FINAL REPORT ON

Byram River Watershed Model Development

SUBMITTED TO

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BY

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PUBLIC SUMMARY

The New York State Department of Environmental Conservation (DEC) sponsored this study through a 604(b) grant appropriated from the American Recovery and Reinvestment Act. The Interstate Environmental Commission (IEC) and Columbia University (as a subcontractor to IEC) performed this study, with IEC leading the overall project and monitoring efforts and Columbia University leading the modeling efforts. Additional entities who directly or indirectly contributed to this project include the active participants of Byram Watershed Coalition (BWC) such as Connecticut Department of Energy and Environmental Protection (CTDEEP) and the Township of Greenwich (ToG).

The Byram River watershed is a regional basin located in the southwestern portion of the State of Connecticut and in Westchester County, New York. It is approximately 29 square miles in size and the main stem of the Byram River is approximately 20 miles in length. Stream segmentation includes six segments (BWC, 2011), namely: Upper main stem, East Branch, Converse Pond Brook, Lower main stem, Pemberwick Brook, and the tidal section at the lower end. The upper reaches in North Castle (NY) and Greenwich (CT) are dominated primarily by residential landuse and the lower reaches are more urbanized with mixed landuses and higher density of urban development.

BWC (2011) summarized the land distribution to be about 62% in Greenwich, about 29% in North Castle and the remainder 9% spread between Port Chester, Bedford, New Castle and Rye Brook (NY). Major concerns in the watershed include flooding, streambank and channel erosion, and high levels of pathogens. The nonpoint sources of pollution are also attributed to pollutants such as nutrients, sediment, metals, pesticides, and thermal impact that cause water quality impairments in the main stem and tributaries of the Byram River watershed.

Pathogen impairment is identified as the primary concern, therefore, the BWC (2011) has developed management goals and strategies to quantify pathogen loads from contributing nonpoint sources of pollution such as septic systems and hobby farms. In addition, the Long Island Sound TMDL (NYSDEC and CTDEP {now CTDEEP}, 2000) requires 10% reduction in Total Nitrogen loads from nonpoint sources as part of the Phase III implementation strategy. BWC (2011) also identifies phosphorus as a concerning water quality parameter. With these, the focus of this 604(b) project was to construct and calibrate hydrologic and hydraulic (H&H) and water quality (WQ) models of the watershed in order to quantify the pathogen and nutrient loads. Specifically, the total coliform, fecal coiform, E. coli, and enterococci indicators of pathogens and the total nitrogen and total phosphorus are quantified in this effort.

Subsequent to a review of various public-domain models, the United States Environmental Protection Agency's Storm Water Management Model (EPA SWMM) was chosen for this project. Existing models (developed in Hydrologic Engineering Center's River Analysis System – HEC RAS) of the Byram River watershed from U.S. Army Corps of Engineers and Federal Emergency Management Agency were developed only for the floodplains. Therefore, stream cross-sections were resurrected from these models and imported into EPA SWMM. Additional cross-sections were derived for the East Byram, Converse Pond Brook, Pemberwick segment and the upper main stem floodplains using the digital elevation model (DEM) of the watershed.

Flow data was available at the United States Geological Survey (USGS) gage at Pemberwick Bridge from Fall 2009. Water quality surveys were performed by the IEC during July 2010 and September 2011, therefore, a long-term simulation was performed for the July 1, 2010 through September 30, 2011 period to perform the H&H and WQ model calibrations and baseline flow and pollutant load characterization. The Byram River watershed was very unique that it exhibited distinctly different rainfall-runoff responses in the winter and non-winter periods. Pervious land cover generated large amounts of runoff with significant delays during winter possibly due to frozen or saturated ground or high groundwater conditions. Therefore, the runoff contributing areas were represented differently for the winter and non-winter months in order to achieve robust model calibration.

Rainfall data available at the Westchester County Airport (HPN), Bridgeport (CT) and LaGuardia Airport (NY) were reviewed to explicitly represent the spatial variability in rainfall over the entire watershed. The rainfall played a major role in assessing the adequacy of H&H model calibration. Initial calibration was performed just using the HPN gage data (which is closer to the watershed) and a sensitivity analysis was performed with spatially varying rainfall derived using an inverse-distance-squared method with data from HPN and LaGuardia Airports.

Six water quality (WQ) surveys performed by IEC consisting of three wet weather and three dry weather periods at 10 locations in the watershed were used to support the water quality calibration. The quarterly data compiled by the Department of Health of ToG were reviewed to assess data trends and also to support model calibration and validation. Data from surveys were available for the seven quarterly monitoring locations and some additional data at special survey locations. Assuming that ToG adopted a Quality Assurance Project Protocol (QAPP) developed in accordance with EPA guidelines, the limited data available from ToG surveys were used for calibration and validation, in addition to the six IEC surveys.

Subsequent to calibration, the H&H and WQ models were used to construct the baseline flows and pollutant loads for a 15-month period from July 1, 2010 through September 30, 2011. Although the dataset from 1988-89 was used for calibration and as long-term average data for the region to develop the LIS TMDL, the 2010-11 data represents more recent and conservative (wet years) estimates for flood flows and pollutant loads. Pollutant loads have been developed and summarized in this study on a subcatchment-scale so that the relative contributions of nutrients and pathogens at this scale can be compared by watershed stakeholders to identify areas that contribute larger flows and pollutant loads and prioritize management measures to reduce them.

Three conceptual green infrastructure (GI) scenarios were developed from a review of impervious covers in the watershed, namely, the parking lots, building footprints (reflecting roof areas) and transportation corridors. Reductions of 1.5 inches of rainfall from each of these using stormwater control practices such as porous pavers, rain barrels/gardens or wetlands were conceptualized as three GI scenarios. Each of these GI scenarios was implemented in EPA SWMM to assess the expected reductions in flows and pollutant loads at both subcatchment and watershed scales.

The overall comparison of monitored data and modeled results was deemed adequate to support the characterization of baseline flows and pollutant loads and also for conceptual evaluation of benefits from GI practices. However, a number of areas have been identified that warrant further research and assessment, by BWC or other stakeholders, to refine the H&H and WQ models and improve the accuracy of estimated flows and pollutant loads. These include: (a) working with the United States Geological Survey, obtain official flow data instead of the provisional data that is being reported since inception and the recently released revised data. Official data is still not released by the agency; (b) collection of additional water quality monitoring data on a regular basis during wet and dry weather periods, for example, 3-4 random samples every month for a continuous period of 2-3 years at selected locations; (c) installation of additional rain gages within the watershed to accurately characterize the spatial variations in rainfall; (d) temporary flow monitoring at the tributaries and Byram Lake outfall to characterize flow conditions upstream, instead of approximating using flows measured at the downstream Pemberwick Bridge location; (e) collection of data at hotspots with high levels of pathogen inputs to determine the causes (e.g., illicit discharges and septic systems) and develop remedial strategies. A program similar to that being conducted by Harbor Watch/River Watch in Saugatuck and Norwalk River watersheds would be ideal to conduct investigations and eliminate hotspots; and (f) incorporation of hobby farms data (to be compiled by BWC) and waterfowl data (being compiled by CTDEEP, for example) into the model to assess their relative contributions and develop appropriate management measures.

It must be emphasized that major deviations of flow values in official data from the USGS provisional data used in this study will require recalibration of the hydrology parameters of the Byram River Watershed in the future. However, the model constructed and results developed in this research project are adequate to support watershed planning efforts and can be effectively used by watershed stakeholders in assessing the relative contributions of flows and pollutant loads from various subcatchments and undertaking stormwater management measures to reduce them.

SECTION 1. INTRODUCTION

The DEC sponsored this study through a 604(b) grant appropriated from the American Recovery and Reinvestment Act (ARRA). Primary goal for this study was to develop the hydrologic and hydraulic (H&H) and water quality (WQ) models of the Byram River watershed that will enable DEC and the other stakeholders to identify dominant sources and/or subwatersheds with high nutrient and pathogen contamination and develop management measures to mitigate them. This project was led by IEC including the task on water quality monitoring and the development of models was performed by Columbia University, as a subcontractor to IEC.

The Byram River watershed is located in the southwestern corner of the State of Connecticut, with the upstream and downstream portions lying in the State of New York. The Byram River estuary is on the southwest edge of the regional Saugatuck watershed boundary, and flows into Long Island Sound (LIS). The Hydrologic Unit Code (HUC) is 011-00006. EPA categorizations define the Southwest Western Regional Complex in the Connecticut region with two sub regional basins: Byram River East Branch - 7410 - the Byram River – 7411 – and Southwestern shoreline - 7000. Figure 1 shows the outline of Byram River watershed in the context of its drainage area in New York and Connecticut and also its relationship to the Long Island Sound - LIS. Transition from freshwater to tidal conditions occurs near and downstream of the Route 1 Bridge.

The BWC led by key stakeholders such as CTDEEP, ToG and North Castle (NY) have been collaboratively developing a comprehensive watershed management plan (WMP) to address the pathogen and nutrient contamination issues. A draft WMP was submitted to CTDEEP in October 2011 by BWC along with specific recommendations for additional work including data compilation on septic systems and hobby farms (BWC, 2011).

Major concerns in the watershed include flooding, streambank and channel erosion, and high levels of pathogens. The U.S. Army Corps of Engineers has studied the flooding issues as early as the 1960s and documented the streambank erosion and sediment transport issues. Similarly, pathogenic and habitat impairment has been documented by various agencies in the recent past (BWC, 2011). For example, the Byram River watershed is on both NY and CT states' impaired water body lists (DEC, 2010a; CTDEEP, 2008), which indicates that the water quality conditions are unable to support the designated beneficial uses for this waterbody. The non-point source (NPS) and point source pathogen-related impairments have been documented based on indicator organisms such as E. coli and Enterococci.

A major storm in April 2007 caused extensive flooding in this watershed, so did Hurricane/ Tropical Storm Irene in September 2011. Port Chester Harbor at the downstream end of Byram River is designated as impaired to support shellfish harvesting and the upper reaches are impaired to support contact recreation. In addition, Phase III of Long Island Sound Total Maximum Daily Load (DEC and CTDEEP, 2000) requires a 10% reduction in total nitrogen contributions from nonpoint sources of pollution. Also, BWC (2011) identifies phosphorus as a pollutant of concern. With these, the primary parameters focused in this study include: Flows, Total Nitrogen (TN), Total Phosphorus (TP), Fecal Colifocms (FC), Eschericha Coli (EC) and Enterococci (ENT).

The primary goal of this project is to develop H&H and WQ models of the Byram River watershed based on flow monitoring data from the United States Geological Survey (USGS) at the Pemberwick Bridge gage location and WQ data collected by IEC in this study. Columbia University being the research institution, participated in the following tasks as part of the modeling effort: (a) provide support to IEC in the identification of WQ monitoring locations; (b) develop a QAPP for the watershed modeling effort; (c) review the IEC data as well as the data being compiled by other agencies such as ToG to understand watershed characteristics; (d) construct, calibrate and validate the H&H and WQ models of the watershed; (e) apply the model(s) to generate baseline flows and pollutant loads for a long-term period (say, 1 year); and (f) evaluate conceptually the estimated reductions in flows and pollutant loads for three green infrastructure (GI) implementation scenarios on a watershed-wide basis. The overall outcome is to provide analytical results to the DEC and other watershed stakeholders for interpretation and decision making pertinent to the development and implementation of specific management measures to achieve peak/volumetric flow and pollutant load reductions.

This research report is organized as follows. The following section provides an overview of data compiled from various sources and interpretations developed from analyses of these datasets. Subsequently a brief description of the selected modeling framework is provided, followed by the details on model construction, calibration and verification in Section 4. Baseline flows and pollutant loads for a 15-month period are developed and summarized on a subcatchment scale in Section 5. Comparative analysis of pollutant loads can be performed by various watershed stakeholders to identify subwatersheds that contribute larger loads so as to prioritize them for implementation of stormwater controls and other management measures such as septic systems management and reductions in contamination from waterfowl, hobby farms and pets. Conceptual implementation of GI scenarios and associated benefits are discussed in Section 6. Discussions on results and recommendations for additional work to improve watershed characterization are provided in the final section, followed by a list of relevant reference material. Due to the large number of figures and tables with different orientation layouts, the figures and tables are organized subsequent to the references section. Appendix A includes in a tabular format the data compiled by IEC during the course of this project and a GIS figure of the ten monitoring locations within the watershed. Appendix B shows the trend analysis performed on water quality data obtained from ToG. Finally, the Appendix C includes comparison of modeled water quality concentrations with monitored data available from quarterly and special surveys conducted by ToG.

SECTION 2: DATA COMPILATION AND ANALYSIS

In the past, several municipal and federal government agencies have performed flooding and water quality-oriented studies in this watershed and have compiled H&H and WQ data as part of their efforts. During the course of this project, discussions were held with various agencies to compile the available information and assess their data adequacy and quality and extent of modeling analysis to gather background information and tools for this project. The goal was to build on existing data and model(s) to support model calibration and validation here. These sources are summarized below, along with the specifics on available data.

USGS Flow Data at Pemberwick Bridge

The USGS has long-established guidelines for gauging stream and river flows. Annual hydrological data reports are prepared in cooperation with the individual States. The USGS is under the jurisdiction of US Department of the Interior.

In association with ToG, the USGS has setup a flow gage at Pemberwick Bridge. Real-time data at 15 to 60-minute intervals are available at this location. Columbia University researchers reviewed the information to confirm that it was complete and adhered to USGS policy and established guidelines. It must be noted that USGS releases real-time data as provisional and publishes the official data after quality control. At this gage however, only the provisional data has been published since its operation in late 2009. We contacted the USGS regarding the official data and had not received them to date. A corrected (revised) version of database was provided within the last week but the USGS indicated that the official dataset would be released later.

NOAA National Climatic Data Center (NCDC) Data

The NOAA National Climatic Data Center (NCDC) has long established guidelines for measuring precipitation and has supervision for quality assurance. The NCDC is under the jurisdiction of the National Oceanic and Atmospheric Administration (NOAA) in the U.S. Department of Commerce. The NCDC has long standing quality control procedures and reports a wide range of climatologic data in a variety of electronic and hard copy formats.

For this project, the ToG provided daily totals of rainfall measured at Bridgeport (CT). We compiled the 15-minute data available at Westchester County Airport (HPN) and 60-minute data available at LaGuardia Airport (LGA) for the period from September 2009 through September 2011.

Additional unofficial data at 5-10 minute intervals were available from NOAA at selected locations such as Danbury (CT) and Yorktown Heights (NY). The site descriptions cautioned that the data were unofficial and were not quality-checked by NOAA. Therefore, these datasets were not compiled.

IEC Water Quality Data

As part of this 604(b) project, the IEC developed a QAPP and obtained approval from DEC to use for the monitoring effort. Various water quality parameters were compiled at 10 locations, identified in the QAPP as BR1 through BR10, during six surveys conducted in 2010 and 2011. A summary of these surveys is shown below. These data were primarily used to support model calibration in this project. A map of the locations of monitoring stations within the Byram River watershed and a table of water quality data from six wet and dry weather surveys are provided in Appendix A.

Survey Date	**Wet (W)/Dry (D)**	**Rainfall during the day of sampling/in the previous 24-hours (inches)**
7/6/2010	D	0.00
7/19/2010	W	0.88
8/3/2010	D	0.00
8/16/2010	W	0.53
9/8/2011	W	2.90
9/20/2011	D	0.00

ToG Water Quality Data

The Department of Health of ToG has been compiling water quality data at seven locations within the Township on a quarterly basis. In addition, special surveys are being conducted at reduced frequencies at 14 locations (some of these coincide with or very adjacent to the seven quarterly survey locations). We requested this dataset through BWC and obtained them for the period from 2005 through May 2011 (personal communications with Michael Long of ToG).

Rainfall and water quality data compiled from ToG were used to assess the baseline water quality conditions in Byram River reaches within ToG. Appendix B shows the time-series charts for various water quality parameters including dissolved oxygen (DO), FC, EC and ENT at the 15 locations. The overall assessment was that the DO levels rarely dipped below 4 milligrams per liter (mg/l) threshold at all the 7 quarterly survey locations and 14 special survey locations within ToG. On the other hand, the pathogen concentrations even during dry weather were above the monthly geometric mean standards of 200 coliform fecal units (CFU) per 100 milliliter (ml) for FC and 126 for EC. It must be noted that there were not adequate number of samples within a calendar month to truly compare the monthly geometric means with the respective water quality standards.

Concurrent with the IEC monitoring period and the duration of this calibration effort, three quarterly survey datasets at seven locations within ToG (designated as BR01 through BR07) and two special surveys at 14 locations (designated as SBR01 through SBR15, excluding SBR07) could support the calibration process pursued in this project. These are primarily dry weather surveys (QUARTERLY: 7/26/2010 with no rainfall; 10/27/2010 with 0.31" during the day; 4/11/2011 with no rainfall; SPECIAL: 11/30/2010 with 0.09" during the day and 3/9/2011 with no rainfall). Considering that there were only six water quality surveys performed during the course of this 604(b) study, we looked into the potential for using ToG data as additional information available to support model calibration/validation. It was assumed that the ToG had developed a QAPP in accordance with EPA approvable procedures/protocols and the datasets for three quarterly surveys and two special surveys compiled during the calibration/validation period of July 2010-September 2011 were reviewed and used in this project.

Physical Watershed Data

The physical attributes of the Byram River Watershed were compiled from publicly available sources and from ToG through a special request to BWC. For the towns in Westchester County, namely, North Castle, Port Chester, New Castle, Bedford, and Rye Brook, the geographical dataset from Westchester County geographical information system (GIS) repository was the only source that we reviewed and utilized (http://giswww.westchestergov.com/wcgis/Data.htm, accessed in August 2010). For the Connecticut portion (ToG), the GIS data from University of Connecticut's CLEAR was the primary source (http://magic.lib.uconn.edu/, accessed in August 2010). In addition, we requested through BWC and obtained landuse/landcover and digital elevation datasets from ToG (personal communications with Joseph Cassone of ToG, 2010). Figure 2 shows the distribution of landuses within the watershed. Landuse categories used by Westchester County and ToG are different, therefore, both categories are shown separately in this figure. Some landuse categories were clustered during the development of model parameters appropriate for specific landuse categories.

In addition, the flooding study performed by FEMA was reviewed to obtain the stream cross-section dataset. ToG has been conducting a parallel flooding study (personal communications with Amy Siebert and Denise Savageau) to identify flood mitigation projects and had expanded or revised the cross-section information within the Township. We obtained both datasets from ToG and reviewed to assess their adequacy for H&H modeling envisioned in this project. Only the main stem of Byram River was characterized in both FEMA and ToG studies with upper portions of Byram River and the entire East Byram and Converse Pond Brook had no available cross-section data. Effort performed to manually compile this information from the digital elevation model (DEM) of the watershed is discussed in Section 4.

SECTION 3. DESCRIPTION OF SELECTED MODEL

As outlined in the modeling QAPP, the United States Environmental Protection Agency's Storm Water Management Model (EPA SWMM) was chosen due to its appropriateness for urban and suburban landscapes and availability in the public domain (http://www.epa.gov/nrmrl/wswrd/wq/models/swmm/, accessed in July 2010). This model has both water quantity and quality characterization features that enable its application for flooding and water quality impairment studies.

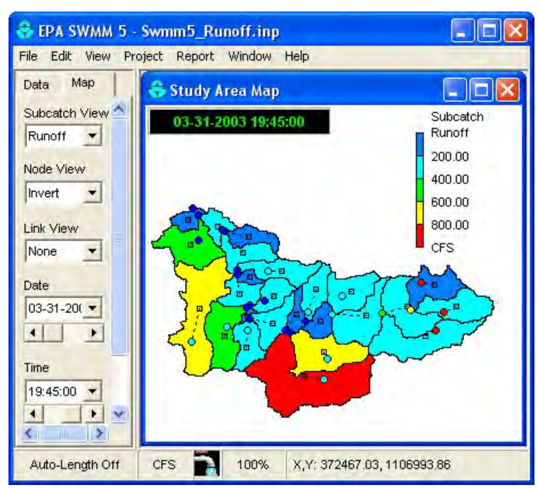
The EPA SWMM model has evolved since early 1970s and is being used extensively throughout the world. The following are components of this model (often referred to as building blocks) that are used sequentially based on modeler's specific objectives and expertise.

Runoff Block – This module computes the amount of overland runoff from individual drainage areas in response to rainfall events. Generally, a runoff area would be a small urban/ suburban drainage area called a subcatchment. In its detailed form, a subcatchment can represent the pervious and impervious areas of a residential lot, i.e., a small parcel within a watershed. In urban areas, the presence of stormwater pipes and catchbasins can significantly influence the time of concentration, i.e., the time it takes for a water drop to reach from the farthest point in a subcatchment to an underground drainage pipe. In a lumped form, when information on the underground drainage system is unavailable, the subcatchments can be in the order of tens of hundreds of acres delineated based on ground slopes. Detailed stormwater pipes for all municipalities within this watershed were unavailable to support sewer-layout based delineations. Therefore, a lumped approach was used to characterize the drainage areas. The Runoff block accounts for the following processes:

- Hydrologic losses such as the depression storage, infiltration, and evaporation/ transpiration that affect the overall volume of runoff generated;

- Surface features such as imperviousness, slope and roughness, curbs and gutters that affect the sheet flow pattern of runoff; and

- Controls such as catch basins that can limit the amount of flow from catchments entering a sewer system



These processes influence the volume of runoff generated, peak runoff rate and duration of the hydrograph resulting from a rain event at the smallest geographic extent (subcatchment) defined in the model. In essence, this module converts rainfall to surface runoff that enters a sewer system or stream network. The physical characteristics of a subcatchment derived from the appropriate GIS datasets include: area, overland flow width, average slope, extent of imperviousness, Manning's roughness factor for overland flow surface, infiltration parameters and any surface storage. Pollutographs can be simulated in this block based on surface accumulation and washoff of pollutants in urban areas, accounting for antecedent dry periods and any management practices such as street cleaning. A non-linear reservoir formulation is used to derive flows and route through the subcatchment (overland) using an equivalent Manning's formulation. Infiltration losses can be estimated using the Horton or Green-Ampt equation. Green-Ampt formulation was used in this study.

Transport Block – This module accepts runoff flows (from the Runoff block) at individual manholes of a storm sewer. Flows are then routed through the sewer system using kinematic wave equation. Flows in excess of the pipe/channel capacity are simply not transferred through the downstream pipes/channel, but are stored in the immediate upstream junction and released once capacities become available in the downstream pipes/channels. This module does not calculate hydraulic grade-lines (water surface elevations) or account for backwater curves or surcharging within the hydraulic network. Simple controls such as flow splits can be included in this module, provided that there is information available on the flow diversion capacity. Due to its limitations for characterizing the dynamic routing of flood flows through stream cross-sections, this block was not utilized.

Extended Transport (EXTRAN) Block – This module improves the Transport block in that actual pipe hydraulics equations (full Saint Venant's) are included so that the backwater curves, water surface elevations, storm sewer surcharging, and tidal effects if applicable can be assessed at the desired spatial and temporal scales. EPA SWMM has undergone 35+ years of development and 100s of applications around the world to characterize dynamic flow and pollutant transport conditions in sewers and waterways.

One limitation with EPA SWMM is its lack of direct GIS connectivity and interfacing. Most commercial equivalent model vendors charge in excess of $10,000 to $50,000 based on their advantages such as direct GIS integration and pre or post-processing utilities. It should be noted that the public domain version of EPA SWMM has a broader user database and support from academic community. Once the GIS databases are processed externally, it is easier to work with EPA SWMM on the import of data into Microsoft Excel (for example) and use for simulation.

Liong et al. (1991) subdivided the calibration parameters of SWMM runoff block into traditional (includes Manning's roughness, depression storage, infiltration) and non-traditional (those obtained from monitoring data or interpretation of available information) groups. The non-traditional group included overland flow width, average slope and imperviousness. Some of these can be accurately characterized at finer spatial scale (e.g., a residential lot) but can have larger variations when lumped at the level of tens of hundreds of acres of drainage area. In addition, there is inherent variability in these non-traditional parameters due to estimation accuracy. For example, it is difficult to quantify the fraction of impervious area directly connected to sewer pipes/drainage channels unless a finer level of characterization (e.g., residential lot) is performed and field verified using flow monitoring data collected at smaller scales such as 10-25 acres. Similarly, the impervious covers interpreted from aerial imagery can have approximations related to impervious patches under urban forestry.

Based on USGS flow data being available only at a downstream location and not on a tributary scale, the calibration metrics set forth for this project included:

- Flow Hydrographs: Peak flows within +/-30% of the measured flows for storm events. Seasonal variation in baseflows will be represented with monthly average flows;

- Flow Hydrographs: Volume of flow for storm events to be within +/- 25% of measured flow volumes;

- Pollutographs: With the six IEC events (three dry weather and three wet weather) and approximately three ToG events being used, a time-series comparison of long-term water quality simulation with measured point values shown to assess the capturing of data trends.

Specific calibration parameters for hydrology included: overland flow width, directly connected impervious area and Green-Ampt infiltration parameters. For hydraulic calibration, only the channel and floodplain roughness values were considered for minor adjustments to achieve a better time-to-peak comparison at the Pemberwick Bridge location.

SECTION 4. MODEL CONSTRUCTION, CALIBRATION AND VALIDATION

Model Construction

The entire Byram River and its tributary watersheds were divided into smaller sub-watersheds. The sub-regional and local basin (sub-watershed) delineations developed by UCONN (http://cteco.uconn.edu/guides/Local_Basin.htm, accessed in July 2010) were adopted as the starting point. Some sub-watersheds along the main stem of Byram River were rather large. Additional subcatchments (smaller drainage areas or sub-watersheds) were created based on watershed topography. Figure 3 shows the 82 subcatchments being used to support the watershed characterization in this study.

With long-term flow data available at the Pemberwick Bridge gage from late 2009 and the two IEC monitoring periods being in the summers of 2010 and 2011, a 15-month period starting from July 1, 2010 through September 30, 2011 was chosen for H&H calibration. Rainfall data at HPN and LGA gages were used since those had verified data from NOAA at 15-60 minute intervals. HPN, being the closest gage, was used as stand-alone dataset and a sensitivity analysis was performed with HPN and LGA together applied on individual subcatchments using a quadrant (inverse-distance-square) methodology.

The ToG model's stream cross-sections were adopted for the main stem of Byram River within the township. Similarly, the FEMA model for downstream reaches in Port Chester was used to obtain stream cross-sections in that region. For all upstream reaches with no cross-section data from ToG or FEMA, the watershed topography (DEM) data was used to develop approximate cross-sections for the floodplain and cross-sections were assumed as triangular or trapezoidal for the primary channel below the waterlines present in the DEM dataset. An example cross-section derived from DEM for the East Branch of Byram River is shown in Figure 4.

Available datasets from Natural Resources Conservation Services (NRCS) on hydraulic conductivity of the soil, capillary suction and saturated moisture content were reviewed and literature values (Rawls et al., 1983) were supplemented to develop Green-Ampt infiltration parameters. Distribution of different hydrological soil groups within each subcatchment was used to develop area-weighted Green-Ampt model parameters.

Monthly variation in evaporation rates were developed for inclusion as model inputs. Overland flow widths were derived by assuming each subcatchment area to be square and by taking the square root of the area to obtain the width. The widths were then adjusted during calibration to reproduce the recession limbs of the runoff hydrographs.

For water quality characterization, various literature on the application of EPA SWMM to watershed management or TMDL development were reviewed (e.g., EPA, 1983; Caraco, 2001; Pitt et al., 2004a and 2004b; Bailey, 2005; Gautam et al., 2006; CWP, 2007; FDOT, 2007; MADEP and EPA, 2007; Evans et al., 2007; Stein et al., 2007; CWP, 2008; and Cambez et al., 2008). Event mean concentrations (EMCs) were derived for TN, TP, TC, FC, EC and ENT based on available information from this literature compilation and applied in the EPA SWMM model as initial values. Table 1 shows a summary of EMCs compiled from literature for the various water quality parameters.

Calibration and Validation

The H&H model calibration was initiated with the use of impervious covers for each subcatchment derived from GIS datasets for CT and NY and comparison for the entire period from July 1, 2010 through September 30, 2011. Peak flows from summer 2010 were represented well, however, the peak flows for winter 2011 and volumes of wet weather events for the entire summer 2010 through April 2011 were much lower than monitored data. Seasonal variations in baseflows could be seen, therefore, monthly average values were derived based on flows observed during days (within each month) with no rainfall in the preceding 24-48 hours. Data comparisons clearly exhibited excessive interflow (flow that persisted for 1-2 days after each rain event, which was more prominent in winter than non-winter periods) and delayed interflow (flow that persisted for 3-days or longer after rain events, particularly during the winter time). Therefore, the calibration was refined through an iterative process with the following three-surface approach.

This three-surface process is analogous to the modeling of inflow and infiltration in sanitary sewer systems where the immediate inflow is represented with a separate runoff surface in the model and the delayed infiltration can be represented with two additional runoff surfaces with longer times of concentration. Superposition of runoff responses from these three surfaces will effectively characterize the immediate inflow and delayed infiltration. Similarly, three surfaces were introduced to characterize the delayed flow components contributing runoff to the watershed. As example, the USEPA's SSOAP tool (http://www.epa.gov/nrmrl/wswrd/wq/models/ssoap/, accessed in March 2011) describes a three-triangular unit hydrograph methodology with the use of three different runoff surfaces to simulate the rainfall-derived inflow and infiltration components.

Surface 1: Percent imperviousness from GIS was used with total subcatchment area to compute the runoff producing area. This fraction was included with 100% imperviousness, so that this area will produce an immediate runoff response;

Surfaces 2 and 3: Remainder of the subcatchment area was divided into two additional runoff surfaces. Surfaces 2 and 3 together were represented as pervious area for the non-winter periods (May 1 through November 30). Surface 2 was represented for the winter months as impervious area with reduced subcatchment widths and increased Manning's roughness to match the initial interflow (seen in the first 1-2 days after rain events). Similarly, the Surface 3 was represented as a combination of pervious and impervious areas, with further reductions in overland flow widths, to reproduce the delayed interflow component that persisted for 3+ days beyond a rainfall event.

It must be noted that the addition of drainage areas corresponding to Surfaces 1 through 3 will yield the total subcatchment area. In typical urban and suburban watersheds, the SWMM model will have an impervious cover and the remainder will act as pervious cover to contribute runoff. The impervious cover will generate runoff after meeting the evaporation and depression storage losses, and the pervious cover will generate runoff after meeting the evaporation, infiltration and depression storage losses. Runoff values produced by the three surfaces are internally accumulated by the model to produce time-series output of the total runoff at the end point of each subcatchment. Flows are then routed through defined cross-sections in the Extran block to produce stream runoff responses in the downstream stream sections. The stream cross-section corresponding to the Pemberwick Bridge was chosen for comparison of the modeled and monitored flows during calibration.

Model calibration is accomplished through a subjective trial-and-error adjustment of model input data because a large number of interrelated factors influence model output. Model calibration "goodness of fit" measures can be either qualitative or quantitative. The following analyses were performed to check model adequacy:

- Graphical time-series plots of observed and predicted data: This is a qualitative metric that compares the trends between observed and predicted values to see if there is similarity in terms of time-to-peak, peak flow and recession curves. Figures 5 through 7 show the time-series comparison of flow rates at the Pemberwick Bridge gage for the three 5-month periods: July-November 2010 (non-winter), December 2010-April 2011 (winter), and May-September 2011 (non-winter).

- Comparison between observed and calculated probability distributions: Modeled flow rates (hourly averages) were compared with monitored data at the Pemberwick Bridge gage for the entire 15-month period as shown in Figure 8. This is also a qualitative metric since the trends are compared to see if the modeled values correlate well with monitored data.

- Relative error between model predictions and observations: This is a quantitative metric defined as the ratio of the absolute mean error to the mean of the observations and is expressed as a percent. A relative error of zero is ideal. Several metrics are available in statistical literature to quantify relative error and one of the common ones used in hydrological time-series comparison is the Nash-Sutcliffe statistical measure recommended by ASCE (1993). With the Nash-Sutcliffe measure, an R^2 coefficient is calculated using the equation:

$$R^2 = 1 - \frac{\sum (Q_o - Q_p)^2}{\sum (Q_o - Q_a)^2}$$

where: Q_o is the observed value

Q_p is the predicted value

Q_a is the average of the observed values.

Coefficient (R^2) values equal to 1 indicate a perfect fit between observed and predicted data, and R^2 values equal to 0 indicate that the model is predicting no better than using the average of the observed data. Therefore, any positive value above 0 suggests that the model has some utility, with higher values indicating better model performance. For the 15-month calibration and validation period, the average flow was computed and the relative errors were quantified in an Excel spreadsheet. The Nash-Sutcliffe R^2 value was estimated to be 0.57 for this calibrated dataset.

Based on the qualitative and quantitative methods used for comparison (as seen in Figures 5 through 8 and evidenced by a positive Nash-Sutcliffe statistical measure), the modeled flows were assessed to correlate well with monitored flows overall. In the July 2010 to April 2011 periods, the model slightly over-predicted the peak flows but the volumes were comparable. Two large storms in Spring 2011 that produced flows in excess of 2,500 cubic feet per second were well captured by the model, although the modeled peak flows were a bit lower. The model appeared to under-predict peak flows in Summer 2011 but those flow ranges were much smaller in comparison to the flood flows. In general, the predictions were observed to be on either side of a 45-degree scatterplot for the entire 15-month period. Two considerations for improvement will be to obtain official flow records from the USGS to ensure that there were no systematic inaccuracies in the monitored data, and also to represent the spatial variability in rainfall that could explain these variations. As mentioned earlier, no official data from USGS was made available to date for the Pemberwick Bridge gage, although a corrected dataset was distributed in mid January 2012. It should be noted that the official data, if revised significantly, will require recalibration of hydrologic parameters in the future to accurately characterize the watershed responses. However, the results developed in this study can be used effectively by watershed stakeholders to assess the relative contributions of flows and pollutant loads from contributing subcatchments and develop stormwater management measures and implementation mechanisms to reduce them.

As sensitivity analysis to enhance confidence on model calibration, the spatial variability in rainfall was explicitly incorporated to assess whether the correlation between modeled and monitored values improved. The HPN and LGA rainfall records were processed using a quadrant (inverse-distance-square) method to generate subcatchment-specific rainfall hyetographs (82 different time-series inputs for rainfall). This sensitivity resulted in improvements for some rain events and further deviations from monitored data in some other rain events. It was primarily due to the fact that LGA was on the other side of East River, quite far from the Byram River watershed. It was probably not a representative gage for this watershed. On the other hand, it was the only other official NOAA gage with continuous records that was amenable to performing this sensitivity analysis. Our conclusion from this sensitivity analysis was that additional raingages would need to be installed within the watershed to capture spatial variability, particularly for future applications such as predicting the potential for flash flooding during spring and early fall seasons.

For the water quality model, two dry weather and two wet weather events from Summer 2010 were used as calibration events. By definition of calibration, these events were used to guide the tuning of model calibration parameters to get good-fit between monitored and modeled data points. One wet and one dry weather event from September 2011 were used to support model validation. Validation, by definition, was performed without adjusting the calibrated model parameters and seeing how the model predicted responses for these two additional independent (those not used for calibration) events in terms of the goodness-of-fit.

Table 2 shows the final EMCs subsequent to water quality calibration, for all the water quality parameters. Figures 9 through 28 show the time-series comparisons for TN, TP, TC, FC, EC and ENT at the 10 IEC monitoring stations. It must be emphasized that the six dry and wet weather survey data (six snap shots of data) at each location are being compared with continuous time-series data predicted by the model at 15-minute intervals. Therefore, it is difficult to quantify the correlation using statistical metrics such as R-square value. Visual comparison of modeled and monitored values were made during the six specific events and a determination was made as to whether both monitored and modeled values showed increasing trend during rainy periods or stayed comparably lower during dry weather periods (baseflow conditions).

Similar comparisons are shown in Appendix C for the quarterly and special survey locations within the freshwater portion of the Byram River watershed. Based on these visual comparisons for all the 10 IEC locations and quarterly/special survey stations of ToG, the model results appeared to correlate well with monitored data.

Based on a comparison of flow data at Pemberwick Bridge USGS gaging location and water quality data at the IEC/ToG stations, the H&H and WQ models were deemed to be calibrated and validated adequately and were ready for application to generate baseline flows and pollutant loads for the six water quality parameters of concern.

SECTION 5: BASELINE FLOWS AND POLLUTANT LOADS

Long-term simulations were performed with the final calibrated model parameters for the period from July 1, 2010 through September 30, 2011. Flows are among the major watershed concerns pertinent to flooding, streambank and channel erosion, and habitat health. This long-term simulation period is same as the period used to support model calibration/validation. Therefore, the overall flow responses discussed in Section 4 are equally applicable to the baseline flow simulation. Flows simulated for each of the 82 subcatchments are provided in Table 3 in acre-feet units. Imperviousness is the primary driver for generation of runoff for each subcatchment. The volumes of runoff summarized in Table 3 correlate well with their corresponding percent imperviousness values. BWC (2011), for example, recommended the reduction of impervious covers in the watershed as the primary means to reduce runoff and associated pollutant loads.

The WQ model was used with the calibrated EMCs to calculate pollutant loads for the 15-month period. Table 3 shows the estimated TN, TP, TC, FC, EC and ENT loads for this period generated from each of the 82 subcatchments. This table does not include loading from point sources (wastewater treatment plants) or dry weather sources such as illicit connections, failed septic systems, and waterfowl/wildlife.

A correlogram was developed to show the relationship between impervious cover and TN/TP loads from all 82 subcatchments. As can be seen in Figure 29, there is direct correlation between these two, indicating that higher impervious covers with larger runoff volumes do contribute to higher nutrient loads into the waterways. At the same time, the less urbanized areas can also contribute significant loads due to improperly functioning septic systems and the presence of hobby farms based on characterizations performed in the nearby watersheds (e.g., NRWIC, 2011; Fuss & O'Neill, 2009). It is important to note that BWC (2011) has identified two recommendations for near-term evaluation in the Byram River watershed and is seeking funding mechanisms to pursue them. These recommendations include septic systems inventory and review of operation and maintenance aspects and the inventory of hobby farms to assess their waste management practices.

SECTION 6: ESTIMATED LOAD REDUCTIONS

A range of management measures can be used to reduce pathogen and nutrient loads into the Byram River main stem and its tributaries. In the absence of specific data on septic systems operations and maintenance (and the associated impacts to result in hotspots with elevated pathogen concentrations), hobby farms, illicit discharges into storm sewers, and waterfowl/wildlife, the analysis here focused only on reducing urban stormwater contributions and associated reductions in pollutant loads. Increase in impervious cover is also attributed to benthic impacts in this watershed. Therefore, BWC (2011) has recommended the reductions in impervious cover as one of the major management measures to improve water quality. With these, our evaluation focused on conceptual implementation of green infrastructure (GI) practices and estimation of consequent potential benefits. The three GI scenarios are described below.

GI-1: All residential, commercial, industrial, institutional and government buildings have sloped or flat roofs that contribute to watershed imperviousness. Control of runoff from these impervious surfaces can be undertaken through diversion to a storage cistern or rain barrel for potential reuse, or diversion to rain gardens or bioretention units or grass swales to infiltrate. This scenario assumes that these types of controls can be implemented to capture up to 1.5 inch of rain volumes falling on these surfaces. For each subcatchment, out of the total impervious area, the fraction of parking lot imperviousness was determined and the depression storage was increased on an area-weighted basis to incorporate the 1.5 inches of rain capture. In essence, this scenario represents 1.5 inches of rainfall capture from portions of the impervious cover occupied by roofs (flat/sloped) in each of the subcatchments.

GI-2: With the presence of I-95, Merritt Parkway and other municipal road network, the transportation corridor in Byram River watershed is a major contributor to imperviousness and also the associated pollutant loads. Control of runoff from these impervious surfaces can be undertaken through diversion to grass swales and curbside bioretention units for infiltration and also to wetlands/wetponds for treatment and infiltration. This scenario assumes that these types of controls can be implemented to capture up to 1.5-inch of rain volumes falling on these surfaces and incorporated in the model as increased depression storage, similar to the scenario

GI-1.

GI-3: Both urban and suburban portions of the Byram River watershed have a lot of public and private parking lots. Control of runoff from these impervious surfaces can be undertaken through underground storage chambers, or diversion to a storage cistern for potential reuse, or porous pavers with infiltration media underneath. This scenario assumes that these types of controls can be implemented to capture up to 1.5-inch of rain volumes falling on these surfaces. The procedure for implementation in the model is similar to the scenarios GI-1 and GI-2.

Expected performance efficiencies to reduce pathogen and nutrient loads were used to reduce the EMCs for runoff volumes leaving these control practices. Table 4 shows the pollutant loads for the three GI scenarios and the percentage reductions in comparison to the baseline scenario. As seen in Table 2, the EMCs are landuse dependent and when the runoff is reduced from certain urban landuses, associated reductions in pollutant loads are realized. Flow and pollutant load reductions are shown in Table 4 on a watershed-scale.

It must be noted that the impervious cover reductions resulting from individual GI scenario implementations reduce the runoff and the EMCs have been applied in this model application to the remainder of runoff to calculate the overall pollutant loading, which has been summarized on a watershed-wide basis in Table 4. Specific practices being targeted for various types of impervious covers can be developed during the development of a watershed management plan and available literature on reduction efficiencies for those practices (best management and low impact development) can then be applied on the treated runoff to refine the expected load reductions.

SECTION 7: CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE WORK

Based on available physiographic datasets and flow/water quality monitoring data in the Byram River watershed, comprehensive H&H and WQ models have been constructed, calibrated and validated. This work built off of the floodplain characterization performed by FEMA and ToG, however, the selection and application of EPA SWMM model allows the DEC, CTDEEP, BWC, ToG and other stakeholders to characterize the watershed responses to various storm events and also evaluate the potential benefits from stormwater control practices in upland areas.

The overall comparison of monitored data and modeled results was deemed adequate to support the characterization of baseline flows and pollutant loads and also for conceptual evaluation of benefits from GI practices. However, a number of areas for additional research and assessment, by BWC or other stakeholders, have been identified to refine the H&H and WQ models and improve the accuracy of estimated flows and pollutant loads. These include: (a) working with the United States Geological Survey, obtain official flow data instead of the provisional data that is being collected since inception; (b) collection of additional water quality monitoring data on a regular basis during wet and dry weather periods, for example, 3-4 random samples every month for a continuous period of 2-3 years at selected locations; (c) installation of additional rain gages within the watershed to accurately characterize the spatial variations in rainfall; and (d) temporary flow monitoring at the tributaries and Byram Lake outfall to characterize flow conditions upstream, instead of approximating using flows measured at the downstream Pemberwick Bridge location.

The model developed and results generated in this study can be effectively used by watershed stakeholders to conceptualize stormwater control measures to reduce flows and pollutant loads. When resources become available to develop additional water quality monitoring data and if the official data from USGS is quite deviant from the provisional data used in this study, further model calibration will be necessary in the future to refine the flow and pollutant load estimates.

<u>Discussions on Pollution Sources and Need for Additional Monitoring</u>

Stormwater discharges are often the primary sources of pathogens in urban and suburban landscapes (NRC, 2008; EPA, 2010) such as those in the Byram River watershed. A number of factors including illicit connections, failing septic systems, waterfowl/wildlife, and pet wastes contribute to pathogen pollution. Similarly, these sources along with atmospheric deposition and inadequate treatment at treatment plants can elevate nutrient levels. Stormwater control practices can be undertaken at site, neighborhood and regional scales based on the guidance provided by DEC (2010) and CTDEEP (2004). EPA (2008) also provides a wide menu of best management practices and low impact development practices aimed at water quantity control and water quality improvement.

Mullaney et al. (2002) reported that significant amounts of nitrogen continue to reach the LIS through groundwater sources. Nutrients infiltrating into the groundwater reappears in streams as base loads and Mullaney (2006) estimates the groundwater residence times can range from two to more than 50 years. Long residence times essentially move nutrients through the watershed slowly and present a long-term source of pollution loads into the LIS even when controlled from other sources with appropriate management practices.

Similarly, the leach field/drain field component of septic systems is designed to infiltrate the effluent that contains dissolved nutrients. This pollutant load reaches groundwater and emerges as part of baseflows into the streams. For controlling pollutants from stormwater, combinations of infiltration and treatment-based practices are undertaken. These also contribute to groundwater contamination. Treatment-based practices can be promoted to reduce the inputs into groundwater.

Failing septic systems and illicit connection of sanitary sewers into storm sewers are common problems that can exhibit elevated levels of pathogens and nutrient loads into the waterways. Targeted monitoring efforts such as those pursued by Harbor Watch/River Watch in the Saugatuck and Norwalk River watersheds can be pursued by BWC stakeholders to identify and rectify these issues. CWP (2004) provides a systematic way of identifying illicit connections and correcting them.

In terms of point sources in the Byram River watershed (personal communications with Jack Stocker of BWC), there is one municipal wastewater treatment plant in North Castle that discharges treated effluent into the river. Sewer District #2 is located in the downtown Armonk area that has a wastewater treatment plant with upgraded plant capacity of 0.45 million gallons per day. Typical flow is about 0.36 million gallons per day and the plant is equipped with rotating biological contactor treatment year-round for nitrogen removals.

Atmospheric deposition and lawn fertilizer application are additional sources of nutrient pollution. Transportation corridors can be targeted for pollutant quantification and treatment with management practices (FHA, 2010; NCHRP, 2006) in the right of ways to reduce pollutant loads for various water quality parameters including nutrients, sediments, hydrocarbons, and metals.

Pet/wildlife/waterfowl can contribute pathogen and nutrient loads at local scales where their populations are concentrated. Localized monitoring efforts are needed to quantify these loads and develop appropriate management measures.

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FIGURES

Figure 1: Byram River Watershed – Main Stem and Tributaries

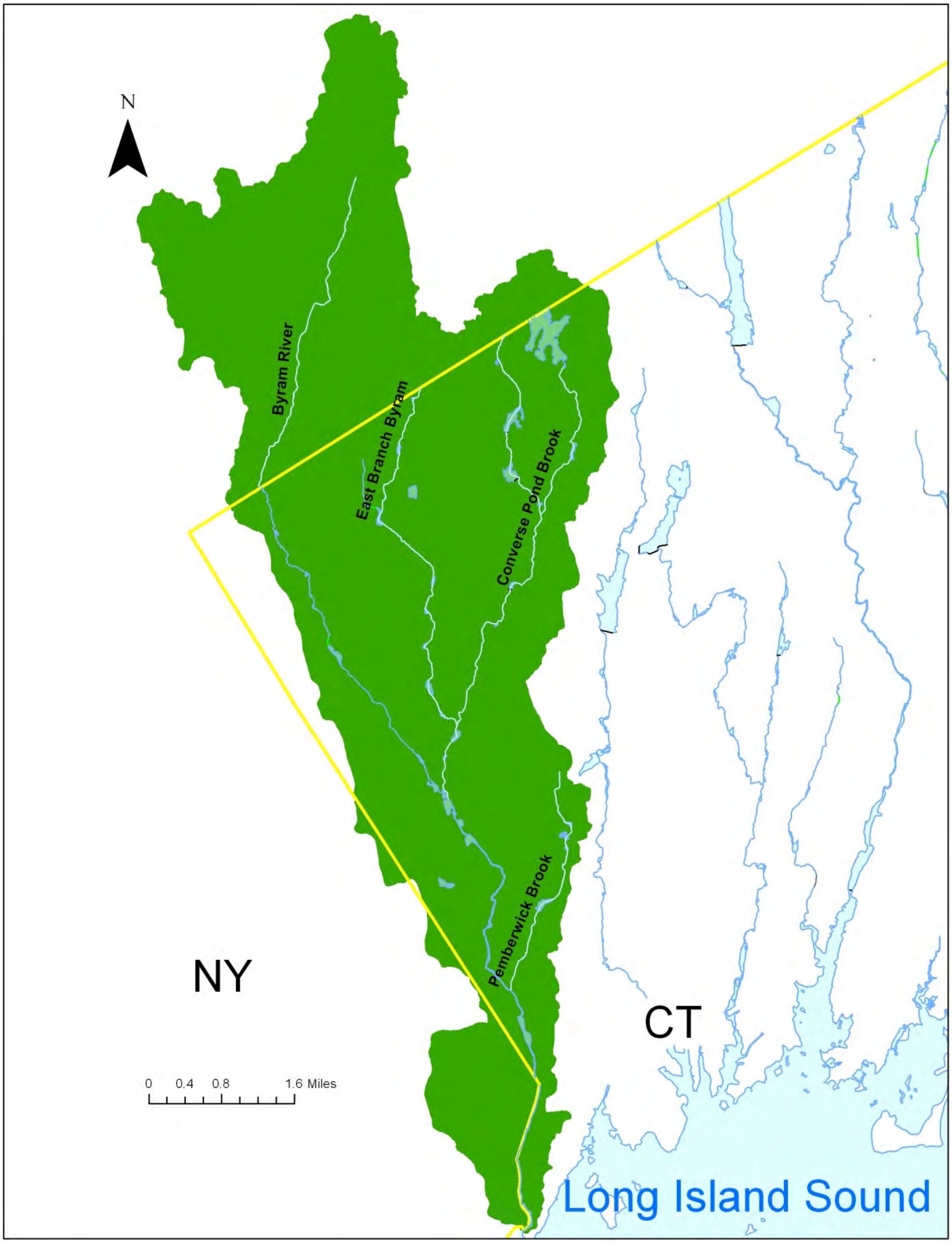


Figure 2: Land Use Distribution in the Byram River Watershed

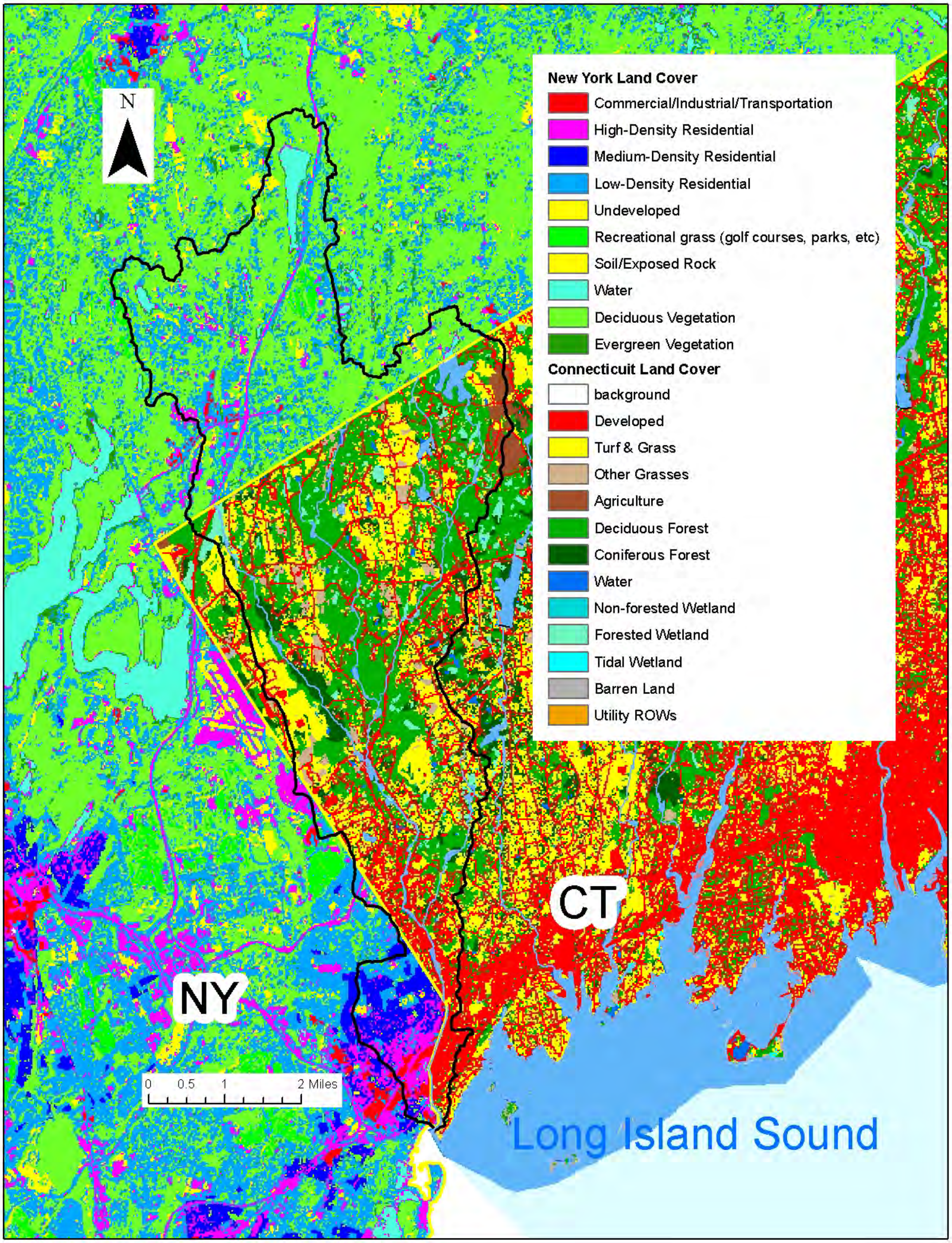


Figure 3: Subcatchments Within the Byram River Watershed

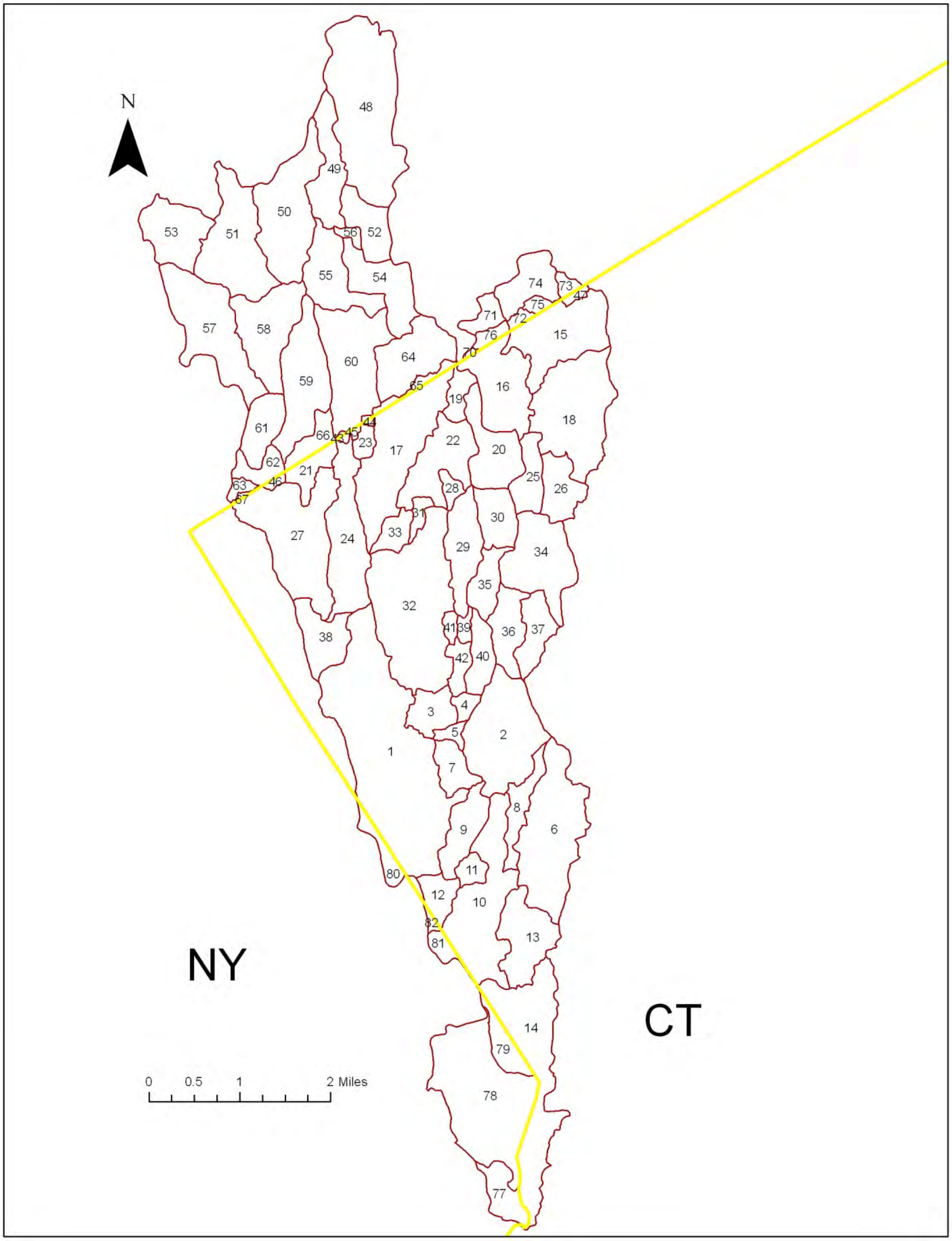


Figure 4: Example Stream Cross-section Derived from Digital Elevation Model

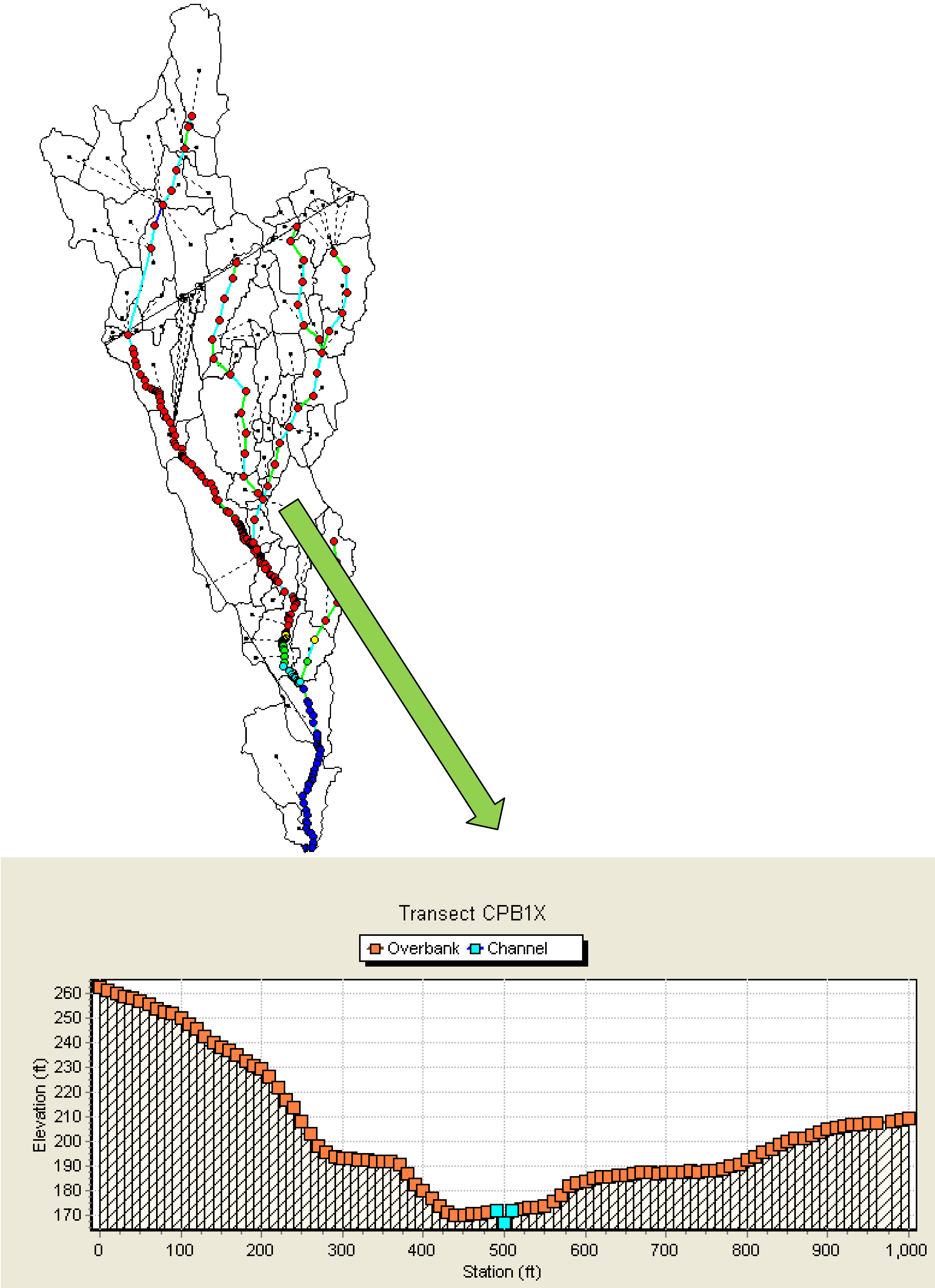
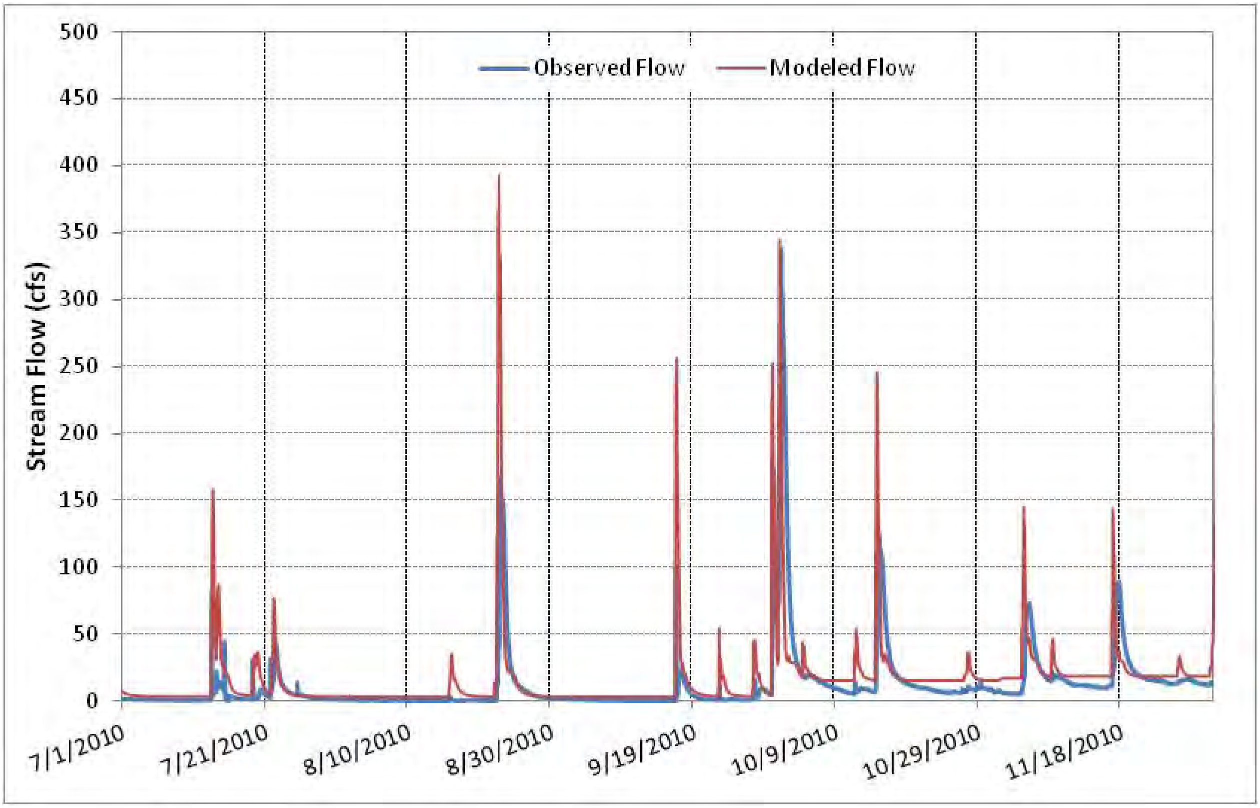


Figure 5: H&H Calibration Results for the July 1, 2010 to November 30, 2010 Period



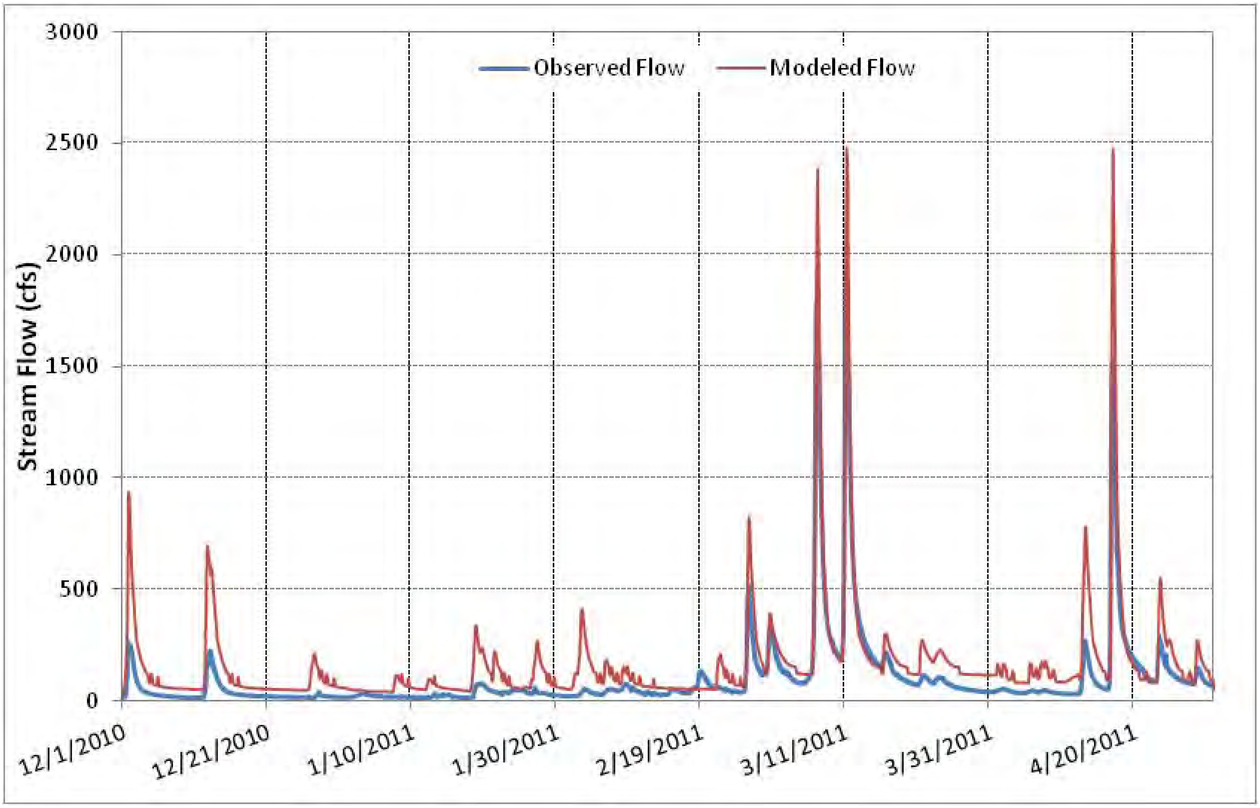


Figure 6: H&H Calibration Results for the December 1, 2010 to April 30, 2011 Period

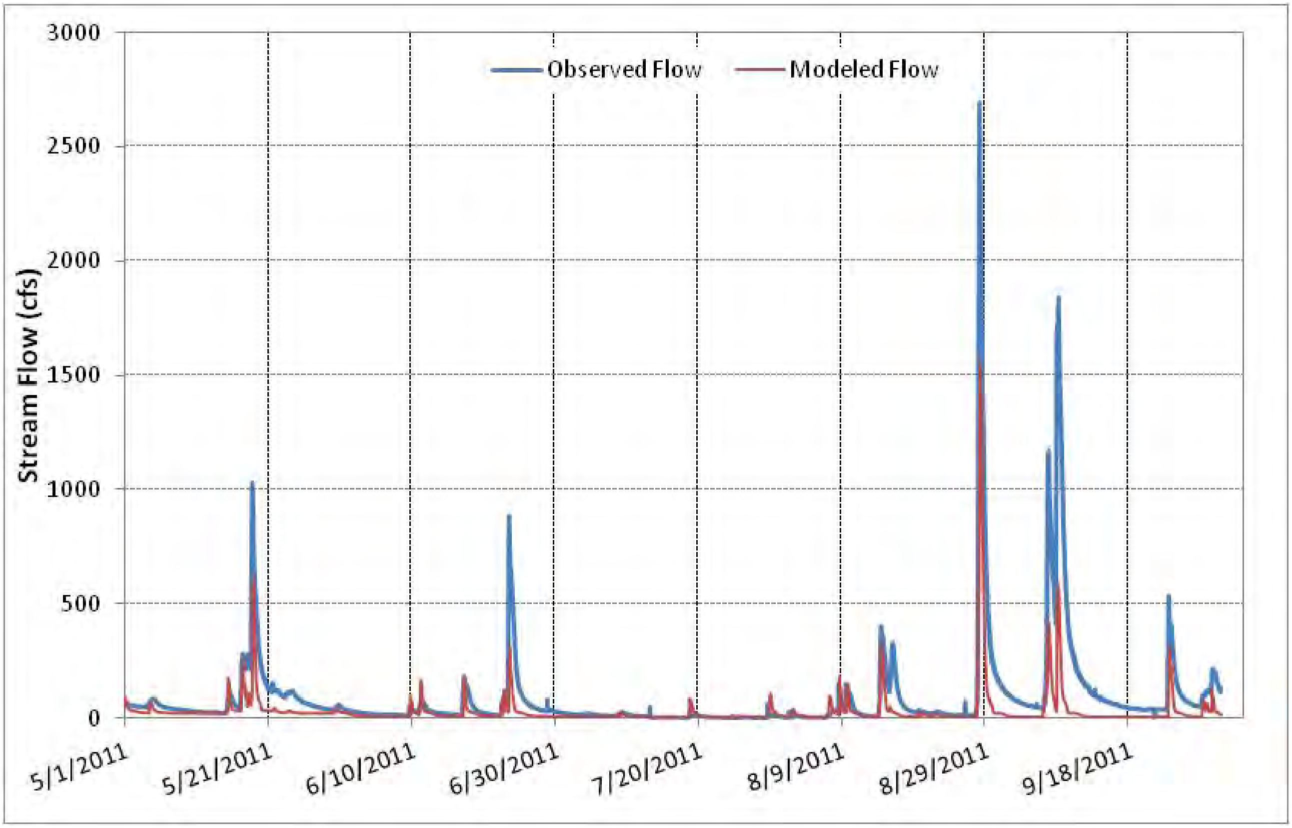


Figure 7: H&H Calibration Results for the May 1, 2011 to September 30, 2011 Period

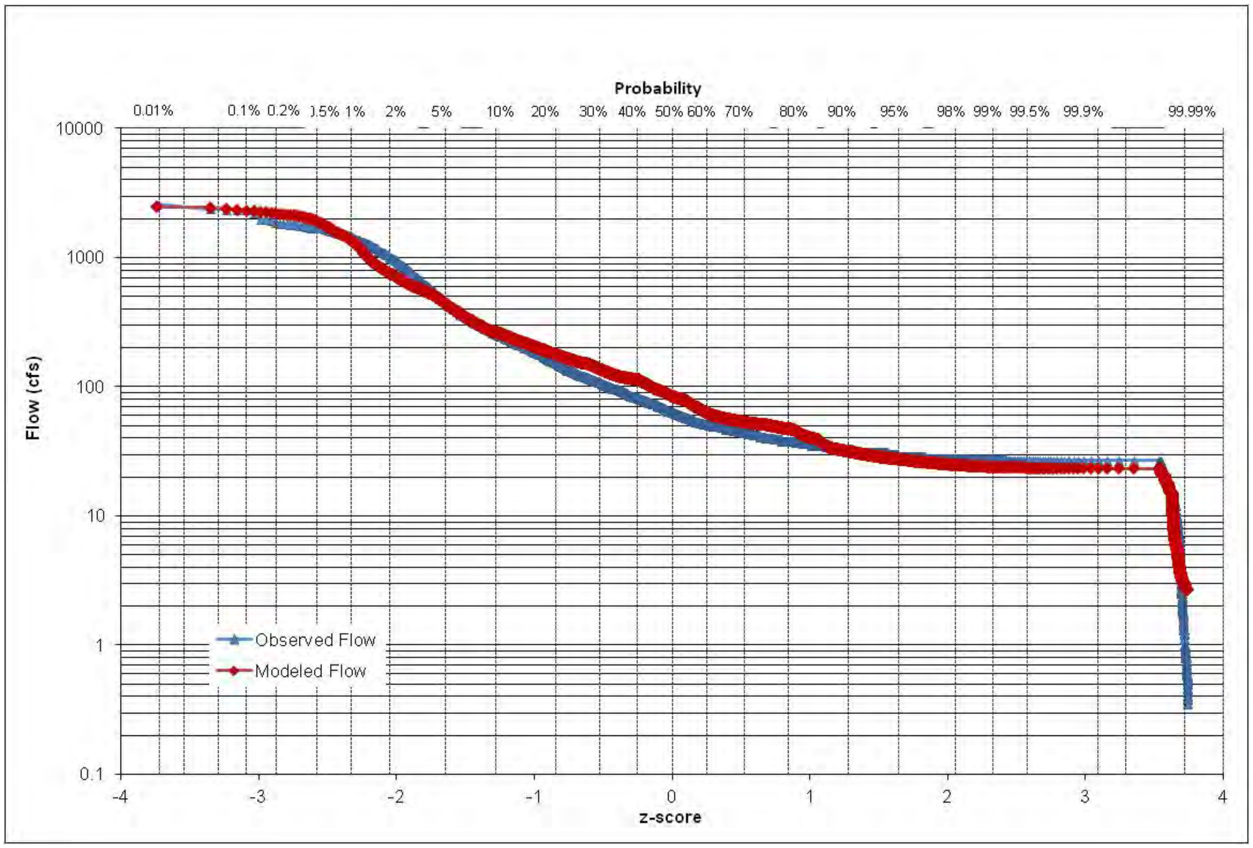


Figure 8: Comparison of Probability Distribution of Modeled and Monitored Flows for the July 1, 2010 to September 30, 2011 Period

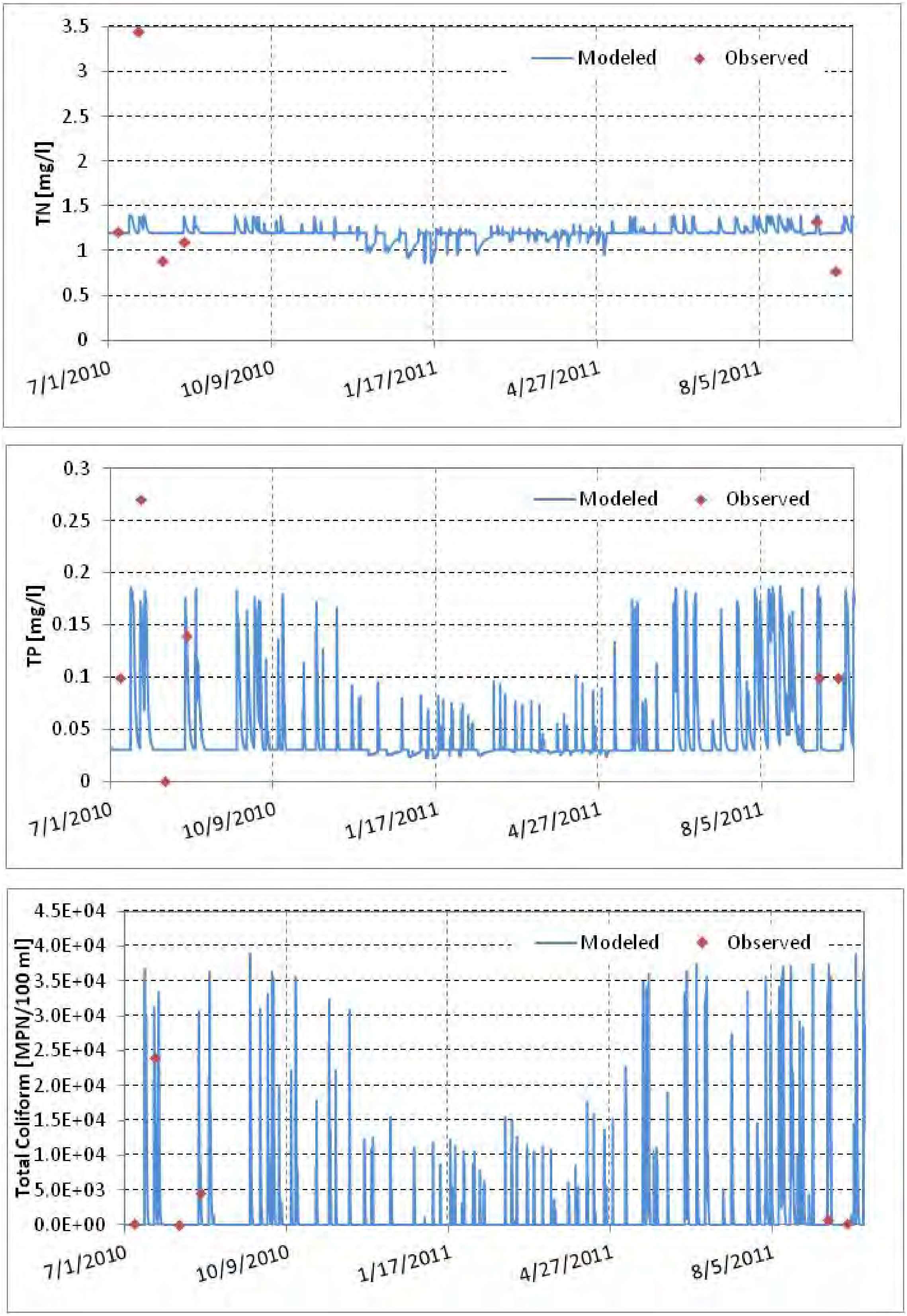


Figure 9: Time Series Plots of TN, TP and TC for BR1

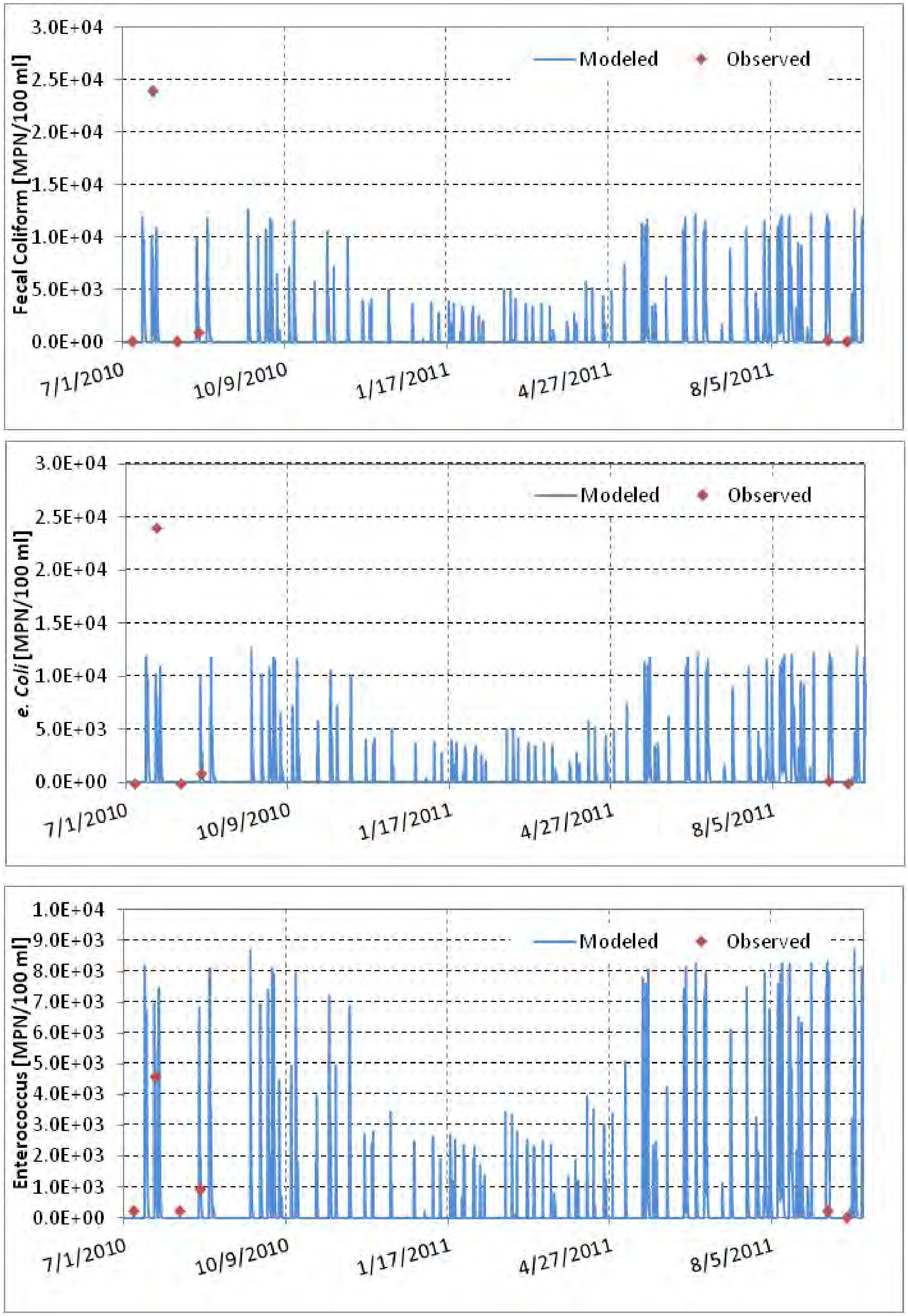


Figure 10: Time Series Plots of FC, EC and ENT for BR1

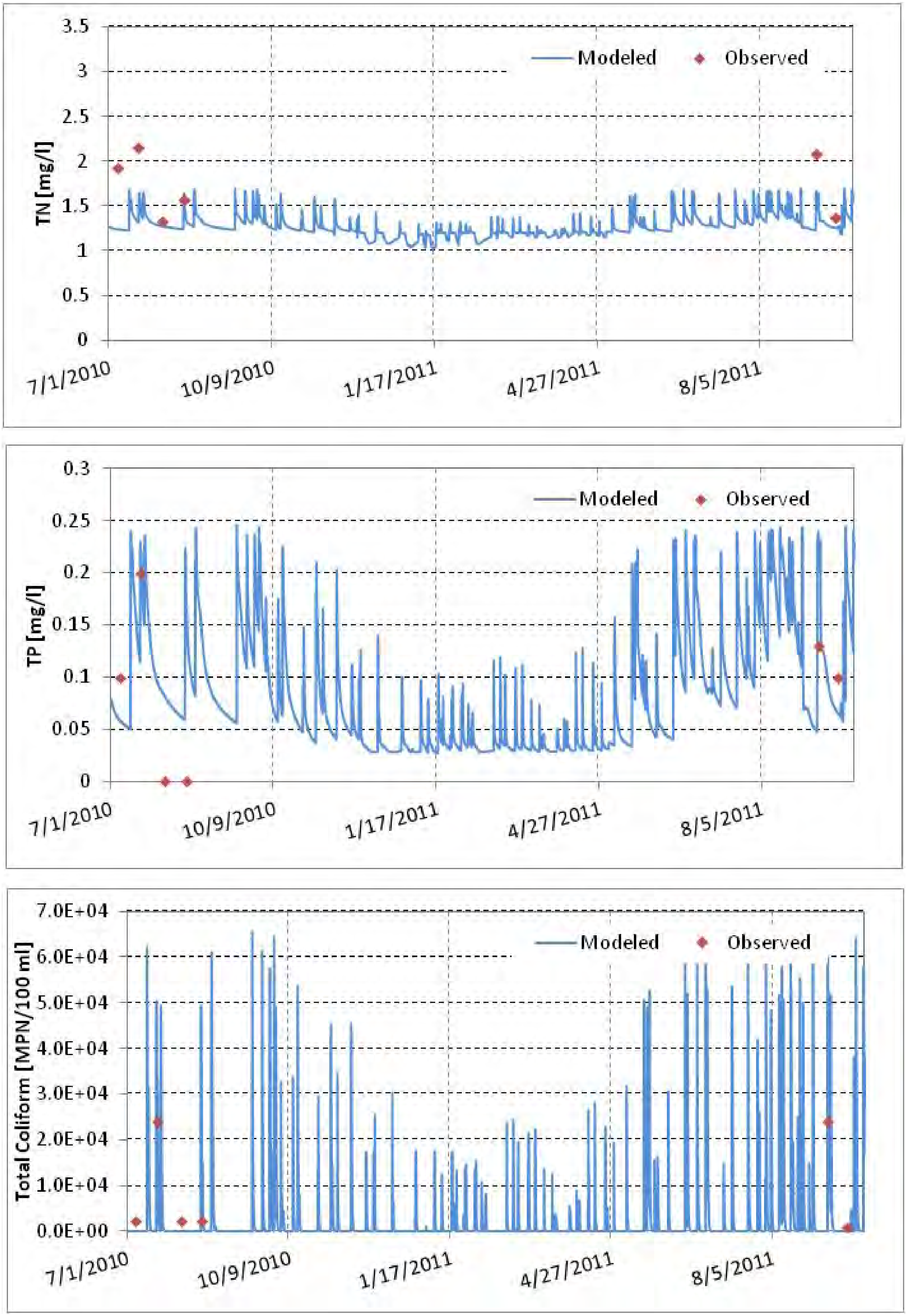


Figure 11: Time Series Plots of TN, TP and TC for BR2

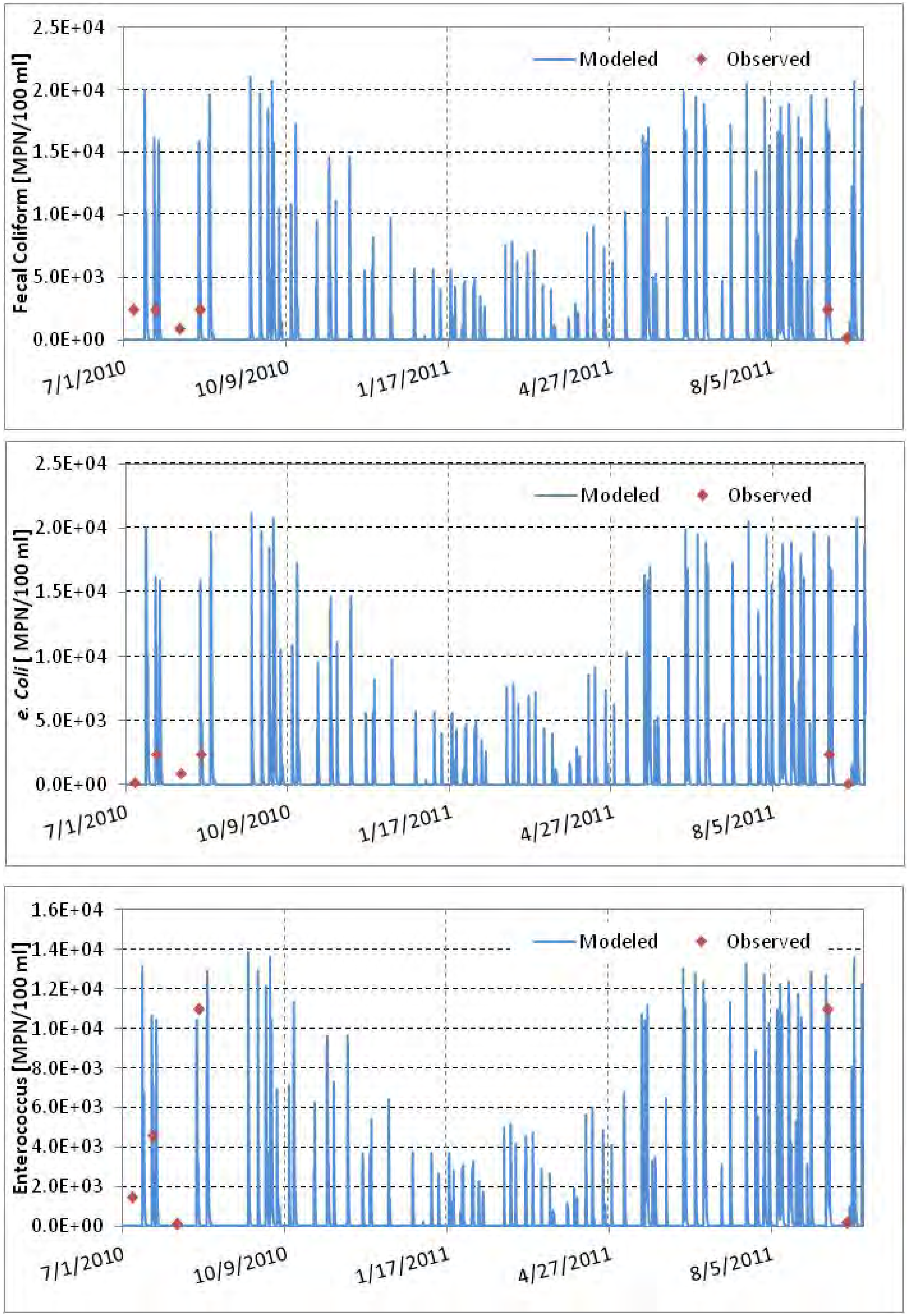


Figure 12: Time Series Plots of FC, EC and ENT for BR2

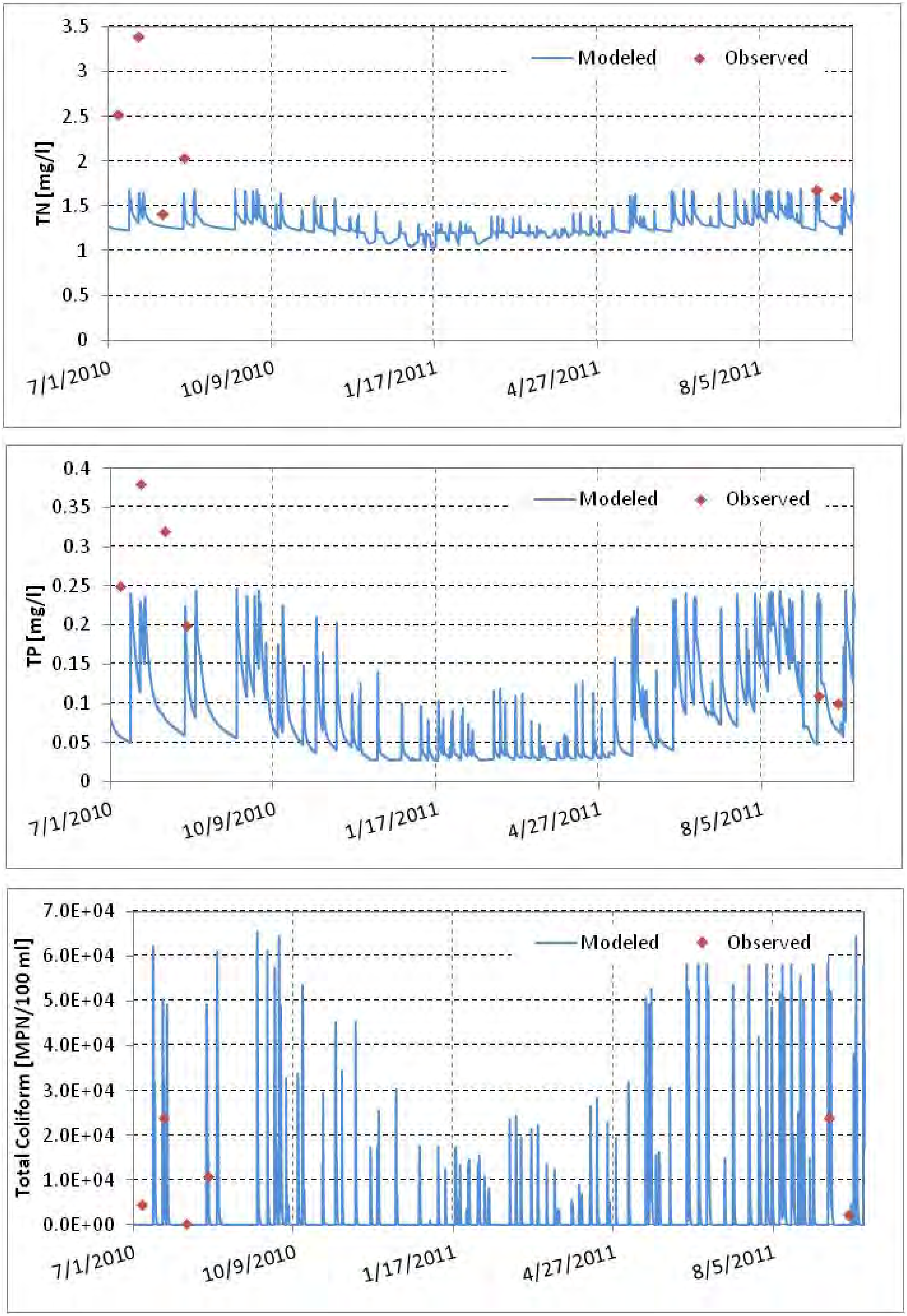


Figure 13: Time Series Plots of TN, TP and TC for BR3

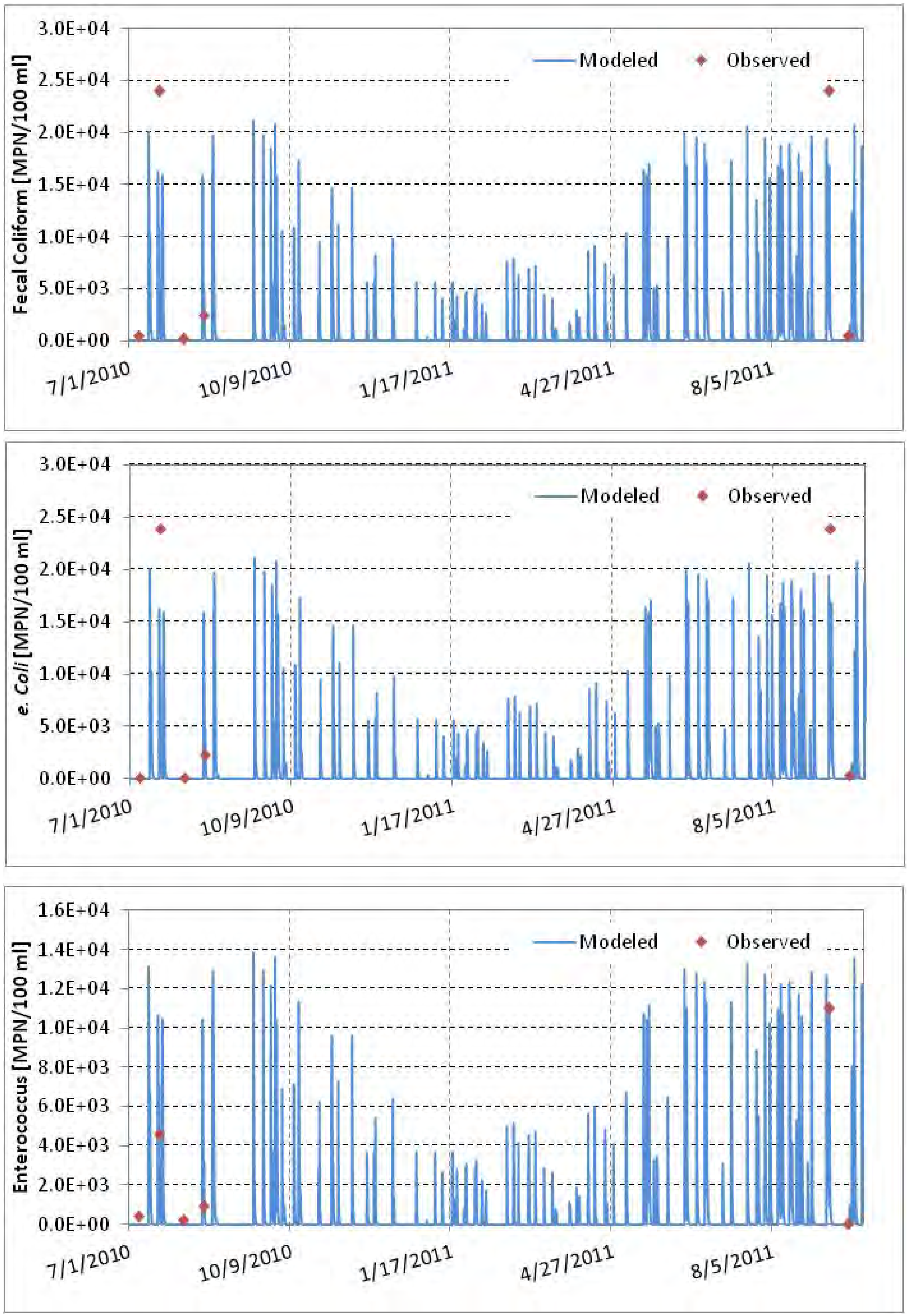


Figure 14: Time Series Plots of FC, EC and ENT for BR3

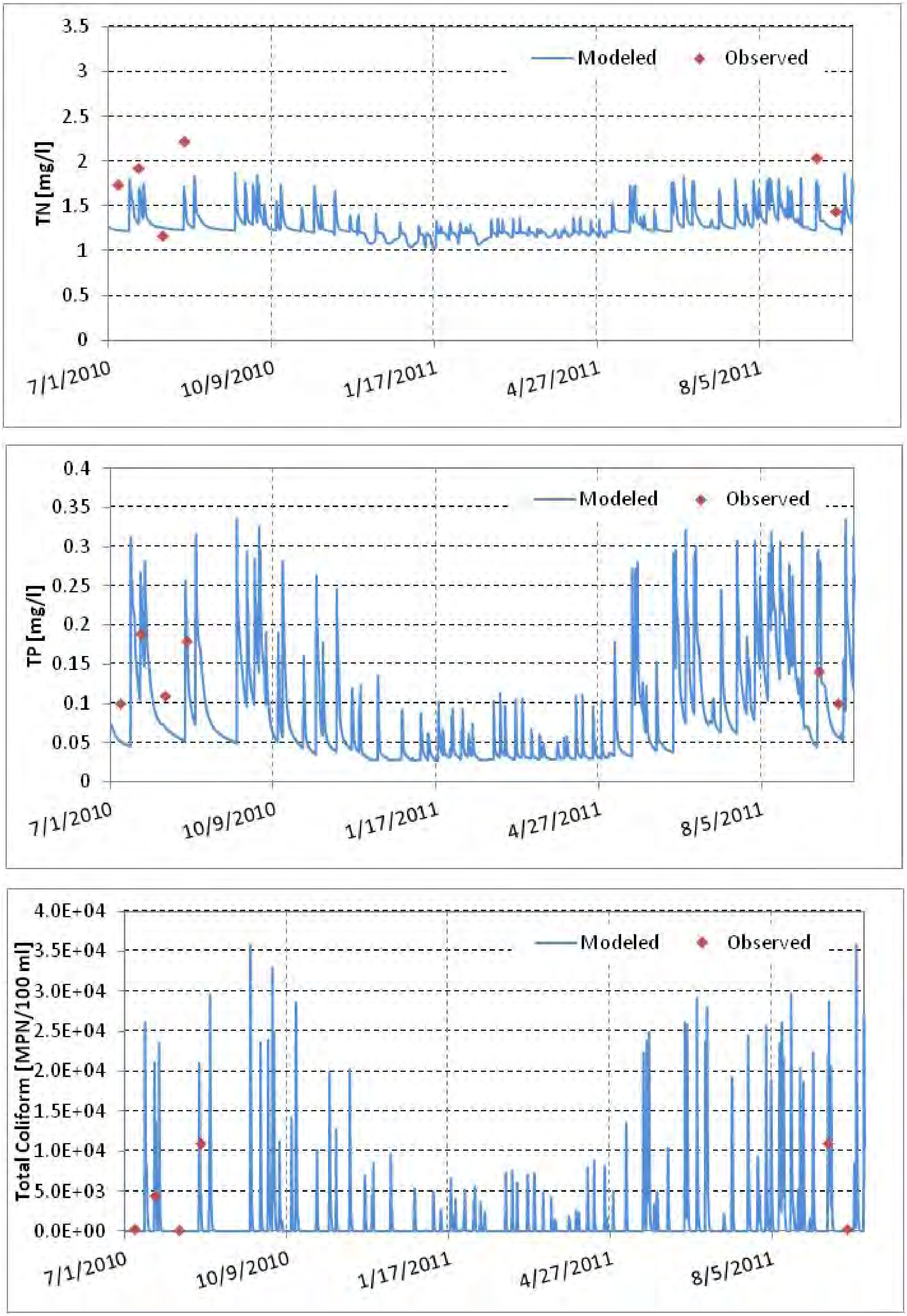


Figure 15: Time Series Plots of TN, TP and TC for BR4

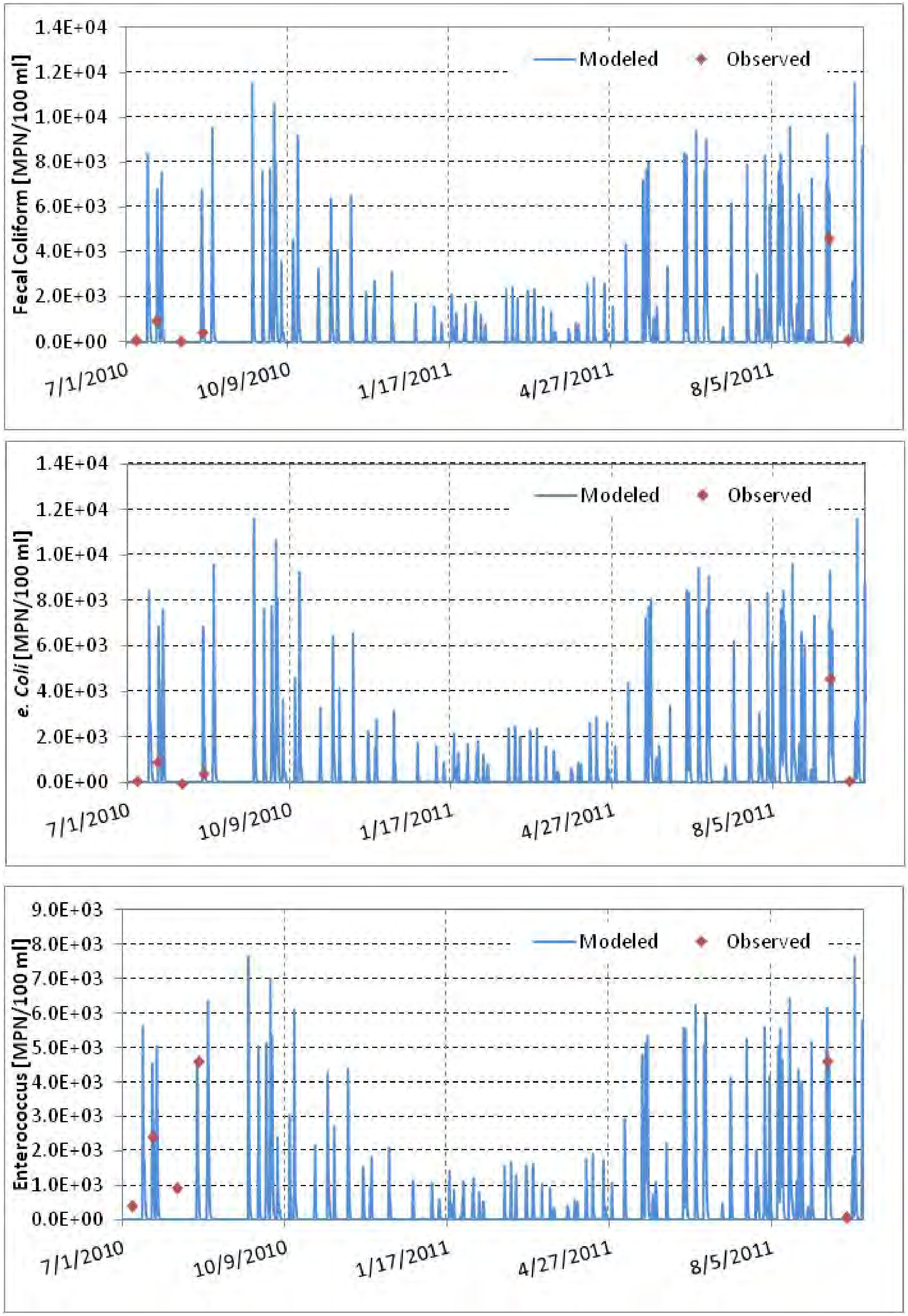


Figure 16: Time Series Plots of FC, EC and ENT for BR4

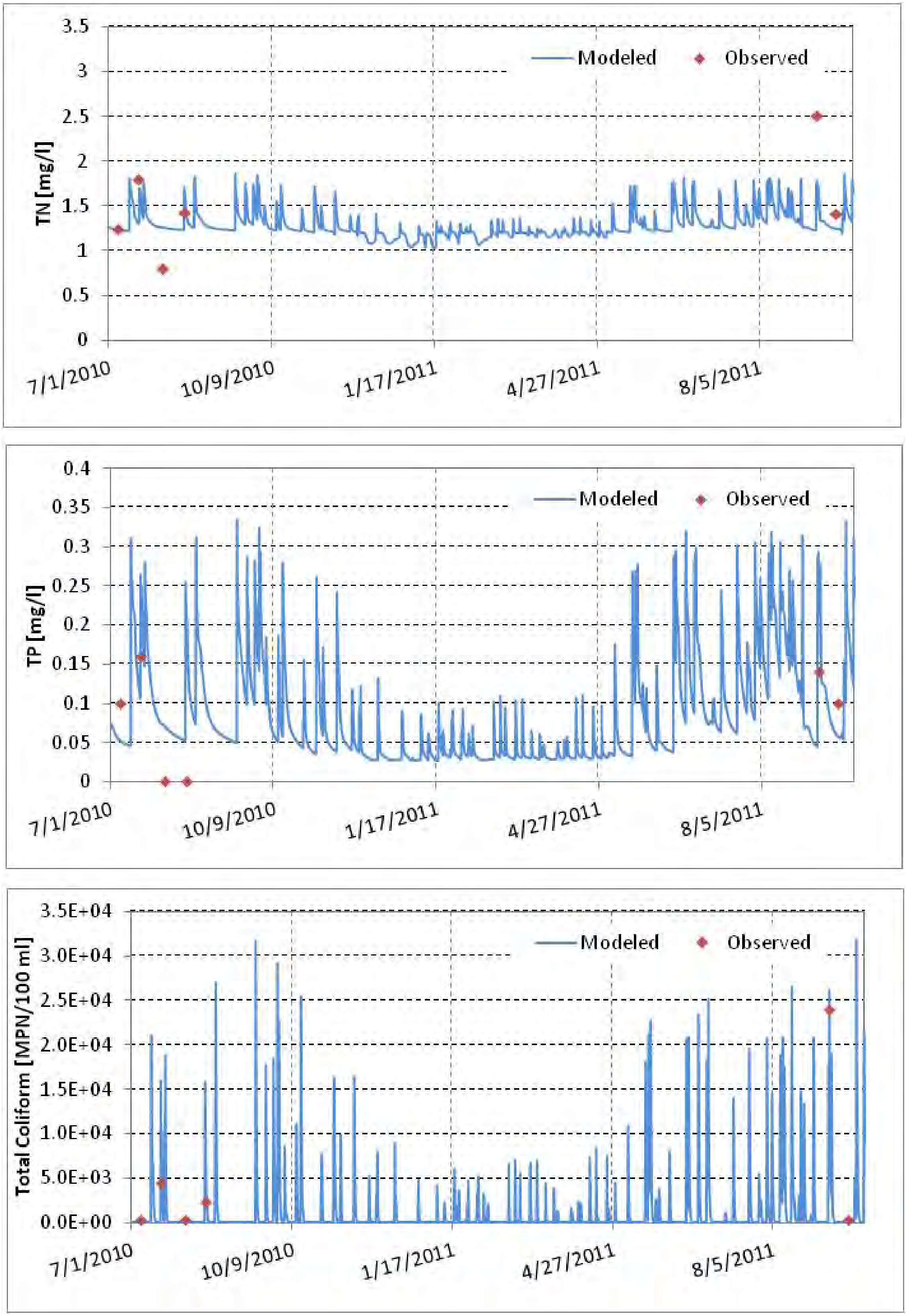
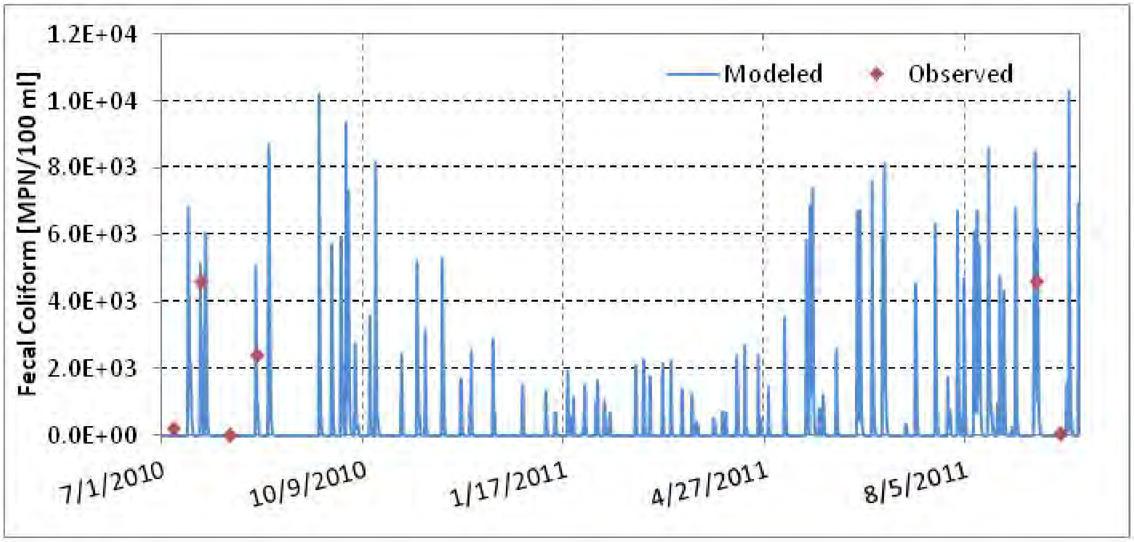
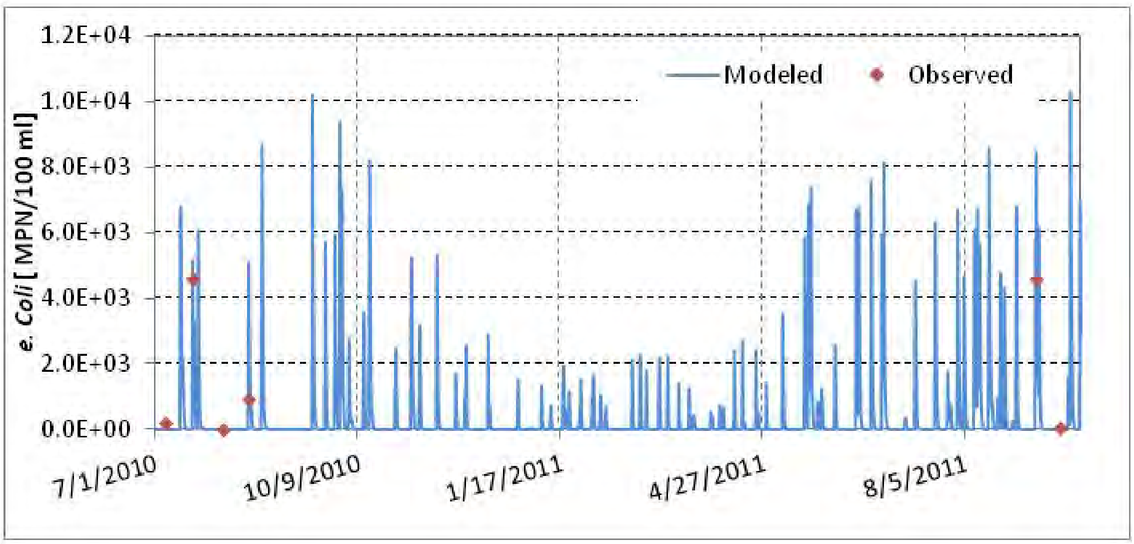


Figure 17: Time Series Plots of TN, TP and TC for BR5





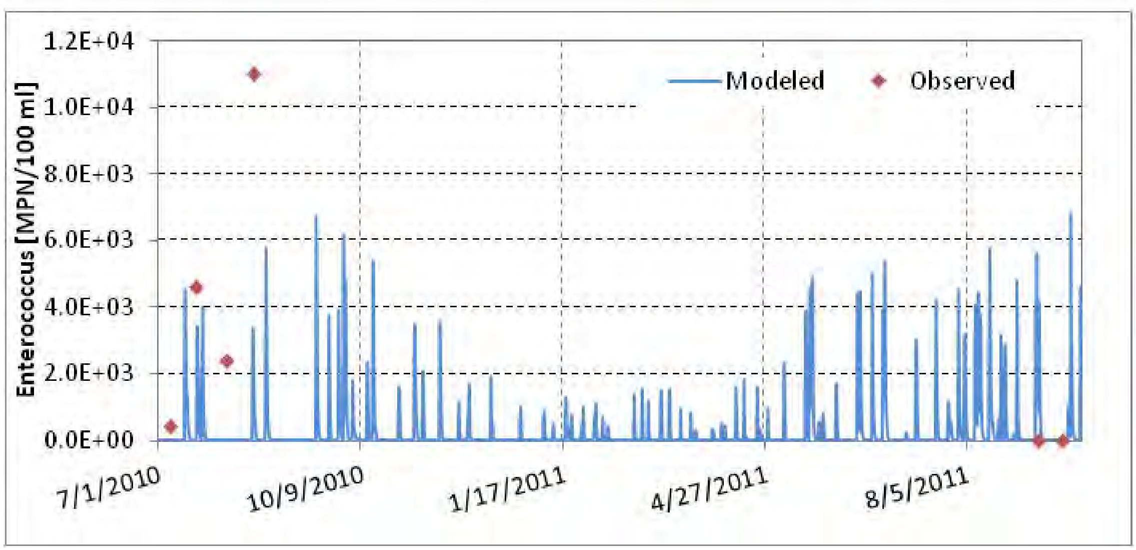


Figure 18: Time Series Plots of FC, EC and ENT for BR5

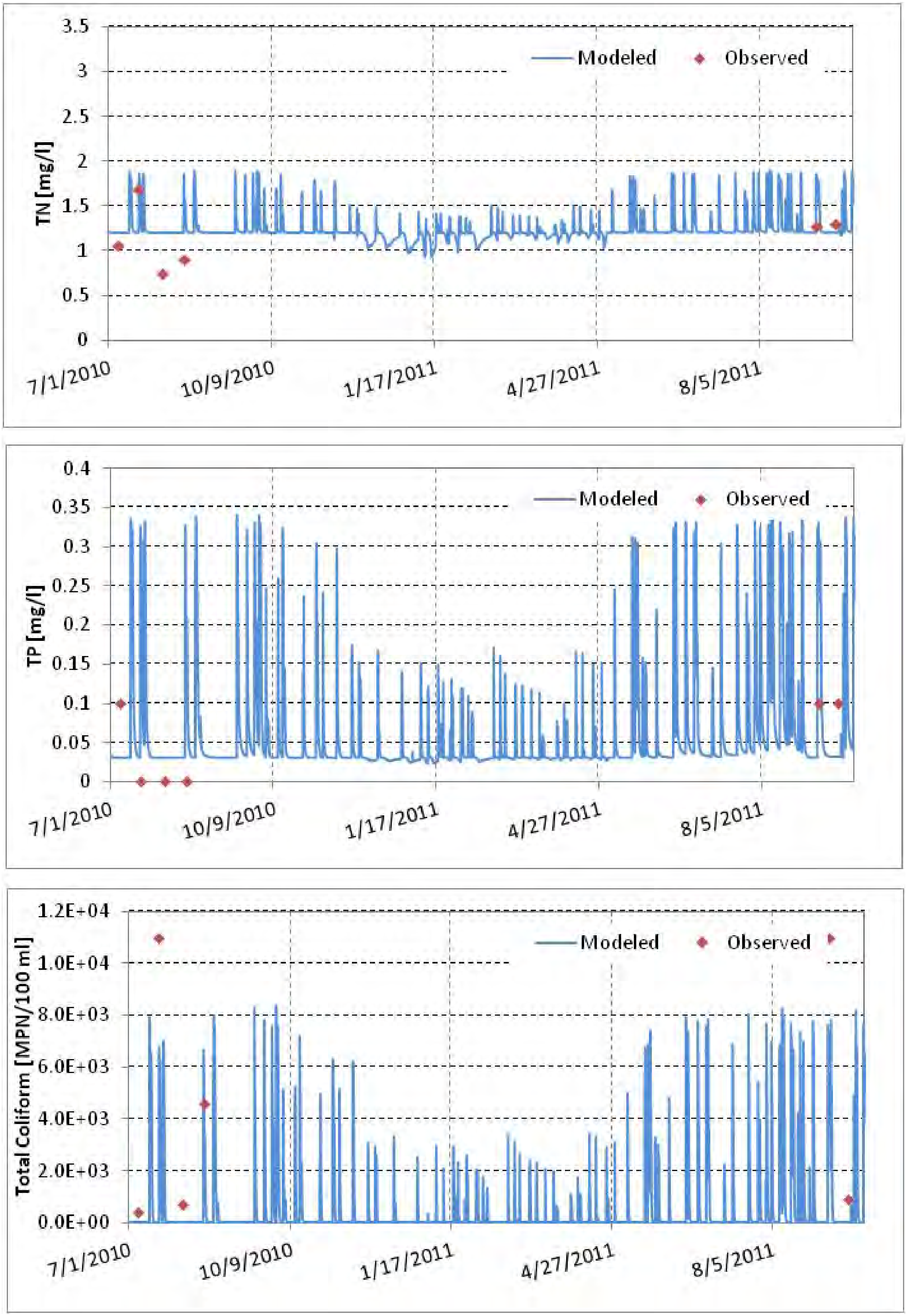


Figure 19: Time Series Plots of TN, TP and TC for BR6

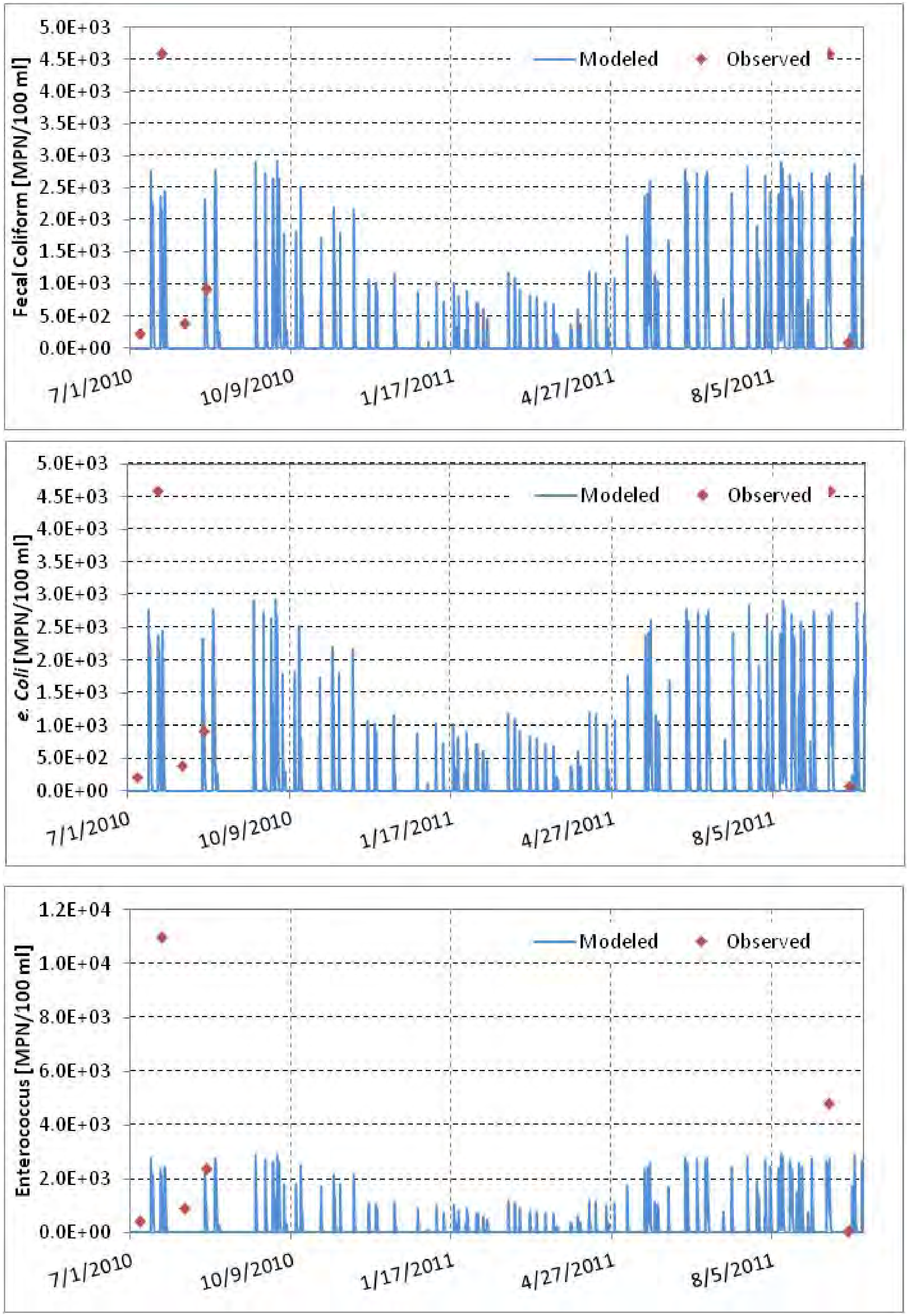


Figure 20: Time Series Plots of FC, EC and ENT for BR6

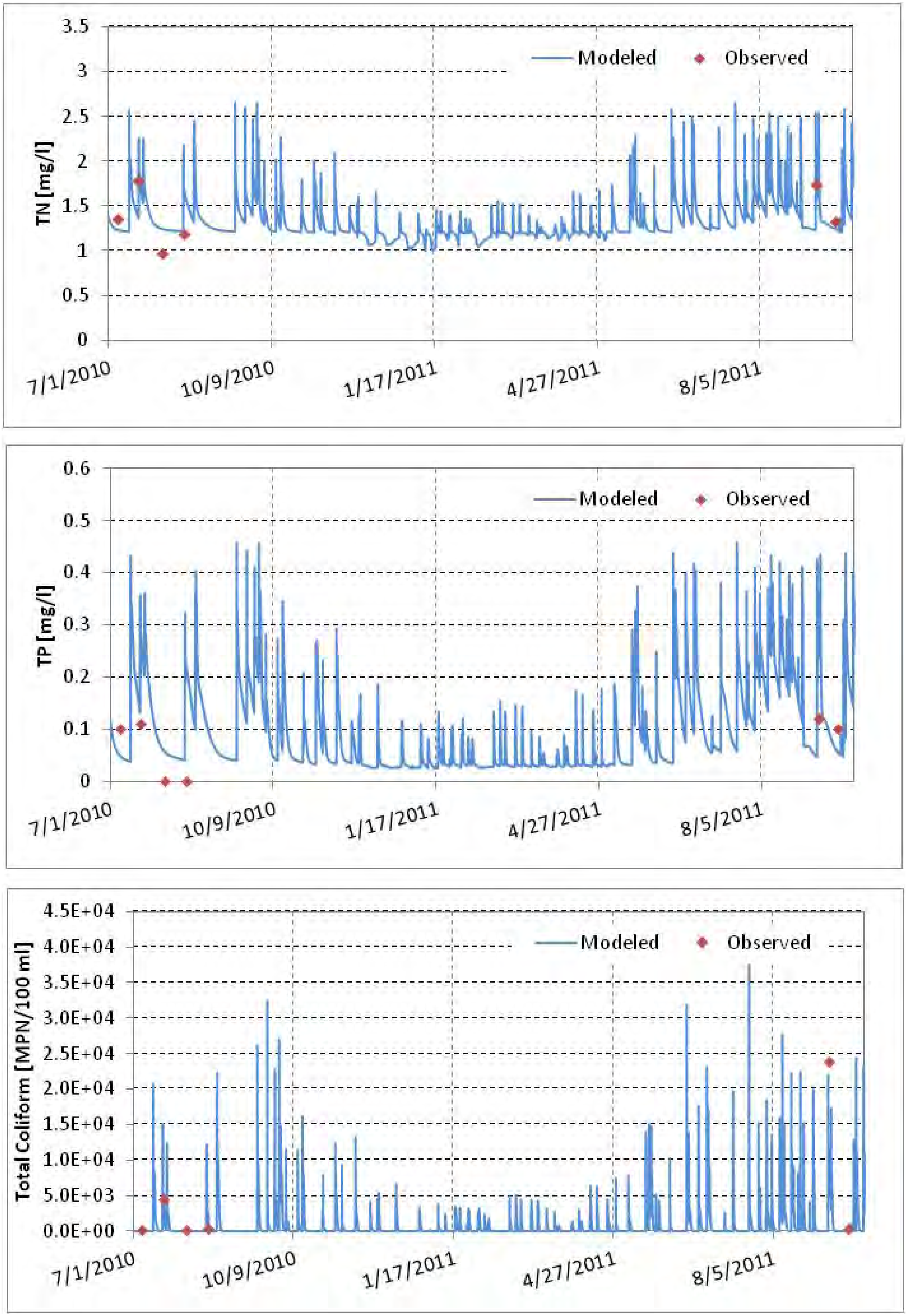


Figure 21: Time Series Plots of TN, TP and TC for BR7

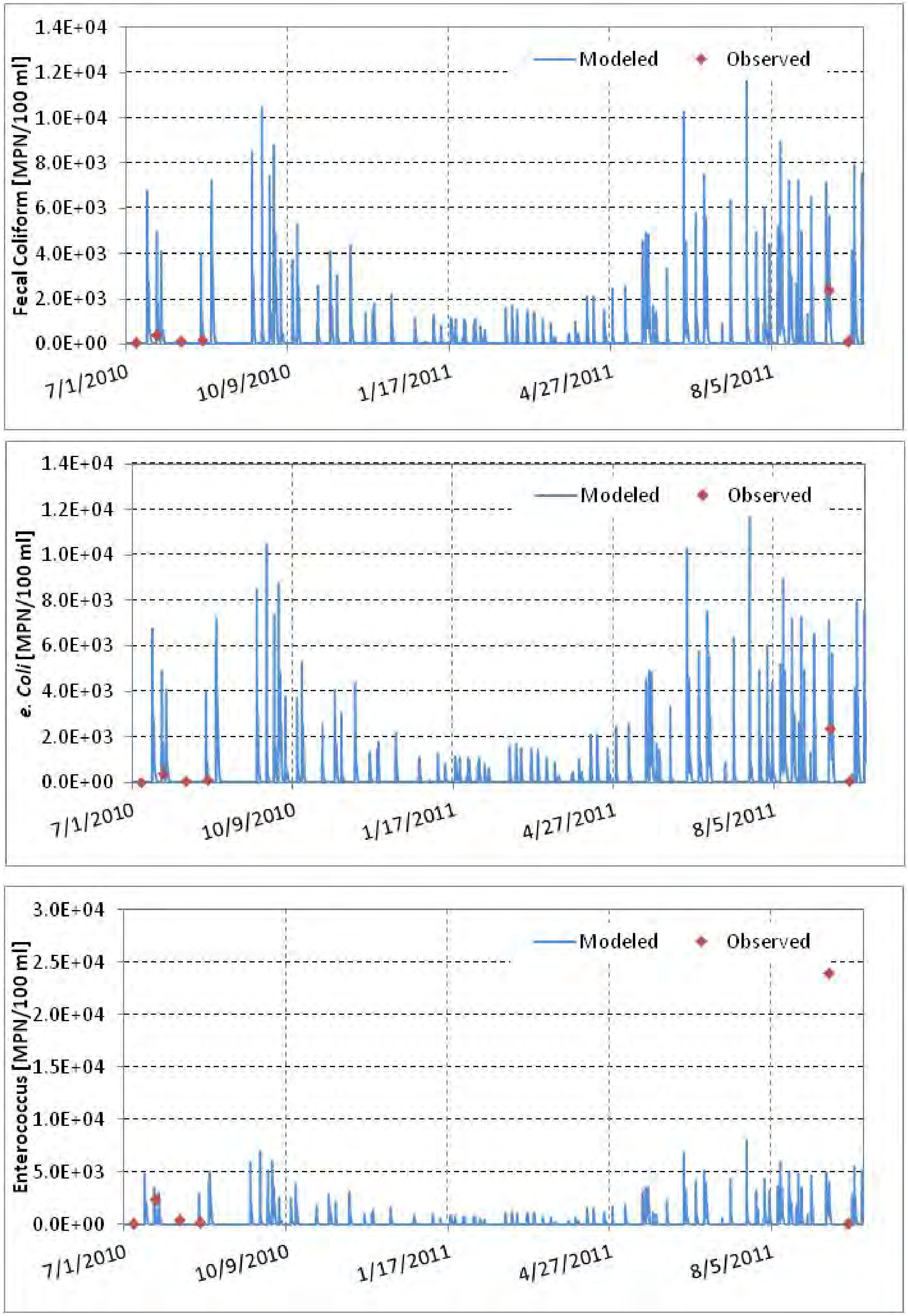


Figure 22: Time Series Plots of FC, EC and ENT for BR7

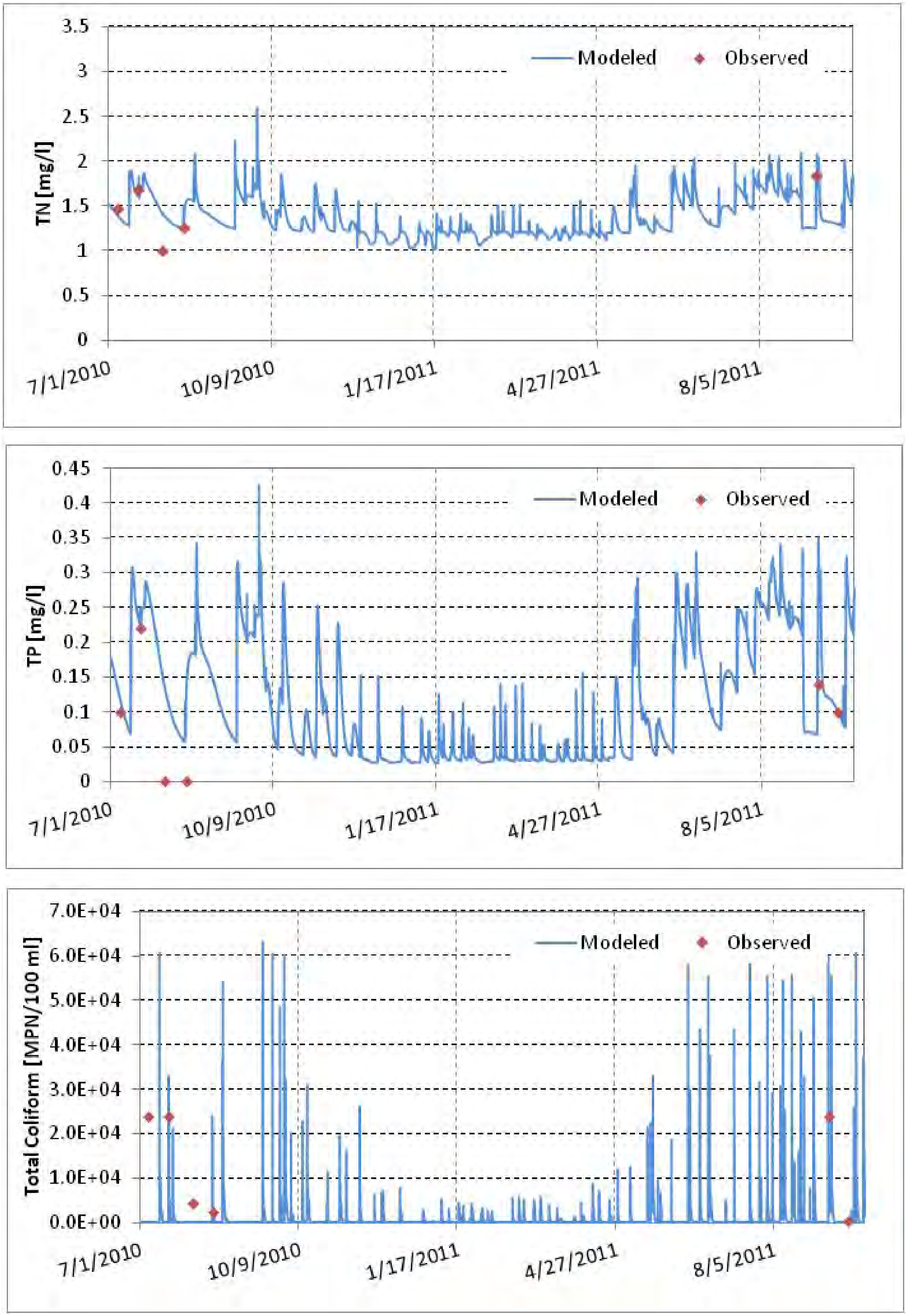


Figure 23: Time Series Plots of TN, TP and TC for BR8

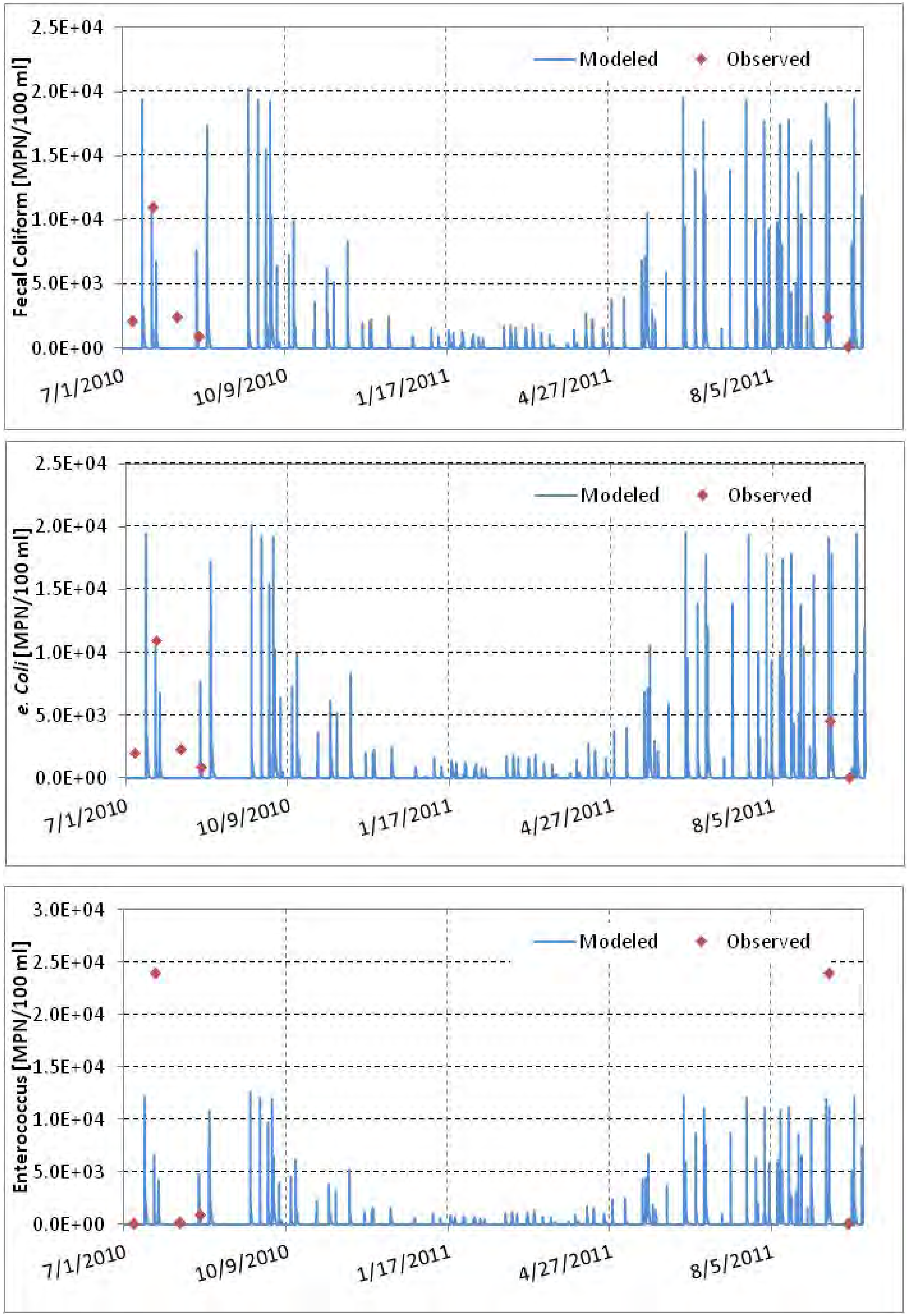


Figure 24: Time Series Plots of FC, EC and ENT for BR8

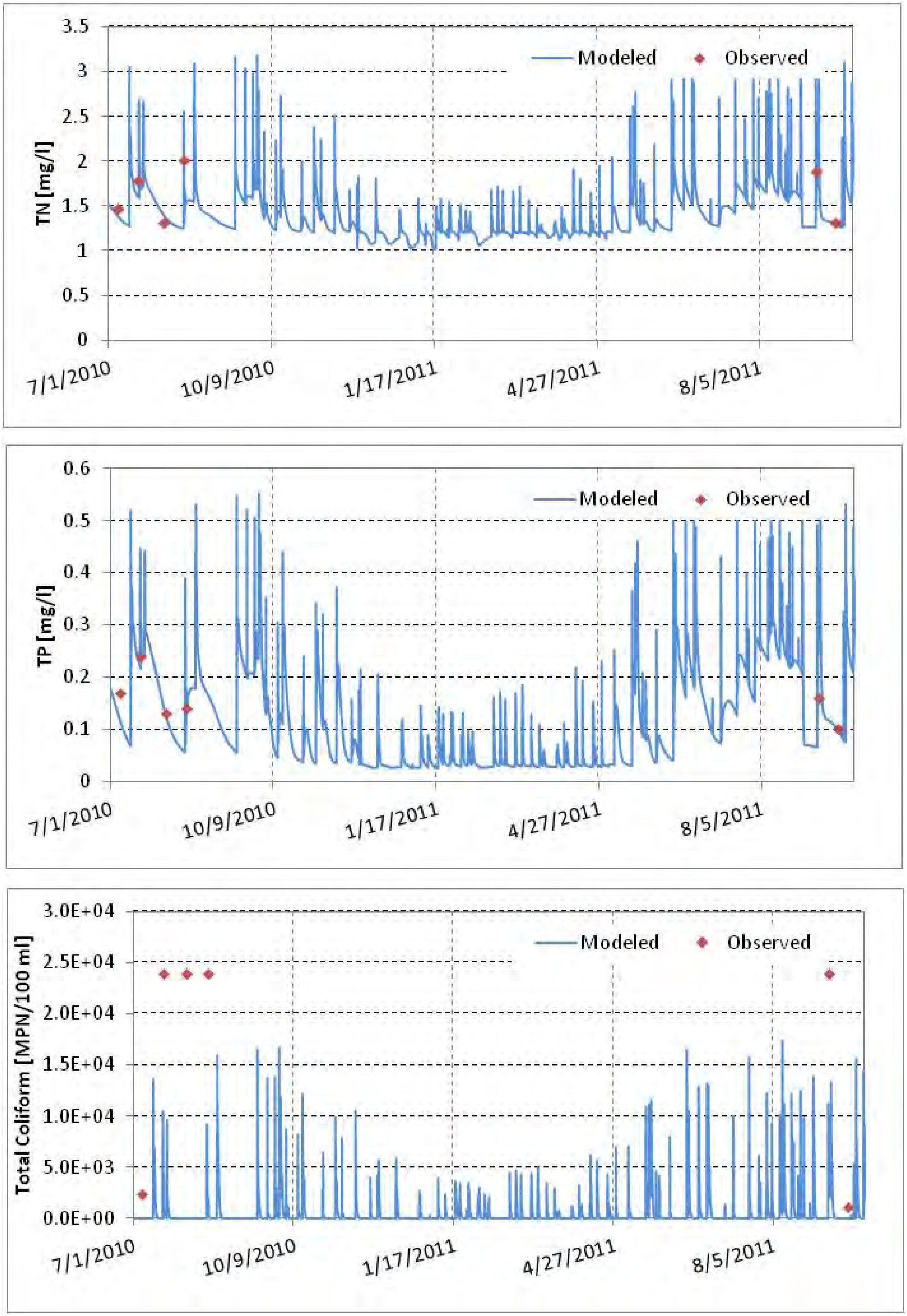


Figure 25: Time Series Plots of TN, TP and TC for BR9

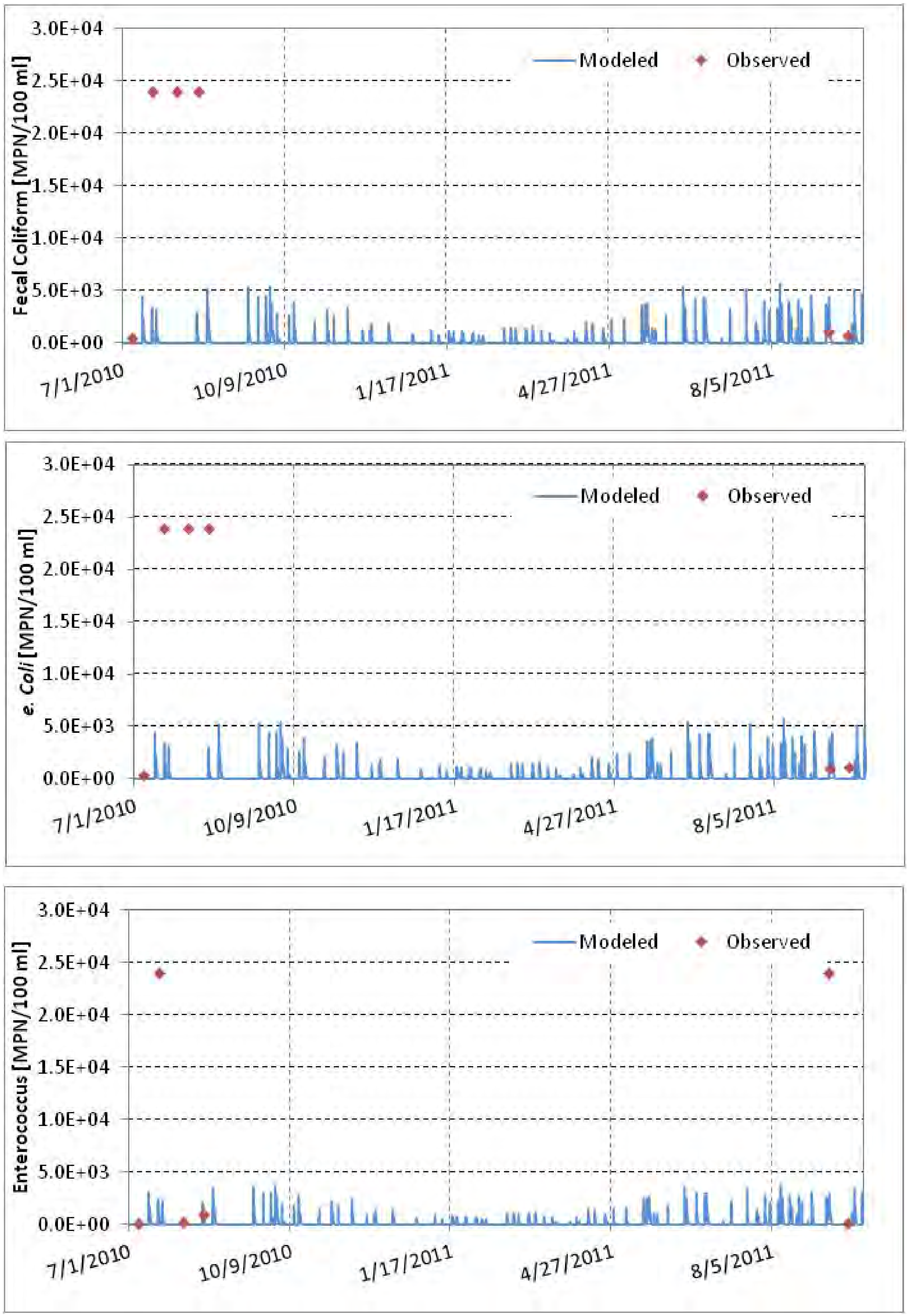


Figure 26: Time Series Plots of FC, EC and ENT for BR9

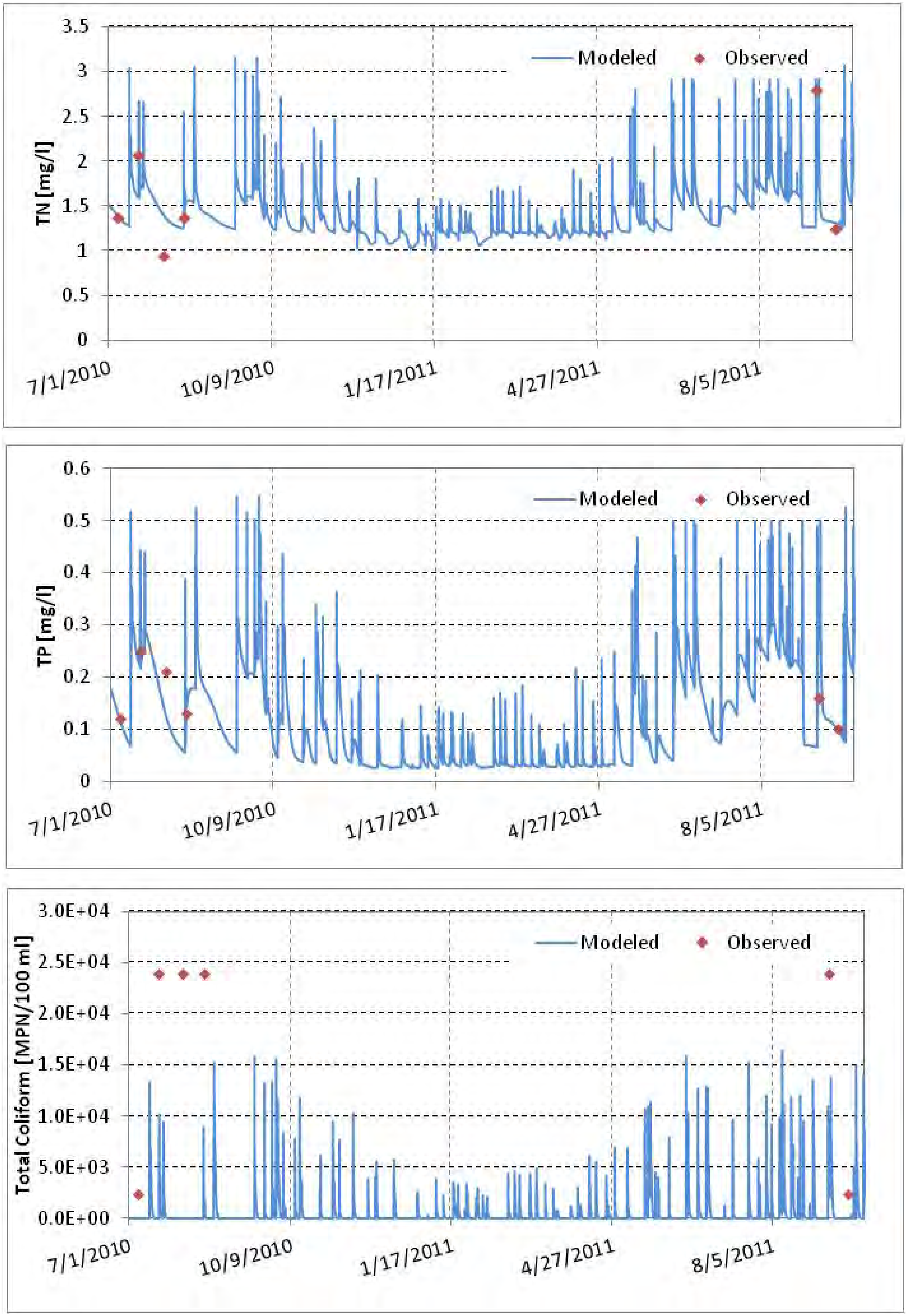


Figure 27: Time Series Plots of TN, TP and TC for BR10

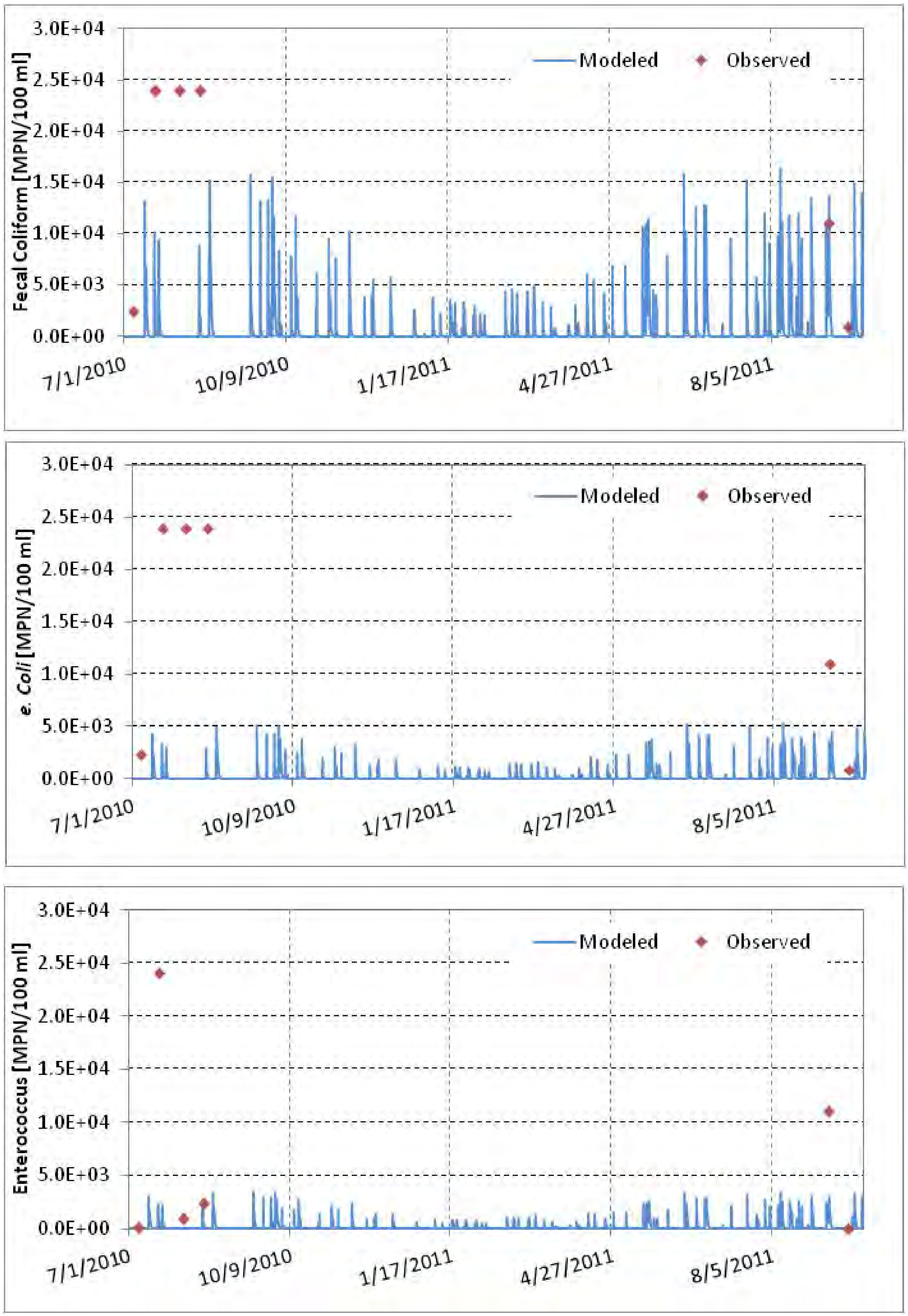
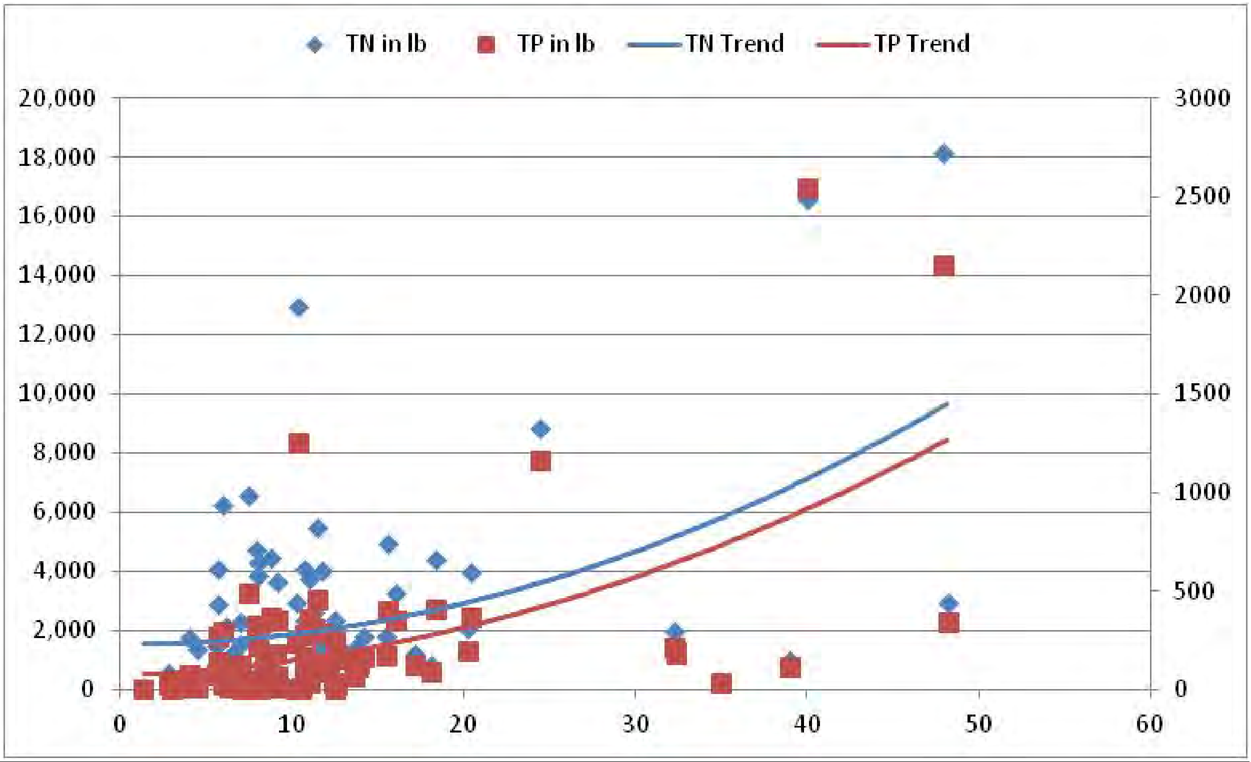


Figure 28: Time Series Plots of FC, EC and ENT for BR10

Figure 29: Correlation between Imperviousness and TN (primary Y-axis) and TP (secondary Y-axis) pollutant loads in the 82 subcatchments



TABLES

Table 1. Literature EMC Values for Water Quality Parameters

Land Use Type	NSQD (Pitt et al., 2004a & 2004b)	WTM (Caraco, 2001)	SCCWRP (Stein et al., 2007)	RUNQUAL (Evans et al., 2007)	NURP (EPA, 1983)
	E. coli	Fecal coliform	*E. coli*	Fecal coliform	*E. coli*
Agriculture	-	-	-	-	-
Low Density Residential	7,500	20,000	6,000	9,600	17,000
High Density Residential	7,500	20,000	6,000	9,600	17,000
Commercial/ Institutional	4,000	20,000	4,000	9,600	16,000
Open Space	8,000	-	6,000	-	-
Transportation	-	20,000	1,000	-	-
Wetland	-	-	-	-	-
Forest	-	-	-	-	-
Hay/Pasture	-	-	-	-	-
Industrial	1,500	20,000	1,500	-	14,000

Table 2. Final EMC Values

Land Cover Code	TN(mg/L)	TP(mg /L)	Various Pathogen Indicators (MPN/100mL)			
			TC	FC	EC	ENT
CT_Developed	2.4	0.315	250000	8750	87500	87500
CT_Turf&Grass	4.2	0.75	2000	700	700	700
CT_OtherGrasses	0.75	0.15	12500	4375	4375	4375
CT_Agriculture	9.86	2.72	2000	700	700	700
CT_DeciduousForest	0.75	0.15	12500	4375	4375	4375
CT_ConiferousForest	1	0.15	12500	4375	4375	4375
CT_Water	2	0.064	0	0	0	0
CT_Non-forestedWetland	1	0.1	0	0	0	0
CT_ForestedWetland	1	0.1	0	0	0	0
CT_TidalWetland	0.5	0.1	0	0	0	0
CT_BarrenLand	1.6	0.064	0	0	0	0
CT_UtilityCorridors(Forest)	0.75	0.15	12500	4375	4375	4375
NY_Evergreen-Vegetation	0.75	0.15	12500	4375	4375	4375
NY_Deciduous-Vegetation	0.75	0.15	12500	4375	4375	4375
NY_Water	1.6	0.064	0	0	0	0
NY_Soil/Exposed-Rock	0	0	0	0	0	0
NY_Recreational-grass	4.2	0.75	2000	700	700	700
NY_Undeveloped	4.2	0.75	2000	700	700	700
NY_Low-Density-Residential	2.4	0.315	250000	8750	87500	87500
NY_Medium-Density-Residential	2.4	0.315	250000	8750	87500	87500
NY_High-Density-Residential	2.4	0.315	250000	8750 0	87500	87500
NY_Commercial-Industrial-Transportation	2.4	0.315	250000	8750 0	87500	87500
Dry Weather Flow	1.2	0.03	0	0	0	0

Table 3. Pollutant Loads from Each Subcatchment for the 15-month Period

Map ID	Sub-catchment ID	Total Runoff (ac-ft)	TN(lbs)	TP(lbs)	Various Pathogen Indicators (10^{12} Organisms)			
					TC	FC	EC	ENT
48	BYRNY0	1,896	6,232	294	173	56	56	39
49	BYRNY1	554	1,771	76	26	9	9	6
50	BYRNY2	1,178	3,876	225	145	47	47	33
51	BYRNY3	1,181	4,073	280	233	76	76	51
52	BYRNY4	413	1,542	109	41	13	13	9
53	BYRNY5	637	2,102	108	52	17	17	12
54	BYRNY6	628	2,062	126	81	27	27	19
55	BYRNY7	686	2,343	165	118	38	38	26
56	BYRNY8	68	254	18	7	2	2	2
15	EBYRCT9	890	2,874	143	15	5	5	5
57	BYRNY10	1,358	4,961	399	424	137	137	90
58	BYRNY11	1,056	3,976	365	425	137	137	90
59	BYRNY12	1,106	4,403	406	452	146	146	95
16	EBYRCT13	816	2,921	235	27	9	9	9
60	BYRNY14	1,175	3,993	289	254	82	82	56
17	EBYRCT15	1,177	4,074	270	26	9	9	9
18	EBYRCT16	1,265	4,311	297	35	12	12	12
19	EBYRCT17	193	714	63	6	2	2	2
20	EBYRCT18	613	2,616	314	21	7	7	7
61	BYRNY19	501	2,050	198	201	65	65	42
21	BYRCT20	246	1,002	89	6	2	2	2
22	EBYRCT21	709	2,448	178	20	7	7	7
23	EBYRCT22	102	329	19	3	1	1	1
24	BYRCT23	924	3,660	352	25	9	9	9
25	EBYRCT24	365	1,494	160	15	5	5	5
62	BYRNY25	235	860	66	70	23	23	15
26	EBYRCT26	369	1,230	72	10	3	3	3
27	BYRCT27	1,361	4,729	324	33	11	11	11
28	EBYRCT28	104	413	37	3	1	1	1
29	EBYRCT29	599	2,357	244	22	8	8	8

Map ID	Sub-catchment ID	Total Runoff (ac-ft)	TN(lbs)	TP(lbs)	Various Pathogen Indicators (10^{12} Organisms)			
					TC	FC	EC	ENT
30	EBYRCT30	396	1,398	121	15	5	5	5
31	EBYRCT31	104	396	33	3	1	1	1
32	EBYRCT32	1,855	6,563	489	51	18	18	18
33	EBYRCT33	171	555	24	2	1	1	1
34	EBYRCT34	911	3,739	363	27	9	9	9
35	EBYRCT35	329	1,381	160	12	4	4	4
36	EBYRCT36	457	1,779	167	17	6	6	6
37	EBYRCT37	416	1,812	175	11	4	4	4
38	BYRCT38	418	1,363	59	6	2	2	2
1	BYRCT39	3,181	12,939	1,254	87	31	31	30
39	EBYRCT40	64	228	15	1	0.29	0.29	0.29
40	EBYRCT41	332	1,264	119	14	5	5	5
41	EBYRCT42	65	214	11	1	1	1	1
42	EBYRCT43	169	590	41	5	2	2	2
2	EBYRCT44	1,213	4,430	368	35	12	12	12
3	EBYRCT45	317	1,063	70	11	4	4	4
4	EBYRCT46	93	323	21	3	1	1	1
5	EBYRCT47	92	343	29	3	1	1	1
6	BYRCT48	1,454	5,470	454	41	14	14	14
7	EBYRCT49	306	1,296	129	11	4	4	4
8	BYRCT50	326	1,074	69	10	3	3	3
9	BYRCT51	470	1,867	168	15	5	5	5
10	BYRCT52	1,667	8,857	1,163	65	23	23	23
11	BYRCT53	164	811	94	5	2	2	2
12	BYRCT54	278	1,208	126	9	3	3	3
13	BYRCT55	746	3,255	348	28	10	10	10
78	BYRNY56	3,217	18,145	2,150	3,619	1,158	1,158	725
63	BYRNY57	81	259	14	9	3	3	2
43	BYRCT58	15	51	2	0.08	0.03	0.03	0.03
44	BYRCT59	11	40	3	0.33	0.12	0.12	0.12
64	EBYRNY60	724	2,297	122	67	22	22	16

Map ID	Sub-catchment ID	Total Runoff (ac-ft)	TN(lbs)	TP(lbs)	Various Pathogen Indicators (10^{12} Organisms)			
					TC	FC	EC	ENT
70	EBYRNY61	19	63	4	4	1	1	1
71	EBYRNY62	185	592	29	11	4	4	3
72	EBYRNY63	55	171	7	2	1	1	1
73	EBYRNY64	76	240	9	2	1	1	1
74	EBYRNY65	450	1,471	75	28	9	9	7
79	BYRNY66	378	1,979	215	345	110	110	69
14	BYRCT67	2,371	16,580	2,539	87	30	30	30
80	BYRNY68	295	1,604	184	210	67	67	42
77	BYRNY69	545	2,943	343	578	185	185	116
81	BYRNY70	188	983	114	165	53	53	33
82	BYRNY71	53	284	32	48	15	15	10
75	EBYRNY72	85	278	10	4	1	1	1
76	EBYRNY73	100	316	15	7	2	2	2
45	BYRCT74	17	58	4	0.46	0.16	0.16	0.16
65	EBYRNY75	128	411	21	12	4	4	3
66	BYRNY76	223	729	37	25	8	8	6
46	BYRCT77	33	126	10	0.26	0.09	0.09	0.09
67	BYRNY78	20	65	2	0.26	0.09	0.09	0.07
68	BYRNY79	10	35	2	0.47	0.16	0.16	0.13
69	BYRNY80	12	38	2	1	0.45	0.45	0.32
47	EBYRCT81	45	172	14	2	1	1	1

Table 4. Estimated Load Reductions for the 15-month Period

Scenario	Runoff* (ac-ft)	TN (lbs)	TP (lbs)	Pathogens (in 10^{12} organism counts)			
				TC	FC	EC	ENT
Baseline	16,786	193,812	17,948	8,686	2,816	2,816	1,915
GI-1	12,449	168,258	13,876	6,080	1,974	1,974	1,353
GI-1: % reduction from baseline	25.8%	13.2%	22.7%	30.0%	29.9%	29.9%	29.4%
GI-2	12,022	166,757	13,613	6,038	1,958	1,958	1,335
GI-2: % reduction from baseline	28.4%	13.96%	24.2%	30.48%	30.5%	30.45%	30.3%
GI-3	14,886	182,272	16,098	7,438	2,414	2,414	1,650
GI-3: % reduction from baseline	11.3%	5.95%	10.3%	14.36%	14.3%	14.26%	13.9%

* Runoff generated from the first of the three EPA SWMM RUNOFF surfaces, that represents immediate response following the rainfall

APPENDIX A: IEC Data and Location Map

Interstate Environmental Commission

A NELAP Accredited laboratory

Byram River Ambient Water Quality Monitoring

Date of Sampling 7/6/2010 Investigation Number 17095 Sampling Team: Evelyn Powers, Caitlyn Nichols, Bate Ning

Weather: Hot, humid, 88° - 102° F Rain previous 24 hours 0.0" Source: USGS-Byram River @ Pemberwick

Station Number	Time DST	Temp Deg. C	Salinity PPT	Cond uS/CM	DO mg/L	pH S.U.	Depth inches	Velocity avg -f/s	Fecal Coliform MPN/ 100 ml	Total Coliform MPN/ 100 ml	Enterococcus MPN/ 100 ml	e. Coli MPN/ 100 ml	Turbidity NTU	Settleable Solids ml/l	Chlorides mg/l	Total Nitrogen* mg/l	Total Phosphorous mg/l
BR1	9:34	20.5	0.0	3	11.93	7.18	5	0.46	15	230	210	7	5	0.2	37	<1.22	<0.1
BR2	10:10	21.3	0.4	799	8.03	7.70	28	0.05	2,400	2,400	1,500	250	4	<0.1	145	<1.93	<0.1
BR3	10:24	23.9	0.6	1,254	8.64	7.70	3.75	0.51	430	4,600	390	150	5	0.1	262	<2.53	0.25
BR4	10:48	25.9	0.4	857	4.98	7.67	No depth	0.13	93	430	430	93	2	<0.1	149	<1.75	<0.1
BR5	11:11	24.7	0.3	666	9.80	7.87	11.5	0.22	230	430	430	230	3	<0.1	115	<1.24	<0.1
BR6	11:26	24.6	0.1	267	7.86	7.48	14	0.17	230	430	430	230	2	<0.1	43	<1.06	<0.1
BR7	11:41	27.6	0.2	539	13.24	8.56	22	0.05	43	230	23	43	2	<0.1	89	<1.36	<0.1
BR8	11:58	26.6	0.2	514	7.48	7.62	6.75	0.38	2,100	≥24,000	93	2,100	4	0.1	86	<1.47	<0.1
BR9	12:11	28.9	19.7	33,780	17.26	8.13	8	0.52	430	2,400	23	430	8	<0.1	11,446	<1.48	0.17
BR10	12:34	23.4	25.7	39,130	12.78	8.22	24	2.04	2,400	2,400	43	2,400	10	<0.1	13,496	<1.38	0.12

Results met all quality requirements

Station	Station Name	Station Description
BR1	Byram Lake Road	Intersection of Byram River and Byram Lake Rd.
BR2	200 Business Park	Behind 200 Business Park Dr. at the end of the parking lot. Adjacent to bridge /outfall pipe
BR3	Wampus Branch	Approach alongside road leading to athletic field, south of treatment plant
BR4	Cliffdale Road	Intersection of Byram River and Cliffdale Road (North Side of Bridge)
BR5	Sherwood Avenue	Intersection of Byram River and Sherwood Ave. Greenwich, CT
BR6	Riversville Road after Merritt Parkway	South side of bridge
BR7	Comly Avenue	Taken at north side of roadway bridge
BR8	777 West Putnam Building	Taken in back parking lot by closed bridge
BR9	Formerly Marvel Mystery	Taken behind building in back of parking lot at N. Main behind former Marvel Mystery.
BR10	Mill Street Bridge	Taken on North side of bridge

Station Number	Nitrite mg/l	Nitrate mg/l	Total K mg/l
BR1	ND	0.29	0.83
BR2	ND	0.91	0.92
BR3	ND	1.19	1.24
BR4	ND	0.54	1.11
BR5	ND	0.32	0.82
BR6	ND	0.28	0.68
BR7	ND	0.29	0.97
BR8	ND	0.28	1.09
BR9	ND	ND	1.28
BR10	ND	ND	1.18

* Total Nitrogen concentration was calculated by adding the concentrations of nitrate, nitrite and TKN. When one of these three components was not detected, the MDL of each non-detect was added to the total and a less than sign (<) was placed in front of it. Nitrate was not detected at any of the stations. The MDLs of nitrite, nitrate , TKN and total phosphorous were 0.1, 0.1, 0.4 and 0.1 mg/l respectively. These four parameters were analyzed by a contracted accredited laboratory.

Interstate Environmental Commission

A NELAP Accredited laboratory

Byram River Ambient Water Quality Monitoring

Date of Sampling 7/19/2010 | Investigation Number 17100 | Sampling Team: Evelyn Powers, Caitlyn Nichols, Bate Ning

Weather: Mostly cloudy, rain heavy at times 78° F | Rain previous 24 hours 0.47" | Source: USGS-Byram River @ Pemberwick

Rain during sampling event 0.29"

Station Number	Time DST	Temp Deg. C	Salinity PPT	Cond uS/CM	DO mg/L	pH S.U.	Depth inches	Velocity avg -f/s	Fecal Coliform MPN/ 100 ml	Total Coliform MPN/ 100 ml	Enterococcus MPN/ 100 ml	e. Coli MPN/ 100 ml	Turbidity NTU	Settleable Solids ml/l	Chlorides mg/l	Total Nitrogen* mg/l	Total Phosphorous mg/l
BR1	9:17	21.1	0.0	5	11.29	7.85	1.4	0.08	≥24,000	≥24,000	4,600	≥24,000	33	1.5	25	<3.45	0.27
BR2	9:37	21.0	0.4	754	9.10	7.73	3.4	0.34	2,400	≥24,000	4,600	2,400	28	0.7	134	<2.15	0.20
BR3	9:46	21.8	0.5	993	8.45	7.86	12	0.10	≥24,000	≥24,000	4,600	≥24,000	39.5	0.7	209	<3.40	0.38
BR4	10:12	23.7	0.4	715	5.45	7.49	17.5	0.06	930	4,600	2,400	930	11.5	<0.1	126	<1.93	0.19
BR5	10:25	22.7	0.3	691	9.33	7.92	7.75	0.27	4,600	4,600	4,600	4,600	3.5	<0.1	121	<1.80	0.16
BR6	10:34	23.7	0.1	233	6.36	6.88	15.5	0.15	4,600	11,000	11,000	4,600	2	0.4	37	<1.69	ND
BR7	10:52	24.8	0	67	10.18	8.10	10	0.66	430	4,600	2,400	430	2	0.1	74.5	<1.79	0.11
BR8	11:04	25.3	0.2	418	8.69	7.57	13.5	2.08	11,000	≥24,000	≥24,000	11,000	10.5	0.4	70	<1.68	0.22
BR9	11:18	24.4	7.3	12,650	7.22	7.31	7.5	1.08	≥24,000	≥24,000	≥24,000	≥24,000	12.5	0.3	3,824	<1.78	0.24
BR10	11:25	24.8	7.7	13,500	9.25	7.58	122	0.14	≥24,000	≥24,000	≥24,000	≥24,000	9	0.3	4,349	<2.07	0.25

Results met all quality requirements

Station	Station Name	Station Description
BR1	Byram Lake Road	Intersection of Byram River and Byram Lake Rd.
BR2	200 Business Park	Behind 200 Business Park Dr. at the end of the parking lot. Adjacent to bridge /outfall pipe
BR3	Wampus Branch	Approach alongside road leading to athletic field, south of treatment plant
BR4	Cliffdale Road	Intersection of Byram River and Cliffdale Road (North Side of Bridge)
BR5	Sherwood Avenue	Intersection of Byram River and Sherwood Ave. Greenwich, CT
BR6	Riversville Road after Merritt Parkway	South side of bridge
BR7	Comly Avenue	Taken at north side of roadway bridge
BR8	777 West Putnam Building	Taken in back parking lot by closed bridge
BR9	Formerly Marvel Mystery	Taken behind building in back of parking lot at N. Main behind former Marvel Mystery.
BR10	Mill Street Bridge	Taken on North side of bridge

Station Number	Nitrite mg/l	Nitrate mg/l	Total K mg/l
BR1	ND	1.03	2.32
BR2	ND	0.72	1.33
BR3	ND	1.01	2.29
BR4	ND	0.5	1.33
BR5	ND	0.34	1.36
BR6	ND	0.34	1.25
BR7	ND	0.28	1.41
BR8	ND	0.26	1.32
BR9	ND	0.4	1.28
BR10	ND	0.49	1.48

* Total Nitrogen concentration was calculated by adding the concentrations of nitrate, nitrite and TKN. When one of these three components was not detected, the MDL of each non-detect was added to the total and a less than sign (<) was placed in front of it. Nitrate was not detected at any of the stations. The MDLs of nitrite, nitrate , TKN and total phosphorous were 0.1, 0.1, 0.4 and 0.1 mg/l respectively. These four parameters were analyzed by a contracted accredited laboratory.

Interstate Environmental Commission

A NELAP Accredited laboratory

Byram River Ambient Water Quality Monitoring

Date of Sampling 8/3/2010 | Investigation Number 17106 | Sampling Team: Evelyn Powers, Caitlyn Nichols, Bate Ning

Weather: Partly cloudy, 77-82° F | Rain previous 24 hours 0.0" | Source: USGS-Byram River @ Pemberwick

Rain during sampling event 0.0"

Station Number	Time DST	Temp Deg. C	Salinity PPT	Cond uS/CM	DO mg/L	pH S.U.	Depth inches	Velocity avg -f/s	Fecal Coliform MPN/ 100 ml	Total Coliform MPN/ 100 ml	Enterococcus MPN/ 100 ml	e. Coli MPN/ 100 ml	Turbidity NTU	Settleable Solids ml/l	Chlorides mg/l	Total Nitrogen* mg/l	Total Phosphorous mg/l
BR1	9:41	20.3	0.1	210	11.25	7.73	3.1	0.04	15	93	210	7	8	0.2	40	<0.89	ND
BR2	10:00	20.2	0.1	672	9.15	7.77	38.15	0.07	930	2,400	150	930	4	<0.1	149	<1.33	ND
BR3	10:10	22.0	0.7	1,246	4.33	7.21	1.1	0.37	230	430	230	230	6	<0.1	248	<1.41	0.32
BR4	10:34	22.7	0.4	825	9.16	7.66	13	0.10	23	230	930	9	2	<0.1	138	<1.18	0.11
BR5	10:50	22.3	0.3	592	10.40	7.91	11	0.13	39	430	2,400	39	2	<0.1	102	<0.80	ND
BR6	11:00	22.7	0.1	249	8.17	7.44	6.7	0.04	390	750	930	390	2	<0.1	39	<0.75	ND
BR7	11:17	24.7	0.2	457	13.47	7.97	11.9	0.37	93	230	430	93	2	<0.1	81	<0.98	ND
BR8	11:30	23.8	0.2	478	10.99	7.42	7.75	0.26	2,400	4,600	230	2,400	2	<0.1	88	<1.01	ND
BR9	11:39	26.0	14.3	24,200	12.33	7.27	4.9	0.80	≥24,000	≥24,000	210	≥24,000	9	<0.1	8,148	<1.32	0.13
BR10	11:45	24.4	25.8	40,070	3.56	6.84	19.7	0.12	≥24,000	≥24,000	930	≥24,000	4	<0.1	9,997	<0.94	0.21

Results met all quality requirements

Station	Station Name	Station Description
BR1	Byram Lake Road	Intersection of Byram River and Byram Lake Rd.
BR2	200 Business Park	Behind 200 Business Park Dr. at the end of the parking lot. Adjacent to bridge /outfall pipe
BR3	Wampus Branch	Approach alongside road leading to athletic field, south of treatment plant
BR4	Cliffdale Road	Intersection of Byram River and Cliffdale Road (North Side of Bridge)
BR5	Sherwood Avenue	Intersection of Byram River and Sherwood Ave. Greenwich, CT
BR6	Riversville Road after Merritt Parkway	South side of bridge
BR7	Comly Avenue	Taken at north side of roadway bridge
BR8	777 West Putnam Building	Taken in back parking lot by closed bridge
BR9	Formerly Marvel Mystery	Taken behind building in back of parking lot at N. Main behind former Marvel Mystery.
BR10	Mill Street Bridge	Taken on North side of bridge

Station Number	Nitrite mg/l	Nitrate mg/l	Total K mg/l
BR1	ND	0.24	0.55
BR2	ND	0.71	0.52
BR3	ND	0.53	0.78
BR4	ND	0.42	0.66
BR5	ND	0.18	0.52
BR6	ND	ND	0.55
BR7	ND	0.28	0.6
BR8	ND	0.25	0.66
BR9	ND	ND	1.12
BR10	ND	ND	0.74

* Total Nitrogen concentration was calculated by adding the concentrations of nitrate, nitrite and TKN. When one of these three components was not detected, the MDL of each non-detect was added to the total and a less than sign (<) was placed in front of it. Nitrate was not detected at any of the stations. The MDLs of nitrite, nitrate , TKN and total phosphorous were 0.1, 0.1, 0.4 and 0.1 mg/l respectively. These four parameters were analyzed by a contracted accredited laboratory.

Interstate Environmental Commission

A NELAP Accredited laboratory

Byram River Ambient Water Quality Monitoring

Date of Sampling 8/16/2010 | Investigation Number 17110 | Sampling Team: Evelyn Powers, Caitlyn Nichols, Bate Ning

Weather: Cloudy, humid 72-86° F | Rain previous 24 hours 0.53" | Source: USGS-Byram River @ Pemberwick

Rain during sampling event 0.0"

Station Number	Time DST	Temp Deg. C	Salinity PPT	Cond uS/CM	DO mg/L	pH S.U.	Depth inches	Velocity avg -f/s	Fecal Coliform MPN/ 100 ml	Total Coliform MPN/ 100 ml	Enterococcus MPN/ 100 ml	e. Coli MPN/ 100 ml	Turbidity NTU	Settleable Solids ml/l	Chlorides mg/l	Total Nitrogen* mg/l	Total Phosphorous mg/l
BR1	12:12	21.0	0.1	270	9.34	7.17	1.5	0.04	930	4,600	930	930	17.5	1.5	39.5	<1.10	0.14
BR2	12:27	19.8	0.3	625	7.70	7.73	27.75	0.16	2,400	2,400	11,000	2,400	6.0	<0.1	93	<1.57	ND
BR3	12:37	27.8	0.2	428	8.00	7.65	2.875	0.92	2,400	11,000	930	2,400	5.5	0.1	181	<2.04	0.2
BR4	12:59	21.2	0.5	891	3.55	7.16	7.75	0.04	430	11,000	4,600	430	2.0	<0.1	185	<2.23	0.18
BR5	13:14	22.0	0.3	590	8.82	7.47	4.75	0.02	2,400	2,400	11,000	930	2.0	<0.1	99	<1.43	ND
BR6	13:25	22.3	0.1	256	9.55	7.05	8.125	0.36	930	4,600	2,400	930	6.5	0.5	43	<0.91	ND
BR7	13:33	23.5	0.2	450	9.96	7.40	11.25	0.47	150	430	230	150	2.0	<0.1	78.5	<1.19	ND
BR8	13:50	23.7	0.6	1,172	6.75	7.15	5.125	1.83	930	2,400	930	930	4.0	<0.1	273	<1.26	ND
BR9	14:03	24.6	12	19,150	5.82	7.40	9.5	1.63	≥24,000	≥24,000	930	≥24,000	7.0	<0.1	7248	<2.01	0.14
BR10	14:20	24.0	27	41,310	7.93	7.42	73.75	0.20	≥24,000	≥24,000	2,400	≥24,000	6.0	<0.1	9647	<1.38	0.13

Results met all quality requirements

Station	Station Name	Station Description
BR1	Byram Lake Road	Intersection of Byram River and Byram Lake Rd.
BR2	200 Business Park	Behind 200 Business Park Dr. at the end of the parking lot. Adjacent to bridge /outfall pipe
BR3	Wampus Branch	Approach alongside road leading to athletic field, south of treatment plant
BR4	Cliffdale Road	Intersection of Byram River and Cliffdale Road (North Side of Bridge)
BR5	Sherwood Avenue	Intersection of Byram River and Sherwood Ave. Greenwich, CT
BR6	Riversville Road after Merritt Parkway	South side of bridge
BR7	Comly Avenue	Taken at north side of roadway bridge
BR8	777 West Putnam Building	Taken in back parking lot by closed bridge
BR9	Formerly Marvel Mystery	Taken behind building in back of parking lot at N. Main behind former Marvel Mystery.
BR10	Mill Street Bridge	Taken on North side of bridge

Station Number	Nitrite mg/l	Nitrate mg/l	Total K mg/l
BR1	ND	0.29	0.71
BR2	ND	0.66	0.81
BR3	ND	0.78	1.16
BR4	ND	1.01	1.12
BR5	ND	0.65	0.68
BR6	ND	0.19	0.62
BR7	ND	0.37	0.72
BR8	ND	0.21	0.95
BR9	ND	0.37	1.54
BR10	ND	0.36	0.92

* Total Nitrogen concentration was calculated by adding the concentrations of nitrate, nitrite and TKN. When one of these three components was not detected, the MDL of each non-detect was added to the total and a less than sign (<) was placed in front of it. Nitrate was not detected at any of the stations. The MDLs of nitrite, nitrate , TKN and total phosphorous were 0.1, 0.1, 0.4 and 0.1 mg/l respectively. These four parameters were analyzed by a contracted accredited laboratory.

Interstate Environmental Commission

A NELAP Accredited laboratory

Byram River Ambient Water Quality Monitoring

Date of Sampling	9/8/2011	Investigation Number	17232	Sampling Team:	Evelyn Powers, Caitlyn Nichols
Weather:	Cloudy, becoming Sunny humid 70's° F	Rain for the previous 24 hours	2.90"	Source:	USGS-Byram River @ Pemberwick
		Rain for the previous 48 hours	6.14"		

Station Number	Time DST	Temp Deg. C	Cond uS/CM	DO mg/L	pH S.U.	Depth inches	Velocity avg -f/s	Fecal Coliform MPN/ 100 ml	Total Coliform MPN/ 100 ml	Enterococcus MPN/ 100 ml	e. Coli MPN/ 100 ml	Turbidity NTU	Settleable Solids ml/l	Chlorides mg/l	Total Nitrogen* mg/l	Total Phosphorous mg/l
BR1	10:49	21.8	234	7.58	8.02	31	1.57	230	750	230	230	4.0	<0.1	47.5	<1.33	<0.1
BR2	11:03	18.3	111	7.38	7.59	62	2.42	2,400	≥24,000	11,000	2,400	33.5	0.2	15.5	2.08	0.13
BR3	11:30	18.7	125	7.18	7.37	66	2.53	≥24,000	≥24,000	11,000	≥24,000	21.0	<0.1	18.0	1.69	0.11
BR4	12:10	18.4	44	8.80	7.58		14.27	4,600	11,000	4,600	4,600	27.5	0.2	18.0	2.04	0.14
BR5	12:40	18.9	139	8.06	7.73		3.89	4,600	≥24,000	9	4,600	28.5	0.3	19.0	2.51	0.14
BR6	13:05	19.1	110	9.79	7.72		4.01	4,600	11,000	4,800	4,600	15.0	<0.1	13.5	1.27	0.10
BR7	13:30	18.9	49	9.50	7.66	69.6	3.96	2,400	≥24,000	≥24,000	2,400	22.0	0.2	16.5	1.74	0.12
BR8	13:47	19.0	127	10.25	7.63		3.22	2,400	≥24,000	≥24,000	4,600	23.0	0.2	16.5	1.85	0.14
BR9	14:10	19.7	140	8.68	8.02	32	3.64	1,000	≥24,000	≥24,000	1,000	22.5	0.2	25.5	1.89	0.16
BR10	14:37	19.2	101	9.24	7.57		4.16	11,000	≥24,000	11,000	11,000	22.5	0.2	19.0	2.8	0.16

Results met all quality requirements

Station	Station Name	Station Description
BR1	Byram Lake Road	Intersection of Byram River and Byram Lake Rd.
BR2	200 Business Park	Behind 200 Business Park Dr. at the end of the parking lot. Adjacent to bridge /outfall pipe
BR3	Wampus Branch	Approach alongside road leading to athletic field, south of treatment plant
BR4	Cliffdale Road	Intersection of Byram River and Cliffdale Road (North Side of Bridge)
BR5	Sherwood Avenue	Intersection of Byram River and Sherwood Ave. Greenwich, CT
BR6	Riversville Road after Merritt Parkway	South side of bridge
BR7	Comly Avenue	Taken at north side of roadway bridge
BR8	777 West Putnam Building	Taken in back parking lot by closed bridge
BR9	Formerly Marvel Mystery	Taken behind building in back of parking lot at N. Main behind former Marvel Mystery.
BR10	Mill Street Bridge	Taken on North side of bridge

Station Number	Nitrate-Nitrate mg/l	TKN mg/l
BR1	<0.1	1.23
BR2	0.47	1.61
BR3	0.50	1.19
BR4	0.48	1.56
BR5	0.48	2.03
BR6	0.52	0.75
BR7	0.60	1.14
BR8	0.63	1.22
BR9	0.71	1.18
BR10	0.71	2.09

* Total Nitrogen concentration was calculated by adding the concentrations of nitrate-nitrite and TKN. When one of these two components was not detected, the MDL of each non-detect was added to the total and a less than sign (<) was placed in front of it. The MDLs of nitrate-nitrite , TKN and total phosphorous were 0.1, 0.4 and 0.1 mg/l respectively. These three parameters were analyzed by a contracted accredited laboratory.

Interstate Environmental Commission

A NELAP Accredited laboratory

Byram River Ambient Water Quality Monitoring

Date of Sampling 9/20/2011 | Investigation Number 17247 | Sampling Team: Evelyn Powers, Caitlyn Nichols

Weather: Cloudy | Rain for the previous 24 hours 0.0" | Source: USGS-Byram River @ Pemberwick

Rain for the previous 48 hours 0.0"

Station Number	Time DST	Temp Deg. C	Cond uS/CM	DO mg/L	pH S.U.	Depth inches	Velocity avg -f/s	Fecal Coliform MPN/ 100 ml	Total Coliform MPN/ 100 ml	Enterococcus MPN/ 100 ml	e. Coli MPN/ 100 ml	Turbidity NTU	Settleable Solids ml/l	Chlorides mg/l	Total Nitrogen* mg/l	Total Phosphorous mg/l
BR1	8:24	19.3	242	8.09	7.98	12.6	0.23	9	230	<3	9	3.5	<0.1	49.5	<0.78	<0.1
BR2	8:38	15.5	392	10.62	8.01	38.4	0.32	150	930	230	150	3.0	<0.1	80.5	1.37	<0.1
BR3	8:50	15.1	520	9.81	7.61	19.2	0.05	430	2,400	15	430	3.0	<0.1	103.5	1.60	<0.1
BR4	9:11	15.3	425	11.17	7.97	24	0.32	93	430	93	93	5.0	<0.1	83.5	1.45	<0.1
BR5	9:27	15.1	90	9.97	8.20	31.2	0.23	75	430	9	75	4.0	<0.1	79.5	1.41	<0.1
BR6	9:36	15.5	189	9.89	8.29	43.2	0.04	93	930	43	93	2.0	<0.1	32.5	1.30	<0.1
BR7	9:48	16.0	323	10.56	8.07	29.4	0.12	93	430	21	93	3.0	<0.1	61.0	1.33	<0.1
BR8	10:02	16.0	326	10.35	8.16	37.2	0.68	150	430	93	150	3.0	<0.1	60.0	7.16	<0.1
BR9	10:14	17.0	1,110	12.83	8.27	63	0.81	640	1,200	15	1,200	2.0	<0.1	337.5	1.32	<0.1
BR10	10:22	17.2	6,860	9.28	7.75	36	0.03	930	2,400	23	930	2.5	<0.1	775.0	1.24	<0.1

Results met all quality requirements

Station	Station Name	Station Description
BR1	Byram Lake Road	Intersection of Byram River and Byram Lake Rd.
BR2	200 Business Park	Behind 200 Business Park Dr. at the end of the parking lot. Adjacent to bridge /outfall pipe
BR3	Wampus Branch	Approach alongside road leading to athletic field, south of treatment plant
BR4	Cliffdale Road	Intersection of Byram River and Cliffdale Road (North Side of Bridge)
BR5	Sherwood Avenue	Intersection of Byram River and Sherwood Ave. Greenwich, CT
BR6	Riversville Road after Merritt Parkway	South side of bridge
BR7	Comly Avenue	Taken at north side of roadway bridge
BR8	777 West Putnam Building	Taken in back parking lot by closed bridge
BR9	Formerly Marvel Mystery	Taken behind building in back of parking lot at N. Main behind former Marvel Mystery.
BR10	Mill Street Bridge	Taken on North side of bridge

Station Number	Nitrate-Nitrate mg/l	TKN mg/l
BR1	<0.1	0.68
BR2	0.62	0.75
BR3	0.81	0.79
BR4	0.63	0.82
BR5	0.67	0.74
BR6	0.57	0.73
BR7	0.66	0.67
BR8	0.72	6.44
BR9	0.67	0.65
BR10	0.64	0.6

* Total Nitrogen concentration was calculated by adding the concentrations of nitrate-nitrite and TKN. When one of these two components was not detected, the MDL of each non-detect was added to the total and a less than sign (<) was placed in front of it. The MDLs of nitrate-nitrite , TKN and total phosphorous were 0.1, 0.4 and 0.1 mg/l respectively. These three parameters were analyzed by a contracted accredited laboratory.

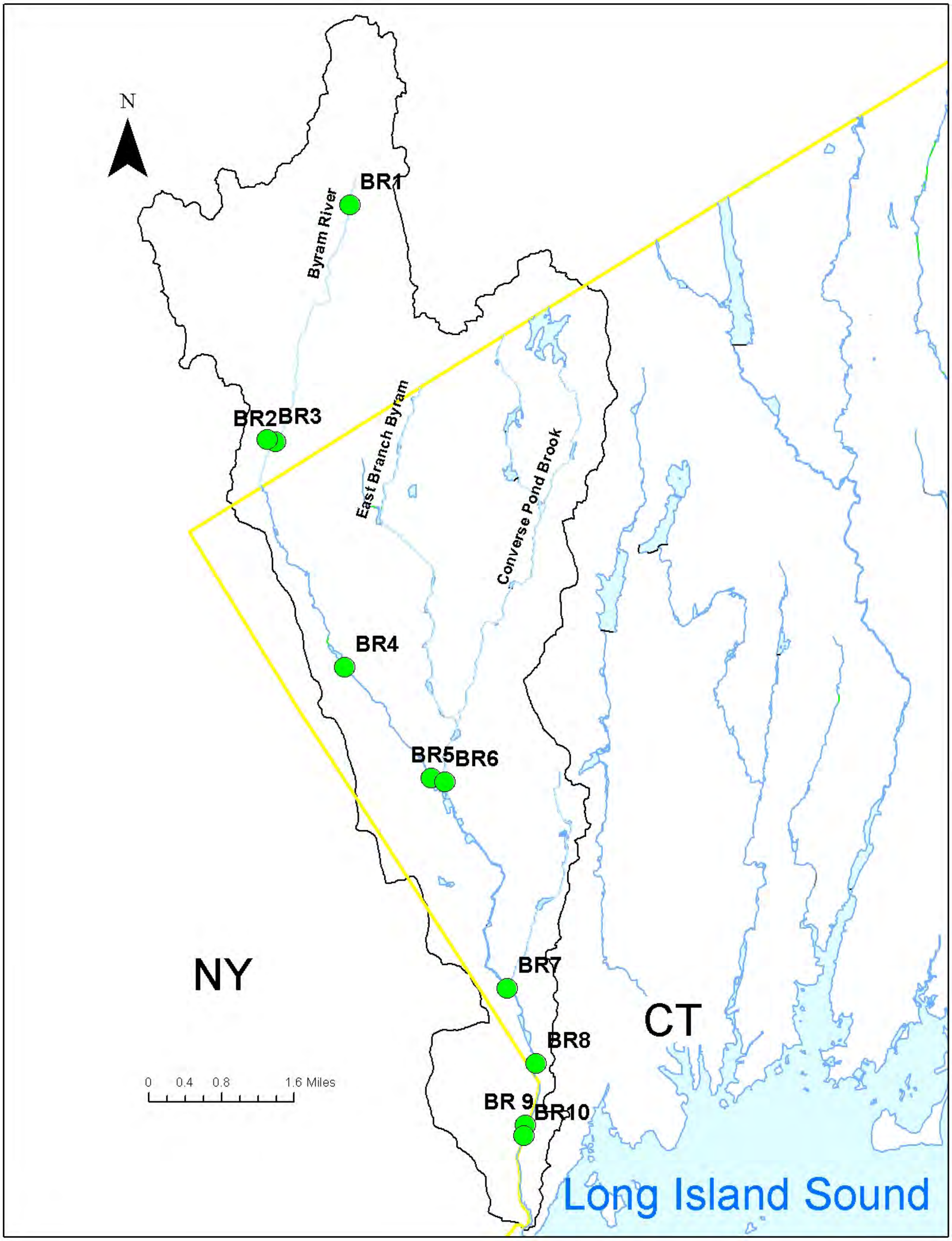
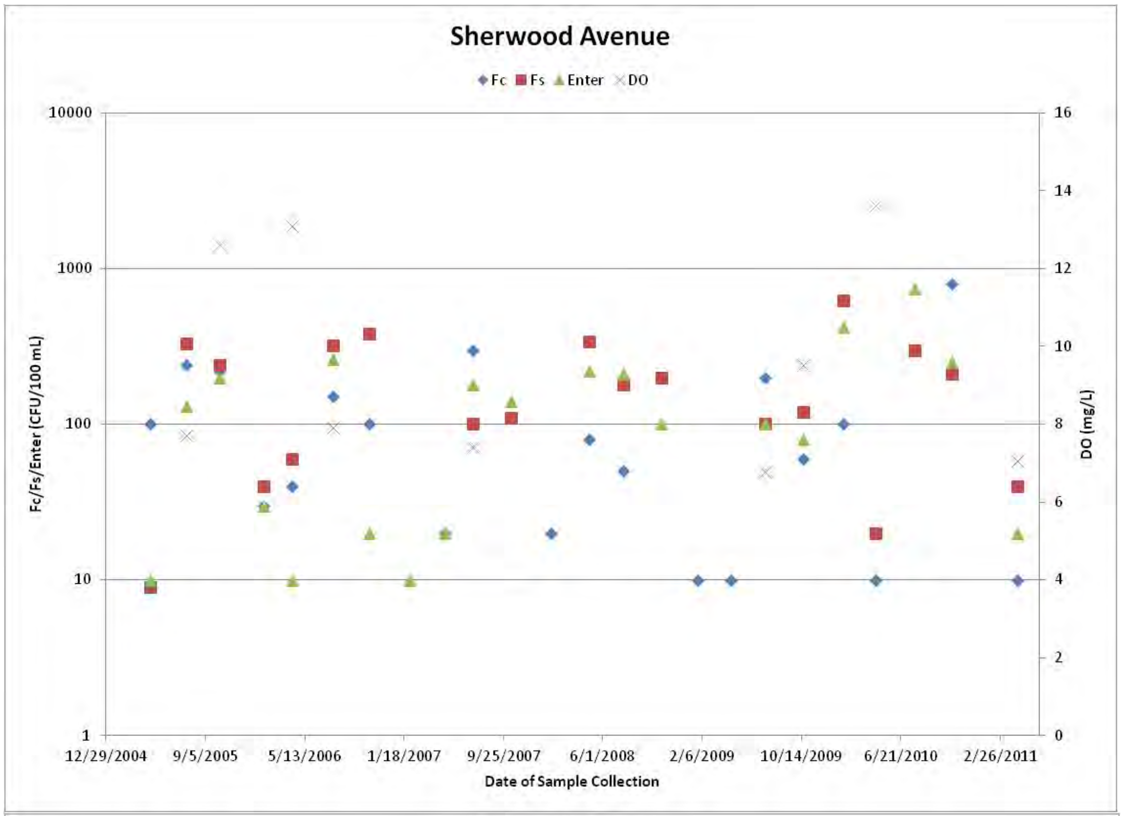


Figure A-1: IEC Water Quality Monitoring Locations in the Byram River Watershed

<u>APPENDIX B:</u> Trend Analysis for the Water Quality Data Collected at the Township of Greenwich Quarterly Survey and Special Survey Locations (Descriptions on these locations are provided in the table below)

Location ID	**Address**
BR01	**Sherwood Avenue**
BR02	**Riversville Road**
BR03	**Upland Road**
BR04	Mill Street Bridge
BR05	Greenwich Bay Marina
BR06	Rudy's Boatyard
BR07	192 Byram Shore Road
SBR01	**215 John Street**
SBR02	**105 Porchuck Road**
SBR03	**Sherwood Avenue**
SBR04	**Riversville Road @ Parkway**
SBR05	**Riversville Road @ Bailiwick Road**
SBR06	**Glenville St. Bridge**
SBR08	**Den Lane**
SBR09	**777 West Putnam Avenue**
SBR10	Port Chester Pump Stn.
SBR11	Cunningham's Auto Body
SBR12	99 Mill St. Bridge
SBR13	Greenwich Bay Marina
SBR14	Rudy's Boat Yard
SBR15	192 Byram Shore Road

* Graphics are prepared only for locations highlighted in bold. Other locations are in the Tidal Zone located South of Route 1 Bridge.
| Due to proximity of some of the monitoring locations, model output from a single model stream segment was used for graphic preparation.



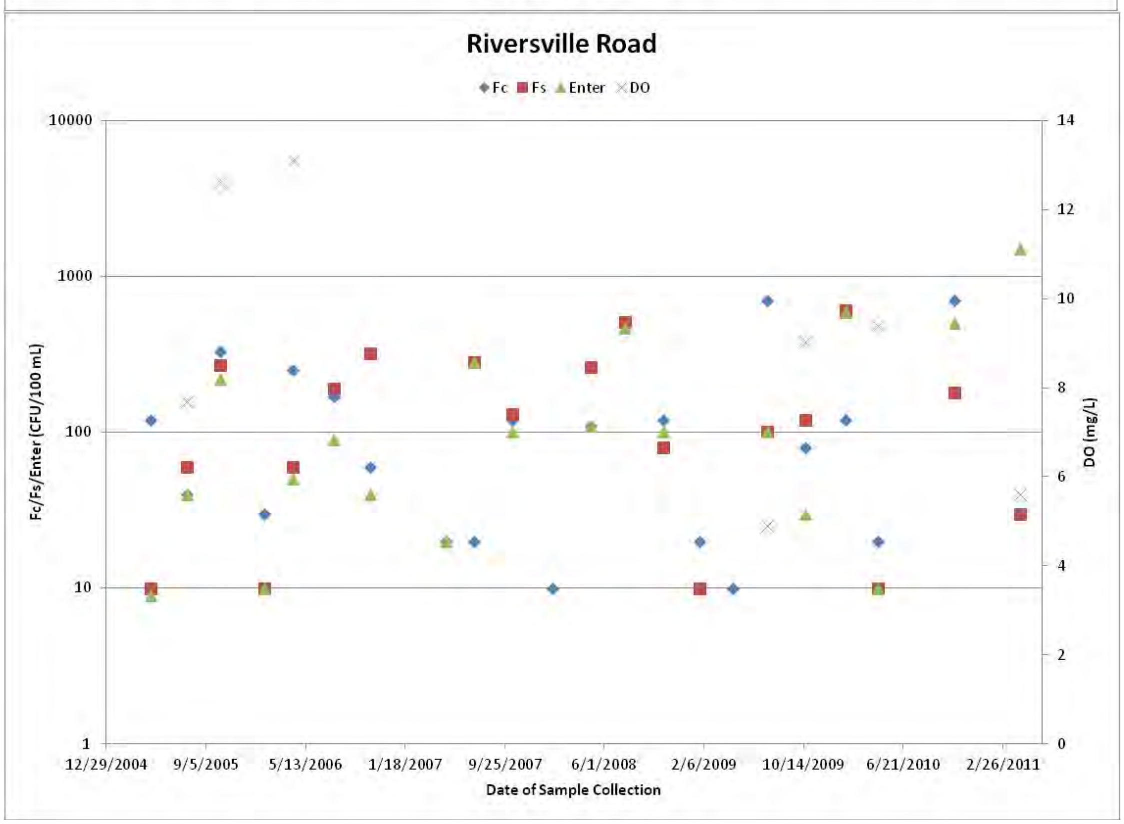
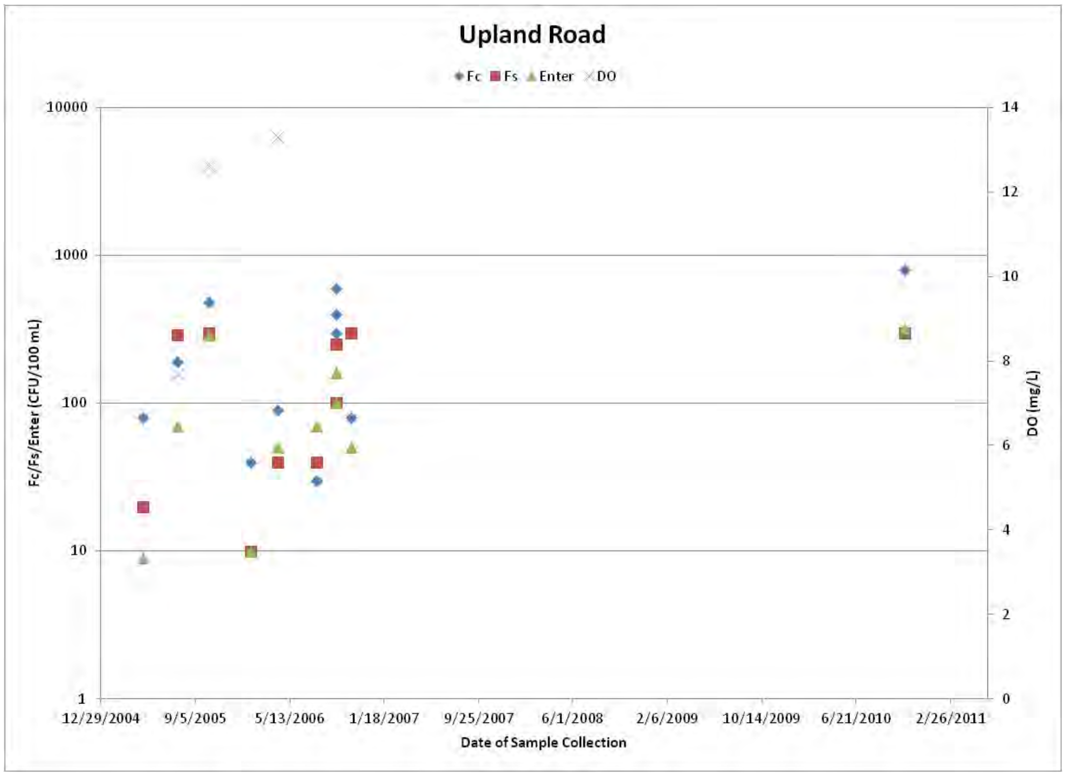


Figure B-1: ToG Water Quality Data Analysis at BR01 and BR02



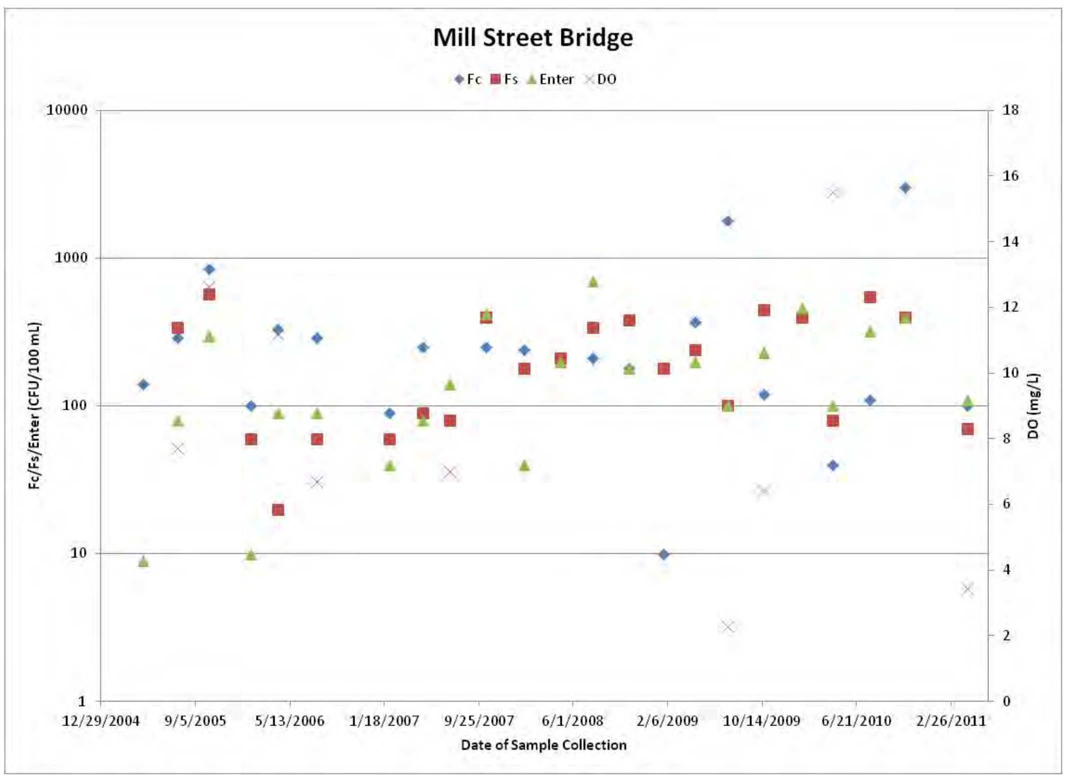
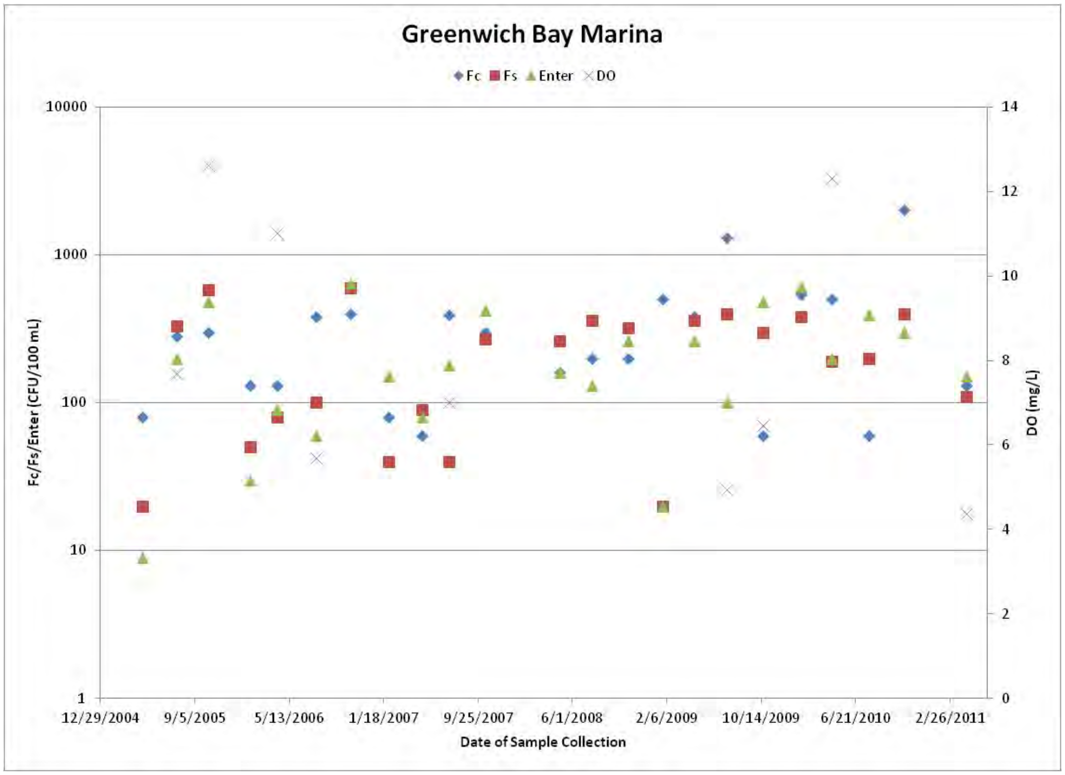


Figure B-2: ToG Water Quality Data Analysis at BR03 and BR04



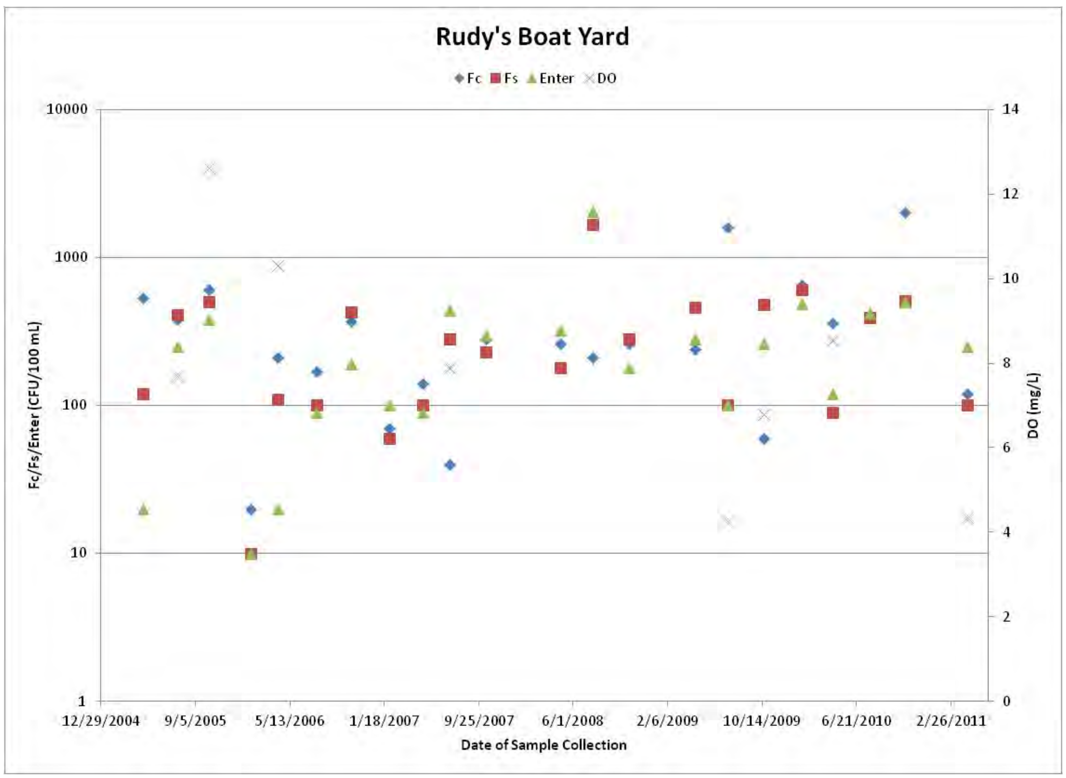


Figure B-3: ToG Water Quality Data Analysis at BR05 and BR06

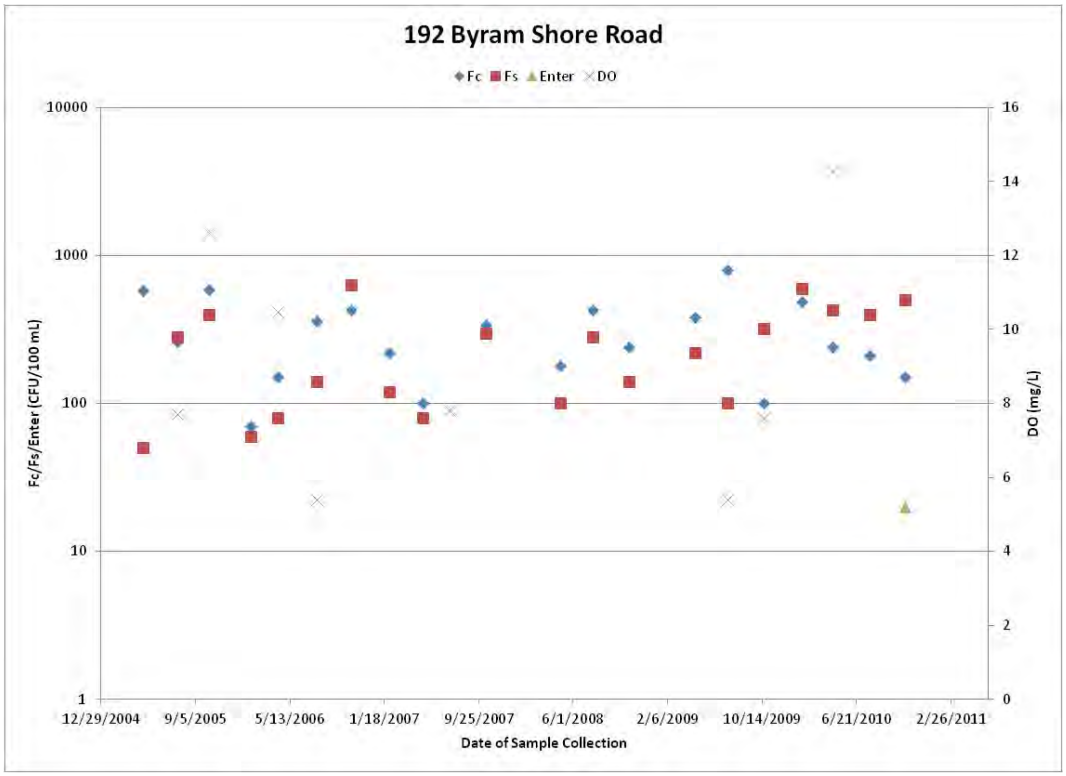
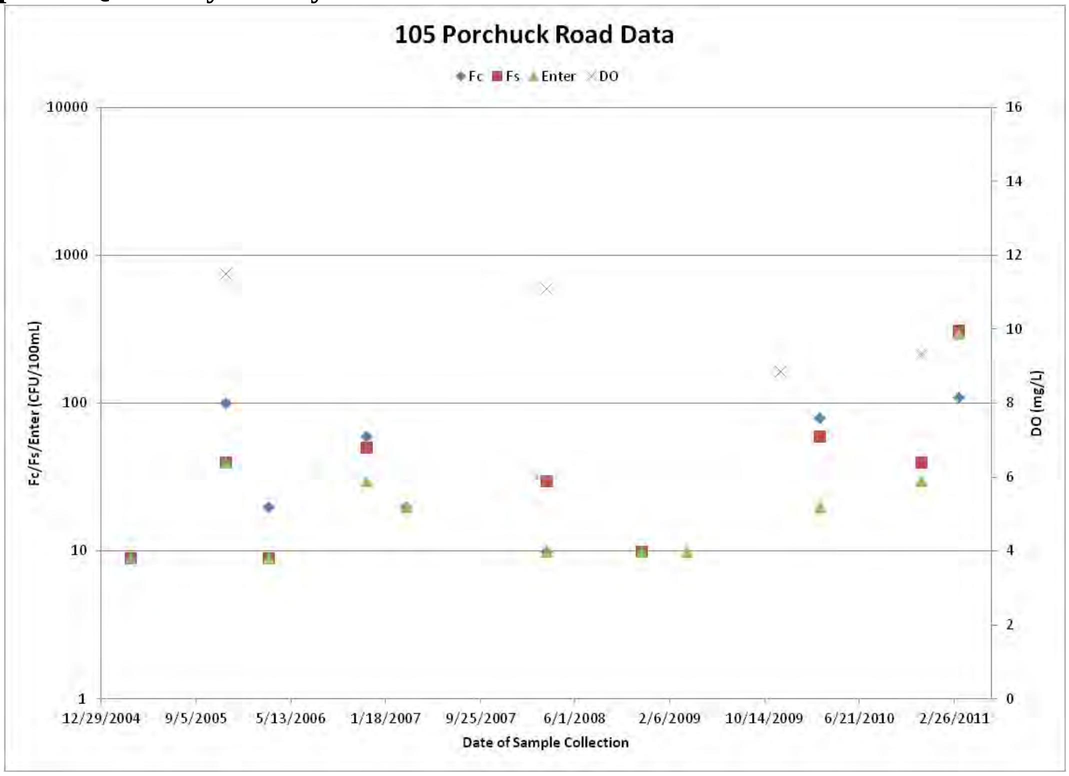


Figure B-4: ToG Water Quality Data Analysis at BR07

ToG Special Quarterly Survey Locations



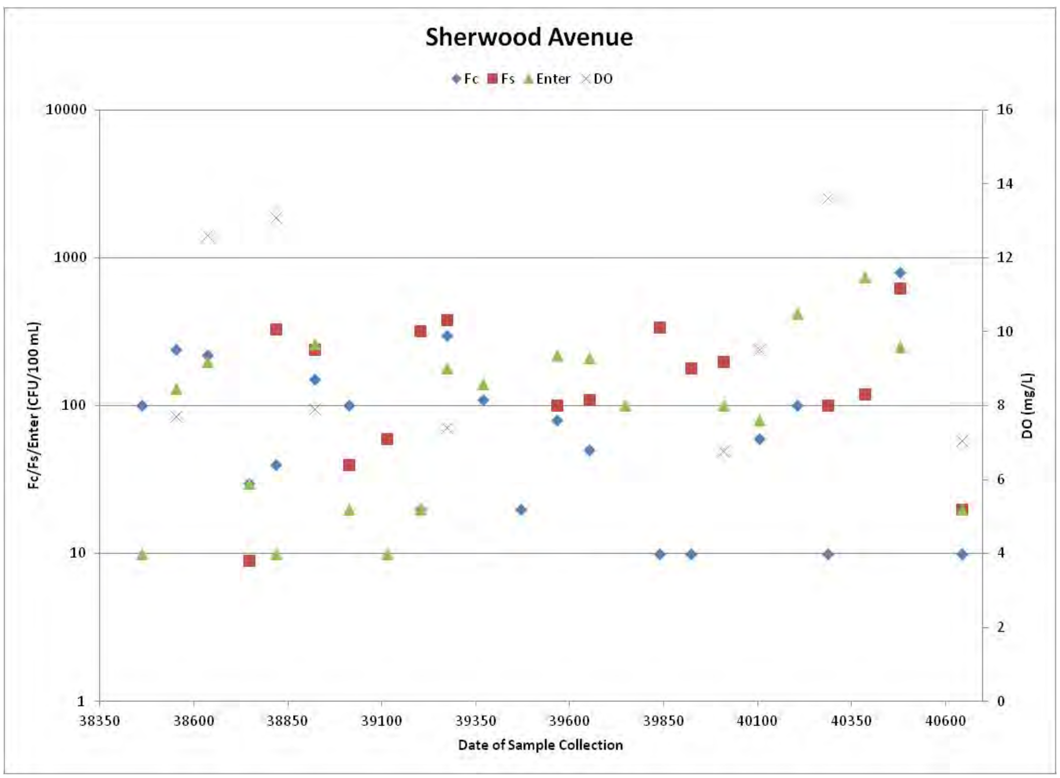
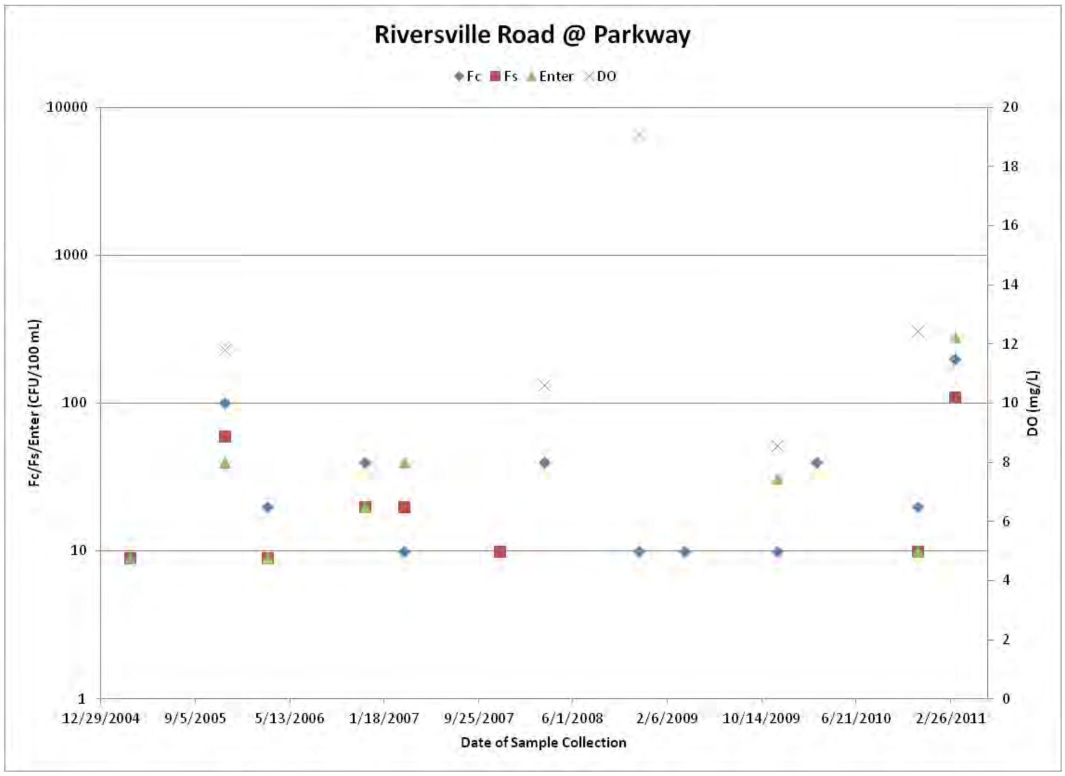


Figure B-5: ToG Water Quality Data Analysis at SBR02 and SBR03



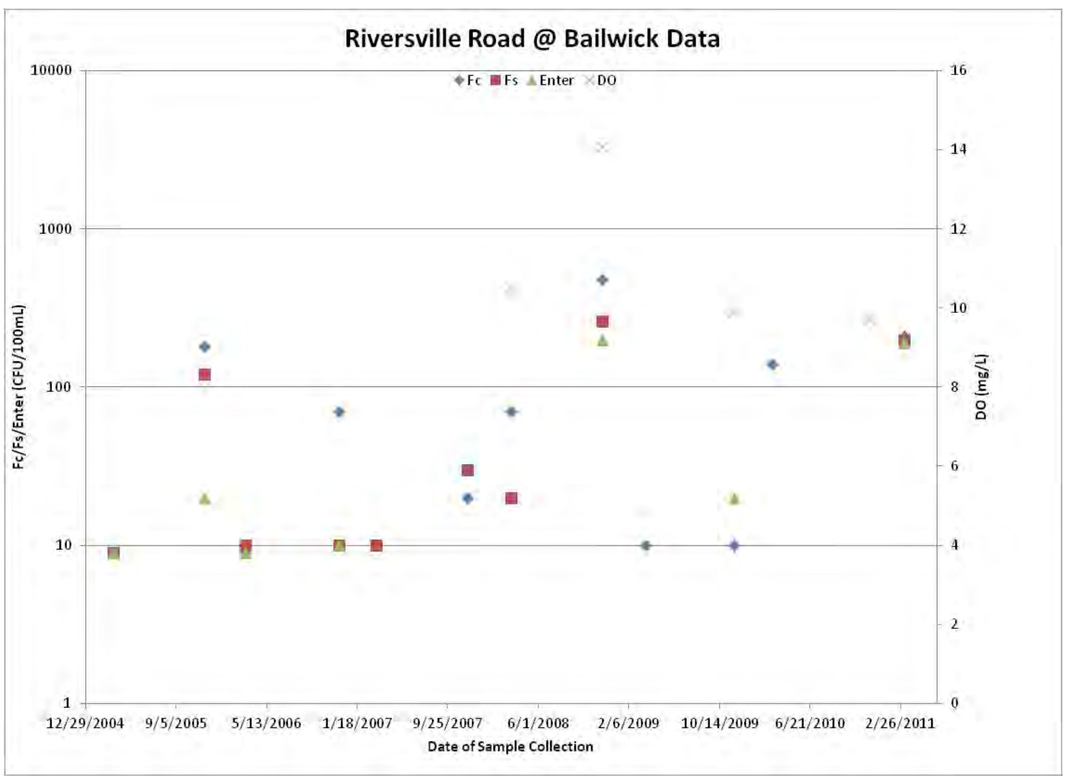


Figure B-6: ToG Water Quality Data Analysis at SBR04 and SBR05

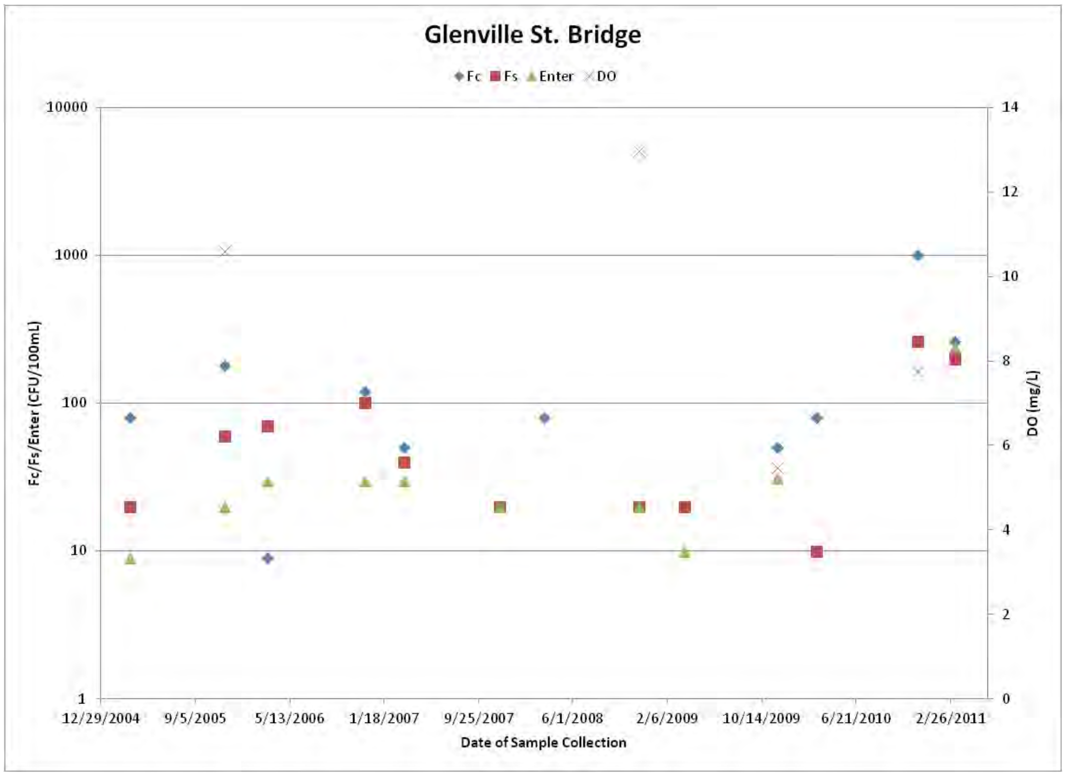
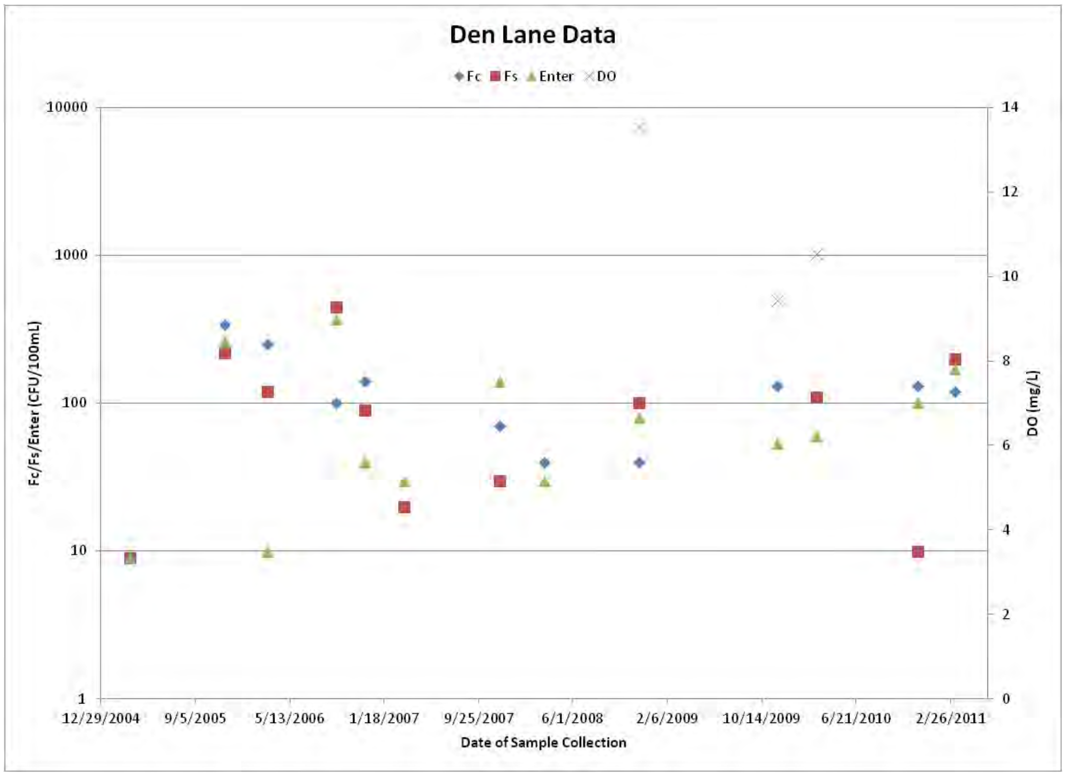


Figure B-7: ToG Water Quality Data Analysis at SBR06 and SBR07



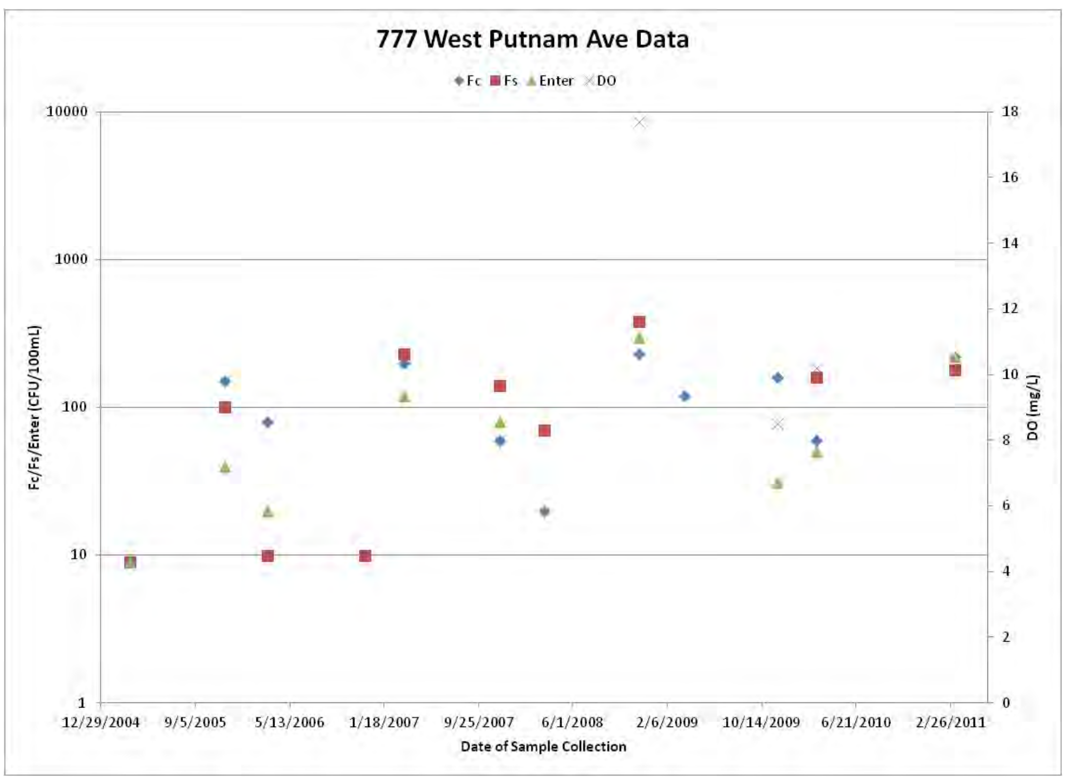
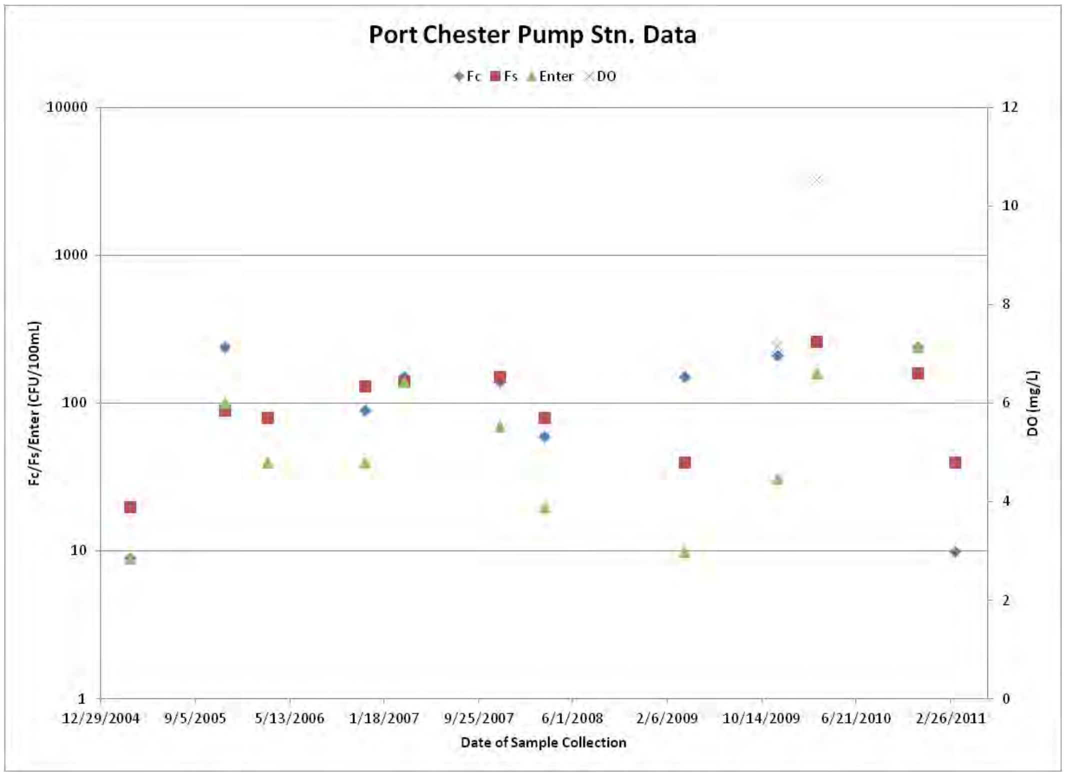


Figure B-8: ToG Water Quality Data Analysis at SBR08 and SBR09



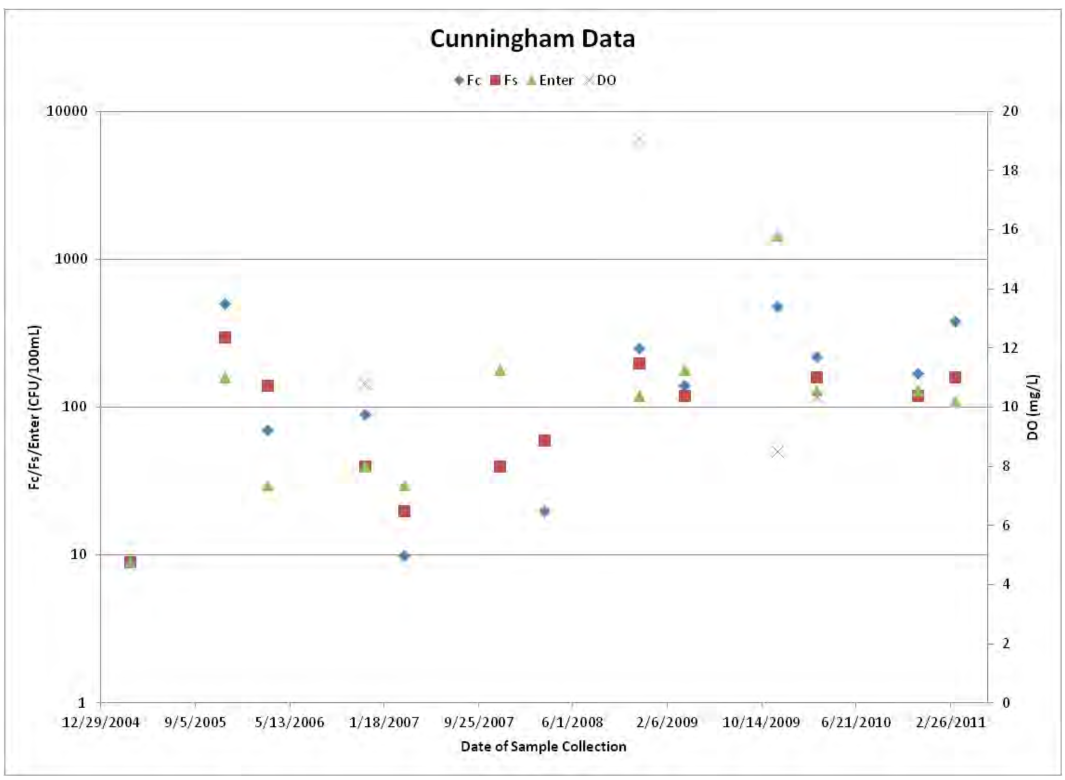
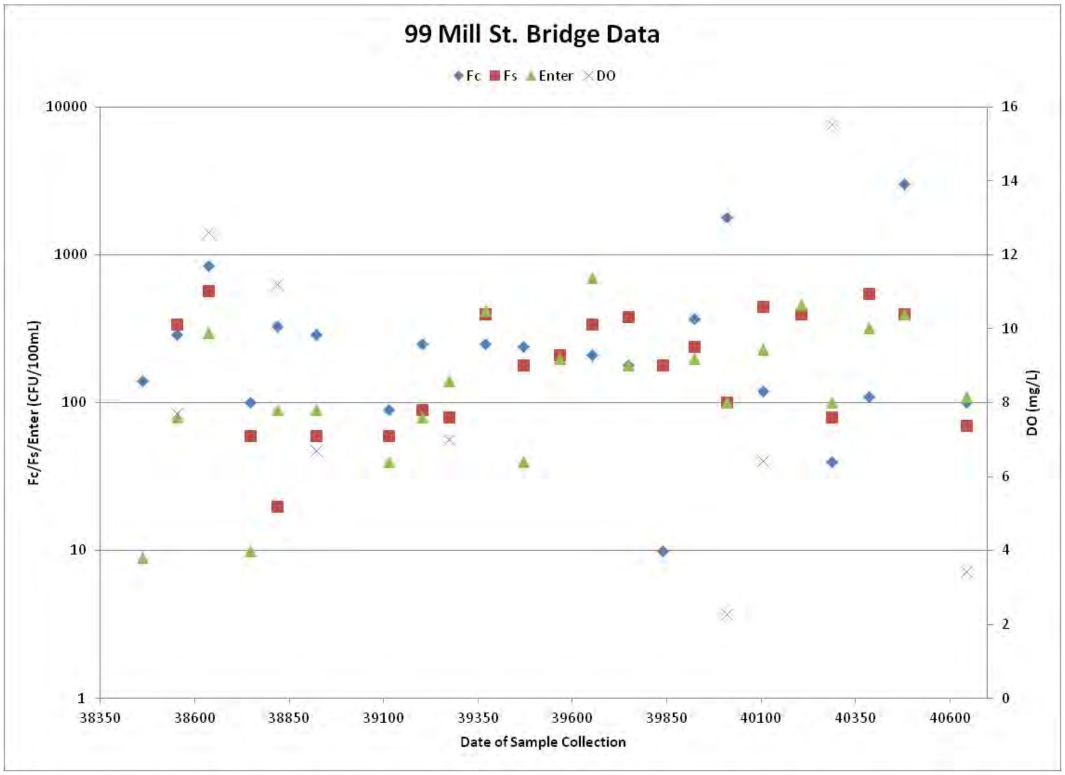


Figure B-9: ToG Water Quality Data Analysis at SBR10 and SBR11



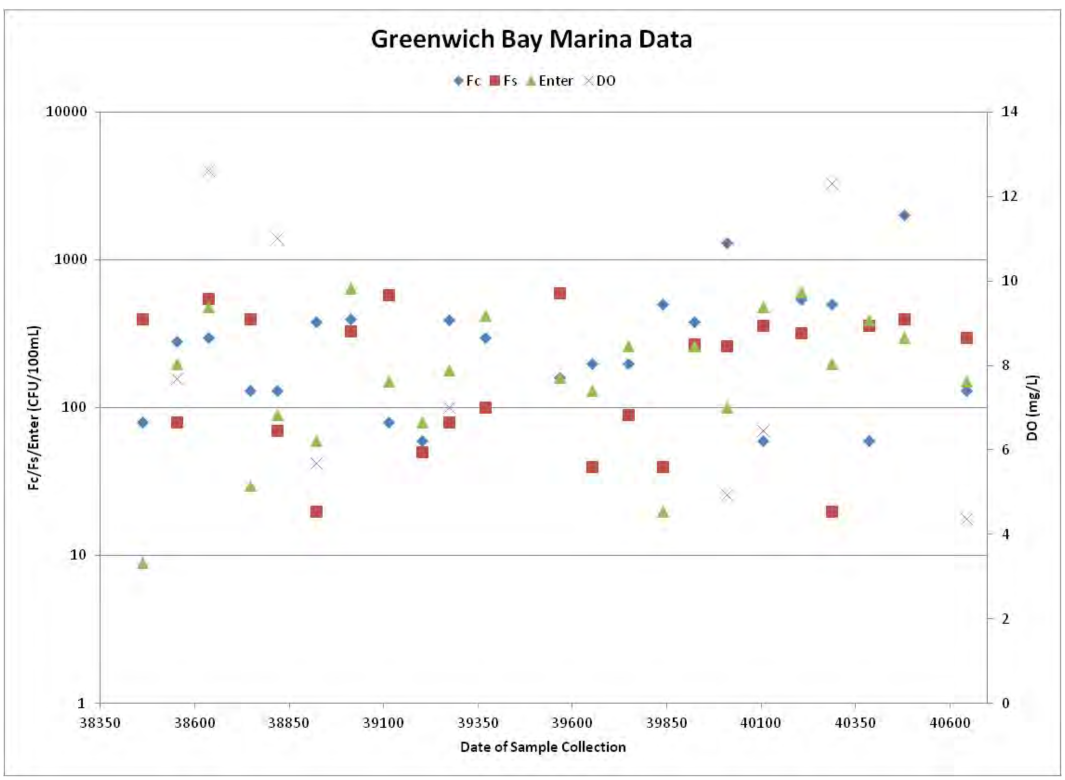
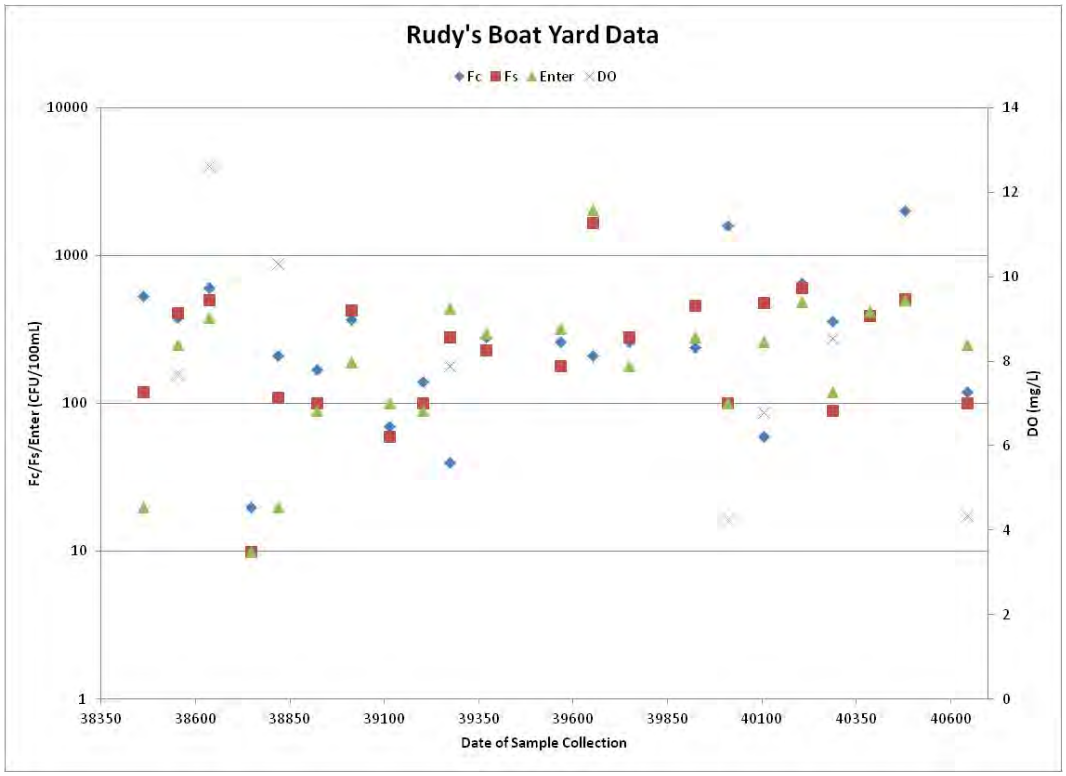


Figure B-10: ToG Water Quality Data Analysis at SBR12 and SBR13



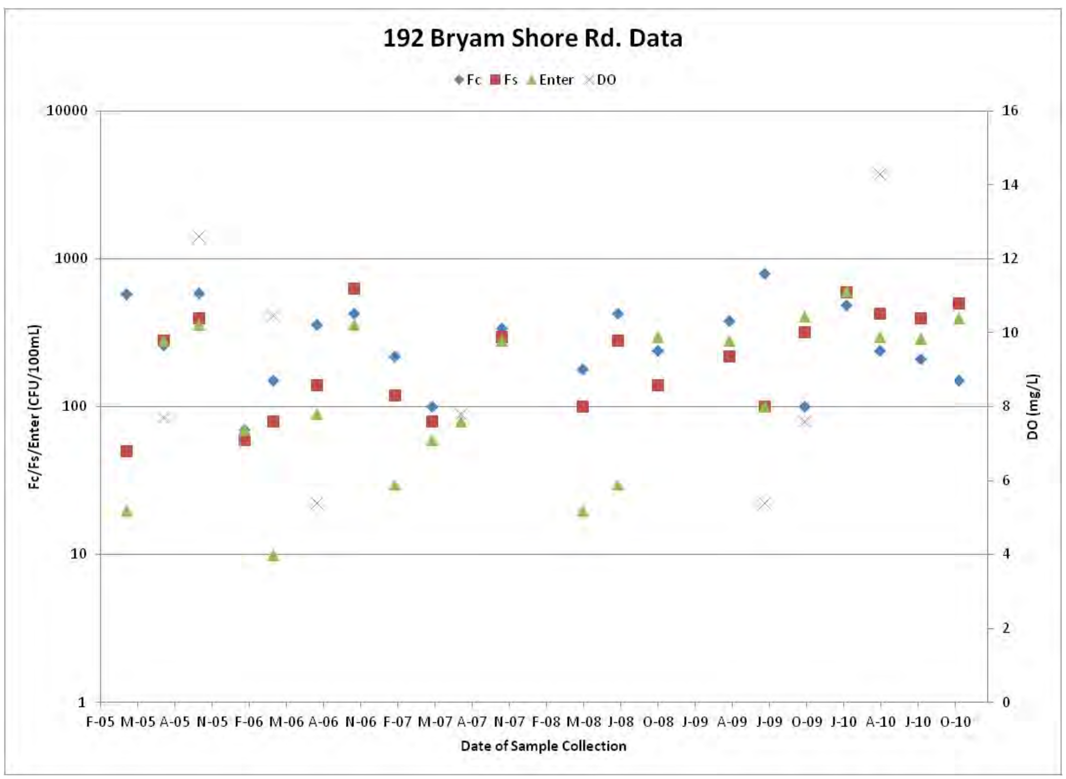


Figure B-11: ToG Water Quality Data Analysis at SBR14 and SBR15

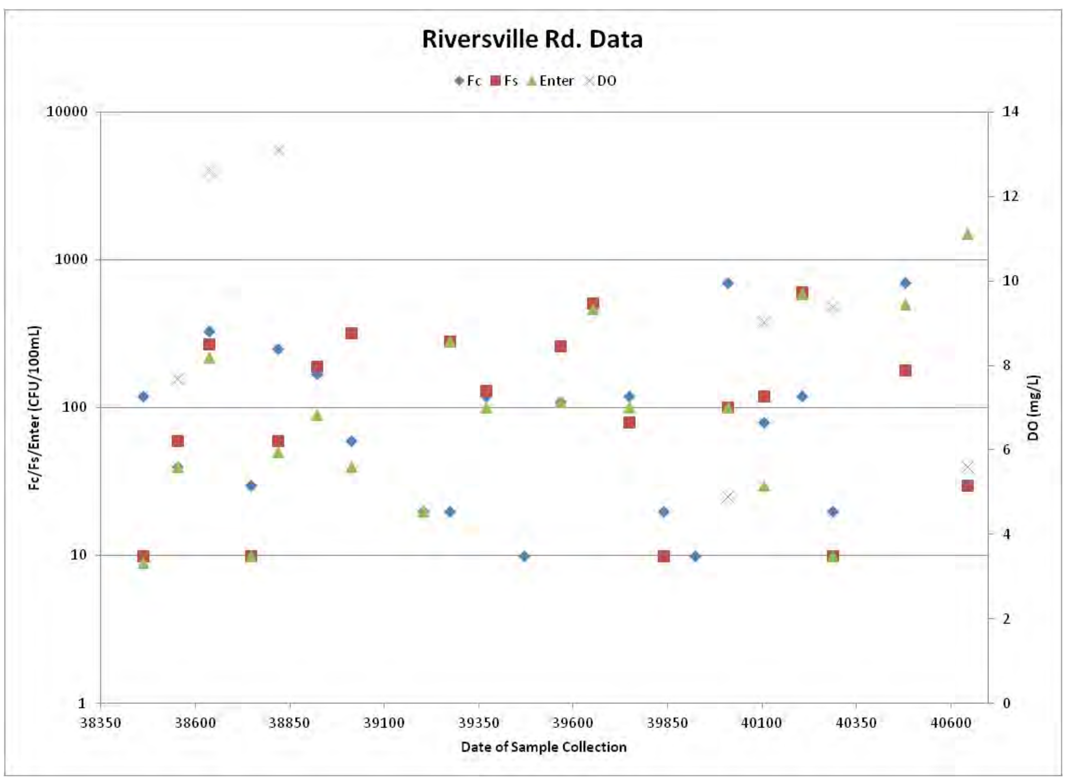


Figure B-12: ToG Water Quality Data Analysis at SBR01 and BR02

Appendix C: Model Calibration/Validation Comparisons at the ToG Quarterly/Special Survey Locations

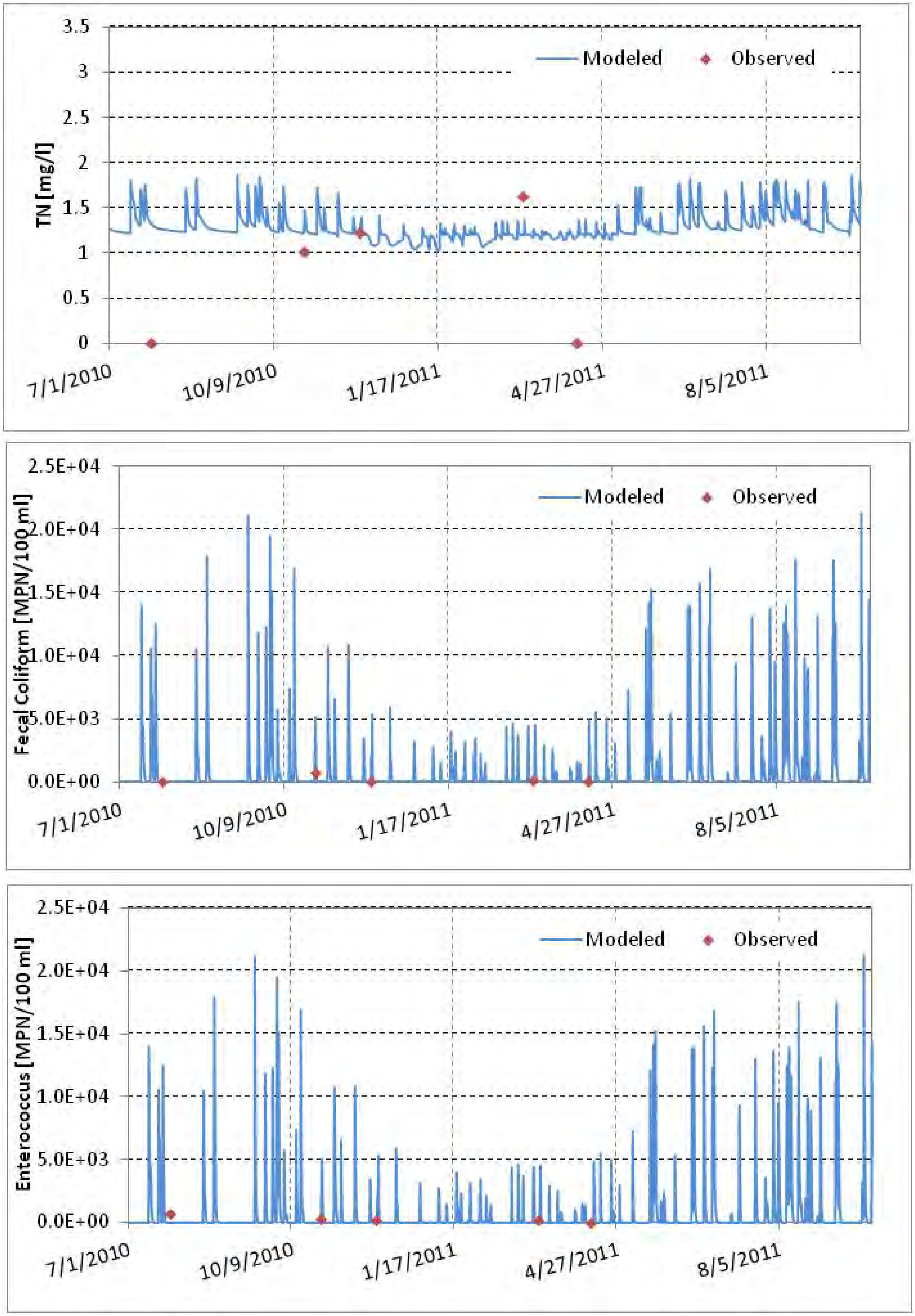


Figure C-1: Time Series Plots of TN, FC and ENT for BR01/SBR03

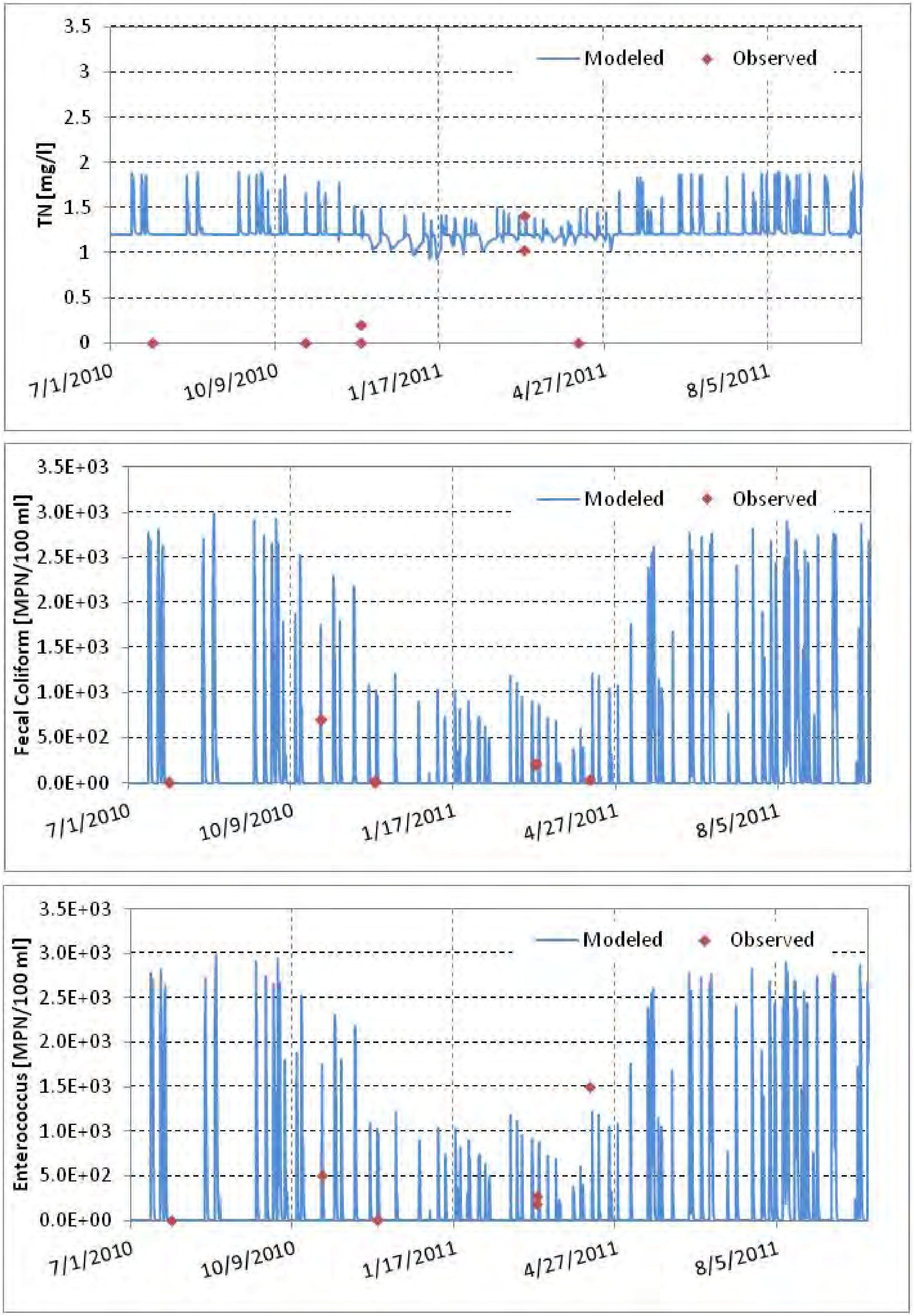


Figure C-2: Time Series Plots of TN, FC and ENT for BR02/SBR04/SBR05

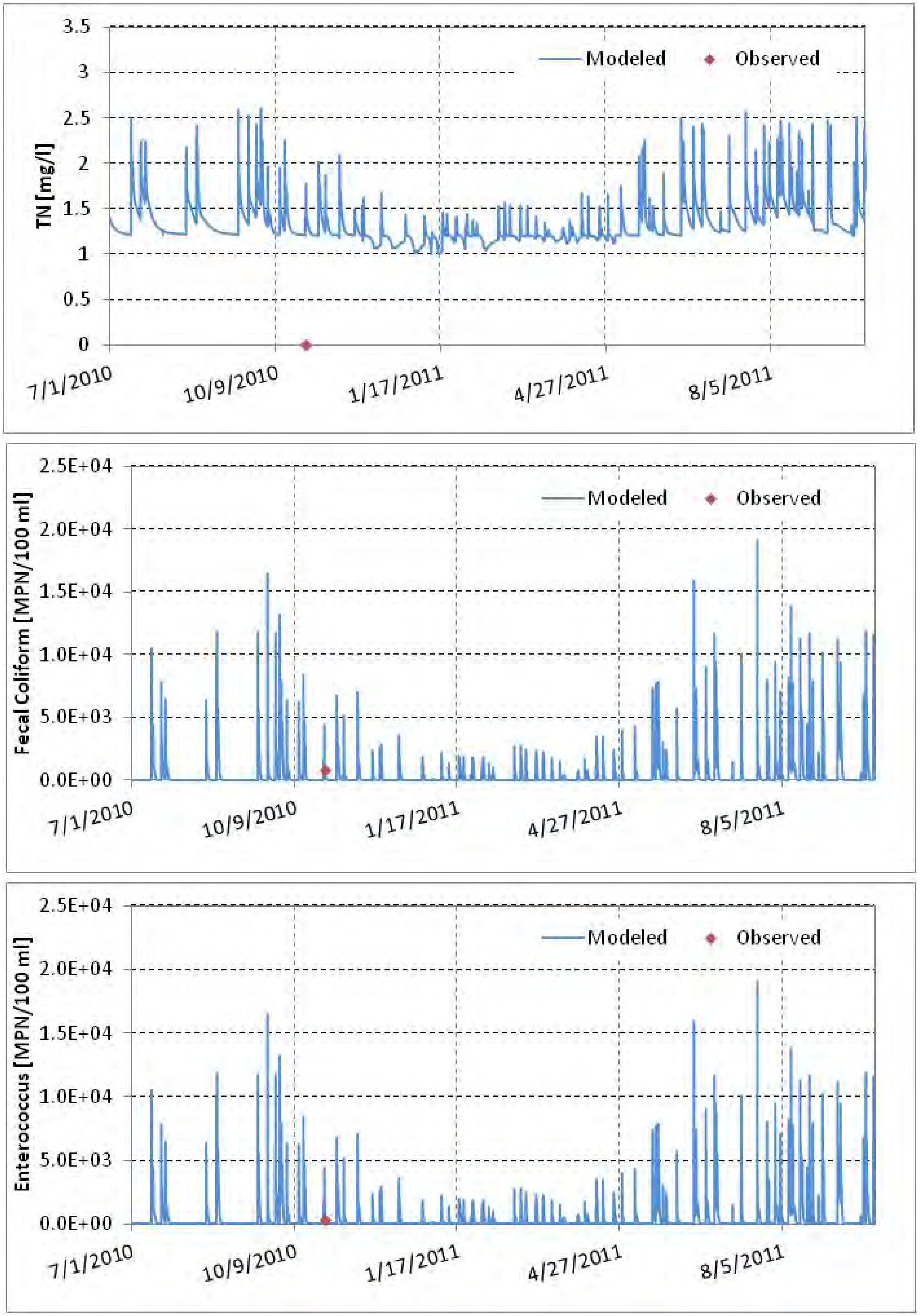


Figure C-3: Time Series Plots of TN, FC and ENT for BR03

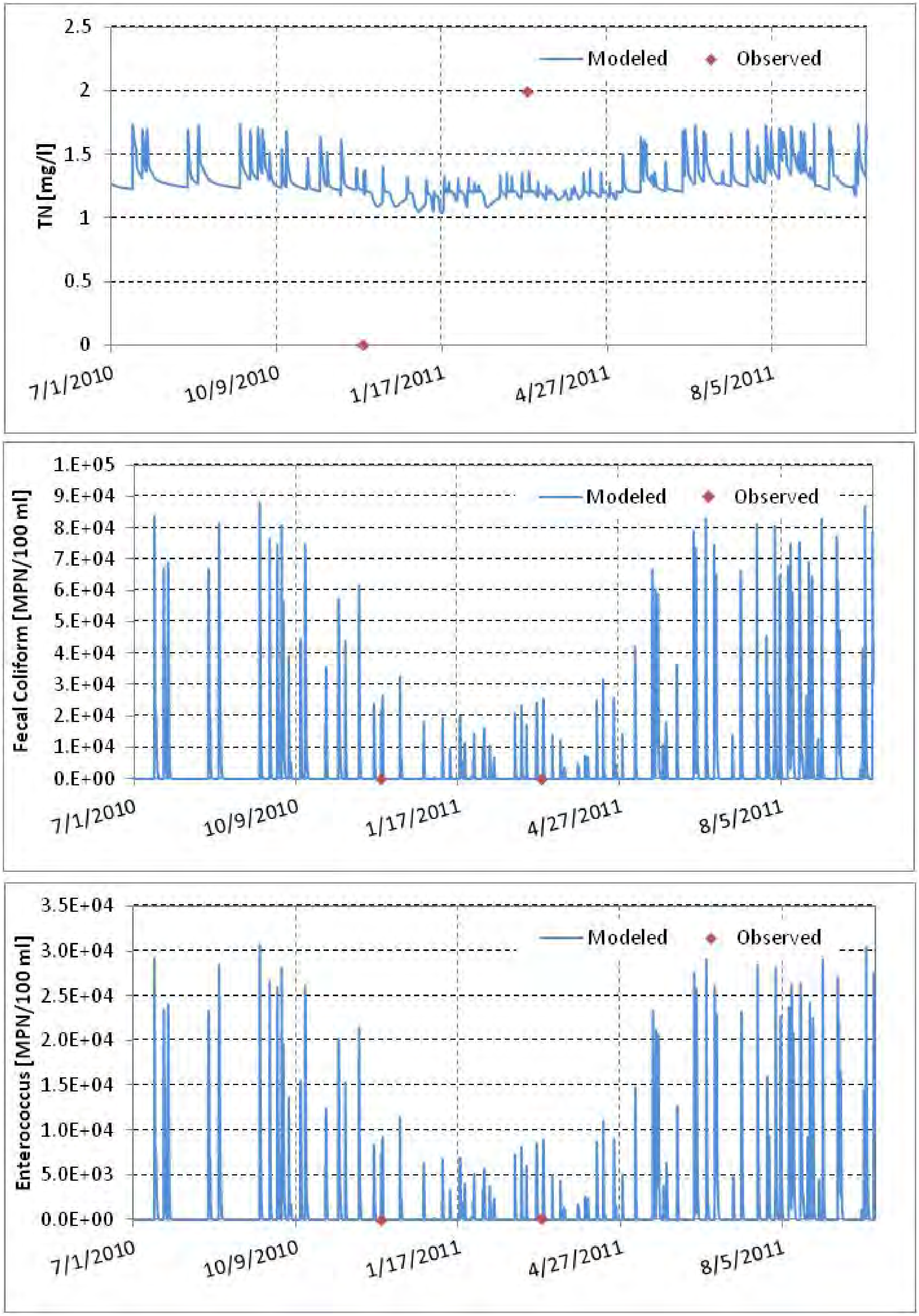


Figure C-4: Time Series Plots of TN, FC and ENT for SBR01

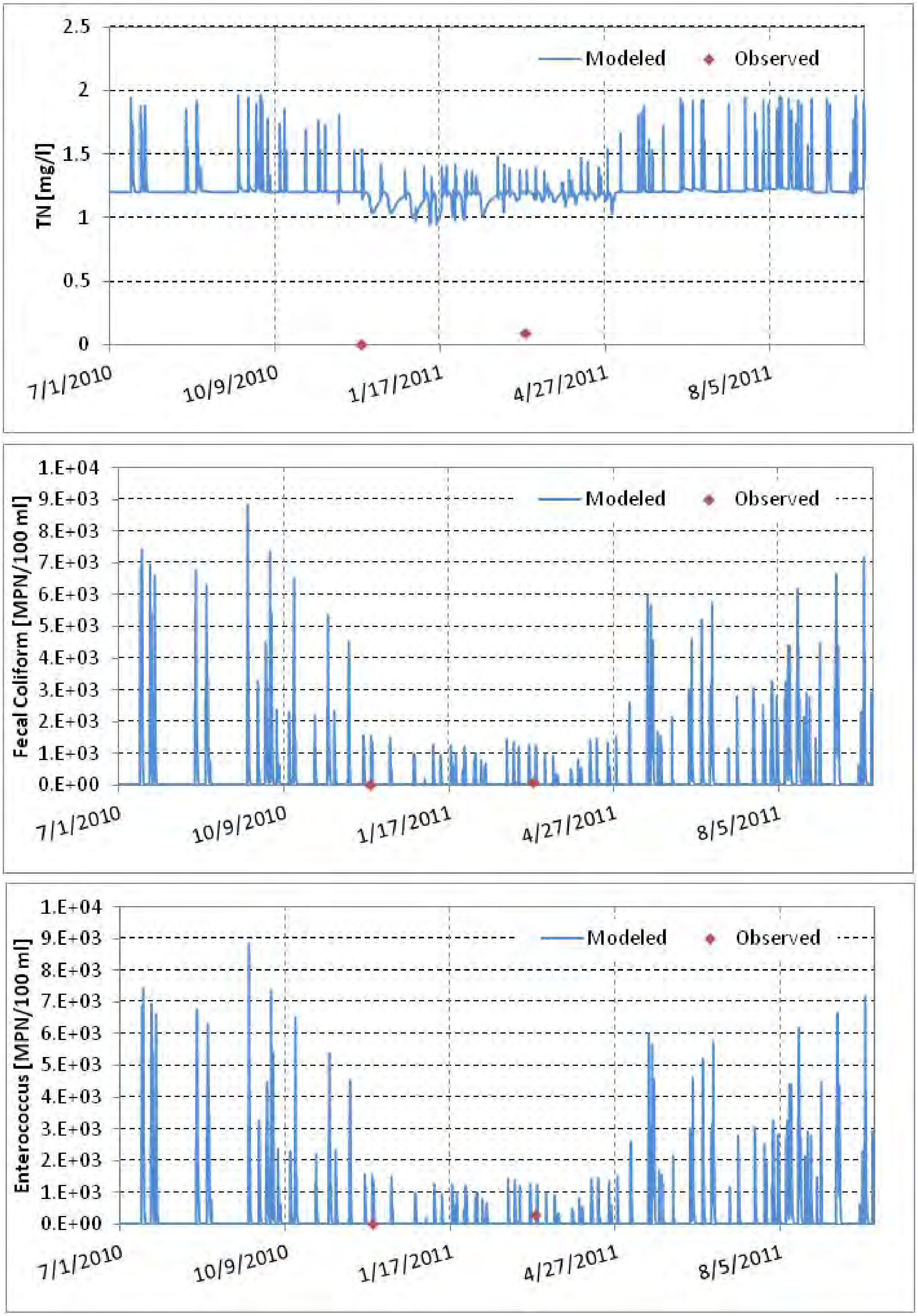


Figure C-5: Time Series Plots of TN, FC and ENT for SBR02

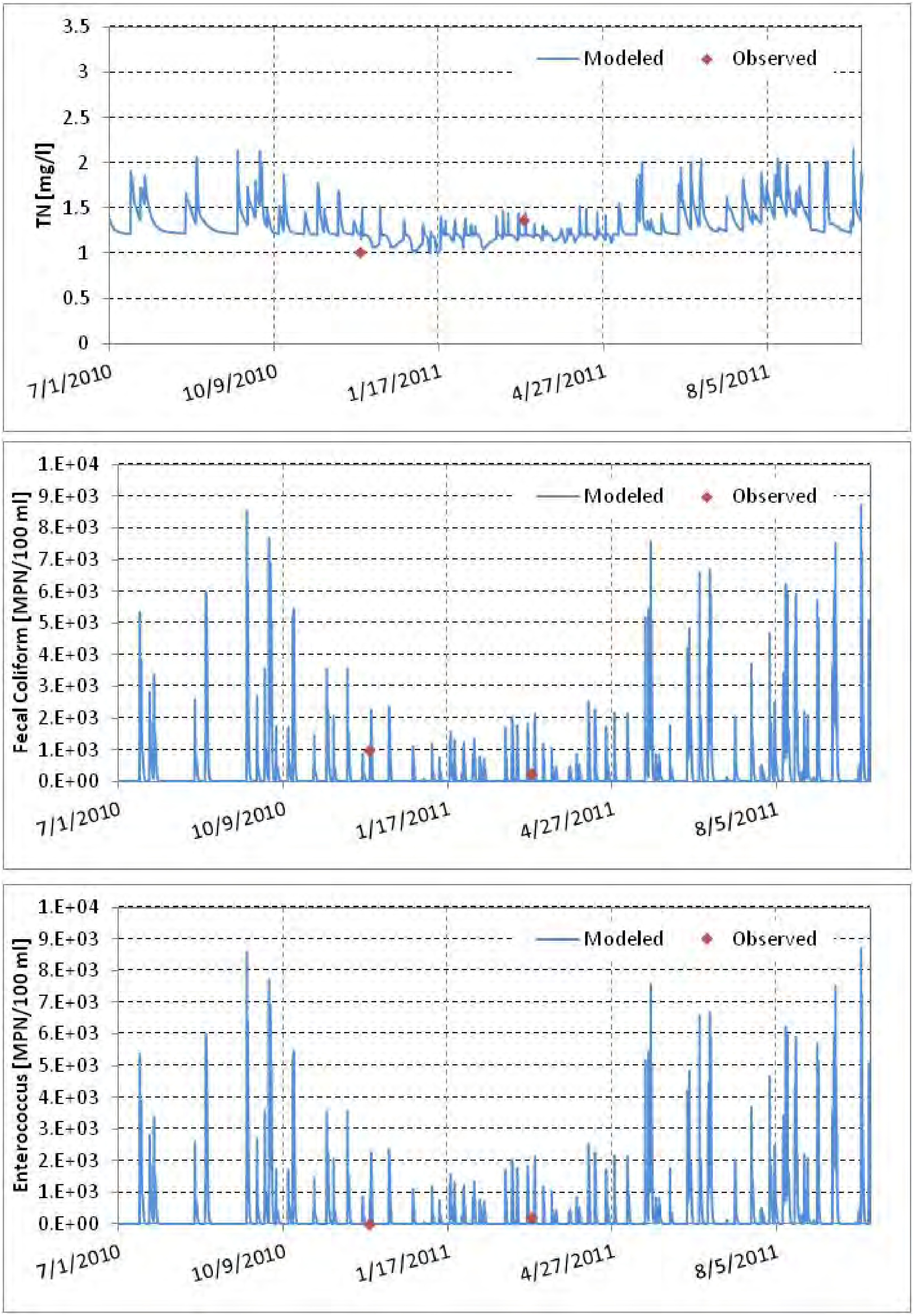


Figure C-6: Time Series Plots of TN, FC and ENT for SBR06

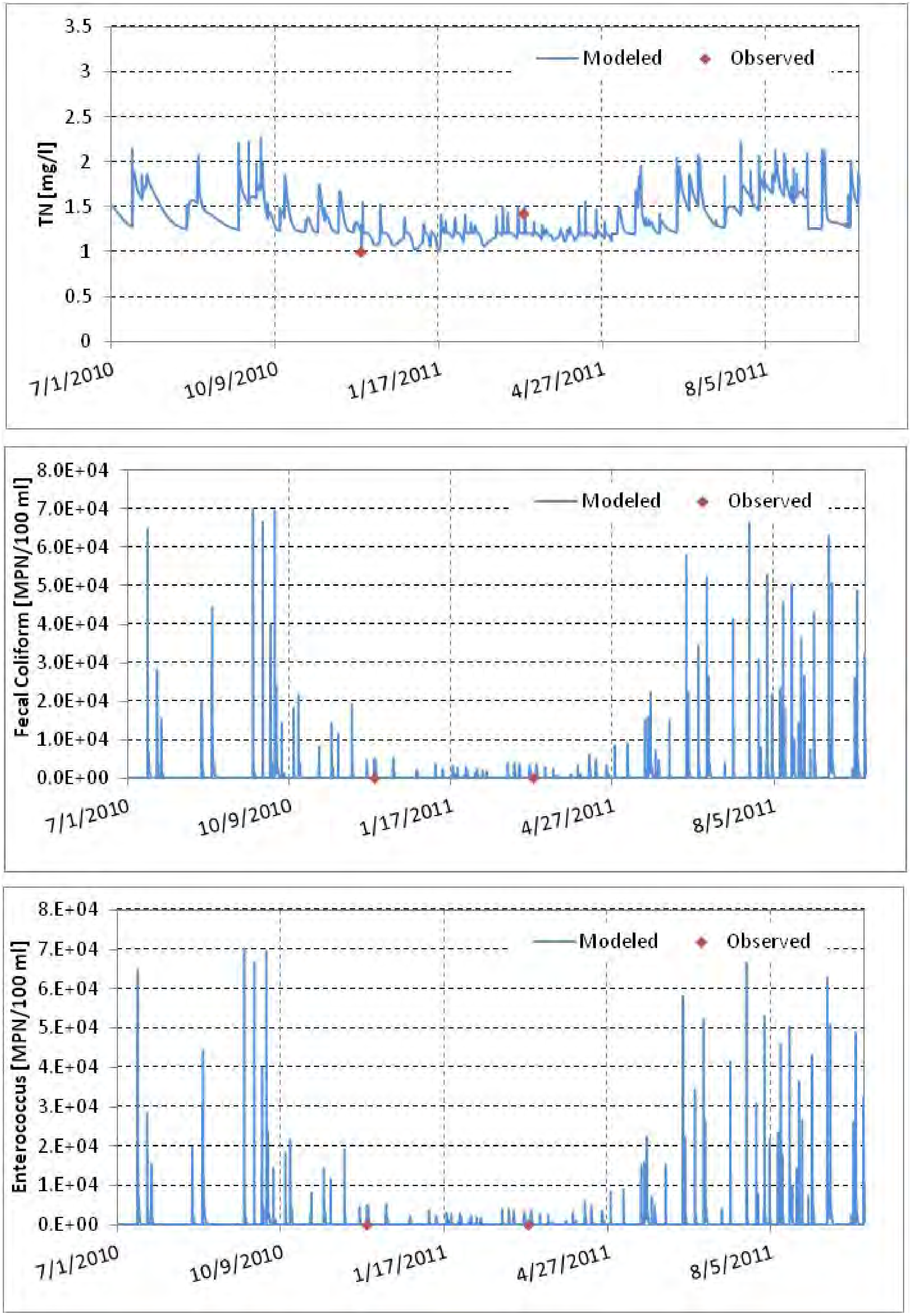


Figure C-7: Time Series Plots of TN, FC and ENT for SBR08

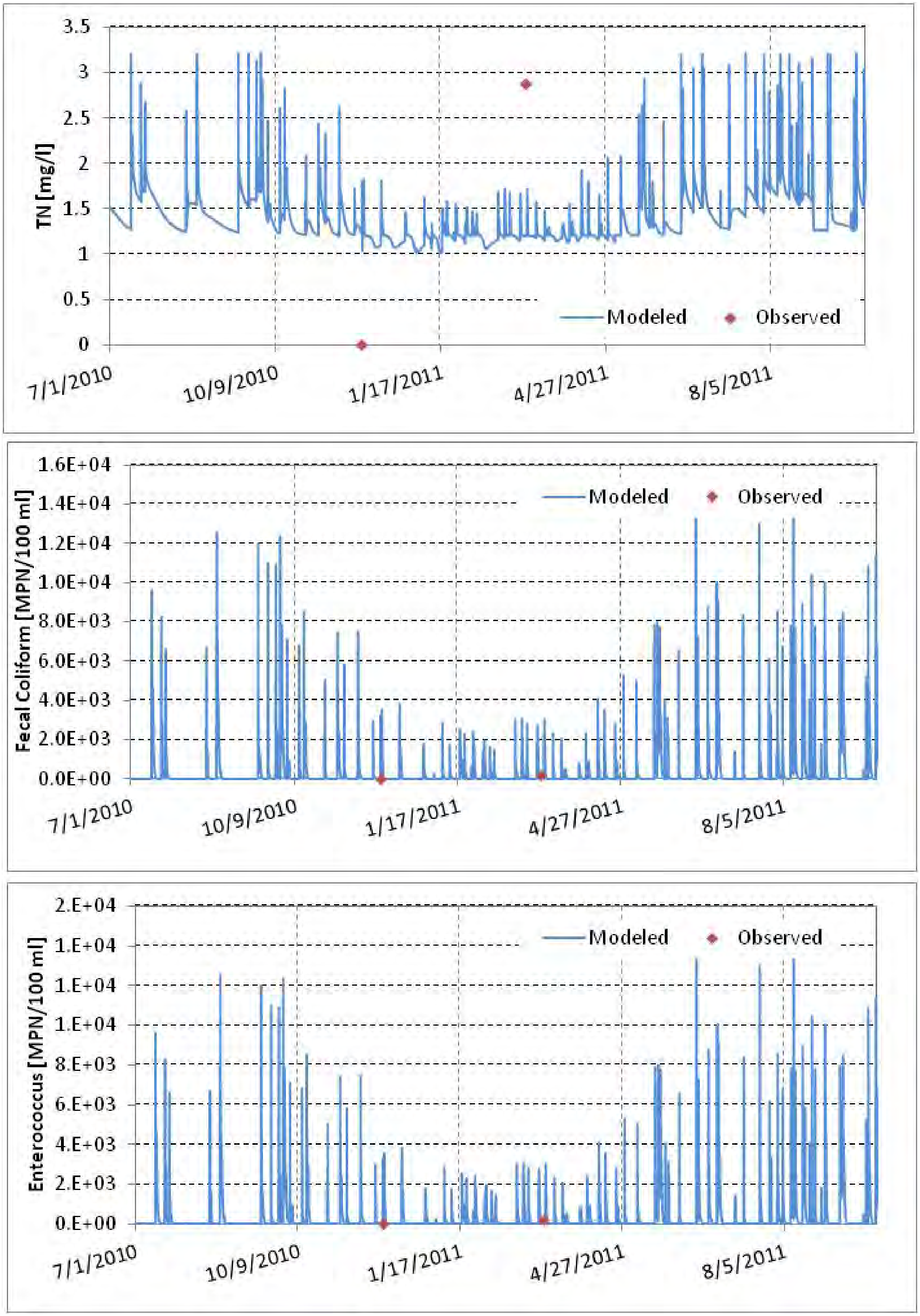


Figure C-8: Time Series Plots of TN, FC and ENT for SBR09