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C-51 Basin Rule Re-evaluation

C-51 HEC-HMS and HEC-RAS Model Update

Water Resources Modeling Unit

Hydrologic & Environmental Systems Modeling Department

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1.0 INTRODUCTION

1.1 STUDY AREA DESCRIPTION

In 2004, the District completed a study to re-evaluate the original C-51 Basin Rule (Part III, Ch. 401E-41, Rules 40E-41.200 through 40E-41.265, FAC) to prevent increased flood damages in the basin until a permanent structural alternative could be implemented in the basin. In 2005, the U.S. Army Corps of Engineers (USACE) led the effort to provide the structural solution which consisted of a reservoir for water quality treatment and storage (Stormwater Treatment Area-1 East [STA-1E]), the S-319 pump station to divert flows from the C-51 Canal to the STA and the S-155A divide structure located within the C-51 Canal approximately 600-feet west of State Road (SR) 7 to separate discharges from the eastern portion of the C-51 Watershed, which discharges to tide via the S-155 structure. **Figure 1** shows the sub-basin delineation used in the study.

In 2012 the District took upon the task of updating the 2004 models to a current base condition (2012 Baseline) by including several drainage projects in the C-51 Basin including the ACME Basin B in the C-51 West Basin and the L-2 Pump and Renaissance Projects in the C-51 East basin. Early in 2015, the 2012 study has been updated by incorporating minor modifications to sub-basin boundaries and recalibrating the HEC-RAS model from recommendations from the Stakeholder Group (City of West Palm Beach, Palm Beach County and 298 Special District's Consultants).

This report is an update of the 2013 report and incorporates the changes mentioned above to the 2013 Draft Report (SFWMD, 2013).

1.2 PROJECT OBJECTIVE

This study's objective is to update the 2004 C-51 Basin Rule Re-evaluation Study (C-51 Study) models to reflect current basin conditions (2015 Baseline) and determine regulatory peak discharges for all the sub-basins in the C-51 Watershed for the 10-yr 72-hr storm event and peak stages for the 100-yr 72-hr event. This revision of the C-51 Basin models will result in a new "Baseline" which will assist the District during rule development and making processes. This objective will be achieved through the completion of the tasks listed below.

Task 1 - HEC-HMS and HEC-RAS model upgrade

This task requires upgrading the HEC-HMS and HEC-RAS models used in the 2004 study to their most current versions HEC-HMS v 3.5 and HEC-RAS v 4.1.

Task 2 - Basin Modeling System update

This includes the update of hydrologic data in the HEC-HMS model and hydraulic data in the HEC-RAS model to reflect current (2015) conditions. Specifically this includes the following tasks:

a) Update ACME Basin B drainage to reflect new discharge to the C-51 Canal via ACME Basin A;
b) Incorporate the cross sections surveyed by Greenhorne and O'Mara (G&O) (August, 2006) into the upgraded C-51 HEC-RAS model. These cross-sections include

surveyed cross-sections of the C-51 Canal along an eight-mile stretch from just east of the Turnpike to Ousley Farm Road.

c) Include revisions to sub-basin areas that have been modified since 2004. Specifically revise the external boundaries of sub-basins 29A and 29B, 33, 34 and 39.
d) Revision to sub-basin stage-storage curves in the model for all the sub-basins to reflect the most recent and accurate topographic data (Digital Elevation Maps [DEM's]) of the County.
e) Revision of operating rules in the model for the C-51 Canal drainage control structures S-155, S-155A and pump station S-319 to reflect the most current flood control operations by the District.
f) Addition of new C-51 Canal bridges in the model.
g) Incorporation of the District's flow rating equations in the model for the S-155 and S-155A structures.
h) Incorporate more recent drainage improvements by the City of West Palm Beach and Palm Beach County, including the Renaissance, the Palm Beach Zoo outfall and the Garden Avenue projects.
i) Update drainage system in sub-basin 29A, north of the airport to reflect the latest permitted structural modifications including the Westgate sub-basin (25B) L-2 canal weir and the L-2 Pump.
j) Modify the 2004 model to remove artificial weir connections between sub-basins 17, 22, 24, 30, 31, 32 and 33 and the receiving Lake Worth Drainage District canals.
k) Modify sub-basin 16B to reflect the latest permitted development of the Target commercial and the Portosol residential developments.

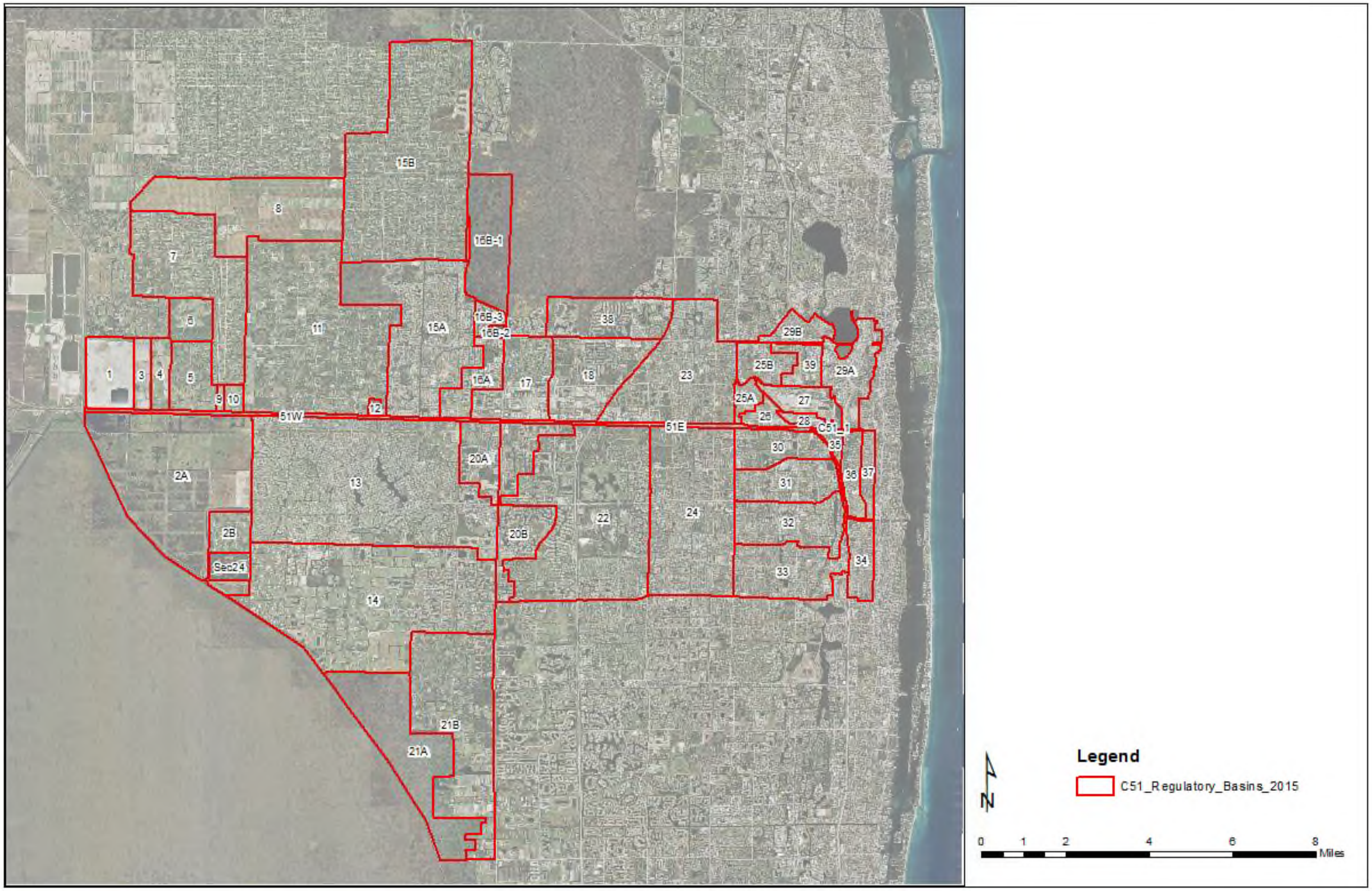

Figure 1. 2015 C-51 Basin Rule Study Sub-basin Map

Task 3 - Model Recalibration.

After completion of Tasks 1 and 2, the model will be re-calibrated with data from Tropical Strom (TS) Isaac (Aug. 26-29, 2012) that reflects the District's flood control operations in Task 2e.

Task 4 – Model Application

This task consists of applying the updated baseline model to the C-51 Basin to the 10-yr, 72hr and 100-yr, 72-hr design storm events. The resulting sub-basin peak flows from the 10-yr, 72hr event simulation and the peak stages from the 100-yr, 72hr event simulation will establish the updated C-51 rule conditions.

1.3 SCOPE OF WORK

The scope of work for this project is included in the Work Plan presented as **Appendix A** of this report.

2.0 TASK 2 – MODEL UPDATE TO CURRENT CONDITIONS

In 2004, The District completed the C-51 Study in which regulatory peak stages and flow discharges were computed for all the sub-basins in the C-51 Basin using HEC-HMS v 2.2.1 and HEC-RAS v3.1.1. Task 1 of this study consisted of upgrading the HEC-HMS and HEC-RAS models to their most recent version. The results of the software upgrade task are included as **Appendix B** of this report.

Since 2004 when the original C-51 Study was completed, several significant modifications to the drainage system in the C-51 Basin have occurred including the construction and activation of the City of West Palm Beach Renaissance Project and the re-direction of ACME Basin B drainage to the C-51 Canal. The inclusion of these projects may result in changes not only the local stages and discharges from each corresponding sub-basin, but also in stages and flow distribution along the C-51 Canal.

Task 2 of this study consisted of updating the 2004 Study HEC-HMS and HEC-RAS models to reflect 2015 drainage conditions in the C-51 Basin. This task was accomplished by including the following projects and datasets:

- Geometry rectification of HEC-RAS files,
- ACME Basin B drainage improvements,
- 2006 C-51 Canal cross-section survey data update,
- Updated topographic data with the most recent DEM's,
- Service Bridge on C-51 Canal near STA-1E,
- Latest District flood control operations for structures S-319, S-155, S-155A and S5AE,
- L-2 sub-basin, Renaissance, Palm Beach Zoo Outfall and Garden Avenue drainage projects.
- Portosol and Target commercial developments in sub-basin 16B.

2.1 HEC-RAS MODEL GEOMETRY GEO-RECTIFICATION

The 2004 version of the C-51 HEC-RAS model was developed with version 3.1.1. Task 1 of this study consisted of upgrading the model software to the most current version (v4.1.) Code changes to the 2004 HEC-RAS model did not address changes in the geometry data of the canal cross-sections and control structures to correctly display the model geometric features on a coordinate system that is compatible with other graphical information such as GIS coverages and aerial photographs. **Figure 2** shows the graphical display of the 2004 C-51 HEC-RAS model with the C-51 Canal oriented on a near-north to south direction and the Lake Worth Drainage District (LWDD) canals on a left to right orientation. The S-155 structure on the tidal end of the C-51 Canal is located on the bottom end of the C-51 Canal.

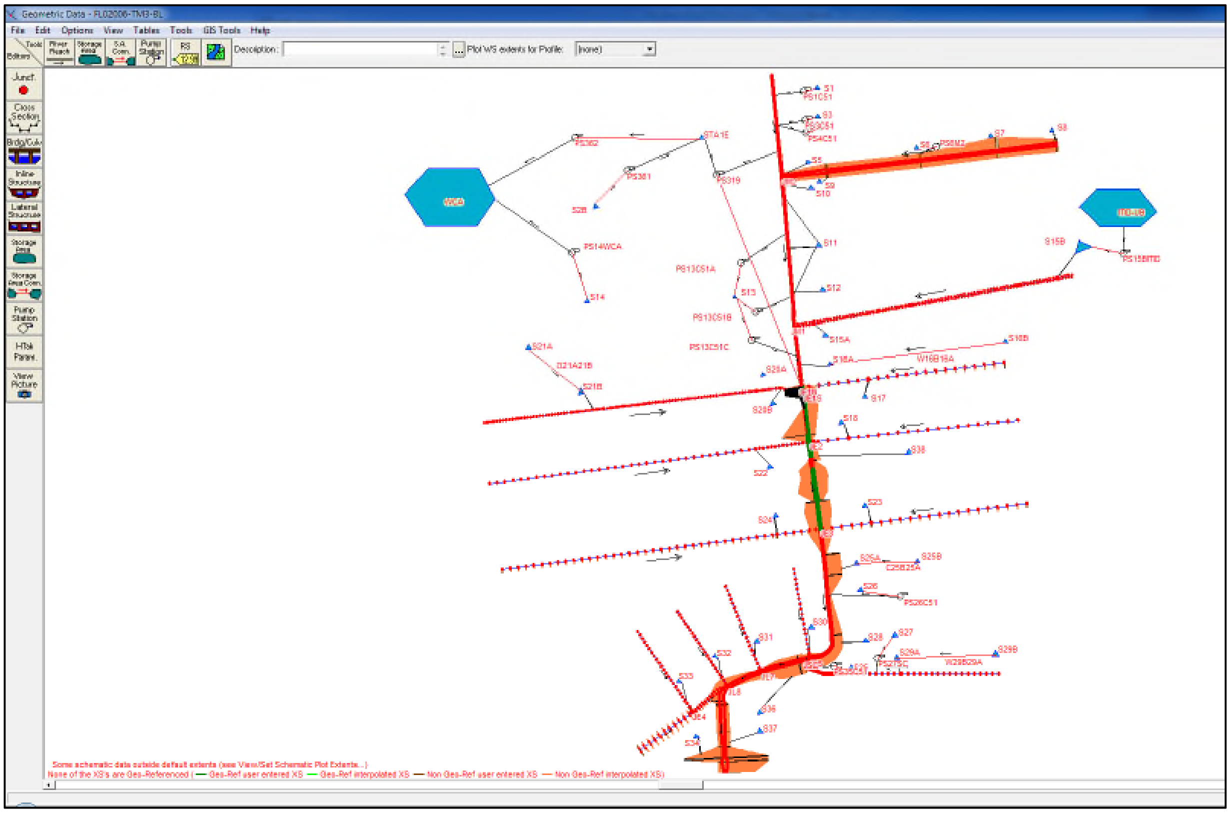

Figure 2. 2004 version of the C-51 HEC-RAS model display

Although this erroneous orientation of the graphical display did not have any significance in the model performance, it made it difficult to locate model features or incorporate background GIS coverages. After Task 1 was completed, the model's canals and structures were adjusted geographically to match the standard geographical projection (NAD 1983 State Plane Florida East FIPS 0901 feet). After the model geometric features were projected onto this coordinate system, the resulting graphical display of the model (**Figure 3**) shows the revised C-51 HEC-RAS graphical model interface with canals and structures properly located in the display. This change to the model makes it easier to locate model features and produce graphical output that can be overlaid with GIS shape files or aerial photographs of the basin. **Figure 3** also shows the C-51 sub-basins GIS coverage overlaid onto the canals.

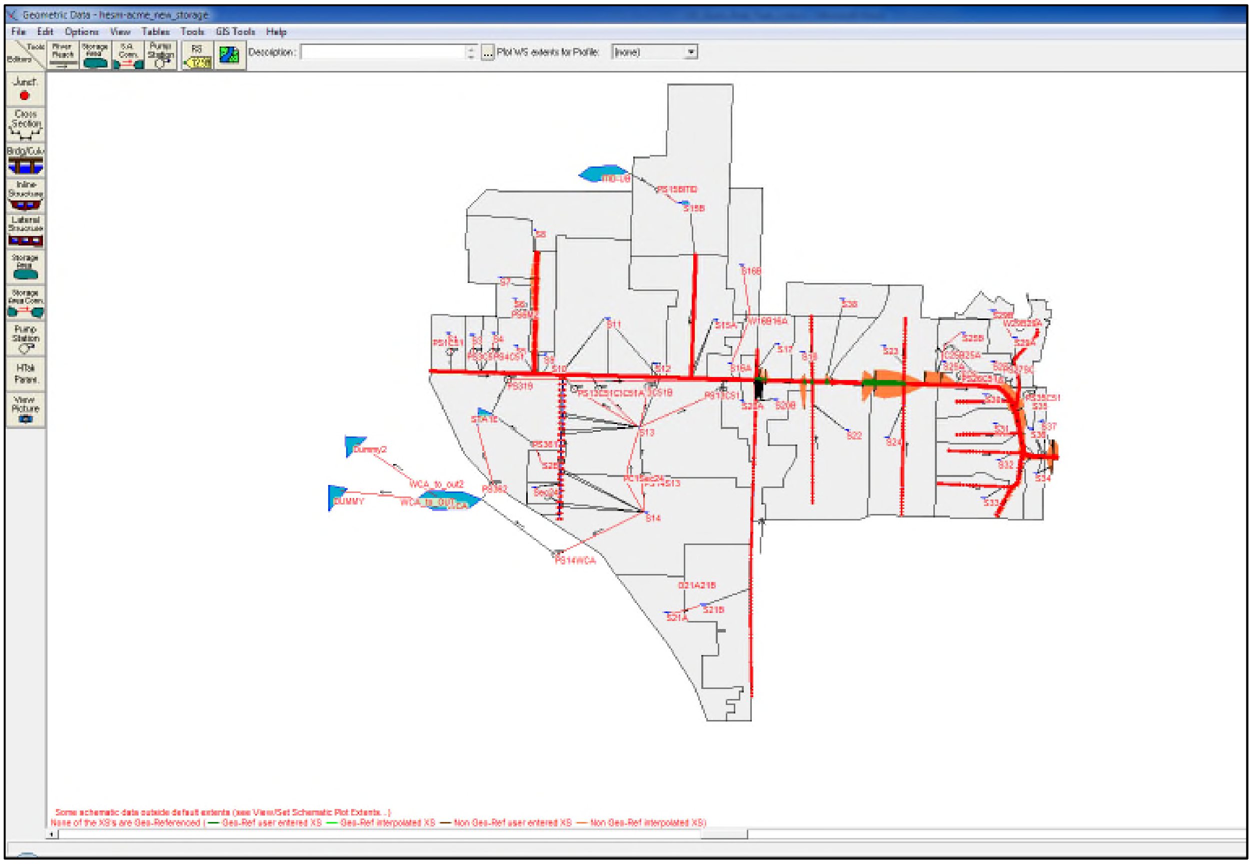

Figure 3. Geo-rectified (2015) version of the C-51 HEC-RAS model Canals and Sub-basins

2.2 ACME BASIN B DRAINAGE IMPROVEMENTS

On November 1st, 2007, the District issued the latest modification to the original ACME Basin B permit issued on April 12, 2006 (Environmental Resource Permit [ERP] No. 50---548-S, Application Nos. 050322-5, 060510-6 and 070330-35). These permit modifications include drainage improvements such as discharges from Basin B into Basin A, as well as discontinued pumpage to the Loxahatchee Wildlife Refuge via pumps 1 and 2. **Figure 4** shows a schematic of the permitted drainage elements for the ACME Basin B which includes:

- A new 220 cfs pump (Pump #7) discharging to the C-51 Canal,
- A new 133 cfs pump (Pump #8) in the C-1 Canal discharging from Basin B to Basin A,
- Improved C-1 Canal conveyance,
- Section 24 Wetland with inflow pump and outlet structure,
- Culvert improvements at structures 40, 42, 43, 44, and 45 between Basins A and B,
- Elimination of discharges from Pump #1 and Pump #2 to the Loxahatchee Wildlife Refuge.

A description of each of the drainage improvements in the permitted plan follows and are shown in **Figure 5** as they appear in the updated HEC-RAS model display.

2.2.1 PUMP STATION #7

A new pump station with a total capacity of 220 cfs was constructed at the northern end of the C-1 canal and discharges into the C-51 Canal. The pump station consists of two 110 cfs diesel fuel pumps with a design elevation of 11.0 ft NGVD and a design TW elevation of approximately 17.0 ft NGVD, which corresponds to the 100-yr peak elevation in the C-51 Canal from the C-51 Study. The pump on elevation is 12.2 ft NGVD while the pump off elevation is 12.0 ft NGVD. All the ACME pumps have flap gates on the discharge side to prevent backflow from the C-51 Canal when the pumps are turned off and the stages in the C-51 are higher than in ACME Basin A.

2.2.2 C-1 CANAL CONVEYANCE IMPROVEMENTS

Conveyance capacity of the C-1 was increased to carry 220 cfs. The design water surface elevation of the C-1 Canal varied from 11.0 ft NGVD at Pump Station 7 to 12.94 ft NGVD at the southern end of the canal with a canal bottom elevation not to exceed 5.0 ft NGVD. Top of rock at the bottom of the canal was established at around elevation 3.8 ft NGVD. The eastern bank's freeboard varies from 0.5 to 4.0 feet and from 3.0 to 5.0 feet on the west bank. The existing canal connection to the C-51 Canal through Pump #7 was made possible by extending the northern end of the canal about 400 feet to the north plus additional 135 feet of inflow canal from Pump #7 to the C-51 Canal. At the intersection of the C-1 and C-23 Canal near Pierson Road, Culvert #40 was improved to the design capacity of 220 cfs.

2.2.3 PUMP STATION #8

A diesel pump of 133 cfs capacity (Pump #8) was constructed at the intersection of the C-2 and C-23 Canals for the purpose of transferring water from Basin B to Basin A with a design HW stage of 11.0 ft NGVD and TW stage of 15.8 ft NGVD. In order to prevent backflows from Basin A into Basin B, the pump has been equipped with a gate in the intake side. Pump operations start when the HW stage rises to elevation 13.2 ft NGVD on the HW side (Basin B) and turn off when the water elevation falls below elevation 13.0 ft NGVD. Just to the east of the new Pump #8 in Canal C-23, culvert #123 has been outfitted with a flap gate on the west side to prevent flow to the east that would occur when Pump #8 is discharging into theC-2 Canal.

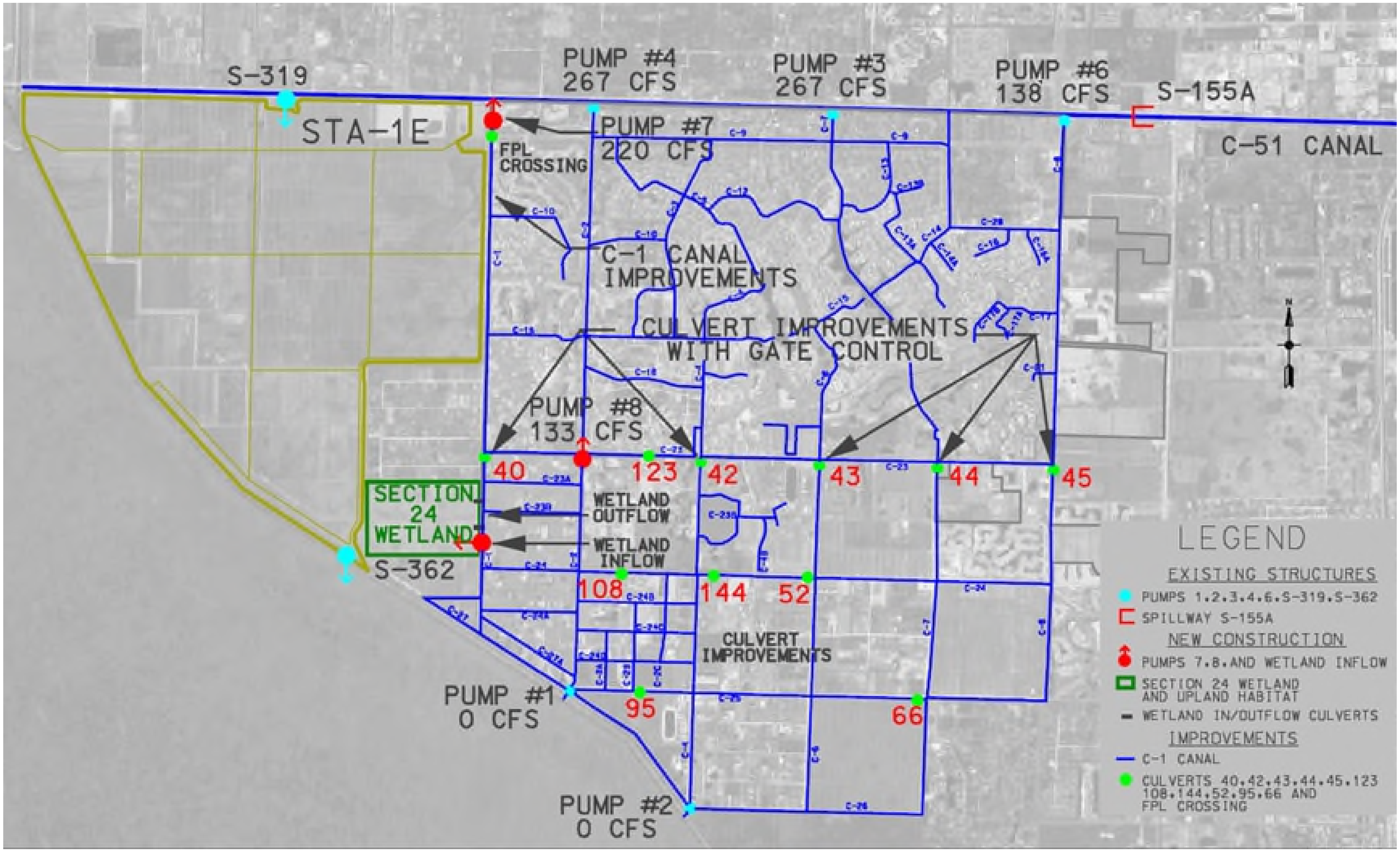

Figure 4. ACME Basin B Permitted Drainage Improvements

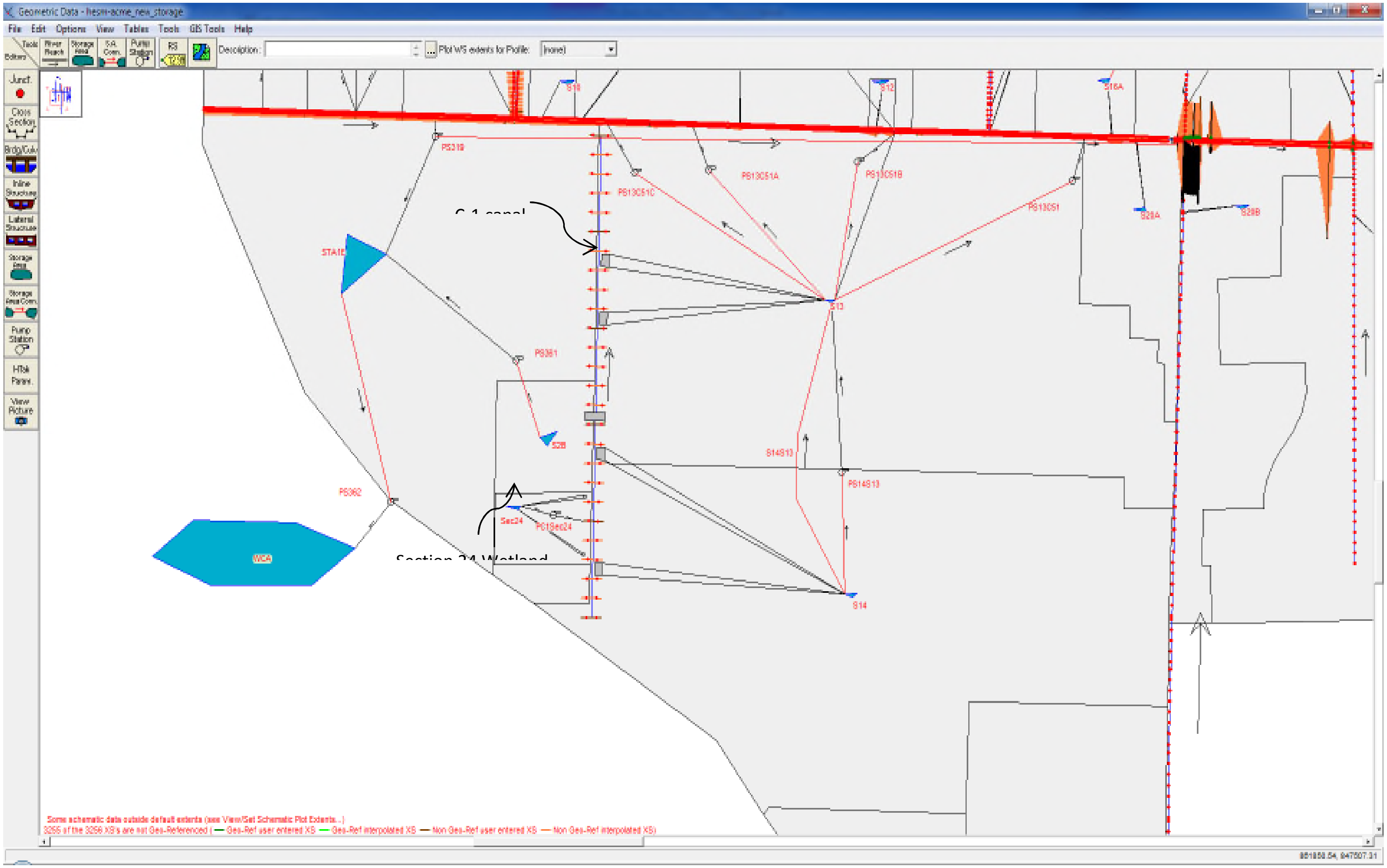

Figure 5. ACME Basin B Permitted Drainage Improvements Setup in the Updated HEC-RAS model

2.2.4 SECTION 24 WETLAND

The stormwater storage area known as the Section 24 wetland and upland system (**Figure 6**) was designed for temporary storage of flood waters from the Acme Basin B. Flood storage is provided between elevations 12 ft NGVD and 16.0 ft NGVD for a maximum storage volume of 1,028 acre-feet. The inflow structure consists of a 200 cfs pump which removes water from the C-1 Canal for temporary storage in the wetland. The pump is equipped with flap gates to prevent backflows from the wetland into the C-1 Canal. The pump is operated for flood control whenever the stages in ACME Basin B are above elevation 12.0 ft NGVD and turned off when the stage in Basin B falls below elevation 12.0 ft NGVD and the stage in the Section 24 wetland reaches elevation 16.0 ft NGVD.

The Section 24 wetland outlet structures consist of two 72" gated culverts sized for 100 cfs peak discharge capacity each. The design HW and TW stages are 12.6 ft NGVD and 12.0 ft NGVD respectively. One gated culvert is located in the southeast corner of the Section 24 parcel and discharges to the C-1 Canal when the stage in the C-1 Canal is below elevation 12.2 ft NGVD. The second gated culvert, located on the northeast corner or the parcel discharges to the C-1 Canal when the stage in the Section 24 wetland is above 12.0 ft NGVD and the C-1 Canal water levels are below elevation 13.5 ft NGVD.

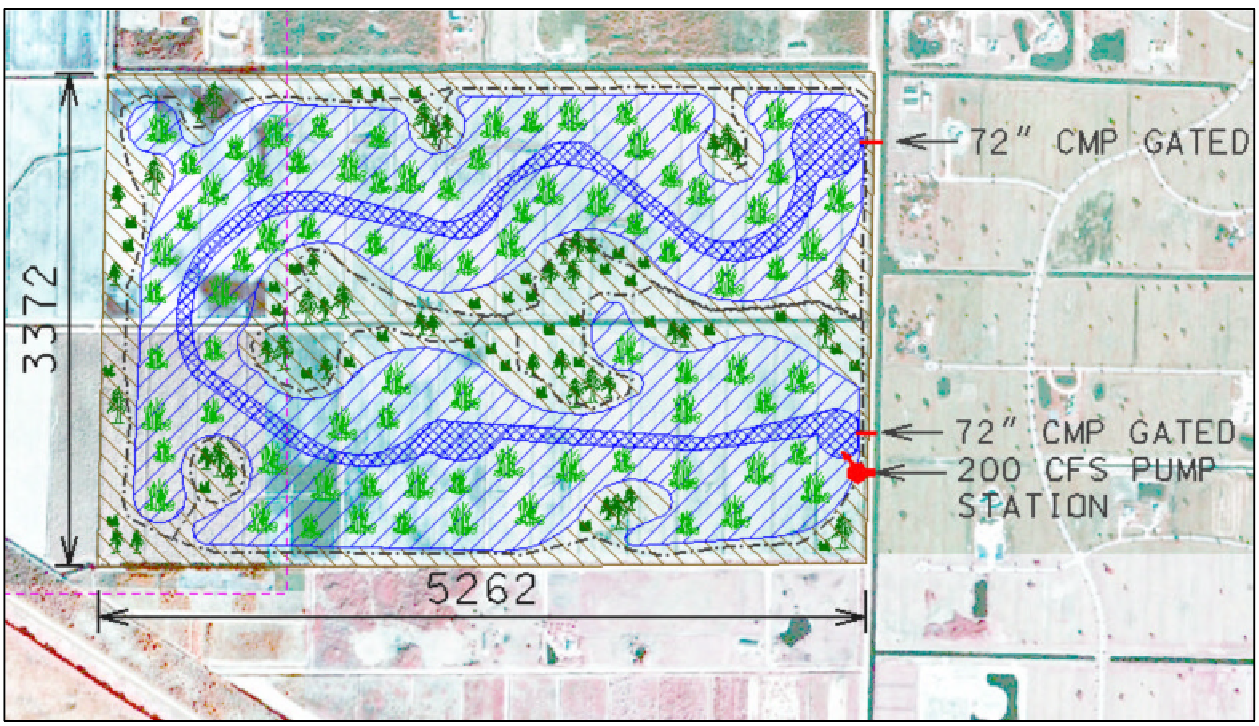

Figure 6. Section 24 Stormwater Detention Wetland and Upland Areas

2.2.5 PIERSON ROAD CONTROL STRUCTURES

Culverts #40, #42, #43, #44, and #45 located on the C-23 canal along Pierson Road have been replaced with larger culverts. Each of the new culverts consists of a 72" diameter Corrugated Metal Pipe (CMP) with gates and controls for remote operation. The gates of the culverts are located on the northern (Basin A) side of the structure where the control elevation of 12.0 ft NGVD is a foot higher than the Basin B control elevation of 11.0 ft NGVD. In addition to the gated culvert, each of the structures has a 45-foot weir with a crest elevation of 13.0 ft NGVD. The gates are four feet wide by four feet high and are normally closed.

2.2.6 ADDITIONAL CULVERT IMPROVEMENTS

Several culverts in Basin B that are in-line with the main canal system and are less than six feet in diameter were replaced with one six-foot diameter culvert at each of the following five locations (shown in **Figure 4**):

- Culvert #52 in C-24 at South Shore Blvd.
- Culvert #108 in C-24 between C-2 and C-4.
- Culvert #144 in C-24 east of C-4.
- Culvert #66 in C-25 west of C-7.
- Culvert #95 in C-25 between C-2 and C-4.

These culvert improvements are internal to Basin B and improve the basin internal conveyance and, therefore, were not included in the HEC-RAS model.

2.3 C-51 CANAL SURVEY (GREENHORNE AND O'MARA, 2006)

In August of 2006 the District sponsored an update of the C-51 Study HEC-RAS model to include as-built canal cross-sections used to evaluate the need for canal dredging in the western portion of the C-51 Canal (**Figure 7**). A total of 55 surveyed canal cross-sections in an eight-mile canal segment between Ousley Farm Road and the Florida Turnpike were added to the original C-51 Study model and the results compared against a "dredged" version of the HEC-RAS model with cross-sections similar to the original 1972 General Design Memorandum (GDM) canal cross-sections in the western C-51-canal. The comparison indicated little to no change in the HEC-RAS computed stages due to the proposed dredging of the canal. The resulting "Existing Condition" version of the HEC-RAS model which included the newly surveyed cross-sections was adopted as the initial model for this study.

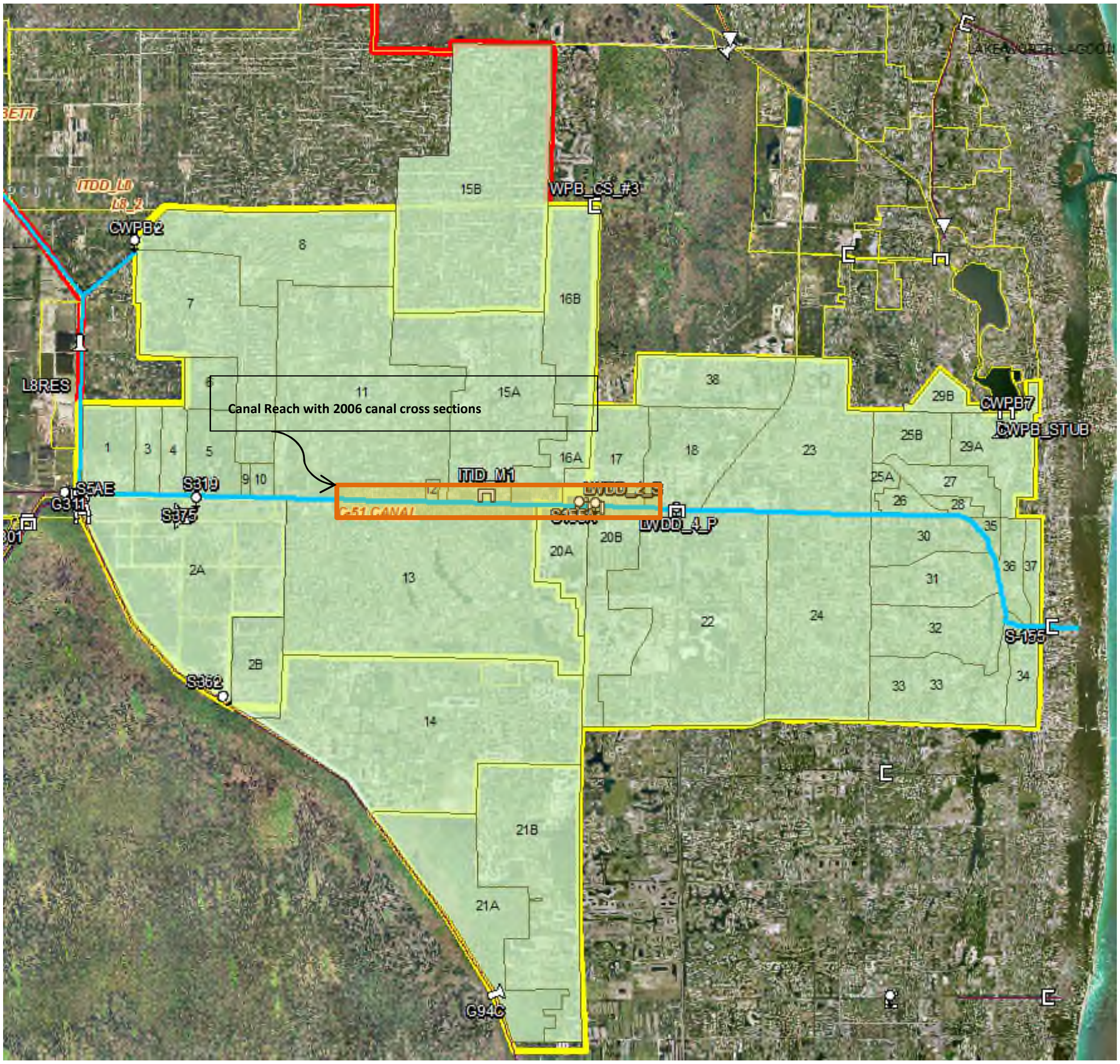

Figure 7. C-51 Canal Reach with 2006 Canal Cross Section Update

2.4 TOPOGRAPHIC DATA AND DIGITAL ELEVATION MAP (DEM)

C-51 Basin topography is used to develop stage-area and stage-storage relationships for all the sub-basins in the C-51 Basin. The topographic LiDAR data sets used in this study are significantly more accurate than those used in the 2004 C-51 Basin study. The following is a description of the topographic datasets used in the 2004 study and the datasets used in this study.

2.4.1 2004 C-51 STUDY TOPOGRAPHY (10-FEET RESOLUTION)

In 2002, when the 2004 C-51 Study was initiated, the best available topographic data was LiDAR from two sources, the USACE and Palm Beach County (PBC)/Florida International University (FIU). The USACE data covered approximately 80% of the C-51 watershed with the remaining 20% (south of Southern Boulevard, east of the Turnpike) from PBC/FIU. Neither dataset was developed following today's quality control practices and there were known conflicts between the two; the difference between the two datasets exceeded 1 foot in areas of overlap. At the time, there was no funding or additional data available for further investigation and, because the USACE had surveyor certification, a decision was made to hold the USACE data as true and adjust the PBC/FIU data to match. This merged dataset was used in the 2004 C-51 Basin Rule study for developing the sub-basin stage-storage relationships.

2.4.2 2007 C-51 STUDY TOPOGRAPHY (10-FEET RESOLUTION)

In 2003, the District became a cooperating technical partner with FEMA and began supporting several FEMA Flood Insurance Rate Map modernization (FIRM MAPMOD) projects, including one for Palm Beach County (PBC). In 2006, using FEMA funding, the District contracted with PBSJ to evaluate the available topographic data and to develop a merged county-wide dataset. The data available came from the same sources (2002 USACE and FIU LiDAR data sets) as for the 2004 C-51 study. Detailed assessment of the available data did not provide conclusive evidence of which data set was more accurate so PBSJ collected 300 additional survey control points. Based on this additional information the FIU LiDAR dataset was found to be superior to the USACE data and the USACE data was adjusted upwards by 0.75-ft then adjusted to conform to a subset of the additional 300 survey points. This task was completed by PBSJ in early 2007 and the fully assessed and documented data set became the preferred topographic data in Palm Beach County. This dataset was used in early stages of this (2015) study to re-calculate the stage-storage relationships for the C-51 sub-basins as is referred in this study as the Pb-sfwmd_v4 dataset. Its metadata file is included in **Appendix C** of this report.

2.4.3 2015 BASIN DIGITAL ELEVATION MAP (DEM)

The latest DEM (2015) created for the study area was developed from a mosaic of three different LIDAR-based DEM's merged into one homogeneous dataset. One DEM covers the eastern portion of the basin and was developed as part of the FDEM state-wide Coastal LiDAR Project (FDEM_Coastal); one DEM covers the northwest portion of the basin and was developed as part of the USACE Herbert Hoover Dike Flood Inundation Study (HHD_EAA); areas not covered by FDEM_Coastal or HDD_EAA still rely on the 2007 Pb-sfwmd_v4 DEM. **Figure 8** shows the aerial extent of each of the datasets in relation to the C-51 Basin study area. In this figure, the green area corresponds to the 2007 10-feet resolution DEM; the yellow area to the east corresponds to the area of coverage of the 5-feet resolution FDEM_Coastal data set; the pink area corresponds to the coverage of the 5-feet resolution HHD_EAA data set.

FEM_Coastal is the 2007-08 Palm Beach East 5-ft DEM in NAVD 1988, Release Version 1 data set. This is a 5-ft x 5 ft raster DEM of bare earth elevations (feet, NAVD 1988). For this specific DEM, SFWMD used the last known set of accepted vendor deliverables from FDEM's delivery block 7, composed of 343 tiles. Each tile is sized 5000-ft by 5000-ft, in accordance with FDEM's tiling system. The DEM was created using deliverables from the 2007 Florida Division of Emergency Management (FDEM) Statewide Coastal LiDAR project, authorized by the Florida House Bill (HB) 7121 - Disaster Preparedness Response and Recovery.

HDD_EAA is the 2007-08 Herbert Hoover Dike/Everglades Agricultural Area 5-ft topographic elevation DEM in NAVD 1988, Release Version 1. This raster dataset covers significant portions of southern Okeechobee, western Martin, western Palm Beach, eastern Hendry, and eastern Glades counties, as well as very small portions of Highlands and Broward counties. HDD_EAA was created using deliverables from an add-on contract to the 2007 Florida Division of Emergency Management (FDEM) Statewide Coastal LiDAR project, authorized by the Florida House Bill (HB) 7121 - Disaster Preparedness Response and Recovery. The contract was managed by the U.S. Army Corps of Engineers. For this specific DEM, SFWMD used the last known set of accepted vendor deliverables from delivery blocks named Area1A, Area1B, Area2, Area3, and Area4. These 5 blocks consist of a total of 2,607 tiles, with each tile sized 5000-ft by 5000-ft, in accordance with FDEM's tiling system.

The resulting merged DEM (2015) from the above datasets is presented graphically in **Figure 9** with the C-51 Sub-basins. New volumetric storage calculations for each sub-basin were carried out by intersecting the sub-basin boundaries with the DEM and computing incremental volumes at specified elevation intervals. Elevations were converted from NAVD88 to NGVD29 at this time. Total incremental storage relations were plotted in Microsoft (MS) Excel and compared against the 2004 stage-storage relationships. **Appendix D** includes the sub-basin stage-storage plots for both 2004 (2004 DEM) and 2007 (2015 DEM) topographic data sets. **Table 1** is a summary of the differences in total volume per sub-basin between the volumes computed with the 2004 and 2015 DEM's. The 2015 sub-basin volumes were 13% less than the volumes computed using the 2004 LiDAR and revised sub-basin boundaries. These differences in basin storage volume will be reflected in the computed regulatory peak stages and flows which will be presented in the Section 4 of this report.

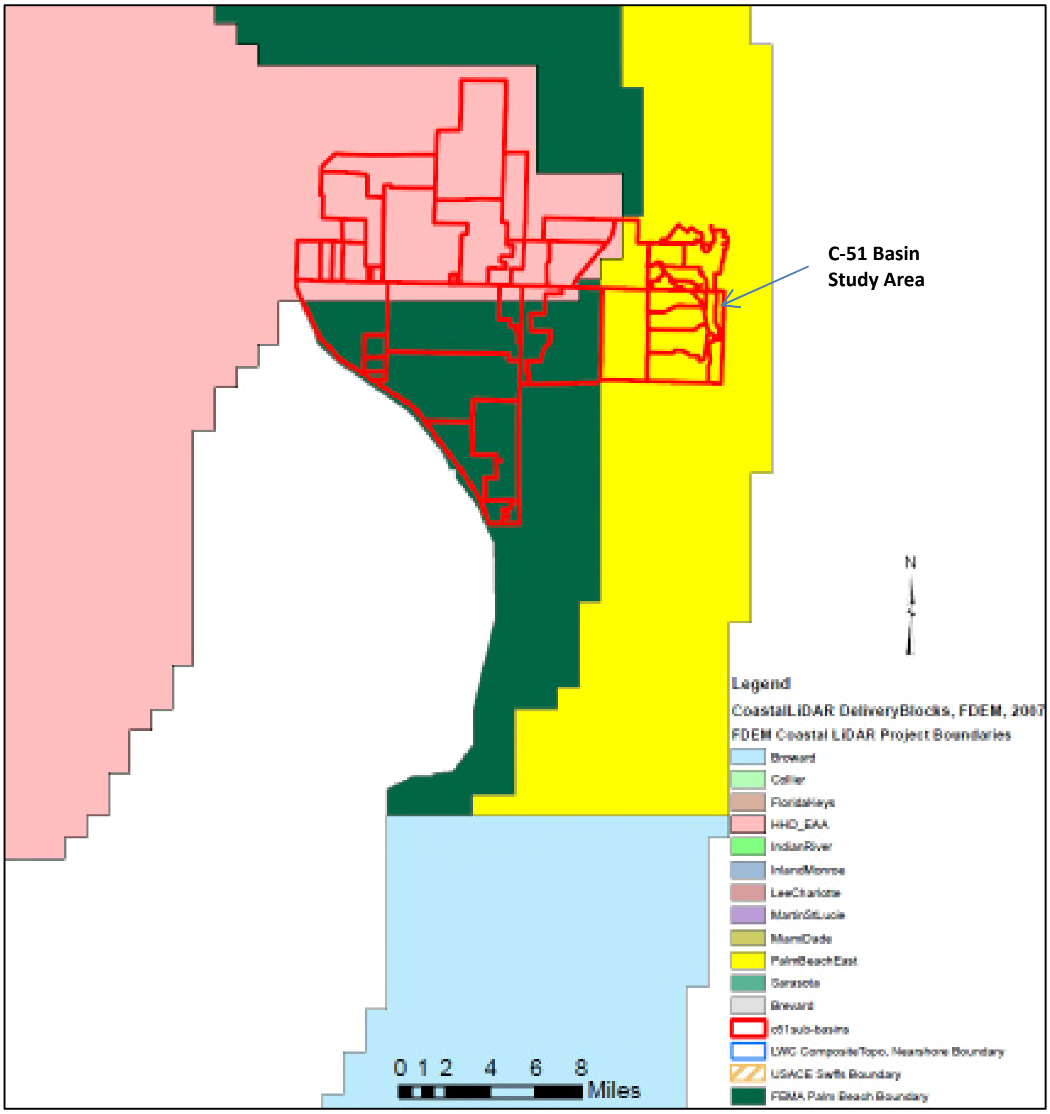

Figure 8. DEM Datasets used for the 2014 C-51 Basin Topography

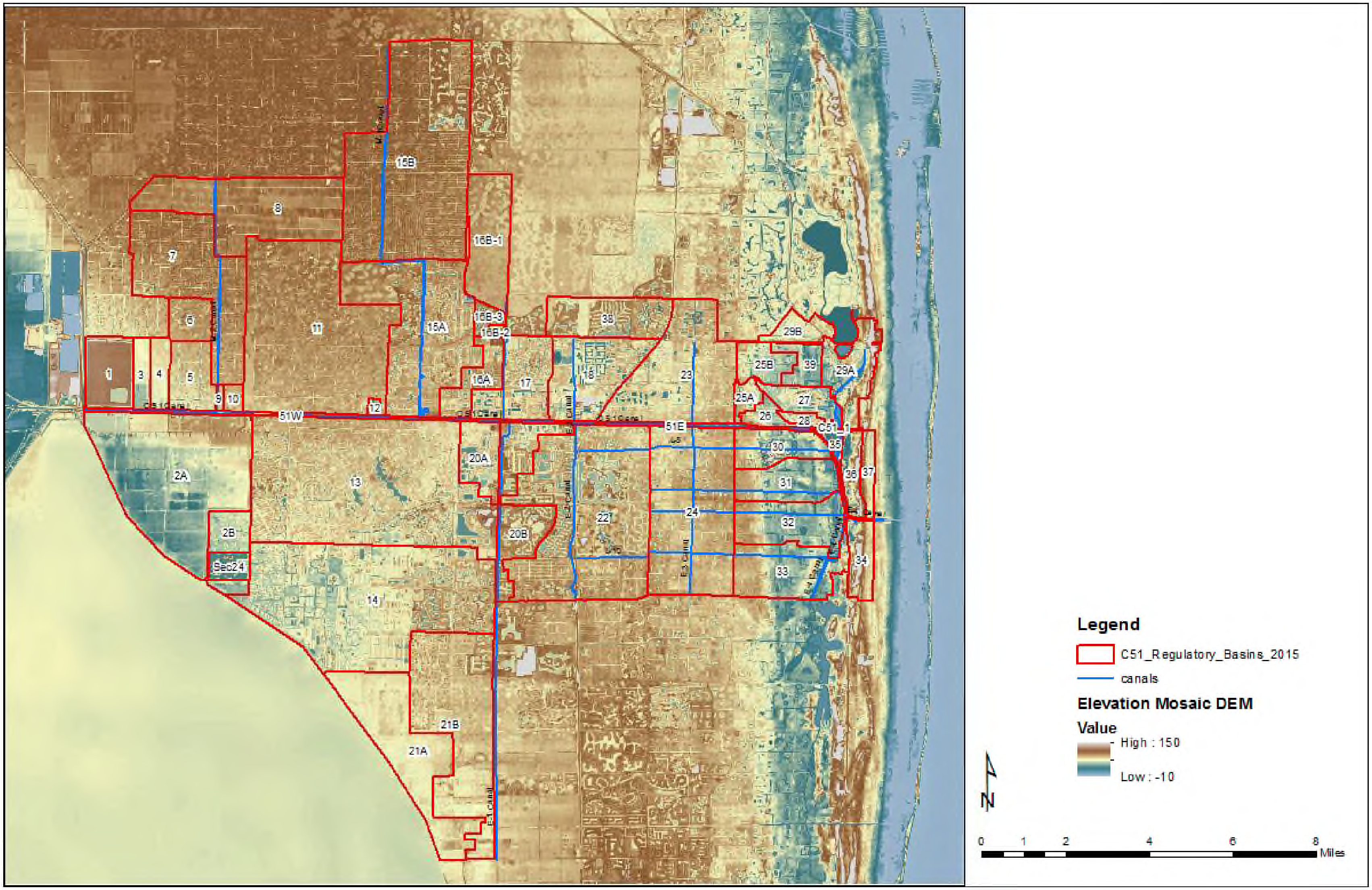

Figure 9. C-51 Basin Digital Elevation Map (2014)

Table 1. Percent Difference of 100-yr basin storage for 2004 and 2015 DEM's

BASIN ID	Area (2015)	Initial Stage. ft NGVD	100-yr Flood Stage ft NGVD	2004 100-yr Storage[1] (in)	2015 100-yr Storage[1] (in)	% Difference in storage 2015 vs. 2004[2]
1	1253	8.5	14.2	11.9	2.7	-95
2A	6663	11.0	15.0(1)	25.9	12.2	-47
2B	843	10.0	13.8(2)	10.4	1.4	-90
3	446	11.5	15.8	11.0	7.0	-33
4	500	11.5	16.6	10.0	6.4	-29
5	1102	11.0	17.4	12.6	8.7	-31
6	674	14.0	19.2	8.7	5.6	-21
7	4109	13.5	19.9	11.9	8.7	-20
8	4086	16.0	20.6	11.7	7.4	-18
9	69	13.5	17.6	9.9	9.9	1
10	190	15.0	18.3	13.3	9.2	-29
11	7975	14.5	18.9	7.0	4.0	-34
12	74	12.5	17.5	7.1	9.7	34
13	10486	11.0	16.6	11.6	6.8	-41
14	9235	12.0	16.5	18.1	9.1	-50
15A	5161	12.5	18.2	8.7	8.1	-6
15B	8605	14.5	18.2	0.4	0.2	488
16A	920	13.3	16.8	6.2	6.3	7
16B-1	1988					
16B-2	57					
16B-3	302	17.5	19.0	14.7	12.5	-40
17	1795	8.5	16.6	8.7	6.9	-6
18	2309	8.5	15.7	10.4	8.3	-4
20A	1011	9.5	16.1	12.1	9.0	-29
20B	2168	13.0	16.8	9.2	6.8	-20
21A	3535	14.5	17.3	16.1	8.8	-49
21B	4915	14.5	17.7	12.3	5.2	-56
22	7580	13.0	17.5	12.2	9.3	-33
23	4049	8.5	17.1	9.1	5.7	-4
24	5204	13.0	17.9	10.9	4.1	-46
25A	299	8.5	14.6	4.0	8.5	93
25B	721	9.5	14.7	7.2	3.3	-34
26	332	10.0	13.8	10.8	6.3	-36
27	753	10.0	13.2	6.5	6.3	-46
28	201	7.5	12.3	3.8	2.0	-50

Table 1. Percent Difference of 100-yr basin storage for 2004 and 2015 DEM's (Cont.)

BASIN ID	Area (2015)	Initial Stage. ft NGVD	100-yr Flood Stage ft NGVD	2004 100-yr Storage[1] (in)	2015 100-yr Storage[1] (in)	% Difference in storage 2015 vs. 2004[2]
29A	1394	8.0	14.8	12.5	9.4	-41
29B	566	10.0	15.2	1.5	1.3	65
30	1121	8.0	14.1	10.9	6.2	-18
31	1433	8.0	13.1	9.8	5.0	-38
32	1804	8.0	13.0	10.9	5.6	-40
33	2091	8.0	13.6	11.6	6.2	-44
34	740	8.5	17.0	8.5	5.0	-27
35	166	8.0	11.3	17.6	10.3	-38
36	607	7.0	14.0	9.4	6.6	-13
37	399	7.5	16.4	6.5	2.2	-21
38	1812	8.0	17.2	11.4	11.4	-20
39	552	8.0	13.7	3	9.6	
Sec24	403	12.0	16.5	--	6.1	--[4]
			BASIN-WIDE VALUES:	**10.2**	**6.8**	**-13**

Notes:

1) Basin total volumes were computed up to the 100-yr flood elevation as established in the C-51 Study minus storage volume below control elevation.
2) % difference = (2015 vol. -2004 vol.)/2004 vol.
3) Sub-basin 39 did not exist in 2004 study
4) Sect 24 sub-basin did not exist in the 2004 C-51 Study

2.4.4 VALIDATION OF THE 2015 DEM

Validation of the 2015 DEM topographic data at a sub-basin level was accomplished by comparing the stage-volume relations for a sub-basin with multiple topographic datasets. Of all forty-four sub-basins in the C-51 Basin, only one had a topographic data set based on ground-based survey. This sub-basin was sub-basin 2A which corresponds to the STA-1E. The STA-1E topographic data set is documented in Appendix 5 of the STA-1E Operation Manual (SFWMD, 2009). **Figure 10** shows the stage-volume curves derived from the 2004, 2015 and STA-1E topographic data sets.

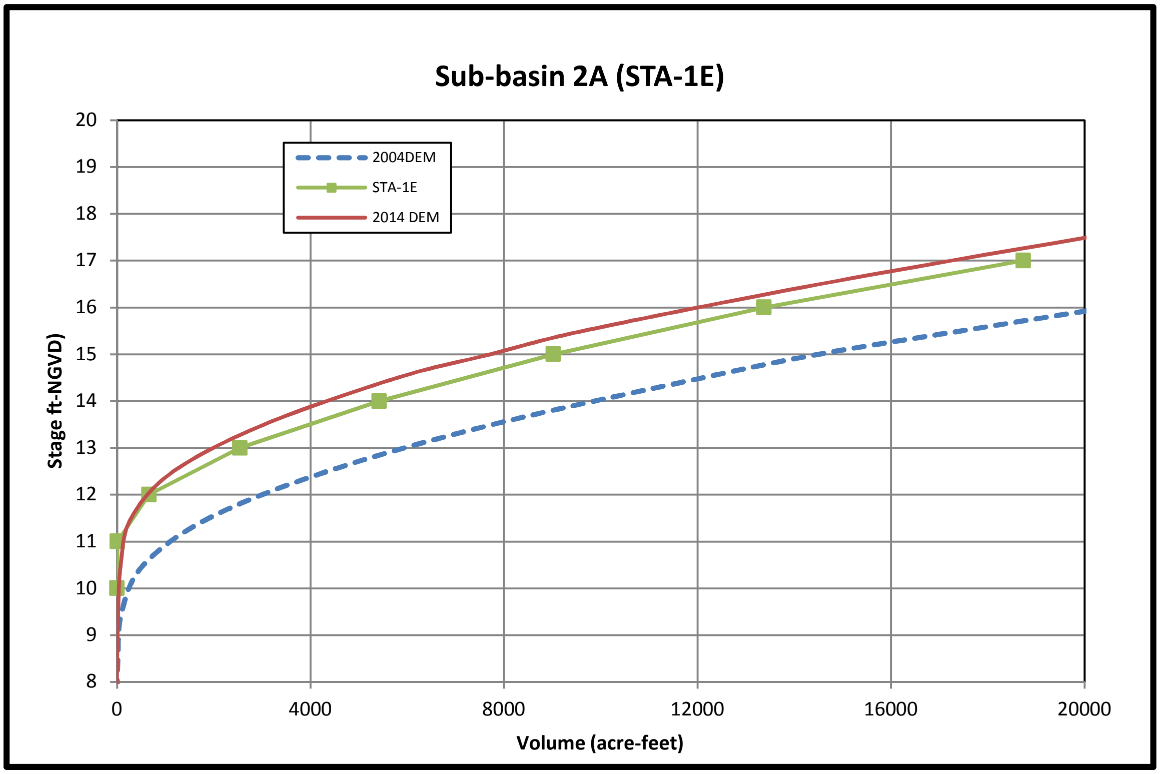

Figure 10. Stage-Volume Relations for Sub-basin S2A for three different topographic data sets

As **Figure 10** shows, the STA-1E stage versus storage curve lies between the curves from the 2004 and 2014 DEM's. Generally, the STA-1E curve is closer to the 2014 curve than it is to the 2004 DEM curve. At elevation 17.0 ft NGVD, the volume from the STA-1E curve is 18,732 acre-feet, and 17,305 acre-feet and 26,895 acre-feet for the 2014 DEM and 2004 DEM, respectively. In other words, the volume from the STA-1E curve is 8% less than the volume from the 2014 DEM curve and 44% greater than the volume from the 2004 DEM curve.

2.4.5 VILLAGE OF WELLINGTON HIGH RESOLUTION GROUND ELEVATION DATA

On February 21, 2014, the District received a DEM for the Village of Wellington. **Appendix E** includes the transmittal letter for this data set which consists of the DEM's processed from LiDAR data collected with a point density resolution of about 2 points per square meter. The DEM's represent bare ground elevations referenced to NAV88 and NGVD29 datums. **Figure 11** below shows the geographic extent of the DEM. In this figure, Sub-basins 13 and 14 represent Wellington's ACME basins A and B. For modeling purposes, the LiDAR data was processed to generate new stage versus storage relationships for these two sub-basins graphically shown in **Figures D14 and D15** of **Appendix D**.

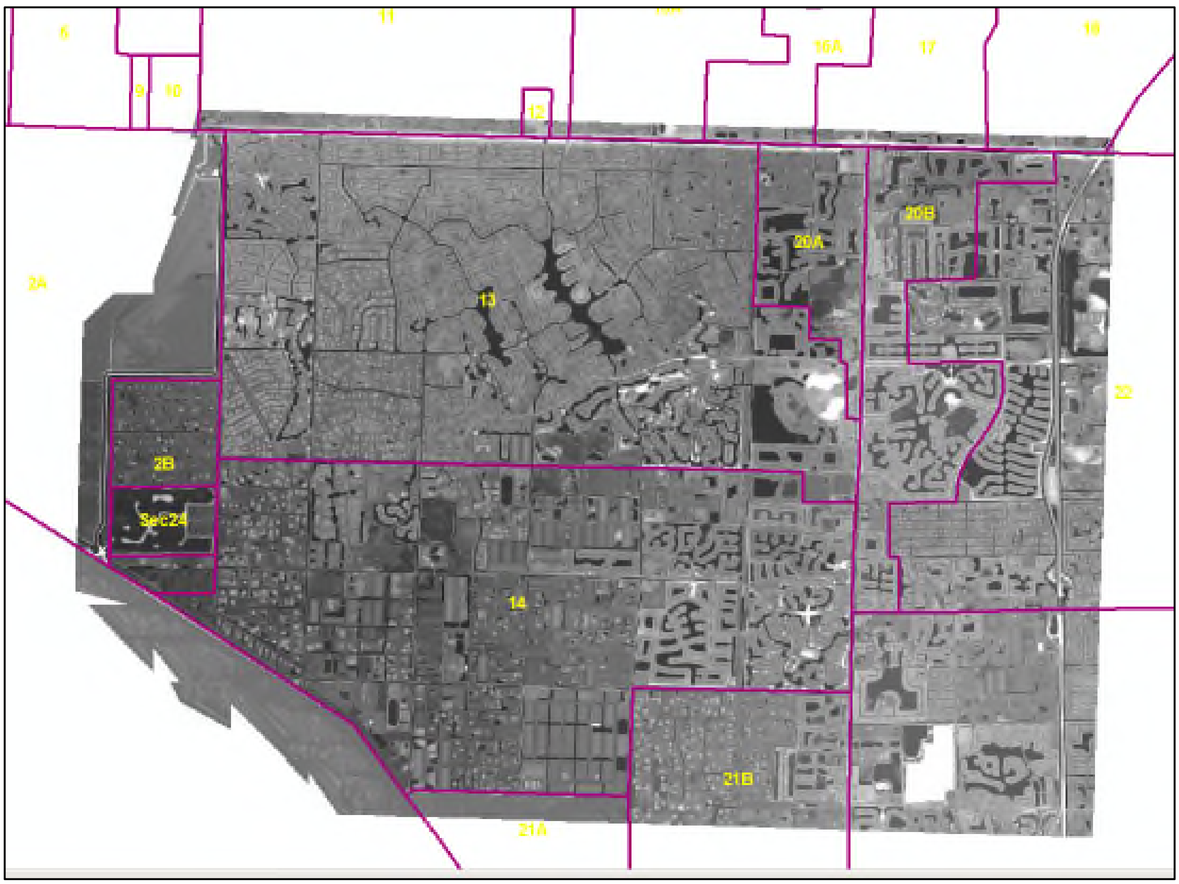

Figure 11. Village of Wellington High-resolution DEM (February, 2014)

2.5 SUB-BASIN BOUNDARY REVISIONS

Since the C-51 Study was completed, several drainage projects in the C-51 Basin have taken place which resulted, in some cases, in modifications to the 2004 sub-basin boundaries. Part of this update consists of revising the 2004 sub-basin boundaries for the updated hydrologic model. The Westgate (sub-basin 25B), the Renaissance and the Stub Canal projects and drainage improvements in Palm Beach International Airport and sub-basins 33 and 34 resulted in the revised sub-basin boundaries (2015) shown in **Figure 12**.

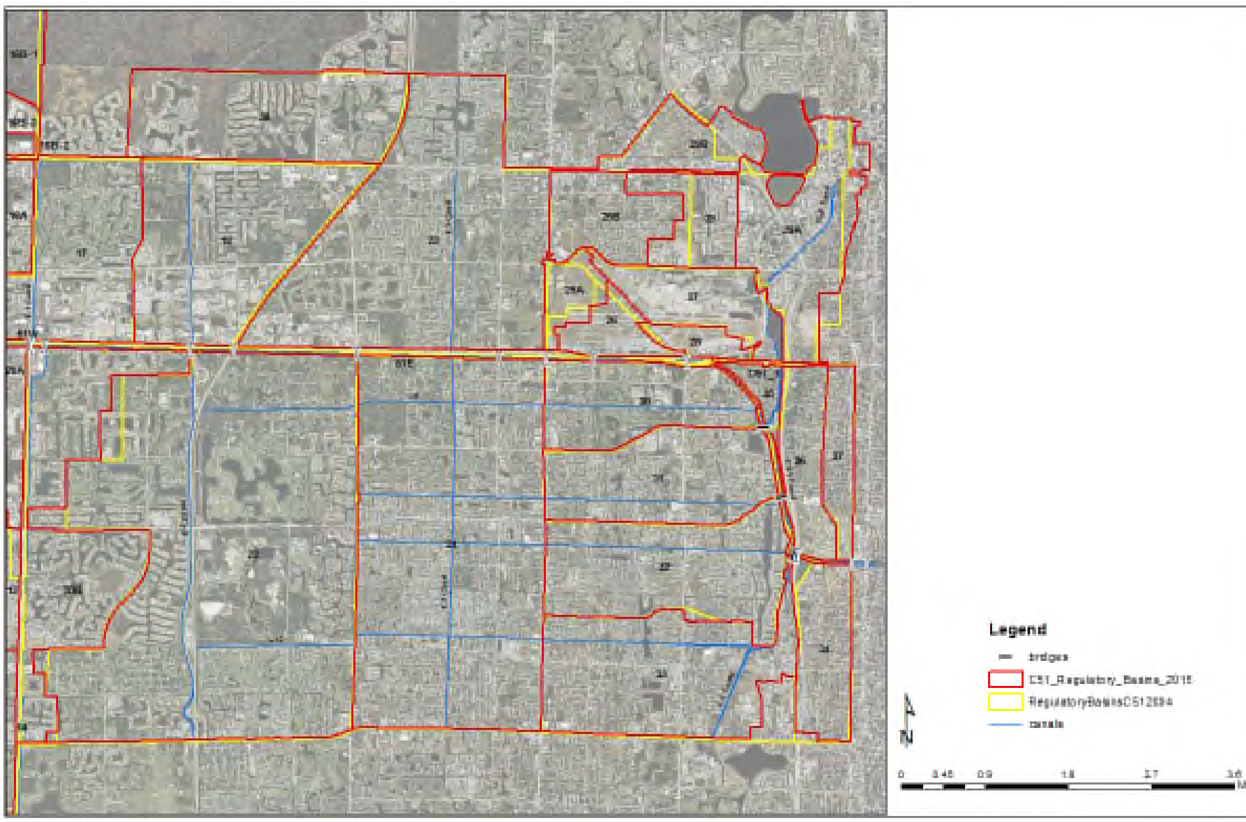

Figure 12. 2004 and 2015 Sub-basin Delineations in the Eastern Portion of the C-51 Basin

Another recent drainage project in the southwestern portion of the C-51 Western Basin consisted of the redirection of stormwater runoff from sub-basin 14 (ACME Basin B) to the C-51 Canal via sub-basin13 (ACME Basin A) (**Figure 13**). Runoff form this sub-basin was originally sent to the Loxahatchee Wildlife Refuge to the west. One storage component of this project is the Section 24 Wetland, a stormwater detention basin that temporarily stores runoff from Sub-basin 14 before it releases it to the C-1 Canal within ACME Basin A and eventually to the C-51 Canal. The construction of the wetland resulted in the division of sub-basin 2B, as the remainder of the sub-basin still pumps water to STA-1E.

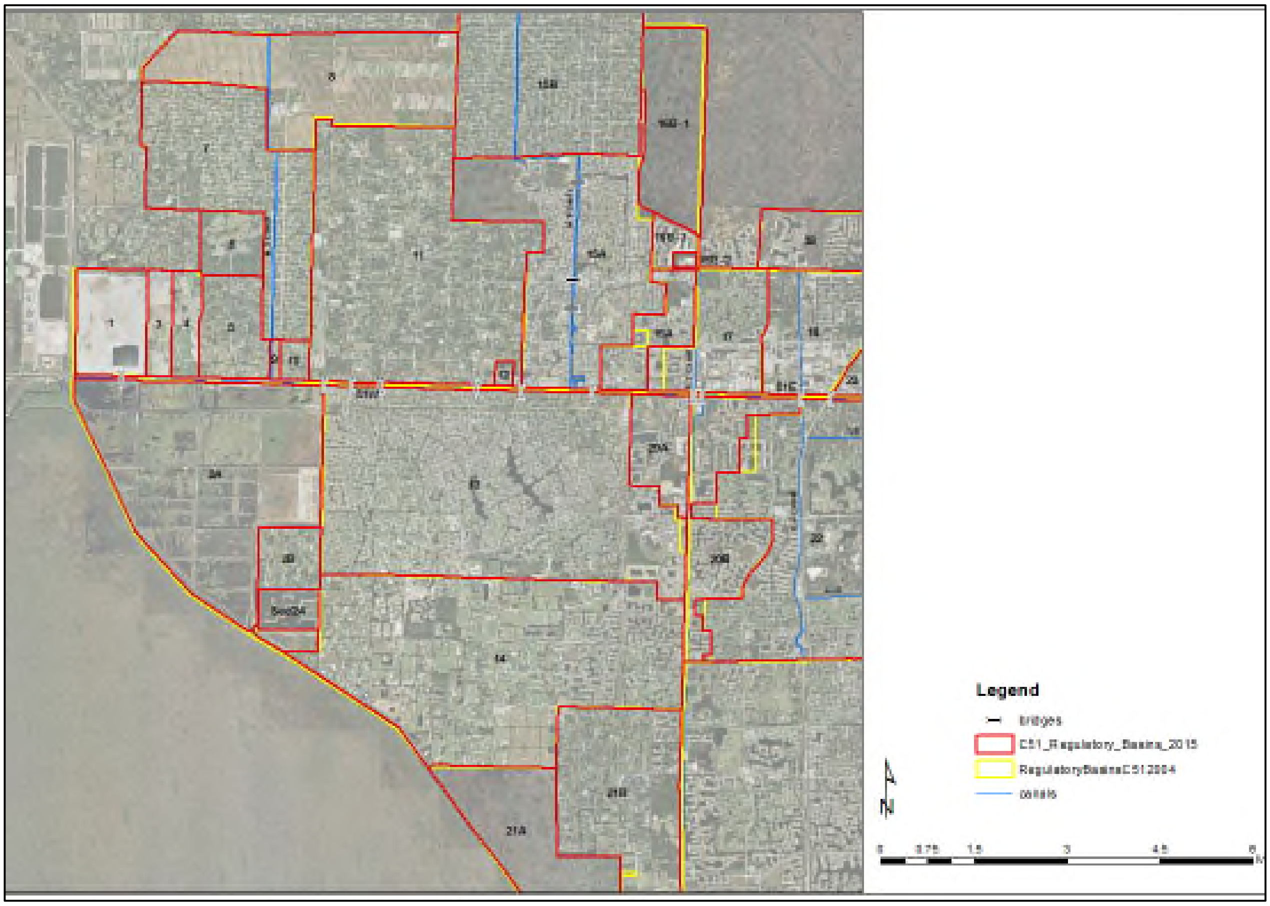

Figure 13. 2004 and 2015 Basin Delineations in the Southwestern Portion of the C-51 Basin

Table 2 summarizes the original (2004) and the revised (2015) sub-basin areas as well as the difference between the two sets. The table shows in bold the sub-basins with area change greater than 2 acres. In this table, the difference in the 2015 area for sub-basin 2B is the area which corresponds to the Section 24 wetland project.

The sub-basins areas modified by the Renaissance and Stub Canal projects include sub-basins 29A and 29B. Most of the Stub Canal and Renaissance project improvements are located within basin 29A with a reduction of about 132 acres over the 2004 study area. The portion of Lake Clark (south of Okeechobee Boulevard) with an area of about 50 acres was subtracted from the basin area since this portion of the lake does not contribute runoff to the C-51 East basin despite the fact that the Renaissance pump discharges to the lake during storm events (out of basin discharge).

The addition of the L-2 Pump and basin divide weir structure at Florida Mango Street between Sub-basins 25B and 29A, resulted in the addition of a new sub-basin (39) west of the pump and reductions of area in sub-basins 25B to the west and 29A to the east of the pump. The new sub-basin has an area of 489 acres while sub-basins 25B and 29A areas were reduced by 223.9 acres and 131.7 acres respectively.

Sub-basin 16B has been modified to reflect two land development projects, the Portosol residential development on the south side of the sub-basin and the Target commercial development on the east side. The original sub-basin area which was mainly a wetland, was broken down into three sub-basins: 16B-1 which corresponds to the Pond Cypress Natural Area to the north (2,135.1 acres), sub-basin 16B-2 or Target commercial parcel with an area of 66.4 acres and the Portosol sub-basin (16B-3) with an area of 249.5 acres. The drainage network between the three sub-basins reflects the latest permit (application No. 130212-13). The outlet structure of the three sub-basins is through the Portosol discharge structure.

Recent internal drainage improvements at the airport resulted in basin boundary adjustment to sub-basins 23, 25A, 26, 27 and 28. The net change in area for all the sub-basins in the C-51 East and West basins is an increase of 100 acres from the 2004 Study area.

Table 2. Basin Areas (2004) and (2015) and difference in Areas

BASIN ID	2004 (acres)	2015 (acres)	Diff (acres)
1	1164.3	1253.3	89.0
2A	6715.8	6662.9	-52.9
2B	**1226.4**	842.9	-383.5
3	579.4	446.2	-133.2
4	540.0	499.8	-40.2
5	1142.4	1102.1	-40.3
6	673.5	674.2	0.7
7	4126.9	4109.5	-17.4
8	3966.8	4085.6	118.8
9	72.8	68.5	-4.3
10	208.0	190.0	-18.0
11	8138.4	7975.3	-163.1
12	74.1	74.4	0.3
13	10537.9	10485.7	-52.2
14	9270.3	9235.1	-35.2
15A	5116.6	5160.8	44.2
15B	8640.6	8605.5	-35.1
16A	1065.1	919.8	-145.3
16B-1	**2448.8**	**1988.4**	**-101.2**
16B-2		**57.0**	
16B-3		**302.2**	
17	1650.5	1795.5	145.0
18	2294.9	2309.3	14.4
20A	1138.6	1010.6	-128.0
20B	2341.8	2167.7	-174.1
21A	3540.4	3535.0	-5.4
21B	5056.2	4915.3	-140.9
22	7375.2	7580.1	204.9
23	**4206.9**	**4048.9**	**-158.0**
24	5282.0	**5204.3**	**-77.7**
25A	**205.8**	**298.6**	**92.8**
25B	**972.1**	**721.0**	**-251.1**
26	**376.1**	**332.0**	**-44.1**
27	**830.7**	**752.8**	**-77.9**

Table 2. Basin Areas (2004) and (2015) and difference in Areas (Cont.)

BASIN ID	2004 (acres)	2015 (acres)	Diff (acres)
28	223.4	201.3	-22.1
29A	**1578.1**	**1394.2**	**-183.9**
29B	**440.3**	**566.2**	**125.9**
30	1153.0	1120.7	-32.3
31	1467.7	1433.4	-34.3
32	1812.7	1804.2	-8.5
33	**2323.8**	**2090.9**	**-232.9**
34	**711.3**	**740.4**	**29.1**
35	172.9	166.1	-6.8
36	603.3	607.4	4.1
37	390.2	398.5	8.3
38	1955.2	1812.0	-143.2
39	-	**551.8**	**551.8**
Sec24	**0.0**	**403.2**	**403.2**
TOTAL:	113,811.2	113,695.2[1]	-116.0

1 - Total basin area includes C51 canal

2.6 C-51 SERVICE BRIDGE NEAR STA-1E

A new bridge over the C-51 (bridge number C51BR01) was built in 2010 by the District to provide access to a public access educational area and to the STA-1E as shown in **Figure 14**. This bridge's design follows similar canal crossings over the C-51 Canal to the east with traditional 18-inch square piers and a concrete deck (**Figure 15**). The lower member elevation of the deck is at elevation 18.0 ft NGVD and the top of the deck at elevation 20.0 ft NGVD. With this design, the bridge piers are not expected to produce significant head loss during major storm events. **Figure 16** is the representation of this bridge in the HEC-RAS model graphical interface.

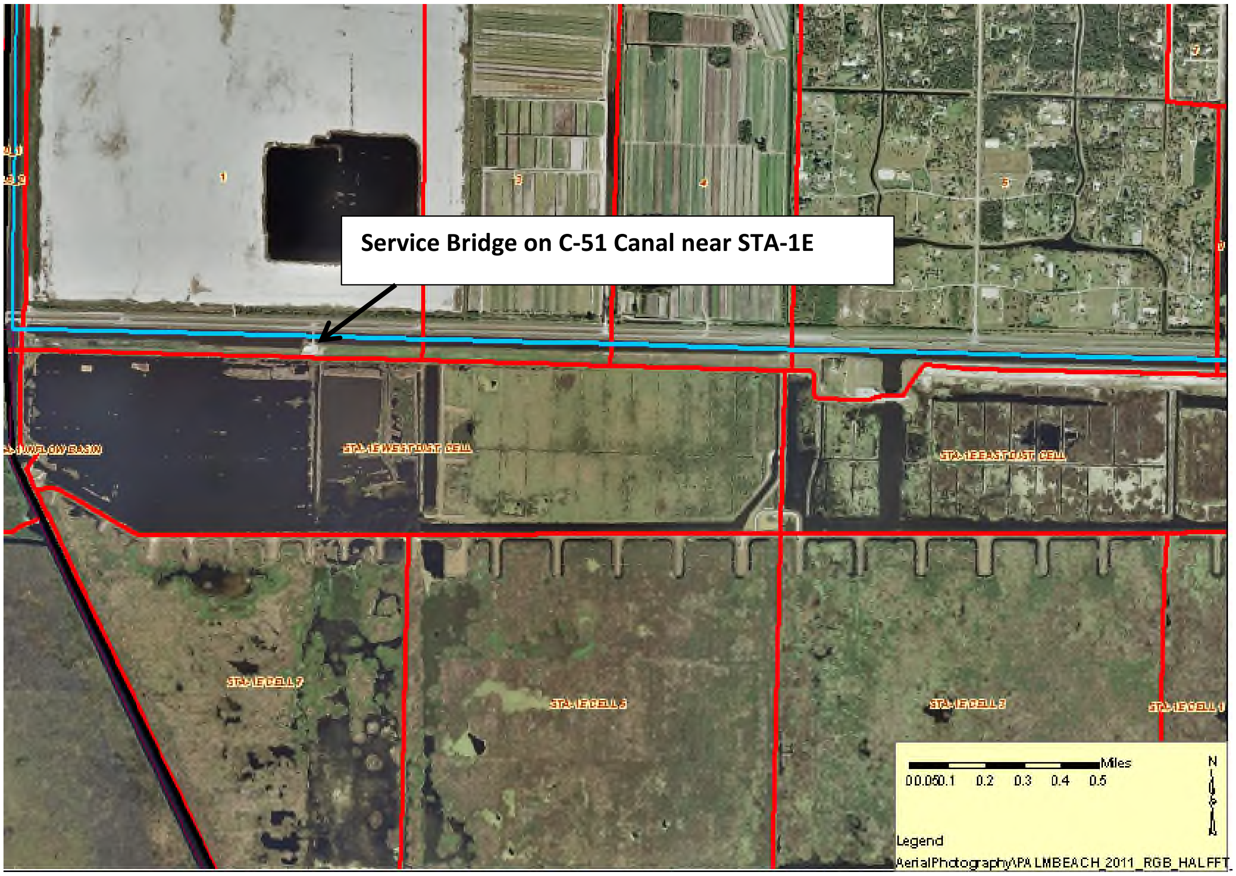

Figure 14. Location of C-51 Service Bridge near STA-1E

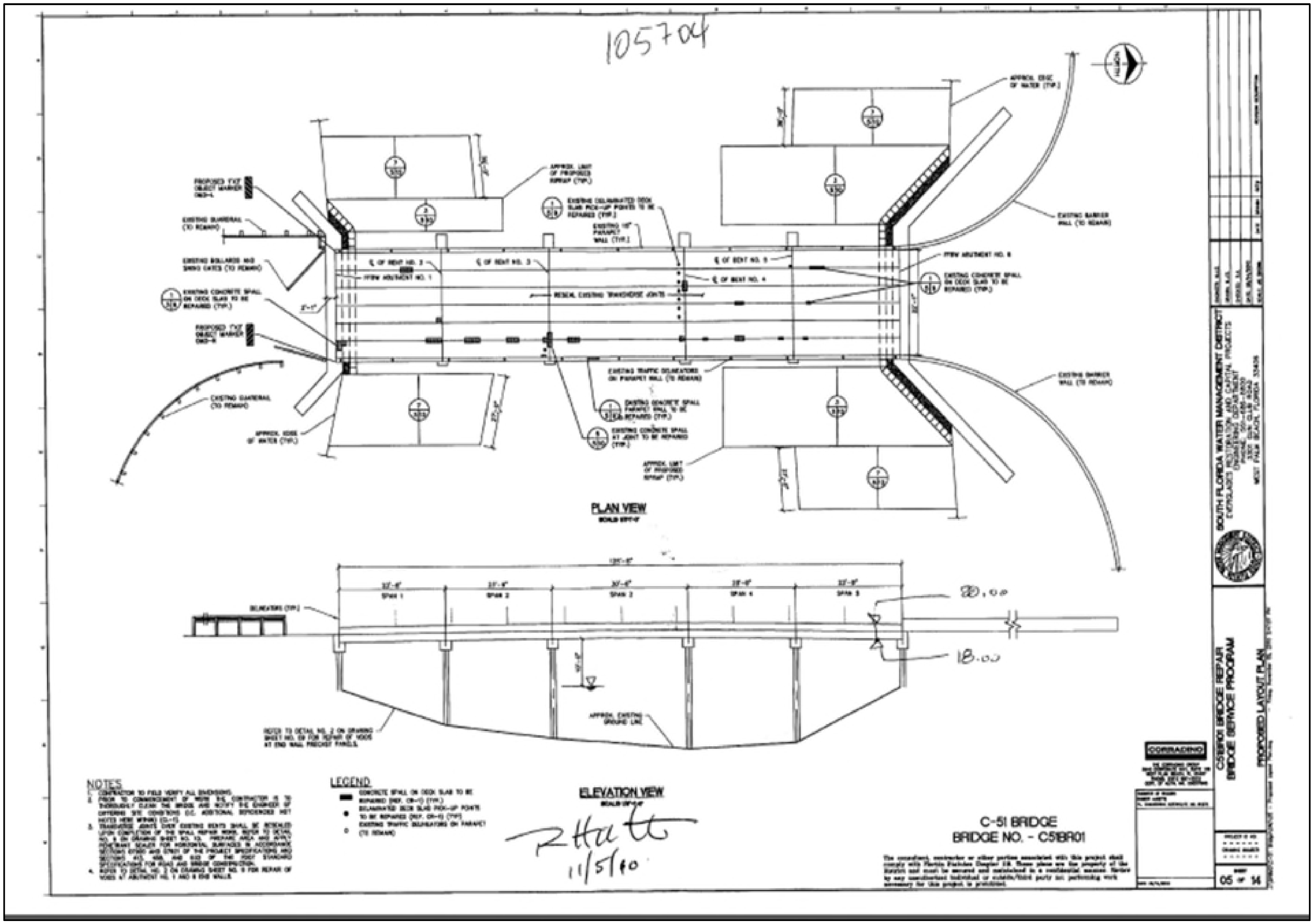

Figure 15. C-51 Canal Service Bridge C51BRO1 near STA1E.

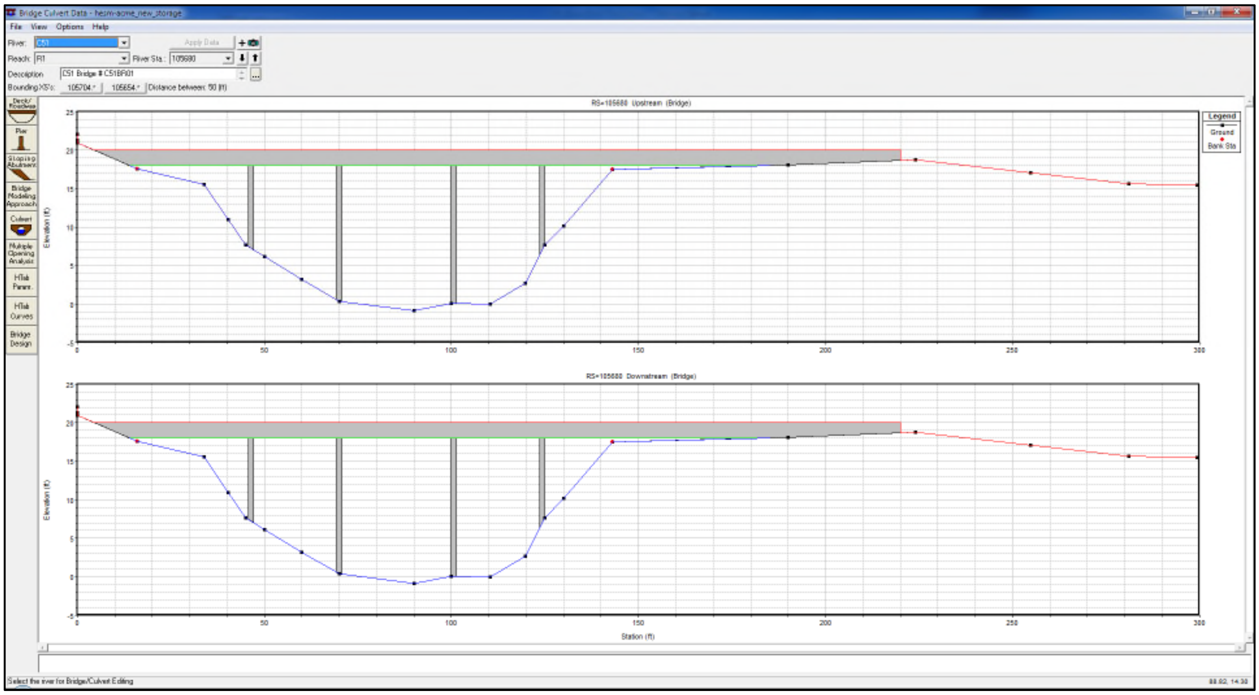

Figure 16. C-51 Service Bridge in HEC-RAS geometric editor

2.7 DISTRICT STRUCTURE OPERATIONS

The main structures in the C-51 Canal are the S-155 tidal structure at the eastern end of the C-51 Canal, the S-155A basin divide just west of SR7, and the S-319 pump station discharging into the STA-1E. A brief description of each structure operations follows.

2.7.1 S-155 STRUCTURE

The automatic operation of this structure is actuated by the HW elevation. In flood control mode, this operation is as follows:

The gates begin to open when the head water rises to 7.5 ft NGVD and they begin to close when it falls to or below 7.0 ft NGVD.

Initially, the gates open one at a time in 0.5-foot increments until they each are opened 2 feet. At this point, if the head water is still rising and above 7.5 ft NGVD, they will all open simultaneously in 0.5-foot increments. The gates close in a reverse manner.

These operations can be altered depending on several factors including rainfall distribution over the basin, water levels in adjacent drainage districts that discharge into the C-51 Canal, weather forecasts, etc. During TS Isaac the S-155 gates were operated at the “normal” range as shown in **Figure 17**. This figure indicates that two days prior to the storm (August 22, 23 and 24) all three gates were partially open (between 0.5 and 1.0 feet) when the HW stage of the structure reached elevation 8.3 ft NGVD and closed when the stage dropped to elevation 7.8 ft NGVD. On August 25, when the forecast indicated the potential heavy rain from TS Isaac, the District conducted a canal drawdown operation which lowered the HW stage to elevation 7.0 ft NGVD in preparation for the storm. Again, all three gates where gradually opened when the water levels on the HW side of the structure rose to elevation 8.3 ft NGVD. The gates were fully opened on August 26 and remained open until August 29.

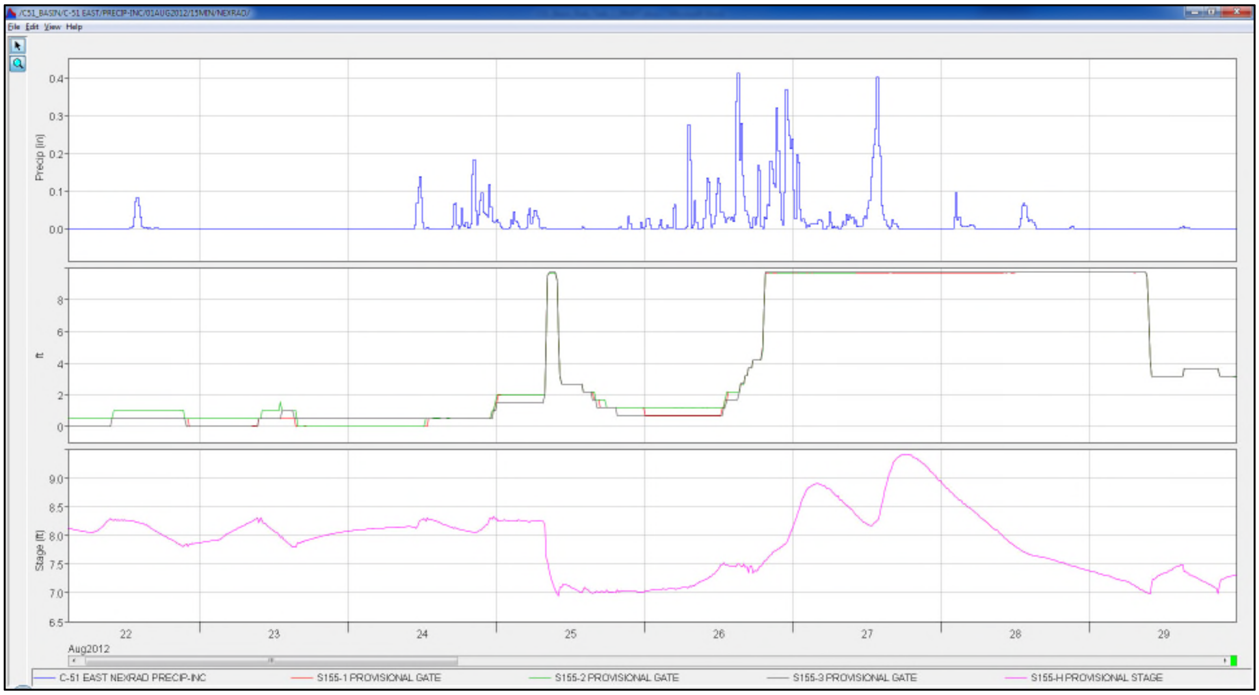

Figure 17. Observed rainfall (blue line), gate openings (green, red and black lines) and HW stage (magenta line) of structure S-155 during Tropical Storm Isaac (August 22 – 29, 2012)

The 2004 HEC-RAS model has slightly different operational trigger elevations that are summarized in **Table 3**.

Table 3. 2004 C-51 HEC-RAS model gate operational triggers

	2004 C-51 HEC-RAS		**Current (2012) District Operations**	
S-155 gate	**Open**	**Close**	**Open**	**Close**
	HW ft NGVD	HW ft NGVD	HW ft NGVD	HW ft NGVD
Gate 1	8.0	7.0	7.5	7.0
Gate 2	8.5	7.25	7.5	7.0
Gate 3	9.0	7.5	7.5	7.0

2.7.2 S-155A STRUCTURE

The basin divide structure S-155A located in the C-51 Canal on the west side of SR7 is a remotely operated dual gate spillway. The structure has a design capacity of 1,460 cfs of stormwater runoff from the C-51 western basin to the east with less than a foot of head loss (design HW = 11.5 ft NGVD and design TW = 10.6 ft NGVD).

The water level upstream of S-155A is maintained at 11 to 12 ft NGVD during the wet condition to divert excess water into STA-1E through pump station S-319.

In any case during flood control operations, the gates close if the TW exceeds 11.7 ft NGVD, the HW rises above 13.0 ft NGVD, the HW falls to or below 11.0 ft NGVD or the discharge through S-155 exceeds 4,800 cfs.

The gates open if the HW rises to 12.0 ft NGVD, as needed to keep the HW from continuing to rise. The discharge is limited to Q_{Design} = 1,460 cfs, checking that the discharge is at least as much as the current flow through structure S-5AE at the west end of the C-51 Canal.

These operations are summarized in **Table 4** together with the operations in the 2004 HEC-RAS model.

Table 4. 2004 C-51 HEC-RAS model gate operation triggers

	2004 C-51 HEC-RAS		**Current (2012) District Operations**			
S-155A Gate	**Open**	**Close**	**Open**	**Close**	**Close**	**Close**
	TW ft NGVD	TW ft NGVD	TW ft NGVD	TW ft NGVD	HW ft NGVD	HW ft NGVD
Gate 1	closed	closed	< 12.0	>11.7	>13.0	<11.0
Gate 2	closed	closed	<12.0	>11.7	>13.0	<11.0

The 2004 C-51 HEC-RAS model was set up to run for storm conditions with the S-155A divide structure closed all the time. In reality, the District allows some discharge to tide from the C-51 west basin prior to the storm event as shown in **Figure 18** where the gates where partially open to maintain the target HW at S-155 of 8.3 ft NGVD. On August 25, when the possibility of the storm increased significantly, the District conducted a drawdown of water levels so that stages could also be lowered in adjacent sub-basins discharging into the C-51 Canal. Form August 26 to 27, through TS Isaac, the gates were closed and began to gradually open late on August 27 to allow drainage from the western C-51 Basin to tide. At the same time, when S-155A was discharging to tide, the pumps at structure S-319 were discharging at full capacity into STA-1E. A detailed description of the pump operation is next.

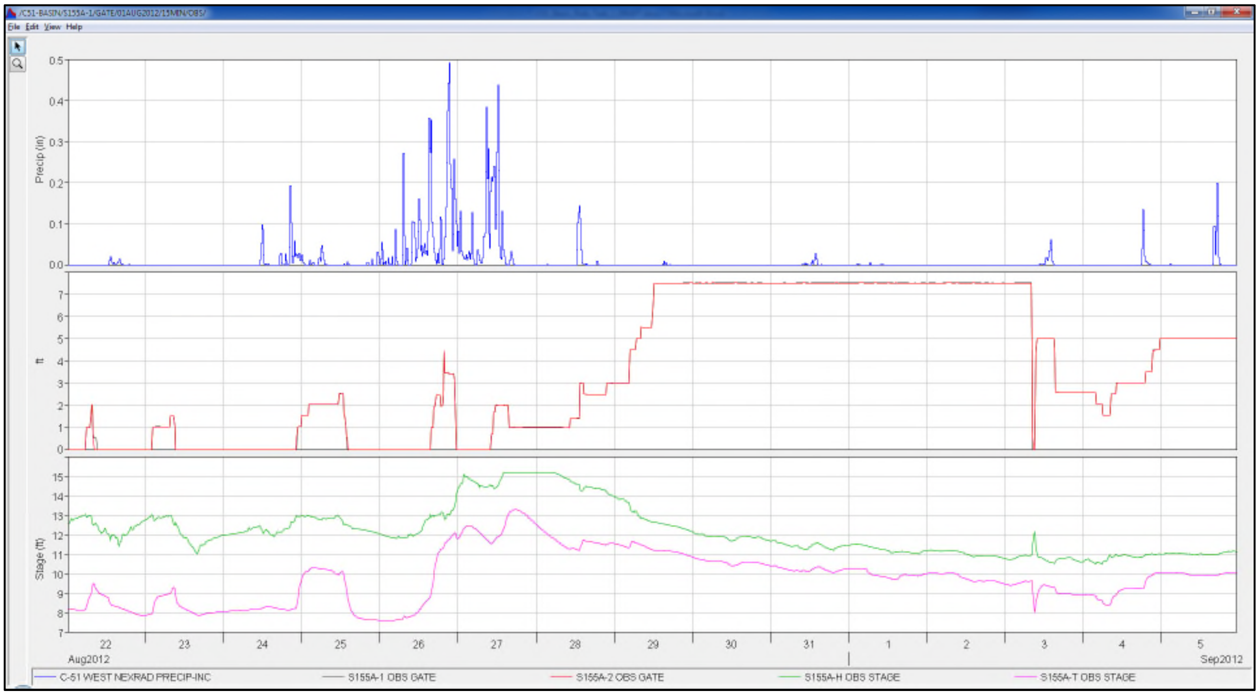

Figure 18. Observed rainfall (blue line), gate openings (red and black lines) and HW and TW stage (green and magenta line) of structure S-155A during Tropical Storm Isaac (August 22 – 29, 2012)

2.7.3 S-319 PUMP STATION

This pump station was built in 2004 as part of the Everglades Construction Project (ECP) as required by the Everglades Forever Act (EFA, Ch. 373.4592, F.S.) and the C-51 Flood Control project (2002). This structure conveys stormwater runoff from the C-51 Canal into STA-1E. It has five diesel pumps with a total capacity of 3,980 cfs. Of the five pumps, three have a capacity of 960 cfs and two have a capacity of 550 cfs.

The S-319 pumps are operated in conjunction with structure S-155A to maintain the stage in the C-51 West Canal between 11.0 and 12.0 ft NGVD in the wet season and 11.5 to 12.5 ft NGVD in the dry season.

During TS Isaac pump station S-319 was operated, along with the S-155A divide structure, in the days prior to TS Isaac in response to rainfall events to maintain the water levels in the C-51 western basin between elevations 11 and 13 ft NGVD (**Figure 19**). On August 26, the S-319 pumps started increasing pumping until they reached full capacity on August 27, while S-155A discharge was significantly reduced or totally curtailed. The S-319 pumped at maximum capacity until August 30th, when it began to gradually reduced pumpage into STA-1E.

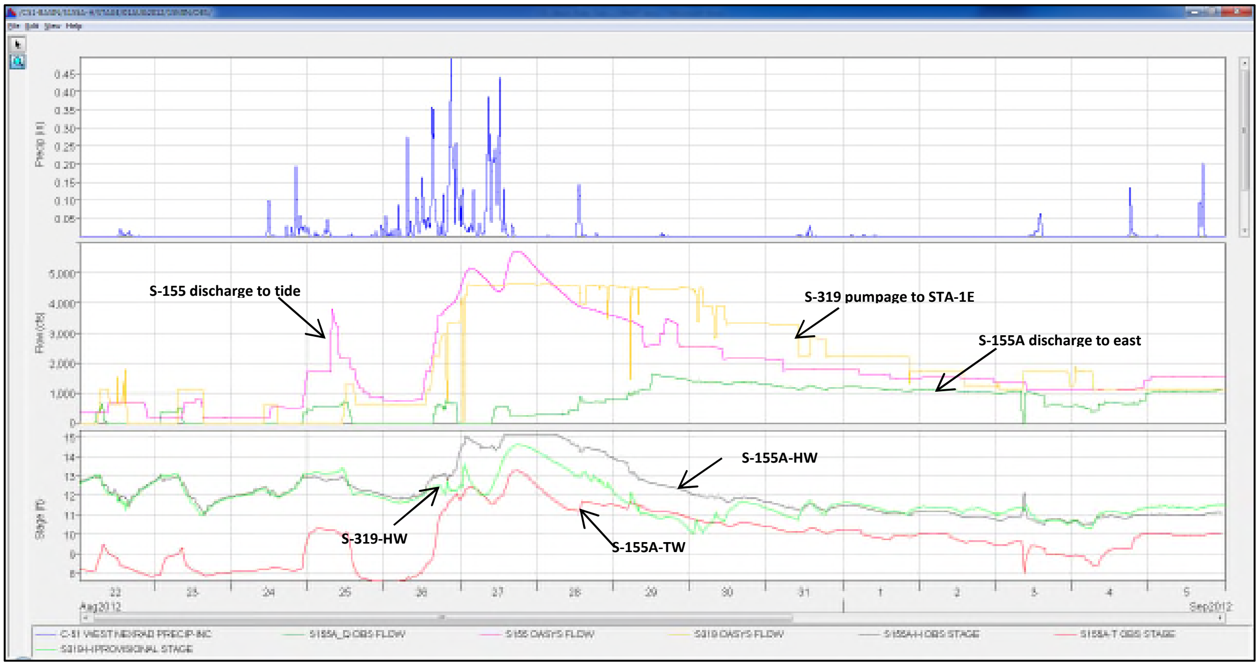

Figure 19. Observed rainfall (blue line), S-319 total pumpage (black line) and HW of S-155A and S-319 (green and magenta lines) during TS Isaac

S-319 pump operations in the 2004 HEC-RAS model are triggered by the HW stage of the S-155A divide structure as shown in **Table 5**.

Table 5. Operational Elevations for Pump Station S-319

Pump Group 1			
Pump Unit	"ON" trigger elevation, ft NGVD	"OFF" trigger elevation, ft NGVD	Pump max. capacity, cfs
P1	12.0	11.0	550
P2	12.1	11.1	550
Pump Group 2			
Pump Unit	"ON" trigger elevation, ft NGVD	"OFF" trigger elevation, ft NGVD	Pump max. capacity, cfs
P1	12.2	11.2	960
P2	12.3	11.3	960
P3	12.4	11.4	960

District water managers have indicated that the water level triggers for the operation of the S-319 pump should be based on the local stage conditions (S-319 HW) and not on the HW stage of S-155A. Additional information regarding the operation of the pumps will be incorporated into the updated HEC-RAS model during model calibration of TS Isaac.

2.8 OTHE DRAINAGE IMPROVEMENT PROJECTS

Drainage improvement projects that have been completed recently within the study area include the Renaissance Project near downtown West Palm Beach, Garden Avenue Outfall (sub-basin 37) and the L-2 Pump, north of the airport. The following is a brief description of each project.

2.8.1 RENAISSANCE PROJECT DRAINAGE IMPROVEMENTS

The Renaissance Project consisted on a series of drainage improvements in downtown West Palm Beach. The project was completed in 2001 and permitted by the District in August 9, 2001 (Permit No. 50-04000-P). The principal components of the project included:

Renaissance Pump Station: 250 cfs pump between the Stub Canal and the Detention Basin.

Detention Basin: 5-acre settling basin for stormwater treatment between the pump station and Clear Lake (control elevation of 16 ft NGVD).

South Lobe of Clear Lake: is an existing water body with a surface area of about 50 acres. The control and maximum elevations of the lake are, respectively, 11.5 ft NGVD and 17.0 ft NGVD.

Severing Structure/ Water Supply Pump: Sheet pile structure separating the receiving lake (north of Okeechobee Boulevard) from Clear Lake (south of Okeechobee Boulevard), a 30 cfs water supply pump and an 84” x 72” sluice gate to transfer water from Clear Lake to the receiving lake.

Boyd Street Gated Structure: Three 60” operable gates between the Stub Canal north and Stub Canal south. Gates are normally closed and open only when the upstream stage exceeds the downstream stage in the Stub Canal.

For the purpose of this study, the only components included in the HEC-RAS model were the pump and the out-of-basin storage (Clear Lake). The pump routs stormwater from sub-basin 29 to Clear Lake with a maximum capacity of 250 cfs, an ON elevation of 8.0 ft NGVD and OFF elevation of 7.0 ft NGVD. The pump also shuts off when the stage in Clear Lake is below elevation 11.5 ft NGVD or above elevation 17.0 ft NGVD.

2.8.2 GARDEN AVENUE DRAINAGE IMPROVEMENTS

There are two outfalls into the C-51 Canal from sub-basin 37, just northwest of the S-155 tidal structure. The 2004 model includes both outfalls, however, recent drainage improvements have resulted in new infrastructure which needs to be incorporated in the latest version of the HEC-RAS model. The information about the revised drainage improvements was provided by the City of West Palm Beach and is reflected in District permit 50-6596-P for the Garden Avenue project. The more westerly outfall described as 1-36” X 2,500 RCP has been replaced by a 60” 2,500 reinforced concrete pipe (RCP). The more easterly outfall described as 1-36” x 2,000’ RCP has been replaced by the Garden Avenue Improvement Project which includes 4,700’ of 54” and 500’ of 48” exfiltration trench into two in-line detention areas. The combined storage for the system is 12.3 acre-feet with bottom elevation of 9.5 ft NGVD. The system then discharges via an existing control structure and 100’ of 36” outfall pipe to the C-51 Canal. The existing outfall structure consists of 1-3.33’ x 4.33’ “L” drop inlet with crest elevation of 12.2 ft NGVD and a rectangular 1.5’ W X 1’ H orifice with invert elevation at 8.5 ft NGVD.

Since the outfall control structure was not modified, the only change in the HEC-RAS model for the Garden Avenue outfall consisted in the additional storage provided by the exfiltration system above elevation 9.5 ft NGVD. This volume was added to the basin’s stage-storage relationship obtained from the DEM. The easterly outfall was modified according to the latest permit.

2.8.3 L-2 PUMP STATION

More recently, in 2009, the City of West palm Beach constructed a pump (permit No. 50-09028-P) on the L-2 Canal, west of the Florida Mango Road Bridge, (sub-basin 29A) to improve drainage conditions upstream of the pump. The pump improves the level of flood protection for an area of approximately 484 acres of high density residential land use prone to severe flooding. The project consists of two 122.5 cfs pumps with one 122.5 cfs back-up pump and a gravity sluice gate with 48' of 72" corrugated aluminum pipe (CAP), a flap gate and trash rack assembly. The first pump begins operation when water elevation on the L-2 Canal west of Florida Mango Road equals or exceeds 8.5 ft NGVD and the second pump at elevation 8.75 ft NGVD. Pumping ceases in the HEC-RAS model if the water elevation on the tailwater side of the pump (Pine Lake) exceeds 12.75 ft NGVD.

2.8.4 PALM BEACH ZOO OUTFALL

The Palm Beach (formerly Dreher Park) Zoo outfall is one of three outfalls for sub-basin 36 discharging into the C-51 Canal. The outfall is located in the C-51 Canal between the Summit Boulevard and Forest Hill Boulevard bridges. Recently permitted modifications to the outfall (permit N0. 50-00487-S,030626-7) include a new 14,000 GPM (31 cfs) pump with ON at elevation at 9.12 ft NGVD and off at elevation of 9.00 ft NGVD; a 4" diameter orifice at elevation 9.0 ft NGVD; and an emergency overflow weir 30 feet long at elevation 13 ft NGVD. These drainage features replace the 30-foot long weir set at elevation 10 ft NGVD.

2.8.5 OTHER DRAINAGE MODIFICATION TO THE HEC-RAS MODEL

In several sub-basins of the model where there is no explicit representation of secondary and tertiary drainage canals weirs representing the control elevation in the sub-basins were conceptualized in the 2004 Model as means to prevent over-drainage from the basin below control elevation. Several of these weirs had crests elevations above the basin's control elevation which were corrected in the 2015 version of the model. Sub-basins where the crest elevation of the weirs were corrected include Sub-basins 17, 18, 22, 23, 24, 30, 31, 32 (Lake Clark Shores) and 33 (**Table 6**).

Table 6. Sub-basins Weir Crest and Control Elevations

Sub-Basin	Weir Crest Elevation (2004 HEC-RAS Model) Ft NGVD	Sub-Basin Control Elevation ft NGVD
17	12.5	10.9
18	11.5	10.9
22	13.5	13.0
23	10.5	12.1
24	13.5	13.0
30	11.5	8.5
31	10.5	8.5
32	10.5	8.5
33	11.0	8.5

In the C-51 West Basin, several structures were revised and modified to comply with the latest permitted structures. These include the following.

Seminole Water Control District (Sub-basin 8). Outfall structure at Sycamore Drive was modified from a 24-ft long weir at elevation 17.5 ft NGVD to a set of four 7' X 7' gates with inverts at 8.7 ft NGVD and four corresponding 84" CMP culverts. During severe storm conditions, the gates are opened depending on the stage of the M-2 Canal. Because of limitations of the HEC-RAS model to models compound structures such as risers, only the pipes were included in the model since they are the flow control at the peak of the storm event.

M2-Canal Outfall Structure. This structure located at the outfall of the M-2 Canal to the C-51 Canal was also modified with information from the Seminole Water Control District's Consultant to reflect orifice flow at the gates, rather than weir flow as in the previous version of the model. The 21-ft long weir at elevation 12 ft NGVD was replaced with three 7' x 7' gates at elevation 12 ft NGVD without the outfall pipes.

3.0 C-51 BASIN MODEL CALIBRATION

In 2004, The District completed the C-51 Study in which regulatory peak stages and flow discharges were computed for all the sub-basins in the C-51 Basin using HEC-HMS v 2.2.1 and HEC-RAS v3.1.1. Task 1 (documented in **Appendix B** 1 of this report) consisted of upgrading the HEC-HMS and HEC-RAS models to their most recent versions. Task 2 (documented in Section 2 of this report) consisted in incorporating recent drainage upgrades in the C-51 Basin to the hydrologic and hydraulic models to bring them to current (2015) conditions. Task 3 of this study (documented in this section of the report) consisted of model calibration with the following information:

- Latest topographic data and sub-basin boundaries,
- Latest surveyed canal cross-sections,
- 15-minute stage and flow data at District structures S-319, S-155, S-155A and S5AE,
- District structure operations and latest flow rating equations at these structures, ,
- Observed stages, flows and gate operations provided by special drainage districts including ACME, the Indian Trail Improvement District (ITID) and the Lake Worth Drainage District (LWDD).

The Current Condition (2015) version of the model incorporates several significant drainage improvements in the C-51 Basin since 2004 when the original C-51 Study was completed. Modifications to the drainage system in the C-51 Basin include the construction and activation of the City of West Palm Beach Renaissance Project, redirection of ACME Basin B drainage to the C-51 Canal via ACME Basin A, and conveyance improvements in the C-51 Basin as part of the construction of the S-319 pump station. The model was re-calibrated in this study with data from TS Isaac, which occurred from August 26-29, 2012 with flooding effects extending for a period of approximately two weeks after the storm.

There are large amounts of data available for model calibration for this storm event, including 15-minute rainfall and canal stages and flows at the District's structures in the C-51 Canal, S-155, S-155A, S-5AE and S-319, however, as it was the case in the 2004 model calibration, there is very limited data for the sub-basins and lateral structures discharging into the C-51 Canal. For TS Isaac, ACME and ITID provided limited discharges from their structures into the C-51 Canal as well as internal canal stages. LWDD provided limited operational information of their structures during the storm. With this available information, the updated HEC-HMS and HEC-RAS models were setup and calibrated.

This section of the report present s the data, process and results of the model calibration performed for the C-51 Basin models during TS Isaac.

3.1 MODEL CALIBRATION

Model calibration is the process of model parameter adjustment performed so that the model predicted results (stage and flows) closely reproduce observed data. Calibration of large models with numerous parameters can be a tedious and time consuming process due to correlations in the parameters which lead to similar or no model response. Automated model calibration software is usually used when there are large sets of parameters in a model. In this study, as in the 2004 C-51 Basin Rule study, model parameters were adjusted manually to produce an acceptable fit of the model results with the observed data.

The 2004 version of the C-51 HEC-RAS model was manually calibrated with observed data from Hurricane Irene (October, 1995) before construction of the Federal Project in the C-51 West Basin. Calibration of the 2004 HEC-HMS model consisted of adjusting runoff curve numbers (CNs) and lag times (t_l), while calibration of the HEC-RAS model included revising canal roughness coefficients during the Hurricane Irene event of mid-October, 1999. Since 2004, there have only been a few storm events representative of flood conditions in the C-51 Basin Rule for establishing allowable discharge rates from the sub-basins (10-year, 72-hour event) and peak stage elevations (100-year, 72-hour event).

The storm selected for model calibration in the 2012 HEC-RAS model was TS Isaac (August 26-29, 2012) reflects recently changes of drainage conditions in the basin as well as changes in operations of the ACME's Pump Station No. 7, the Section 24 impoundment, the S-319 pump station and the S-155A divide structure. In this model update, the 2012 version of the HEC-RAS model was recalibrated with minor adjustments to Manning's n in the C-51 Canal and adjustment of lateral boundary inflows into the canal from information on gate operations provided by 298 Special Districts, including Loxahatchee Groves, Indian Trail and Village of Royal Palm Beach.

3.2 CALIBRATION PERIOD

Given the lack of severe storm events since the construction of the Federal project in 2004, the obvious choice was TS Isaac which produced three-day rainfall totals over 15 inches in western Palm Beach County. The selected period of calibration started on August 24th in order to give the hydraulic model sufficient "warm-up" time before the beginning of the storm on August 26th 00:00am and ending on September 5th, 23:00pm. This extended period allows the model to stabilize from errors in initial conditions and provides output on the extended period after the peak stages occurred. Observed data at structure S-155 indicate that water levels in the C-51 Canal returned to pre-storm elevations around September 5th, 2012.

3.3 CALIBRATION LOCATIONS

Data in the District's DBHYDRO database from TS Isaac was used to calibrate the C-51 HEC-HMS and HEC-RAS models. Data consisted of 15-minute stage and flow at structures S319, S5AE, S-155A and S-

155. In addition to this data, the District obtained hourly stages from ACME at several of their structures and daily pumpage during the storm event. ITID also provided hourly discharges into the M-1 canal from its 40th Street Structure. The data is further described in the next section of this report.

3.4 CALIBRATION DATA

For model calibration, the TS Isaac was chosen primarily because it was an event that closely followed the characteristics of the 100-year event (SFWMD, 2000), particularly in western Palm Beach County. The following is a description of the data sets used in this study.

3.4.1 RAINFALL

The District has kept continuous records of radar rainfall (Nexrad) data over the entire District area since 2000. The Nexrad rainfall grid is a two-kilometer by two-kilometer grid and is shown over the C-51 Sub-basins in **Figure 20**. For TS Isaac modeling in HEC-HMS, 15-minute rainfall was extracted and averaged over each of the C-51 Sub-basins for the period of August 20 to September 30, 2012. Sub-basin rainfall volumes for the three-day period of August 25-28, 2012 are summarized in **Table 7**. According to this table, Sub-basin 9 (parcel within permit No. 50-00909-S) had the largest observed rainfall with a total three-day volume of 14.9 inches in the C-51 West Basin and Sub-basin 24 (parcel with Permit No. 50-01578-S) had a rainfall of 11.5 inches in the C-51 East Basin. **Figure 21** illustrates the total average rainfall in the C-51 East and West Basins in incremental and cumulative form. At a more local scale, the Nexrad cumulative rainfall for Sub-basins 10 in the C-51 West Basin and Sub-basin 24 in the C-51 East Basin during TS Isaac are plotted in **Figure 22** against the SFWMD 100-year, 72-hour rainfall distribution used in the 2004 C-51 Study.

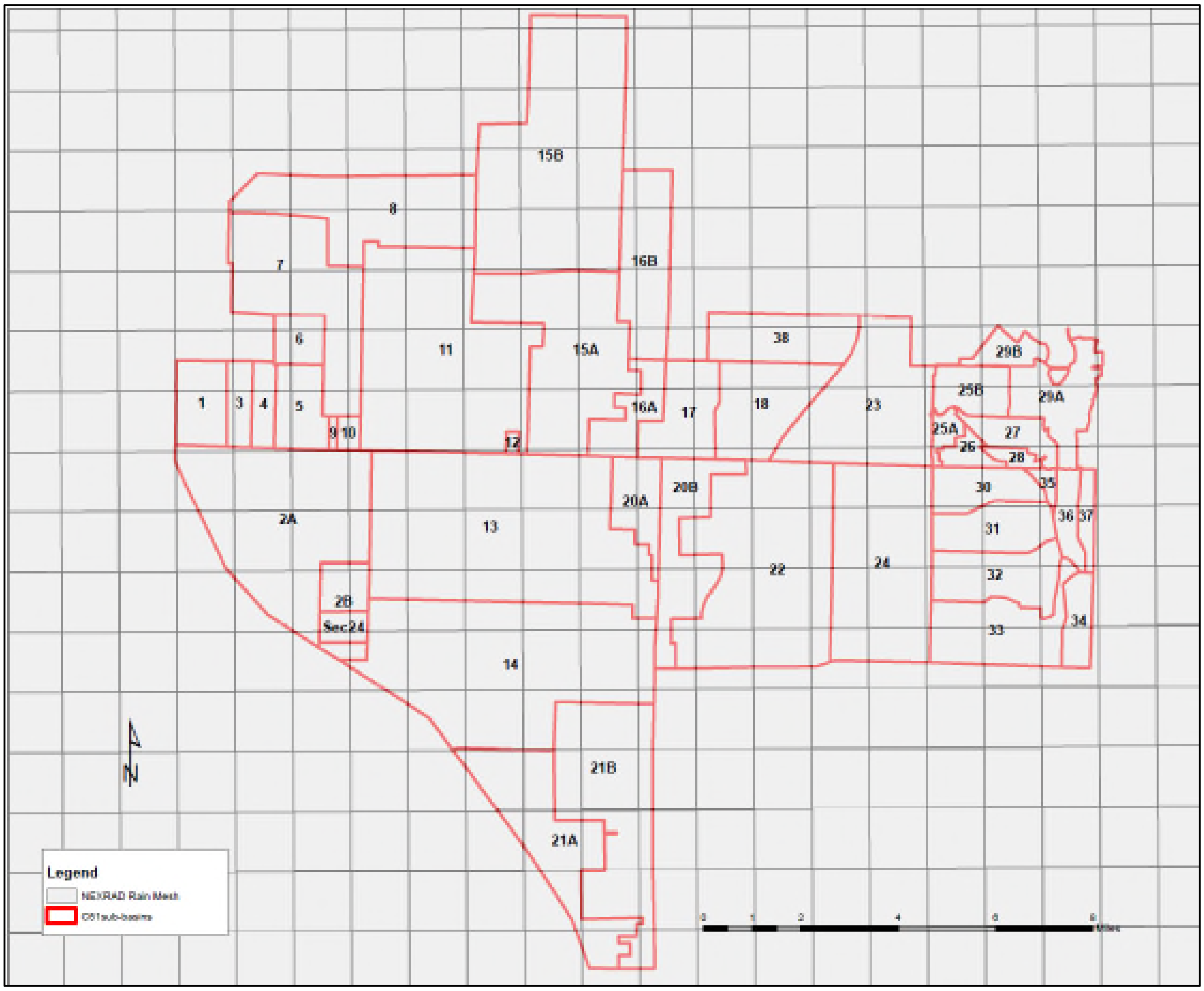

Figure 20. Nexrad Rainfall Grid over the C-51 sub-basins

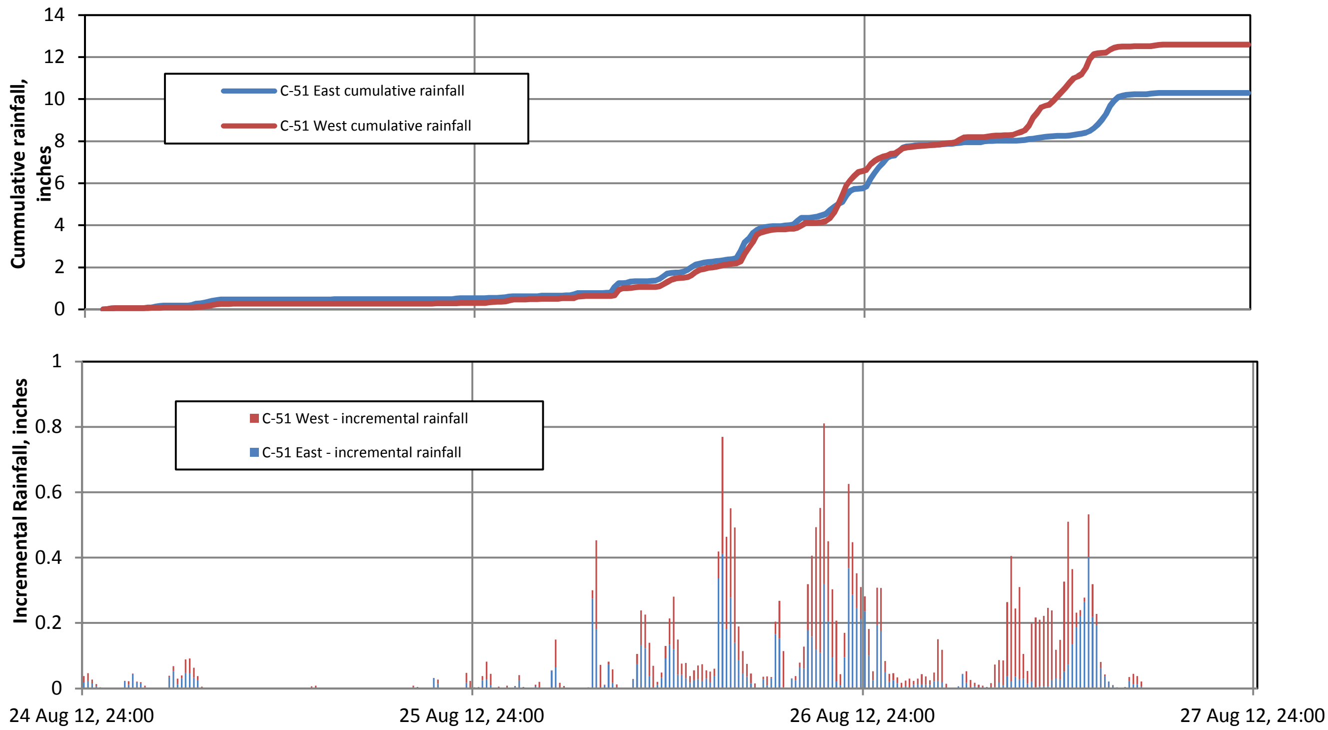

Figure 21. 15-min Cumulative and Incremental Rainfall Volume Distributions on C-51 East and West Basins Before and During Tropical Storm Isaac.

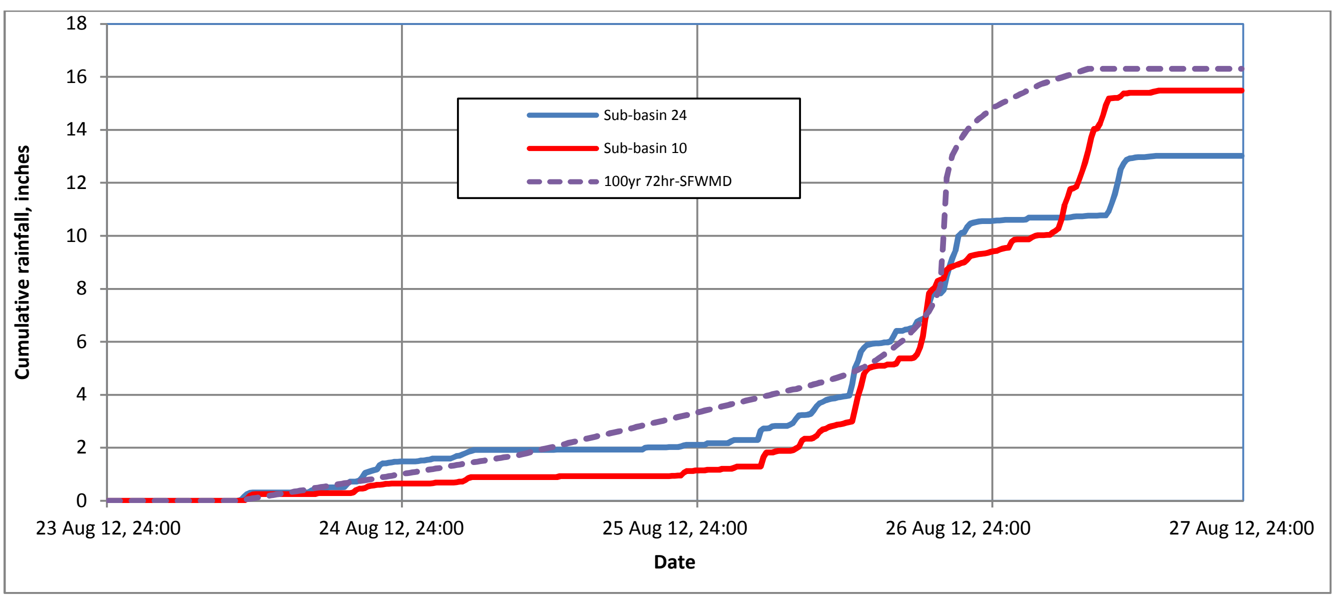

Figure 22. TS Isaac Observed Nexrad Rainfall and SFWMD 100-yr, 72-hr Cumulative Rainfall

Table 7. Nexrad Rainfall over C-51 East and West Sub-basins during TS Isaac, Aug 25-27, 2012)

C-51 West		C-51 East	
Sub-basin ID	Rainfall (in)	Sub-basin ID	Rainfall (in)
1	12.7	17	7.3
2A[1]	13.5	18	11.2
2B	13.5	20A	10.6
3	13.7	20B	10.7
4	14.2	21A	10.5
5	14.6	21B	10.2
6	14.6	22	11.2
7	14.2	23	10.5
8	12.8	24	11.5
9	14.9	25A	9.9
10	14.8	25B	8.9
11	12.0	26	9.5
12	8.6	27	8.9
13	11.5	28	9.3
14	11.9	29A	5.7
15A	11.0	29B	4.6
15B	10.3	30	9.6
16A	7.2	31	9.3
16B	10.1	32	9.5
Sec24	13.5	33	9.8
		34	8.8
		35	8.7
		36	8.4
		37	8.4
		38	10.5
AVG:	**12.5**	**AVG:**	**9.3**

1. Sub-basin 2A (STA-1E) is not part of the C-51 West Basin

3.4.2 STAGE AND FLOW DATA

Observed canal stage and flow data during TS Isaac was used to assess model performance by comparing computed against observed values at several locations in the C-51 Canal. Observed data was available from the District's DBHYDRO database at four sites in the C-51 Canal, which provided breakpoint data for HW and TW stages, gate openings and computed flows. The four monitoring sites on the C-51 Canal are located at control structures S-5AE at the western end of the C-51 canal, S-319 at the intake of the pump station, east of the S-5AE structure, structure S-155A which divides the C-51 Basin into East and West Basins, and structure S-155, at the eastern end of the C-51 Canal. **Figure 23** shows the location of these structures on the C-51 canal.

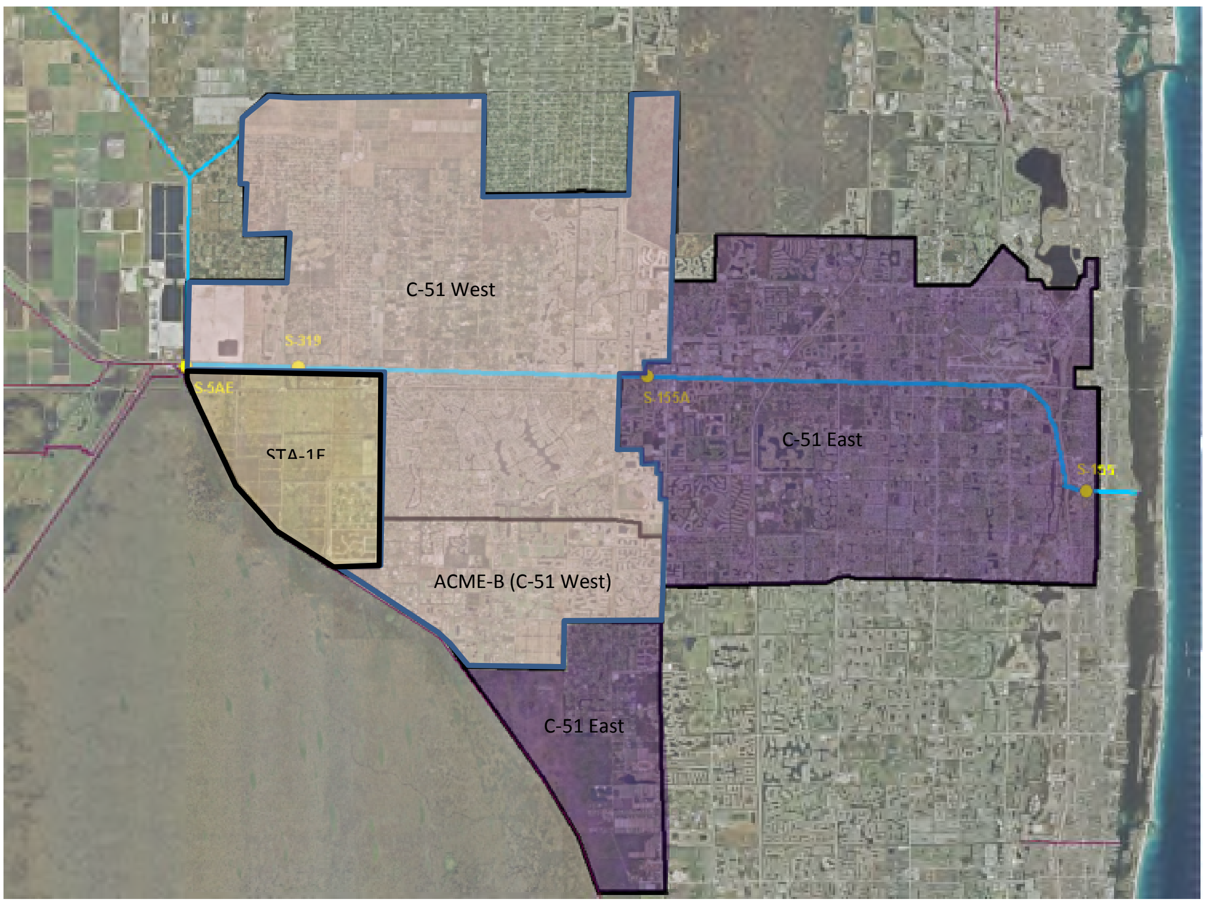

Figure 23. Stage and Flow Data Sites on the C-51 Canal

The breakpoint datasets were converted to uniform time interval of 15 minutes to facilitate comparison with model results. The 15-minute datasets are presented in **Figures 24 through 28** for the period of August 24 to September 4, 2012. For structures S-155 and S-155A, the observed gate openings were initially used in the calibration of HEC-RAS as internal boundary conditions at the structures to compute HW and TW stages as well as flows. At structure S-319, the measured pumpage was used initially as boundary condition to compute the stages in the C-51 Canal at the location of the pump, however, this boundary condition resulted in model instability and unreasonable water levels at this location, therefore, the use of the pumpage data was discontinued and used to history match computed pumpage by the model. The pump rating curves developed by the District (SFWMD, 2008) were used to replace the pump curves in the 2004 C-51model. **Figure 28** shows the performance curves for the 550 cfs and 950 cfs pumps used in the new version of the model.

At the western end on the C-51 Canal, observed 15-min flow data corresponding to observed discharges through structure S-5AE was used as boundary condition to compute the canal stage at this location.

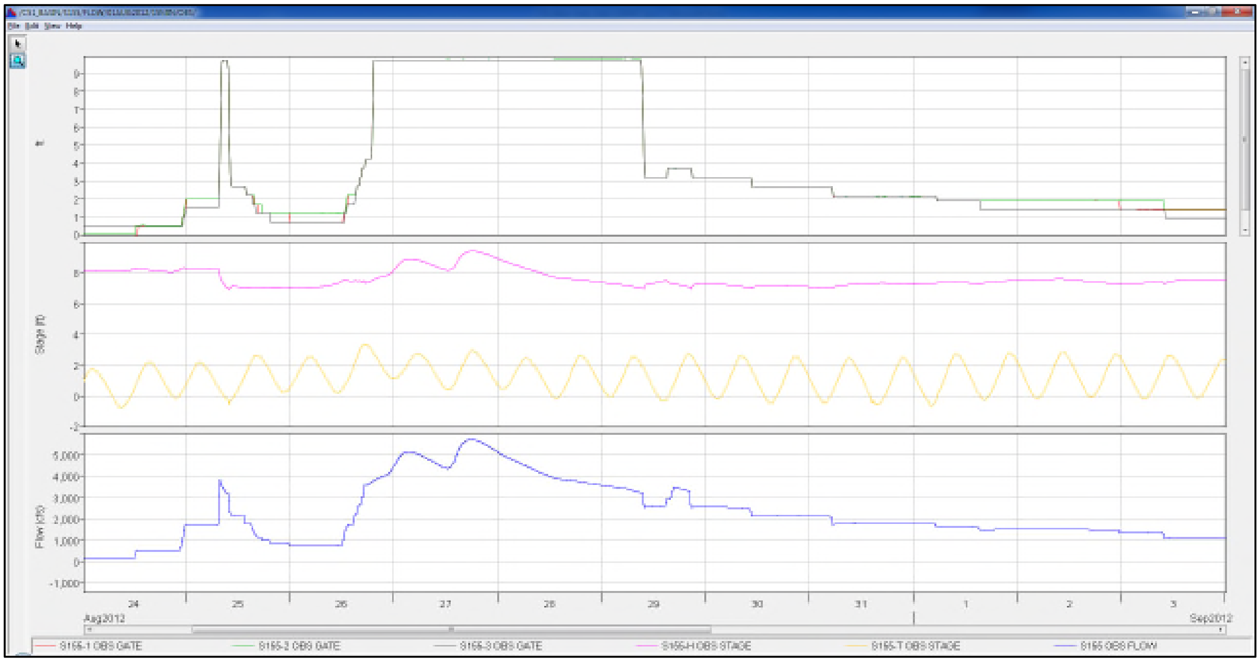

Figure 24. Observed Gate Openings, HW, TW and Flow at Structure S-155

Figure 25. Observed Gate Openings, HW, TW and Flow at Structure S-155A

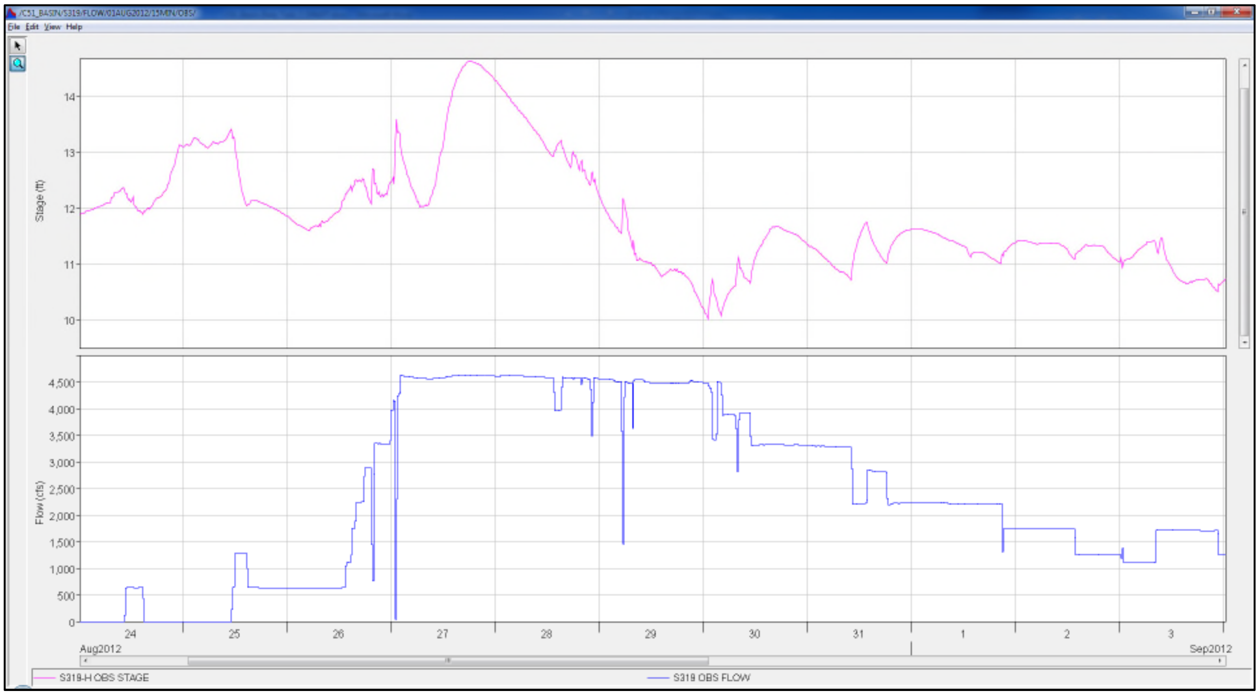

Figure 26. Observed HW and Flow at Pump Station S-319

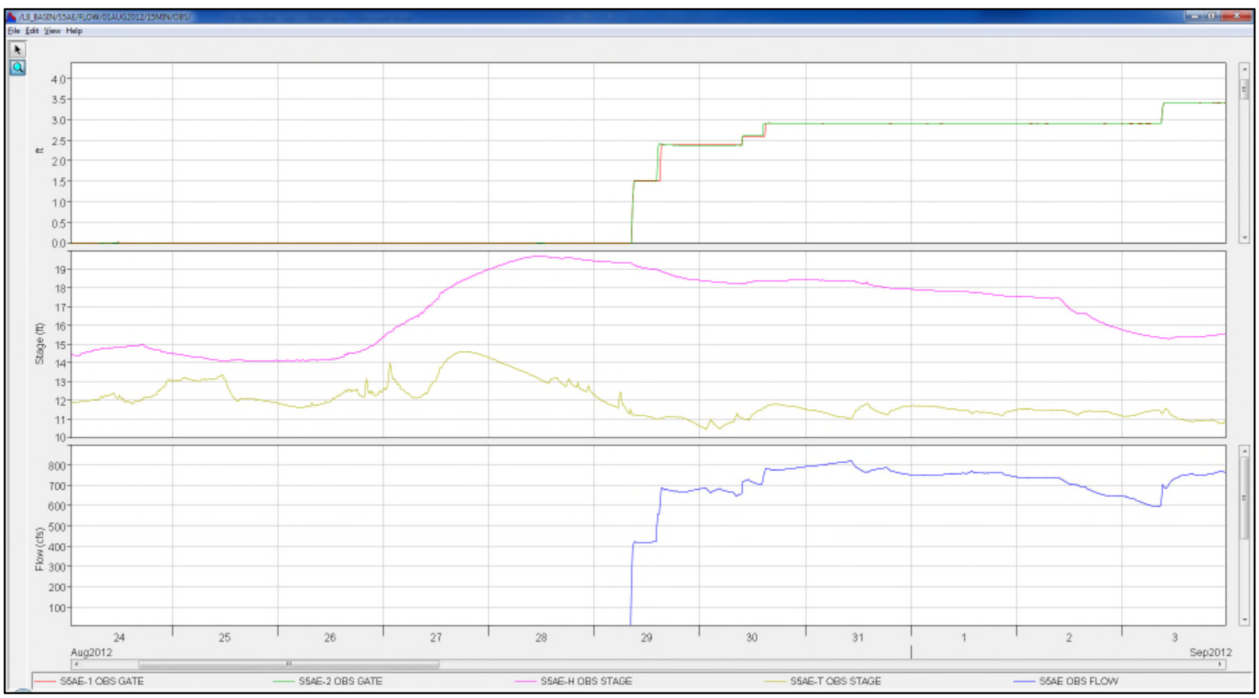

Figure 27. Observed Gate Openings, HW, TW and Flow at Structure S-5AE

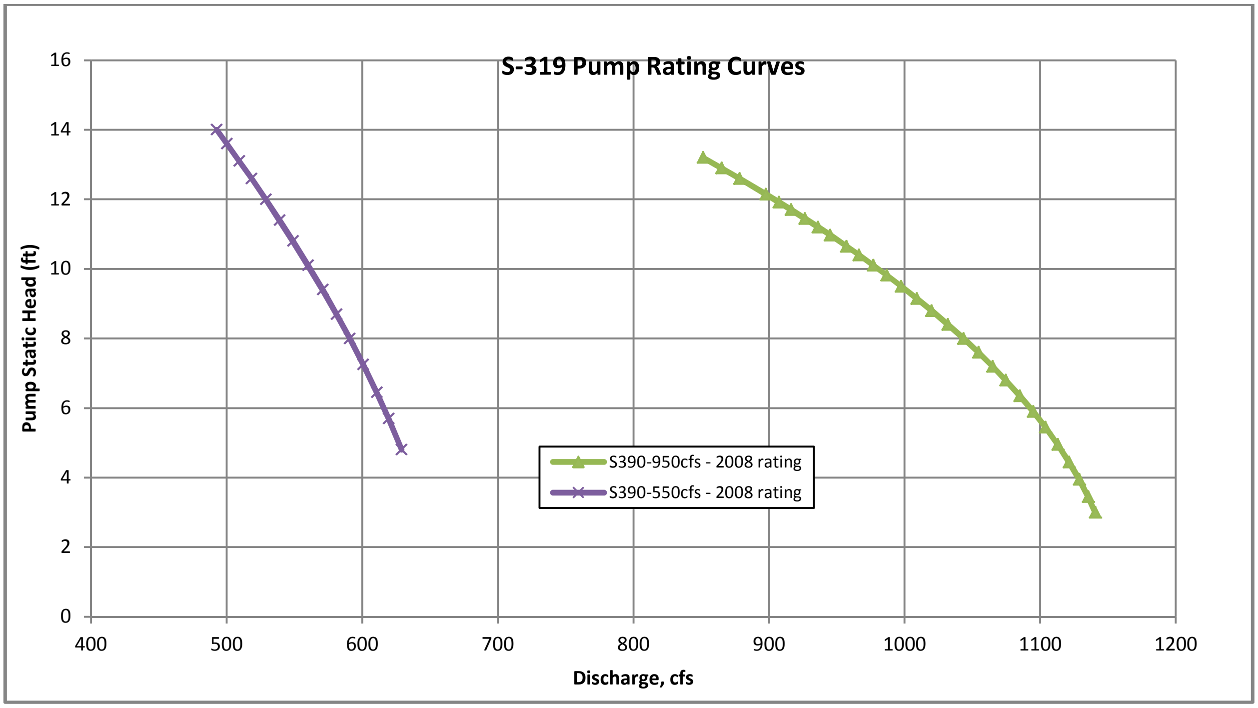

Figure 28. S-319 Pump Station Performance Curves for the 550-cfs and 950 cfs Pumps

3.4.3 INDIAN TRAIL IMPROVEMENT DISTRICT (ITID) DATA

ITID provided observed stage and flow data collected during TS Isaac at several gauges operated by the drainage district. **Figure 29** is a map with the gauge locations in the ITID supervisory control and data acquisition (SCADA) system. Gauge data that could potentially be used for model calibration was reviewed by the District and plotted in **Figures 30 through 35**. **Figure 30** shows the HW stage, TW stage and gate openings at the 40th Street Structure. After reviewing the data, it was observed that the TW stage data was inaccurate during the peak of the storm due to an inoperable sensor.

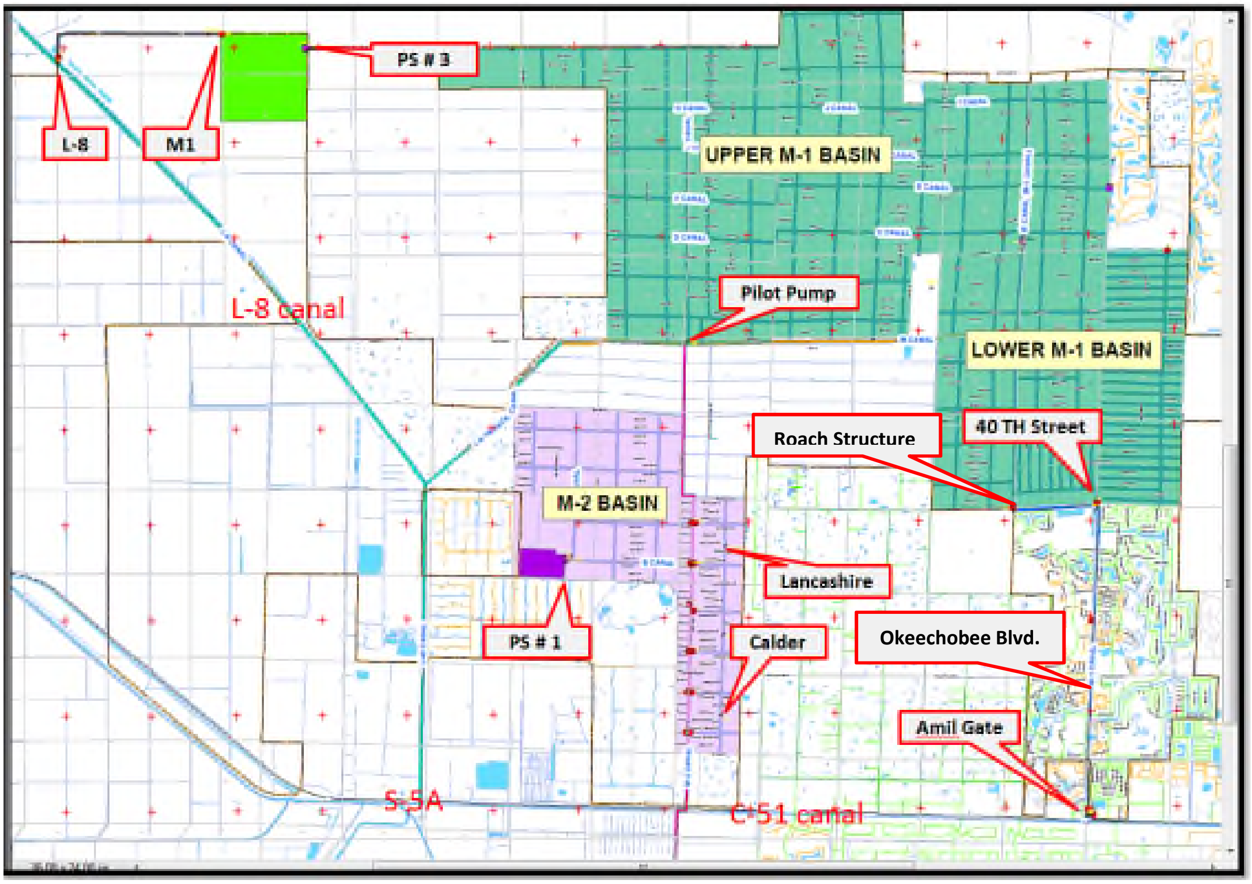

Figure 29. Indian Trail Improvement District Stage and Flow Monitor Stations

Figure 31 shows the observed water levels in the M-1 canal at the Okeechobee Boulevard gauge and **Figure 32** demonstrates the HW stages at the M-1 canal outfall (Amil and slide gate structure). These two hydrographs indicate that the water levels were higher at the outfall (Amil gate) at Southern Boulevard than at the upstream gauge at Okeechobee Boulevard. For these reason, these two gauges were excluded from the calibration. **Figure 33** shows the observed daily average flows through the Roach and 40th Street structures and the combined total discharge to the C-51 canal from ITID. **Figures 34 and 35** are observed stages in the upper M-2 basin at the Lancashire and Calder gauges which can be used to history match computed stages in this sub-basin.

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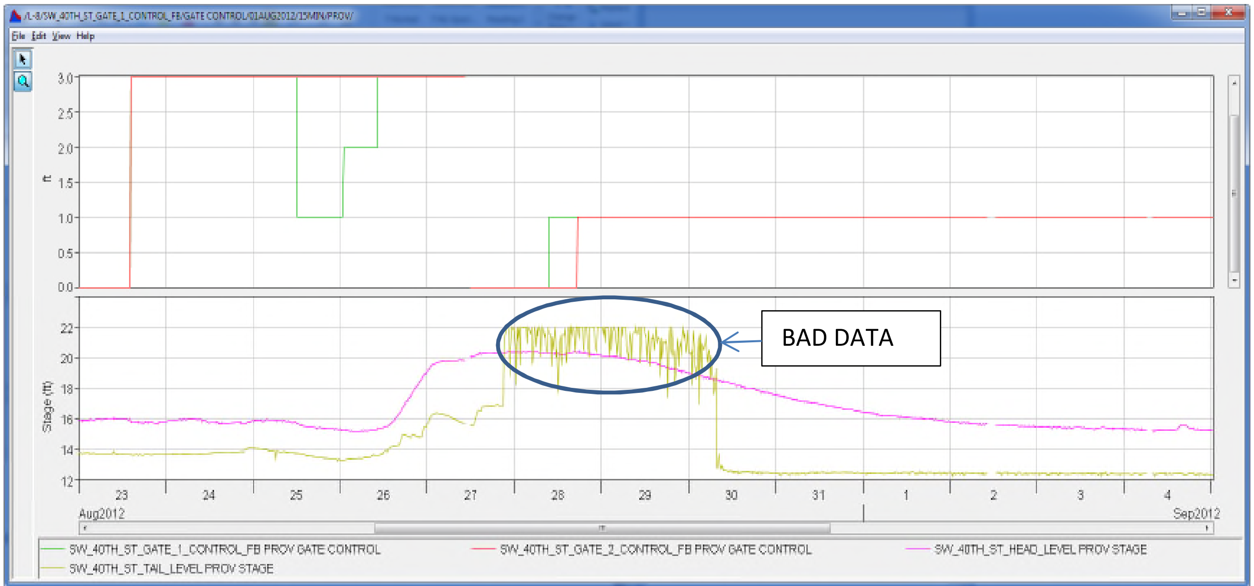

Figure 30. Observed Gate Openings, HW and TW Stage at ITID 40^{th} Street Structure

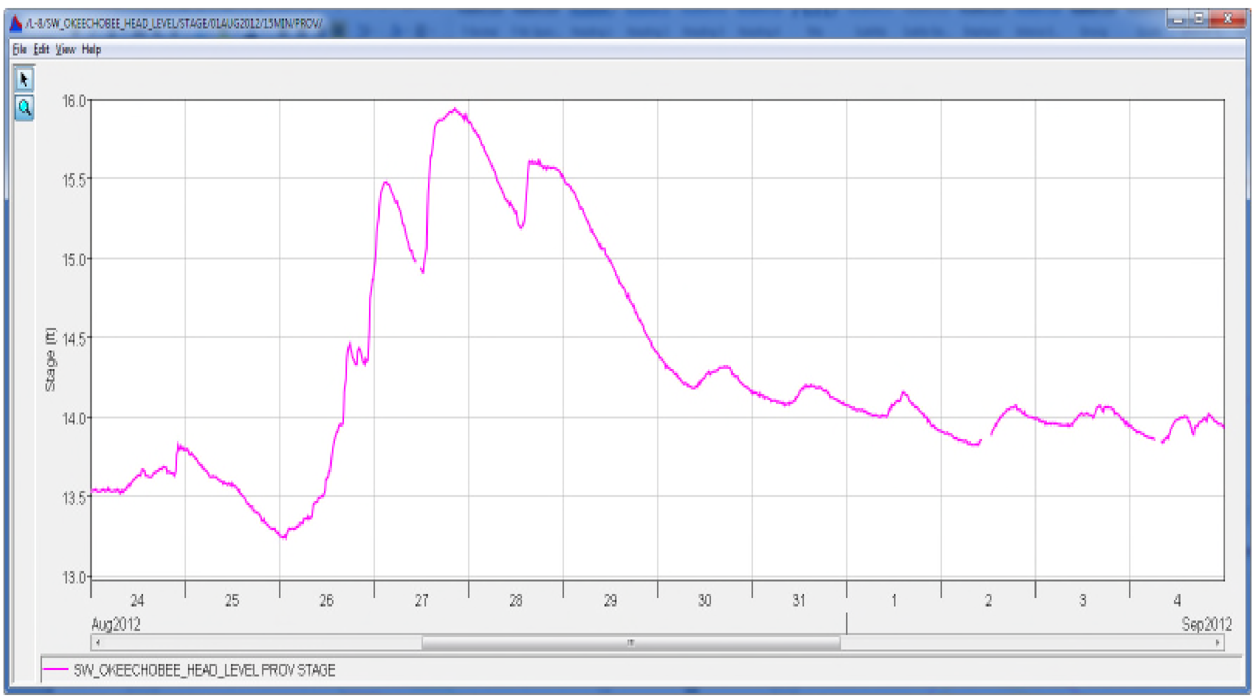

Figure 31. Observed Stage on M-1 Canal at Okeechobee Boulevard

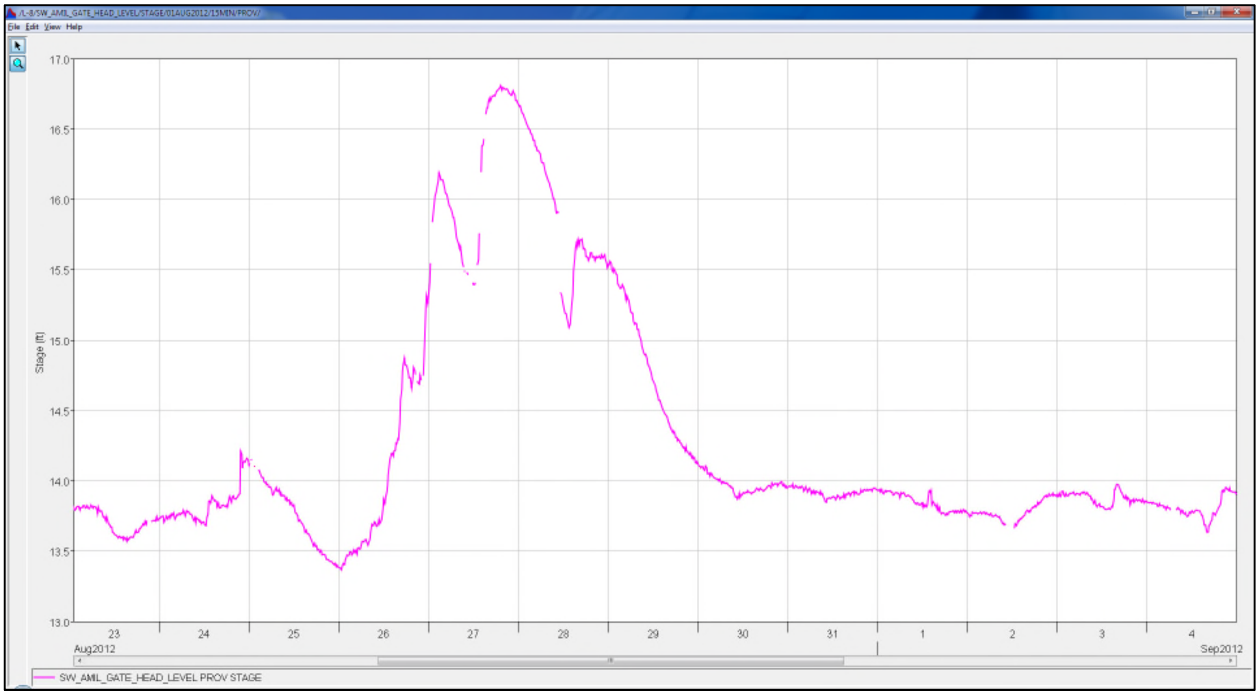

Figure 32. Observed HW Stage at M-1 Outfall (Amil Gate) Structure

Figure 33. Observed Daily Flow through ITID 40th Street Structure, Roach Structure and Total Flow

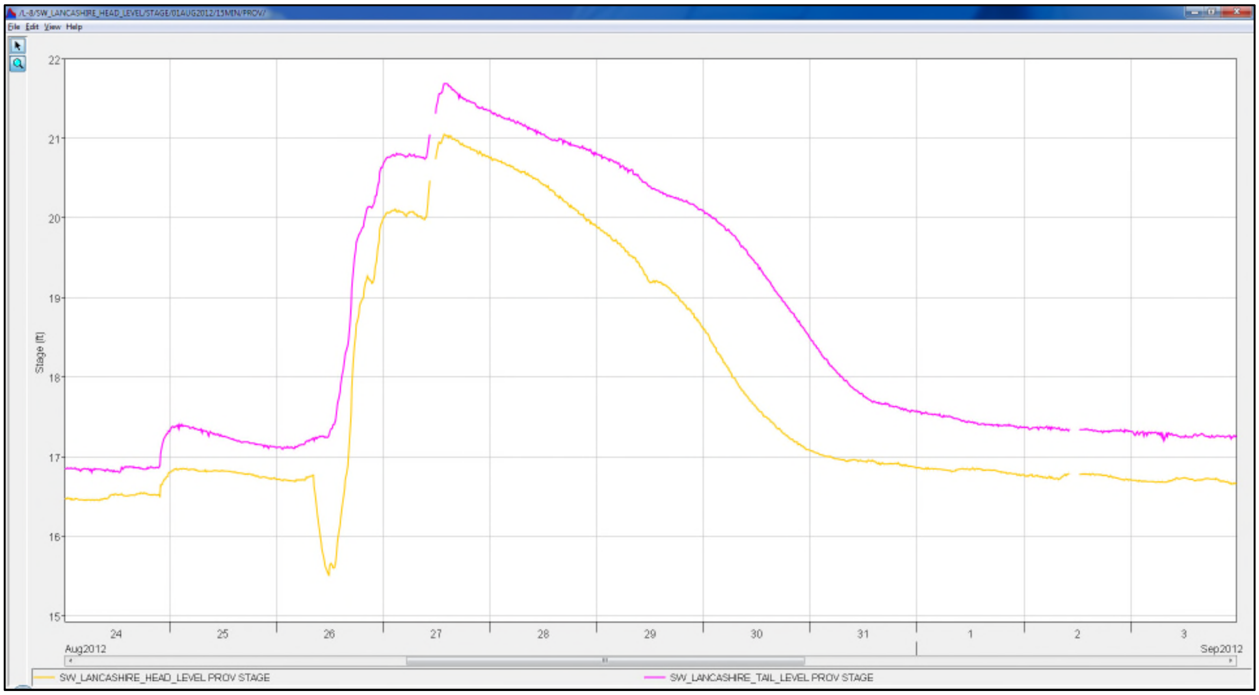

Figure 34. Observed HW and TW Stages at Lancashire Gauge

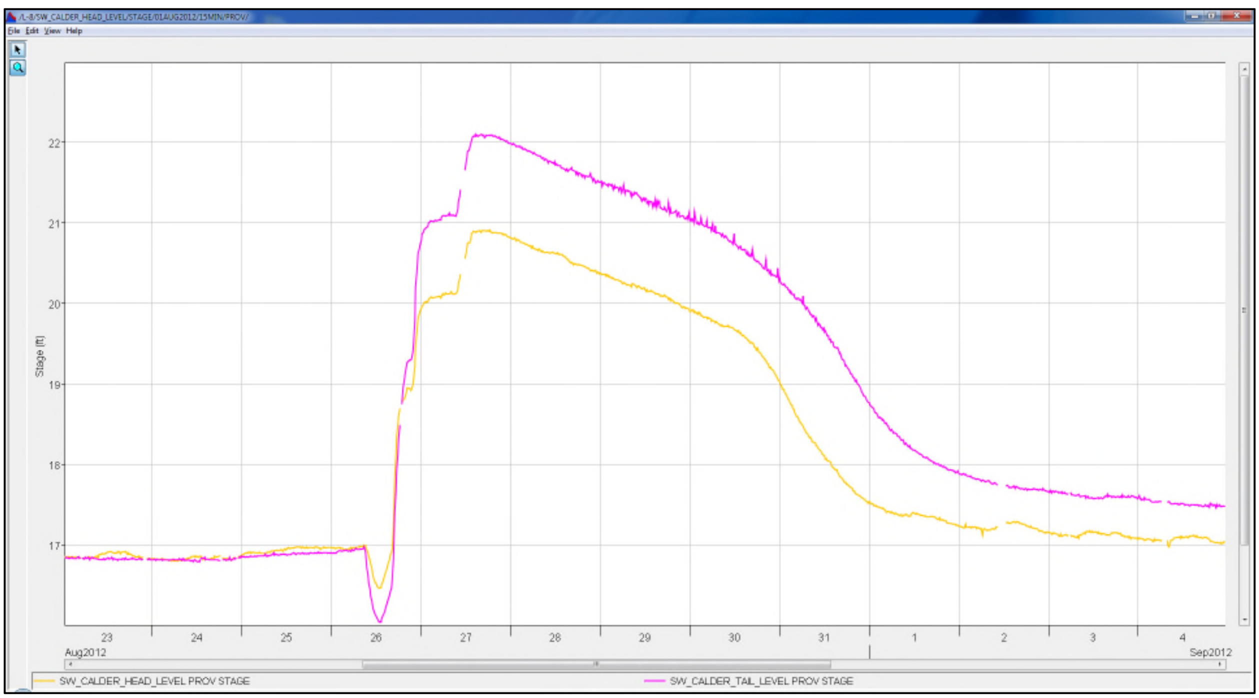

Figure 35. Observed HW and TW Stages at Calder Gauge

3.4.4 VILLAGE OF WELLINGTON (ACME BASINS A AND B) DATA

The Village of Wellington (VOW) provided stage and flow information recorded during TS Isaac. **Figure 36** shows the location of the monitoring stations. Measured pump discharges from the village into the C-51 Canal were provided as daily average flows at pump stations (PS) No. 3, No. 4, No. 6 and No. 7. Also, at the pumps, hourly HW and TW stages were available. **Figures 37–41** show the stage and pumpage data at the pump stations and **Figures 41 – 44** demonstrates the HW and TW stages at control structures (CS) No. 43, No. 44, No. 8 and No. 9.

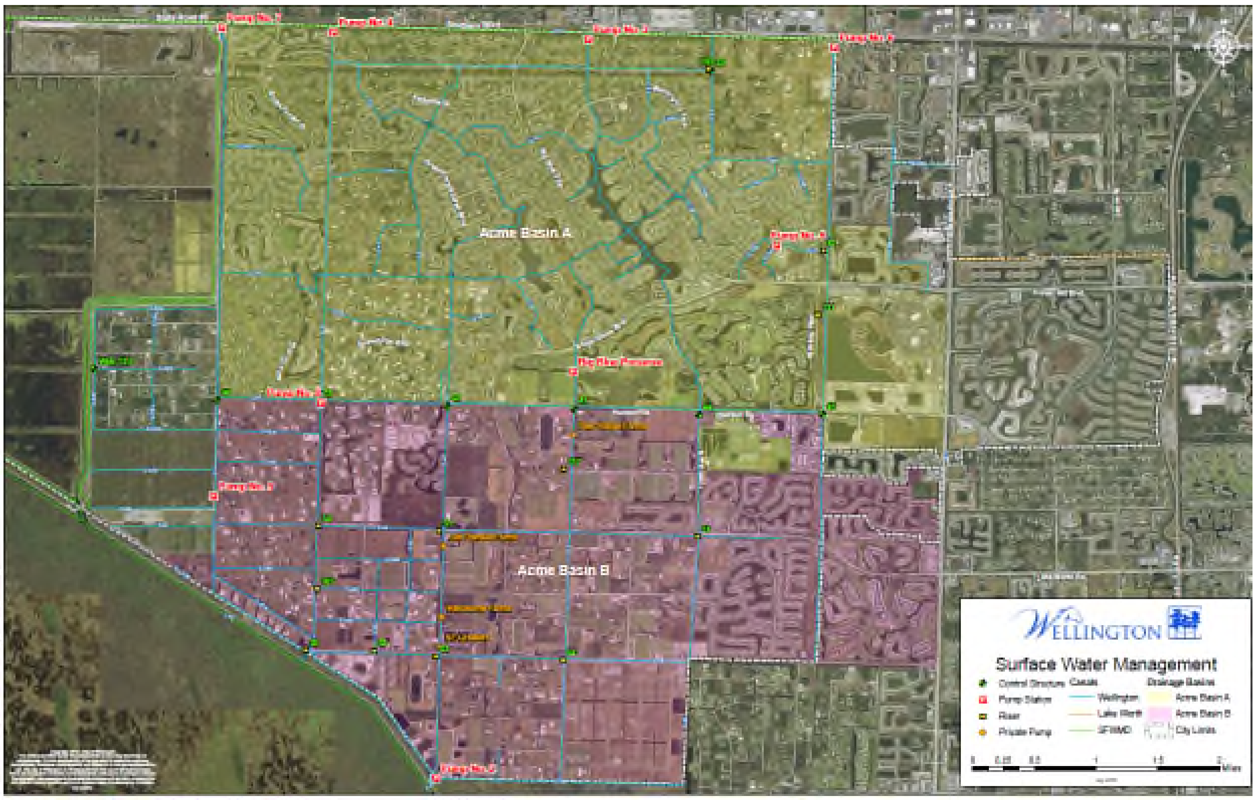

Figure 36. Location of ACME Drainage Structures

Figure 37. Observed HW Stage at ACME PS No. 2

Figure 38. Observed Daily HW Stage, TW Stage and Flows at ACME PS No. 3

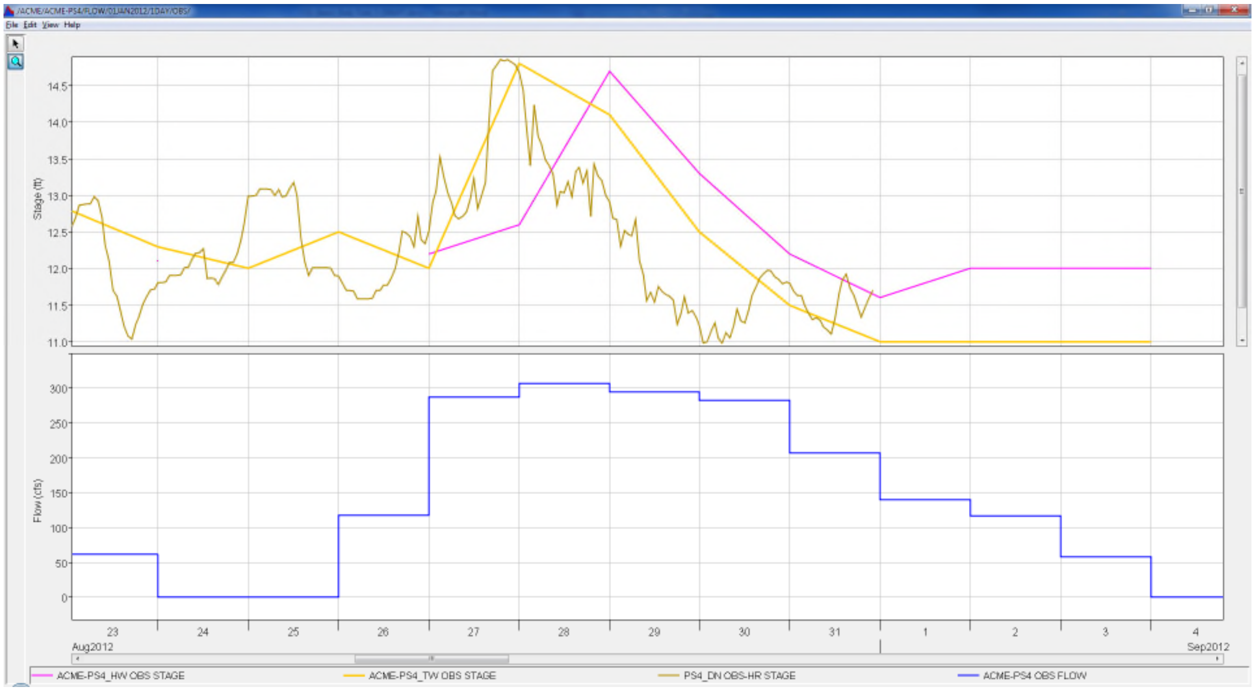

Figure 39. Observed TW Stage and Flows at ACME PS No. 4

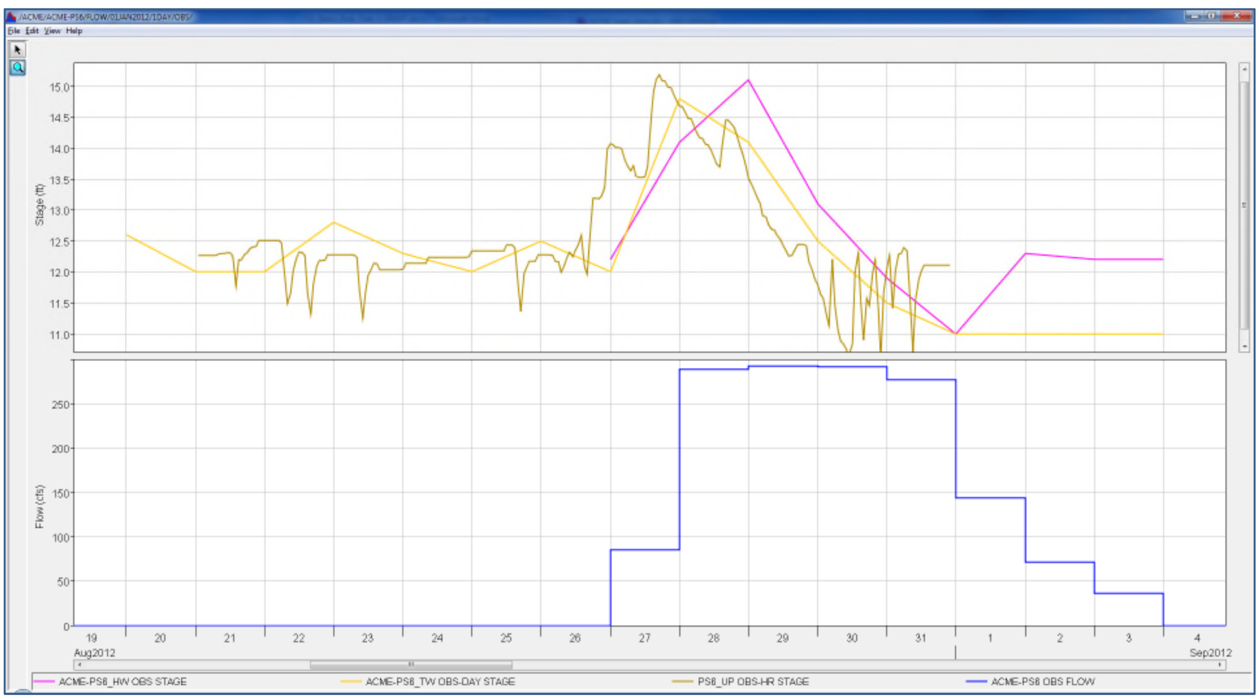

Figure 40. Observed HW, TW Stage and Daily Flows at ACME PS No. 6

Figure 41. Observed HW, TW Stage and Daily Flows at ACME PS No. 7

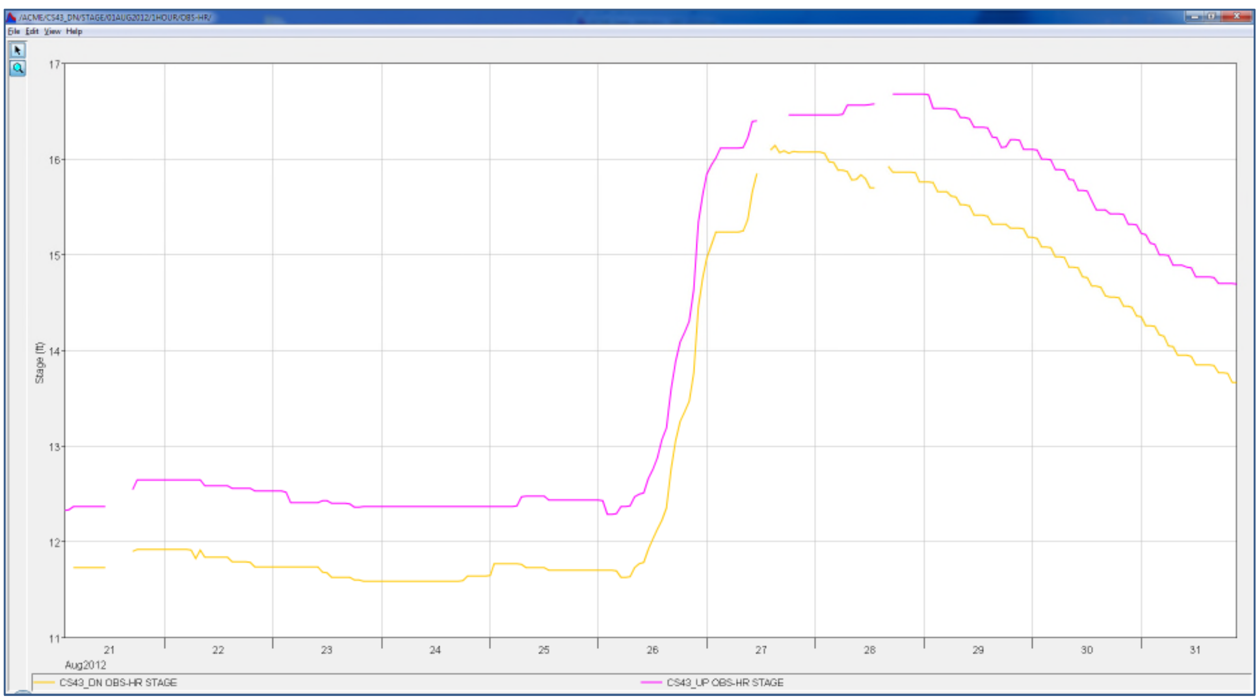

Figure 42. Observed HW and TW Stage at ACME CS No. 43

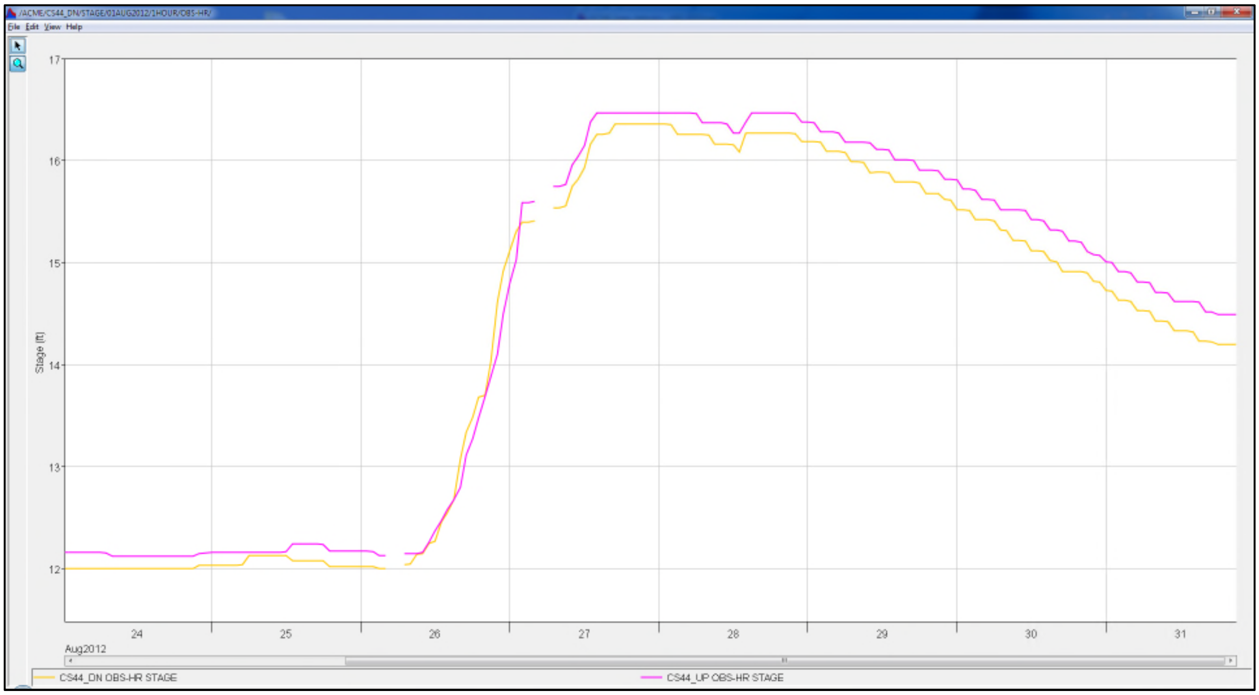

Figure 43. Observed HW and TW Stage at ACME CS No. 44

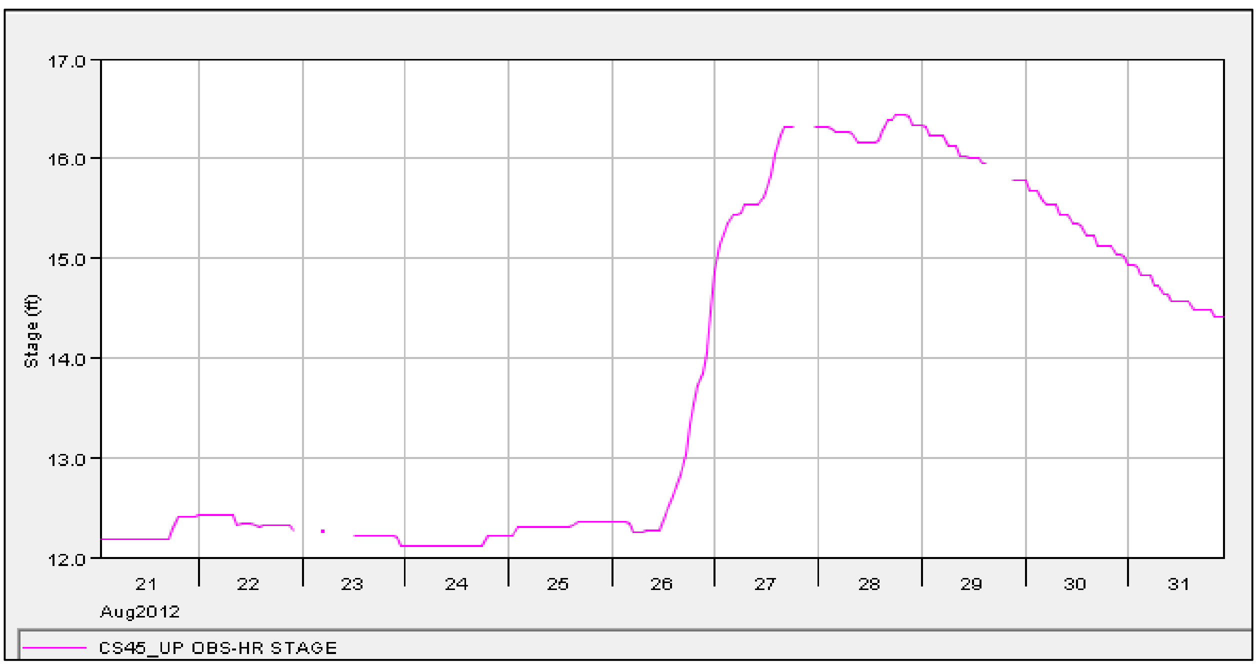

Figure 44. Observed HW Stage at ACME CS No. 45

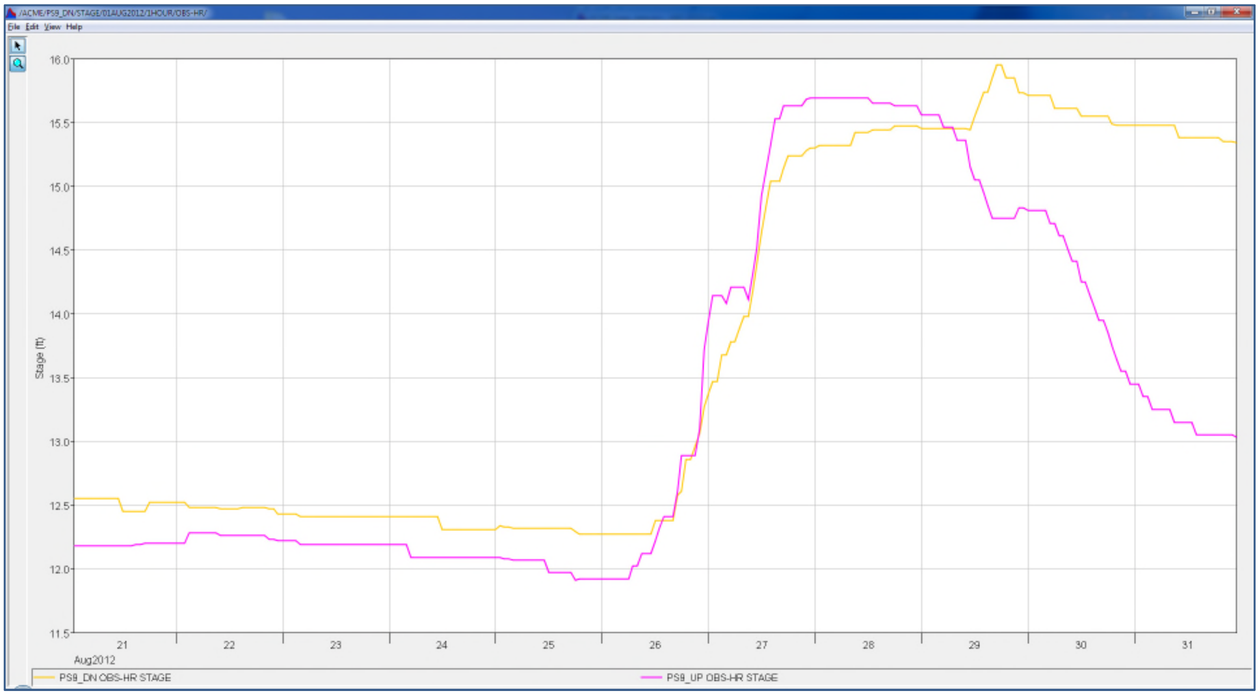

Figure 45. Observed HW and TW Stage at ACME PS No. 9 (Section 24)

There is no recorded stage or flow data in the middle of both ACME Basin A and B. The HEC-RAS model computes the stage on each basin as level pool in a storage basin. This level-pool assumption was not valid during TS Isaac when water levels varied considerably from south to north across the ACME Basin A. **Figure 46** shows the HW stage hydrographs at PS No. 7 on the northern boundary of the Basin A together with the TW stages at PS No. 8 located at Pierson Road. As this figure shows, there is significant hydraulic head gradient between the two locations at the northern and southern ends of Basin A. During the storm, as much as 2.7 feet of head difference is observed in the two hydrographs, particularly when the pumpage reached maximum values of about 1,280 cfs into the C-51 canal on August 28 and 29. These large differences in stages at the pump stations are highly influenced by the local effects of the pumps. It is therefore recommended that the TW stages at structure CS No. 44, which are more representative of the stages in the interior of the basin, be used for history matching stages in ACME Basin A. For Basin B, the HW stage of structure CS No. 45 is recommended for history matching.

Figure 46. HW Stage of PS7 (red line), TW Stage of PS8 (green line) and Total ACME Pumpage (blue line) into the C-51 canal

3.4.5 LWDD DATA

Although no time series stage or flow data were collected by the LWDD, staff gauge readings at several locations within the drainage district were collected. **Figure 47** is a map of the canals and structures managed by LWDD within the C-51 Basin. This figure shows the location of lateral canals E-1, E-2 and E-3 discharging into the C-51 via control structures CS2, CS4 and CS6, respectively. In the eastern portion of the C-51 Basin, lateral canals L-5 through L-11 discharge into the lower C-51 Canal upstream of the S-155 structure.

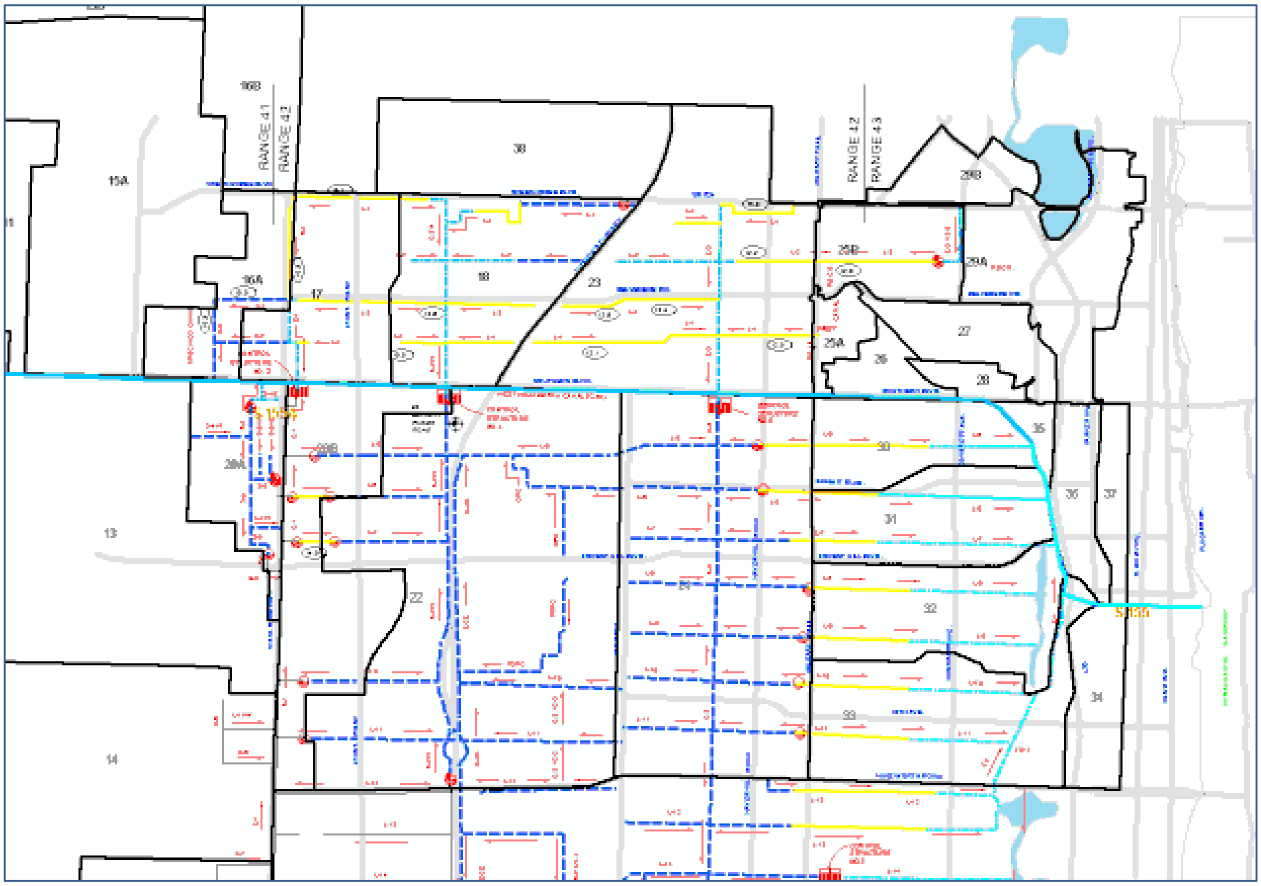

Figure 47. Lake Worth Drainage District Drainage Canals and Control Structures in the C-51 East basin

Figure 48 is a table with the recorded water levels for the period of August 17 through August 31. There are no time stamps in this data set that shows the time of the day when these values were recorded so they can only be used for comparison to approximate peak stage values computed by the model. The table includes several staff gauge locations within the C-51 East basin including the E-3 Canal at Forest Hill Boulevard and Control 6 structure at the C-51 Canal for Sub-basin 24, the E-2W canal at Lake Worth Road and staff gauge E-2W at Control 4 structure for Sub-basin 22, the E-2 canal at Belvedere Road for Sub-basin 18, and the Control 2 structure at the C-51 Canal for Sub-basin 20B.

Aug-12 | STAFF GAUGE READINGS | 6/24/2013 STAFF Aug

NO.	LOCATION OF STAFF GAUGE	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
1	LAKE WORTH RD & E-4				7.70	7.68	7.86	7.76	8.42			N/A	9.34	8.28	8.44	7.60
2	BOYNTON BEACH & E-4				7.92	7.86	8.06	7.94				10.00	9.76		7.82	7.58
3	ATLANTIC AVE & E-4				8.02	8.08	8.16	8.00				10.08	9.66	8.44	7.52	7.30
4	GLADES RD & E-3	9.46		9.84	9.84	9.74	9.44	9.48	9.44	10.02	8.60	9.80	9.66	10.14	10.00	9.64
5	LAKE WORTH RD & E-3	13.52	13.04	13.04	13.50	13.36	13.40	13.24	13.38	12.16	8.00	14.18	12.48	12.46	11.50	13.28
6	BOYNTON BEACH BLVD & E-3				15.92	15.76	15.84	15.52	15.58	15.62		15.60	15.00	14.34	13.94	15.02
7	ATLANTIC AVE & E-3			15.58	15.96	15.94	15.94	15.68	15.50	15.50	15.16	14.64	13.96	15.06	14.96	15.56
8	FOREST HILL BLVD & E-3				13.54	13.40	13.44	13.36	13.72	13.72		13.52	12.00		10.98	13.54
9	LAKE WORTH RD & E-2W NORTH				13.44	13.28	13.42	13.40				14.24	13.34	13.18	14.12	14.00
10	LAKE WORTH RD & E-2W SOUTH				15.90	15.96	16.00	15.68				17.30	16.84	16.50	15.84	15.64
11	LAKE WORTH RD & E-2				13.40	13.30	13.36	13.24				13.76	13.74	13.06	13.88	13.82
12	BOYNTON BEACH BLVD & E-2				15.88	15.78	15.86	15.50				16.38	15.82	15.26	14.72	15.34
13	ATLANTIC AVE & E-2				15.84	15.80	15.76	15.56				15.80	15.44	14.80	14.80	15.44
14	GLADES RD & E-2				16.00	16.02	16.00	15.70	15.96	15.74	15.16	15.28	14.80	14.12	14.30	15.56
15	CONTROL 4 & E-2W @ PB CANAL				8.02/13.48	7.94/13.40	8.50/13.46	8.52/13.44	13.80	9.44/13.54	6.10/13.24	11.22/12.7	10.50/11.9	10.00/13.3	9.38/14.14	8.88/14.04
16	BELVEDERE RD & E-2				8.30	8.22	8.36	8.50				N/A	N/A	N/A	N/A	N/A
17	LAKE WORTH RD & E-1				15.90	15.88	15.98	15.64	15.94	15.30		17.06	16.58	16.28	15.80	15.50
18	BOYNTON BEACH BLVD & E-1	15.74	15.76	15.58	15.96	16.00	16.02	15.72	15.58	15.72	15.10	16.94	16.60	16.14	15.30	15.52
19	ATLANTIC AVE & E-1				15.84	15.82	15.86	15.56	15.46			16.54	15.74	15.32	14.82	15.44
20	CONTROL 1 A LOWER				12.70	12.86	12.68	11.60				14.10	14.16	14.70	14.08	13.80
21	CONTROL 1 B HIGH				15.72	15.70	15.70	15.44				16.54	15.72	15.28	14.76	15.32
22	PB CANAL & CONTROL 2				8.26/16.00	8.04/16.00	9.32/16.10	8.94/15.82	12.06		7.60/10.10	12.38/12.4	11.34/12.4	11.32/12.7	10.46/10.7	10.00/13.36
23	CONTROL 3 A LOWER	13.32			12.88	13.02	12.90	11.84	12.82	12.98	8.00	13.90	13.88	14.81	14.26	13.96
24	CONTROL 3 B HIGH	15.70			15.86	15.88	15.88	15.56	15.52	15.66	15.08	16.32	15.60	15.18	14.76	15.44
25	CONTROL 6 & PB CANAL				7.88/13.32	7.70/13.20	7.96/13.24	8.16/13.16	10.18/10.22		7.10/8.00	10.72/10.8	9.78/9.90	8.62/12.30	8.20	7.86/13.34
26	CONTROL 8 & LAKE OSBORNE			8.20/11.66	7.96/13.44	7.92/13.22	8.12/13.30	8.08/12.66	7.62/10.46		7.62/10.46	11.10/12.2	10.00/10.8	8.70/11.76	8.54/10.10	8.20/11.60
27	CONTROL 16 & E-3				9.70	9.64	9.30	9.40	9.86	9.86		8.20	8.10	9.90	9.82	9.68
28	HILLSBORO & CONTROL 17W															
29	CONTROL 19 A LOWER				13.10	13.10	13.08	13.06				11.60	12.90	13.24	13.18	13.18
30	CONTROL 19 B HIGH				15.86	15.90	15.90	15.58				16.20	15.14	15.20	14.76	15.44
31	WC 1				16.28	16.30	16.30	16.36				17.10	17.44	17.46	17.44	17.40
32	G94-A				CLD	CLD	CLD	CLD				CLD	CLD	CLD	CLD	CLD
33	G94-B				CLD	CLD	CLD	CLD				CLD	CLD	CLD	CLD	CLD
34	G94-C				CLD	CLD	CLD	CLD				CLD	CLD	CLD	CLD	CLD
35	CS-20 A LOWER				8.10	7.80	7.80	8.66				12.94	13.16	12.24	10.90	10.50
36	CS-20 B HIGH				12.82	13.00	12.88	11.74	12.68			13.30	13.82	14.64	14.32	13.86
37	CS-11				8.10/15.94	8.06/16.00	8.18/16.00	8.00/15.56	14.90			N/A 13.10	N/A N/A	9.69/13.48	8.00/14.90	7.50/15.44

Figure 48. Staff Gauge Readings at LWDD Canals and Structures during TS Isaac (Aug 17-31, 2012)

3.5 CALIBRATION PARAMETERS

As in the 2004 C-51 Study model calibration, the parameters of interest used in adjusting the model's response to rainfall were the CN and t_l in the HEC-HMS and the Manning's roughness coefficients (n's) for the main canal in the HEC-RAS model. It was assumed that the sub-basin areas correspond to those in the 2004 study since the L-2 pump (new sub-basin 39) did not operate during TS Isaac.

Although in this study the HEC-HMS parameters were not changed from their 2004 values, the unit hydrograph method was altered. During the calibration process, the Delmarva unit hydrograph method was applied in place of the SCS unit hydrograph. This resulted in a lowering of the peak rate factor from the SCS unit hydrograph peak rate factor of 484 to 284. The Delmarva unit hydrograph assumes that 22% of the total runoff volume occurs before the peak of the event versus 37.5 % in the SCS Unit hydrograph while the time to peak (T_p) is 0.2 of the base or total time length of the hydrograph versus 0.1 in the SCS unit hydrograph. Although the total volume computed with the Delmarva method is the same as with the SCS method, the peak values computed with the Delmarva method are lower and occur later. The Delmarva hydrograph is recommended and has been used for coastal areas that have slopes less than 5% and permeable soils and are characterized by "ponded" topography capable of capturing and holding some degree of precipitation prior to runoff occurring. Other peak rate factors have been established and recommended for the District (USCOE, 1955) however, HEC-HSM only allows peak factors for SCS (484) and Delmarva (284) in its current version 3.5. For this reason, the Delmarva unit hydrograph was chosen in HEC-HMS to compute the runoff hydrographs for the C-51 Sub-basins. **Figure 49** shows a comparison of the runoff hydrographs generated in HEC-HMS with the standard SCS and Delmarva unit hydrographs for Sub-basin 14. The difference in computed peak values is an approximately 30% reduction with the Delmarva method and no difference in the total volumes.

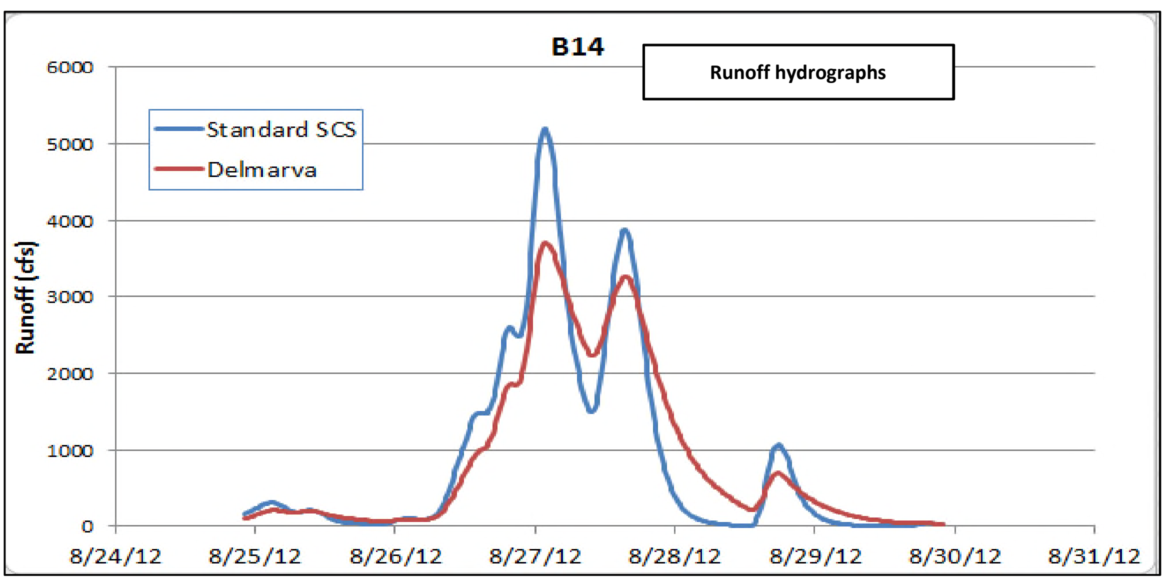

Figure 49. Standard SCS versus Delmarva Runoff Hydrographs for Sub-basin 14

3.5.1 CURVE NUMBER

The runoff CN values established in the 2004 C-51 Study were also used as initial values prior to re-calibration of the C-51 HEC-HMS and HEC-RAS models. The 2004 calibrated CN values were not changed during the re-calibration of the models. **Table 8** is a summary of the 2004 CNs, times of concentration (t_c) and time lags (t_l) used in the HEC-HMS model.

3.5.2 TIME OF CONCENTRATION AND TIME LAG

HEC-HMS uses the unit hydrograph method to generate excess runoff from the C-51 Sub-basins. The unit hydrograph method uses the CN, t_l, derived from the t_c, and a peaking factor to establish the shape of the hydrographs, which in turn determines the peak value and the time to peak. The 2004 calibrated sub-basin t_l used in HEC-HMS were not changed during re-calibration, instead, the peak rate factor of the unit hydrographs were changed by switching the unit hydrograph peak rate factor as described previously. **Table 8** also summarizes the t_l and t_c used in HEC-HMS model.

Table 8. 2015 Calibrated C-51 sub-basin Runoff CN, T_c and T_l

Sub-basin		Area		Weighted Curve Number (CN)	Time of Concentration (min)	Time Lag (min)
ID	Other ID	(acre)	(sq mi)			
1	B1	1253.3	1.96	71.5	252	151
2A	B2A	6662.9	10.41	99.0	651	390
2B	B2B	842.9	1.32	74.3	139	83
3	B3	446.2	0.70	73.9	232	139
4	B4	499.8	0.78	75.2	261	156
5	B5	1102.1	1.72	77.4	232	139
6	B6	674.2	1.05	81.5	147	88
7	B7	4109.5	6.42	76.0	501	300
8	B8	4085.6	6.38	76.0	402	241
9	B9	68.5	0.11	76.1	94	56
10	B10	190.0	0.30	81.9	227	136
11	B11	7975.3	12.46	77.0	518	310
12	B12	74.4	0.12	86.0	94	56
13	B13	10485.7	16.38	82.0	523	313
14	B14	9235.1	14.43	75.0	431	258
15A	B15A	5160.8	8.06	86.0	551	330
15B	B15B	8605.5	13.45	78.0	593	355
16A	B16A	919.8	1.44	83.4	309	185
16B-1	B16B-1	1988.4	3.11	89.0	752	450
16B-2	B16B-2	57.0	0.09	91.0	30	18
16B-3	B16B-3	302.2	0.47	87.0	65.	39
17	B17	1795.5	2.81	84.8	304	182
18	B18	2309.3	3.61	83.5	287	172

Table 8. 2004 Calibrated C-51 sub-basin Runoff CN, T_c and T_l (Cont.)

Sub-basin Area		Sub-basin Area(CN) Time of Concentration (min)		Weighted Curve Number	Time of Concentration	Time Lag
ID	Other ID	(acre)	(sq mi)	(CN)	(min)	(min)
20A	B20A	1010.6	1.58	80.0	256	153
20B	B20B	2167.7	3.39	80.7	364	218
21A	B21A	3535.0	5.52	96.9	534	320
21B	B21B	4915.3	7.68	76.4	494	296
22	B22	7580.1	11.84	80.0	518	310
23	B23	4048.9	6.33	81.0	364	218
24	B24	5204.3	8.13	81.5	441	264
25A	B25A	298.6	0.47	77.0	105	63
25B	B25B	721.0	1.13	79.0	132	79
26	B26	332.0	0.52	80.1	162	97
27	B27	752.8	1.18	84.5	274	164
28	B28	201.3	0.31	83.0	92	55
29A	B29A	1394.2	2.18	80.5	130	78
29B	B29B	566.2	0.88	85.9	144	86
30	B30	1120.7	1.75	78.3	159	95
31	B31	1433.4	2.24	80.0	157	94
32	B32	1804.2	2.82	81.0	271	162
33	B33	2090.9	3.27	80.0	229	137
34	B34	740.4	1.16	75.0	262	157
35	B35	166.1	0.26	82.7	75	45
36	B36	607.4	0.95	72.1	187	112
37	B37	398.5	0.62	69.0	185	111
38	B38	1812.0	2.83	86.0	225	135
39	B39	551.8	0.86	80.0	109	65
Sec24	Sec24	403.2	0.63	70.0	115	69

3.5.3 MANNING'S ROUGHNESS COEFFICIENT

The 2004 values of Manning's roughness coefficients (n) for the left bank, main channel and right bank were used as initial values prior to calibration of the revised HEC-RAS model with changes to the left and right overbank from 0.5 to 0.08. **Table 9** shows the 2004 calibrated canal n values and the revised values for the 2015 condition HEC-RAS model. The 2015 n values represent those used prior to adjustment in the calibration. The values of the calibrated n coefficients are discussed at the end of this section of the report.

Table 9. n Values for Left Bank, Main Channel and Right Bank per Canal Reach

River	Reach	2004 Manning's n Value			Pre-calibration 2015 Manning's n Value		
		left bank	channel	right bank	left bank	channel	right bank
C1	R1	0.5	0.04	0.5	0.08	0.04	0.08
C51	R1	0.5	0.04	0.5	0.08	0.04	0.08
	R2	0.5	0.04	0.5	0.08	0.04	0.08
	R3	0.5	0.04-0.05	0.5	0.08	0.04-0.05	0.08
	R4	0.5	0.05	0.5	0.08	0.05	0.08
	R5	0.5	0.05	0.5	0.08	0.05	0.08
	R6	0.5	0.05	0.5	0.08	0.05	0.08
	R7	0.5	0.05	0.5	0.08	0.05	0.08
	R8	0.5	0.05	0.5	0.08	0.05	0.08
	R9	0.5	0.05	0.5	0.08	0.05	0.08
	R10	0.5	0.05	0.5	0.08	0.05	0.08
	R11	0.5	0.05	0.5	0.08	0.05	0.08
E1N	RE1N	0.5	0.03	0.5	0.08	0.03	0.08
E1S	RE1S	0.5	0.03	0.5	0.08	0.03	0.08
E2N	RE2N	0.5	0.03	0.5	0.08	0.03	0.08
ES2	RES2	0.5	0.03	0.5	0.08	0.03	0.08
E3N	RE3N	0.5	0.03	0.5	0.08	0.03	0.08
E3S	RE3S	0.5	0.03	0.5	0.08	0.03	0.08
E4	RE4	0.5	0.03	0.5	0.08	0.03	0.08
L5	RL5	0.5	0.03	0.5	0.08	0.03	0.08
L7	RL7	0.5	0.03	0.5	0.08	0.03	0.08
L8	RL8	0.5	0.03	0.5	0.08	0.03	0.08
L10	RL10	0.5	0.03	0.5	0.08	0.03	0.08
M1	RM1	0.5	0.03	0.5	0.08	0.03	0.08
M2	RM2	0.5	0.03	0.5	0.08	0.03	0.08
Stub Canal	RSC	0.5	0.03	0.5	0.08	0.03	0.08

3.5.4 TRANSIENT CONDITION PARAMETERS

The theta implicit weighting factor,Ɵ, is used in the unsteady flow HEC-RAS model as a means for providing numerical stability through the implicit solution of the St. Venant Equations. A value of 1 for theta provides the most stability, but sacrifices some accuracy. A value of 0.6 provides the most accuracy, but is more difficult to stabilize. The HEC-RAS manual (USACOE, 2010) (page 8-32) suggests working with a Theta value of 1.0, then when the model is stabilized, reduce it as close to 0.6 as possible. The C-51 HEC-RAS model was developed and initially run for calibration with a theta value of 1. This value was not reduced during subsequent calibrations runs because of high instability in the model at structures S-155A and S-319.

3.5.5 INITIAL ABSTRACTION

In the SCS Runoff Curve Number Method (SCS method) the initial abstraction (I, inches) is the volume of interception, depression storage and infiltration that occurs prior to runoff. The SCS method assumes I is equal to 0.2 times the basin storage (S, inches), which in turn is calculated with the formula:

$$S = \frac{1000}{CN} - 10$$

where:

S = basin storage, inches
CN = curve number

The HEC-HMS model allows the user to use the 0.2*S value as a default by leaving blank the entry for I in the HEC-HMS entry menu. The 2004 version of the HEC-HMS model had entry values of 0.2 inches for initial abstraction for all the sub-basin which means that the initial storage was calculated in the HEC-HMS model as 0.2 inches instead of the product of 0.2*S. Generally, this resulted in values of I too low for sub-basins with high CN's. In the revised 2015 condition HEC-HMS model all the I entries were left blank to use the default value as explained above.

3.6 BOUNDARY AND INITIAL CONDITIONS

3.6.1 BOUNDARY CONDITIONS

The calibration of the hydrologic and hydraulic models for TS Isaac required the imposition of initial and boundary conditions throughout the model. Boundary conditions typically consisted of observed stage hydrograph at the downstream end of a canal and a flow hydrograph at the upstream end. At the locations of control structures classified as gated in-line and lateral structures in the HEC-RAS model, observed gate openings were initially used to compute stages upstream and downstream as well as flows through the structure. Also, at the locations where lateral flows enter or leave the C-51 Canal, either, lateral structures from upstream sub-basins were connected to the canal or known inflow hydrographs were added as local boundary conditions.

Several types of boundary conditions are used in the C-51 to represent known flows or stages along the main canals. These boundary conditions are forms of data that restrict the solution by the model within certain values and are necessary to produce meaningful solutions of the 1-D flow equations. For transient solutions, HEC-RAS allows the modeler to enter known flows or stages in the canals as sequences of observed data which are described next.

3.6.1.1 STAGE HYDROGRAPH

Time series of observed water level data can be specified at any location along a canal in HEC-RAS where reliable data exists. At a minimum a time series of know water levels that span the length of the simulation period must be entered at the downstream end of a simulated canal. A stage hydrograph boundary condition was used at the eastern end of the C-51 canal with 15-minute observed stages on the downstream side of the S-155 structure. Although the eastern end of the canal is approximately 720 feet downstream of the structure, the TW stages at the structure were assumed to be the same as the stages at the C-51 Canal's end. During TS Isaac, there was no significant surge from the storm. At the peak of the storm event, the maximum stage recorded at the TW side of the S-155 structure was 3.4 ft NGVD as shown in **Figure 50**.

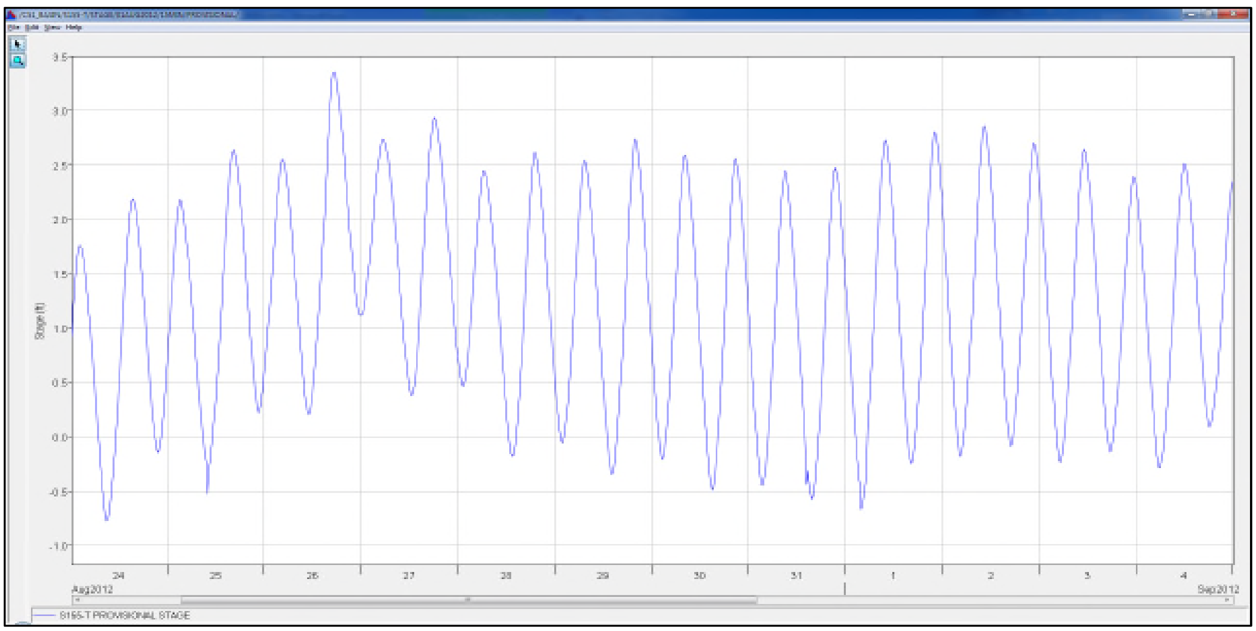

Figure 50. Observed TW Stage at Structure S-155 – TS Isaac

3.6.1.2 FLOW HYDROGRAPH

Observed flows entering or leaving the simulated canal are entered in HEC-RAS at the upstream end of a canal. The western end of the C-51 canal uses a specified flow boundary condition during TS Isaac's calibration run. The flow hydrograph corresponds to the observed flows discharged through structure S-5AE as shown in **Figure 51**.

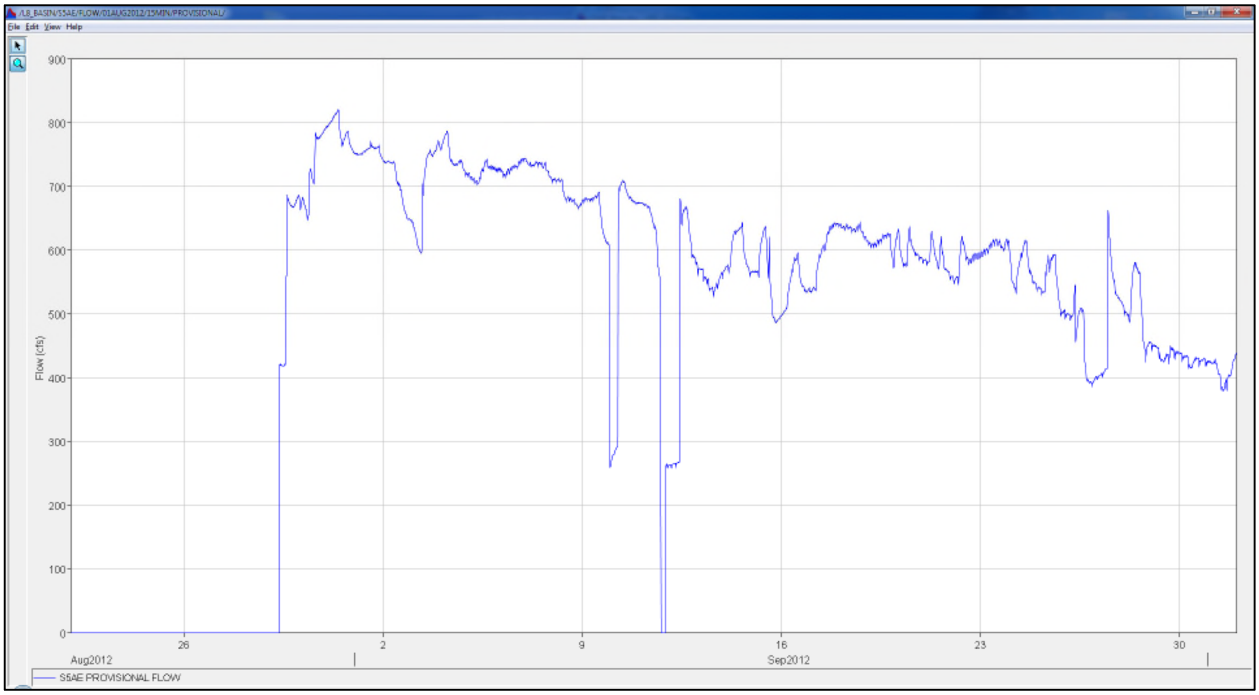

Figure 51. Flow Hydrograph at Structure S-5AE

3.6.1.3 LATERAL INFLOW HYDROGRAPH

The lateral inflow hydrograph is an internal boundary condition in the HEC-RAS model that represent lateral flow contributions or diversions along a canal. Lateral flows can represent seepage flows, overland flow from adjacent sub-basins or discharges from areas not included explicitly in the model.

In the C-51 HEC-RAS model, seepage flow estimates are entered at several locations along the canal. Seepage estimates can be established from other studies or observations but in this study they corresponds to the estimates and locations used in the 2004 HEC-RAS version.

Surface runoff contributions from adjacent sub-basins to the C-51-Canal are computed in the HEC-HMS model and entered into the storage basins in HEC-RAS as time series of runoff for routing to the C-51 Canal through the sub-basins outlet structures. **Figure 52** is an example of a runoff hydrographs generated with HEC-HMS for Sub-basin 13.

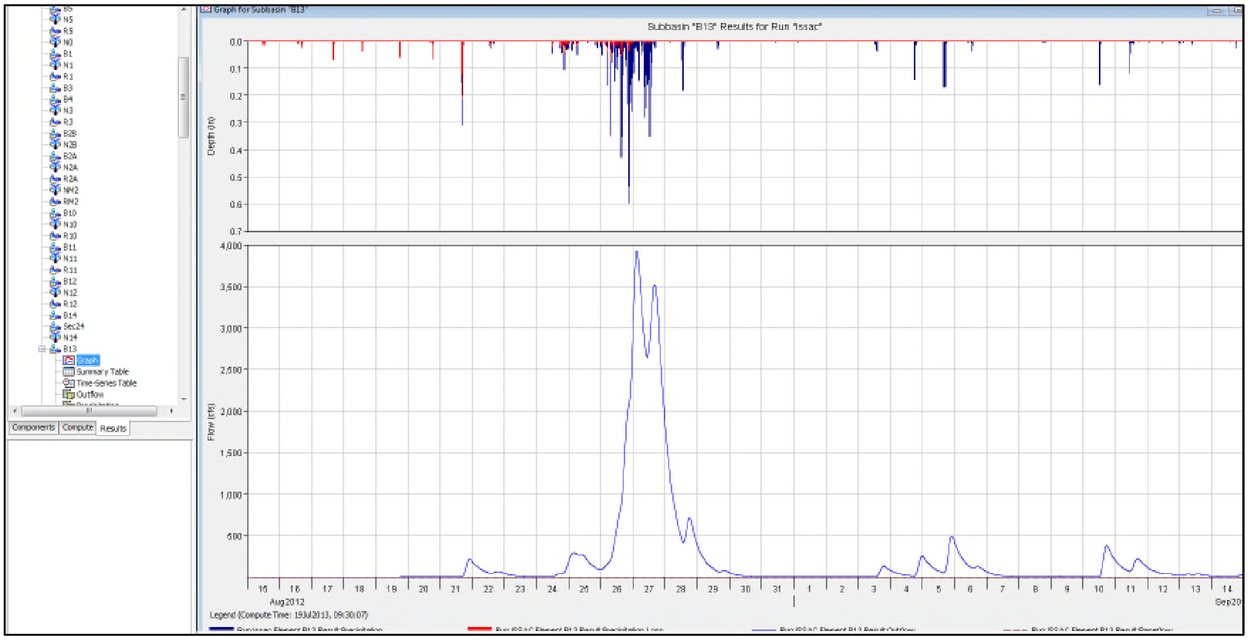

Figure 52. Runoff Hydrograph for Sub-basin 13

3.6.1.4 ELEVATION CONTROLLED GATES AND TIME SERIES OF GATE OPENINGS

Another type of internal boundary conditions in HEC-RAS is observed time series of gate openings or flows for an in-line structure that is not explicitly computed by the model. In the C-51 HEC-RAS model, flows through the S-155 and S-155A spillway structures are computed using 15-minute time series of observed gate openings during the period of calibration. Since each of these structures have multiple gates that are operated independently of each other, time series of gate openings are imposed in the model at the location of the structures for each of the gates. With this data, the model computes the flows through each of the gates using one of the standard USACOE spillway equations or a “User Defined” flow equation for the structure.

Alternatively, flow through a structure in HEC-RAS can be computed using a different type of internal boundary condition at a structure called the “Elevation Controlled Gate”. This boundary condition computes the gate opening based on a stage-based rule that described how the gates are opened or closed according to the HW elevation, TW elevation or head differential across the structure. **Figure 53** is an example of an Elevation Controlled Gate rule for lateral structure S11. **Figure 54** is the history of gate opening observed at structure S-155.

In this version of the calibration C-51 HEC-RAS model, several important revisions to the previous model (October, 2013) helped improve the calibration, particularly in the C-51 West Canal where previous computed stages at the peak of the storm event were severely under estimated. The changes to the mode were described in Section 2.8 of this report

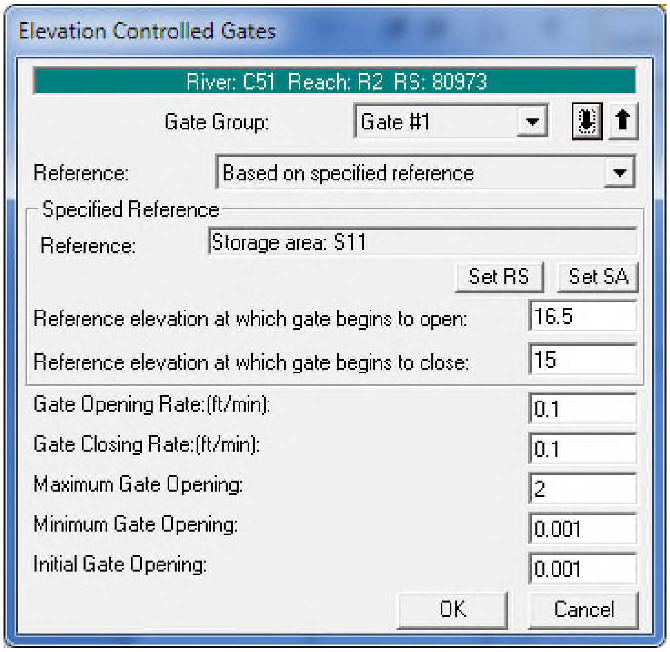

Figure 53. Elevation Controlled Gate Rule for Sub-basin 11

Figure 54. Observed Gate Openings for Structure S-155 during Tropical Storm Isaac

3.6.1.5 USER DEFINED RULES

User defined flow equations can be entered in HEC-RAS to override the standard gate or spillway flow equations in HEC-RAS. In the C-51 HEC-RAS model, the District latest flow rating equations were entered as user defined rules for the S-155 and S-155A spillways. These rating flow equations have been developed for most of the District structures and are used to generate flows in the DBHYDRO database. For structures S-155 and S-155A, the District's flow rating equations were used to compute the flow through the structures given the observed gate openings during TS Isaac. **Figure 55** shows, as an example, the user defined rules for operation of the Section 24 impoundment's gates.

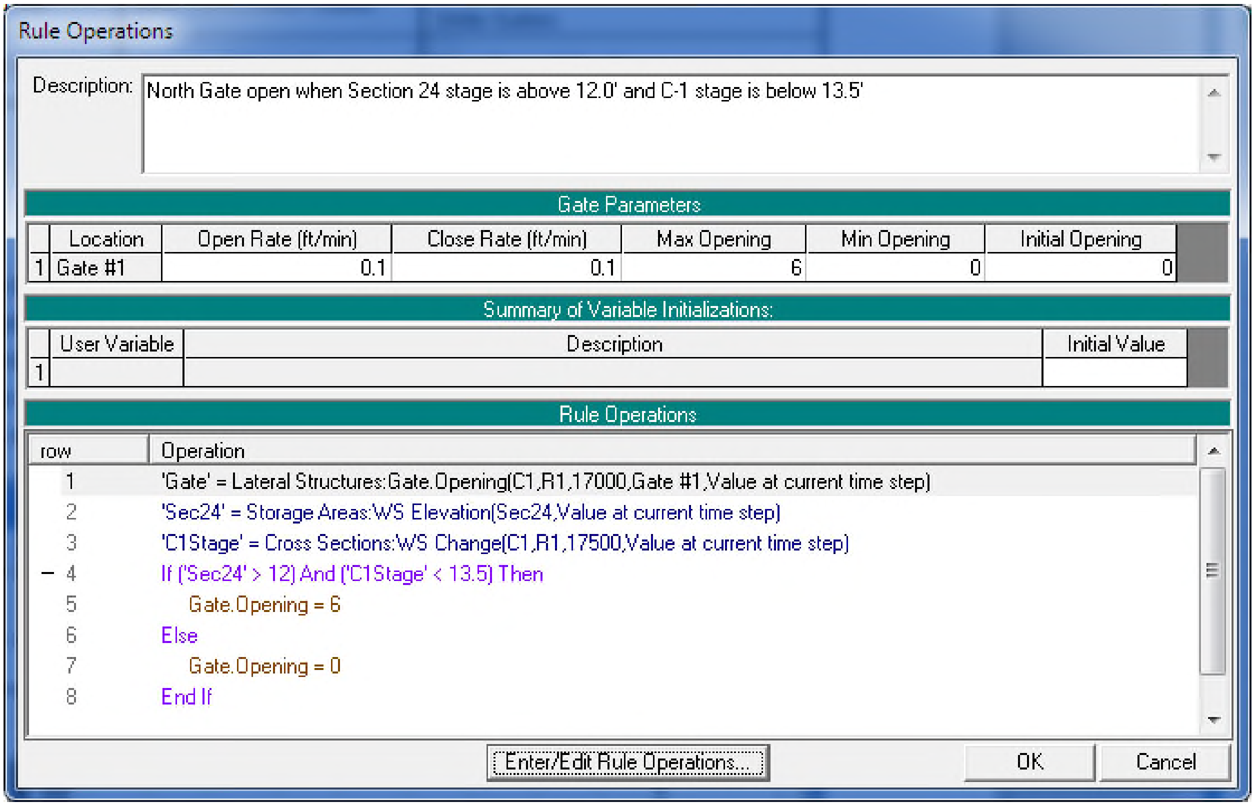

Figure 55. User Defined Rules for ACME-Basin B Section 24 Impoundment Structure

In the calibration of the HEC-RAS model, all three types of boundary conditions were used. For structure S-155, the User Define Rule with imposed gate openings was replaced with the Elevation Controlled Gates type of boundary condition while at the S-155A structure, the User Define Rule with imposed gate openings gave the best results. **Table 10** summarizes the boundary conditions used on the C-51 HEC-RAS model used for calibration.

Table 10. C-51 HEC-RAS Boundary Conditions for Initial Calibration of TS Isaac

River	Reach	River Station	Boundary Condition Type	Description
C1	R1	18250 LS	Elev. Controlled Gates	Gate operation triggers
	R1	17000 LS	Rules	Gate operation for Sect 24 inflow
C51	R1	109730	Flow hydrograph	Flow release estimate from STA1E = 300 cfs
	R2	88526 LS	Elev. Controlled Gates	S11 Gate "A" lateral structure
	R2	86136	Lateral Inflow Hydr.	Zero seepage for calibration run
	R2	80973 LS	Elev. Controlled Gates	S11-Gate "D" (1-12' radial gate & 2-7' slide gates open)
	R2	72778 LS	Elev. Controlled Gates	S11-Gate "G", 1-6' wide Slide gate, top @18'
	R2	72605.1 LS	Rules	S13 bleeder gate operations
	R3	57700 IS	Rules	S-155A spillway
	R6	45825 LS	Elev. Controlled Gates	S38 gate operations
	R7	28070 LS	Elev. Controlled Gates	S25A (PBIA-1) gate operations
	R11	720 IS	Elev. Controlled Gates	S-155 Spillway
	R11	0.00	Stage hydrograph	C-51 Canal tidal end
E1N	RE1N	5185	Flow hydrograph	Baseflow of 20 cfs
E1S	RE1S	51128	Flow hydrograph	Baseflow of 30 cfs
	RE1S	150 LS	Elev. Controlled Gates	LWDD CS #2: 2-12' radial gates
E2N	RE2N	10459	Flow hydrograph	Baseflow of 20 cfs
E2S	RE2S	20300	Flow hydrograph	Baseflow of 20 cfs
E2S	RE2S	170 LS	Elev. Controlled Gates	LWDD CS #4: 2-12' radial gates
E3N	RE3N	10629	Flow hydrograph	Baseflow of 20 cfs
E3S	RE3S	20000	Flow hydrograph	Baseflow of 25 cfs
E3S	RE3S	75 LS	Elev. Controlled Gates	LWDD CS #6 - 3-12' radial gates
E4	RE4	12005	Flow hydrograph	Baseflow of 20 cfs
L10	RL10	11653	Flow hydrograph	Baseflow of 20 cfs
L5	RL5	8900	Flow hydrograph	Baseflow of 20 cfs
L7	RL7	10030	Flow hydrograph	Baseflow of 20 cfs
L8	RL8	11971	Flow hydrograph	Baseflow of 20 cfs
M1	RM1	21173	Flow hydrograph	M-1 canal base flow of 10 cfs
M1	RM1	20073 LS	Elev. Controlled Gates	S15B to M1 Canal structure at 40th St sluice gate
M1	RM1	775 IS	Elev. Controlled Gates	Amil Gate at M-1 canal River Station 01+00
M2	RM2	20100	Flow hydrograph	Baseflow of 20 cfs
M2	RM2	15788	Elev. Controlled Gates	S7 to M-2 Canal through2- 6' wide slide gates
Stub Canal	RSC	16726	Flow hydrograph	Baseflow of 20 cfs

Notes:

LS= Lateral structure
IS = In-line structure

3.6.2 INITIAL CONDITIONS

In addition to boundary conditions, initial water levels and flows were specified throughout the canal system and in the storage areas connected to the canals. The initial canal reach inflows for the new baseline runs summarized in **Table 11** along the C-51 canal were taken from the 2004. Initial stage elevations were also taken from the 2004 with exception of Sub-basins 13 and 14 (ACME basins A and B) whose initial stages were set at their corresponding control elevation and sub-basin 38 which had to be adjusted due to instability in the model. The model initial sub-basins elevations are summarized in **Table 12**.

Table 11. Initial Canal Flows for HEC-RAS Model Calibration

River	Reach	River Station	Initial Flow (cfs)
C1	R1	20000	10
C51	R1	109730	300
	R2	92708	300
	R2	93049	300
	R3	67607	300
	R4	57302	100
	R5	56384	100
	R6	48108	200
	R7	33441	200
	R8	14723	200
	R9	13784	200
	R10	9168	200
	R10	9138	200
	R11	6281	200
E1N	RE1N	5185	20
E1S	RE1S	51128	30
E2N	RE2N	10459	20
E2S	RE2S	20300	20
E3N	RE3N	10629	20
E3S	RE3S	20000	25
E4	RE4	12005	20
	RE4b	6663	40
L10	RL10	11653	20
L5	RL5	8900	20
L7	RL7	10030	20
L8	RL8	11971	20
M1	RM1	21173	10
M2	RM2	21100	20
Stub Canal	RSC	16726	20

Table 12. Initial Sub-basin Stages for HEC-RAS model Calibration Run

C-51 West		C-51 East	
Sub-basin ID	Initial Stage ft NGVD	Sub-basin ID	Initial Stage ft NGVD
1	8.5	17	8.5
2A	11.0	18	8.5
2B	10.0	20A	9.5
3	11.5	20B	13.0
4	11.5	21A	14.5
5	11.0	21B	14.5
6	14.0	22	13.0
7	13.5	23	8.5
8	16.0	24	13.0
9	13.5	25A	8.5
10	15.0	25B	9.5
11	14.5	26	10.0
12	12.5	27	10.0
13	11.0	28	7.5
14	12.0	29A	8.0
15A	12.5	29B	10.0
15B	14.5	30	8.0
16A	12.5	31	8.0
16B-1	17.5	32	8.0
16B-2	18.0	33	8.0
16B-3	16.5	34	8.5
Sec24	12.0	35	8.0
		36	7.0
		37	7.5
		38	12.0
		39	8.0

3.7 CALIBRATION METHODOLOGY

The calibration processes for the C-51 HEC-HMS and HEC-RAS models was performed manually by adjusting the value of calibration parameters that reduced the error between the computed and observed stage and flow values at the calibration locations described in the previous section. Given the model setup and available data sets, several important facts about the C-51 model calibration were brought to light:

a) One of the most significant deficiencies of the C-51 HEC-RAS model is the lack of lateral inflow data for calibration. The response of the C-51 Canal to hydrologic stresses is highly dependent on the timing and magnitude of lateral inflows from the contributing sub-basins. The adjustment of CN's in HEC-HMS is only guided by the response of the HEC-RAS model in the C-51 Canal at two locations: structures S-155A and S-155. The calibration of individual sub-basin flows and stages cannot be adequately done without data for the sub-basins. Of the 45 sub-basins in the model only four (ACME and ITID sub-basins) had some form of stage and flow data that could be used for model calibration.

b) The HEC-RAS model tends to become unstable relative to the operations of the S-319 pump station. This instability is due in part to the relatively large capacity of the pump station within a very narrow range of water levels. Pumping can increase from zero to full capacity (3,980 cfs) with only a rise of 0.4 foot in the C-51 canal at the HW side of the pump.

c) The location of the water levels that trigger the operation of the S-319 pump is not at the pump but several miles downstream, at the S-155A structure. Without local control of water levels in the model at the location of the pump (i.e., reduction of pumpage), large drawdowns can result in the C-51 canal where the pump diverts the water into the STA1E. During TS Isaac, the District operated the pump based on the water levels at the HW of the pump which is also reflected in the HEC-RAS model calibration.

d) Flow diversions from LWDD sub-basins 20B, 22 and 24 prior and during the storm event were significant and could only be approximated during the calibration process by observing the effect of these out of basin withdrawals on the stages east of the S-155A structure and on the headwater side of the S-155 structure. The total runoff from each of these three sub-basins (computed by the HEC-HMS model) were reduced by a fraction when imposed as a flow boundary condition in the HEC-RAS model during the calibration process.

3.7.1 CALIBRATION TARGETS

The evaluation of performance of a simulation model is typically carried out and reported through comparisons of simulated and observed water levels and flows. Error statistics and efficiency criteria can be used to provide an objective assessment of goodness of fit of the simulated behavior to the observed data. The metrics and criteria used for the calibration of the C-51 models are discussed next.

3.7.2 CALIBRATION METRICS

Error bias is used as a metric to indicate the presence of systematic error in a process. This error causes all computed values to deviate from the measured values by a consistent amount and in a consistent direction (higher or lower than). The bias is calculated as:

$$bias = \frac{\sum_{i=1}^{n} \left(\hat{x}_i - x_i \right)}{n} \qquad -\infty \le bias \le \infty$$

where:

n	=	number of data points
x_i	=	observed data point
$\hat{x}_i$	=	simulated data point

Root mean squared error (RMSE) is a statistic that represents the fit standard error. A RMSE value closer to 0 indicates a better fit. The formula for RMSE is:

$$rmse = \sqrt{\frac{\sum_{i=1}^{n} \left(\hat{x}_i - x_i \right)^2}{n-1}} \qquad 0 \le rmse \le \infty$$

R-square is a statistic that measures how successful the fit is in explaining the variation of the data. Put another way, R-square is the square of the correlation between the response values and the predicted response values. It is also known as the coefficient of determination or the square of the correlation coefficient. Values of R greater than 0.7 indicate good correlation between the model computed and the observed values.

$$R^2 = \left[\frac{\sum_{i=1}^{n} (x_i - x_m)(\hat{x}_i - \hat{x}_m)}{\sqrt{\sum_{i=1}^{n} (x_i - x_m)^2 \sum_{i=1}^{n} (\hat{x}_i - \hat{x}_m)^2}} \right]^2 \qquad 0 \le R^2 \le 1$$

where:

x_m	=	mean of observed data points
$\hat{x}_m$	=	mean of simulated data points

In this calibration exercise, all the data points were considered with equal weight. Automatic calibration algorithms allow higher weights for relevant observations, such at the peak of the storm. A total of 1,245 15-minute observations at each calibration location were used to calculate the calibration fit statistics.

3.7.3 CALIBRATION CRITERIA

Water level and flow tolerances for an acceptable model calibration are established prior to the calibration process as a guideline for a successful calibration. These criteria are typically based on the quantity and quality of the observation data as well as the ultimate purpose of the calibrated model. Previous model calibration exercises can provide guidelines as to the magnitude of the error tolerances in the C-51 basin. For the Glades-LECSA regional model (SFWMD, undated draft) a bias value within ±1.0-foot and an RMSE value less than 2.0 feet were applied at all observation locations were the criteria for long term calibration performance.

The 2004 C-51 HEC-HMS and HEC-RAS models were calibrated for a single storm event and to a single value of peak stage and flow at four gauge locations: S-5AE, C51WEL, C51SR7 and S-155-H. In the calibration of the 2004 model for the storm of October 16, 1999 (Hurricane Irene), the errors in peak stage were 0.0, 0.02, 0.23 and -1.23 feet respectively at these locations and a 10 cfs error in peak flow at structure S-155.

In this model calibration exercise, error tolerance for bias and RMSE of ±1.0 and 1.0 feet respectively were used for stages at monitoring sites S-5AE-TW, S-319-HW, S-155AHW, S-155A-TW and S-155-HW. The tolerance for error in flows was set at ±10% of the design flow for bias and 10% of the design flow for RMSE. **Table 13** summarizes the proposed calibration error criteria for flow and stages in the C-51 HEC-RAS model.

Table 13. Stage and Flow Error Tolerances for Calibration

	Stage		Flow	
	Bias (ft)	**RMSE (ft)**	**Bias (cfs)**	**RMSE (cfs)**
S-5AE TW	±1.0	±1.0	-	-
S-319 HW			-	-
S-155A HW, TW			±155	155
S-155 HW			±488	488

3.8 SIMULATED VS. OBSERVED PEAK STAGE AND FLOW COMPARISON

Prior to adjusting model parameters in the C-51 HEC-HMS and HEC-RAS models, attention was focused on capturing the state of the system both prior to and during the TS Isaac event of late August, 2012. Several significant changes to the pre-calibration version of the models were made to reflect actual stage and flow conditions during the storm event. Among the most significant changes to the models were the following:

- Replaced the runoff peaking factors in HEC-HMS for all sub-basins by switching to the Delmarva unit hydrograph method in HEC-HMS.

- Reduction of the runoff from the LLWD E-1 Canal to the C-51 canal pre-storm operations by the drainage district. LWDD lowered canal levels by discharging to tide via the C-15 and C-16 canals to the south. Reduction in runoff ranging from 50% to 80% in sub-basins 20B, 21A and 21B were applied to the inflow hydrograph from HEC-HMS into the HEC-RAS model during calibration.

- Loxahatchee Groves Water Control District (LGWCD) and other special drainage districts in the western portion of the basin also lowered water levels by discharging to the C-51 canal prior to the storm event. Although no data was available to account for the magnitude of these releases, gates operations at the outlet structures were adjusted to account for these releases in the calibration version of the model.

- Adjustment to channel roughness coefficients during calibration varied between 0.05 and 0.02.

Table 14 summarizes the calibration error statistics for stages at the five observation sites where data was available. Similarly, **Table 15** shows the calibration error statistics at the two sites where flow data was available.

Table 14 indicates that error biases were below the 1.0 foot tolerance for all sites. The largest positive bias of 0.41 ft corresponds to the TW stage at structure S-5AE and smallest bias of 0.15 ft corresponds to S-155A-HW. The RMSE criterion was acceptable at all locations with values of 0.98, 0.85, 0.85, 0.83 and 0.43 ft for sites S-5AE-TW, S-319-HW, S-155A-HW, S-155A-TW and S-155-HW, respectively. Errors in model response from instabilities induced by the pumpage of S-319 are likely the cause of the high RMSE at S-5AE-TW and S-319-HW and errors in the runoff response from LWDD entering the C-51 canal on the TW side of the S-155A structure are likely the cause of the high RMSE at S-155A-TW.

Table 15 also shows a high RMSE value of 274 cfs for flows computed at structure S-155A, above the 10% tolerance of 155 cfs. Again, the error caused by the higher than observed TW elevations at the divide structure translates to errors in the computed flows. At structure S-155, the bias and RMSE were below the tolerance limits and the correlation coefficients for flows at both structures were above 0.7.

Table 14. Stage Error Statistics for Model Calibration - TS Isaac (Aug 24 – Sep 5, 2012)

	Stage			
	Bias (ft)	RMSE (ft)	R^2	R
S-5AE TW	0.41	0.98	0.11	0.33
S-319 HW	0.23	0.85	0.28	0.53
S-155A HW	0.15	0.85	0.85	0.92
S-155A TW	0.53	0.83	0.83	0.91
S-155 HW	0.20	0.43	0.61	0.78

Table 15. Flow Error Statistics for Model Calibration - TS Isaac (Aug 24 – Sep 5, 2012)

	Flow			
	Bias (cfs)	RMSE (cfs)	R^2	R
S-155	58	389	0.93	0.96
S-155A	-163	274	0.80	0.89

Error statistics for peak stages and flows are summarized in **Tables 16 and 17**. These maximum values are presented to compare the goodness of fit of the current calibration against the values obtained in the 2004 calibration of the C-51 models for Hurricane Irene (October, 1999). The 2004 model calibration had corresponding observation sites at S-155-HW and S-5AE-TW. In the 2004 models the calibration for Hurricane Irene did not include the S-155A and S-319 structures which did not exist in 1999. The peak stage statistics at S-155-HW were 2.5% which is less than the 11.3% difference of the 2004 calibration. At structure S-155A, the simulated peak HW stage of 16.71 ft NGVD closely matched the observed peak value of 16.25 ft NGVD and on the TW side of the structure, the computed peak stage value of 13.42 ft NGVD was 0.15 feet above the observed peak stage value of 13.27 ft NGVD. At structure S-5AE-TW the peak stage percent difference was -3.2%, below the 0% in the 2004 model calibration.

Table 16. Error Statistics for Peak Stages - TS Isaac (Calibration Period: Aug 24 – Sep 5, 2012)

Location	Reach Name	River Station	Peak Flow (cfs)			Time to Peak		
			Measured	Simulated	Diff (%)	Measured	Simulated	Difference
S-155	R11	750	5718	5608	-2.0	8/27 18:15	8/27 07:00	-11.75
S-155A	R3	57830	1609	1547	-3.8	8/29 12:15	8/29 12:15	0.00

Table 17. Error Statistics for Peak Flows - TS Isaac (Calibration Period: Aug 24 – Sep 5, 2012)

Location	Reach Name	River Station	Peak Stage (ft NGVD)			Time to Peak		
			Measured	Simulated	Difference	Measured	Simulated	Difference
S-155-HW	R11	750	9.42	9.66	2.5	8/27 17:45	8/27 22:45	5.0
S-155A-TW	R3	57630	13.27	13.42	<0.1	8/27 17:15	8/27 15:15	2.0
S-155A-HW	R3	57830	16.25	16.71	2.8	8/27 18:00	8/28 07:45	13.8
S-319-HW	R1	97736	14.62	14.15	-3.2	8/27 18:15	8/28 06:30	12.3
S-5AE-TW	R1	109730	14.59	14.23	-2.5	8/27 18:30	8/28 06:30	12.0

The computed peak flow of 5,608 cfs at structure S-155 was 110 cfs lower than the observed value, resulting in a -2.0 % difference. This is slightly higher than the 0.13% difference in the 2004 calibration. Similarly, at structure S-155A a percent difference of -3.8% resulted, which is below the calibration tolerance of 10%. The above comparison of peak stage and flow errors in calibration indicate similar performance for the 2004 and the updated models in computing peak stage and flow at the S-155 structure. At structure S-155A, additional work is recommended to decrease errors in stages and flows, however, in order to accomplish this, additional data is necessary to adjust runoff timing from lateral contributor sub-basins into the C-51 West and East Canals.

Graphics showing the comparison between the computed and observed stages and flows are presented in **Figures 56 through 62**. **Figures 56 and 57** show the computed and simulated HW stages and flows at tidal structure S-155. Simulating the gate operation based on the open-closed triggers for flood control operations resulted in an improved fit of HW stages throughout the event, including the pre-storm drawdown on August 24.

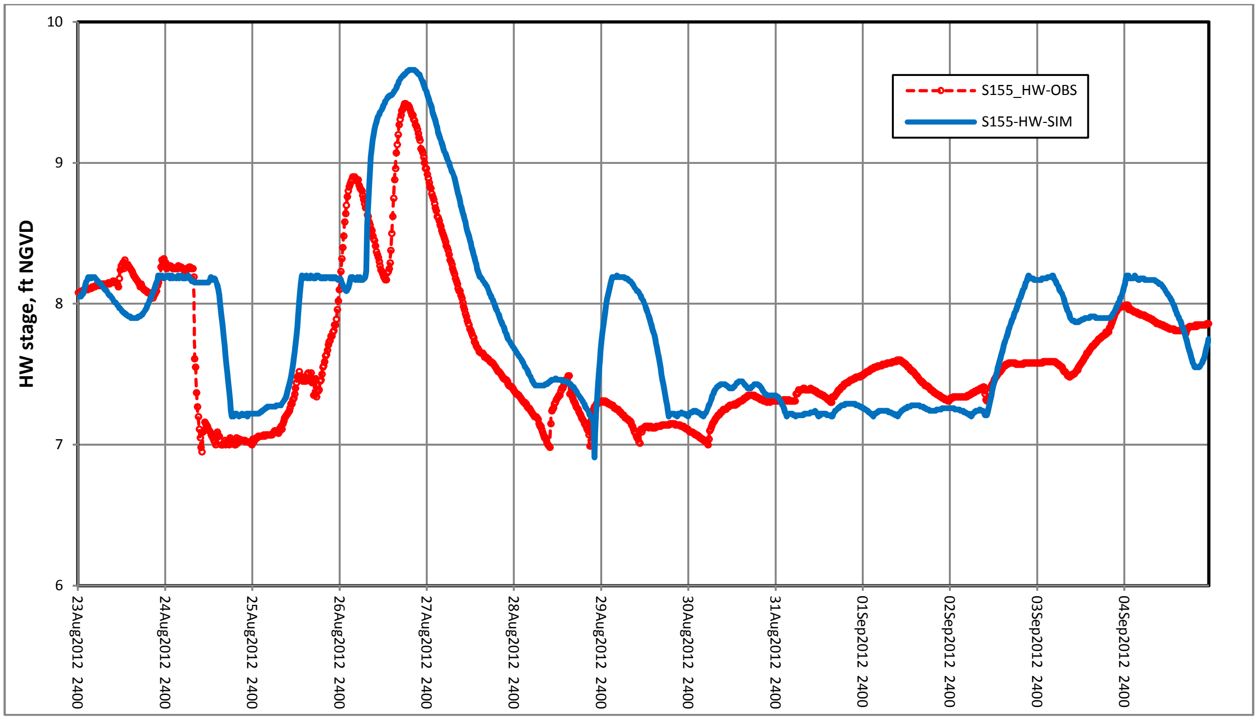

Figure 56. Computed and Observed HW Stage at Structure S-155 for Calibration of TS Isaac (Calibration Period: Aug 24- Sep 5, 2012)

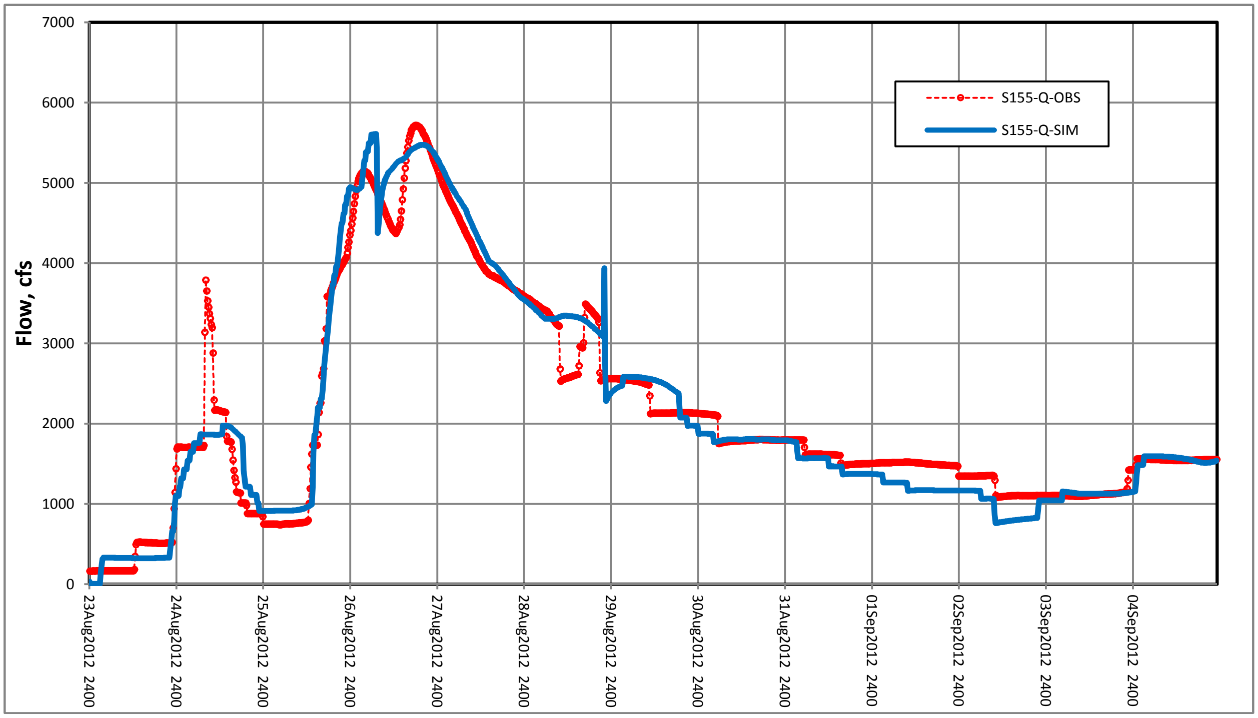

Figure 57. Computed and Observed Flows at Structure S-155 for Calibration of TS Isaac (Calibration Period: Aug 24- Sep 5, 2012)

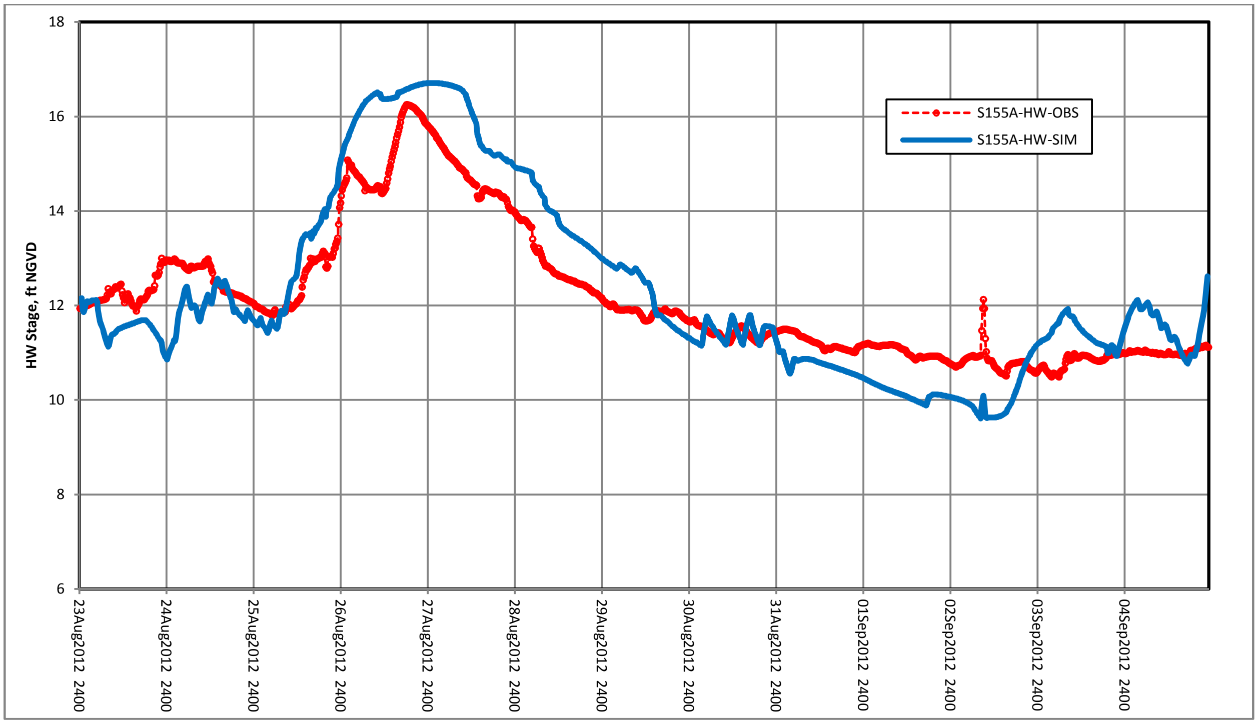

Figure 58. Computed and Observed HW Stage at Structure S-155A for Calibration of TS Isaac (Calibration Period: Aug 24- Sep 5, 2012)

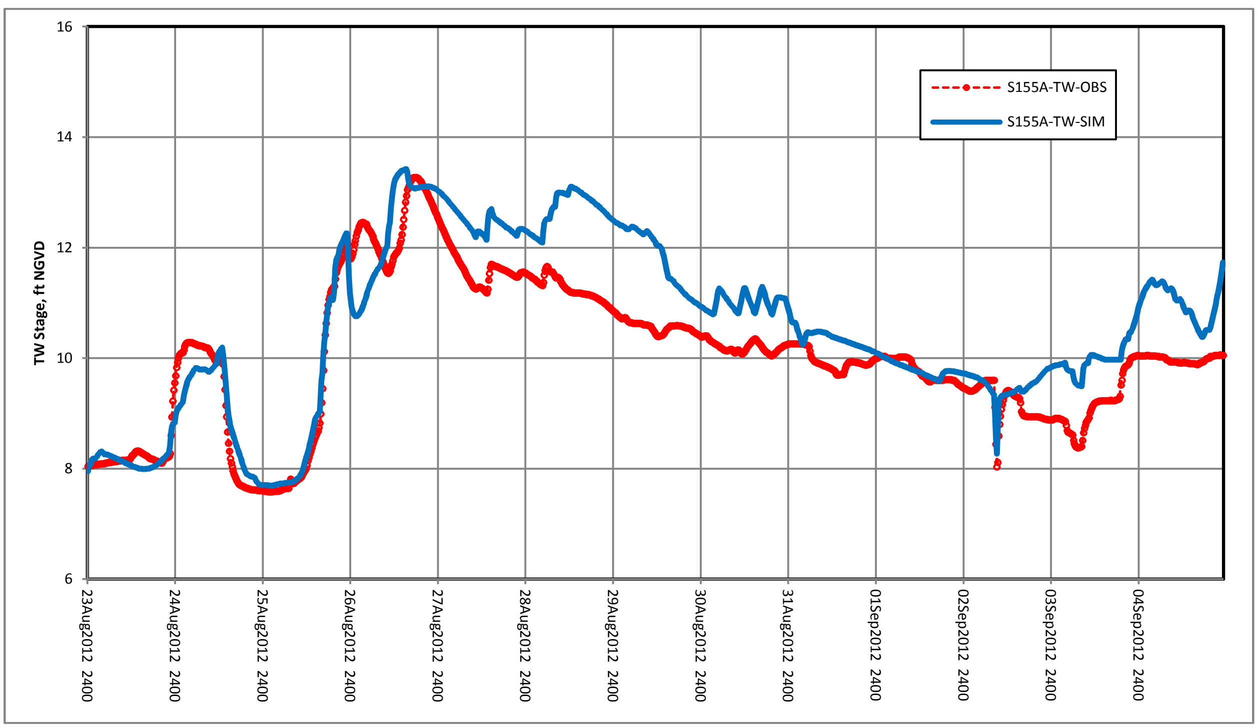

Figure 59. Computed and Observed TW Stage at Structure S-155A for Calibration of TS Isaac (Calibration Period: Aug 24- Sep 5, 2012)

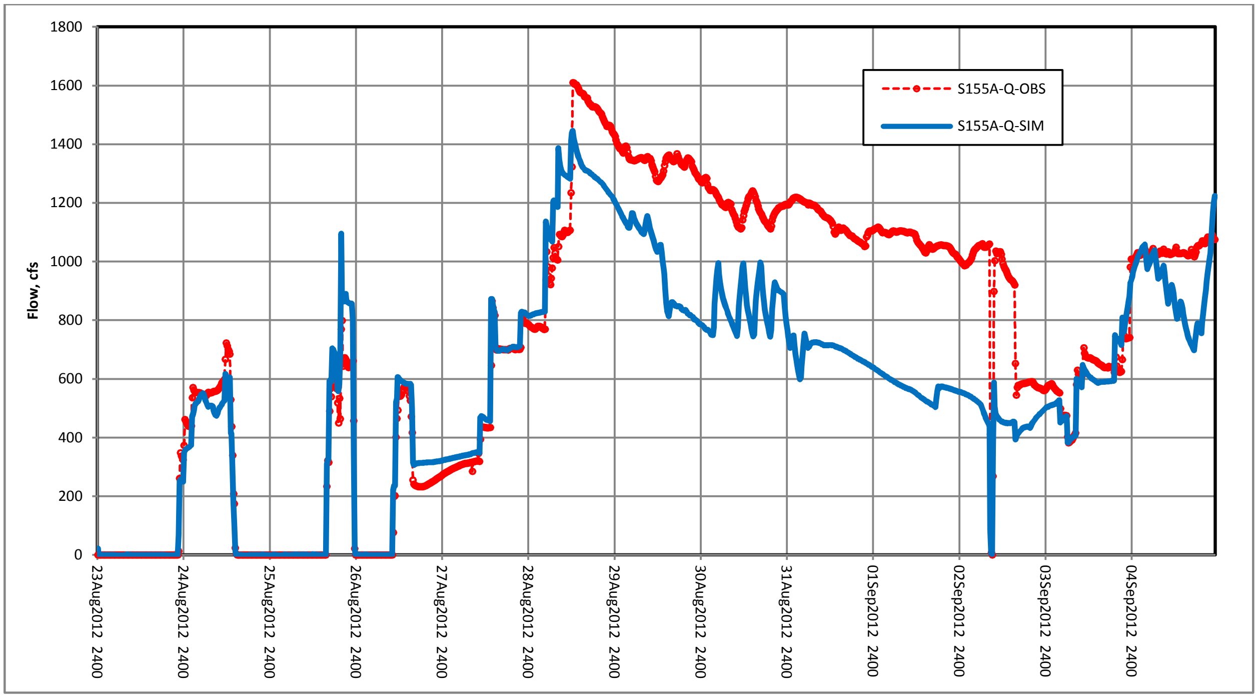

Figure 60. Computed and Observed Flows at Structure S-155A for Calibration of TS Isaac (Calibration Period: Aug 24- Sep 5, 2012)

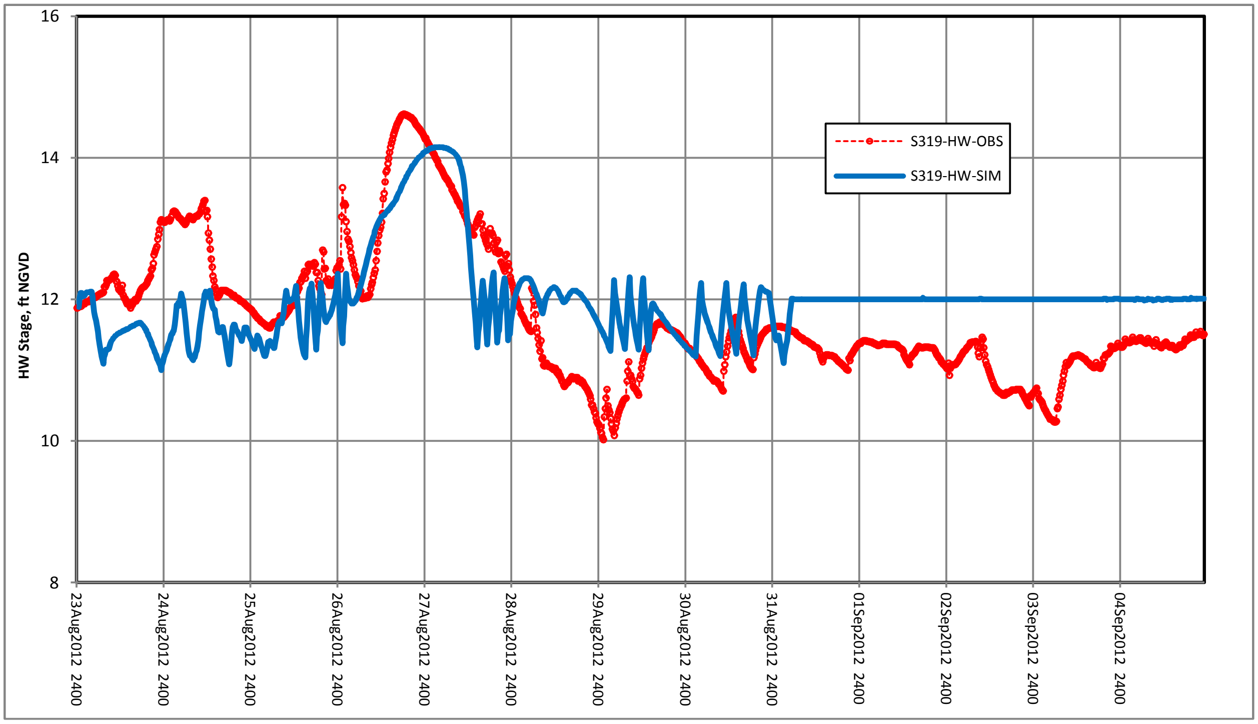

Figure 61. Computed and Observed HW Stage at Structure S-319 for Calibration of TS Isaac (Calibration Period: Aug 24- Sep 5, 2012)

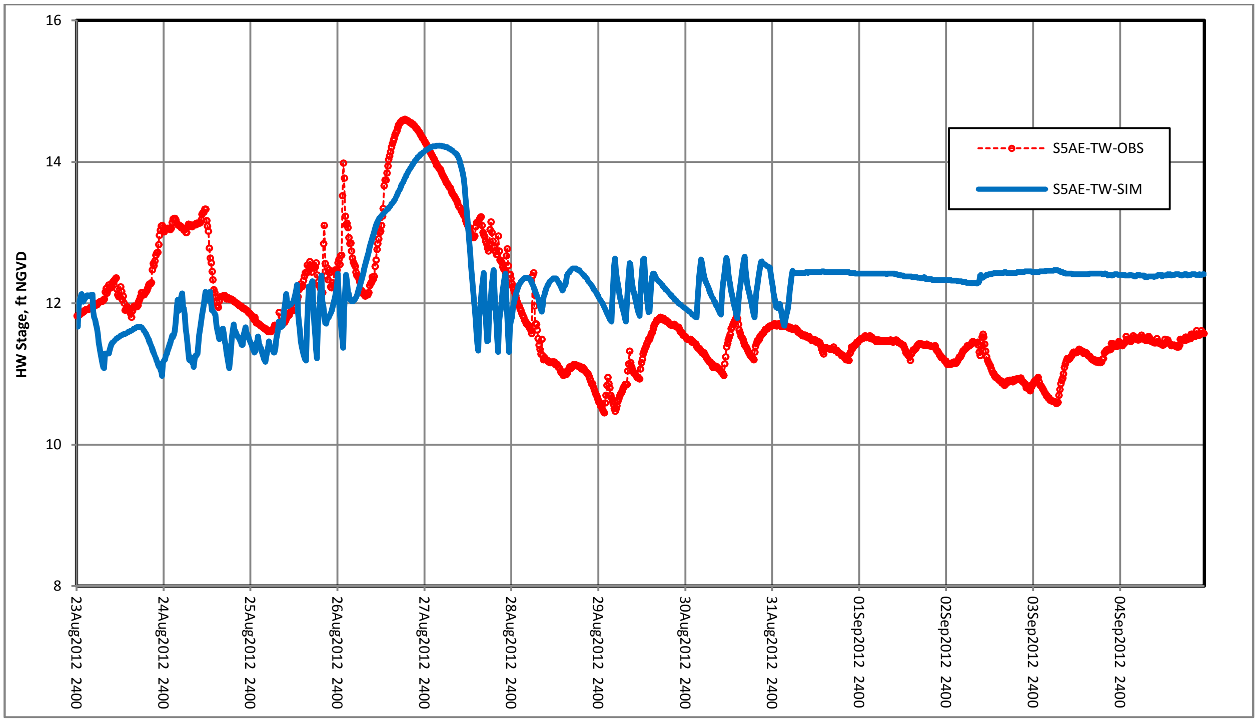

Figure 62. Computed and Observed TW Stage at Structure S-5AE for Calibration of Tropical Storm Isaac (Calibration Period: Aug 24- Sep 5, 2012)

Modeled and simulated stages were also compared at three other locations in the model where stage and flow data from ACME and ITID were available during TS Isaac. At ACME Structure CS No. 44 located at Pierson Road, the recorded TW stages were used to compare the simulated values for sub-basin 13. **Figure 63** shows the comparison which indicates computed and observed peak values of 16.13 ft NGVD and 16.36 ft NGVD, respectively. Similarly, for Sub-basin 14, HW stages at ACME Structure CS No. 45 also located at Pierson Road, were used to compare observed and simulated stages, shown in **Figure 64**. This figure shows computed and observed peak stage values of 16.13 ft NGVD and 16.43 ft NGVD, respectively. At the Section 24 impoundment, the computed and observed stages are presented in **Figure 65**. This figure shows computed and observed peak stages of 16.26 ft NGVD and 15.93 ft NGVD respectively.

The last stage comparison site used in the calibration was the ITID site at 40th Street whose HW observed stages are compared against computed values in **Figure 66**. This calibration location used observed gate openings at the 40th St. Structure which were approximated from ITID telemetry data and District's operating criteria for this structure. The computed peak stage of 20.6 ft NGVD at this site closely matched the observed peak value of 20.4 ft NGVD.

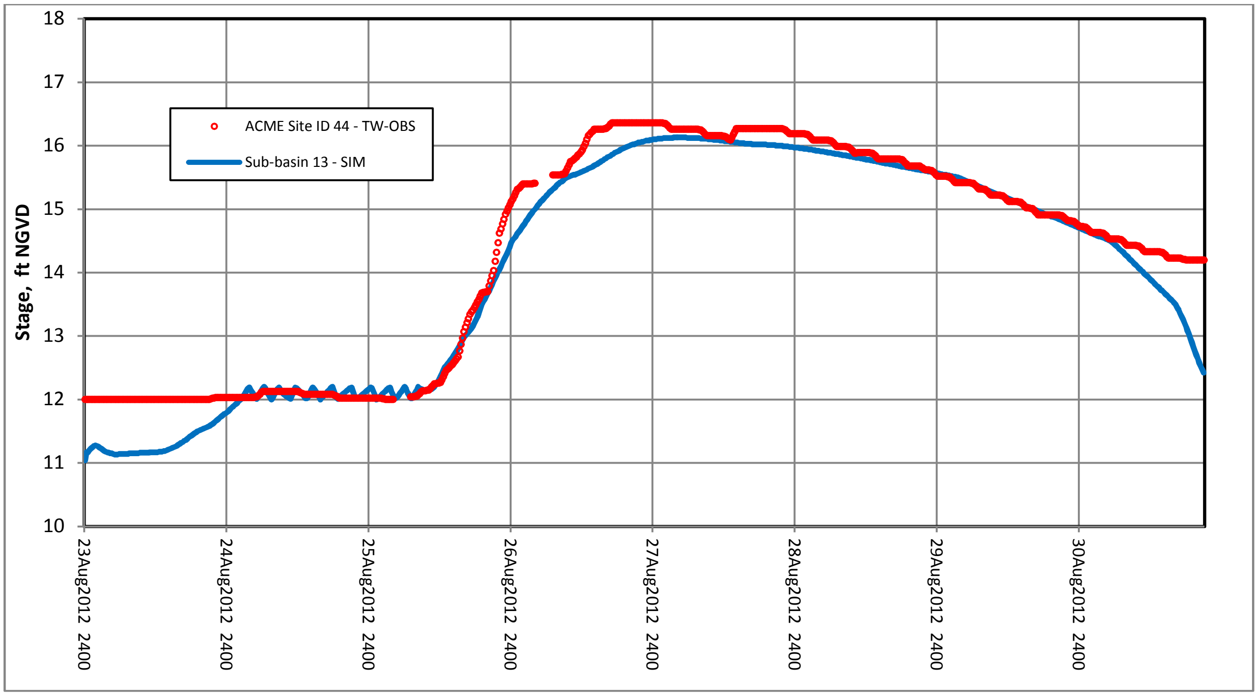

Figure 63. Computed and Observed TW Stage at ACME Site ID 44 (Sub-basin13) for Calibration of TS Isaac (Calibration Period: Aug 24- Sep 5, 2012)

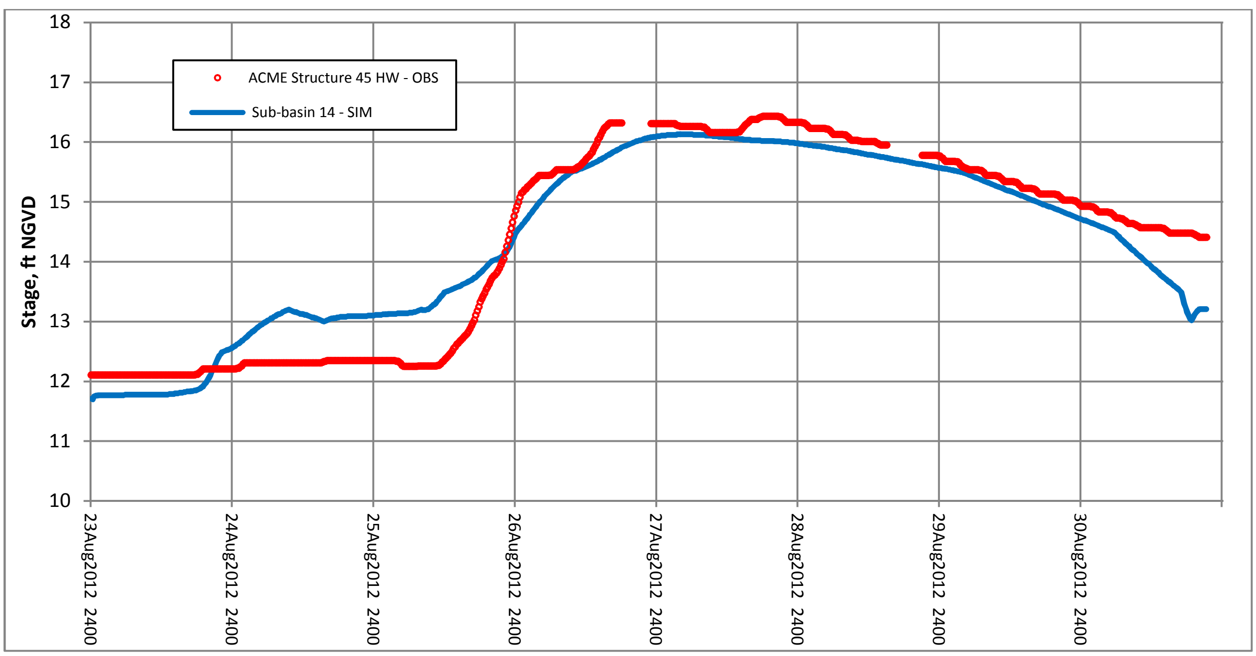

Figure 64. Computed and Observed HW Stage at ACME Site ID 45 (Sub-basin14) for Calibration of TS Isaac (Calibration Period: Aug 24- Sep 5, 2012)

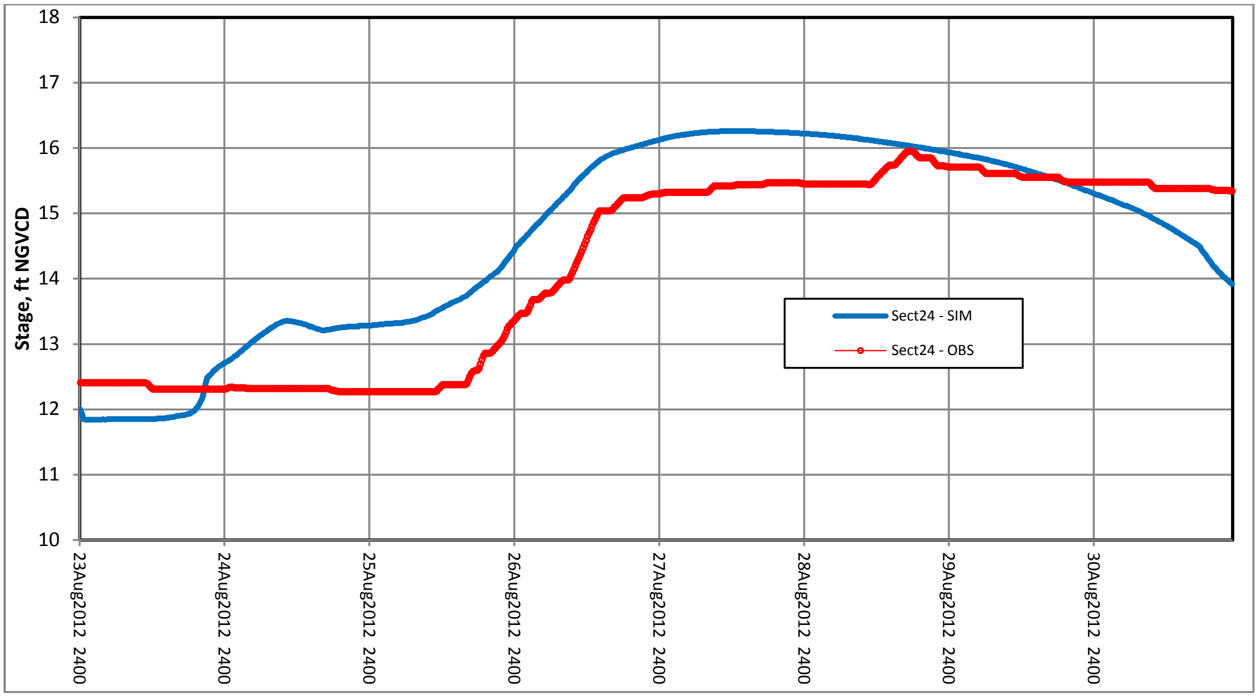

Figure 65. Computed and Observed TW Stage at ACME Section 24 Impoundment for Calibration of TS Isaac (Calibration Period: Aug 24- Sep 5, 2012)

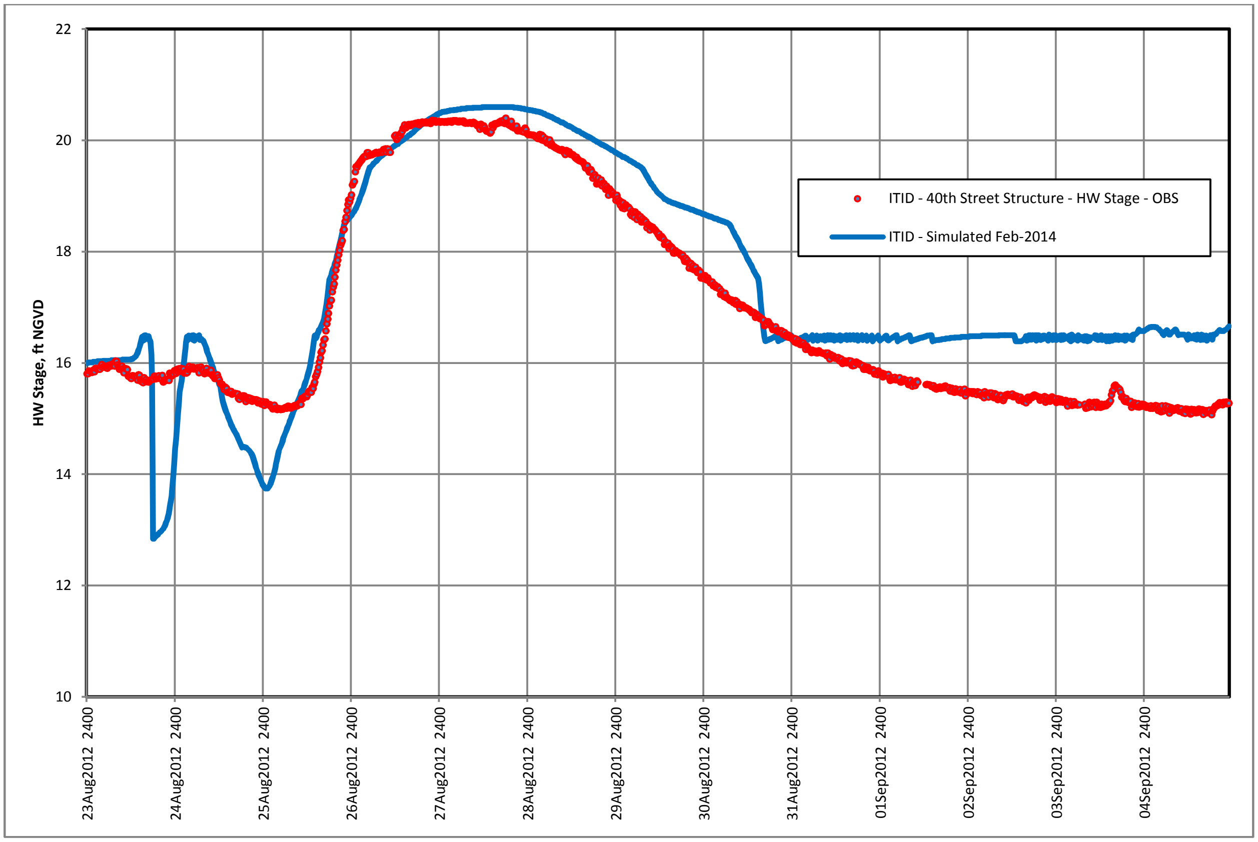

Figure 66. Computed and Observed HW Stage at ITID 40th St. Site (Sub-basin 15B) for Calibration of TS Isaac (Calibration Period: Aug 24- Sep 5, 2012)

3.9 BASIN STORAGE RESULTS

For informational purposes basin storage conditions simulated during the calibration of TS Isaac are summarized in **Table 18**. A similar table was produced in the calibration report of the 2004 HEC-RAS model for Hurricane Irene. This table shows the summary of computed sub-basin runoff volume, peak runoff and time to peak runoff form the HEC-HMS model, as well as the computed peak stage and outflow from the HEC-RAS model. The largest increased discharges between the revised and the 2004 models were in Sub-basins 2A (STA-1E), 13 (ACME Basin A) and 14 (ACME Basin B). The differences are due to the inclusion of the S-319 inflows to Sub-basin 2A and the modification to the drainage regime of ACME, neither of which was completed prior to the release of the 2004 model.

Table 18. C-51 Sub-basin Storage Results from Calibration Run

Sub-basin ID	Results from HEC-HMS Model			Results from HEC-RAS Model			
	Peak Runoff (cfs)	Time to Peak Runoff	Total Runoff Volume (ac-ft)	Peak Stage (ft NGVD)	Time to Peak Stage	Peak Outflow (cfs)	Time to Peak Outflow
1	648	27Aug2012, 13:45	1244	14.75	26Aug2012, 12:00	48	26Aug2012, 13:45
2A	3031	27Aug2012, 17:00	9581	15.62	29Aug2012, 16:45	4200	27Aug2012, 17:00
2B	705	27Aug2012, 13:00	978	14.91	27Aug2012, 20:45	50	26Aug2012, 15:30
3	387	27Aug2012, 13:45	670	16.46	28Aug2012, 01:45	26	24Aug2012, 19:15
4	367	27Aug2012, 14:00	642	17.19	28Aug2012, 02:45	29	24Aug2012, 23:15
5	846	27Aug2012, 13:45	1428	17.92	28Aug2012, 03:00	83	28Aug2012, 01:30
6	602	27Aug2012, 13:15	897	19.70	27Aug2012, 20:15	67	24Aug2012, 14:00
7	2090	27Aug2012, 16:00	5206	20.05	28Aug2012, 01:30	367	28Aug2012, 07:45
8	1929	27Aug2012, 15:15	4868	20.65	28Aug2012, 01:30	436	28Aug2012, 01:05
9	75	27Aug2012, 12:00	88	17.64	28Aug2012, 01:30	48	28Aug2012, 01:30
10	151	27Aug2012, 13:30	278	18.94	27Aug2012, 19:45	47	27Aug2012, 12:45
11	2957	27Aug2012, 16:15	9815	18.79	28Aug2012, 02:30	1424	28Aug2012, 01:30
12	45	26Aug2012, 22:30	67	16.56	28Aug2012, 07:15	25	27Aug2012, 01:15
13	3927	27Aug2012, 02:45	12134	16.13	28Aug2012, 04:30	1252	28Aug2012, 01:30
14	3650	27Aug2012, 01:45	10690	16.13	28Aug2012, 04:45	623	26Aug20, 20:00
15A	1979	27Aug2012, 03:45	6776	17.70	28Aug2012, 01:30	746	27Aug2008, 16:35
15B	2791	27Aug2012, 05:00	10488	20.32	28Aug2012, 03:30	1152	29Aug2012, 15:45
16A	357	27Aug2012, 02:00	866	16.67	28Aug2012, 07:30	275	28Aug2012, 14:30
16B	767	27Aug2012, 06:30	3514	18.80	29Aug2012, 14:45	48	29Aug2012, 14:45
17	588	27Aug2012, 02:15	1510	15.15	27Aug2012, 07:30	280	27Aug2012, 07:45
18	1707	27Aug2012, 02:15	3501	15.32	27Aug2012, 19:15	376	27Aug2012, 15:20
20A	619	27Aug2012, 01:15	1345	16.19	28Aug2012, 21:30	190	29Aug2012, 23:45
20B	1133	27Aug2012, 02:15	2894	15.47	27Aug2012, 08:00	360	27Aug2012, 08:00
21A	1243	27Aug2012, 02:30	4920	17.25	30Aug2012, 24:00	0	--
21B	1804	27Aug2012, 02:15	5821	17.59	29Aug2012, 02:45	148	29Aug2012, 02:00
22	3081	27Aug2012, 03:45	9426	17.01	28Aug2012, 05:45	427	28Aug2012, 04:40
23	1821	27Aug2012, 03:15	5612	16.67	27Aug2012, 21:00	764	27Aug2012, 21:00
24	2472	27Aug2012, 03:30	6716	17.81	27Aug2012, 23:15	582	27Aug2012, 22:30
25A	182	27Aug2012, 01:45	325	13.59	27Aug2012, 04:00	344	27Aug2012, 04:15
25B	491	27Aug2012, 02:00	1025	13.66	27Aug2012, 04:00	270	27Aug2012, 04:30
26	186	27Aug2012, 02:15	399	13.17	27Aug2012, 04:15	107	26Aug2012, 19:00
27	287	27Aug2012, 03:00	812	10.33	27Aug2012, 05:15	213	26Aug2012, 22:00
28	136	27Aug2012, 01:45	246	10.70	27Aug2012, 02:15	118	27Aug2012, 02:00

Table 18. C-51 Sub-basin Storage Results from Calibration Run (Cont.)

Sub-basin ID	Results from HEC-HMS Model			Results from HEC-RAS Model			
	Peak Runoff (cfs)	Time to Peak Runoff	Total Runoff Volume (ac-ft)	Peak Stage (ft NGVD)	Time to Peak Stage	Peak Outflow (cfs)	Time to Peak Outflow
29A	518	27Aug2012, 02:00	1173	13.42	27Aug2012, 05:00	242	27Aug2012, 04:15
29B	142	27Aug2012, 02:15	334	13.42	27Aug2012, 05:00	124	27Aug2012, 02:15
30	576	27Aug2012, 02:00	1162	13.52	27Aug2012, 05:15	186	27Aug2012, 05:35
31	719	27Aug2012, 02:00	1478	12.39	27Aug2012, 03:45	369	27Aug2012, 03:45
32	824	27Aug2012, 02:30	1852	12.36	27Aug2012, 06:45	329	27Aug2012, 06:45
33	1229	27Aug2012, 02:00	2467	13.01	27Aug2012, 07:00	370	27Aug2012, 07:15
34	287	27Aug2012, 02:30	651	14.65	27Aug2012, 06:45	115	27Aug2012, 09:30
35	106	27Aug2012, 01:30	177	10.5	26Aug2012, 17:15	45	26Aug2012, 17:15
36	235	27Aug2012, 02:30	524	12.47	27Aug2012, 05:45	82	27Aug2012, 06:15
37	149	27Aug2012, 02:30	325	15.56	27Aug2012, 04:45	70	26Aug2012, 22:45
38	1155	27Aug2012, 02:00	1155	16.62	27Aug2012, 23:00	148	27Aug2012, 22:20
Sec24	358	27Aug2012, 13:00	452	16.26	28Aug2012, 12:15	524	31Aug2012, 18:30

3.10 CALIBRATED PARAMETERS

As indicated previously, the hydrologic runoff parameters in HEC-HMS, CN and t_l, were not modified as part of the model calibration. The runoff model peaking factors were changed from the standard SCS unit hydrograph to Delmarva unit hydrograph. This change dampened the peak runoff rates of the hydrographs without changing the runoff volumes.

In the HEC-RAS model, the only calibration parameter subject to change was the canal roughness coefficients, mainly in the C51 West Basin, where the largest changes occurred in the three western-most reaches of the main channel where roughness coefficients decreased from 0.05 to 0.035 in reaches R1, R2 and R3. **Table 19** summarizes the pre- and post-calibration values of the canal roughness coefficients by canal reach.

Table 19. Pre- and Post-calibration Canal Roughness Coefficient Values

River	Reach	Pre-calibration Manning's n Value			Post-Calibration Manning's n Value		
		left bank	channel	right bank	left bank	channel	right bank
C1	R1	0.08	0.04	0.08	0.08	0.04	0.08
C51	R1	0.08	0.04	0.08	0.08	0.043	0.08
	R2	0.08	0.04	0.08	0.08	0.043	0.08
	R3	0.08	0.04-0.05	0.08	0.08	0.035	0.08
	R4	0.08	0.05	0.08	0.08	0.048	0.08
	R5	0.08	0.05	0.08	0.08	0.048	0.08
	R6	0.08	0.05	0.08	0.08	0.041	0.08
	R7	0.08	0.05	0.08	0.08	0.041	0.08
	R8	0.08	0.05	0.08	0.08	0.041	0.08
	R9	0.08	0.05	0.08	0.08	0.03 - 0.041	0.08
	R10	0.08	0.05	0.08	0.08	0.03	0.08
	R11	0.08	0.05	0.08	0.08	0.03	0.08
E1N	RE1N	0.08	0.03	0.08	0.08	0.03	0.08
E1S	RE1S	0.08	0.03	0.08	0.08	0.03	0.08
E2N	RE2N	0.08	0.03	0.08	0.08	0.03	0.08
ES2	RES2	0.08	0.03	0.08	0.08	0.03	0.08
E3N	RE3N	0.08	0.03	0.08	0.08	0.03	0.08
E3S	RE3S	0.08	0.03	0.08	0.08	0.03	0.08
E4	RE4	0.08	0.03	0.08	0.08	0.03	0.08
L5	RL5	0.08	0.03	0.08	0.08	0.03	0.08
L7	RL7	0.08	0.03	0.08	0.08	0.03	0.08
L8	RL8	0.08	0.03	0.08	0.08	0.03	0.08
L10	RL10	0.08	0.03	0.08	0.08	0.03	0.08
M1	RM1	0.08	0.03	0.08	0.08	0.03	0.08
M2	RM2	0.08	0.03	0.08	0.08	0.03	0.08
Stub Canal	RSC	0.08	0.03	0.08	0.08	0.03	0.08

3.11 SUMMARY OF CALIBRATION RESULTS

The manually calibrated HEC-RAS model did not completely produce stage and flow biases and RMSE below the pre-established error tolerances at all the calibration canal sites. Stage biases of less than a foot were achieved at all five calibration locations S-5AE TW, S-319 HW, S-155A HW, S-155A TW and S-155 HW. RMSE of less than one-foot were obtained at the main canal structures S155A-TW and S155-HW, but slightly exceeded the one-foot error criteria at the C-51 West Canal gauge locations (S155A-HW, S319-HW and S5AE). The largest errors in computed in the October, 2013 version of the calibrated model stages at locations S319-HW and S5AE-TW that occurred at the peak of the storm event on August 26th, were corrected in this revision of the model by correction to outlet structures into the C-51 Canal, including S8, S11, and M-2 Canal. The resulting calibrated peak stages at S319-HW compare well with observed data resulting in peak stage conditions at this location of 14.7 ft NGVD. This increase in peak stage in the portion of the C-51 West Canal also resulted in reduced discharge for gravity structures including the M-1 Canal and, M-2 Canal.

Computed flows at structures S-155 and S-155A were history matched reasonably well with biases of 58 and -79 cfs, however, structure S-155A had a RMSE of 246 cfs or 91 cfs above the tolerance of 10% of the design flow. Despite negative flow bias at S-155A, the largest error occurred at the peak of the storm event on August 26th when the model over predicted the peak flow largely because of high stages on the HW side of the structure. Overestimated discharges from the special drainage districts located between the S-155 and S-319 structures are the cause of for the high stages in this portion of the canal. The simulated C-51 canal capacity was reduced during and shortly after the peak of the event.

Calibrated peak stage and flow errors favorably compare with errors from the 2004 calibration for Hurricane Irene. Furthermore, peak stages and volumes computed by the model in sub-basins 13 and 14 (ACME) and in sub-basin 15B (ITID) closely replicated observed data indicating that, at least for these three sub-basins, the model predictions of allowable discharge and peak stage are adequate for basin rule application.

4.0 MODEL APPLICATION TO CURRENT BASELINE

4.1 BASIN DESCRIPTION

The C-51 Basin and sub-basin boundaries from the 2004 study have been modified to reflect recent drainage projects but the overall boundaries of the basin remain unchanged covering an area of 114,097 acres bounded to the north by Northlake Boulevard and Grassy Water Preserve, Lake Worth Road to the south, levees L-8 and L-40 to the west and US-1 to the east. This basin area is approximately 100 acres larger than the area of the 2004 basin.

Internally to the basin there are 44 sub-basins of which 24 are in the C-51 East Basin and 20 in the C-51 West Basin as shown in **Figure 66**. Sub-basin 2A which corresponds to the STA-1E is not considered part of the basin but it is included in the model to receive stormwater runoff pumped from the C-51 canal via the S-319 pump. **Table 20** shows the sub-basin areas.

Table 20 indicates that the C-51 West Basin did not change in area from the 2004 condition. Section 24 is a new sub-basin of 401 acres that was part of sub-basin 2B. In the C-51 East Basin, the net change in area was 286 acres that were added from adjustments and corrections to boundaries to sub-basins 23, 25A, 25B, 26, 27, 28, 29A, 29B, 35, 36 and 37.

4.2 STORMWATER CONVEYANCE FEATURES

The stormwater drainage features in the C-51 Basin to be included for basin rule development were identified in the 2004 study and are shown in **Figure 67**. Canals included in the model are the C-51 Canal and several secondary system canals including the M-1 and M-2 Canals in the C-51 West Basin, the Homeland Canal, and Lake Worth Drainage District (LWDD) equalizer/lateral canals E-1, E-2 and E-3 E-4, L-5, L-7, L-8 and L-10 in the C-51 East Basin. Lateral structures discharging from the sub-basins into the canals typically consist of culverts, pumps, fixed weirs and gated structures. A summary of the stormwater conveyance features in the C-51 Basin is shown in **Table 21A** for the C-51 West Basin and **Table 21B** for the C-51 East Basin. Further details of these drainage features as represented in the model are given in **Section 2.6** of this report.

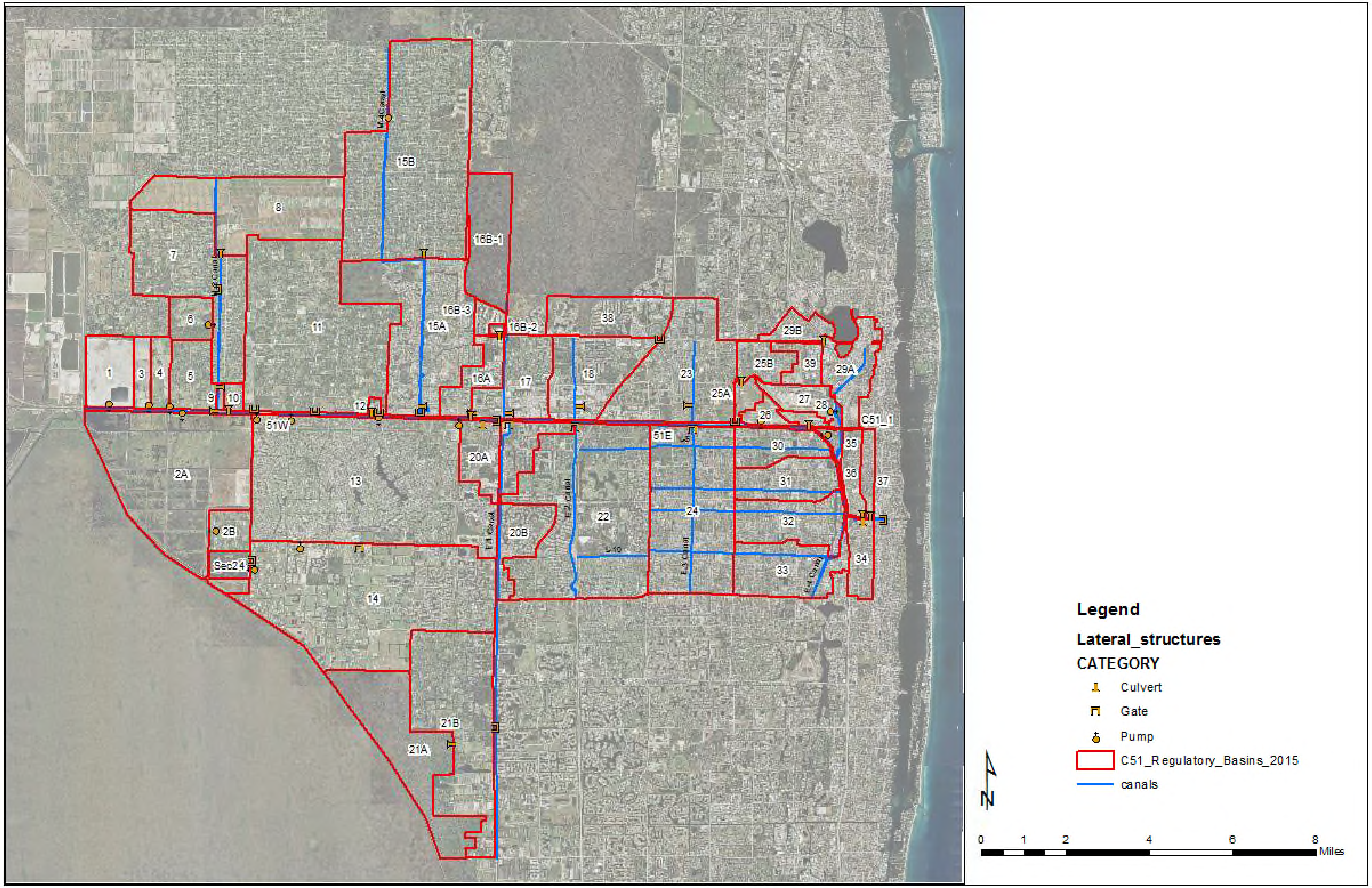

Figure 67. C-51 Basin Location of In-line and Lateral Drainage Structures

Table 20. Sub-basin Areas in 2004 and 2015 C-51 Models

C-51 West Basin			
BASIN ID	2004 (acres)	2015 (acres)	Diff (acres)
1	1164.3	1253.3	89.0
2A[1]	6715.8	6662.9	-52.9
2B	1226.4	842.9	-383.5
3	579.4	446.2	-133.2
4	540	499.8	-40.2
5	1142.4	1102.1	-40.3
6	673.5	674.2	0.7
7	4126.9	4109.5	-17.4
8	3966.8	4085.6	118.8
9	72.8	68.5	-4.3
10	208	190.0	-18.0
11	8138.4	7975.3	-163.1
12	74.1	74.4	0.3
13	10537.9	10485.7	-52.2
14	9270.3	9235.1	-35.2
15A	5116.6	5160.8	44.2
15B	8640.6	8605.5	-35.1
16A	1065.1	919.8	-145.3
16B-1	2448.8	1988.4	-101.2
16B-2		57.0	
16B-3		302.2	
20A	1138.6	1010.6	-128.0
Sec24	0	403.2	403.2
TOTAL:	60131[2]	59961[3]	-170

C-51 East Basin			
BASIN ID	2004 (acres)	2015 (acres)	Diff (acres)
17	1650.5	1795.5	145.0
18	2294.9	2309.3	14.4
20B	2341.8	2167.7	-174.1
21A	3540.4	3535.0	-5.4
21B	5056.2	4915.3	-140.9
22	7375.2	7580.1	204.9
23	4206.9	4048.9	-158.0
24	5282	5204.3	-77.7
25A	205.8	298.6	92.8
25B	972.1	721.0	-251.1
26	376.1	332.0	-44.1
27	830.7	752.8	-77.9
28	223.4	201.3	-22.1
29A	1578.1	1394.2	-183.9
29B	440.3	566.2	125.9
30	1153	1120.7	-32.3
31	1467.7	1433.4	-34.3
32	1812.7	1804.2	-8.5
33	2323.8	2090.9	-232.9
34	711.3	740.4	29.1
35	172.9	166.1	-6.8
36	603.3	607.4	4.1
37	390.2	398.5	8.3
38	1955.2	1812.0	-143.2
39		551.8	551.8
TOTAL:	46965	47071[4]	106

1.- Sub-basin not part of the C-51 Watershed
2.- Total area does not include sub-basin 2A
3 - Total area does not include sub-basin 2A, but includes C51 canal west
4 - Total area includes C51 canal east

Table 21A. Summary of Stormwater Conveyance Features (2015 Baseline: C-51 West)

Sub-Basin		Control Structure	Structure Description and Operations[1]	Conveyance System
ID	Other ID			
1	Palm Beach Aggregates	Pump	1-20,000 gpm Pump and 1-25,000 gpm (56 cfs) Pump; Only one pump at a time. Allowable discharge = 47.6 cfs	C-51 Canal
2A	STA-1E	Pump	Pump Station 319; 2-550 cfs and 3-960 cfs Pumps; on @ 12’ to 12.4’ (at 0.1’ increment) and off @ 11’ to 11.4’ (at 0.1’ increment) at S-319 HW on C-51 canal.	C-51 Canal to STA-1E
2B	Rustic Ranches	Pump	Pump Station 361; 2-25 cfs pumps; on @ 12’, off @ 11’	STA-1E
3	Fleming Property	Pump	11,830 gpm (26 cfs) pump on @ 13.5’; off @ 11.5’	C-51 Canal
4	Leonard Property	Pump	13,170 gpm (29 cfs) pump on @ 13.5’; off @ 11.5’	C-51 Canal
5	Fox Trail	Culvert	1-54” x 40’ CMP Invert elevation. @ 13.5’; allowable discharge = 47 cfs	M-2 Canal
6	Lion Country	Pump	30,000 gpm (67 cfs) pump on @ 16.5’; off @ 14.0’	M-2 Canal
7	M-2 Acreage	Slide Gate	1-slide gate 17’ wide x 6.25 high Inv @ 17.5’ and 6-36” diameter gated culverts (open)	M-2 Canal
8	Seminole WCD	Slide Gate and pipes	Four 7’ X 7’ gates with inv=8.7 ft NGVD with four 100’ long 84” diameter CMP at Sycamore Drive and three risers with 7’ X 7’ gates with inv=12.0 ft NGVD and three 70’ long 84” diameter CMP culverts at Southern Blvd.	M-2 Canal
9	Sluggett Property	Weir	2 ft Flash Board Riser ; inv. @ 16.0’	M-2 Canal
		Channel M-2 Canal	M-2 discharges to C-51 via 3-84” CMP with Risers with control elevation @ 12’	C-51 Canal
10	Entrada Acres	Riser Weir	36” Riser with Control Elevation at 17.5’	C-51 Canal
11	LGWCD	Slide Gates	1-6’ Slide Gate (4’ opening, open @ 16’, close @ 15’, sill @ 10’) at A and at G; 2-12’ Sluice Gates (7’ opening, open @ 16.5’, close @ 15’, sill @ 9’) and 2-12’ wide x 8’ high gates with invert @ 9.0’) at D.	C-51 Canal
12	Palm West Hospital	Riser Weir	24” x 250’ RCP Riser (Palms West Hospital), crest @ 14’.	C-51 Canal
13	ACME Basin A	Pump	2-60,000 gpm (267 cfs) discharge pump (PS#4); 2-60,000 gpm (267 cfs) discharge pump (PS#3); 1-62,000 gpm (138 cfs) discharge pump (PS#6); on @ 13’, off @ 12’ (same as Existing).	C-51 Canal
		Pump	1-100,000 gpm (220 cfs) discharge pump (PS#7)	
		Gate	Gravity flow bleeder - 54” gate @ Elev. 3.4 ‘ when stage in Basin A is between 11’ and 12’.	
14	ACME Basin B	Pump	1-100,000 gpm (220 cfs) and 1-120,000 gpm (267 cfs) discharge pumps; on @ 13’, off @ 12’ discharging to WCA discontinued. PS No. 8 1-90,000 gpm (200 cfs); on@13.2’ and off @ 13.0’.	C-51 Canal
15A	Village of Royal Palm Beach (VRPB)	Channel	Open Channel flow to M-1, weir crest @ 13’.	M-1 Canal
		Culvert	3-72” RCP to C-51 from Lake Challenger –sand-filled to elev. 13.5’	C-51 Canal
		Amil Gate & Slide Gate	1-Automatic D-710 Amil Gate (20’ wide x 10.3’ high, sill @ 3.5’) and 4 Slide Gates (5.9’ wide each, sill @ 2.7’) on M-1 controlling the discharge to C-51 Canal.	C-51 Canal

1. All elevations are referenced to ft NGVD29 datum

Table 21A. Summary of Stormwater Conveyance Features (2015 Baseline: C-51 West) (Cont.)

Sub-Basin		Control Structure	Structure Description and Operations[1]	Conveyance System
ID	Other ID			
15B	Lower M-1 (ITID)	Culvert	Roach Structure: 2-84" x 80' RCP with Slide Gates. 40th Structure: 4-large & 2-small Gates. Outflow controlled by 1-60" x 76' RCP.	M-1 Canal
16A	NPBCID	Weir	30' wide Weir; Control Elevation @ 13 ft NGVD	C-51 Canal
16B-1	PBC	Weir	Pond Cypress Natural Area weir to Portosol - 1' weir @ elev 17.5 ft NGVD	Discharges to 16B-3
16B-2	Target	Weir and orifice	Target store outlet 4.0 ft weir @ elev. 20.6 ft NGVD plus 0.4 ft X 2.7 ft orifice @ elevation 18.0 ft NGVD	Discharges to 16B-3
16B-3	Portosol	Weir and orifice	Portosol basin outflow structure. 11.0 ft weir @ elev. 19.0 ft NGVD plus 3.5' X 1.25' orifice @ elev. 16.5 ft NGVD.	Discharges to Sub-Basin 16A
20A	Lowes	Culvert	2-60" CMP upstream of STA 4+94 on S-4 Canal, Invert @ 10'.	C-51 Canal
Sect 24	ACME Section 24 Wetland	Pump	PS No. 9 1-90,000 gpm (200 cfs) pump; on @ 12.2'; off @ 12.0' or if stage in Sect 24 higher than elevation 16.0'. 2 – 72" diameter gravity discharge gates	C-51 Canal
--	S-155A	Gated Spillway	In flood control mode, gates close when: 1. TW stage reaches 11.7 ' or higher 2. HW stage reaches 13.0' or higher 3. Q exceeds design flow capacity of 1,460 cfs	C-51 Canal

1. All elevations are referenced to ft NGVD29 datum

Table 21B. Summary of Stormwater Conveyance Features (2015 Baseline: C-51 East)

Sub-Basin		Control Structure	Structure Description and Operations[1]	Conveyance System
ID	Other ID			
17	Permit No. 50-01172	Channel	L-1, L-2, L-3, L-4 Lateral Canals to E-1 Canal ; weir with crest @ 10.9' (C.E. in sub-basin 17)	LWDD
18	-	Culvert	E-2 Canal discharging through 10' wide x 11' high FDOT Box Culvert, crest @ 10.9'.	LWDD
20B	Home Depot	Radial Gate	Control Structure #2: 2-12' Radial Gates on E-1, sill @ 13.5'.	C-51 Canal
21A	Strazulla Wetlands	Overflow	Land Locked Basin controlled by Stage-Storage relationship. Overflows to Basin 21B when stage reaches 18.5'.	Sub-Basin 21B
21B		Channel	Homeland Canal discharging to E-1 Canal.	E-1 Canal
22		Radial Gate	Control Structure #4: 2-12' Radial Gates on E-2, sill @ 8.5'.	LWDD
23		Channel	L-1, L-2, L-3, L-4 Lateral Canals to E-3 Canal.	LWDD
24	Permit No. 50-01578	Radial Gate	Control Structure #6: 3-12' Radial Gates on E-3, sill @ 6.5'.	LWDD
25A	PBIA-1	Slide gate	2-10' wide x 8' high Box Culverts with Slide Gate, sill @ 8.5'.	C-51 Canal
25B	PBC	Culvert	2-8' high x 10' wide Box Culverts under Belvedere Road.	Sub-Basin 25A
26	PBIA	Pump	Southern PBIA Pump Station: 4-106.6 cfs pumps. Pump 4 only operates when one of the other 3 fails.	C-51 Canal
27	PBIA	Pump	Eastern PBIA Pump Station: 4-106.6 cfs pumps. Pump 4 only operates when one of the other 3 fails.	Stub Canal
28	PBIA	Culvert	40' wide x 8' high FDOT Box Culvert: Structure S-199, invert @7'.	C-51 Canal
29A	Renaissance Project	Channel	Discharge to C-51 through Stub Canal, weir crest @ 8.1' Discharge to Clear Lake(out of C-51 basin) via 255 cfs pump	Stub Canal
29B	Upper Stub Canal	Weir	6-6' wide Weirs with Gates	Sub-Basin 29A
30		Channel	L-5 Canal Open Channel flow to C-51, weir crest @ 8.5'.	C-51 Canal
31		Channel	L-6, L-7 Canals Open Channel flow to C-51, weir crest @ 8.5'.	C-51 Canal
32		Channel	L-8, L-9 Canals Open Channel flow to C-51, weir crest @ 8.5'.	C-51 Canal
33		Channel	L-10, L-11 Open Channel flow to C-51, weir crest @ 8.5'.	E-4 Canal
34		Culvert	1-48"x1800' RCP; 1-36"x1000' RCP, invert @ 7.5'	C-51 Canal
35	Town of Cloud Lake	Pump	Pump Station: 45 cfs pump	C-51 Canal
36	Palm Beach (Dreher Park)	Culvert	Dreher Zoo control structure: 62.6'wide weir (crest @ 13') plus 31 cfs pump ON=9.12' and OF=9.0' plus 4" diameter orifice at elev.=9.0';	C-51 Canal
37	PB Golf Club	Culvert	1-36" x 2000' RCP; 1-60" x 2500' RCP, invert @ 7.5'.	C-51 Canal
38		Slide Gate	2-66" RCP; One is plugged and the other is controlled by a 5.5 ft wide Gate (sill @ 8.5', opening 2').	C-51 Canal
39	L2 Pump	Pump	Discharge to Sub-basin 29A via 245 cfs pump	-
-	S-155	Gated Spillway	Outfall Structure, designed discharge capacity approximately 4,800 cfs. During flood events, the operation of the gates is: - Open gates when HW stage rises to elev. 7.5'; - When HW stage reaches elev. 7.3, the gates become stationary; - Close gates when HW stage falls below 7.0 ft NGVD	C-51 Canal

1. All elevations are referenced to ft NGVD29 datum

4.3 MODELING METHODOLOGY

4.3.1 ASSUMPTIONS

Table 22 summarizes the main assumptions made for the modeling of the baseline condition.

Table 22. Summary of Modeling Assumptions for 2015 Baseline

MODEL FEATURE	ASSUMPTION
VERTICAL DATUM	All elevations in the models are referenced to NGVD-29 vertical datum.
PERIOD OF SIMULATION	Event-based simulations: 3-day rainfall events with 9-day simulation periods were used for all model runs.
CLIMATE	• SFWMD rainfall distributions used for the 10-yr, 72-hr and 100-yr, 72-hr events. • Rainfall is applied uniformly over sub-basins. • No evaporation losses are included in simulations.
TOPOGRAPHY	• Ground elevations are a composite of three Digital Elevation Maps (DEM's) generated from the following datasets: a) 2007-2008 HDD_EAA 5-ft DEM (Northwest portion of the C-51 Basin) b) 2007-2008 Palm Beach East 5-ft DEM (Eastern C-51 Basin) c) Palm Beach FEAM LiDAR 10-ft DEM, 1999-2002 (Southwest C-51 Basin) d) 2014 Village of Wellington LiDAR 2 pts. per square meter resolution. • Surveyed canal cross-sections were taken from US Corps of Engineers and FEMA as-built drawings supplemented with more recent canal surveys (2006) by the District.
SOFTWARE	• HEC-HMS version 3.5 and HEC-RAS 4.1
HEC-HMS HYDROLOGY	• The SCS Curve Number method with Delmarva peaking factors of 284 was used for all event runs. • The CN's and times of concentration were from the 2004 C-51 Basin Rule study. • Event runoff computations assumed rainfall applied uniformly over sub-basins.
HEC-RAS HYDRAULICS	• Hydraulic computations were carried only for the primary and some major secondary canal systems in the C-51 Basin (M-1, M-2, E-1 through E-4 and L-5 through L-10 canals). • Runoff from contributing sub-basins to the C-51 canal was routed through local sub-basin storage and outlet structure(s). • Level-pool assumption holds for water levels within each sub-basin. • Overflows are allowed in some sub-basins through fixed weirs at the boundaries between sub-basins or between sub-basins and the C-51 Canal.
SYSTEM OPERATIONS	• The District structures (S-155, S-155A and S-319) are operated throughout the design storm event runs according to latest flood control operations by the District. • LWDD and special drainage district structures were operated according to rules established in the 2004 C-51 Basin Rule Study with exception of ITID and ACME whose operations have been revised to reflect their latest drainage permits. • A minimum discharge of 200 cfs from ITID sub-basin S15B is allowed to the C-51 Canal for peak conditions in the C-51 Canal. • For the 10-yr Baseline run, all operable structures discharging to the C-51 Canal were restricted to pass up to the Basin Rule allowable discharge. • For the 100-yr Baseline run, all operable structures discharging to the C-51 Canal were unrestricted.
BOUNDARY CONDITIONS	• C-51 Canal tidal boundary condition for event simulations was constant tide elevation of 4.6 feet which corresponds to the highest TW stage observed during a storm event (Hurricane Jeannie) in the period of record (1985 – 2013.) • Western C-51Canal boundary condition was assumed to equal flow releases from structure S-5AE of 300 cfs regulated for peak flood conditions in the C-51 West Basin according to operation of the S-155A structure. • Constant flows from the 2004 study representing seepage contributions to the canals were entered as boundary condition at the upstream end of canal in the model.
INITIAL CONDITIONS	• Initial lake and canal stage set to the water control elevation of each sub-basin. • Initial stages in the C-51 canal set to wet season control elevation.

4.3.2 METHODOLOGY

The modeling methodology in this study follows the same principles established in the 2004 study in which the basin hydrology is simulated in HEC-HMS as direct runoff from precipitation for each sub-basin. The application of the C-51 model for the baseline condition requires synthetic rainfall patterns for the 10-yr, 72-hr and the 100-yr, 72-hr design storm events to be entered into the hydrologic HEC-HMS model uniformly distributed over the sub-basins. HEC-HMS calculates each of the sub-basins runoff hydrographs which are then entered into their corresponding available storage and then routes it to the primary canal via a control structure. Once a sub-basin releases its runoff, it is then routed through the primary canal to the downstream (tide) end of the system as shown in **Figure 68**. Further details on the model components and calibration can be found in Sections 2 and 3 of this report.

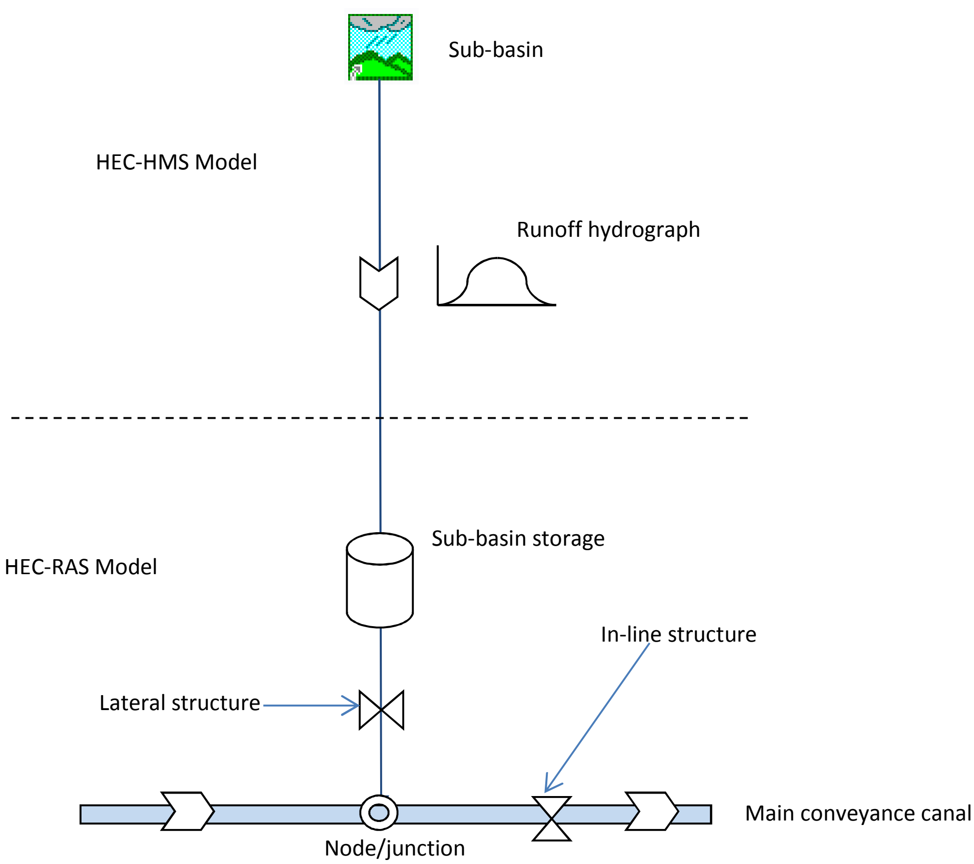

Figure 68. Schematic Representation of Modeling Process

4.3.3 CALIBRATION

The calibration of the updated C-51 Model was presented in Section 3 of this report. In summary, the calibration of both HEC-HMS and HEC-RAS models consisted of history matching stages and flows at several location of the system for a period corresponding to Tropical Storm (TS) Isaac which occurred in the period of September 26 – 29, 2012. For calibration purposes the period of calibration including pre- and post- storm simulation was set from September 24 to August 5, 2012. Rainfall data consisted of 15-minute Nexrad gauge-corrected data for each sub-basin. Also in 15-minute increments, observed stage, flow and gate openings were available for the calibration period from the District's DBHYDRO database. Calibration locations for stages in the C-51 Canal included the TW side of structure S-5AE at the western end of the canal, the HW side of pump S-319, the HW and TW sides of structure S-155A and the HW side of structure S-155 near the tidal end of the canal. Structure flows were calibrated at S-155A, S-319 pump and structure S-155.

The model calibration was extended to four sub-basins in the model: Sub-basins 13, 14 (ACME Basins A and B), as well as Section 24 wetland, and Indian Trail Improvement District (ITID) Sub-basin 15B (Lower M-1) with limited flow and stage data provided by these two special drainage districts.

4.4 MODEL BASIN PARAMETERS

4.4.1 BASIN AREA AND LAND USE

The 2015 baseline reflects changes in the 2004 sub-basin areas that were described in Section 2 of this report. In the calibration of the model described in Section 3 of this report, there were no adjustments to the land use that translated into changes to the runoff curve numbers (CN's) in the HEC-HMS model. For the purpose of this study, the sub-basin areas are the revised areas in **Table 20** and the CN's are identical to those presented in Technical Memorandum (TM) #2 of the 2004 study and described next in **Tables 3A** and **3B** for C-51 West and C-51 East, respectively.

4.4.2 RUNOFF CURVE NUMBER (CN)

As described above, the calibrated CN's from the 2004 study are still in effect for hydrologic computations in this study. During the calibration effort (Task 3) a sensitivity analysis of CN's was performed with the CN's from the 2004 study with little to no effect in computed stages and flows at the calibration sites in the C-51 canal. The sub-basins with data for calibration of CN's (ACME sub-basins 13, 14 and ITID sub-basin 15B) did not require adjustments to the CN's. **Tables 23A and 23B** show the 2004 calibrated CN's. The peaking factors were changed from the standard SCS unit hydrographs method value of 484 to a value of 284, consistent with the Delmarva unit hydrograph.

Table 23A. Sub-basin Runoff CN, T_c and T_l (2015 Baseline: C-51 West)

Sub-basin		Area		Weighted Curve Number	Time of Concentration	Time Lag
ID	Other ID	(acre)	(sq mi)	(CN)	(min)	(min)
1	B1	1253.3	1.96	71.5	252	151
2A[1]	B2A	6662.9	10.41	99.0	651	390
2B	B2B	842.9	1.32	74.3	139	83
3	B3	446.2	0.70	73.9	232	139
4	B4	499.8	0.78	75.2	261	156
5	B5	1102.1	1.72	77.4	232	139
6	B6	674.2	1.05	81.5	147	88
7	B7	4109.5	6.42	76.0	501	300
8	B8	4085.6	6.38	76.0	402	241
9	B9	68.5	0.11	76.1	94	56
10	B10	190.0	0.30	81.9	227	136
11	B11	7975.3	12.46	77.0	518	310
12	B12	74.4	0.12	86.0	94	56
13	B13	10485.7	16.38	82.0	523	313
14	B14	9235.1	14.43	75.0	431	258
15A	B15A	5160.8	8.06	86.0	551	330
15B	B15B	8605.5	13.45	78.0	593	355
16A	B16A	919.8	1.44	83.4	309	185
16B-1	B16B	1988.4	3.11	89.0	611	450
16B-2	B16B-2	57.0	0.09	87.0	65	39
16B-3	B16B-3	2451.2	3.83	91.0	30	18
20A	B20A	1010.6	1.58	80.0	256	153
Sec24	Sec24	403.2	0.63	70.0	115	69

1. Not part of the C-51 Basin

Table 23B. Sub-basin Runoff CN, T_c and T_l (2015 Baseline: C-51 East)

Sub-basin Area		Sub-basin Area (CN)		Weighted Curve Number (CN)	Time of Concentration (min)	Time Lag (min)
ID	Other ID	(acre)	(sq mi)			
17	B17	1795.5	2.81	84.8	304	182
18	B18	2309.3	3.61	83.5	287	172
20B	B20B	2167.7	3.39	80.7	364	218
21A	B21A	3535.0	5.52	96.9	534	320
21B	B21B	4915.3	7.68	76.4	494	296
22	B22	7580.1	11.84	80.0	518	310
23	B23	4048.9	6.33	81.0	364	218
24	B24	5204.3	8.13	81.5	441	264
25A	B25A	298.6	0.47	77.0	105	63
25B	B25B	721.0	1.13	79.0	132	79
26	B26	332.0	0.52	80.1	162	97
27	B27	752.8	1.18	84.5	274	164
28	B28	201.3	0.31	83.0	92	55
29A	B29A	1394.2	2.18	80.5	130	78
29B	B29B	566.2	0.88	85.9	144	86
30	B30	1120.7	1.75	78.3	159	95
31	B31	1433.4	2.24	80.0	157	94
32	B32	1804.2	2.82	81.0	271	162
33	B33	2090.9	3.27	80.0	229	137
34	B34	740.4	1.16	75.0	262	157
35	B35	166.1	0.26	82.7	75	45
36	B36	607.4	0.95	72.1	187	112
37	B37	398.5	0.62	69.0	185	111
38	B38	1812.0	2.83	86.0	225	135
39	B39	551.8	0.86	80.0	109	65

4.4.3 TIME LAG (T_L) AND TIME OF CONCENTRATION (T_C)

The 2004 calibrated values of the time lag (T_l) and time of concentration (T_c) for each sub-basin were adopted without change in this study and were summarized in **Tables 23A and 23B** for the C-51 West and East basins, respectively.

4.4.4 STAGE-AREA-STORAGE RELATIONSHIPS

One of the major tasks of this model update consisted in revising the 2004 C-51 Model stage-storage curves for all the sub-basins using the latest (2015) Digital Elevation Map produced by merging three LiDAR datasets:

- 2002 USACE and Palm Beach County (PBC)/Florida International University (FIU) (10-feet resolution)
- 2007-2008 Herbert Hoover Dam-Everglades Agricultural Area (5-feet resolution)
- 2007-2008 Palm Beach County - East (5-feet resolution)

A detailed description of these datasets was presented in Section 2 Report of this study.

In general, the 2015 stage-storage curves indicate less basin storage than the 2004 curves which translates in higher stage in the HEC-RAS model. Basin wide, the average storage reduction was about 35% of the 2004 value. The impact of the reduced storage is reflected in the final computed sub-basin stages for the 10-yr, 72-hr and 100-yr, 72-hr design storms as shown later in this report. For purposes of this study, the revised stage-storage relationships described in Section 2 of this report were used to establish the storage in each sub-basin in the model.

4.5 DESIGN STORM EVENTS

The rainfall distributions identified in the 2004 study for the basin rule evaluation were the 10-yr, 72-hr event for allowable discharge and the 100-yr 72-hr event for peak stage in the basin. For consistency with the 2004 study, the updated baseline will be established using the same rainfall volumes summarized in **Table 24** (SFWMD, 2000).

Table 24. Design Storm Event Rainfall Volumes for Basin Rule Development

Strom Frequency (years)	Strom Duration (hours)	Storm Depth (inches)
10	72	10.1
100	72	16.3

4.6 MODEL GEOMETRIC AND STRUCTURAL FEATURES

4.6.1 REACHES AND JUNCTIONS

The C-51 Basin HEC-RAS model was developed to represent conveyance conditions in the primary canal system which includes the C-51 Canal and major secondary tributaries M-1 and M-2 Canals, Homeland Canal, LWDD equalizer/lateral canals E-1 through E-4 and L-5 through L-10, and Stub Canal. These canals are explicitly represented in the model with surveyed canal cross-sections. In the model, the C-51 Canal was divided into eleven reaches with each of its tributaries as a single reach, for a total of 26 canal reaches. Junctions in the model represent the locations where the tributaries join the C-51 Canal. **Table 25** summarizes the discretization of canal reaches in the HEC-RAS model. The canal reach discretization is the same as in the 2004 model.

Table 25. Summary of Canal Reaches and Junctions in HEC-RAS model (2015 Baseline)

Canal Name	Reach Name	Reach Length (feet)	Junction Name
C-51	R1	16681	
	R2	25442	
	R3	10305	
	R4	918	
	R5	8276	
	R6	14667	
	R7	18718	
	R8	939	
	R9	4646	
	R10	2857	
	R11	6281	
M1	RM1	21163	JM1
M2	RM2	20065	JM2
E1N	RE1N	5175	JE1N
E1S	RE1S	51118	JE1S
E2N	RE2N	10449	JE2
E2S	RE2S	20290	
E3N	RE3N	8039	JE3
E3S	RE3S	19990	
E4	RE4b	6653	JE4
L5	RL5	8890	JL5
L7	RL7	10020	JL7
L8	RL8	11961	JL8
L10	RL10	11643	
Stub Canal	RSC	16716	JSC

4.6.2 CANAL CROSS-SECTION

The HEC-RAS model uses surveyed canal cross-sections to represent the conveyance or capacity of the canal to carry the flows from the western end to tide. The data used to represent the cross-sections of the canal were discussed in Section 2 of this report. The C-51 Canal cross-sectional data includes data from several sources of which the most relevant are data from the USACE for the C-51 East portion of the canal, the Federal Emergency Management Agency (FEMA) in the East portion of the canal and the Greenhorne and O'Mara study (2006) which incorporates survey data in the C-51 Canal from the Ousley Farm Road bridge to Florida's Turnpike. **Figure 69** shows the C-51 Canal bottom and left (LOB) and right (ROB) overbank profiles in the HEC-RAS model.

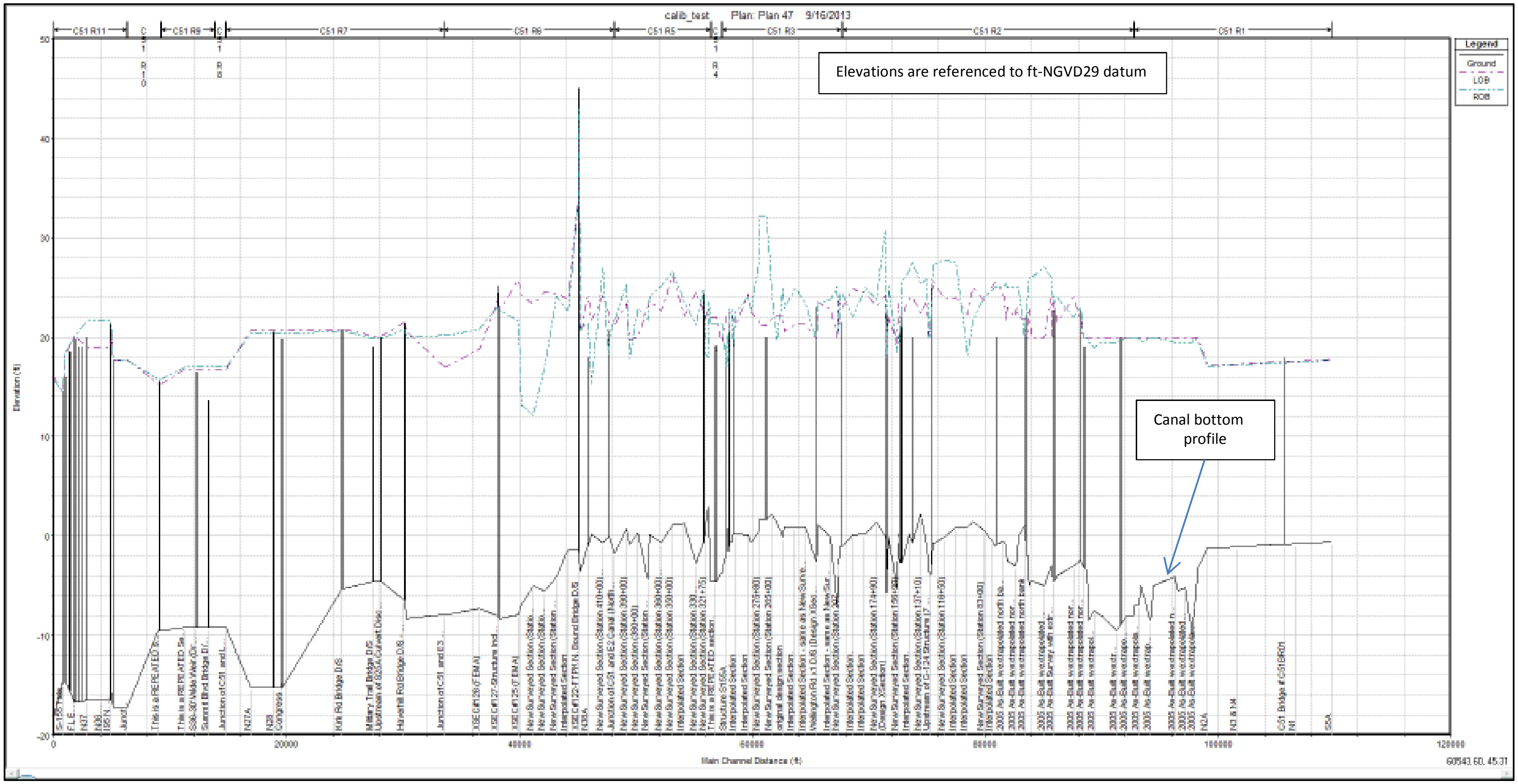

Figure 69. Channel Bottom Profile for the C-51 Canal (2015 Baseline)

4.6.3 BRIDGES

Bridge structures in the C-51 Model were defined in the 2004 model using as-built data from the Florida Department of Transportation (FDOT) and the Florida East Coast Railway (FEC) for the bridge structure and the USACE and FEMA studies for the bridge approach and exit canal cross-sections. A total of 28 bridge structures of which 25 were in the C-51 Canal were included in the 2004 model. An additional bridge was added to the HEC-RAS model as part of this study. This bridge was completed in 2010 by the District near the western end of the C-51 Canal at station 105680 (access road to STA-1E) in the HEC-RAS model. The only other canal with bridge structures in the model is the M-1 Canal with bridges at the crossing of Okeechobee Boulevard, Crestwood Road and Sparrow Drive. **Table 26** summarizes the location of bridges in the model while **Figure 70** shows the locations over the canals in the model.

4.6.4 IN-LINE STRUCTURES

In-line structures that control the flow in the HEC-RAS model consist mainly of gated structures such as weirs, spillways and culverts (**Figure 67**). There are 13 in-line structures in the model of which two, S-155A and S-155, are located in the C-51 Canal. In the updated C-51 Basin model, the standard flow equations in HEC-RAS were by-passed at these two structures for the District's own rating equations. The rating equations for these two District structures and for the Amil gate structure in the M-1 canal were entered into the model as "user-defined rules" which is a new feature of the model not available in 2004. The other 10 in-line structures were simulated with the standard HEC-RAS gate and spillway flow equations. **Table 25** also summarizes the type and location of the in-line structures in the baseline model.

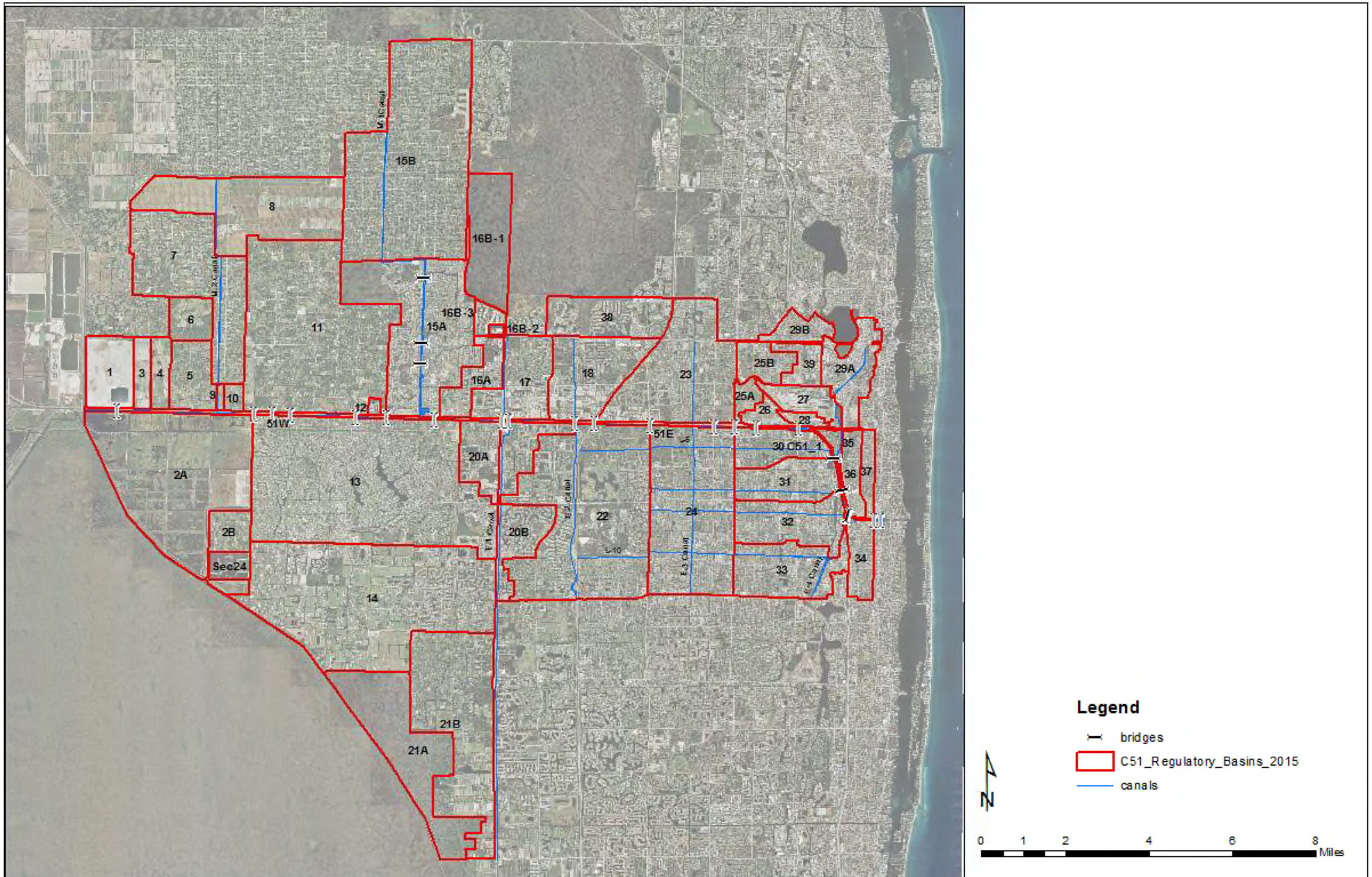

Figure 70. Location of Modelled Bridges over the Canals in the HEC-RAS Model

Table 26. Location of Bridge, Culvert and In-line Structures in the HEC-RAS model (2015 Baseline)

Canal Name	Reach Name	River Station	Structure Width	Structure Description
M1	RM1	17104	88	Bridge: Crestwood Blvd.
		8834	98	Bridge: Okeechobee Blvd.
		6314	38	Bridge: Sparrow Drive
		775	10	Inline Structure: Amil Gates (B15A)
E1S	RE1S	150	10	Inline Structure: CS# 2 2-12' Radial Gates (B20B)
E2N	RE2N	150	90	Culvert: FDOT Culvert - from E2N to C51 (B18)
E2S	RE2S	170	10	Inline Structure: CS# 4 2-12' Radial Gates (B22)
E3S	RE3S	75	10	Inline Structure: CS# 6 3-12' Radial Gates (B24)
L5	RL5	160	5	Inline Structure: Weir (B30)
C1	R1	14800	45	Inline Structure: CS #40 45' weir with crest elevation at 13'
Stub Canal	RSC	160	5	Inline Structure: Weir (B35)
L7	RL7	160	5	Inline Structure: Weir (B31)
L8	RL8	160	5	Inline Structure: Weir (B32)
E4	RE4b	160	5	Inline Structure: Weir (B33)
M2	RM2	600	10	Inline Structure: 65.9' wide weir on M-2
C51	R1	109730	--	S-5AE Inline structure not simulated but represented as a flow boundary condition
	R1	105680	25	Bridge: STA-1E access Rd
	R2	88162	30	Bridge: Flying Cow Road
		85845	89	Bridge: Binks Forest Blvd.
		83435	30	Bridge: Ousley Sod Farm Rd
		75318	30	Bridge: Big Blue Trace Rd
		71496	30	Bridge: Forest Hill Blvd.
	R3	65473	30	Bridge: Wellington Rd
		57926	45	Lowes Bridge
		57926	45	Inline Structure: S-155A (gated spillway)
	R4	56807	40	Bridge: Highway 441
	R5	55775	40	Bridge: Mall Entrance
	R6	47587	30	Bridge: Benoist Farms Rd
		45052	31	Bridge: Florida's Turnpike Southbound
		45010	31	Bridge: Florida's Turnpike Northbound
		38183	149	Bridge: Jog Road
		30088	85	Bridge: Haverhill Road
		27392	95	Bridge: Military Trail

Table 26. Location of Bridge, Culvert and In-line Structures in the HEC-RAS model (2015 Baseline) (Cont.)

Canal Name	Canal Name	River Station	Structure Width*	Structure Description
C51	R7	24757	49	Bridge: Kirk Road
C51	R7	19589	76	Bridge: Congress Ave
C51	R9	13238	60	Bridge: Summit Blvd
C51	R10	9093	70	Bridge: Forest Hill Blvd
C51	R11	5112	10	Bridge: Seaboard Coastline Railroad
C51	R11	4956	51	Bridge: I-95 Southbound
C51	R11	4853	51	Bridge: I-95 Northbound
C51	R11	1801	19	Bridge: Florida East Coast Railroad
C51	R11	999	77	Bridge: US Highway 1
C51	R11	720	15	Inline Structure: S-155 (gated spillway)

4.6.5 LATERAL STRUCTURES

Lateral structures comprised of weirs, pumps, culverts or gates were defined in the 2004 study and revised in this study to connect sub-basin storage areas to a channel reach in the model. **Tables 27A and 27B** for structures in the C-51 West Basin and C-51 East Basin, respectively, summarizes the locations in the model (river stations) where the lateral structures connect to the canal reaches in baseline model. There is at least one lateral structure for each sub-basin.

Table 27A. Location and description of Lateral Structures (2015 Baseline: C51 West)

Basin ID	Storage Name	Canal Name	Reach Name	Structure		Description
				River St.	Type	
1	S1	C51	R1	106604	Pump	PS1C51: 47.6 cfs pump
2A	STA1E	C51	R1	97736	Pump	PS319a: 2-550 cfs pumps
		C51	R1	97736	Pump	PS319b: 3-960 cfs pumps
2B	S2B	STA1E	-	-	Pump	PS361: 2-25cfs pumps
3	S3	C51	R1	101625	Pump	PS3C51: 26.3 cfs pump
4	S4	C51	R1	101625	Pump	PS4C51: 29.3 cfs pump
5	S5	M2	RM2	436	Culvert	54" CMP
6	S6	M2	RM2	10124	Pump	PS6M2: 66.8 cfs pump
7	S7	M2	RM2	15788	Gate	6.25' high x 17' wide slide gate plus 6-36"diameter culverts into M-2 canal
8	S8	M2	RM2	20000	Weir	4-72" wide weir
9	S9	M2	RM2	3262	Weir	2' Flash Board Riser (Weir)
10	S10	C51	R2	91618	Weir	9' wide Weir
11	S11	C51	R2	88526	Gate	Gate A: 1-6' Slide Gate
		C51	R2	80973	Gate	Gate D: 2-8' high x 12'Slide Gate
		C51	R2	72778	Gate	Gate G: 1-6' Slide Gate
12	S12	C51	R2	73679	Weir	2' wide Weir
13	S13	C1	R1	8700	Weir	S13 to C1 Canal
		C1	R1	4700	Weir	S13 to C1 Canal
		C51	R2	88336	Pump	PS13C51: 220 cfs pump PS No.7
		C51	R2	83455	Pump	PS13C51A: 267 cfs pump PS No. 3
		C51	R2	72838	Pump	PS13C51B: 267 cfs pump PS No. 4
		C51	R2	72605.1	Gate	Gravity Discharge Gate at PS No. 3
		C51	R2	62580	Pump	PS13C51B: 138 cfs pump PS No. 6
		--	--	--	Pump	PS14WCA: 0 cfs pump * Inactive
14	S14	--	--	--	Pump	PS13PS14: 133 cfs pump PS No. 8
		C1	R1	18750	Weir	S14 to C1 Canal
		C1	R1	16100	Weir	S14 to C1 Canal
Sect24	Sec24	C1	R1	18250	Gate	Section 24 to ACME C-1 Canal
		C1	R1	17000	Gate	Section 24 to ACME C-1 Canal
		C1	R1	18000	Pump	PC1Sec24: 200 cfs pump
15A	S15A	C51	R3	67560	Culvert	2-72" RCP
		M1	RM1	1438	Weir	Open Channel
15B	S15B	M1	RM1	20073	Gate	8'H x 20'W slide gate Inv=8.0'
16A	S16A	C51	R3	61174	Weir	30' Wide Weir
17	S17	E1N	RE1N	1712	Weir	S17 to E1N
18	S18	E2N	RE2N	1979	Weir	S18 to E2N

Table 27B. Location and description of Lateral Structures for (2015 Baseline: C-51 East)

Basin ID	Storage Name	Canal Name	Reach Name	Structure		Description
				River Station	Type	
20A	S20A	C51	R3	58375	Culvert	2-60" CMP
20B	S20B	E1S	RE1S	3951	Weir	S20B to E1S
21B	S21B	E1S	RE1S	33752	Canal	Homeland Canal
38	S38	C51	R6	45825	Gate	1-5.5' Wide Slide Gate
22	S22	E2S	RE2S	3423	Weir	S22 to E2S Canal
23	S23	E3N	RE3N	2641	Channel	S23 to E3N Canal; weir crest @ 12.1 ft NGVD
24	S24	E3S	RE3S	2713	Weir	S24 to E3S Canal
25A	S25A	C51	R7	28070	Gate	2 Slide Gates
26	S26	C51	R7	24880	Pump	PS26C51: 3-106.6 cfs pumps
28	S28	C51	R7	18858	Culvert	8' x 40' Box Culvert
27	S27	C51	R7	16882	Pump	PS27C51: 3-106.6 cfs pumps
29A	S29A	Stub	RSC	8615	Channel	S29A to Stub Canal; weir crest @ 8.1 ft NGVD
30	S30	L5	RL5	450	Channel	S30 to L5 Canal; weir crest @ 8.5 ft NGVD
31	S31	L7	RL7	1930	Channel	S31 to L7 Canal; weir crest @ 8.5 ft NGVD
32	S32	L8	RL8	1771	Channel	S32 to L8 Canal; weir crest @ 8.5 ft NGVD
33	S33	L10	RL10	1453	Channel	S33 to L10 Canal; weir crest @ 8.5 ft NGVD
34	S34	C51	R11	2843	Culvert	1800' of 48" RCP
		C51	R11	1400	Culvert	1000 of 36" RCP
35	S35	C51	R8	14700	Pump	PS35C51: 45 cfs pump
36	S36	C51	R9	12243	Weir	4" orifice + 31 cfs pump +62.5' weir at Dreher Park
		C51	R11	2853	Culvert	2500' of 60" RCP
		C51	R11	2467	Culvert	3000' of 36"RCP
37	S37	C51	R11	2167	Culvert	2000' of 36" RCP
		C51	R11	1335	Culvert	2500' of 60" RCP
38	S38	C51	R6	45825	Gate	1-5.5' wide slide gate
L8	--	C51	R1	109600	Gate	Simulate S5AE boundary flow

4.6.6 BASIN-TO-BASIN CONNECTORS AND OVERFLOWS

The C-51 HEC-RAS model also includes several structural connections between sub-basins which include pumps, weirs and culverts. **Table 28** summarizes the physical characteristics of these connectors.

Table 28. Basin-to-Basin Connector Characteristics

From Basin	To Basin	Connector Type	Description
14	13	Weir and pump	133 cfs pump and weirs 9.5 ft NGVD @ elevation 12 ft NGVD and 170' at elevation 13ft NGVD
16B-1	16B-3	weir	Pond Cypress Natural Area weir to Portosol 1' weir @ elev 17.5 ft NGVD
16B-2	16B-3	Weir + orifice	Portosol outfall structure. 11-ft weir @ elev. 19.0 ft NGVD plus 3.5' X 1.25' orifice @ elev. 16.5 ft NGVD.
16B-3	16A	Weir + orifice	Target store outlet 4.0 weir @ elev. 20.6 plus 0.4 X 2.7 orifice @ elev 18.0
21A	21B	weir	Basin overflow weir L = 2500 ft at elevation 19 ft NGVD
25A	25B	culvert	Two 8' x' 10' culverts under Belvedere Road
39	29A	pump	L2 Pump (245 cfs) at Florida Mango
29A	Clear Lake	pump	Renaissance Project pump (255 cfs) to Clear Lake (out of C-51 basin)

For large storm events such as the 100-yr 72-hr design storm, peak water levels in some sub-basins can rise above the elevation of basin boundary divides such as levees and roads producing water exchange between sub-basins. The 2004 model did not include these drainage features. However, close examination of peak water levels across basin boundaries, particularly for the 100-yr 72-hr storm event, suggests that basin overflow can occur during peak stage conditions. Furthermore, as it was witnessed during the flooding that occurred during TS Isaac in September of 2012, several basin overflow locations were evident where roads that serve as basin divides were overtopped and even intentionally breached in order to lower water levels in flooded areas. In order to account for these inter-basin overflows, several weirs were added to the model to simulate the overland flow between sub-basins during peak stage conditions. **Table 29** summarizes the overflow weir characteristics which were obtained from the FEMA version (2013) of the model currently under review by the District.

Table 29. Sub-basin Overflow Weir Characteristics

From Sub-basin	To Sub-basin	Length (ft)	Elev. (NGVD ft)
S6	S5	2000	18.5
S7	S6	1500	19.0
S7	S10	1000	17.5
S11	S10	1000	17.5
S11	S12	300	18.5
S15A	S16A	3000	18.0
S15B	S16B	5000	20.0
S16B	S38	500	19.5
S21A	S21B	2500	19.0
S21B	S14	2000	18.0
S29A	S27	4000	14.0
S1	C51	1000	20.5
S5	M2	1000	16.5
S34	C51	300	11.5
S35	Stub Canal	1000	12.0

4.6.7 MODEL NODE/LINK DIAGRAM

Figure 71 is a node-link diagram representing the connectivity of storage elements (sub-basins) with canal links (C-51 Canal). In this figure, the storage elements, or nodes represent the storage in each sub-basin which receives runoff from the HEC-HMS model. The black arrows connecting nodes to other nodes or to the main canal, represent conveyance features such as pumps, outlet structures, culverts, or channels. Storage nodes can have one or more links to a canal such as Sub-basin 11 (Loxahatchee Groves) which has three outlet structures to the C-51 Canal. Overflow weirs between sub-basins are shown as thick dashed lines and were added to the model to represent road overtopping during extreme flood events.

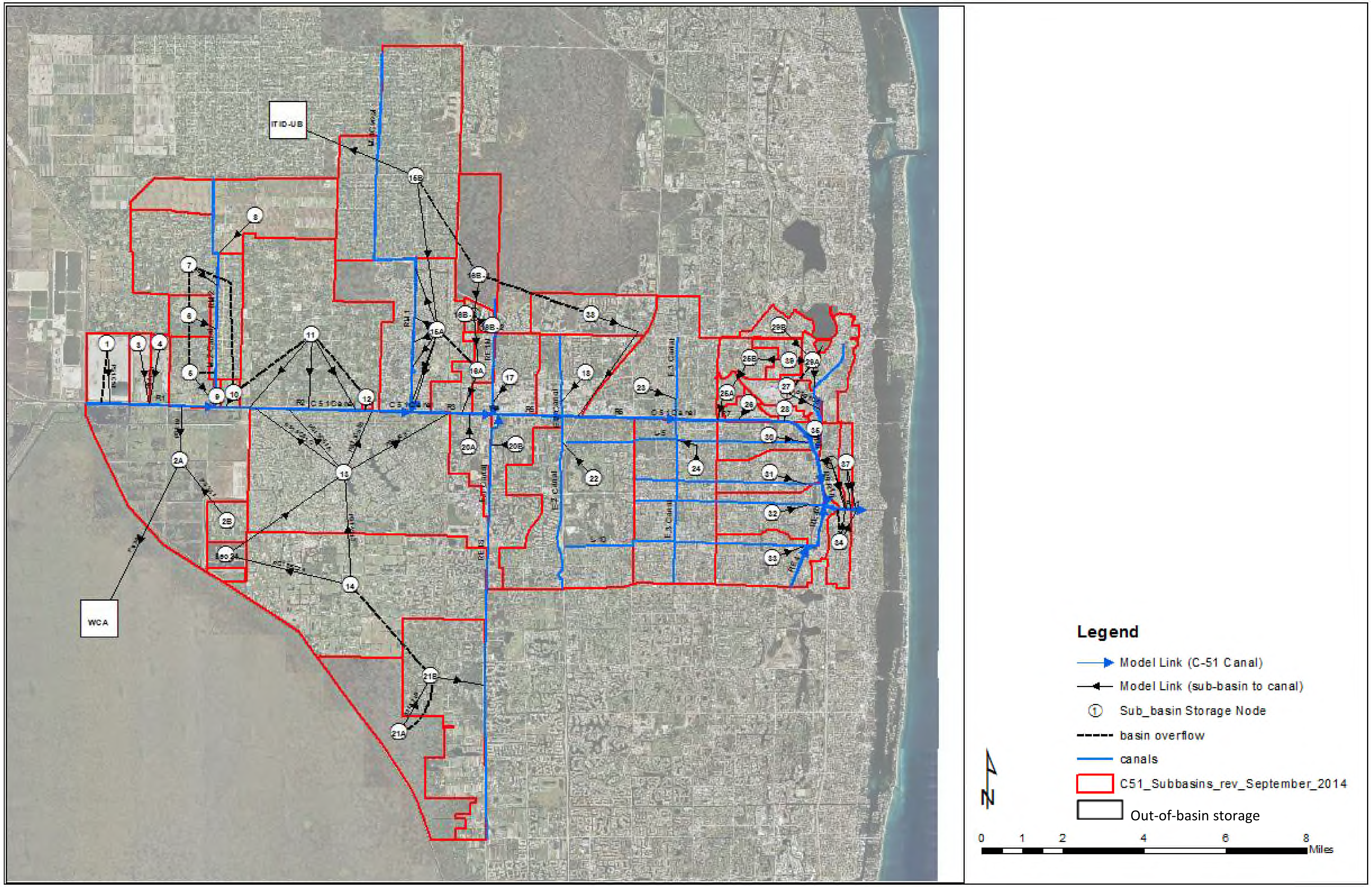

Figure 71. C-51 Model Node-Link Diagram

4.7 UNSTEADY FLOW CONDITIONS

4.7.1 SIMULATION PERIOD

As in the 2004 unsteady model runs, the design storm event runs (10-yr, 72-hr and 100-yr, 72-hr) were extended beyond the three-day storm duration to a period of 96 hours to allow for equilibrium conditions prior to the storm and to allow computed stages and flows to recede after the peak.

4.8 STRUCTURE OPERATIONS

The 2004 baseline C-51 model did not model the gate operations at the District structures S-155 and S-155A. Instead, as a conservative approach, the model modeled the gates at structure S-155 as completely open and at S-155A completely closed. In reality, the District applies flood control protocols prior, during and after a flood event in order to increase conveyance in the system prior to the storm and to protect the integrity of the structures. In this study, the current flood control operations for the District structures were incorporated into the model. In addition, some Special District operations have been revised and incorporated into the model and are described next.

4.8.1 STRUCTURE S-155

The gates begin to open when the head water rises to 7.5 ft NGVD and they begin to close when it falls to or below 7.0 ft NGVD.

Initially, the gates open one at a time in 0.5-foot increments until they each are opened 2 feet. At this point, if the head water is still rising and above 7.5 ft NGVD, they will all open simultaneously in 0.5-foot increments. The gates close in a reverse manner.

4.8.2 STRUCTURE S-155A

In any case, the gates close if the TW exceeds 11.7 ft NGVD, the HW rises above 13.0 ft NGVD, the HW falls to or below 11.0 ft NGVD or the discharge through S-155 exceeds 4,800 cfs.

The gates open if the HW rises to 12.0 ft NGVD, as needed to keep the HW from continuing to rise. The discharge is limited to Q_{Design} = 1,460 cfs, checking that the discharge is at least as much as the current flow through structure S-5AE at the west end of the C-51 Canal.

4.8.3 STRUCTURE S-5AE

In the 2004 study model, the flow through this structure was represented as a constant boundary flow of 300 cfs. The operation of the S-5AE structure during peak flood conditions in the C-51 Canal, requires the closing of the structure whenever Structure S-155A is closed. In order to reflect this operation in the model, the boundary flow of 300 cfs is calculated by the model to equal 300 cfs whenever the S-155A structure is open and zero if the structure is closed.

4.8.4 PUMP S-319

During storm conditions, pumpage at S-319 is normally triggered by the HW stage of structure S-319. When the HW stage rises to 12.0 ft NGVD, pumpage commences. The number of pumps used depends on the rate of rise along with the stage, and is at the discretion of the pump operators. Pumpage generally continues until the HW stage drops to or below 11.0 ft NGVD, where all pumps are shut off. In the model, there are 2 pump groups. The first pump group has two pumps of 550 cfs each for a total capacity of 1100 cfs. The second group has three 960 cfs pumps for a total capacity of 2,880 cfs. The stage triggers are as follows in **Table 30**.

Table 30. Pump S-319 ON and OFF Trigger Elevations and Pump Capacities

Pump	Capacity cfs	ON Trigger Elevation ft NGVD	OFF Trigger Elevation ft NGVD
Group 1	550	12.0	11.0
	550	12.1	11.1
Group 2	960	12.2	11.2
	960	12.3	11.3
	960	12.4	11.4
Total:	**3,980**		

4.8.5 ACME STRUCTURES

Drainage structures associated with the latest ACME Basin B permit (November, 2007) were added to the C-51 Model and discussed in detail in the Section 2 of this report. The permitted operation of the structures, including the old ACME Basin A pumps discharging into the C-51 Canal are summarized next.

The control elevation of Basin A is 11.0 ft NGVD. ACME Basin A pumps discharge capacity and control trigger elevations are as shown in **Table 31**.

Table 31. ACME Basin A Pump Capacity and Control Trigger Elevations

Pump ID	Capacity cfs	ON Elevation ft NGVD	OFF Elevation ft NGVD
Pump Station No. 3	267	12.2	12.0
Pump Station No. 4	267	12.2	12.0
Pump Station No. 6	138	12.2	12.0
Pump Station No. 7	220	12.2	12.0

Gravity discharge at Pump Station Nos. 4, 6 and 7 through the existing gates is allowed when water levels in the C-51 Canal are below elevation 12.0 ft NGVD and the water levels in Basin A are above 12.0 ft NGVD. Gates are closed once Basin A levels recede to elevation 12.0 ft NGVD.

Bleeder discharge at Pump Station No. 3 is allowed through a 54-inch gate open 3.4 feet when stages in Basin A are between stages 11.0 ft NGVD and 12.0 ft NGVD. Also, if the water elevation in the C-51 Canal is above 11.0 ft NGVD, Pump Station No. 3 can discharge at a rate of 133.5 cfs for four hours per day. Basin B has two pumps as described in **Table 32**. Section 24 has two gated structures. The gates are always closed except as indicated in **Table 33**.

Table 32. ACME Basin B Pump Capacity and Control Trigger Elevations

Pump ID	Capacity cfs	ON Elevation ft NGVD	OFF Elevation ft NGVD
Pump Station No. 8	133	13.2	13.0
Section 24	200	12.2	12.0 or if stage in Section24 is above 16.0- ft NGVD

Table 33. ACME Section 24 Structure and Control Trigger Elevations

Section 24 Structure	Diameter ft	OPEN Elevation ft NGVD
South Gate	5	If C-1 Canal stage is below 12.2 ft NGVD
North Gate	5	When Section 24 stage is above 12.0 ft NGVD and C-1 Canal stage is below 13.5 ft NGVD

There are five control structures on Pierson Road with a fixed weir and an operable bleeder gate as described in **Table 34**.

Table 34. Pierson Road Control Structures Weir and Gate Size

Control Structure ID	Fixed Weir Length ft	Weir Elevation ft NGVD	Gate Size Width (ft) x Height (ft)	Gate status for flood control
No. 40	45	13.0	4 x 4	Closed
No. 42	35.5	13.0	4 x 4	Closed
No. 42	9.5	12.0	4 x 4	Closed
No. 43	45	13.0	4 x 4	Closed
No. 44	45	13.0	4 x 4	Closed
No. 45	45	13.0	4 x 4	Closed

4.8.6 LOXAHATCHEE GROVES WATER CONTROL DISTRICT (LGWCD)

The operations of the LGWCD structures as stated in its permit objectives are summarized as follows:

Discharges only occur when the stage in sub-basin 11 reaches or exceeds elevation 16.0 ft NGVD and the stage in the C-51 Canal is lower than 16.0 ft NGVD.

The D road structure is the primary outfall. It is opened first, followed by the A road structure and then the G road structure.

At the D Road structure, the gates open one at a time. Gate 1 opens first as needed to achieve the maximum permitted flow of 337 cfs, all the way if necessary. If the maximum permitted discharge is not reached, gate 2 opens until the total flow reaches 337 cfs.

If both gates at D road are open all the way (seven feet) and the total discharge is still less than 337 cfs, the gate at the A Road structure opens until the total flow between both structures equals the permitted rate.

If structure overflow occurs, the gate openings account for this. Once the gates are all closed, however, no additional actions are taken to address any overflow.

For simplicity, the G Road structure is not used in the model. However, it would in reality be opened if both the D and A road structures could not produce the permitted flow. In such a case it would open last and close first.

If the permitted discharge is exceeded, the gates close in reverse order until the flow is reduced to 337 cfs.

4.8.7 INDIAN TRAIL IMPROVEMENT DISTRICT (ITID)

Operations of the ITID control structures for flood control are described in detail in the Memorandum of Agreement (MOA) between the District and ITID (SFWMD-ITID, 1997, 1998). ITID flood control releases to the M-1 Canal are accomplished via the 40th Street and Roach Structures located on the northern end of the M-1 Canal. ITID releases from the M-1 Canal to the C-51 Canal are through four slide gates located in the western half of the Amil gate location. According to the MOA, no discharges from ITID are allowed during emergency conditions in the C-51 Canal which correspond to the period when the gates of Structure S-155A are closed or the stages on the HW side of the M-1 Amil structure is above elevation 14.5 ft NGVD. Releases during other storm conditions are allowed as described in the MOA. ITID has requested a modification of the MOA via a proposed modification to Environmental Resource Permit (ERP) 50-00761-S, Application No. 130628-6, which includes increasing releases during restrictive conditions to 200 cfs. This release from ITID Sub-basin 15B is included in the 2015 Baseline model.

4.9 BOUNDARY AND INITIAL CONDITIONS

Boundary conditions in the C-51 Canal have been modified from those in the 2004 model as described below.

At the tidal end of the canal, a fixed stage of elevation 4.6 ft NGVD has been added to the model in place of the Normal Depth condition of the 2004 model. This water elevation was obtained from the recorded stages (1985-2013) at the TW side of structure S-155 and corresponds to the highest observed 15-min stage observed in October of 2004 (Hurricane Jeanne). This value is used conservatively as a constant stage throughout the duration of the simulated events.

Canal upstream boundary flows are used in the model to provide model stability during simulation runs. At the western end of the C-51 Canal, the 2004 model has a constant flow of 300 cfs for the duration of the simulation as external boundary condition. For the new baseline, this flow is assumed to be the discharged through the S-5AE structure at the rate of 300 cfs whenever structure S-155A is discharging to the east and equals zero when the S-155A structure is closed.

At the upstream end of the other canals in the model including the ITID M-1 and M-2 Canals, the Homeland Canal, LWDD equalizer/lateral E-1 to E-4 and L-5 to L-10 Canals and the Stub Canal, inflow hydrographs with values ranging between 10 to 30 cfs from the 2004 model were also used in the new baseline runs.

In addition to boundary conditions, initial water levels and flows were specified throughout the canal system and in the storage areas connected to the canals. The initial canal reach inflows for the new baseline runs summarized in **Table 35** along the C-51 Canal were taken from the 2004 study. Initial stage elevations also taken from the 2004 study with the exception of sub-basins 13 and 14 (ACME basins A and B) whose initial stages were set at their corresponding control elevations and sub-basin 38, which had to be adjusted due to instability in the model. The model initial sub-basin elevations are summarized in **Table 36**.

Table 35. Initial Canal Flows for HEC-RAS Model Calibration

River	Reach	River Station	Initial Flow (cfs)
C1	R1	20000	10
C51	R1	109730	300
	R2	92708	300
	R2	93049	300
	R3	67607	300
	R4	57302	100
	R5	56384	100
	R6	48108	200
	R7	33441	200
	R8	14723	200
	R9	13784	200
	R10	9168	200
	R10	9138	200
	R11	6281	200
E1N	RE1N	5185	20
E1S	RE1S	51128	30
E2N	RE2N	10459	20
E2S	RE2S	20300	20
E3N	RE3N	10629	20
E3S	RE3S	20000	25
E4	RE4	12005	20
	RE4b	6663	40
L10	RL10	11653	20
L5	RL5	8900	20
L7	RL7	10030	20
L8	RL8	11971	20
M1	RM1	21173	10
M2	RM2	21100	20
Stub Canal	RSC	16726	20

Table 36. Initial Sub-basin Stages for HEC-RAS model Calibration Run

C-51 West	
Sub-basin ID	Initial Stage ft NGVD
1	8.5
2A	11.0
2B	10.0
3	11.5
4	11.5
5	11.0
6	14.0
7	13.5
8	16.0
9	13.5
10	15.0
11	14.5
12	12.5
13	11.0
14	12.0
15A	12.5
15B	14.5
16A	12.5
16B-1	17.5
16B-2	18.0
16B-3	16.5
Sec24	12.0

C-51 East	
Sub-basin ID	Initial Stage ft NGVD
17	10.9
18	10.9
20A	9.5
20B	13.0
21A	14.5
21B	16.0
22	13.0
23	8.5
24	13.0
25A	8.5
25B	9.5
26	10.0
27	10.0
28	7.5
29A	8.0
29B	10.0
30	8.5
31	8.5
32	8.5
33	8.5
34	8.5
35	8.0
36	7.0
37	7.5
38	12.0
39	8.0

4.10 MODEL APPLICATION FOR BASELINE EVALUATION

The model simulations summarized in this section represent an update of the 2004 study baseline in which the hydrologic conditions of each sub-basin were established under the existing rule with the federal projects in operation including Structures S-319, S-155A, S-361 and S-362. Updating the 2004 baseline model in this study consisted of the following revisions to the 2004 C-51 model:

- Revision of the topographic data set with the latest available LiDAR data collected since 2004. This resulted in new sub-basin stage-storage relationships in the HEC-RAS model.

- Inclusion of the latest surveyed canal cross-sections including those from the Greenhorne and O'Mara study (2006) and latest USCOE as-built drawings from the construction of the STA-1E project.

- Revision of sub-basin boundaries which, in most cases, resulted in minor changes in sub-basin storage.

- Addition of recent drainage improvements including Renaissance Project (sub-basin 29A), L-2 Pump Station (between Sub-basins 25B and 29A), Garden Avenue outfall (Sub-basin 37) and Palm Beach Zoo outfall (Sub-basins 36)

- Redirection of ACME Basin B discharges from the Water Conservation Area (WCA) to the C-51 Canal.

- Revision of C-51 Canal boundary conditions such as at the tidal end of the canal which in the 2004 model was changed from normal depth to a specified water (tide) elevation.

- Incorporation of the District's rating flow equations to compute flows at structures S-155 and S-155A and at the ITID's 40th Street and Amil gated structures in the M-1 Canal.

- Incorporation of District's latest operating rules for flood control in the C-51 Basin. In the 2004 model runs, both structures S-155 and S-155A were not operated according to the District's protocols for pre- and post-storm conditions. The S-155 structure was simulated as open and the S-155A structure was completely closed. The application of flood operations allows for limited releases from structure S-155A to tide early in the storm event prior to closure of the structure. These pre-peak storm releases may have an effect in peak flood stage and discharges from the C-51 West sub-basins.

- Included several overflow connections to simulate road overtopping between adjacent sub-basins and from sub-basins to the C-51 Canal.

- Calibrated the revised model with data from TS Isaac (September 2012)

- The revised baseline presents the model results for the 10-yr, 72hr and 100-yr, 72-hr design storm events with the sub-basin outlet structures as built (**Tables 27A and 27B**) with no additional restrictions imposed. Peak stages and flow discharges from these structures may differ from those established in the current basin rule (SFWMD, 2004) and shown in **Table 37**. In the 2004 study a model run was made in which the flows from the sub-basin were restricted to match those of the basin rule (restricted flow).

4.10.1 PEAK DISCHARGE SIMULATION FOR BASELINE

The C-51 Model was applied to the 10-yr, 72-hr design storm event with restricted flow through the sub-basin outlet structures for all structures with operable control to limit their peak discharge at the allowable discharge established in the current Basin Rule. The only exception was for sub-basin 15B (ITID Lower M-1 Basin) whose discharge to the C-51 Canal is permitted under the conditions of the SFWMD-ITID MOA (1997, 1998) with a modification to allow a maximum discharge of 200 cfs to the M-1 Canal and eventually to the C-51 Canal during restrictive conditions. The discharge restrictions from this sub-basin are consistent with the proposed modification to ERP 50-00761-S, Application No. 130628-6. Gravity-driven and pumped outlet structures were not restricted in this run. Model results for this run are summarized in **Table 38** which shows the results for the 2004 and 2015 model runs for comparison with the current basin rule. The values of peak stages are included for information purposes only.

4.10.2 PEAK STAGE SIMULATION FOR BASELINE

The C-51 model was applied to the 100-yr, 72-hr design storm event with unrestricted flow through all the sub-basin outlet structures. The basin outlet structures that have operable controls such as gates, were set up in the HEC-RAS model to allow full discharge capacity limited only by the physical characteristics of the structure without operational restrictions, with the exception of ITID's 40th Street outfall to the M-1 Canal which has an on-peak allowable discharge of up to 200 cfs according to the latest permit (ERP 50-00761-S, Application No. 130628-6). The flood control operational rule for this structure was fully coded in the model. District structures S-5AE, S-319, S-155A and S-155 were also programmed to follow current flood control operations established by the Operations Department of the District.

The computed 100-yr peak stages values are summarized in **Table 39** which includes the computed peak stages of the 2004 and 2015 model results for comparison to the peak stages under the current basin rule established in the Interim Guidance Memorandum (October 18, 2004). The values of peak flows are included for information purposes only.

Table 37. Summary of C-51 Basin Rule (1987) and Interim Guidance (2004) Flow and Stage

Sub-Basin		Area[1]		Basin Rule[2] Q (10-yr, 72-hr)		Allowable Stage (100-yr, 72-hr)	
ID	Other ID	(acres)	(sq mi)	(CSM)	(cfs)	Basin Rule[2]	Interim Guidance Memorandum[3] (ft NGVD)
1	B1	1164	1.82	27	49	18.2	14.2
2A	STA1E	6716	10.49	-[4]	-[4]	17.2	13.3
2B	B2B	1226	1.92	27	52	17.2	14.0
3	B3	579	0.91	27	24	18.3	15.8
4	B4	540	0.84	27	23	18.3	16.6
5	B5	1143	1.78	27	48	18.7	17.7
6	B6	674	1.05	24	25	21.0	19.2
7	B7	4127	6.45	24	155	21.0	19.9
8	B8	3967	6.20	54	335	22.0	20.8
9	B9	73	0.11	24	3	21.0	18.0
10	B10	208	0.32	0	0	20.1	18.3
11	B11	8138	12.71	27	343	20.2 – 21.0	19.1
12	B12	74	0.12	27	3	20.2	17.9
13	B13	10538	16.46	18	296	17.5	16.7
14	B14	9270	14.48	-	-	-	-
15A	B15A	5117	7.99	70	560	19.0	18.2
15B	B15B	8641	13.50	-	-	-	-
16A	B16A	1064	1.66	0	0	18.1	17.1
16B	B16B	2449	3.83	0	0	19.1	19.0
17	B17	1651	2.58	27	70	18.0	16.8
18	B18	2295	3.58	27	97	17.9	16.0
20A	B20A	1139	1.78	0	0	18.1	16.5
20B	B20B	2342	3.66	16	59	18.3	17.0
21A	B21A	3540	5.53	0	0	19.8	17.3
21B	B21B	5056	7.90	0	0	19.8	17.7
22	B22	7375	11.52	35	403	19.0	17.5
23	B23	4207	6.57	35	230	19.1	17.1
24	B24	5282	8.25	35	289	19.3	17.9
25A	B25A	206	0.32	35	11	16.6	14.6
25B	B25B	972	1.52	35	53	16.6	14.7
26	B26	376	0.59	35	21	15.9	13.8
27	B27	831	1.30	35	45	15.6	13.2
28	B28	223	0.35	35	12	15.6	12.4
29A	B29A	1578	2.46	35	86	15.6	14.8
29B	B29B	440	0.69	35	24	15.6	15.2
30	B30	1153	1.80	35	63	16.4	14.1
31	B31	1468	2.29	35	80	15.2	13.1
32	B32	1813	2.83	35	99	15.3	13.0
33	B33	2324	3.63	35	127	15.3	13.6
34	B34	711	1.11	35	39	20.0	17.0
35	B35	173	0.27	35	9	15.6	13.0
36	B36	603	0.94	35	33	15.7	14.0
37	B37	390	0.61	35	21	20.0	16.5
38	B38	1955	3.05	0	0	18.8	17.3
Sect 24	Sect24	401	0.62	-	-	-	-

1. Table reflects sub-basin areas in the 2004 report
2. 1987 Basin Rule
3. Peak flood stage from the Interim Guidance Memorandum (October 18, 2004)
4. Sub-basin 2A (STA-1E) not part of the C-51 Basin

Table 38. Summary of Peak Discharge Simulation Results for 2004 and 2015 Baseline

Sub-Basin ID	Area[1] (acres)	Existing Rule Peak Flow[2] (cfs)	2004 10-yr, 72-hr Event			2015 10-yr, 72-hr Event		
			Peak Stage ft NGVD	Peak Flow (cfs)	Peak Flow Diff (cfs)	Peak Stage ft NGVD	Peak Flow (cfs)	Peak Flow Diff (cfs)
1	1253	49	13.4	48	-1	18.9	48	-1
2A	6663	--	-	-	--		--	--
2B	843	35	13.1	50	15	14.6	67	15
3	446	24	15.0	26	2	15.2	26	2
4	500	23	15.8	29	6	16.5	29	6
5	1102	48	16.6	53	5	17.4	61	13
							329[3]	--
6	674	25	18.6	67	42	18.6	67	42
							196	--
7	4110	155	19.2	151	-4	19.1	133	-22
							969[4]	--
8	4086	335	19.9	260	-75	19.7	335	0
9	69	3	17.1	9	6	17.4	27	24
10	190	0	17.8	3	3	19.1	53	53
11	7975	343	18.1	1360	1071	19.1	448	105
12	74	3	16.7	35	32	19.1	89	86
13	10486	296	15.7	406	110	15.6	894	598
14	9235	--	--	-	--	15.6	--	--
15A	5161	560	17.5	826	266	16.0	1026	466
15B	8605	--	-	-	-	19.5	565[5]	--
16A	920	0	16.0	384	384	16.0	279	279
16B-1	1988	0	18.4	26	26	19.2	22	40
16B-2	57					19.4	7	
16B-3	302					19.1	40[6]	
17	1796	70	15.4	131	61	14.5	448	378
18	2309	97	15.8	384	287	14.5	305	208
20A	1011	0	14.7	322	322	15.5	146	146
20B	2168	59	16.1	535	476	16.0	545	486
21A	3535	0	16.7	0	0	17.5	0	0
21B	4915	0	17.0	111	111	17.8	159	159
22	7580	403	16.7	371	-32	16.8	497	94
23	4049	229	16.3	675	446	16.2	657	428
24	5204	289	17.1	452	163	16.9	1149	860
25A	299	17	13.8	370	353	14.7	17	0
25B	721	53	14.0	344	291	14.7	17	-36
26	332	21	13.1	107	86	13.3	213	192
27	753	42	12.0	320	278	10.9	320	278
28	201	12	11.6	270	258	11.4	233	221
29A	1394	94	13.8	309	215	13.6	839	745
29B	566	31	14.5	628	597	14.0	500	469
30	1121	63	13.0	123	60	12.5	369	306
31	1433	80	12.3	333	253	10.6	712	632
32	1804	99	12.2	278	179	10.8	470	371
33	2091	127	12.6	272	145	11.0	829	702
34	740	39	15.7	137	98	12.3	45	7
							402[7]	--
35	166	9	10.5	45	36	11.2	45	36
36	607	33	12.7	79	46	12.8	88	55
37	399	21	15.7	93	72	15.6	131	110
38	1812	0	16.2	145	145	16.9	0	0
39	552					13.4	280	--
Sect24	403	--	--	--		15.7	--	--

1. 2015 Revised sub-basins areas
2. Peak stages from 2004 Interim Guidance Memorandum
3. Overbank flow from sub-basin S5 to M-2 Canal
4. Overbank flow from sub-basin 7 to sub-basin 6 & 10
5. ITID off-peak release with on-peak release of 200 cfs
6. 16B-3 outflow (2012 baseline) = sub-basin 16B (2004 baseline)
7. Overbank flow from sub-basin 34 to C-51 Canal

Table 39. Summary of Peak Stage Simulation Results for 2004 and 2015 Baseline

Sub-Basin ID	Area[1] (acres)	Existing Rule Peak Stage[2] (ft NGVD)	2004 100-yr, 72-hr Event			2015 100-yr, 72-hr Event		
			Peak Stage ft NGVD	Peak Flow (cfs)	Peak Stage Diff with Rule (ft)	Peak Stage ft NGVD	Peak Flow (cfs)	Peak Stage Diff with Rule (ft)
1	1253	14.2	14.2	48	0.0	20.8	48	6.6
2A	6663	13.3	-	-	-		--	--
2B	843	14.0	13.8	50	-0.2	15.4	66	0.9
3	446	15.8	15.8	26	0.0	16.1	26	0.3
4	500	16.6	16.6	29	0.0	17.1	29	0.5
5	1102	17.7	17.4	80	-0.3	18.8	107 465[3]	1.1
6	674	19.2	19.2	67	0.0	18.8	67 673[4]	-0.4
7	4109	19.9	19.9	226	0.0	19.2	84 3017[5]	-0.7
8	4086	20.8	20.6	418	-0.2	20.1	831	-0.7
9	69	18.0	17.6	38	-0.4	18.8	57	0.8
10	190	18.3	18.3	17	0.0	19.2	61	0.9
11	7975	19.1	18.9	1424	-0.2	19.2	2856	0.1
12	74	17.9	17.5	52	-0.4	19.2	93	1.3
13	10486	16.7	16.6	406	-0.1	17.0	894	0.2
14	9235	-	-	-	-	17.0	--	
15A	5161	18.2	18.2	1000	0.0	18.4	1482	0.2
15B	8605	-	-	-	-	20.2	490[6]	-
16A	920	17.1	16.8	508	-0.3	18.4	427	1.3
16B-1	1988	19.0	19.0	58	0.0	20.2[7a]	65	1.2
16B-2	57					20.4[7b]	8	1.4
16B-3	302					19.9[7c]	74	0.9
17	1795	16.8	16.1	126	-0.7	16.1	615	-0.7
18	2309	16.0	16.6	534	0.6	16.1	446	0.1
20A	1011	16.5	15.7	431	-0.8	17.6	203	0.6
20B	2168	17.0	16.8	750	-0.2	17.1	706	0.0
21A	3535	17.3	17.3	0	0.0	18.0	0	0.7
21B	4915	17.7	17.7	143	0.0	18.2	177	0.6
22	7580	17.5	17.5	527	0.0	18.1	703	0.4
23	4049	17.1	17.1	849	0.0	17.4	921	0.3
24	5204	17.9	17.9	602	0.0	18.0	1421	0.0
25A	299	14.6	14.6	449	0.0	14.1	761	-0.4
25B	721	14.7	14.7	391	0.0	14.2	566	-0.5
26	332	13.8	13.8	320	0.0	14.0	320	0.2
27	753	13.2	13.2	320	0.0	14.3	320	1.1
28	201	12.4	12.3	428	-0.1	13.1	394	0.7
29A	1394	14.8	14.8	474	0.0	14.3	1245	-0.5
29B	566	15.2	15.2	830	0.0	15.0	770	-0.2
30	1121	14.1	14.1	268	0.0	13.5	679	-0.6
31	1433	13.1	13.1	670	0.0	12.7	1134	-0.4
32	1804	13.0	13.0	527	0.0	12.9	639	-0.1
33	2091	13.6	13.6	546	0.0	12.7	1286	-0.9
34	740	17.0	17.0	169	0.0	12.6	59 729[8]	-4.4
35	166	13.0	13.0	45	-1.7	13.2	45	0.2
36	607	14.0	14.0	158	0.0	14.1	225	0.1
37	399	16.5	16.4	108	-0.1	16.5	140	0.0
38	1812	17.3	17.2	151	-0.1	19.0	165	1.8
39	552	14.8[9]	---	----	---	13.5	374	---
Sect24	403	--			--	17.1	--	

1. 2015 Revised Sub-basins Areas
2. Peak stages from 2004 Interim Guidance Memorandum
3. Overbank flow from Sub-basin S5 to M-2 Canal
4. Overbank flow from Sub-basin S6 to M-2 Canal
5. Overbank flow from sub-basin S7 to sub-basin 6&10
6. ITID off-peak release with on-peak release of 200 cfs

7a,7b,7c. Sub-basin 16B was sub-divided into sub-basins 16a-1, 16B-2 and 16B-3

8. Overbank flow from sub-basin 34 to C-51 Canal
9. Sub-basin 39 was part of original sub-basin 29A

Tables 38 and 39 above summarize the computed sub-basin peak stages and outflows for the 10-yr 72-hr and the 100-yr 72-hr storm events. Peak stages in the canals are summarized in **Tables F1 through F11** in **Appendix F**. The profiles correspond to the peak stages at the location of canal cross-sections for the 10-yr 72-hr and 100-yr 72-hr storm events. The peak values represent maximum stage values and do not occur at the same time.

Table F1 summarizes the canal maximum stages in the C-51 Canal. The table runs from the eastern (tidal end) of the canal to the western end at Structure S5AE. Similar tables are included for the rest of the canals in the HEC-RAS model as described in the following table. **Figures F1 and F2** correspond to the 10- and 100-yr peak stage profiles for the C-51 Canal in **Table F1**. This figure and tables indicate that the maximum value of peak stage in the C-51 Canal occur just upstream of the S-155A Structure with maximum peak values of 15.1 ft NGVD and 18.1 ft NGVD for the 10- and 100-yr storm events respectively. Similar tables and figures are included in **Appendix F** for all the canals modeled with HEC-RAS as indicated in **Table 40**.

Table 40. Location of Canal Maximum Stage Proifiles Tables and Plots for 2015 Baseline

Canal in HEC-RAS model	Canal Reach	Table	Figures (10-yr and 100-yr profiles)
C-51	R1 through R11	Appendix F - F1	Appendix F – F1, F2
E-4	RE4, RE4b	Appendix F – F2	Appendix F – F3, F4
Stub Canal	RSC	Appendix F – F3	Appendix F – F5, F6
E-3S	RE3S	Appendix F – F4	Appendix F – F7, F8
E-3N	RE3N	Appendix F – F5	Appendix F – F9, F10
E-2S	RE2S	Appendix F – F6	Appendix F – F11, F12
E-2N	RE2N	Appendix F – F7	Appendix F – F13, F14
E-1S	RE1S	Appendix F – F8	Appendix F – F15, F16
E-1N	RE1N	Appendix F – F9	Appendix F – F17, F18
M1	RM1	Appendix F – F10	Appendix F – F19, F20
M2	RM2	Appendix F – F11	Appendix F – F21, F22

4.11 DISCUSSION OF BASELINE EVALUATION RESULTS

This section presents a brief discussion of the comparisons of computed peak flows for the 10-yr, 72-hr event and stages for the 100-yr, 72-hr events between the current basin rule and the 2004 and updated (2015) baseline. The results for the two storm events were presented in **Tables 38 and 39**.

Table 38 summarizes the differences in allowable peak discharges (from the 10-yr, 72-hr model run) between the current basin rule and the 2004 and 2015 baseline runs. The table also includes the revised (2015) sub-basin areas and the corresponding allowable discharge rate under the existing rule. In general, the computed peak discharges under the 2015 baseline are greater than the existing rule with exceptions in sub-basins 1 and 7. The largest percent increases in peak discharge relative to the current basin rule were in Sub-basins 28 and 25A which had percent increases in peak discharge of 2,150% and 2,076% respectively. The large relative increase in peak discharge in Sub-basin 12 was caused by overflow inflow from Sub-basin 11 which was not included in the 2004 study. Other sub-basins with increased allowable peak discharges are Sub-basins 30, 31, 32 and 33 in the lake Clarke Shores basin. The increase in peak discharge from these sub-basins is a result of modifying fictitious weirs at the outlet of the sub-basins placed in order to restrict flow. These weirs were lowered to match the control elevation of each sub-basin in this revision of the model since there is no physical basis for the presence of these weirs in the model other than to prevent over-drainage below the sub-basins control elevations.

In sub-basin 13, the increase in peak discharge is a result of the additional pumpage from ACME sub-basin 13 pump PS No. 7 as specified in the permit for ACME Basin B (2007). Other major differences in computed allowable discharge between the 2004 and 2015 models are also due to improvements in topographic data, structure operations and overflows between sub-basins.

Recalibration of the 2015 HEC-RAS model and unrestricted flow releases from gated structures resulted in higher peak stages in the C-51 West Canal by as much as 2.1 ft west of the S-155A structure. The peak stage increase in the 100-yr peak stages in the C-51 West Canal led to reduced peak flow releases from gravity driven structures during the 100-yr event simulation, including M-1 Canal Amil gated structure and Sub-basins S-15A, 16B, 20A, and 20B. The results for the peak stage simulation are summarized in **Table 39**, which also includes the basin rule peak stages from the Interim Guidance Memorandum for comparison to the 2004 and 2015 baseline results.

Table 39 shows that the 2004 baseline run reduced the magnitude of the Basin Rule peak stage for all the sub-basins within a range from 0.0 feet for Sub-basin 16B to -1.7 feet for Sub-basin 35. The average peak stage change for the 2004 stages was -0.5 feet with respect to the existing rule peak stages.

The 2015 baseline peak stage results do not show as much decrease of stages compared to the existing rule values. Twenty-seven (63%) sub-basins experienced increased stage ranging from 0.1 feet (sub-basin 18) to 6.6 feet (sub-basin 1) from the 2004 peak stage values. The average stage increase in peak stage from the 2004 computed values was 0.9 feet. In general, the increases in peak stage were due to reduced storage from the new topographic data, however, in six sub-basins (5, 12, 16B-1, 16B-2, 27 and 38), where the peak stage increased over one foot, overflow from adjacent sub-basins was the main cause of higher stages. For example, sub-basin 10 and 12 receive overflow from sub-basin 11 which results in all three sub-basins with peak stage of 19.2 ft NGVD. In sub-basin 1 the increase in peak stage was to correction of erroneous topographic data which in 2004 did not reflect the recent site development.

There were sixteen sub-basins with lower peak stages than the 2004 values with an average of 0.7 feet. The largest decrease in peak stage for the 100-yr simulation occurred in sub-basin 34 with a 4.4 feet peak stage decrease over the current basin rule value. In this case, the lower peak is caused by the placement of an overflow weir between the sub-basin and the C-51 Canal. Sub-basins 7 and 8 had their outlet structures updated in the model to reflect the most recent permits, which in turn resulted in lower peak stage values of 0.6 feet and 0.7 feet, respectively. Sub-basins 13 and 14 (ACME basins A and B) increased their peak stages by 0.2 ft from the Existing Rule values as a result of newer topographic data with reduced storage. Sub-basin 29A also experienced a reduction in the 100-yr peak stage of 0.5 ft from the existing Rule peak stage of 14.8 ft NGVD. This peak stage reduction was a result of inclusion of the Renaissance Project pump and out of basin storage in Clear Lake.

Maximum stage profiles for the 10-yr 72- hr and 100-yr 72-hr storm events are included in graphical and tabular form for all the modelled canals in **Appendix F**. The peak stage values in these tables correspond to the maximum computed stages at the locations of canal cross-sections in the canals and do not necessarily occur at the same time. The canal profile figures also show the canal bottom, the left and right overbanks, and the location of inline and lateral structures connecting to the C-51 Canal.

5.0 REFERENCES

SFWMD-ITID. 1997, 1998. Memorandum of Agreement (MOA) Between the Indian Trail Improvement District (ITID) and South Florida Water Management District (SFWMD).

South Florida Water Management District. 2000. Environmental Resource Permit Information Manual. Volume IV.

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South Florida Water Management District. 2008. Wilsnack, M. Flow Rating Analysis for Pump Station S-319 – Stormwater Treatment Area 1 East. Operations and Hydro Data Management Department. Technical Publication SHDM Report # 2008-003.

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US Department of Agriculture. 2004. Part 630 Hydrology National Engineering Handbook. Chapter 10 - Estimation of Direct Runoff from Storm Rainfall.

APPENDIX A: WORK PLAN FOR C-51 BASIN RULE MODEL UPDATE

Work Plan

C-51 Basin Rule Model Update

Water Resources Modeling Unit

Hydrologic & Environmental Systems Modeling Department

Table of Contents

Revision History

Document each revision made to the approved work plan.

Version#	Date	Reviser	Description of Revision
1.0		Ruben Arteaga	

Summary

The objective of this project is to update the existing C-51 hydrologic and hydraulic models, developed in 2004 by the District and updated in 2005 by the County, for the re-evaluation of the C-51 Basin Rule (SFWMD, 2004). The model data set update specifically includes improved ground elevation data, canal cross sections and newly constructed bridges. The C-51 sub-watersheds and major District structures are shown in Attachment 1. Also, the update of the models requires software upgrades of both the hydrologic (HEC-HMS) and hydraulic (HEC-RAS) models to their most recently released versions.

Requirements

The following work is requested by Jesse Markel (Client) from the Regulation Division. The Modeling Request Form associated with this modeling work is MRF # 5174 dated 11/26/12 (see Attachment 3). The requirements for this project were discussed at a meeting with Jesse Markle on 11/19/2012 and are summarized as follows:

Update the hydrologic and hydraulic modeling software previously used in the 2004 study to their most recently released versions (HEC-HMS v3.5 and HEC-RAS v4.2).

Revise basin stage vs. storage relationships with the revised ground elevations data.

Update datasets used in the hydrologic and hydraulic models to reflect current conditions in the basin. The updates to the datasets should include the most recent ground elevations, C-51 canal cross-sections, revised drainage features, structures and patterns in the western portion of the study area (ACME Basin B) and the Palm Beach County Stub canal and Renaissance project modifications.

Re-calibrate model using recent storm event data.

Perform simulation of “Existing Condition” for the 10- and 100-yr storm events. The “Existing Condition” should include the updates in item 2 above as well as the STA-1E and S-155A structure and current operations.

Summarize above tasks in a Draft Technical Memorandum which will be delivered to the Client for review and comments.

All modeling elevation data will be in NGVD29 datum.

Scope of Work

Tasks:

Task 1. Upgrade HEC Hydrologic and Hydraulic Models

Update both the hydrologic (HEC-HSM) and hydraulic (HEC-RAS) software packages to their most recent versions. Currently HEC-RAS 4.2 Beta and HEC-HMS 3.5 are available from the United States Army Corps of Engineers website. The model updates shall include a review of computation methods in the new version of HEC-RAS, such as bridge/culvert modeling routines, lateral structure modeling, and revise/correct (if necessary) any geometric data. Following the software updates, rerun the Alternative A1 (10-yr and 100-yr storms) from the C-51 Basin Rule Re-evaluation Study, (2004) matching the performance of the original study results. Document any differences between computed flows and stages between the two model runs.

Task 2. Incorporate updated ground elevation and canal geometric data

Since completion of the original C-51 Basin Rule Re-evaluation Study in 2004, additional information has become available for three components of the C-51 geometric data whose locations are shown in Attachment 2. The information is readily available and will be incorporated into the C-51 Model Upgrade. These three additional datasets are as follows:

Add ACME Basin B Discharge to the C-51 Model

ACME Basin B has recently begun discharging to the C-51 canal downstream of the S-155A structure. The Consultant shall incorporate the ACME Basin B Discharges based on information from the SFWMD Engineering and Construction Bureau on the final design and construction into the upgraded model for the 10-yr and 100-yr storms.

Add Canal Cross Sections Surveyed by Greenhorne and O'Mara (G&O)

Incorporate the cross sections surveyed by G&O into this upgraded C-51 model. These canal cross sections include surveyed cross sections of the C-51 along an 8 mile stretch from just east of the Turnpike to Ousley Sod Farm Bridge.

Add Palm Beach County Stub Canal/Renaissance Project Modifications

Mock Roos completed a project for Palm Beach County in the vicinity of the Stub Canal and the Renaissance Project. Changes that have been made in the area will be incorporated into this upgrade. These changes include:

• Revision of the external boundaries of S29B and S29A sub-watershed delineations per Mock Roos delineations in consultation with SFWMD.

• Revision of the stage-storage relationship in this basin. Since the LiDAR was flown before the control elevation was lowered to 11.5 ft, revise the stage-storage curve manually to reflect the revised control elevation of the south lobe of Clear Lake, which is 51 acres in size. Determine the average elevation of the LiDAR for the south lobe and add an appropriate Storage volume to elevations above 11.5 ft NGVD in Sub-watershed 29A. (Additional Storage = [LiDAR elevation ft NGVD – 11.5 ft] x 51 acres). Information received from Mock Roos on behalf of Palm Beach County outlining the necessary changes in the C-51 model will be provided.

Update sub-basin stage-storage relationships for the entire C-51 Basin with the most recent county-wide topographic data from the FEMA Map Modernization project accepted by the SFWMD in January 2007. This task will also include a sensitivity analysis consisting of rising and lowering the stage-storage elevations globally by 0.5 ft in order to determine the impact on the results solely based on the change in stage-storage relationships. Also, as part of this task, the left and right bank elevations of the model from the DEM should be compared to the left and right banks in the HEC-RAS model.

Include in the HEC-RAS model the latest S-155, S-155A and S-319 operating rules.

Task 3. Model Recalibration

Model recalibration should be performed to the updated models with recent storm data. The 2004 models without STA-1E and structure S-155A were calibrated with data from storm Irene in October, 1999. The updated models with ACME Basin B discharging into the C-51 Canal, pump S-319 discharging into STA-1E and the divide structure S-155A in place will have a very different response as the 2004 model, thus it is necessary to recalibrate the model with recent storm data. It is suggested to use the recent storm Isaac (August, 2012) which represents close to a 100-yr storm event and during which all the new above mentioned updates to the models were in place. Model calibration will follow the methodologies used in the original calibration of the 2004 HEC-HMS and HEC-RAS models.

Task 4. Internal Review

At the completion of the model calibration task, a report describing the model modifications and calibration procedures will be submitted to designated District staff for internal review. The review will focus only in the evaluation of the newly incorporated data set, calibration/validation procedure and model results. Deficiencies will be corrected and Client's concerns addressed before proceeding to subsequent task.

Task 5. Updated Existing (Baseline) Model Run

After model recalibration, "Existing Conditions" model runs for the 3-day 10-yr and 100-yr events will be carried out to replace the results from the 2004 baseline.

Technical Approach

Model software and data updates.

The execution of Tasks 1 through 4 above will require updating the C-51 hydrologic (HEC-HMS) and hydraulic (HEC-RAS) models developed in 2004 as part of the C-51Basin Rule development of Tasks 1 and 2 as described above. The software upgrade of the models to HEC-HSM v3.5 and HEC-RAS v4.2 beta should not result in significant differences in computed stages and flows between the 2004 and updated models since minimum changes to computational methods have taken place in the most recent releases of the software. Any differences in stages and flows between the two versions will be documented and discussed with the Client.

Upgrade the sub-basins stage-storage curves with the latest DEM data approved for FEMA related work.

Recalibrate updated models with more recent storm data. A calibration of the updated models is necessary to incorporate the effects of the Acme Basin B new discharge point into the C-51 canal, the S-155 structure and, more importantly, the diversion of storm water from the C-51 canal to the STA-1E. These projects were not present in the model in the 2004 version when it was last calibrated.

After model has been reviewed by the Client and other District staff, comments will be addressed to correct and/or improve model's accuracy and performance.

Re-run updated "Existing Condition" for the 3-day 10- and 100-yr storm events.

Prepare Draft Technical Memorandum with updated discharge coefficients for the 3-day 10-yr and peak stages for the 3-day 100-yr event.

Modeling Assumptions:

Off-peak releases from the Indian Trail improvement District (ITID) will not be included in the model.

Cell storage and internal structures in the STA-1E will not be simulated individually; instead, the total cell storage will be used.

Structure S-5AE at the western end of the C-51 canal will be simulated as a flow boundary condition in HEC-RAS.

Tidal stages will be imposed at the eastern end of the C-51 canal as a boundary condition.

Initial conditions for each storm event will be same as in the original 2004 C-51 Basin Rule study.

Achieving Objectives

After each task's completion a meeting will be scheduled with the Client to discuss the results and request comments.

Timeline

This project will have duration of nine months, starting the first week of January, 2013 and ending on September 30, 2013. The duration and completion date for each task is shown in Section 5.

Progress Reporting

Monthly progress meetings will be held in addition to meetings at the end of task completions.

Risk Management

There is a small risk of obtaining different results (water levels and flows) when upgrading the software for the hydrologic and hydraulic models (HEC-HSM and HEC-RAS) to their most current versions. Although HEC has not significantly changed computational methods for culverts and bridges, differences may be significant.

Calibration will be limited to using data for one storm event (Hurricane Isaac – August, 2012) and parameter adjustment to history match flows and stages will be limited to runoff curve numbers and canal roughness coefficients.

Model acceptance by external stakeholders will have to be added as a separate task to this Work Plan. Stakeholder involvement includes model review of updated modeling work, coordination to add additional data or projects from stakeholders and meetings and presentations.

Potential resource conflicts with higher priority projects may result in schedule slippage.

Resources

Name	**Role / Responsibilities**	**Internal Labor Hours**
Ken Konyha	Technical lead	80
Ruben Arteaga	Project Manager, Modeler	430
Chen Qi	Modeler, GIS	550
Jun Han	Modeling support, data processing, graphics	380

Deliverables Schedule

Task #	**Deliverable**	**Due Date**
1	A letter report documenting the changes made to the HEC-HMS v3.5 and HEC-RAS v4.2 to run in a current District computer with Windows XP and Service Packs 1 and 2. The results shall include the stages and flows for the 3-day 10-yr and 100-yr storm events comparison with the results from the 2004 Re-evaluation of the C-51 Basin Rule.	Feb 15, 2013
2	A letter report documenting 1) the changes incorporated into the HEC-HMS and HEC-RAS models, 2) the changes and differences in the results from Task 1 as a result of the data revisions (incorporating ACME Basin B discharge to the C-51 canal, the surveyed cross sections and the Stub Canal/Renaissance Project modifications) and the new stage-storage relationships; 3) the sensitivity of the model to the elevation	April 15, 2013

	data used to derive the stage-storage relationships; 4) an assessment of the need for recalibration prior to further modifications and model application; and 5) a work plan for recalibration of the models (HEC-HMS and HEC-RAS).	
3	A letter report documenting the calibration process, modifications, and results, including how the Task 2 model will be revised based on the calibration. The letter report shall incorporate the comments from the internal review.	May 31, 2013
4	A letter report documenting the changes made to run the Existing Conditions configuration and differences in the results against the Task 2 results.	July 15, 2013
5	A Draft Technical Memorandum documenting all of the above tasks for review and comments. The Technical Memorandum shall also describe the limitations and assumptions used in the model development. Included in this deliverable will be the C-51 discharge coefficients for the 3-day 10-year storm event; flood elevations for the 3-day 100-year storm event; tabular information on discharge coefficients and flood stages within the sub-basins; and revised Figures 41-8 and 41-9 of Rule 40E-41.263 based on Task 5 and an interim guidance set of tables and figures based on Task 6. The Client will have two weeks to provide comments. A follow up meeting will be set-up to discuss and review any comments or issues. The Final Technical Memorandum will then be prepared with all issues, concerns and comments addressed and resolved. The final submittal shall also include electronic submittals of all models, comparison tables, meeting minutes, correspondence, technical notes, GIS and excel files used for the study and/or in preparation of the letters and final reports.	Sep 16, 2013
6	Project closeout meeting	Sep 30, 2013

Cost

Task #	Task / Deliverable	Hours	Cost
	N/A--no costs are expected for this work effort other than internal labor		

Approvals

___________________________ __________________

HESM Unit Leader Date

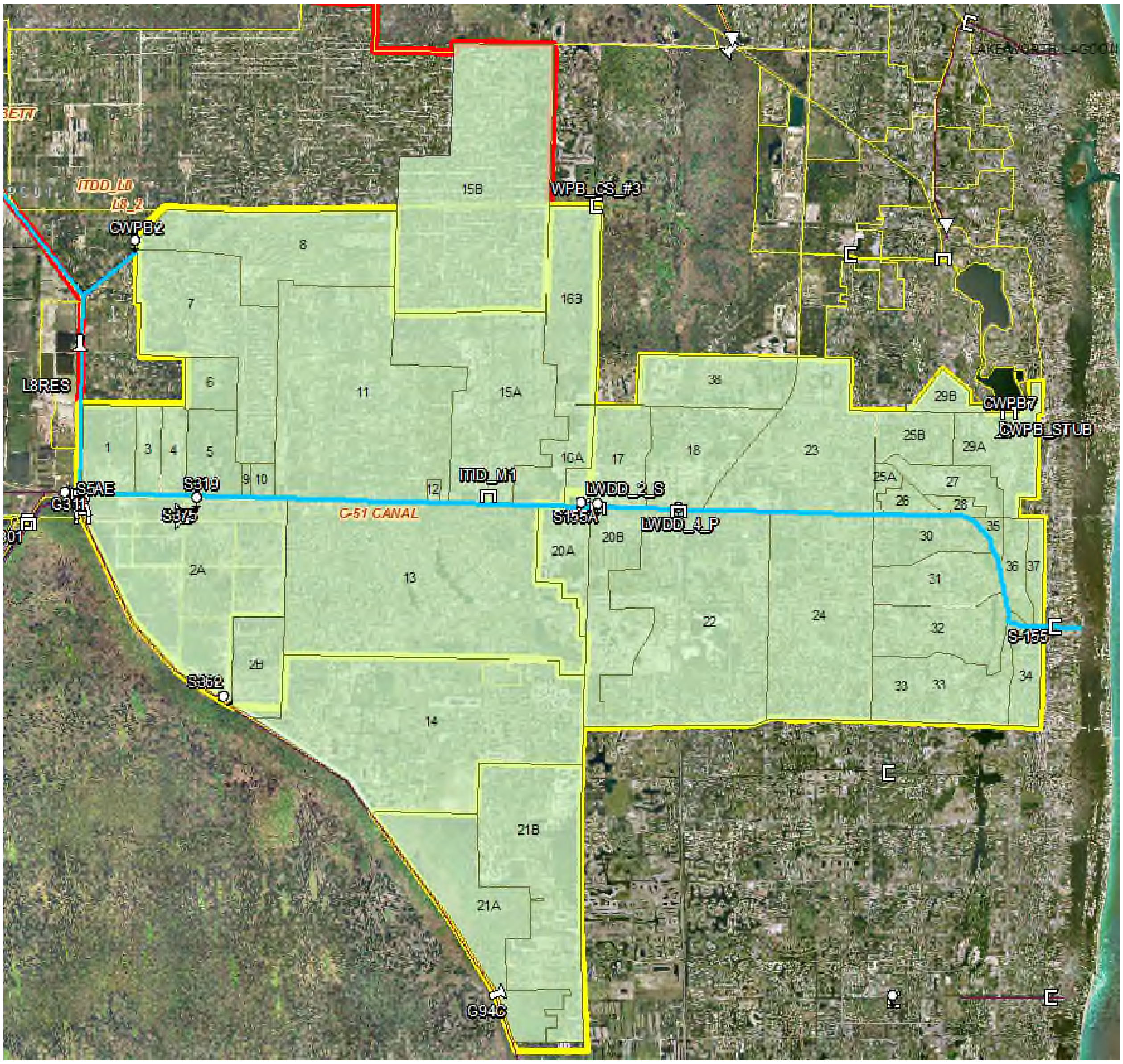
___________________________ __________________

HESM Section Administrator Date

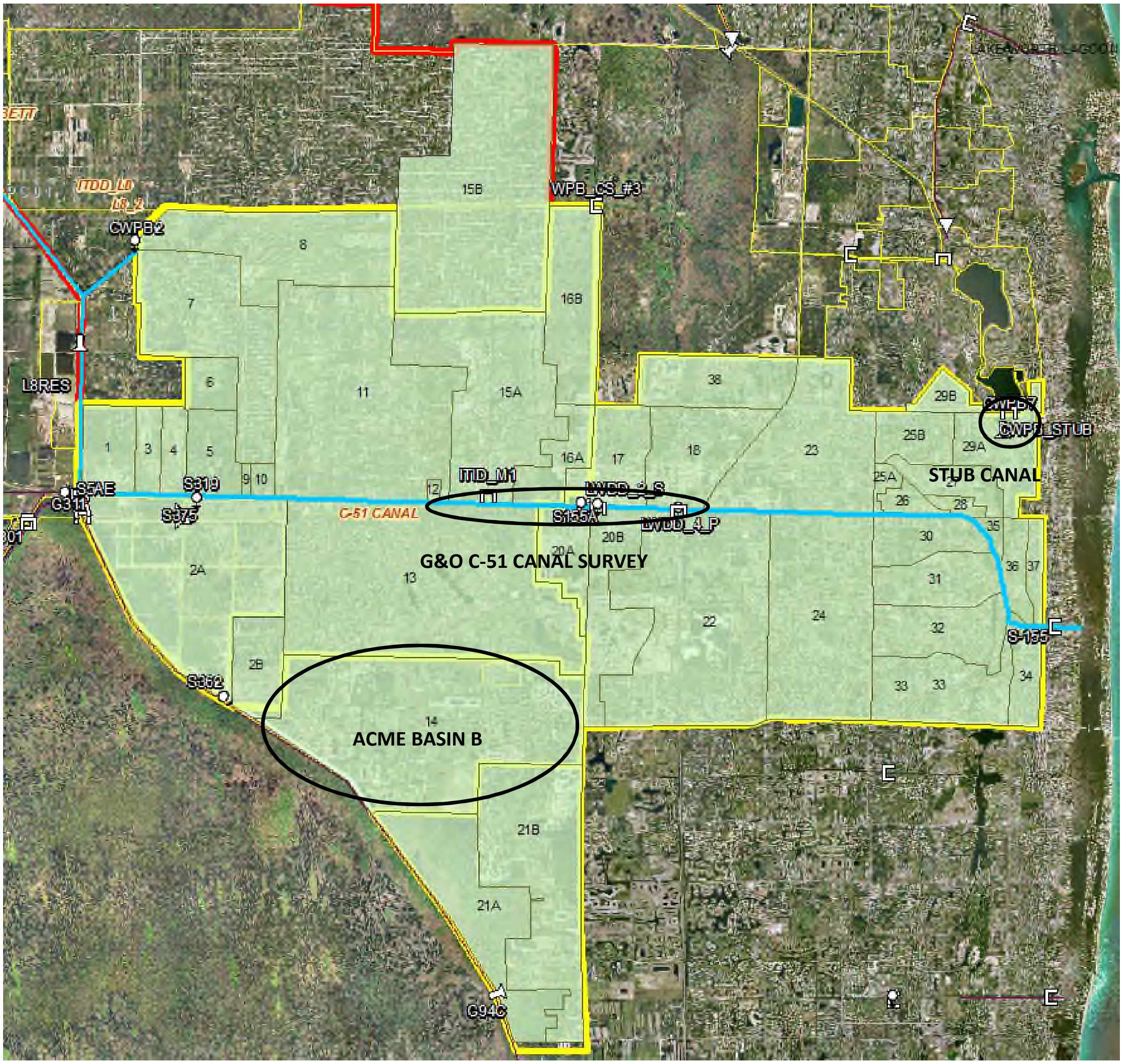
Attachments

ATTACHMENTS

Attachment 1 **. 2004 C-51 Basin Rule Sub-basins and Structures**



Attachment 2. Additional Dataset Updates for HEC_RAS Model


15B
WPB_CS_#3
CWPB2
8
7
16B
L8RES
6
11
15A
38
29B
CWPB7
CWPB_STUB
1
3
4
5
16A
17
18
23
25B
29A
STUB CANAL
9
10
12
ITTD_M1
25A
26
28
S319
LWDD_3_S
S155A
LWDD_4_P
C-51 CANAL
35
S375
20B
30
20A
G&O C-51 CANAL SURVEY
2A
13
36
37
31
22
24
32
S-155
2B
S362
33
33
34
14
ACME BASIN B
21B
21A
G94C
C-51 CANAL

Attachment 3. Modeling Request Form (MRF # 5174)

Modeling Request Form

Tracking#: 5174	**CERP Project:** No

Requestor Information

Today's Date:	11/26/2012	*** Due Date:**	01/11/2013
*** Requestor:**	JESSE MARKLE	*** Requestor Phone#:**	561-682-6873
*** Requestor E-mail:**	jmarkle@sfwmd.gov	*** Section Administrator:**	Anita Bain
*** Org. / Dept. Name:**	Regulation Department	*** Section Admin. E-mail:**	abain@sfwmd.gov

Project Information

*** Project Name:**	C-51 BASIN RULE DEVELOPMENT SOW		
*** Project Manager:**	Jesse Markle	*** Phone #:**	561-682-6873
SAP-PS Project#:	N/A	**Business Area:**	3210
Timesheet Code:		**Functional Area:**	HA00

Work Description

*** Request Type:** Other

*** Brief Description of Requested Work:** Develop SOW and time estimate for updates/revisions to the C-51 Basin model (HEC-HMS & HEC-RAS) to support completion of the C-51 Basin Rule Development as discussed w/ Ken Konyha and Ruben Arteaga of HESM and Jesse Markle of Regulation on 11/19/12, and based on a draft SOW prepared by Suelynn Kirkland in 2008.

Attachments: **File:** 2007_2008 Draft SOW, cost estimate, and final SOW.pdf

Description: Draft SOW, cost estimate and final SOW from 2008

HESM Director: ____

Print

APPENDIX B: TASK 1 – HEC-HMS AND HEC-RAS MODEL SOFTWARE UPGRADE

TASK 1-HEC-HMS AND HEC-RAS MODEL UPGRADE

In 2004, The District completed the C-51 Basin Rule study in which regulatory peak stages and flow discharges were computed for all the sub-basins in the C-51 watershed using HEC-HMS v 2.2.1 and HEC-RAS v3.1.1. Task 1 of the study consists of upgrading the HEC-HMS and HEC-RAS models to their most recent version. The 2004 HEC-RAS model was developed with version v 3.1.1 of HEC-RAS which only runs under Windows XP without Service Packs 1 and 2. Standard Windows XP include Service packs 1 and 2 and in order to run the 2004 model these two software patches have to be removed from the system, which is not feasible in an network enterprise system such as the District's. For this reason, the models have to be upgraded to their most recent versions running under Windows XP with Service Packs 1 and 2.

SOFTWARE UPGRADE

The most recent versions of HEC-HMS and HEC-RAS released by the USACE are v3.5 and 4.1 respectively which have many enhancements and modifications to their previous versions (HEC-HMS 2.2.1 and HEC-RAS 3.1.1.)

The objectives of this task were completed by executing the actions listed next.

- Modify input files for the C-51 Basin Rule models developed in 2004 and modified in 2006 to be accepted by the latest version of HEC-HMS v3.5 and HEC-RAS v4.1.

- Run the C-51 Basin Rule models for the 10-, 25- and 100-yr events and compare the computed peak stages and flows with the results from the 2006 version of the model.

- Develop tables for peak stage and discharges and corresponding differences between 2004 and newly computed values.

The following sections of the report document the software process and modifications to the model's input files necessary to make them run in their current versions under Windows XP with Service Packs 1 and 2.

HEC-HMS UPGRADE

The upgrade of the C-51 Basin Rule HEC-MHS files consisted on uploading the most recent version of the software v.3.5 and read the import files from the v2.1.1 version. There has been no reported changes in the algorithms used to compute the runoff with the SCS curve number method from version v2.1.1 to version v3.5. After reading the input HEC-HMS input files from the C-51 Basin Rule project (2006), results from the computation of runoff volume and peak flow values for each sub-basin indicate virtually no difference between the results from the two versions of HEC-HMS. **Table B-1** summarizes the peak discharges and volumes for the 10-yr 72-hr and 100-yr 72-hrstage and volume events.

HEC-RAS UPGRADE

The upgrade of the C-51 HEC-RAS model from version 3.1.1 to version 4.1 required several modifications to the input files just to get it to run. After the model was modified to run in version 4.1, the results from v3.1.1 (peak stage and maximum discharge per sub-basin) were compared against the results from v4.1. **Table B-2** summarizes the differences in computed stages and flows between the two versions of then model. **Table B-2** also includes a column with the difference in computed peak stages and percent difference in peak flows with respect to the v3.1.1 values. The table highlights in yellow the sub-basins with differences greater than 0.1 ft in peak stage or greater than 10% in peak flow. The sub-basin with the largest difference in computed 100-yr 72-hr peak stage are S28 (PBIA) and S32 with a difference of 0.4 ft and, for 10-yr 72-hr peak flow, sub-basin S32 (LWDD - Lake Clark) has the largest percent difference of 42%.

Table B- 1. Computed Peak Stages and Peak Discharge Rates with HEC-HMS v2.1.1 and v3.5 (Baseline C-51 East and West)

		HEC-HMS v2.2.1				HEC-HMS v3.5			
Sub-basin	Drainage Area (mi^2)	10-yr Peak Discharge (cfs)	10-yr Volume (inches)	100-yr Peak Discharge (cfs)	100-yr Volume (inches)	10-yr Peak Discharge (cfs)	10-yr Volume (inches)	100-yr Peak Discharge (cfs)	100-yr Volume (inches)
B1	1.82	1157	7.1	2036	12.9	1157	7.1	2036	12.9
B10	0.32	241	8.1	405	14.2	241	8.1	405	14.2
B11	12.71	5203	7.6	8955	13.6	5203	7.6	8955	13.6
B12	0.12	164	8.5	272	14.6	164	8.5	272	14.6
B13	16.46	6998	8.1	11797	14.2	6998	8.1	11797	14.2
B14	14.48	6613	7.4	11480	13.3	6613	7.4	11480	13.3
B15A	7.99	3373	8.5	5603	14.6	3373	8.5	5603	14.6
B15B	13.5	5067	7.7	8689	13.7	5067	7.7	8689	13.7
B16A	1.66	1029	8.2	1722	14.3	1029	8.2	1722	14.3
B16B	3.83	1322	8.8	2177	14.9	1322	8.8	2177	14.9
B17	2.58	1632	8.4	2718	14.5	1632	8.4	2718	14.5
B18	3.58	2333	8.3	3906	14.3	2333	8.3	3906	14.3
B20A	1.78	1220	7.9	2069	13.9	1220	7.9	2069	13.9
B20B	3.66	1981	8.0	3355	14.0	1981	8.0	3355	14.0
B21A	5.53	2508	9.6	4054	15.8	2508	9.6	4054	15.8
B21B	7.9	3322	7.6	5732	13.5	3322	7.6	5732	13.5
B22	11.52	4848	7.9	8240	13.9	4848	7.9	8240	13.9
B23	6.57	3566	8.0	6031	14.1	3566	8.0	6031	14.1
B24	8.25	3935	8.1	6647	14.1	3935	8.1	6647	14.1
B25A	0.32	376	7.6	644	13.6	376	7.6	644	13.6
B25B	1.52	1586	7.8	2698	13.8	1586	7.8	2698	13.8

Table B-1. Computed Peak Stages and Peak Discharge Rates with HEC-HMS v2.1.1 and v3.5 (Baseline C-51 East and West) (Cont.)

		HEC-HMS v2.2.1				HEC-HMS v3.5			
Sub-basin	Drainage Area (mi^2)	10-yr Peak Discharge (cfs)	10-yr Volume (inches)	100-yr Peak Discharge (cfs)	100-yr Volume (inches)	10-yr Peak Discharge (cfs)	10-yr Volume (inches)	100-yr Peak Discharge (cfs)	100-yr Volume (inches)
B26	0.59	548	7.9	928	14.0	548	7.9	928	14.0
B27	1.3	878	8.4	1465	14.5	878	8.4	1465	14.5
B28	0.35	474	8.2	793	14.3	474	8.2	793	14.3
B29A	2.46	2615	8.0	4420	14.0	2615	8.0	4420	14.0
B29B	0.69	723	8.5	1198	14.6	723	8.5	1198	14.6
B2A	10.49	4149	9.8	6698	16.0	4149	9.8	6698	16.0
B2B	1.92	1866	7.3	3241	13.3	1866	7.3	3241	13.3
B3	0.91	628	7.3	1094	13.2	628	7.3	1094	13.2
B30	1.8	1664	7.7	2839	13.7	1664	7.7	2839	13.7
B31	2.29	2160	7.9	3660	13.9	2160	7.9	3660	13.9
B32	2.83	1879	8.0	3176	14.1	1879	8.0	3176	14.1
B33	3.63	2677	7.9	4539	13.9	2677	7.9	4539	13.9
B34	1.11	715	7.4	1239	13.3	715	7.4	1239	13.3
B35	0.27	407	8.2	683	14.3	407	8.2	683	14.3
B36	0.94	735	7.1	1290	13.0	735	7.1	1290	13.0
B37	0.61	463	6.8	825	12.6	463	6.8	825	12.6
B38	3.05	2372	8.5	3936	14.6	2372	8.5	3936	14.6
B4	0.84	544	7.4	943	13.4	544	7.4	943	13.4
B5	1.78	1272	7.7	2180	13.6	1272	7.7	2180	13.6
B6	1.05	1049	8.1	1768	14.1	1049	8.1	1768	14.1
B7	6.45	2676	7.5	4627	13.5	2676	7.5	4627	13.5
B8	6.2	3000	7.5	5182	13.5	3000	7.5	5182	13.5
B9	0.11	139	7.5	239	13.5	139	7.5	239	13.5

Table B-2. Computed Peak Stages for 10- and 100-yr 72-hr storm events with HEC-RAS v3.1.1 and v 4.1 (Baseline C-51 East and West)

	100-yr, 72-hr Stage (ft NGVD)			100-yr, 72-hr Peak Flow (cfs)			10-yr, 72-hr Stage (ft NGVD)			10-yr, 72-hr Peak Flow (cfs)		
Basin ID	HEC-RAS 3.1.1	HEC-RAS 4.1	Diff (ft)	HEC-RAS 3.1.1	HEC-RAS 4.1	%Diff	HEC-RAS 3.1.1	HEC-RAS 4.1	Diff (ft)	HEC-RAS 3.1.1	HEC-RAS 4.1	%Diff
1	14.2	14.2	0.0	48	48	0%	13.4	13.4	0.0	48	48	0%
2A	--	--	--	--	--	--	--	--	--	--	--	--
2B	13.8	13.8	0.0	50	50	0%	13.1	13.1	0.0	50	50	0%
3	15.8	15.8	0.0	26	26	0%	15	15.0	0.0	26	26	0%
4	16.6	16.6	0.0	29	29	0%	15.8	15.8	0.0	29	29	0%
5	17.4	17.4	0.0	80	80	0%	16.6	16.6	0.0	53	49	-7%
6	19.2	19.2	0.0	67	67	0%	18.6	18.6	0.0	67	67	0%
7	19.9	19.9	0.0	226	226	0%	19.2	19.2	0.0	151	151	0%
8	20.6	20.6	0.0	418	418	0%	19.9	19.9	0.0	260	260	0%
9	17.6	17.6	0.0	38	38	0%	17.1	17.1	0.0	9	9	0%
10	18.3	18.3	0.0	17	18	3%	17.8	17.8	0.0	3	3	0%
11	18.9	18.9	0.0	1424	1419	0%	18.1	18.1	0.0	1360	1362	0%
12	17.5	17.6	0.1	52	52	0%	16.7	16.7	0.0	35	35	0%
13	16.6	16.6	0.0	406	406	0%	15.7	15.7	0.0	406	406	0%
14	--	--	--	--	--		-	--	--	--		
15A	18.2	18.3	0.1	1000	874	-13%	17.5	17.6	0.1	826	679	-18%
15B	--	--	--	--	--	--	--	--	--	--	--	--
16A	16.8	16.8	0.0	508	528	4%	16	16.0	0.0	384	404	5%
16B	19	19.0	0.0	58	58	0%	18.4	18.4	0.0	26	26	0%
20A	16.1	16.0	-0.1	126	133	6%	15.4	15.1	-0.3	131	123	-6%
17	16.6	16.6	0.0	534	533	0%	15.8	15.8	0.0	384	384	0%
18	15.7	15.8	0.1	431	404	-6%	14.7	14.7	0.0	322	304	-6%

Table B-2. Computed Peak Stages for 10- and 100-yr 72-hr storm events with HEC-RAS v3.1.1 and v 4.1 (Baseline C-51 East and West) (Cont.)

	100-yr, 72-hr Stage (ft NGVD)			100-yr, 72-hr Peak Flow (cfs)			10-yr, 72-hr Stage (ft NGVD)			10-yr, 72-hr Peak Flow (cfs)		
ID	HEC-RAS 3.1.1	HEC-RAS 4.1	Diff (ft)	HEC-RAS 3.1.1	HEC-RAS 4.1	%Diff	HEC-RAS 3.1.1	HEC-RAS 4.1	Diff (ft)	HEC-RAS 3.1.1	HEC-RAS 4.1	%Diff
20B	16.8	16.9	0.1	750	695	7%	16.1	16.1	0.0	535	535	0%
21A	17.3	17.3	0.0	0	0		16.7	16.7	-0.1	0	0	0%
21B	17.7	17.7	0.0	143	127	-11%	17	17.0	0.0	111	105	6%
22	17.5	17.5	0.0	527	528	0%	16.7	16.7	0.0	371	371	0%
23	17.1	17.1	0.0	849	850	0%	16.3	16.3	0.0	675	676	0%
24	17.9	17.9	0.0	602	603	0%	17.1	17.2	0.1	452	455	1%
25A	14.6	14.6	0.0	449	452	1%	13.8	13.9	0.1	370	374	1%
25B	14.7	14.7	0.0	391	364	-7%	14	14.0	0.0	344	322	-6%
26	13.8	13.8	0.0	320	320	0%	13.1	13.1	0.0	107	107	0%
27	13.2	13.2	0.0	320	320	0%	12	12.0	0.0	320	320	0%
28	12.3	12.6	0.3	428	503	18%	11.6	12.0	0.4	270	359	33%
29A	14.8	14.8	0.0	474	476	0%	13.8	13.8	0.0	309	311	1%
29B	15.2	15.2	0.0	830	773	-7%	14.5	14.5	0.0	628	628	0%
30	14.1	14.1	0.0	268	269	0%	13	13.0	0.0	123	123	0%
31	13.1	13.2	0.1	670	722	8%	12.3	12.6	0.3	333	451	35%
32	13	13.2	0.2	527	591	12%	12.2	12.6	0.4	278	394	42%
33	13.6	13.7	0.1	546	564	3%	12.6	12.7	0.1	272	299	10%
34	17	17.0	0.0	169	138	-19%	15.7	15.7	0.0	137	124	-9%
35	11.3	11.3	0.0	45	45	0%	10.5	10.5	0.0	45	44	-2%
36	14	14.2	0.2	158	168	6%	12.7	13.0	0.3	79	107	36%
37	16.4	16.5	0.1	108	75	-31%	15.7	15.7	0.0	93	70	-24%
38	17.2	17.2	0.0	151	144	-5%	16.2	16.3	0.1	145	143	-2%

APPENDIX C: METADATA FOR THE PB_SFWMD_V4 DIGITAL ELEVATION MAP

DESCRIPTION:

Horizontal coordinate system

Projected coordinate system name: NAD_1983_StatePlane_Florida_East_FIPS_0901_Feet

Geographic coordinate system name: GCS_North_American_1983

Details

Altitude System Definition

Datum Name: North American Vertical Datum of 1988

Resolution: 10

Distance Units: feet

Encoding Method: Explicit elevation coordinate included with horizontal coordinates

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Bounding coordinates

Horizontal

In decimal degrees

West: -80.626305

East: -80.023728

North: 26.974255

South: 26.311202

In projected or local coordinates

Left: 778579.420000

Right: 974149.420000

Top: 959995.020000

Bottom: 719995.020000

Vertical

Minimum elevation: -21.8

Maximum elevation: 92.9

Lineage

FGDC lineage

Process step 1

Process description: Converted L8 ASCII text files to bin files in order to be imported into TerraScan, the software used for the analysis and modifications to the LiDAR points.
Process software and version: TerraScan
Process date: 200608

Process step 2

Process description: Drew a line along the eastern edge of the L8 data where it meets the COE data. This line was drawn so that as much COE data was used as possible. Then plotted a series of points along the L8 edge of this line. Extracted the elevations for both data sets and derived a delta value at

these locations. Then plotted a series of points 250 ft west of these "delta" points and assigned an elevation of 0. The delta points values were used as the distance to adjust the L8 data to meet the COE data at the edge line. The 0 elevation points served as a barrier to prevent the L8 data from moving beyond the 250 ft.
Process software and version: TerraScan, Microsoft Excel
Process date: 200608

Process step 3

Process description: Clipped both L8 and COE points to the line of adjustment.
Process software and version: TerraScan
Process date: 200608

Process step 4

Process description: Merged L8 and COE points together.
Process software and version: TerraScan
Process date: 200608

Who did this process

Process step 5

Process description: Raised L8/COE data by a global offset of 0.75ft. This distance brought the L8/COE data as close as possible to the FIU data while still allowing some room for the final adjustment.
Process software and version: TerraScan, Microsoft Excel
Process date: 200608

Process step 6

Process description: Merged the L8/COE data to the FIU data along the border using same process as outlined in step 2.
Process software and version: TerraScan, Microsoft Excel
Process date: 200608

Process step 7

Process description: Used 60 survey control points to make a final adjustment to the merged dataset. These 60 points were all bare earth or urban and had deltas (between merged/raised data and survey control) between -1 to 1 ft.
Process software and version: TerraScan, ESRI's ArcMap 9.0
Process date: 200609 - 200610

Process step 8

Process description: Divided the resulting bins into a 5000 ft tile scheme provided by state of Florida (Florida State Plane East HARN Ortho Tiles).
Process software and version: TerraScan, ESRI's ArcCatalog 9.0
Process date: 200610

Process step 9

Process description: Converted the bins to text files and the text files to shapefiles.
Process software and version: TerraScan, Dewberry's LiDAR to Shapefile Converter
Process date: 200610

Process step 10

Process description: In order to make the building of TINs more manageable, divided the shapefiles into groups of 36 tiles (+ 1 tile overlap on all sides). Built TINs for each of these groups (40 total).
Process software and version: ESRI's ArcMap 9.0, 3D Analyst, Spatial Analyst
Process date: 200610

Process step 11

Process description: Converted TINs to TG (10 ft cell size).
Process software and version: ESRI's ArcMap 9.0, 3D Analyst, Spatial Analyst
Process date: 200610

Process step 12

Process description: Clipped each TG by 2500 feet in order to eliminate erroneous cells on the outside edge of each TG (introduced by TIN process).
Process software and version: ESRI's ArcMap 9.0, Spatial Analyst
Process date: 200610

Process step 13

Process description: In order to merge all TGs into one file, had to first group them into 4 areas. Then performed a mosaic of these 4 areas using a mean calculation on the overlapping cells between them.
Process software and version: ESRI's ArcMap 9.0, Spatial Analyst
Process date: 200610

Process step 14

Process description: The outside edge of the merge TG has an irregular shape, this produces areas of significant interpolation where the TIN was forced to "jump" over areas of no data. In order to eliminate these values, a polygon was drawn around the dataset where there were actual LiDAR points. This polygon was then used to clip out the unusable data resulting in a clean mosaic.
Process software and version: ESRI's ArcMap 9.0, Spatial Analyst
Process date: 200610

Process step 15

Process description: Dataset copied.
Source used: \\ad\DFSRoot\data\coastal\GIS\LIDAR\PBCounty_Dewberry\Combined\TG\pb_sfwmd_v4

Sources

Source 1: C - 111 Basin LiDAR Topography (USACE)

Media: online: http://mapsrv.sfrestore.org/lidar/lidar.php
Contribution: One of 3 separate LiDAR datasets that cover specific areas of Palm Beach County, Florida that were merge into one homogeneous Digital Elevation Model (DEM).

Currentness of this source

Source 2: Water Preserve Areas LiDAR Topography (USACE)

Media: online: http://mapsrv.sfrestore.org/lidar/lidar.php
Contribution: One of 3 separate LiDAR datasets that cover specific areas of Palm Beach County, Florida that were merge into one homogeneous Digital Elevation Model (DEM).

Currentness of this source

Source 3: Unfiltered Gridded DEMs of Palm Beach County (FIU)

Media: CD-ROM
Contribution: One of 3 separate LiDAR datasets that cover specific areas of Palm Beach County, Florida that were merged into one homogeneous Digital Elevation Model (DEM).

Currentness of this source

ESRI geoprocessing history

1. Create Raster Dataset

2. Mosaic

Spatial data quality

Horizontal positional accuracy

Vertical positional accuracy

Spatial data description

Raster dataset information

Raster format: ESRI GRID

SDTS raster type: Grid Cell

Number of raster bands: 1

Raster properties

Origin location: Upper Left

Has pyramids: FALSE

Has colormap: FALSE

Data compression type: Default

Display type: matrix values

Cell information

Number of cells on x-axis: 19557

Number of cells on y-axis: 24000

Number of cells on z-axis: 1

Number of bits per cell: 32

Cell Size

X distance: 10.000000

Y distance: 10.000000

SPATIAL:

Horizontal coordinate system

Projected coordinate system name: NAD_1983_StatePlane_Florida_East_FIPS_0901_Feet

Geographic coordinate system name: GCS_North_American_1983

Details

Altitude System Definition

Datum Name: North American Vertical Datum of 1988

Resolution: 10

Distance Units: feet

Encoding Method: Explicit elevation coordinate included with horizontal coordinates

---

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Process software and version: TerraScan, Microsoft Excel
Process date: 200608

Process step 3

Process description: Clipped both L8 and COE points to the line of adjustment.
Process software and version: TerraScan
Process date: 200608

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Process software and version: TerraScan
Process date: 200608

Who did this process

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Process date: 200608

Process step 6

Process description: Merged the L8/COE data to the FIU data along the border using same process as outlined in step 2.
Process software and version: TerraScan, Microsoft Excel
Process date: 200608

Process step 7

Process description: Used 60 survey control points to make a final adjustment to the merged dataset. These 60 points were all bare earth or urban and had deltas (between merged/raised data and survey control) between -1 to 1 ft.
Process software and version: TerraScan, ESRI's ArcMap 9.0
Process date: 200609 - 200610

Process step 8

Process description: Divided the resulting bins into a 5000 ft tile scheme provided by state of Florida (Florida State Plane East HARN Ortho Tiles).
Process software and version: TerraScan, ESRI's ArcCatalog 9.0
Process date: 200610

Process step 9

Process description: Converted the bins to text files and the text files to shapefiles.
Process software and version: TerraScan, Dewberry's LiDAR to Shapefile Converter
Process date: 200610

Process step 10

Process description: In order to make the building of TINs more manageable, divided the shapefiles into groups of 36 tiles (+ 1 tile overlap on all sides). Built TINs for each of these groups (40 total).
Process software and version: ESRI's ArcMap 9.0, 3D Analyst, Spatial Analyst
Process date: 200610

Process step 11

Process description: Converted TINs to TG (10 ft cell size).
Process software and version: ESRI's ArcMap 9.0, 3D Analyst, Spatial Analyst
Process date: 200610

Process step 12

Process description: Clipped each TG by 2500 feet in order to eliminate erroneous cells on the outside edge of each TG (introduced by TIN process).
Process software and version: ESRI's ArcMap 9.0, Spatial Analyst
Process date: 200610

Process step 13

Process description: In order to merge all TGs into one file, had to first group them into 4 areas. Then performed a mosaic of these 4 areas using a mean calculation on the overlapping cells between them.
Process software and version: ESRI's ArcMap 9.0, Spatial Analyst
Process date: 200610

Process step 14

Process description: The outside edge of the merge TG has an irregular shape, this produces areas of significant interpolation where the TIN was forced to "jump" over areas of no data. In order to eliminate these values, a polygon was drawn around the dataset where there were actual LiDAR points. This polygon was then used to clip out the unusable data resulting in a clean mosaic.
Process software and version: ESRI's ArcMap 9.0, Spatial Analyst
Process date: 200610

Process step 15

Process description: Dataset copied.
Source used: \\ad\DFSRoot\data\coastal\GIS\LIDAR\PBCounty_Dewberry\Combined\TG\pb_sfwmd_v4

Sources

Source 1: C - 111 Basin LiDAR Topography (USACE)

Media: online: http://mapsrv.sfrestore.org/lidar/lidar.php
Contribution: One of 3 separate LiDAR datasets that cover specific areas of Palm Beach County, Florida that were merged into one homogeneous Digital Elevation Model (DEM).

Currentness of this source

Source 2: Water Preserve Areas LiDAR Topography (USACE)

Media: online: http://mapsrv.sfrestore.org/lidar/lidar.php
Contribution: One of 3 separate LiDAR datasets that cover specific areas of Palm Beach County, Florida that were merged into one homogeneous Digital Elevation Model (DEM).

Currentness of this source

Source 3: Unfiltered Gridded DEMs of Palm Beach County (FIU)

Media: CD-ROM
Contribution: One of 3 separate LiDAR datasets that cover specific areas of Palm Beach County, Florida that were merged into one homogeneous Digital Elevation Model (DEM).

Currentness of this source

ESRI geoprocessing history

1. Create Raster Dataset

2. Mosaic

Spatial data quality

Horizontal positional accuracy

Vertical positional accuracy

Spatial data description

Raster dataset information

Raster format: ESRI GRID

SDTS raster type: Grid Cell

Number of raster bands: 1

Raster properties

Origin location: Upper Left

Has pyramids: FALSE

Has colormap: FALSE

Data compression type: Default

Display type: matrix values

Cell information

Number of cells on x-axis: 19557

Number of cells on y-axis: 24000

Number of cells on z-axis: 1

Number of bits per cell: 32

Cell Size

X distance: 10.000000

Y distance: 10.000000

APPENDIX D: STAGE-VOLUME CURVES FROM 2004, 2012 AND 2015 DEM'S

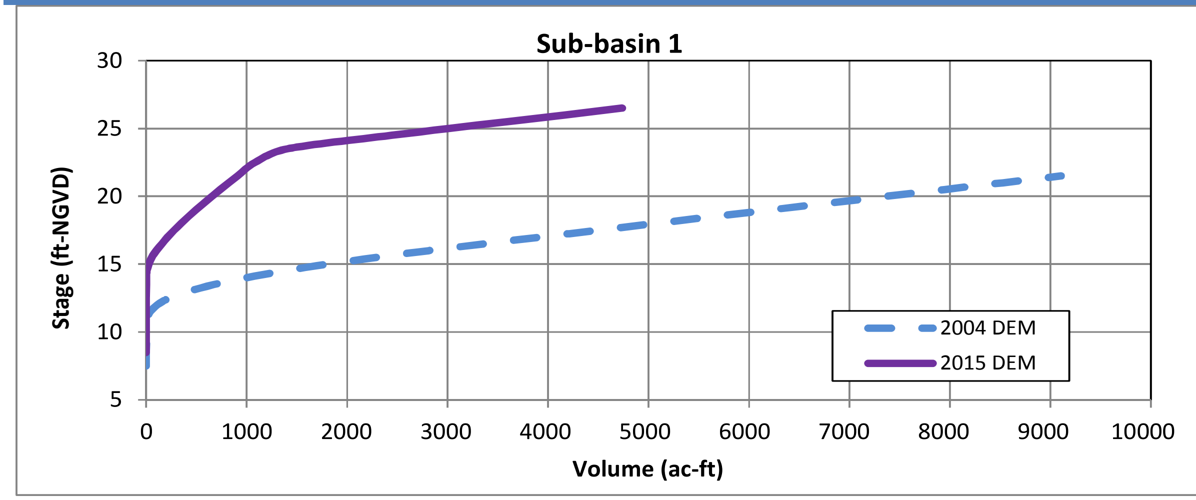

Figure D1. Stage-Volume Curves for Sub-basin 1

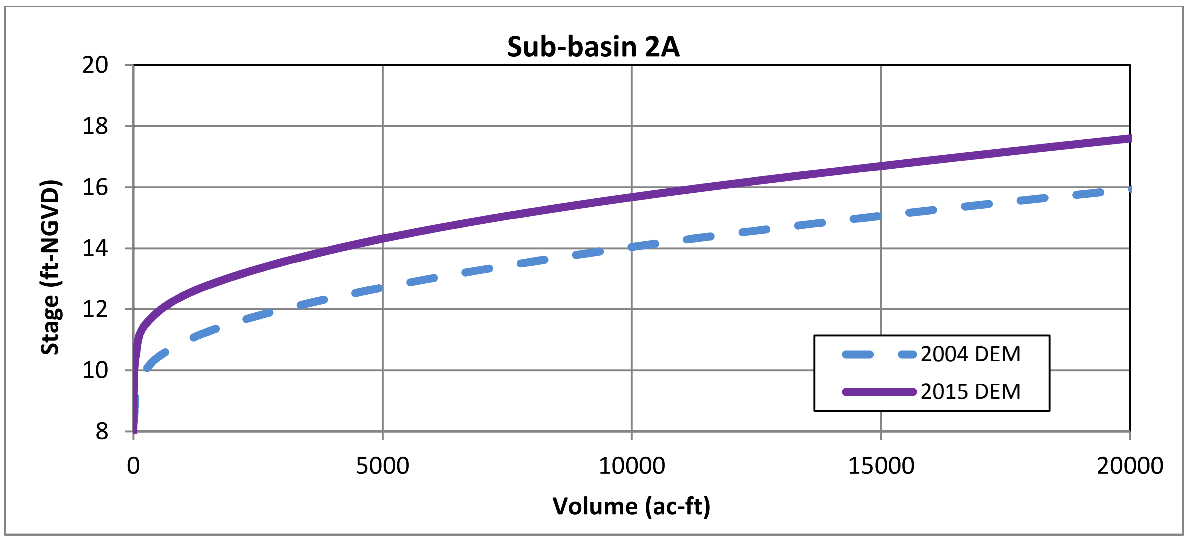

Figure D2. Stage-Volume Curves for Sub-basin 2A

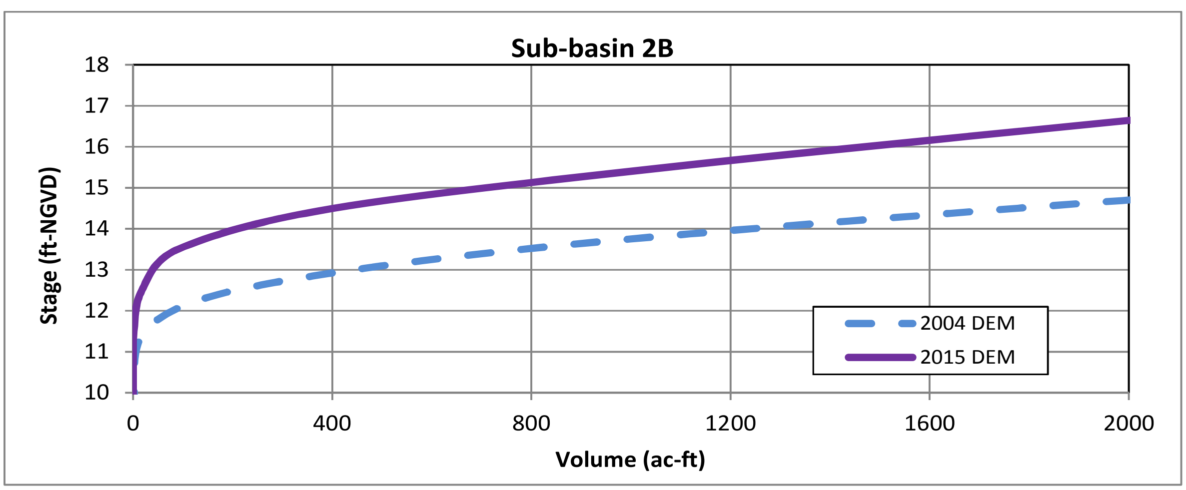

Figure D3. Stage-Volume Curves for Sub-basin 2B

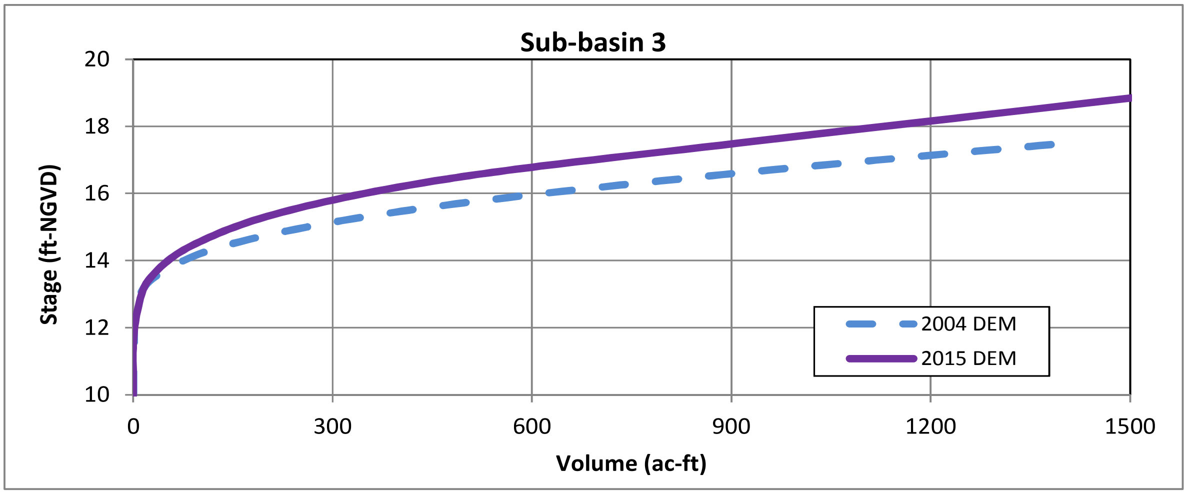

Figure D4. Stage-Volume Curves for Sub-basin 3

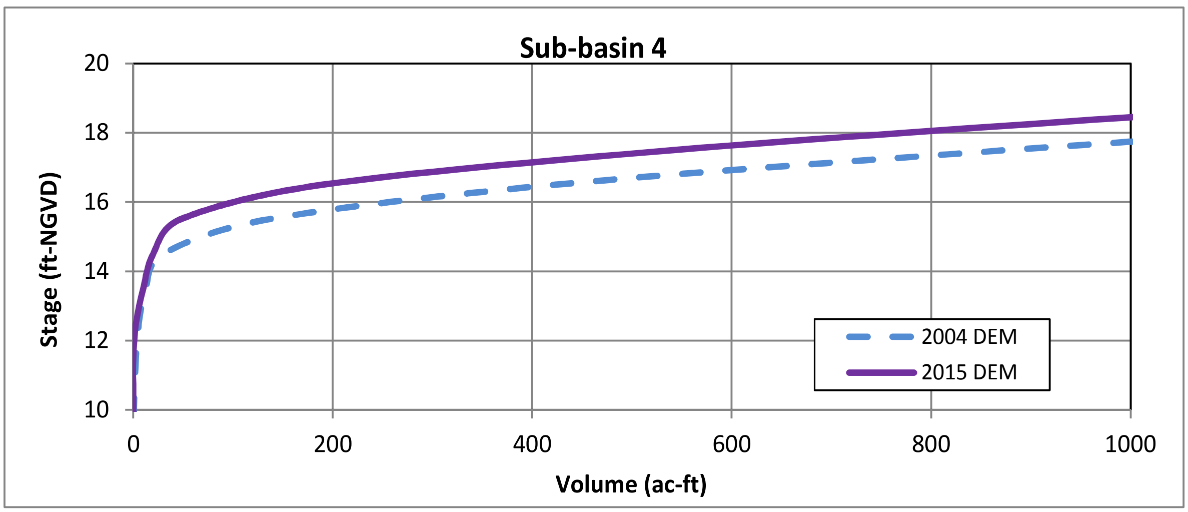

Figure D5. Stage-Volume Curves for Sub-basin 4

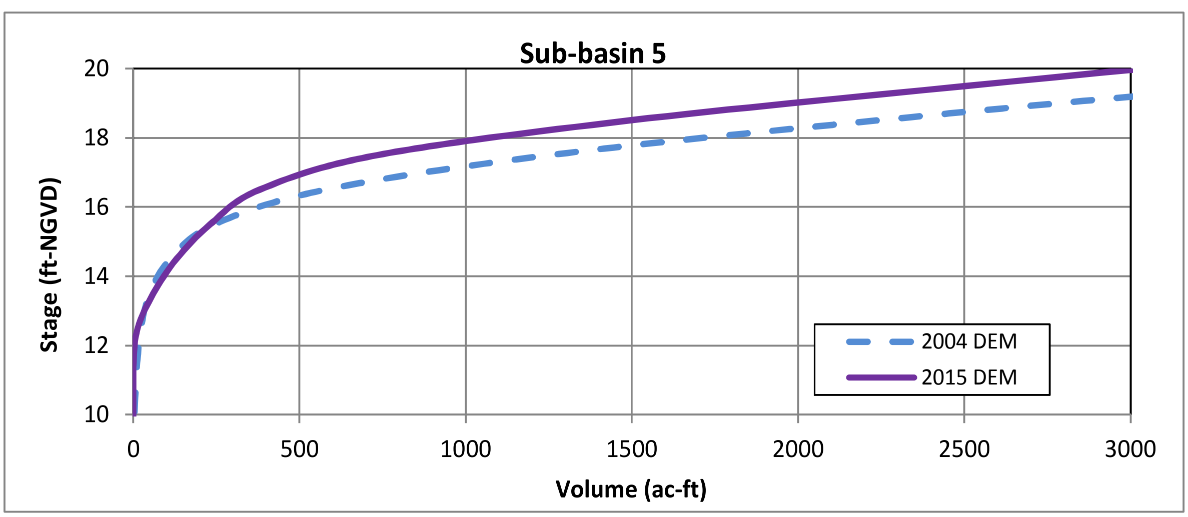

Figure D6. Stage-Volume Curves for Sub-basin 5

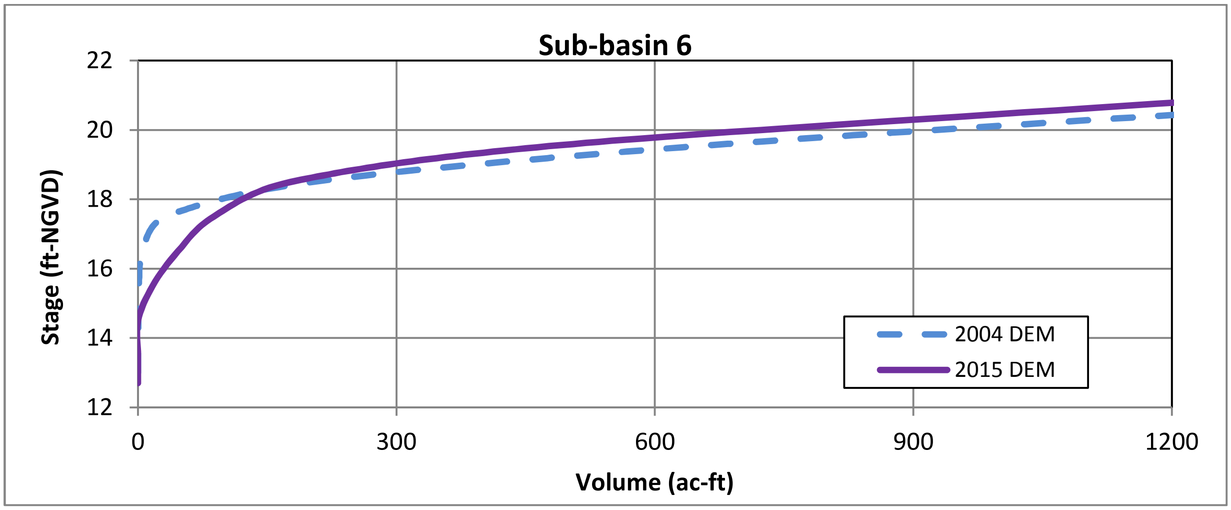

Figure D7. Stage-Volume Curves for Basin 6

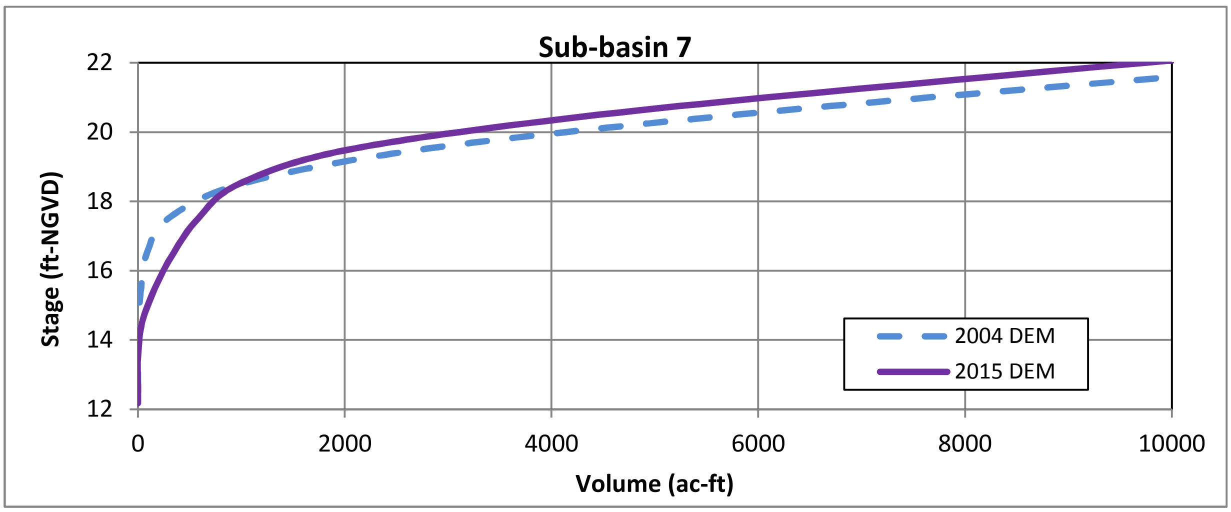

Figure B8. Stage-Volume Curves for Sub-basin 7

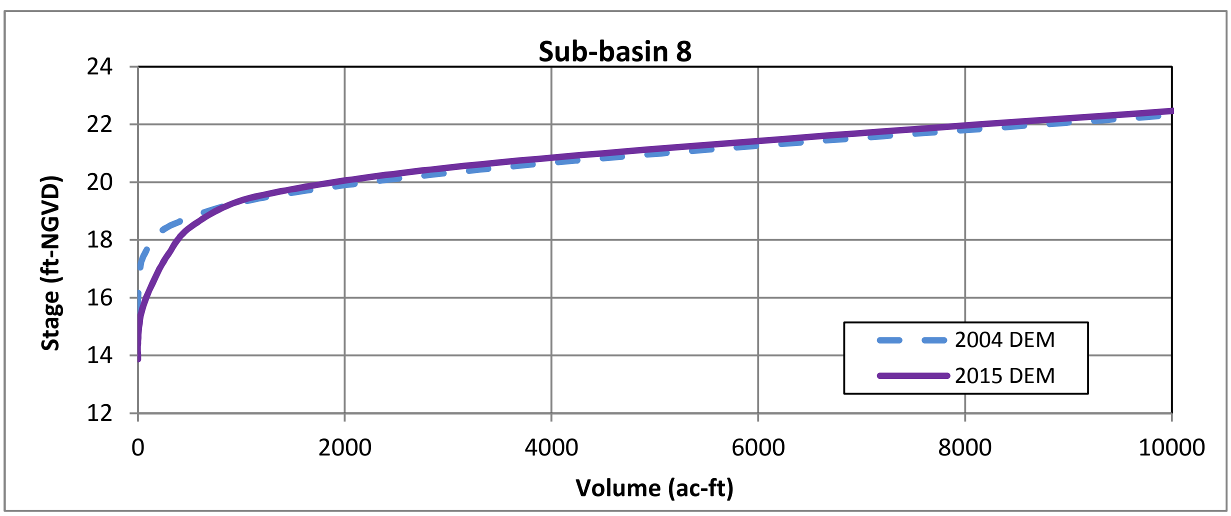

Figure D9. Stage-Volume Curves for Sub-basin 8

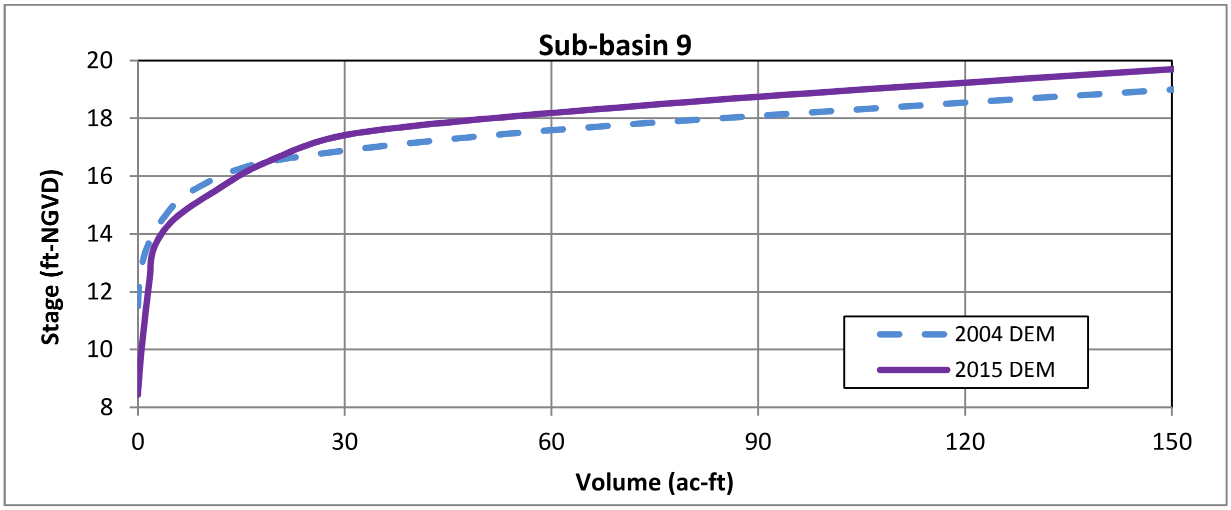

Figure D10. Stage-Volume Curves for Sub-basin 9

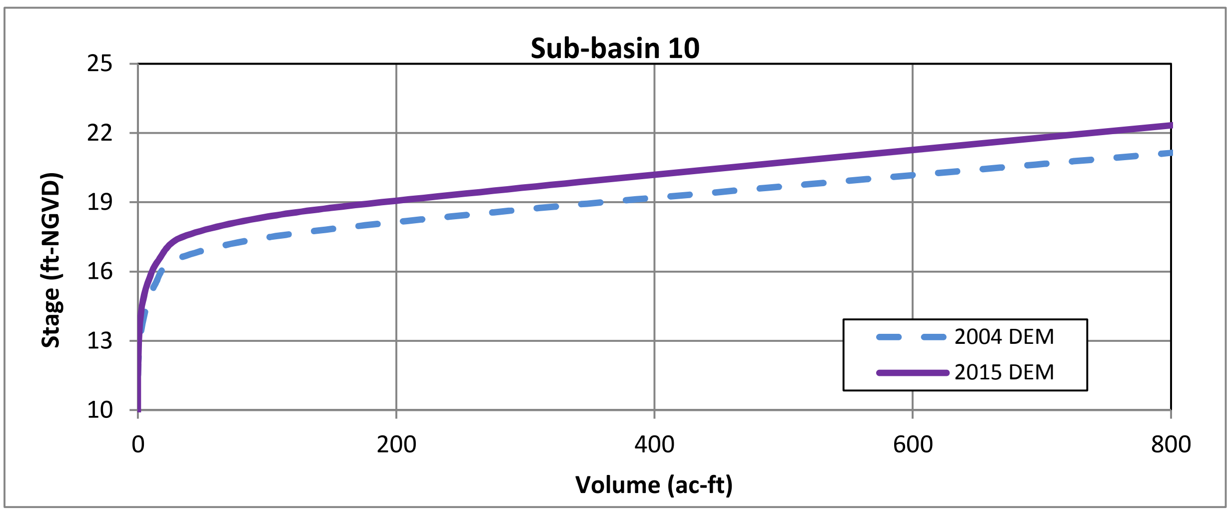

Figure D11. Stage-Volume Curves for Sub-basin 10

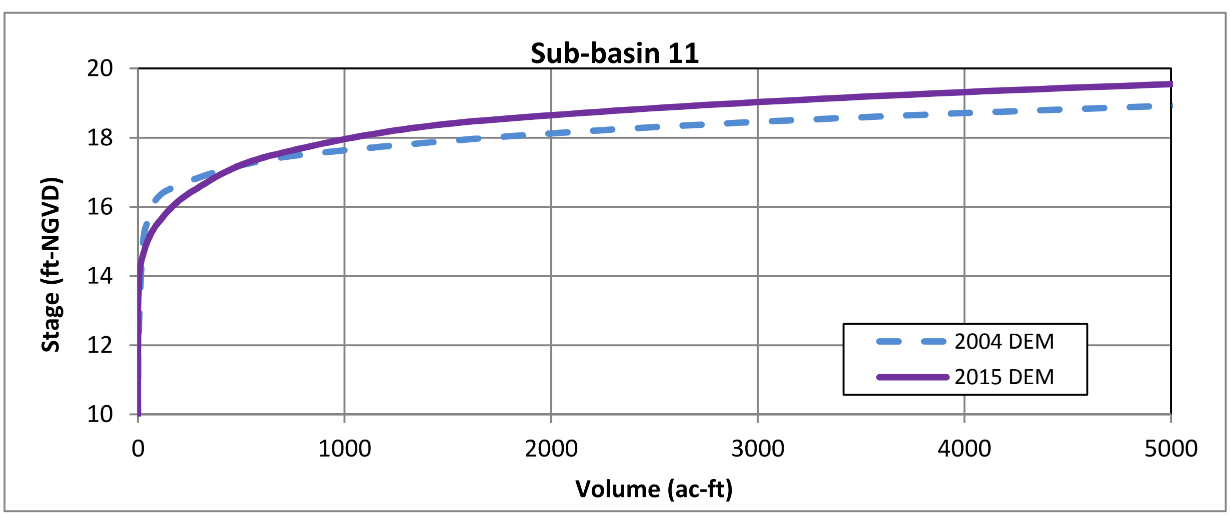

Figure D12. Stage-Volume Curves for Sub-basin 11

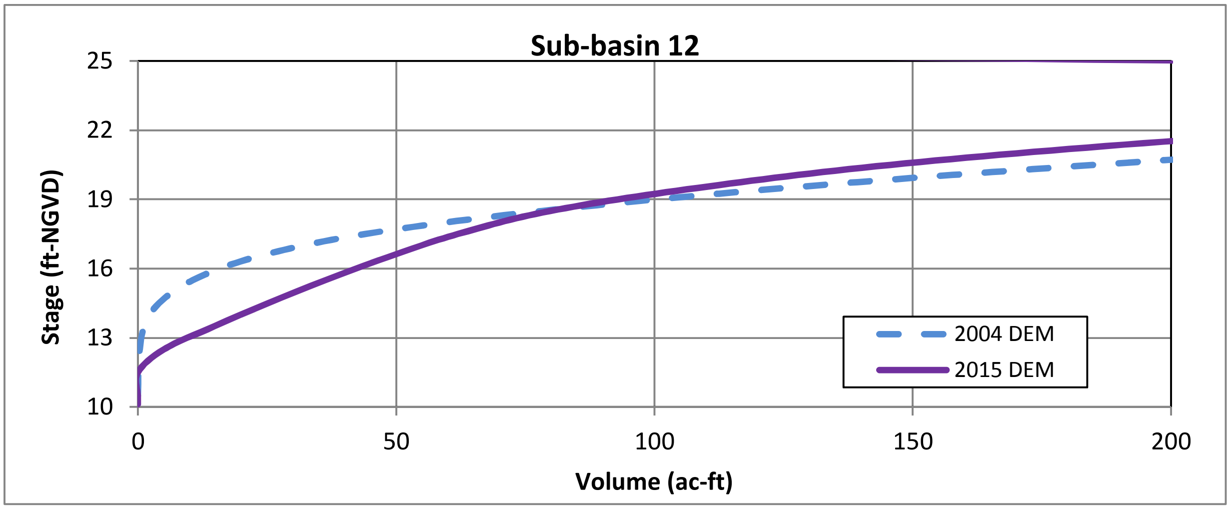

Figure D13. Stage-Volume Curves for Sub-basin 12

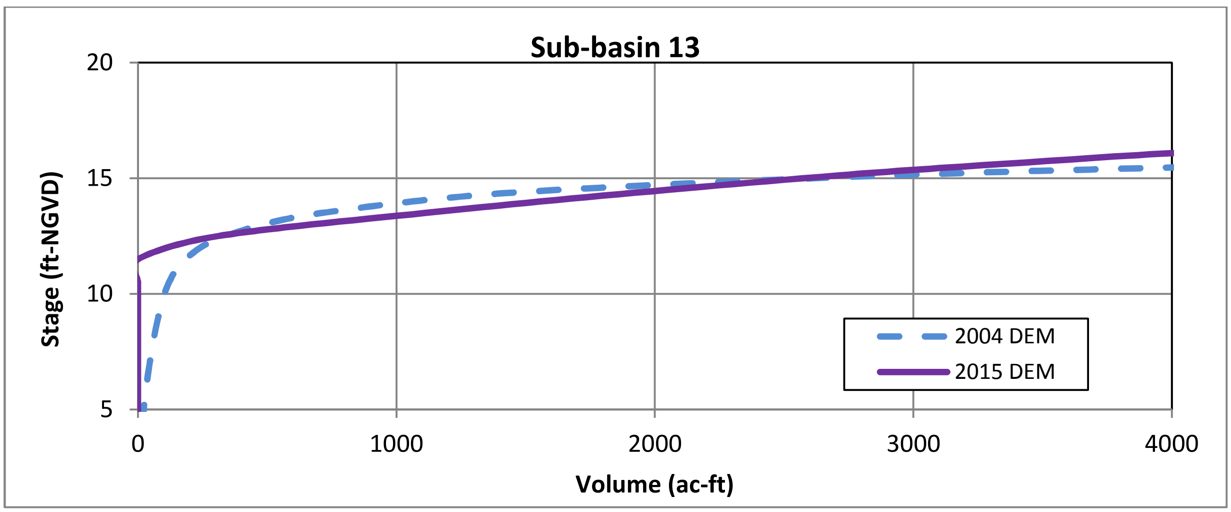

Figure D14. Stage-Volume for Sub-basin 13

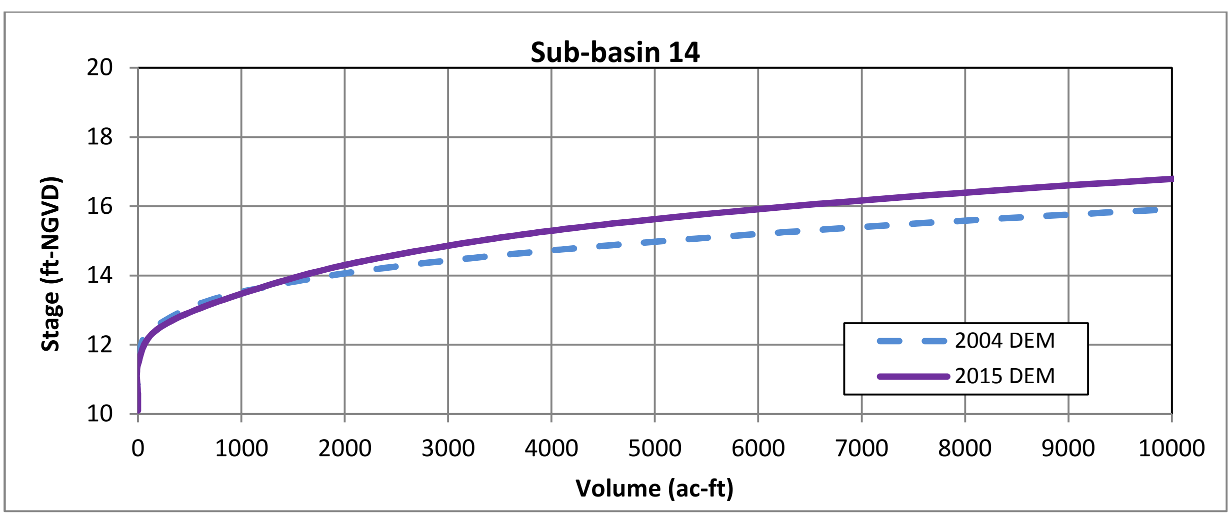

Figure D15. Stage-Volume Curves for Sub-basin 14

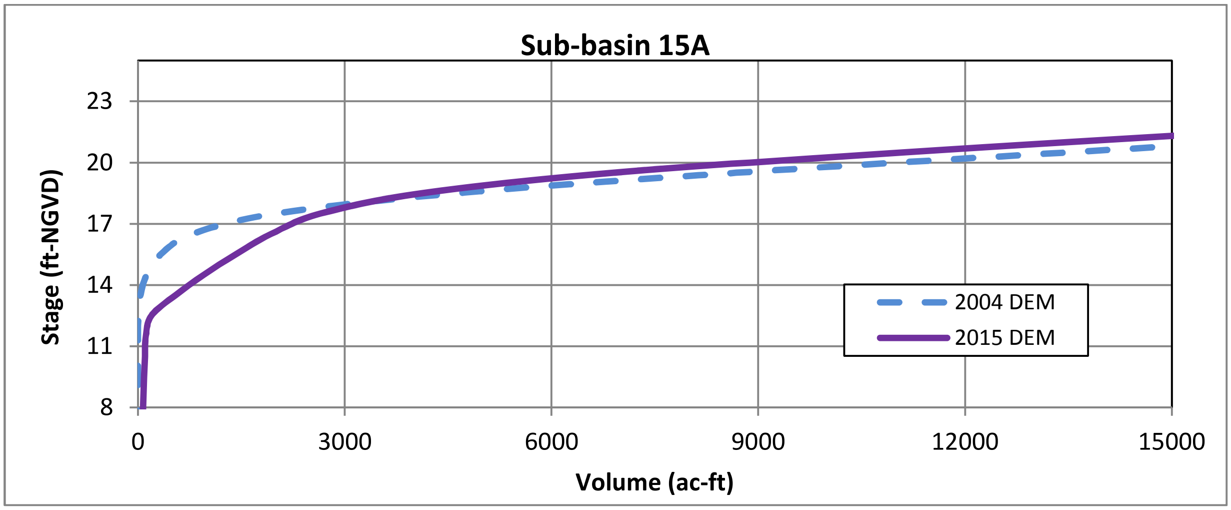

Figure D16. Stage-Volume Curves for Sub-basin 15A

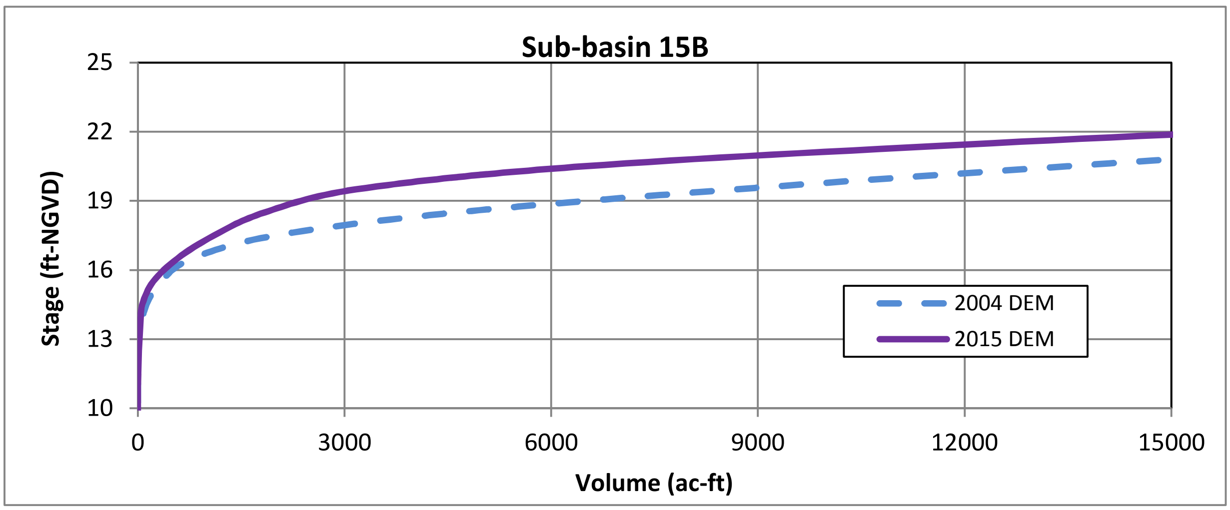

Figure D17. Stage-Volume Curves for Sub-basin 15B

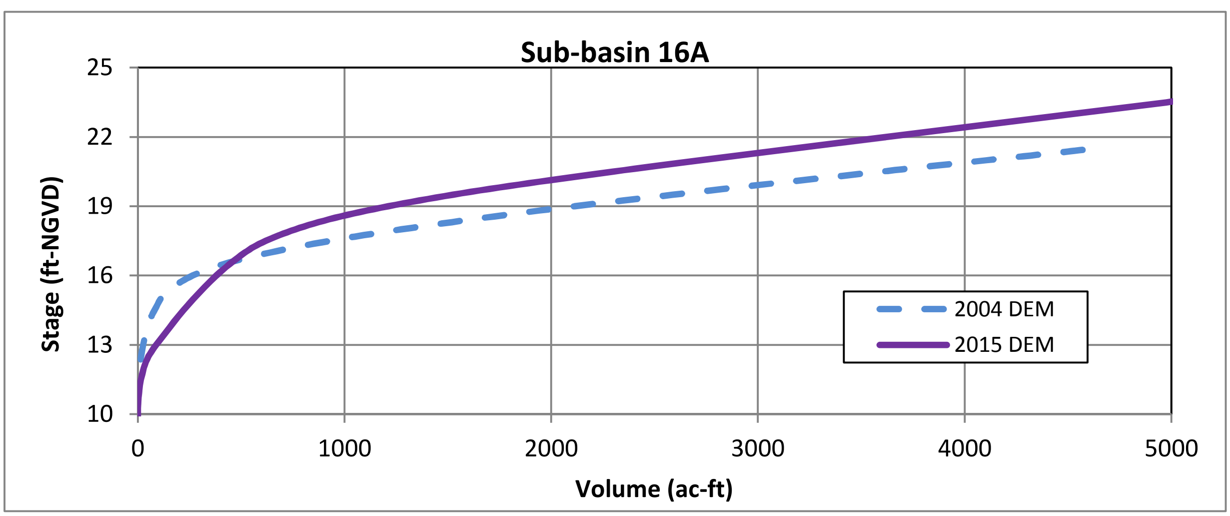

Figure D18. Stage-Volume Curves for Sub-basin 16A

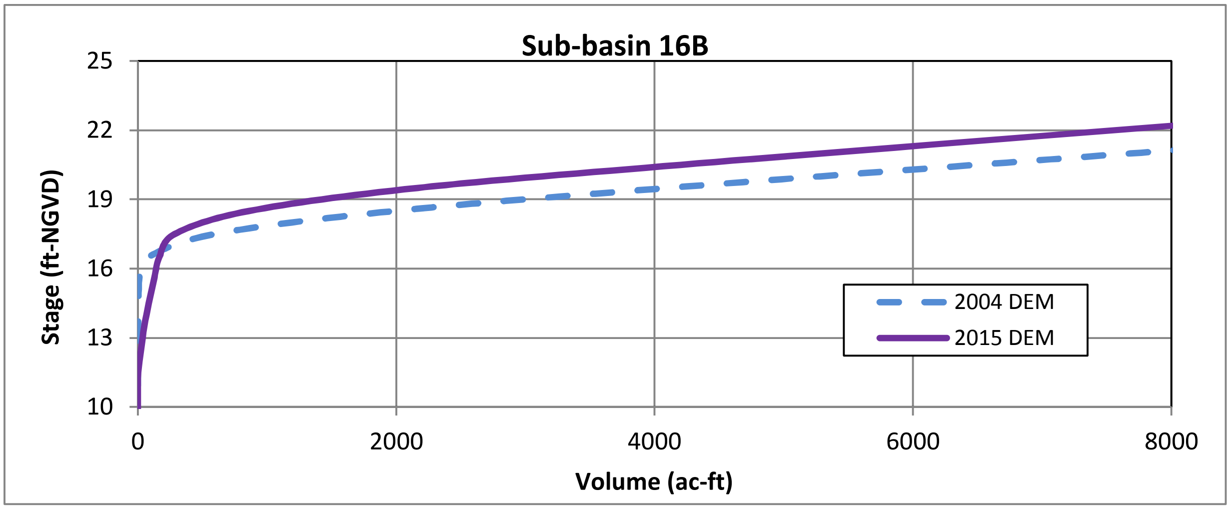

Figure D19. Stage-Volume Curves for Sub-basin 16B

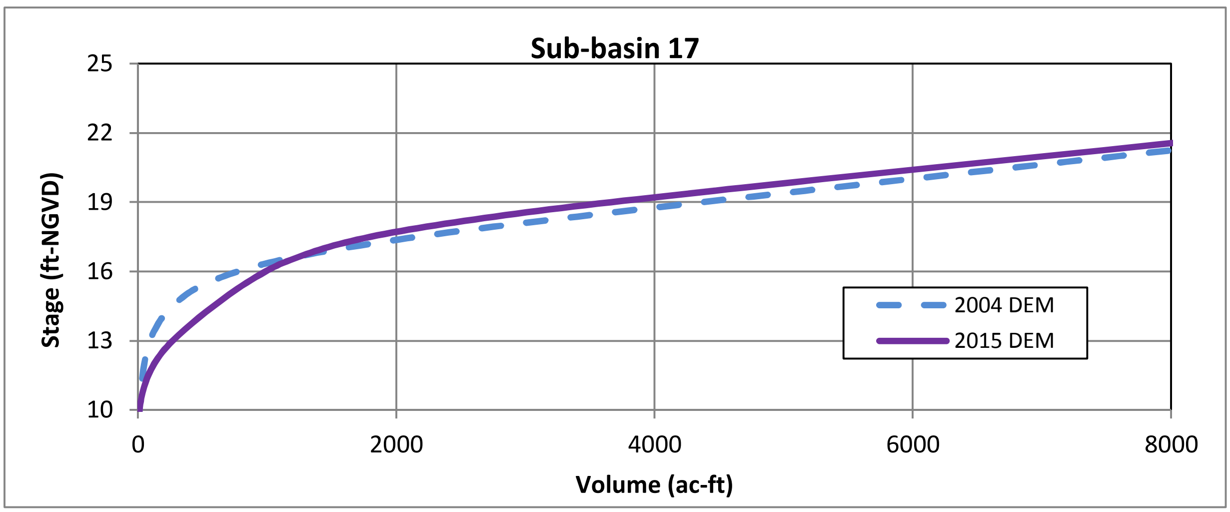

Figure D20. Stage-Volume Curves for Sub-basin 17

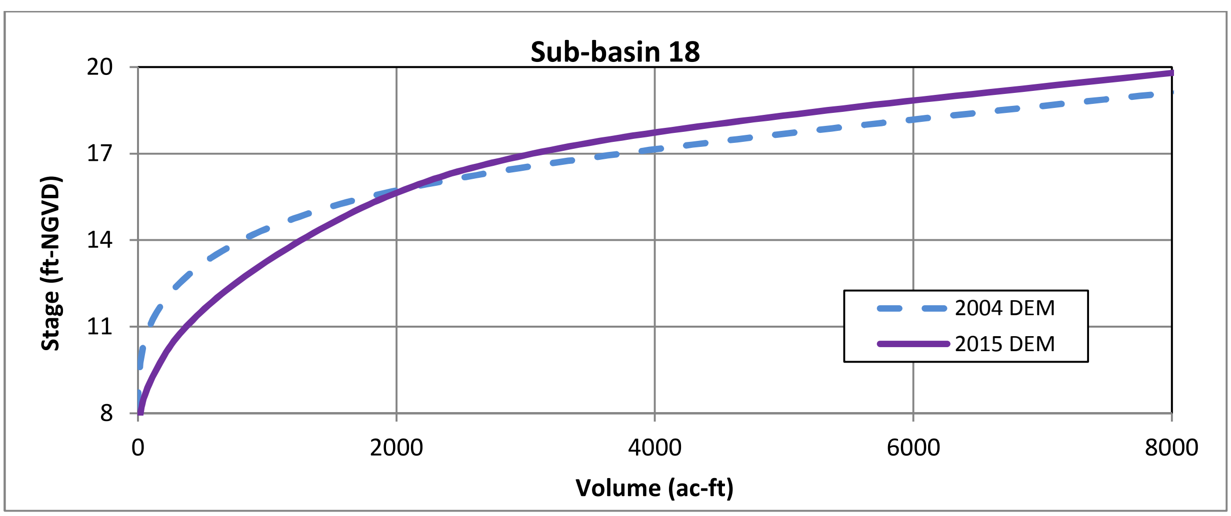

Figure B21. Stage-Volume Curves for Sub-basin 18

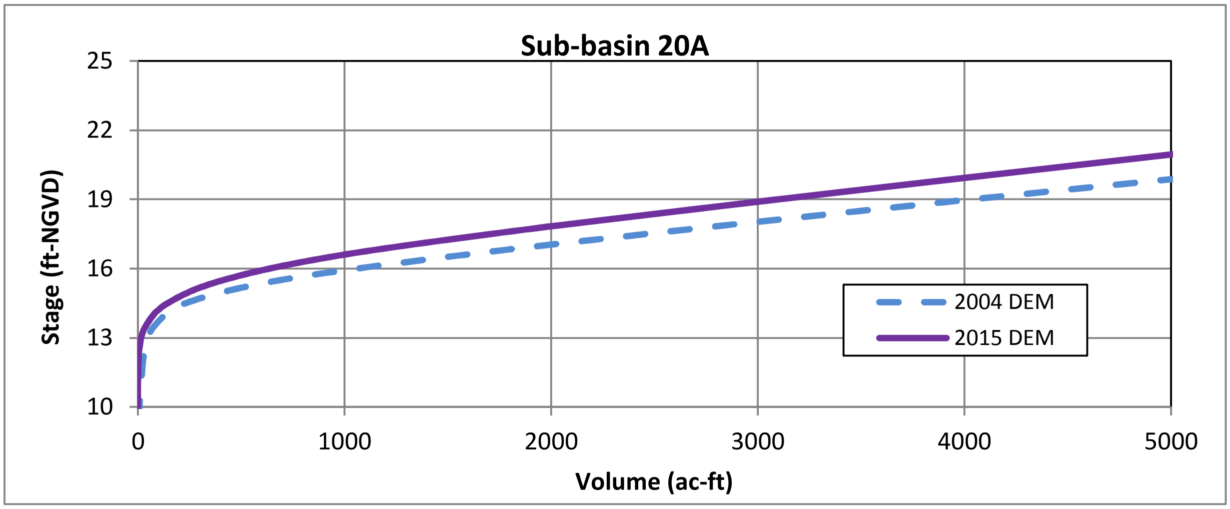

Figure D22. Stage-Volume Curves for Sub-basin 20A

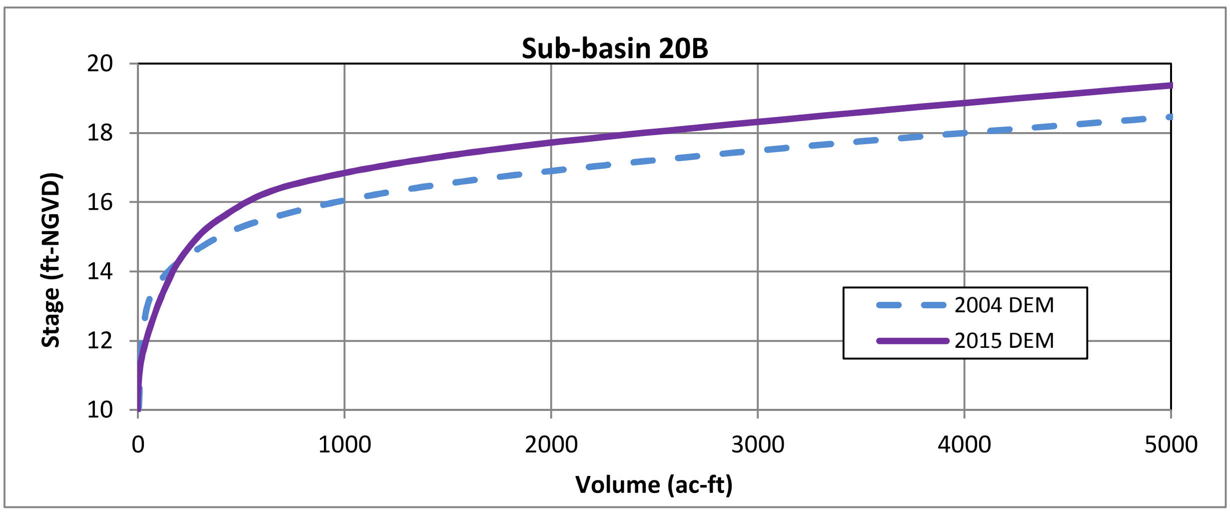

Figure D23. Stage-Volume Curves for Sub-basin 20B

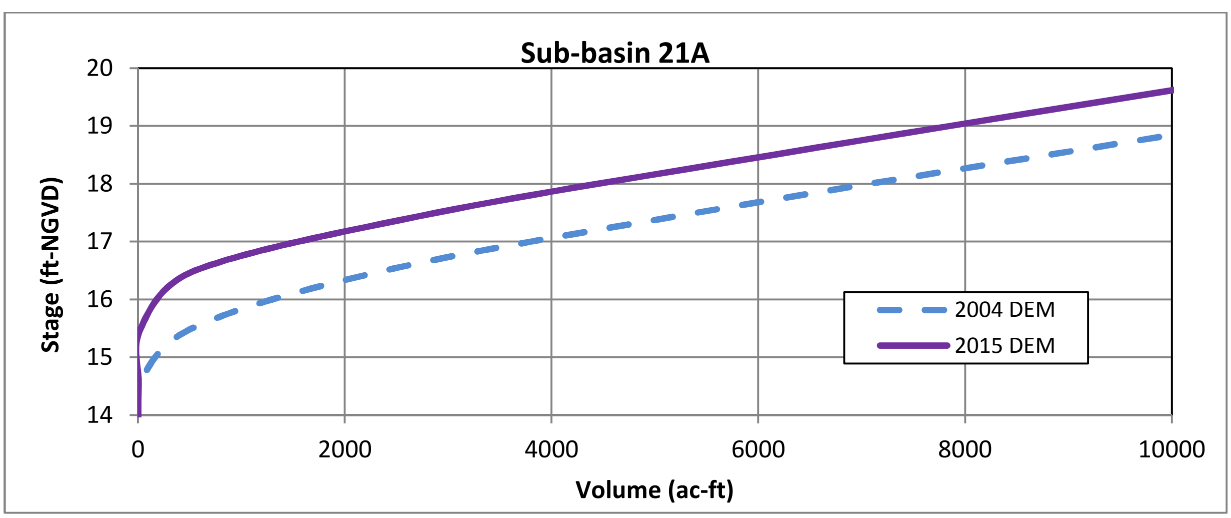

Figure D24. Stage-Volume Curves for Sub-basin 21A

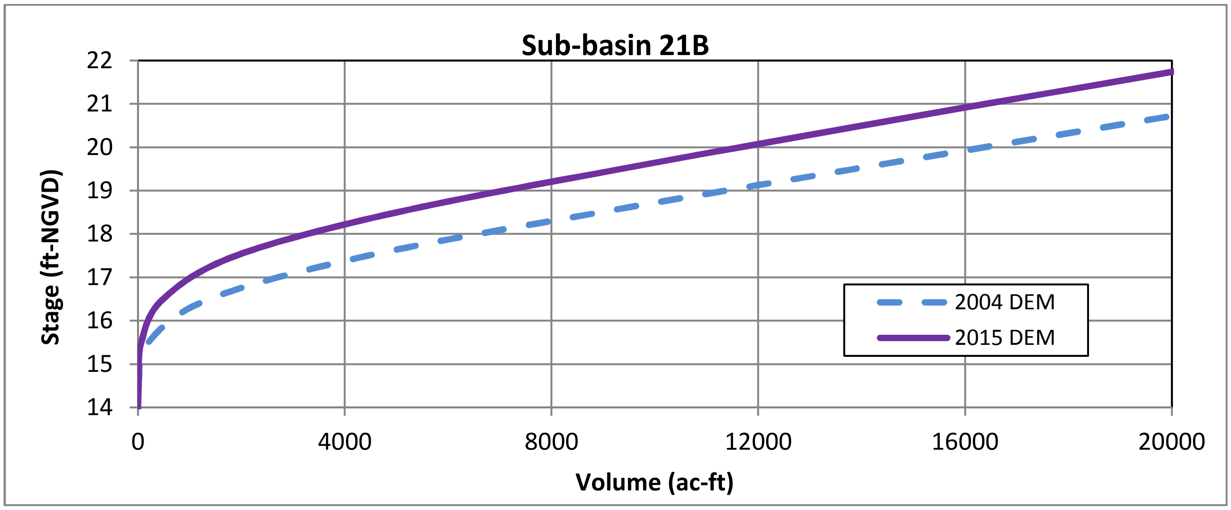

Figure D25. Stage-Volume Curves for Sub-basin 21B

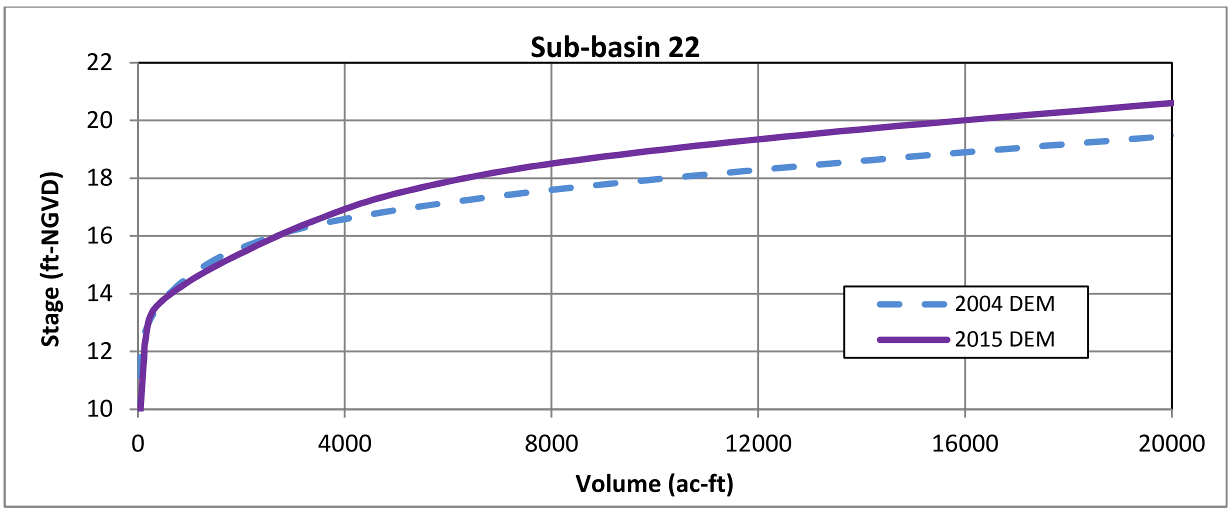

Figure B26. Stage-Volume Curves for Sub-basin 22

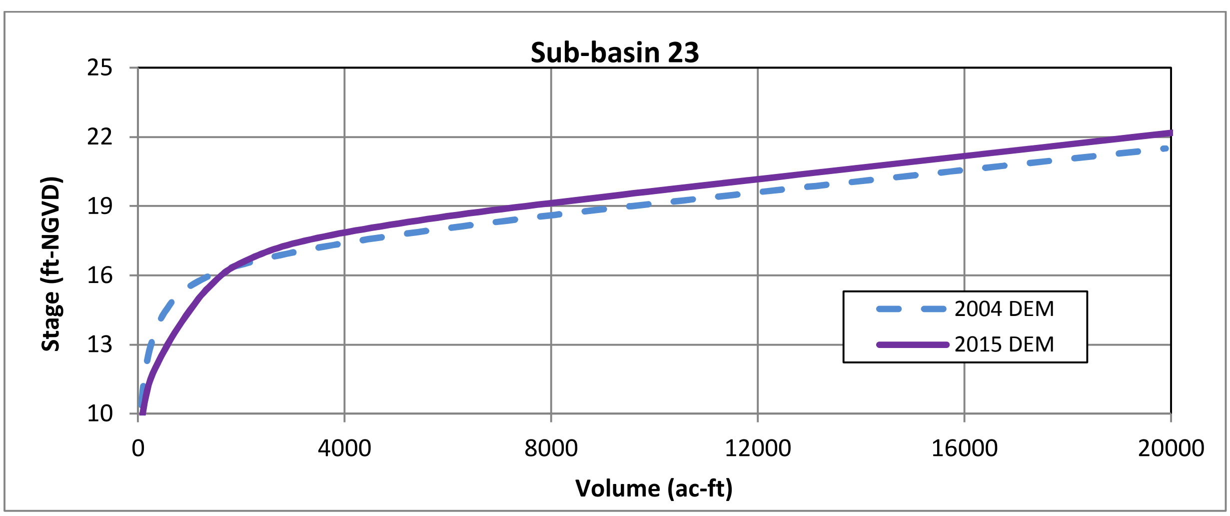

Figure D27. Stage-Volume Curves for Sub-basin 23

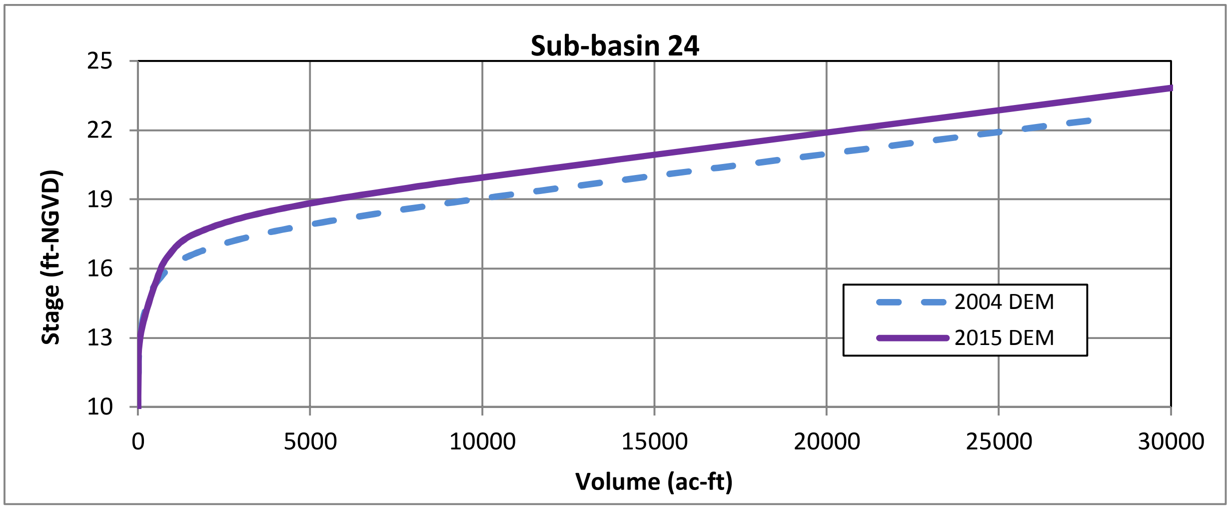

Figure D28. Stage-Volume Curves for Sub-basin 24

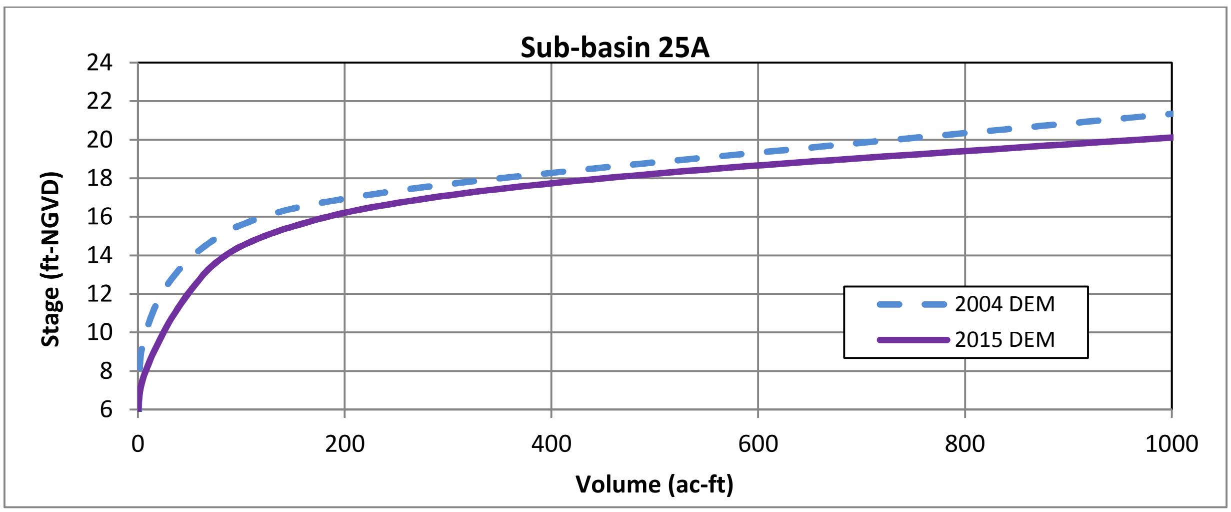

Figure D29. Stage-Volume Curves for Sub-basin 25A

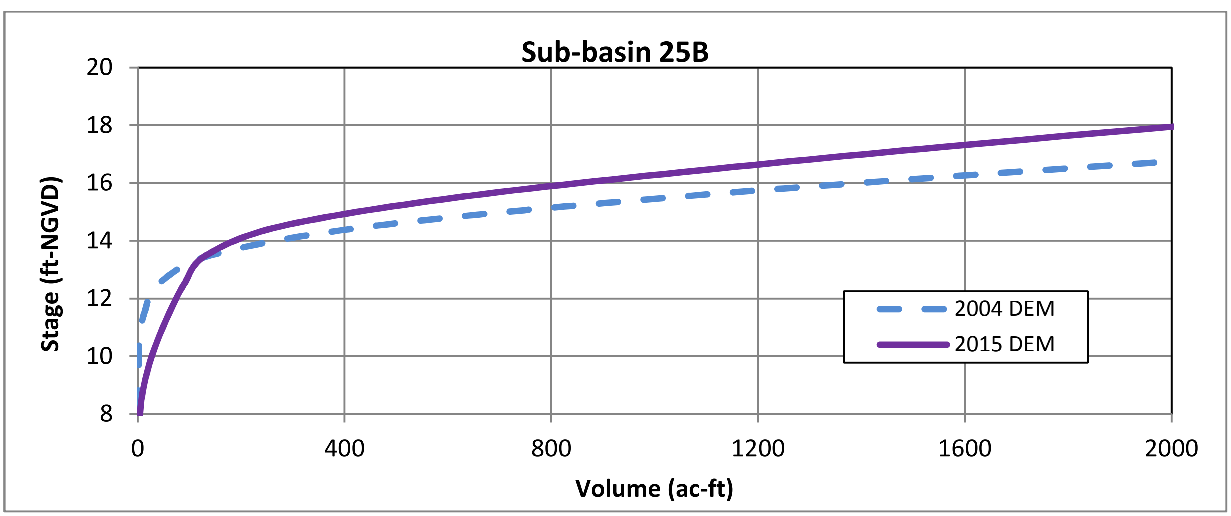

Figure D30. Stage-Volume Curves for Sub-basin 25B

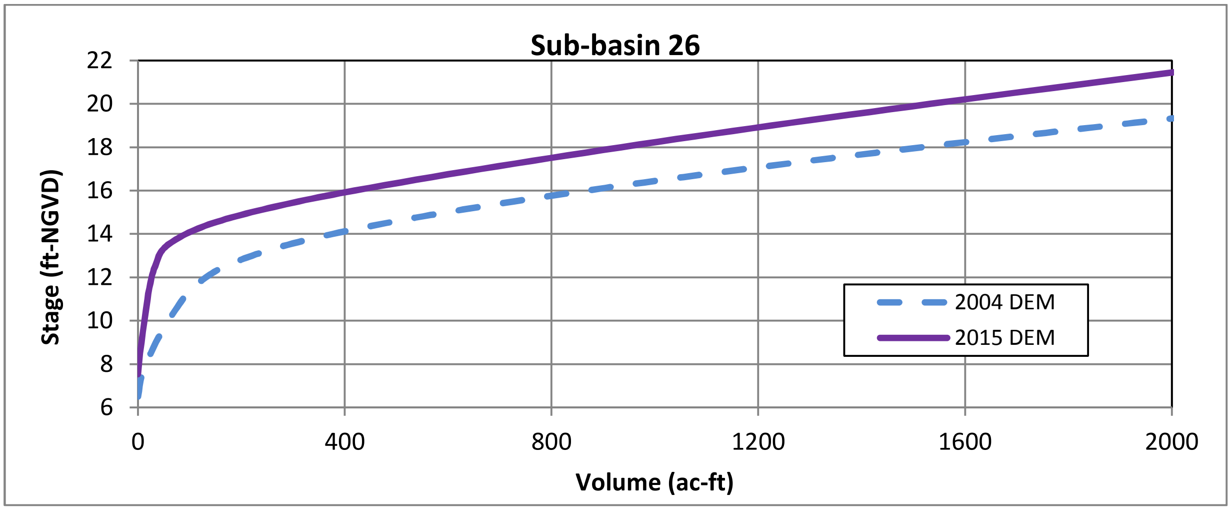

Figure D31. Stage-Volume Curves for Sub-basin 26

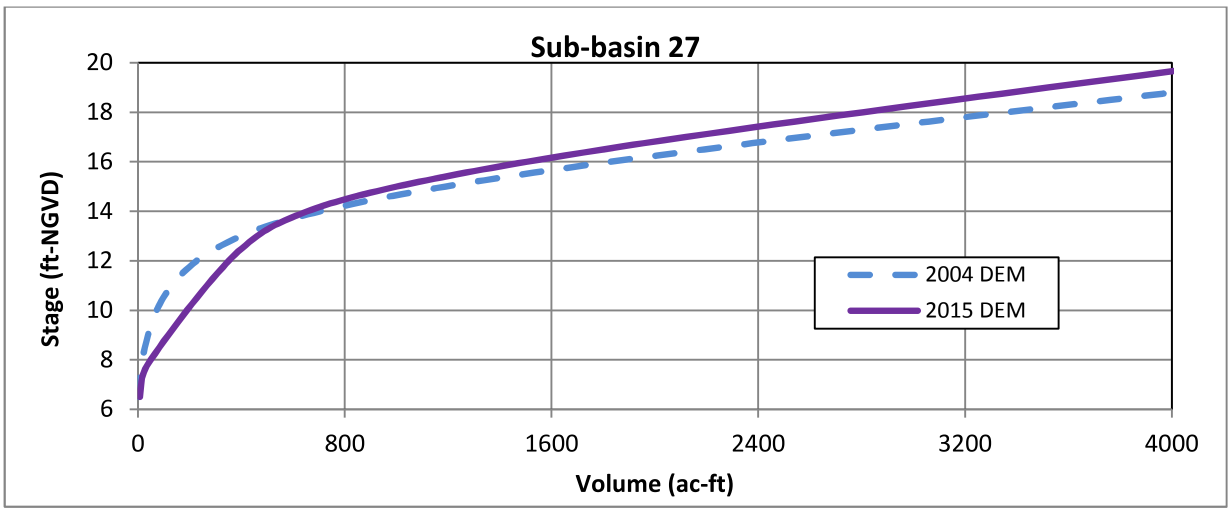

Figure D32. Stage-Volume Curves for Sub-basin 27

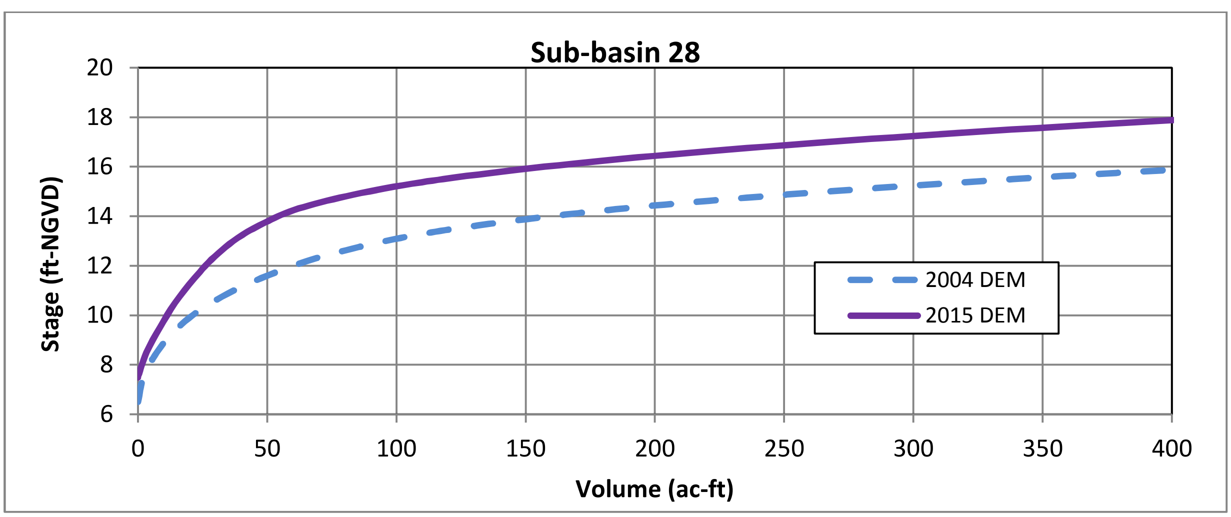

Figure D33. Stage-Volume Curves for Sub-basin 28

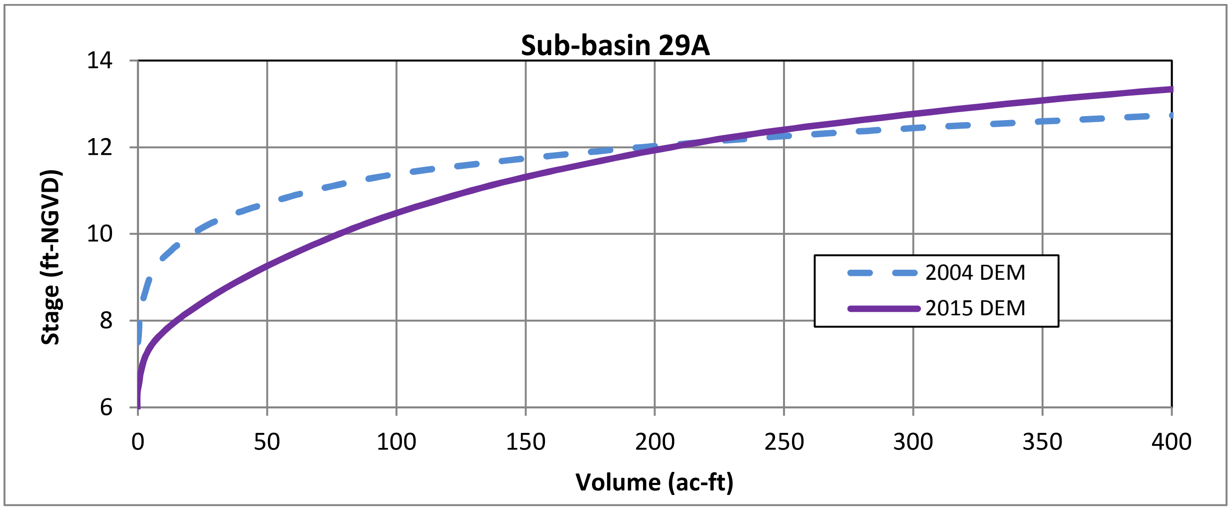

Figure D34. Stage-Volume Curves for Sub-basin 29A

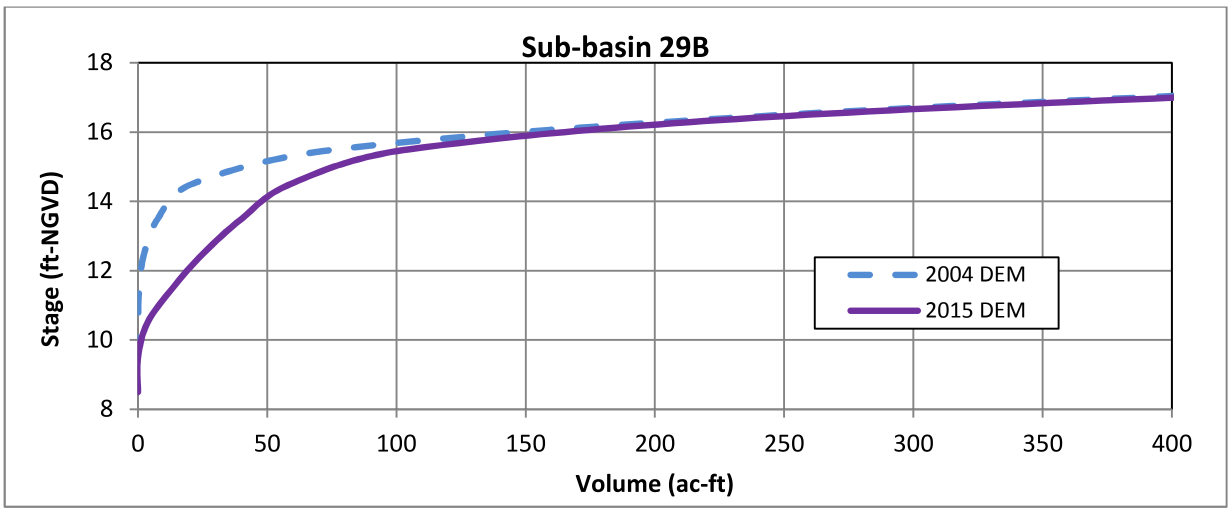

Figure D35. Stage-Volume Curves for Sub-basin 29B

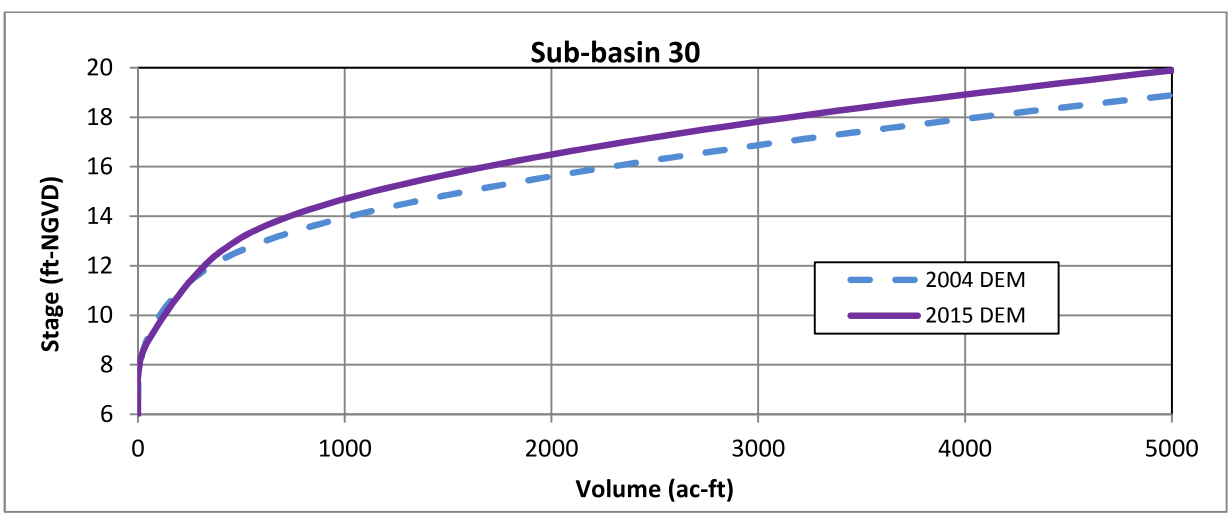

Figure D36. Stage-Volume Curves for Sub-basin 30

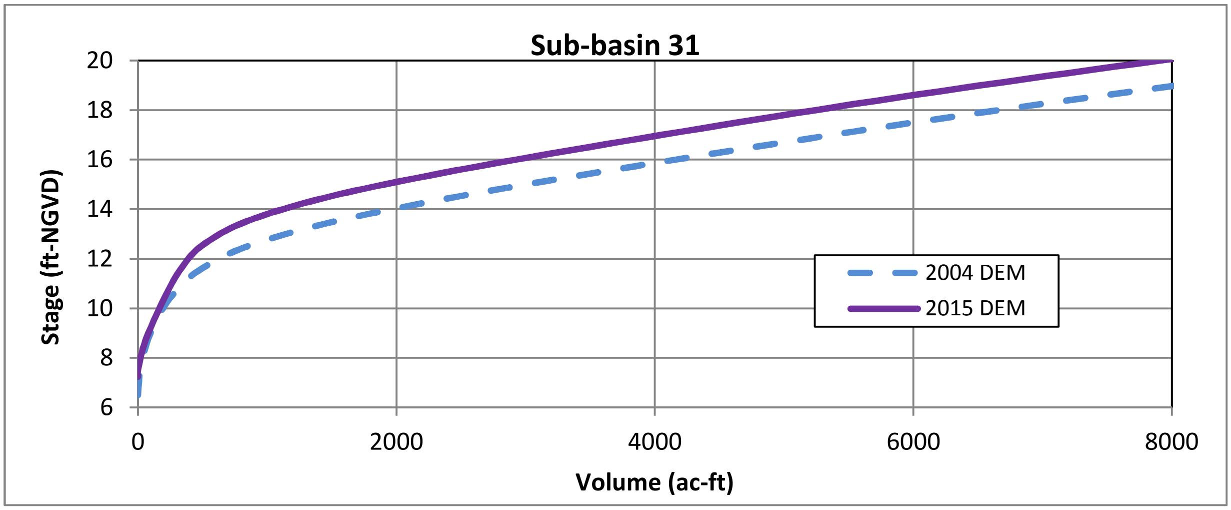

Figure D37. Stage-Volume Curves for Sub-basin 31

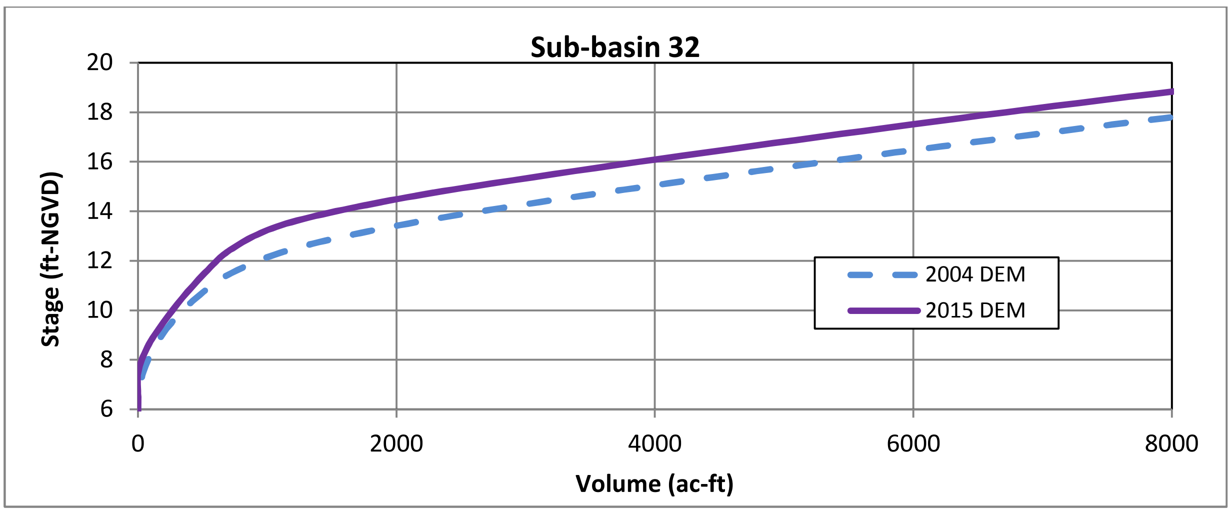

Figure D38. Stage-Volume Curves for Sub-basin 32

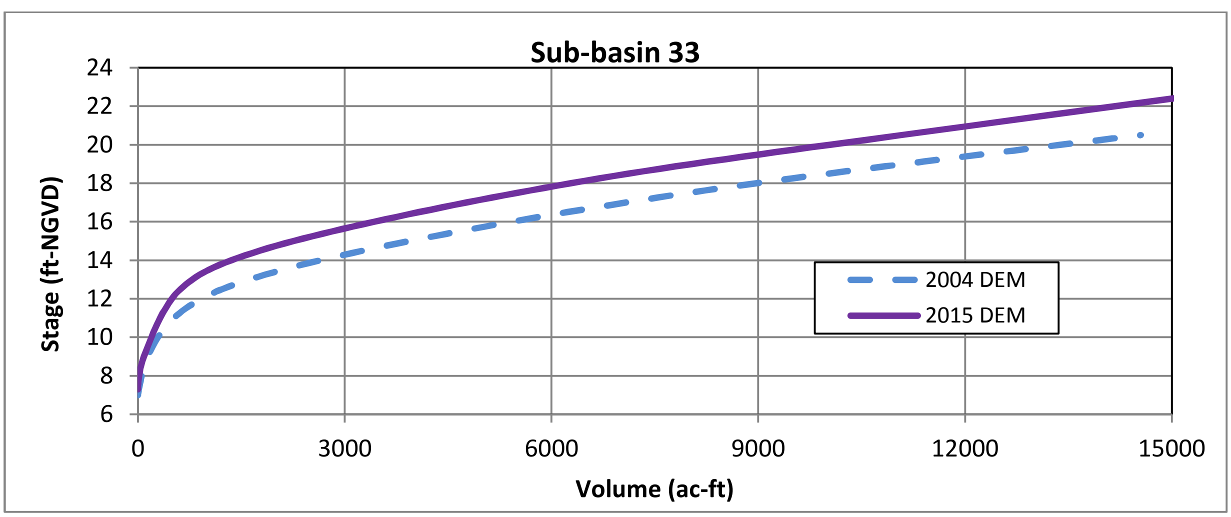

Figure D39. Stage-Volume Curves for Sub-basin 33

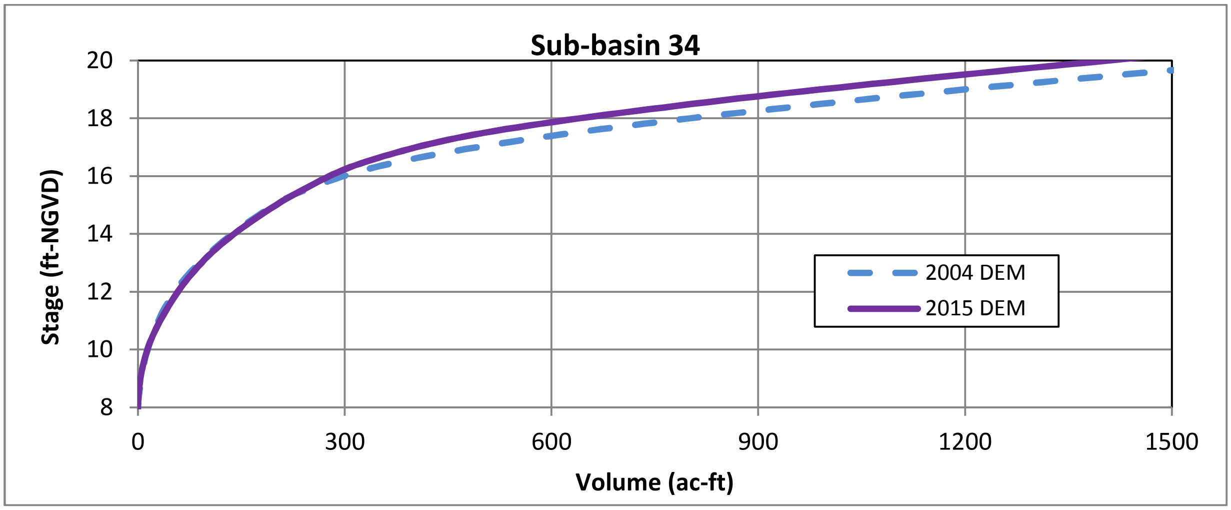

Figure D40. Stage-Volume Curves for Sub-basin 34

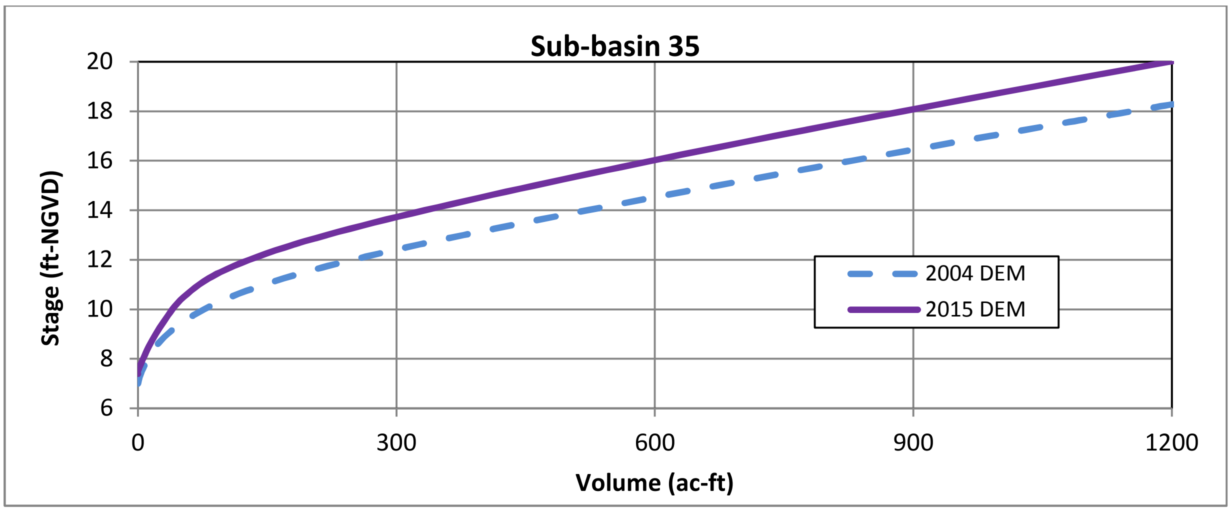

Figure D41. Stage-Volume Curves for Sub-basin 35

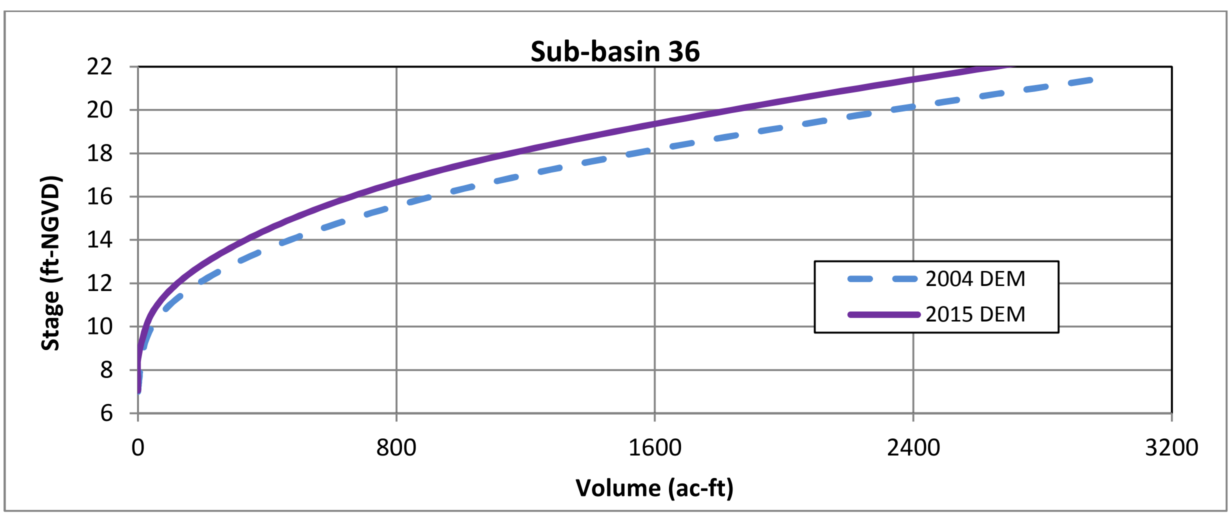

Figure D42. Stage-Volume Curves for Sub-basin 36

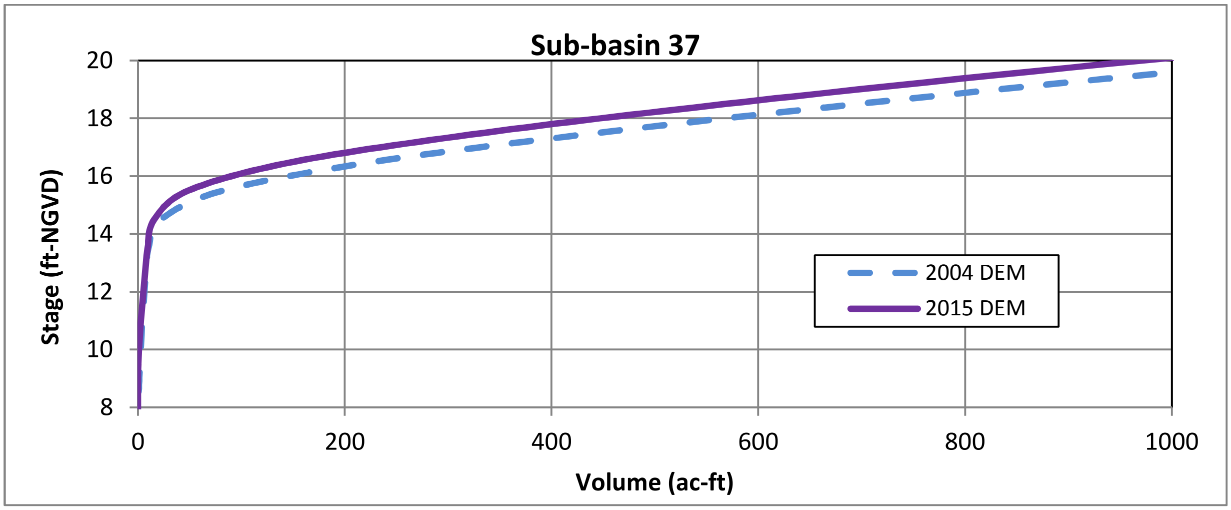

Figure D43. Stage-Volume Curves for Sub-basin 37

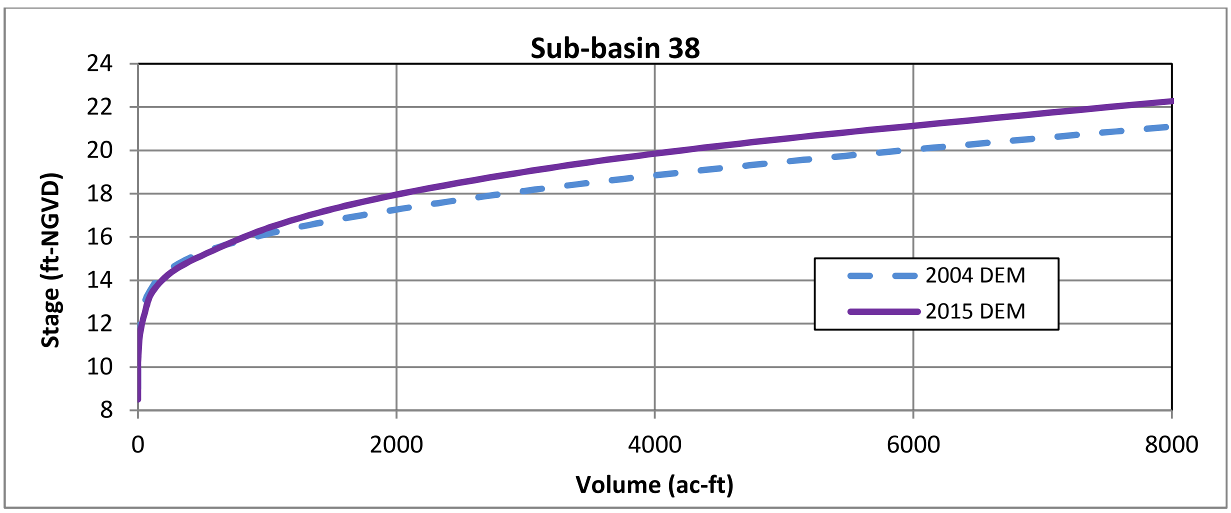

Figure D44. Stage-Volume Curves for Sub-basin 38

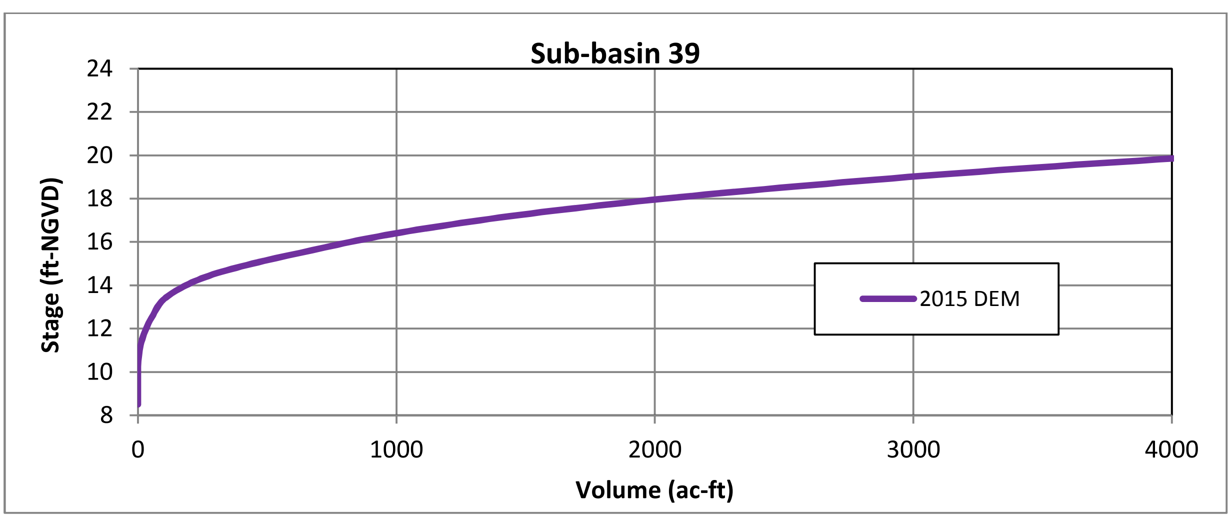

Figure D45. Stage-Volume Curves for Sub-basin 39

ACA Aerial Cartographics of America, Inc.
Digital Mapping - LAMP - Helicopter LiDAR - Mobile LiDAR - Digital Orthophotography - HD Video

Survey and Map Report

Provided by:

AERIAL CARTOGRAPHICS OF AMERICA, INC. LB # 0006748

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Orlando, FL 32809-3846	Orlando, FL 32810

Phone (407) 851-7880 Fax (407)855-8250

P.S.M. in responsible charge: Edward C. Beute P.S.M. 5429

Title: Topographic Survey

Date of Survey (LiDAR): December 19, 2013

Subject Name: Wellington Floodplain Mapping

Reference No.: 2013155

File Names: 227 LAS Files (000001-000227. LAS), 13155_Wellington_Contours.DWG

Field Surveys provided by: Wantman Group, Inc. 2035 Vista Parkway, Suite 200 West Palm Beach, FL 33411

Purpose

The purpose of the survey is to obtain airborne Light Detection and Ranging (LiDAR) survey data of a specific area in the Village of Wellington, Florida covering approximately 48 square miles as depicted on a .PDF file provided by the Wantman Group, Inc.

Acquisition

The laser data was acquired on December 19, 2013 between 1308 and 1808 hours utilizing a Riegl LMS-Q680i full waveform laser scanner (Serial Number SS9994878) at an approximate altitude of 2,800 feet above ground level (AGL), at a nominal ground speed of 100 knots with a Pulse Rate Repetition (PRR) of 220kH, resulting in a swath width of approximately 2800 feet and a point density of approximately 2 points per square meter.

A boresite calibration was performed to define the misalignment angles between the laser sensor and the IMU.

Airborne GPS Processing

Global Positioning System (GPS) data were collected in the aircraft using a Novatel® dual frequency GPS receiver during the flight sessions to provide positional information for the sensor platform. Airborne Global Positioning System (ABGPS) and Inertial Measurement Unit (IMU) data were post-processed and corrected in accordance with simultaneous GPS observations collected at a base station set up on NGS monument Designation Z536 (PID AJ8761). GPS positional information was recorded at the base station at one second epochs. IMU data was recorded at 200 hertz. Each station remained in operation for the duration of the project flight.

The GPS data from the ground base stations and the airborne platform were processed using Applanix POSPac MMS 6.2 software module. The IMU solution was processed to provide information regarding the attitude of the sensor platform. The solutions were integrated and adjusted using a Kalman filter in a forward/reverse solution to provide a Smoothed Best Estimate of Trajectory (SBET).

LiDAR Processing

The raw laser data were merged to the SBET by time stamps using Riegl RiProcess software. The data were processed using RiProcess, RiAnalyze, and RiWorld software modules where each flight line was processed to a point cloud. The data were adjusted flight line to flight line using Riegl's Scan Data Adjustment tool to ensure a proper match between flight lines. Each flight was checked for project coverage, data gaps between overlapping flight lines, point density and then exported in LAS 1.2 format. The entire project was collected without gaps with a Nominal Point Spacing (NPS) of approximately 2 points per square meter. The files were projected to the North American Datum 1983 (2011) Florida State Plane Coordinate System, East Zone (901) and National American Vertical Datum of 1988 (NAVD88) Geiodl2A. All units are U.S. Survey Feet. The LAS files were imported to TerraSolid, LTD TerraScan software to be classified to bare earth ground.

Breakline polygons were drawn around water bodies and conveyances for hydro-flattening and hydro-enforcing purposes. The water points were conflated using Data Transfer Solutions EarthShaper software. One-half foot contours were generated and the shape file converted to Autodesk Civil 3D format.

Accuracy Statement

The bare earth ground Lidar data was compared to the ground control supplied by Wantman Group, Inc. A Triangulated Irregular Network (TIN) of the laser points was constructed at the horizontal location of each ground control point. A difference measurement was made between the laser point and the control point elevations.

The elevations in open, flat, or gently sloping terrain demonstrated a Vertical Root Mean Square Error (RMSEz) of 0.08 foot. The calculated Fundamental Vertical Accuracy (FVA) is 0.16 foot at the 95% Confidence Level (1.96*RMSEz) for points in open, flat, or gently sloping areas.

The elevations in areas obscured by ground cover, brush, or trees demonstrated a RMSEz of 0.34 foot. The calculated Supplemental Vertical Accuracy (SVA) is 0.68 foot at the 95% Confidence Level for points in areas obscured by ground cover, brush, or trees.

The elevations in all areas combined demonstrated a RMSEz of 0.30 foot resulting in a calculated Consolidated Vertical Accuracy (CVA) of 0.60 foot at the 95% Confidence Level (1.96*RMSEz).

These values were calculated using the Federal Geodetic Data Committee (FGDC) Geospatial Positional Accuracy Standards, Part 3 (FGDC-STD-007.3-1998) National Standards for Spatial Data Accuracy (NSSDA).

Absolute horizontal positional accuracy was within contract requirements.

The survey data provided by the Wantman Group, Inc. is not certified by this document.

This survey is neither full nor complete without this Survey and Map Report and is not valid without the signature and original raised seal of a Florida Licensed Surveyor and Mapper.

All work was accomplished under the supervision of a Professional Surveyor and Mapper pursuant to Chapter 472, Florida Statutes and a Certified Photogrammetrist as recognized by the American Society for Photogrammetry and Remote Sensing.

This Topographic Survey was done under my responsible charge and meets the Minimum Technical Standards of the Florida Board of Professional Surveyors and Mappers, Chapter 5J-17.050 through 17.052, Florida Administrative Code, pursuant to Section 472.027, Florida Statutes.

Signed: ___(f3,2___________________

Date: 0²1244/14 6, Zet

Edward C. Beute, PSM, CP

Florida Professional Surveyor and Mapper.:11:*642Y

423 SOUTH KELLER RD., SUITE 300, ORLANDO, FLORIDA 32810 P: 407-851-7880 P: 407-855-8250 www.aca-net.com

APPENDIX F: CANAL MAXIMUM STAGE PROFILES FOR 10-YR AND 100-YR 72-HR EVENTS

Canal in HEC-RAS model	Canal Reach	Table	Figures (10-yr and 100-yr profiles)
C-51	R1 through R11	F1	F1, F2
E-4	RE4, RE4b	F2	F3, F4
Stub Canal	RSC	F3	F5, F6
E-3S	RE3S	F4	F7, F8
E-3N	RE3N	F5	F9, F10
E-2S	RE2S	F6	F11,F12
E-2N	RE2N	F7	F13, F14
E-1S	RE1S	F8	F15, F16
E-1N	RE1N	F9	F17, F18
M1	RM1	F10	F19, F20
M2	RM2	F11	F21, F22

Table F1. C-51 Canal 10-yr and 100-yr 72-hr Peak Stage Surface Water Profile

Reach	River Station (ft)	Structure Type	Channel Bottom Min. Elevation (ft NGVD29)	10-yr Max. Water Surface Elevation (ft NGVD29)	100-yr Max. Water Surface Elevation (ft NGVD29)
R11	0	Tidal end of C-51	-18.2	4.6	4.6
R11	177.5		-17.4	4.7	4.7
R11	355		-16.5	4.7	4.7
R11	532.5		-15.7	4.7	4.8
R11	710		-14.8	4.7	4.8
R11	720	Gated Spillway	S-155 Structure		
R11	750		-14.8	10.3	12.0
R11	854		-14.8	10.3	12.0
R11	958		-14.7	10.2	11.9
R11	999	Bridge	U.S. Highway 1		
R11	1040		-14.7	10.2	11.9
R11	1227.5		-15.2	10.2	12.0
R11	1335	Lateral structure	Sub-basin 37 outfall -2500' Long 60" RCP (Along Dixie Hwy) outfall		
R11	1400	Lateral structure	Sub-basin 34 outfall -1000' Long 36" RCP (DOT, Dixie Hwy)		
R11	1415		-15.7	10.2	12.0
R11	1602.5		-16.2	10.3	12.0
R11	1790		-16.7	10.3	12.0
R11	1811		-16.7	10.3	12.0
R11	1981.16		-16.7	10.3	12.1
R11	2151.33		-16.6	10.3	12.1
R11	2167	Lateral structure	Sub-basin 37 outfall -2000' Long 36" RCP (200' East of Georgia Ave)		
R11	2321.5		-16.6	10.4	12.1
R11	2467	Lateral structure	Sub-basin 36 outfall - 3000' Long 36" RCP (Georgia Ave)		
R11	2491.66		-16.6	10.4	12.2
R11	2661.83		-16.5	10.4	12.2
R11	2832		-16.5	10.4	12.2
R11	2843	Lateral structure	Sub-basin 34 outfall -1800' Long 48" RCP (Lake Worth)		
R11	2853	Lateral structure	Sub-basin 36 outfall -2500' Long 60" RCP (Golf Course)		
R11	2875		-16.5	10.4	12.2
R11	2900		-16.5	10.4	12.2
R11	3094.16		-16.5	10.4	12.2
R11	3288.33		-16.5	10.4	12.2
R11	3482.5		-16.5	10.4	12.2
R11	3676.66		-16.5	10.4	12.2
R11	3870.83		-16.5	10.4	12.2
R11	4065		-16.5	10.4	12.2
R11	4100		-16.5	10.4	12.2
R11	4281.5		-16.5	10.4	12.2
R11	4300	Lateral structure	Sub-basin 34 overbank discharge to C-51 Canal @ elev. 11.5 ft NGVD		
R11	4463		-16.5	10.4	12.3
R11	4644.5		-16.5	10.4	12.3
R11	4826		-16.5	10.4	12.3
R11	4853	Bridge	I-95 Northbound bridge		
R11	4880		-16.5	10.4	12.3
R11	4929		-15.8	10.4	12.3
R11	4983		-15.8	10.4	12.3

Table F1. C-51 Canal 10-yr and 100-yr 72-hr Peak Stage Surface Water Profile (Cont.)

Reach	River Station (ft)	Structure Type	Channel Bottom Min. Elevation (ft NGVD29)	10-yr Max. Water Surface Elevation (ft NGVD29)	100-yr Max. Water Surface Elevation (ft NGVD29)
R11	5105		-17.2	10.5	12.3
R11	5112	Bridge	Seaboard Coastline Railroad bridge		
R11	5118		-17.2	10.5	12.6
R11	5311.83		-17.2	10.5	12.6
R11	5505.66		-17.2	10.5	12.6
R11	5699.5		-17.2	10.5	12.6
R11	5893.33		-17.2	10.5	12.6
R11	6087.16		-17.2	10.5	12.6
R11	6281		-17.2	10.5	12.6
R10	6325		-17.2	10.5	12.6
R10	6520.07		-16.7	10.5	12.6
R10	6715.14		-16.1	10.5	12.6
R10	6910.21		-15.6	10.5	12.6
R10	7105.28		-15.0	10.5	12.6
R10	7300.35		-14.5	10.5	12.6
R10	7495.42		-13.9	10.5	12.6
R10	7690.5		-13.4	10.5	12.6
R10	7885.57		-12.8	10.5	12.6
R10	8080.64		-12.3	10.5	12.6
R10	8275.71		-11.7	10.5	12.6
R10	8470.78		-11.2	10.5	12.6
R10	8665.85		-10.6	10.5	12.6
R10	8860.92		-10.1	10.5	12.6
R10	8993	Bridge	Forest Hill Boulevard bridge		
R10	9056		-9.5	10.5	12.7
R10	9168		-9.5	10.5	12.7
R9	9200		-9.5	10.5	12.7
R9	9382.36		-9.5	10.5	12.7
R9	9564.72		-9.5	10.6	12.7
R9	9747.09		-9.4	10.6	12.7
R9	9929.45		-9.4	10.6	12.7
R9	10111.8		-9.4	10.6	12.7
R9	10294.1		-9.4	10.6	12.7
R9	10476.5		-9.3	10.6	12.7
R9	10658.9		-9.3	10.6	12.7
R9	10841.2		-9.3	10.6	12.8
R9	11023.6		-9.2	10.6	12.8
R9	11206		-9.2	10.6	12.8
R9	11406		-9.2	10.6	12.8
R9	11606		-9.2	10.6	12.8
R9	11806		-9.2	10.6	12.8
R9	12006		-9.2	10.7	12.8
R9	12206		-9.2	10.7	12.8
R9	12243	Lateral structure	Sub-basin 36 (Dreher Zoo) outfall		
R9	12406		-9.2	10.7	12.8
R9	12606		-9.2	10.7	12.8

Table F1. C-51 Canal 10-yr and 100-yr 72-hr Peak Stage Surface Water Profile (Cont.)

Reach	River Station (ft)	Structure Type	Channel Bottom Min. Elevation (ft NGVD29)	10-yr Max. Water Surface Elevation (ft NGVD29)	100-yr Max. Water Surface Elevation (ft NGVD29)
R9	12806		-9.2	10.7	12.8
R9	13006		-9.2	10.7	12.8
R9	13206		-9.2	10.7	12.9
R9	13238	Bridge	Summit Blvd. bridge		
R9	13269		-9.2	10.7	12.9
R9	13440.6		-9.2	10.7	12.9
R9	13612.3		-9.2	10.7	12.9
R9	13784		Junction of C-51 Canal with Stub Canal		
R9	13784		-9.2	10.7	12.9
R8	13825		-9.2	10.7	12.9
R8	14004.6		-9.2	10.7	12.9
R8	14184.2		-9.2	10.8	12.9
R8	14363.8		-9.2	10.8	12.9
R8	14543.4	Pump	Sub-basin 35 discharge to C-51 Canal		
R8	14543.4		-9.2	10.8	12.9
R8	14723		-9.2	10.8	12.9
R7	14775		-9.2	10.8	12.9
R7	14966.5		-9.8	10.8	12.9
R7	15158		-10.3	10.8	12.9
R7	15349.6		-10.9	10.8	12.9
R7	15541.1		-11.4	10.8	12.9
R7	15732.7		-11.9	10.8	13.0
R7	15924.2		-12.5	10.8	13.0
R7	16115.8		-13.0	10.8	13.0
R7	16307.3		-13.6	10.8	13.0
R7	16498.9		-14.1	10.8	13.0
R7	16690.4		-14.7	10.8	13.0
R7	16882		-15.2	10.8	13.0
R7	17075.3		-15.2	10.8	13.0
R7	17268.6		-15.2	10.8	13.0
R7	17461.9		-15.2	10.8	13.0
R7	17655.2		-15.2	10.9	13.0
R7	17848.5		-15.2	10.9	13.0
R7	18041.8		-15.2	10.9	13.0
R7	18235.1		-15.2	10.9	13.0
R7	18428.4		-15.2	10.9	13.1
R7	18621.7		-15.2	10.9	13.1
R7	18815		-15.2	10.9	13.1
R7	18858	Lateral structure	Sub-basin 28 outfall to C51 - 8'x40' Box Culvert @7.0'		
R7	18900		-15.2	10.9	13.1
R7	19062		-15.2	10.9	13.1
R7	19224		-15.2	10.9	13.1
R7	19386		-15.2	10.9	13.1
R7	19548		-15.2	10.9	13.1
R7	19589	Bridge	Congress Ave. bridge		

Table F1. C-51 Canal 10-yr and 100-yr 72-hr Peak Stage Surface Water Profile (Cont.)

Reach	River Station (ft)	Structure Type	Channel Bottom Min. Elevation (ft NGVD29)	10-yr Max. Water Surface Elevation (ft NGVD29)	100-yr Max Water Surface Elevation (ft NGVD29)
R7	19629		-15.2	10.9	13.1
R7	19825.2		-14.8	10.9	13.1
R7	20021.4		-14.5	10.9	13.1
R7	20217.6		-14.1	10.9	13.1
R7	20413.9		-13.7	10.9	13.1
R7	20610.1		-13.3	10.9	13.2
R7	20806.3		-12.9	11.0	13.2
R7	21002.6		-12.5	11.0	13.2
R7	21198.8		-12.2	11.0	13.2
R7	21395		-11.8	11.0	13.2
R7	21591.3		-11.4	11.0	13.2
R7	21787.5		-11.0	11.0	13.2
R7	21983.7		-10.6	11.0	13.2
R7	22180		-10.3	11.0	13.2
R7	22376.2		-9.9	11.0	13.3
R7	22572.4		-9.5	11.0	13.3
R7	22768.6		-9.1	11.0	13.3
R7	22964.9		-8.7	11.1	13.3
R7	23161.1		-8.4	11.1	13.3
R7	23357.3		-8.0	11.1	13.3
R7	23553.6		-7.6	11.1	13.3
R7	23749.8		-7.2	11.1	13.4
R7	23946		-6.8	11.1	13.4
R7	24142.3		-6.4	11.1	13.4
R7	24338.5		-6.1	11.2	13.4
R7	24534.7		-5.7	11.2	13.4
R7	24731		-5.3	11.2	13.5
R7	24757	Bridge	Kirk Road bridge		
R7	24783		-5.3	11.2	13.5
R7	24880	Pump	Sub-basin 26 discharge to C-51 Canal		
R7	24880		-5.3	11.2	13.5
R7	25069.3		-5.3	11.2	13.5
R7	25258.6		-5.2	11.2	13.5
R7	25447.9		-5.1	11.3	13.5
R7	25637.2		-5.1	11.3	13.6
R7	25826.5		-5.0	11.3	13.6
R7	26015.8		-5.0	11.3	13.6
R7	26205.1		-4.9	11.3	13.6
R7	26394.4		-4.9	11.4	13.7
R7	26583.7		-4.8	11.4	13.7
R7	26773		-4.8	11.4	13.7
R7	26962.3		-4.7	11.4	13.7
R7	27151.6		-4.7	11.5	13.8
R7	27341		-4.6	11.5	13.8
R7	27392	Bridge	Military Trail bridge		
R7	27443		-4.6	11.5	13.8

Table F1. C-51 Canal 10-yr and 100-yr 72-hr Peak Stage Surface Water Profile (Cont.)

Reach	River Station (ft)	Structure Type	Channel Bottom Min. Elevation (ft NGVD29)	10-yr Max. Water Surface Elevation (ft NGVD29)	100-yr Max. Water Surface Elevation (ft NGVD29)
R7	27642		-4.6	11.5	13.8
R7	27841		-4.6	11.6	13.9
R7	28040		-4.6	11.6	13.9
R7	28070	Lateral structure	Sub-basin 25A outfall - Culvert Discharge to C51 through 2 Slide Gates		
R7	28100		-4.6	11.6	13.9
R7	28294.3		-4.8	11.6	13.9
R7	28488.6		-5.0	11.7	14.0
R7	28682.9		-5.2	11.7	14.0
R7	28877.2		-5.3	11.7	14.0
R7	29071.5		-5.5	11.7	14.0
R7	29265.8		-5.7	11.8	14.1
R7	29460.1		-5.9	11.8	14.1
R7	29654.4		-6.1	11.8	14.1
R7	29848.7		-6.3	11.9	14.2
R7	30043		-6.4	11.9	14.2
R7	30088	Bridge	Haverhill Road bridge		
R7	30178		-8.3	11.9	14.2
R7	30369.9		-8.3	12.0	14.3
R7	30561.8		-8.3	12.0	14.3
R7	30753.8		-8.3	12.0	14.3
R7	30945.7		-8.2	12.0	14.3
R7	31137.7		-8.2	12.0	14.3
R7	31329.6		-8.2	12.1	14.4
R7	31521.5		-8.2	12.1	14.4
R7	31713.5		-8.1	12.1	14.4
R7	31905.4		-8.1	12.1	14.4
R7	32097.4		-8.1	12.2	14.5
R7	32289.3		-8.1	12.2	14.5
R7	32481.2		-8.0	12.2	14.5
R7	32673.2		-8.0	12.2	14.5
R7	32865.1		-8.0	12.2	14.5
R7	33057.1		-8.0	12.3	14.6
R7	33249		-7.9	12.3	14.6
R7	33441		Junction of C-51 Canal with LWDD E-3 canal		
R7	33441		-7.9	12.3	14.6
R6	33500		-7.9	12.3	14.6
R6	33641		-7.9	12.3	14.6
R6	33782		-7.9	12.3	14.6
R6	33977.9		-7.9	12.3	14.6
R6	34173.8		-7.8	12.3	14.6
R6	34369.7		-7.8	12.3	14.6
R6	34565.7		-7.7	12.3	14.6
R6	34761.6		-7.7	12.3	14.6
R6	34957.5		-7.6	12.3	14.6
R6	35153.5		-7.6	12.3	14.6
R6	35349.4		-7.6	12.3	14.7

Table F1. C-51 Canal 10-yr and 100-yr 72-hr Peak Stage Surface Water Profile (Cont.)

Reach	River Station (ft)	Structure Type	Channel Bottom Min. Elevation (ft NGVD29)	10-yr Max. Water Surface Elevation (ft NGVD29)	100-yr Max Water Surface Elevation (ft NGVD29)
R6	35545.3		-7.5	12.3	14.7
R6	35741.2		-7.5	12.3	14.7
R6	35937.2		-7.4	12.4	14.7
R6	36133.1		-7.4	12.4	14.7
R6	36329		-7.3	12.4	14.7
R6	36525		-7.3	12.4	14.7
R6	36721		-7.4	12.4	14.7
R6	36917		-7.5	12.4	14.7
R6	37113		-7.6	12.4	14.7
R6	37309		-7.7	12.4	14.7
R6	37505		-7.8	12.4	14.7
R6	37701		-7.9	12.4	14.7
R6	37897		-7.9	12.4	14.7
R6	38093		-8.0	12.4	14.8
R6	38183	Bridge	Jog Road bridge		
R6	38258		-8.3	12.4	14.8
R6	38437.4		-8.3	12.4	14.8
R6	38616.8		-8.2	12.4	14.8
R6	38796.3		-8.2	12.4	14.8
R6	38975.7		-8.1	12.4	14.8
R6	39155.2		-8.1	12.4	14.8
R6	39334.6		-8.0	12.4	14.8
R6	39514.1		-8.0	12.4	14.8
R6	39693.5		-8.0	12.4	14.8
R6	39873		-7.9	12.4	14.8
R6	40001.5		-7.4	12.4	14.8
R6	40130		-6.9	12.5	14.8
R6	40330		-6.6	12.5	14.8
R6	40530		-6.2	12.5	14.8
R6	40730		-5.8	12.5	14.8
R6	40930		-5.4	12.5	14.8
R6	41130		-5.0	12.5	14.8
R6	41330		-5.1	12.5	14.8
R6	41530		-5.2	12.5	14.9
R6	41730		-5.3	12.5	14.9
R6	41930		-5.4	12.5	14.9
R6	42130		-5.5	12.5	14.9
R6	42330		-5.3	12.5	14.9
R6	42530		-5.0	12.5	14.9
R6	42730		-4.7	12.5	14.9
R6	42930		-4.4	12.5	14.9
R6	43130		-4.1	12.5	14.9
R6	43330		-3.6	12.5	14.9
R6	43530		-3.0	12.6	14.9
R6	43730		-2.5	12.6	14.9
R6	43930		-2.0	12.7	14.9

Table F1. C-51 Canal 10-yr and 100-yr 72-hr Peak Stage Surface Water Profile (Cont.)

Reach	River Station (ft)	Structure Type	Channel Bottom Min. Elevation (ft NGVD29)	10-yr Max. Water Surface Elevation (ft NGVD29)	100-yr Max. Water Surface Elevation (ft NGVD29)
R6	44130		-1.4	12.6	14.9
R6	44302.8		-1.4	12.6	14.9
R6	44475.6		-1.4	12.6	15.0
R6	44648.4		-1.4	12.6	15.0
R6	44821.2		-1.4	12.6	15.0
R6	44994		-1.4	12.7	15.0
R6	45010	Bridge	Florida Turnpike Northbound bridge		
R6	45027		-1.4	12.7	15.0
R6	45036		-2.0	12.7	15.0
R6	45052	Bridge	Florida Turnpike Southbound bridge		
R6	45069		-2.0	12.7	15.0
R6	45130		-3.5	12.7	15.0
R6	45305		-3.2	12.7	15.0
R6	45471		-2.5	12.7	15.0
R6	45637		-1.7	12.7	15.0
R6	45803		-1.0	12.7	15.0
R6	45825	Lateral structure	Sub-basin 38 outfall - 5.5' wide slide gate		
R6	45850		-1.0	12.7	15.0
R6	45990		-0.4	12.7	15.1
R6	46130		0.2	12.7	15.1
R6	46330		0.0	12.7	15.1
R6	46530		-0.2	12.7	15.1
R6	46730		-0.3	12.7	15.1
R6	46930		-0.5	12.8	15.1
R6	47130		-0.7	12.8	15.1
R6	47278.3		-0.5	12.8	15.2
R6	47426.6		-0.3	12.8	15.2
R6	47575		-0.1	12.8	15.2
R6	47587	Bridge	Benoist Farms Rd bridge		
R6	47604		-0.1	12.8	15.2
R6	47660		-0.1	12.8	15.2
R6	47809.3		-0.6	12.8	15.2
R6	47958.6		-1.2	12.9	15.2
R6	48108		Junction of C-51 Canal with LWDD E-2 Canal		
R6	48108		-1.7	12.9	15.2
R5	48175		-1.7	12.9	15.2
R5	48366		-1.2	12.9	15.2
R5	48557		-0.8	12.9	15.2
R5	48748		-0.3	12.9	15.2
R5	48939		0.2	12.9	15.2
R5	49130		0.7	12.9	15.2
R5	49271.5		-0.1	12.9	15.2
R5	49413		-0.9	12.9	15.2
R5	49592.2		-0.6	12.9	15.2
R5	49771.5		-0.3	12.9	15.2

Table F1. C-51 Canal 10-yr and 100-yr 72-hr Peak Stage Surface Water Profile (Cont.)

Reach	River Station (ft)	Structure Type	Channel Bottom Min. Elevation (ft NGVD29)	10-yr Max. Water Surface Elevation (ft NGVD29)	100-yr Max. Water Surface Elevation (ft NGVD29)
R5	49950.7		0.0	12.9	15.2
R5	50130		0.3	12.9	15.3
R5	50298.6		-0.6	12.9	15.3
R5	50467.2		-1.6	12.9	15.3
R5	50635.8		-2.5	12.9	15.3
R5	50804.4		-3.4	12.9	15.3
R5	50973		-4.3	12.9	15.3
R5	51130		0.1	13.0	15.3
R5	51330		-0.1	13.0	15.3
R5	51530		-0.2	13.0	15.3
R5	51730		-0.4	13.0	15.3
R5	51930		-0.5	13.0	15.3
R5	52130		-0.7	13.0	15.3
R5	52330		-0.3	13.0	15.3
R5	52530		0.0	13.0	15.3
R5	52730		0.4	13.0	15.4
R5	52930		0.8	13.1	15.4
R5	53130		1.1	13.1	15.4
R5	53330		1.2	13.1	15.4
R5	53530		1.2	13.1	15.4
R5	53730		1.2	13.1	15.4
R5	53930		1.2	13.2	15.5
R5	54130		1.3	13.2	15.5
R5	54330		0.5	13.2	15.5
R5	54530		-0.3	13.2	15.5
R5	54730		-1.2	13.2	15.5
R5	54930		-2.0	13.3	15.5
R5	55130		-2.8	13.3	15.5
R5	55286		-2.2	13.3	15.5
R5	55442		-1.7	13.3	15.5
R5	55598		-1.2	13.3	15.5
R5	55754		-0.7	13.3	15.6
R5	55775	Bridge	Mall Entrance bridge		
R5	55796		-0.7	13.3	15.6
R5	55955		0.8	13.3	15.6
R5	56130		2.9	13.3	15.6
R5	56230		0.8	13.3	15.6
R5	56384		Junction of C-51 Canal with LWDD E1S Canal		
R5	56384		-4.6	13.3	15.6
R4	56450		-4.6	13.3	15.6
R4	56593		-4.6	13.3	15.6
R4	56736		-4.6	13.3	15.6
R4	56807	Bridge	Highway 441 bridge		
R4	56878		-4.6	13.3	15.6
R4	57019.3		-4.3	13.3	15.6

Table F1. C-51 Canal 10-yr and 100-yr 72-hr Peak Stage Surface Water Profile (Cont.)

Reach	River Station (ft)	Structure Type	Channel Bottom Min. Elevation (ft NGVD29)	10-yr Max. Water Surface Elevation (ft NGVD29)	100-yr Max Water Surface Elevation (ft NGVD29)
R4	57160.6		-4.0	13.3	15.6
R4	57302		-3.7	13.3	15.6
R3	57350		-3.7	13.3	15.6
R3	57540		-2.7	13.3	15.6
R3	57700	Inl Struct -Spillway	Structure S-155A		
R3	57730		-1.6	15.5	18.3
R3	57750		-0.9	15.5	18.3
R3	57800		0.7	15.5	18.3
R3	57830		-1.6	15.5	18.3
R3	57926	Bridge	Lowes Bridge		
R3	58190		-0.6	15.5	18.3
R3	58350		0.3	15.5	18.3
R3	58375	Lateral structure	Sub-basin 20A outfall - 2-60" CMP @10' Invert		
R3	58460		0.3	15.5	18.3
R3	58570		0.2	15.5	18.3
R3	58741.6		0.2	15.5	18.3
R3	58913.3		0.2	15.5	18.3
R3	59085		0.2	15.5	18.3
R3	59256.6		0.1	15.5	18.3
R3	59428.3		0.1	15.5	18.3
R3	59600		0.1	15.5	18.3
R3	59719		-0.3	15.5	18.3
R3	59838		-0.6	15.5	18.3
R3	59900		-0.6	15.5	18.3
R3	60062.5		-0.3	15.5	18.3
R3	60225		-0.1	15.5	18.3
R3	60387.5		0.2	15.5	18.3
R3	60550		0.5	15.5	18.3
R3	60610		1.7	15.5	18.3
R3	60806.6		1.7	15.5	18.3
R3	61003.3		1.7	15.5	18.3
R3	61174	Lateral structure	Sub-basin 16A outfall - 30'wide Weir, Crest @13'		
R3	61200		1.7	15.5	18.3
R3	61343.3		1.9	15.5	18.3
R3	61486.6		2.0	15.5	18.3
R3	61630		2.2	15.5	18.3
R3	61780		1.9	15.5	18.3
R3	61930		1.6	15.5	18.3
R3	62080		1.3	15.5	18.3
R3	62246.6		0.8	15.5	18.3
R3	62413.3		0.4	15.5	18.3
R3	62580	Pump	Discharge from Wellington pump PS#6		
R3	62580		-0.1	15.5	18.3
R3	62690		0.9	15.5	18.3
R3	62880.6		0.9	15.5	18.3
R3	63071.2		0.9	15.5	18.3
R3	63261.8		0.9	15.5	18.3

Table F1. C-51 Canal 10-yr and 100-yr 72-hr Peak Stage Surface Water Profile (Cont.)

Reach	River Station (ft)	Structure Type	Channel Bottom Min. Elevation (ft NGVD29)	10-yr Max. Water Surface Elevation (ft NGVD29)	100-yr Max Water Surface Elevation (ft NGVD29)
R3	63452.4		0.9	15.5	18.3
R3	63643		0.9	15.5	18.3
R3	63843		0.5	15.5	18.3
R3	64043		0.1	15.5	18.3
R3	64243		-0.3	15.5	18.3
R3	64443		-0.7	15.5	18.3
R3	64643		-1.0	15.5	18.3
R3	64843		-1.4	15.5	18.3
R3	65043		-1.8	15.5	18.3
R3	65243		-2.2	15.5	18.3
R3	65473	Bridge	Wellington Road bridge		
R3	65502		-2.6	15.5	18.3
R3	65590		1.1	15.5	18.3
R3	65766.6		0.9	15.5	18.3
R3	65943.3		0.7	15.5	18.3
R3	66120		0.5	15.5	18.3
R3	66296.6		0.3	15.5	18.3
R3	66473.3		0.1	15.5	18.3
R3	66650		-0.1	15.5	18.3
R3	66846.6		-2.4	15.5	18.3
R3	67043.3		-4.8	15.5	18.3
R3	67240		-7.1	15.5	18.3
R3	67355		-2.6	15.5	18.3
R3	67530		-1.0	15.5	18.3
R3	67560	Lateral structure	Sub-basin 15A outfall (Lake Challenger) to C51 (3-72" RCP)		
R3	67580		-1.0	15.5	18.3
R3	67607		Junction of C-51 Canal with M-1 Canal		
R3	67607		-1.0	15.5	18.3
R2	67700		-1.0	15.5	18.3
R2	67883		-0.8	15.5	18.3
R2	68066		-0.6	15.5	18.3
R2	68249		-0.3	15.5	18.3
R2	68432		-0.1	15.5	18.3
R2	68615		0.1	15.5	18.3
R2	68790.8		0.1	15.5	18.3
R2	68966.6		0.1	15.5	18.2
R2	69142.5		0.2	15.4	18.2
R2	69318.3		0.2	15.4	18.2
R2	69494.1		0.2	15.4	18.2
R2	69670		0.2	15.4	18.2
R2	69864		0.4	15.4	18.2
R2	70058		0.7	15.4	18.2
R2	70252		0.9	15.4	18.2
R2	70446		1.2	15.4	18.2
R2	70640		1.4	15.4	18.2
R2	70818.7		1.1	15.3	18.2
R2	70997.5		0.7	15.4	18.2

Table F1. C-51 Canal 10-yr and 100-yr 72-hr Peak Stage Surface Water Profile (Cont.)

Reach	River Station (ft)	Structure Type	Channel Bottom Min. Elevation (ft NGVD29)	10-yr Max. Water Surface Elevation (ft NGVD29)	100-yr Max. Water Surface Elevation (ft NGVD29)
R2	71176.2		0.4	15.3	18.2
R2	71355		0.0	15.3	18.2
R2	71496	Bridge	Forest Hill Blvd. Bridge		
R2	71498		-5.7	15.3	18.2
R2	71660		-0.1	15.3	18.2
R2	71855		0.0	15.3	18.2
R2	72050		0.1	15.3	18.2
R2	72245		0.1	15.3	18.2
R2	72440		0.2	15.3	18.2
R2	72605		-2.6	15.3	18.2
R2	72605.1	Lateral structure	Wellington PS3 Bleeder - 4.5 x 4.5 Gate Inv = 3.4 ft NGVD		
R2	72721.5		-2.7	15.2	18.2
R2	72778	Lateral structure	Sub-basin 11 outfall Gate G, 1-6' wide Slide Gate, Top @18'		
R2	72838		Discharge from Wellington pump PS#3		
R2	72838		-2.7	15.2	18.2
R2	73028.6		-1.8	15.2	18.2
R2	73219.3		-0.9	15.2	18.2
R2	73410		0.0	15.2	18.2
R2	73445		0.2	15.2	18.2
R2	73572.5		-0.3	15.2	18.1
R2	73679	Lateral structure	Sub-basin 12 outfall - 2' wide Weir @14' Crest		
R2	73700		-0.7	15.1	18.1
R2	73880		0.0	15.1	18.1
R2	74060		0.8	15.1	18.1
R2	74240		1.5	15.1	18.1
R2	74420		2.2	15.0	18.1
R2	74586.6		1.2	15.0	18.1
R2	74753.3		0.2	15.0	18.1
R2	74920		-0.8	15.0	18.1
R2	75120		-3.6	15.0	18.1
R2	75180		-3.6	15.0	18.1
R2	75286		-3.9	15.0	18.1
R2	75318	Bridge	Big Blue Trace Road Bridge		
R2	75345		-3.6	15.0	18.1
R2	75465		-0.8	15.0	18.1
R2	75634.1		-0.7	15.0	18.1
R2	75803.3		-0.6	14.9	18.1
R2	75972.5		-0.5	14.9	18.0
R2	76141.6		-0.3	14.9	18.0
R2	76310.8		-0.2	14.9	18.0
R2	76480		-0.1	14.9	18.0
R2	76674		0.1	14.8	18.0
R2	76868		0.3	14.8	18.0
R2	77062		0.5	14.8	18.0
R2	77256		0.7	14.8	18.0
R2	77450		0.9	14.8	18.0

Table F1. C-51 Canal 10-yr and 100-yr 72-hr Peak Stage Surface Water Profile (Cont.)

Reach	River Station (ft)	Structure Type	Channel Bottom Min. Elevation (ft NGVD29)	10-yr Max. Water Surface Elevation (ft NGVD29)	100-yr Max. Water Surface Elevation (ft NGVD29)
R2	77648		0.9	14.7	18.0
R2	77846		0.9	14.7	18.0
R2	78044		0.9	14.7	18.0
R2	78242		0.9	14.7	18.0
R2	78440		0.9	14.6	17.9
R2	78600		1.1	14.6	17.9
R2	78760		1.2	14.6	17.9
R2	78920		1.4	14.6	17.9
R2	79102		1.3	14.6	17.9
R2	79284		1.1	14.5	17.9
R2	79466		0.9	14.5	17.9
R2	79648		0.8	14.5	17.9
R2	79830		0.6	14.4	17.9
R2	80009		0.3	14.4	17.9
R2	80188		0.1	14.4	17.9
R2	80367		-0.2	14.4	17.8
R2	80546		-0.5	14.3	17.8
R2	80736		-1.0	14.3	17.8
R2	80936		-0.9	14.3	17.8
R2	80973	Lateral structure	Sub-basin 11 outfall - Gate D (1-12' Radial Gate & 2-12' Weir @18.5' Crest)		
R2	81136		-0.8	14.2	17.7
R2	81336		-0.6	14.2	17.7
R2	81536		-0.5	14.1	17.7
R2	81736		-1.0	14.1	17.6
R2	81836		-2.5	14.1	17.6
R2	82011		-2.6	14.0	17.6
R2	82186		-2.8	14.0	17.6
R2	82361		-2.9	14.0	17.6
R2	82536		-3.0	14.0	17.5
R2	82636		-2.5	14.0	17.5
R2	82836		0.0	13.9	17.5
R2	83002.6		0.3	13.8	17.5
R2	83169.3		0.7	13.8	17.4
R2	83336		1.0	13.7	17.4
R2	83410		1.0	13.7	17.4
R2	83435	Bridge	Ousley Sod Farm Bridge		
R2	83460		-2.0	13.7	17.3
R2	83586	Pump	Discharge from Wellington pump PS#4		
R2	83586		-2.0	13.7	17.3
R2	83736		-5.0	13.6	17.3
R2	83936		-4.5	13.6	17.3
R2	84119.3		-4.6	13.6	17.3
R2	84302.6		-4.7	13.6	17.2
R2	84486		-4.8	13.6	17.2
R2	84669.3		-4.8	13.5	17.2
R2	84852.6		-4.9	13.6	17.2

Table F1. C-51 Canal 10-yr and 100-yr 72-hr Peak Stage Surface Water Profile (Cont.)

Reach	River Station (ft)	Structure Type	Channel Bottom Min. Elevation (ft NGVD29)	10-yr Max. Water Surface Elevation (ft NGVD29)	100-yr Max. Water Surface Elevation (ft NGVD29)
R2	85036		-5.0	13.4	17.2
R2	85236		-4.3	13.4	17.1
R2	85436		-3.7	13.3	17.1
R2	85636		-3.0	13.3	17.1
R2	85736		-3.7	13.3	17.1
R2	85795		-4.5	13.3	17.1
R2	85895		-4.5	13.3	17.1
R2	85956		-4.5	13.3	17.1
R2	86136		-4.0	13.2	17.0
R2	86336		-3.9	13.2	17.0
R2	86536		-3.7	13.2	17.0
R2	86736		-3.6	13.2	17.0
R2	86936		-3.4	13.1	17.0
R2	87136		-3.3	13.1	16.9
R2	87336		-3.1	13.0	16.9
R2	87536		-3.0	13.0	16.9
R2	87724.6		-2.8	13.0	16.9
R2	87913.3		-2.7	12.9	16.8
R2	88102		-2.5	12.9	16.8
R2	88136		-2.5	12.9	16.8
R2	88188		-2.5	12.8	16.8
R2	88336	Pump	Discharge from Wellington pump PS7		
R2	88336		-3.0	12.8	16.8
R2	88526	Lateral structure	Sub-basin 11 outfall -Gate A, 1-6' wide Slide Gate, Top @18'		
R2	88536		-3.3	12.8	16.7
R2	88736		-3.5	12.8	16.7
R2	88836		-8.5	12.8	16.7
R2	89002.6		-8.2	12.8	16.7
R2	89169.3		-7.8	12.8	16.7
R2	89336		-7.5	12.8	16.7
R2	89502.6		-7.7	12.7	16.6
R2	89669.3		-7.8	12.7	16.6
R2	89836		-8.0	12.7	16.6
R2	89936		-8.0	12.7	16.6
R2	90121.7		-8.2	12.7	16.6
R2	90307.4		-8.4	12.7	16.6
R2	90493.1		-8.6	12.7	16.6
R2	90678.8		-8.9	12.7	16.6
R2	90864.5		-9.1	12.7	16.6
R2	91050.2		-9.3	12.7	16.6
R2	91236		-9.5	12.7	16.6
R2	91416		-9.2	12.7	16.6
R2	91596		-8.9	12.7	16.6
R2	91618	Lateral structure	Sub-basin 10 outfall - 9' wide Weir @17.5' Crest		
R2	91776		-8.6	12.7	16.5
R2	91956		-8.3	12.6	16.5

Table F1. C-51 Canal 10-yr and 100-yr 72-hr Peak Stage Surface Water Profile (Cont.)

Reach	River Station (ft)	Structure Type	Channel Bottom Min. Elevation (ft NGVD29)	10-yr Max. Water Surface Elevation (ft NGVD29)	100-yr Max. Water Surface Elevation (ft NGVD29)
R2	92136		-8.0	12.6	16.5
R2	92326.6		-8.0	12.6	16.5
R2	92517.3		-8.0	12.6	16.5
R2	92708		Junction of C-51 Canal with M-2 Canal		
R2	92708		-8.0	12.6	16.5
R1	92808		-7.0	12.6	16.5
R1	92972		-7.0	12.6	16.5
R1	93136		-7.0	12.6	16.5
R1	93336		-5.0	12.6	16.5
R1	93536		-5.9	12.6	16.5
R1	93736		-6.8	12.5	16.4
R1	93936		-7.6	12.5	16.4
R1	94136		-8.5	12.5	16.4
R1	94286		-6.8	12.5	16.4
R1	94436		-5.0	12.5	16.4
R1	94636		-4.9	12.5	16.4
R1	94836		-4.8	12.5	16.4
R1	95036		-4.7	12.5	16.4
R1	95236		-4.6	12.5	16.3
R1	95436		-4.5	12.4	16.3
R1	95636		-4.4	12.4	16.3
R1	95836		-4.3	12.4	16.3
R1	96036		-4.2	12.4	16.3
R1	96236		-4.1	12.4	16.3
R1	96386		-4.8	12.4	16.2
R1	96536		-5.5	12.4	16.2
R1	96736		-5.4	12.3	16.2
R1	96936		-5.3	12.3	16.2
R1	97136		-5.2	12.3	16.2
R1	97336		-6.8	12.3	16.2
R1	97536		-8.4	12.3	16.2
R1	97736	Pump	S-319 pump discharge from C-51 Canal to STA-1E		
R1	97736		-10.0	12.3	16.2
R1	97936		-7.0	12.3	16.2
R1	98086		-5.1	12.3	16.2
R1	98236		-3.2	12.3	16.2
R1	98402.4		-2.8	12.4	16.2
R1	98568.8		-2.4	12.4	16.2
R1	98735.2		-2.0	12.4	16.2
R1	98901.6		-1.6	12.4	16.2
R1	99068		-1.2	12.4	16.2
R1	99261		-1.2	12.4	16.2
R1	99454.1		-1.2	12.4	16.2
R1	99647.2		-1.2	12.4	16.2

Table F1. C-51 Canal 10-yr and 100-yr 72-hr Peak Stage Surface Water Profile (Cont.)

Reach	River Station (ft)	Structure Type	Channel Bottom Min. Elevation (ft NGVD29)	10-yr Max. Water Surface Elevation (ft NGVD29)	100-yr Max. Water Surface Elevation (ft NGVD29)
R1	99840.3		-1.2	12.4	16.2
R1	100033		-1.2	12.4	16.2
R1	100226		-1.2	12.4	16.2
R1	100419		-1.2	12.4	16.2
R1	100612		-1.1	12.4	16.2
R1	100805		-1.1	12.4	16.2
R1	100998		-1.1	12.4	16.2
R1	101191		-1.1	12.4	16.2
R1	101384		-1.1	12.4	16.2
R1	101578		-1.1	12.4	16.2
R1	101625	Pump	Sub-basin S-4 Sub-basin pump discharge		
R1	101625	Pump	Sub-basin S-3 Sub-basin pump discharge		
R1	101625		-1.1	12.4	16.2
R1	101819		-1.1	12.4	16.2
R1	102014		-1.1	12.4	16.2
R1	102208		-1.1	12.4	16.2
R1	102403		-1.0	12.4	16.2
R1	102598		-1.0	12.4	16.2
R1	102792		-1.0	12.4	16.2
R1	102987		-1.0	12.4	16.2
R1	103182		-1.0	12.4	16.2
R1	103376		-1.0	12.5	16.2
R1	103571		-1.0	12.5	16.2
R1	103766		-0.9	12.5	16.2
R1	103960		-0.9	12.5	16.2
R1	104155		-0.9	12.5	16.2
R1	104350		-0.9	12.5	16.2
R1	104537		-0.9	12.5	16.2
R1	104725		-0.9	12.5	16.2
R1	104913		-0.9	12.5	16.2
R1	105101		-0.9	12.5	16.2
R1	105289		-0.9	12.5	16.2
R1	105477		-0.9	12.5	16.2
R1	105664		-0.8	12.5	16.2
R1	105680	Bridge	C51 Bridge # C51BR01		
R1	105852		-0.8	12.5	16.2
R1	106040		-0.8	12.5	16.2
R1	106228		-0.8	12.5	16.2
R1	106416		-0.8	12.6	16.2
R1	106604	Pump	Sub-basin S-1 pump discharge to C-51 Canal		
R1	106604		-0.8	12.6	16.2

Table F1. C-51 Canal 10-yr and 100-yr 72-hr Peak Stage Surface Water Profile (Cont.)

Reach	River Station (ft)	Structure Type	Channel Bottom Min. Elevation (ft NGVD29)	10-yr Max. Water Surface Elevation (ft NGVD29)	100-yr Max. Water Surface Elevation (ft NGVD29)
R1	106700		-0.8	12.6	16.2
R1	106889		-0.8	12.6	16.2
R1	107078		-0.8	12.6	16.2
R1	107104	Lateral structure	Overbank flow from Sub-basin S-1 to C-51 Canal		
R1	107268		-0.8	12.6	16.2
R1	107457		-0.8	12.6	16.2
R1	107646		-0.7	12.6	16.2
R1	107836		-0.7	12.6	16.2
R1	108025		-0.7	12.6	16.2
R1	108215		-0.7	12.6	16.2
R1	108404		-0.7	12.6	16.2
R1	108593		-0.7	12.6	16.2
R1	108783		-0.7	12.6	16.2
R1	108972		-0.7	12.6	16.2
R1	109161		-0.6	12.6	16.2
R1	109351		-0.6	12.6	16.2
R1	109540		-0.6	12.6	16.2
R1	109730		-0.6	12.6	16.2

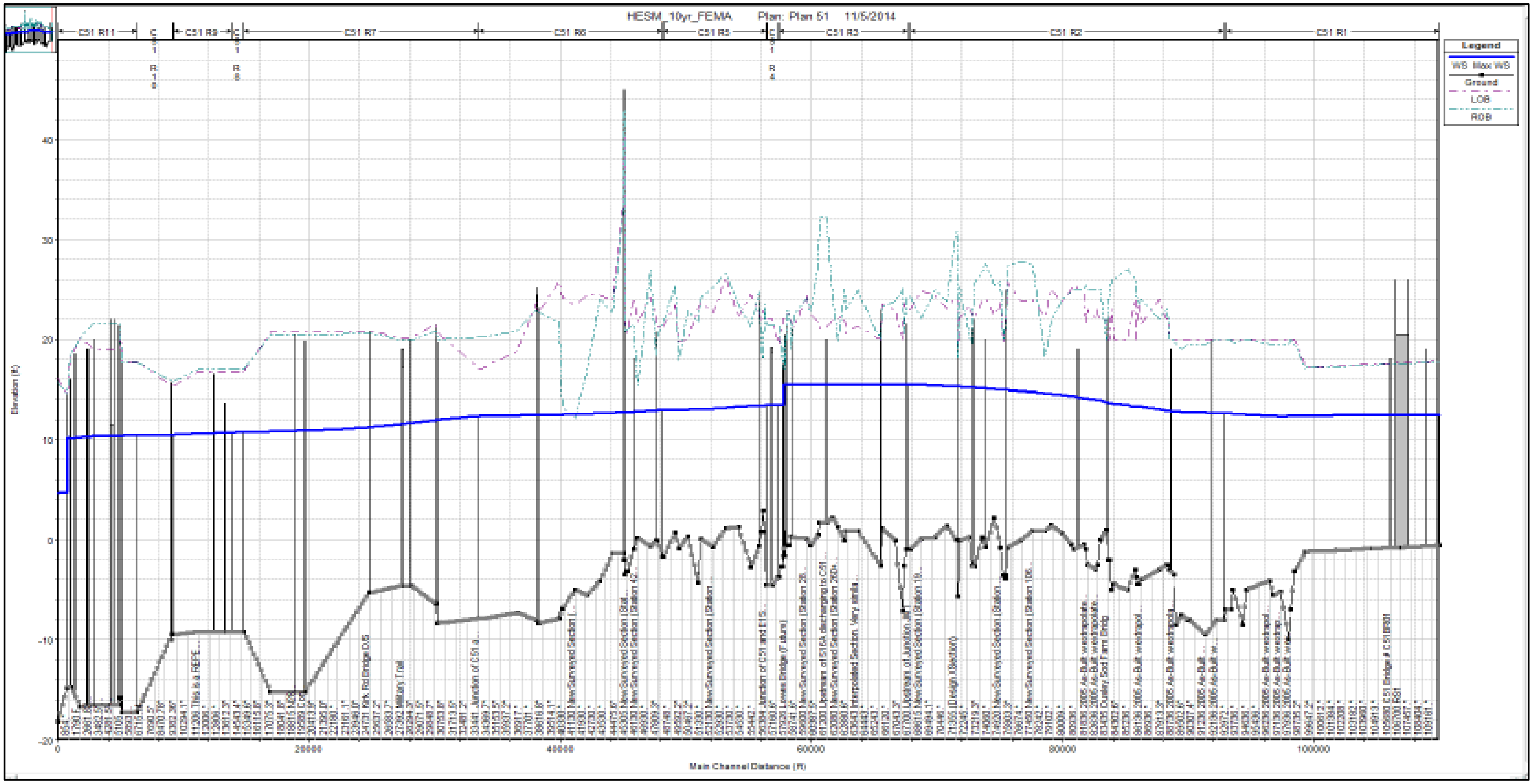

Figure F1. C-51 Canal Computed Maximum Stage Profile for the 10-yr, 72-hr Storm Event

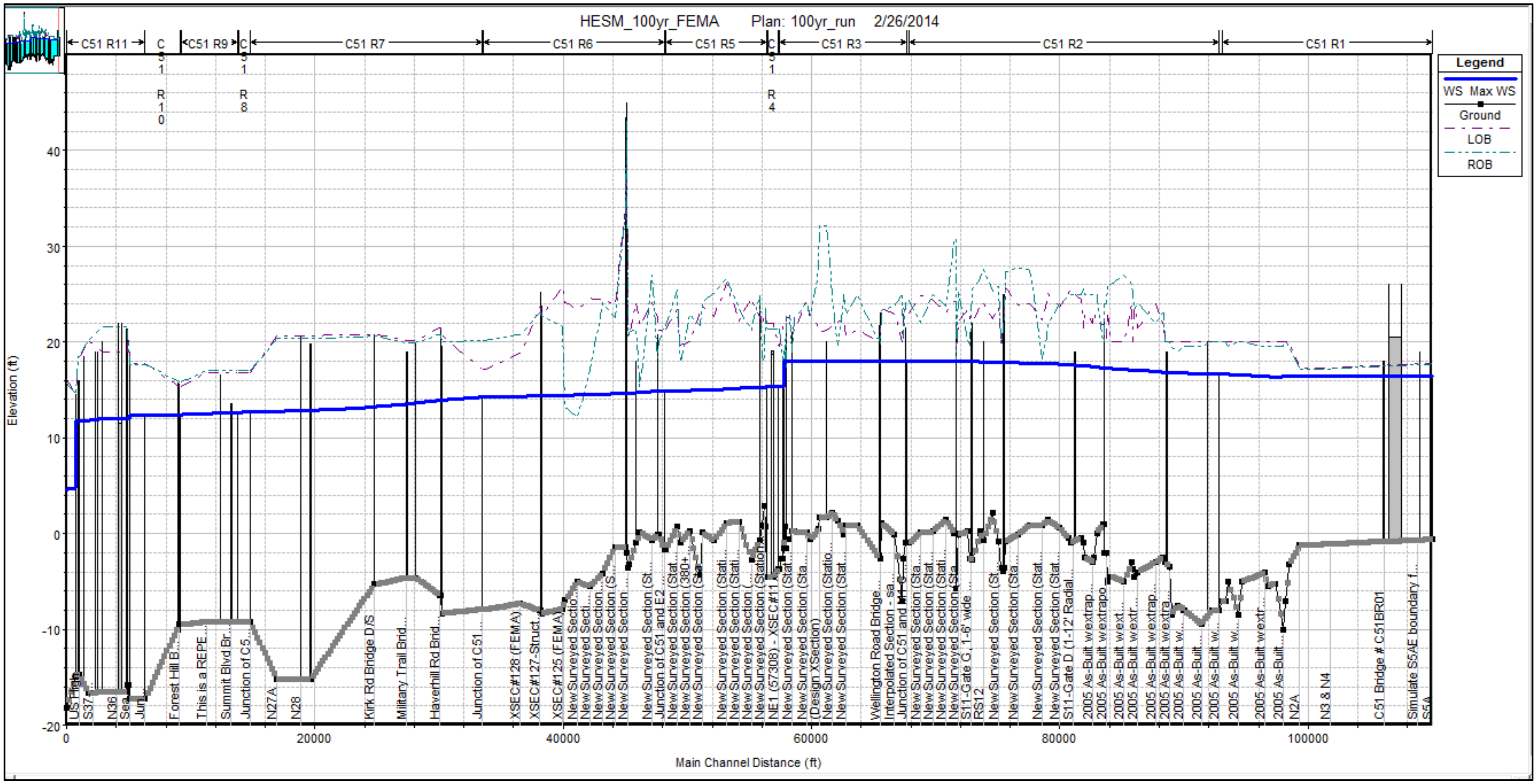

Figure F2. C-51 Canal Computed Maximum Stage Profile for the 100-yr, 72-hr Storm Event

Table F2. E-4 Canal 10-yr and 100-yr 72-hr Peak Stage Surface Water Profile

Reach	River Station (ft)	Structure Type (cfs)	Channel Bottom Min. Elevation (ft NGVD29)	10-yr Max. Water Surface Elevation (ft NGVD29)	100-yr Max. Water Surface Elevation (ft NGVD29)
RE4b			Junction with C-51 Canal		
RE4b	10		-10.00	10.5	12.6
RE4b	50		-5.71	10.5	12.6
RE4b	100		-0.36	10.5	12.6
RE4b	150		5.00	10.5	12.6
RE4b	160		Inl Struct		
RE4b	163		5.02	10.5	12.6
RE4b	662		5.09	10.5	12.6
RE4b	1163		5.17	10.5	12.6
RE4b	1663		5.24	10.5	12.6
RE4b	2163		5.32	10.5	12.6
RE4b	2663		5.40	10.5	12.6
RE4b	3163		5.47	10.6	12.6
RE4b	3663		5.55	10.6	12.6
RE4b	4163		5.62	10.6	12.6
RE4b	4663		5.70	10.6	12.6
RE4b	5163		5.77	10.6	12.6
RE4b	5663		5.85	10.6	12.6
RE4b	6163		5.92	10.7	12.6
RE4b			Junction with LWDD L10 lateral canal		
RE4b	6663		6.00	10.7	12.6
RE4	6800		6.00	10.7	12.6
RE4	7011		6.00	10.7	12.6
RE4	7510		6.00	10.7	12.6
RE4	8010		6.00	10.7	12.6
RE4	8509		6.00	10.7	12.6
RE4	9008		6.00	10.7	12.6
RE4	9508		6.00	10.7	12.6
RE4	10007		6.00	10.7	12.6
RE4	10506		6.00	10.7	12.6
RE4	11006		6.00	10.7	12.6
RE4	11505		6.00	10.7	12.6
RE4	12005		6.00	10.7	12.6

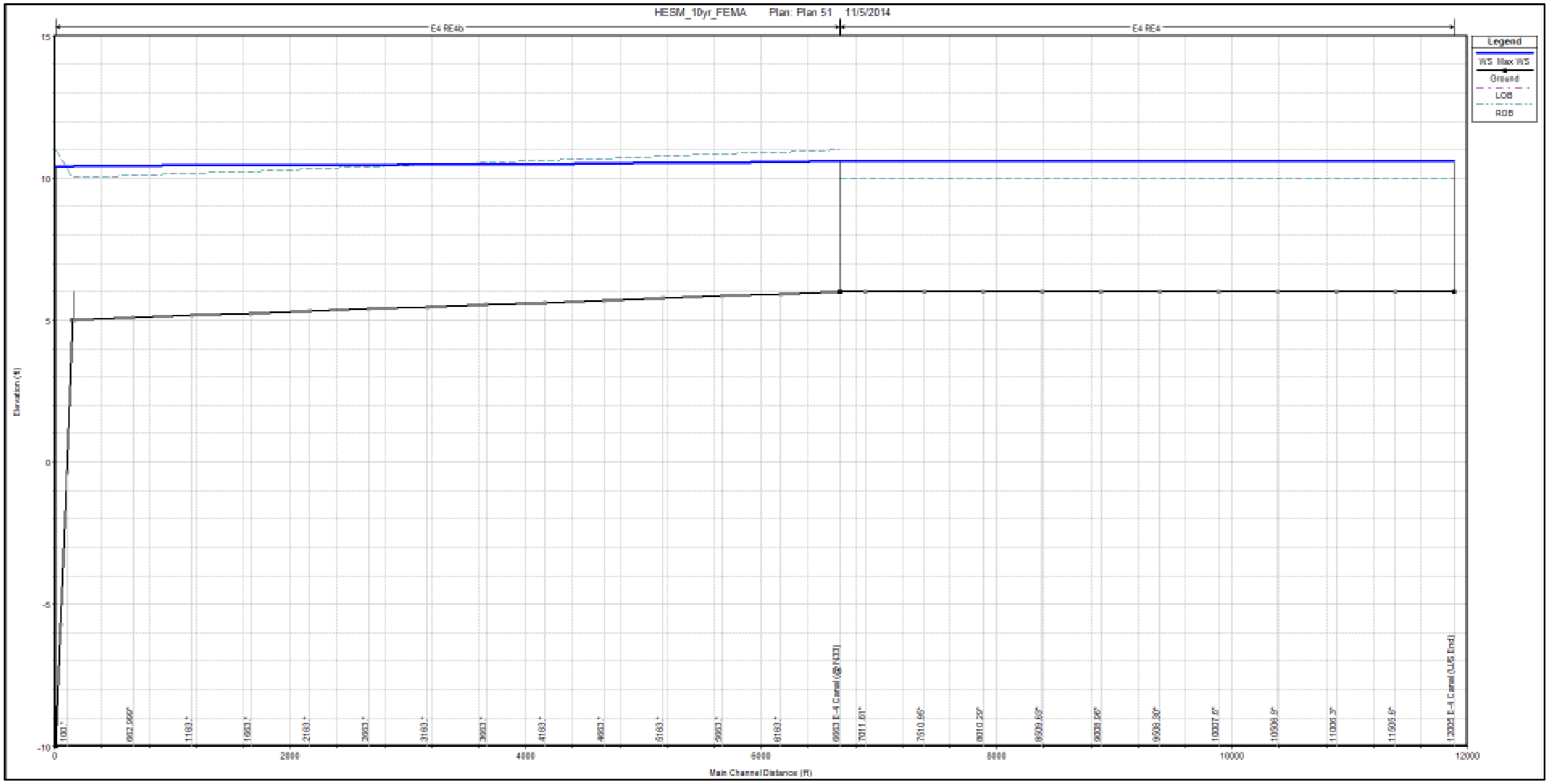

Figure F3. E-4 Canal Computed Maximum Stage Profile for the 10-yr, 72-hr Storm Event

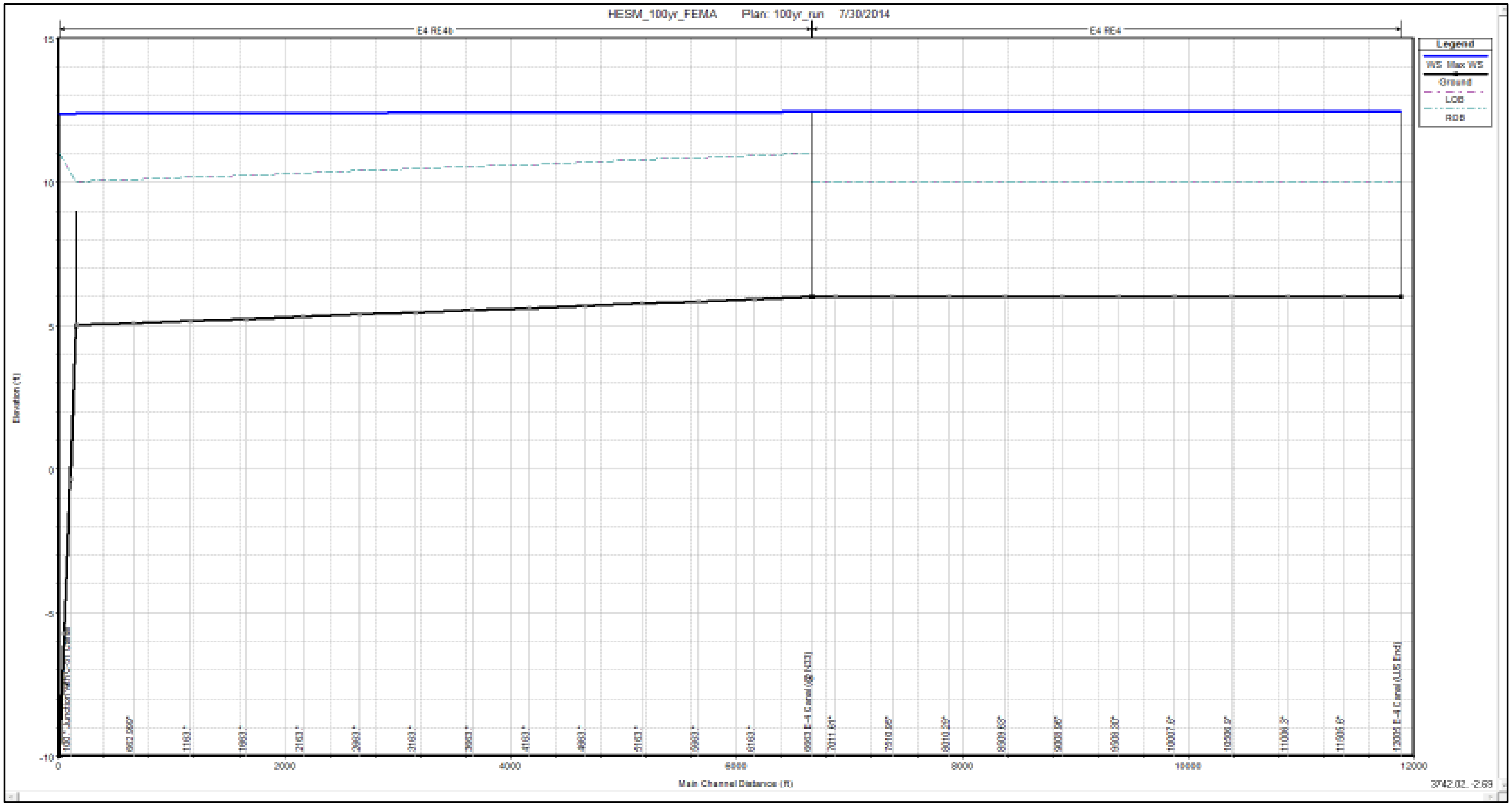

Figure F4. E-4 Canal Computed Maximum Stage Profile for the 100-yr, 72-hr Storm Event

Table F3. Stub Canal 10-yr and 100-yr Peak Stage Surface Water Profile

Reach	River Station (ft)	Structure Type (cfs)	Channel Bottom Min. Elevation (ft NGVD29)	10-yr Max. Water Surface Elevation (ft NGVD29)	100-yr Max. Water Surface Elevation n (ft NGVD29)
RSC	0	Junction with C-51 Canal			
RSC	10		-6.0	10.7	12.9
RSC	150		3.0	10.7	12.9
RSC	200		3.0	10.7	12.9
RSC	300		3.0	10.8	12.9
RSC	400		3.0	10.8	12.9
RSC	499		3.0	10.9	12.9
RSC	599		3.0	10.9	12.9
RSC	699		3.0	10.9	12.9
RSC	800		3.0	11.0	13.0
RSC	900		3.0	11.0	13.0
RSC	1000		3.0	11.0	13.0
RSC	1100		3.0	11.1	13.0
RSC	1200		3.0	11.1	13.0
RSC	1300		3.0	11.1	13.0
RSC	1400		3.0	11.2	13.0
RSC	1500		3.0	11.2	13.1
RSC	1600		3.0	11.2	13.1
RSC	1700		3.0	11.3	13.1
RSC	1800		3.0	11.3	13.1
RSC	1900		3.0	11.3	13.1
RSC	2000		3.0	11.4	13.1
RSC	2100		3.0	11.4	13.1
RSC	2200		3.0	11.4	13.2
RSC	2300		3.0	11.4	13.2
RSC	2400		3.0	11.5	13.2
RSC	2500		3.0	11.5	13.2
RSC	2600		3.0	11.5	13.2
RSC	2700		3.0	11.6	13.2
RSC	2800		3.0	11.6	13.2
RSC	2900		3.0	11.6	13.2
RSC	3000		3.0	11.6	13.2
RSC	3100		3.0	11.7	13.2
RSC	3150	Overbank weir	Sub-basin S-35 to C-51 Canal (weir length = 1000 ft @ elevation 12.0 ft NGVD)		
RSC	3200		3.0	11.7	13.2
RSC	3300		3.0	11.7	13.2
RSC	3400		3.0	11.7	13.2
RSC	3500		3.0	11.8	13.3
RSC	3600		3.0	11.8	13.3
RSC	3700		3.0	11.8	13.3
RSC	3800		3.0	11.8	13.3
RSC	3900		3.0	11.8	13.3

Table F3. Stub Canal 10-yr and 100-yr Peak Stage Surface Water Profile (Cont.)

Reach	River Station (ft)	Structure Type	Channel Bottom Min. Elevation (ft NGVD29)	10-yr Max. Water Surface Elevation (ft NGVD29)	100-yr Water Surface Elevation (ft NGVD29)
RSC	4090		3.0	11.9	13.3
RSC	4590		3.1	12.0	13.4
RSC	5090		3.1	12.1	13.4
RSC	5590		3.2	12.2	13.5
RSC	6090		3.2	12.3	13.5
RSC	6590	Pump	Discharge from Sub-basin 27		
RSC	6590		3.3	12.5	13.6
RSC	7090		3.3	12.5	13.7
RSC	7590		3.4	12.6	13.7
RSC	8090		3.5	12.6	13.8
RSC	8590		3.5	12.7	13.8
RSC	8615	Lat Struct	Discharge form Sub-basin 29A		
RSC	8726		3.5	12.7	13.8
RSC	9226		3.6	12.7	13.8
RSC	9726		3.6	12.7	13.8
RSC	10226		3.7	12.7	13.8
RSC	10726		3.8	12.7	13.8
RSC	11226		3.8	12.7	13.8
RSC	11726		3.9	12.7	13.8
RSC	12226		3.9	12.7	13.8
RSC	12726		4.0	12.7	13.8
RSC	13226		4.1	12.7	13.8
RSC	13726		4.1	12.7	13.8
RSC	14226		4.2	12.7	13.8
RSC	14726		4.3	12.7	13.8
RSC	15226		4.3	12.7	13.8
RSC	15726		4.4	12.7	13.8
RSC	16226		4.4	12.7	13.8
RSC	16726		4.5	12.7	13.8

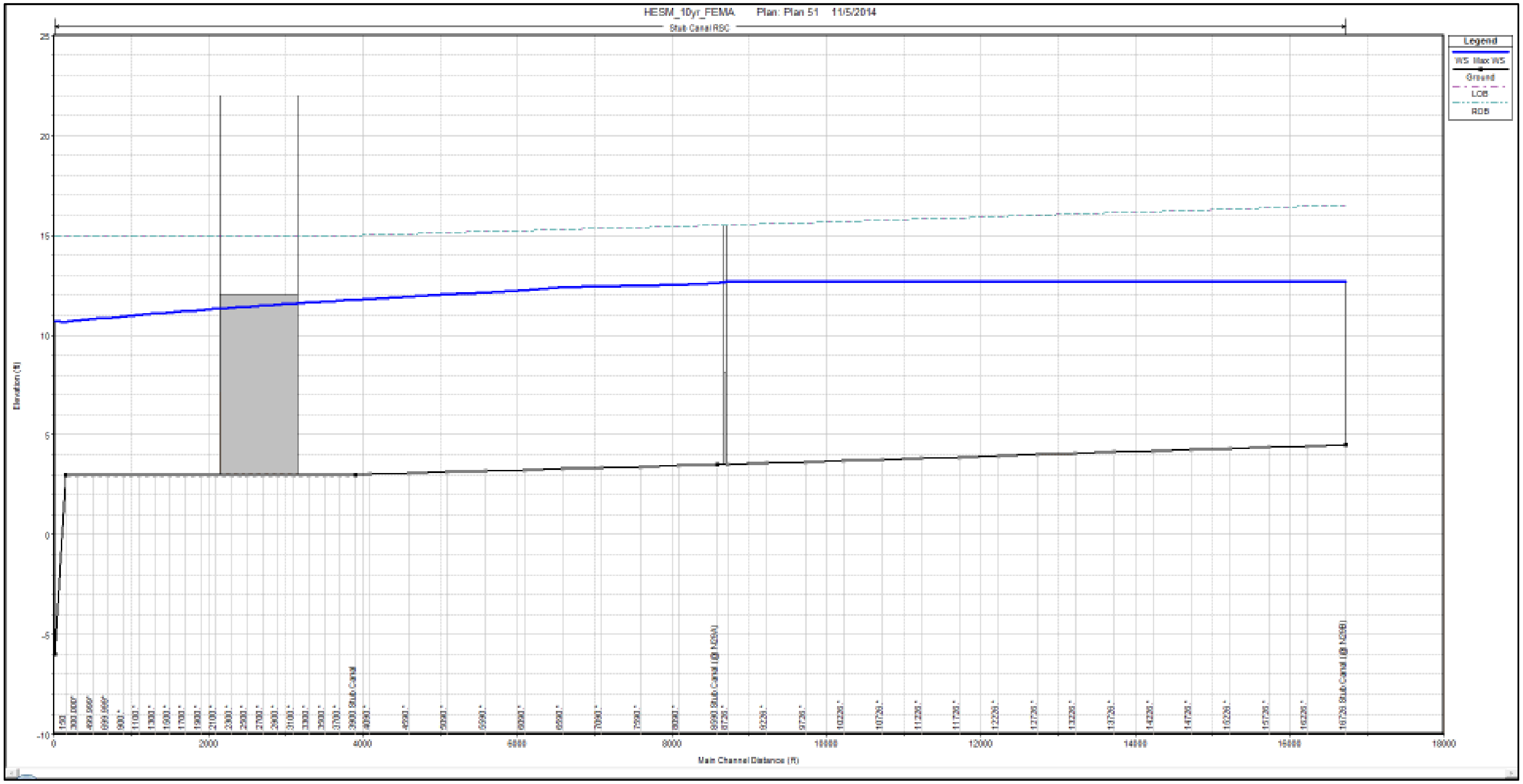

Figure F5. Stub Canal (RSC) Computed Maximum Stage Profile for the 10-yr, 72-hr Storm Event

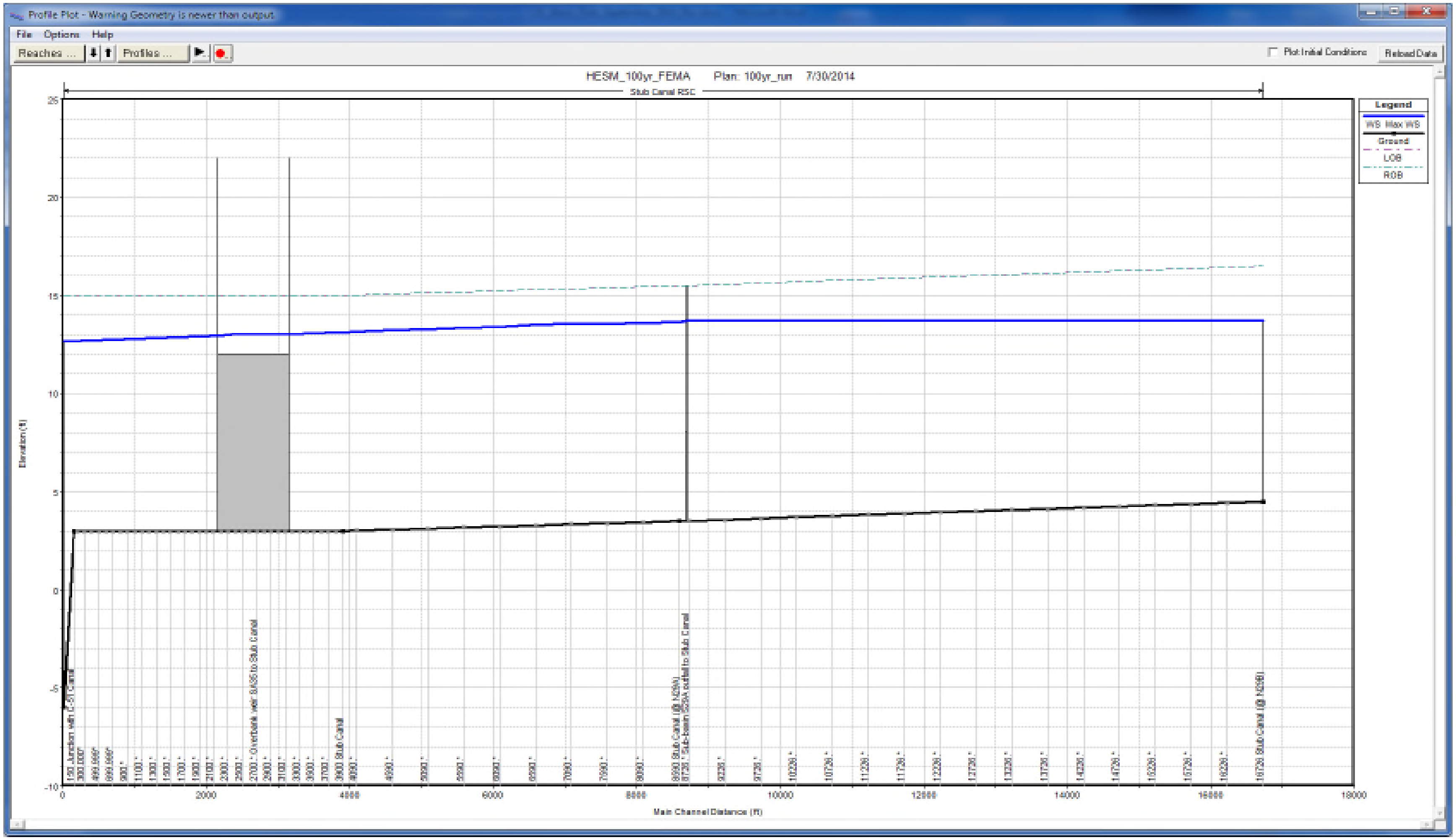

Figure F6. Stub Canal (RSC) Computed Maximum Stage Profile for the 100-yr, 72-hr Storm Event

Table F4. E-3S Canal 10-yr and 100-yr Peak Stage Surface Water Profile

Reach	River Station (ft)	Structure Type	Channel Bottom Min. Elevation (ft NGVD29)	10-yr Max. Water Surface Elevation (ft NGVD29)	100-yr Max Water Surface Elevation (ft NGVD29)
RE3S	10		3.3	12.3	14.6
RE3S	50		3.3	12.3	14.7
RE3S	75	Inl Struct	Control Structure #6 - 3-12' Radial Gates		
RE3S	275		3.3	13.3	15.5
RE3S	688		3.4	13.4	15.6
RE3S	1188		3.5	13.6	15.7
RE3S	1688		3.6	13.7	15.8
RE3S	2188		3.7	13.9	15.9
RE3S	2688		3.8	14.2	16.1
RE3S	2713	Lat Struct	Artificial weir connection from sub-basin 24 to E3S @ elev. 10. ft NGVD		
RE3S	3000		3.8	14.6	16.5
RE3S	3500		3.9	14.6	16.5
RE3S	4000		3.9	14.6	16.5
RE3S	4500		3.9	14.6	16.5
RE3S	5000		4.0	14.6	16.5
RE3S	5500		4.0	14.6	16.5
RE3S	6000		4.0	14.6	16.5
RE3S	6500		4.1	14.6	16.5
RE3S	7000		4.1	14.6	16.5
RE3S	7500		4.1	14.6	16.5
RE3S	8000		4.2	14.6	16.5
RE3S	8500		4.2	14.6	16.5
RE3S	9000		4.2	14.6	16.5
RE3S	9500		4.3	14.6	16.5
RE3S	10000		4.3	14.6	16.5
RE3S	10500		4.4	14.6	16.5
RE3S	11000		4.4	14.6	16.5
RE3S	11500		4.5	14.6	16.5
RE3S	12000		4.5	14.6	16.5
RE3S	12500		4.6	14.6	16.5
RE3S	13000		4.6	14.6	16.5
RE3S	13500		4.7	14.6	16.5
RE3S	14000		4.7	14.6	16.5
RE3S	14500		4.8	14.6	16.5
RE3S	15000		4.8	14.6	16.5
RE3S	15500		4.9	14.6	16.5
RE3S	16000		4.9	14.6	16.5

Table F4. E-3S Canal 10-yr and 100-yr Peak Stage Surface Water Profile

Reach	River Station (ft)	Structure Type	Channel Bottom Min. Elevation (ft NGVD29)	10-yr Max. Water Surface Elevation (ft NGVD29)	100-yr Max. Water Surface Elevation (ft NGVD29)
RE3S	16500		5.0	14.6	16.5
RE3S	17000		5.0	14.6	16.5
RE3S	17500		5.1	14.6	16.5
RE3S	18000		5.1	14.6	16.5
RE3S	18500		5.2	14.6	16.5
RE3S	19000		5.2	14.6	16.5
RE3S	19500		5.3	14.6	16.5
RE3S	20000		5.3	14.6	16.5

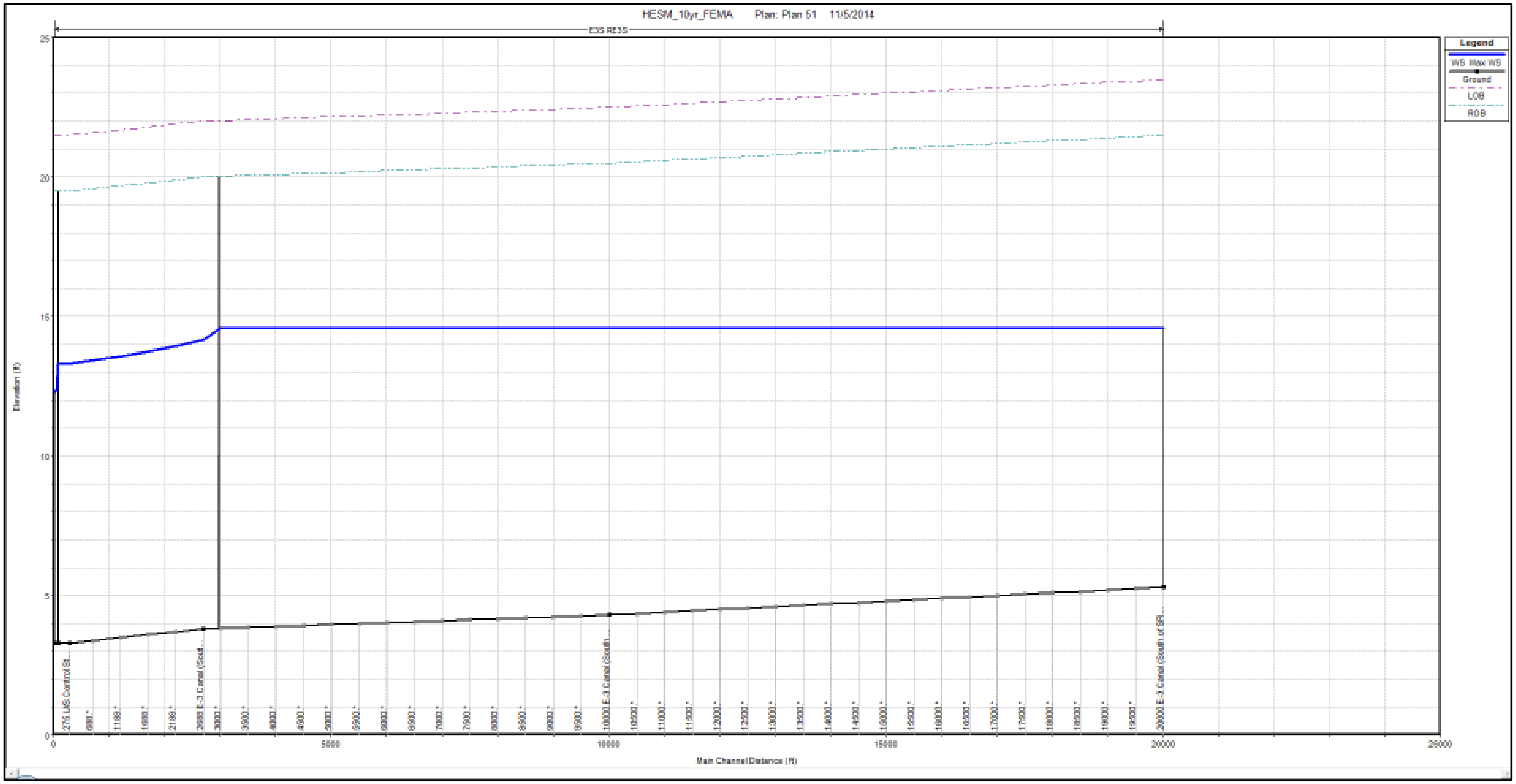

Figure F7. E-3S Canal Computed Maximum Stage Profile for the 10-yr, 72-hr Storm Event

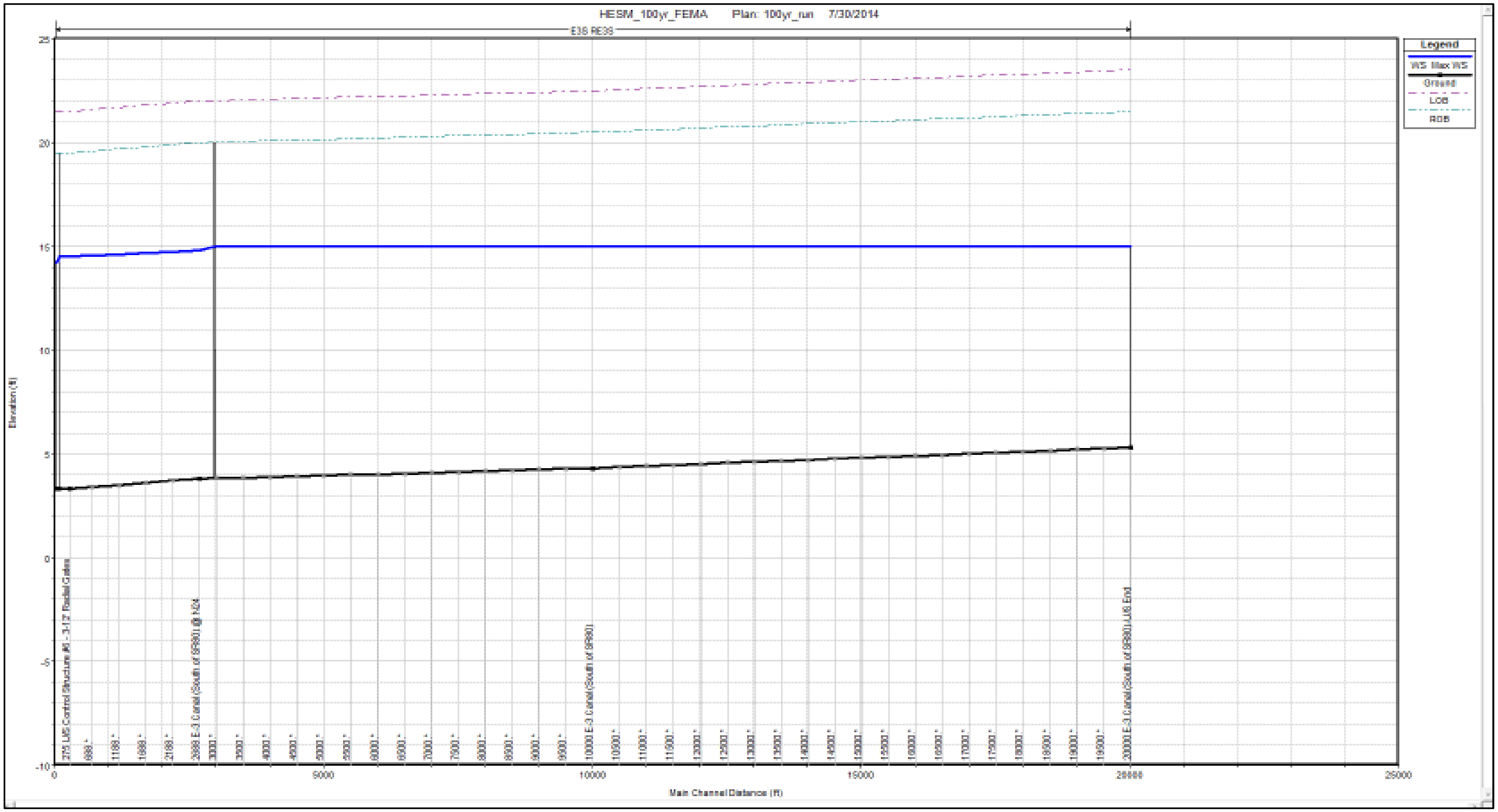

Figure F8. E-3S Canal Computed Maximum Stage Profile for the 100-yr, 72-hr Storm Event

Table F5. E-3N Canal 10-yr and 100-yr Peak Stage Surface Water Profile

Reach	River Station (ft)	Structure Type	Channel Bottom Min. Elevation (ft NGVD29)	10-yr Max. Water Surface Elevation (ft NGVD29)	100-yr Max. Water Surface Elevation (ft NGVD29)
RE3N	10		3.3	12.3	14.6
RE3N	115.999		3.3	12.3	14.7
RE3N	616		3.4	12.5	14.8
RE3N	1116		3.5	12.6	14.9
RE3N	1616		3.6	12.8	15.0
RE3N	2116		3.7	12.9	15.1
RE3N	2616		3.8	13.0	15.1
RE3N	2641	Lat Struct	Artificial weir connection from sub-basin 23 to E3S @ elev. 11.5. ft NGVD		
RE3N	3129		3.8	13.3	15.4
RE3N	3629		3.9	13.3	15.4
RE3N	4129		3.9	13.3	15.4
RE3N	4629		3.9	13.3	15.4
RE3N	5129		4.0	13.3	15.4
RE3N	5629		4.0	13.3	15.4
RE3N	6129		4.0	13.3	15.4
RE3N	6629		4.1	13.3	15.4
RE3N	7129		4.1	13.3	15.4
RE3N	7629		4.1	13.3	15.4
RE3N	8129		4.1	13.3	15.4
RE3N	8629		4.2	13.3	15.4
RE3N	9129		4.2	13.3	15.4
RE3N	9629		4.2	13.3	15.4
RE3N	10129		4.3	13.3	15.4
RE3N	10629		4.3	13.3	15.4

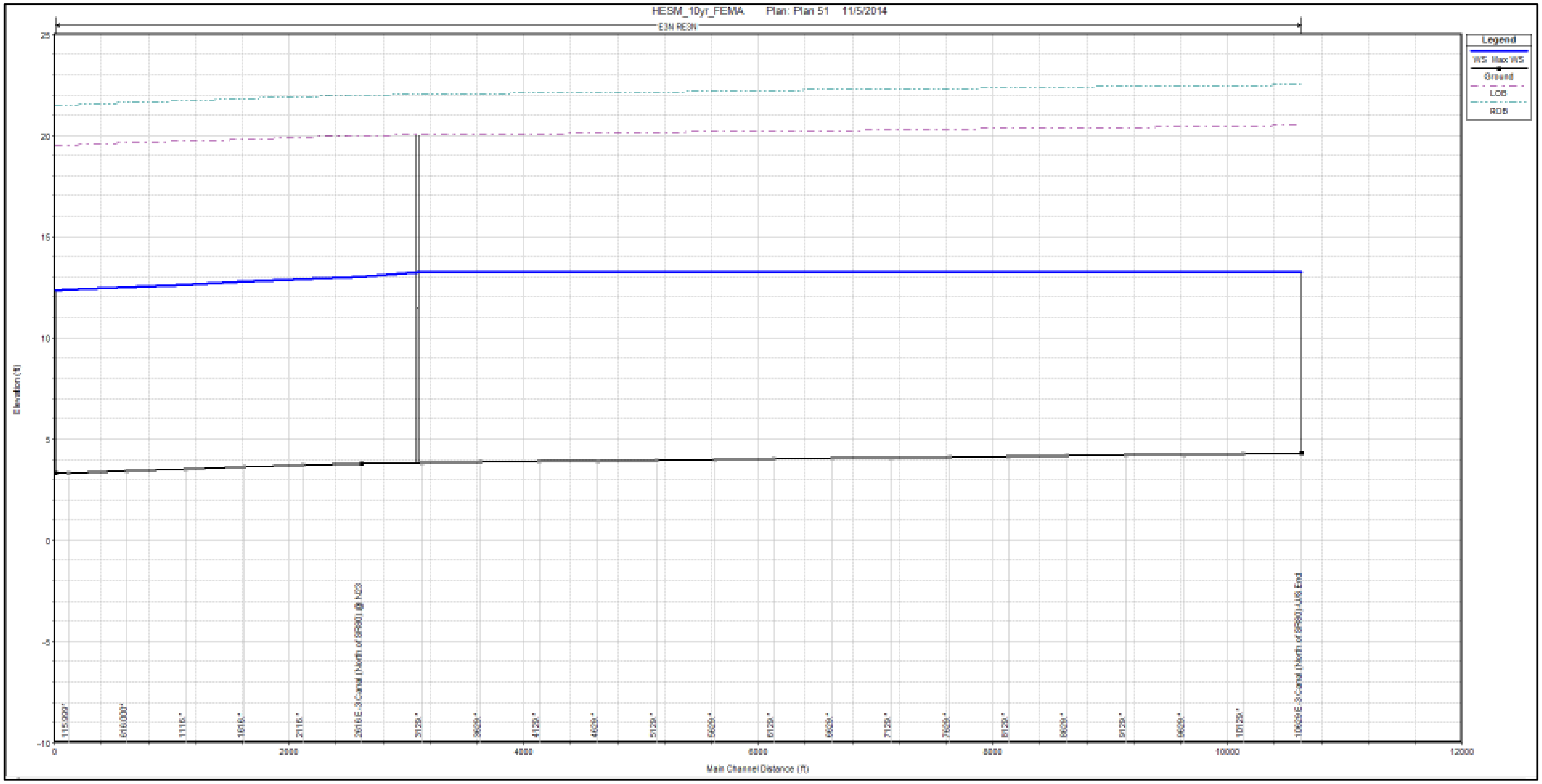

Figure F9. E-3N Canal Computed Maximum Stage Profile for the 10-yr, 72-hr Storm Event

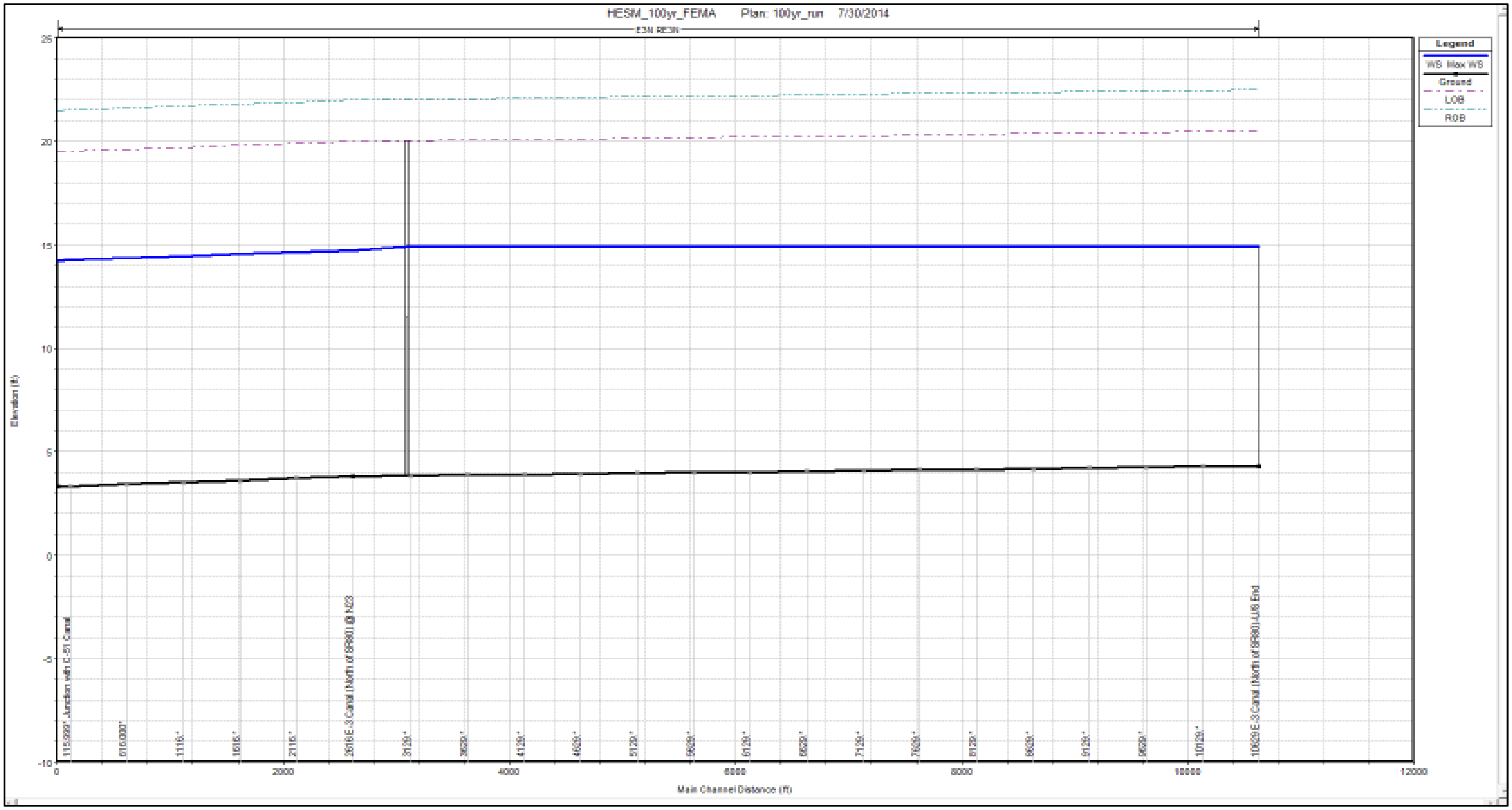

Figure F10. E-3N Canal Computed Maximum Stage Profile for the 100-yr, 72-hr Storm Event

Table F6. E-2S Canal 10- and 100-yr Peak Stage Surface Water Profile

Reach	River Station (ft)	Structure Type	Channel Bottom Min. Elevation (ft NGVD29)	10-yr Max. Water Surface Elevation (ft NGVD29)	100-yr Max. Water Surface Elevation (ft NGVD29)
RE2S	10		6.7	12.9	15.1
RE2S	100		6.7	12.9	15.2
RE2S	170	Inline Struct	Control Structure #4: 2-12' Radial Gates		
RE2S	175		6.8	13.1	15.5
RE2S	398		6.7	13.2	15.6
RE2S	648		6.8	13.3	15.6
RE2S	898		6.7	13.4	15.7
RE2S	1148		6.9	13.6	15.8
RE2S	1398		6.7	13.7	15.9
RE2S	1648		6.9	13.8	15.9
RE2S	1898		6.7	14.0	16.0
RE2S	2148		7.0	14.1	16.1
RE2S	2398		6.7	14.3	16.2
RE2S	2648		7.0	14.4	16.3
RE2S	2898		6.7	14.6	16.5
RE2S	3148		7.2	14.7	16.7
RE2S	3398		6.7	14.9	16.8
RE2S	3423	Lat Struct	Connection of Sub-basin 22 to E2S		
RE2S	3800		7.2	15.3	17.3
RE2S	4300		7.3	15.3	17.3
RE2S	4800		7.3	15.3	17.3
RE2S	5300		7.3	15.3	17.3
RE2S	5800		7.4	15.3	17.3
RE2S	6300		7.4	15.3	17.3
RE2S	6800		7.4	15.3	17.3
RE2S	7300		7.5	15.3	17.3
RE2S	7800		7.5	15.3	17.3
RE2S	8300		7.6	15.3	17.3
RE2S	8800		7.6	15.3	17.3
RE2S	9300		7.6	15.3	17.3
RE2S	9800		7.7	15.3	17.3
RE2S	10300		7.7	15.3	17.3
RE2S	10800		7.8	15.3	17.3
RE2S	11300		7.8	15.3	17.3
RE2S	11800		7.9	15.3	17.3
RE2S	12300		7.9	15.3	17.3
RE2S	12800		8.0	15.3	17.3
RE2S	13300		8.0	15.3	17.3
RE2S	13800		8.1	15.3	17.3
RE2S	14300		8.1	15.3	17.3
RE2S	14800		8.2	15.3	17.3
RE2S	15300		8.2	15.4	17.3
RE2S	15800		8.3	15.4	17.3
RE2S	16300		8.3	15.4	17.3

Table F6. E-2S Canal 10- and 100-yr Peak Stage Surface Water Profile (Cont.)

Reach	River Station (ft)	Structure Type	Channel Bottom Min. Elevation (ft NGVD29)	10-yr Max. Water Surface Elevation (ft NGVD29)	100-yr Max. Water Surface Elevation (ft NGVD29)
RE2S	16800		8.4	15.5	17.3
RE2S	17300		8.4	15.5	17.3
RE2S	17800		8.5	15.5	17.3
RE2S	18300		8.5	15.5	17.3
RE2S	18800		8.6	15.5	17.3
RE2S	19300		8.6	15.5	17.3
RE2S	19800		8.7	15.5	17.3
RE2S	20300		8.7	15.5	17.3

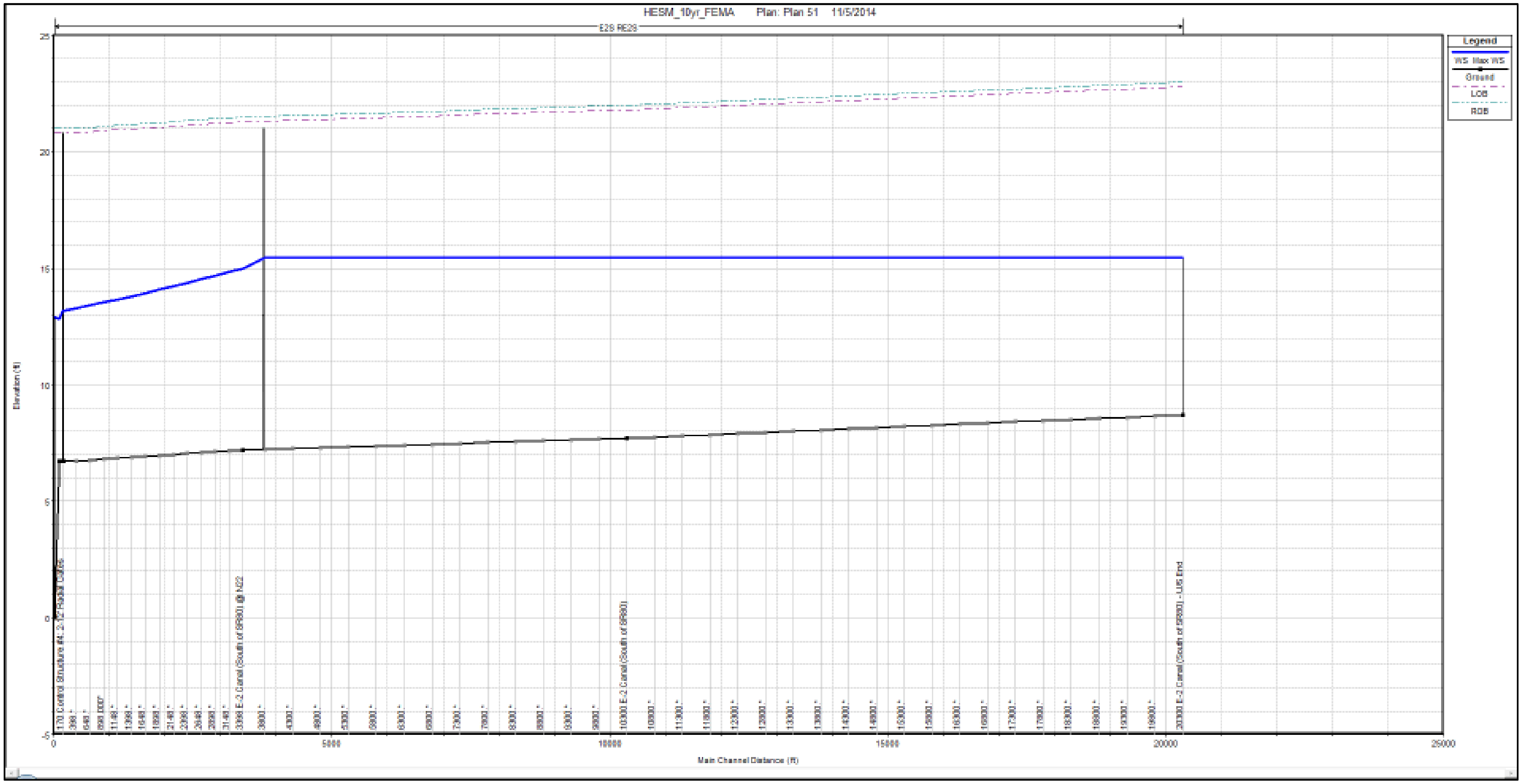

Figure F11. E-2S Canal Computed Maximum Stage Profile for the 10-yr, 72-hr Storm Event

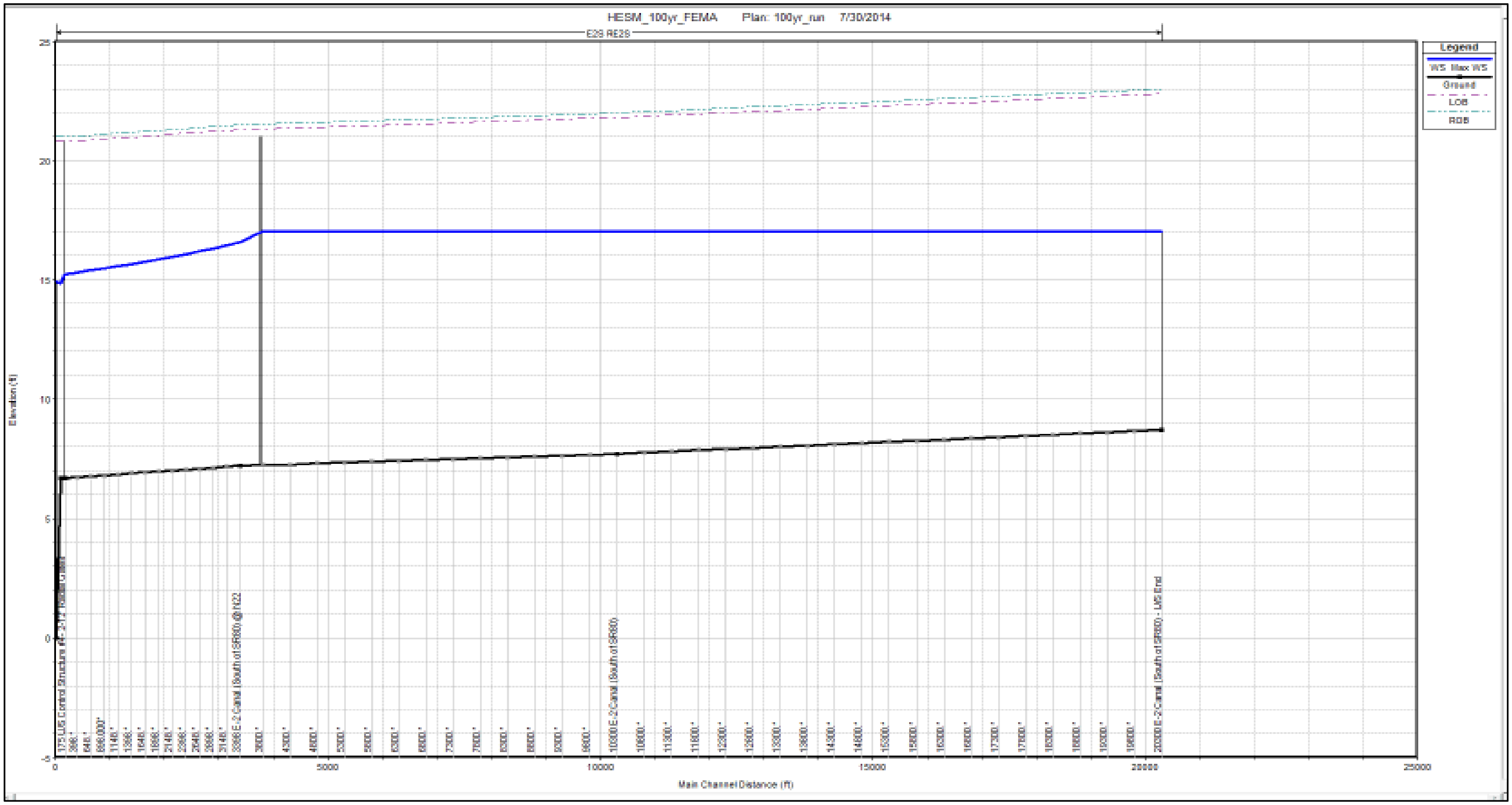

Figure F12. E-2S Canal Computed Maximum Stage Profile for the 100-yr, 72-hr Storm Event

Table F7. E-2N Canal 10-yr and 100-yr Peak Stage Surface Water Profile

Reach	River Station (ft)	Structure Type	Channel Bottom Min. Elevation (ft NGVD29)	10-yr Max. Water Surface Elevation (ft NGVD29)	100-yr Max. Water Surface Elevation (ft NGVD29)
RE2N	10		0.0	12.9	15.2
RE2N	45		5.7	12.9	15.2
RE2N	150	Culvert	FDOT Box Culvert - Discharging from E2N to C51		
RE2N	160		6.7	13.5	15.5
RE2N	275		6.7	13.6	15.5
RE2N	454		6.7	13.7	15.5
RE2N	954		6.7	13.9	15.7
RE2N	1454		6.7	14.0	15.8
RE2N	1954		6.7	14.2	15.9
RE2N	1979	Lat Struct	S18 to E2N Canal (No Control Structure) CE 10.9		
RE2N	2459		6.8	14.4	16.0
RE2N	2959		6.8	14.4	16.0
RE2N	3459		6.9	14.4	16.0
RE2N	3959		6.9	14.4	16.0
RE2N	4459		7.0	14.4	16.0
RE2N	4959		7.1	14.4	16.1
RE2N	5459		7.1	14.4	16.1
RE2N	5959		7.2	14.4	16.1
RE2N	6459		7.2	14.5	16.1
RE2N	6959		7.3	14.5	16.1
RE2N	7459		7.4	14.5	16.1
RE2N	7959		7.4	14.5	16.1
RE2N	8459		7.5	14.5	16.1
RE2N	8959		7.5	14.5	16.1
RE2N	9459		7.6	14.5	16.1
RE2N	9959		7.6	14.5	16.1
RE2N	10459		7.7	14.5	16.1

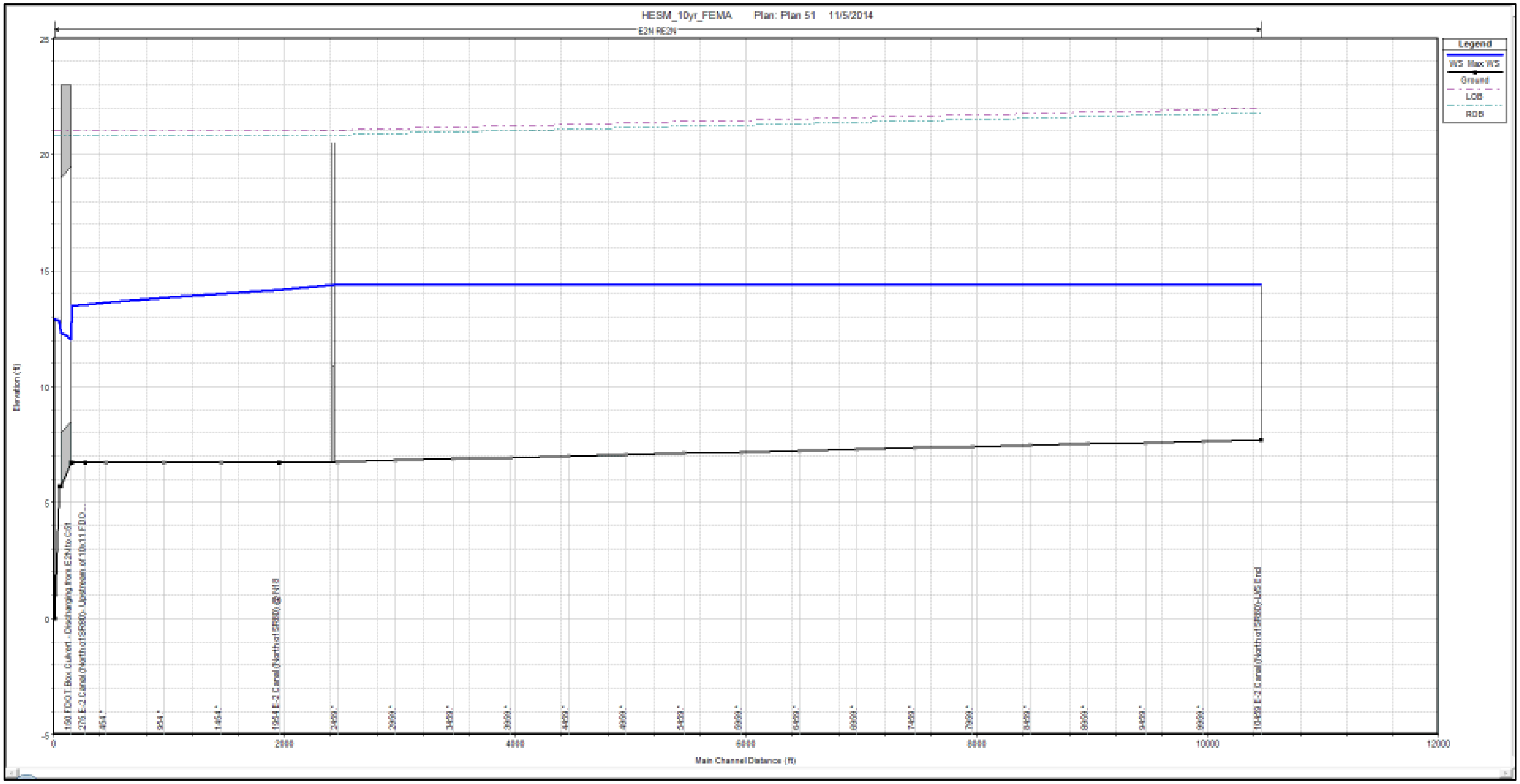

Figure F13. E-2N Canal Computed Maximum Stage Profile for the 10-yr, 72-hr Storm Event

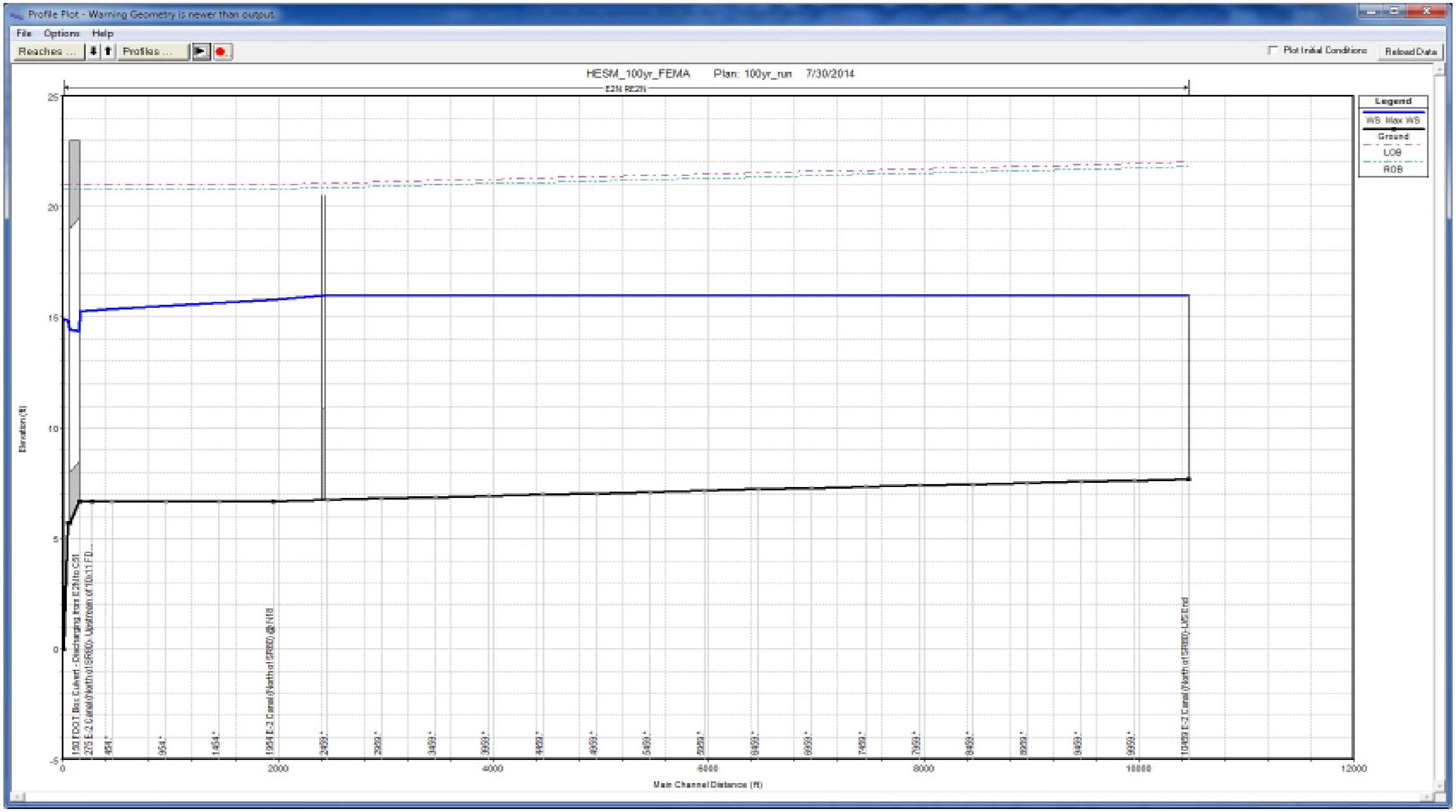

Figure F14. E-2N Canal Computed Maximum Stage Profile for the 100-yr, 72-hr Storm Event

Table F8. E-1S Canal 10-yr and 100-yr Peak Stage Surface Water Profile

Reach	River Station (ft)	Structure Type	Channel Bottom Min. Elevation (ft NGVD29)	10-yr Max. Water Surface Elevation (ft NGVD29)	100-yr Max. Water Surface Elevation (ft NGVD29)
RE1S	10		5.5	13.3	15.6
RE1S	50		5.5	13.4	15.6
RE1S	150	In-line Struct	Control Structure #2: 2-12' Radial Gates		
RE1S	275		5.5	13.9	16.0
RE1S	426		5.6	13.9	16.1
RE1S	925.999		5.7	14.1	16.2
RE1S	1426		5.9	14.3	16.2
RE1S	1926		6.1	14.4	16.3
RE1S	2426		6.3	14.6	16.5
RE1S	2926		6.4	14.8	16.6
RE1S	3426		6.6	15.0	16.8
RE1S	3926		6.8	15.2	16.8
RE1S	3951	Lat Struct	S20B to E1S Canal (No Control Structure) CE 13.5 ft NGVD		
RE1S	4026		6.8	15.4	17.0
RE1S	4315		6.9	15.4	17.0
RE1S	4815		7.0	15.4	17.0
RE1S	5315		7.0	15.4	17.0
RE1S	5815		7.1	15.4	17.0
RE1S	6315		7.2	15.4	17.1
RE1S	6815		7.3	15.5	17.1
RE1S	7315		7.4	15.5	17.1
RE1S	7815		7.5	15.5	171
RE1S	8049		7.4	15.5	17.1
RE1S	8549		7.3	15.5	17.1
RE1S	9049		7.2	15.5	17.1
RE1S	9549		7.1	15.5	17.1
RE1S	10049		6.9	15.6	17.1
RE1S	10549		6.8	15.6	17.1
RE1S	11122		7.1	15.6	17.1
RE1S	11622		7.3	15.6	17.1
RE1S	12122		7.5	15.6	17.1
RE1S	12622		7.8	15.6	17.1
RE1S	13122		8.0	15.6	17.1
RE1S	13651		8.1	15.7	17.2
RE1S	14151		8.3	15.7	17.2
RE1S	14651		8.4	15.7	17.2
RE1S	15151		8.6	15.7	17.2
RE1S	15651		8.7	15.8	17.2
RE1S	16151		8.8	15.8	17.2
RE1S	16651		9.0	15.8	17.2
RE1S	17151		9.1	15.9	17.2
RE1S	17651		9.2	15.9	17.3
RE1S	18151		9.4	16.0	17.3
RE1S	18651		9.5	16.0	17.3

Table F8. E-1S Canal 10-yr and 100-yr Peak Stage Surface Water Profile (Cont.)

Reach	River Station (ft)	Structure Type	Channel Bottom Min. Elevation (ft NGVD29)	10-yr Max. Water Surface Elevation (ft NGVD29)	100-yr Max. Water Surface Elevation (ft NGVD29)
RE1S	19209		9.6	16.1	17.3
RE1S	19709		9.8	16.1	17.3
RE1S	20209		9.9	16.2	17.4
RE1S	20709		10.0	16.2	17.4
RE1S	21209		10.1	16.3	17.4
RE1S	21709		10.3	16.3	17.4
RE1S	22209		10.4	16.4	17.5
RE1S	22709		10.5	16.4	17.5
RE1S	22844		10.5	16.5	17.5
RE1S	23344		10.7	16.5	17.5
RE1S	23844		10.8	16.6	17.6
RE1S	24344		10.9	16.6	17.6
RE1S	24844		11.0	16.7	17.6
RE1S	25165		11.0	16.7	17.6
RE1S	25665		10.9	16.7	17.7
RE1S	26165		10.9	16.8	17.7
RE1S	26665		10.9	16.9	17.7
RE1S	27165		10.8	16.9	17.8
RE1S	27665		10.8	17.0	17.8
RE1S	28165		10.7	17.1	17.9
RE1S	28665		10.7	17.2	17.9
RE1S	29069		10.7	17.2	17.9
RE1S	29569		10.6	17.3	18.0
RE1S	30069		10.5	17.4	18.0
RE1S	30569		10.5	17.5	18.0
RE1S	31069		10.4	17.6	18.1
RE1S	31569		10.4	17.5	18.1
RE1S	32069		10.3	17.6	18.1
RE1S	32227		10.2	17.7	18.1
RE1S	32727		10.1	17.7	18.2
RE1S	33227		9.9	17.7	18.2
RE1S	33727		9.7	17.7	18.2
RE1S	33752	Lat Struct	S21B (Homeland Canal) to E1S Canal CE=15.5 ft NGVD		
RE1S	33777		9.7	17.7	18.2
RE1S	33872		9.7	17.7	18.2
RE1S	34372		9.9	17.7	18.2
RE1S	34872		10.0	17.7	18.2
RE1S	35372		10.1	17.7	18.2
RE1S	35872		10.2	17.7	18.2
RE1S	36372		10.4	17.7	18.2
RE1S	36872		10.5	17.7	18.2
RE1S	37372		10.6	17.7	18.2
RE1S	37872		10.7	17.7	18.2

Table F8. E-1S Canal 10-yr and 100-yr Peak Stage Surface Water Profile (Cont.)

Reach	River Station (ft)	Structure Type	Channel Bottom Min. Elevation (ft NGVD29)	10-yr Max. Water Surface Elevation (ft NGVD29)	100-yr Max Water Surface Elevation (ft NGVD29)
RE1S	38372		10.9	17.7	18.2
RE1S	38872		9.7	17.7	18.2
RE1S	39372		11.0	17.7	18.2
RE1S	39872		11.1	17.7	18.2
RE1S	40372		11.3	17.7	18.2
RE1S	40872		11.4	17.7	18.2
RE1S	41252		11.5	17.7	18.2
RE1S	41752		11.3	17.7	18.2
RE1S	42252		11.1	17.7	18.2
RE1S	42752		10.9	17.8	18.2
RE1S	43252		10.7	17.8	18.2
RE1S	43752		10.5	17.8	18.2
RE1S	44252		10.3	17.8	18.2
RE1S	44752		10.1	17.8	18.2
RE1S	45252		9.9	17.8	18.2
RE1S	45752		9.7	17.8	18.2
RE1S	46128		9.5	17.8	18.2
RE1S	46628		9.4	17.8	18.2
RE1S	47128		9.3	17.8	18.2
RE1S	47628		9.2	17.8	18.2
RE1S	48128		9.1	17.8	18.2
RE1S	48628		9.0	17.8	18.2
RE1S	49128		8.9	17.8	18.2
RE1S	49628		8.8	17.8	18.2
RE1S	50128		8.7	17.8	18.2
RE1S	50628		8.6	17.8	18.2
RE1S	51128		8.5	17.8	18.2

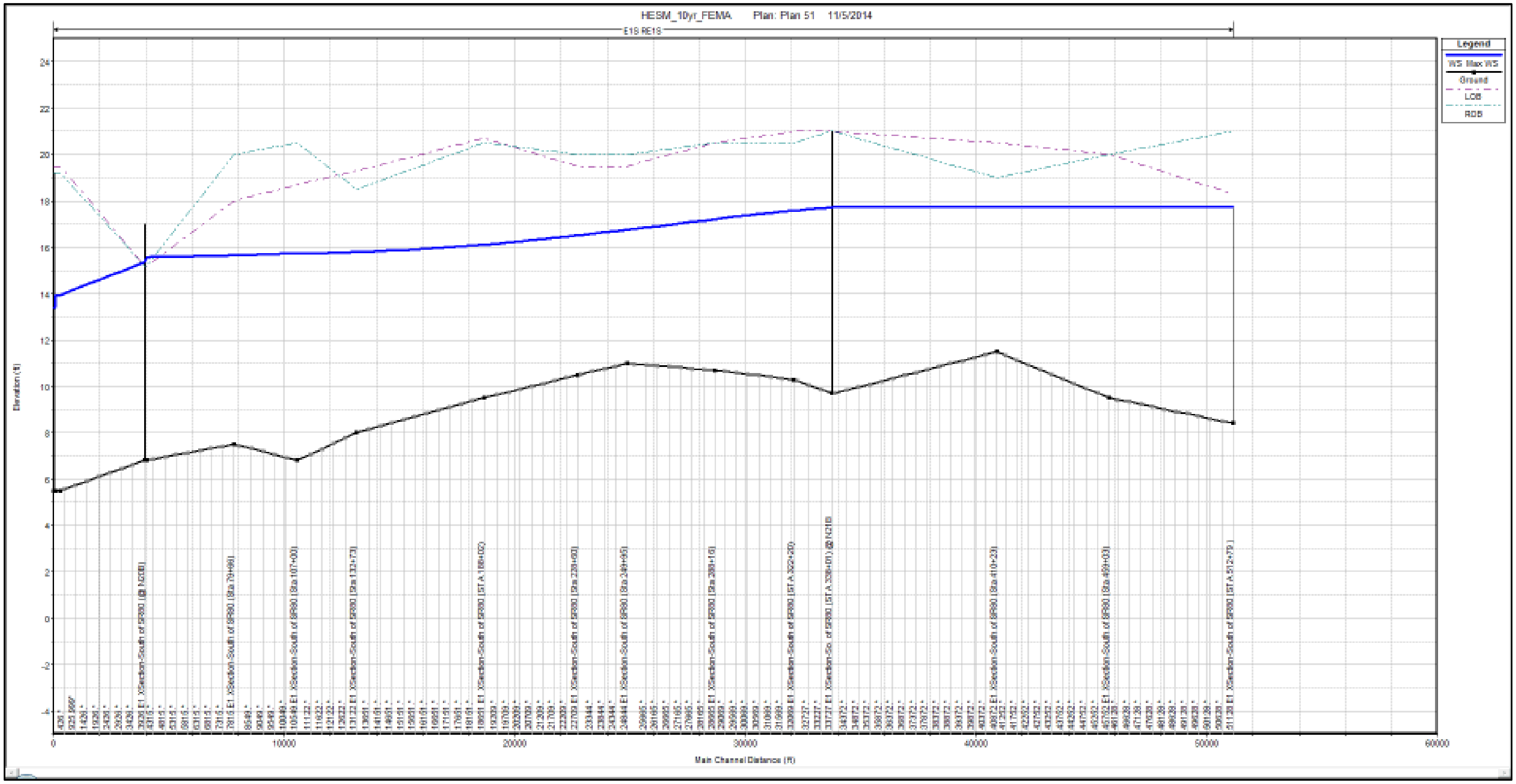

Figure F15. E-1S Canal Computed Maximum Stage Profile for the 10-yr, 72-hr Storm Event

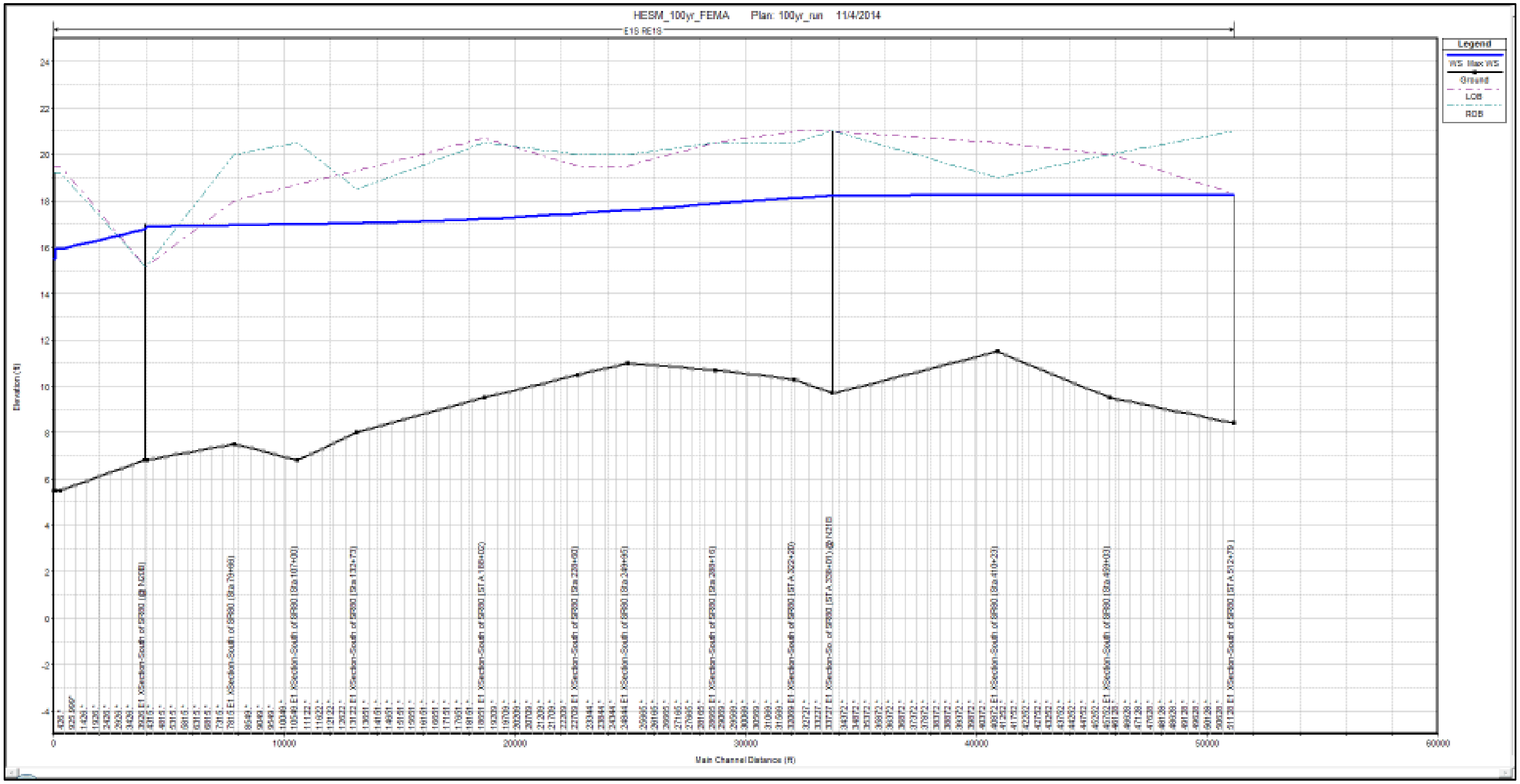

Figure F16. E-1S Canal Computed Maximum Stage Profile for the 100-yr, 72-hr Storm Event

Table F9. E-1N Canal 10-yr and 100-yr Peak Stage Surface Water Profile

Reach	River Station (ft)	Structure Type	Channel Bottom Min. Elevation (ft NGVD29)	10-yr Max. Water Surface Elevation (ft NGVD29)	100-yr Max. Water Surface Elevation (ft NGVD29)
RE1N	10		5.1	13.3	15.6
RE1N	187		5.3	13.4	15.6
RE1N	437		5.4	13.4	15.6
RE1N	687		5.6	13.5	15.7
RE1N	937		5.7	13.5	15.7
RE1N	1187		5.9	13.6	15.7
RE1N	1437		6.0	13.6	15.8
RE1N	1687		5.1	13.7	15.8
RE1N	1712	Lat Struct	S17 to E1N Canal (No Control Structure) weir elevation at 10.9 ft NGVD		
RE1N	1737		6.0	13.9	16.0
RE1N	1951		6.2	13.9	16.0
RE1N	2201		6.3	13.9	16.0
RE1N	2451		6.5	13.9	16.0
RE1N	2685		6.7	13.9	16.0
RE1N	2935		6.9	13.9	16.0
RE1N	3185		7.2	13.9	16.0
RE1N	3435		7.4	13.9	16.0
RE1N	3685		7.6	13.9	16.0
RE1N	3935		7.9	13.9	16.0
RE1N	4185		8.1	13.9	16.0
RE1N	4435		8.3	13.9	16.0
RE1N	4685		8.5	13.9	16.0
RE1N	4935		8.8	13.9	16.0
RE1N	5185		9.0	13.9	16.0

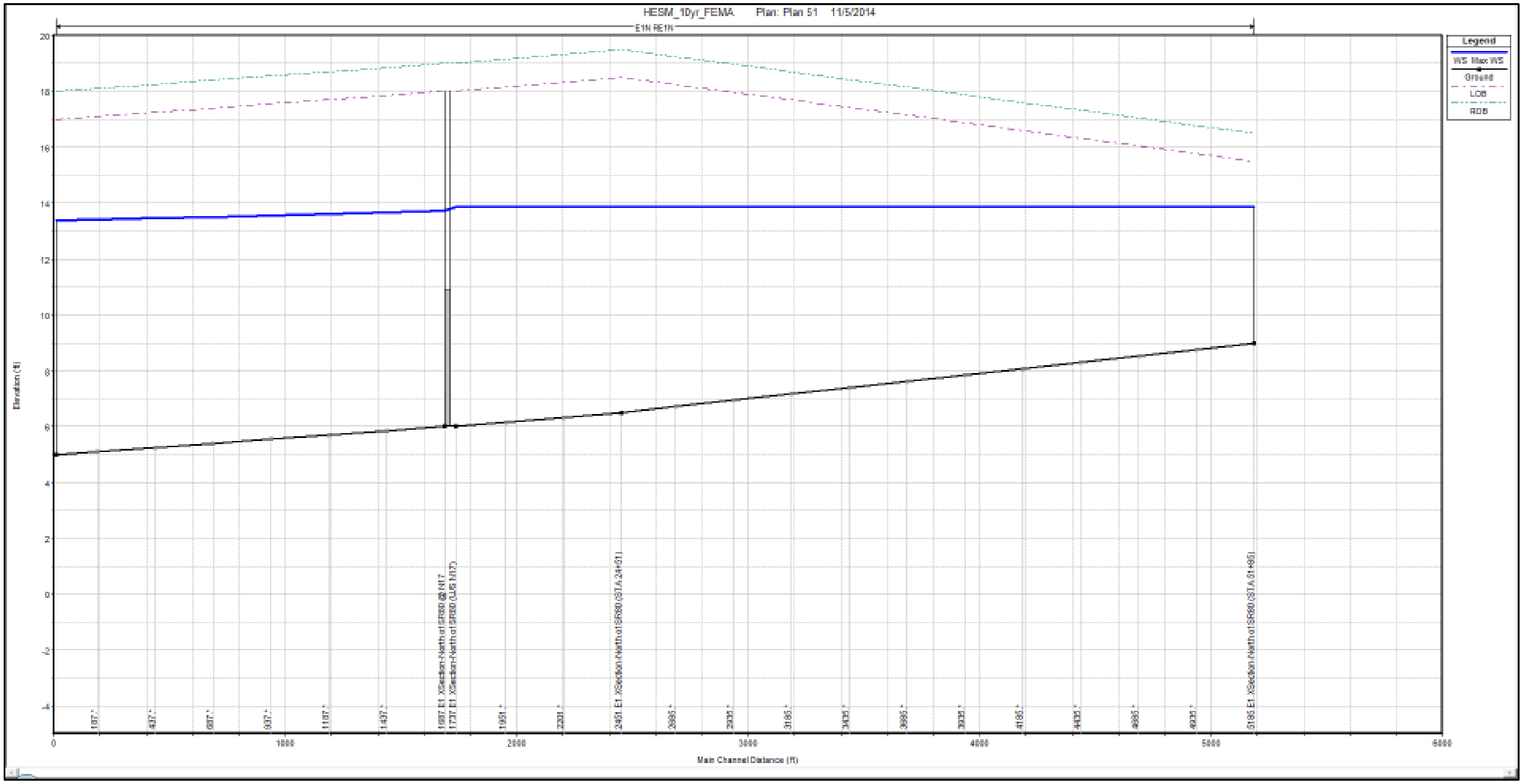

Figure F17. E-1N Canal Computed Maximum Stage Profile for the 10-yr, 72-hr Storm Event

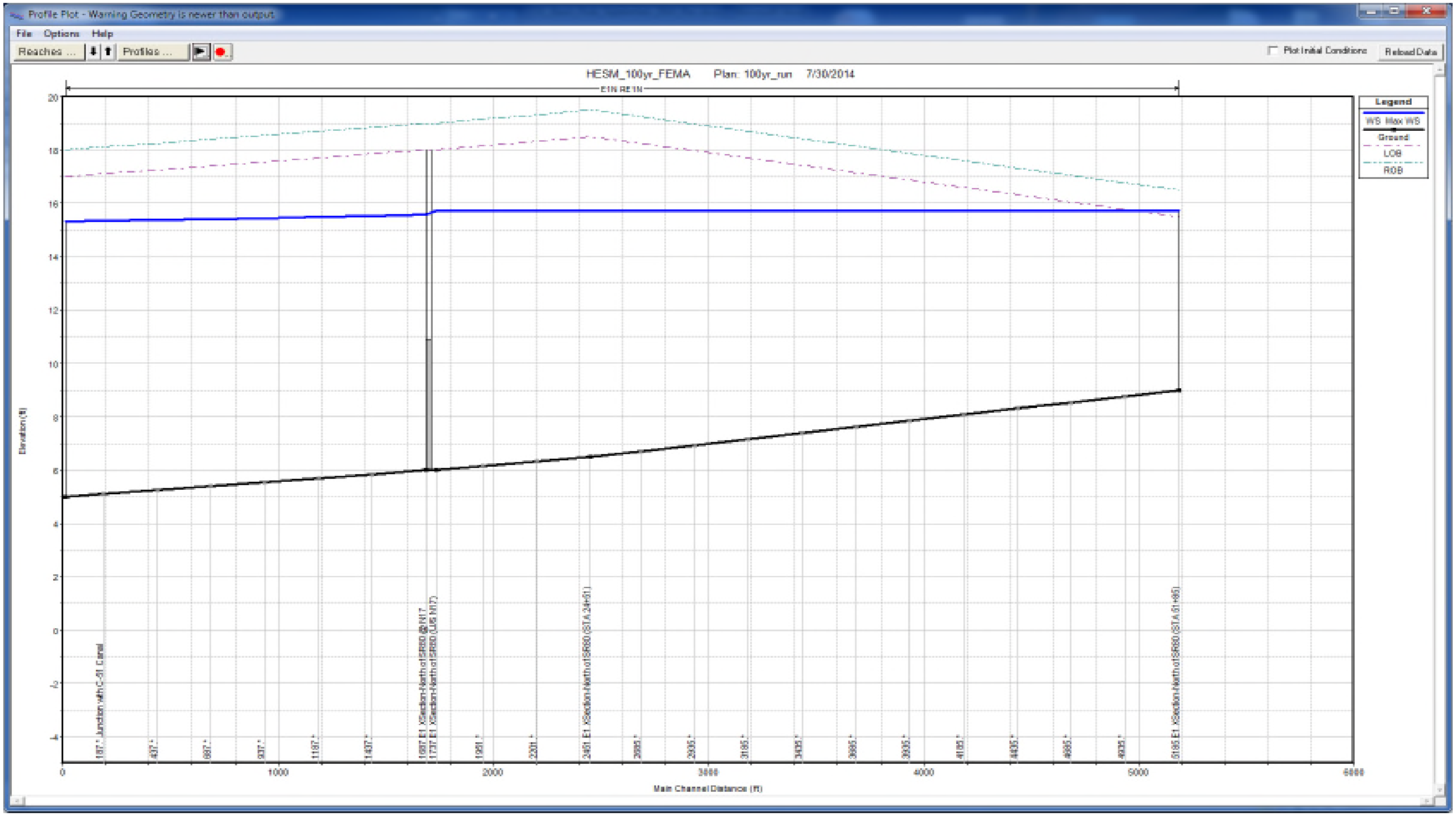

Figure F18. E-1N Canal Computed Maximum Stage Profile for the 100-yr, 72-hr Storm Event

Table F10. M-1 Canal 10-yr and 100-yr Peak Stage Surface Water Profile

Reach	River Station (ft)	Structure Type	Channel Bottom Min. Elevation (ft NGVD29)	10-yr Max. Water Surface Elevation (ft NGVD29)	100-yr Max. Water Surface Elevation (ft NGVD29)
RM1	10		0.2	15.5	18.3
RM1	50		0.2	15.5	18.3
RM1	275		0.2	15.5	18.3
RM1	413		0.2	15.5	18.3
RM1	663		0.2	15.5	18.3
RM1	775	Inl Struct	Amil Gated structure		
RM1	913		0.3	15.9	18.4
RM1	1163		0.3	15.9	18.4
RM1	1413		0.3	15.9	18.4
RM1	1438	Lat Struct	S15A to M1 Canal through Concrete Weir at 13.3' Crest		
RM1	1463		0.3	15.9	18.4
RM1	1525		0.4	15.9	18.4
RM1	1775		0.6	15.9	18.4
RM1	2025		0.8	15.9	18.4
RM1	2275		1.0	15.9	18.4
RM1	2525		1.2	15.9	18.4
RM1	2775		1.4	15.9	18.4
RM1	3025		1.6	15.9	18.4
RM1	3275		1.8	15.9	18.4
RM1	3525		2.0	15.9	18.4
RM1	3775		2.2	15.9	18.4
RM1	4025		2.4	15.9	18.4
RM1	4275		2.6	15.9	18.4
RM1	4525		2.8	15.9	18.4
RM1	4775		3.0	16.0	18.4
RM1	4973	Lat Struct	Open channel connection to M-1 Canal on Sandpiper Avenue		
RM1	5025		3.2	16.0	18.4
RM1	5275		3.4	16.0	18.4
RM1	5525		3.6	16.0	18.4
RM1	5775		3.8	16.0	18.4
RM1	6025		4.0	16.0	18.4
RM1	6275		4.2	16.0	18.4
RM1	6314	Bridge	Sparrow Drive Bridge		
RM1	6315		4.2	16.0	18.4
RM1	6485		4.3	16.0	18.4
RM1	6735		4.5	16.0	18.4
RM1	6985		4.7	16.0	18.4
RM1	7235		4.9	16.0	18.4
RM1	7485		5.1	16.0	18.4
RM1	7671	Lat Struct	Open channel connection to M-1 canal between Sparrow Dr a		
RM1	7735		5.3	15.9	18.2

Table F10. M-1 Canal 10-yr and 100-yr Peak Stage Surface Water Profile (Cont.)

Reach	River Station (ft)	Structure Type	Channel Bottom Min. Elevation (ft NGVD29)	10-yr Max. Water Surface Elevation (ft NGVD29)	100-yr Max Water Surface Elevation (ft NGVD29)
RM1	7985		5.5	16.0	18.4
RM1	8235		5.7	16.0	18.4
RM1	8485		5.9	16.0	18.4
RM1	8735		6.1	16.0	18.4
RM1	8834	Bridge	Okeechobee Blvd Bridge		
RM1	8835		6.0	16.0	18.4
RM1	9015		5.8	16.0	18.4
RM1	9265		5.4	16.0	18.4
RM1	9515		5.1	16.0	18.4
RM1	9765		4.8	16.0	18.4
RM1	10015		4.4	16.0	18.4
RM1	10265		4.1	16.0	18.4
RM1	10515		3.8	16.0	18.4
RM1	10765		3.4	16.0	18.4
RM1	11015		3.1	16.0	18.4
RM1	11265		2.8	16.0	18.4
RM1	11515		2.4	16.0	18.4
RM1	11765		2.1	16.0	18.4
RM1	11890	Lat Struct	Open channel connection to M- 1 canal U.S. of Okeechobee Blvd		
RM1	12015		1.8	16.0	18.4
RM1	12265		1.4	16.0	18.4
RM1	12515		1.7	16.0	18.4
RM1	12765		2.1	16.0	18.4
RM1	13015		2.4	16.0	18.4
RM1	13265		2.7	16.0	18.4
RM1	13515		3.0	16.0	18.4
RM1	13765		3.3	16.0	18.4
RM1	14015		3.7	16.0	18.4
RM1	14265		4.0	16.0	18.4
RM1	14515		4.3	16.0	18.4
RM1	14765		4.6	16.0	18.4
RM1	15015		4.9	16.0	18.4
RM1	15265		5.3	16.0	18.4
RM1	15515		5.6	16.0	18.4
RM1	15765		5.9	16.0	18.4
RM1	16015		6.2	16.0	18.4
RM1	16265		6.5	16.0	18.4
RM1	16515		6.9	16.0	18.4
RM1	16765		7.2	16.0	18.4
RM1	16965		7.5	16.0	18.4
RM1	17104	Bridge	Crestwood Blvd Bridge		

Table F10. M-1 Canal 10-yr and 100-yr Peak Stage Surface Water Profile (Cont.)

Reach	River Station (ft)	Structure Type	Channel Bottom Min. Elevation (ft NGVD29)	10-yr Max. Water Surface Elevation (ft NGVD29)	100-yr Max. Water Surface Elevation (ft NGVD29)
RM1	17115		7.5	16.0	18.4
RM1	17273		7.2	16.0	18.4
RM1	17523		6.7	16.0	18.4
RM1	17773		6.3	16.0	18.4
RM1	18023		5.8	16.0	18.4
RM1	18273		5.4	16.0	18.4
RM1	18523		4.9	16.0	18.4
RM1	18773		4.5	16.0	18.4
RM1	19023		4.0	16.0	18.4
RM1	19273		3.6	16.0	18.4
RM1	19523		3.1	16.0	18.4
RM1	19673		Open channel connection to M-1 U.S. of Crestwood Bridge		
RM1	19773		2.7	16.0	18.4
RM1	20023		2.2	16.0	18.4
RM1	20073	Lat Struct	Connection from S15B to M1 Canal at 40th St Sluice Gate		
RM1	20123		2.2	16.0	18.4
RM1	20423		2.2	16.0	18.4
RM1	20673		2.2	16.0	18.4
RM1	20923		2.2	16.0	18.4
RM1	21173		2.2	16.0	18.4

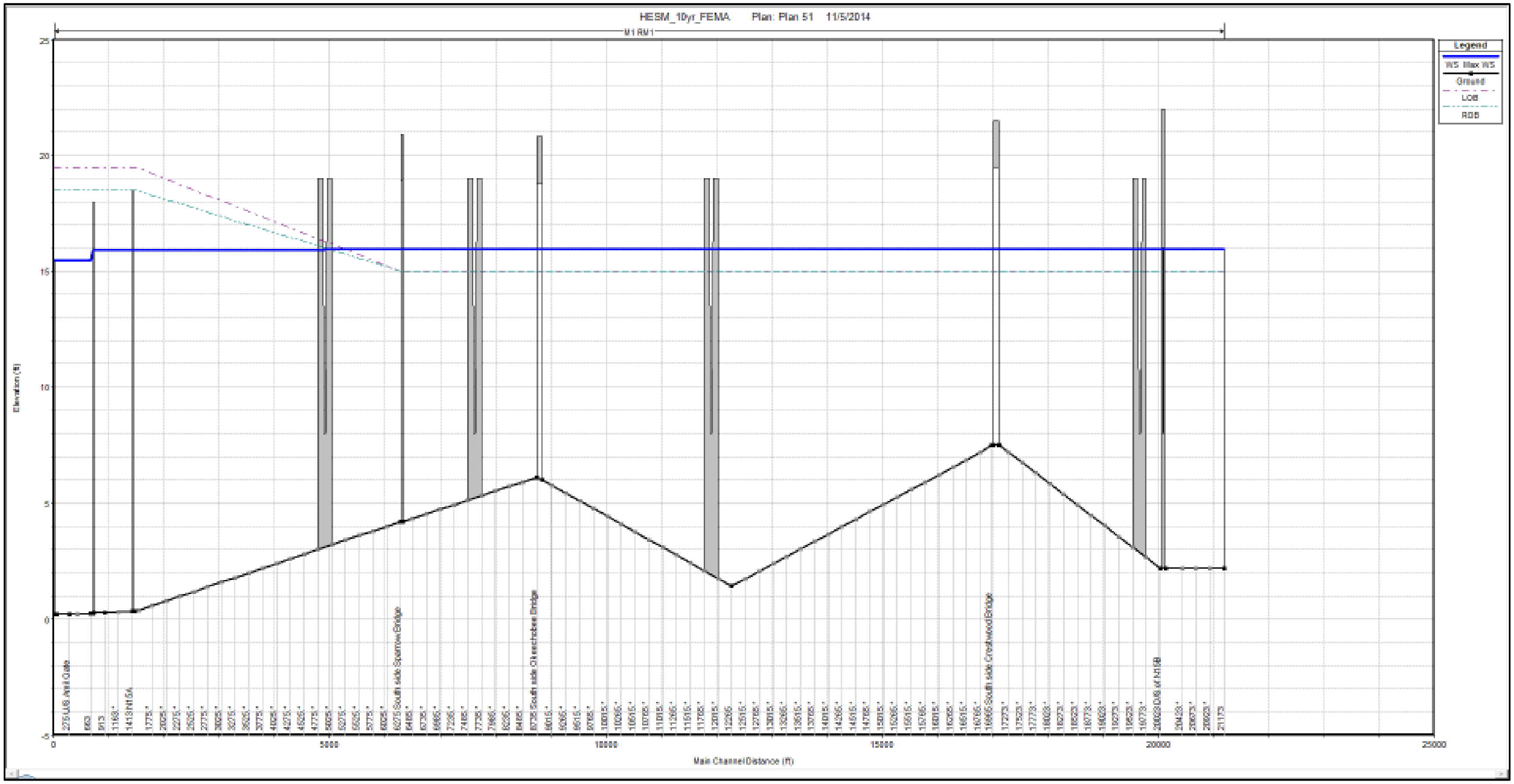

Figure F19. M-1 Canal Computed Maximum Stage Profile for the 10-yr, 72-hr Storm Event

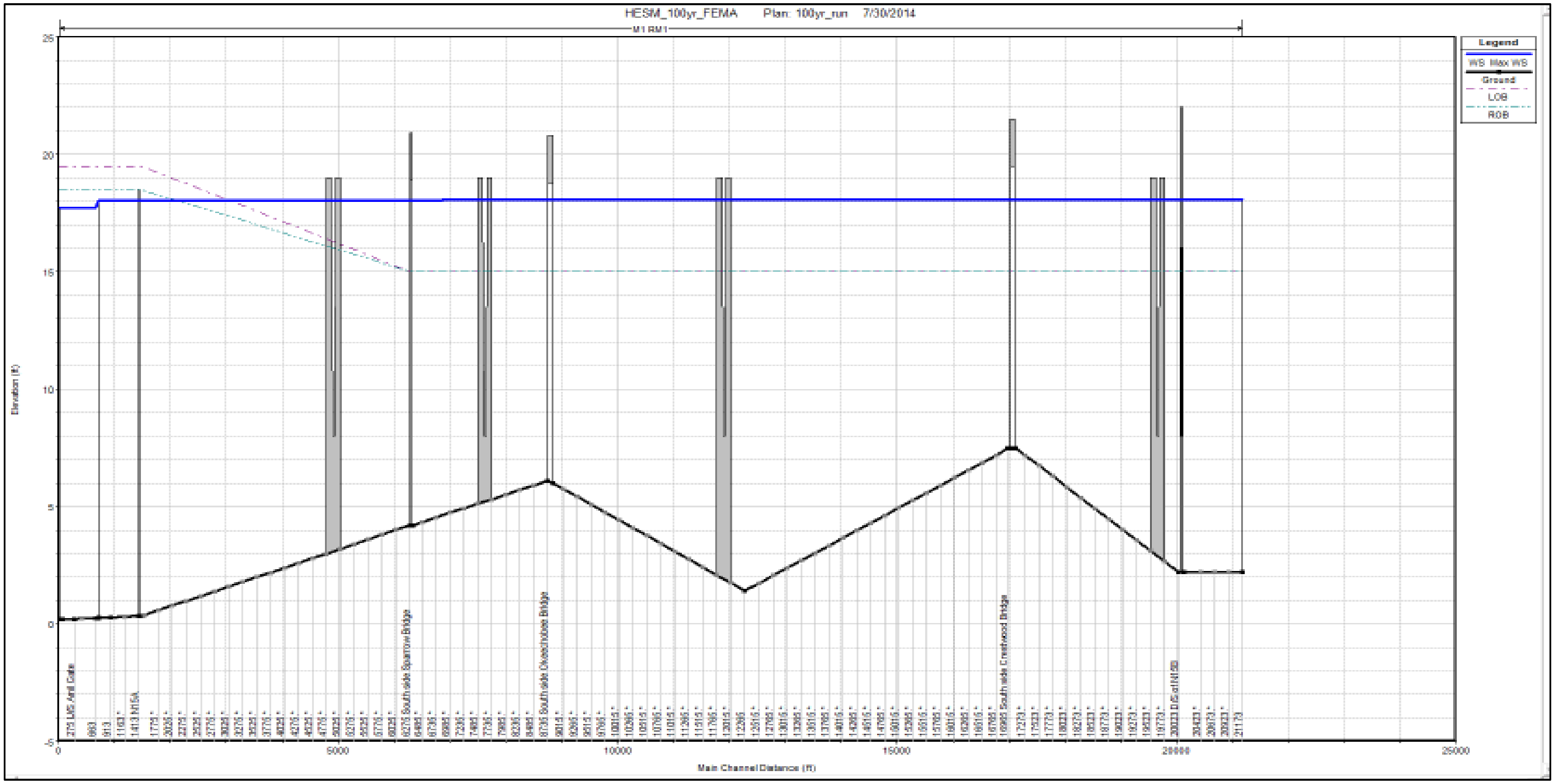

Figure F20. M-1 Canal Computed Maximum Stage Profile for the 100-yr, 72-hr Storm Event

Table F11. M-2Canal 10-yr and 100-yr Peak Stage Surface Water Profile

Reach	River Station (ft)	Structure Type	Channel Bottom Min. Elevation (ft NGVD29)	10-yr Max. Water Surface Elevation (ft NGVD29)	100-yr Max Water Surface Elevation (ft NGVD29)
RM2	10		1.0	12.6	16.5
RM2	210.5		5.8	12.6	16.5
RM2	411		6.5	12.6	16.5
RM2	436	Lat Struct	Outlet from sub-basin S5 to M2 Canal through 54" CMP @13.5'		
RM2	461		6.5	12.6	16.5
RM2	600	Culvert	3 X 84" RCP with inv=6.7 ft NGVD. Inv = 12 =control elevation from slide gates		
RM2	687		8.5	17.4	18.8
RM2	964.777		10.6	17.4	18.8
RM2	1242.55		10.6	17.4	18.8
RM2	1520.33		10.7	17.4	18.8
RM2	1798.11		10.7	17.4	18.8
RM2	2075.88		10.8	17.4	18.8
RM2	2353.66		10.8	17.4	18.8
RM2	2500	Lat Struct	overflow from sub-basin S5 to M2 canal		
RM2	2631.44		10.9	17.4	18.8
RM2	2909.22		10.9	17.4	18.8
RM2	3187		11.0	17.4	18.8
RM2	3262	Lat Struct	Outlet from sub-basin S9 to M2 through 2' Flash Board Riser (weir)		
RM2	3337		12.0	17.4	18.8
RM2	3632.08		12.0	17.4	18.8
RM2	3927.17		12.1	17.4	18.8
RM2	4222.26		12.1	17.4	18.8
RM2	4517.34		12.2	17.4	18.8
RM2	4812.43		12.2	17.4	18.8
RM2	5107.52		12.3	17.4	18.8
RM2	5402.6		12.3	17.4	18.8
RM2	5697.69		12.4	17.4	18.8
RM2	5992.78		12.4	17.4	18.8
RM2	6287.87		12.4	17.5	18.8
RM2	6582.95		12.5	17.5	18.9
RM2	6878.04		12.5	17.5	18.9
RM2	7173.13		12.6	17.5	18.9
RM2	7468.21		12.6	17.5	18.9
RM2	7763.3		12.7	17.5	18.9
RM2	8058.39		12.7	17.5	18.9
RM2	8353.47		12.7	17.5	18.9
RM2	8648.56		12.8	17.5	18.9
RM2	8943.65		12.8	17.5	18.9
RM2	9238.73		12.9	17.5	18.9
RM2	9533.82		12.9	17.5	18.9
RM2	9828.91		13.0	17.5	18.9

Table F11. M-2 Canal 10-yr and 100-yr Peak Stage Surface Water Profile (Cont.)

Reach	River Station (ft)	Structure Type	Channel Bottom Min. Elevation (ft NGVD29)	10-yr Max. Water Surface Elevation (ft NGVD29)	100-yr Max. Water Surface Elevation (ft NGVD29)
RM2	10124	Pump outfall	Discharge from sub-basin S6 pump PM6M2 to M2 canal		
RM2	10124		13.0	17.6	18.9
RM2	10174		13.0	17.6	18.9
RM2	10465.5		13.1	17.6	19.0
RM2	10757		13.1	17.6	19.0
RM2	11048.5		13.2	17.6	19.0
RM2	11340.1		13.2	17.6	19.0
RM2	11631.6		13.3	17.6	19.0
RM2	11923.1		13.3	17.6	19.0
RM2	12214.6		13.4	17.6	19.0
RM2	12506.2		13.4	17.6	19.0
RM2	12797.7		13.5	17.7	19.0
RM2	13089.2		13.5	17.7	19.0
RM2	13380.7		13.6	17.7	19.0
RM2	13672.3		13.6	17.7	19.0
RM2	13963.8		13.7	17.7	19.0
RM2	14255.3		13.7	17.7	19.1
RM2	14546.8		13.8	17.8	19.1
RM2	14838.4		13.8	17.8	19.1
RM2	15129.9		13.9	17.8	19.1
RM2	15421.4		14.0	17.9	19.1
RM2	15713		8.0	17.9	19.1
RM2	15788	Lat Struct	Outfall from sub-basin S7 to M2 Canal through2- 6' wide Slide Gates		
RM2	15863		8.0	17.9	19.1
RM2	16151.3		8.0	17.9	19.1
RM2	16439.7		8.0	17.9	19.1
RM2	16728		8.0	17.9	19.1
RM2	17016.4		8.0	17.9	19.1
RM2	17304.7		8.0	17.9	19.1
RM2	17593.1		8.0	17.9	19.2
RM2	17881.5		8.0	17.9	19.2
RM2	18169.8		8.0	17.9	19.2
RM2	18458.2		8.0	17.9	19.2
RM2	18746.5		8.0	17.9	19.2
RM2	19034.9		8.0	17.9	19.2
RM2	19323.2		8.0	17.9	19.2
RM2	19611.6		8.0	18.0	19.2
RM2	19900		8.0	18.0	19.2
RM2	19960	Lat Struct	Control structure at M-1 @ Sycamore Dr 4 7x7 gated culverts		
RM2	20050		8.0	18.0	19.2
RM2	20100		8.0	18.0	19.2

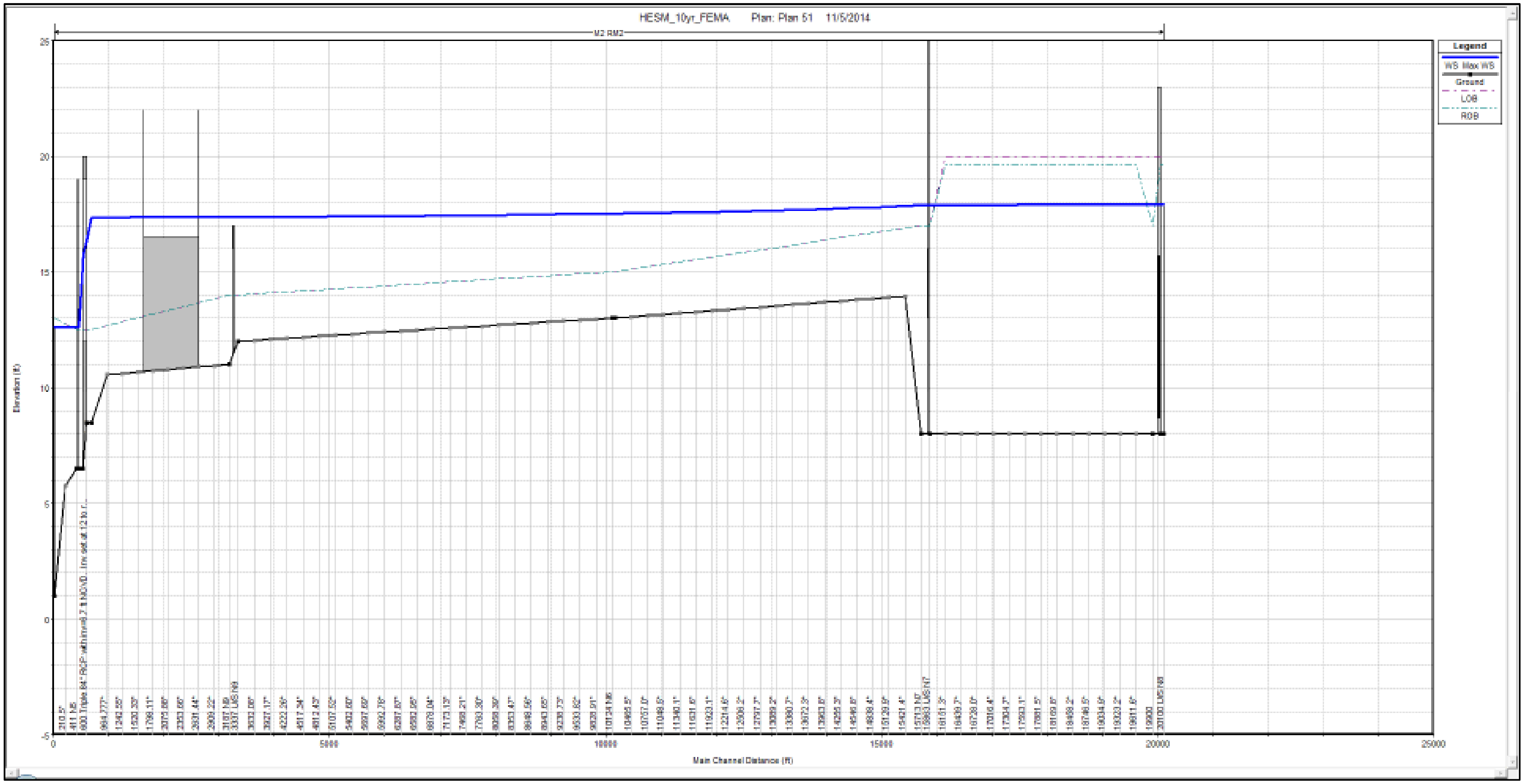

Figure F21. M-2 Canal Computed Maximum Stage Profile for the 10-yr, 72-hr Storm Event

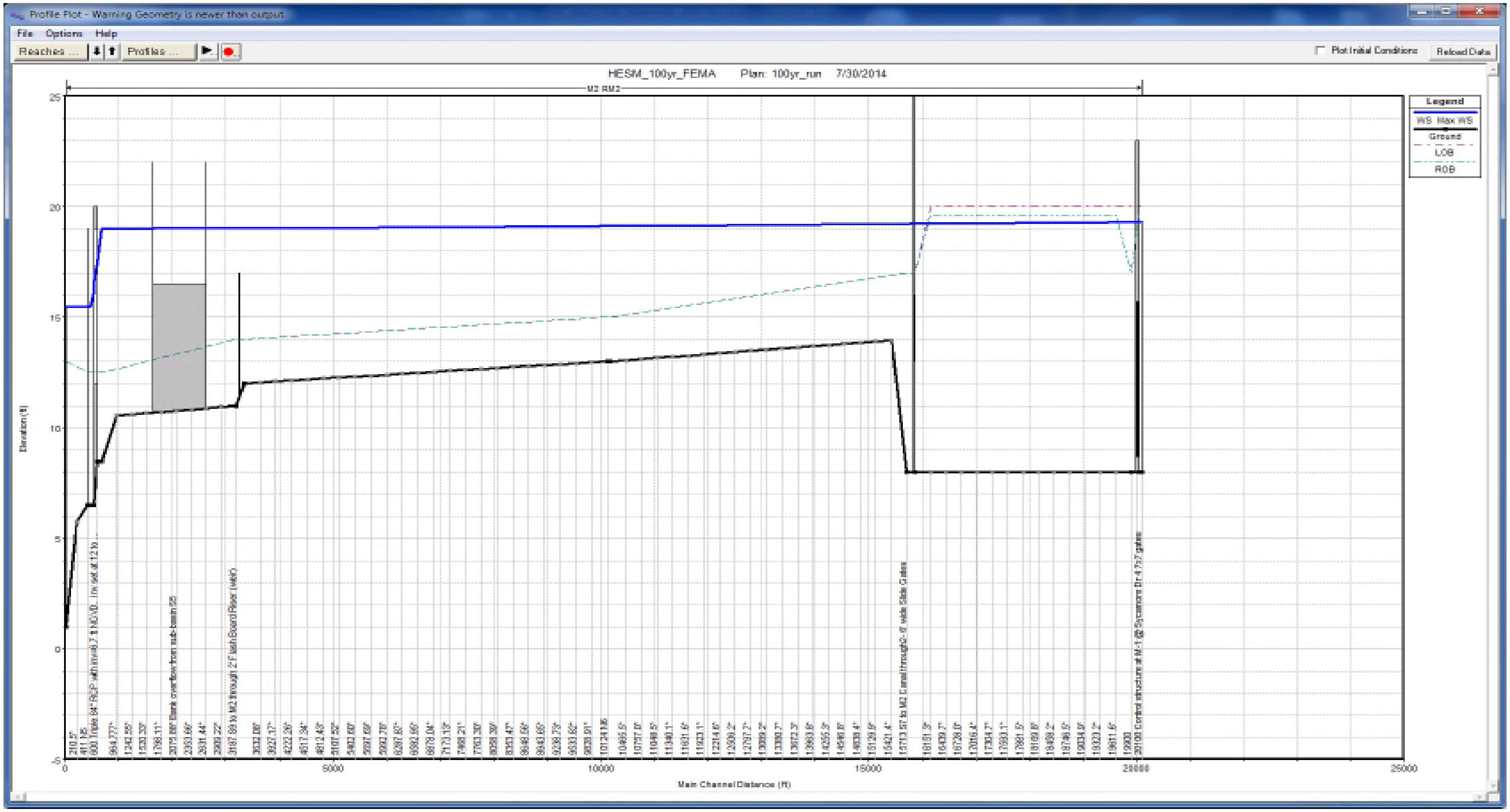

Figure F22. M-2 Canal Computed Maximum Stage Profile for the 100-yr, 72-hr Storm Event