Broward County Water Preserve Areas Stormwater Treatment Potential of C-11 Impoundment

(Final Report)

(Purchase Order No. PC P502437)

Prepared for:

South Florida Water Management District (SFWMD)
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May 12, 2006

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South Florida Water Management District
Broward County Water Preserve Areas
Final Report on the Stormwater
Treatment Potential of C-11 Impoundment
BMCD Project No. 39788

Dear Mr. Adorisio:

Burns & McDonnell is pleased to submit the Final Report on our study of the Stormwater Treatment Potential of the C-11 Impoundment for the Broward County Water Preserve Areas (WPA) Project. This study was conducted under the District's Purchase Order No. PC P502437. The scope of work for this study included the following two principal components:

- An assessment of previously-developed alternatives to enhance the stormwater treatment potential of the C-11 Impoundment. These alternatives were developed by MACTEC Engineering and Consulting but changing design assumptions for the C-11 Impoundment required a reassessment of these alternatives.
- A simulation model for the Broward County WPA project area to extend the simulation results available from the latest South Florida Water Management Model (SFWMM) simulation for this area. This new simulation was necessary to determine the impact of fully adopting the operational changes recommended previously by Burns & McDonnell.

We wish to express our appreciation to you and to the other members of the District's staff who participated in this effort for your helpful direction, advice and assistance during the preparation of this report. We are available at your convenience to discuss the information, analyses, conclusions and recommendations presented in this report.

Sincerely,

Galen E. Miller, P.E.
Associate Vice President

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Report Index and Certification

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Certification

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Galen E. Miller, P.E., Florida P.E. #40624
Date:________________

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EXECUTIVE SUMMARY

This report section presents an executive summary of the Broward County Water Preserve Areas, Stormwater Treatment Potential of C-11 Impoundment study. This study was completed by Burns & McDonnell Engineering Company, Inc. (Burns & McDonnell) for the South Florida Water Management District (SFWMD or District) under Purchase Order No. PC P502437. The background, methodology and results of this study are described in the following sections.

ES.1 Study Background and Scope of Work

The Comprehensive Everglades Restoration Plan (CERP) was approved in the Water Resources Development Act of 2000 (WRDA2000). CERP is as a framework and guide for modifications and operational changes to the Central and Southern Florida (C&SF) Project that are needed to restore and protect the South Florida ecosystem. Three of the initial projects that were authorized for implementation under WRDA2000 are listed below:

- C-11 Impoundment – An above-ground impoundment with a storage capacity of 5,960 acre-feet that will be located in the western C-11 drainage basin
- C-9 Impoundment – An above-ground impoundment located in the western C-9 drainage basin with a storage capacity of 6,600 acre-feet
- Water Conservation Areas 3A/3B (WCA-3A/3B) Levee Seepage Management project – A 4,312-acre wetland buffer area, which is located between the eastern boundary of WCA-3A/3B and U.S. Highway 27

These three projects have been merged into a single CERP project known as the Broward County Water Preserve Areas (WPA) Project. The primary goals of the Broward County WPA Project are to capture and store stormwater, reduce delivery of phosphorus and other unwanted nutrients to the Everglades, and reduce seepage from the Everglades.

In May 2004, the District authorized Burns & McDonnell to complete an analysis of the Broward County WPA Project to assess the extent to which the level of flood protection in the western C-11 and C-9 drainage basins may be impacted by implementation of this project (Flood Protection Analysis study). In this study, Burns & McDonnell recommended certain modifications to the design and operations of the Broward County WPA Project. Many of these suggested modifications have now been integrated into the Selected Plan for this project. The current study is an extension of the

Flood Protection Analysis study in that it further assesses the effectiveness of these proposed modifications on the operations of this project.

On March 6, 2006, the U.S. Army Corps of Engineers, Jacksonville District and SFWMD released their report on the *Central and Southern Florida Project, Broward County Water Preserve Areas, Draft Integrated Project Implementation Report and Environmental Impact Statement, November 2005* (Draft PIR/EIS) for public comment. This draft report describes the purpose and need for the project, and the Selected Plan for the project. The Selected Plan identifies the proposed locations, design data and operations of all project features (impoundments, levees/embankments, canals and control structures).

ES.2 Analysis of MACTEC Engineering & Consulting Study

MACTEC Engineering & Consulting, Inc. (MACTEC) developed and evaluated design alternatives to enhance the stormwater treatment potential of the C-11 Impoundment in 2003 and 2004 under SFWMD Contract No. C-15982-WO06-05. The principal intent of these design alternatives was to maximize the hydraulic retention time of the impoundment and thus, maximize the removal of pollutants from the stormwater that travels through this impoundment. Because of design and operational modifications that have been adopted since the MACTEC study was completed, Burns & McDonnell was contracted to reevaluate these alternatives.

The two design alternatives developed by MACTEC both consist of constructing internal levees within the C-11 Impoundment to route stormwater and prevent short-circuiting to the outfall. For Alternative 1, the internal levee is L-shaped; it starts at the midpoint of the southern external impoundment levee, extends north for 6,680 feet and then east for 3,300 feet. A secondary internal levee, which extends out from the west side of the impoundment in an east-northeast direction for about 2,000 feet, is also included. This secondary levee is intended to help limit wave action.

In Alternative 2, the internal levee is shaped like a hockey stick; it starts from the western external impoundment levee about 2,500 feet north of the southwest corner, runs north-northeast for 5,700 feet, and then east for another 3,000 feet. For this alternative, the impoundment’s outfall structure (S-504) would have to be relocated from the southwest corner of the impoundment to a point in the western embankment about 3,300 feet north of the C-11 Canal. Along with this relocation, the C-502A Canal would also have to be extended farther north.

In its evaluation of these two design alternatives, MACTEC estimated phosphorus removal efficiencies ranging from 3.4 to 5.2 percent during storm events and as high as 52.8 percent during low-flow conditions. MACTEC concluded the only significant difference between the two alternatives was cost, with Alternative 2 being less expensive than Alternative 1. However, the latest design for this impoundment shows the S-504 spillway relocated to the southern embankment where it would discharge directly to the C-11 Canal, permitting elimination of Structure S-504A (culverts under U.S. Highway 27) and construction of the C-502A Canal north of the C-11 Canal. This relocation is compatible with Alternative 1 but not Alternative 2. Therefore, the S-504A culverts and C-502A Canal would have to be restored to the project to make Alternative 2 practicable. Although no specific estimates of these costs have been prepared, the incremental cost of these added features would certainly make the estimated cost of Alternative 2 greater than that for Alternative 1 under current conditions.

In its reevaluation of the MACTEC study, Burns & McDonnell developed the following principal conclusions:

1 The projected phosphorus reduction in the impoundment would, particularly under high rates of inflow, be nominal at best for either alternative.

2. Because of its anticipated lower cost and lesser operational problems, Alternative 1 would be preferable to Alternative 2.

3. With high inflow rates, average velocities through the impoundment would exceed typical design limits for stormwater treatment areas. These high velocities would tend to mobilize and transport vegetative material, which could cause outflow phosphorus concentrations to be elevated above inflow concentrations.

4. For construction and operation of either of these alternatives, the associated incremental project expenditures would not appear to be cost-effective, given little or no benefit in phosphorus reduction.

5. The relatively small size of the C-11 Impoundment, in combination with anticipated high rates of inflow, effectively prevents development of a vegetative community capable of increasing phosphorus reduction potential because of excessive flow-through velocities.

6. In lieu of attempting phosphorus reduction in the C-11 Impoundment by development of these or other design modifications, the more effective strategy for reducing phosphorus discharges to the Everglades Protection Area at S-9 would be to minimize discharge volumes at S-9 by implementation of the recommendations in the Flood Protection Analysis.

At times, the C-11 Impoundment will have simultaneous inflow and outflow. These flow-through discharges will tend to short-circuit directly from S-503 to S-504 along the southern boundary of the impoundment. The planned borrow and fish refuge areas in this area should be configured to limit flow velocities during flow-through discharges to 0.5 feet per second (fps). Also, impoundment drawdown release rates should be limited to yield maximum flow velocities of 0.1 fps in the balance of the impoundment.

ES.3 Simulation Model

The latest available South Florida Water Management Model (SFWMM) simulation for the project area is version 5.4.3.1, dated November 3, 2005. While most of the design modifications recommended in the Flood Protection Analysis study have been incorporated into the preferred project plan, some of the key recommended operational modifications are not reflected in this SFWMM run. In order to better assess the impacts of these recommended operational changes on the project, Burns & McDonnell developed a hydrologic simulation model for the Broward County WPA project area (BCWPA model).

One of the primary goals of the BCWPA project is to reduce the amount of C-11 West Basin runoff that is discharged to the Everglades Protection Area at Pump Stations S-9 and S-9A. To accomplish this intent, basin runoff will be managed as follows in the Broward County WPA Project:

- Step 1 – The preferred destination for C-11 West Basin runoff shall be east through the S-13A culverts to tide. The allowable discharge rate at S-13A is based on the available conveyance capacity of S-13A, the C-11 East Canal, and S-13 pump station/spillway. The S-13A discharge is assumed to be limited 250 cubic feet per second (cfs).
- Step 2 – All C-11 West Basin runoff that cannot be conveyed directly eastward through S-13A is delivered to the C-11 Impoundment. These deliveries are limited only by the net capacity of the S-503 pump station (2,500 cfs).

- Step 3 – Any remaining basin runoff that cannot be discharged eastward at S-13A or delivered to the C-11 Impoundment (Steps 1 and 2) must be discharged to WCA-3A at the S-9 or S-9A pump station.

Steps 1 through 3 determine the initial distribution of runoff from the western C-11 drainage basin. The remaining steps in this model protocol deal with the management of those runoff volumes that are initially delivered to the C-11 Impoundment in Step 2.

- Step 4 – When the current storage depth in the C-11 Impoundment exceeds one foot, all storage volumes above this level and additional deliveries to this impoundment will be conveyed southward to the C-9 Basin, subject to the limits described below. These southward deliveries are routed through the proposed C-502B conveyance canal and Structure S-30 to the C-9 Canal. During transfers from the C-11 Impoundment to C-9 Basin, the return of WCA-3A/3B seepage at Pump Station S-9A is discontinued to prevent the direct transfer of C-11 West Basin runoff to WCA-3A. The maximum delivery rate for these transfers to the C-9 Basin is 1,000 cfs but may be further limited as discussed in Step 6 below.
- Step 5 – C-11 West Basin runoff and WCA seepage/runoff that is delivered to the C-9 Basin (Step 4) is first conveyed directly to tide via the proposed S-511 culverts and existing S-29 spillway, up to the available conveyance capacity of the C-9 Canal. These discharges are further limited to 250 cfs at S-511.
- Step 6 – C-9 Basin imports that cannot be delivered directly to tide (Step 5) are discharged to the C-9 Impoundment as long as there is available storage space in this impoundment. Should desired C-9 Basin imports (Step 4) exceed the current basin import capacity (available conveyance capacity of C-9 Canal at S-511 plus storage capacity in C-9 Impoundment), C-9 Basin imports are further limited to the current import capacity.
- Step 7 – When the current inflow rate to the C-11 Impoundment (Step 2) exceeds the available transfer capacity to the C-9 Basin (Step 4), then these excess inflows are stored in this impoundment until such time as the C-11 Impoundment reaches its normal pool elevation (10.0 feet NGVD).
- Step 8 – Finally, any net C-11 Impoundment inflow that cannot be stored in this impoundment (Step 7) is discharged to WCA-3A via the S-9 or S-9A pump station.

A comparison of the annual SFWMM and BCWPA model simulation results is presented in Table ES.1 for the C-11 Basin and C-11 Impoundment. Some of the significant differences between the results for these two simulations are discussed below.

Table ES.1: Comparison of Annual Simulation Results for C-11 Basin (acre-feet)

Structure or Flow Component	SFWMM v5.4.3.1			BCWPA Model		
	Avg Year	Min Year	Max Year	Avg Year	Min Year	Max Year
S-13	70,756	31,793	108,454	134,200	62,759	198,178
S-13A	5,034	0	21,243	68,478	26,353	104,129
S-381 East	0	0	0	601	0	2,797
S-381 West	186	0	3,957	0	0	0
S-9/S-9A:						
C-11 Runoff[a]	23,760	2,099	48,529	990	0	11,198
WCA Seepage[b]	73,079	41,615	116,480	59,090	41,236	76,483
Total	96,678	43,630	154,511	60,080	41,236	87,681
Net Basin Runoff:						
East Basin	65,722	31,793	94,049	65,722	31,793	94,049
West Basin	77,453	26,693	127,753	77,453	26,693	127,753
Total	143,176	63,099	221,802	143,182	63,099	221,802
C-11 Impoundment Inflow						
S-503 Pump Station	72,233	25,050	112,507	9,576	141	32,236
Rainfall	5,943	3,855	8,838	5,943	3,855	8,838
Groundwater	8,259	4,930	13,629	15,770	10,865	26,074
C-11 Impoundment Outflow						
S-504 Spillway	52,904	6,372	96,837	9,030	0	29,435
Evapotranspiration	6,430	6,058	6,814	6,430	6,068	6,814
Groundwater	26,825	19,606	31,877	15,810	10,014	18,773
Stage (feet NGVD)	8.68	7.19	9.57	6.58	5.29	7.23

a. C-11 West Basin runoff that must still be pumped to WCA-3A.
b. Seepage component of S-9/S-9A discharge.

- With a preference to deliver the maximum amount of C-11 Basin runoff to tide, average annual discharge at S-13A is increased by a factor of over 13 in the BCWPA model. A similar discharge increase is also seen at S-13.
- Runoff from the C-11 Basin was calculated in the SFWMM and not modified by the BCWPA model.
- Average C-11 Impoundment stages are significantly less in the BCWPA Model (6.58 feet NGVD) as compared to the SFWMM run (8.68 feet NGVD).

- With typically reduced storage amounts and lower impoundment stages in the BCWPA model, groundwater inflow to the C-11 Impoundment will nearly double and groundwater discharge decreases by an estimated 40 percent.
- Most importantly, deliveries of C-11 Basin runoff to WCA-3A at S-9/S-9A decrease from an average of 23,760 to 990 acre-feet per year in the BCWPA model. This value of 990 acre-feet per year is much less than projections from the Long-Term Plan (LTP) for 2010 (18,300 acre-feet per year) and is only 10 percent higher than the LTP projection for 2037 (900 acre-feet per year).
- Because it is assumed that some WCA seepage and seepage management area runoff will also be transferred to the C-9 Basin along with C-11 Basin runoff, seepage return flows to WCA-3A will also decrease by an average of about 14,000 acre-feet per year.

For the C-9 Basin and C-9 Impoundment, a comparison of the annual SFWMM and BCWPA model simulation results is presented in Table ES.2. Some of the significant differences between the results for these two simulations are discussed below.

Table ES.2: Comparison of Annual Simulation Results for C-9 Basin (acre-feet)

Structure or Flow Component	SFWMM v5.4.3.1			BCWPA Model		
	Avg Year	Min Year	Max Year	Avg Year	Min Year	Max Year
S-29	214,873	71,530	329,829	196,897	71,217	352,266
S-30[a]	55,749	5,299	97,274	23,725	475	99,712
Net Basin Runoff	174,988	65,918	262,832	174,988	65,918	262,832
C-9 Impoundment Inflow						
S-509 Pump Station	53,452	0	97,274	9,507	0	29,894
Rainfall	7,255	4,909	9,823	7,255	4,909	9,823
Groundwater	3,897	3,352	4,720	3,932	2,783	4,814
C-11 Impoundment Outflow						
S-510 Spillway	37,586	313	66,998	3,640	0	13,668
Evapotranspiration	6,724	6,076	7,462	6,724	6,076	7,462
Groundwater	20,420	6,682	35,000	10,885	2,970	27,480
Stage (feet NGVD)	5.46	3.50	7.51	4.16	2.99	6.47

a. Includes transfers from C-11 Impoundment to C-9 Basin.

- Transfers from the C-11 Impoundment to the C-9 Basin are shown to decrease significantly, by approximately 32,000 acre-feet per year in the BCWPA model. This decrease results primarily because of the greatly increased delivery of C-11 West Basin runoff directly to tide via S-13A and S-13.

- In the SFWMM run, all interbasin transfers between the C-11 and C-9 basins were assumed to be delivered to the C-9 Impoundment. In the BCWPA model about 60 percent of these transfers are released directly to tide via S-29 and not pumped into the C-9 Impoundment.
- Average impoundment stages are also less for the C-9 Impoundment, declining from 5.46 to 4.16 feet NGVD, but these declines are not as significant as for the C-11 Impoundment. As a result, the average annual groundwater inflow is largely unchanged but average groundwater discharge decreases by nearly half.

ES.4 Conclusions

The conclusions reached as a result of the investigations and analyses conducted during this study, organized by their primary subject matter, are listed below

ES.4.1 Stormwater Treatment Potential of C 11 Impoundment

MACTEC Engineering and Consulting, Inc. developed alternatives to enhance the stormwater treatment potential of the C-11 Impoundment. From Burns & McDonnell's assessment of these alternatives, it is concluded that:

1. Projected phosphorus reduction in the C-11 Impoundment would, particularly under high rates of inflow, be nominal at best under either of the alternatives considered in the MACTEC analysis.

2. It is considered likely that outflow concentrations under high rates of inflow would actually be elevated above inflow concentrations due to mobilization and transport of vegetative material for either of the alternatives considered.

3. Incremental project expenditures associated with the construction and operation of additional project features under either of the two alternatives considered would not appear to be cost-effective, given little or no benefit in phosphorous reduction.

4. The basic footprint of the reservoir, when considered in combination with the anticipated high rates of inflow, effectively prevents the development of a vegetative community capable of increasing phosphorous reduction due to excessive velocities.

5. The most effective strategy for reducing phosphorous discharges at S-9 will consist of minimizing S-9 discharge volumes in lieu of attempting phosphorus reduction in the C-11 Impoundment.

ES.4.2 Design and Operations of Broward County WPA Project

From the simulation model developed for the BCWPA project area, the following conclusions were drawn:

1. Because of limitations in the capabilities of the South Florida Water Management Model, the latest SFWMM simulation for the BCWPA project area does not well represent the recommended operations of this project, in particular increased conveyance of Western C-11 Basin runoff directly to tide via Structure S-13A.

2. One of the principal goals of the BCWPA project is to reduce the discharge of untreated basin runoff to WCA-3A at S-9. The effectiveness of the project in meeting this goal can be greatly enhanced by maximizing the volumes of C-11 Basin runoff released directly to tide.

3. The amount of untreated basin runoff that will continue to be discharged to WCA-3A after project implementation is highly sensitive to the available conveyance capacity for releases directly to tide via the C-11 and C-9 canals. For example, reducing the allowable discharge rate at S-13A from 250 to 120 cfs increases the discharge of untreated basin runoff at S-9 nearly four fold, from an average of 990 to 3,698 acre-feet/year. A ten-fold increase would result using the conveyance limits for the eastern C-11 and C-9 canals proposed by the District's Operating Division.

ES.5 Recommendations

Given the conclusions reached during this study, the following recommendations for project design or operational changes, and additional analyses are offered for consideration by the District and Corps of Engineers.

1. Inclusion of additional design features in the C-11 Impoundment to enhance its stormwater treatment potential, such as internal levees to maximize residence time, would not be cost effective and should not be implemented. However, care should be taken to limit internal velocities in the impoundment to reduce the potential for erosion, reduce the likelihood that fish

will be swept out of the impoundment when the spillway is open, and reduce the potential for resuspension of vegetative matter that could increase the phosphorus concentrations in impoundment discharges.

2. The BCWPA Project Operating Manual should be revised to make releasing Western C-11 Basin runoff to tide via structure S-13A a first priority. Similarly, during transfers from the C-11 Impoundment to C-9 Basin, the available capacity of the C-9 Canal should be utilized to convey these interbasin transfers directly to tide via structure S-511 to the extent practicable.

3. A detailed hydraulic analysis of the C-11 East Canal, including Structure S-13A, should be completed to better define the available capacity of this canal to convey Western C-11 Basin runoff directly to tide under a broad range of possible antecedent conditions. A similar hydraulic analysis should also be completed for the C-9 Canal between S-30 and S-29.

4. The proposed design for the C-11 Impoundment should be modified to include a small spillway, or similar gravity discharge structure, that would be located adjacent to the S-503 pump station. This new spillway would allow drawdown releases from this impoundment to be discharged to the C-11 Canal east of S-381 and eliminate the need to open the S-381 and S-504A spillways before making such drawdown releases.

* * * * *

1. INTRODUCTION

This document and the analyses it summarizes were prepared by Burns & McDonnell Engineering Company, Inc. (Burns & McDonnell) for the South Florida Water Management District (SFWMD or District). The conduct of these analyses was authorized by the District through its issuance of Purchase Order No. PC P502437, dated July 14, 2005. The background of this study and its scope of work are summarized below.

1.1 Background

The Water Resources Development Act of 2000 (WRDA2000) was signed into law on December 11, 2000 (Public Law 106-541). Section 601 of this act approved the Comprehensive Everglades Restoration Plan (CERP) as a framework and guide for modifications and operational changes to the Central and Southern Florida (C&SF) Project that are needed to restore and protect the South Florida ecosystem while providing for other water-related needs of the region, including water supply and flood protection. Three of the initial projects that were authorized for implementation under WRDA2000 are listed below:

- C-11 Impoundment
- C-9 Impoundment
- Water Conservation Areas 3A/3B (WCA-3A/3B) Levee Seepage Management

These three projects have been merged into a single CERP project known as the Broward County Water Preserve Areas (WPA) Project. Collectively, the components of the Broward County WPA Project are intended to capture and store stormwater, reduce delivery of phosphorus and other unwanted nutrients to the Everglades, reduce seepage from the Everglades, increase urban drinking water supplies, and reduce saltwater intrusion in underground water supplies. Existing conditions within the project area, and the features and intended operation of this project are described in Sections 1.3 and 1.4 below.

In May 2004, the District authorized Burns & McDonnell to complete an analysis of the Broward County WPA Project to assess the extent to which the level of flood protection in the western C-11 and C-9 drainage basins may be impacted by implementation of this project (Work Order No. C-C20104P-WO03). The results of these analyses are summarized in the report titled *Flood Protection Analysis for Broward County Water Preserve Areas, C-11 and C-9 Impoundments (Final*

Report), February 2006 (Flood Protection Analysis study). In that report, Burns & McDonnell proposed certain modifications to the design and operations of the Broward County WPA Project. These modifications are described below in Section 1.5. The current study is an extension of the Flood Protection Analysis study in that it further assesses the effectiveness of these proposed modifications on the operations of this project.

On March 6, 2006, the U.S. Army Corps of Engineers, Jacksonville District and SFWMD released their report on the *Central and Southern Florida Project, Broward County Water Preserve Areas, Draft Integrated Project Implementation Report and Environmental Impact Statement, November 2005* (Draft PIR/EIS) for public comment. This draft report describes the purpose and need for the project; and the locations, design data and operations of all proposed project features (impoundments, levees/embankments, canals and control structures).

1.2 Scope of Work

The principal goal of this study, as originally conceived, was to evaluate the stormwater treatment potential of the C-11 Impoundment and develop a conceptual design for any recommended modifications to the Broward County WPA project for the purpose of improved stormwater treatment. The original scope of work for this project was segregated into the following six tasks:

- Task 1 – Initial Kickoff Meeting
- Task 2 – Evaluate Phosphorus Removal Performance of Base Design
- Task 3 – Evaluate Phosphorus Removal Performance of Alternative 1
- Task 4 –Propose Further Modifications for Improved Phosphorus Removal
- Task 5 – Prepare Conceptual Design
- Task 6 – Present Conceptual Design

During the initial kickoff meeting (Task 1), which was held June 8, 2005, the goals of this study were discussed and revised. As a result of these discussions and subsequent project developments, project Tasks 2 – 6 were revised. These revised tasks are described briefly below:

- Task 2 – IMC Meeting: Meet with District staff from Interagency Modeling Center (IMC) to discuss inclusion of recommended operational modifications in the South Florida Water Management Model (SFWMM) simulation being prepared for the Broward County WPA project's Project Implementation Report (PIR).

- Task 3 – Simulation Model: Develop hydrologic simulation model for Broward County WPA Project that extends the results of the latest SFWMM simulation run and implements the operational recommendations of the Flood Protection Analysis study to the extent practicable.

- Task 4 – Develop assessment of stormwater treatment alternatives for C-11 Impoundment that were developed by MACTEC Engineering & Consulting Company.

- Task 5 – Technical Review Meeting: Attend technical review meeting in District's offices and present study results.

- Task 6 – Study Report: Prepare draft study report for District review and comment, and then publish final report after District comments have been addressed.

1.3 Existing Conditions

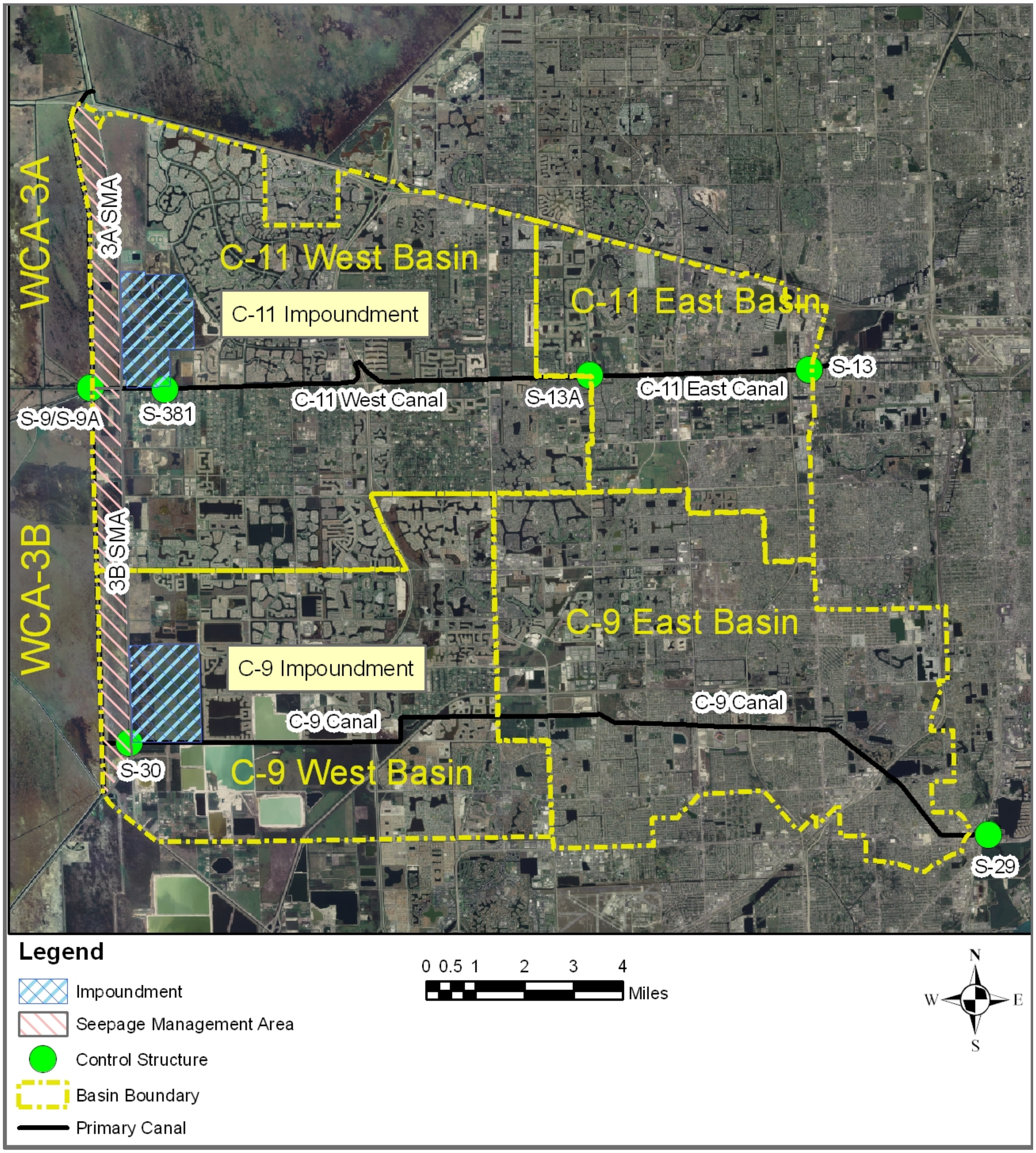
This section presents a brief summary of existing conditions within the Broward County WPA Project area (that is, conditions existing prior to development of the initial phases of this project). A more thorough description of these conditions is presented in Section 1.1 of the Flood Protection Analysis study report.

1.3.1 C-11 Basin

The C-11 drainage basin is located in south-central Broward County and covers approximately 97 square miles. About 71 square miles (73 percent) of this area is located within the western portion of the basin and 26 square miles (27 percent) in the eastern portion. A map of this basin is included in Figure 1.1. The primary drainage canal within this basin is the C-11 Canal, which bisects the basin in an east-west direction. When constructed in the 1950s, this canal's primary purpose was to provide drainage for flood control and its secondary purpose was for water supply. The principal control structures that currently exist on the C-11 Canal, ordered from west to east, are listed below:

- Pumping Station S-9 – The S-9 pump station is located at the western end of the C-11 Canal, approximately 0.5 mile west of U.S. Highway 27. This pump station has a nominal capacity of 2,880 cubic feet per second (cfs) and discharges basin runoff and conservation area seepage to Water Conservation Area 3A (WCA-3A).

Figure 1.1: Broward County WPA Project Area



- Pumping Station S-9A – The S-9A pump station was developed along with the S-381 spillway as part of the Western C-11 Water Quality Project. This pump station, which has a nominal capacity of 500 cfs, is located at the western end of the C-11 Canal adjacent to Pump

Station S-9. S-9A is a seepage control station that returns the collected seepage from WCA-3A and WCA-3B back to WCA-3A.

- Structure S-381 – S-381 is a gated spillway located on the C-11 Canal approximately 4,300 feet east of U.S. Highway 27. This Obermeyer-type spillway acts as a divide structure to keep seepage from the water conservation areas separate from runoff from the more urbanized portions of the C-11 West Basin.
- Structure S-13A – The S-13A control structure is located on the C-11 Canal approximately 4.5 miles west of State Route 7. This structure serves as the divide structure between the western and eastern portions of the C-11 Basin.
- S-13 Pump Station and Spillway – Structure S-13 is located at the eastern end of the C-11 Canal. It consists of a pump station and spillway whose primary purpose is to discharge floodwaters from the eastern C-11 Basin (C-11 East Basin) to tide.

Under current operating protocols, the runoff from the eastern portion of the C-11 Basin is discharged directly to tide at S-13 while most of the western basin runoff is discharged to WCA-3A at S-9 or S-9A. The gates at S-13A, the divide structure between the eastern and western basins, are typically left open except when eastward discharge at this structure exacerbates flood conditions in the C-11 East Basin.

The S-381 divide structure, which was only recently completed, is normally left closed (that is, in its raised position) to maintain higher stages on its west (tailwater) side where these higher stages help reduce WCA seepage. During higher runoff events, this spillway can be lowered to convey C-11 West Basin runoff to S-9 and can also be lowered to allow regulatory or water supply releases from WCA-3A.

1.3.2 C-9 Basin

The C-9 drainage basin, which covers approximately 102 square miles, is located immediately south of the C-11 Basin in south-central Broward County. New Flamingo Road and State Route 823 form the boundary between the eastern and western portions of the C-9 Basin, which are nearly equal is size (approximately 53 and 49 square miles, respectively). There is however, no control structure on the C-9 Canal that divides the two halves of this basin hydraulically.

The two principal existing control structures on the C-9 Canal, which is also known as Snake Creek, are listed below:

- Structure S-30 – S-30 is a series of gated culverts located near the western end of the C-9 Canal at U.S. Highway 27. This structure serves to help limit seepage losses from WCA-3A and WCA-3B by allowing for higher stages in the C-9 Canal west of U.S. Highway 27.
- S-29 Spillway – The S-29 spillway regulates the discharge of basin runoff to tide at the eastern end of the C-9 Canal.

1.4 Description of Broward County WPA Project

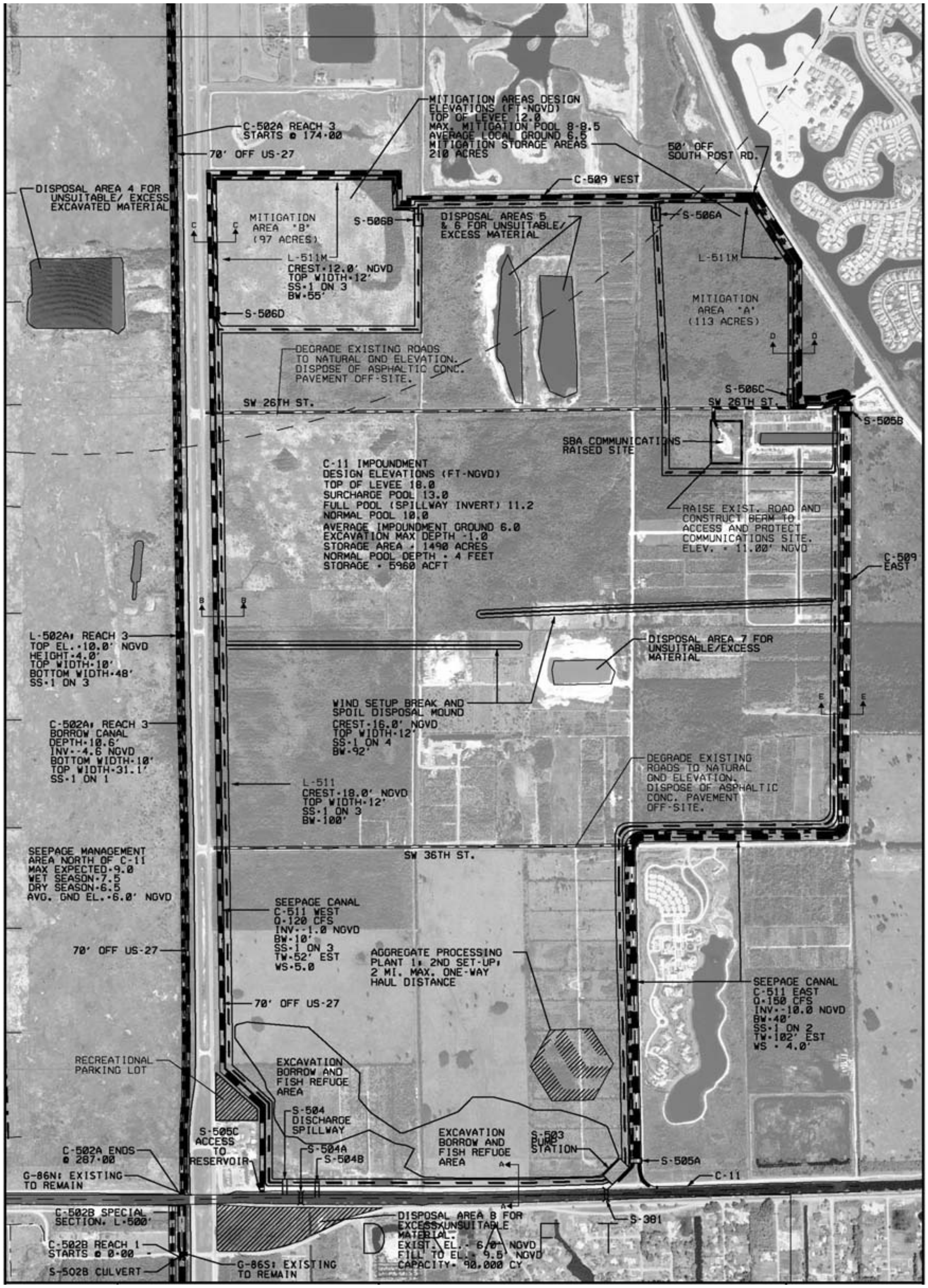
As mentioned above, the Broward County WPA Project will consist of three principal components: the C-11 Impoundment, the C-9 Impoundment, and the WCA-3A and WCA-3B seepage management project. There are additional components of this project, such as the North and Central Lake Belt Storage Areas, that are not scheduled for development for many years so these future components are not addressed in this study. The three Broward County WPA Project features listed above are all scheduled for implementation by 2010 and are described in the Draft PIR/EIS. Summary descriptions of these three components are included in the following sections.

1.4.1 C-11 Impoundment

The C-11 Impoundment will be located in western Broward County, immediately north of the C-11 Canal and east of U.S. Highway 27, on a site with a total footprint of approximately 1,850 acres. The principal feature of this development will be an above-ground impoundment with a design operating depth of four feet and effective storage area of 1,490 acres. At the northern end of the site, a wetland mitigation area of approximately 205 acres is to be developed. Figure 1.2 is a general plan of the C-11 Impoundment. The other principal features of the C-11 Impoundment are listed below:

- Pump Station S-503 – Inflow pump station with capacity of 2,575 cfs located at southeast corner of impoundment on C-11 Canal
- S-504 Spillway – Gated spillway with design capacity of 1,000 cfs located at southwest corner of impoundment on C-11 Canal
- S-504A Spillway – Obermeyer-type spillway located in C-11 Canal immediately east of S-504 (duplicate of S-381 spillway with design capacity of 2,880 cfs)
- S-504B Spillway – Uncontrolled overflow spillway with design capacity of 450 cfs; located on C-11 Canal near southwest corner of impoundment between S-381 and S-504A
- Structures S-505A/B/C – Weirs and culverts located in C-511 seepage canal

Figure 1.2: General Plan of C-11 Impoundment



Derived from Plate G-3 of Draft PIR/EIS, November 2005.

- Culverts S-506A/B – Gated culverts with capacity of 50 cfs each that control water supply discharges from main impoundment to wetland mitigation area
- Culverts S-506C/D – Gated culverts (capacity 17 cfs each) that control mitigation area discharges to C-511 seepage canal
- Levee 511 (L-511) – Perimeter levee/embankment around C-11 Impoundment
- Levee 511M (L-511M) — Perimeter levee around wetland mitigation area
- Canal 511 (C-511) – Seepage collection canal around perimeter of L-511 and L-511M

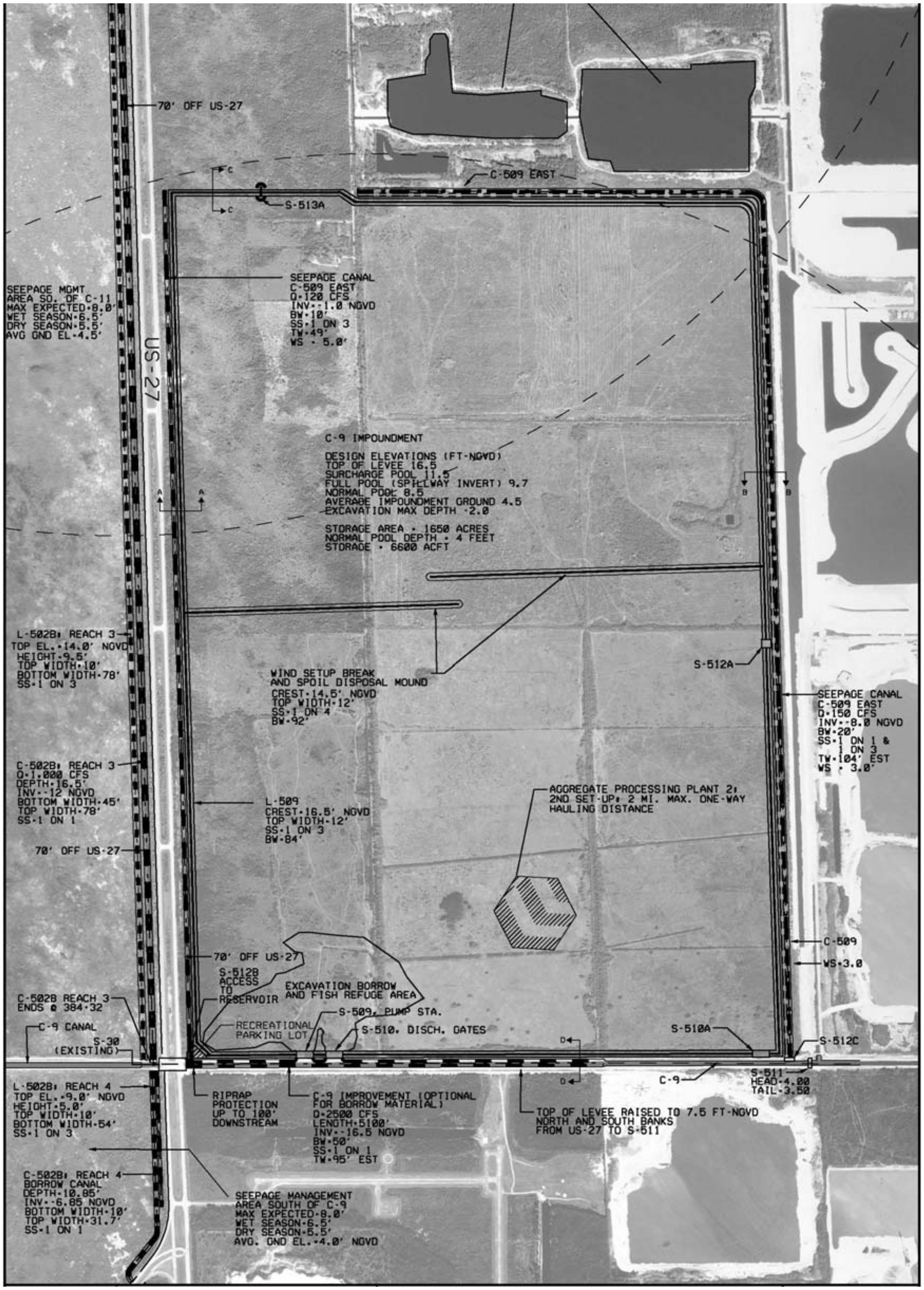
The overall intent in the design of this impoundment is that all stormwater runoff from the C-11 West Basin be directed into this impoundment through Pumping Station S-503. Structure S-381, which is located in the C-11 Canal immediately west of S-503, will normally remain closed to keep this basin runoff separate from conservation area seepage. Delivery of basin runoff to this impoundment would continue until the impoundment is full and the available transfer capacity to the C-9 Impoundment has been exceeded. Under these conditions, S-381 and S-504A would be opened (lowered) to convey basin runoff directly to the S-9 or S-9A pump station.

1.4.2 C-9 Impoundment

The C-9 Impoundment will be located in southwestern Broward County, immediately north of the C-9 Canal and east of U.S. Highway 27, on a site with a total footprint of approximately 1,792 acres. The principal feature of this development will be an above-ground impoundment with a design operating depth of four feet and effective storage area of 1,650 acres. In the 2001 Feasibility Study, a wetland mitigation area was included at the northern end of the site. This wetland mitigation area will now be managed by the Florida Department of Transportation (FDOT) and is no longer a feature of the Selected Plan for the BCWPA Project. Figure 1.3 is a general plan of the C-9 Impoundment. The other principal features of the C-9 Impoundment are listed below:

- Pump Station S-509 – Inflow pump station with capacity of 1,075 cfs located near southwest corner of impoundment on C-9 Canal
- S-510 Spillway – Gated spillway with design capacity of 500 cfs located immediately east of S-509 on C-9 Canal
- S-510A Spillway –Uncontrolled overflow spillway with design capacity of 450 cfs which is located on C-9 Canal at southeast corner of impoundment

Figure 1.3: General Plan of C-9 Impoundment



Derived from Plate G-6 of Draft PIR/EIS, November 2005.

- Culverts S-511 – Gated culverts in C-9 Canal with capacity of 500 cfs located east of southeast corner of impoundment
- Pump Station S-512A – Seepage control pump station (150-cfs capacity) located on C-509 seepage collection canal near middle of eastern side of impoundment
- Structure S-512B – Weir and gated culverts in C-509 seepage canal located near southwest corner of impoundment
- Structure S-512C – Weir and gated culverts in C-509 seepage canal located near southeast corner of impoundment
- Culvert S-513A – Gated culvert (50-cfs capacity) that controls water supply discharges from the impoundment to the adjacent FDOT wetland mitigation area
- Levee 509 (L-509) – Perimeter levee/embankment around C-9 Impoundment
- Canal 509 (C-509) – Seepage collection canal around perimeter of L-509

Over the near term, the C-9 Impoundment will function primarily for temporary storage of runoff transferred from the C-11 Impoundment. When the C-11 Impoundment reaches capacity and there is still excess C-11 West Basin runoff, water will be released from this impoundment through the S-504 spillway into the C-11 Canal and then routed via the C-502B Canal, S-30, and C-9 Canal to the intake for S-509, the inflow pump station for the C-9 Impoundment.

1.4.3 Water Conservation Area 3A/3B Seepage Management Area

The WCA-3A/3B Seepage Management Area (SMA) consists of a relatively long, narrow strip of land that is located between the perimeter levees of WCA-3A and WCA-3B (L-37, L-33 and L-30) and U.S. Highway 27. This area is approximately 11 miles long (north-south orientation) by 0.5 mile wide and covers 4,312 acres of wetlands that have been heavily invaded by exotic vegetation species. The SMA will be surrounded by a perimeter levee, which will allow stages within the SMA to be maintained at a higher elevation than on lands farther east. These higher water stages within the SMA will help limit the seepage of natural system water out of WCA-3A and WCA-3B.

The seepage management area project will include the following elements:

- Culverts S-502B – Gated culverts located on C-502B Canal immediately south of its confluence with the C-11 Canal
- Culverts S-515 – Gated culverts on C-6 (Miami) Canal near junction with U.S. Highway 27

- Structures S-516A/B – Weirs located at confluence of C-502B and C-6, and C-6 and C-503 canals
- FP&L Culverts 1-19 – Ungated culverts along access road for Florida Power & Light (FP&L) transmission line
- B-500 – Bridge across C-502B Canal that provides access to F&PL substation from U.S. Highway 27
- B-501 – Bridge across C-502B Canal that provides access to Holly Lakes Trailer Park from U.S. Highway 27
- Canal 502A (C-502A) – Borrow canal that parallels west side of U.S. 27 from Interstate 75 to C-11 Canal
- Canal 502B (C-502B) – Conveyance and borrow canal that parallels west side of U.S. 27 from C-11 Canal to C-6 (Miami) Canal at S-516A.
- Canal 503 (C-503) – Borrow canal from C-6 Canal at S-516B to intersection with L-30 Borrow Canal
- Levees 502A/B (L-502A/B) – Levees that parallel U.S. Highway 27 and form eastern boundary of seepage management areas
- Levee 503 (L-503) – Levee located south of C-6 Canal that forms balance of eastern SMA boundary
- Holly Lakes Trailer Park Flood Damage Reduction System – Perimeter levee (L-502C), seepage collection canal (C-502C) and seepage control pump station (S-507A)
- Jones Trailer Park Flood Damage Reduction System – Perimeter levee (L-502D), seepage collection canal (C-502D) and seepage control pump station (S-507B)

For operational purposes, the SMA has been divided into two zones. The zone associated with WCA-3A, which is referred to as the 3A SMA (SMA-3A), is located north of the C-11 Canal. Stages within the 3A SMA will be maintained at 7.5 feet NGVD during the wet season and 6.5 feet NGVD during the dry season. Control water levels within the zone south of the C-11 Canal, the 3B SMA (SMA-3B), will be 6.5 feet NGVD during the wet season and 5.5 feet during the dry season. Stages in the L-37 Borrow Canal (SMA-3A) and L-33 Borrow Canal (SMA-3B) will be maintained at the same levels as their respective seepage management areas. The C-502A Borrow Canal and C-502B Conveyance and Borrow Canal will be separated from the body of the SMAs by levees (L-502A and L-502B, respectively). Stages within these canals may be maintained at similar levels as the adjacent SMAs but will also be managed to limit impacts to the adjacent U.S. Highway 27.

1.5 Recommendations of Flood Protection Analysis Study

In the report on the Flood Protection Analysis study, Burns & McDonnell made a number of recommendations for changes in the conceptual design and conceptual operational plans for the Broward County WPA Project. These recommended changes were intended to satisfy one or more of the following goals:

- Identify operational or structural changes to reduce or eliminate the potential flood protection impacts that were identified during the Flood Protection Analysis study
- Identify operational or structural changes to improve conformance with stated design criteria
- Identify such operational or structural changes that might further reduce stormwater pumping from the C-11 West Basin into WCA-3A
- Identify other operational or structural changes that might reduce project costs or at least delay some capital expenditures until future phases of the project are implemented

The recommendations in the Flood Protection Analysis study were made relative to the Selected Plan identified in the document titled *Central and Southern Florida Project, Water Preserve Areas, Draft Integrated Feasibility Report and Supplemental Environmental Impact Statement*, October 2001 (Feasibility Study). As reflected in the more recent Draft PIR/EIS report, some of the elements of the BCWPA Project have been modified or eliminated since publication of the Feasibility Study. Where appropriate, the recommendations from the Flood Protection Analysis study that have been adopted or are no longer applicable are identified below.

1.5.1 Recommended Design Adjustments

The specific design adjustments recommended in the Flood Protection Analysis study are summarized below:

- Conduct more detailed subsurface investigations and seepage analyses to confirm proposed design capacity of 2,575 cfs for S-503 inflow pump station
- Eliminate Siphon Structure S-502 – The S-502 siphon structure is not included in the Selected Plan identified in the Draft PIR/EIS.
- Eliminate Culvert S-502C – This control structure is not included in the Draft PIR/EIS but the existing structure G-86N at this same general location will remain.

- Relocate S-504 spillway to southwest corner of C-11 Impoundment where it would discharge directly to C-11 Canal – The recommended relocation of S-504 is reflected in the Draft PIR/EIS.
- Eliminate Structure S-504A – The relocation of the S-504 spillway makes the original S-504A structure (culverts underneath U.S. Highway 27) unnecessary. However, as discussed in Section 1.4.1 and in the next bullet, the S-504A designation has been reassigned to a proposed Obermeyer-type spillway to be located in the C-11 Canal.
- Add new seepage control facilities along C-11 Canal east of U.S. Highway 27 and west of Structure S-381 – In the Draft PIR/EIS, a new Obermeyer-type spillway (S-504A) has been included in the C-11 Canal immediately east of S-504 to eliminate higher canal stages between S-504 and S-381 during transfers to the C-9 Impoundment. This new spillway should help reduce stages in this canal reach during transfers and thereby reduce potential impacts due to increased seepage south of the C-11 Canal.
- Add new gated spillway, anticipated to be similar in design and capacity to Structure S-381, in the C-11 Canal between its confluence with Canal C-502B and Pump Station S-9.
- Automate Structure S-13A so that is may be remotely monitored and operated – This structure is now automated.
- Delay replacement of Structure S-30 until implementation of the North Lake Belt Storage Area (NLBSA) or Central Lake Belt Storage Area (CLBSA) components of CERP — The Selected Plan described in the Draft PIR/EIS does not include replacement of Structure S-30.
- Automate existing Structure S-30 so that it may be remotely monitored and operated
- Initially construct Canal C-502B for a conveyance capacity of 1,000 cfs between S-30 and C-11 Canal – The design capacity of C–502B is 1,000 cfs in the Draft PIR/EIS.
- Delay enlargement of C-9 Canal east of S-30 until implementation of NLBSA or CLBSA components – The Draft PIR/EIS indicates this canal enlargement is optional (as a potential source of borrow material) until development of the NLBSA.
- Initially construct Spillway S-510 in C-9 Impoundment with capacity of 500 cfs – The Draft PIR/EIS lists the capacity of S-510 as 500 cfs.

1.5.2 Recommended Operational Adjustments

The recommended operational adjustments contained in the Flood Protection Analysis study are summarized below:

- The first destination for C-11 West Basin runoff should be eastward through Structure S-13A. — In the draft project operating manual (Annex D of Draft PIR/EIS), there is no mention of releasing western C-11 Basin runoff to tide at S-13A.
- All C-11 West Basin runoff, in excess of the current conveyance capacity of S-13A, should be pumped into the C-11 Impoundment at S-503.
- When the C-11 Impoundment reaches a stage of roughly 7.0 feet NGVD, operate S-504, S-30 and S-509 to transfer inflow at S-503 to the C-9 Impoundment.
- Continue inflow pumping to C-11 Impoundment and transfers to C-9 Impoundment until either or both reach normal storage depth.
- At C-9 Impoundment, initiate releases to C-9 wetland mitigation area once its stage reaches approximately 7.0 feet NGVD (depth of 2.5 feet). Limit stages in wetland mitigation area to 6.5 feet NGVD. The wetland mitigation area adjacent to the C-9 Impoundment will now be managed by FDOT and has been deleted from the Selected Plan described in the Draft PIR/EIS.
- At C-11 Impoundment, initiate releases to C-11 wetland mitigation area once its stage reaches 9.5 feet NGVD (depth of 3.5 feet). Limit maximum stage in wetland mitigation area to 8.5 feet NGVD.
- Once the C-9 Impoundment reaches normal storage depth (stage 8.5 feet NGVD), discontinue operation of S-509 inflow pump station, and close S-30 and S-504.
- Once the C-11 Impoundment reaches normal storage depth (stage 10.0 feet NGVD), reopen S-504 and release up to 2,000 acre-feet of water to SMA-3A and SMA-3B, exhausting the available storage space in these SMAs. Discontinue operation of S-9A pump station (if any) and resume operation only after water released to SMAs is evacuated.
- When all available storage areas (C-11 Impoundment, C-9 Impoundment, wetland mitigation areas and SMA-3A/3B) are full, initiate operation of S-9 pump station.
- At the earliest opportunity after recession of a runoff event, begin evacuating the water stored in the SMAs, and C-11 and C-9 impoundments by releases to tide via S-13A/S-13 and S-511/S-29.

* * * * *

2 ANALYSIS OF MACTEC ENGINEERING & CONSULTING STUDY

MACTEC Engineering & Consulting, Inc. (MACTEC) developed and evaluated design alternatives to enhance the stormwater treatment potential of the C-11 Impoundment in 2003 and 2004 under SFWMD Contract No. C-15982-WO06-05. These design alternatives and their evaluations are documented in the following MACTEC final reports:

- *Evaluation of Stormwater Treatment Potential of the Western C-11 Impoundment, Task 2: Alternatives Formulation Report*, December 2003

- *Evaluation of Stormwater Treatment Potential of the Western C-11 Impoundment, Task 4: Alternatives Evaluation Report*, March 2004

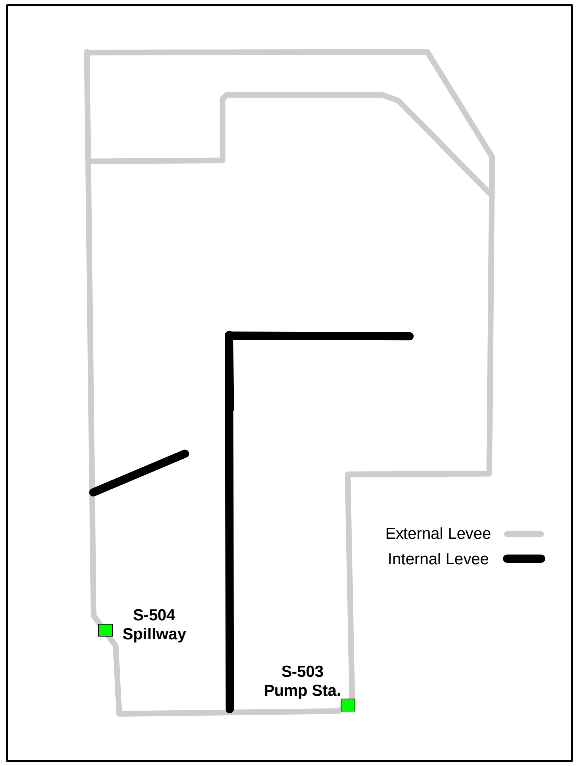
In these two documents, MACTEC presents two alternative modifications to the internal design of the Western C-11 Impoundment that would maximize the hydraulic retention time of the impoundment and thus, would maximize the removal of pollutants within the impoundment before this stormwater is returned to the C-11 West Canal downstream (west) of the Structure S-381. At the time MACTEC prepared these documents, the base design for the Western C-11 Impoundment was as presented in the October 2001 *Central and Southern Florida Project, Water Preserve Areas Feasibility Study, Draft Integrated Feasibility Report and Supplemental Environmental Impact Statement*, prepared by the Jacksonville District, U.S. Army Corps of Engineers and the SFWMD. As described previously in Section 1.5, Burns & McDonnell has recommended certain modifications to the design and operation of this impoundment in its Flood Protection Analysis study and many of these recommendations have now been incorporated into the Selected Plan presented in the Draft PIR/EIS for the Broward County WPA project. In light of these changes, the District has contracted with Burns & McDonnell to provide an assessment that reexamines the alternatives presented in the MACTEC reports.

2.1 Description of Alternatives

The two alternatives formulated for evaluation under the MACTEC contract consisted of constructing internal berms or levees within the C-11 Impoundment to route stormwater and prevent short-circuiting to the outfall. The following description of the two alternatives is generally taken from MACTEC's Task 2: Alternatives Formulation Report.

2.1.1 MACTEC Alternative 1

Figure 2.1: MACTEC Alternative 1

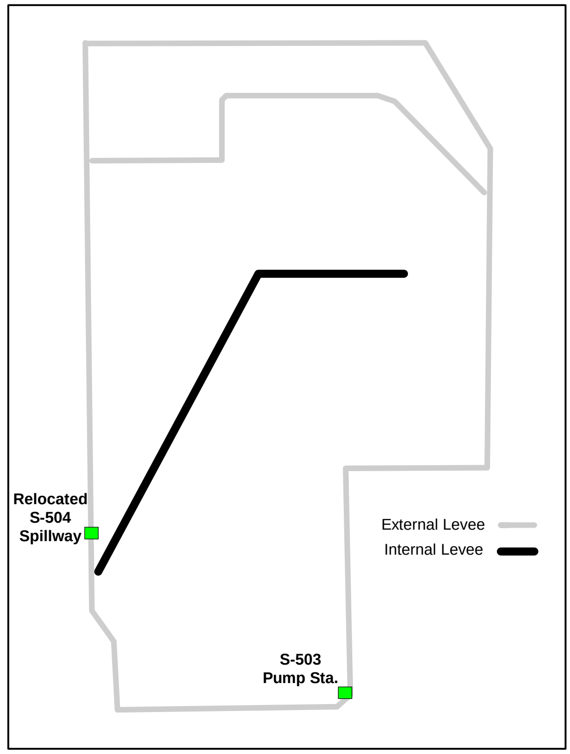


Alternative 1 consists of an internal levee placed along the north-south axis of the impoundment. This internal levee would extend from the exterior southern levee northward approximately 6,880 feet. An additional levee would extend from the northern end of the first levee approximately 3,300 feet eastward forming an L-shaped internal levee. The general configuration of this internal levee is shown in Figure 2.1. Two to three fish refuge basins would be constructed within the impoundment to provide habitat for fish during dry periods. In addition to the main internal levee, one additional secondary (fetch-reduction) levee would be placed near the north-south midway point on the west side of the impoundment to provide a point for dissipation of energy resulting from wave action. This secondary levee was intended to reduce the overall fetch length in the impoundment and allows waves to dissipate, reducing the potential erosion. The fetch reduction levee would be placed approximately perpendicular to the axis of the longest fetch length (to the south-southeast) and would extend from the western wall of the impoundment approximately 2,000 feet to the east-northeast at a three-to-one angle. For Alternative 1, the influent and effluent structures (Pumping Station S-503 and Spillway Structure S-504, respectively) would remain in the southeast and southwest corners of the impoundment as shown in the Feasibility Study. An approximate 1,600-foot long revetment would be added along the east side of the internal central levee to provide erosion protection from influent flow. Additional revetments would be added at interior and exterior corners and at the termination points of the internal levees.

2.1.2 MACTEC Alternative 2

Alternative 2 would consist of a 5,700-foot long internal levee extending from the western wall of the impoundment approximately 3,000 feet north of the southern end to the northeast at an angle of 1.2 to 1 (to a point approximately 3,800 feet from the western wall of the impoundment). At that point, the levee would bend, and extend an additional 2,400 feet to the east. The general configuration of this internal levee is shown in Figure 2.2. Two fish refuge pools would be placed within the impoundment to protect fish during extended dry periods. Those refuges would be placed along the southern end of the impoundment and near the location of the outfall structure. The impoundment inflow structure (S-503) would remain in the southeasterly corner of the impoundment as shown in the Feasibility Study. The impoundment outfall structure (S-504) would be relocated approximately 2,200 feet northward of the location (on the southwestern edge of the impoundment) indicated in the Feasibility Study. Revetments for erosion protection would be provided at the interior and exterior of the internal levee “corner”, and where the internal levee would intersect the western wall of the impoundment.

Figure 2.2: MACTEC Alternative 2



As discussed in MACTEC’s Task 4: Alternatives Evaluation Report, both Alternative 1 and Alternative 2 were subsequently modified to add a sump near the outfall to provide a sediment trap.

2.2 Summary of MACTEC Evaluation of Alternatives

The following summary evaluation of Alternatives 1 and 2 is generally taken from MACTEC’s Task 4: Alternatives Evaluation Report.

Review of the phosphorus removal performance of each alternative using three design storms indicated little difference in the removal efficiency of the two alternatives. For the design storms the flow weighted average removal was relatively low (3.4 to 5.2 percent). However, during low-flow events, removal was estimated to be as high as 52.8 percent. Given those results, MACTEC concluded that, for low-flow conditions, the use of an internal levee may substantially increase phosphorus removal. MACTEC’s review of the potential environmental impacts of each alternative indicated little difference between the two designs and no significant additional impacts over the base design of the impoundment as it was presented in the Feasibility Study. The main differences noted were an increase in shallow water habitat from the longer levee design for Alternative 1 and the loss of approximately one acre of wetland along the C-502A canal for Alternative 2.

The major difference between Alternative 1 and 2 was presented in the opinion of costs. The 50-year present worth of Alternative 1 was estimated at $9.23 million; the capital cost of Alternative 1 was estimated at $6.68 million. The 50-year present worth of Alternative 2 was estimated at $8.15 million; the capital cost of Alternative 2 was estimated at $5.75 million. The difference in cost was attributed principally to the longer length of levee for Alternative 1.

MACTEC's penultimate conclusion was that, based on the information presented, Alternative 2 may be the more cost-effective of the two alternatives and could provide significant phosphorus removal under low flow conditions.

2.3 Significant Assumptions Used in MACTEC Analysis

The evaluation of alternatives presented in MACTEC's Task 4: Alternatives Evaluation Report proceeded employing the following significant assumptions:

- Phosphorus removal estimates were based on simulations of three separate storm events (October 1967, July 1985, and November 1984). Mean daily inflows and total phosphorus concentrations were based on data furnished by the District. These design storm events had the following characteristics:
    - Each of the three modeled events had a storm inflow duration of 9 days
    - Mean daily flow rates varied from 3.1 cfs to 2,126.8 cfs
    - Total phosphorus concentrations in impoundment daily inflows varied from 13 parts per billion (ppb) to 33.2 ppb; the flow-weighted mean inflow concentrations during the three storms varied from 18.4 to 26.1 ppb.

- For each alternative, the impoundment was modeled as five subareas in series (the fifth, or most downstream, subarea was eventually modeled as three subareas in series to reflect the presence of the sump added to each alternative)

- The impoundment was considered full (that is, the impoundment depth was assigned at four feet throughout each simulation)

- Daily outflow to each of the subareas was assigned equal to the daily inflow

- The ratio of orthophosphorus to total phosphorus was assigned as 0.3 throughout the simulations

- The analysis assumed the impoundment as an "open water" system (that is, no consideration was given to the potential influence of vegetation on phosphorus reduction in the impoundment).

The simulations were reported to be based on an analytical methodology presented in Phosphorus Removal by Urban Runoff Detention Basins; Lake and Reservoir Management: Volume III; William W. Walker, Jr.; 1987. The analysis progressed along a daily time step; the daily outflow from each subarea was taken as the daily inflow to the next downstream subarea.

2.4 Evaluation of Significant Assumptions and Results

It is not clear that the methodology presented in the Walker paper is applicable to analyses on a time step as short as one day; the methodology appears to have been developed with an eye to long-term average phosphorus removal efficiency, employing seasonal or longer-term inflows, outflows, and impoundment characteristics. In addition, the assumption of seven subareas in series, each considered as a continuously stirred tank reactor without back-mixing, suggests the analysis closely approached that which would result from a plug-flow analysis. The net effect of those factors, taken in combination, would suggest that the simulations would result in a favorable projection of overall phosphorus removal.

Nonetheless, the results of the simulations presented in the MACTEC final report suggest that, for the three nine-day events each taken as a whole, flow-weighted phosphorus removal ranged from 2.9 percent to 4.2 percent. From that, it may be readily concluded that little phosphorus removal would be projected under any inflow event resulting from a storm of sufficient magnitude as to trigger operation of Pumping Station S-9. The reduction in event-total flow-weighted mean total phosphorus concentration in the MACTEC analysis can be generally characterized as less than 1 ppb. For inflow rates equal to the nominal capacity of inflow pumping station S-503 (2,500 cfs), the MACTEC simulations suggest total phosphorus reductions of less than 0.5 ppb.

The assumption of a four-foot depth throughout any given event would appear reasonable for those periods in which operation of Pumping Station S-9 would be necessary (all operational criteria considered in the design of the C-11 Impoundment contemplates that the impoundment would be full prior to any discharge of C-11 West Basin runoff through S-9).

The assumption of an "open water" system (that is, little vegetative contribution to phosphorus removal) would also be considered consistent with the project operation contemplated in long-term simulations conducted in development of the Feasibility Study. In those simulations, the C-11 Impoundment was held at or near its maximum storage depth of four feet for extended periods of time. The hydropattern resulting from those earlier simulations would have effectively prevented the development of emergent vegetation. It is possible that submerged aquatic vegetation might have developed under those conditions, although a maintained depth of four feet could be expected to effectively limit light penetration. In all likelihood, impoundment vegetation under those conditions would have consisted primarily of floating aquatic plants and photoplankton.

Under Alternative 1, the flow paths through the impoundment can be characterized as roughly 2,400 feet in width. At a depth of four feet and a maximum flow rate of 2,500 cfs, the average cross-sectional velocity in the impoundment would be computed as roughly 0.3 feet per second (fps). Floating or suspended vegetative matter within the impoundment could be mobilized under such velocities, which would result in solids handling and potentially elevated total phosphorus concentrations at the outfall structure (S-504). That concern is much more pronounced for Alternative 2, which further concentrates the flow as it approaches the impoundment outflow structure.

2.5 Influence of Subsequent Changes to Project Design and Operation

Subsequent to the completion of MACTEC's Task 4: Alternatives Evaluation Report, numerous modifications have been made to the basic arrangement and intended operation of the C-11 Impoundment. With respect to basic arrangement, the outflow control structure S-504 has been relocated to the south line of the impoundment (Figure 1.2), discharging directly to the C-11 West Canal west of Structure S-381. This relocation eliminates the need for Structure S-504A (culverts beneath U.S. Highway 27) and construction of Canal C-502A north of the C-11 West Canal. Further consideration of Alternative 2 would require the relocation of S-504 back to the west line of the impoundment; restitution of Structure S-504A to the project; and construction of Canal C-502A between the relocated S-504 and the C-11 West Canal. The restitution of those two project elements would further increase the cost of Alternative 2. Although no specific estimate of those costs has been prepared, the cost for construction of new culverts having a design capacity of 2,500 cfs beneath U.S. Highway 27 (S-504A) would clearly exceed the estimated cost differential of roughly $1 million between Alternatives 1 and 2, making the estimated cost of Alternative 2 greater than that for Alternative 1.

Given no significant difference in anticipated phosphorus removal performance for the two alternatives; an increased concern for mobilization and transport of floating and suspended vegetative matter under Alternative 2; and a greater estimated cost for Alternative 2, it is concluded that Alternative 2 may be removed from further consideration.

Modifications to the intended project operation developed subsequent to publication of the 2001 Feasibility Study can be expected to substantively modify the hydropattern in the impoundment. It is probable that, under that modified hydropattern, rooted macrophytic vegetation (both emergent and nonemergent) can be expected to colonize the impoundment. While such a development might be expected to increase the phosphorus removal performance of the impoundment, the cross-sectional velocities under Alternative 1 would greatly exceed the 0.1 fps limiting velocity applied in the design of the various stormwater treatment areas of the Everglades Construction Project. Under high rates of inflow, it could be anticipated that loose flocculant material on the floor of the impoundment would be mobilized and transported to the impoundment outlet, potentially increasing outflow total phosphorus concentrations as compared to inflow concentrations. Even if the full width of the impoundment were employed in the flow path (that is, elimination of the central internal levee suggested in Alternative 1), the mean cross-sectional velocity through the impoundment under the maximum design inflow of 2,500 cfs would, given a depth of four feet, exceed the maximum velocity criteria for stormwater treatment area design.

2.6 Summary of Principal Conclusions

Given the above discussion, it is concluded that:

1. Projected phosphorus reduction in the impoundment would, particularly under high rates of inflow, be nominal at best under either of the alternatives considered in the MACTEC analysis.

2. It is considered likely that outflow concentrations under high rates of inflow would actually be elevated above inflow concentrations due to mobilization and transport of vegetative material for either of the alternatives considered.

3. Incremental project expenditures associated with the construction and operation of additional project features under either of the two alternatives considered would not appear to be cost-effective, given little or no benefit in phosphorous reduction.

4. The basic footprint of the reservoir, when considered in combination with the anticipated high rates of inflow, effectively prevents the development of a vegetative community capable of increasing phosphorous reduction due to excessive velocities.

All the above suggest that the most effective strategy for reducing phosphorous discharges at S-9 will consist of minimizing S-9 discharge volumes in lieu of attempting phosphorus reduction in the C-11 Impoundment. It is that strategy that is embodied in the suggestions made in the February 2006 Flood Protection Analysis for Broward County Water Preserve Areas, C 11 and C 9 Impoundments (Final Report), and further developed in Part 3 of this document.

2.7 Design Criteria for Internal Impoundment Velocities

While neither of the proposed MACTEC alternatives are recommended for development, some of the concerns expressed above about excessive internal velocities would also apply to the current design for the C-11 Impoundment, as described in the Draft PIR/EIS. The following velocity limits should be incorporated into the design criteria for this impoundment:

2.7.1 Flow-through Velocity Limits

At times, the C-11 Impoundment will experience significant flow-through discharges. That is, periods when most or all of the current inflow at Pump Station S-503 is immediately discharged back to the C-11 Canal (west of the S-381 and S-504A spillways) at the S-504 spillway. The bulk of these flow-through discharges would tend to short-circuit directly from inlet to outlet and stay concentrated in the extreme southern end of the impoundment. In this same area, there are proposed borrow and fish refuges areas. These borrow/fish refuge areas should be sized so as to limit velocities in these flow-through discharges. In order to reduce the potential for erosion, a maximum velocity of 2 fps is recommended; however, to limit the potential for fish to be swept out of the impoundment, a maximum velocity of 0.5 fps or less is recommended.

There are two design conditions for excessive flow-through velocities. The first design condition would be when the impoundment stage is at its minimum level for releases (7.0 feet NGVD) and flow-through discharges are at the maximum rate for transfers to the C-9 Basin (1,000 cfs). The second design condition would occur when the impoundment is full (stage 10 feet NGVD) and all flow-through discharges at being routed to S-9. Under these conditions, flow-through discharges could be as high as 2,500 cfs, the design capacity of the S-503 pump station. For either of these design conditions, the borrow/fish refuge areas should be configured so as to provide sufficient flow area to limit velocities to 0.5 fps.

2.7.2 Drawdown Velocity Limits

A third design condition would apply when the C-11 Impoundment is being drawn down. Draw downs could occur when the water stored in the impoundment is being evacuated to tide or during transfers to the C-9 Basin. As discussed above, internal velocities within the marsh portion of the impoundment — bulk of the impoundment north of the borrow/fish refuge areas — should be limited to 0.1 fps to reduce the potential for resuspension of vegetative material. The maximum draw down rate would be 1,000 cfs, the design rate for interbasin transfers, and maximum internal velocities would occur at minimum stages (7.0 feet NGVD). If internal marsh velocities at low stages exceed 0.1 fps, then drawdown discharge rates should be limited under these conditions.

* * * * *

3 SIMULATION MODEL

A hydrologic simulation model for the Broward County WPA Project was developed to extend the analyses contained in the latest South Florida Water Management Model (SFWMM) for this region. The results of this SFWMM run are summarized below, followed by a description of the simulation model developed for this project.

3.1 SFWMM Results

The latest SFWMM run available for use in this study is Version 5.4.3.1, dated November 3, 2005. Electronic files containing the simulation results from this SFWMM run were provided by the District. A summary of the SFWMM operating results, which are pertinent to the Broward County WPA Project, is presented below.

3.1.1 C-11 Basin

There are five principal control structures on the C-11 Canal at present: S-13 pump station and spillway; S-13A culverts; S-381 spillway; and S-9 and S-9A pump stations. The SFWMM-simulated flow at these structures is summarized in Table 3.1. This table lists the average, minimum and maximum flows on both a daily and annual basis. Also listed in this table are estimates of the net basin runoff from the eastern and western portions of the C-11 Basin.

Review of this table shows that C-11 West Basin runoff averages 106.9 cfs or 77,459 acre-feet per year (AF/yr). In the SFWMM simulation, an average of only 6.9 cfs, or 5,034 AF/yr of this runoff is discharged into the eastern portion of the basin at S-13A. One of the recommendations of the Flood Protection Analysis study was to maximize these eastward discharges. A small amount of this runoff is discharged westward at S-381 but the majority of the C-11 West Basin runoff is discharged to the proposed C-11 Impoundment through its inflow pump station, S-503.

Based on estimates received from SFWMD, the discharge to WCA-3A at the S-9/S-9A complex has been segregated by source. As shown in Table 3.1, approximately one quarter of the discharge to WCA-3A is estimated to be C-11 Basin runoff (23,760 AF/yr average) and the balance is seepage from the WCA and runoff from the seepage management areas (73,079 AF/yr average). This WCA seepage and seepage management area runoff are considered to be of relatively good quality but C-11 Basin runoff is runoff from urban areas that may not meet the applicable water quality standards. Reducing the contribution of C-11 Basin runoff in S-9/S-9A discharge is one of the primary goals of the Broward County WPA Project.

Table 3.1: SFWMM Simulation Results for C-11 Basin[a]

Structure or Flow Component	Daily Flow Data (cfs)			Calendar Year Flow Data (acre-feet)		
	Avg. Day	Min. Day	Max. Day	Avg. Year	Min. Year	Max. Year
S-13 Pump Station[b]	97.7	0.0	1,020.4	70,756	31,793	108,454
S-13A Culverts[c]	6.9	0.0	374.4	5,034	0	21,243
S-381 Spillway[d]	0.3	0.0	1,252.7	186	0	3,957
S-9/S-9A Pump Sta						
C-11 Runoff[e]	32.8	0.0	1,436.7	23,760	2,099	48,529
WCA Seepage[e]	100.9	0.0	1,152.6	73,079	41,615	116,480
Total[f]	133.4	23.6	1,858.9	96,678	43,630	154,511
Net Basin Runoff[g]						
East Basin[h]	90.7	0.0	1,020.4	65,722	31,793	94,049
West Basin[i]	106.9	0.0	2,226.3	77,453	26,693	127,753
Total[j]	197.6	0.0	2,798.1	143,176	63,099	221,802

a. SFWMM version 5.4.3.1 for 2010 Conditions with period of simulation of 1/1/1965–12/31/2000.
b. Flow term S13.
c. Flow term S13A.
d. Sum of flow terms S381 and S381BK.
e. From District estimates of flow contribution at S-9 and S-9A. WCA seepage component includes actual seepage plus runoff from the 3A and 3B SMAs.
f. Sum of flow terms S9 and S9A.
g. Net basin runoff is total runoff less coincident water supply withdrawals.
h. Calculated from flow terms S13 - S13A.
i. Calculated from flow terms S13A + S381 + S381BK + C11RIN.
j. Calculated from flow terms S13 + S381 + S381BK + C11RIN.

Similar summary data for the proposed C-11 Impoundment are included in Table 3.2. The principal simulated inflow to the C-11 Impoundment is from C-11 West basin runoff, which accounts for approximately 84 percent of its inflow. The other inflow comes from direct precipitation (7 percent) and groundwater inflow (10 percent). Impoundment outflow is apportioned as follows: 61 percent to the C-11 Canal at S-504, 7 percent to evapotranspiration (ET), and 31 percent to seepage (discharge to groundwater).

The C-11 Impoundment has an average ground surface elevation of 6.0 feet NGVD and a normal (full) stage of 10.0 feet NGVD, for a total storage depth of 4.0 feet. As listed in Table 3.2, the average impoundment stage from the SFWMM simulation is 8.68 feet, which is equivalent to an average depth of 2.68 feet. Compared to its total storage depth, the simulated storage contents in

Table 3.2: SFWMM Simulation Results for C-11 Impoundment[a]

Structure or Flow Component	Daily Data (cfs[b])			Calendar Year Data (acre-feet[b])		
	Avg. Day	Min. Day	Max. Day	Avg. Year	Min. Year	Max. Year
Inflow						
S-503 Pump Sta[c]	99.7	0.0	1,719.8	72,233	25,050	112,507
Rainfall						
Depth (inches)	0.13	0.00	7.88	47.86	31.05	71.18
Volume	8.2	0.0	493.3	5,943	3,855	8,838
Groundwater	11.4	0.0	24.4	8,259	4,930	13,629
Outflow						
S-504 Spillway[d]	73.0	0.0	695.7	52,904	6,372	96,837
Evapotranspiration						
Depth (inches)	0.14	0.05	0.23	51.78	48.87	54.88
Volume	8.9	3.1	14.4	6,430	6,068	6,814
Groundwater	37.0	7.3	59.4	26,825	19,606	31,877
Stage (feet NGVD)	8.68	4.41	10.01	8.68	7.19	9.57

a. SFWMM version 5.4.3.1 for 2010 Conditions with period of simulation of 1/1/1965–12/31/2000.
b. Units for daily and annual data are respectively cfs and acre-feet unless noted otherwise.
c. Inflow from C-11 Canal at S-503 pump station (flow term C11RIN).
d. Discharge to C-11 Canal at S-504 spillway (flow term C11RO).

this impoundment average about two-thirds full. The minimum impoundment stage (4.41 feet) is more than 1.5 feet below average ground surface.

3.1.2 C-9 Basin

At present, there are only two primary control structures on the C-9 Canal: the S-29 spillway and S-30 culverts. The simulated discharge from these structures and C-9 Basin runoff are summarized in Table 3.3. As shown in this table, discharge to tide at S-29 averages nearly 300 cfs but the discharge at S-30 is only a little more than 3 cfs. Readers should note that the S30 flow term in SFWMM does not include the transfers from the C-11 Impoundment to C-9 Basin that would actually pass through these culverts into the C-9 Canal. However, the net runoff listed in Table 3.3 does exclude discharges from the C-9 Impoundment at S-510. These impoundment discharges are comprised primarily of C-11 Basin runoff transferred from the C-11 Impoundment.

Table 3.3: SFWMM Simulation Results for C-9 Basin[a]

Structure or Flow Component	Daily Flow Data (cfs)			Calendar Year Flow Data (acre-feet)		
	Avg. Day	Min. Day	Max. Day	Avg. Year	Min. Year	Max. Year
S-29 Spillway[b]	296.6	0.0	2,208.2	214,873	71,530	329,829
S-30 Culverts[c]	3.2	0.0	107.2	2,298	0	12,536
Net Basin Runoff[d]	241.5	-130.5	2,208.2	174,988	65,918	262,832

a. SFWMM version 5.4.3.1 for 2010 Conditions with period of simulation of 1/1/1965–12/31/2000.
b. Flow term S29.
c. Flow term S30.
d. Net basin runoff is total runoff less coincident water supply withdrawals and is calculated as S29 – S30 – C9RTC9.

A summary of the operating results for the C-9 Impoundment is contained in Table 3.4. The principal simulated inflow to the C-9 Impoundment is transfers from the C-11 Impoundment, which accounts for approximately 83 percent of its inflow. The other inflow comes from direct precipitation (11 percent) and groundwater inflow (6 percent). Impoundment outflow is apportioned as follows: 58 percent to the C-9 Canal at S-510, 10 percent to evapotranspiration (ET), and 32 percent to seepage (discharge to groundwater).

Table 3.4: SFWMM Simulation Results for C-9 Impoundment[a]

Structure or Flow Component	Daily Data (cfs[b])			Calendar Year Data (acre-feet[b])		
	Avg. Day	Min. Day	Max. Day	Avg. Year	Min. Year	Max. Year
Inflow						
S-509 Pump Sta[c]	73.8	0.0	1,000.0	53,452	0	97,274
Rainfall						
Depth (inches)	0.14	0.00	4.93	52.76	35.70	71.44
Volume	10.0	0.0	341.8	7,255	4,909	9,823
Groundwater	5.4	0.0	15.4	3,897	3,352	4,720
Outflow						
S-510 Spillway[d]	51.9	0.0	100.0	37,586	313	66,998
Evapotranspiration						
Depth (inches)	0.13	0.05	0.23	48.90	44.19	54.27
Volume	9.3	3.5	15.9	6,724	6,076	7,462
Groundwater	28.2	1.1	67.0	20,420	6,682	35,000
Stage (feet NGVD)	5.46	2.14	9.04	5.46	3.50	7.51

a. SFWMM version 5.4.3.1 for 2010 Conditions with period of simulation of 1/1/1965–12/31/2000.
b. Units for daily and annual data are respectively cfs and acre-feet unless noted otherwise.
c. Inflow from C-9 Canal at S-509 pump station (flow term C9RC11). All modeled impoundment inflow comes from C-11 Basin.
d. Discharge to C-9 Canal at S-510 spillway (flow terms C9RTC9 + C9RWS).

The C-9 Impoundment has an average ground surface elevation of 4.5 feet NGVD and a normal (full) stage of 8.5 feet NGVD, for a total storage depth of 4.0 feet. As listed in Table 3.4, the average impoundment stage is 5.46 feet, which is equivalent to an average depth of 0.96 feet. Compared to its total storage depth, the simulated storage in this impoundment averages about one quarter full.

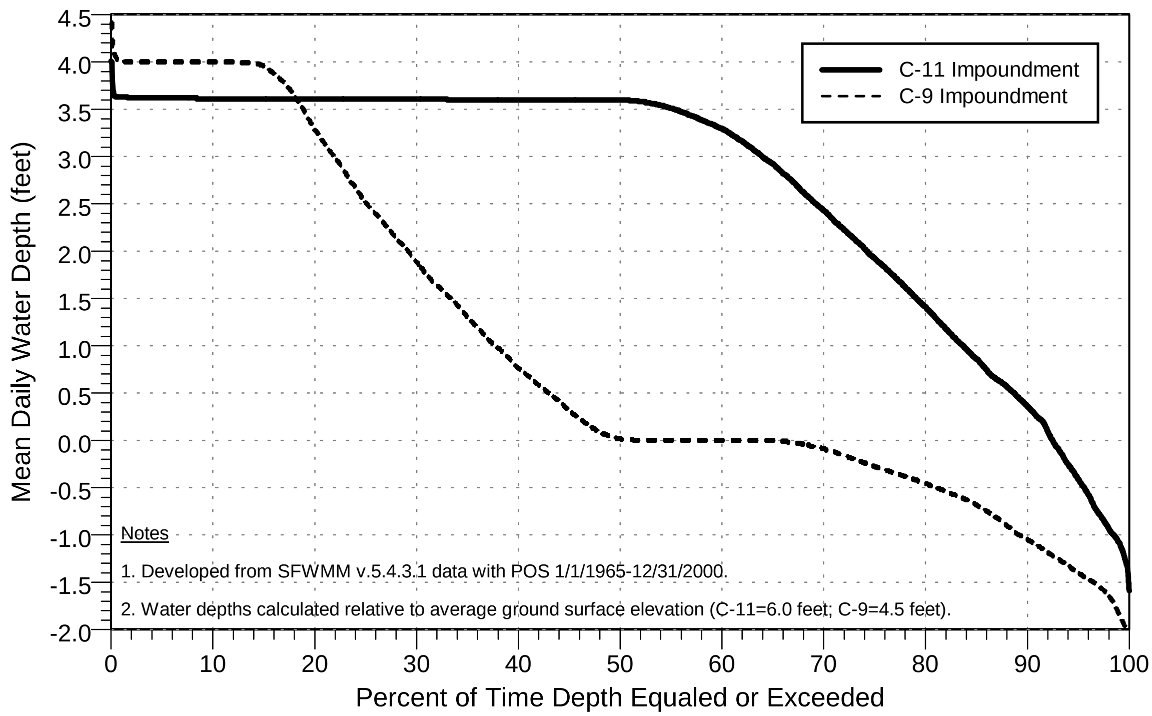
3.1.3 Observations from Review of SFWMM Results

From review of the SFWMM modeling results, the following conditions were observed:

- Virtually all C-11 West Basin runoff is pumped into the C-11 Impoundment and little is released to tide via S-13A and S-13.
- The C-11 Impoundment is maintained in a relatively full state.
- Most C-11 Impoundment discharge is conveyed to the C-9 Impoundment.
- Storage depths in the C-9 Impoundment average less than one foot, which indicates this impoundment is drawn down as soon as practicable.
- C-9 Impoundment discharge is released to tide at S-29.

Figure 3.1 contains depth duration curves for the C-11 and C-9 impoundments. These curves clearly show that the C-11 Impoundment is typically maintained at a greater depth than the C-9 Impoundment in the SFWMM simulation. The C-11 Impoundment is kept nearly full (depth greater than 3.6 feet) about 50 percent of the time while the C-9 Impoundment is full only 15 percent of the time and empty (depth zero or less) half of the time. It would not appear that the C-11 Impoundment is kept full much of the time because of limited conveyance capacity for transfers to the C-9 Impoundment or because the C-9 Impoundment is typically full already. As shown in Table 3.4, transfers between the C-11 and C-9 impoundments average only 73.8 cfs and exceeded 500 cfs (50 percent of design capacity) on only 121 days during the POS (0.9 percent of the time).

Figure 3.1: SFWMM Depth Durations for C-11 and C-9 Impoundment



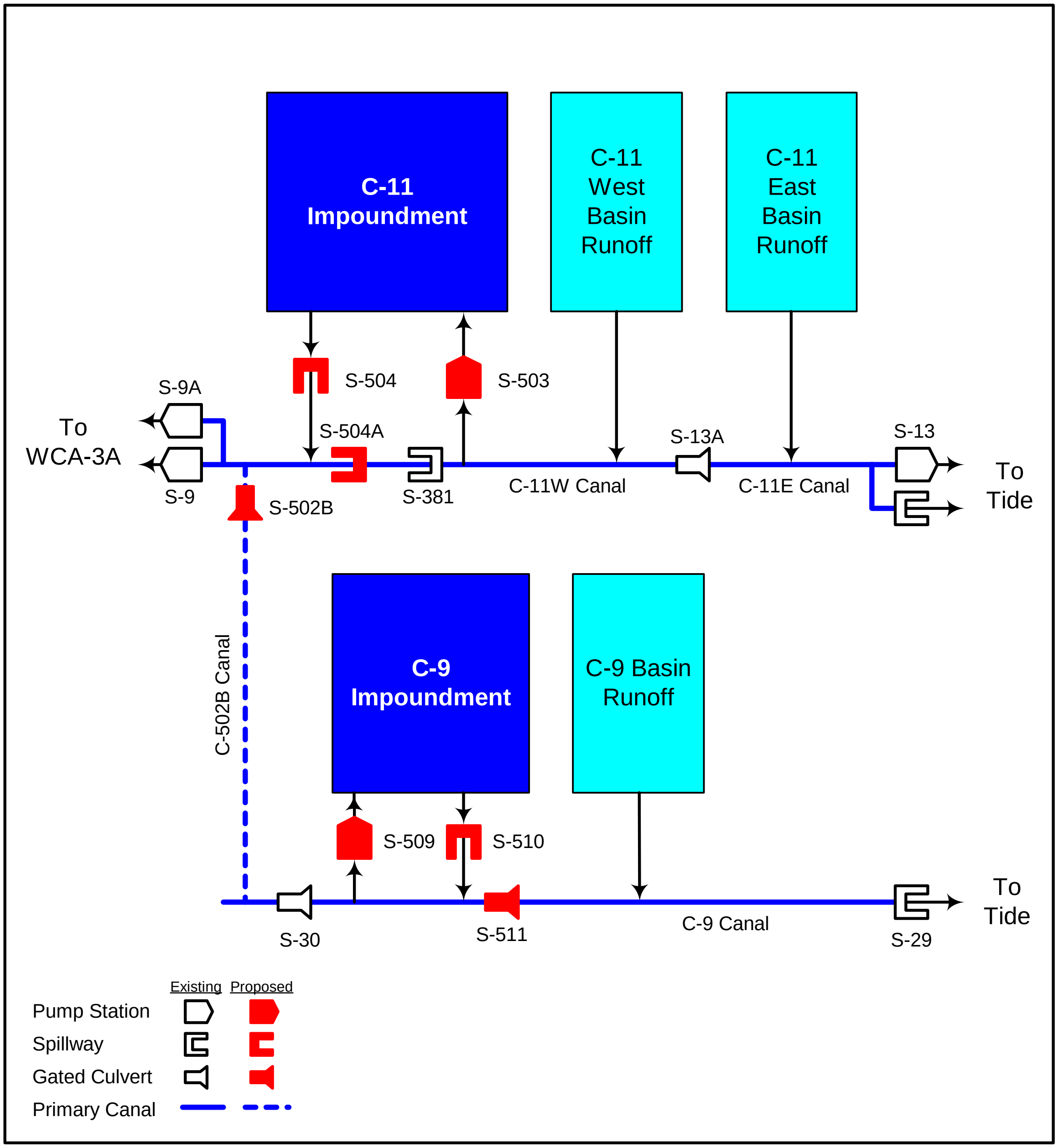
3.2 Simulation Model Protocol

As stated previously in the Introduction, the SFWMM run described above implements some, but not all, of the operations enhancements recommended in the Flood Protection Analysis study (Section 1.5.2). In an effort to more fully assess the impact of these recommendations, Burns & McDonnell has developed a new simulation model for the Broward County WPA Project area (BCWPA model), which implements all of these recommendations to the extent practicable. Figure 3.2 is a schematic of this model, which shows the relationships between the major canals, control structures and other flow components included in the model. The methods and assumptions built into the BCWPA model are described below.

3.2.1 Model Limitations

Before introducing the specifics of the BCWPA model, it is important to note some of the limitations of this modeling approach. The BCWPA model resimulates the operation of the C-11 and C-9 impoundments and related project features, using the modeling results from the SFWMM run as input data. Unlike the SFWMM, this post-processing model does not simulate the interactions between surface water and groundwater, canal stages, or the relationships between flow conditions within the project area and those throughout the District's integrated water management system. Specifically, there will be some error in the following data:

Figure 3.2: BCWPA Model Schematic



- Basin Runoff – The BCWPA model modifies discharges in the C-11 and C-9 Canals from the flows reported in the SFWMM data. These changes in flow rates will in turn have an impact on canal stages, groundwater levels and basin runoff rates.
- Impoundment Groundwater Budgets – The net seepage from the C-11 and C-9 impoundments is directly related to impoundment stage and these daily stages will also be recalculated in the BCWPA model. Initially, the SFWMM-generated groundwater budgets were used in

the BCWPA model without modification but this assumption proved to yield unrealistic results so these budgets were adjusted using simple regression procedures.

- WCA Water Budgets – Changes in pump station operation, and canal and impoundment stages can also impact the amount of discharge to and seepage from the water conservation areas.

3.2.2 C-11 West Basin Runoff

Daily C-11 West Basin runoff was quantified from the available SFWMM data as the sum of the following flow terms:

- C11RIN — Inflow to C-11 Impoundment from C-11 West Canal at S-503 pump station
- S13A – Discharge from C-11 West Basin to east at Structure S-13A
- S381 – Westward discharge in C-11 West Canal at S-381 spillway

The primary focus of the BCWPA project is to eliminate, to the extent practicable, the discharge of C-11 West Basin runoff to WCA-3A at Pump Station S-9. To accomplish this goal, this basin runoff is conveyed as described below by the BCWPA model.

- Step 1 –The preferred destination for C-11 West Basin runoff is east through the S-13A culverts. These discharges at S-13A continue eastward via the C-11 East Canal and S-13 pump station/spillway to tide. The maximum discharge rate at S-13A is limited by the available conveyance capacity of S-13A, the C-11 East Canal and S-13. The procedure used to determine this discharge limit is described in Section 3.2.3 below.

- Step 2 – All C-11 West Basin runoff that cannot be conveyed directly eastward through S-13A (Step 1) is delivered to the C-11 Impoundment via its inflow pump station (S-503). These deliveries are limited only by the net capacity of the S-503 pump station [2,500 cubic feet per second (cfs)]. This inflow rate limitation, and the other modeling assumptions specific to the C-11 Impoundment, are discussed further in Section 3.2.5 below.

- Step 3 – Any remaining basin runoff that cannot be discharged eastward at S-13A or delivered to the C-11 Impoundment (Steps 1 and 2) must be discharged directly to WCA-3A via the S-381 spillway and S-9/S-9A pump station.

Steps 1 through 3 determine the initial distribution of runoff from the western C-11 drainage basin. The remaining steps in this model protocol (Steps 4 through 8) deal with the management of those runoff volumes that are initially delivered to the C-11 Impoundment in Step 2.

- Step 4 – When the current stage in the C-11 Impoundment is less than 7.0 feet NGVD (average depth 1.0 foot), the basin runoff delivered to this impoundment (Step 2) is stored until its stage rises to 7.0 feet NGVD. At that time, all additional deliveries to this impoundment are conveyed southward to the C-9 Basin, subject to the limits described below. These southward deliveries are routed as follows:

    - Through S-504 spillway to C-11 West Canal
    - Via C-11 West and proposed C-502B canals to S-30
    - Eastward through S-30 culverts into C-9 Canal west of S-511

    During transfers from the C-11 Impoundment to C-9 Basin, the return of WCA-3A/3B seepage (and runoff from SMA-3A/3B) at Pump Station S-9A is discontinued to prevent the direct transfer of C-11 West Basin runoff to WCA-3A. This shutdown at S-9A is necessary because no control structure is planned for the C-11 Canal between its confluence with the C-502B Canal and the S-9 and S-9A pump stations. While the S-9A pump station is shut down, southward transfers include both WCA seepage/runoff and C-11 Impoundment releases. The affected seepage volumes are calculated as the total SFWMM-simulated discharge at Pump Stations S-9 and S-9A less that portion of these discharges that is attributed to C-11 Basin runoff. Another component of these interbasin transfers is the existing simulated eastward discharge at S-30.

    The maximum delivery rate for these combined transfers to the C-9 Basin is 1,000 cfs, the initial design capacity of S-509 (inflow pump station for C-9 Impoundment) and C-502B Conveyance Canal. This delivery limit of 1,000 cfs is also assigned to Structure S-30 (see Section 6.3.6 of Flood Protection Analysis study). The maximum delivery rate to the C-9 Basin may be further limited as discussed in Step 6 below.

- Step 5 – C-11 West Basin runoff and WCA seepage/runoff that is delivered to the C-9 Basin (Step 4) is first conveyed directly to tide via the proposed S-511 culverts and existing S-29 spillway, up to the available conveyance capacity of these structures and the C-9 Canal. The procedure used to determine this discharge limit is described in Section 3.2.4 below.

- Step 6 – C-9 Basin imports that cannot be delivered directly to tide (Step 5) are discharged to the C-9 Impoundment as long as there is available storage space in this impoundment. Should desired C-9 Basin imports (Step 4) exceed the current basin import capacity (available conveyance capacity of C-9 Canal at S-511 plus storage capacity in C-9 Impoundment), C-9 Basin imports are further limited to the current import capacity. The modeling assumptions specific to the C-9 Impoundment are discussed in Section 3.2.6 below.

- Step 7 – When the current inflow rate to the C-11 Impoundment (Step 2) exceeds the available transfer capacity to the C-9 Basin (Step 4), then these excess inflows are stored in this impoundment until such time as the C-11 Impoundment reaches its normal pool elevation (10.0 feet NGVD).

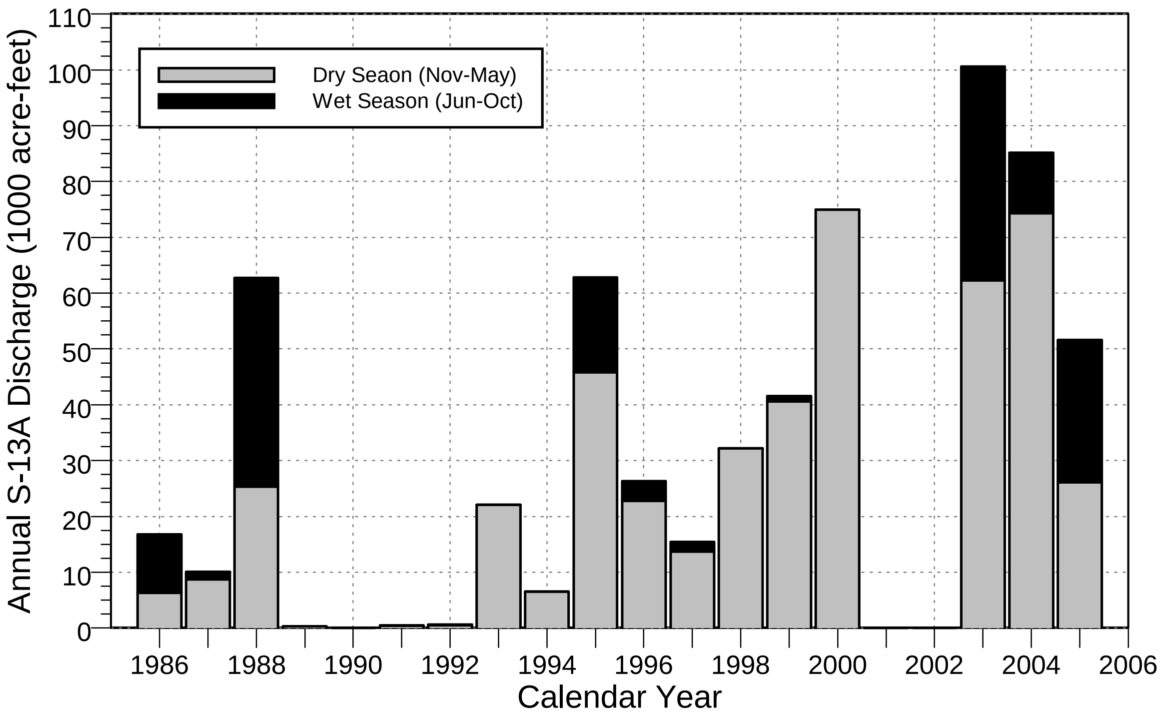
- Step 8 – Finally, any net C-11 Impoundment inflow that cannot be stored in this impoundment (Step 7) is discharged to the C-11 West Canal at S-504 and then to WCA-3A via the S-9 or S-9A pump station. Stages in the C-11 Canal west of the S-381 and S-504A spillways are expected to be generally higher (by approximately two feet) than stages to the east of S-381. These spillways cannot be opened under these conditions so operation of the S-503 inflow pump station will be continued even when the impoundment is full and all inflow will be routed directly through the S-504 spillway back to the C-11 Canal west of S-504A.

3.2.3 Available C-11 Canal Discharge Capacity at S-13A

One of the principal operating recommendations for the C-11 West Basin in the Flood Protection Analysis study was to convey as much of its runoff as possible to tide via S-13A, the C-11 East Canal and S-13. In the latest SFWMM data provided, the simulated discharges at S-13A are relatively modest when compared to C-11 West Basin runoff (Table 3.1). This disparity is even more pronounced during the wet season (June–October) with average discharges at S-13A and S-13 of 0.2 and 181 cfs, respectively.

In contrast to these data, the average annual S-13A discharge from the earlier (May 2004) SFWMM run used in the Flood Protection Analysis study was 54,342 acre-feet (75 cfs average). The actual recorded annual discharges at S-13A are summarized in Figure 3.3, which distinguishes between wet-season and dry-season discharge. These historic data were retrieved from the District's DBHYDRO environmental database for DBKEYs P0955 (1/1/1986–12/31/2003) and 15147 (1/1/2004–10/31/2005). As shown in this figure, the annual discharge at S-13A has ranged from zero to just over 100,000 AF/yr. Except for 1988 and the most recent three years, almost all historic discharge has occurred during the dry season. Starting in 2003, these data show a distinct shift in the operations of S-13A when the total annual discharge at S-13A has increased to an average of 79,121 AF/yr (109 cfs average) and the wet-season component of this discharge has averaged approximately 24,910 AF/yr (about 82 cfs average).

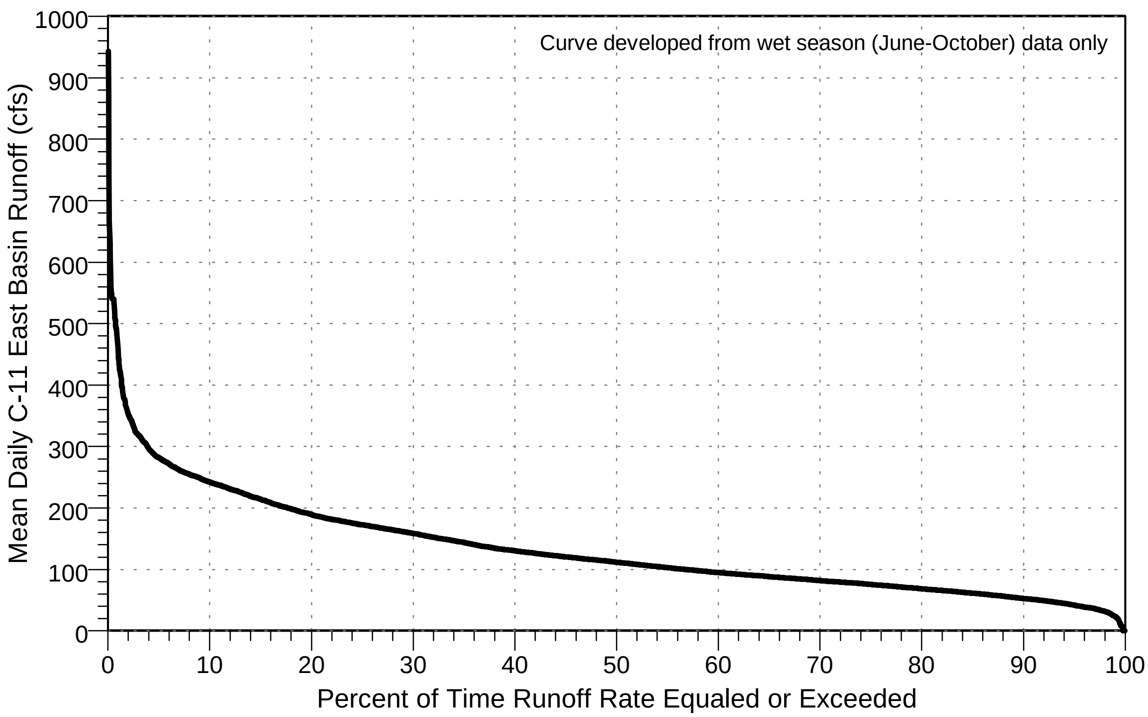
Figure 3.3: Recorded Annual S-13A Discharge



From review of the discharge data for S-13A from earlier simulations and actual flow records, it would appear that maximizing discharge of C-11 West Basin runoff through S-13A was not an operating goal of the latest SFWMM model. For this reason, an analysis of the available simulated flows at S-13A and S-13 was completed to develop a method for estimating the available discharge capacity at S-13A.

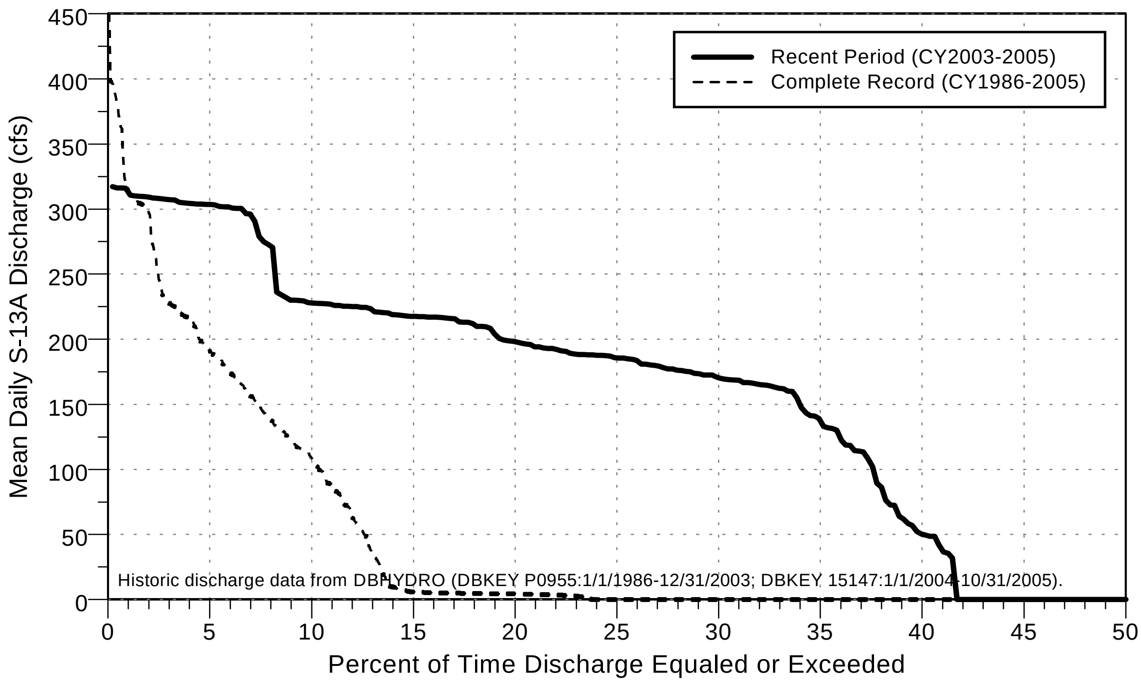
Because the SFWMM-simulated discharge at S-13A is at or near zero most of the time during the wet season, nearly all of the SFWMM-simulated discharge at S-13 is from C-11 East Basin runoff. Figure 3.4 shows the wet-season durations of C-11 East Basin runoff. As this figure indicates, this simulated runoff ranges from zero to nearly 950 cfs but the design capacity of S-13 (500 cfs) was exceeded less than 1 percent of the time. For the BCWPA model, it is assumed that the firm conveyance capacity of the C-11 East Canal is 500 cfs, equal to the S-13 design capacity. Under this assumption, there should be excess conveyance capacity in the C-11 East Canal whenever C-11 East Basin runoff is less than 500 cfs.

Figure 3.4: C-11 East Basin Runoff Durations



At Structure S-13A, the official design capacity is 120 cfs but actual operating history shows this value is routinely exceeded. From the historic monitoring data at S-13A, a peak flow of 560 cfs was recorded through S-13A. Figure 3.5 shows historic wet-season discharge durations at S-13A for the entire period of record and most recent three years only. Considering the more recent three years only, wet-season discharge has been above 150 cfs about one third of the time and above 250 cfs about 9 percent of the time. District staff has suggested that 300 cfs may be a more realistic design capacity for S-13A.

Figure 3.5: Historic Wet-season Flow Durations at S-13A

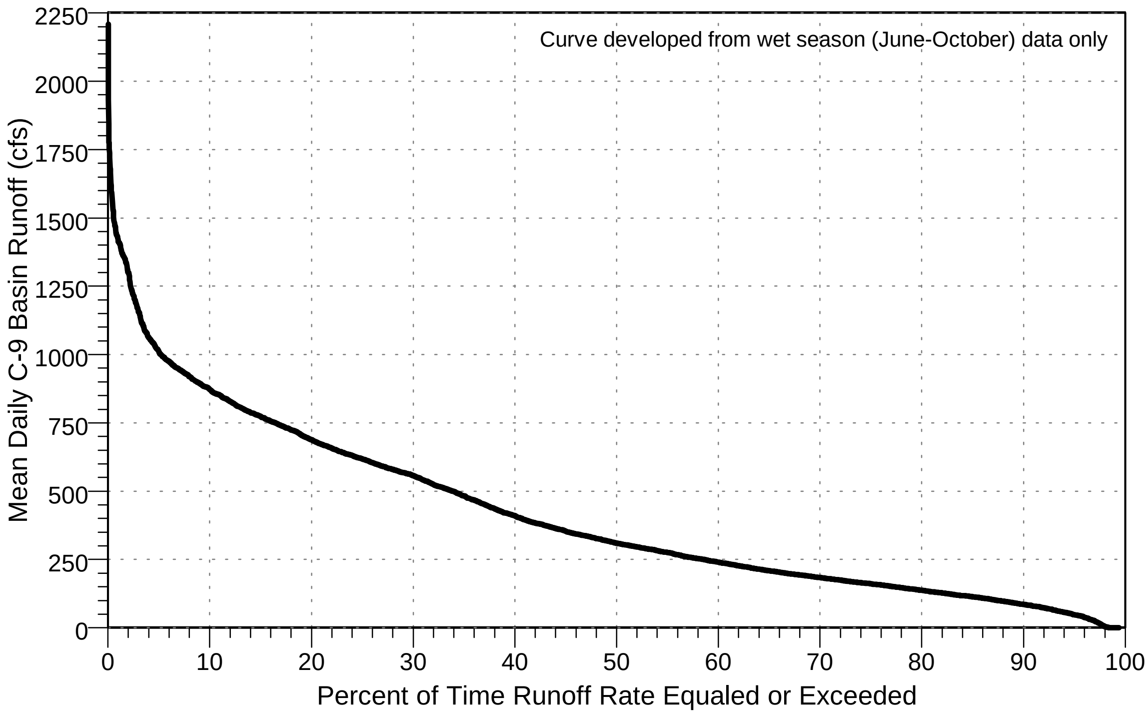


In the BCWPA simulation model, the available conveyance capacity of the C-11 East Canal is defined as the difference between 500 cfs and the current runoff rate in the C-11 East Basin. The allowable discharge rate at S-13A (Section 3.2.2, Step 1) is set equal to this available conveyance capacity up to a maximum of 250 cfs. A limit of 250 cfs was selected because it is 50 percent of the design capacity at S-13 and well within the range of historic flow rates at S-13A, even though it exceeds the official design capacity. Referring to Figure 3.4, the allowable wet-season discharge at S-13A will be zero only about 1 percent of the time (whenever C-11 East Basin runoff exceeds 500 cfs) and at its maximum value (250 cfs) about 91 percent of the time (whenever basin runoff is less than 250 cfs). Sensitivity cases, with more restrictive discharge limits at S-13A, were also executed (Section 3.3.4).

3.2.4 Available C-9 Canal Discharge Capacity at S-511

The available conveyance capacity of the C-9 Canal at the proposed S-511 culverts was investigated in a similar manner as that used for the C-11 Canal. Figure 3.6 is a duration curve for wet-season runoff in the C-9 Basin. C-9 Basin runoff is estimated from the SFWMM data as the discharge at S-29 less the discharges at S-30 and S-510. The discharge from the C-9 Impoundment at S-510 is primarily runoff transferred from the C-11 Basin. The S-29 spillway has a design capacity of 4,700 cfs but the maximum simulated discharge during the 36-year POS was 2,208 cfs. A more typical discharge limit is assumed to be one that is exceeded only 10 percent of the time, which equates to 872 cfs for wet-season runoff in the C-9 Basin. Therefore, the simulation model uses 872 cfs as the typical peak runoff rate at S-29 in lieu of its actual design capacity.

Figure 3.6: C-9 Basin Runoff Durations



In the simulation model, the allowable discharge at S-511 (Section 3.2.2, Step 5) is defined as the difference between 872 cfs and the current runoff rate in the C-9 Basin (SFWMM flow terms S29-S30-C9RTC9) with a maximum rate of 250 cfs. The maximum discharge rate is based on 50 percent of this structure's design capacity. From Figure 3.6, the allowable wet-season discharge at S-511 will be zero 10 percent of the time (whenever C-9 Basin runoff exceeds 872 cfs) and at its maximum value (250 cfs) about 75 percent of the time (whenever basin runoff is less than 622 cfs).

In order to control salinity levels at the mouth of Snake Creek (C-9 Canal) for the benefit of oyster populations located there, the U.S. Fish and Wildlife Service has recommended that discharges at S-29 average between 1,120 and 41,470 acre-feet per month (18.6 and 687 cfs). These recommendations are contained in the performance measure titled *SE-E8 Snake Creek Surface Water Discharges to North Biscayne Bay*, posted July 6, 2004. The BCWPA model uses a daily time step so it cannot readily honor these monthly flow targets. Therefore, the allowable daily discharge limits for S-29 stated above were not modified but the resulting average monthly S-29 discharges are calculated for later comparison to these flow targets.

3.2.5 Modeling Assumptions for C-11 Impoundment

The current design for the proposed C-11 Impoundment includes an impoundment with the following characteristics:

- Effective storage area – 1,490 acres
- Average ground surface elevation – 6.0 feet NGVD
- Normal (full) pool elevation – 10.0 feet NGVD
- Uncontrolled overflow spillway (S-504B) crest elevation – 11.2 feet NGVD
- Net inflow pump station (S-503) capacity – 2,500 cfs (plus additional 75 cfs for seepage control)
- Outflow spillway (S-504) capacity – 1,000 cfs (based on conservative head differential of 0.5 foot)
- Uncontrolled overflow spillway (S-504B) capacity – 450 cfs

Another feature of this development is an adjacent, 205-acre wetland mitigation area. In the Flood Protection Analysis study, it was recommended that this mitigation area could be used to provide a small amount of additional storage at this site and this option is included in the BCWPA Project's draft operating manual (Annex D of Draft PIR/EIS). However, it is unknown if this use would be compatible with the preferred management of this mitigation area so this additional storage option was not included in the BCWPA model and the mitigation area as a whole was not explicitly modeled. There may be occasional water supply releases to this area from the C-11 Impoundment but these releases are likely to be relatively small, occur during the dry season and not be significant to the overall project water balance.

Also in the Flood Protection Analysis study, it was recommended that up to an additional 2,000 acre-feet of basin runoff from the C-11 Impoundment could be stored temporarily in the 3A or 3B Seepage Management Areas, when there is available storage space in these areas. This additional storage option was also not included in the BCWPA Model because it would further increase the operational complexity of this project with relatively small increases in project performance.

The simulation model maintains a water balance for the C-11 Impoundment for each day during the 36-year simulation period. This water balance considers the following inflow and outflow vectors:

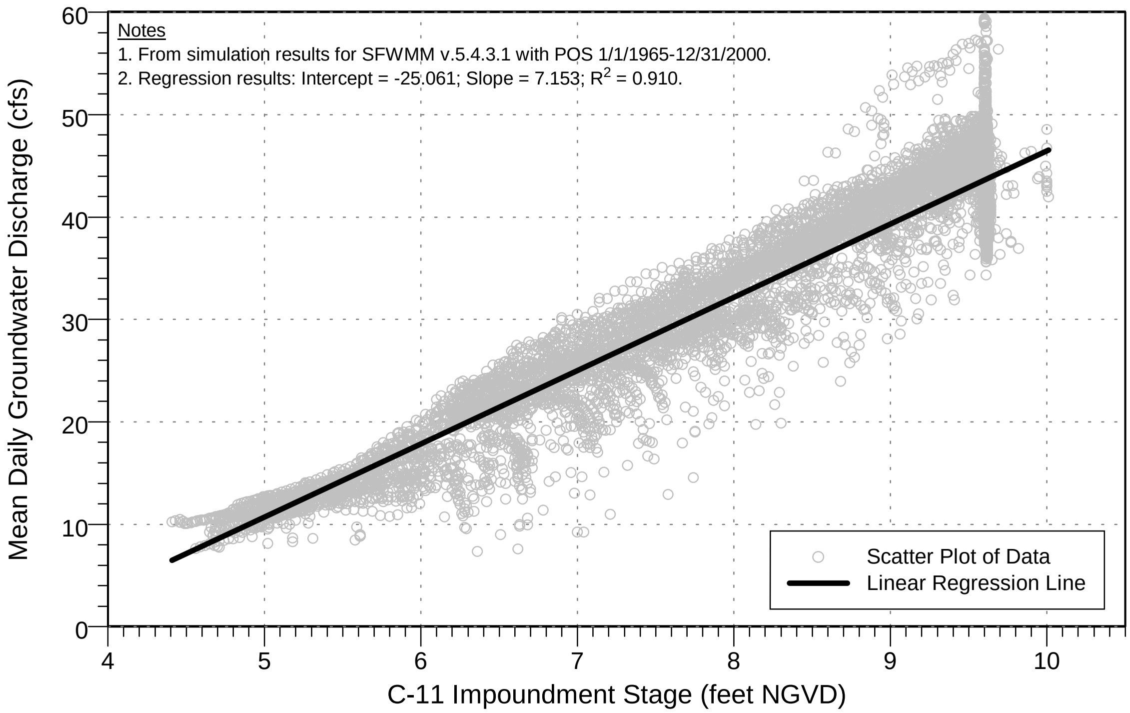
- C-11 Impoundment inflow
  - S-503 pump station – Discussed in Section 3.2.2, Step 2 and further below
  - Direct precipitation – Calculated from daily rainfall depths provided by District times effective storage area
  - Groundwater inflow – See discussion below

- C-11 Impoundment outflow
  - S-504 spillway – Spillway releases may include transfers to C-9 Basin (discussed in Section 3.2.2, Step 4), releases for reservoir drawdown (discussed below) or excess impoundment storage that must be discharged to WCA-3A via the S-9 or S-9A pump station (Section 3.2.2, Step 8).
  - Evapotranspiration (ET) – Calculated from daily ET depths provided by District times effective storage area
  - Groundwater discharge (seepage) – See discussion below

In the BCWPA model, the daily groundwater inflow to and discharge from the C-11 Impoundment was initially assumed to be identical to the values developed in the SFWMM simulation. However with this assumption, the net seepage losses from this impoundment proved to be unrealistically high and estimated impoundment stages averaged well below average ground surface as a result. Therefore, additional analyses were conducted to develop a means to adjust the SFWMM-simulated groundwater budget.

Figure 3.7 is a scatter plot of simulated groundwater discharge versus impoundment stage for the C-11 Impoundment. Review of this figure shows there is a distinct linear relationship between these two variables. The linear regression model for groundwater discharge verses stage has an intercept of -25.061 cfs and a slope of 7.153 cfs/foot. The coefficient of determination (R^2) for this model is 0.910, which indicates that 91 percent of the variation in the dependent variable (groundwater discharge) is explained by this regression model. With these favorable regression results, the identified model was used to estimate the groundwater discharge from the C-11 Impoundment with the following procedure:

Figure 3.7: C-11 Impoundment Groundwater Discharge vs. Stage



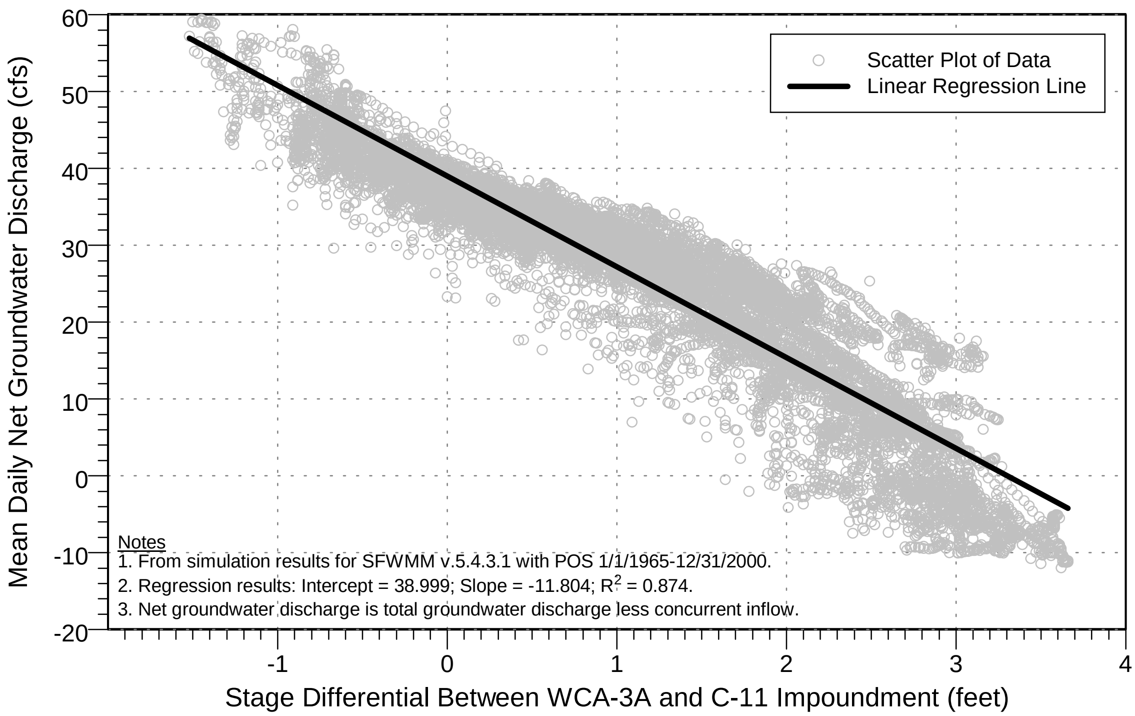
1. Use regression model to estimate groundwater discharge based on both the SFWMM- and BCWPA-simulated stages at start of day.

2. Use rates developed in Step 1 to calculate a ratio of BCWPA- to SFWMM-based groundwater discharge.

3. Estimate groundwater discharge to be used in BCWPA model as the SFWMM-simulated groundwater discharge on the current date times the ratio developed in Step 2.

A similar analysis of the groundwater inflow to the C-11 Impoundment was conducted. The best relationship proved to be between net groundwater discharge (total discharge less inflow) and the stage differential between WCA-3A and the impoundment. Reference WCA-3A stages were calculated as the average of the stages at gages 3A-3, 3A-4 and 3A-28. A scatter plot of these data is included as Figure 3.8. Again, review of this figure shows there is a distinct linear relationship between these two variables. The linear regression model for net groundwater discharge verses the stage differential between WCA-3A and the C-11 Impoundment has an intercept of 38.999 cfs, a slope of -11.804 cfs/foot and a R^2 of 0.874. With this regression model, the groundwater inflow to the C-11 Impoundment was estimated with the following procedure:

Figure 3.8: C-11 Impoundment Net Groundwater Discharge vs. Stage Differential



1. Use regression model to estimate the net groundwater discharge based on stage differential calculated using both the SFWMM- and BCWPA-simulated stages at start of day.

2. Add a fixed offset of 30 cfs to the rates developed in Step 1 to eliminate negative results and use these adjusted rates to calculate a ratio of BCWPA- to SFWMM-based net groundwater discharge.

3. Estimate net groundwater discharge to be used in BCWPA model as the SFWMM-simulated net groundwater discharge on the current date times the ratio developed in Step 2.

4. Calculate groundwater inflow estimate as difference between previously-estimated groundwater discharge and net groundwater discharge from Step 3.

The simulation model calculates a water balance for the C-11 Impoundment by executing the following steps:

- Starting with end-of-day impoundment storage from previous day, add S-503 inflow, direct precipitation, and groundwater inflow volumes; and subtract ET and groundwater discharge volumes to yield preliminary estimate of end-of-day storage.
- Calculate pool elevation from preliminary storage estimate (see additional discussion below regarding below-ground storage).
- If preliminary pool elevation estimate exceeds 7.0 feet NGVD, estimate allowable releases for reservoir drawdown. With the current design, these releases would be discharged to the C-11 West Canal through the S-504 spillway and then routed eastward through S-504A, S-381, S-13A and S-13 to tide. A further discussion of this routing is included below. Drawdown releases are assumed to occur only during the five-month wet season (June–October) and only when there is a net available discharge capacity at S-13A. Actual drawdown releases will be the lesser of the pool storage volume above stage 7.0 feet NGVD and the available discharge volume through S-13A. If current drawdown release is not zero, revise estimates of end-of-day storage and pool elevation.
- If revised pool elevation estimate exceeds 7.0 feet NGVD, estimate net allowable transfer capacity to C-9 Basin (as described in Section 3.2.2, Step 4). If transfer capacity is greater than zero, revise estimate of end-of-day storage and pool elevation.
- If revised pool elevation estimate exceeds normal (full) impoundment stage (10.0 feet NGVD), the volume of water stored above 10.0 feet must be released through S-504 and pumped to WCA-3A at S-9 or S-9A pump station, limited only by the available discharge capacities of S-504 and S-9. Although the design capacity of S-504 is 1,000 cfs, this discharge capacity is based on a head differential of only 0.5 foot across this spillway. With the C-11 Impoundment full (stage 10.0 feet), the head differential across this spillway would likely be at least three feet and its maximum discharge under these conditions would be at least as large as the inflow pump station capacity, 2,500 cfs. In the BCWPA model, a discharge capacity of 2,500 cfs was assigned to the S-504 spillway whenever the impoundment is full.

The District’s simulation results for the C-11 Impoundment show that water levels may fall below the average ground surface during dry periods. From groundwater modeling conducted for the Flood Protection Analysis study (Figure 2.22), the storage capacity of these near-surface soils is estimated to be approximately 3 inches (0.25 foot) of water per foot of soil. For purposes of the BCWPA simulation model, the minimum C-11 Impoundment stage is assumed to be two feet below average ground surface (4.0 feet NGVD). With these assumptions, the estimated impoundment storage at average ground surface (6.0 feet NGVD) would be 745 acre-feet (2.0 feet times 0.25 foot of water per foot of soil times 1,490 acres).

As described above, drawdown releases from the C-11 Impoundment would have to be routed eastward in the C-11 Canal from the S-504 spillway through structures S-504A, S-381, S-13A and S-13. Both the existing S-381 and proposed S-504A structures are Obermeyer-type spillways. Obermeyer spillways consist of gate panels that are hinged on their upstream (headwater) side. These panels are raised by inflating rubber bladders located under the panels. One problem with this configuration is that headwater stages must be higher than tailwater stages in order to lower these gates. At S-381 and S-504A, the principal flow direction is from east to west so C-11 West Canal stages on the east (headwater) side of these structures must be higher than stages on the west (tailwater) side in order to lower these gates. Except during rare high runoff events when it may be necessary to operate the S-9 pump station, tailwater stages at S-381 and S-504A will routinely be maintained at higher elevations than headwater stages. Therefore, in order to open these two spillways for drawdown releases, it may be necessary to operate the pumps at S-9 or S-9A for a time to temporarily lower C-11 Canal stages west of these structures below headwater elevations. After the gates are open, these pumps would then have to be shut down before drawdown releases from the C-11 Impoundment could commence.

In order to facilitate making drawdown releases from the C-11 Impoundment, inclusion of a small spillway adjacent to the S-503 pump station would be beneficial. The design capacity of this new spillway would need to be no more than the allowable discharge capacity at S-13A (currently assumed to be 250 cfs). Releases from this new spillway would enter the C-11 Canal east of S-381, eliminating the need to open both the S-504A and S-381 spillways. However, such a design change — changing the release point for C-11 Impoundment drawdown releases — would have no material impact on the simulation results from the BCWPA Model.

3.2.6 Modeling Assumptions for C-9 Impoundment

The current design for the proposed C-9 Impoundment includes an impoundment with the following characteristics:

- Effective storage area – 1,650 acres
- Average ground surface elevation – 4.5 feet NGVD
- Normal (full) pool elevation – 8.5 feet NGVD

- Uncontrolled overflow spillway (S-510A) crest elevation – 9.7 feet NGVD
- Net inflow pump station (S-509) capacity – 1,000 cfs (plus additional 75 cfs for seepage control)
- Outflow spillway (S-510) capacity – 500 cfs
- Uncontrolled overflow spillway (S-510A) capacity – 450 cfs

There is a wetland mitigation area adjacent to the C-9 Impoundment but this mitigation area is no longer considered a part of the BCWPA project. Although there may be occasional water supply releases from the impoundment to the mitigation area, this mitigation area was not explicitly modeled.

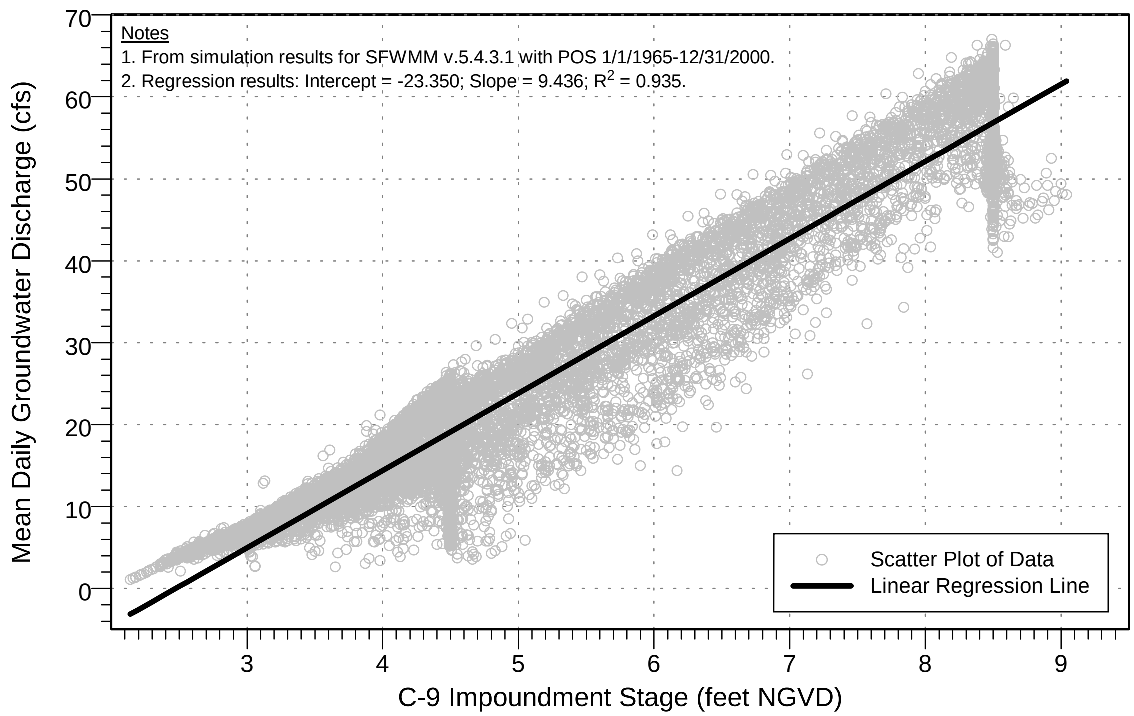
The simulation model maintains a water balance for the C-9 Impoundment similar to that described above for the C-11 Impoundment. This water balance considers the following inflow and outflow vectors:

- C-9 Impoundment inflow
  - S-509 pump station – Discussed in Section 3.2.2, Step 6 above
  - Direct precipitation – Calculated from daily rainfall depths provided by District times effective storage area
  - Groundwater inflow – See discussion below

- C-9 Impoundment outflow
  - S-510 spillway – Releases required for reservoir drawdown (discussed below) or when normal pool elevation (8.5 feet NGVD) is exceeded.
  - Evapotranspiration (ET) – Calculated from daily ET depths provided by District times effective storage area
  - Groundwater discharge (seepage) – See discussion below

Figure 3.9 is a scatter plot of simulated groundwater discharge verses impoundment stage for the C-9 Impoundment. Review of this figure shows there is a distinct linear relationship between these two variables. The linear regression model for groundwater discharge versus stage has an intercept of -23.350 cfs, a slope of 9.436 cfs/foot and a R^2 of 0.935. This regression model was used to estimate the groundwater discharge from the C-9 Impoundment with the following procedure:

Figure 3.9: C-9 Impoundment Groundwater Discharge vs. Stage



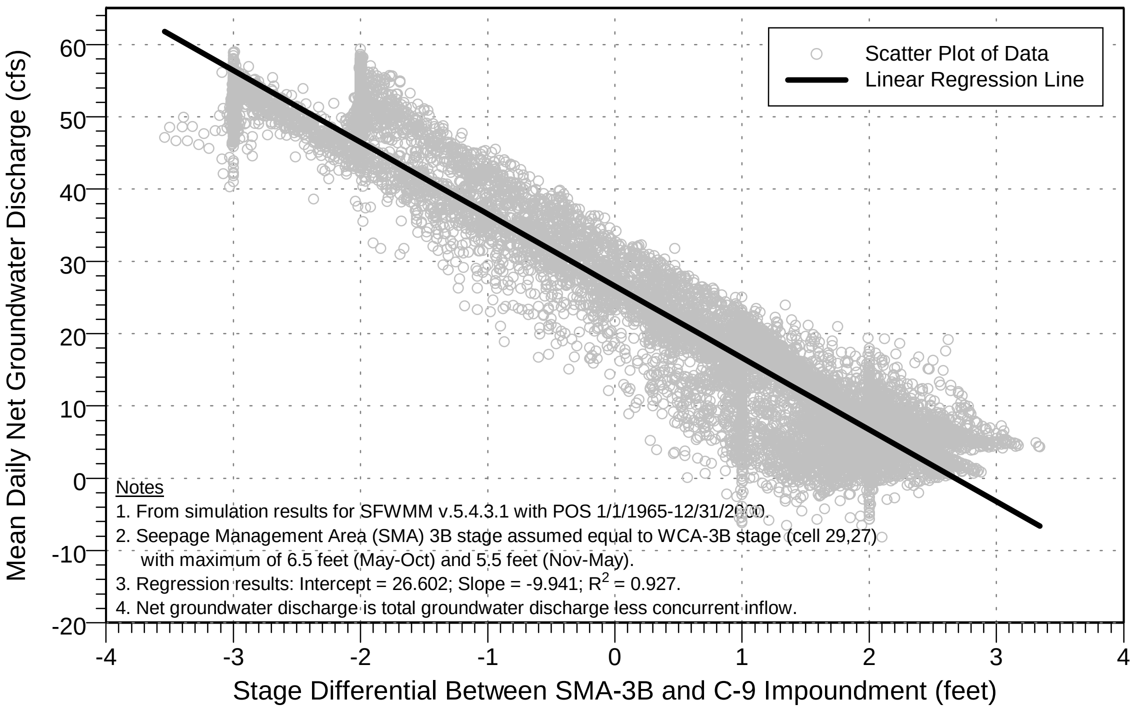
1. Use regression model to estimate groundwater discharge based on both the SFWMM- and BCWPA-simulated stages at start of day.

2. Use rates developed in Step 1 to calculate a ratio of BCWPA- to SFWMM-based groundwater discharge.

3. Estimate groundwater discharge to be used in BCWPA model as the SFWMM-simulated groundwater discharge on the current date times the ratio developed in Step 2.

A similar analysis of the groundwater inflow to the C-9 Impoundment was conducted. The best relationship proved to be between net groundwater discharge (total discharge less inflow) and the stage differential between the 3B SMA (SMA-3B) and the impoundment. Reference SMA-3B stages were estimated as the simulated stages in adjacent WCA-3B at SFWMM cell (29,27) limited to a maximum of 6.5 feet NGVD during the wet season (June–October) and 5.5 feet NGVD during the dry season (November–May). These maximum stages are the wet-season and dry-season control stages for SMA-3B. A scatter plot of these data is included as Figure 3.10. Again, review of this figure shows there is a distinct linear relationship between these two variables. The linear regression model for net groundwater discharge verses the stage differential between SMA-3B and the C-9 Impoundment has an intercept of 26.602 cfs, a slope of -9.941 cfs/foot and a R^2 of 0.927. With this regression model, the groundwater inflow to the C-9 Impoundment was estimated with the following procedure:

Figure 3.10: C-9 Impoundment Net Groundwater Discharge vs. Stage Differential



1. Use regression model to estimate the net groundwater discharge based on both the SFWMM- and BCWPA-simulated stages at start of day.

2. Add a fixed offset of 10 cfs to the rates developed in Step 1 to eliminate negative results and use these adjusted rates to calculate a ratio of BCWPA- to SFWMM-based net groundwater discharge.

3. Estimate net groundwater discharge to be used in BCWPA model as the SFWMM-simulated net groundwater discharge on the current date times the ratio developed in Step 2.

4. Calculate groundwater inflow estimate as difference between previously-estimated groundwater discharge and net groundwater discharge from Step 3.

The simulation model calculates a water balance for the C-9 Impoundment by executing the following steps:

- Starting with end-of-day impoundment storage from previous day, add S-509 inflow, direct precipitation, and groundwater inflow volumes; and subtract ET and groundwater discharge volumes to yield preliminary estimate of end-of-day storage.
- Calculate pool elevation from preliminary storage estimate (see additional discussion below regarding below-ground storage).
- If preliminary pool elevation estimate exceeds 5.5 feet NGVD (average depth 1.0 foot), estimate allowable releases for reservoir drawdown. These releases would be discharged to the C-9 Canal through S-510 spillway and then routed eastward through the C-9 Canal, S-511 and S-29 to tide. Drawdown releases are assumed to occur only during the five-month wet season (June–October) and only when there is a net available conveyance capacity in the C-9 Canal at S-511. Actual drawdown releases will be the lesser of the pool storage volume above stage 5.5 feet NGVD and the available discharge volume through S-511. If current drawdown release is not zero, revise estimate of end-of-day storage and pool elevation.
- If revised pool elevation estimate exceeds normal (full) impoundment stage (8.5 feet NGVD), the volume of water stored above 8.5 feet must be released through S-510 into the C-9 Canal.

As described above for the C-11 Impoundment, the simulation model assumes a minimum impoundment stage of two feet below average ground surface (2.5 feet NGVD) for the C-9 Impoundment. Therefore, the estimated impoundment storage at average ground surface (4.5 feet NGVD) would be 825 acre-feet (2.0 feet times 0.25 foot of water per foot of soil times 1,650 acres).

3.3 BCWPA Model Results

The simulation results from the BCWPA model are summarized in this section for the C-11 and C-9 Basins.

3.3.1 C-11 Basin

From the BCWPA model, the simulated flows at the principal control structures on the C-11 Canal are summarized in Table 3.5. This table lists the average, minimum and maximum flows on both a daily and annual basis. Also listed in this table are estimates of the net basin runoff from the eastern and western portions of the C-11 Basin. These basin runoff values are the same as those reported in Table 3.1. The BCWPA model does not modify basin runoff estimates but some of the proposed operational changes could have an impact on runoff volumes.

Table 3.5: BCWPA Model Simulation Results for C-11 Basin

Structure or Flow Component	Daily Flow Data (cfs)			Calendar Year Flow Data (acre-feet)		
	Avg. Day	Min. Day	Max. Day	Avg. Year	Min. Year	Max. Year
S-13[a]	184.2	0.0	1,020.4	134,200	62,759	198,178
S-13A	94.5	0.0	250.0	68,478	26,353	104,129
S-381 East[b]	0.8	0.0	114.0	601	0	2,797
S-381 West[b]	0.0	0.0	0.0	0	0	0
S-9/S-9A:						
C-11 Runoff[c]	1.4	0.0	1,183.6	990	0	11,198
WCA Seepage[d]	81.6	0.0	1,152.6	59,090	41,236	76,483
Total[e]	82.9	0.0	2,336.3	60,080	41,236	87,681
Net Basin Runoff[f]						
East Basin	90.7	0.0	1,020.4	65,722	31,793	94,049
West Basin	106.9	0.0	2,226.3	77,453	26,693	127,753
Total	197.6	0.0	2,798.1	143,182	63,099	221,802

a. SFWMM flow term S13 plus difference between SFWMM and BCWPA flow estimates at S-13A.
b. Eastward discharge at S-381 is for C-11 Impoundment drawdown; westward discharges are excess C-11 West runoff that must be delivered to WCA-3A.
c. C-11 West Basin runoff that must still be pumped to WCA-3A.
d. Seepage component of S-9/S-9A discharge (from District estimates) less seepage volumes diverted to C-9 Impoundment along with C-11 Impoundment releases.
e. Total discharge to WCA-3A at S-9/S-9A (total of C-11 runoff and WCA seepage components).
f. Net basin runoff is total runoff less coincident water supply withdrawals. Derived from SFWMM results and not modified by BCWPA model.

Review of Table 3.5 shows the discharge at S-13A averages 94.5 cfs, which is about 87.6 percent of the total C-11 West Basin runoff (average 106.9 cfs). The balance of C-11 West Basin runoff is discharged to the C-11 Impoundment (13.2 cfs average or 12.4 percent). None of this runoff is discharged directly to WCA-3A via S-381 in the BCWPA model. In contrast, the average distribution of C-11 West Basin runoff in the SFWMM simulation is 6.5 percent to S-13A, 93.3 percent to the C-11 Impoundment and 0.2 percent directly to WCA-3A via S-381.

In the BCWPA model, the total discharge to WCA-3A at the S-9/S-9A complex decreases to an average of about 82.9 cfs, or 60,080 acre-feet/year as compared to 133.4 cfs and 96,678 acre-feet/year in the SFWMM (Table 3.1). The most significant value in Table 3.5 is the C-11 Basin runoff component of S-9/S-9A discharge, which is shown to average only 1.4 cfs or 990 acre-feet/year. This discharge component is only 4.2 percent of the values reported from the latest

SFWMM simulation. The return of WCA seepage at S-9/S-9A also decreases by about 19 percent in the BCWPA model, from an average of 100.9 cfs to 81.6 cfs.

Similar summary data for the C-11 Impoundment are included in Table 3.6. With the simulation results reflected in the BCWPA model, inflow to the C-11 Impoundment from C-11 West basin runoff is greatly reduced compared to the SFWMM simulation, decreasing from an average of 97.7 cfs to 13.2 cfs. Overall, the inflow to this impoundment is 31 percent from basin runoff, 19 percent from rainfall and 50 percent from groundwater. C-11 Impoundment outflow is apportioned as follows: 31 percent to the C-11 Canal at S-504; 21 percent to evapotranspiration (ET), and 51 percent to seepage (discharge to groundwater).

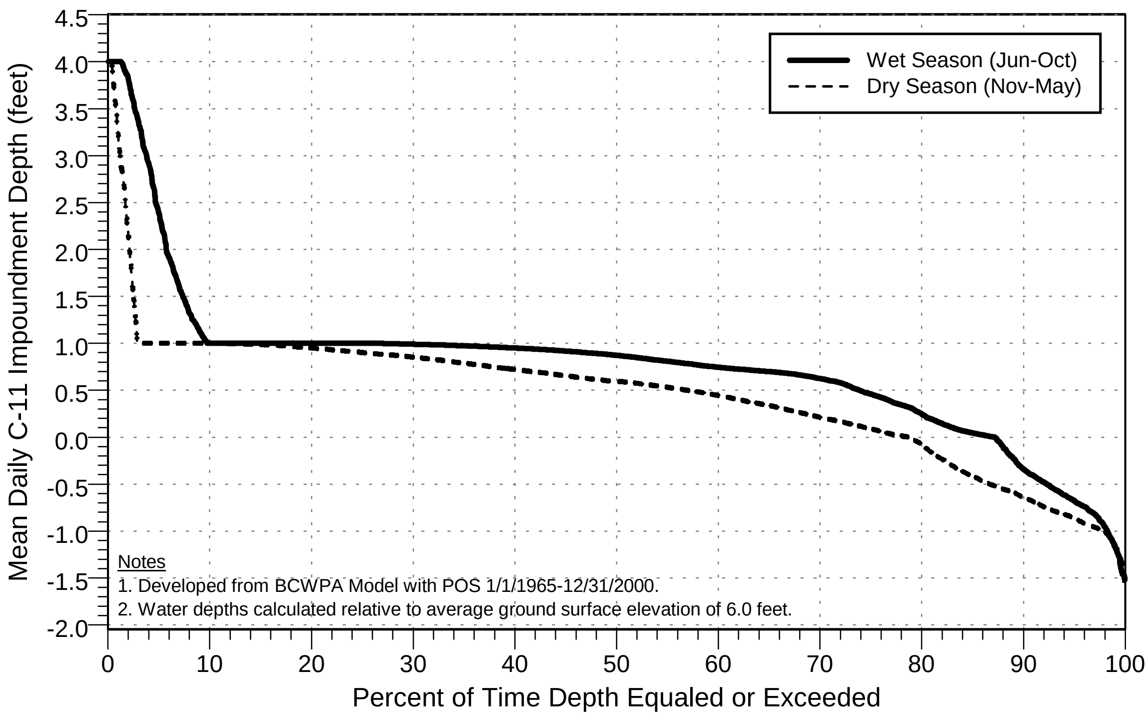
Table 3.6: BCWPA Model Simulation Results for C-11 Impoundment

Structure or Flow Component	Daily Data (cfs[a])			Calendar Year Data (acre-feet[a])		
	Avg. Day	Min. Day	Max. Day	Avg. Year	Min. Year	Max. Year
Inflow						
S-503	13.2	0.0	2,226.3	9,576	141	32,236
Rainfall[b]						
Depth (inches)	0.13	0.00	7.88	47.86	31.05	71.18
Volume	8.2	0.0	493.3	5,943	3,855	8,838
Groundwater[c]	21.8	0.0	53.6	15,770	10,865	26,074
Outflow						
S-504	12.5	0.0	1,183.6	9,030	0	29,435
Evapotranspiration[b]						
Depth (inches)	0.14	0.05	0.23	51.78	48.87	54.88
Volume	8.9	3.1	14.4	6,430	6,068	6,814
Groundwater[c]	21.8	7.2	48.6	15,810	10,014	18,773
Stage (feet NGVD)	6.58	4.40	10.00	6.58	5.29	7.23

a. Units for daily and annual data are respectively cfs and acre-feet unless noted otherwise.
b. From SFWMM simulation. These quantities are assumed to be unchanged in BCWPA model.
c. SFWMM-simulated groundwater budgets adjusted using regression equations.

The C-11 Impoundment has an average ground surface elevation of 6.0 feet NGVD and a normal (full) stage of 10.0 feet NGVD, for a total storage depth of 4.0 feet. As listed in Table 3.6, the average impoundment stage is 6.58 feet, which corresponds to an average depth of 0.58 feet (7 inches). This value is approximately two feet lower than the average SFWMM-simulated stage (Table 3.2). Figure 3.11 includes wet-season and dry-season depth duration curves for this impoundment. These curves show that the impoundment would be full (4-foot depth) less than one percent of the time and greater than the 1-foot control depth about 10 percent of the time during the wet season and 3 percent of the time during the dry season. The operating policy described above will encourage storage depths to hover near one foot because transfers to the C-9 Basin or drawdown releases are made whenever the impoundment is above one foot and discontinued when depths are less than one foot. The BCWPA model results also show that C-11 Impoundment stage will be at or below average ground surface about 13 and 21 percent of the time during the wet and dry seasons, respectively.

Figure 3.11: BCWPA Model Depth Durations for C-11 Impoundment



As stated in Section 3.2.5, regression equations are used in the BCWPA model to adjust groundwater inflows to and discharges from the C-11 Impoundment. Table 3.6 shows that inflows and outflows occur at about the same rate, on average. For the base SFWMM values however, groundwater discharge averages over threes times higher than groundwater inflow. This decrease in net groundwater discharge is explained by the lower storage depths. The average and median storage depths are respectively about two and three feet lower than those from the SFWMM simulation.

3.3.2 C-9 Basin

S-29 and S-30 are the two primary control structures on the C-9 Canal. The simulated discharge at these structures and C-9 Basin runoff are summarized in Table 3.7. As shown in this table, discharge to tide at S-29 decreases about 14 percent from the values in the SFWMM simulation. This decrease is largely a result of changes in operation of S-13A. In the SFWMM model, most C-11 West Basin runoff is routed through the C-11 Impoundment to the C-9 Impoundment to tide at S-29. However, most C-11 West Basin runoff is delivered directly to tide via S-13A and S-13 in the BCWPA model.

Table 3.7: BCWPA Model Simulation Results for C-9 Basin

Structure or Flow Component	Daily Flow Data (cfs)			Calendar Year Flow Data (acre-feet)		
	Avg. Day	Min. Day	Max. Day	Avg. Year	Min. Year	Max. Year
S-29[a]	271.8	0.0	2,208.2	196,897	71,217	352,266
S-30[c]	32.8	0.0	1,000.0	23,725	475	99,712
Net Basin Runoff[c]	241.5	-130.5	2,208.2	174,988	65,918	262,832

a. Calculated from SFWMM flow term S29 plus differential discharge at S-511.
b. Includes SFWMM flow (flow term S30) plus transfers from C-11 Basin.
c. From SFWMM simulation. Basin runoff is assumed unchanged in BCWPA model. Negative values indicate net water supply demand within basin.

As discussed in Section 3.2.4, the U.S. Fish and Wildlife Service has recommended that average monthly discharge rates at S-29 range between 18.6 and 687 cfs. Monthly average discharges at S-29 were calculated from the simulated daily discharges for three scenarios:

- Current: Existing conditions within project area without construction of the BCWPA Project. The discharge at S-29 under current conditions is assumed to be equivalent to estimated C-9 Basin runoff.
- SFWMM: With project conditions as reported in the SFWMM simulation.
- BCWPA Model: With project conditions as simulated in the BCWPA Model.

A comparison of the average monthly discharges at S-29 for these three scenarios is presented in Table 3.8. Review of this table shows that development of the BCWPA Project would reduce the number of months with under-target flows at S-29. This effect would be expected because this project will transfer some C-11 Basin runoff into the C-9 Basin. These transfers are significantly higher in the SFWMM simulation (average 73.8 cfs) as compared to those simulated in the BCWPA model (average 32.8 cfs) so there would be more months with under-target flows under the operating assumptions used in the BCWPA model; however, there would still be fewer under-target flow months than under existing conditions.

Table 3.8: Analysis of Flow Targets at S-29

Parameter	Under Target Months[a]			Over Target Months[b]		
	Current	SFWMM	BCWPA Model	Current	SFWMM	BCWPA Model
Number of Months	71	54	65	30	41	47
Average Flow (cfs)[c]	2.9	3.0	3.5	842	857	857
Minimum Flow (cfs)[c]	0.0	0.0	0.0	687	694	687
Maximum Flow (cfs)[c]	18.4	16.9	17.0	1,149	1,206	1,160

a. Months with average S-29 discharge less than 18.6 cfs (1,120 acre-feet total).
b. Months with average S-29 discharge greater than 686.9 cfs (41,470 acre-feet total).
c. Discharge statistics calculated from average monthly flows in months that are either under or over target flow range only.

In months with higher runoff, development of the BCWPA project would be expected to increase the number of months with average discharges at S-29 over the recommended range. For the 36-year (432-month) period of simulation, the number of over-target flow months would increase from 30 (7 percent) for current conditions to 41 months (9 percent) and 47 months (11 percent) in the SFWMM and BCWPA model simulations, respectively. Somewhat unexpected is the larger number of over-target flow months with the operating assumptions used in the BCWPA model as compared to the SFWMM simulation, even though average transfers from the C-11 Basin are significantly higher in the SFWMM simulation. This difference in the number of over-target flow months is a result of the assumed release rate from the C-9 Impoundment. In the SFWMM model, all transfers from the C-11 Impoundment are first pumped into the C-9 Impoundment and then released at a maximum rate of 100 cfs. In the BCWPA model it is assumed that C-11 Basin transfers or impoundment drawdown releases can occur at rates up to 250 cfs through S-511.

It would be possible to alter the proposed operation of the C-9 Impoundment to help mitigate some of the over- or under-range flow months indicated in Table 3.8 but these changes would have consequences. If more water is retained in the C-9 Impoundment to provide a supplemental water supply during dry periods or the impoundment is used to attenuate higher flows at S-29 by storage of C-9 Basin runoff, its effectiveness as a temporary storage location for C-11 Basin runoff would be reduced. Inevitably, the quantities of C-11 Basin runoff discharged to WCA-3A would increase.

A summary of the operating results for the C-9 Impoundment is included in Table 3.9. As with the C-11 Impoundment, the simulated inflow to the C-9 Impoundment at S-509 is significantly reduced in the BCWPA model (by 82 percent) as compared to the SFWMM results. Transfers from C-11 Impoundment account for approximately 46 percent of this impoundment's total inflow. Direct precipitation (35 percent) and groundwater inflow (19 percent) account for the balance of inflow. Impoundment outflow is apportioned as follows: 17 percent to the C-9 Canal at S-510, 32 percent to evapotranspiration (ET), and 51 percent to seepage (discharge to groundwater).

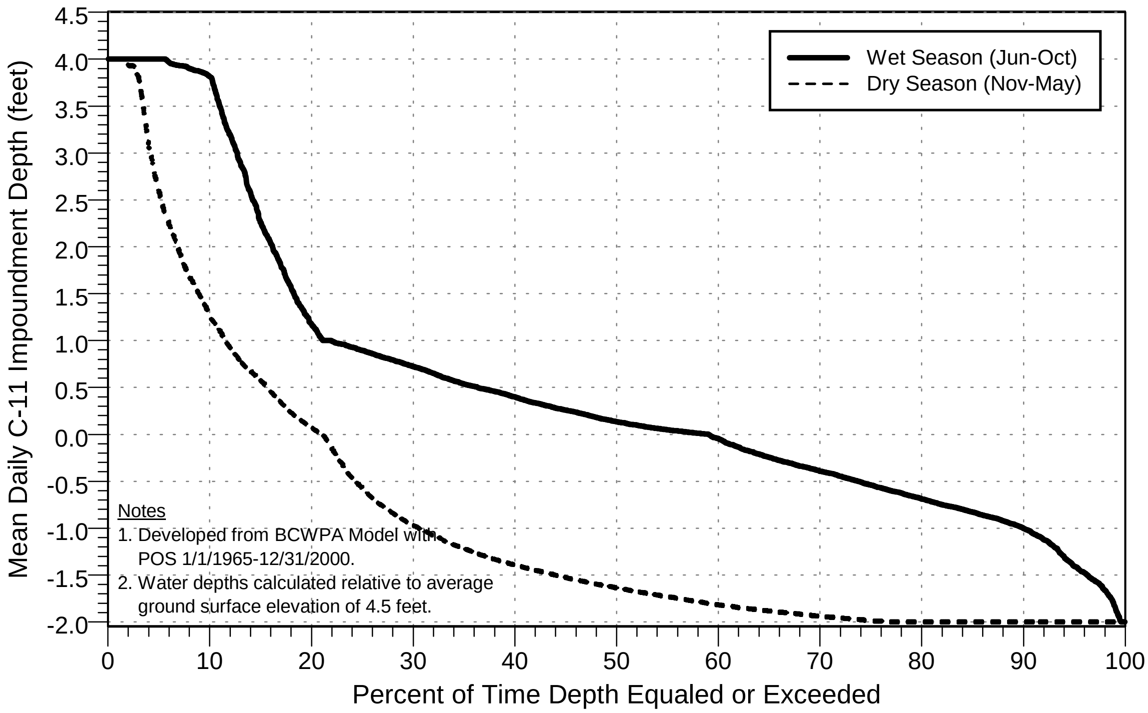
Table 3.9: BCWPA Model Simulation Results for C-9 Impoundment

Structure or Flow Component	Daily Data (cfs[a])			Calendar Year Data (acre-feet[a])		
	Avg. Day	Min. Day	Max. Day	Avg. Year	Min. Year	Max. Year
Inflow						
S-509	13.1	0.0	1,000.0	9,507	0	29,894
Rainfall[b]						
Depth (inches)	0.14	0.00	4.93	52.76	35.70	71.44
Volume	10.0	0.0	341.8	7,255	4,909	9,823
Groundwater[b]	5.4	0.0	53.6	3,932	2,783	4,814
Outflow						
S-510	5.0	0.0	250.0	3,640	0	13,668
Evapotranspiration[b]						
Depth (inches)	0.13	0.05	0.23	48.90	44.19	54.27
Volume	9.3	3.5	15.9	6,724	6,076	7,462
Groundwater[b]	15.0	0.0	64.3	10,885	2,970	27,480
Stage (feet NGVD)	4.16	2.50	8.50	4.16	2.99	6.47

a. Units for daily and annual data are respectively cfs and acre-feet unless noted otherwise.
b. From SFWMM simulation. These values are assumed unchanged in the BCWPA model.

The C-9 Impoundment has an average ground surface elevation of 4.5 feet NGVD and a normal (full) stage of 8.5 feet NGVD, for a total storage depth of 4.0 feet. As listed in Table 3.9, the average impoundment stage from the BCWPA model is 4.16 feet, which is approximately 4 inches below average ground surface and 1.3 feet less than the average from the SFWMM simulation. Figure 3.12 includes wet-season and dry-season depth duration curves for this impoundment. These curves show that the impoundment would be empty (depth less than zero) about 41 percent of the time during the wet season and 79 percent of the time during the dry season. On the other extreme, the C-9 Impoundment is shown to be full about 4 and 2 percent of the time respectively during the wet and dry seasons.

Figure 3.12: BCWPA Model Depth Durations for C-9 Impoundment



As stated in Section 3.2.6, regression equations are used in the BCWPA model to adjust groundwater inflows to and discharges from the C-9 Impoundment. Comparing Tables 3.4 and 3.8 shows that groundwater inflows are approximately the same, on average, in the SFWMM and BCWPA models. The adjustments made in the BCWPA model however, reduced average groundwater discharge by nearly half.

3.3.3 WCA-3A Impacts

The BCWPA model redirects some of the discharge to WCA-3A at S-9/S-9A, as simulated by SFWMM, to the C-9 Basin. This redirected discharge consists of C-11 Basin runoff, WCA-3A and WCA-3B seepage, and runoff from SMA-3A and SMA-3B. Under certain conditions, these discharges may satisfy an important water supply need within WCA-3A so a discharge reduction could negatively impact the operations of this conservation area.

The regulation schedule for WCA-3A identifies several zones which vary by time of year and stage. For each of these zones, allowable discharge locations and rates are identified. The lowest of these zones (Zone E) can be considered to represent the conservation, or water supply, pool in this conversation area so it is desirable to maintain stages near the top of this zone. The stage at the top of Zone E varies from a maximum 10.5 feet NGVD (November 1 – December 31) to a minimum of 8.7 feet NGVD on July 15. The SFWMM-simulated stages in WCA-3A were compared with the regulation schedule to identify times when stages are within Zone E (that is, less than desired) and any discharge reductions at S-9/S-9A during these times were tracked. These data can be used by planners to help evaluate potential operational impacts to the conservation area. For this analysis, none of the proposed operational changes within the BCWPA project area are assumed to have a significant impact on stages within WCA-3A.

Table 3.10 summarizes the amounts of S-9/S-9A discharge that are diverted away from WCA-3A when the conservation area is in Zone E of its regulation schedule. Based on the SFWMM results, WCA-3A stages are in Zone E approximately 20 percent of the time. Review of Table 3.10 shows that an average of only 108 AF/yr of C-11 West Basin runoff is diverted away from WCA-3A under these conditions, which is an average rate of less than 0.75 cfs. More importantly, no seepage is diverted to the C-9 Impoundment when the conservation area is in Zone E. Because of its superior quality characteristics, return of WCA seepage (and SMA runoff) is the first choice to meet any apparent water supply demand in the conservation area. Total diversions equal C-11 Basin runoff diversions because seepage diversions are zero when WCA-3A is in Zone E.

Table 3.10: Potential Water Supply Reductions to WCA-3A at S-9/S-9A

Discharge Component	Annual Discharge Reduction at S-9/S-9A When WCA-3A in Zone E (acre-feet)		
	Average Year	Minimum Year	Maximum Year
C-11 Basin Runoff[a]	108	0	2,161
WCA Seepage[a]	0	0	0
Total[a]	108	0	2,161
Total C-11 West Runoff[b]	3,262	0	16,947

a. Reductions calculated relative to simulated discharges in SFWMM v.5.4.3.1.
b. Total C-11 West Basin runoff that occurs when simulated stages in WCA-3A put it in Zone E of its regulation schedule.

Historically, nearly all C-11 West Basin runoff was discharged to WCA-3A at S-9/S-9A. The last row in Table 3.10 shows in total how much of this runoff occurs when WCA-3A stage is within Zone E. The values in this row represent potential water supply impacts to WCA-3A as compared to historic operating policies without the Broward County WPA Project in place.

3.3.4 Sensitivity Analyses

The primary reason for the significant differences between the operating results shown in the latest SFWMM simulation and those from the BCWPA model is the greatly increased discharge of C-11 West Basin runoff to tide, both via S-13A and S-511. With the base modeling assumptions, approximately 88 percent of the total C-11 West Basin runoff is conveyed to tide at S-13A. An additional 6 percent is transferred to the C-9 Basin and conveyed to tide via S-511. The base assumptions used to estimate the available discharge limit at S-13A and S-511 are described in Sections 3.2.3 and 3.2.4

The first sensitivity case (Case 1) uses an alternative discharge limit at S-13A only. Instead of the base assumption of 250 cfs, a limit equal to the official design capacity of this structure, 120 cfs, is used. The impacts of this revised model assumption are summarized in Table 3.11. As expected with this change, the average discharge at S-13A decreases significantly, from 68,478 AF/yr (94.5 cfs) to 48,454 AF/yr (66.9 cfs). The basin runoff that is discharged to the C-11 Impoundment at S-503 increases by a like amount, from 9,576 AF/yr (13.2 cfs) to 29,084 AF/yr (40.1 cfs). The most significant change is the increase in the amount of C-11 West Basin runoff that is discharged to WCA-3A. This discharge increases by a factor of nearly four, from an average of 990 AF/yr (1.4 cfs) to 3,698 AF/yr (5.1 cfs). Although there is more basin runoff discharged to WCA-3A with this lower discharge limit at S-13A, this increase is more than offset by a decrease in the amount of seepage returned at S-9/S-9A. This flow component decreases because there would be more frequent transfers to the C-9 Basin under this alternative and correspondingly more seepage diverted to this basin along with C-11 Basin runoff.

Table 3.11: Sensitivity Case 1

Flow Component	S-13A Discharge Limit of 250 cfs			S-13A Discharge Limit of 120 cfs		
	Avg. Year	Min. Year	Max. Year	Avg. Year	Min. Year	Max. Year
S-13A	68,478	26,353	104,129	48,454	22,614	68,514
S-503	9,576	141	32,336	29,084	4,079	63,205
S-9/S-9A:						
C-11 Runoff	990	0	11,198	3,698	0	19,298
Seepage	59,090	41,236	76,483	41,487	22,761	52,644
Total	60,080	41,236	87,681	45,185	26,968	65,676

In comments received from the staff of the Operations Division on the draft version of this report, they recommend even more conservative discharge limits for the C-11 and C-9 canals:

- At S-13A, a maximum discharge rate of 100 cfs

- At S-30, a maximum discharge rate of 300 cfs
- Maximum available conveyance in C-9 Canal equal to 400 cfs less current runoff rate in C-9 Basin

The second of these recommendations, a discharge limit of 300 cfs at S-30, would limit the maximum transfer rate between the C-11 and C-9 basins to 300 cfs also. This would violate one of the base design assumptions for the BCWPA Project that these transfers can be made at a maximum rate of 1,000 cfs. The BCWPA model already uses a discharge limit of 250 cfs at S-511, which is assumed to satisfy the intent of this recommended limit at S-30. Also, basing the available conveyance capacity of the C-9 Canal on a discharge of 400 cfs would seem to be quite conservative. Simulated wet-season runoff in the C-9 Basin is greater than 400 cfs about 40 percent of the time (Figure 3.6) or two months of every five-month wet season, on average. However, this recommendation and the recommended lower discharge limit at S-13A were implemented as a second sensitivity case, Case 2. The impacts of these revised discharge limits are summarized in Table 3.12.

Table 3.12: Sensitivity Case 2

Flow Component	Base Model Assumptions			Operations Division Recommendations		
	Avg. Year	Min. Year	Max. Year	Avg. Year	Min. Year	Max. Year
S-13A	68,478	26,353	104,129	42,750	20,893	60,006
S-503	9,576	141	32,336	34,703	5,799	71,683
S-511[a]	14,218	201	69,818	24,110	5,943	47,535
S-9/S-9A:						
C-11 Runoff	990	0	11,198	9,897	0	37,487
Seepage	59,090	41,236	76,483	45,949	33,785	65,915
Total	60,080	41,236	87,681	55,846	33,785	103,402

a. C-11 Basin transfers conveyed directly to tide at S-511. Does not include C-9 Impoundment drawdown releases that would also pass through S-511.

Review of Table 3.12 shows the average discharge at S-13 is further reduced from Sensitivity Case 1 to 42,750 AF/yr and C-11 Impoundment inflows at S-503 increase correspondingly. Average discharges at S-511 actually increase over the base modeling results even with the more restrictive discharge limits but this is a result of the much more frequent transfers from the C-11 Impoundment. The key result though is the significant increase in the amount of C-11 West Basin runoff that is discharged to WCA-3A. This discharge increases by a factor of nearly ten, from an average of 990 AF/yr (1.4 cfs) to 9,897 AF/yr (13.7 cfs). Although there is more basin runoff discharged to WCA-3A with these discharge limits, this increase is more than offset by a decrease in the amount of seepage returned at S-9/S-9A. This flow component decreases because there would be more frequent transfers to the C-9 Basin under this alternative and correspondingly more seepage diverted to this basin along with C-11 Basin runoff.

Although the revised discharge limit assumptions in both sensitivity cases are shown to have a significant impact on the amount of C-11 West Basin runoff that is discharged to WCA-3A, these average discharges are still much less than those estimated in the SFWMM simulation (23,760 AF/yr). These simulation results show the significant benefits of releasing C-11 West Basin runoff directly to tide, even at modest discharge rates.

3.4 Comparison of Model Results to Prior Studies and Plans

In this section, the key modeling result for the SFWMM and BCWPA simulations — the amount of C-11 West Basin runoff discharged to WCA-3A — is compared to estimates reported in prior studies and plans. These comparisons are summarized in Table 3.13. The analyses in this current study assume 2010 conditions after the initial development phase of the Broward County WPA Project. For these conditions, several of the prior studies report similar projections for the amount of C-11 Basin runoff discharged to WCA-3A. The Basin Specific Feasibility Studies (BSFS), Long-Term Plan (LTP) and Flood Protection Analysis all list a value of approximately 18,300 AF/yr for 2010 conditions. The District's estimates developed from the latest SFWMM simulation are only slightly higher at 23,760 AF/yr. With implementation of all of the operating changes recommended in the Flood Protection Analysis, the quantities of basin runoff discharged to WCA-3A drop dramatically to less than 1,000 AF/yr. This estimate (990 AF/yr) is only about 10 percent higher than the projections for future (2037) conditions stated in the BSFS and LTP of about 900 AF/yr. Even with the more restrictive discharge limits explored in the two sensitivity cases, the amount of basin runoff discharged to WCA-3A is about half of previous projections, or less.

Table 3.13: Model Result Comparison Summary

Study or Plan	Average Annual C-11 West Runoff to WCA-3A[a] (acre-feet/year)		
	Historic Conditions[b]	2010 Conditions[c]	2037 Conditions[d]
Baseline Data[e]	210,077[f]	---[g]	---
Basin Specific Feasibility Studies[h]	---	18,283	885
Long-Term Plan[i]	194,000	18,300	900
Flood Protection Analysis[j]	---	18,283	---
SFWMM version 5.4.3.1[k]	---	23,760	---
BCWPA Model[l]	---	990	---
BCWPA Model–Sensitivity Case 1[m]	---	3,698	---
BCWPA Model–Sensitivity Case 2[n]	---	9,897	---

a. Discharge to WCA-3A at S-9 and S-9A pump stations.
b. Historic conditions prior to development of Western C-11 Water Quality Project (S-9A and S-381). Values reported in this column are for total discharge at Pump Station S-9 (C-11 Basin runoff plus WCA seepage).
c. Includes development of Western C-11 Water Quality Project (S-9A and S-381) plus initial development of Broward County WPA Project (C-11 Impoundment, C-9 Impoundment, and 3A/3B Seepage Management Areas).
d. Includes ultimate planned development of Broward County WPA Project with North Lake Belt Storage Area Project, etc.
e. SFWMD, *Baseline Data for the Basin-Specific Feasibility Studies to Achieve Long-Term Water Quality Goals for the Everglades*, May 2001.
f. Total S-9 discharge, which includes C-11 West Basin runoff and WCA seepage.
g. Indicates data are not available or not applicable.
h. Brown and Caldwell, *Basin Specific Feasibility Studies, Everglades Stormwater Program Basins, Contract C-E024*, October 2002.
i. Burns & McDonnell, *Everglades Protection Area Tributary Basins, Conceptual Plan for Achieving Long-Term Water Quality Goals, Final Report*, March 2003.
j. Burns & McDonnell, *Flood Protection Analysis for Broward County Water Preserve Areas, C-11 and C-9 Impoundments (Final Report)*, February 2006. Data extracted from SFWMM simulation dated May 2004.
k. SFWMM version 5.4.3.1 (November 2005) for 2010 Conditions. Total discharge at S-9/S-9A was apportioned between C-11 West Basin runoff and WCA seepage based on District estimates.
l. Simulation results from BCWPA model described in Section 3.3.
m. S-13A discharge limit lowered from 250 to 120 cfs.
n. S-13A discharge limit lowered from 250 to 100 cfs and available conveyance capacity of C-9 Canal based on limit of 400 cfs instead of 872 cfs.

* * * * *

4 CONCLUSIONS AND RECOMMENDATIONS

This report section presents a summary of the conclusions reached as a result of the investigations and analyses conducted during this study, and offers recommendations for the District and Corps of Engineers to consider as they continue their planning process for the Broward County WPA project.

4.1 Conclusions

The conclusions reached during this study are presented below, organized by their primary subject matter.

4.1.1 Stormwater Treatment Potential of C-11 Impoundment

MACTEC Engineering and Consulting, Inc. developed alternatives to enhance the stormwater treatment potential of the C-11 Impoundment. From Burns & McDonnell's assessment of these alternatives, it is concluded that:

1. Projected phosphorus reduction in the C-11 Impoundment would, particularly under high rates of inflow, be nominal at best under either of the alternatives considered in the MACTEC analysis.

2. It is considered likely that outflow concentrations under high rates of inflow would actually be elevated above inflow concentrations due to mobilization and transport of vegetative material for either of the alternatives considered.

3. Incremental project expenditures associated with the construction and operation of additional project features under either of the two alternatives considered would not appear to be cost-effective, given little or no benefit in phosphorous reduction.

4. The basic footprint of the reservoir, when considered in combination with the anticipated high rates of inflow, effectively prevents the development of a vegetative community capable of increasing phosphorous reduction due to excessive velocities.

5. The most effective strategy for reducing phosphorous discharges at S-9 will consist of minimizing S-9 discharge volumes in lieu of attempting phosphorus reduction in the C-11 Impoundment.

4.1.2 Design and Operations of Broward County WPA Project

From the simulation model developed for the BCWPA project area, the following conclusions were drawn:

1. Because of limitations in the capabilities of the South Florida Water Management Model, the latest SFWMM simulation for the BCWPA project area does not well represent the recommended operations of this project, in particular increased conveyance of Western C-11 Basin runoff directly to tide via Structure S-13A.

2. One of the principal goals of the BCWPA project is to reduce the discharge of untreated basin runoff to WCA-3A at S-9. The effectiveness of the project in meeting this goal can be greatly enhanced by maximizing the volumes of C-11 Basin runoff released directly to tide.

3. The amount of untreated basin runoff that will continue to be discharged to WCA-3A after project implementation is highly sensitive to the available conveyance capacity for releases directly to tide via the C-11 and C-9 canals. For example, reducing the allowable discharge rate at S-13A from 250 to 120 cfs increases the discharge of untreated basin runoff at S-9 nearly four fold, from an average of 990 to 3,698 acre-feet/year. A ten-fold increase would result using the conveyance limits for the eastern C-11 and C-9 canals proposed by the District's Operating Division.

4.2 Recommendations

Given the conclusions reached during this study, the following recommendations for project design or operational changes, and additional analyses are offered for consideration by the District and Corps of Engineers.

1. Inclusion of additional design features in the C-11 Impoundment to enhance its stormwater treatment potential, such as internal levees to maximize residence time, would not be cost effective and should not be implemented. However, care should be taken to limit internal velocities in the impoundment to reduce the potential for erosion, reduce the likelihood that fish will be swept out of the impoundment when the spillway is open, and reduce the potential for resuspension of vegetative matter that could increase the phosphorus concentrations in impoundment discharges.

2. The BCWPA Project Operating Manual should be revised to make releasing Western C-11 Basin runoff to tide via structure S-13A a first priority. Similarly, during transfers from the C-11 Impoundment to C-9 Basin, the available capacity of the C-9 Canal should be utilized to convey these interbasin transfers directly to tide via structure S-511 to the extent practicable.

3. A detailed hydraulic analysis of the C-11 East Canal, including Structure S-13A, should be completed to better define the available capacity of this canal to convey Western C-11 Basin runoff directly to tide under a broad range of possible antecedent conditions. A similar hydraulic analysis should also be completed for the C-9 Canal between S-30 and S-29.

4. The proposed design for the C-11 Impoundment should be modified to include a small spillway, or similar gravity discharge structure, that would be located adjacent to the S-503 pump station. This new spillway would allow drawdown releases from this impoundment to be discharged to the C-11 Canal east of S-381 and eliminate the need to open the S-381 and S-504A spillways before making such drawdown releases.

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