# C-139 Basin Phosphorus Water Quality and Hydrology Analysis

## Deliverable 6.4 – Final Calibration, Validation and Baseline Condition WAM Hydrologic and Phosphorus Water Quality Modeling Report

(Work Order No. CN040912-WO07-A2)

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# EXECUTIVE SUMMARY

## Background

Florida's 1994 Everglades Forever Act (EFA), F.S. 373.4592, establishes long-term water quality goals designed to restore and protect the Everglades Protection Area (EPA). The EFA mandates that landowners within the C-139 Basin should not collectively exceed the average annual historic total phosphorus (TP) load adjusted for rainfall. In 2002, the C-139 Basin Best Management Practices (BMPs) Regulatory Program was adopted to ensure that TP load requirements would be met. This BMP program is defined in Chapter 40E-63, F.A.C. ("Rule 40E-63").

During the 2003 legislative session, a Long-Term Plan objective was adopted for the C-139 Basin to identify urban and agricultural discharges within the basin that are candidates for cost-effective implementation of source controls. After two years of implementing the mandatory BMP program, the C-139 Basin has not been able to meet the historic TP load required by Rule 40E-63. Both the South Florida Water Management District (District) and permittees are interested in additional TP load reduction programs within the basin that will be prioritized and addressed in future BMP program optimization plans, as necessary to meet rule requirements.

In order to address TP load reduction, the Everglades Regulation Division of the District contracted ADA through Work Order CN040912-WO07 to implement the C-139 Basin Phosphorus Water Quality and Hydrology Analysis. The objective of the C-139 Basin Phosphorus Water Quality and Hydrology Analysis is to assess the current hydrologic and water quality conditions of the basin, identify locations where additional water quality and flow data is required, and identify and evaluate opportunities for water quality improvement. The project is to be completed in two phases.

## Phase I

Phase I was finalized in February 2006 and included four main tasks;

1. Records Review and Action Plan
2. Field Review and Data Collection
3. Subwatershed Segmentation and Screening Level TP Assessment
4. Location of Monitoring Stations

As a result of the Phase I report, four additional monitoring stations were constructed within the C-139 Basin at locations representative of subwatershed outlets. The results are summarized in the February 1, 2006 submission of C-139 Basin Phosphorus Water Quality and Hydrology Analysis Deliverable 5.4 – Phase I Report.

## Phase II

Phase II consists of developing a hydrologic and water quality model and to evaluating the technical and regulatory feasibility of water quality improvement projects. The following objectives define the scope of Phase II.

1. Develop a calibrated hydrologic and water quality modeling tool to analyze flows and phosphorus loads in the C-139 Basin. Everglades Regulatory Program staff shall be able to use the model as a tool for prioritizing resources and tailoring Best Management Practice strategies towards achieving compliance with Everglades Forever Act-mandated water quality levels. The simulation results of the calibrated WAM simulation will be visually and statistically compared to all available measured data within the basin to provide an estimate of the modeling error. The water quality model shall be user-friendly and compatible with District applications. The Consultant shall train District staff in the use of this application.
2. Identify and evaluate a maximum of five water quality improvement projects (selected projects). The recommendations/needs or project types described by C-139 Basin landowners shall be considered.
3. Describe regulatory constraints that may affect implementation of water quality improvement projects within the C-139 Basin. Evaluate the regulatory feasibility of the selected water quality improvement projects or types of projects. Provide recommendations for pursuing viable rule or policy changes.
4. Identify technical issues, cost and schedule considerations for the selected projects. Evaluating site-specific technical issues, cost and schedule does not apply to farm-level projects.
5. Note uncertainties and limitations associated with project implementation. Along with any other unidentified issues that are uncovered as the contract progresses [e.g., results of the EAA Regional Feasibility Study, Phase 2 (CN040912-WO04)].

This report documents a component of Phase II, referred to in the scope of work as Task 6, which serves to meet the development of the calibrated, validated model described in the first objective listed above. This model will ultimately be used to evaluate viable regional alternatives to reduce TP loads from the C-139 Basin.

## Task 6: Hydrologic and Phosphorus Water Quality Modeling

The model selected for Phase II implementation is the Watershed Assessment Model (WAM), which has been used in numerous agricultural basins throughout Florida. This document presents the calibrated hydrologic and water quality model that will be used in subsequent tasks to examine the benefits of the five regional water quality improvement projects. The model was calibrated to measured data for calendar years 2004 and 2005 and validated to calendar year 2003.

There are a variety of limitations associated with the development of the calibrated model including the limited availability of groundwater data, recorded structure operations, rainfall and evapotranspiration data and private land management practices. There are also deficiencies in the ability of WAM to represent the interaction between the Surficial and Lower Tamiami aquifers. Due to these limitations, the results of the calibration vary by location specifically with respect to high temporal resolution, such as at the daily timescale. However, the focus of this project is to utilize the calibrated model to evaluate basin-level water quality improvement project. Therefore it is useful to evaluate the models predictive accuracy at a coarser temporal resolution, such as quarterly. Mean absolute error (MAE), root mean squared error (RMSE) and r-squared were computed for quarterly average flow (cubic meters per second) and TP concentration (parts per million) n order to evaluate the predictive accuracy of the model. The model showed reasonable agreement with respect to quarterly loads as described in the **Table ES-1** below.

**Table ES-1: Statistical comparison of quarterly average flows and concentrations**

| STATION | FLOW [CMS] | | | TP CONCENTRATION [PPM] | | |
|---|---|---|---|---|---|---|
| | MAE | RMSE | R-SQUARED | MAE | RMSE | R-SQUARED |
| **G-135** | 0.47 | 0.65 | 0.17 | N/A | N/A | N/A |
| **G-136** | 0.37 | 0.46 | 0.78 | 0.08 | 0.09 | 0.53 |
| **STA-5 INFLOW / G-406** | 2.50 | 3.34 | 0.81 | N/A | N/A | N/A |
| **G-96** | 0.18 | 0.26 | 0.68 | N/A | N/A | N/A |
| **G-150** | 0.02 | 0.03 | 0.90 | N/A | N/A | N/A |
| **G-151** | 1.28 | 1.83 | 0.01 | N/A | N/A | N/A |
| **G-342A** | 0.22 | 0.33 | 0.96 | 0.10 | 0.13 | 0.66 |
| **G-342B** | 0.90 | 1.27 | 0.90 | 0.09 | 0.11 | 0.65 |
| **G-342C** | 0.93 | 1.24 | 0.42 | 0.08 | 0.10 | 0.71 |
| **G-342D** | 0.75 | 1.09 | 0.30 | 0.12 | 0.14 | 0.29 |
| **G-406** | 0.92 | 1.32 | 0.83 | 0.13 | 0.17 | 0.33 |

With respect to r-squared, the quarterly average simulated flows show reasonable agreement with quarterly averaged measurements, with the exception of measured data at G-135, G-151, G-342C and G-342D. The measured flow at G-135 is significantly larger than the simulated flow due to variable flood protection practices by the Central County Drainage District that effectively increase the contributing area of the structure during large runoff events. Since these practices could not be identified as part of any specific operational conditions, they were not represented in the model. There is no flow monitoring equipment or gate opening telemetry collocated with the G-151 structure, as such the measured flow data at G-151 is likely based on manually recorded gate opening data and appears questionable.

With respect to the low r-squared values for G-342C and G-342D, a comparison of the MAE and RMSE for these structures with the G-342B structure illustrates that the discrepancies between simulated and measured flows are not incongruously large. The variability of measured flows for G-342C and G-342D are small, meaning that errors that would be acceptable for G-342B create significantly lower r-squared values. The statistical evaluation of TP concentration shows that the simulation is not as accurate with respect to water quality. However based on an r-squared greater than 0.5, there is positive agreement for all monitoring locations other than G-342D and G-406. Both of these structures are at the confluence of the S&M, DeerFence and L-3 Canals, and as such these disparities may be due to physical processes outside of WAM's capabilities such as sediment re-suspension.

These results are reflective of the calibration and validation of the C-139 WAM model at the regional or watershed scale. There is not a significant distribution of measured data to validate the prediction capabilities of the basin-level calibration at the farm-level. There are limitations associated with the sensitivity and accuracy of farm-level hydrology and hydraulic parameters, since in many cases these parameters are reflective of average management practices for a specific land-use.

In addition to calibration results, this document reports the results of the baseline simulation. The baseline simulation is an execution of the calibrated model with the existing land-use for a 36-year rainfall period of record (1965 to 2000), or “Baseline Period”. The purpose of this methodology is to provide an assessment of the long-term effects of the existing conditions over a wide range of climactic conditions, and as part of a subsequent task determine relative benefits of proposed regional alternatives compared to the baseline condition. The temporal, spatial and tabular results of the baseline simulation are illustrated in **Figures ES-1** and **ES-2** and **Table ES-2** below, respectively.

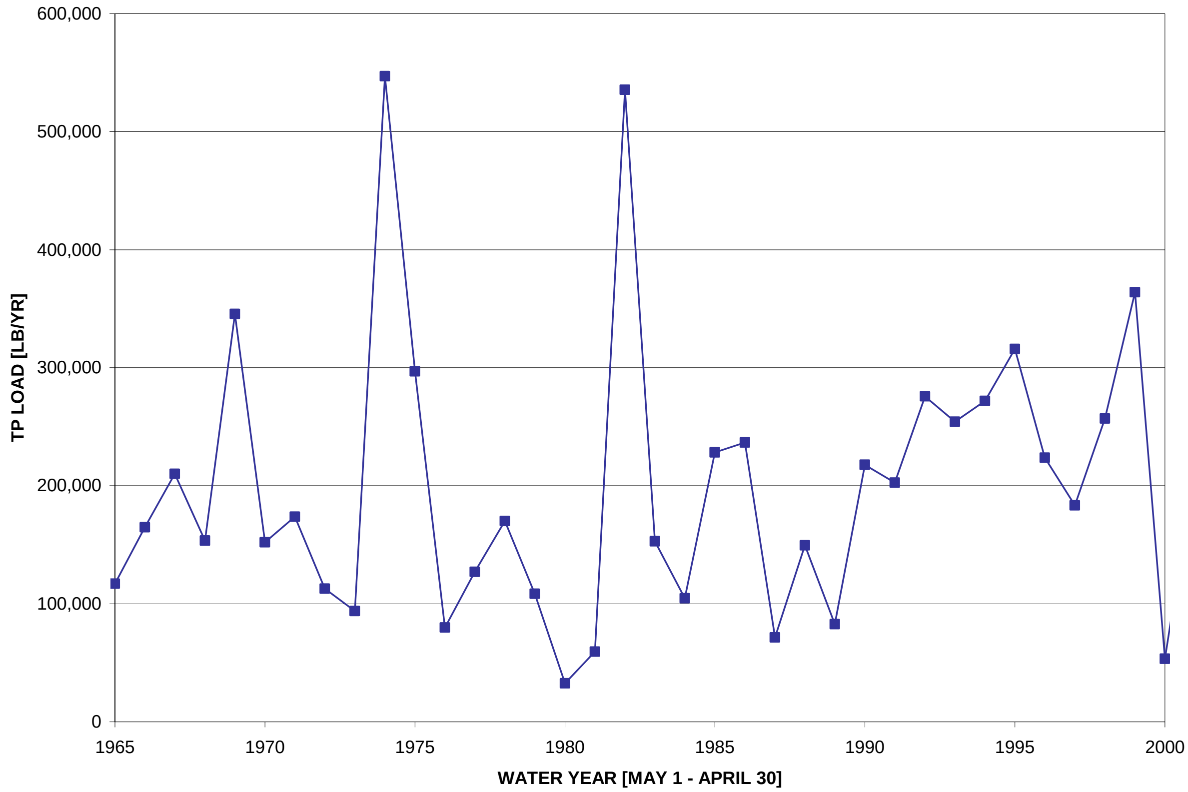


**Figure ES-1: Annual Simulated TP Loads for the C-139 Basin**

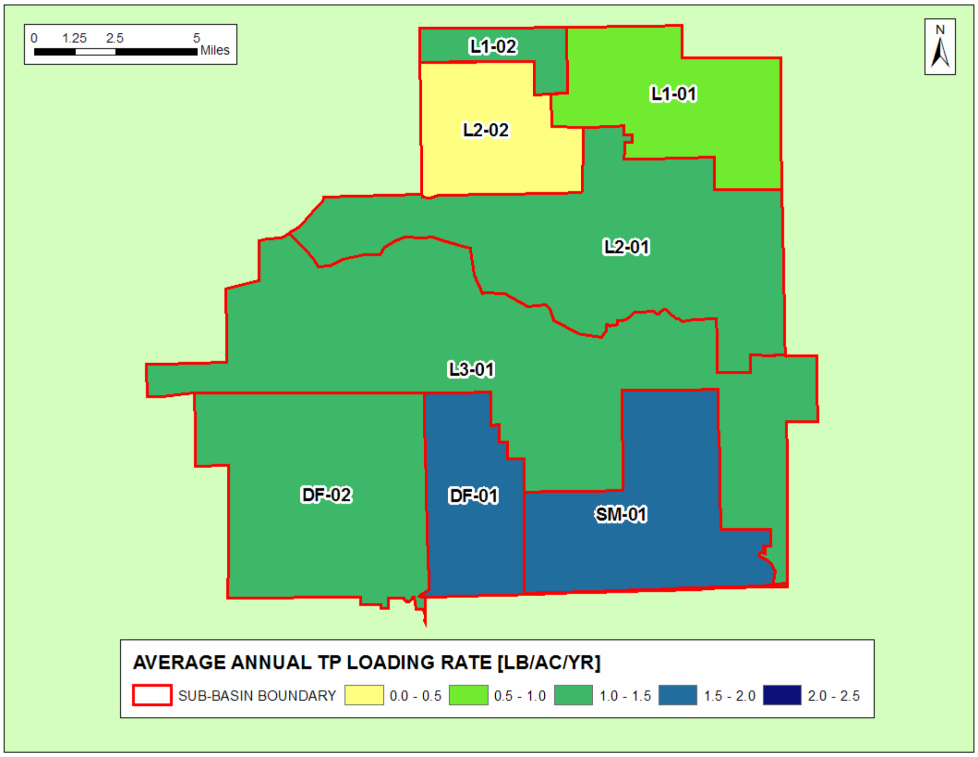


**Figure ES-2: Simulated Average Annual TP Loading Rates for the Sub-basins**

**Table ES-2: Average Annual TP Loading Rate and Runoff Volumes per Sub-basin**

| SUB-BASIN NAME | AVERAGE ANNUAL LOADING RATE [LB/AC/YR] | AVERAGE ANNUAL RUNOFF RATE [IN/AC/YR] | AVERAGE ANNUAL DISCHARGE [AC-FT/YR] |
|---|---|---|---|
| DF-01 | 1.53 | 9.71 | 7,679 |
| DF-02 | 1.50 | 9.88 | 32,148 |
| L1-01 | 0.68 | 7.07 | 20,966 |
| L1-02 | 1.47 | 11.43 | 3,394 |
| L2-01 | 1.15 | 9.44 | 50,028 |
| L2-02 | 0.37 | 15.41 | 26,496 |
| L3-01 | 1.13 | 8.94 | 57,681 |
| SM-01 | 1.61 | 11.51 | 18,089 |
| C-139 BASIN | 1.19 | 9.84 | 216,481 |

The results of the baseline simulation presented above demonstrate how the C-139 WAM simulation can be used as a planning tool in the evaluation of the regional water quality improvement projects. In future tasks each proposed improvement project will be represented within a scenario simulation, and the temporal, spatial and tabular results of that scenario will be presented in comparison with the existing condition baseline results. The relative reduction in flows and loads demonstrated by this comparison will indicate the benefits associated with the scenario.

# 1.0 INTRODUCTION

## 1.1 Background

Florida's 1994 Everglades Forever Act (EFA), F.S. 373.4592, establishes long-term water quality goals designed to restore and protect the Everglades Protection Area (EPA). The C-139 Basin is an approximately 170,000-acre tributary to the EPA. **Figure 1.1** depicts the C-139 Basin and other tributary basins to the EPA. The EFA mandates that landowners within the C-139 Basin should not collectively exceed average annual historic total phosphorus (TP) load adjusted for rainfall. In 2002, the C-139 Basin Best Management Practices (BMPs) Regulatory Program was adopted to ensure that TP load requirements would be met. This BMP program is defined in Chapter 40E-63, F.A.C. ("Rule 40E-63").

During the 2003 legislative session, the 1994 EFA was amended to include reference to the March 17, 2003, Conceptual Plan for Achieving Long-term Water Quality Goals (Long-Term Plan), which includes the C-139 Basin. A Long-Term Plan objective for the C-139 Basin is to identify urban and agricultural discharges within the basin that are candidates for cost-effective implementation of source controls.

After four years of implementing the mandatory BMP program, the C-139 Basin has not been able to meet the historic TP load required by Rule 40E-63. In accordance with the EFA, if the basin is determined to be out of compliance in a given year, remedial action shall be based on the landowners' proportional share of the total TP load. Rule 40E-63, requires that all permittees within the basin uniformly increase the level of BMP implementation in response to an out of compliance determination. In addition, some permittees have expressed interest in TP load reduction programs that can be implemented economically or with funding assistance, such that the basin has the best overall opportunity to comply with the rule. Rule 40E-63 also provides that, should the basin exceed the compliance requirements in four consecutive years more than four times, the rule can be revised to address compliance. Both the South Florida Water Management District (District) and permittees are interested in additional TP load reduction programs within the basin that will be prioritized and addressed in future BMP program optimization plans, as necessary to meet rule requirements.

To date, permittees in the C-139 Basin have elected not to participate in an optional farm-level monitoring program. The rationale for this non-participation may be because the type of monitoring required may not be feasible considering the hydrology of the farm basins and economic considerations. As such, recorded TP concentrations and flow data within the basin are limited.

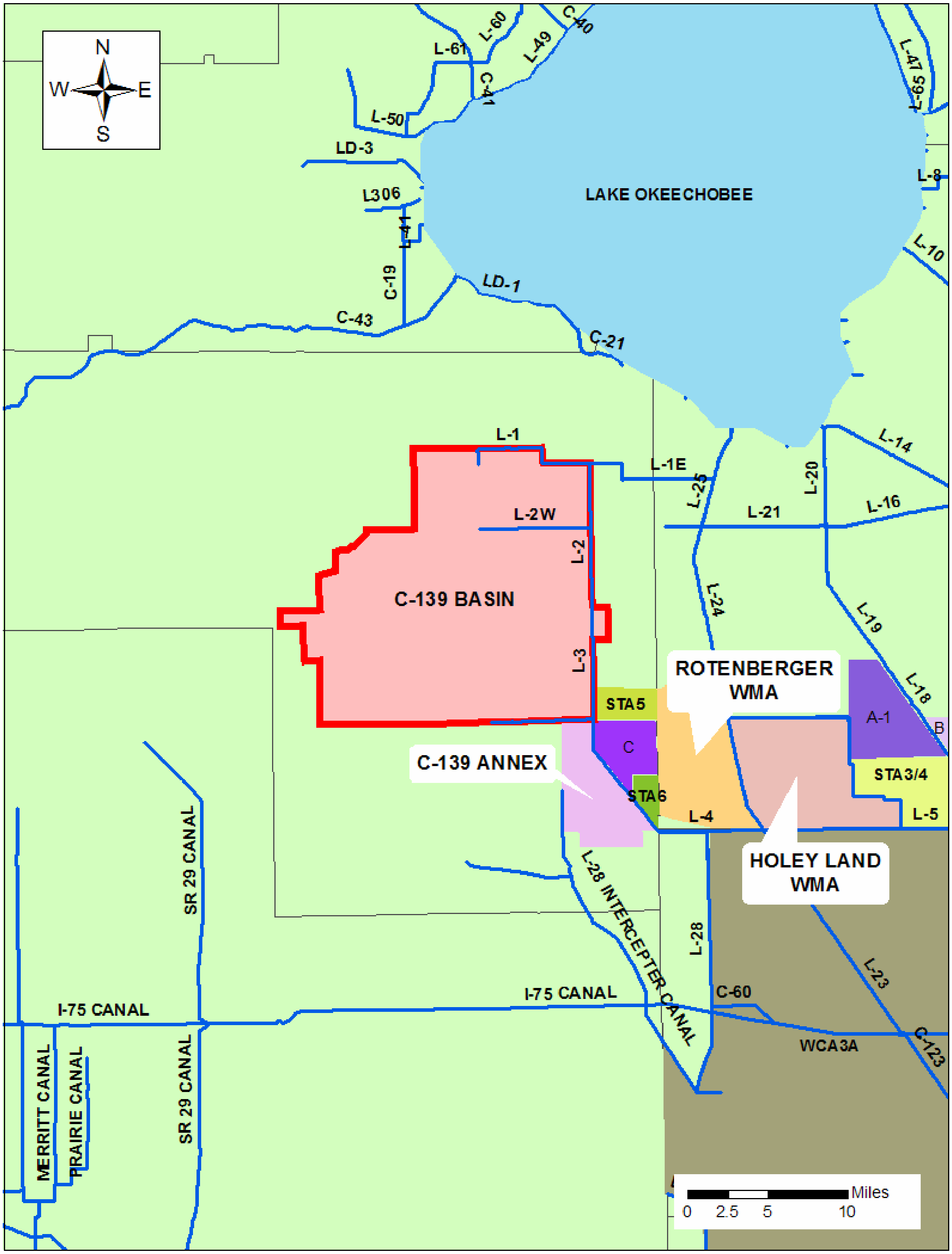


**Figure 1.1: C-139 Basin Location Map**

## 1.2 Phase I Summary

The District contracted A.D.A. Engineering, Inc. (ADA) under the General Engineering Services Contract (CN04912), between the District and ADA, to complete the work items associated with the C-139 Basin Phosphorus Water Quality and Hydrology Analysis. The objective of the analysis is to assess the current hydrologic and water quality conditions of the basin, identify locations where additional water quality and flow data is required, and identify and evaluate opportunities for water quality improvement. The project is to be completed in two phases. The Phase I report submitted in February 2006 covered the following tasks and objectives:

| Task | Objective |
|---|---|
| 1. Records Review and Action Plan | Review and evaluate relevant and available documentation, and prepare data collection action plan. |
| 2. Field Review and Data Collection | Characterize flow along main C-139 canals, including direction of flow, flow rates and contributing tributaries, and District structures operation and its influence on basin hydrology. |
| 3. Sub-basin Segmentation and Screening Level TP Assessment | Segment the C-139 Basin into drainage sub-basins based on existing hydrologic conditions and the reasons for the sub-basin delineation. Provide screening level assessment of the spatial distribution of potential TP loads within the C-139 Basin. |
| 4. Location of Monitoring Stations | Identify feasible locations for the installation of permanent flow and TP monitoring stations to be representative of the sub-basins identified above. |

The information collected as part of Phase I was used in the development of the water quality model described in this report.

## 1.3 Phase II Objectives

The objective of this report (Deliverable 6.2) is to develop a calibrated and verified hydrologic and water quality modeling tool to analyze flows and phosphorus loads in the C-139 Basin. The Everglades Regulatory Program staff will be able to use the resulting model as a tool for prioritizing resources and tailoring Best Management Practice (BMP) strategies towards achieving compliance with the Everglades Forever Act-mandated water quality levels. The simulation results of the calibrated WAM model, will be visually and statistically compared to all available measured data within the basin to provide an estimate of the modeling deviations from measured data. The water quality model shall be user-friendly and compatible with District applications.

## 1.4 Phase II Scope

Under the General Engineering Services Contract (CN04912) the District contracted ADA to complete the work items associated with Phase II (Work Order No. CN040912-WO07-A2). For the purposes of preparing Deliverable 6.2, ADA assembled a team comprised of professional staff knowledgeable in hydraulics and hydrology, water quality, and Everglades Restoration to accomplish the following key work items:

- Develop a WAM model to assess the overall TP loading distribution within the C-139 Basin and to determine further optimization of flow and TP load monitoring locations identified as part of Phase I;
- Refine, calibrate and verify the WAM model to establish TP baseline conditions for a 36-year period (1965-2000) within the C-139 Basin[1]. The baseline condition results will be used to evaluate benefits of proposed farm and regional alternatives.

The following sections and subsections describe the parameters used and assumptions made in the development of the model. The report will also document the results of model calibration and the baseline simulation.

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[1] The baseline referred to in this document should not be confused with the C-139 Basin phosphorus load baseline (10/1/1978 to 09/30/1988) established by the Everglades Forever Act and Chapter 40E-63, F.A.C., Appendix B-2, "C-139 Basin Compliance Methodology", dated October 2001.

# 2.0 MODEL DESCRIPTION

## 2.1 Watershed Assessment Model (WAM)

WAM version 1.3 was developed by Soil and Water Engineering Technologies (SWET) to simulate the hydrologic, hydraulic and nutrient transport processes of watersheds with significant agricultural land uses. There have been many WAM simulations developed throughout Florida including in the Suwannee River Water Management District, St. Johns River Water Management District and South Florida Water Management District. In the region of the C-139 Basin, there have been simulations developed of the C-43 Basin to the north, the Lake Okeechobee Watershed to the northeast and the EAA to the east. WAM has been selected to simulate all of these watersheds because it is primarily suited for agricultural basins and is very capable of simulating land-surface processes in locations with high water table elevations.

## 2.2 Basic Model Components

### 2.2.1. Hydrology

WAM is a cell based model. The C-139 simulation uses a resolution of one (1) hectare, that describes the smallest spatial extent where unique topographic, land-use and soil parameters can be described. Within WAM, there are essentially two types of representation of the hydrologic processes that occur for each unique 1 hectare pixel based on the GLEAMS and EAAMOD models. The GLEAMS (Groundwater Loading Effects of Agricultural Management Systems) model was originally developed in 1984 to simulate edge-of-field and bottom-of-root-zone loadings of water, sediment, pesticides, and plant nutrients from the complex climate-soil-management interactions. EAAMOD (Everglades Agricultural Area MODel) was developed in the early 1990's as a field-scale model that would simulate hydrologic processes in high water table environments. EAAMOD was developed with a focus on simulating water and phosphorus transport in flat organic soils (histosoils).

The GLEAMS submodel is a one-dimensional model, simulating each cell as a vertical soil column using precipitation and evapotranspiration as forcing functions at the surface layer. Surface runoff generation and infiltration are simulated based on the SCS curve number method and the land-use and soil characteristics specified for each location. The resulting seepage or percolation from the lowest layer is routed to the nearest stream reach as subsurface runoff. **Figure 2.1** provides a general schematic of the GLEAMS submodel schematic.

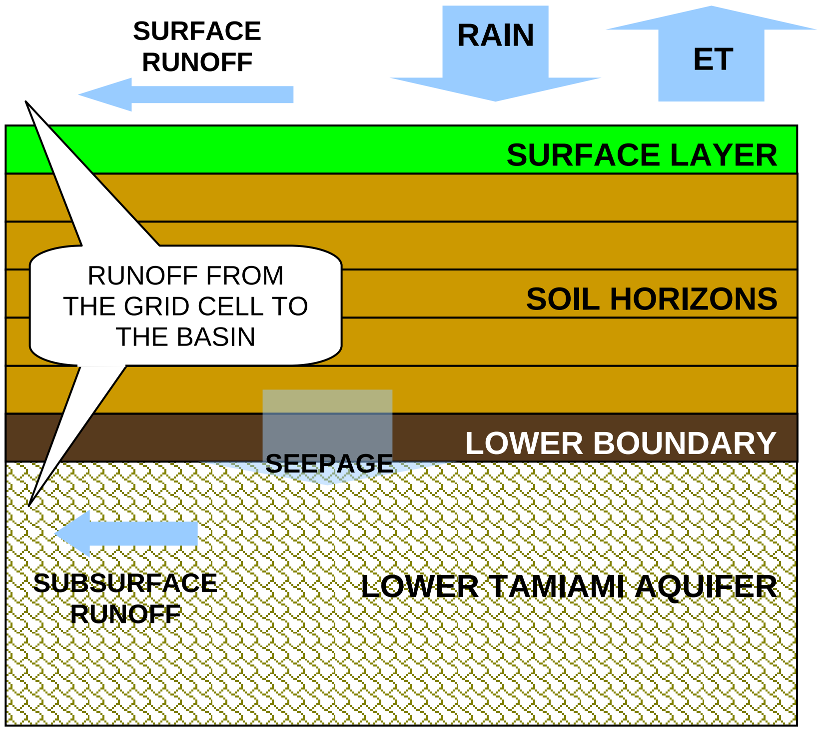



**Figure 2.1: General schematic of GLEAMS processes**

**Figure 2.2** illustrates a schematic of the hydrologic processes within EAAMOD. Based on each land-use, EAAMOD assumes a default field configuration, as specific as default surface elevation, the location of an internal drainage canal and the width of furrows between planted rows, described in the field control files. Within the land-use parameterization scheme of EAAMOD, the geometry of the discharge structure for each field is included. When rainfall exceeds the infiltration capacity of the soil or the water table increases to the surface elevation, surface runoff is generated. This surface runoff is then routed to the internal drainage canal. The surface runoff water is then stored in the canal until it reaches a stage sufficient to discharge over the control structure. This discharge is the runoff that is generated for each grid cell within the model domain. The EAAMOD discharge structure is sized and operated differently depending on the land-use and the time of year. Although the ability for seepage is built into the model, the default parameterization of EAAMOD is an impermeable confining layer with no seepage.

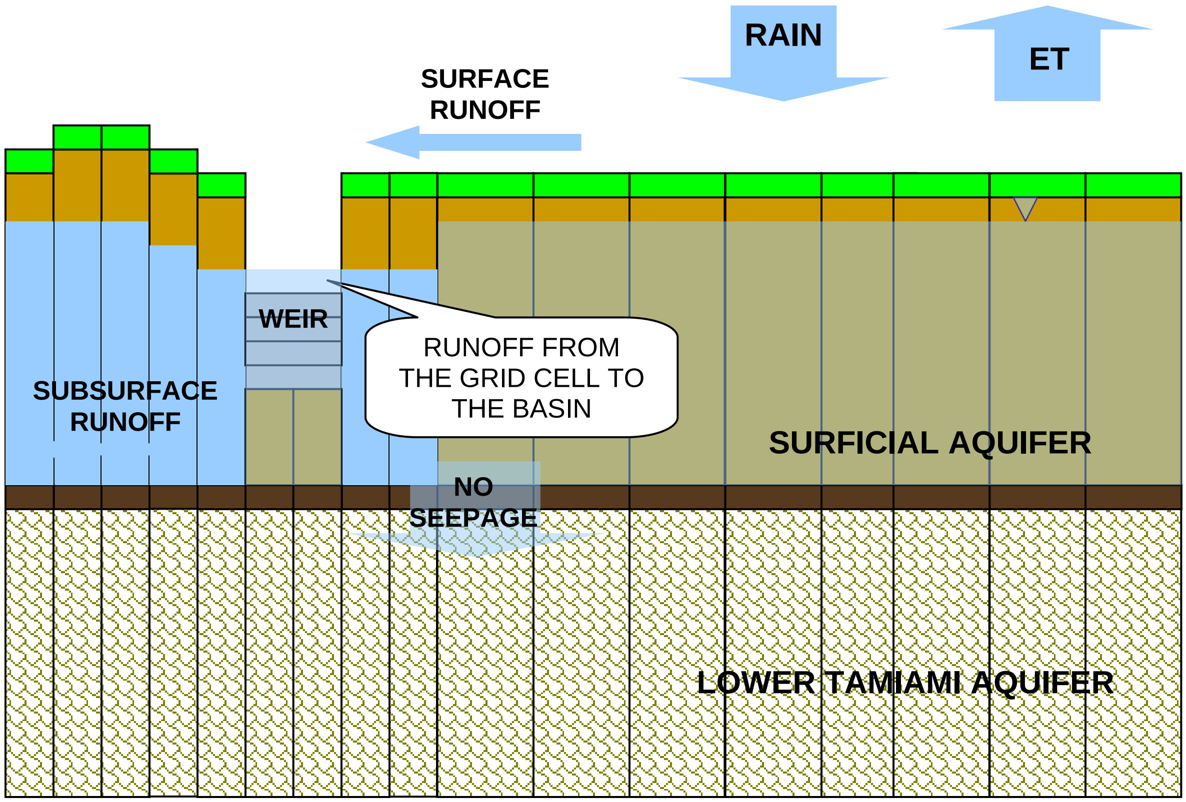



**Figure 2.2: General schematic of EAAMOD processes**

WAM utilizes a submodel called BUCSHELL to categorize each grid cell into unique classes based on the combination of rainfall input data, soil-type and land-use. The hydrologic calculations required for the run are then simulated for each unique class regardless of spatial location using the assumptions described above. The results of these calculations are a series of "dayfiles" that store the daily conditions of each unique hydrologic class. Once the dayfiles are generated, the results are mapped back to the basin based on spatial location. In addition to providing output files of the hydrologic processes of each unique class, this methodology reduces the runtime by limiting redundant calculations.

Evapotranspiration within WAM is calculated using the Priestly-Taylor methodology. The equation for potential evapotranspiration using this methodology is as follows:

$$PET = \frac{\alpha_{PT}\left[s(T_a)\right](K+L)}{\rho_w \lambda_v \left[s(T_a)+\gamma\right]}$$

Where

$\alpha_{PT}$ = *Priestly-Taylor coefficient (1.26)*

*$s(T_a)$ =* *Slope of the saturation-vapor-versus-temperature curve at the air temperature ($T_a$)*
*K =* *Net shortwave radiation*
*L =* *Net longwave radiation*
*$\rho_w$ =* *Density of water*
*$\lambda_v$ =* *Latent heat of vaporization (597.3 – 0.564($T_a$))*
*$\gamma$ =* *Psychrometric constant (dependent on heat capacity, air pressure and latent heat of vaporization*

As shown above the required inputs to determine potential evapotranspiration are air temperature, net radiation and air pressure. Within WAM the air pressure is assumed to be constant, while air temperature and net radiation are read from the input files temp.tem and *default.bnz*. In order to enable accessible calibration parameters external to the Priestly-Taylor methodology, WAM includes two coefficients in the fifth line of the *default.bnz* input file, PETFAC and PETFACEAAMOD. The Priestly-Taylor estimate of evapotranspiration is multiplied by the PETFAC coefficient to generate a potential evapotranspiration time-series that assumes no specific land-use and a homogeneous saturated surface. This time series is recreated for each run and stored in a file called et-eaa.csv.

In order to predict actual evapotranspiration, each land-use within WAM has a specific coefficient that is multiplied by the potential evapotranspiration. This coefficient is dependent on the crop type and changes seasonally to reflect the variations found in natural systems. Within the GLEAMS submodel, the values for this coefficient can be found within the *default.bnz* input file. When EAAMOD is used, the potential evapotranspiration estimate described within the *et-eaa.csv* file is first multiplied by the PETFACEAAMOD calibration coefficient, and then multiplied by the land-use specific actual evapotranspiration coefficient that is found in the *lu-eaa.bnz* file.

The default values for PETFAC and PETFACEAAMOD (0.89 and 1.06) were derived based on the calibration of WAM within various locations around the state of Florida. Within Section 4.2.2.1 these calibration parameters are adjusted and the resulting potential evapotranspiration time-series is compared with the best available estimates for C-139 regional evapotranspiration.

### 2.2.2. Hydraulics

During the development of any WAM model, the GIS interface generates various input files based on the spatial relationships between each 1 hectare grid-cell and the nearest stream reach, wetland and topographic depression. This information in combination with other hydraulic routing parameters, such as the Manning's n for overland flow, define the characteristics necessary for the BLASROUTE submodel to route the water in two-dimensions following the appropriate flow path to the stream reach. From the stream reach, the runoff is routed in one-dimension to the outlet. The hydraulic characteristics of the stream network include the cross-section, invert elevation, length, Manning's n of the channel and control structure dimensions and operation. **Figure 2.3** illustrates a schematic of the hydrologic and hydraulic processes of WAM.

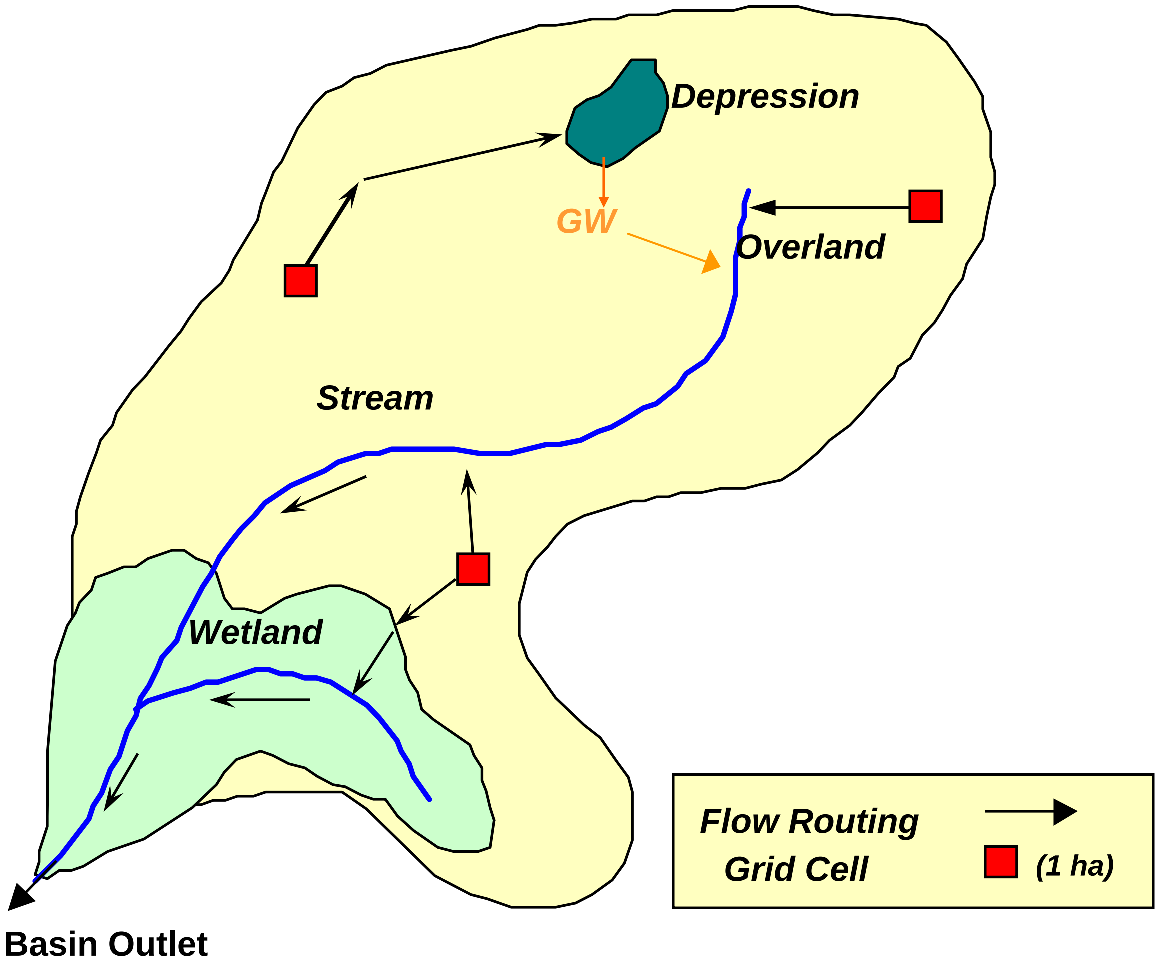



**Figure 2.3: General schematic of WAM processes**

The runoff that leaves each grid cell, as illustrated in **Figures 2.1** and **2.2**, is routed by both surface and subsurface mechanisms to the nearest stream reach that is within the same sub-basin. The runoff from each grid cell is assumed to be routed utilizing one of two hydrographs fit to the basin characteristics. Within the *hydsurf.in* and *hydssurf.in* files is the percentage of the total runoff generated that leaves the grid cell each day. The default *hydsurf.in* assumes that the percentage of the total surface runoff leaving the basin the first, second and third day are 65%, 25% and 10%, respectively. The default *hydssurf.in* file assumes that the total subsurface runoff leaving the basin fits an asymptotic curve with a duration of 90 days and a maximum daily percentage of 33% on the first day. These assumptions can be changed depending on the basin characteristics.

### 2.2.3. Water Quality

Water quality in WAM is simulated in parallel with water quantity. Pollutant loads are generated in the BUCHSHELL sub-model using land use and point source input files. The pollutant loads are transported and attenuated in the BLASROUTE sub-model using stream reach characteristics that include flow rates, flow distance, and attenuation parameters. The water quality parameters simulated in WAM include Suspended Solids, Nitrogen (Sediment and soluble), Phosphorus (sediment and soluble), and Biochemical Oxygen Demand (BOD). Based on the objective of this study and the nature of the C-139 Basin, TP is the pollutant of interest in the C-139 Basin WAM model. Sources of TP in the C-139 Basin are fertilizer applications, cow manure, precipitation, and/or basin boundaries. All precipitation input to the system has a default TP concentration of 0.07 ppm in WAM. TP is reduced by land and stream attenuation, decay, treatment, plant uptake, and flushing out of the Basin. Fertilization rates and animal density are defined in the *landuse.bnz* and *lu-eaa.bnz* input files that are attached in **Appendix A**.

# 3.0 WAM SET-UP DEVELOPMENT

## 3.1 General

This section describes the data and assumptions used to create the physical representation of the C-139 Basin within the WAM framework. This includes the topography, hydrography, soils and land-use of the C-139 Basin. The following sections present the type and quality of data used by the model for these purposes. As illustrated in these sections, the input data for WAM is in International System of Units (SI) units and in keeping with the specifications of the scope of work, all elevations are relative to the North America Vertical Datum of 1988 (NAVD88). One notable exception, the unit consistency is within the EAAMOD submodel which maintains all of the parameterization in English Units.

## 3.2 Topography

Staff from the Fort Myers Service Center of the District made available a 100-foot (ft) grid-resolution Digital Elevation Model (DEM) which provided elevations in feet relative to the North America Vertical Datum of 1988 (NAVD88), for much of Charlotte, Collier, Glades, Hendry and Lee counties. According to the accompanying metadata, this dataset was created from a composite of Light Detection And Ranging (LIDAR) data, United States Geological Survey (USGS) 5-ft contours and available spot elevations which was originally available relative to the National Geodetic Vertical Datum of 1929 (NGVD29). This topographic dataset was converted from NAVD88 feet to NAVD88 meters using a conversion factor of 0.3048 meters per foot for use in WAM. The 100-ft grid resolution was then aggregated into a grid with 1-hectare cells in order to match with WAM set-up recommendations. The resulting dataset is illustrated in **Figure 3.1** below.

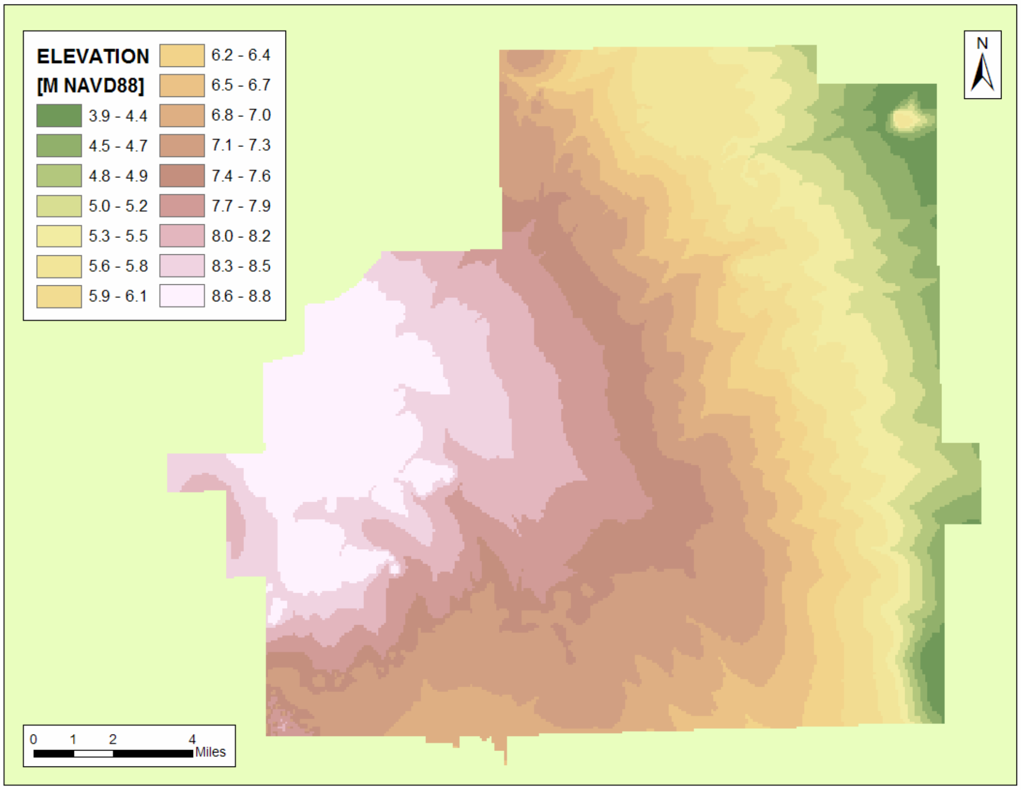



**Figure 3.1: DEM used in the WAM Simulation (topogrid)**

## 3.3 Soils Data

ADA utilized the Soil Survey Geographic (SSURGO) dataset made available by the District through the www.sfwmd.gov website. The metadata associated with the SSURGO data describes the source date for Hendry County data as 1990. This spatial data was derived from Soil Surveys that were developed by the Natural Resources Conservation Service (NRCS). The original SSURGO dataset was in the format of a polygon shapefile. In order to prepare the data for use in the WAM simulation, the polygons were converted to a grid file with the same 1-hectare cell size as the topography input. WAM contains default parameterization schemes for 428 different soiltypes based on the soil COMP name, and of the 428 types of soil identified by WAM, there are 32 that make up the soils of the C-139 Basin. However, as described in Section 2.2, WAM utilizes two submodels to simulate the land surface GLEAMS and EAAMOD. One of the land surface characteristics that determine which submodel is used in the simulation is the soil type. **Figures 3.2** and **3.3** illustrate the spatial distribution of the seventeen EAAMOD soils and fifteen GLEAMS soils. As is illustrated in these figures, EAAMOD is the submodel that is used for the majority of the agricultural land-uses.

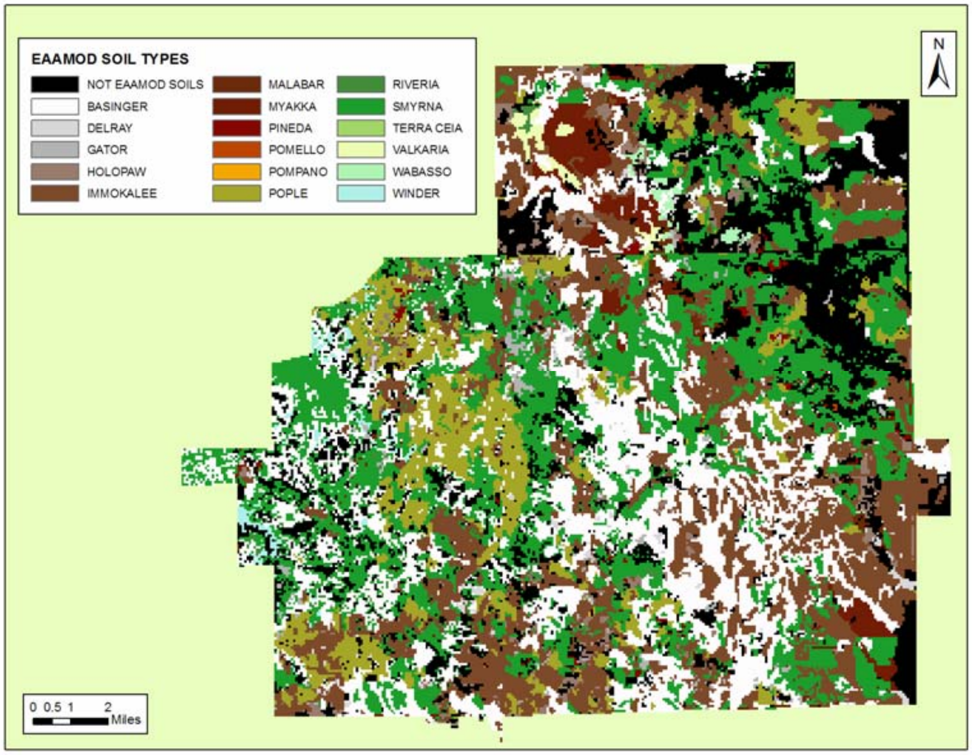



**Figure 3.2: Soil types used by EAAMOD**

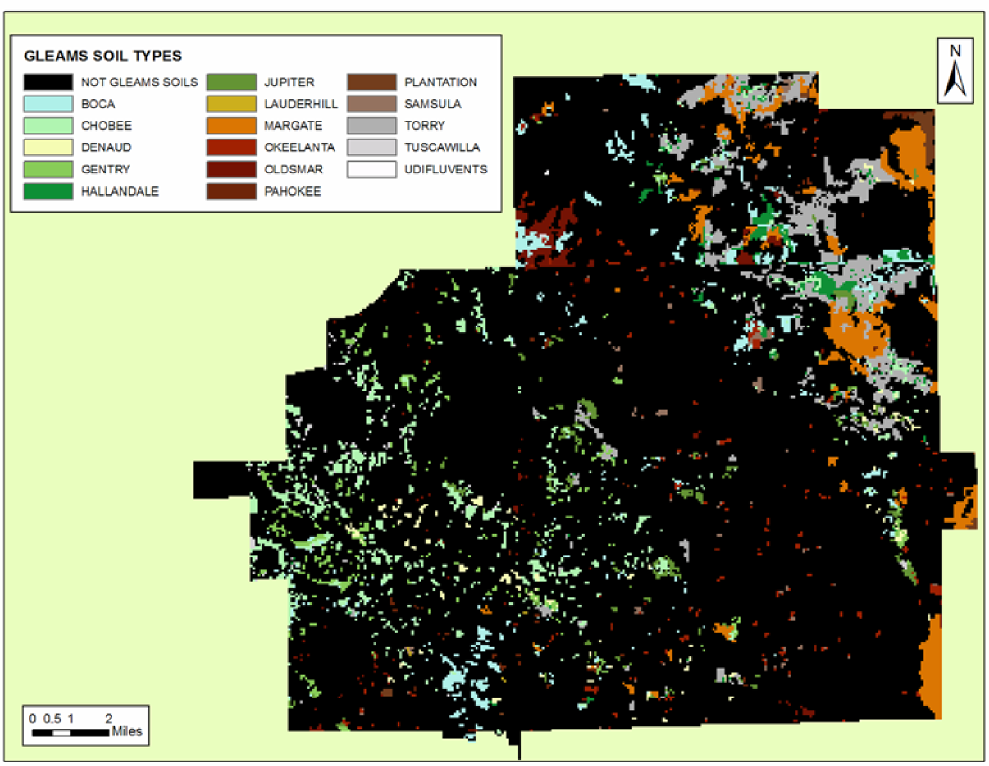



**Figure 3.3: Soil types used by GLEAMS**

## 3.4 Land-use

Similarly to the SSURGO data, the land-use data was made available in the format of a polygon shapefile from the District. This shapefile is based on photo-interpretation from 1:40,000 scale USGS National Aerial Photography Program NAPP color infrared aerial photography. The categorization of land-uses is based on the District modified Florida Land Use and Cover Classification System (FLUCCS) scheme and represents the conditions in 1999. The polygon shapefile was converted into a 1-hectare grid in order to be incorporated into the WAM cell-based framework. Based on the FLUCCS classification system, the 1999 land-use data showed a total of 50 different land-uses within the 170,000 acre C-139 Basin. However, similar to the soils parameterization scheme, the 50 land-uses are grouped in cases where the similarities are significant and assigned a land-use code specific to the WAM nomenclature. The 1999 land-use data as described by the WAM specific land-use classification shows 23 individual land-uses within the C-139 Basin. **Figure 3.4** illustrates these 23 land-uses as classified within the WAM parameterization scheme.

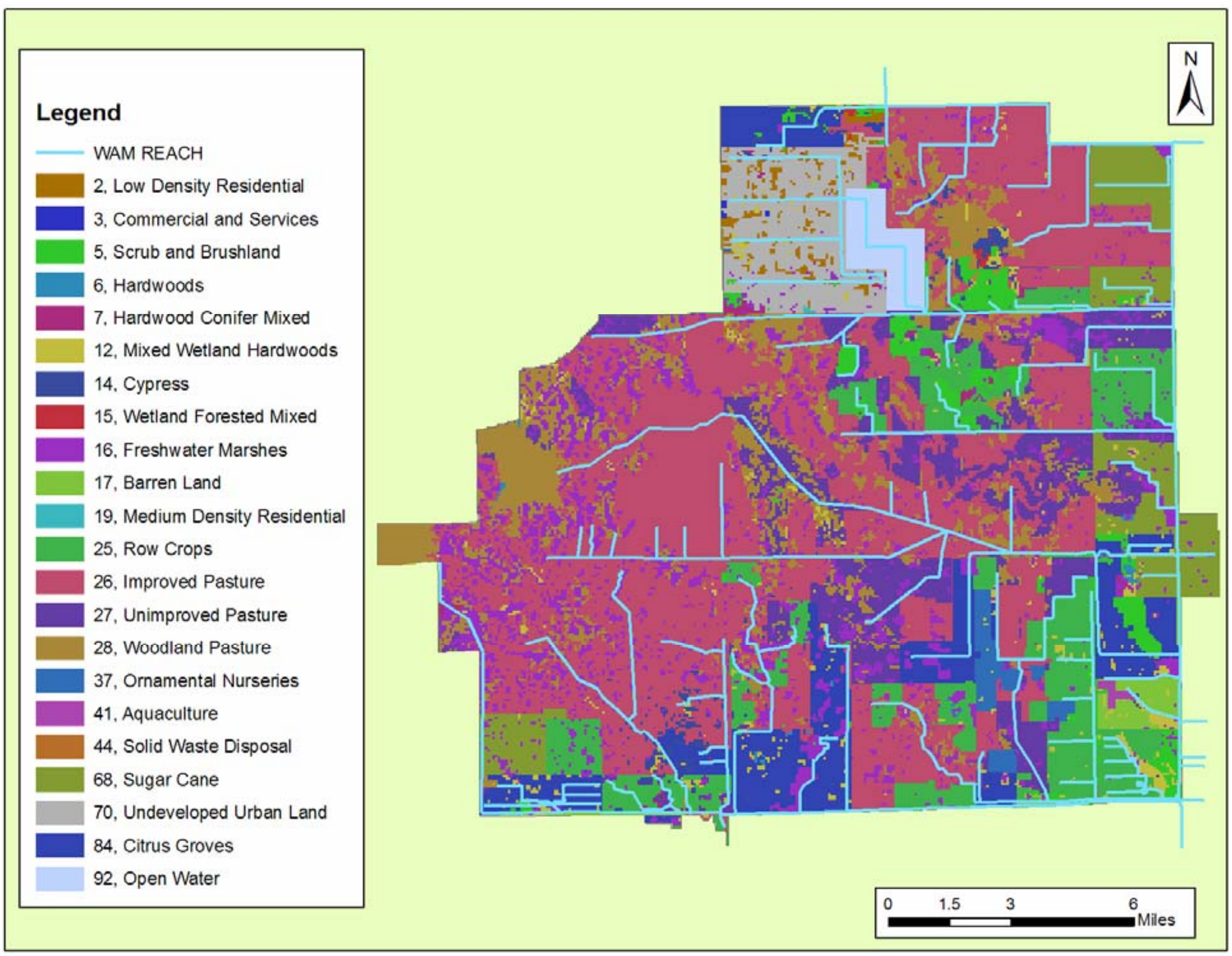



**Figure 3.4: Land-uses utilized by WAM in the C-139 Basin**

Similar to soils input data, land-use is a land surface characteristic that WAM utilizes to determine which submodel is used in the hydrologic simulation. Managed agricultural lands such as pastures, row crops or citrus groves are simulated within EAAMOD, whereas un-managed or residential lands are simulated within GLEAMS. Cells that are simulated within EAAMOD meet both the soil-type and land-use conditions, cells with what WAM classifies as a non-EAA soil type or land-use type is generally simulated within GLEAMS (with the exception of open-water). **Figure 3.5** illustrates the breakdown within WAM between the EAAMOD and GLEAMS submodels for the C-139 Basin.

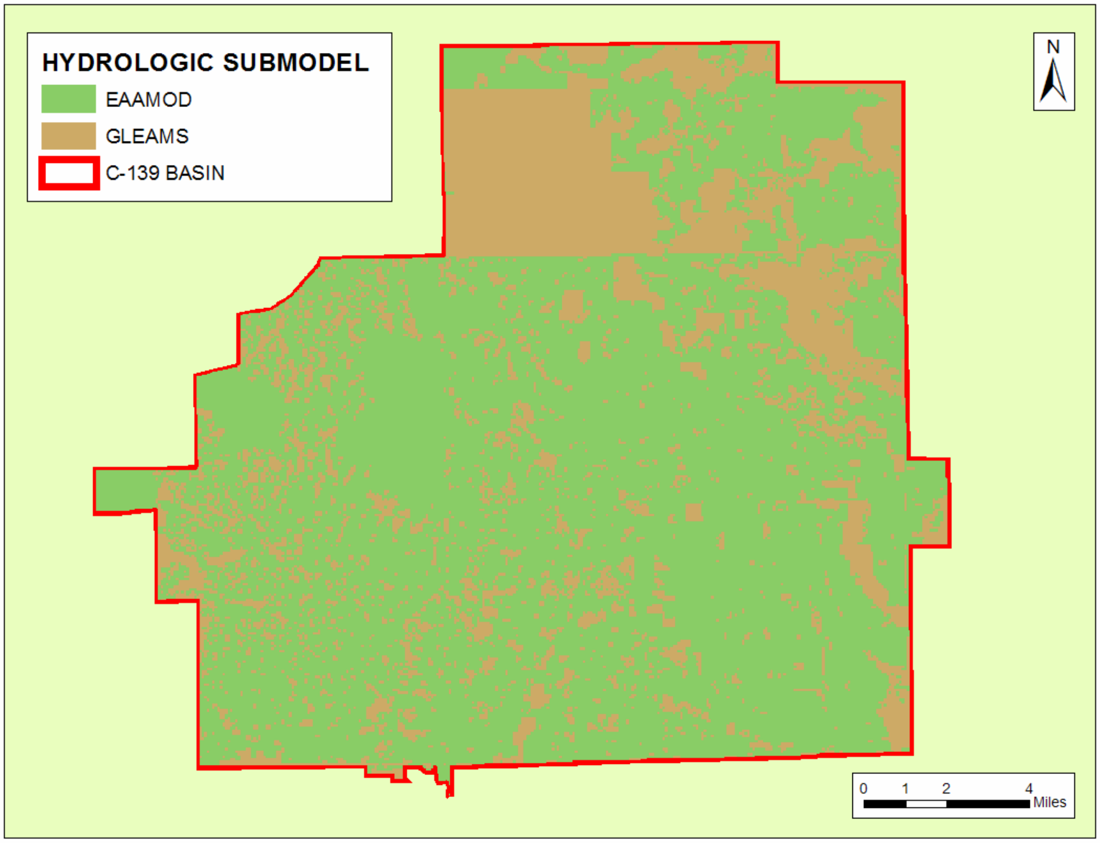



**Figure 3.5: Delineation of EAAMOD and GLEAMS submodel usage**

## 3.5 Hydrography

Phase I of the C-139 Basin Phosphorus Water Quality and Hydrology Project included the collection of extensive information defining the hydrography of the basin. The Phase I report documented canal cross-section surveys, location of reservoirs, identification of structures and the delineation of the C-139 Basin into 8 subwatersheds and 44 catchments. The 44 catchments delineated in Phase I were used in the development of the model to appropriately represent flow distance and flow path characteristics in the WAM hydraulic submodel.

The reach network developed for the WAM simulation is based on the stream networks described in the Phase I report. However, during the WAM set-up the stream network had to be refined. Since WAM is a cell-based model, it is important that the reaches are spatially within the cells that are within the catchment that contributes to that reach. If a model reach is spatially defined within a catchment that should not contribute to that reach, WAM will misinterpret the contributing area for that reach. Since catchment boundaries are defined along the edges of the grid cells in WAM, in some cases the reaches need to be re-positioned to a location that may not be spatially correct but creates the appropriate representation of the system. **Figure 3.6** illustrates the WAM reach network, while **Figure 3.7** demonstrates an example of a location along the L-2W Canal, where the WAM reach was located within the grid cells of catchment L2-01-10 to ensure that no runoff from catchment L2-02-02 would contribute to the L-2W Canal west of G-152 control structure.

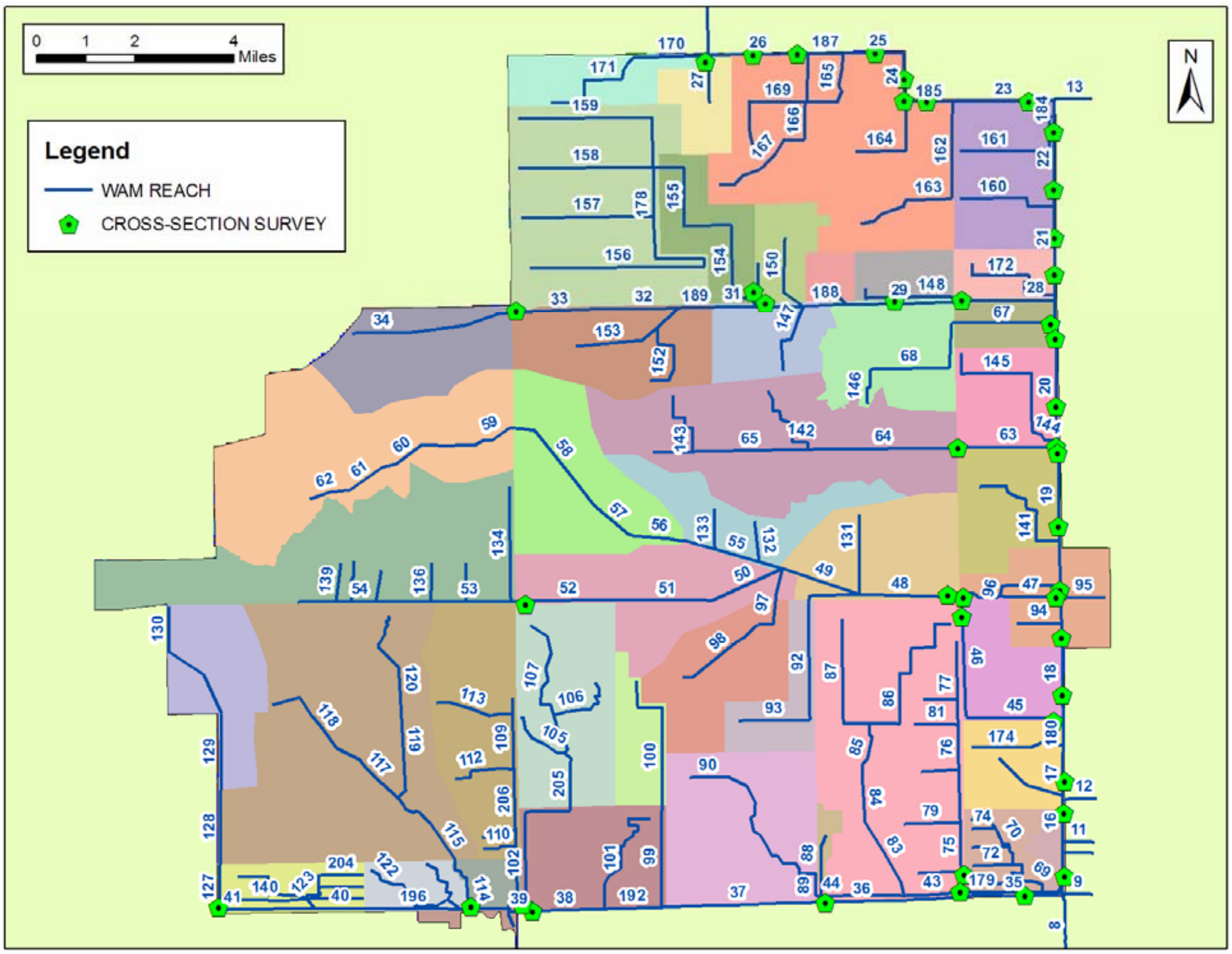



**Figure 3.6: Reach Network and Cross-Section Locations for the WAM Simulation**

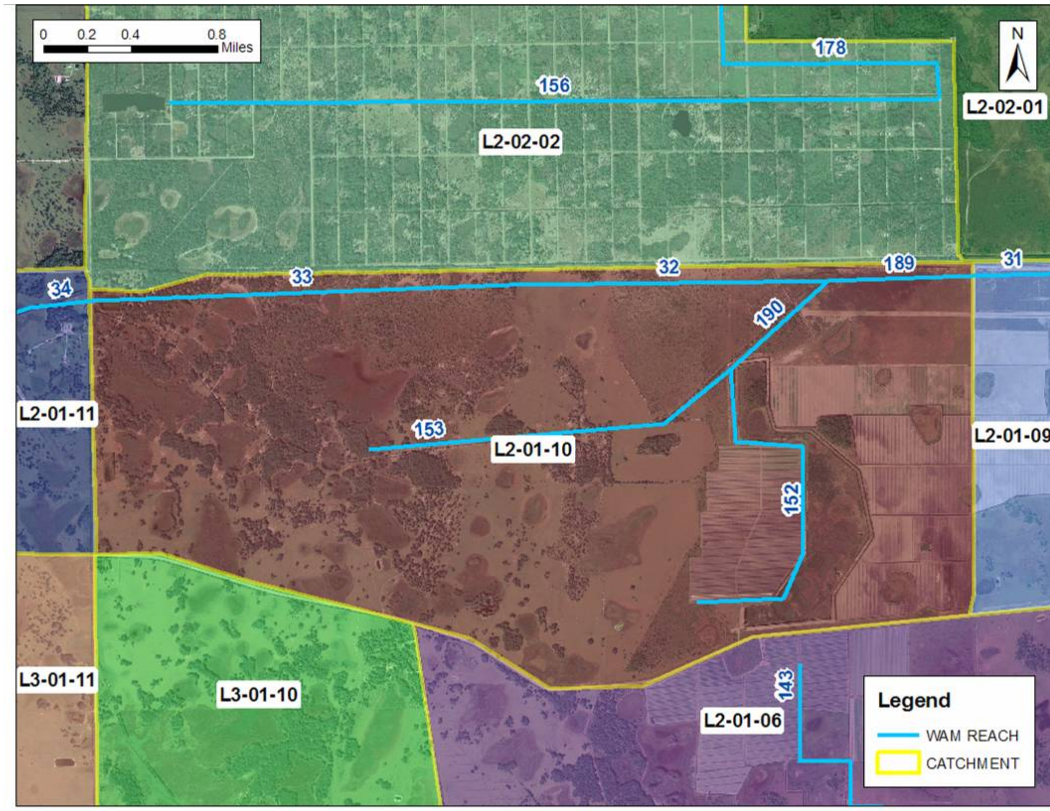



**Figure 3.7: Example of WAM Reach Re-positioning**

Additionally, **Figure 3.6** illustrates the survey cross-sections collected as part of the Phase I report as well as surveyed canal cross-sections collected as part of a Compartment C Hydraulic Assessment Report prepared under Work Order CN040936-WO26, an Acceler8 project. The basin topographic and canal survey data were compiled to create the *streams.in* and *streamprofile.in* files that WAM utilizes to characterize basin hydrography. The contents of the *streams.in* and *streamprofile.in* files can be found in **Appendix A**.

Major water control structures within the C-139 Basin were simulated based on the best available operations data. For the purposes of the calibration simulation, there are two types of water control structures: structures with documented operations and structures with un-documented operations. For the majority of the District owned water control structures, the operation of the flashboard risers or underflow gate is recorded and made publicly available through records requests and DBHYDRO. Within the simulation, the operations for documented structures are input into the model in the form of a time series of flashboard elevations or underflow gate openings, with the notable exception of the G-406 structure. For all privately owned and operated water control structures the operations are unavailable for public request. Additionally privately owned and operated structures generally do not have a specific operation schedule, but are operated based on local conditions and landowner preference. Within the C-139 Basin there is an exception for documentation of District controlled structures. In the case of G-151 and G-152, there is an agreement between the District and the neighboring landowner that allows the structure to be privately operated; therefore a record of flashboard operation is unavailable. For the

G-406 structure there is available archived operation records, however there are periods during the simulation where if the gates are operated as documented the simulated results are significantly incorrect, as will be described in Section 4.0 of this report. As such, the structure operations for G-406 follow the operational strategy documented in District manuals, as described in **Table 3.1** below. Characteristics that do not apply to the structure are not included in the table, which is indicated by N/A or Not Applicable.

A significant parameter for each structure is the weir or gate coefficient used to calculate flow using the upstream and downstream head conditions. For overflow structures or weirs the default gate coefficient is 1.78, and for underflow gates the default coefficient is 0.5. Within the simulation the default weir coefficient is used for all overflow gates and weirs, however for underflow gates the coefficients are calculated for each structure from measured stage and flow data, with the resulting coefficients ranging from 0.5 to 4.6.

**Figure 3.8** illustrates the location of all of the major structures simulated within WAM. The structure parameterization and documented gate opening data used as part of the development of the calibrated validated model can be found in the *structures.in* file included as a part of **Appendix A**. In cases where the operations are un-documented, the operation of the structure within the simulation is assumed based on measured upstream and downstream stages, documented operations plans, surface water management permits or engineering judgment, as described in **Table 3.1**. Within the *structures.in* file these parameters are entered within the same NAVD88 vertical datum, but are described in metric units. For G-151 and G-152 the flashboard elevations are assumed based on stage data made available on DBHYDRO. The Central County Drainage District (CCDD) Reservoir operations are based on the CCDD surface water management permit.

**Table 3.1: Geometry and assumed operations of un-documented structures**

| NAME | TYPE | Width (ft) | Invert Elevation (ft NAVD88) | Open/On (ft NAVD88) | Close/Off (ft NAVD88) | Pump Capacity (cfs) |
|---|---|---|---|---|---|---|
| SMWeir | Weir | 75.0 | 12.1 | N/A | N/A | N/A |
| Flaghole Road Culvert | Culvert | 9.8 | 21.3 | N/A | N/A | N/A |
| Deer Fence Structure | Weir | 23.4 | 21.3 | N/A | N/A | N/A |
| Deer Fence Structure | Underflow Gate | 23.4 | 14.8 | Above 23.6 | Below 21.3 | N/A |
| CCDD Inflow Pump | Underflow Gate | 20.0 | N/A | Above 19.0 | Below 18.7 | 670.0 |
| CCDD Outflow Structure | Underflow Gate | 12.1 | 5.2 | Above 24.6 | Below 20.7 | N/A |
| G151 | Flashboard Riser | 24.0 | ASSUMED* | ASSUMED* | ASSUMED* | N/A |
| G152 | Flashboard Riser | 24.0 | ASSUMED* | ASSUMED* | ASSUMED* | N/A |
| G406 | Underflow Gate | 20.0 | 4.7 | Above 14.7 | Below 14.3 | N/A |

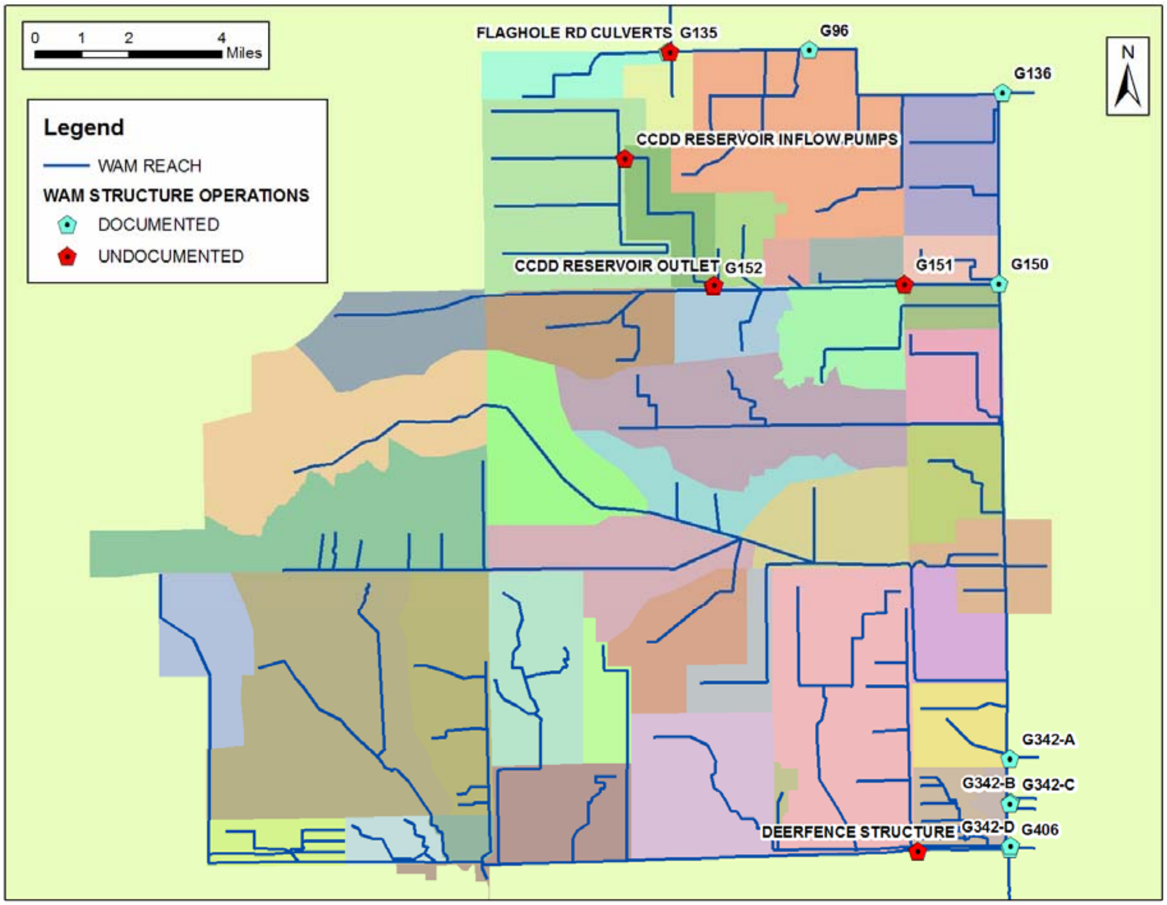



**Figure 3.8: Water control structures incorporated into the C-139 Basin**

The WAM parameterization of the stream reaches and structures is detailed in the *streams.in*, *streamprofile.in* and *structures.in* files, samples of which are included in Appendix A. With respect to the L-1, L-2, L-2W, L-3 and Deer Fence canals, canal profiles are included below to illustrate the canal bottom and bank profile (in meters NAVD88) as well as structures found in the simulation. **Figures 3.9** through **3.16** illustrate the location and profile of each of the primary canals as they are represented within WAM.

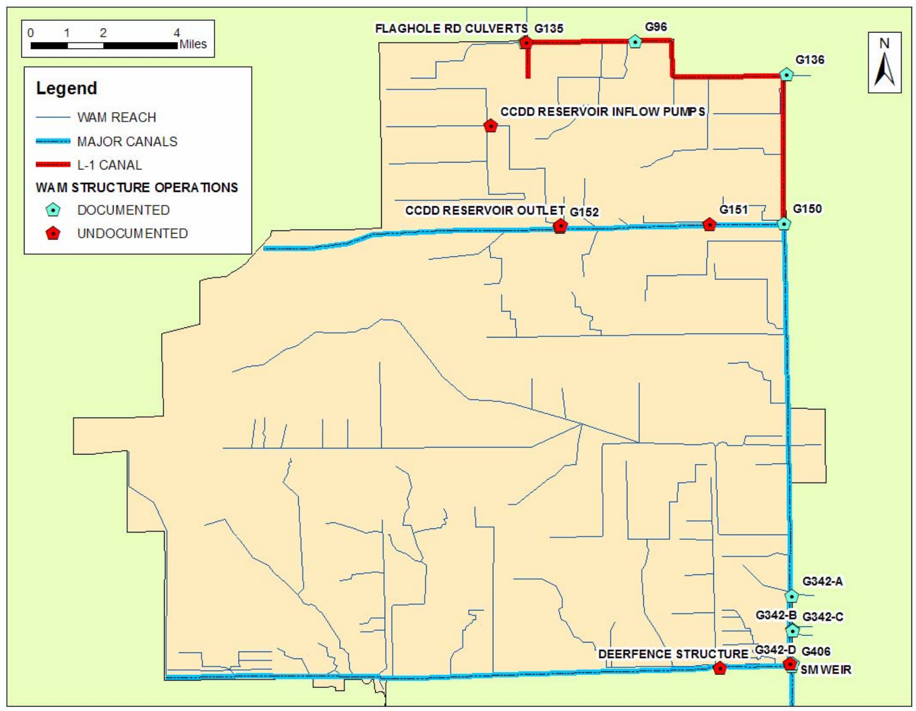



**Figure 3.9: L-1 Canal Location**

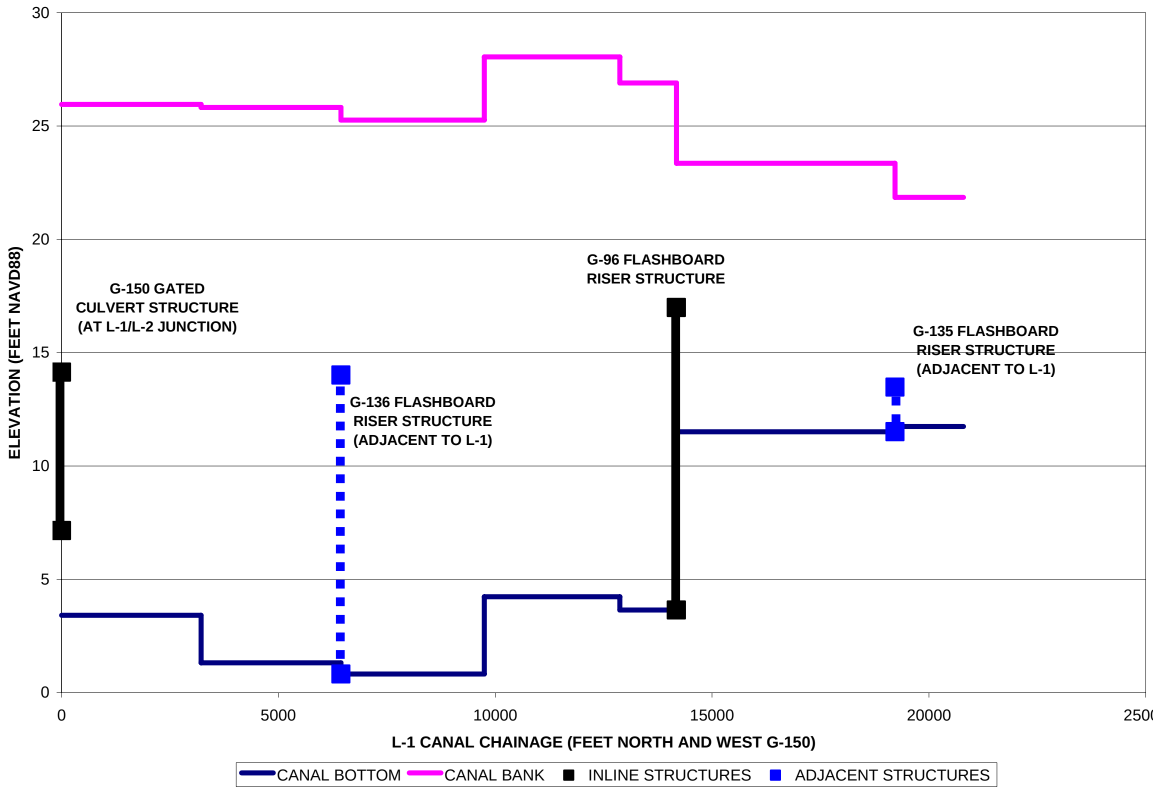



**Figure 3.10: L-1 Canal Bottom and Bank Profile**

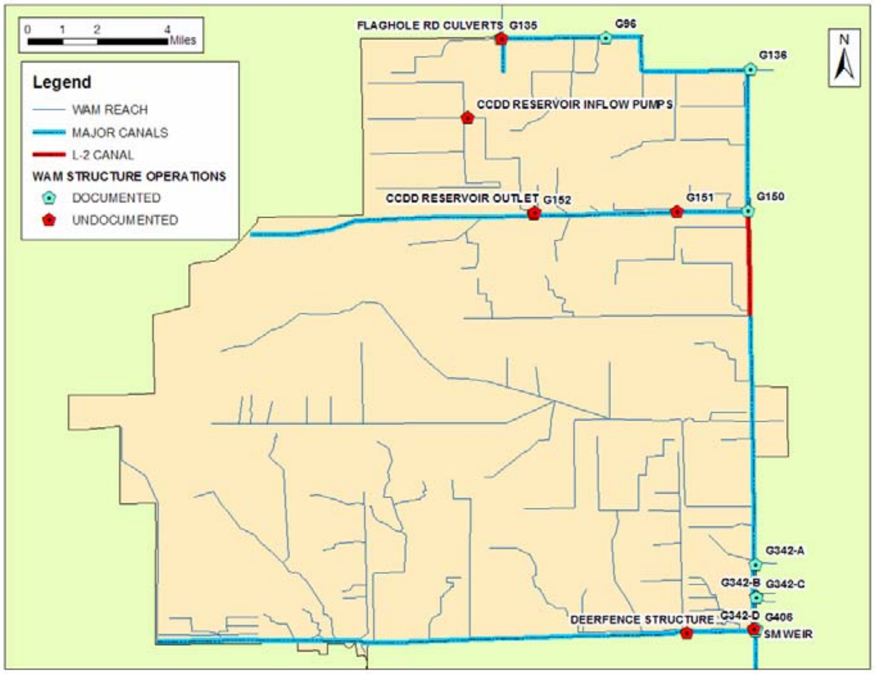



**Figure 3.11: L-2 Canal Location**

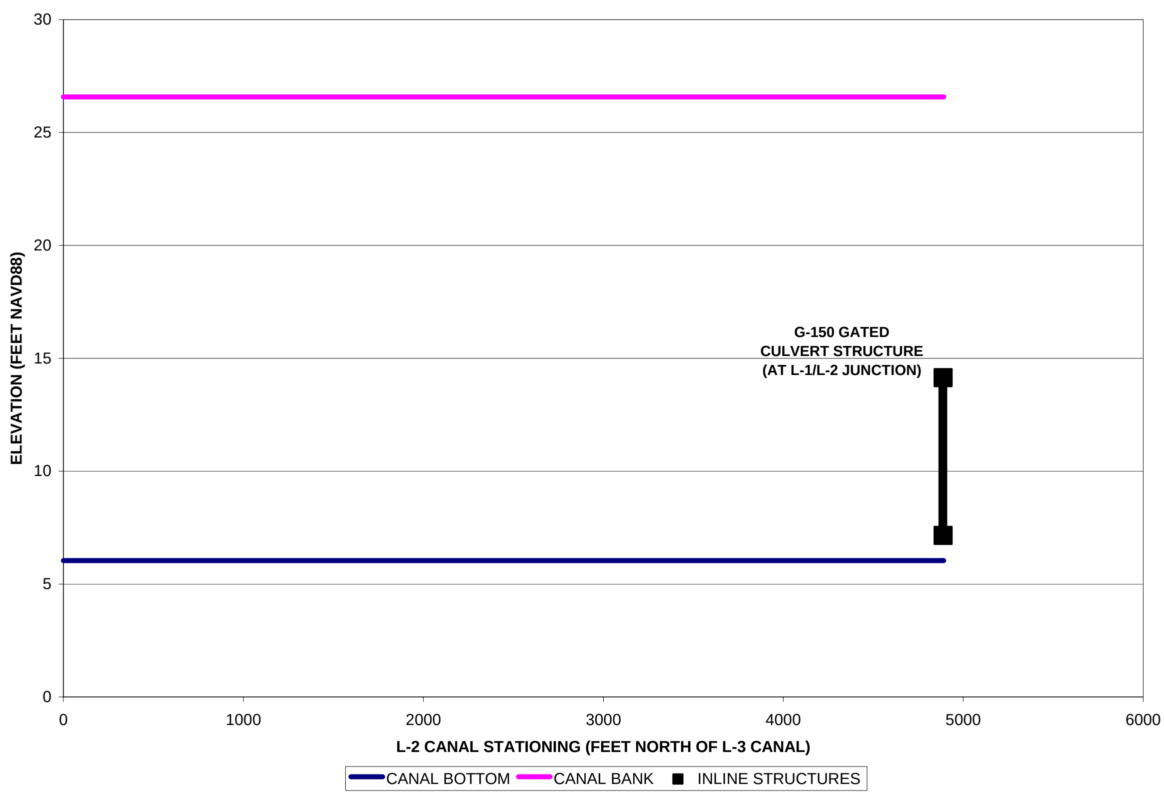



**Figure 3.12: L-2 Canal Bottom and Bank Profile**

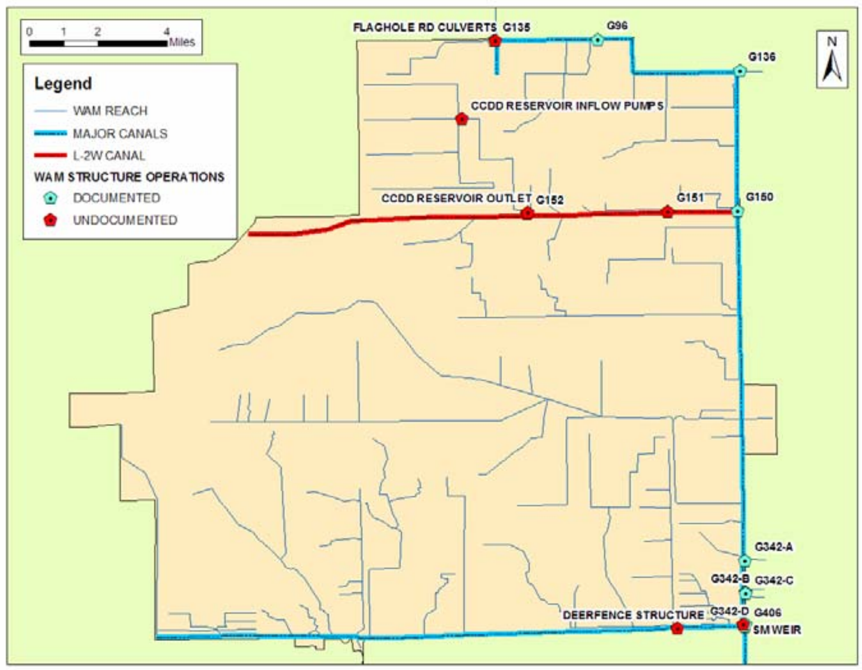



**Figure 3.13: L-2W Canal Location**

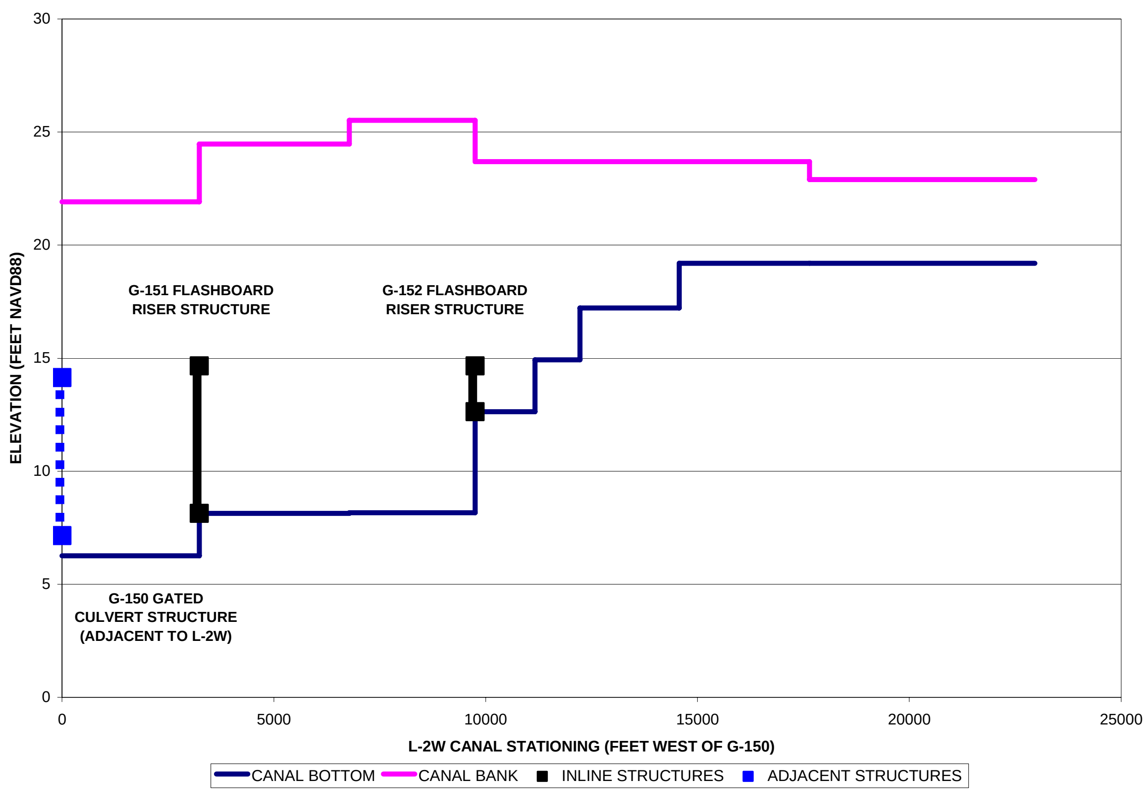



**Figure 3.14: L-2W Canal Bottom and Bank Profile**

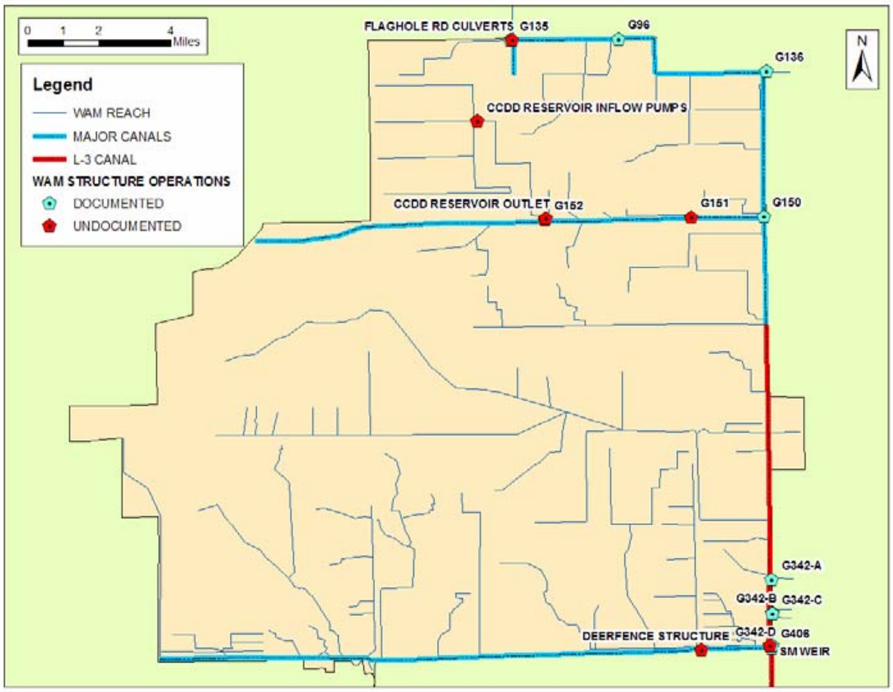



**Figure 3.15: L-3 Canal Location**

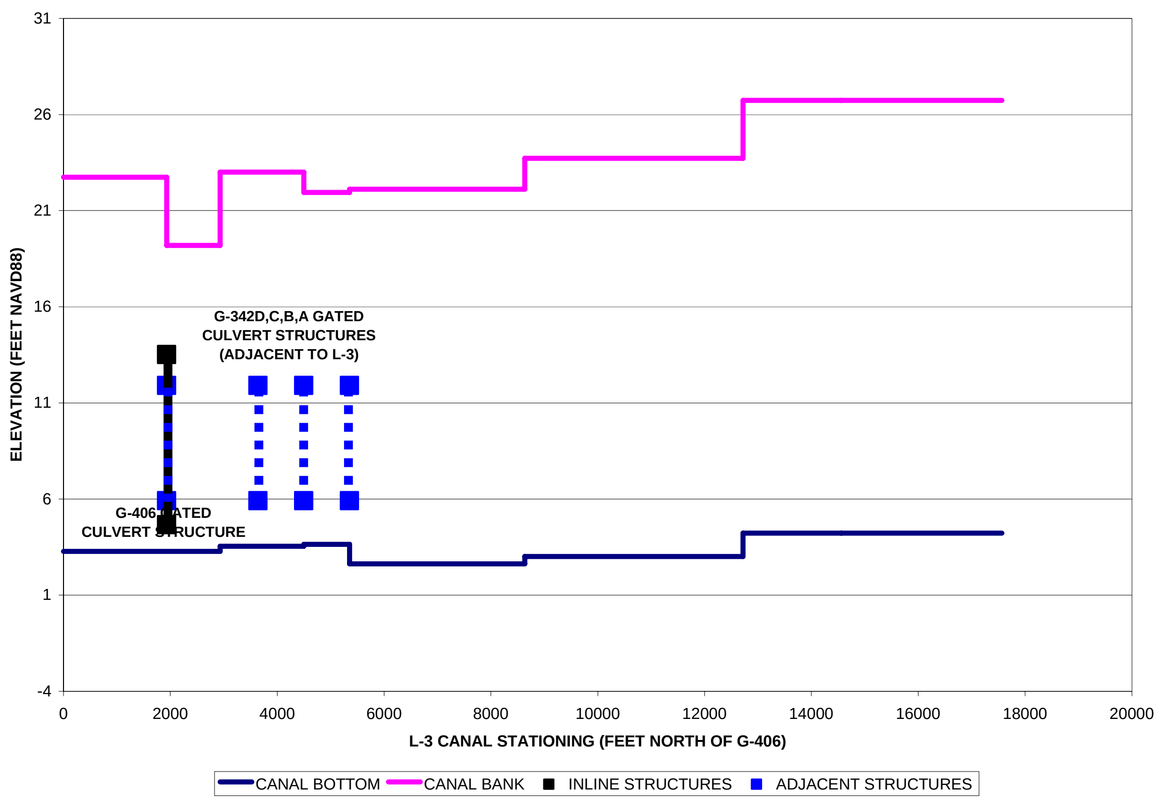



**Figure 3.16: L-3 Canal Bottom and Bank Profile**

Since the EAAMOD hydrology set-up includes farm-level surface water management infrastructure the inclusion of farm-level controls in the WAM hydrography was unnecessary. During the set-up, a simulation was executed that included all of the applicable farm-level water control structures identified within the Phase I report, however this simulation reported water quantity and quality results were negligibly different from the simulation where these structures were excluded. As such, it can be assumed that for the purposes of a watershed-scale calibration the farm-scale control structures are being sufficiently represented within the hydrology submodels of WAM.

Any future farm-scale scenario simulations can be done using one of two methods. The simplest method would be to modify the water management parameters defined in the hydrology sub-models (such as edge-of-field board controls or retention facility sizes). The more complex method would include creating new WAM reaches and control structures to represent the specific geometry of the farm-scale water management system. The model tools being developed as part of Task 12 of this project will assist in these efforts.

## 3.6 Hydrogeology

### 3.6.1. Conditions of the Natural System

The hydrogeology of the C-139 Basin can be characterized as having three main components: a surficial aquifer, a leaky confining unit and the lower Tamiami aquifer. These components are illustrated in the generalized cross-section shown in **Figure 3.17** (Smith and Adams, 1988).

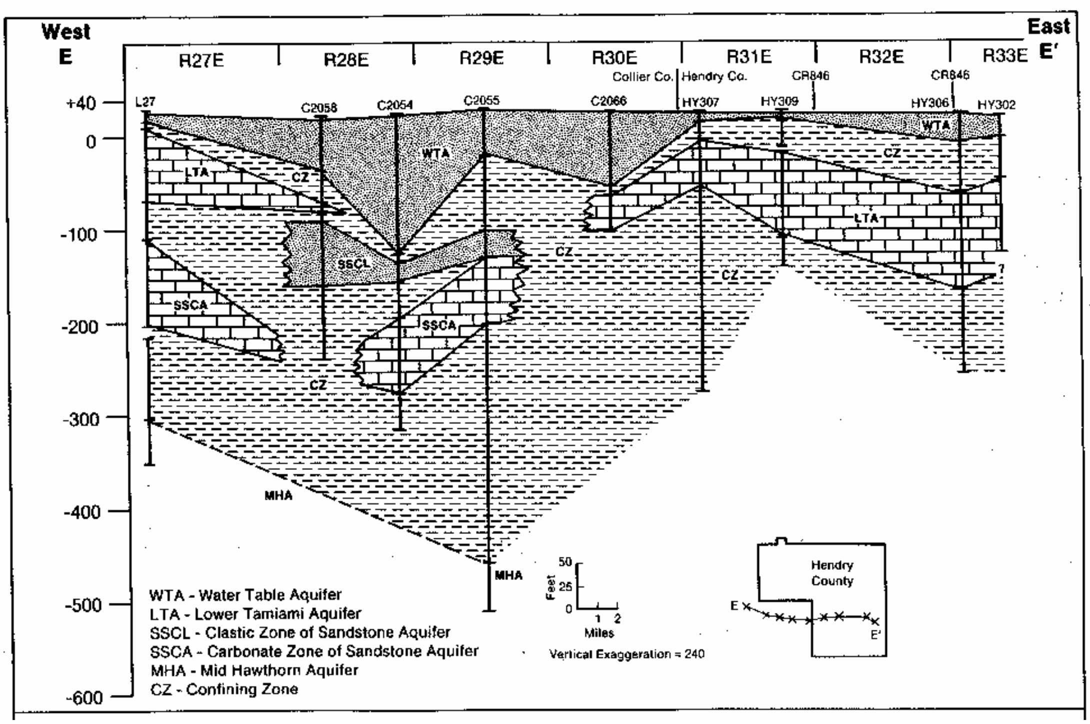



**Figure 3.17: Hydrostratigraphic subsurface cross-section within Hendry County**

Within the C-139 Basin the majority of irrigation is performed using pumped well withdrawals from the lower Tamiami aquifer. **Figures 3.18 – 3.21** illustrate exaggerated diagrams of the coupled surface water groundwater system that is representative of the C-139 Basin hydrogeology during normal wet and dry seasons, these illustrations represent the subsurface conditions in the natural system and do not represent the processes within the WAM simulation.

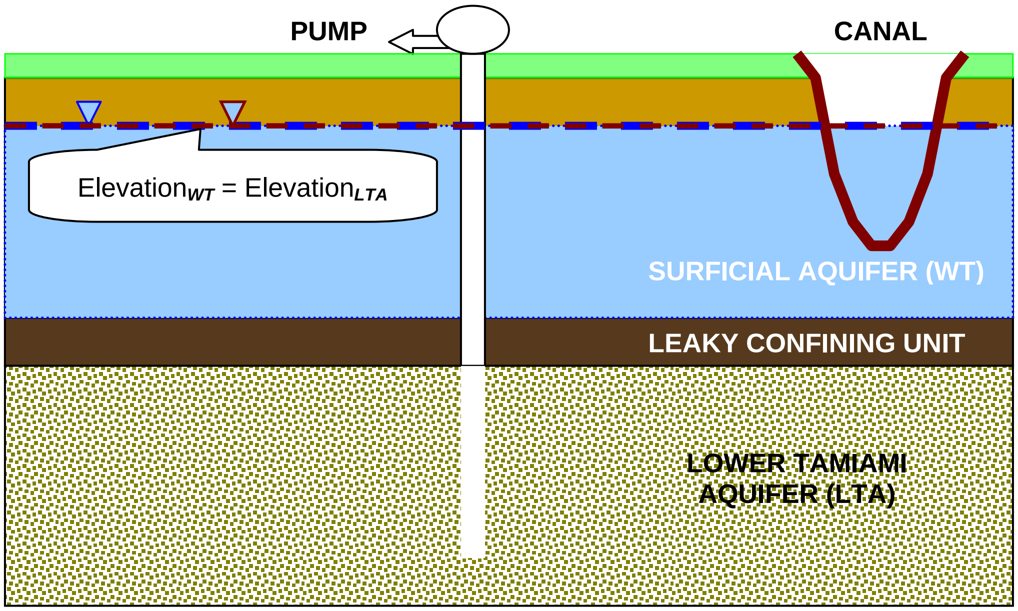



**Figure 3.18: Diagram of subsurface conditions during the wet-season**

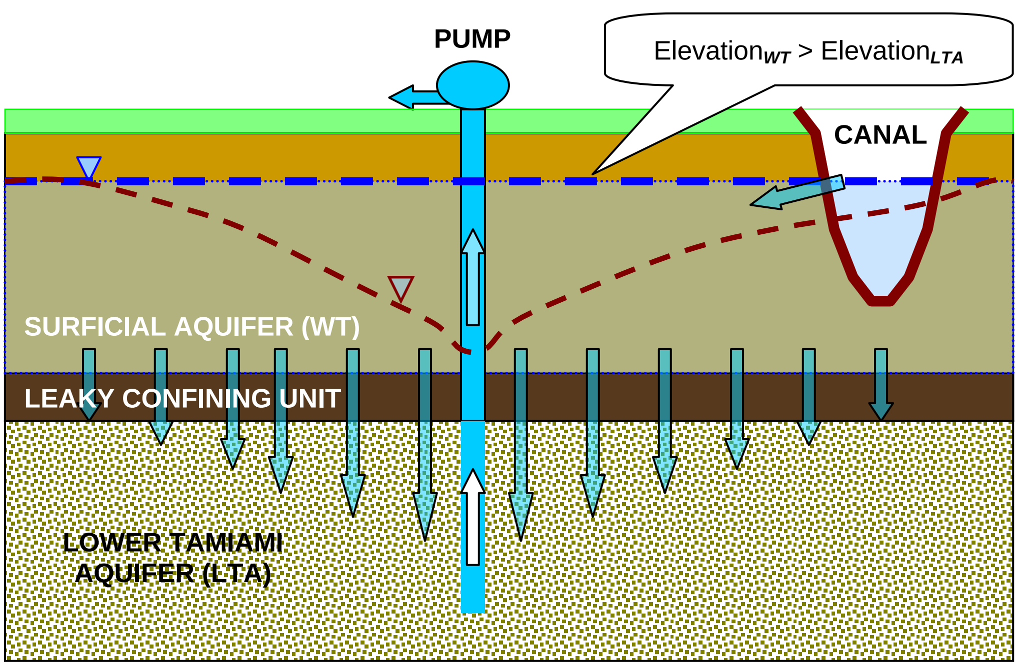



**Figure 3.19: Transitional subsurface conditions during the dry season**

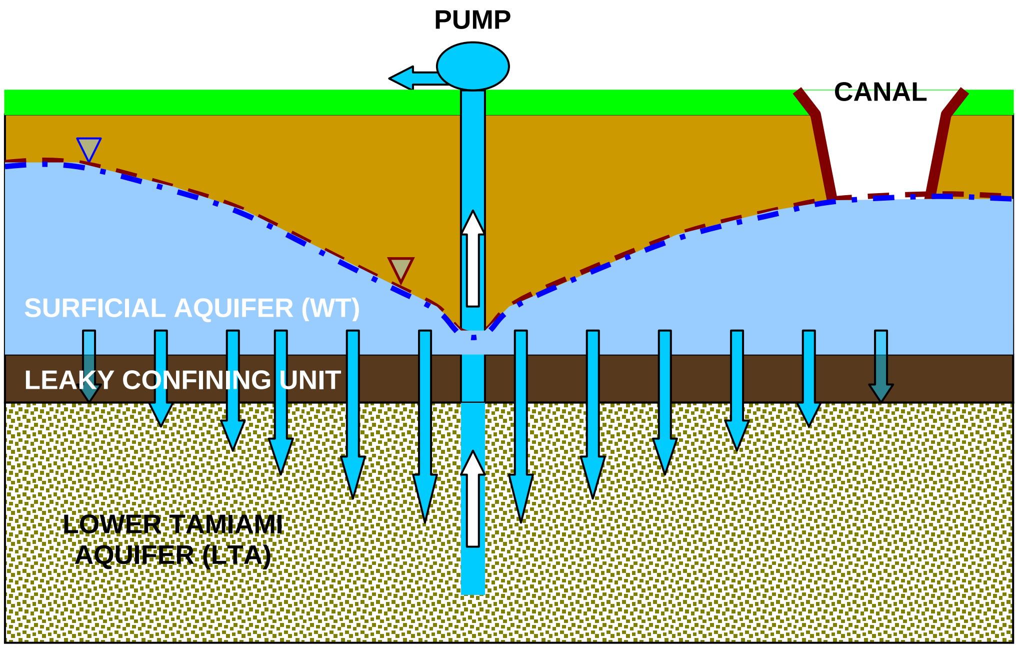



**Figure 3.20: Potential impacts of steady-state pumping during the dry season**

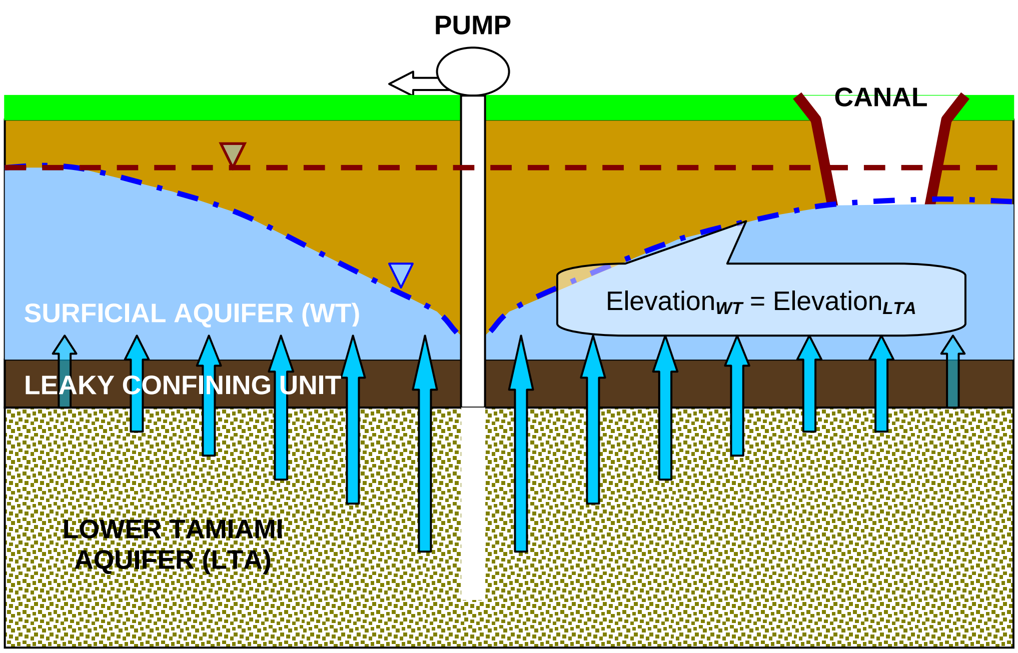



**Figure 3.21: Transitional subsurface conditions after dry season pumping**

**Figure 3.18** illustrates that during the wet season the elevation of the top of the surficial aquifer (water table) is relatively equal to the piezometric head of the Lower Tamiami aquifer. In the wet season there is little movement of water between the surficial and Lower Tamiami aquifers since the driving force for the transport of water across the leaky confining unit is based on the difference in head. **Figure 3.19** illustrates a scenario during the dry-season where water-supply withdrawals are being made from a permitted well for irrigation use. These withdrawals cause the piezometric head adjacent to the well to be lowered, generally in the form of a cone of depression. The head difference between the surficial and Lower Tamiami aquifers drives seepage through the leaky confining unit, at a rate determined by the confining units hydraulic conductivity, as is also illustrated in **Figure 3.19**. Over time the seepage process also acts to draw down the water table. If allowed to reach a steady-state condition the elevation head of the surficial aquifer reaches equilibrium at the piezometric surface of the Lower Tamiami aquifer, as is illustrated in **Figure 3.20**. This would assume the unlikely event of constant pumping for an extended period. However, **Figure 3.20** serves to illustrate what are the potential impacts of lowering the piezometric head of the Lower Tamiami aquifer, which includes decreased runoff due to an increase in soil storage and decreased stages in adjacent canals due to channel seepage. **Figure 3.21** illustrates the transitional conditions after pumping withdrawals have ceased. The drawdown of the piezometric head of the Lower Tamiami aquifer caused by pumping is removed, and the resulting head difference with the surficial aquifer causes the flux of water to reverse and move upward across the semi-confining layer. Ideally, the net result of these processes has zero effect on the water balance of the basin.

### 3.6.2. Review of Available Regional Groundwater Models

The C-139 is a rain-fed system, closed to external sources of surface water. Therefore, if the volume of water removed from the Lower Tamiami aquifer is greater than the seepage from the surficial aquifer then the water balance would show the total runoff volume at the discharge as greater than rainfall minus evapotranspiration minus the change in basin storage. For the purposes of this report it is assumed that the water budget of the basin is closed and the net flux is zero. Very little research is available to determine the validity of this assumption, however a three-dimensional finite difference groundwater flow model was created for Hendry County by District staff but the model calibration was never finalized (Butler and Rani). The simulation included 3 vertical layers; the surficial, the Lower Tamiami and the Sandstone aquifer.

A review of an interim copy of the technical publication described two calibrations performed: a transient calibration and a steady-state calibration. The transient calibration was performed for the calendar years 1986 and 1987, with an accuracy of 3 feet. Since the calibration and validation period for the C-139 WAM simulation is 2003-2005, as will be discussed in Section 4.0 of this report, the results of the transient simulation are not pertinent to the C-139 project. The results of the steady-state calibration are illustrated in **Figure 3.22**. Additionally post-processing was recently performed on the results of the steady state simulation to try and determine the net flux of water from the surficial aquifer to the Lower Tamiami. According to the steady-state model results there is 2.25 cubic feet per day moving from the Lower Tamiami to the surficial aquifer within the boundaries of the C-139 Basin. This is a negligible amount when considering the size of the basin at nearly 170,000 acres. As such even though the model calibration was never finalized, the results do offer some validation of the assumption that the water budget for the C-139 Basin is closed.

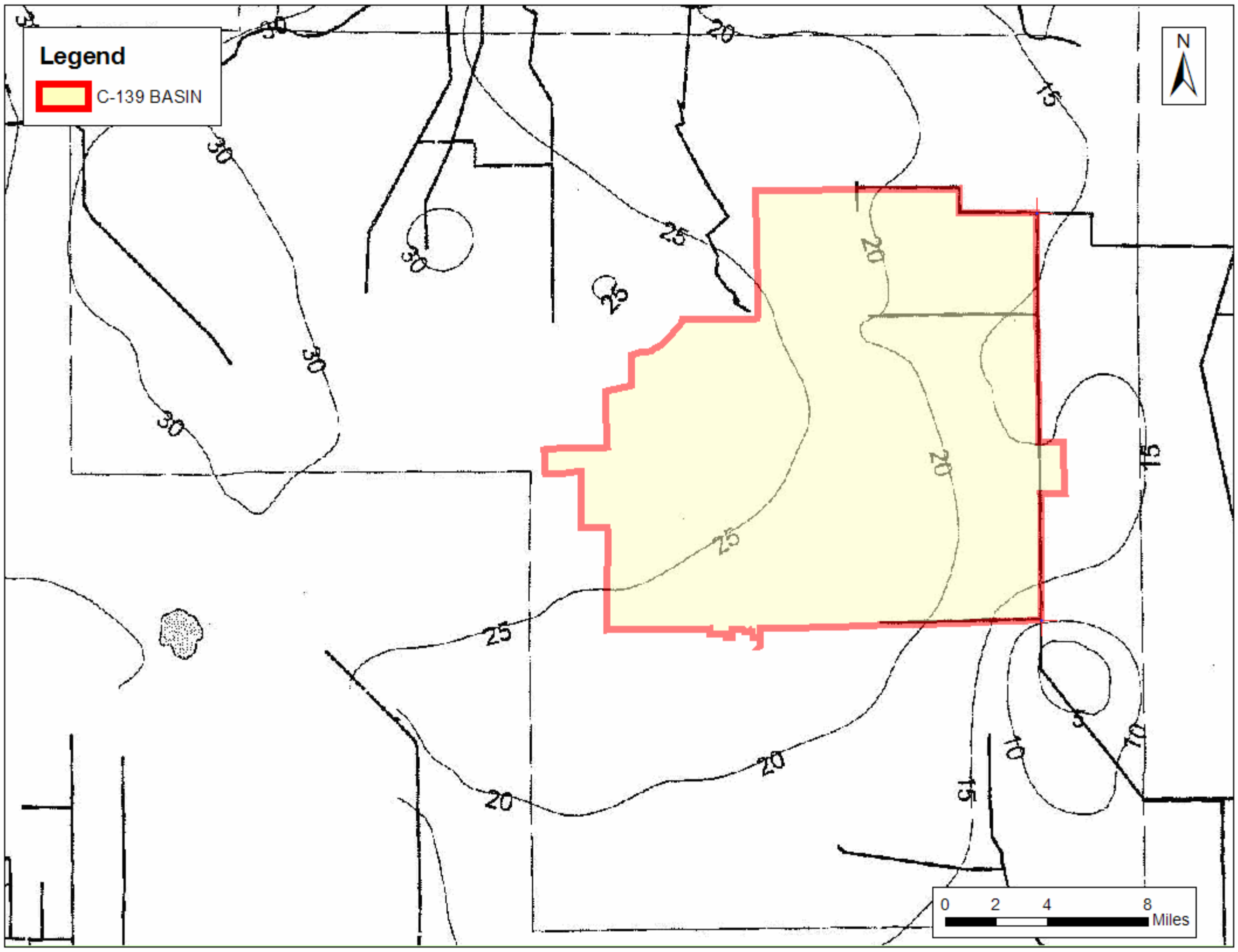



**Figure 3.22: Steady-state water level results for the Lower Tamiami Aquifer**

## 3.6.3. Modifications to the WAM Set-up

### 3.6.3.1 Allowing Seepage from the Surficial Aquifer System

In order to represent the conditions of the C-139 Basin hydrogeology, two changes were made to the WAM code. The first modification allowed for seepage from EAAMOD based on soil-type and driven by a time series describing depth to the regional pieziometric surface (the Lower Tamiami aquifer), which becomes a time-varying boundary condition at the bottom of the soil column. For each soil type a value for hydraulic conductivity of the semi-confining unit is described along with the name of the input file containing the lower boundary time-series. Therefore the modified WAM code allows for a seepage condition that varies in time, but can only vary spatially within the framework of soil-type. Since the vertical conductivity of the semi-confining unit is described within the framework of soil-type, the value was kept uniform for all soils and was determined as part of calibration. The data required to create the time-series for the lower boundary was generated from the groundwater monitoring wells within Hendry County. **Figure 3.23** illustrates the location of all the wells included in DBHYDRO for Hendry County, while **Table 3.2** describes the well parameters, despite the fact that the topographic DEM used by WAM and illustrated in **Figure 3.1** is in metric units, inputs to the subsurface hydrology routines and the well parameters available from DBHYDRO are described in English units. As such, **Table 3.2** describes these characteristics in English units.

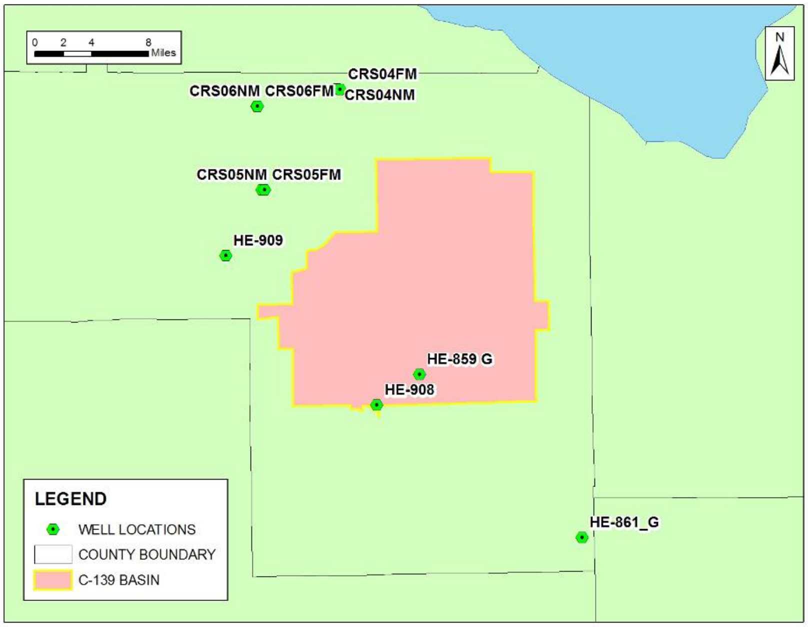



**Figure 3.23: Groundwater Monitoring Wells within Hendry County**

**Table 3.2 Topographic elevation of well location and well depth**

| | DEM SURFACE ELEVATION (FT NAVD88) | STRATA (FT) |
|---|---|---|
| **HE-861_G** | 13.52 | 70.0 |
| **CRS04NM** | 19.45 | 52.7 |
| **CRS05NM** | 26.24 | 53.7 |
| **CRS06NM** | 19.94 | 53.7 |
| **CRS04FM** | 19.57 | 51.2 |
| **CRS05FM** | 26.10 | 66.0 |
| **CRS06FM** | 19.87 | 54.3 |
| **HE-908** | 22.48 | 75.0 |
| **HE-909** | 28.38 | 148.0 |
| **HE-859** | 23.66 | 59.0 |
| **AVERAGE** | 21.92 | 68.4 |

WAM uses depth to the potentiometric surface as the input parameter. So the groundwater elevations reported at each monitoring well need to be converted to depth from the surface by subtracting the average surface elevation for well locations (derived from the best available DEM), from the recorded groundwater elevation. Based on coordination with District staff, the following monitoring wells were excluded due to potential impacts from agricultural operations external to the C-139 Basin: CRS04NM, CRS05NM, CRS06NM, CRS04FM, CRS05FM and CRS06FM. **Figure 3.24** illustrates the depth to the potentiometric surface based on the remaining Hendry County monitoring wells. The green crosses represent the average depth of all the monitoring wells in Hendry County.

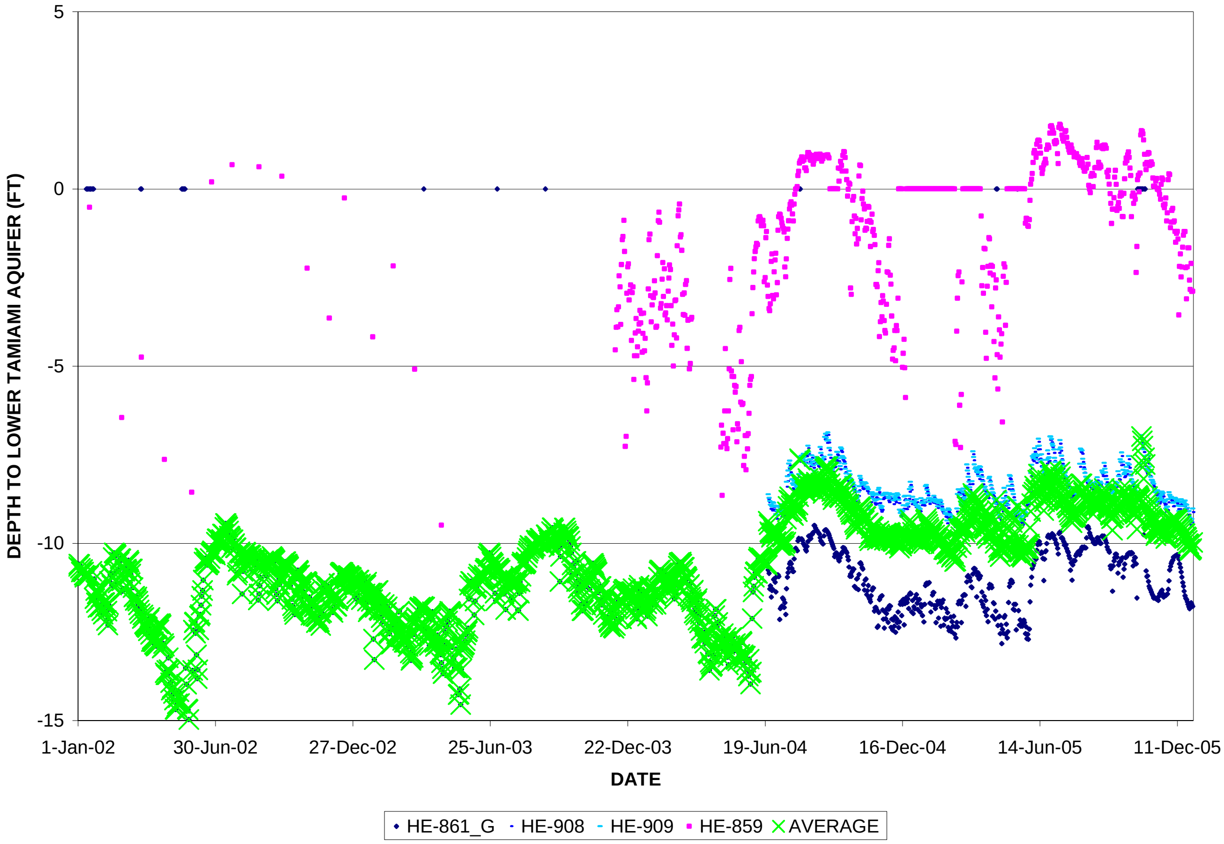



**Figure 3.24: Average depth to the Lower Tamiami aquifer**

### 3.6.3.2 Maintaining the Water Balance due to Seepage

Even though the modification to WAM described above does provide a more accurate representation of the natural system; the resulting process provides a pathway for water to leave the simulated system unaccounted. In order to prevent this and to maintain the initial assumption that the net flux from the lower boundary is zero, the WAM code was modified such that all of the water that is seeped from the soil column due to the processes described above is lumped into the subsurface runoff for that grid cell. Subsequently the subsurface runoff for each cell is routed to the appropriate stream node based on a subsurface specific unit hydrograph found in the *hydssurf.in* file.

### 3.6.4. Modifications to the WAM Set-up

However, WAM does not have any mechanisms for allowing the transfer of water between these water sources. Therefore within WAM, water withdrawn from the lower Tamiami aquifer does not cause any drawdown to the phreatic surface of the surficial aquifer. Additionally, any lowering of the simulated phreatic surface of the surficial aquifer within WAM does not cause any seepage from the canal. These model constraints can cause substantial difficulties in representing an agricultural system that uses subsurface withdrawals for irrigation in a region with sandy soils and a leaky confining layer, such as the C-139 Basin. Since at the beginning of the C-139 project these effects were not readily represented within WAM, the model was modified in order to simulate these effects.

## 3.7 Irrigation Methodology

Within WAM an irrigation source can be quantified spatially for each cell, such that any land-use which incorporates irrigation demand will withdraw water from the source specified for the cell. Based on the original WAM code, the three sources available for irrigation withdrawals are surface water (canal network), subsurface (surficial aquifer) or external (lower Tamiami aquifer or municipal source). As described above, the WAM code was modified to provide communication between the surficial and Lower Tamiami aquifers. As such, the irrigation demands within the C-139 Basin are met within WAM from the subsurface stores.

Nevertheless, the specification of the source is independent from the amount of irrigation demand that is calculated as a function of the land-use, soil type and the elevation of the water table. WAM incorporates management practices for specific crop types that are consistent with common practices of landowners throughout the state. WAM contains a set of parameters for each soil type that help to define soil characteristics such as porosity and infiltration rate. In combination with measured rainfall and simulated seepage and evapotranspiration, WAM simulates the elevation of the phreatic surface of the water table aquifer. During the growing season of a specific crop, the model determines the irrigation demand based on elevation of the water table (in terms of depth of void space) and the crop type. **Table 3.3** describes the irrigation timing, demands and rates as described within WAM for the common crop types within the C-139 Basin. The irrigation-on and irrigation-off dates represent the start and end dates of the default growing season for each crop-type. All water depth values represent WAM defaults with the exception of row crop. For the row crop land-use, the original water table depth for irrigation off was 23 inches, which was 1 inch above the default weir crest for the internal farm control (conceptually depicted in **Figure 2.2**). This is not reflective of the conservationist management practices of current land-owners, and as such the irrigation-off depth was increased to 25 inches so that simulated irrigation volumes would be kept within the farm and not be diverted to basin-wide runoff.

**Table 3.3: Irrigation timing, demands and rates within WAM**

| Land Use | Irrigation On | Irrigation Off | Irrigation On (Water Table Depth) | Irrigation Off (Water Table Depth) | Irrigation Rate [IN/HR] |
|---|---|---|---|---|---|
| Row Crop | 20-Mar | 21-Jun | More than 27 inches of void space | Less than 25 inches of void space | 4.3 |
| Ornamental | 1-Jan | 19-Mar | More than 3 inches of void space | Less than 2 inches of void space | 0.5 |
| Ornamental | 20-Mar | 29-Apr | More than 2.5 inches of void space | Less than 2 inches of void space | 0.5 |
| Ornamental | 30-Apr | 31-Dec | More than 3 inches of void space | Less than 2 inches of void space | 0.5 |
| Sugar Cane | 1-Jan | 31-Dec | More than 2 inches of void space | Less than 1.7 inches of void space | 0.25 |
| Citrus Grove | 30-Jun | 29-Apr | More than 3 inches of void space | Less than 2 inches of void space | 0.5 |
| Citrus Grove | 30-Apr | 31-Dec | More than 2.5 inches of void space | Less than 2 inches of void space | 0.5 |

## 3.8 Land Management or BMPs

In an agricultural watershed such as the C-139 Basin, land-uses within the WAM model are not only used to describe the type of agricultural use but also to describe the management practices. The methodology for representing varying levels of nutrient, sediment, pasture and water management practices is to create additional land-uses for the agricultural type of interest.

The only information describing agricultural management practices available for incorporation with the 1999 land-use data was the Everglades Works of the District (WOD) permits held by landowners within the C-139 Basin in accordance with Chapter 40E-63, Florida Administrative Code (F.A.C.). These permits present a menu that allows the landowner to select a series of management practices that provide the plan for reduction of phosphorus discharges. Within the framework of the WOD permit, each selected management practice is assigned a value based on a point system. In order to correlate the management practices selected by the landowners with the WAM hydrologic and nutrient parameterization scheme, a system for relating model parameters with the points assigned to nutrient, water and pasture management practices was developed.

Within WAM there are two ways to represent a management practice: modifying the (physically-based) practice that is impacted or reducing the BMP factor. As an example of the physically based technique, if the selected WOD BMP for a specific land use was “Reduce P Fertilization” then the application rate for that landuse would be reduced by 30% within both the *landuse.bnz* and *lu-eaa.bnz* file. As an example of reducing the BMP factor, if the selected WOD BMP for a specific land use was “Restricted Placement of Cowpens to Reduce "Hot Spots" near Drainage Ditches” the BMP Factor within the *landuse.bnz* file would be reduced from the default value of 1.0 to 0.95.

The BMP Factor is a multiplier that is applied to any of the following constituent loads leaving the cell: Total Suspended Solids (TSS), Total Nitrogen (TN), Total Phosphorus (TP) and Biological Oxygen Demand (BOD). The BMP Factor can also be applied separately to TN and TP for subsurface runoff. The purpose of the BMP Factor is to represent management practices that positively affect the water quality of off-site discharge, but cannot be directly represented by the physical practices that are simulated within WAM.

The process of assigning a quantitative change in the model parameters based on qualitative descriptions of management practices is imprecise at best. Dr. Del Bottcher is the primary author of the University of Florida Cooperative Extension Service Circular 1177 (UF-IFAS, 1997). This document is one of the primary references for determining the potential benefits of several fertility and water management BMPs in the EAA. Dr. Bottcher is also a principal developer of WAM and is the foremost reference on land-use parameterization schemes within WAM. Utilizing the qualitative descriptions found in the BMP Equivalent Points Table in Appendix B-1 of the F.A.C Chapter 40E-63, Dr. Bottcher described how to modify the land-use parameterization schemes to provide an analogous representation within WAM. BMPs are best prescribed and evaluated on a farm specific basis, however based on the available information and for the purposes of a C-139 basin wide representation within WAM, a farm-by-farm evaluation is inefficient. Therefore the reductions recommended by Dr. Bottcher represent an expected average benefit. **Table 3.4** describes each WOD BMP option and the analogous representation within the WAM parameterization scheme, based on Dr. Bottcher's best professional judgment.

**Table 3.4: WAM land-use management practice scheme**

| Works of the District Permit BMP Plans | Fertility Reduction | BMP Factor Reduction | Detention Method |
|---|---|---|---|
| **NUTRIENT CONTROL PRACTICES** | | | |
| Nutrient Application Control | 20% | | |
| Nutrient Spill Prevention | | 2% | |
| Manage Successive Vegetable Planting to Minimize P | 20% | | |
| Recommended Nutrient Application based on Plant Tissue Analysis | 20% | | |
| Recommended Nutrient Application based on Soil Testing | 20% | | |
| Split Nutrient Application | 10% | | |
| Slow Release P Fertilizer | 30% | | |
| Reduce P Fertilization | 30% | | |
| No Nutrients Imported via Direct Land Application | 50% | | |
| No Nutrients Imported Indirectly through Cattle Feed | 50% | | |
| **WATER MANAGEMENT PRACTICES** | | | |
| 0.5 inches Detained | | | Flashboard Management |
| 1.0 inches Detained | | | Flashboard Management |
| Improvements to Water Management System Infrastructure for Water Quality Treatment | | 25% | |
| Reduced Flow Through Water Table Management | | | Flashboard Management |
| Approved and Operational Surface Water Reservoir | | | Reservoir |
| Temporary Holding Pond | | | Reservoir |
| No Direct Discharge | | 10% | |
| **PARTICULATE MATTER AND SEDIMENT CONTROLS** | | | |
| Each Particulate Matter and Sediment Control | | 2% | |
| **PASTURE MANAGEMENT** | | | |
| Restricted Placement of Feeders to Reduce "Hot Spots" near Drainage Ditches | | 5% | |
| Restricted Placement of Cowpens to Reduce "Hot Spots" near Drainage Ditches | | 5% | |
| Restricted Placement of Feed and Water to Reduce "Hot Spots" near Drainage Ditches | | 10% | |
| Provide Shade Structures to Prevent Cattle in Waterways | | 5% | |
| Low Cattle Density | | | |
| Reduced P in Feed | 20% | | |
| Restrict Cattle from Waterways through Fencing | | 20% | |

### 3.8.1. Nutrient Control, Sediment Control and Pasture Management

The nutrient reduction is described as a percent reduction from the default value. The WAM parameterization scheme contains default values of initial and applied phosphorus amounts for each of the land-uses illustrated in **Figure 3.4**. The default Initial TP values are reflective of which values allow the model to reach equilibrium in the shortest duration for WAM simulations performed in other locations. The default TP application rates are based on available data and the best professional judgment of the WAM developers with respect to agricultural practices in Florida. The nutrient application rates and on-site retention associated with each land-use as it applies to specific farm basins is detailed in **Appendix B**. For each of the nutrient control practices, with the exception of spill prevention, the methodology for representing BMPs was based on reducing the Initial TP and the TP application rates by a set percentage based on available literature and best professional judgment. The reason nutrient controls are not represented by changes to the BMP Factor is because these management practices generally affect fertilization amounts and timing which are represented within WAM. However, for sediment control and pasture management, there is generally no physically based process to modify, and the BMP factor is the best available tool.

### 3.8.2. Water Management

Water management BMPs are represented within WAM similarly to nutrient management using either a physically-based or BMP Factor approach. In the case of a 1-inch retention facility, the definition of the impoundment is based on a fraction of the 1-hectare cell area being set aside for retention storage. The model was set-up to assume that each cell that meets the criteria of retaining 1.0 inch of runoff will include a reservoir within each cell that is 3.3 feet deep and 2,734 square feet in area (1.0 hectare-inch). If the runoff amount exceeds 1.0 hectare-inch in volume, then the excess is routed to the nearest stream reach. The retention facility includes all hydrologic processes including percolation to the surficial aquifer system and evaporative losses to the atmosphere. With respect to water quality impacts, the retention pond attenuates the loads during the retention time, based on the parameters found in the *attenuate.in* input file.

In the case of a large farm, the characteristics of the grid cells that define that large farm scale-up from the grid cell to the large farm. This means that the total area of on-site retention summed up over the large farm is still sized to hold the first 1.0 inch of runoff from the entire farm. **Figure 3.25** describes the conceptual arrangement of this type of on-site retention.

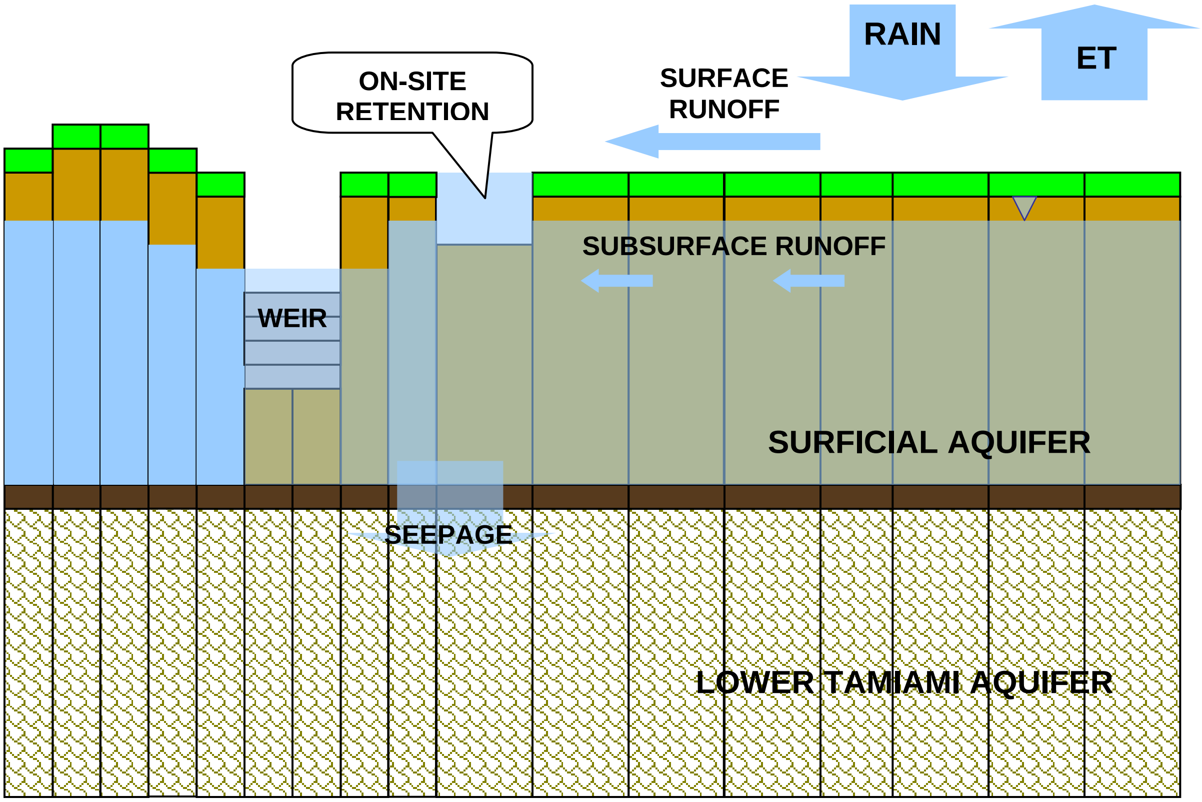



**Figure 3.25: Conceptual application of a retention BMP**

Water management BMPs that specify that the landowner holds the first 0.5 or 1 inch of runoff on-site prior to discharge are represented by raising the elevation of the weir crest of the internal field ditch drainage structure. In actual farm management, this BMP can be provided by changes in the operation of either gravity flashboard structures or pump discharge structures. However within WAM, both methods are represented by modifying the weir controls of the internal field ditch, shown in **Figure 3.25**.

In the case of the BMP “No Direct Discharge”, the BMP Factor is reduced from 1.0 to 0.9, while in the case of “Improvements to Water Management Infrastructure to Further Increase Water Quality Treatment” the BMP Factor is reduced from 1.0 to 0.75. These specific parameterizations contradict the valuation described in BMP Equivalent Points Table (Appendix B1, F.A.C. Chapter 40E-63). Although for specific farms it may be possible for the entire property to discharge via sheet flow, instead of from a specific structure. It is unlikely that these conditions are available for many fields. As such, it is the experience of Dr. Bottcher that when considering a comparison of the average benefits for any given farm, improvements to water management infrastructure would be more beneficial than no direct discharge.

### 3.8.3. WAM Parameterization Scheme

There are 25 unique BMPs described within the WOD permit document. In order to parameterize the *landuse.bnz* and *lu-eaa.bnz* file properly to represent all of the combinations found within the C-139 Basin, an analysis of all the possible combinations was filtered to derive 27 unique combinations of BMPs selected by landowners within the C-139 Basin. These 27 combinations were divided into two categories: pasture and crop. **Tables 3.5** and **3.6** illustrate the unique combinations of WOD BMPs found for pastures and crops in the C-139 Basin, respectively. The first column of each table (BMP ID) coincides with the prefix added to each land-use code illustrated in **Figure 3.4**, therefore improved pasture (26) for which the landowner has selected "No Nutrients Applied" and "No Direct Discharge" as the applicable WOD BMP, would be recognized within WAM by the BMP Land-use Code 326. Correspondingly in this sample case, the parameters defining the land-use characteristics would show a fertility reduction of 50% and a BMP Factor of 0.90. These tables reflect the best available data and best professional judgment. Although the parameterization scheme described below is incorporated into the final calibrated and validated model presented as part of this document, the parameterization scheme described in **Tables 3.4, 3.5** and **3.6** could be modified based on future datasets and new information.

**Table 3.5: BMP scheme for crops within the C-139 Basin**

| BMP ID | WOD BMPs Selected | | | Model Parameters Modified | |
|---|---|---|---|---|---|
| | Sediment Controls | Nutrient Application | Water Management | Fertility Reduction | BMP Factor |
| C-0 | - | - | - | 0% | 1.00 |
| C-1 | - | - | 1" Retention Impoundment | 0% | 1.00 |
| C-2 | Sediment Controls (6) | Spill Prevention / Soil Testing / Application Control | No Direct Discharge | 30% | 0.76 |
| C-3 | Sediment Controls (6) | Spill Prevention / Soil Testing / Application Control | Detention via Flashboard Management | 30% | 0.86 |
| C-4 | Sediment Controls (8) | Spill Prevention / Soil Testing / Application Control | - | 0% | 0.82 |
| C-5 | Sediment Controls (8) | Spill Prevention / Soil Testing / Plant Testing / Manage Successive Plantings | - | 40% | 0.82 |
| C-6 | - | Soil Testing / Plant Testing | Detention via Flashboard Management | 20% | 1.00 |
| C-7 | Sediment Controls (2) | Spill Prevention / Soil Testing / Plant Testing | 1" Retention Impoundment | 20% | 0.94 |
| C-8 | Sediment Controls (6) | Spill Prevention / Soil Testing / Application Control | Detention via Flashboard Management | 30% | 0.86 |

## Table 3.6: BMP scheme for pastures within the C-139 Basin

| BMP ID | WOD BMPs Selected | | | | Model Parameters Modified | |
|---|---|---|---|---|---|---|
| | Reduce Hot Spots Sediment Controls | Nutrient Application Amount | Nutrient Application Control | Water Management | Fertility Reduction | BMP Factor |
| P-0 | - | - | - | - | 0% | 1.00 |
| P-1 | Sediment Controls (6) | - | - | 1" Retention Impoundment | 0% | 0.88 |
| P-2 | Sediment Controls (8) | - | Spill Prevention / Application Control | - | 20% | 0.82 |
| P-3 | Sediment Controls (4) | No Nutrients Applied | - | No Direct Discharge | 50% | 0.82 |
| P-4 | Hot Spot Reduction (1) Sediment Controls (2) | No Nutrients In Feed | Spill Prevention / Soil Testing / Application Control | - | 65% | 0.89 |
| P-5 | Hot Spot Reduction (2) | Split Application / Slow-Relase P | Spill Prevention / Application Control | - | 52% | 0.88 |
| P-6 | Hot Spot Reduction (3) Sediment Controls (6) | Reduced P | Spill Prevention / Soil Testing / Application Control | - | 51% | 0.66 |
| P-7 | - | No Nutrients Applied | - | Detention via Flashboard Management | 50% | 1.00 |
| P-8 | Hot Spot Reduction (1) Sediment Controls (6) | No Nutrients Applied / No Nutrients in Feed | Spill Prevention | - | 100% | 0.81 |
| P-9 | Hot Spot Reduction (2) | - | Spill Prevention / Soil Testing / Application Control | No Direct Discharge | 30% | 0.78 |
| P-10 | Hot Spot Reduction (2) Sediment Controls (6) | Reduced P | Spill Prevention / Soil Testing / Application Control | - | 51% | 0.76 |
| P-11 | Hot Spot Reduction (2) Sediment Controls (6) | Split Application | Spill Prevention / Soil Testing / Application Control | - | 37% | 0.76 |
| P-12 | Hot Spot Reduction (2) Sediment Controls (6) | No Nutrients Applied / No Nutrients in Feed | - | - | 100% | 0.78 |
| P-13 | Hot Spot Reduction (3) Sediment Controls (2) | No Nutrients In Feed | - | No Direct Discharge | 50% | 0.66 |
| P-14 | Hot Spot Reduction (3) Sediment Controls (2) | Reduced P / No Nutrients in Feed | Spill Prevention / Soil Testing | - | 72% | 0.76 |
| P-15 | Hot Spot Reduction (1) Sediment Controls (2) Fencing | No Nutrients Applied | - | - | 50% | 0.71 |
| P-16 | Fencing Only | - | - | - | 0% | 0.75 |
| P-17 | Sediment Controls (2) | - | - | - | 0% | 0.96 |
| P-18 | Sediment Controls (6) | - | - | - | 0% | 0.88 |
| P-19 | Hot Spot Reduction (2) Sediment Controls (2) | No Nutrients Applied / No Nutrients in Feed | - | - | 100% | 0.86 |

## 3.9 Water Quality

WAM incorporates two main processes for simulating TP loads: load generation and load attenuation. For the purposes of the C-139 simulation, load generation is based on initial TP in the soil column or applied TP in the form of fertilizer or cow manure. These parameters are represented in the land-use and BMP portion of the set-up. WAM is not currently capable of simulating re-suspension of particulates or sediments within canal reaches.

The *attenuate.in* file describes the background concentrations and decay parameters that apply to various types of overland flow and channel flow. In the case of overland flow there are various values for uplands and wetlands. In the case of channel flow there are various values for reach types such as canals or streams. Within the development of the WAM C-139 simulation major canals (L-1, L-2, L-2W, L-3, Deer Fence, S&M and Midway Canals) are categorized as canals, whereas the remaining reaches are categorized as streams. Within the C-139 simulation there is no difference in the parameterization or the algorithms that are applied to canals and streams, but the delineation was provided with the intent of allowing for future modifications to canal parameterization that may differ between the primary and secondary drainage network. WAM includes default parameterization schemes specific to each land-use and reach type to define various types of attenuation. The attenuation processes for overland flow and in-stream are simulated using the following equations:

***Land Attenuation***

$$\Delta C = \left(C - C_b\right) \times e^{\left(-a \times q^{-b} \times d\right)}$$

*Where:*
*$\Delta C$ = Change in concentration (ppm)*
*C = Current concentration (ppm)*
*$C_b$ = Background concentration (ppm)*
*a = Attenuation multiplier*
*b = attenuation exponent*
*q = Flow rate ($m^3/s$)*
*d = Flow distance (m)*

***Stream Attenuation***

$$\Delta C = \left(C - C_b\right) \times e^{\left(\frac{-at}{R}\right)}$$

*Where:*
*$\Delta C$ = Change in concentration (ppm)*
*C = Current concentration (ppm)*
*$C_b$ = Background concentration (ppm)*
*a = Attenuation multiplier*
*t = Time (s)*
*R = Hydraulic radius (m)*

The attenuation algorithm can also be applied to surface runoff retained by on farm impoundments. There are two settings for on-farm impoundments: the first is for a stormwater facility with no water quality attenuation, the second is described as a wetland treatment facility and utilizes the above attenuation algorithm, with the default values described in **Table 3.7**. These values are based on observed data collected by the Center for Wetlands Studies (University of Florida).

**Table 3.7: Default attenuation parameters for wetland retention**

| Parameter | Soluble $PO_4$ | Sedimentary $PO_4$ |
|---|---|---|
| **a** | 0.001 | 0.0002 |
| **b** | 0.65 | 0.5 |
| **$C_b$ (ppm)** | 0.1 | 0.05 |

# 4.0 CALIBRATION AND VALIDATION

## 4.1 Setup

Deliverable 6.1 (WAM Set-up Technical Design Document) describes calibration and validation simulations during the period of 2003-2005 due to changes to the regional hydraulic conveyance infrastructure and the implementation of the Everglades WOD BMP plan. The calibration years selected were the wettest and driest years of 2005 and 2004, respectively. The median precipitation year, 2003, was selected for validation.

### 4.1.1. Precipitation

In order to provide the most effective calibration it is important to utilize a time period where hydrologic, hydraulic and meteorologic data is prevalent. Based on the review of available input datasets, the most recent years offer the most comprehensive set of available data. For the calendar years of 2003, 2004 and 2005 the average annual rainfall measured at nearby District gauging stations is 48.5, 44.9 and 52.1 inches, respectively. Based on the annual rainfall amounts the model was calibrated to the wettest and driest of the three years (2005 and 2004, respectively) and verified against the median year (2003).

The scope of work did not specify a method for the development of a precipitation forcing data set. Based on a review of available data and discussions with District staff, it was determined that the best available option is to utilize the closest rainfall gages and create a grid-based coverage of rainfall station zones using the Thiessen Method with coverage of the C-139 Basin. The utility of NEXRAD precipitation data was analyzed as part of this effort, however the available datasets showed large spatial discrepancies in annual rainfall amounts that were recognized as unlikely in a natural system. There are nine rainfall gage locations that are near the C-139 Basin. However, there is not a uniform spatial distribution of these monitoring locations. By illustrating the Thiessen polygons developed based on the spatial relationship of each station and the basin boundaries, **Figure 4.1** illustrates that only four monitoring locations will be used in the analysis: G136_R, PAIGE_R, DEVILS_R and ALICO_R. Therefore, **Figure 4.2** illustrates the final Theissen polygon arrangement used as rainzones in the WAM calibration and validation simulations.

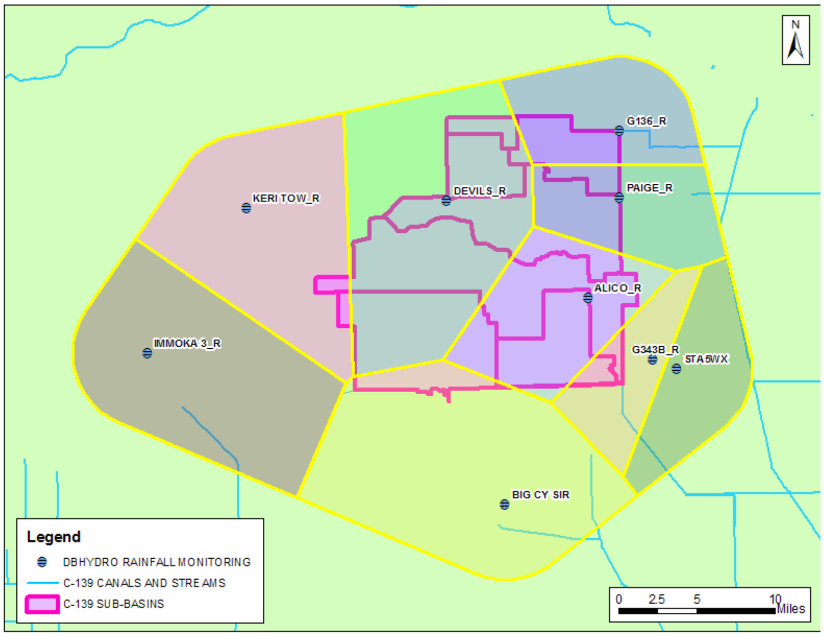



**Figure 4.1: Theissen polygon analysis of neighboring stations**

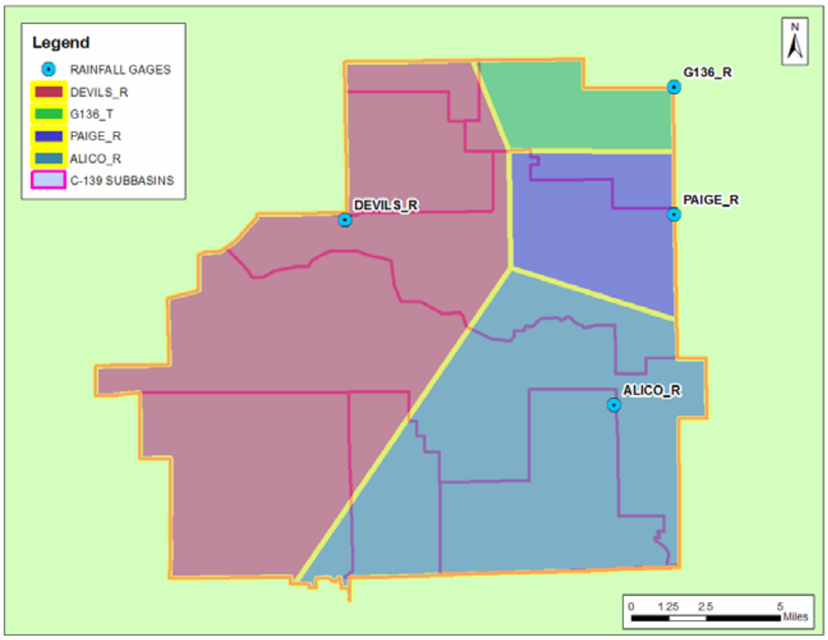



**Figure 4.2: Theissen polygons for calibration and validation**

In order to properly initialize WAM, the model is set-up to simulate a "spin-up" time period of 2000 through 2002. This allows the hydrology and hydraulics of the model to properly simulate the initial conditions of all watershed characteristics, such as antecedent moisture and initial canal stages. Therefore, although only simulation results are reported for 2003-2005, the rainfall datasets were prepared for 2000-2002 as well.

### 4.1.2. Boundary Conditions

The boundaries of the WAM C-139 Basin model are downstream of the G-135, G-136, G-342A, G-342B, G-342C, G-342D and G-406 water control structures, as illustrated in **Figure 3.5**. Recorded downstream canal stage and gate opening data have been made available for these structures for the period of 2000 through 2005, as is illustrated in **Figure 4.3** below. These data were used to establish the hydraulic downstream boundary conditions for the calibration (2004 and 2005) and validation (2003) simulations. The boundaries within WAM allow for three operations: inflow only, outflow only or stage dependent on both inflow and outflow. The boundaries of the C-139 simulation are set for outflow only. For the wet and dry season, this assumption is considered to be accurate for the C-139 Basin boundaries since there are water control structures at each location that are operated with the intent to release runoff from the basin. Although the boundary files were developed including water quality boundary conditions based on available measured data, the simulation is unaffected by these boundaries since all of the boundaries are assumed to be outflow only.

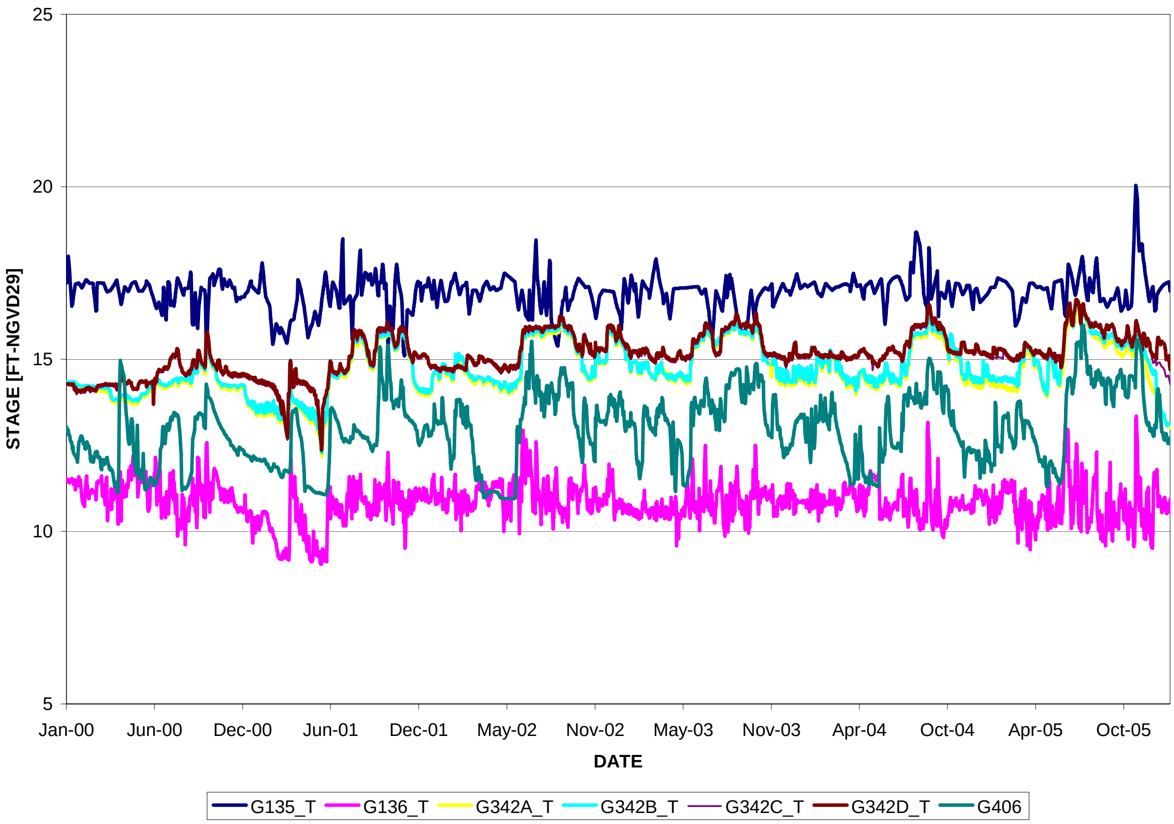



**Figure 4.3: Tailwater stages at the boundaries of the C-139 Basin**

## 4.2 Water Quantity Calibration

WAM is a physically based model, therefore, a simulation that is developed using the appropriate soils and land-use and being forced with accurate rainfall, hydraulic and boundary condition data should yield results that are similar to measured stage and flow data. WAM is also a planning tool that provides simulation results at a daily resolution. As such, the calibration process is not necessarily linear in nature, and there are numerous parameters associated with defining and routing the various components of the water balance.

### 4.2.1. Initial Water Quantity Calibration

Based on the original WAM configuration prior to the model modification described in Section 3.6.3.2 above, the original calibration methodology and results were submitted to the District. This calibration was insufficient to meet the objectives of the project. The following sections outline the methodology, results and District comments that define the initial water quantity calibration.

#### 4.2.1.1 General Parameter Modifications and Initial Calibration Results

There were various Manning's n values tested for primary, secondary and tertiary streams. These values ranged from 0.03 and 0.10. The canal stages and flows in the primary canals were not sensitive to changes in Manning's n. It appears that the hydraulics in the primary canals are controlled by the runoff input, hydrology, and the structure geometries and operations. This analysis determined that the optimal and most representative value for Manning's n throughout the stream network was 0.03 instead of the default value 0.05.

Another modification was made to the *hydsurf.in* and *hydssurf.in* files. These modifications were made since the low-relief and land management practices of the C-139 Basin demonstrate lower magnitude and longer duration runoff hydrographs. Instead of releasing 65% of the surface water runoff from the field in the first day and 100% of the runoff within the first three days, the *hydsurf.in* file was modified to release 25% of the surface water runoff on the first day and to release 100% of the runoff over 10 days. The *hydssurf.in* file was similarly modified.

The irrigation supply for the initial calibration was assumed to be the Lower Tamiami aquifer; with respect to the terminology described in Section 3.7, this is an external source. The initial calibration assumes an impermeable confining layer between the surficial and Lower Tamiami aquifers. **Figure 4.4** illustrates a comparison of measured and cumulative combined flow for the G-342 and G-406 structures for the calibration year 2004. The cumulative flow for 2004 was overestimated by 17.4%. **Figure 4.5** illustrates a comparison of simulated and measured stages relative to NAVD88, in the L-3 Canal immediately upstream of G-406 and G342-D. As was described in Section 4.1.1 above, 2004 was a dry year. The effects of lowered water tables due to irrigation demand are most prevalent during dry periods since this is when irrigation demand is highest, and the stages illustrated in **Figure 4.5** illustrate the significance of the inability of the initial calibration and the default WAM configuration to represent this system.

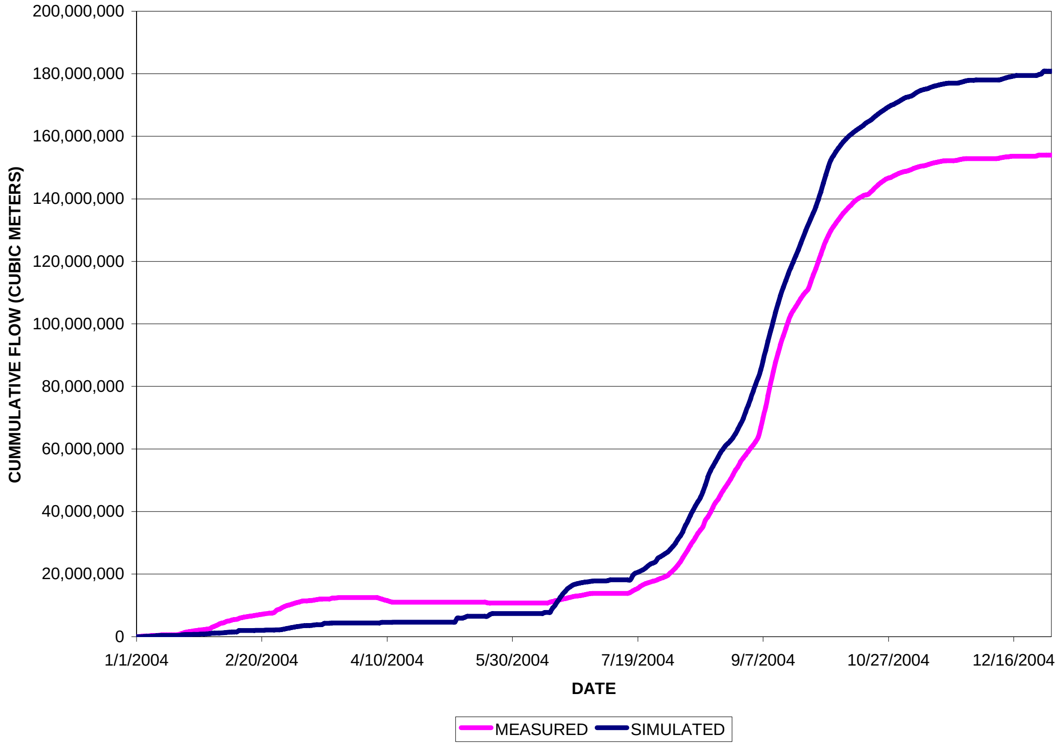



**Figure 4.4: Initial calibration cumulative flow for 2004 at STA-5 and G-406**

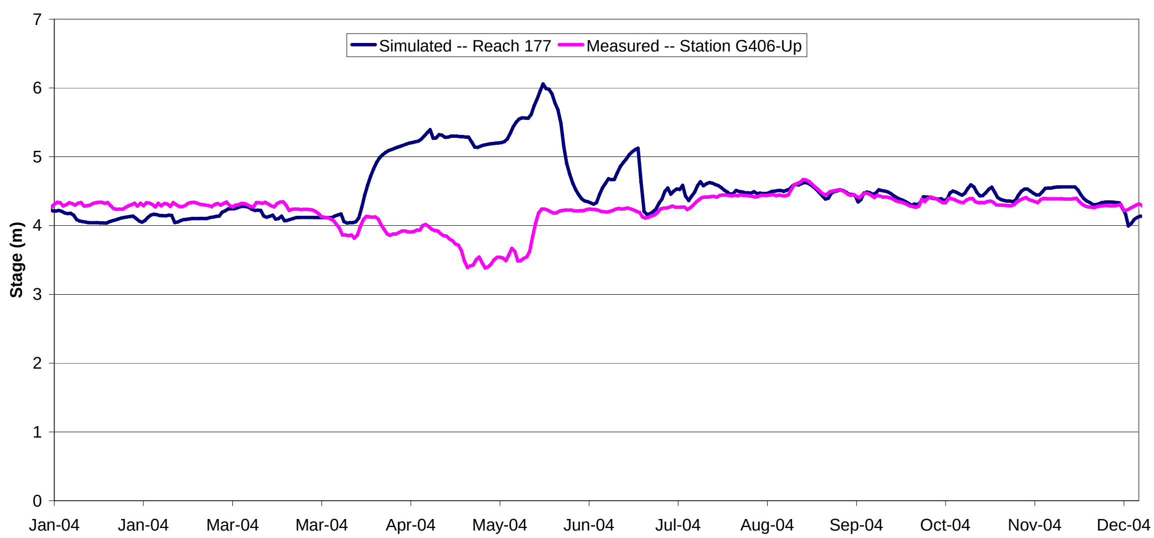



**Figure 4.5: Initial calibration stages upstream of G-406 for 2004**

### 4.2.1.2 Irrigation Source Modification

There are two hydrologic processes that are not represented in the original configuration of WAM, seepage from the surficial aquifer to the Lower Tamiami aquifer and seepage from canal reaches to the surficial aquifer. As part of the initial water quantity calibration, the irrigation setup was changed in an attempt to recreate the impacts of seepage.

The irrigation source input file was modified such that not all irrigation demand utilizes the Lower Tamiami aquifer as a source. The irrigation source file allows WAM to define spatial extents that utilize water stored in the surficial aquifer or the canal network. An irrigation source file was developed that defines surface water as the irrigation source to meet any demand in a grid cell within 350 meters of an internal farm canal reach instead of the lower Tamiami aquifer. In this case surface water is utilized for any land-use that incorporates irrigation demand and is within 350 meters of an internal farm canal reach. The 350 meter buffer was derived by the trial and error methodology with buffers ranging from 50 to 1000 meters to determine which simulation yielded the most accurate comparison with measured stages and flows. The 350 meter buffer was not applied to the L-1, L-2, L-3, Deer Fence or S&M Canal to limit the influence of the irrigation buffer to upstream areas. **Figure 4.6** illustrates the irrigation source grid that indicates if there are irrigation demands in that cell, where the irrigation water comes from.


**Figure 4.6: Irrigation source to meet simulated demands in the C-139 Basin**

As is illustrated in **Figures 4.7** the cumulative flow for the irrigation source modification is not significantly different from the cumulative flows for the initial WAM parameterization (overestimated by 21.1%). However, **Figures 4.8** illustrates the effect of the change to the WAM irrigation source parameterization. This modified simulation is a more effective representation of the dry season effects on the watershed, since the model illustrates a reduction in stages similar to the measured data. Notably, since the period with the greatest discrepancy is the dry season when there is less runoff, the cumulative flows are very similar between the separate parameterization schemes.

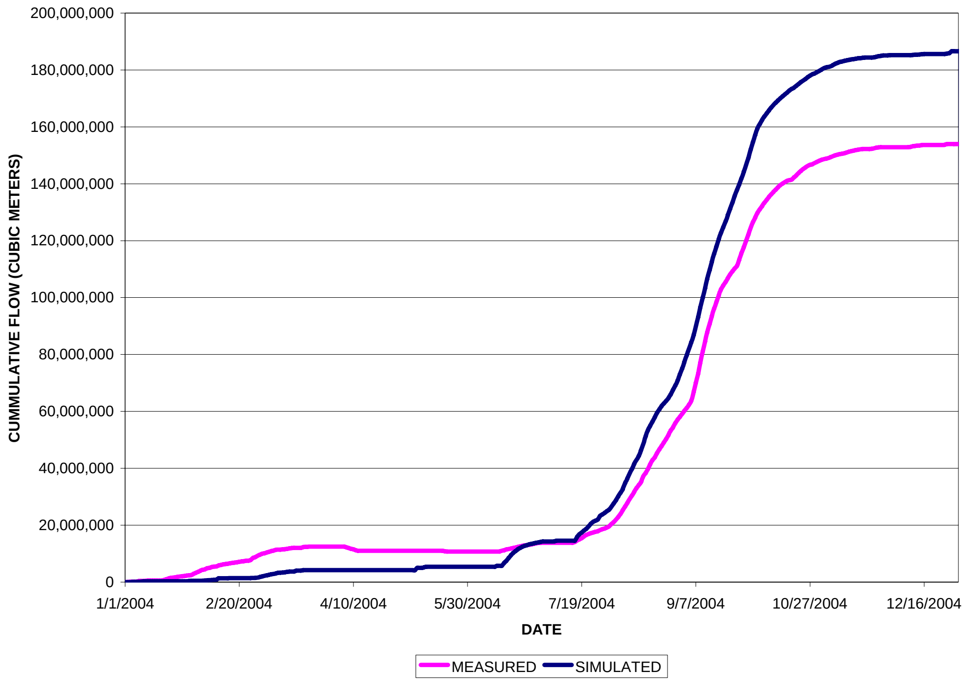



**Figure 4.7: Irrigation scenario cumulative flow for 2004 for STA-5 and G-406**

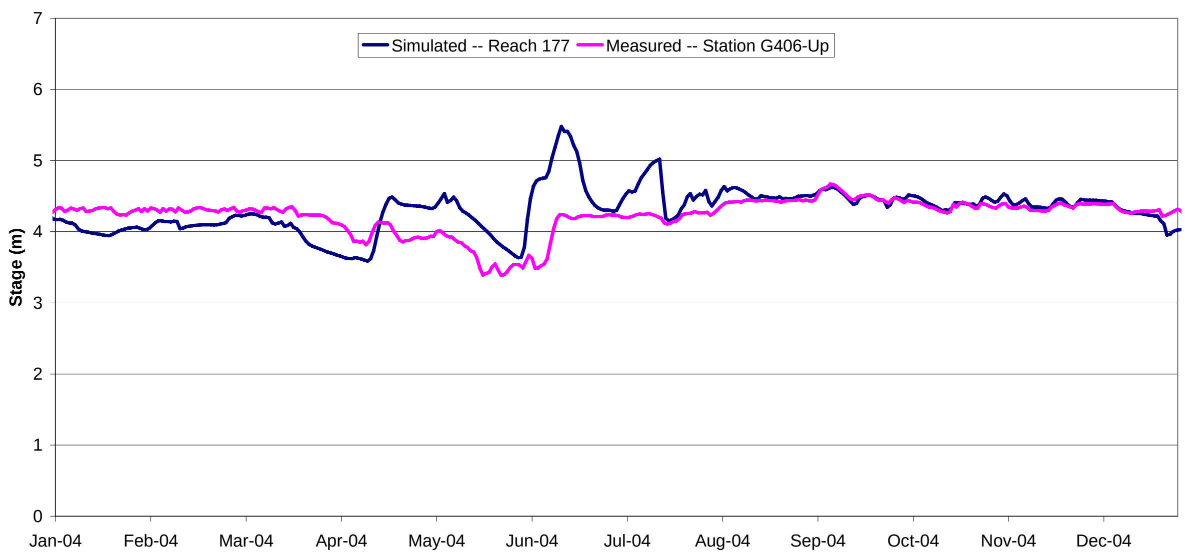



**Figure 4.8: Irrigation scenario stages upstream of G-406 for 2004**

### 4.2.1.3 Seepage Modification

The final calibration scenario presented in the initial calibration involved the modifying the WAM model set-up as is described in Section 3.6.3.1. As was described above, this change to the code allows seepage to be represented by defining a time-series of the potentiometric head of the Lower Tamiami aquifer and the vertical conductivity of the semi-permeable confining unit.

As part of the initial calibration the vertical conductivity was assumed to be 0.017 inches per hour, based on literature review for Hendry County (Smith and Adams, 1988) and the depth to the potentimetric surface was calculated similarly to the description in Section 3.6.31, with the exception that all 9 available monitoring wells were used. The results of this configuration are illustrated in **Figures 4.9** and **4.10**.

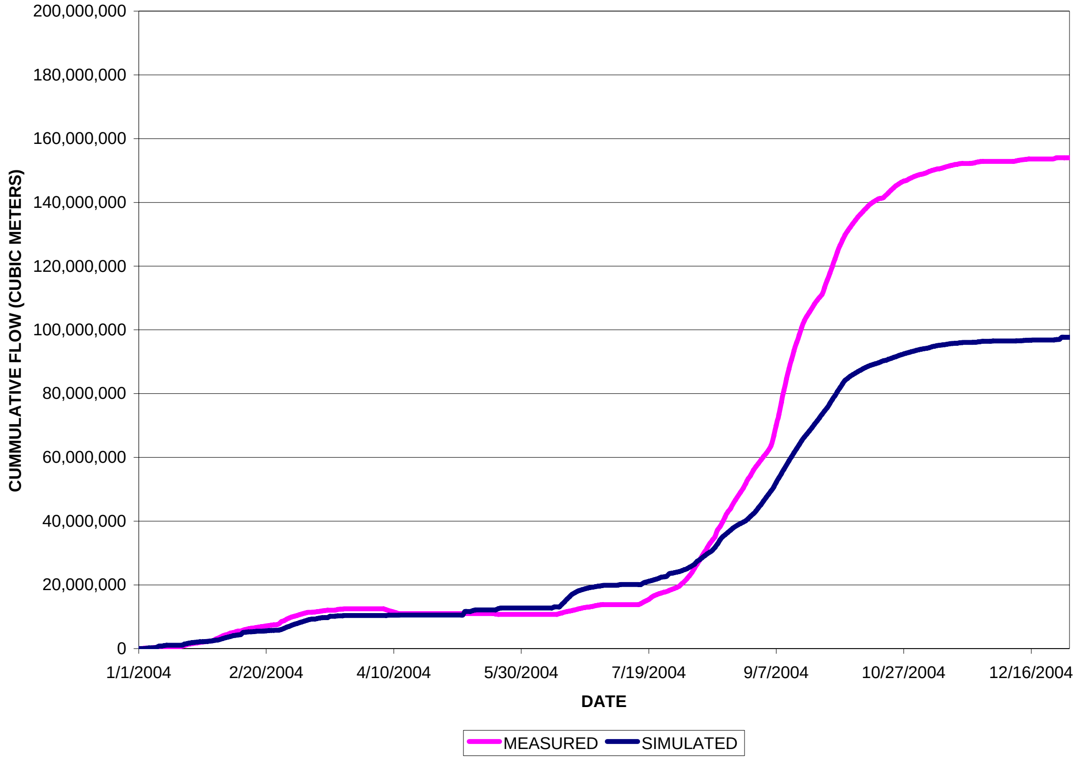



**Figure 4.9: Seepage scenario cumulative flow for 2004 for STA-5 and G-406**

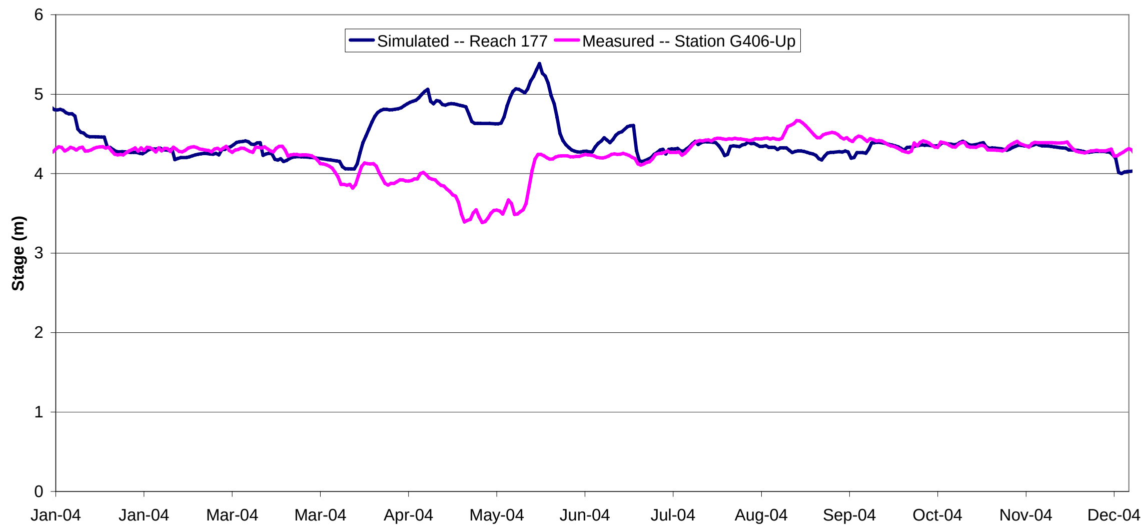



**Figure 4.10: Seepage scenario stages upstream of G-406 for 2004**

## 4.2.2. Revisions to the Initial Calibration

The initial water quantity calibration did not demonstrate the ability of WAM to accurately represent the physical processes of the C-139 Basin. Based on District review and comment, there were three potential deficiencies that would need to be addressed within further calibration phases:

- Local seepage from canals caused by agricultural practices outside the basin;
- Potential inaccuracies in the prediction of evapotranspiration; and
- Improvement to the ability of WAM to represent subsurface interaction with the Lower Tamiami aquifer.

### 4.2.2.1 Local Seepage from Canals

The initial comment addressing local seepage from canals caused by agricultural practices outside the basin was directed toward drawdown of surface water reservoirs within the C-139 Annex and potential seepage through canal levees to recharge the reservoir. However, upon inspection the only surface water reservoirs within the C-139 Annex and adjacent to the L-3 Canal are south of the G-406 structure. Since the G-406 structure is closed during the dry season it is unlikely that any drawdown of the surface water impoundment would have a significant impact on the C-139 canal stages. **Figure 4.11** below illustrates the location of the C-139 Annex reservoir with respect to the major drainage features of the southeastern portion of the C-139 Basin.

One potential source of local canal seepage could be derived from the groundwater modeling results exhibited in **Figure 3.22** (from Section 3.6.2), where a significant local drawdown of the Lower Tamiami aquifer is exhibited in the steady state results south of G-406 to the east of the L-3 Canal, at the site of the proposed Compartment C. The significant drawdown at that location may be attributable to pumped withdrawals from groundwater for the agricultural operation at that location. These high groundwater withdrawals may have depressed canal elevations upstream of G-406. However, if the groundwater pumping is the cause of the low canal stages then this concern is not significant with respect to any existing condition scenario analysis, since this property is no longer in agricultural production.

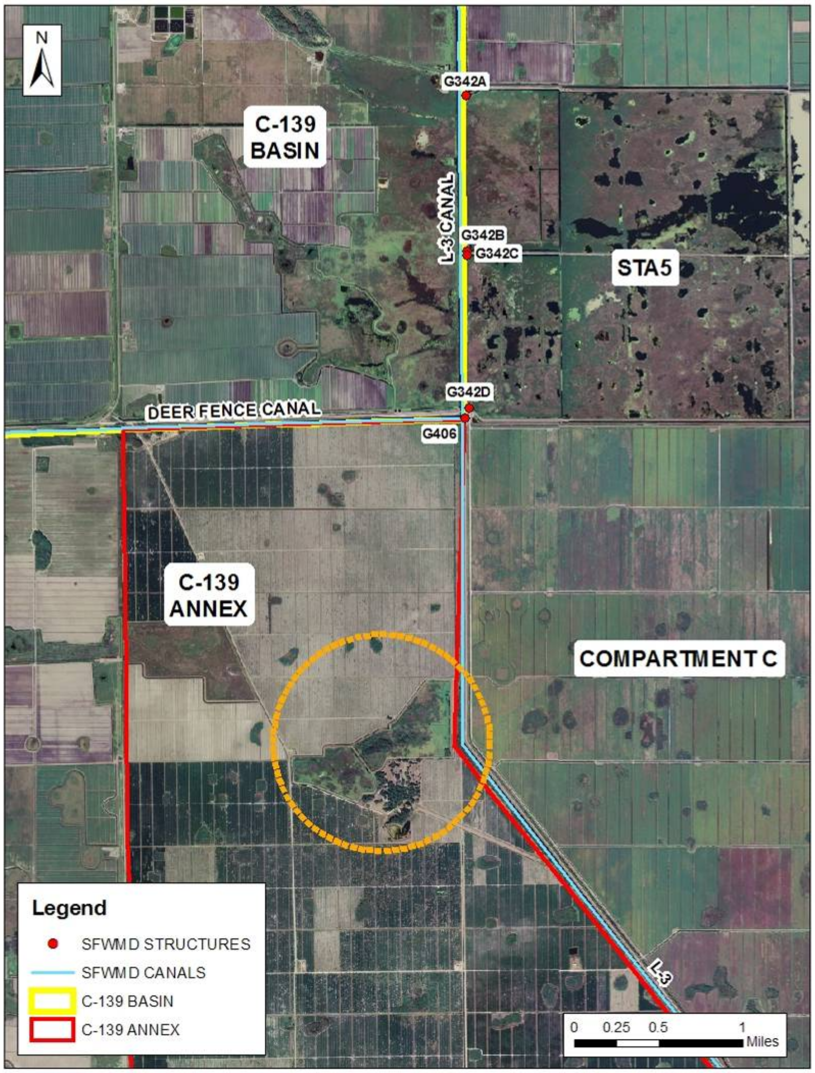



**Figure 4.11: Location of the C-139 Annex surface water reservoir**

### 4.2.2.2 Evapotranspiration (ET)

As described in Section 2.2.1, there are calibration parameters within WAM that can be used to adjust potential ET based on available regional data. However, ET is a component of the water balance for which little measured data is readily available. The District makes estimated potential ET data available via the DBHYDRO interface. This data is called ETP data and represents potential ET data estimated based on measurements at climate monitoring stations within the District. Within Hendry County this data is available at two locations: Big Cypress and Clewiston Field Station. The parameters used by this method are solar radiation ($R_{Solar}$), the latent heat of vaporization ($\lambda_{vap}$) and the coefficient $K_1$ (0.53), as shown in the equation below (Abtew, 1996):

$$ETP = K_1\left(\frac{R_{Solar}}{\lambda_{vap}}\right)$$

As described within Section 2.2.1, the ET calculation methodology for WAM segregates ET into separate pieces, potential and actual. The calibration parameters within WAM for potential ET are PETFAC and PETFACEAAMOD. Assuming the default calibration values are used, 0.93 and 1.06, **Figure 4.12** below illustrates a comparison of ETP for each day of the year for the years 2000 – 2005, with simulated potential ET (PETFAC) and a representation of EAAMOD estimates of actual ET for several crop types (PETFACEAAMOD and crop coefficients). **Figure 4.13** illustrates a similar comparison for the final calibration settings of 0.93 and 1.06, instead of the default 0.89 and 1.06. Both **Figures 4.12** and **4.13** do not incorporate moisture availability, and therefore are representations of the pattern of simulated ET during a typical year. As an additional component of the revised calibration, the reference file for daily average air temperature, temp.tem, was modified to incorporate daily air temperatures reported at Clewiston Field Station with missing data filled using temperature measurements from the STA5 weather station.

Based on a literature review of WAM and ETP references, there was no conclusive rationale for any other modifications to the WAM methodology for generating potential or actual ET. **Figures 4.12** and **4.13** do however illustrate that the District estimated ETP and the WAM simulated potential ET have a similar order of magnitude and pattern. The most notable difference between District and WAM estimates are the timing of peak ET during the year, which is 1-2 months earlier according to District estimates. This is consistent with the concept that a few months earlier than the anticipated peak seasonal temperature in each year, cloud cover and rainfall prevent ET from peaking at the same time.

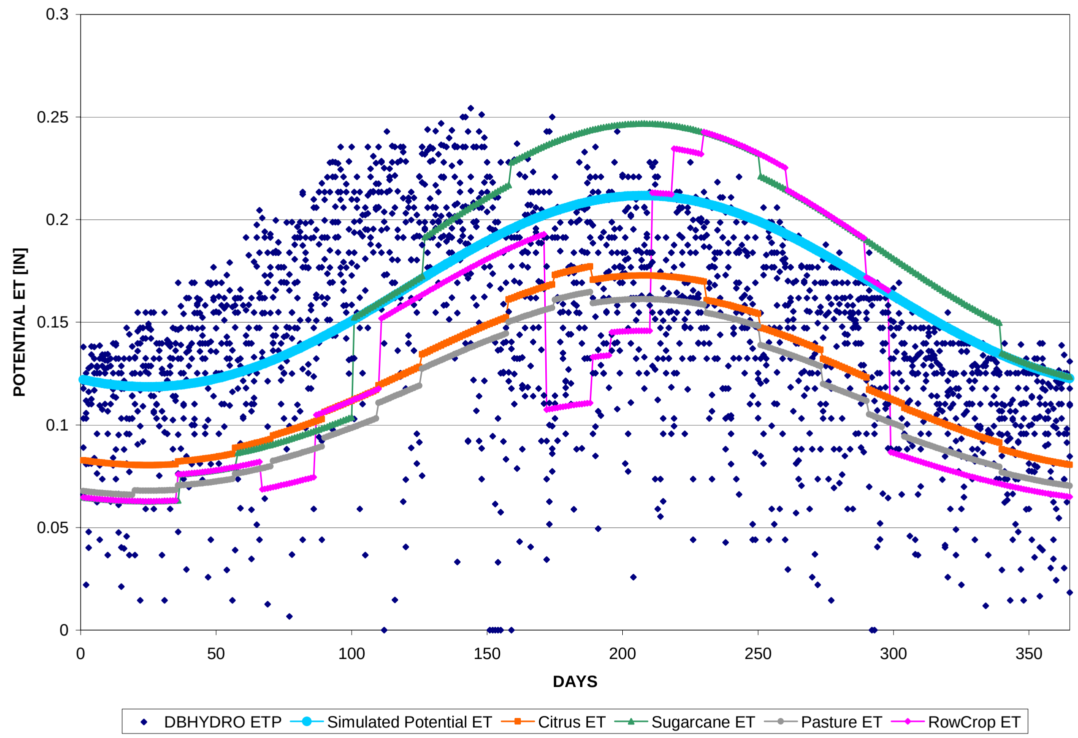



**Figure 4.12: Comparison of District ETP and the default WAM Potential ET**

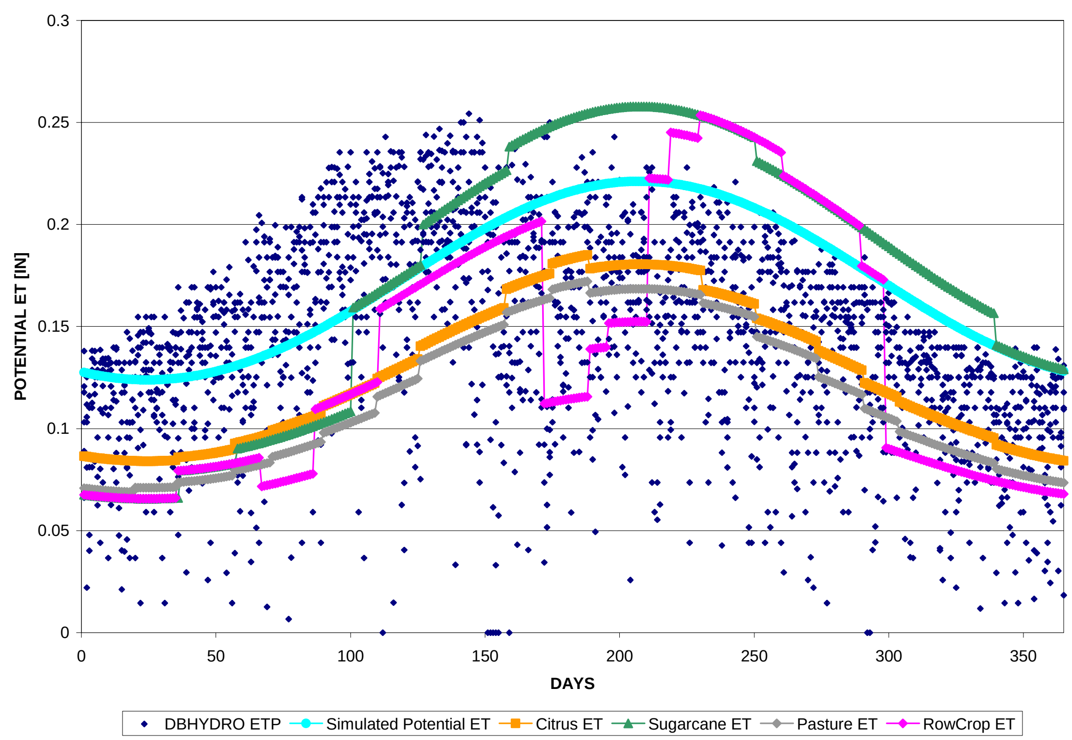



**Figure 4.13: Comparison of District ETP and calibrated WAM potential ET**

### 4.2.2.3 Regional Seepage

The revisions to the initial calibration to improve the representation of interaction between the surficial and Lower Tamiami aquifers is incorporated in the final calibration set-up and as such, is described in detail in Section 3.6. Within this framework, the vertical conductivity of the semi-permeable layer was varied across a wide range of values from 0.017 (initial calibration value) to 0.00001 inches per day. The trial-and-error process of calibration determined that the value of 0.0001 yielded the most accurate representation of the basin discharges.

## 4.3 Modified Parameters for Water Quantity Calibration

WAM is a physically based model, therefore, a simulation that is developed using the appropriate soils and land-use and being forced with accurate rainfall, hydraulic and boundary condition data should yield results that are similar to measured stage and flow data. However, in order to simulate the complexity associated with highly managed agricultural systems there are numerous parameters that can be modified based on available information, or in an attempt to improve the predictive abilities of the simulation. **Table 4.1** provides a description of some of the model parameters that were modified as part of the water quantity calibration process.

**Table 4.1: Calibration parameters and sensitivity**

| INPUT FILE(S) | PARAMETER | RANGE | SENSITIVITY | FINAL |
|---|---|---|---|---|
| ***default.bnz*** | PETFAC | 0.89 - 0.98 (Unitless) | Significant | 0.93 |
| | PETFACEAAMOD | 1.06 - 1.10 (Unitless) | Significant | 1.06 |
| ***field.1, field.2, field.3 and field.4*** | Field Elevation | 12.0 - 22.0 (FT NGVD) | No notable effect | 22 |
| | Internal Ditch Width | Default Width - Double Width | No notable effect | Default |
| ***Hydsurf.in and*** | Unit Hydrograph | Default Duration - Triple Duration | Significant | Default |
| ***Irrigsource.asc*** | Irrigation Source Location | Surface - Subsurface - External | Significant (Surface) - Moderate (Subsurface/External) | Subsurface |
| ***Lu-eaa.bnz*** | Farm control structure width | Default - Half-width | No notable effect | Default |
| ***Soil-eaa.bnz*** | Verical conductivity of confining unit | 0.017 - 0.00001 (inches per hour) | Significant | 0.0001 |
| ***Streamprofile.in*** | Top width of cross section above canal berm | Measured width of canal - 100 meters wider than canal | Significant | 100 meter increase |
| ***Streams.in*** | Length of secondary and tertiary canals | Measured length - Ten times measured length | Moderate | Measured length |
| ***Structures.in*** | Gate Coefficients | 0.5 - 4.6 (Unitless) | Significant | Structure dependent |
| | Gate Opening Conditions | Recorded break-point - Based on published operational strategy - Based on observed stage data | Significant | Structure dependent |
| ***Timedelay.in*** | Overland Flow Velocity | 20,000 - 1,000 (meters/day) | Moderate | 2,000 |
| | Subsurface Flow Velocity | Instantaneous - 50 (meters/day) | Moderate | 50 |

## 4.4 Water Quantity Calibration Results

For the purposes of this project WAM is to be primarily used as a planning tool. WAM is an appropriate fit for this purpose in that it provides simulation results for a variety of management practices at a daily resolution. The following results are presented first at the location of primary basin discharge structures, and then at the location of other monitored sites within the basin. The results are presented as a comparison of simulated and measured time-series. Additionally, there are three statistical measures presented for each comparison of simulated and observed stage and flow: mean-absolute error (MAE), root-mean-squared-error (RMSE) and r-squared. Although r-squared is often used as a statistical metric to indicate the predictive qualities of a simulation, it does not provide insight into the magnitude of the difference between predictions and observations. The RMSE is a useful stastical tool for analyzing the discrepancies, but RMSE can oftentimes overemphasize extreme values (Wilmott, 1982). Also when the distribution of the measured parameter being evaluated does not incorporate a large standard deviation, the range of acceptable errors for the r-squared evaluation is smaller. This is often the case for stage and flow data at structures where operational controls are designed to maintain stages or flows within a specified range.

Unfortunately, although the runoff, percolation and irrigation components of the water balance can be evaluated per land-use, it is not a straight-forward process to generate the water balance components for a given upstream area. In addition, there is no way to output simulated evapotranspiration for a given land-use or spatial extent within the WAM framework. Without an estimate of simulated evapotranspiration, it is difficult to provide any meaningful results from water budget calculations.

### 4.4.1. G-135 Calibration Results

The G-135 structure is at the western most turn of the L-1 Canal. As is illustrated in **Figure 4.14** the G-135 structure has a smaller contributing area than any other structure within the C-139 Basin (approximately 3,600 acres). However, the G-134 structure allows District staff at the Clewiston Field Station to modify the size of the contributing area of the G-135 structure based on the flood protection needs of the nearby residential properties. Since, these operational modifications do not coincide with a regional operational plan, but are instead done on an “as-needed” basis; the opening of G-134 was not included in the calibration, verification or baseline simulations.

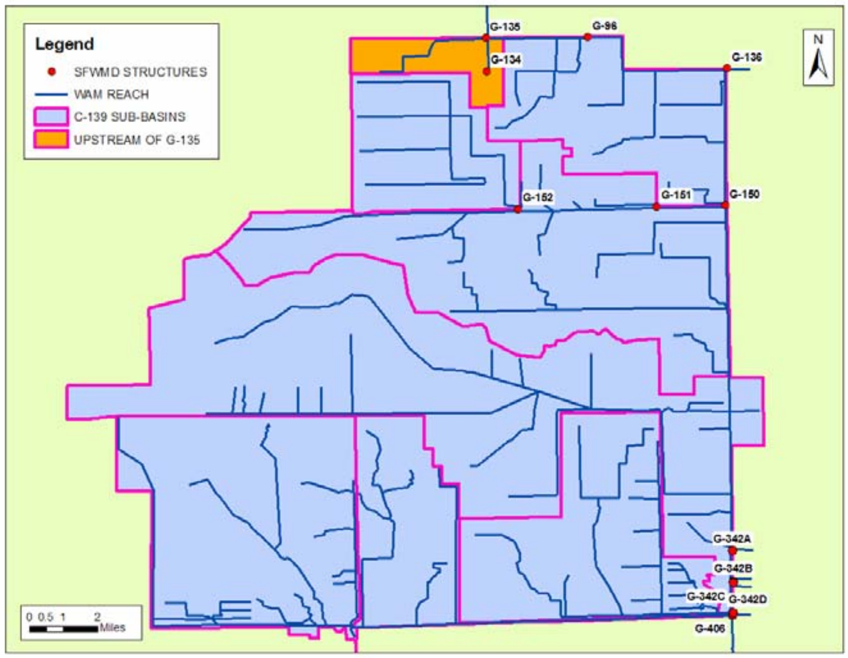
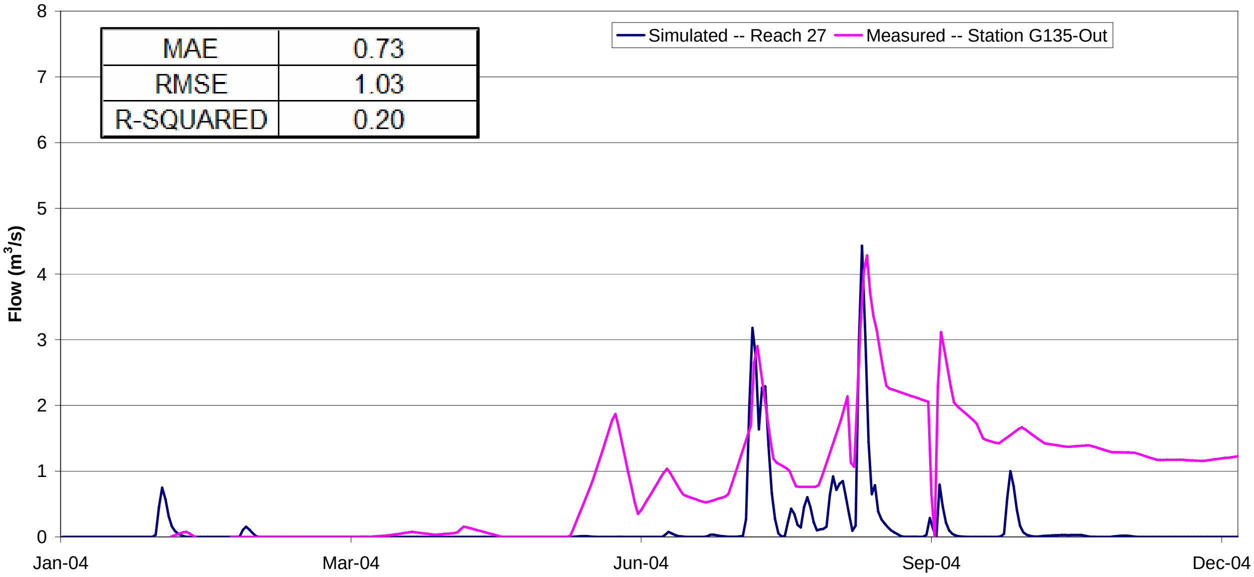



**Figure 4.14: Contributing area for the G-135 structure**

**Figures 4.15** and **4.16** illustrate the daily and cumulative flow at G-135 during 2004, while **Figures 4.17** and **4.18** illustrate the daily and cumulative flow at G-135 during 2005. As was described above there are periods of 2004 and 2005 where the G-134 structure is opened to provide flood protection to a portion of the area that normally contributes to STA5/6 inflows at the southeast corner of the basin. Based on the contributing area outlined in **Figure 4.14** the cumulative flow volume measured for 2004 and 2005 represents 65 and 67 inches of runoff, while the simulated cumulative flow volume represents 11 and 17 inches of runoff, respectively. This calculation provides further support that the operations of the structure were such that the contributing area was dramatically increased. Since the added contributing area is not included in the calibration run, the modeled results for G-135 do not match the measurements.




| | |
|---|---|
| MAE | 0.73 |
| RMSE | 1.03 |
| R-SQUARED | 0.20 |

**Figure 4.15: Daily flows at G-135 for 2004**

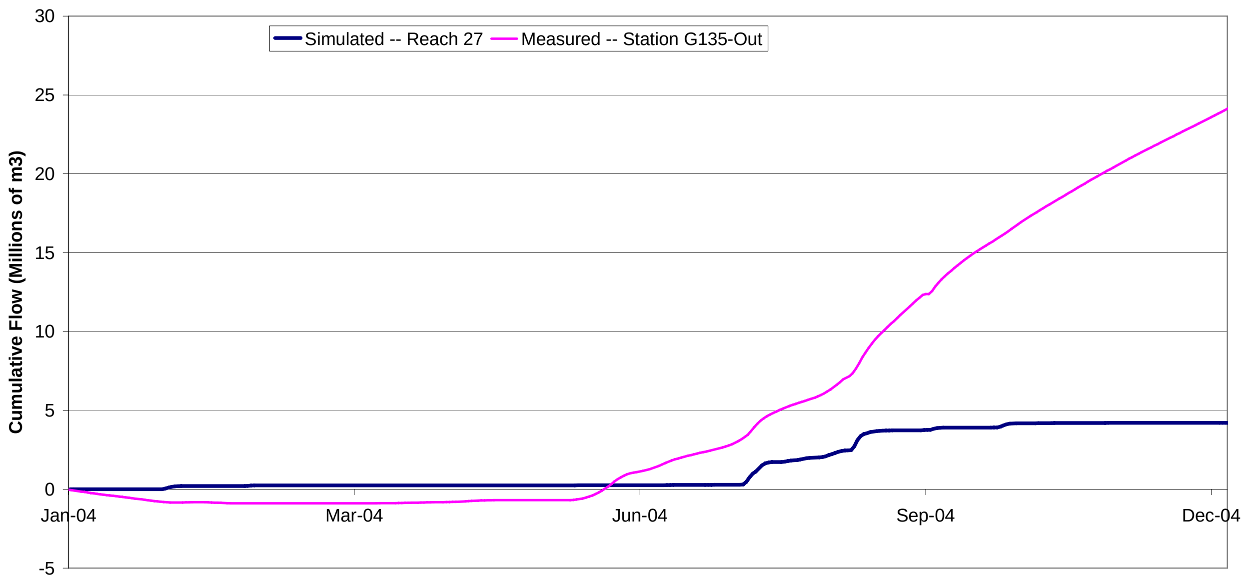



**Figure 4.16: Cumulative flows at G-135 for 2004**

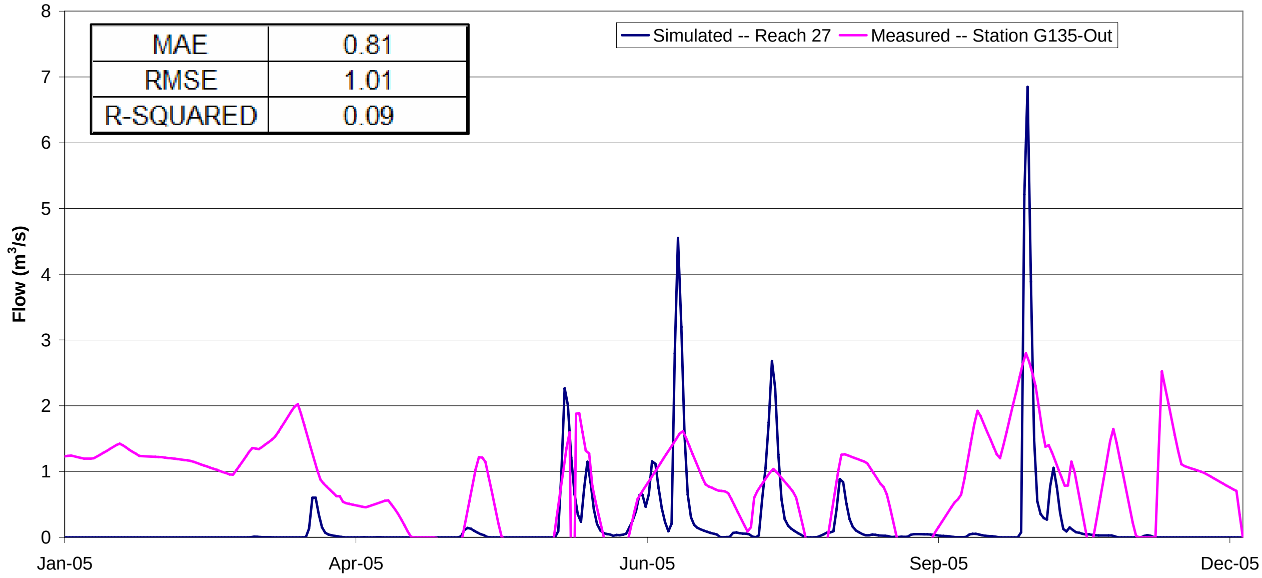



**Figure 4.17: Daily flows at G135 for 2005**

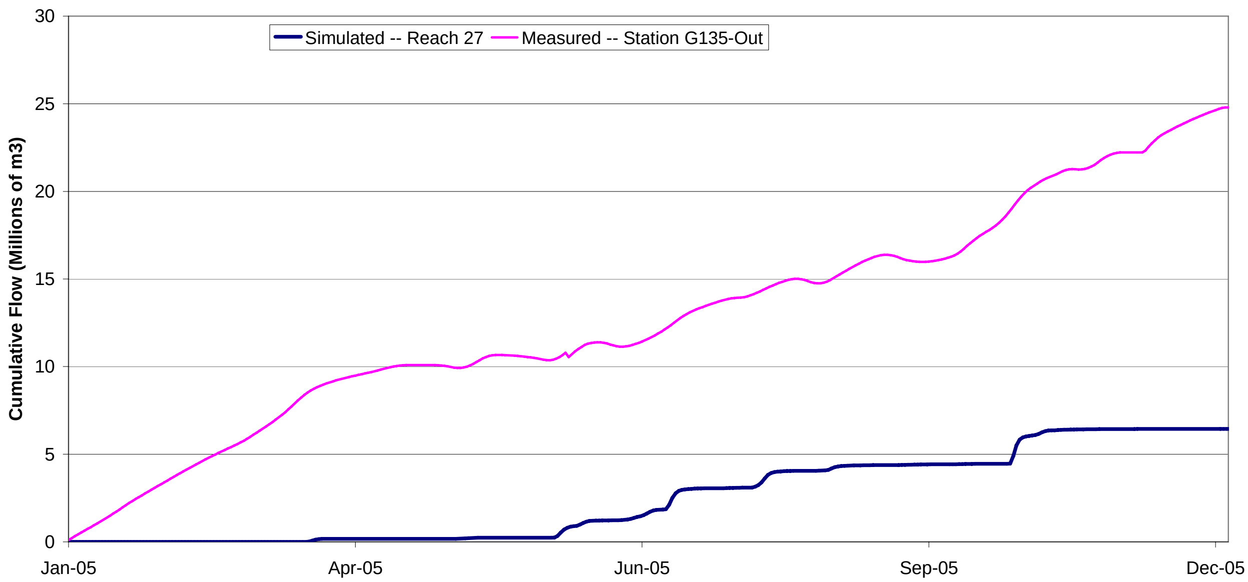



**Figure 4.18: Cumulative flows at G-135 for 2005**

## 4.4.2. G-136 Calibration Results

The G-136 structure is at the north eastern corner of the C-139 Basin and represents the junction between the L-1 and L-1E Canal. As is illustrated in **Figure 4.19,** the G-136 structure is the outlet for 10% of the C-139 Basin (roughly 15,000 acres). The G-136 structure is a manually-operated flashboard riser, and the contributing area is largely improved and unimproved pasture with a portion also in sugar cane production.

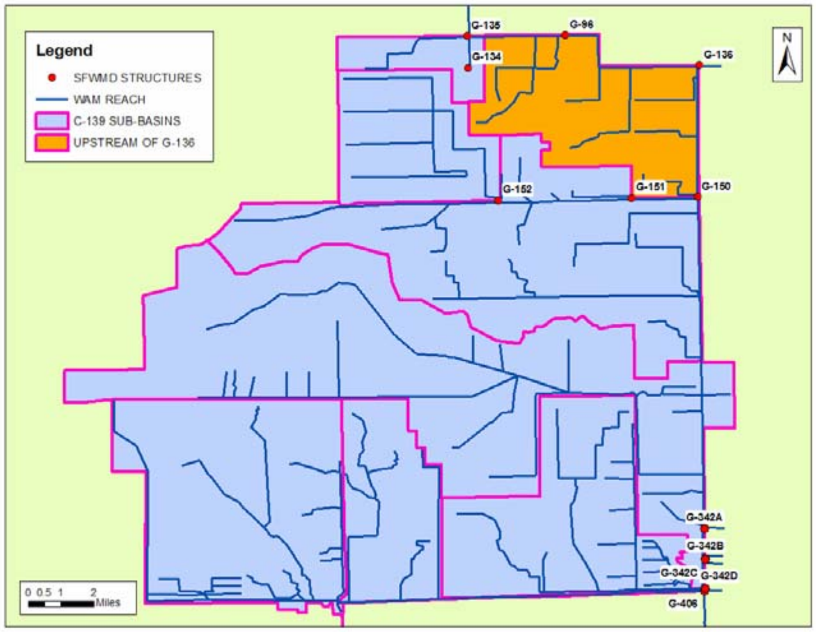



**Figure 4.19: Contributing area for the G-136 structure**

**Figures 4.20** through **4.22** illustrate the daily and cumulative flow and upstream stage at G-136 during 2004, while **Figures 4.23** through **4.25** illustrate the daily and cumulative flow and upstream stage at G-136 during 2005. Based on the contributing area outlined in **Figure 4.19** the cumulative flow volume measured for 2004 and 2005 represents 12.9 and 22.0 inches of runoff, while the simulated cumulative flow volume represents 12.5 and 16.8 inches of runoff, respectively.

For both 2004 and 2005, the model appears to overestimate flow during the dry season and underestimate flow during the later portion of the wet season. This could potentially mean that within the simulation the fields are being over drained during the dry season resulting in simulated soil storage during the wet season, that is not available in the natural system. As was described in Section 3.6 above, the C-139 Basin is rain-fed and as such the landowners' management practices are designed to hold water during times when rainfall is scarce, leaving less available storage when rainfall occurs. This practice may describe the results shown in **Figures 4.20** through **4.25**.

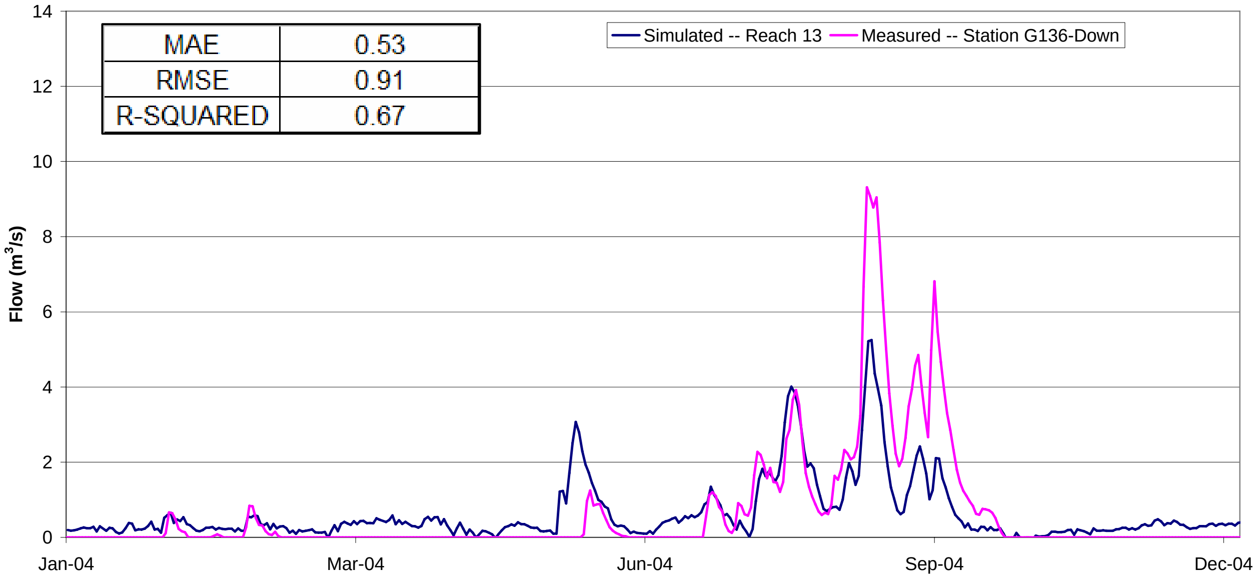



**Figure 4.20: Daily flows at G-136 for 2004**

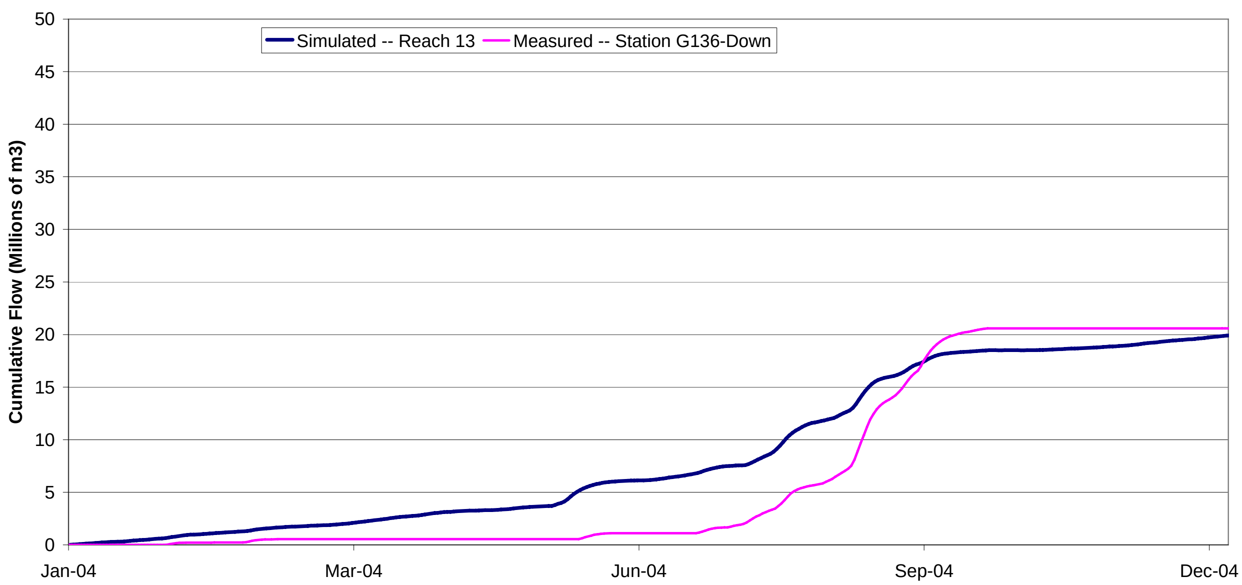



**Figure 4.21: Cumulative flows at G-136 for 2004**

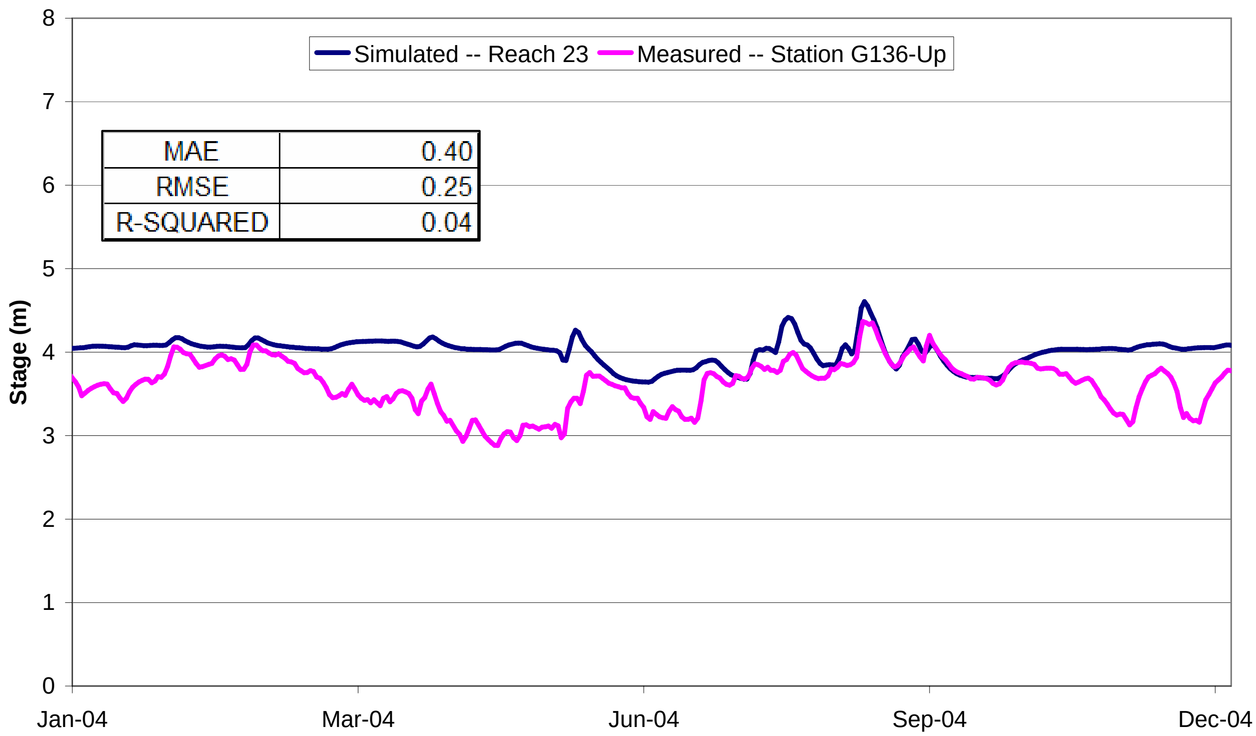



**Figure 4.22: Stages upstream of G136 for 2004**

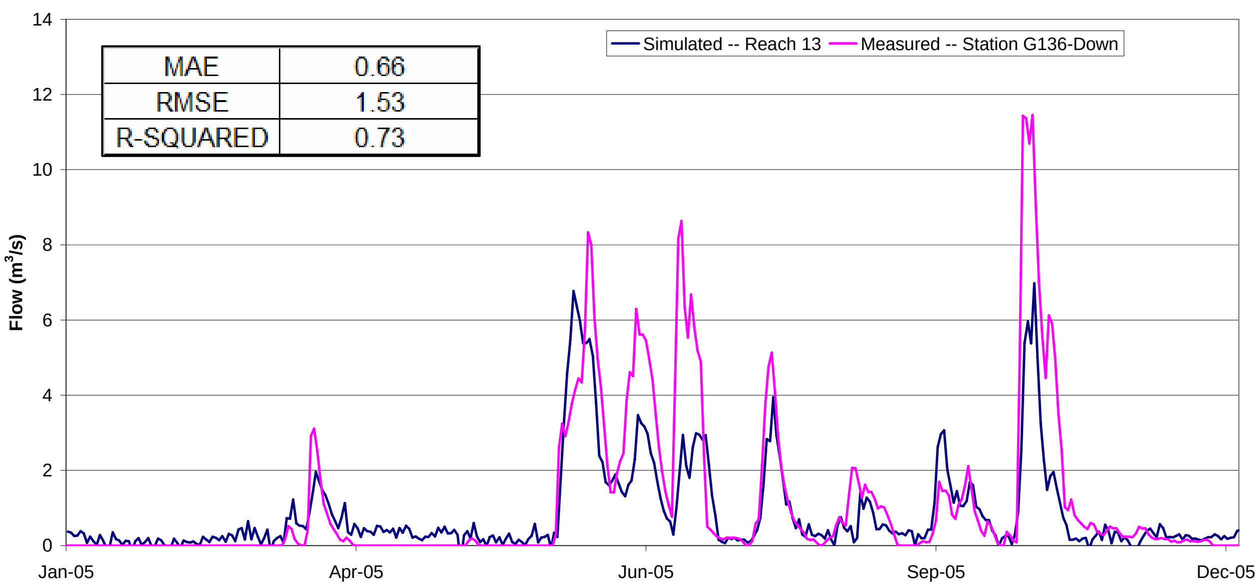



**Figure 4.23: Daily flows at G136 for 2005**

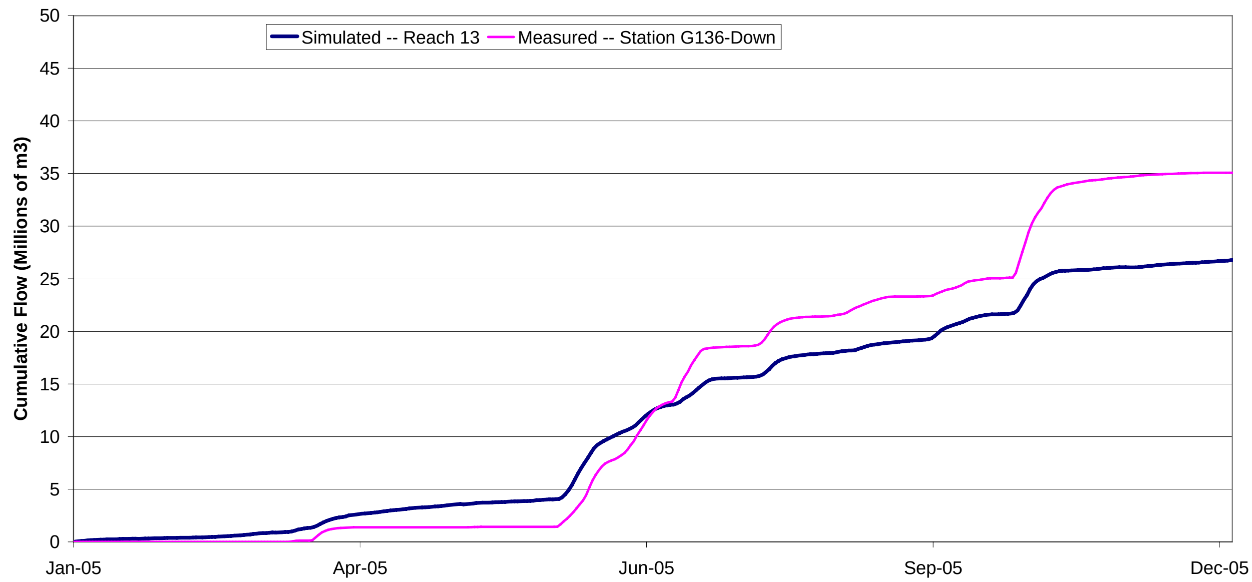



**Figure 4.24: Cumulative flows at G-136 for 2005**

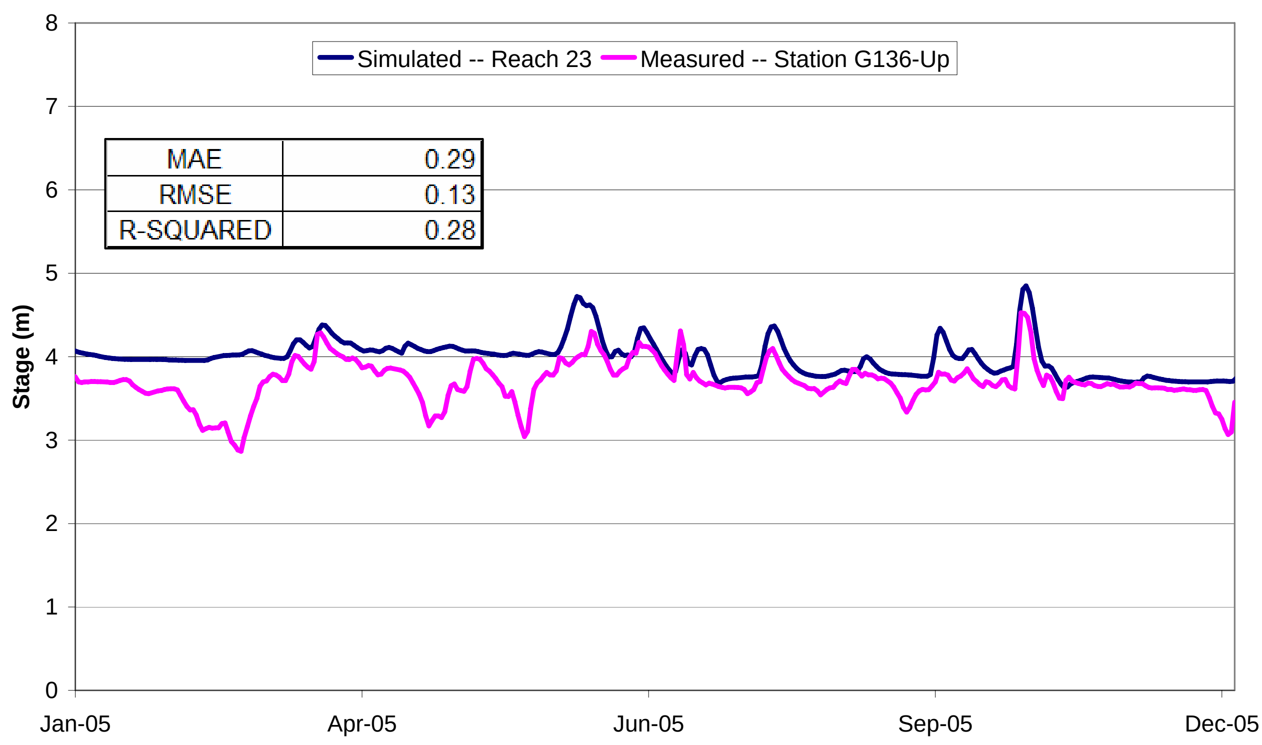



**Figure 4.25: Stages upstream of G136 for 2005**

## 4.4.3. STA5 Inflow and G-406 Calibration Results

The portion of the basin that does not contribute to either the G-135 or G-136 structure contributes to the G-342A, G-342B, G-342C, G-342D and G-406 structures. The G-342A and G-342B structures are the inflows for STA5 Cell 1, and the G-342C and G-342D structures are the inflows for STA5 Cell 2. Operationally, G-406 is to remain closed during average conditions to allow all C-139 runoff to be diverted into STA5, however, when flood protection becomes a concern, the G-406 structure is opened diverting water south towards Compartment C, STA6 and Water Conservation Area 3A (WCA3A). For the purposes of the regional calibration of the hydrologic and hydraulic portions of WAM, the simulated and measured flows for all five control structures are combined in comparisons. As is illustrated in **Figure 4.26,** the STA5 and G-406 structures act as the outlet for nearly 90% of the C-139 Basin (approximately 150,000 acres). The STA5 Inflow and G-406 structures are underflow gates operated by telemetry.

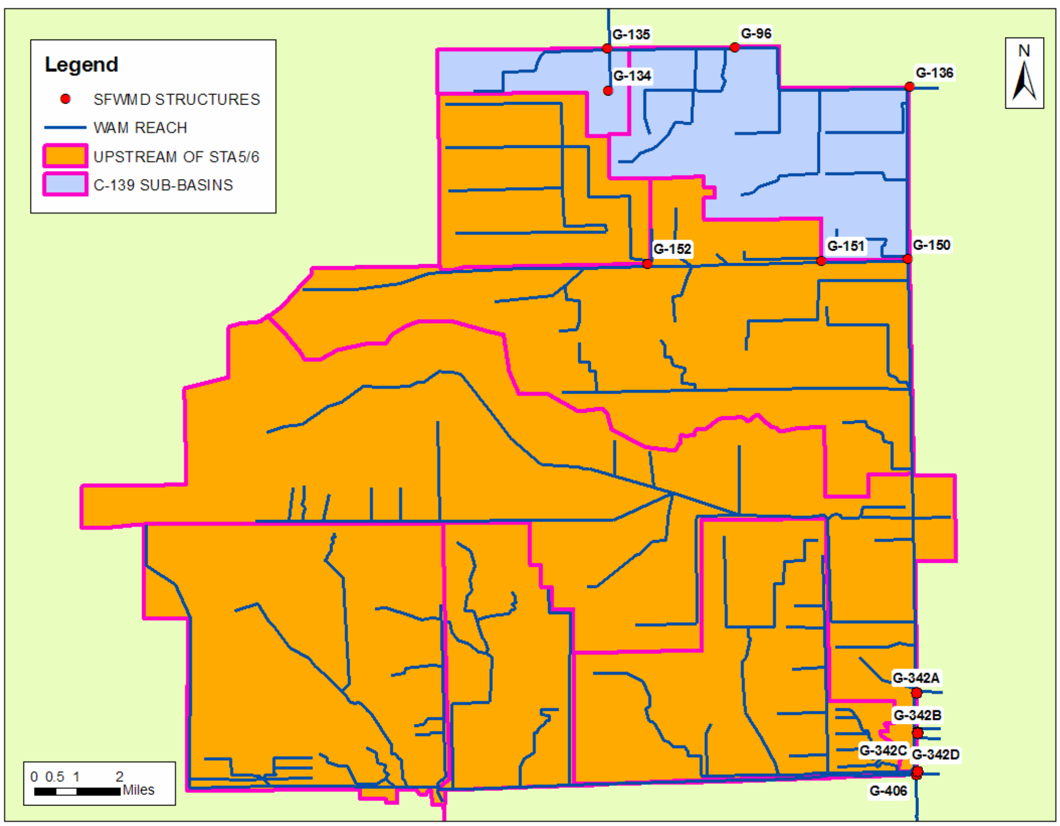



**Figure 4.26: Contributing area for STA5 and the G-406 structure**

**Figures 4.27** and **4.28** illustrate the daily and cumulative combined flow at the STA5 inflow structures and G-406 during 2004. Based on the contributing area outlined in **Figure 4.26** the cumulative flow volume measured for 2004 represents 15.8 inches of runoff, while the simulated cumulative flow volume represents 11.1 inches of runoff. The calibration results shown in **Figure 4.27** for 2004 illustrate simulated flow during the period from March until June with peaks as large as 20 cms, where no measured flow exists. This phenomenon results in overestimation in cumulative flow as is shown in **Figure 4.28**. During this period, according to available records the STA5 Inflow and G-406 structures are closed; however as was described in Section 3.5 above the G-406 gate is operated based on the District's documented operational strategies and not based on the archived gate opening data. This modification insures that the dramatic increase in stages characteristic of the initial calibration results is not repeated. Upon review of archived log books made available by the operations division of the District, the following anomalies were discovered:

- Regular preventive maintenance operations that caused control to be diverted to local control for periods less than one-day;
- One day where the G-342C gate was unable to be closed (5/20); and
- Isolated incidences of power loss (4/13-4/16, 5/14, 6/1).

However, none of this was significant or wide-spread enough to explain the flows shown in **Figure 4.15** below. **Figure 4.29** illustrates that the majority of flow occurring during this period is at the G-406 structure and not into STA5. **Figure 4.30** illustrates that the stages within the L-3 Canal upstream of the G-406 structure are overestimated significantly while the measured stages are significantly drawn down during this period. One potential rationale for the canal stage drawdown is described in Sections 4.2.2.4 above. Since the source of the measured drawdown is unclear, accordingly, it was not possible to modify model input parameters appropriately in an attempt to recreate this phenomenon.

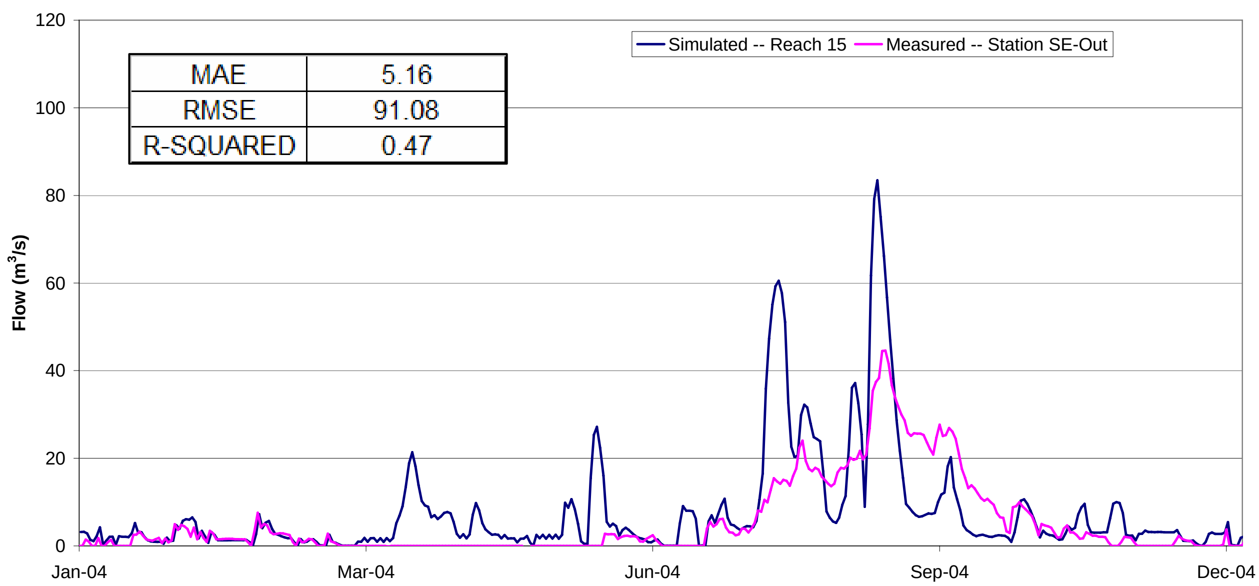



**Figure 4.27: Daily flows at STA5 Inflow and G-406 for 2004**

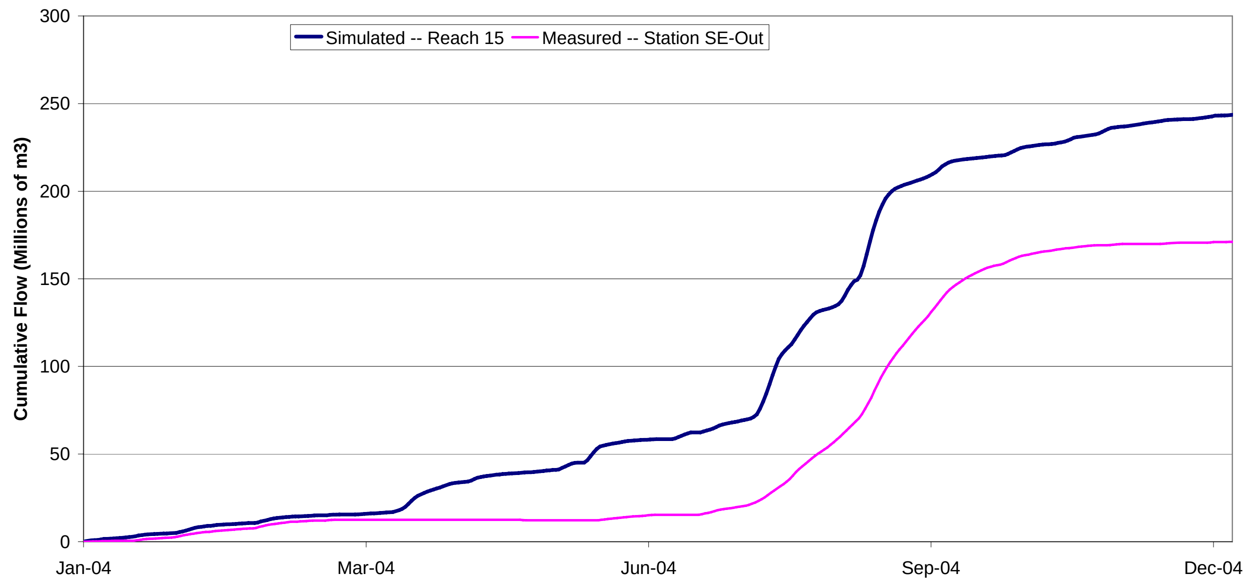



**Figure 4.28: Cumulative flows at STA5 Inflow and G-406 for 2004**

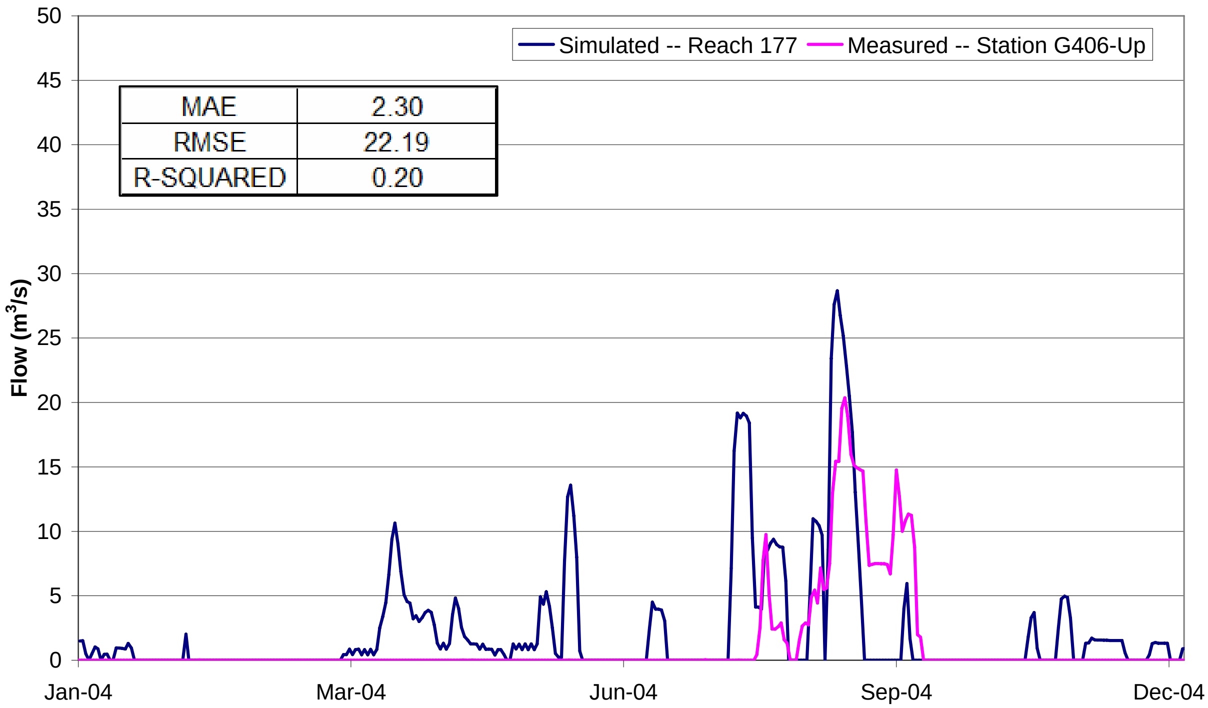



**Figure 4.29: Daily flows at G-406 for 2004**

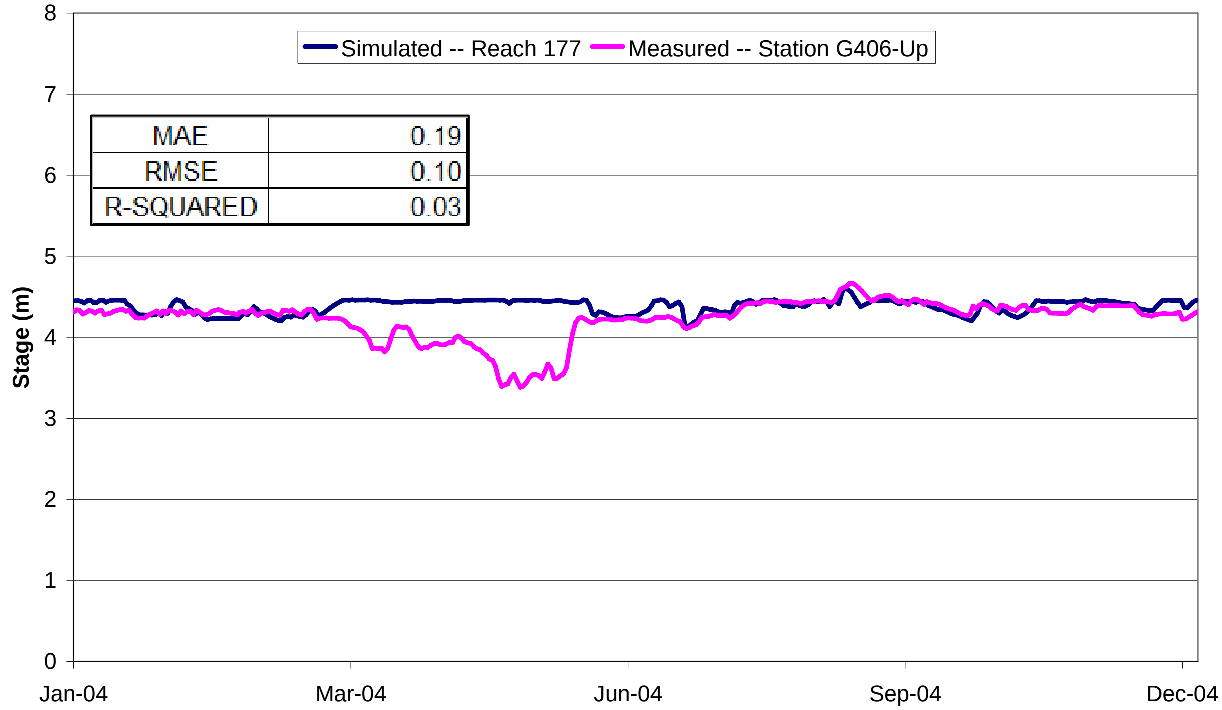



**Figure 4.30: Daily Stages Upstream of G-406 for 2004**

**Figures 4.31** and **4.32** illustrate the daily and cumulative combined flow at the STA5 inflow structures and G-406 during 2005. Based on the contributing area outlined in **Figure 4.26** the cumulative flow volume measured for 2005 represents 25.5 inches of runoff, while the simulated cumulative flow volume represents 23.2 inches of runoff. **Figures 4.33** and **4.34** demonstrate a comparison of the simulated and measured flows and stages at the G-406 structure during 2005. Since 2005 contained more rainfall, the phenomenon exhibited in 2004 with an overprediction of stages and flows during the dry season, does not appear as significant.

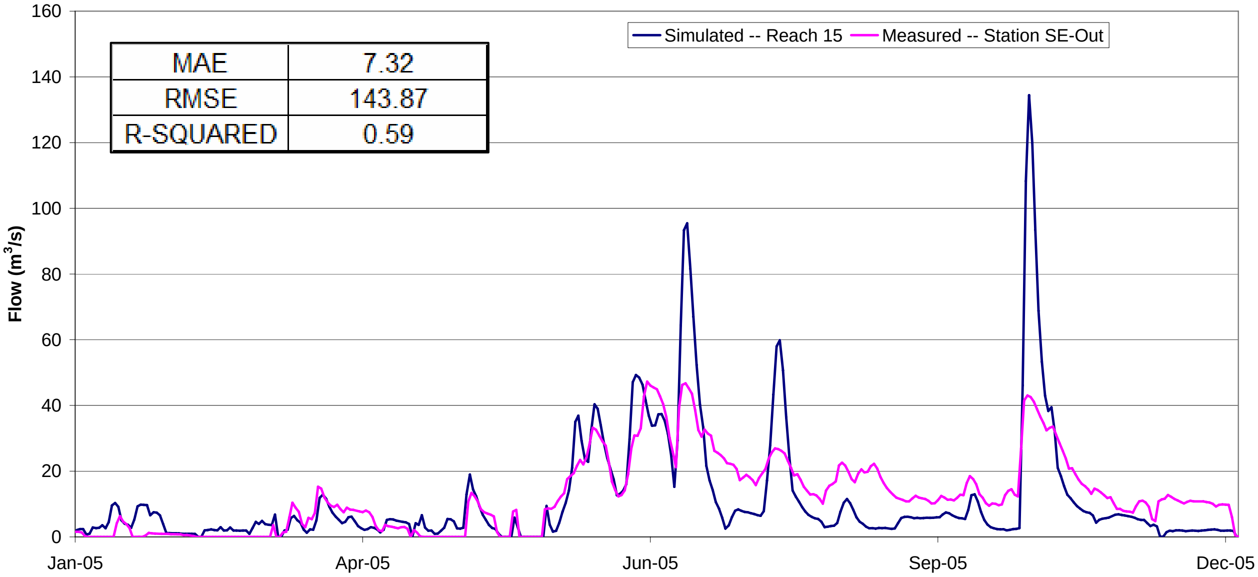



**Figure 4.31: Daily flows at STA5 Inflow and G-406 for 2005**

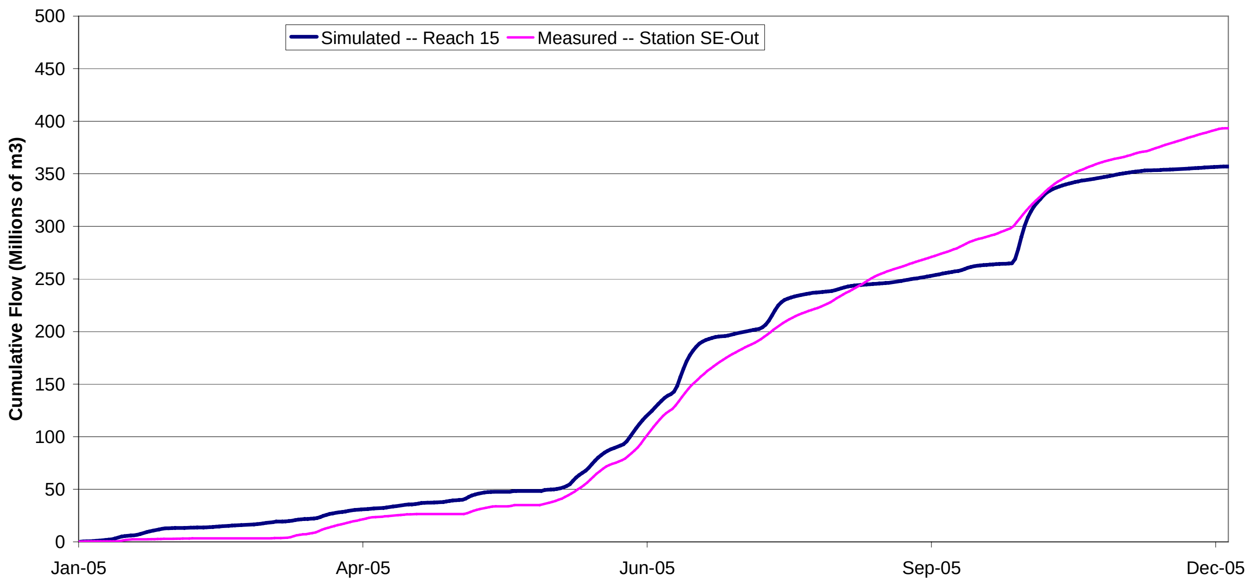
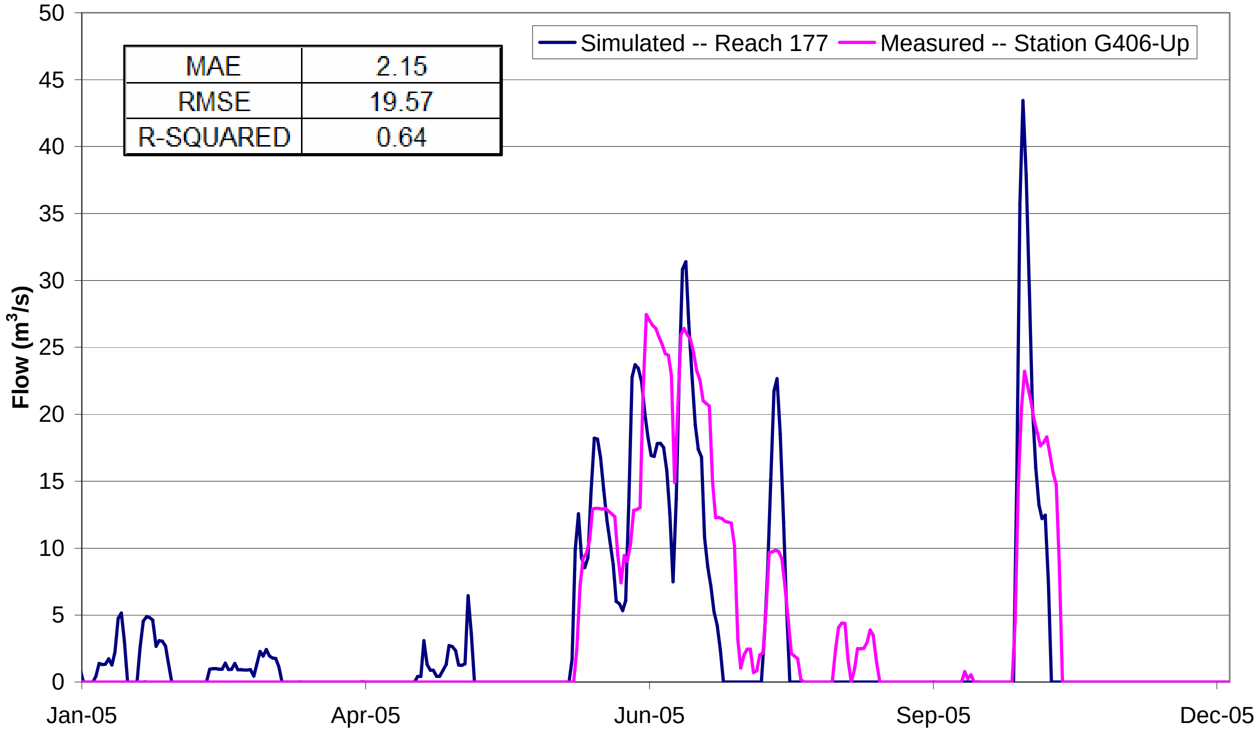
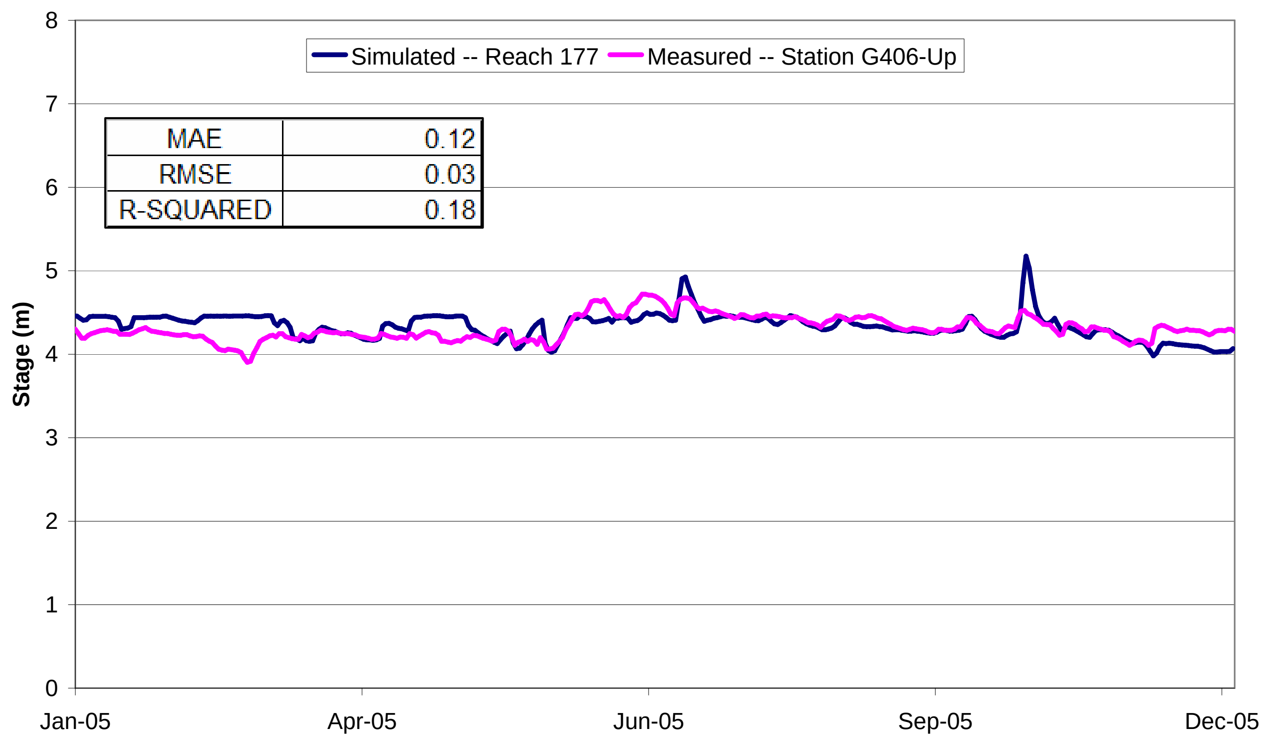



**Figure 4.32: Cumulative flows at STA5 Inflow and G-406 for 2005**




| | |
|---|---|
| MAE | 2.15 |
| RMSE | 19.57 |
| R-SQUARED | 0.64 |

**Figure 4.33: Daily flows at G-406 for 2005**




| | |
|---|---|
| MAE | 0.12 |
| RMSE | 0.03 |
| R-SQUARED | 0.18 |

**Figure 4.34: Daily Stages Upstream of G-406 for 2005**

## 4.4.4. Secondary Structures Calibration Results

Based on the calibration finalized at the regional level, the following results describe the simulated stages and flows at upstream monitoring locations. The G-96 structure is two 66-inch corrugated metal pipes with flashboard risers on the upstream (west) side. This structure is manually operated by District staff from the Clewiston field station, and the operations are recorded and made available through the District. For the purposes of the model, the operations are based on daily averages of the recorded flashboard elevation data. **Figures 4.35** and **4.36** illustrate a comparison of the calibrated stages on the upstream and downstream side of the G-96 structure for the year 2004. Since 2004 was a dry year, the stage stays relatively constant at the weir elevation on the upstream side, however on the downstream side of the structure the model over predicts the stages. **Figure 4.37** and **4.38** illustrate the daily and cumulative flow comparison, which does not compare favorably during the wet season, however, since there are no monitoring stations on-site for flow or gate opening, estimates at G-96 are not always accurate. **Figures 4.39** and **4.40** illustrate a comparison of the calibrated stages on the upstream and downstream side of the G-96 structure for the year 2005. Since 2005 was a relatively wet year, there is significantly more variability upstream of the structure. Since the contributing area for G-96 is mostly pasture, which is not irrigated, these results do not demonstrate a significant drawdown of stage during the dry season, as was seen at G-136 and G-406. **Figure 4.41** and **4.42** illustrate the daily and cumulative flow comparison for 2005.

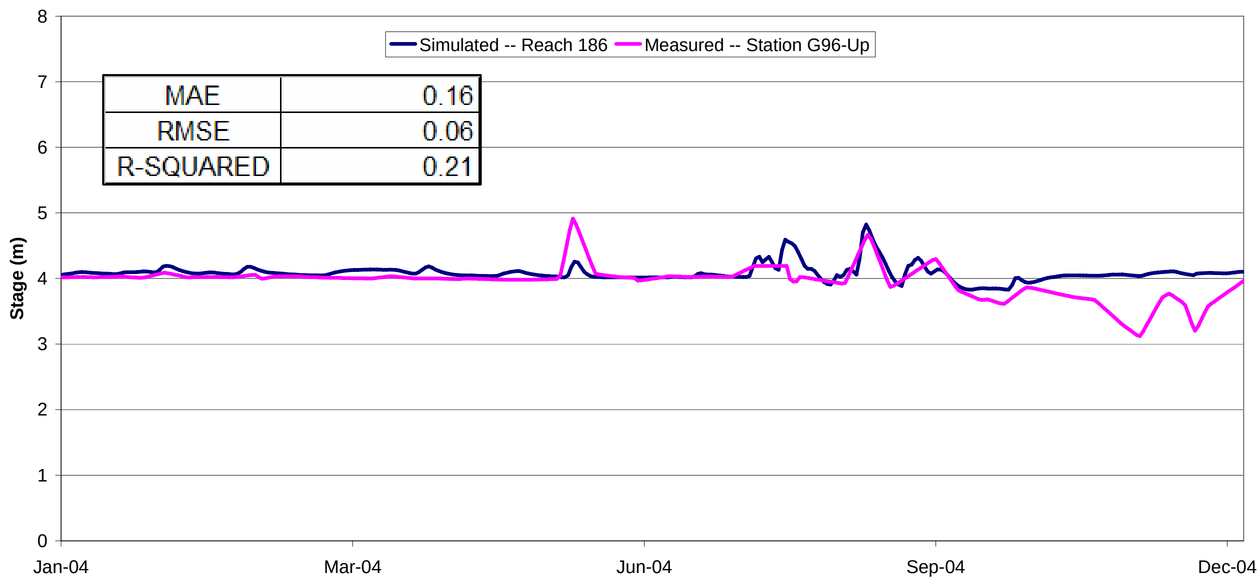
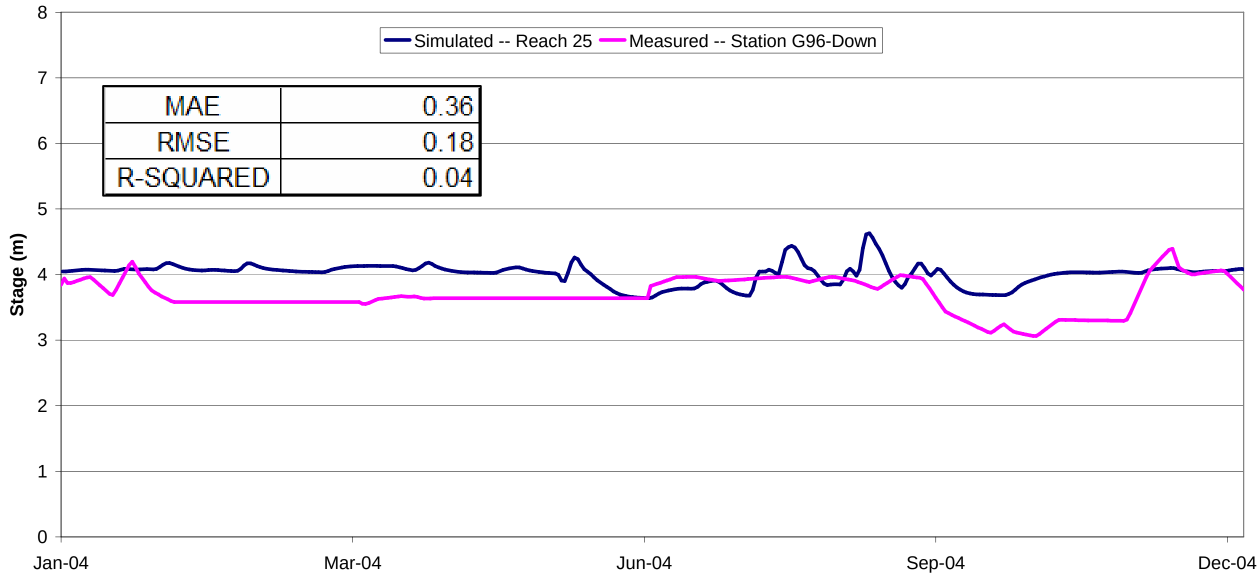
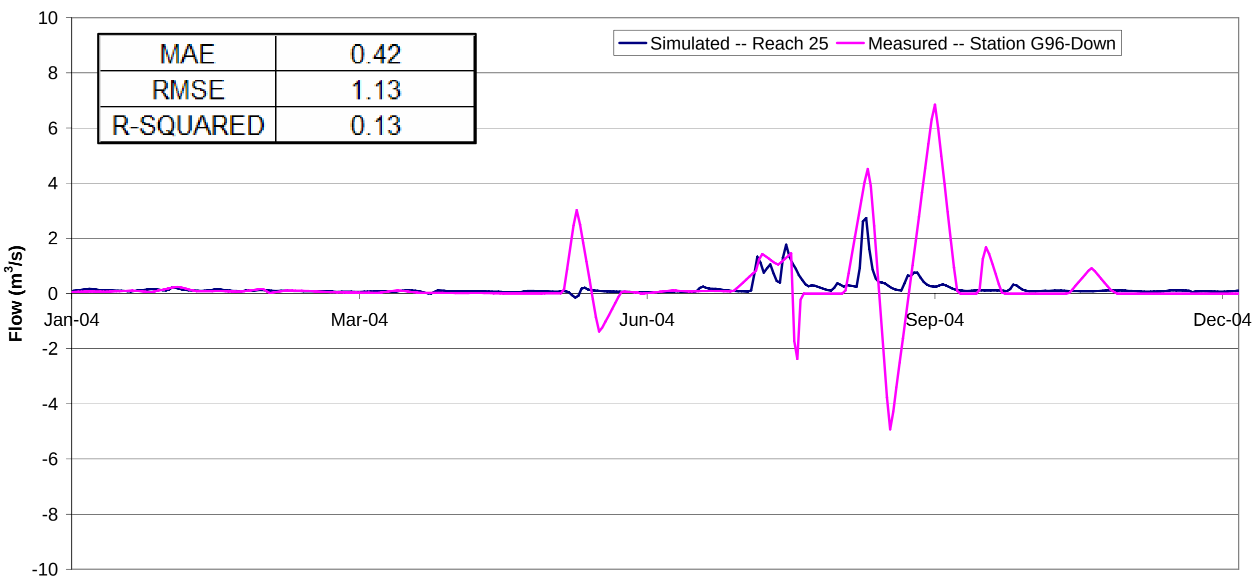



**Figure 4.35: Calibration stages upstream of G-96 (west) for 2004**




| | |
|---|---|
| MAE | 0.36 |
| RMSE | 0.18 |
| R-SQUARED | 0.04 |

**Figure 4.36: Calibration stages downstream of G-96 (east) for 2004**




| | |
|---|---|
| MAE | 0.42 |
| RMSE | 1.13 |
| R-SQUARED | 0.13 |

**Figure 4.37: Daily flows at G-96 for 2004**

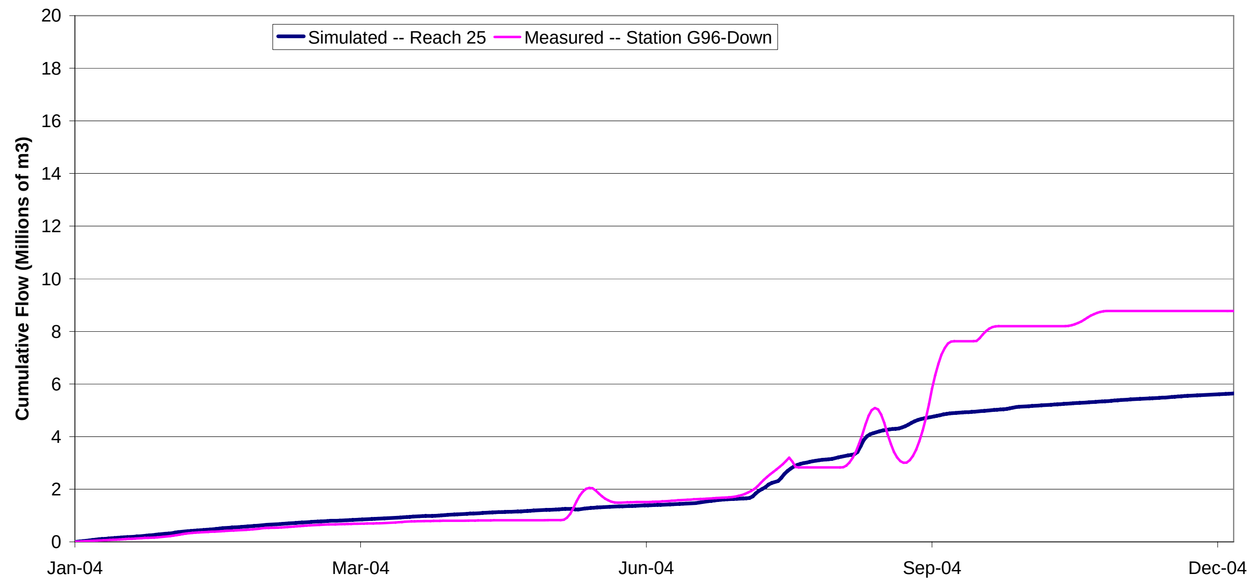
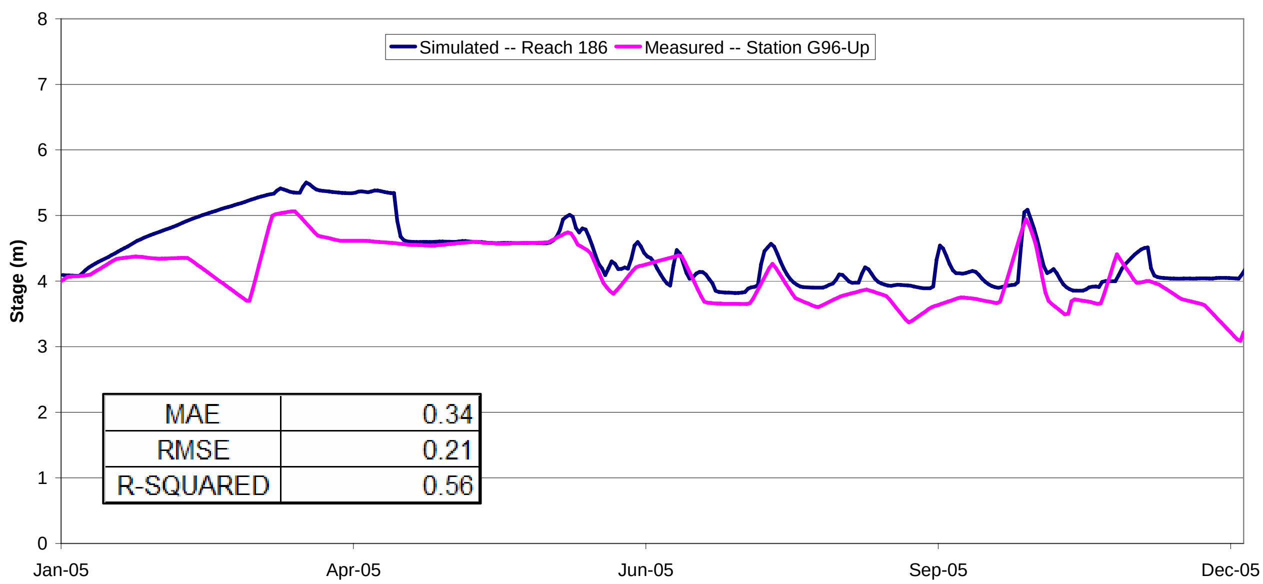



**Figure 4.38: Cumulative flows at G-96 for 2004**




| | |
|---|---|
| MAE | 0.34 |
| RMSE | 0.21 |
| R-SQUARED | 0.56 |

**Figure 4.39: Calibration stages upstream of G-96 (west) for 2005**

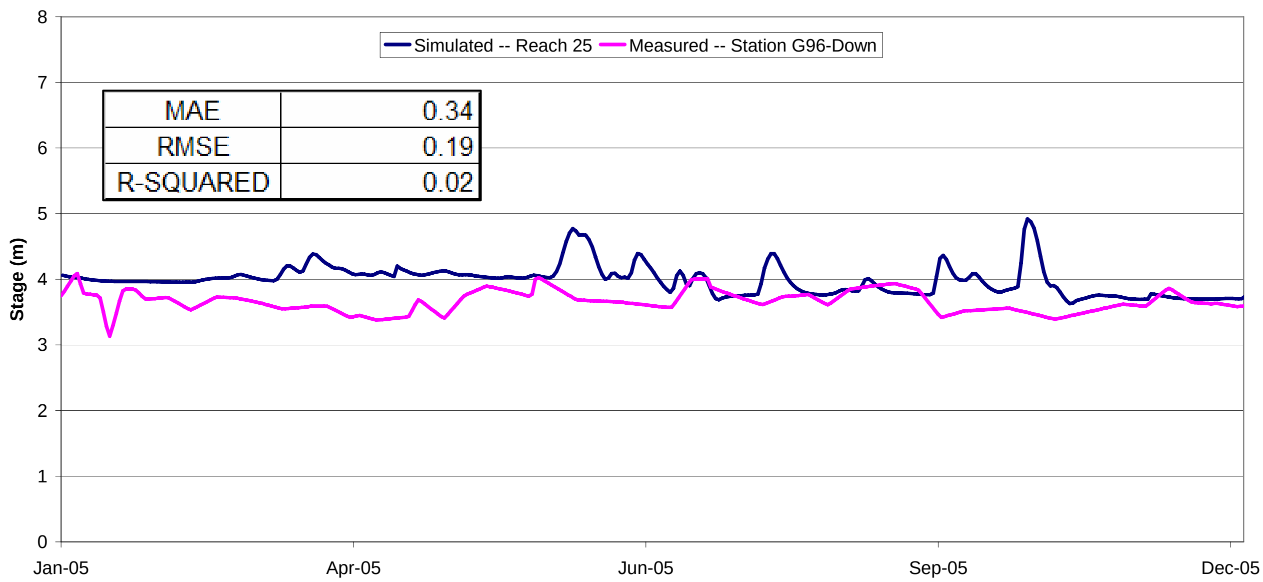



**Figure 4.40: Calibration stages downstream of G-96 (east) for 2005**

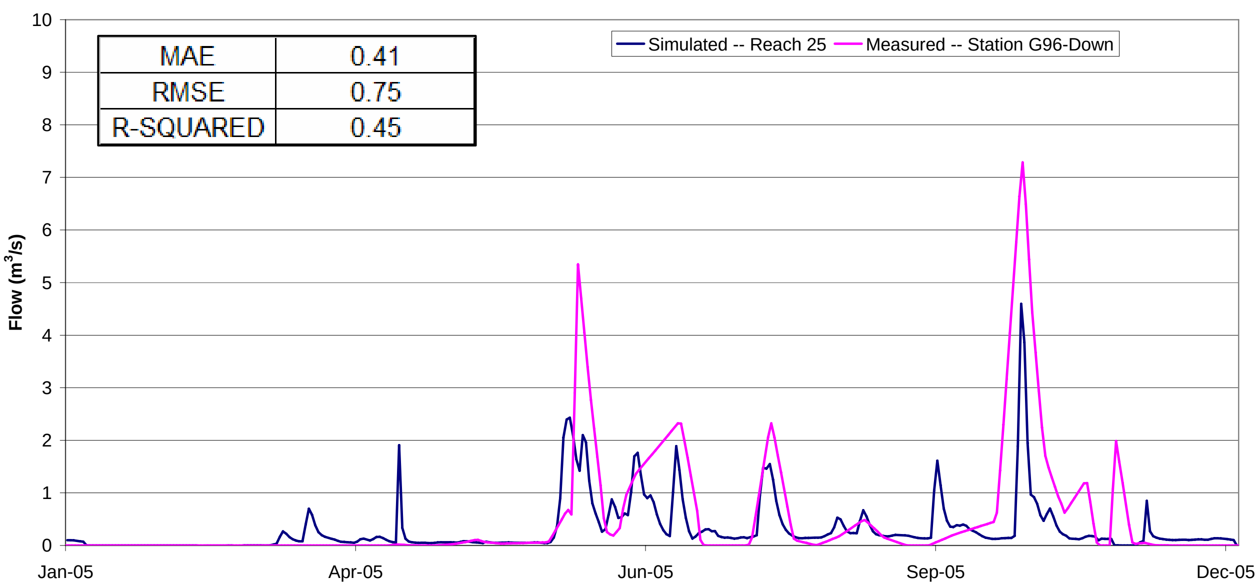



**Figure 4.41: Daily flows at G-96 for 2005**

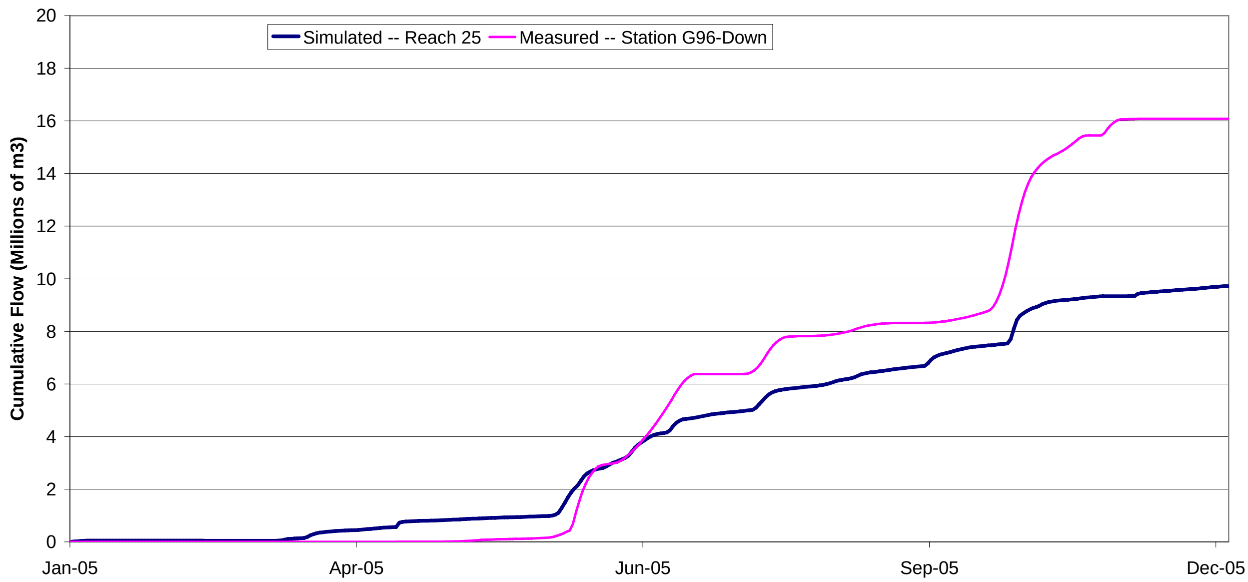



**Figure 4.42: Cumulative flows at G-96 for 2005**

**Figures 4.43** through **4.44** illustrate a comparison of the simulated and measured stages upstream and downstream of the G-150 water control structure for 2004. The flows at G-150 are more accurately measured since stage and gate opening data is obtained via telemetry. The daily and cumulative flows illustrated in **Figures 4.45** and **4.46** are indicative of the fact that the specifics concerning the site's geometry and operation are well documented. This structure consists of three 84-inch corrugated metal pipes with underflow gates on the downstream (south) side. The operation of this gate is via telemetry, and the opening of the gate is limited to major events, thereby making the structure a sub-basin divide for much of the year. As such there is often no correlation between the upstream and downstream stages. The calibration demonstrates reasonable agreement for the upstream stages in 2004 and 2005 (**Figures 4.47** and **4.48**), while the daily and cumulative flow results indicate that the model is accurately representing the G-150 structure (**Figure 4.49** and **4.50**).

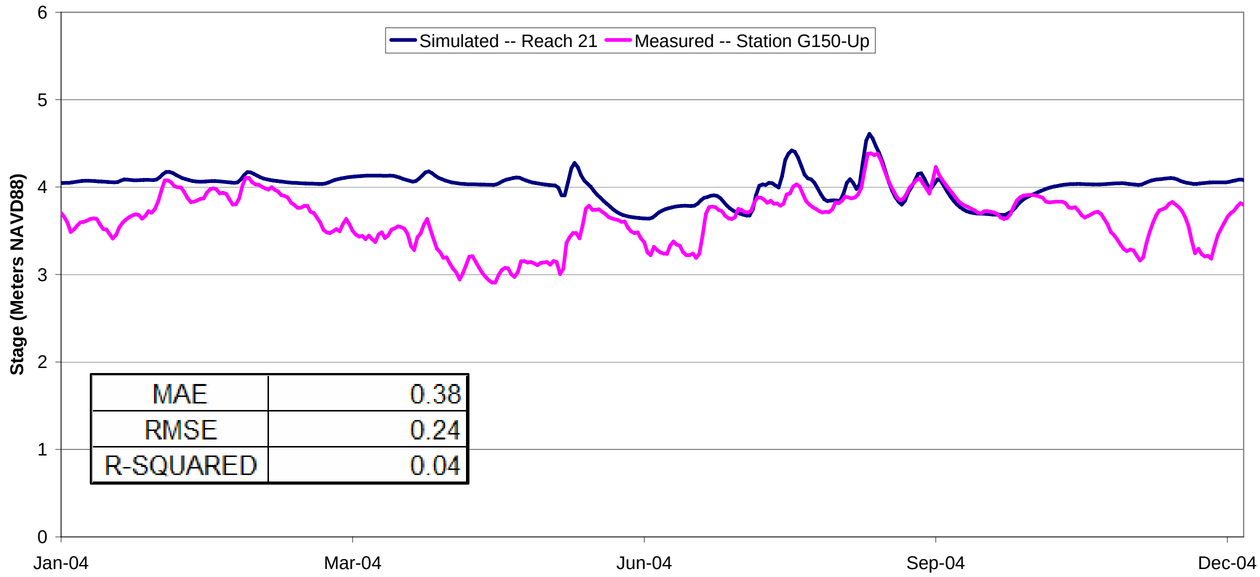



**Figure 4.43: Calibration stages upstream of G-150 (north) for 2004**

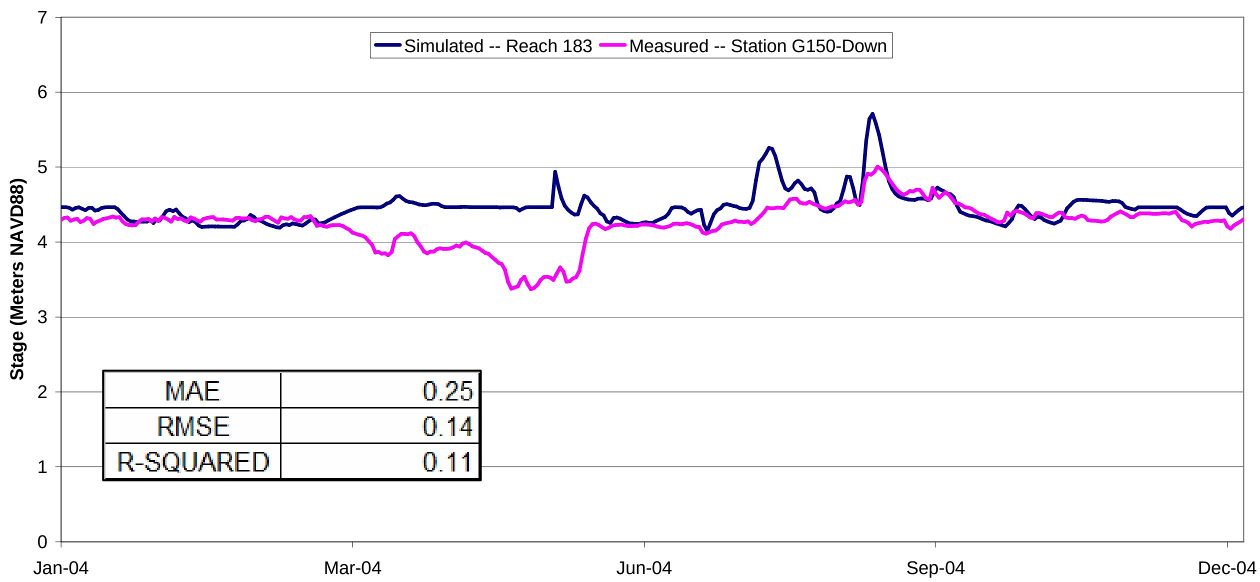



**Figure 4.44: Calibration stages downstream of G-150 (south) for 2004**

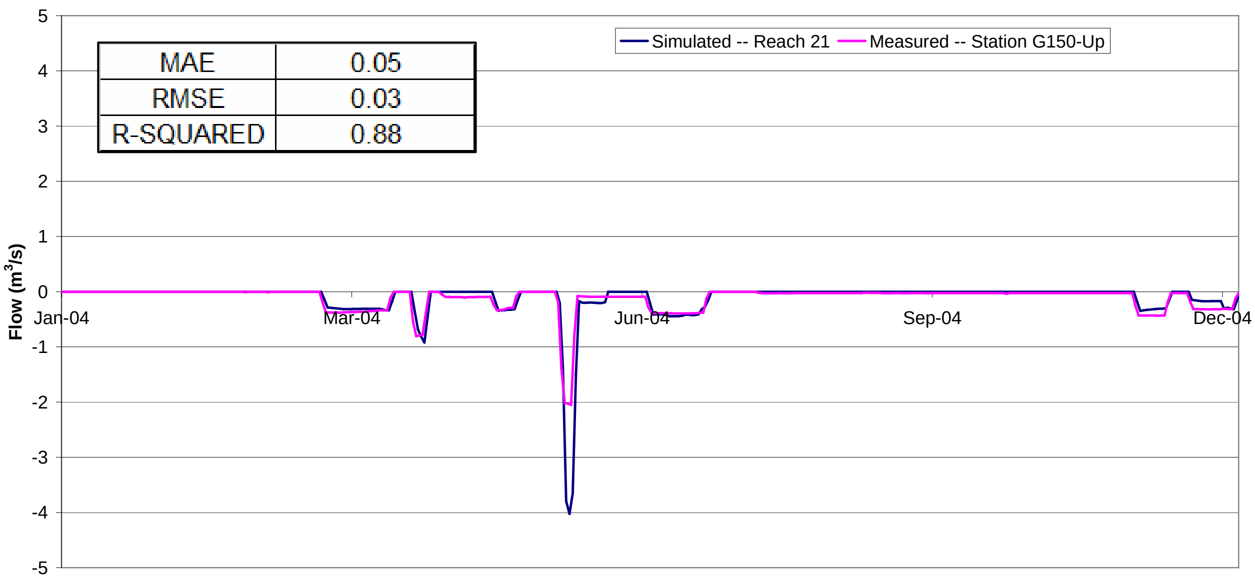



**Figure 4.45: Daily flows at G-150 for 2004**

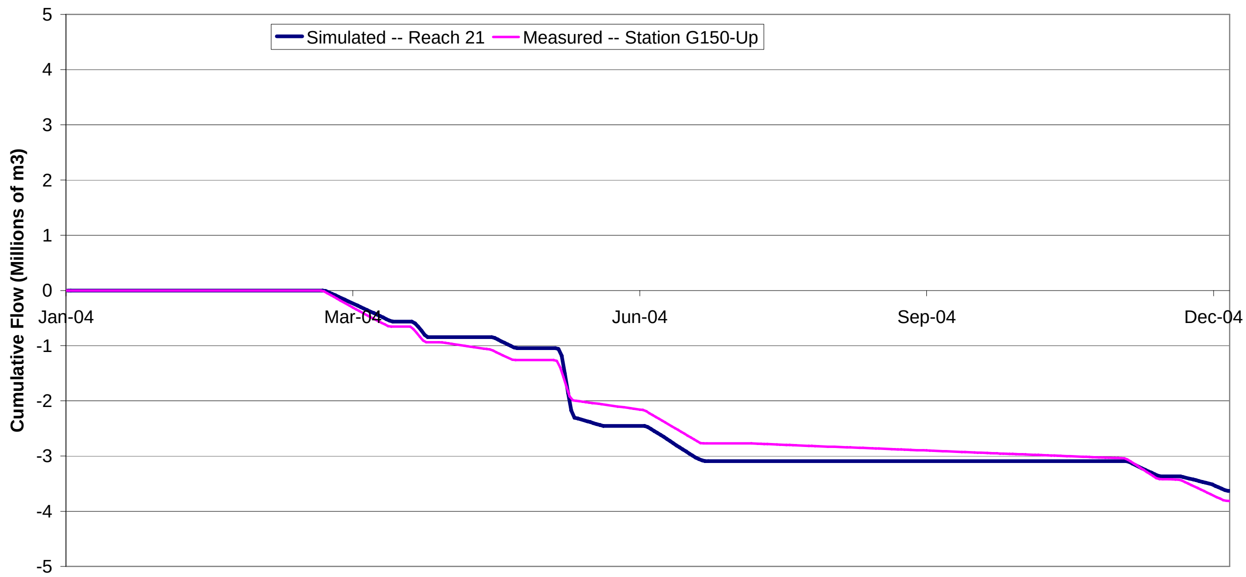



**Figure 4.46: Cumulative flows at G-150 for 2004**

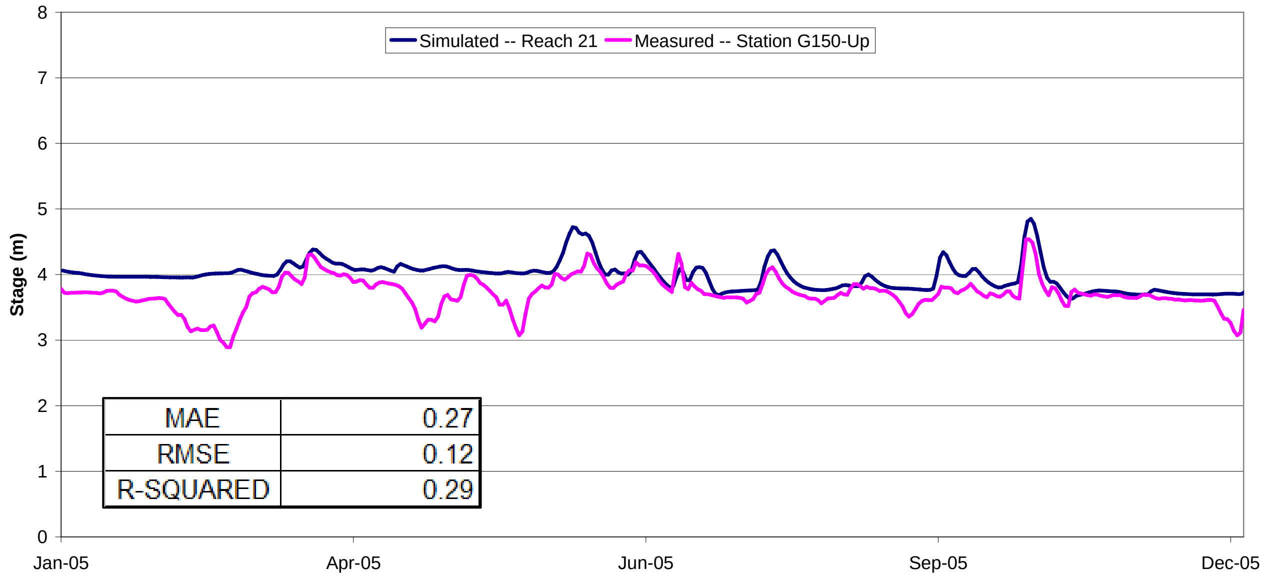



**Figure 4.47: Calibration stages upstream of G-150 (north) for 2005**

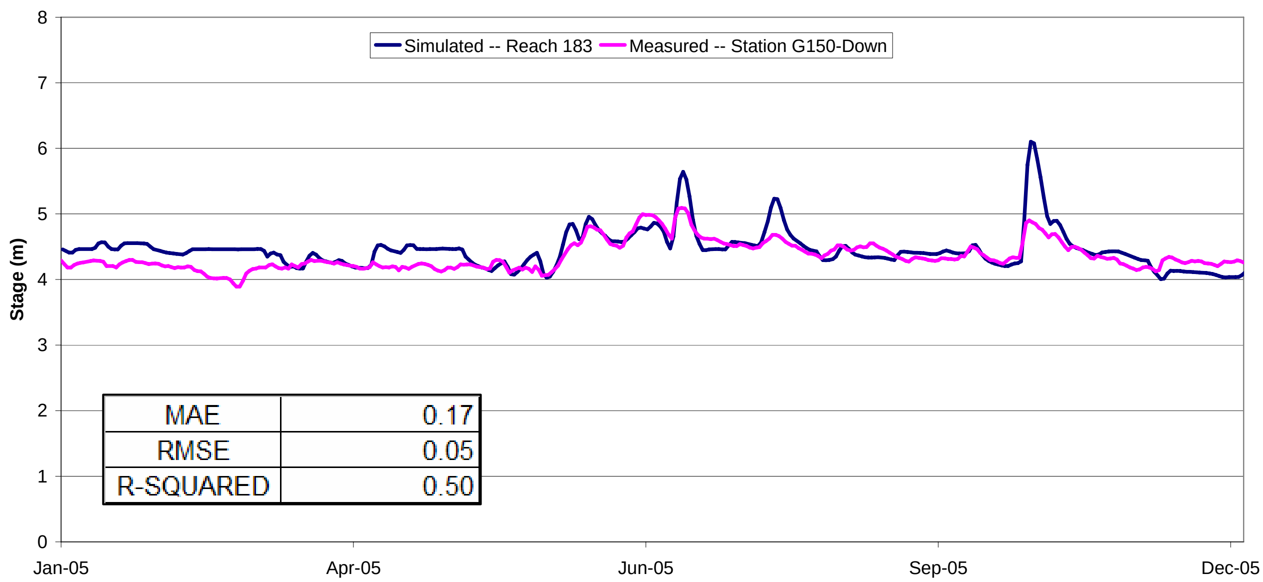



**Figure 4.48: Calibration stages downstream of G-150 (south) 2005**

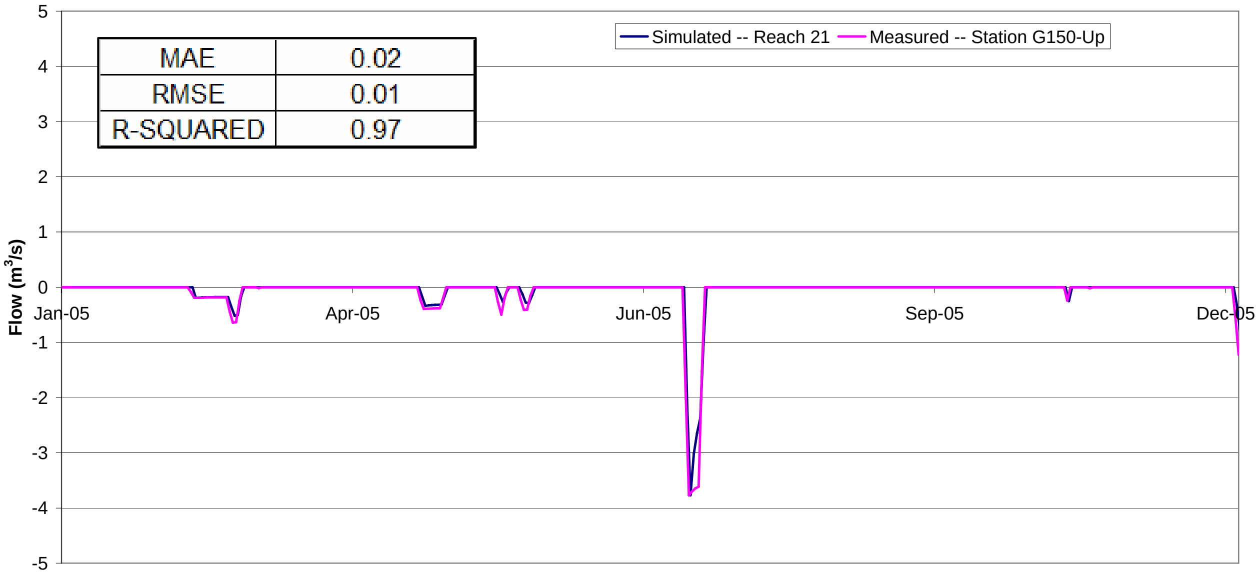



**Figure 4.49: Daily flows at G-150 for 2005**

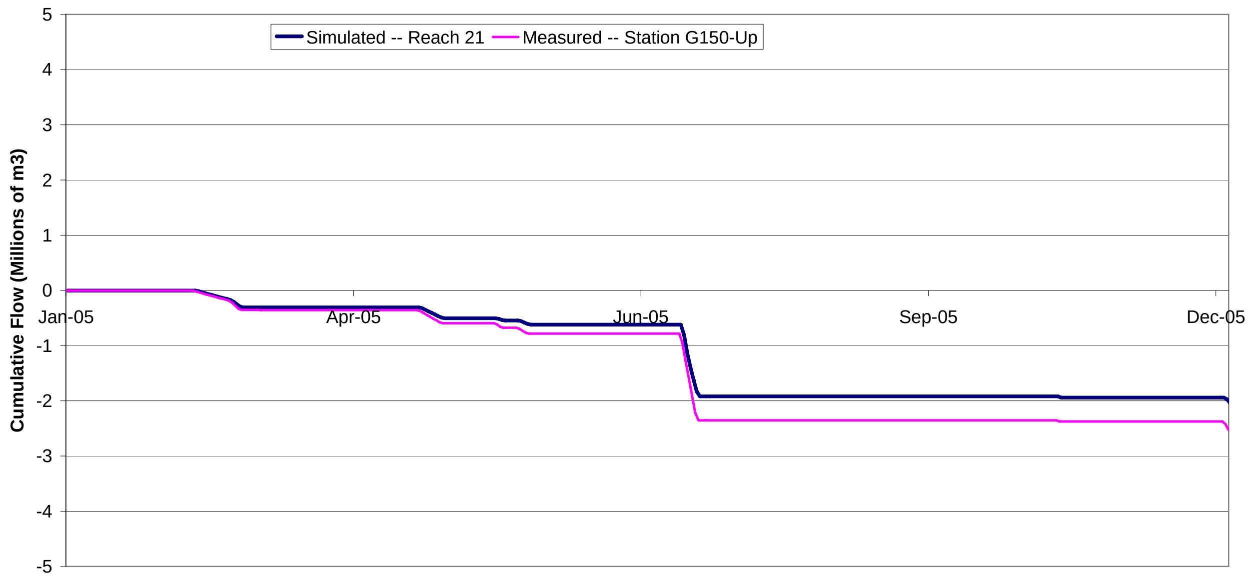
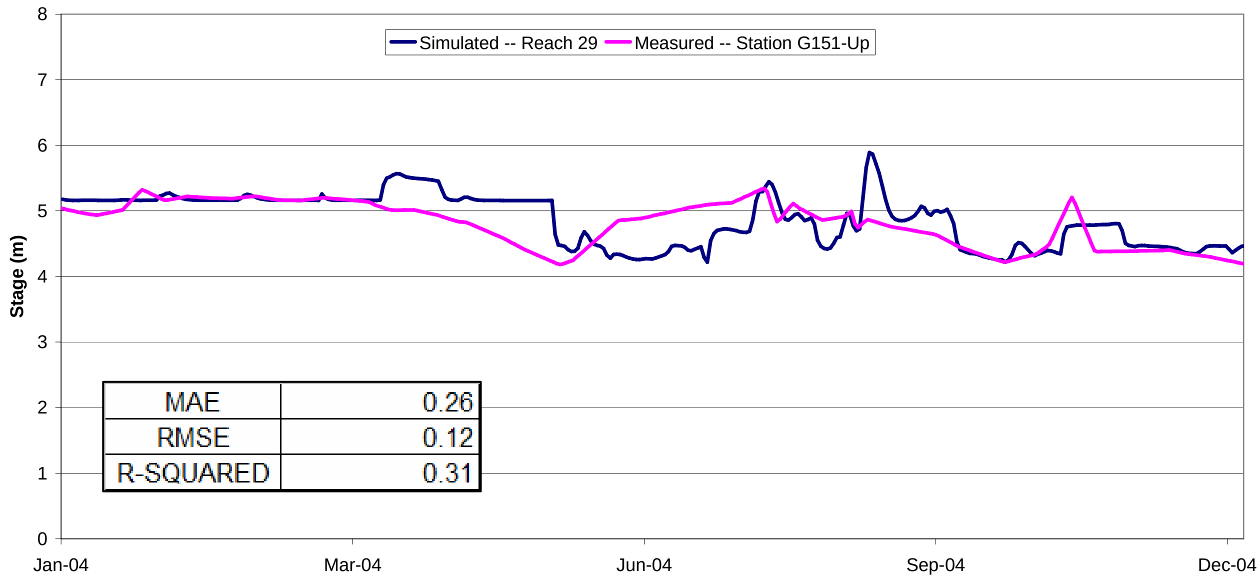



**Figure 4.50: Cumulative flows at G-150 for 2005**

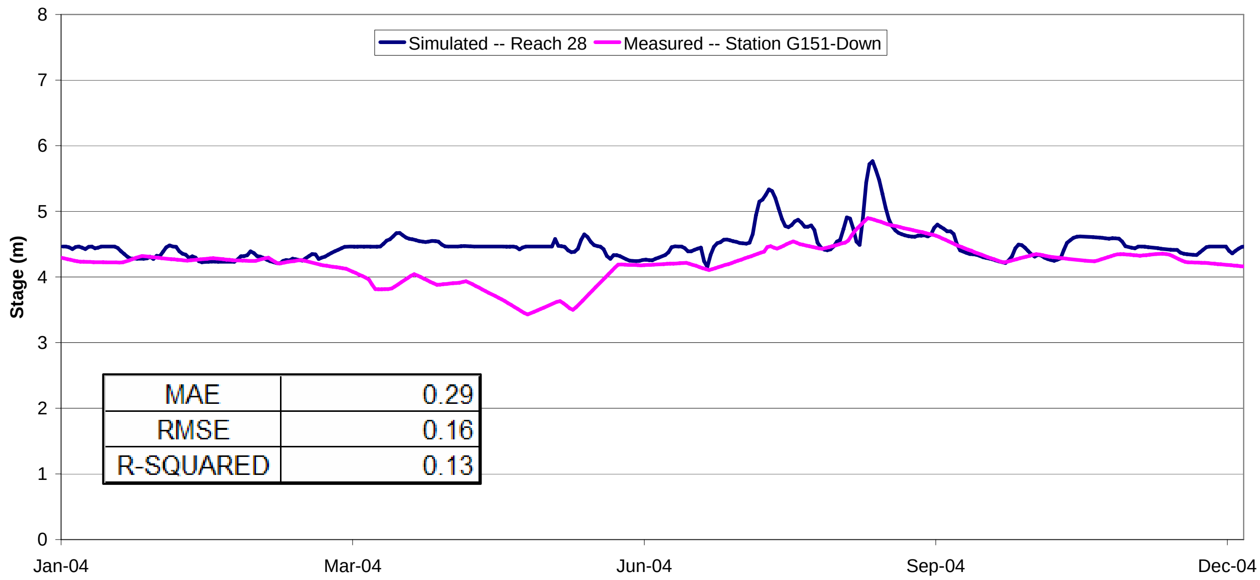
**Figures 4.51** through **4.62** illustrate the comparison of simulated and measured results for the G-151 and G-152 structures. The G-151 structure is two concrete box culverts, measuring 10-foot by 8-foot with flashboard risers on the upstream (west) side, and the G-152 structure is four 72-inch corrugated metal pipes with a flashboard riser on the upstream (west) side. As was described in Section 3.5 above, both gates are operated by private landowners under a cooperative agreement with the Clewiston Field Station staff of the District. Therefore within the simulation, operation of the G-151 and G-152 structures is assumed based on a review of measured data.

Measured flow data is reported on DBHYDRO for the G-151 structure, however, since there no flow monitoring equipment or gate opening telemetry collocated with the structure it is likely that this record is based on manually recorded gate opening data. As such, the validity of the recorded flow data illustrated in **Figure 4.53** and **4.54** appears questionable, especially with respect to the large magnitude negative flow. Measured flow is not available for the G-152 structure.




| | |
|---|---|
| MAE | 0.26 |
| RMSE | 0.12 |
| R-SQUARED | 0.31 |

**Figure 4.51: Calibration stages upstream of G-151 (west) for 2004**




| | |
|---|---|
| MAE | 0.29 |
| RMSE | 0.16 |
| R-SQUARED | 0.13 |

**Figure 4.52: Calibration stages downstream of G-151 (east) for 2004**

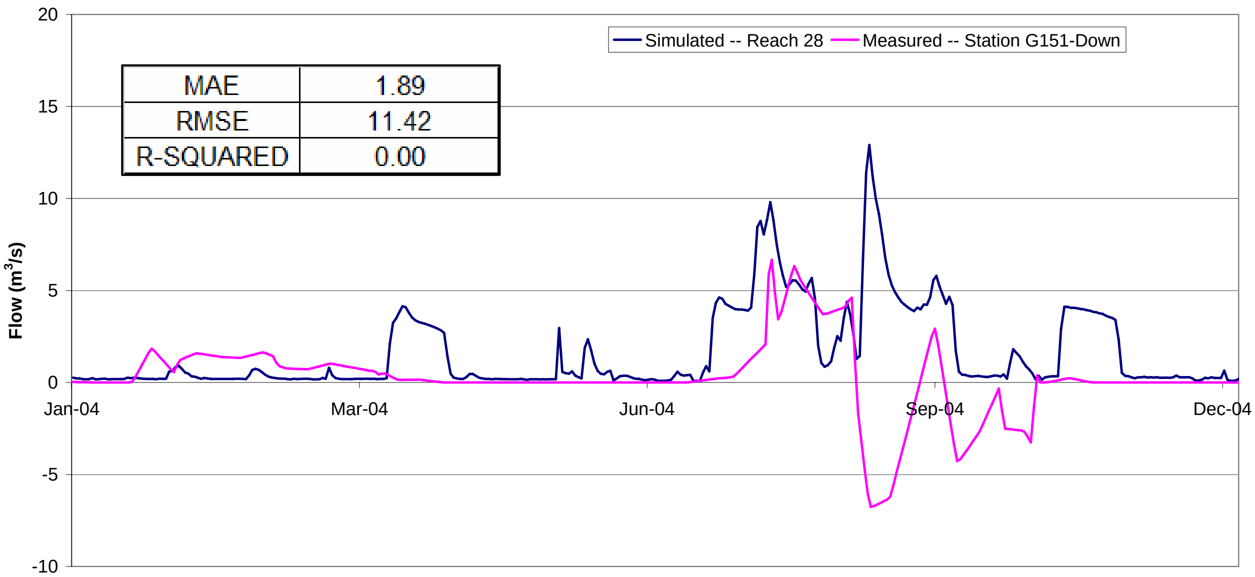



**Figure 4.53: Daily flows at G-151 for 2004**

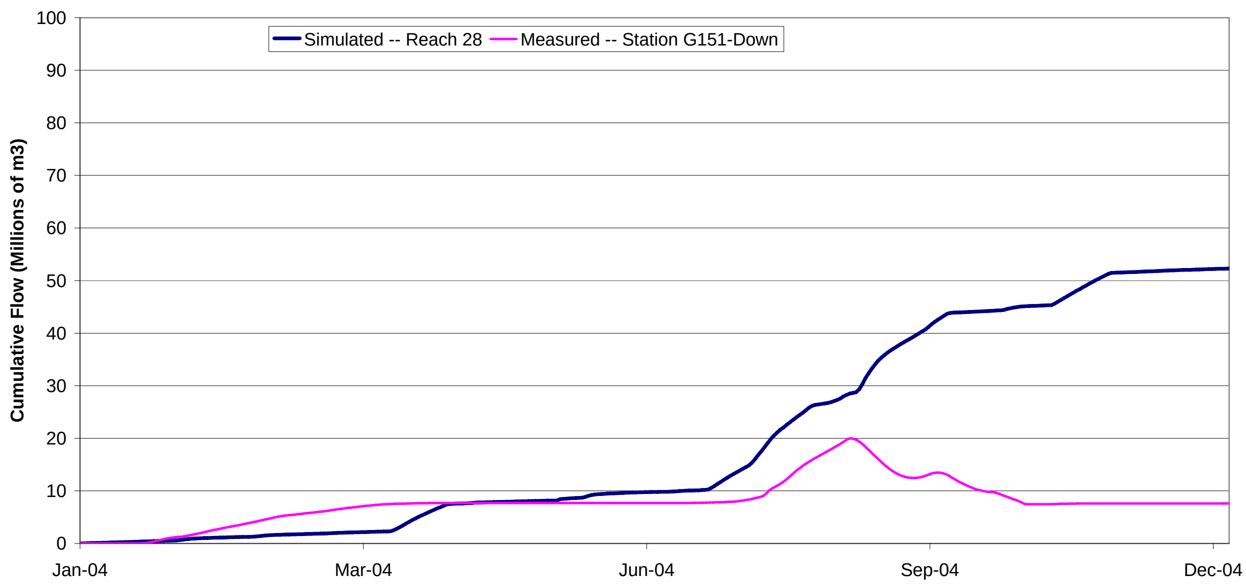



**Figure 4.54: Cumulative flows at G-151 for 2004**

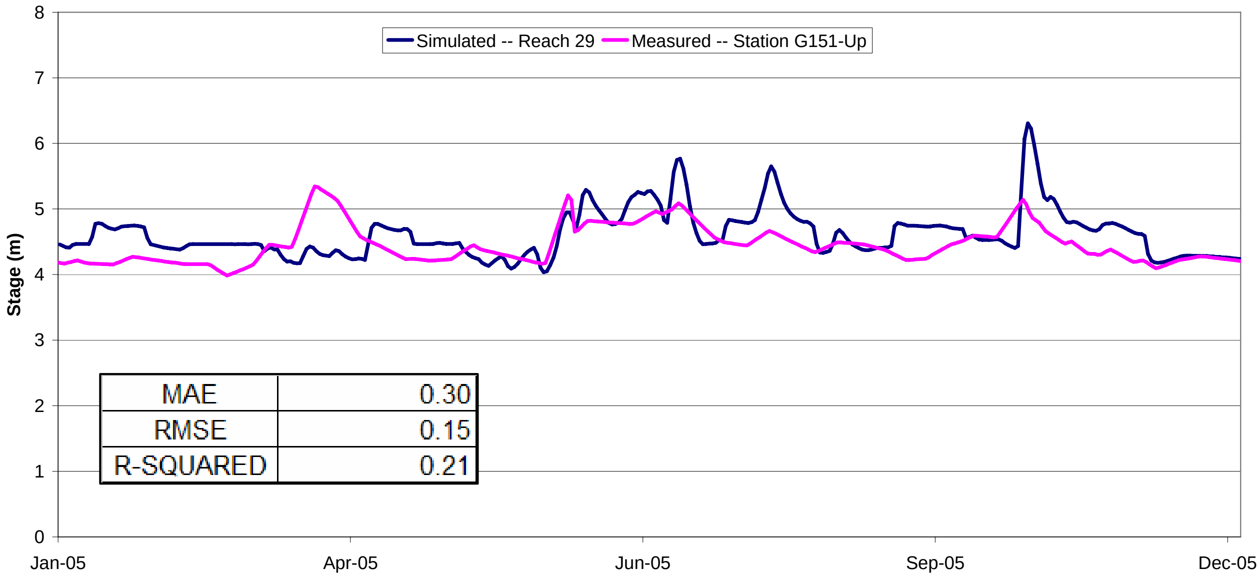



**Figure 4.55: Calibration stages upstream of G-151 (west) for 2005**

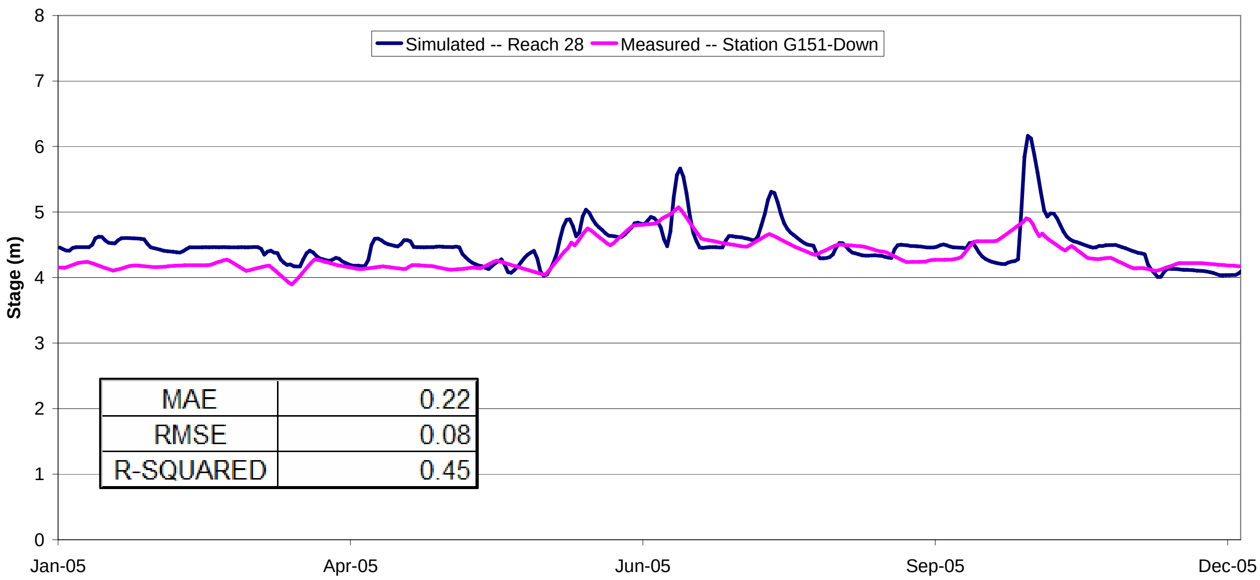



**Figure 4.56: Calibration stages downstream of G-151 (east) for 2005**

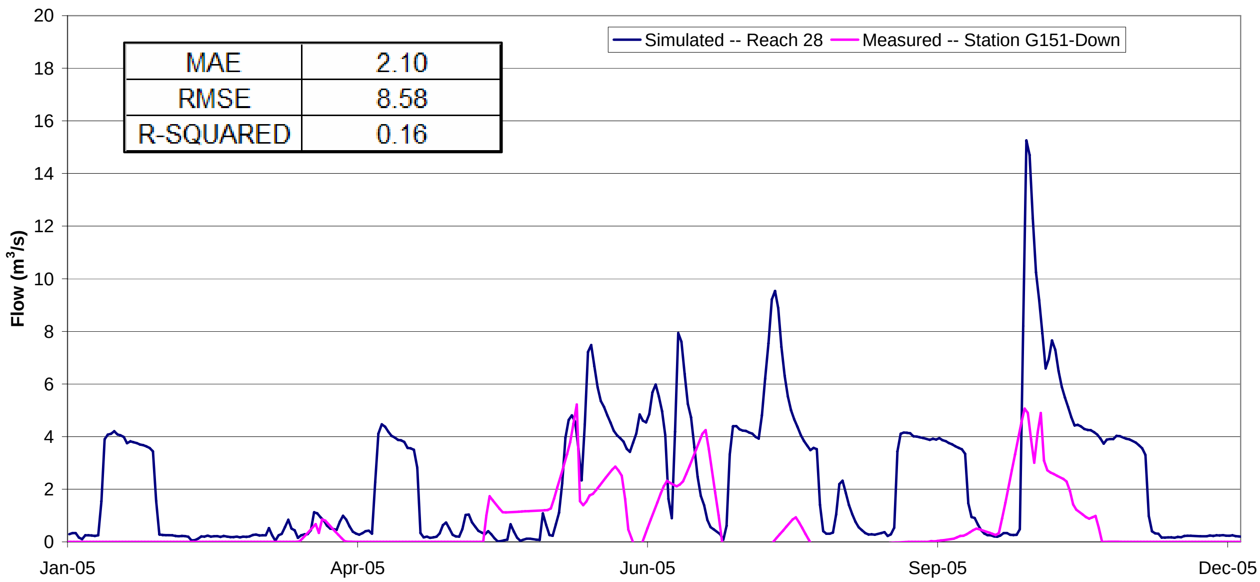



**Figure 4.57: Daily flows at G-151 for 2005**

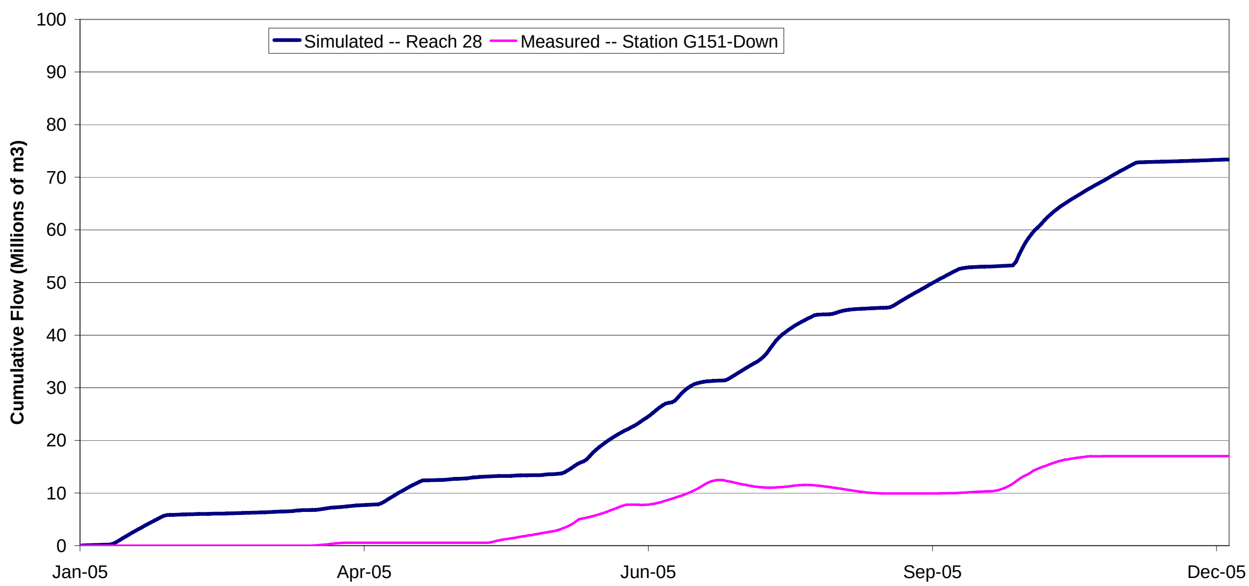
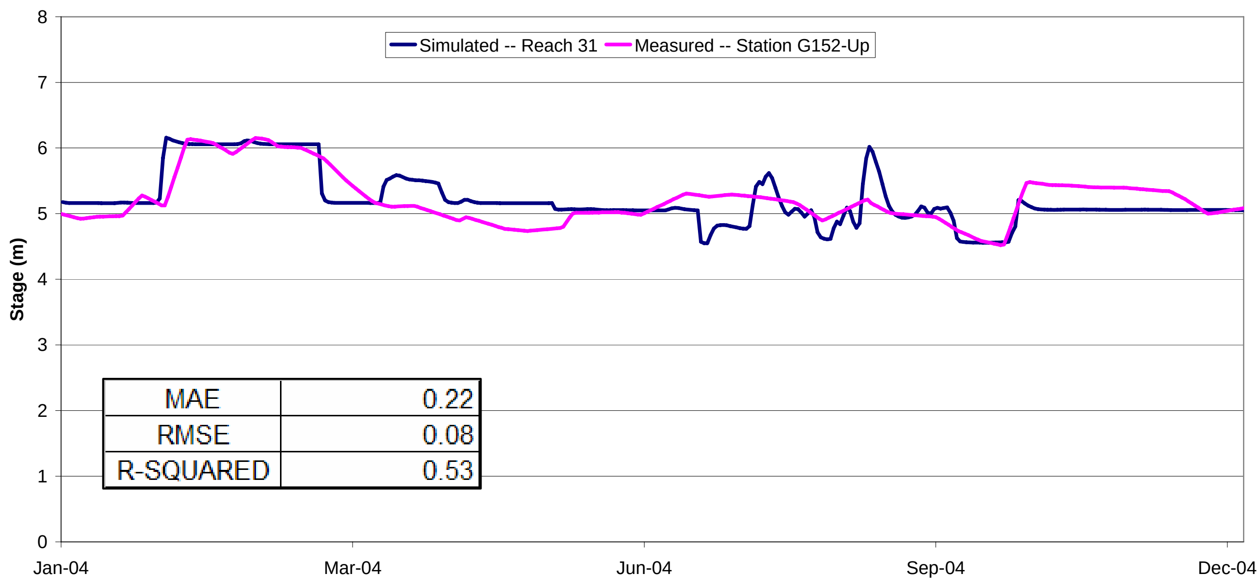
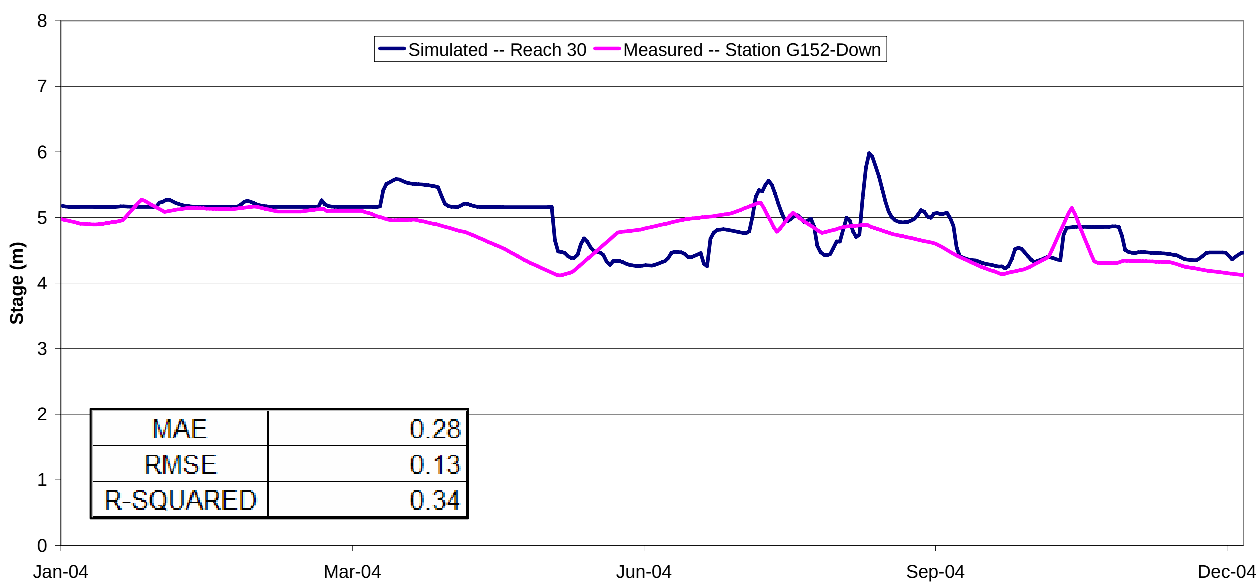



**Figure 4.58: Cumulative flows at G-151 for 2005**




| | |
|---|---|
| MAE | 0.22 |
| RMSE | 0.08 |
| R-SQUARED | 0.53 |

**Figure 4.59: Calibration stages upstream of G-152 (west) for 2004**




| | |
|---|---|
| MAE | 0.28 |
| RMSE | 0.13 |
| R-SQUARED | 0.34 |

**Figure 4.60: Calibration stages downstream of G-152 (east) for 2004**

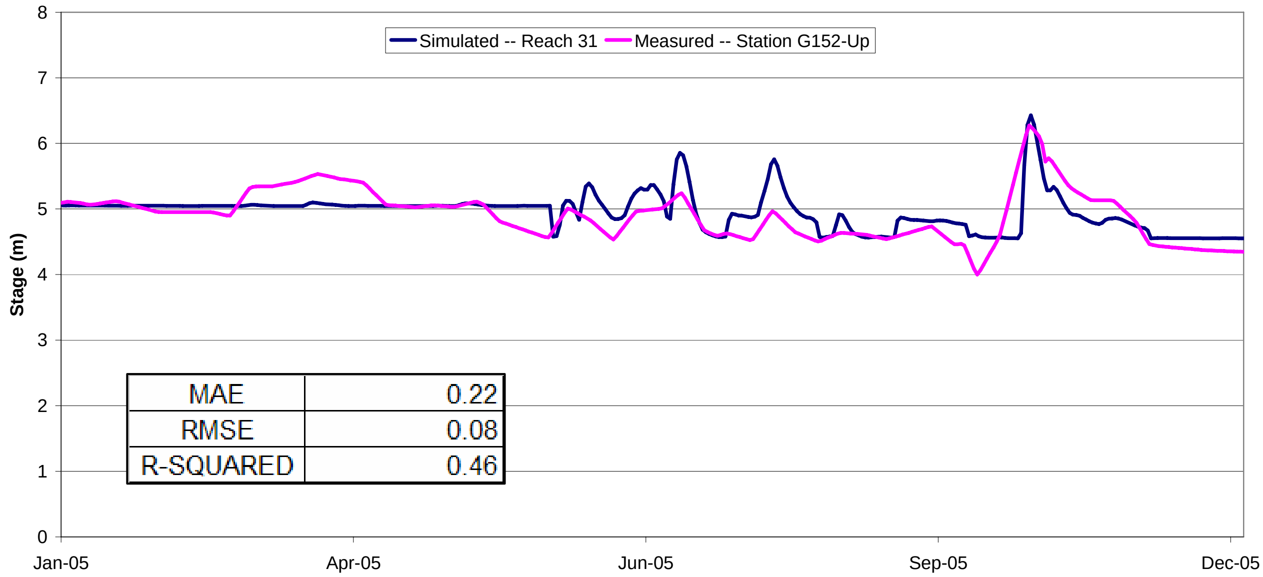



**Figure 4.61: Calibration stages upstream of G-152 (west) for 2005**

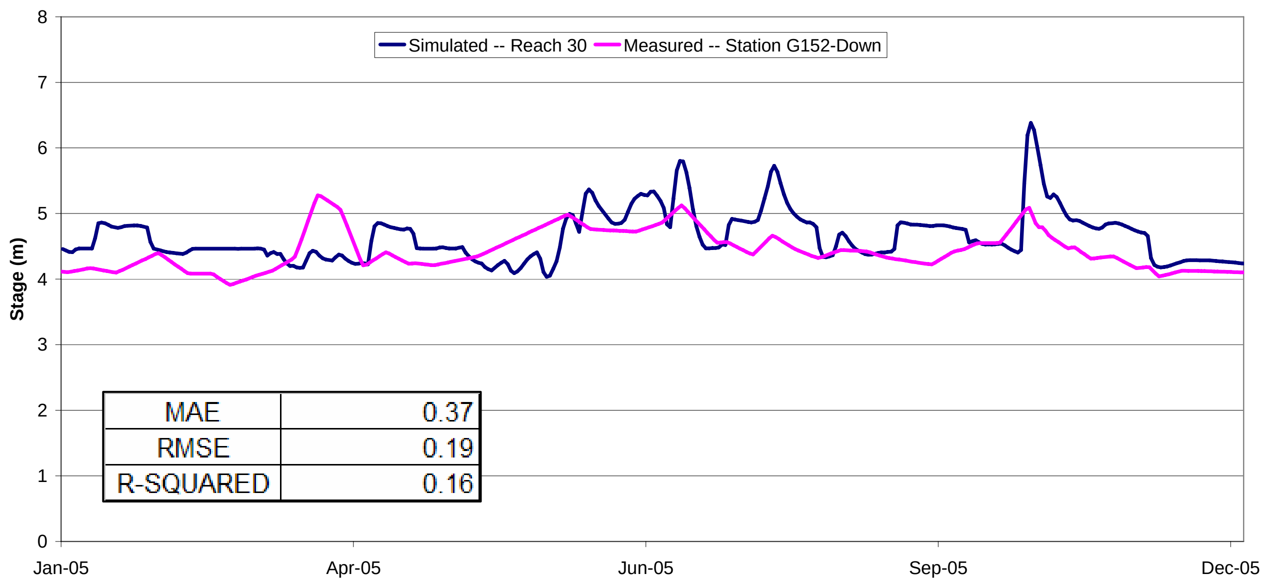



**Figure 4.62: Calibration stages downstream of G-152 (east) for 2005**

## 4.5 Water Quality Calibration

As is described in Section 3.9, WAM incorporates two main processes for simulating TP loads: load generation and load attenuation. Within WAM the parameters for load generation are defined within the *landuse.bnz* and *lu-eaa.bnz* input files and are related to the management practices of the landowners. For the purposes of the C-139 simulation, it is assumed that the practices defined within the WOD permit documents define these parameters explicitly. As such, the load generation parameters are assumed to be a part of the set-up and are not modified during the calibration process.

Load attenuation can occur within the soil column, during overland flow or within the stream reach. The load attenuation within the soil column is defined by the parameters within the *soil-eaa.bnz* input file. Simulated TP concentrations downstream were determined to be sensitive to the following seven parameters:

1. Initial Phosphorus mass in the surface residue
2. Initial Phosphorus content in the aerobic and anaerobic zone
3. Initial Phosphorus content in the layer below the impeding layer
4. Coefficient in fresh organic mineralization equation
5. Partition coefficients for aerobic and anaerobic soil
6. Partition coefficient for below the impeding layer
7. Coefficients for ditch and surface erosion

During calibration, the initial Phosphorus mass in the surface residue was increased for all soils to 70 kg/ha based on a review of the initial behavior of TP pools in improved, unimproved and woodland pastures. However, this impact was not largely significant for the calibration results since the model spin-up period reduces the influence of initial analysis shows that all of the parameters are sensitive except for initial Phosphorus mass for which the effects were not seen due to the model "spin-up" period. This modification is also reflected in the initial P values presented in **Appendix B**. No other modifications to these parameters were made due to a lack of available basin-specific research providing contrary values.

A sensitivity analysis on the effect of stream attenuation was conducted and the results revealed that the model is sensitive to load attenuation. The background concentrations and attenuation multiplier values described in Section 3.8 were modified over the course of the calibration. The final background concentrations were changed to reflect the pre-event concentrations measured in the streams, whereas the attenuation multiplier values were modified from zero to double the default value, however, based on a comparison to the measured results the default attenuation multiplier values were used for the calibration simulation.

Overland flow attenuation is based on the parameters described in the *attenuate.in* input file. Additionally in locations where there are topographic depressions, overland flow is routed and attenuated to these locations. The basic WAM set-up revealed no topographic depressions within the basin, however there were a significant number of depressions defined based on the location of depressional wetland soils, as described in Section 3.3. In reviewing the calibration results it was determined that this assumption does not apply in the C-139 Basin since there is significant percolation and drainage. Therefore, all of the depressions generated as part of the set-up were removed from the *depress.asc* input file.

## 4.6 Water Quality Calibration Results

**Figures 4.63** through **4.66** represent temporal comparisons of model computations to observed Total Phosphorus concentrations at G-136, G-342A, G-342C, and G-406 control structures during the 2004 calibration period. For all TP comparisons the same stastical measures provided for the water quantity results are provided here as well: MAE, RMSE and R-squared. Overall, the model over-predicted the dry weather TP concentration and over-predicted the wet weather TP concentrations. This trend is consistent with water quantity calibration results described in Section 4.3. The higher concentration at the G-136 structure is caused by over-estimating the flow at the end of 2003. The dry weather operation of the C-139 structures reduces the stream velocity and enhances settling of sediment phosphorus upstream of structures. **Figure 4.66** demonstrates the same pattern as the hydraulic results demonstrated in **Figure 4.29** for the G-406 structure. The autosampler located at the G-406 structure does not collect any samples during periods of little or no-flow, which is indicative of the dry-season. However, as was illustrated in Section 4.4.3, the model simulates flow during the dry season at G-406 and correspondingly the load is greater for this period. Additionally, **Figures 4.67** through **4.71** illustrate the simulated partitioning of sedimentary and soluble P as compared with observed values for all stations where the measurements are available.

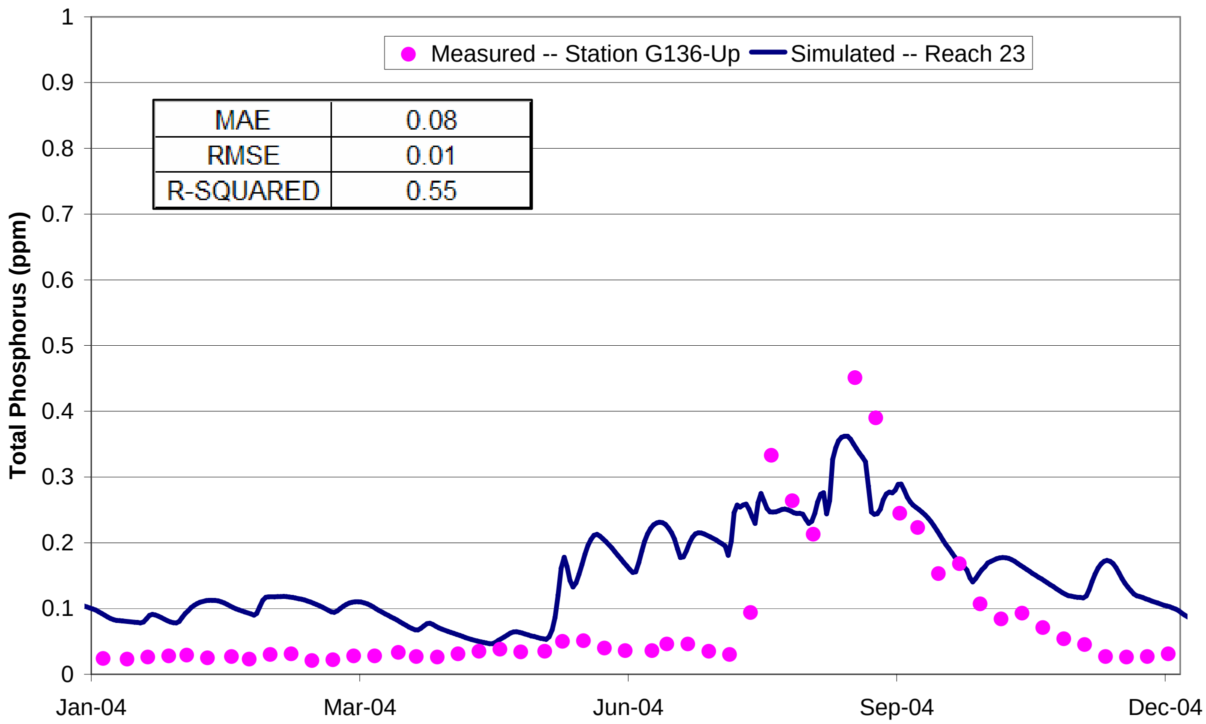



**Figure 4.63: Calibration TP concentration for G-136 in 2004**

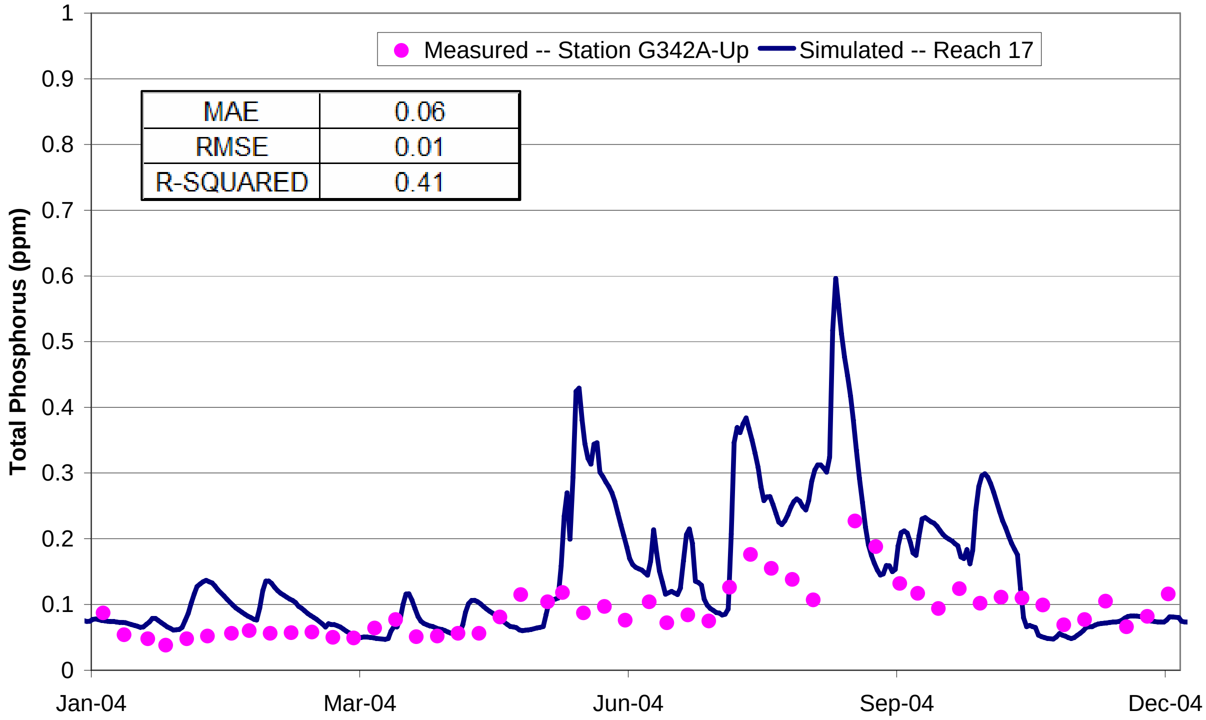



**Figure 4.64: Calibration TP concentration for G-342A in 2004**

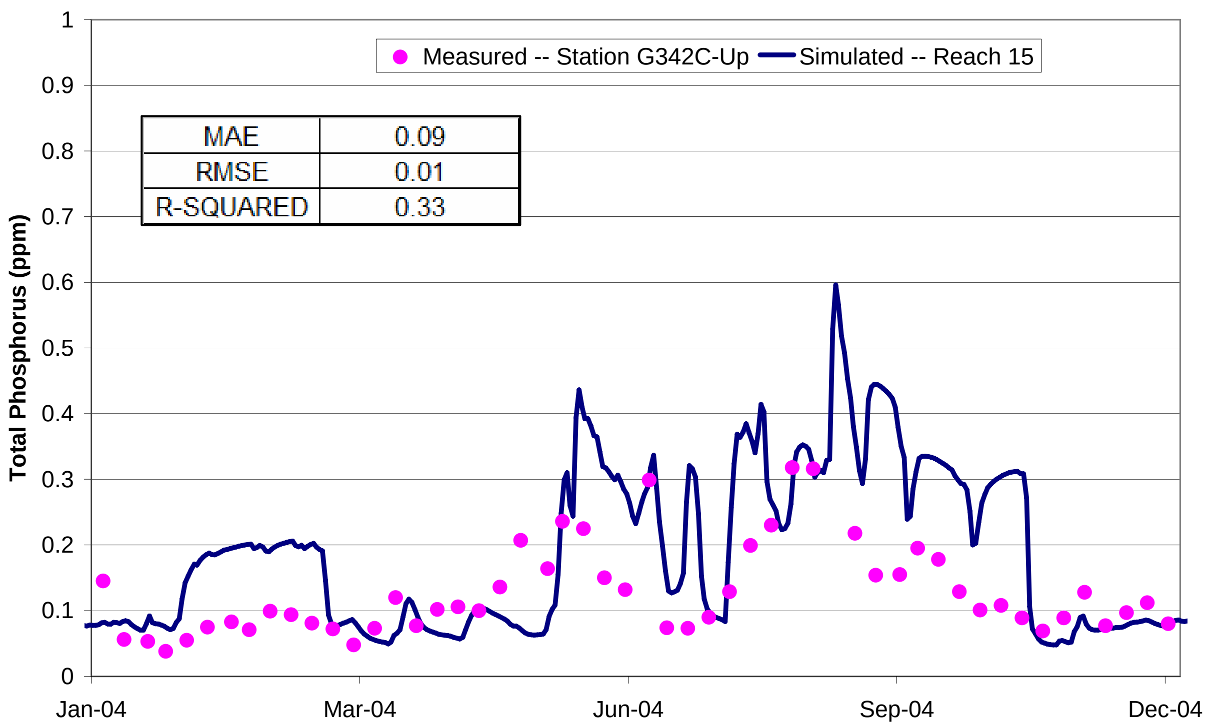



**Figure 4.65: Calibration TP concentration for G-342C in 2004**

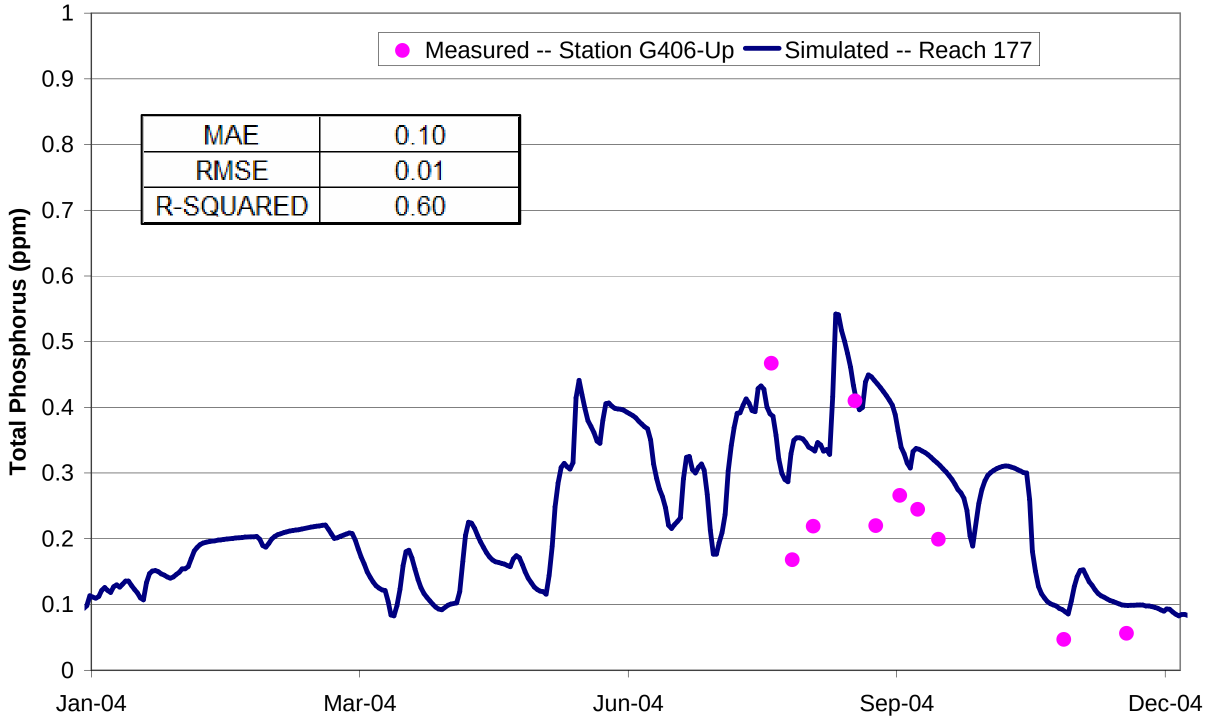



**Figure 4.66: Calibration TP concentration for G-406 in 2004**

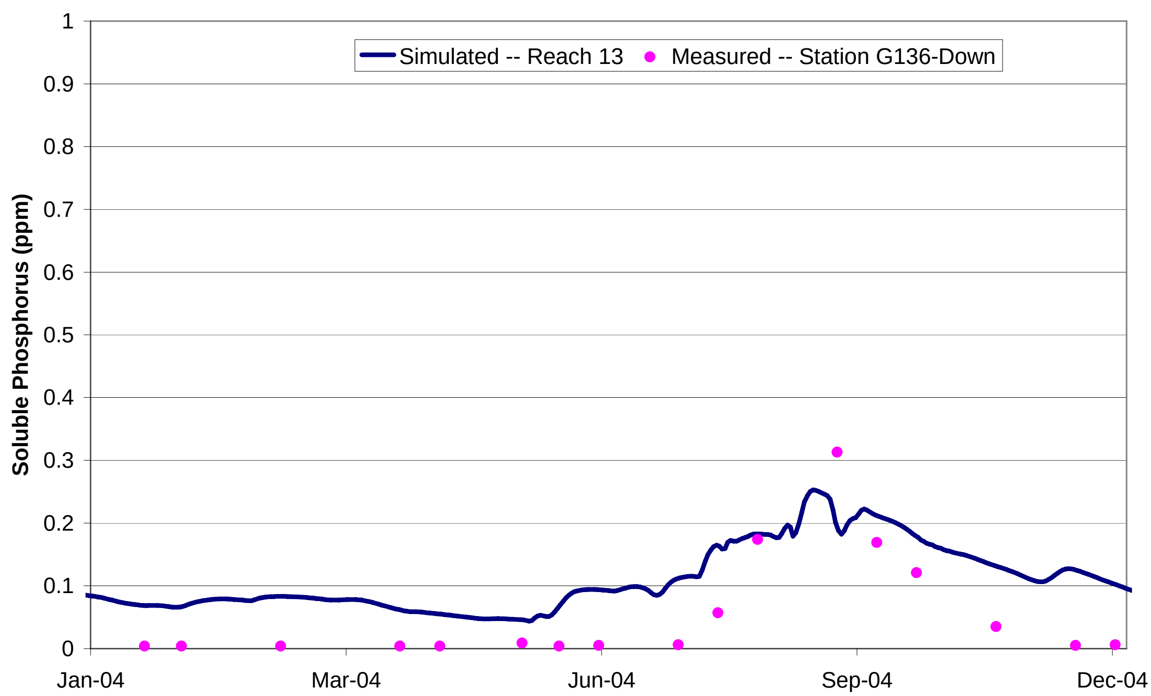



**Figure 4.67: Calibration Soluble P concentration for G-136 in 2004**

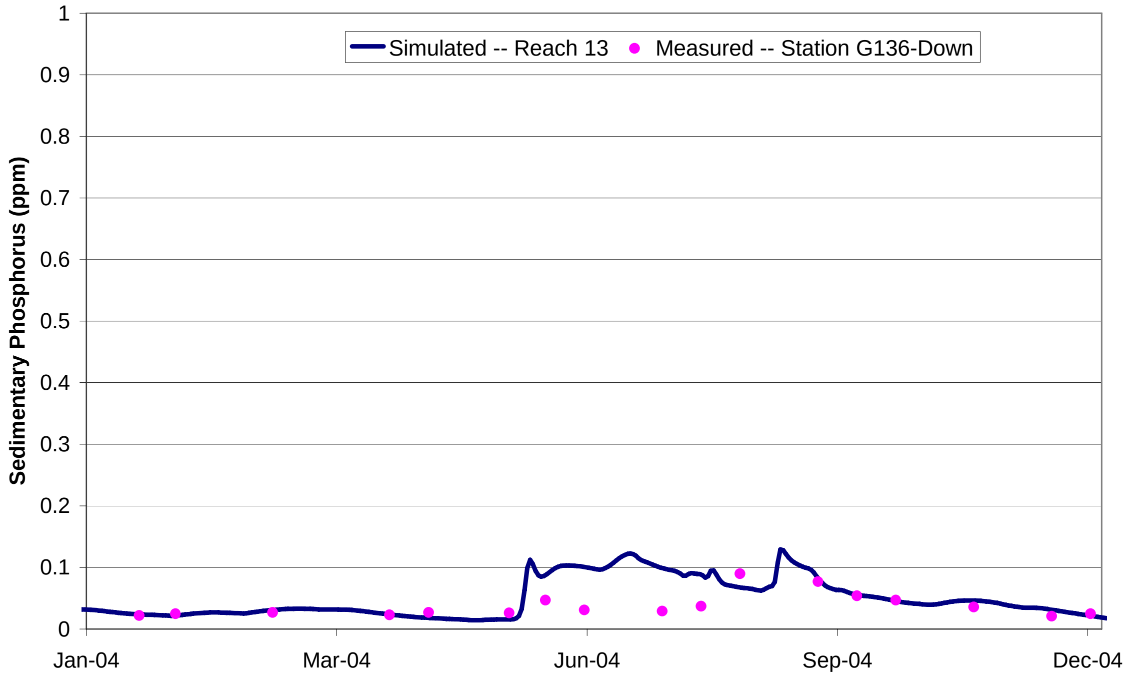



**Figure 4.68: Calibration Sedimentary P concentration for G-136 in 2004**

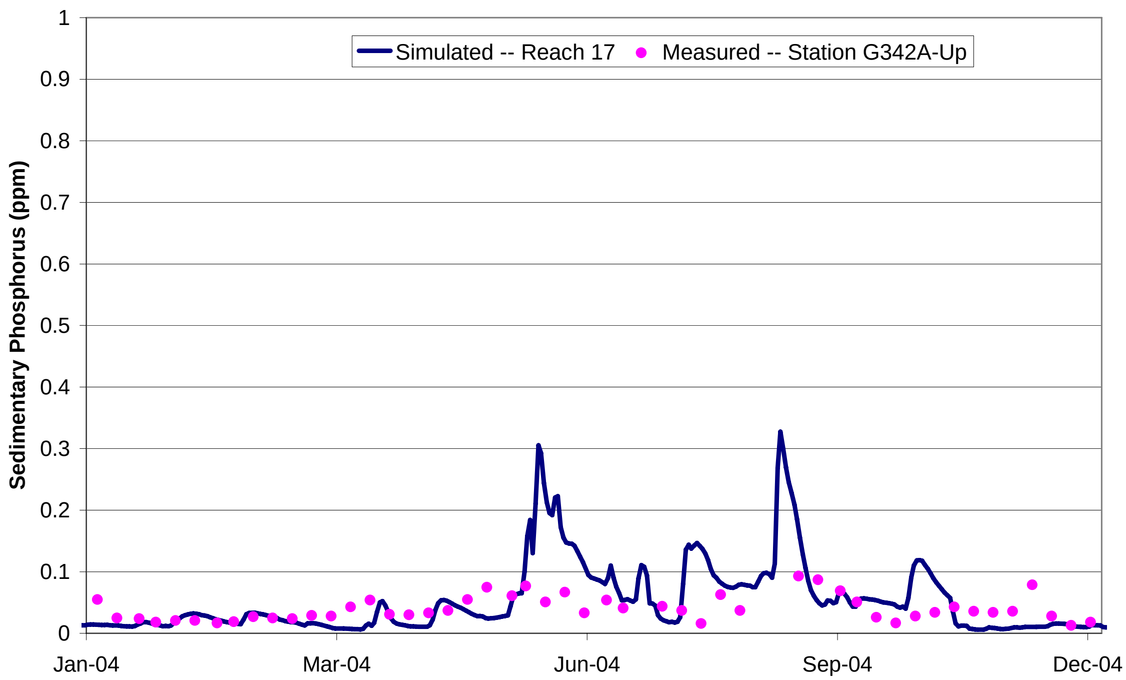



**Figure 4.69: Calibration Soluble P concentration for G-342A in 2004**

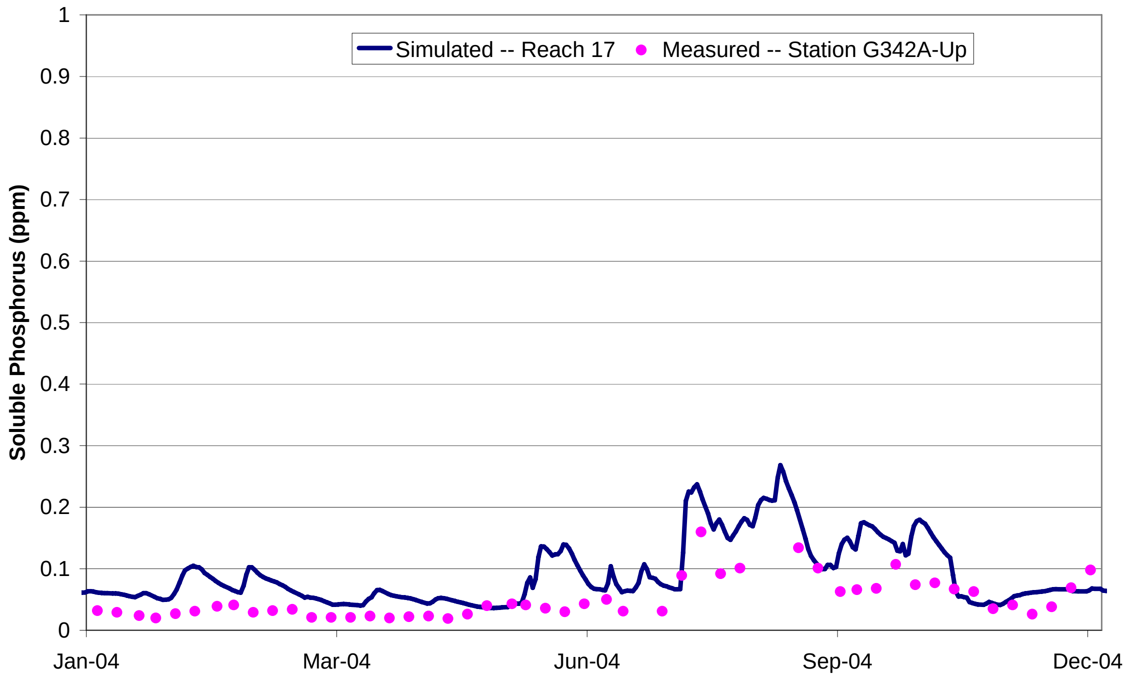



**Figure 4.70: Calibration Sedimentary P concentration for G-342A in 2004**

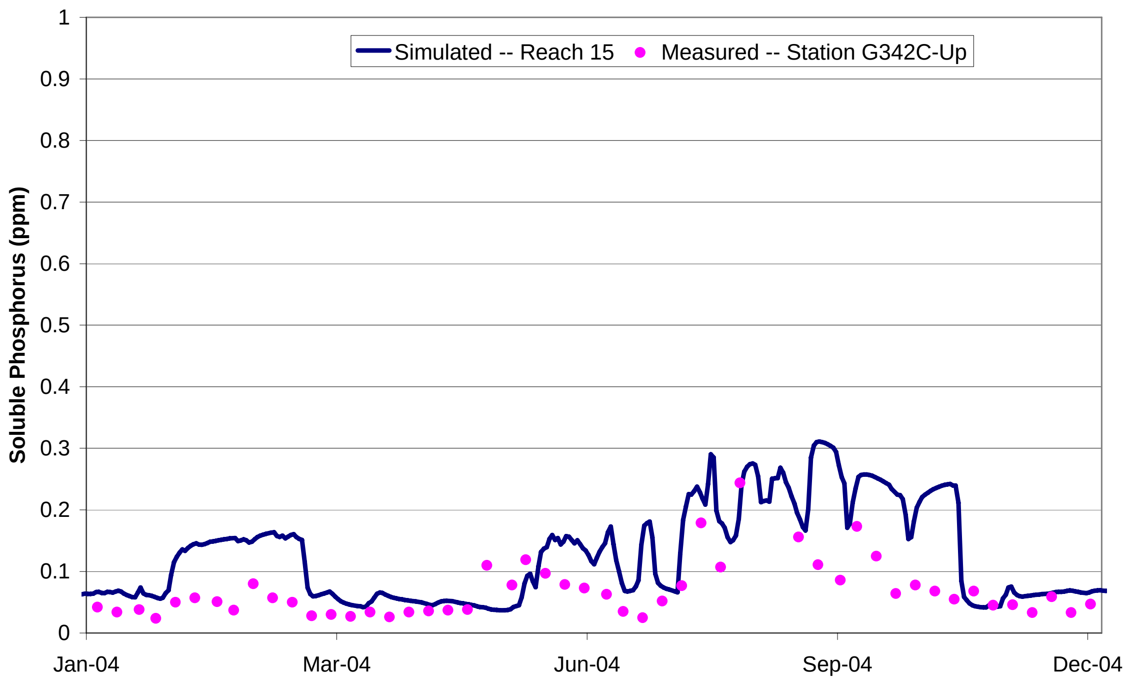



**Figure 4.71: Calibration Soluble P concentration for G-342C in 2004**

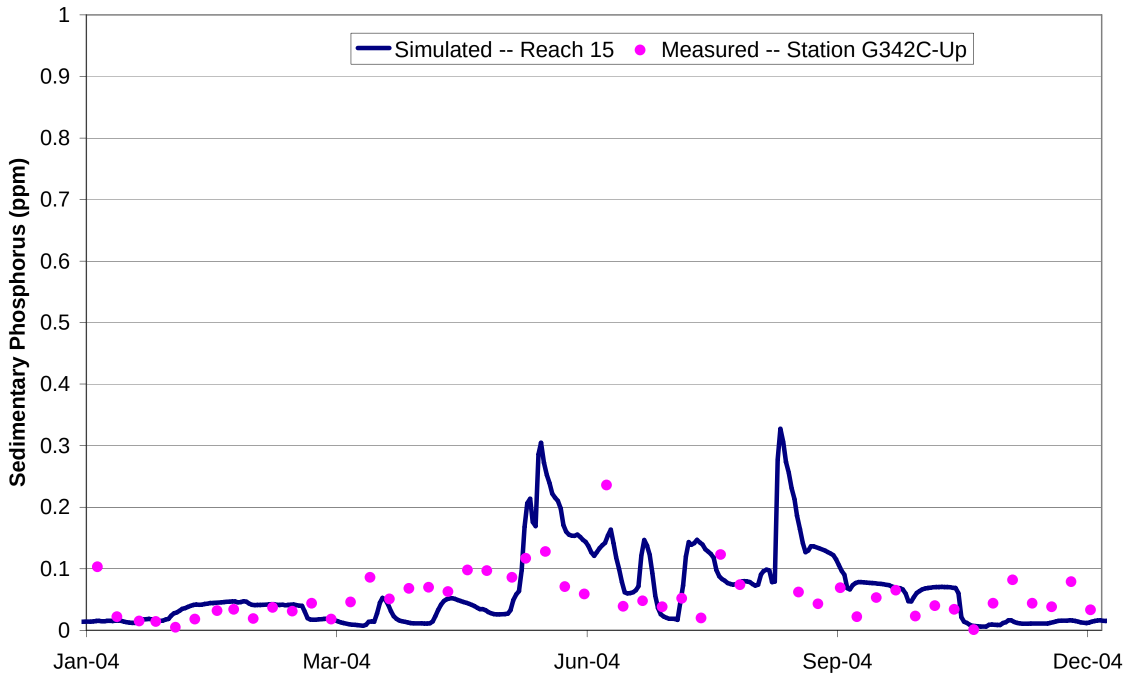



**Figure 4.72: Calibration Sedimentary P concentration for G-342C in 2004**

**Figures 4.73** through **4.76** represent temporal comparisons of model computations to observed Total Phosphorus concentrations at G-136, G-342A, G-342C, and G-406 control structures during the 2005 calibration period. Overall, the model over-predicted the dry weather TP concentration which is consistent with water quantity calibration results described in Section 4.3.2. The wet weather calculated TP concentration for the G-136 and G-342A structures are in agreement with observed data. However, the model over-predicted the wet weather TP concentrations at G-342C and G-406 structures. The discrepancy in TP concentrations is potentially caused by re-suspension of settled TP. Additionally, **Figures 4.77** through **4.82** illustrate the simulated partitioning of sedimentary and soluble P as compared with observed values for all stations where the measurements are available.

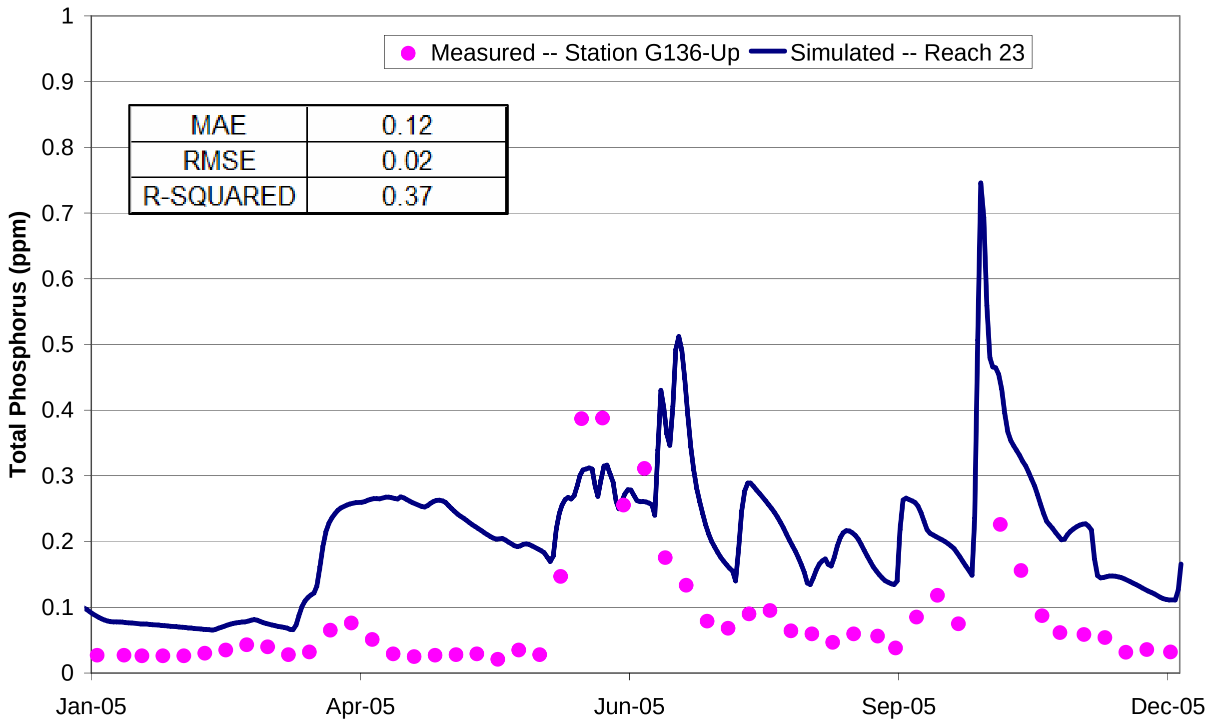



**Figure 4.73: Calibration TP concentration for G-136 in 2005**

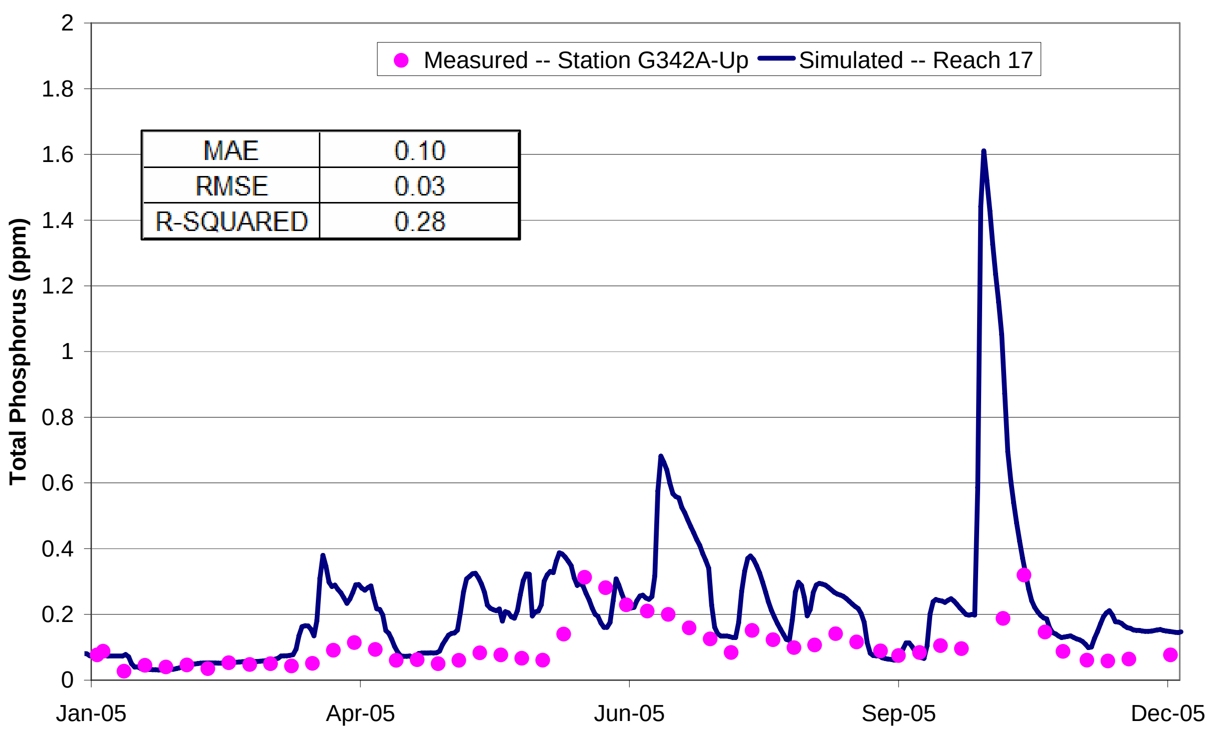



**Figure 4.74: Calibration TP concentration for G-342A in 2005**

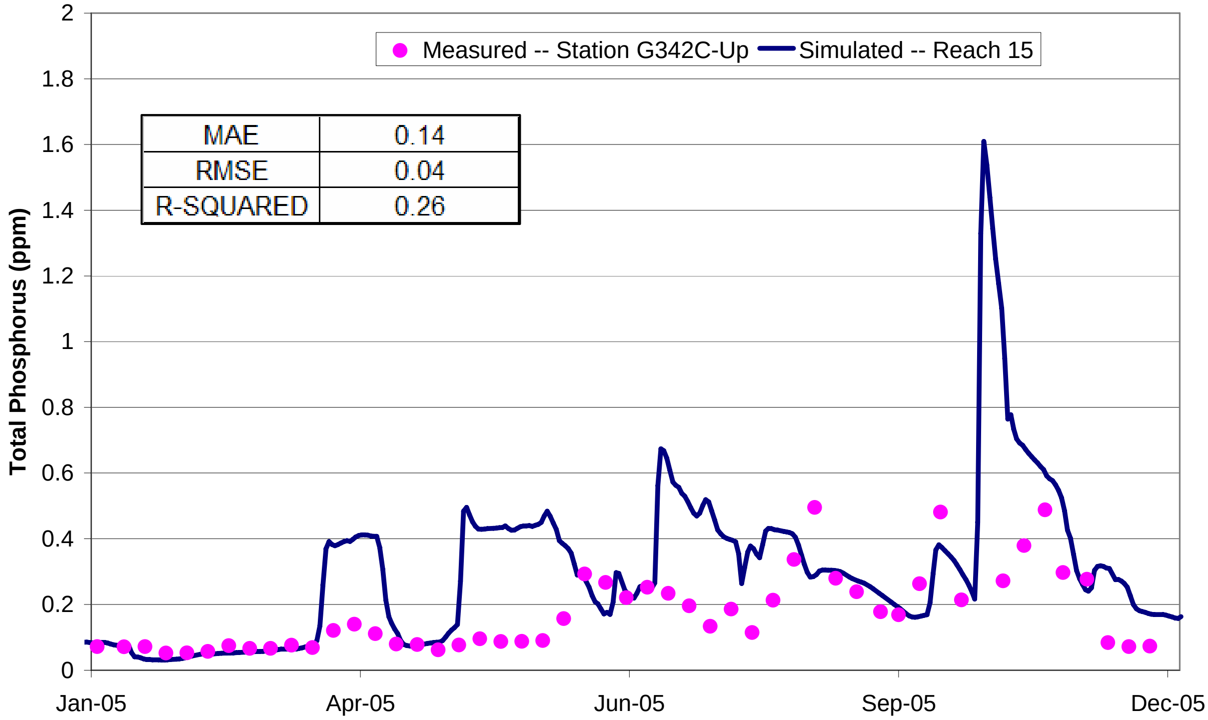



**Figure 4.75: Calibration TP concentration for G-342C in 2005**

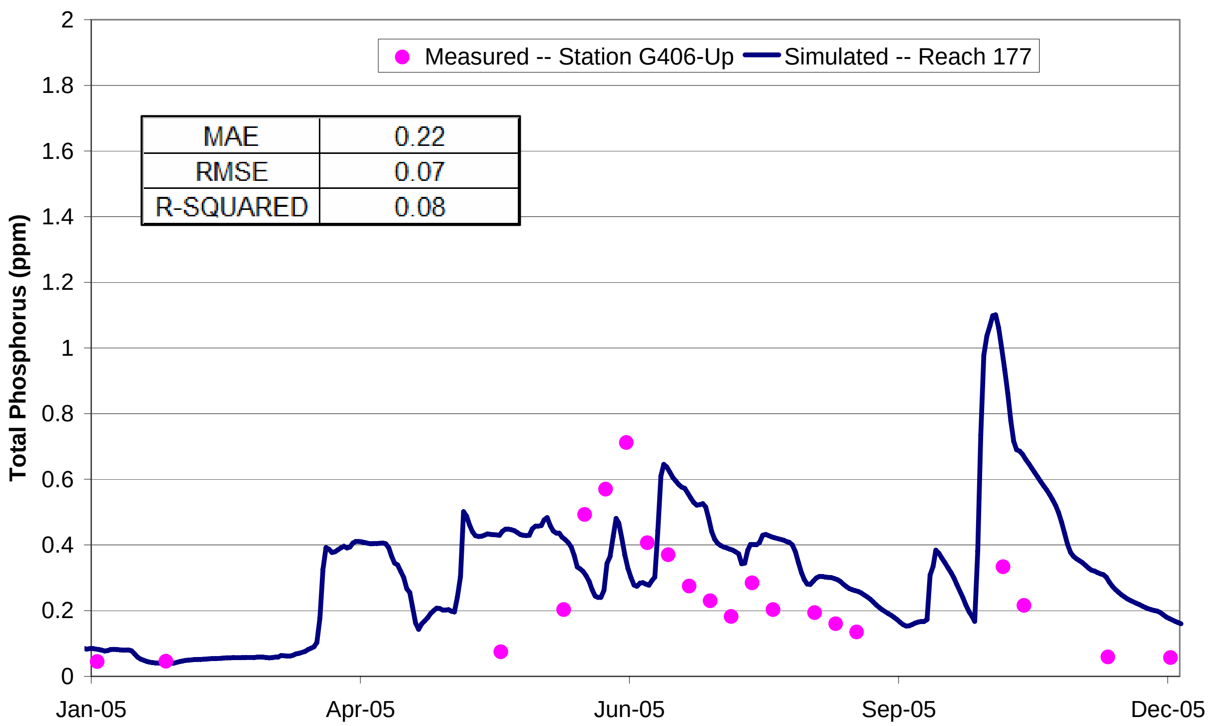



**Figure 4.76: Calibration TP concentration for G-406 in 2005**

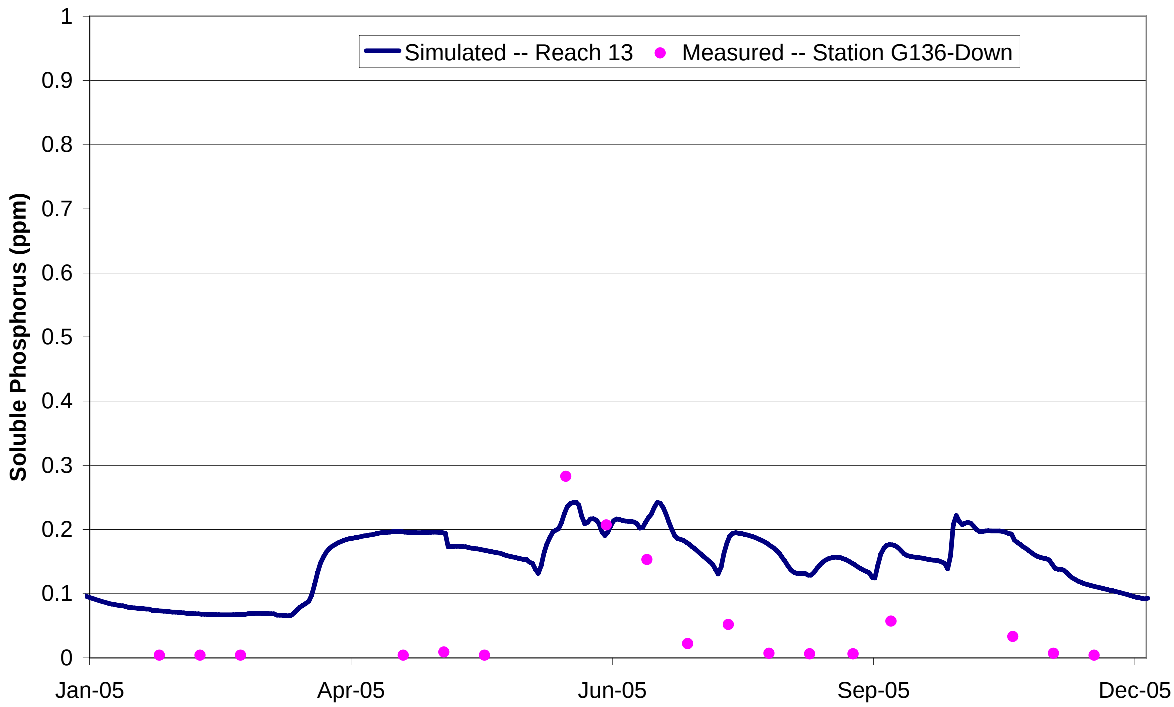



**Figure 4.77: Calibration Soluble P concentration for G-136 in 2005**

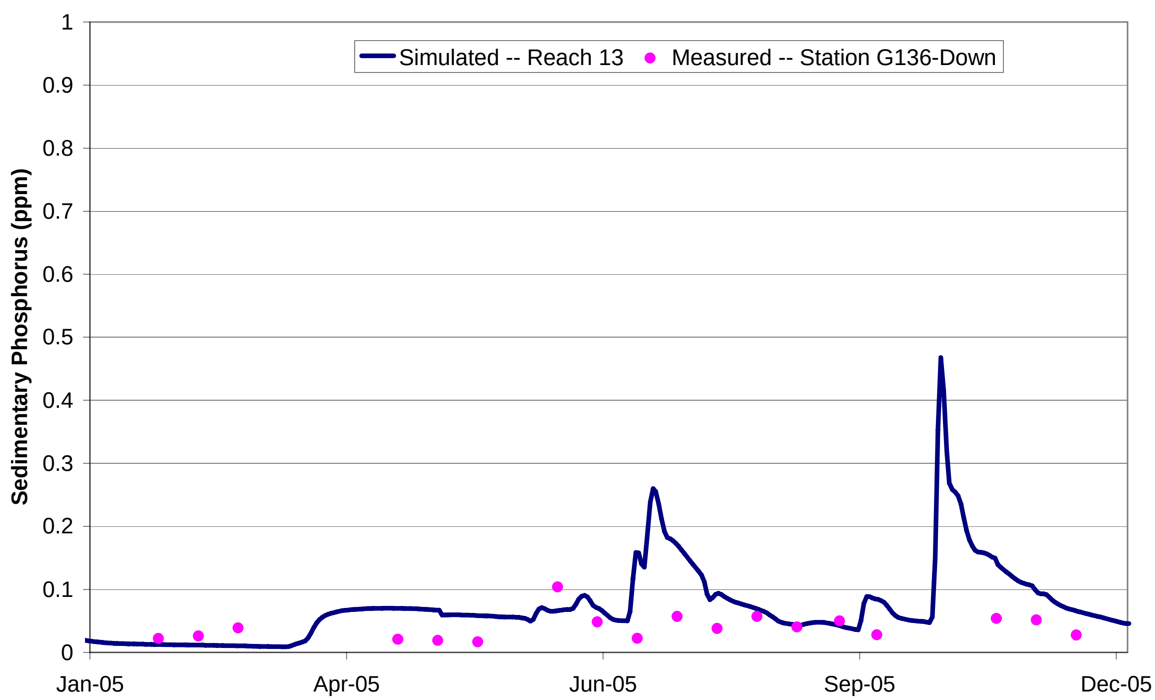



**Figure 4.78: Calibration Sedimentary P concentration for G-136 in 2005**

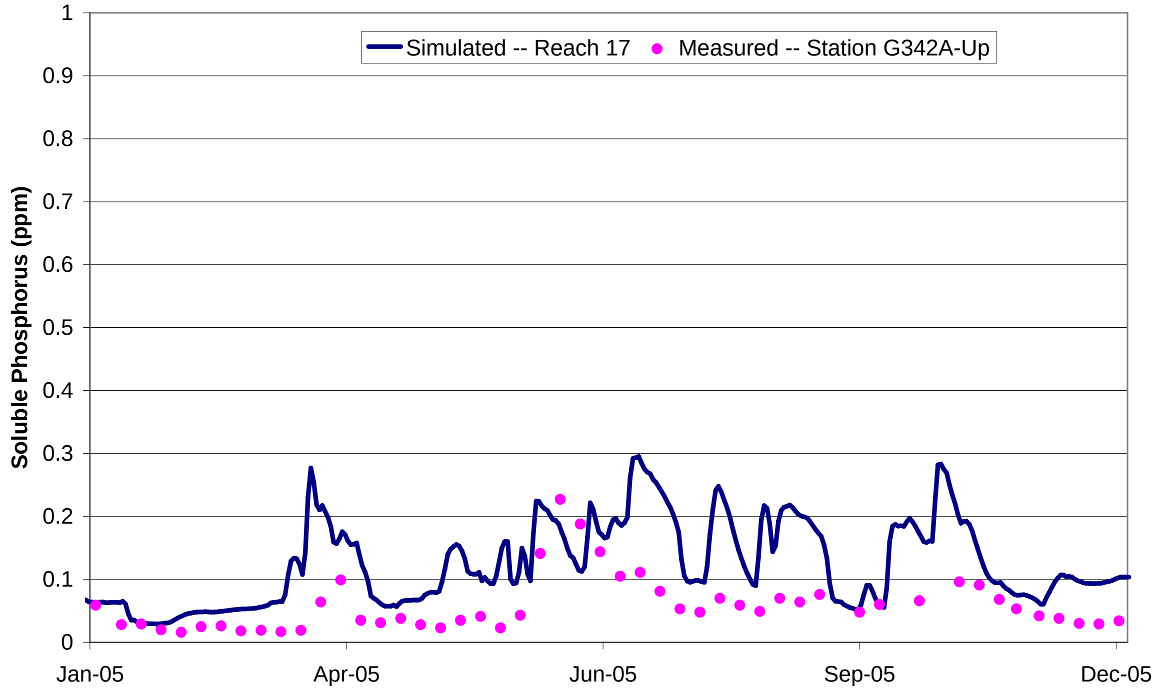



**Figure 4.79: Calibration Soluble P concentration for G-342A in 2005**

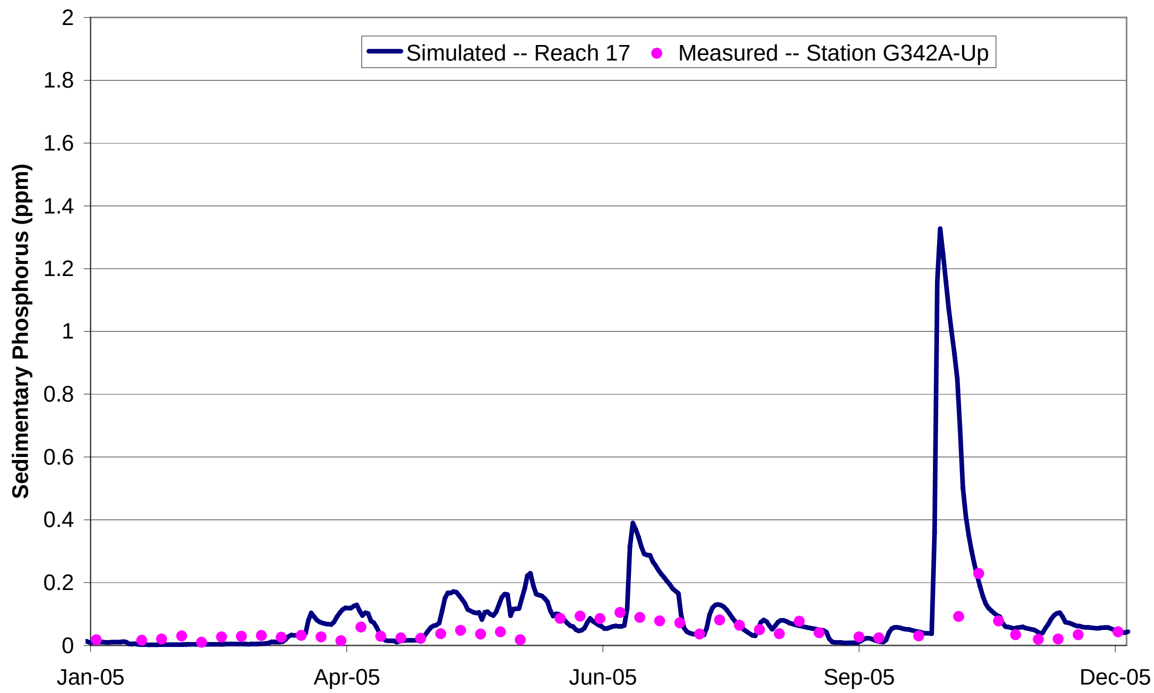



**Figure 4.80: Calibration Sedimentary P concentration for G-342A in 2005**

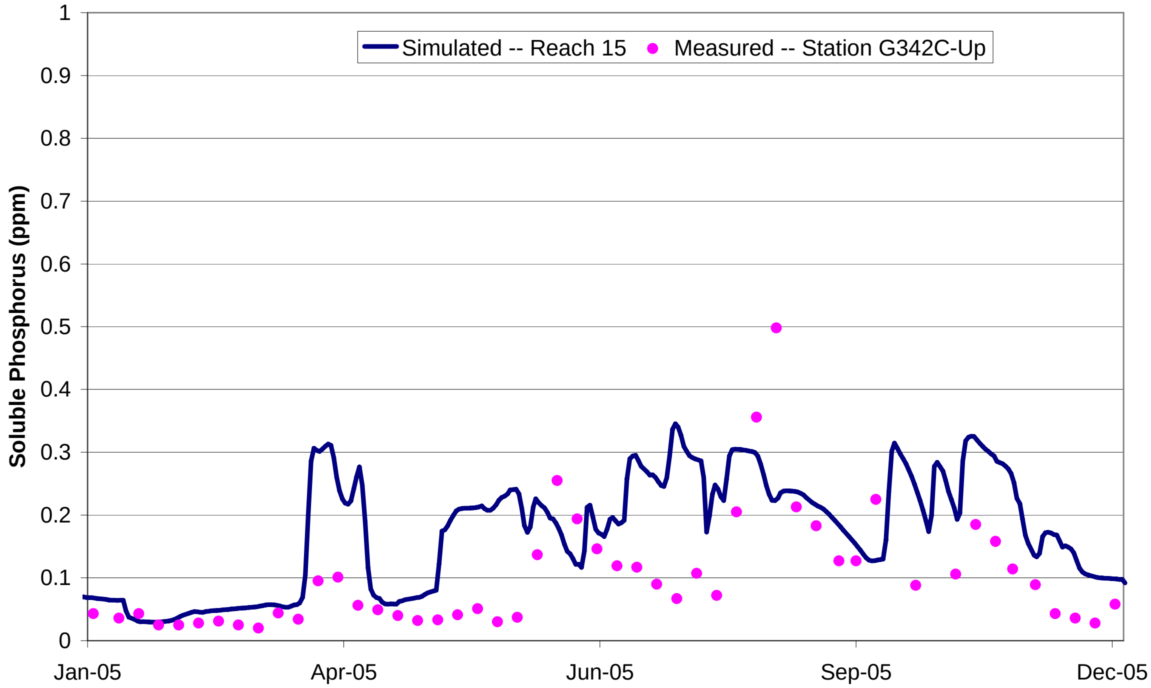



**Figure 4.81: Calibration Soluble P concentration for G-342C in 2005**

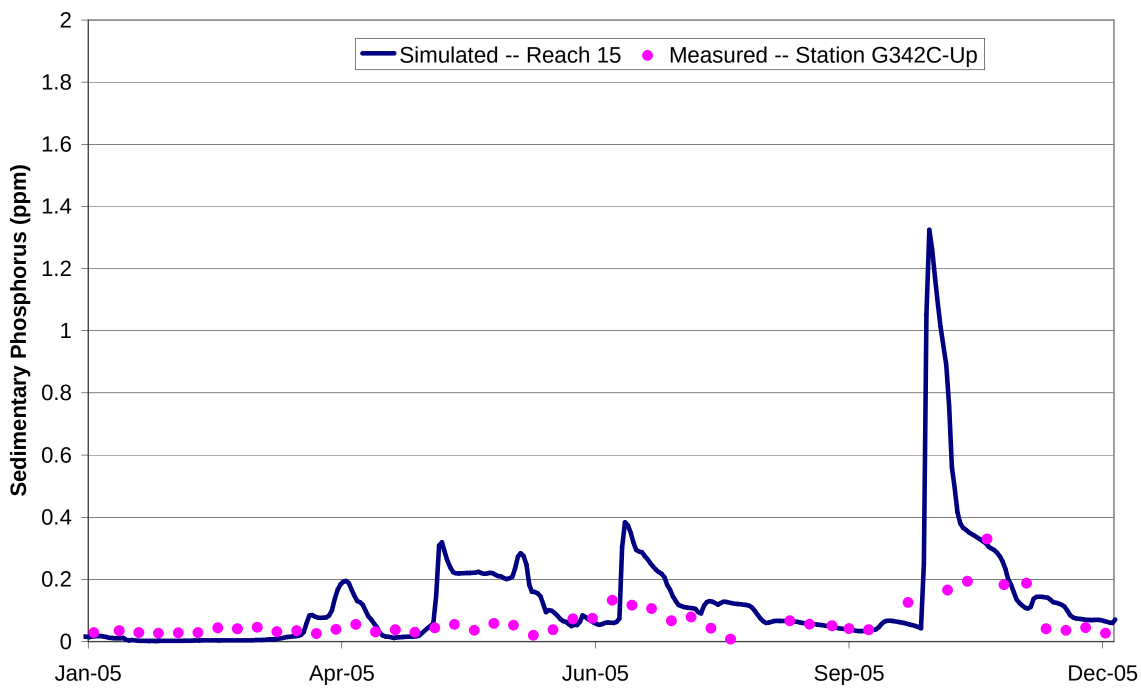



**Figure 4.82: Calibration Sedimentary P concentration for G-342C in 2005**

## 4.7 Validation Results

The validation simulation is for the 2003 calendar year. Whereas 2004 was a relatively dry year and 2005 was a relatively wet year, 2003 was an average rainfall year. Accordingly, a comparison of simulated results with measured values for 2003 illustrates similar results as the validation runs.

### 4.7.1. Validation Water Quantity

**Figures 4.83** through **4.101** illustrate the validation results for the water quantity simulation of the year 2003. As is shown in **Figure 4.83**, the model under-predicts the cumulative flow for the validation year by 10%. **Figure 4.84** illustrates that this under-prediction is largely due to poor representation of the wet-season, while the wet season stages appear reasonable, the flows are underestimated. **Figure 4.87** illustrates the cumulative flow for the G-136 structure. The model under-predicts the measured cumulative flow by 5%. This under-prediction appears to be due to an under-estimate of runoff for the dry season as well as in August and September. The stages for the validation simulation at other gauged locations throughout the basin appear reasonable.

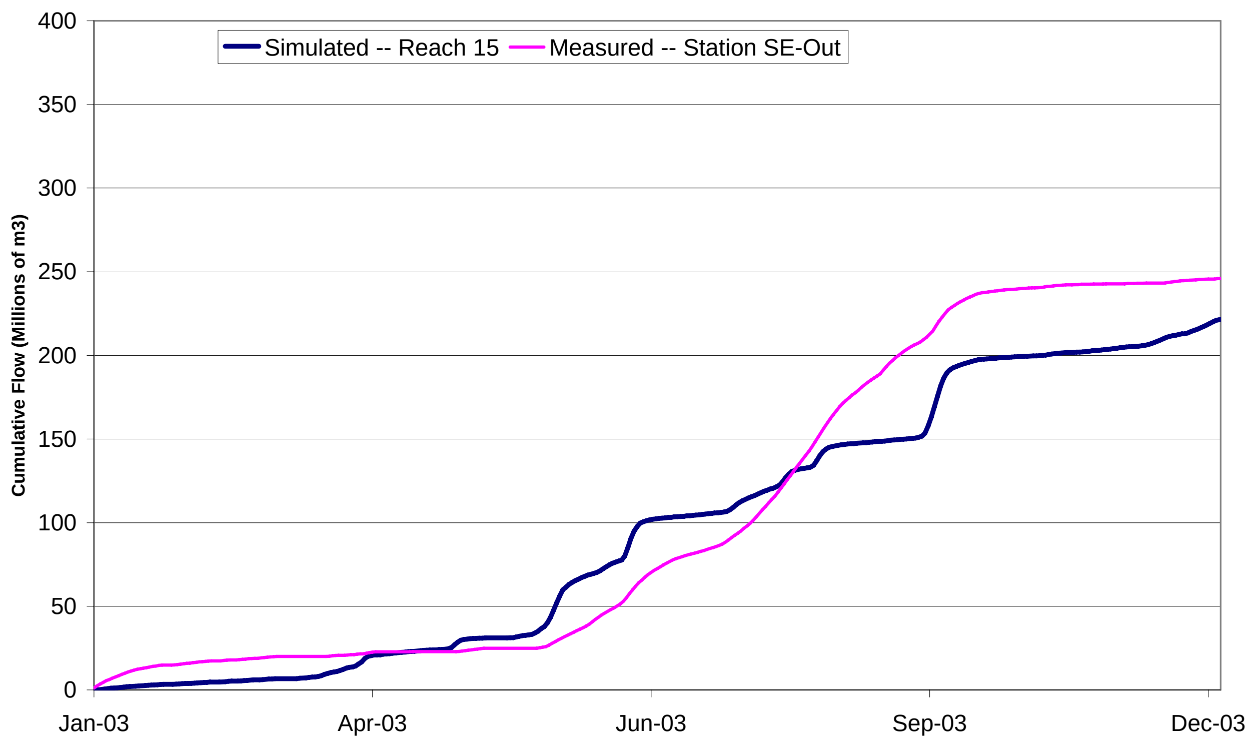



**Figure 4.83: Validation cumulative flow for 2003 into STA-5 and through G-406**

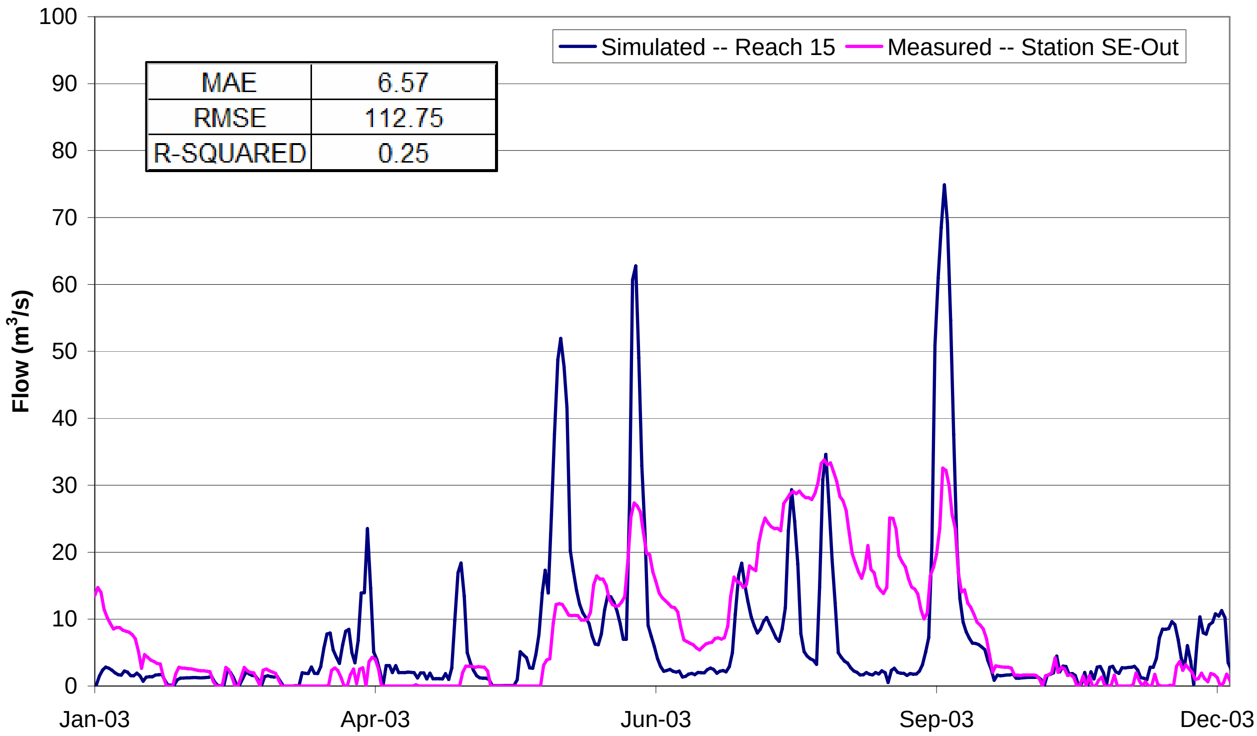



**Figure 4.84: Validation daily flow for 2003 into STA-5 and through G-406**

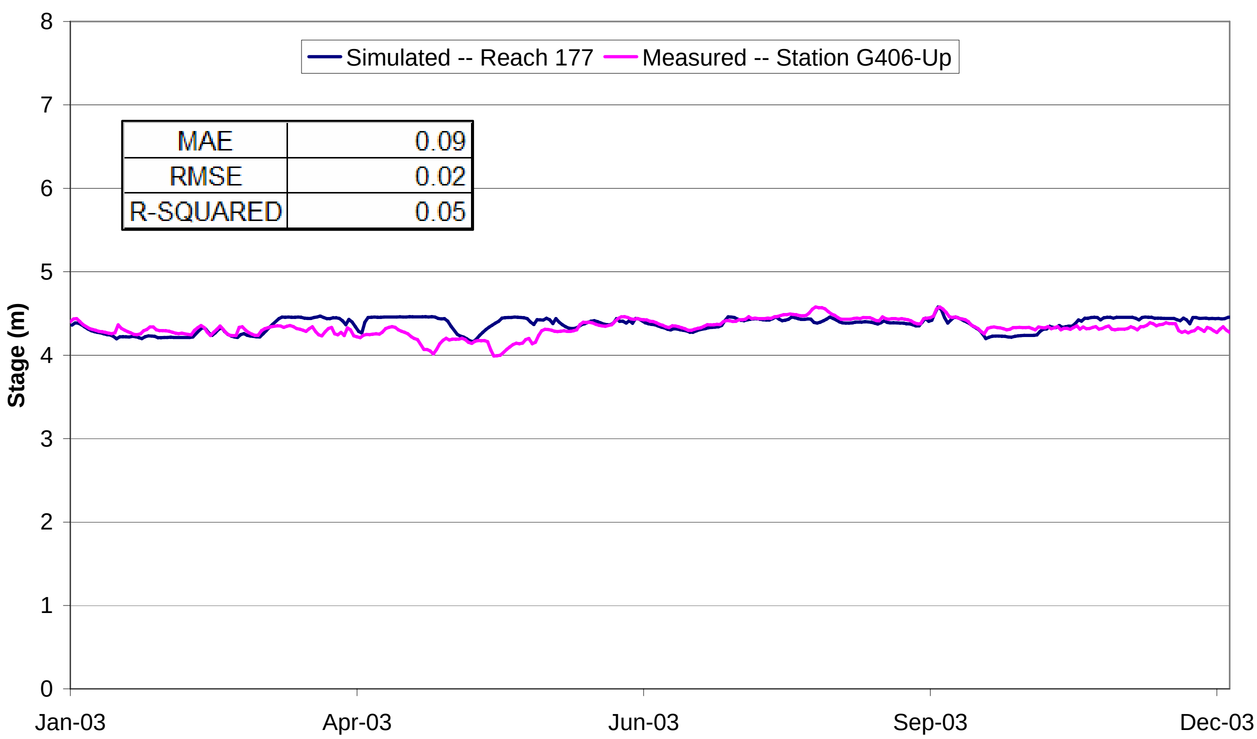



**Figure 4.85: Validation stages upstream of G-406 in the L-3 Canal for 2003**

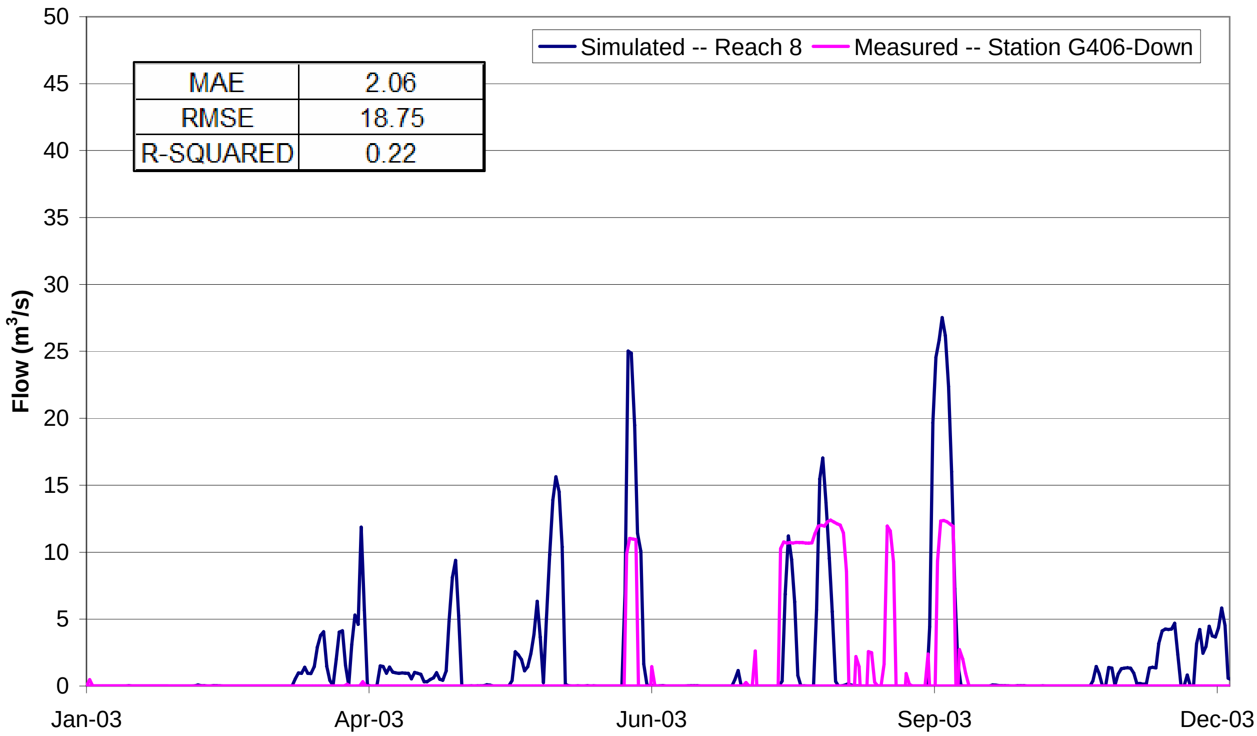



**Figure 4.86: Validation daily flows for G-406 for 2003**

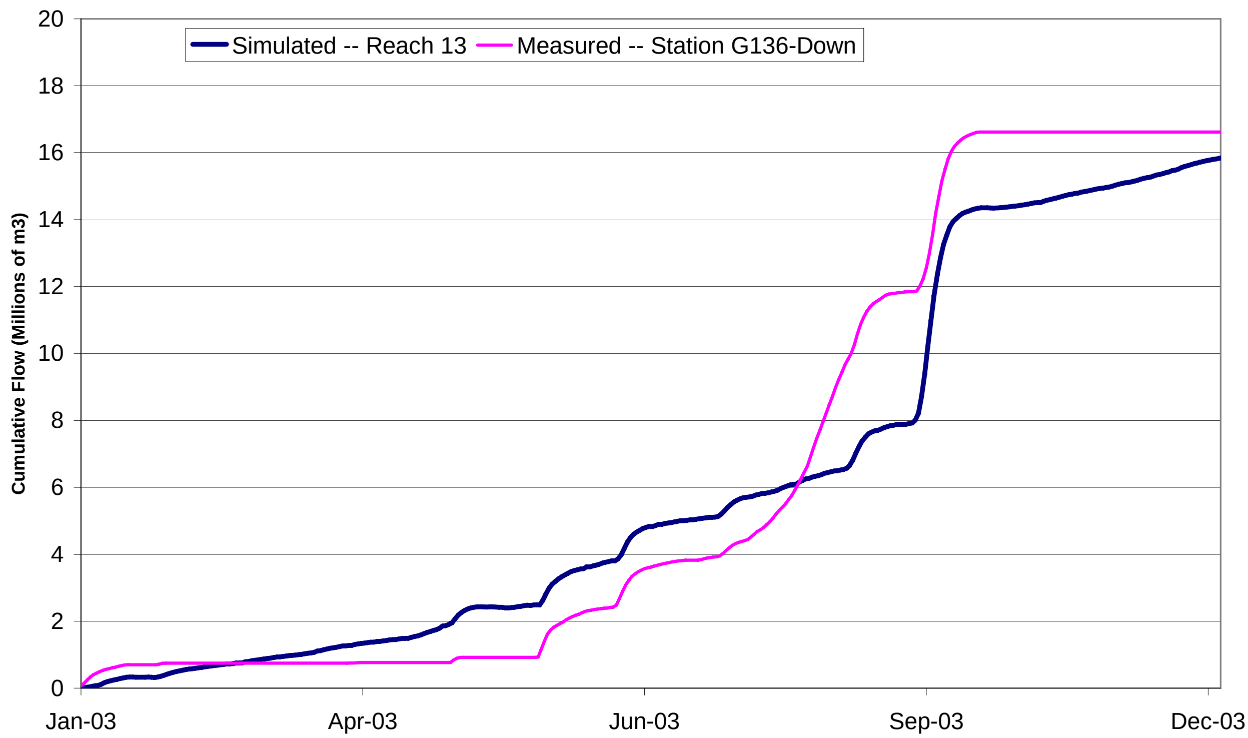



**Figure 4.87: Validation cumulative flow for 2003 through G-136**

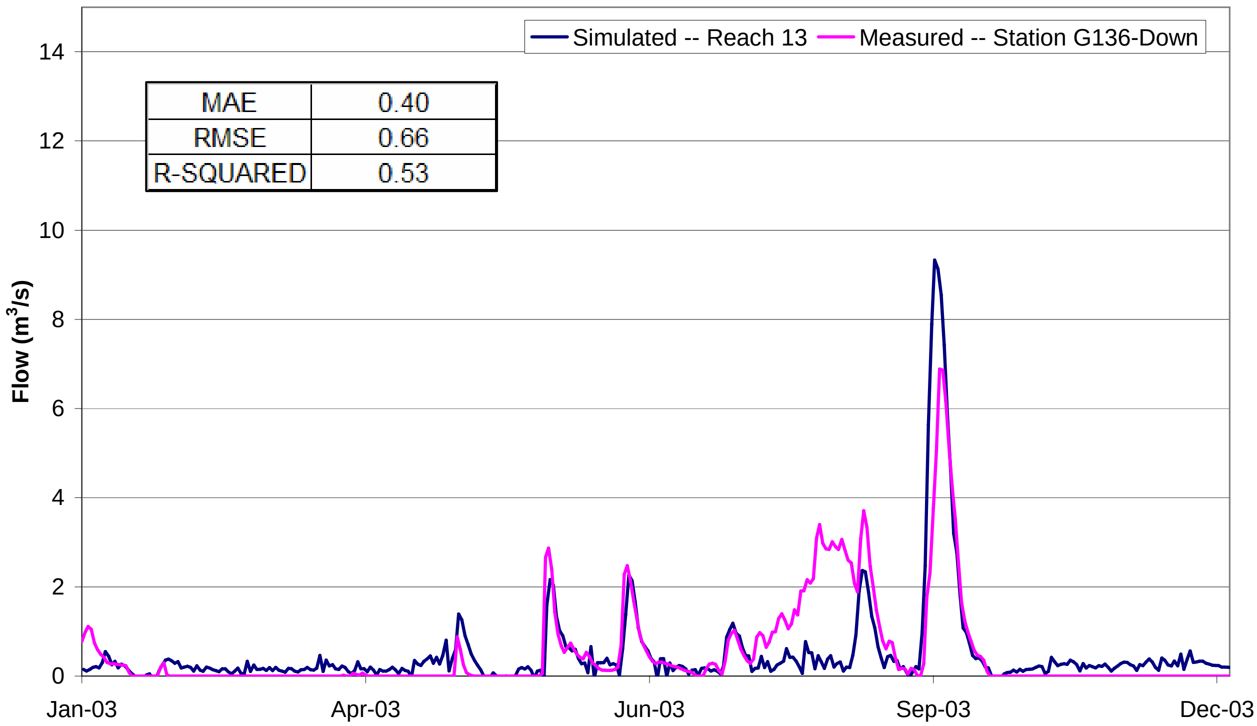



**Figure 4.88: Validation daily flows for G-136 for 2003**

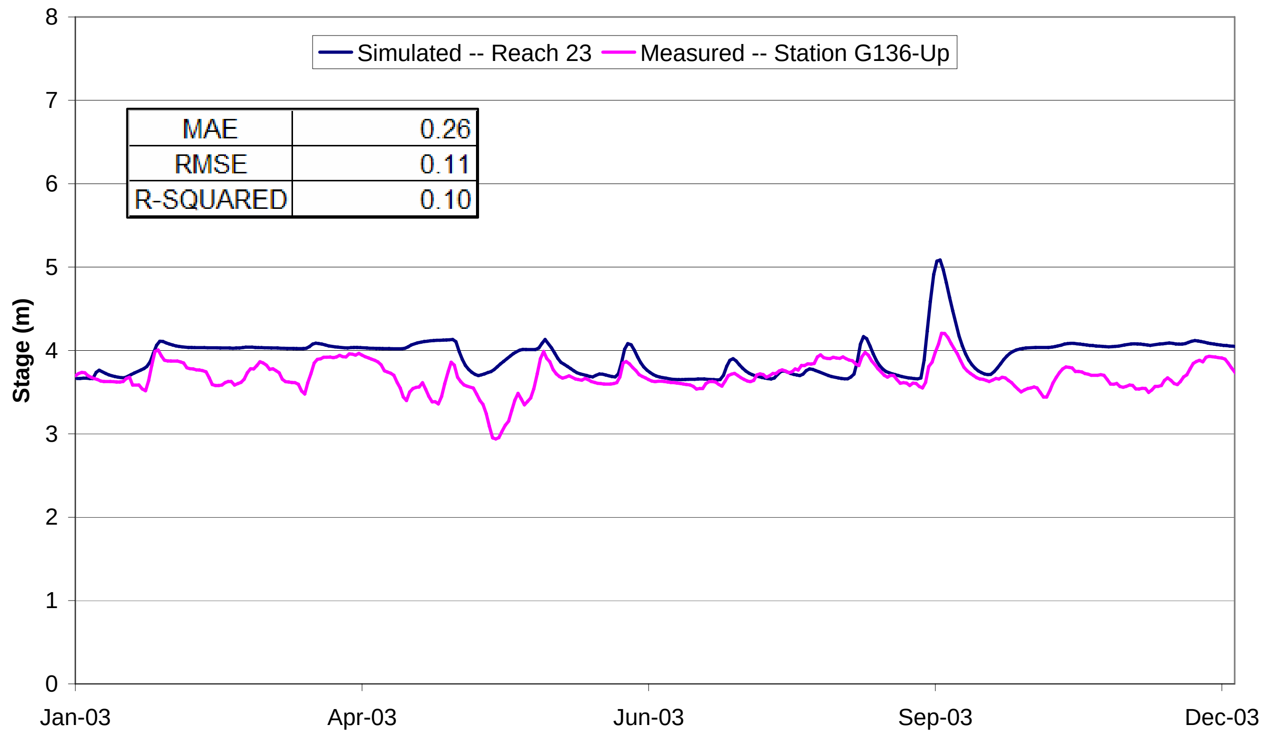



**Figure 4.89: Validation stages upstream of G-136 (west) for 2003**

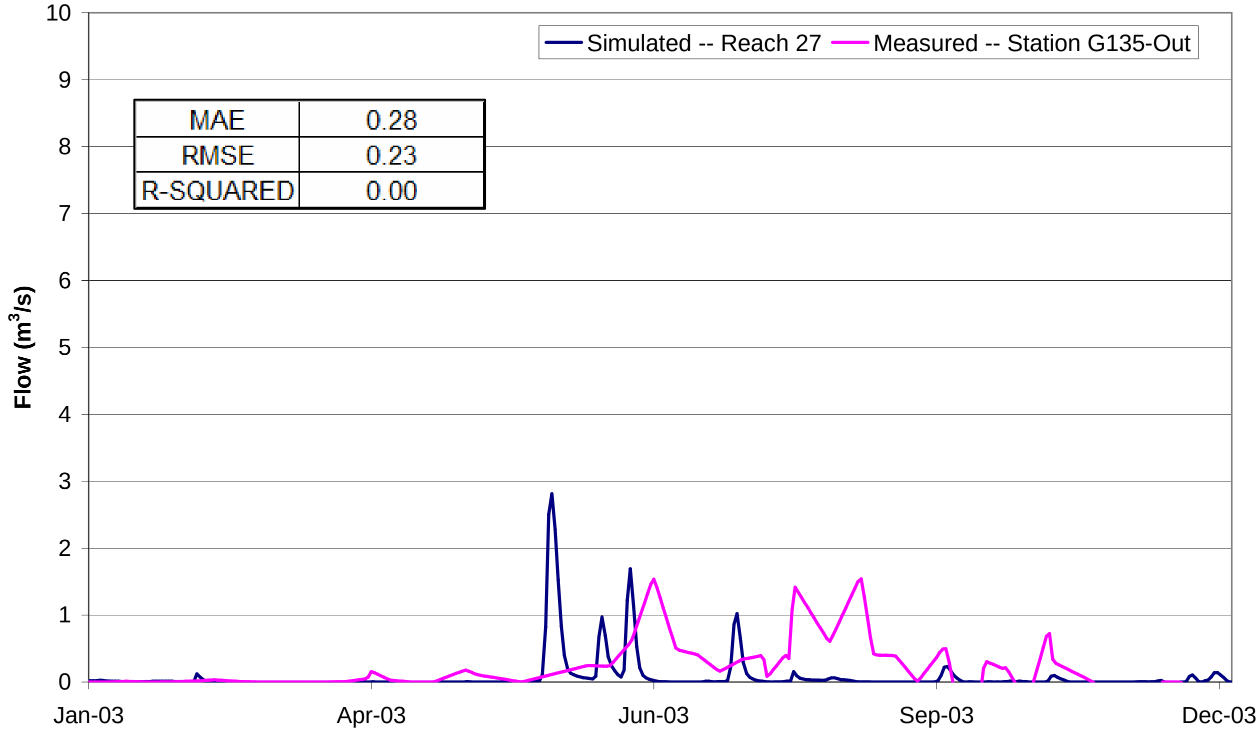



**Figure 4.90: Validation daily flows for G-135 for 2003**

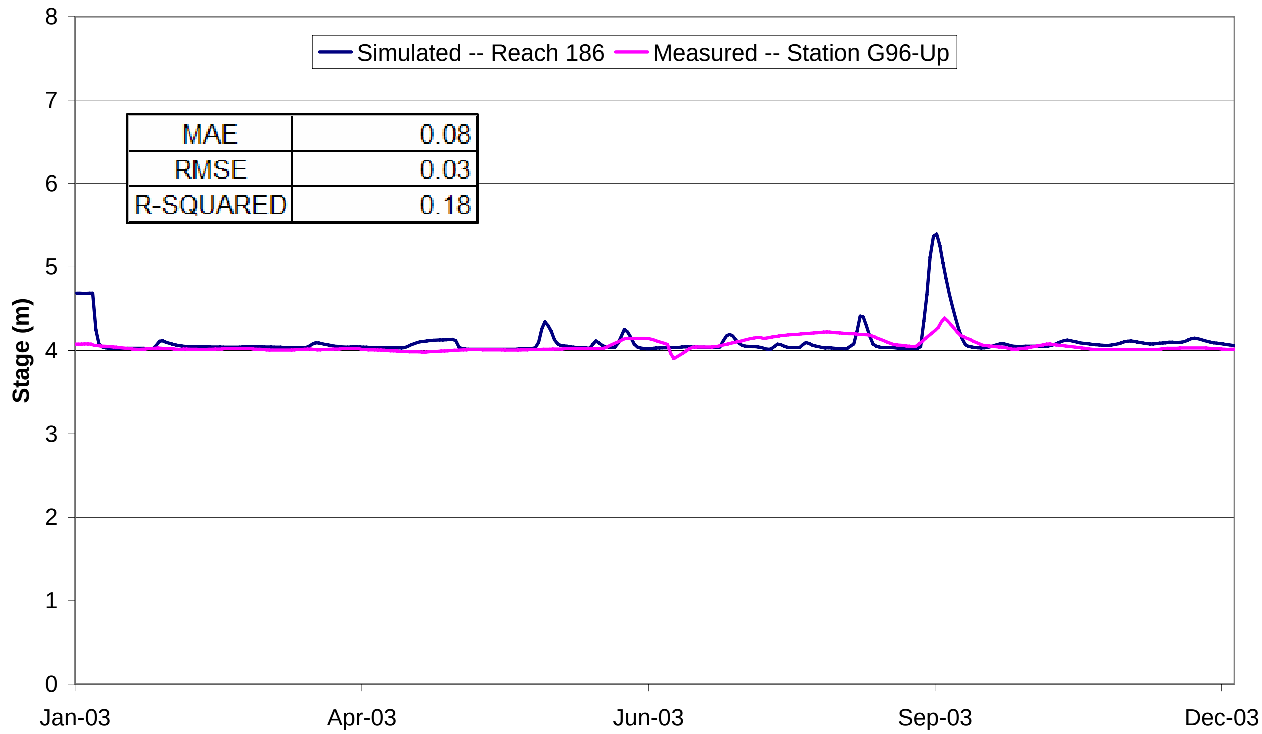



**Figure 4.91: Validation stages upstream of G-96 (west) for 2003**

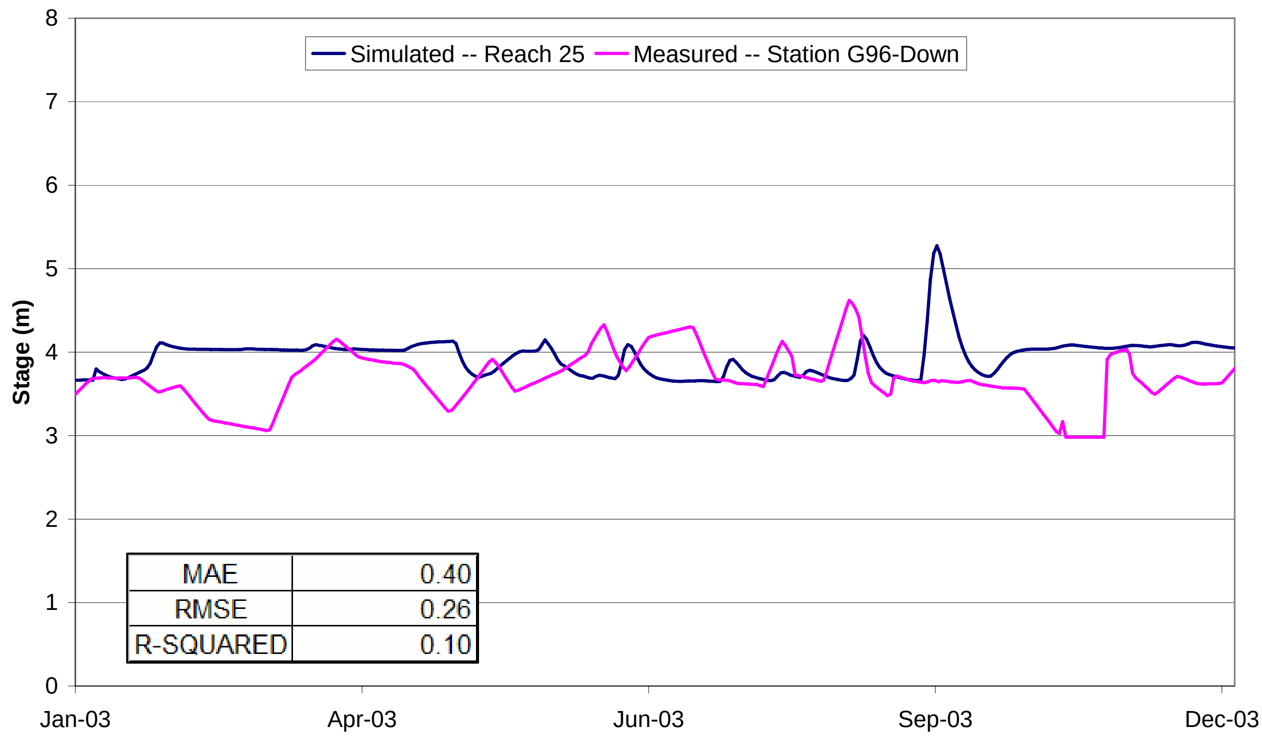



**Figure 4.92: Validation stages downstream of G-96 (east) for 2003**

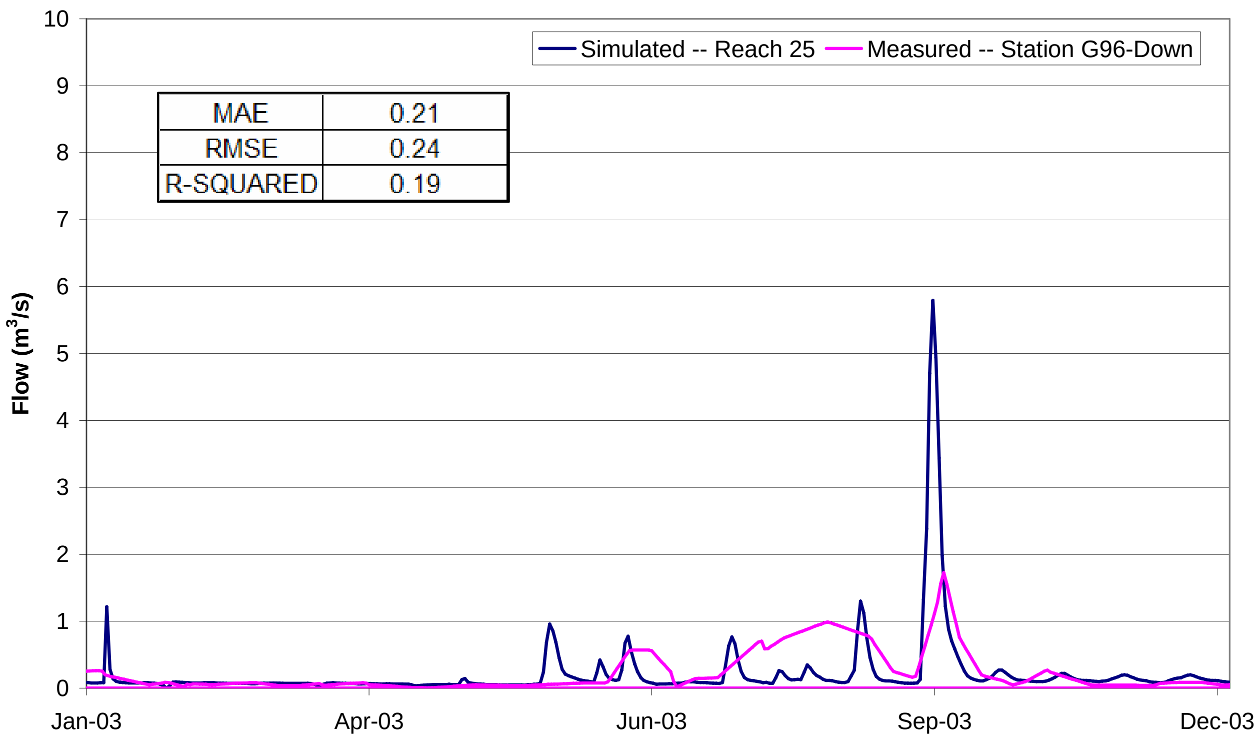



**Figure 4.93: Validation daily flows for G-96 for 2003**

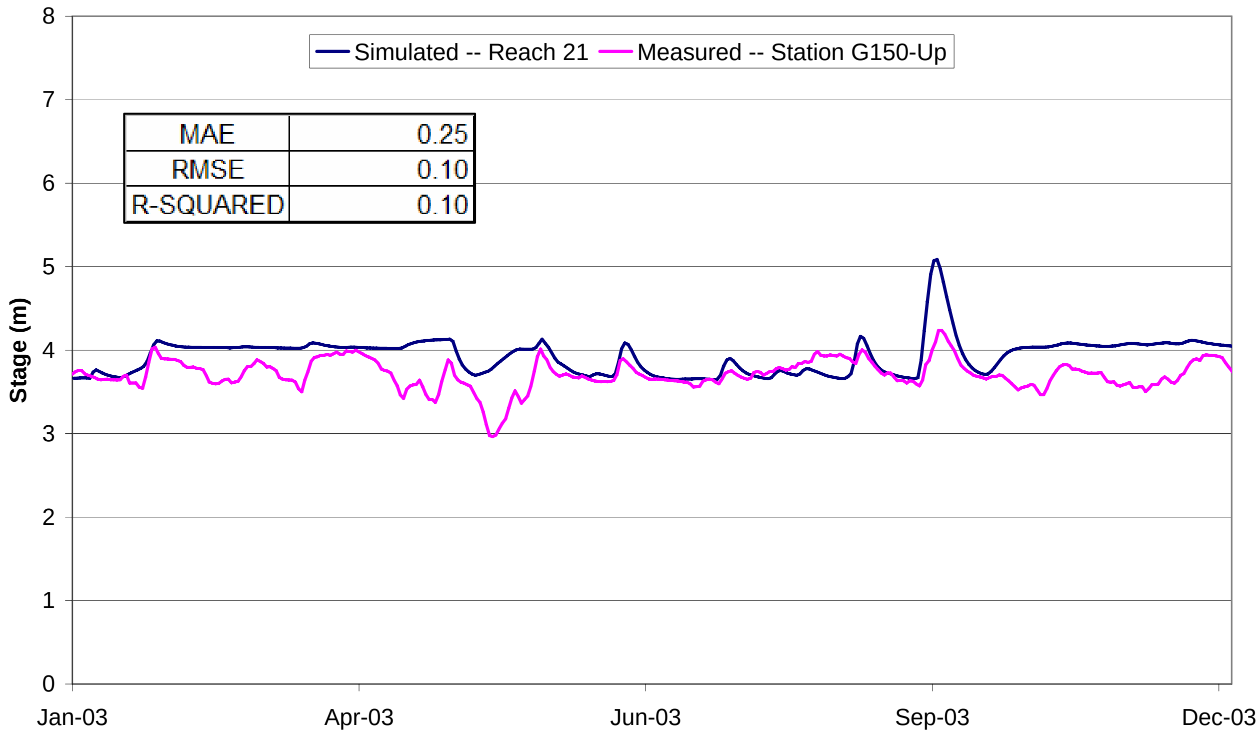



**Figure 4.94: Validation stages upstream of G-150 (north) for 2003**

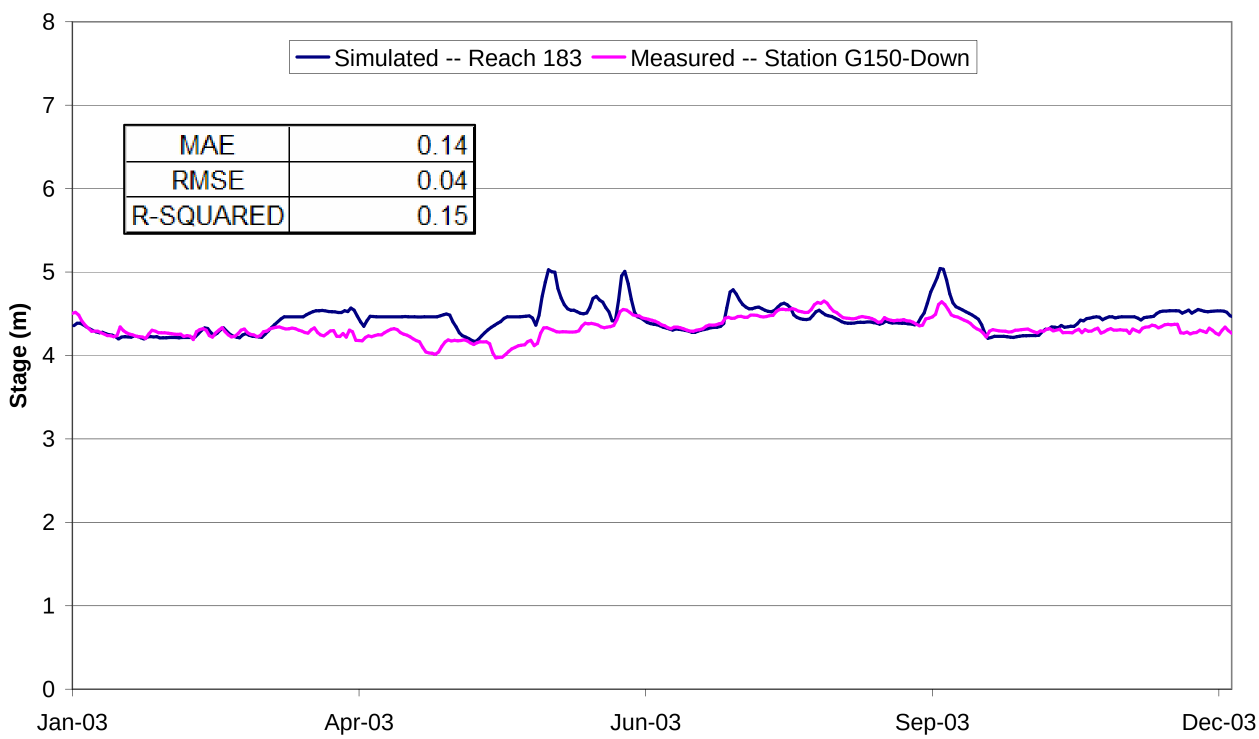



**Figure 4.95: Validation stages downstream of G-150 (south) for 2003**

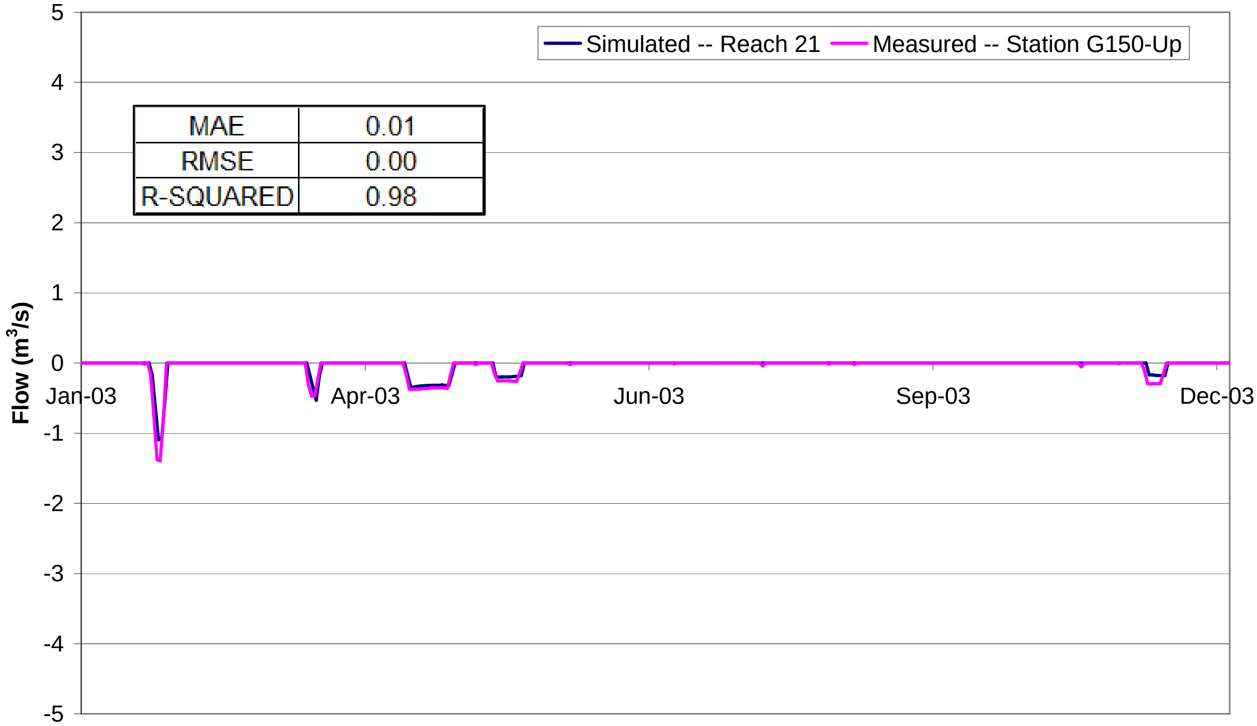



**Figure 4.96: Validation daily flows for G-150 for 2003**

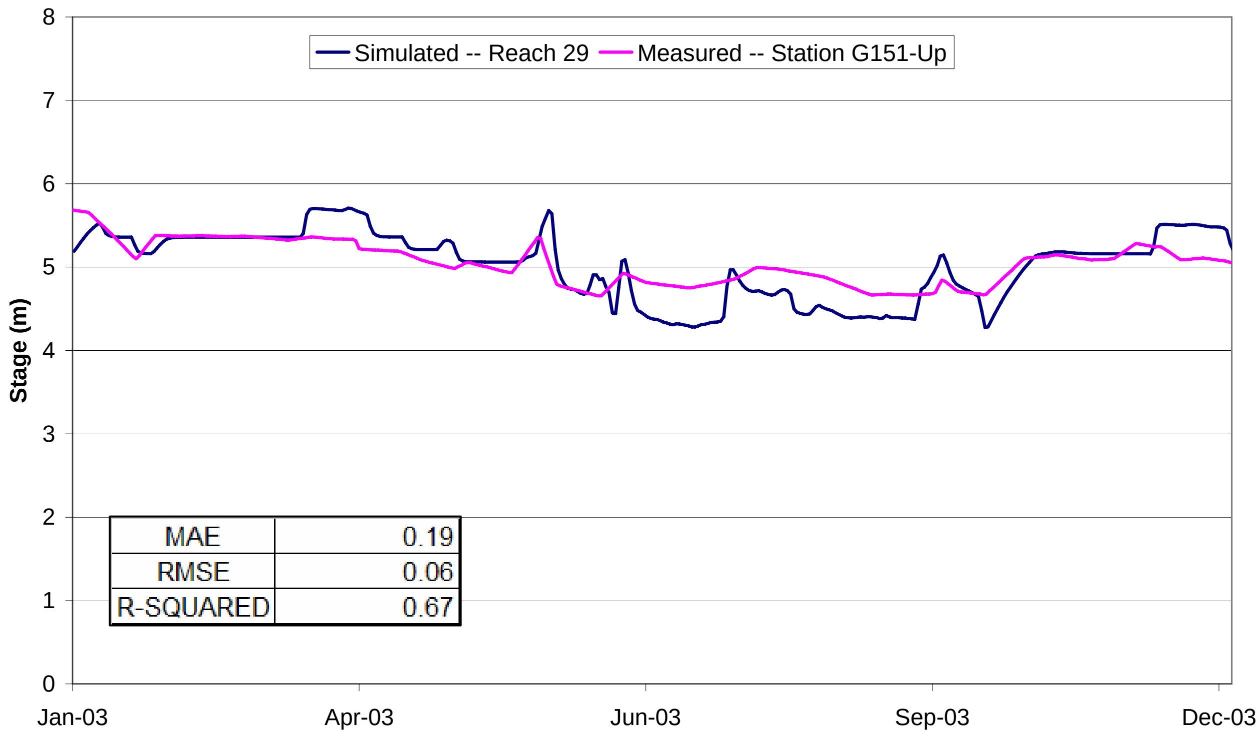



**Figure 4.97: Validation stages upstream of G-151 (west) for 2003**

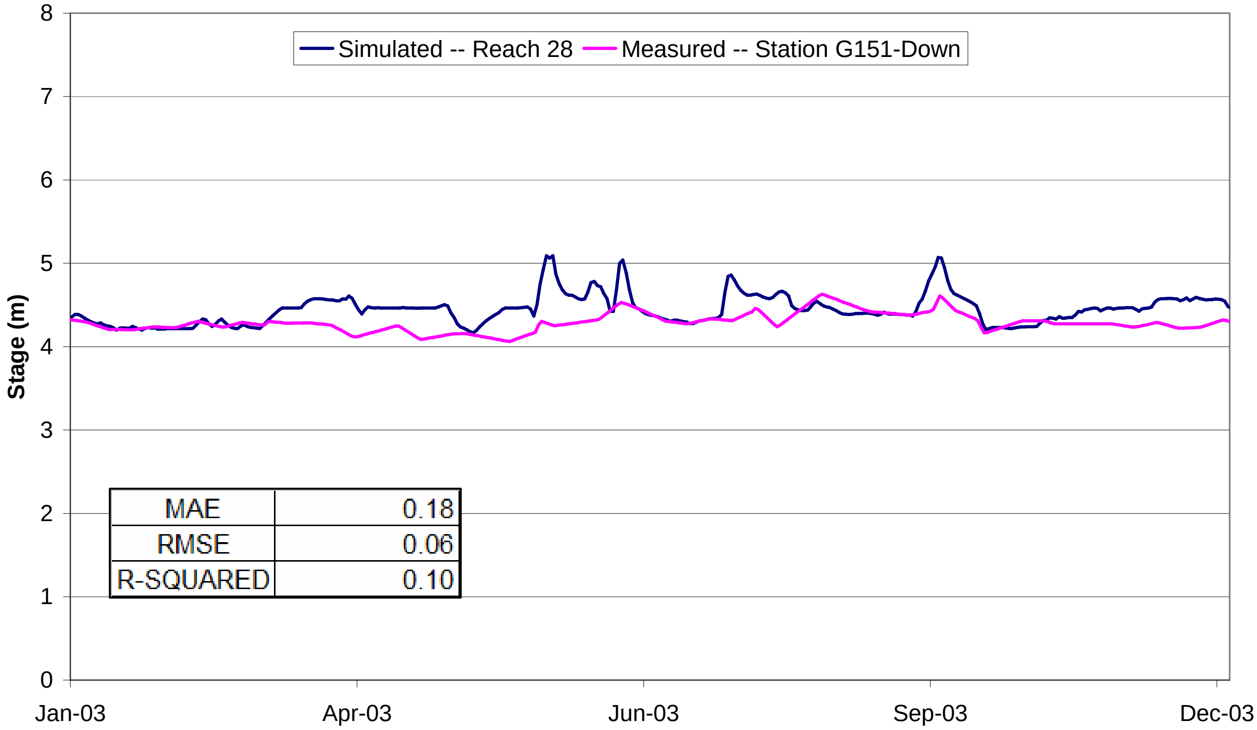



**Figure 4.98: Validation stages downstream of G-151 (east) for 2003**

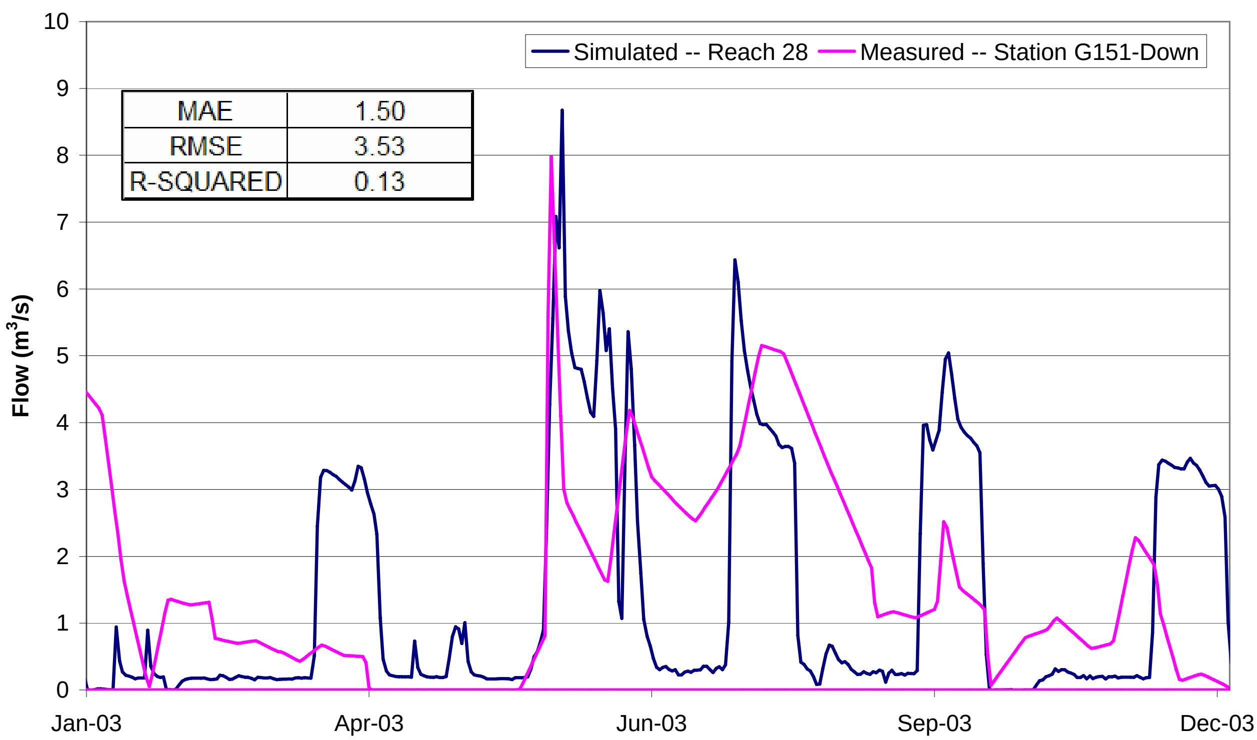



**Figure 4.99: Validation daily flows for G-151 for 2003**

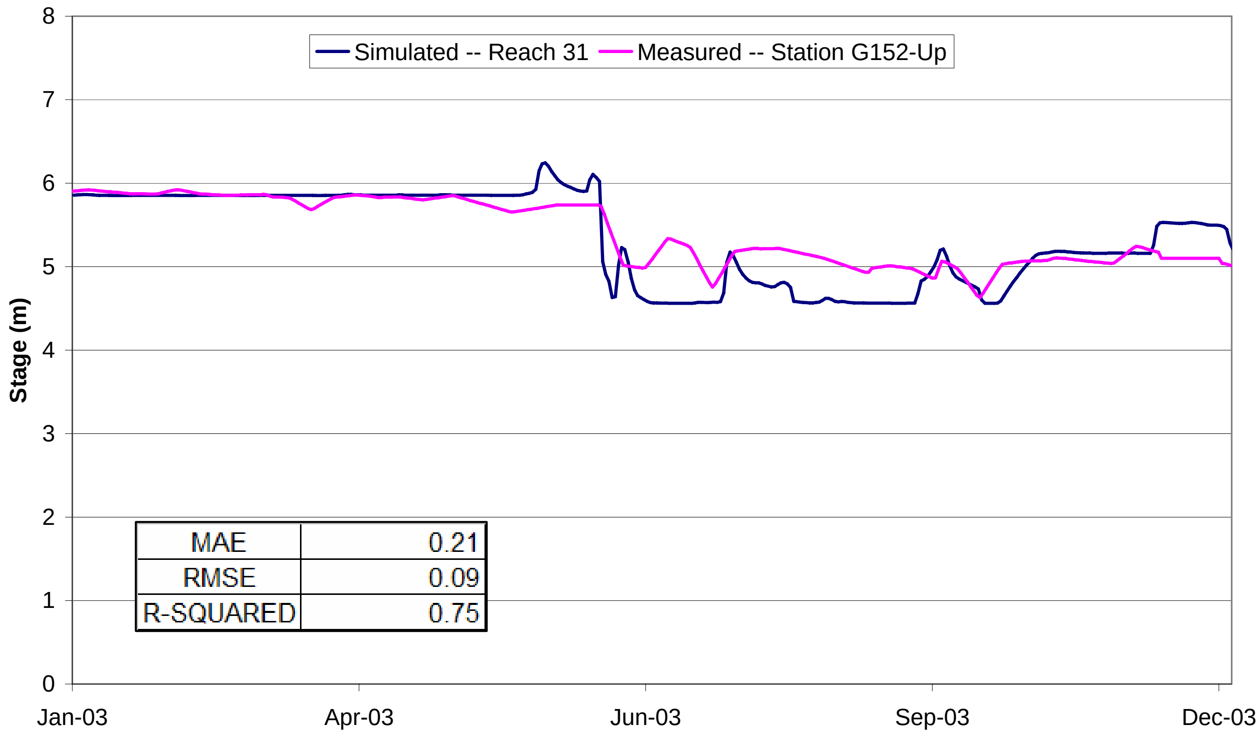



**Figure 4.100: Validation stages upstream of G-152 (west) for 2003**

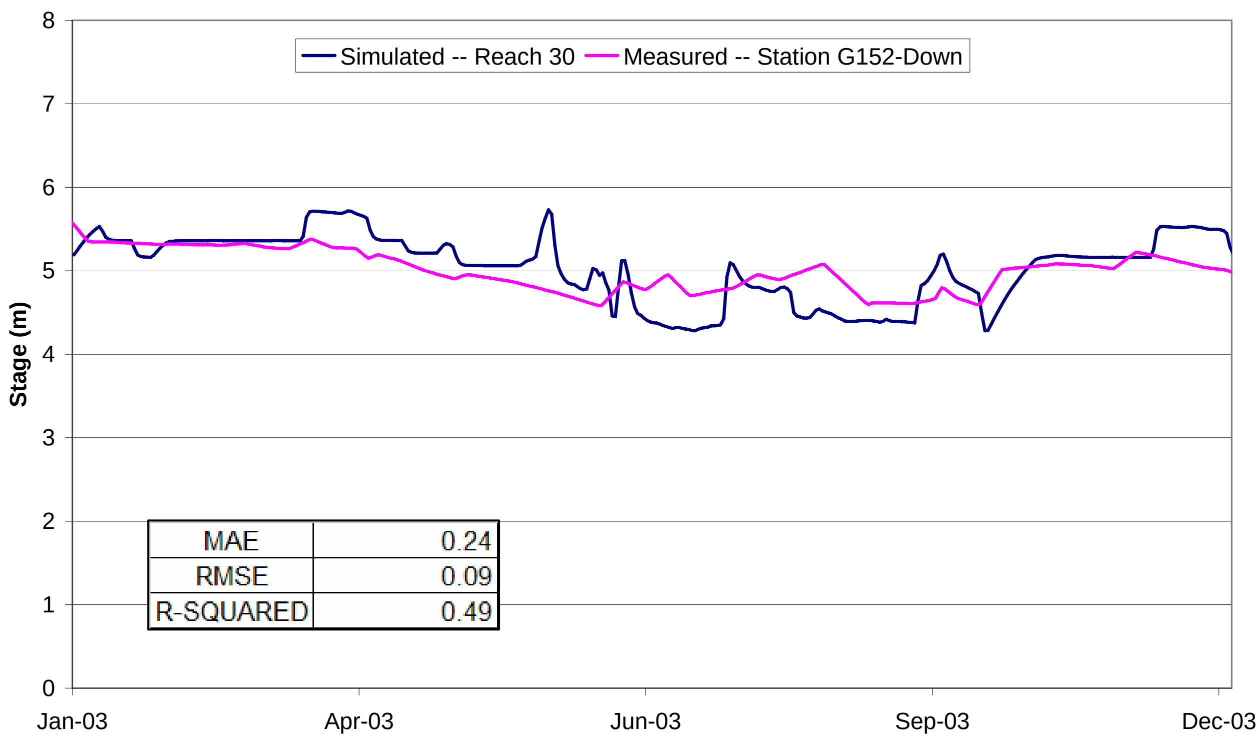



**Figure 4.101: Validation stages downstream of G-152 (east) for 2003**

## 4.7.2. Validation Water Quality

The validation of a computer model relies on information developed during the calibration process and tests the validity of the model parameters that would be used when simulating projections. Specifically, the set of hydrologic, hydraulic, and water quality parameters developed during the calibration are finalized and used in validation simulations with out any event-specific adjustments. The calendar year 2003 was selected to validate the C-139 WAM model.

**Figures 4.102** through **4.105** represent temporal comparisons of model computations to observe Total Phosphorus concentrations at G-136, G-342A, G-342C, and G-406 control structures during the 2003 validation period. Also, **Figures 4.106** through **4.111** illustrate the simulated partitioning of sedimentary and soluble P as compared with observed values for all stations where the measurements are available. Overall, the model reasonably reproduced TP concentrations observed during the wet season. However, the model consistently over-predicted the early season dry weather TP concentrations. This pattern is indicative of an insufficient spin-up time for the basin-wide model. Hydrologic data was only included starting in 2000, and it is reasonable to assume that initial conditions that may have exaggerated loads or concentrations.

Overall, the WAM water quality model tracks TP in the watershed and develops a relationship between runoff and water quality in the C-139 Canals. The model calibration is influenced by quantity calibration. It is believed that improvements in the quantity calibration will likely improve quality calibration.

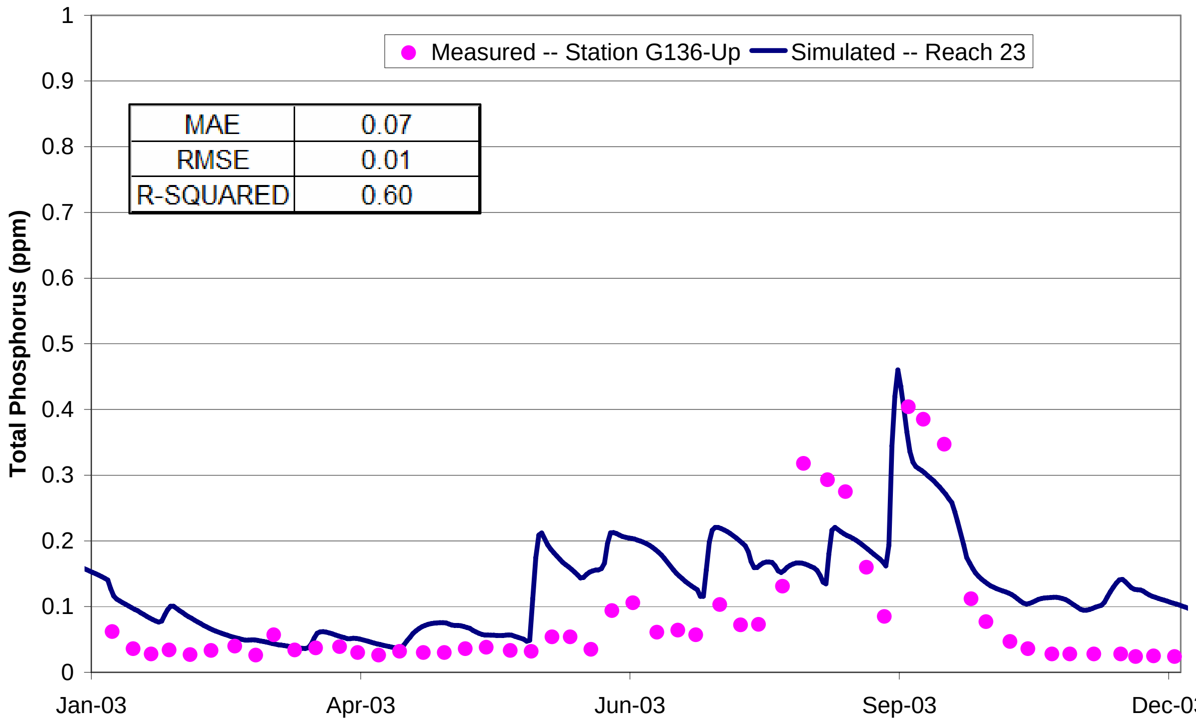



**Figure 4.102: Validation TP concentration for G-136 in 2003**

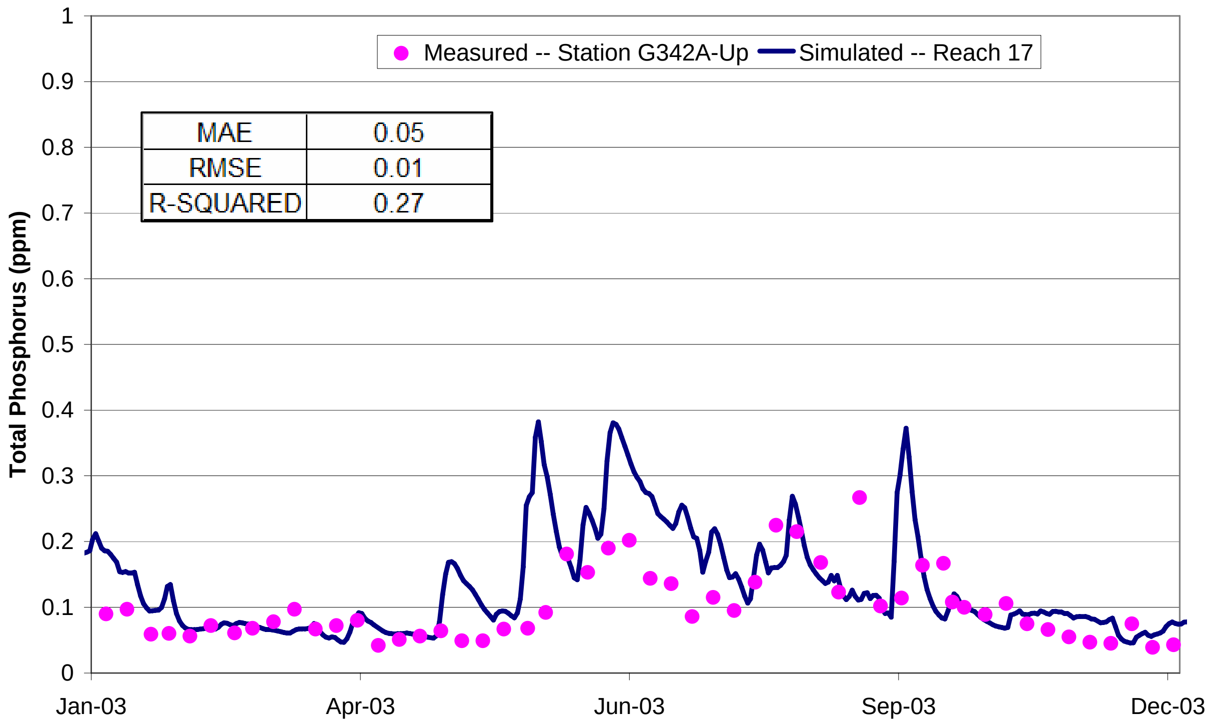



**Figure 4.103: Validation TP concentration for G-342A in 2003**

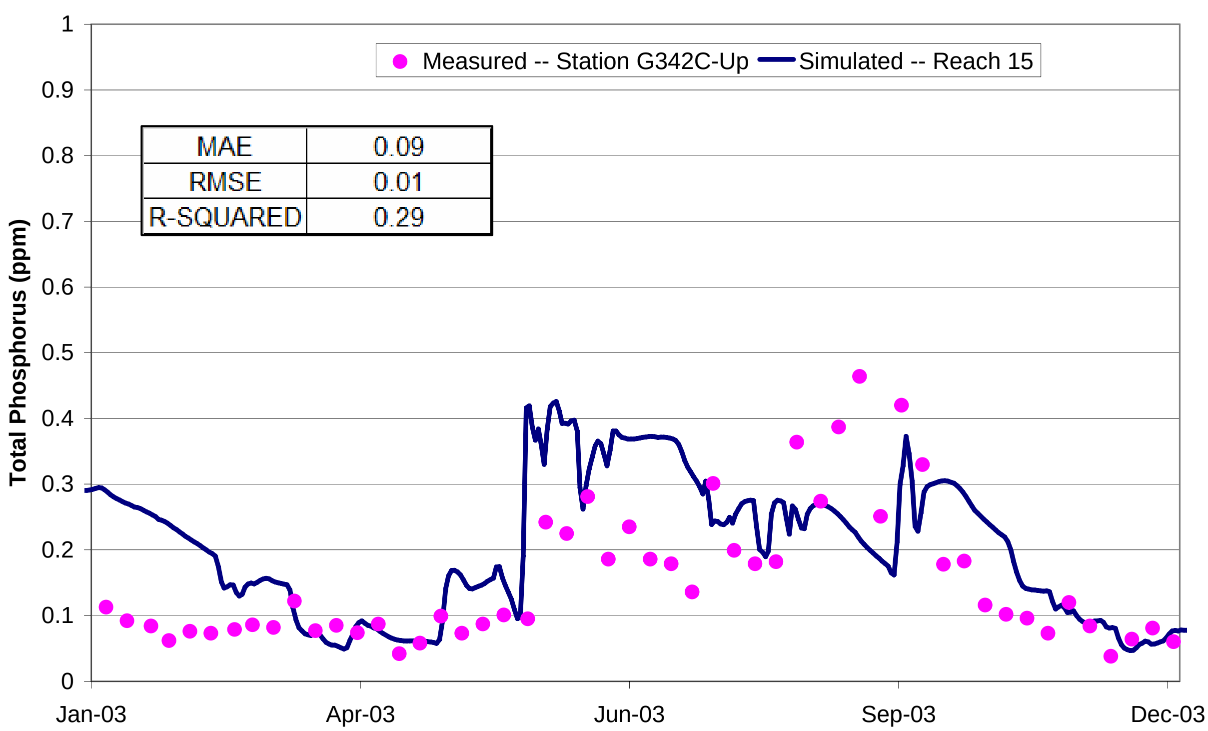



**Figure 4.104: Validation TP concentration for G-342C in 2003**

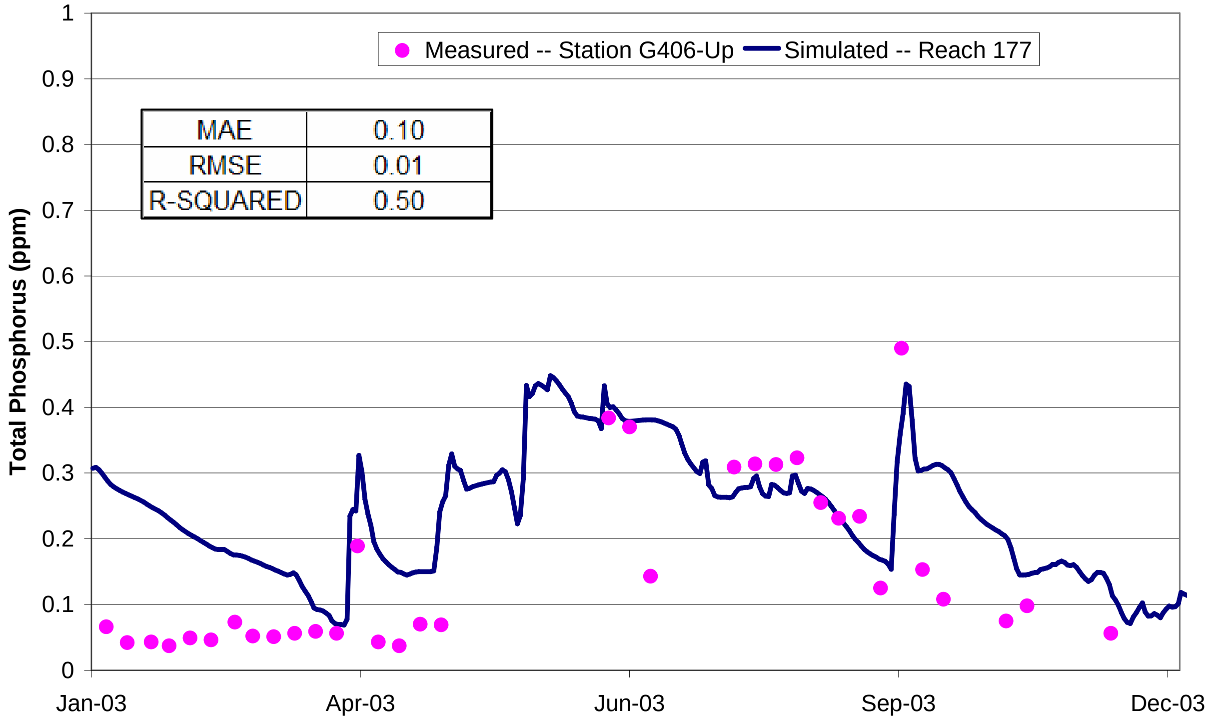



**Figure 4.105: Validation TP concentration for G-406 in 2003**

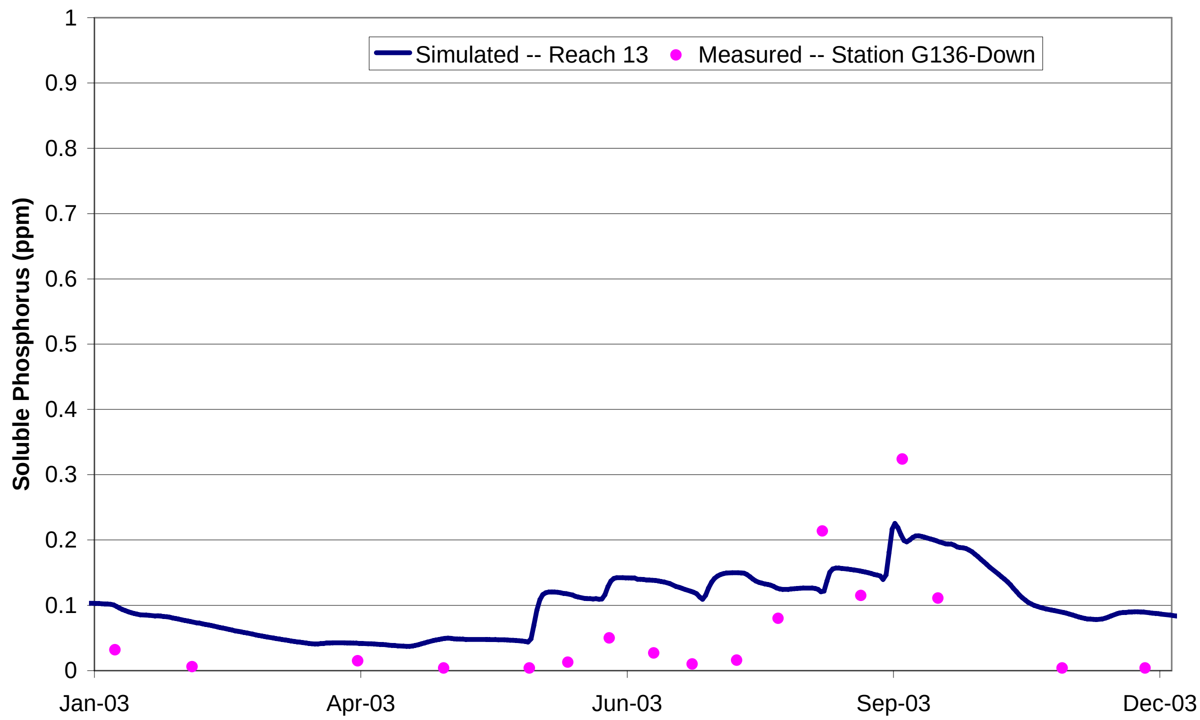



**Figure 4.106: Validation Soluble P concentration for G-136 in 2003**

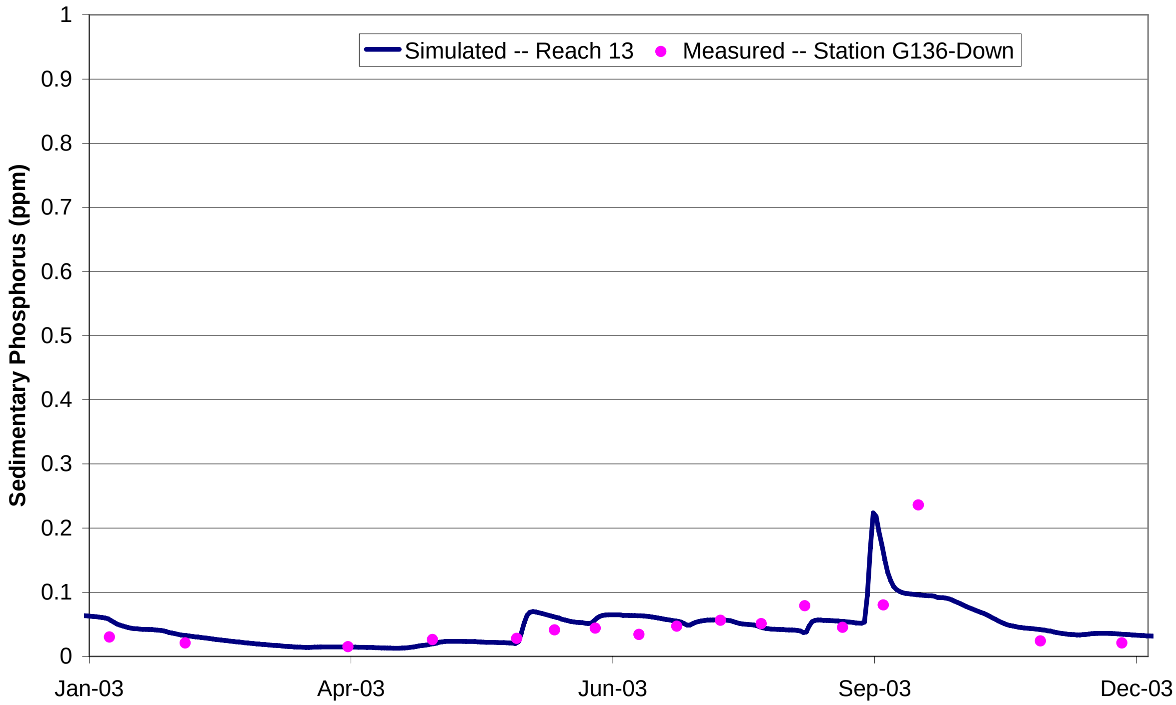



**Figure 4.107: Validation Sedimentary P concentration for G-136 in 2003**

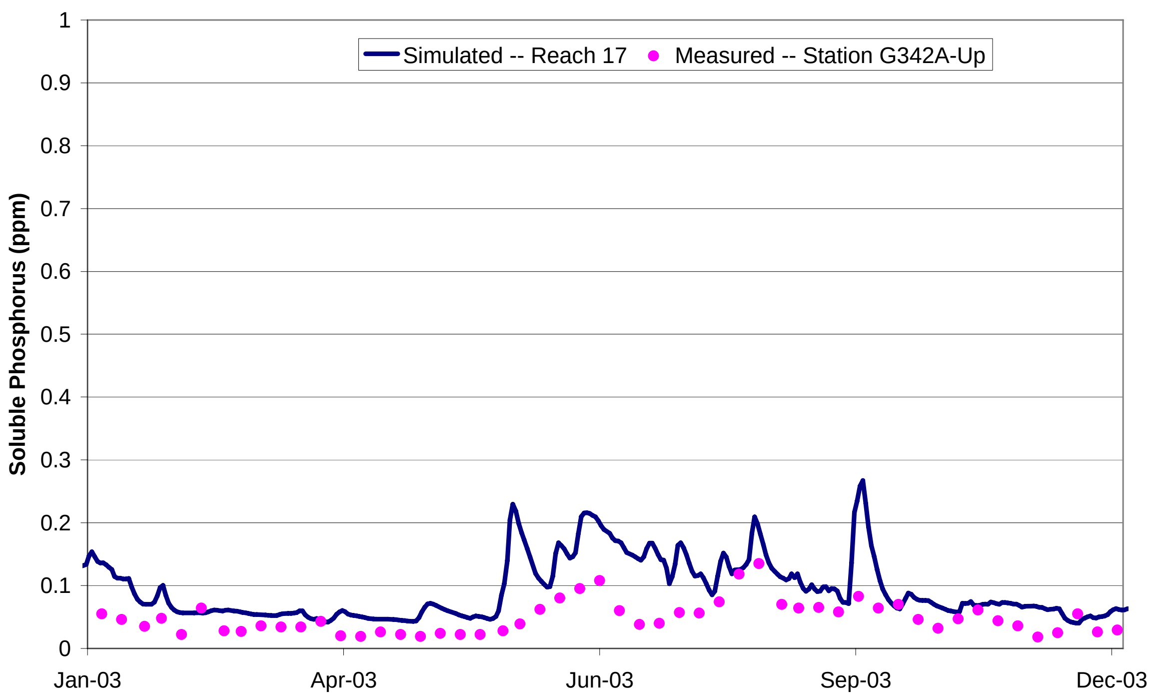



**Figure 4.108: Validation Soluble P concentration for G-342A in 2003**

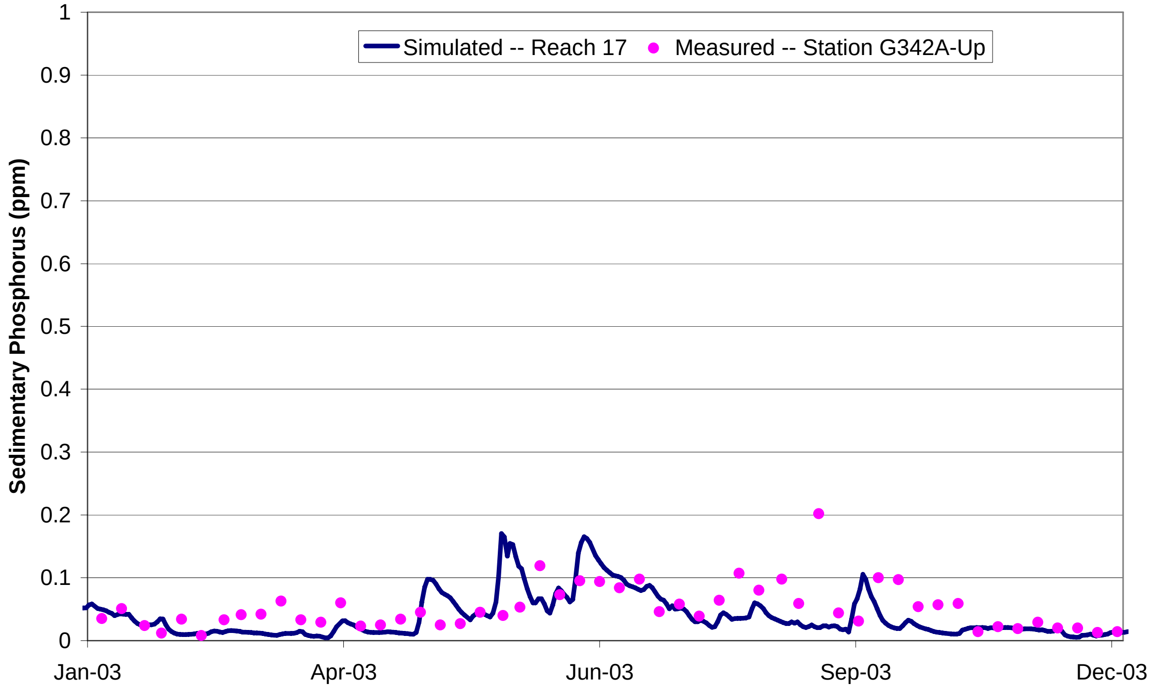



**Figure 4.109: Validation Sedimentary P concentration for G-342A in 2003**

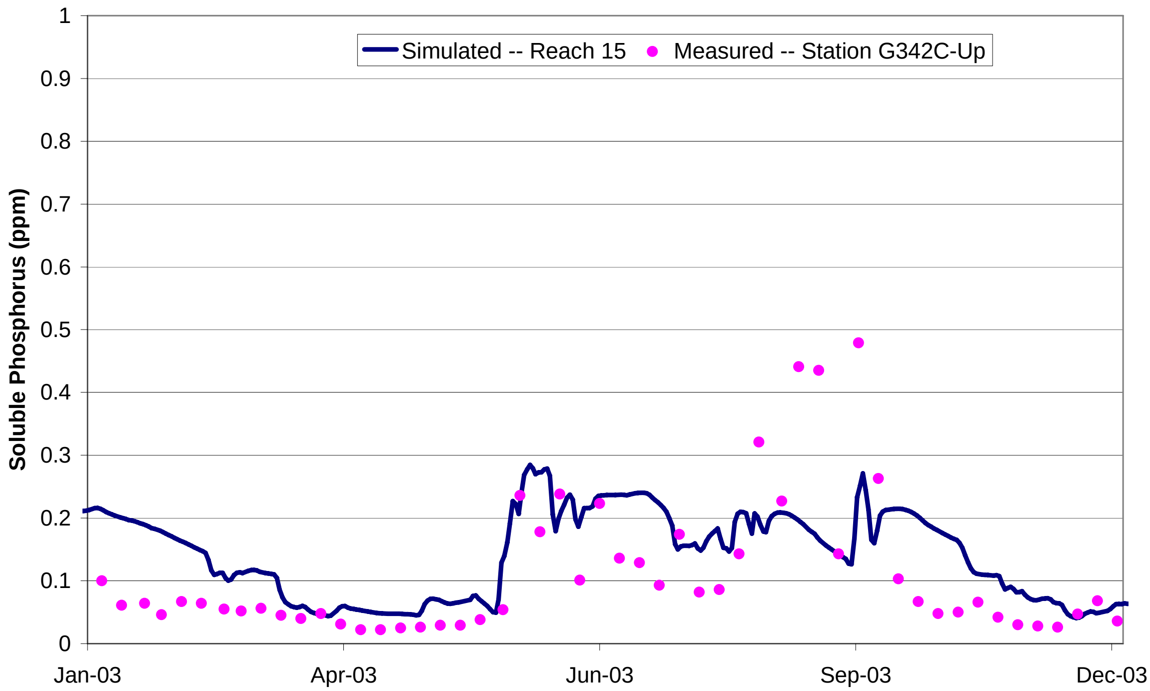



**Figure 4.110: Validation Soluble P concentration for G-342C in 2003**

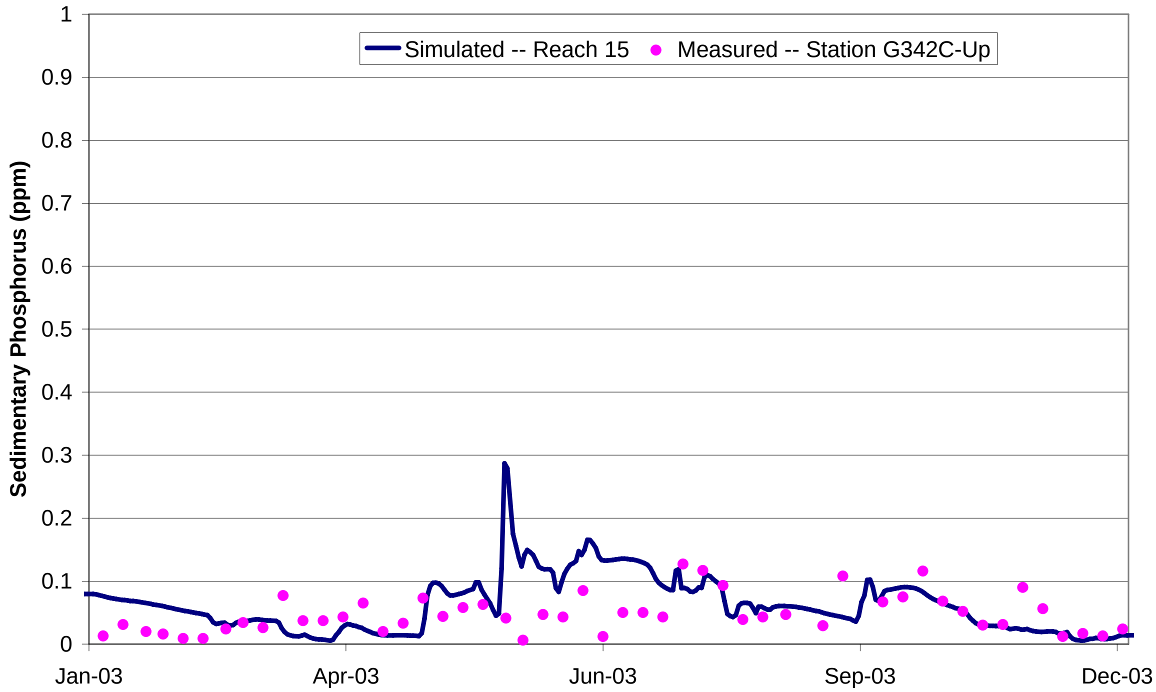



**Figure 4.111: Validation Sedimentary P concentration for G-342C in 2003**

## 4.8 Statistical Evaluation

The results presented in the calibration and validation section above provide some insight as to the ability of WAM to represent the natural processes occurring within the C-139 Basin. **Tables 4.2**, **4.3** and **4.4** below summarize the statistical metrics used to evaluate the performance of the model at each location for the years 2003, 2004 and 2005, respectively. For some characteristics or locations, the statistical comparison would be duplicative and is not presented in these tables, but is instead represented by N/I or Not Included. An example would be a comparison of measured and modeled flow at both the upstream and downstream side of a structure, since for these locations there is only one flow measurement. Another example is the flow measurements for the individual structures that provide inflow to STA-5, which are represented in a single comparison in conjunction with the G-406 bypass structure. A statistical evaluation of TP concentrations at G-342B and G-342D are also not included, since the G-342A and G-406 structures are physically adjacent. There are also locations where there is no measurement available, such as flow at G-152 or TP concentration at any of the locations that are not basin discharges. For these locations the comment N/A is used to indicate that the measured data is Not Available.

## Table 4.2: Summary of statistical comparison of daily characteristics for 2003

| STATION | FLOW [CMS] | | | STAGE [M] | | | TP CONCENTRATION [PPM] | | |
|---|---|---|---|---|---|---|---|---|---|
| | MAE | RMSE | R-SQUARED | MAE | RMSE | R-SQUARED | MAE | RMSE | R-SQUARED |
| **G-135** | 0.28 | 0.23 | 0.00 | N/I | N/I | N/I | N/A | N/A | N/A |
| **G-136** | 0.40 | 0.66 | 0.53 | 0.26 | 0.11 | 0.10 | 0.07 | 0.01 | 0.6 |
| **G-96 Upstream** | N/I | N/I | N/I | 0.08 | 0.03 | 0.18 | N/A | N/A | N/A |
| **G-96 Downstream** | 0.21 | 0.24 | 0.19 | 0.40 | 0.26 | 0.10 | N/A | N/A | N/A |
| **G-150 Upstream** | 0.01 | 0.00 | 0.98 | 0.25 | 0.10 | 0.10 | N/A | N/A | N/A |
| **G-150 Downstream** | N/I | N/I | N/I | 0.14 | 0.04 | 0.15 | N/A | N/A | N/A |
| **G-151 Upstream** | N/I | N/I | N/I | 0.19 | 0.06 | 0.67 | N/A | N/A | N/A |
| **G-151 Downstream** | 1.50 | 3.53 | 0.13 | 0.18 | 0.06 | 0.10 | N/A | N/A | N/A |
| **G-152 Upstream** | N/A | N/A | N/A | 0.21 | 0.09 | 0.75 | N/A | N/A | N/A |
| **G-152 Downstream** | N/A | N/A | N/A | 0.24 | 0.09 | 0.49 | N/A | N/A | N/A |
| **G-342A** | N/I | N/I | N/I | N/I | N/I | N/I | 0.05 | 0.01 | 0.27 |
| **G-342B** | N/I | N/I | N/I | N/I | N/I | N/I | N/I | N/I | N/I |
| **G-342C** | N/I | N/I | N/I | N/I | N/I | N/I | 0.09 | 0.01 | 0.29 |
| **G-342D** | N/I | N/I | N/I | N/I | N/I | N/I | N/I | N/I | N/I |
| **G-406** | 2.06 | 18.75 | 0.22 | 0.09 | 0.02 | 0.05 | 0.10 | 0.01 | 0.50 |
| **STA5 Inflow and G-406** | 6.57 | 112.75 | 0.25 | N/A | N/A | N/A | N/A | N/A | N/A |

## Table 4.3: Summary of statistical comparison of daily characteristics for 2004

| STATION | FLOW [CMS] | | | STAGE [M] | | | TP CONCENTRATION [PPM] | | |
|---|---|---|---|---|---|---|---|---|---|
| | MAE | RMSE | R-SQUARED | MAE | RMSE | R-SQUARED | MAE | RMSE | R-SQUARED |
| **G-135** | 0.73 | 1.03 | 0.20 | N/I | N/I | N/I | N/A | N/A | N/A |
| **G-136** | 0.53 | 0.91 | 0.67 | 0.40 | 0.25 | 0.04 | 0.08 | 0.01 | 0.55 |
| **G-96 Upstream** | N/I | N/I | N/I | 0.16 | 0.06 | 0.21 | N/A | N/A | N/A |
| **G-96 Downstream** | 0.42 | 1.13 | 0.13 | 0.36 | 0.18 | 0.04 | N/A | N/A | N/A |
| **G-150 Upstream** | 0.05 | 0.03 | 0.88 | 0.38 | 0.24 | 0.04 | N/A | N/A | N/A |
| **G-150 Downstream** | N/I | N/I | N/I | 0.25 | 0.14 | 0.11 | N/A | N/A | N/A |
| **G-151 Upstream** | N/I | N/I | N/I | 0.26 | 0.12 | 0.31 | N/A | N/A | N/A |
| **G-151 Downstream** | 1.89 | 11.42 | 0.00 | 0.29 | 0.16 | 0.13 | N/A | N/A | N/A |
| **G-152 Upstream** | N/A | N/A | N/A | 0.22 | 0.08 | 0.53 | N/A | N/A | N/A |
| **G-152 Downstream** | N/A | N/A | N/A | 0.28 | 0.13 | 0.34 | N/A | N/A | N/A |
| **G-342A** | N/I | N/I | N/I | N/I | N/I | N/I | 0.06 | 0.01 | 0.41 |
| **G-342B** | N/I | N/I | N/I | N/I | N/I | N/I | N/I | N/I | N/I |
| **G-342C** | N/I | N/I | N/I | N/I | N/I | N/I | 0.09 | 0.01 | 0.33 |
| **G-342D** | N/I | N/I | N/I | N/I | N/I | N/I | N/I | N/I | N/I |
| **G-406** | 2.30 | 22.19 | 0.20 | 0.19 | 0.10 | 0.03 | 0.10 | 0.01 | 0.60 |
| **STA5 Inflow and G-406** | 5.16 | 91.08 | 0.47 | N/I | N/I | N/I | N/A | N/A | N/A |

**Table 4.4: Summary of statistical comparison of daily characteristics for 2005**

| STATION | FLOW [CMS] | | | STAGE [M] | | | TP CONCENTRATION [PPM] | | |
|---|---|---|---|---|---|---|---|---|---|
| | MAE | RMSE | R-SQUARED | MAE | RMSE | R-SQUARED | MAE | RMSE | R-SQUARED |
| **G-135** | 0.81 | 1.01 | 0.09 | N/I | N/I | N/I | N/A | N/A | N/A |
| **G-136** | 0.66 | 1.53 | 0.73 | 0.29 | 0.13 | 0.28 | 0.12 | 0.02 | 0.37 |
| **G-96 Upstream** | N/I | N/I | N/I | 0.34 | 0.21 | 0.56 | N/A | N/A | N/A |
| **G-96 Downstream** | 0.41 | 0.75 | 0.45 | 0.34 | 0.19 | 0.02 | N/A | N/A | N/A |
| **G-150 Upstream** | 0.02 | 0.01 | 0.97 | 0.27 | 0.12 | 0.29 | N/A | N/A | N/A |
| **G-150 Downstream** | N/I | N/I | N/I | 0.17 | 0.05 | 0.50 | N/A | N/A | N/A |
| **G-151 Upstream** | N/I | N/I | N/I | 0.30 | 0.15 | 0.21 | N/A | N/A | N/A |
| **G-151 Downstream** | 2.10 | 8.58 | 0.16 | 0.22 | 0.08 | 0.45 | N/A | N/A | N/A |
| **G-152 Upstream** | N/A | N/A | N/A | 0.22 | 0.08 | 0.46 | N/A | N/A | N/A |
| **G-152 Downstream** | N/A | N/A | N/A | 0.37 | 0.19 | 0.16 | N/A | N/A | N/A |
| **G-342A** | N/I | N/I | N/I | N/I | N/I | N/I | 0.10 | 0.03 | 0.28 |
| **G-342B** | N/I | N/I | N/I | N/I | N/I | N/I | N/I | N/I | N/I |
| **G-342C** | N/I | N/I | N/I | N/I | N/I | N/I | 0.14 | 0.04 | 0.26 |
| **G-342D** | N/I | N/I | N/I | N/I | N/I | N/I | N/I | N/I | N/I |
| **G-406** | 2.15 | 19.57 | 0.64 | 0.12 | 0.03 | 0.18 | 0.22 | 0.07 | 0.08 |
| **STA5 Inflow and G-406** | 7.32 | 143.87 | 0.59 | N/I | N/I | N/I | N/A | N/A | N/A |

The results presented in **Tables 4.2**, **4.3** and **4.4** demonstrate that for some parameters and in some locations, the model does not demonstrate considerable agreement with the measured values. As previously described, this lack of agreement could be attributed to the limited availability of groundwater data, recorded structure operations, rainfall and evapotranspiration data and private land management practices. However, the WAM representation of the C-139 Basin is intended to be used as a planning tool that demonstrates basin-level hydrologic and water quality response to various rainfall and planning scenarios. The calibration and validation results shown above illustrate the C-139 WAM simulation's capabilities at a daily time scale. Daily temporal resolution often includes a variety of confounding variables that make simulated predictions inaccurate. In order to evaluate the capabilities of the C-139 WAM simulation to predict general trends, the simulated and measured flow and concentration can be aggregated into quarterly averages. A comparison of the quarterly average simulated and measured flow and TP concentration is described in **Table 4.5**. The quarterly evaluation assumes the segregation of the year into 3 month quarters as described by District staff and detailed below:

- December – February
- March – May
- June – August
- September – November

**Table 4.5: Statistical comparison of quarterly average flows and concentrations**

| STATION | FLOW [CMS] | | | TP CONCENTRATION [PPM] | | |
|---|---|---|---|---|---|---|
| | MAE | RMSE | R-SQUARED | MAE | RMSE | R-SQUARED |
| **G-135** | 0.47 | 0.65 | 0.17 | N/A | N/A | N/A |
| **G-136** | 0.37 | 0.46 | 0.78 | 0.08 | 0.09 | 0.53 |
| **STA-5 INFLOW / G-406** | 2.50 | 3.34 | 0.81 | N/A | N/A | N/A |
| **G-96** | 0.18 | 0.26 | 0.68 | N/A | N/A | N/A |
| **G-150** | 0.02 | 0.03 | 0.90 | N/A | N/A | N/A |
| **G-151** | 1.28 | 1.83 | 0.01 | N/A | N/A | N/A |
| **G-342A** | 0.22 | 0.33 | 0.96 | 0.10 | 0.13 | 0.66 |
| **G-342B** | 0.90 | 1.27 | 0.90 | 0.09 | 0.11 | 0.65 |
| **G-342C** | 0.93 | 1.24 | 0.42 | 0.08 | 0.10 | 0.71 |
| **G-342D** | 0.75 | 1.09 | 0.30 | 0.12 | 0.14 | 0.29 |
| **G-406** | 0.92 | 1.32 | 0.83 | 0.13 | 0.17 | 0.33 |

With respect to r-squared, the quarterly average simulated flows show reasonable agreement with quarterly averaged measurements, with the exception of measured data at G-135, G-151, G-342C and G-342D. The measured flow at G-135 is significantly larger than the simulated flow due to variable flood protection practices by the Central County Drainage District that effectively increase the contributing area of the structure during large runoff events. Since these practices could not be identified as part of any specific operational conditions, they were not represented in the model. As discussed in Section 4.4.4, there is no flow monitoring equipment or gate opening telemetry collocated with the G-151 structure. The measured flow data at G-151 is likely based on manually recorded gate opening data and appears questionable. With respect to the low r-squared values for G-342C and G-342D, a comparison of the MAE and RMSE for these structures with the G-342B structure illustrates that the discrepancies between simulated and measured flows are not incongruously large. The variability of measured flows for G-342C and G-342D are small, meaning that errors that would be acceptable for G-342B create significantly lower r-squared values.

The statistical evaluation of TP concentration shows that the simulation is not as accurate with respect to water quality. However based on an r-squared greater than 0.5, there is positive agreement for all monitoring locations other than G-342D and G-406. Both of these structures are at the confluence of the S&M, DeerFence and L-3 Canals, and as such these disparities may be due to physical processes outside of WAM's capabilities such as sediment re-suspension. **Figures 4.112** through **4.122** illustrate the temporal comparison of simulated and measured quarterly average flow and TP concentration.

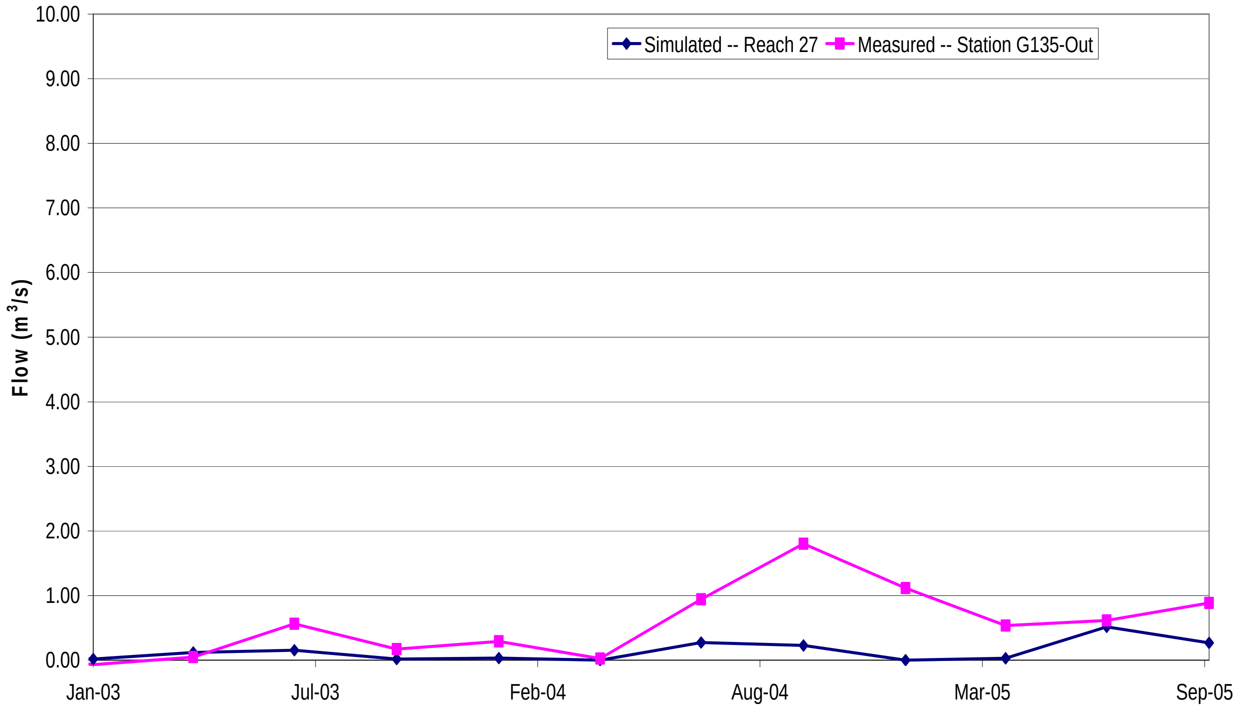



**Figure 4.112: Comparison of Average Quarterly Flows at G-135**

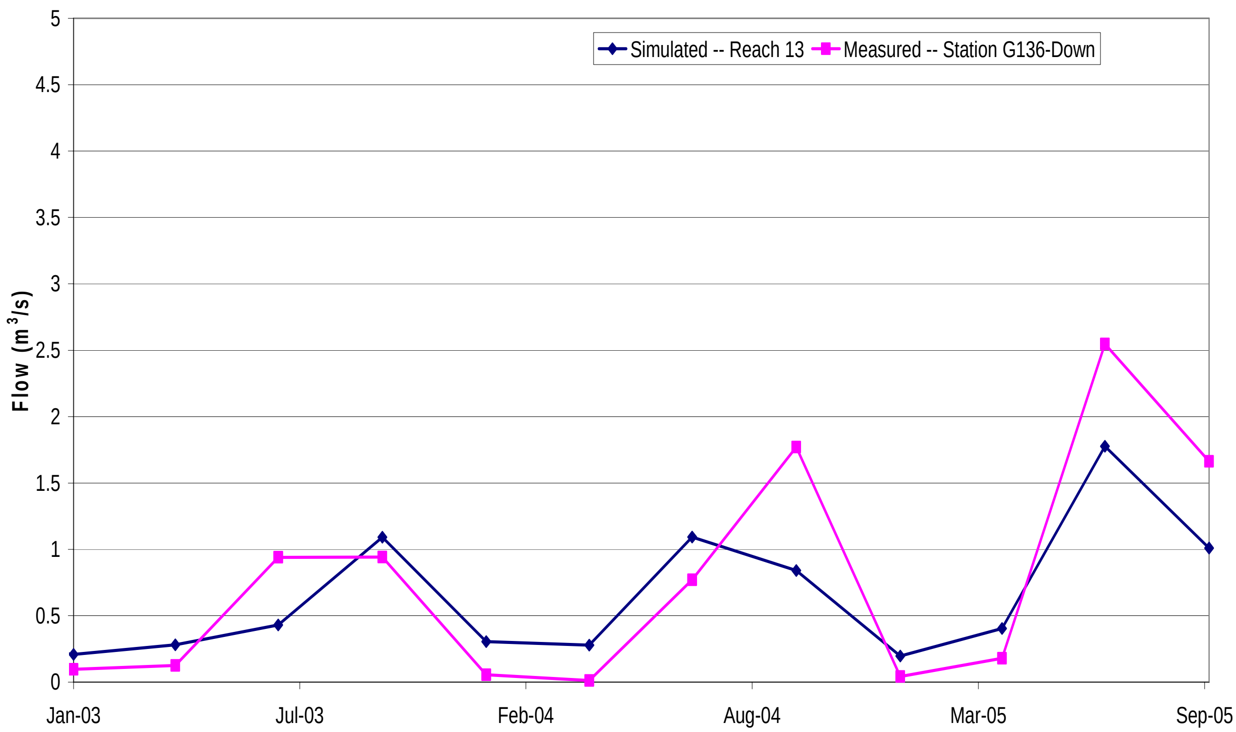



**Figure 4.113: Comparison of Average Quarterly Flows at G-136**

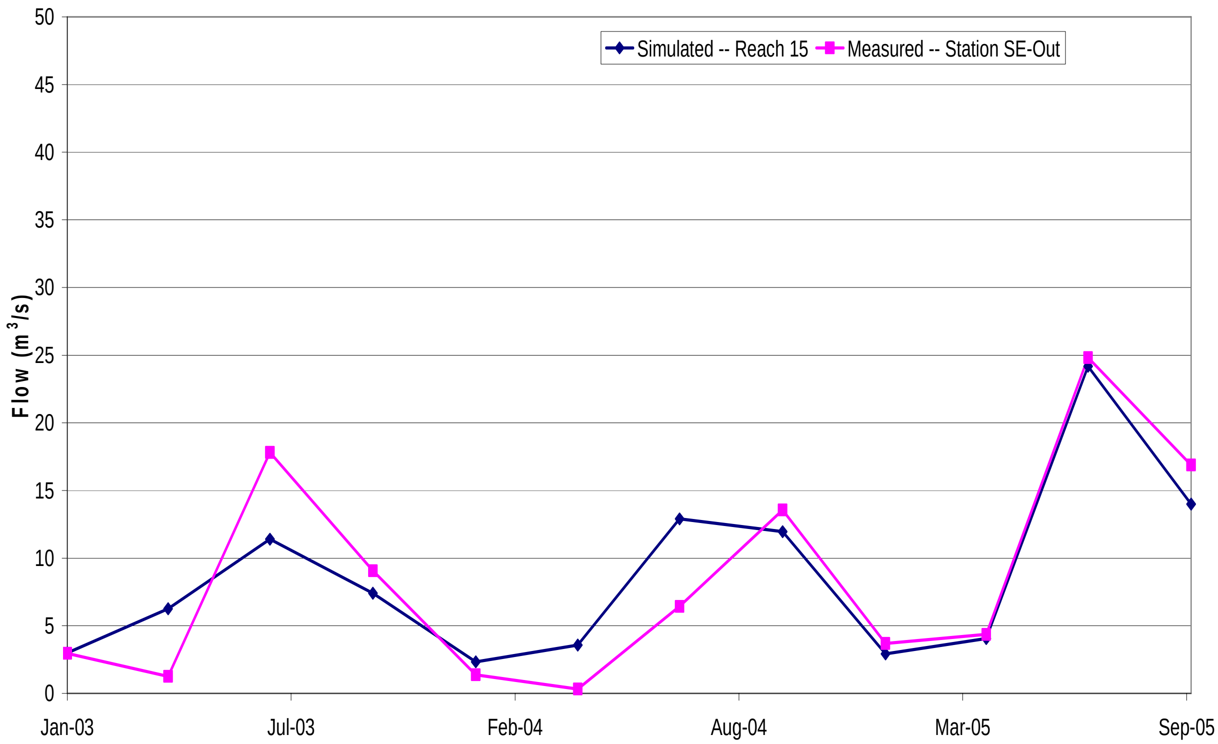



**Figure 4.114: Comparison of Average Quarterly Flows for STA-5 Inflow and G-406**

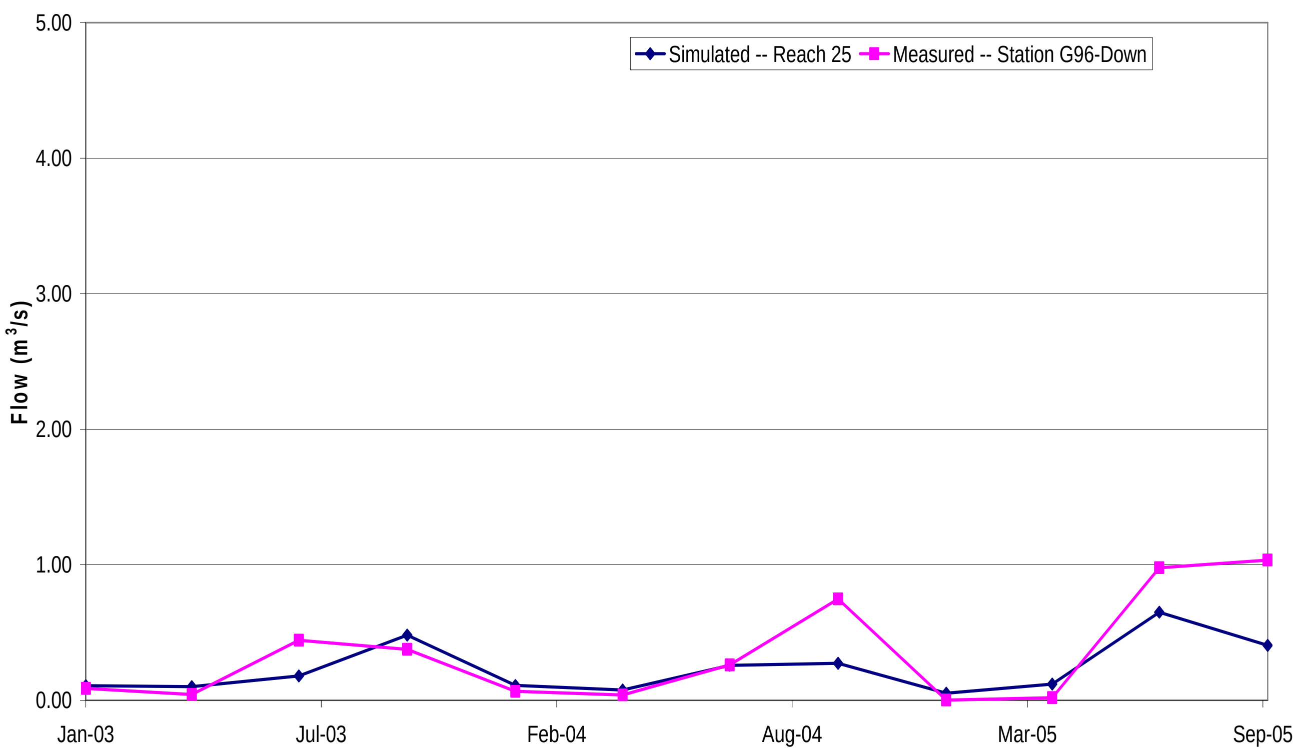



**Figure 4.115: Comparison of Average Quarterly Flows at G-96**

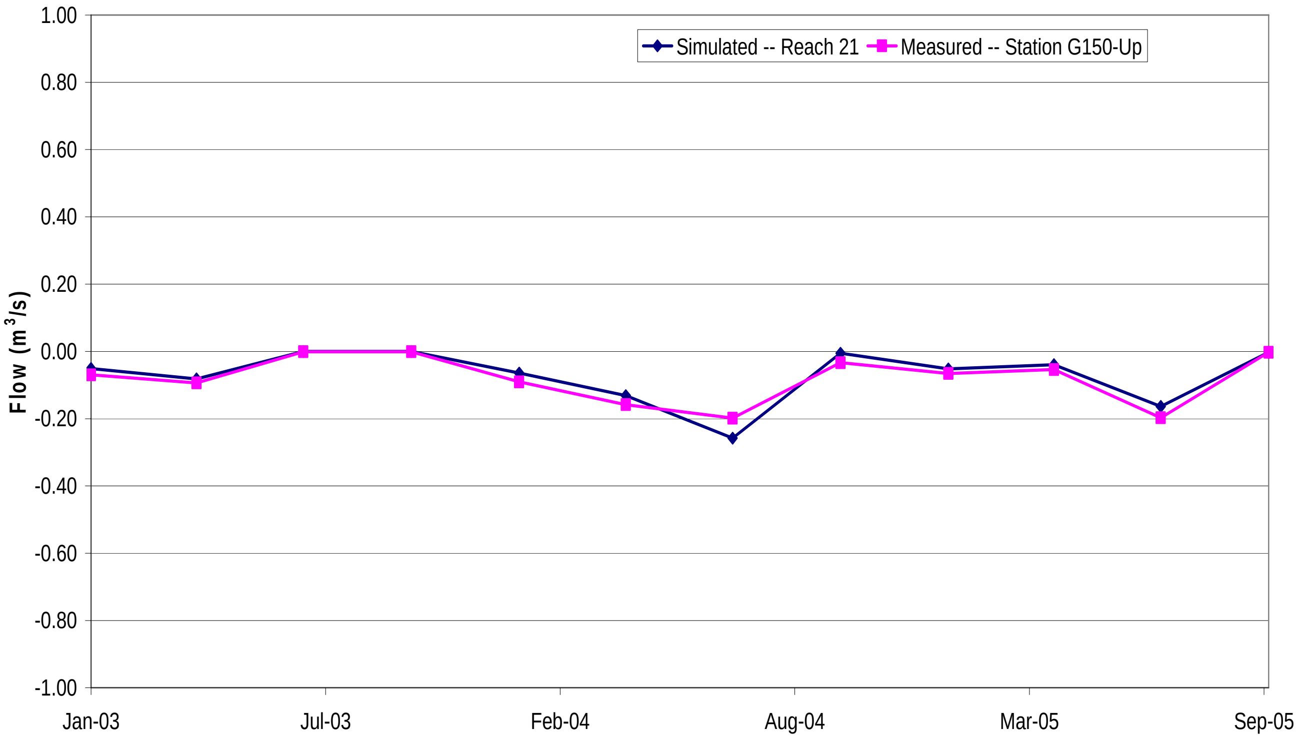



**Figure 4.116: Comparison of Average Quarterly Flows at G-150**

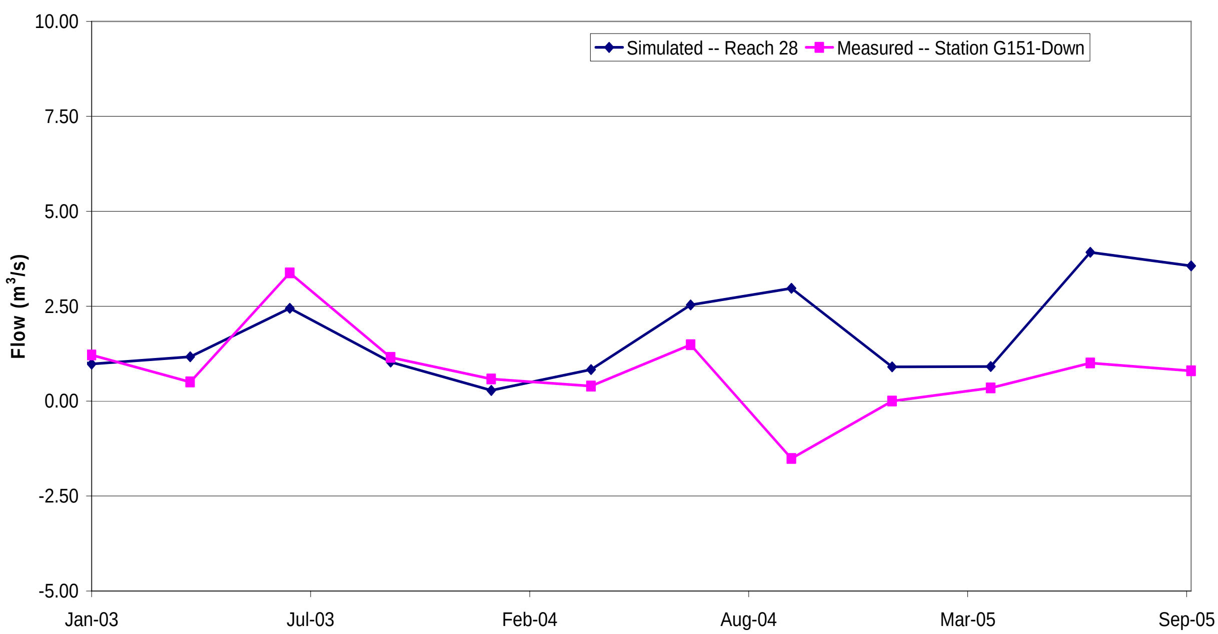



**Figure 4.117: Comparison of Average Quarterly Flows at G-151**

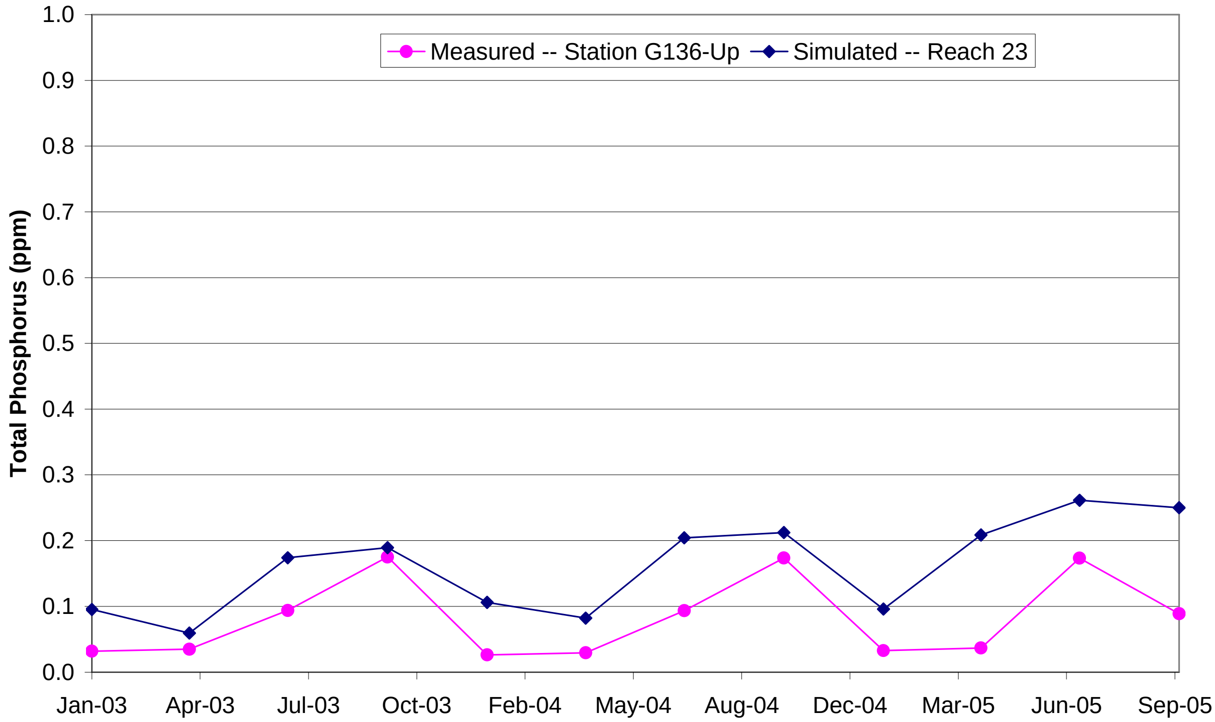



**Figure 4.118: Comparison of Quarterly Average TP Concentration at G-136**

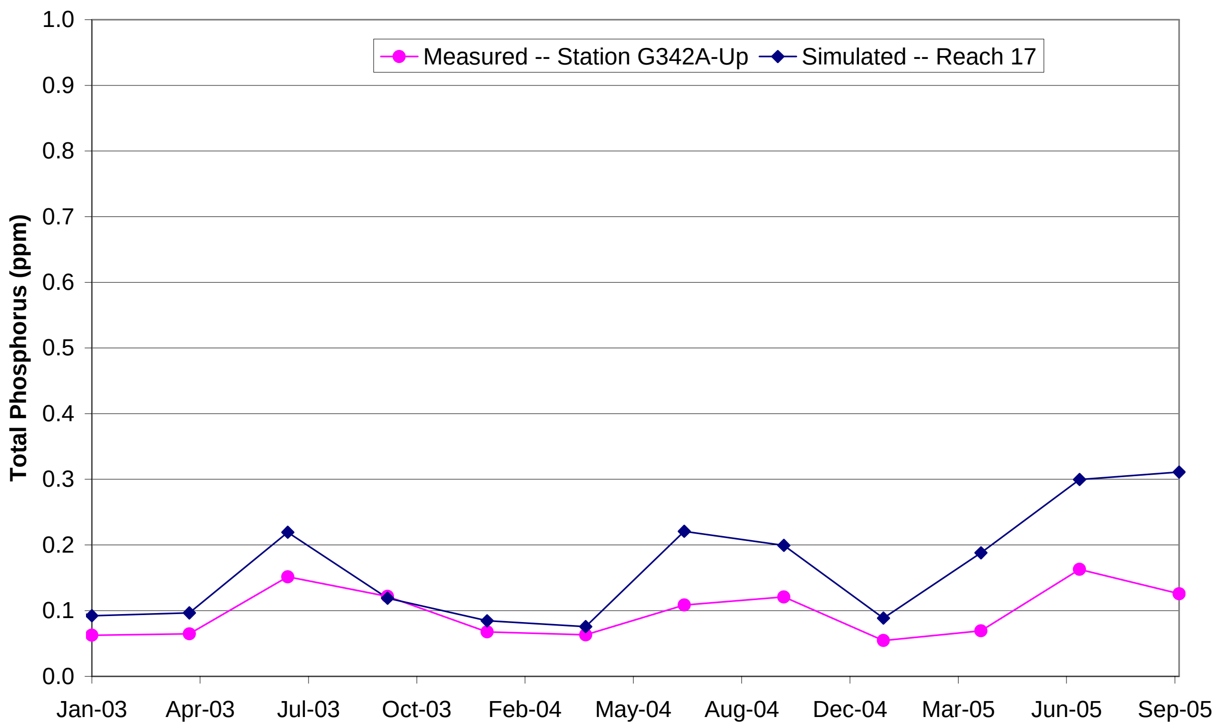



**Figure 4.119: Comparison of Quarterly Average TP Concentration at G-342A**

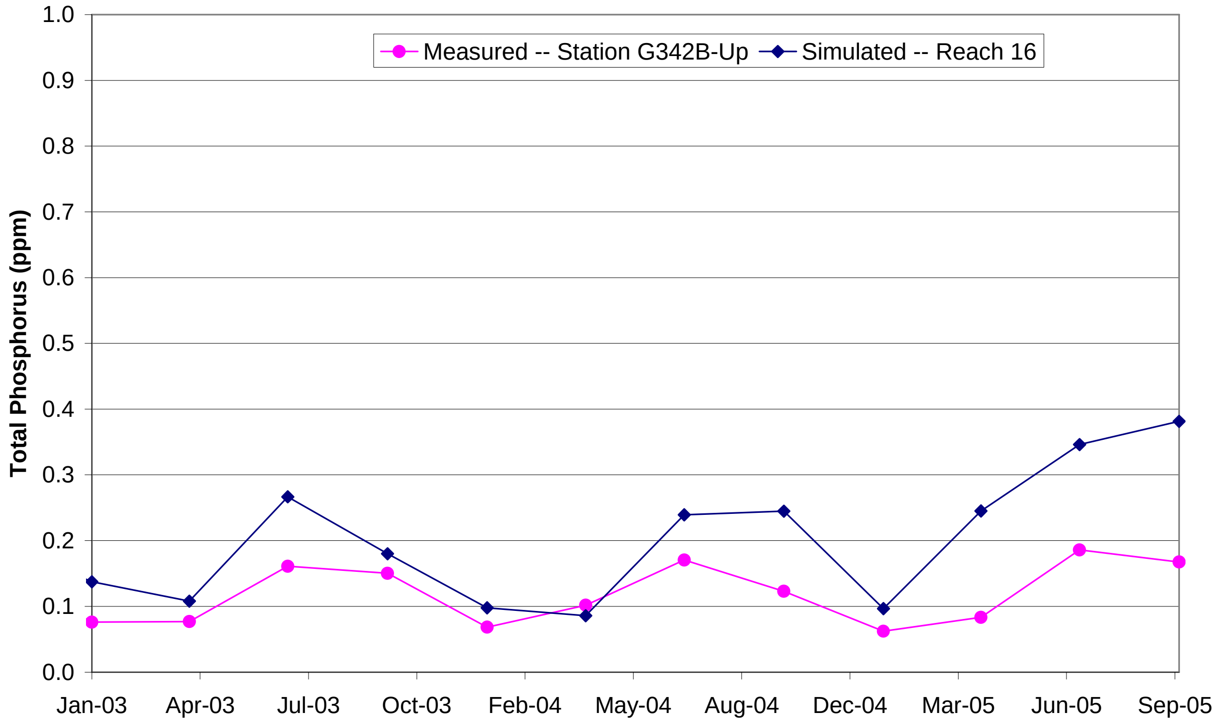



**Figure 4.120: Comparison of Quarterly Average TP Concentration at G-342B**

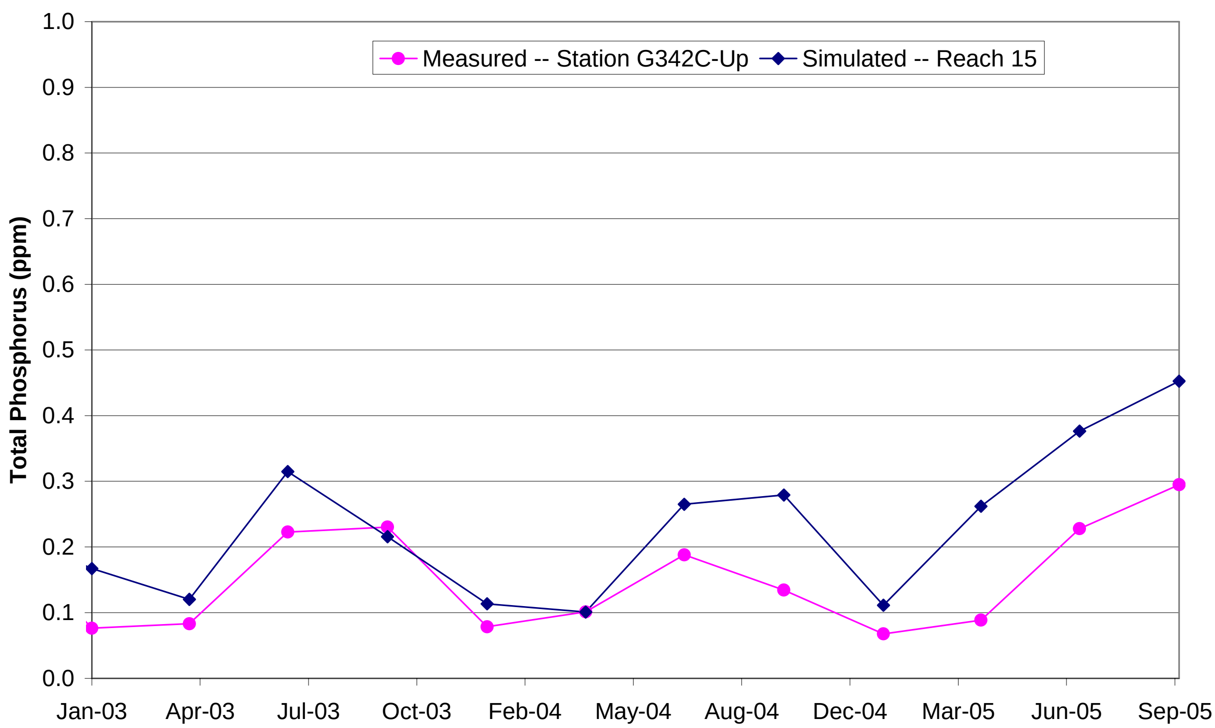



**Figure 4.121: Comparison of Quarterly Average TP Concentration at G-342C**

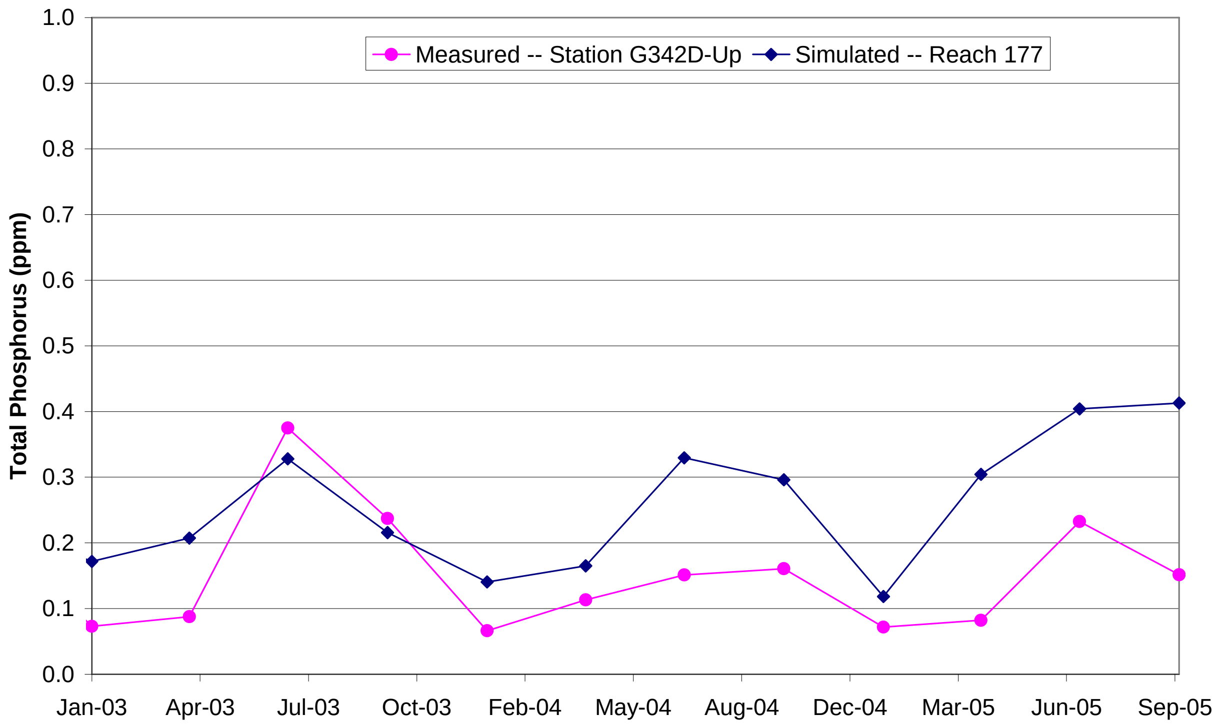



**Figure 4.122: Comparison of Quarterly Average TP Concentration at G-342D**

# 5.0 BASELINE SIMULATION

## 5.1 Purpose

As described in the scope of work, once the C-139 Basin WAM simulation has been calibrated for two years and validated for one year, the model will be executed with the existing land-use for a 36-year period of record (1965 to 2000), or “Baseline Period”. This simulation will be used to estimate the agricultural water demands and simulate the farm-scale BMP practices, regional scale BMP practices, farm scale water supply systems, and the regional scale water supply system to the extent data is available.

The baseline simulation is not intended to be a simulation of conditions within the C-139 Basin during the 36-year period of record. The fundamental assumption of the baseline condition is that the existing condition land-use and drainage infrastructure are used throughout the simulation period. The purpose of this methodology is to provide an assessment of the long-term effects of the existing conditions over a wide range of climactic conditions, and determine relative benefits of proposed regional alternatives compared to the baseline condition. The determination of boundary conditions and structure operations for canal infrastructure that did not exist during the simulation period requires several assumptions.

### 5.1.1. Precipitation

Precipitation data was collected from the District for the 1965-2000 period. This data included a patchwork of rainfall information from various gaging stations. Only three locations contained data which included the entire period. As illustrated in **Figure 5.1**, the three locations are Devil’s Garden Tower, L-1 Ranch and ALICO Property.

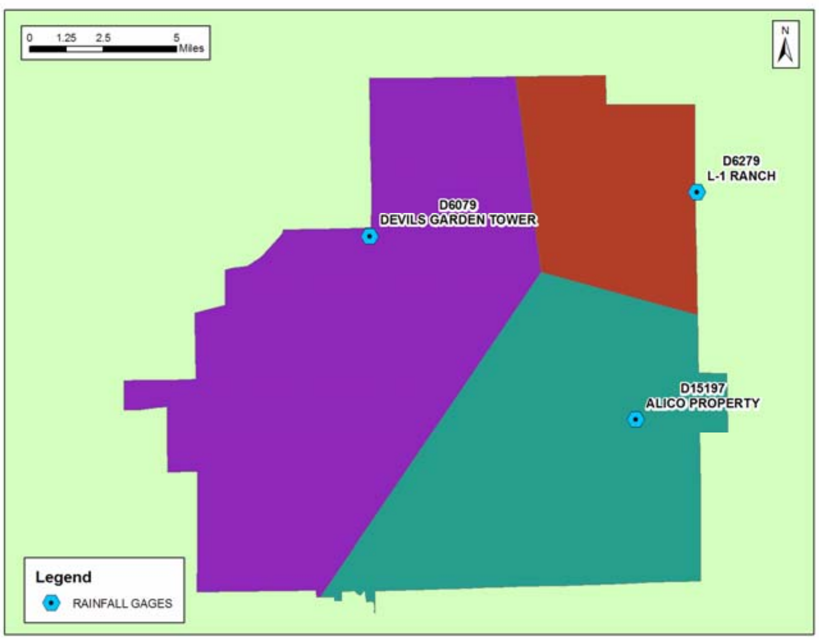



**Figure 5.1: Precipitation stations for the baseline simulation**

The rainfall record for the ALICO property station was missing for 1965-1973. For this period average measurements for the L-1 Ranch and Devil's Garden Tower were used. The Theissen polygon method was used to generate the "Rainzone" coverage required by WAM to define the distribution of rainfall over the Basin.

### 5.1.2. Boundary Conditions

By definition, the baseline simulation is not intended to reflect actual conditions during the 36-year period of record. Instead the baseline simulation represents the effects of the existing conditions over a long period that includes substantial wet and dry periods. For most of the Baseline Period the downstream infrastructure was substantially different from existing conditions. In particular the G-342A-D and G-406 control structures constructed to allow inflows to STA-5 were not in place until the end of the Baseline Period. As such, any recorded stage measurements during 1965-2000, would not be reflective of the stages that would be expected from the current infrastructure for the same rainfall conditions.

Since none of the available recorded data could be used as a boundary condition, the boundary condition stages need to be generated by another regional simulation of the existing conditions over the Baseline Period. The most readily available regional simulation that meets these criteria would be the South Florida Water Management Model (SFWMM); however the SFWMM does not include the C-139 Basin. The boundary of the SFWMM is the eastern extent of the C-139 Basin and any stages simulated in STA-5 or the L-1 and L-3 canals would be representative of the SFWMM inflow boundary conditions and not suitable for use as a downstream boundary of the baseline simulation.

The only available long-term regional hydrologic and hydraulic model available was developed by ADA as part of the EAA Compartment C Watershed Hydraulic Study which was prepared in accordance with District Work Order No. CN040936-WO26. The overall objective of this study was to provide analyses of various stormwater delivery alternatives to the Compartment C. As such, the Compartment C simulation was developed using the Soil Conservation Service (SCS) curve number method for event based hydrologic analysis of stormwater runoff, and as such the calibration does not directly apply to continuous simulations. In addition, the EAA Compartment C Watershed Hydraulic Study is not yet completed and is still subject to review and modification. However, since each boundary of the C-139 model is downstream of a water control structure it is assumed that the model would not be significantly sensitive to changes made to the EAA Compartment C model as part of the review process. Therefore simulated stages from the EAA Compartment C model were used to define the boundary condition of the baseline simulation.

### 5.1.3. Control Structure Operations

In the case of the calibration and validation simulations, there were documented structures and un-documented structures. The documented structures were operated based on recorded conditions, while the undocumented structures were operated based on general operations guidelines or local knowledge. Since there is no recorded gate elevation or opening data available for the baseline period, all documented structures are also simulated based on operational guidelines. **Table 5.1** describes the assumptions to be used for the baseline simulation.

**Table 5.1: District structure operation guidelines used in the baseline simulation**

| NAME | TYPE | Width (m) | Invert Elevation (m NAVD88) | Open/On (m NAVD88) | Close/Off (m NAVD88) |
|---|---|---|---|---|---|
| G-96 | Flashboard Riser | 4.88 | 5.18 | Constant | Constant |
| G-135 | Flashboard Riser | 1.42 | 4.11 | Constant | Constant |
| G-136 | Flashboard Riser | 2.84 | 4.27 | Constant | Constant |
| G-150 | Flashboard Riser | 6.4 | 2.18 | 3.86 | 3.70 |
| G-151 | Underflow Gate | 7.32 | 4.47 | Constant | Constant |
| G-342A&B | Underflow Gate | 3.00 | 1.80 | 3.55 | 5.50 |
| G-342C&D | Underflow Gate | 3.00 | 1.80 | 3.55 | 5.50 |
| G-406 | Underflow Gate | 6.10 | 1.42 | 4.47 | 4.35 |

## 5.2 Baseline Results

### 5.2.1. Spatial Distribution of TP Loads

The results of the baseline simulation can be viewed in a variety of ways. **Figure 5.2** illustrates the average annual loading rate Total P in pounds per year per acre for each 1-hectare cell in the basin over the 36-year period of record. This figure demonstrates that not only are soils, land-uses and BMPs a factor in loading rate, but rainfall distribution is as well. The sharp and unnatural gradation of the loading rates simulated for the improved pasture land in the center of the basin, is caused by the apparent discrepancy between the Devils Garden and ALICO rainfall totals during the baseline period. **Figure 5.3** aggregates the results described in **Figure 5.2** into an average annual loading rate in pounds per acre per year for each sub-basin, while **Figure 5.4** illustrates an aggregated average annual loading rate for each catchment.

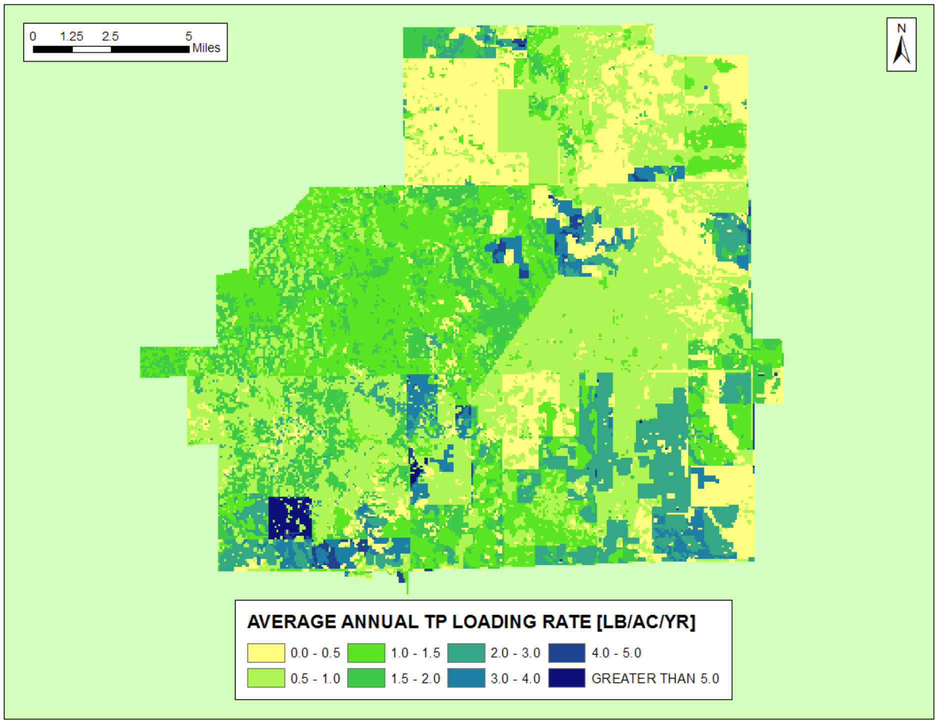



**Figure 5.2: Average Annual Total P Loading Rates per Grid Cell**

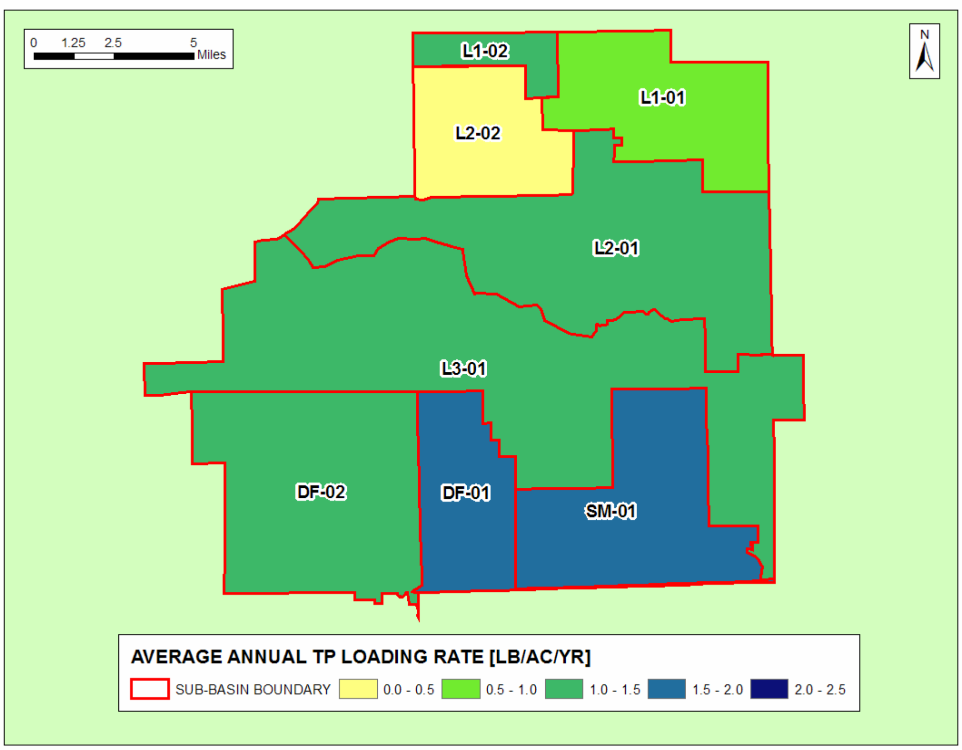



**Figure 5.3: Average Annual Total P Loading Rates per Sub-basin**

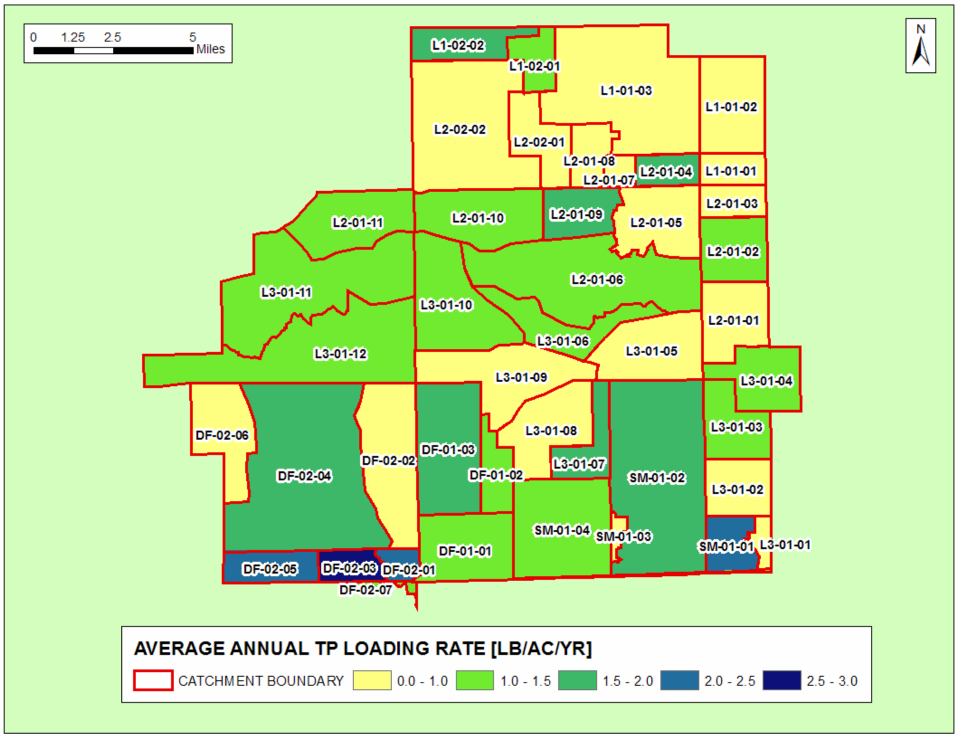



**Figure 5.4: Average Annual Total P Loading Rates per Catchment**

Average annual loading rates are a reflection of two components: runoff volume and nutrient concentration. In order to discern any divergences between total load and runoff volume **Figures 5.5** and **5.6** illustrate the average runoff rate for each sub-basin and catchment in inches per year. A comparison of **Figures 5.3** and **5.5** illustrates that for the majority of sub-basins high runoff volumes are accompanied by high loads with the exception of L2-02, which has a low TP loading rate and a high runoff rate. This divergence is expected since the L2-02 sub-basin contains no agricultural operations and accordingly is simulated to have low nutrient concentrations. **Table 5.2** presents the numerical results for each sub-basin.

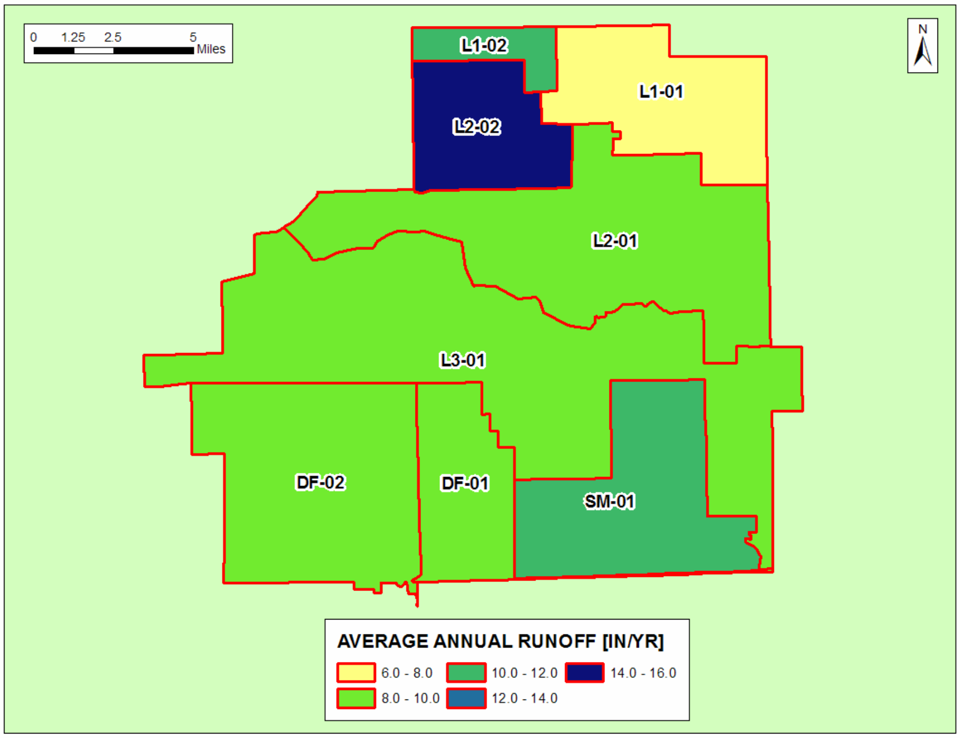



**Figure 5.5: Average Annual Runoff Rates per Sub-basin**

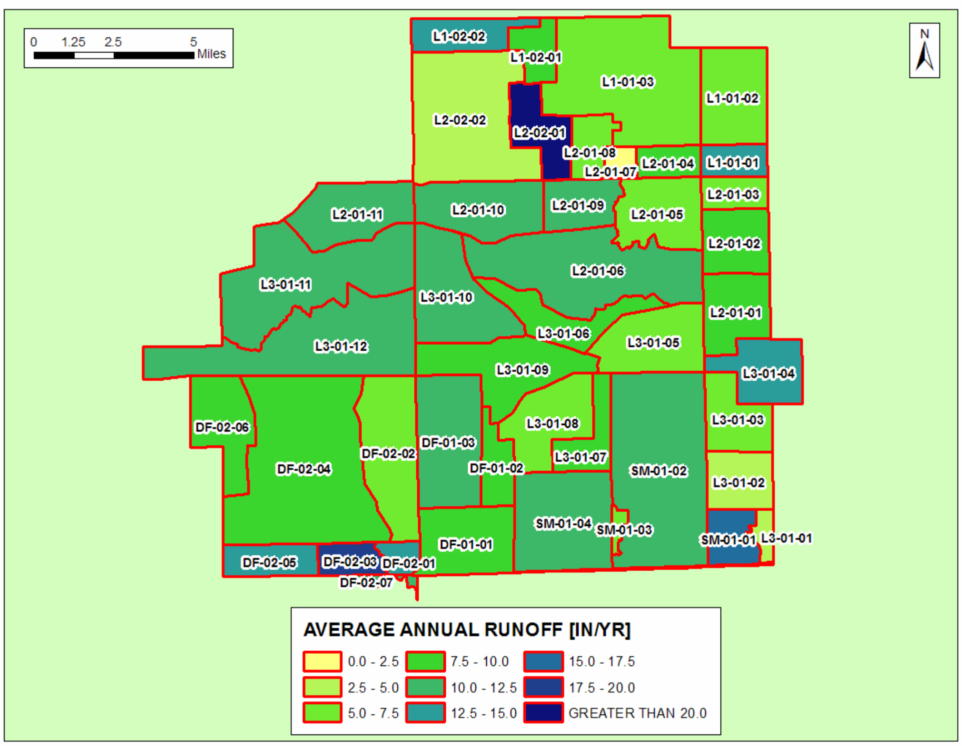



**Figure 5.6: Average Annual Runoff Rates per Catchment**

**Table 5.2: Average Annual TP Loading Rate and Runoff Volumes per Sub-basin**

| SUB-BASIN NAME | AVERAGE ANNUAL LOADING RATE [LB/AC/YR] | AVERAGE ANNUAL RUNOFF RATE [IN/AC/YR] | AVERAGE ANNUAL DISCHARGE [AC-FT/YR] |
|---|---|---|---|
| DF-01 | 1.53 | 9.71 | 7,679 |
| DF-02 | 1.50 | 9.88 | 32,148 |
| L1-01 | 0.68 | 7.07 | 20,966 |
| L1-02 | 1.47 | 11.43 | 3,394 |
| L2-01 | 1.15 | 9.44 | 50,028 |
| L2-02 | 0.37 | 15.41 | 26,496 |
| L3-01 | 1.13 | 8.94 | 57,681 |
| SM-01 | 1.61 | 11.51 | 18,089 |
| C-139 BASIN | 1.19 | 9.84 | 216,481 |

### 5.2.2. Temporal Distribution of TP Loads

With reference to the total load leaving the C-139 Basin, via the G-135, G-136, STA5 Inflow structures and G-406, **Figure 5.4** illustrates the TP load (pounds/year) for each of the 36 years simulated, plus an additional 5 years for comparison purposes. Also included in **Figure 5.4**, is a plot of the observed TP load from the C-139 Basin reported in Volume 1 of the South Florida Environment Report (SFWMD, 2006). This comparison shows disparities between simulated and measured TP loading during the twenty year period of 1980 through 2000. Since the baseline simulation is reflective of existing conditions, as of 2005, the simulation results are not meant to be similar to past observations. The higher TP loads simulated may be reflective of changes in the intensity of agricultural practices in the existing condition as compared with the past. The comparison of the simulated and measured TP loads for 2003-2005 illustrate that the baseline simulation corresponds to the measured data during the calibration and validation period, as expected. **Figure 5.5** illustrates the TP load (pounds/month) leaving the C-139 Basin for each month of the Baseline Period.

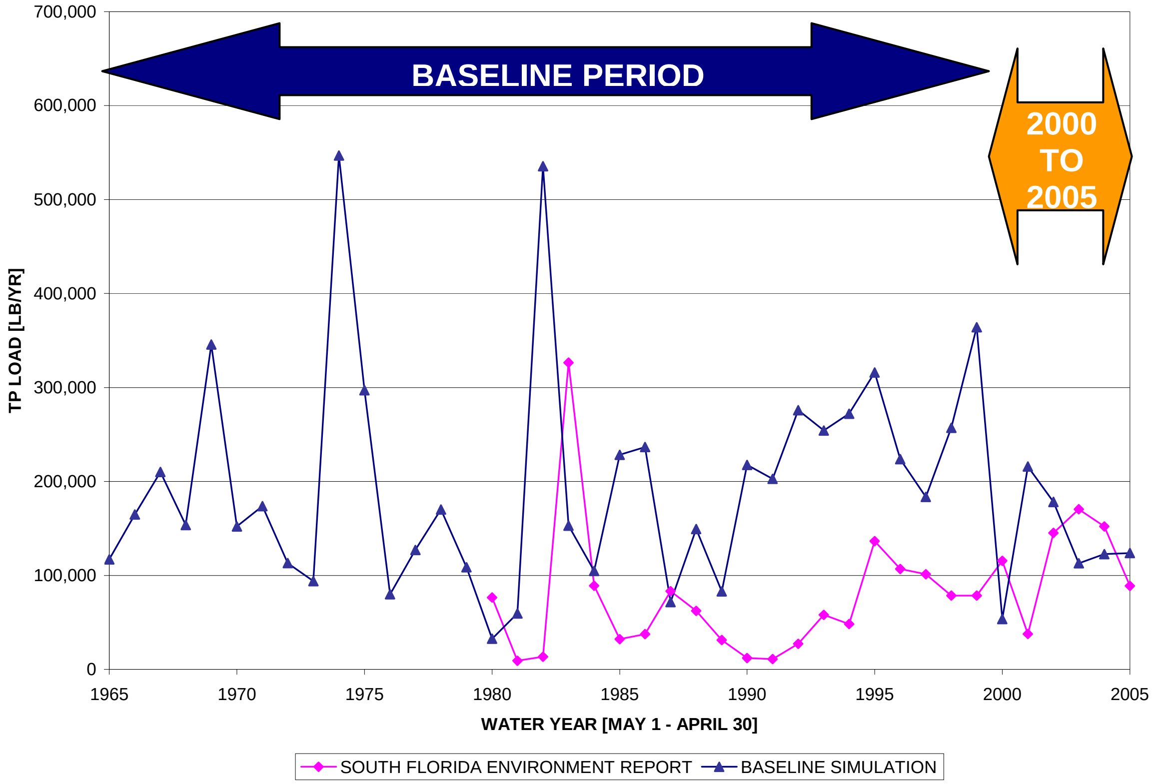



**Figure 5.4: Annual Total P Loads for the C-139 Basin**

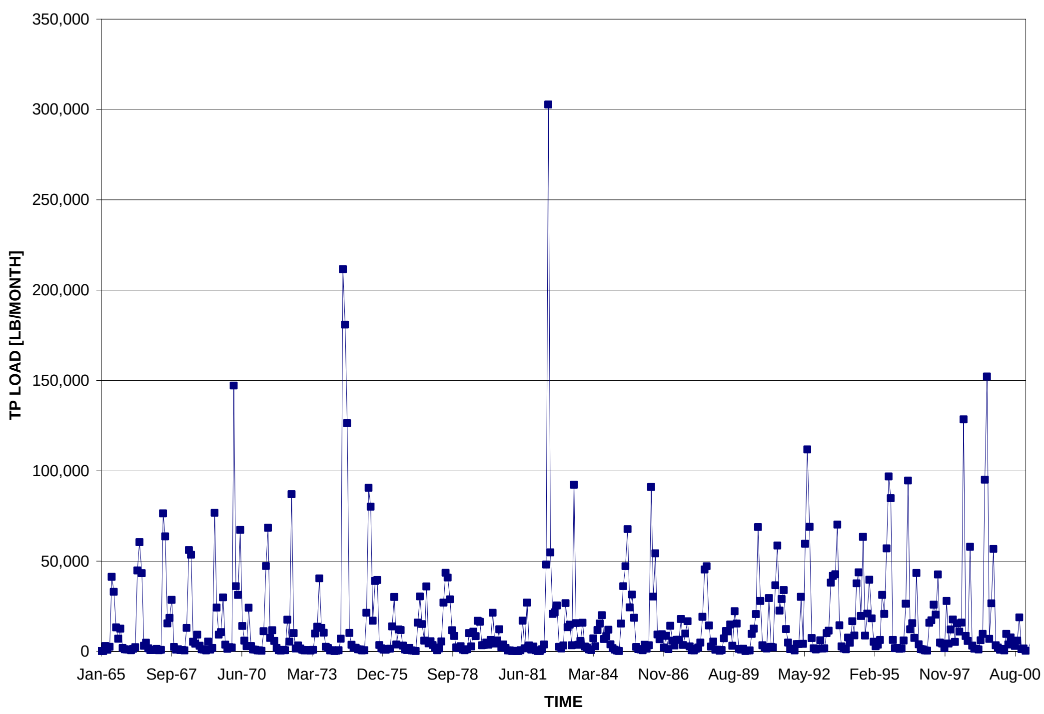



**Figure 5.5: Monthly Total P Loads for the C-139 Basin**

The variability illustrated in **Figure 5.5** is further demonstrated in **Figures 5.6, 5.7** and **5.8**, which shows the average, maximum and minimum monthly TP load for each month of the Baseline Period.  A comparison of the range of TP loads simulated during the baseline period illustrates the variability that is characteristic of the C-139 Basin and South Florida as a whole, due to the year to year variability of precipitation.  During an uncharacteristically dry period, there will be minimal runoff which minimizes the loads significantly, as is shown in **Figure 5.8**.  This type of variability is the reason that the baseline simulation can be such a valuable tool for comparative analyses of future alternatives.  This 36 year period of record includes the effects of wet and dry conditions and the baseline simulation allows for the evaluation of future alternatives with respect to those extremes.

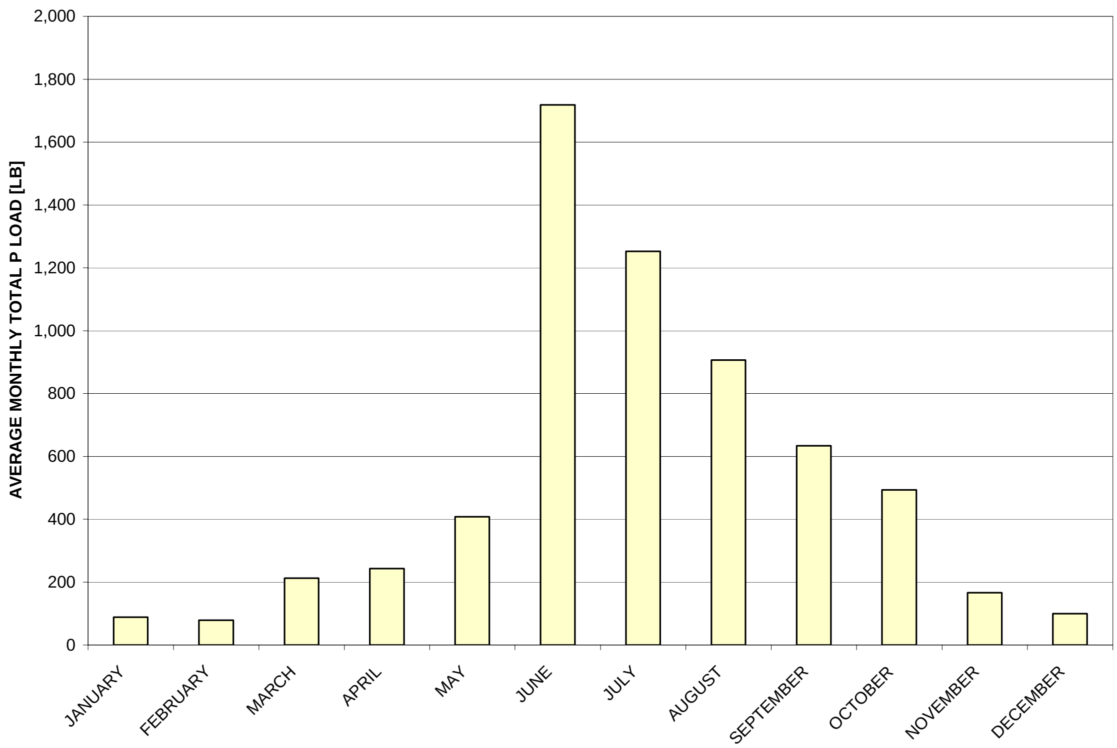



**Figure 5.6: Average Monthly Total P Loads for the C-139 Basin**

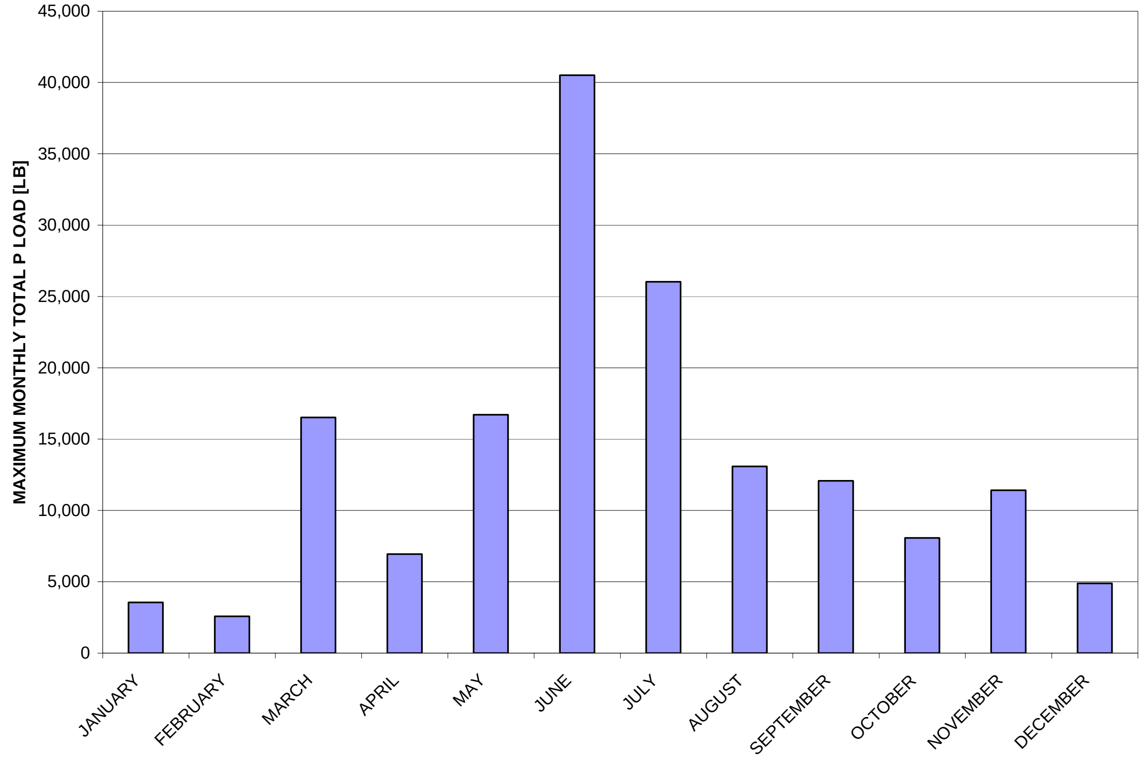



**Figure 5.7: Maximum Monthly Total P Loads for the C-139 Basin**

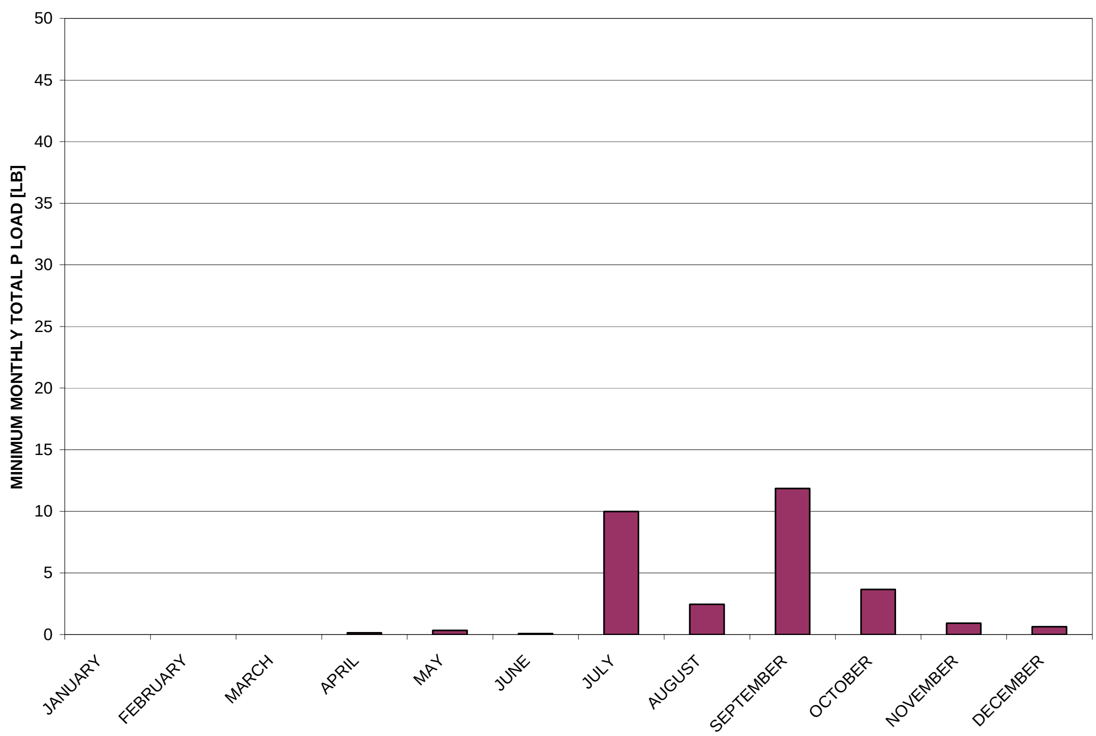



**Figure 5.8: Minimum Monthly Total P Loads for the C-139 Basin**

## 5.3 Baseline Results

The analysis methodology for determining the utility of each proposed regional project as part of Task 10 (Water Quality Improvement Projects Analysis) is based on comparing the existing condition baseline results, presented above, with the proposed condition(s) baseline simulation. As described in the scope of work, the parameters of each of the five proposed conditions will be developed and presented as part of Deliverable 10.1 (Water Quality Improvement Project Methodology Technical Letter). The simulated spatial and temporal TP loads and runoff volumes from each sub-basin and the whole basin for the proposed conditions will be compared with the existing conditions results described above. Deliverable 10.4 (Final Water Quality Improvement Projects Analysis Technical Report) will summarize the benefits of each proposed project in terms of the simulated reduction in loading rate, as well as providing a planning-level evaluation of each proposals cost and construction schedule.

# 6.0 CONCLUSIONS AND RECOMMENDATIONS

## 6.1 Phase II Objectives

Based on the scope of work, the objectives of Phase II of the C139 Basin Phosphorus Water Quality and Hydrology Analysis are as follows:

1. Develop a calibrated hydrologic and water quality modeling tool to analyze flows and phosphorus loads in the C-139 Basin. Everglades Regulatory Program staff shall be able to use the model as a tool for prioritizing resources and tailoring Best Management Practice strategies towards achieving compliance with Everglades Forever Act-mandated water quality levels. The simulation results of the calibrated WAM model will be visually and statistically compared to all available measured data within the basin to provide an estimate of the modeling error. The water quality model shall be user-friendly and compatible with District applications. The Consultant shall train District staff in the use of this application.
2. Identify and evaluate a maximum of five water quality improvement projects (selected projects). The recommendations/needs or project types described by C-139 Basin landowners shall be considered.
3. Describe regulatory constraints that may affect implementation of water quality improvement projects within the C-139 Basin. Evaluate the regulatory feasibility of the selected water quality improvement projects or types of projects. Provide recommendations for pursuing viable rule or policy changes.
4. Identify technical issues, cost and schedule considerations for the selected projects. Evaluating site-specific technical issues, cost and schedule does not apply to farm-level projects.
5. Note uncertainties and limitations associated with project implementation along with any other unidentified issues that are uncovered as the contract progresses [e.g., results of the EAA Regional Feasibility Study, Phase 2 (CN040912-WO04)].

## 6.2 Conclusions

Deliverable 6.2 is the development of the calibrated hydrologic and water quality model that will be used to perform the feasibility analyses described as part of the central objectives of the project. This report describes the benefits and functionality of WAM as it applies to this objective, as well as the associated uncertainties and limitations. The C-139 WAM calibration and validation illustrates the model's ability to predict regional trends and showcases the utility of the model for the evaluation of regional water quality improvement projects. This evaluation is to be completed as part of the second Phase II objective.

The C-139 WAM simulation is developed primarily as a planning and decision making tool. An examination of the existing condition baseline simulation results presented in Section 5.2 demonstrates the utility of the model for this purpose. In successive tasks of Phase II the baseline period will be simulated with the addition of each proposed regional project, and the resulting simulated TP loads can be compared both spatially and temporally with the existing condition.

### 6.2.1. Limitations of Sub-surface Hydrology

Although the WAM code was reconfigured for the purposes of this project to allow for improved representation of the seepage of water from the surficial aquifer to the Lower Tamiami aquifer, the revised functionality requires a value for the depth of the elevation head of the Lower Tamiami aquifer that acts as a subsurface time-varying boundary condition. This boundary condition is a depth that is uniformly applied to all similar soil types throughout the basin. WAM currently does not have the capability to represent the reduction in regional groundwater elevation that also varies spatially as a result of pumping to meet irrigation demand.

In order for a more accurate representation of the effects of groundwater withdrawals, WAM would have to be further modified to incorporate a regional groundwater elevation to act as a subsurface boundary condition that can vary with space as well as time. Additionally, this boundary condition would have to be generated externally by a groundwater model such as MODFLOW. As was presented in Section 3.6, there has been preliminary MODFLOW modeling of Hendry County performed: none of the simulations for the basin have been finalized, and the preliminary results that are available do not have transient results for the calibration period. Therefore both WAM and the best available data lack the level of detail required to fully simulate the interaction of the surficial and Lower Tamiami aquifers. This is a limitation in the C-139 basin, since the majority of irrigation demand is met by subsurface withdrawals that can have a significant effect on regional hydrology in the dry-season.

### 6.2.2. Limitations of Basin-Level Calibration

The results demonstrated within this report detail the calibration and validation of the C-139 WAM model at the regional or watershed scale. There is not a significant distribution of measured data to validate the prediction capabilities of the basin-level calibration at the farm-level. At the farm-level, the basin-level calibration is primarily valuable for comparative analyses and planning, only. The distinction between basin-level and farm-level calibration is pertinent, since the second component of the first objective of Phase II is to create a tool to be used by District staff for future evaluation of farm-level practices.

In addition, there is a distinction between the basin-level hydrography and the farm-level hydrography within the WAM simulation. Since WAM utilizes the hydrologic submodels, EAAMOD and GLEAMS, to simulate farm-level processes, the basin-level model does not incorporate individual reservoirs and water control structures within the hydrography. The farm ditches that transport water from the field to the reservoir to the outlet are not represented as stream reaches, nor are the flashboard risers used to control the outlet of an individual reservoir incorporated in the structures input file. These features are incorporated within the hydrologic submodels, and any future modifications to farm-level surface water management systems will require modifications to the land-use input files rather than the hydrography.

## 6.3 Recommendations

WAM is best suited for use as a regional planning tool. Within the context of a regional planning tool the C-139 Basin simulation represents the physical processes occurring within the Basin and can be used to describe the potential impacts of a proposed regional improvement project. However, the calibration of the C-139 simulation is limited by the availability of the data used in parameterization. The operation of the un-documented structures within the C-139 Basin can have significant impacts on the ability of the model to accurately predict flows and loads. The effects of sub-surface pumping to meet irrigation demand can also have a significant effect on the ability of WAM to properly represent the C-139 Basin. Any additional information pertaining to the operation of un-documented structures or to irrigation demand and water table elevations could improve the calibration of the C-139 WAM simulation.

Additionally, as described in Section 6.2 above, the calibration of the C-139 was performed at the basin-level. At the basin scale the impacts of BMP implementation at the farm-level can be diluted by runoff from non-agricultural land-uses. A farm-level sensitivity analysis would provide a clear assessment of the capabilities of the C-139 WAM simulation to provide valuable comparative analyses at the farm scale.

# 7.0 REFERENCES


Abtew, W., 2005 *Evapotranspiration in the Everglades: Comparison of Bowen Ratio Measurements and Model Estimations.* ASAE Meeting Presentation Paper Number: 052188. Tampa, Florida

Belz, D.J., L.J. Carter, D.A. Dearstyne, and J.D. Overing. 1991. Soil Survey of Hendry County, Florida. USDA, SCS. Washington, DC.

Bottcher, D., B. Jacobson, 2006. *WAM Training Manual*. Soil & Water Engineering Technology, Inc. Gainesville, FL.

Butler, D., R. Rani, N/A – Unpublished Technical Publication – *A Revised Three Dimensional Finite Difference Ground Water Flow Model for Hendry County, Florida*. SFWMD

Everglades Regulation Division (EREG). 2005. Everglades Regulatory Program Critical FY06 “New” Projects – Planned Needs, SFWMD.

Howard T. Odum Center for Wetlands at University of Florida (http://www.cfw.ufl.edu)

Lukasiewicz, J, E. Rectenwald, D. Medellin, and P. Petry. 2006. *Crook’s and Golden Ox Ranches Hydrogeologic Assessment*. Water Supply Department. SFWMD.

Smith and Adams. September 1988, Ground water resource assessment of Hendry County, Florida. Technical Publication 88-12, SFWMD

South Florida Water Management District, 2006. The South Florida Environment Report (SFER), SFWMD (www.sfwmd.gov/sfer)

Wilmott, C.J. 1982. Some comments on the evaluation of model performance. Bulletin of American Meteorological Society, 63, 1309-1313