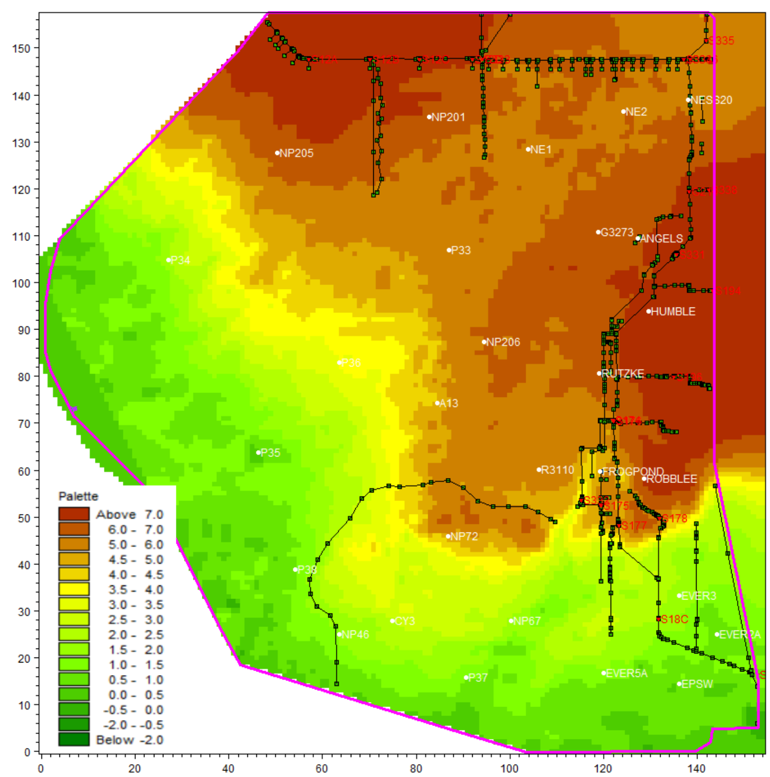
National Park Service
U.S. Department of the Interior

South Florida Natural Resources Center
Everglades National Park

Model Documentation
M3ENP Version V914V3

MIKE Marsh Model

of Everglades National Park



HYDROLOGIC MODEL REPORT

SFNRC Technical Series 2016:DRAFT

Cover picture shows M3ENP topography. Can explain this more here...

MODEL DOCUMENTATION
M3ENPVersion V914V3

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HYDROLOGIC MODEL REPORT

SFNRC Technical Series 2016:DRAFT

South Florida Natural Resources Center
Everglades National Park
Homestead, Florida

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Model Documentation: M3ENP version V914V3
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HYDROLOGIC MODEL REPORT

SFNRC Technical Series 2016:DRAFT

EXECUTIVE SUMMARY

Introduction

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The M3ENP Model

Put text here...

Model Performance Evaluation

Put text here...

Simulation of Water Management Alternatives

Put text here...

Conclusions

Put text here...

TABLE OF CONTENTS

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FOREWORD

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1 Introduction

The ongoing structural and operational modifications to the regional Central and Southern Florida project present challenges in evaluating the effects of these activities on the hydrologic resources of Everglades National Park (ENP). An integrated surface and subsurface hydrological modeling tool has been developed to analyze and assess the performance of these projects and enable SFNRC staff to effectively participate in planning of these projects so that they could provide benefits to the natural resources of ENP. The location of the model area is shown in Fig. 1. This documentation report covers work which was completed since the first release of the model (Tachiev and Cook, 2011). Additional documentation and applications of the model can also be found in Cook (2012), Long (2014), Long (2015b), and Long (2015a).

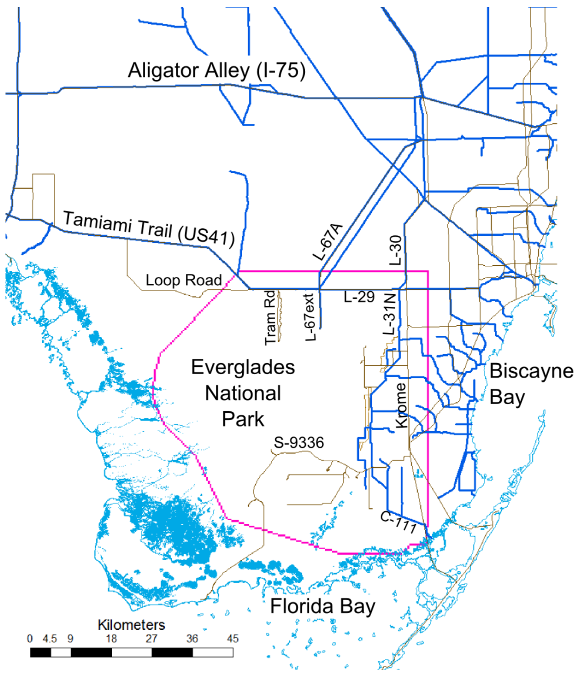


Figure 1. Model Domain Location

Documentation is provided herein for the latest release of Mike Marsh Model for Everglades National Park (M3ENP), V914V3, which can cover the time period 1987through 2010. This version includes all the Central and Southern Project (C&SF) canals and the more recent constructed features documented in the C-111 General Re-evaluation Report (GRR) (U.S. Army Corps of Engineers, 1994) and the Modified Water Deliveries to Everglades National Park (MWD) General Design Memorandum (GDM) (U.S. Army Corps of Engineers, 1993). The canal operational rules used in the model are for the recent time period and as prescribed by the Interim Operational Plan (IOP) (U.S. Army Corps of Engineers, 2002) and its renewal under the Everglades Restoration Transition (ERTP) (U.S. Army Corps of Engineers, 2011) program. The resulting output of the model reflects the structural components and operational rules in place post ca. 2010. This includes fully operational pumps discharging in the constructed built-out detention areas, including the S-357 area, but excluding the Northern Detention Area (NDA). Operational rules in the model reflect actual field operations as determined from observed data and may be slightly different from the rules defined officially in the various programs. This is done in part to achieve better model calibration as well as to incorporate the minor deviations from authorized operations. An extensive set of MATLAB scripts were developed to pre- and post-process observed and computed data and to compare multiple simulations. Probability exceedance cumulative values, boxplots and conventional statistical parameters calculations are provided for representative stations throughout the model domain. A comprehensive appendix section detailing the model output is part of this document and provides in-depth information on the simulation results of the current version for monitoring stations during model time period 1999-2000. M3ENP is a combination of the MIKE SHE and M11 packages of the DHI (Danish Hydraulic Institute) software product (Environment (2011) and Environment (2007)) and produces a fully integrated model environment. Advantages of this product include the incorporation of complicated and detailed dynamic structural operations in the canal network, allowing a full exploration and evaluation of operational strategies. This software has been extensively peer reviewed and has been implemented throughout the world. In addition to the MIKE SHE and M11 components, it is possible to further integrate this model with coastal and water quality packages.

The important natural features, Shark and Taylor Slough are included, as well as all the inflow features (gates and pumps) to the Park. Detailed representation of the detention areas, including the yet-to-be-built Northern Detention Area (NDA) and yet-to-be-of-use S-356 and S-357 allow the evaluation of infrastructure design and operational rules to ensure benefits to the Natural Resources of the Park. The model area covering the eastern developed areas provides opportunities to evaluate flood control conditions adjacent to the L-31N/C-111 complex.

In addition to the overland flow component, three aquifer layers are included in the MIKE SHE model to enable evaluation of the near-surface characteristics as well as to quantify the seepage flows to the adjacent canals. A peat, and two limestone aquifer layers provide the subsurface component, with the peat layer allowing the evaluation of the distinct natural separation between surface water and groundwater and is an important feature near canals (e.g., in the northern reach of L-31N).

1.1 Calibration and Operational Versions

This report emphasizes an operational version of M3ENP. Canal infrastructure and operations are based on fully built-out detention areas, including operations at the S-332B, C and D, S-357, S-199 and S-200 pumps. Calibration of the original two-layer model is discussed in detail in Tachiev and Cook (2011). The expansion of the model domain and conversion to three geological layers in the current model (Version 914) was done to not break the calibration achieved in the earlier version. A calibration run of this model (V914calibV0) has been done and the output is available as ?REF?Appendix B. The calibration run uses prescribed flows for many structures as discussed in ?REF?Section 6.1, however it should be noted that fully built-out detention areas are used in the model, but actual construction of these areas spanned much of the decade from 2000 to 2010, the period used in the run. For the operational run the time period from 2000 to 2010 is used for this documentation, since this was the period when operations were changed to the current IOP/ERTP rules. The model has been constructed to be able to use the time period from 1987 to 2010, the first year used as a warm-up year and generally discarded in the analysis. The early period 1987 to 1999, is a period of different operational rules and there were no detention areas. A separate model the No-Detention (ND) version has been used for this early time period with Test 7 Phase 1 rules (see ?REF?Table 1). This model aided during the calibration phase of the MIKE SHE parameters. When the model is used for alternative analyses, the entire 1987 to 2010 time period can be used with the actual documented operational rules and alternative proposed rules. Care should be taken at certain structures (e.g., S-334), which do not use rules, but actual prescribed discharges which were changed after IOP was implemented. A complete set of output is available as ?REF?Appendix A. A Nash-Sutcliffe model efficiency coefficient comparison of the calibration and the operational model is presented in ?REF?Fig. 4 and ?REF?Fig. 3. An efficiency of 1 means that there is a perfect match between the model and the observed data. An efficiency of 0 indicates that the model predictions are as accurate as the mean of the observed data. In the figures values below 50 are not shown. The data set was culled for readability and the canal data has been eliminated. The calibration version (V914calib) are the lower numbers in blue. The operational version (V914V1) are the green values at the top.

RJF Figure 3 was here but has not been copied over to this version: Nash-Sutcliffe values for the northern portion of the domain.

RJF Figure 4 was here but has not been copied over to this version: Nash-Sutcliffe values for the southern portion of the domain.

1.2 Model Output

Output from the model is available at all the observation well locations in the domain. Surface water and each of the three groundwater layers are presented in the output for each model run in the form of timeseries plots, boxplots and exceedance graphs. Canal stages and structure flows with headwater and tailwater stages is also available in the output. The resulting 400 page pdf-formatted output file can be augmented with additional location specific information as well as spatial plots of flows, heads and stages.

2 MIKE SHE Module of M3ENP

2.1 Introduction

The MIKE SHE (MSHE) component is a distributed, three-dimensional saturated and unsaturated groundwater flow model with two-dimensional overland/sheet flow which uses Richard's equation and known van Genuchten's parameters to determine flow in the unsaturated zone (UZ) (Environment, 2007). Using the law of conservation of mass and the laws of momentum and energy (three-dimensional Boussinesq and transport equations), MSHE solves the subsurface flow and transport by coupling several partial differential equations (PDEs) which describe flow in the saturated zone (SZ) and unsaturated zone (UZ) with surface water (overland) and channel flow. Different numerical solution schemes are then used to solve the different PDEs for each process. A solution to the system of equations associated with each process is found iteratively by use of different numerical solvers.

In M3ENP, a most important component for evaluating the hydrologic condition of the natural resources of ENP is output from the overland flow model. MSHE solves the actual overland flow equations allowing for a proper model evaluation of surface water quantities and directions. The MSHE subsurface component solves the groundwater equations with surface water/groundwater interaction facilitating for the infiltration between surface water and groundwater. MSHE groundwater layers interact with the M11 canal network through a seepage link where exchange flows are computed based on head differences. The exchange quantities are adjusted by a seepage coefficient established during calibration. Only aquifer layers that intersect fully or partially with the canal are used in the computation of the leakage.

The canal network can also interact with the surface water through the implementation of an overbank flow setting and the exchange configured through manipulating the cross-section elevations. Another canal/surface-water interaction feature is to assign cell flood codes, which allow for interaction between surface and canal water through a continuity equation calculation instead or in addition of the dynamic overbank flow computation. Both methods are useful in M3ENP and have been implemented downstream of the Tamiami Trail culverts, the L-31W, upper C-111E and detention areas canals.

The most commonly used version of the M3ENP suite uses a grid cell size of 400x400m. The software has the ability to change easily to other grid cell sizes and to run smaller areas of the domain (subdomains). A version using a 200X200m cell size has also been constructed and is used in a subdomain concentrating on the major canals adjacent to the Park. The input coverages such as topography can be input as smaller grid cell values, which the software will use and convert either to a larger or smaller grid as needed, for example, the topography layer can be input as a 50x50m gridded coverage of large spatial extent. The model will interpolate these grids to the relevant cell size.

2.2 Model Domain and Grid

The model domain includes an area of approximately 1200 square miles and 110 miles of canals shown in Fig. 2. The north boundary of the model domain is 2.5 miles north of L-29 and starts near S-343A at the western boundary and extends 2.5 miles east of Krome Ave. The eastern boundary parallels Krome avenue from north of L-29 to south of S-197. The southwestern boundary was set near the 0.5 ft. elevation contour line and extends westward to Lostman's River. The northwestern boundary intersects the north boundary near Loop Road. The model domain was divided in a regularly-spaced grid of 158 rows and 155 columns, with a square cell size of 400 meters. There are 18299 active interior cells.

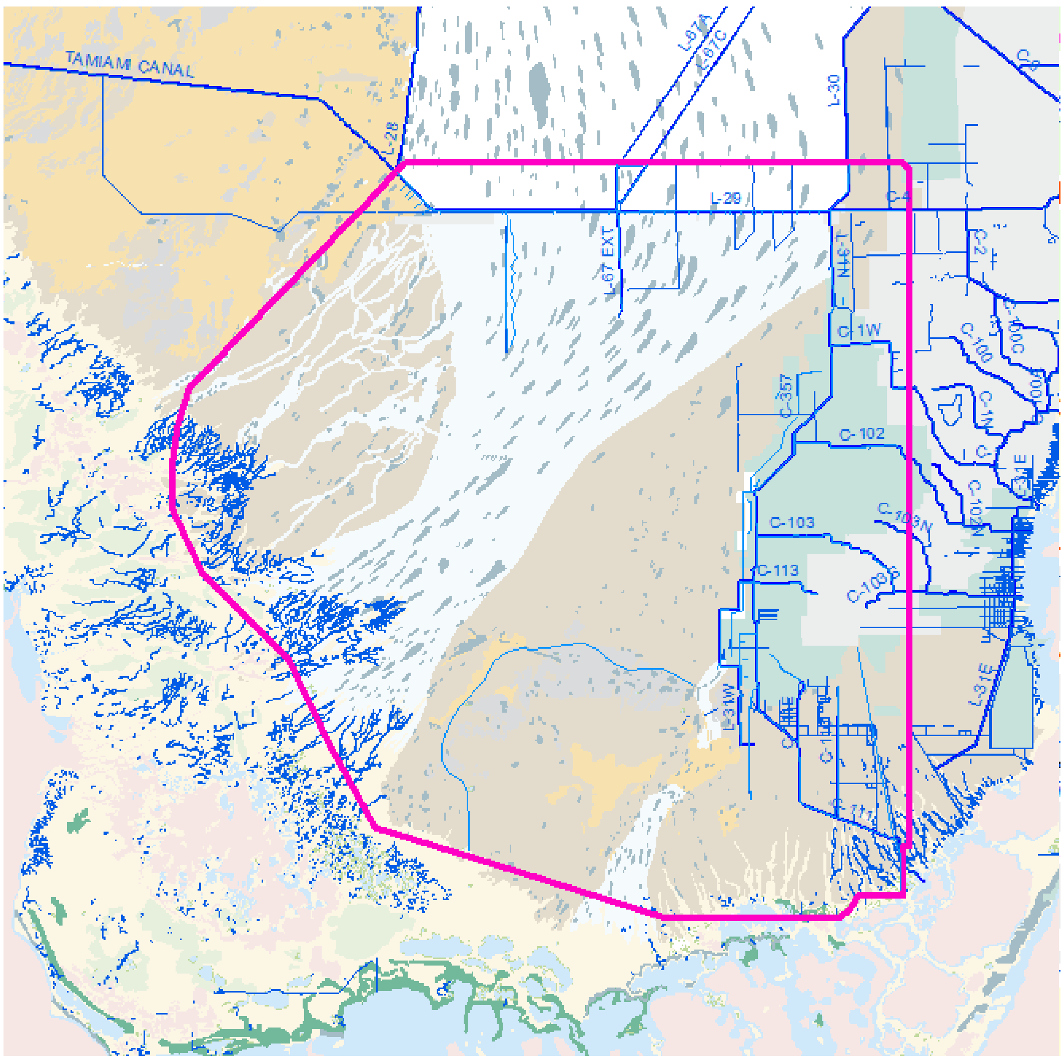


Figure 2. NEEDS UPDATED: Detail of the model domain (in pink) showing canals, structures and major observation points. The interior domain is over 1200 mi2 (3100 km2) with a cell size of 400 by 400 meters. The observation points, including wells, canal flow and stages total 350. (File: DOMAINeastV1.dfs2)

2.3 Topography

The topography of the domain was updated from the original version (Tachiev and Cook, 2011) using a combination of field surveys and LIDAR information. An extensive field survey conducted by contractors (Beadman) for Everglades National Park was conducted in the mid 1980s, and was combined with similar field surveys conducted by private entities (Frogpond) and by the Corps of Engineers (C-111 and 8.5SMA). The USGS conducted a helicopter survey (HAED) which covered much of the same area as the earlier surveys within Everglades National Park. The LIDAR coverage obtained from the Corps of Engineers, covering all of South Florida was also used. These sources were combined and visually inspected for accuracy. Contour lines were generated via ARCMAP based on the available data and adjusted manually to incorporate smaller features such as the upper reach of Taylor Slough, Frog Pond, 8.5SMA and lower C-111. An elevation model was generated as a 50m square raster and point file and resampled from elev33 to 400m grid cells as shown in Fig. 3. The file was modified to include the 8.5SMA levee and higher elevation cells were incorporated at canal intersections to prevent spurious surface water flows.

The southern boundary of the model domain was terminated at approximately the 0.5 ft. contour. Some elevation adjustments were made in the southeast area of the model to even the topography of the boundary cells. This was done to reduce the large variation in flows in adjacent boundary cells causing some local instability. In addition the elevation file used for input to the model has higher elevation values corresponding to the levee around the 8.5SMA. To prevent spurious overland flow occurring at canal intersections, several cells have been elevated to prevent surface flow from taking place at these locations.

The native datum used in M3ENP is NGVD29.

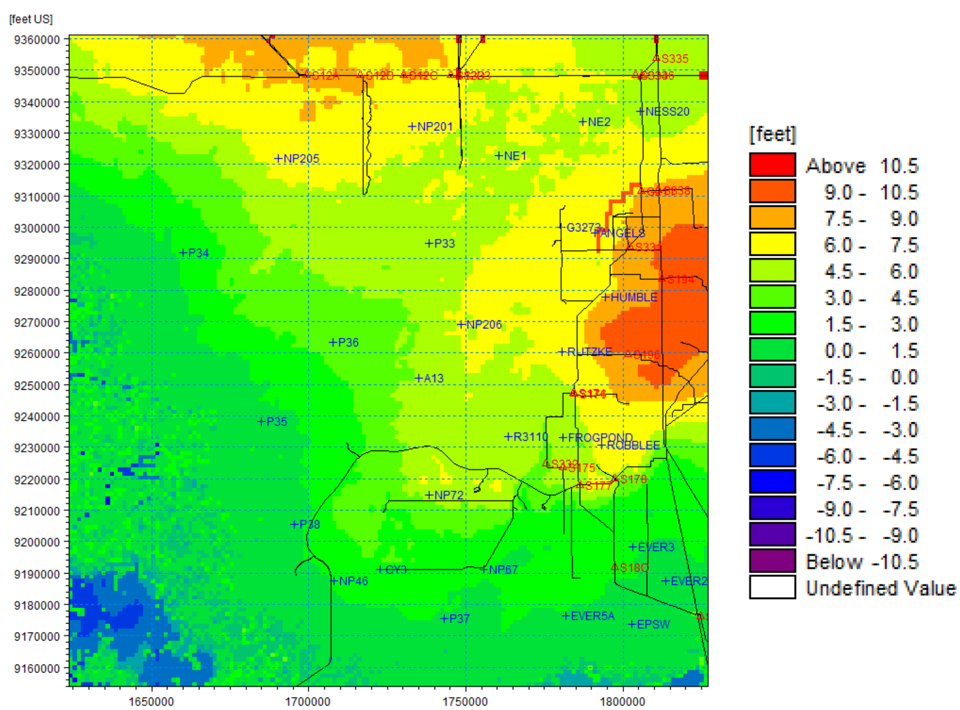


Figure 3. Model topography used in M3ENP. (File: Elev33V2.dfs2)

2.4 Climate

2.4.1 Precipitation

The gridded timeseries from the SFWMM was used to generate the daily rainfall input from 1987 to 2005, the data set was concatenated with the NEXRAD rainfall data from 2005 to 2010. Model comparisons were done on the output of the overlapping year (2005) for the SFWMM data and the NEXRAD data and achieved similar response across the model domain. A separate test was also completed using Thiessen polygons of the observed data sets and the response was also similar.

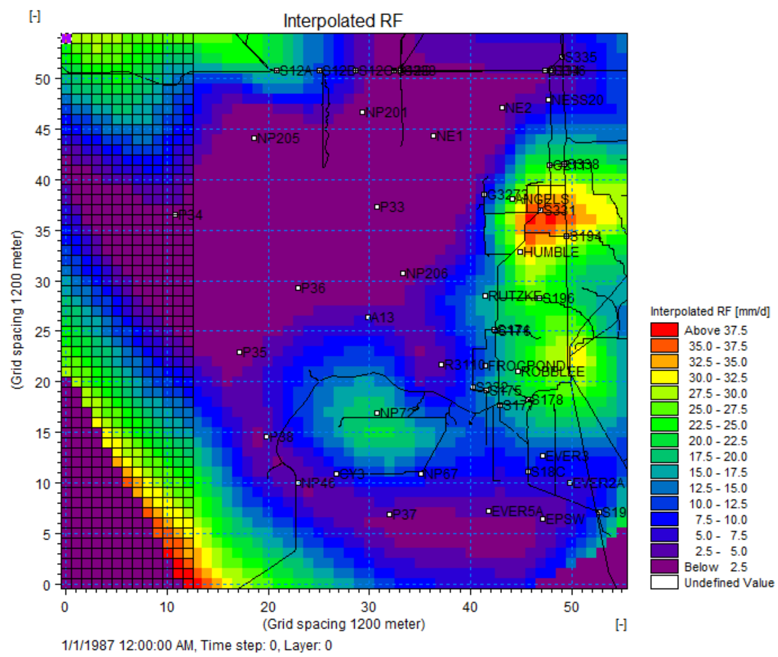


Figure 4. Rainfall for 1/1/1987. (File: V6_RF_87_10.dfs2)

2.4.2 Reference Evapotranspiration

The evapotranspiration (ET) process is of major importance, the process extracts a large quantity from the water budget. The term refers to both evaporation from the soil and plant surfaces and transpiration from the plant canopies. The "potential" evapotranspiration (PET) is established from observed data and subsequently modified in the model based on land use (vegetation, crop) through the use of proper crop coefficients (Kc) to arrive at the actual crop evapotranspiration. For many crops the adjustments are made based on a reference value, obtained through experiments. Ground-based pyranometers have been used to estimate the regional daily PET values, however today the estimates are derived from solar radiation values from satellites.

The earlier versions of M3ENP used interpolated and extrapolated daily values from the South Florida Water Management Model (SFWMM) for each grid cell. The data set was subsequently updated with the satellite estimates by ?REF?Jacobs et al. (2008) from 2000 to 2010, replacing the SFWMM data from 2000 to 2004 and adding new satellite data for 2005 to 2010.

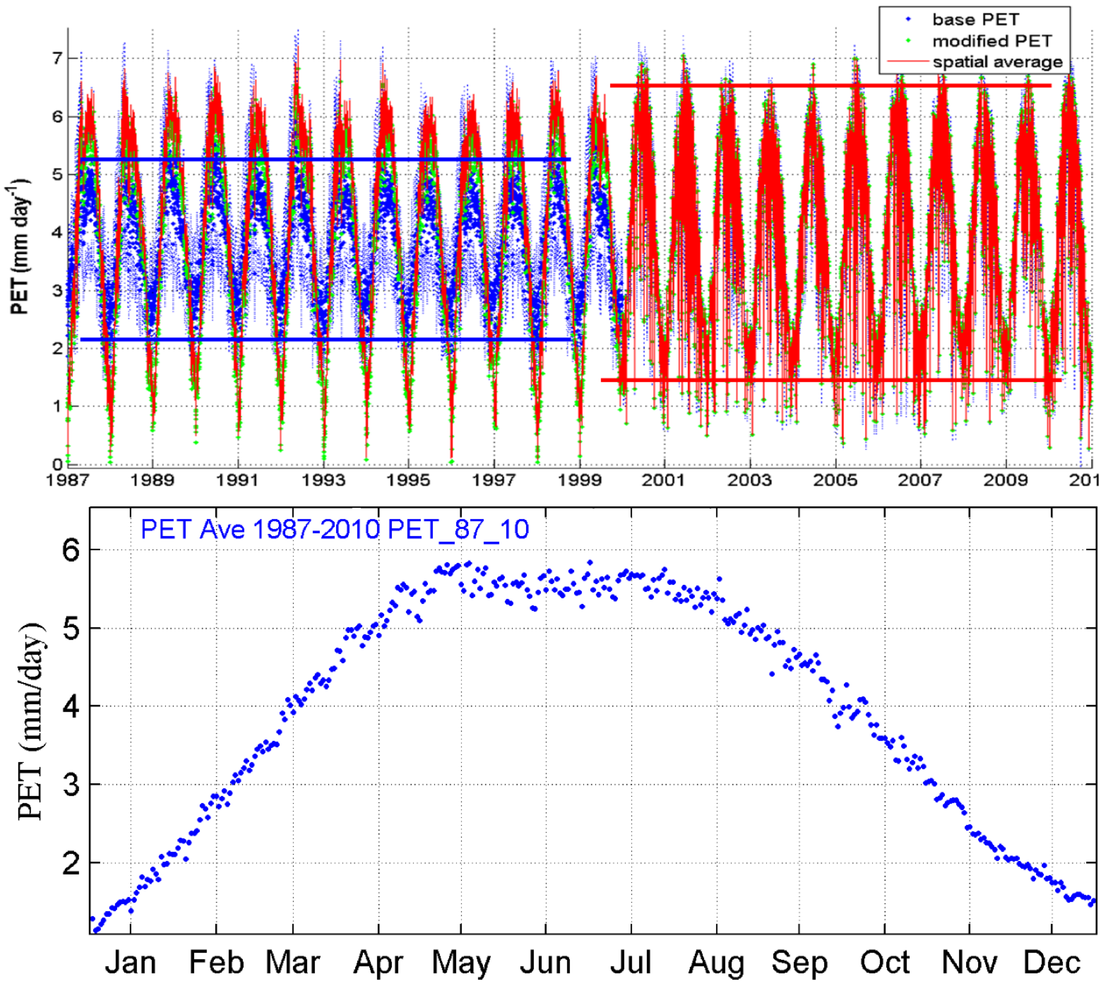


Figure 5. Potential Evapotranspiration (PET) Timeseries Derivation. The SFWMM data (blue) set was merged with satellite data in 2000. The earlier data was modified to increase the variability (maximums and minimums) using the later data as a guide.

The earlier time period (1987-2004) exhibited less variability in the daily rates; to increase the bandwidth of the older data, the timeseries was modified based on the recent data's variability to increase this bandwidth. Subsequently the spatial data set was replaced by a single timeseries and tested. The derivation of this timeseries is shown in Figure 5 and the final dataset used is shown in Figure 6).

No significant changes were observed going from a spatial PET distribution to a single timeseries (?REF?Jordan Barr SFNRC 2014, unpublished). In the upper plot of the figure the original data set (spatial average of the gridded data set, with the bandwidth shown in blue) is compared with the modification to increase the variability (larger bandwidth as displayed in red). The temporal annual average of the adjusted timeseries used in the model is shown in the bottom plot. The parameters associated with the vegetation classification are used in the model to adjust the daily potential evaporation input along with the representative water levels for each time step.

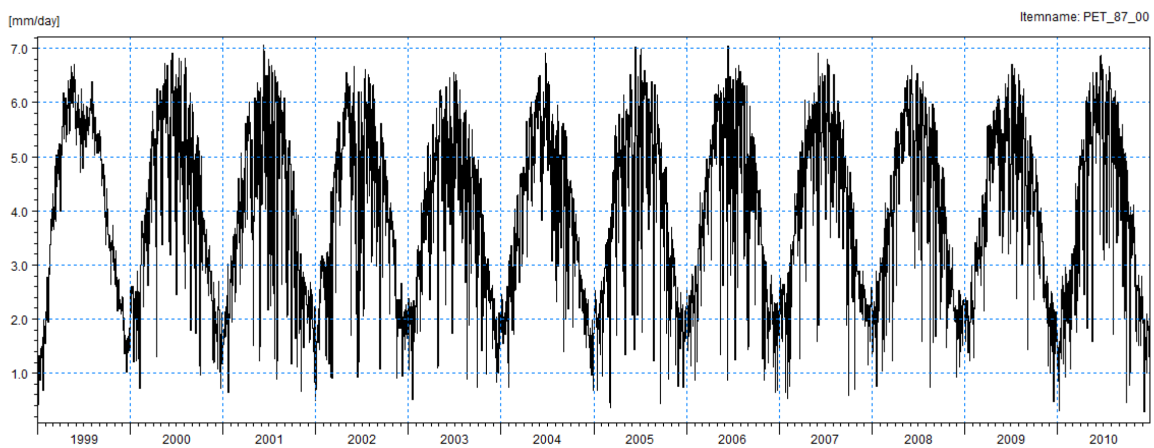


Figure 6. Potential Evapotranspiration (PET) Timeseries. (File: PET_87_10.dfs0)

2.5 Land Use

2.5.1 Vegetation and Adjusted Evapotranspiration

Vegetation categories (land use types) are used in the model to calculate adjustments to the potential evapotranspiration (PET) at every timestep. The model parameters associated with the vegetation categories are the Crop Coefficient (Kc), the Leaf Area Index (LAI) and the Root Depth (*Root*) (Environment, 2007).

The Kc values adjust based on the "reference" evapotranspiration for the crop type, and the *Root* is the depth at which point no ET will occur. The LAI is used to adjust for interception storage, e.g., on bare ground the LAI is zero and no water will be removed from the unsaturated zone. These values are input as a monthly timeseries for each year of the simulation. In M3ENP annual changes do not occur, so every year the monthly sequence of values is the same. An example of the timeseries for Marl is shown in Figure 7.

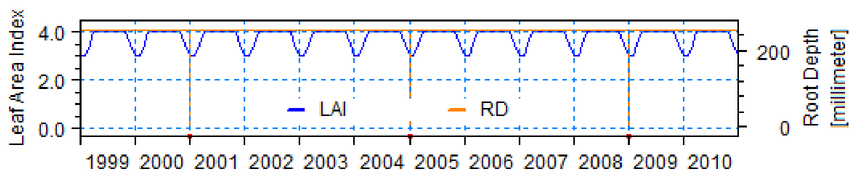


Figure 7. Leaf Area Index and Root Depth Timeseries for Sawgrass

The following parameters are used in the model:

CanIntc, C_{int}	Canopy interception (mm)
C1	Slope of the linear relation between LAI and Ea/Ep; which LAI the actual ET equals PET at ample water supply
C2	Fraction of PET which is always allocated to basic soil ET
C3	Regulates water stress on transpiration (light soils higher than heavy soils)
Aroot	Root distribution, one means 60% of roots are located in upper 20 cm of soil at root depth of 1m
LAI	Leaf area index (leaf area/ground area)
Root	Rooting depth
Kc	Crop coefficient

Computation The calculation of evapotranspiration uses meteorological and vegetative data to predict the total evapotranspiration and net rainfall due to (Environment, 2007):

- Interception of rainfall by the canopy
- Drainage from the canopy to the soil surface
- Evaporation from the canopy surface
- Evaporation from the soil surface
- Uptake of water by plant roots and its transpiration, based on soil moisture in the unsaturated root zone

Vegetation Category	Crop Coefficient (Kc)	Leaf Area Index	Root Depth (in.)
Agriculture and Urban	1.3	3–4	80
Emergent Marsh (Open Marsh and Graminoid)	0.6–1.0	3–4	12
Exotics	1.0	3–4	72
Hammock (Willow, Cypress and Bayhead)	0.6–1.0	3–4	60
Mangrove	1.0	3–4	16
Open Water	1.0	0	100
Pine Forest	1.0-1.2	3–4	72
Sawgrass	0.9	3–4	10
Sawgrass, Deep	0.9–1.5	3–4	36
Sawgrass, Deep, South	0.7–1.1	3–4	12
Wet Prairie (Muhly and Rush)	0.9	2–3	80
Wet Prairie (Muhly and Rush), Deep	0.9–1.4	3–4	36
Wet Prairie (Muhly and Rush), Deep, South	0.7–1.3	3–4	12

Table 1. Vegetation Parameters. (File: VegDataV13.etv) Need to update to VegDataV14, which fixes a leap year issue

The primary ET model is based on empirically derived equations that follow the work of Kristensen and Jensen (1975). This model is used whenever the detailed Richards equation or Gravity flow methods are used in the Unsaturated Zone. In M3ENP the Gravity flow method is used and the parameters defined in the Land Use section of the model adjust the timeseries of potential evapotranspiration.

The sequence to arrive at the net ET is first: to calculate the net rainfall by subtracting water intercepted by the leaves (Environment, 2007). Net rainfall is added to the ground surface where it either infiltrates or ponds. Evapotranspiration is first removed from intercepted rainfall, followed by ponded water at the Reference ET rate. If the Reference ET is not yet satisfied for the current time step, then water is removed from the root zone via transpiration. The actual soil moisture content, soil field capacity and wilting point in each vertical cell are used to control the amount of transpiration. The vertical distribution of transpiration is controlled by the root depth and a root shape factor to distribute the ET within the root zone.

The actual evapotranspiration is the sum ET from the canopy, ponded water, unsaturated zone, and saturated zone. The actual ET cannot be greater than ET max and the ET is calculated in a specific order until ET max is reached. After the ET is removed from any available snow storage, ET is removed from the canopy storage until the canopy storage is exhausted or ET max is satisfied. If the interception storage cannot satisfy ET max, water is evaporated from the ponded water until the ponded water is exhausted. If ET max has not yet been satisfied, water is removed from the unsaturated zone until ET max is satisfied or the water content of the upper UZ layer is reduced to the minimum. If the water table is above the extinction depth, then ET is removed from SZ until ET max is satisfied. Potential evapotranspiration is the amount of water that could be evaporated and transpired if there were sufficient water available. It represents the evapotranspiration rate of a short green crop, completely shading the ground, of uniform height and with adequate water status in the soil profile.

The largest values in NCT were evaluated and a starting set of parameters determined for each new category, Table 1.

Vegetation Categories The Florida GAP land cover classification, a subset of the National Gap Analysis Program (NGAP) (USGS, 2012) was used to provide the base vegetation map and covers all the relevant land use types. The NGAP recognized the need for a consistent classification and supported the development of the National Vegetation Classification System (NVCS) (The Nature Conservancy, 1997). The NVCS is based on a hierarchical structure with vegetation physiognomic and floristic elements. In Florida, the program used Landsat TM satellite imagery from 1992 to 1994. This was coupled with existing soil and wetland maps, and low-level flight videography to improve the field accuracy assessment of the south Florida classification. Mapping land cover to the alliance level (a physiognomically uniform group of plant associations sharing one of more dominant or diagnostic species) was a stated goal of the program (Pearlstine et al., 1998).

The large number of land use classes used in the first versions of M3ENP proved to be cumbersome in its implementation. The bio branch at SFNRC reduced the number of categories to 22 classes (?REF? ELVES), these were further reduced to the current 13 classes for this model application. This reclassification of vegetation is shown in Fig. 8, the raster data is with a 50m grid, which for use in M3ENP was resampled to a 400m grid aligned with the model domain grid cells.

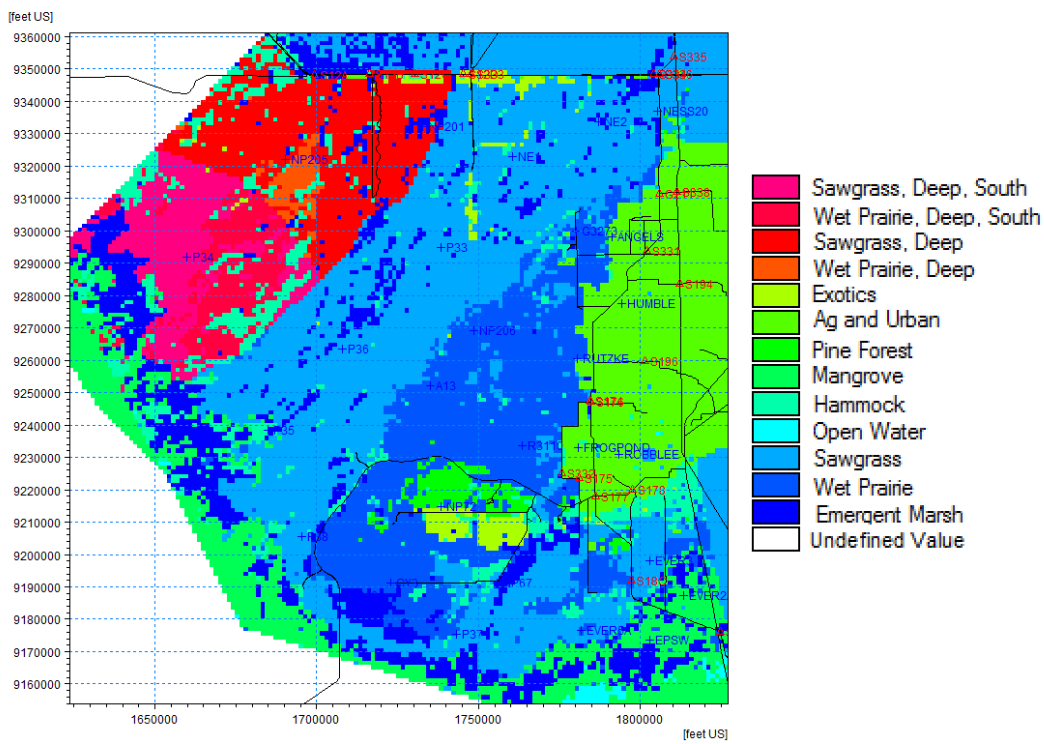


Figure 8. Vegetation categories. (File: VEGeastV2.dfs2)

Leaf Area Index The LAI is defined as the area of leaves per area of ground surface. The LAI values are characteristic of the plant type, season, and plant stress. LAI values are widely available in the literature for most major plant types. The LAI is a lumped parameter for a cell that defines the average leaf area of the cell. In forests, it includes both the leaf area of the forest canopy and the understory. In more open areas, it is an average for all vegetation types, such as grass, brush and trees. In areas of largely open water the LAI is usually zero.

If the LAI is zero, there will be no interception storage and no water will be removed from the unsaturated zone (Environment, 2007).

Root Depth The root depth defines the depth to which water will be removed from the unsaturated zone, if the depth is deeper than the depth of the capillary zone water will be extracted from the saturated zone. The depth is measured below ground in millimeters to which roots extend. The root depth is not necessarily the average root depth. In some cases it may be the maximum root depth. The thickness of the capillary zone is defined by the pedotransfer function in the soil properties for the Richards and Gravity flow methods. In the 2Layer UZ method, the thickness of the capillary zone is defined by the ET Surface Depth (Environment (2007) V.2? p. 141?). If the Richards or Gravity Flow UZ methods is used, then the Root Shape factor (AROOT) is available for each vegetation type. This allows it, for example, to extract more water from the upper UZ cells than the lower cells, which is typical of grasses in semi-arid climate zones. Due to the karstic conditions in South Florida most of the root depth adjustments have little influence on the solution.

Crop Coefficient The crop coefficient, Kc, is used to adjust the reference evapotranspiration. ET has different values depending on the landuse type. The Kc can be adjusted on a monthly basis and is input via the Vegetation property file alongside the LAI and Root parameters. Adjustments to Kc are an important calibration parameter in M3ENP for the different vegetation categories.

2.5.2 Paved Runoff Coefficient

As shown in Figure 9.

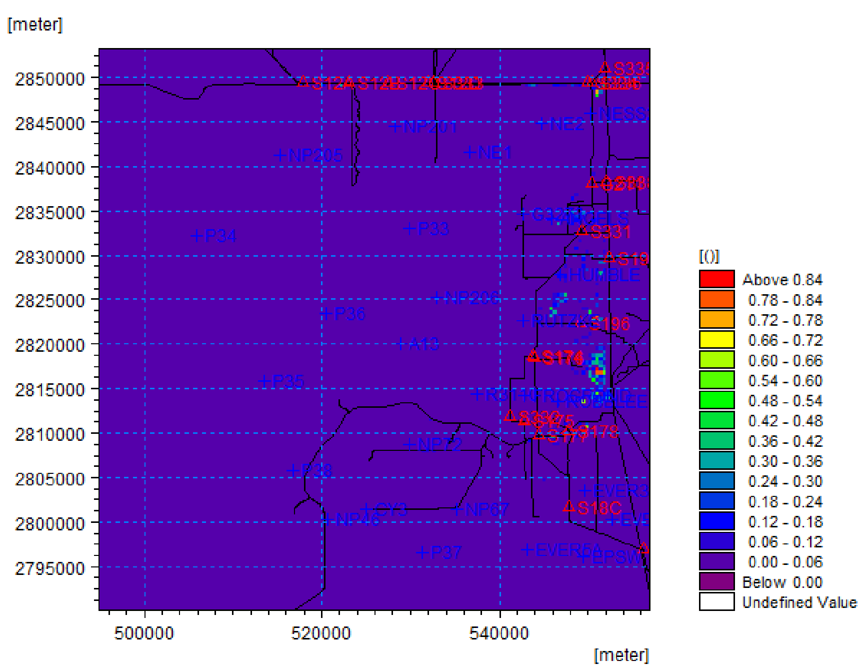


Figure 9. Paved Runoff Coefficient. (File: IMPERVIOUSv003.dfs2)

2.6 Overland Exchange With Canal System

Several overland cells in M3ENP are designated to interact with the canal network using floodcodes. These cells are shown in Figure 10. More information on this process can be found in the Canal structure section of this report.

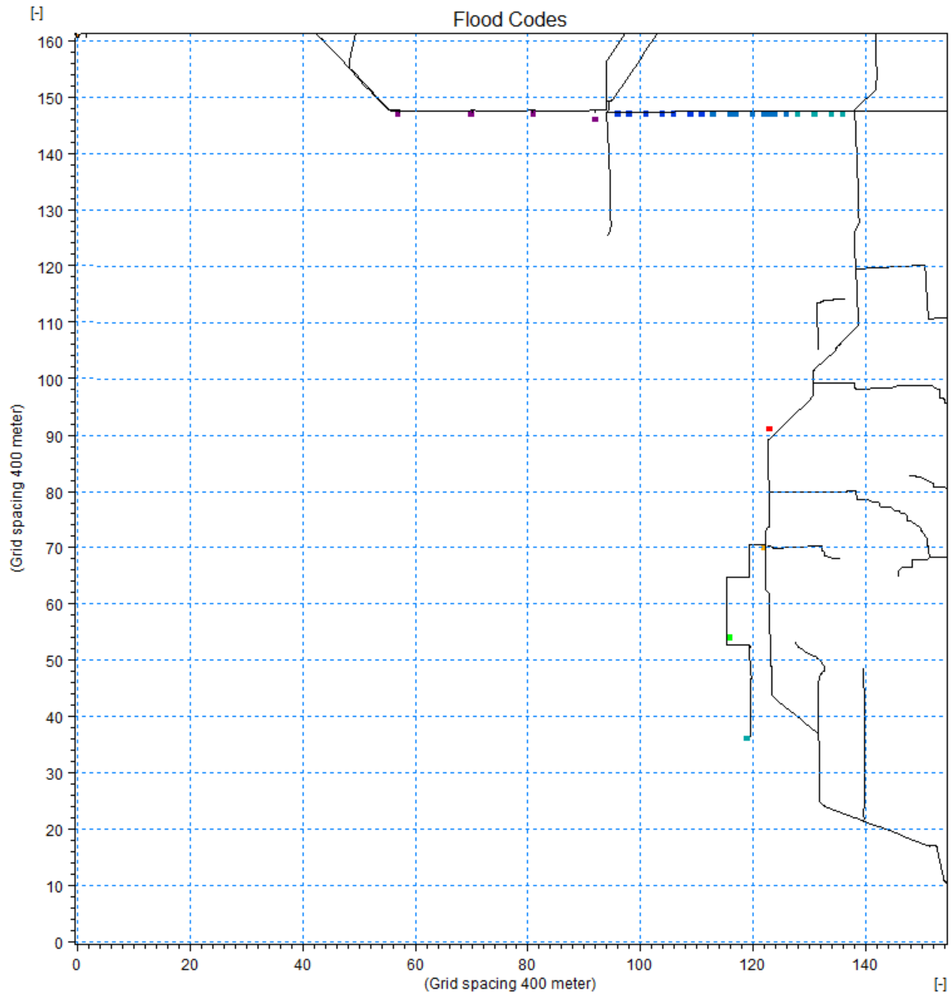


Figure 10. Flood-coded Cells. (File: FCeastbridgeV0.dfs2)

2.7 Overland Flow

Overland flow in MSHE is represented using the diffusive wave approximation of the Saint Venant equations computed in two dimensions. Use of the diffusive wave approximation allows the depth of flow to vary significantly between neighboring cells and backwater conditions to be simulated. The Explicit Numerical Solution method is used in M3ENP. This method requires smaller timesteps, but is more accurate, especially in the interaction with the M11 canal network. In MSHE the resistance of the bed to overland flow is defined through the Strickler's coefficient M, which is an inverse of the Manning's n number.

The initial simulations were conducted using uniformly distributed Manning's n equivalent to $M = 2m^{1/3} * s^{-1}(n = 0.5s * m^{-1/3})$. The value of $n = 0.5s * m^{-1/3}$ is based on experimental data reported for the Everglades. The recommended values of n are typically in the range of 0.01 (smooth surface) to 0.10 (thickly vegetated surface), which correspond to values of M between 100 and 10, respectively and this parameter has major effect on velocity and gradient of flow. The differential term is the inverse of the derivative of the Manning equation, with respect to h, which approaches zero as the gradient approaches zero. Thus, very low gradients, for example in very flat areas, will require very small time steps. Likewise, smaller grid spacing will also lead to smaller time steps. For simulations of flooding using the Direct Overbank Spilling to and from M11 option, then the M11 cross-sections are normally restricted to the main channel and the flood plain is defined as part of the MIKE SHE topography. It is usually necessary to have a very fine grid and a detailed Digital Elevation Model for such simulations, which tends to reduce the inconsistencies because it reduces the amount of interpolation and averaging when creating the model topography. A software feature to reduce the Courant numbers during these low-gradient computations is to apply a threshold gradient value which the software will use to apply a low-gradient flow reduction and damp the numerical instabilities.

The spatial distribution of the Manning M (Strickler) coefficient is shown in Fig. 11.

2.7.1 Low Gradient Damping Function

In at areas with ponded water, the head gradient between grid cells will be zero or nearly zero, which means that as the gradient goes to zero Δt also goes to zero. To allow the simulation to run with longer time steps and dampen any numerical instabilities in areas with low lateral gradients, the calculated intercell flows are multiplied by a damping factor when the gradients are close to zero (Environment, 2007). This condition arises in the model in the lower C-111 area, near the boundary, the southwest coastal zone, in the mangrove zone, and in WCA-3A, essentially a pool north of the S-12 structures. The threshold gradient value is changed in OL Computational Control Parameters and set to 1.0E-005 for the model runs. This value provides some smoothing, especially in WCA-3A and decreases the run time by at least 20%.

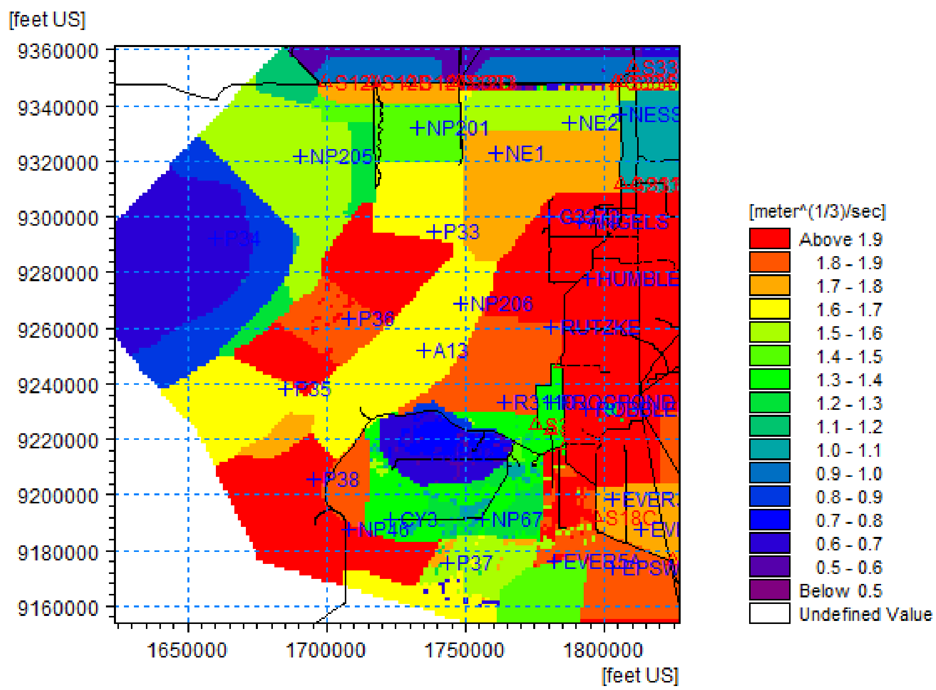


Figure 11. Manning M (Strickler) Coefficient. (File: MANNeastV2.dfs2)

2.8 Unsaturated Zone Flow

Unsaturated flow refers to the process whereby soil moisture is replenished by rainfall and removed by evapotranspiration and subsequently interacts with the saturated zone. The downward infiltration is primarily one-dimensional vertical flow and sufficient for this model application to calculate the infiltration from surface water to the saturated zone. The Gravity Flow procedure is used in the model to calculate the vertical flow, thereby ignoring capillary forces and the dynamics within the unsaturated zone. The different soil types define the unsaturated flow properties and the vertical discretization of the soil profile. Infiltration can be modified by the land use (vegetation), the actual evapotranspiration is calculated spatially and temporally from the reference evapotranspiration as modified by the vegetation properties. In M3ENP, for the unsaturated zone solution the simplified gravity flow computation is selected instead of the Richard's equation to reduce unneeded complexity (soil processes, such as capillarity etc.).

2.8.1 Soil

South Florida Everglades soils consist of peat, muck, marl and silica sand associations. The low relief of South Florida provided a suitable landscape to build up a thick layer of partially decomposed organic materials in the geological depressions. The central flow way of the Everglades consisted of these fibrist soils and established the pre-drainage landscape. In post-drainage times, fire, cultivation and lowered water levels caused the disappearance of the peat. In many areas the entire peat layer has vanished down to the limestone bedrock. In remaining poorly drained areas, the exposed bedrock became overlain by thin deposits of marl, especially where shallow depths (1 to 2 feet) of peat existed. Along the Atlantic shoreline the soil coverage consists of both marl and silica sand deposits. In Everglades National Park, subsidence has reduced the spatial coverage of peat; today much of the east and west side of the Park consists primarily of limestone pinnacle rock, in some areas overlain with a thin layer of marl.

Because of the peat layer, soil is an important layer in an Everglades hydrologic model application, the hydraulic properties, such as hydraulic conductivity and storage, vary markedly from the underlying limestone rock. The different soil parameters are key input components in the models and these have not been well quantified for Everglades peat and marl. Locally, soil properties can vary widely, peat layers alternate with marl layers, and poorly decomposed peats will vary in their properties spatially. Peat soil in the Everglades are typically made up of at least 70 percent organic matter and accumulate under fully saturated conditions. The absence of oxygen causes the remains of plants to not fully rot away, in areas where the organics are fully decomposed the soil is called a muck, with different hydraulic properties, peat and muck dominate the landscape in the central model domain.

Peat, unlike most soils is non-rigid, thus wetting and drying cycles may produce changes in storage and hydraulic conductivity. These non-linear changes are referred to as hysteresis and in peat are irreversible. Drying of peat soils cause compaction which permanently changes the hydraulic conductivity and storage. The periphyton that grows on the calcium bicarbonate laden surface water during the wet season precipitates calcite and the resulting soil formation is called a marl. Shorter hydroperiods reduce the accumulation of organic matter from decaying surface vegetation through the oxidation of the peat and allow the marl to be all calcareous. Like peat these soils drain poorly.

The annual fluctuation of the periphyton and the variability in vegetation density causes changes in the friction coefficient applied to surface water flow. Both the hysteresis effects of the peat and the annual changes due to vegetation differences in the water column are not incorporated in this modeling application. The field data of the current soil coverage is based on the work done by the Soil Conservation Service and documented in Jones et al. (1948). Little additional field investigation has been done in the wetlands since these surveys were completed and most of the recent interpretations are a result of reclassifications of the original descriptions.

An intensive soil mapping project was initiated in 1940 by the Soil Conservation Service (SCS) which resulted in the 1948 data set on the various types of land in the Everglades Drainage District and their capabilities. This 1948 set of soil associations were published as maps by SCS and subsequently digitized by the South Florida Water Management District (SFWMD).

This SOHISUNT48 soil map was used as the starting point and the missing data in the southwest region of the model domain was filled by interpreting imagery and the SFWMD Florida GAP analysis vegetation data set. In this region the GAP data was assumed to be based on a peat substrate in areas were mangrove exists and marl elsewhere. Imagery helped distinguish between dwarf mangroves and the taller mangroves. Dwarf mangroves were assumed to be on marl soils, since a deep root zone for full development would not be possible on the comparatively thin marl soil layer.

The resulting data categories were generalized and combined into five distinct soil associations as shown in Fig. 12. The new soil associations allow for a reduced set of parameter values to be used in the model. In addition to the spatial extent of the different soil types, the depth to bedrock of each soil layer is important in the model for adjusting the evapotranspiration and transmissivity values.

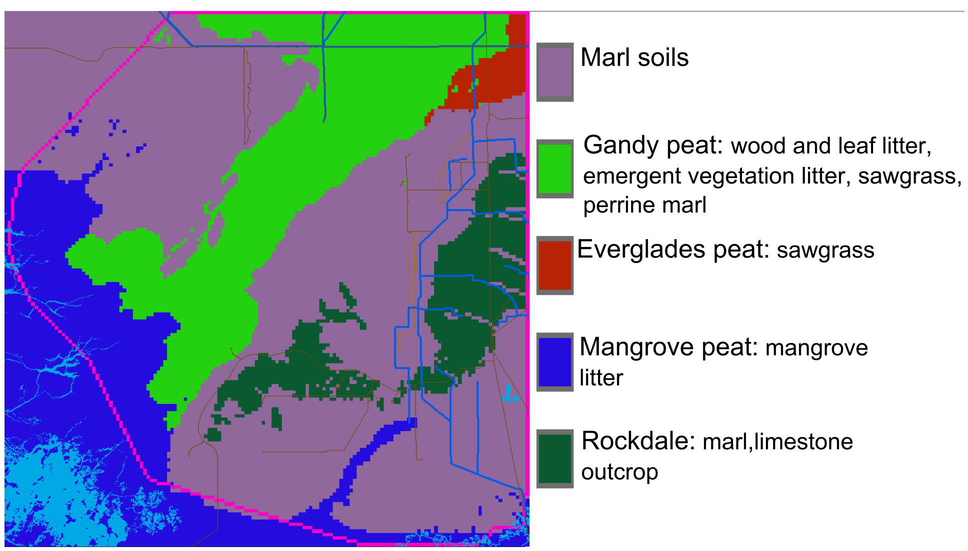


Figure 12. Soil categories used in M3ENP. (File: SoilV5.dfs2)

The spatial extent of soil depth was obtained from point data collected by several sources, the principal one the United States Environmental Protection Agency's Everglades Ecosystem Assessment Program (Scheidt et al., 2000). This is a monitoring program which assesses the condition of the ecosystem by measuring key parameters in the canals and wetlands of the Everglades Basin. A component of the field study documents the status of the remnant

Soil Profile	???	Depth Below Ground (m)
Everglades Peat	0.25 to 3 ft	0.9144
Gandy Peat	0.5 to 3 ft	0.9144
Mangrove Peat	2 to 5 ft	1.524
Marl	0.25 to 1 ft	0.3048
Rockdale	0 to 1 ft	0.3048

Table 2. Unsaturated Zone Soil Categories

peat soils and quantifies the depth of the soil layer at each sampling site. The soil thickness information was compiled for over 2800 square miles of natural landscape and over 1000 points were used to generate the spatial thickness layer.

Based on the soil association and depth, five categories were established. The maximum values were used to determine the UZ Soil Profile Definition in the model (Table 2).

Typically the vertical discretization included 5 cells for the top 0.5 feet and 2 cells for the next one foot increment, as shown in Figure 13.

Vertical Discretization:

	From depth	To depth	Cell height	No of cells
1	0	0.1524	0.03048	5
2	0.1524	0.4572	0.1524	2
3	0.4572	12.6492	0.6096	20

Figure 13. Vertical Discretization of Unsaturated Zone cells.

Depth data for the 1998, 2001 and 2007 field surveys was compiled and combined with additional information from other efforts (USGS TS and Gordon REF) into a spatial map of current soil depths for the M3ENP domain. The soil associations and thickness data are shown in Fig. 14). The bedrock topography is not smooth, karst limestone often contains many surface solution holes, which can locally extent to many feet below average ground surface. The EPA samples of average soil depth at each sampling point were obtained about every 3 mi2, causing local anomalies to occur in the landscape. These local deep points in the data set were likely obtained in solution holes and misrepresent the adjacent landscape. A few of these anomalous points were removed from the data set.

The associations used in M3ENP provide an adequate distribution to define the important regional changes in hydraulic properties. A set of parameters define the soil characteristics along a vertical profile for each association. The necessary parameters can then be used for computations in the unsaturated soil zone. The water retention and hydraulic conductivity are related to the soil moisture moisture content and have values characterized by the van Genuchten function (van Genuchten, 1980). An example for Marl soil is shown in Figure 15.

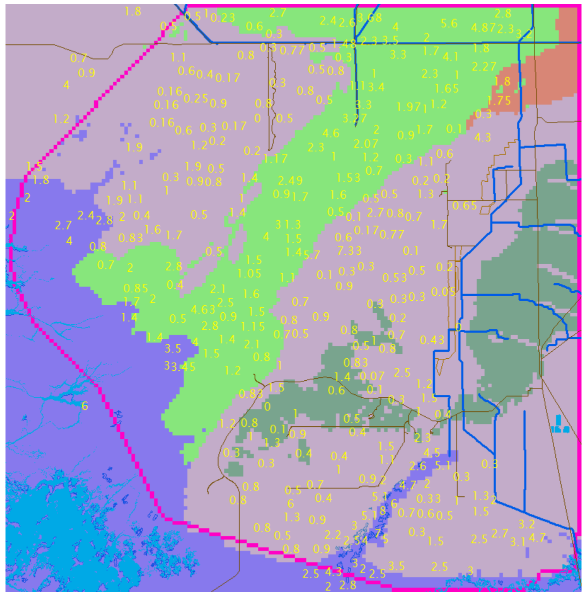


Figure 14. Soil Associations and Thickness Data.

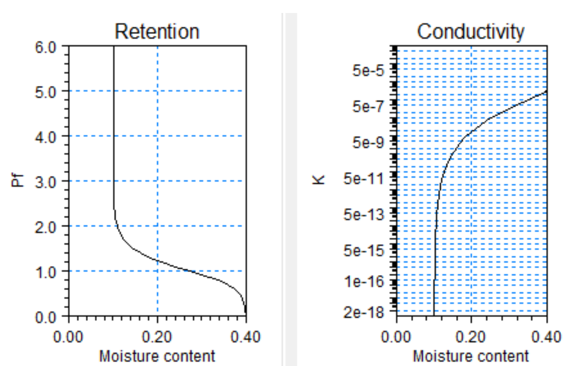


Figure 15. Example Retention and Conductivity Profiles for Marl Soil. (File: UZv6.uzs)

2.9 Hydrogeology and Saturated Zone Flow

The southern Everglades is a low-lying marginal area which is bounded on the east by the coastal ridge and on the west by slowly increasing land elevations of the Big Cypress Swamp. During the Pleistocene glacial periods, rising and falling sea levels and the resulting weathering and erosion processes brought complex depositional sequences of marine and fresh-water limestones (Schroeder et al., 1958). At the higher sea level marine limestones were deposited. During periods of lower sea level the fresh-water lakes and swamps deposited fresh-water limestones in the lower elevations. The depositional sequences gave rise to a complex system of marine and fresh-water limestones (Schroeder et al., 1958). The layering and depositional sequences of these limestones resulted in zones of different hydraulic conductivities. Along Tamiami Trail and east of Krome Avenue a persistent zone of fresh-water limestone occurs and one that appears to be a single layer. This zone is located between 8 and 15 feet below mean sea level, with the thickness ranging from 1 to 5 feet. The thicker occurrences are possibly filled solution holes in the marine limestone. A second layer exists about 20 to 30 feet below sea level. The geologic sections indicate that each fresh-water bed was probably deposited on an undulating and solution-pitted marine limestone (Schroeder et al., 1958). These lenses and the discontinuity surfaces exhibit different hydraulic conductivities than the rest of the matrix and if regionally continuous may retard the vertical flow of groundwater.

The hard limestone and marl found in southern Broward county gradates into the oolitic limestone in Dade county. In the investigation of water supply systems drawing from the Biscayne, Klein and Hull (1978) reported hydraulic conductivities of the Miami Oolite and Fort Thompson formations about 5,000 and 40,000 ft/day, respectively. The oolitic limestone thickens eastward and disappears west of L-30/L-31N canals.

A description of the geologic framework of the surficial aquifer system in Dade County was published by ?REF?Causaras(1986) following a study by the USGS and SFWMD. The project drilled 33 test wells into the relatively impermeable layers of the Tamiami Formation. The major aquifer is named the Biscayne aquifer, a highly permeable limestone that occurs near land surface over Dade County, thinning westward where they are underlain by nearly impermeable clastic sediments. Two distinct limestone units are recognized: the Miami Limestone (Miami Oolite) and the Fort Thompson Formation. The Miami Limestone is thickest in southeastern Dade County and thins westward where it interfingers with the Fort Thompson (see Fig.17). The oolitic limestone is cross-bedded and fine to medium grained sand fill many of the cavities within the Miami Oolite (Klein and Hull, 1978). The contact between the two units is usually denoted by a subaerial crust of solid ("hard") limestone (?REF?Causaras,1986).

An investigation of the aquifer properties was documented in Fish and Stewart (1991). Test drilling and aquifer tests provided aquifer properties of the heterogeneous karstic limestone dominated surficial aquifer in Dade County, the Biscayne. Very high hydraulic conductivities leading to large groundwater flows under relatively low head conditions were found to occur under much of Dade County. At some locations large solution cavities have given rise to preferential flow zones which behave like conduits and thus allow for even more rapid transport of groundwater. Fish and Stewart (1991) reported the high transmissivities in central and eastern Dade County to exceed 300,000 ft2/day, decreasing in the western portion to 75,000 ft2/day. The Biscayne aquifer consists of several geologic formations, the Miami Oolite (Miami Limestone) and the Fort Thompson Formation being the principal near-surface units. Fish and Stewart (1991) do not explicitly distinguish between the two geologic formations, they do mention that the Miami Oolite does not appear to have as well developed a network of open cavities as the Fort Thompson. The thickness of this latter unit along the L-31N/C-111 canal alignment is between 6 and 20 ft. The internal classification of the Miami Limestone and Fort Thompson Formation was modified by Perkins (1977), who recognized that the units could be subdivided based on unconformities in the marine units. The five sequences were labeled by a "Q" (Quartenary) terminology to recognize the subaerial exposure discontinuities of the depositional sequences. Two units, Q5 and Q4 are defined in the Miami Oolite, while Q3, Q2 and Q1 differentiate the Fort Thompson. The unconformities are usually defined by a subaerial exposure surface and may have denser freshwater limestone layers. In order to develop a stratigraphic framework of tree islands in the Water Conservation Areas, two detailed sites were examined based on the cores and borehole geophysics Bevier and Krupa (2001) and McNeill and Cunningham (2003). Of interest is the information obtained from Tree Island 3BS1, in the southeastern corner of WCA-3B. Four test holes on and around the island were drilled penetrating between 5 and 8.5 feet of peat to a depth of 23 to 28.5 feet. Five distinct lithologic units were identified. Well-developed calcrete horizons and dense, well-cemented soil breccias were identified and thought to restrict the direct vertical exchange of ground water. All the units showed numerous voids of varying sizes likely related to vuggy, highly dissolved, or poorly cemented rock fabric. Using the classification of Perkins (1977), all the unit Q1, Q2, Q3, Q4 and Q5, the last nearest the base of the peat, showed voids, but not in all wells. In one well (3BS1-GW4) Q5 was not found. Slug test gave values between 0.85(14ft below wl, 1 ft screen) and 184(31.45 ft below wl., 2 ft screen) ft/day. The competency and lateral continuity of these low-permeability units are unknown at this site, but are likely an important component in the vertical exchange of fluids. A further refinement of the Biscayne Aquifer in north-central Dade County using additional test wells and borehole technology was presented in Cunningham et al. (2004b), Cunningham et al. (2004a) and in Cunningham et al. (2005). The "Q" terminology was subdivided into several high frequency cyclic (HFC) units,the classifications analogous to the 5 Q layers. The Q4 and upper portion of the Q3 are regarded as low-permeability units. The aerial extent of a frequently reported dense limestone was investigated by (?REF?Krupa and Mullen Jr 2005) for the north-central Miami-Dade County area including the northeastern area of the model domain. This layer is from 1 to 3 feet thick and several other confining units are also present in the top of the Biscayne aquifer, but may not be homogeneous. The aquifer's water levels may thus exhibit semi-confined behavior, especially in the early stages of pumping.

The surficial aquifer system (SAS) comprises all the rocks and sediments from land surface downward to the top of the intermediate confining unit (ICU) which is approximately 950 to 1000 ft below sea level (Fish and Stewart, 1991). The top of the system is land surface, and the base of the system is defined hydraulically by several orders of magnitude change in average permeability. The SAS consists primarily of limestones and sandstones, sand, shell, and clayey sand with minor clay or silt and include the Biscayne Aquifer and the Gray Limestone Aquifer. From the land surface downward, the Biscayne aquifer is composed of Pamlico Sand, Miami Oolite, Anastasia Formation, Key Largo Limestone, and Fort Thompson Formation (all of Pleistocene age), and contiguous, highly permeable beds of the Tamiami Formation (Pliocene and late Miocene age).

The Biscayne aquifer boundary is presumed to be where the Fort Thompson Formation, Anastasia Formation, or Key Largo Limestone grade laterally into less-permeable facies. At least 10 ft of the Biscayne aquifer has a horizontal hydraulic conductivity of about 1000 ft/day or more (Fish and Stewart, 1991). Miami-Dade and Broward Counties' sandstones and limestones have a well-developed secondary porosity with hydraulic conductivities com-

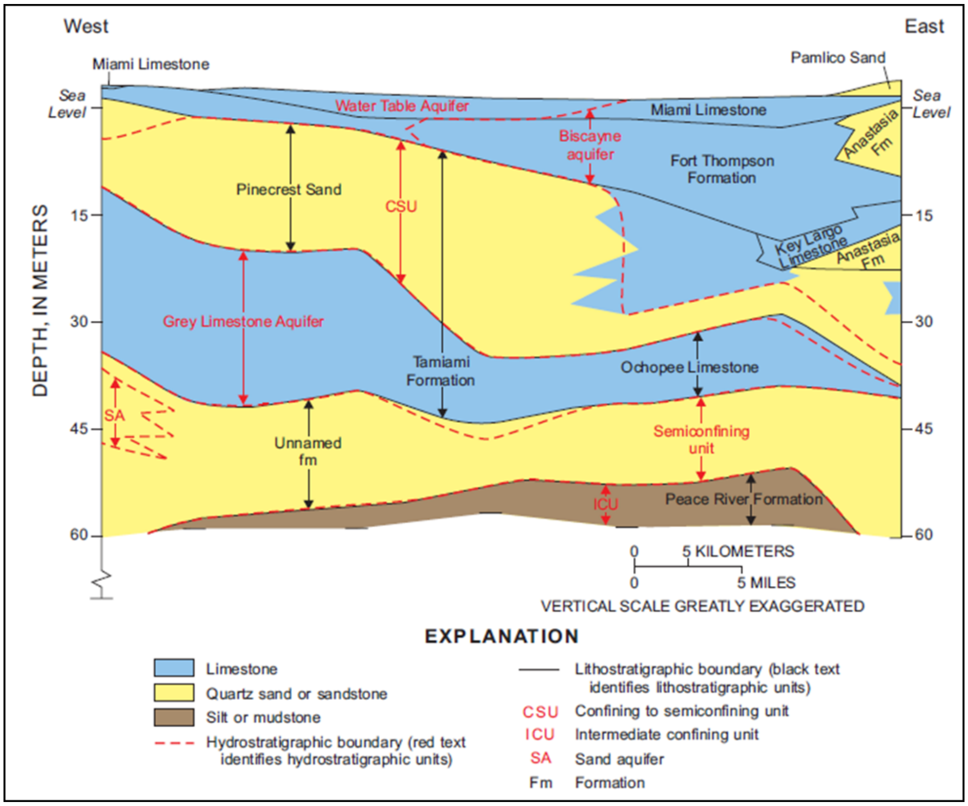


Figure 16. Cross section of the surficial aquifer system along Tamiami Trail (L-29) (Reese and Cunningham, 2000)

monly exceeding 10,000 ft/day (Fish and Stewart, 1991). Silt, clay, and mixtures of lime mud, shell, and sand in the upper and lower clastic units of the Tamiami Formation have hydraulic conductivities of 0.001 to 1 ft/day (Fish and Stewart, 1991). Some dense limestones within the SAS also have relatively low hydraulic conductivities. Figure 16, from Reese and Cunningham (2000), provides the generalized composition of the SAS along Tamiami Trail.

2.9.1 Detailed Subsurface Investigations within the Area of Interest

Following the hurricane of 1947, the Central and Southern Florida flood Control Project (C&SF) was formed and flood control improvements were initiated. The project included a series of dikes and berms to control flooding. Investigations were conducted by the USACE and many core borings were done along future levee and canal alignments. The results were documented in USACE publications and a detailed investigation of the proposed L-29 and L-30 was published in (?REF?U.S. Army Corps of Engineers 1951). Fig. 17 shows a generalized cross-section along Tamiami Trail.

The Biscayne aquifer boundary in the region of interest is presumed to be where the Fort Thompson Formation grades laterally into less-permeable facies. Regionally, at least 10 ft. of the Biscayne aquifer has a horizontal hydraulic conductivity of about 1000 ft/day or more and Miami-Dade and Broward Counties' sandstones and limestones have a well-developed secondary porosity with hydraulic conductivities commonly exceeding 10,000 ft/day (Fish and Stewart, 1991). Silt, clay, and mixtures of lime mud, shell, and sand in the upper and lower clastic units of the Tamiami Formation have hydraulic conductivities of 0.001 to 1

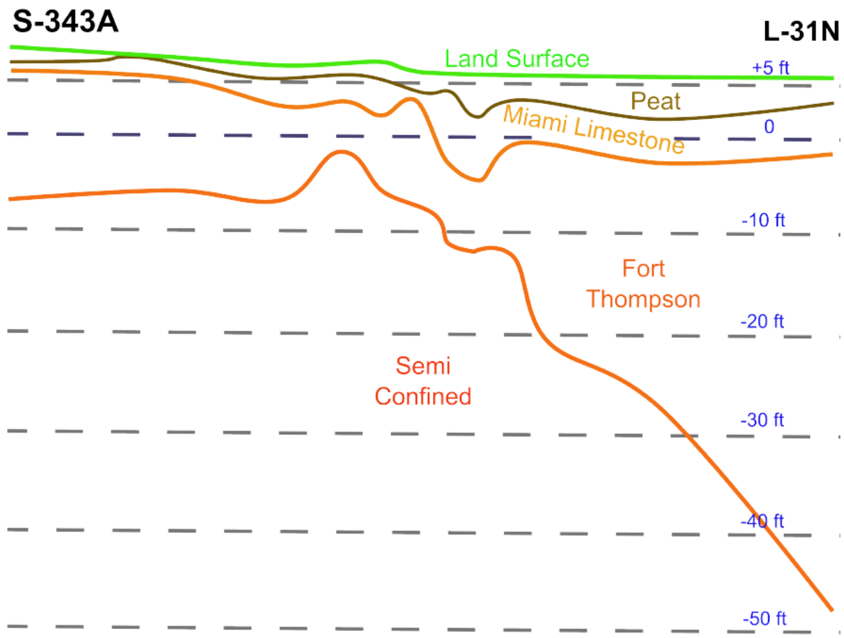


Figure 17. Cross-section of the surficial aquifer system along Tamiami Trail (L-29)

ft/day (Fish and Stewart, 1991). Recent investigations (?REF?Chandler and Wissler, 2013) near the northeast boundary of the model indicate that the transition from Fort Thompson to the upper clastic unit of the Tamiami Formation (Pinecrest Sand) is shallower (and extends farther east) than is suggested by ?REF?Causaras(1986) and Fish and Stewart (1991).

2.9.2 Previous Investigations on Defining Model Layers

The original two layer model relied on the work by (?REF?U.S. Army Corps of Engineers 1951), Fish and Stewart (1991), Reese and Cunningham (2000), Nemeth et al. (2000) and others to develop the parameters and spatial extent for the aquifer layers in M3ENP. The development of the vertical discretization of the MIKE SHE hydrogeological model is documented in detail in Tachiev and Cook (2011) and in Cook (2012). The change from a two layer to a three layer was a minor transition to the hydrogeology setup and done to enable local (L-30/L-31N) analysis of the surface water/groundwater interaction. A fork of M3ENP was developed for analysis of this area (?REF?Tachiev 2013) in which the local hydrogeology was changed to include the semi-confining unit. The transition to a three layer model for analysis of local features in the northeast corner was based on this work and gave rise to the current three-layer model V914, used in this report. Much of the re-configuration of the aquifer system along the northern boundary relied on the excellent work detailed in ?REF?U.S. Army Corps of Engineers 1951.

2.9.3 Current Subsurface Layers in Model

In the V914 version of the MIKE Marsh Model of Everglades National Park (M3ENP) the subsurface was divided into three layers:

Peat A peat layer was generated from existing information obtained during several surveys, most notably the REMAP (Scheidt et al., 2000) program. Transmissivity values for the peat (top layer) are shown in Fig. 18.

Miami Oolite The near surface layer (middle layer) is shown in Fig. 18. This is also known as the Miami Limestone.

Fort Thompson The bottom layer also includes a portion of the underlying semi-confined clastic layer in western areas, Fig. 18

Surface maps and model grids of the bottom level and the thickness of each layer and the hydraulic conductivity of the surface layer were generated using triangulation and linear interpolation. The initial hydraulic conductivity was generated from the observed measurements (Tachiev and Cook, 2011) and (Cook, 2012). Calibration efforts refined the values to match model versus observed water levels. The layer 2 hydraulic conductivities is the most important calibration parameter in this model.

The peat layer and its properties are discussed in more detail in Section ?REF?2.6.1. For the model application, the transmissivity is the operative parameter. The numerical computation of an aquifer layer in MSHE requires a continuous layer across the entire domain. The top layer is defined as peat (Fig. **??**). Since the peat is not regional, there are areas where the peat is not present and the Miami Limestone crops out at the surface. This model performs best if a layer thickness exceeds several feet, therefore the upper layer was made four feet thick and the hydraulic conductivity values were adjusted to ensure that transmissivity was as desired (obtained through calibration). Regionally this layer has little influence on the results, except near canals, where the difference in water levels with the wetland is often several feet. The local differences have been documented in the field and are detailed in ?REF?Section 3.

The Miami Limestone has lower hydraulic conductivity than the Fort Thompson Formation and thus has lower transmissivity values (Fig. **??**). The layer this westward and appears to have an unconformity near its surface. This zone is overlain by peat across much of the domain and may have very low transmissivity. In the model this zone is not explicitly modeled, but can be regarded as being represented in the properties of the peat layer.

The interface between the Miami Limestone (Fig. **??**) and the Fort Thompson (Fig. **??**) may have a dense zone as discussed in Section ?REF?2.5, but is not explicitly represented in the model. Regionally this zone may not be continuous and as discussed in ?REF?Section 3, the available water level data is not sufficiently different across the layers. Hydrologically his zone is not important, even near the canals. The Fort Thompson, especially the upper facies are highly transmissive, pump tests in the productive zones can only hint at the transmissivities. The thickness of the aquifer in the model is from the Miami Limestone to the upper level of the clastic zone (Fig. **??**) and the hydraulic conductivities are obtained during calibration.

A cross-section along Tamiami Trail of the Miami Oolite and Fort Thompson elevations is shown in Fig. 19 and a cross-section of the north-south alignment near the L-31N/C-111 canal system is shown in Fig. 20. The elevation of the Fort Thompson was deliberately kept below the depth of the L-29 canal to allow full exchange to take place between groundwater and canal water.

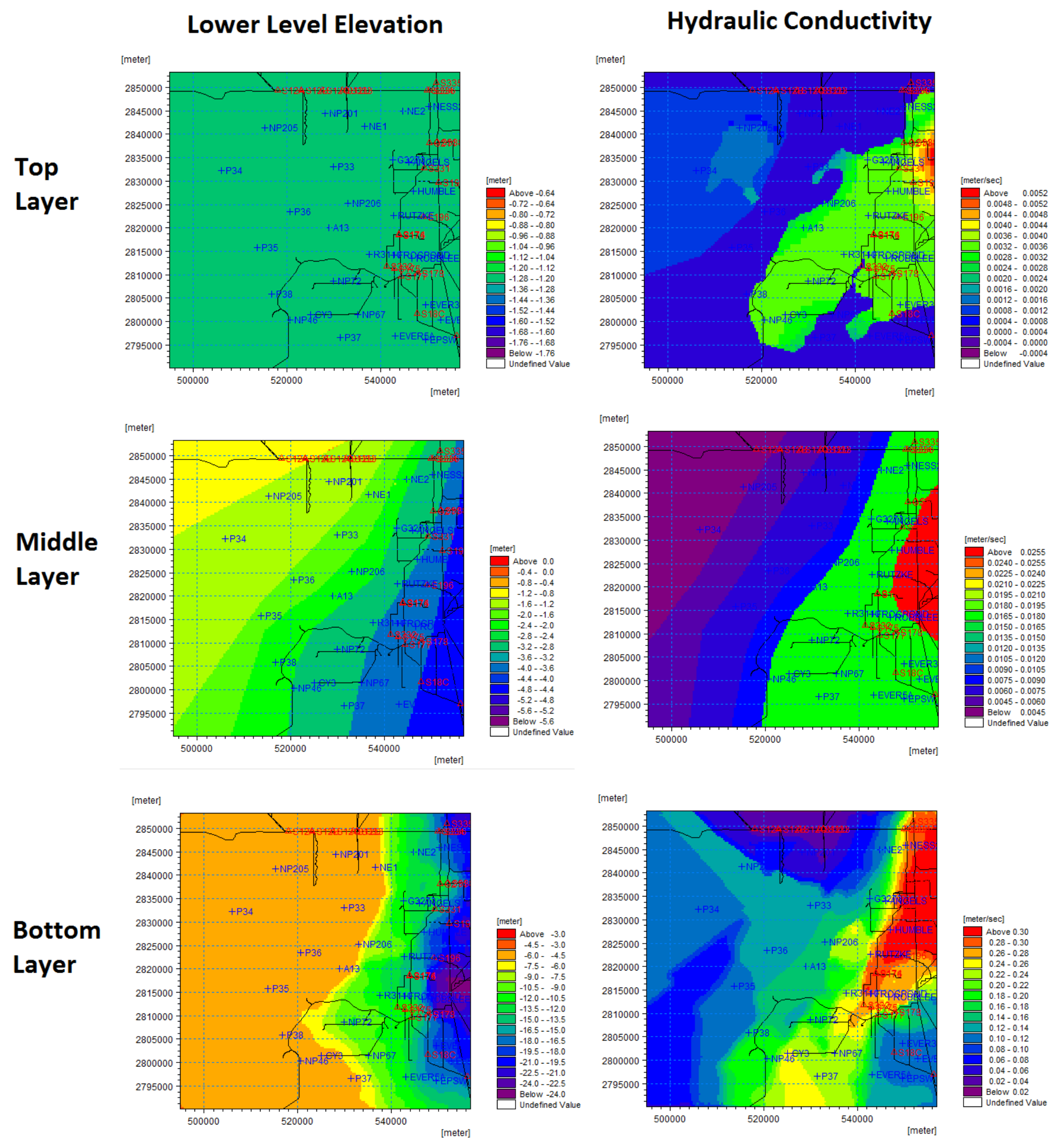


Figure 18. Saturated Zone Layer Levels and Conductivities

Files:

- K0peatV5.dfs2
- K1ooliteV2.dfs2
- K2ftthompsonV2.dfs2
- L0peatV4.dfs2
- L1ooliteV2.dfs2
- L2ftthompsonV4.dfs2

Specific Yield and Specific Storage. Specific Yield is used in unconfined aquifers and is defined as the volume of water released per unit surface area of aquifer per unit decline in head. The specific yield of the top layer is forced to be equal to the the specific yield of the UZ zone, as defined by the difference between the specified moisture contents at saturation, θ_s, and field capacity, θ_{fc}. In a confined aquifer, the specific storage is defined as the volume of water released per volume of aquifer per unit decline in head. These parameters have a

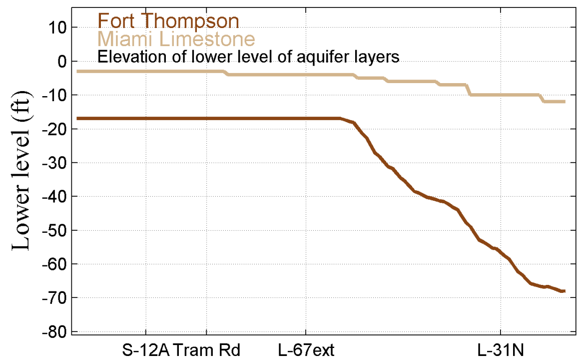


Figure 19. Cross section of the model layer along Tamiami Trail (L-29)

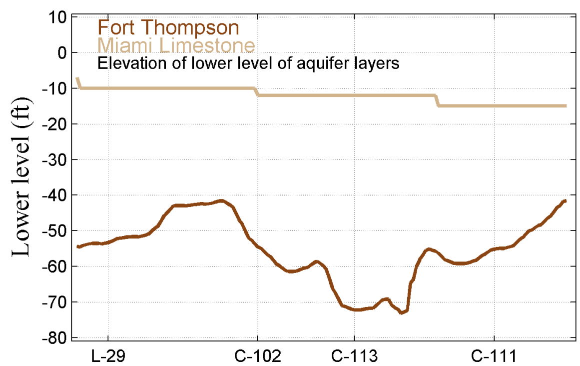


Figure 20. Cross section of the model layer along col 137

small influence on model output within the acceptable range. Most of the time, important for ENP wetland resources, the aquifer is full of water.

2.9.4 Wellfields

Two wellfields are included in the model. The Miami-Dade West Well Field, located east of the Rock Mine lakes in the northeastern portion of the model domain, has a constant pumping rate of 28 cfs (18.1 mgd), and extracts from 16.76 to 19.81 meters depth (however the Ft. Thompson ends at around 17 meters in depth). The Florida Keys Aqueduct Authority well field is located east of the Frogpond along SR-9336, has a constant pumping rate of 33 cfs (21.3 mgd), and extracts from 18.90 to 21.95 meters depth (however the Ft. Thompson ends at around 19 meters in depth).

2.10 Boundary Conditions

Boundary conditions in the M3ENP are defined for the overland flow layer and for each of the subsurface layers. MIKESHE has four available boundary types (Zero-Flux, Fixed Head, Flux and Gradient) for the saturated zone. Also available is the 'Time-varying Overland Flow Boundary Conditions', implemented as a 'Special Parameter'.

To create the dataset used for head boundaries, data from over 200 observation stations were used to generate daily water surface plots for the entire domain and time period. MATLAB linear interpolation was applied to calculate water levels within a grid with cell size of 800 meters. Fig. 21 shows an example of these gridded water levels for 1/1/1987. The information is used to specify the daily stage whenever a boundary cell has a specified fixed head condition in the saturated zone calculation and/or a specified stage in the overland flow computation. One advantage of this daily water level file is that it can also be used for subdomains (smaller regional areas) of the model.

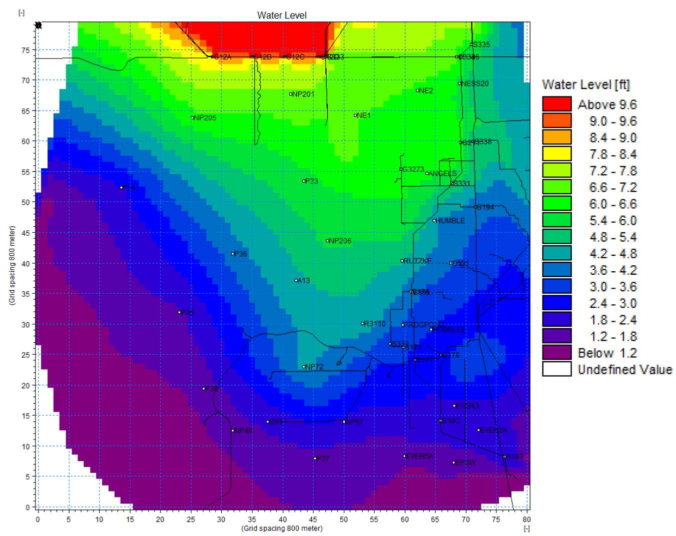


Figure 21. An example of gridded water levels for 1/1/1987. (File: BCTS20151119.dfs2)

In areas were data is missing (or not available) for the beginning years of the simulation, a temporal interpolation scheme was devised to generate an artificial time series. These timeseries were then used in the spatial interpolation described above. This technique was particularly important along the coast where fewer data was collected in the 1980s and 1990s. Fig. 22 shows one such station at Highway Creek.

In other areas that were data-sparse, the data from a given observation station was copied and applied at a nearby location as a 'pseudo-station', then spatially interpolated. Give example here...

For the overland flow layer, the default is to set the boundary cells to zero depth, but along several sections, as shown in Fig. 23, the cell values are set to observed daily stage. There is not a gradient boundary option in MIKESHE for the overland flow layer.

For the saturated zone, M3ENP uses the daily specified head timeseries for the boundary cells, except in some areas where a Zero-Flux (no flow) boundary is applied. This is shown in Fig. 24.

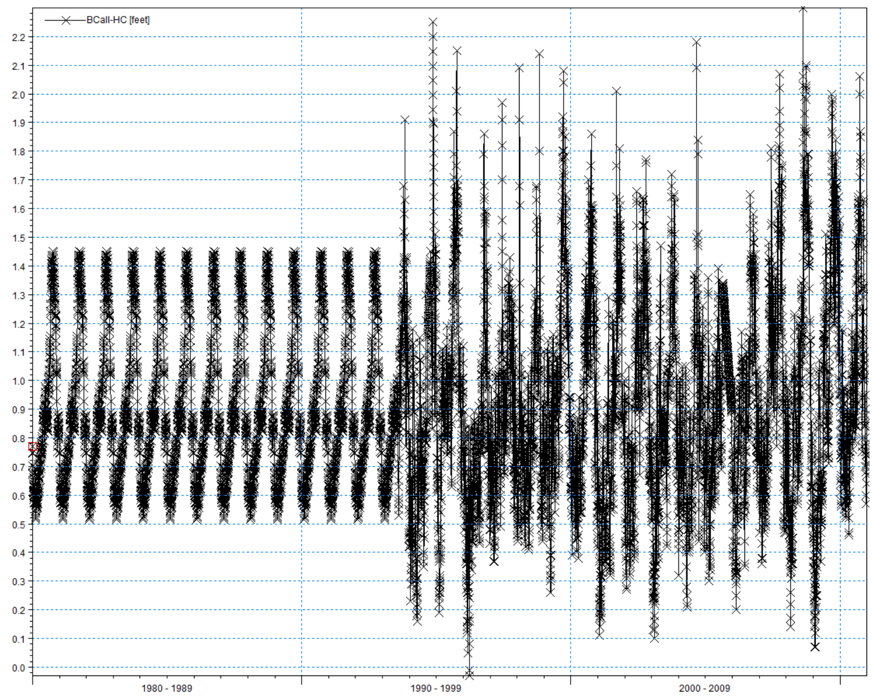


Figure 22. Highway Creek Timeseries. The observed data starts 7/29/1993. The daily average of the timeseries to 12/31/2010 was obtained from these observed values. These daily averages were concatenated into an annual timeseries and repeated each missing year, until 7/28/1993.

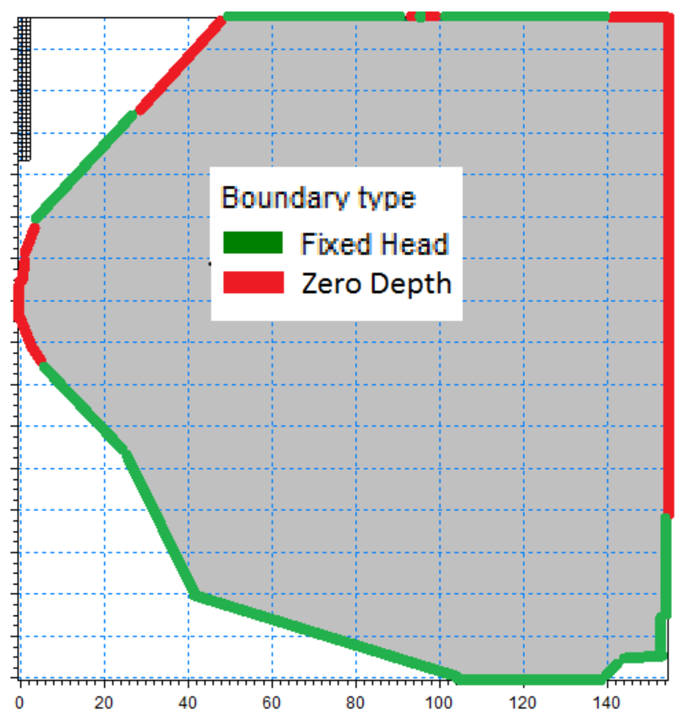


Figure 23. Overland Flow Boundary Condition Types. 'Fixed Head' cells use the daily gridded stage timeseries data, 'Zero-Depth' cells are set to a constant value equal to the elevation for that cell. The two isolated sections of 'Zero-Depth' at the north-central portion of the boundary correspond to where canals intersect that area. (File: OLBCCODEeastV1.dfs2)

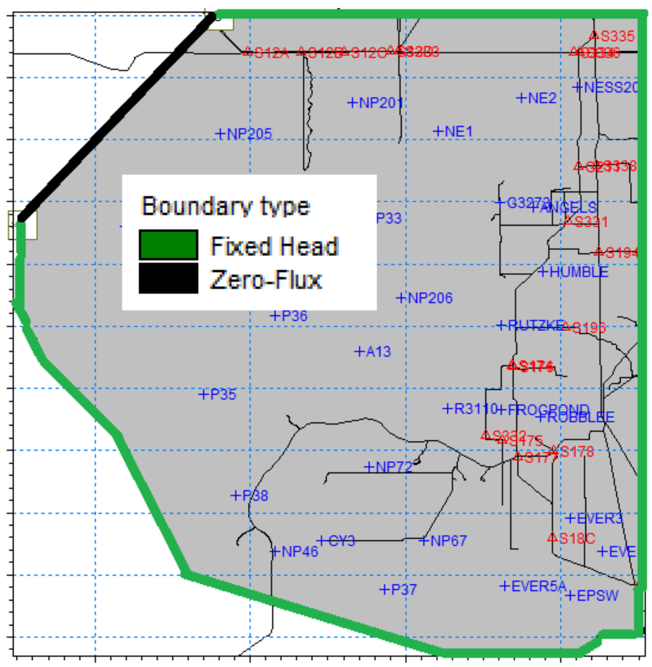


Figure 24. Saturated Zone Boundary Condition Types. 'Fixed Head' cells use the daily gridded stage timeseries data, 'Zero-Flux' cells are defined as no-flow cells. All three subsurface layers are the same.

2.11 Initial Conditions

Initial conditions for the overland flow layer are set to the land surface elevation, indicating that there is a uniform value of zero depth across that layer.

The saturated zone initial conditions are set to a spatially varying head value, and are shown in Fig. 25.

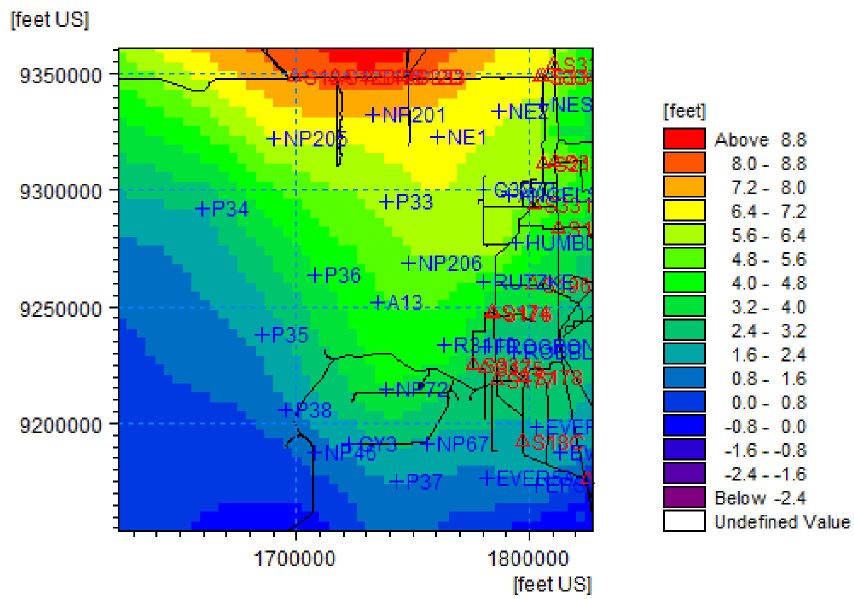


Figure 25. Saturated Zone Initial Potential Head. All three subsurface layers are the same. (File: INITIAL_HOBSv003.dfs2)

3 M11 Physical Layout and Integration with MIKESHE

3.1 Overview

The M11 component is a one-dimensional dynamic flow model for rivers, channels, irrigation systems, and canals and includes structure operations and schedules. The complete Saint Venant equations are solved between all grid points at a specified time step for the given boundary conditions. The hydrodynamic module of M11 contains an implicit finite difference computation of unsteady flows in rivers and canals. Both sub-critical and supercritical flows are described by a numerical scheme which adapts according to local flow conditions. In addition, the model includes options for diffusive wave, kinematic wave, quasi-steady state, kinematic routing, and high order, fully dynamic flow descriptions Environment (2011).

The simulations with M11 were represented using high order fully dynamic flow description, which is recommended for tidal flow situations and canal systems where the water surface slope, the bed slope, and the bed resistance forces are small.

The initial M11 model of primary canals and pertinent water management structures was developed for simulation of the period of 1987-1999. None of the features of MWD and C-111 projects were implemented in the real world and operations during this time period were primarily Test 7 Phase I rules. The selected control structures and canals which directly modify the water flux through the north and east limits of the ENP were implemented in the model.

The M11 model includes all relevant canals and water management structures. In conjunction with the MSHE module, M11 simulates the period of 1987-2010, using operations as implemented circa 2010, under the IOP/ERTP set of rules. The canal network discretization is based on approximately 900 unevenly distributed cross sections. Canals and operations are computed with a 30 minute time step. Version 914 has both a calibration and an operational model. In the calibration model the pertinent structures are set to observed historical data whenever possible and in the operational version a set of rules are simulated based on the complete (except Northern Detention Area) build-out of the detention areas. In the model documented herein, operational strategies are based on an analysis of the observed data from the period 2007 to 2010.

The canal network discretization is based on approximately 900 unevenly distributed cross sections. Canals and operations are computed with a 30 minute time step. Overland flow is computed with a variable time step of up to 30 minutes. The unsaturated zone and saturated zone are computed with a variable time step of up to 2 hours and 12 hours, respectively. Daily timeseries are saved for the canals, overland flow, unsaturated zone, and saturated zone. Multiprocessing using 4 parallel processors complete a 10 year simulation in approximately 10 hours.

Canals are a series of reaches making up the named branch. Each individual reach is defined as an h-point at a cross-section. Halfway between cross-sections a point is defined as a q-point. These hand q-points provide output in the .res11 files or may be defined for specific output during the run in the "Detailed M11 timeseries output" tab in "Storing of Results". The location of the h-points are defined by the location of a cross-section and can thus be adjusted as desired. Placing cross-sections immediately upstream and downstream of structures ensures good control on upstream and downstream canal stages.

Canals are realigned to be between cells in the preprocessing step. Fig. 26 shows the result in the L-31N area, found in the interface under the Processed Data tab. The river links are shown as they are used in the M11 computation and interaction with the MSHE module. The area shown in the model is the L31N in the S-331 region and also shows the re-alignment of the S-357 detention area and Angels trigger well (modeled as a short canal) location.

Fig. 27 is an example of a branch profile from east to west of L-29. The chainages define the distance from the origin of the branch.

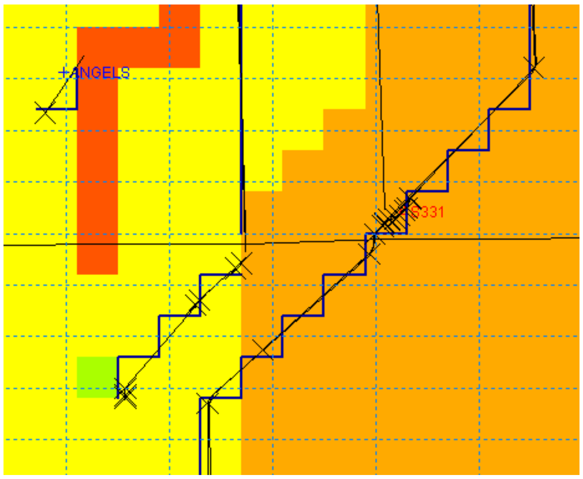


Figure 26. Pre-processed canal network locations. The canals are re-aligned with the grid cell boundaries.

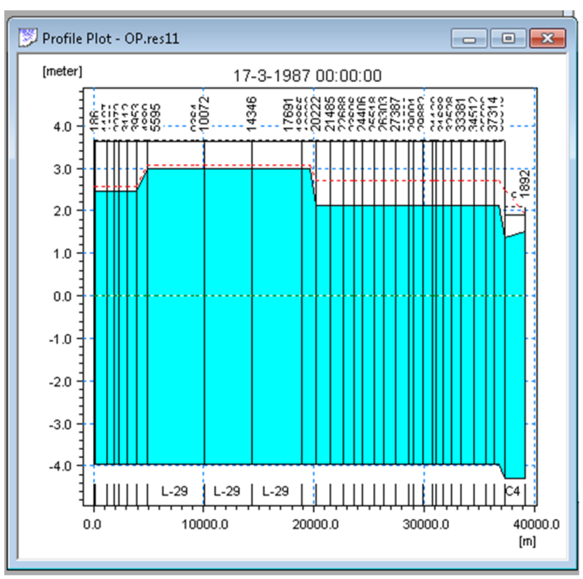


Figure 27. Typical Canal Profile along L-29 and C-4.

3.2 Canal Seepage/Leakage/Overflow and Linkage with MIKESHE

The actual model coupling is defined in MIKE11, which specifies the branches to be coupled, the leakage coefficients, and the flood codes.

3.2.1 Surface Water Exchange

Two options are available for the overland and canal exchange: overbank spilling or flood codes. Both methods are implemented in the model.

The overbank spilling option treats the river bank as a weir. When the overland flow water level or the river water level is above the left or right bank elevation, then water will spill across the bank based on the standard weir formula. Numerical problems can occur when the slope of the water surface profile is very shallow and the velocities are very low causing water to form a wall along the bank instead of flowing to neighboring cells as overland flow. Overbank spilling is used for shallow ditch/berm system representing the road at Shark River (tram road) and the main park road as well as the L-67 ext. Overbank spilling was not needed for the other canals.

Flood codes are numerically more stable than overbank spilling for shallow water surface profiles and low velocity flow. When the MIKE 11 water level is above the topography the water level of the canal becomes the level of water on the bank of adjacent cells. The threshhold water depth value for overland flow is 0.0001 m. Overland flow within the flooded cell is part of the M11 water balance calculation; however, lateral flow into neighboring non-flooded cells is included in the MSHE calculations for exchange between the overland flow, saturated zone, and unsaturated zone.

3.2.2 Groundwater Exchange

The leakage coefficient (conductance) for the canal defines the amount of flow between the aquifer and the canal, the volume exchanged is calculated as the water level difference between canal and the grid cell modified by the leakage coefficient. Most of the canals use the wetted perimeter and the conductance for the exchange calculation, but it is also possible to use the aquifer parameters of hydraulic conductivity and the canal water depth for the computation. Through experimentation it was found that using the wetted perimeter and a conductance value best calibrated the model to observed data. A detailed description of individual canal reaches are provided in the next subsections.

The exchange (seepage) flow, Q, between a saturated zone (SZ) grid cell and the river link is calculated as a conductance, C, multiplied by the head difference, Δh, the river and the grid cell Environment (2007).

$$Q = C \times \Delta h$$

This equation is calculated for each cell on either side of the river link. This allows for inflow and outflow, in case of a head gradient across the river, to be calculated and tabulated for each grid cell (400 m). Fig. 28 is a typical diagram of the output file containing the exchange rates. The colors represent amounts of SZ seepage flow to and from the river, The river is aligned between two grid cells and with diagonal canals is wrapped around the grid cell (One mile L-30, from S-335 to L-29). The head difference is calculated between the grid cell and interpolated from the M11 H-points for the river link. Three options exist to define the conductance: 1) the conductivity of the aquifer material only, 2) the conductivity of the river bed material only, 3) the conductivity of both river bed and aquifer material. In areas where the river crosses multiple aquifer layers e.g., Miami Oolite and Fort Thompson, the exchange is based on the available saturated thickness of each layer (Fig. 29). In the model, areas of high rates of exchange that have been identified through observed field data are typically assigned a river bed-only conductance with a coefficient determined through calibration. In reaches such as L-30 and L-31N where large head gradient exist across the canal, the coefficients are at their maximum values, i.e., the model will develop instabilities if the coefficients are further increased.

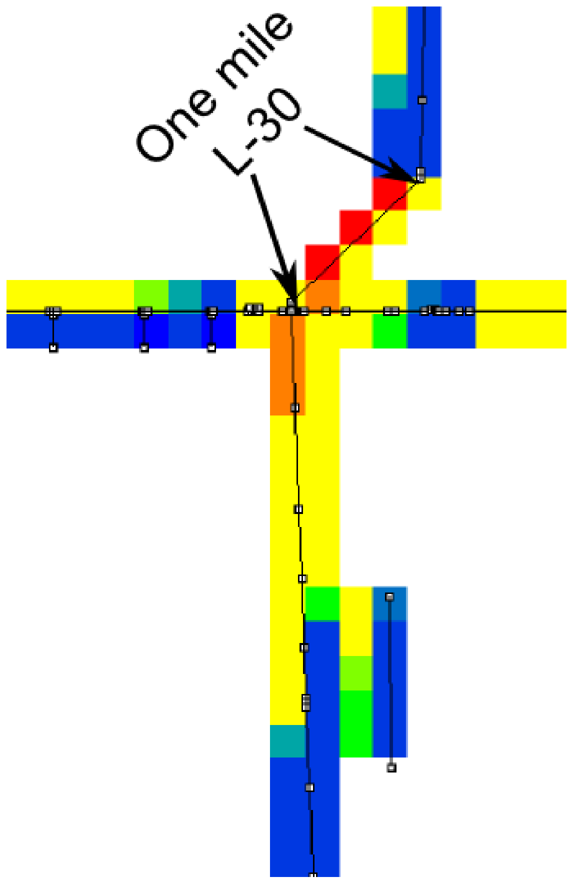


Figure 28. Modeled Canal to Groundwater exchange. Colored cells are MSHE locations adjacent to the canal used in the computation of seepage.(comment: this fig needs context and explanation of what colors are: are these colors related to colors in the canal section fig?)

In Fig. 29 the three-layer aquifer is shown, the levee is for reference, the height of the levee has influence in the calculations of the wetted perimeter in some of the options. The left side of the figure is a cross-sectional view and the right side is a plan view of a typical four cell area. Seepage values are calculated for each of the grid cells, for each of the three layers with the adjacent canal link. In the figure the peat (brown) is present on the left side, but absent on the right. In this case the value of the layer's hydraulic conductivity has been set to the value of the underlying layer (Miami Oolite) as discussed in Section ??2.5.3??. In the model the canal will be aligned with the grid cells, in this case along the N-S axis. Results for the model version V914 are tabulated in Fig. ??36??.

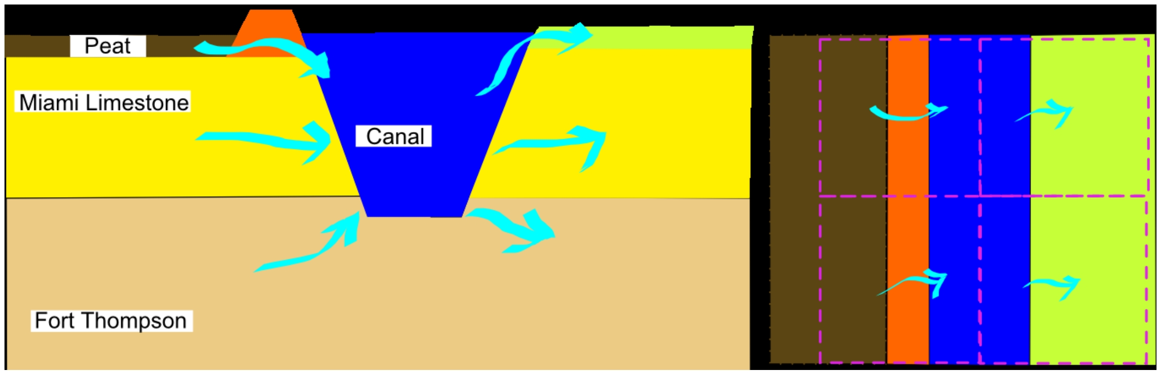


Figure 29. Sketch of canal section detailing the exchange with saturated zone. Cross section across the canal shown on left details the exchange of each of the aquifer layers with the canal. The exchange rate is modified depending on the penetration into the aquifer layer. The right sketch is a plan view showing the grid cells as an overlay. The canal is aligned in the software with the cell boundaries.

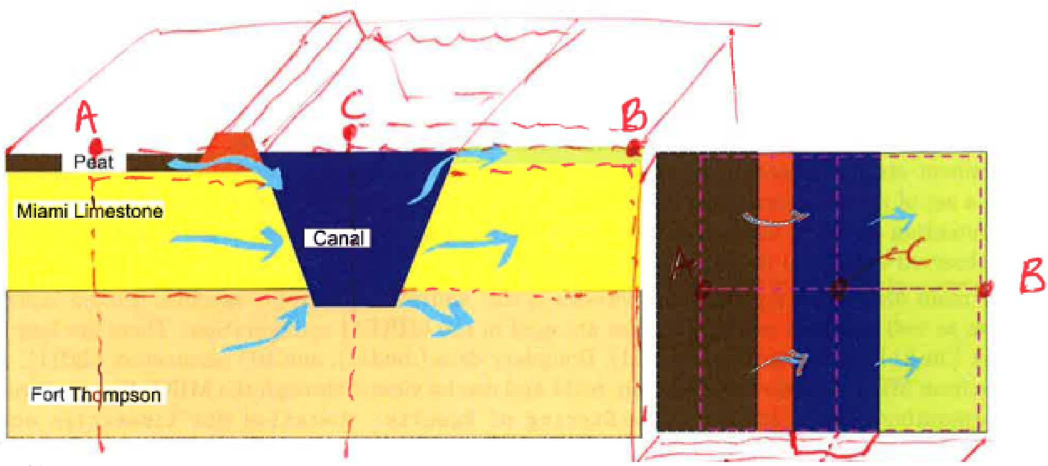


Figure 41:

split into fig 41a and 41b. maybe add dotted lines to 41a?

orange levee is a bit misleading as we do not have any model flow through levees.

maybe go 3-D for this?

it would be helpful to have this fig before fig 40, so fig 40 makes more sense.. but change fig 40 colors

or just remove fig 40

Figure 30. Figure comments.

3.3 M11 Modeling Techniques

3.3.1 Tailwater Drainage

A typical profile of a culvert getaway canal is shown in Fig. 31. The top view is a longitudinal profile from L-29 through the first cell south of the canal and the bottom plot is a typical cross section of a culvert. In the current formulation (V914) the overbank spilling option is not used, instead each culvert has an associated flood code and the M11/MSHE flow exchange is solved with the continuity equation only.

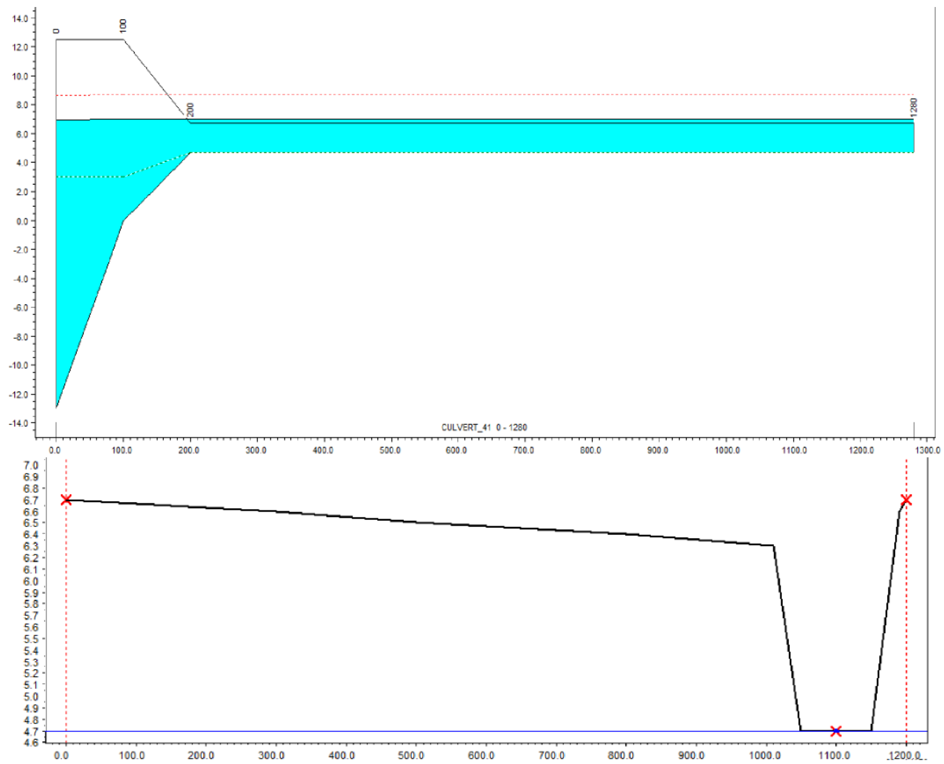


Figure 31. Typical profile and cross section in Culvert 41.

Figure 6 shows the implementation of M11 boundary conditions on the west end of L-29. The culvert cross sections were primarily implemented with a bottom depth of -13 ft. The depth of the canal has no influence on the MSHE nor M11 stages because the end of the canal uses CLOSED boundary conditions, i.e. no flow is allowed in the longitudinal direction at the canal boundary. The water flow in the longitudinal direction is minimal (zero at the boundary) and the entire flow is forced to overflow the canal banks and spill laterally.

M11 canals are the exchange boundary between overland (2D) and canal flow (1D) and at peak flows instabilities may develop. To reduce the instabilities, overland discharges are implemented as short canals which gradually widen to a width of 1 cell (400 m). In addition, M11 links that discharge overland flow and interact with the subsurface flow must have length at least two cells which additionally reduces potential instabilities of the transition from M11 canal flow to overland flow in MSHE.

All culvert discharges have been implemented using this approach using the following strategy:

- Culvert discharge links are approximately 1300-1400 feet in length to cover a minimum of 2 cells (400 m resolution)
- All discharge links are closed at the point of discharge and water overflows the canal
- All discharge links use overbank spilling for discharge rather than flood codes

3.3.2 Extended canal width for groundwater/surface water exchange

3.3.3 Floodcodes for groundwater/surface water exchange with canals

Currently floodcodes are used for the S12A-D structure getaways, culverts 41-59, and the southern end of L-31W. They are not used for culverts 24-28, but I am not sure why. There are a couple slight differences between the Calib and Ops models. The first is that the Operational model does not have floodcode for culvert 52 but Calib does. The second is that the Ops model has a bridge at culvert 57 so uses floodcode 57 for the three get and does not use FC56 or 58, Calib model has culverts 56, 57, and 58, and uses FC56, FC57,and FC58. I am not completely sure if this is the correct interpretation of how MIKE uses these so check this.

A specific input feature is to assign a “flood code” to a cell, which allows for interaction between surface water and canal water through a continuity equation calculation instead of or in addition to the dynamic overbank flow computation. Flood codes define exchanges between the branches and the overland flow within a grid cell. A flood code maps the MIKE SHE grid to MIKE 11 h-points. Unique flood codes are used to ensure correct mapping.

A regional overview of the flood codes assigned to cells to aid in the dispersal of water through use of the continuity equation and/or the full St. Venant equations. The use of flood codes is necessary downstream of the culverts and S-12 structures, due to the rapid and angular dispersal patterns, which the model can not capture accurately with a 400m by 400m cell size. The large discharges through the S-12 structures, particularly the S-12D structure, which is in close proximity to the L-67EXT canal can be problematic. The flood code for S-12D was moved a cell downstream from the actual location to facilitate the getaway during high discharge rates. Flood codes were also implemented downstream of the culverts along eastern L-29 and no overbank flow is enabled. None of the detention area flood codes are used in this version of the model. At the terminus of L-31W, south of the S-175 structure, a flood code was used to facilitate the discharge in what is usually a rapid moving stream into the wetlands during high L-31W flow volumes.

A flood-code grid is used to assign unique id numbers to downstream cells at the S12 structures, the eastern Tamiami Trail culverts, and downstream of L-31W (Fig. 32). These constructs aid in the dispersal of water to the downstream environs, something diffcult to accomplish dynamically in these high discharge locations. When flood codes are enabled and no overbank flow is allowed, the getaway canals are not used for a dynamic computation. This resulted in better calibration of the flow volumes through the eastern L-29 culverts.

To improve model stability, a flood code may be used, which causes water to fill the corresponding flood cell as function of time. When the water level exceeds a prescribed threshold (0.0001m), the flood cell water continues flowing in the MIKE SHE domain where it is solved as 2D flow. The MIKE 11 cross section at the closed end of the discharge canal has a width of 1 cell and is at the same height as the ground level. These specifications for the cross section improves the stability of the model when solving for exchange of groundwater and surface water.

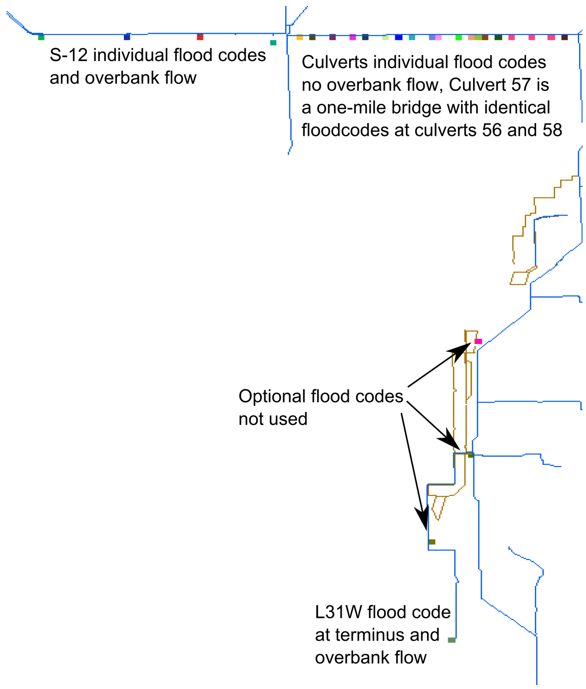


Figure 32. Flood Codes.

3.3.4 Canals as detention areas

3.3.5 Canals as monitoring well locations

Angel's Well and G-3273 In order to facilitate the interaction of trigger wells, observation points that force an operational action to take place at a structure, the actual field wells are modeled as short (one cell) canals. The canals have no operation and rise and fall with local groundwater. The location of a point in the canal is used to affect operations at a structure.

Angel's Well is implemented as a short channel (2300 ft, reaching depth of -20 ft, and 10 ft wide) with a very high leakage factor to provide a link for the M11 structures. Figure 33 shows the implementation of Angel's Well as a canal closed on both ends, as well as its cross section in M11.

Figure 34 shows a cross section for the Angel's well canal reach, G-3273 is similar. Angel's well is used in the operations of S-331P and G-3273 is not used in this version, but is available to test alternatives dealing with S-333 operations and has been used to look at operations of S-356.

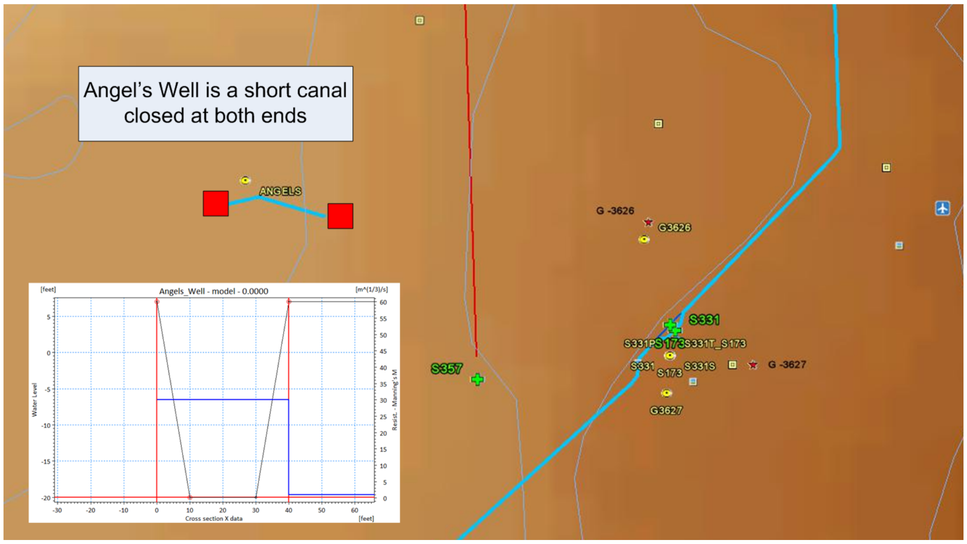


Figure 33. Implementation of of Angel's Well. A short canal (2300 ft, reaching depth of -20 ft, and 10 ft wide) with a very high leakage factor to provide a link for the MIKE 11 structures

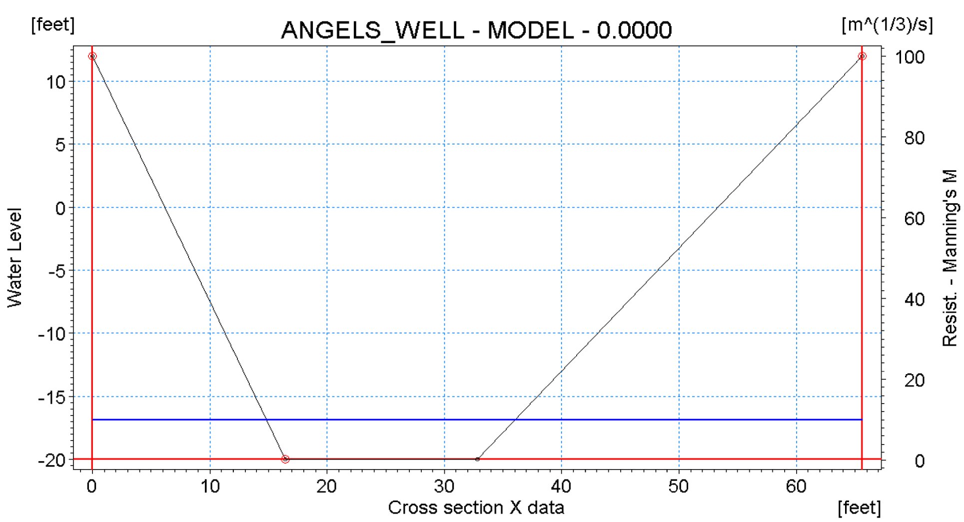


Figure 34. Cross section for Angel's Well.

3.4 Canal Cross-Sections

The model for the canal system was implemented using polyline GIS maps obtained from SFWMD's GIS site. M11 requires at least 1 canal structure between canal junctions. Furthermore, the control structures require upstream and downstream cross sections. In general, canal cross sections are required for slope change of the canal bed, changes in the cross section area and, changes in the canal resistance or leakage factors. Considering that no significant changes occur in the canals within the domain, only the minimum number cross sections were provided. For some of the canals (L-31N, C-111W, C-102, C103), AUTOCAD files were obtained from DERM and approximately 60 cross sections were extracted.

The remaining cross sections were obtained using the procedure described below:

- Using the aerials of the canals, the canal was zoomed in ARC MAP and the distance between the two canal berms were measured with the distance measurement tool (Fig. 35). The raster of the domain (using 200m resolution) was used to determine the approximate elevation of the banks in the canal.

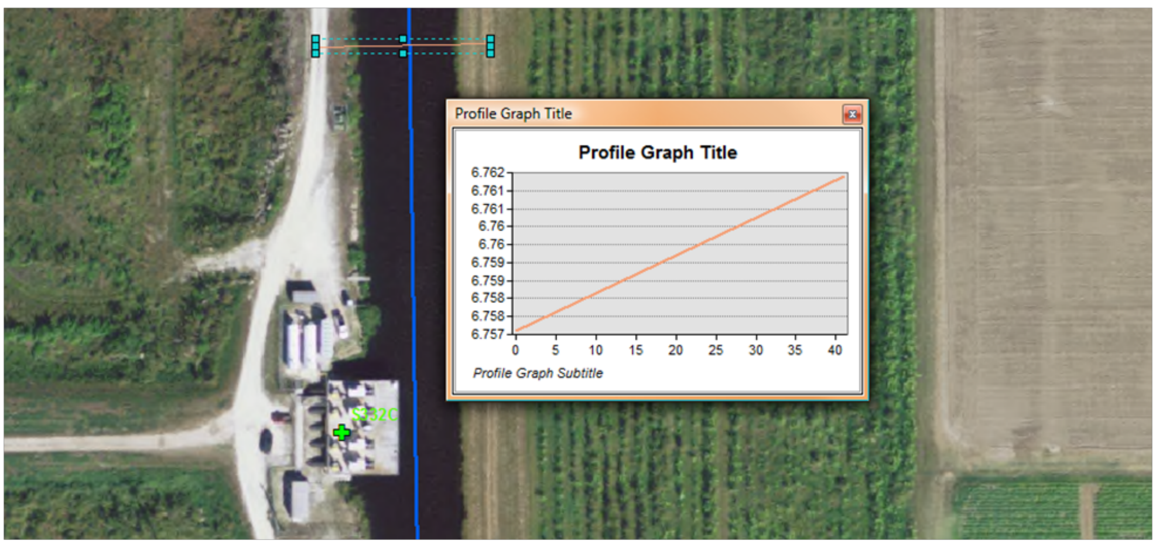


Figure 35. Approximation of canal cross section.

- After determining the approximate cross section width, a slope, H:V of 1:2 was assumed.
- The cross section was generated by adding points to define the bottom of the canal and the overall geometry. One of the considerations for building the model was to have smooth transitions along the canal bottom along the flow and to keep the approximate slope of the canal as obtained from "as built" surveys.
- To define the resistance of the canal a uniform Manning number M of 30 $m^{1/3}s^{-1}$ was used for all cross sections (Manning number M is reciprocal of the commonly used Manning n).
- AS BUILT surveys provided by the SFWMD Map room (a DVD with scanned drawings) were used to review the cross sections and canal profiles and to ensure that there are no significant deviations along the canals (deviations between the cross sections in the model and "as built" surveys are within 5% for canal bottoms and 10% for canal widths).

Figure 36 demonstrates the approach for building a cross section upstream of structure S-18C.

- Most of the cross sections were implemented using low and high flow resistance zones within the canal cross sections. The low flow Manning's number in most cases was assumed equal to 30, and the high flow Manning's number (representing flow with greater resistance, normally observed in the floodplain) equal to 1 to 5.

This methodology provides an approximation for the geometric and resistance parameters of the canals given that the canal conveyances are at least ten fold of the maximum flow observed in the canals.

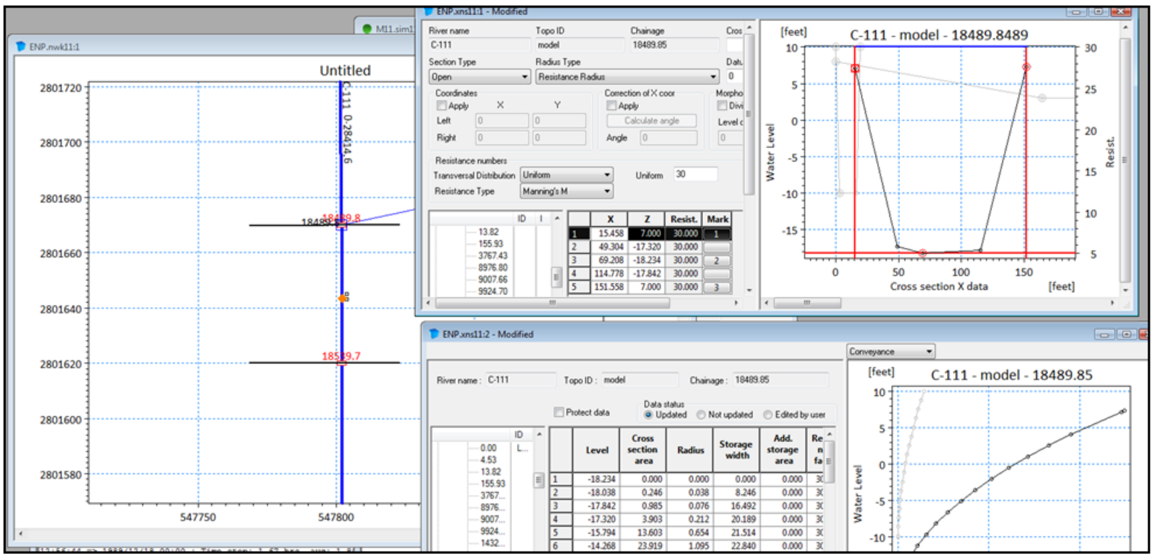


Figure 36. Example of building cross sections upstream of S-18C. The left insert is a section of the canal network (nwk11 file) overview showing two cross sections (black horizontal lines) The right side of the figure shows details of the cross section file with a typical section (top) and a plot of the conveyance rating curve.

3.5 M11 Canal Network Structure Overview

3.5.1 Canals

The original file of the canals was obtained from SFWMD's GIS Data Catalog. High resolution aerials were used to adjust minor inconsistencies in the shapefile. A KML file was provided to NPS for visual information about the canals included in the model and the spatial configuration of the canals. The canal network is shown in Fig. 37. The major branches are labeled, with detailed descriptions following in the next subsections.

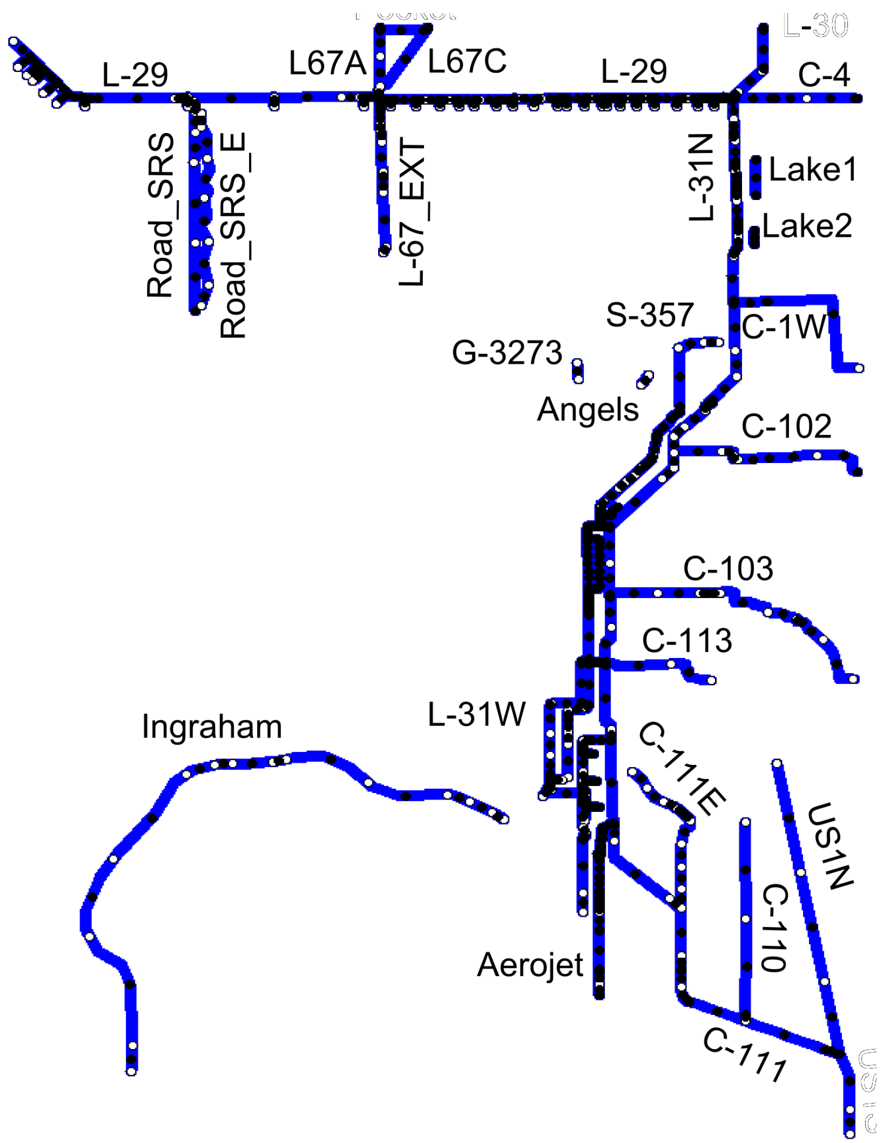


Figure 37. River network showing the major canal branches. The names for each of the culverts along Tamiami Trail and the detention areas are not listed.

C-4: Canal C-4 is the eastward continuation of the L-29 canal along Tamiami Trail, starting with structure S-336 and continuing to the model boundary for a total length of 20514 ft. The structure G-119 is at chainage 6802 ft.

C-1W: The canal C-1W intersects L-31N, just north of structure G-211 and allows water to be diverted to the east. Structure S-338 is used to control flow to the east. A total of 32260 ft. of canal is included in the model. There is no structure along the boundary and the next structure (S-148) in the canal is another 6 miles east and outside the model domain.

C-102: Provides drainage between L-31N to the east boundary and contains structure S-194, length is 33514 ft.

C-103 and C-113: Provides drainage east of L-31N to S-196 and S-167 for a length of 50100 ft. Provides drainage east of C-111 for a length of 19609 ft. There are no structures in this canal.

C-111E and C-110: Drains water south through structure S-178 into C-111. The upstream reach of the canal has overbank spillage to aid in drainage of ag lands. Total length is 3986 ft. Drains water south into C-111 through an overflow (flash board controlled) culvert, labeled C-110culv, length is 35131 ft.

L-29 (Tamiami Trail): L-29 canal is included in the model from just upstream of Culvert 24 on the western side to the eastern terminus, the intersection with C-4, L-30 and L-31N. The canal is important for the supply of water to western Shark Slough through the S-12 structures and Northeast Shark Slough (NESS) through the culverts (41 through 59) and the one-mile bridge. Total length is 122421 ft.

L-30: Approximately 2.8 miles of the canal is in the model. Half of the canal is north of the structure S-335. The canal picks up seepage from WCA-3B and passes the flow into the L-31N canal.

L-31N: The entire canal (21 miles) and its relevant structures are included (G-211, S-331, S-173, S-176, S-332B, S-332C, S-332D). Provides drainage south of junctions with L-30, L-29, C-4 and C-1W, C-102 and C-103 for a length of 110774. Included in this section is a description of the rockmine lakes, two lakes adjacent to L-31N in the northeast section of the model west of the West Wellfield. The two trigger wells implemented as lakes are also discussed. Angel's Well is implemented as a short channel (length of 2634 ft., reaching depth of -20 ft., and 10 ft. wide) with a very high leakage factor to provide a MSHE groundwater link with the M11 short canal. G-3273 is also implemented as a short canal with a length of 2920 ft. This configuration allows both Angel's and G-3273 to be used as trigger wells in the operational rules.

Frogpond: Provides drainage west of C-111, the entire canal and relevant structures (S-174, S-175, pump station S-332) are included in the No-dention area version for a total of 11.2 miles. The version discussed herein has a closed S-175.

S-357, S-332BN and BW, and S-332C: S-357 is a drainage canal for the 8.5 SMA and terminates at the S-357 pump station. Which in turn releases water to the S-357 detention area. S332BN, S332BW and S332C are short canals leading to the Southern Detention Area (SDA) and the S-332BN detention area.

C-111 and US-1: Conveys water from L-31N to the south side of the domain (south of S-176). The structure S-197 has a set of operational rules for the 13 culverts and the canal terminates with the observed tailwater at the edge of the domain, length is 93225 ft.

Aerojet and Aerojet-EXT: A lined canal reach starts from C-111 just north of S-177. The reach receives water from C-111 via the S-199 pump station. A weir (Aerojet-concrete) at chainage 6525 ends the lined reach and the canal flows into the next reach labeled Aerojet. This canal has weirs at chainages 5600, 8700 (Aerojet-rock1), 14000 (Aerojet-rock2) and 25700 ft. Overbank spilling to the west is allowed in Aerojet.

State Road SR-9336: A ditch north and west of the road, which blocks any overland flow. Culverts are not simulated in the model, a gap has been created in the road to allow water to flow uninterrupted into lower Taylor Slough.

LAKE1 and LAKE2: Two lakes in the north east section of the model (Lake1 is 1.6 miles, Lake2 is 0.5 miles)

ROAD_SRS: A a ditch west of the Shark River Slough Road (7.1 miles)

ROAD_SRS_E: A a ditch east of the Shark River Slough Road (7.0 miles)

US1N: A ditch west of US1 (10.0 miles)

US1S: A ditch west of US1 (2.0 miles)

3.5.2 Control Structures

Table 3. Broad Crested Weir Dimensions. All values are in feet.

Structure Location	Canal	Datum	Sill Level	Width at Sill	Max Width
W-S359-FLOWWAY	SDAN	0.0	7.95	350	410
W-S360E	SDAN	0.0	10.49	350	386
W-S360W	SDAN	0.0	10.99	350	374
W-S332BN-E	B-WS332BN-E	0.0	10.49	400	485
W-S332B-PC	SDAC	0.0	7.0 calib 9.83 ops	350	410
W-S332C-PC	SDAC	0.0	7.0 calib 9.8 ops	500	520
FPhighhead	FP	0.0	8.0	1900	2000
FPearth	FP	0.0	6.4	1900	2000
B3	FP	0.0	5.9	1900	2000
S202-A	FPDA-C1	5.1	0.0	150	250
S202-B	FPDA-C2	5.1	0.0	300	400
S202-C	FPDA-C3	5.1	0.0	400	500
W-AJ-CONC	AeroJet-EXT	8.0	0.0	50	50
weir57 (TT bridge)	culvert_57	0.0	5.6	5100	5200

3.6 Tamiami Trail (L-29, the Tram Road, L-67, and C-4)

The western portion of L-29 is divided into two reaches: a reach from the model boundary to a closed structure upstream of S-12A, which includes structures with prescribed (observed) discharges into the domain at culverts 24, 25, 26, 27 and 28, and a reach from just upstream of S-12A to S-333, which includes structures S-12A, B, C and D, also implemented with prescribed historical discharges to western Shark Slough. A connection to L-67A allows water to flow from WCA-3A into L-29. Overbank flow from WCA-3A into L-29 is also modeled, the conservation area is maintained at the observed level of station 3A-28 prescribed along the northern MSHE boundary and the canal levels in L-67A are prescribed by a northern boundary set to observed S-12D headwater values.

3.6.1 L-29 Reach from Culvert 24 to S12A

Historical Layout

Current Layout In 2016 the L-29 reach between culvert 24 and S12A consists of two parallel canals extending in a NW-SE direction. The NE canal is not named, and has direct inflow along its entire length from WCA3A. S343A and S343B are the two structures that release water from this canal reach (hence WCA3A). These structures allow water to flow between the NE and SW parallel canals, which are separated by a levee which defines the SW extent of WCA3A. The SW canal is called L-29, and has 5 culverts (24-28) and one control structure (S14) that allow flow between L-29 and Big Cypress National Preserve. The culverts are never blocked?, and the S14 structure is rarely used?

M3ENP Calibration Model Layout

M3ENP Operational Model Layout Figure 38 shows the nwk11 representation with the satellite image for the relevant area.

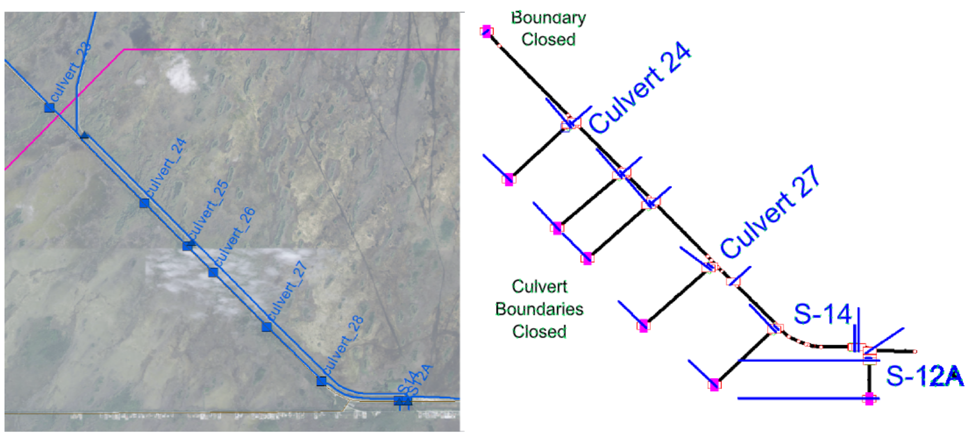


Figure 38. Western Reach of L-29, Culvert 24 to S12A.

Only the L-29 canal, Culverts 24-28, and S14 are modeled, the northern borrow canal and the S343s are omitted. This section of the L29 canal is essentially closed on both ends, so all water gains/losses must come through interaction with the MSHE model. Water from WCA-3A is allowed to enter the L-29 canal since there is no berm on the north side of the canal and a wide canal cross section interacts with the adjacent MSHE cells. The northwestern boundary of the L-29 canal is a closed boundary condition. The culverts are prescribed flow timeseries in the model. The data source used to derive these flow timeseries is unknown. S-14 is a closed structure, separating the borrow canal north of culverts 24 to 28 from the L-29 reach north of the S-12 structures. S12A is discussed in the next section.

Just west of the S12A structure, the L-29 is filled in. In M11, this has been implemented as a control structure that is always closed at this location, preventing the exchange of flow between the sections of the L-29 to the east and west.

3.6.2 L-29 Reach from S12A to S333

Historical Layout

Current Layout

M3ENP Calibration Model Layout

M3ENP Operational Model Layout This reach of the L-29 allows overbank flow from/to WCA3A. It is closed just west of S12A, and has 5 associated structures: S12A, S12B, S12C, S12D, and S333. It has a connection to the L-67A canal to the north. The Tram Road canal extends almost to the L-29, but does not have any direct connection. The S12 structures are all prescribed flow timeseries. The S333 has a prescribed tailwater stage timeseries.

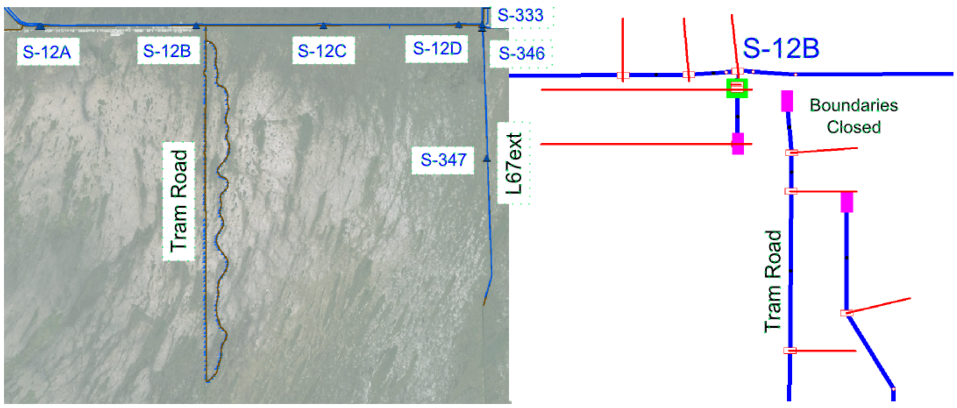


Figure 39. Western Reach of L-29, S12A to S-333 and the Tram road at Shark Valley.

3.6.3 Tram Road at Shark Valley

Historical Layout

Current Layout The road at Shark Valley (Tram Road) is a loop road with corresponding borrow canal (see Figure 39). The east loop has 98 culverts and the west loop has 80 culverts under the roadway. Are these sandbagged?

The road at Shark Valley can redirect the flow during storm events. Explain how? The model has implemented a shallow ditch (width of 20 ft and depth of 4 ft) with an adjacent low height berm (0.25 ft) to model the obstruction of flow between the areas east and west of the road. The height of 0.25 ft was selected after performing simulations and observing the model response at adjacent monitoring stations.

M3ENP Calibration Model Layout

M3ENP Operational Model Layout The model implementation of the Tram Road and borrow canal is as a shallow ditch (width of 40 ft and depth of 1.5 ft or m) with an adjacent low height berm (0.25 ft). No water control structures exist within this canal. The ditch begins just south of L-29, extends approximately 7 miles to the south, then loops back to the north and ends again near L-29, and is closed at both ends (Figure 40), and is not connected to L-29. Labeled ROAD_SRS and ROAD_SRS_E in the model. The culverts under the road are not individually modeled, so the low height berm is used to model the obstruction of flow between the areas east and west of the road. The height of 0.25 ft was selected after performing simulations and observing the model response at adjacent monitoring stations.??

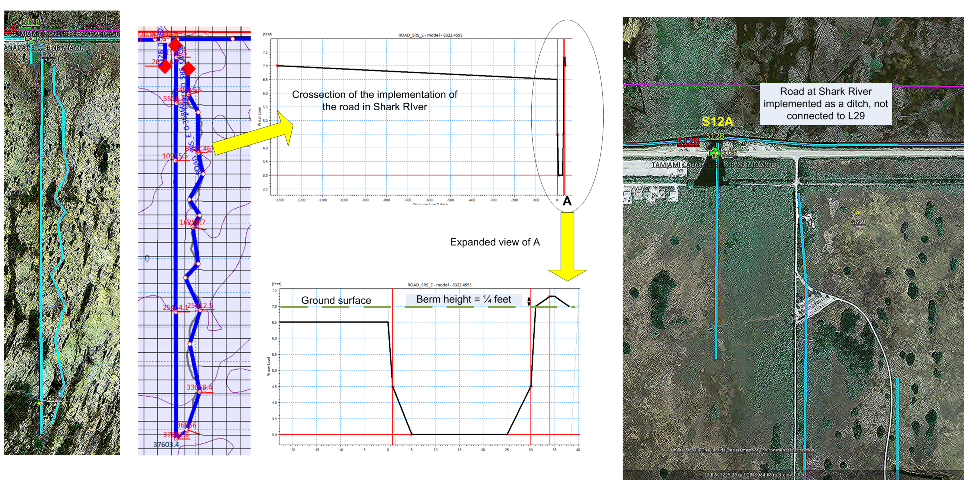


Figure 40. Implementation of the road at Shark River. A shallow ditch (3 ft depth? and 20 ft width?) and a berm with height of 0.25ft were used to implement the road and model the flow obstruction by the road between the areas west and south of the road.

3.6.4 L-67A, L-67C, and the Pocket

Historical Layout

Current Layout The area between the L-67A and L-67C canals is commonly referred to as the "Pocket". This transition area between WCA-3A and B generally has a steep gradient as higher WCA-3A stages seep underneath the levees to WCA-3B.

M3ENP Calibration Model Layout

M3ENP Operational Model Layout The intersection of the L-67A, L-67C, L-29, L-67EXT in the model is shown in 41. The top map is the satellite image overlain by the .nwk11 representation of the canals. The center plot is the .nwk11 view showing the canal cross sections in red. The sections having a large width are set up to interact with the MSHE cells to facilitate the exchange of surface water. Structures are shown in green and include S-333, S-346 and culvert 41.

The steep gradient of stages in the "Pocket" area is achieved by creating a short canal from WCA-3A to WCA-3B (42) along the northern boundary. The eastern edge of the canal has an open boundary condition with a prescribed daily stage timeseries obtained from model output (file INPUTFILES\MSHE\BOUNDARY\tsr79c49.dfs0). The timeseries was generated by averaging the output from adjacent cells in WCA-3A and B.

In the model, the canals L-67A and C bound the artificial "Pocket" canal. The L-67A canal connects to the L-29. L-67C does not connect to any other canals, and the "Pocket" canal does not connect to any other canals. The L-67A canal has an open boundary condition at its northern end, with a prescribed stage timeseries set to S-12D water levels (file INPUTFILES\M11\TIMESERIES\S12D_HW.dfs0).

What does this mean? "The canal sets the timeseries to identical values along its entire length, which eliminates any spurious velocity vectors in the MIKE SHE cells adjacent to the canal."

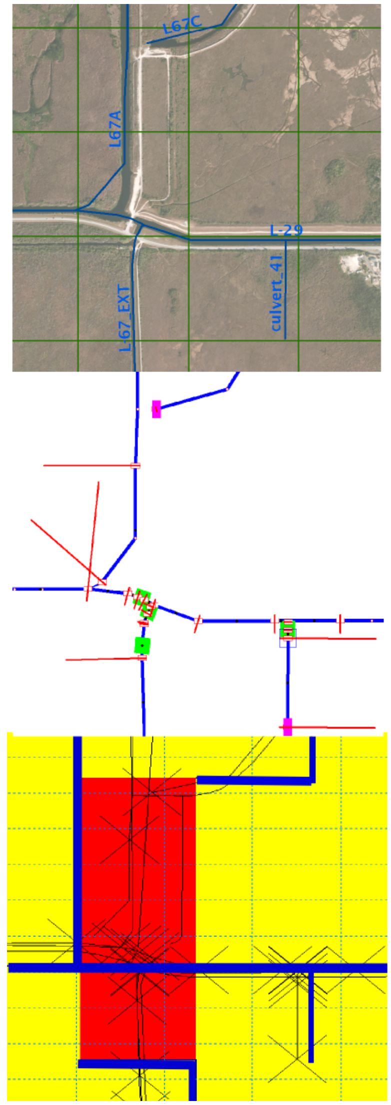


Figure 41. L-67A, L-67C, L-29, L-67EXT and Culvert 41. Top: Regional view of the intersection of the L-67A,L-67C, L-29, L-67EXT and Culvert 41 canal network. L-67EXT is implemented as a canal closed at both ends and a berm on the east side of the ditch. The cross sectional depth is assumed about 20 ft, the flow in the canal is allowed to over flow to the west and it uses CLOSED boundary conditions at both ends. Middle: Detail of the area from the .nwk11 file, showing canals in blue and xsections in red, structures/culverts in green and boundary conditions in magenta. Bottom: Discretization of the canal network in M3ENP, canals are shifted within the model to align with grid cell boundaries. TODO: labels

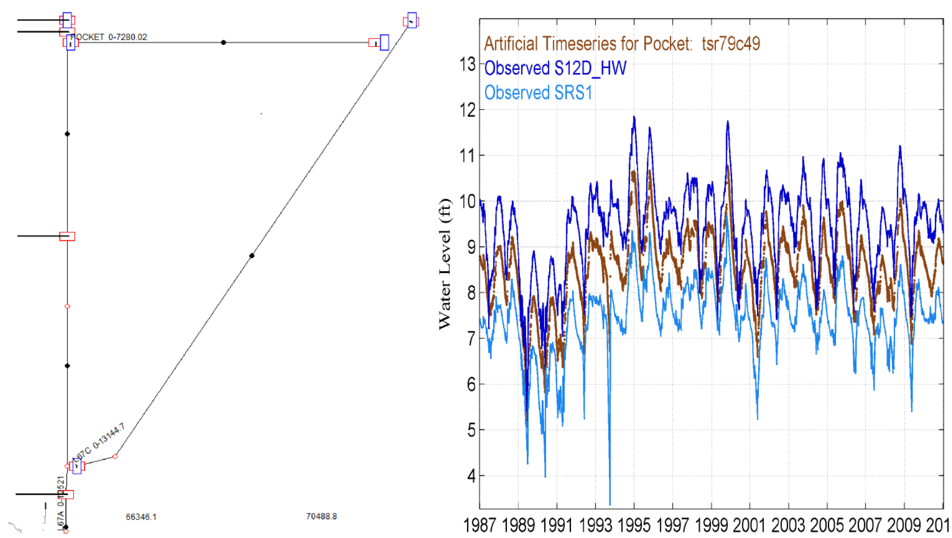


Figure 42. Pocket canal. The northern boundary of the model domain within the "Pocket" area is modeled in M11 as a canal with a stage timeseries boundary condition.

3.6.5 L-67EXT

Historical Layout L-67 EXT was partially filled in sometime...

Current Layout North end connected to L-29 just East of S333. Closed at south end (no flow).

M3ENP Calibration Model Layout

M3ENP Operational Model Layout L-67-EXT is implemented as a ditch that connects on its north end (via the S12E structure) with L-29 just downstream of S333. It is closed on its southern end, and has a berm on the east side of the ditch (see Figure 43). Thus the cross sections in L-67EXT interact with the west side of the canal. While the cross sectional depth is assumed about 20 ft, the flow in the canal is small because it uses CLOSED boundary conditions at both ends.

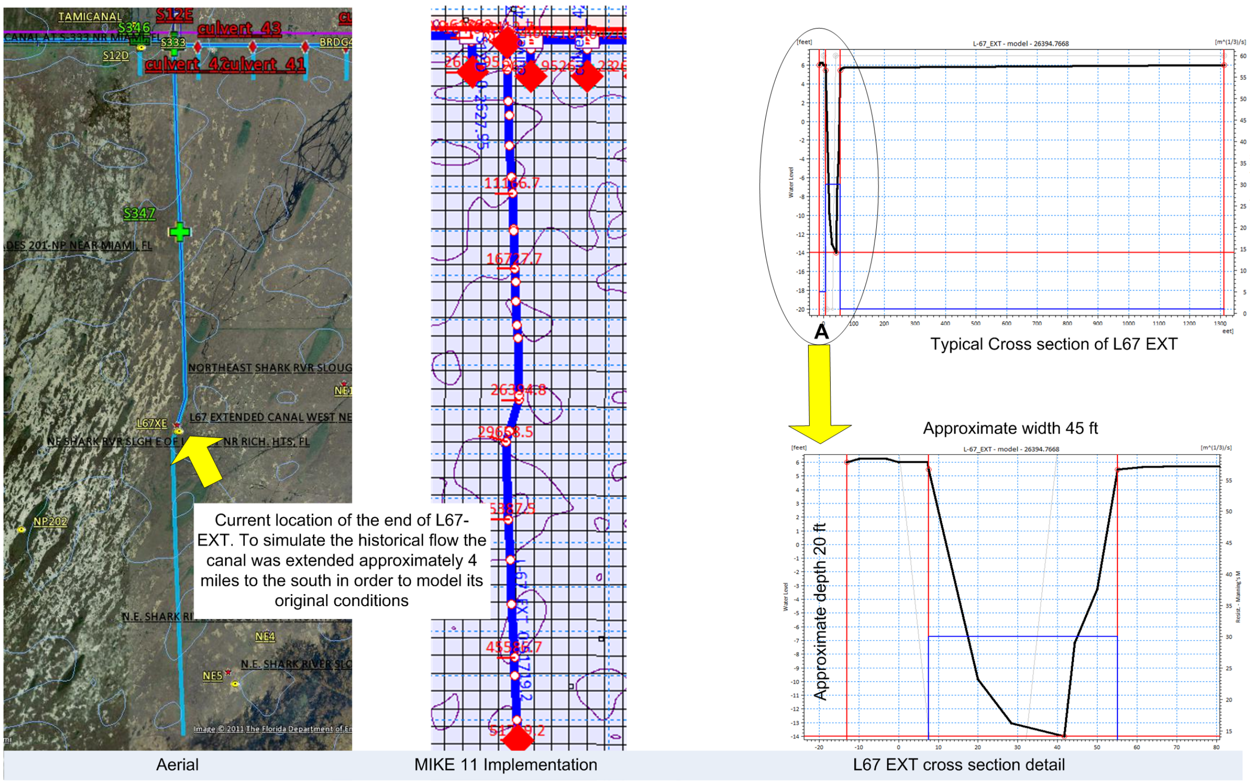


Figure 43. Implementation of L-67 EXT. The model implements the original L-67-EXT canal. The canal is closed from both sides and is not connected to L-29

Structures in the L-67EXT canal are the S12E, S346, and S347. S12E is an underflow structure that controls flow into the L-67EXT at its north end, and is kept closed? S346 and S347 are overflow structures that are always left open.

3.6.6 L-29 Reach from S-333 to S-334

Flow into L-29 through S-333 leaves the canal through S-334 and culverts 41 to 59. With the construction of the eastern one-mile bridge, culverts 56, 57 and 58 are now closed. The bridge is modeled as a one-mile long broad-crested weir and centered at the location of culvert 57. There is exchange between the groundwater and the L-29 canal as well, flow from WCA-3B enters L-29 and subsurface flow from L-29 enters the groundwater system below Tamiami Trail into NESS.

The culvert along L-29 were implemented as short canals with cross sections with approximate depth of 2 ft below surface. The depth of the canal has no influence on the MSHE nor M11 stages because the end of the canal uses CLOSED boundary conditions, i.e. no flow is allowed in the longitudinal direction at the canal boundary. The water flow in the longitudinal direction is minimal (zero at the boundary) and the entire flow is forced to overflow the canal banks and spill laterally.

3.6.7 C-4

A schematic of the C-4 canal is shown in Fig. 44. The upper plot represents the canal reach as displayed in the nwk11 file and bottom plot is the reach as displayed in a satellite image. The Miami-Dade flood control facility near the eastern boundary is not included in the model. Structure S-336 is located on the western start of canal C-4 and is in an always closed condition. A mile downstream is the structure G-119 which is also kept in an always closed condition. The stage in the reach between G-119 and the eastern boundary of the model is set to the observed daily tailwater timeseries of G-119, imposed as a water level boundary condition at the endpoint of the canal.

Figure 44. C-4. Conductance: river bed only; Leakage Coeffcient= 4E-005. Red indicates a cross section location, green is a structure and magenta is the boundary condition.

3.7 L-30

The canal L-30 enters the model domain approximately 1.4 miles north of S-335, the in flow point is a boundary condition with prescribed water levels, set to the observed timeseries data of S-335 headwater. The canal continues to the intersection with L-29, C-4 and L-31N as shown in Fig. 45.

The left diagram in the figure is a plot from the .nwk11 file and shows the structure S-335 (green) and the intersection at Dade Corners. The center plot is from the pre-processed data and shows the re-alignment of the canal with the grid cells and the stair-step pattern south of S-335 where L-30 turns to the southwest. The red cells are higher elevation cells to prevent spurious surface water from going across the canal.

L-30 captures a substantial amount of seepage fromWCA-3B which is conveyed to L-31N, in addition to any operations north of the model domain sending flow south for flood control and water supply.

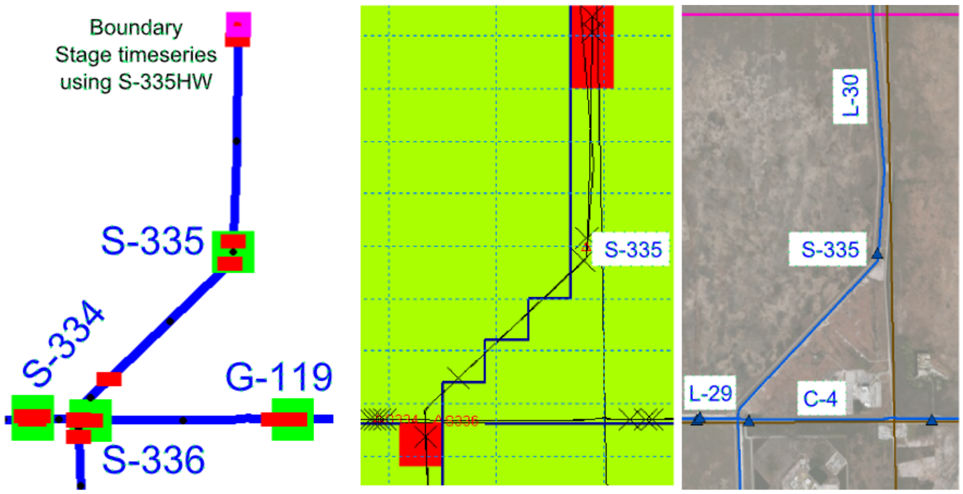


Figure 45. L-30

3.8 L-31N and L-31W

3.8.1 L-31N from L30 to G211 (L-31N Upper Reach)

The main canal affecting the eastern section of ENP is the L-31N, low canal water levels in this canal and C-111 account for the majority of the seepage from the Park to the canal and as groundwater flow under the developed lands east of L-31N. The canal begins at Dade Corners (near S334, see Fig. 46) and extends south to S-176/S-332D. Intersections with foure west to east canals (C-1W, C-102, C-103 and C-113) allow flows as flood control or water supply to take place. Control in the canal is through the G-211 structure and S-331/S173 complex. For implementation of future restoration plans S-332B, C and D pumps were built, currently the pumps are used for flood control operations.

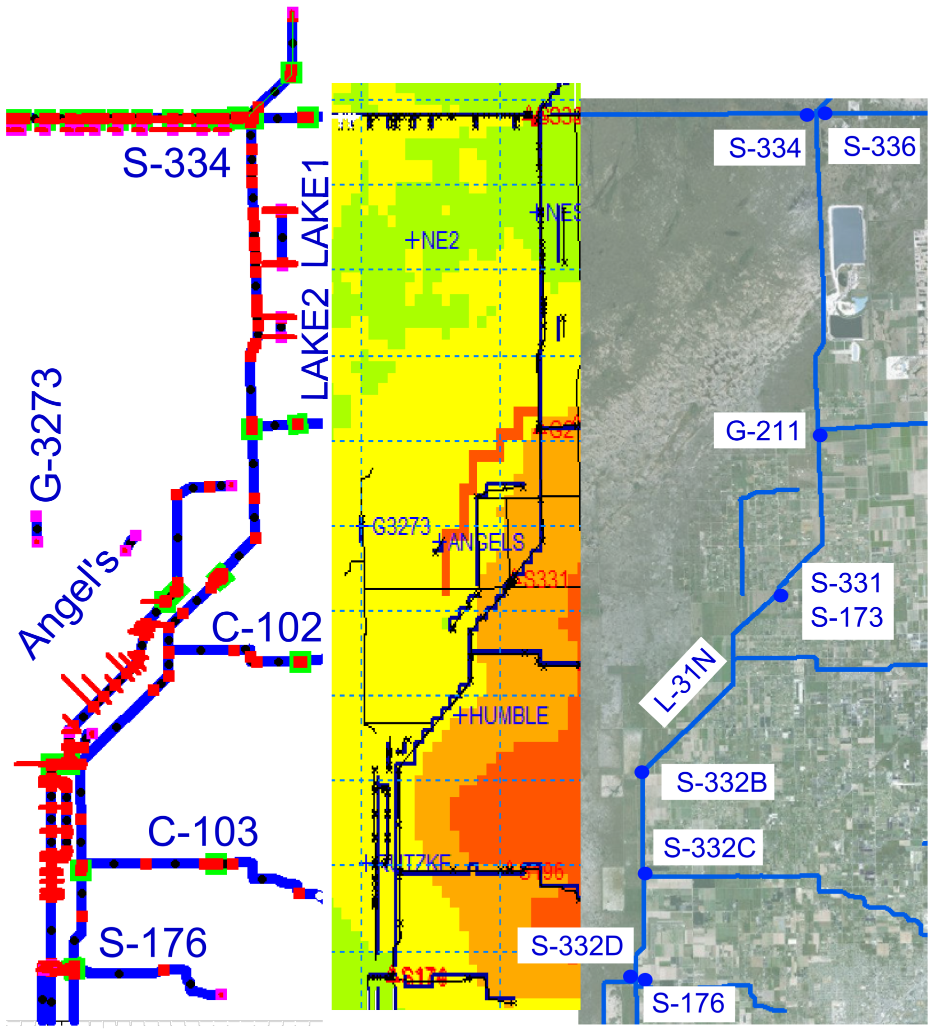


Figure 46. L-31N.

Rockmine Lakes Adjacent to the upper reach of L-31N, on the east side, are a set of lakes excavated during rock mining operations. Thes lakes are still being excavated, the northern most (LAKE1 in Fig. 46) completed. The lakes are represented in M11 as canals with cross sections as shown in the left side plot of Fig. 47. No operations are associated with the lakes and interaction is allowed with MSHE in the model, thereby rising and falling with the adjacent groundwater.

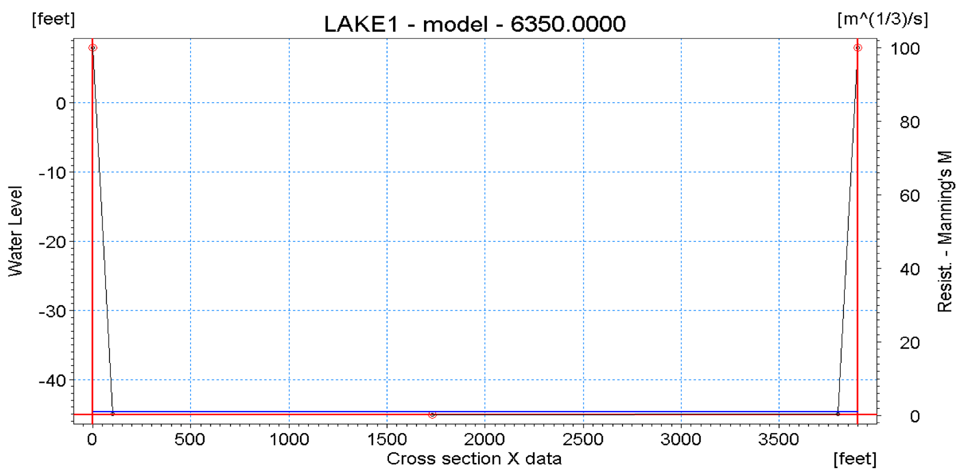


Figure 47. Cross section for the Rockmine lakes

3.8.2 L-31N from G211 to S331 (L-31N Middle Reach)

At the structures S-331/S-173 three associated operations are possible, S-173 is a set of gated culverts, S-331S is a syphon mode of the pumps and S-331P are three pumps used when gravity flow is not suffcient (Fig. 48). Thes structures are modeled in individual canals, with the canal reach associated with S-331P interacting with MSHE. The other two are placed for convenience to separate the various operational strategies in manageable chunks. In this form the individual contribution of the structures can be easily output. Thus, syphon (S-331S), pump (S-331P) and gated (S-173) components are tabulated and also shown as a total (S-331T) in the output.

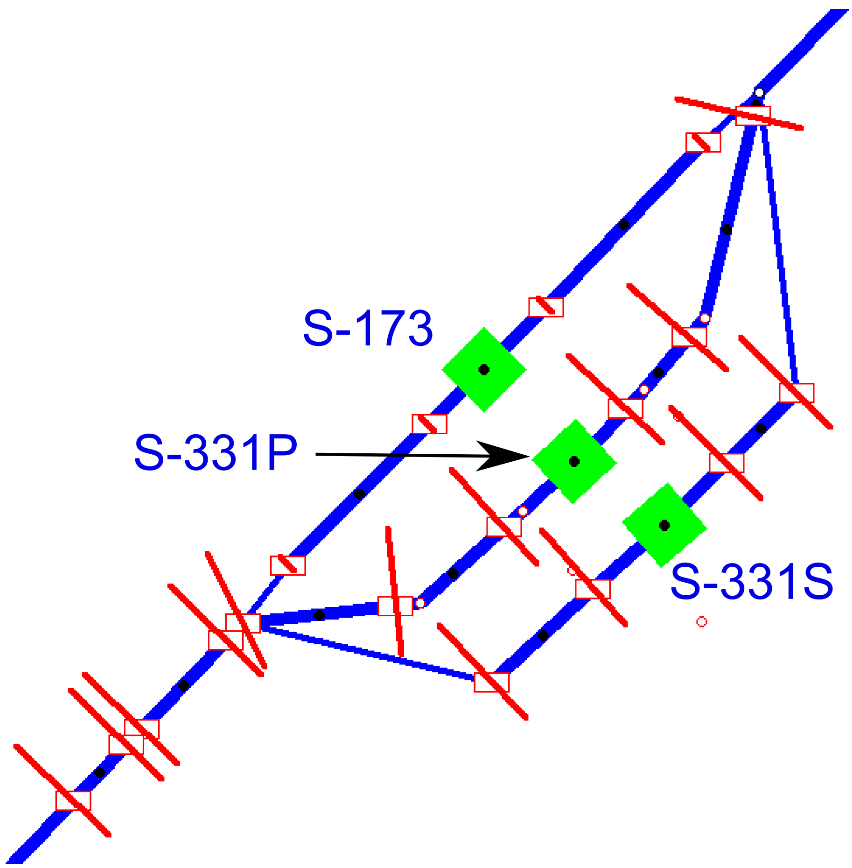


Figure 48. Configuration of S331/S173 area.

3.8.3 L-31N from S331 to S176 (L-31N Lower Reach)

3.8.4 L-31W

3.9 South Dade Coastal Canals (C-102, C-103, C-103N, C-103S, and C-113)

3.9.1 C-1W

C-1W allows flood control flow and water supply to the east through structure S-338. At the model domain boundary the canal is ended with a stage boundary condition. The observed data from S-338 and S-148 was used to generate an artificial timeseries, the tailwater of S-338 and headwater of S-148 were averaged. Fig. 49 shows the nwk11 representation with an inset of the satellite image for the relevant area.

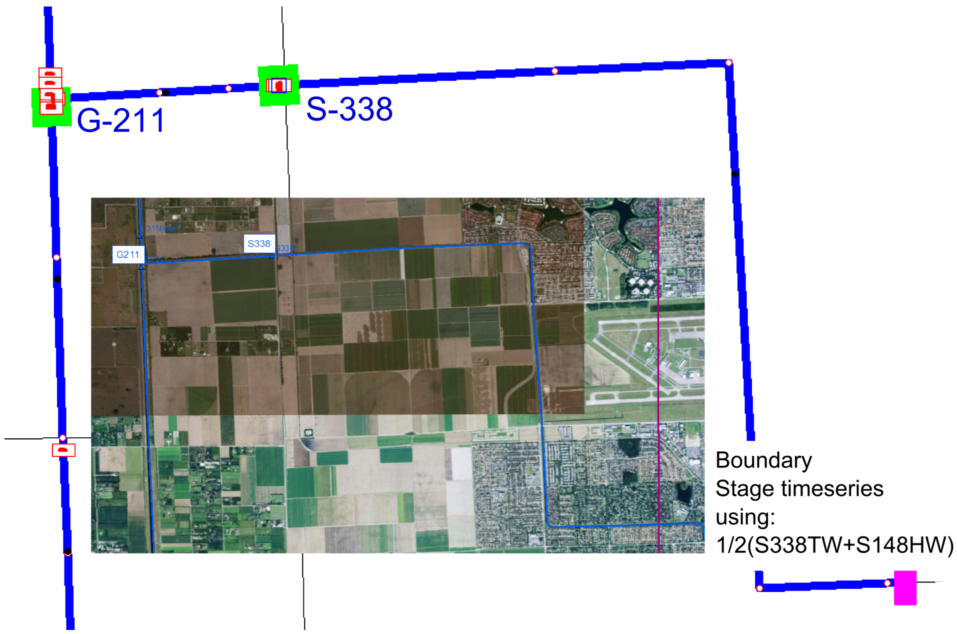


Figure 49. C-1W. Conductance: river bed only; Leakage Coeffcient= 2E-004. Red indicates a cross section location, green is a structure and magenta is the boundary condition.

3.9.2 C-102

C-102 provides drainage between L-31N to the east boundary and contains structure S-194. Fig. 50 shows the nwk11 representation with an inset of the satellite image for the relevant area. The structure is used primarily for flood control during peak summer events. The addition of the detention areas and S-332 pumps have provided much relief to the downstream developed areas by reducing the flow through this structure. The downstream boundary of the canal at the eastern extent of the model domain is set by an artificial time series, the average of the S-194 tailwater and S-165 headwater is used.

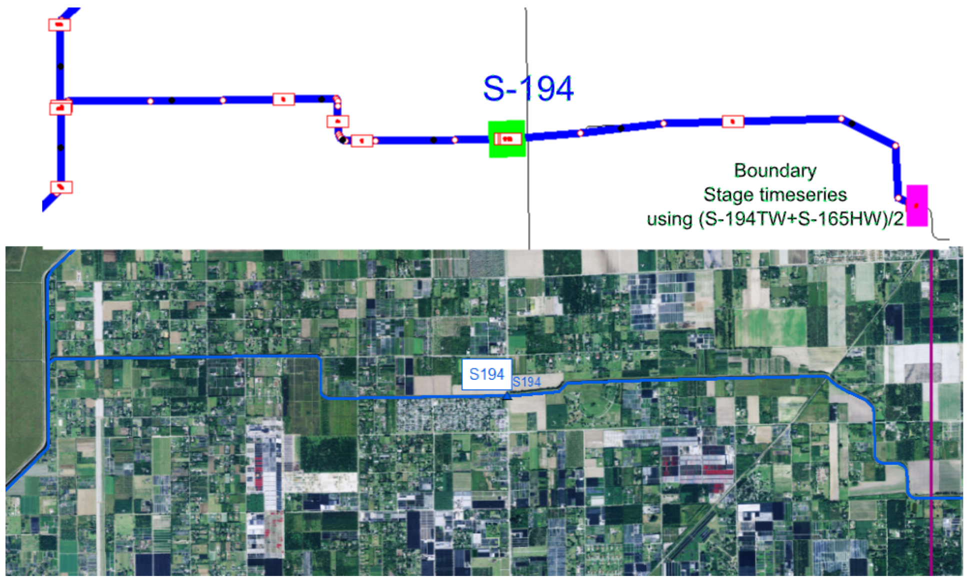


Figure 50. C-102. Conductance: river bed only; Leakage Coeffcient= 4E-005. The observed data from S-194 and S-165 was used to generate an artificial timeseries, the tailwater of S-194 and headwater of S-165 were averaged. Red indicates a cross section location, green is a structure and magenta is the boundary condition.

3.9.3 C-103

The C-103 canal in the model extends past S-167 and ends near the con uence of C-103 and C-103S. C-103S is not incorporated in the model. The boundary is using an artificial timeseries set to the average of S-167 tailwater and S-179 headwater. Fig. 51 shows the nwk11 representation on top with a satellite image for the relevant area shown below.

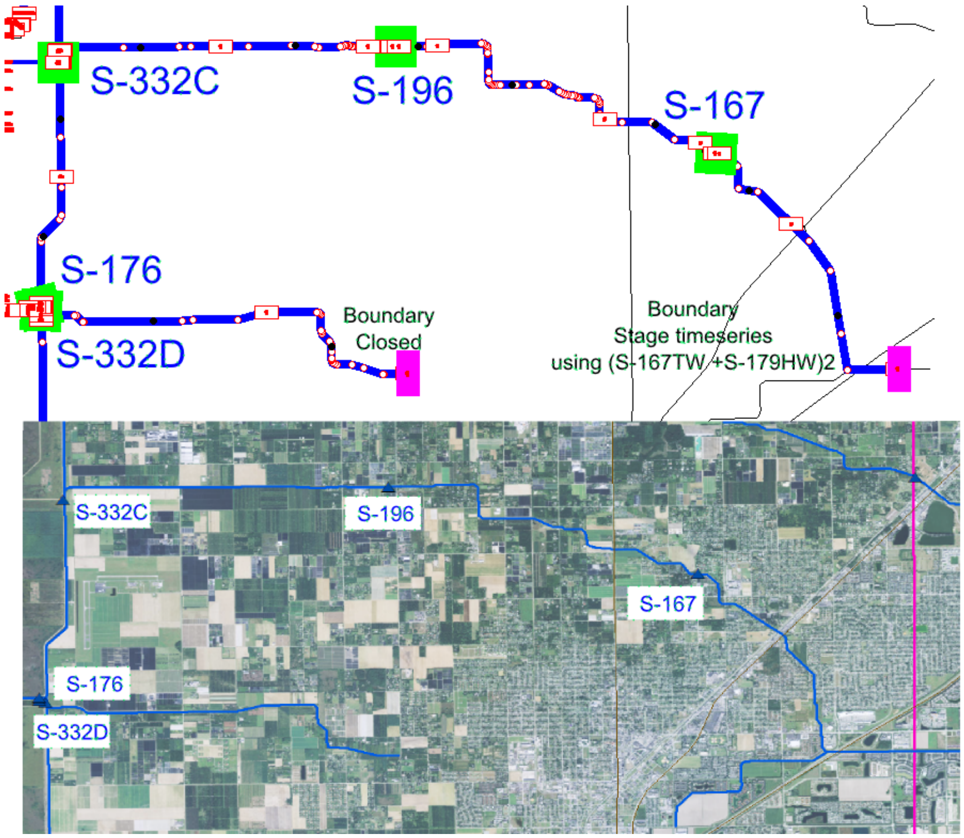


Figure 51. C-103 and C-113. Conductance: river bed only; Leakage Coeffcients C-103=6E-005 and C-113=2E-004. The observed data from S-167 and S-179 was used to generate an artificial timeseries, the tailwater of S-167 and headwater of S-179 were averaged. Red indicates a cross section location, green is a structure and magenta is the boundary condition.

3.9.4 C-103N

3.9.5 C-103S

Upstream of the structure S-176 is a short canal to the east which functions both to capture groundwater and send it west and as a water supply canal during the dry season. This canal is shown also in Fig. 51.

3.9.6 C-113

Upstream of the structure S-176 is a short canal to the east which functions both to capture groundwater and send it west and as a water supply canal during the dry season. This canal is shown also in Fig. 51.

3.10 State Road SR-9336 (Main Park Road)

The Main Park Road was implemented as a shallow ditch (width of 25 ft and depth of 3.5 ft) with an adjacent low height berm (0.5 ft) to model the obstruction to flow between the areas separated by the road (Fig. 52). The height of 0.5 ft was selected after performing simulations and observing the model response at adjacent monitoring stations.

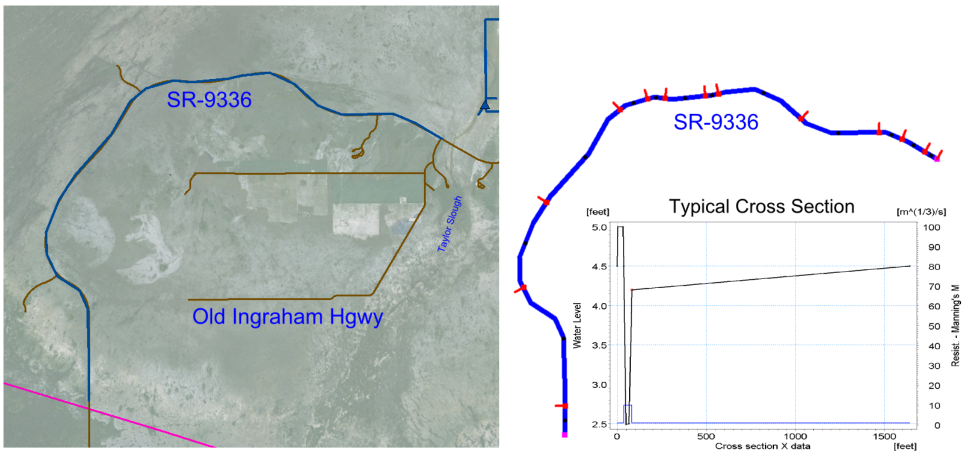


Figure 52. Implementation of Main Park Road. A shallow ditch (3.5 ft depth and 25 ft width) following the surface configuration and a berm with height of 0.5ft were used to implement the road and model the flow obstruction between the areas west and south of the road.

3.11 C-111 and such.... (C-111, S200 and S199, AeroJet, C-110, C111E, and US1)

3.11.1 C-111 from S176 to S18C (C-111 Upper Reach)

3.11.2 Aerojet and Aerojet-EXT

A lined canal reach starts from C-111 just north of S-177 (Fig. 53). The reach receives water from C-111 via the S-199 pump station. A weir (Aerojet-concrete) at chainage 6525 ends the lined reach and the canal flows into the next reach labeled Aerojet. This canal has weirs at chainages 5600, 8700 (Aerojet-rock1), 14000 (Aerojet-rock2) and 25700.

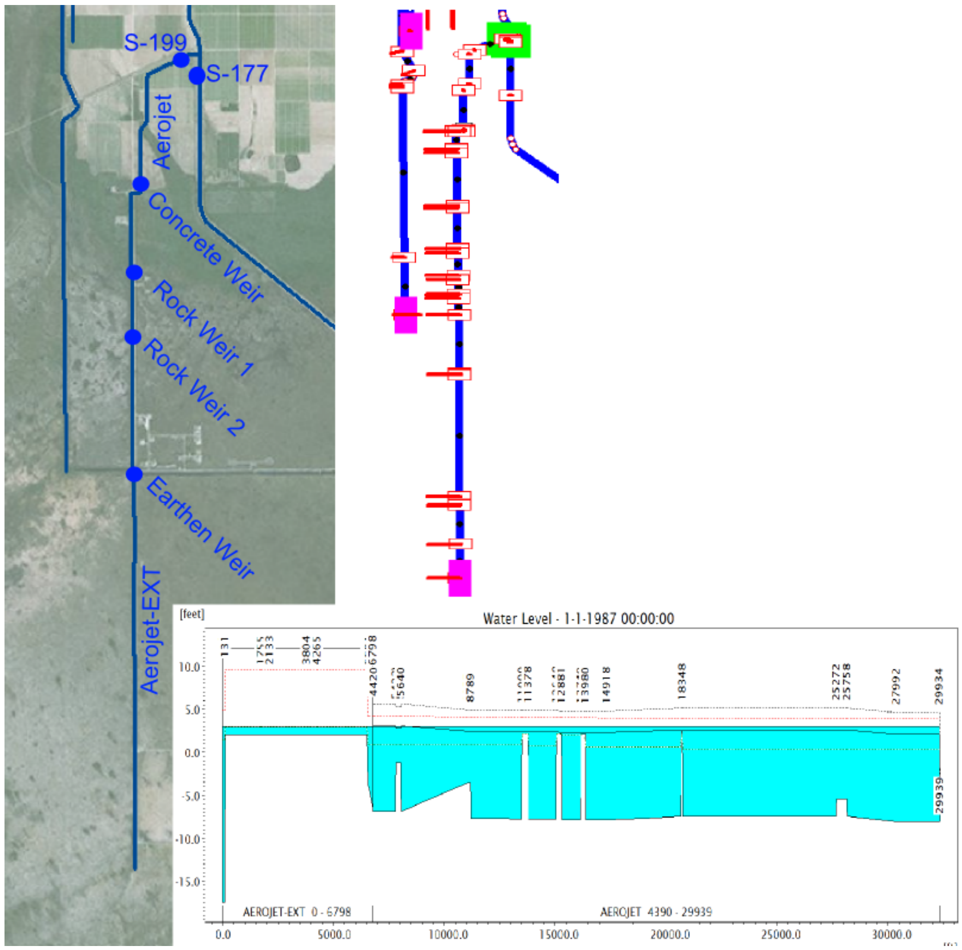


Figure 53. Aerojet and Aerojet-EXT. Conductance: river bed only; Leakage Coeffcient= 5E-005. A profile is shown in the bottom insert detailing the weirs in the canal as elevated cross sections. The .nwk11 representation is shown in the upper right plan view.

3.11.3 S-200 and S199

3.11.4 C-111 from S18C to S197 (C-111 Lower Reach)

Flows past S-176 in the L-31N canal enter the C-111 canal which terminates at structure S-197, controlling out flow to Manatee bay. Two structures, S-177 and S-18C, divide the canal into three reaches. South of S-18C, the canal is capable of over flow to the south, eventually entering Florida Bay. C-111E flows into C-111 halfway between S-177 and S-18C, Fig. 54. The Park anticipated that operations at S-18C would be able to maintain canal levels higher to keep surface water in the surrounding wetlands following the completion of the C-111 project. This project constructed the S-332B, C and D pumps close to areas where flood control was needed and reduce the reliance on gravity drainage through S-18C and S-197. This has not happened and S-18C is held at lower stages than during the Test 7 experiment, not only providing enhanced flood control for the developed areas, but also encouraging reclamation by draining vast areas of wetlands in the southern Everglades. In the model S-197 has an operational schedule established when there were thirteen culverts and the canal terminates downstream of S-197 with a boundary fixed to observed S-197TW.

US-1 is modeled as a shallow ditch with a berm to simulate the obstruction of the road.and separate the Model Lands from the Triangle area between Card Sound Road and US-1. Two reaches are modeled, US1N and US1S, with the separation occurring at S-197, to ensure no connection exists between the C-111 canal and US-1.

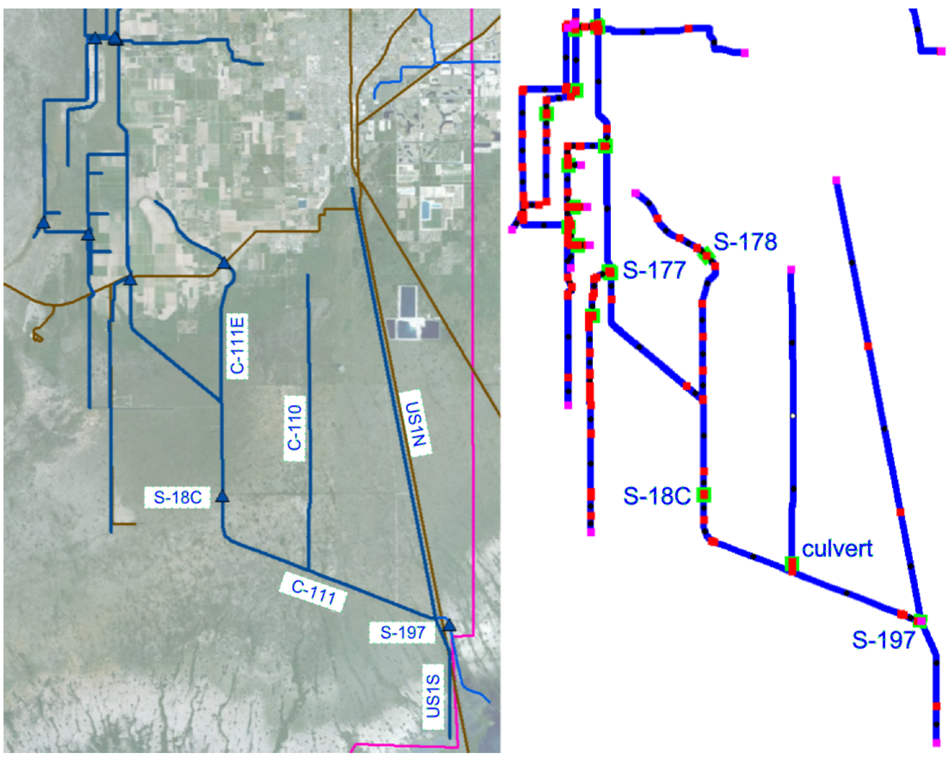


Figure 54. C-111 canal and US-1. A satellite image with the canal overlay is shown in the left panel. The boundary of the model domain is shown in magenta. US1 is divided into a northern and southern reach and not connected near S-197 where the road crosses the C-111 canal. The structures relevant for this model section are shown on the right in green, cross sections are shown in red and boundaries are magenta.

3.11.5 C-111E

C-111E is a drainage canal following the contours of the historical Ludlam Slough drainage. The canal flows past SR-9336 where a structure (S-178) is located. This structure is ineffective, the aquifer is highly conductive in the area and substantial drainage flows around the structure in the downstream reach of C-111E, which joins C-111 downstream of S-177. Fig. 55 shows the nwk11 representation on the left with a satellite image for the relevant area on the right.

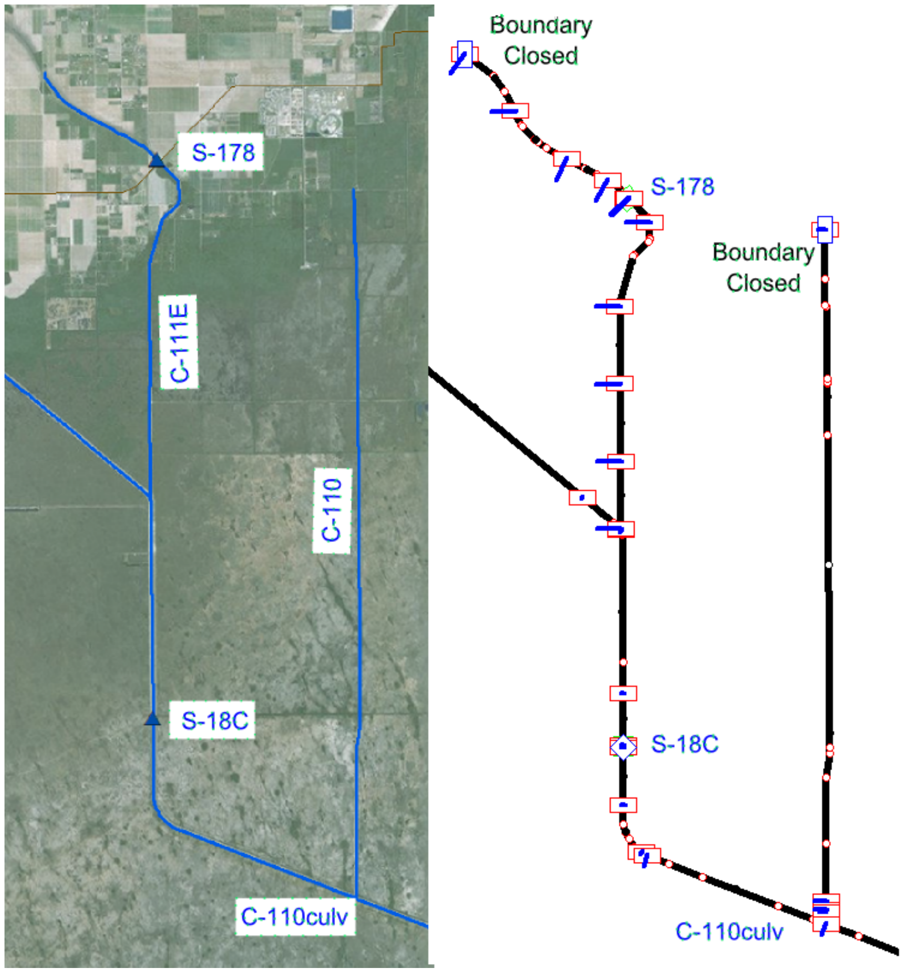


Figure 55. C-111E and C-110. Conductance: river bed only; Leakage Coeffcients C-111E=4E-005 for the reach upstream of S-178 and C-111E=8E-005 for the downstream reach (River Bed) and C-110=1E004 (Aquifer+Bed). C-111E connects to C-111 and C-110 connects via an over flow culvert to C-111, a flashboard set at two feet elevation controls the spillage. Red indicates a cross section location, green is a structure and magenta is the boundary condition.

3.11.6 C-110

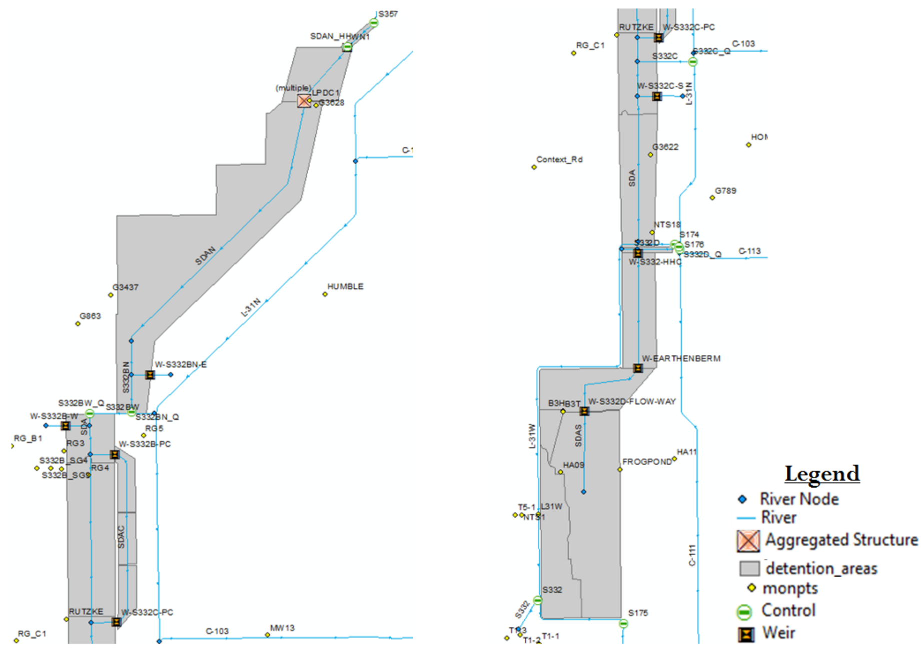
C-110 is a drainage canal which has a structure at its southern terminus connecting it to C-111. The structure are culverts with flashboards set at two feet elevation. The canal has been plugged at selected intervals to prevent extensive drainage of these wetlands, these plugs are not represented in the model. Fig. 55 shows the nwk11 representation on the left with a satellite image for the relevant area on the right.

3.11.7 US1-N and US1-S

3.12 Detention Areas

Detention areas and the associated pumps, weirs, and culverts included in the model and constructed under the Central and Southern Florida Project and Comprehensive Everglades Restoration Plan are outlined in the following sections.

The detention areas are implemented as a broad, shallow canal which extends from the southern end of C357 at the S357 pump to S332D (Frog Pond) Cell 3. Figure 56 shows the configuration of detention areas in grey and the canal in blue. The built southern and planned northern detention areas currently included in the model; however, there is an option to include the detention areas in sections as a function of the time they were built. Canal cross sections define the boundaries of the detention areas, see Figure 57. The implementation within M11 allows a more accurate representation of the detention area geometry and an accurate calculation of detained volumes than using overland flow cells.



S357, NDA, S332BN, S332BW, C111 SDA, and BC connectors

S332C, C111 SDA, and Frog Pond cells

Figure 56. Configuration of detention areas included in the model along with associated pumps, weirs, and culverts. The canal which provides the shape of the each area is shown in blue.

A part of the Modified Water Deliveries and C-111 projects are the pumps and detention areas shown in Fig. 58.

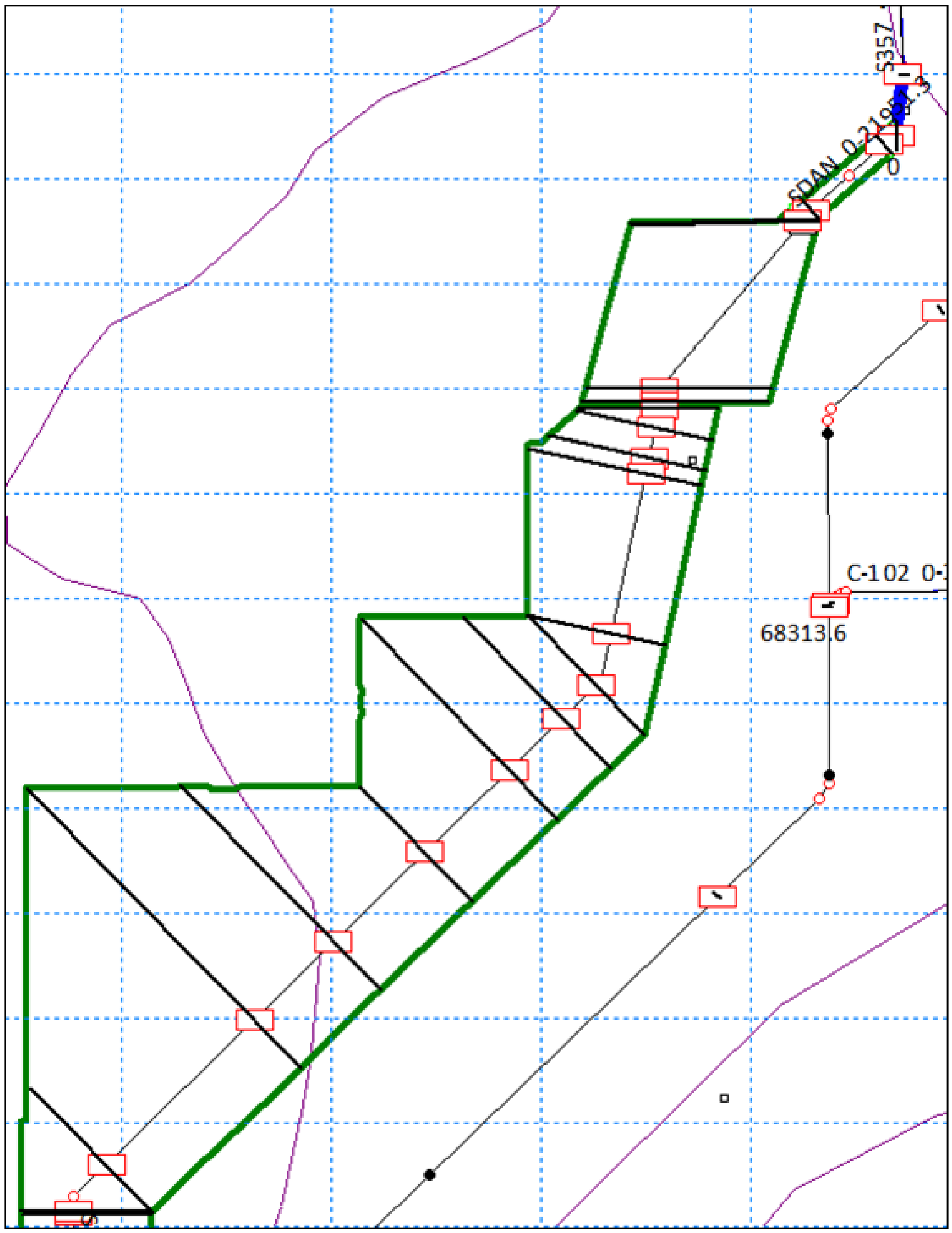


Figure 57. Canal (blue line) cross sections defining the S357 and C111 NDA (black lines).

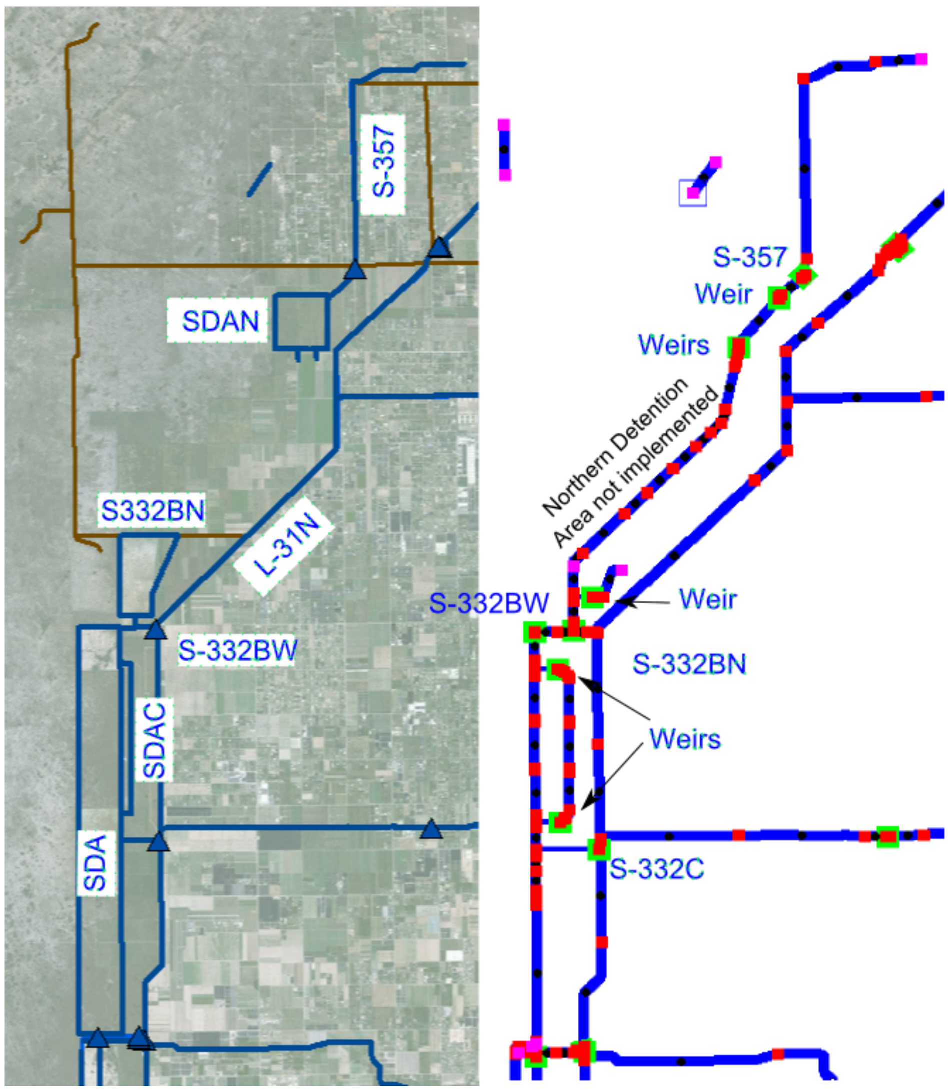


Figure 58. S357 and Southern Detention Areas: S332BN and S332BW (SDA and SDAC).

3.12.1 Northern Detention Area (NDA)

The C111 North Detention Area is currently in the planning phase. The area is included in the model.

S357 Detention Area The S357 detention area includes an inflow weir along the north end of the detention area (W-S359) which connects the detention area with the S357 getaway. The weir is 400ft long and 9.5 NGVD29 high. Water is pumped from C357 to getaway by the S357 pump and reaches the detention area via the S359 weir. Two out flow weirs (W-S360W and W-360E)are located along the southern end of the detention area. W-360W has a length of 350ft and a height 11.0ft NDVG29. W-360E has a length of 350ft with a height of 10.5ft NGVD29. The weirs are implemented with no overflow. C357 is a seepage collection canal. The canal is implemented with a closed boundary on the north, a pump on the south, and recharge by groundwater infiltration. Overland flow is not active and does not directly collect surface water runoff. The S357 pump operations control the water level within the canal and prevents overland flow.

To increase the flood protection of the 8.5 SMA, a canal (C-357) labeled S-357 in the model was constructed and connected to a pump station S-357, which discharges in the detention area SDAN via a short flowway with weirs. The model incorporates the S-357 system, and has an operational component in V914.

The S-357 pumps into the high-head cell with a bottom elevation between 6.5 and 7.5 feet, downstream the over flow weir is 9.4 feet. Two emergency spillways (weirs) of 400 feet length have crest elevations of 8.5 and 10.3 feet. All three weirs are incorporated in the model.

S332BN The S332BN detention area is implemented with an emergency out flow weir along the eastern side (W-S332BN-E). The weir is approximately 400ft long with a height of 11ft NGVD29. The southern boundary includes a control structure which discharges water into the S332BN detention area (S332BN-Q).

The Northern Detention Area (NDA) south of the S-357 dention basin has been constructed in the model but is not activated. The next detention area is the S332BN which receives its water from the S-332BN pump from L-31N. The pipes from S-332BN pump station (a component of the field station S-332B) discharge into the area.

3.12.2 Southern Detention Area (SDA)

S332BW The north side of the S332BW detention area includes a control structure to release discharge from the S332BN detention area (S332BW-Q). The west side of the area has a 1500ft by 9ft emergency out flow weir(W-S332B-W). The east side includes 8 culverts and a 350ft long, 9.5ft NGVD29 high weir. The connector culverts are 66ft long, with a diameter of 4ft. The culverts are currently not included in the model.

S332 Partial Connectors Current construction includes only the S332B partial connector and the S332C partial connector. The USACOE plans to join the partial connectors and create one large southern detention area (SDAC). The model currently implements the entire SDAC detention area.

The model includes a weir (W-S332B-PC) along the S332BW and S332B partial connector, north half, boundaries. The model also implements the weir (W-S332C-PC) between the S332C detention area and the S332C partial connector, south half, boundaries. The weir is 500ft long with a height of 3.6ft. There are also 15 culverts between the connector and detention area. The model does not currently include the culverts.

S332C Detention Area The S332C detention area receives flow along the east side from the weir adjoining the S332C partial connector (W-S332C-PC), as well as flow from pump S332C discharging from L-31N. An over flow weir along the southern east side of the detention area (W-S332C-S) provides a discharge outlet. The weir is 1500ft long and 4.1ft high.

The pump stations S-332B and C are each capable of delivering 575 cfs to the detention areas. Each location consists of four 125 cfs diesel pumps and one 75 cfs electric pump. Two 125 cfs diesel pumps direct from S-332B direct water in the S-332BN detention area, while the remaining two and the 75 cfs electric pump flow into the S-332BC detention area.

The pumps from S-332BW, the westward facing components of the field station S-332B deliver water into the Southern Detention Area (SDA), which is made up of former farm lands (scraped down to remove the soil) and the natural, never farmed, areas. The SDA is modeled as a canal in the 400m model, since it incorporates only two full cells. In addition The connector canal/flowway, SDAC, constructed because some of the lands were not yet purchased at the time of construction, is also modeled, with a set of weirs connecting it to SDA. The entry and exit points of the connector contain both weirs and culverts in the field, these have not been included in detail since they were never used. By the time construction completed on this infrastructure all the lands were under government control and the SDA was completed as one unit before operation of the culvert/weir complex was established. A fully open connector is modeled.

Details of the detention areas are shown in Fig. 59. The top diagram is the preprocessed output of the SDAN flowway in the left half of the plot, the canal is shown aligned with the cell boundaries. The left plot shows the L357 levee, a feature that is included in the MSHE topography input, simulating the existing levee around the 8.5 SMA.

The bottom plots show S-332BW detention area on the left, which also has the overflow weir modeled, the weir has never functioned, seepage from the detention area is suffcient to keep up with maximum pumping rates. On the left is the modeled connection of the detention area SDA with the flowway SDAC. Note the closeness of the model canals. Each canal is aligned north-south with a grid cell boundary, all with interactions to the groundwater module in MSHE.

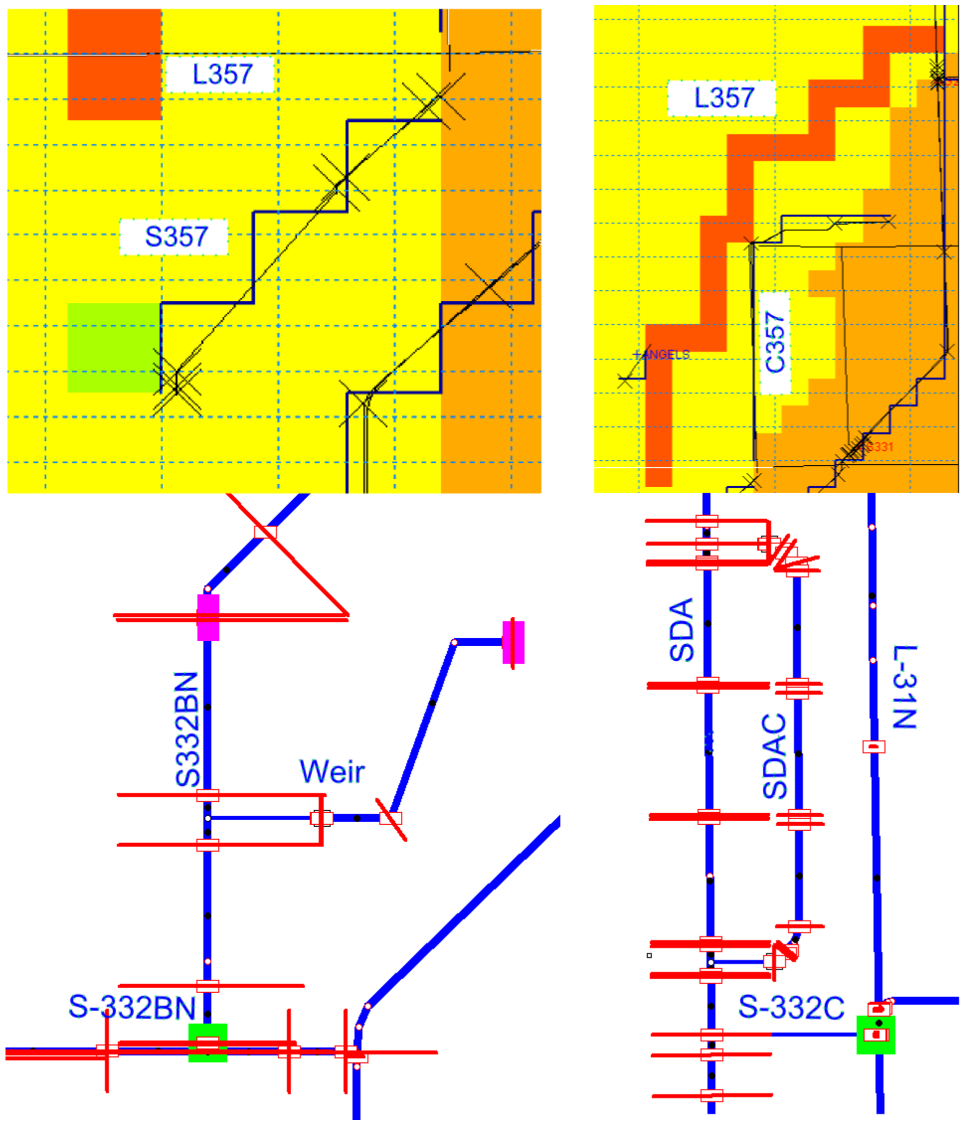


Figure 59. S357, S332BN and SDA Detention Areas Details. The re-alignment of the S357 detention area with the grid (upper left) and the L357 levee (as a topographic feature) with the C357 canal (upper right). The S332BN detention area (bottom left) and the emergency over flow weir is shown with the location of the S-332BN pump. The SDA and SDAC detention areas with the S-332C pump are presented in the bottom right.

3.12.3 Frog Pond Detention Areas

The former agricultural area between C-111 and L-31W, in large part, has been converted to a series of detention areas with associated infrastructure (Fig. 60). Adjacent and to the north of S-176 are the S-332D pumps designed to pump westward into a high-head cell with an over flow weir on the west side allowing flow to enter the western two sections of the Frogpond. The high-head cell stacks water to an elevation of 8 feet before over flow, thereby (because it is a highly permeable karstic geology underneath) resulting in large seepage into the C-111 canal. It has been estimated that in excess of 50% of the pumpage returns to this canal as seepage. On the western end seepage also enters L-31W directly downstream of corner plugs in the canal and also enter into the remnants of L-31W on the north side where, during high water levels, return flow goes directly across abandoned structure S-174. It is not clear what possible reason there is for a high-head cell in this environment. The weir crest elevation is at 8.2 feet for a length of 1900 feet, which gives it a design of 500 cfs at 8.45 feet.

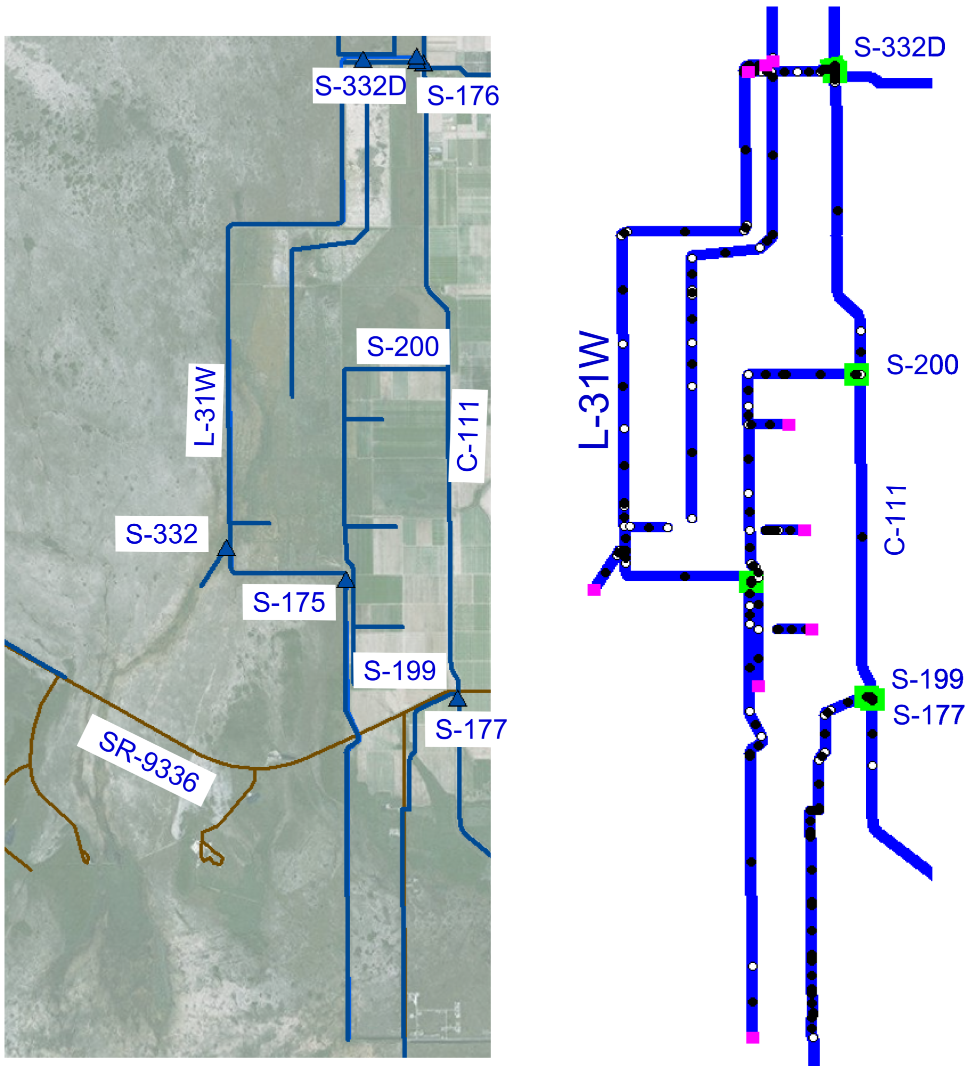


Figure 60. Frogpond canal/detention basin complex. L-31W, S-332D and Frogpond detention areas. The Frogpond is a low-lying former agricultural area bounded by C-111 and L-31W Detention areas associated with the S-332D pump and high head cell allow flows to enter the western sections of the Frogpond.
Three detention areas are downstream of S200 (FPDA-1, FPDA-2 and FPDA-3). The canal from the Pump S-200 is lined to the western corner in order to minimize seepage back into C-111 canal. The purpose of the detention areas are to maintain a higher hydraulic head in the area to minimize eastern groundwater flows from ENP to C-111, thereby encouraging flows into Taylor Slough.

Flows that cross the weir and discharge into a flowway encounter another weir downstream set to over flow at 6.4 feet elevation. Little flow enters the two western sections of the Frogpond under normal conditions. Opposite the old pump station S-332 the embankment has been lowered to provide a direct exchange with the western sections allowing water to flow east or west. Lowering of the embankment on the west side, adjacent to S-332 facilitates flow into Taylor Slough and is modeled with a short canal to the southwest labeled S-332 in the model (Fig. 61).

Fig. 61 are two detailed representations of the .nwk11 M11 canal layout file. The top map shows the configuration of the S-332D high-head cell and adjacent canals. The southern terminus of the Southern Detention Area (SDA), the start of the Frogpond (FP) flowway and the northern reach of L-31W are shown. S-332D pumps from L-31N canal, north of S-176, into the high-head cell and S-176 structure controls southward flow into C-111. The pump station is capable of delivering 575 cfs using four diesel pumps at 125 cfs each and on electric pump at 75 cfs.

The bottom map in Fig. 61 is the .nwk11 representation of the southern part of the Frogpond system. The flowway Fp delivers water from the high-head cell to the western section of the Frogpond, where the canal reach intersects with the MSHE cells for both surface water flow and groundwater flow.

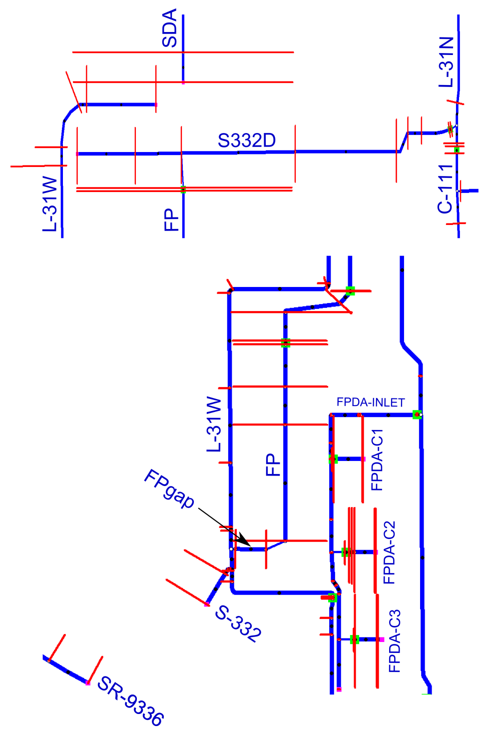


Figure 61. Details of the Frogpond canal complex.
Top: The northern portion of the Frogpond includes the high-head cell (S332D) represented as a canal with cross section from field surveys. The L-31W canal was eliminated from the intersection with L-31N (at S-174) to facilitate the M11/MSHE interaction of the high-head cell in the 4000m model, since both canals fall on the same cell interface.
Bottom: Detail of the area from the .nwk11 file, showing the central Frogpond area. Both the deep canal L-31W and the shallow owway FP convey water from north. FPgap is a short canal representing the elimination of the L-31W western berm allwing exchange between canal and flowway. S-332 takes L-31W water and distributes it to MSHE cells into Taylor Slough. Each of the Frog Pond Detention Area cells have weirs from the inlet canal, FPDA-INLET, connected to pump station S-199.

S332D High Head Cell The S332D high head cell receives discharge from the S332D pump. The high head cell is implemented as an additional canal and the area of the cell is defined by the canal cross sections. There is a weir along the south side of the cell (W-S332-HHC) which is 1900ft long and 8.1ft NGVD29 high. The weir connects the high head cell with S332D cell 1.

S332D Cell 1 and Cell 2 The S332D Cell 1 detention area has an earthen berm (W-EARTHENBERM) along the south side with a length of 2100ft and a height of 6.5ft NGVD29. The berm is implemented as a weir and connects Cell 1 with Cell 2. Cell 2 has a 1900ft long, 6ft NGVD29 high, weir (W-S332D-FLOW-WAY) along the south side. The weir connects Cell 2 with S332D Cell 3.

S332D Cell 3 S332D Cell 3, also called Frog Pond or Flow Way, is the southern most detention area. Flow is received across the weir joining the S332D Cell 2 and Cell 3 (W-S332D-FLOW-WAY). The canal implemented in the model to represent flow through the detention areas ends in the center of Cell 3.

4 M11 Operations

4.1 History of Operations in the South Dade Conveyance System

In November 1983 Congress authorized the Experimental Water Deliveries Program which suspended the Minimum Delivery Schedule in favor of the rainfall plan to provide water deliveries to ENP that corresponded to local climatic conditions. The first five tests dealt with distribution and timing of flows to Northeast and Western Shark Slough.

Throughout the 1980's disagreements persisted between the agencies and agricultural interests over L-31W and C-111 drawdowns and G-596 use as a trigger well to control S-333 flows. In June 1985 the USCOE issued an EA and a FONSI on operations which lowered L-31N and C-111 canal levels and implemented a rainfall based delivery schedule developed by Neidrauer and Cooper (1989). Frogpond drawdowns persisted until after 1992 and were eventually terminated by acquisition of the Frogpond in 1995.

The Test 6 iteration (July 1993) provided two additional 100 cfs pumps at S-332 for a total of 565 cfs. Operationally the pumps were allowed to operate throughout the year, but the USFWS recommended limiting the output to 200 cfs during January to May to prevent CSSS nest flooding.(REF FWS BO for the Modified Water Deliveries to Everglades National Park project, Experimental Water Deliveries Program, and the C-111 Project (1999))

The construction of the detention areas and associated infrastructure under the auspices of the Modified Water Deliveries to Everglades National Park (MWD) and the C-111 General Re-evaluation Report (C111-GRR) changed the ability to manage eastern flows to the Park. The construction efforts were undertaken in conjunction with the Experimental Water Deliveries Program. The first five tests dealt with the distribution and timing of flows to Northeast and Western Shark Slough. A rainfall plan Neidrauer and Cooper (1989) was also implemented to provide for water deliveries to ENP corresponding to local climatic conditions.

The Frogpond drawdowns to benefit dry season agriculture persisted until after 1992 and were eventually terminated by acquisition of the Frogpond in 1995.

TODO fig. of S332 q under exp prog

Acquisition of the Frogpond, HA stopped march 1995

G-211 went in 1991 oct data starts

Experimental Program: Test 7 Phase I.			
Canal	Structure	Phase I	
		Open	Close
L-29	S-334	Closed	
L-31N	S-338	5.8	5.5
L-31N	G-211	6.0	5.5
L-31N	S-331	Angel's Well[a]	
L-31N	S-194	5.7	5.3 (5.2)
L-31N	S-196	5.7	5.3 (5.2)
L-31N	S-174	4.85	4.65
L-31N	S-176	5.0	4.75 (4.6)
L-31W	S-332	Taylor Slough Rainfall Plan (465 cfs)	
		Mar 1 to Jul 15 limit pumping to 165 cfs	
L-31W	S-175	4.7	4.3
C-111	S-177	4.2	3.6
C-111	S-18C	2.6	2.3
C-111	S-197	S-197 Criteria[b]	
Source: Knight 2000 and USACE 2006			

[a] If 5.5 < Angel's well < 6.0, pump to maintain S-331 HW between 4.5 and 5.0; If Angel's > 6.0 pump to maintain S-331HW between 4.0 and 4.5 until Angel's well is below 5.7 ft.; Terminate pumping if S-176 HW > 5.5; Resume pumping when S-176 HW falls below 5.0.

[b] If S-177 HW > 4.1 or S-18C > 2.8 open 3 culverts; If S-177 HW > 4.2 or S-18C > 3.1 open 7 culverts; If S-177 HW > 4.3 or S-18C > 3.3 open 13 culverts.

Figure 62. Experimental Program Test 7 Phase I.

Table 4. Experimental Program Test 7 Phase I. Source: Knight 2000

Canal	Structure	Open	Close	Note
L-31N	S-338	5.8	5.5	
L-31N	G-211	6.0	5.5	
L-31N	S-331			Angel's Well [a]
L-31N	S-194	5.7	5.3 (5.2)	
	S-194	5.3 [b]	4.8 [b]	
L-31N	S-196	5.7	5.3 (5.2)	
	S-196	5.3 [b]	4.8[b]	
L-31N	S-174	4.85	4.65	
L-31N	S-176	5.0	4.75 (4.6)	
L-31W	S-332			Use prescribed [c]
L-31W	S-332B			Non-existent [b]
L-31W	S-332B Reservoir			Non-existent [b]
L-31W	S-332D			Non-existent [b]
L-31W	S-175	4.7	4.3	
C-111	S-177	4.2	3.6	
C-111	S-18C	2.6	2.3	
C-111	S-197			S-197 Criteria[d]
L-29	S-343 A/B and S-344			WCA-3A regulation schedule[b]
L-29	Canal			Constraint 8.0 ft [b]
L-29	S-12 A/B/C/D			10/20/30/40% west to east [e]
L-29	S-333			G-3273 Criteria [f]
L-29	S-334			Closed[b]
L-29	S-355 A/B [g]	8.5	6.50	
L-67A	S-151			WCA-3A regulation schedule
L-30	S-337			Water supply only [b]

[a] If 5.5 < Angel's well < 6.0, pump to maintain S-331 HW between 4.5 and 5.0; If Angel's > 6.0 pump to maintain S-331HW between 4.0 and 4.5 until Angel's well is below 5.7 ft.; Terminate pumping if S-176 HW > 5.5; Resume pumping when S-176 HW falls below 5.0.

[b] According to 95 Base Modified 2

[c] Operated according to Taylor Slough rainfall plan with 465-cfs capacity, subject to 165-cfs limitations from Mar 1 to Jul 15

[d] If S-177 HW > 4.1 or S-18C > 2.8 open 3 culverts; If S-177 HW > 4.2 or S-18C > 3.1 open 7 culverts; If S-177 HW > 4.3 or S-18C > 3.3 open 13 culverts.

[e] According to 95 Base Modified 2: Operated according to current regulation schedule, which includes rainfall plan target

[f] 95 Base Modified 2: If G-3273 < 6.8, S-333 open to deliver 55% of Shark River Slough target flows as per rainfall plan target (rainfall formula + WCA-3A regulatory discharge); If G-3273 > 6.8, S-333 closed.

[g] 95 Base Modified 2: Regulatory releases are constrained by L-29 and G-3273 triggers

The final Test 7, Phase 1 (base95) operations of the experimental program are defined in Table-Fig. 62. The objective was to implement a 45% flow volume to Western Shark Slough and a 55% flow volume through the S-333 to Northeast Shark Slough. In order to prevent the short-circuiting of Taylor Slough and C-111 basin wetland flows, stages in the SDCS, particularly south of S-176 would be increased. While a Test 7, Phase 2 operational scheme had been developed (with higher stages in the SDCS), non-concurrence between USACE and USFWS, principally on the lack of sufficient information on the design and potential effects on the CSSS, delayed the implementation.

The Experimental Water Deliveries Program was suspended in December 1999, however the rainfall plan continued to be the method for calculating the quantity of water to be delivered to ENP. Termination of the Experimental Program was a result of an opinion by the USFWS and USACE that the above average rainfall and the resulting in flows to WCA-3 from the Everglades Agricultural Area from 1992 to 1996 were damaging to CSSS population and habitat. The cause of these events was given as conditions provided by the Experimental Program, however the regulatory releases through the S-12 structures and flood control operations in the South Dade Conveyance System, components of water management which overshadow any operations (the rainfall formulas) for environmental purposes were not mentioned as probable causes.

The subsequent modifications to the restoration plans, abandoning the experimental program and implementing the ISOP/IOP/ERTP programs brought about changes to operations at the major inflow points to the Park.

In 1998, 1999, 2000 and 2001 emergency deviations from Test 7 were made to protect the CSSS. These operational and structural modifications were made under the authority of the President's Council of Environmental Quality (CEQ) (REF SEIS37) and included (see USACE 1999b(fix this citation), 1999c(fix this citation) and U.S. Army Corps of Engineers (2000)).

U.S. Army Corps of Engineers. 1999b. 1998 Emergency Deviation From Test 7 of the Environmental Program of Water Deliveries to Everglades National Park to Protect the Cape Sable Seaside Sparrow, Central and Southern Florida Project For Flood Control and Other Purposes. Final Environmental Assessment. Jacksonville District, Jacksonville, Florida. U.S. Army Corps of Engineers. 1999c. 1999 Emergency Deviation From Test 7 of the Environmental Program of Water Deliveries to Everglades National Park to Protect the Cape Sable Seaside Sparrow, Central and Southern Florida Project For Flood Control and Other Purposes. Final Environmental Assessment. Jacksonville District, Jacksonville, Florida. U.S. Army Corps of Engineers. 2000a. Final Environmental Assessment, Central and Southern Florida Project for Flood Control and Other Purposes, Interim Structural and Operational Plan (ISOP), Emergency Deviation from Test 7 of the Experimental Program of Water Deliveries to Everglades National Park for Protection of the Cape Sable Seaside Sparrow, Dade County, Florida. Jacksonville District, Jacksonville, Florida.

Water Supply Water supply is not implemented as a rule in M3ENP, available water for adhering to the rules is determined by upstream supply conditions. When water is not available, which often is the case, the rules are not followed.

4.1.1 C111-GRR and MWD

The C-111 GRR and Modified Water Deliveries project brought about structural changes in the form of pumps S-357, S332B, C, and D, and provided the opportunity to implement environmentally beneficial operational strategies to ENP. The 1994 C-111-GRR states that the flood protection preservation objective involves maintaining the original design canal stages and discharge capacities while restoring more natural hydrologic conditions within ENP. The design optimal canal stages are summarized in Section 2.2 of the 1994 GRR and provided in Fig. 63. Therefore, the purpose of the 1994 GRR was to maintain the level of flood damage reduction already provided by the authorities of the flood Control Acts of 1962 and 1968, not to augment or diminish these already existing benefits. The table in Fig. 63 maintains low canal stages north of S-331, thereby draining NESS wetlands and pumping the seepage south into L-31N. This particular strategy is not optimal for both environmental and flood control purposes and was not implemented in the experimental program or in subsequent IOP/ERTP strategies.

Table 1

Optimum Stages in ENP-South Dade Conveyance System

Canal	Reach	Elevation (Feet, NGVD)
Levee 31(N) Borrow Canal	US 41 to S-331	5.0
Levee 31(N) Rem. Borrow Canal	S-331 to S-176	5.5
Canal 111	S-176 to S-177	4.5
Canal 111	S-177 to S-18C	2.0
Levee 31(W) Borrow Canal	S-174 to S-175	4.5
Canal 103	L-31(N) Rem. To S-167	5.5
Canal 103	S-167 to S-179	3.5
Canal 103	S-179 to S-20F	2.0
Canal 102	L-31(N) Rem. To S-165	5.5
Canal 102	S-165 to S-21A	2.0
Canal 1	S-319(N) to S-148	5.0
Canal 1	S-148 to S-21	2.0

Figure 63. Optimum Stages in the SDCS.

4.1.2 Interim Structural and Operational Plan (ISOP)

U.S. Fish and Wildlife Service (USFWS) issued a Biological Opinion (BO) in February 1999 under provisions of the Endangered Species Act (ESA) that presented a Reasonable and Prudent Alternative (RPA) to avoid jeopardizing the Cape Sable Seaside Sparrow (CSSS) during the interim period leading up to completion of the Modified Water Deliveries project. The Central and Southern Florida project operations, particularly the Test 7, Phase 1 of the Experimental Program of Modified Water Deliveries (initiated in October 1995) to restore more natural flows to Everglades National Park placed the CSSS in jeopardy.

The jeopardy opinion was based on a decline in CSSS populations in 1993 observed from surveys in 1974, 1975, and 1978-1981 and detailed systematic field surveys conducted in 1983, 1992 and 1993 (Fig. 64). It should be noted that the sharp decline in CSSS Population A was following the Category 5 Hurricane Andrew prior to the subsequent breeding season (1993), in conjunction with large S-12 flood control discharges in 1993 and two subsequent years. Annual surveys since that time have not shown a recovery in the affected subpopulation.

The USFWS BO brought about the Interim Structural and Operational Plan (ISOP). The ISOP was designed to meet the conditions of the USFWS RPA included in the USFWS BO from March 2000 until implementation of the Interim Operational Plan (IOP) in 2002.

The principal actions were:

- Protect the Cape Sable Seaside Sparrow habitat from unusually high water levels in subpopulation A lowering water levels at NP205 to less than 6.0 ft. NGVD29 for at least 45 consecutive days in between March 1st and July 15th. Protect subpopulations C, E, F from unusually low water levels by implementing operations from Test 7 Phase 2 of the Experimental Water Deliveries Program.
- Increase water levels in the Eastern marl prairies to re-establish muhly grass.
- Initiate a fire management strategy.
- Remove woody vegetation from sparrow habitat.

4.1.3 Interim Operational Plan (ISOP)

The Record of Decision (ROD) for the Interim Operational Plan (IOP) was signed in July 2002, and IOP was implemented to continue USFWS RPA protective measures for the CSSS. By an order issued in March

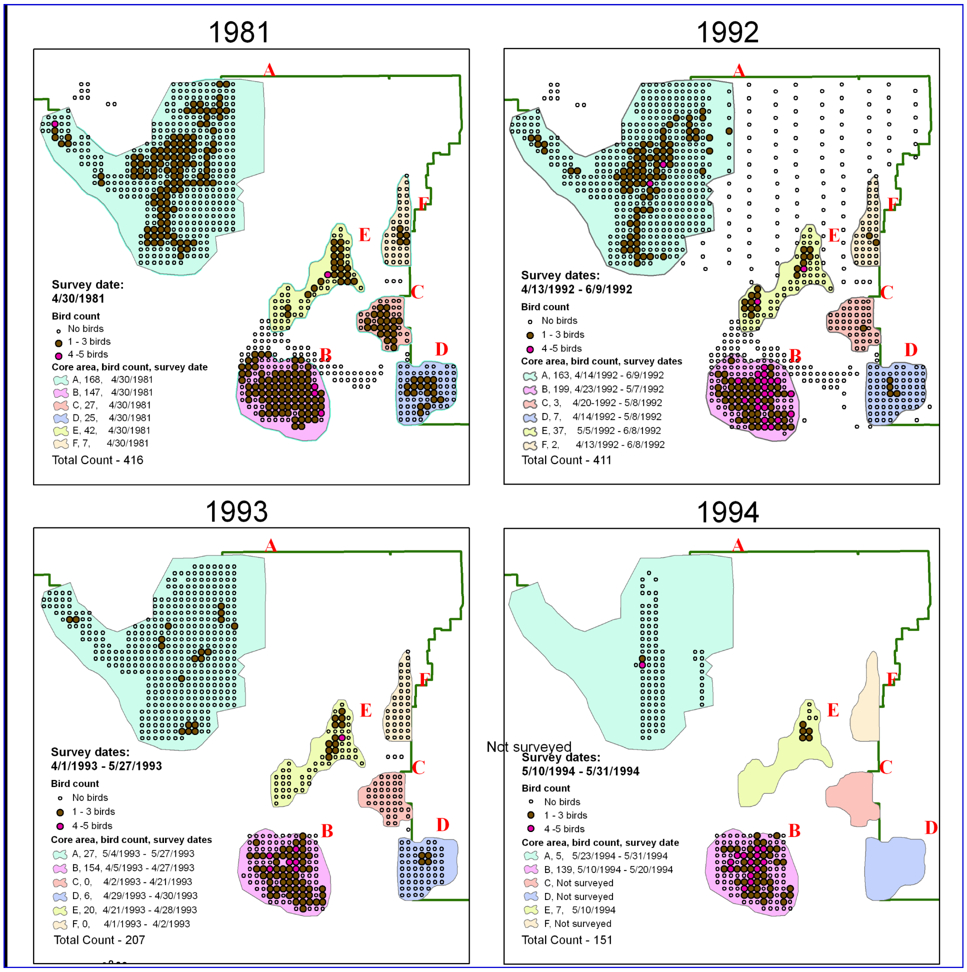


Figure 64. Sparrow population A.

2006 by the United States District Court for the Southeastern District of Florida Miami Division, resolving a lawsuit by the Miccosukee Tribe regarding the National Environmental Policy Act (NEPA) compliance and other matters related to IOP, the Corps was required to issue a supplement to its 2002 FEIS, which resulted in the December 2006 Final Supplemental EIS (FEIS) for IOP for the Protection of the CSSS. A ROD for the December 2006 FEIS was signed May 2007. (REF EDDR)

A comparison of the change in operations is shown in Table-Fig. 65.

The plan proposed during this process, Alternative 7, consisted of two different modes of water management operation for SDCS and a structural modification of the L-67 extension levee. The first mode was No WCA 3A regulatory releases to SDCS operation in which L-31N canal would be maintained at Test 7, Phase I level when there were no WCA 3A regulatory releases. Citing a concern that maintaining L-31N canal at ISOP level would impact ENP resources, a "NoWCA 3A regulatory releases to SDCS" operation was proposed that essentially reverted back to Test 7, Phase I canal level when no regulatory releases were routed through S-333 and S-334 to SDCS. The Corps and SFWMD agreed to incorporate this operation as part of IOP Alternative 7.

In addition to the change in operations at the S-12 structures, a pre-storm drawdown set of rules was issued to ensure additional flood protection for the developed areas during potential heavy rainfall phases. The canal levels would be drawn down from G-211 (to 4 ft.) to S-18C (to 2 ft.).

Structural modifications authorized under the C-111 GRR were started to be implemented with the construction of the S332B, C, and D pumps and associated detention areas. Construction began in 1999 and continued past 2008 when the majority of components were operational.

Interim Operational Plan (IOP) Alternative 7.					
Canal	Reach	ISOP wet	ISOP dry	Alt 7I	Alt 7II
L-29	S-333 to S-334	9.0	9.0	8.0	8.0
L-31N	S-335 to G-211	5.8	6.0	6.0	6.0
L-31N	G-211 to S-331	Angels	Angels	Angels	Angels
L-31N	S-331 to S-332B	4.7	4.7	5.0	5.2
L-31N	S-332B to S-176	4.7	4.7	5.0	5.2
C-111	S-176 to S-177	3.8	4.0	4.2	4.2
C-111	S-177 to S-18C	2.25	2.25	2.6	2.6

Figure 65. Interim Operational Plan canal operations.

4.1.4 Everglades Restoration Transition Plan (ERTP)

After 10 years of IOP operations, USACE and FWS revisited the the endangered species concerns and began consultation on modifying the plan and start the Everglades Restoration Transition Plan (ERTP). In addition to attempts to further lower water levels in Western Shark Slough, efforts began to lower water levels in WCA-3A to improve conditions for the Everglade snail kite and wood stork. Operations were changed by adjustments to the WCA-3A regulation schedule, but water management for SDCS remained the same (cite: U.S. Army Corps of Engineers, 2011).

4.1.5 Detention areas

Detention areas were constructed to enable a transition region between the wetlands of ENP and the developed areas. These areas were designed to extent from the 8.5 SMA to the Frogpond. The S357, Southern Detention Area and Frogpond areas are completed and incorporated in the model. The Northern Detention area, extending from S-332BN to the 8.5 SMA has not yet been built, but is included in the model in inactive mode.

S-357 test operations. The EA U.S. Army Corps of Engineers (2008) for the implementation of the 8.5 SMA included a provision to experiment with operations during the wet season of 2009, and provide field data to assess the operations of the S-357 pump on surrounding water levels. Proposed operations included the use of G-3273 and a new trigger gage, Las Palmas was added in addition to Angels to guide pump operations:

- The G-3273 gage defines "wet and dry" conditions as greater than or less than 6.8 feet (NGVD), respectively.
- During "wet" conditions, S-357 Pump Station may be operated up to 500 acre-feet per day to maintain C-357 at the Las Palmas gage between 5.2 and 4.9 feet, NGVD. The pump(s) will be off when the Las Palmas gage is less than 4.9 feet, NGVD.
- During "dry" conditions, S-357 may be operated up to 500 acre-feet per day to maintain C-357 at the Las Palmas gage between 5.7 and 5.4 feet, NGVD. The pump(s) will be off when the Las Palmas gage is less than 5.4 feet, NGVD.

Angels is currently referenced for S-331 flood control operations, however during this interim period, the Las Palmas gage can also be considered in the determination of S-331 flood control operations. The S-331 operations are guided by the two trigger gauges:

- Existing S-331 operations include the ability to make WCA-3 regulatory releases to the South Dade Conveyance System, if permitted by downstream conditions (existing S-331 off criteria). This includes conveying water from S-334 (excess water fromWCA-3), the ability to convey excess water from the

L-30 Canal via S-335, the ability to convey excess water from L-31N between S-335 and G-211 (S-336 closed or discharging east), or a combination of these sources for low S-332B and S-332C pumping rate (125 cfs or less per pump station).

- If Angels well or the Las Palmas gage is between elevations 5.5 and 6.0 feet the average daily water level upstream of S-331 may be maintained between elevations 4.5 feet and 5.0 feet if permitted by downstream conditions.
- If Angels Well or the Las Palmas gage is above elevation 6.0 feet the average daily water level upstream of S-331 will be maintained between elevations 4.0 feet and 4.5 feet, if permitted by downstream conditions (existing S-331 off criteria).
- If pumping (500 acre feet per day) at S-357 does not effectively lower Las Palmas water level and/or detention cell water level is causing pumping to cease at S-357, Angels Well criteria (per IOP) will be followed for S-331 pumping.

A constraint had to be added to the experiment, since the detention pond is relatively small and the expansion into the Northern Detention Area (NDA) has not been built. This involved a stage limit on the amount of water allowed in the detention pond. The structures S-360W and S-360E are the southern passive weirs controlling discharge from the detention cell. The S-357 Pump Station would be shut down when stages within the southern part of the detention cell are within 0.5 feet of the crest of the S-360E passive weir.

S-332B, C and D operations The pump station located on the L-31N canal became operational in 2000. The five pumps delivered at times over 500 cfs to the west (labeled S332BW) portion of the Southern Detention Area (SDA), which was at this time not fully build, but functional. In 2004 the northern portion of the detention area was completed (labeled S332BN) and two pumps (250 cfs) were diverted to serve this new area. All the pumps are connected via culvert to the detention areas to reduce the seepage losses. In the model the pumps are delivering to the fully build-out detention areas in their completed state (circa 2010). The design operation criteria for each of the pumps is shown in Table-Fig. 66.

The pump station located south of S-332B in L-31N canal is constructed in a similar manner and also pumps to the west into the detention area SDA via a culvert. All pumps discharge at the same location and have been operational since 2002. The design operation criteria for each of the pumps is shown in Table-Fig. 66.

S-332D pump station is located upstream of S-176 gate and discharges into the "High-Head Cell" which in turn discharges across a high weir towards the western sections of the Frogpond. Large seepage losses at this pump station return a significant portion of the pumpage to C-111 canal downstream of S-176. The design operation criteria for each of the pumps is shown in Table-Fig. 66. The pump station has been active since 1999 and delivers as much as 560 cfs. during the rainy season. Due to Cape Sable Sparrow concerns full capacity of the pumps is not allowed until July.

Pump Station S-332B and S-332C					
Wet Season			Dry Season		
On	Off	Capacity (cfs)	On	Off	Capacity (cfs)
4.5	4.3	75	4.6	4.4	75
4.6	4.4	125	4.7	4.5	125
4.6	4.4	250	4.7	4.5	250
4.7	4.5	375	4.8	4.6	375
4.8	4.6	500	4.9	4.7	500
Pump Station S-332D					
Wet Season			Dry Season		
On	Off	Capacity (cfs)	On	Off	Capacity (cfs)
4.6	4.4	125	4.5	4.3	75
4.7	4.5	250	4.7	4.5	125
4.8	4.6	375	4.8	4.6	250
4.9	4.7	500	4.9	4.7	375
			5.0	4.8	500

Figure 66. Design Operations.

4.2 Current (Observed) Operations in the South Dade Conveyance System

4.3 Canal Operations: Overview and Caveats

4.3.1 Operations used in Calibration

For calibration of the model, structures are using observed flow data where possible. In order not to overspecify, several structures have flows based on canal stages (rating curves). For example it is not possible to specify both S-331 flows and G-211 flows from the published observed data. Data gaps, changes made during daily operations will invariably result in unreasonable canal stages, so certain operations are kept in the model to maintain canal stages close to actual field operations.

Structures which are used with prescribed, field observed, flows during calibration are as follows: (need to verify this)

- S-335: Observed data
- S12A to D: Observed data, in all model runs
- Culverts 41 to 59: Observed data, no bridge
- S-334: Observed data, in all model runs
- S-357: Observed in 2009
- S-332B: S-332BN starts in 2004, S-332BW starts in 2000, initially all flow was directed west
- S-332C: Starts in 2002
- S-332D: Starts in 1999
- S-338: Observed data, in all model runs
- S-194: Observed data, in all model runs
- S-196: Observed data, in all model runs
- S-167: Observed HW data, in all model runs

4.3.2 Column 1 and Column 2

This is a model limitation, because WCA3A trigger is driven primarily by prescribed boundary condition

4.3.3 Pre-Storm Ops

Not modeled.

Significant storms during the modeled time period are:

4.3.4 Summary of Model Operations

Table 5. Summary of Model Operations

Structure/ Location	Canal	Calib. Model	Ops. Model	Filename
W boundary	L-29	closed	closed	n/a
CUL24	culvert_24	Q prescribed	Q prescribed	M11/TIMESERIES/culvert_24.dfs0
CUL25	culvert_25	Q prescribed	Q prescribed	M11/TIMESERIES/culvert_25.dfs0
CUL26	culvert_26	Q prescribed	Q prescribed	M11/TIMESERIES/culvert_26.dfs0
CUL27	culvert_27	Q prescribed	Q prescribed	M11/TIMESERIES/culvert_27.dfs0
CUL28	culvert_28	Q prescribed	Q prescribed	M11/TIMESERIES/culvert_28.dfs0
L29 plug at 15501ft	L-29	closed	closed	n/a
S14	L-29	not modeled	not modeled	n/a
S12A	S12A	Q prescribed	Q prescribed	M11/TIMESERIES/S12A_Q.dfs0
S12B	S12B	Q prescribed	Q prescribed	M11/TIMESERIES/S12B_Q.dfs0
S12C	S12C	Q prescribed	Q prescribed	M11/TIMESERIES/S12C_Q.dfs0
S12D	S12D	Q prescribed	Q prescribed	M11/TIMESERIES/S12D_Q.dfs0
S12E	L-67_EXT	closed	closed	n/a
N boundary ++	L-67_A	H prescribed	H prescribed	M11/TIMESERIES/S12D_HW.dfs0
E boundary	POCKET	closed	closed	n/a
W boundary ++	POCKET	H prescribed	H prescribed	MSHE/BOUNDARY/tsr79c49.dfs0
N boundary	L-67_C	closed	closed	n/a
S boundary	L-67_C	closed	closed	n/a
S346	L-67_EXT	fully open	fully open	n/a
S347	L-67_EXT	fully open	fully open	n/a
S333	L-29	prescribed TW	prescribed TW	M11/TIMESERIES/S333_TW.dfs0

Note: ++ indicates a boundary condition that generates or removes water from the model.

Table 6. Summary of Model Operations

Structure/ Location	Canal	Calib. Model	Ops. Model	Filename
CUL41	culvert_41	Q prescribed	passive	M11/TIMESERIES/culvert_41.dfs0
CUL42	culvert_42	Q prescribed	passive	M11/TIMESERIES/culvert_42.dfs0
CUL43	culvert_43	Q prescribed	passive	M11/TIMESERIES/culvert_43.dfs0
CUL44	culvert_44	Q prescribed	passive	M11/TIMESERIES/culvert_44.dfs0
CUL45	culvert_45	Q prescribed	passive	M11/TIMESERIES/culvert_45.dfs0
CUL46	culvert_46	Q prescribed	passive	M11/TIMESERIES/culvert_46.dfs0
CUL47	culvert_47	Q prescribed	passive	M11/TIMESERIES/culvert_47.dfs0
CUL48	culvert_48	Q prescribed	passive	M11/TIMESERIES/culvert_48.dfs0
CUL49	culvert_49	Q prescribed	passive	M11/TIMESERIES/culvert_49.dfs0
CUL50	culvert_50	Q prescribed	passive	M11/TIMESERIES/culvert_50.dfs0
CUL51	culvert_51	Q prescribed	passive	M11/TIMESERIES/culvert_51.dfs0
CUL52	culvert_52	Q prescribed	closed	M11/TIMESERIES/culvert_52.dfs0
CUL53	culvert_53	Q prescribed	passive	M11/TIMESERIES/culvert_53.dfs0
CUL54	culvert_54	Q prescribed	passive	M11/TIMESERIES/culvert_54.dfs0
CUL55	culvert_55	Q prescribed	passive	M11/TIMESERIES/culvert_55.dfs0
CUL56	culvert_56	Q prescribed	closed	M11/TIMESERIES/culvert_56.dfs0
CUL57	culvert_57	Q prescribed	closed	M11/TIMESERIES/culvert_57.dfs0
CUL58	culvert_58	Q prescribed	closed	M11/TIMESERIES/culvert_58.dfs0
CUL59	culvert_59	Q prescribed	passive	M11/TIMESERIES/culvert_59.dfs0

Note: ++ indicates a boundary condition that generates or removes water from the model.

Table 7. Summary of Model Operations

Structure/ Location	Canal	Calib. Model	Ops. Model	Filename
S334	L-29	Q prescribed	Q prescribed	M11/TIMESERIES/S334_Q.dfs0
N boundary ++	L-30	H prescribed	H prescribed	M11/TIMESERIES/S335_HW.dfs0
S335	L-30	Q prescribed	ops	M11/TIMESERIES/S335_Q.dfs0
S336	C-4	closed	closed	n/a
G119	C-4	closed	closed	n/a
E boundary ++	C-4	H prescribed	H prescribed	M11/TIMESERIES/BC-G119TW.dfs0
S356	S356	closed	closed	n/a
S338	C-1W	Q prescribed	Q prescribed	M11/TIMESERIES/S338_Q.dfs0
E boundary ++	C-1W	H prescribed	H prescribed	M11/TIMESERIES/BC-S338TW-S148HW.dfs0
S194	C-102	Q prescribed	Q prescribed	M11/TIMESERIES/S194_Q.dfs0
E boundary ++	C-102	H prescribed	H prescribed	M11/TIMESERIES/BC-S194TW-S165HW.dfs0
E boundary ++	C-103N	not in model	H prescribed	M11/TIMESERIES/S166_HW.dfs0
S196	C-103	Q prescribed	Q prescribed	M11/TIMESERIES/S196_Q.dfs0
S167	C-103	ops	ops	n/a
E boundary ++	C-103	H prescribed	H prescribed	M11/TIMESERIES/BC-S167TW-S179HW.dfs0
G211	L-31N	ops	ops	n/a
S331 pump	L-31N	ops	ops	n/a
S331 siphon	L-31N	ops	ops	n/a
S173	L-31N	ops	ops	n/a
SDAN_HH	SDAN	ops		
S357	SDAN	Q prescribed	ops	M11/TIMESERIES/S357_Q.dfs0
S332BN	S332BN	Q prescribed	ops	M11/TIMESERIES/S332BN_Q
S332BW	S332BW	Q prescribed	ops	M11/TIMESERIES/S332BW_Q
S332C	S332C	Q prescribed	ops	M11/TIMESERIES/S332C_Q
S332D	S332D	Q prescribed	ops	M11/TIMESERIES/S332D_Q
S174	L-31N	not in model	not in model	n/a
West of S174	L-31W	closed	closed	n/a
S332	L-31N	not in model	not in model	n/a
S175	L-31W	closed	closed	n/a
S boundary	L-31W	closed	closed	n/a

Note: ++ indicates a boundary condition that generates or removes water from the model.

Table 8. Summary of Model Operations

Structure/ Location	Canal	Calib. Model	Ops. Model	Filename
S200	FPDA-INLET	closed	ops	n/a
S boundary	FPDA-INLET	not in model	closed	n/a
S199	AeroJet-EXT	closed	ops	n/a
S boundary	AeroJet-EXT	closed	closed	n/a
S176	C-111	ops	ops	n/a
S177	C-111	ops	ops	n/a
S178	C-111E	ops	ops	n/a
S18C	C-111	ops	ops	n/a
C110culv	C-110	fully open	passive	n/a
S197-03	C-111	ops	ops	n/a
S197-10	C-111	ops	ops	n/a
S197-13	C-111	ops	ops	n/a
S boundary ++	C-111	H prescribed	H prescribed	M11/TIMESERIES/S197_TW.dfs0

Note: ++ indicates a boundary condition that generates or removes water from the model.

Table 9. Broad Crested Weirs in Models.

Structure Location	Canal	Calib. Model	Ops. Model
W-S359-FLOWWAY	SDAN	present	present
W-S360E	SDAN	present	present
W-S360W	SDAN	present	present
W-S332BN-E	B-WS332BN-E	present	present
W-S332B-PC	SDAC	present	present
W-S332C-PC	SDAC	present	present
FPhighhead	FP	present	present
FPearth	FP	present	present
B3	FP	present	present
S202-A	FPDA-C1	present	present
S202-B	FPDA-C2	present	present
S202-C	FPDA-C3	present	present
W-AJ-CONC	AeroJet-EXT	present	present
weir57 (TT bridge)	culvert_57	No Flow	present

4.3.5 RJF section 6: M11 Canal Operations

In this section analysis is shown which includes observed data in the plots. The operations applicable in the model are defined by more recent operations of the South Dade Conveyance System (SDCS) and thus may not accurately reflect actual operations in the early part of the time period (1999-2000) used for this analysis. The detention areas were under construction for much of the decade and the model run used in most of this section assumes the full present day build-out.

4.3.6 RJF section 6.2: Operations based on Observed Data

The following sections detail the operations used in this operational version V914V1 . Control strategies detail the sequence of operations as a table of priorities describing the calculation mode for each set. Tables of the control point values (generally water level) and the corresponding target point value (generally discharge) are presented where applicable. Plots of discharge versus water level (headwater, HW and tailwater, TW) are produced, either as Q vs dH (HW-TW) or Q vs H (TW or HW) plots. Additional information in the form of cumulative discharges and additional output are also presented. In some cases e.g., the S-333 to S-334 flows are tabulated using a No-Bridge run (V914V1aNB), since no flow information of the one-mile bridge exists for the model time period.

4.4 M11 Boundary Conditions

Boundary conditions are required in MIKE11 at all upstream and downstream ends of canals which are not connected at a junction.

The condition applied at these limits is specified through head (h) or flow (Q) values, and will be one of the following:

- Closed (no-flow) boundary ($Q = 0$)
- Constant values of h or Q
- Time varying values of h or Q
- Relationship between h and Q (e.g., a rating curve generally applied at a structure)

The relationships are required to close the system of equations to be solved by the double sweep method (add reference here?).

The M3ENP prescribed boundary conditions which can add or remove mass (water) from the domain will be defined as 'open' boundary conditions. These are differentiated from 'internal' prescribed conditions that merely redistribute water within the model domain.

Complete lists of all prescribed conditions in MIKE11 can be found in the M11 Operations section.

4.4.1 Operational Model

The operational model has open and closed boundary conditions as listed in Table 10 and shown in Figure 67. The M3ENP 'open' boundary locations, which allow water to enter or exit the model domain, are located at the upstream (northern) ends of L67A, the "Pocket", and L30, and at the downstream (southeastern) ends of C-4, C-1W, C-102, C-103N, C-103, and C111. Each of the Open and Closed boundary conditions are defined in detail, by canal reach, in the MIKE11 Operations section of this report.

4.4.2 Calibration Model

The calibration model has the same open and closed boundary conditions as the Operational Model. The calibration model has many more *internally* prescribed head and flow timeseries than the operational model, which are described in the M11 Operations section of this report.

Canal	Location	Datatype	Datafile
L-67A	North	Head	S12D_HW.dfs0
Pocket	North	Head	tsr79c49.dfs0
L-30	North	Head	S335_HW.dfs0
C-4	East	Head	BC-G119TW.dfs0
C-1W	East	Head	BC-S338TW-S148HW.dfs0
C-102	East	Head	BC-S194TW-S165HW.dfs0
C-103N	East	Head	to be determined...
C-103	East	Head	BC-S167TW-S179HW.dfs0
C-111	SouthEast	Head	S197_TW.dfs0

Table 10. Prescribed Boundary Condition Timeseries in MIKE11.

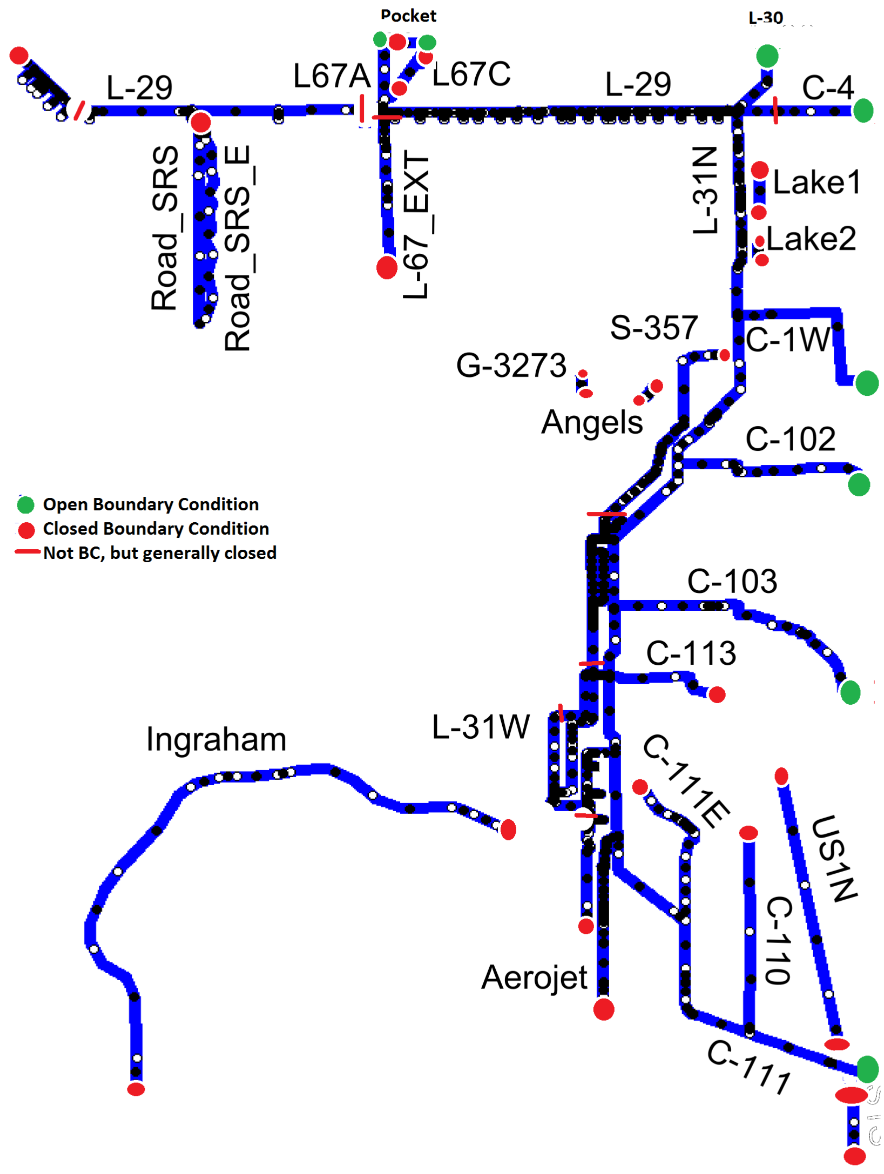


Figure 67. Operational M11 model open/closed location map. Boundaries specified as 'open' are points where water is added or removed from the model domain.

4.5 M11 Initial Conditions

4.5.1 Operational Model

Initial water levels in the canal network are set to 3 feet. The only exception is C111 at chainage 60827 feet which is set to 2.5 feet.

4.5.2 Calibration Model

Same as Operational Model

4.6 Canal Operations: L-67A, L-67C, and the Pocket

4.6.1 L-67A

Historical

Operational Model North boundary of the canal in the model is a prescribed head timeseries, shown in Figure 68. It is derived from the observed S12D headwater dataset.

Calibration Model Same as Operational model.

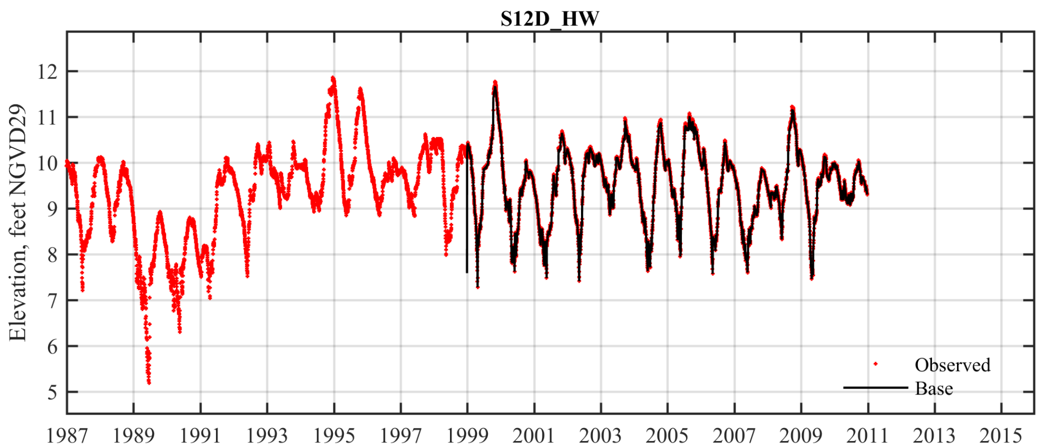


Figure 68. Prescribed Flow at L67A North Boundary

4.6.2 L-67C

Historical

Operational Model The north and south boundaries of the canal are closed.

Calibration Model Same as Operational model.

4.6.3 The Pocket

Historical

Operational Model The east boundary of this canal is closed, and the west boundary of the canal is a prescribed head timeseries, shown in Figure 69. It is derived from the timeseries output for Row 79 and Column 49, we think.

Calibration Model Same as Operational model.

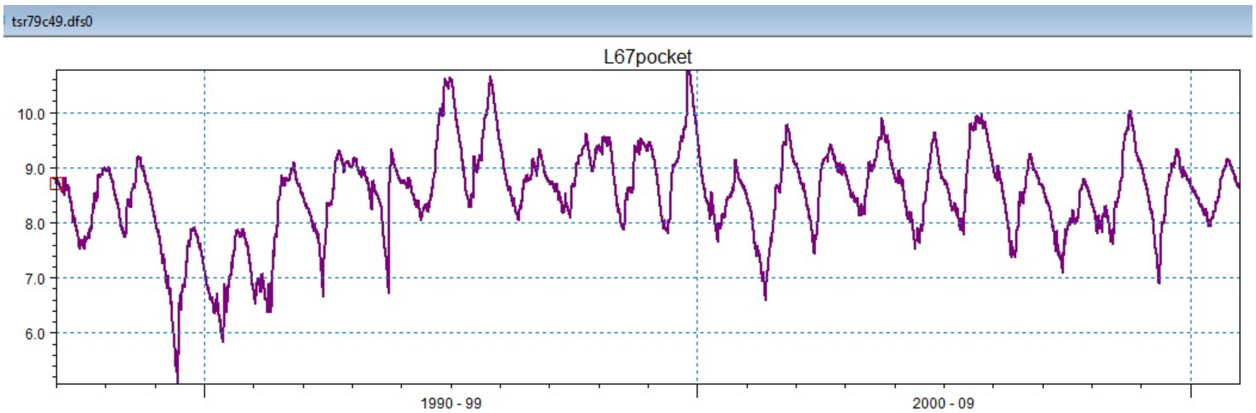


Figure 69. Prescribed Flow at West Boundary of the Pocket Canal

4.7 Canal Operations: L-29

4.7.1 L-29 western boundary

Historical

Operational Model Closed boundary

Calibration Model Same as Operational model.

4.7.2 Culverts 24-28

Historical Flows from L-29 to Big Cypress/ENP

Operational Model Prescribed flow timeseries, data source unknown. Implemented as Control Structures. Flow timeseries for culverts shown in Figures 70-74.

Calibration Model Same as Operational model.

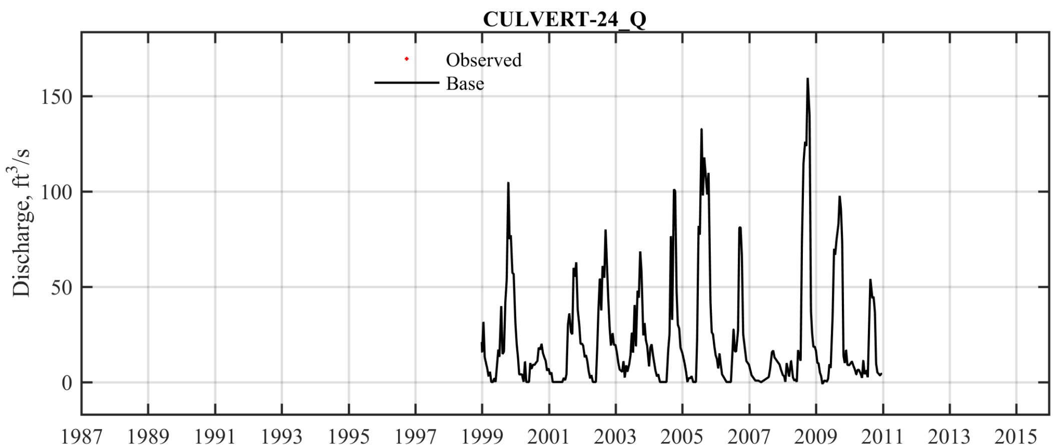


Figure 70. Prescribed Flow at Culvert 24

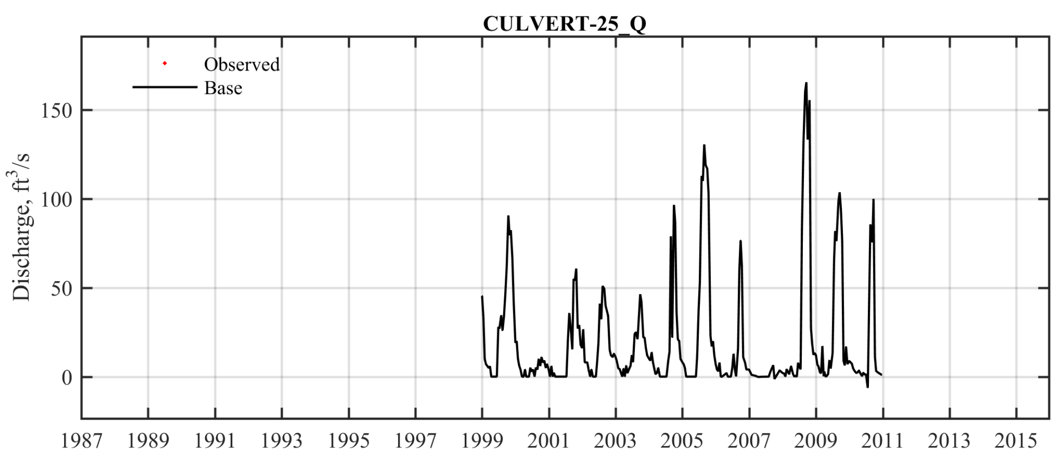


Figure 71. Prescribed Flow at Culvert 25

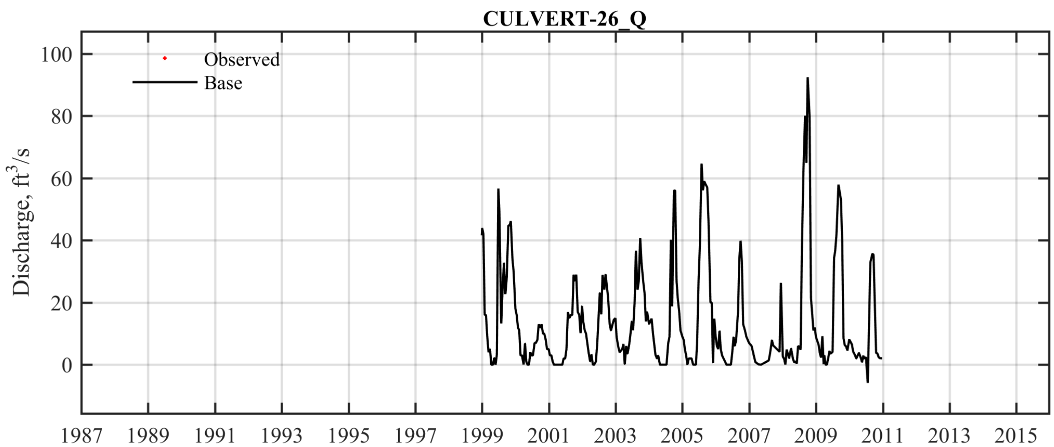


Figure 72. Prescribed Flow at Culvert 26

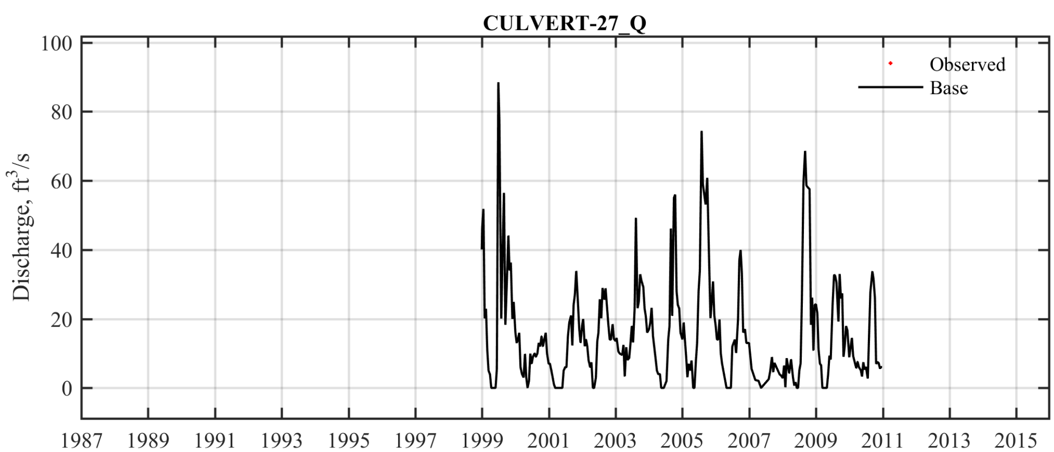


Figure 73. Prescribed Flow at Culvert 27

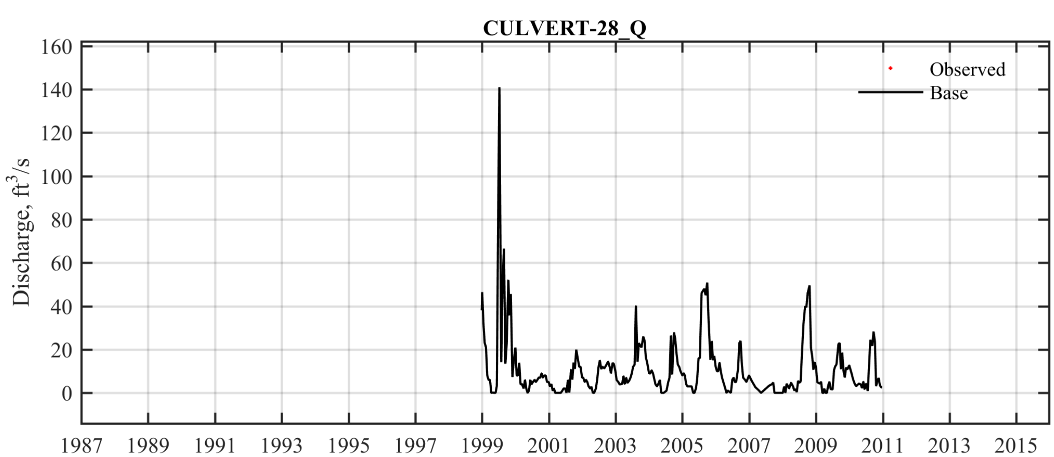


Figure 74. Prescribed Flow at Culvert 28

4.7.3 S14

Historical Flows from L-29 to ENP

Operational Model Not included in model

Calibration Model Same as Operational model.

4.7.4 L29 plug between S14 and S12A

Historical L29 plug between S14 and S12A, separates the western reach of L29 from WCA3A

Operational Model Present, implemented as a closed control structure with name "CLOSED"

Calibration Model Same as Operational model.

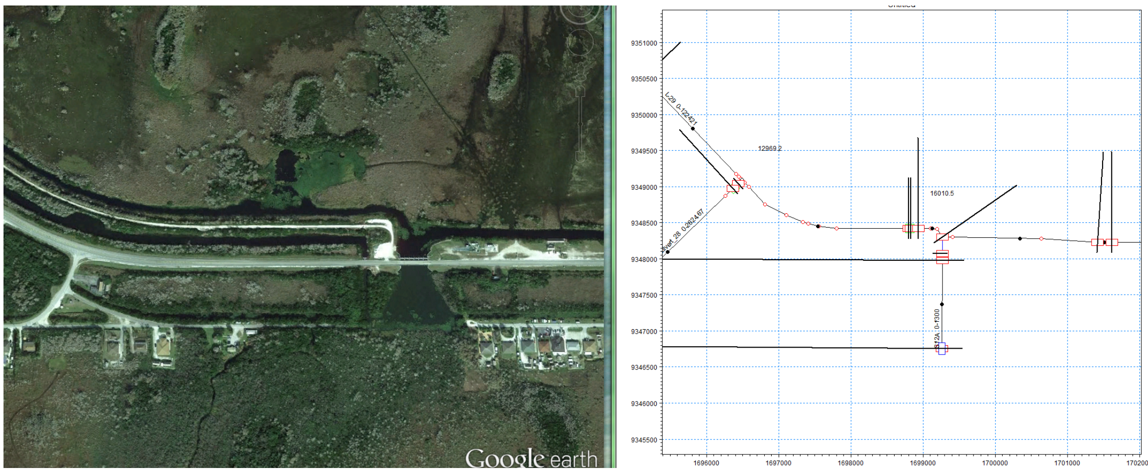


Figure 75. S12A area, including S14 and L29 "plug".

4.7.5 S12A-D

Historical Flows from L-29/WCA3A to ENP

Operational Model Prescribed flow timeseries, S12_A.dfs0, S12_B.dfs0, S12_C.dfs0, S12_D.dfs0, data source unknown. Flow timeseries for S12A-S12D are shown in Figures 76-79.

Calibration Model Same as Operational model.

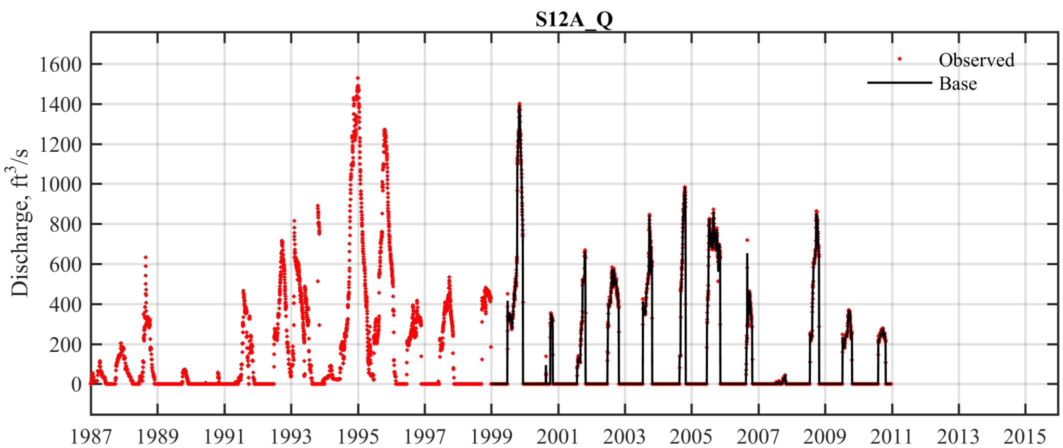


Figure 76. Prescribed Flow at Structure S12A

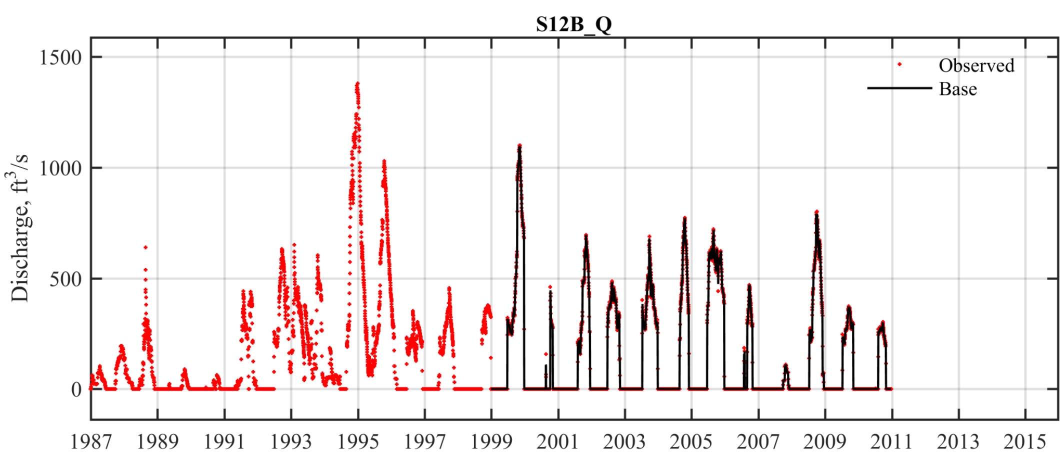


Figure 77. Prescribed Flow at Structure S12B

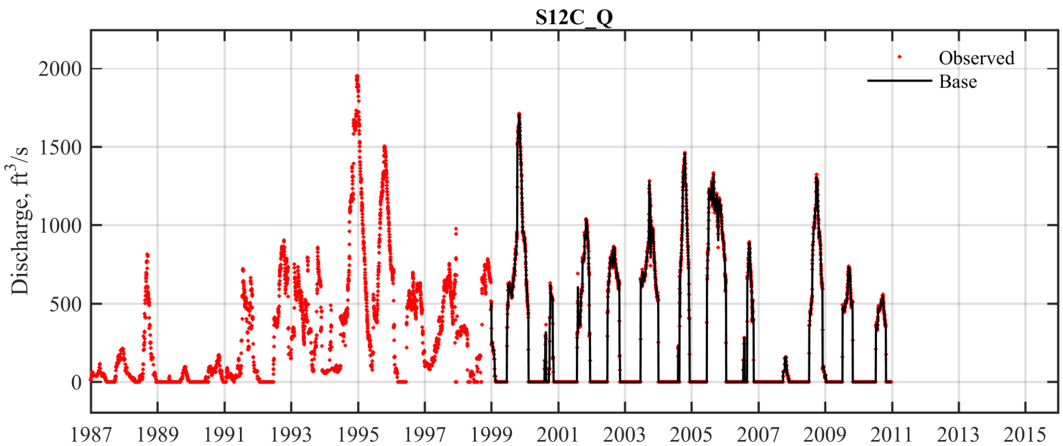


Figure 78. Prescribed Flow at Structure S12C

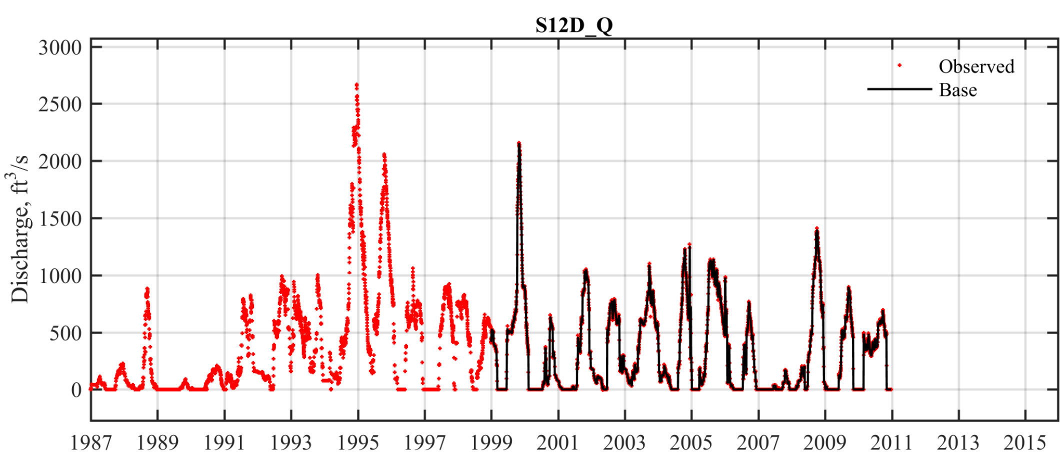


Figure 79. Prescribed Flow at Structure S12D

4.7.6 S12E

Historical Connects L29 (just east of S333) to Old Trail Borrow Canal (at north end of L67EXT)

Operational Model Closed.

Calibration Model Same as Operational model.

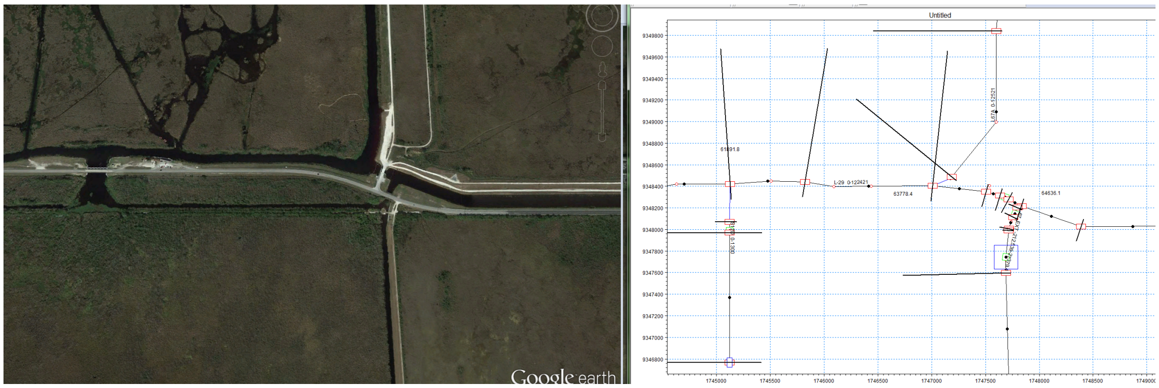


Figure 80. S333 area, including S12E and S346.

4.7.7 S333

Historical S333 is operated to make releases from Conservation Area 3A into the Tamiami Canal. This structure functions principally to make water deliveries from Conservation Area 3A to south and eastern Dade County, to the Shark River and Taylor Slough areas of the Everglades National Park. It can be used to make regulation releases from Conservation Area 3A. The total delivery will be the amount necessary to maintain the appropriate stages at S-331, S-25B, and S-22.

Operational Model Tailwater stage prescribed timeseries: S333_TW.dfs0

The M11 model implements this structure using the timeseries of tailwater, i.e. the structure passes the required amount of water to maintain the tailwater at the structure equal to observed timeseries. For modeling future scenarios, the structure need to be changed to use operations.

Operations at the control structure S-333 are based on meeting the observed downstream tailwater. The observed timeseries (S333 TW) is used to control the flow through the structure. Each timestep the difference between upstream and downstream water level is used to determine the flow rate for that timestep.

The control strategy associated with computing the discharge based on the observed headwater minus tailwater is shown in Table 11. The prescribed tailwater timeseries for S333 is shown in Figure **??**.

Table 11. Control strategy for S333

HW-TW (ft)	Q (cfs)
0	0
0.25	418
0.5	598
0.75	737
1	855
1.25	959
1.5	1053
1.75	1141
2	1222
2.25	1298
2.5	1371
2.75	1440
10	1440

Calibration Model Same as Operational model.

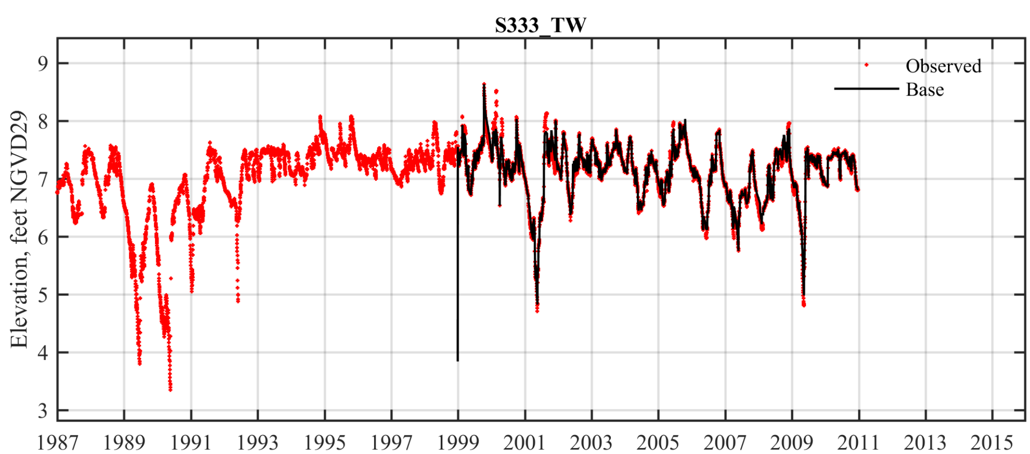


Figure 81. Prescribed Tailwater at Structure S333

4.7.8 Culverts 41-59

Historical

Operational Model Culverts 41-51, 53-55, and 59 are implemented as passive culverts allowing flow.
Culverts 52, and 56-58 are implemented as closed.
Culvert 52 should not be closed in the model, but it is.
Culverts 56-58 are closed because they were removed when the bridge was constructed.
RJF: There are occurrences when flow is "backwards" from NESS into L-29 canal through culverts 41 to 48 in both the observed and modeled data.

Calibration Model Culverts 41-59 are all implemented as control structures with prescribed flow timeseries, see Figures 82- 100

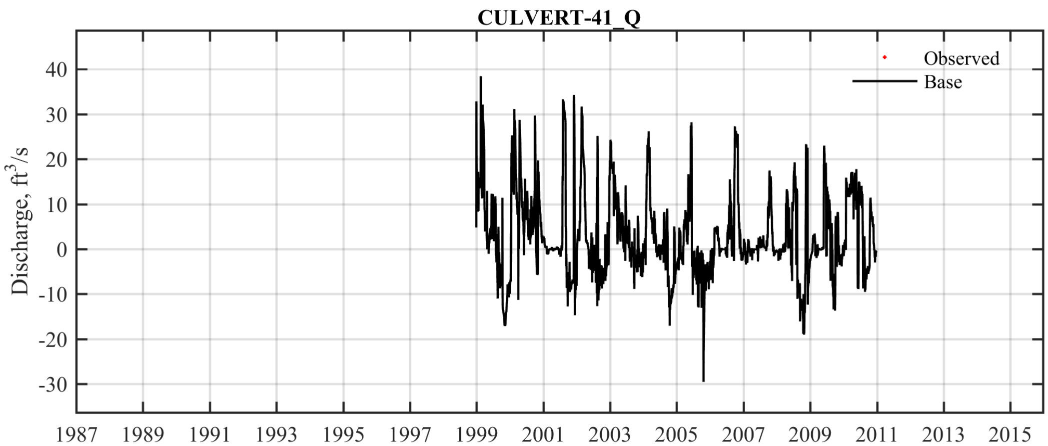


Figure 82. Prescribed Flow at Culvert 41

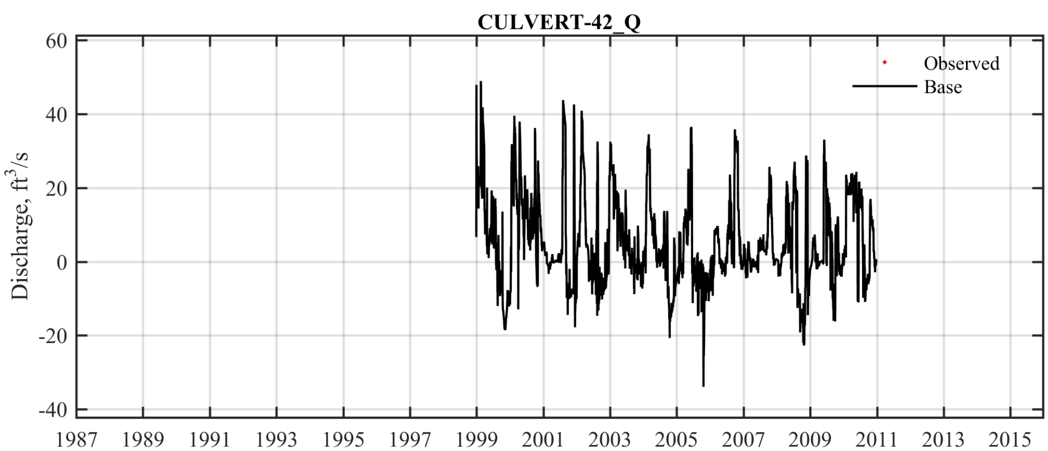


Figure 83. Prescribed Flow at Culvert 42

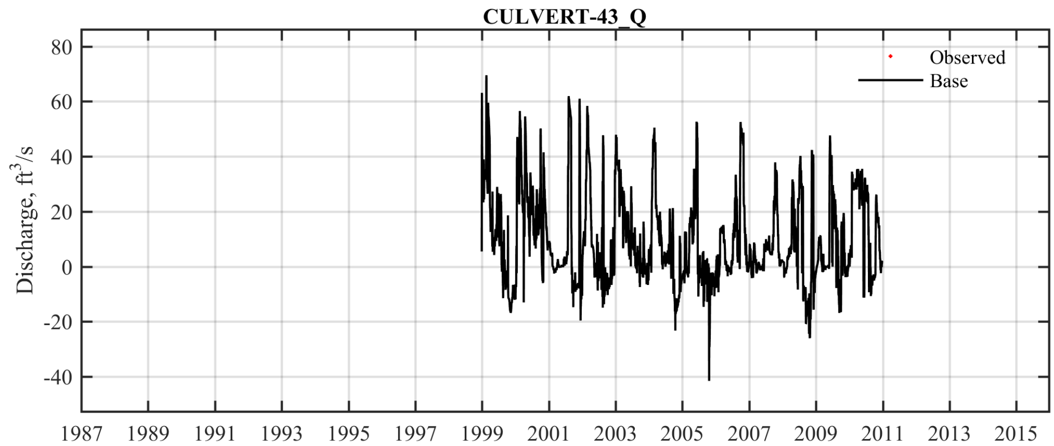


Figure 84. Prescribed Flow at Culvert 43

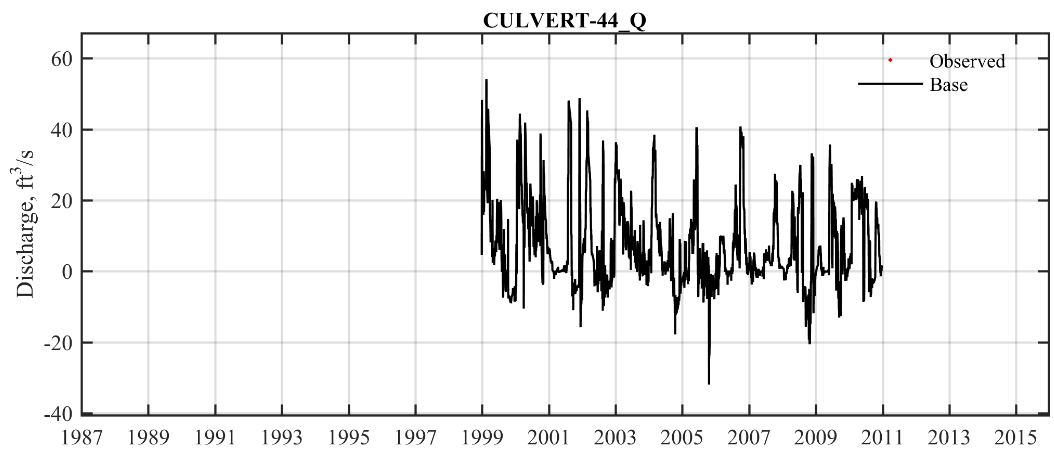


Figure 85. Prescribed Flow at Culvert 44

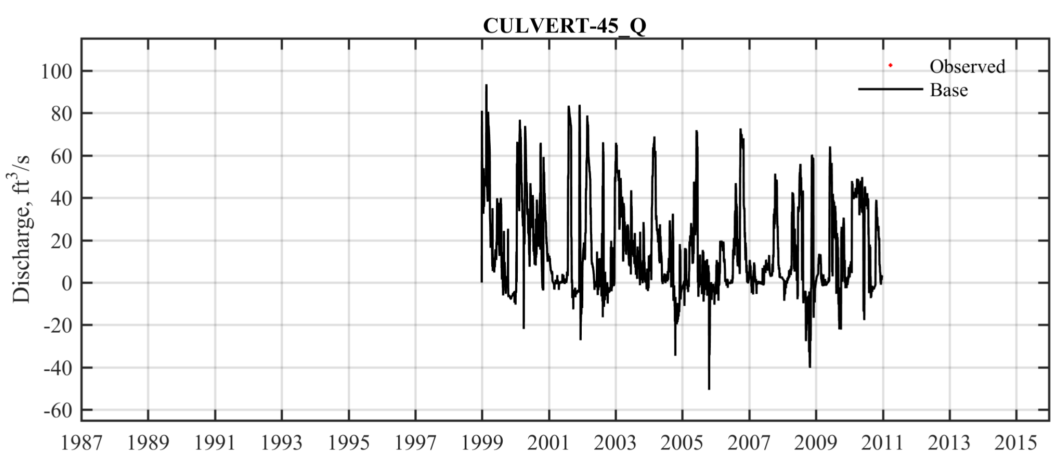


Figure 86. Prescribed Flow at Culvert 45

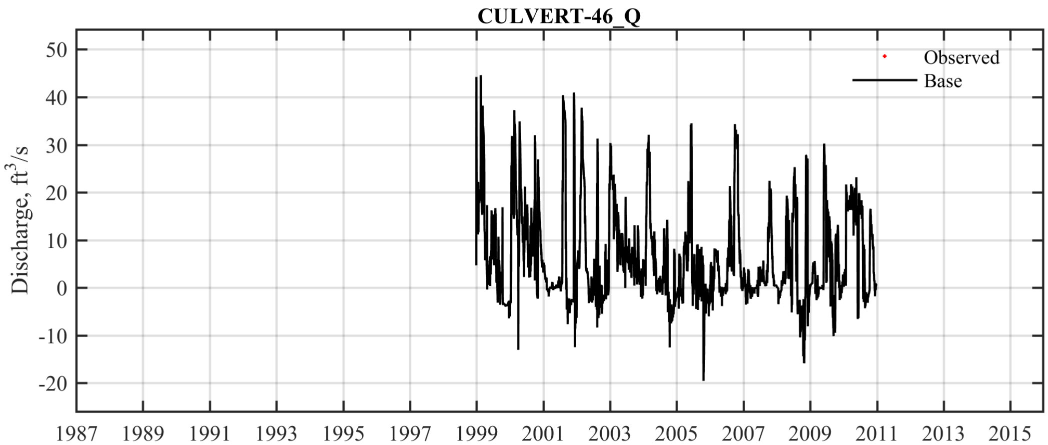


Figure 87. Prescribed Flow at Culvert 46

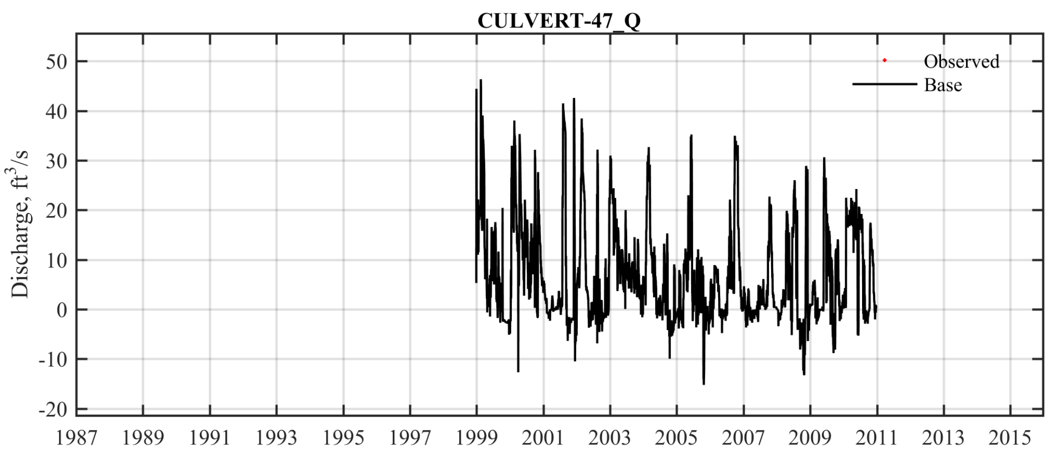


Figure 88. Prescribed Flow at Culvert 47

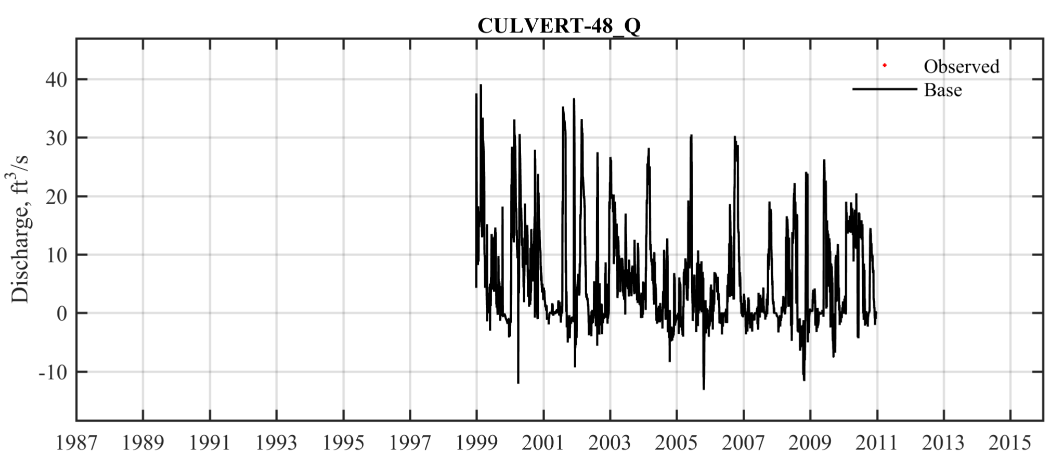


Figure 89. Prescribed Flow at Culvert 48

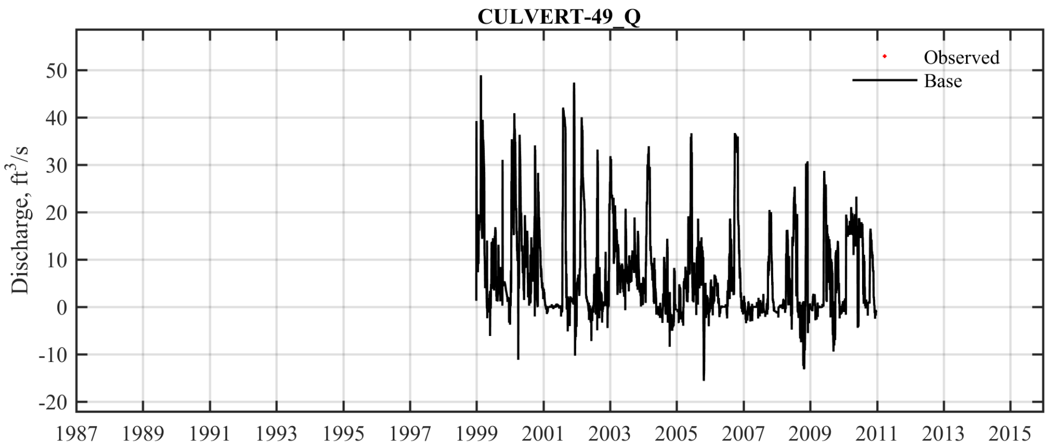


Figure 90. Prescribed Flow at Culvert 49

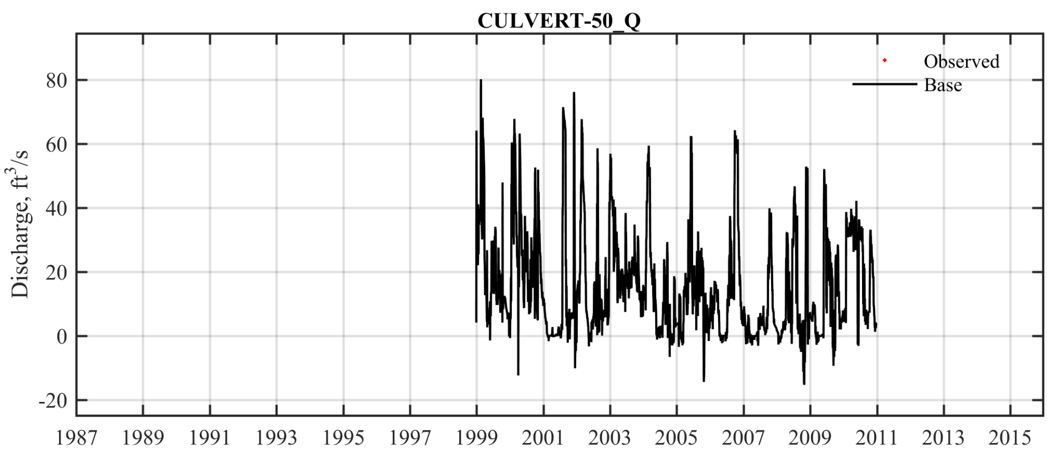


Figure 91. Prescribed Flow at Culvert 50

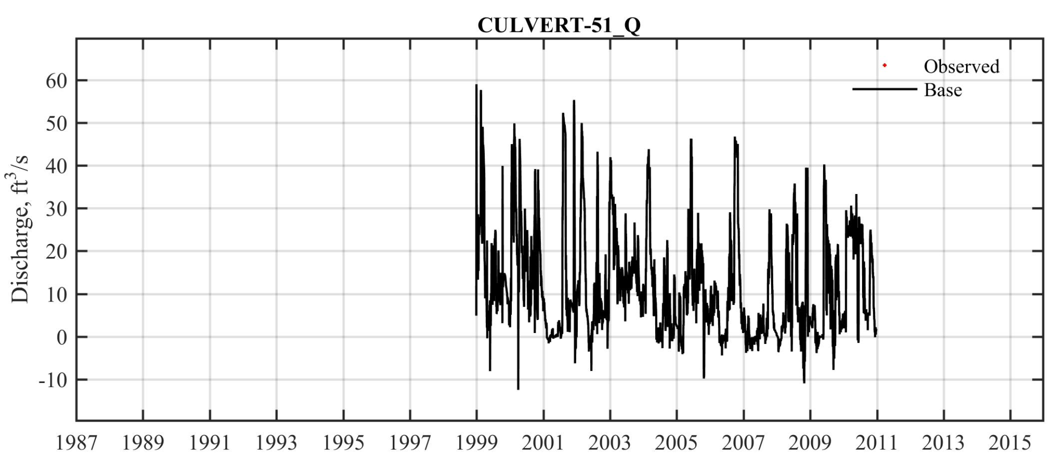


Figure 92. Prescribed Flow at Culvert 51

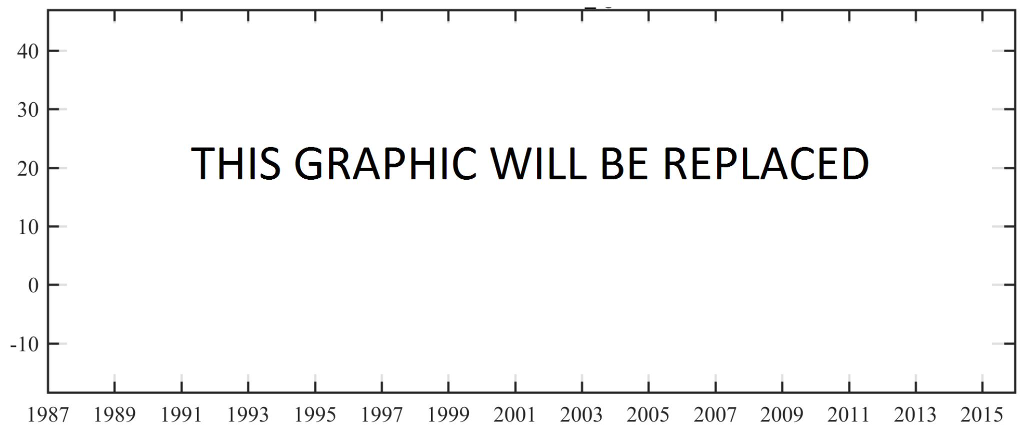


Figure 93. Prescribed Flow at Culvert 52

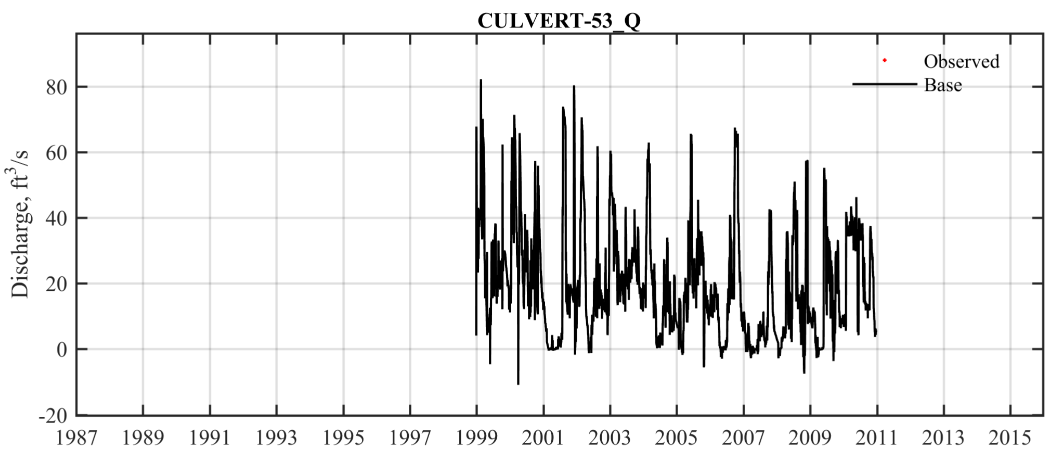


Figure 94. Prescribed Flow at Culvert 53

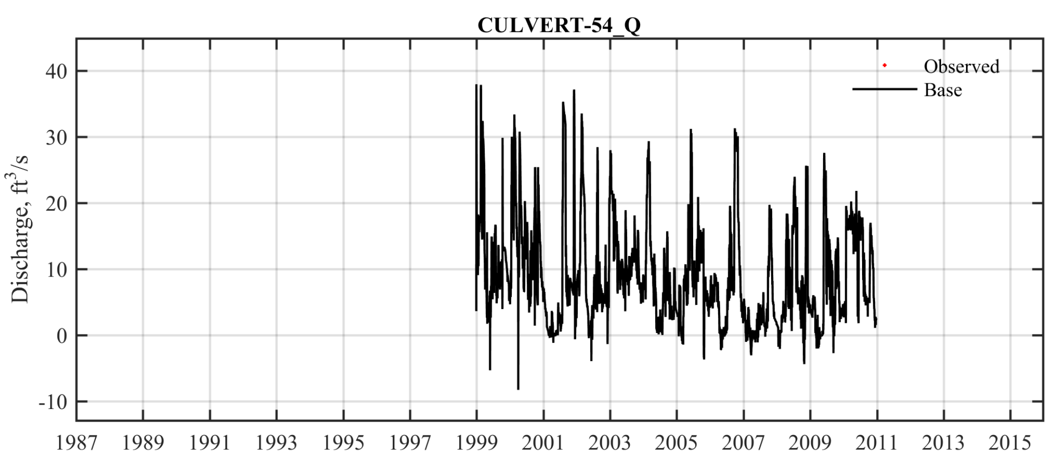


Figure 95. Prescribed Flow at Culvert 54

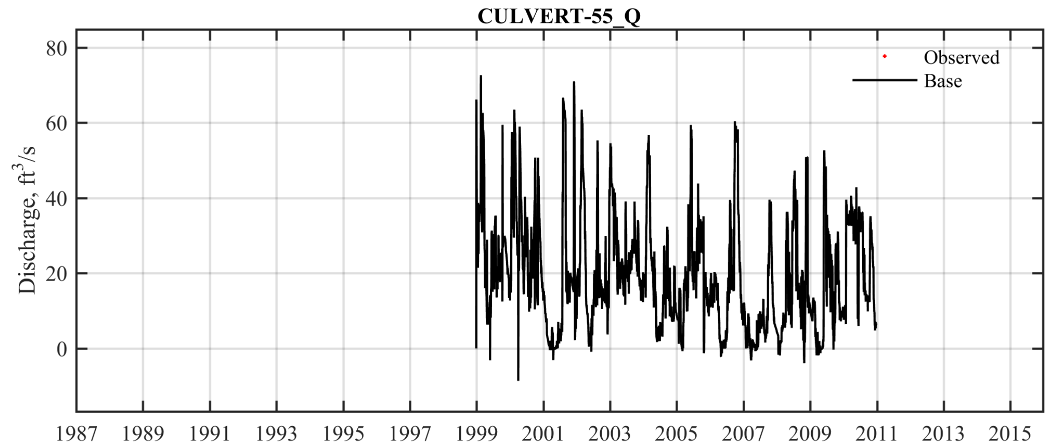


Figure 96. Prescribed Flow at Culvert 55

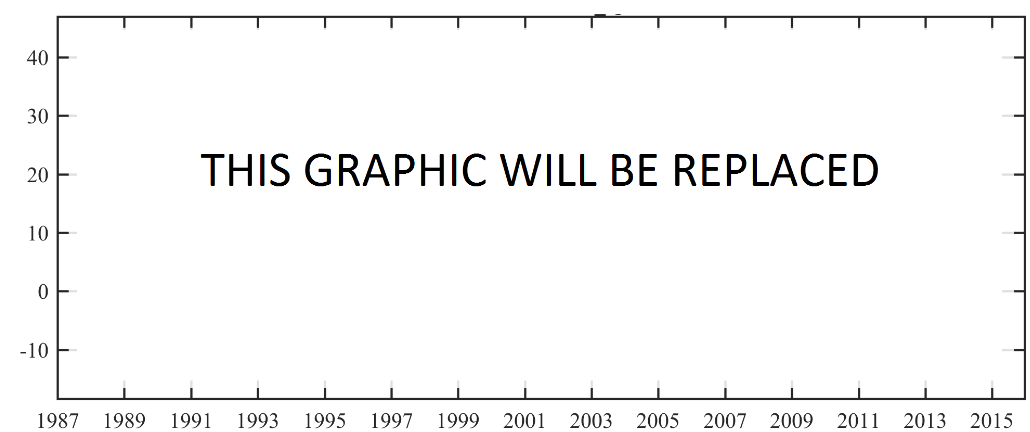


Figure 97. Prescribed Flow at Culvert 56

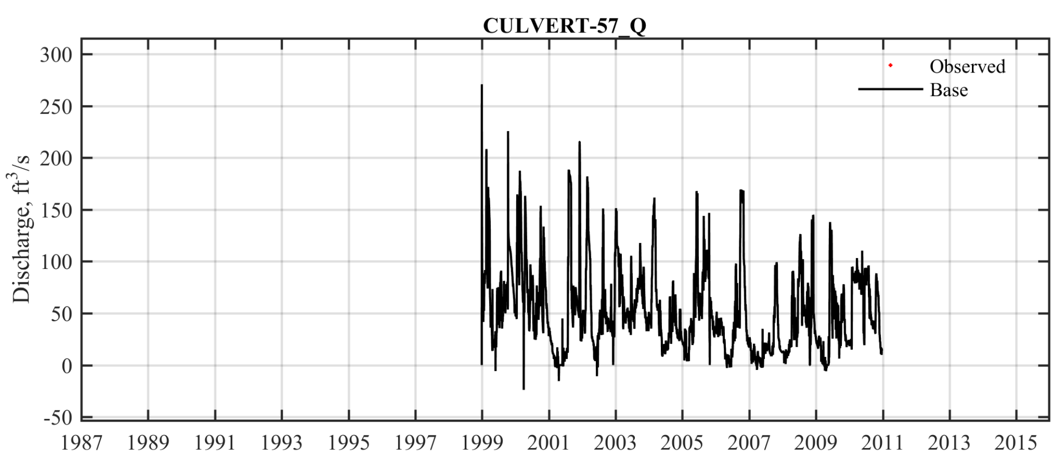


Figure 98. Prescribed Flow at Culvert 57

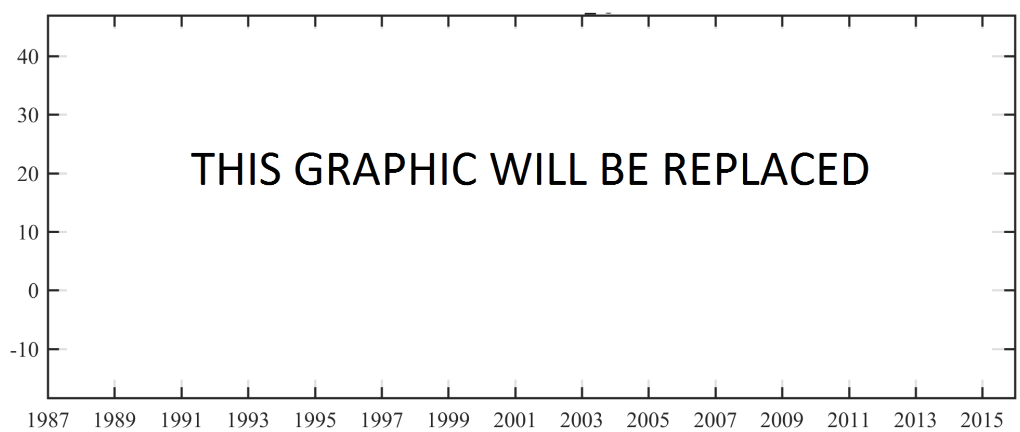


Figure 99. Prescribed Flow at Culvert 58

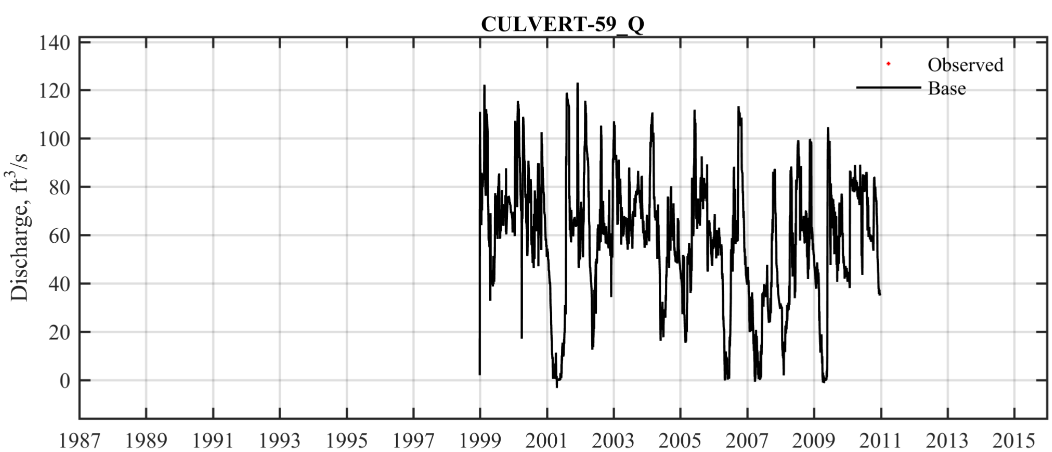


Figure 100. Prescribed Flow at Culvert 59

4.7.9 Tamiami Trail Bridge

Historical

Operational Model RJF: The one-mile bridge centered on culvert 57 adds to the total flow, the observed data is based on the timeperiod prior to construction of the period.

RJF: In the bridge model run the bridge adds 16 kAF/yr of extra flow through S-333 and results in an additional 20 kAF/yr through the culverts.

The bridge is implemented as a broad (1-mile?) overflow weir, centered at the previous modeled location of culvert 57.

Calibration Model The Tamiami Trail Bridge is not implemented in the calibration model.

4.7.10 S334

Historical S-334 allows water to be delivered from L-29 to L-31N and is used for both water supply and flood control. Since IOP and under ERTP the structure has been increasingly used to in an attempt to lower water levels of WCA-3A. This "wrap-around" strategy delivers water into L-31N and is pumped into the detention areas in addition to the local flood control pumping. This "column II operation" is designed to bypass ENP wetlands which may be too wet, i.e. water level is above ground surface in the principal historical slough area, Northeast Shark Slough (NESS).

Structure S334 is implemented in the model to maintain headwater and tailwater levels according to the timeseries for the structure. This structure functions principally to make supplemental water deliveries to South and East Dade County. It can also be used when regulatory releases from Conservation Area 3A are being made. This structure is operated in conjunction with S-335 to make supplemental deliveries to South and East Dade County. When supplemental deliveries are not being made, this structure is closed. When regulatory releases are being made from Conservation Area 3A, this structure is operated in conjunction with S-333 to maintain a maximum stage of 7.05 ft at the L-29-1 culvert U.S. Army Corp of Engineers (2005); District (1994). Higher stages cause flooding at the Indian Village adjacent to the canal.

Operational Model The M11 model implements this structure using the discharge timeseries, i.e. the structure passes the required amount of water equal to observed timeseries, as shown in Figure 101.

Calibration Model Same as Operational model.

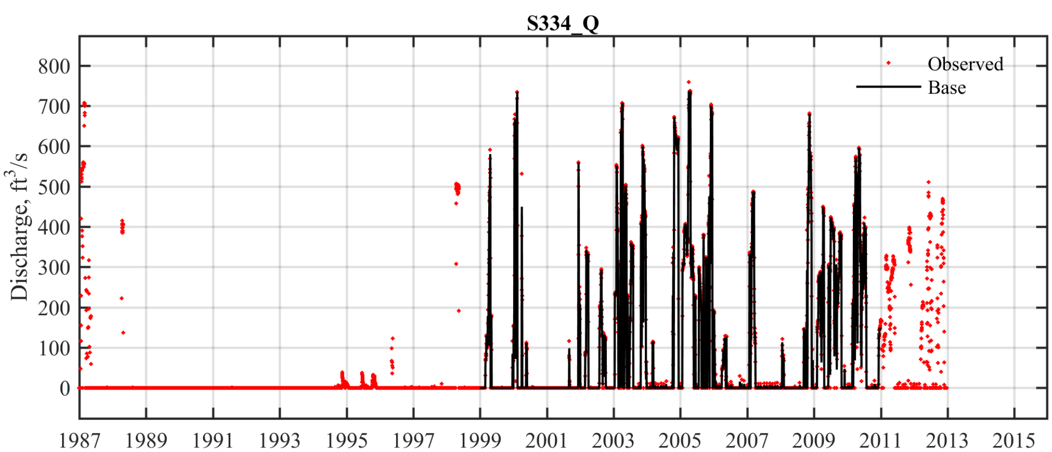


Figure 101. Prescribed Flow at Structure S334

4.7.11 S356 Pump

Historical The S-356 pumps are part of the Modified Water Deliveries project to mitigate for the increased seepage which will occur if L-29 water levels are raised allowing re-inundation of the NESS wetlands. The pumps would take the increased seepage into L-31N and pull it north for release back into L-29 where it would flow through the bridges and culverts back into the wetlands (aka Pumping in Circles Scheme).

Operational Model The S-356 structure is closed in the model.

Calibration Model Same as Operational model.

4.7.12 L-29 eastern boundary

Connected to L30, C-4, and L31N.

4.8 Canal Operations: L-67EXT

4.8.1 S346

Historical Connects Old Trail Borrow Canal to L67 EXT. Structure 346 is located in the borrow canal of the L-67 Extension just south of U.S. 41.S-346 is a double-barreled, 72-inch, CMP culvert with riser pipes.

Operational Model The M11 model implements this structure as fully open. Fully open when stage $<$ 0.0??. Implemented as overflow weir with sill level at ??7.0 ft.

Calibration Model Same as Operational model.

4.8.2 S347

Historical Stage divide in L67 EXT

Operational Model Fully open when stage < 0.0??. Implemented as overflow weir with sill level at ??5.8 ft.

Calibration Model Same as Operational model.

4.9 Canal Operations: L-30

4.9.1 North Boundary

Historical Not applicable.

Operational Model Prescribed stage as shown in Figure 102.

Calibration Model Same as Operational model.

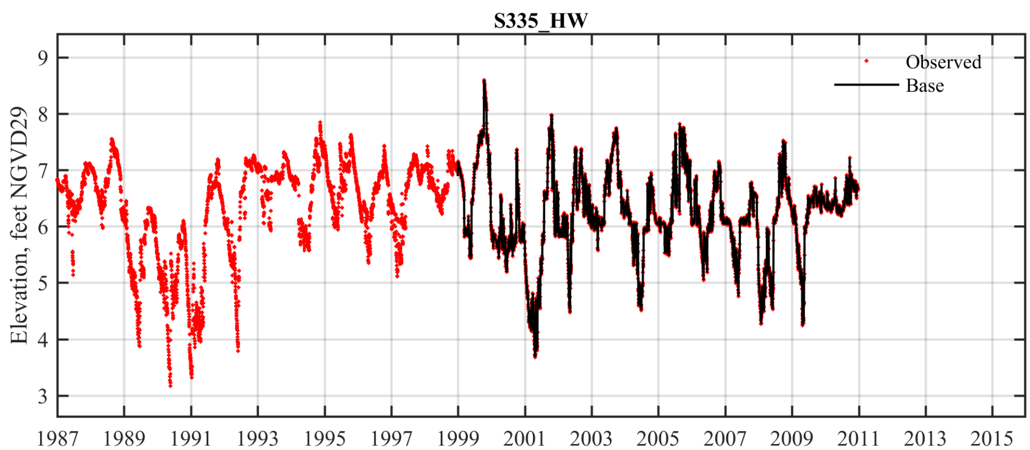


Figure 102. Prescribed Stage at North Boundary of L-30

4.9.2 S335

Historical In addition to the water supply route through L-29 via S-334, the L-30 canal can deliver water to L-31N through the control structure S-335.

Operational Model In the model the structure has several calculation modes according a sequence of four priorities. L-31N maximum canal water levels impose a closure of S-335 when the tailwater reaches 6 feet. Then if this is not the case the gate will open when the headwater reaches 6.2 feet and remains in that mode until the headwater reaches 5.8 feet. In order to meet some of the water supply criteria, the discharge will be one-half of the G-211 flows during the latter part of the dry season (January through May). When priority 2 is active in M11, Fig. ?76? shows the relationship between the observed and modeled discharges vs the difference in water levels (HW-TW) across the structure. The control strategy (rating curve) is shown in Table 12. The daily average flow is shown in Fig. ?78? and Fig. ?79? is a cumulative discharge plot of the flows through the structure.

- Priority 1: Close when downstream water level TW > 6 ft.
- Priority 2: Upstream water level is HW > 6.2 ft. discharge according to control strategy
- Priority 3: Unchanged when upstream > 5.8 ft.
- Priority 4: From January to end of May, if G-211 discharge is greater than 10cfs let S-335Q be one half G-211Q

Table 12. Control strategy for S335

HW-TW (ft)	Q (cfs)
0.0	0
0.2	100
0.4	170
0.6	220
0.8	240
1.0	260
1.2	280
1.4	300
2.0	300
2.2	300
2.4	525
2.8	571
10.0	1170

Calibration Model Prescribed flow timeseries as shown in Figure 103.

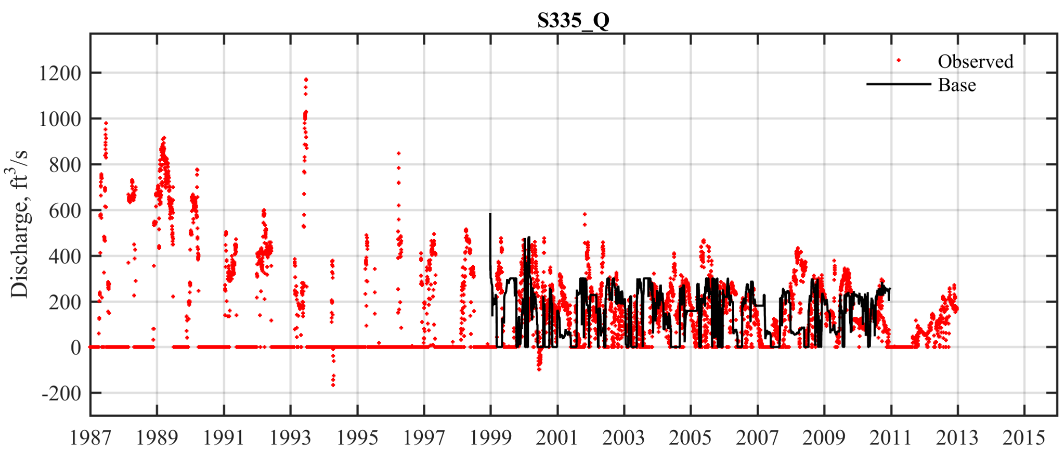


Figure 103. Prescribed Flow at Structure S335

4.10 Canal Operations: C-4

4.10.1 S336

Historical Structure 336 is located in the Tamiami Canal (C-4), where the L-30 and L-31N borrow canals intersect. S-336 is a gated, three barrel, 54-inch, CMP culvert.This structure permits supplemental deliveries from WCA 3 to help fulfill water needs in eastern Dade County via the L-30 or L-29 canals. It also can be used to discharge excess water from WCA 3A when capacity is available in the Tamiami Canal.

Operational Model Closed.

Calibration Model Same as Operational model.

4.10.2 G119

Historical

Operational Model Closed.

Calibration Model Same as Operational model.

4.10.3 C-4 East Boundary

Historical Not Applicable

Operational Model Prescribed stage as shown in Figure 104.

Calibration Model Same as Operational model.

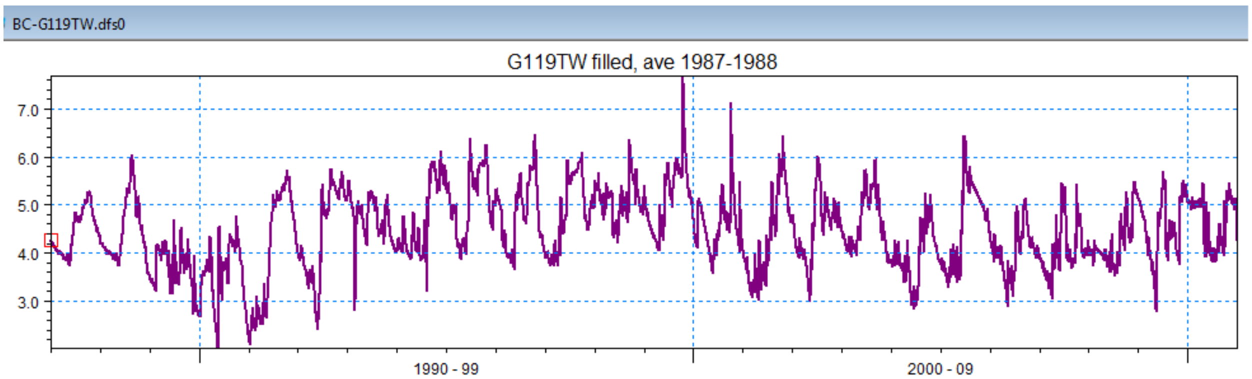


Figure 104. Prescribed Stage at East Boundary of C-4

4.11 Canal Operations: L-31N

4.11.1 G211

Historical G-211 was constructed in 1991 by the SFWMD and made operational in October. Its purpose is to provide additional control upstream of S-331 pumps in L-31N for additional flood protection of the 8.5 mi^2 area. The structure is a divide structure for L-31N Canal between the north section, S335 to G211, and the south section S331 to G211. The SFWMD Structure Book specifies that the stage in the south section can be lowered to facilitate the drainage in the area along the south section without lowering the stage in the north section. The goal is to keep stages upstream of the structure between 5.5 ft and 6.0 ft District (1994).

The SFWMD Structure Book specifies that during flood control operations or making water supply deliveries, stages outside the range, either high or low, may occur for extended periods of time. If the reach of L-31N Canal between G211 and S331 is higher than the reach between G211 and Tamiami Trail, and S331P is unable to pump due to downstream constraints, G211 and S338 may be opened to facilitate flow to the north and east through C-1N. This is not implemented in the structure operations.

The structure consists of 10 culverts and is operated to maintain low canal stages between G-211 and S-331 during flood control operations for the lands west of the protective levee system. The recent addition of the S-357 complex should allow for a modification of the operational strategy.

Operational Model The M11 Calculation Mode for this structure has a sequence of four priorities. The structure is closed (the model assumes there is one structure, not 10 individual culverts) when the water level in the reach between G-211 and S-331 is greater then 5.3 feet. Priority 4 is a water supply mode and equates the flow through G-211 with that of S-331 from January through May.

- Priority 1: Close when headwater at S-331 > 5.3 ft.
- Priority 2: Upstream water level is > 5.85 ft. discharge according to control strategy
- Priority 3: Unchanged when upstream > 5.7 ft.
- Priority 4: From January to end of May, if S-331 discharge is greater than 10cfs let S-331Q be the same as G-211Q
- Priority 5: Close when headwater is less than 5.5 ft.

The control strategy associated with computing the discharge based on the observed tailwater data as defined in priority 2 is shown in Table 13. The structure becomes active when HW>5.85 ft. and remains in that flow position until the upstream water level reaches 5.85 ft. Fig. ?82? ia a plot of the observed and modeled discharge vs water level difference across the structure.

The daily average flow is shown in Fig. ?84? and Fig. ?85? is the cumulative discharge for the IOP time period.

Table 13. Control strategy for G211

HW-TW (ft)	Q (cfs)
0.00	0.0
0.25	262.5
0.50	443.0
0.75	588.7
1.00	703.5
1.25	791.3
1.50	856.0
1.75	901.4
2.00	931.4
2.25	950.0
2.50	960.8
2.75	968.0
10.0	1100.0

Calibration Model Same as Operational model.

4.11.2 S331/S173 Complex

Historical Structure S331 delivers a supplementary water supply to South Dade County and provides continuous supply to the Everglades National Park at Taylor Slough and to the Panhandle Area. In addition, this structure controls the level in L-31N north of S331 as a function of the water levels in the Rocky Glades residential area. The operation of this structure is in either a water supply or a flood control mode. S331 is a three unit pumping plant located in L-31N borrow canal. The pumping station is equipped with three vertical axial flow pumps, each rated for 387cfs at 3.0ft static head District (1994). According to Iteration 7 this structure controls the level in L-31N north of S331 as a function of the water levels in the Rocky Glades residential areaDistrict (1994). The discharge is accomplished by:

- i) siphoning through the pumps (S331S),
- ii) operation of the adjacent culvert (S173), or
- iii) pumping (S331P).

Structure S173 is located in the Levee 31 North borrow canal adjacent to the east boundary of the ENP. It is a single-barreled, 72-inch reinforced concrete pipe (RCP) culvert with a manually operated sluice gate on a reinforced concrete head structure at the northeast end of the structure. S173 is used in conjunction with pump station S331P to pass water to the south to protect areas to the west of L-31. This structure is operated in conjunction with S331P in either the water supply or flood control mode .

The structure book (SFWMD) specifies additional rules for water supply and flood mode. These rules were not implements since they differed from the Experimental Program Test 7 Phase I.

The purpose of the pumps is to provide flood control for the 8.5 mi^2 area and in combination of S-173 to gravity flow (as S-331S in the model) for water supply and flood control.

Operational Model In the model there are three separate structures at the S-331 location. The first structure is the original S-173 culverts, which was near the termination of the historical L-31N canal. The second is the S-331P pumps, a set of three pumps, and third is the S-331S structure which is activated when the S-331 pumps are in siphon mode.

S-173.

The S-173 observed and modeled data of Q vs dH for S-173 is shown in Fig. ?87?. The structure closes if the difference in water level between upstream and downstream is negative to prevent having S-331S discharge recirculate back upstream. Otherwise the structure opens if the headwater at S-176 falls below 5.5 feet and S-331 pumps are off. The Control Strategy in M11 is shown in Table 14.

- Priority 1: Close when HW-TW < 0 ft.
- Priority 2: Close when S331P flow > 0 cfs.
- Priority 3: When S176 HW < 5.5 ft. discharge according to control strategy in Table 14 (for calibration model use Table 14
- Priority 4: Close when headwater is less than 0.0 ft.

Table 14. Control strategy for S173 Operational Model

HW-TW (ft)	Q (cfs)
0	0
0.25	98.6
0.5	141
0.75	185.5
1	223.5
1.25	255.2
1.5	281.1
10	339

Figure ?86?: Observed and modeled data of Q vs dH for S331S. Plot when S-331 is in siphon mode.

Table 15. Control strategy for S173 Calibration Model

HW-TW (ft)	Q (cfs)
0	0
0.25	89.6
0.5	141
0.75	185.5
1	223.5
1.25	255.2
1.5	281.1
1.75	301.6
2	317.1
2.25	327.9
2.5	334.4
2.75	337.1
10	339

Figure ?87?: Observed and modeled data of Q vs dH for S-173. S-173 closes when dH=HW-TW is negative to prevent recirculation.

S331 Siphon.

Fig. ?86? is a plot of the difference between upstream and downstream water levels (dH=HW-TW) versus discharge when the pumps are in siphon mode. The upper bound of the model data corresponds to the rating curve tabulated as the Control Strategy in M11 (Table 16). The siphon starts to operate if the headwater at S-176 falls below 5.5 feet and S-331 pumps are off.

- Priority 1: Open when S176 HW < 5.5 ft. and S331P flow < 0.1 cfs. Calculate discharge based on control strategy in Table 16 (for calibration model use Table 17.
- Priority 2: Close when headwater is less than 0.0 ft.

Table 16. Control strategy for S331S Operational Model

HW-TW (ft)	Q (cfs)
0	0
0.25	216.8
0.5	330.2
0.75	423.3
1	497.4
1.25	553.8
1.5	593.7
10	600.0

S-331 Pump.

The pumps at S-331 operate based on the water level at the observation well Angels. A set of rules is defined under the IOP/ERTP programs which increases pumping when the trigger well water level reaches higher levels. The rules are defined in Section ?5?, Table ?tab:Test7ph1.? This trigger well is to be abandoned in favor of a new well closer to the C-357 canal, but in this model Angels remains the operative trigger well. The priorities are listed in Table ?7?.

- Priority 1: Close when headwater at S-176 > 4.95 ft.
- Priority 2: Close when headwater at S-176 < 4.0 ft.
- Priority 3: When water level at Angels Well is > 6.0 ft. discharge according to control strategy, Table 18
- Priority 4: When water level at Angels Well is > 5.75 ft. discharge according to control strategy, Table 19

Table 17. Control strategy for S331S Calibration Model

HW-TW (ft)	Q (cfs)
0	0
0.25	216.8
0.5	330.2
0.75	423.3
1	497.4
1.25	553.8
1.5	593.7
1.75	618.2
2	628.6
2.25	626.1
2.5	611.9
2.75	587.3
10	553.4

- Priority 5: When water level at Angels Well is > 5.5 ft. discharge according to control strategy, Table 20
- Priority 6: Close

Since S-331P is triggered by Angels Well stage, Fig. ?93? shows a plot of the observed and modeled discharge vs Angels water level. Fig. ?94? is the cumulative discharge of total S-331/S-173 complex discharge for the IOP time period. In the model the output is known as S331T and measured at the downstream junction of the three canals.

Table 18. Control strategy for Priority 3 at S331P

HW (ft)	Q (cfs)
0	0
4.0	0
4.1	200
4.2	250
4.3	300
4.4	450
4.5	600
4.6	700
4.7	800
4.8	850
4.9	900
5.0	925
5.2	950
5.6	1000
6.0	1000
6.5	1000
10	1000

Figure ?93?: Observed and modeled data of S331P discharge vs Angels stage.
Figure ?94?: Cumulative Discharge Curve for total flow S-331.

Calibration Model Essentially the same as Operational Model, except for S173 substitute Table 15 for Table 14, and for S331S substitute Table 17 for Table 16.

Table 19. Control strategy for Priority 4 at S331P

HW (ft)	Q (cfs)
0	0
4	0
4.1	200
4.2	250
4.3	300
4.4	350
4.5	400
4.6	450
4.8	500
5	550
5.2	600
5.4	650
5.6	700
5.8	750
6	800
6.5	900
10	900

Table 20. Control strategy for Priority 5 at S331P

HW (ft)	Q (cfs)
0	0
4	0
4.1	0
4.2	0
4.3	0
4.4	0
4.5	0
4.6	150
4.8	200
5	250
5.1	300
5.2	350
5.3	400
5.4	450
5.5	700
6	900
10	900

4.11.3 S332BN Pump

Historical In 2000 the pump station S-332B became operational, initially discharging all pumps to the western portion of the partially completed SDA. Upon completion of the S332BN detention area, two pumps of the S-332B station were diverted to deliver water to the enclosed area. The pumps were turned on in 2004. They were initially referred to as the S332B Pump, but when the discharge of the pump became partially diverted, the Pump took on the new names of S332BN and S332BW.

Operational Model Fig. ?113? is a plot of the discharge versus the headwater (HW) of the two 125 cfs pumps. The modeled rating curve is based on the recorded data, not on the design data detailed in Table ?3?.

In the model the pump turns on when L-31N stage (S332BW HW) reaches 4.65 ft. and remains unchanged until the water level falls below 4.5 ft. The rating curve is shown in Table 21.

The daily average flow is plotted in Fig. ?115?, since the model runs the above detailed operational scheme during the entire period, both the average and cumulative (Fig. ?116?) flows are larger in the model than observed.

In the model the pumps discharge according to the following rules:

- Priority 1: When HW > 4.65 ft, discharge according to Table 21
- Priority 2: When HW > 4.5 ft, remain unchanged
- Priority 3: When stage < 0.0, close

Table 21. Control strategy for S332BN

HW (ft)	Q (cfs)
0.00	0
4.40	0
4.45	0
4.50	0
4.55	50
4.60	75
4.68	75
4.70	130
4.78	130
4.80	265
4.85	265
4.90	265
10.0	265

Calibration Model Prescribed flow timeseries, as shown in Figure 105.

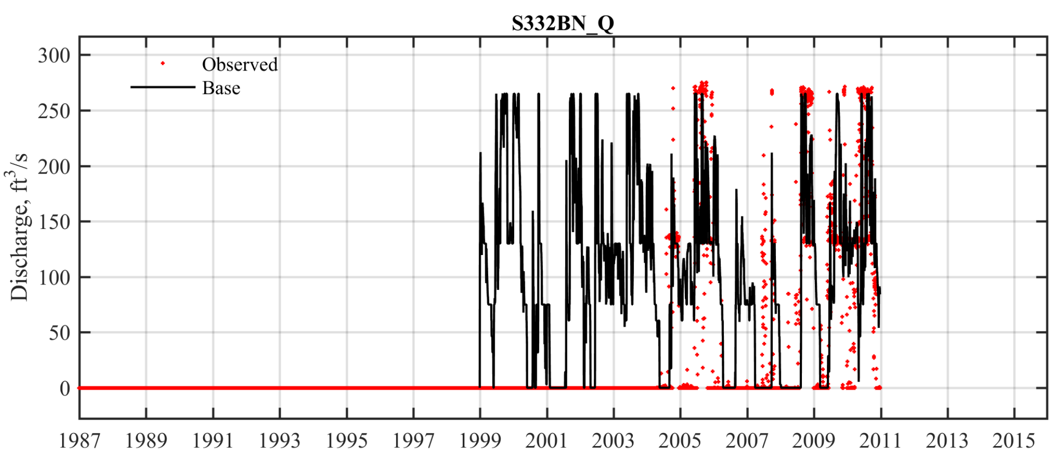


Figure 105. Prescribed Headwater at Structure S332BN

4.11.4 S332BW Pump

Historical In 2000 the pump station S-332B became operational, initially discharging all pumps to the western portion of the partially completed SDA. Upon completion of the S332BN detention area, two pumps of the S-332B station were diverted to deliver water to the enclosed area. The pumps were turned on in 2004. They were initially referred to as the S332B Pump, but when the discharge of the pump became partially diverted, the Pump took on the new names of S332BN and S332BW.

Operational Model In Fig. ?117? the larger discharges above 265 cfs in the observed data are from the early period. The pumps turn on when L-31N stage (S332BW HW) reaches 4.65 ft. and remains unchanged until the water level falls below 4.5 ft. identical to S-332BN. Average flows are plotted in Fig. ?119? and the cumulative in Fig. ?120?.

In the model the pumps discharge according to the following rules:

- Priority 1: When HW > 4.65 ft, discharge according to Table 22
- Priority 2: When HW > 4.5 ft, remain unchanged
- Priority 3: When stage < 0.0, close

Table 22. Control strategy for S332BW

HW (ft)	Q (cfs)
0.00	0
4.40	0
4.45	0
4.50	0
4.55	50
4.60	75
4.68	75
4.70	130
4.78	130
4.80	265
4.85	265
4.90	265
10.0	265

Calibration Model Prescribed flow timeseries, as shown in Figure 106.

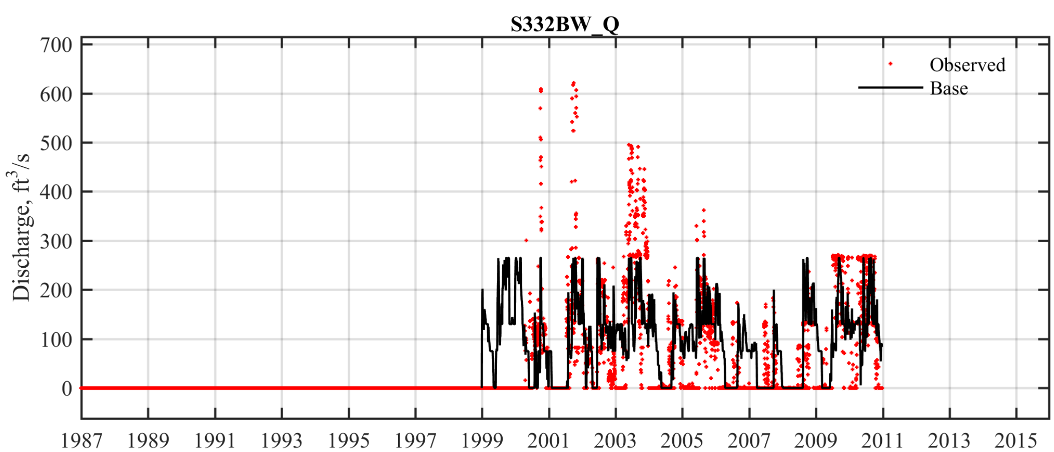


Figure 106. Prescribed Headwater at Structure S332BW

4.11.5 S332C Pump

Historical Pump station S-332C started operating in 2002 and all pumps are directed into the SDA through halfmile long culverts, preventing direct seepage back to L-31N.

Operational Model The pumps turn on when L-31N stage (S332C HW) reaches 4.65 ft. and remains unchanged until the water level falls below 4.5 ft. (identical to S-332BN and S-332BW).

The control strategy is as follows:

- Priority 1: When HW > 4.65 ft, discharge according to Table 23
- Priority 2: When HW > 4.5 ft, remain unchanged
- Priority 3: When stage < 0.0, close

Table 23. Control strategy for S332C

HW (ft)	Q (cfs)
0.00	0
4.40	0
4.45	0
4.50	0
4.55	80
4.60	100
4.68	100
4.70	280
4.78	280
4.80	575
4.85	575
4.90	575
10.0	575

Calibration Model Prescribed flow timeseries, as shown in Figure 107.

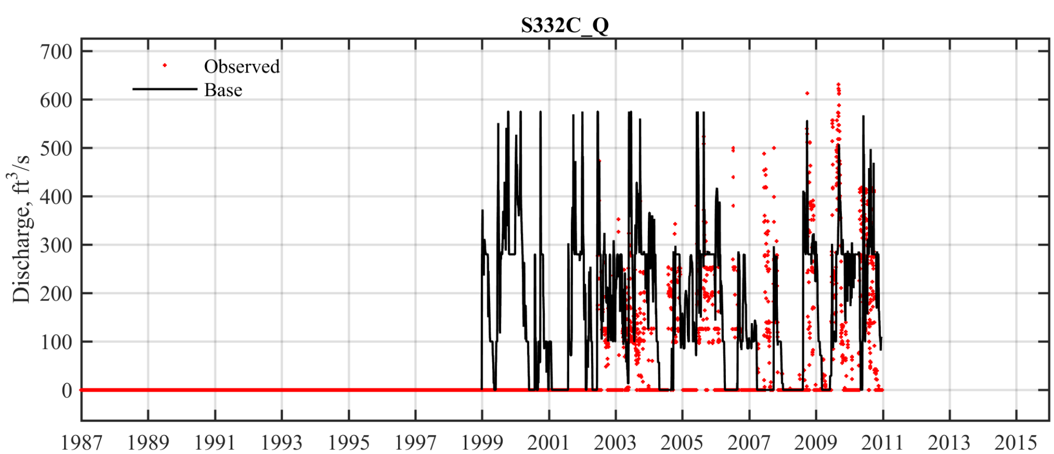


Figure 107. Prescribed Headwater at Structure S332C

4.11.6 S332D Pump

Historical The S-332D pump station was constructed in 1999 and all pumps deliver water to the "High-Head Cell" immediately adjacent to the pump station.

Operational Model In the model two control structures are implemented at the same location, to allow for different operations during the wet and dry seasons.

The first control structure (S332D1) operates all year: it allows pumps to start up when L-31N water level (S332D HW) reaches 4.6 ft, and remain unchanged until headwater reaches 4.5 ft. The S332D1 control strategy is as follows:

- Priority 1: When HW > 4.6 ft, discharge according to Table 24
- Priority 2: When HW > 4.5 ft, remain unchanged
- Priority 3: When stage < 0.0, close

The second control structure (S332D2) operates after July: it allows additional discharge according to Table 24. The S332D2 control strategy is as follows:

- Priority 1: For January through July, remain closed
- Priority 2: When HW > 4.6 ft, discharge according to Table 24
- Priority 3: When HW > 4.5 ft, remain unchanged
- Priority 4: When stage < 0.0, close

Table 24. Control strategy for S332D

HW (ft)	S332D1 Q (cfs)	S332D2 Q (cfs)
0	0	0
4.4	0	0
4.45	0	0
4.5	60	0
4.55	80	0
4.6	80	125
4.65	100	125
4.7	130	250
4.75	165	250
4.8	165	375
4.85	165	375
4.9	165	375
10	165	375

Calibration Model Prescribed flow timeseries, as shown in Figure 108.

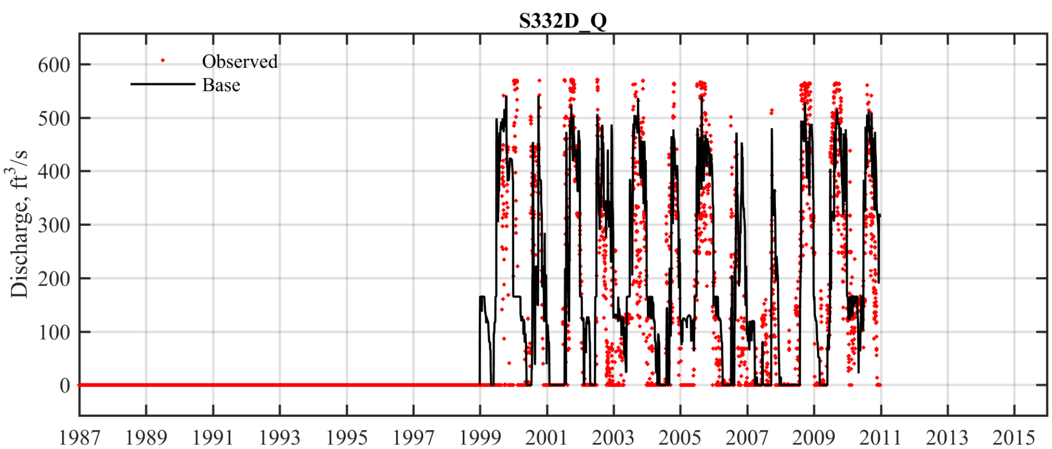


Figure 108. Prescribed Headwater at Structure S332D

4.12 Canal Operations: C-357

In order to provide enhanced flood protection for the remaining 8.5 SMA, the canal C-357, the levee L-357 and the pump station S-357 were built.

4.12.1 SDAN_HH

Historical

Operational Model Not present in operational model.

Calibration Model Overflow weir. Closed before 1-1-1987, otherwise fully open.

4.12.2 S357 Pump

Historical The pumps were operational in 1999.

Operational Model In the model the pumps are operational throughout the time period and discharge according to the following rules:

- Priority 1: When HW > 6.0 ft, discharge according to Table 25
- Priority 2: When HW > 5.5 ft, remain unchanged
- Priority 3: When stage < 0.0, close

Table 25. Control strategy for S357

HW (ft)	Q (cfs)
0	0
5.4	0
5.45	0
5.5	0
5.6	80
5.7	100
5.8	150
5.9	200
6	300
6.1	325
6.2	325
6.3	325
10	325

Calibration Model Prescribed flow timeseries, as shown in Figure 109.

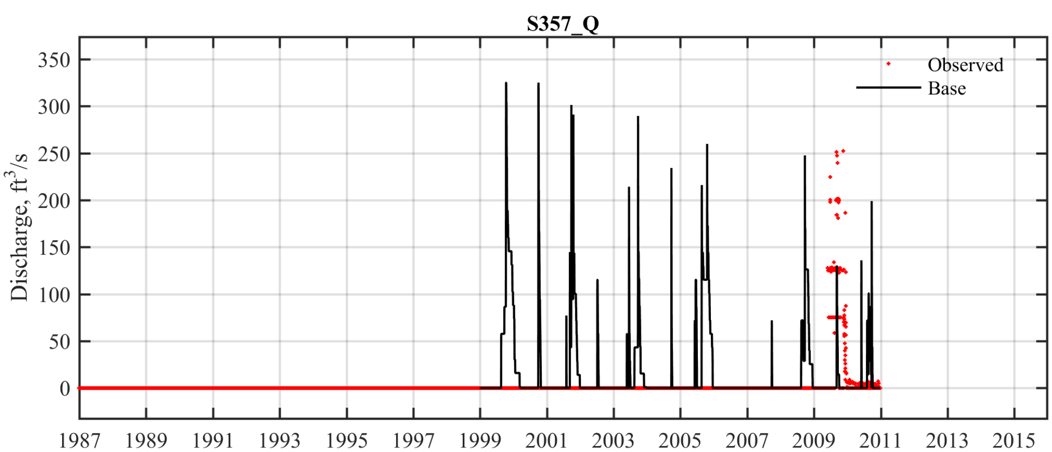


Figure 109. Prescribed Flow at Structure S357

4.13 Canal Operations: C-1W

4.13.1 S338

Historical The structure S-338 provides discharge into C-1W from L-31N for both water supply and flood control. Structure 338 is located in Canal C-l, just west of State Highway 27. S338 is a gated, double-barreled, 84-inch, CMP culvert.S338 supplies water to the C-l area to maintain adequate canal stages, to prevent saltwater intrusion at east coast structures, to provide water to the root zone of growing plants, and to permit groundwater withdrawals for water supply. S338 also provides flood control releases from the area between Krome Avenue and L-31N and north of S331.This structure is normally closed except during flood events when the gates are opened fully.

Operational Model In the model the discharge is prescribed as shown in Figure 110 (presumably the historical observed flow data). The M11 model implements this structure using the discharge timeseries, i.e. the structure passes the required amount of water equal to observed timeseries.

Calibration Model Same as Operational Model.

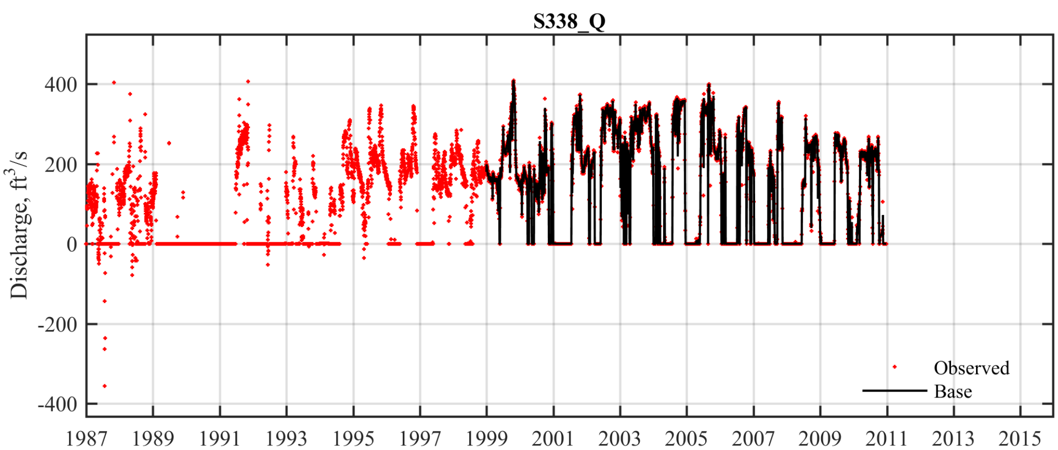


Figure 110. Prescribed Flow at S338.

4.13.2 East Canal Boundary

Historical Not applicable.

Operational Model Prescribed head timeseries, set to S338TW-S148HW (we think), as shown in Figure 111.

Calibration Model Same as Operational Model.

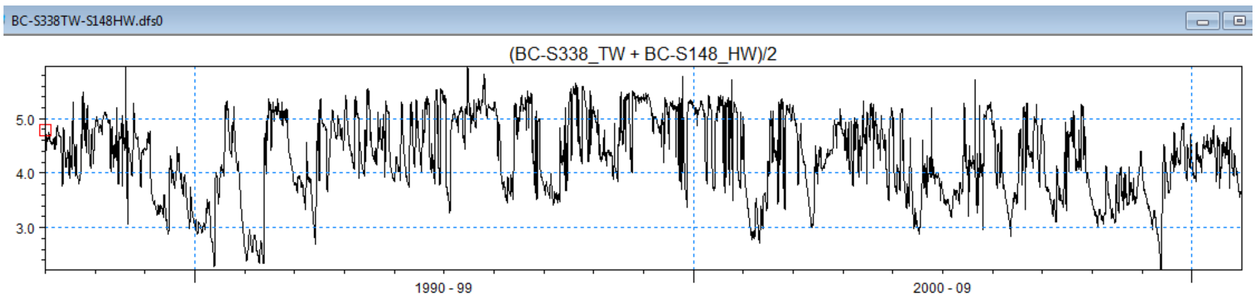


Figure 111. Prescribed Stage at Eastern Boundary of C1-W canal

4.14 Canal Operations: C-102

4.14.1 S194

Historical The first control structure in C-102 is S-194.

Operational Model In the model the structure discharge is a prescribed timeseries S194_Q.dfs0 (probably derived from the observed flow data?), as shown in Figure 112.

Calibration Model Same as in Operational Model.

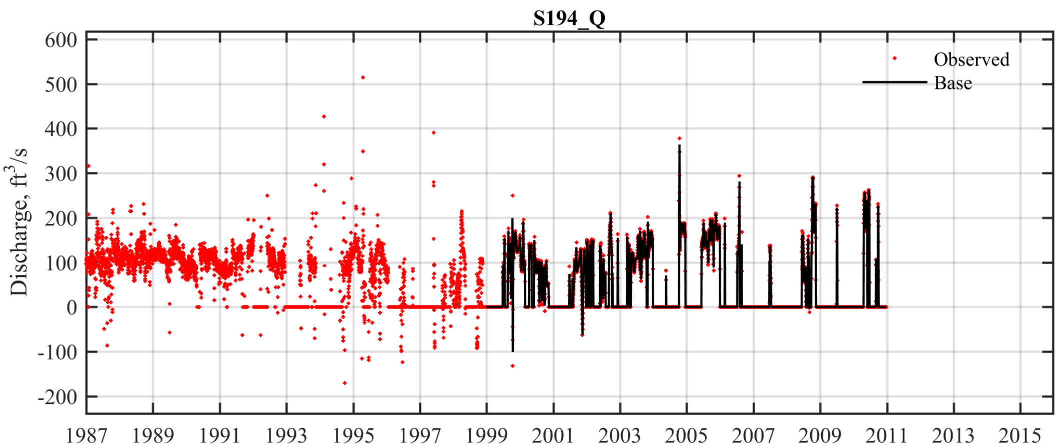


Figure 112. Prescribed Flow at S194

4.14.2 East Canal Boundary

Historical Not applicable.

Operational Model Prescribed head timeseries, set to S194TW-S165HW (we think), as shown in Figure 113.

Calibration Model Same as Operational Model.

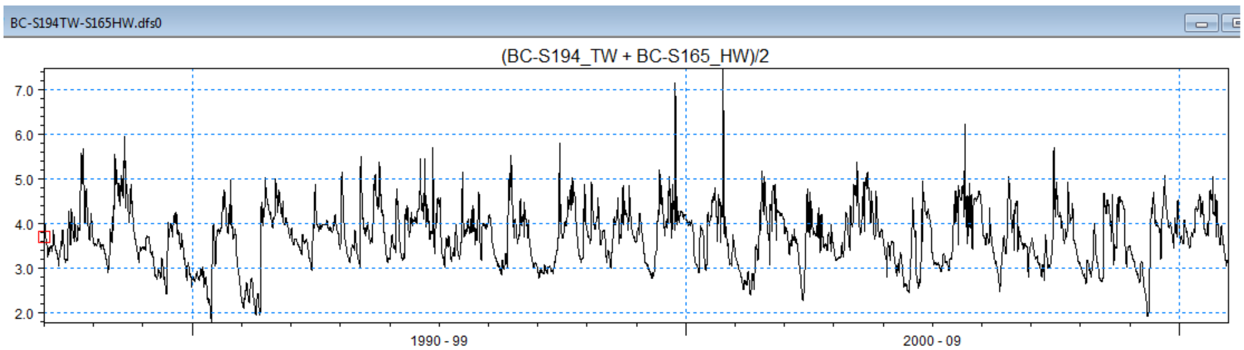


Figure 113. Prescribed Stage at Eastern Boundary of C-102 canal

4.15 Canal Operations: C-103

4.15.1 S196

Historical The first control structure in C-103 is S-196.

Operational Model In the model the structure discharge is a prescribed timeseries S196_Q.dfs0 (probably derived from the observed flow data?), as shown in Figure 114.

Calibration Model Same as in Operational Model.

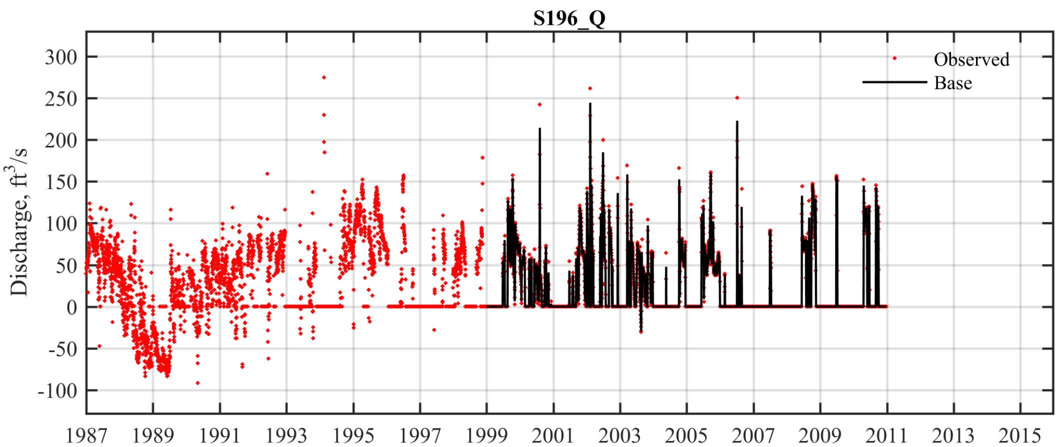


Figure 114. Prescribed Flow at S196

4.15.2 S167

Historical

Operational Model Discharge based only on headwater stage, according to Table 26.

Table 26. Control strategy for S167.

HW (ft)	Q (cfs)
0	0
4.5	0
5	120
6	500
10	700

Calibration Model Same as Operational model.

4.15.3 East Canal Boundary

Historical Not applicable.

Operational Model Prescribed head timeseries, set to S167TW-S179HW (we think), as shown in Figure 115.

Calibration Model Same as Operational Model.

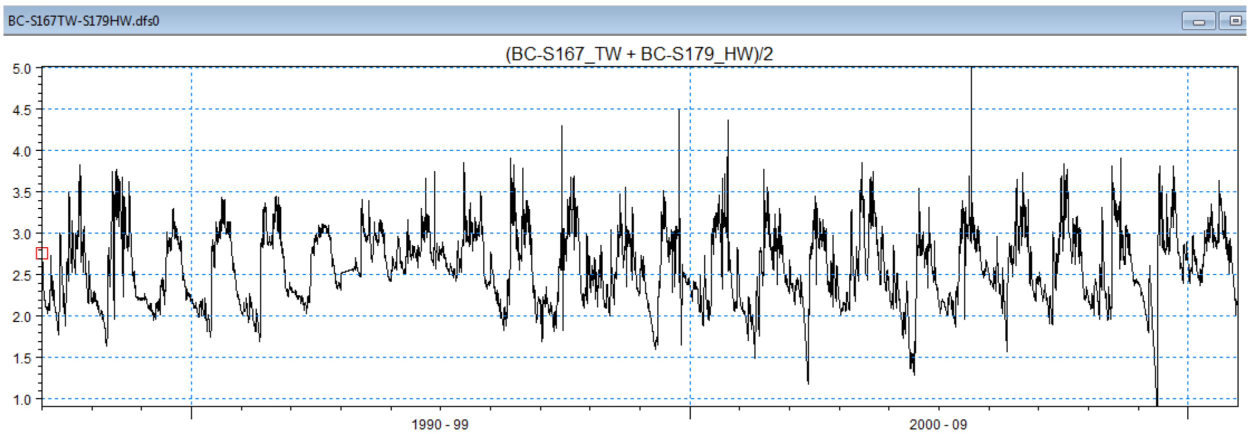


Figure 115. Prescribed Stage at Eastern Boundary of C-103 canal

4.16 Canal Operations: L-31W

4.16.1 S174

The structure is located on the L-31W borrow canal near its junction with Canal C-111, about 5 miles west of Homestead. This structure, together with S176, maintains a desirable water control stage in upstream L-31N, it passes the design flood (40% of the Standard Project Flood) without exceeding upstream flood design stage, and restricts downstream flood stages and discharge velocities to non-damaging levels. It also passes the required flows to the Everglades National Park into Taylor Slough. During the dry period, S174 may be opened to meet water supply requirements in the Everglades National Park - South Dade Conveyance System.

Historical

Operational Model Not in model.

Calibration Model Not in model.

4.16.2 S332 Pump

Historical This structure is a six unit pumping plant located at the head of Taylor Slough in the Everglades National Park on L-31W about 6 miles west of Homestead, Florida. The purpose of the structure is to make water deliveries to the Everglades National Park via Taylor Slough.

Operational Model Not in model.

Calibration Model Not in model.

4.16.3 S175

Historical This structure is located on the Levee 31W borrow canal approximately 1.5 miles north of State Road 27. The structure maintains optimum upstream water control stages in the Levee 31W borrow canal; it passes the design flood (40% of the Standard Project Flood) without exceeding the upstream flood design stage and restricts downstream flood stages and channel velocities to non-damaging levels. It is also used to pass maximum available flows into Taylor Slough. For flood control, when a rainfall event occurs which causes the S-175 headwater to rise above its target stage, the stage will be returned to its target elevation as quickly as practicable.

Operational Model Closed.

Calibration Model Closed.

4.17 Canal Operations: C-111

4.17.1 S176

Historical At the terminus of L-31N is the structure S-176 which allows discharge into C-111 to the next structure S-177. The structure is located on Canal 111 about 5 miles west of Homestead. This structure, together with S-174, maintains a desirable water control stage upstream in L-31N, it passes the design flood (40% of the Standard Project Flood) without exceeding upstream flood design stage, and restricts downstream flood stages and discharge velocities to non-damaging levels.

Operational Model The control strategy associated with computing the discharge based on the observed difference of headwater and tailwater data is shown in Fig. ?99?. The structure opens when the headwater is above 4.9 feet and remains unchanged until the headwater drops to 4.7. The model flow is less than observed, due to the S-332B, C and D pumps coming online incrementally during the IOP timeperiod, the model Control Definition is with more recent operational rules (Table 27). The average daily flow is shown in Fig.? 101? and Fig. ?102? shows the cumulative flows.

Figure ?99?: Observed and modeled data of S-176 discharge versus dH=HW-TW.

- Priority 1: When HW > 4.9 ft, discharge according to Table 27
- Priority 2: When HW > 4.7 ft, remain unchanged
- Priority 3: When stage < 0.0, close

Table 27. Control strategy for S176.

HW-TW (ft)	Q (cfs)
0	0
0.25	207.8
0.5	346.8
0.75	478.5
1	587.3
1.25	677.1
1.5	751.7
1.75	815.1
2	871.2
2.25	923.8
2.5	976.9
2.75	1034.3
10	1100.0

Figure ?101?: Daily average flow for S-176. Observed and modeled data in cfs.
Figure ?102?: Cumulative Discharge Curve for total flow S-176.

Calibration Model Same as in Operational Model.

4.17.2 S200 Pump

Historical A pump station was constructed (by SFWMD) to pump into a newly built detention area in the Frogpond.

Operational Model The complex was constructed post model period, thus no observed data is available for comparison.

Control Strategy for S200:

- Priority 1: When HW > 3.8 ft, discharge according to Table 28
- Priority 2: When HW > 3.6 ft, remain unchanged
- Priority 3: When stage < 0.0, close

Table 28. Control strategy for S200.

HW (ft)	Q (cfs)
0	0
3.59	0
3.6	75
3.8	75
3.89	75
3.9	150
3.99	150
4	225
4.2	225
10	225

Calibration Model Closed.

4.17.3 S177

Historical The first structure in C-111 is S-177. Flow to the structure is partially from S-176 and mostly from seepage out of the high head cell of S-332D when the pumps are on. This due to the large transmissivity of the aquifer with the high head cell too close to the C-111 canal. Knowledgeable hydrologists do not understand why there is a high head cell in the first place.

Structure S177 maintains optimum water control upstream in Canal 111; it passes the design flood (40% of the Standard Project Flood) without exceeding upstream flood design stage, and restricts downstream flood stages and discharge velocities to non-damaging levels.

Operational Model The observed and modeled data of S-177 discharge versus headwater is shown in Fig. 103.

- Priority 1: From January to end of May, if upstream water level > 3.3 ft use rating curve tabulated in Table 29
- Priority 2: From January to end of May, remain unchanged if upstream water level > 3.1 ft
- Priority 3: From November to December, if upstream water level > 3.3 ft use rating curve tabulated in Table 29
- Priority 4: If upstream water level > 4.3 ft use rating curve tabulated in Table 30
- Priority 5: Remain unchanged if upstream water level > 3.7 ft
- Priority 6: Close when H < 0.0

Table 29. Control strategy for Priority 1 and 3 at S177

HW (ft)	Q (cfs)
3	0
3.1	100
3.3	200
3.5	300
3.7	450
10	1398

Table 30. Control strategy for Priority 4 at S177

HW-TW (ft)	Q (cfs)
0	0
0.25	233.6
0.5	418.1
0.75	560
1	668.3
1.25	751.8
1.5	819.5
1.75	880.5
2	943.8
2.25	1018.1
2.5	1112.7
2.75	1236.3
10	1398

Figure ?103?: Observed and modeled data of S-177 discharge versus headwater
Fig. ?111? Fig. ?112? shows the cumulative.
The model is less than observed, due to the S-322 pumps being fully online with recent operational rules.
Figure ?105?: Daily average flow for S-177.
Observed and modeled data in cfs.
Figure ?106?: Cumulative Discharge Curve for total flow S-177.

Calibration Model Same as in Operational Model.

4.17.4 S199 Pump

Historical A recent addition is the S199 pumps just north of S-177, which pump into the Aerojet borrow canal, a SFWMD complex which was designed as a hydraulic barrier between the wetlands and the low stages of the C-111 canal. The project intends to enhance flow through Taylor Slough, and continue the low canal and wetland stages south of S-177.

Operational Model This feature was completed after the model time period (1987 to 2010), so no data is available for comparison.

Control Strategy for S199:

- Priority 1: When HW > 3.8 ft, discharge according to Table 31
- Priority 2: When HW > 3.6 ft, remain unchanged
- Priority 3: When stage < 0.0, close

Table 31. Control strategy for S199.

HW (ft)	Q (cfs)
0	0
3.59	0
3.6	75
3.8	75
3.89	75
3.9	150
3.99	150
4	225
4.2	225
10	225

Calibration Model Closed.

4.17.5 S18C

Historical The structure S-18C is a large structure with two gates designed to allow large gravity flows into the last reach of C-111. Flows downstream are designed to discharge into the wetlands just north of Florida Bay or to be released through S-197 into Manatee Bay. Generally small head differences exist across the structure, so the headwater is used to control flow rates.

Under the operational regime of IOP/ERTP the gates are designed to be operated when the wetland water level north of S-18C reaches ground surface, allowing large quantities of water to be intercepted and released to lower C-111 as shallow overbank flow or as a release to Manatee Bay via S-197. The additional benefit of maintaining low C-111 canal levels to promote gravity canal flow from L-31N was precisely the reason why the S-332 pumps were built close to the sources needed for flood control under the C-111 GRR. Under current operations the flood control discharge benefits have more than doubled for the L-31N/C-111 system while, with the lowering of operational levels at S-18C under IOP/ERTP, decreasing any environmental benefit as originally anticipated by ENP.

Structure S18C maintains optimum water control stages upstream in Canal 111; it passes the design flood (40% of the Standard Project Flood) without exceeding upstream flood design stage, and restricts downstream flood stages and discharge velocities to non-damaging levels; and assists in preventing saline intrusion. It also makes discharges to the eastern panhandle of the Everglades National Park.

Operational Model A different operational scheme is used during the dry season as opposed to the wet season.

- Priority 1: From January to end of May, if upstream water level > 2.1 ft use rating curve for the Dry Season in Table 32
- Priority 2: From November to December, if upstream water level > 2.1 ft use rating curve for the Dry Season in Table 32
- Priority 3: If upstream water level > 2.55 ft use use rating curve for the Wet Season in Table 32
- Priority 4: Remain unchanged if upstream water level > 2.2 ft
- Priority 5: Close if stage < 0.0

Table 32. Control strategy for Priority 1, 2 and 3 at S-18C

HW (ft)	Priority 1 and 2 Dry Season Q (cfs)	Priority 3 Wet Season Q (cfs)
0	0	0
1.5	0	0
1.75	30	100
2	60	200
2.2	100	300
2.4	130	400
2.6	160	500
2.7	190	700
2.8	200	900
3	400	1200
3.2	800	1500
3.5	1800	1800
10	3500	3500

The model cumulative discharge is less than observed, as depicted in Fig. ?109?, due to the S-322 pumps being fully online in the model with recent operational rules derived from observed data.

Calibration Model Same as Operational Model.

4.17.6 S197

Historical This structure is located near the mouth of Canal 111 about 3 miles from the shore of Manatee Bay and 750 feet east of U.S. Highway 1. The structure maintains optimum upstream water control stage in Canal 111 and prevents saline intrusion during high tides. Most of the time S197 diverts discharge from S18C overland to the panhandle of the Everglades National Park and releases water only during major floods according to the established guidelines.

This structure is a thirteen-barreled corrugated metal pipe culvert. The culverts 4 through 13 have been replaced since 2010.

The structure is closed except for the conditions described below ?U.S. Army Corp of Engineers (2005); District (1994):?

- ?If S-177 headwater > 4.10ft or S-18C headwater > 2.80ft: open 3 culverts.?
- ?S-177 headwater > 4.20ft or S-18C headwater > 3.10ft: open 7 culverts?
- ?S-177 headwater > 4.30ft or S-18C headwater > 3.30ft: open 13 culverts?

Operational Model The S-197 structure in the model are underflow gates, all 13 gates are being modeled. The M11 model implements S197 as three structures: S197-03 (contains 3 culverts), S197-10 (7 culverts), and S197-13 (3 culverts). These simulate the opening of 3, 10 and 13 culverts total.

This was designed to maintain simplicity in the rules for each of the complicated operational IOP/ERTP schemes. The opening criteria are based on the water levels upstream of S-18C and/or S-177 as prioritized below for the three schemes. The culverts 4 through 13 have been replaced since 2010, however the model is based on the time period before the construction. Adjustments to the operational rules can be implemented in future model versions to account for the infrastructure changes.

Location of trigger points in model:

- S-176 HW: Branch C-111 chainage 0 ft.
- S-177 HW: Branch C-111 chainage 29452 ft.
- S-18C HW: Branch C-111 chainage 60663 ft.
- S-197: Branch C-111 chainage 92963 ft.

Table 33 defines the gate opening range for control of the structure.

Priority and Calculation Mode for S197-03, (3 gates):

- Priority 1: If S-18C upstream water level HW>2.8 ft. use Table 33 for gate operations
- Priority 2: If S-177 upstream water level HW>4.1 ft. use Table 33 for gate operations
- Priority 3: Close if upstream water level S-176 HW<5.2 ft. and if S-177 HW<4.2 ft.
- Priority 4: Remain unchanged if stage < 0

Priority and Calculation Mode for S197-10, (7 gates):

- Priority 1: If S-18C upstream water level HW>3.1 ft. use Table 33 for gate operations
- ???? check this ???? Priority 2: If S-177 upstream water level HW>4.2 ft. use Table 33 for gate operations
- Priority 3: Close if upstream water level S-176 HW<5.2 ft. and S-177 HW<4.2 ft.
- Priority 4: Remain unchanged if stage < 0

Priority and Calculation Mode for S197-13, (3 gates):

- Priority 1: If S-18C upstream water level HW>3.3 ft. use Table 33 for gate operations
- Priority 2: If S-177 upstream water level HW>4.3 ft. use Table 33 for gate operations
- Priority 3: Close if upstream water level S-176 HW<5.2 ft. and S-177 HW<4.2 ft.
- Priority 4: Remain unchanged if stage < 0

The range of the potential gate openings is defined in the figure by the white "gates", vertically the possible gate opening ranges from -8 to -1 feet. The other 10 gates are similar and located to the right of the three gates shown in the figure.

Figure ?110?: S-197 cross section and gates.

Table 33. Control strategy for S-197

riv geometry (ft.)	Q (cfs)
-8	-7.99
-1.01	-1

In this example the first three gates are shown in the cross section. The inset defines the range of gate openings.

Figure ?111?: Daily average flow for S-197. Observed and modeled data in cfs.

Figure ?112?: Cumulative Discharge Curve for total flow S-197.

Calibration Model Same as in Operational Model.

4.17.7 Southeast Canal Boundary

Historical Not applicable.

Operational Model Prescribed head timeseries, set to S197TW (we think), as shown in Figure 116.

Calibration Model Same as Operational Model.

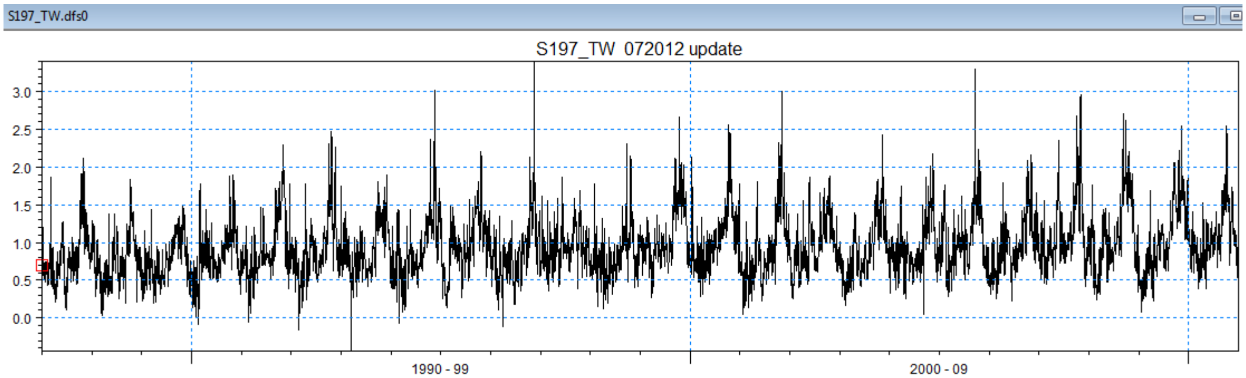


Figure 116. Prescribed Stage at Southeastern Boundary of C-111 canal

4.18 Canal Operations: C-111E

4.18.1 S178

Historical

Operational Model This structure is located at the north end of Canal 111E at State Road 27. The structure maintains optimum upstream water control stages in Canal 111E; it passes the design flood (40% of the Standard Project Flood) without exceeding the upstream flood design stage and restricts downstream flood stages and channel velocities to non-damaging levels.

Priority and Calculation Mode for S178:

- Priority 1: If S178 HW > 4.0 ft, use Table 34 for gate operations
- Priority 2: Close if stage < 0

Table 34. Control strategy for S178

riv geometry (ft.)	water level (ft.)
-3	-2.99
4.99	5

Calibration Model Same as Operational Model.

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LITERATURE CITED

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