Phillippi Creek: One Dimensional Hydrodynamic and Water Quality Modeling Report

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Table of Contents

List of Figures

List of Tables

1. INTRODUCTION

Phillippi Creek is a tidal estuarine creek and drains approximately 56 square miles of northern Sarasota County, including part of the city of Sarasota. The watershed consists of a network of natural streams and man-made channels that carry water away from relatively flat, low-lying, and poorly drained soils. Heading upstream Phillippi Creek branches into two drainage systems between Sarasota and Fruitville. One branch heads north toward the Manatee County line and the other branch heads east draining Fruitville and Hyde Park. Heading downstream, Phillippi Creek flows southwesterly toward its mouth, emptying into a southern segment of Sarasota Bay called Roberts Bay. The sub-basin, which is the third largest in Sarasota County, is the largest contributor of freshwater, nutrients, and metals to Roberts Bay (FDEP, 2003). Phillippi Creek episodically receives large volumes of stormwater and has historically had elevated levels of ammonium, low dissolved oxygen concentrations, and high fecal coliform (Dillon and Chanton, 2008). Dillon and Chanton (2008) state that data support the idea that Phillippi Creek is a major nitrogen source to Sarasota Bay.

Historically, Phillippi Creek was a small tributary to Sarasota Bay. The Florida Mortgage Inv. Company conducted one of the first drainage projects in Florida in 1887. The success resulted in construction of a massive drainage network that methodically drained the sawgrass ponds and marshes (100,000 acres in the Bay watershed). The straight ditches were cut to the center of each of the hundreds of isolated ponds. The Phillippi Creek watershed was likely expanded 10 fold from 3,500 to 35,000 acres. Large flooding events were recorded in the 50's and 60's resulting in the expansion of the Phillippi Creek conveyance system in the lower reaches; and later a large stormwater retrofit project in the 90's that included construction of the Celery Fields regional treatment system. Areas serviced by septic tanks and small wastewater treatment plants were constantly inundated prior to the construction of the regional system and associated levee construction. As a result of the drainage projects, flow has expanded 10 fold to the smallest size embayment in the region, Roberts Bay which is impaired for nutrients as indicated by increasing levels of chlorophyll-a (Mark Alderson, personal communication).

Phillippi Creek has been studied over the years along with other tidal creeks in the Florida peninsula. The Year 2000 Biological Community Analysis For Big Slough, Hudson Bayou and Phillippi Creek Basin, Sarasota County, Florida documented anaerobic sediment odors, tannic water color, and the presence of aquatic macrophytes and periphyton April of 2000 at two sites in Phillippi Creek.

The Sarasota County Phillippi Creek Basin Master Plan, Characterization of Ecological Conditions and Impacts of Stormwater Runoff, describes Phillippi Creek as a detrital based system that receives large loads of detritus from the watershed (Estevez, E.D., 1994). This detritus decomposes and through BOD and SOD consumes dissolved oxygen from the water column.

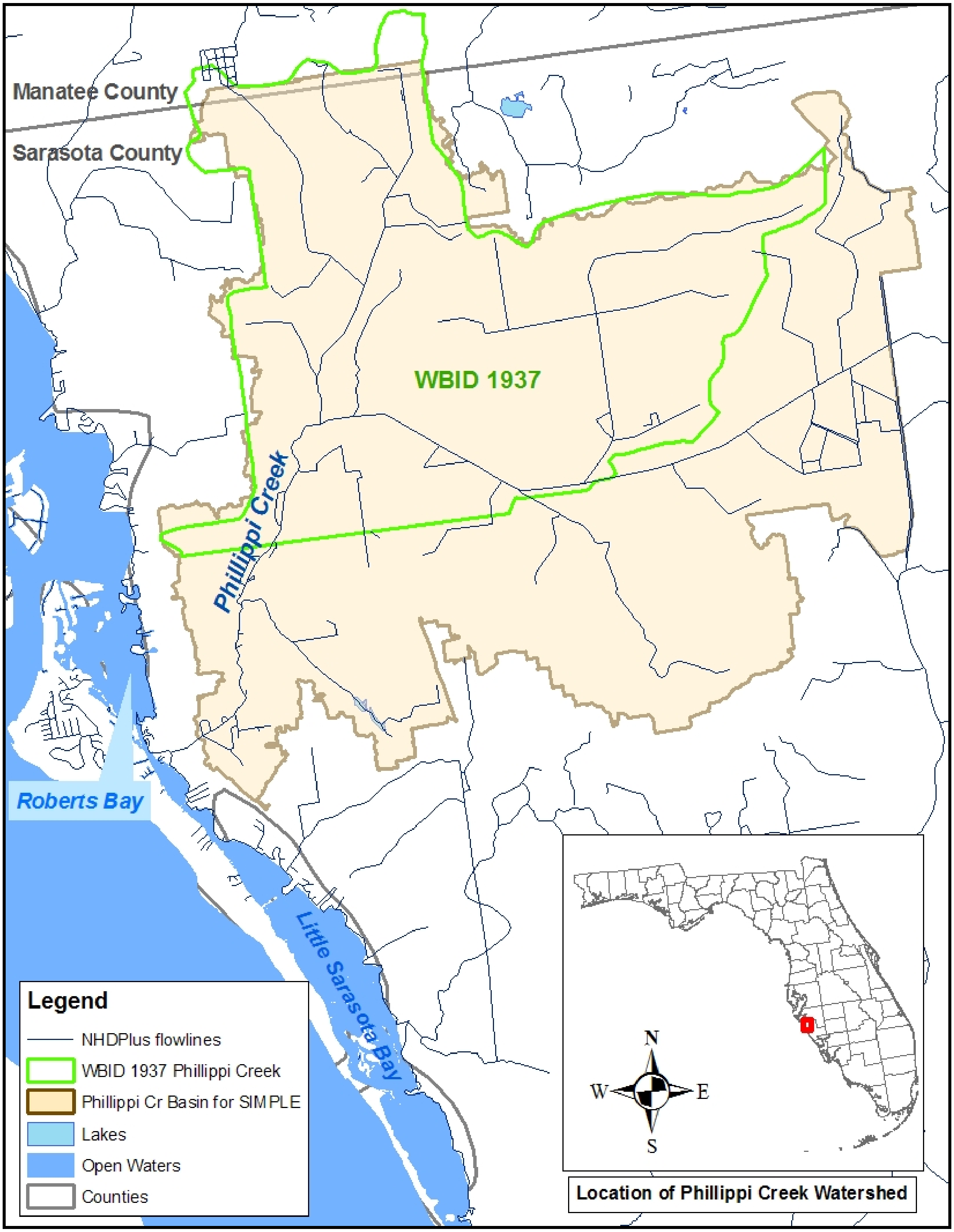

Figure 1: Phillippi Creek WBID Boundary and SIMPLE Watershed Model Delineation

The list of impaired waters created under section 303(d) of the 1972 Clean Water Act (CWA) includes WBID 1937, Phillippi Creek, as impaired by low dissolved oxygen, excess nutrients and fecal coliform bacteria. The CWA mandates a Total Maximum Daily Load (TMDL) to scientifically understand and control the sources of pollutants that impair water quality and create detrimental conditions for aquatic ecosystems. This TMDL is being established pursuant to EPA commitments in the 1999 Consent Decree in the Florida TMDL lawsuit (Florida Wildlife Federation, et al. v. Carol Browner, et al., Civil Action No. 4: 98CV356-WS, 1998) that TMDLs be developed for all of the impairments on the approved 1998 303(d) list.

To address these water quality impairments a fully dynamic, one dimensional modeling approach was utilized. In this report, a hydrodynamic model, Dynamic Estuary Model Hydrodynamics Program (DYNHYD), for Phillippi Creek was developed and calibrated. Also, a water quality model, Water Quality Analysis Simulation Program (WASP), was developed to predict the response of water quality on changes in pollutant loading and management practices. Nonpoint source runoff from Sarasota County's Spatially Integrated Model for Pollutant Loading Estimates (SIMPLE) was used for the watershed pollutant loadings.

2. MODELING APPROACH

Although many studies have been conducted in Florida tidal creeks, the results are mostly qualitative and not detailed enough to quantify the cause and effect of the nutrient enrichment and low dissolved oxygen. Phillippi Creek water quality measurements of the water column show low BOD at near detection limits, relatively low total nitrogen of 1.1 mg/L, and low phytoplankton levels with a mean chlorophyll-a of 2.4 ug/L (see Table 3 of the TMDL Report). However, Figure 2 shows that the measured DO varies widely during the day indicating high production and respiration. Due to the lack of SOD measurements, reaeration measurements, aquatic macrophyte and periphyton measurements the approach for developing this TMDL is based primarily on the water chemistry data and the evidence of low reaeration, high detrital loading, strong photosynthetic activity, and strong SOD.

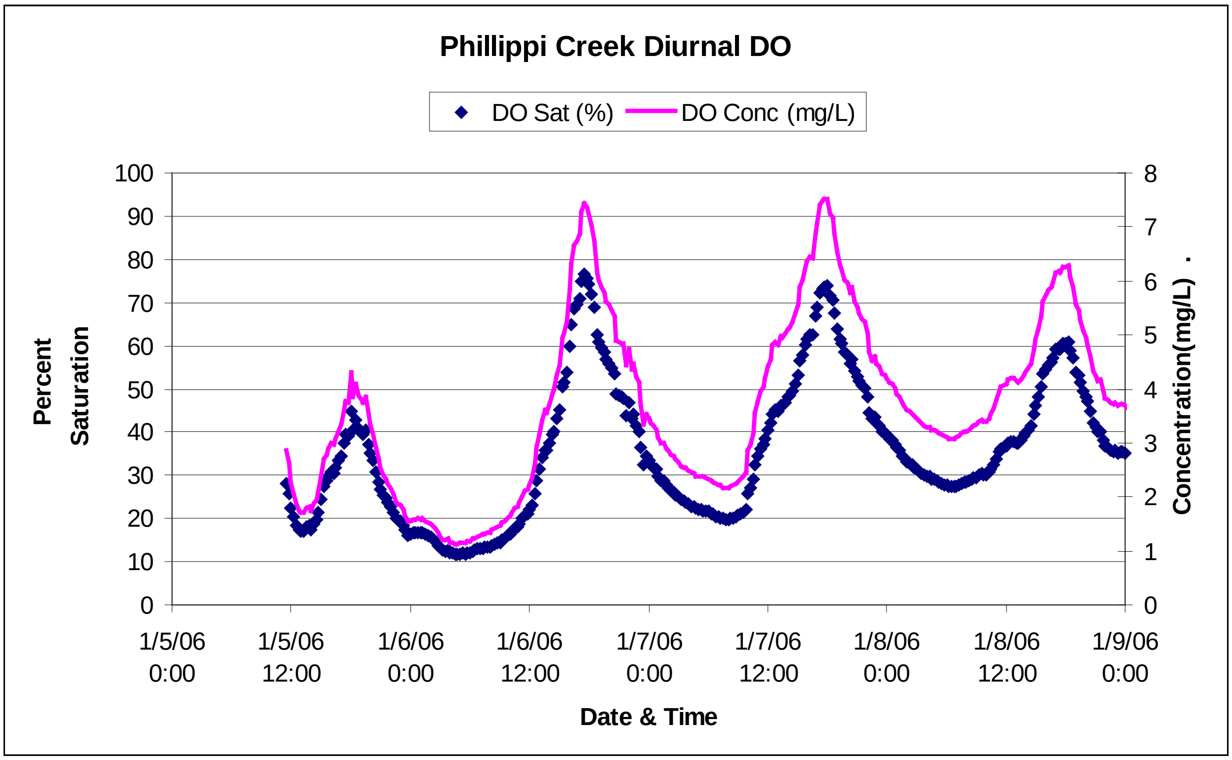

Figure 2: Phillippi Creek Measured Diurnal DO during FDEP special DO monitoring study.

Since Phillippi Creek is tidally influenced, the DYNHYD hydrodynamic model that can represent the downstream tidal water surface elevations was selected. The WASP water quality eutrophication model was selected to simulate the oxygen demanding processes, and the pollutant loads from storm-water and other sources were provided by the SIMPLE-Monthly watershed model.

3. DYNHYD HYDRODYNAMIC MODEL DEVELOPMENT

3.1 Hydrodynamic Model Background

The hydrodynamic model DYNHYD is an update of DYNHYD4 (Ambrose, et al., 1988), which was an enhancement of the Potomac Estuary hydrodynamic model DYNHYD2 (Roesch et al., 1979) derived from the original Dynamic Estuary Model (Feigner and Harris, 1970). DYNHYD solves the one-dimensional equations of continuity and momentum for a branching or channel-junction (link-node), computational network. The model is driven by variable upstream flows and downstream water surface elevations. The resulting unsteady hydrodynamics are output to a hydrodynamic input file for later use by the water-quality program.

The hydrodynamic model solves one-dimensional equations describing the propagation of a long wave through a shallow water system while conserving both momentum (energy) and volume (mass). The equation of motion, based on the conservation of momentum, predicts water velocities and flows. The equation of continuity, based on the conservation of volume, predicts water heights (heads) and volumes. This approach assumes that flow is predominantly one-dimensional, that Coriolis and other accelerations normal to the direction of flow are negligible, that channels can be adequately represented by a constant top width with a variable hydraulic depth (i.e., "rectangular"), that the wave length is significantly greater than the depth, and that bottom slopes are moderate. Although no strict criteria are available for the latter two assumptions, most natural flow conditions in large rivers and estuaries would be acceptable. Dam-break situations could not be simulated with DYNHYD, nor could small mountain streams (Ambrose, Wool, Martin. 1995).

3.2 Hydrodynamic Data, Configuration, and Calibration

The calibration objectives for the hydrodynamic model were to adequately represent the physics of the system by propagating momentum and energy based upon freshwater inflow, and the downstream tidal water surface elevation.

Deterministic time variable models predict conditions within the computational domain of the model based upon changes within the model system caused by outside forcing functions. These forcing functions need to be described to the model in order to predict the perturbations that occur within the model. The forcing functions that are required in the hydrodynamic model for Phillippi Creek include freshwater inflow and tidal water surface elevation.

For calibration purposes, time dependent or constant values for each of these parameters must be applied at each of the appropriate boundaries for the entire model simulation period. These values were applied at all of the boundaries within the system including:

- Phillippi Creek Headwater;
- Tidal boundary;
- Tributary boundary;
- Incremental flows.

The following presents a discussion of how the boundary conditions were determined and applied for the hydrodynamic model calibration simulations.

The simulation period for the purposes of the calibration study was from January 2006 through December 2007. The data utilized in the development of hydrodynamic boundary conditions and for the purpose of model calibration consists of the following types:

- Measured water surface elevation;
- Measured stream flows;
- Estimated incremental inflows from the watershed (runoff).

The data used in this study were archived within the Water Resources Database (WRDB) platform as a project specific dataset. As a part of the TMDL Toolbox, the WRDB software is available to download for free at www.wrdb.com.

3.2.1 Water Surface Elevation

Hourly tidal water surface elevation data from the NOAA Port Manatee, FL station 8726384, were downloaded from NOAA's Tides and Currents website at http://tidesandcurrents.noaa.gov/. The mean tide range is 0.475 meters (m) and the diurnal range is 0.668 m for this station. The downstream model boundary was forced with water surface elevation data from the NOAA Port Manatee station.

Figure 3 shows the predicted and observed water surface elevations at the mouth of Phillippi Creek at Roberts Bay. Figure 4 shows a zoomed in view of this plot. Figure 5 shows the predicted and observed water surface elevations about 4.8 miles upstream at the USGS gage 02299800 (same location as Phillippi Creek ARMS station PH-4), and Figure 6 shows a zoomed view of this plot. Figure 7 shows predicted and observed water surface elevations farther upstream at USGS gage 02299780 (same location as Phillippi Creek ARMS station PH-5, and FDEP station 3520). See Figure 8 and Figure 9 for locations of monitoring stations.

The model predictions of water surface elevations match the observations extremely well at the river mouth station and the USGS gage 4.8 miles upstream. The predictions near the headwaters of the model shown in Figure 7 are about 0.1 meter ,or roughly one foot lower than the observed. This is likely due to the presence of weirs in Phillippi Creek. These weirs were not included in the model as they are only expected to influence the flow and water quality during extreme low flow situations.

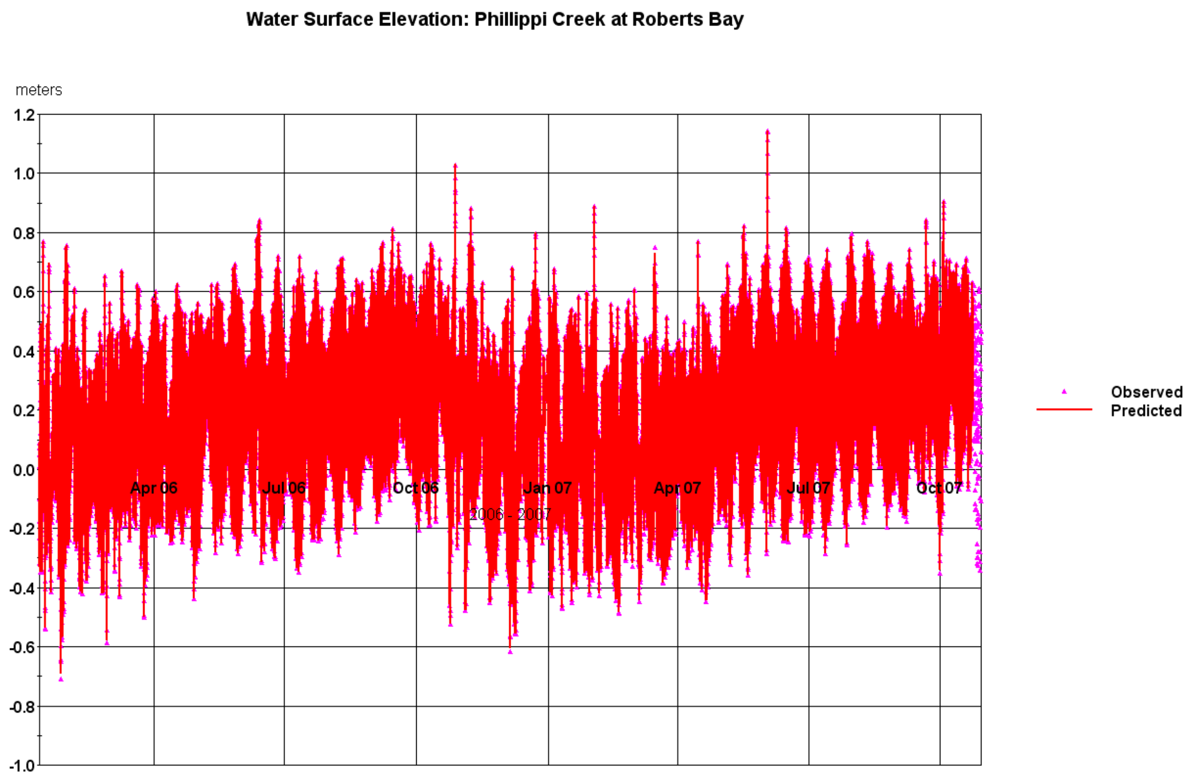

Figure 3: Predicted and Observed Water Surface Elevations at Phillippi Creek in Sarasota County, Hydrologic Unit 03100201, at Roberts Bay.

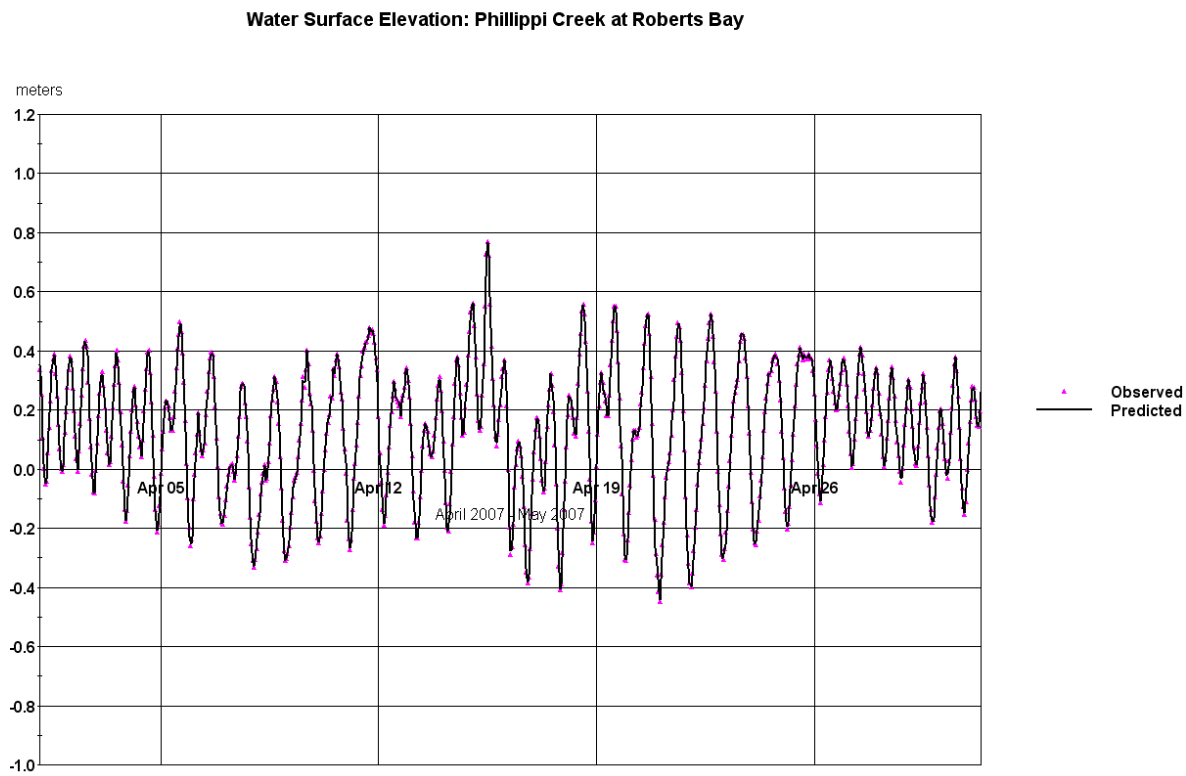

Figure 4: Zoomed; Predicted and Observed Water Surface Elevations at Phillippi Creek in Sarasota County, Hydrologic Unit 03100201, at Roberts Bay.

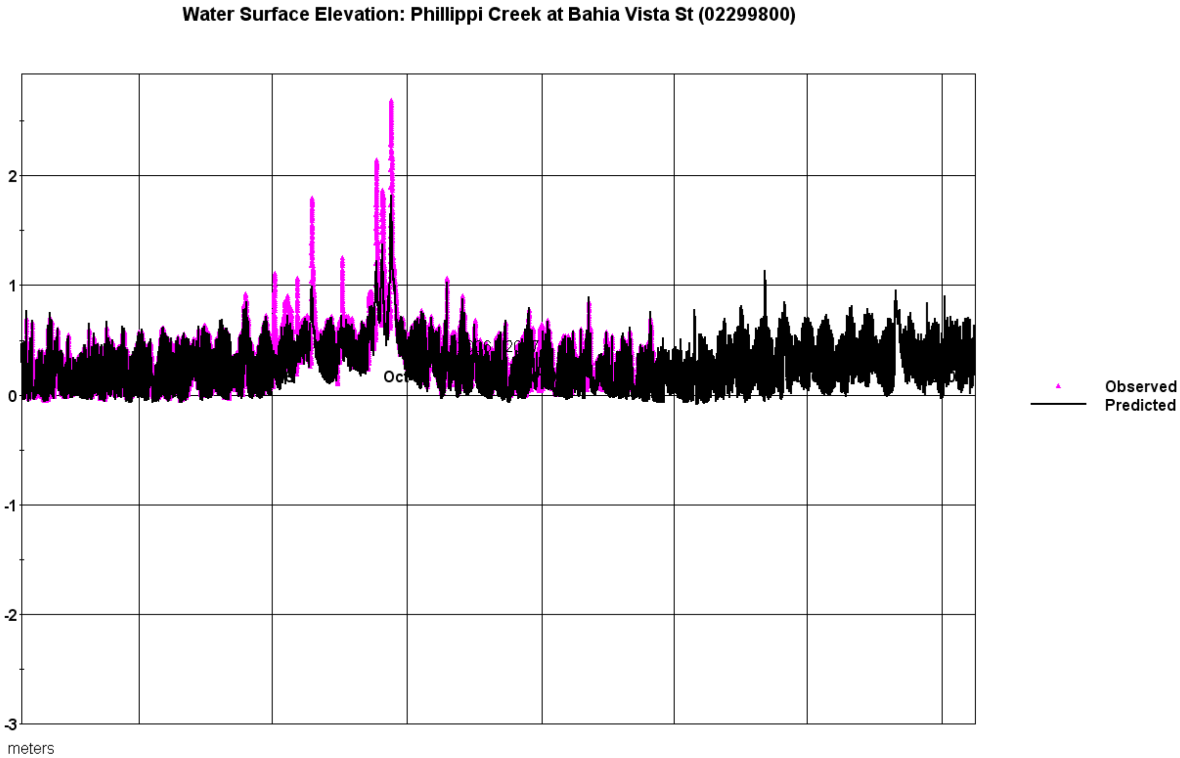

Figure 5: Predicted and Observed Water Surface Elevations at Phillippi Creek, Hydrologic Unit 03100201, USGS 02299800 at bridge on Bahia Vista St., Sarasota, 1.5 mi east of U.S. Highway 41, and 4.8 mi upstream from mouth.

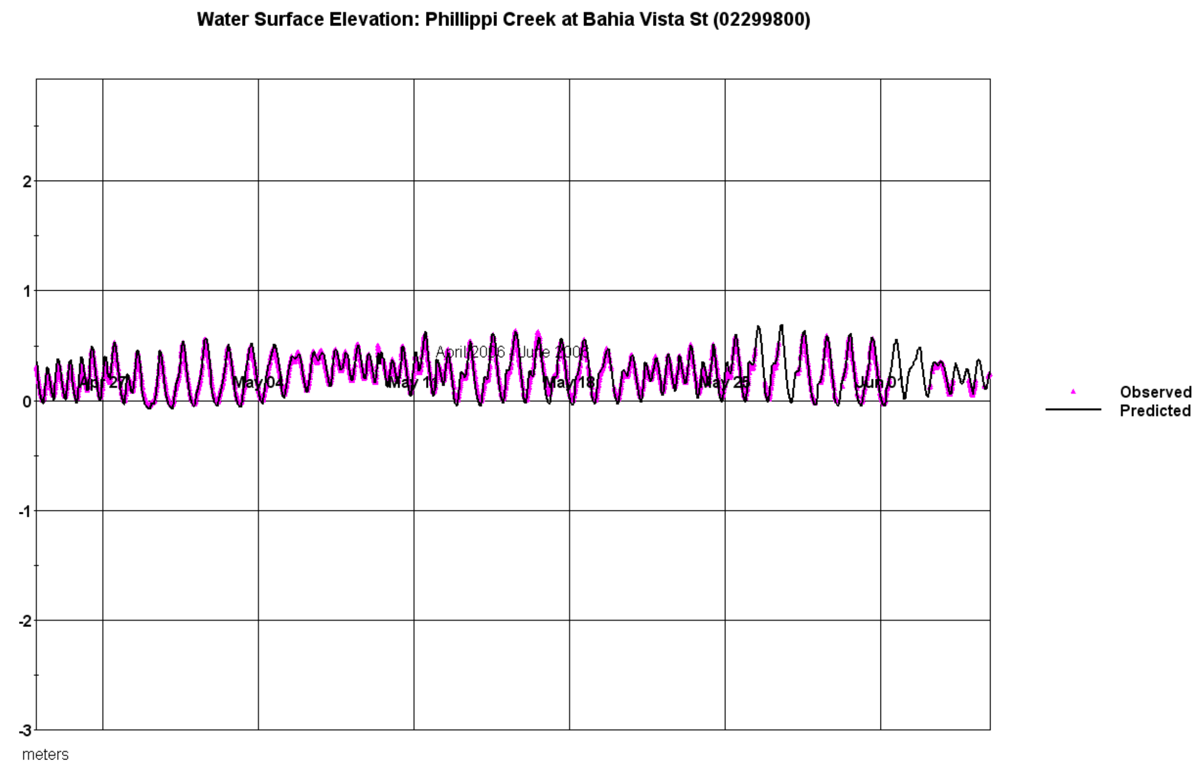

Figure 6: Zoomed: Predicted and Observed Water Surface Elevations at Phillippi Creek, Hydrologic Unit 03100201, USGS 02299800 at bridge on Bahia Vista St., Sarasota, 1.5 mi east of U.S. Highway 41, and 4.8 mi upstream from mouth.

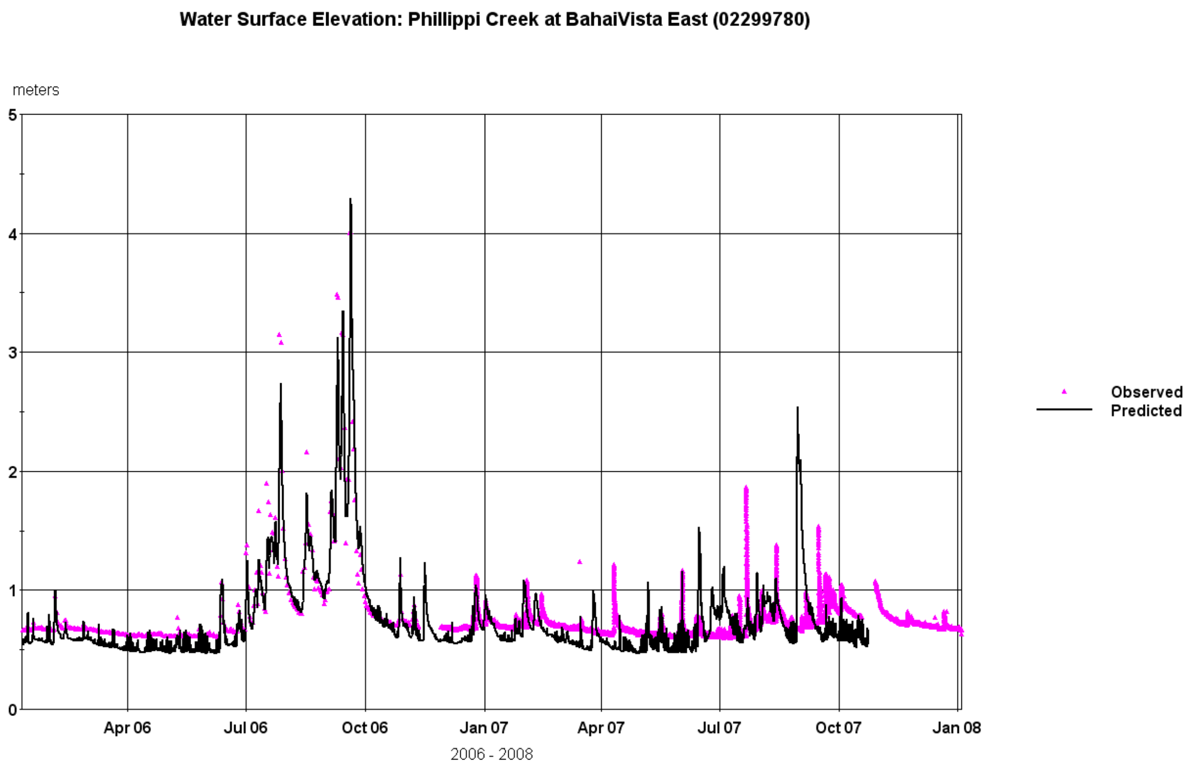

Figure 7: Sarasota County, Hydrologic Unit 03100201, USGS 02299780, Bahia Vista St. East

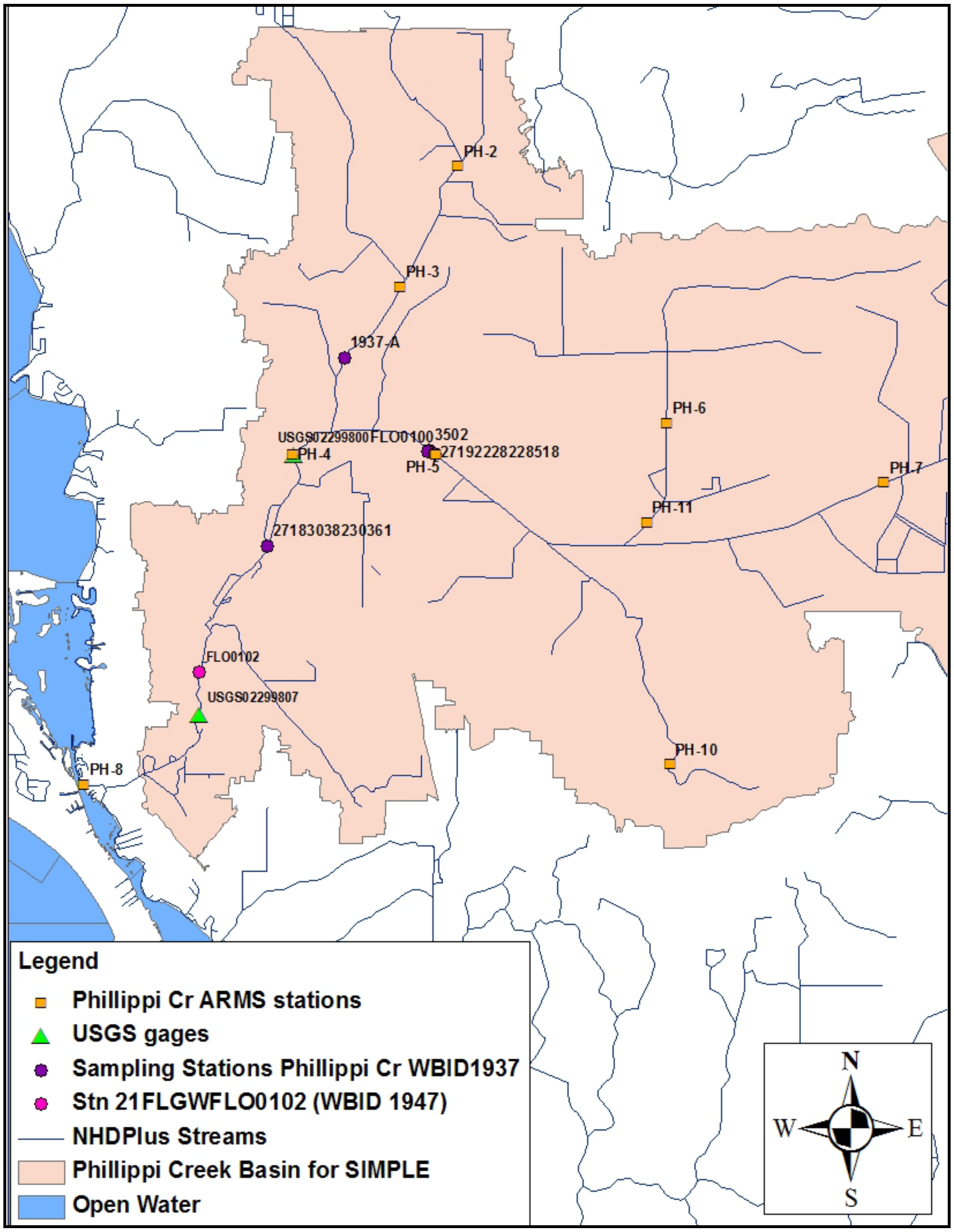

Figure 8: Locations of monitoring stations in Phillippi Creek.

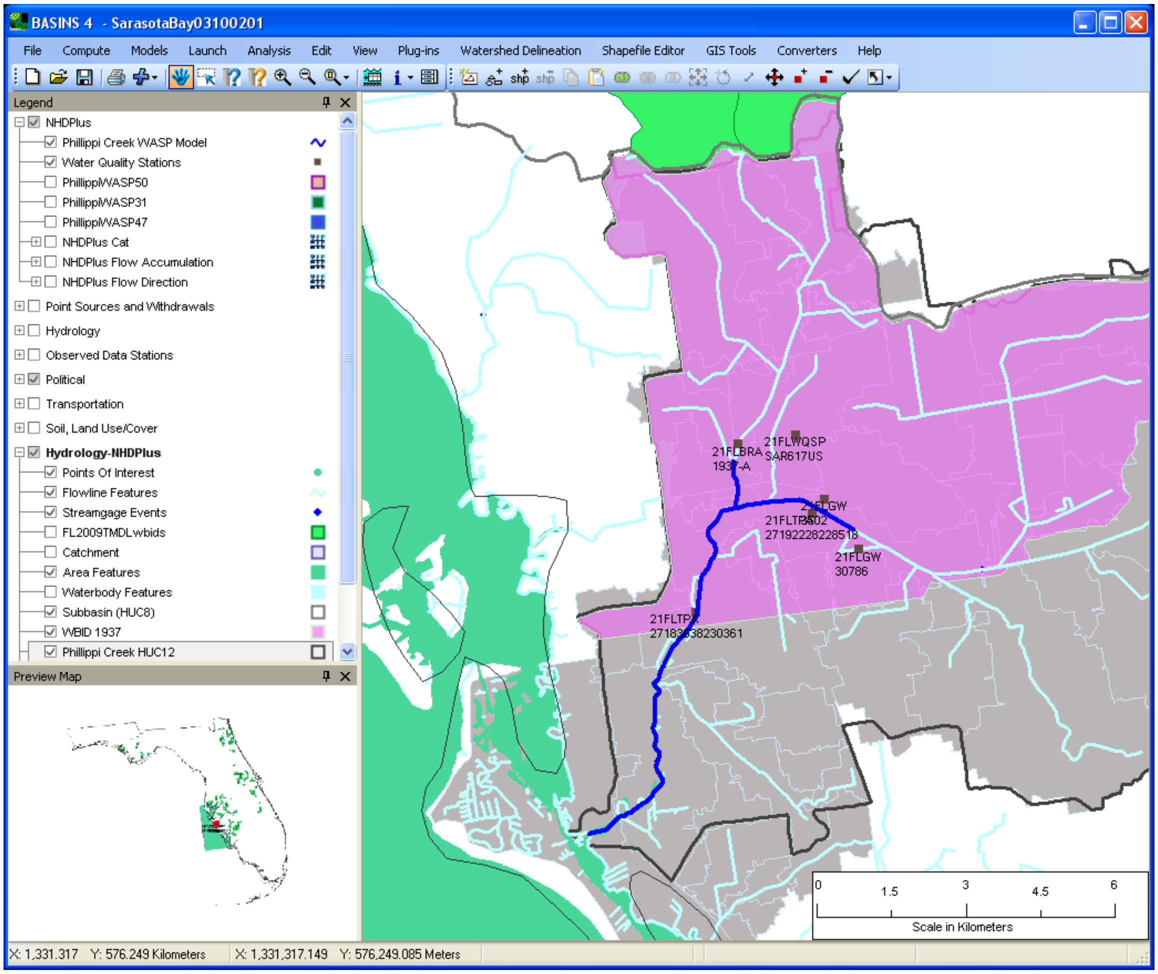

Figure 9: Phillippi Creek WASP model domain, watershed, WBID, and monitoring stations.

3.2.2 Freshwater Flows

Stream flow is an important factor affecting water quality, especially insofar as it determines the available loading capacity for pollutants such as nutrients and bacteria. Flow conditions also influence DO concentrations more directly. Typically, higher flows are associated with higher DO, since the increased flow leads to greater turbulence and aeration. Measurements taken at the United States Geological Survey (USGS) Gage #02299780, near Bee Ridge Florida (and monitoring stations PH-5, 21FLGW3502, and 21FLTPA2719228228518), show that the streamflow of Phillippi Creek is highly variable, but usually below 60 cubic feet per second (cfs; Figure 10).

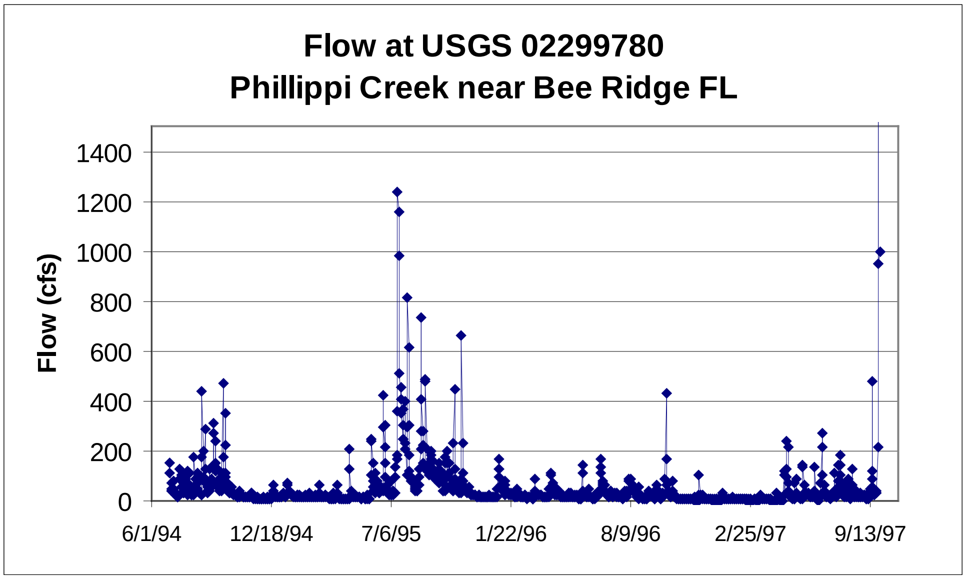

Figure 10. Flow in WBID 1937 of Phillippi Creek at USGS Gage 02299780.

A flow duration curve displays the cumulative frequency distribution of daily flow data over the period of record. The curve in Figure 11 relates flows measured or estimated for a particular location on the stream to a duration interval representing the percent of time those flows are equaled or exceeded. Values toward the right side of the plot indicate low-flow conditions that are surpassed with greater frequency. Values on the left side of the plot represent high flows that occur less frequently. For example, the stream's discharge is expected to be equal to or greater than the flow corresponding to a duration interval of 30 approximately 30 percent of the time, and less than that value approximately 70 percent of the time. Flow duration curves are limited to the period of record available at a flow gage.

Flow data from USGS gage 02299780, located on Phillippi Creek near Bee Ridge, FL and flow data collected by Sarasota County at station PH-5, located on Phillippi Creek near the USGS gage, were used to generate the flow duration curve. The flow record at the USGS gage, which drains approximately 32 square miles, extends from July 1994 to September 1997. The flow data from Sarasota County were collected between June 2003 and September 2008 at a station estimated to drain approximately 31 square miles. As can be seen in the flow duration curve, flow in Phillippi Creek near Bee Ridge Florida is below 60 cfs about 80 percent of the time (Figure 11).

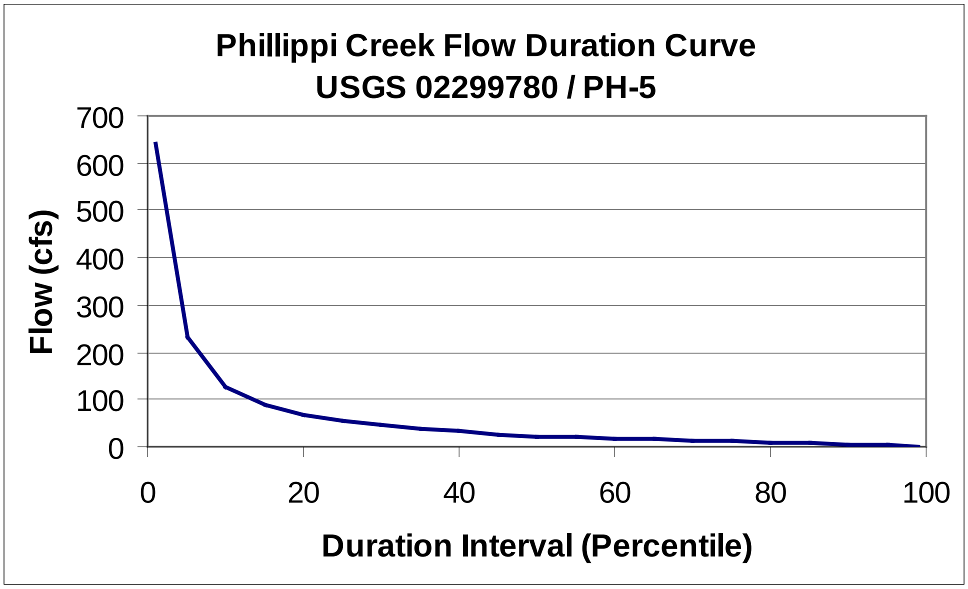

Figure 11. Flow Duration Curve for Phillippi Creek.

Flow from this location was used to estimate the flow at the model boundaries. The Phillippi Creek application of DYNHYD has two upstream boundaries, one at the headwater of Phillippi Creek and one at the main tributary. Drainage area ratios for these two model boundary locations were used to estimate the boundary flows. For example, the drainage area at the modeled headwater divided by the drainage area of the USGS gage times the measured flow at the gage was used as the headwater flow.

Pollutant loads and flows from Sarasota County's SIMPLE model were used in the DYNHYD and WASP models. Flows for the DYNHYD headwater and tributary were based on measured flows as described above. Incremental flows entering Phillippi Creek downstream of these model boundaries add about 1.3 cubic meters per second (cms; 45 cfs) to the creek flow. These flows which had been estimated by the County in their SIMPLE model were also entered into the DYNHYD flow model.

3.2.3 Channel Geometry and Segmentation

In addition to boundary forcing tidal water surface elevation and freshwater inflow, accurate bathymetry is important to adequately simulate water temperature, salinity, water surface elevation, and ultimately other water quality parameters. Channel cross section data from the Sarasota County ICPR hydrodynamic model was used to configure this model. This included channel cross-section data at approximately 300-meter intervals from the headwater down to the mouth at Roberts Bay. Bottom elevations were as deep as 1.4 meters below the NGVD vertical datum and up to 1.1 meters above NGVD. The channels segments used in the DYNHYD model are depicted in Figure 12. Please read the DYNHYD model section in the TMDL report for a description of DYNHYD Channels and Junctions, and refer to Figure 18 of the TMDL report for a depiction that explains how DYNHYD channels and WASP segments generally correspond to one another.

The water quality model includes 51 segments ranging from 100 to 700 meters long and from 5 to 142 meters wide. A total length of 13 kilometers is included in the Phillippi Creek water quality model.

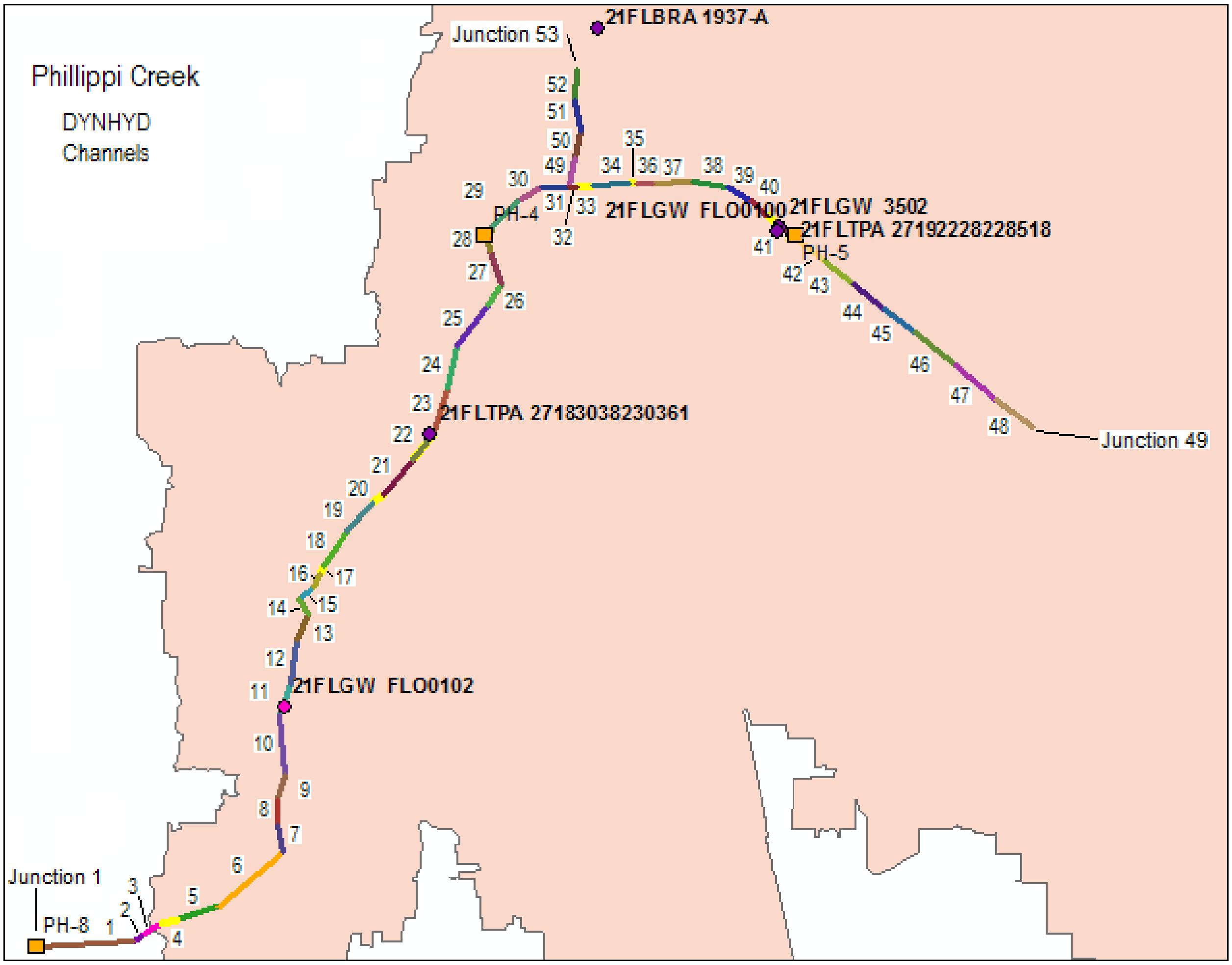

Figure 12. DYNHYD Channels and Junctions.

3.2.4 Point Source Discharges

A TMDL wasteload allocation (WLA) is given to NPDES permitted facilities discharging to surface waters within an impaired watershed. Twenty-five facilities were included in the SIMPLE-Monthly watershed model. These are listed in Table 1. Only four of these are facilities with permits to discharge to surface water. These four NPDES-permitted facilities that discharge within the Phillippi Creek watershed include two water treatment facilities and two wastewater treatment plants (Figure 12). The flows associated with these facilities were entered indirectly into the hydrodynamic model in the boundary flows or the incremental flows.

Table 1: Point Source NPDES Facilities in the Phillippi Creek Watershed.

FACILITY
Lake Tippecanoe (FL0188981)
Beekman Place Utilities
Peterson Manufacturing
Bahia Vista Estates Mhp
Medical Center Of Sarasota
Sylvan Lea
Lake Forest Condominium
Atlantic WRF
Camelot Lakes Mhp (FL0188999)
Yoders Restaurant
Meadowood WRF
Houghton Wagman Partnership (Scott Paint)
Dolomite Utilities / Fruitville (FL0134589)
Bee Ridge Water Reclamation Facility
Dana Corporation
Oak Hammock Professional Ctr
South Gate (FL0032808)
Oakwood Gardens Condo
Healthsouth Of Sarasota
Barclay House Apart (Park Place Villas)
Woodbridge Estates
Proctor Road
Bath & Racquet Club
Cafe Baci Sw Restaurant
Siesta Key Utility Authority
Field Club
Gulf Gate
Coral Cove Trust

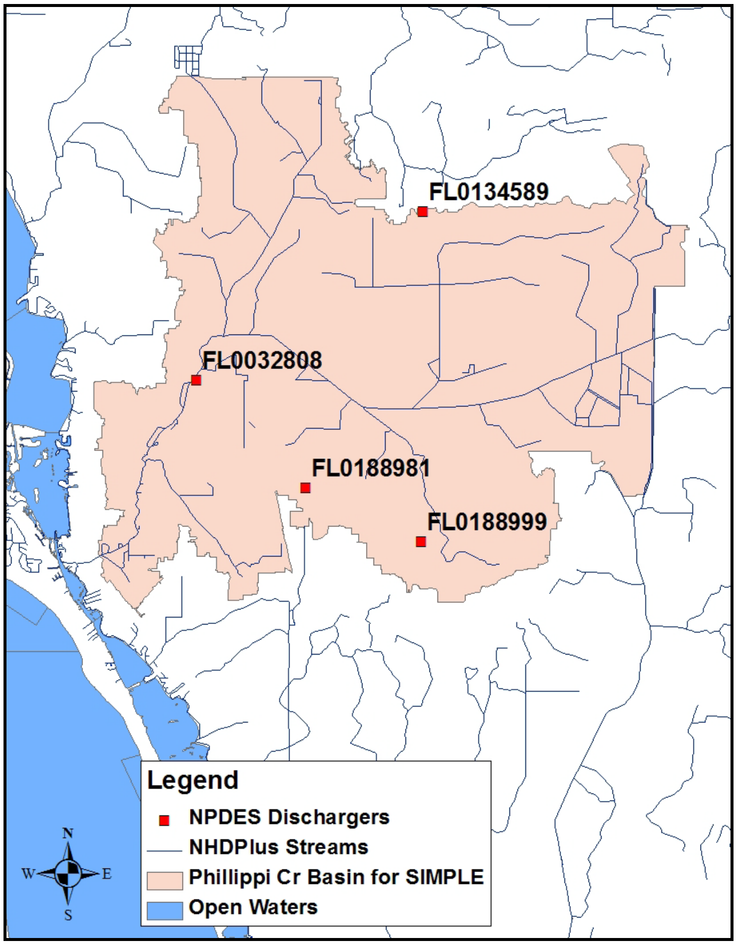

Figure 13: Locations of NPDES facilities in the Phillippi Creek Watershed.

The South Gate WWTP (FL0032808) is a major domestic wastewater treatment plant that discharged its effluent directly to Phillippi Creek until June 2008. The permit for this facility includes limits for fecal coliform bacteria, nutrients, BOD, DO, and total suspended solids (TSS), as well as a few other parameters (FDEP, 2004a). The construction of a master lift station at the site allowed the effluent to be sent to the Bee Ridge Water Reclamation Facility. This facility sends reclaimed water to Sarasota County's North Master Reuse System (permit #FLA177008; David Pouso, personal communication). Pollutant loads from this facility are included in the TMDL analysis. However, since the facility does not currently have a surface water discharge, it will be included in the TMDL LA, rather than the WLA.

The Dolomite Utilities Fruitville WWTP (FL0134589) is permitted to discharge up to 2.4 million gallons per day (MGD) 3-Month Average Daily Flow (FDEP, 2004b). The effluent eventually flows from contact basins, over weirs, to a common wet well, from which water is pumped into different reclaimed water storage ponds. Some of the reclaimed water is discharged into a storm water storage lake system at the Tatum Ridge Golf Course Lake #6/7, which can intermittently overflow to the Sarasota County Celery Fields storm water facility and then into Phillippi Creek, when the water level rises above the daily storage capacity of the lakes. The other storage ponds flow to other areas. Pollutant loads from this facility are included in the TMDL modeling analysis and are incorporated into the allowable (i.e. TMDL) loads.

Camelot Lakes (FL0188999) is a water treatment facility which utilizes reverse osmosis to provide potable water to the residents of Camelot Communities (FDEP, 2006a). The facility has a design flow of 0.041 MGD (0.063 cfs). The filtered concentrate is not treated prior to being discharged to an on-site stormwater pond for dilution and storage. During periods of high rainfall, water may overflow from this pond into an unnamed ditch which carries it to Phillippi Creek. Because the discharge is rainfall dependent, it is highly variable. Pollutant loads from this facility are included in the TMDL modeling analysis and are incorporated into the allowable (i.e. TMDL) loads.

The Lake Tippecanoe Owners Association (FL0188981) is a water treatment plant which provides drinking water to residents of Lake Tippecanoe Condominiums (FDEP, 2006b). The water plant uses reverse osmosis to remove minerals from water, before discharging them to on-site stormwater pond. The only treatment for the mineral concentrate is the dilution provided by any stormwater in the pond, so the actual degree of dilution will vary depending on the antecedent rainfall conditions. The maximum daily flow to the pond is 0.014 MGD (0.022 cfs). Any overflow from the pond is discharged through a concrete pipe to a ditch along Bliss Road, where it may drain to Phillippi Creek. As such, this facility is only expected to result in a discharge to Phillippi Creek during periods of high rainfall. Pollutant loads from this facility are included in the TMDL modeling analysis and are incorporated into the allowable (i.e. TMDL) loads.

4. WASP WATER QUALITY MODEL DEVELOPMENT

4.1 Water Quality Model Background

The Water Quality Analysis Simulation Program (WASP) model was used to evaluate the effect of BOD, nutrients, algae, and other oxygen demanding substances on DO processes. The Water Quality Analysis Simulation Program version 7 (WASP7) is an enhancement of the original WASP. This model helps users interpret and predict water quality responses to natural phenomena and man made pollution for various pollution management decisions. WASP7 is a dynamic compartment-modeling program for aquatic systems, including both the water column and the underlying benthos. The time varying processes of advection, dispersion, point and diffuse mass loading, and boundary exchange are represented in the basic program (Wool et al, 2001).

Water quality processes are represented in special kinetic subroutines that are either chosen from a library or written by the user. WASP is structured to permit easy substitution of kinetic subroutines into the overall package to form problem specific models. WASP7 comes with two such models -- TOXI for toxicants and EUTRO for conventional water quality. Earlier versions of WASP have been used to examine eutrophication of Tampa Bay; phosphorus loading to Lake Okeechobee; eutrophication of the Neuse River and estuary; eutrophication and PCB pollution of the Great Lakes, eutrophication of the Potomac Estuary, kepone pollution of the James River Estuary, volatile organic pollution of the Delaware Estuary, and heavy metal pollution of the Deep River, North Carolina (Wool et al, 2001).

The flexibility afforded by the Water Quality Analysis Simulation Program is unique. WASP7 permits the modeler to structure one, two, and three-dimensional models; allows the specification of time variable exchange coefficients, advective flows, waste loads and water quality boundary conditions (Wool et al, 2001). The eutrophication module of WASP7 was applied in the development of these TMDLs.

4.2 Water Quality Data

In addition to the data needed for configuring and calibrating the DYNHYD hydrodynamic model, data for the water quality model is needed. These data include:

- Measured meteorological conditions;
- Fresh water water temperature;
- Tidal boundary water temperature at Roberts Bay;
- Tidal boundary water salinity at Roberts Bay;
- Fresh water water quality;
- Tidal boundary water quality at Roberts Bay.

4.2.1 Meteorological Conditions

As discussed in section 3.2, the meteorological data needed for the hydrodynamic model calibration were obtained from the NCDC weather station at Sarasota, FL WBAN 12871. Air temperature, solar radiation, and wind speed are used in the water quality model and affect reaeration, and phytoplankton productivity.

4.2.2 Freshwater Inflow Water Temperature

Direct measurements of water temperature was not available at either of the model boundaries. Water temperature measurements were available at station 21FLGW3502, about three kilometers downstream of the headwater boundary. Therefore, the water temperature for all of the fresh water boundaries was based on a sine curve fit to measurements at this station.

4.2.3 Tidal Boundary Water Temperature

A sine curve fit to measured water temperature in Roberts Bay was used for the downstream water temperature boundary. The WRDB program includes a sine fit utilty that was used for this water temperature estimation. Water temperature varies sinusoidally from about 19 to almost 31 degrees C.

4.2.4 Tidal Boundary Salinity

Salinity for the model tidal boundary was set equal to the measured values from Roberts Bay.

4.2.5 Fresh Water Quality And Pollutant Loads From SIMPLE

Dissolved oxygen was not measured at the fresh water model boundaries and estimates were needed for all fresh water entering the model. Therefore, DO was estimated as 80 percent of the saturation concentration. Chlorophyll-a for the fresh water inflow was entered as a constant 15 ug/l.

Pollutant loads from Sarasota County's SIMPLE model were used in the WASP model. Monthly total nitrogen, total phosphorus, total suspended solids, and BOD loads from the SIMPLE monthly model were distributed daily using the measured daily flows and then entered into

WASP as daily loads in kg per day. Total nitrogen was divided into ammonia, nitrite plus nitrate, and organic nitrogen according to observed water quality data at station 21FLGW3502 since this is needed for WASP. These fractions are 0.07 for NH3, 0.16 for NO3 plus NO2, and 0.77 for OrgN. Similarly total phosphorus was divided into orthophosphate, 0.67, and organic phosphorus, 0.33. Ultimate carbonaceous biochemical oxygen demand (CBODu) was estimated from BOD assuming a first order decay rate (deoxygenation constant) of 0.06 per day and solving for the CBODu to 5-day BOD ratio which results in 3.86.

The SIMPLE-Monthly Model was developed by Sarasota County and the Southwest Florida Water Management District. The Sarasota County Pollutant Loading Model Development SIMPLE-MONTHLY Design Report describes this model as follows. The model is referred to as the Spatially Integrated Model for Pollutant Loading Estimates (SIMPLE), and was configured as a county-wide pollutant loading model within a GIS framework for Sarasota County. The objective of this verified pollutant loading model is to accurately estimate pollutant loads and the effectiveness of projects intended to reduce pollution. The Sarasota County SIMPLE model uses computational methods from the Watershed Management Model (WMM) and the Harvey Harper Method (used in the Lemon Bay Model) as well as additional methods to predict monthly loads from point sources, non-point sources (e.g., direct runoff and base flow), and septic tanks. The SIMPLE-MONTHLY Model includes wet and dry deposition of pollutants and three forms of irrigation, septic tank loading, direct non-point source runoff loading, and point source loading. As in the first version of the model, simulations of best management practices (BMPs), wastewater discharges, and septic tanks are included but now have the added dimension of time. Additional details about the SIMPLE-Monthly model can be found in the design report and the operations manual (Jones Edmunds and Associates, 2009a and 2009b).

Table 2: Watershed Pollutant Loads from SIMPLE-Monthly (average pounds per month)

	BOD	TP	TN
Baseflow	13123	1312	4921
Direct Runoff	42854	1825	12089
Irrigation	437	649	401
Point Source	1657	1092	1482
Septic	3762	168	743
Wet Dry Fall	0	562	428

4.2.6 Tidal Boundary Water Quality

Water quality for the tidal boundary were set equal to the measured values from Roberts Bay.

4.3 Water Quality Sensitivity Analysis

An analysis showing the major sources consuming DO is shown in Figure 13. This shows that sediment oxygen demand (SOD) consumes the most oxygen followed by plant respiration and then biochemical oxygen demand (BOD). Plant consumption of oxygen during respiration is largely offset by oxygen production during the day. To better understand the sensitivity of the water quality model to unmeasured SOD and reaeration rates, sensitivity tests were performed.

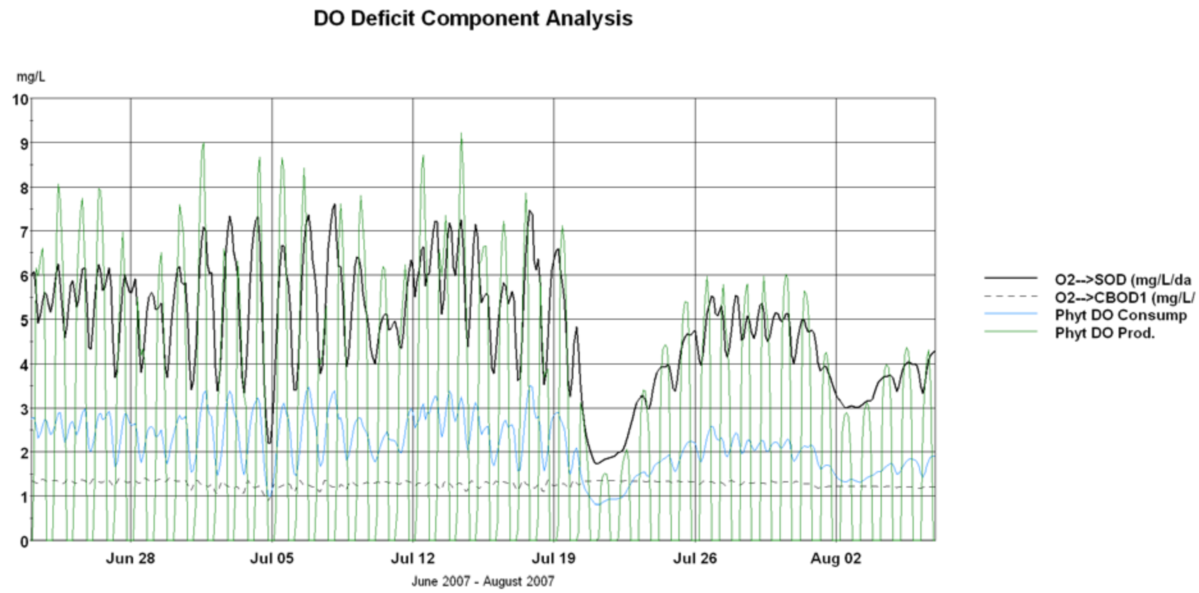

Figure 14: DO deficit component analysis.

4.3.1 Reaeration

In the water quality model flow-induced reaeration is often calculated based on the Covar method (Covar, 1976). This method calculates reaeration as a function of velocity and depth by one of three formulas: Owens, Churchill, or O'Connor-Dobbins, respectively. The Owens formula is automatically selected for segments with depth less than 2 feet. For segments deeper than 2 feet, the O'Connor-Dobbins or Churchill formula is selected based on a consideration of depth and velocity. Deeper, slowly moving rivers require O'Connor-Dobbins; moderately shallow, faster moving streams require Churchill. Each formula estimated that reaeration rates were proportional to depth-average velocity and inversely proportional to total depth.

The low DO in Phillippi Creek required a low reaeration rate constant of 0.5 per day to reflect the DO in this system. However, in order to understand the impact of the reaeration option, a scenario with reaeration computed with the Covar method was compared to a scenario using the constant rate of 0.5. Figure 14 shows predicted DO for the two scenarios at model segment 28, near water quality station PH-4. The DO is generally much higher with the Covar reaeration option. Both greater depths and slower velocities will result in lower reaeration and lower DO under the Covar option. In summary, model predictions of DO are sensitive to the reaeration rate constant and measurements of reaeration would improve model certainty. The reaeration rate of 0.5 per day was selected for this model because the predicted DO with this rate better fit the observed DO data. It is suspected that the Covar method is inaccurate in this model because predicted velocities are too high.

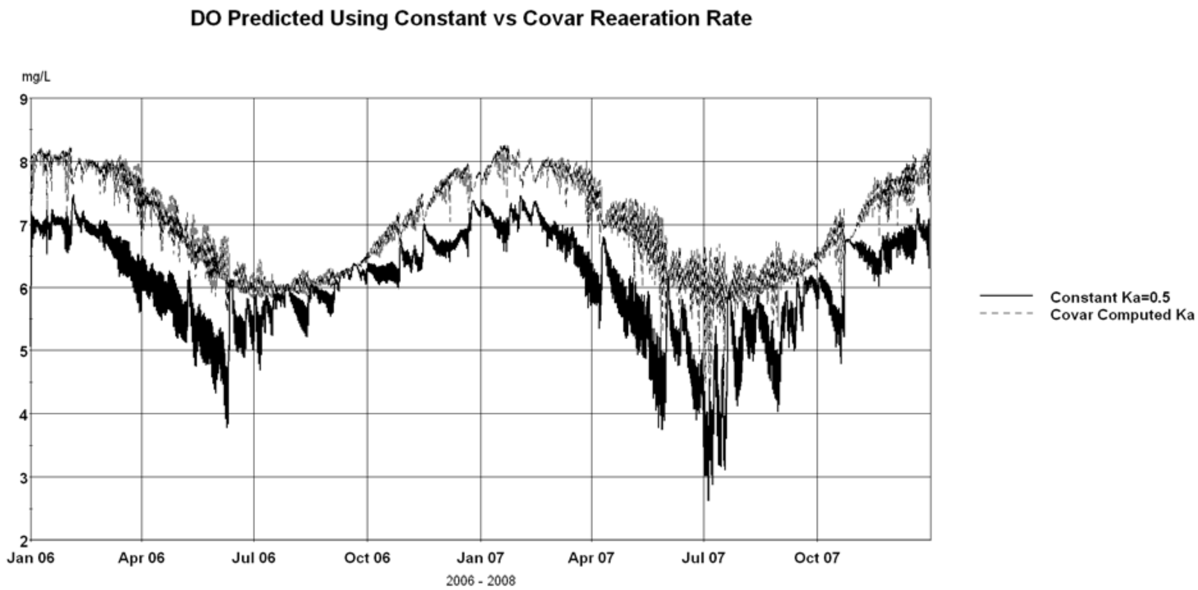

Figure 15: DO predicted with Covar reaeration rate option versus constant rate of 0.5/day.

4.3.2 SOD Rate

Sediment Oxygen Demand (SOD) is the sum of all biological and chemical processes in sediment that take up oxygen from the water column. To explore the model sensitivity to the SOD rate two scenarios were compared. A scenario with the SOD rate at 1.5 gram of oxygen per square meter per day was compared to a scenario with half that SOD rate (0.75 $g/m^2/d$). The DO predicted using two different SOD rates at model segment 28, near water quality station PH-4, is shown in Figure 15. The mean DO predicted by the model with a SOD rate of 1.5 is 6.07 mg/L and the mean DO predicted by the model with a SOD rate of 0.75 is 6.44 mg/L, which is 0.37 mg/L higher. Similarly, the fifth percentile of the DO with the SOD of 1.5 is 4.55 mg/L and with a SOD rate of 0.75 the fifth percentile DO is 5.32 mg/L which is a difference of 0.77 mg/L. In summary, model predictions of DO are sensitive to the SOD rate and direct measurements of SOD would improve model certainty. For this model application, a database of measured SOD rates in other similar waterbodies and an SOD flux model were utilized to support the selection of proper rates.

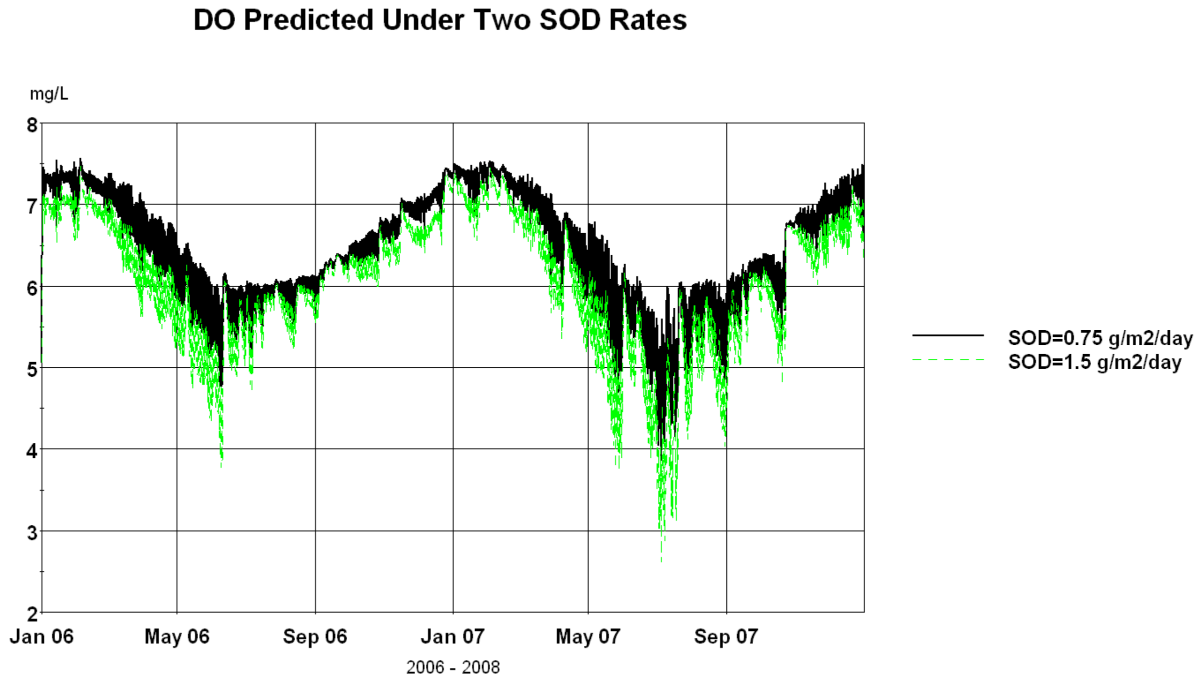

Figure 16: DO predicted under two different SOD rates; 1.5 and 0.75 g/m2/day.

4.4 Water Quality Configuration, Calibration, and Validation

Comparisons of model predictions and measured values for various constituents are shown in this section. The objective here is to demonstrate that this set of models adequately predicts water quality in the Phillippi Creek tidal river system, and to demonstrate the level of pollutant load reductions necessary to meet water quality standards. The following sections discuss model configuration and calibration efforts. Included in the discussions are dissolved oxygen, reaeration, sediment oxygen demand, plant productivity, nutrients, and BOD. Table 3 shows the WASP water quality model environmental and chemical constants for the configured model.

4.4.1 Dissolved Oxygen, Reaeration, and Sediment Oxygen Demand

Figure 16 shows the predicted and the observed DO at model segment 41, which corresponds to station FLGW3502 near Bee Ridge Road. The predicted DO follows a similar seasonal pattern as the observed data, and shows the diurnal variation observed in FDEP's special DO monitoring seen in Figure 2. However, the observed monthly trend data in Figure 16 is generally lower than the predicted data with a few observations higher than the predicted. Several factors may affect this difference. For instance, as discussed in Section 4.2.5 the DO at the fresh water model boundaries was estimated as 80 percent of the saturation concentration. Water flowing to the boundaries from the connected lakes, tributaries, and overland runoff will likely vary from this assumption.

In addition, as described in Section 2, Modeling Approach, there were no direct measurements of SOD, reaeration, aquatic macrophytes nor periphyton in Phillippi Creek. Therefore, the approach for developing this TMDL is based primarily on the water chemistry data and the evidence of low reaeration, high detrital loading, strong photosynthetic activity, and elevated SOD. This involved adjusting SOD and reaeration within expected ranges to mimic the observed DO in the system. Chlorophyll-a measurements were low although the measured DO showed evidence of productivity. As discussed in Section 2, observations from existing reports indicated that macrophytes and periphyton were the cause of this diurnal DO pattern. This photosynthetic activity was represented in the water quality model by phytoplankton kinetics with transport switched off. With transport off phytoplankton will not move in the model with the water current, thus simulating periphyton or macrophytes. While the modeling approaches used for phytoplankton and periphyton are similar, periphyton differ from phytoplankton in a number of fundamental ways:

• Periphyton do not move with the water current, as do phytoplankton,

• Periphyton typically dwell on or near the bottom, so are not impacted by the average light in the water column but the light reaching the bottom (substrate).

• Periphyton are limited by the amount of substrate available for growth.

• There is typically a maximum density for attached plants.

These differences were considered when configuring the model so that the model would represent the actual DO dynamics as close as possible. Chlorophyll-a is not a calibration parameter since it is not a good indicator of macrophyte and periphyton density.

Since SOD rates were not measured in Phillippi Creek measured rates from similar tidal rivers were used as a starting point in this water quality model. These rates were then adjusted to reflect the measured DO in Phillippi Creek. Measured rates in the Hillsborough River ranged from 2.31 to 8.65 with an average of 4.57 grams O_2 per square meter per day when corrected to 20 degrees Celcius. SOD rates were also computed with the Quantitative Environmental Analysis, LLC (QEA) and Mississippi State University sediment flux model that is based on DiToro's sediment flux model (QEA, 5/29/2003). This SOD model estimates SOD rates from the observed water column nitrogen, phosphorus and carbon loads, volume, flow rate and water temperature. These estimated rates are approximately 1.5 g/m^2/day. A rate of 1.75 g/m^2/day was determined to be appropriate for this Phillippi Creek model.

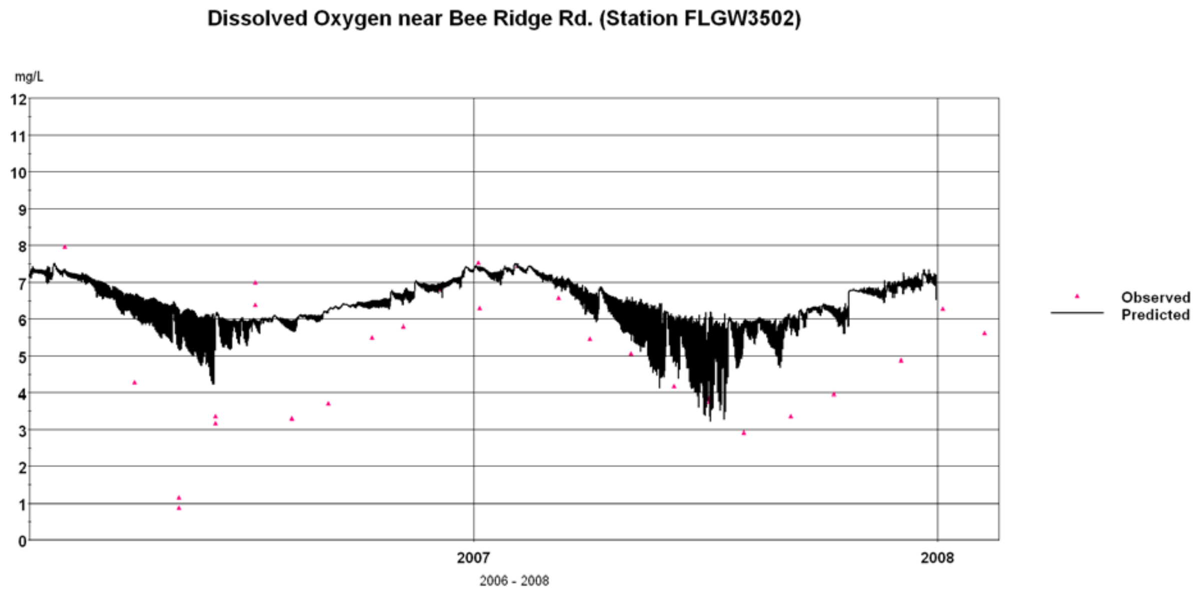

Figure 17: DO; Observed vs Predicted

4.4.2 Nitrogen and Phosphorus

Predicted and observed ammonia, nitrate, organic nitrogen, total phosphorus, ortho-phosphate, and organic phosphorus are shown in Figure 17 through Figure 22. The model predicts each of these nutrient parameters reasonably well. Recall from section 4.2.5 that total nitrogen and total phosphorus were predicted in Sarasota County's SIMPLE-Monthly model and entered into the WASP water quality model as daily loads. The total nitrogen and phosphorus was divided into the specific forms according to observed water quality data.

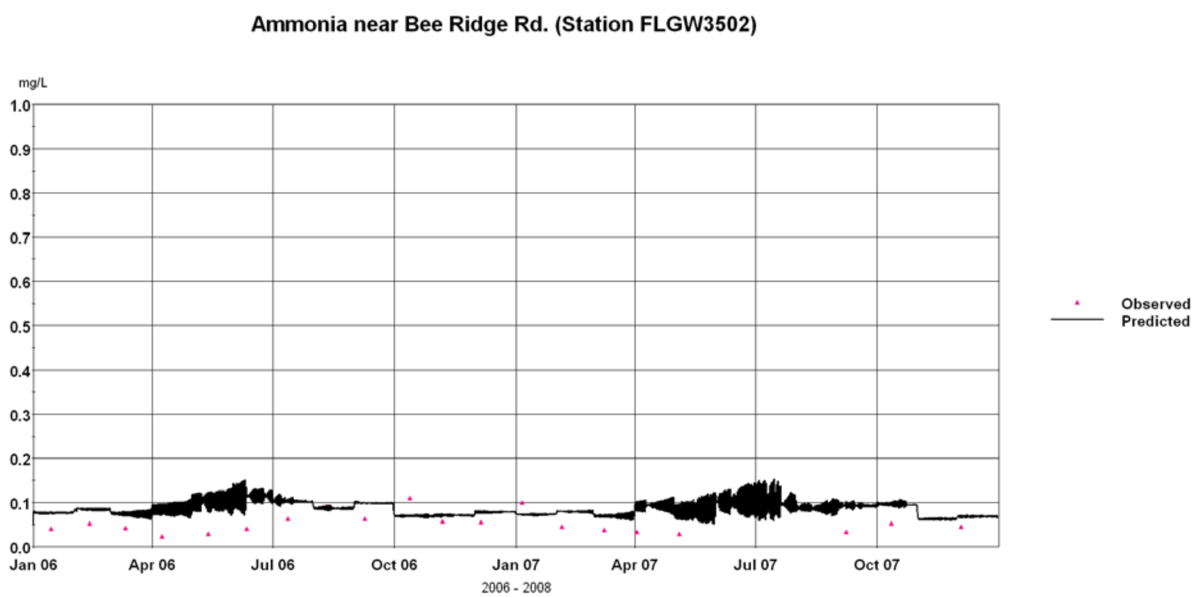

Figure 18: Observed and Predicted Ammonia.

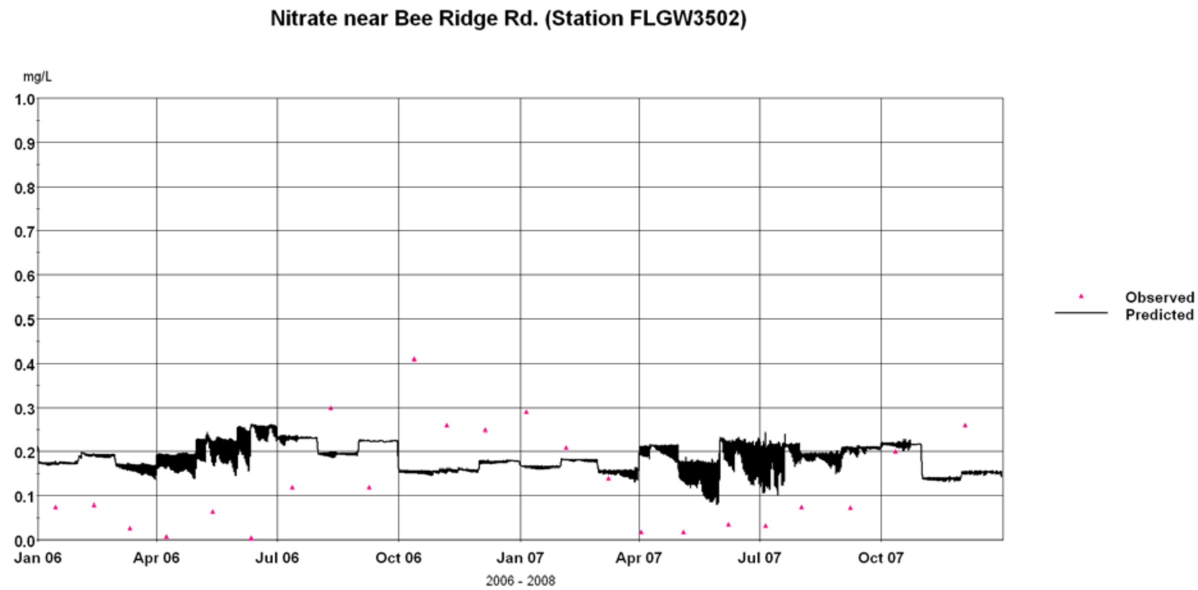

Figure 19: Observed and Predicted Nitrate and Nitrite.

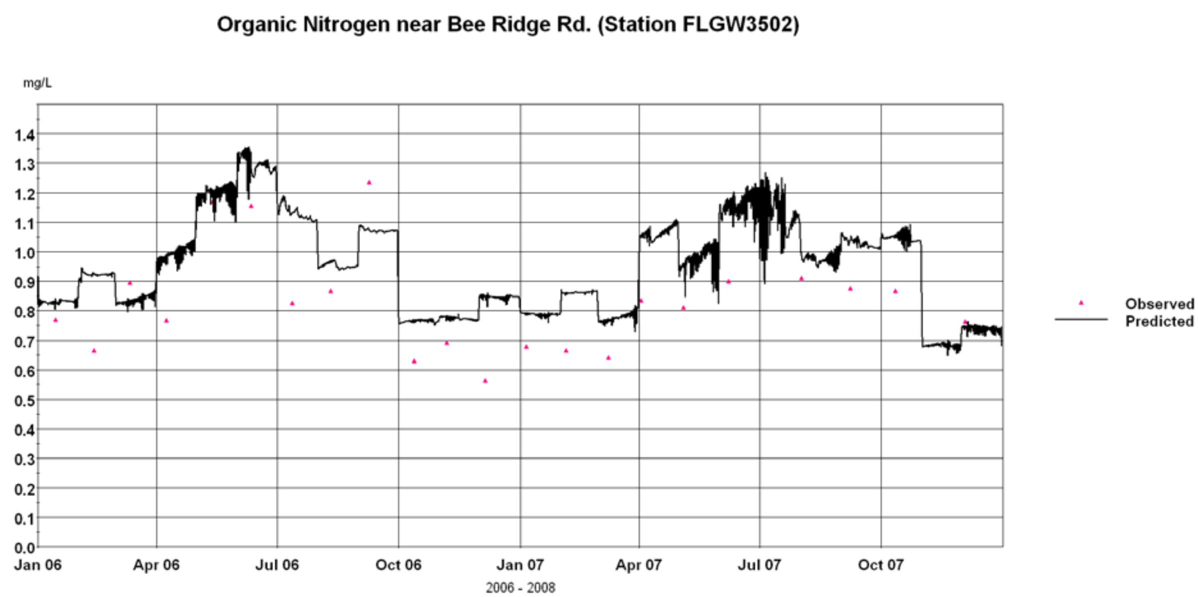

Figure 20: Observed and Predicted Organic Nitrogen.

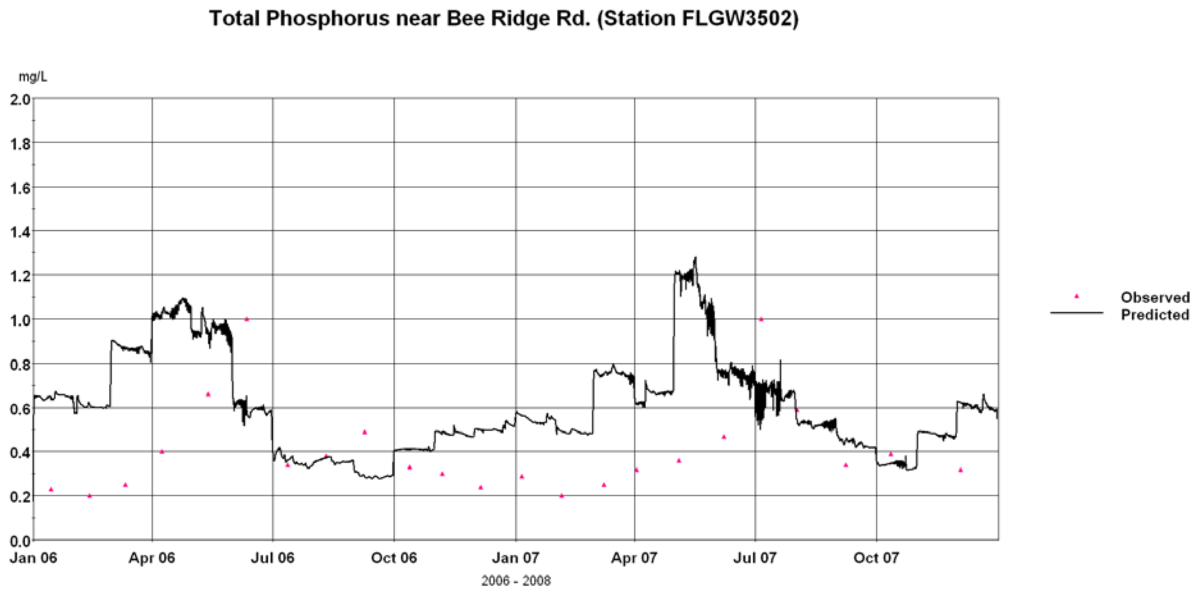

Figure 21: Observed and Predicted Total Phosphorus.

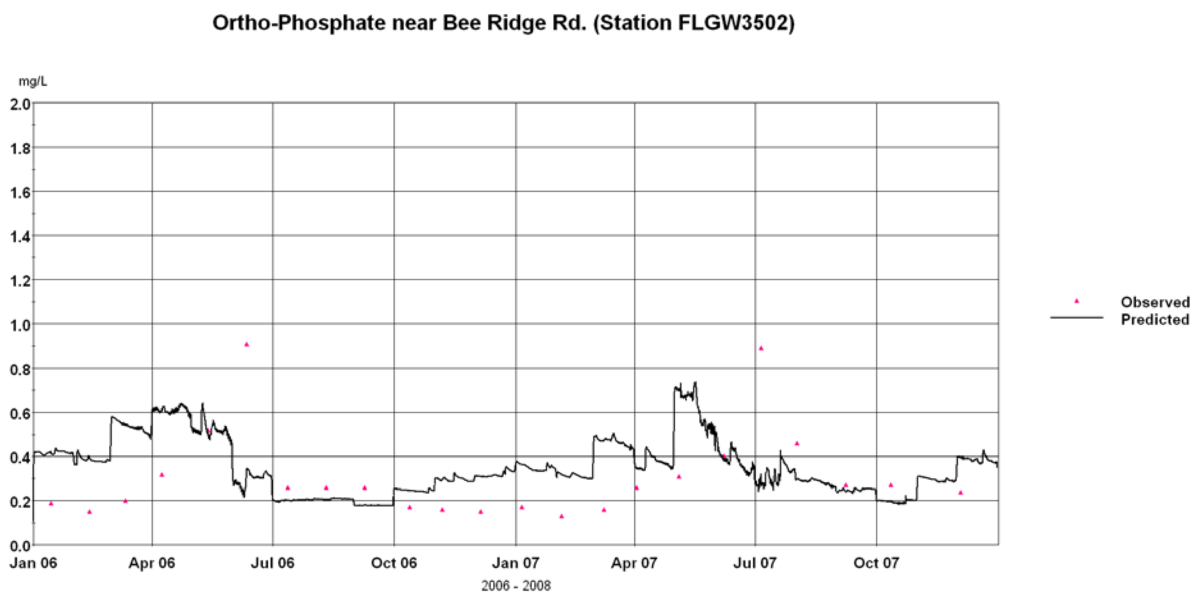

Figure 22: Observed and Predicted Ortho-Phosphate.

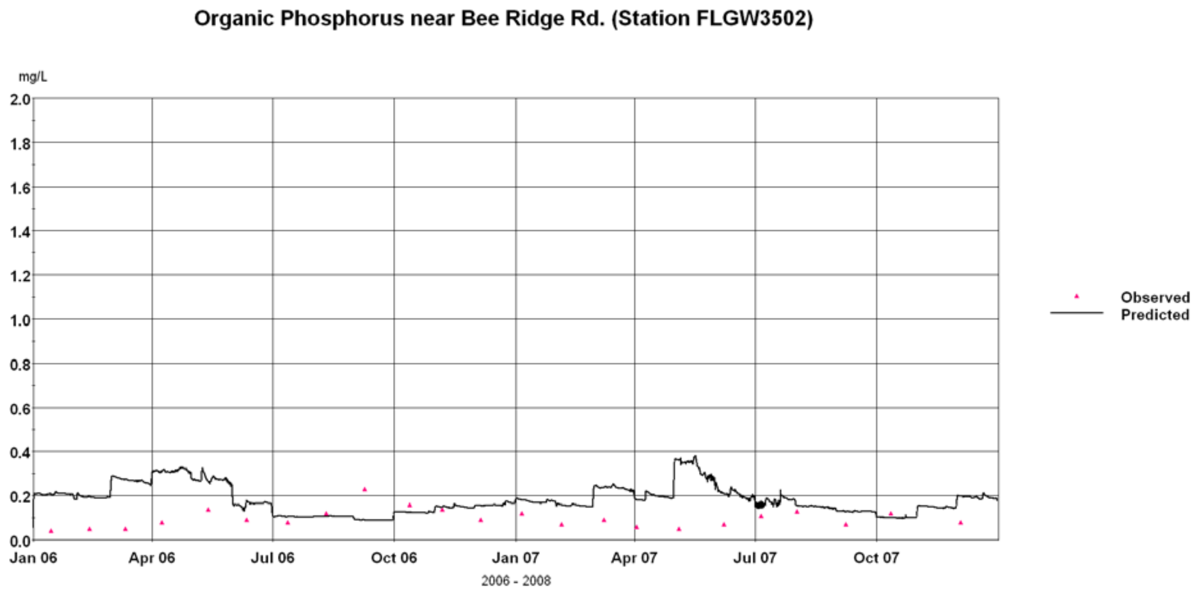

Figure 23: Observed and Predicted Organic Phosphorus.

4.4.3 Carbonaceous Biochemical Oxygen Demand

Ultimate carbonaceous biochemical oxygen demand (CBODu) was estimated from BOD assuming a first order decay rate (deoxygenation constant) of 0.06 per day and solving for the $CBOD_u$ to 5-day BOD ratio which results in 3.86. SIMPLE-Monthly loads of BOD were considered ultimate BOD for the water quality model. Figure 23 shows the predicted ultimate CBOD and the observed 5-day BOD. If these observed BOD values were converted to ultimate with the 3.86 fector, they would be comparable to the predicted $CBOD_u$. There are very few BOD observations and most were reported at 2 mg/L which is the method detection limit. Additionally, there were no long-term BOD test upon which to base the ultimate to 5-day ratio and decay rate. The decay rate of 0.06 per day is generally recognized as a common rate for ambient rivers and streams in Region 4 states. The low five-day BOD confirms that there are no major BOD loads entering this river system.

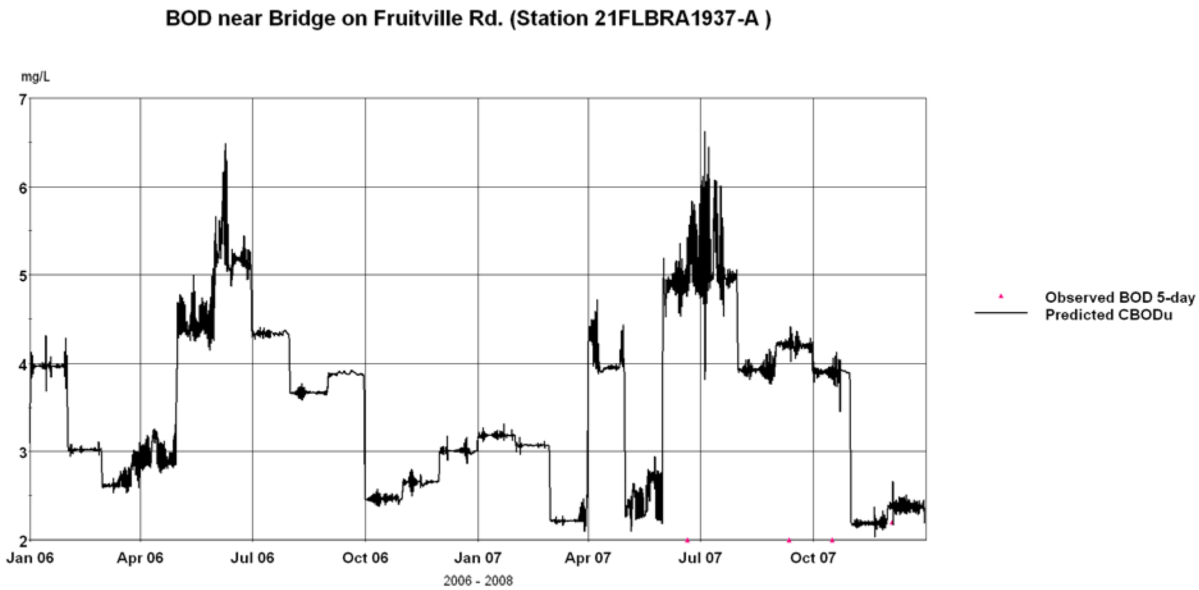

Figure 24: BOD; Observed vs Predicted

Table 3: WASP Environmental and Chemical Constants

Nitrification Rate Constant @20 °C (per day)	1.0
Nitrification Temperature Coefficient	1.047
Half Saturation Constant for Nitrification Oxygen Limit (mg O/L)	2
Denitrification Rate Constant @20 °C (per day) actor	0.03
Denitrification Temperature Coefficient	1.045
Half Saturation Constant for Denitrification Oxygen Limit (mg O/L)	0.1
Dissolved Organic Nitrogen Mineralization Rate Constant @20 °C (per day)	0.1
Dissolved Organic Nitrogen Mineralization Temperature Coefficient	1.047
Organic Nitrogen Decay Rate Constant in Sediments @20 °C (per day)	0.03
Organic Nitrogen Decay in Sediment Temperature Coefficient	1.07
Fraction of Phytoplankton Death Recycled to Organic Nitrogen	0.1
Mineralization Rate Constant for Dissolved Organic P @20 °C (per day)	0.01
Dissolved Organic Phosphorus Mineralization Temperature Coefficient	1.047
Organic Phosphorus Decay Rate Constant in Sediments @20 °C (per day)	0.001
Organic Phosphorus Decay in Sediments Temperature Coefficient	1.047
Fraction of Phytoplankton Death Recycled to Organic Phosphorus	0.1
Phytoplankton Maximum Growth Rate Constant @20 °C (per day)	1
Phytoplankton Growth Temperature Coefficient	1.045
Phytoplankton Carbon to Chlorophyll Ratio	50
Phytoplankton Half-Saturation Constant for Nitrogen Uptake (mg N/L)	0.05
Phytoplankton Half-Saturation Constant for Phosphorus Uptake (mg P/L)	0.005
Phytoplankton Endogenous Respiration Rate Constant @20 °C (per day)	0.1
Phytoplankton Respiration Temperature Coefficient	1.045
Phytoplankton Death Rate Constant (Non-Zooplankton Predation) (per day)	0
Light Option (1 uses input light; 2 uses calculated dial light)	2

Phytoplankton Optimal Light Saturation	500
Background Light Extinction Multiplier	0.5
Detritus & Solids Light Extinction Multiplier	0.1
DOC Light Extinction Multiplier	0.1
Waterbody Type Used for Wind Driven Reaeration Rate	2
Calc Reaeration Option (0=Cover, 1=O'Connor, 2=Owens, 3=Churchill, 4=Tassioglou)	1
Global Reaeration Rate Constant @ 20 °C (per day)	0.5
Elevation above Sea Level (meters) used for DO Saturation	0
Reaeration Option (Sums Wind and Hydraulic Ka)	0
Theta -- Reaeration Temperature Correction	1.024
Oxygen to Carbon Stoichiometric Ratio	2.67
BOD (1) Decay Rate Constant @20 °C (per day)	0.06
BOD (1) Decay Rate Temperature Correction Coefficient	1.045
BOD (1) Half Saturation Oxygen Limit (mg O/L)	0.5
Fraction of Detritus Dissolution to BOD (1)	1
Detritus Dissolution Rate (1/day)	0.4
Temperature Correction for detritus dissolution	1.045

4.4.4 TMDL; Load Reduction Scenario

The calibrated model was used to evaluate reductions of nutrients and oxygen demanding substances. A scenario that demonstrates attainment of the water quality criteria for DO is termed the TMDL model. Figure 24 shows the predicted DO under the calibrated model and the TMDL model which includes a 70 percent reduction in BOD, nutrients, and SOD.

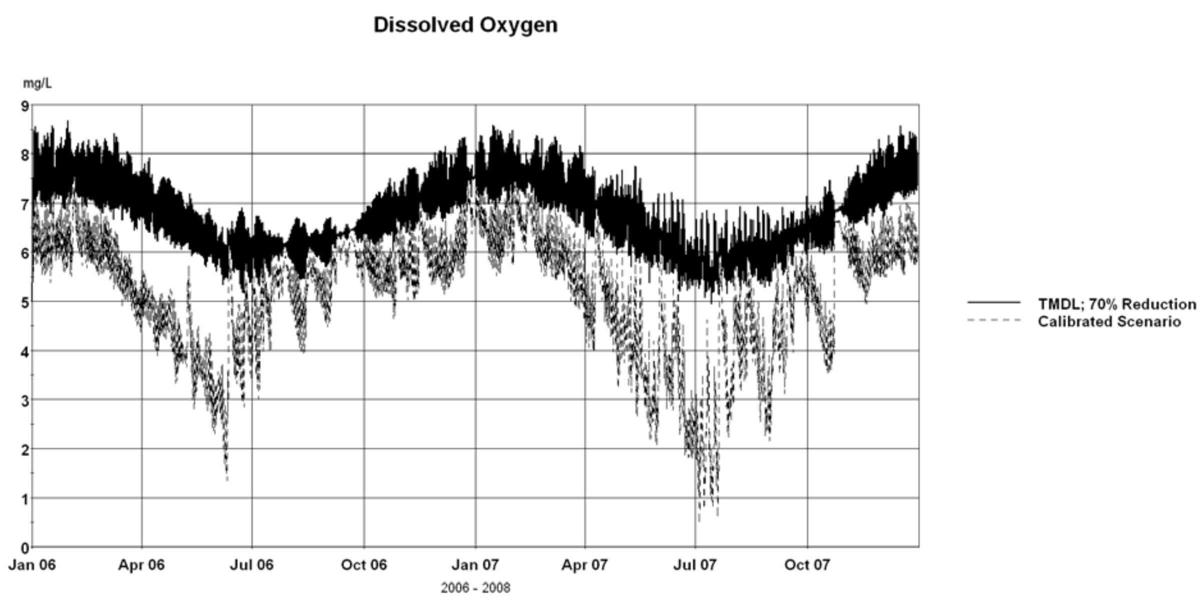

Figure 25: Predicted DO at WASP segment 20 near downstream end of WBID boundary; Calibrated simulation versus TMDL simulation.

5. SUMMARY AND CONCLUSIONS

The Phillippi Creek hydrodynamic DYNHYD model and WASP eutrophication model was developed to represent the water quality in the system, and to calculate the load reductions necessary to attain and maintain the water quality criteria for DO. The model was calibrated to the water surface elevations and observed water quality at several stations in the Phillippi Creek system. Overall, reasonably good calibrations of both the water surface elevations and water quality were achieved.

The calibrated water quality model was used to evaluate load reductions necessary to attain and maintain the DO water quality criterion. A load reduction of 70 percent was necessary to meet this water quality standard. This model result is based on 2006 through 2007 load estimates, so some of the reductions already in place have not been realized in this result. For example, the removal of the South Gate WWTP in 2008 resulted in a reduction of about 32 kg/day (71 lbs/day) BOD, and about 19 kg/day (43 lbs/day) TN, and 6 kg/day (14 lbs/day) TP. Thus, the removal of the South Gate discharge resulted in reductions of approximately 3 percent BOD, 6 percent TN and 7 percent TP from existing conditions.

This mechanistic modeling of the dissolved oxygen and eutrophication processes is based on the available meteorologic data, hydrologic data, stream geometry, water chemistry data and the evidence of low reaeration, high detrital loading, strong photosynthetic activity, and strong SOD. The lack of SOD measurements, reaeration measurements, aquatic macrophyte and periphyton measurements introduces uncertainty into these results. Collection of these additional data will help reduce uncertainty and better assess the contribution of potential sources, the timing of any water quality exceedances, and necessary reductions. Although collection of this data would help reduce uncertainty, it is well known that in lakes and slow moving rivers, or rivers with high levels of organic matter in the bed sediment, SOD can be a major cause of low dissolved oxygen (DO) concentrations in the water column. In addition to calculating the TMDL, another goal is to provide useful information and tools that can aid restoration of water quality. Accordingly, additional conclusions of this project are summarized below.

- Phillippi Creek water quality measurements of the water column show low BOD at near detection limits, relatively low total nitrogen of 1.1 mg/L, and low phytoplankton levels with a mean chlorophyll-a of 2.4 ug/L (see Table 3 of the TMDL Report).
- The largest source of BOD and nutrients is direct runoff as shown in Table 2: Watershed Pollutant Loads from SIMPLE-Monthly (average pounds per month).
- SOD likely causes the most depletion of DO from the water column.
- SOD comes from the break down of organic matter (detritus) and to a lessor extent, ammonia and orthophosphate.
- Additional research is needed to determine whether the organic matter is mostly from in-stream algae, periphyton, and macrophytes, or mostly from plant material in the watershed.
- Once the source of the SOD is determined, a plan to improve water quality can be developed. This plan may include nutrient control and/ or development of site specific DO and nutrient criteria.

6. REFERENCES

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