for additional topographic and bathymetric data acquisition along the river and its major tributaries should be based on its utility for developing model geometric data, boundary conditions and to improve model calibration and validation results.

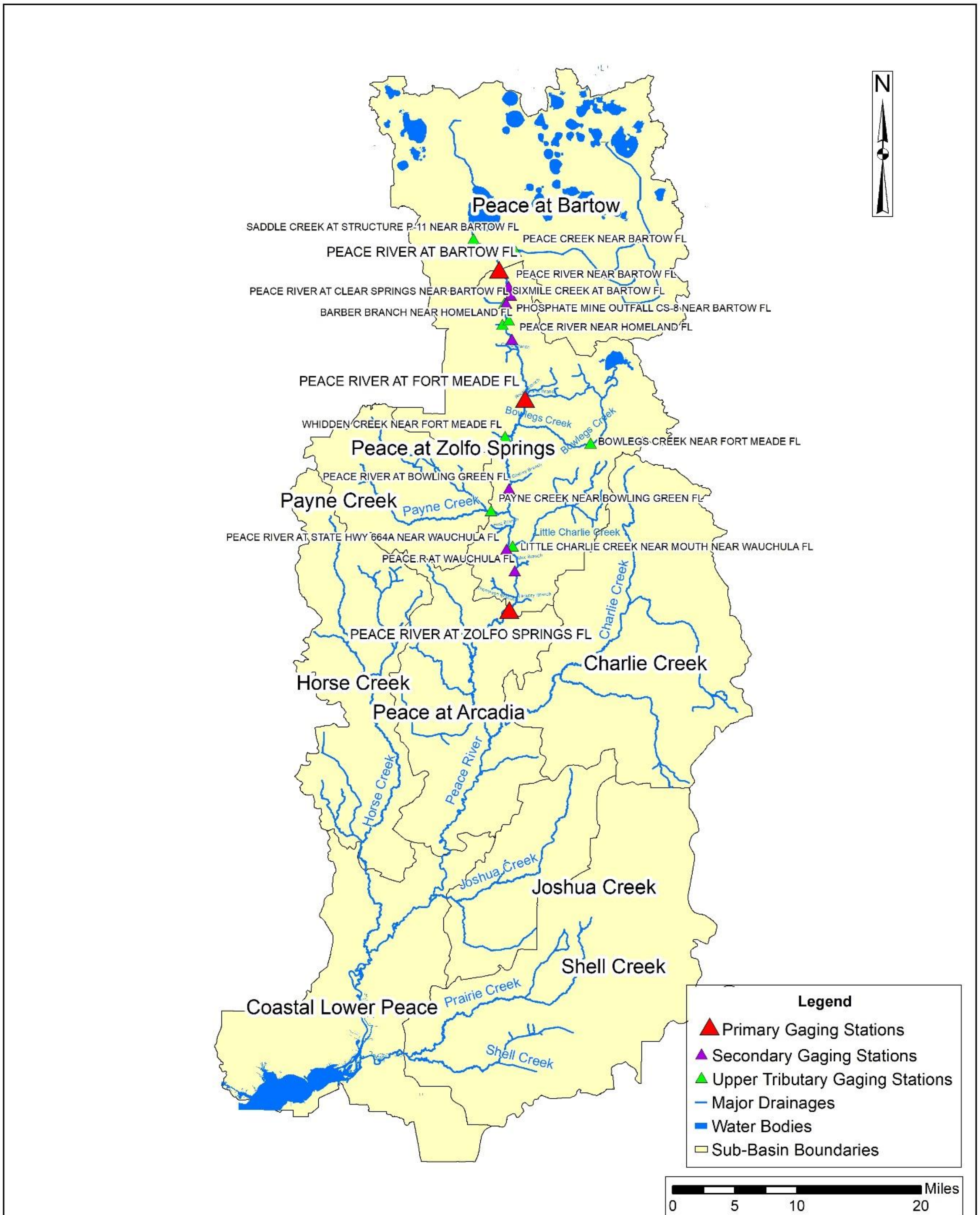
In Task 5, BFA obtained and reviewed data and information relevant to *structures* (e.g., bridges and culverts) between the USGS gages between Zolfo Springs and Bartow for both main channel and tributaries, which should be considered for the HEC-RAS unsteady flow analysis. BFA also evaluated additional structure data that could be collected if existing data are not adequate or too outdated to conduct the steady/unsteady flow analysis of the UPR between the USGS Zolfo Springs gauge and Bartow gauge. Recommendations for additional structure data acquisition along the river should be based on its utility for developing model data and to improve model calibration and validation results.

In Task 6, BFA prepared a Draft and Final report. Recommendations for additional data acquisition along the river and its major tributaries should be based on its utility for developing model geometric data, boundary conditions and to improve model calibration and validation results. This report includes relevant supporting data tables, GIS maps, and illustrations.



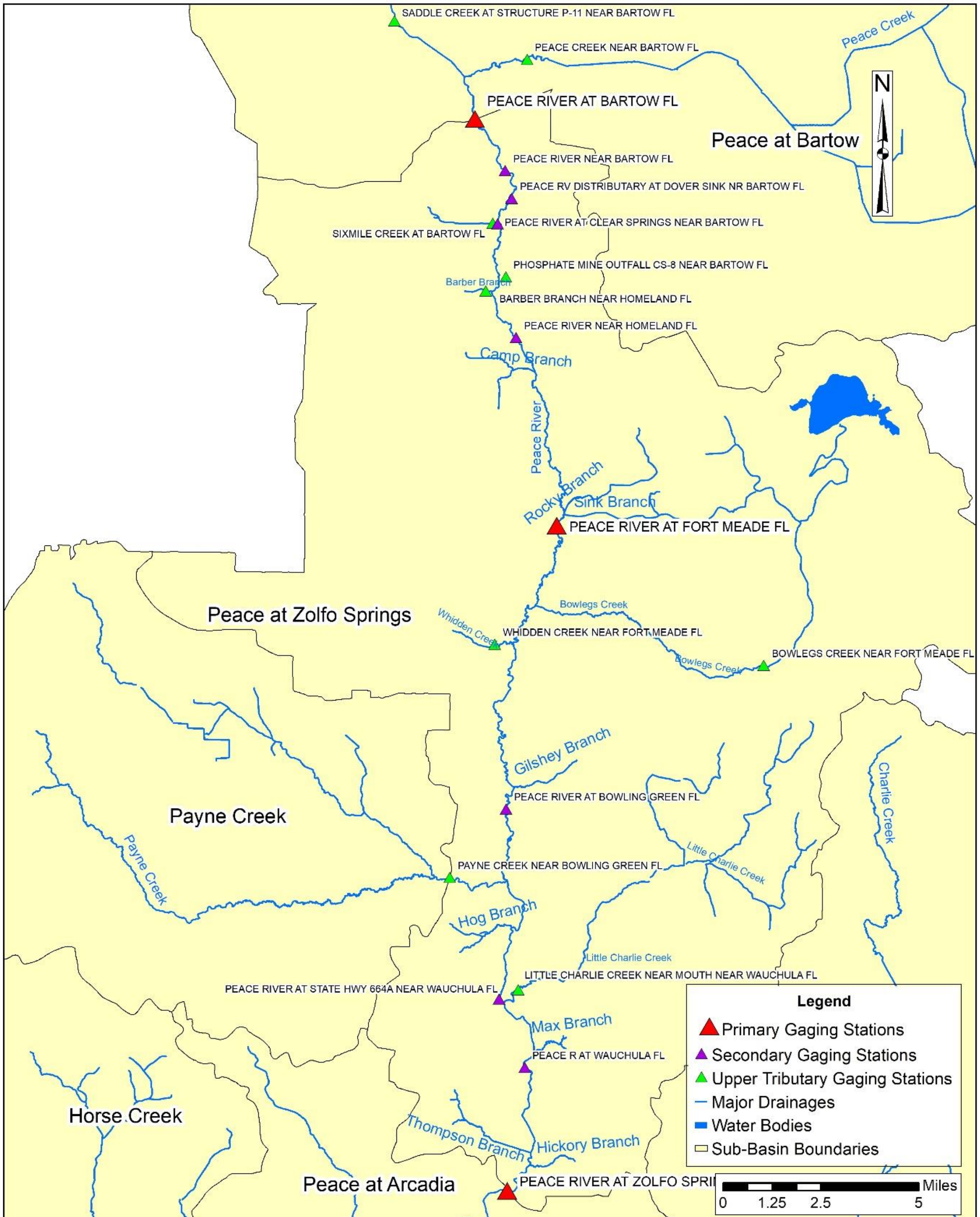
Upper Peace River Water Basin Features with City Boundaries and Stream Gaging Stations

Figure 1



Peace River Watershed Sub-Basins and Major Streams and Rivers

Figure 2a



BFA | **Upper Peace River Watershed Sub-Basins and Gaging Stations** | **Figure 2b**

Section 2 - Summary of Task 2 Technical Memorandum

Project Task 2 involved preparing a technical memorandum (TM) to document our review the existing steady UPR HEC-RAS Steady Flow Model. The scope of work for this task included the following three subtasks:

Subtask 2.1 - Review the existing steady flow model using the latest version of HEC-RAS to identify any improvements and revisions that are necessary including, but not limited to:

- unsteady flow analysis; and
- additional data collection that may be associated with the Project Tasks 3, 4 and 5.

This review will include the performance of two model runs with the existing model to help assess its behavior in select areas and under certain conditions.

Subtask 2.2 - Based on evaluations under Subtask 2.1 BFA will then assess the necessity of unsteady flow analysis in terms of model improvements in support of the UPR MFLs reevaluation.

Subtask 2.3 - Provide a technical memo and receive approval from District staff before moving forward with the remaining tasks.

The following provides a summary of the Task 2 technical memorandum. The complete TM is included in the Appendix.

2.1 Findings of Review

In 2011, Dr. XinJian Chen of the SWFWMD extensively revised the 2001/2002 UPR HEC-RAS model (SWFWMD 2002) by a new model (Chen 2011). The revised model has been made available to BFA for review. Chen lists the following shortcomings in the 2001/2002 model.

1. Because of the existence of sinkholes in the riverbed, flow can be lost to ground water along the river segment between Bartow and Fort Meade (sink phenomenon mostly occurs between Fort Meade and Bartow) and the flow percentiles simulated in the USGS model did not account for this fact. Therefore, low flows with high exceedance percentages simulated in the USGS HEC-RAS model may not be accurate.

2. The 2001/2002 modeling for the period 1940 to 1998 was done by dividing the river reach into two segments: Bartow to Fort Meade and Fort Meade to Zolfo Springs. Fort Meade gaging station was established prior to 1964, but continuous flow measurement at this site started June 1, 1974, while the other two gaging stations started recording continuous flow records from 1940. Hence, concurrent continuous flow data for the three gaging stations was not available before June 1974. The study estimated flow percentiles at the Fort Meade station by interpolating from those at Zolfo Springs and Bartow stations with the assumption that the increment of river flow along the river reach between Bartow and Zolfo Springs is proportional to the increment of the drainage area. This

assumption, due to limitation on the then short period of concurrent records, ignored the sinkhole losses in the area and caused overestimated discharges for Fort Meade, especially for the low flow range.

3. The cross-sectional data used were generally outdated, because they were generated using old aerial 1-foot topographic contour maps, old field surveys, or similar analyses conducted more than 30 years ago. Because the morphology of the Upper Peace River slowly varies over the years, these old cross sections may not be suitable to represent the present bathymetric condition of the Upper Peace River.

Chen used 165 river cross sections in building up his HEC-RAS model, including the 18 extensively surveyed sections from the 2001/2002 model, 101 new sections that were surveyed from time to time during 2000 – 2010, and 46 sections extracted from the USGS HEC-RAS model (Figure 3). The 46 extracted sections served primarily the purpose of filling large gaps in the river segments. The 18 sections surveyed in 2001 extended into the floodplain while the survey for the 101 new sections was done primarily for the channel portion. These 101 sections were extended 1,000 feet into the floodplain on either side using LiDAR data shown by the brown line in Figure 3. Chen also developed a single river reach model from Bartow to Zolfo Springs. The Zolfo Springs rating curve served as the downstream boundary condition while the rating curves at Fort Meade and Bartow served for model calibration.

Based on gaged data from June 1, 1974 (the inception date of Fort Meade gaging station) to July 12, 2011, Chen obtained 18 flow rates for different exceedance percentages, ranging from 0.1% to 99% for the three gaging stations at Bartow, Fort Meade and Zolfo Springs (Table 1). In this process Chen excluded the 1940 – 1974 flow data that was available for Bartow and Zolfo Springs and used in the 2001/2002 HEC-RAS model. Chen justifies excluding the 1940 – 1974 data stating the period chosen by him had concurrent data at the three stations representing true flow conditions, represents the more recent flow conditions in the river, which is perhaps more important in the MFLs evaluation process than the data of 40 years or older with uncertainties of sink-hole loss issue. BFA considered this fully under Section 3, Existing Flow and Stage data in the Upper Peace River.

From the then (2011) available rating curves provided by the USGS for the three gaging stations (USGS Bartow, Fort Meade, and Zolfo Springs), Chen obtained the water surface elevations corresponding to the 18 flow values (Table 2). BFA downloaded the current USGS rating curves for Bartow (6/11/2020); Fort Meade (6/8/2020) and Zolfo Springs (6/8/2020) (e.g., Figure 4 for Fort Meade gauging station). A discussion of these rating curves is provided under Section 3.

Chen developed a HEC-RAS model to compute 18 flow profiles corresponding to the 18 sets of discharge values presented in Table 1. The stages at Zolfo Springs (Table 2) served as the boundary condition. Chen calibrated the model by adjusting Manning's roughness values in the main channel and floodplains along the river to match the stages at Fort Meade and Bartow. Discharges at different transects between the gaging stations were apportioned based on drainage basin ratios (As explained by the District Staff during the teleconference between SWFWMD and BFA on 6/16/2020).

The HEC-RAS Version 4.0 was used in Chen's 2011 model, but the software has continuously gone through multiple upgrades with the current Version 5.0.7 (March 2019). BFA obtained HEC-RAS for both Versions 4.0 and 5.0.7 and found that Chen's 2011 model executed smoothly with both versions of HEC-RAS. Figure 5 presents the 18 water surface profiles computed with HEC-RAS Version 5.0.7. In the report (Chen 2011), Chen presented Figure 6 comparing the modeled and the targeted stages at the Fort Meade and Bartow stations, which showed a close match of the stages. To verify whether HEC-RAS versions 4.0 and 5.0.7 produced identical results for Chen's 2011 model, the 50-percentile water surface profile was randomly chosen and 'Detailed Output Tables' from the two HEC-RAS versions were reviewed. The review revealed exactly matching results from the two versions as seen in Tables 3 and 4 for the River Station (RS) 588. The computed elevations for additional selected River Stations are as follows.

River Station	Computed Elevations by Two Versions of HEC-RAS
588	90.20 ft. NAVD
500	79.93
450	71.33
400	57.60
350	49.03
300	41.40
280	40.75

2.2 Summary and Conclusions

2.2.1 Review Existing HEC-RAS Steady Flow Model

In 2002, the District established MFLs for the UPR within its jurisdiction. Generalized data developed by the US Army Corps of Engineers' HEC-RAS computer model formed the basis for determining minimum flows for three locations in UPR (Bartow, Fort Meade, and Zolfo Springs). The model developed in 2001/2002, however, was based on somewhat limited resources (e.g., discharge and stage data, river cross sections).

In 2011, XinJian Chen of SWFWMD extensively revised the 2001/2002 UPR HEC-RAS model by using large number of field surveyed river cross sections and concurrent discharge records and performed model calibration as detailed earlier. BFA fully reviewed the model procedures used by Chen, and ran the model using two versions of HEC-RAS; HEC-RAS Version 4.0, the version originally used by Chen in 2011 in developing the model and Version 5.0.7, the current version (2019). BFA found that Chen's model executes smoothly by both versions of HEC-RAS. From these observations it is concluded that Dr. Chen's model is well developed.

2.2.2 Needed Improvements and Revisions

The UPR exhibits unsteady flow conditions as explained in the section "Need for Unsteady Flow Analysis". Therefore, an unsteady flow analysis that attempts to account for the unsteady nature of sinkhole losses, tributary and runoff inflows, base flows, and spatial and temporal variation of rainfall that occur in the river basin, could yield more accurate results. Adding unsteady flow analysis as a basis for the development or refinement of a steady flow model can improve the accuracy of the steady flow model results that are used in the MFLs analysis based on the modeling practices in support of MFLs evaluation reported and peer reviewed (SRWMD 2019; SWFWMD 2017).

The unsteady flow analysis has the capability to provide improved hydraulic parameters, such as Manning's roughness coefficient (n) that can be used as input for the steady flow model. Therefore, the steady flow model can provide more accurate results, such as water surface elevations or stage heights along the river for specific flow scenarios. The calibration and verification processes for the unsteady flow analysis can be used to adjust the hydraulic parameters to better predict the observed water surface elevations for selected periods of records that reflect the conditions that are more critical for the establishment of the MFLs. Also, the unsteady flow model can provide hydrographs and rating curves that can be used to develop boundary conditions for the steady flow model for selected cross sections where data is not readily available or incomplete. In addition, results of a two-dimensional (2-D) unsteady flow model, such as water levels across a given cross-section and flow exchange between the main channel and floodplain areas, can enhance the MFLs analysis.

The calibration and verification processes of the unsteady flow model requires running the model for a continuous time span that should reflect the conditions that are more relevant for the posterior analysis of MFLs, while considering the data requirements and limitations of the model, such as instability problems and handling very low flows, and limitations of the platform used for running the model and project time constraints.

In the UPR, between Bartow and Fort Meade gaging stations, very low or zero flows occur mainly at the end of the dry season. The unsteady flow model cannot have a zero base flow and the channel cannot become dry during a simulation. A minimum flow threshold value could be used at inflow boundaries to prevent the base flow from falling below a defined threshold, which could improve model stability. Also, model stability can be very sensitive to the computational time step. Modifying the computation time step can resolve this issue but also increase the time needed for running the model. Alternatively, the simulation time span could be separated in distinctive periods that reflect the conditions more likely to affect MFLs, while minimizing instabilities and avoiding zero flow issues, as well as optimizing model running time.

Acquiring the data required for the development of the unsteady flow model could become a difficult task. For example, there may not be readily available flow data for tributary and lateral inflows or it may be difficult to assess the sinkhole losses for the simulation period. For the lateral inflows, the unsteady flow model could compute lateral inflow hydrographs, which may be used as internal boundary conditions in the steady state model to represent inflow from tributaries at specific points or cross sections in the river. Alternative procedure could also be used to estimate the tributaries flow contributions (regression analysis, water budget, etc.). These efforts should focus on the inflows that have a larger impact on dynamics of the river system. As part of Task 3, BFA researched reported sinkhole data sources specifically within in the UPR (https://ca.dep.state.fl.us/mapdirect/?focus=fgssinkholes).

In order to improve both steady and unsteady flow analyses, additional cross sections and a longer period of record to perform the simulations may be needed. Also, future improvements and revisions should incorporate updated LiDAR, river bathymetric surveys and structures' geometric information, as well as updated information about sinkholes, water demands and tributary/lateral inflow, among other relevant information. Subsequently Sections 3, 4 and 5 provide better insight into the data and information needs and needed improvements and revisions of the UPR HEC-RAS model.

2.2.3 Additional Data and Information Needed

The discharge and stage data that are reviewed under Task 3 are about 9 years longer in record length compared to Chen's. In Task 3 the contents of Tables 1 and 2 were revised using current records and current USGS rating curves and may be recommended for use in the HEC-RAS model. Subsequently completed Tasks 4 and 5 provide information on new developments in the basin and assessment of need to revise HEC-RAS data to reflect these new occurrences.

The discharge data used in the HEC-RAS model, both HEC-RAS 2001/2002 and Chen's 2011 model, for generalized production of river-wide stage-discharge data was rather 'hypothetical.' The data assumes that discharges, at a chosen percentile, would occur simultaneously at all locations. This is very unlikely to occur because rainfall would be rarely uniform throughout the basin. This anomaly/shortcoming was acknowledged by Chen, and it is further examined/discussed under Section 3, specifically to find whether HEC-RAS unsteady flow modeling would remedy that situation.

2.2.4 Need for Unsteady Flow Analysis

Due to local karst features/sinkholes along the riverbed and floodplain in the UPR between Bartow and Fort Meade, there is stream flow lost to the groundwater system. Flow losses are larger during low stream conditions that usually occur in the spring dry season. On the other hand, south of Fort Meade there is good confinement between the river and the underlying aquifers and no major losses to the groundwater system (Basso, 2004). There are also tributary inflows along the river that can largely determine the quantity and timing of flow that discharges into a section/reach of the river. The impact of these tributaries on the UPR flows are more pronounced during low flow conditions. Channelization and control structures in some of these tributaries, for example in the Peace Creek Drainage Canal and Saddle Creek upstream of Bartow, affect the quantity and timing of the inflows to the UPR. During low-flow conditions, storage in these tributaries reduces the discharge into the UPR. This ponding effect has been also observed in naturally formed tributaries of the UPR that have flat low gradient. Also, surface water inflows include urban runoff through ditches during intense storm events, and reclaimed phosphate – mine channels and outfalls that supply water to the river except under extremely dry conditions. There are also distributary channels (Dover Sink Distributary and Gator Sink Distributary) that drain river water from the main channel under certain hydrologic conditions (Metz and Lewelling, 2009). Additionally, there are spatial and temporal variation of precipitation throughout the basin.

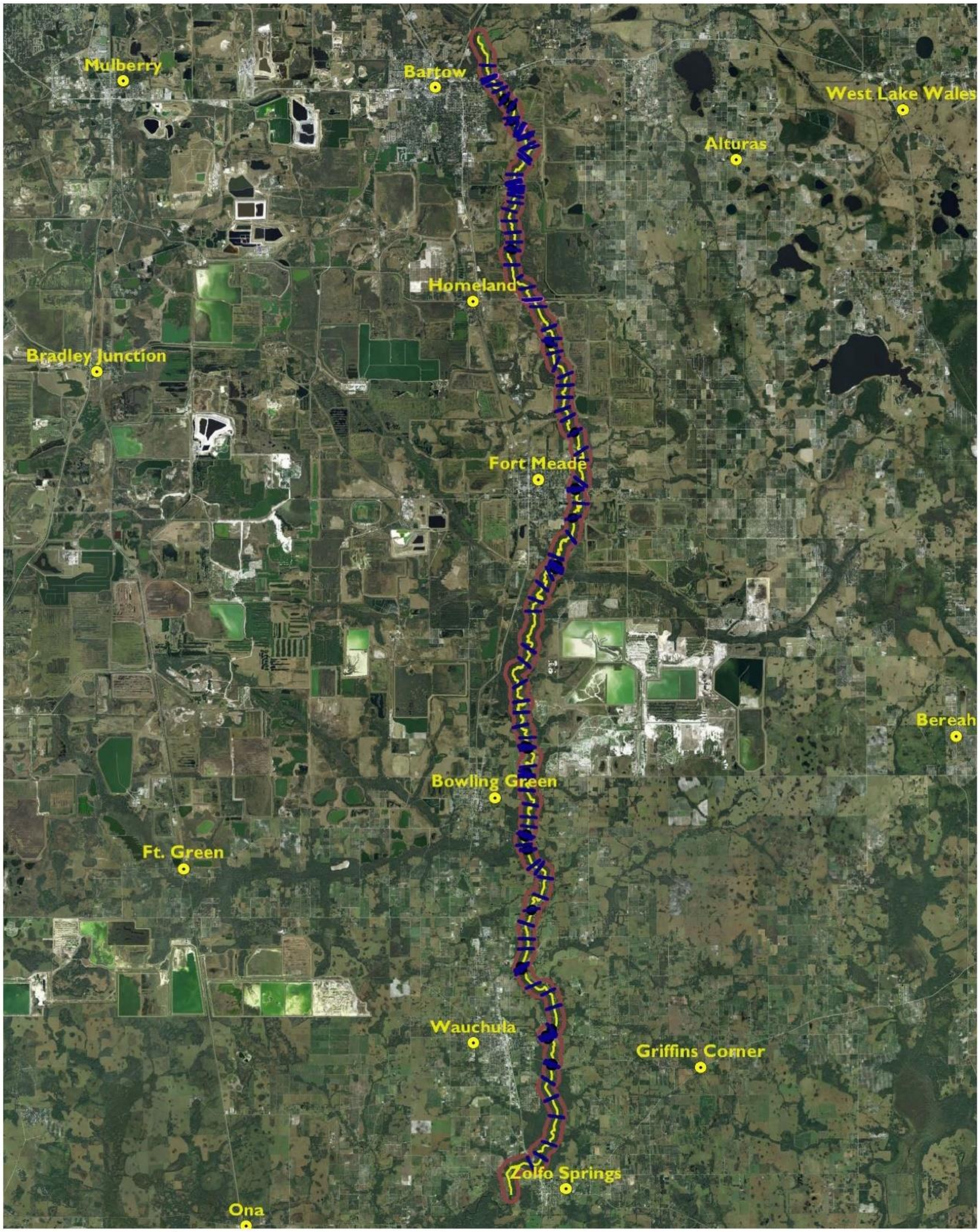
These characteristics imply that most of the time the actual river flow behaves as an unsteady flow, attenuating as it moves downstream. Consequently, the discharge-stage ratings at any cross section will be unique, and flow rates with the same exceedance percentage will not occur at the same time at all locations along the river.

The existing steady flow HEC-RAS model cannot adequately capture the unsteady features of the river, generally described above, By contrast the unsteady flow model could better account for the unsteady nature of the UPR and provides more accurate results. The calibrated unsteady flow model can provide a basis for the development/refinement of the steady flow model and subsequent modeling of flow scenarios. For example, the hydraulic properties, such as Manning's roughness coefficient (n), resulting from the calibration of the unsteady flow model can be used as input for the steady flow model to improve the accuracy of the simulated water surface elevation or stage heights. Also, the hydrographs and rating curves at specific cross-sections can be used to establish the boundary conditions for different steady-flow scenarios as needed for the MFLs analysis. In addition, the use of the 2-D model unsteady flow model can provide additional information that may improve the analysis of MFLs, such as water levels across a given cross-section and flow exchange between the main channel and floodplain areas.

BFA concluded that unsteady flow analysis will be needed in support of the UPR MFLs evaluation. More correctly both steady and unsteady flow analyses are required for a more complete reevaluation. Moreover, both steady and unsteady flow models will be needed for implementation and management of the adopted MFLs. Management of adopted MFLs routinely involves the assessment of potential impact of water management actions on the MFLs, specifically their potential to cause significant harm. Steady and unsteady flow analyses will be used to predict impacts to hydrologic regime of the UPR.

With the completion of Task 2 evaluations, BFA concludes**:**

1. The steady flow HEC-RAS model runs in the current version of the software. The model appears to be a stable platform for use in the MFLs reevaluation.
2. The steady flow model will be a good platform from which to develop an unsteady flow model.
3. BFA finds that it is wise and prudent for the District to continue with the development of both steady and unsteady flows models for this reevaluation
4. Data and information gaps have been identified. This needs analysis is interim, and will be expanded in the subsequent Tasks 3, 4 and 5.
5. This report's content, summary and recommendations are also interim, and will be finalized as part of the final report, the Task 6 final deliverable.
6. The expected next steps following acceptance of the TM by the District are then a continuation to subsequent Tasks 3 through 6.



BFA	Aerial Photo of the Upper Peace River with the locations of cross-sections (green points) used in the HEC-RAS model and provided Upper Peace River LiDAR Data (Chen, 2011)	Figure 3

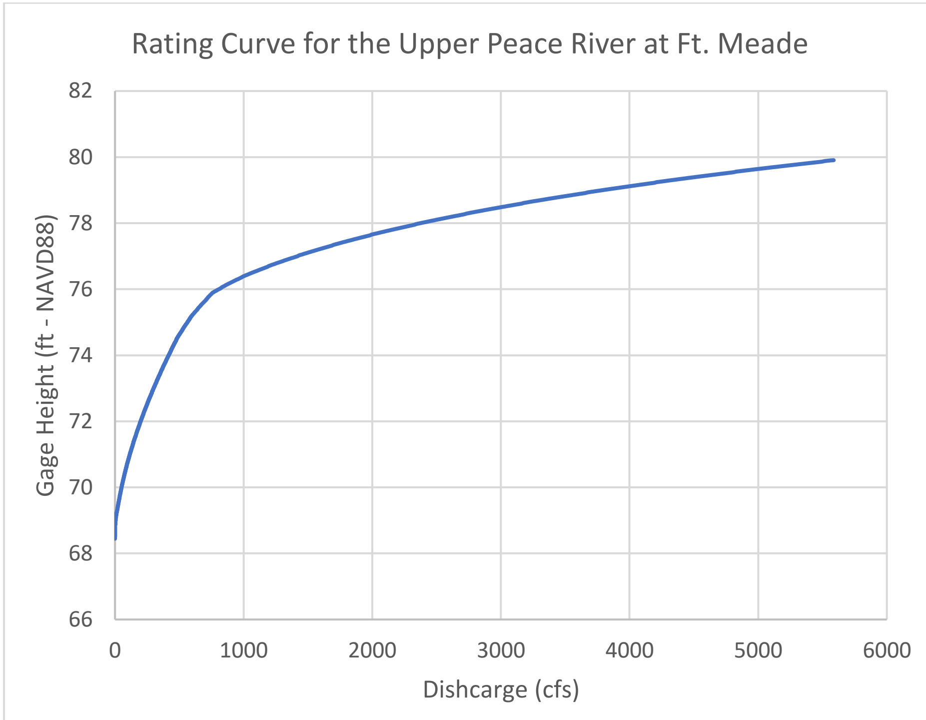


Figure 4 - Rating Curve for Upper Peace River at Fort Meade, Station 02294898

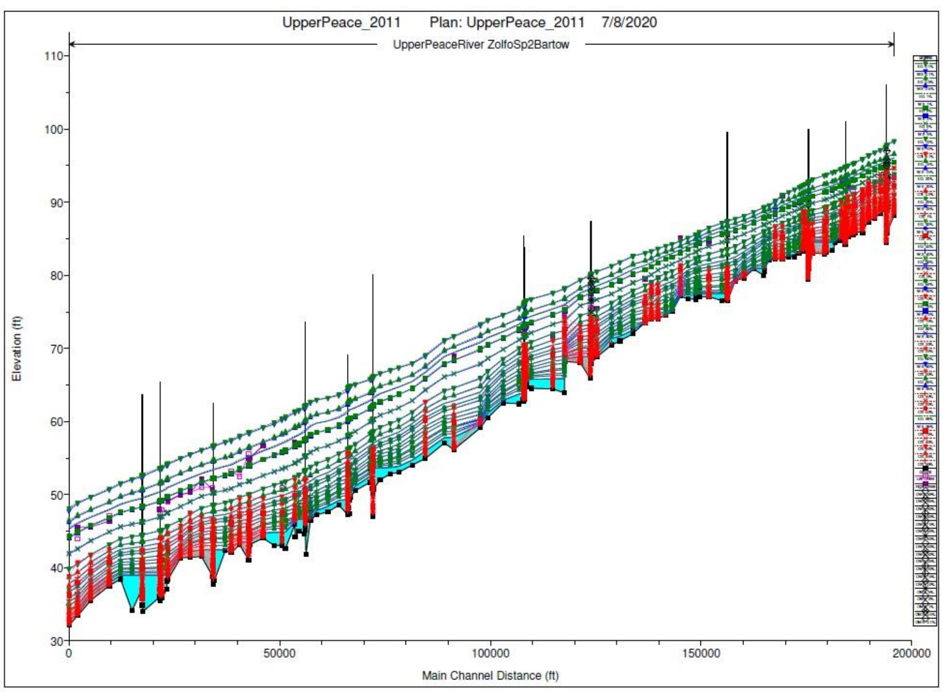


Figure 5 - Upper Peace River Water Surface Profiles by Chen's 2011 HEC-RAS Model Run, Version 5.0.7

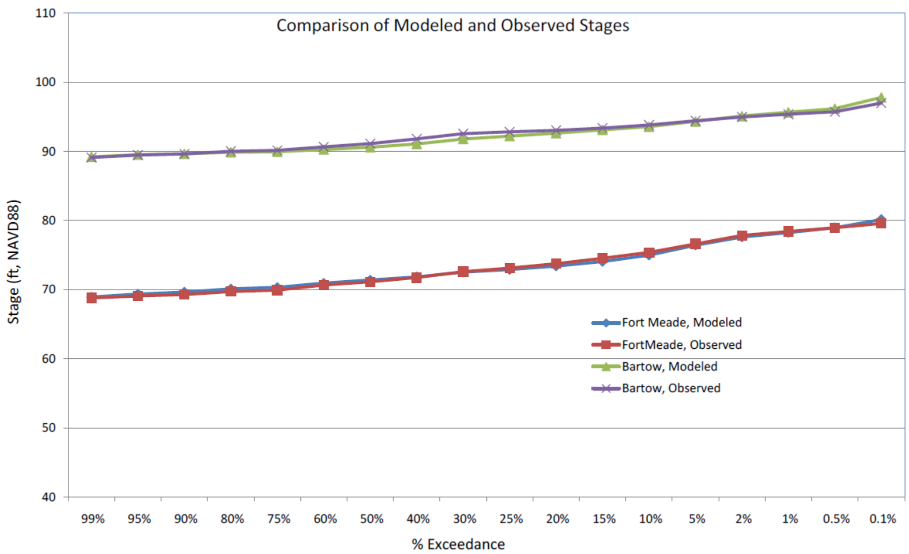


Figure 6 - Comparison of Modeled and Observed Stages at the Fort Meade and Bartow Stations for 18 Percent Exceedance Flows (Chen, 2011)

Table 1. Eighteen Different Percent Exceedance Flows at the USGS Zolfo Springs, Fort Meade, and Bartow Stations (Chen, 2011)

No.	Percent	Bartow Flow (cfs)	Fort Meade Flow (cfs)	Zolfo Springs Flow (cfs)
1	99.0	0.9	0.42	14
2	95.0	5.4	2.9	36
3	90.0	8.6	5.9	55
4	80.0	16	15	92
5	75.0	19	21	110
6	60.0	33	48	180
7	50.0	49	72	243
8	40.0	78	107	320
9	30.0	133	169	452
10	25.0	176	210	541
11	20.0	226	270	677
12	15.0	312	366	865
13	10.0	469	534	1170
14	5.0	756	881	1850
15	2.0	1090	1340	2920
16	1.0	1410	1600	3700
17	0.5	1732	1880	4570
18	0.1	3254	2230	6403

Table 2. Stages Corresponding to 18 Different Percent Exceedance Flows at the USGS Zolfo Springs, Fort Meade & Bartow Stations (Chen, 2011)

No.	Percent	Bartow Stage (ft)	Fort Meade Stage (ft)	Zolfo Springs Stage (ft)
1	99.0	89.131	68.792	32.800
2	95.0	89.470	69.075	33.220
3	90.0	89.650	69.280	33.520
4	80.0	90.030	69.710	34.000
5	75.0	90.160	69.920	34.200
6	60.0	90.660	70.650	34.860
7	50.0	91.130	71.140	35.360
8	40.0	91.830	71.740	35.900
9	30.0	92.565	72.610	36.705
10	25.0	92.830	73.110	37.190
11	20.0	93.057	73.760	37.845
12	15.0	93.380	74.545	38.665
13	10.0	93.825	75.385	39.840
14	5.0	94.450	76.627	41.900
15	2.0	94.980	77.850	44.110
16	1.0	95.380	78.410	45.310
17	0.5	95.743	78.960	46.220
18	0.1	96.992	79.570	47.803

NOTE: The datum for the stage values listed in Table 2 is NAVD88

Table 3. Detailed Output Table for River Station 588, HEC-RAS Version 4.0

E.G. Elev (ft)	90.21	Element	Left OB	Channel	Right OB
Vel Head (ft)	0.01	Wt. n-Val.		0.045	
W.S. Elev (ft)	90.20	Reach Len. (ft)	865.36	1338.07	1182.33
Crit W.S. (ft)	89.26	Flow Area (sq ft)		57.67	
E.G. Slope (ft/ft)	0.000532	Area (sq ft)		57.67	
Q Total (cfs)	49.00	Flow (cfs)		49.00	
Top Width (ft)	48.37	Top Width (ft)		48.37	
Vel Total (ft/s)	0.85	Avg. Vel. (ft/s)		0.85	
Max Chl Dpth (ft)	1.75	Hydr. Depth (ft)		1.19	
Conv. Total (cfs)	2125.4	Conv. (cfs)		2125.4	
Length Wtd. (ft)	1338.07	Wetted Per. (ft)		48.92	
Min Ch El (ft)	88.45	Shear (lb/sq ft)		0.04	
Alpha	1.00	Stream Power (lb/ft s)		0.03	
Frctn Loss (ft)	0.17	Cum Volume (acre-ft)	2.64	778.84	1.76
C & E Loss (ft)	0.00	Cum SA (acres)	3.53	334.10	3.54

Plan: UPR_2011 UpperPeaceRiver ZolfoSp2Bartow RS: 588 Profile: 50%

Table 4. Detailed Output Table for River Station 588, HEC-RAS Version 5.0.7

E.G. Elev (ft)	90.21	Element	Left OB	Channel	Right OB
Vel Head (ft)	0.01	Wt. n-Val.		0.045	
W.S. Elev (ft)	90.20	Reach Len. (ft)	865.36	1338.07	1182.33
Crit W.S. (ft)	89.26	Flow Area (sq ft)		57.67	
E.G. Slope (ft/ft)	0.000532	Area (sq ft)		57.67	
Q Total (cfs)	49.00	Flow (cfs)		49.00	
Top Width (ft)	48.37	Top Width (ft)		48.37	
Vel Total (ft/s)	0.85	Avg. Vel. (ft/s)		0.85	
Max Chl Dpth (ft)	1.75	Hydr. Depth (ft)		1.19	
Conv. Total (cfs)	2125.40	Conv. (cfs)		2125.40	
Length Wtd. (ft)	1338.07	Wetted Per. (ft)		48.92	
Min Ch El (ft)	88.45	Shear (lb/sq ft)		0.04	
Alpha	1.00	Stream Power (lb/ft s)		0.03	
Frctn Loss (ft)	0.17	Cum Volume (acre-ft)	2.64	778.84	1.76
C & E Loss (ft)	0.00	Cum SA (acres)	3.53	334.10	3.54

Plan: UPR_2011 UpperPeaceRiver ZolfoSp2Bartow RS: 588 Profile: 50%

Section 3 - Existing Flow and Stage Data in the Upper Peace River

3.1 Relevance of Flow and Stage Data to the Unsteady HEC-RAS Model

Stage and discharge records for the Upper Peace River Basin are available for three long-term gaging stations on the main stem of the river and a number of short-term stations located on the main channel and tributaries (Figure 2). The three long-term stations from upstream to downstream are:

1. PEACE RIVER AT SR 60 AT BARTOW, FL
2. PEACE RIVER AT FORT MEADE, FL
3. PEACE RIVER AT US 17 AT ZOLFO SPRINGS, FL

USGS is the primary source of stage and discharge data for the UPR basin. For both long-term and short-term stations, Tables 5a and 5b summarize station reference data such as site name, latitude and longitude, USGS site ID, drainage area, geodetic datum of gage location and parameter, etc. The discharge and stage data available from these stations form the basis for the unsteady flow model calibration and simulation and for determining boundary conditions.

The flow profiles used in the steady flow HEC-RAS model, both HEC-RAS 2001/2002 and Chen's 2011 model, for generating generalized river-wide stage-discharge data was rather 'hypothetical.' The flow profiles were prepared with assumption that discharges, at a chosen percentile, would occur simultaneously at all locations, which may not be true. This assumption/approach, however, has become a typical practice in many freshwater system MFLs analysis. Improvements in flow profile development could be considered as part of future study since it is beyond the scope of this project.

For the MFLs determination, WMDs are now developing a dynamic (unsteady flow) HEC-RAS model first and then performing the steady flow HEC-RAS modeling based on the dynamic HEC-RAS model to produce the needed generalized discharge/stage data for establishing MFLs. The dynamic HEC-RAS model will be based on concurrent discharges and stages to tune in geometric data, calibrate model parameters such as Manning's roughness coefficient, and estimate lateral surface runoffs, hence, it will help improve the model accuracy. Examples of the MFLs projects that used the preceding procedures are: 1) Recommended Minimum Flow for Rainbow River System (SWFWMD, 2017) and 2) MFLs re-evaluation for the Lower Santa Fe and Ichetucknee Rivers (SRWMD, 2019). The District intends to follow similar procedures for the UPR MFLs re-evaluation. The objective of this section of the report is a review of the available stage and discharge data for the UPR and determine suitability of the data for conducting a dynamic HEC-RAS model for the UPR.

3.1.1 Discharge Records for the Long-Term Gaging Stations of the UPR

Discharge records for Peace River at Bartow began from 10/1/1939, Fort Meade from 6/1/1974 and Zolfo Springs from 9/1/1933 and the stations are current. Since the common period for the three stations began on 6/1/1974, for his steady flow HEC-RAS model Chen (2011) chose the discharge data starting from 6/1/1974. Chen also gave additional reasons for excluding data prior to 6/1/1974 as explained in the earlier sections of this report. This report, however, reviews and analyzes discharge and stage data for the entire period of record with additional focus on data for the period 6/1/1974 - 5/31/2020.

The period of record discharge hydrographs for Bartow and Zolfo Springs stations indicate that generally higher discharges occurred during the 1940s to 1960 and again from around 1994, Fort Meade joining the trend from 1995 (Figures 7 - 9, the annual mean discharges shown in these figures are the USGS Water Year discharges). Although no rainfall analyses are performed as part of this report, it may be stated that the higher discharges for the indicated periods are the result of the climatic conditions of the time. Enfield et al. (2001) showed that variation in the North Atlantic sea surface temperatures (SSTs), commonly denoted by the phrase Atlantic Multidecadal Oscillation (AMO), has a bearing on the rainfall/streamflow occurrences in South Florida; specifically, higher SSTs caused higher rainfall and the lower SSTs caused lower rainfall. Developing an updated AMO graph using the January 1856 - December 2009 SST data (Figure 10), Rao (2011) studied the effects of AMO on Northeast Florida and found that there is a strong qualitative resemblance between AMO and the rainfall and streamflow patterns of Northeast Florida. A warm phase of North Atlantic SSTs occurred during 1928 - 1965 and another warm phase commenced in 1994 and the discharges in the UPR closely followed the AMO phases. Thus, this North Atlantic SST phenomenon satisfactorily explains the occurrence of higher discharges in the UPR during the respective AMO warm phases.

As observed, the UPR experienced significant wet conditions during the early years of its records. Kelly and Gore (2008) also studied the effects of AMO on peninsular Florida river flows and rainfall, especially in the context of MFLs. They emphasize the importance of selecting an appropriate baseline flow period (for MFLs analysis) and suggest that it may be appropriate to have at least two baseline periods; one based on a wet period and one based on a dry period.' They also state:

> *These results have important implications not only for the establishment of ecological flows, but also for water supply planning and development, flood control and stream ecology in general, since there are considerable differences in the magnitude of flows that should naturally be expected between multidecadal periods. Relatively large decreases and increases in flow are attributable to rainfall differences between multidecadal periods.*

As per SWFWMD, minimum flows associated with medium and high flow ranges were not determined for the UPR and they will be developed as part of the reevaluation of the UPR MFLs that is currently scheduled for 2025. Therefore, the data selected for the scheduled reevaluation of MFLs should be sufficiently representative of the medium and high flows. Bartow and Zolfo Springs gaging stations have common discharge records from 10/1/1939 to the present. The missing period records for Fort Meade (10/1/1939 to 5/31/1974) may be estimated by a correlation of Bartow – Fort Meade discharges (Figure 11) by developing two or three regression relationships for different ranges of discharges in Figure 11, Fort Meade discharges for the period 10/1/1939 to 5/31/1974 may be estimated; the estimated discharges may not be a replica of the discharges occurred, but they may sufficiently capture the medium and high flows. In Figure 11, the lower line is a linear relationship and the upper line is a power equation, both lines for the same data. We may choose different regression equations for different ranges of data, say, linear for the Bartow discharges below 1,500 cfs, and the power equation for the higher flows. Further comments are made later, in Section 3.1.6 on improving the available data.

As an additional note, the District's Lake Hancock Lake Level Modification Project was completed in 2013. The goal of this project is to store additional water in Lake Hancock to meet minimum flow requirements in the UPR. The project practically imposes some impacts on the streamflow of the Peace River because Lake Hancock is located at the headwaters of the Peace River. Yang et al. (2020) thoroughly presented and modeled such impacts. Consideration of the impacts on the streamflow in this report is beyond of the scope of this project, but is necessary in the future model development and historical streamflow related analysis on the Peace River.

3.1.2 Stage Records for the Long-Term Gaging Stations of the UPR

Stage data for the UPR is available from the USGS database both as gage heights in feet (ft) and also as stream water level elevation in ft NAVD for Bartow, Fort Meade and Zolfo Springs. BFA downloaded these data for the period of record and converted gage heights to ft NAVD by adding the respective datum values. The datum values are 86.70 feet above NAVD88 for Bartow gaging station and 30.20 feet above NGVD29 for Zolfo Springs and the source of these datum values are available at https://waterdata.usgs.gov/nwis/inventory/?site_no=02294650&agency_cd=USGS. Fort Meade NGVD stages are converted to NAVD by subtracting a value of 0.954 ft and Zolfo Springs NGVD stages are converted to NAVD by subtracting a value of 1.01; these correction factors were confirmed by SWFWMD. These corrections factors may vary from the ones used and published by the USGS.

Figures 12 through 14 present stage hydrographs for the period of record for the three long-term gaging stations. The plots of stage data obtained by adding their respective datum value uniformly for the full period of record, however, showed an upward shift by three ft from May 1, 1975 for Bartow and five feet from October 1, 1964 for Zolfo Springs (Figures 12a and 14a). When contacted, the USGS drew the attention of BFA to the water year summary pages for each site, and the following comments were found.

Bartow: https://waterdata.usgs.gov/fl/nwis/wys_rpt/?site_no=02294650&agency_cd=USGS
GAGE - Water-stage recorder. Datum of gage is 87.56 ft above National Geodetic Vertical Datum of 1929 and 86.70 ft above North American Vertical Datum of 1988. Prior to July 12, 1940, nonrecording gage and July 12, 1940, to Nov. 5, 1948, water-stage recorder at site 200 ft downstream; prior to May 1, 1975, at datum 3.00 ft higher.

Zolfo Springs: https://waterdata.usgs.gov/fl/nwis/wys_rpt/?site_no=02295637&agency_cd=USGS
GAGE - Water-stage recorder. CSG (crest stage gage) on left bank. Datum of gage is 30.20 ft. above National Geodetic Vertical Datum of 1929. Prior to Oct. 1, 1964, the datum of the gage was 5.00 ft. higher.

The corrected stage data plots for Bartow and Zolfo Springs are shown by Figures 12b and 14b, respectively. Stage records show the same trend as discharges, with generally higher stages occurring during the AMO warm periods. Daily stage hydrographs exhibit the wide stage fluctuations occurring in the river while the annual means are rather subdued stage values. Figures 12c and 14c do not show mean annual stages for the years prior to 1942 and for some later years because minor data gaps occurred in the stage data and USGS does not compute the mean annual stages for such years. The USGS, however, estimates the discharge values corresponding to the days with the missing stage values by suitable interpolation of discharge data and thus the mean annual discharge values are available as seen in the figures presented earlier (Figures 7b, 8b, and 9b).

3.1.3 Flow Duration Curves for the Long-Term Gaging Stations of the UPR

Flow duration curves have a major role in determining discharges for the HEC-RAS steady flow model; the discharge values for different percentiles are drawn from the flow duration curves. Figures 15 and 16 are the flow duration curves for Bartow and Zolfo Springs gaging stations, respectively, for the data period 10/1/1939 – 5/31/2020; these graphs started on 10/1/1939 because that is the start of the common period for Bartow and Zolfo Springs stations. Figures 17 – 19 are the flow duration curves for Bartow, Fort Meade, and Zolfo Springs gaging stations, respectively, for the data period 6/1/1974 – 5/31/2020. Flow duration curves for the data period 10/1/1939 – 5/31/2020 have greater discharge ranges compared to 6/1/1974 – 5/31/2020 period because of the occurrence of higher discharges during 1939 to early 1960s (AMO warm period). Table 6 summarizes the 20, 40, 60, and 80 percentile discharge values from these flow duration curves. As may be observed, the discharge values for the chosen four percentiles are higher for the period 10/1/1939 – 5/31/2020, indicating thereby the period 6/1/1974 – 5/31/2020 is not representative of higher and medium flows, hence not suitable for MFLs re-evaluation.

3.1.4 Discharge Rating Curves for the Long-Term Gaging Stations of the UPR

USGS uses discharge rating curves for computing daily or continuous discharges for a given gaging station by relating gage heights and the measured discharges for the station. These rating curves are updated periodically by re-measuring discharges. BFA downloaded the rating curves for Bartow on 06/11/2020 (Figure 20) and for Fort Meade (Figure 21) and Zolfo Springs (Figure 22) on 06/08/2020; the rating curves are regarded as 'current' for the dates they were downloaded. These rating curves are useful to determine stages that may be currently experienced under a given discharge. For the steady state HEC-RAS model the discharges of interest for given gaging station are determined from the selected flow duration curves and the corresponding stages may be obtained from the rating curves.

3.1.5 Streamflow Losses to Sinkholes in the UPR

A number of studies identified/documented streamflow loss through sinkholes in the UPR reach between Bartow and Fort Meade gaging stations. Some of these publications are:

Basso, R.J., 2004, An Evaluation of Stream Flow Loss during Low Flow Conditions in the Upper Peace River, Southwest Florida Water Management District.

Knochenmus, L. A. and Sava, L.A., 2003, Streamflow Losses through Karst Features in the Upper Peace River Hydrologic Area, Polk County, Florida, May 2002-May 2003, USGS Fact Sheet 102-03.

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

Metz, P.A., and Lewelling, B.R., 2009, Hydrologic Conditions that Influence Streamflow Losses in a Karst Region of the Upper Peace River, Polk County, Florida: U.S. Geological Survey Scientific Investigations Report 2009-5140.

Spechler, R.M., and Kroening, S.E., 2007, Hydrology of Polk County, Florida: U.S. Geological Survey Scientific Investigations Report 2006-5320.

The USGS report by Metz and Lewelling is a detailed report, and the following are some excerpts from the report:

> *"Seepage runs conducted along the upper Peace River, from Bartow to Fort Meade, indicate that the greatest streamflow losses occurred along an approximate 2-mile section of the river, beginning about 1 mile south of the Peace River at Bartow gaging station. Along the low-water and floodplain channel of this 2-mile section, there are about 10 prominent karst features that influence streamflow losses. Losses from the individual karst features ranged from 0.22 to 16 cubic feet per second based on measurements made between 2002 and 2007. Along the upper part of this 2-mile section the largest and most consistent streamflow losses occurred at the Ledges Sink, with measured losses ranging from 1 to 8 cubic feet per second. At the end of this 2-mile section is the most influential karst feature along the upper Peace River, Dover Sink, which had measured losses ranging from 2 to 16 cubic feet per second. The largest measured flow loss for all the karst features was about 50 cubic feet per second, or about 32 million gallons per day, on June 28, 2002."*
>
> *"During this investigation, most karst features were altered to some degree due to depositional processes, such as scouring and sediment infilling. During 2002, many karst features were exposed and could be easily identified. However, subsequent field surveys after the 2004 hurricane season and the high-water period of 2005 indicated that some karst features had silted in and had become unidentifiable."*

A broad conclusion from the foregoing observations is that streamflow loss to sinkholes in the UPR downstream of Bartow gaging station is not a systematic process, but rather an irregular process mainly because the Karst features causing the streamflow loss are not constant but varying. For this reason, no satisfactory criteria can be formulated to apply a correction to streamflow data at Fort Meade, either the past or the ongoing USGS monitored data. This issue will be re-visited in the next section.

3.1.6 Investigation of Discharges and Stages for the Period 6/1/1974 - 5/30/2020

Developing a dynamic HEC-RAS model for the entire period of record may not be practical and the District/modelers may choose some representative periods from the total length of record for modeling. The common period for the three long-term gaging stations on the UPR began on 6/1/1974, and the river also has a few short-term stations in the later years. For a greater understanding of data, the period 6/1/1974 – 5/30/2020 is divided into four segments and the discharge and stage hydrographs developed (Figures 23 – 26). In general, Fort Meade discharges are not substantially higher than Bartow discharges. Further, Bartow discharges are greater than Fort Meade discharges on a number of days, including zero flows at Fort Meade. Very likely, the primary reason for the Fort Meade discharges lower than Bartow discharges is the loss of flow to sinkholes in this reach of the river and lack of any discharge contribution by tributaries (Figure 2). For the HEC-RAS modeling purposes, Fort Meade discharges may be made compatible to Bartow discharges by an ad hoc procedure. It is suggested that when Fort Meade discharges are below Bartow discharges, add, for example, one (1) to 10 cfs to Bartow discharges and treat them as Fort Meade discharges. The discharge value added will be based on the magnitude of Bartow discharges. A more detailed study also may be conducted by collecting data on sinkhole losses measured by different past investigators and relating the losses to the observed discharges at Fort Meade. The corrected discharges may be used in developing the Bartow-Fort Meade discharge correlation (Figure 11).

Overall, Zolfo Springs discharges are much higher than Fort Meade discharges probably because of the contribution by the tributaries (Figure 2). The stage hydrographs of the three gaging stations exhibited the trends of discharge hydrographs.

The numerous rapidly rising/falling discharge and stage hydrographs (Figures 23 - 26) are an indication that the flow is generally unsteady. There are, however, some more or less stationary flow (horizontal) segments in the hydrographs, which are generally low flows and may be regarded as steady gradually varied flows.

3.2 Recommended Additional Flow and Stage Data

The HEC-RAS steady flow model data developed by Dr. Chen (2011) needs revision to reflect the available stage and discharge data at the time of the updated model development. This report also identifies the need to extend a number of river cross sections that did not sufficiently cover the floodplain on one or both sides of the main river, by bathymetric survey and/or LiDAR. BFA, however, does not see a need for establishing additional gaging stations on the main river or tributaries unless the District intends to develop MFLs for additional locations. The HEC-RAS unsteady flow model requires lateral inflow data for modeling and the following is a description of the available data and suggestions for using it expeditiously.

Along the path of the UPR, surface waters enter the river as tributary inflows, directly entering surface runoff (as distinguished from tributary inflows), direct rainfall and by the storm drains, if any. Regarding storm drains discharging into the UPR, BFA made extensive inquiries from Hardee and Polk counties including verifying the MS4 (Municipal Separate Storm Sewer System) data; it is found that no storm drains discharge into the UPR.

In the study area, UPR has seven tributaries discharging runoff into it, three major tributaries between UPR at Bartow and Fort Meade gaging stations: Six Mile Creek at Bartow FL, Phosphate Mine Outfall CS-8 Near Bartow FL, and Barber Branch near Homeland FL; and four major tributaries between Fort Meade and Zolfo Springs gaging stations: Whidden Creek near Fort Meade FL, Bowlegs Creek near Fort Meade, Payne Creek near Bowling Green FL, and Little Charlie Creek near mouth near Wauchula FL (Figure 2b and Table 5b). The USGS monitors stage and discharge data on all seven tributaries and the gages are current (Table 5b). Little Charlie Creek has the shortest record starting from 9/30/2012 while all other gages have records exceeding 18 years of data with Payne Creek having the longest record starting from 10/1/1963. These data, however, are not downloaded or analyzed in anyway by BFA.

While the gaged discharge data on the aforementioned seven tributaries provide spot hydrographs, generating the required lateral inflow hydrographs at different transects as input data for the unsteady flow HEC-RAS model would require additional calculations. A hydrograph based on the daily discharge differences between the UPR at Bartow and Fort Meade gaging stations is essentially the accumulated lateral inflow hydrographs at all the transects between the two gaging stations. Using the spot hydrographs data from the tributaries and apportioning the discharge differences between Bartow and Fort Meade gaging stations among the various transects based on the intervening drainage areas, the lateral inflow hydrographs for various transects between the two gaging stations can be generated; a correlation based on rainfall distribution is also possible. The preceding procedure may also be applied to generate lateral inflow hydrographs for the transects between Fort Meade and Zolfo Springs gaging stations.

In conclusion, BFA believes that the UPR basin has sufficient gaged stage and discharge data to develop both HEC-RAS unsteady and steady flow models using additional calculations.

3.3 Recommendation on the Period of Unsteady Flow Simulation in the HEC-RAS Model

For the HEC-RAS unsteady flow modeling, following the recommendation of Kelly and Gore (2008), BFA believes the modelers should consider choosing a wet period (1994-2006) and a dry period (1984-1994). In addition, the period starting from 6/1/2010 (Figure 26b) also may be considered because two intermediate/short-term gaging stations became operational during this period and this would provide a stronger streamflow database for modeling.

3.4 HEC-GeoRAS

USACE Hydrologic Engineering Center and the Environmental Systems Research Institute, Inc. (ESRI) developed HEC-GeoRAS to aid HEC-RAS geometric data development and for enhanced presentation and viewing of numerous HEC-RAS results (HEC 2009). HEC-GeoRAS is essentially an ArcGIS extension aiding HEC-RAS model. The following is cited from https://www.hec.usace.army.mil/software/hec-georas/.

"HEC-GeoRAS is a set of procedures, tools, and utilities for processing geospatial data in ArcGIS using a graphical user interface (GUI). The interface allows the preparation of geometric data for import into HEC-RAS and processes simulation results exported from HEC-RAS. To create the import file, the user must have an existing digital terrain model (DTM) of the river system in the ArcInfo TIN format. The user creates a series of line themes pertinent to developing geometric data for HEC-RAS. The themes created are the

Stream Centerline, Flow Path Centerlines (optional), Main Channel Banks (optional), and Cross Section Cut Lines referred to as the *RAS Themes*. Additional RAS Themes may be created/used to extract additional geometric data for import in HEC-RAS. These themes include Land Use, Levee Alignment, Ineffective Flow Areas, and Storage Areas.

Water surface profile data and velocity data exported from HEC-RAS simulations may be processed by HEC-GeoRAS for GIS analysis for floodplain mapping, flood damage computations, ecosystem restoration, and flood warning response and preparedness."

This section is provided for information only.

Figure 7a. Mean Daily Discharges for the Upper Peace River at Bartow, 11/1939-6/2020

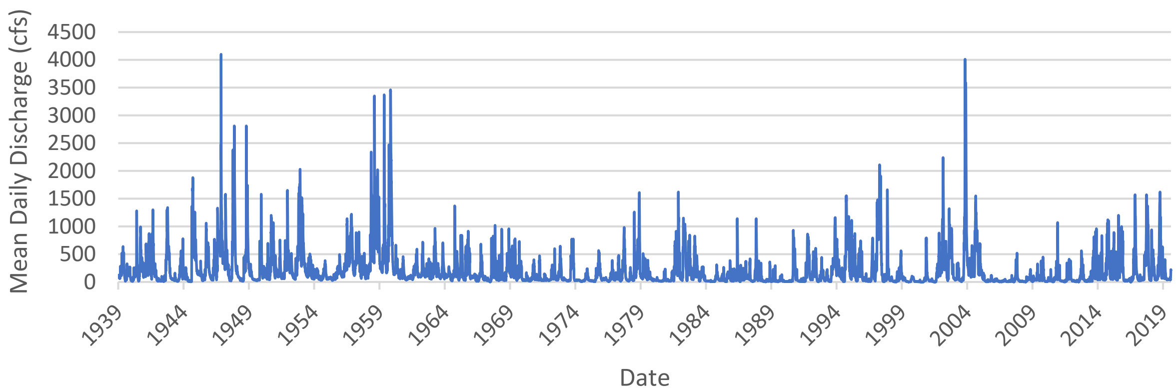
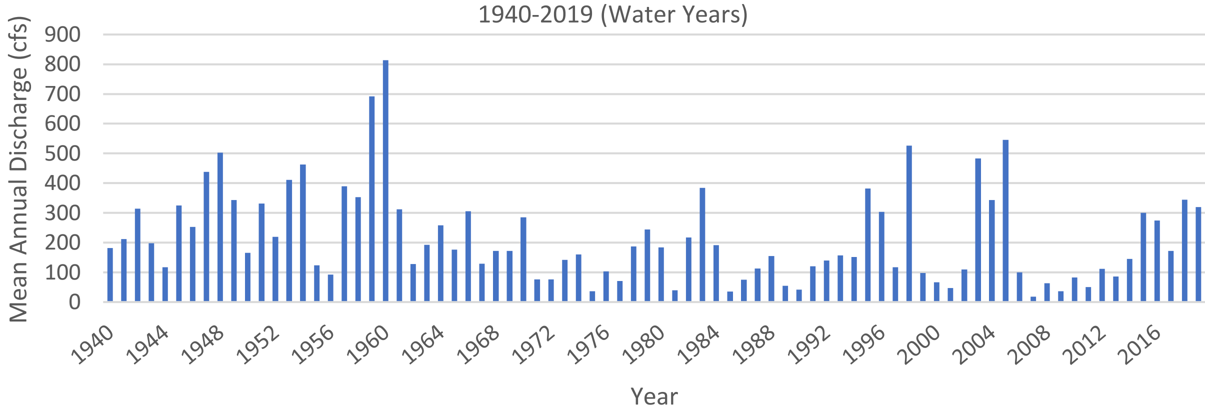


Figure 7b. Mean Annual Discharges for the Upper Peace River at Bartow, 1940-2019 (Water Years)



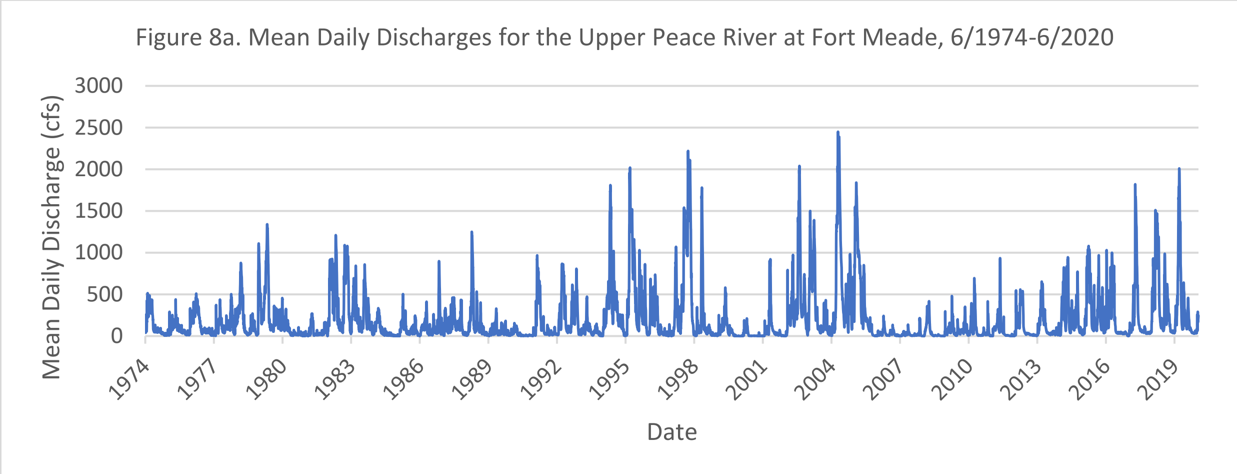


Figure 8a. Mean Daily Discharges for the Upper Peace River at Fort Meade, 6/1974-6/2020
Mean Daily Discharge (cfs)
3000
2500
2000
1500
1000
500
0
1974 1977 1980 1983 1986 1989 1992 1995 1998 2001 2004 2007 2010 2013 2016 2019
Date

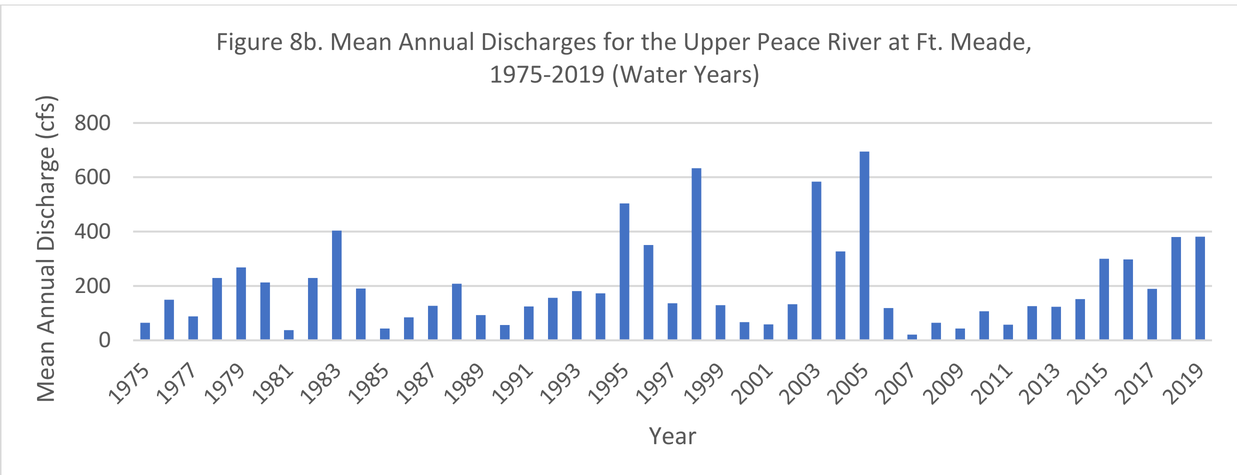


Figure 8b. Mean Annual Discharges for the Upper Peace River at Ft. Meade, 1975-2019 (Water Years)
Mean Annual Discharge (cfs)
800
600
400
200
0
1975 1977 1979 1981 1983 1985 1987 1989 1991 1993 1995 1997 1999 2001 2003 2005 2007 2009 2011 2013 2015 2017 2019
Year

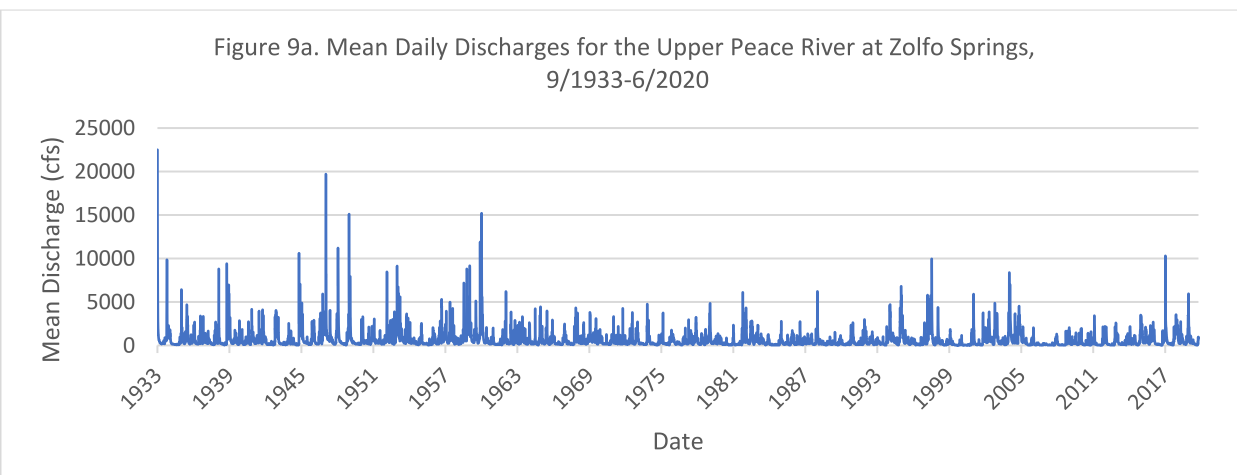
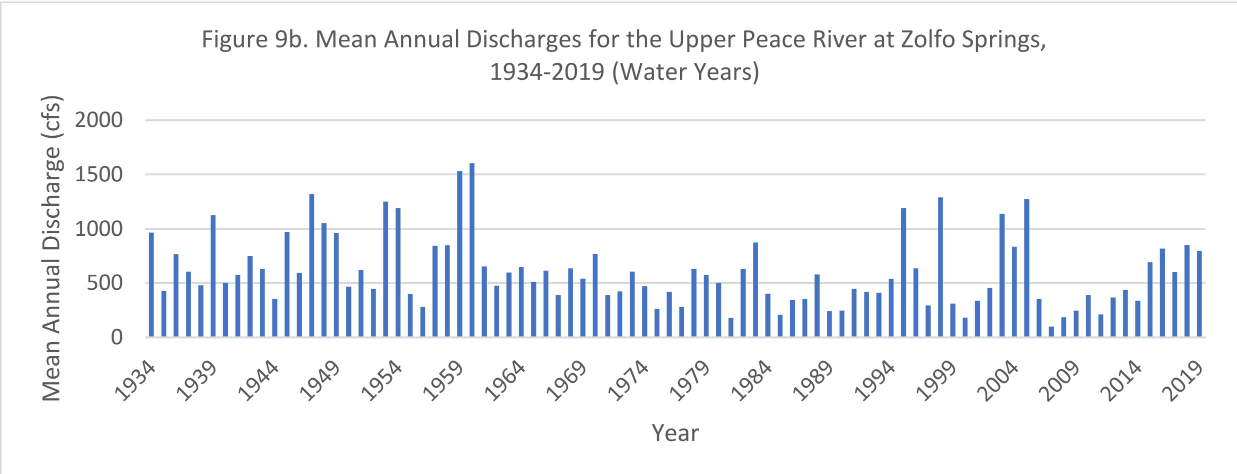


Figure 9a. Mean Daily Discharges for the Upper Peace River at Zolfo Springs, 9/1933-6/2020
Mean Discharge (cfs)
25000
20000
15000
10000
5000
0
1933 1939 1945 1951 1957 1963 1969 1975 1981 1987 1993 1999 2005 2011 2017
Date



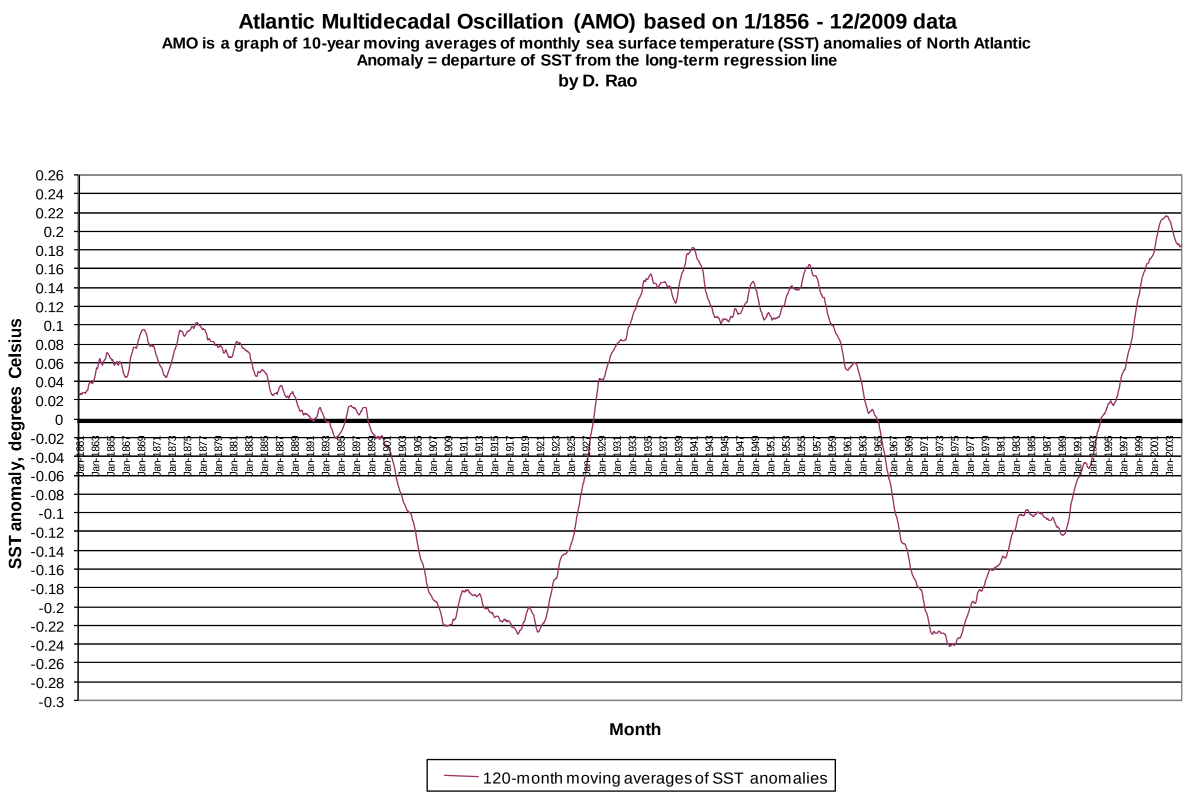


Figure 10. Atlantic Multidecadal Oscillation, AMO (Source: Rao, SJRWMD 2011)

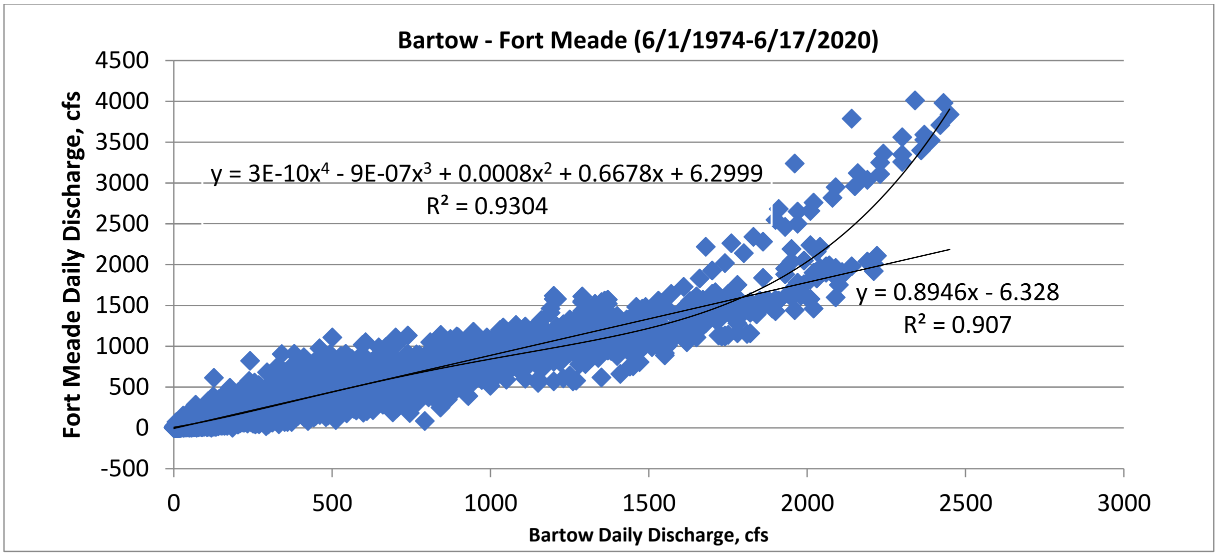


Figure 11. Bartow - Fort Meade Discharge Correlation

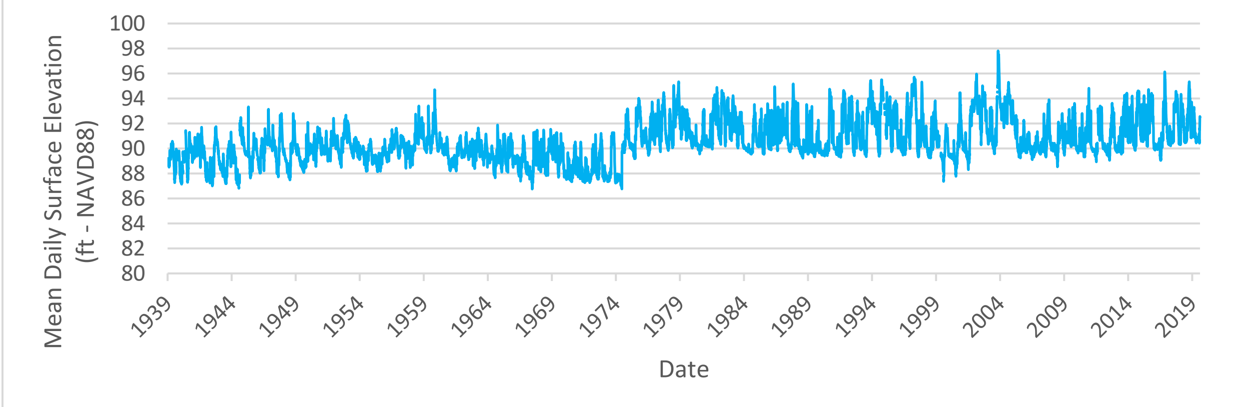


Figure 12a. Mean Daily Surface Elevation for the Upper Peace River at Bartow, 1939-2020

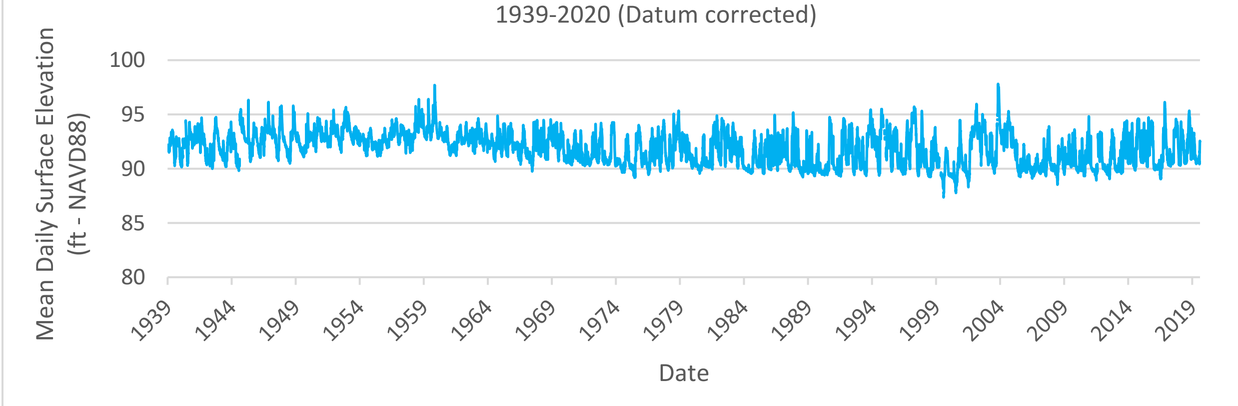


Figure 12b. Mean Daily Surface Elevations for the Upper Peace River at Bartow, 1939-2020 (Datum corrected)

Figure 12c. Mean Annual Surface Water Elevations for the Upper Peace River at Bartow, 1942-2019 (Water Years)

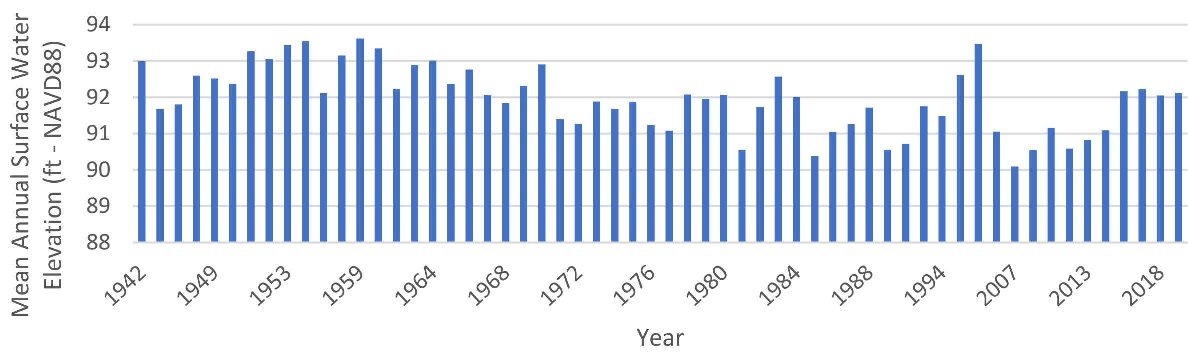


Figure 13a. Mean Daily Surface Water Elevations for the Upper Peace River at Ft. Meade, 1974-2020

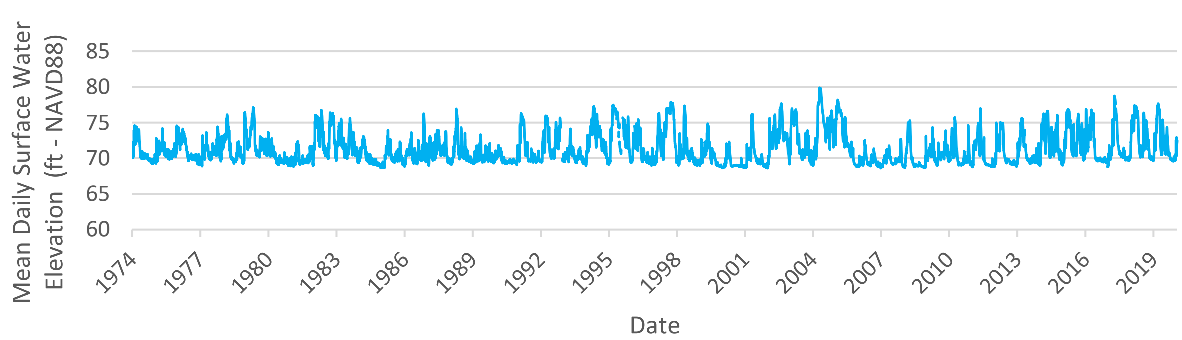
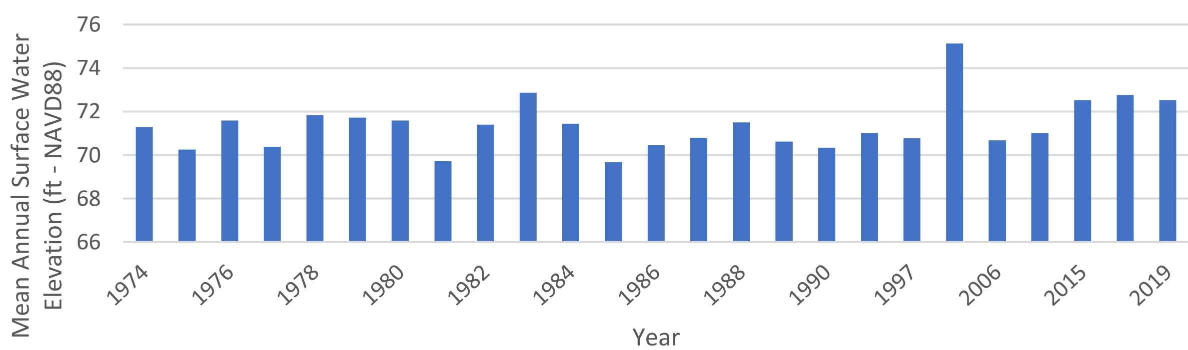


Figure 13b. Mean Annual Surface Water Elevations for the Upper Peace River at Ft. Meade, 1974-2019 (Water Years)



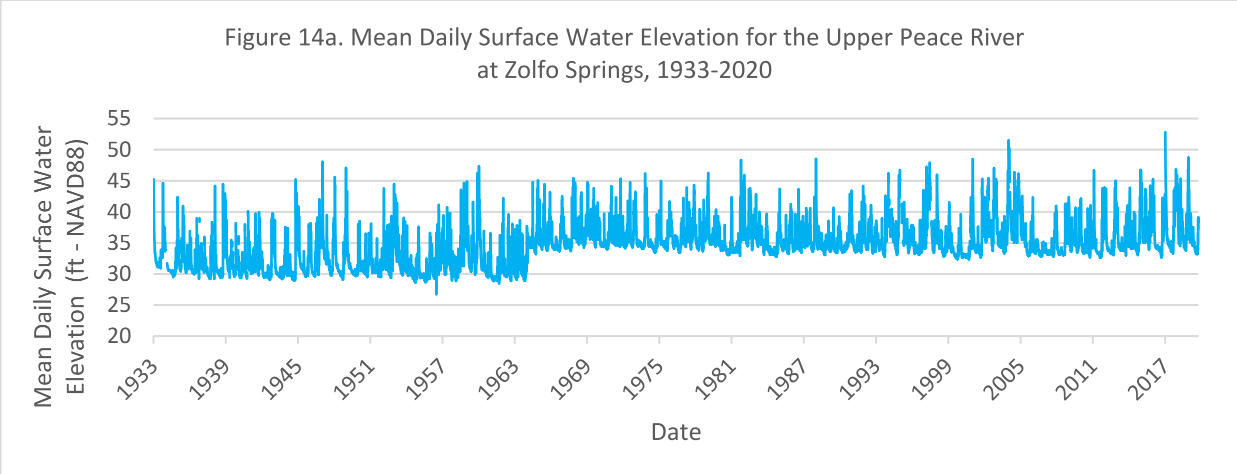


Figure 14a. Mean Daily Surface Water Elevation for the Upper Peace River at Zolfo Springs, 1933-2020
Mean Daily Surface Water Elevation (ft - NAVD88)
55
50
45
40
35
30
25
20
1933
1939
1945
1951
1957
1963
1969
1975
1981
1987
1993
1999
2005
2011
2017
Date

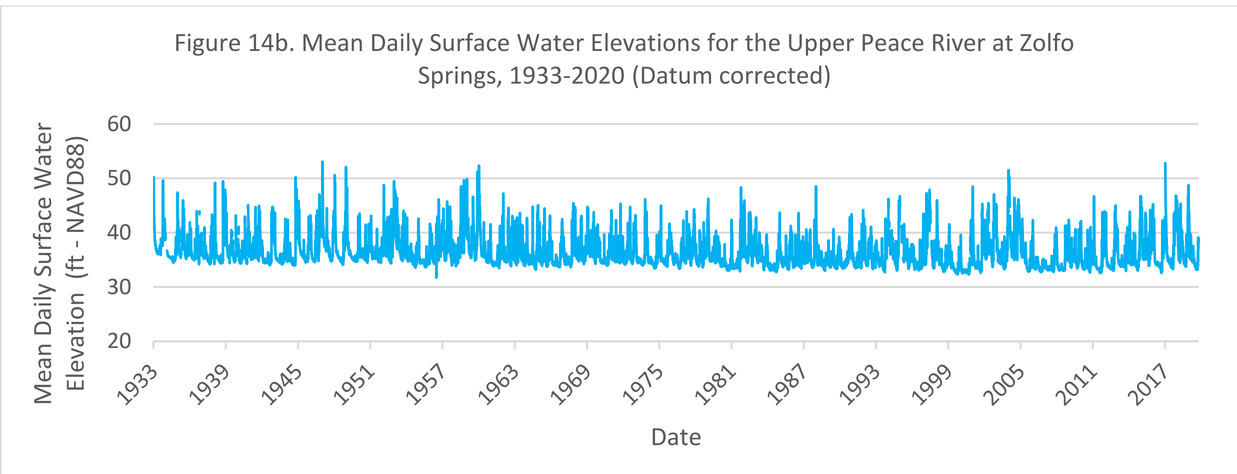


Figure 14b. Mean Daily Surface Water Elevations for the Upper Peace River at Zolfo Springs, 1933-2020 (Datum corrected)
Mean Daily Surface Water Elevation (ft - NAVD88)
60
50
40
30
20
1933
1939
1945
1951
1957
1963
1969
1975
1981
1987
1993
1999
2005
2011
2017
Date

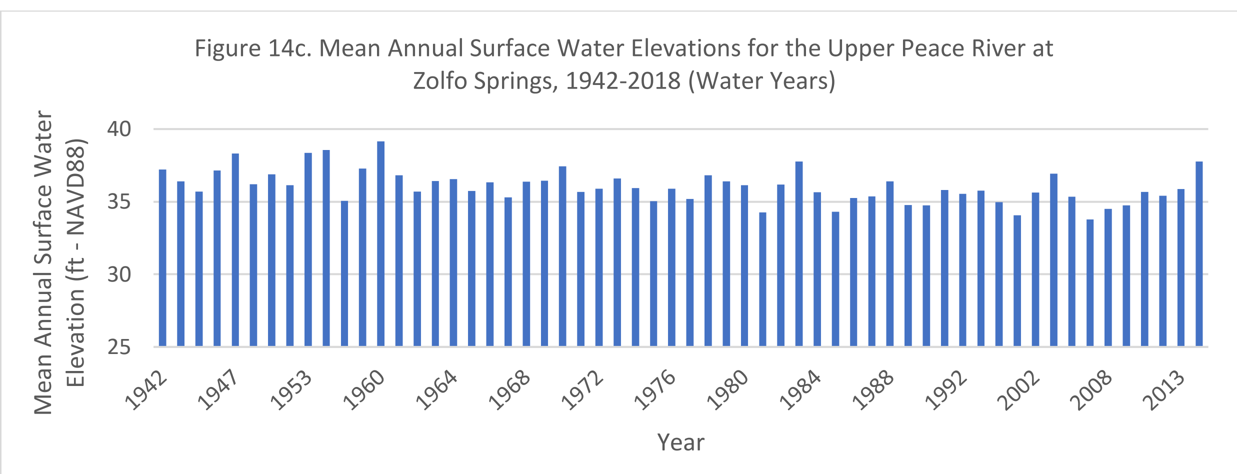


Figure 14c. Mean Annual Surface Water Elevations for the Upper Peace River at Zolfo Springs, 1942-2018 (Water Years)
Mean Annual Surface Water Elevation (ft - NAVD88)
40
35
30
25
1942
1947
1953
1960
1964
1968
1972
1976
1980
1984
1988
1992
2002
2008
2013
Year

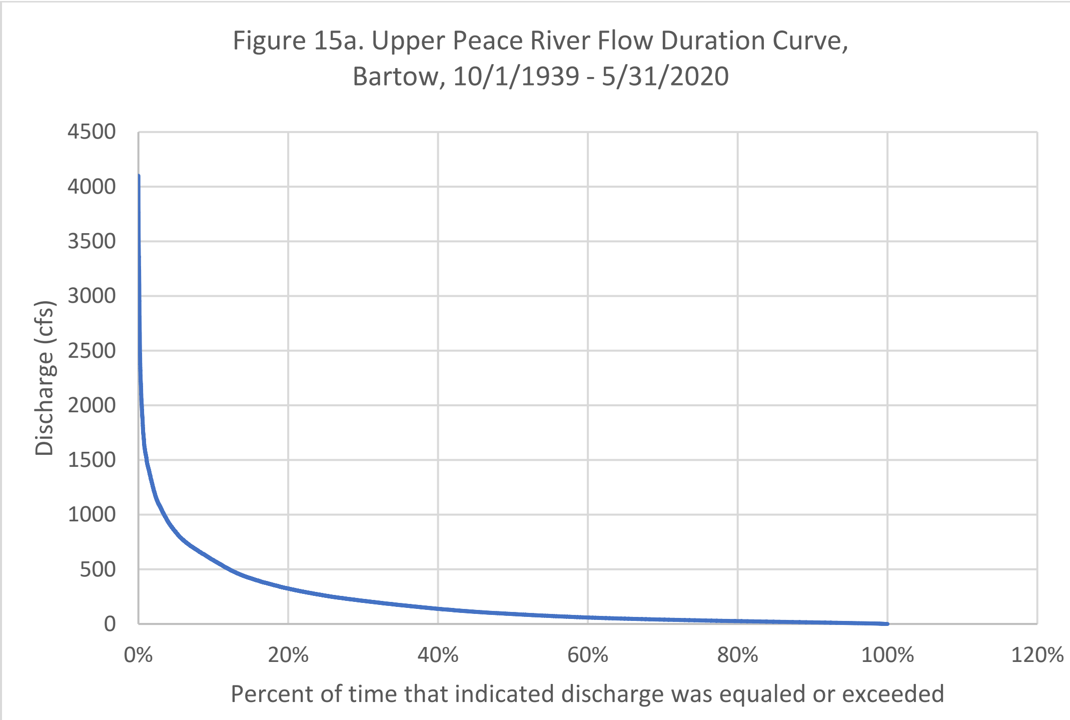


Figure 15a. Upper Peace River Flow Duration Curve,
Bartow, 10/1/1939 - 5/31/2020
Discharge (cfs)
4500
4000
3500
3000
2500
2000
1500
1000
500
0
0%
20%
40%
60%
80%
100%
120%
Percent of time that indicated discharge was equaled or exceeded

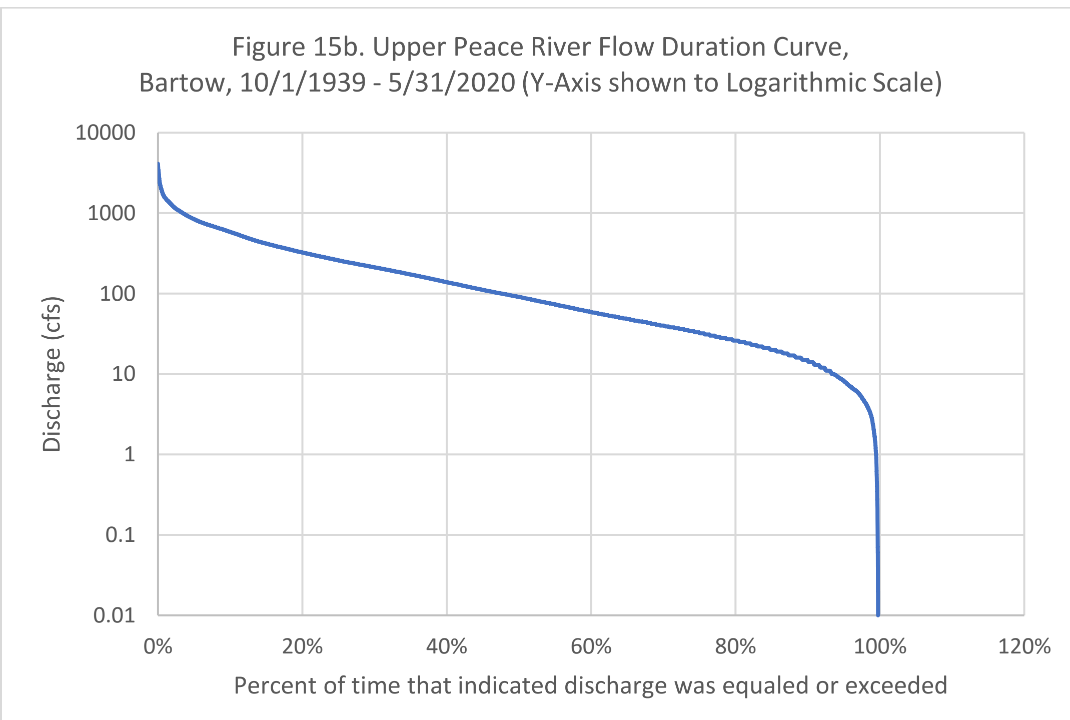


Figure 15b. Upper Peace River Flow Duration Curve,
Bartow, 10/1/1939 - 5/31/2020 (Y-Axis shown to Logarithmic Scale)
Discharge (cfs)
10000
1000
100
10
1
0.1
0.01
0%
20%
40%
60%
80%
100%
120%
Percent of time that indicated discharge was equaled or exceeded

Figure 16a. Upper Peace River Flow Duration Curve, Zolfo Springs, 10/1/1939 - 5/31/2020

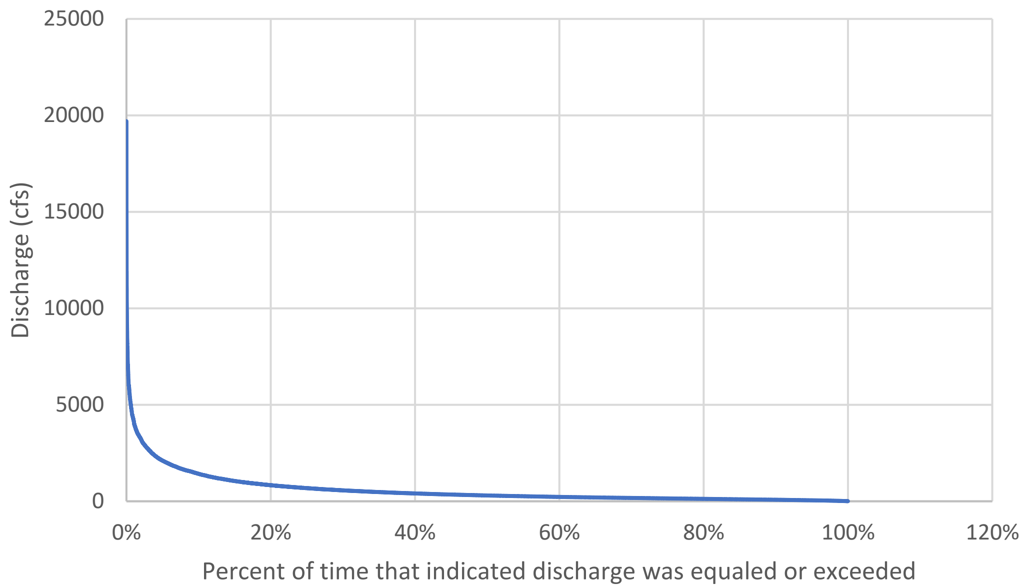
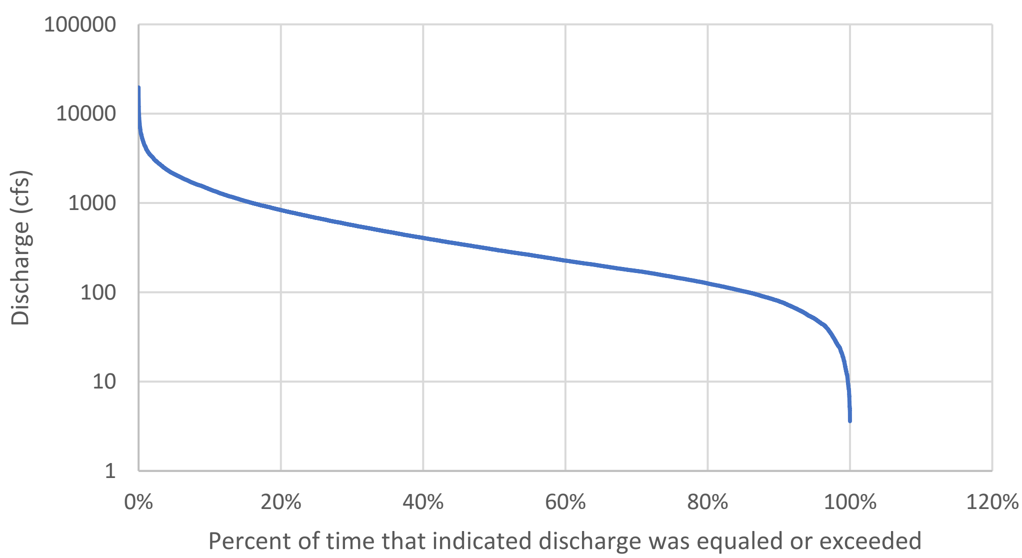


Figure 16b. Upper Peace River Flow Duration Curve, Zolfo Springs, 10/1/1939-5/31/2020 (Y-Axis shown to Logarithmic Scale)



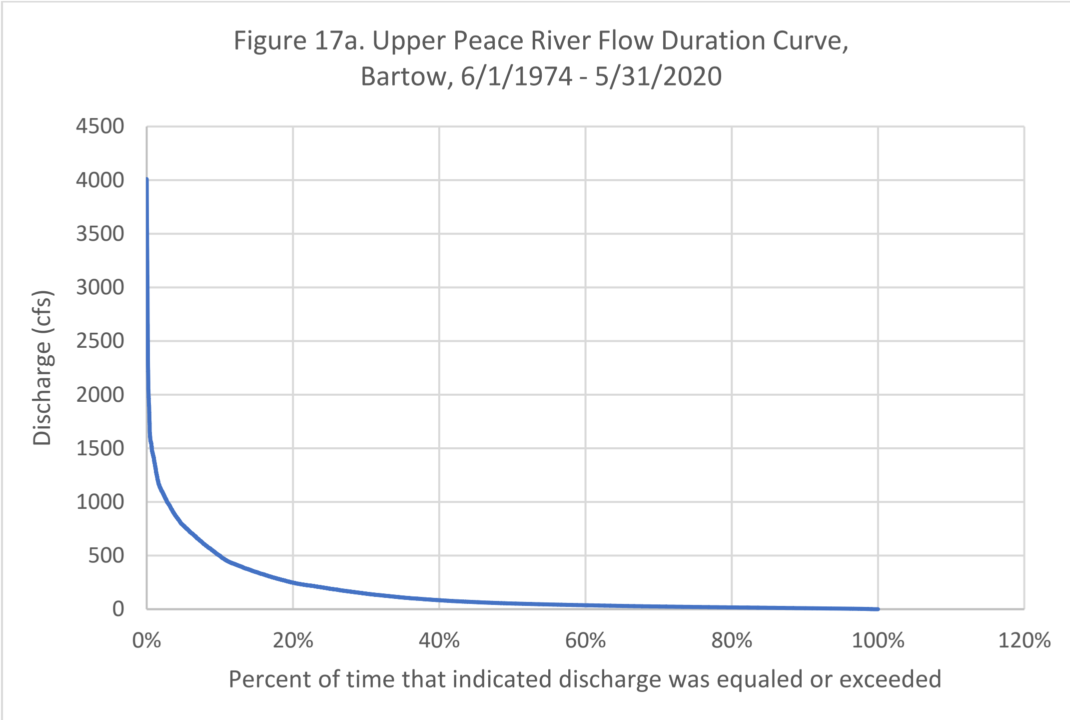


Figure 17a. Upper Peace River Flow Duration Curve,
Bartow, 6/1/1974 - 5/31/2020
Discharge (cfs)
4500
4000
3500
3000
2500
2000
1500
1000
500
0
0%
20%
40%
60%
80%
100%
120%
Percent of time that indicated discharge was equaled or exceeded

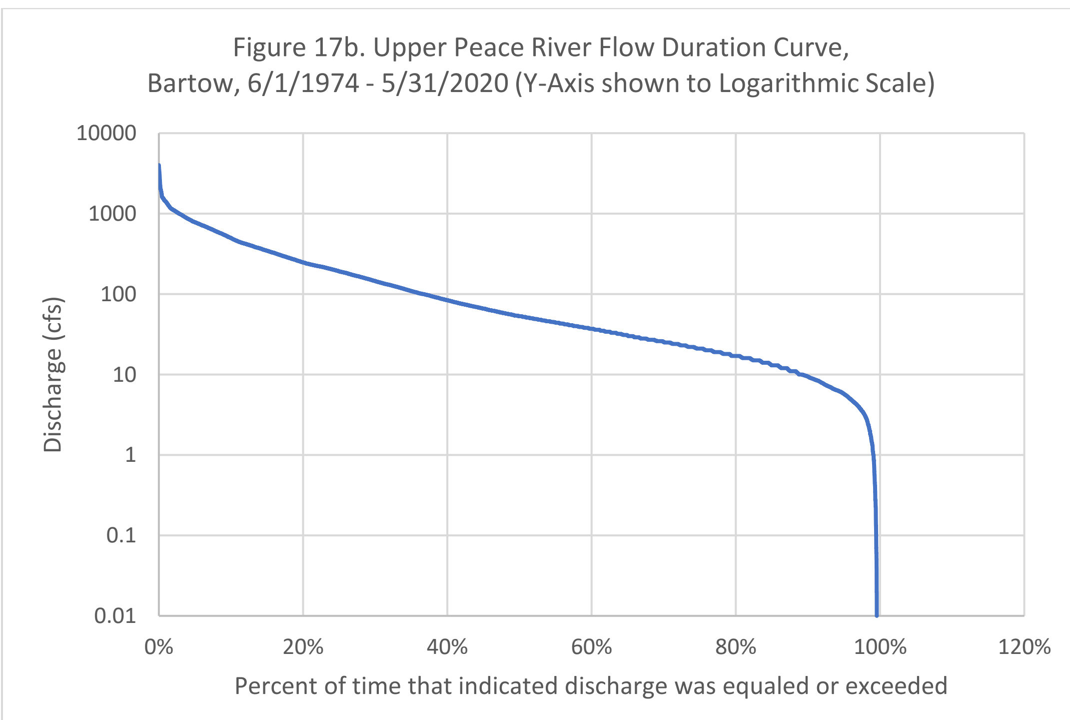


Figure 17b. Upper Peace River Flow Duration Curve,
Bartow, 6/1/1974 - 5/31/2020 (Y-Axis shown to Logarithmic Scale)
Discharge (cfs)
10000
1000
100
10
1
0.1
0.01
0%
20%
40%
60%
80%
100%
120%
Percent of time that indicated discharge was equaled or exceeded

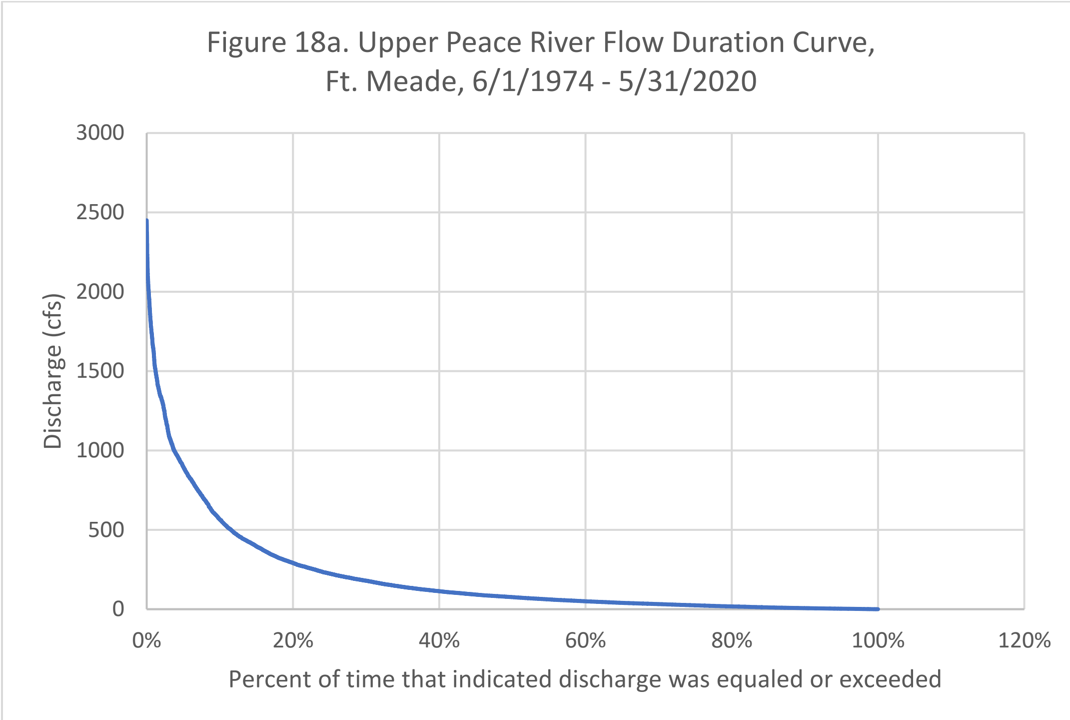


Figure 18a. Upper Peace River Flow Duration Curve, Ft. Meade, 6/1/1974 - 5/31/2020
Discharge (cfs)
3000
2500
2000
1500
1000
500
0
0%
20%
40%
60%
80%
100%
120%
Percent of time that indicated discharge was equaled or exceeded

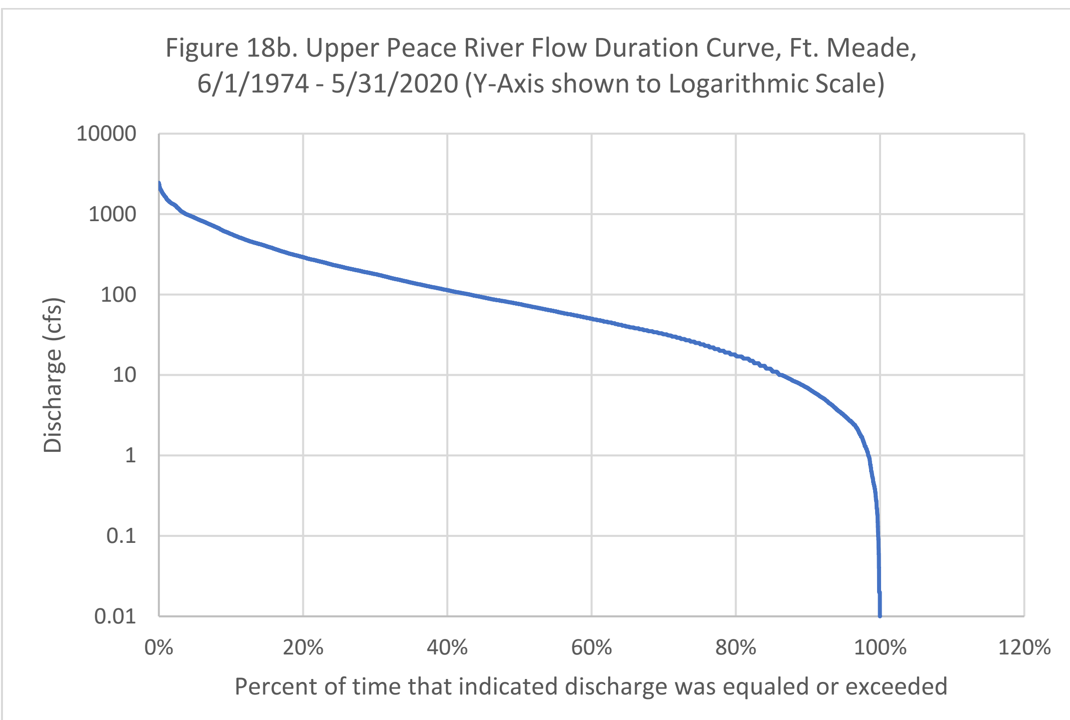


Figure 18b. Upper Peace River Flow Duration Curve, Ft. Meade, 6/1/1974 - 5/31/2020 (Y-Axis shown to Logarithmic Scale)
Discharge (cfs)
10000
1000
100
10
1
0.1
0.01
0%
20%
40%
60%
80%
100%
120%
Percent of time that indicated discharge was equaled or exceeded

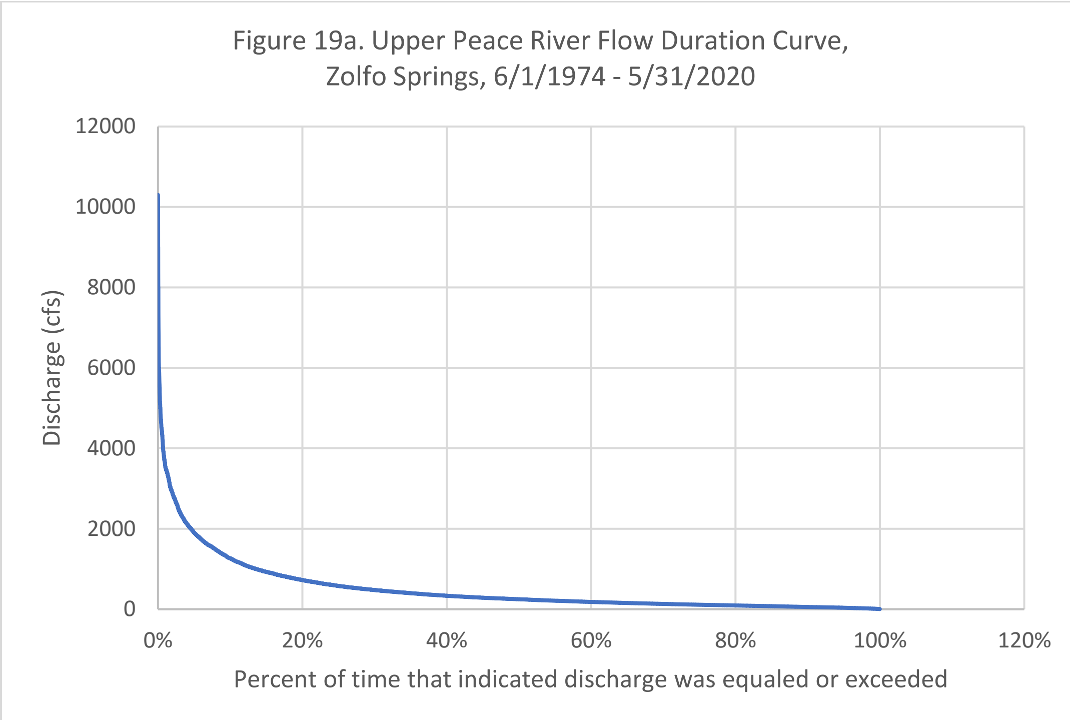


Figure 19a. Upper Peace River Flow Duration Curve,
Zolfo Springs, 6/1/1974 - 5/31/2020
12000
10000
8000
6000
4000
2000
0
Discharge (cfs)
0%
20%
40%
60%
80%
100%
120%
Percent of time that indicated discharge was equaled or exceeded

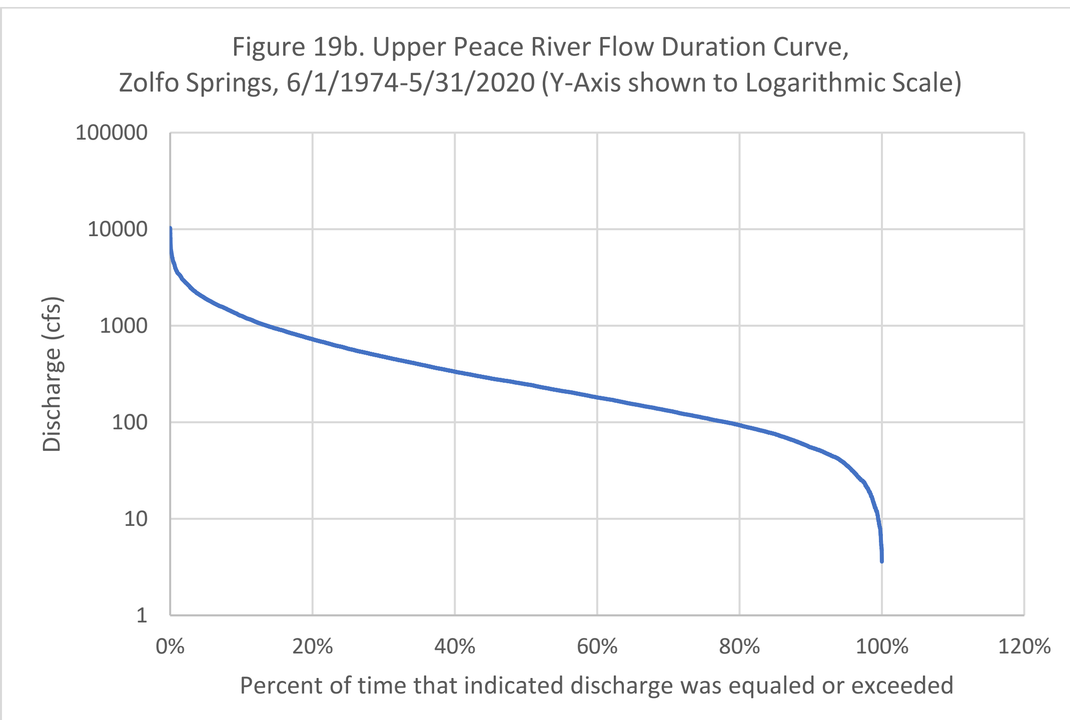


Figure 19b. Upper Peace River Flow Duration Curve,
Zolfo Springs, 6/1/1974-5/31/2020 (Y-Axis shown to Logarithmic Scale)
100000
10000
1000
100
10
1
Discharge (cfs)
0%
20%
40%
60%
80%
100%
120%
Percent of time that indicated discharge was equaled or exceeded

Figure 20. Rating Curve for the Upper Peace River at Bartow

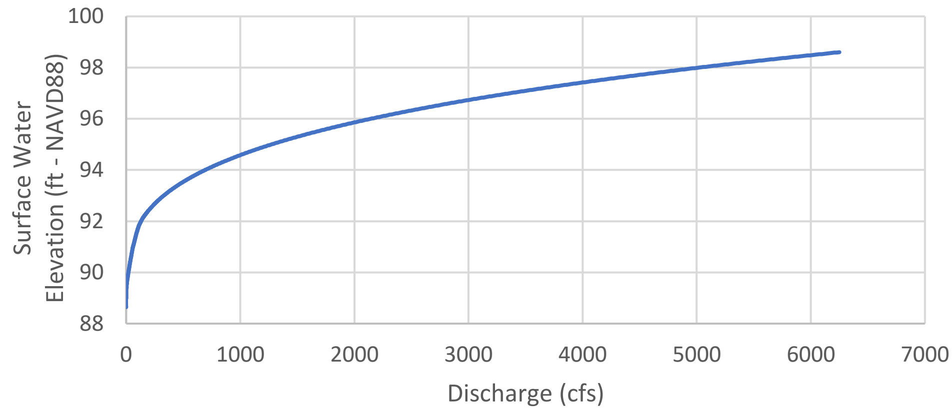


Figure 21. Rating Curve for the Upper Peace River at Ft. Meade

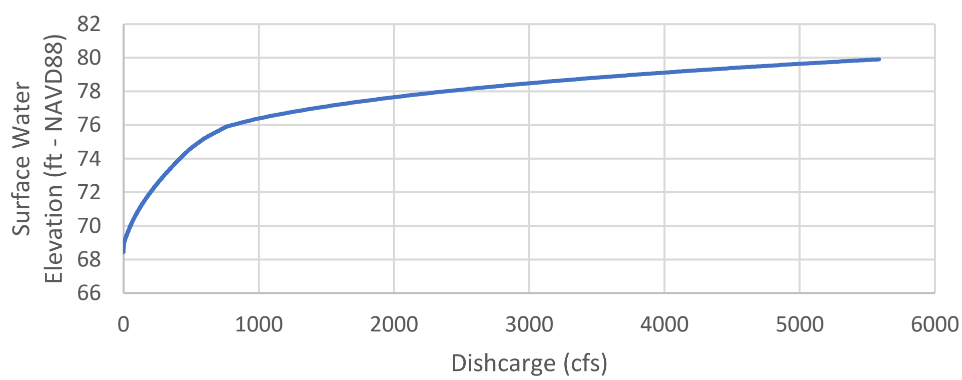


Figure 22. Rating Curve for the Upper Peace River at Zolfo Springs

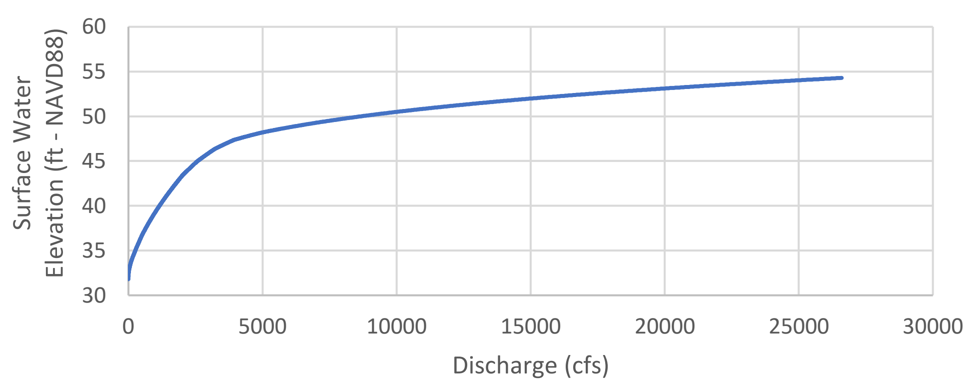


Figure 23a. Upper Peace River Mean Daily Flows, 6/1/1974 - 5/31/1986

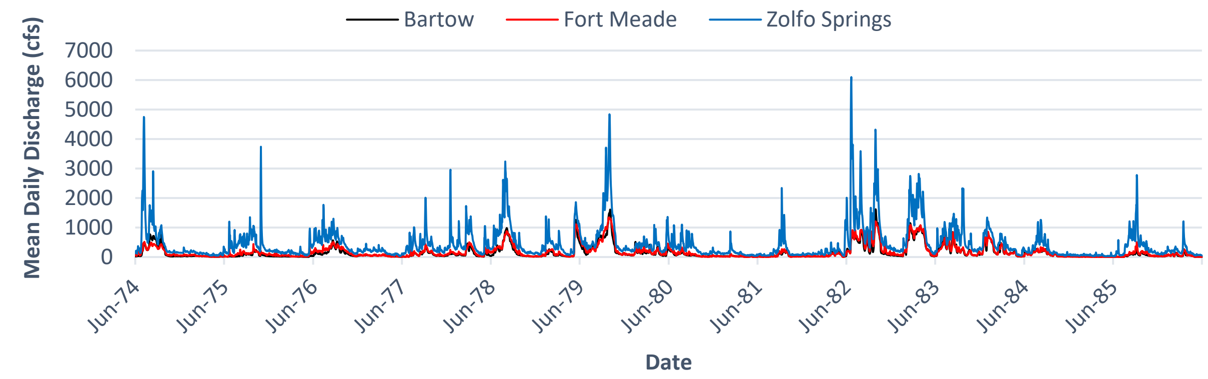


Figure 23b. Upper Peace River Mean Daily Surface Elevations, 6/1/1974 - 5/31/1986

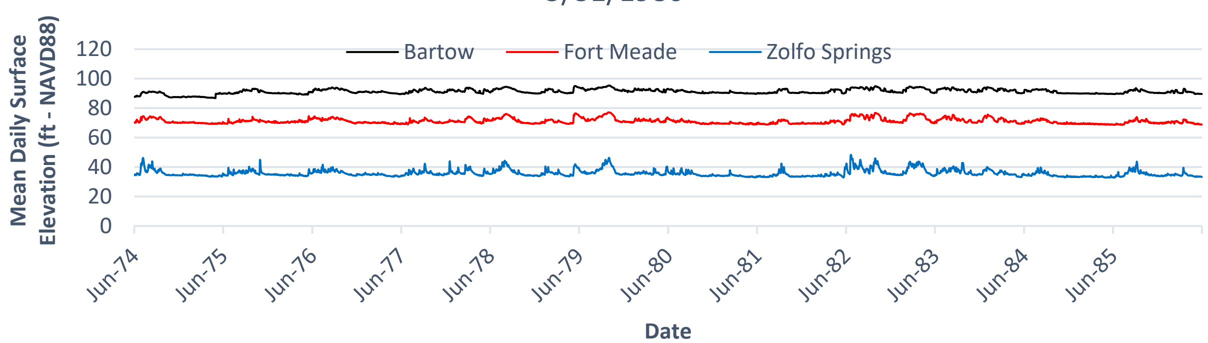


Figure 23c. Upper Peace River Mean Daily Flows at Bartow and Fort Meade, 6/1/1974 -5/31/1986

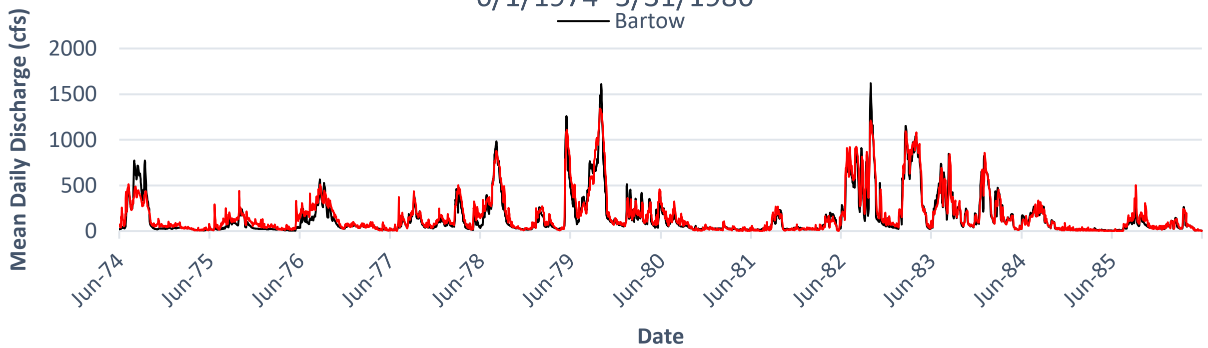


Figure 24a. Upper Peace River Mean Daily Flows, 6/1/1986 - 5/31/1998

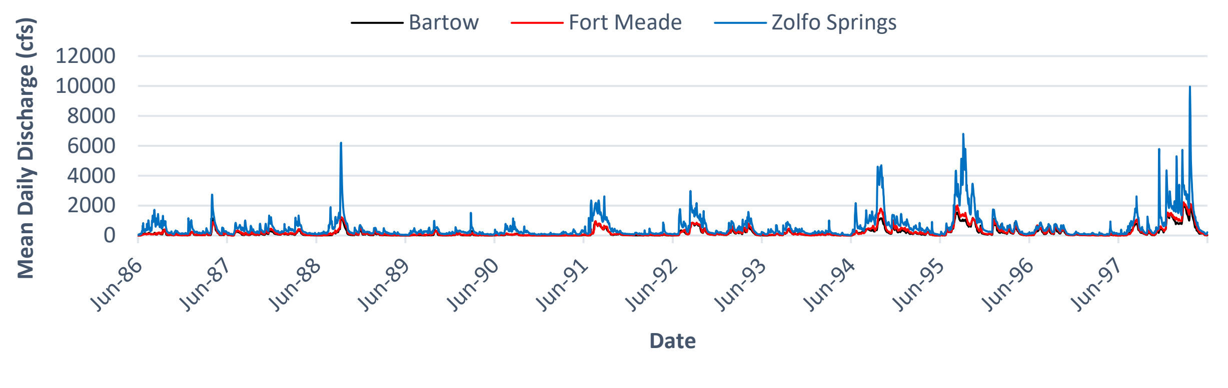


Figure 24b. Upper Peace River Mean Daily Surface Elevations, 6/1/1986 - 5/31/1998

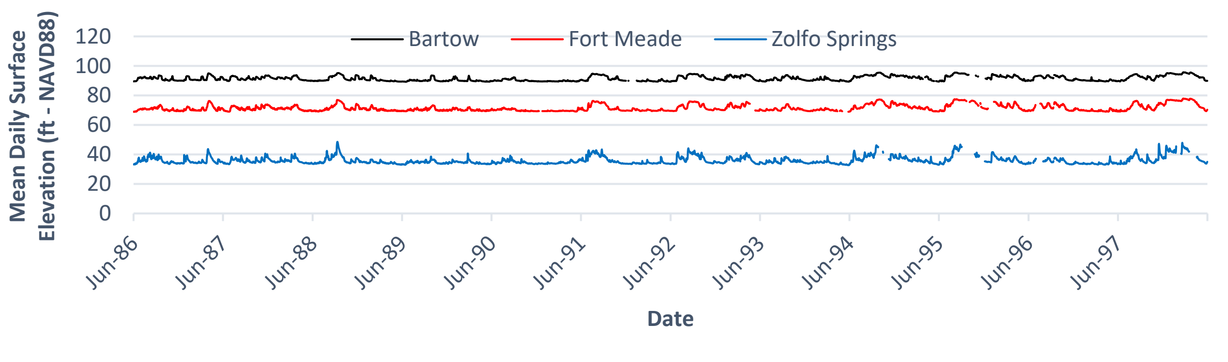
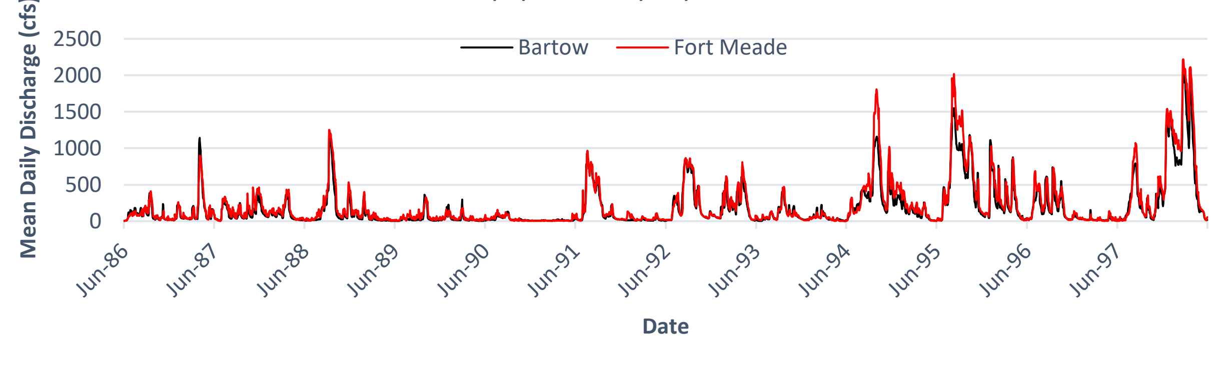


Figure 24c. Upper Peace River Mean Daily Flows at Bartow and Fort Meade, 6/1/1986 - 5/31/1998



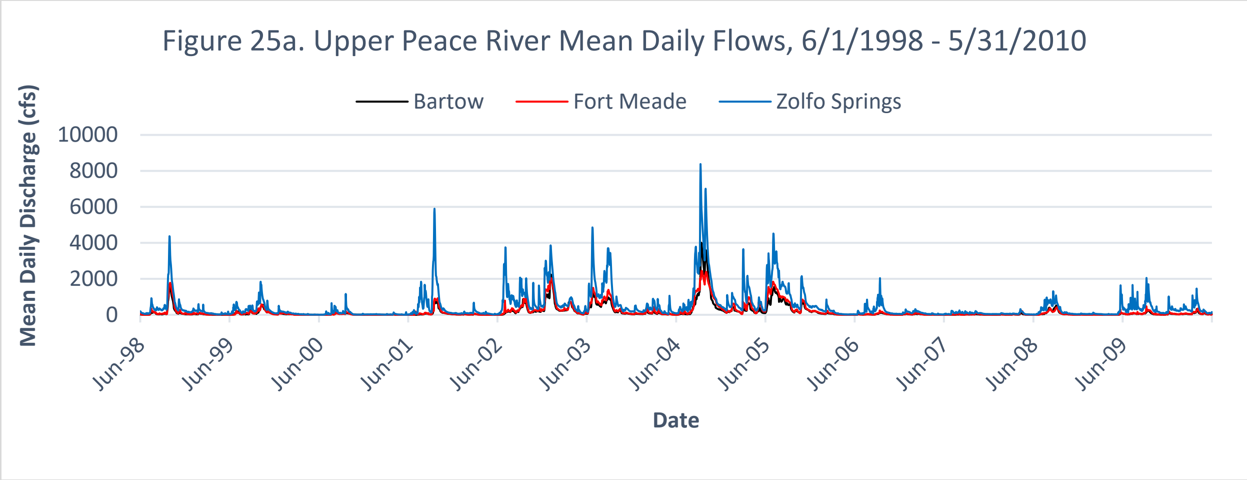


Figure 25a. Upper Peace River Mean Daily Flows, 6/1/1998 - 5/31/2010
Bartow
Fort Meade
Zolfo Springs
Mean Daily Discharge (cfs)
10000
8000
6000
4000
2000
0
Jun-98
Jun-99
Jun-00
Jun-01
Jun-02
Jun-03
Jun-04
Jun-05
Jun-06
Jun-07
Jun-08
Jun-09
Date

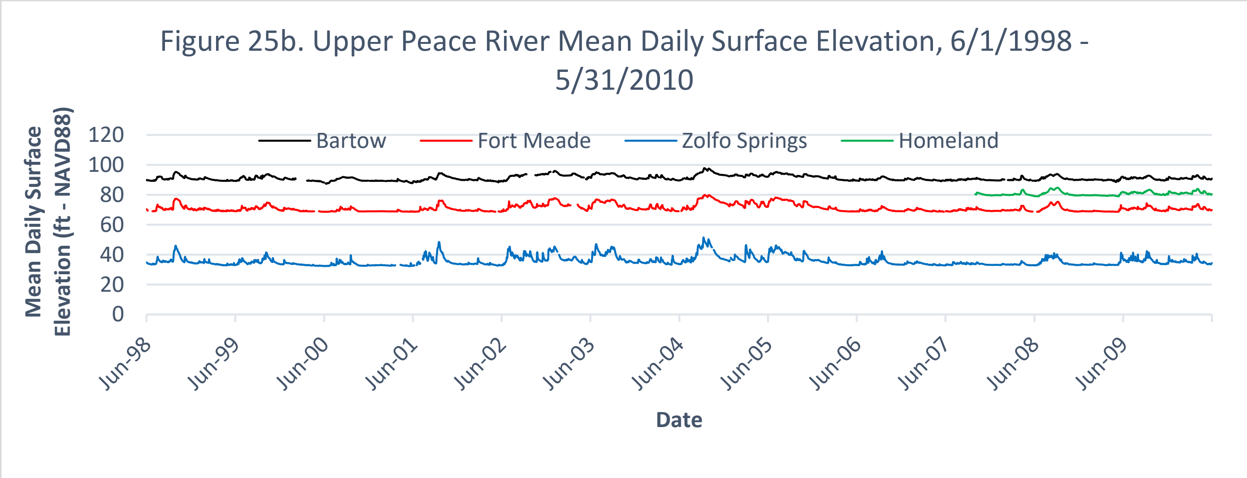


Figure 25b. Upper Peace River Mean Daily Surface Elevation, 6/1/1998 - 5/31/2010
Bartow
Fort Meade
Zolfo Springs
Homeland
Mean Daily Surface Elevation (ft - NAVD88)
120
100
80
60
40
20
0
Jun-98
Jun-99
Jun-00
Jun-01
Jun-02
Jun-03
Jun-04
Jun-05
Jun-06
Jun-07
Jun-08
Jun-09
Date

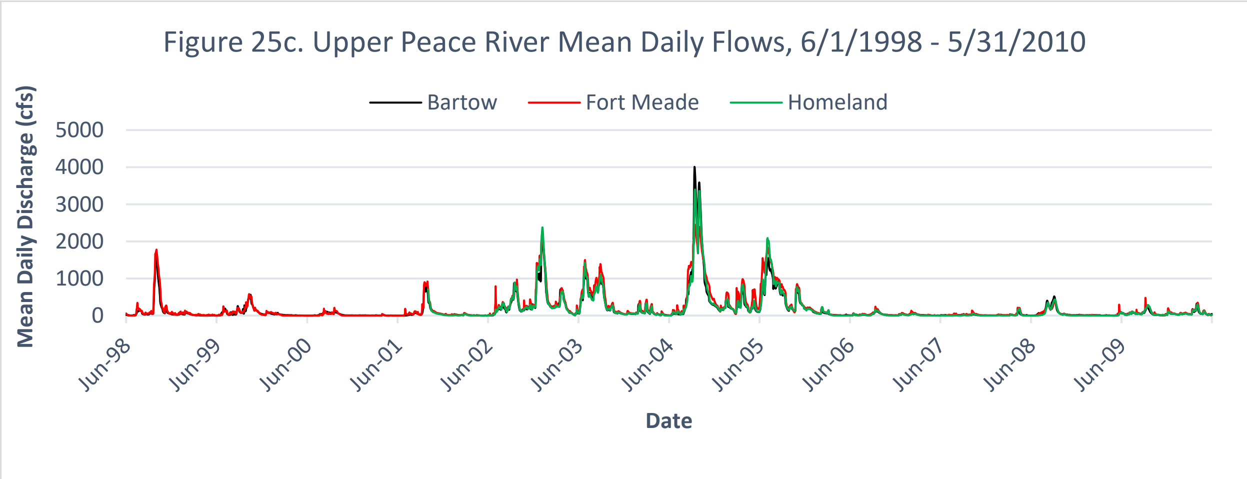


Figure 25c. Upper Peace River Mean Daily Flows, 6/1/1998 - 5/31/2010
Bartow
Fort Meade
Homeland
Mean Daily Discharge (cfs)
5000
4000
3000
2000
1000
0
Jun-98
Jun-99
Jun-00
Jun-01
Jun-02
Jun-03
Jun-04
Jun-05
Jun-06
Jun-07
Jun-08
Jun-09
Date

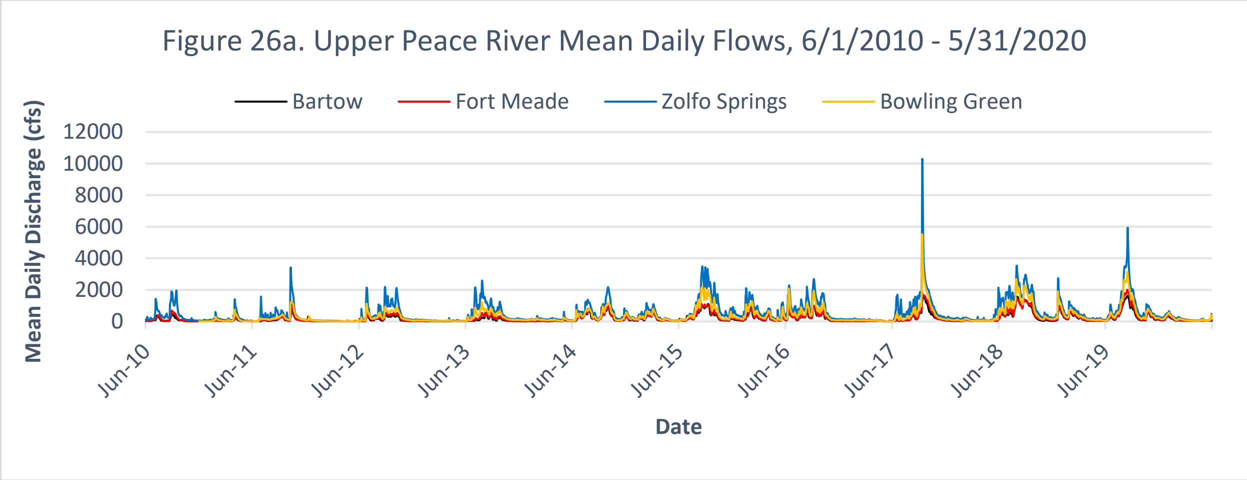


Figure 26a. Upper Peace River Mean Daily Flows, 6/1/2010 - 5/31/2020
Bartow
Fort Meade
Zolfo Springs
Bowling Green
Mean Daily Discharge (cfs)
12000
10000
8000
6000
4000
2000
0
Jun-10
Jun-11
Jun-12
Jun-13
Jun-14
Jun-15
Jun-16
Jun-17
Jun-18
Jun-19
Date

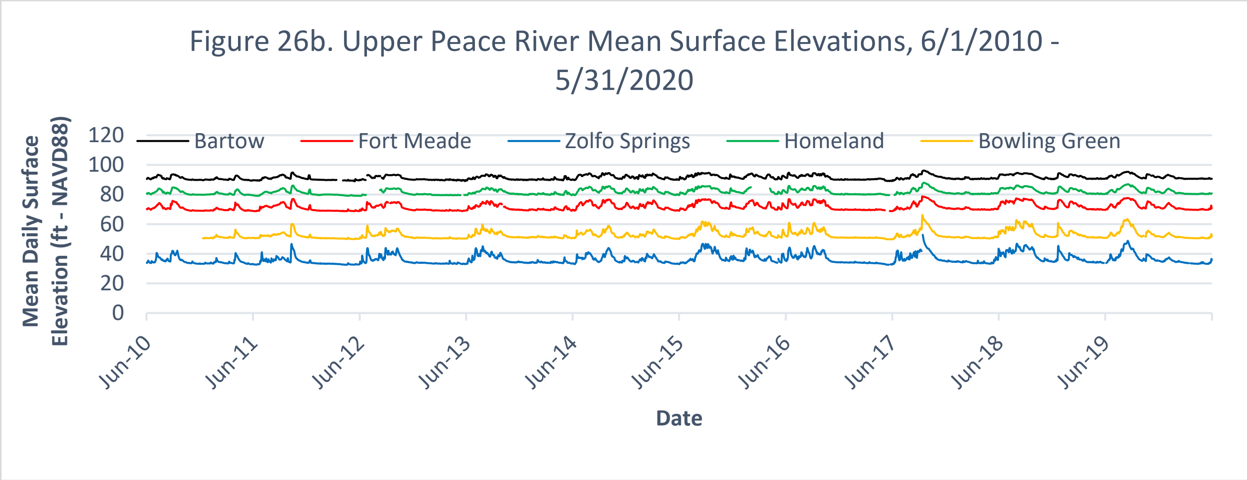


Figure 26b. Upper Peace River Mean Surface Elevations, 6/1/2010 - 5/31/2020
Bartow
Fort Meade
Zolfo Springs
Homeland
Bowling Green
Mean Daily Surface Elevation (ft - NAVD88)
120
100
80
60
40
20
0
Jun-10
Jun-11
Jun-12
Jun-13
Jun-14
Jun-15
Jun-16
Jun-17
Jun-18
Jun-19
Date

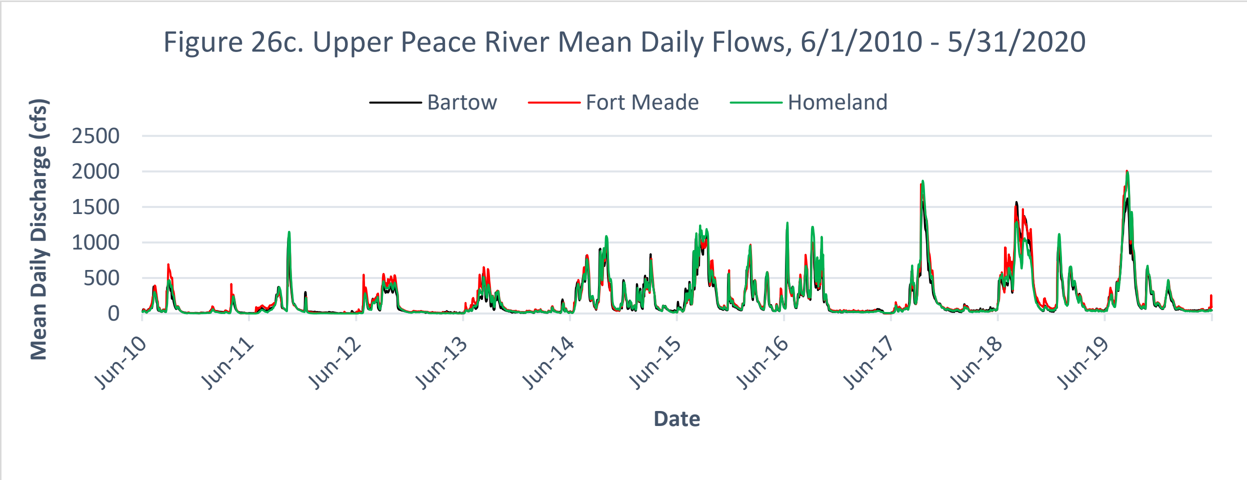


Figure 26c. Upper Peace River Mean Daily Flows, 6/1/2010 - 5/31/2020
Bartow
Fort Meade
Homeland
Mean Daily Discharge (cfs)
2500
2000
1500
1000
500
0
Jun-10
Jun-11
Jun-12
Jun-13
Jun-14
Jun-15
Jun-16
Jun-17
Jun-18
Jun-19
Date

Table 5a - Upper Peace River Streamflow Gaging Sites, Main Channel

Site Name	Latitude	Longitude	Geodetic Datum	USGS Site ID	SWFWMD Site ID	Drainage Area (sq.mi)	Parameter[1]	Start Date	End Date[2]	Data Count
Peace River at SR 60 at Bartow, FL	27°54'07"	81°49'03"	NAD27	02294650	24833	390	Gage height (ft)	1939-11-09	2020-08-25	29074
							Discharge (cfs)	1939-10-01	2020-08-25	29550
							Water level elevation (ft)	2011-10-10	2020-08-25	3220
							Flow measurements (cfs)	1939-11-09	2020-06-09	761
Peace River near Bartow FL	27°52'59"	81°48'16"	NAD83	02294655	670663	395	Gage height (ft)	2002-05-15	2020-08-25	625
							Discharge (cfs)	2002-05-15	2020-08-25	6675
							Water level elevation (ft)	2007-10-01	2020-08-25	3842
							Flow measurements (cfs)	2002-06-24	2020-06-09	130
Peace RV distributary at Dover Sink nr Bartow FL	27°52'22"	81°48'06"	NAD83	02294705	700395	-	Gage height (ft)	2006-06-13	2020-08-25	4180
							Discharge (cfs)	-	-	-
							Water level elevation (ft)	2007-10-01	2020-08-25	3803
							Flow measurements (cfs)	2006-04-11	2007-03-23	6
Peace River at Clear Springs near Bartow FL	27°51'48"	81°48'27"	NAD83	02294775	700355	396	Gage height (ft)	2002-05-16	2020-08-25	6672
							Discharge (cfs)	2002-05-15	2020-08-25	6672
							Water level elevation (ft)	2007-10-01	2020-08-25	4392
							Flow measurements (cfs)	2002-07-15	2020-08-12	107
Peace River near Homeland FL	27°49'15"	81°47'59"	NAD27	02294781	24823	411	Gage height (ft)	1998-07-18	2020-08-25	7757
							Discharge (cfs)	2001-10-01	2020-08-25	6904
							Water level elevation (ft)	2007-10-01	2020-08-25	4569
							Flow measurements (cfs)	1974-07-11	2020-08-12	247
Peace River at Fort Meade FL	27°45'04"	81°46'56"	NAD27	02294898	24805	480	Gage height (ft)	1964-04-22	2020-08-25	19251
							Discharge (cfs)	1974-06-01	2020-08-25	16888
							Water level elevation (ft)	2007-10-01	2020-08-25	4637
							Flow measurements (cfs)	1931-05-18	2020-08-13	414
Peace River at Bowling Green FL	27°38'45"	81°48'09"	NAD27	02295194	785819	613	Gage height (ft)	2010-12-11	2020-08-25	3537
							Discharge (cfs)	2010-12-01	2020-08-25	3556
							Water level elevation (ft)	2010-12-11	2020-08-25	3536
							Flow measurements (cfs)	1982-02-14	2020-08-13	75
Peace River at State HWY 664A near Wauchula FL	27°34'32"	81°48'17"	NAD83	02295440		754	Gage height (ft)	2016-10-17	2020-08-25	1408
							Discharge (cfs)	-	-	-
							Water level elevation (ft)	-	-	
							Flow measurements (cfs)	1982-12-01	1983-05-24	3

Site Name	Latitude	Longitude	Geodetic Datum	USGS Site ID	SWFWMD Site ID	Drainage Area (sq.mi)	Parameter[1]	Start Date	End Date[2]	Data Count
Peace River at Wauchula FL	27°33'01"	81°47'38"	NAD27	02295607		808	Gage height (ft)	1969-10-01	1972-02-29	882
							Discharge (cfs)	-	-	-
							Water level elevation (ft)	-	-	
							Flow measurements (cfs)	1974-07-11	1983-05-24	5
Peace River at US 17 at Zolfo Springs, FL	27°30'15"	81°48'04"	NAD27	02295637	23917	826	Gage height (ft)	1933-09-07	2020-08-25	31222
							Discharge (cfs)	1933-09-01	2020-08-25	31762
							Water level elevation (ft)	2007-10-01	2020-08-25	4631
							Flow measurements (cfs)	1919-10-05	2020-08-11	783
Peace River at SR 70 at Arcadia, FL (site in Lower Peace River)	27°13'14"	81°52'35"	NAD27	02296750	24149	1367	Gage height (ft)	1931-04-07	2020-08-25	32347
							Discharge (cfs)	1931-04-01	2020-08-25	32655
							Water level elevation (ft)	2007-10-01	2020-08-25	4683
							Flow measurements (cfs)	1930-06-06	2020-08-14	833

Note: [1] The reference system for the datum of gages varies between NGVD29 and NAVD 88. Water level elevation is above NAVD 1988; [2] The cutoff date for acquiring data is 8/25/2020.

Table 5b - Upper Peace River Streamflow Gaging Sites, Tributaries

Site	Latitude	Longitude	Datum	USGS Site ID	SWFWMD Site ID	Drainage Area (sq. mi)	Parameter[1]	Start Date	End Date[2]	Data Count
Peace Creek near Bartow FL	27°55'28"	81°47'44"	NAD83	02294161	670208	204.8	Gage height (ft)	2005-07-08	2020-08-25	5528
							Discharge (cfs)	2005-07-08	2020-08-25	5426
							Water level elevation (ft)	2007-10-01	2020-08-25	4632
							Flow measurements (cfs)	1945-04-13	2020-08-21	116
Saddle Creek at Structure P-11 near Bartow FL	27°56'17"	81°51'05"	NAD27	02294491	24764	135	Gage height (ft)	1973-10-01	2014-10-07	14414
							Discharge (cfs)	1963-12-01	2014-10-07	18574
							Water level elevation (ft)	2010-10-04	2014-10-07	1377
							Flow measurements (cfs)	1963-11-27	2014-08-05	313
Six Mile Creek at Bartow FL	27°51'48.59"	81°48'34.12"	NAD83	02294747	700394	-	Gage height (ft)	2002-12-04	2020-08-25	6338
							Discharge (cfs)	2002-12-01	2020-08-25	6478
							Water level elevation (ft)	2007-10-02	2020-08-25	4590
							Flow measurements (cfs)	2002-06-20	2020-08-11	132
Phosphate Mine Outfall CS-8 Near Bartow, FL	27°50'37"	81°48'14"	NAD83	02294759	702863	-	Gage height (ft)	2003-02-04	2020-08-25	4218
							Discharge (cfs)	2003-02-01	2020-08-25	5720
							Water level elevation (ft)	2007-10-01	2020-08-25	3142
							Flow measurements (cfs)	2003-01-21	2020-10-08	113
Barber Branch near Homeland FL	27°50'18"	81°48'44"	NAD83	02294760	700356	-	Gage height (ft)	2002-12-04	2020-08-25	6248
							Discharge (cfs)	2002-12-01	2020-08-25	6278
							Water level elevation (ft)	2009-10-01	2020-08-25	3522
							Flow measurements (cfs)	2002-08-23	2020-08-12	120
Whidden Creek near Fort Meade FL	27°42'25"7	81°48'28"	NAD27	02295163	24879	43	Gage height (ft)	2000-11-21	2020-08-25	7127
							Discharge (cfs)	2000-11-21	2020-08-12	5192
							Water level elevation (ft)	2007-10-01	2020-08-25	4672
							Flow measurements (cfs)	1939-05-13	2020-06-01	141
Bowlegs Creek near Fort Meade	27°41'59"	81°41'44"	NAD27	02295013	24867	47.2	Gage height (ft)	1991-02-22	2020-08-25	10133
							Discharge (cfs)	1964-03-01	2020-08-25	12447
							Water level elevation (ft)	2007-10-01	2020-08-25	4271
							Flow measurements (cfs)	1964-04-01	2020-08-10	254
Payne Creek near Bowling Green FL	27°37'13"	81°49'33"	NAD27	02295420	24943	121	Gage height (ft)	1979-10-01	2020-08-25	14259
							Discharge (cfs)	1963-10-01	2020-08-25	16766
							Water level elevation (ft)	2007-10-01	2020-08-25	4662
							Flow measurements (cfs)	1939-05-14	2020-08-10	372

Site	Latitude	Longitude	Datum	USGS Site ID	SWFWMD Site ID	Drainage Area (sq. mi)	Parameter[1]	Start Date	End Date[2]	Data Count
Little Charlie Creek near mouth near Wauchula FL	27°34'44.6"	81°47'48.6"	NAD27	02295580	893414	-	Gage height (ft)	2012-09-30	2020-08-25	2551
							Discharge (cfs)	2012-09-30	2020-08-25	2860
							Water level elevation (ft)	2012-09-30	2020-08-25	2539
							Flow measurements (cfs)	2012-09-11	2020-08-14	57

Note: [1] The reference system for the datum of gages varies between NGVD29 and NAVD 88. Water level elevation is above NAVD 1988; [2] The cutoff date for acquiring data is 8/25/2020.

Table 6. Discharges at Different Percentiles on Flow-Duration Curves

Gaging Station	Period of Record	Percentile			
		20	40	60	80
		Discharge (cfs)			
Bartow	10/1/1939 - 5/31/2020	325	135	59	26
Zolfo Springs	10/1/1939 - 5/31/2020	830	410	225	125
Bartow	6/1/1974 - 5/31/2020	245	84	37	17
Fort Meade	6/1/1974 - 5/31/2020	285	45	50	17
Zolfo Springs	6/1/1974 - 5/31/2020	715	330	180	91

Section 4 - Existing Topographic and Bathymetric Data in the Upper Peace River

4.1 Inventory and Assessment of Topographic and Bathymetric Data for the Upper Peace River

BFA obtained and reviewed available topographic and bathymetric data, and digital elevation data for the UPR between the USGS gauges at Bartow and at Zolfo Springs. Also, BFA reviewed the data used to represent the cross-sections in the 2011 HEC-RAS model. This data can be utilized as geometric data input that is required to characterize the cross-sections in the unsteady flow model of the UPR.

Multiple sources of topographic and bathymetric data were provided by Dr. Lei Yang of the SWFWMD. This information is summarized in Table 7 and includes the following:

1. A 2008 PLSS Survey performed by Lombardo, Foley & Kolarik through a contract with Ardaman & Associates, Inc. This survey included a total of 57 cross sections of Bear Branch, Six Mile Creek and along bridges on the Peace River between Bartow and Fort Meade.

2. Multiple cross sections (a total of 165) and data sources were used for a HEC-RAS Model developed by the District in 2011. Among the 165 cross-sections, 46 were inherited from the previous USGS work as discussed in Section 2.1. The remining 119 cross-sections were based on multiple survey works, including a 2002 survey of vegetation along the Peace River that collected information such as habitat length and distribution, station gage data, wetted perimeter and inundation data, the 2008 PLSS survey mentioned above, a survey conducted in 2010 collected field data at four locations along the Peace River for use in the Physical Habitat Simulation (PHABSIM) model, and two additional surveys performed in 2011 by the District and Pickett & Associates further detail elevation information of some shoal and bridge locations for the Upper Peace River.

3. A 2014 Survey performed by the District collected data for 31 cross-sections and bridges across Peace Creek, Saddle Creek and on the Peace River north of Bartow and near Zolfo Springs.

4. A recent bathymetric survey was also conducted in 2020 of the Upper Peace River by Pickett & Associates. Transect data was collected at ninety (90) locations (or 93 transects) as specified by the District: at the eighty-nine (89) typical locations a single transect line was collected and at the one (1) bridge survey a total of four transect lines were collected.

5. LiDAR (Light Detection and Ranging) data collected by the SWFWMD in 2015 was also provided covering the areas of Polk County and Hardee County.

6. Statewide LiDAR for both Polk and Hardee counties are currently under a QC process review by USGS and would become available in the next 1- or 2-year time frame. The LiDAR data has higher vertical and horizontal accuracies than currently available LiDAR data, and may better serve future model development.

7. Upcoming data collections related to System for Environmental Flow Assessment (SEFA) for instream habitats and vegetation transect survey for floodplain habitats would provide additional channel and floodplain transect data for consideration in the model development.

4.2 Need for Model Geometry Improvements and Revisions

In order to evaluate the need for future model improvements and revisions of the model geometry, BFA visually inspected the cross-sections obtained after running the 2011 HEC-RAS Model with HEC-RAS 5.07, assuming steady and subcritical flow.

In HEC-RAS if a cross section does not extend sufficiently into the flood plain for a given flow, the program adds a fictious "vertical wall" to the height of the computed water surface at the end of the cross section. Table 8 presents a list of the cross-sections that show a vertical wall on one or both sides for the 2011 HEC-RAS model. Hence, there are 126 cross-sections in the model that do not sufficiently extend into the floodplain to accommodate medium and high flows. Figure 27 depicts one of these HEC-RAS cross-sections with a vertical wall on the floodplain (River Station 504).

The use of a vertical wall introduces errors in the computed water surface elevation. In particular, errors in cross sectional area derived from the use this method, may lead to overestimated surface water levels. Also, some cross-sections may be missing a significant amount of wetted/flow area, and inundated areas may not show up correctly in mapping tools like RAS Mapper and HEC-GeoRAS. The magnitude of these errors will depend on the size of the missing wetted/flow area, the location of the missing wetted area (main channel, overbank or flow separation area), and the type of analysis used for modelling (steady/unsteady). For example, in HEC -RAS the missing flow area may be/is considered as ineffective area, which is accounted as hydraulic storage in the unsteady flow model. This approach may produce significant errors. Therefore, future modelling efforts should consider extending cross-sections further into the floodplain to improve the model's accuracy for MFLs analyses.

A more detailed analysis should be performed in the next phase of the study to identify which cross-sections need to be revised/replaced and/or modified, and if additional cross-sections are needed. Newer surveys and LIDAR data listed above can be used to improve cross-sections geometry data.

In addition, future model revisions could consider georeferencing the model to develop and refine the model geometry. One advantage of a georeferenced HEC-RAS model is that the model geometry can be overlaid on aerial imagery, facilitating the task of checking for geometric errors and inconsistencies and geometric data needs. Also, the results of a georeferenced HEC-RAS model can be visualized in a GIS application, such as RAS Mapper, to identify hydraulic model deficiencies and perform model improvements. Additionally, the georeferenced model results can be visualized and overlaid with other data that may be useful for MFLs development and other District's needs.

4.3 Summary

BFA concludes that identified topographic and bathymetric database consisting of many surveyed cross sections, especially the recent 2020 survey conducted by Pickett, and the 2015 LiDAR and the upcoming statewide LiDAR covering the UPR is sufficient to support development of unsteady flow model of the UPR, and revision of the existing steady flow model. Future model revisions should consider extending cross-sections further into the floodplain to improve the model's accuracy for MFLs analyses.

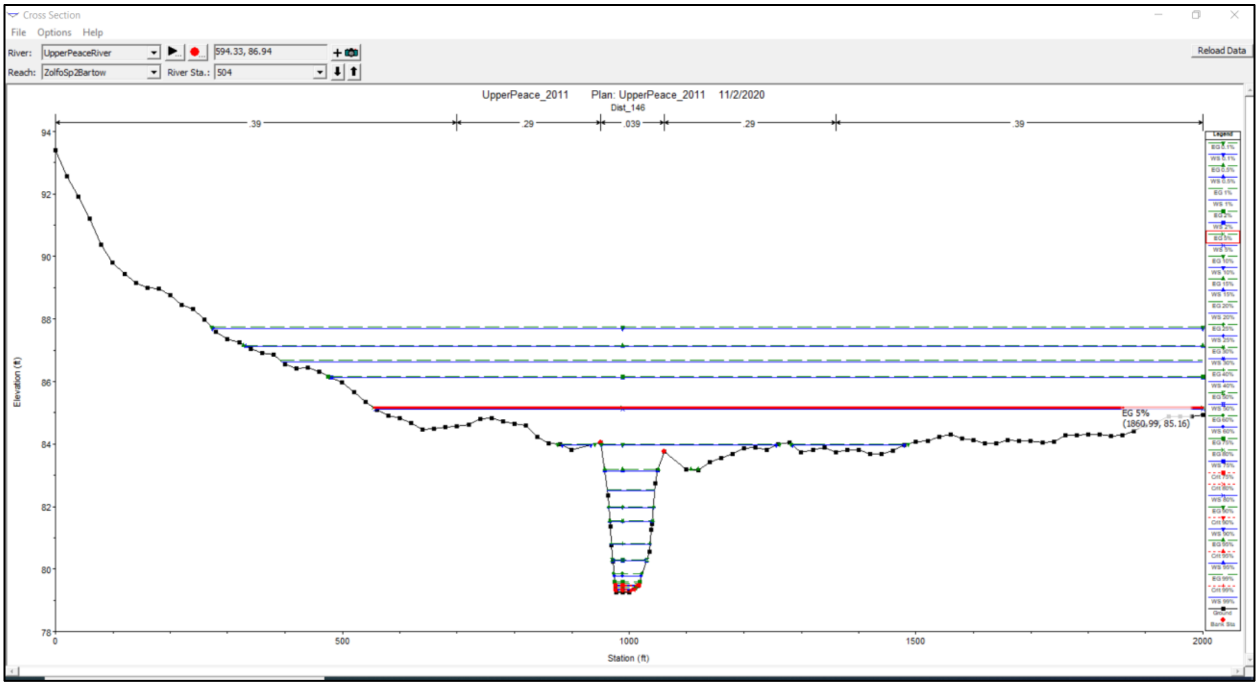


Figure 27: Example of HEC-RAS Cross-Section with a Vertical Wall on the Floodplain (River Station 504)

Table 7. Summary of Bathymetry and Topography Data Provided by SWFWMD

Data Source Name	No. of Cross Sections	Description
2015 LiDAR DEM	-	Elevation data that covers Polk County and Hardee County
2011 HEC-RAS Model Data	142	GIS Geodatabase point features (X, Y, Z), Excel Tables; Upper Peace River Transects between Peace River at Bartow and Zolfo Springs Sites
→ 2008 PLSS Survey	57	Survey data of Bear Branch/Six Mile Creek and Peace River Bridges between Bartow and Fort Meade; Field Notes, GIS Point Shapefiles (X, Y, Z) and Site Photos
→ 2002 Woody Vegetation & Floodplain Data	-	Excel Files (Habitat Length, Habitat Distribution, Station Gage data, Wetted Perimeter, Inundation), Summary Report PDF
→ 2010 PHABSIM Survey	-	Excel Tables (4 Site Locations/Descriptions, Field Data), Site Maps
→ 2011 District Shoal Survey	-	Excel Tables (X, Y, Z)
→ 2011 Pickett Survey	-	Excel Tables (X, Y, Z); PDF of Survey Report
2014 District Survey	31	GIS Geodatabase line and point features (X,Y,Z) of Peace Creek, Saddle Creek and Peace River north of Bartow and near Zolfo Springs
2020 Pickett Survey	93	GIS Point Shapefile and MS Excel Table (X,Y,Z) of elevations on the Upper Peace River between Bartow and Zolfo Springs

Table 8. List of the 2011 HEC-RAS Model Cross-Sections with Added Vertical Walls[1]
Cross-Sections identified by the River Station Number

600	598	596	588	586	584	582	580	578	576	574	572	570
566	560	558	556	554	552	548	546	544	534	532	530	528
526	524	522	518	516	514	512	510	506	504	502	492	488
486	484	482	480	478	476	472	470	468	466	464	462	460
458	456	450	448	446	444	442	440	438	436	434	432	430
424	422	416	414	412	410	408	406	404	402	400	398	396
394	392	386	384	382	380	378	376	374	372	370	364	362
360	358	356	350	302	300	298	292	290	284	282	280	278
276	274	348	346	344	342	340	338	336	334	332	330	328
326	324	322	318	312	310	308	306	304				

Note: [1] These results were obtained by visually inspecting the cross sections after running the UPR 2011 HEC-RAS Model assuming steady and subcritical flow with HEC-RAS 5.07. It does not consider cross-sections right upstream and downstream of bridges.

Section 5 - Existing Structure Data in the Upper Peace River

5.1 Inventory and Assessment of Structure Data for the Upper Peace River

There are 15 bridges in the UPR between the USGS gages between Bartow and Zolfo Springs, as summarized in Table 9. All these bridges were included in the 2011 HEC-RAS model, except for the US 17 Bridge at Zolfo Springs. This bridge is located immediately upstream of the USGS gage at Zolfo Springs.

Relevant data and information of the bridges in the study area were obtained from the SWFWMD, FDOT, Polk County and CSX. This information is needed to determine the bridge location, geometry and associated hydraulic parameters that will be used in the future HEC-RAS model. Below is a summary of the type of available information from each agency.

5.1.1 Southwest Florida Water Management District (SWFWMD)

The following topographic surveys provided by the SWFWMD were reviewed:

- 2008 survey by Lombardo, Foley & Kolarik, Inc.
  - SR 60 Bridge at Bartow
  - Abandoned Phosphate-Mine Bridge near Bartow
  - Clear Spring Mine Bridge near Bartow
  - Three Pipes (66, 48, & 48 cm)
  - SR 640 Bridge at Homeland
- 2011 survey by Pickett Surveying & Photogrammetry
  - US 98 Bridge (John Singletary Bridge)
  - Pipeline Bridge 54
  - Mt Pisgah Road Bridge
  - Old Railroad Bridge 5
  - County Line Bridge
  - Lake Branch Road Bridge
  - Heard Bridge Road Bridge
  - Main Street Bridge (SR- 64A)
  - Griffin Road Bridge (CR 652)
- 2020 survey by Pickett Surveying & Photogrammetry
  - US 17 Bridge at Zolfo Springs

The 2010 survey by BCI Engineers & Scientists, Inc. was not provided, but it was included in the 2011 HEC-RAS Model. This survey includes the following bridges:

  - SR 60 Bridge at Bartow
  - Abandoned Phosphate-Mine Bridge near Bartow
  - Clear Spring Mine Bridge near Bartow
  - Three Pipes (66, 48, & 48 cm)

In the 2011 survey by Pickett, the bridge identified as "Old Railroad Bridge" is located where the "Pipeline Bridge" is, and vice versa. The locations of these bridges were verified using the data from the survey and browsing the latest aerial imagery in Polk County GIS and Google and Bing Maps.

The SWFWMD also provided the 2011 HEC-RAS model that includes the bridge geometry for 14 bridges. This model did not include the bridge at US 17 Bridge at Zolfo Springs. In the HEC-RAS Model, the 2008, 2010, and 2011 surveys include the geometric data of the bridges in the channel portions, and LiDAR DEM data within 2000-ft buffer zone along the river (1000 feet on each side) was used to cover the floodplain. The modelers for the dynamic flow HEC-RAS model should decide whether the US 17 Bridge at Zolfo Springs needs to be included in the model.

The SWFWMD also provided the 2015 LiDAR DEM that covers the area around Peace River, Polk County and Hardee County. This dataset could be used to update the LiDAR DEM Data in the future HEC-RAS model. If any additional or updated hydraulic structural data are needed in the future model, they could be obtained from the entities listed as owner in Table 8.

5.1.2 Florida Department of Transportation (FDOT)

The following information and GIS applications from FDOT were reviewed:

- “Florida Bridge Information, 2020 3rd Quarter”, Rev. 07-01-20, at https://www.fdot.gov/maintenance/bridgeinfo.shtm
- Facility Crossed TDA (Transportation Data Analytics), at https://gis-fdot.opendata.arcgis.com/datasets/facility-crossed-tda/data?geometry=-81.853%2C27.894%2C-81.788%2C27.908
- Current 5-year Adopted Work Program, Web Application (GIS), at https://gis-fdot.opendata.arcgis.com/app/current-5-year-adopted-work-program

The “Florida Bridge Information, 2020 3rd Quarter”, Rev. 07-01-20 is a quarterly summary of FDOT’s inspections of all the bridges in the State of Florida. This report includes the following information: FDOT identification number, owner, facility crossed, year built, and date of the bridge reconstruction, among other data. According to this report none of the bridges in the study area have been reconstructed since they were built.

Also, according to FDOT’s Current 5-year Adopted Work Program, the US 98 Bridge (John Singletary Bridge) is planned to be replaced in the next 5 years. The project is in the Preliminary Engineering phase.

5.1.3 Polk County and Hardee County

The following GIS Map Applications were reviewed to verify the location of the bridges and find the owners of the bridges not listed in FDOT’s databases.

- Polk County GIS Map Viewer at: https://gis.polk-county.net/portal/apps/webappviewer/index.html?id=9b5b2b3b9e99493fa25ae5f0400b835c

- Hardee County InfoMap GIS Viewer at http://hardee.maps.arcgis.com/apps/webappviewer/index.html?id=b0107323152941baae0cb5ed75247da1

5.1.4 CSX Railroad

The CSX System Map was reviewed to verify the location of the Old Railroad Bridge and find the location of the nearest CSX Railroad. This Map can be found at:
https://www.csx.com/index.cfm/customers/maps/csx-system-map/.
The Old Railroad Bridge is part of the railroad that transports products from Mosaic Fertilizer's facility to the CSX Railroad that runs east of US 17.

In addition to the GIS applications listed above, Google and Bing Maps were browsed to verify bridge locations, and check if there were any other structures in the study area of the UPR. No other significant structures were found in the main channel of the UPR.

5.2 Summary

BFA concludes that database compiled for existing structures in the UPR is sufficient to support development of unsteady flow model, and subsequent steady flow model in support of development of MFLs.

Table 9 - Bridge Information in the Upper Peace River

No	Name	County	Latitude	Longitude	Data Source[1]	Surveys[2]	Owner	FDOT ID	Year Built[3]
1	SR 60 Bridge at Bartow	Polk	27°54'7.75"N	81°49'3.19"W	SWFWMDF DOT	2010, 2008	FDOT	160042	1964
2	Abandoned Phosphate-Mine Bridge near Bartow	Polk	27°52'59.56"N	81°48'14.57"W	SWFWMD	2010, 2008	TIITF / DEP Mgmt. Services	N/A	-
3	Clear Spring Mine Bridge near Bartow	Polk	27°51'51.46"N	81°48'25.62"W	SWFWMD	2010, 2008	TIITF / DEP Mgmt. Services	N/A	-
4	Three Pipes (66, 48, & 48 cm)	Polk	27°51'50.47"N	81°48'25.40"W	SWFWMD	2010, 2008	TIITF / DEP Mgmt. Services	N/A	-
5	SR 640 Bridge at Homeland	Polk	27°49'15.73"N	81°47'58.74"W	SWFWMD FDOT	2008	Polk County	160108	1969
6	US 98 Bridge (John Singletary)[4]	Polk	27°45'5.96"N	81°46'55.09"W	SWFWMD FDOT	2011	FDOT	160064	1931
7	Pipeline Bridge[5]	Polk	27°39'25.06"N	81°48'8.80"W	SWFWMD	2011	TIITF / DEP Mgmt. Services	N/A	-
8	Mt Pisgah Road Bridge	Polk	27°43'21.75"N	81°47'24.25"W	SWFWMDF DOT	2011	Polk County	160107	1961
9	Old Railroad Bridge[5]	Polk	27°43'22.78"N	81°47'23.94"W	SWFWMD Polk County	2011	Mosaic Fertilizer[6]	N/A	-
10	County Line Bridge	Hardee	27°38'46.31"N	81°48'7.75"W	SWFWMDF DOT	2011	Polk County	160101	1958
11	Lake Branch Road Bridge	Hardee	27°37'28.69"N	81°48'9.13"W	SWFWMDF DOT	2011	Hardee County	060031	1962
12	Heard Bridge Road Bridge	Hardee	27°34'32.76"N	81°48'16.11"W	SWFWMDF DOT	2011	Hardee County	060017 064080	1954 1965
13	Main Street Bridge (SR-64A)	Hardee	27°33'1.99"N	81°47'37.10"W	SWFWMDF DOT	2011	FDOT	060054	1999
14	Griffin Road Bridge (CR 652)	Hardee	27°32'26.76"N	81°47'31.11"W	SWFWMDF DOT	2011	FDOT	060030	1970
15	US 17 Bridge at Zolfo Springs[7]	Hardee	27°30'16.03"N	81°48'1.34"W	SWFWMDF DOT	2020	FDOT	060052 060053	2001 2001

Notes:
1. FDOT Open Data Hub and FDOT "Florida Bridge Information, 2020 3rd Quarter", Rev. 07-01-20. Polk County GIS Map Viewer
2. FDOT "Florida Bridge Information, 2020 3rd Quarter", Rev. 07-01-20
3. Available surveys provided by SWFWMD are: 2008 by Lombardo, Foley & Kolarik, Inc., 2011 by Pickett Surveying & Photogrammetry, and 2020 by Pickett Surveying & Photogrammetry. The 2010 by BCI Engineers & Scientists, Inc. was not provided but is included in the 2011 HEC-RAS Model.
4. This bridge is planned to be replaced in the next 5 years (FDOT); Pre-construction underway (Preliminary Engineering).
5. The bridge identified as "Old Railroad Bridge" in the 2011 survey by Pickett is located where the "Pipeline Bridge", and vice versa.
6. The Old Railroad Bridge is part of the railway that transports products from Mosaic Fertilizer's facility to the CSX railway that runs east of US 17.
7. This bridge was not included in the 2011 HEC-RAS Model of the UPR. It is upstream of the USGS Site Peace River at US 17 at Zolfo Springs, FL.

Section 6 - Findings, Conclusions and Recommendations

With the completion of the HEC-RAS modeling evaluation, BFA concludes:

1. The 2011 steady flow HEC-RAS model runs in the current version of the software. The model appears to be a stable platform for use in the MFLs reevaluation.
2. The 2011 steady flow model could be a starting platform from which to develop an unsteady flow model. Alternatively, the unsteady flow model could be developed from scratch.
3. Data and information sources needed for the intended unsteady flow model development and revisions to existing steady flow model have been inventoried, reviewed, and assessed.
4. Development of unsteady flow model and revisions to the existing steady flow model can be done with existing and upcoming data sources for flow and stage data, topographic and bathymetric data, and data for existing structures.
5. Use of paired unsteady and steady flow UPR HEC-RAS models could be a sound approach to improve the model accuracy.
6. Once the UPR MFLs are reevaluated and adopted, then use of paired unsteady and steady flow UPR HEC-RAS models would provide a reference to other freshwater system MFLs evaluation.

6.1 Running the Steady Flow HEC-RAS Model

BFA hydrologists ran the existing model in two different versions of HEC-RAS. BFA fully reviewed the model procedures used by Chen, and ran the model by two versions of HEC-RAS; HEC-RAS Version 4.0, the version originally used by Chen in 2011 in developing the model and Version 5.0.7, the current version (2019). Chen's model executed smoothly by both versions of HEC-RAS, hence BFA concluded that the model is well developed.

6.2 Need for Unsteady Flow Analysis

Due to local karst features/sinkholes along the riverbed and floodplain in the UPR between Bartow and Fort Meade, there is stream flow lost to the groundwater system. Flow losses are larger during low stream conditions that usually occur in the spring dry season. On the other hand, south of Fort Meade there is good confinement between the river and the underlying aquifers and no major losses to the groundwater system (Basso, 2004). There are also tributary inflows along the river that can largely determine the quantity and timing of flow that discharges into a section/reach of the river. The impact of these tributaries on the UPR flows are more pronounced during low flow conditions. Channelization and control structures in some of these tributaries, for example in the Peace Creek Drainage Canal and Saddle Creek upstream of Bartow, affect the quantity and timing of the inflows to the UPR. During low-flow conditions, storage in these tributaries reduces the discharge into the UPR. This ponding effect has been also observed in naturally formed tributaries of the UPR that have flat low gradient. Also, surface water inflows include urban runoff through ditches during intense storm events, and reclaimed phosphate – mine channels and outfalls that supply water to the river except under extremely dry conditions. There are also distributary channels (Dover Sink Distributary and Gator Sink Distributary) that drain river water from the main channel under certain hydrologic conditions (Metz and Lewelling, 2009). Additionally, there are spatial and temporal variations of precipitation throughout the basin.

These characteristics imply that most of the time the actual river flow behaves as an unsteady flow, attenuating as it moves downstream. Consequently, the discharge-stage ratings at any cross section will be unique, and flow rates with the same exceedance percentage will not occur at the same time at all locations along the river.

The existing steady flow HEC-RAS model cannot adequately capture the unsteady features of the river, generally described above. The unsteady flow model could better account for the unsteady nature of the UPR and provide more accurate results. The calibrated unsteady flow model can provide a basis for the development/refinement of the steady flow model and subsequent modeling of MFL flow scenarios. For example, the hydraulic properties, such as Manning's roughness coefficient (n), resulting from the calibration of the unsteady flow model can be used as input for the steady flow model to improve the accuracy of the simulated water surface elevation or stage heights. Also, the hydrographs and rating curves at specific cross-sections can be used to establish the boundary conditions for different steady-flow scenarios as needed for the MFL analysis. In addition, the use of the 2-D model unsteady flow model can provide additional information that may improve the analysis of MFLs, such as water levels across a given cross-section and flow exchange between the main channel and floodplain areas.

6.3 Data Source Inventory and Evaluation

BFA completed an inventory and evaluation of the data sources needed to develop unsteady and steady flow versions of the HEC-RAS models for the UPR. The data inventory and evaluation covered three categories of model inputs: flow and stage data, topographic and bathymetric data, and structures data. This report's Sections 3, 4, and 5 respectively describe at length these three data review efforts. Below is a summary of the work performed.

The inventory and evaluation of existing flow and stage data included review of the following USGS data: discharge records for the long-term gaging stations of the UPR; stage records for the long-term gaging stations of the UPR; flow duration curves for the long-term gaging stations of the UPR; and discharge rating curves for the long-term gaging stations. BFA performed numerous data verification procedures and analyses. BFA also reviewed information related to streamflow losses to sinkholes in the UPR. Additionally, BFA performed an investigation of discharges and stages for the period from 6/1/1974 to 5/30/2020. This review showed that there is sufficient and adequate stage and flow data to develop the unsteady and steady flow models.

The inventory and evaluation of existing topographic and bathymetric data included review of topographic and bathymetric surveys, and digital elevation models (LiDAR) provided by the SWFWMD. BFA also reviewed the data used to represent the cross-sections in the 2011 HEC-RAS model. This review showed that the available data is sufficient for preparing geometric data inputs needed to characterize the cross-sections in the unsteady and steady flow models.

The inventory and evaluation of structure data in the UPR included review of existing topographic surveys and geometric data of the 2011 HEC-RAS model, and inspection of GIS applications and maps. This review revealed that there are 15 bridges in the UPR between the USGS gages Bartow and Zolfo Springs. No other relevant hydraulic structures were found in the study area. Relevant data and information of the bridges in the study area were obtained from the SWFWMD, FDOT, Polk County and CSX. This review showed that there is sufficient bridge data to develop the geometric input for the unsteady and steady flow models.

6.4 Existing Data Sources

Upper Peace River has extensive streamflow and stage data monitored and recorded by the USGS. BFA downloaded this data from the USGS database and conducted data verification procedures. BFA performed data analyses and produced the results relevant to HEC-RAS unsteady flow and steady flow modeling choosing a data period from October 1940 to May 2020. Based on these analyses and results BFA concludes that the UPR has the required streamflow and stage, topographic and bathymetric, and structure data to conduct both HEC-RAS dynamic flow analysis and the ensuing steady flow HEC-RAS analysis.

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APPENDIX
Existing HEC-RAS Steady Flow Model Task 2 Technical Memo

BFA Environmental Consultants
Barnes, Ferland and Associates, Inc.

TECHNICAL MEMORANDUM

TO: Danielle Rogers, PWS, PMP, Environmental Project Manager, Environmental Flows and Assessments Section, Natural Systems and Restoration Bureau, Southwest Florida Water Management District

FROM: Barnes, Ferland and Associates, Inc. (BFA)

DATE: September 2, 2020

PROJECT NAME: Data Assessment for HEC-RAS Unsteady Flow Modeling of Upper Peace River (B041), TWA 20TW0002966

RE: Task 2 Deliverable - A Review of the Upper Peace River HEC-RAS Steady Flow Models

Overview

Barnes, Ferland and Associates, Inc. (BFA) received Task Work Assignment (TWA) No. 20TW0002966, in June of 2020, for the project titled, *Data Assessment for HEC-RAS Unsteady Flow Modeling of Upper Peace River (Project).* The HEC-RAS steady flow model was developed by the Southwest Florida Water Management District (SWFWMD or District) in support of previous minimum flow evaluation of the Upper Peace River (UPR). Model calibration and verification are anticipated to be included as part of the Minimum Flows and Levels (MFLs) reevaluation through conducting an unsteady flow analysis before running the HEC-RAS model for steady flow analysis for selected flow profiles that will be used for the UPR MFLs reevaluation.

The authorizing TWA covers seven tasks. This technical memorandum (TM) addresses Task 2, the Review of Existing HEC-RAS Steady Flow Model. The scope of work for this task includes the following three subtasks:

Subtask 2.1 - Review the existing steady flow model using the latest version of HEC-RAS to identify any improvements and revisions that are necessary including, but not limited to:

- unsteady flow analysis; and
- additional data collection that may be associated with the Project Tasks 3, 4 and 5.

This review will include the performance of two model runs with the existing model to help assess its behavior in select areas and under certain conditions.

Subtask 2.2 - Based on evaluations under Subtask 2.1 BFA will then assess the necessity of unsteady flow analysis in terms of model improvements in support of the UPR MFLs reevaluation.

Subtask 2.3 - Provide a technical memo and receive approval from District staff before moving forward with the remaining tasks.

This TM summarizes BFA's review of the Upper Peace River HEC-RAS Steady Flow Models including the following documentation:

- Chen, XinJian 2011. HEC-RAS simulation of the Upper Peace River, Southwest Florida Water Management District.
- Gore, J. A., Dahm, C., and Klimas, C. 2002. A review of 'Upper Peace River: An Analysis of Minimum Flows and Levels.'
- Southwest Florida Water Management District 2002. Upper Peace River - An Analysis of Minimum Flows and Levels (Draft).

Background

Section 373.042, Florida Statutes, mandates Water Management Districts (WMDs) of Florida to establish MFLs for surface waters and aquifers in their Jurisdictions. The definitions of MFLs are: "**The minimum flow for a given watercourse is the limit at which further withdrawals would be significantly harmful to the water resources or ecology of the area,**" and "**The minimum water level is the level of groundwater in an aquifer and the level of surface water at which further withdrawals would be significantly harmful to the water resources or ecology of the area.**" WMDs conduct detailed ecologic studies to formulate specific criteria in applying these rules for various locations of a chosen watershed. The Upper Peace River from Bartow gage to Zolfo Springs gage (Figures 1 and 2) is a watercourse for which the District established the minimum "low" flows in 2002 (SWFWMD 2002).

A computer program commonly used by WMDs both in establishing numerical values of MFLs and verifying compliance of the MFLs is the US Army Corps of Engineers' HEC (Hydrologic Engineering Center) RAS (River Analysis System). HEC-RAS is developed to analyze steady/gradually varied river flow conditions, and unsteady flow conditions (known as dynamic wave). HEC-RAS steady flow model develops water surface profiles for the specified flow values, giving depths of water for different locations (transects) for the river reach analyzed. For the past few decades WMDs used the HEC-RAS steady flow model for the MFLs studies, but recently unsteady flow HEC-RAS models are also being applied in these evaluations (e.g., Rainbow River by SWFWMD, 2017).

The District's resource management goals for the UPR MFLs are:

- Maintain minimum depths for fish passage and canoeing in the upper river;
- Maintain depths above inflection point in the wetted perimeter of the stream;
- Inundate woody habitats in the stream channel; and
- Meet the hydrologic requirements of floodplain biological communities.

HEC-RAS is helpful to develop the necessary stage and discharge data in a generalized fashion to evaluate the foregoing goals. As part of the UPR MFLs study, during late 2001 and early 2002 the District obtained and modified a USGS (US Geological Survey) HEC-RAS model, which, revised from a mid-1970s step-backwater, flood profile model developed by USGS for the Peace River, included cross-sectional data collected at 183 sites on the river between Bartow and Arcadia (SWFWMD 2002). The USGS HEC-RAS model was developed on Version 2.2 of HEC-RAS, in which the UPR was divided into two segments: 1) from Bartow to Fort Meade and 2) from Fort Meade to Zolfo Springs. The District modified the USGS HEC-RAS model by adding more flow profiles, adding 18 cross sections surveyed by the District in 2001, and fine tuning Manning's roughness coefficients. The output from this District's revised 2001/2002 HEC-RAS model and the field investigation at the 18 surveyed transects served as the basis for establishing the recommended MFLs that was completed in 2002.

Gore, Dahm, and Klimas (2002) peer reviewed the District's 2002 MFLs report (SWFWMD 2002) and expressed: "The District goals represent a reasonable subset of potential goals for an improved biotic community in the degraded upper basin. The rationale for choosing these goals is clearly presented and scientifically justified. The application of the HEC-RAS model to generate a wetted perimeter versus flow plot for each transect also is a justifiable scientific approach".

In 2011, Chen further modified the 2001/2002 HEC-RAS model to address the shortcomings discussed in the following section and incorporated data collected since the completion of the 2001/2002 model in support of the then scheduled 2012 UPR "middle" and "high" minimum flows evaluation. This Task 2 does not include a review of that 2001/2002 HEC-RAS model, instead focuses on Chen's 2011 HEC-RAS model because it represents the latest model for the UPR and has not gone through peer review. The District anticipates that the review through this task would provide insights to the next version of HEC-RAS model for the UPR MFLs reevaluation.

For fish passage, the District determined the desired elevation is 0.6 feet above channel minimum elevation. For general inundation of the basin water should rise above the surveyed wetted perimeter "inflection" point. The HEC-RAS model is run in a generalized fashion for the range of expected discharges, giving a range of water surface profiles for the study reach of the river. These water surface profiles would yield discharges satisfying fish passage elevations and the desirable inundation elevations at various transects. Based on the 2001/2002 HEC-RAS data the District established the following MFLs for UPR.

Minimum flows for fish passage are proposed to be set at 16 cubic feet per second (cfs) at Bartow, 27 cfs at Fort Meade, and 45 cfs at Zolfo Springs. These minimum flows should be achieved at least for 95% of the time annually.

Flows required to inundate transects to the surveyed wetted perimeter "inflection" points provided similar values (17 cfs at Bartow, 26 cfs at Fort Meade, and 26 cfs at Zolfo Springs). Based both on fish passage and wetted perimeter analyses, low minimum flows of 17 cfs at Bartow, 27 cfs at Fort Meade, and 45 cfs at Zolfo Springs are recommended for exceedance 95% of the time annually.

Findings of Review

In 2011, Dr. XinJian Chen of the SWFWMD extensively revised practically replacing the 2001/2002 UPR HEC-RAS model by a new model. The revised model has been made available to BFA for review. Chen lists the following shortcomings in the 2001/2002 model.

1. Because of the existence of sinkholes in the riverbed, flow can be lost to ground water along the river segment between Bartow and Fort Meade (sink phenomenon mostly occurs between Fort Meade and Bartow) and the flow percentiles simulated in the USGS model did not recognize this fact. Therefore, low flows with high exceedance percentages simulated in the USGS HEC-RAS model may not be accurate.

2. The 2001/2002 modeling for the period 1940 to 1998 was done by dividing the river reach into two segments: Bartow to Fort Meade and Fort Meade to Zolfo Springs. Fort Meade gaging station was established prior to 1964, but continuous flow measurement at this site started June 1, 1974, while the other two gaging stations started recording continuous flow records from 1940. Hence, concurrent continuous flow data for the three gaging stations was not available before June 1974. The study estimated flow percentiles at the Fort Meade station by interpolating from those at Zolfo Springs and Bartow stations with the assumption that the increment of river flow along the river reach between Bartow and Zolfo Springs is proportional to the increment of the drainage area. This assumption, due to limitation on the then short period of concurrent records, ignored the sinkhole losses in the area and caused overestimated discharges for Fort Meade, especially for the low flow range.

3. The cross-sectional data used were generally outdated, because they were generated using old aerial 1-foot topographic contour maps, old field surveys, or similar analyses conducted more than 30 years ago. Because the morphology of the Upper Peace River slowly varies over the years, these old cross sections may not be suitable to represent the present bathymetric condition of the Upper Peace River.

Chen used 165 river cross sections in building up his HEC-RAS model, including the 18 extensively surveyed sections from the 2001/2002 model, 101 new sections that were surveyed from time to time during 2000 – 2010, and 46 sections extracted from the USGS HEC-RAS model (Figure 3). The 46 extracted sections served primarily the purpose of filling large gaps in the river segments. The 18 sections surveyed in 2001 extended into the floodplain while the survey for the 101 new sections was done primarily for the channel portion. These 101 sections were extended 1,000 feet into the floodplain on either side using LiDAR data shown by the brown line in Figure 3. Chen also developed a single river reach model from Bartow to Zolfo Springs. The Zolfo Springs rating curve served as the downstream boundary condition while the rating curves at Fort Meade and Bartow served for model calibration.

Based on gaged data from June 1, 1974 (the inception date of Fort Meade gaging station) to July 12, 2011, Chen obtained 18 flow rates for different exceedance percentages, ranging from 0.1% to 99% for the three gaging stations at Bartow, Fort Meade and Zolfo Springs (Table 1). In this process Chen excluded the 1940 – 1974 flow data that was available for Bartow and Zolfo Springs and used in the 2001/2002 HEC-RAS model. Chen justifies excluding the 1940 – 1974 data stating the period chosen by him had concurrent data at the three stations representing true flow conditions, represents the more recent flow conditions in the river, which is perhaps more important in the MFLs evaluation process than the data of 40 years or older with uncertainties of sink-hole loss issue. BFA will consider this fully under Task 3, review of available discharge and stage data.

From the then (2011) available rating curves provided by the USGS for the three gaging stations (USGS Bartow, Fort Meade, and Zolfo Springs), Chen obtained the water surface elevations corresponding to the 18 flow values (Table 2). BFA downloaded the current USGS rating curves for Bartow (6/11/2020); Fort Meade (6/8/2020) and Zolfo Springs (6/8/2020) (e.g., Figure 4 for Fort Meade gauging station). A discussion of these rating curves will be provided under Task 3.

Chen developed a HEC-RAS model to compute 18 flow profiles corresponding to the 18 sets of discharge values presented in Table 1. The stages at Zolfo Springs (Table 2) served as the boundary condition. Chen calibrated the model by adjusting Manning's roughness values in the main channel and floodplains along the river to match the stages at Fort Meade and Bartow.

The HEC-RAS Version 4.0 was used in Chen's 2011 model, but the software has continuously gone through multiple upgrades with the current Version 5.0.7 (March 2019). BFA obtained HEC-RAS for both Versions 4.0 and 5.0.7 and found that Chen's 2011 model executed smoothly with both versions of HEC-RAS. Figure 5 presents the 18 water surface profiles computed with HEC-RAS Version 5.0.7. In the report (Chen 2011), Chen presented Figure 6 comparing the modeled and the targeted stages at the Fort Meade and Bartow stations, which showed a close match of the stages. To verify whether HEC-RAS versions 4.0 and 5.0.7 produced identical results for Chen's 2011 model, the 50 percentile water surface profile was randomly chosen and 'Detailed Output Tables' from the two HEC-RAS versions were reviewed. The review revealed exactly matching results from the two versions as seen in Tables 3 and 4 for the River Station (RS) 588. The computed elevations for additional selected River Stations are as follows.

River Station	Computed Elevations by Two Versions of HEC-RAS
588	90.20 ft. NAVD
500	79.93
450	71.33
400	57.60
350	49.03
300	41.40
280	40.75

Summary and Conclusions

Review Existing HEC-RAS Steady Flow Model

In 2002, the District established MFLs for the UPR within its jurisdiction. Generalized data developed by the US Army Corps of Engineers' HEC-RAS computer model formed the basis for determining minimum flows for three locations in UPR (Bartow, Fort Meade, and Zolfo Springs). The model developed in 2001/2002, however, was based on somewhat limited resources (e.g., discharge and stage data, river cross sections).

In 2011, XinJian Chen of SWFWMD extensively revised the 2001/2002 UPR HEC-RAS model by using large number of field surveyed river sections and concurrent discharge records. BFA fully reviewed the model procedures used by Chen, and ran the model using two versions of HEC-RAS; HEC-RAS Version 4.0, the version originally used by Chen in 2011 in developing the model and Version 5.0.7, the current version (2019). BFA found that Chen's model executed smoothly by both versions of HEC-RAS, hence it is concluded that the model is well developed.

Needed Improvements and Revisions

The UPR exhibits unsteady flow conditions as explained in the section "Need for Unsteady Flow Analysis". Therefore, an unsteady flow analysis that attempts to account for the unsteady nature of sinkhole losses, tributary and runoff inflows, base flows, and spatial and temporal variation of rainfall that occur in the river basin, could yield more accurate results. Adding unsteady flow analysis as a basis for the development or refinement of a steady flow model can improve the accuracy of the results of the steady flow model that are used in the MFLs analysis.

The unsteady flow analysis has the capability to provide improved hydraulic parameters, such as Manning's roughness coefficient (n) that can be used as input for the steady flow model. Therefore, the steady flow model can provide more accurate results, such as water surface elevations or stage heights along the river for specific flow scenarios. The calibration and verification processes for the unsteady flow analysis can be used to adjust the hydraulic parameters to better predict the observed water surface elevations for selected periods of records that reflect the conditions that are more critical for the establishment of the MFLs. Also, the unsteady flow model can provide hydrographs and rating curves that can be used to develop boundary conditions for the steady flow model for selected cross sections where data is not readily available or incomplete. In addition, results of a 2-D model unsteady flow model, such as water levels across a given cross-section and flow exchange between the main channel and floodplain areas, can enhance the MFLs analysis.

The calibration and verification processes of the unsteady flow model requires running the model for a continuous time span that should reflect the conditions that are more relevant for the posterior analysis of MFLs, while considering the data requirements and limitations of the model, such as instability problems and handling very low flows, and limitations of the platform used for running the model and project time constraints.

In the UPR, between Bartow and Fort Meade gaging station, very low or zero flows occur mainly the end of the dry season. The unsteady flow model cannot have a zero base flow and the channel cannot become dry during a simulation. A minimum flow threshold value could be used at inflow boundaries to prevent the base flow from falling below a defined threshold, which could improve model stability. Also, model stability can be very sensitive to the computational time step. Modifying the computation time step can resolve this issue but also increase the time needed for running the model. Alternatively, the simulation time span could be separated in distinctive periods that reflect the conditions more likely to affect MFLs, while minimizing instabilities and avoiding zero flow issues, as well as optimizing model running time.

Acquiring the data required for the development of the unsteady flow model could become a difficult task. For example, there may not be readily available flow data for tributary/lateral inflows or it may be difficult to assess the sinkhole losses for the simulation period. For the lateral inflows, the unsteady flow model could compute lateral inflow hydrographs, which may be used as internal boundary conditions in the steady state model to represent inflow from tributaries at specific points or cross section in the river. Alternative procedure could also be used to estimate the tributaries flow contributions (regression analysis, water budget, etc.). These efforts should focus on the inflows that have a larger impact on dynamics of the river system. As part of Task 3, BFA will research reported sinkhole data sources specifically within in the UPR (https://ca.dep.state.fl.us/mapdirect/?focus=fgssinkholes).

BFA will be addressing the unsteady flow modeling issues in detail in the final report after completion of Tasks 3, 4 and 5. Our comments on the unsteady flow modeling in this TM are rather introductory/preliminary.

In order to improve both steady and unsteady flow analyses, additional cross sections and a longer period of record to perform the simulations may be needed. Also, future improvements and revisions should incorporate updated LiDAR, river bathymetric surveys and structures' geometric information, as well as updated information about sinkholes, water demands and tributary/lateral inflow, among other relevant information. Subsequent Tasks 3, 4 and 5 will provide better insight into the data and information needs and facilitate the analysis of needed improvements and revisions of the UPR HEC-RAS model.

Additional Data and Information Needed

BFA has additional tasks to complete: Review of Existing Flow and Stage Measurements (Task 3), Review of Existing Topographic and Bathymetric Data (Task 4), and Review of Structure Data in the Upper Peace River (Task 5). The discharge and stage data that would be reviewed under Task 3 would be 9 years longer in record length compared to Chen's. Tables 1 and 2 would be revised using current records and current USGS rating curves and may be recommended for use in the HEC-RAS model. Tasks 4 and 5 would provide information on new developments in the basin and if these are substantial a recommendation would be made to revise HEC-RAS data to reflect these new occurrences.

The discharge data used in the HEC-RAS model, both HEC-RAS 2001/2002 and Chen's 2011 model, for generalized production of river-wide stage-discharge data was rather 'hypothetical.' The data assumes that discharges, at a chosen percentile, would occur simultaneously at all locations. This is very unlikely to occur because rainfall would be rarely uniform throughout the basin. This anomaly/shortcoming was acknowledged by Chen, and it would be further examined/discussed under Task 3, specifically to find whether HEC-RAS unsteady flow modeling would remedy that situation.

Need for Unsteady Flow Analysis

Due to local karst features/sinkholes along the riverbed and floodplain in the UPR between Bartow and Fort Meade, there is stream flow lost to the groundwater system. Flow losses are larger during low stream conditions that usually occur in the spring dry season. On the other hand, south of Fort Meade there is good confinement between the river and the underlying aquifers and no major losses to the groundwater system (Basso, 2004). There are also tributary inflows along the river that can largely determine the quantity and timing of flow that discharges into a section/reach of the river. The impact of these tributaries on the UPR flows are more pronounced during low flow conditions. Channelization and control structures in some of these tributaries, for example in the Peace Creek Drainage Canal and Saddle Creek upstream of Bartow, affect the quantity and timing of the inflows to the UPR. During low-flow conditions, storage in these tributaries reduces the discharge into the UPR. This ponding effect has been also observed in naturally formed tributaries of the UPR that have flat low gradient. Also, surface water inflows include urban runoff through ditches during intense storm events, and reclaimed phosphate – mine channels and outfalls that supply water to the river except under extremely dry conditions. There are also distributary channels (Dover Sink Distributary and Gator Sink Distributary) that drain river water from the main channel under certain hydrologic conditions (Metz and Lewelling, 2009). Additionally, there are spatial and temporal variation of precipitation throughout the basin.

These characteristics imply that most of the time the actual river flow behaves as an unsteady flow, attenuating as it moves downstream. Consequently, the discharge-stage ratings at any cross section will be unique, and flow rates with the same exceedance percentage will not occur at the same time at all locations along the river.

The existing steady flow HEC-RAS model cannot adequately capture the unsteady features of the river, generally described above, and the attenuation of the flow wave as it moves downstream. By contrast the unsteady flow model could better account for the unsteady nature of the UPR and provides more accurate results. The calibrated unsteady flow model can provide a basis for the development/refinement of the steady flow model and subsequent modeling of flow scenarios. For example, the hydraulic properties, such as Manning's roughness coefficient (n), resulting from the calibration of the unsteady flow model can be used as input for the steady flow model to improve the accuracy of the simulated water surface elevation or stage heights. Also, the hydrographs and rating curves at specific cross-sections can be used to establish the boundary conditions for different steady-flow scenarios as needed for the MFLs analysis. In addition, the use of the 2-D model unsteady flow model can provide additional information that may improve the analysis of MFLs, such as water levels across a given cross-section and flow exchange between the main channel and floodplain areas.

BFA concludes that unsteady flow analysis will be needed in support of the UPR MFLs evaluation. More correctly both steady and unsteady flow analyses are required for a more complete reevaluation. Moreover, both steady and unsteady flow models will be needed for implementation and management of the adopted MFLs. Management of adopted MFLs routinely involves the assessment of potential impact of water management actions on the MFLs, specifically their potential to cause significant harm. Steady and unsteady flow analyses will be used to predict impacts to hydrologic regime of the UPR.

Routine applications of paired steady and unsteady flow models can be used:

- to generate the time series inputs to habitat assessment models (SEFA);
- to develop daily flow and stage time series reflecting no withdrawal conditions, that is an un-impacted flow regime;
- to develop water surface profiles and water discharge profiles for rivers;

- to conduct MFLs compliance analysis;
- for water supply planning efforts (needs and source surveys, District Water Supply Plans, etc.);
- to evaluate benefits of proposed and/or actual alternative water supply (AWS) projects, such as watershed restoration, aquifer recharge, ASR, etc.; and
- to develop MFLs prevention and recovery plans.

With the completion of Task 2 evaluations, BFA concludes**:**

1. The steady flow HEC-RAS model runs in the current version of the software. The model appears to be a stable platform for use in the MFLs reevaluation.
2. The steady flow model will be a good platform from which to develop an unsteady flow model.
3. BFA finds that it is wise and prudent for the District to continue with the development of both steady and unsteady flows models for this reevaluation
4. Data and information gaps have been identified. This needs analysis is interim, and will be expanded in the future Tasks 3, 4 and 5.
5. This report's content, summary and recommendations are also interim, and will be finalized as part of the final report, the Task 6 final deliverable.
6. The expected next steps following acceptance of this TM by the District are then a continuation to subsequent tasks 3 through 7.

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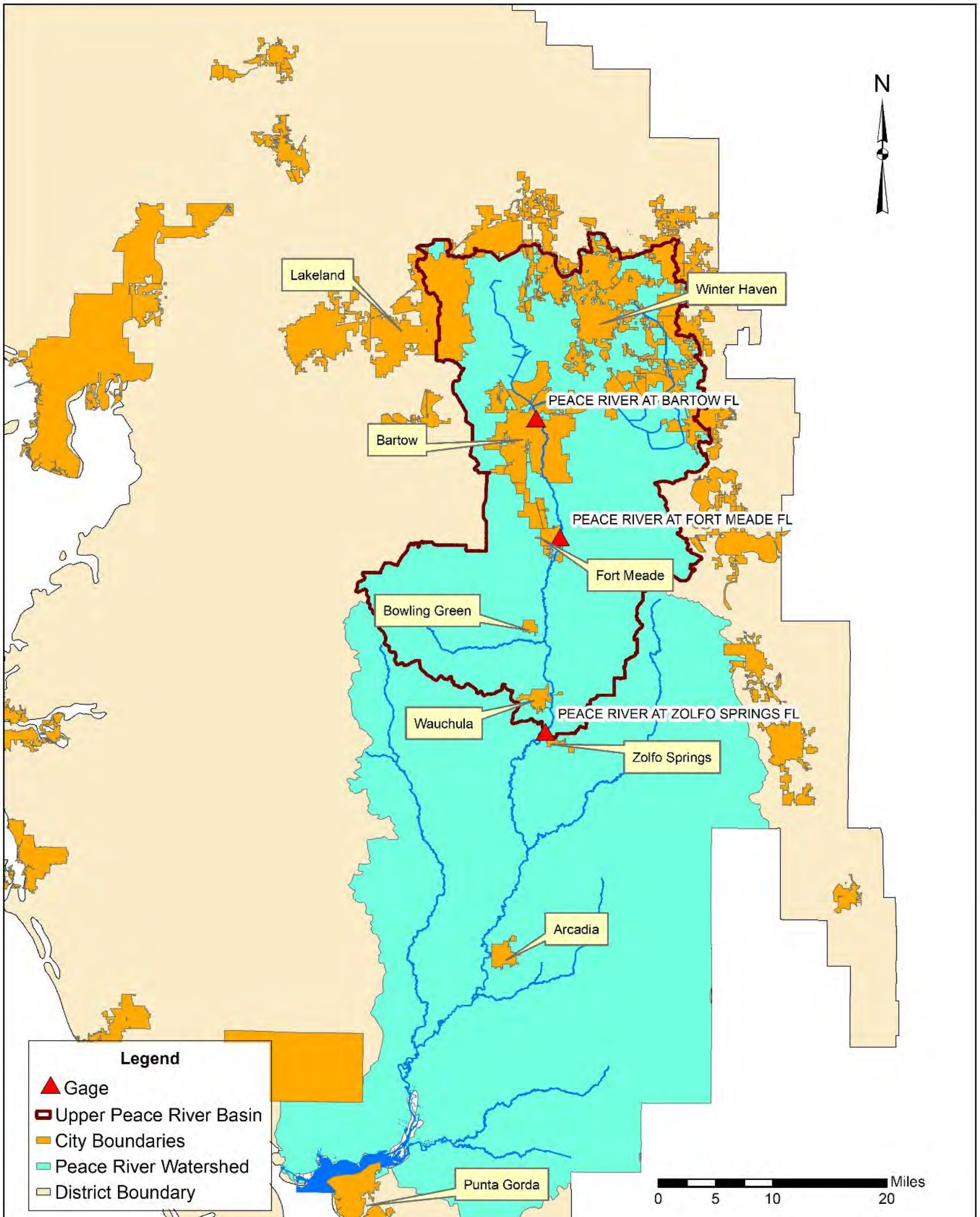
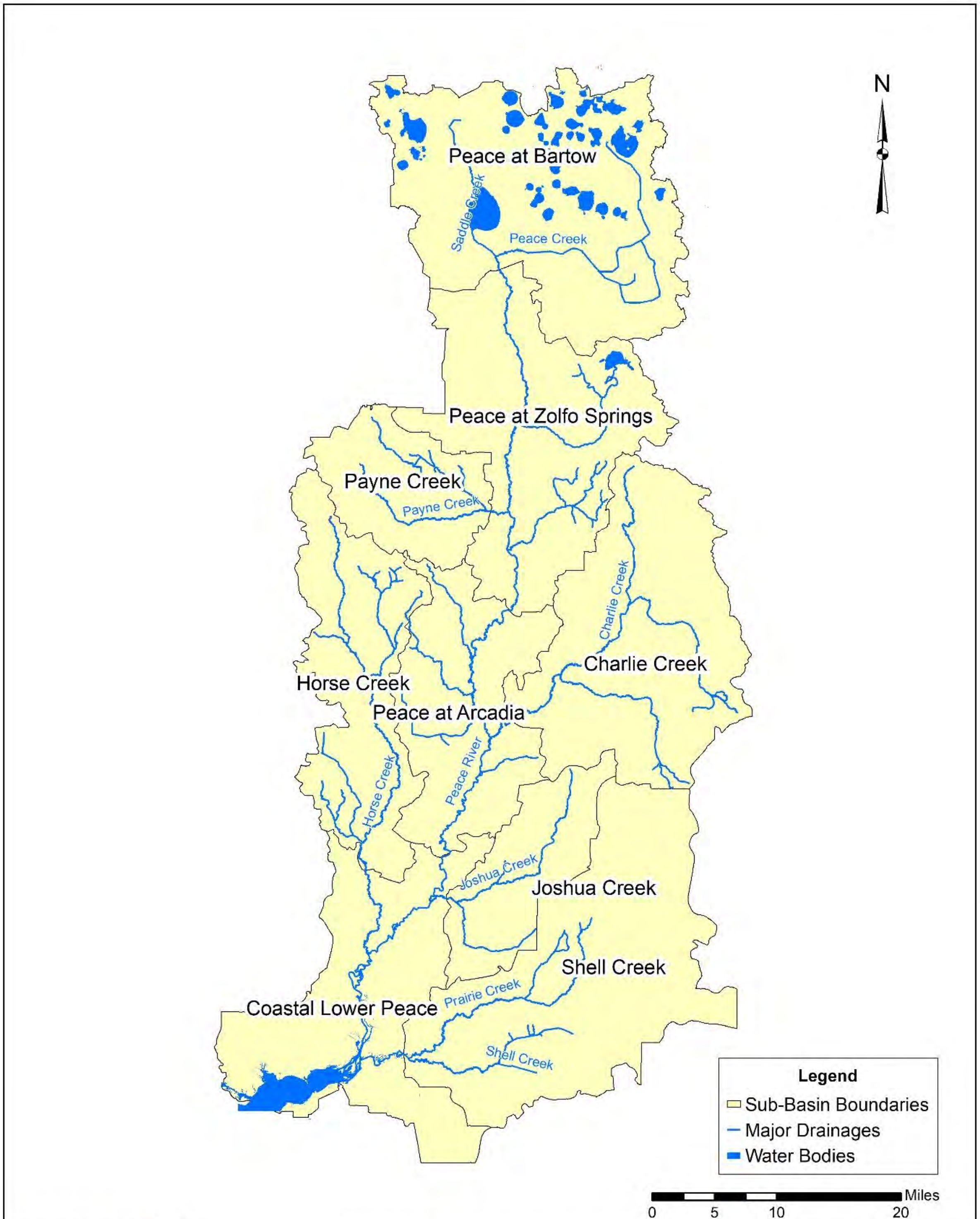


BFA

Upper Peace River Water Basin with City Boundaries and Stream Gaging Stations

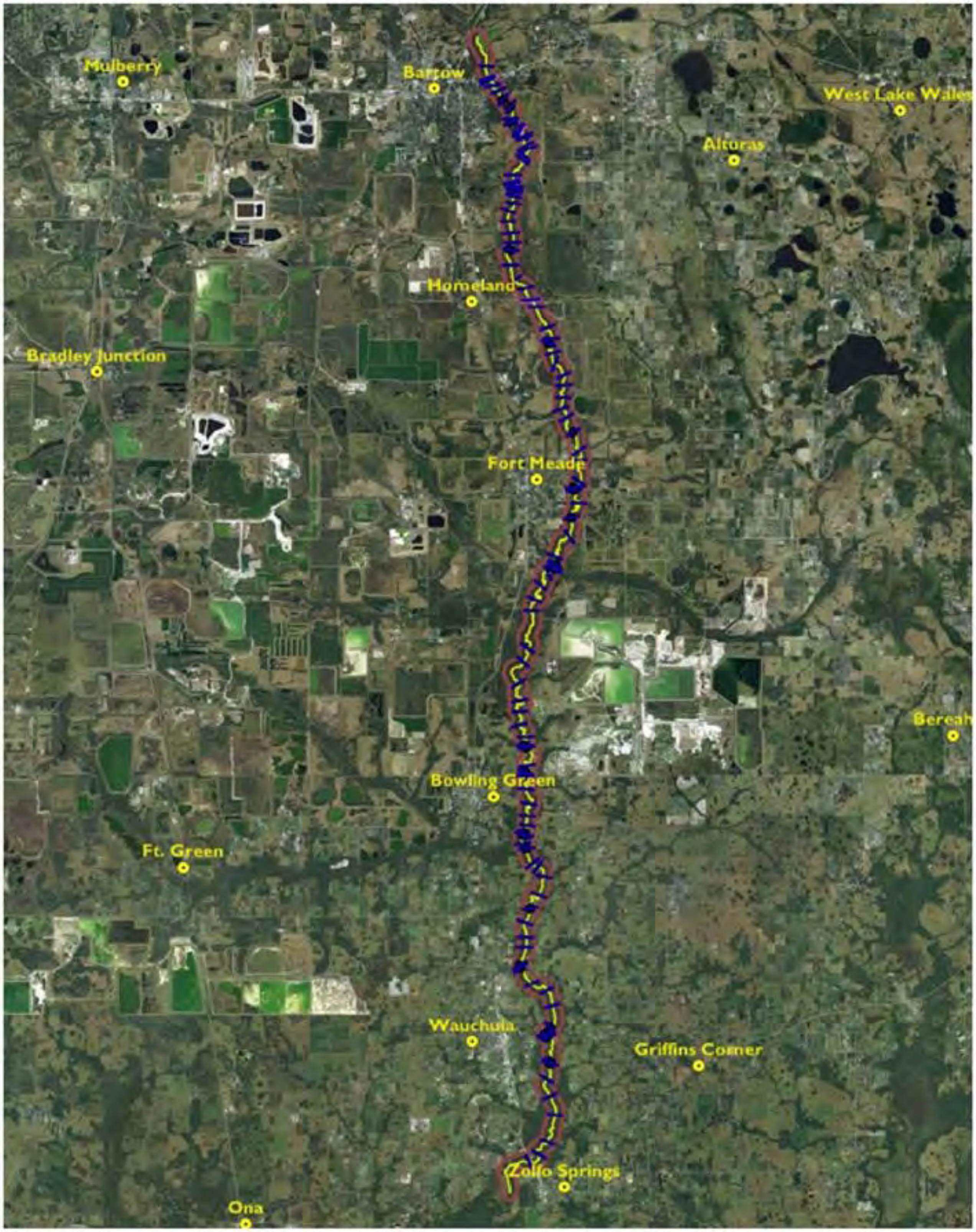
Figure 1



BFA

Peace River Watershed Sub-Basins
Major Streams and Rivers

Figure 2



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Aerial photo of the Upper Peace River with locations of the 165 cross sections (blue lines) used in the HEC-RAS model and the buffer zone of the LiDAR data (brown line) (Chen, 2011)

Figure 3

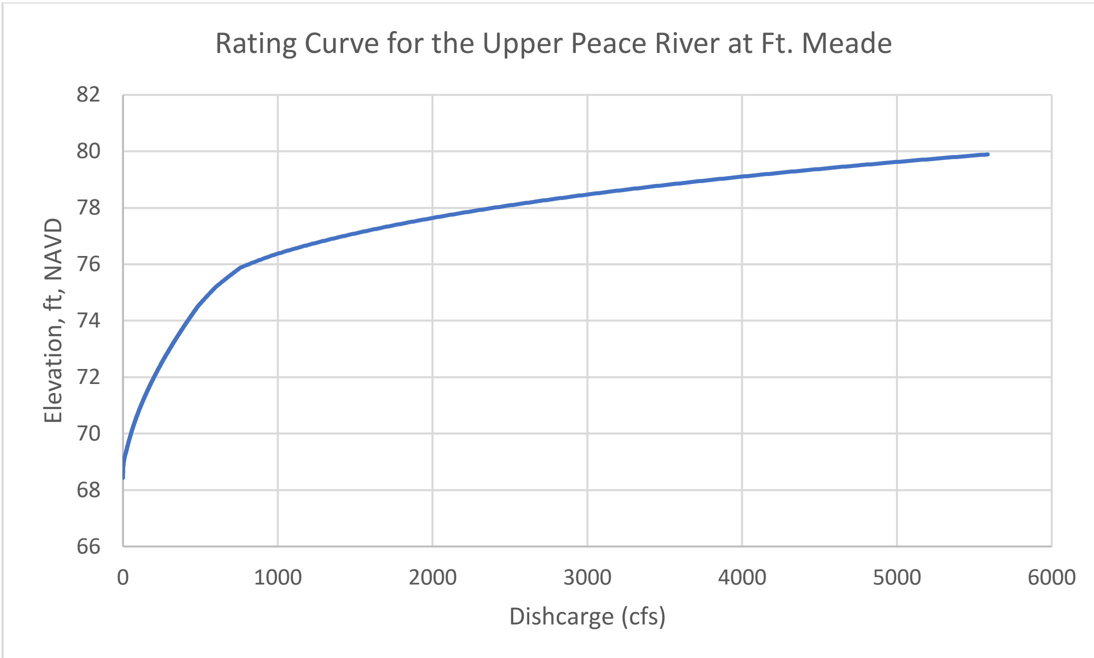

Figure 4 - Rating Curve for Upper Peace River at Fort Meade, Station 02294898

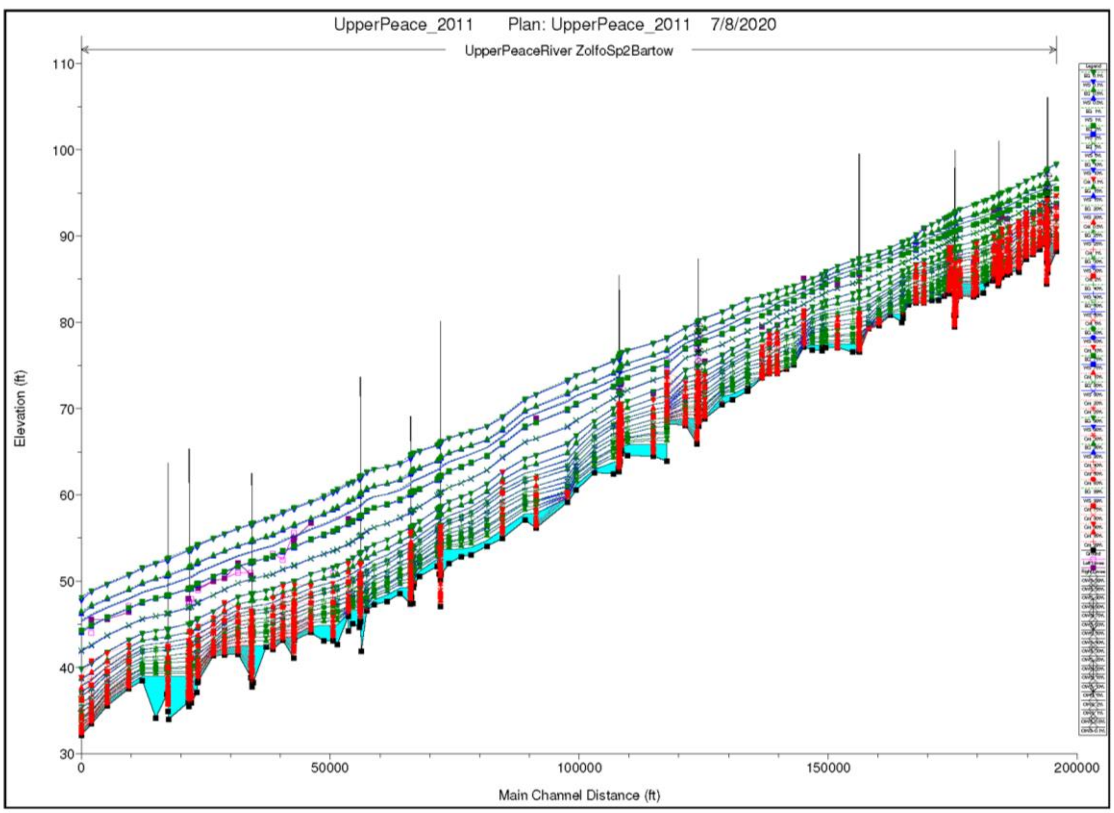

Figure 5 - Upper Peace River Water Surface Profiles by Chen's 2011 HEC-RAS Model Run, HEC-RAS Version 5.0.7

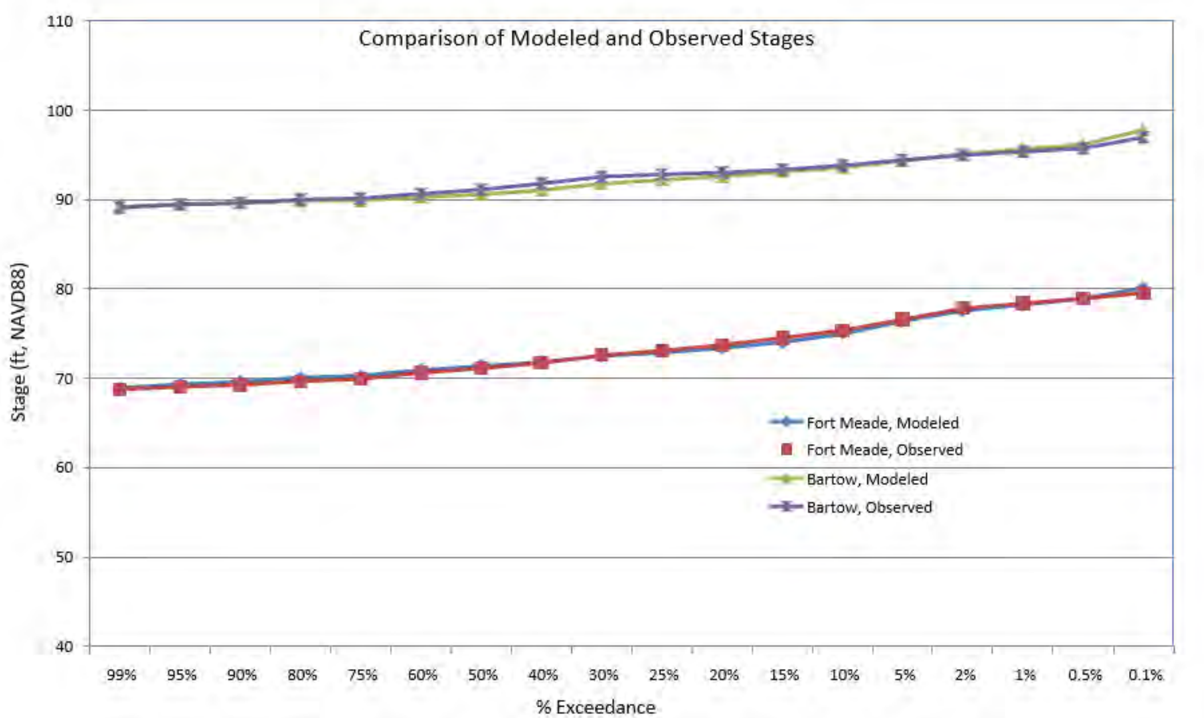

Figure 6: Comparison of modeled and observed stages at the Fort Meade and Bartow stations for 18 percent exceedance flows. (Chen, 2011)

Table 1 - Eighteen different percent exceedance flows at the USGS Zolfo Springs, Fort Meade, and Bartow stations (Chen, 2011).				
No.	Percent	Bartow Flow (cfs)	Fort Meade Flow (cfs)	Zolfo Springs Flow (cfs)
1	99.0	0.9	0.42	14
2	95.0	5.4	2.9	36
3	90.0	8.6	5.9	55
4	80.0	16	15	92
5	75.0	19	21	110
6	60.0	33	48	180
7	50.0	49	72	243
8	40.0	78	107	320
9	30.0	133	169	452
10	25.0	176	210	541
11	20.0	226	270	677
12	15.0	312	366	865
13	10.0	469	534	1170
14	5.0	756	881	1850
15	2.0	1090	1340	2920
16	1.0	1410	1600	3700
17	0.5	1732	1880	4570
18	0.1	3254	2230	6403

Table 2 - Stages corresponding to 18 different percent exceedance flows at the USGS Zolfo Springs, Fort Meade & Bartow stations (Chen, 2011)				
No.	Percent	Bartow Stage (ft)	Fort Meade Stage (ft)	Zolfo Springs Stage (ft)
1	99.0	89.131	68.792	32.800
2	95.0	89.470	69.075	33.220
3	90.0	89.650	69.280	33.520
4	80.0	90.030	69.710	34.000
5	75.0	90.160	69.920	34.200
6	60.0	90.660	70.650	34.860
7	50.0	91.130	71.140	35.360
8	40.0	91.830	71.740	35.900
9	30.0	92.565	72.610	36.705
10	25.0	92.830	73.110	37.190
11	20.0	93.057	73.760	37.845
12	15.0	93.380	74.545	38.665
13	10.0	93.825	75.385	39.840
14	5.0	94.450	76.627	41.900
15	2.0	94.980	77.850	44.110
16	1.0	95.380	78.410	45.310
17	0.5	95.743	78.960	46.220
18	0.1	96.992	79.570	47.803

NOTE: The datum for the stage values listed in Table 2 is NAVD88.

Table 3 - Detailed Output Table for River Station 588, HEC-RAS Version 4.0

E.G. Elev (ft)	90.21	Element	Left OB	Channel	Right OB
Vel Head (ft)	0.01	Wt. n-Val.		0.045	
W.S. Elev (ft)	90.20	Reach Len. (ft)	865.36	1338.07	1182.33
Crit W.S. (ft)	89.26	Flow Area (sq ft)		57.67	
E.G. Slope (ft/ft)	0.000532	Area (sq ft)		57.67	
Q Total (cfs)	49.00	Flow (cfs)		49.00	
Top Width (ft)	48.37	Top Width (ft)		48.37	
Vel Total (ft/s)	0.85	Avg. Vel. (ft/s)		0.85	
Max Chl Dpth (ft)	1.75	Hydr. Depth (ft)		1.19	
Conv. Total (cfs)	2125.4	Conv. (cfs)		2125.4	
Length Wtd. (ft)	1338.07	Wetted Per. (ft)		48.92	
Min Ch El (ft)	88.45	Shear (lb/sq ft)		0.04	
Alpha	1.00	Stream Power (lb/ft s)		0.03	
Frctn Loss (ft)	0.17	Cum Volume (acre-ft)	2.64	778.84	1.76
C & E Loss (ft)	0.00	Cum SA (acres)	3.53	334.10	3.54

Plan: UPR_2011 UpperPeaceRiver ZolfoSp2Bartow RS: 588 Profile: 50%

Table 4 - Detailed Output Table for River Station 588, HEC-RAS Version 5.0.7

E.G. Elev (ft)	90.21	Element	Left OB	Channel	Right OB
Vel Head (ft)	0.01	Wt. n-Val.		0.045	
W.S. Elev (ft)	90.20	Reach Len. (ft)	865.36	1338.07	1182.33
Crit W.S. (ft)	89.26	Flow Area (sq ft)		57.67	
E.G. Slope (ft/ft)	0.000532	Area (sq ft)		57.67	
Q Total (cfs)	49.00	Flow (cfs)		49.00	
Top Width (ft)	48.37	Top Width (ft)		48.37	
Vel Total (ft/s)	0.85	Avg. Vel. (ft/s)		0.85	
Max Chl Dpth (ft)	1.75	Hydr. Depth (ft)		1.19	
Conv. Total (cfs)	2125.40	Conv. (cfs)		2125.40	
Length Wtd. (ft)	1338.07	Wetted Per. (ft)		48.92	
Min Ch El (ft)	88.45	Shear (lb/sq ft)		0.04	
Alpha	1.00	Stream Power (lb/ft s)		0.03	
Frctn Loss (ft)	0.17	Cum Volume (acre-ft)	2.64	778.84	1.76
C & E Loss (ft)	0.00	Cum SA (acres)	3.53	334.10	3.54

Plan: UPR_2011 UpperPeaceRiver ZolfoSp2Bartow RS: 588 Profile: 50%